Institut de Radioastronomie Millimétrique

Journée IRAM France

January 31st, 2019, Paris

Program: Morning

09h00-09h30 Welcome coffee

09h30-11h00 IRAM and its environment. Chair: Jean-Loup Puget

- **09h30-09h40** Introduction, Guy Perrin (INSU)
- **09h40-10h30** IRAM (NOEMA & 30m), Karl Schuster & Frédéric Gueth (IRAM)
- **10h30-10h35** SKA/IRAM synergy, Chiara Ferrari (SKA-France)
- **10h35-10h45** MUSE/IRAM synergy, Thierry Contini (IRAP)
- **10h45-11h00** Discussion animated by Raphael Moreno and Fabienne Casoli

11h00-11h15 Coffee

11h15-12h25 Cosmology & Redshifted Galaxies. Chair: Nicole Nesvadba

- **11h15-11h30** Cosmology & SZ, Juan Macias-Pérez (LPSC)
- **11h30-11h45** Evolution of galaxies and AGN, Françoise Combes (LERMA)
- **11h45-12h05** 4 Flash-talks of 5 minutes
  - The CMB in High Definition, Jean-Baptiste Melin (CEA)
  - Dead and Dusty ETGs at $z \sim 3$, Chiara Deugenio (CEA)
  - Towards a NOEMA survey of $z > 2$ protoclusters?, Hervé Dole (IAS)
  - Model of black hole magnetospheres for EHT, Benoit Cerutti (IPAG)
- **12h05-12h25** Discussion animated by David Elbaz and Alexandre Beelen

12h25-13h25 Lunch

Program: Afternoon (1)

13h25-15h15 ISM & Star Formation. Chair: Antoine Gusdorf

- **13h25-13h40** ISM in nearby galaxies, Annie Hughes (IRAP)
- **13h40-13h55** ISM structures, Marc-Antoine Miville-Deschênes (AIM)
- **13h55-14h10** Star formation, Frédérique Motte (IPAG)
- **14h10-14h45** 7 Flash-talks of 5 minutes
  - Molecular gas in Brightest Cluster Galaxies, Philippe Salome (LERMA)
  - Dense Gas and Star Formation Across Nearby Galaxy Disks: The EMPIRE Survey, Diane Cormier (CEA)
  - Millimeter-centimeter emission excess in nearby galaxies, Katharina Lutz (Strasbourg)
  - The molecular cloud interacting with cosmic rays in IC443G, Pierre Dell'Ova (LERMA)
  - Galactic cold cores IRAM follow-up: colliding filaments in Monoceros, Julien Montillaud (UTINAM) & Isabelle Ristorcelli (IRAP)
  - ALMA, SMA and PdBI interferometric observations observations of the youngest solar-type protostars, Maud Galametz (CEA)
  - Searching for pre-brown dwarf cores in nearby starforming clouds with NIKA2 and NOEMA, Philippe André (CEA)
- **14h45-15h15** Discussion animated by Karine Demyk and Pierre Guillard

15h15-15h45 Dying stars, Young Stellar Objects, & Astrochemistry (1). Chair: Antoine Gusdorf

- **15h15-15h30** Circumstellar envelopes of evolved stars, Fabrice Herpin (LAB)
- **15h30-15h45** Protoplanetary disks and jets, Anne Dutrey (LAB)

15h45-16h00 Coffee

Program: Afternoon (2)

16h00-16h55 Dying stars, Young Stellar Objects, & Astrochemistry (2). Chair: Maryvonne Gerin

- **16h00-16h15** Astrochemistry (dust and molecules) and its link with exobiology, Charlotte Vastel (IRAP)
- **16h15-16h35** 4 Flash-talks of 5 minutes
  - NOEMA observations of the circumstellar environment of μ Cep, Miguel Montarges (Leuven)
  - A survey of the HCN and HNC C and N isotopic ratios in nearby star formation regions, Victor de Souza Magalhaes (IRAM)
  - Hot corino aging: molecular complexity and deuteration towards the Class I source SVS13-A, Eleonora Bianchi (IPAG)
  - Complex Organics in the NGC 1333 IRAS 4A Outflows, Marta de Simone (IPAG)
- **16h35-16h55** Discussion animated by Agnès Lebre and Cecilia Ceccarelli

16h55-17h45 Solar system, Chair: Maryvonne Gerin

- **16h55-17h10** Disque de débris, Jean-François Lestrade (LERMA)
- **17h10-17h25** Solar system, Nicolas Biver (LESIA)
- **17h25-17h35** 2 Flash-talks of 5 minutes
  - Long-term monitoring and chemical inventory in Jupiter and Saturn's atmospheres, Thibault Cavalié (LAB)
  - Probing the subsurface of Iapetus two faces, Lea Bonnefoy & Alice Le Gall (LATMOS)
- **17h35-17h45** Discussion animated by Thierry Fouchet and Emmanuel Lellouch

17h45-18h00 Conclusions

Session # 1
IRAM and its environment

Karl Schuster

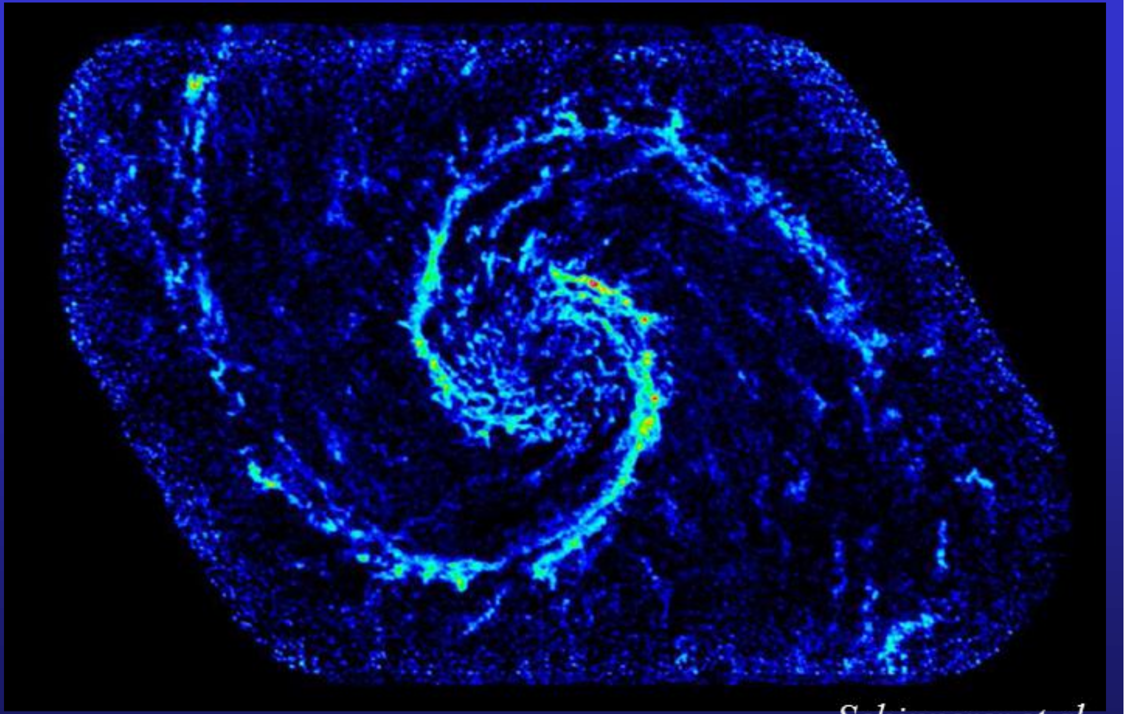
IRAM: NOEMA and the 30m telescope

Journee IRAM France
Paris - 31st Jan. 2019

IRAM,
NOEMA and the IRAM 30m telescope

K.F. Schuster IRAM

- Structure and Organization of IRAM
- NOEMA and the 30m Telescope
- Policies
- Some Conclusions



Schinnerer et al

IRAM Organization

- Founded 1978 as non-profit organization — CNRS (France), MPG (Germany), IGN (Spain) joins 1989
- HQ Grenoble (~75 Pers.) — Science Operation and Technical Dev., Softw. & Data Center, Admin.
- Observatories: (~50 Pers.) — Pico Veleta (Spain), Plateau de B. (France)
- Annual Budget — 15 Mio. EU (consolidated)

IRAM Mission

- Operate two world class mm/submm observatories
  - NOEMA Northern Extended Millimeter Array
  - IRAM 30m telescope Pico Veleta Spain
- Develop advanced technology for millimeter Astronomy and act as a center of excellence in this field.
- Develop the related science community and training of forthcoming generations of scientists.

cnrs advancing the frontiers

MAX-PLANCK-GESELLSCHAFT

GOBIERNO DE ESPAÑA

MINISTERIO DE FOMENTO

INSTITUTO GEOGRÁFICO NACIONAL

Interferometer NOEMA (8/12), France

Headquarter Grenoble, France

30 m Telescope, Spain

IRAM Governance

Governance Bodies:

- IRAM Steering Committee (3 Pers. from each associate) – and attached AG and FC subcommittee. Meets 1 time /year.

- Scientific Advisory Committee (SAC), reports to Steering Committee (3 Pers. from each associate + 1 external member. Meets 1 time /year).

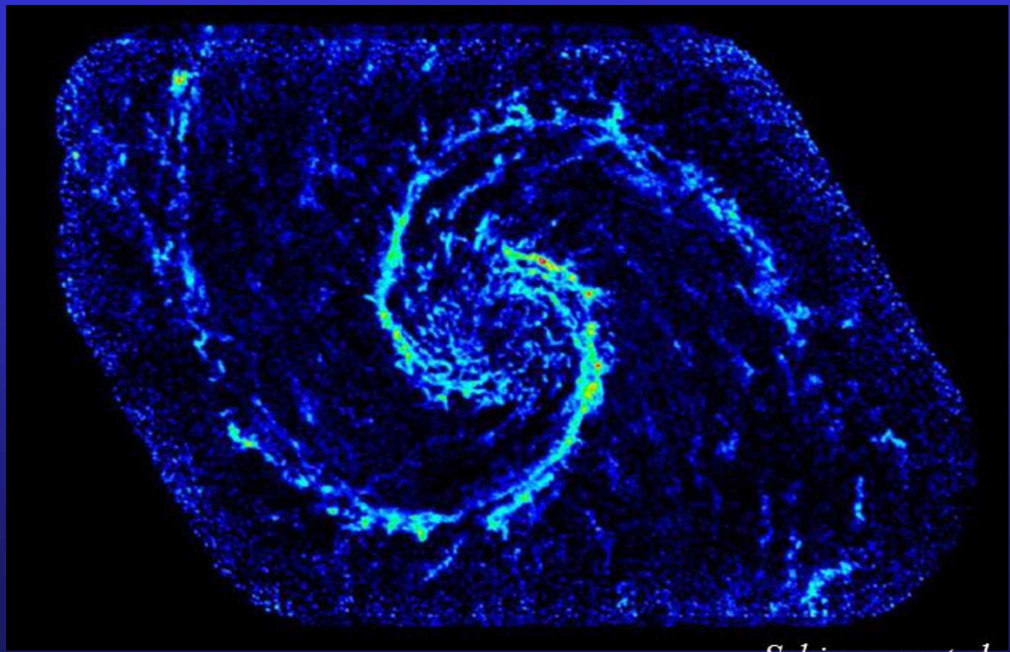
- IRAM program committee (PC), report ranking to IRAM director 3 Pers. from each associate + 5 external members. Meets 2 times /year.

Institutes Agreement:

- Current associate agreement runs up to 2024. 10 years extension in preparation.

NOEMA
the Northern Extended Millimeter Array

- NOEMA – global description and motivations
- Key Technology
- Status
- Things to come



Schinnerer et al

Millimeter Wave Astronomy fundamentally changed during the last 15 years:

- Became important pillar of multi-wavelength Astronomy.
- Transition from single object projects to multi object surveys.
- Arrival of ALMA, a 1.3 billion Euro world wide project in the southern hemisphere.

NOEMA
Northern **E**xtended **M**illimeter **A**rray

The Concept

- Double the number of 15 m antennas at PdB from 6 to 12

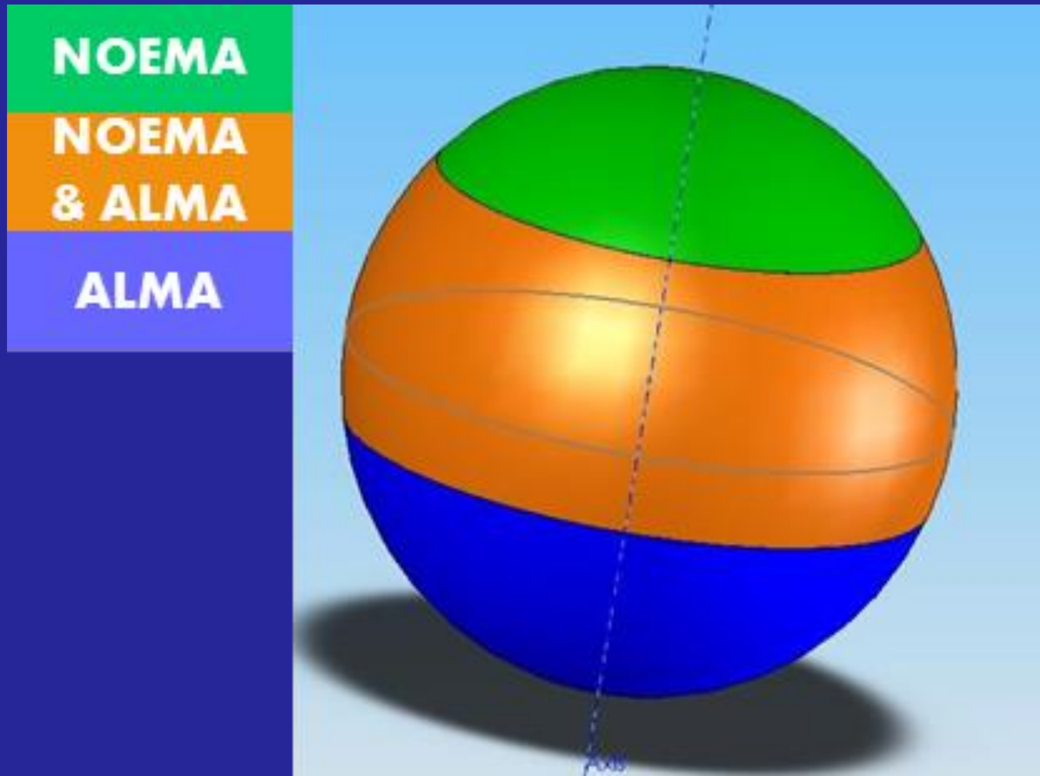
- Increase of IF bandwidth from 8 GHz to 32 GHz

- New Correlator: Full low resolution coverage + 128 flexible high resolution windows

- Extension of the Baselines from 0.8 to 1.7 km

- Organize ~50 MEu for this !

NOEMA Motivations



- ts

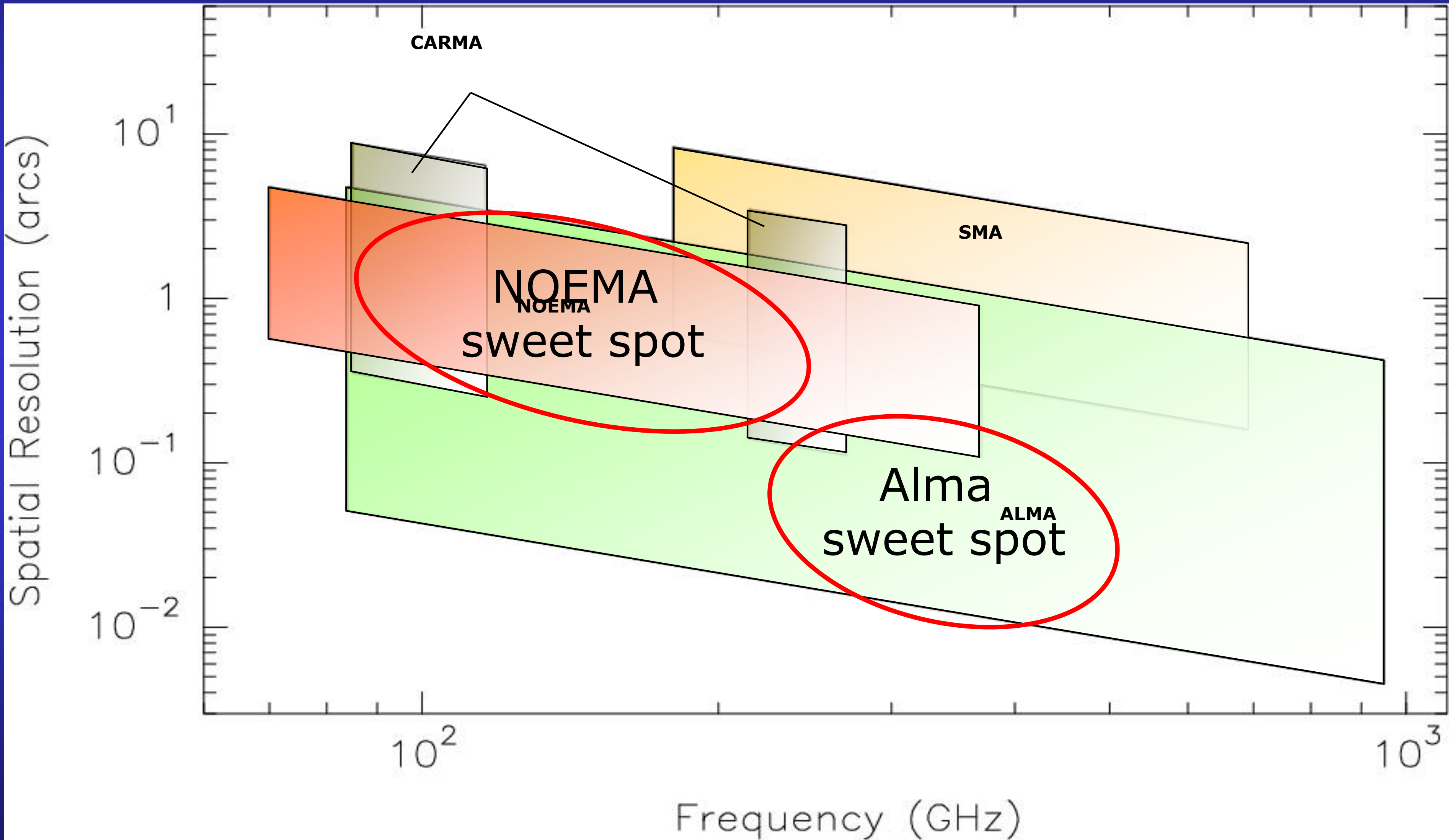
- Generate full sky coverage in the millimeter range.

- Enhance IRAM partners use of ALMA and other existing or upcoming facilities (VLT, SOFIA, JWST, ELT….)

ALMA as a benchmark

NOEMA Point Source Sensitivity Goals		
	Continuum and Frequency Survey	Single Line
NOEMA vs ALMA	> 65%	> 45%

Angular Resolutions



Phase I - Phase II

In order to allow start of construction before full funding is achieved a two Phase approach was implemented by the IRAM partners in 2011:

PHASE I (34 MEu):

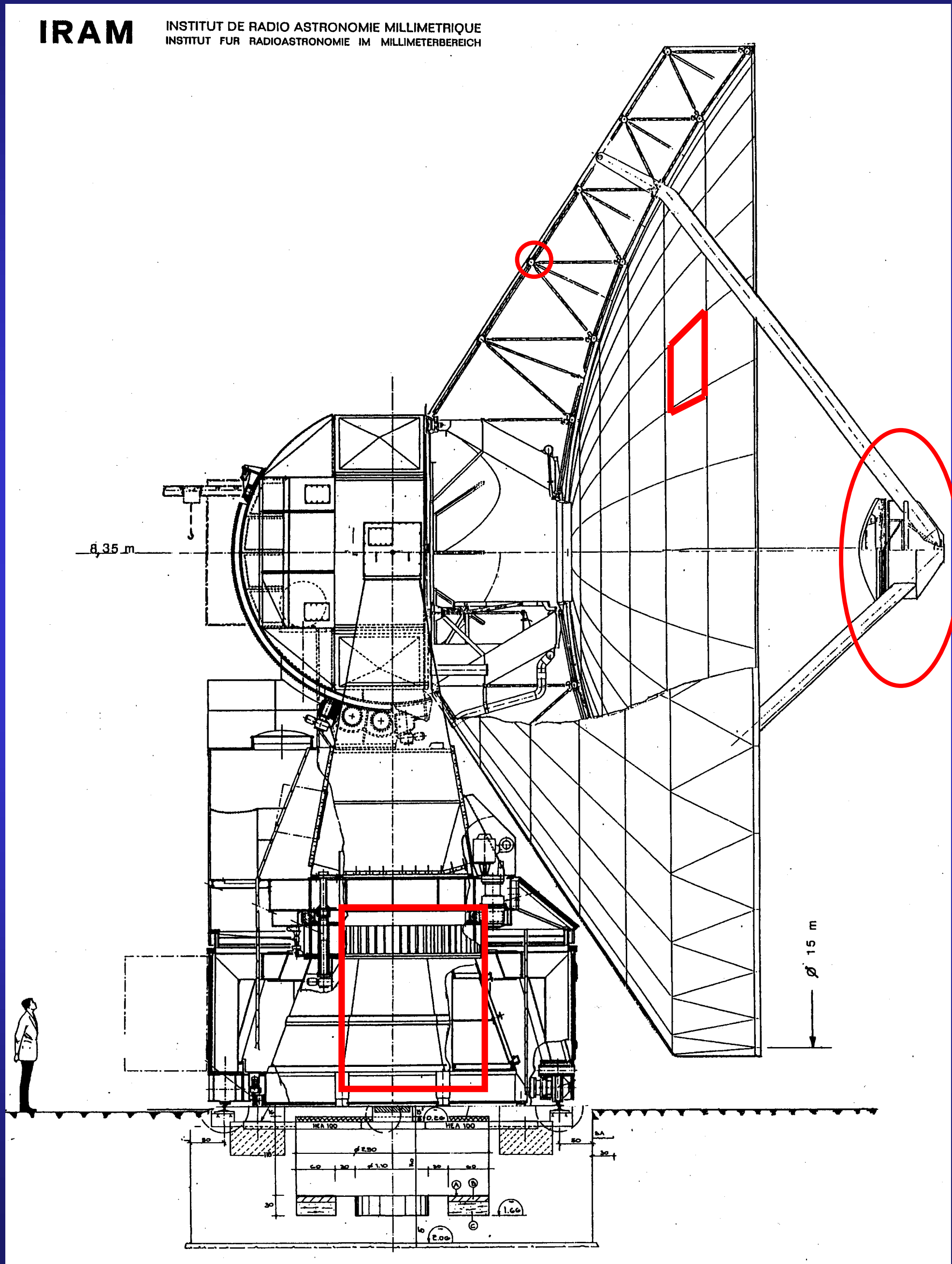
- Construction of additional 4 Antennas
- Equip all 10 Antennas with 8GHz 2SB receivers
- Development and construction of a correlator for 12 Antennas

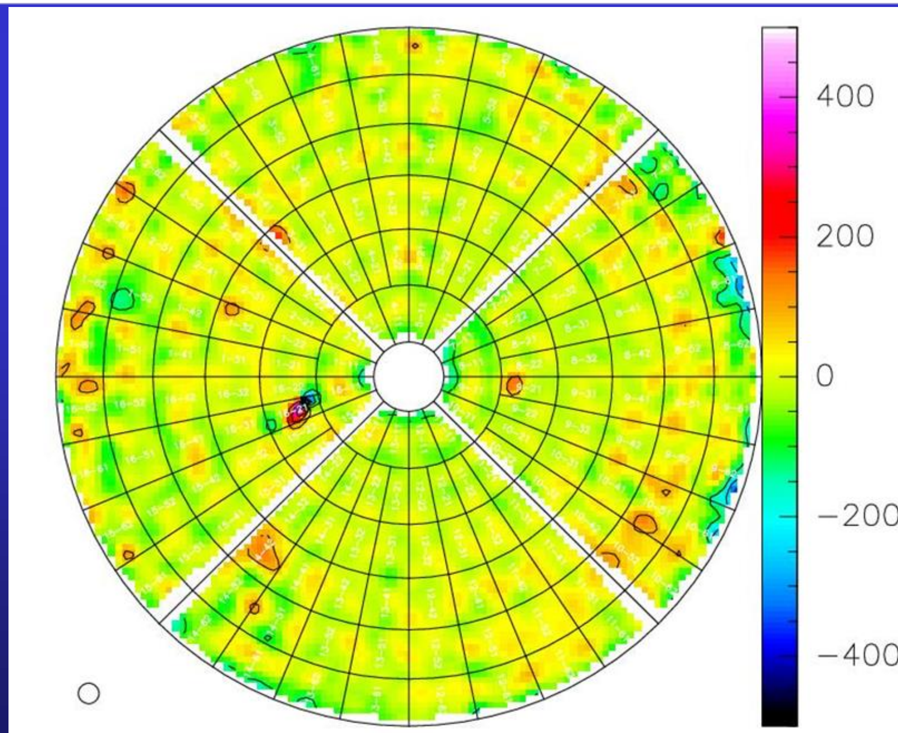
PHASE II (18 MEu):

- Construction of 2 additional Antennas
- Extension of EW Baseline from 800m to 1700m

+ several add-on which are financed seperatly

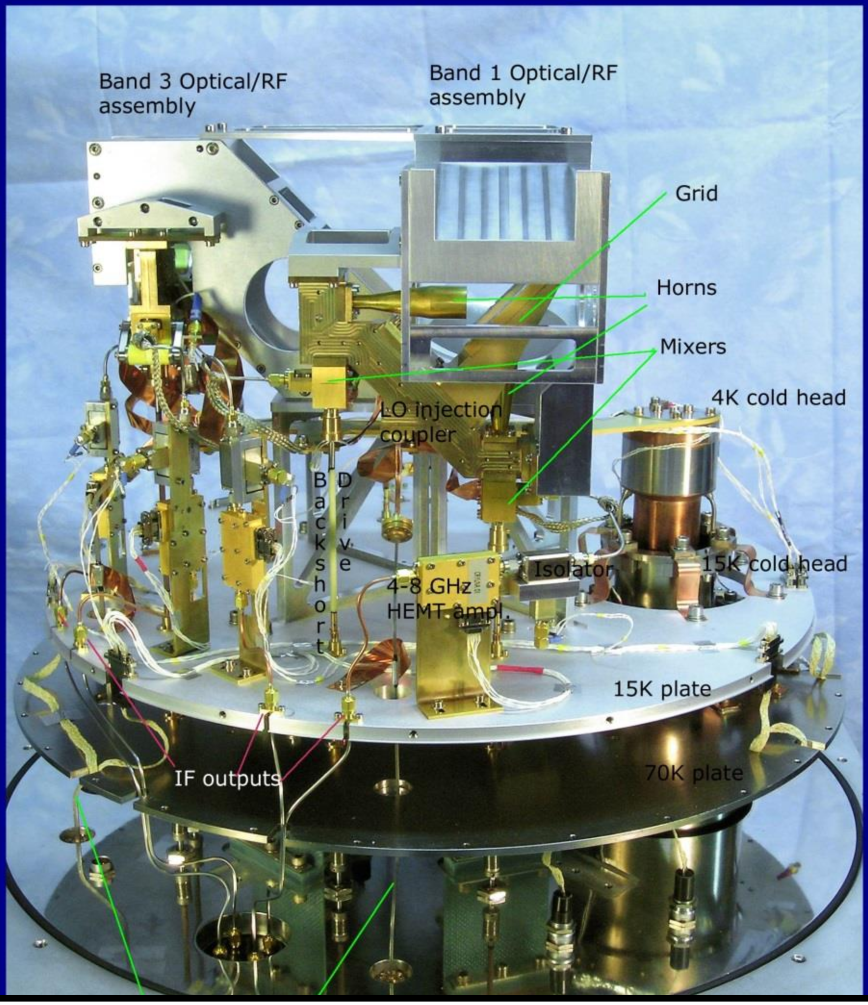
The NOEMA Antenna

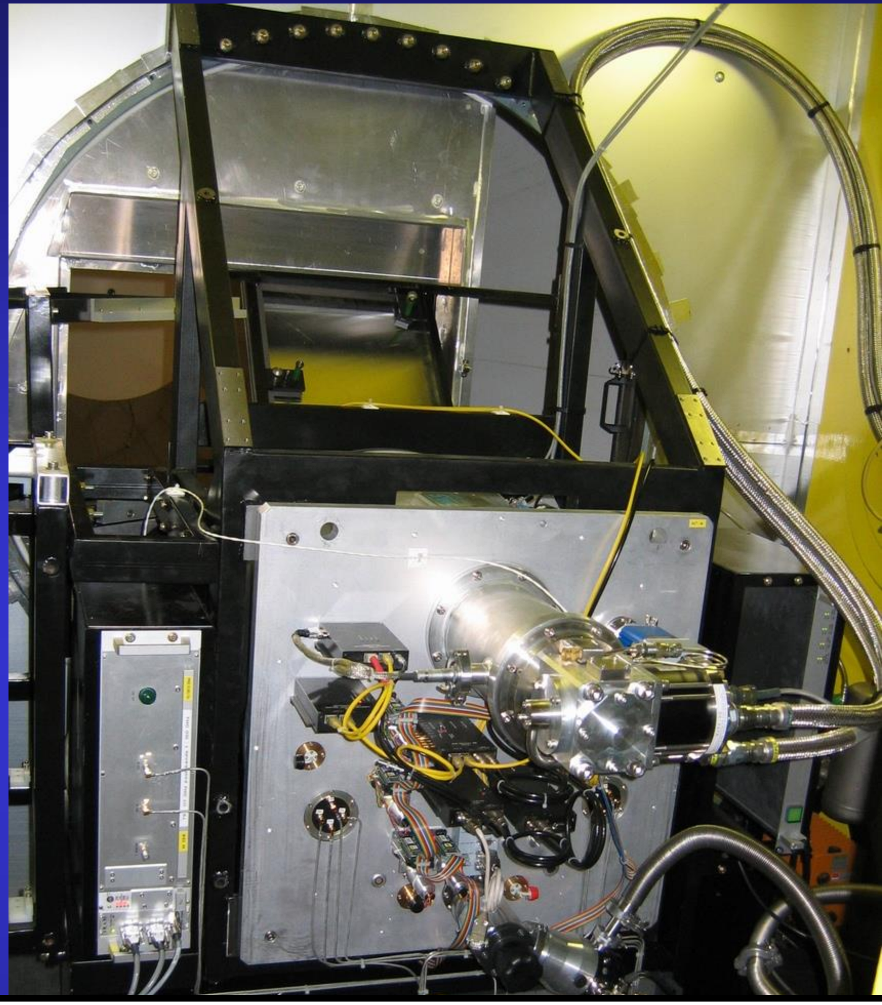




<35 μm rms

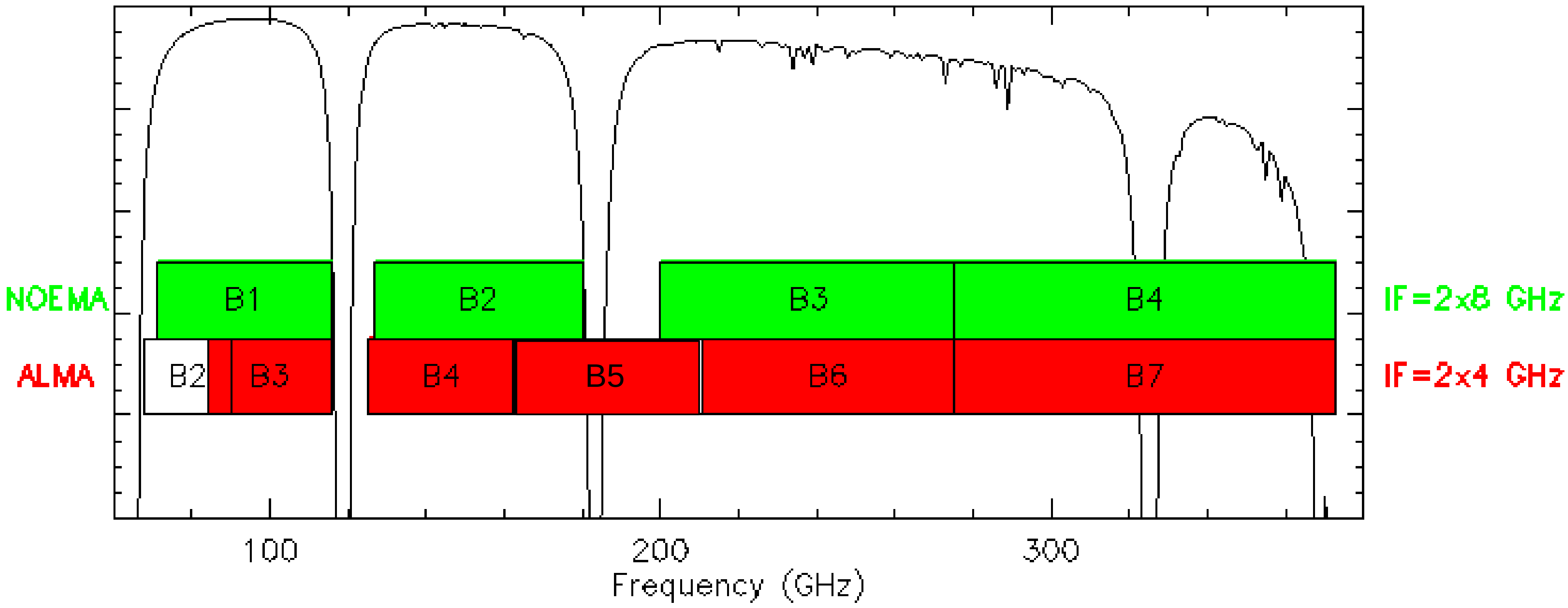
The NOEMA Receivers





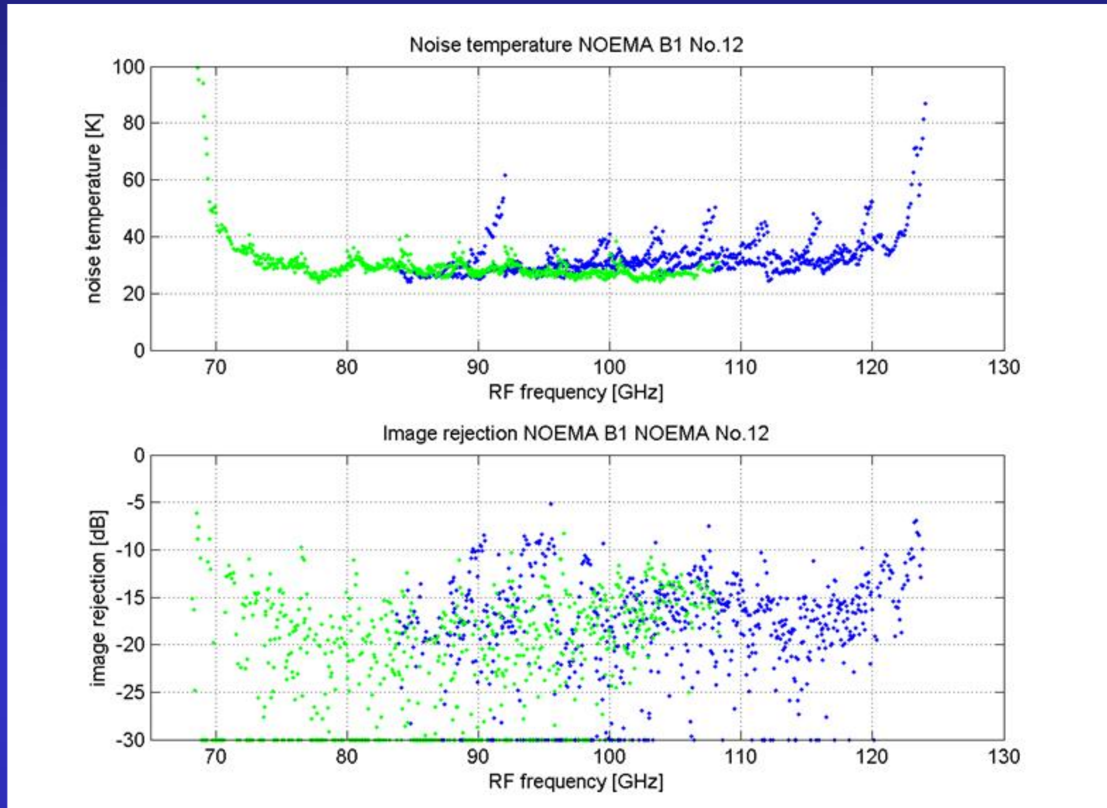
NOEMA RF Band Specifications				
Band	NOEMA-1	NOEMA-2	NOEMA-3	NOEMA-4
RF Frequency (GHz)	**70**-116	127-179	200-276	275-373

NOEMA receivers



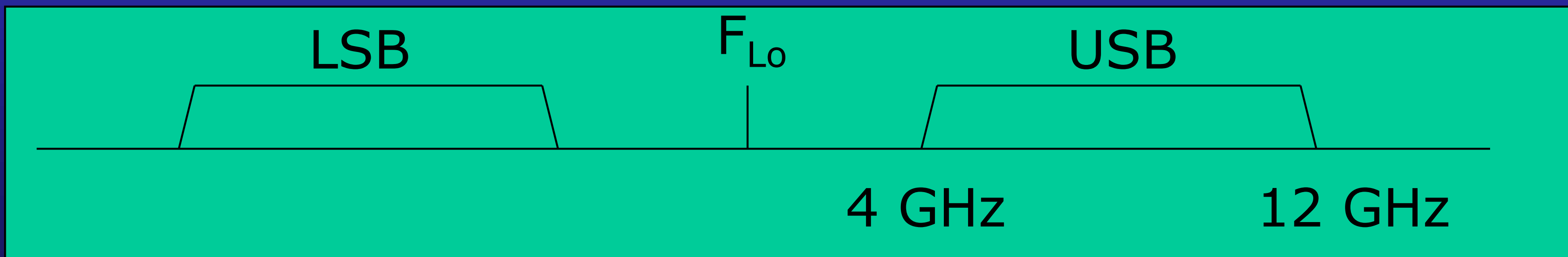
NOEMA 8 GHz 2SB Technology

Since summer 2013 commissioned in all 4 bands at the 30m telescope, newest version is fully integrated

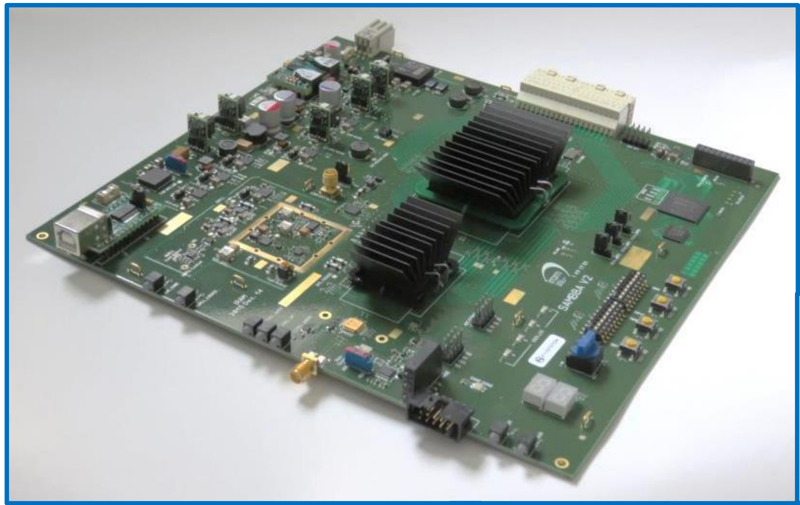


D. Maier et al.

Delivers 16 GHz of IF band per polarization !



Correlator PolyFiX System Overview



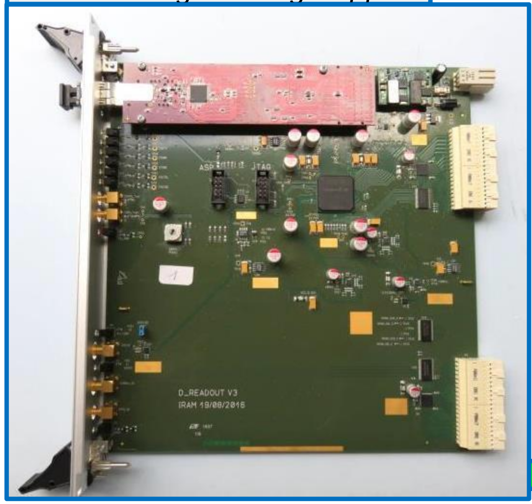
Correlator Card
Per FPGA:
66+12×½ Baseline Support
18432 Channels per Baseline Processed BW = 256MHz Low + 64MHz High. Res

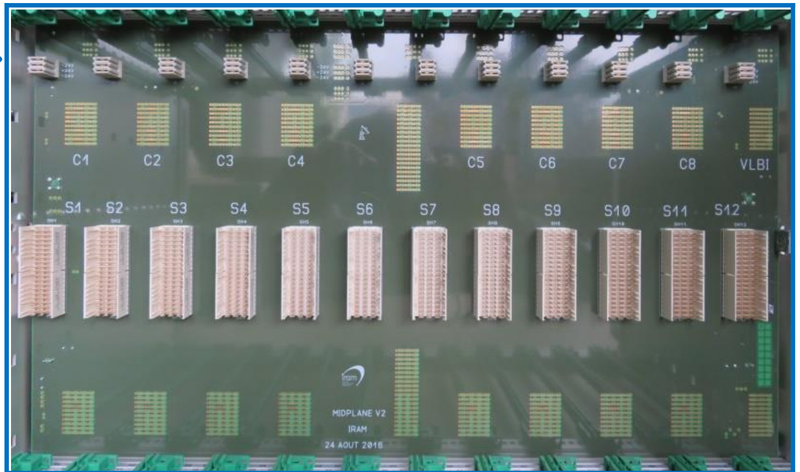
Digitizer Card
4GHz analog bandwidth 5-Bit resolution ADC
On-board 8GHz sampling clock 96 Gb/s net data output rate

×12

×8

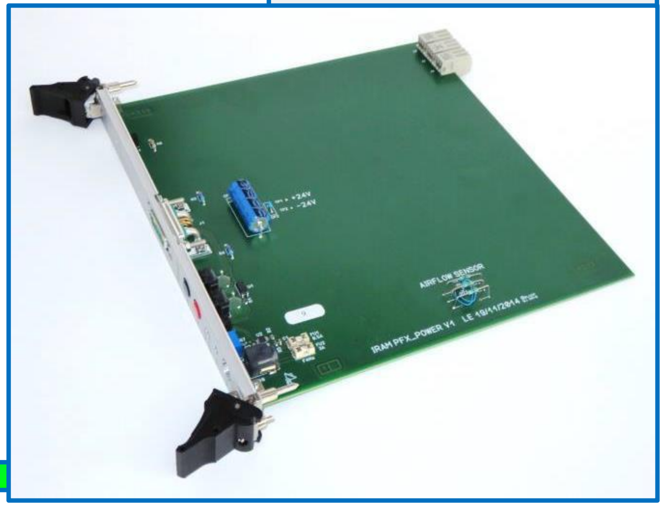
Readout Card
1.3M Channels Transfer
170MB/s Output Data Rate
Remote Programming Support





Midplane Card
Custom Fullmesh Backplane supporting 1.7 Tb/s

Power Supply Card
Cooling Supervision
1KW Power Distribution



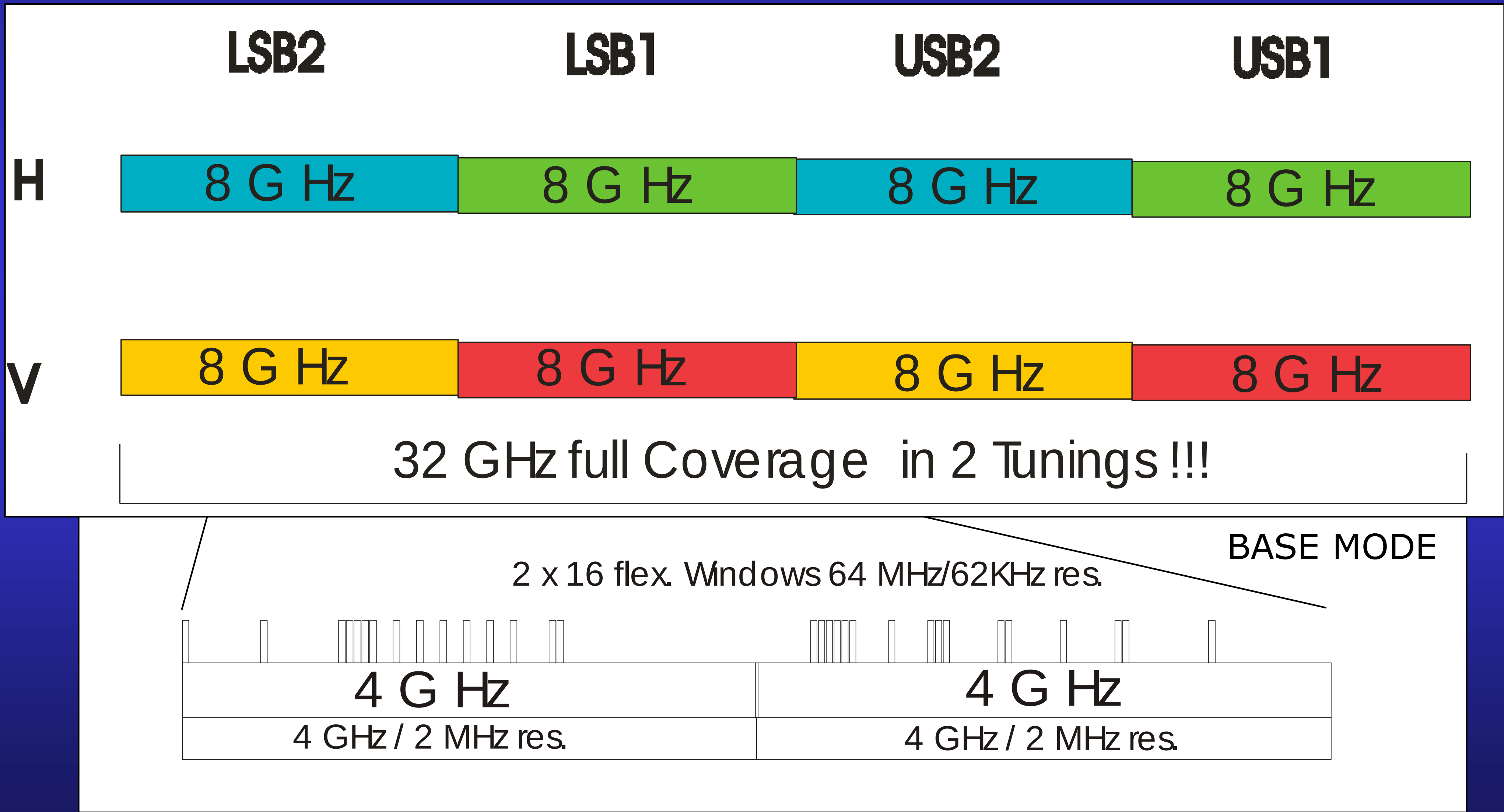
×1

×1

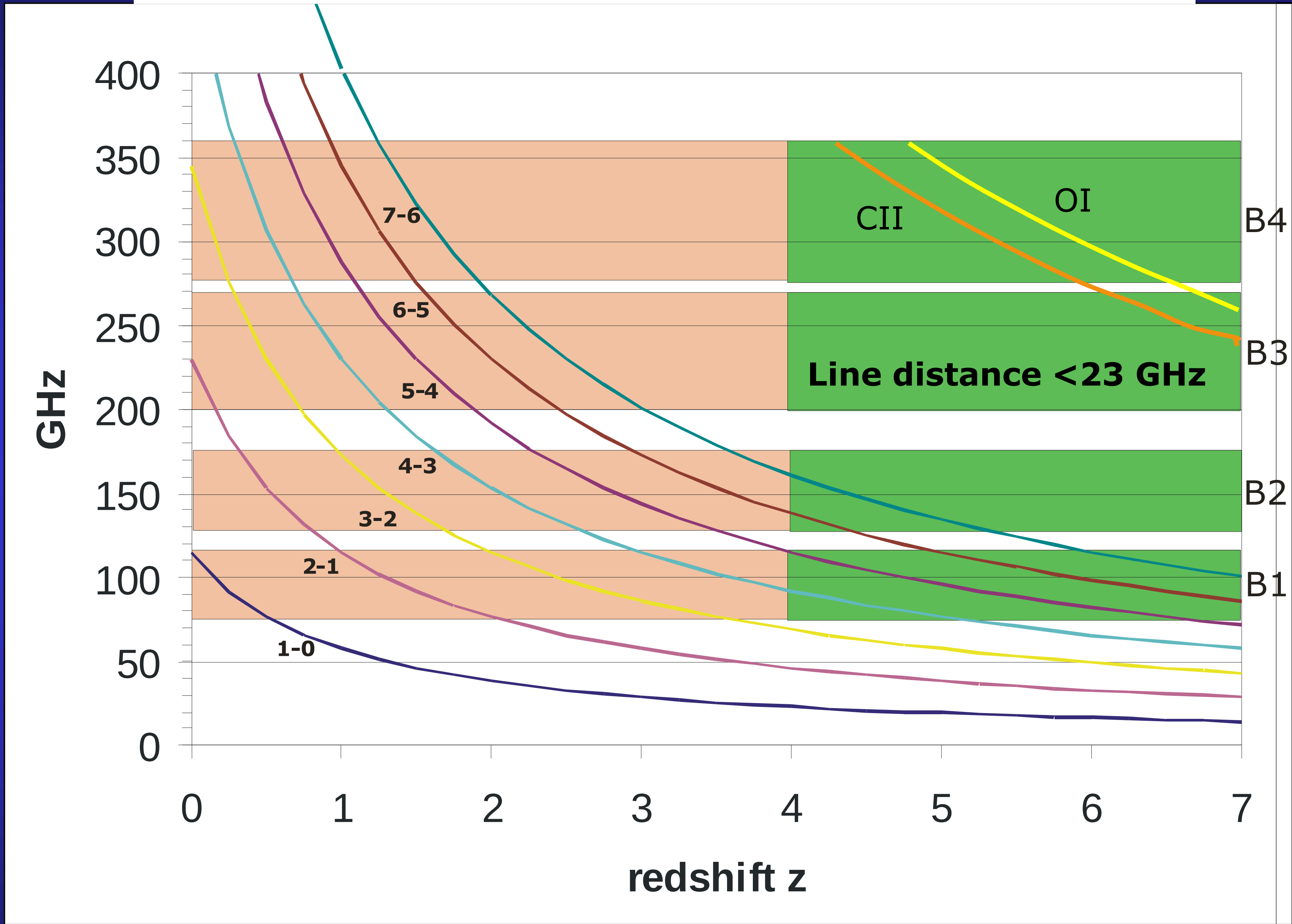
These hardware runs with <u>a lot</u> of firmware (**50% min.** of total work)

NOEMA Special Features

Backend POLYFIX



Redshifted CO, CII and OI transitions



NOEMA Construction Status

iram
Institut de
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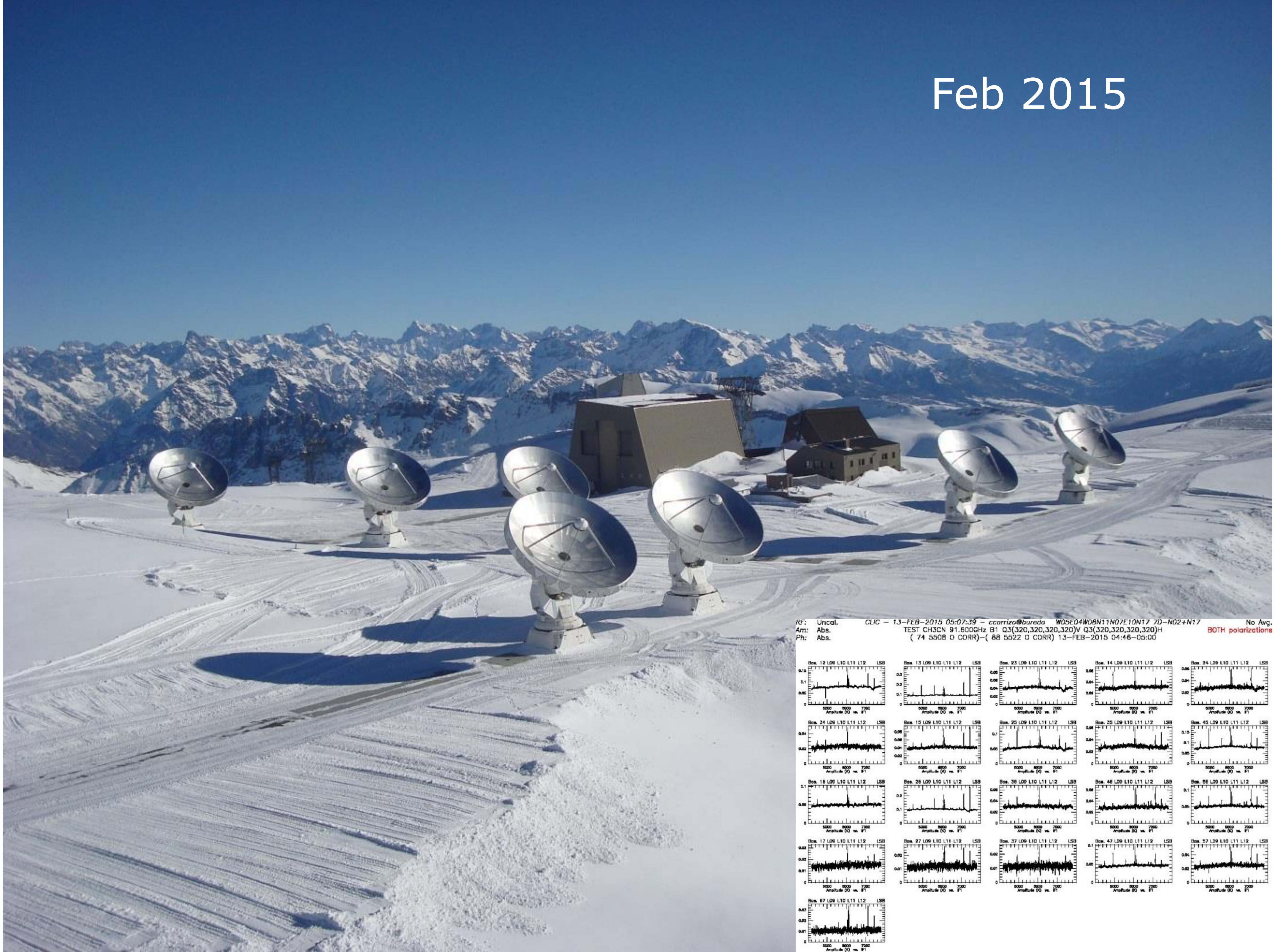
Millimétrique

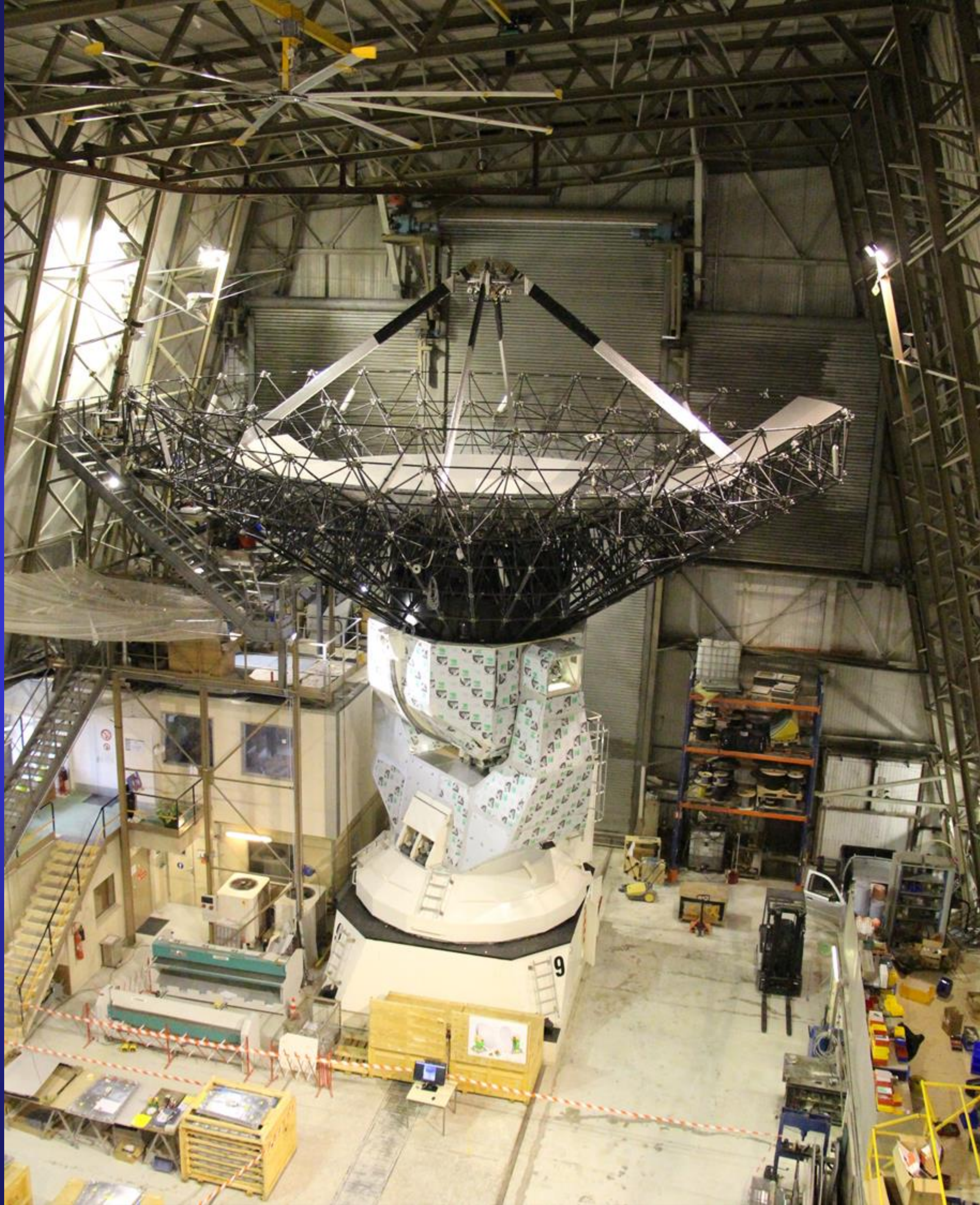
Antenna 7 inauguration **22 Sept. 2014**

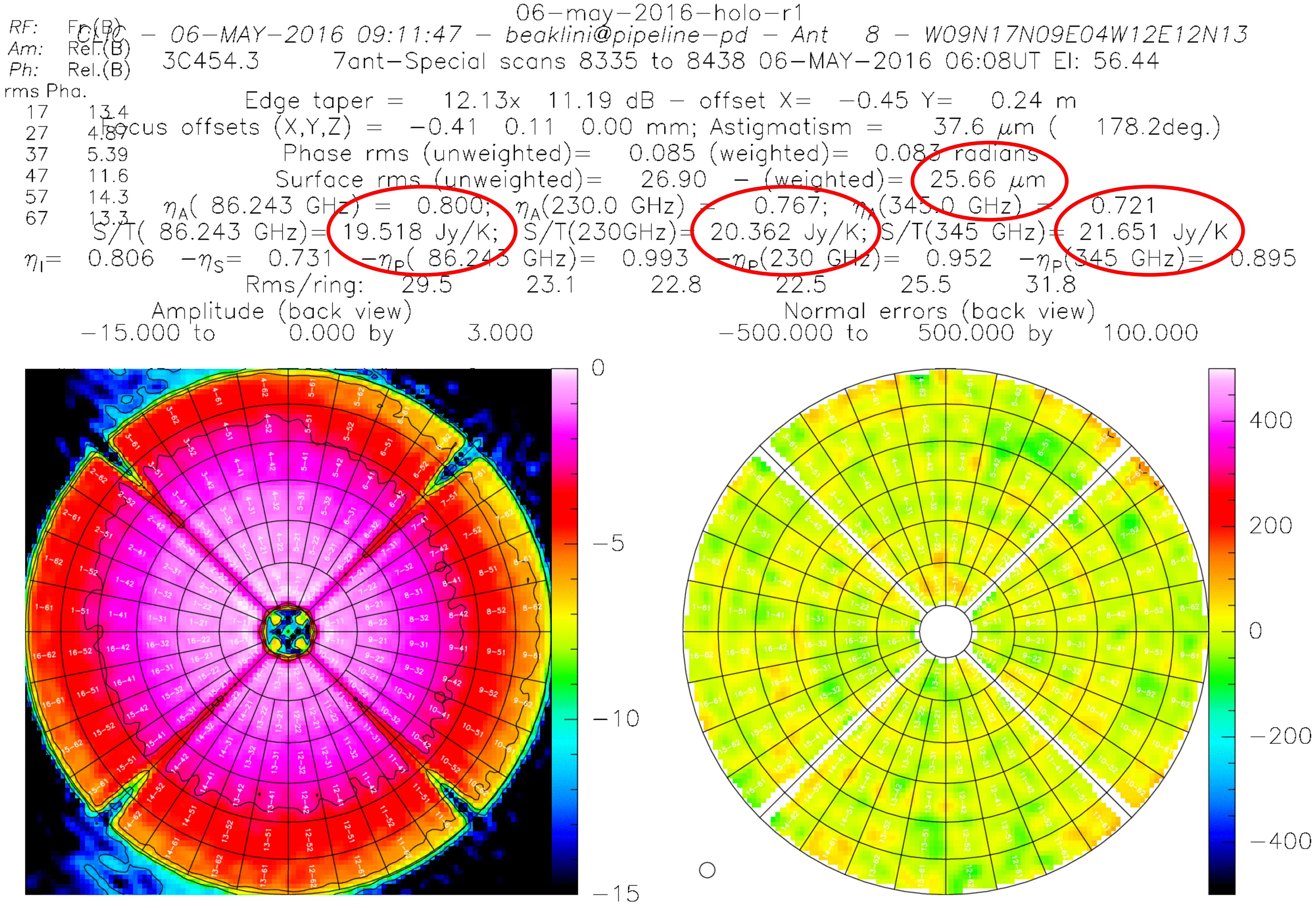
Feb 2015



RF: Uncal.
Am: Abs.
Ph: Abs.
CLIC – 13–FEB–2015 05:07:39 – ccarrizo@bureda W05E04W08N11N07E10N17 7D–N02+N17
TEST CH3CN 91.600GHz B1 Q3(320,320,320,320)V Q3(320,320,320,320)H
(74 5508 0 CORR)–(88 5522 0 CORR) 13–FEB–2015 04:46–05:00
No Avg.
BOTH polarizations

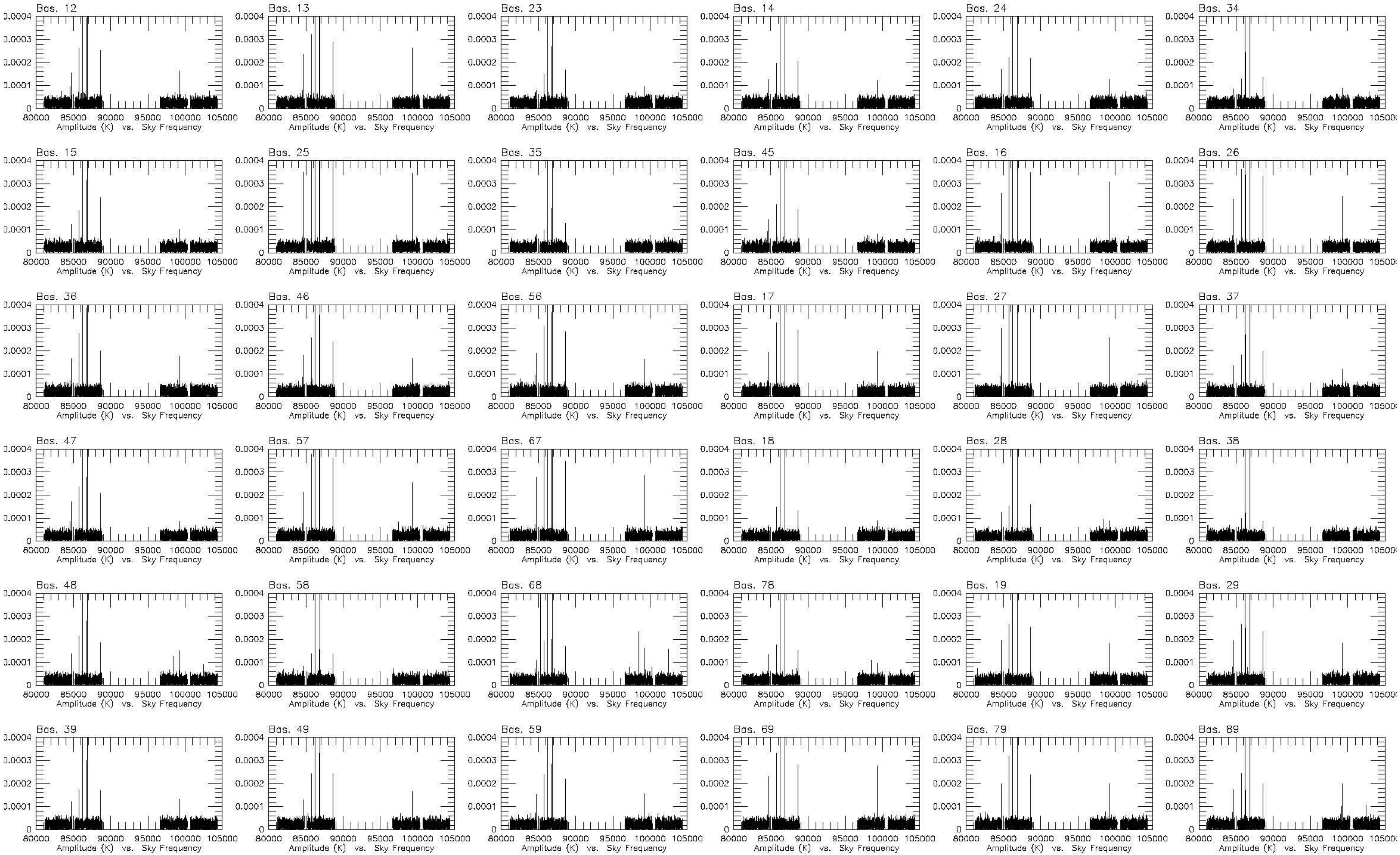
Ant 9 – Status
Sept 2016




06-may-2016-holo-r1
CLIC - 06-MAY-2016 09:11:47 - beaklini@pipeline-pd - Ant 8 - W09N17N09E04W12E12N13
RF: Fr.(B)
Am: Rel.(B)
Ph: Rel.(B)
3C454.3 7ant-Special scans 8335 to 8438 06-MAY-2016 06:08UT El: 56.44
rms Pha.
17 13.4
27 4.87
37 5.39
47 11.6
57 14.3
67 13.3
Edge taper = 12.13x 11.19 dB - offset X= -0.45 Y= 0.24 m
Focus offsets (X,Y,Z) = -0.41 0.11 0.00 mm; Astigmatism = 37.6 μm (178.2deg.)
Phase rms (unweighted)= 0.085 (weighted)= 0.083 radians
Surface rms (unweighted)= 26.90 - (weighted)= 25.66 μm
ηA(86.243 GHz) = 0.800; ηA(230.0 GHz) = 0.767; ηA(345.0 GHz) = 0.721
S/T(86.243 GHz)= 19.518 Jy/K; S/T(230GHz)= 20.362 Jy/K; S/T(345 GHz)= 21.651 Jy/K
ηI= 0.806 -ηS= 0.731 -ηP(86.243 GHz)= 0.993 -ηP(230 GHz)= 0.952 -ηP(345 GHz)= 0.895
Rms/ring: 29.5 23.1 22.8 22.5 25.5 31.8
Amplitude (back view)
-15.000 to 0.000 by 3.000
Normal errors (back view)
-500.000 to 500.000 by 100.000
0
-5
-10
-15
400
200
0
-200
-400

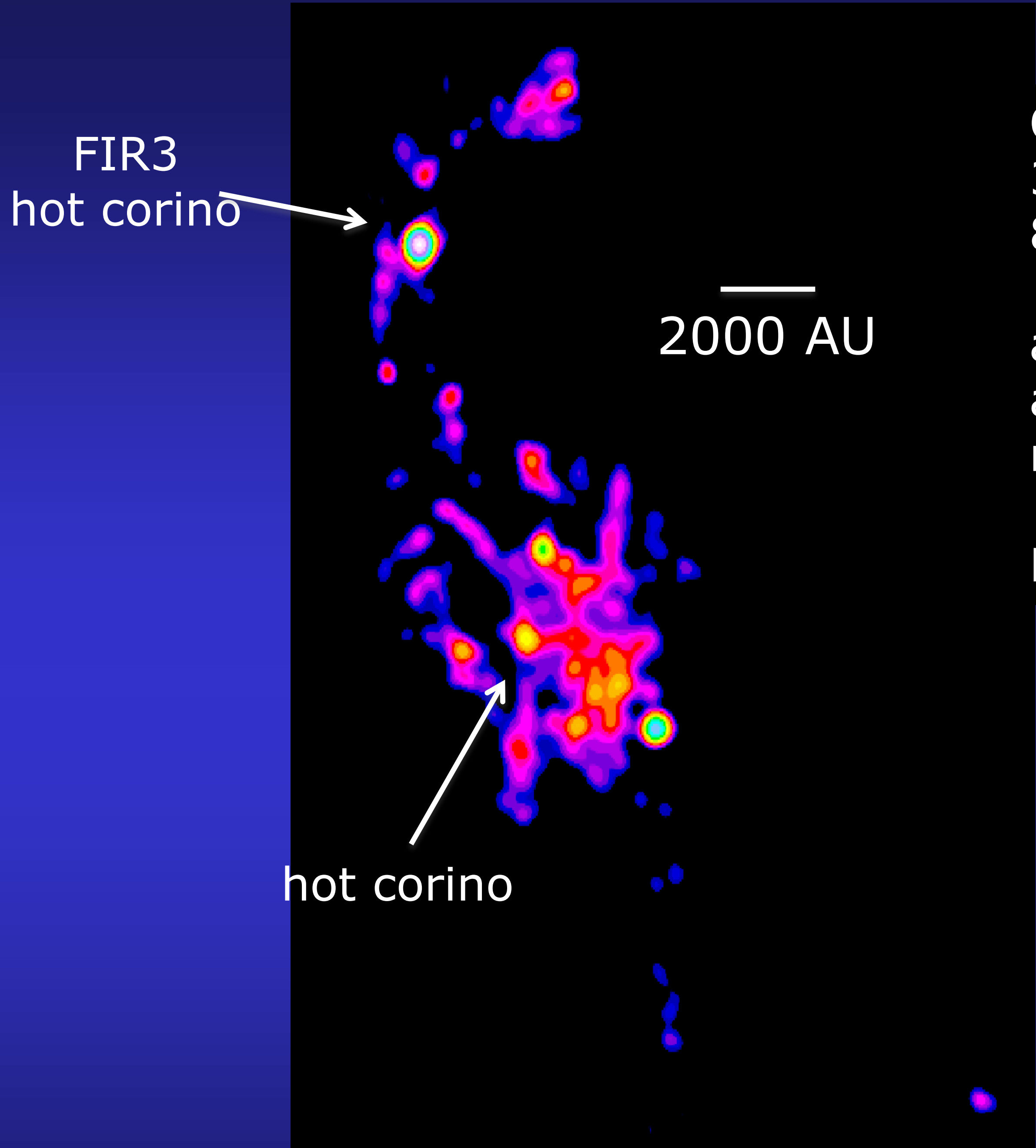
June 2017

RF: Uncal. CLIC – 27-SEP-2017 20:23:51 – oper@bure1 E04W09E10N13W12N02W05N09N05 9D No Avg.
Am: Abs. TSOFTEST SIOV1 86.243GHz B1 Q0() Q0() HORIZONTAL pol.
Ph: Abs. (297 4387 0 GAIN)–(327 4417 0 GAIN) 27-SEP-2017 20:04–20:22



ANT 10
roll out
May 18

With full commissioning of Ant 10
NOEMA Phase I was completed in September 2018



OMC2-FIR4
3mm continuum with
8 antennas

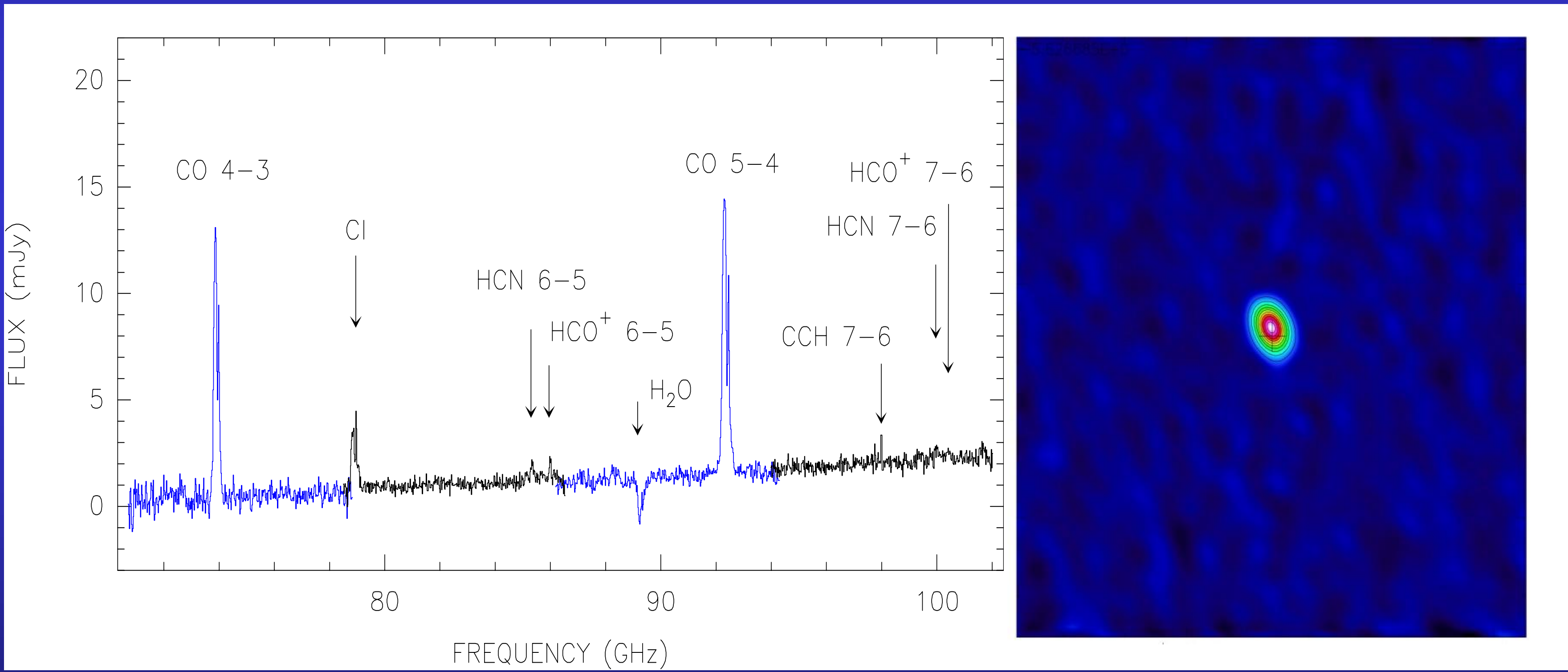
an extremely dense
and prolific stellar
nursery

Neri et al in prep

wide-band spectroscopy with PolyFiX

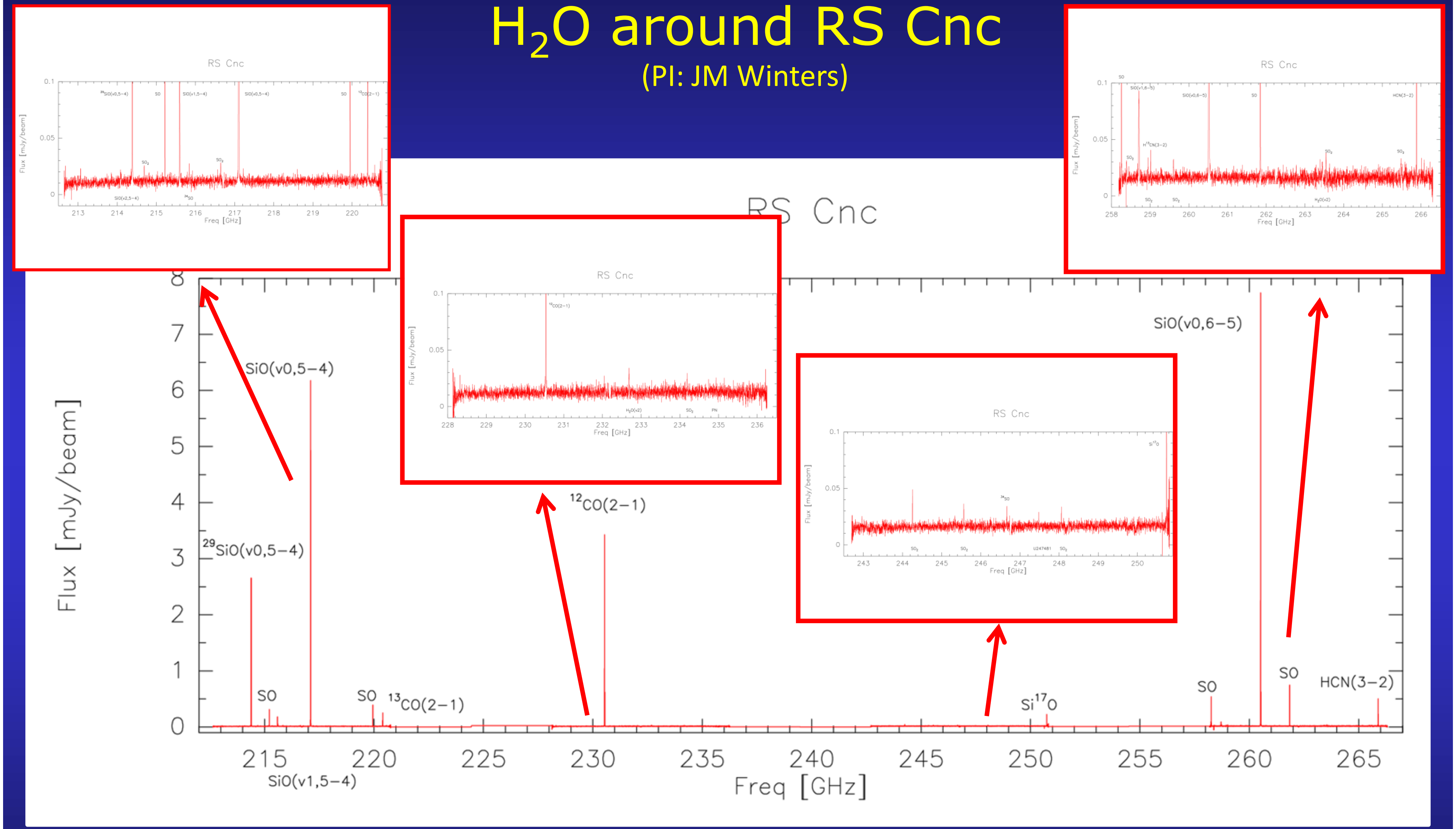
- 7.2 hr observing with nine antennas, two frequency setups
- continuum detected with a dynamic range 200:1

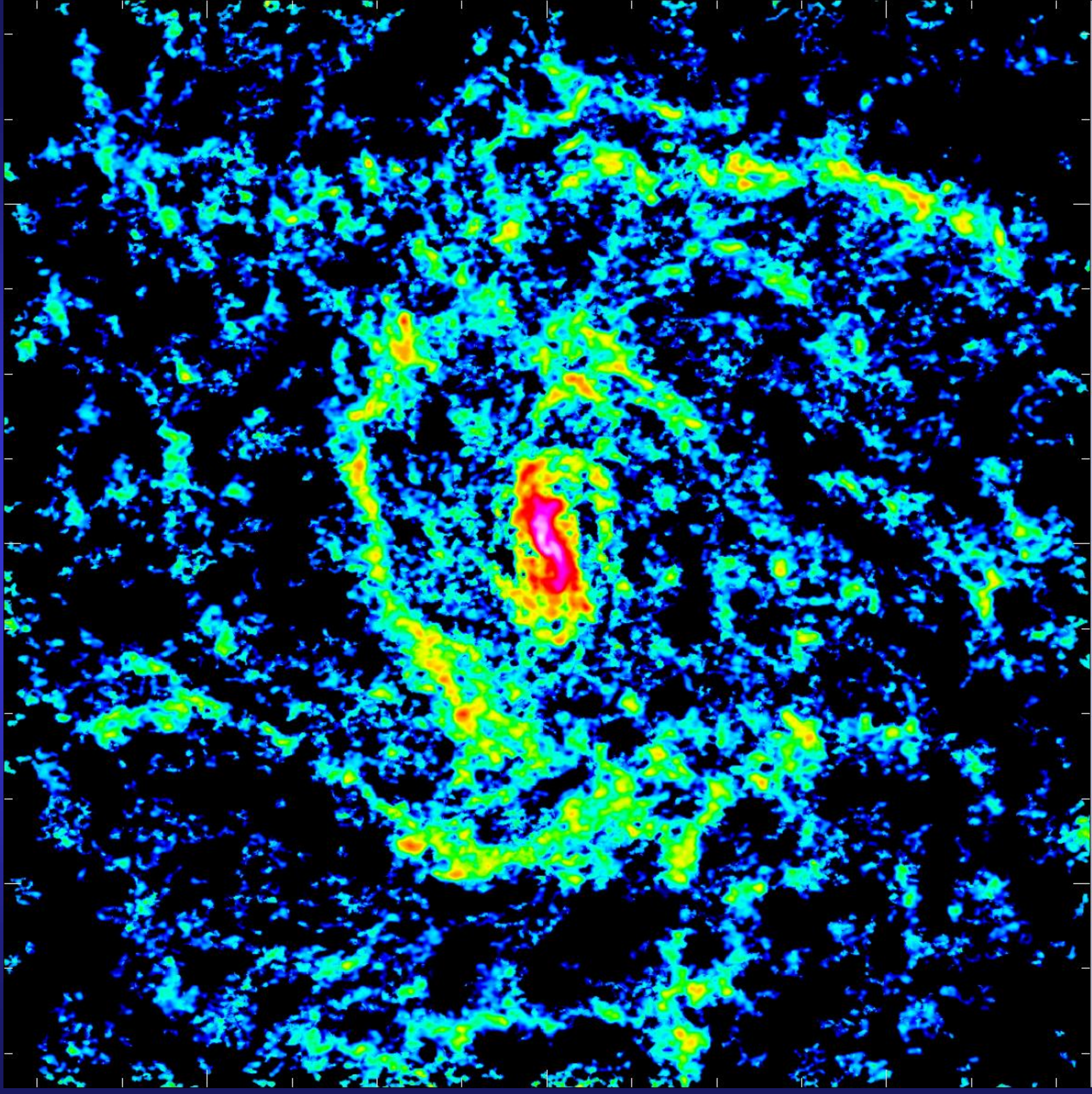
HLS J091828+5414223 (z = 5.2) Herrera et al. in prep



1^{st} 1mm line scan on evolved sta: H_2O around RS Cnc

(PI: JM Winters)





IC 342

seen by

NOEMA 8
+
IRAM 30m

Schruba et al

NOEMA Phase II

Institut de Radioastronomie Millimétrique

- Antenna 11 - funded- in construction
- Baseline Extension - funded- in preparation
- Antenna 12 - funded-

NOEMA Phase II is also supported by strategic partnerships with:

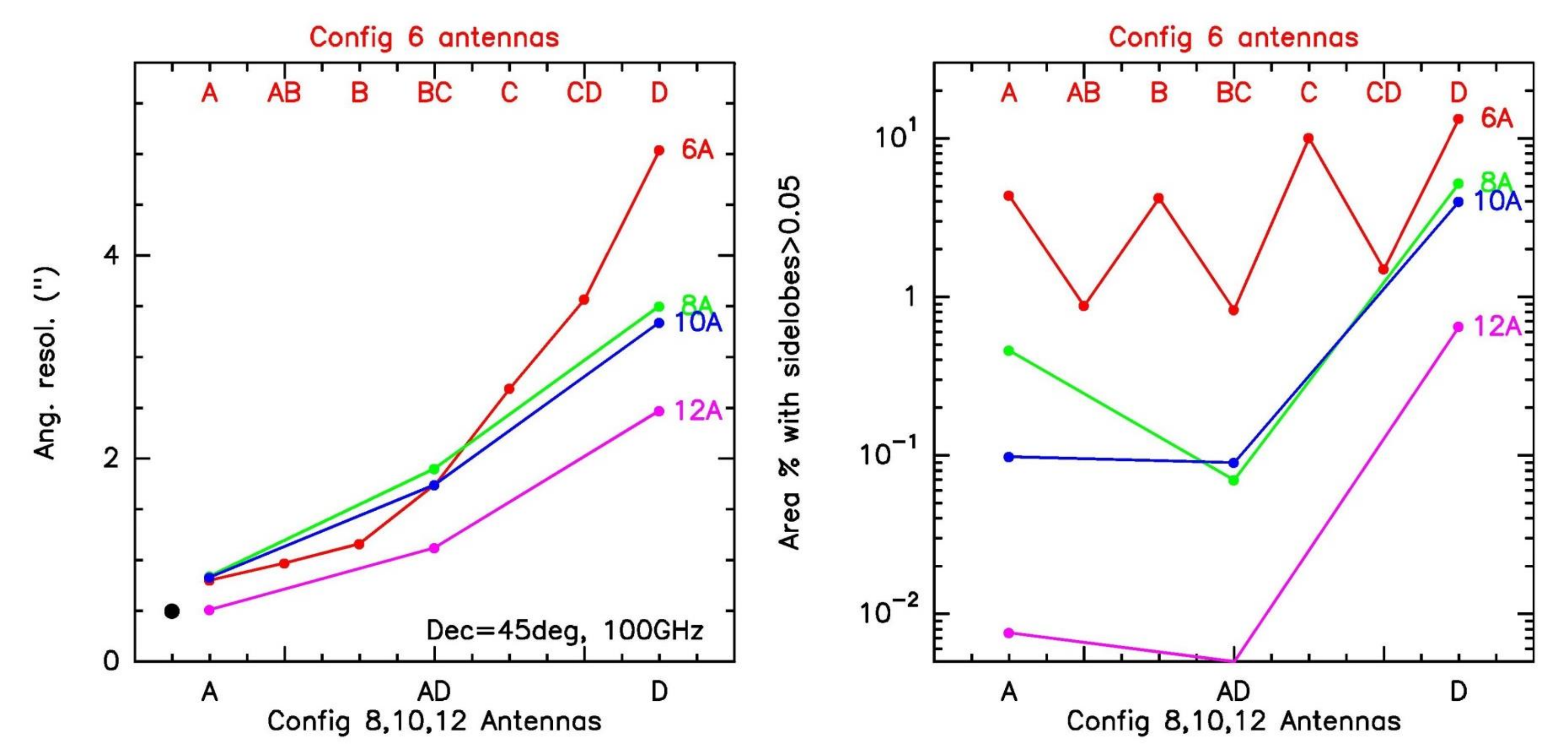
University of Michigan

Purple Mountain Observatory/CAS

Nanjing University

In preparation: University of Wisconsin

Imaging Beams and Sidelobes

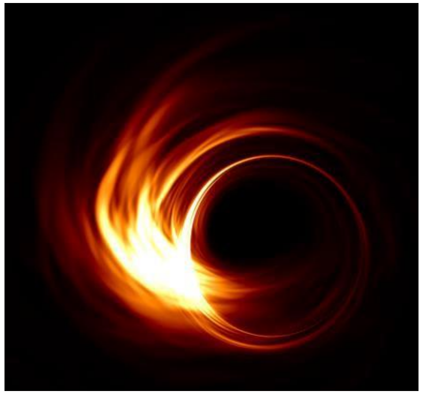


Boissier 2008

Next Steps beyond Phase II

• Full Phasing for mm-VLBI	-funded- through ERC-Black-Hole Cam, in work
• Full Sensitivity Dual Band Extension	-funded- by MPG ref. distribution installed, design study started
• Full Stokes Polarimetry	-to be funded-

Phased NOEMA for EHT

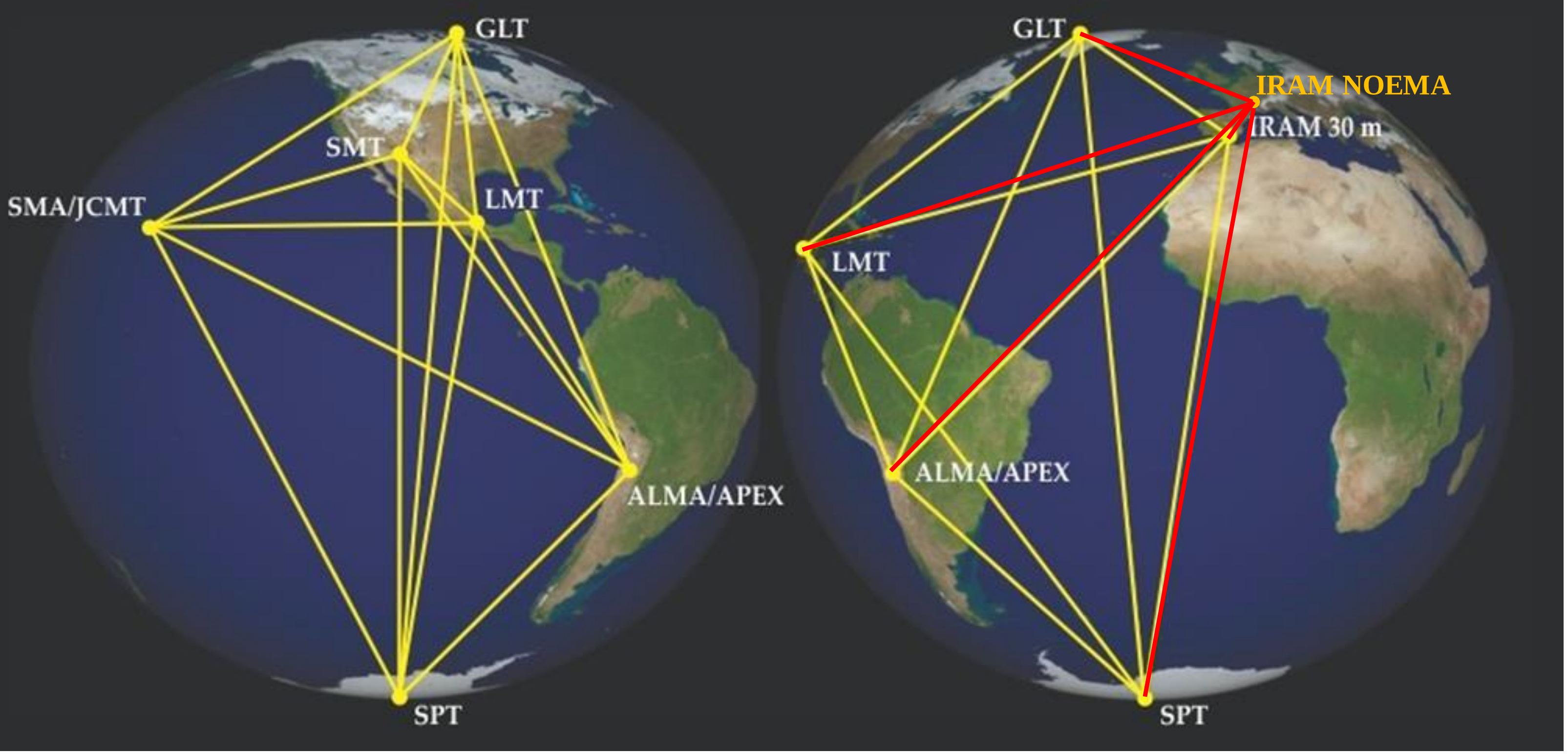


•Capture the very first picture of a Black Hole at 1.3mm and 0.8mm (230/345GHz) with unsurpassed angular resolution (~20µas)

•Targets: Sgr A* (center of milky way, 4 million Solar Mass) + M87

EHT Network Stations
(as of May 2018)

- Chile: ALMA + APEX
- Hawaii: SMA+JCMT
- Antarctica: SPT
- Greenland: GLT
- Arizona: SMT
- Mexico: LMT
- Spain: PV



Next Steps beyond Phase II

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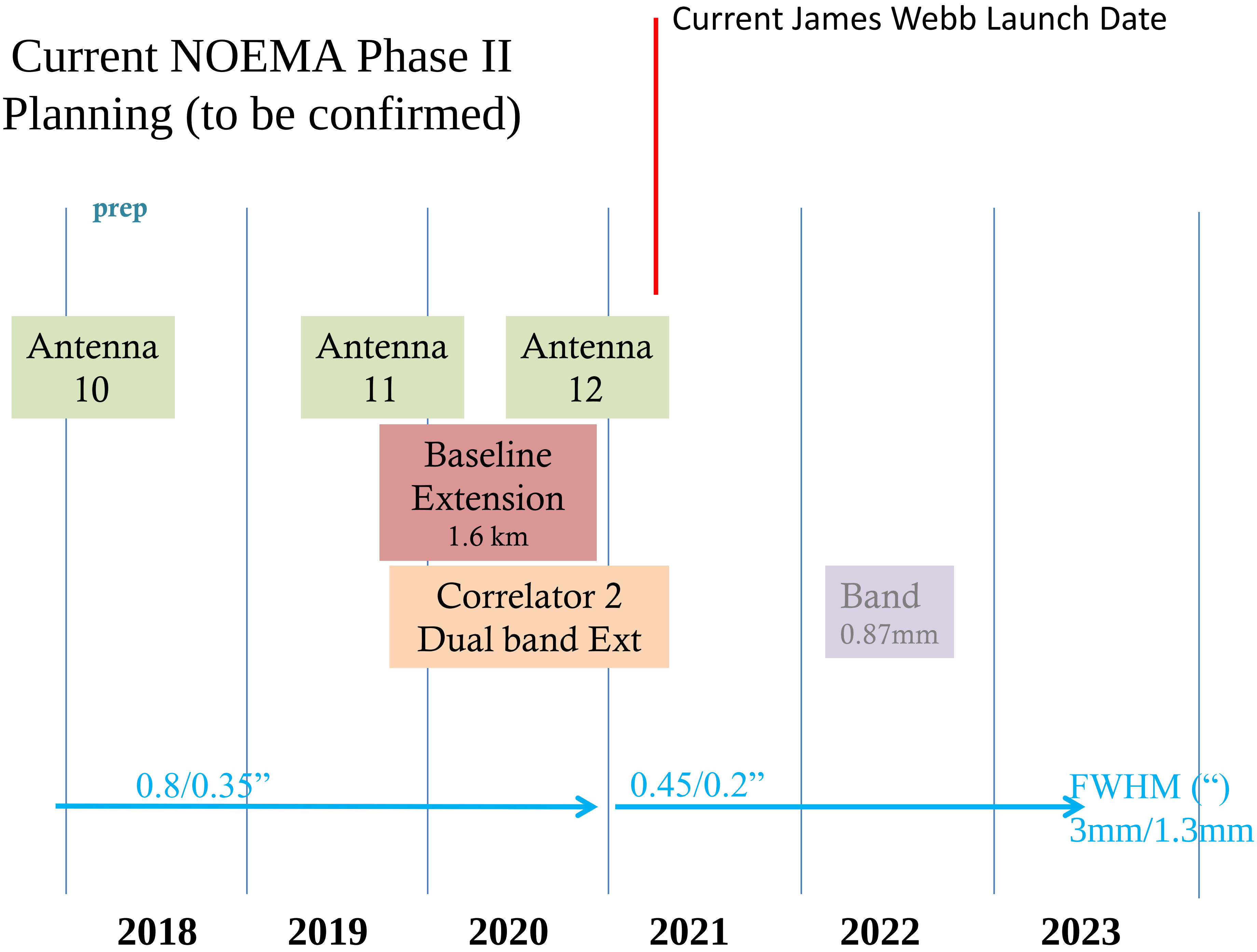
- Full Sensitivity Dual Band Extension — -funded- by MPG ref. distribution installed, design study started
- Full Stokes Polarimetry — -to be funded-

Assembling of Antenna 11 has been started :

Current NOEMA Phase II Planning (to be confirmed)



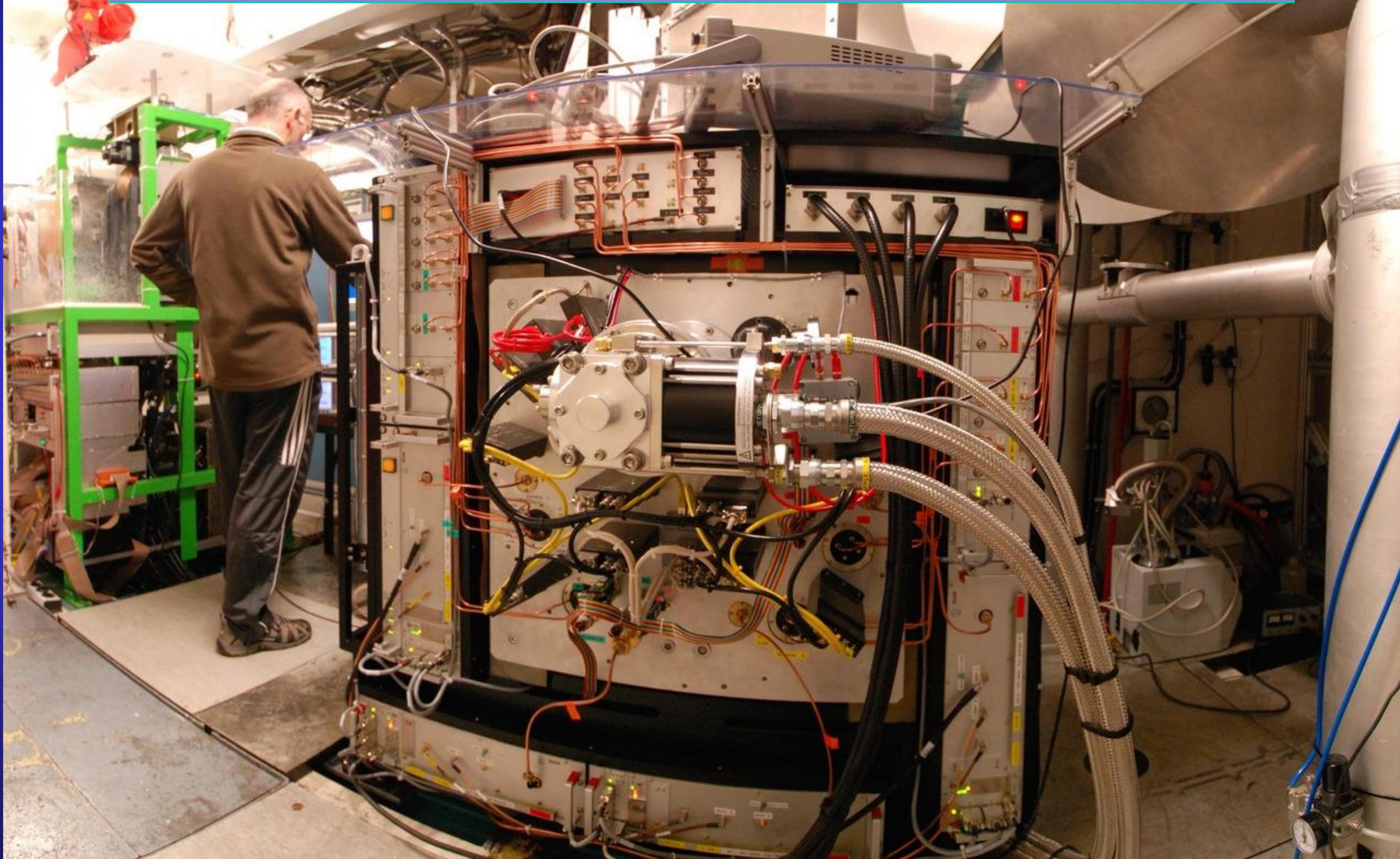
IRAM 30m, Status, Instrumentation and Future Evolution

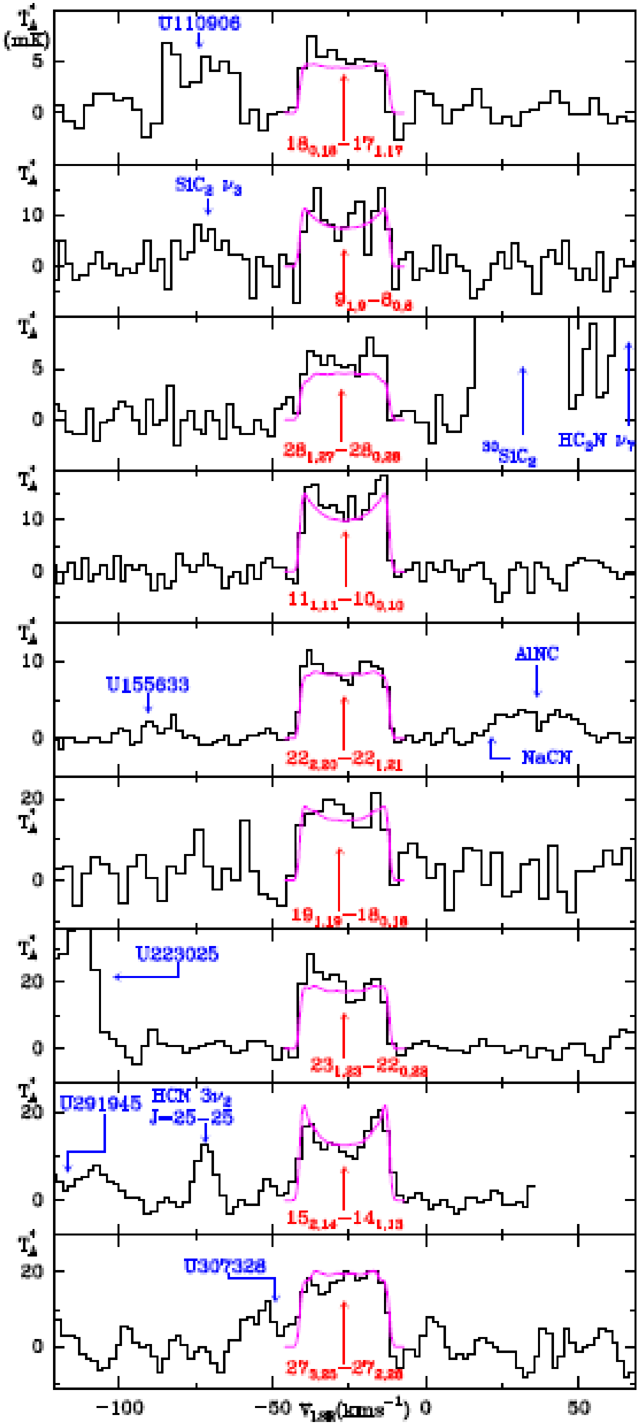
- EMIR with high resolution backends for up to 64 GHz total bandwidth
- HERA the 18 pixel 1.3 mm Heterodyne Array
- NIKA 2, a dual band continuum imager with 6 arcmin FOV and polarization option.
- The future 50 pixel 3mm and 98 pixel 1.3 mm Heterodyne Arrays

Todays and Future Role of 30m telescope

- Large bandwidth multiband spectroscopy in range from 70 to 370 GHz.
- Large high sensitivity maps in line and continuum with resolutions 10”-25”.
  - Mapping-out structure of gas in MW and NB galaxies
  - Source finding.
  - Low Surface Brightness Science (SZ - diffuse mol gas….).
- Essential short spacing tool for NOEMA and ALMA
- Polarimetry of Galactic Structures
- Essential high sensitivity mm VLBI Station

EMIR,
the worlds most powerful mm wave receiver
(produces up to 64 GHz of IF band)





Blossoming Chemistry with the 30m

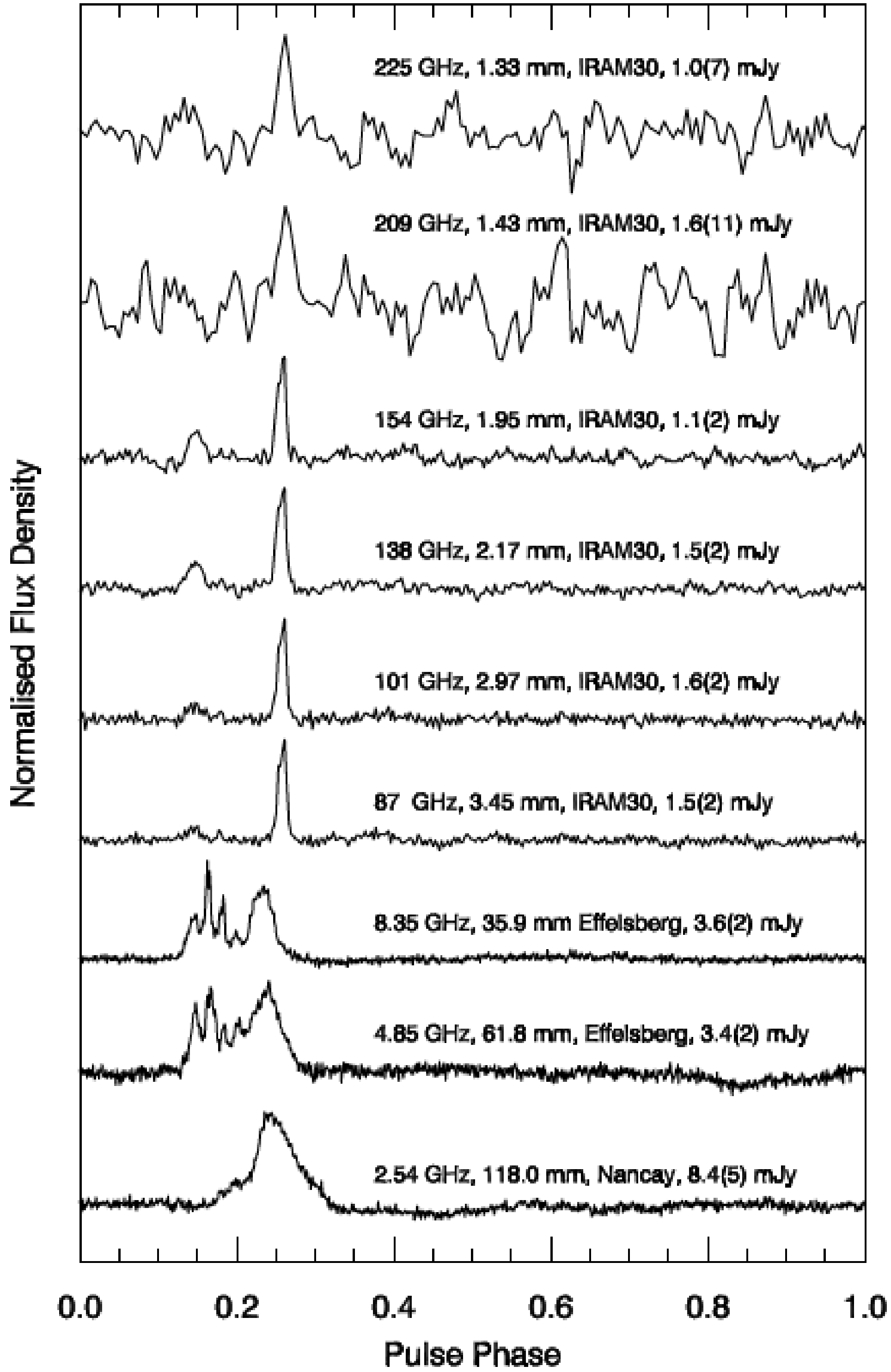
EMIR – a Game Changer

First Detection/Identification of interstellar Si-C-Si

A missing link in the dust formation around CW LEO

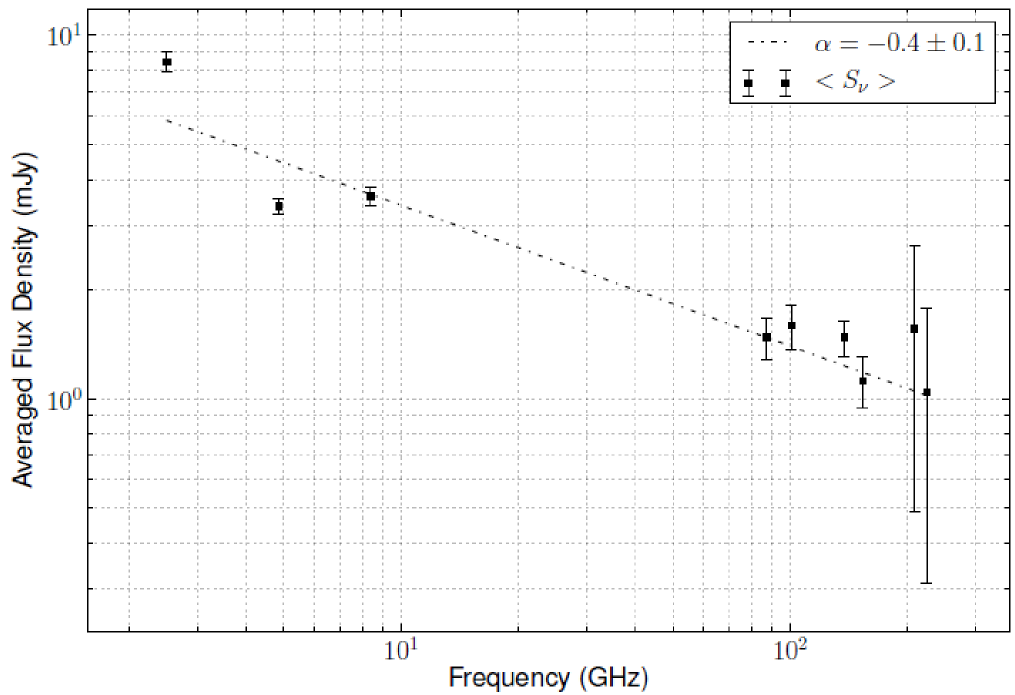
Cernicharo et al. 2015

A result from the 3mm, 2mm, 1.3mm and 0.8mm survey with the EMIR at the IRAM 30m telescope

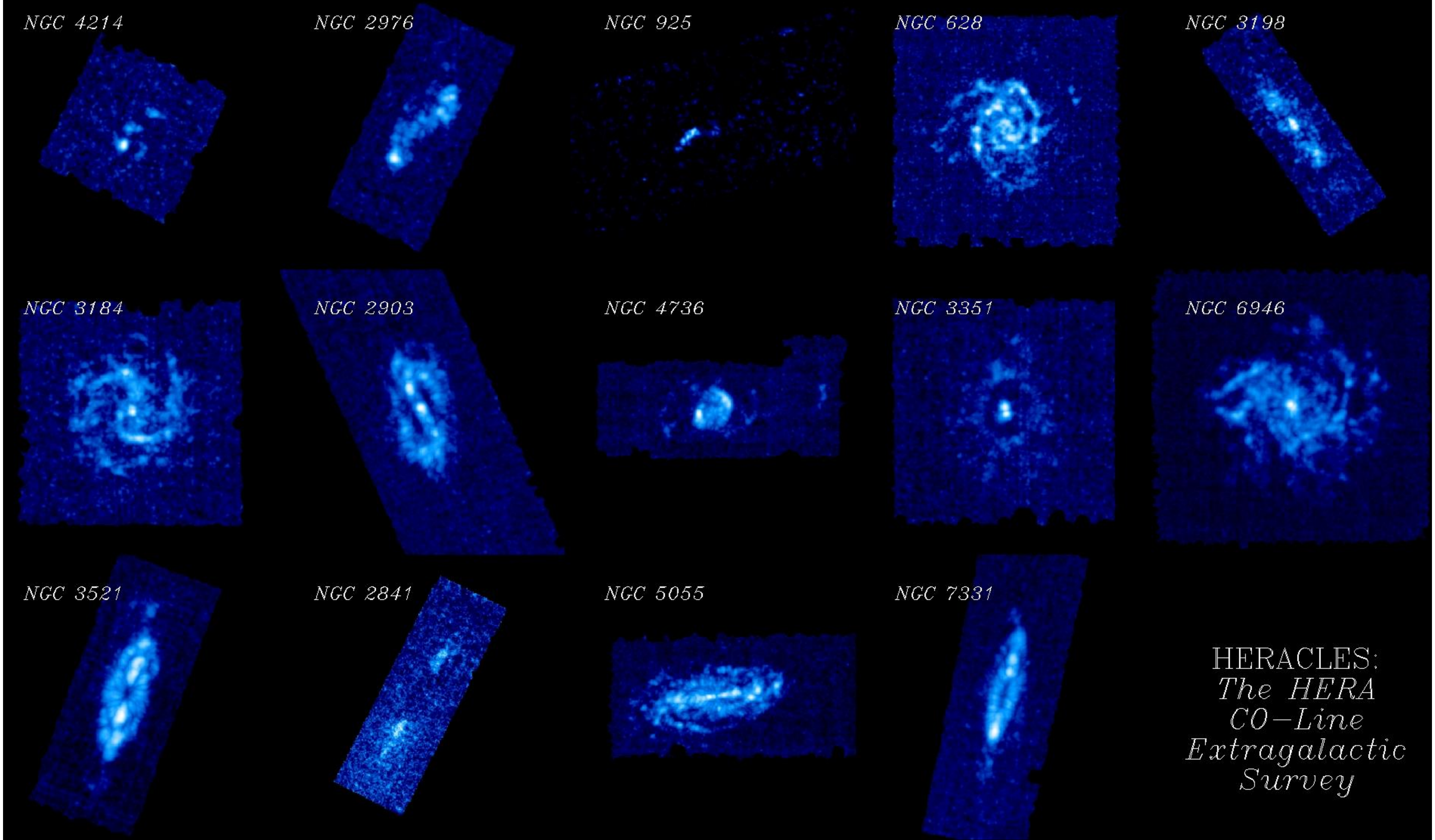


SGR J1745−2900

a MM-Wave Pulsar/Magetar in GC
P. Torne et al 2015

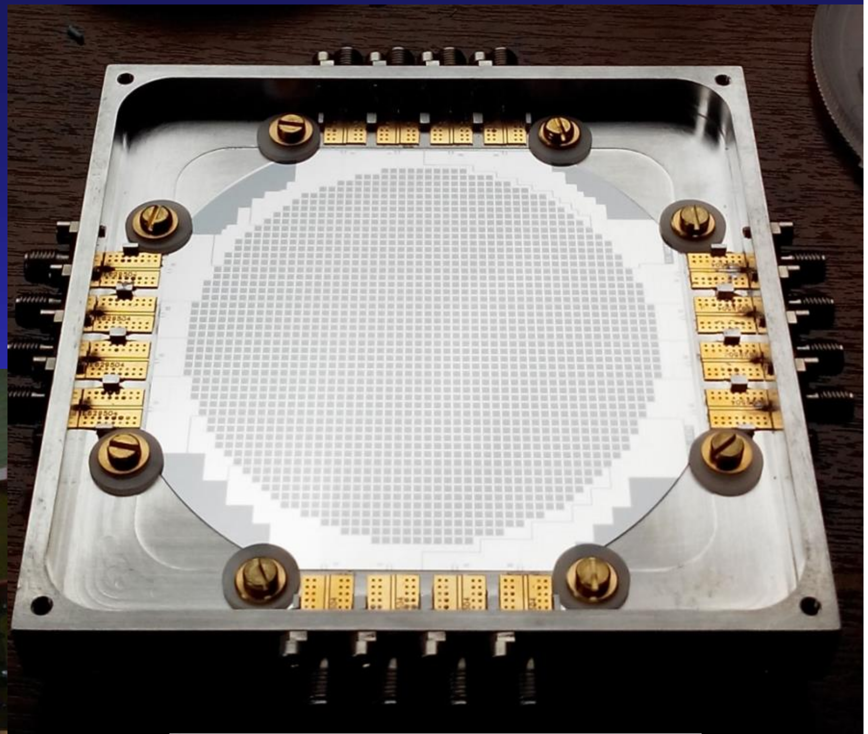


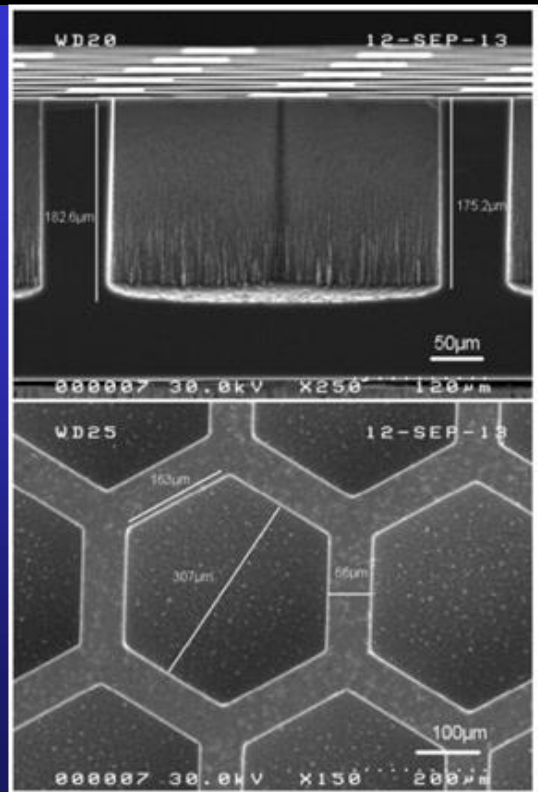
Heterodyne Large Scale Mapping



Leroy, Walter et al

NIKA 2 (PI Benoit et Monfardini)
6′ FOV KID Camera
Dual band 2 + 1.3 mm
including 1.3mm Polarimetry

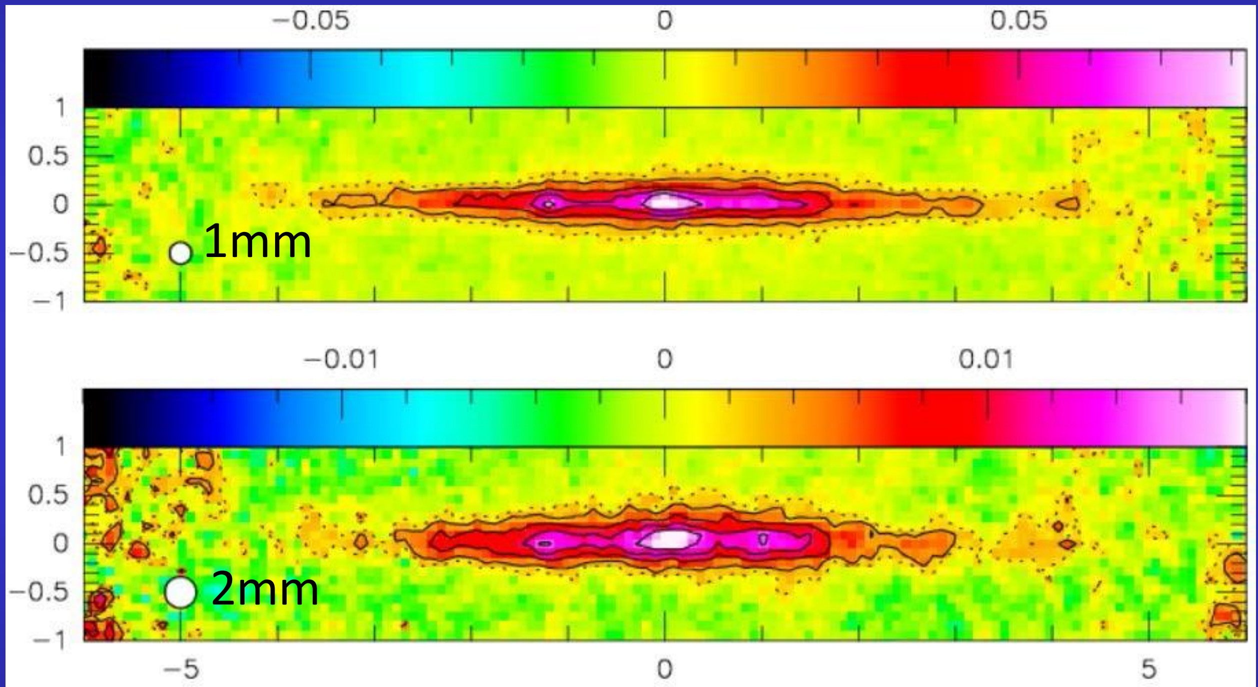




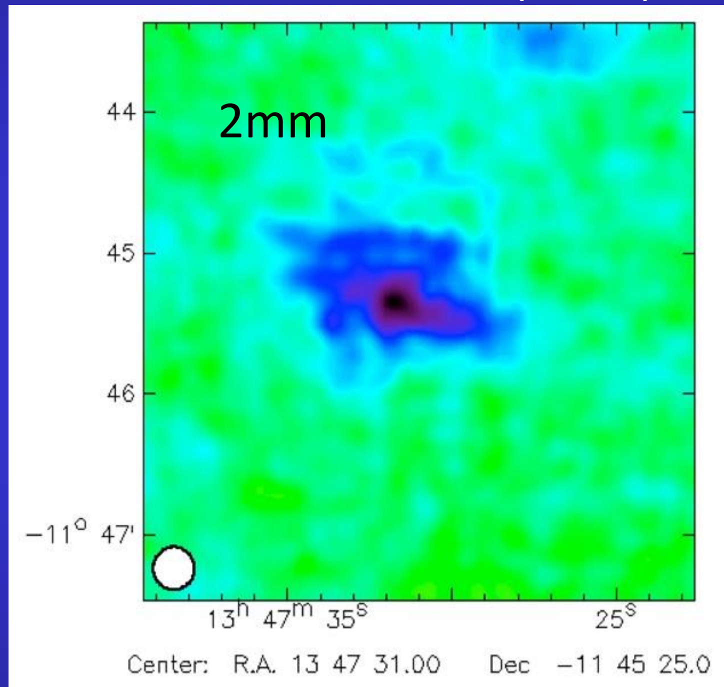
French Consortium with GTO scheme

NIKA 2
Examples of maps from Commissioning

NGC891 (run 1)



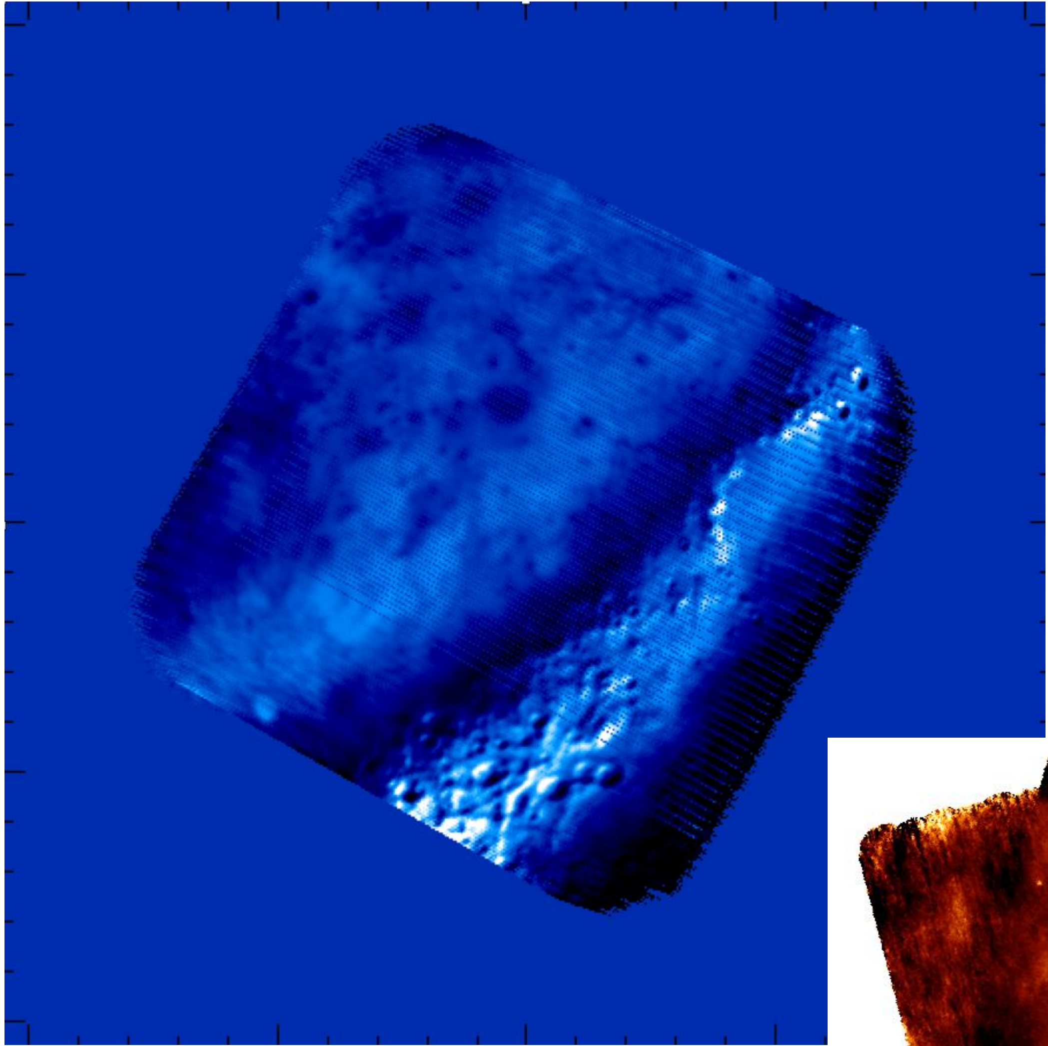
RXJ1347-1145 (run 4)



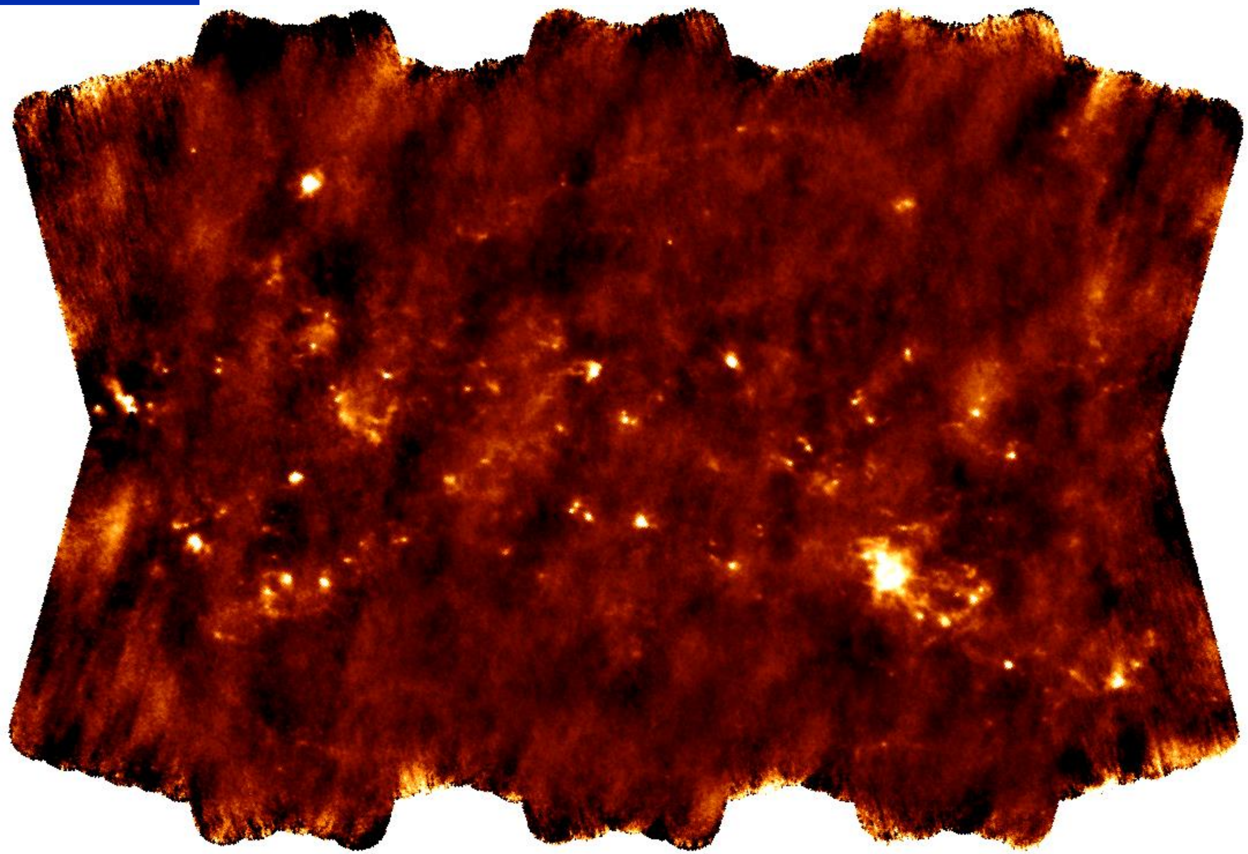
Preliminary NEFD:

8 ±3 mJy·√s @ 2.0 mm

30 ±5 mJy·√s @ 1.2 mm



GTO LP GASTON Peretto et al



Next Steps (1)

Considering

- the 30m as integral part of the NOEMA concept and its crucial role of high calibration accuracy for successful short spacing measurements for NOEMA.
- the importance of large scale mapping and surveys
- the Importance of low surface brightness astronomy
  - -SZ -diffuse gas -galactic clouds in weak tracers
  - -nb galaxies in CO isotopomeres
- the importance of new step in calibration accuracy in millimeter astronomy. Line ratios central for understanding the chemical universe, photometric redshifts => the need to go from 20% to < 3% accuracy.
- The multi-million € effort into powerful mapping instruments

Next Steps (2)

IRAM is preparing an ambitious 30m upgrade program :

- Improve surface to: Goal 40 mu rms for El 15-85 deg, Spec 45 mu
- Improve Thermal Control
- Replace/Upgrade Drive system and control loops

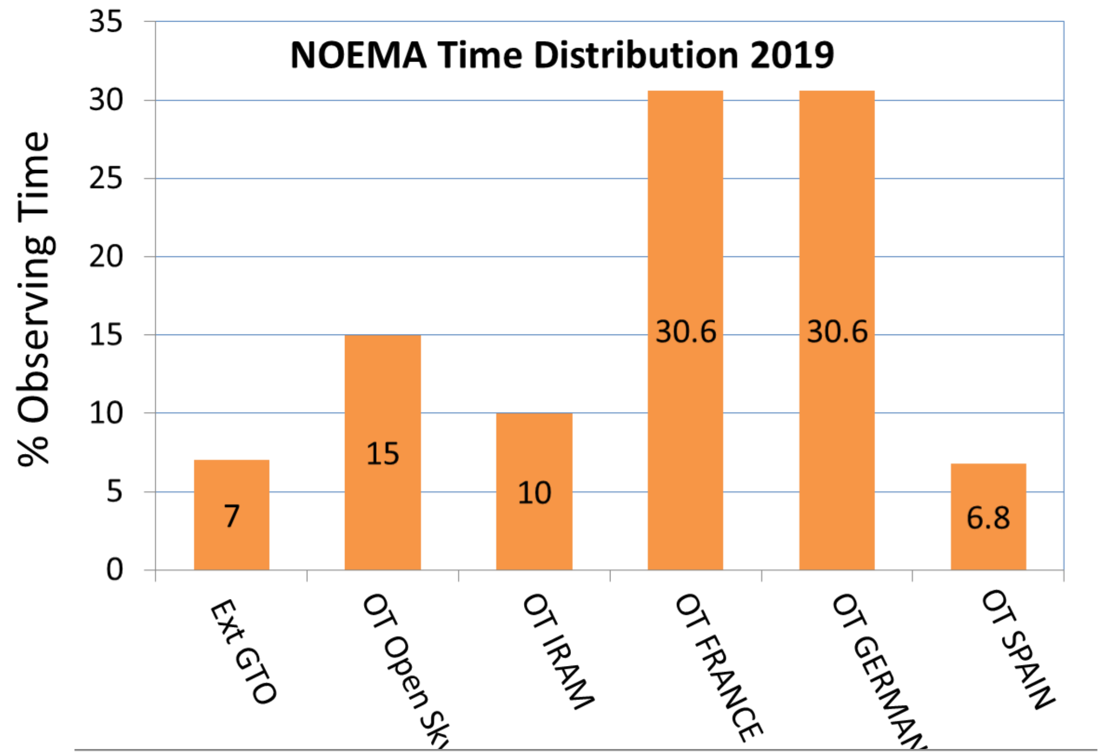
Observing Time Policy

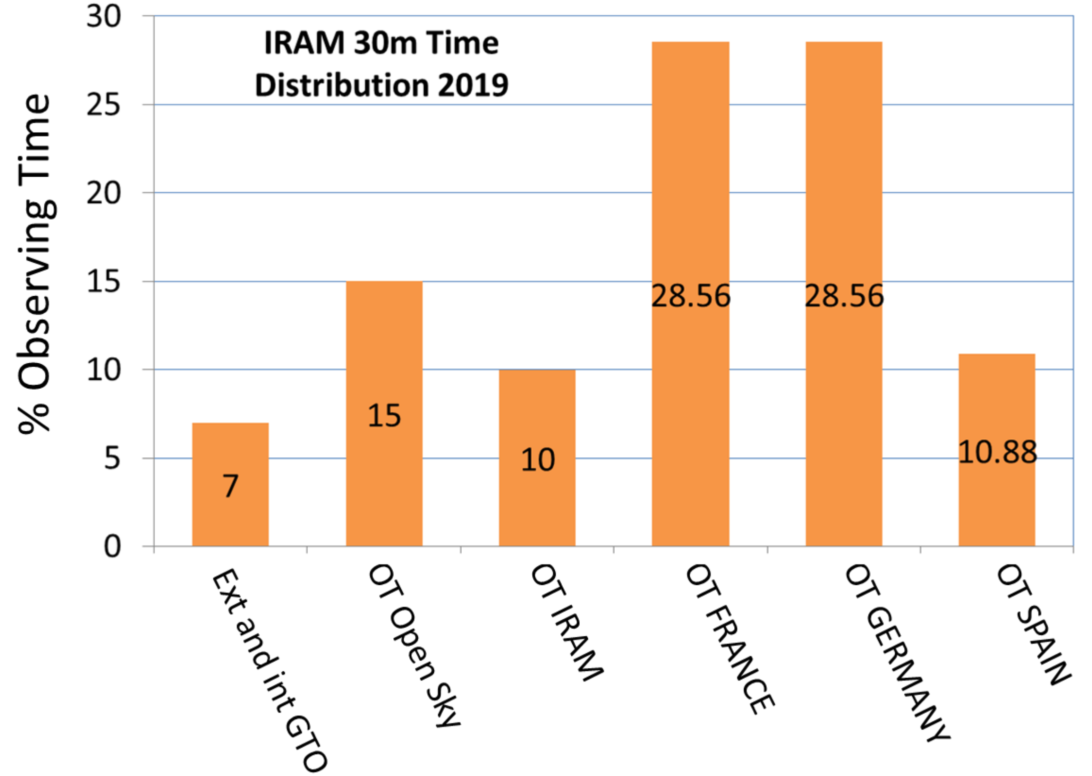
iram
Institut de Radioastronomie Millimétrique

- 2 calls for proposals per year (deadlines April and September).
- Director is responsible for scientific program and receives input from a Program Committee (PC) in form of ranking (A,B,C).
- Program committee meets two times a year and treats 30m and NOEMA proposals on same occasion.
- PC nominations are done by the IRAM steering committee (“Council”)
- PC consist of 2 panels (galactic, extragalactic), LPs and VLBI proposals are treated by both panels.
- No science type quotas. All proposed observations except DDT are evaluated by the PC.
- IRAM currently reserves 15 % observing time for open sky. In reality this number is often higher.
- Up to 7% DDT can be distributed by director, but DDT is accounted for in the individual slots.
- LPs (all programs >100 h) can be proposed and can run over several semesters.
- LP need PI from partner countries and collaborating institutions, LP PI is not admitted for other PI-ships until end of corresponding LP observing.
- LPs may be accepted up to a total of 50% of global observing time.

Current Time Distribution Goal

Time distributions evolve over time to account for external or asymmetric investments.





Data Policy and Archiving

- Data are made available to PI as soon as observed.
- Propriety period is 36 months for normal programs and 18 months for LPs (as of end of observing).
- Requests for data can be made through IRAM without contacting PI and will be served unless data have special flags (thesis or similar…)
- Header of all observations are visible in CDS after ~ 6months.
- All observations are kept indefinitely in raw data format and calibrated data format. 2 copies are kept for NOEMA, currently 1 copy for 30m with 2nd copy installed in near future.
- Fully reduced science data of LPs are made available through the IRAM LP data archive.

My personal observations over the years (on average) :

- French IRAM community (FIC) relatively well connected in international collaboration and networks – space for further progress, in particular for taking on leads.
- FIC is often front-running with innovative and unconventional ideas, often requesting utmost limits of instruments.
- FIC is less focused on how to optimize programs to instruments performance for high throughput.
- On average FIC has tendency to work in smaller groups and thus so far is less active in large program sector.
- On average FIC has somewhat longer laps from data to publication.
- Last two points might be related to number of available PhD and Post-Doc positions. IRAM has and will always support funding requests from users to funding agencies (nat or EU) through various paths (support letters etc).

- **Unique opportunities for French Community with the access to IRAM instruments. Use them !**

Thank You for Your Attention

Frédéric Gueth

IRAM next instrumental developments

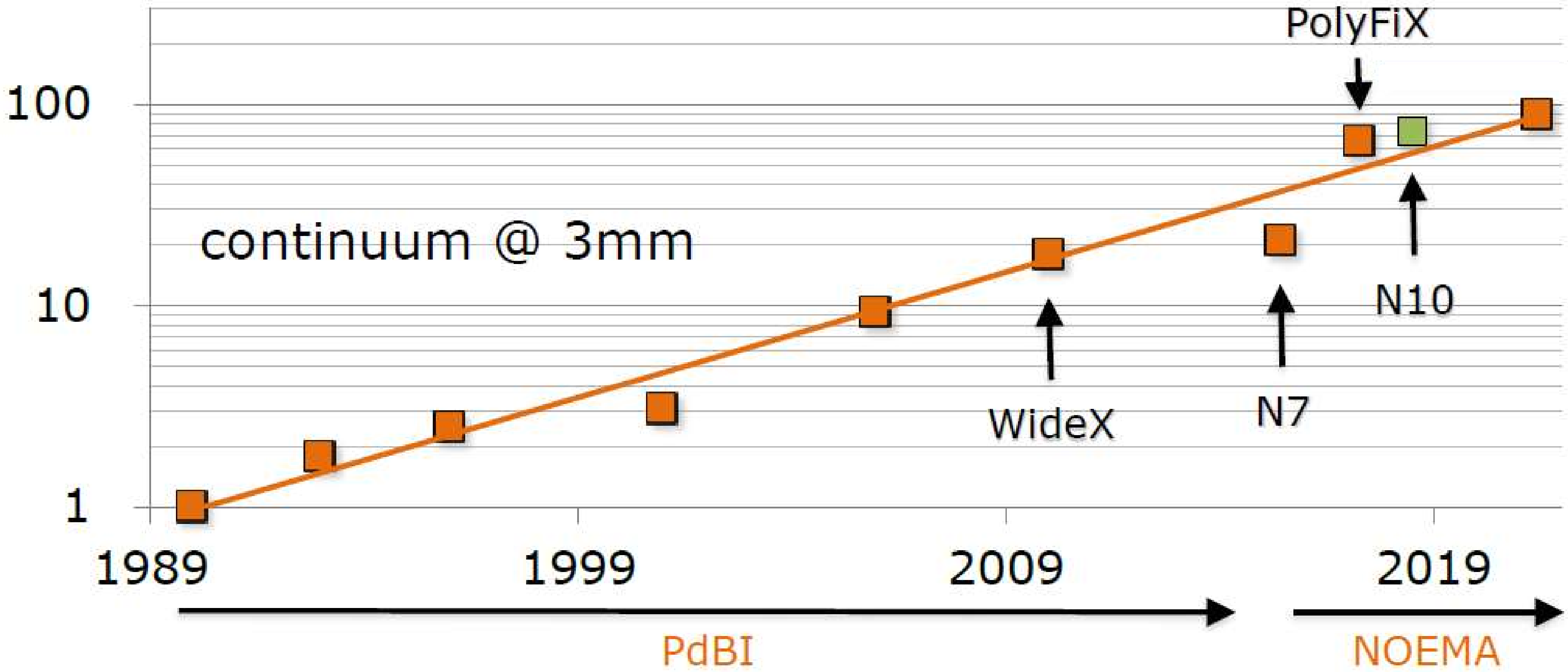
iram
Institut de
Radioastronomie
Millimétrique

IRAM next instrumental developments

F. Gueth, Journée IRAM, 31.01.2019

Evolving instruments

- 30-m and NOEMA are currrently operated with **5th generation** receivers
- PdBI/NOEMA continuum sensitivity increased by a factor 100



Evolving instruments

- 30-m and NOEMA are currrently operated with **5th generation** receivers
- PdBI/NOEMA continuum sensitivity increased by a factor 100
- Four EMIR upgrades between 2009 and 2016

- **Possible future gains**
  - Sensitivity
  - Bandwidth
  - Multi-line simultaneous observations
  - Multi-band simultaneous observations
  - Field of view
  - Polarization

PolyFiX observing modes

Mode 1 : continuum + lines	**complete 16 GHz coverage in each polar. with 2 MHz channels** **AND** **128 windows of 64 MHz** (= 8 GHz coverage) with 62.5 kHz channels, each window tunable individually in steps of 64 MHz*
Mode 2 : survey mode	**complete 16 GHz coverage in each polar. with 250 kHz channels**
Mode 3 : continuum + high-res. lines	same as mode 1, but with 64/32/16 windows of 64 MHz with 32/15/8 kHz channels

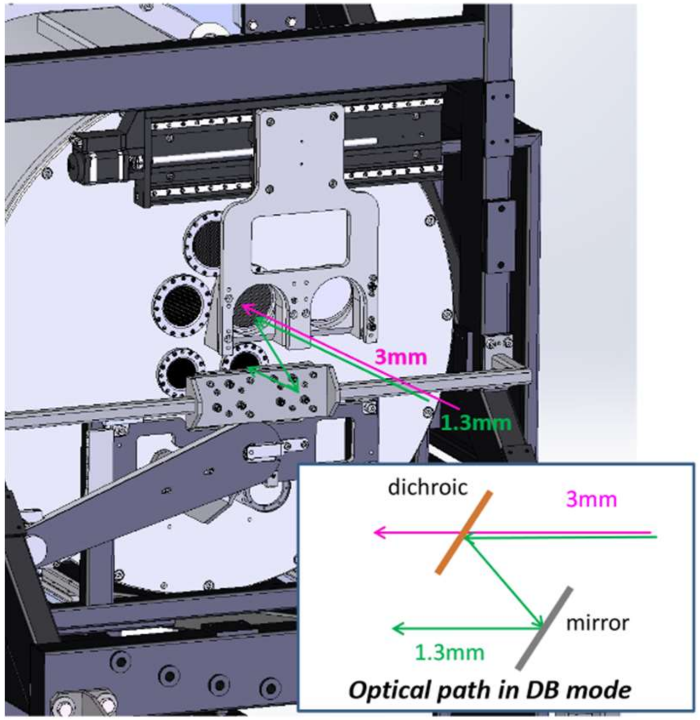
* With the constrain of having 16 windows in each of the 8 4 GHz-wide correlator units

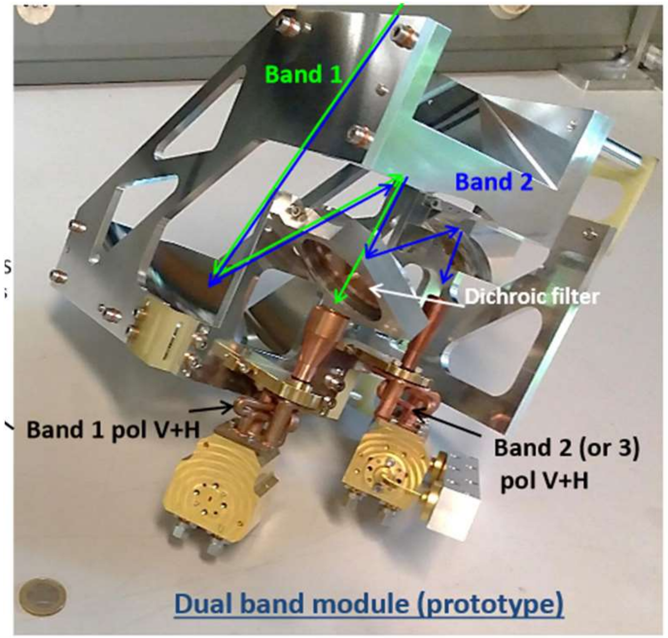
Dual-Band NOEMA

- Goal = **observe simultaneously with two frequency bands** (typically: 3 + 1.3 mm)
- Gains: factor of two in observing time, improve relative calibration, allow simultaneous observations
- **<u>Correlator</u>**: PolyFix2 under construction → **process 64 GHz/ant**

Dual-Band NOEMA

- **Receivers**:





Step 1: ambiant temperature combination (like EMIR)
Lab. tests this spring!

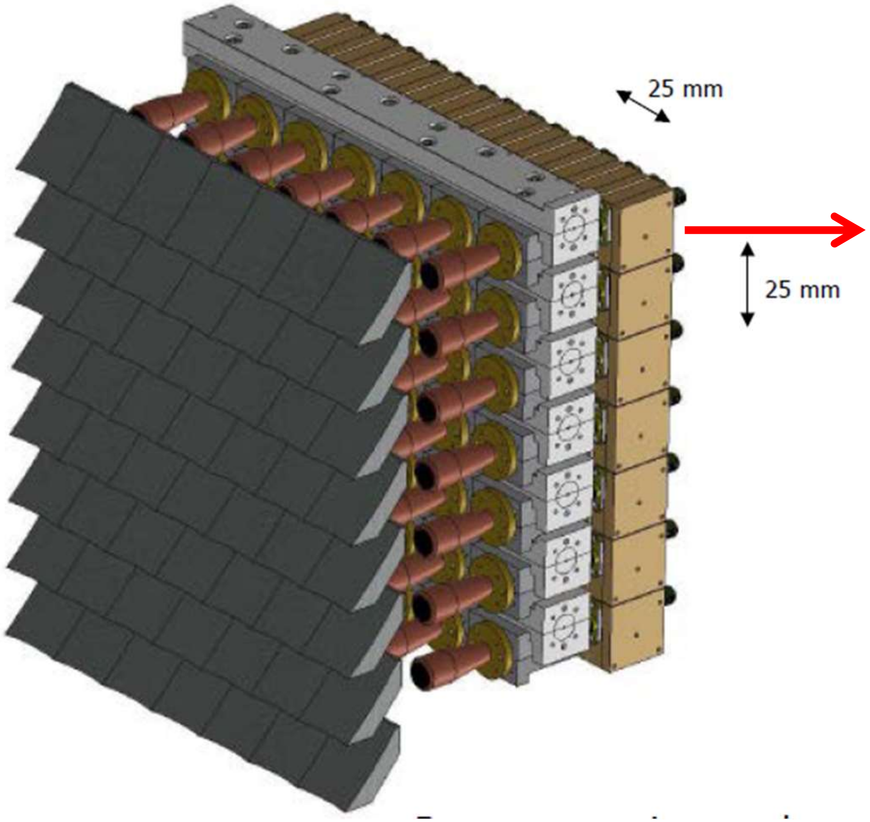
Step 2: Cryogenic temp. combination

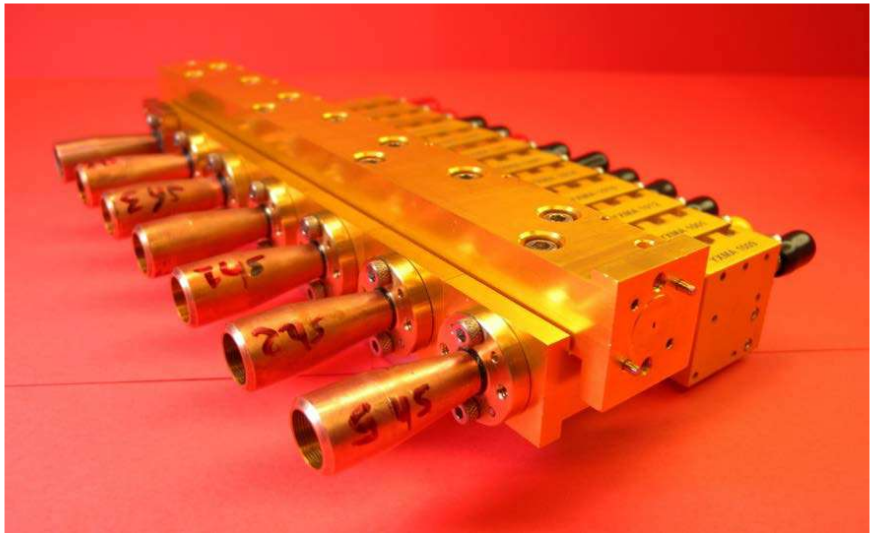
Multi-beams 30-m

- **Current instrumentation at the30-m**
  - EMIR: Heterodyne 4 bands x 2 polar, 4-12 GHz IF, multi-bands mode
  - HERA: Heterodyne multi-beams, 9 pixels x 2 polar
  - NIKA2: Continuum, 2 mm + 1.3 mm x 2 polar

- **In development: new generation multi-beam arrays**
  - **3-mm** 5x5 pixels
  - **1-mm** 7x7 pixels
  - Each pixel = EMIR performances, 4-12 GHz IF x 2 polar

Multi-beams 30-m



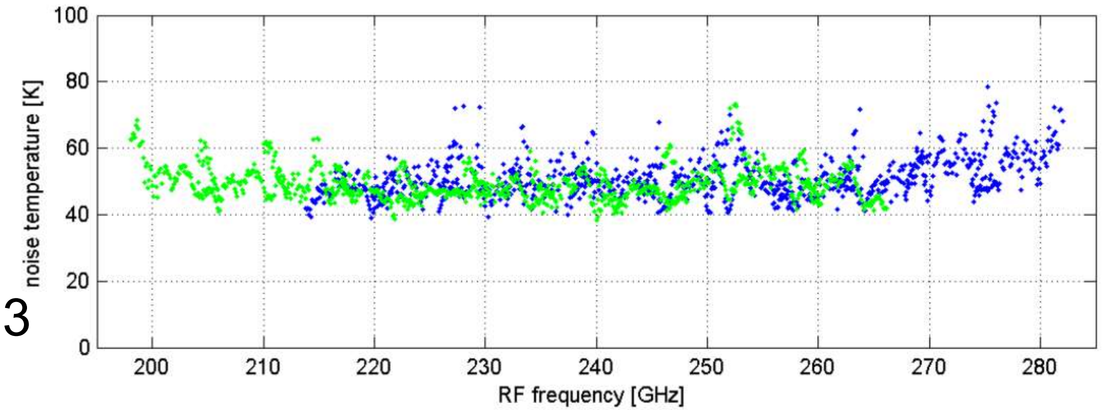


Prototype 7 pixel module

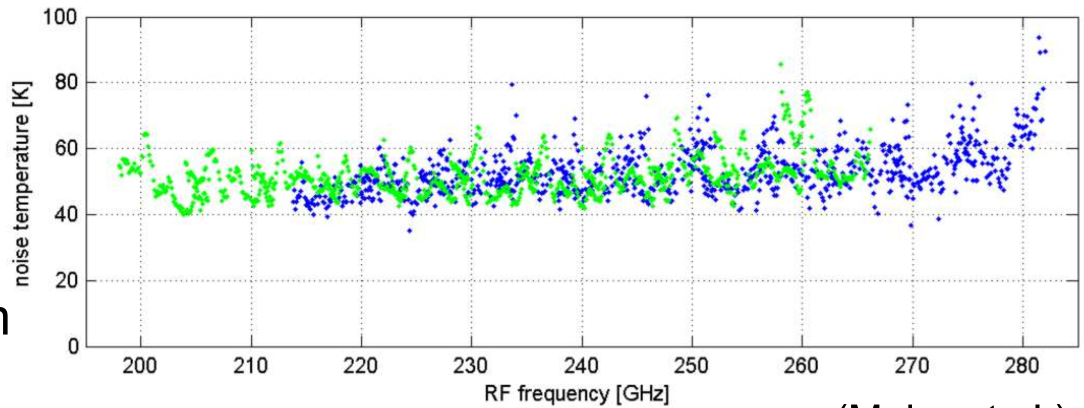
Multi-beams 30-m

Lab measurements
Trec vs Freq

NOEMA B3



MB 1.3mm

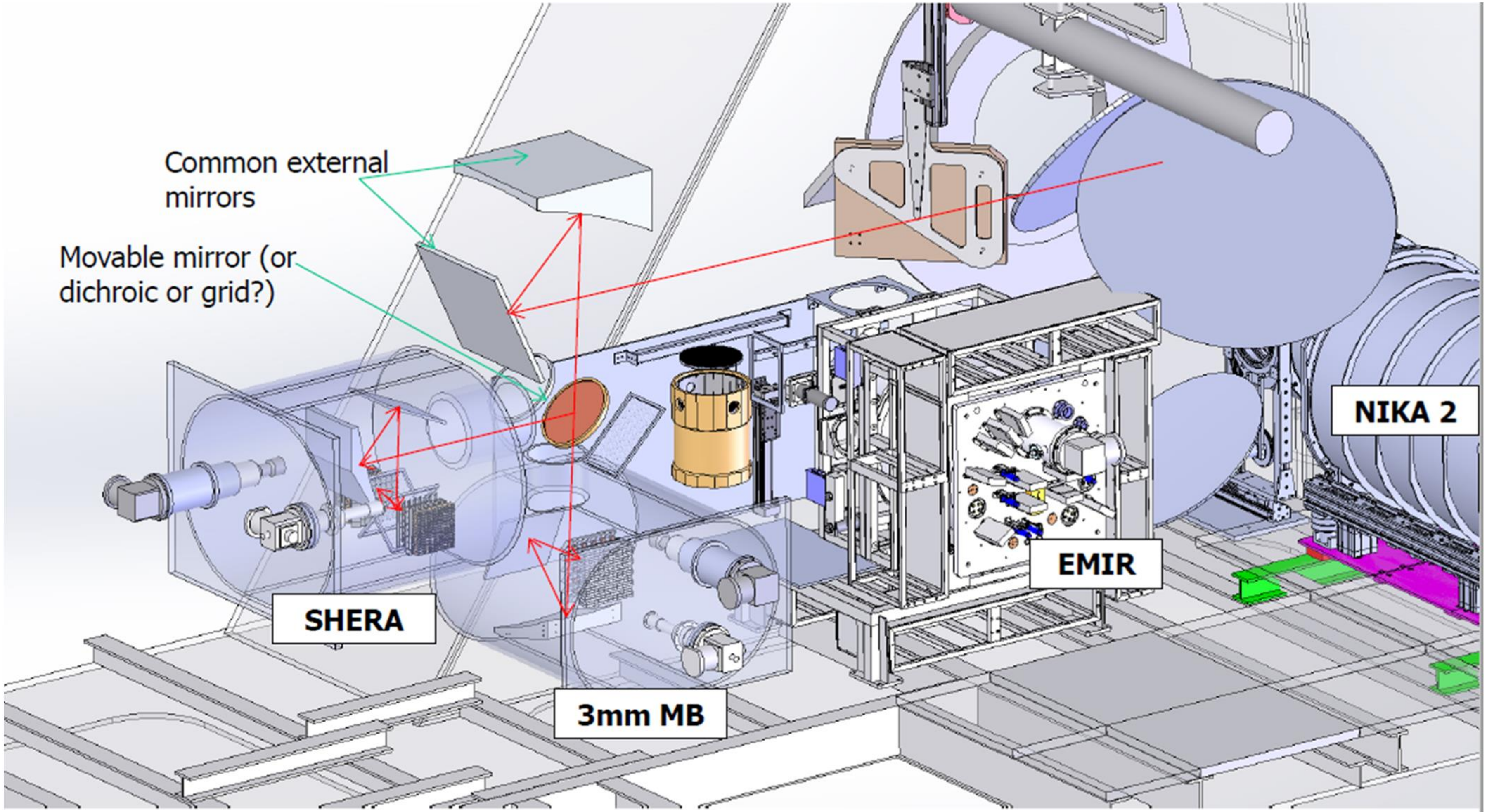


(Maier et al.)

Multi-beams 30-m

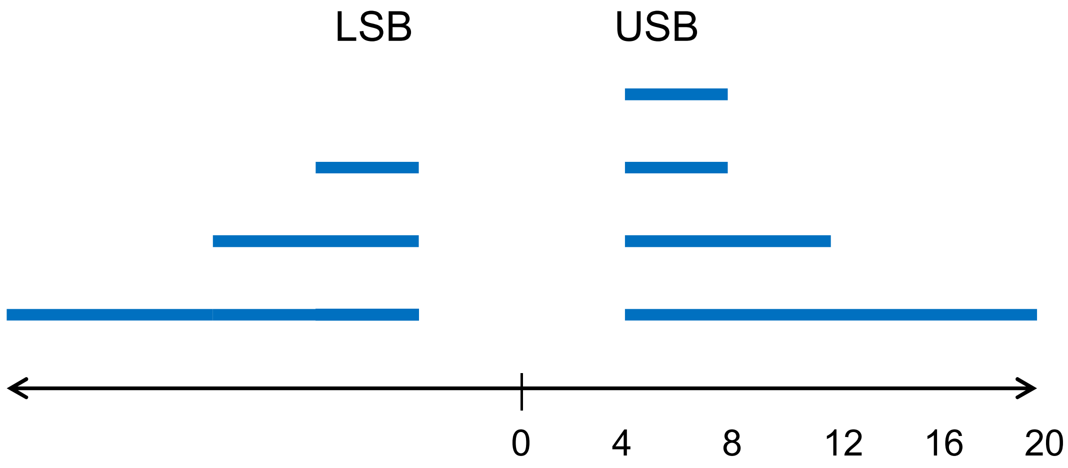
HERA **EMIR** **NIKA2**

Multi-beams 30-m



IF bandwidth

Increasing the instantaneous IF bandwidth per polar.



PdBI 4-8 GHz

ALMA 2x 4-8 GHz

NOEMA/EMIR 2x 4-12 GHz

4-20 GHz

Detectors at prototyping stage

Scientific gains

- Continuum observations (sensitivity)
- Spectral/redshift surveys (time)
- Multi-lines observations flexibility
- Spectral indexes measurements
- …

Summary

Under development

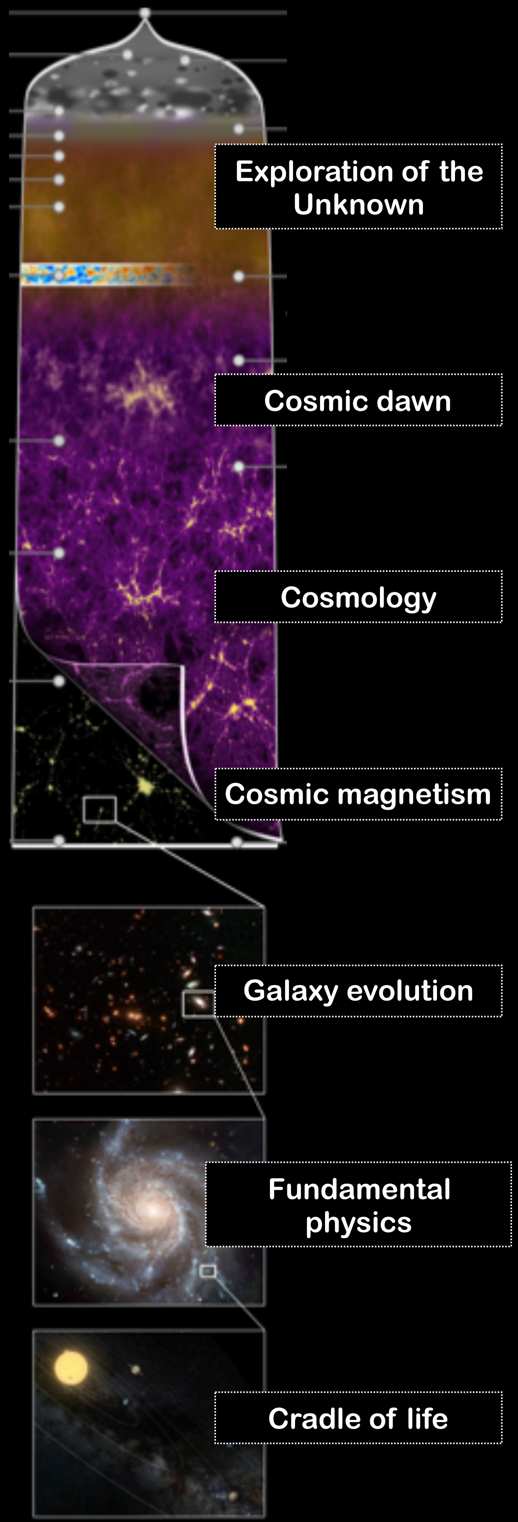
- **2019**: NOEMA VLBI mode
- **2020**: NOEMA PolyFix survey mode
- **2021**: dual-band NOEMA
- **2022+**: new multi-beams @ 30-m
- Possible upgrade EMIR (ultra-wide IF)
- Possible upgrade NIKA2 (new detectors)

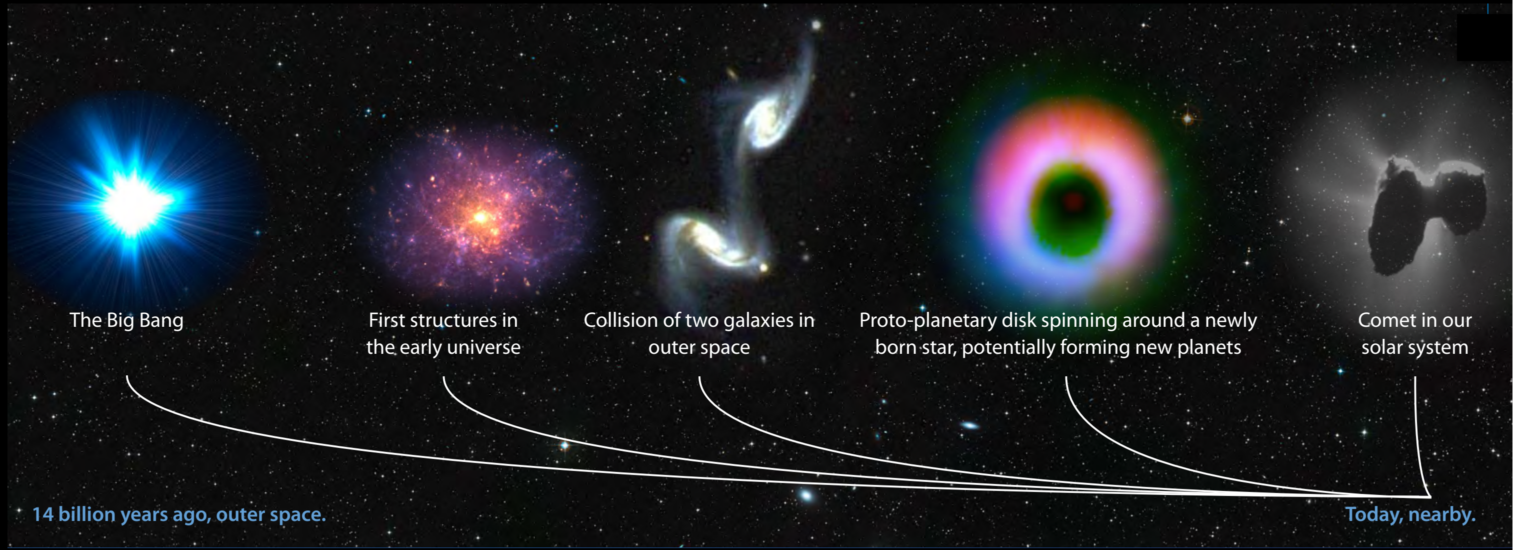
What's next?

- Horizon 5-10 y: multi-beam systems at NOEMA
  - Needs significant investments
  - Pilot technological project: 3 antennas x 3 pixels

Chiara Ferrari

SKA/IRAM synergy



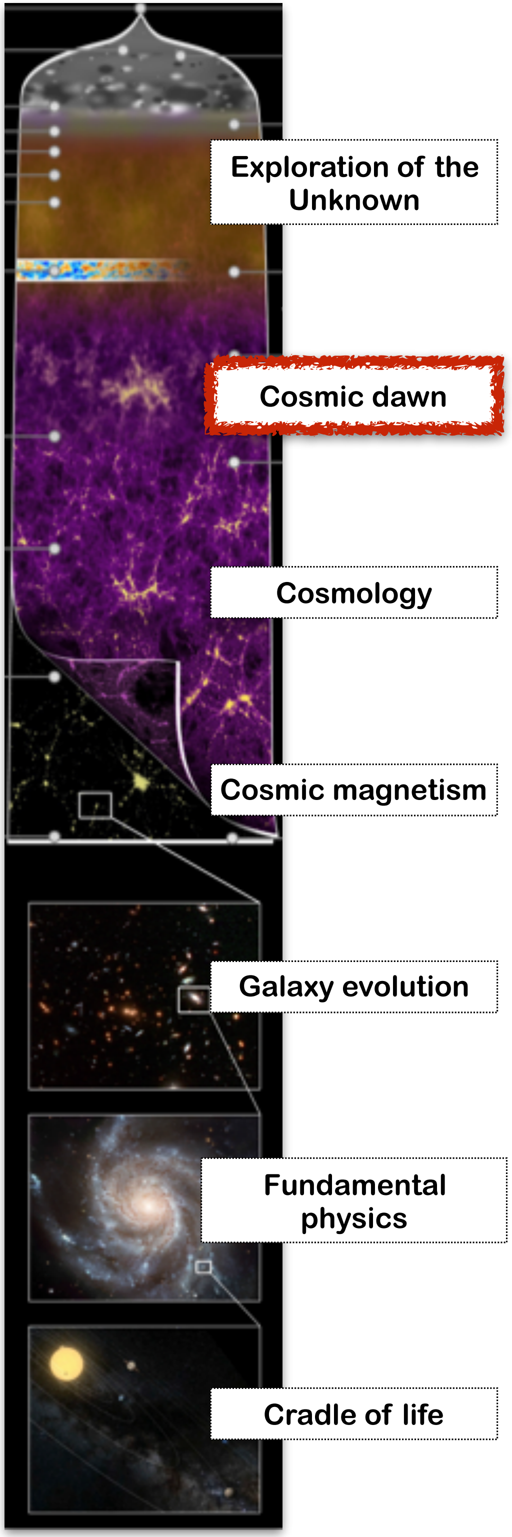


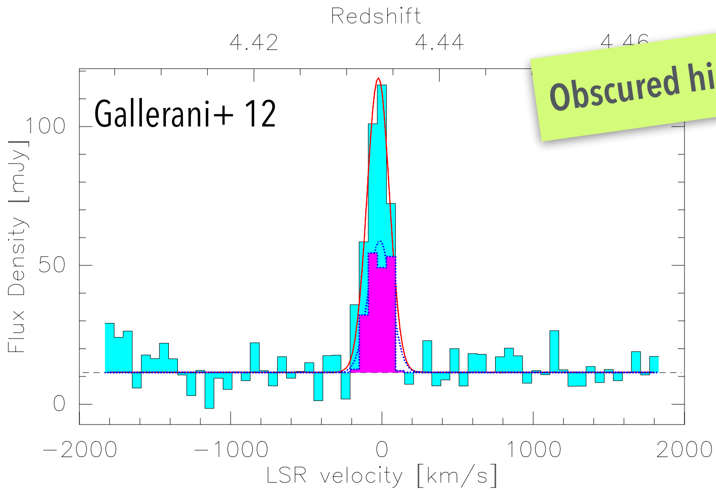
Changing our understanding of the Universe...

from mm to m wavelengths

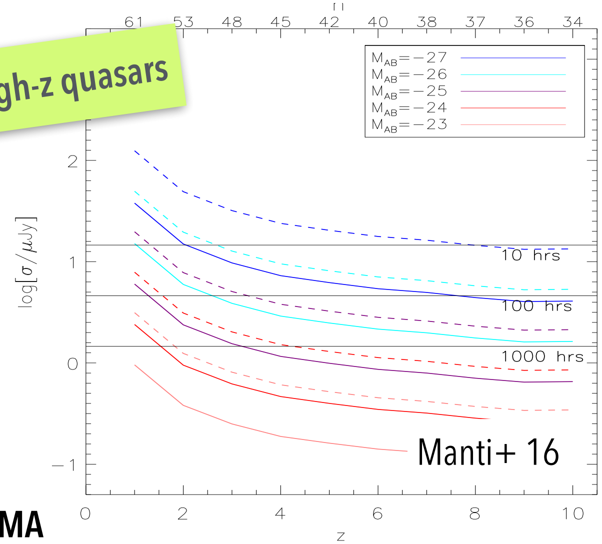
Chiara Ferrari
Astronome (OCA)
SKA France Director

SKA FRANCE
SQUARE KILOMETRE ARRAY



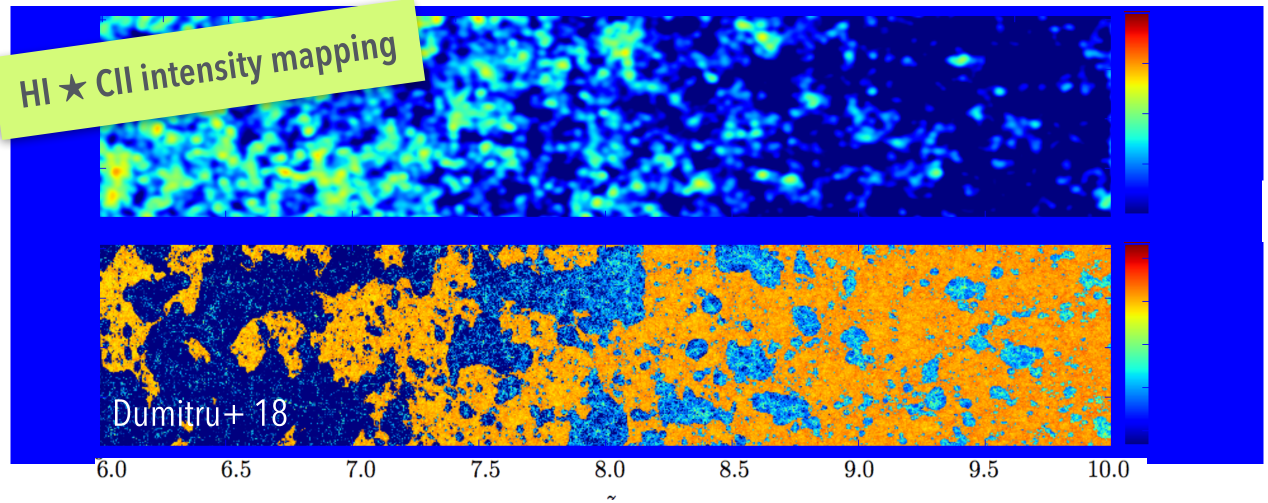


Obscured high-z quasars

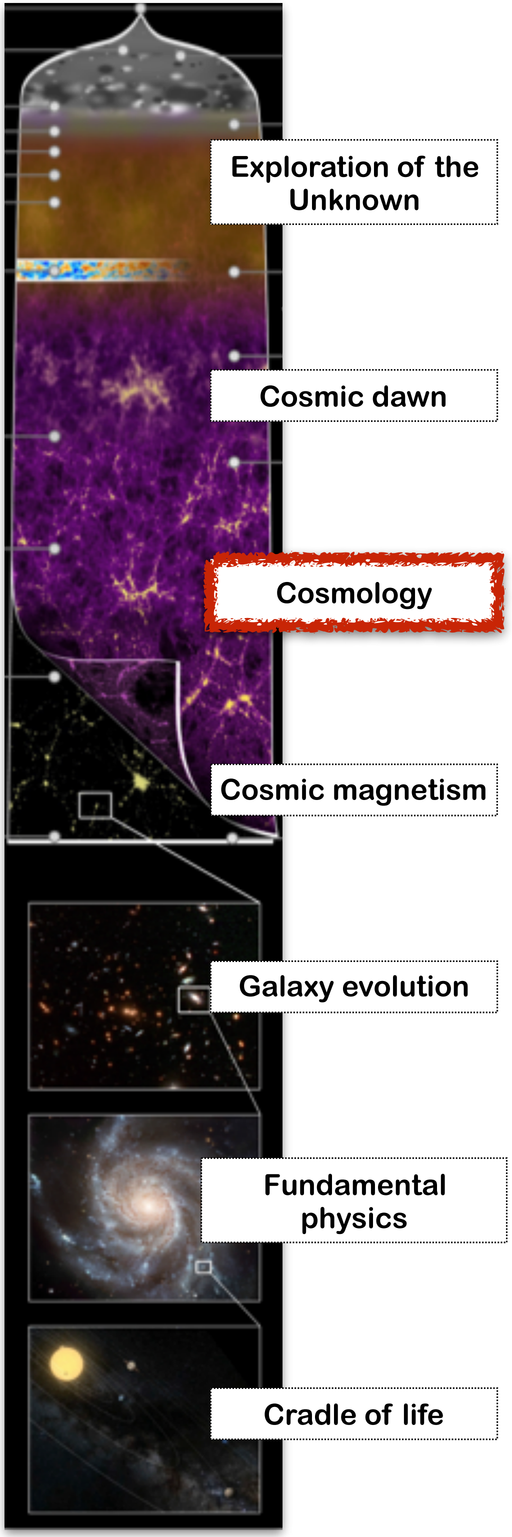


SKA + NOEMA

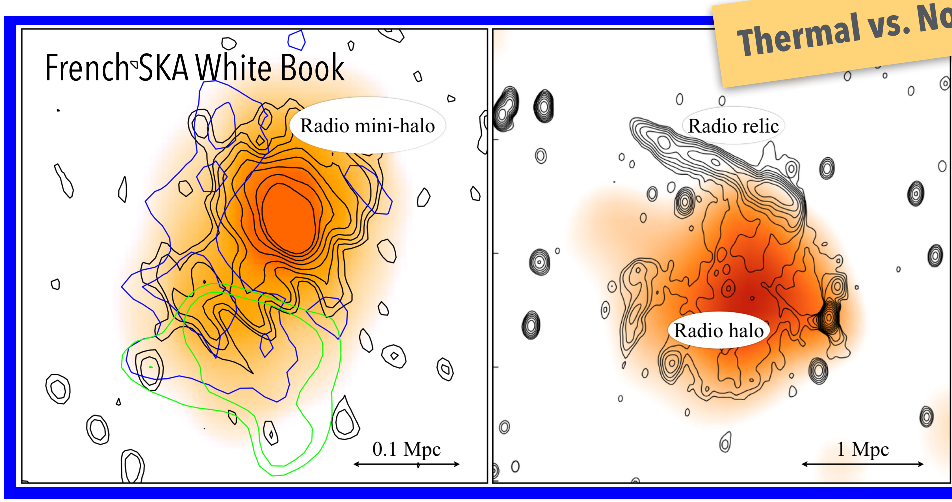
HI ★ CII intensity mapping



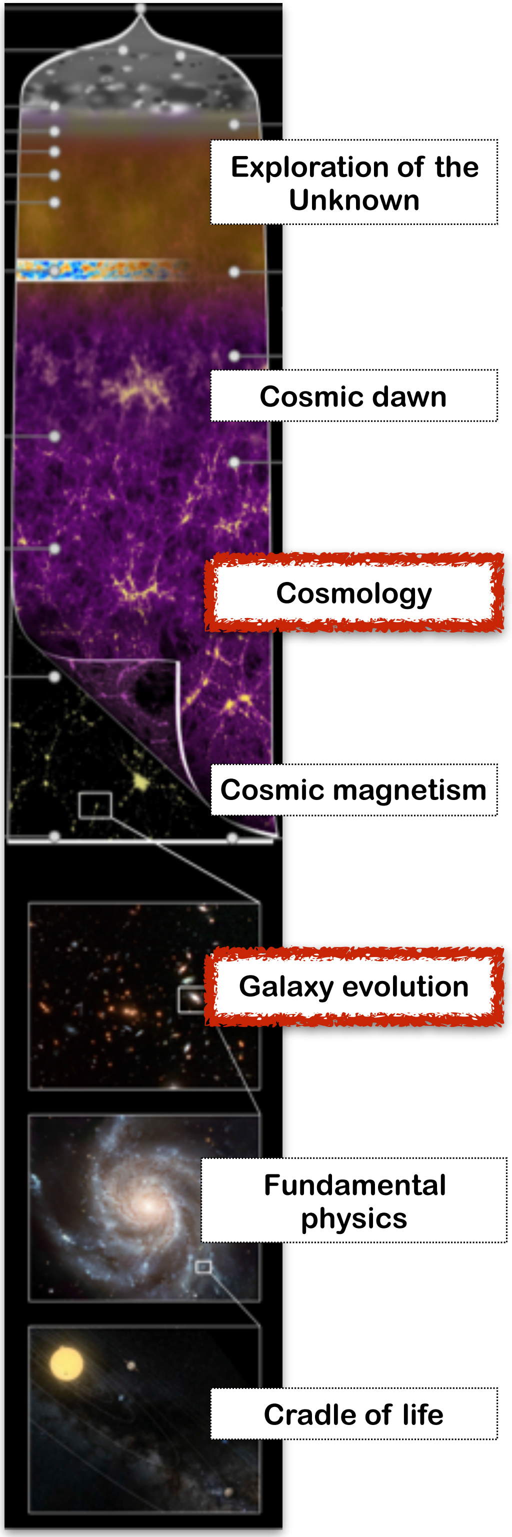
SKA + CONCERTO



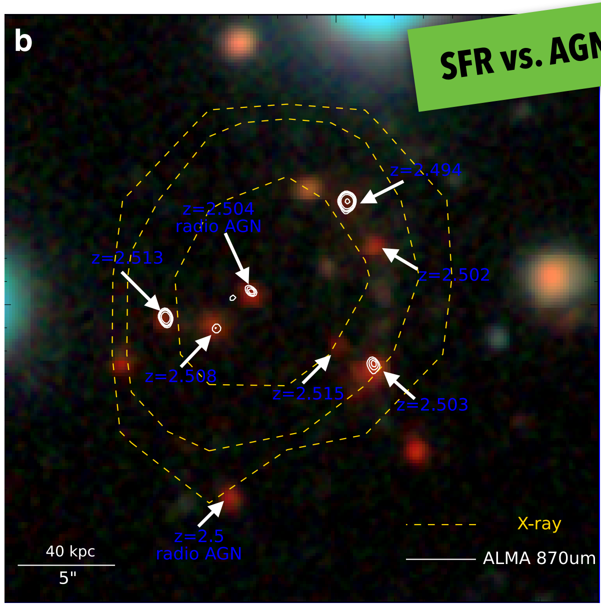
Thermal vs. Non-thermal ICM

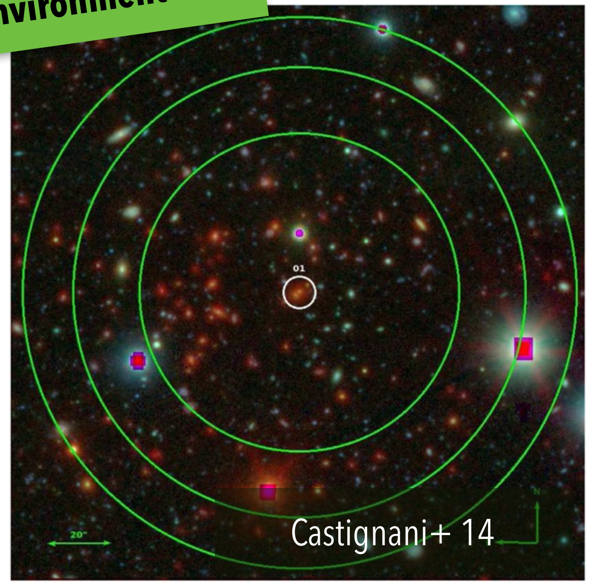


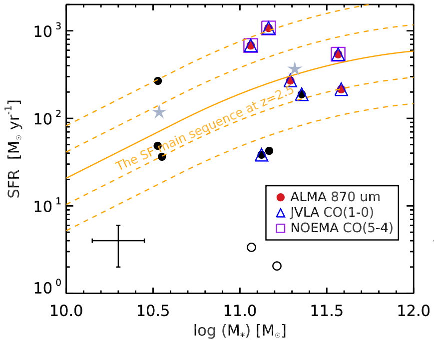
SKA + NIKA 2



SFR vs. AGNs vs. environment vs. z

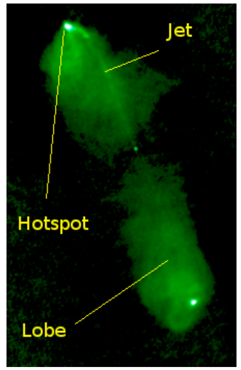


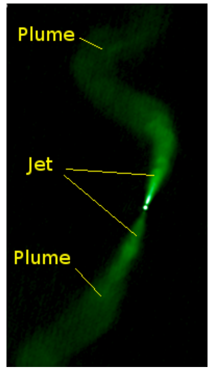


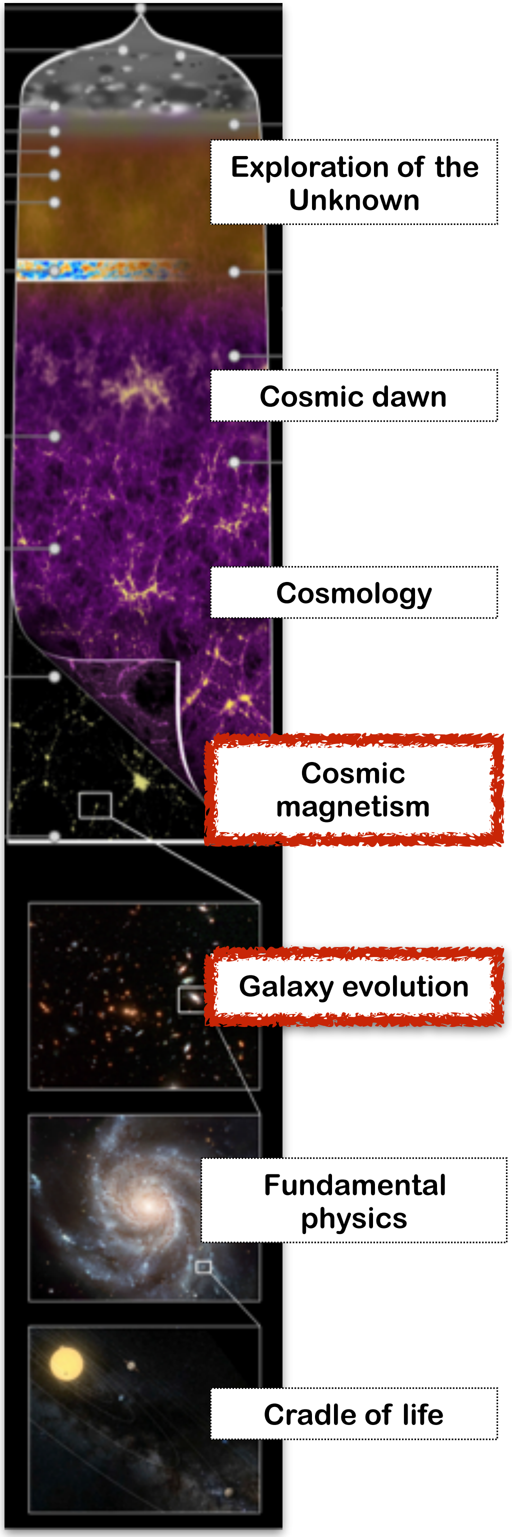


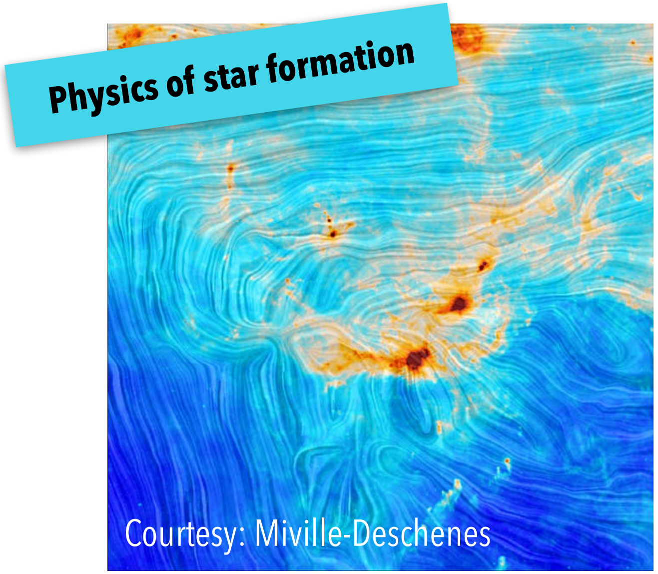
SKA + NIKA 2 & NOEMA

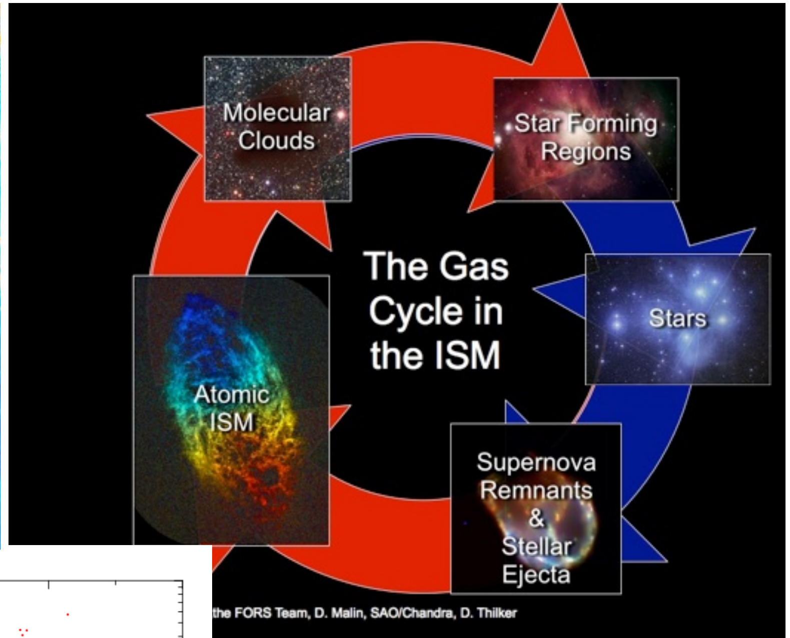
Wang+ 16



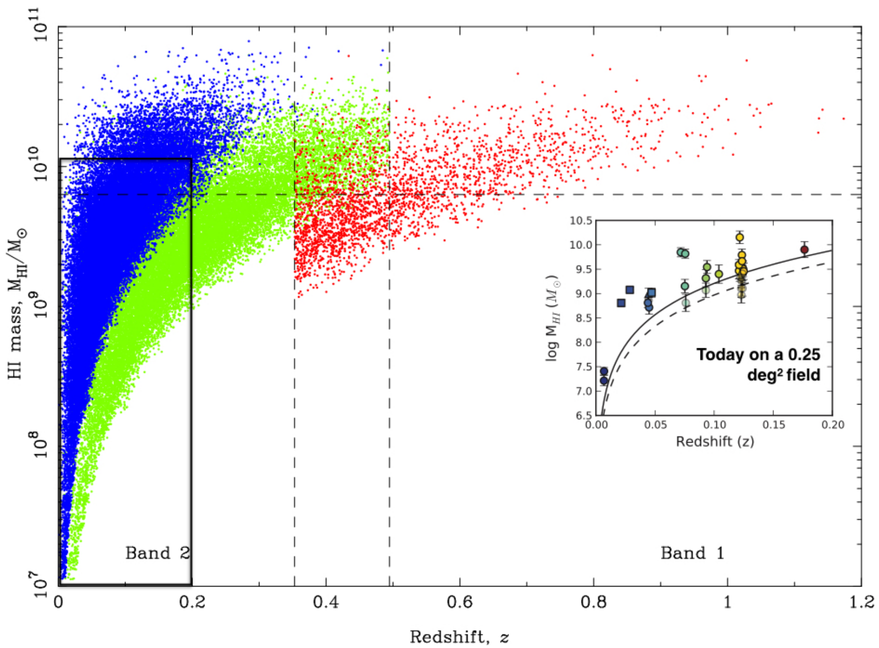




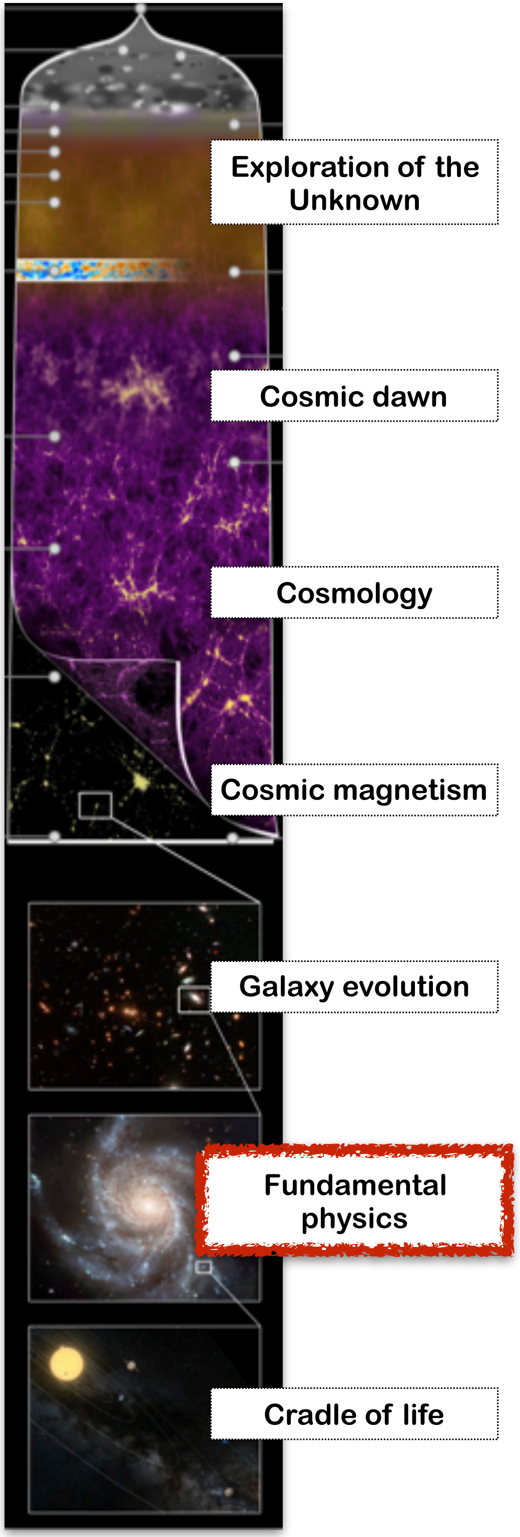




SKA + NIKA 2 & NOEMA

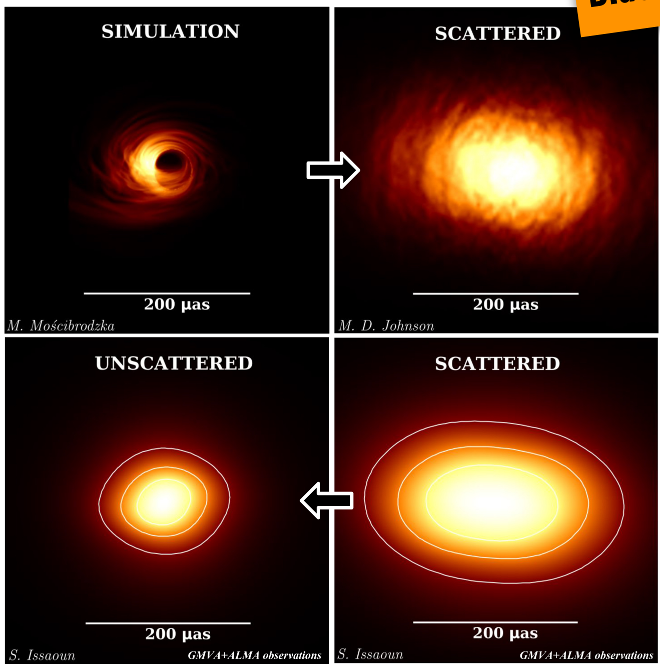


French SKA White Book

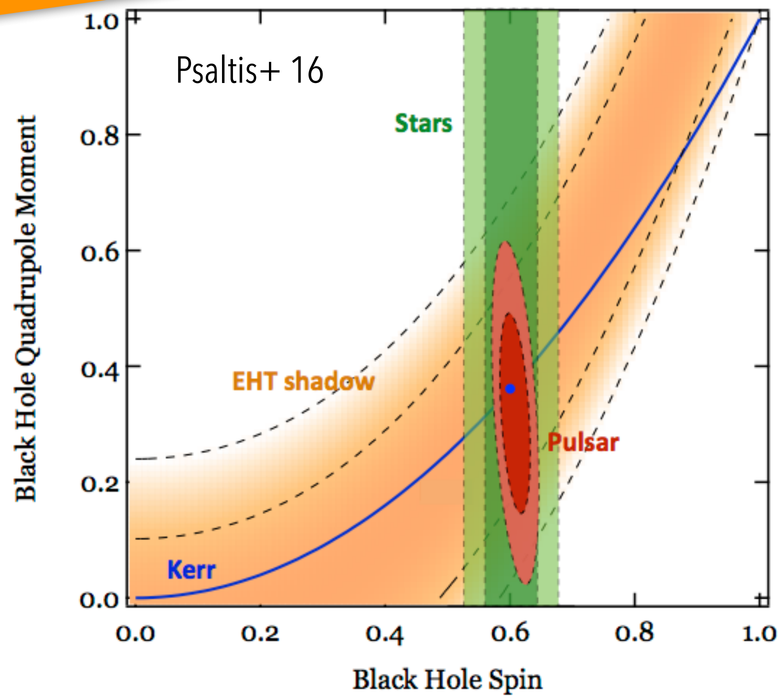


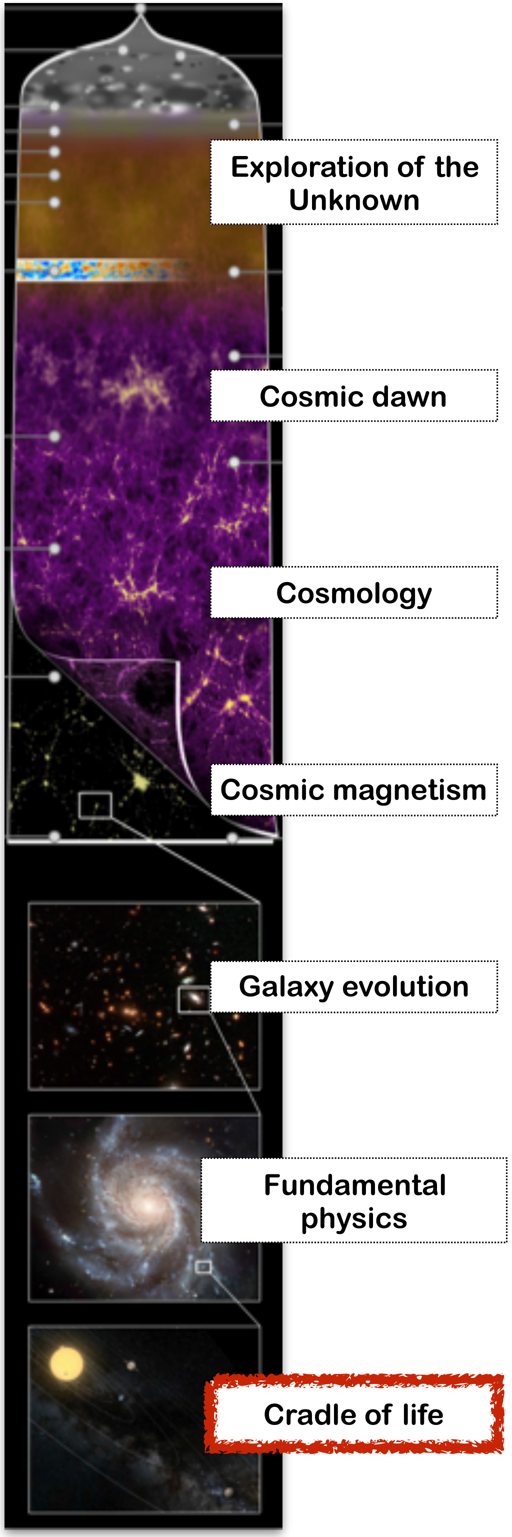
Black hole spacetime in Sgr A*

Issaoun+ 19

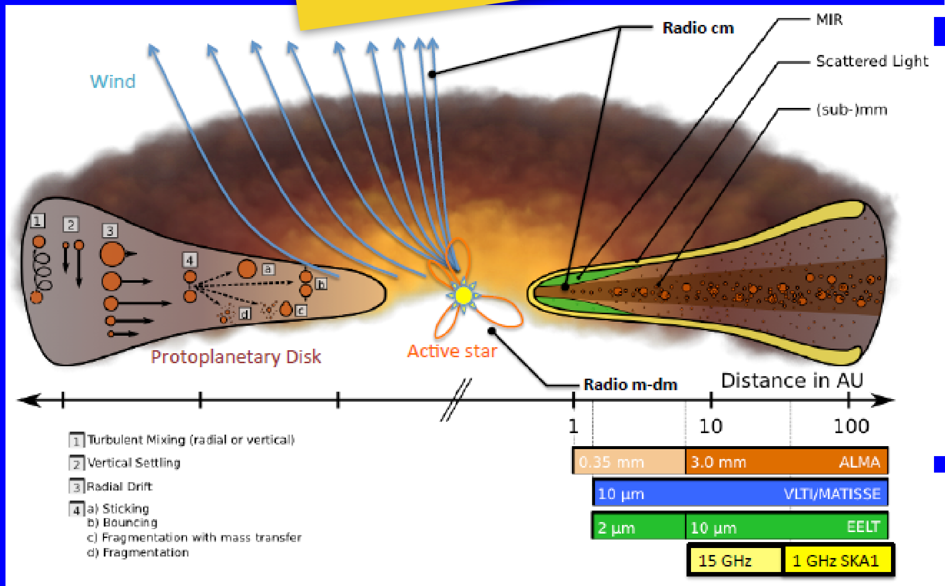


SKA + GMVA & EHT



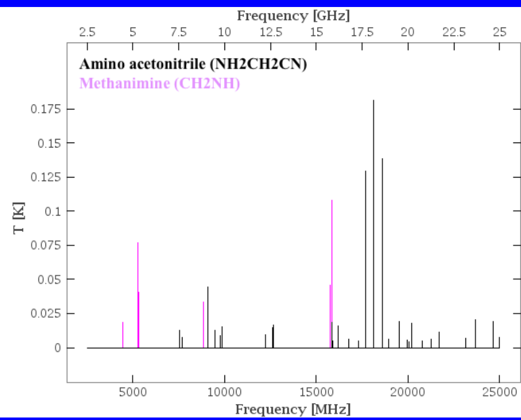


Protoplanetary disks & Pre-stellar cores (?)

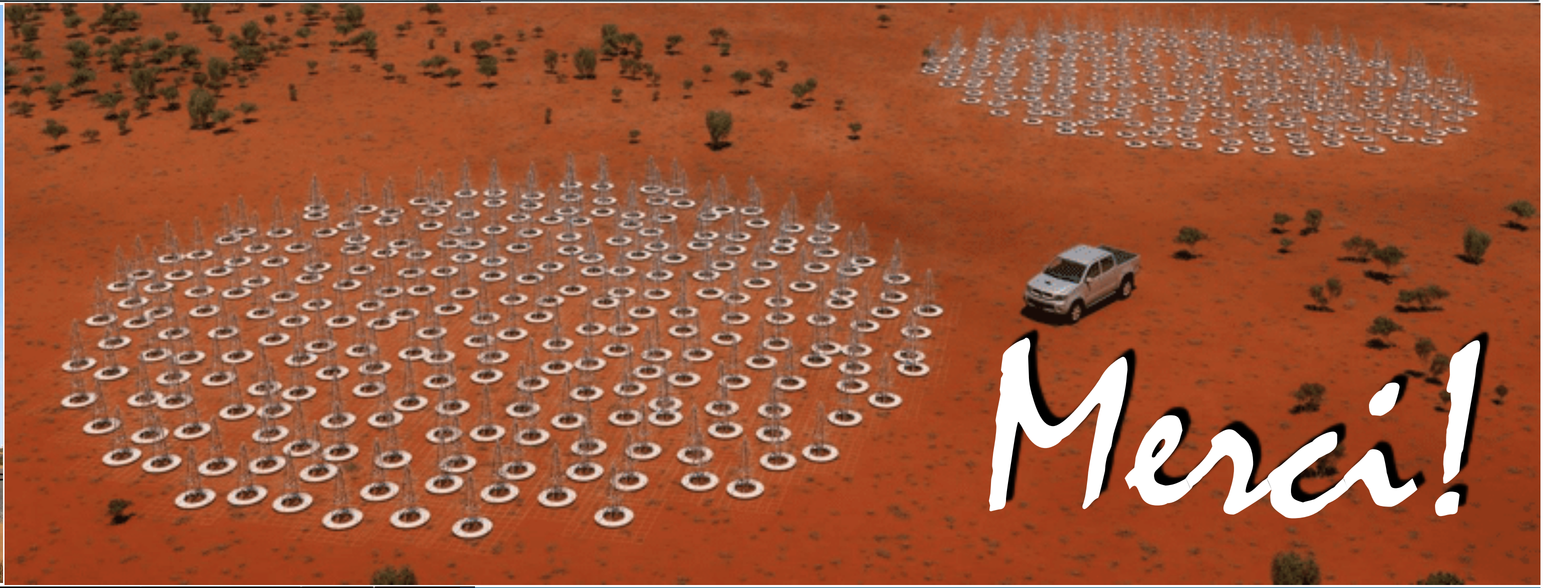


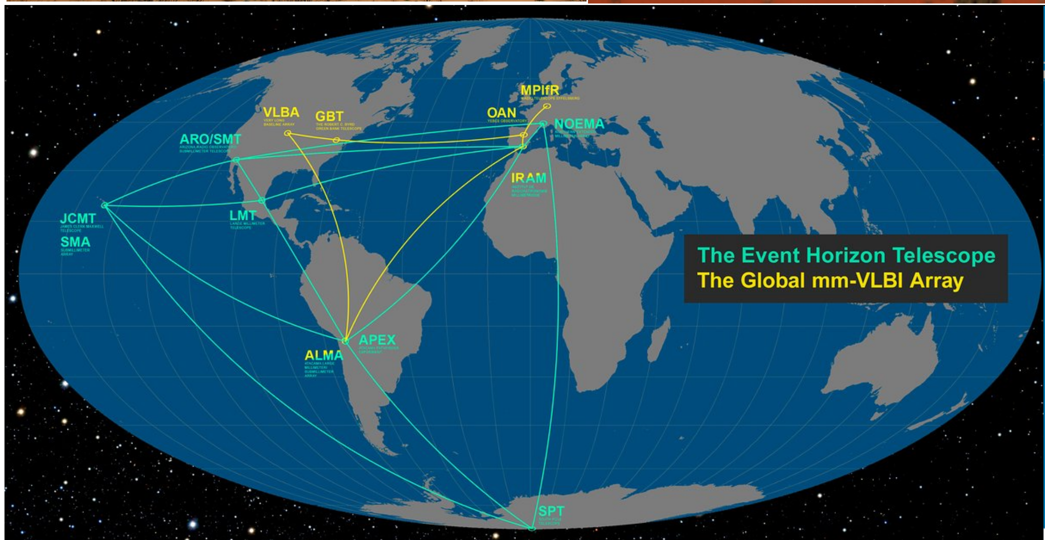
Testi+ 15

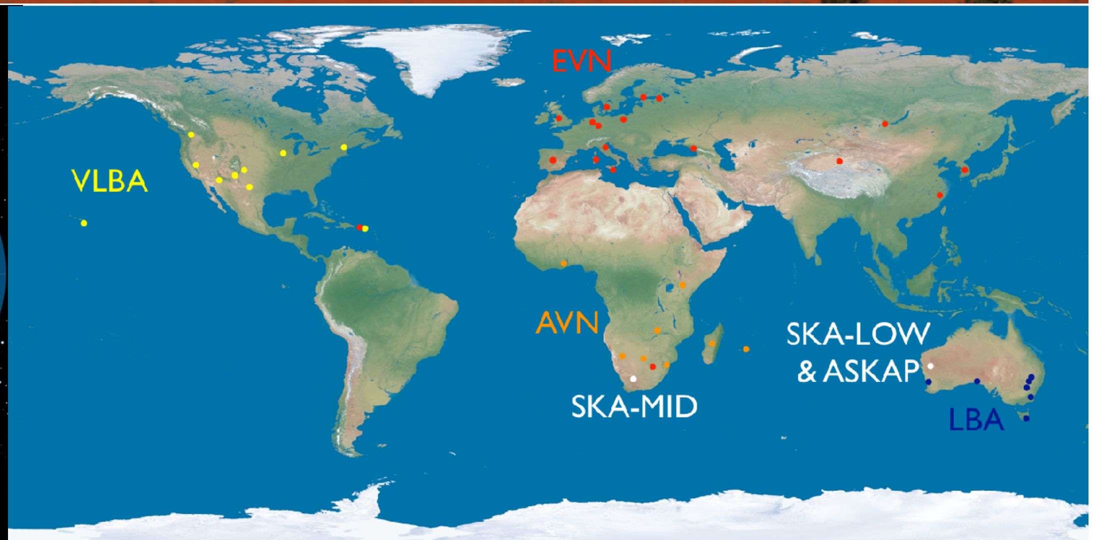
French White Book



SKA + NOEMA

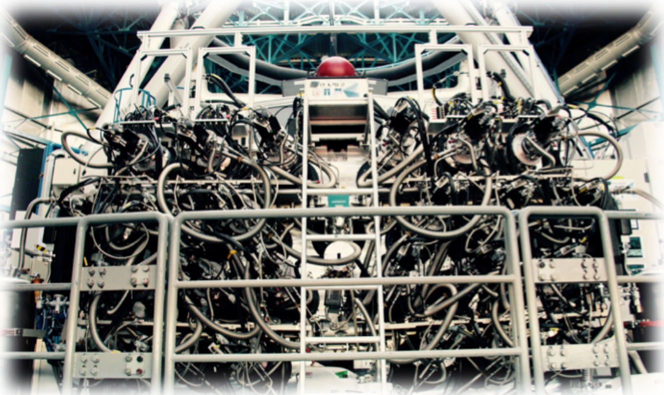

Merci!


MPIfR
OAN
NOEMA
VLBA
GBT
ARO/SMT
IRAM
JCMT
SMA
LMT
The Event Horizon Telescope
The Global mm-VLBI Array
APEX
ALMA
SPT


EVN
VLBA
AVN
SKA-LOW
& ASKAP
SKA-MID
LBA

Thierry Contini

MUSE/IRAM synergy



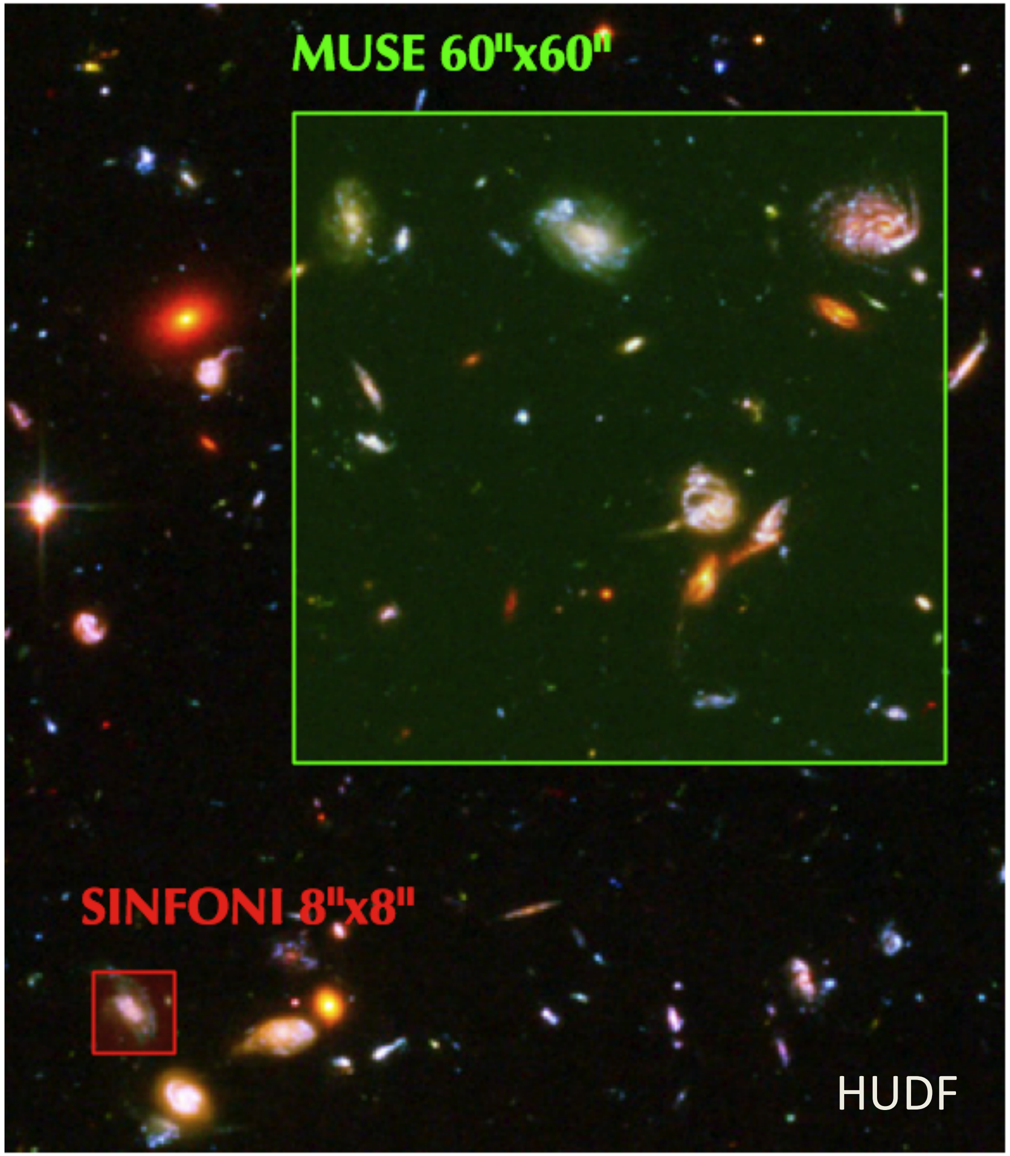
MUSE / IRAM Synergy

Thierry Contini
IRAP – Toulouse

With (main) contributions from:
N. Bouché, B. Epinat, J. Freundlich, P. Salomé, I. Schroetter, and J. Zabl

A wide-field IFU for deep surveys

muse
multi unit spectroscopic explorer



Main advantages

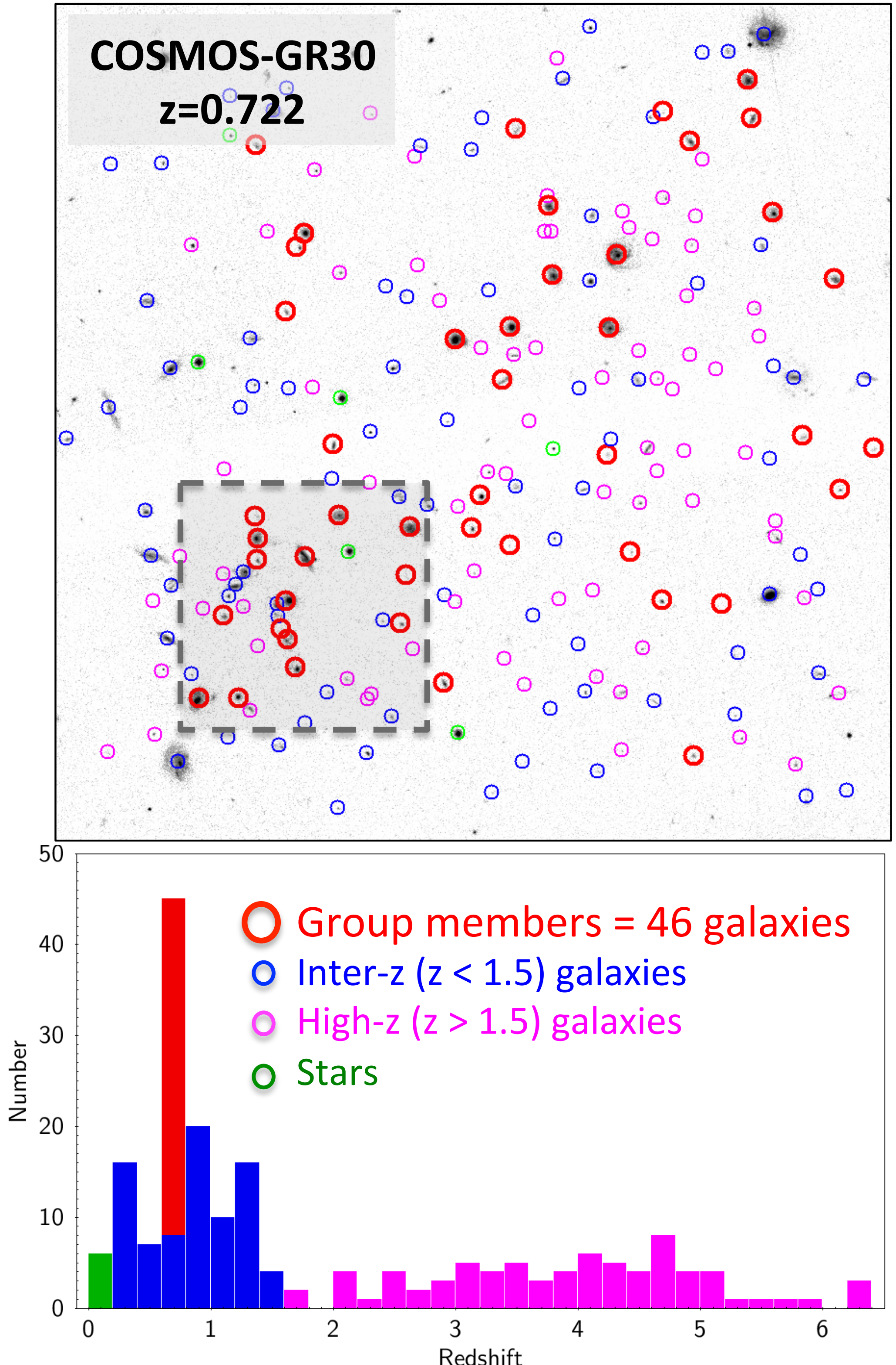
- No pre-selection
  → blind surveys
  → high potential for discoveries
- **Broad spectral range @ high resolution**
  → physical properties
- **High throughput (~3 x 10^{-19} erg/s/cm^2 in 100h)**
  → cosmic web, faint / low-mass galaxies
- **Wide Field-of-View**
  → statistics, environment

IRAM (NOEMA) / MUSE Synergy

- Optimal for **galaxies at 0.2 < z < 1.5**, need for ALMA for fainter objects at z > 3, especially for resolved properties. See **A. Hughes talk for nearby galaxies**.
- **Reference** samples with **PHIBSS1/2** IRAM Legacy Program (Tacconi +13,18, Freundlich+19,)
  - **60 galaxies** at **0.5 < z < 3** selected around the Main Sequence for SFGs
  - $M^* > 10^{10} M_{sun}$ and SFR > 3 $M_{sun} yr^{-1}$
- **Southern vs Northern sky**, constraints on target declination → need for « **equatorial** » **fields**
- **Two examples** of on-going **IRAM follow-ups of MUSE-GTO** programs
  - Environmental SF quenching in a **galaxy group** at z~0.7
  - Molecular content in **galaxies with gas flows** at z~1

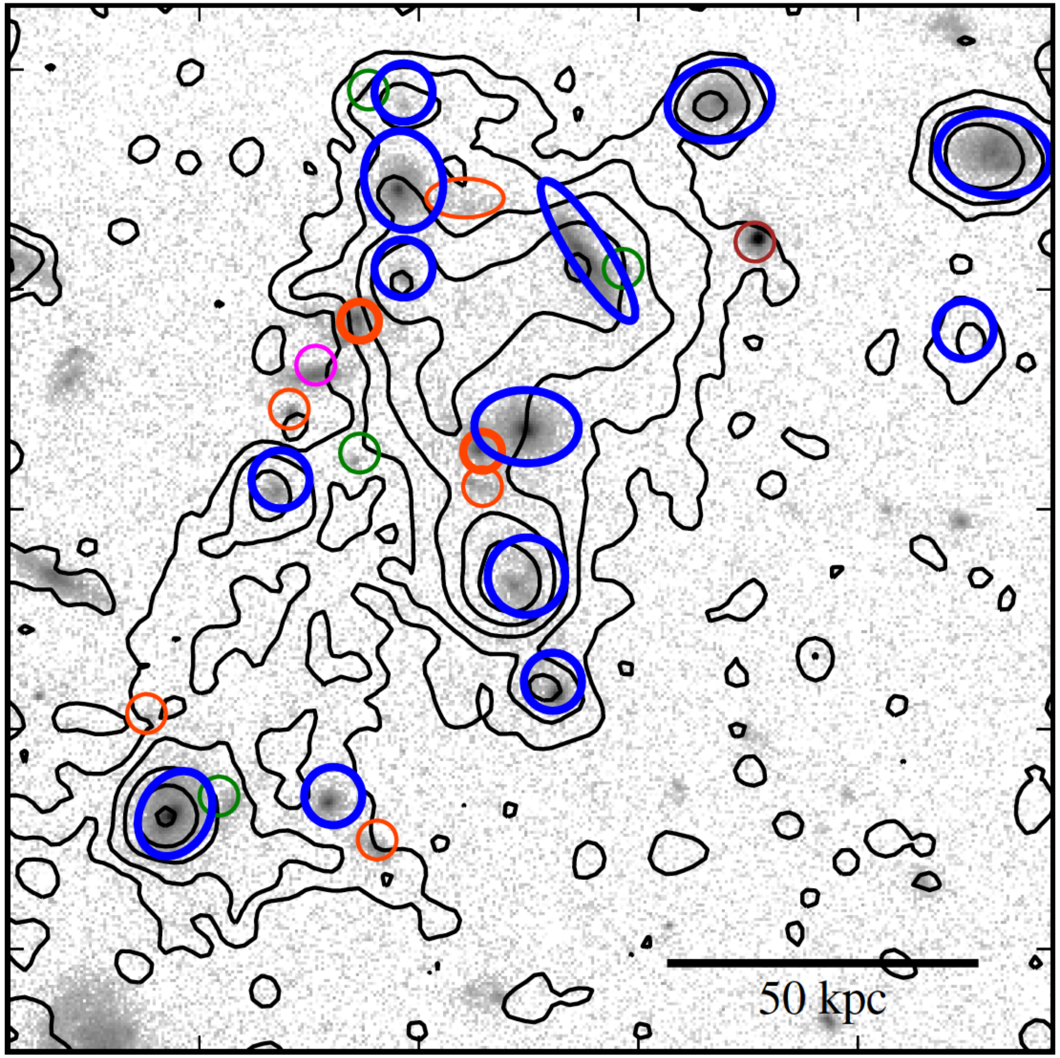
MUSE-GTO survey of galaxy groups

- **15** galaxy **groups** at **0.3<z<1** selected in COSMOS
- **Medium-deep** (~5-10h) **MUSE** (+AO) observations @ 0.6'' resolution
- Best example: **CGR30**
  - **~50 galaxies** identified **in the group** (x 8 wrt to previous VIMOS spectroscopy!)



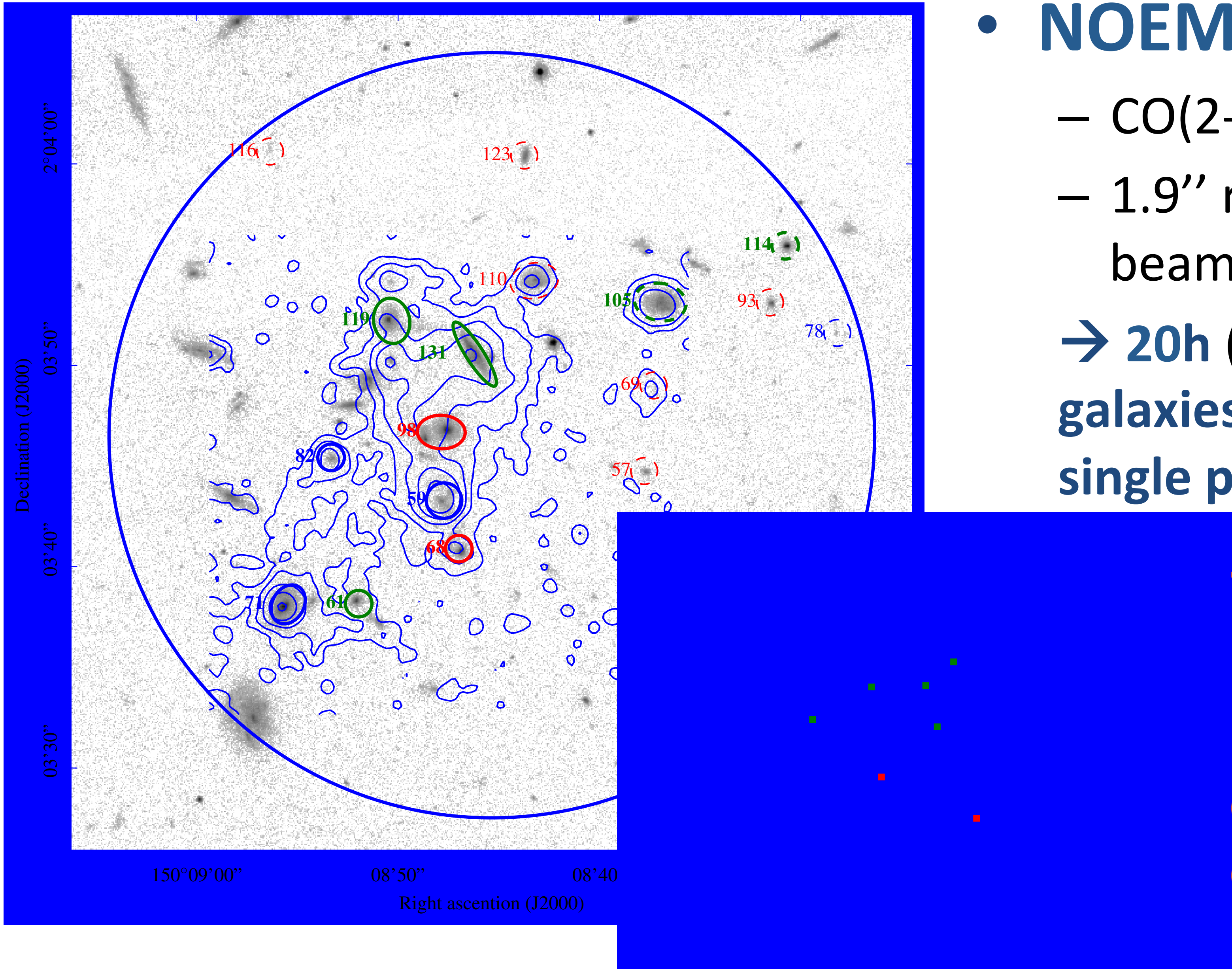
Discovery of a huge gas cloud wrapping ~10 galaxies in the group

- **Discovery of a [OII]-bright gas structure** extending over ~10000 kpc^2
- **Origin** of this gas ?
  - Superwinds (SNe, AGN)
  - Gas stripped due to tidal interactions, ram pressure, etc
- Source(s) of **ionisation?**
  - Star formation in tidal tails
  - Shocks?, AGN?
- **Follow-ups** with **IRAM**, ALMA and KMOS



Epinat+18

Molecular gas content in group galaxies: a test case for environmental quenching



- **NOEMA**
  - CO(2-1) @ 2 mm
  - 1.9'' resolution in 38'' beam (C config)

→ **20h** (total) to detect **10 galaxies** with SNR>5 **in one single pointing**

+ 30m antenna

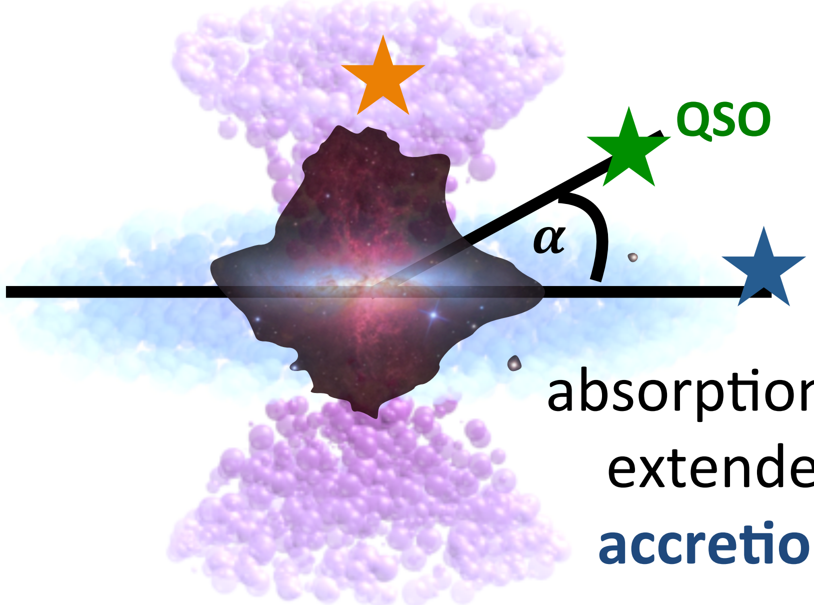
- 20'' beam

→ **upper limit on extended CO emission**

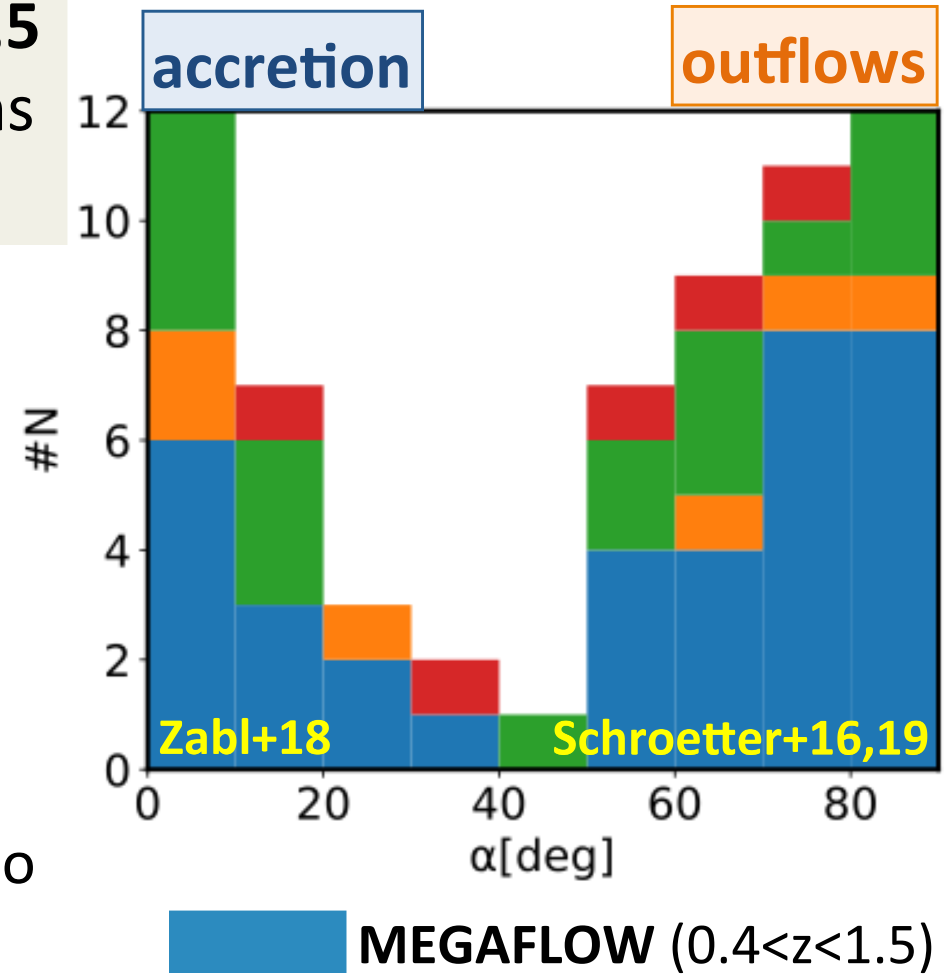
MUSE-GTO survey of gas flows around galaxies

MEGAFLOW: 30+ galaxies at 0.4<z<1.5
associated to **MgII absorption** systems
→ probe **accretion** or **outflows**

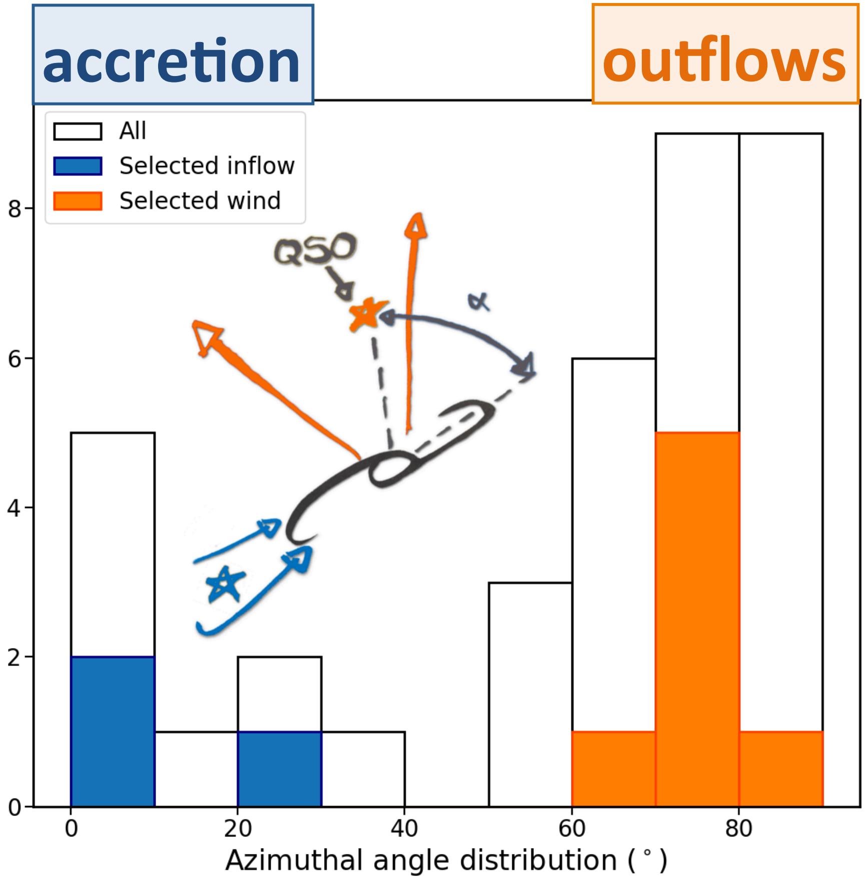
absorption due to
outflowing gas

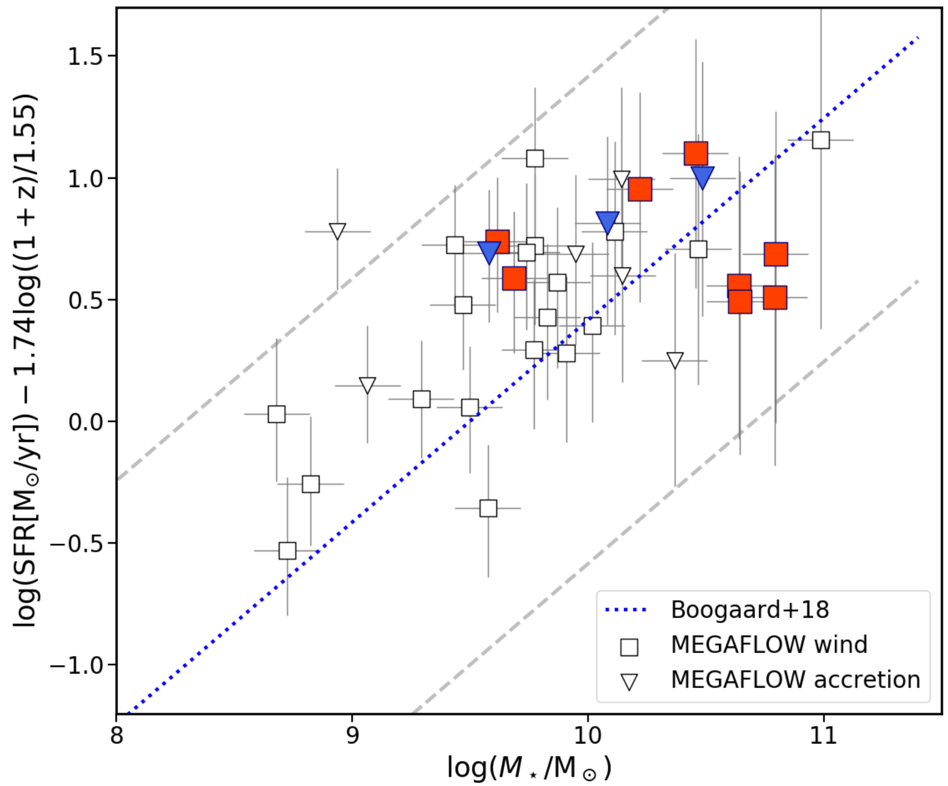


absorption due to
extended gas
accretion disk



Molecular content in galaxies with gas flows: a test case for self-regulated star formation





- **NOEMA**
  - CO(3-2) or CO(4-3) @ 1.3 mm - D config

  →**25h** (total) to detect **11 galaxies** with SNR>5

Conclusion

- Interesting synergy between **MUSE** and **NOEMA** for **intermediate-redshift galaxies**, in terms of sensitivity and FoV
- Allow to adress **key questions** in **galaxy evolution**
  - Gas reservoir & SF regulation
  - Feedback, quenching mechanisms
  - Dense environments

Supplementary material for the discussion of session # 1

Emmanuel Di Folco

IMAGER: an alternative to Mapping for large data files

IMAGER: an alternative to Mapping for large data files

E. Di Folco, S. Guilloteau, T. Jacq (LAB, Service d'observation IRAM-ALMA à l'OASU)

E. Chapillon (LAB/IRAM), V. Piétu (IRAM)

IMAGER: offered as a contribution package to the current Gildas release (gildas-/contrib/imager)

Documentation:
https://github.com/JacqLAB/IMAGER_IRAM/blob/master/imager.pdf

- **IMAGER** principle and new features:
  - ✓developped and optimized to handle spectra cubes with large bandwith
  - ✓**simplified interface**
  - ✓optimized commands providing intelligent default parameters
  - ✓Mostly works on **internal buffers**, not intermediate files
  - ✓**Parallel programming**
  - ✓Includes **new Tools**: improved **HELP**, faster **visualization** commands including automatic line identification, implementing **self-calibration** in phase and/or amplitude, processing of Mosaics including **short-spacings, etc…**

- **IMAGER - Basic principles**
  - reduces the number of actions to the strict minimum
  - based on the same MAPPING algorithms, but re-arranged

    Example of a typical imaging sequence

    READ UV mydata.uvt
    UV_MAP
    CLEAN
    VIEW CLEAN
    *WRITE * mydata*

The new *UV_MAP* command will treat at once (user-controlled) ensembles of contiguous channels sharing the same synthesized beam ; deconvolution with *CLEAN* will use the synthesized beam with the appropriate frequency for each channel.
Beams can be 4-D arrays (Frequency, Field).

- IMAGER implements **self-calibration** (in phase & amplitude)

Dominant (phase/amplitude) errors are antenna-based, while source information is baseline-based. Self-calibration will use your source to iteratively improve the calibration of the antenna-based (complex) gains as a function of time, based on a preliminary deconvolution solution.
Quality assessment is currently based on the improvement of the image dynamic range.

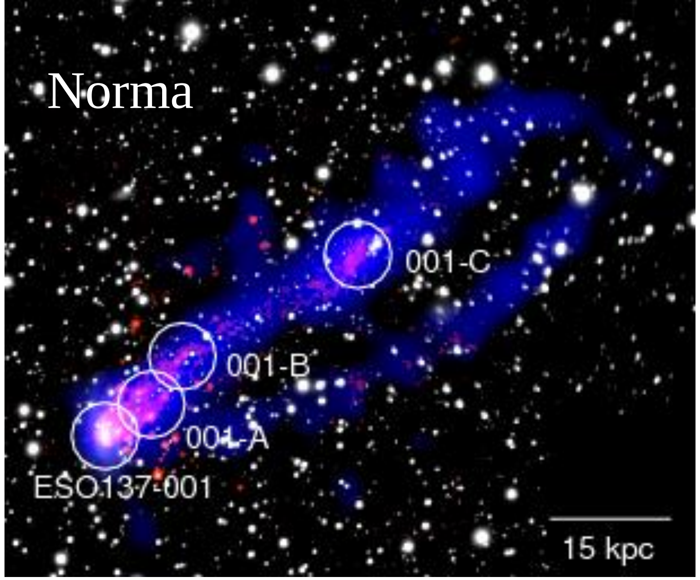
- **Automated suite to Image an ensemble of spectral lines**

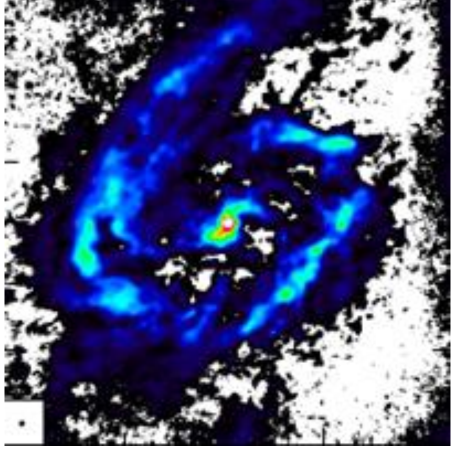
Data sorting, spectral line identification, continuum subtraction, self-calibration, imaging in 1 click…

Session # 2
Cosmology and reshifted galaxies

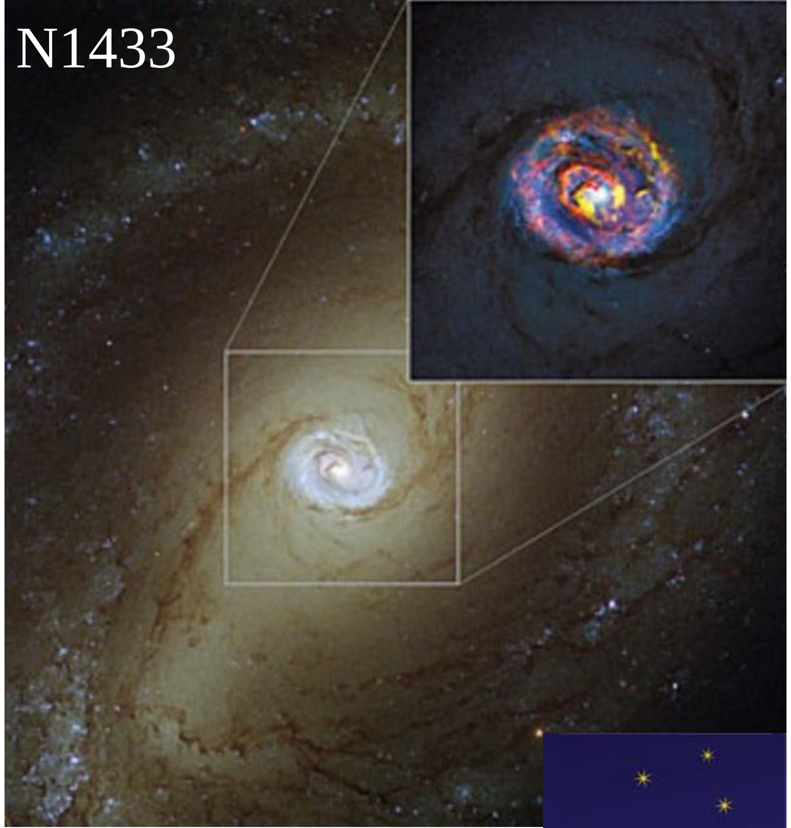
Françoise Combes

Evolution of galaxies and AGN

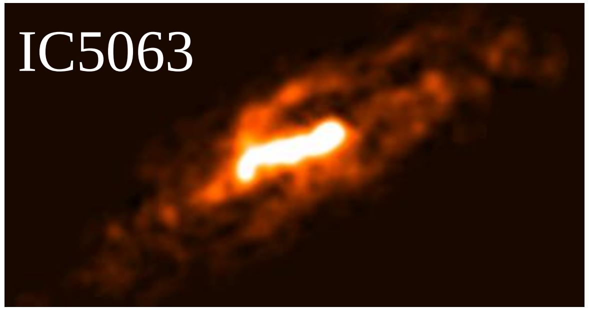


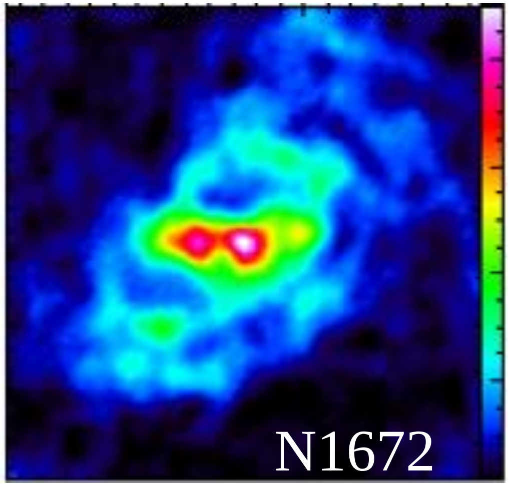


N613



Evolution of galaxies and AGN





ALMA

Françoise Combes
Observatoire de Paris

31 January 2019

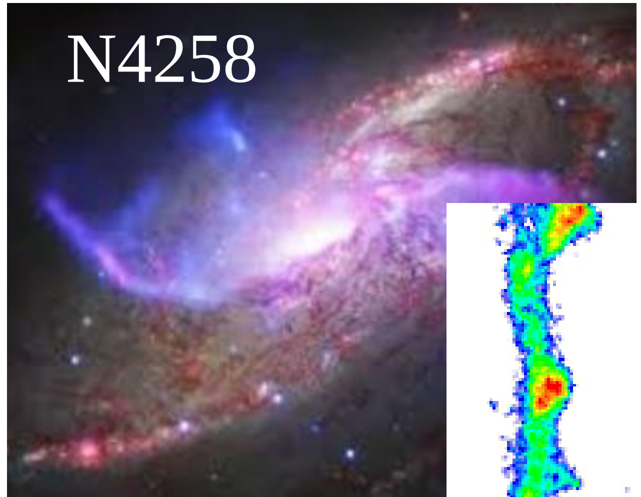
Outline

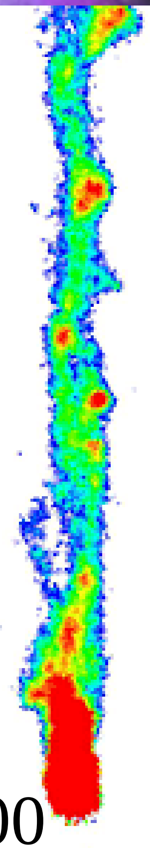
➔Fueling due to gravity torques
➔Feedback, outflows (SF, AGN)

➔Molecular tori
➔Decoupling, different orientations

➔Effect of environment
➔Quenching through ram-pressure and tides

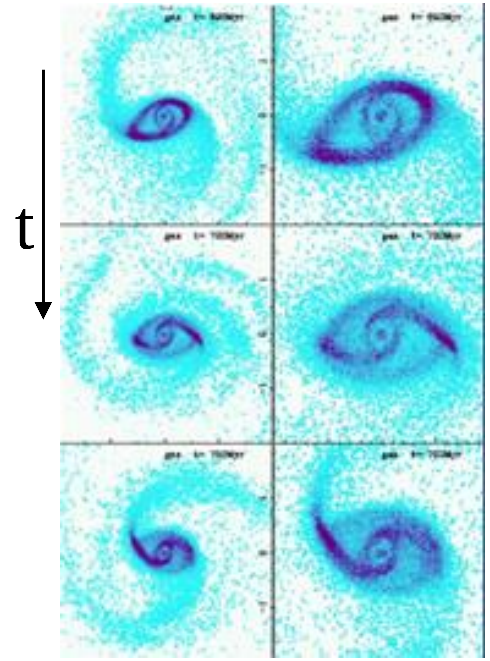
N6951





D100

Statistics -- Time-scales
10-100pc fueling



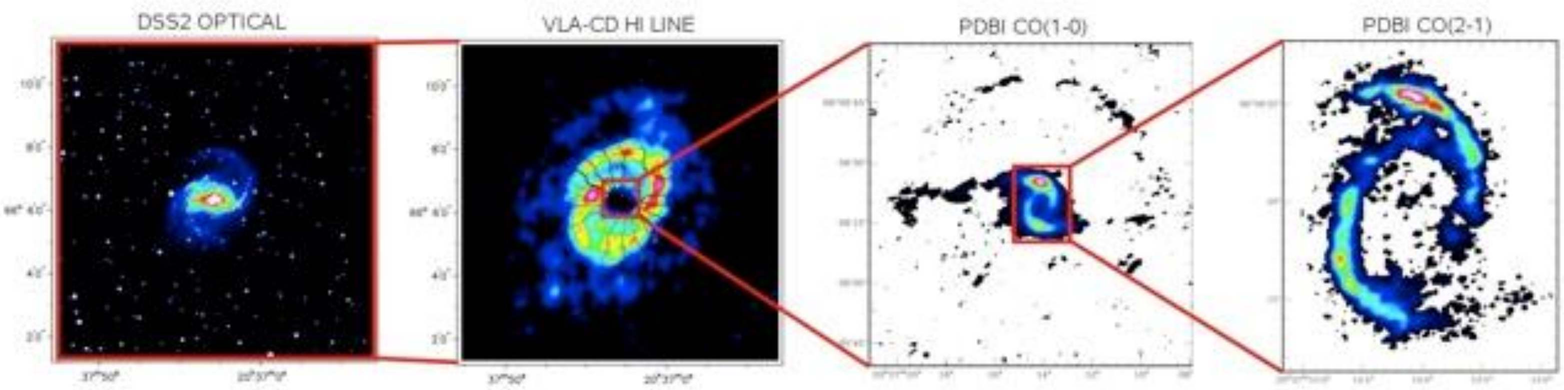
Simulation

➔ **Only ~35%** of negative torques in the center, **NUGA: 20 galaxies** *(Garcia-Burillo & Combes 2012)*

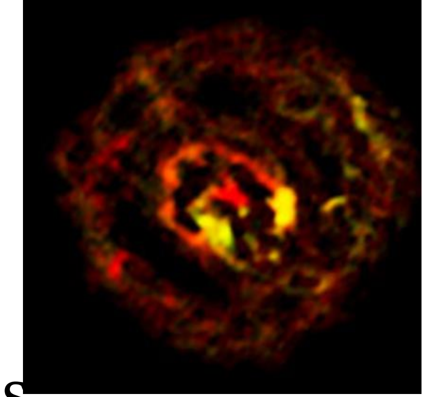
➔ Rest of the times, positive torques, gas stalled in ring

➔ **Fueling phases are short, a few 10^7 yrs** (feedback)

➔ Star formation fueled by the torques, always associated to AGN activity, but with longer time-scales



Several gas rings, outflow



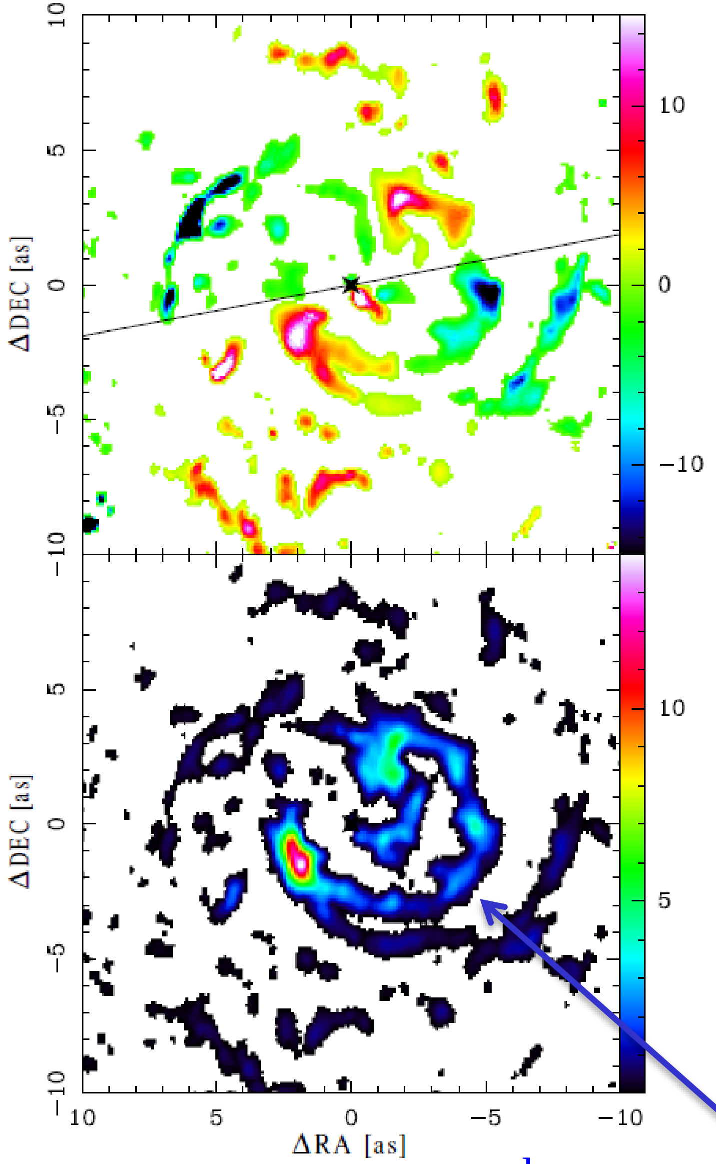
NGC 1433: barred spiral, **CO(3-2) with ALMA**
Molecular gas fueling the AGN, + outflow // the minor axis

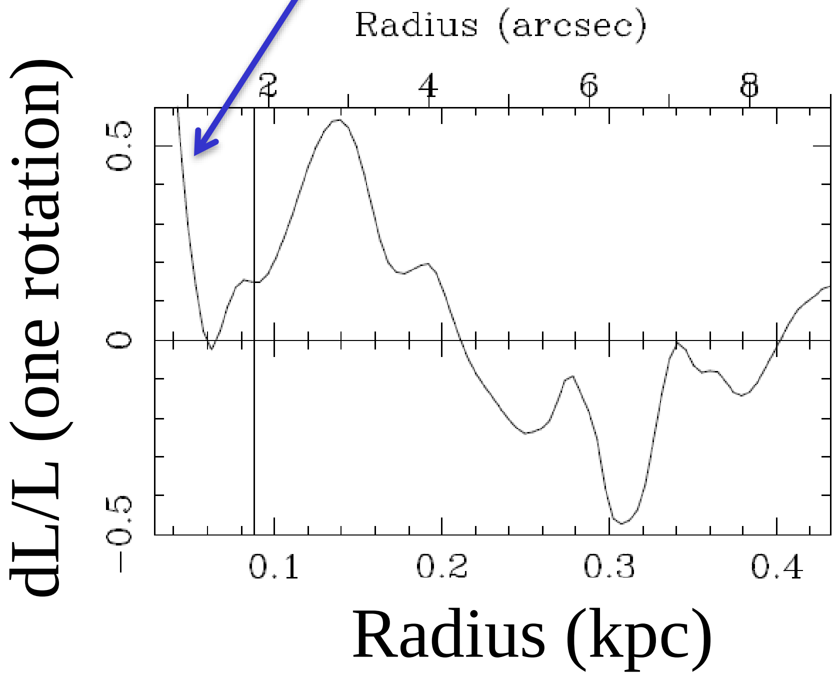
M_{H2}= 5.2 10^7 $M_\odot$ in FOV=18"
100km/s flow
Smallest flow detected

➔ L_{kin}=0.5 dM/dt v^2 ~2.3 10^{40} erg/s
L_{bol} (AGN)= 1.3 10^{43} erg/s
Combes et al 2013

Gravity torques fuel the ring, where gas is stalled
Smajic et al 2014

Torque map in NGC1433





Torques are positive inside 200pc and negative outside

➔ Gas is piling at the 2nd ring

2nd ring at 200pc= ILR of the nuclear bar

Smajic et al 2014

The NGC1566 barred Sy1: feeding phase

N1566 SAB Sy1

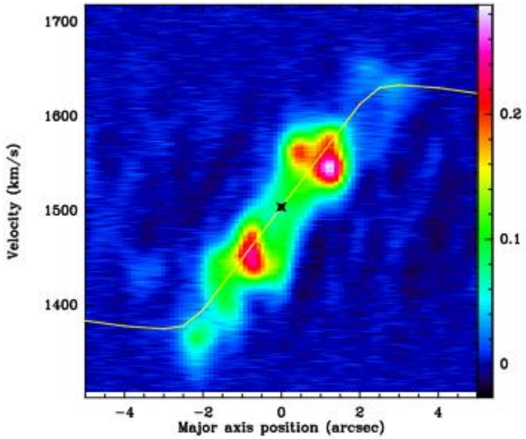
4 arcmin

FOV=18 ”

Spatial resolution

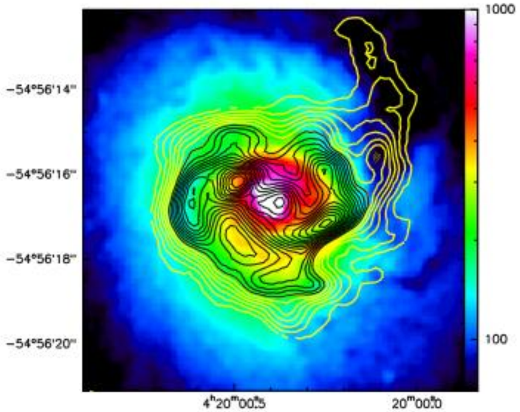
0.5 arcsecond ~25pc

Combes et al 2014

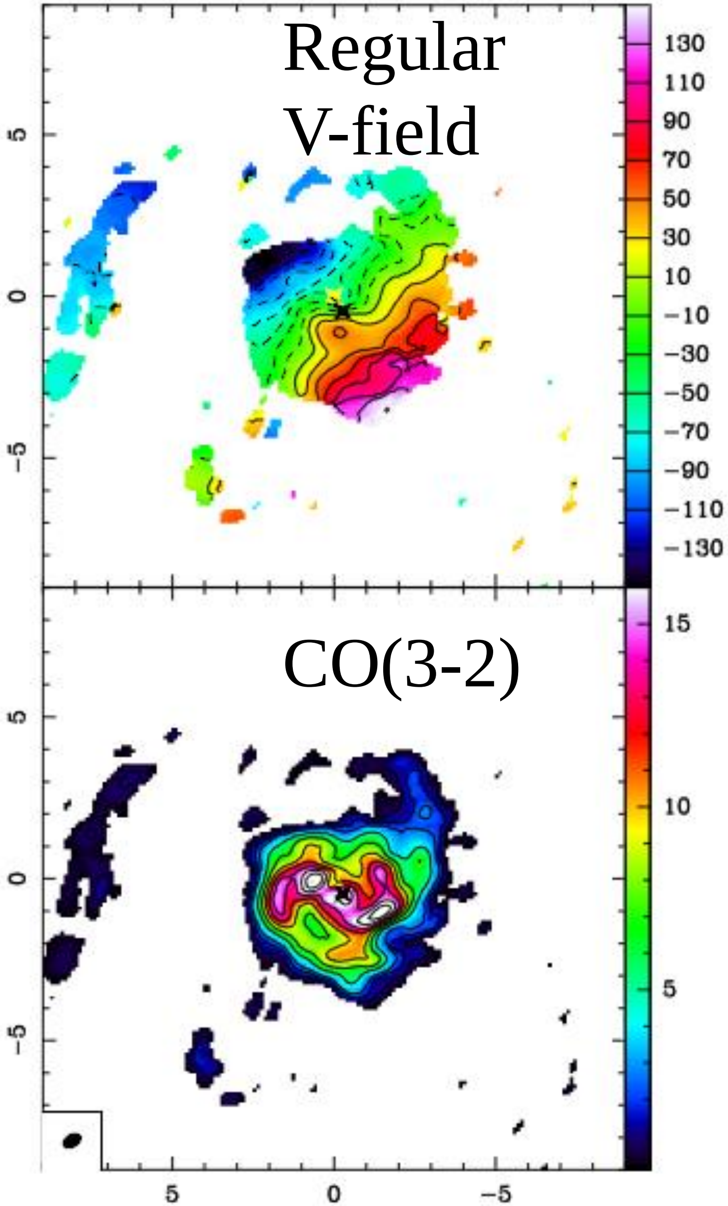


PV major axis

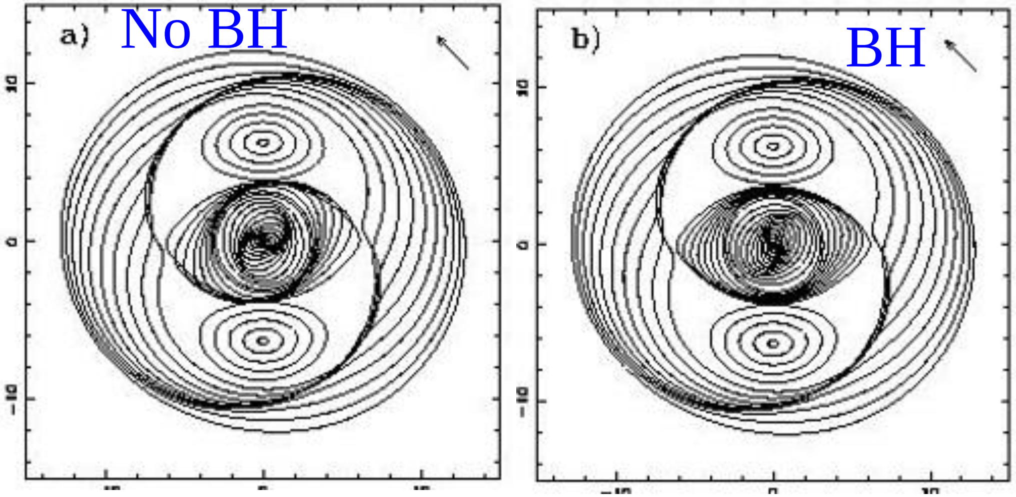
No outflow



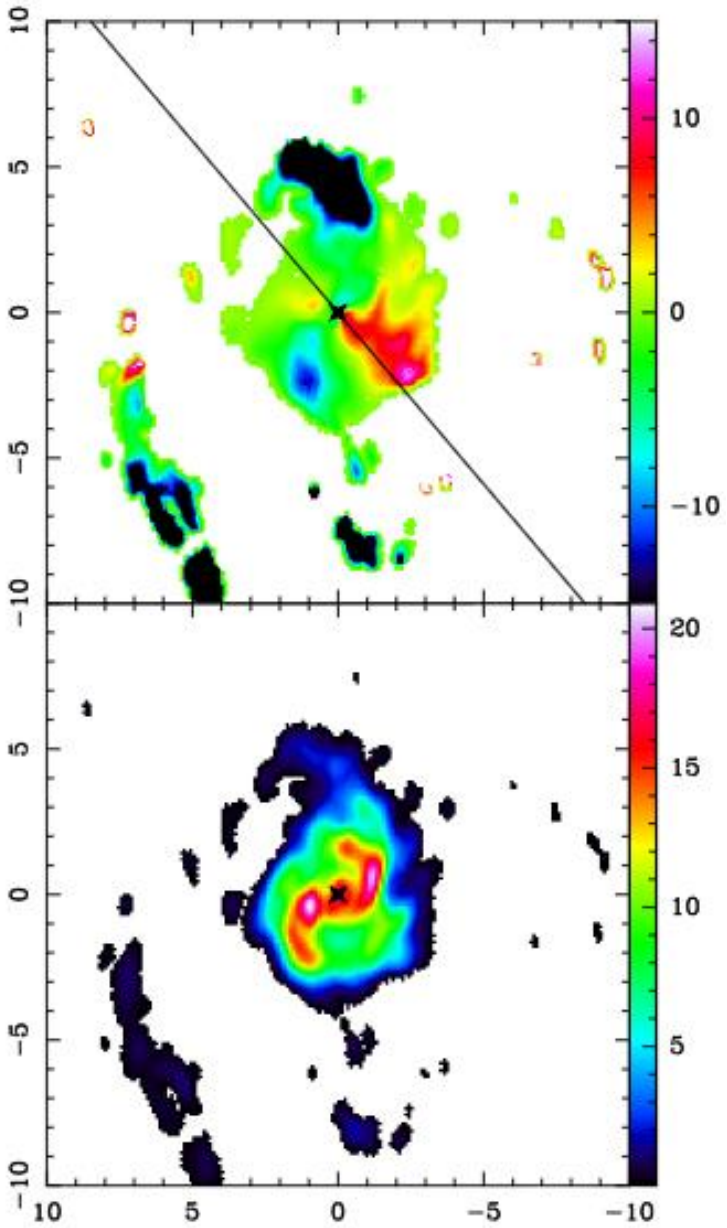
Overlay CO(3-2) contours on HST image



NGC1566: gravitational torques

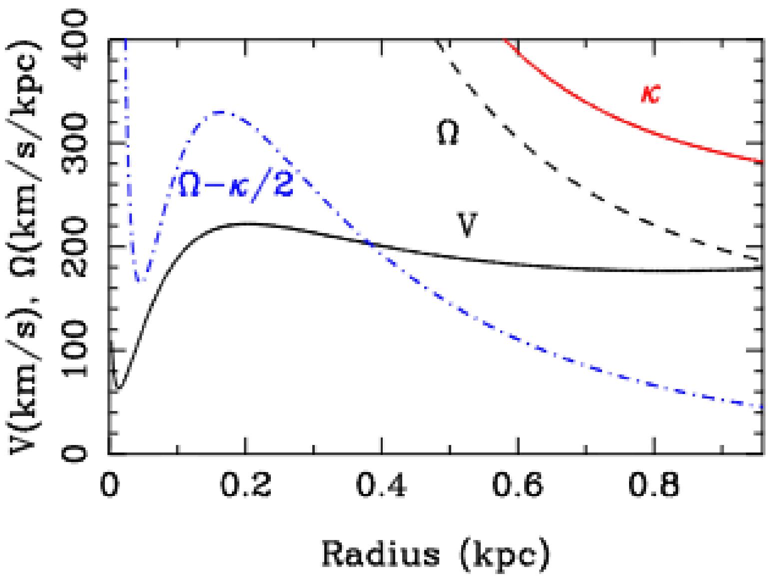


Torques on deprojected image



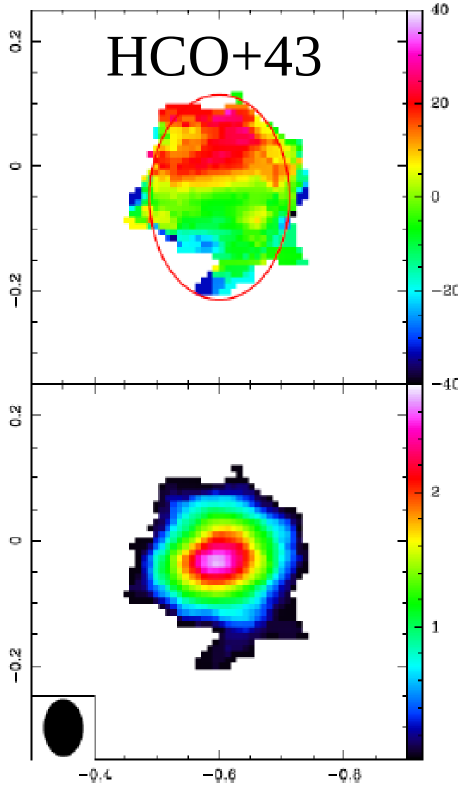
Trailing spiral inside the ILR ring of the bar

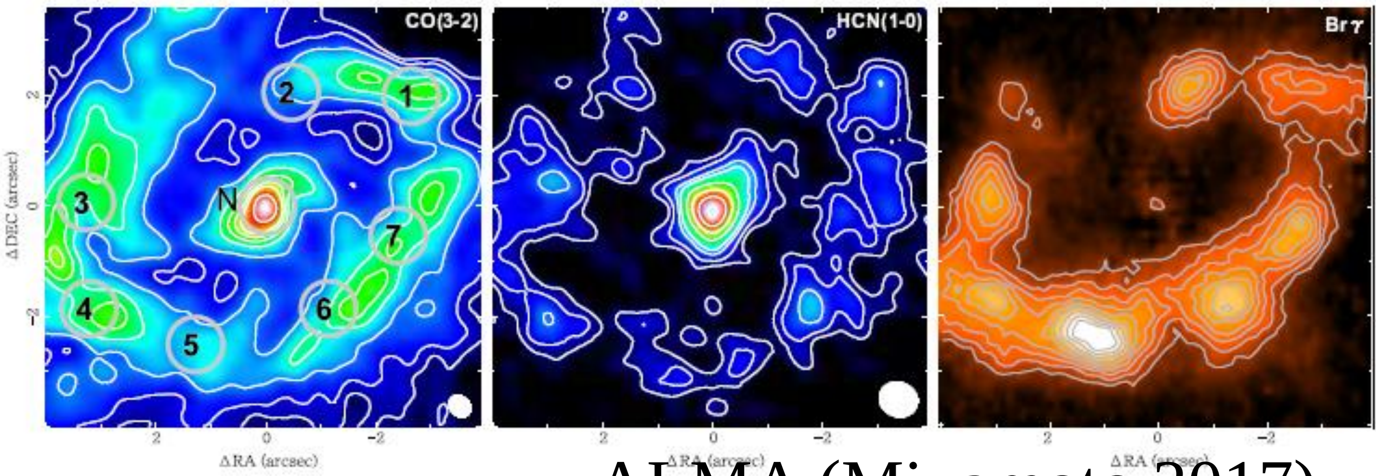
➔ BH influence on the dynamics



Gas is driven inwards

0.6” 50pc



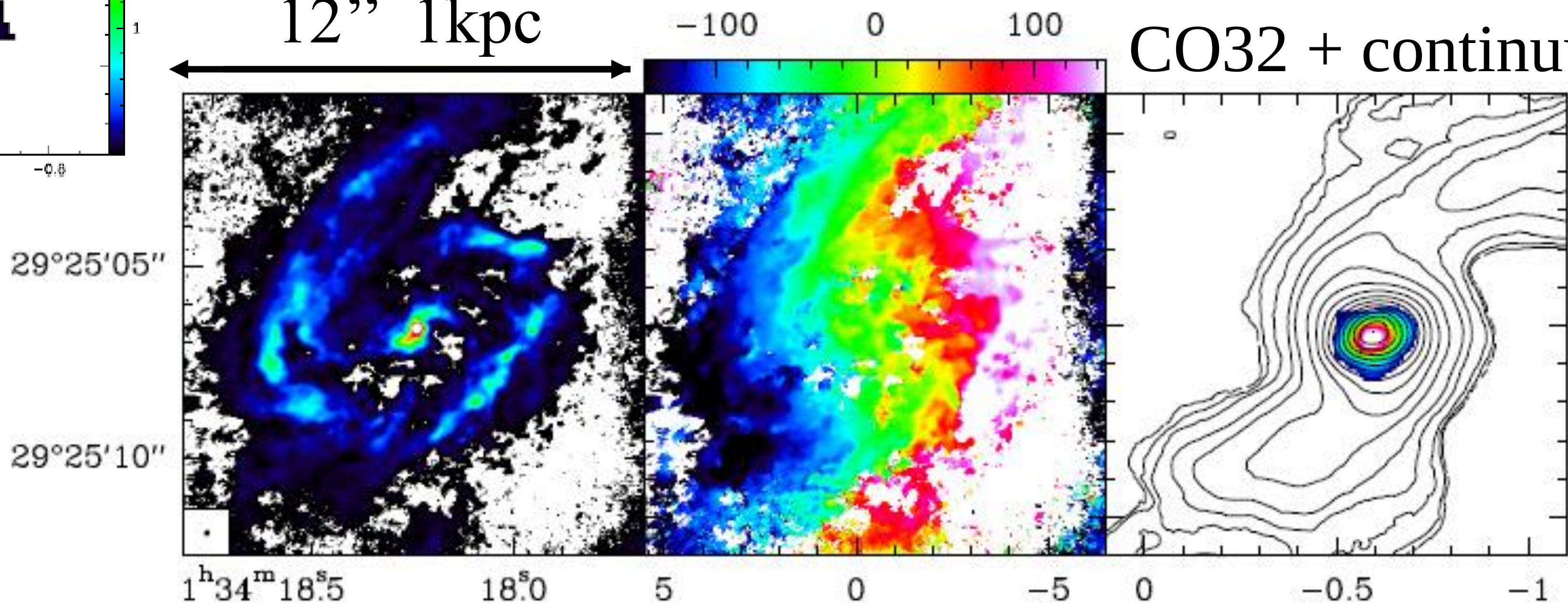


ALMA (Miyamoto 2017)

NGC613

12” 1kpc

CO32 + continuum



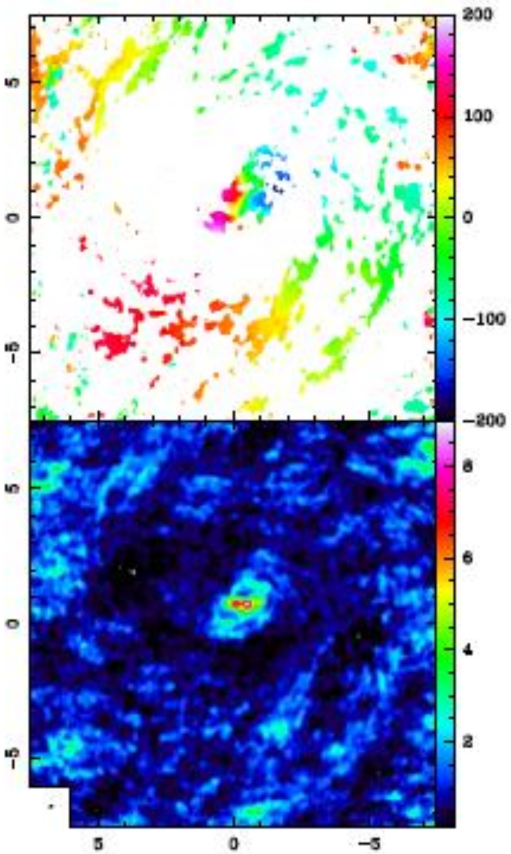
0.6” 50pc

Beam 0.09” x 0.06” (5pc): nuclear spiral +torus

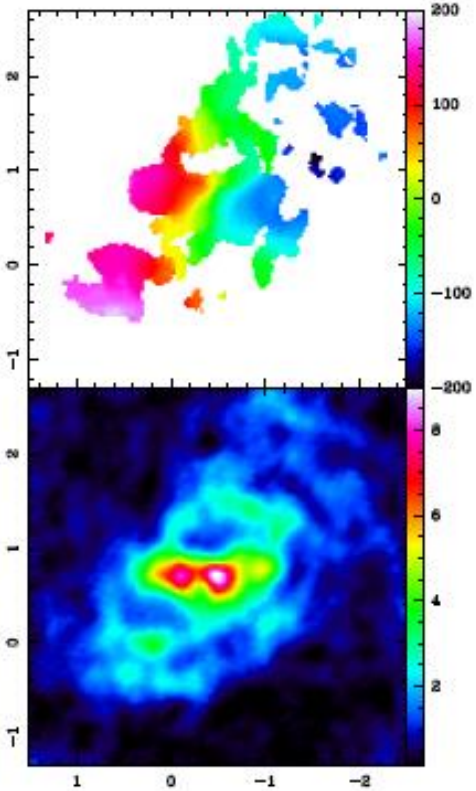
Combes et al 2018

NGC1672

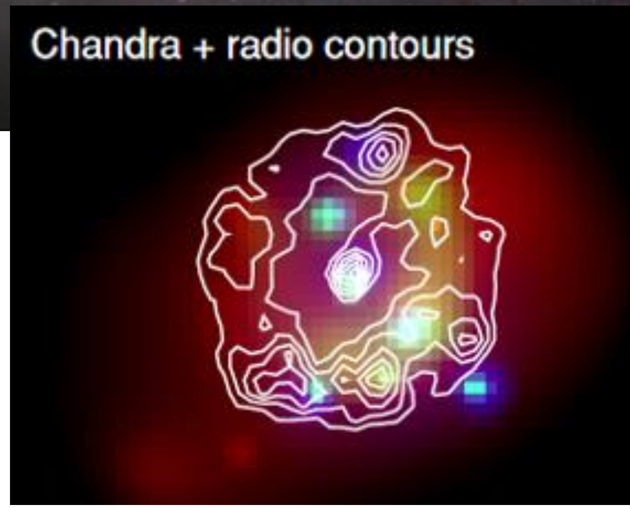
- Sy 2, SB(s)b
- 11.4 Mpc, i~30°
- 3pc resolution



15” (820pc) CO32



4” (220pc)

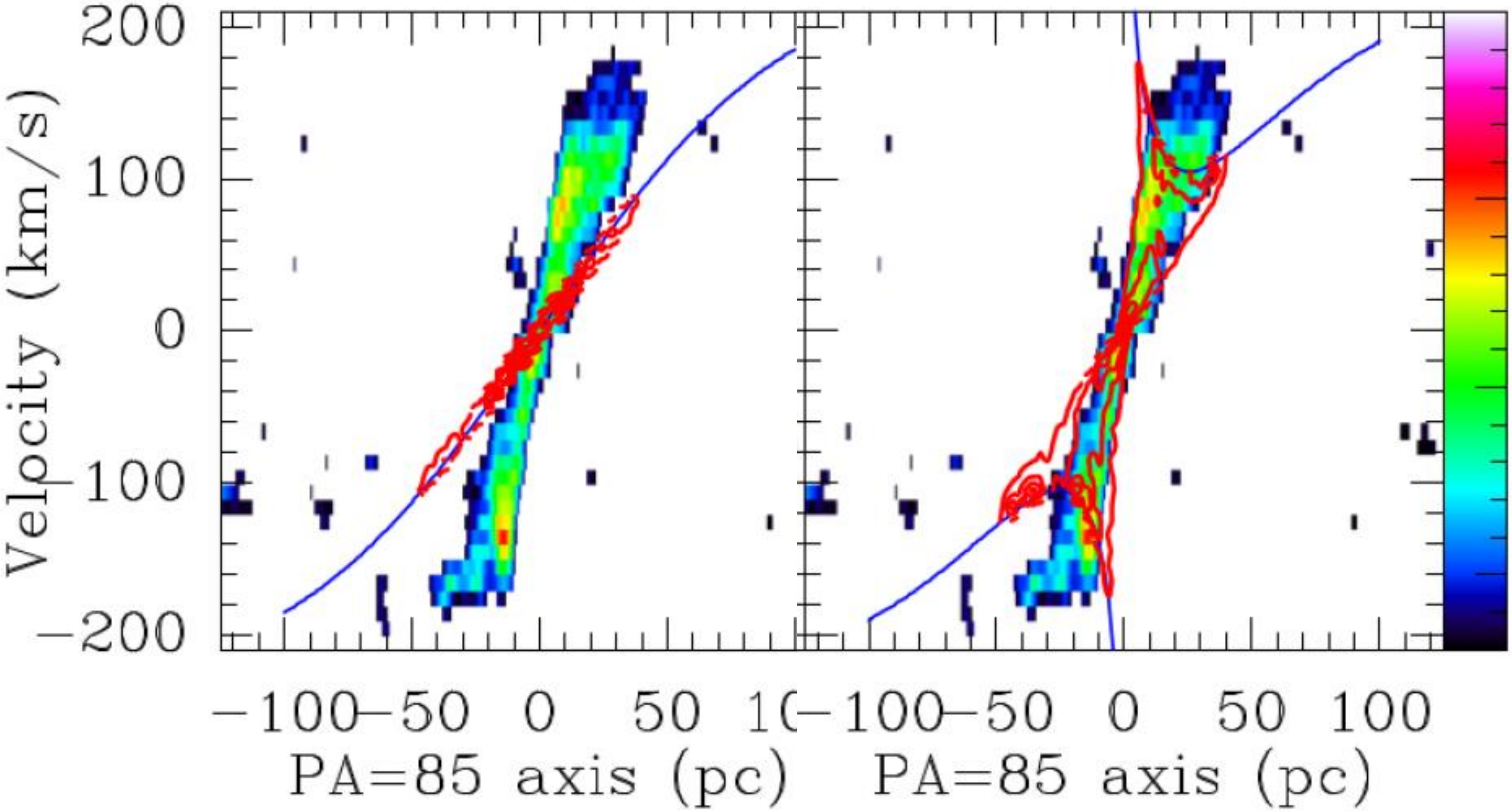


Torus edge-on R=27pc

Beam 0.09” x 0.06”

Combes et al 2018

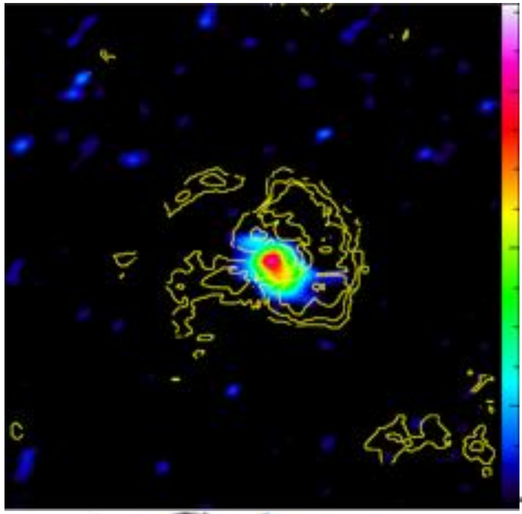
N1672: Black hole mass

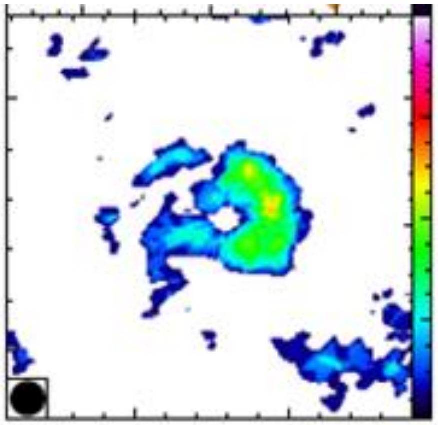


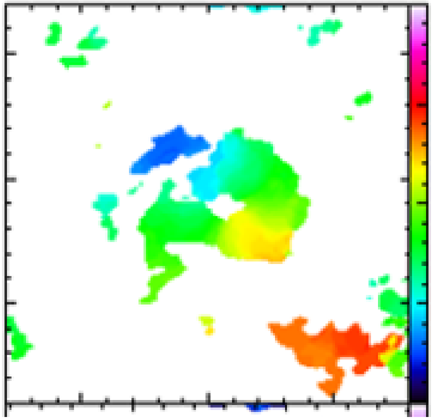
Without BH

With BH, of
M= 5 10^7 $M_{\odot}$

Frequency of « molecular tori » : 7/8







NGC 1365

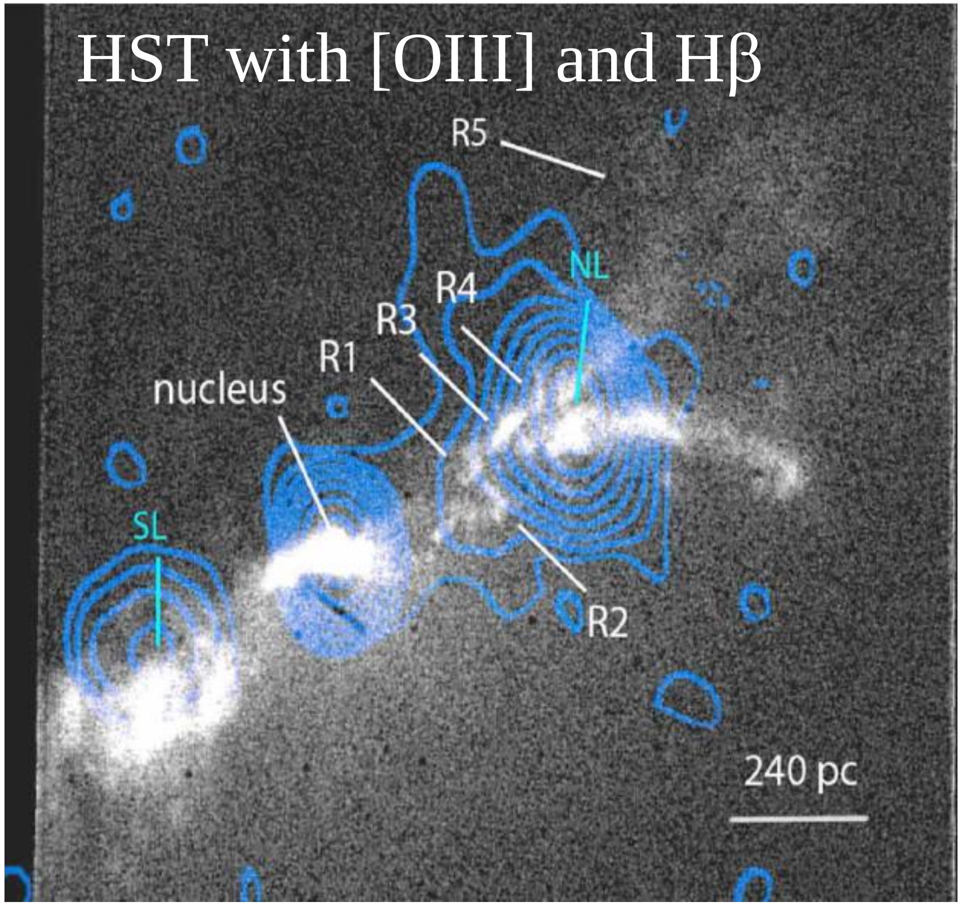
Galaxy	Radius (pc)	$M(H_2)^a$ $10^7\ M_\odot$	inc(°) torus	inc(°)[b] gal
NGC 613	14±3	3.9±1.4	46±7	36
NGC 1326	21±5	0.95±0.1	60±5	53
NGC 1365	26±3	0.74±0.2	27±10	63
NGC 1433	–	–	–	67
NGC 1566	24±5	0.88±0.1	12±12	48
NGC 1672	27±7	2.5±0.3	66±5	28
NGC 1808	6±2	0.94±0.1	64±7	84
NGC 1068	3.5	0.01	80	24

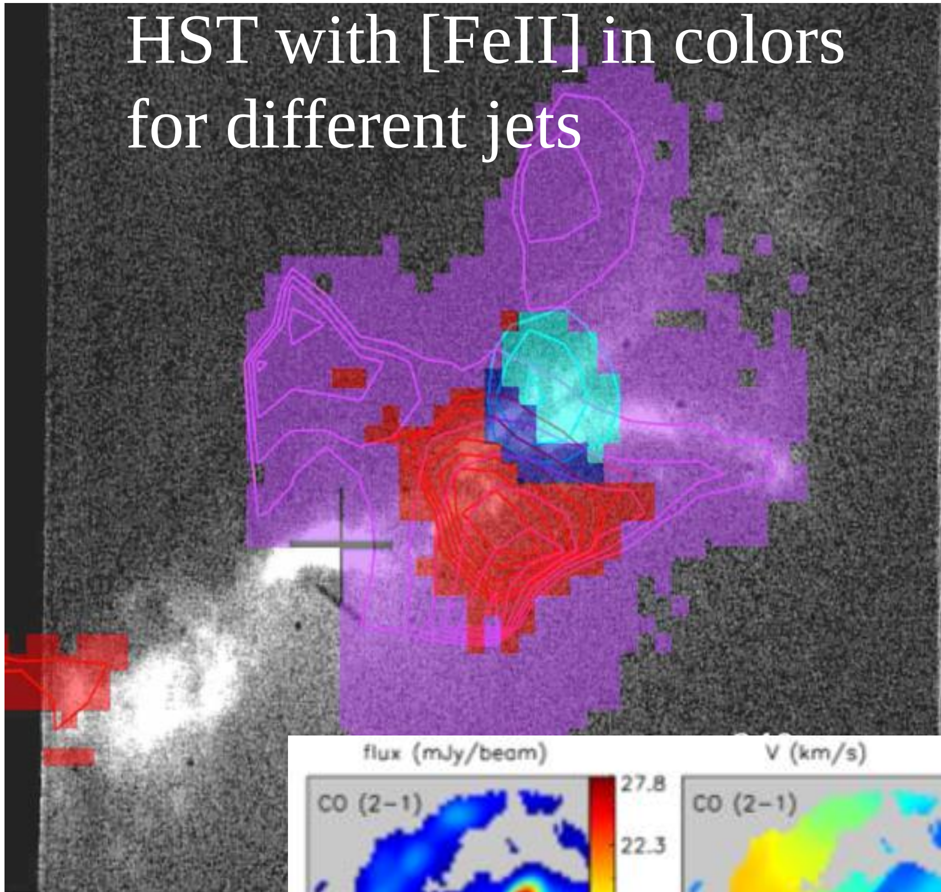
IC5063: multiple winds along the jet

S0

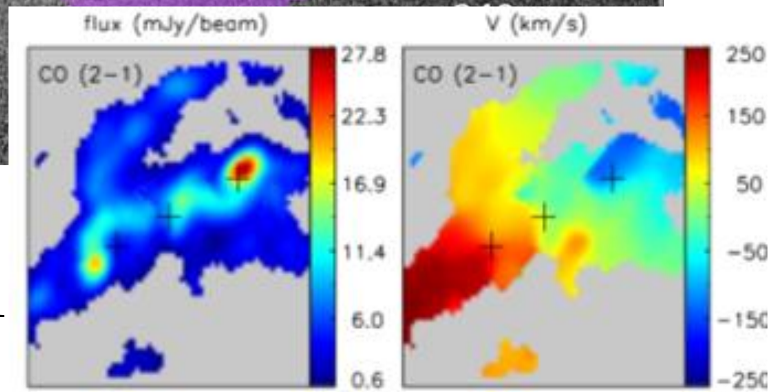
VLT SINFONI, NIR H_2, Fe lines

Blue and Red-shifted lines in 4 points, where the jet is diverted

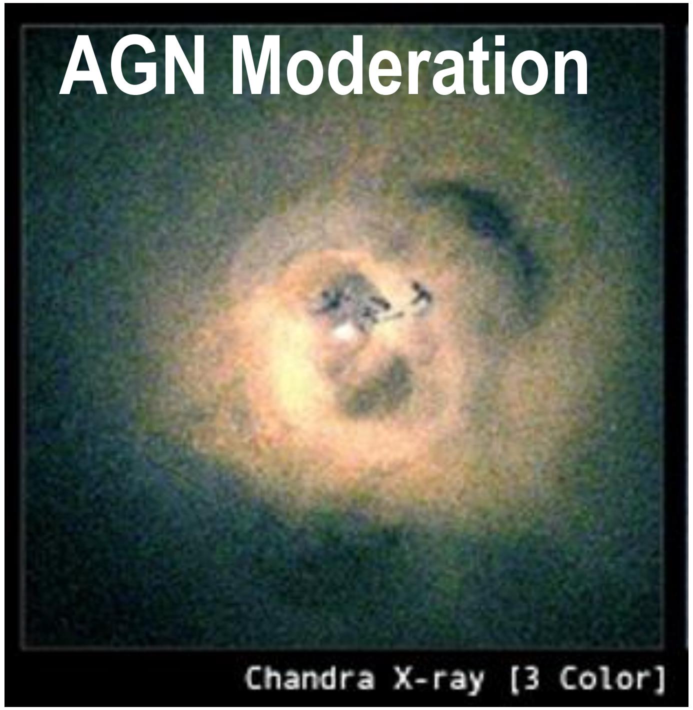


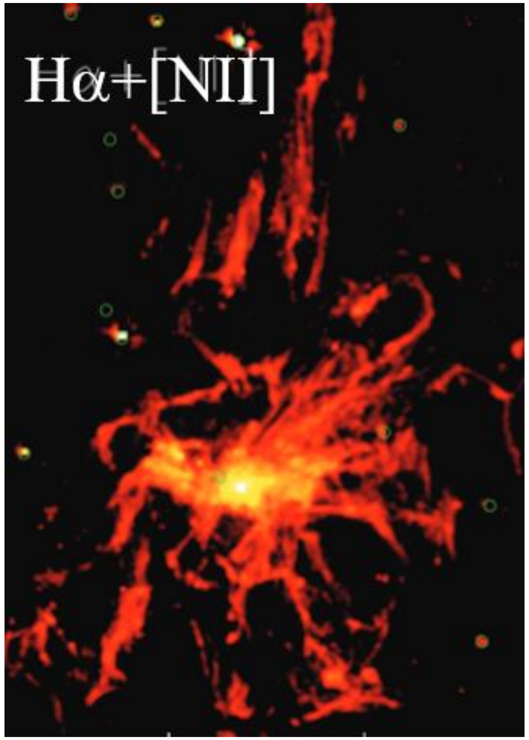


ALMA, CO21



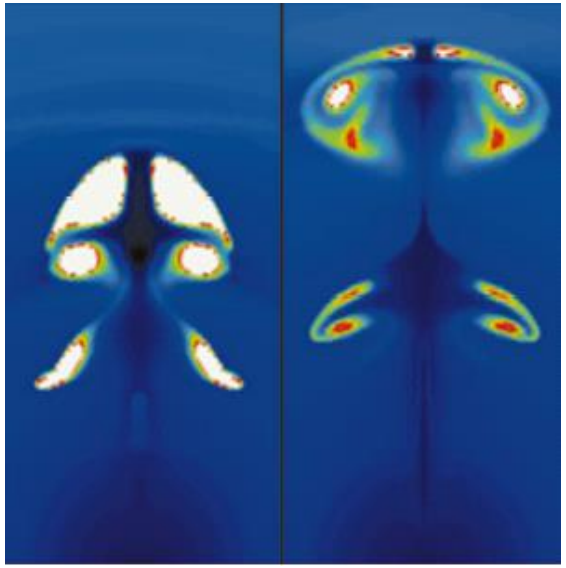
Dasyra et al 2015, 2016

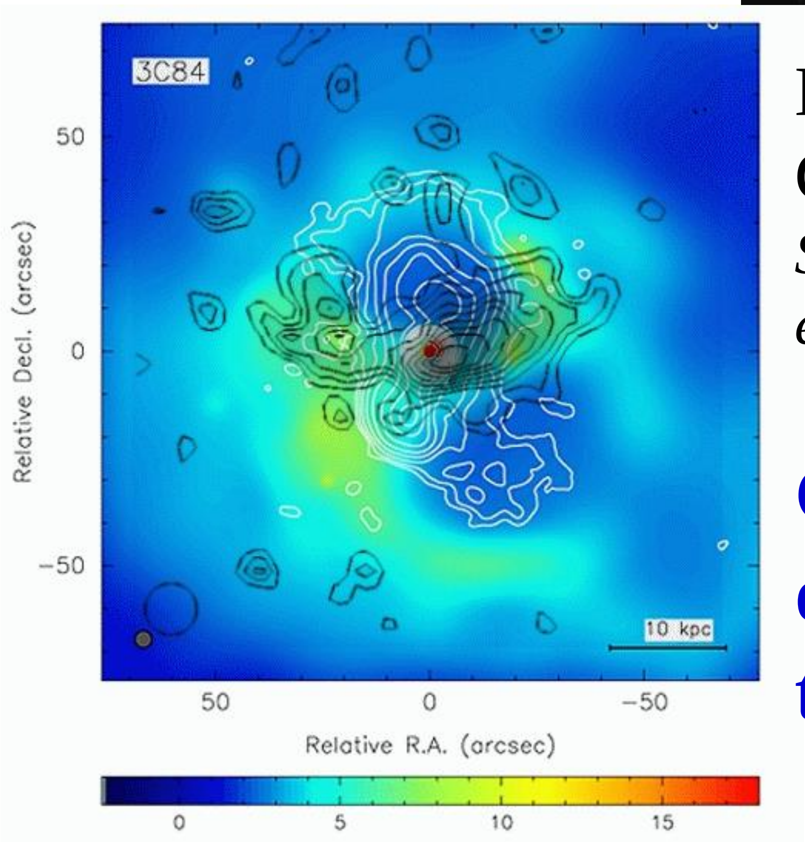




Gas flow in cool core clusters

Simulations, Churazov 2001

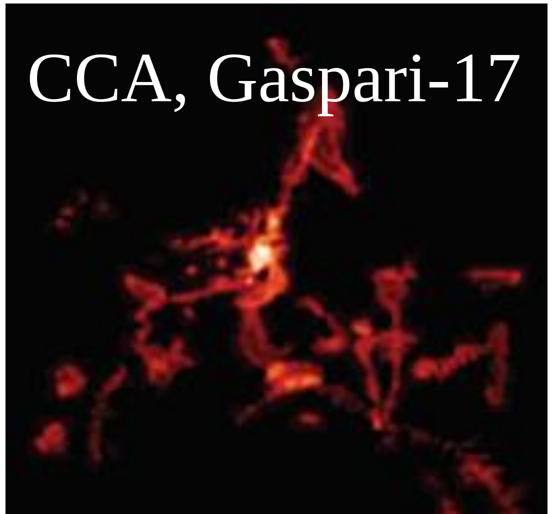


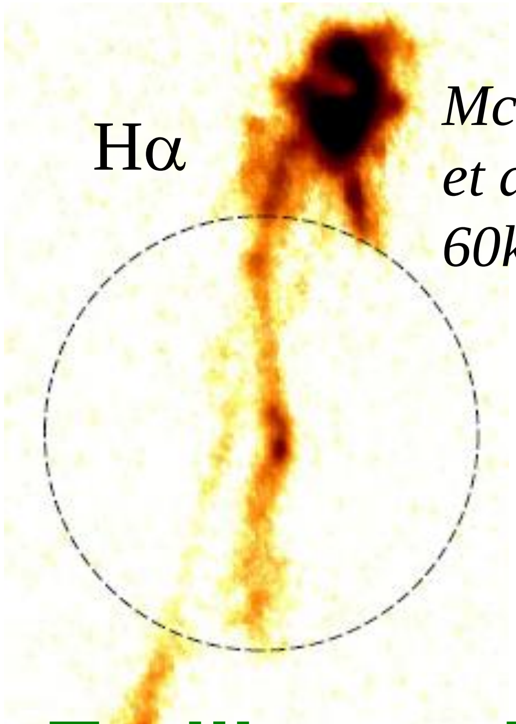


Molecular Gas, Perseus
Salomé et al 2006

Gas raining down towards the AGN

Chaotic Gas Accretion





McDonald et al 2009 60kpc tail

Inflow & outflow coexist

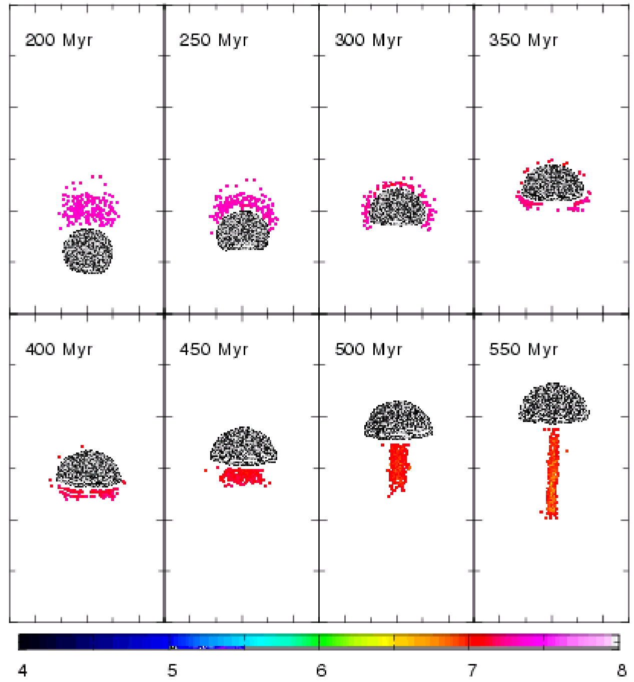
Molecular gas dragged out by the AGN feedback

The bubbles create further cooling

At R~20kpc, tc/tff ~10

➔thermal instability

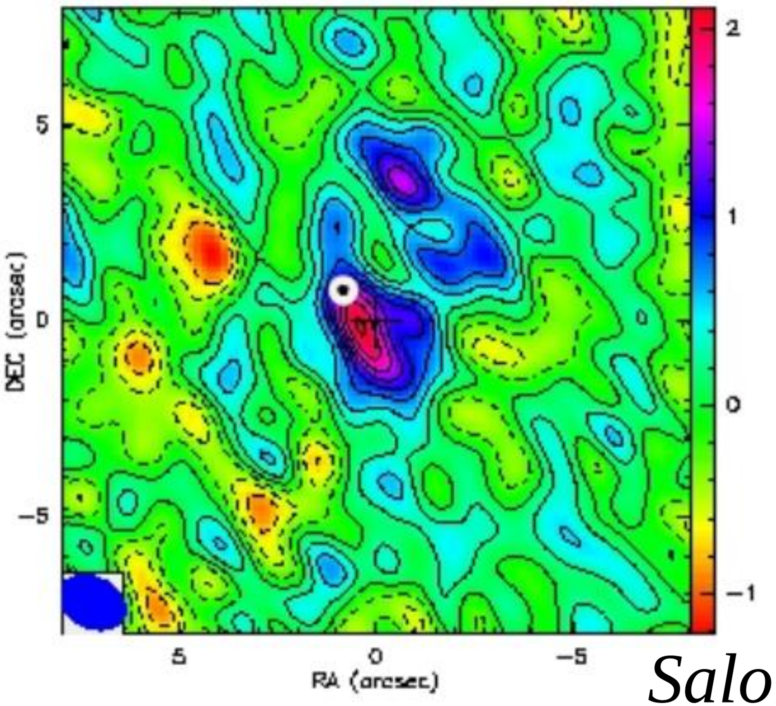
(McCourt et al 12)

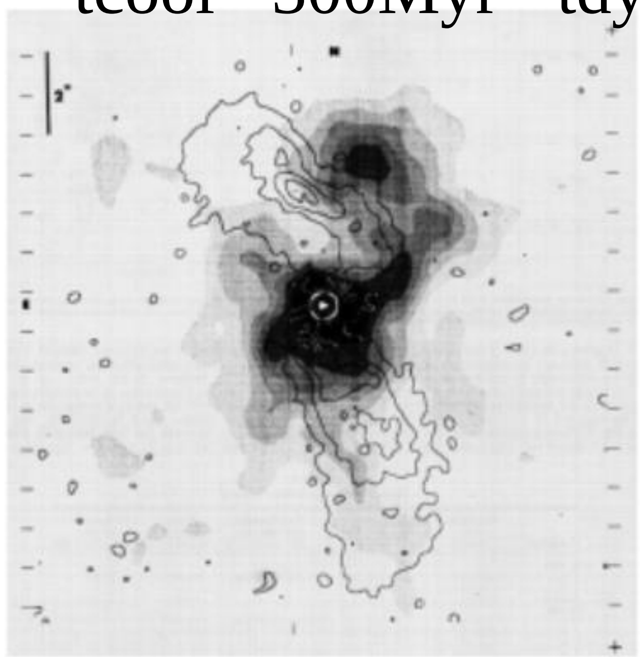


Revaz et al 2008

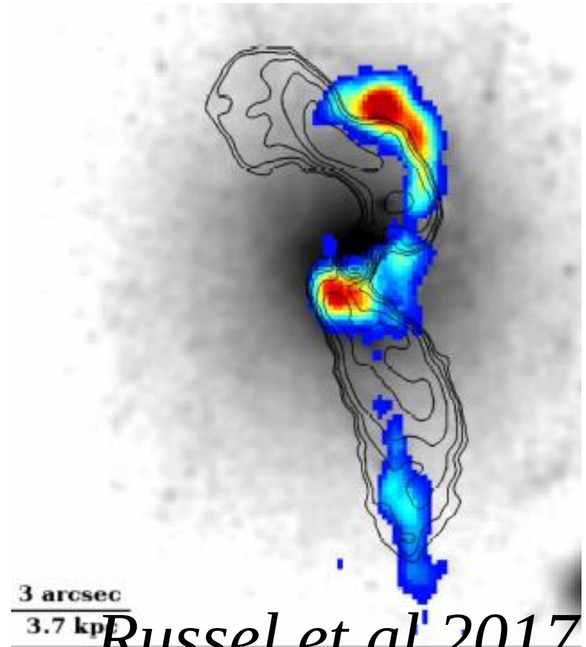
Trailing wake A1795

tcool= 300Myr= tdyn



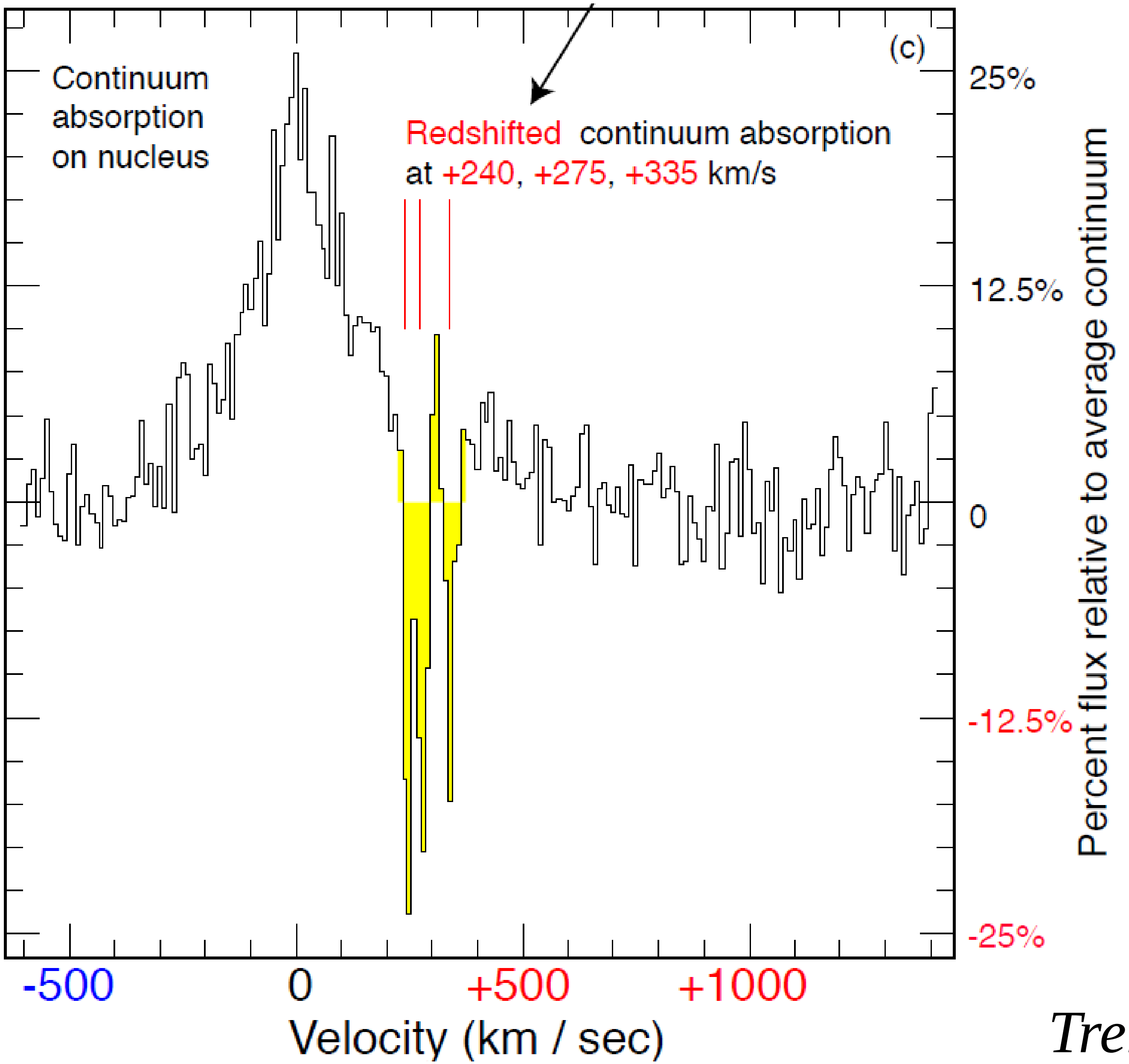


Salome & Combes 2004



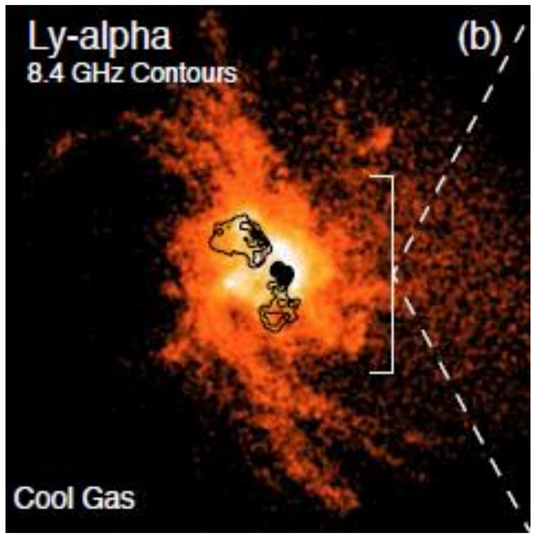
Russel et al 2017

Cold gas in absorption: inflow



Abell 2597 ALMA CO(2-1) absorption in front of the AGN synchrotron

Red-shifted only
Dense clouds fueling the AGN



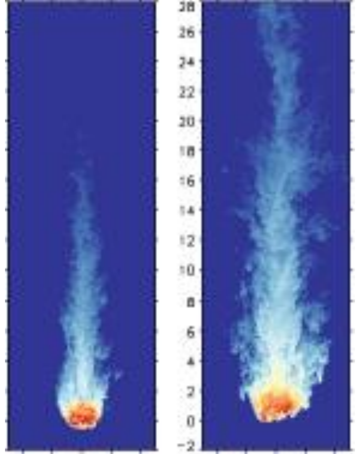
Tremblay et al 2016, 2018

Environmental quenching

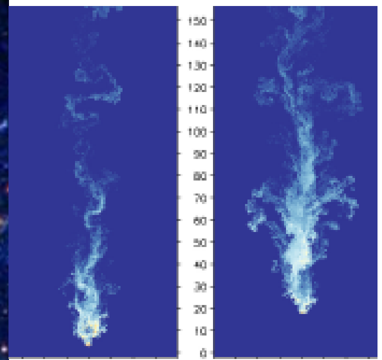
Ram pressure in clusters ➔ **Jelly-fish galaxies**

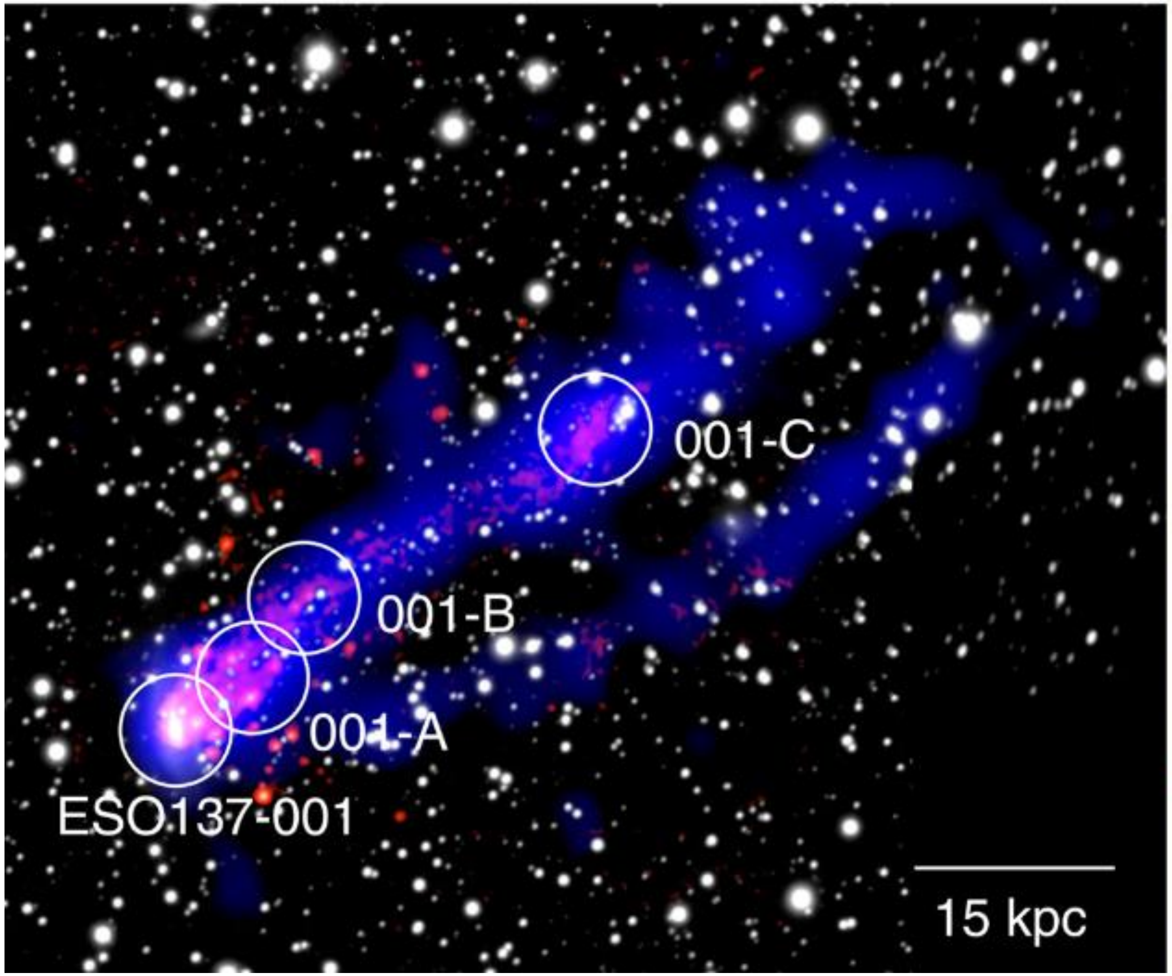
In Virgo, HI deficient, but not H_2 *(Kenney & Young 1989)*

can be fast in exceptional cases: ESO137-001



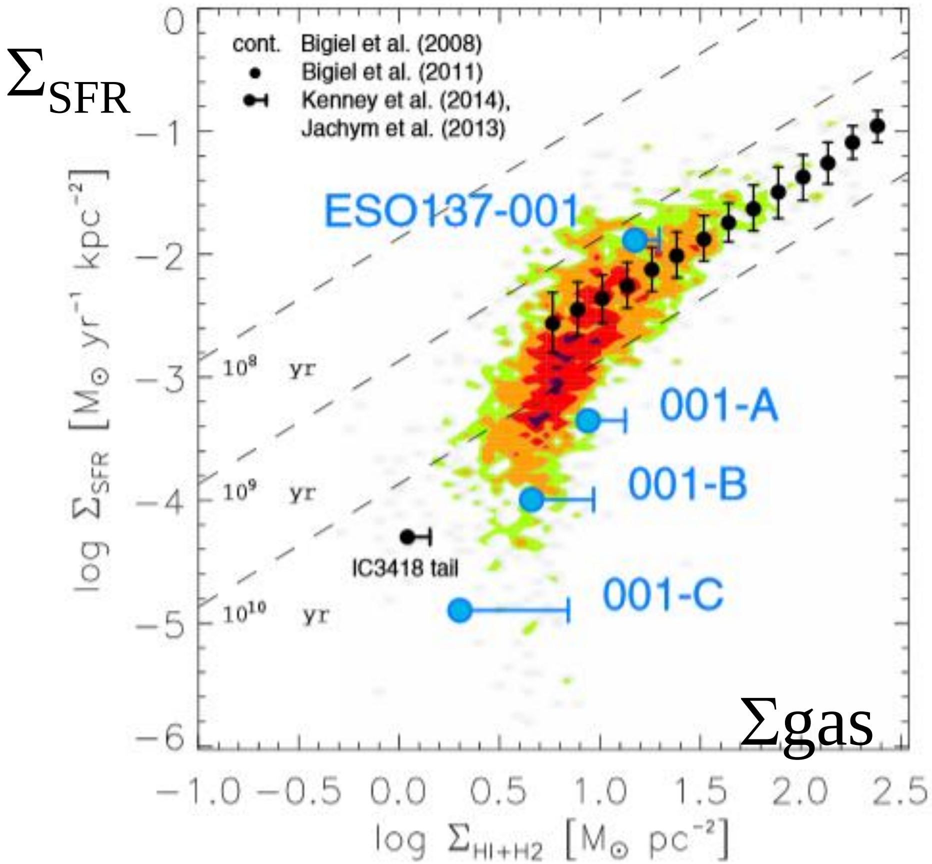
Banda-Barragan et al 2019

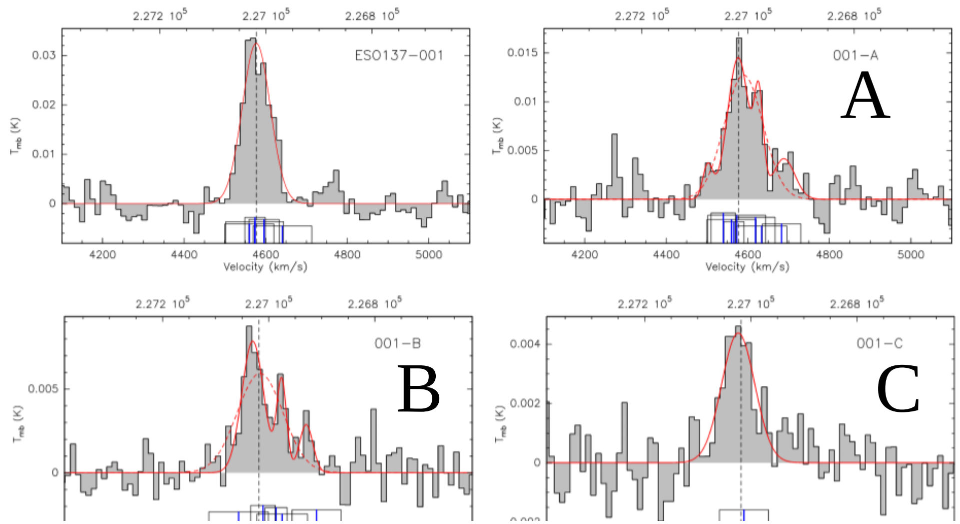


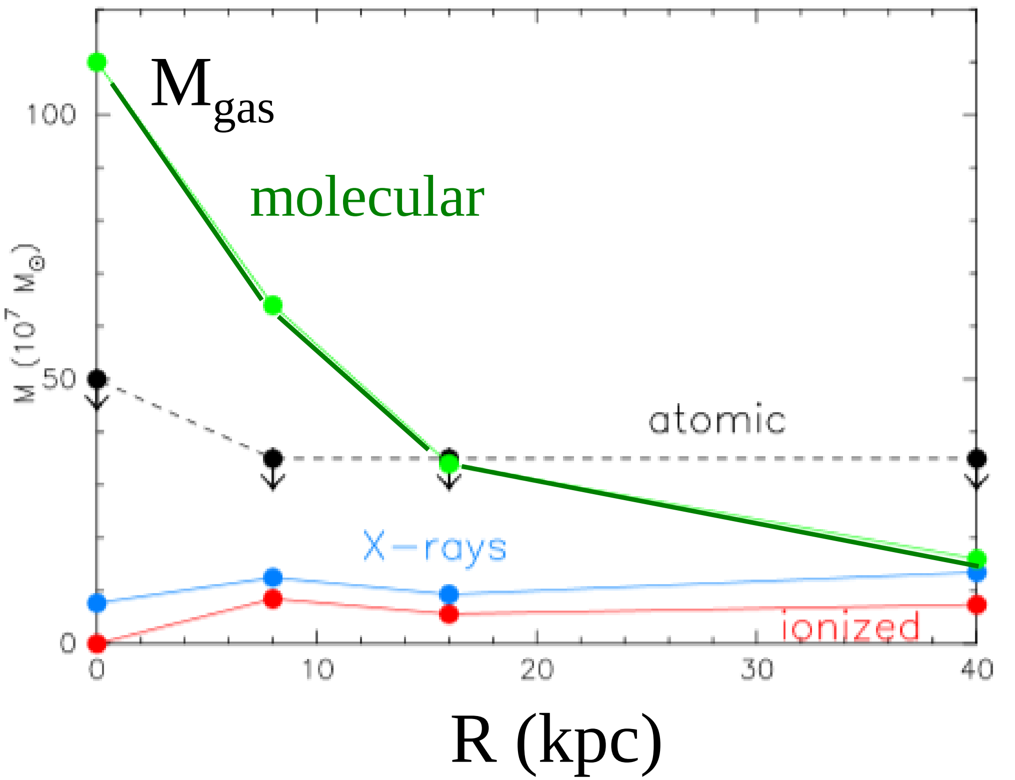


Jachym et al 2014

Ram-pressure quenching





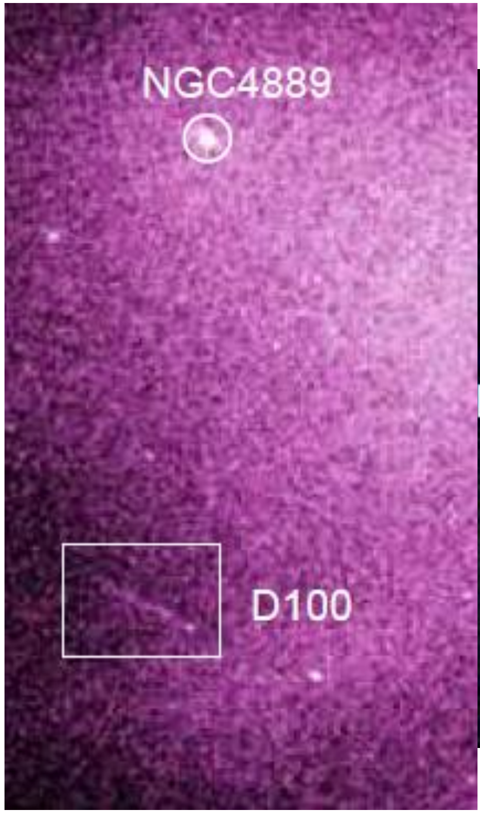


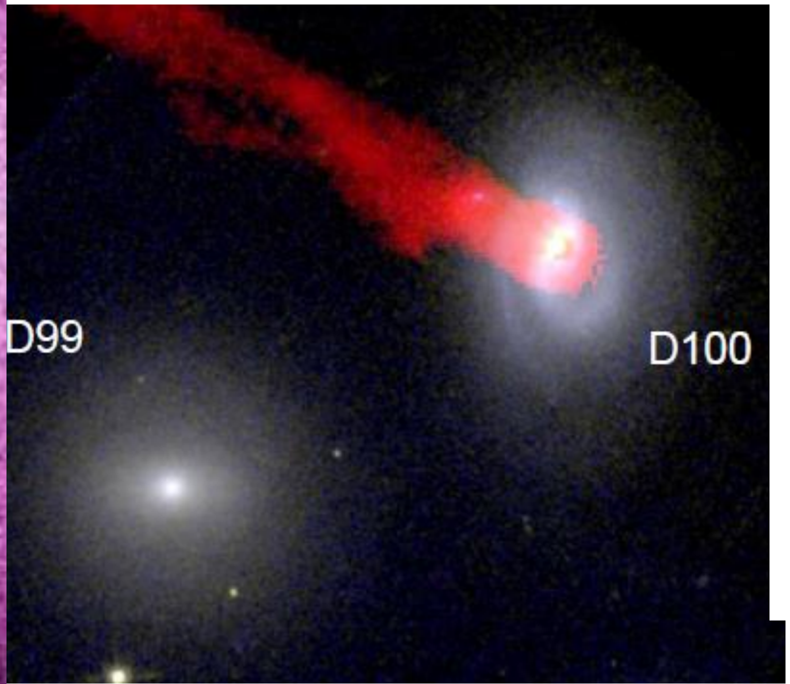
Tail of 80kpc in X-ray gas,
40kpc in CO
$M(H_2)$ in C =1.5 $10^8 M_\odot$

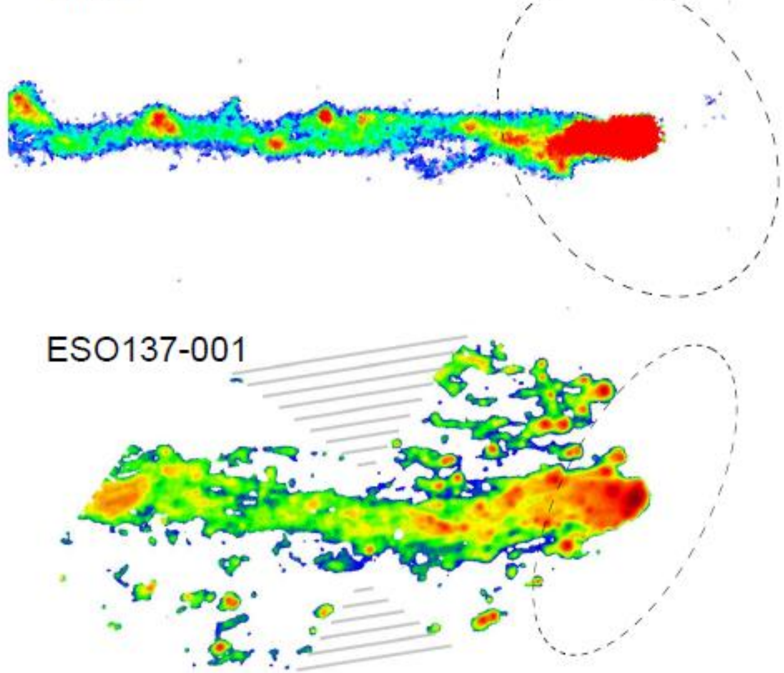
Jachym et al 2014

Ram-pressure in Coma

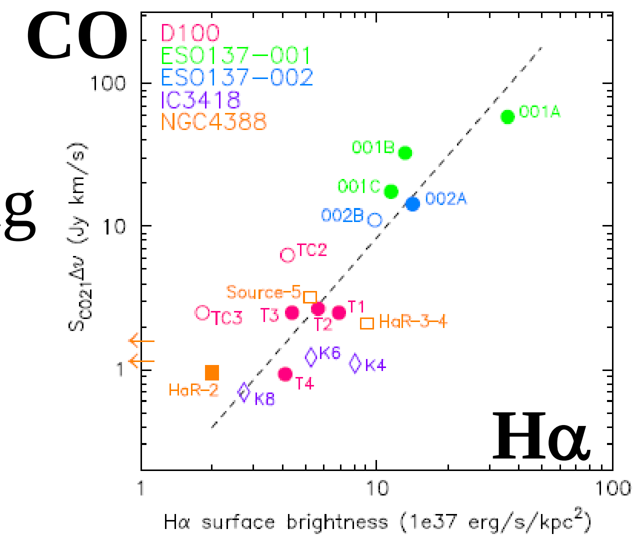
MUSE Fumagalli et al 2014

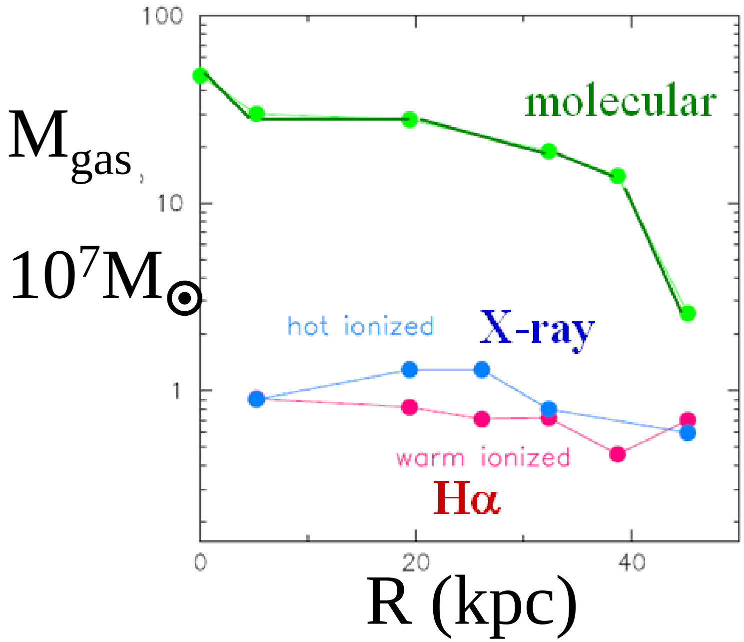






D100 tail: thinner
Last stage of stripping

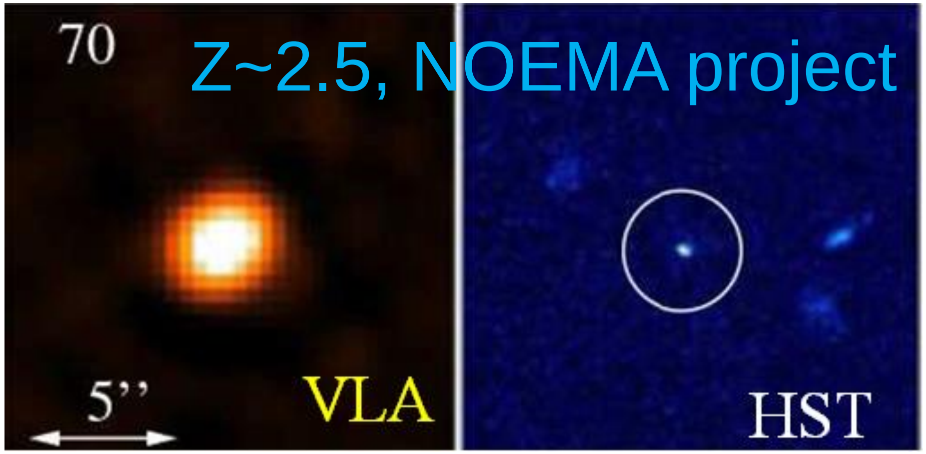




Jachym et al 2017

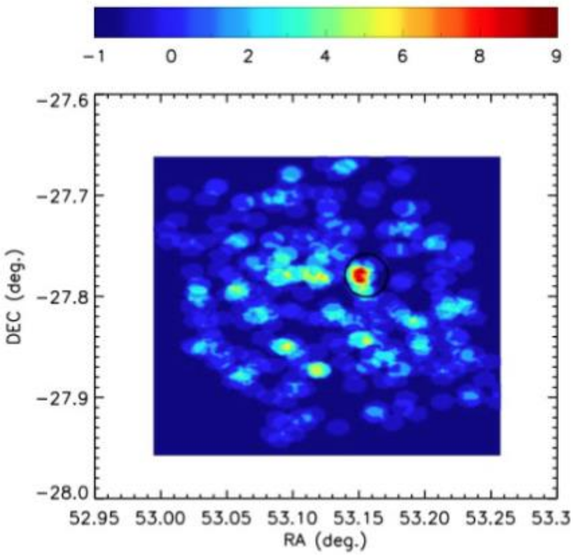
Reversal of SFR-Density relation

Observation of CO in galaxies in clusters and proto-cluster up to z~2-3

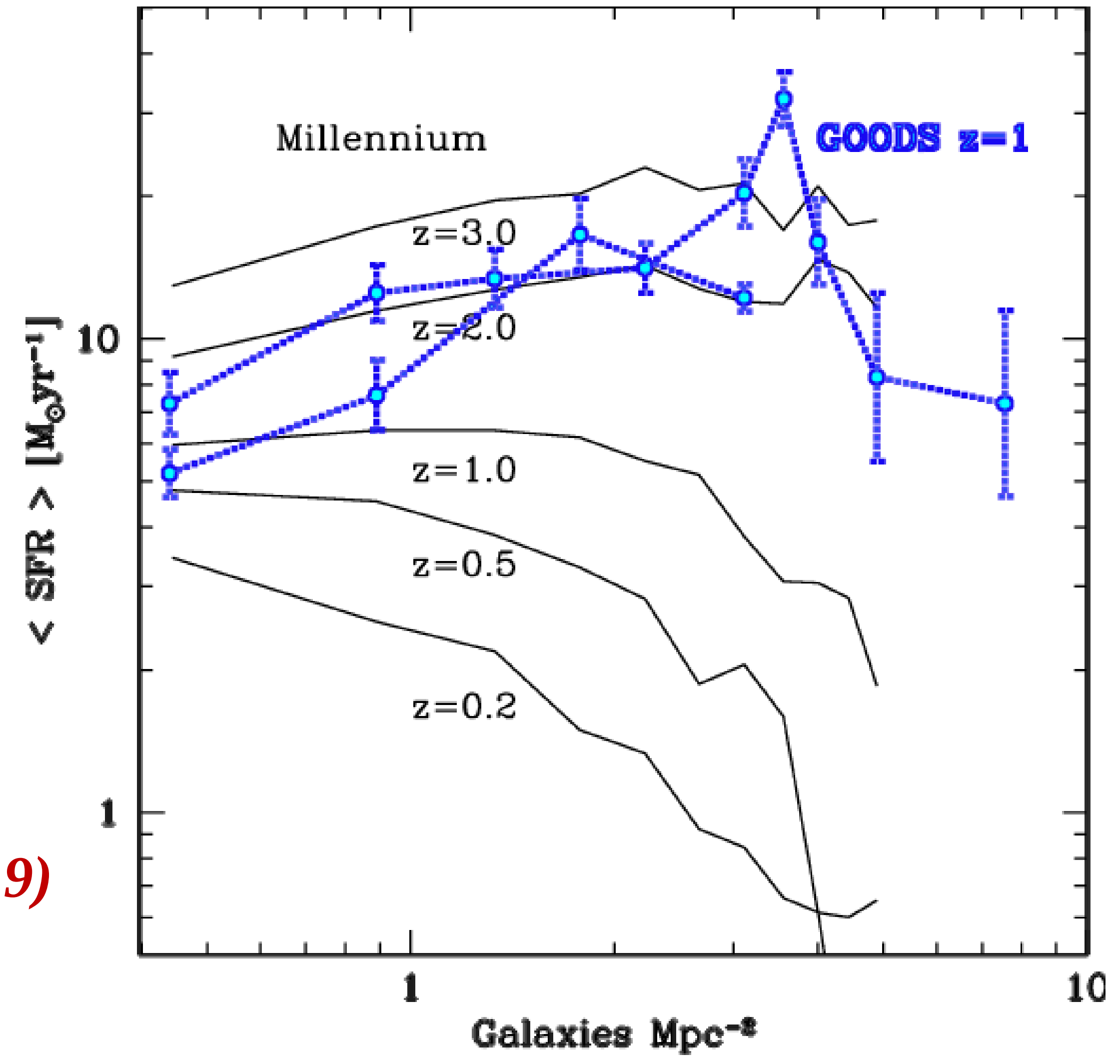


Castignani, Combes, Salome +2018-19

+ CARLA
NOEMA project

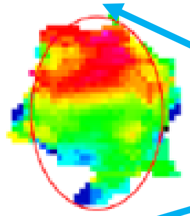


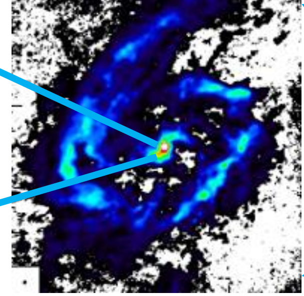
Galametz,
Mei et al 2018-19)



Elbaz et al 2007

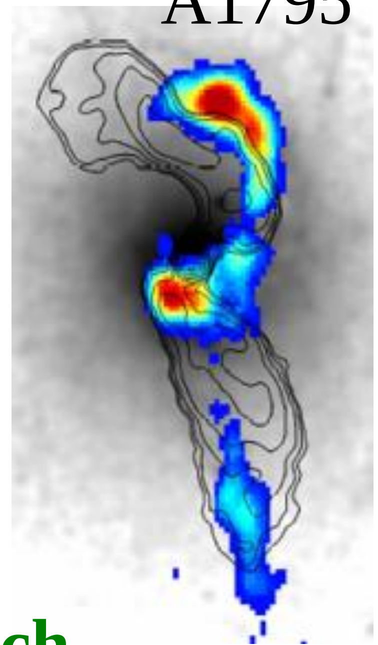
SUMMARY





➔ **Fueling: Primary bar** drives gas → **100pc**
Then nuclear bar from 100pc to 10pc

A1795

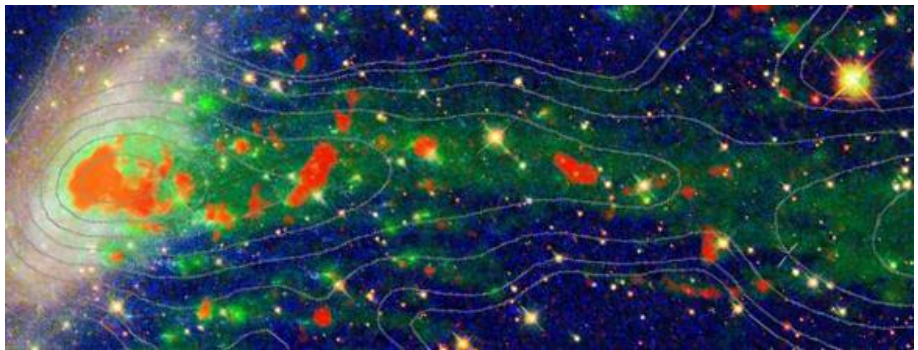


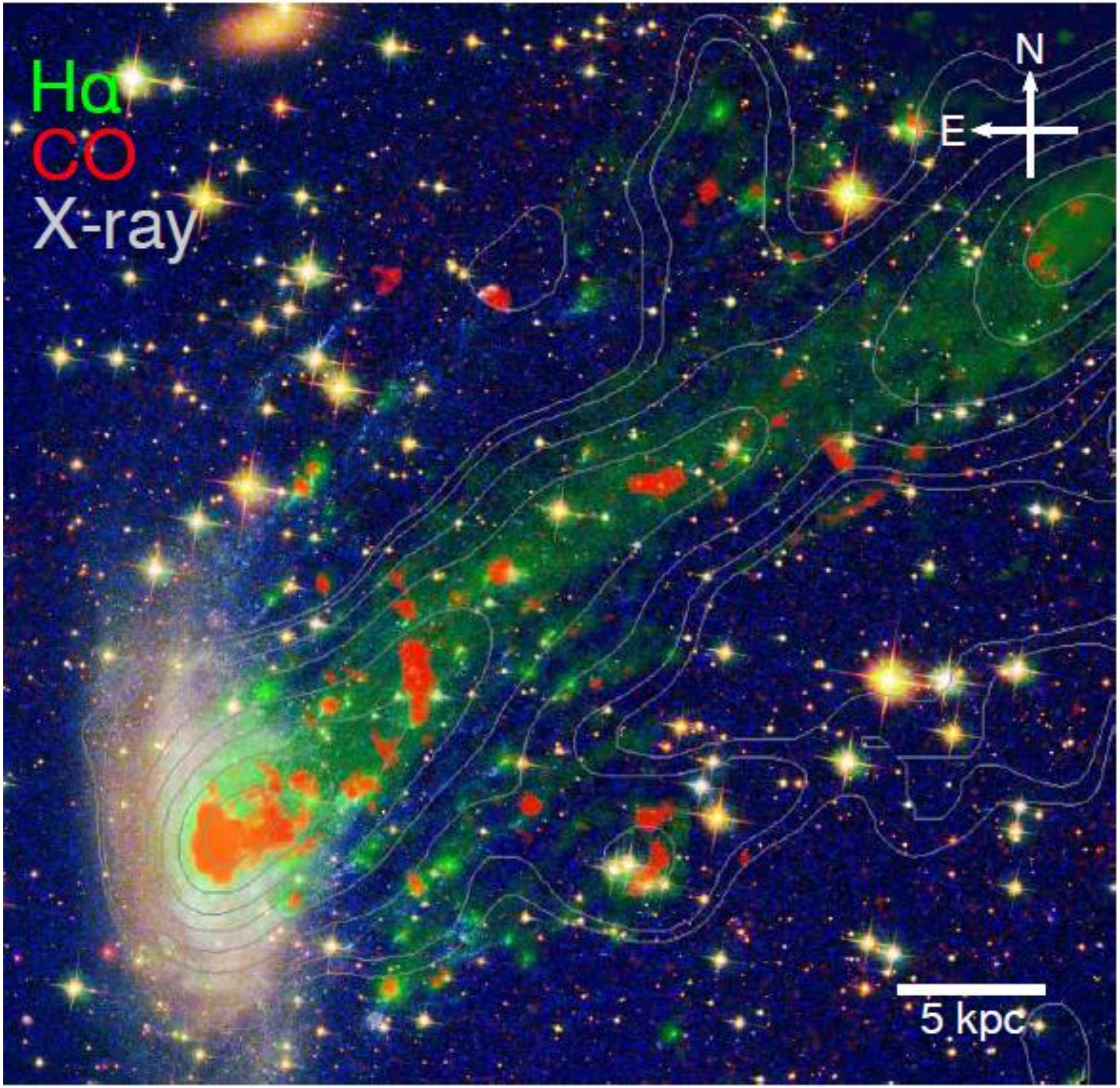
➔ **At scales ~1-10pc,** macro-turbulence, clumps, warps, dynamical friction, formation of **thick disks/torus**

➔ **Feedback:** outflows due to starbursts and to AGN
Strong coupling due to mis-alignment

➔ **Environmental effects (ram-pressure, tides) can quench efficiently star formation → red sequence**

ESO137-001





Hα
CO
X-ray
N
E
5 kpc

Jean-Baptiste Melin

The CMB in High Definition

The CMB in High Definition

- Future CMB experiments (LiteBIRD, Simons Observatory, CMB-S4) primarily designed for B-mode search ➔ **High resolution** (sub arcmin), **low noise** (sub μK.arcmin) frontier**?**



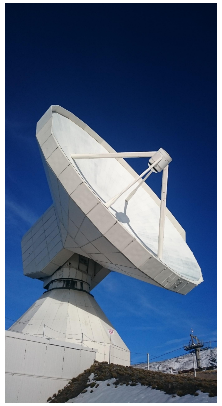
- A rich science case (Cosmology & Astrophysics) to explore
  - Dark matter (small scale CMB lensing)
  - Reionization (via kSZ)
  - tSZ cluster survey (higher z, lower mass)
  - Follow-up of clusters (mass via CMB halo lensing, gas via tSZ, internal motions via kSZ)
  - Cluster peculiar velocities (via kSZ)
  - tSZ & kSZ 2D power spectra
  - Extragalactic mm/submm sources
  - Planetary science
  - …

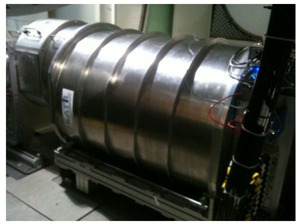
The CMB in High Definition

- The community started to organize around projects (GBT, CCAT, AtLAST) and meetings
https://www.simonsfoundation.org/event/the-cmb-in-hd-the-low-noise-high-resolution-frontier/

- “Ideal” instrument
  - ~10-20 arcsec resolution
  - ~0.1μK.arcmin sensitivity
  - ~1deg^2 fov
  - ~10% sky coverage
- Many instrumental constraints (telescope, detectors, site, cost…)

- Can IRAM facilities (30m+NIKA2) evolve towards this new high res, low noise frontier?





Chiara d'Eugenio

Dead and Dusty galaxies at $z \sim 3$?

C.D'Eugenio, E. Daddi, R. Gobat, V. Strazzullo, S. Jin

Dead and Dusty galaxies at z~3 ?

Goal: Trace galaxy mass assembly and quenching timescales

Sample: 10 passive galaxy <u>candidates</u> in COSMOS

$M_\star > 5 \times 10^{10}\ M_\odot$

UVJ passive + BzK passive/uncertain

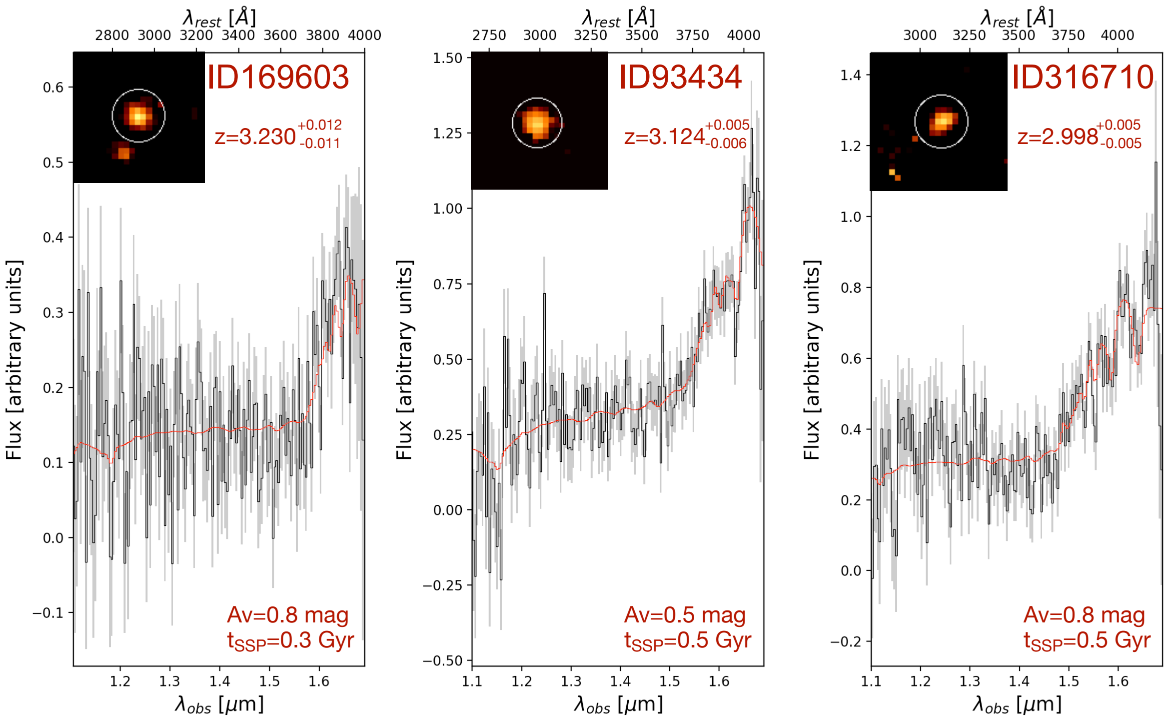
$2.5 < z_{phot} < 3.5$

24μm undetected in McCracken+10

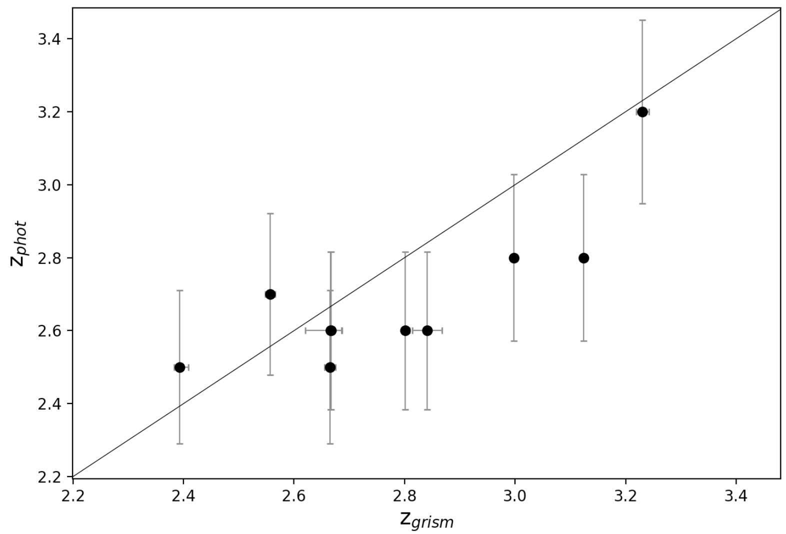
HST Grism Spectra (WFC3/G141)

Fit with 4 SFHs:

- spectroscopic confirmation
- passive or dusty star-forming?

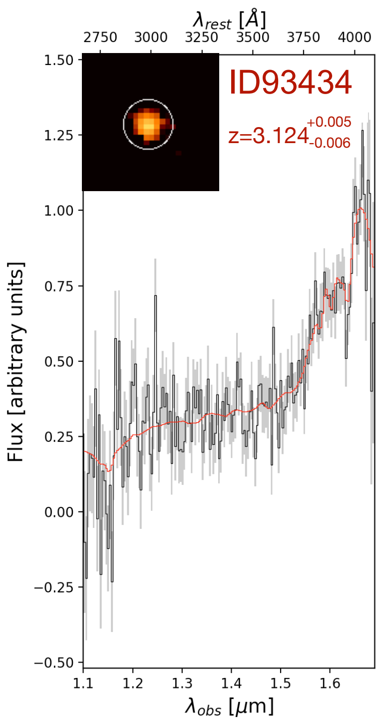


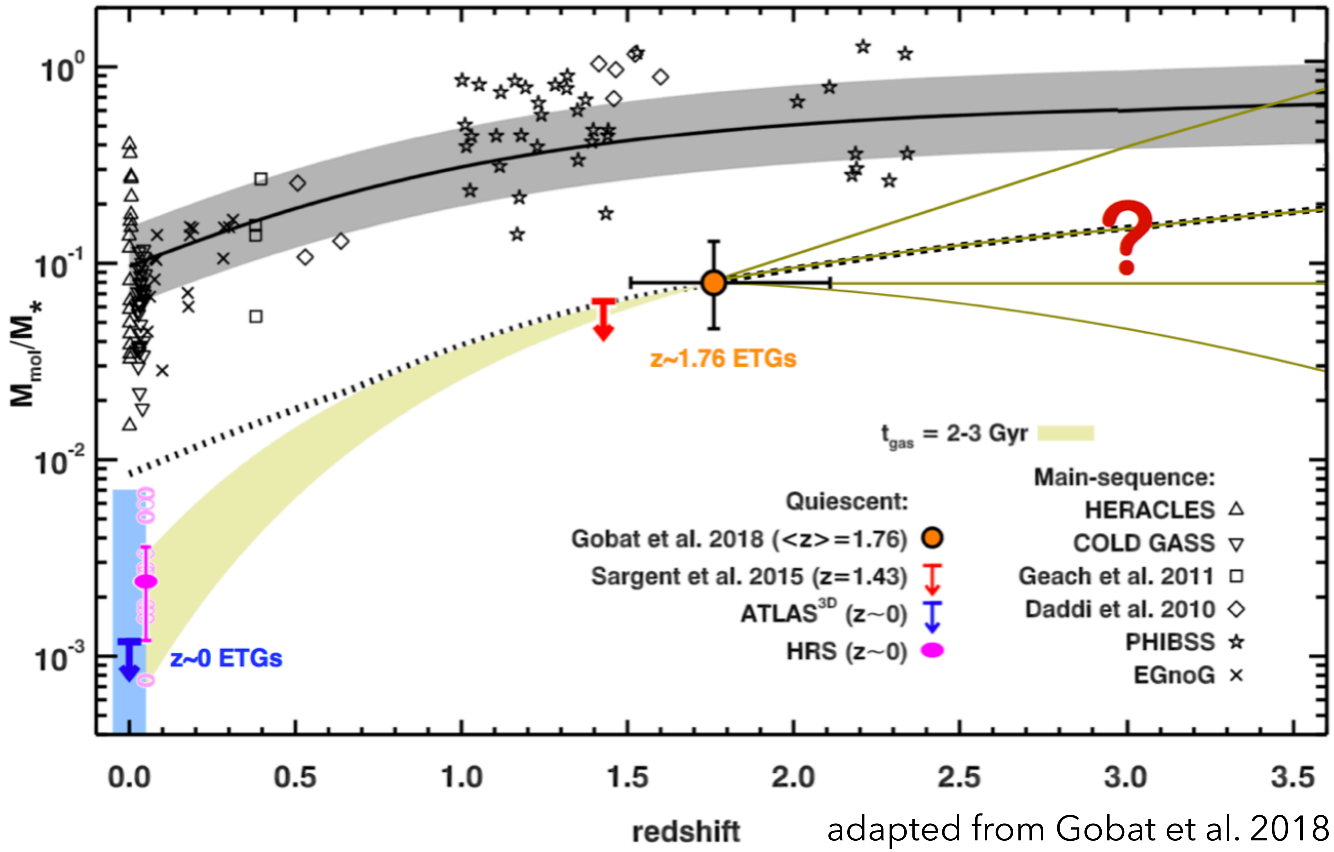
- 7/10 passive (≥0.5 Gyr of passive evolution)
- 1 most likely star-forming
- 2 ambiguous



C.D'Eugenio, E. Daddi, R. Gobat, V. Strazzullo, S. Jin

Dead and Dusty galaxies at z~3 ?





adapted from Gobat et al. 2018

NOEMA to probe M_{dust}, if any, in a confirmed quiescent galaxy z=3.124, $M_\star \sim 10^{11}\ M_\odot$ (8.13h on source)

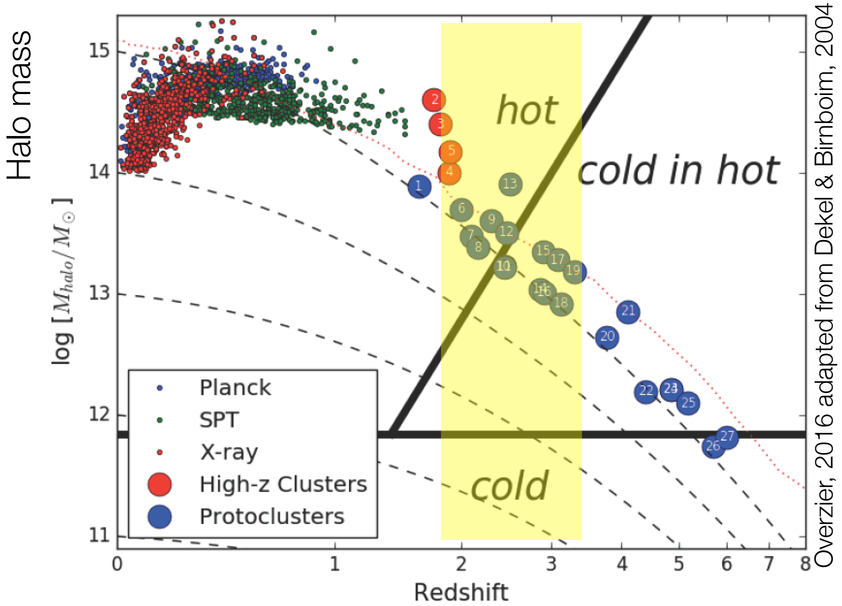
Flux at 260 GHz as a proxy for M_{dust} (→ M_{mol})

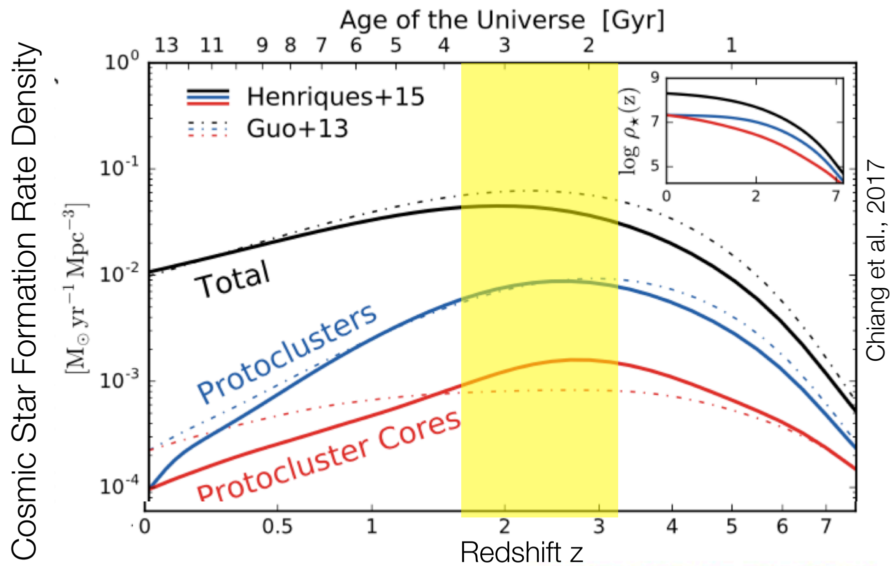
How much gas is there?
Residual gas after quenching or produced by stellar evolution?

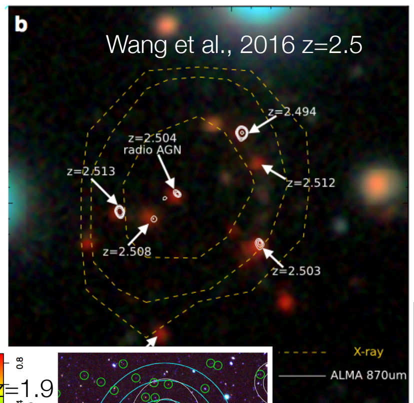
Hervé Dole

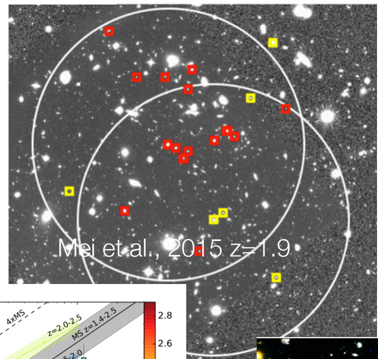
Towards a NOEMA survey of $z > 2$ protoclusters?

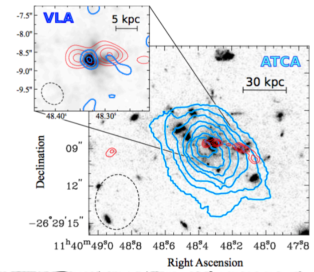
Towards a NOEMA survey of z>2 protoclusters at the Euclid and JWST era

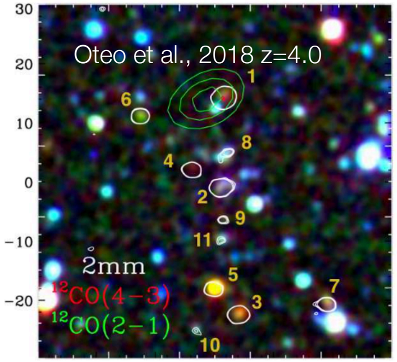


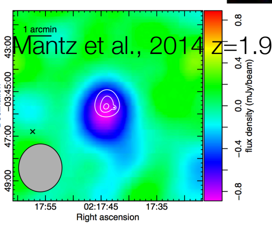


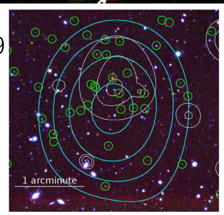


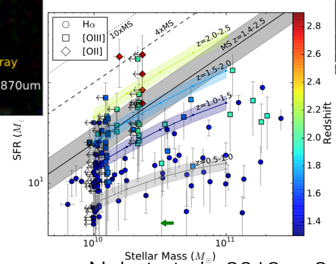


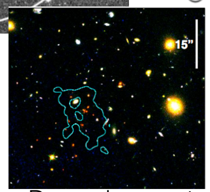


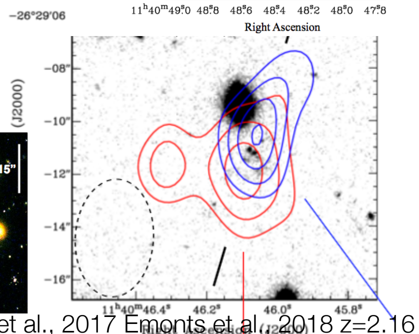




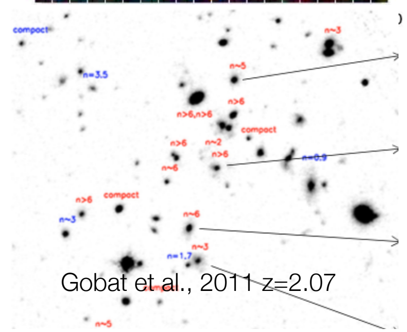






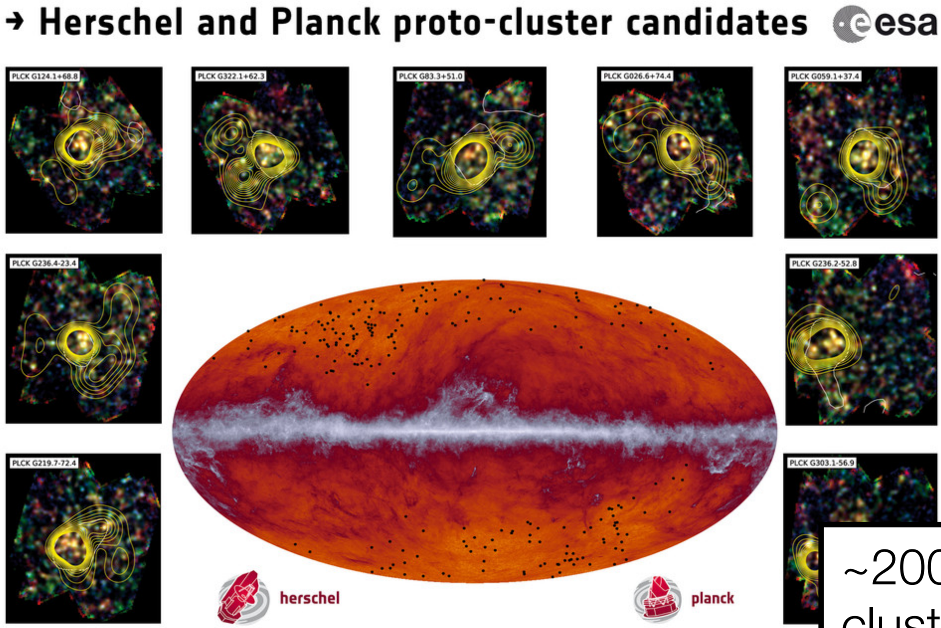


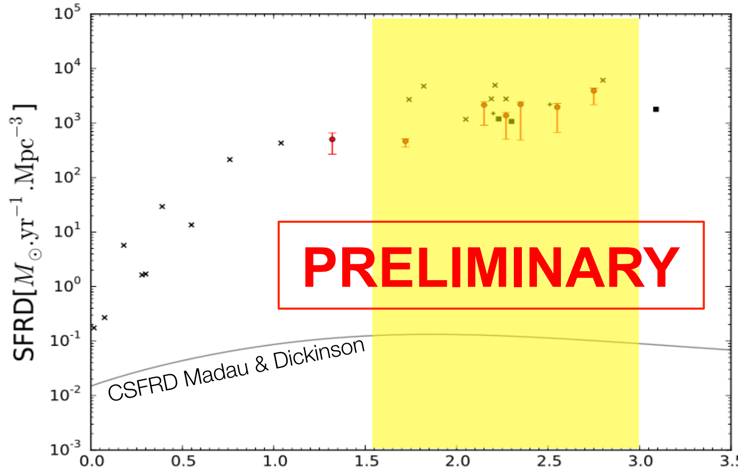
Dannerbauer et al., 2017 Emonts et al., 2018 z=2.16
Valentino et al., z=1.99



Towards a NOEMA survey of z>2 protoclusters at the Euclid and JWST era

Planck Collab., 2015, Int XXVII, arXiv:1506.01962
Planck Collab., 2016, Int XXXIX, arXiv:1508.04171
Press Releases: ESA, NASA, INSU, A&A

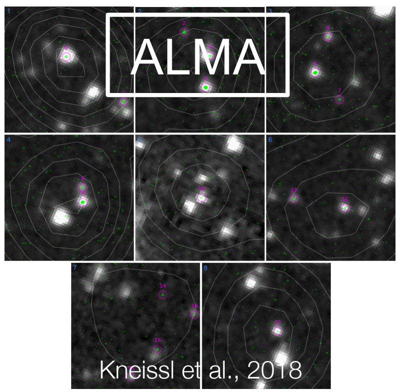




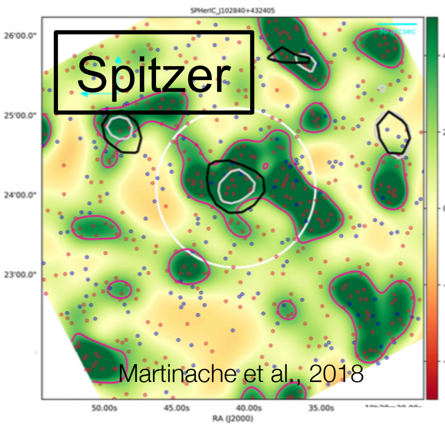
Adapted from Kato+2016
Courtesy Clément Martinache et al.

~200 targets: census and statistical view of cluster formation, high-SFR proto-clusters, fate and phases of the gas.
Complementarity w/ Euclid & JWST.

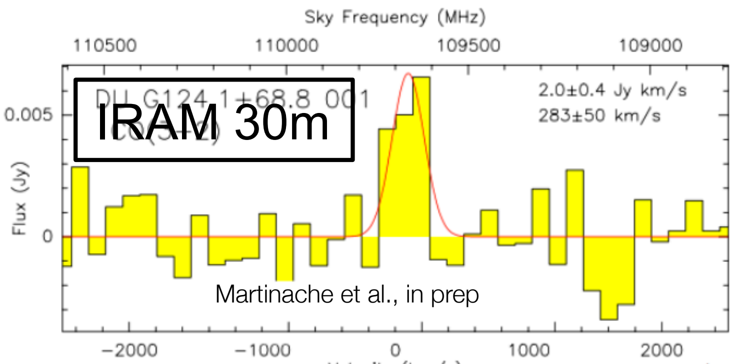
« we need more than one object at the time »



Kneissl et al., 2018

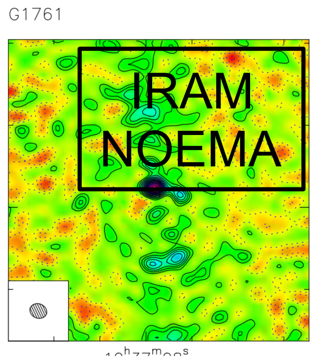


Martinache et al., 2018

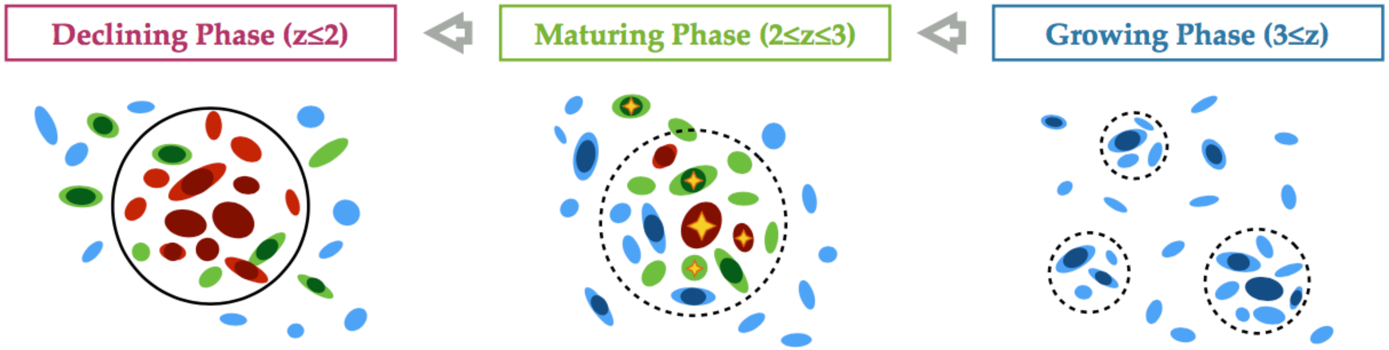


Martinache et al., in prep

4.6σ detection $z = 2.1532 \pm 3.10^{-4}$

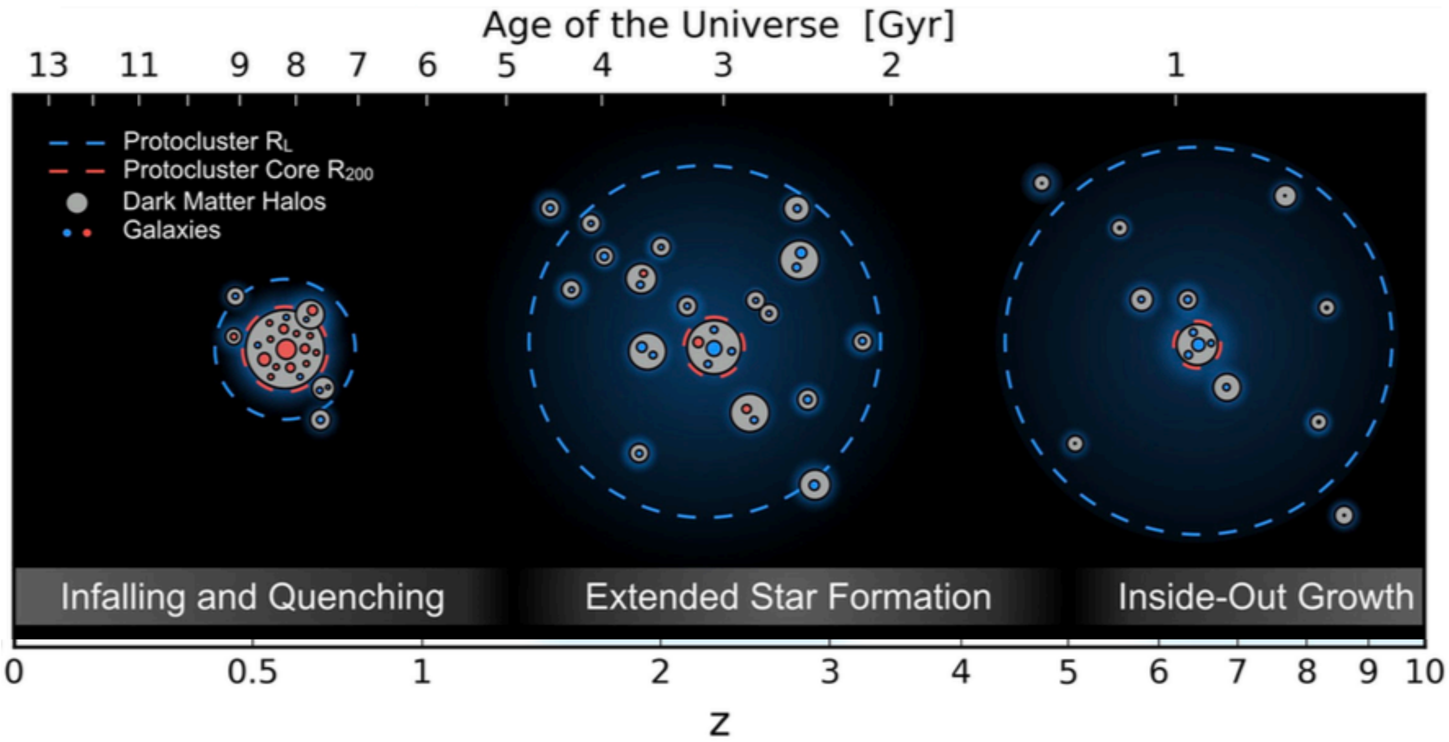


protoclusters, clusters: formation scenarii



	Declining Phase	Maturing Phase	Growing Phase
Galaxies	Starvation / Environmental quenching	Energetic AGN feedback	Massive galaxy formation
Halo Gas	Cold gas depletion / Superheated plasma	Pre-heating / Core collapse	Cold gas stream in hot gas

Schimakawa et al., 2018
arXiv:1809.08755



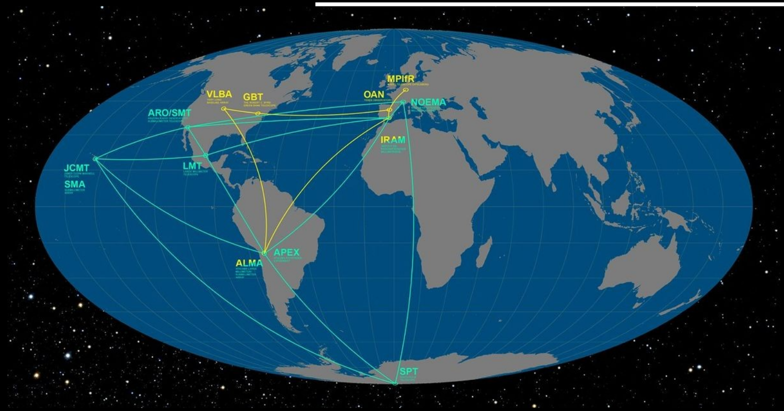
Chiang et al., 2017
arXiv:1705.01634

Benoît Cerutti

Model of black hole magnetospheres for EHT

Model of black hole magnetospheres for the EHT

Benoît Cerutti, Université Grenoble Alpes, CNRS, IPAG, France



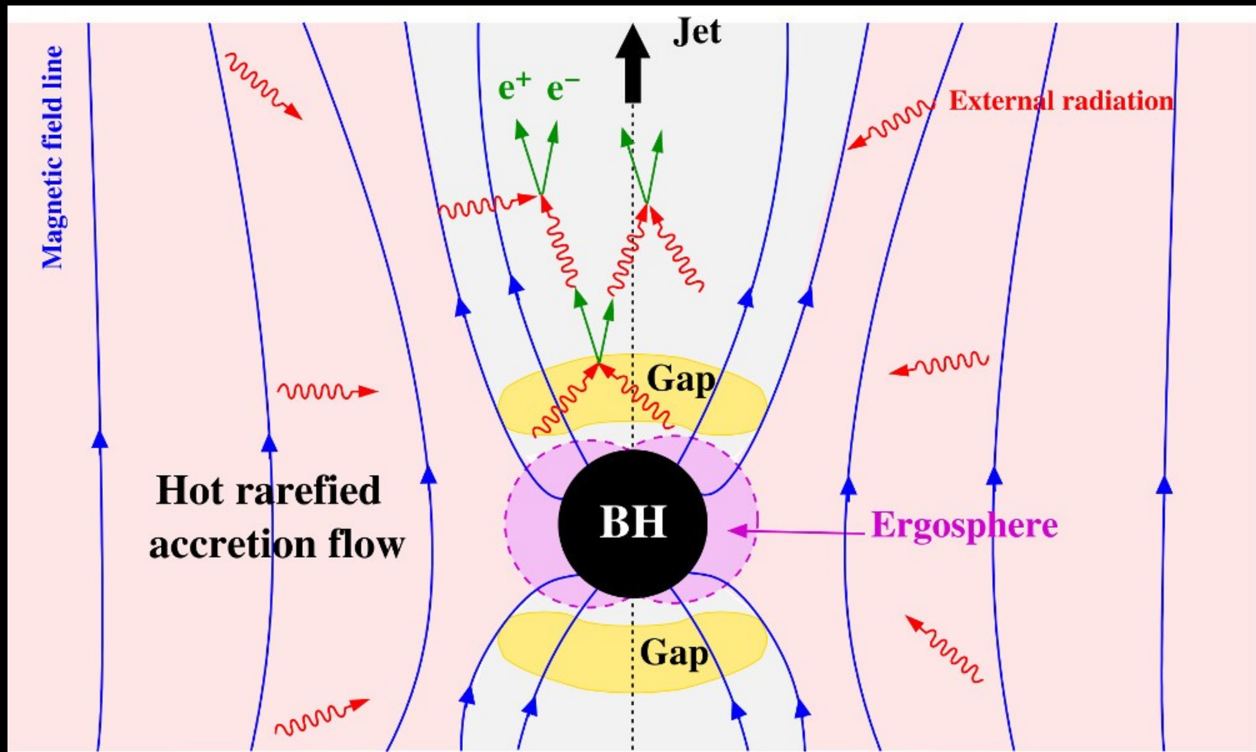
Earth-sized interferometer

Main targets: Sgr A* & M87 nucleus

Aims: Imaging the black hole “shadow” and accreting mater under strong gravity
=> Need precise model of the closest environment: the “magnetosphere”

Standard paradigm:

+ **Rotating black hole**
+ **Low-density plasma**
+ **Large-scale magnetic field**



Model of black hole magnetospheres for the EHT

Benoît Cerutti, Université Grenoble Alpes, CNRS, IPAG, France

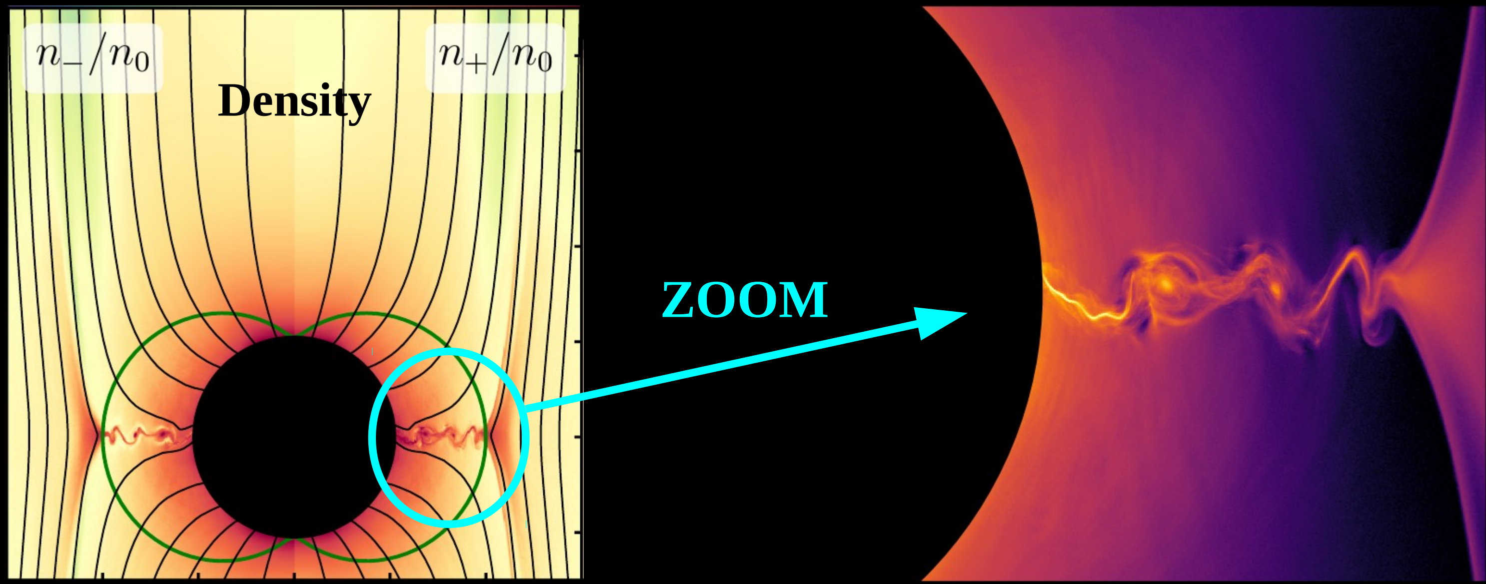
- **State-of-the-art models: General Relativistic MHD simulations**

Caveat: No particle acceleration, thermal distributions. mm emission is synchrotron
=> Need for a kinetic model of black hole magnetospheres to fully interpret EHT observations

- **Developed the first GRPIC code (*Levinson & Cerutti 2018; Parfrey, Philippov & Cerutti 2019*)**

=> First ab-initio modeling of plasma around black holes

Proof-of-principle simulation



Courtesy Kyle Parfrey

Efficient particle acceleration via relativistic reconnection
Magnetic extraction of the black hole rotational energy ("Blandford-Znajek")

Coming up: Radiative transfer (synchrotron, pair creation, inverse Compton) and synthetic images
STAY TUNED!

Supplementary material for the discussion of session # 2

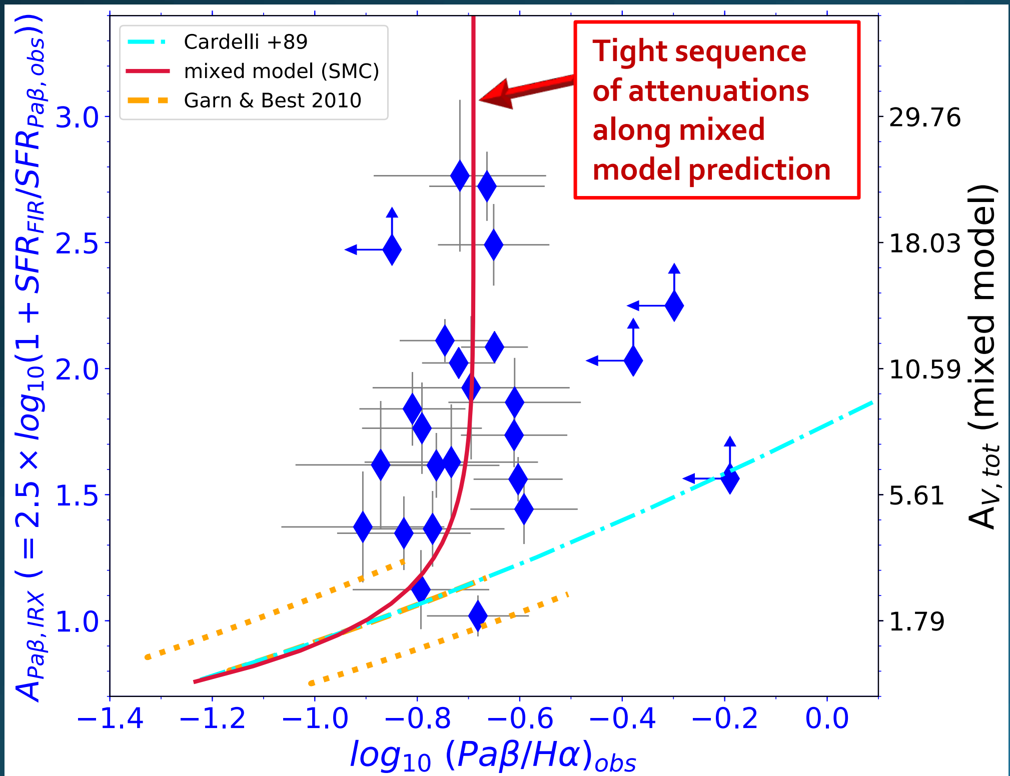
Antonello Calabro

Investigating the nature of high redshift starbursts: new insights from their dust obscuration

Antonello Calabrò - CEA-Saclay

Investigating the nature of high redshift starbursts: new insights from their dust obscuration

25 starburst galaxies (off-Main Sequence)
Herschel detected ; 0.5 < redshift < 0.9



A.Calabrò et al. 2018 (ApJL)

FIRST SAMPLE OF GALAXIES AT z ~ 0.7 with NEAR-INFRARED REST-FRAME SPECTRA

Advantage: near-IR lines are less attenuated than optical
We can test: attenuation, metallicity, and other properties
Crucial for: dusty starburst galaxies (and AGNs) at high-z

Two main results :

1) Starbursts at *z* ~ 0.7 are extremely obscured: A_V ~ 9 mag toward the core centers (x 4000 suppression of optical light)

Starbursts are triggered by mergers

2) The Calzetti and Cardelli attenuation laws are not valid anymore

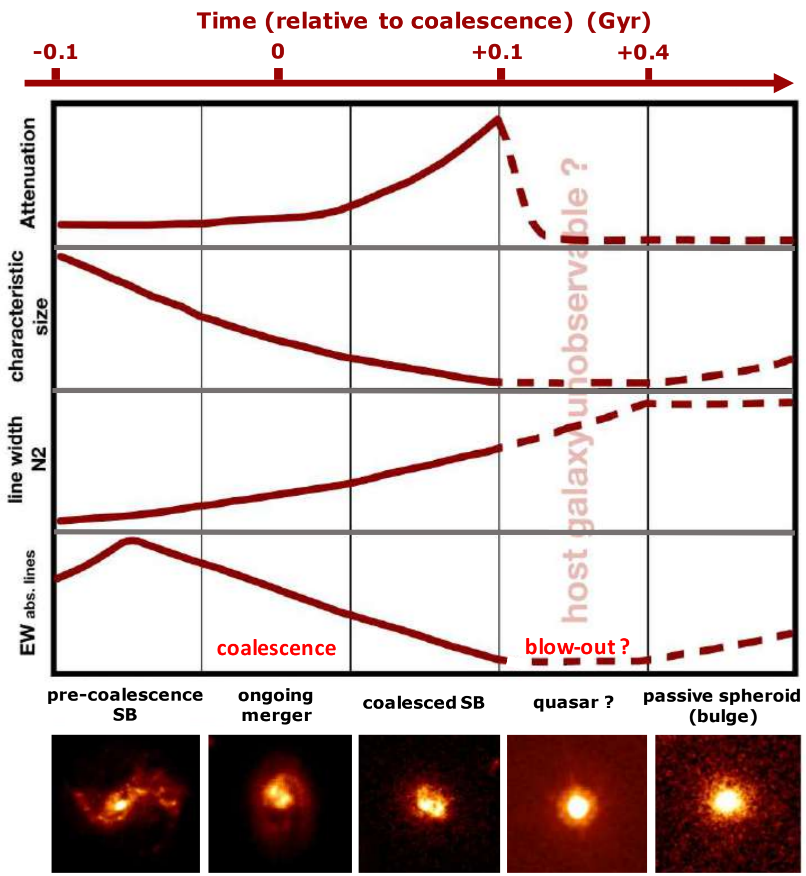
Dust and stars are homogeneously mixed !
There is no dust screen

Time-evolutionary sequence of mergers at z ~ 0.7

These properties are all good time tracers of the merger phase :

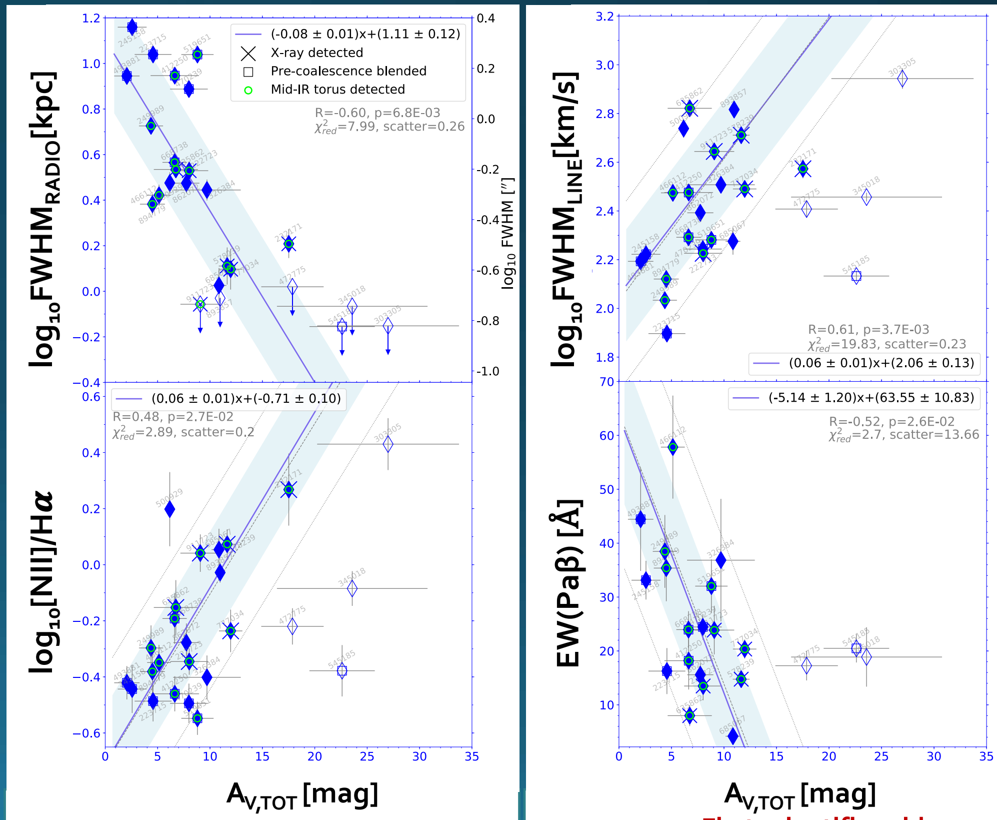
- **RADIO SIZE** : late mergers are more compact
- **[NII]/Hα** and **line width** : increased shocks driven by deeper potential wells towards the coalescence
- **Equivalent Width hydrogen lines :** older stars (=low EW) in late phases

INTERPRETATION



Tight correlations among : ATTENUATION, RADIO SIZE, [NII]/Hα, line velocity width, equivalent width hydrogen lines

DATA



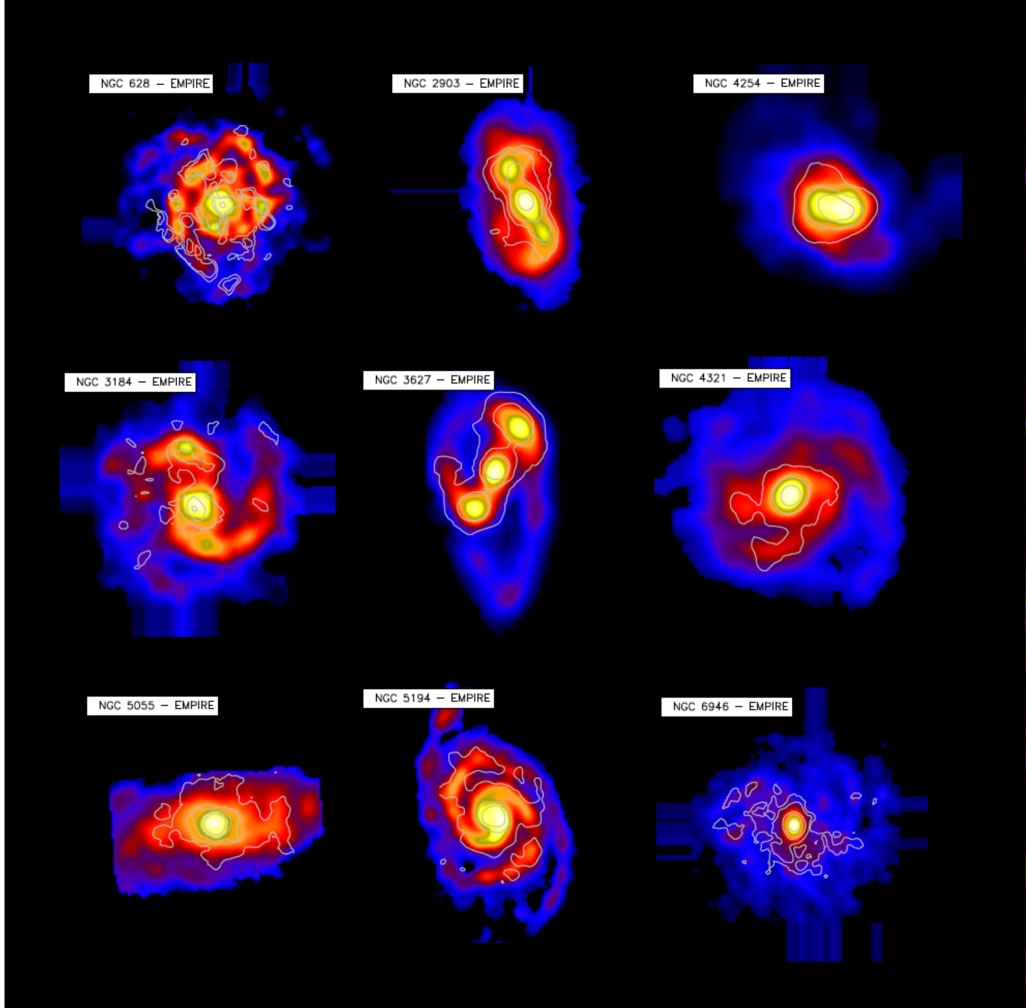
A.Calabrò et al. 2019 (A&A)

First scientific evidence of these correlations !!

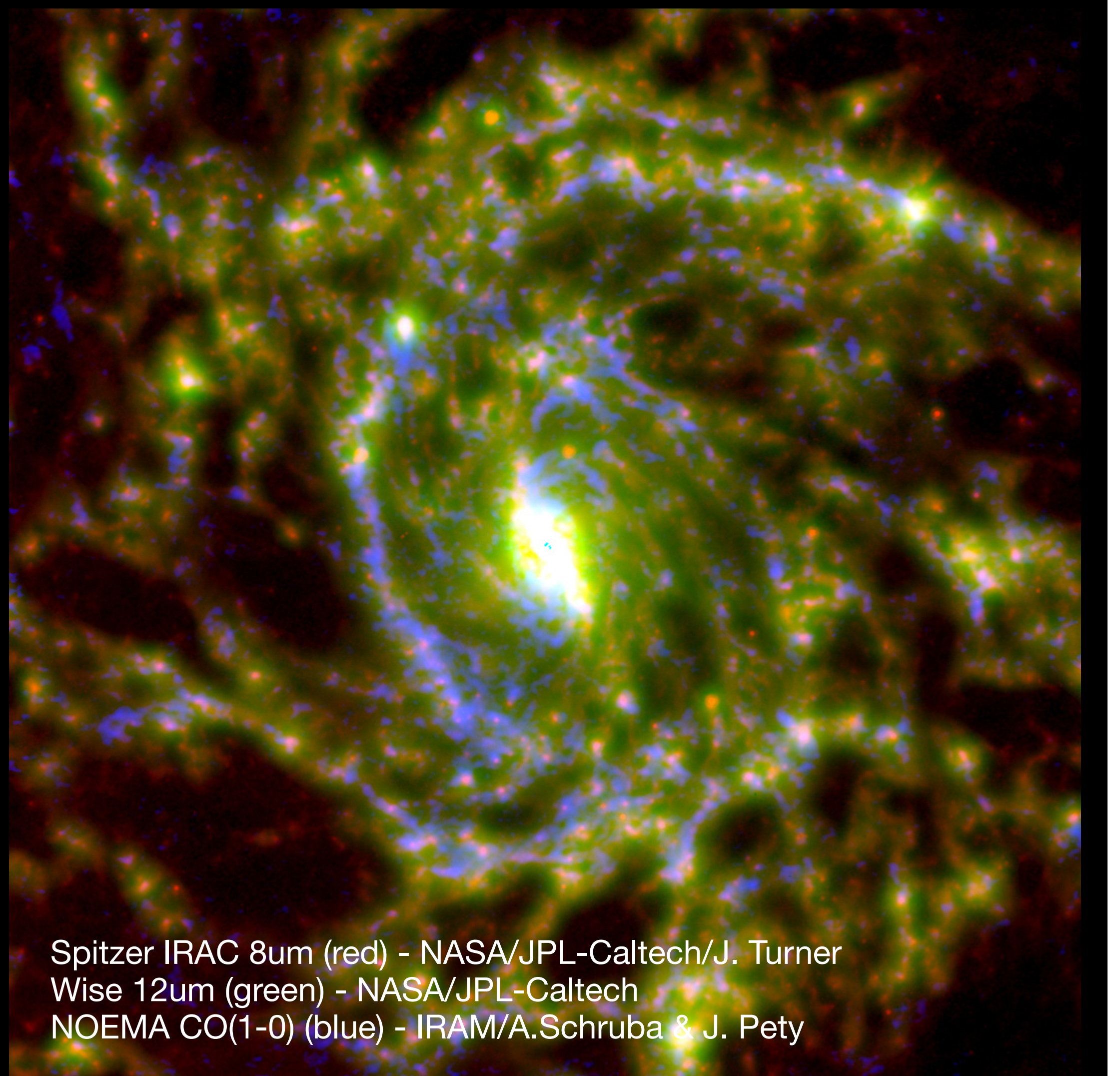
Session # 3
ISM and star formation

Annie Hughes

Studies of the cold ISM in nearby galaxies



EMPIRE Dense Gas Tracers in 9 Nearby Galaxies



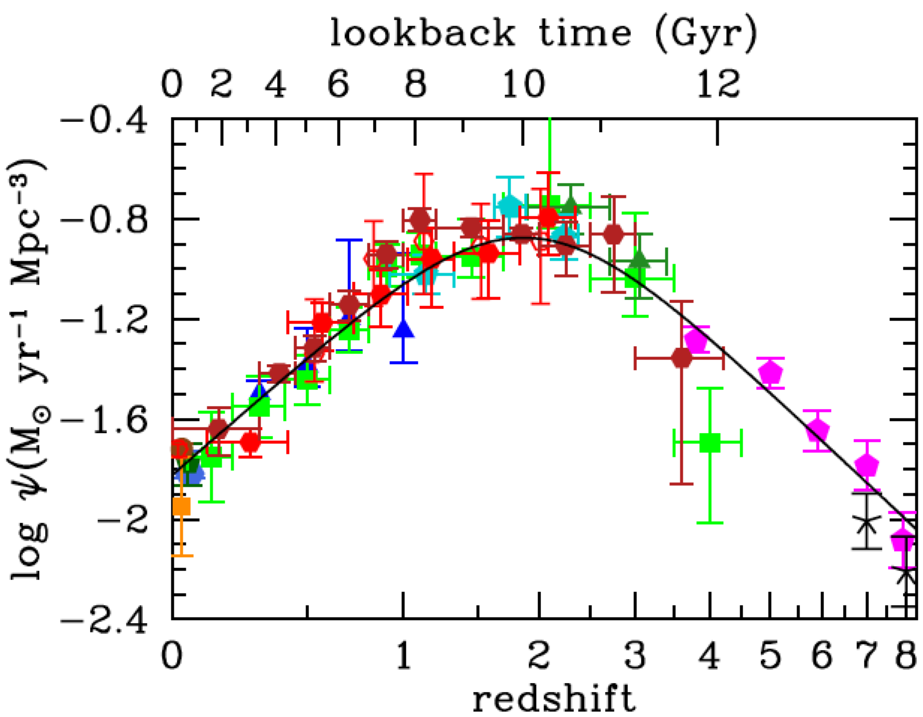
Spitzer IRAC 8um (red) - NASA/JPL-Caltech/J. Turner
Wise 12um (green) - NASA/JPL-Caltech
NOEMA CO(1-0) (blue) - IRAM/A.Schruba & J. Pety

Studies of the Cold ISM in Nearby Galaxies

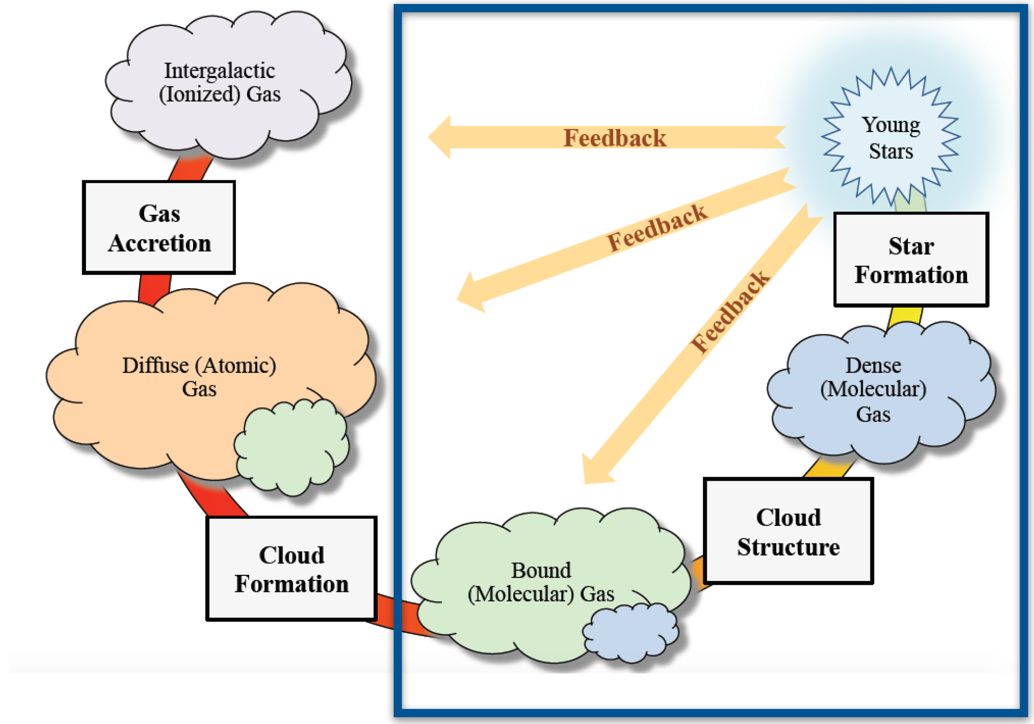
Annie Hughes (IRAP), on behalf of the PHANGS & EMPIRE collaborations especially: F. Bigiel, J. Braine, I. Chiang, D. Chatzigiannakis, D. Cormier, M. Gallagher, C. Herrera, M. Jimenez-Donaire, K. Kreckel, A. Leroy, S. Meidt, J. Pety, M. Querejeta, K. Sandstrom, E. Schinnerer, A. Schruba, N. Tomicic

The Gas-SF Cycle in Galaxies

Important questions for cosmic star formation that cannot be (fully) answered by studies of individual star-forming regions, single galaxies, or unresolved samples.



Madau & Dickinson 2014



cartoon by Adam Leroy

Which physical processes regulate the conversion of gas to stars?

What are the efficiencies and timescales of each step?

How do these vary across the galaxy population?

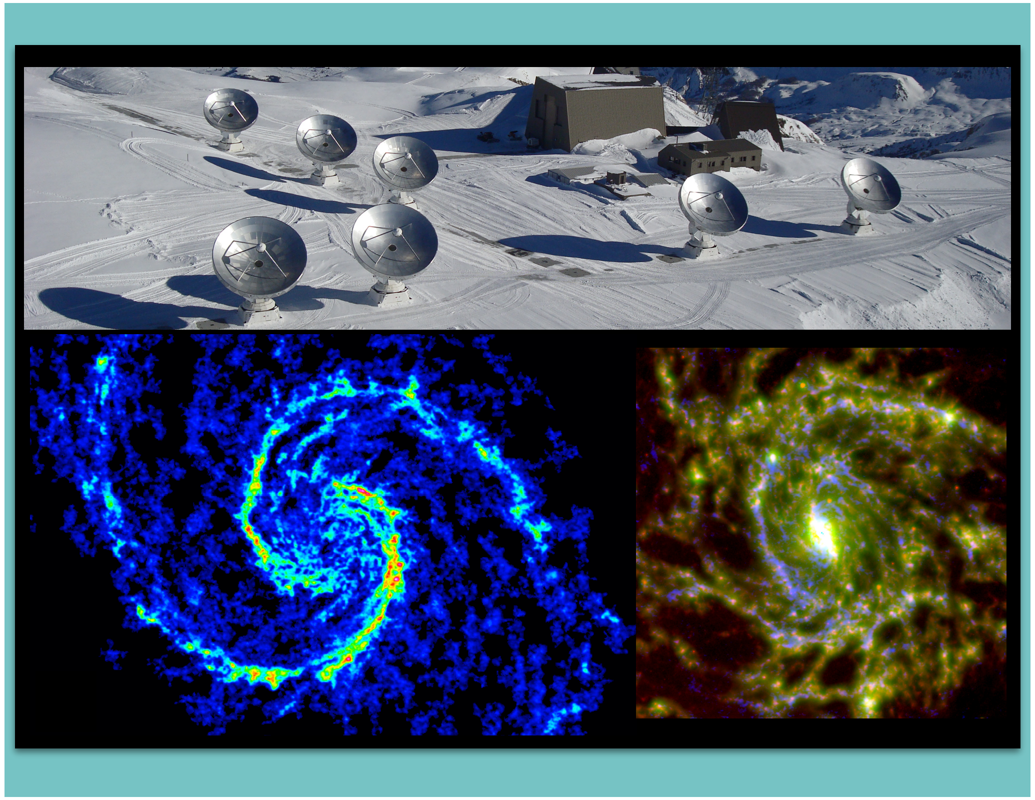
This Talk

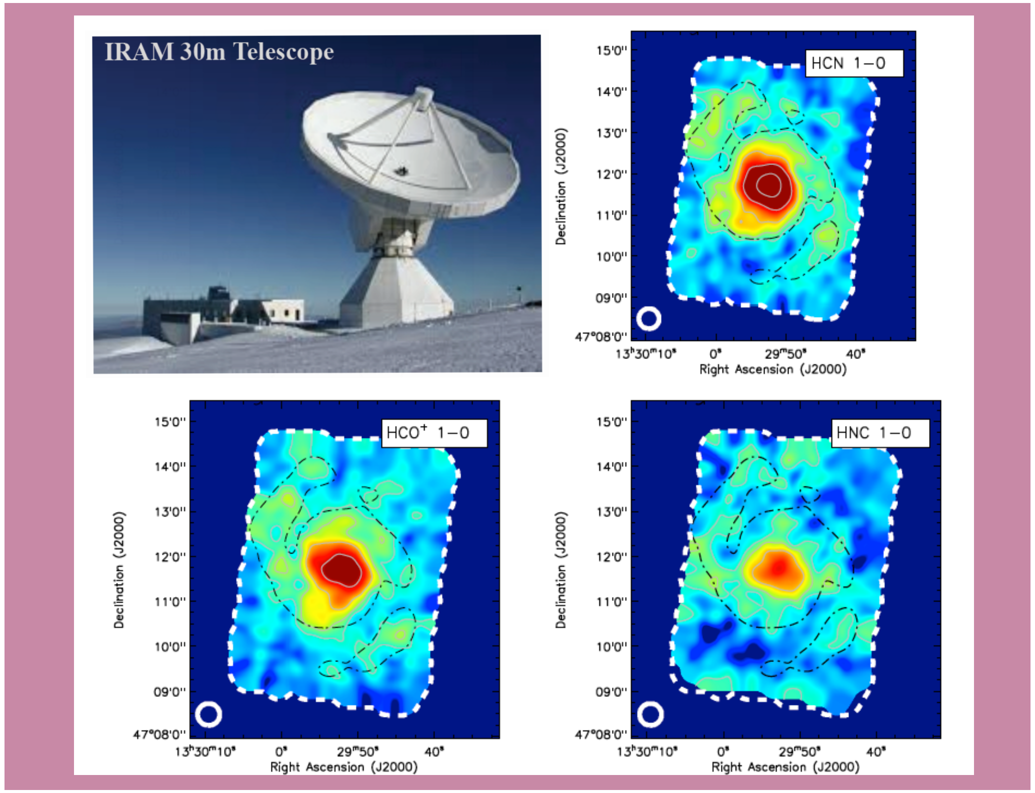
Structure and Kinematics of the Cold ISM
Molecular Clouds
High-resolution imaging

Accessing Physical Conditions of the Cold ISM
Gas Density
mm spectroscopy

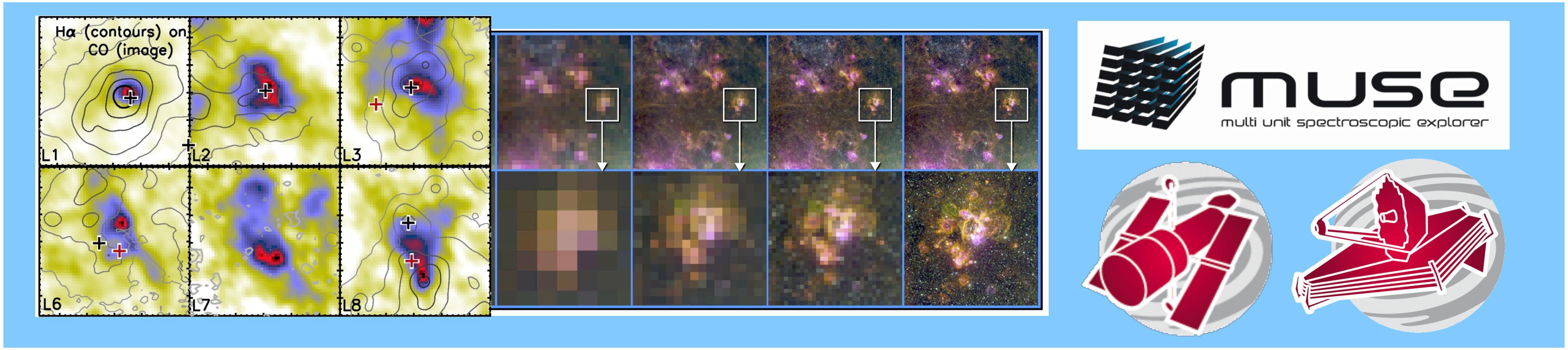
Star formation and stellar feedback

This Talk





IRAM 30m Telescope
HCN 1–0
HCO+ 1–0
HNC 1–0
Declination (J2000)
Right Ascension (J2000)

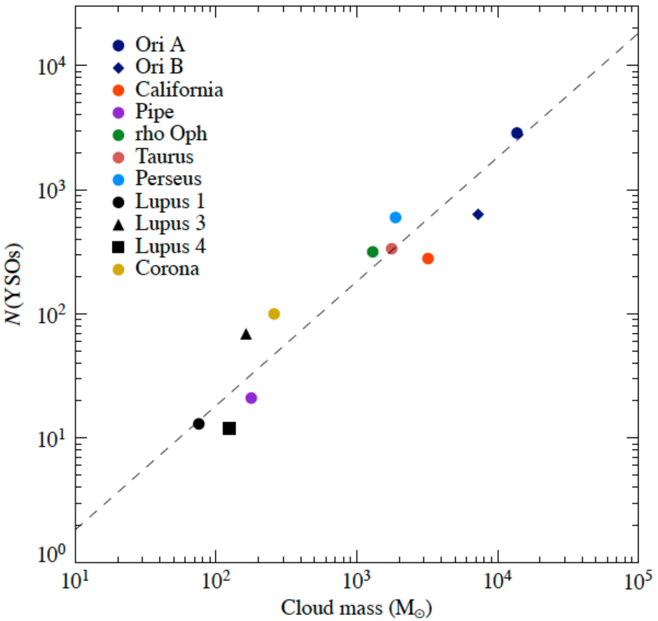


Hα (contours) on CO (image)
L1
L2
L3
L6
L7
L8
muse
multi unit spectroscopic explorer

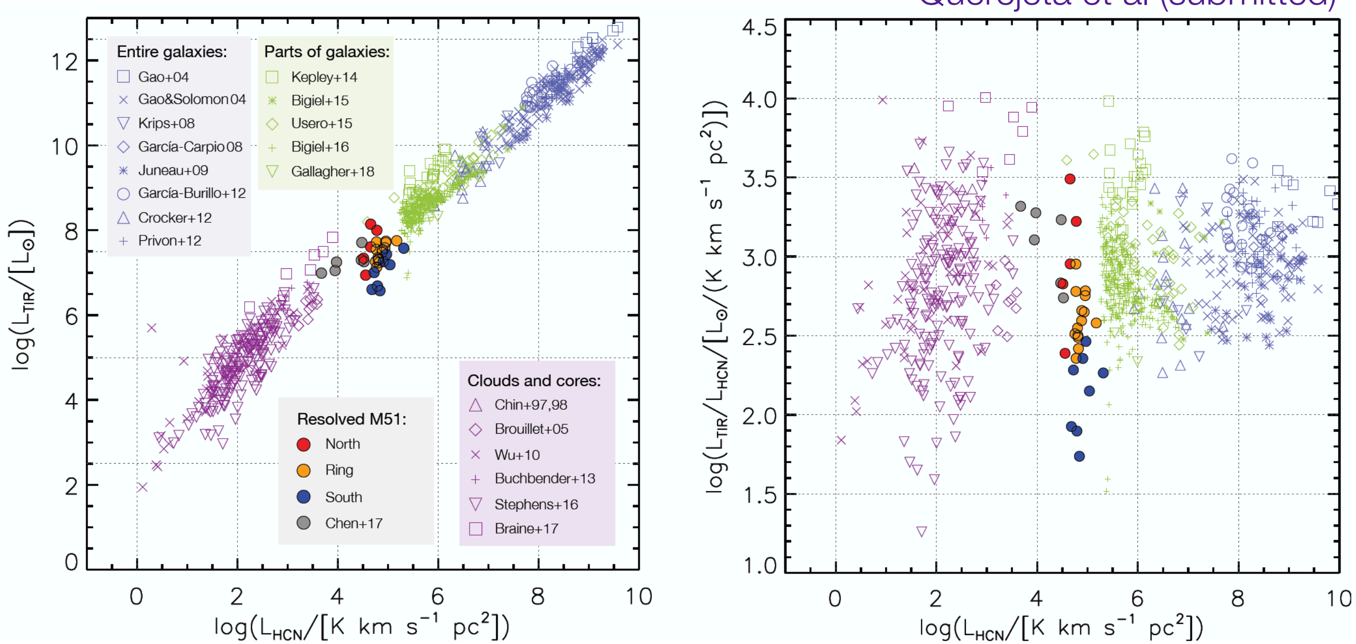
Accessing Gas Density in Nearby Galaxies

The Role of Gas Density in SF

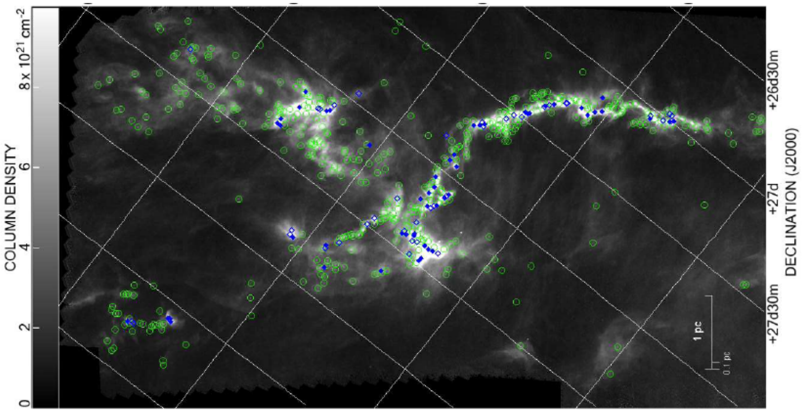
Lada et al (2010)



Querejeta et al (submitted)



Marsh et al (2016)

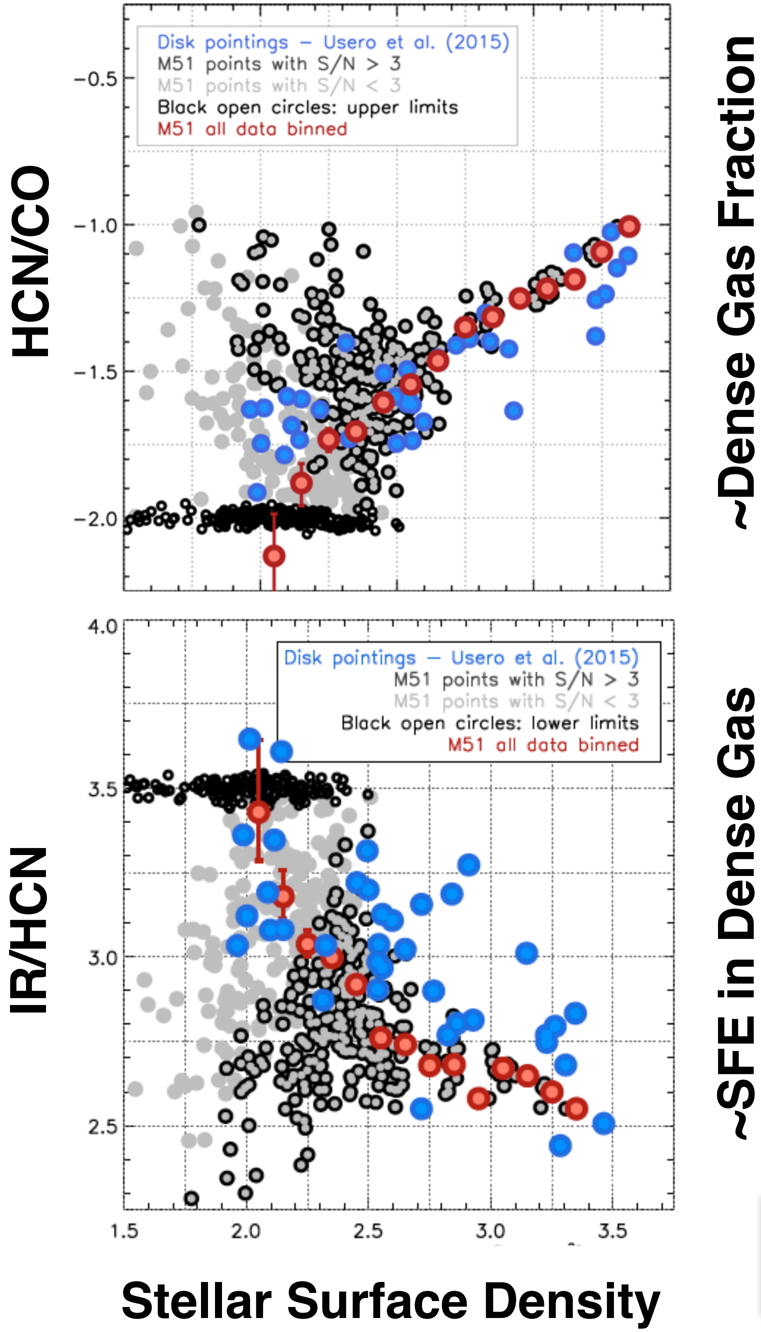


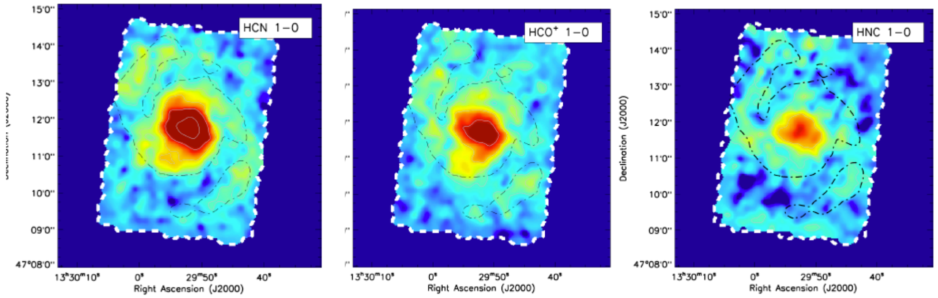
Gas density relates closely to the dynamical time and self-gravity of a cloud.

Observations of local clouds show a direct link between the dense gas & star formation.

Dense gas efficiencies (SFR-to-dense gas) appear broadly similar from starbursts to local clouds, *but the scatter contains physics*.

EMPIRE: Dense Gas Tracers in NGs





For latest super exciting results: talk by Diane!

EMPIRE++ (PI Bigiel) – IRAM 30m Large Program to map dense gas tracers from nine whole galaxy disks: HCN, HCO+, CS, HNC, 13CO, C18O, CO

(1) how the cold gas density distribution responds to environment across galaxies and

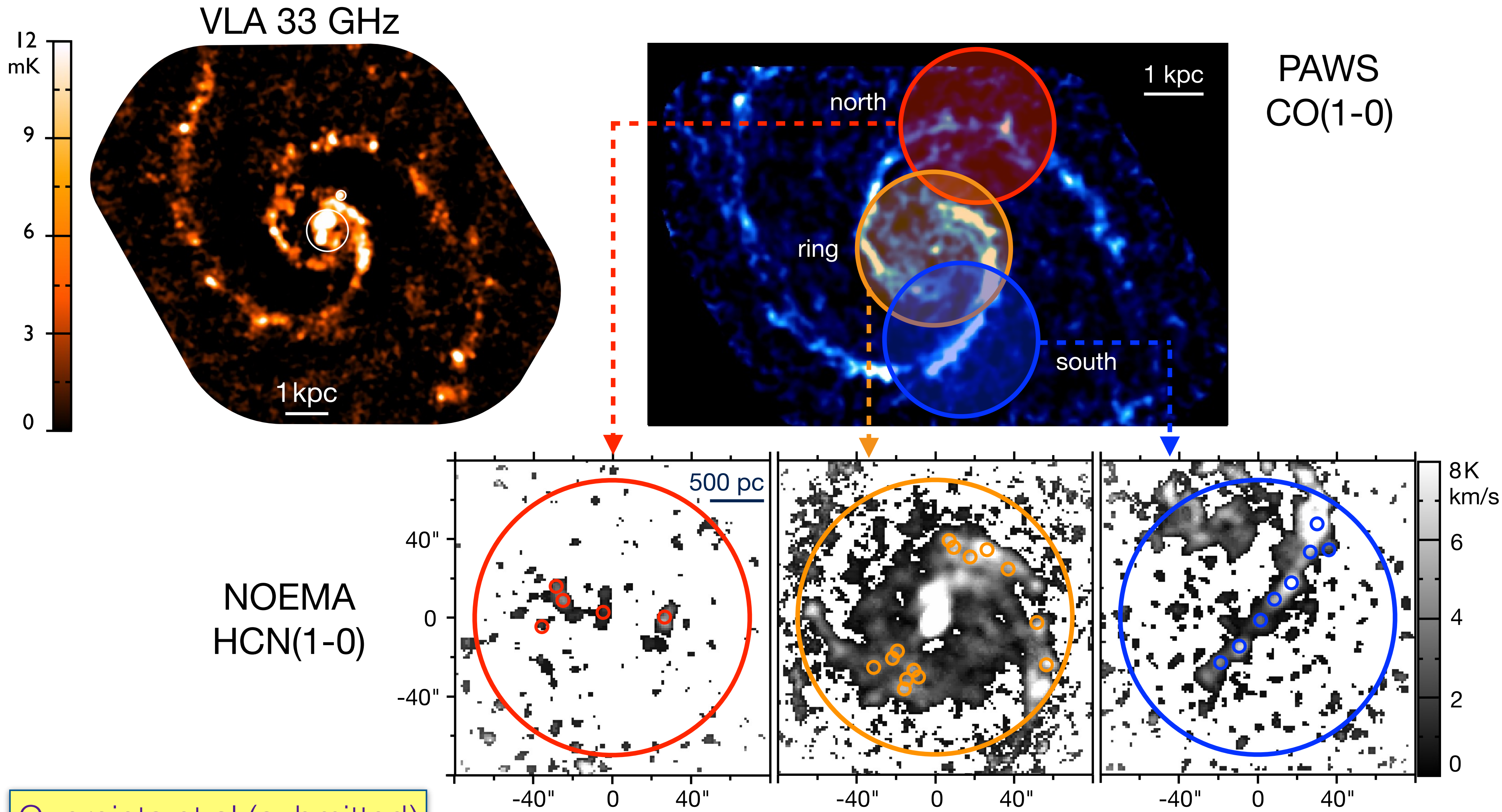
(2) how the gas density distribution affects star formation and feedback processes.

New projects with similar objectives: DEGAS@GBT, PHANGS @ ALMA ACA, MALATANG @ JCMT

Cormier ea (2018), Gallagher ea 2018ab, Jimenez-Donaire ea (2017, 2018, 2019), Usero et al (2015), Bigiel et al (2016)

NOEMA mapping of M51 dense gas

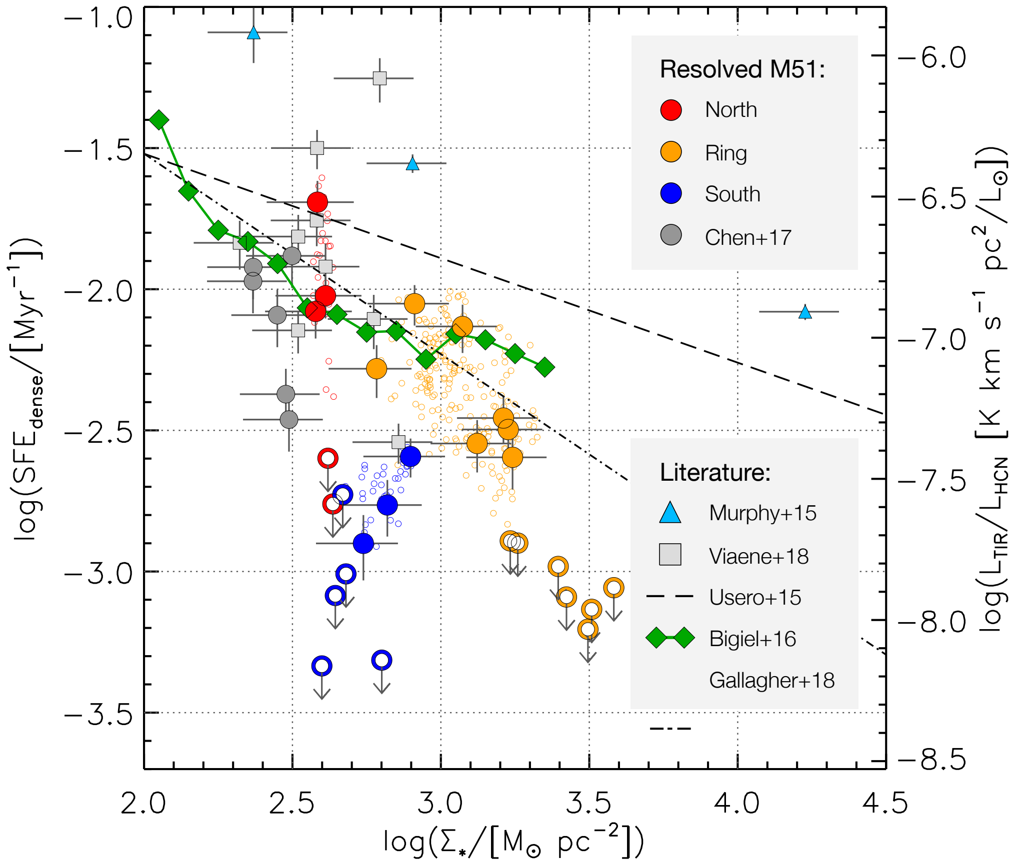
- VLA: map of 33 GHz continuum in M51 ➡ free-free emission probing star formation
- NOEMA: CO(1-0) from PAWS, new HCN(1-0) ➡ trace (dense) molecular gas reservoir

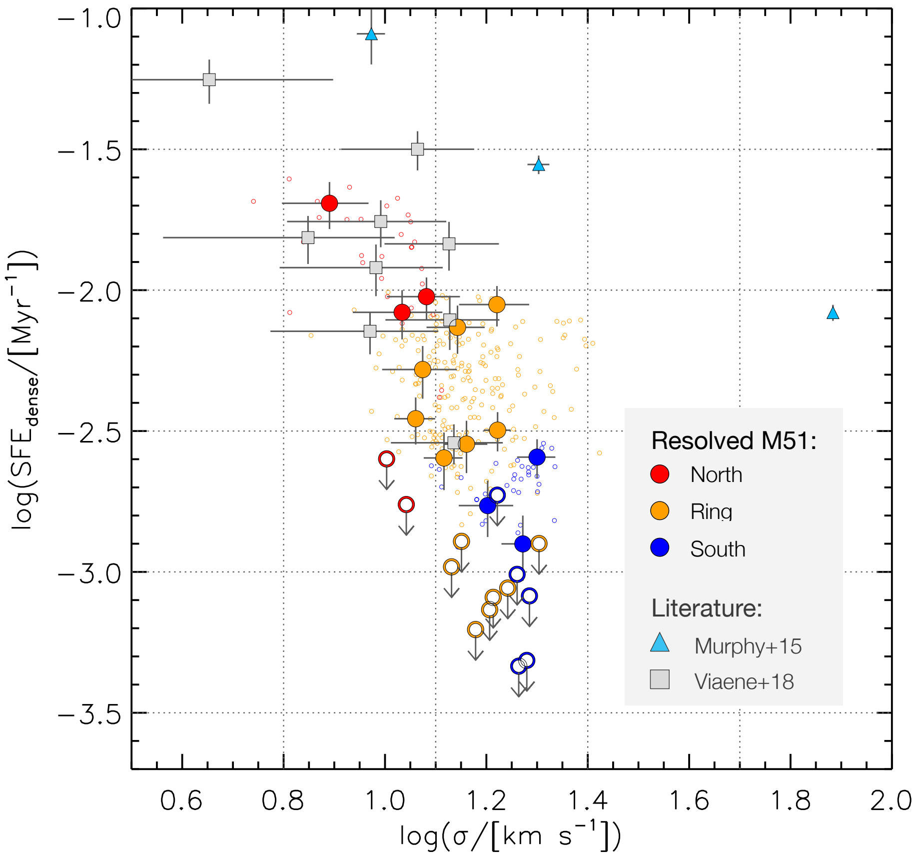


Querejeta et al (submitted)

Dense gas is not enough

- Environmental variation of star formation efficiency of dense gas (SFE_{dense})
- SFE_{dense} anti-correlates with stellar mass surface density and HCN velocity dispersion
- Turbulence and galactic dynamics modulate conversion of gas into stars





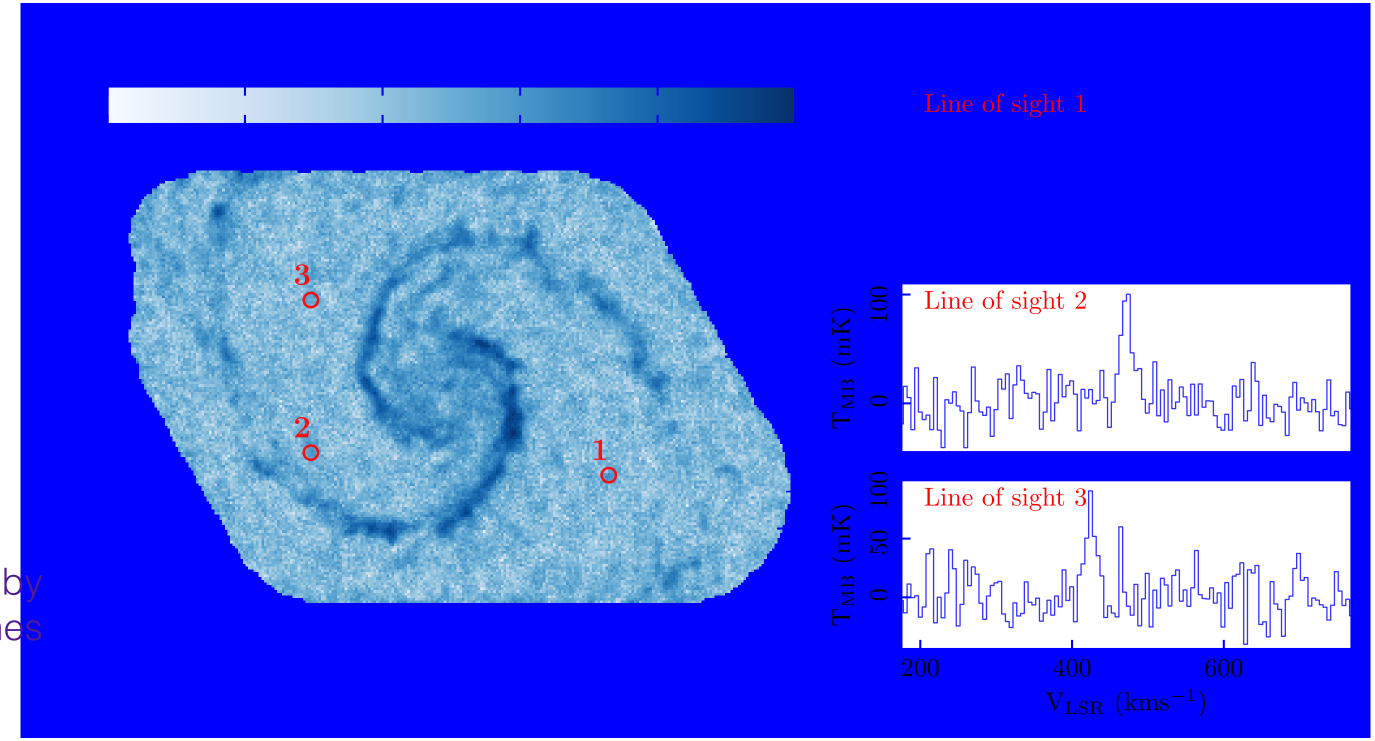
Querejeta et al (submitted)

irap PHANGS pcmi

Future: PAWS-Dense @ NOEMA

The first cloud-by-cloud dense gas map of an external galaxy, unifying the science themes of several previous IRAM large programs, e.g. LEGO, ORION-B, EMPIRE & PAWS.

Mock observation of
HCN(1-0) in M51
HCN/CO = 1/30
400hr total time



simulated observation by
Ashley Barnes

How does the dense gas fraction relate to the properties and environment of individual clouds?

How does star formation and feedback relate to dense gas cloud-by-cloud

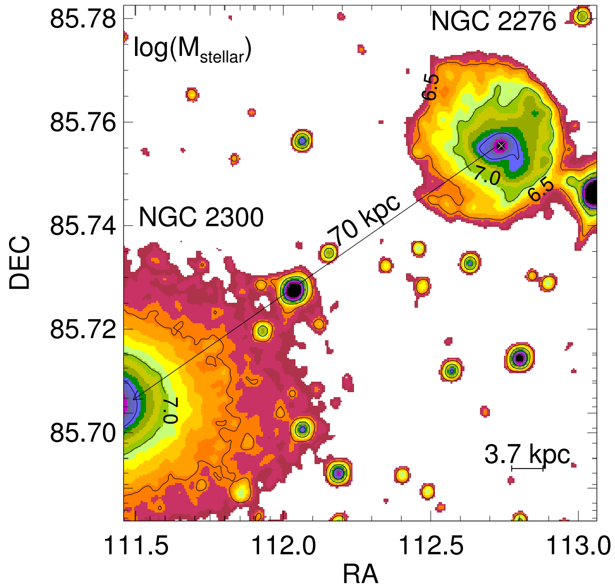
How do tracers of gas density compare cloud-by-cloud?

The Importance of Galaxy Dynamics

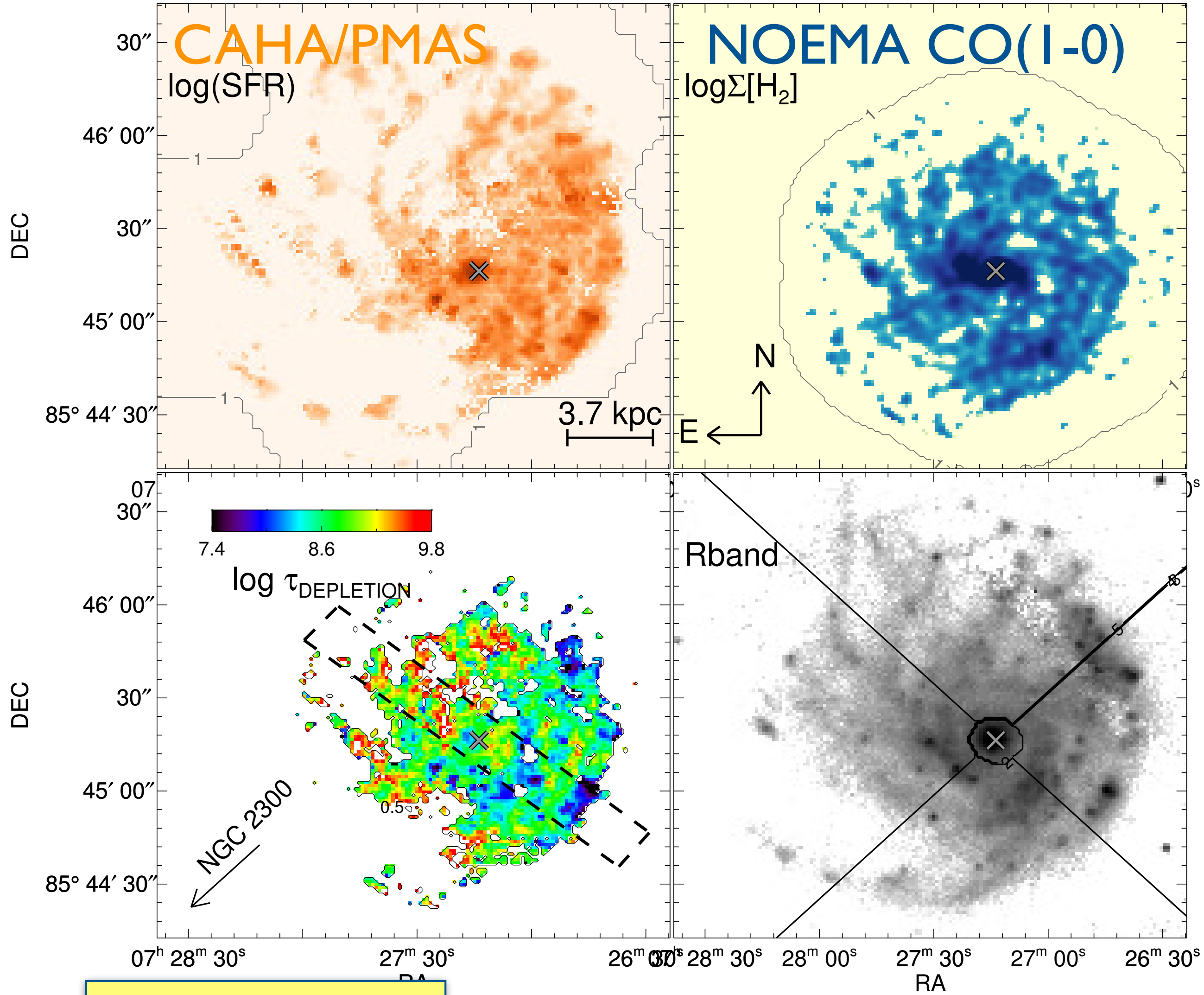
Molecular Gas in Galaxy Interactions

Galaxy dynamics plays a major role in regulating the physical state, the evolution and SF activity of molecular gas on cloud-scales. This was a key result of PAWS, but the story is far from over…

Target: NGC2276 @ D≈35Mpc interacting w/ NGC2300 pre-coalescence



Telescope: NOEMA + 30m
Spectral Line: CO(1-0)
Resolution: 2”~300pc x 5 km/s



Tomičić et al 2018

irap PHANGS pcmi

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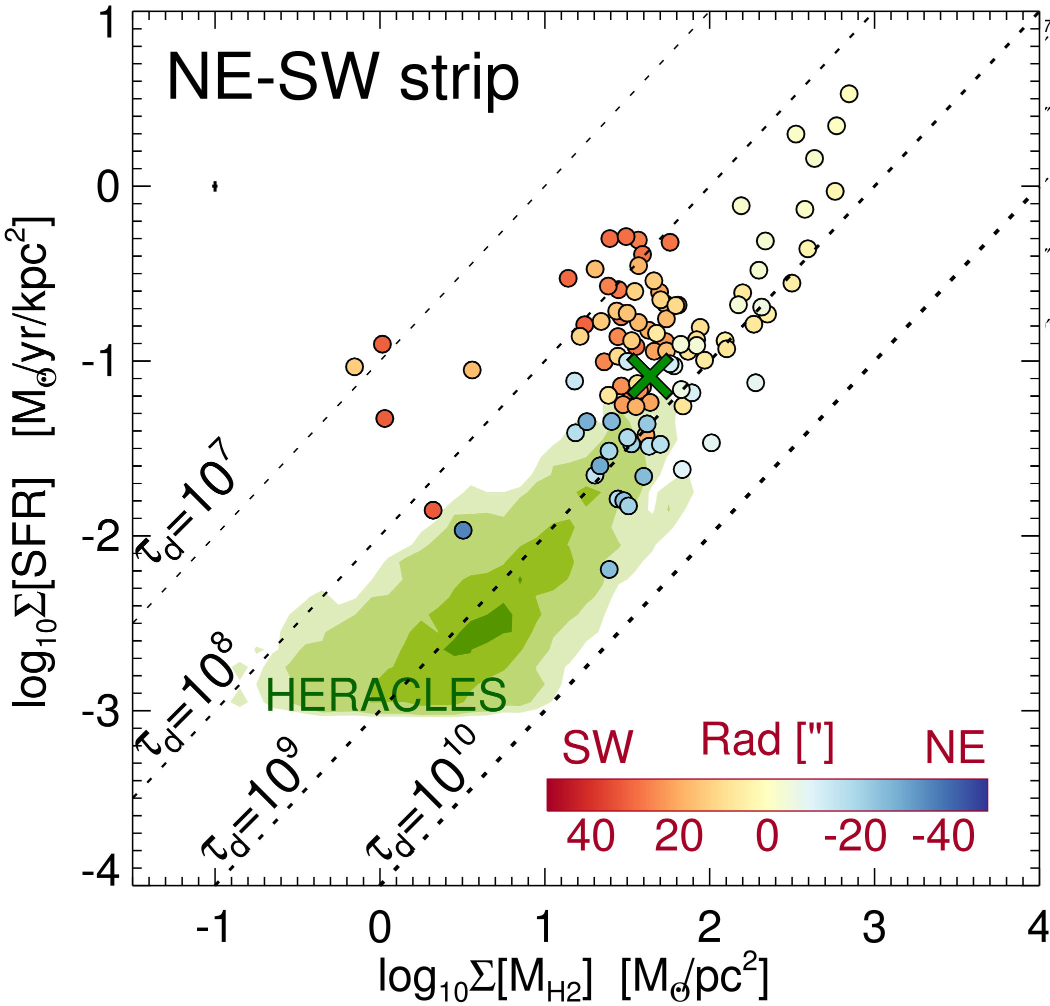
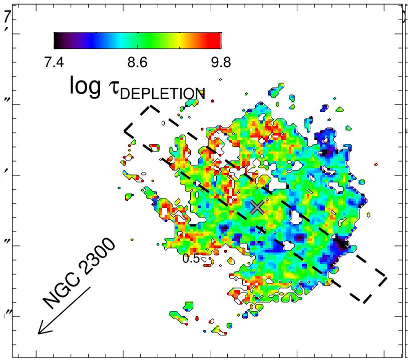
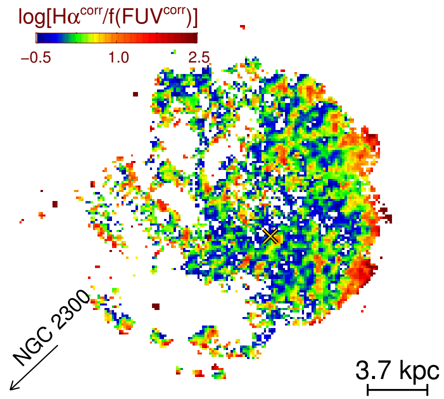






The depletion time varies by 2 orders of magnitude within the disk over a length scale of ~8kpc. Yet NGC2276's global depletion time is standard.

Tomičić et al 2018

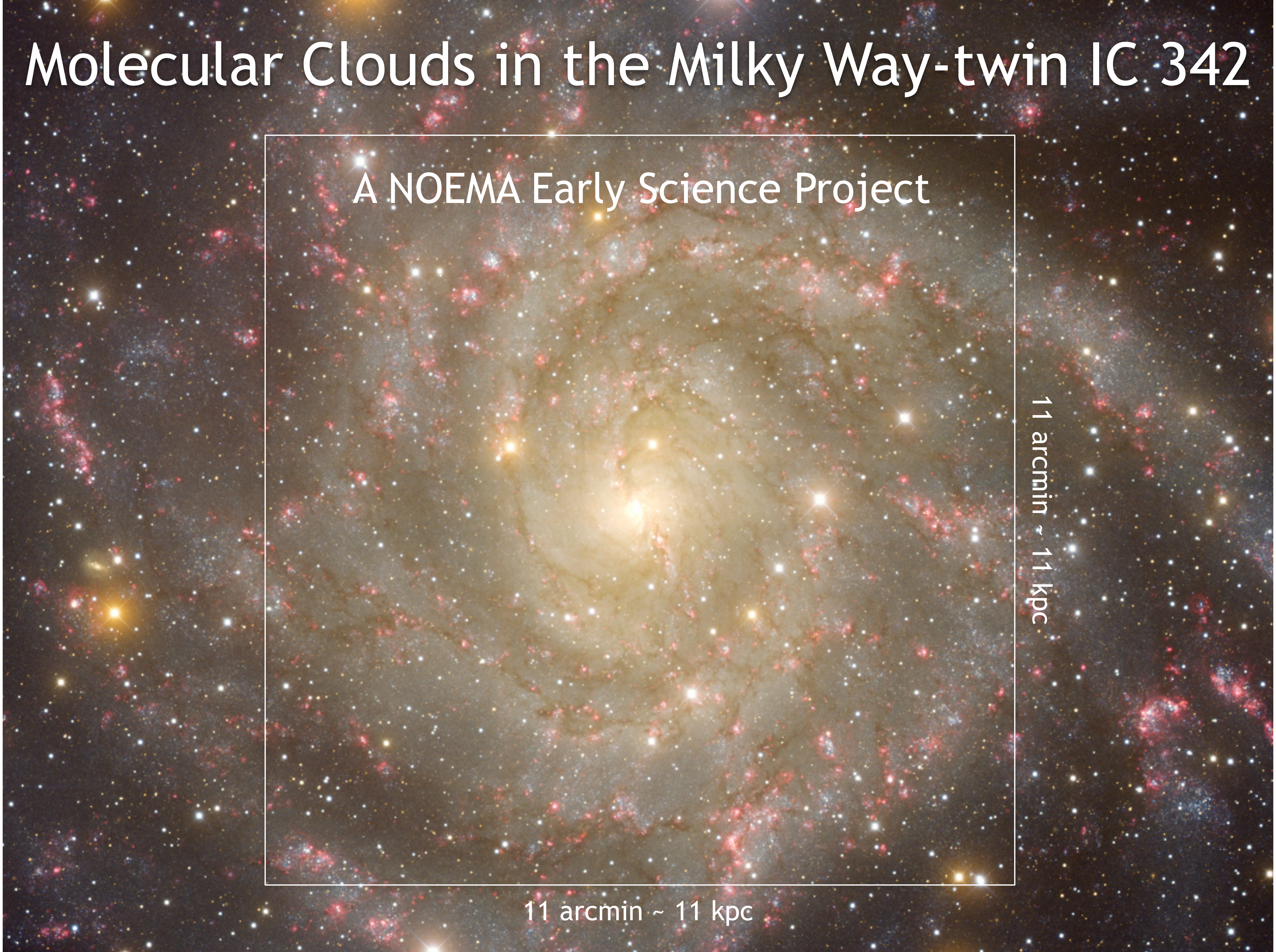
irap PHANGS pcmi

Cloud-Scale Imaging with IRAM

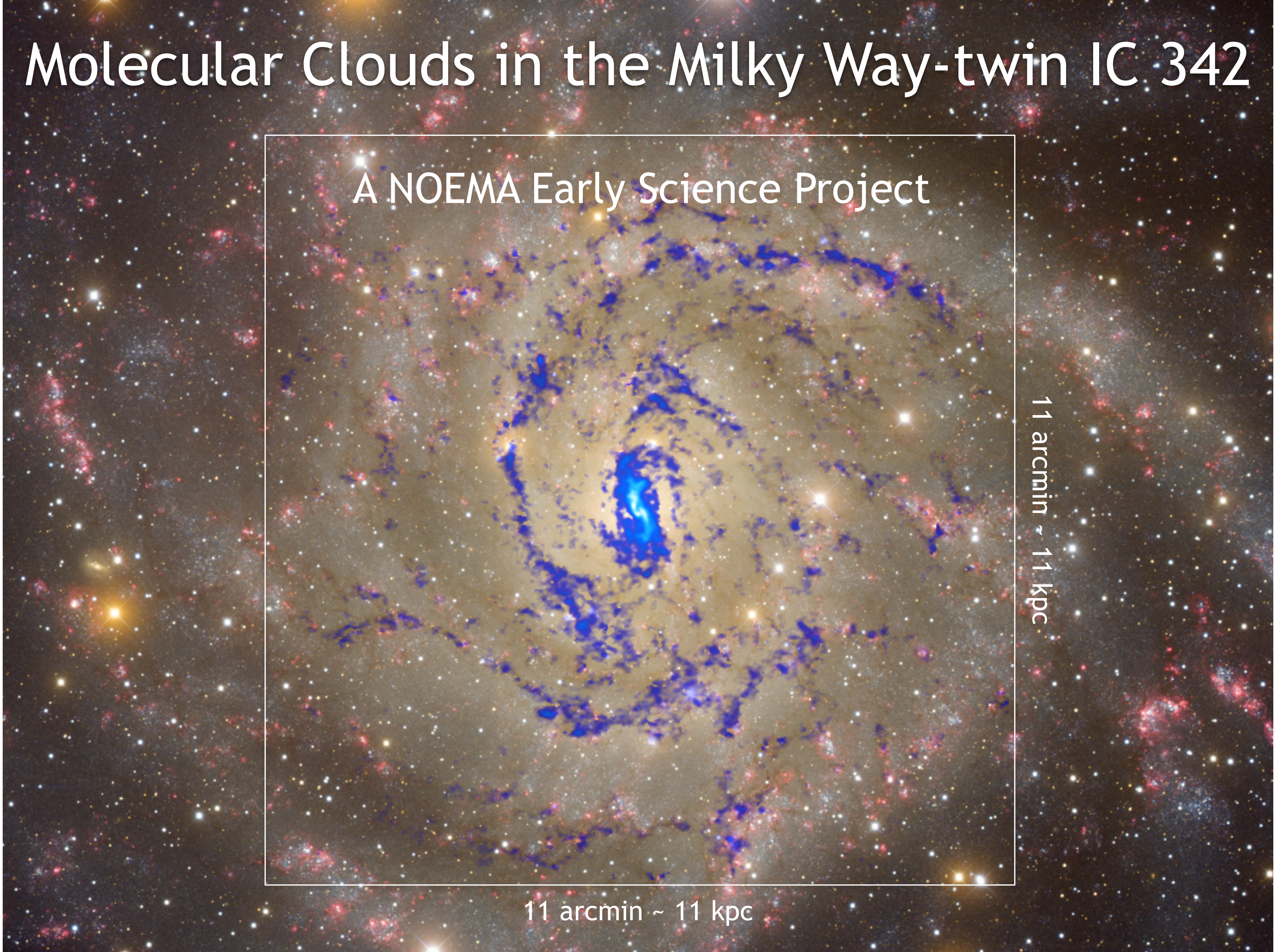
Molecular Clouds in the Milky Way-twin IC 342

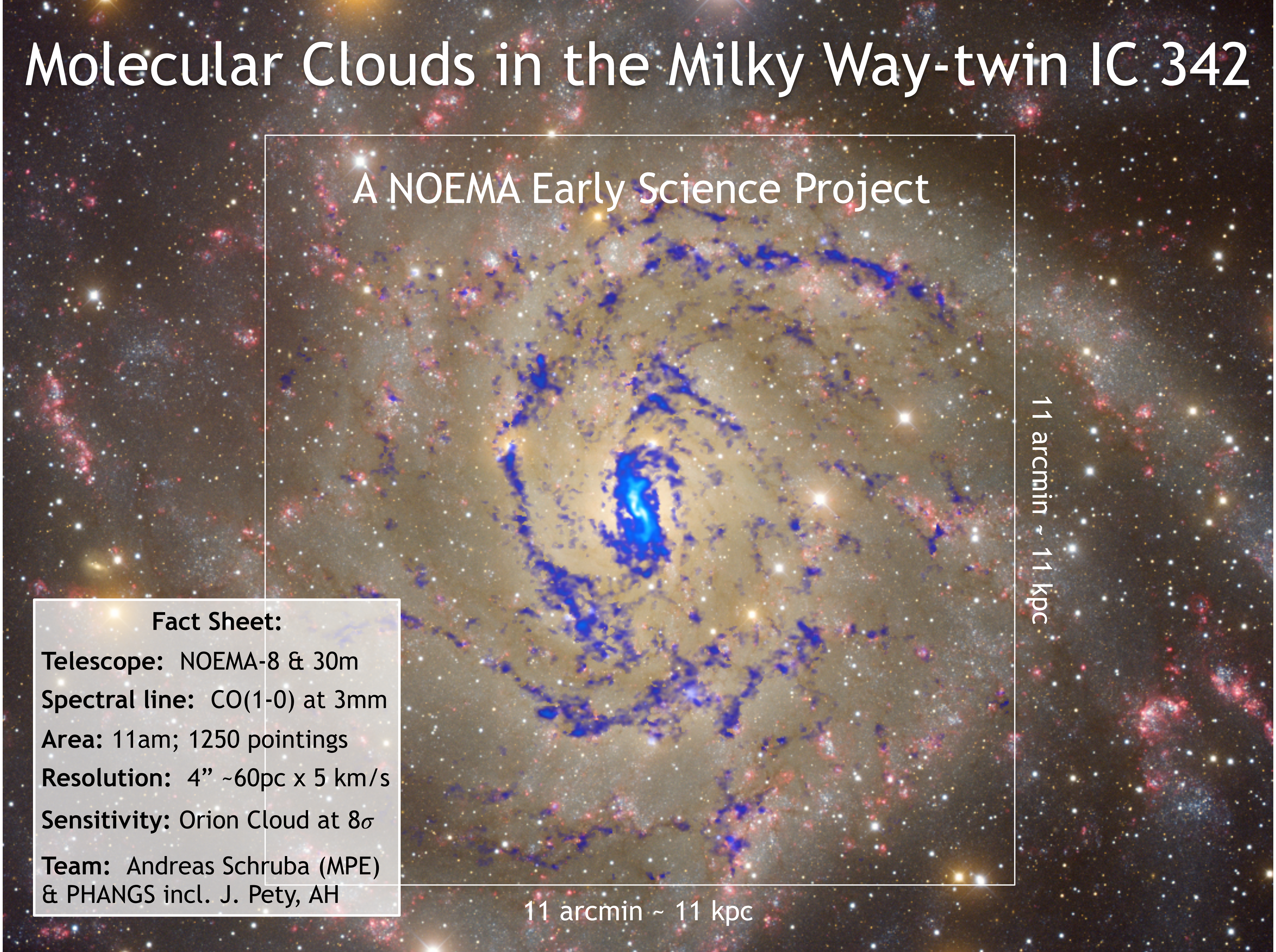
Molecular Clouds in the Milky Way-twin IC 342

A NOEMA Early Science Project



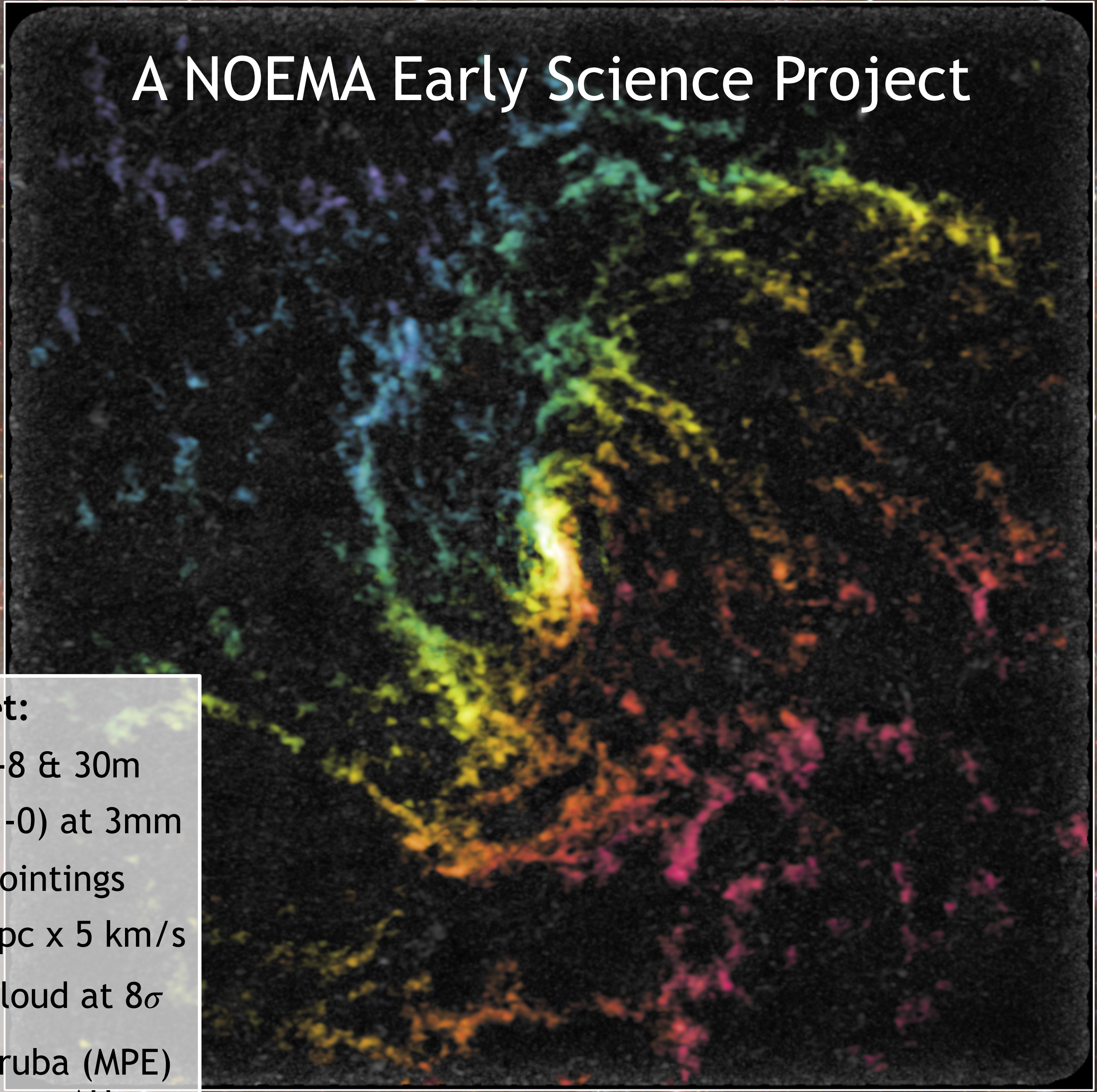
Molecular Clouds in the Milky Way-twin IC 342




Molecular Clouds in the Milky Way-twin IC 342
A NOEMA Early Science Project
11 arcmin ~ 11 kpc
11 arcmin ~ 11 kpc
Fact Sheet:
Telescope: NOEMA-8 & 30m
Spectral line: CO(1-0) at 3mm
Area: 11am; 1250 pointings
Resolution: 4” ~60pc x 5 km/s
Sensitivity: Orion Cloud at 8σ
Team: Andreas Schruba (MPE) & PHANGS incl. J. Pety, AH

Molecular Clouds in the Milky Way-twin IC 342

A NOEMA Early Science Project



11 arcmin ~ 11 kpc

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Resolution: 4” ~60pc x 5 km/s

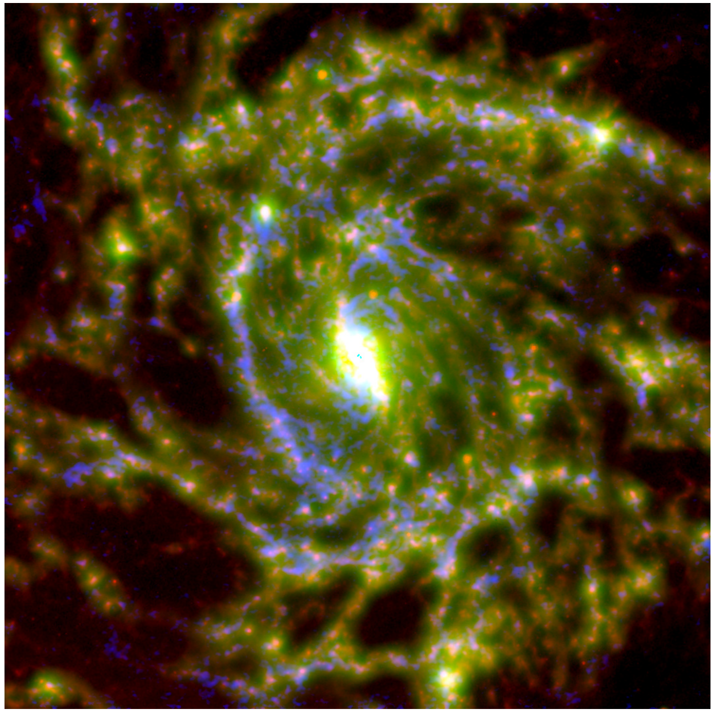
Sensitivity: Orion Cloud at 8σ

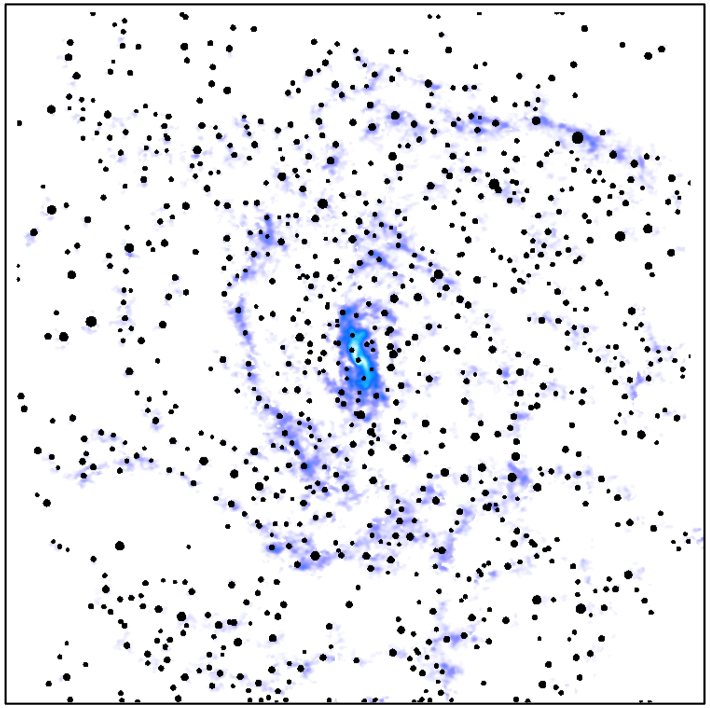
Team: Andreas Schruba (MPE) & PHANGS incl. J. Pety, AH

IRAM @ IC342: A Census of GMCs

Team: PhD student Dimitris Chatzigiannakis, Schruba, Bigiel, AH & PHANGS

Goal: Investigate the properties of molecular clouds as a function of spiral arm location and star formation activity in a MW like galaxy



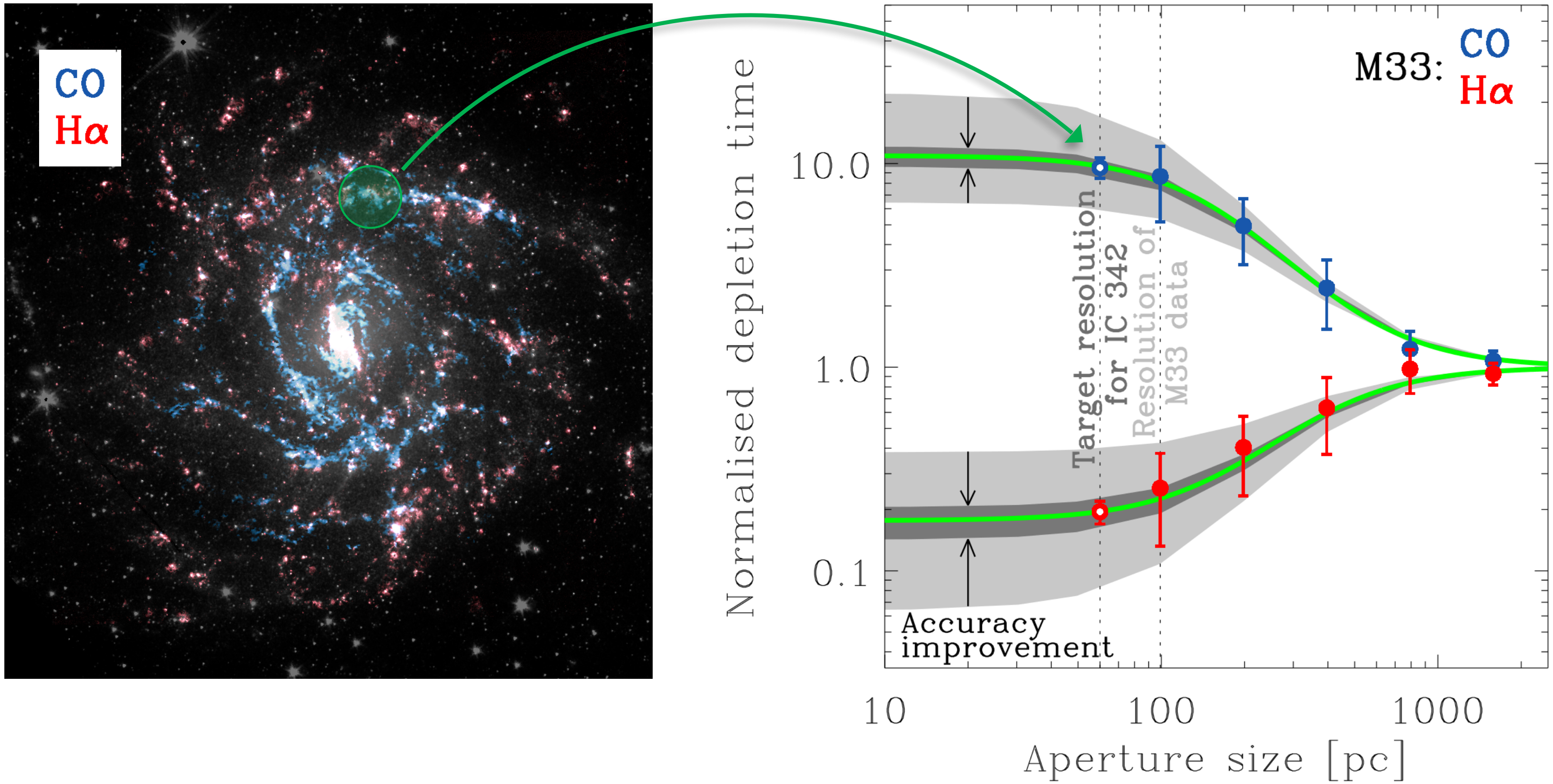


- Characterize ~1000 molecular clouds (mass ~ 10^5—10^7 $M_\odot$)
- Determine mass function and dynamical state with environment
- Study link between cloud properties and star formation activity

IRAM @ IC342: the SF-GMC Cycle

Team: PhD student Alex Hygate, Melanie Chevance & PHANGS

Goal: Timescales! Measure GMC lifetime, duration of active star formation & timescale and efficiency of feedback

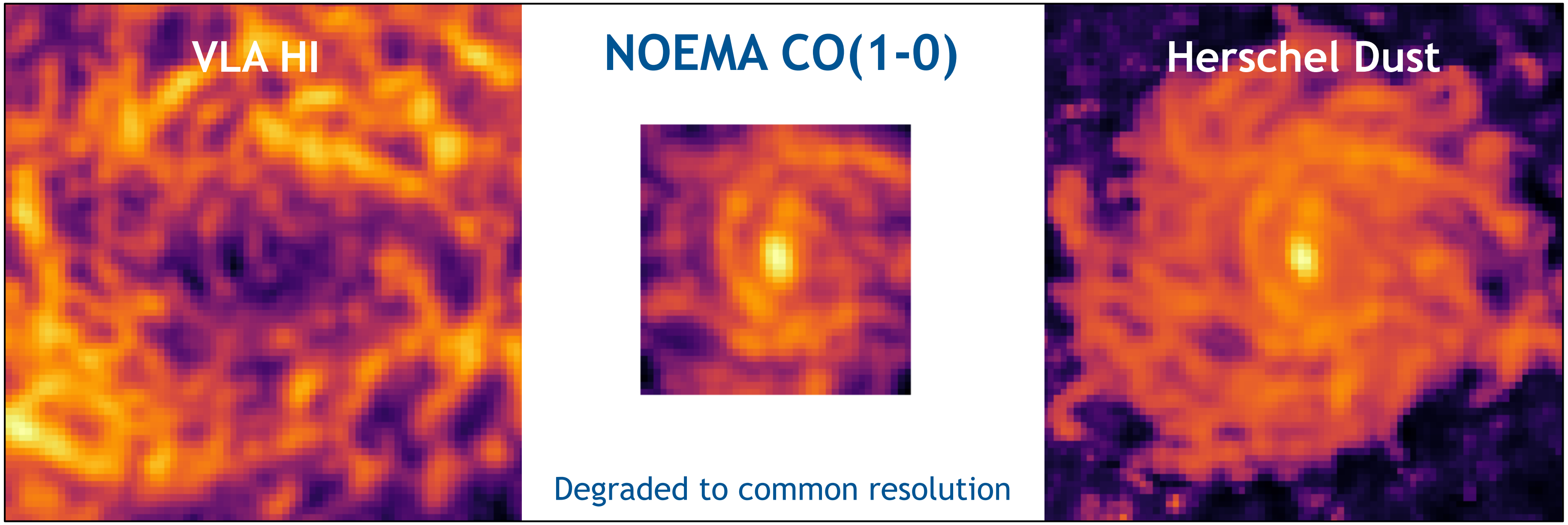


- Apply statistical model for gas—star cycle (Kruijssen et al 2014, 2018) to infer GMC lifetime, star formation duration, and feedback efficiency


IRAM @ IC342: the SF-GMC Cycle

Team: PhD student I-Da Chiang, Sandstrom, Leroy, Schruba & PHANGS

Goal: Determine the Gas-to-Dust Ratio (GDR) & the CO-to-H2 conversion factor (XCO) to obtain a quantitative inventory of the neutral ISM phase balance



$$\text{Dust} \times \text{GDR} = \text{HI} + X_{CO} \times \text{CO}$$

Solve for GDR & XCO in local patches of ~1 kpc size

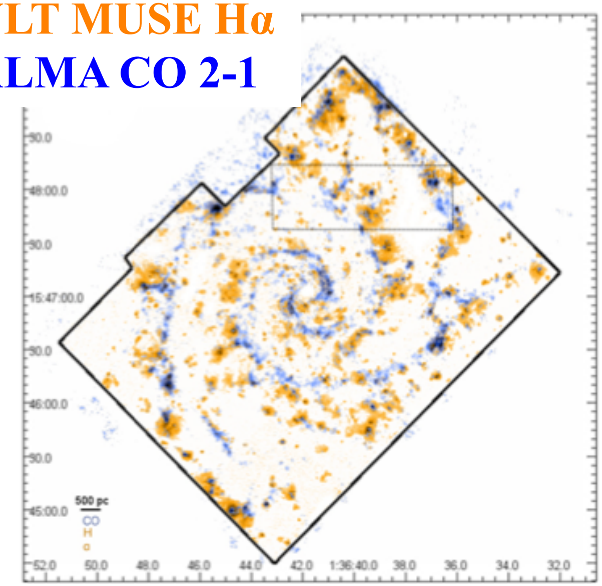
Search for dependencies on density, metallicity, radiation field

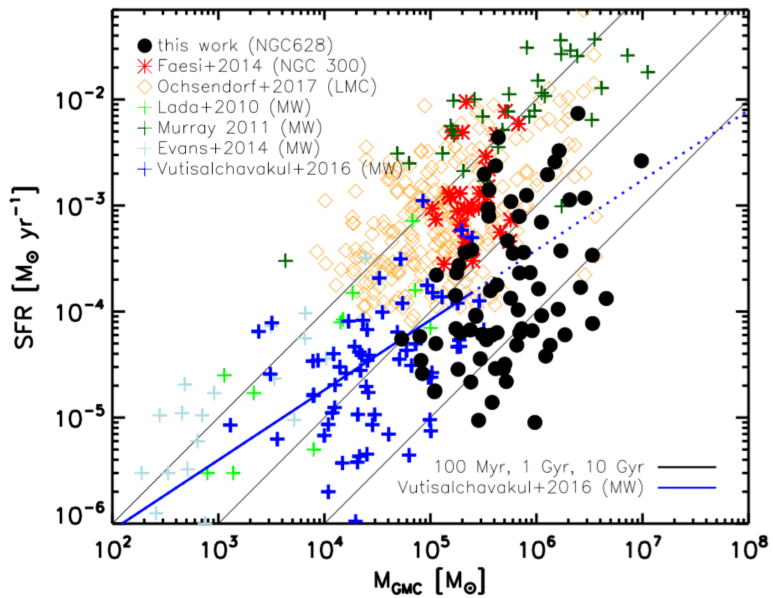
Synergies with other facilities including MUSE

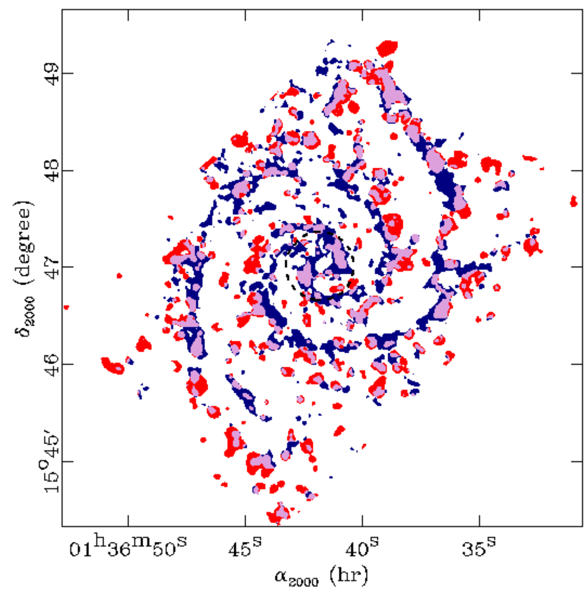
Tracing the Cloud Life Cycle

MUSE provides a gold standard tracer of recent high mass SF (no more problems with DIG, NII contamination, internal extinction) & HII region properties

VLT MUSE Hα
ALMA CO 2-1







Systematic spatial offsets between molecular clouds & HII regions illustrate the time evolution of star-forming regions

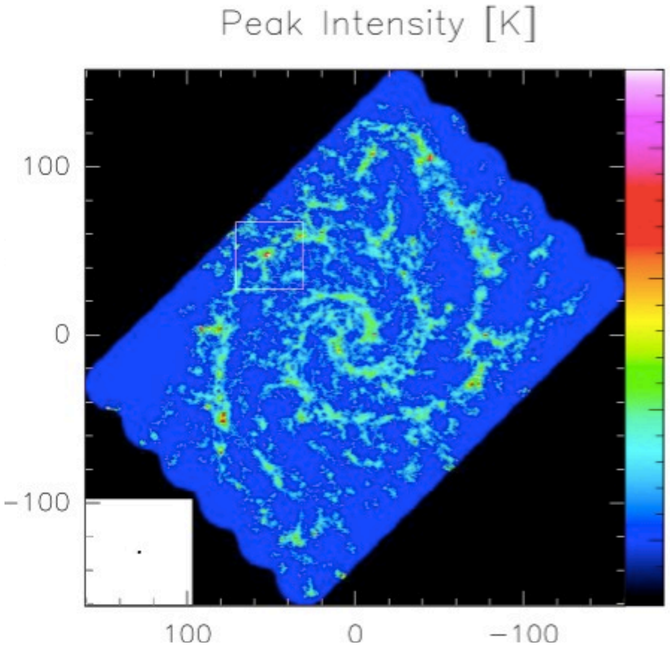
Scatter in the KS relation likely due to GMC evolution: in NGC 628, the overlap phase is remarkably short.

Connection between GMC mass spectrum & HII region LF is complex (1 GMC hosts many HII regions)

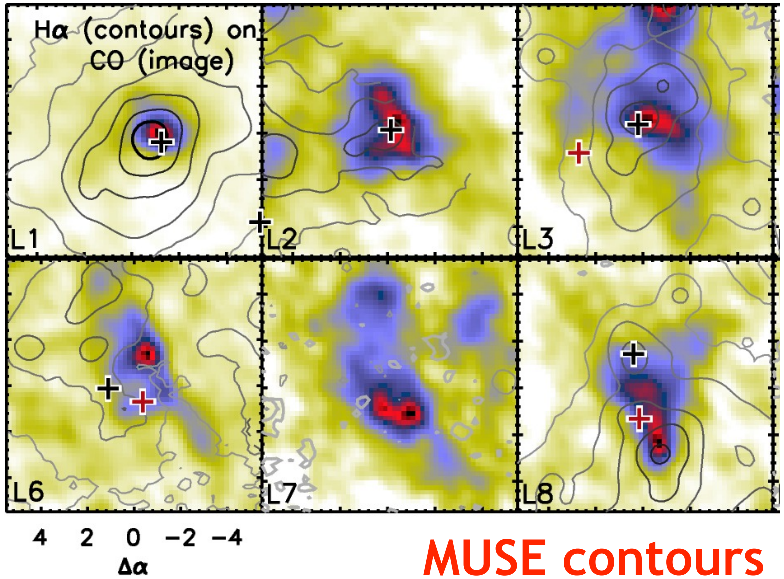
Kreckel et al (2018), see also Melanie Chevance et al (in prep), Schinnerer (in prep),

Tracing Formation & Evolution of YMCs

- CO(2-1) imaging traces the bulk molecular gas reservoir
- Targeted 90GHz observations trace the H2 density distribution
- HST/LEGUS observations trace the YMC population (future: JWST)
- PHANGS MUSE observations trace the HII region properties

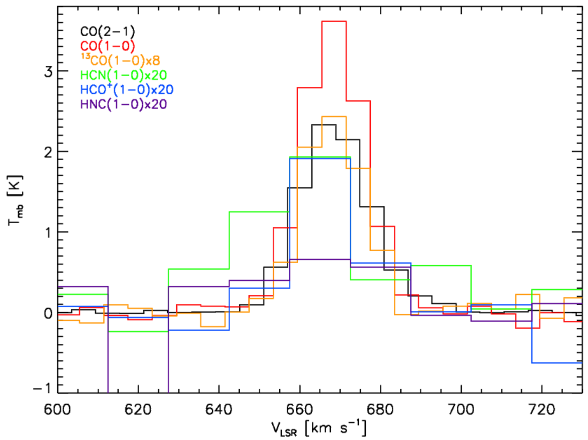


Cycle 2 ALMA CO(2-1)



MUSE contours

HST-LEGUS clusters



90-110 GHz lines

Multi-wavelength datasets and modelling enable a comprehensive picture of the ISM conditions leading to formation of YMCs and their feedback on the ISM

Cinthya Herrera et al (in prep)

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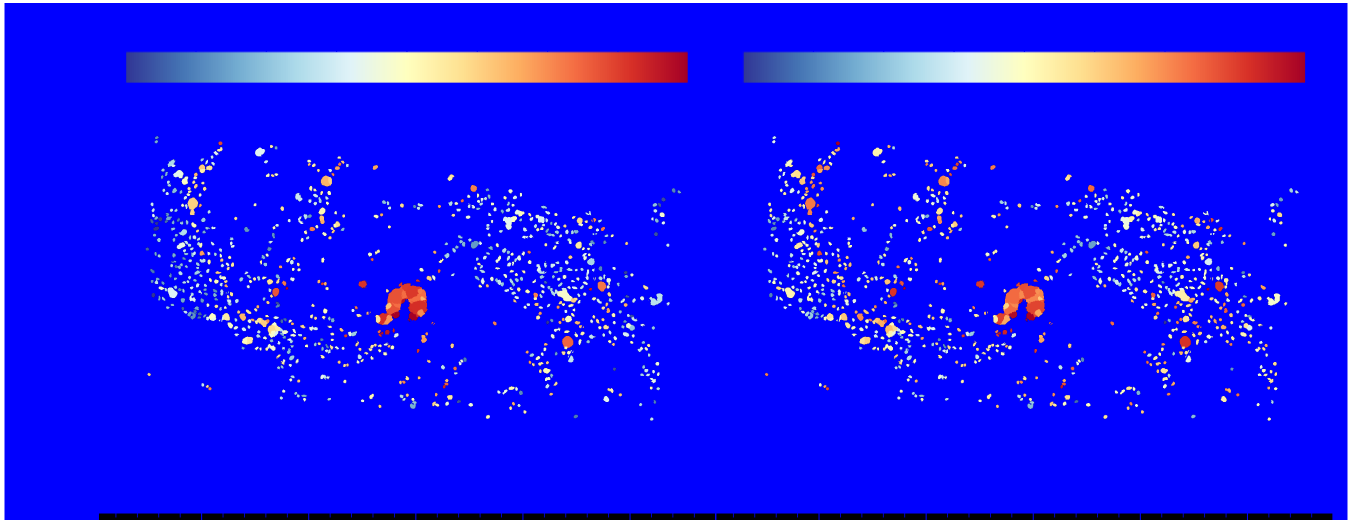
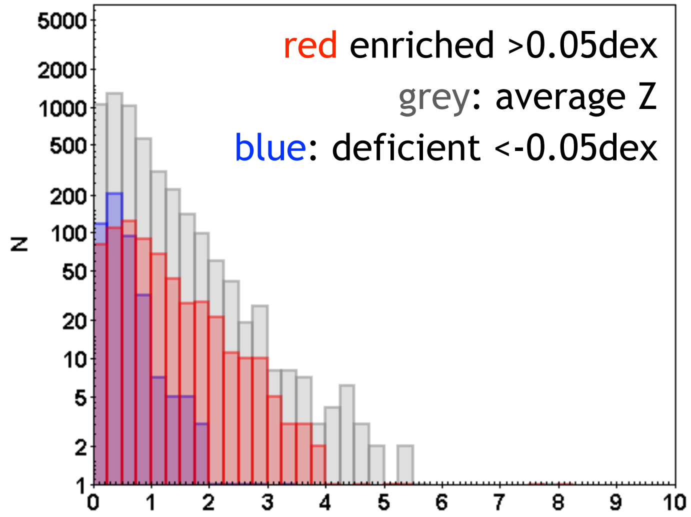
Tracing Enrichment of the cold ISM

MUSE traces local metallicity enrichment by HII regions on 100 pc scales

Metallicity of HII regions in NGC1672 by MUSE





CO(2-1) peak brightness

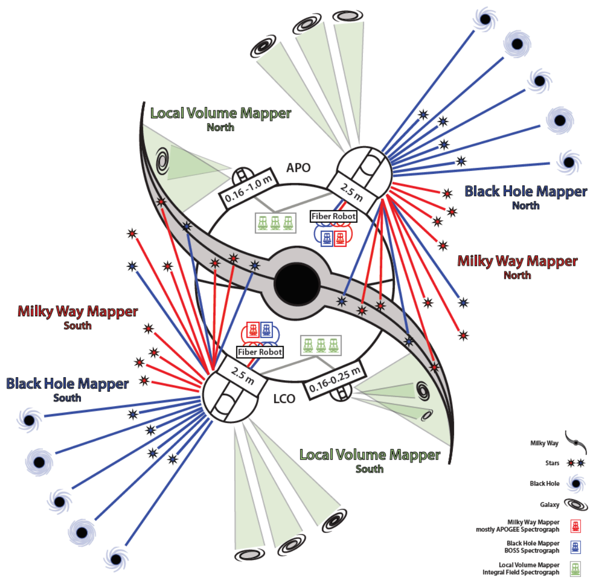
Clear relation between HII metallicity properties and properties of CO(2-1) emission: enriched regions show enhanced CO peak brightness.

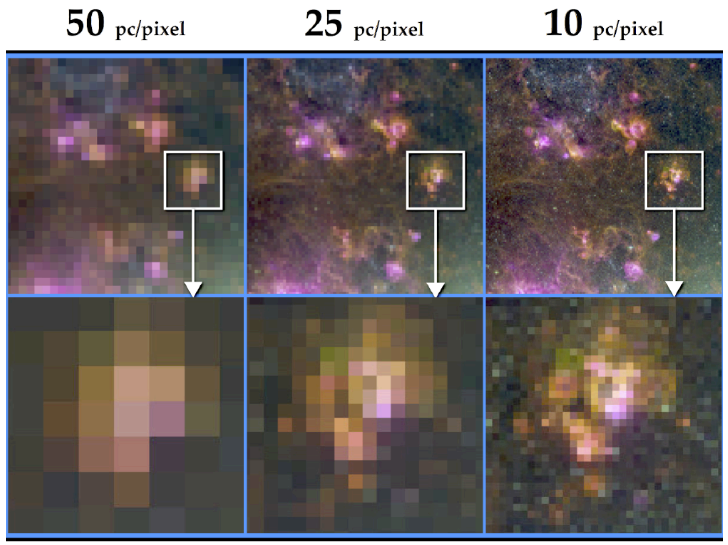
Molecular gas may be warmer and pre-enriched by previous generations of SF

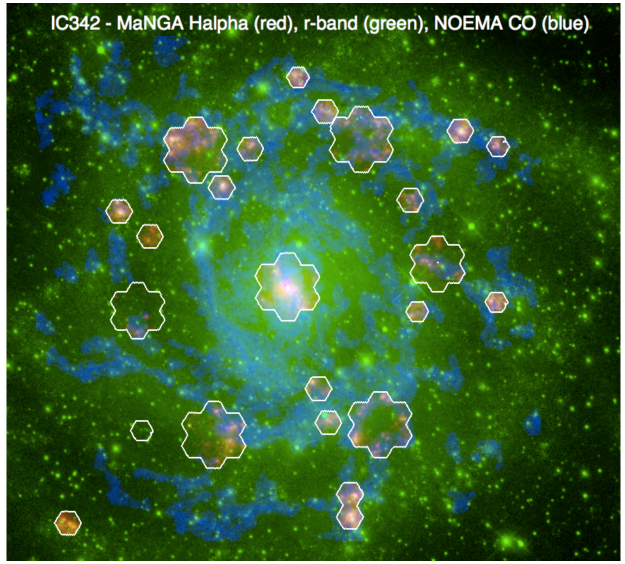
This is just a taster: MUSE accesses many properties of the ionised gas (incl. important feedback diagnostics) and of the underlying stellar population

Kreckel et al (in prep), Ho (in prep)

Future Synergies: SDSS-V/LVM







Optical IFU data at 3600–10000 Å, R~4000, ~6” resolution
(20pc in M31& M33, <100pc in galaxies within 5 Mpc)

Key Science is the Baryon Cycle within Galaxies, including
- connection between ionized gas, star formation, and feedback across scales
- geometry of the ionized and dusty ISM to understand chemical abundances & enrichment
- co-evolution of stellar populations and the surrounding ISM

NOEMA +30m is the only facility that can provide the information about the dense gas for the northern sky : this information will be essential to the success of LVM science goals

Summary

There are major efforts underway to survey the physical state of the cold gas in nearby galaxies. IRAM has been and remains a pioneer for the work in this field.

We are making good progress in accessing gas density in nearby galaxies. The density distribution and the SFE of the dense gas is not universal.

Cloud-scale imaging (including kinematics) demonstrates the importance of galactic environment: your favourite SF region resides in a galactic potential that can't be ignored.

Key emerging science questions address processes that involve the interplay of molecular and ionised gas (star formation and feedback). Imperative to combine millimetre and optical data.

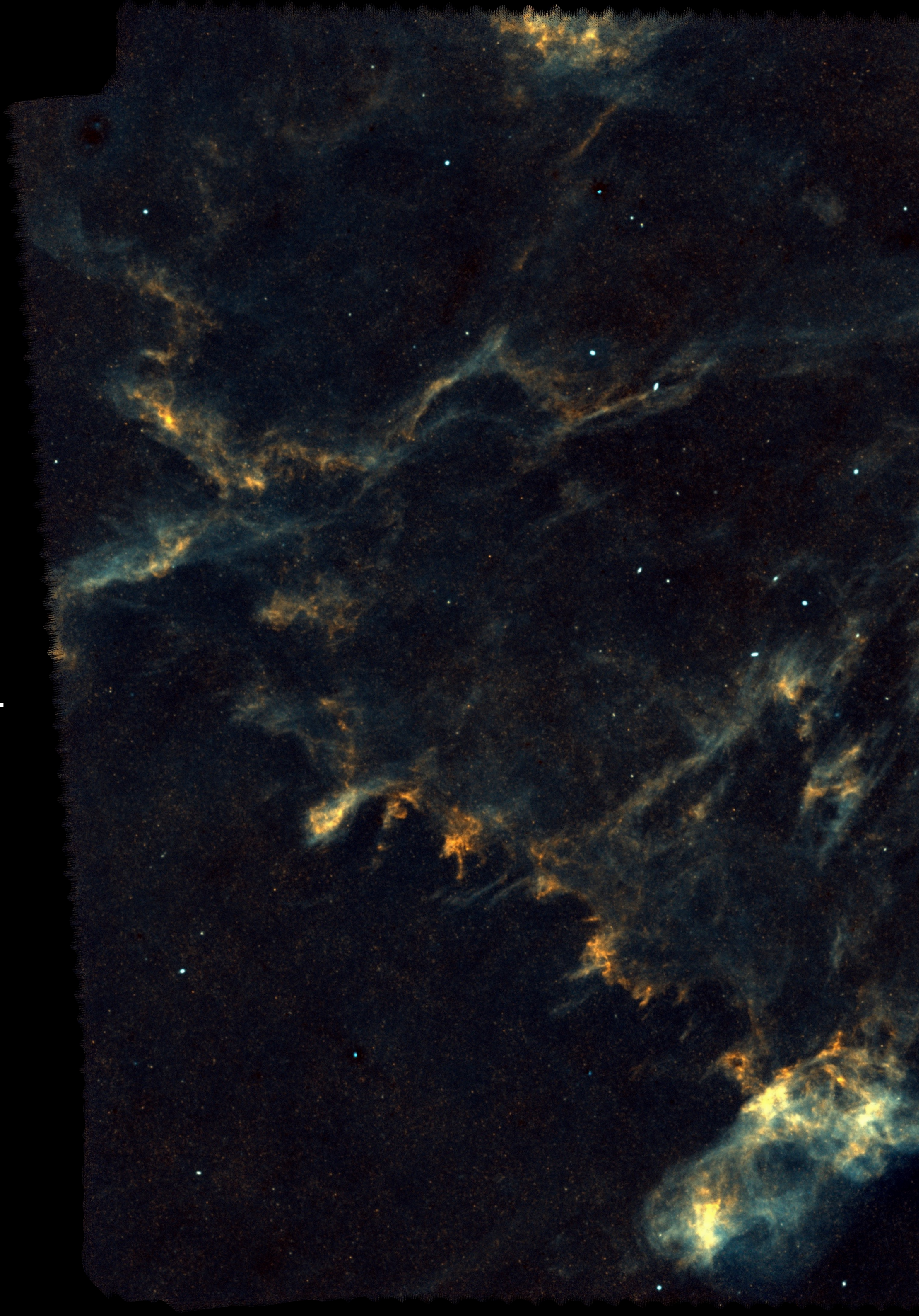
Marc-Antoine Miville-Deschênes

Interstellar structures

AIM
Astrophysique
Instrumentation
Modélisation

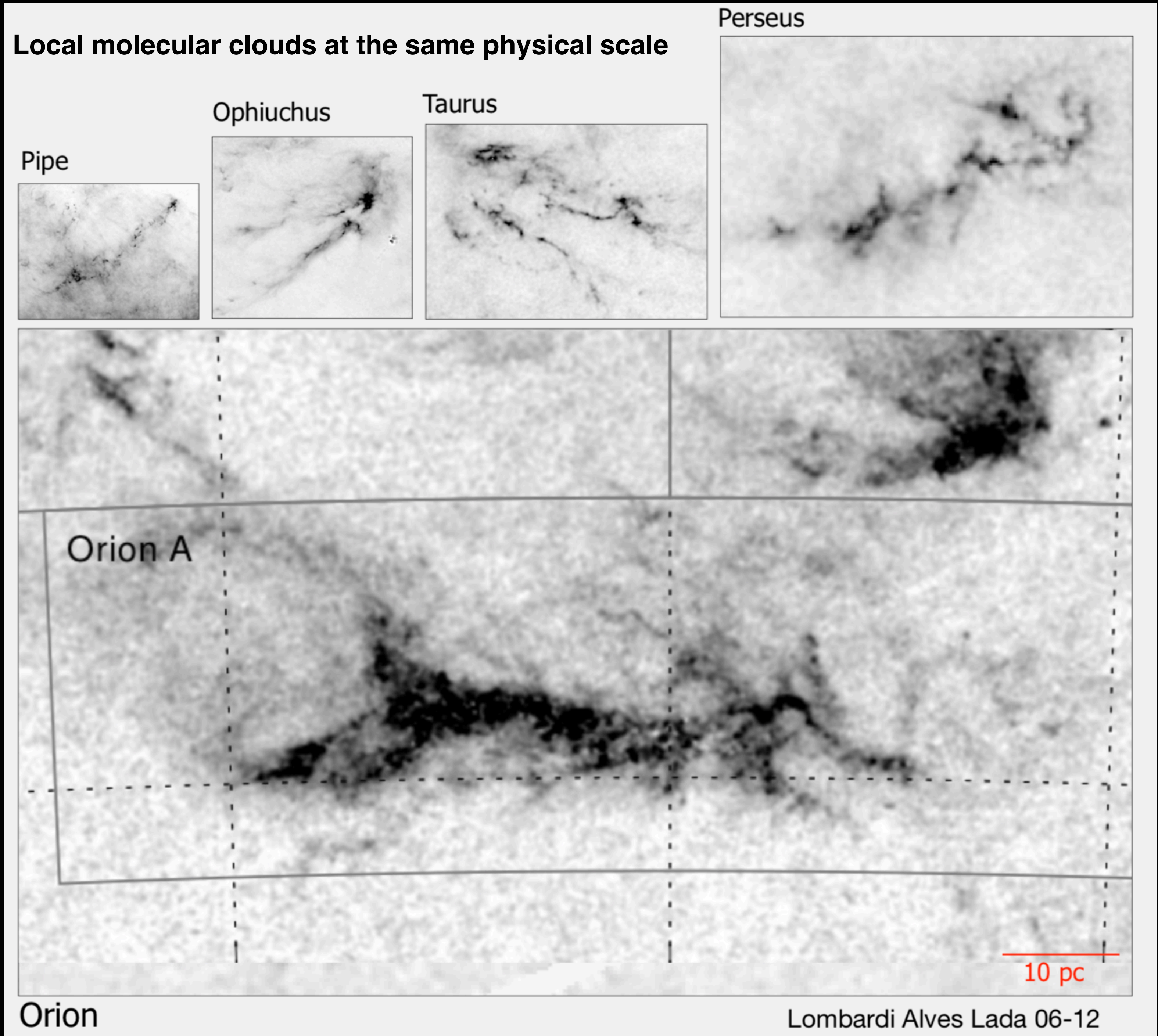
Interstellar structure

Marc-Antoine Miville-Deschênes
CNRS



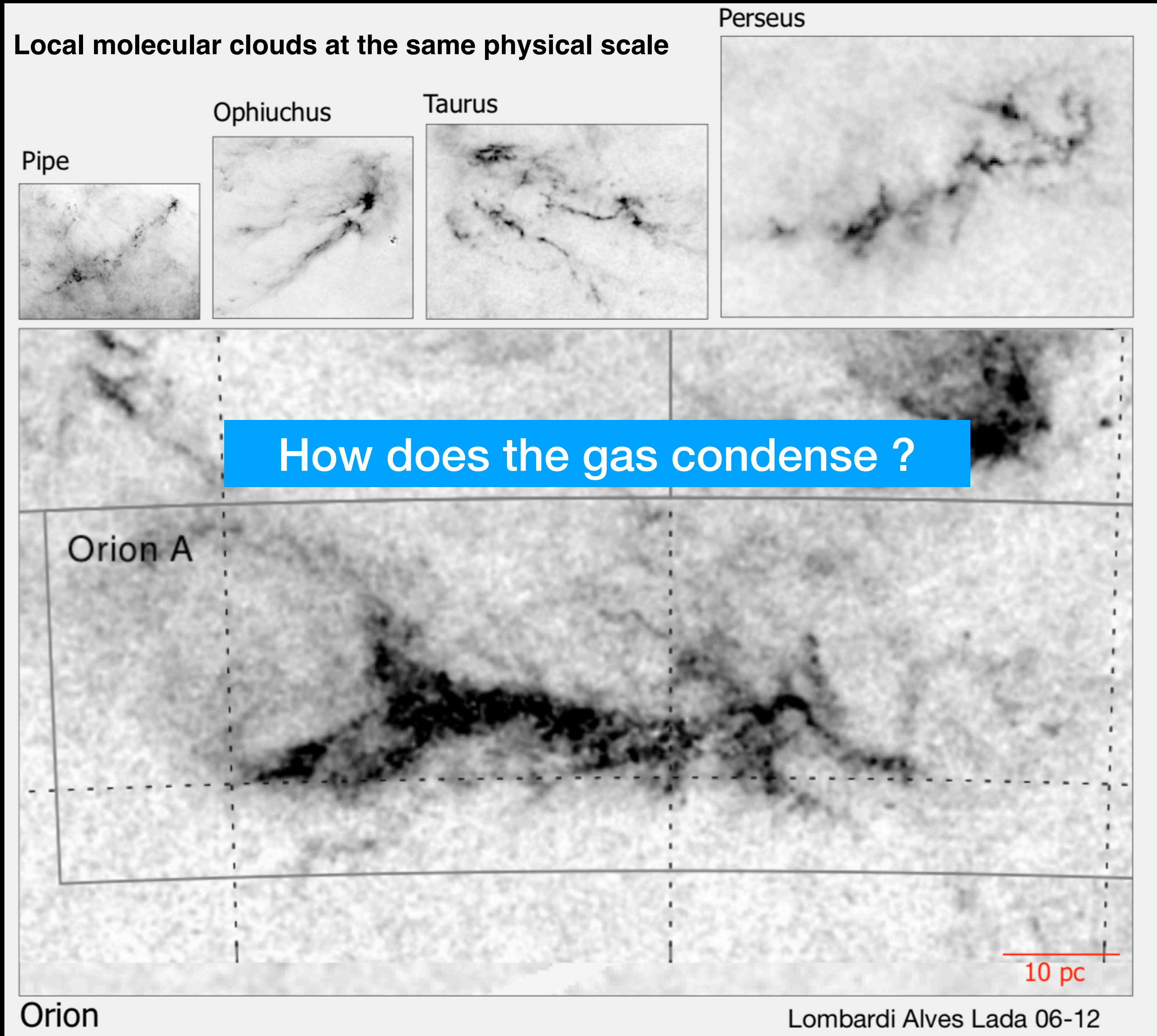
université PARIS-SACLAY
cea
cnrs

Density is key to star formation



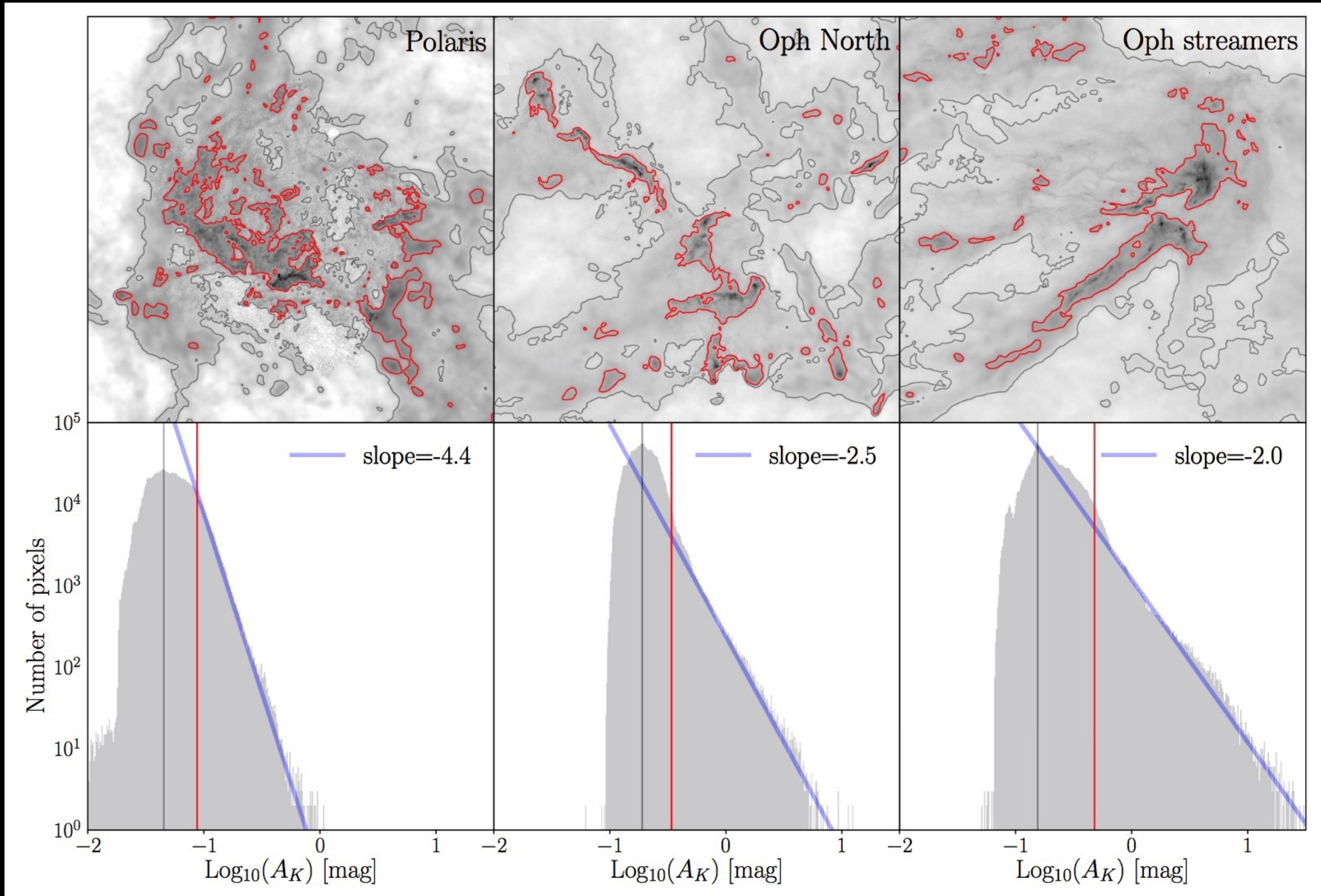
Slide from
Joao Alves

Density is key to star formation



Slide from Joao Alves

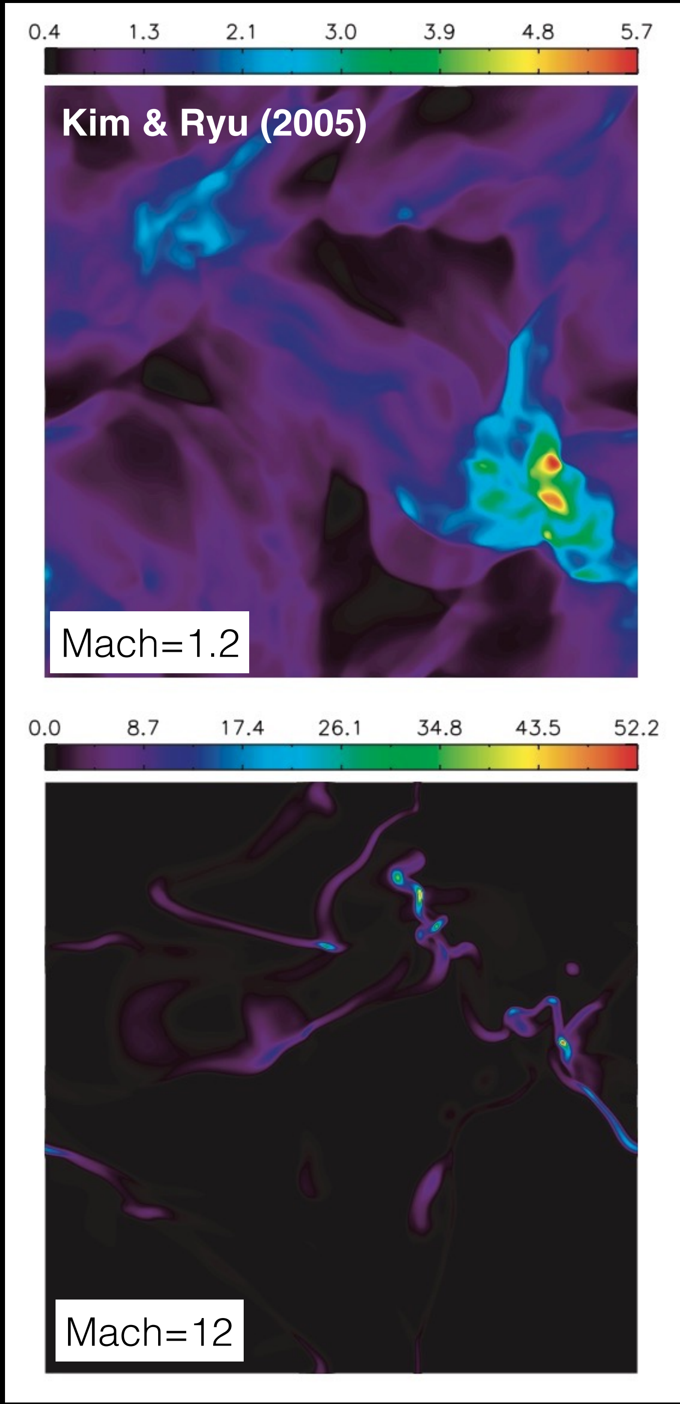
Isothermal supersonic turbulence has a log-normal PDF of density (Kritsuk et al. 2007)

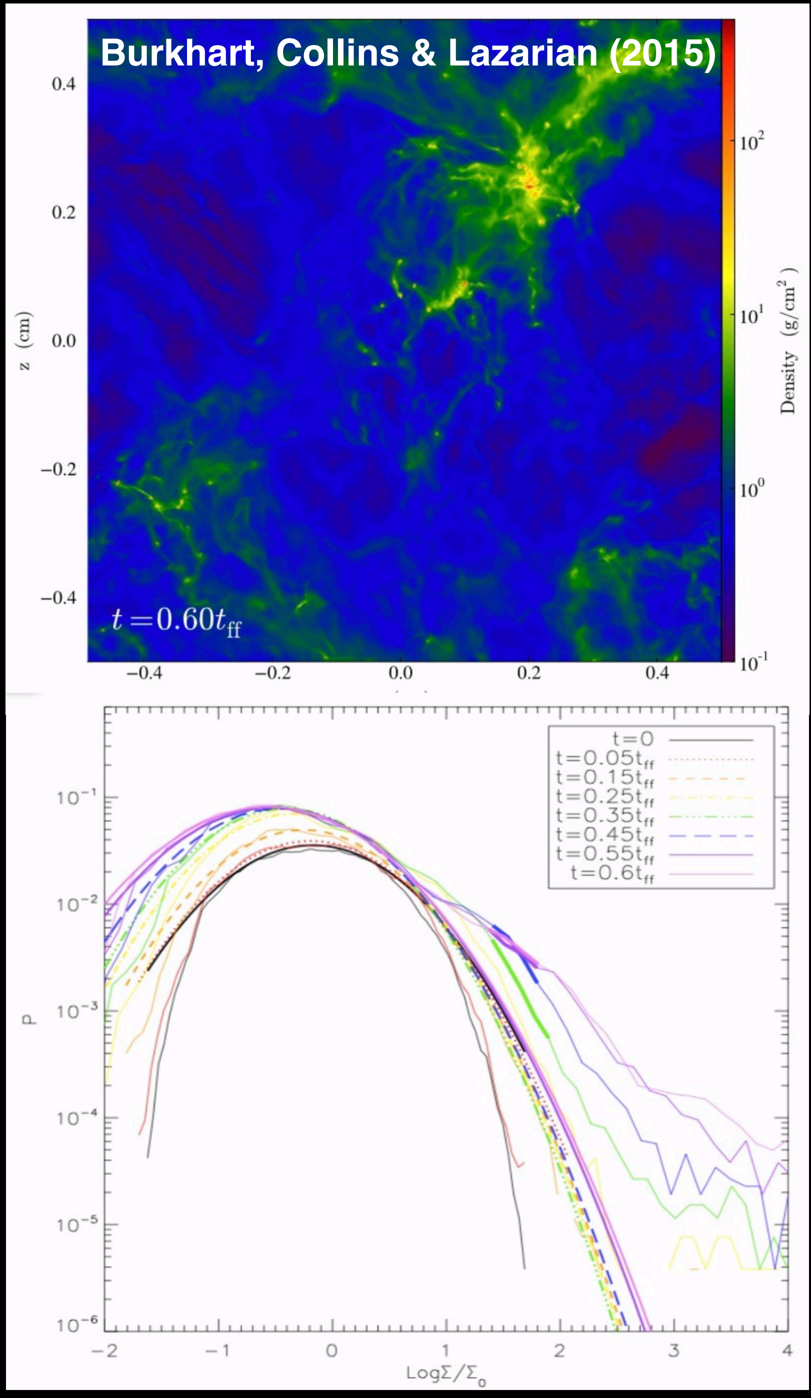


Alves+ (2017)

- log-normal part of the PDF is due to completeness, not supersonic turbulence
- Information in the power law slope changes from diffuse to dense.

Paradigm : increase of small scale structures with Mach number, then amplification by self-gravity

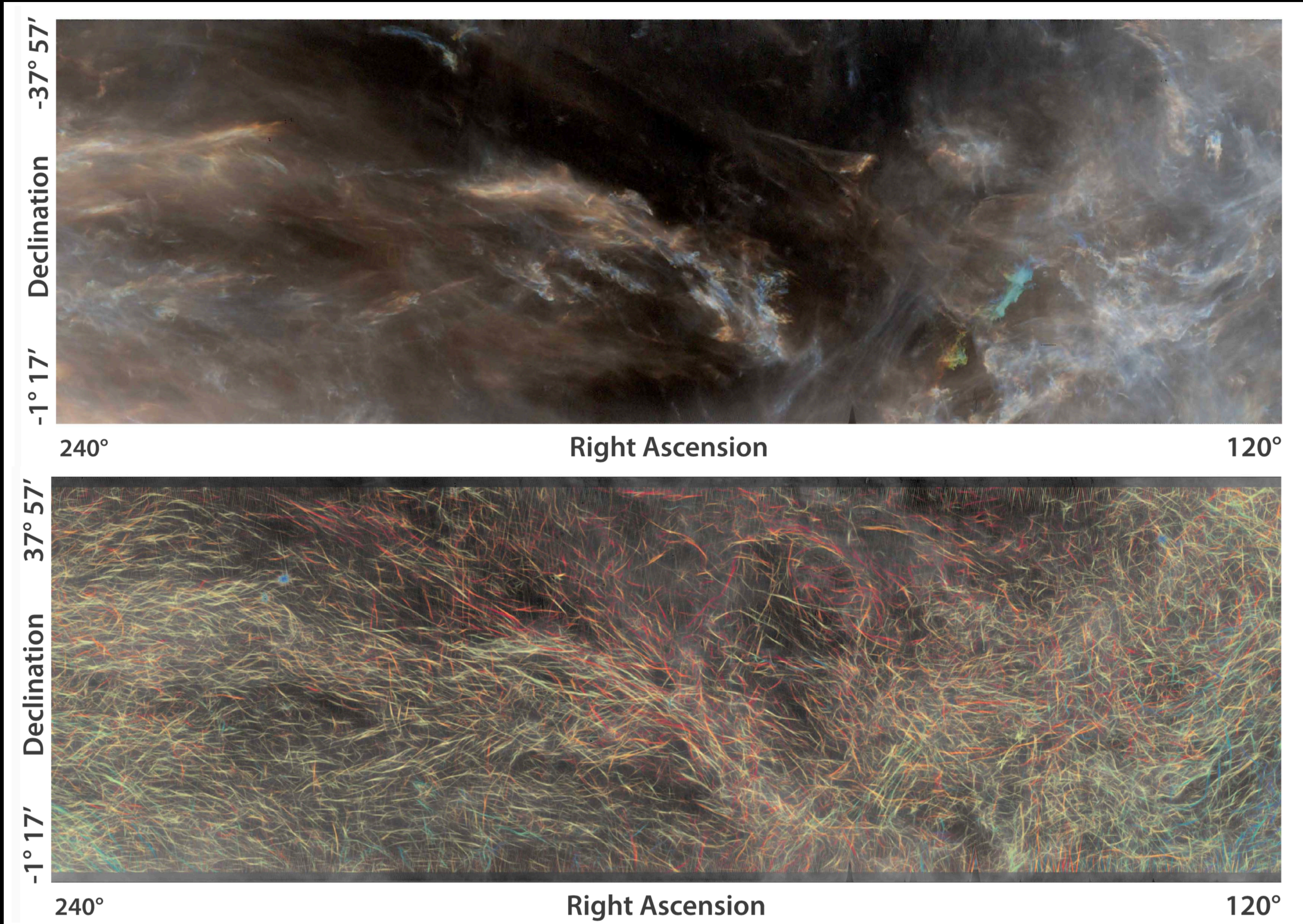




21 cm - GALFA, Arecibo. credit Joshua Peek

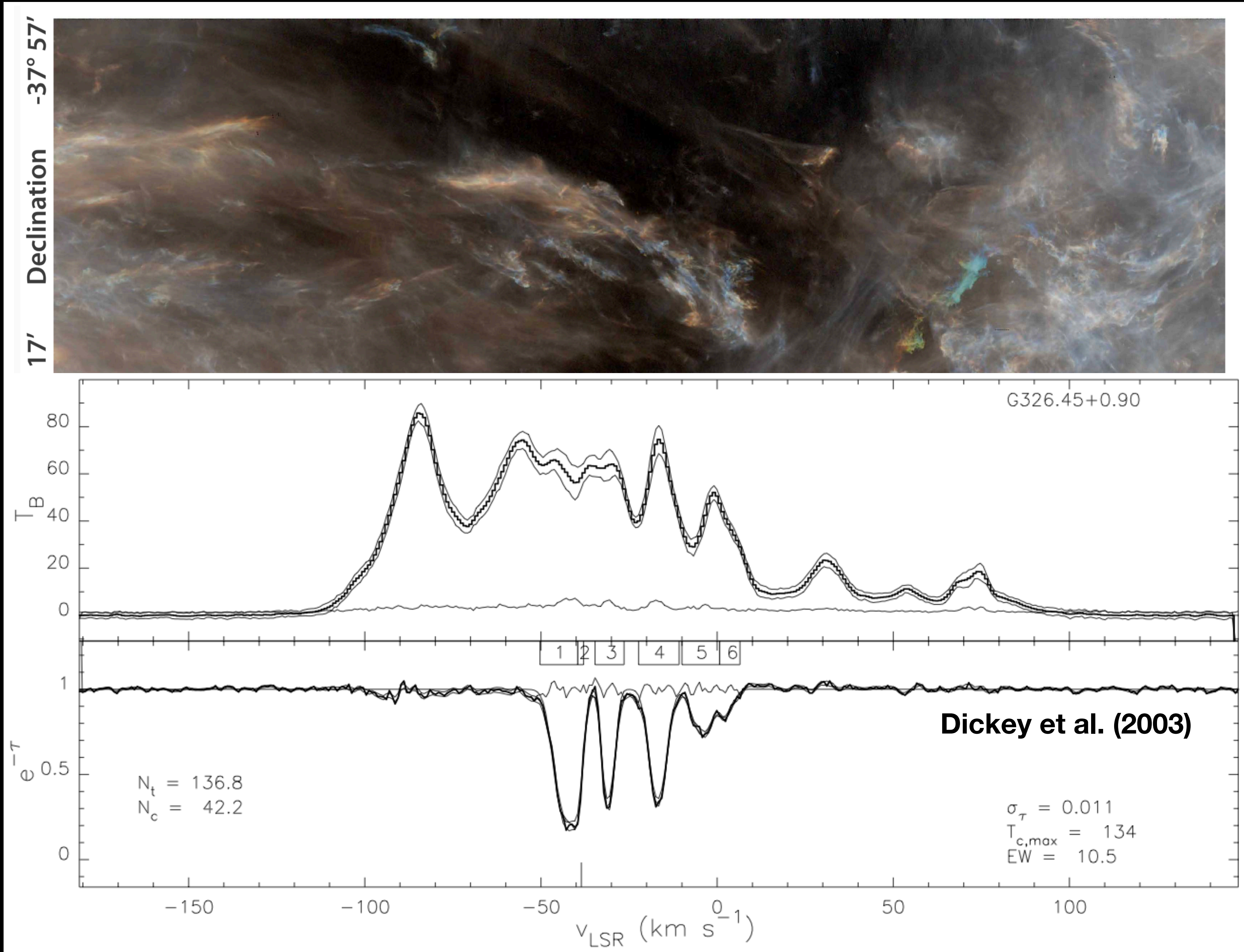
21 cm - GALFA, Arecibo. credit Joshua Peek

The atomic phase is filamentary and multi-phase



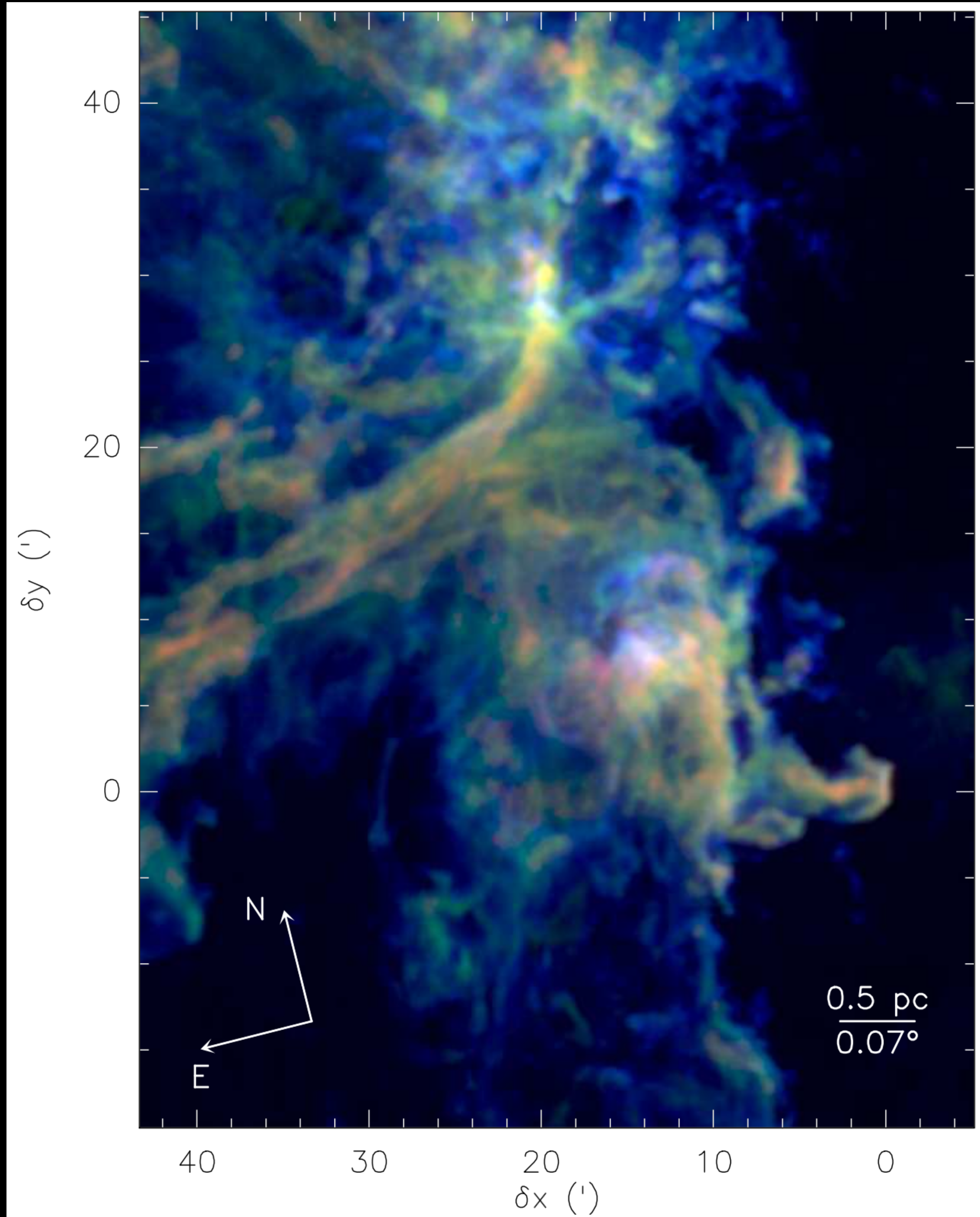
Peek et al. (2018) - 21 cm data from the GALFA survey (Arecibo)

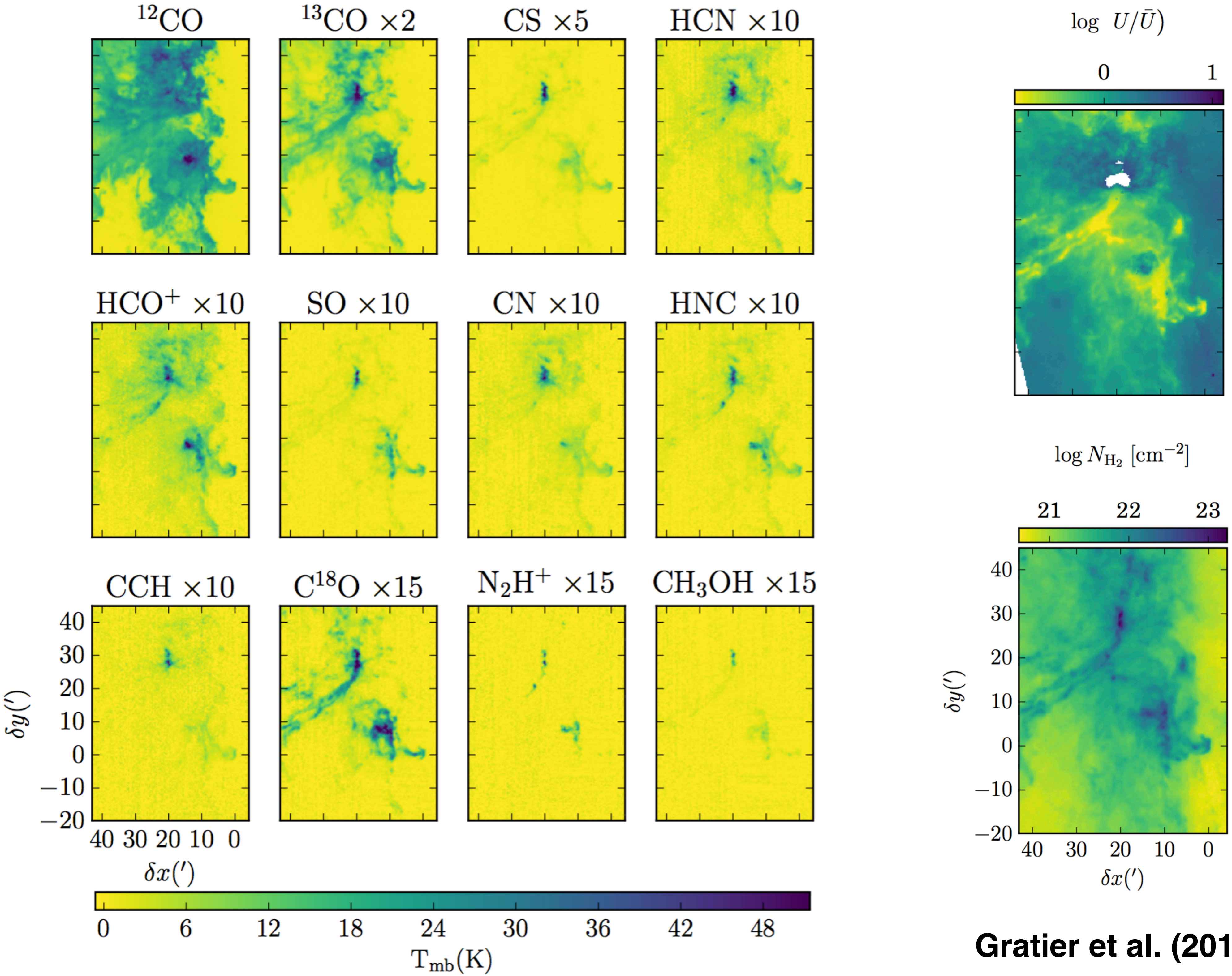
The atomic phase is filamentary and multi-phase



Orion-B

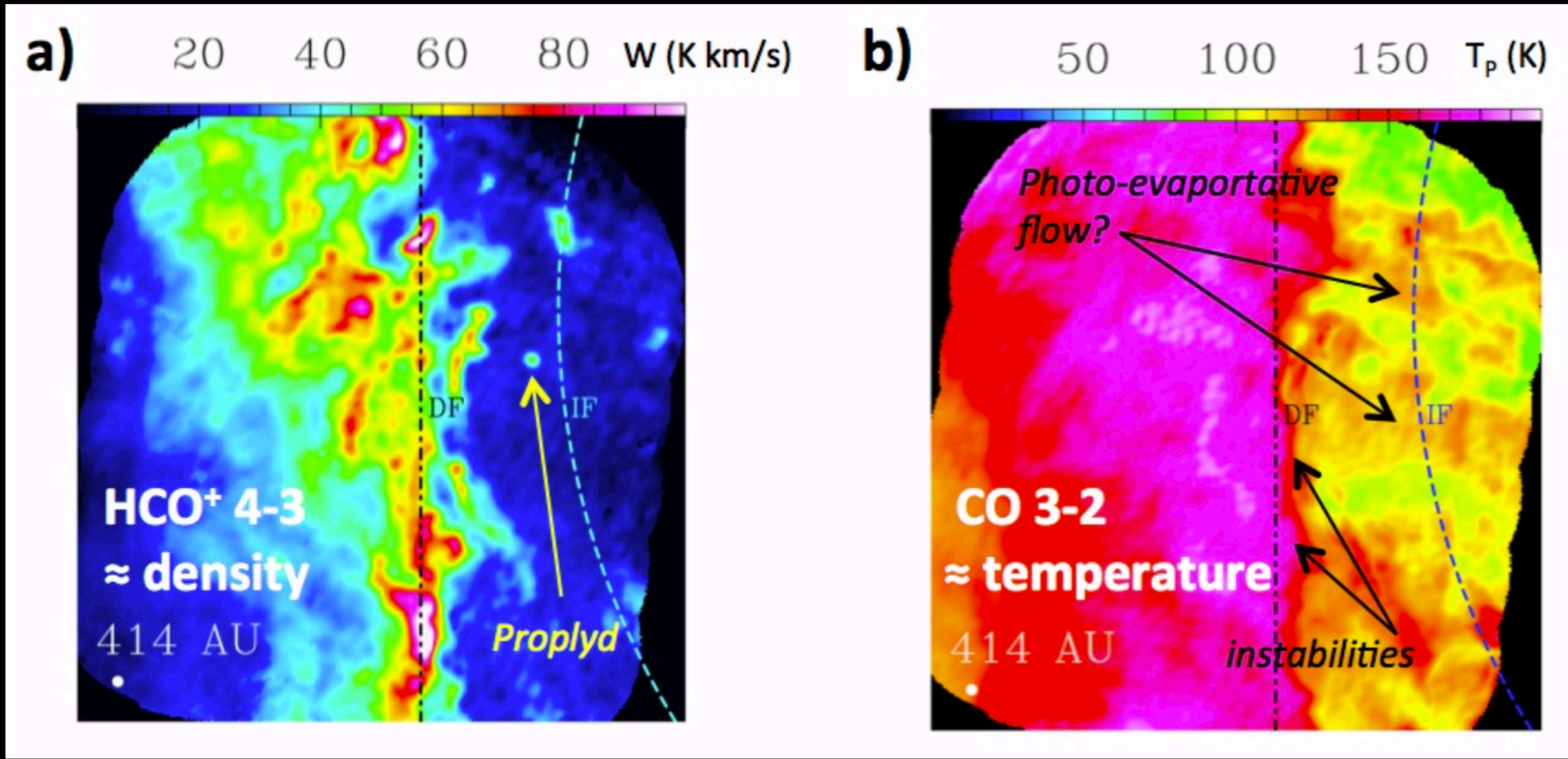
- Pety et al. (2017), Gratier et al. (2017), Orkisz et al. (2017), Bron et al. (2018)
- Observation IRAM-30m - 84 à 116 GHz, 26 arcsec de résolution sur un degré carré.
- Plusieurs transitions, dont ^{12}CO, ^{13}CO, $C^{18}O$, $C^{17}O$, HCN, HNC, ^{12}CN, C_2H, HCO^+, N_2H^+ (1–0), ^{12}CS, ^{32}SO, SiO, c-C_3H_2, CH_3OH.





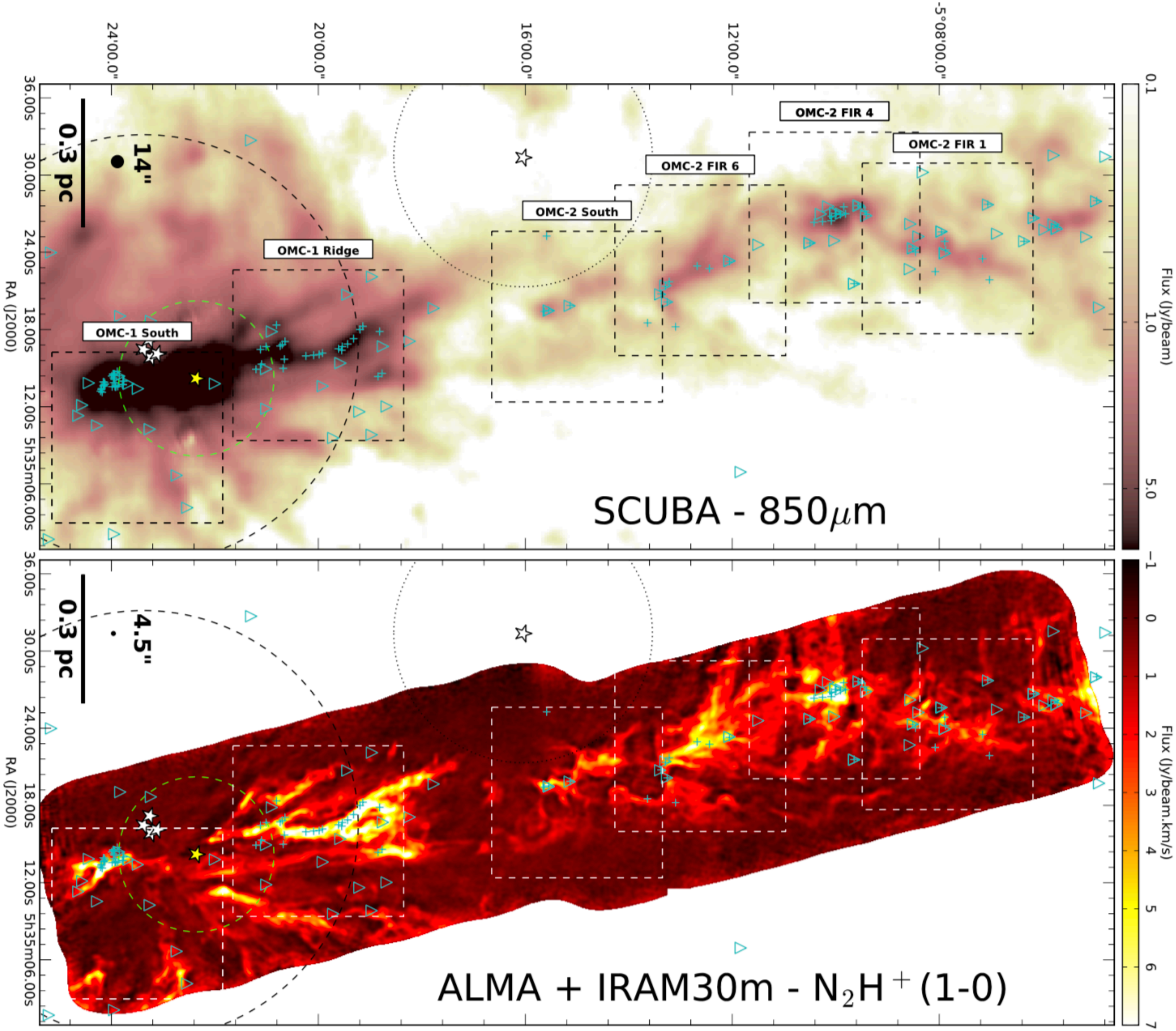
Gratier et al. (2017)

Strong density fluctuations in photo-dominated region



- Javier Goicoechea+(2017) : ALMA + IRAM observations of the HI-H2 transition in the Orion bar
- Large density fluctuations at very small scales. More complex than the classical clump-interclump pictures of static PDRs

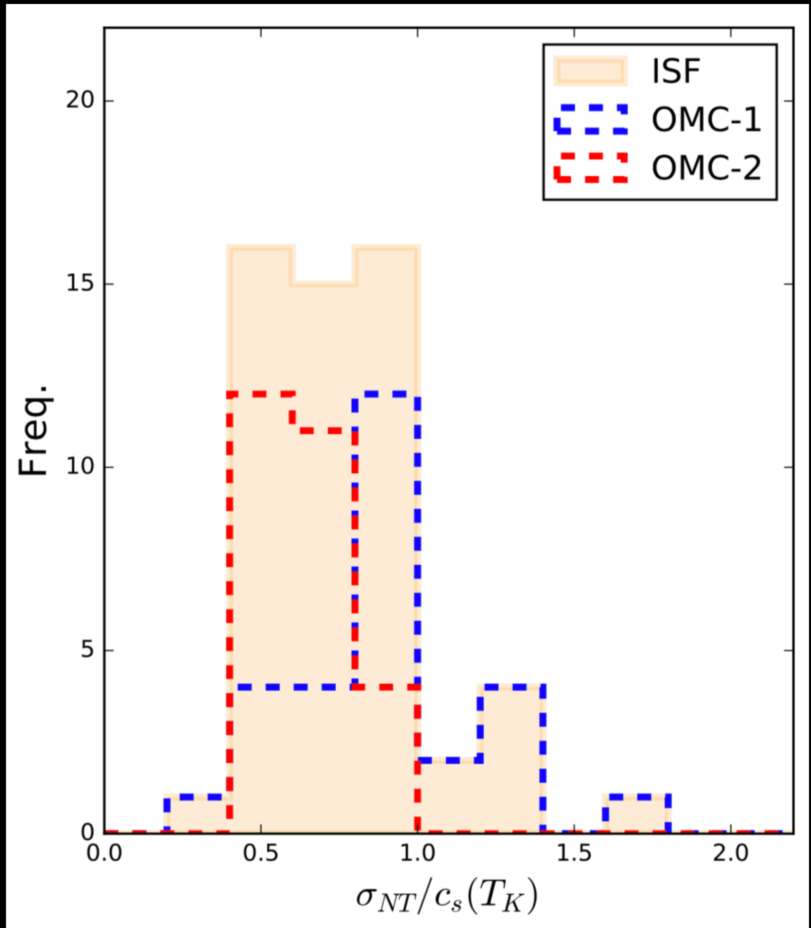
Orion Integral Filament : N2H+ (ALMA)



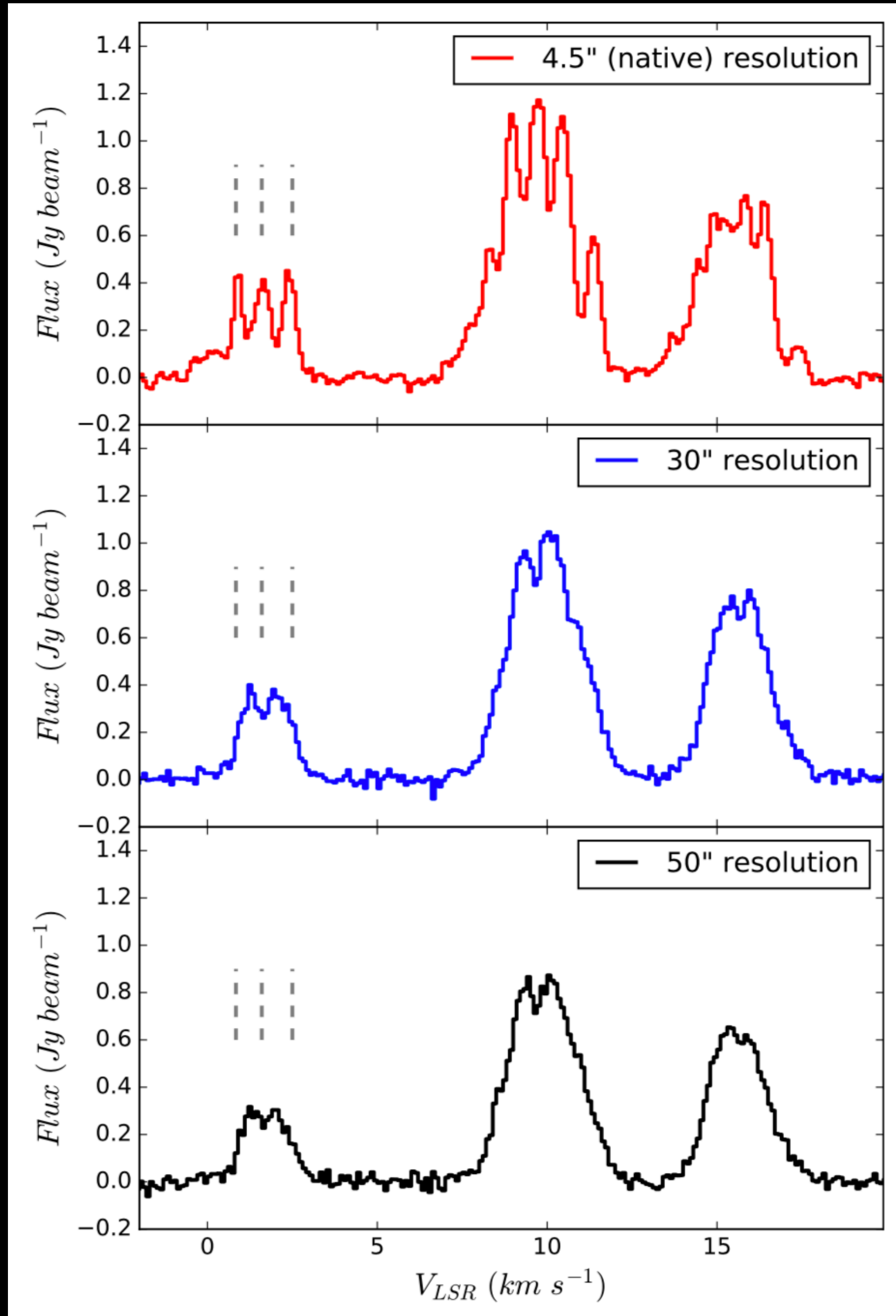
Hacar et al. (2018)

What is the Mach number really ?

- WIM / WNM, CNM and cores are trans-sonic.
- The apparent low density of molecular clouds implies that the dense gas occupies a small fraction of the volume.
- What about the impact on the line-width ?



Orion Integral Filament : N2H+ (ALMA)



Hacar et al. (2018)

Take away messages

- We knew that ISM turbulence was complex, now we see it !
  - MHD turbulence
  - Self-gravity
  - Micro-physics : heating and cooling, metallicity, grain abundance, radiation field
- Hyper-spectral data analysis is key : getting beyond the column density structure
- New methods are being developed.
  The complexity of the data can now be tackled

Frédérique Motte

Star Formation

Star Formation

Frédérique Motte (IPAG Grenoble)

Special credits to Thomas Nony and Isabelle Joncour (IPAG Grenoble), Fabien Louvet (U. Chile), Yueh-Ning Lee and Patrick Hennebelle (CEA-Saclay) and Sylvain Bontemps (LAB Bordeaux)

in the framework of the *Herschel*/HOBYS, IRAM/W43-HERO, and ALMA-IMF consortia

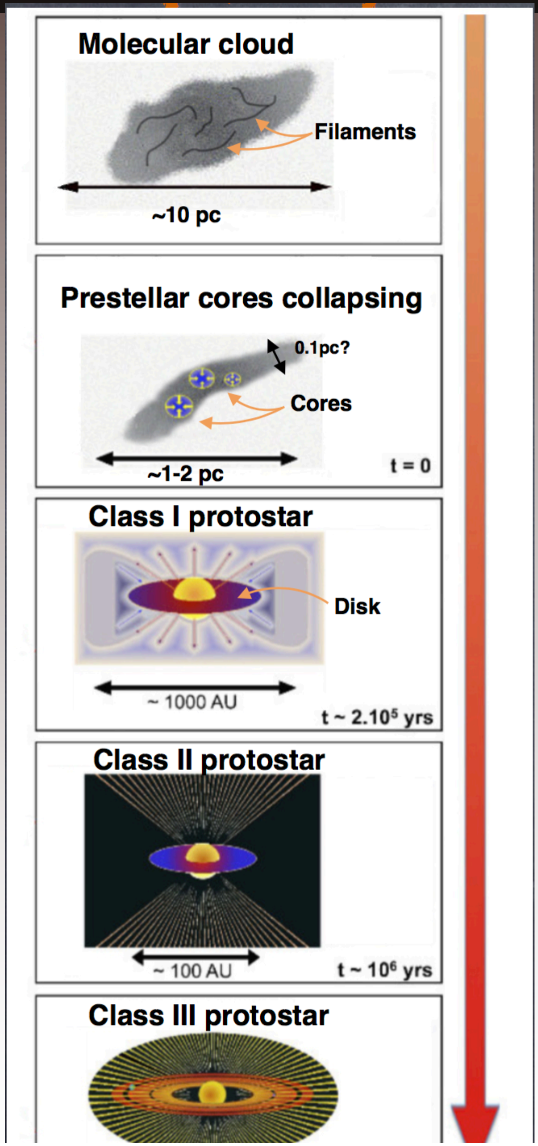
The French Star Formation Community

Strengths:

- Collaboration between observers & modellers
- Benefits from the IRAM utilities and expertise
- Develops links with the ISM community
- the stellar cluster community

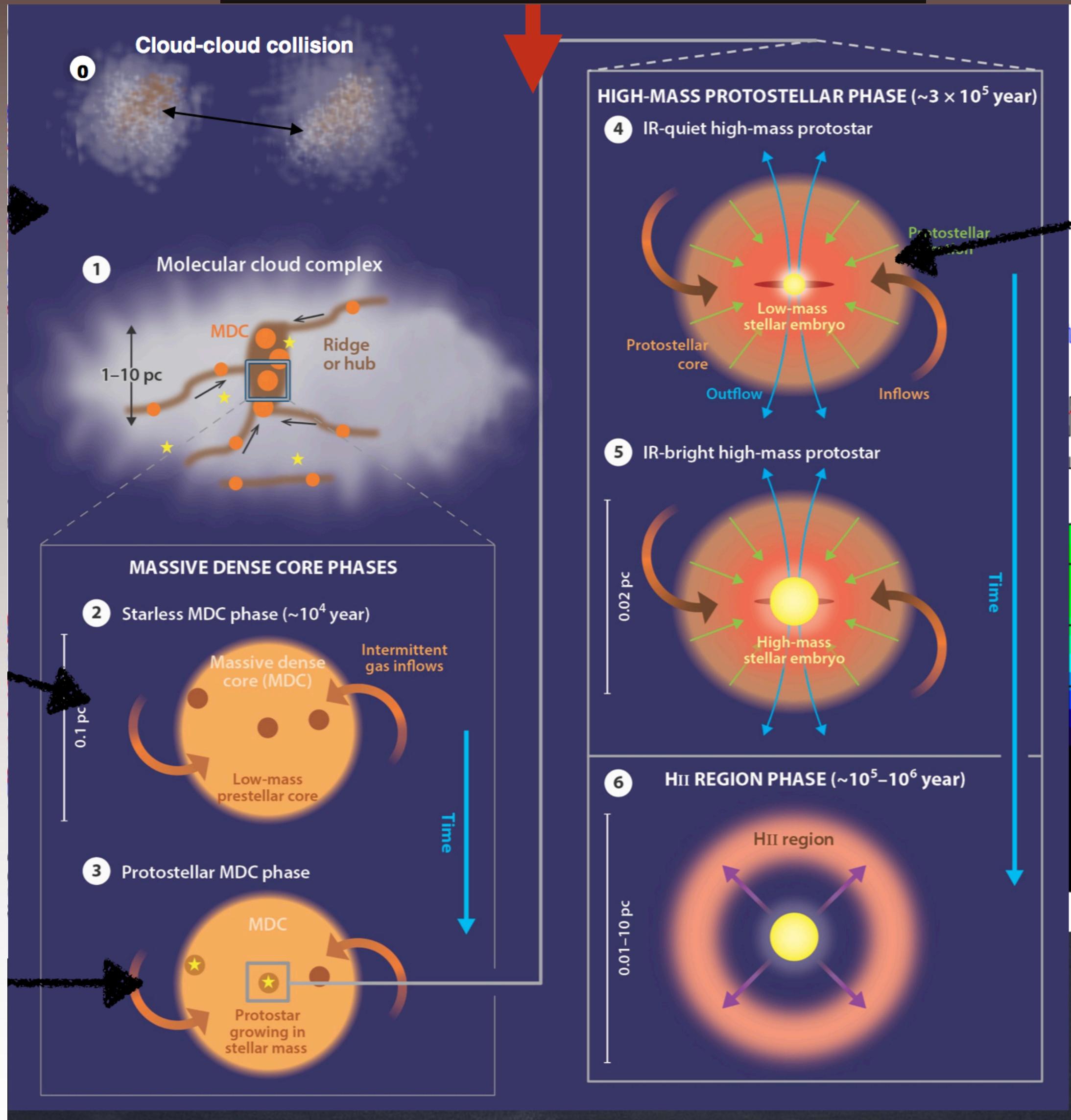
Star formation scenarios

Low-mass star formation



André et al. 1994, 2014

High-mass star formation



Motte, Bontemps & Louvet ARA&A 2018

Major open questions

Origin of stellar masses

- Formation of high-mass stars and brown dwarfs

or

- Effect of cloud formation

Talk by P. André

Talks by M.-A. Miville-Deschenes, A. Hughes

Origin of disks, jets, and star multiples

- Angular momentum problem

or

- Role of turbulence, cloud dynamics, and B fields

Talks by A. Dutrey, M. Galametz

Star formation rates

- Universal or varying with galactic environments?

Talks by D. Cormier, J. Montillaud

Molecular complexity and seeds of life

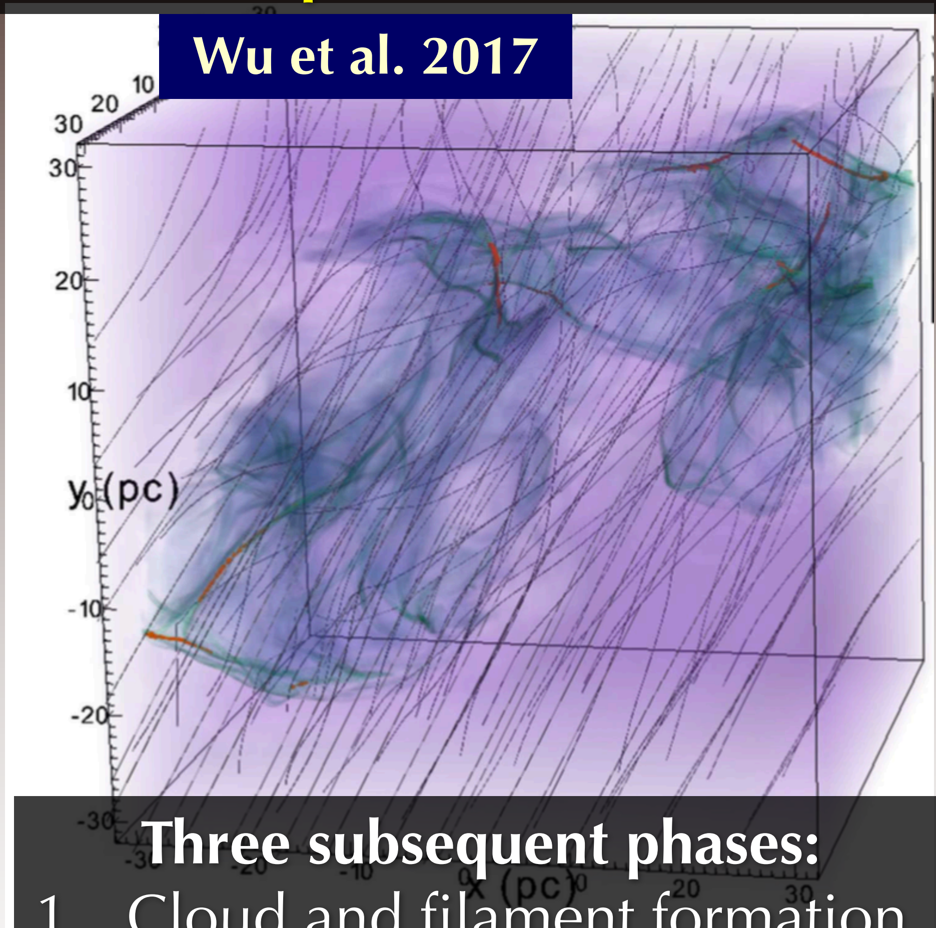
- Inherited from the ISM?

Talks by C. Vastel, E. Bianchi, M. de Simone

Quiescent versus dynamic cloud formation

Low-mass/quiescent star formation

Wu et al. 2017



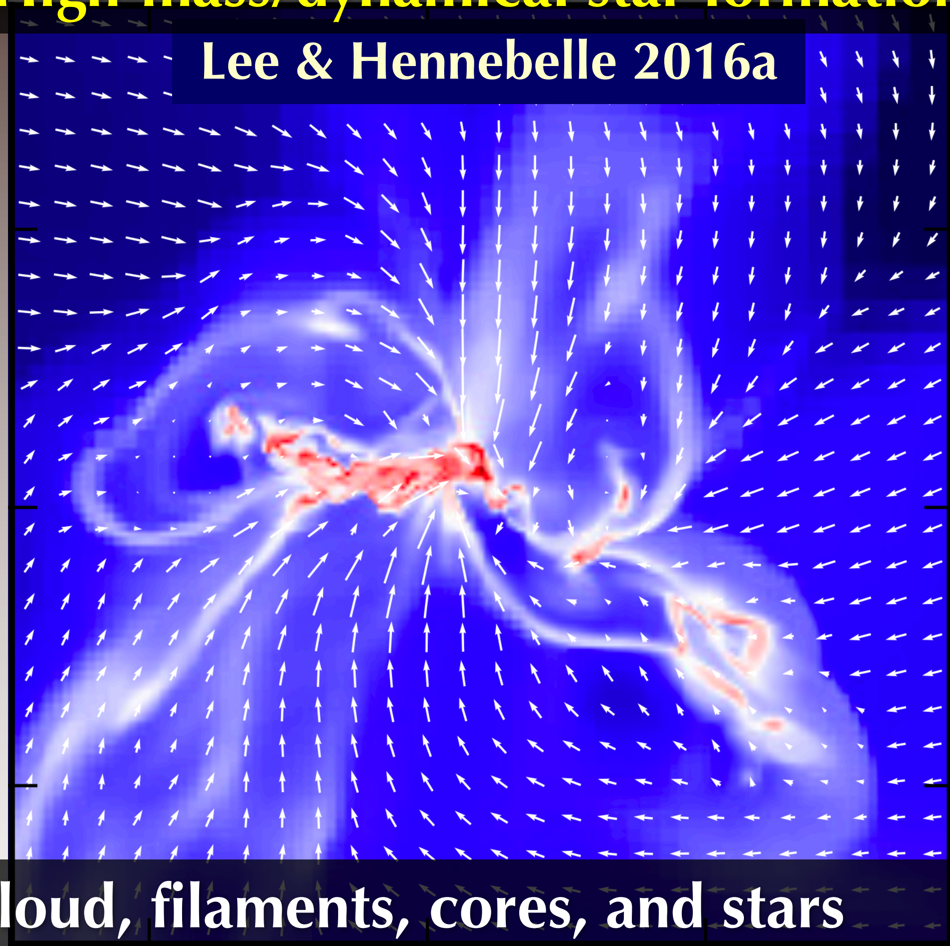
Three subsequent phases:

1. Cloud and filament formation
2. Core formation
3. Protostellar collapse

→ Low-mass stars

High-mass/dynamical star formation

Lee & Hennebelle 2016a

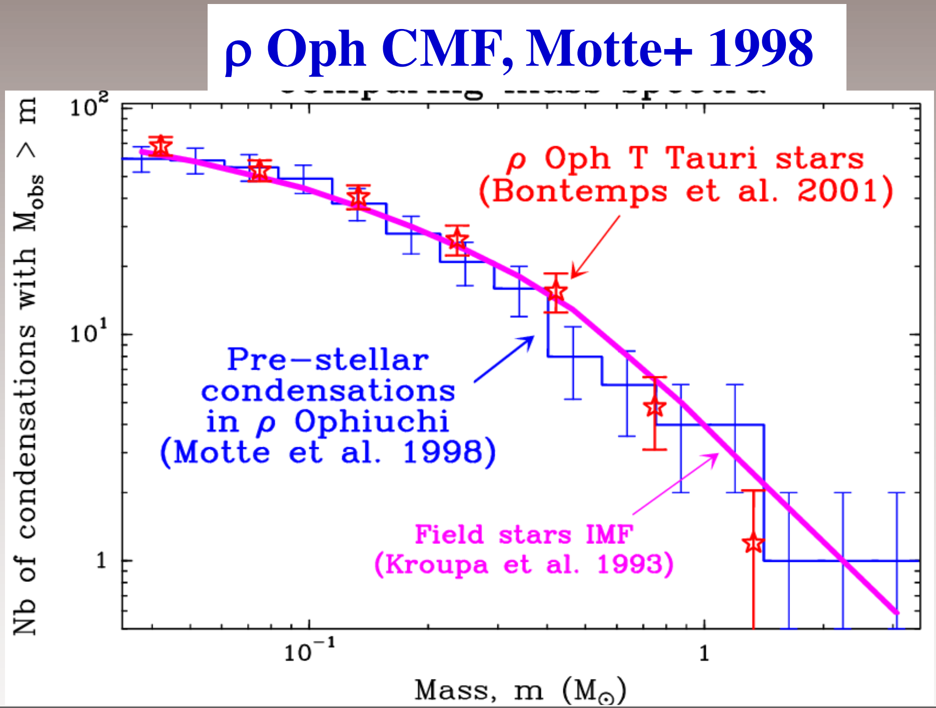


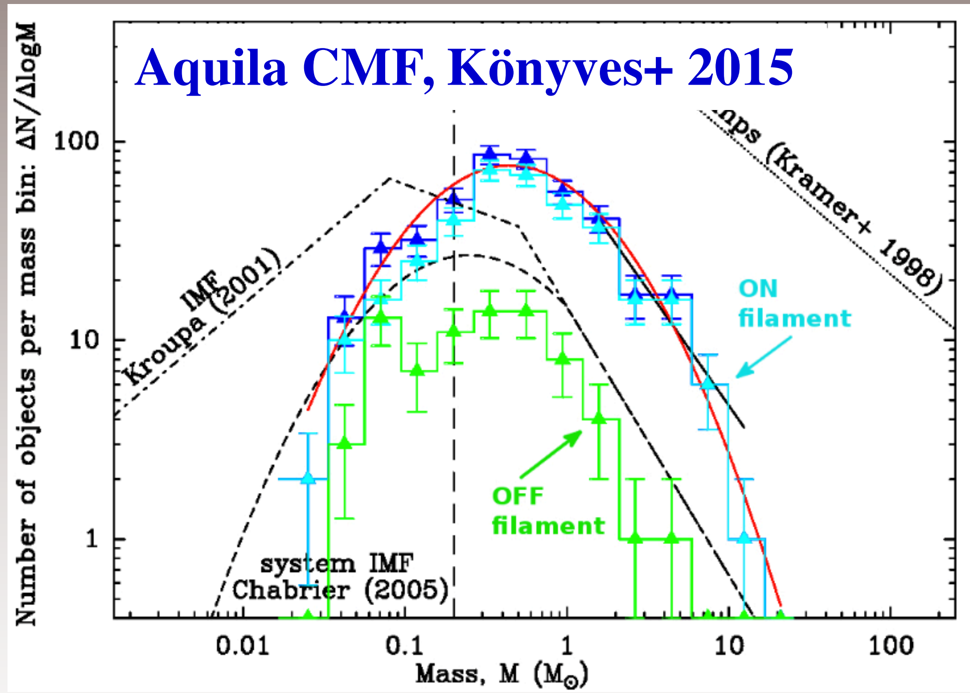
Cloud, filaments, cores, and stars simultaneously grow in mass.

→ The mass reservoir to form a star varies in size and mass with time!

Initial results on the origin of stellar masses: one-to-one relationship CMF vs IMF

Submm ground-based, *Herschel*, and NIR extinction surveys of the past 2 decades (Motte+ 1998, 2001; Testi & Sargent 1998; Johnstone+ 2000; Stanke+ 2006; Alves+ 2007; Nutter & Ward-Thompson 2007; Enoch+ 2008; André+ 2010; Könyves+ 2015, …).





The IMF is at least partly determined by fragmentation at the pre-stellar stage

BUT: studies limited to <5 $M_\odot$ stars…

in regions not typical of the main mode of star formation in galaxies

Core Mass Function within the W43-MM1 ridge

The 1.6-100 $M_{\odot}$ part of the CMF is much flatter than usually found.
=> It would suggest an atypical IMF for stars of 1-50 $M_{\odot}$ (ε=50%).

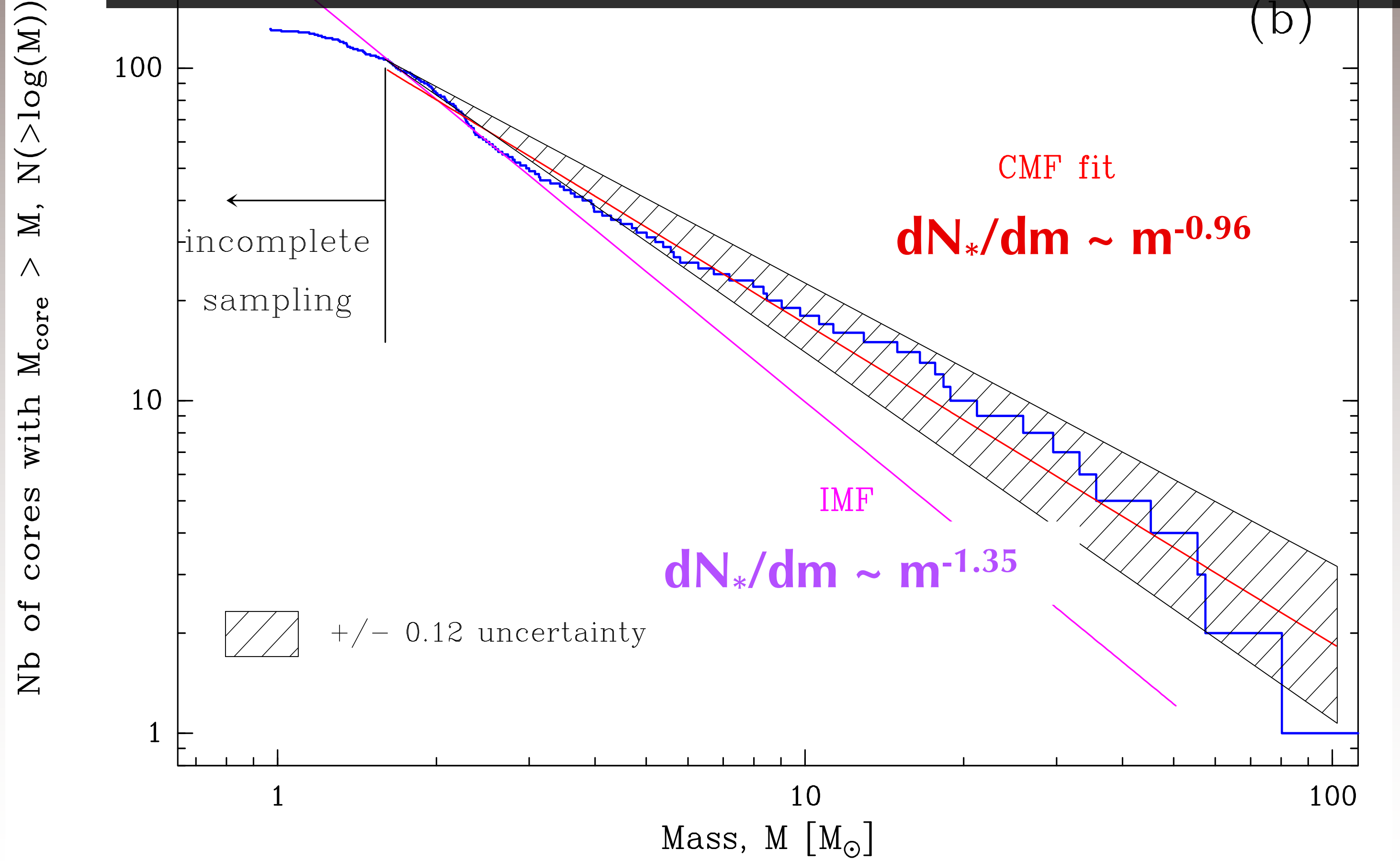
Or CMF evolution

Or complex CMF/IMF relation

But why would the "conspiracy" not apply for low-mass cores in W43-MM1?

See also Zhang+2015; Sanchez-Monge+2017; Cheng+2018; …

(Motte, Nony, Louvet et al. 2018, Nature Astronomy.)



Core Mass Function within the W43-MM1 ridge

The 1.6-100 $M_\odot$ part of the CMF is much flatter than usually found.
=> It would suggest an atypical IMF for stars of 1-50 $M_\odot$ (ε=50%).

(Motte, Nony, Louvet et al. 2018, Nature Astronomy.)

Or CMF evolution:

- Continuous mass growth of cores

$\Rightarrow$ flatter

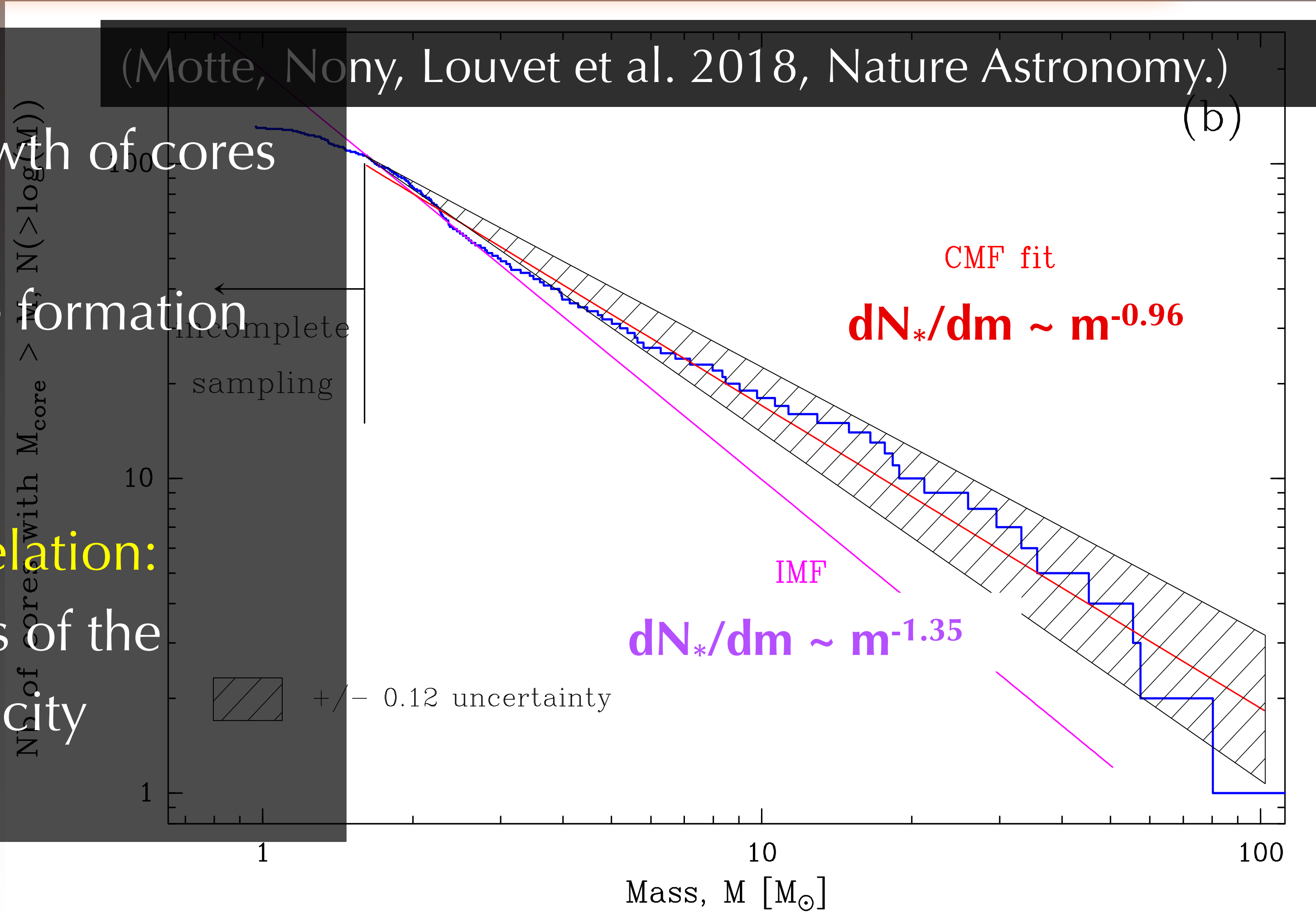
- New episodes of core formation

$\Rightarrow$ maybe steeper

Or complex CMF/IMF relation:

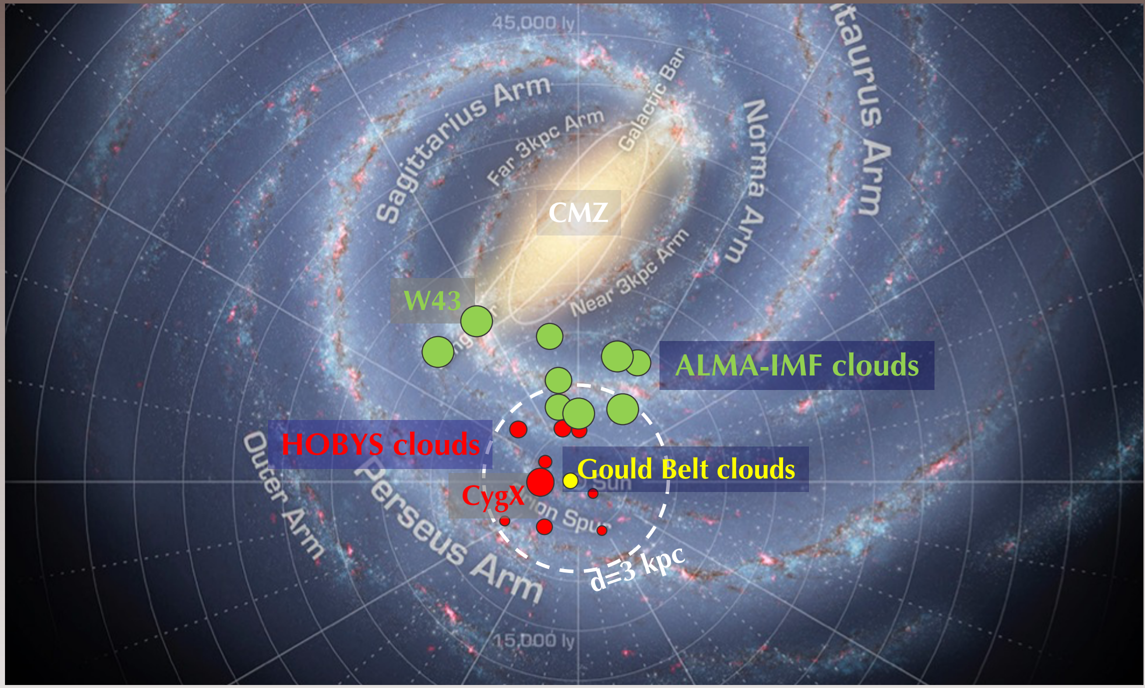
Variation with core mass of the

- Core and star multiplicity
- Core lifetime, …



ALMA-IMF LP (PI: Motte, Louvet, Ginsburg, Sanuheza)

Cycle 5: 64h (12M) + 300h (ACA)



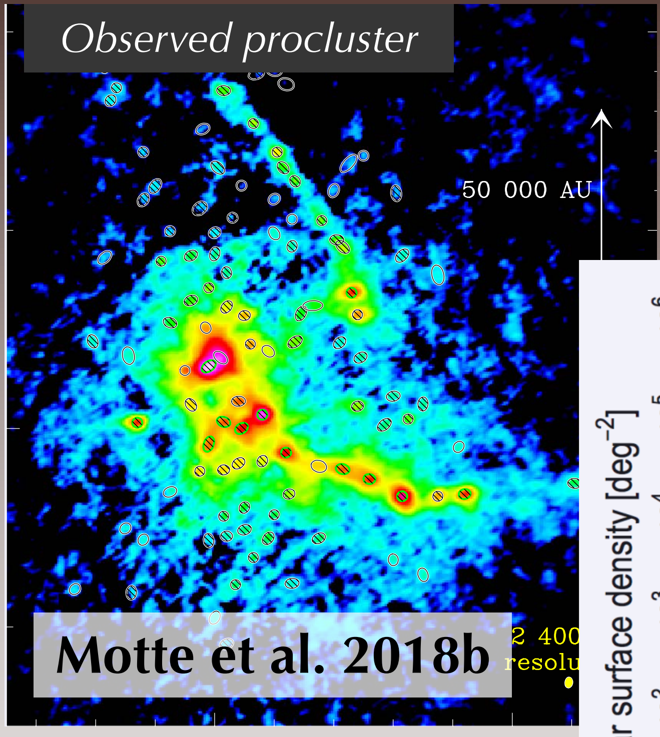
Targets:

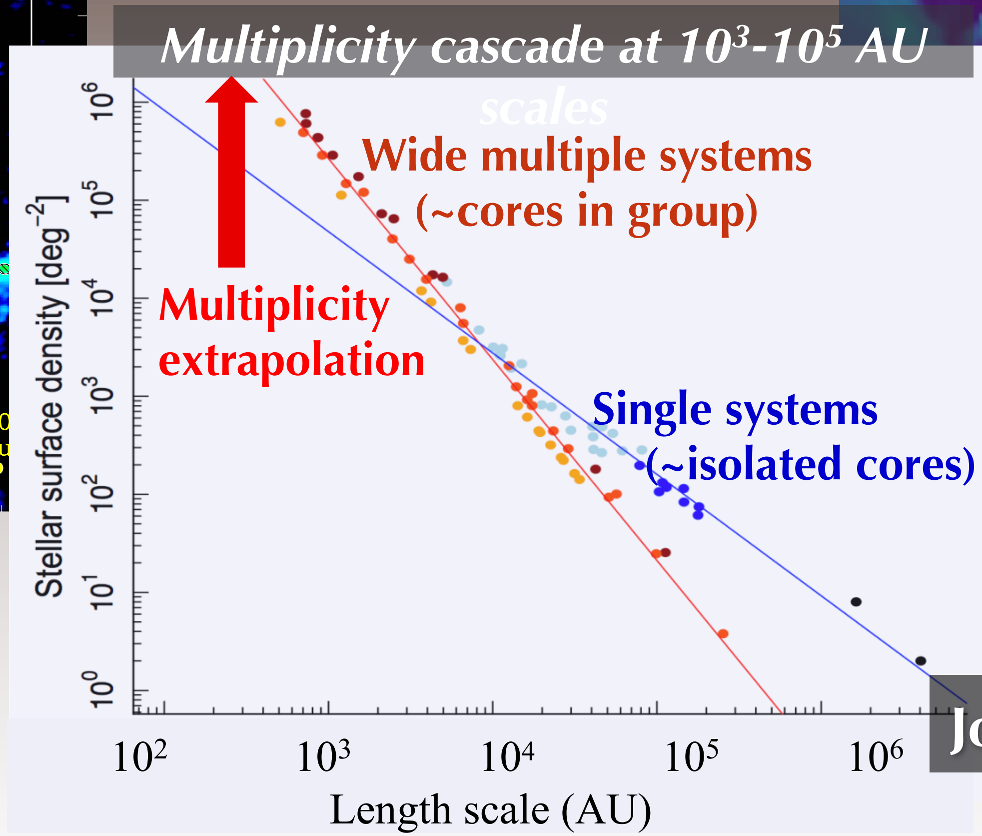
- A complete sample of massive clouds at <6 kpc
- More representative of Milky Way star-forming clouds
- At various evolutionary state

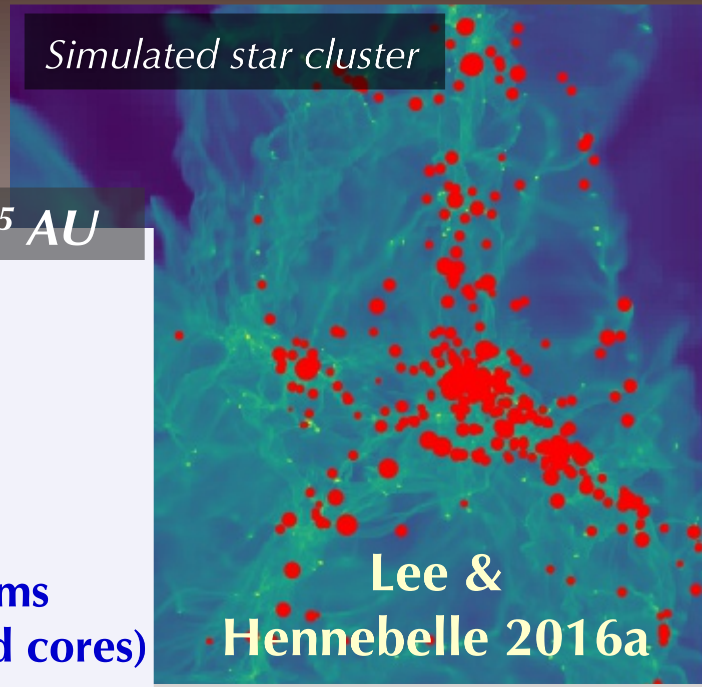
Future plans: A NOEMA-IMF LP focusing on HOBYS clouds

- Origin of stellar masses and their distribution (IMF)
- Gas mass inflow from cloud to core scales
- Scenario for the formation of high-mass stars
- Chemical enrichment of the gas through cloud and star formation

Multiplicity cascade in protoclusters



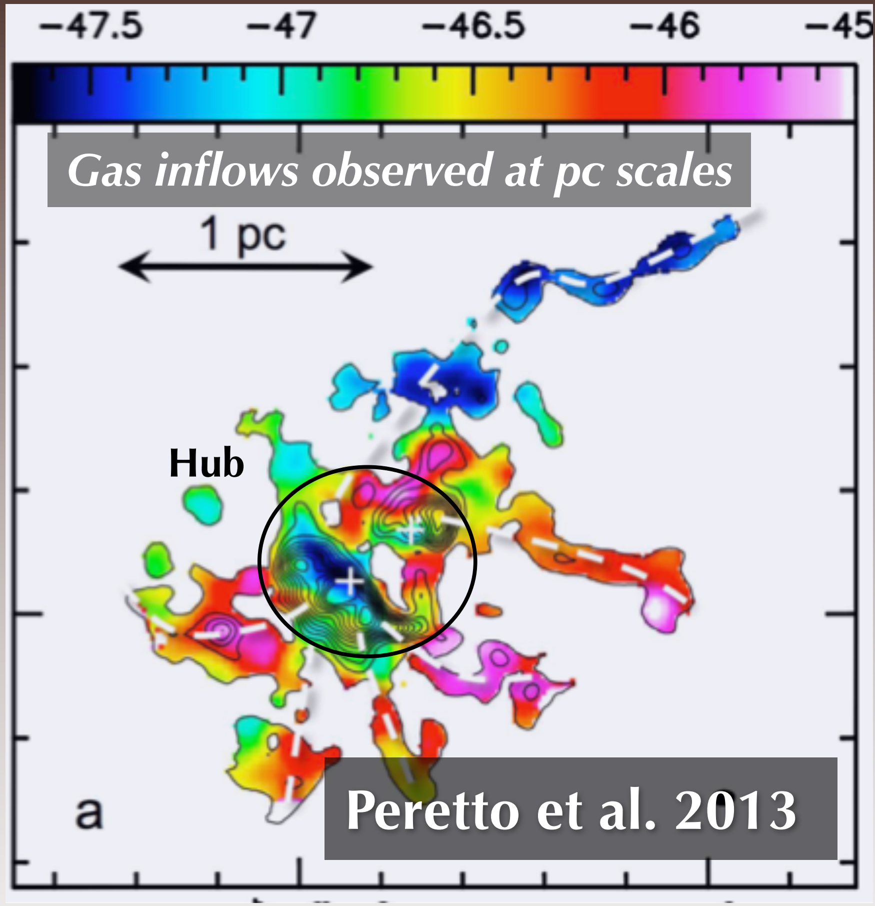


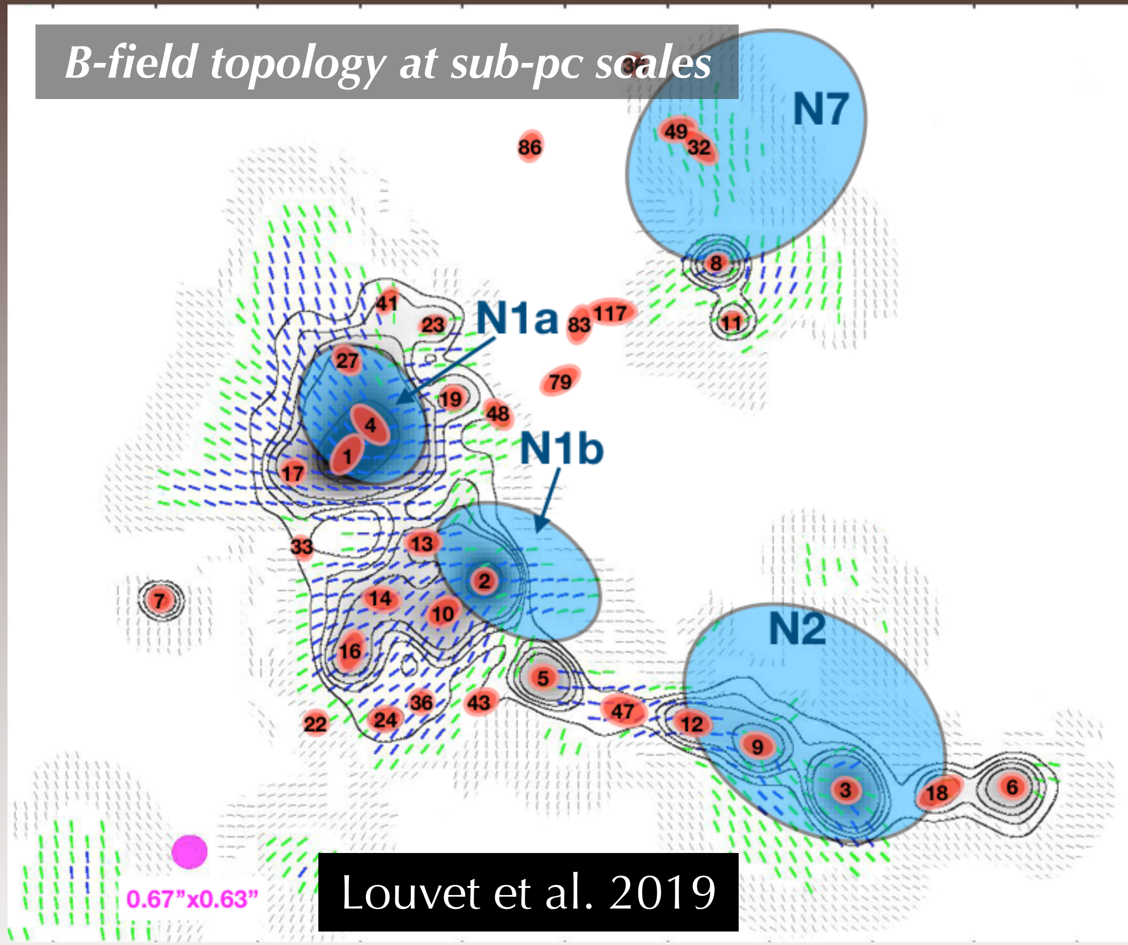


→ NOEMA + 30m large-scale mapping

Impact on the CMF/IMF relation,
on the initial conditions for stellar multiples and disk formation.

Kinematics, B-fields and their coupling





→ NOEMA large-scale mapping (gas flows and shocks)

→ NIKA-Pol + ALMA-Pol + NOEMA-Pol(?)

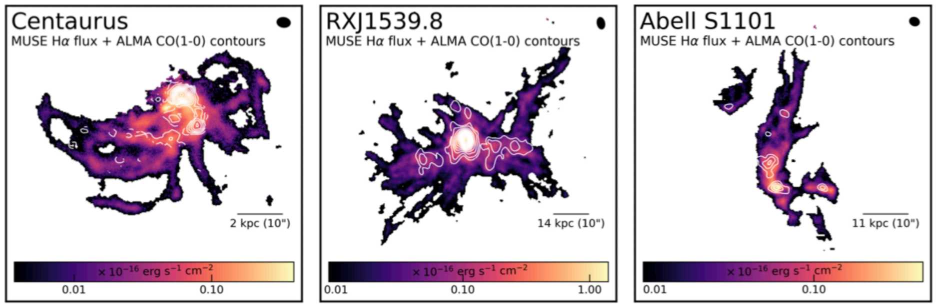
Gas inflow and magnetic fields are largely unknown in high-density medium

Philippe Salomé

Molecular gas in Brightest Cluster Galaxies

Molecular gas in Brightest Cluster Galaxies (BCGs)

- In Cool Core Clusters : X-ray ICM gas cooling onto the BCG
- Regulated by some mechanism (possibly radio AGN-feedback)
- **Molecular gas detected in large quantities**
- Reservoir to feed the BH / SF
- **Very extended molecular filaments**



ANR LYRICS (ALMA + Muse) —> Origin and States of the molecular Filaments

Salomé, Guillard, Dubois, Godard, Combes, Lehnert, Pineau des Forêts, Boulanger + Polles, Beckmann, Olivares

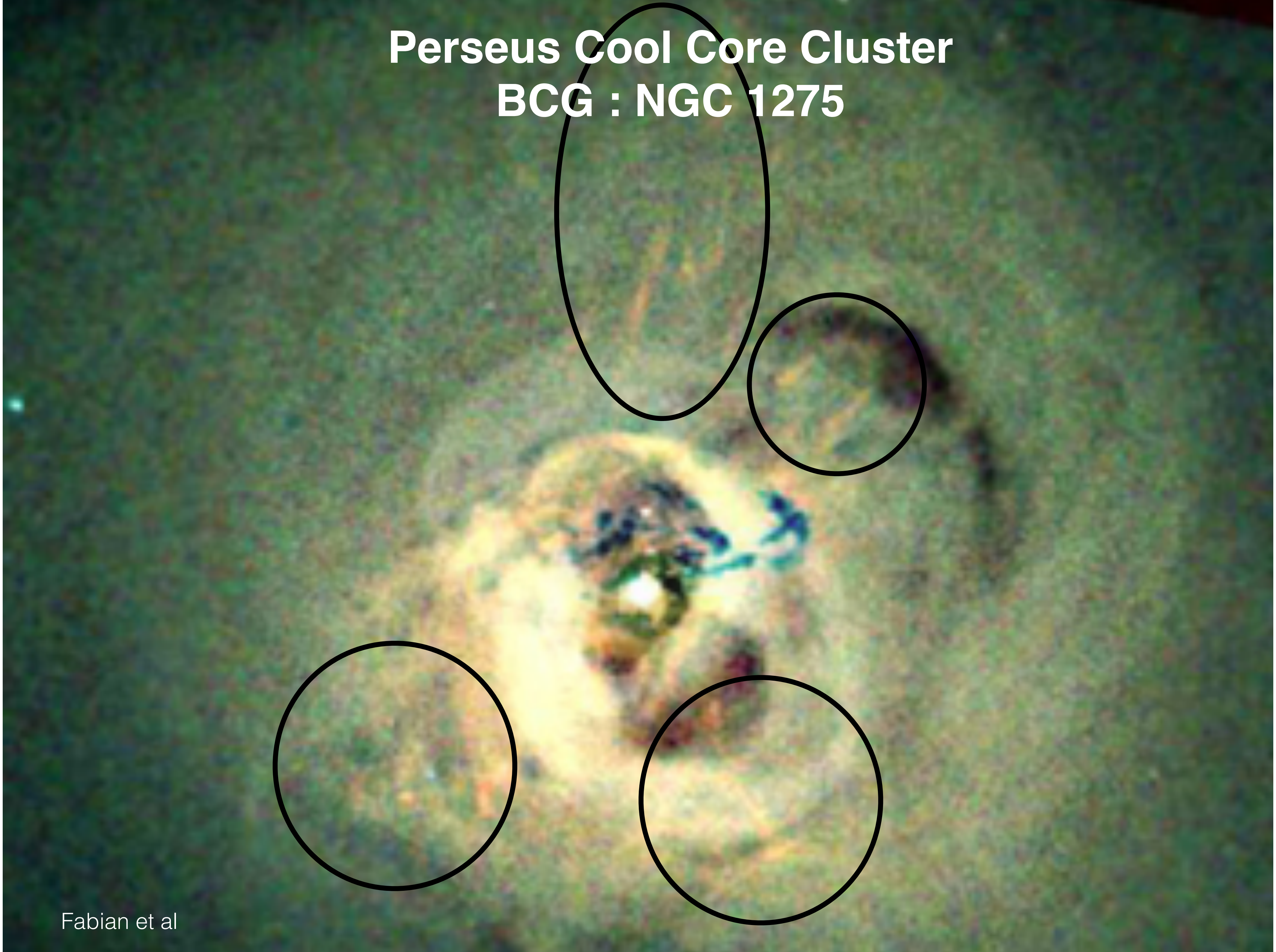
- **IRAM 30m-telescope** + JCMT : First CO detections (Edge 2001, Salomé et Combes 2003, Pulido et al., 2018) —> 20-30 galaxies
- **IRAM PdB** + OVRO : First mapping (Edge et al., 2003, Salomé et al., 2004, 2008)
- **IRAM 30m telescope + IRAM PdB : Discovery of the filaments in NGC 1275 (Salomé et al., 2006, 2011) : 30 kpc-long in CO**
- **Herschel** : First detection of atomic line + dust
- **Spitzer : First detection of H2 in some regions of the filaments of NGC 1275**
- **ALMA** mapping a dozen of sources in the Southern Hemisphere. Filaments are ubiquitous (a dozen of publications, Olivares et al., 2018 in prep).
- **Modelling** with CLOUDY (Ferland et al., 2008, 2012; Canning et al., 2017, Polles et al., 2018, in prep)

Deep study of NGC 1275 : the most nearby Cool Core Cluster (76 Mpc)

Barely resolved filaments - detected (30m, IRAM-PdB, SMA) in CO(1-0) and CO(2-1)

- **Resolve the filamentary sheets inside well detected filaments (compare to HST imaging)**
- **Spot 2-3 different kind of filaments (BPT properties : SF / Shocks) cf. JWST proposal (H2)**

Perseus Cool Core Cluster
BCG : NGC 1275



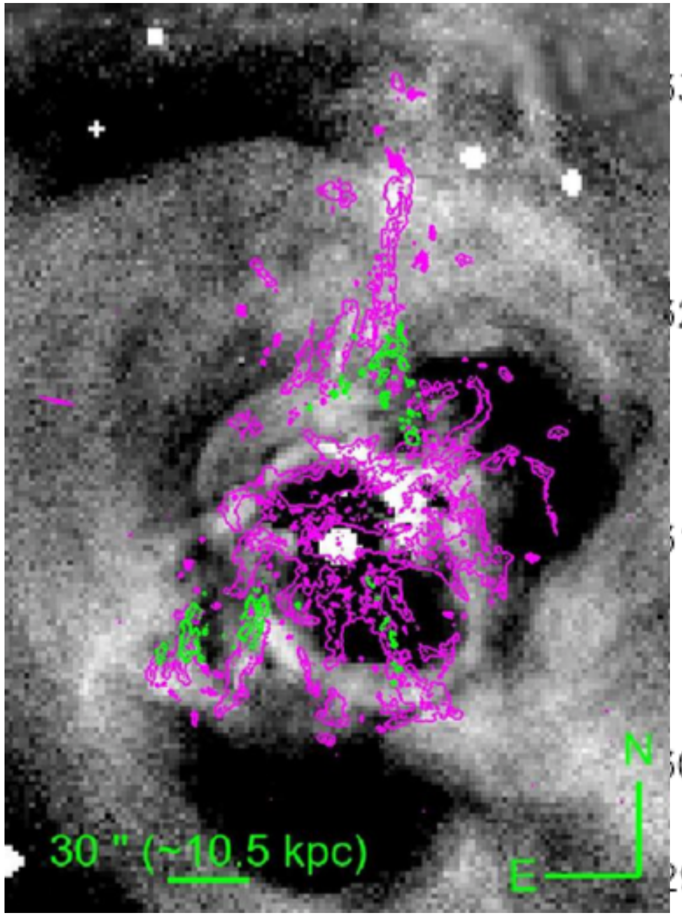
Fabian et al


Hα+[NII]
Conselice et al. (2001)
Fabian et al

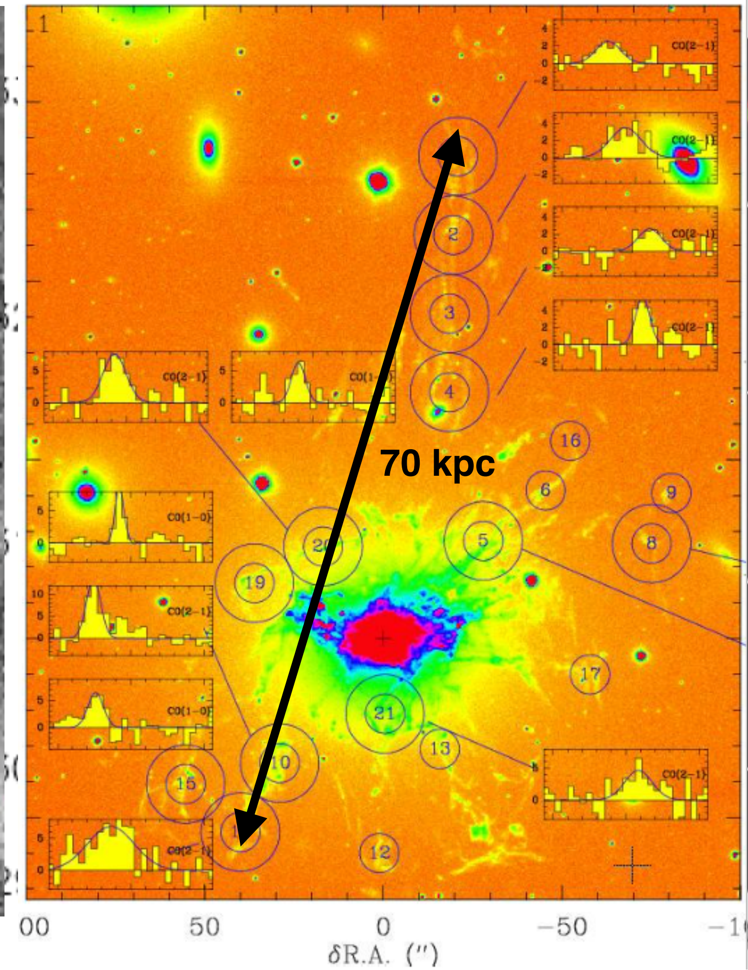
Deep study of NGC 1275 : the most nearby Cool Core Cluster (76 Mpc)

Unresolved filaments - detected (30m, IRAM-PdB, SMA) in CO(2-1) and barely in CO(3-2)

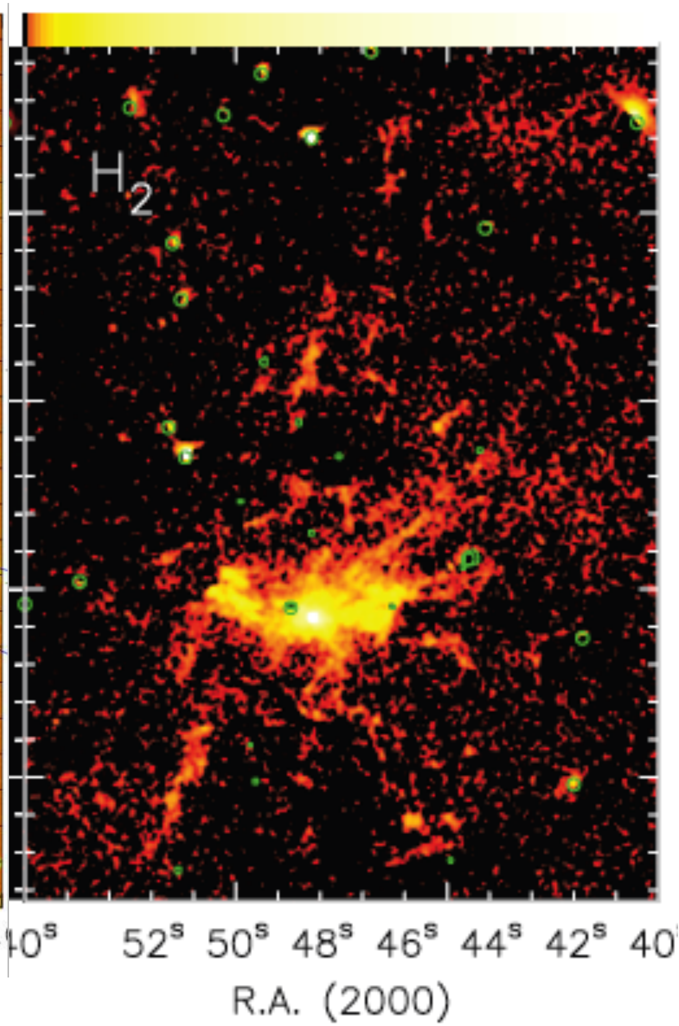
- Resolve the filamentary sheets inside well detected filaments (compare to HST imaging)
- Spot 2-3 different kind of filaments (BPT properties : SF / Shocks) cf. JWST proposal (H2)



Chandra X-ray surface brightness image from (**Fabian et al. 2011b**) overlaid with contours of Hα emission (magenta; **Conselice et al. 2001**) and young star-forming regions (from HST, **Canning et al., 2014**).



Molecular gas CO(1-0) and CO(2-1) from the **IRAM 30m-telescope** (**Salomé et al., 2012**)

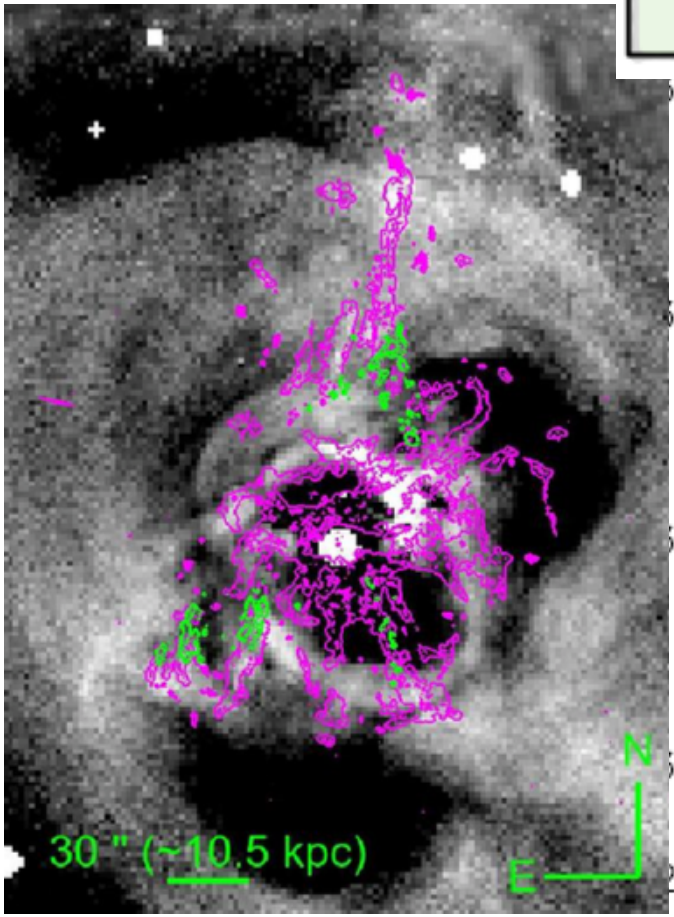


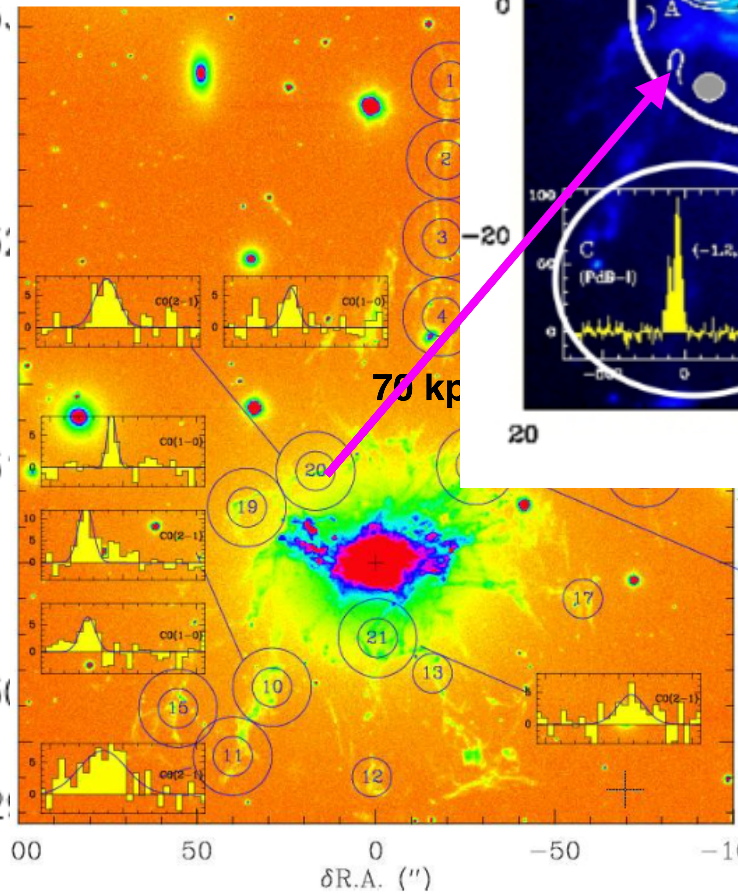
Warm H2 **(Lim et al., 20012)** @ 2.12um from CHFT

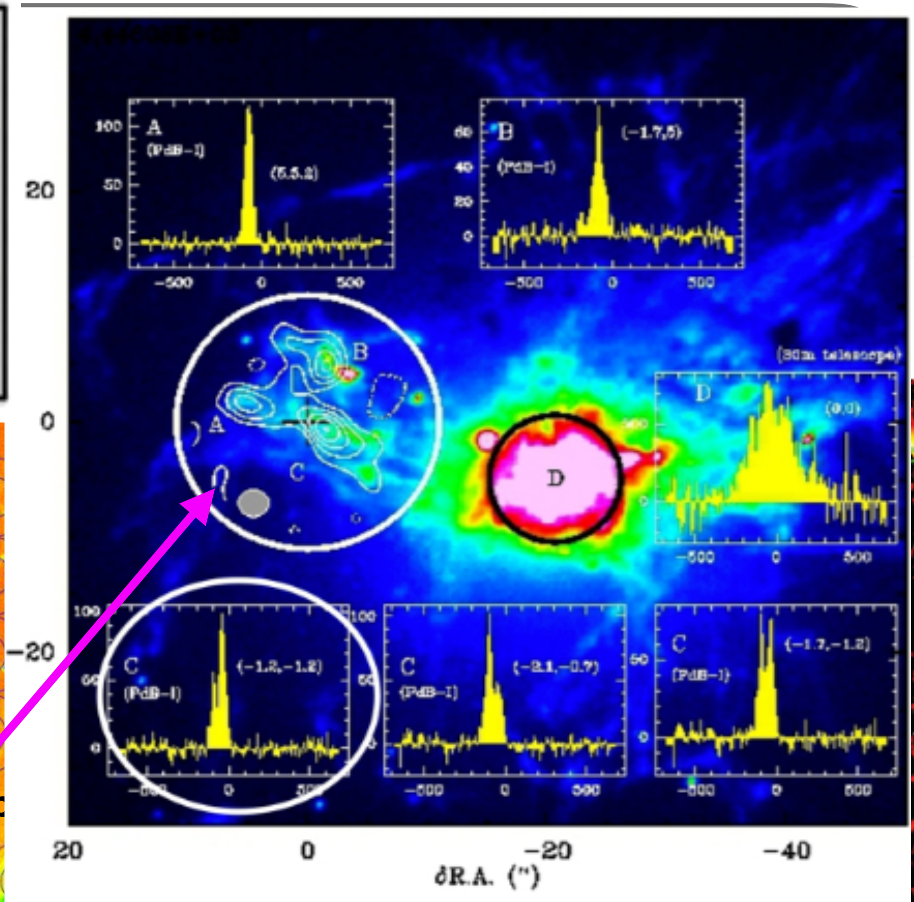
Unresolved filaments - dete

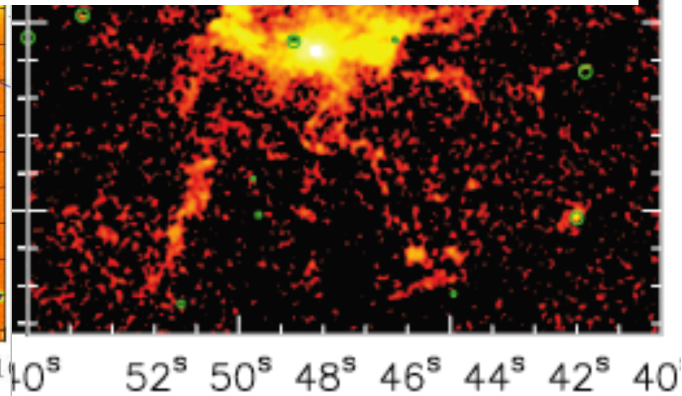
- Resolve the filamentary sh
- Spot 2-3 different kind of f

- Resolution ~2.5 ''
- 7 clumps (d ~ 900 pc, dV~ 30km/s, Mass ~ 3-9 x 10^7 Msol)
- Not Resolved : made of 10 GMCs (d ~ 30 pc, Mass ~ 10^6 Msol ,@ 20-40 K)









Need spatial resolution (sub-arcsec) ie < 350 pc (A,B-config)

Need sensitivity (weak signal of ~5-10 mJy/beam)

Need spectral resolution (linewidth ~ 30-50 km/s) : Dv~ 5km/s

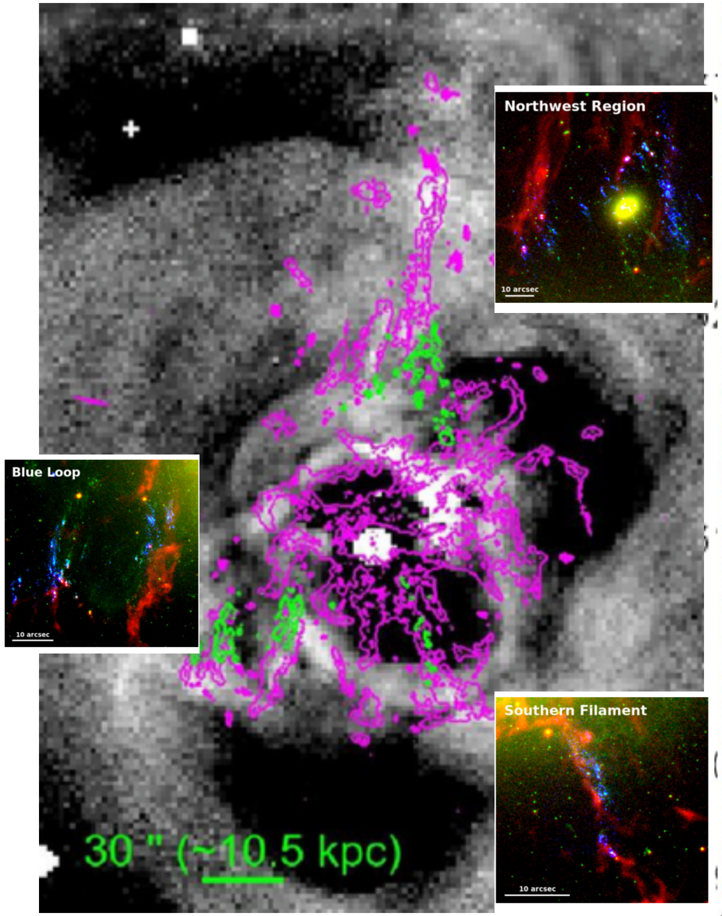
Challenging !

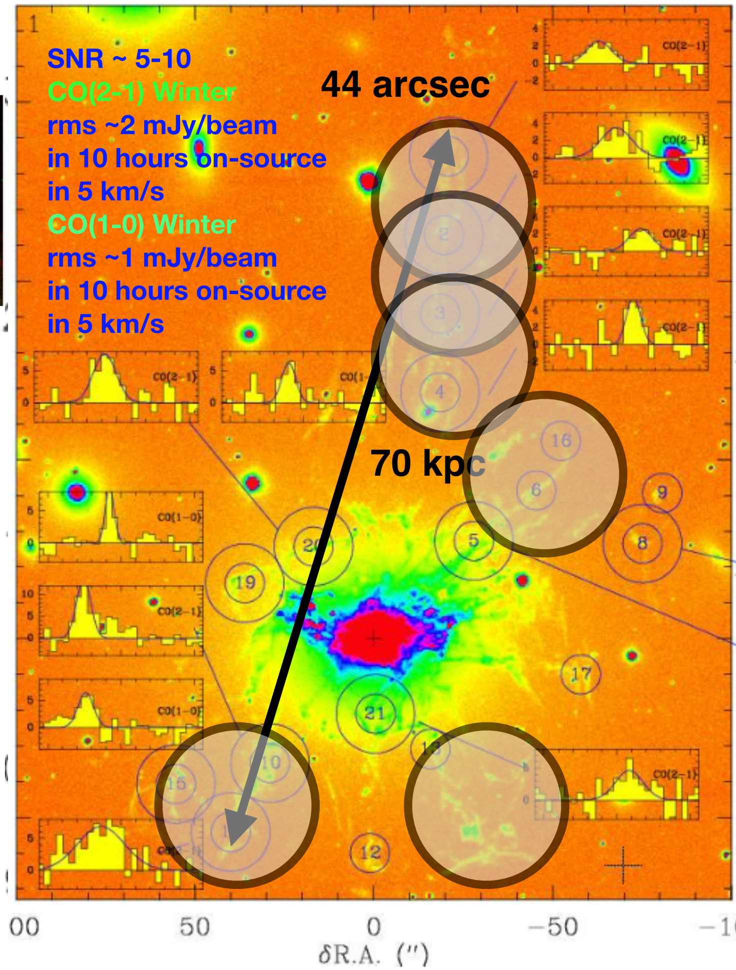
DEC=41 —> not for ALMA

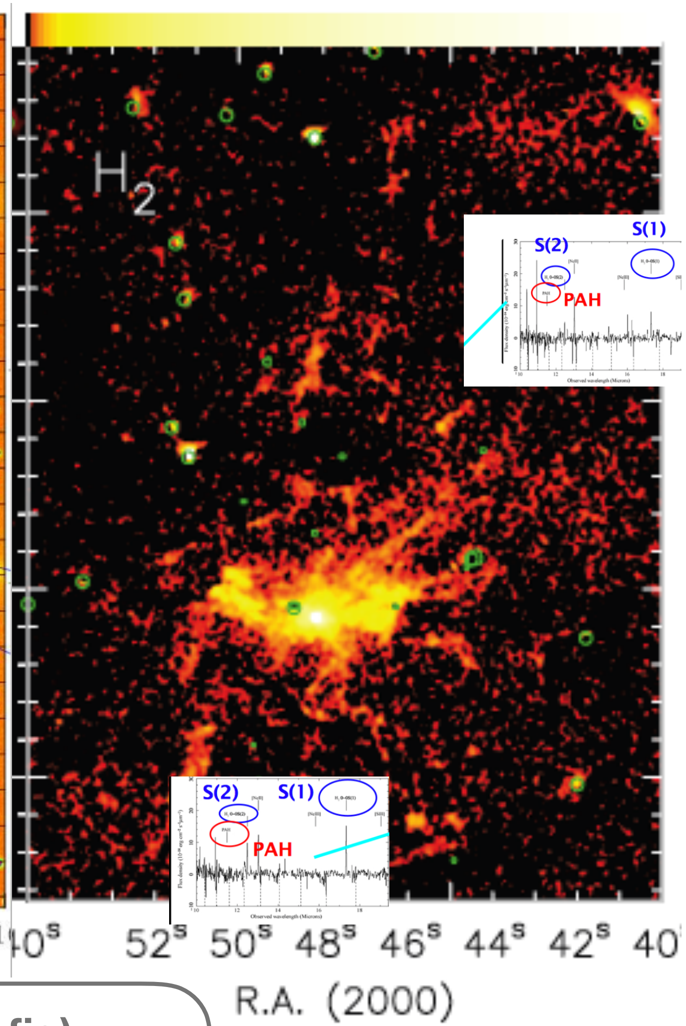
Deep study of NGC 1275 : the most nearby Cool Core Cluster (76 Mpc)

Unresolved filaments - detected (30m, IRAM-PdB, SMA) in CO(2-1) and barely in CO(3-2)

- Resolve the filamentary sheets inside well detected filaments (compare to HST imaging)
- Spot 2-3 different kind of filaments (BPT properties : SF / Shocks) cf. JWST proposal (H2)







Need spatial resolution (arcsec or sub-arcsec) ie < 350 pc (A,B-config)

Need sensitivity (weak : 5-10 mJy/beam) —> well suited for winter if CO(2-1)

Need spectral resolution (linewidth ~ 30-50 km/s) : Dv~ 5km/s

Challenging !

DEC=41 —> not for ALMA

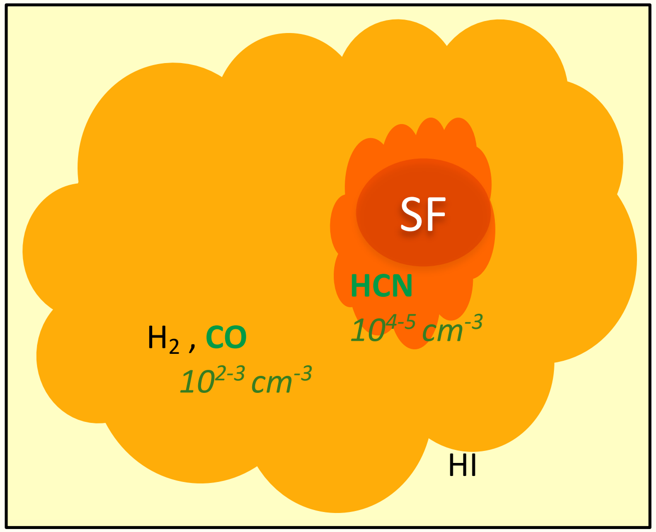
Diane Cormier

Dense Gas and Star Formation Across Nearby Galaxy Disks: The EMPIRE Survey

Dense Gas and Star Formation Across Nearby Galaxy Disks: The EMPIRE Survey

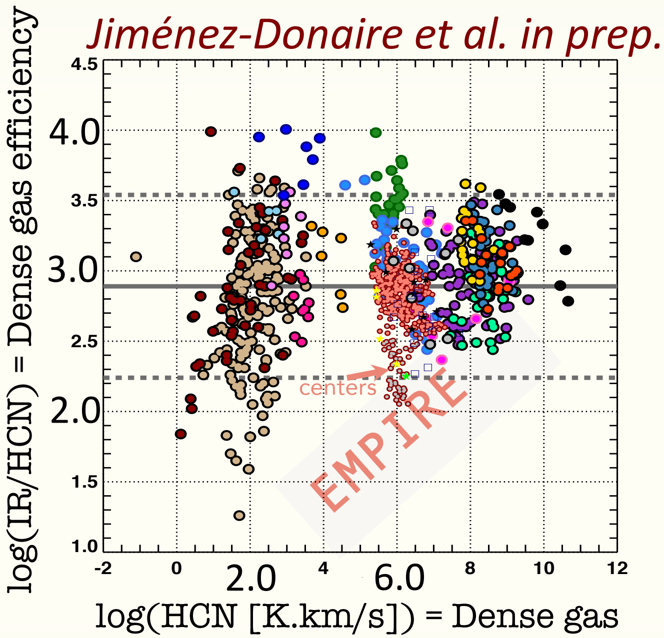
What is the role of density in SF?

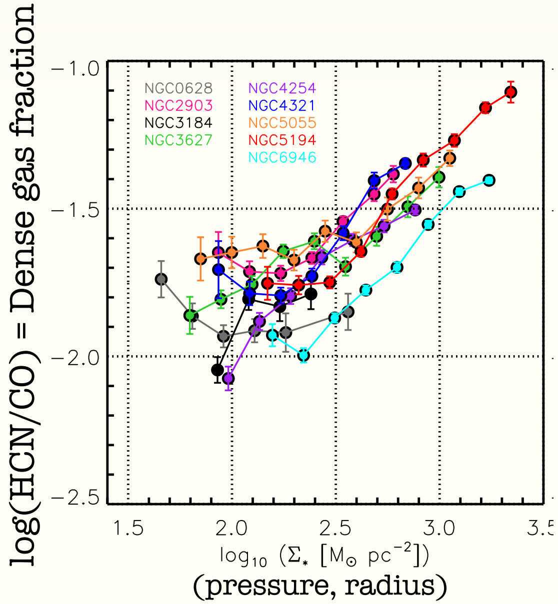
How to best trace density in galaxies?



e.g. Lada+2010, Evans+2014

IRAM-30m Large Program 2015-2017
(600h, PI Bigiel)
Full maps of 9 disk galaxies, 1.5kpc resolution

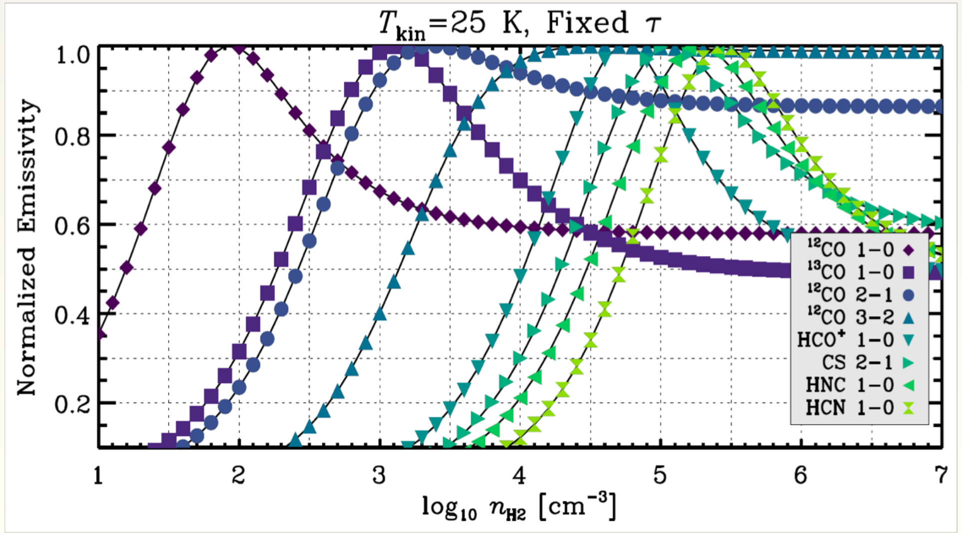




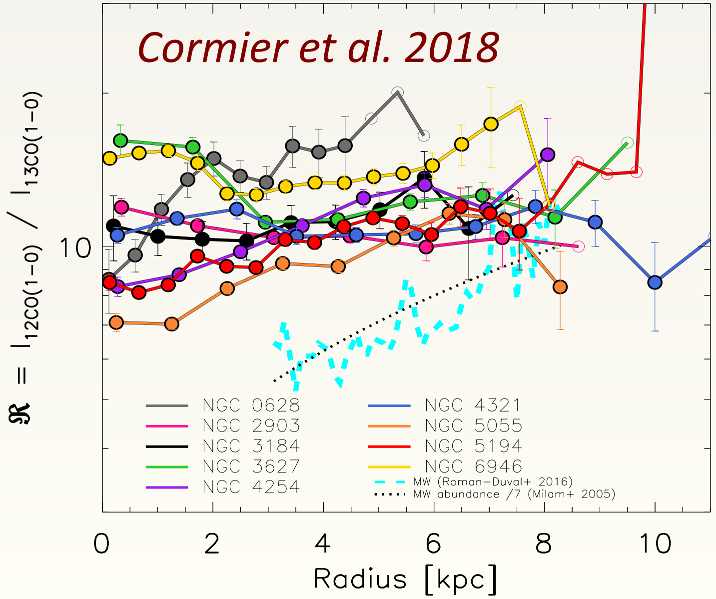
The fraction of dense gas and its ability to form stars seem to depend on environment

Diane Cormier (*Marie-Curie Fellow, AIM/CEA Saclay*), María-Jesús Jiménez-Donaire (*CfA Harvard*), Frank Bigiel, Johannes Puschnig, Dimitris Dchatzigiannakis, Ivana Beslic (*U. Bonn*), Adam Leroy, Molly Gallagher (*Ohio State*), Antonio Usero (*OAN Madrid*) and the EMPIRE collaboration (incl. Jerome Pety, Annie Hughes)

Leroy et al. 2017a, Puschnig et al. in prep.



A full suite of spectroscopic tracers to map density distributions

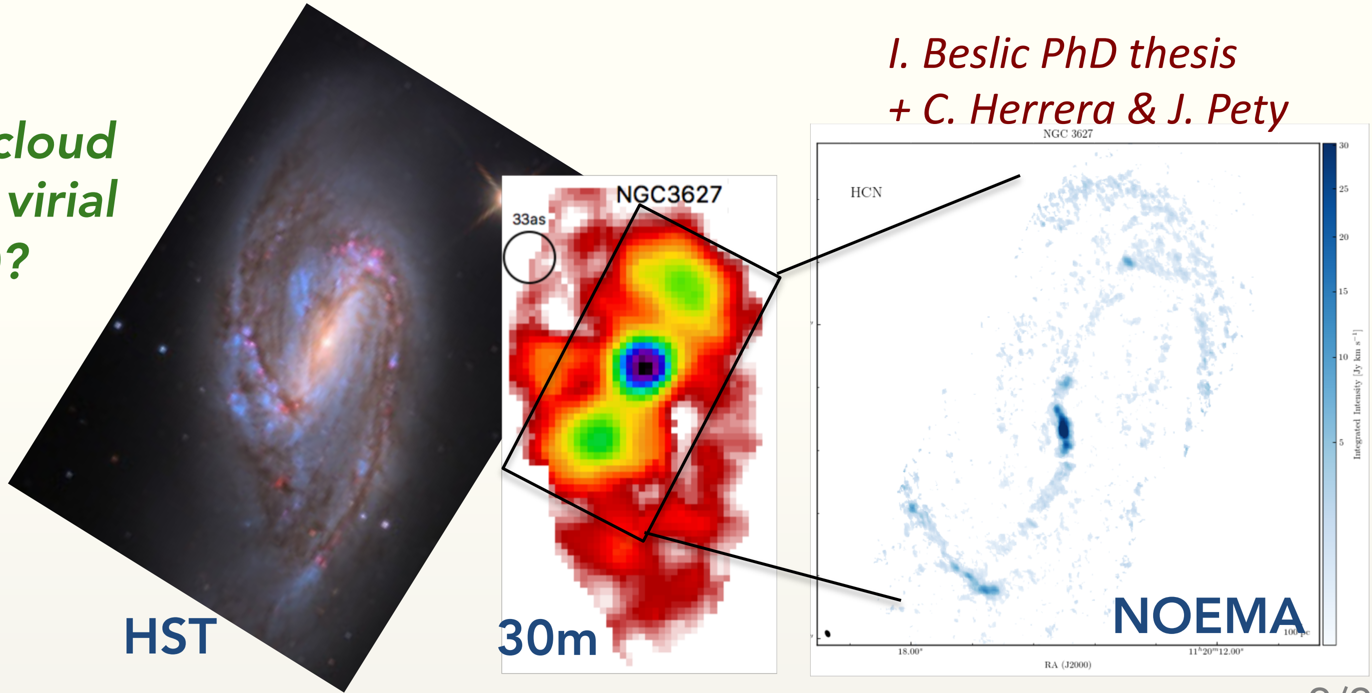


Variations in opacity, abundances, beam filling factor, excitation

How to relate large-scale density/emission to local cloud properties (mean density, virial parameter, Mach number)?

NOEMA NGC3627: 24h
1.5″ = 75pc resolution
rms 50mK per 12.5km/s

I. Beslic PhD thesis
+ C. Herrera & J. Pety



Katharina Lutz

mm-cm excess in local galaxies

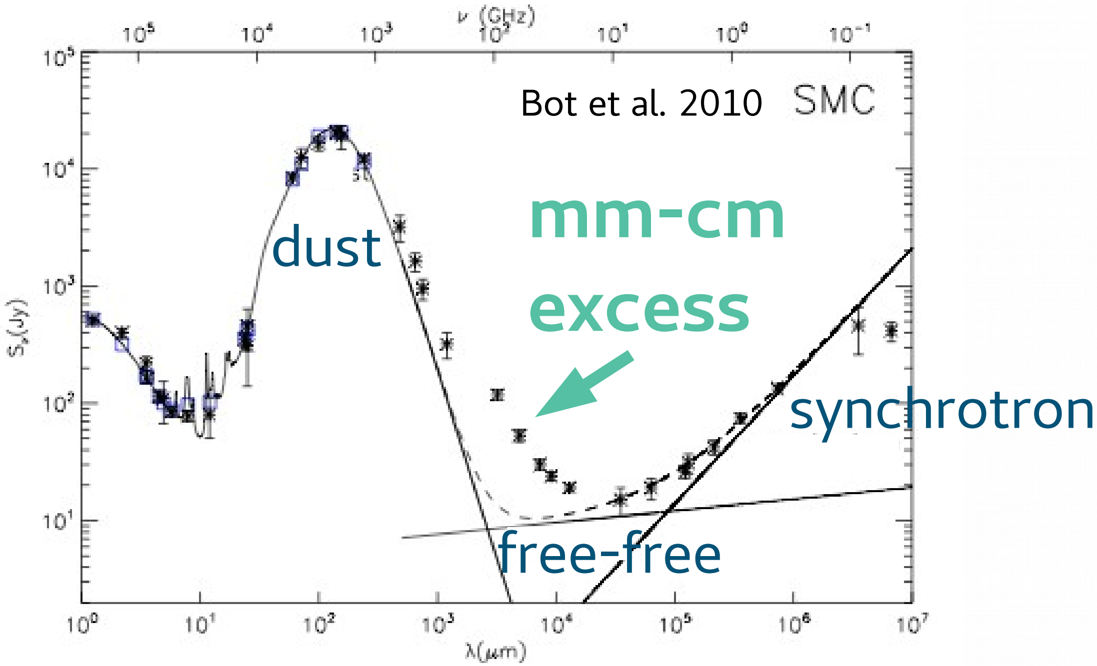
mm – cm excess in local galaxies

Katharina Lutz
&
Caroline Bot

CDS / CNRS / Observatoire Astronomique de Strasbourg

Observatoire astronomique de Strasbourg | ObAS

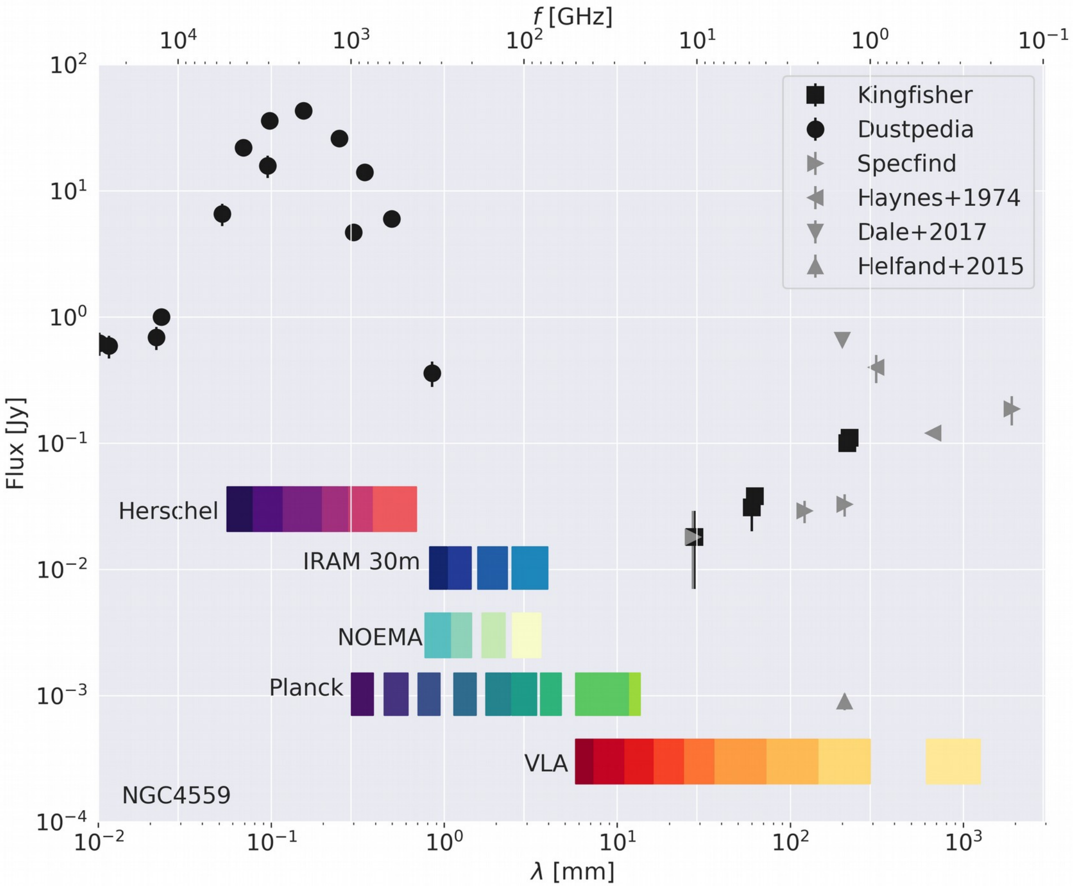
Background



- SMC (Bot et al. 2010, Israel et al. 2010, Planck Collaboration 2011), LMC (Bot et al. 2010, Israel et al. 2010, Planck Collaboration 2011), M31 (Planck Collaboration 2015), M33 (Hermelo et al. 2016, Tibbs et al. 2018):
  - Some have mm-cm excess
  - **All need to sit on a CMB hotspot**

Recently
- New dust models
- Form of synchrotron emission
- Planck calibration

Idea



- Remeasure excess in a consistent way
- Increase sample size
- Improve resolution (5’ < Planck < 32’)
- Collaboration with researchers interested in molecular line emission?

Pierre Dell Ova

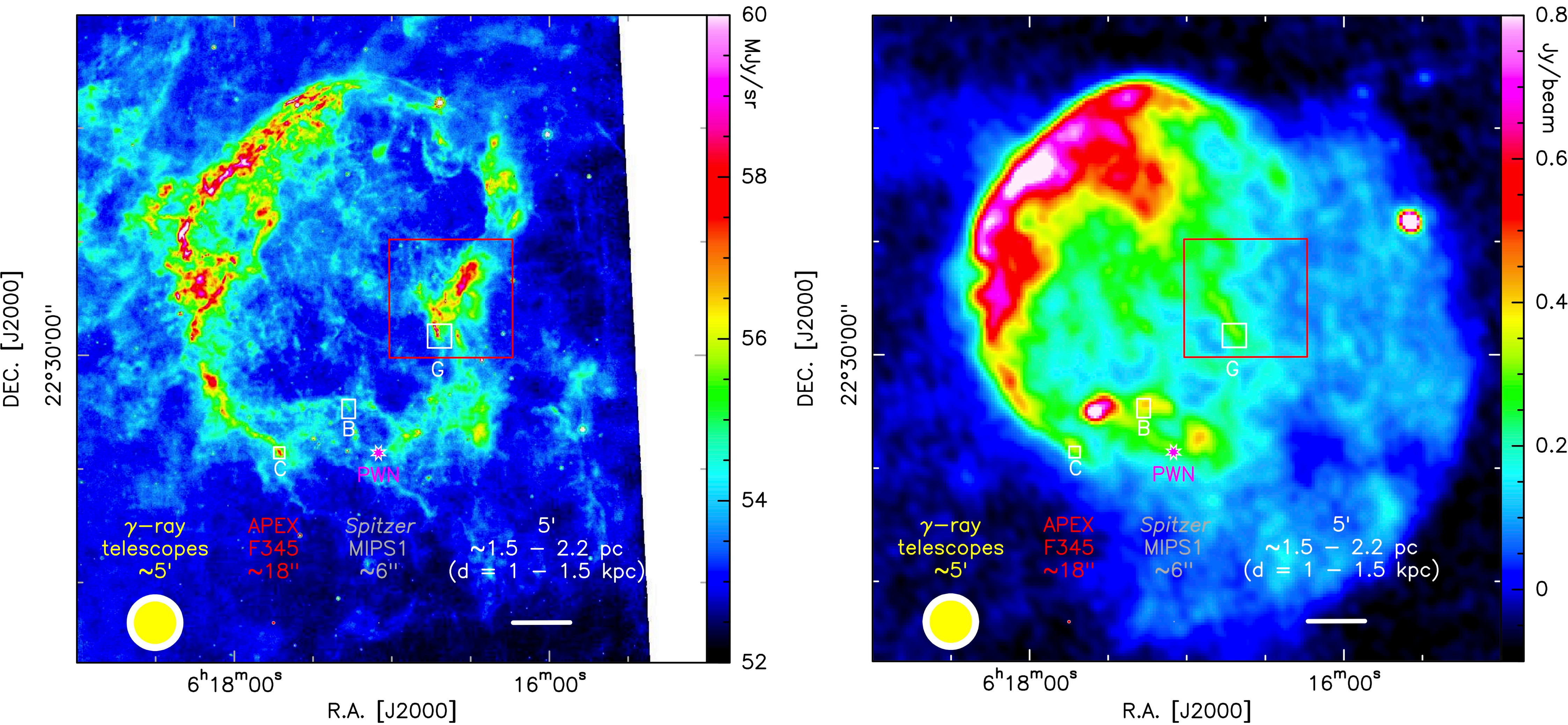
The molecular clouds interacting with cosmic rays in IC443G

The molecular clouds interacting with cosmic rays in IC443G

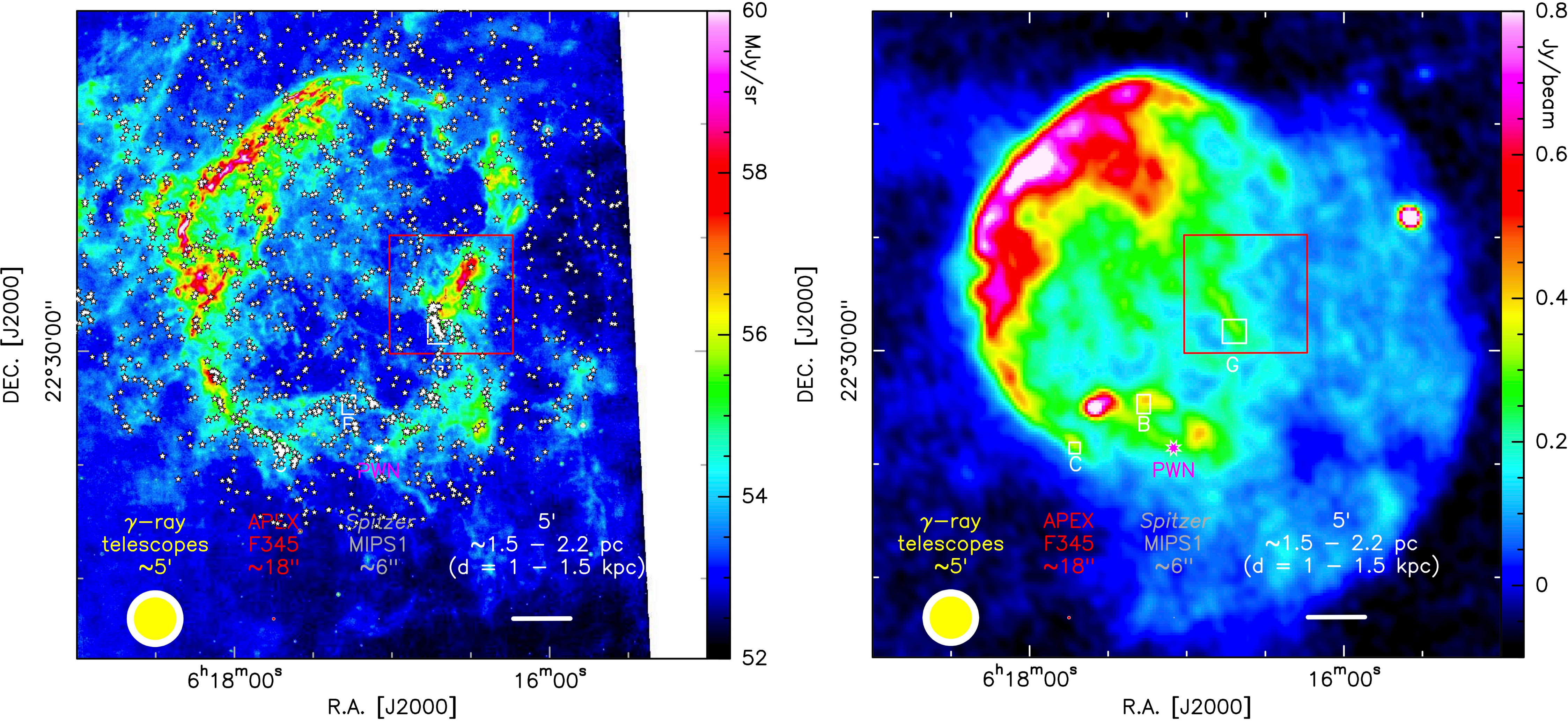
Pierre Dell'Ova[1,2], Antoine Gusdorf[1,2] & Maryvonne Gerin[2]

[1]LPENS, École Normale Supérieure

[2]LERMA, Observatoire de Paris



60
58
56
54
52
MJy/sr
DEC. [J2000]
22°30'00"
R.A. [J2000]
6h18m00s
16m00s
G
B
C
PWN
γ−ray
telescopes
~5'
APEX
F345
~18"
Spitzer
MIPS1
~6"
5'
~1.5 − 2.2 pc
(d = 1 − 1.5 kpc)
0.8
0.6
0.4
0.2
0
Jy/beam



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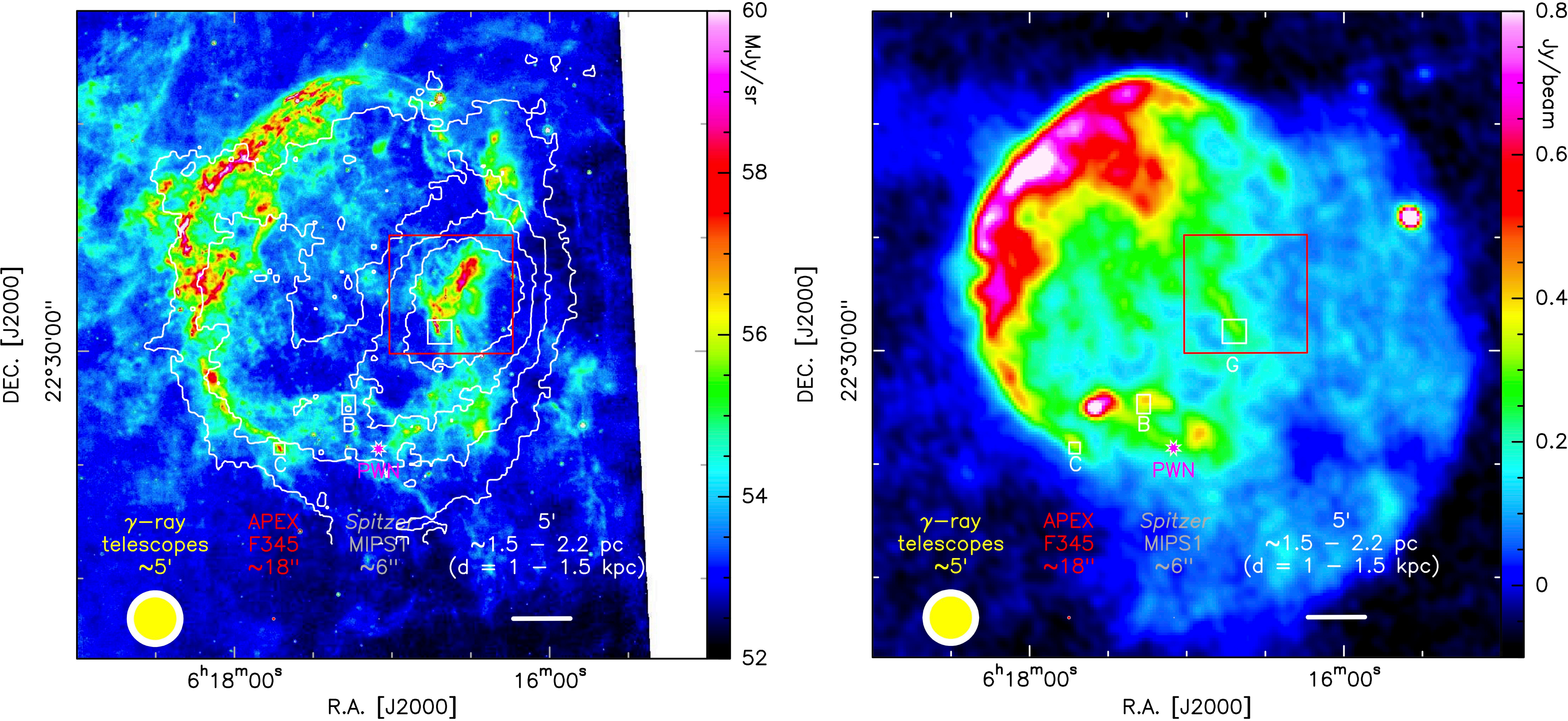
G
B
C



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DEC. [J2000]
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5'
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B
C
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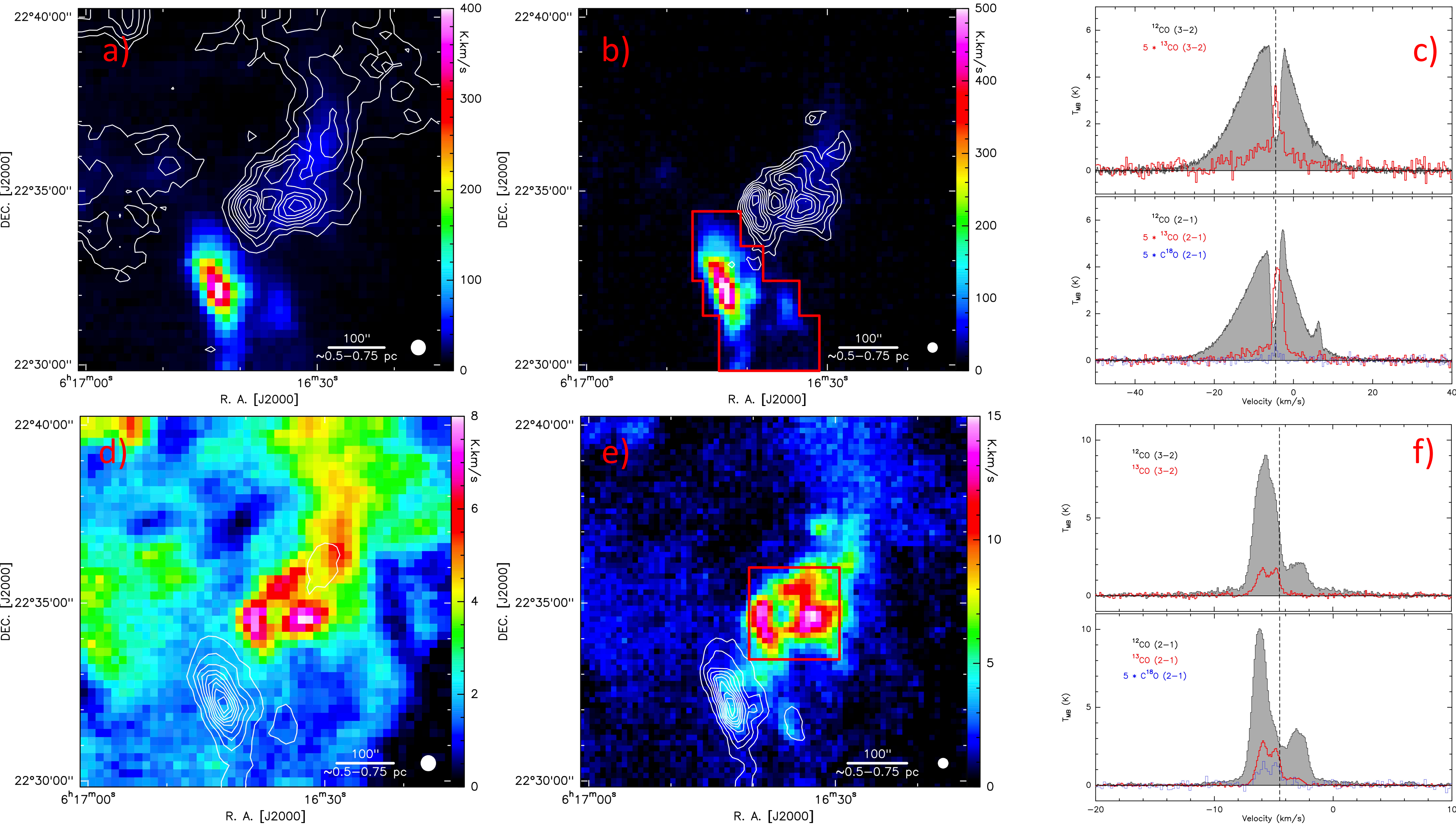
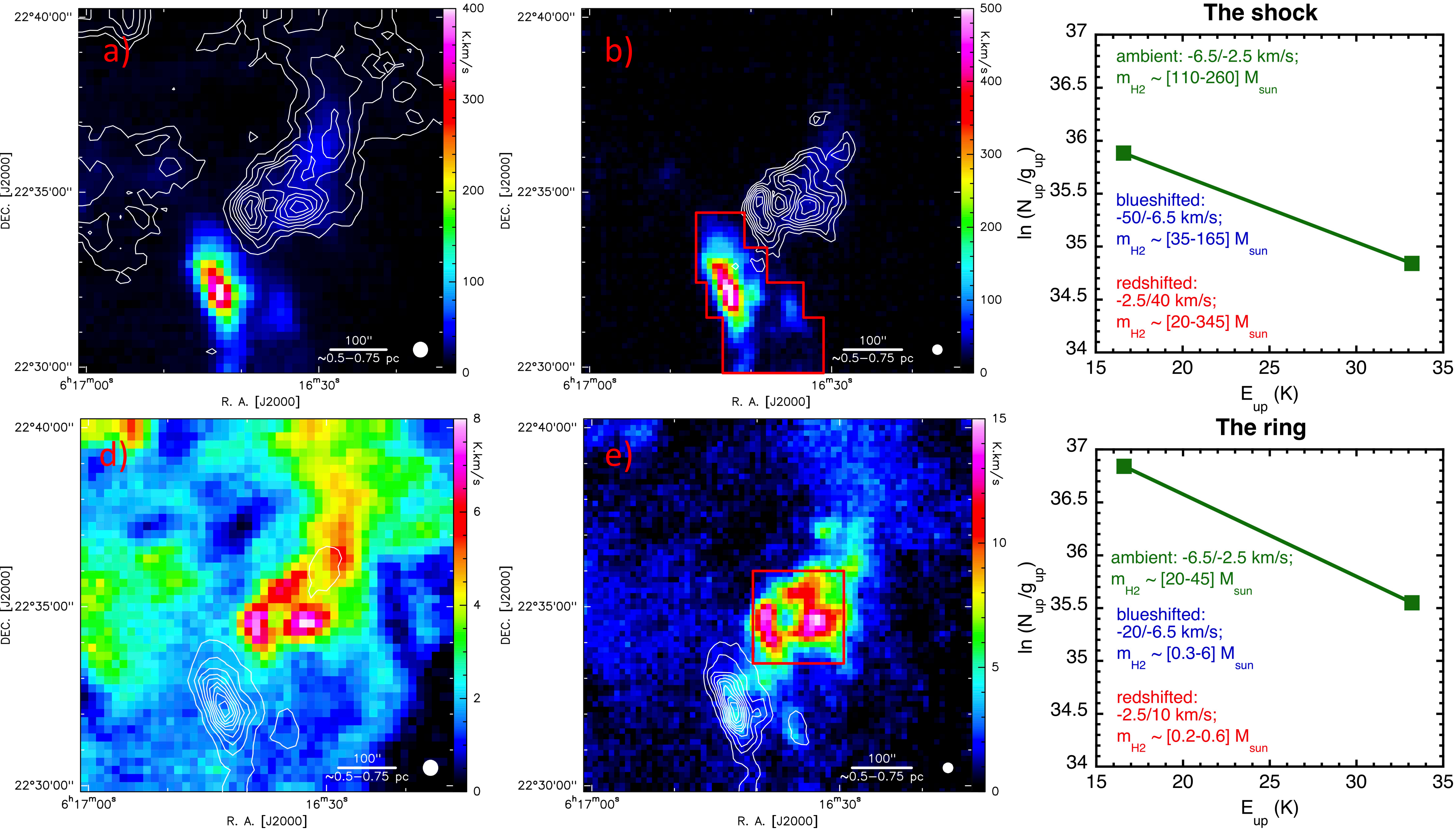
PWN
0.8
0.6
0.4
0.2
0
Jy/beam


a)
b)
c)
d)
e)
f)
K.km/s
100"
~0.5–0.75 pc
DEC. [J2000]
R. A. [J2000]
22°40'00"
22°35'00"
22°30'00"
6h17m00s
16m30s
^{12}CO (3–2)
5 * ^{13}CO (3–2)
^{12}CO (2–1)
5 * ^{13}CO (2–1)
5 * C^{18}O (2–1)
^{13}CO (3–2)
^{13}CO (2–1)
T_{MB} (K)
Velocity (km/s)



a)
b)
d)
e)
The shock
The ring
ambient: -6.5/-2.5 km/s;
m H2 ~ [110-260] M sun
blueshifted:
-50/-6.5 km/s;
m H2 ~ [35-165] M sun
redshifted:
-2.5/40 km/s;
m H2 ~ [20-345] M sun
ambient: -6.5/-2.5 km/s;
m H2 ~ [20-45] M sun
blueshifted:
-20/-6.5 km/s;
m H2 ~ [0.3-6] M sun
redshifted:
-2.5/10 km/s;
m H2 ~ [0.2-0.6] M sun
ln (N up /g up)
E up (K)
K.km/s
100''
~0.5–0.75 pc
DEC. [J2000]
R. A. [J2000]

Julien Montillaud & Isabelle Ristorcelli

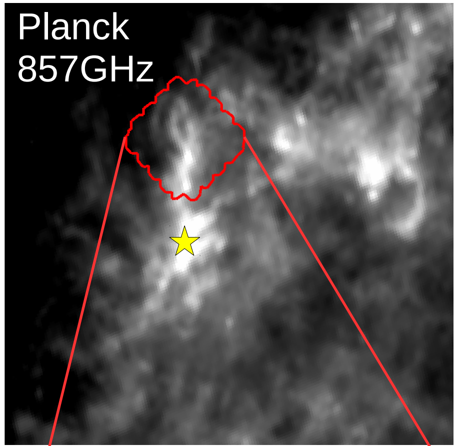
Galactic cold cores IRAM follow-up: colliding filaments in Monoceros

Galactic cold cores IRAM follow-up : colliding filaments in Monoceros OB1

Montillaud et al. 2019, submitted

- Turbulent or gravitational fragmentation ?
- Star-formation feedback ?

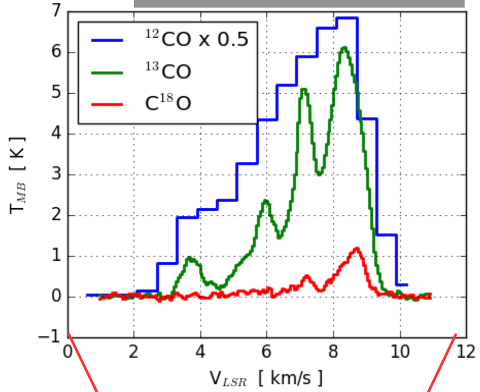
► multiscale study



Mon OB1 molecular complex:
L ~ 40 pc
M ~ 10000 Msun

☆ Open cluster NGC2264
> 1000 stars
> 5 Myr old
O7 ionising star
→ expanding HII bubble

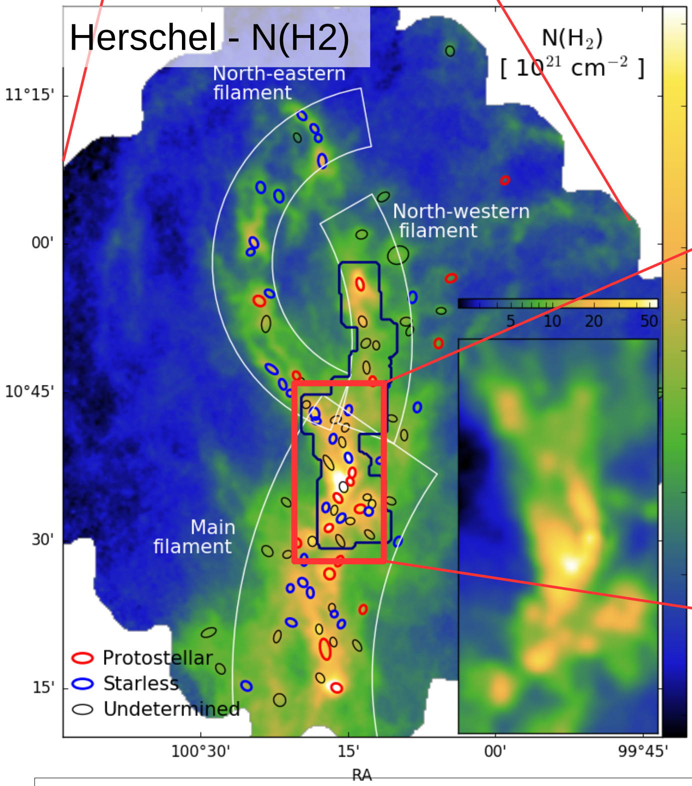
IRAM CO isot.



S1446 core:
L ~ 0.1 pc
M ~ 20 Msun

Gravitationally unstable

Protostellar Class 0/I



IRAS 27 clump:
L ~ 1 pc
M ~ 200 Msun

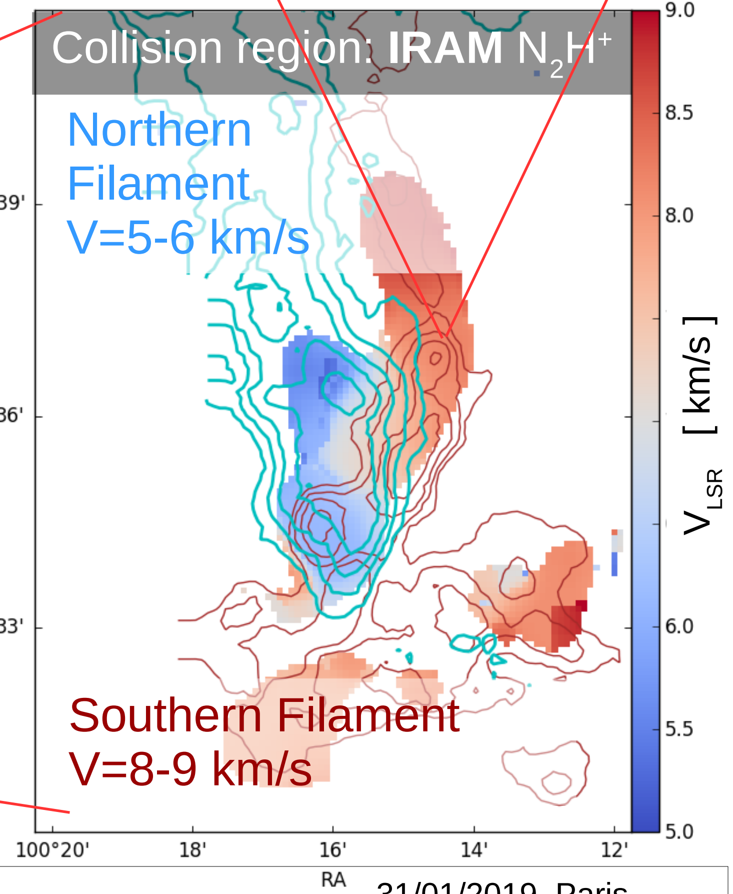
nH ~ 1e5 cm-3
5+ cores

Velocity gradient from 5 to 9 km/s

Collision between 2 filaments

G202+2.8 filaments:
L ~ 10 pc
M ~ 1000 Msun
Branched structure

A few clumps
~100 cores

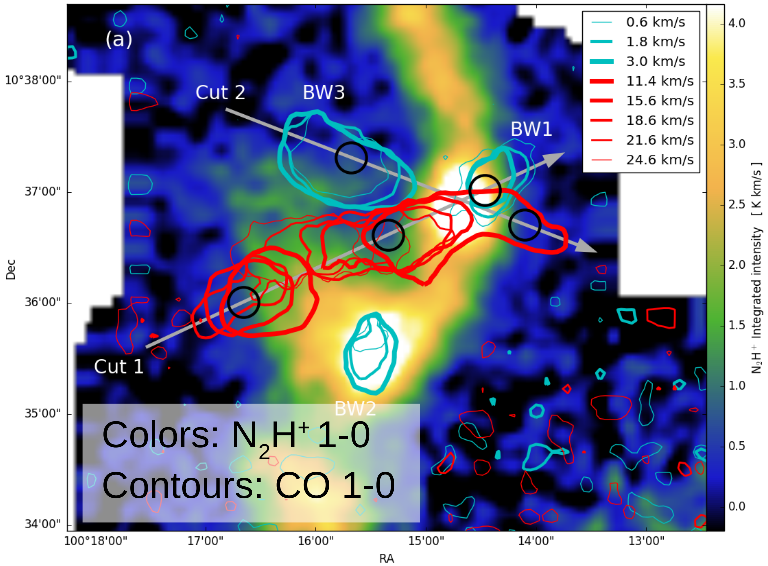


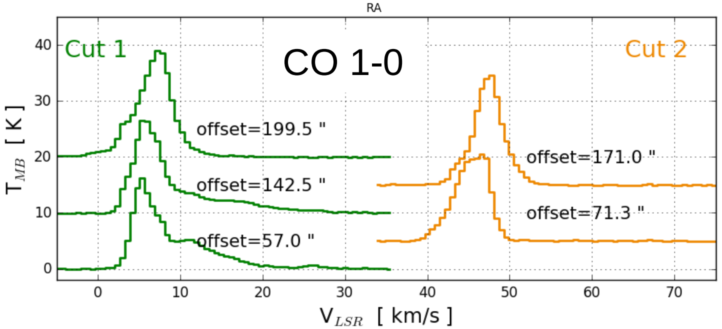
Galactic cold cores IRAM follow-up : colliding filaments in Monoceros OB1

Montillaud et al. 2019, submitted

IRAM $^{12}CO + N_2H^+$; dv=0.6 km/s

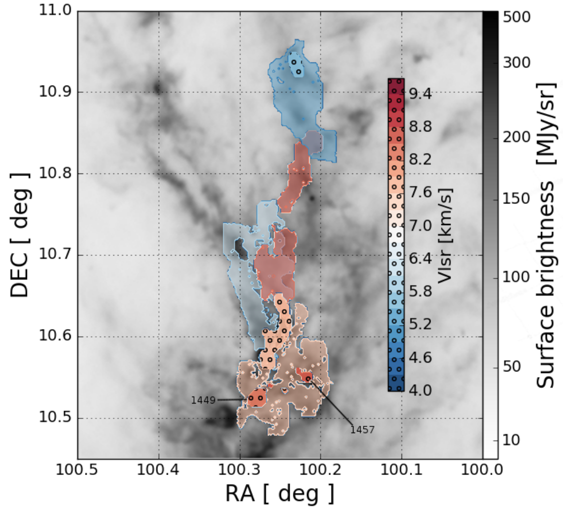
^{12}CO line wings :
Candidate **double outflow** from s1446

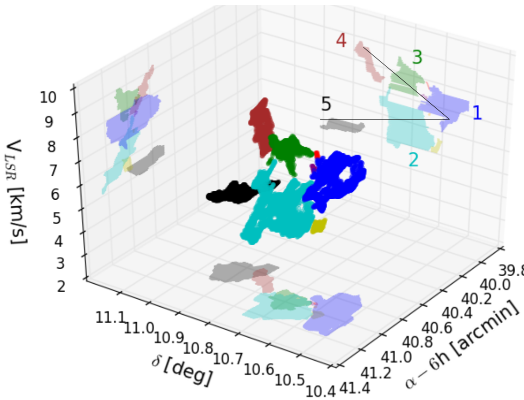


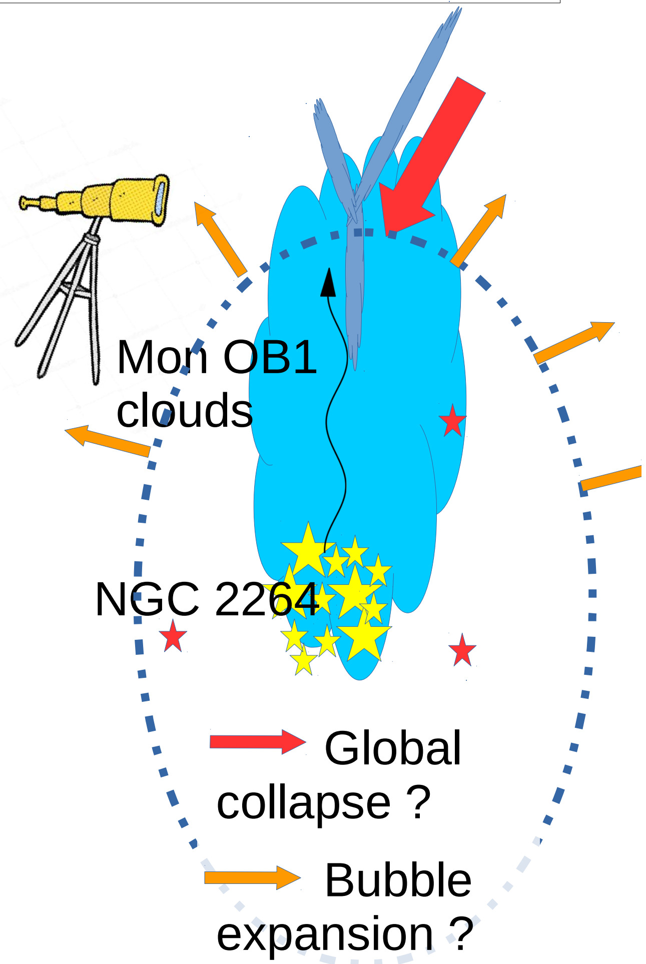


IRAM $^{13}CO + C^{18}O$; dv=0.06 km/s (same setup !)

Velocity coherent structures:
- local energetic balance
- sample of global kinematics







Conclusions :

- very good candidate for colliding filaments
- possible increase in star-formation efficiency
- origin : global collapse ? Bubble expansion ? Other ?
- all data in 1 setup => **unique capability of IRAM-30m**

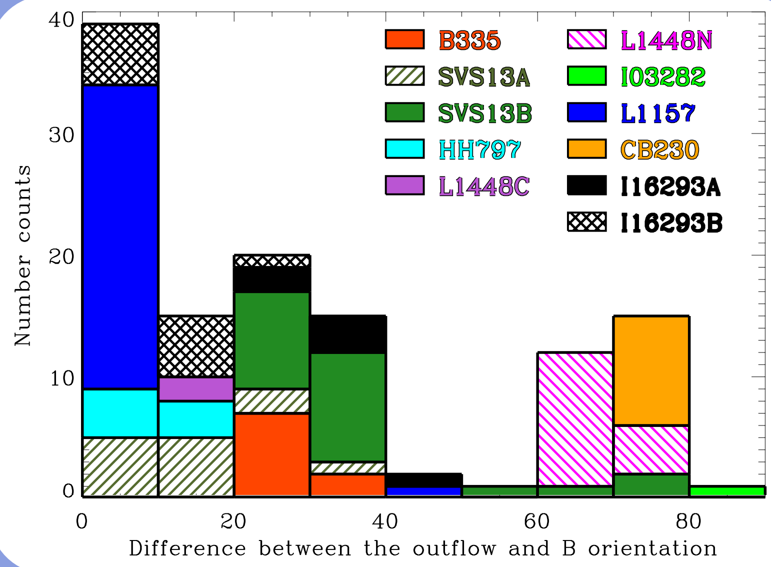
Perspectives :

- test global collapse: need fast large scale mapping
- search for shock tracers (accepted IRAM proposal)
- search for infall signatures (idem)

Maud Galametz

Understanding the formation of the youngest protostars

Understanding the formation of the youngest protostars



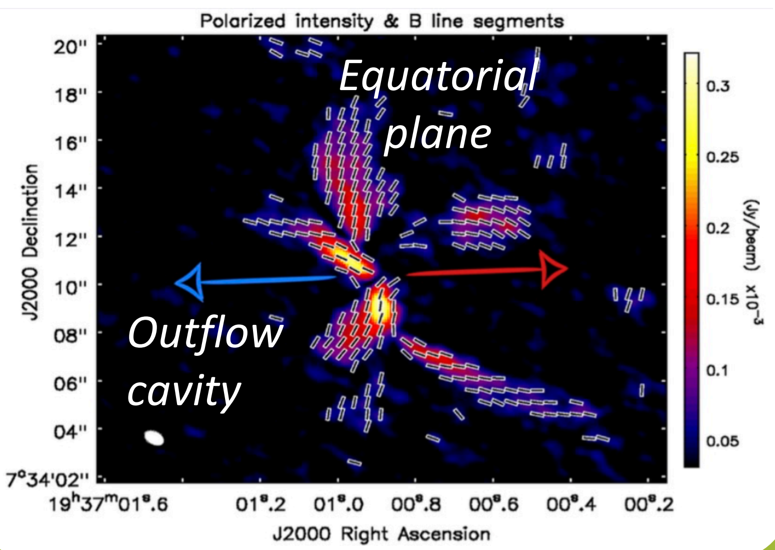
Orientation of B @ envelope scales

Detection of polarisation in all objects
Correlation between misalignment B-outflow / envelope velocity / fragmentation

Scales: Envelope (2000-10000 au)

Observations: Class 0 protostars - SubMm Array

Galametz et al. 2018



Impact of B in the accretion process

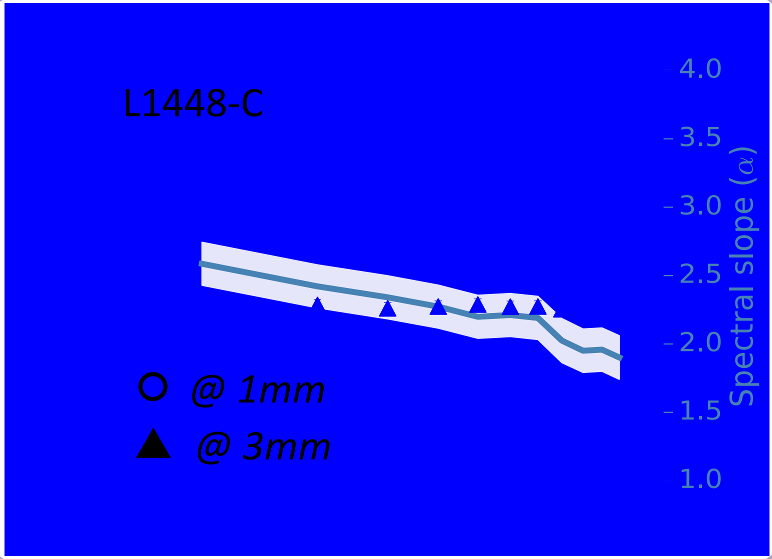
Bimodal distribution of the position angles
Strong pinching of the B lines
→ Magnetically regulated collapse

Scales: Reaching the disk scales (50-500 au)

Observations: The class 0 B335 - ALMA

Maury et al. 2018

Understanding the formation of the youngest protostars



Dust evolution, growth

Radial trends @ 1 and 3 mm

Variations of the dust opacity index β

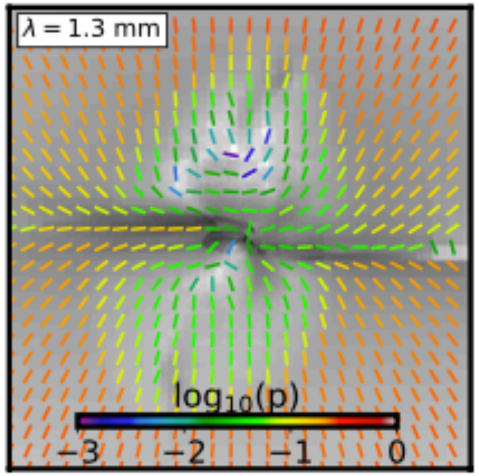
Comparison with simulation predictions

Scales: Envelope (200-2000 au)

Observations: Class 0 protostars - PdBI (CALYPSO)

Galametz et al. in prep

Peripheral analysis in the Magnetic YSOs team

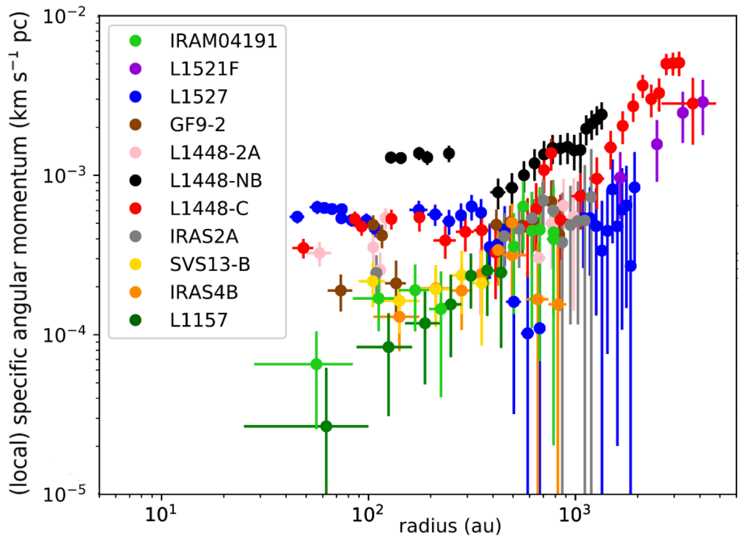


Variation of B with grain size distribution, alignment hypothesis

Valdivia et al in prep.

Angular momentum profiles

Gaudel et al in prep.



Philippe André

Searching for pre-brown dwarf cores in nearby star-forming clouds with NIKA2 & NOEMA

Searching for pre-brown dwarf cores in nearby star-forming clouds with NIKA2 & NOEMA

Philippe André

CEA - Lab. AIM Paris-Saclay

With:

B. Ladjelate, Y. Shimajiri, N. Peretto, D. Ward-Thompson, J. Greaves

Are pre-brown dwarfs the main channel of brown dwarf formation?

- **Pre-BDs = Ultra-low-mass, self-gravitating prestellar cores with** $M_{core} < M_{BD} = 0.08\ M_\odot$
- May be produced by strong shock compression in the gravo-turbulent fragmentation picture (Padoan/Nordlund '04; Hennebelle/Chabrier '08)
- Not expected in other BD formation scenarios
- Should be **compact, cold, very dense**:

  $M_{Jeans} \sim 0.08\ M_\odot \times (R/800\ AU) \times (T/10\ K)$

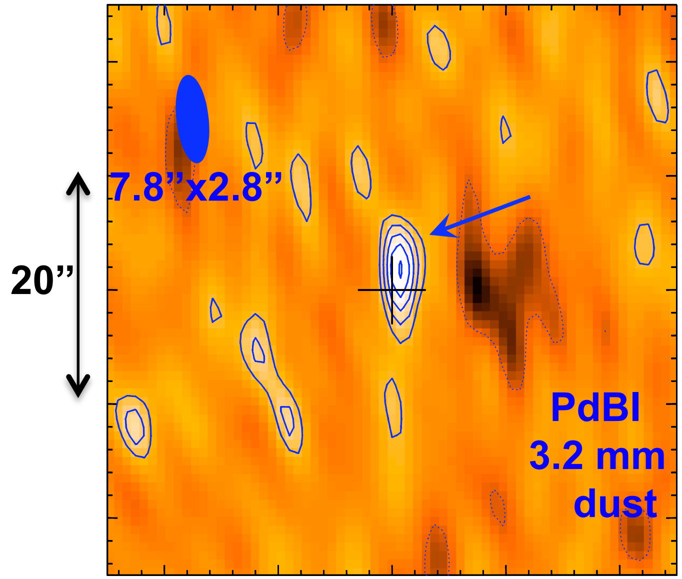
  $\Rightarrow R_{pre-BD} < 100\ AU \times (M_{pre-BD}/10\ M_{Jup})$

  $n_{pre-BD} \gtrsim 10^7\ cm^{-3}$

Best candidate pre-brown dwarf in L1688 (Oph)

IRAM PdBI detection of OphB-11

($M \sim 10$-$30\ M_{Jup}$)



Greaves+2003; André+2012, Science

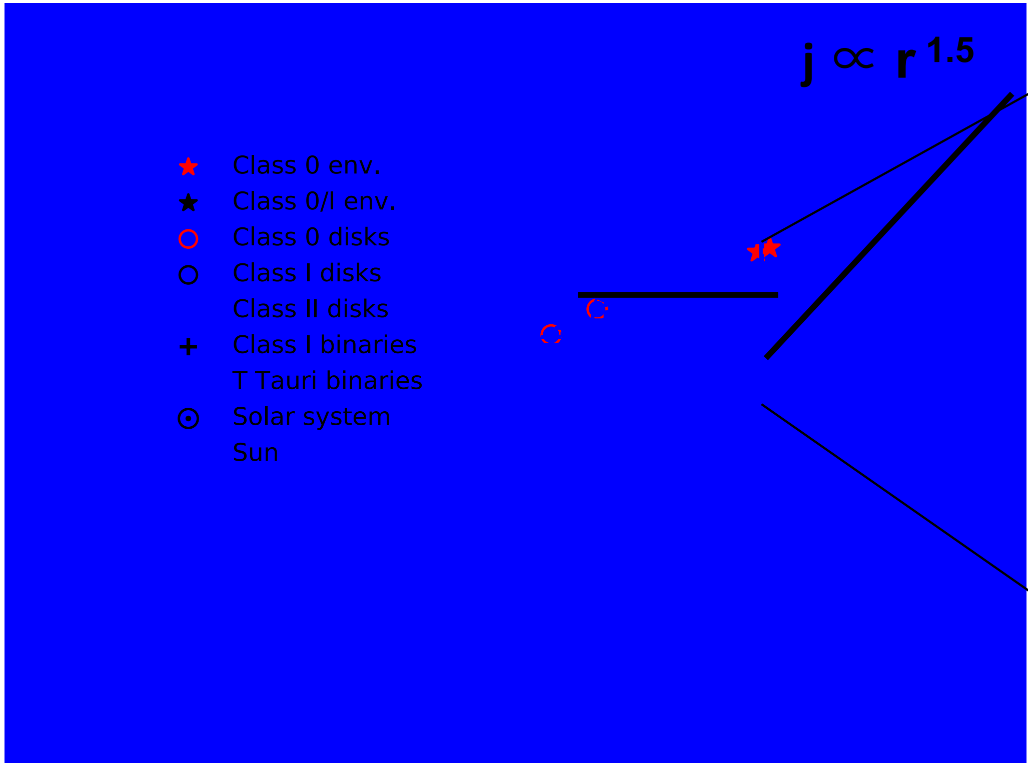
Supplementary material for the discussion of session # 3

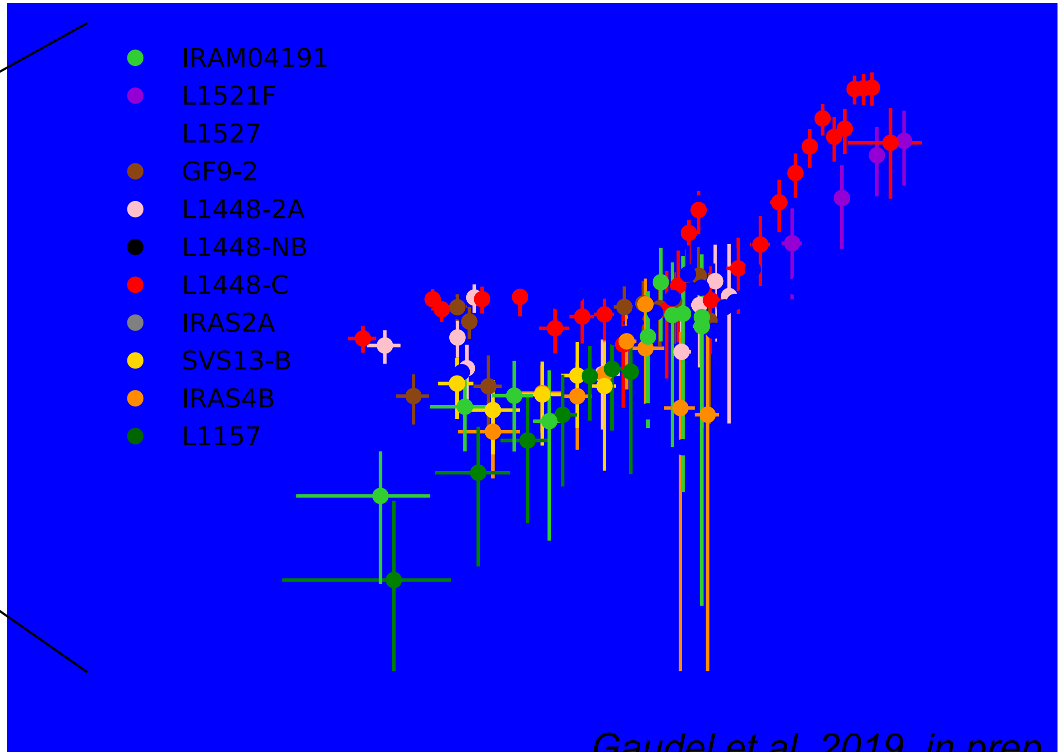
Mathilde Gaudel

Kinematic studies of protostellar envelopes at high angular resolution

Kinematic studies of protostellar envelopes at high angular resolution

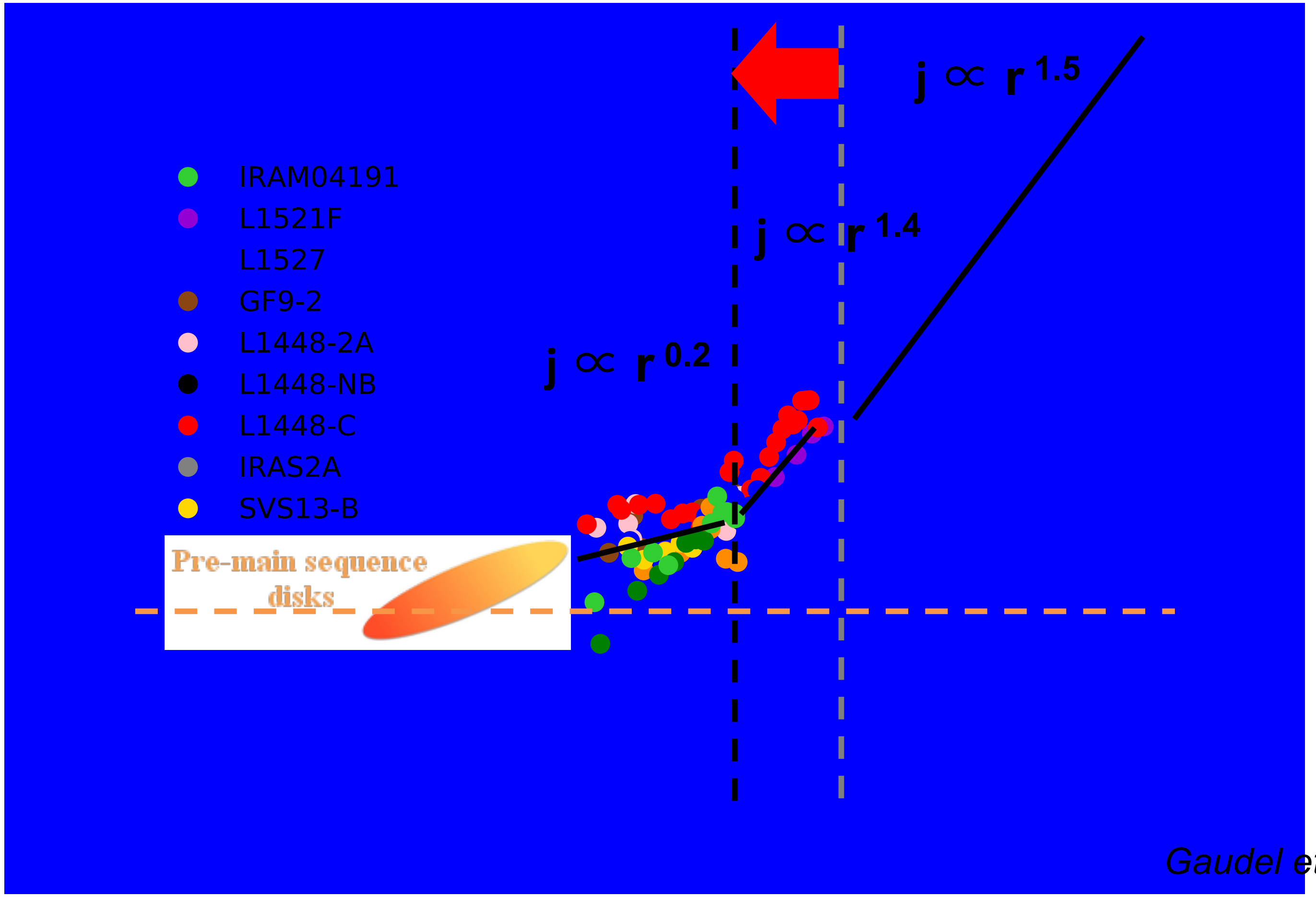
- CALYPSO (PI: Ph. André) observations from IRAM PdBI and 30m of $C^{18}O$ and N_2H^+ to probe envelope kinematics on all scales for a sample of 12 Class 0 protostars (d < 250 pc)
- From position-velocity diagram, identification of 11 objects with differential rotation motions of the envelope
- Building of the first distributions of angular momentum in a large sample at different scales comparing to mean value in different object (Belloche 2013)





Gaudel et al. 2019, in prep.

Quantifying the angular momentum problem



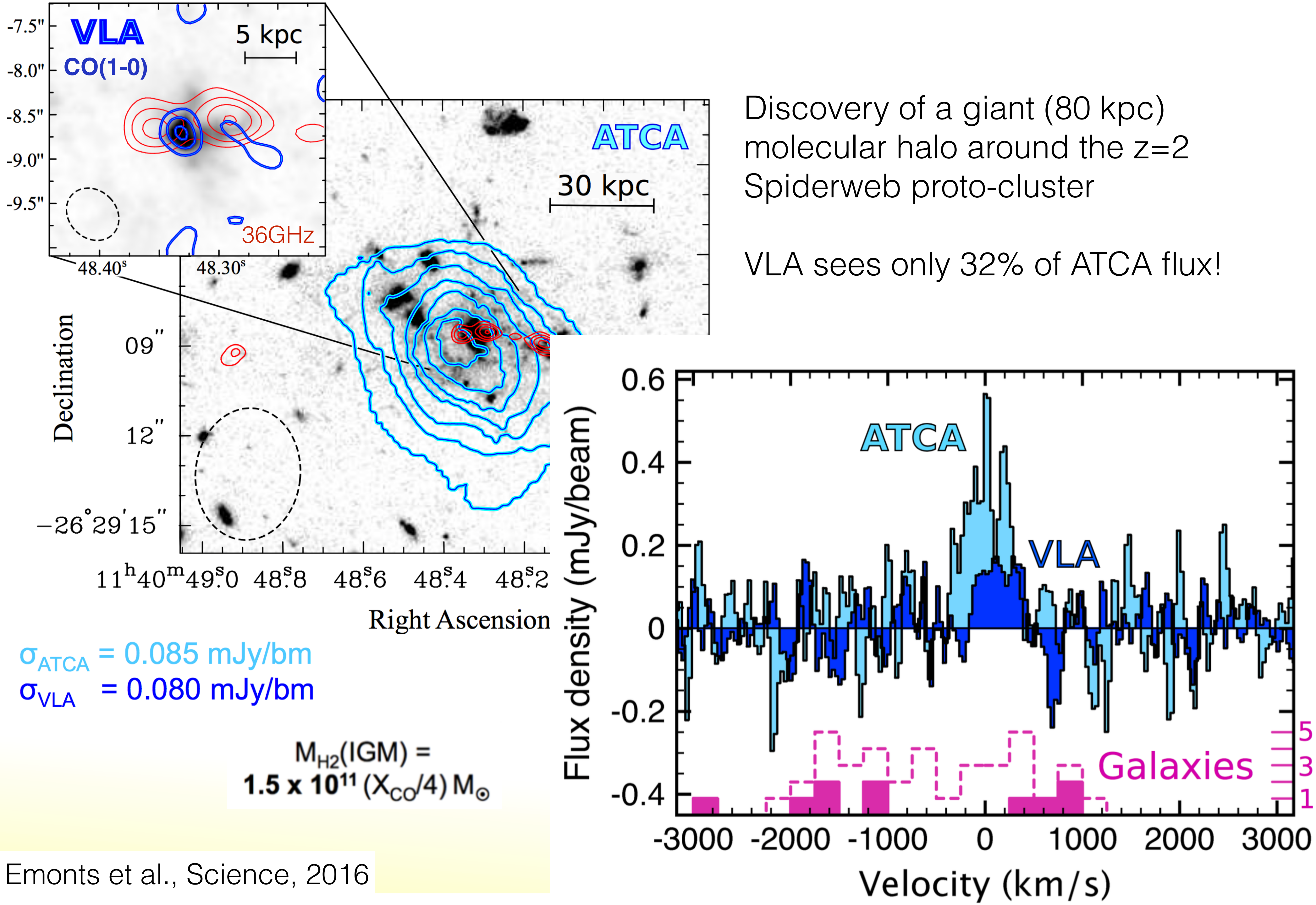
Gaudel et al. 2019, in prep.

- 2 regimes with a broken radius solved for the first time at ~1000 au
- Estimate in the inner envelope (r <1000 au) : j ~ 3.10^{-4} km s^{-1} pc
- Disk formation and magnetic braking can solve the angular momentum problem?
- Signature of turbulent cascade in the outer envelopes or contamination on the line of sight?

Pierre Guillard

Towards low surface brightness observations of gas accretion and cold gas recycling in high-redshift galaxies

The power of low-surface brightness observations



Discovery of a giant (80 kpc) molecular halo around the z=2 Spiderweb proto-cluster

VLA sees only 32% of ATCA flux!

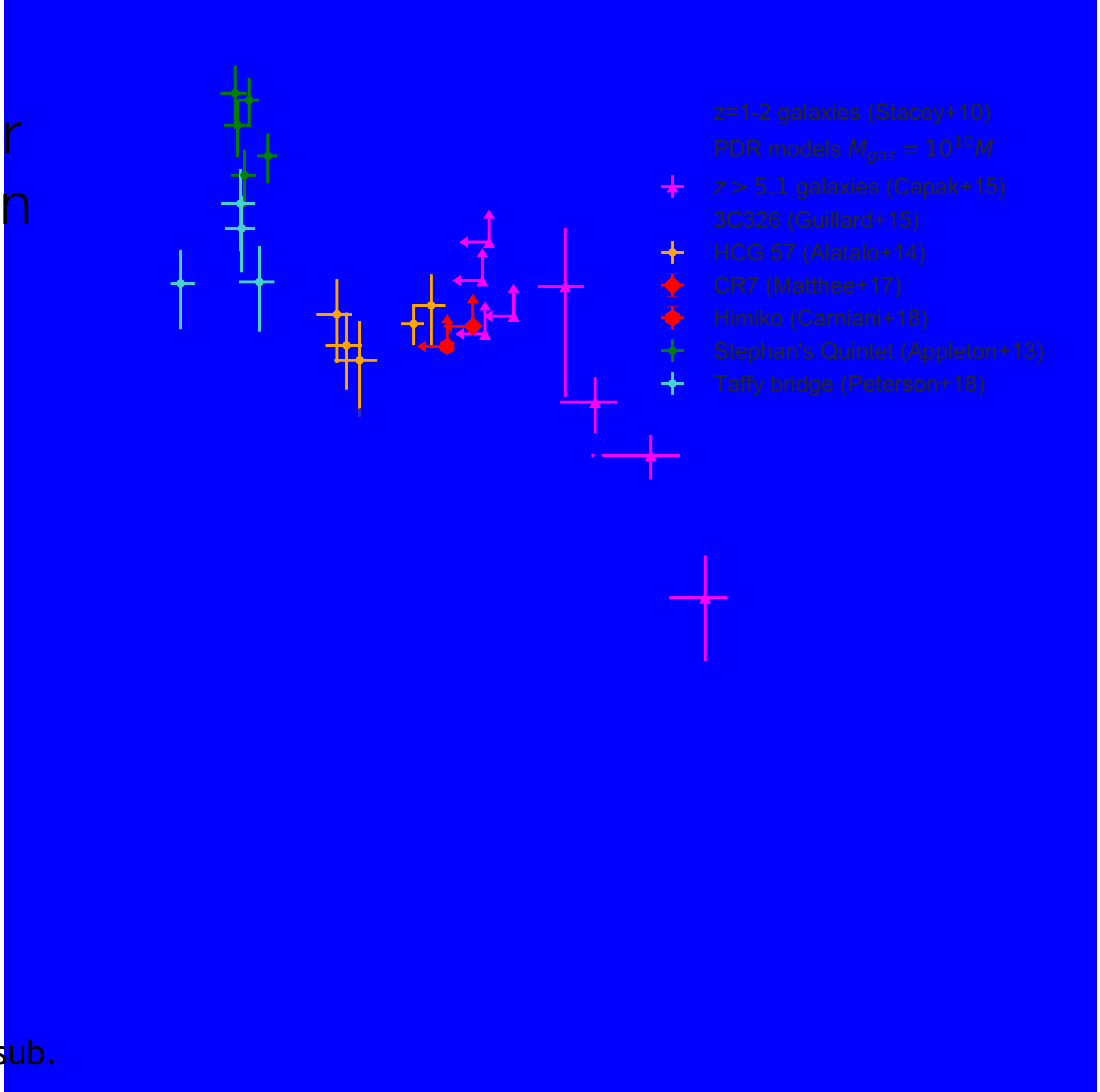
σ_{ATCA} = 0.085 mJy/bm

σ_{VLA} = 0.080 mJy/bm

$M_{H2}(IGM)$ = **1.5×10^{11}** $(X_{CO}/4)\ M_{\odot}$

Emonts et al., Science, 2016

[CII]/IR as a diagnostic for [CII] excitation



Some of the high equivalent width [CII] emitters are not only UV-powered

Guillard et al. 2019, sub.

Valeska Valdivia

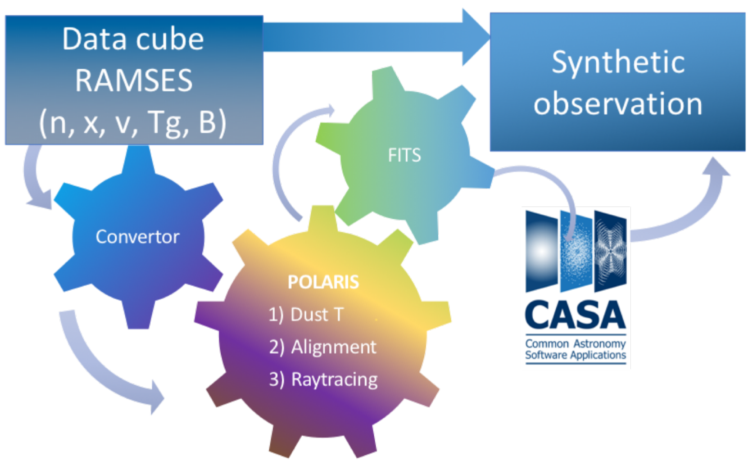
Synergy between observations and numerical simulations in the context of low-star formation

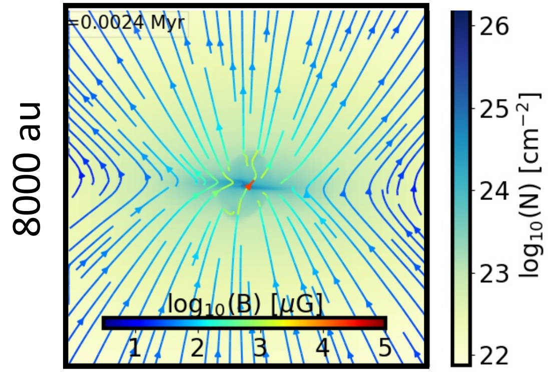
Synergy between observations and numerical simulations in the context of low-star formation

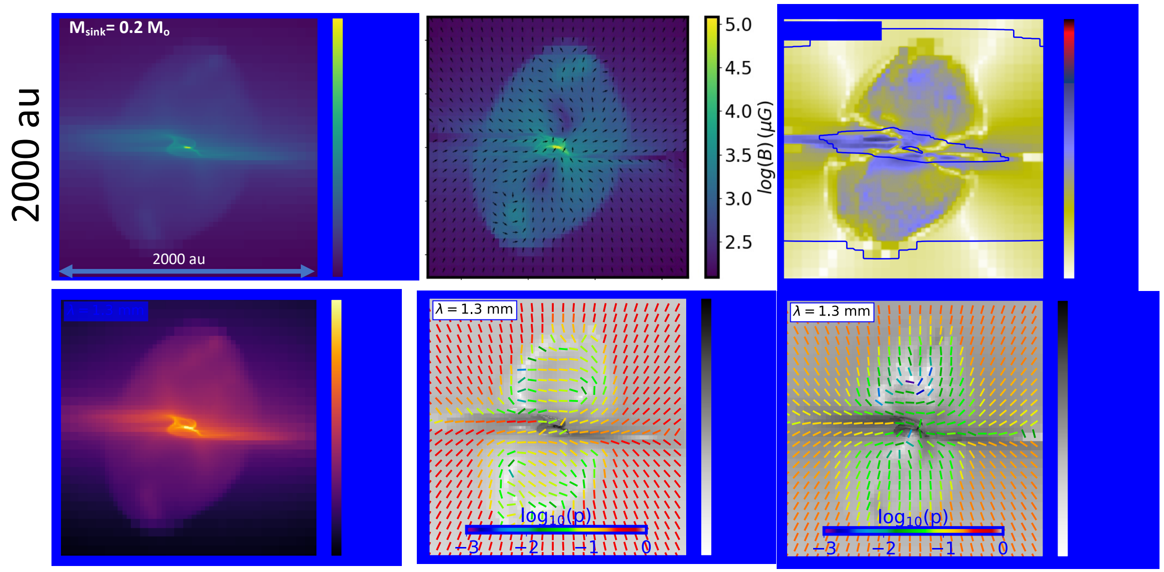
V. Valdivia[1], A. Maury[1], P. Hennebelle[1], R. Brauer[1], M. Galametz[1], M. Gaudel[1] & S. Reissl[2]

[1] Laboratoire AIM, Paris-Saclay, CEA/IRFU/SAp - CNRS - Université Paris Diderot, 91191 Gif-sur-Yvette Cedex, France; [2] ZAH Universität Heidelberg · Institut für Theoretische Astrophysik

- MHD simulations with **RAMSES**
- Post-processing with **POLARIS**:
  - Dust heating, grain alignment, dust emission
  - MRN distribution
- Perfect alignment approximation vs radiative torques

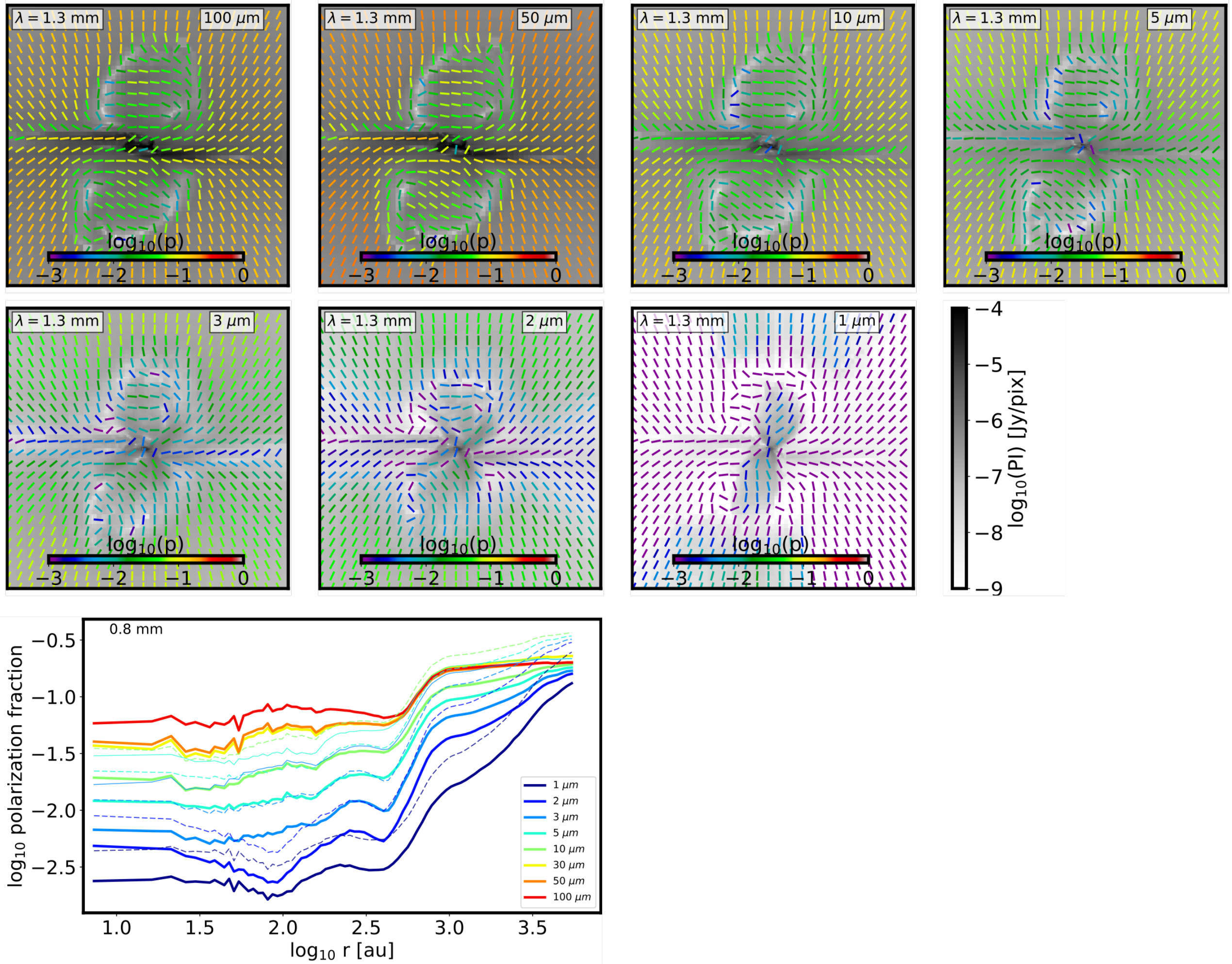


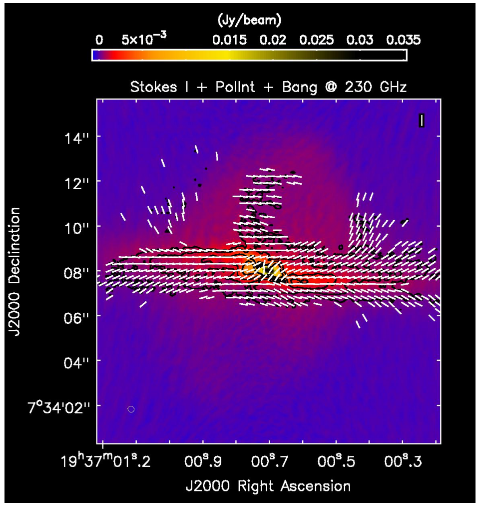




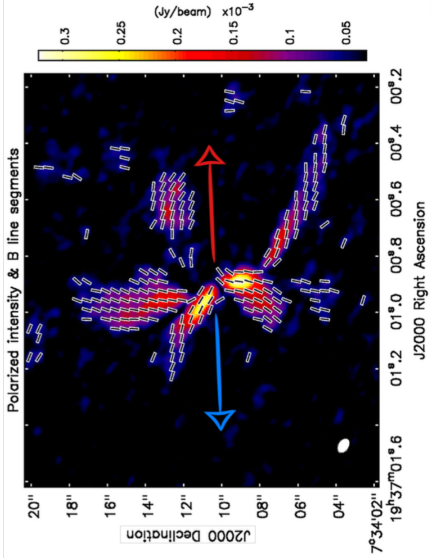
Synergy between observations and numerical simulations

The polarized intensity and polarization fraction increase with the dust size





ALMA synthetic observation (1-3-5-8) showing the total dust emission (background), the polarized intensity (contours) and the magnetic field orientation.



Maury+2018

Session # 4

Dying stars, young stellar objects, and astrochemistry

Fabrice Herpin

Circumstellar envelopes of evolved stars

Circumstellar envelopes of evolved stars

Fabrice Herpin

Journée IRAM France

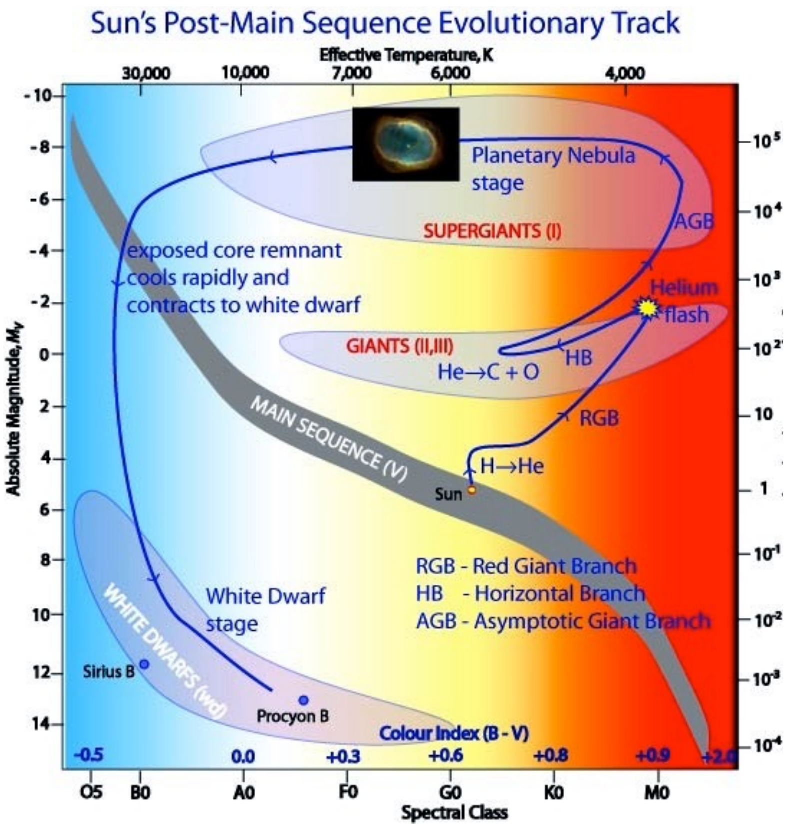
31 janvier 2019

Why do you want to observe evolved stars?

RGBs, AGBs and post-AGB stars, and their massive counterparts the RSGs

- **Incredible chemistry.** Inner wind is a factory of dust and stable molecules, while in its outer layers the photochemistry driven by the penetration of interstellar UV photons produces a wealth of exotic molecules.
- **Main recycling agents in the Universe.** Due to the radiation pressure likely combined to other factors, they undergo strong dM/dt (up to 10^{-4} M_{sol}/yr).
- **Main dust factory.** Interstellar dust grains are synthesised in the inner winds of AGB stars and the ejecta of massive stars, mainly supernovae (SNe).
- Hot topics: **wind/binarity/magnetic field/shaping.**

The spherical shape evolve to a large diversity of nebular morphologies in the PN stage.



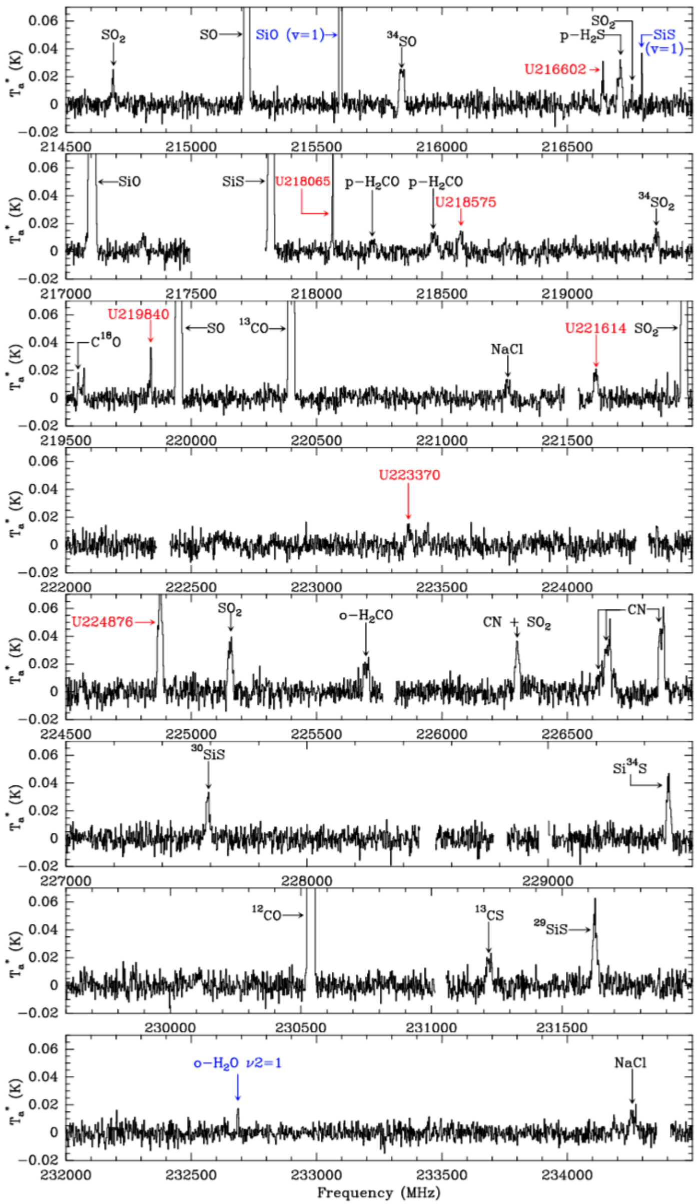
⟹ Needed instruments: IRAM-30m

⟹ Mandatory instrument: NOEMA, ALMA

CSE chemistry

Spectral surveys or focus «chemistry» observations *thanks to the powerful capabilities of the IRAM-30m (large bandwidth, huge spectral resolution and sensitivity) and NOEMA.*

Velilla-Prieto et al (2017), 30m survey of o-rich AGB IK Tau
~ 34 molecular species, *including carbon bearing molecules*
+ abundances different from models predictions
⇒ ***revision of standard chemical models.***



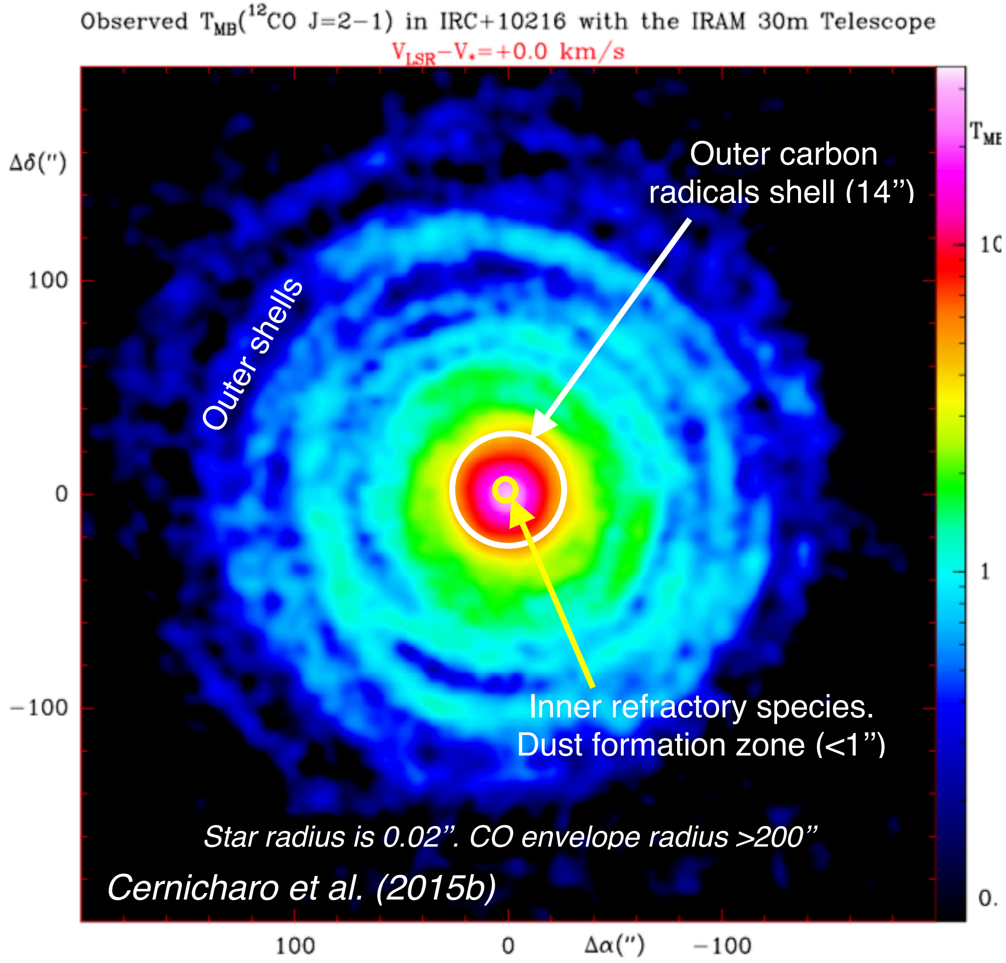
CSE chemistry: IRC+10216

C-rich. Central star at the tip of the AGB, nearby 130 pc.

• **More than 80 molecules,** dominated by carbon chains, exotic molecules containing phosphorus or metals, and negatively charged carbon chains.
cf Cernicharo's group papers, e.g. Agúndez et al. 2010.

- *Agundez, Cernicharo & Guélin (2014)*: ***new molecules***, e.g. C_5S + three molecules not yet observed in space (MgCCH, NCCP and SiH_3CN)
Species are formed in the outer circumstellar layers.

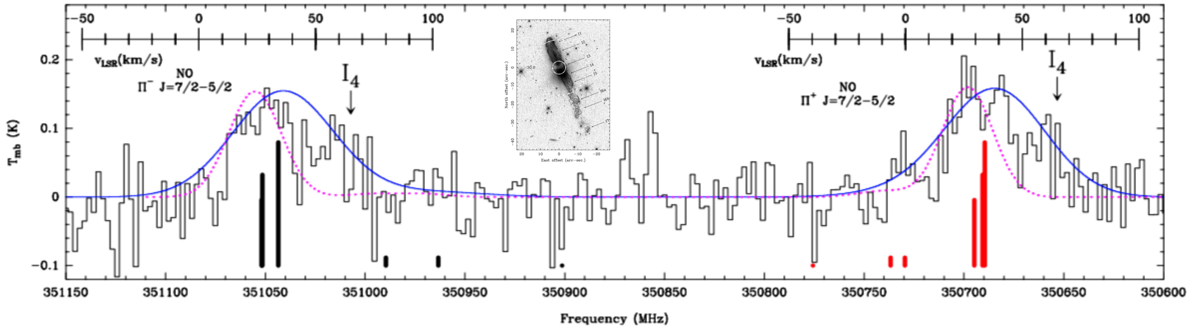
• ***Ideal playground:*** *due to its spherical shape and uniform expansion, its envelope allows to follow how molecular abundances evolve with time over intervals to thousands of years,* ***1" corresponds to a time resolution of 43 years.***
⟹ to check time-dependent chemical models.



CSE chemistry and winds…

1) Influence of shocks on the chemistry (with the 30m)

- Velilla-Prieto et al. (2015) in OH 231.8+4.2 (bipolar outflow around QX Pup).
N-bearing species (HNCO, HNCS, HC_3N, NO) in the molecular outflow
+ Contreras et al. (2015)



= exceptional molecular richness due to shock-induced chemical processes.

⟹ ***most molecules in the fast outflow must have been dissociated and reformed in the post-shock gas.***
See also ***De Beck et al. (2013)*** in IK Tau.

2) How CSE chemistry varies depending on winds and mass-loss rates?

- ***Massalkhi et al. (2018),*** *Agundez et al. (2010):* high dM/dt result in high gas densities accelerating the chemical reactions

+ mass loss rate regulates the degree of extinction and shielding against the Galactic UV radiation and influence the chemistry in the middle shells of the CSE.

Wind density plays an important role in determining the chemical composition of AGB CSE.

See ***Danilovich et al. (2018)***.

Chemistry: Planetary Nebulae

Molecular complexity of PNe remains globally unexplored.

Some observations, e.g. Schmidt & Ziurys (2016, 2017), Zhang et al. (2008): *polyatomic molecules appear to be common constituents of PNs*.

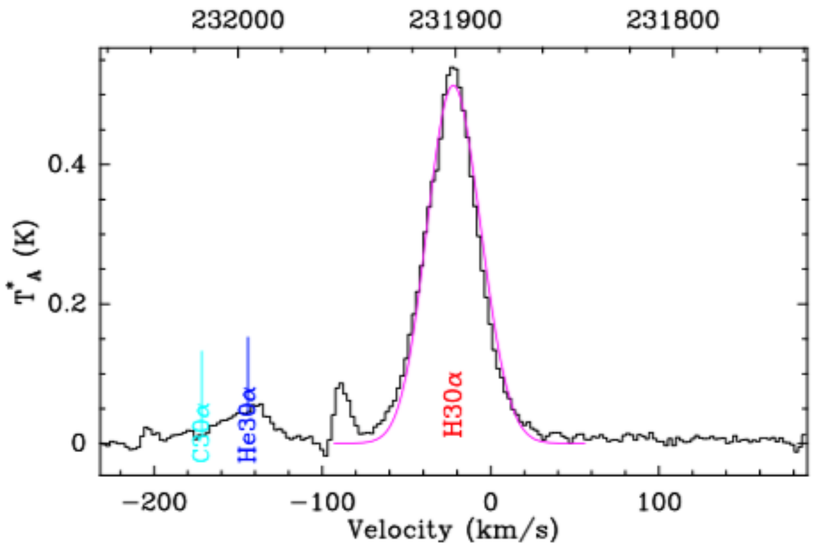
Only a few PNe have been studied in details.

⟹ **more observations** to understand the chemistry and constrain models, to compare to AGBs.

- ***Contreras et al (2017)*** 30m

Radio recombination line emission at mm wavelengths in a small sample of PPNe and young PNe.

= **excellent probes of the dense inner** (10-100 au) and heavily obscured **regions** of these objects, where the yet unknown agents for PN-shaping originate.



Synthesis of dust grains

Synthesis of dust grains takes place in the ejecta of dying stars, mostly AGBs in two steps:

1- condensation nuclei of nm size are formed near the stellar photosphere from precursor refractory gas-phase seeds

2- the nuclei grows to micrometer sizes as the material is pushed out by the stellar wind.

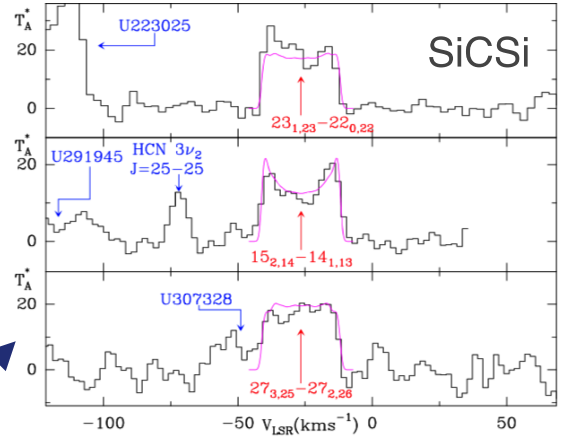
The chemical nature of the synthesis dust strongly depends on the C/O ratio:

C-rich ⟹ SiC dust (Treffers & Cohen 1974)

O-rich ⟹ mainly silicate dust.

⟹ **to investigate potential gas-phase precursors of dust**.

In C-rich AGB stars, molecular (gas-phase) precursors of SiC dust grains are still unknown: could be SiC_2, SiC, Si_2C

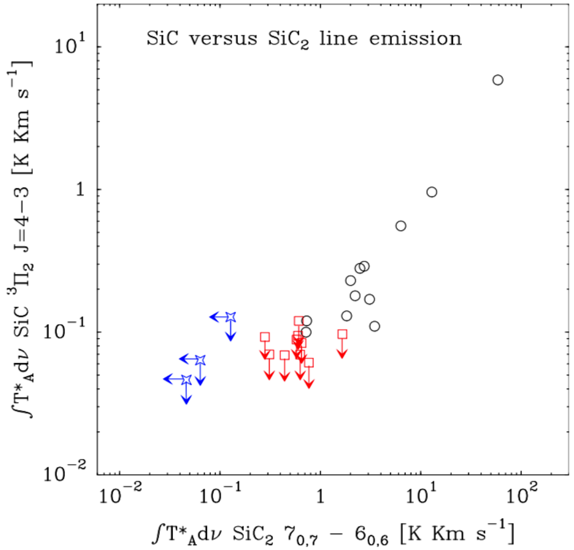


1) IRC+10216: SiC molecules detected in the external shell (*Cernicharo & Gottlieb 1989; Patel et al. 2013*).

In the inner layers, SiC_2 (*Cernicharo et al. 2010, Agúndez et al. 2012*), SiS, SiO, SiCSi by *Cernicharo et al. (2015),* methyl silane CH_3SiH_3 (*Cernicharo et al. 2017*)

2) *Massalkhi et al. (2018)*: **SiC_2 is one of the main precursors of SiC dust.**

To do ⟹ spatial distribution of SiC and SiC_2 with NOEMA.



CSE shaping → PN

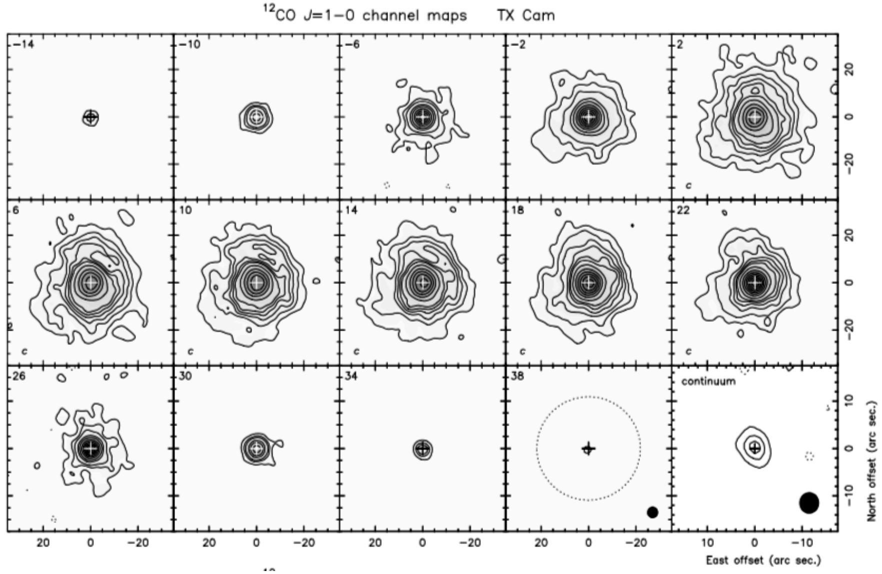
Star's geometry changes drastically after the AGB.

Several mechanisms could explain the PN morphologies: B, binary companions or high-speed collimated outflows operating during the late AGB or early PN stages.

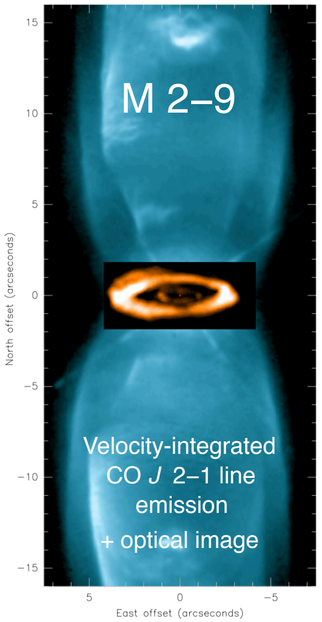
⟹ important to study winds/outflows and any departure from sphericity at pre-PN stage.

1) Castro-Carrizo et al. (2010) with PdB

In most AGB CSEs, clear (but moderate) ***departures from spherical symmetry*** are found. Effect of a ***binary companion*** seen for TX Cam.



2) Castro-Carrizo et al. (2012), PPN nebula M2–9 with PdB: appearance and properties of bipolar winds.



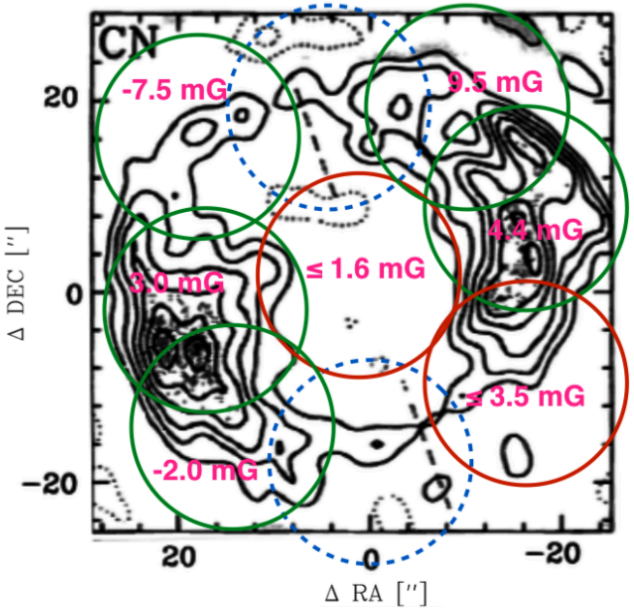
Two mass-loss events likely gave rise to the two coaxial lobes seen in infrared and optical images, shaped, accelerated by interaction with post-AGB fast and collimated jets.

Evidence that there is a binary system at the center of M 2–9.

⟹ supports the binary-based models, easily able to explain the axisymmetric ejections in PNe.

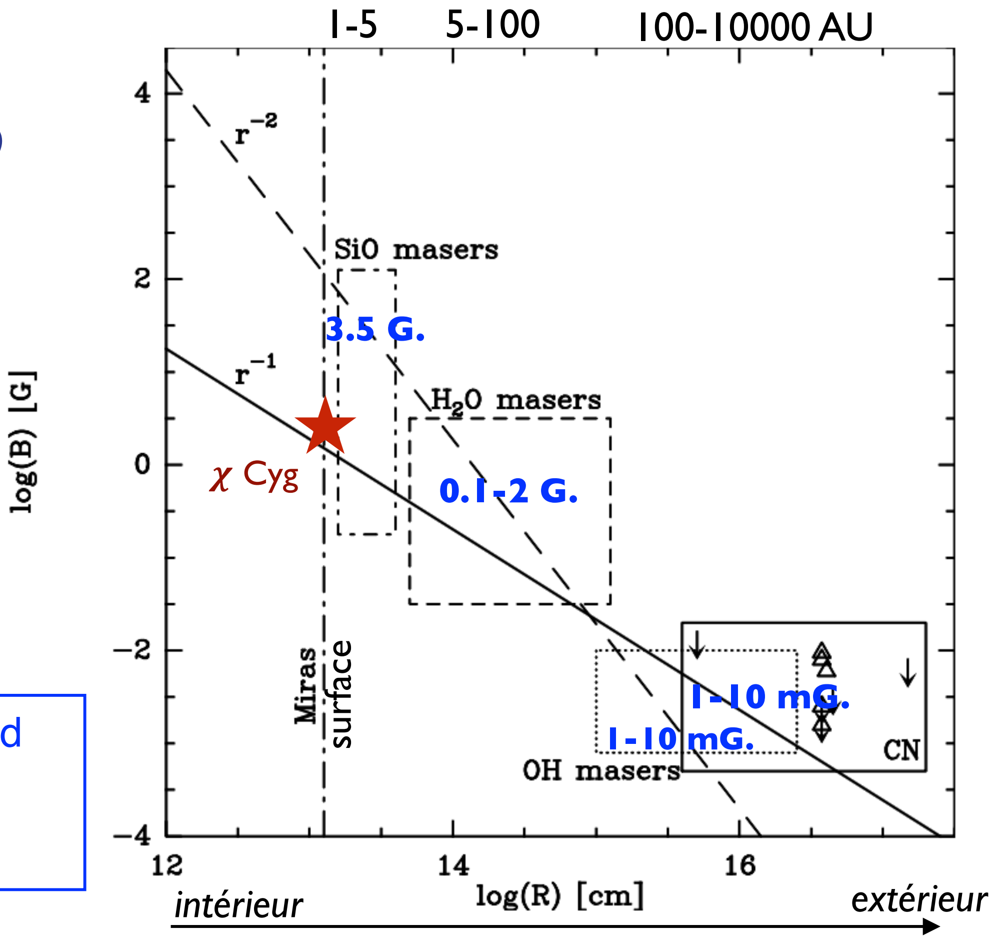
Magnetic field

B-field, even weak at the surface (a few Gauss) could play a key-role in the ignition and support process of a strong dM/dt and /or in the shaping of the nebula (by privileging some axes). Several works have been done to search for and estimate B field.



Duthu, Herpin et al. (2017)

IRC+10216 B_{los} is not homogeneously strong or aligned in the envelope.



⟹ B varies as 1/r, as expected for a toroidal magnetic field

⟹ Field produced by a dynamo between the rotating envelope and the convective zone (??)

Magnetic field is too weak to ignite winds but sufficient to play an important role in the mass-loss process

LAB

PNPS

Programme National de Physique Stellaire

Observatoire Aquitain des Sciences de l'Univers

université de BORDEAUX

cnrs

Miguel Montarges

NOEMA observations of the circumstellar environment of μ Cep

NOEMA observations of the circumstellar environment of μ Cep

Miguel Montargès (KU Leuven, BE)
FWO [PEGASUS]^2 Marie Skłodowska-Curie fellow
&
Ward Homan, Denise Keller,
Nicola Clementel, Shreeya Shetye,
Leen Decin et al.

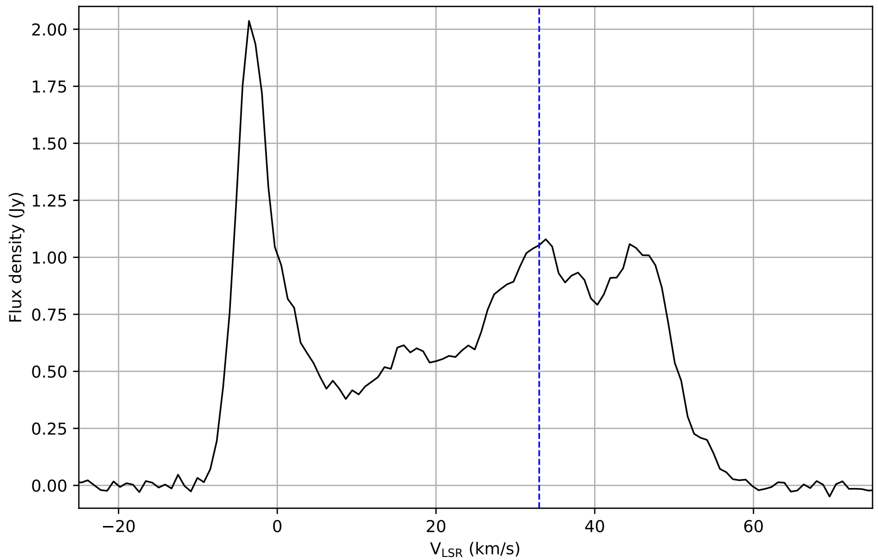
IRAM France meeting
Paris - 31st January 2019

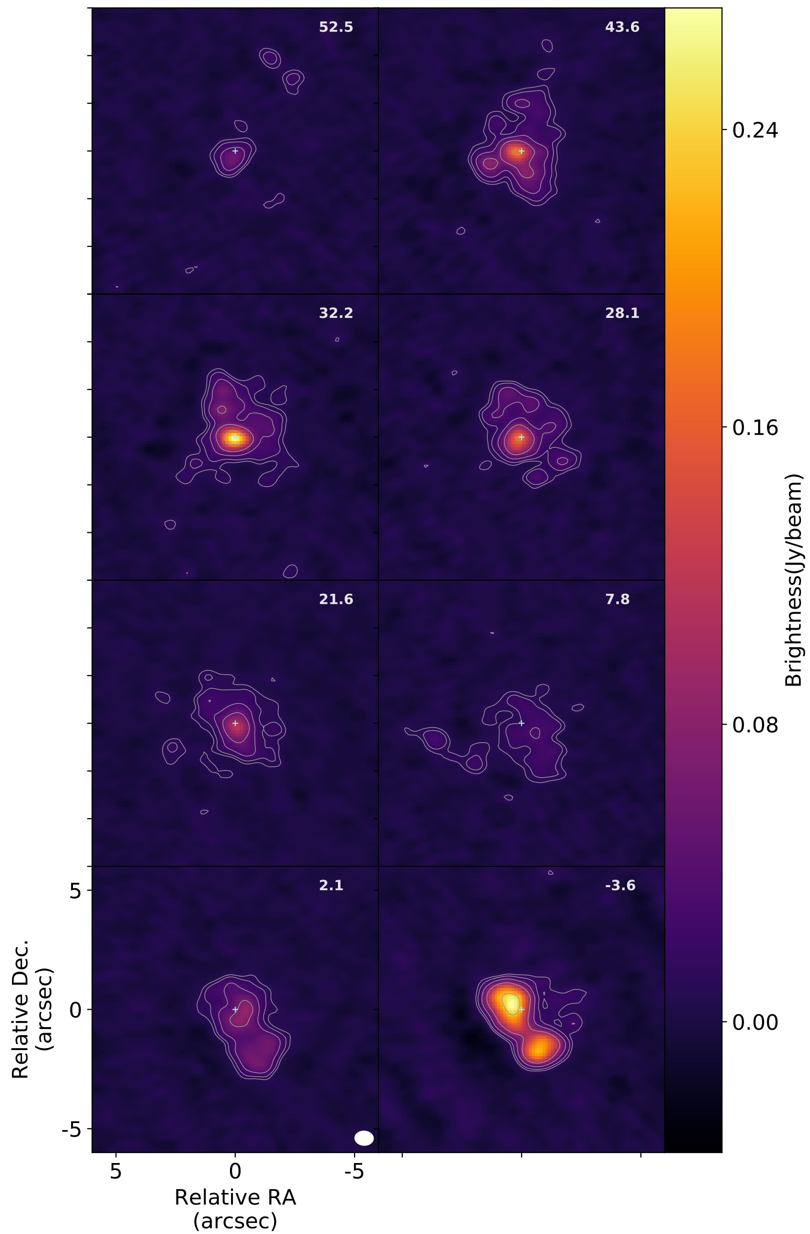
This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie Grant agreement No. 665501 with the research Foundation Flanders (FWO)

NOEMA observations

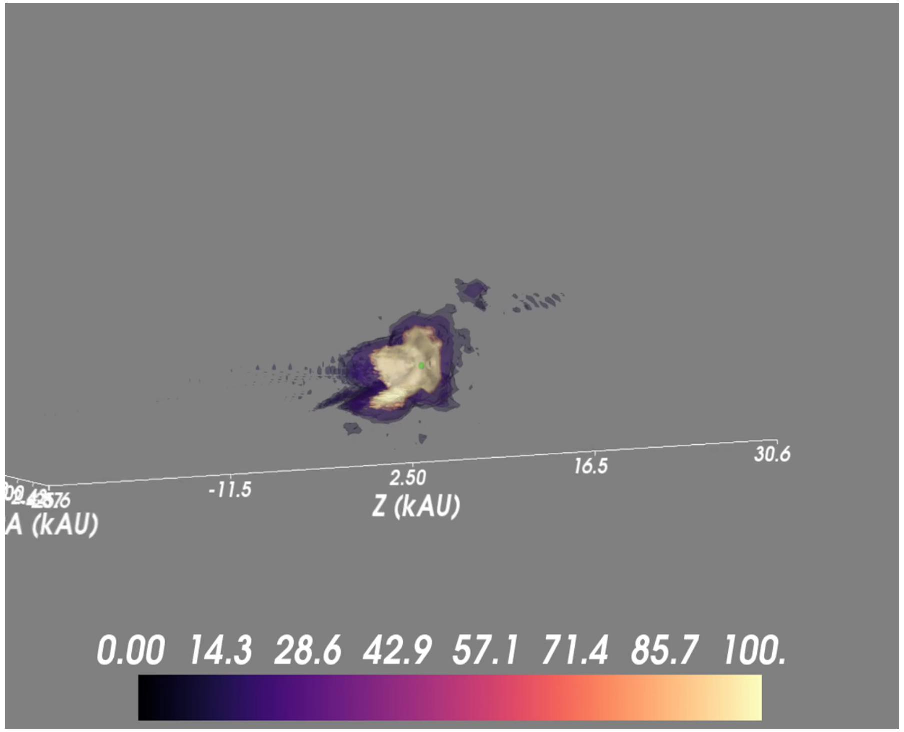
- 7B and 7C
  (beam $= 0.93 \times 0.70$ arcsec)
- μ Cep, M2-Ia RSG,
  $\theta_\star \sim 0.014$ arcsec (d $= 641^{+148}_{-144}$ pc)
- CO $J = 2-1$ line (230.538 GHz)

$\longrightarrow$ Montargès et al. subm.





Deprojection and mass loss rate estimate



(movie available at `https://frama.link/muCep_3D`)

- Deprojection + radiative transfer modeling (LIME)
- Mass loss rate : $(2.5 \pm 0.5) \times 10^{-6}$ $M_\odot$ yr^{-1}

$\longrightarrow$ $\geq 25\%$ from the clumps

Victor de Souza Magalhaes

A survey of the HCN and HNC C and N isotopic ratios in nearby star formation regions

A survey of the HCN and HNC C and N isotopic ratios in nearby star formation regions

V. S. Magalhães

- Context:
  - Heritage of Stellar systems still an open question.
  - Nitrogen is a Key element
  - How to trace its heritage?
    - Isotopic ratios and chemistry
  - Key species:
    - N_2, HCN, HNC, CN, NH_3, N_2H^+
- Focus:
  - HCN/HC^{15}N, HNC/H^{15}NC and HCN/HNC in various prestellar cores
  - Why?
    - Early stage of star formation, inheritance from the ISM?
    - Variations in mixed isotopic ratios, Time evolution of N/^{15}N?
  - How?
    - Detailed Radiative transfer to fit observed spectra

A survey of the HCN and HNC C and N isotopic ratios in nearby star formation regions

V. S. Magalhães

- Limitations:
  - Time consuming observations and data analysis
- Sample:
  - 3 cores (L1498, L1512, L183)
- Status:
  - 1 Paper on HCN/$HC^{15}N$ in L1498 (Magalhães et al. 2018)
  - J=1-0 Transitions observed (Aug 2018)
  - J=3-2 Transitions accepted (current semester)
  - L1498 observed with NIKA 2 (Jan 2019)
- Perspectives:
  - Larger sample
  - All cores with NIKA 2
- Potential results:
  - Better understanding of N chemistry (HCN/HNC ratio)
  - Identification of interstellar reservoirs of cometary materials
- Byproducts:
  - HCN and HNC carbon isotopic ratios

Eleonora Bianchi

Hot corino agins: Molecular complexity and deuteration towards the Class I source SVS13-A

Hot corino aging: molecular complexity and deuteration towards the Class I source SVS13-A

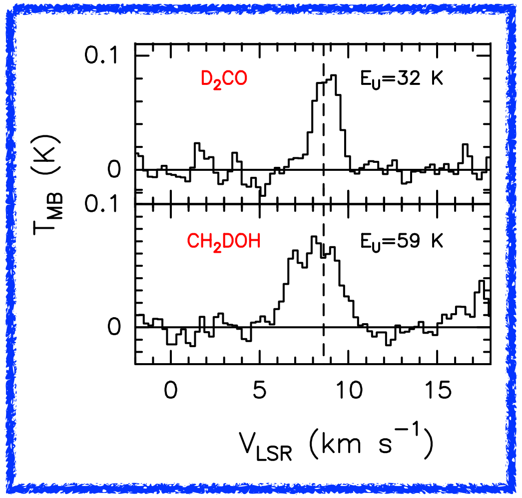
Eleonora Bianchi
Univ. Grenoble Alpes, IPAG

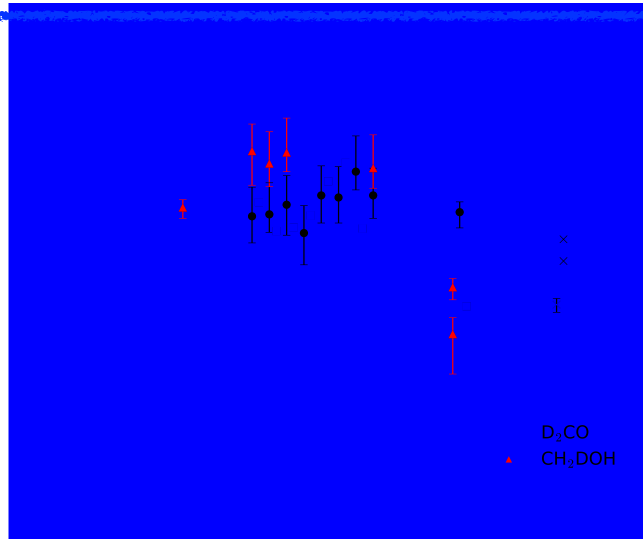
And the DOC team:
C. Ceccarelli, C. Codella, B. Lefloch, M. Bouvier, A. Dehghanfar, M. De Simone, J. Enrique-Romero, C. Favre, A. Jaber Al-Edhari, C. Kahane, A. López-Sepulcre, J. Ospina-Zamudio, F. Vazart, N. Balucani, R. Neri, C. Vastel

SVS13-A: Class I vs Class 0 sources

Astrochemical Surveys At IRAM 30m

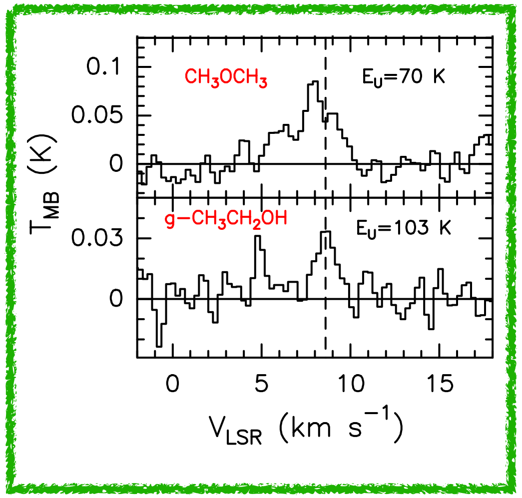
IRAM 30-m Large Program (PI B. Lefloch & R. Bachiller: *Lefloch et al. 2018*)





CH_2DOH/CH_3OH decreases by 2 orders of magnitude wrt Class 0

Bianchi et al. 2017



iCOMs ratios approximatively similar to Class 0

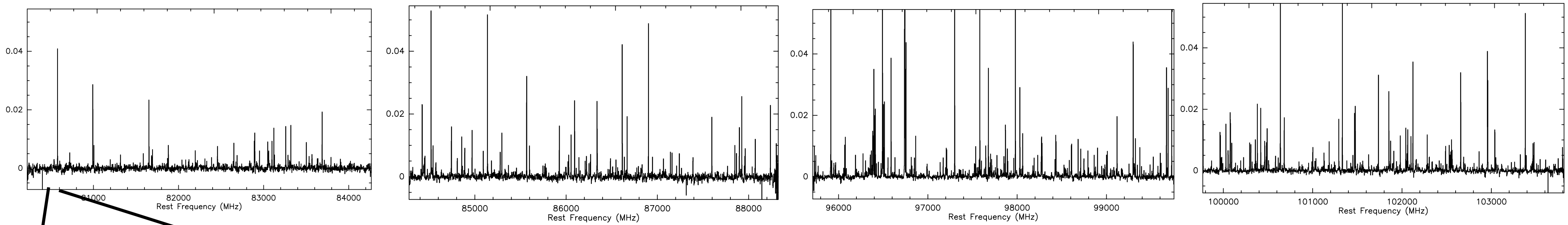
Bianchi et al. 2019

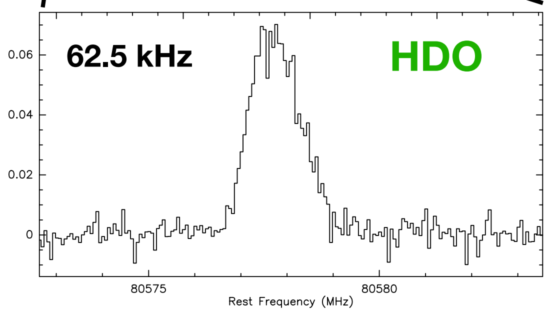
SVS13-A: a chemically rich hot corino

Seeds Of Life In Space

NOEMA Large Program (PI C. Ceccarelli & P. Caselli: *Ceccarelli et al. 2017*)

POLYFIX (10/2018) **8 GHz + 8 GHz**





128 high-resolution narrow bands

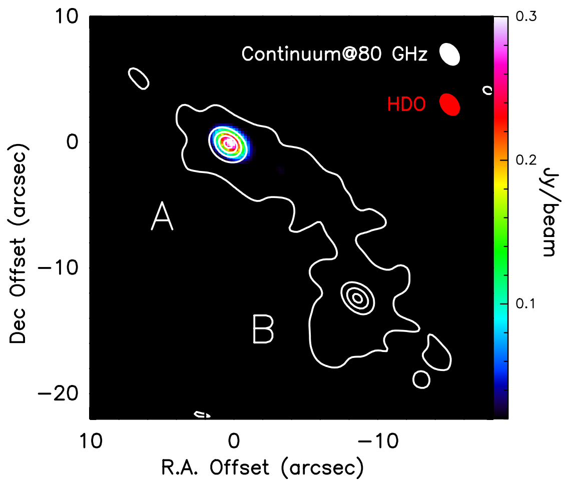
More than 100 lines detected

iCOMs: CH_3OCH_3, $HCOOCH_3$, CH_3CHO, H_2CO, H_2CCO, C_2H_5OH, CH_3OH, CH_3COCH_3, $HCOCH_2OH$,..

N-bearing: NH_2CHO, H_2NCH_2CN,..

D-bearing: CH_2DOH, HDO, HDCO, D_2CO,..

S-bearing: SO, SO_2,..



STAY TUNED… *Bianchi et al. in prep.*

Martha de Simone

Complex Organics in the NGC 1333 IRAS 4A Outflows

Complex Organics in the NGC 1333 IRAS 4A Outflows

Marta De Simone
Université Grenoble Alpes, IPAG

And the DOC Team:

C. Ceccarelli, C. Codella, E. Bianchi, M. Bouvier, A. Dehghanfar, J. Enrique-Romero, C. Fabre, A. Jaber Al-Edhari, C. Kahane, B. Lefloch, A. López-Sepulcre, J. Ospina-Zamudio, F. Vazart, N. Balucani, C. Favre, R. Neri, C. Vastel

IRAM Day

31 January 2019

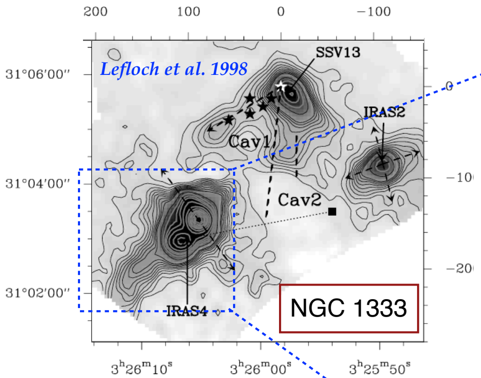
Complex Organics in the IRAS 4A Outflows

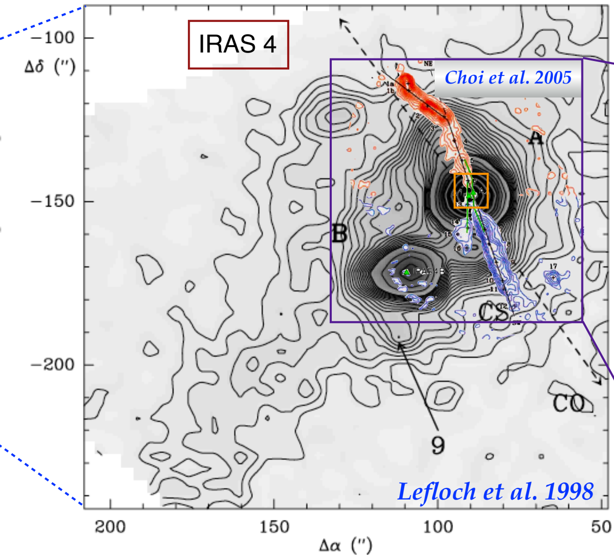
Geography of the binary system IRAS 4A:
NGC 1333 region (~299 pc, *Zucker et al. 2018*) in the Perseus Cloud

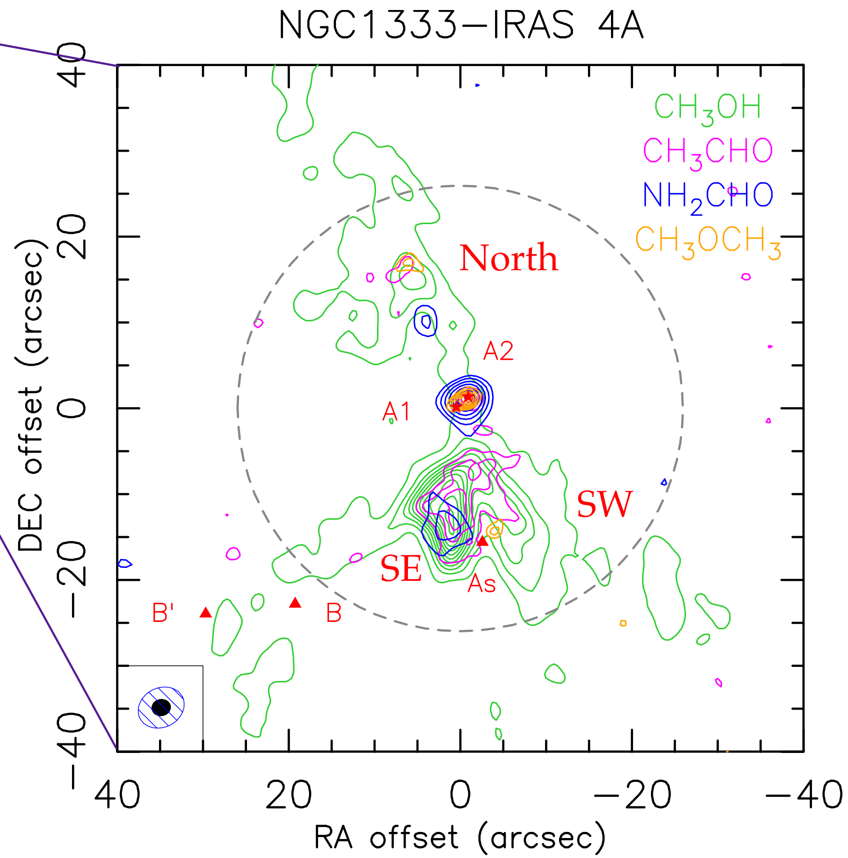
NOEMA/SOLIS

(Ceccarelli et al. 2017)

De Simone et al. in prep.







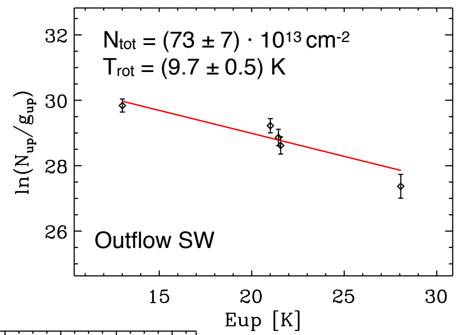
Emission Distribution:

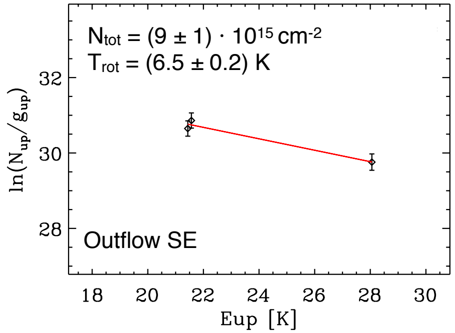
- Large scale (~1′): Methanol (CH_3OH, green)
- Intermediate scale (~15″): Acetaldehyde (CH_3CHO, magenta)
- Compact (~6″): Formamide (NH_2CHO, blue)
- Ultracompact (~2″): Dimethyl-Ether (CH_3OCH_3, orange)

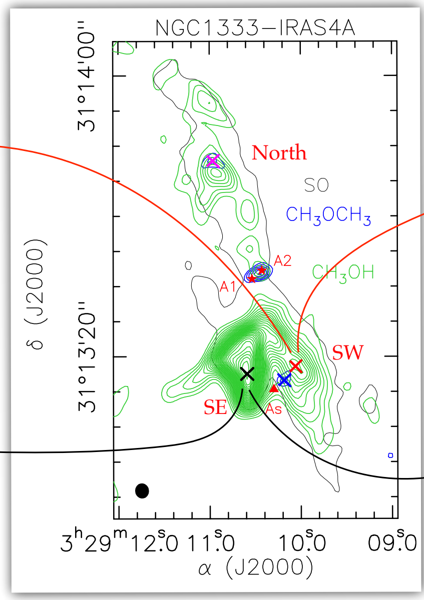
Complex Organics in the IRAS 4A Outflows

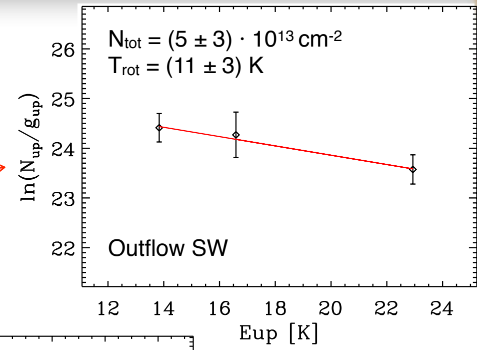
Rotational Diagram Analysis

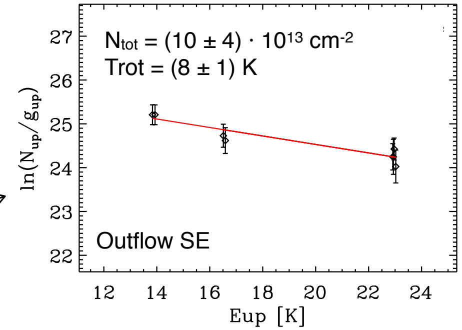
Methanol











Acetaldehyde

Preliminary Results:

Abundance Ratios:

Outflow SE:

$$\frac{CH_3OH}{CH_3CHO} = 90 \pm 40$$

Outflow SW:

$$\frac{CH_3OH}{CH_3CHO} = 15 \pm 9$$

Evidence of chemical differentiation along the outflows of IRAS 4A

likely due to a gas-phase time dependent effect (see L1157-B1, *Codella et al. 2017*)

Supplementary material for the discussion of session # 4

Mathilde Bouvier

IRAM hunt for hot corinos and WCCC objects in the OMC-2/3 filament

IRAM hunt for hot corinos and WCCC objects in the OMC-2/3 filament

Mathilde Bouvier

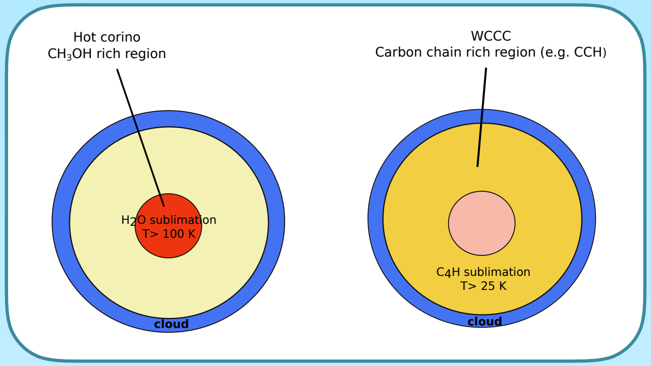
Université Grenoble-Alpes, IPAG

Collaborators:

A. López-Sepulcre, C. Ceccarelli, E. Bianchi, M. De Simone, A. Dehghanfar, J. Enrique-Romero, A. Jaber Al-Edhari, C. Kahane, B. Lefloch, J. Ospina-Zamudio, F. Vazart, M. Imai, N. Sakai, S. Yamamoto

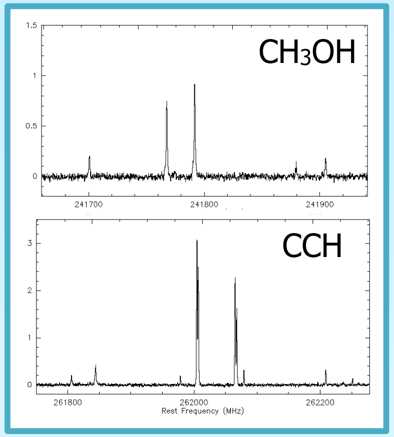
hot corino vs WCCC

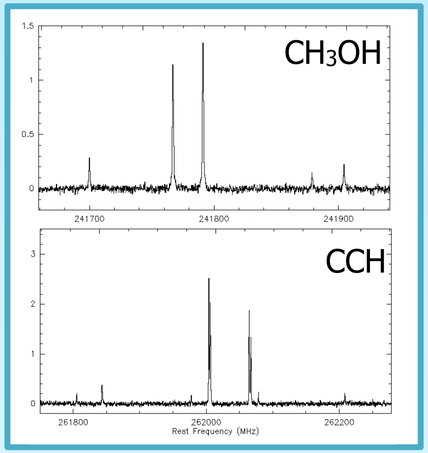
Birth environment of Solar-Sytem close to high-mass stars:
What is the typical chemical nature of protostars? hot corino, WCCC, neither?

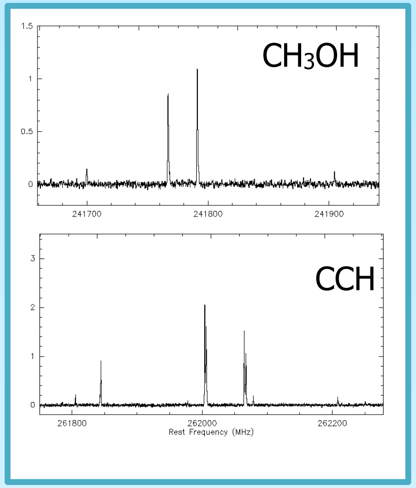


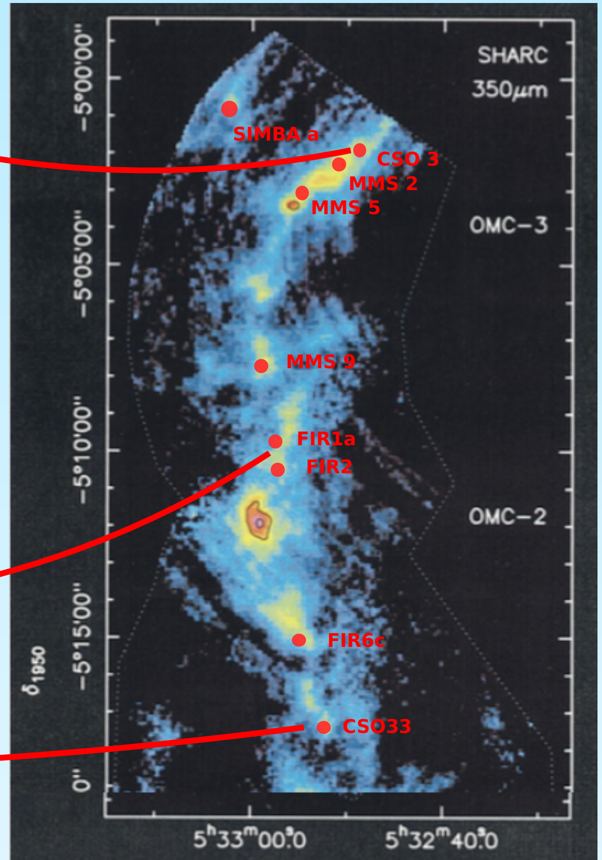
Characterisation in OMC-2/3, the closest high-mass star forming region, using typical molecular tracers: CCH (WCCC) and CH_3OH (hot corino)

IRAM 30m: 1.3 mm









Lis et al. 1998

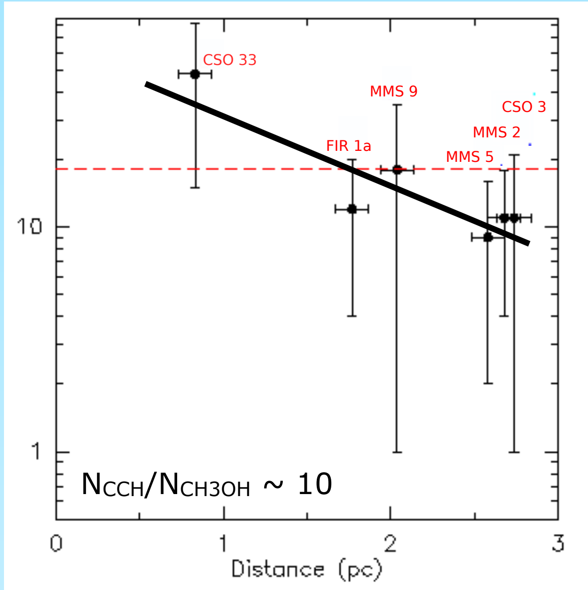
Small variation of the lines intensity ➨ dominated by cloud emission?

hot corino vs WCCC

The CCH/CH_3OH ratio

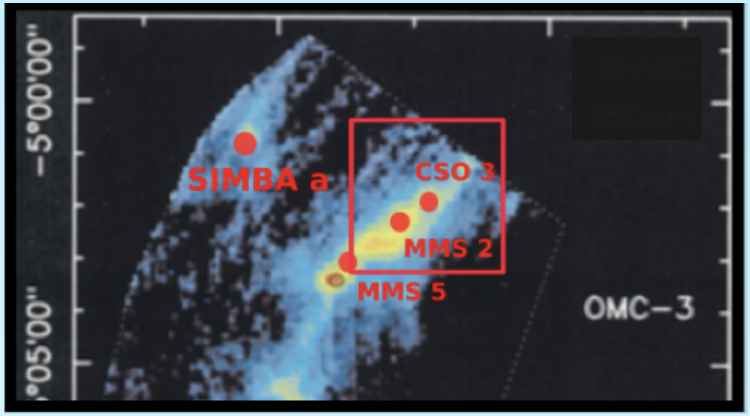
Object	Type	CCH/CH3OH[1]
L1527	WCCC	4.1 ± 0.5
NGC1333-IRAS4A	Hot Corino	0.08 ± 0.02

[1] Higuchi et al. 2018



The CCH/CH_3OH ratio likely refers to a diffuse component.
What is the origin of emission of CCH and CH_3OH?

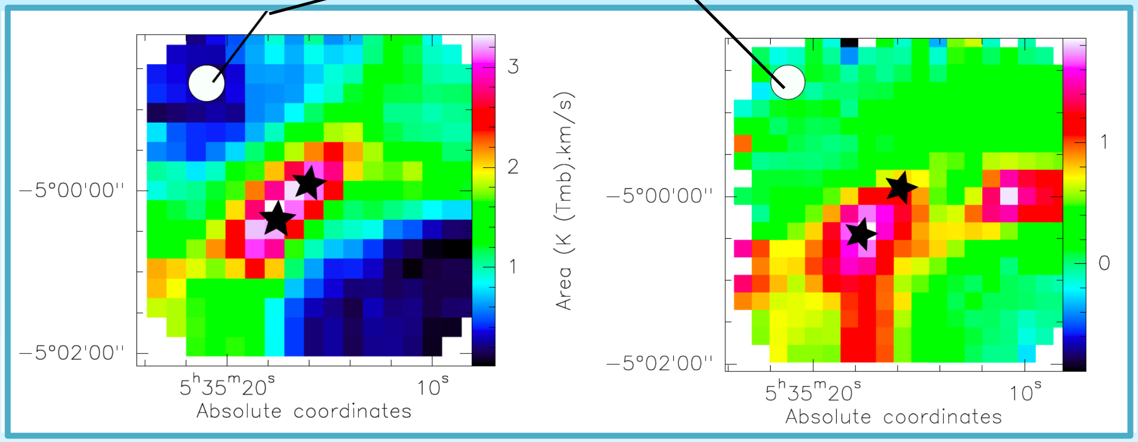
IRAM 30m: OTF map @ 3mm



CCH, N=1-0
87.328 GHz

Beam size

CH_3OH, N=2-1
96.741 GHz



Emission of CCH not exclusively associated with the protostars => High resolution needed!

High resolution will be crucial to probe only the protostellar envelopes

CCH and CH_3OH may not be suitable to characterise protostars with single-dish observation, the emission being likely dominated by large-scale cloud.

Session # 5
Solar system

Jean-François Lestrade

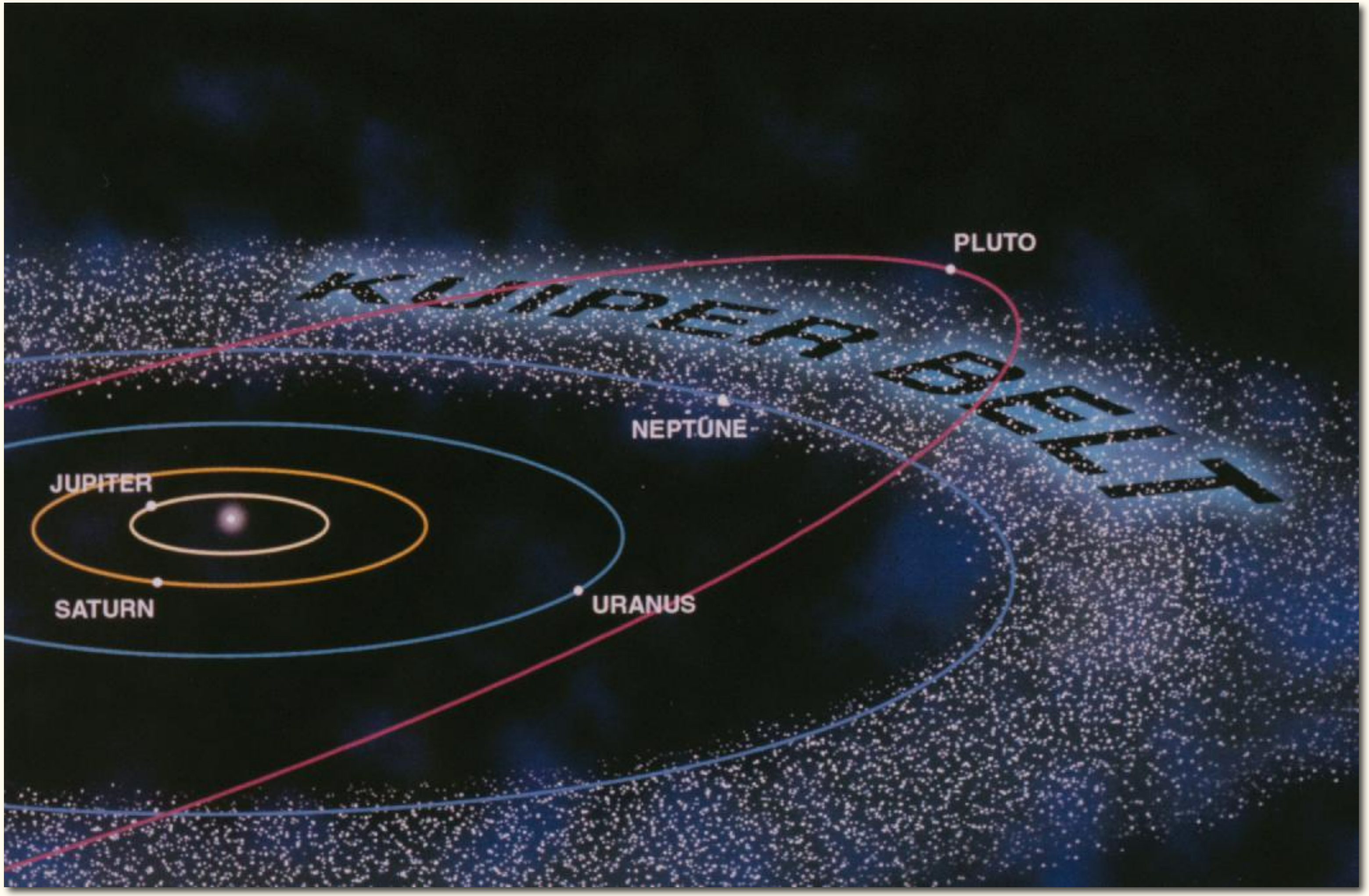
Debris discs

DEBRIS DISKS

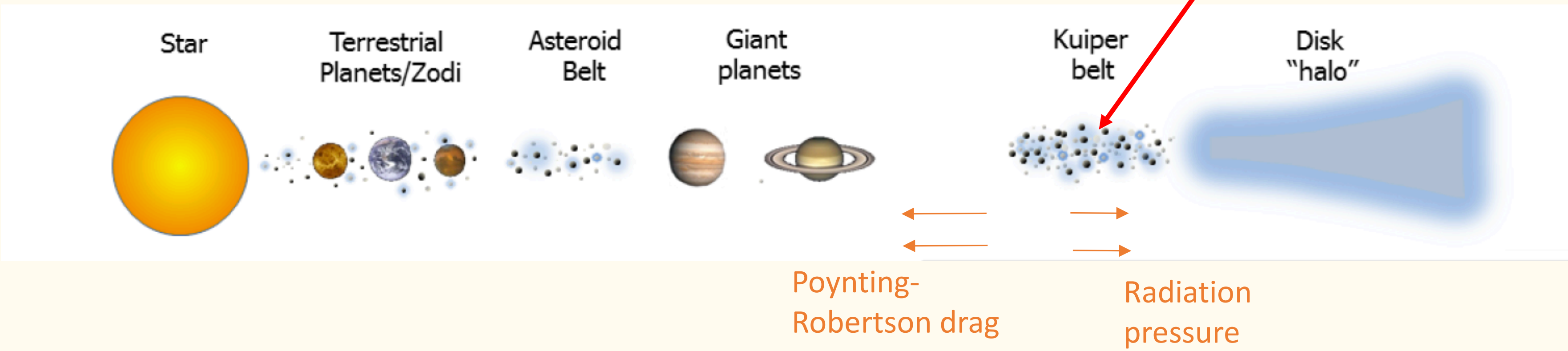
Jean-François Lestrade

Observatoire de Paris – CNRS
jean-francois.lestrade@obspm.fr

The Edgeworth-Kuiper Belt of the Solar System



In **exo**-Kuiper belts (debris disks), we do not observe individual KBO's directly but dust from their mutual collisions.



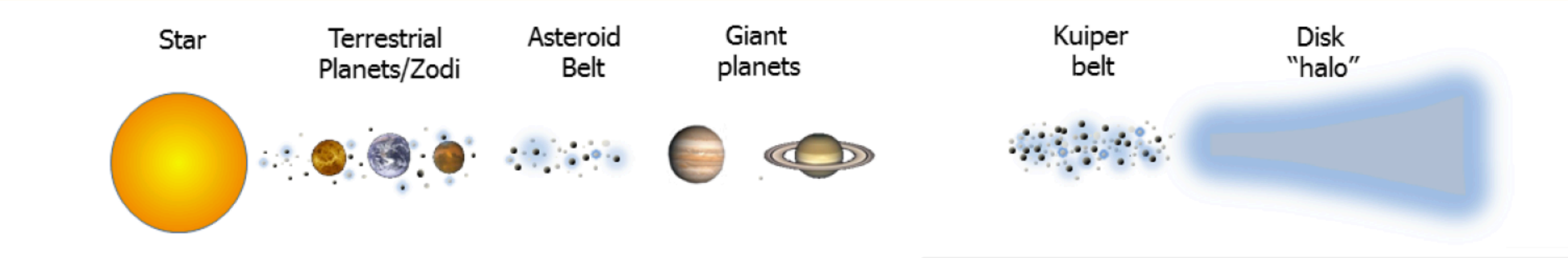
Collisional cascade :

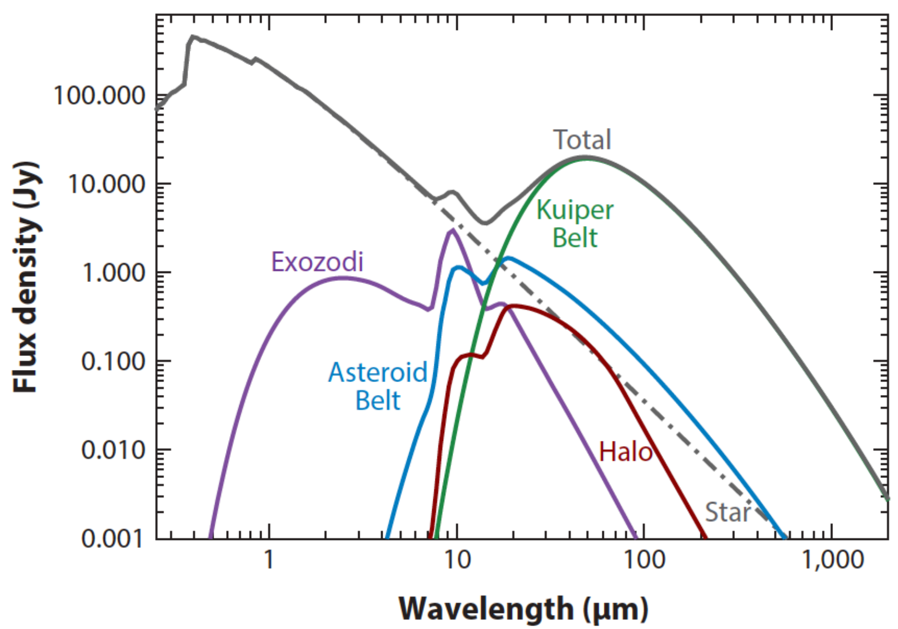
$$\text{Dust size distribution :} \quad dN \propto a^{-3.5} da$$

$$\text{Blow out size :} \quad D_{bl} \propto L_*^{5/7} \times \frac{1}{\rho}$$

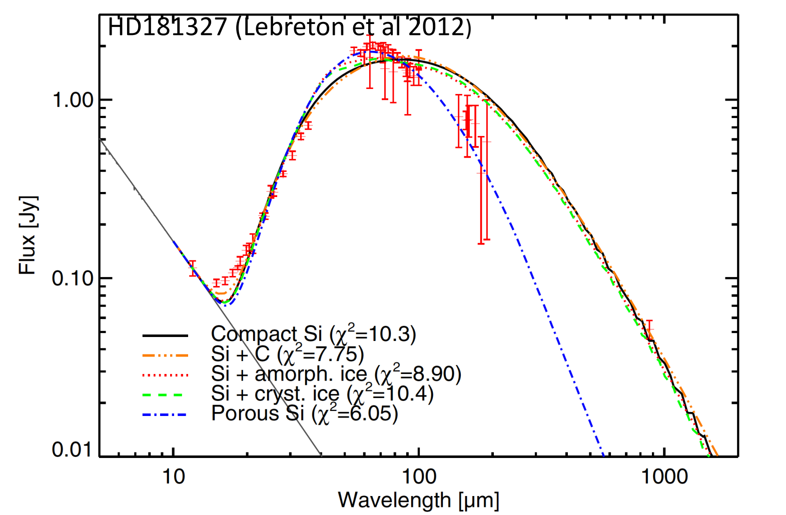
Adapted from Hughes et al (2018) and Holland (2019)

Disk dust detected as excess above photospheric emission by photometry





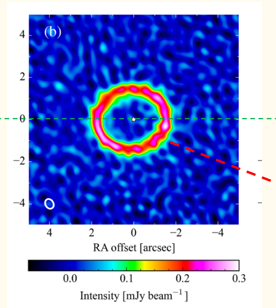
Fractional dust luminosity : $f_d = \dfrac{L_{dust,IR}}{L_*}$



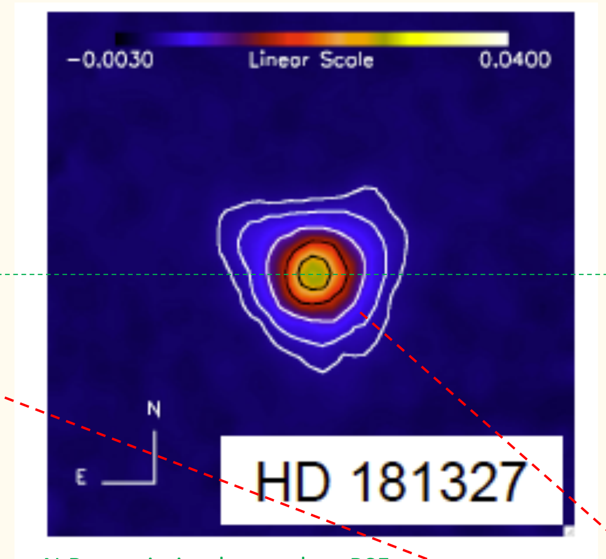
Adapted from Hughes et al (2018)
and Holland (2019)

Disk dust imaged in thermal emission and scattered light

ALMA 1.3mm

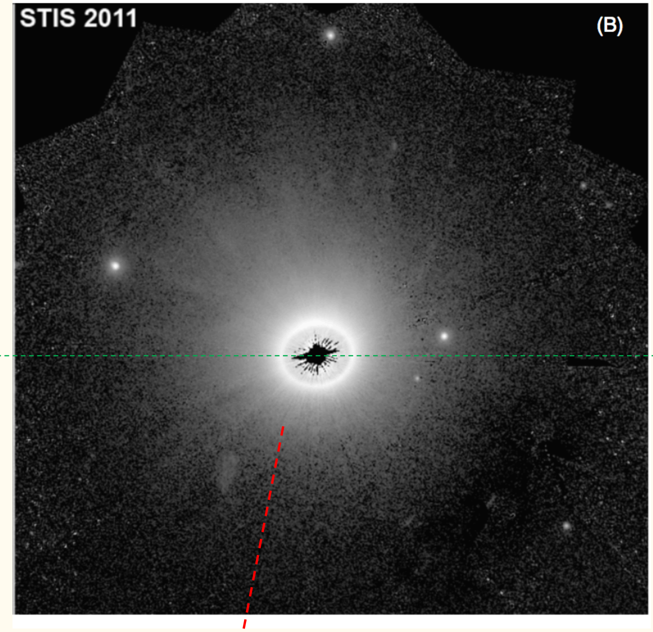


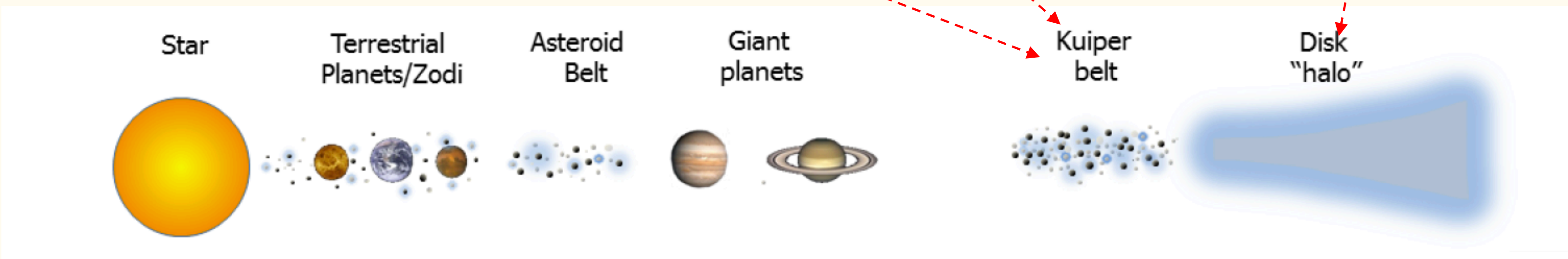
Herschel 70 micron



N.B. : emission larger than PSF

HST/STIS





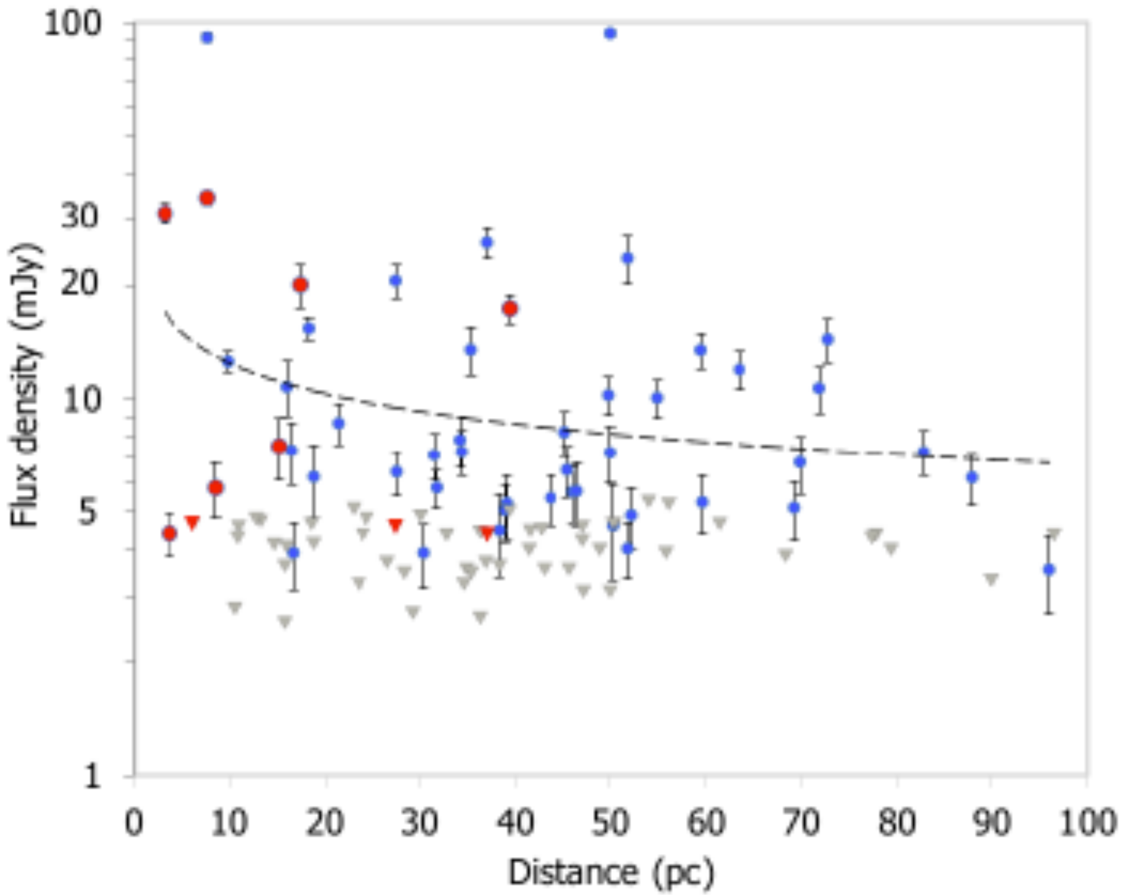
Progress to date

Studies of debris disks falls into two categories :

a) place debris disks in context with **statistical samples,** mostly by **photometry,** providing correlations with stellar properties (age, spectral type, metallicity) and known planets.

b) probe architectures and properties of **individual systems**, specifically by **high angular resolution imaging**.

SONS: SCUBA-2 Observations of Nearby Stars (SONS)
The JCMT legacy survey of debris discs in the submillimetre



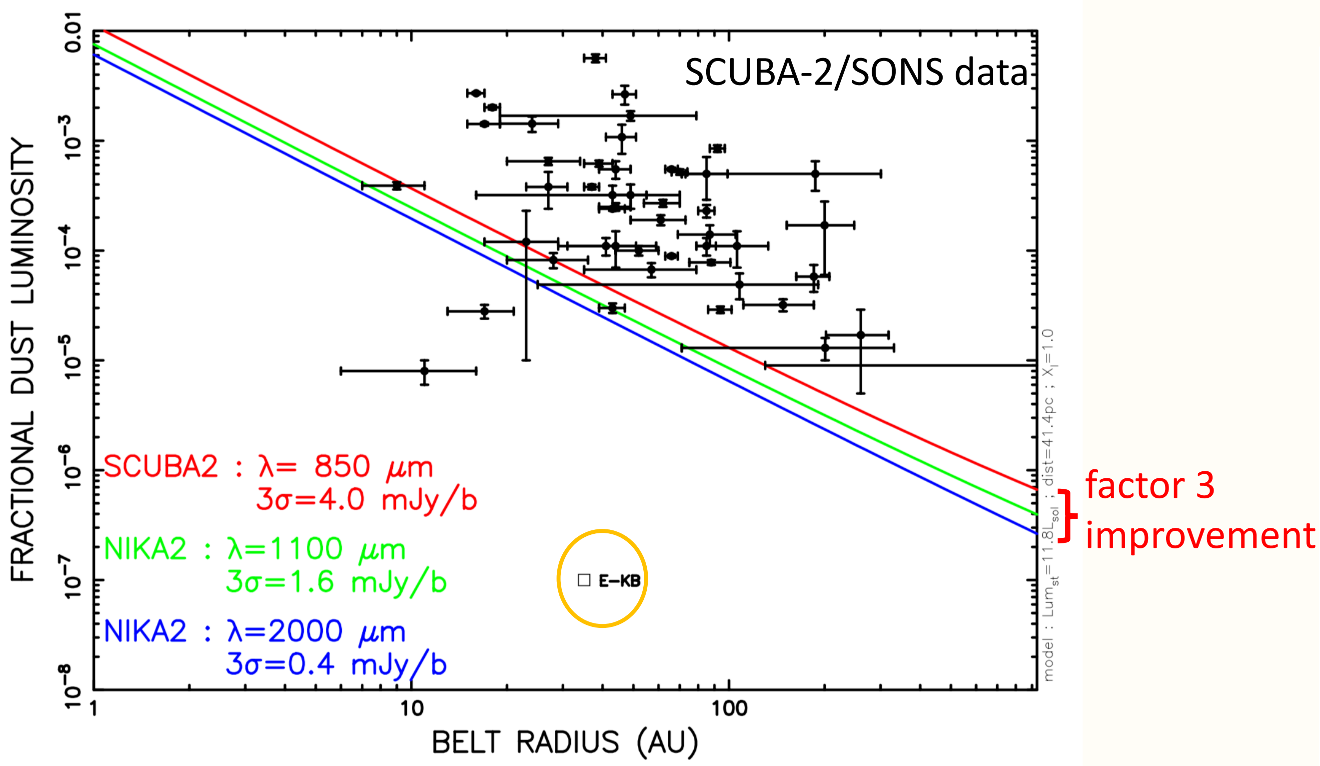
Red circle : detected disk with known planets

Holland et al 2017

GOAL :
115 target stars
270 hrs
1σ=1.0 mJy per star at 850µm

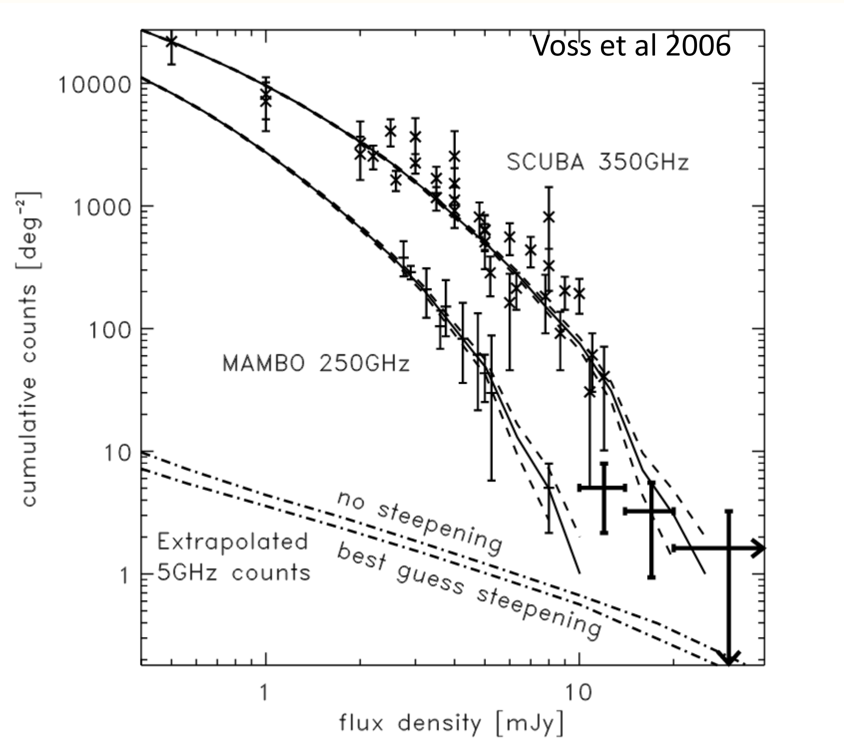
OBSERVED :
100 stars
1σ=1.4 mJy per star at 850µm

Photometry : deeper survey of debris disks with NIKA-2 at 2mm



$$\mathrm{f_d} \propto \mathrm{flux_{lim}} \times d^2 \times r_{BB}^{-2} \times [B_\nu(\nu, T_{dust})]^{-1}$$

Cumulative extragalactic source count $N(S>S_0)$



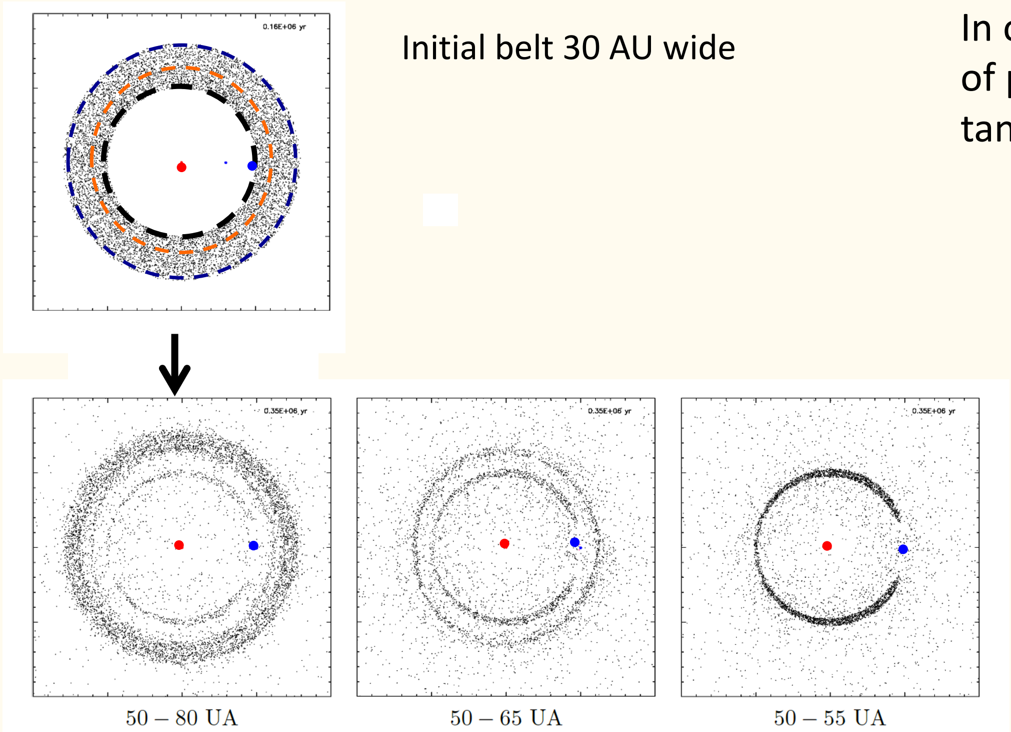
Confusion limit : about 1-2% chance to hit an extragalactic source within the beam for the three surveys.

Sculpting disks under the gravitational influence of a planet

Mean motion resonance 3:2

Mean motion resonance 2:1

Resonance 1:1



Initial belt 30 AU wide

In our S.S. : TROJANS are a population of primitive asteroids orbiting in tandem with Jupiter

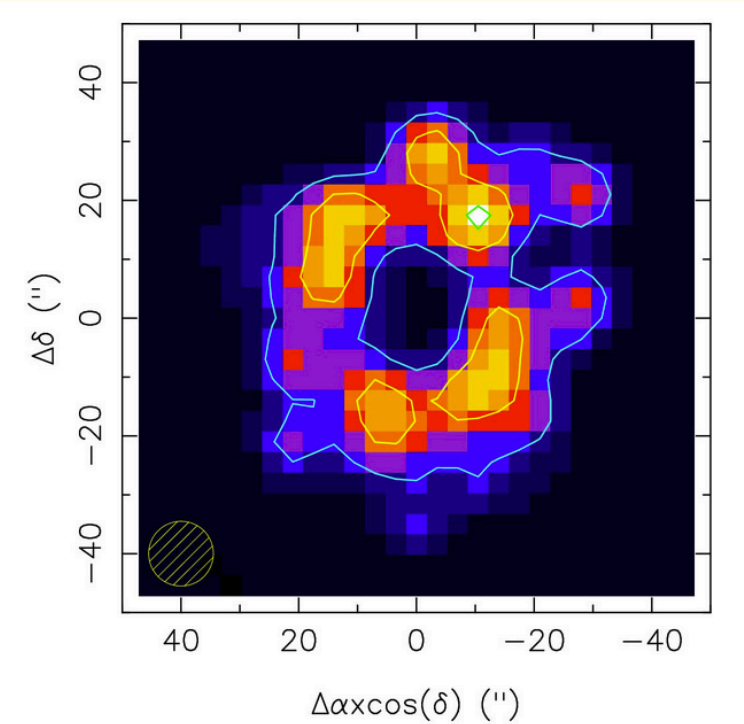
Stepping through disk width ΔR_D (30, 15, 5 AU)

Fixed parameters :

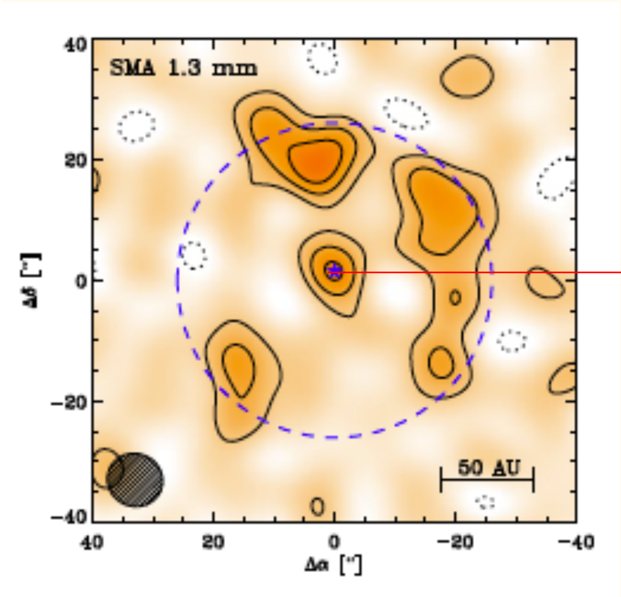
Planet : $a_{pl}=50$ AU, $e_{pl}=0.0$, $i_{pl}=0.0°$, $\mu=m_{pl}/m_*=10^{-3}$

Disk : $R_{inner,D}=50$ AU, $i_D=+/-3°$, $e_{max}=0.05$

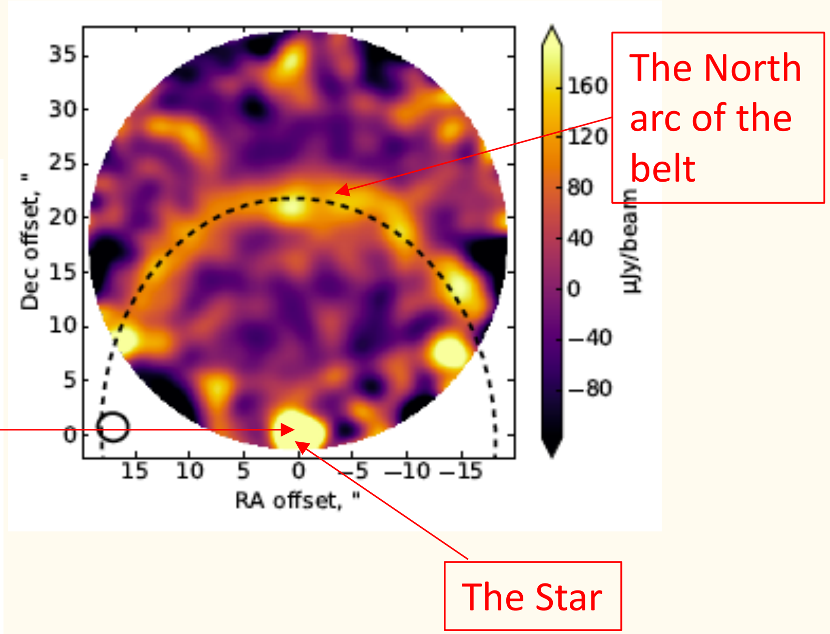
Imaging : the closest disk around the K2-type star Epsilon Eridani at 3.2 pc



Disk around Epsi Eri with MAMBO (11.2hrs) with a beam of 11''
+2σ,+3σ,+4σ
(Lestrade et al 2015)

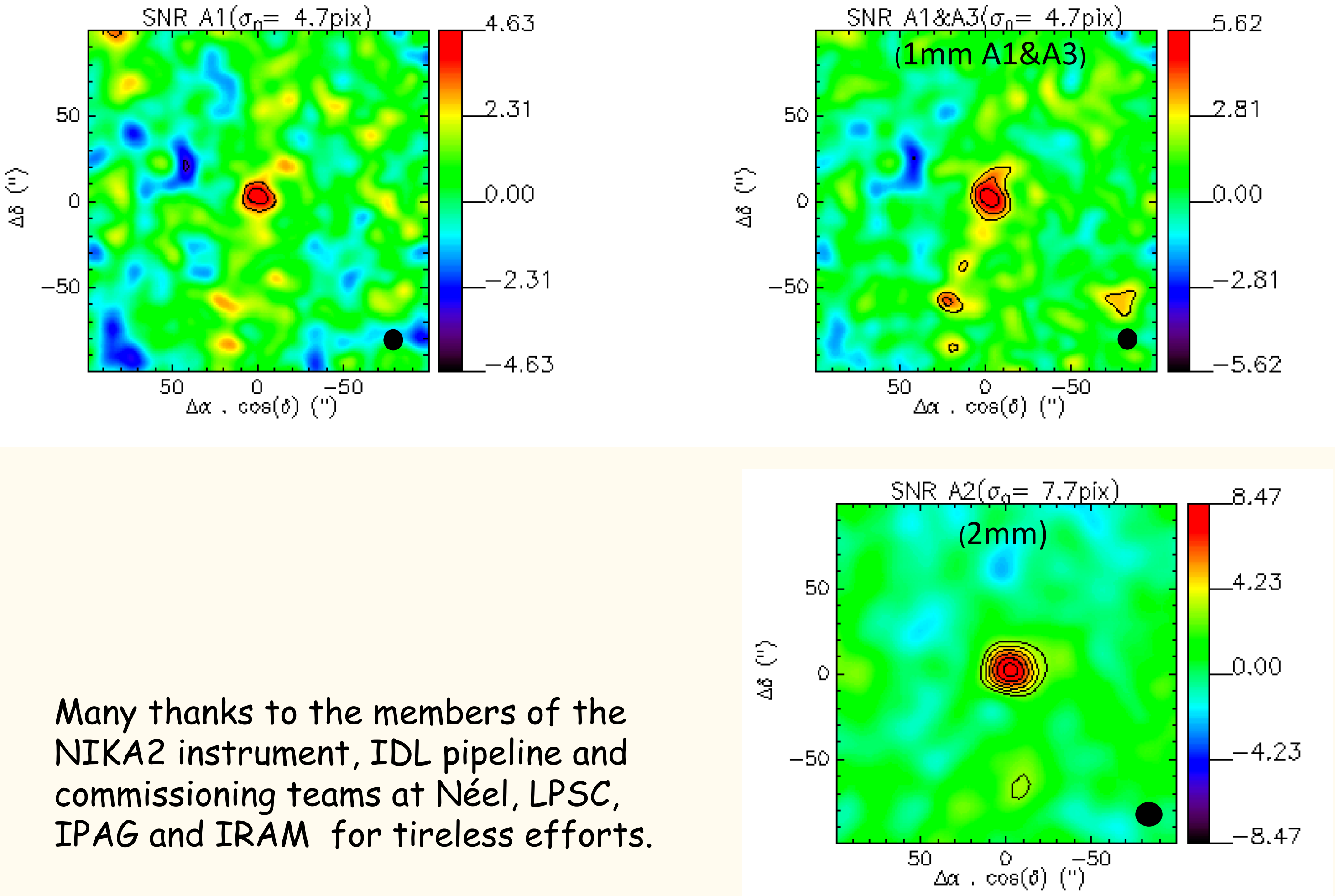


Disk around Epsi Eri with SMA at 1.3mm with a synthesised beam of 9.2'' x 7.0'' +3σ,+5σ,+7σ
(McGreggor et al 2016)



North arc of the disk around Epsi Eri with ALMA at 1.34mm with a synthesised beam of 1.6'' x 1.1'' (Booth et al 2016)

HR8799 NIKA-2



Many thanks to the members of the NIKA2 instrument, IDL pipeline and commissioning teams at Néel, LPSC, IPAG and IRAM for tireless efforts.

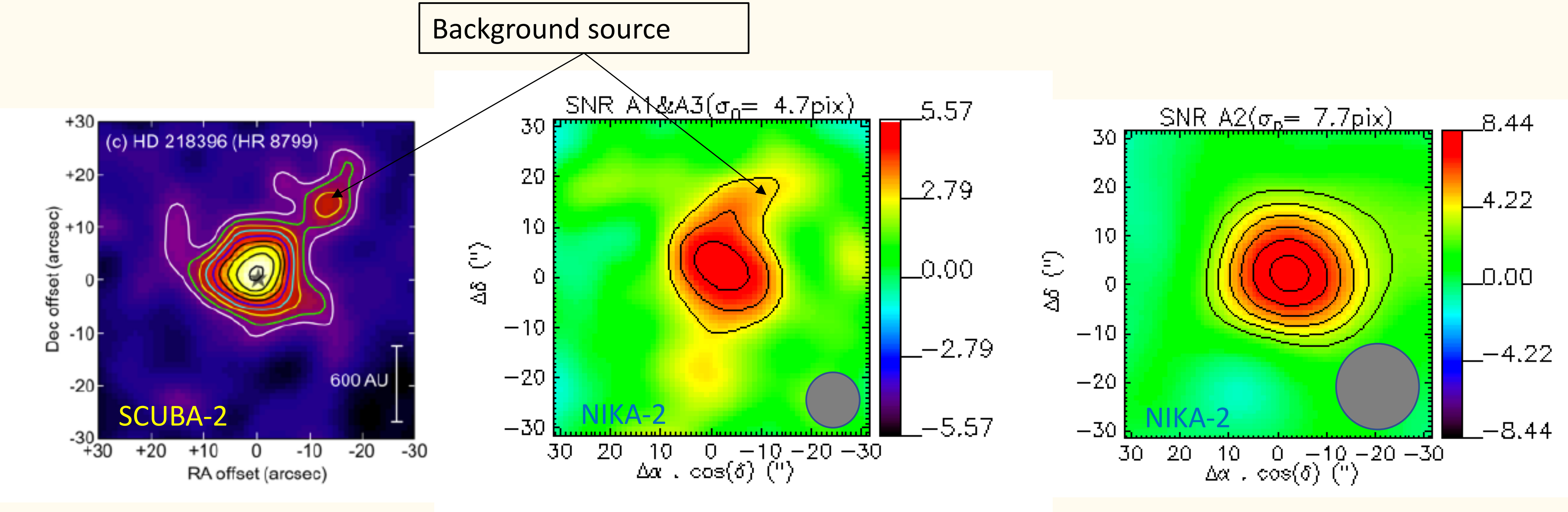
Peak brightness at 1mm : 3.0mJy/b

Peak brightness at 2mm : 1.2mJy/b

T_int=3hrs (29 & 30 october 2017)

Contours : +3σ, +4σ,+5σ, …

HR8799 NIKA-2



HR8799 SCUBA2 850µm
Peak brightness 10.9 +/-1 mJy/b
Contours : +4σ, +6σ, ….+20σ
Holland et al 2017 (SONS survey)

HR8799 NIKA2 1150µm
Peak brightness 3.0 +/-0.6mJy/b
Contours : +3σ,+4σ,+5σ

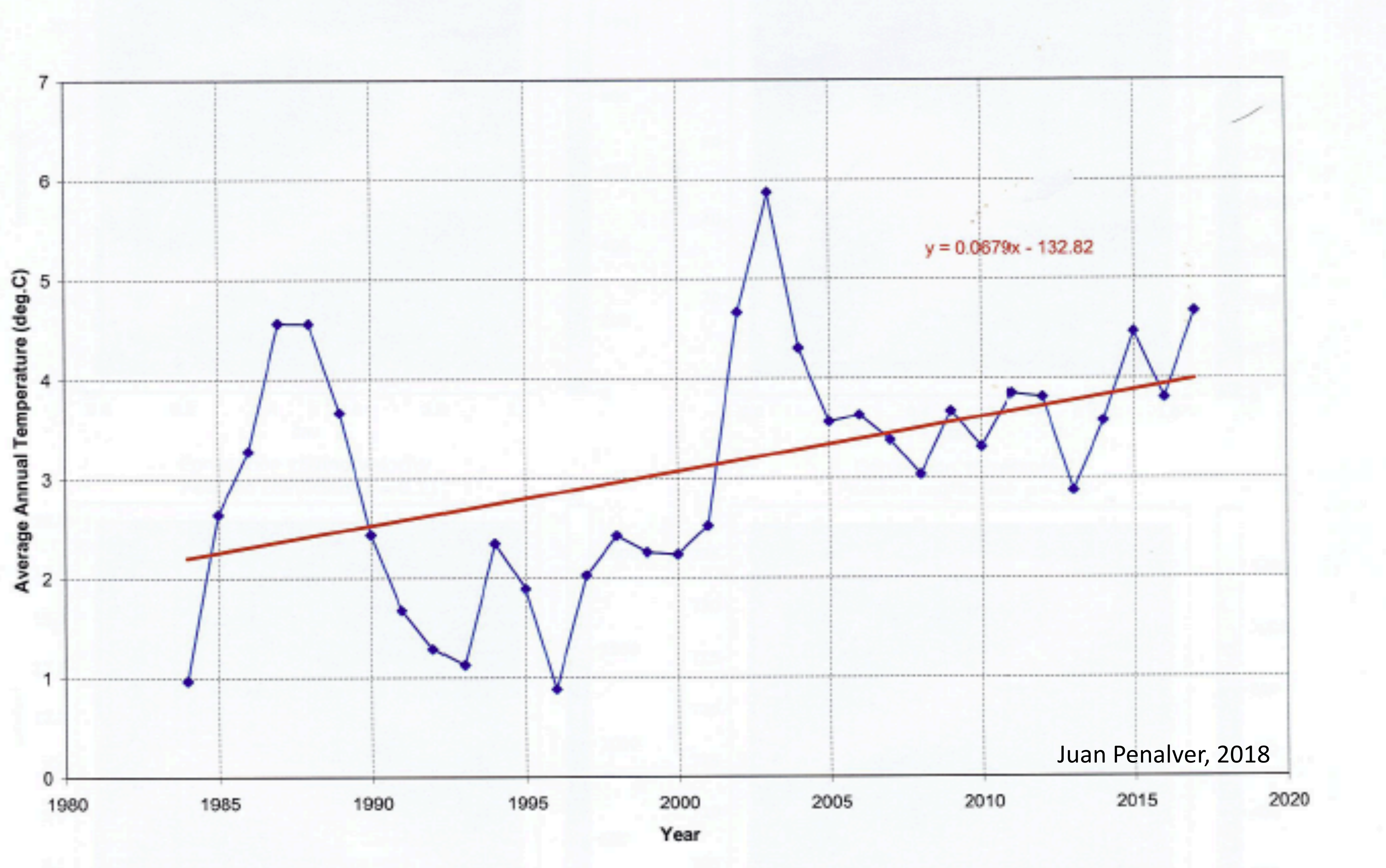
HR8799 NIKA2 2000µm
Peak brightness 1.2 +/-0.15mJy/b
Contours : +3σ,+4σ,…. ,+8σ

Concluding remarks

Understanding why debris are left at some particular radius from the host star is key to better understanding planet formation processes.

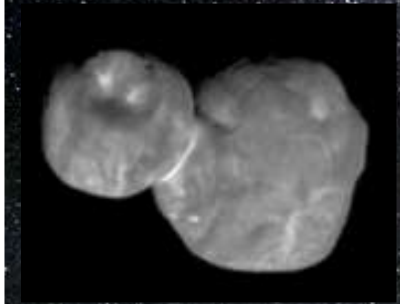
Outgasing from exocomets in extra solar planetary systems is amendable to high resolution spectral observations.

Debris disks we can detect are nearby (< 50 pc) and single dish observations are key to recover all the emission.


Average Annual Temperature (deg.C)
y = 0.0679x - 132.82
Year
Juan Penalver, 2018

Nicolas Biver

Solar System observations with IRAM-30m and NOEMA



Solar System observations with IRAM-30m and NOEMA,…

N. Biver, E. Lellouch, J. Boissier, R. Moreno, et al.

Comets

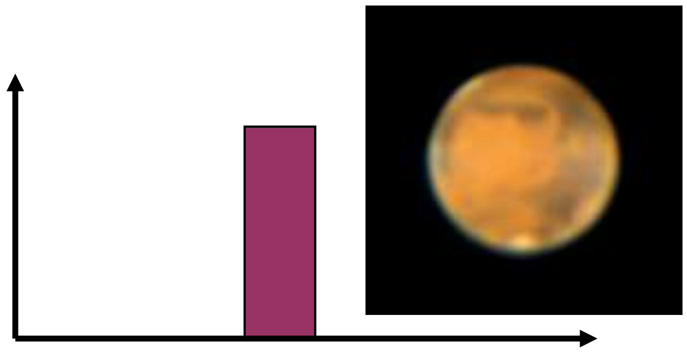
Planetary atmospheres

Trans-neptunian objects

l'Observatoire de Paris — LESIA
Laboratoire d'Études Spatiales et d'Instrumentation en Astrophysique

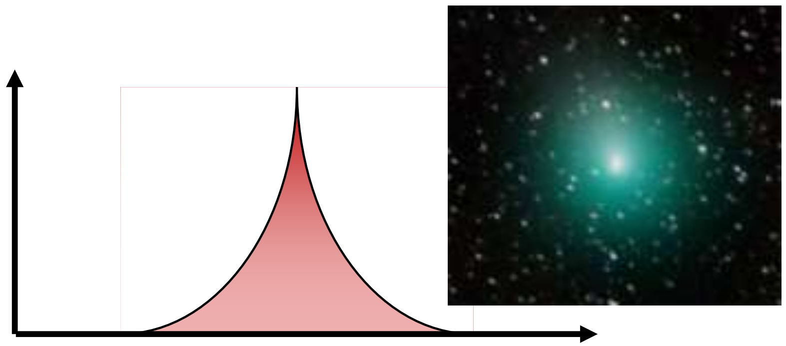
Source and line mm profiles

Planets atmospheres Comets "atmosphere" TNOs, asteroïds



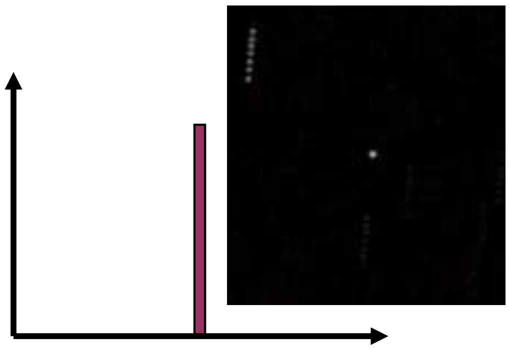
angle

Finite, small disk
Resolved or not



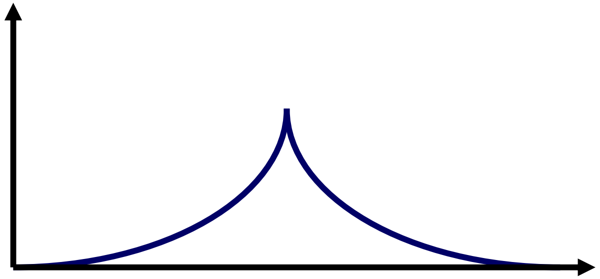
angle

No edge,
1/r column density profile



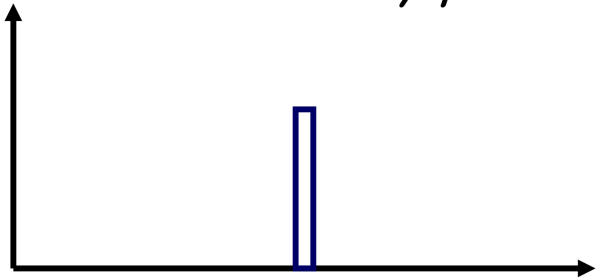
angle

Point source,
unresolved



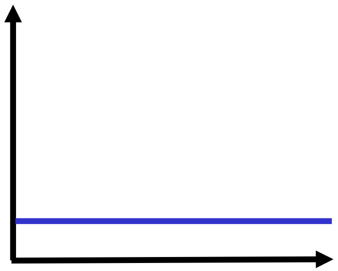
frequency

Broad (GHz) lorentzian lines



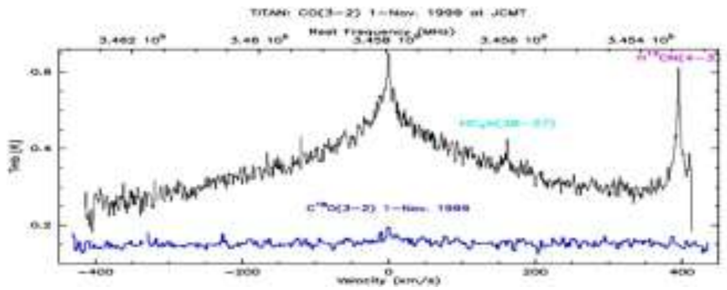
frequency

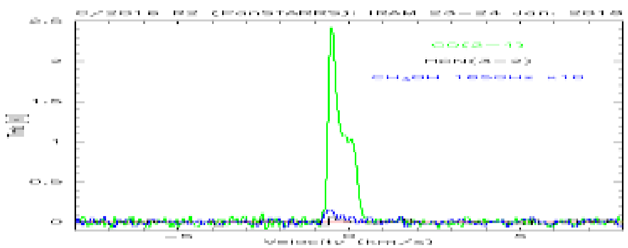
Sharp, very narrow lines



frequency

Continuum





Emission lines in cometary atmospheres

Historical background:

Molecules detected remotely in comets in the IR-Radio (in addition to OH/H_2O):

1989: 2 molecules (HCN,H_2CO)

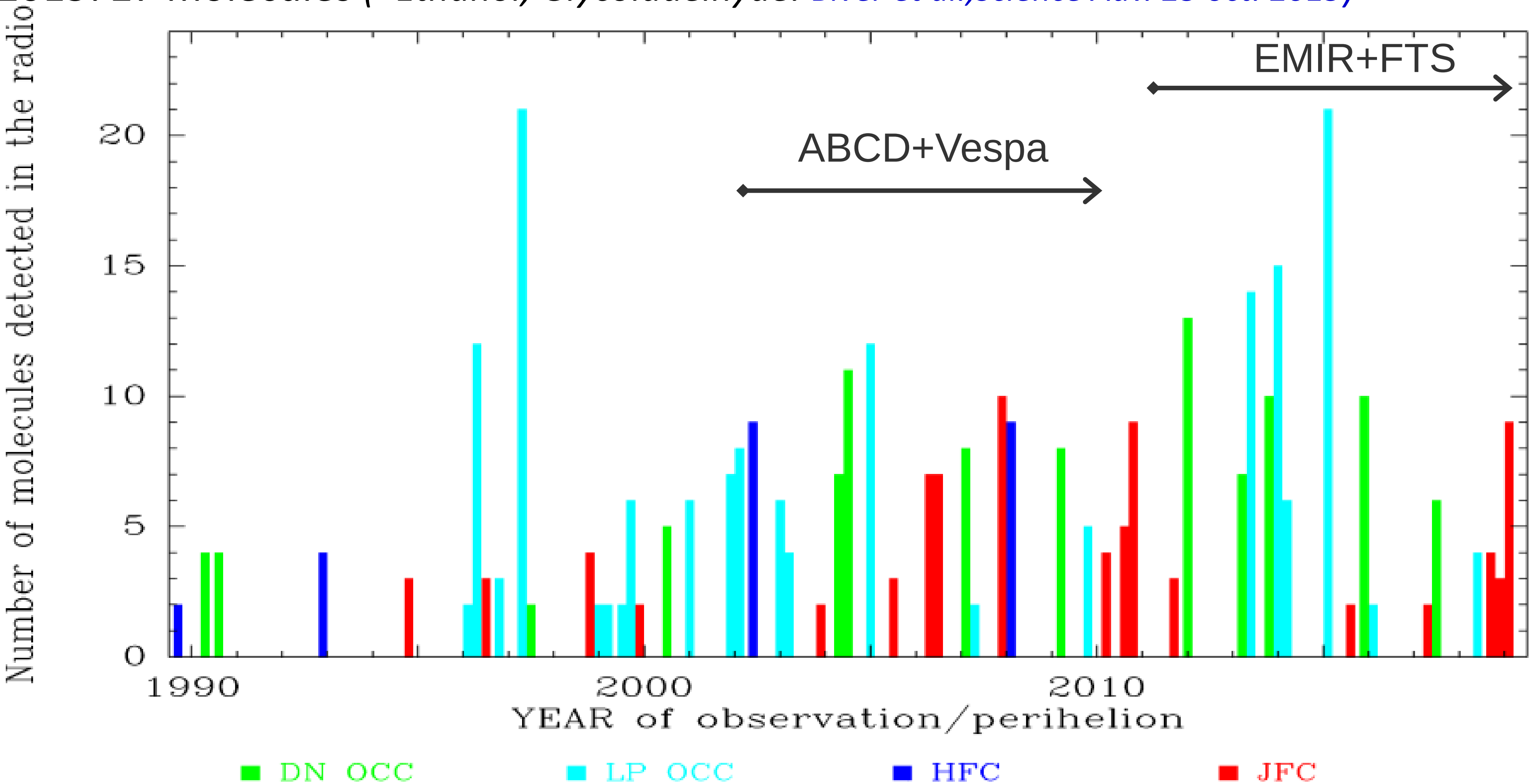
1990: 4 molecules (+H_2S, CH_3OH)

1994: 5 molecules (+CO)

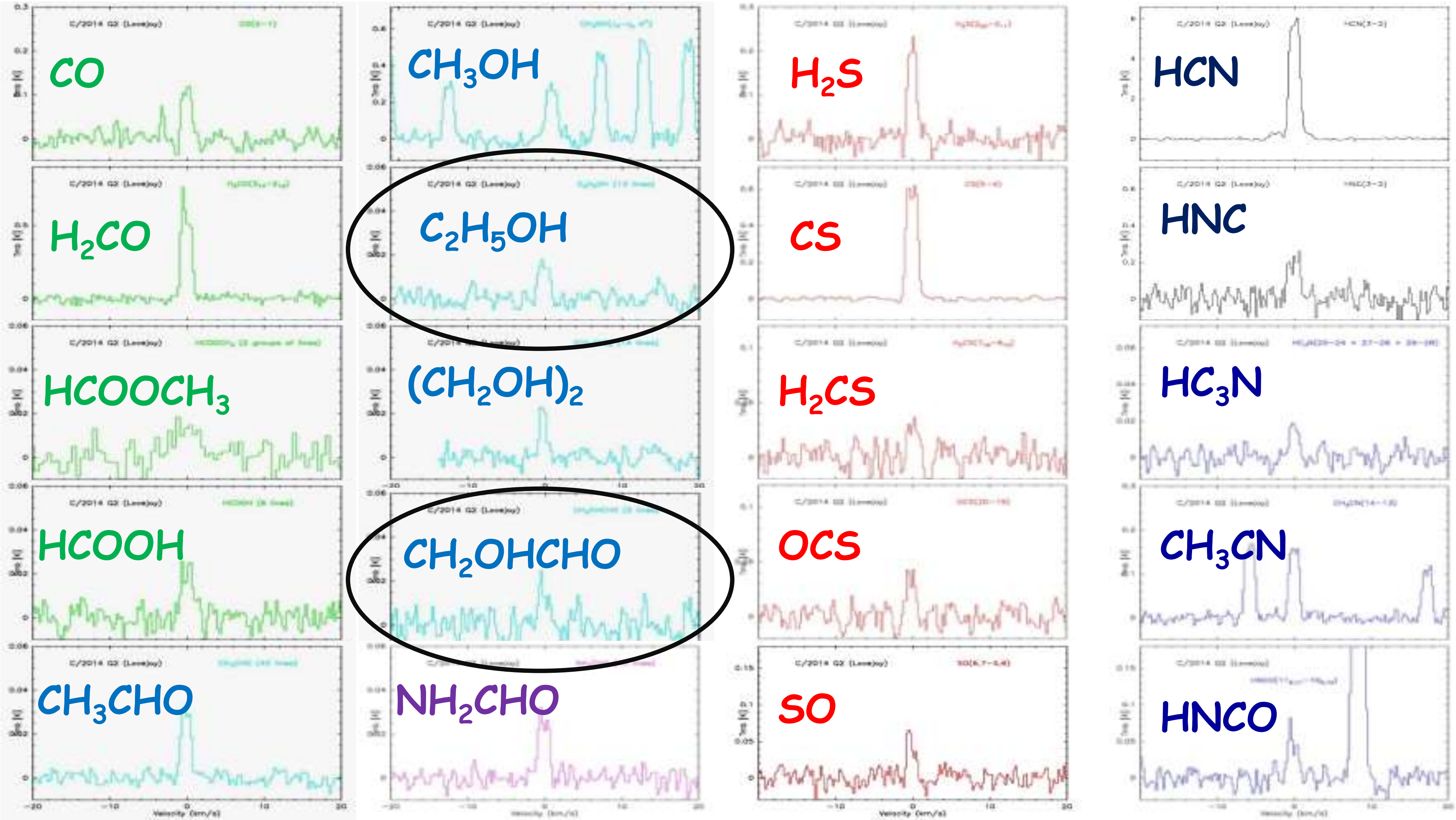
1996: 16 molecules (+CS, HNC, CH_3CN, HNCO, HC_3N, OCS, NH_3, CH_4,C_2H_2,C_2H_6, CO_2)

1997: 25 molecules (+SO, SO_2, NS, HCOOH, H_2CS, $HCOOCH_3$, CH_3CHO, NH_2CHO, $(CH_2OH)_2$)

2015: 27 molecules *(+Ethanol, Glycoladelhyde: Biver et al.,Science Adv. 23 oct. 2015)*

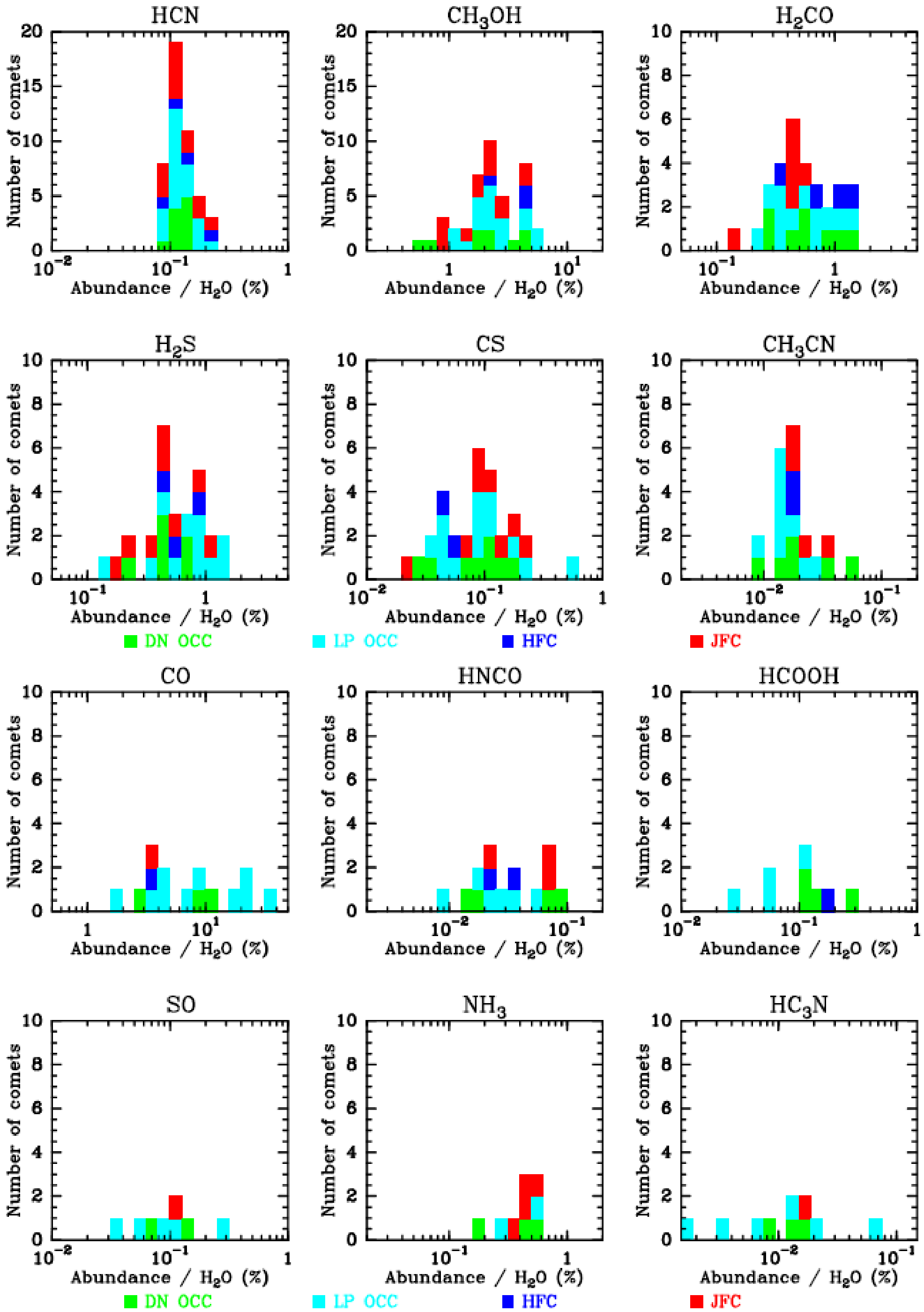


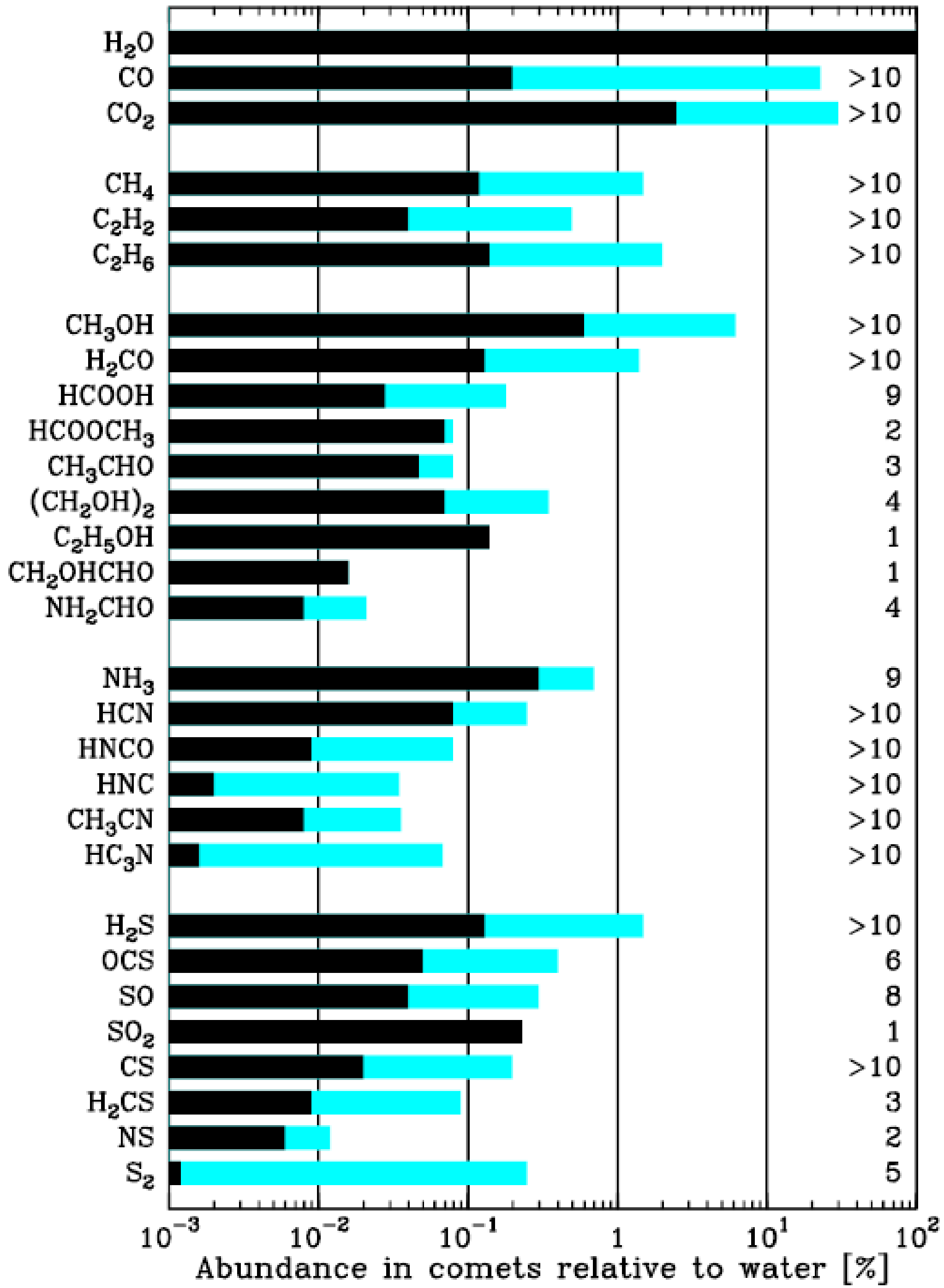

C/2014 Q2 (Lovejoy):
19+2 new molecules
IRAM – Jan. 2015
It's happy hour on comet Lovejoy! Nasa discovers space rock releasing as much alcohol as 500 bottles of wine every second
By ELLIE ZOLFAGHARIFARD FOR DAILYMAIL.COM


CO
CH$_3$OH
H$_2$S
HCN
H$_2$CO
C$_2$H$_5$OH
CS
HNC
HCOOCH$_3$
(CH$_2$OH)$_2$
H$_2$CS
HC$_3$N
HCOOH
CH$_2$OHCHO
OCS
CH$_3$CN
CH$_3$CHO
NH$_2$CHO
SO
HNCO

Diversity in the Composition of comets (and dynamical category)

(Bockelée-Morvan & Biver, Phil. Trans. R. Soc. 2016)

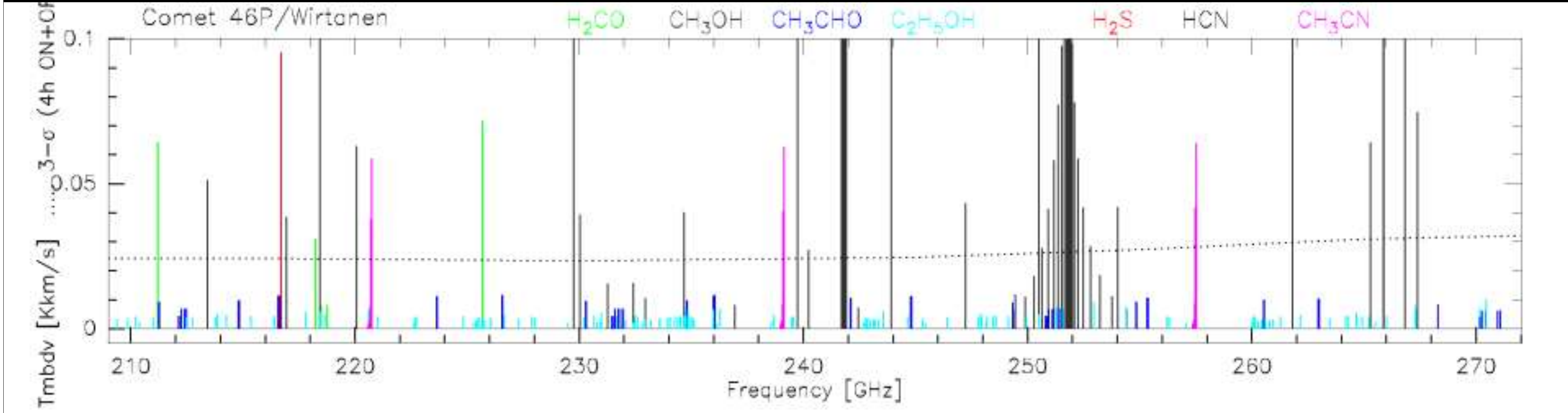


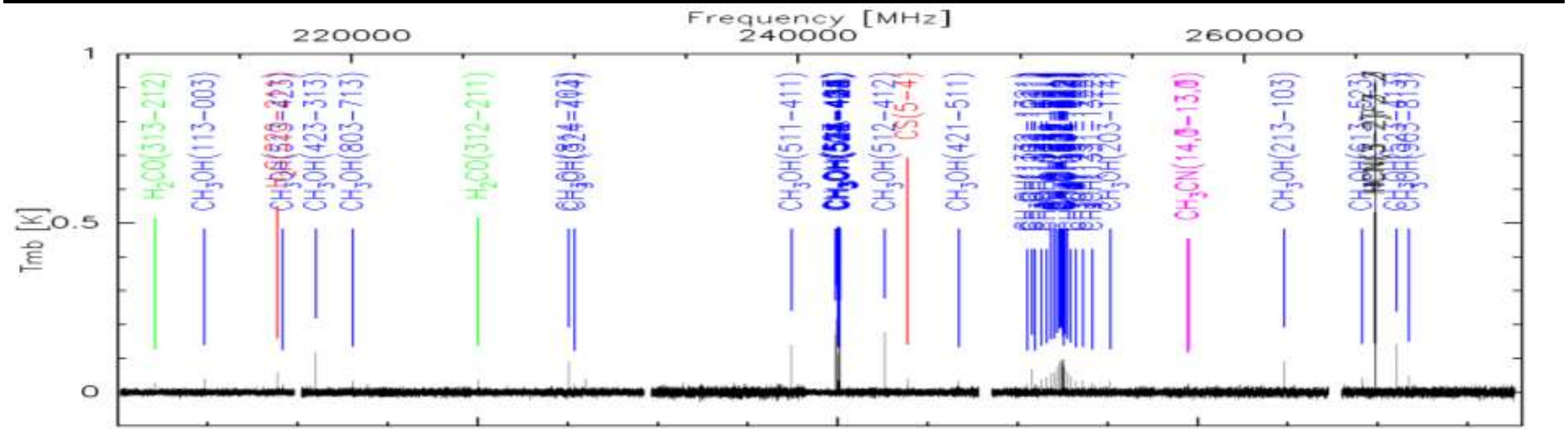


Cometary line intensities and frequency surveys

Rotational lines: energy spread over more and more lines with increasing molecular complexity, but with large survey, many lines can be recombined:

ex.: 209-272 GHz:	CO:	H_2CO	CH_3CHO	C_2H_5OH
	1 line	5 lines	64 lines	143 lines
∑Line areas (S/N)	15mKkm/s (2)	183mKkm/s (11)	502 mKkm/s (8)	568mKkm/s (6)



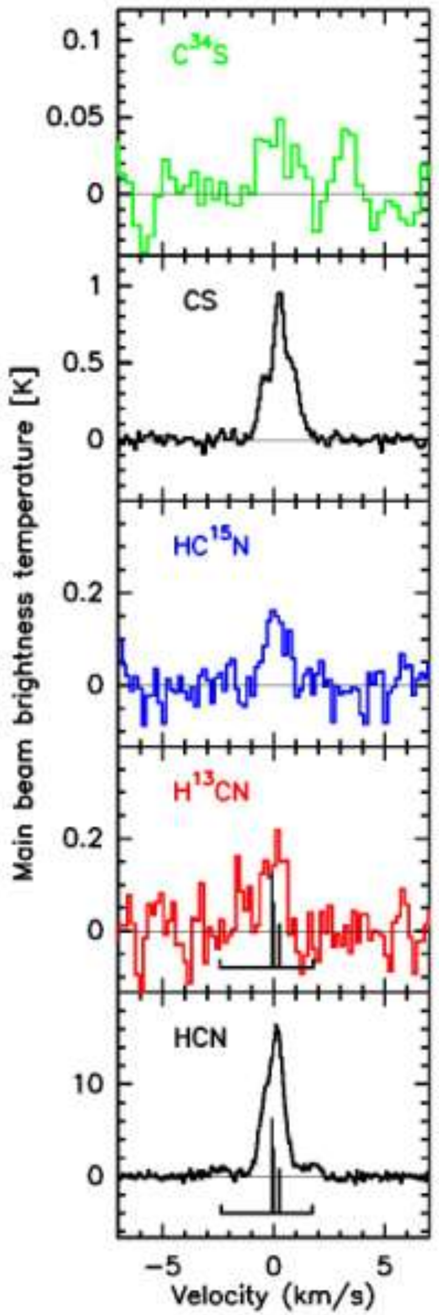


Sensitivity to detect COMs

Instantaneous frequency sampling needed to resolve the lines : df < 0.5 MHz,

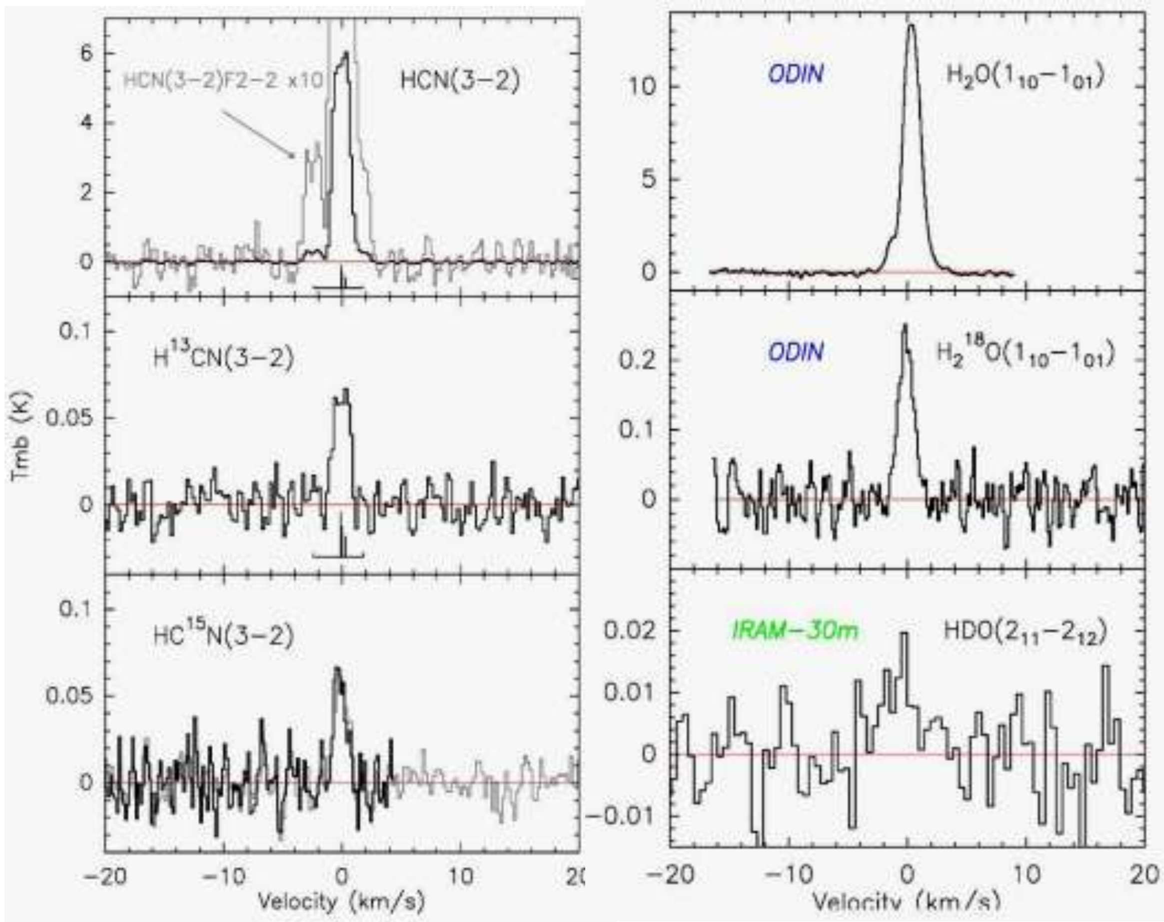
	Δf	Average number of CH_3CHO lines	S/N combined
IRAM-30m			
1997 + correlator:	2 x 0.5 GHz	1	0.5
2003→ ABCD+ Vespa	4 x 0.42 GHz	1.6	1
2012→ EMIR+ FTS	2 x 7.78 GHz	16	4
NOEMA 2018	4 x 1 GHz	4	
SD (autocorrelation 10 antennas)			3
ALMA 2018	4x 0.94 GHz	4	
C43-1			2.2
C43-6			0.3
TP (4 antennas)			2.5
SD (12m antennas autocorrelated - not possible yet)			*8*

Isotopes in comets



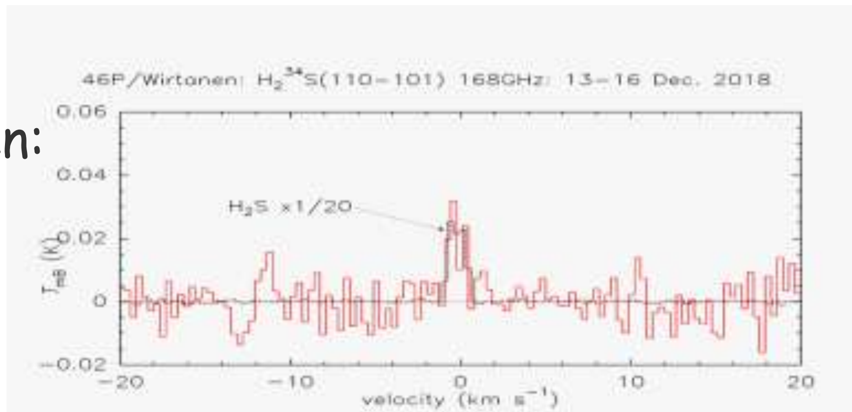
17P/Holmes: *(IRAM)*
Bockelée-Morvan et al. (2008)

$^{13}C/^{12}C$
$^{34}S/^{32}S$
$^{15}N/^{14}N$
$^{18}O/^{16}O$
D/H

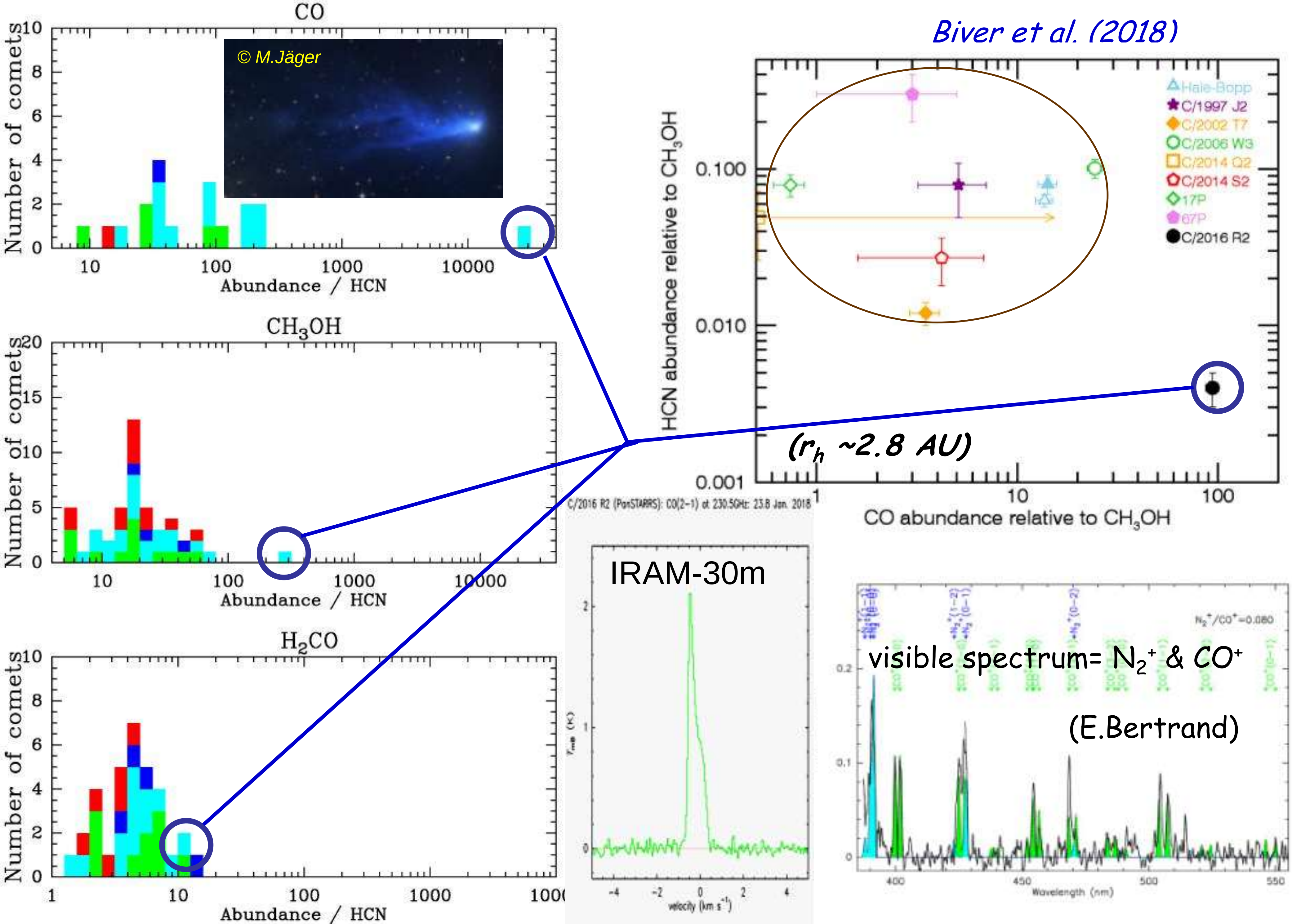


C/2014 Q2 (Lovejoy): *(IRAM/Odin/Nançay)*
Biver et al. (2016)

46P/Wirtanen:
IRAM
$H_2S/H_2{}^{34}S$,
dec. 2018



Blue comet C/2016 R2 (PanSTARRs): N_2/CO ~7% N_2/H_2O > 60%!



Summary

Recent highlights:

- Molecular diversity of comets *(Bockelée-Morvan & Biver 2016)*
- Detection of complex organic molecules: new molecules, diversity between comets for COMs *(Biver et al. 2014, 2015,…)*
- Isotopic ratio: D/H and $^{15}N/^{14}N$ *(Biver et al. 2016,…)*
- Spatial distribution (e.g. HNC with ALMA, *Cordiner et al. 2014, 2017*)
- Composition of atypical « blue comet » C/2016 R2 *(Biver et al. 2018)*

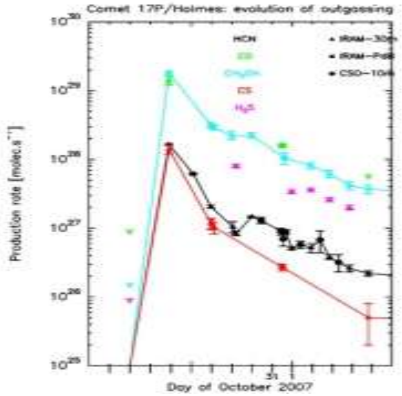
Need for Reactivity / TOO:

Comets can be unpredictable, on shorter time scales than normal proposal timeline:

- Outburst: e.g. 17P/Holmes: **x10000 in 24h**

  + exponential decrease **x1/10 in 3 days**
- late discovery / rise in activity: delay= 1-3 months

  (e.g. C/2018 Y1 discovered 2 months before perihelion)



Ephemeris at IRAM-30m:

Current two-body program used by the NCS lacks accuracy (**errors up to 25" and 0.2 km/s** for nearby sources)

- Need to check / map emission (→ multi-beam?)

→ option to use interpolated ephemeris (as with NOEMA/ALMA)?

Observations of planetary atmospheres:

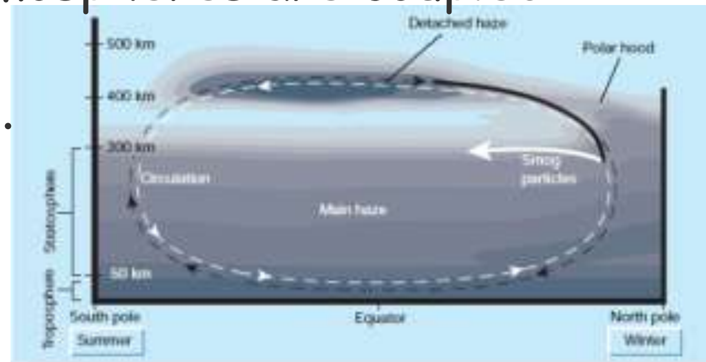
Planetary atmospheres

Pluto: 0.1" (ALMA) Titan: 0.8" (ALMA/NOEMA) - - - > Venus→62" (IRAM)

<u>Winds</u>: Spectral (Doppler shifts) + spatial resolution to resolve the disk → NOEMA
(for each observable compounds) ALMA

Chemical, thermal and dynamical state of planetary atmospheres are coupled:
the thermal field drives the wind field
→ affects the horizontal distribution of minor species.
→ impact the temperature field (heating/cooling).

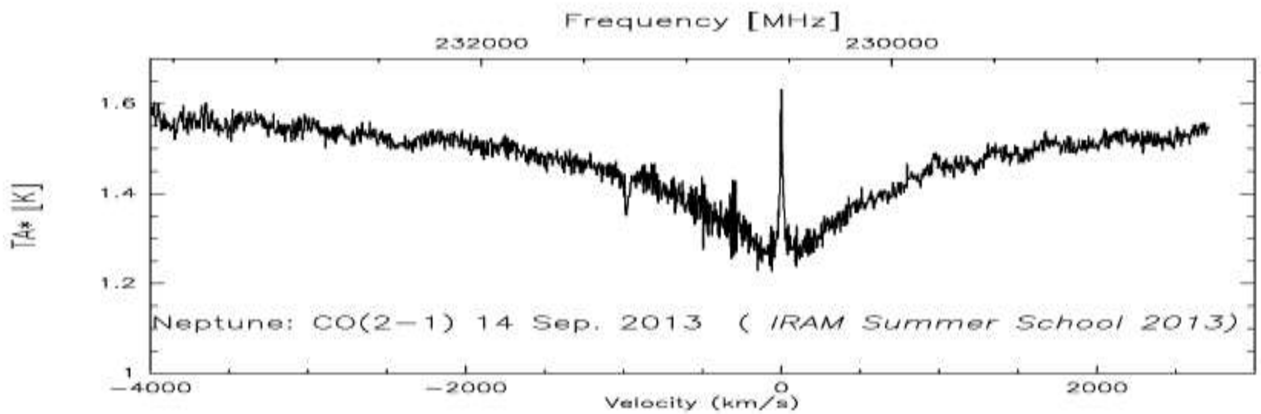
NOEMA → monitoring seasonal and variability effects

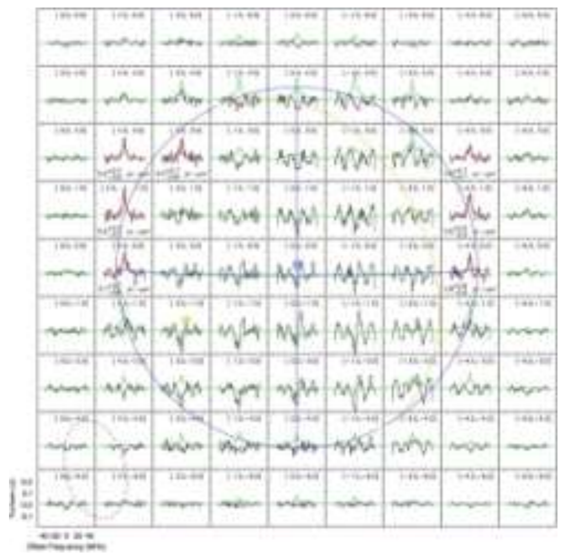


e.g. Atmospheric Circulation on Titan
(Rannou etal 2002, Hourdin etal 2004)

<u>Composition</u>:

Vertical distribution => need for wide band coverage and high spectral resolution



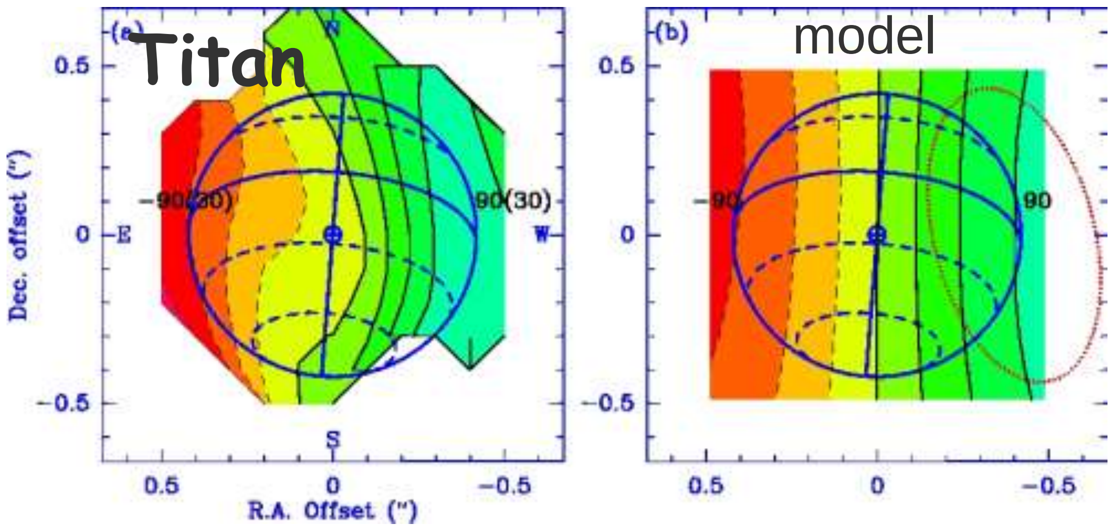


Local distribution: need for spatial resolution
(NOEMA/ALMA) + frequency coverage

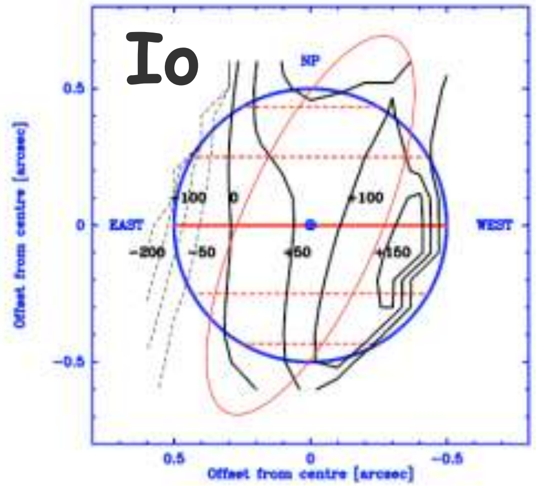
Trace species,
+ Cf Talk by T. Cavalié

HDO in Mars with PdBi in 2003
(Fouchet et al. 2011)

Winds observed with IRAM-PdBi

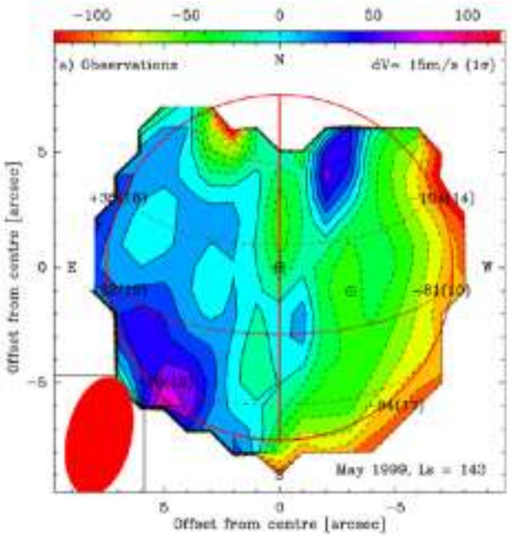


CH_3CN Wind= +160 m/s @300 km
(Moreno et al 2005)



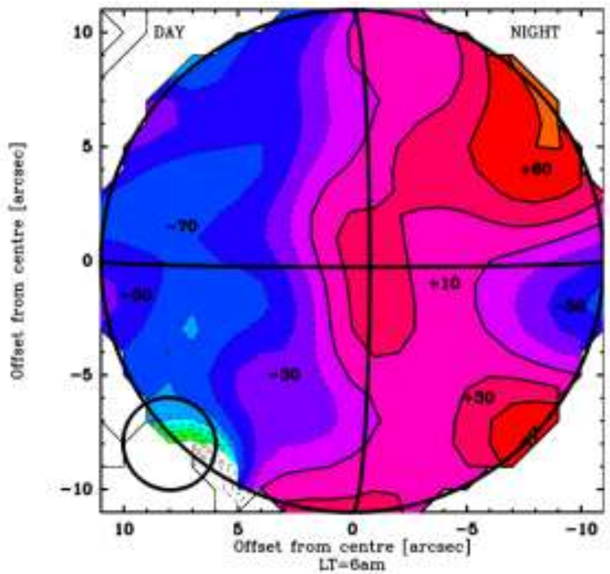
SO_2 :Dynamics not explained : prograde winds of ~200 m/s
(Moullet et al 2008)

Mars



CO(1-0):
Retrograde wind (70-170 m/s)
GCM + sensitive to dust distribution

Venus



CO(1-0):
Combination of subsolar-to-antisolar flow (SSAS) ~200 m/s and zonal retrograde wind. ~50 m/s

(Moreno et al. 2009)

(Moullet et al. 2012.)

Continuum emission of small bodies, TNOs

Comets nucleus size and coma properties with NOEMA

		NOEMA (2x16GHz) 8h/winter comet at 0.1 AU	1.0 AU
Detection of nucleus:	100 GHz	r=0.2km	2 km
	250 GHz	r=0.16km	1.7km

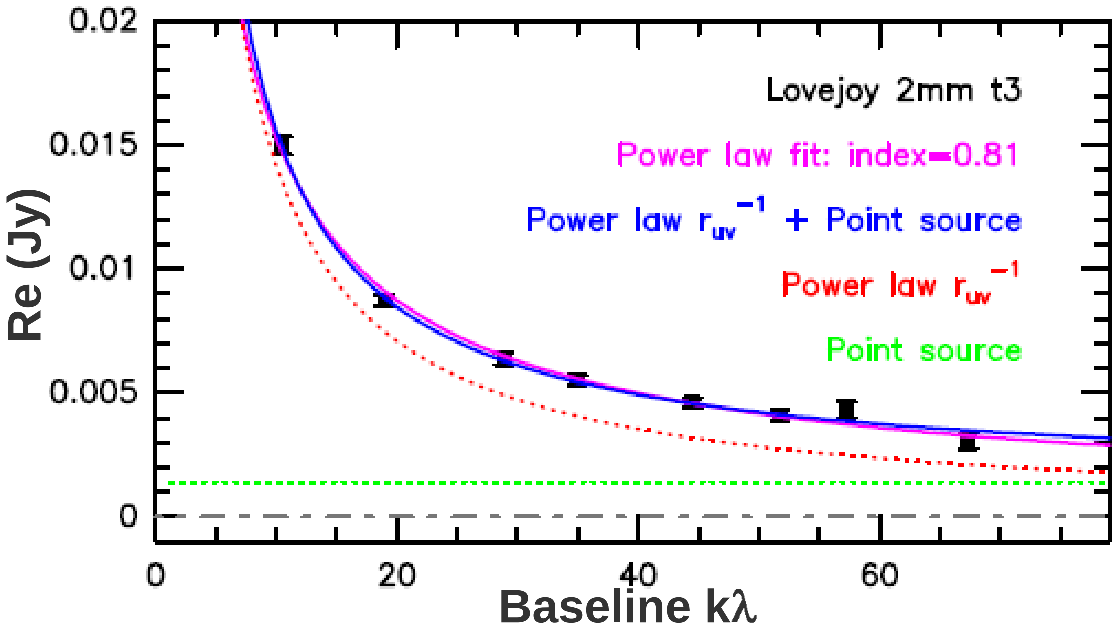
Thermal properties and rotation phase (e.g. 8P: *Boissier et al. 2011*)

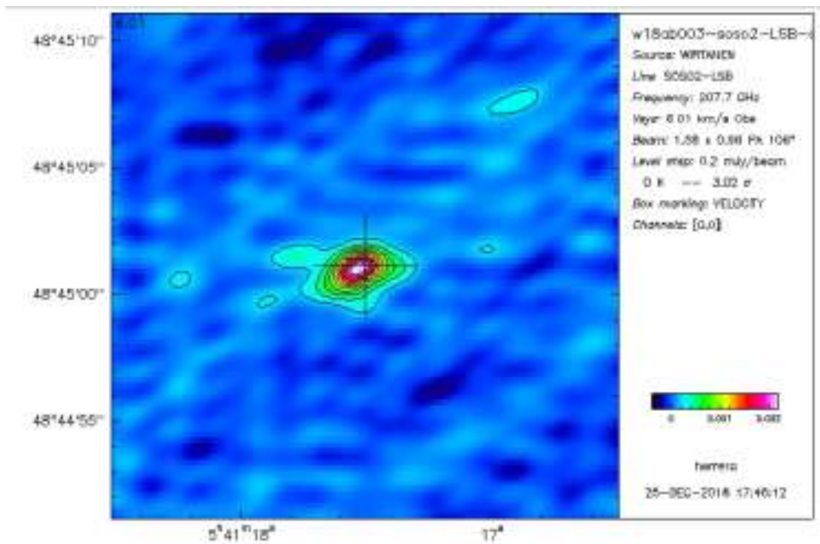
Dust properties (mass, size distribution, temperature) *(Boissier et al. 2012)*

Spatial distribution of molecules, temperature profile

(e.g. Boissier et al. 2014, Cordiner et al. 2017 (ALMA))

C/2014 Q2: Dust + nucleus continuum - 46P/Wirtanen: nucleus at 3mm

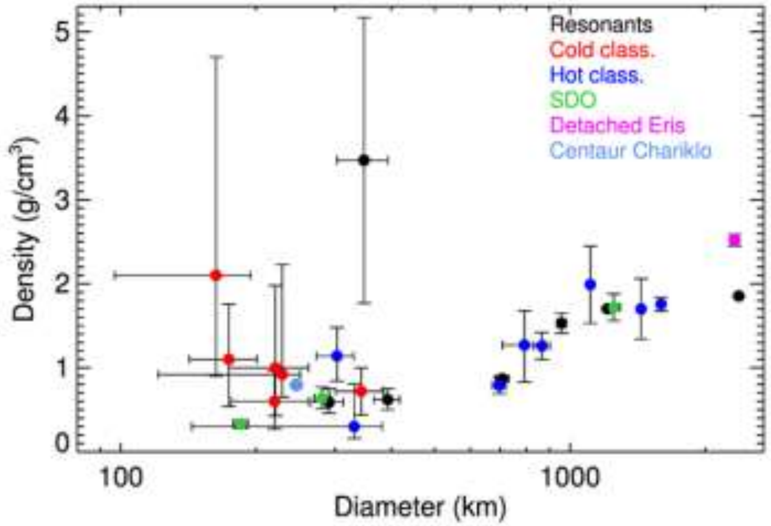




Thermal emission of Trans Neptunian Objects

- Thermal emission → size, albedo + *optical observations:*
  stellar occultation and light curves → shape
- Binary systems: *mass* + size → density

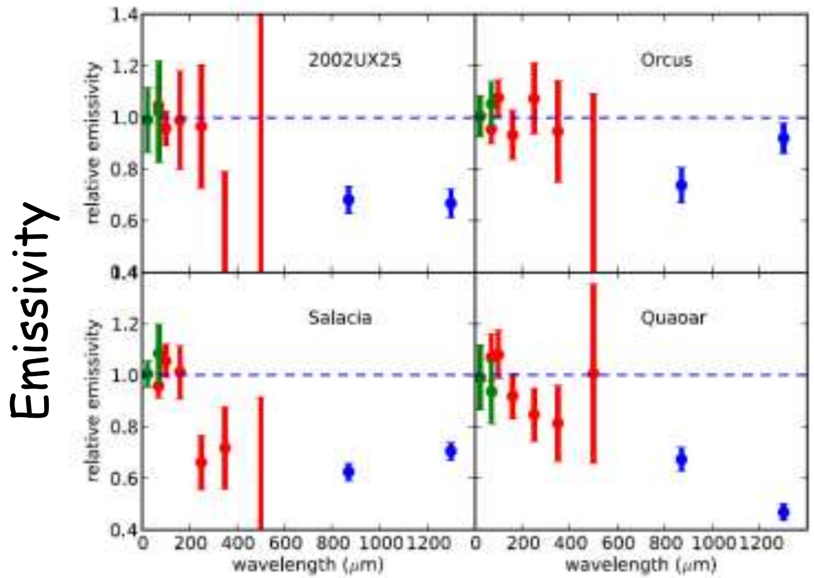
→Constraints on formation location and
mechanism



Müller et al. TNO book, 2019

- Shape → possible deviation from
  hydrostatic equilibrium (e.g. Haumea)
- Thermal properties: inertia, emissivity

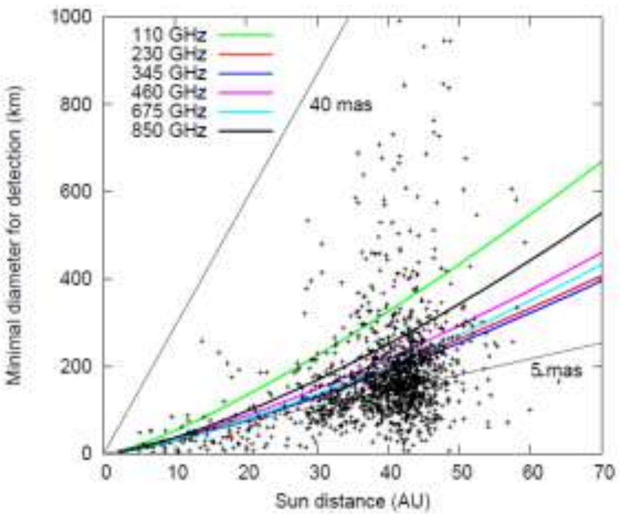
~180 objects measured (25 binary systems)
- mostly with Herschel/Spitzer
- From the ground:
  - IRAM, JCMT (~2000)
  - ALMA (2010+)



Brown et al. 2017, ALMA

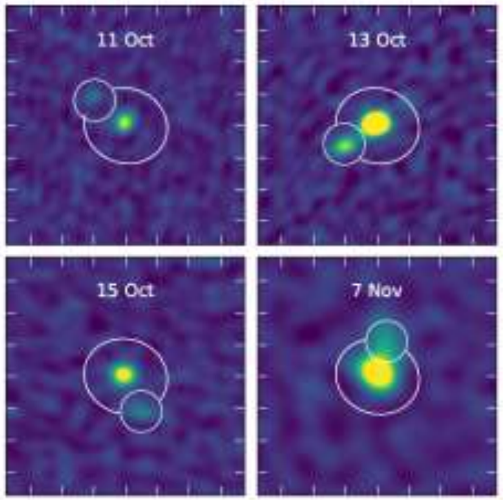
TNOs with IRAM & ALMA *(sizes = 5-40 mas)*

- Hundreds of object can be detected with ALMA *(Moullet et al. 2011)*
- About 15 object observed with ALMA, half binaries… but tough competition.



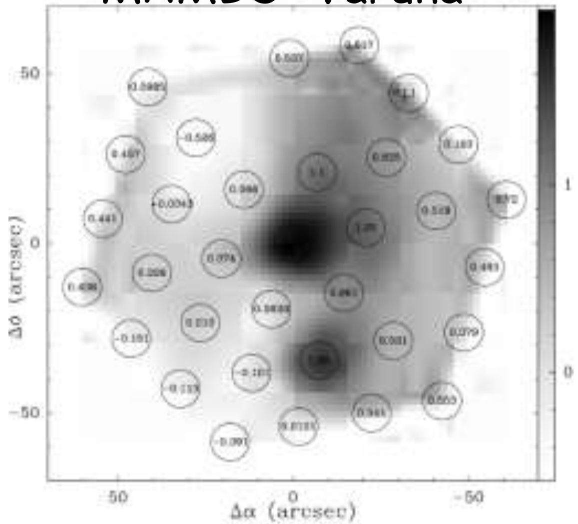
Moullet et al. (2011)

ALMA Band 7: Orcus/Vanth



Brown et al. (2018)

MAMBO: Varuna



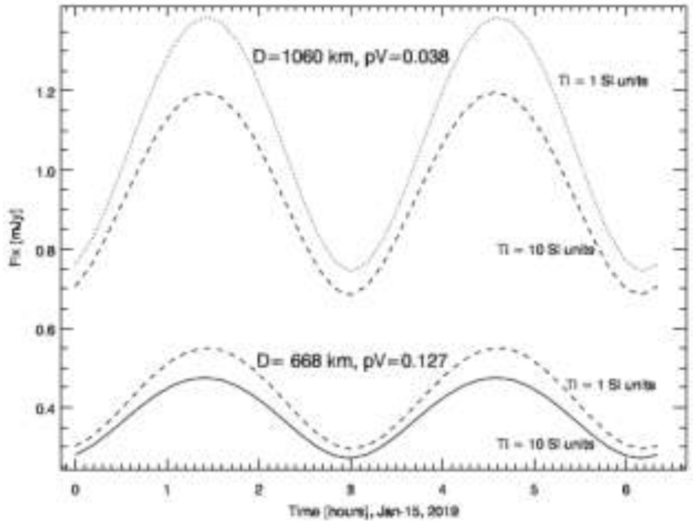
Lellouch et al. (2002)

- 1h NOEMA:~ 1 mJy at 250 GHz

  → 10-sigma detection

  → Estimates of fluxes for follow-up ALMA proposals (including direct imaging)

  → Search for thermal light curve: flexibility of NOEMA

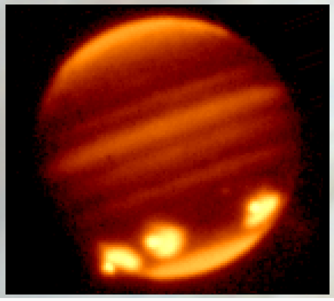


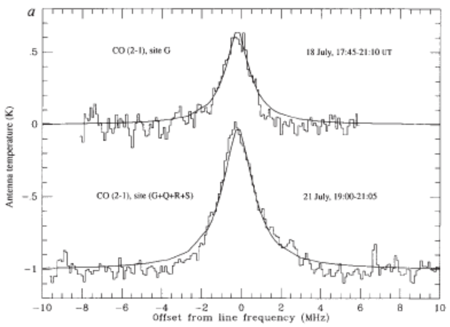
+ Icy bodies: cf talk by A. LeGall, L. Bonnefoy et al.

Thibault Cavalié

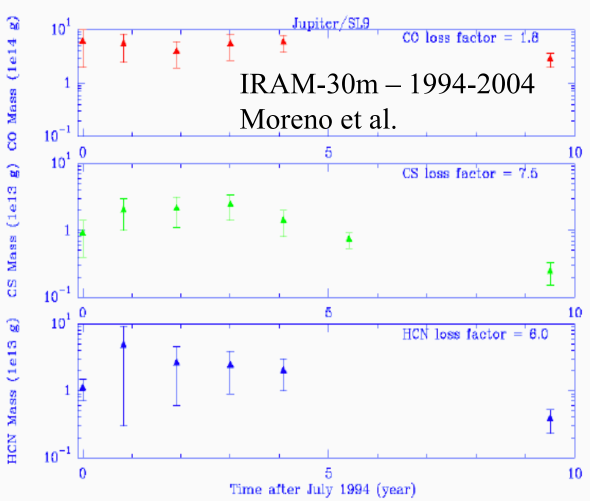
Long-term monitoring and chemical inventory in Jupiter and Saturn’s atmospheres

1) Monitoring post-SL9 species in Jupiter

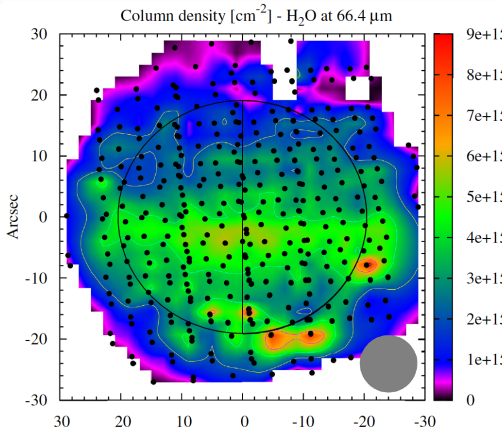




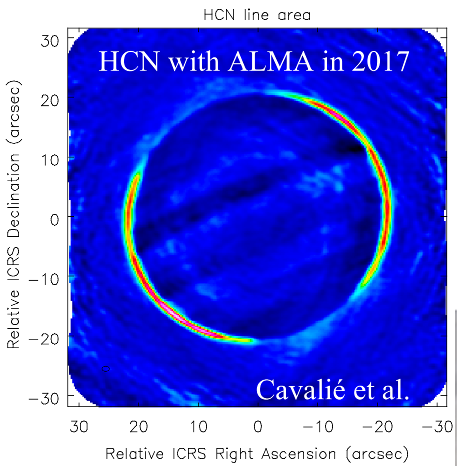
IRAM-30m – Lellouch et al. (1995)



IRAM-30m – 1994-2004
Moreno et al.



Herschel in 2010 Cavalié et al. (2013)

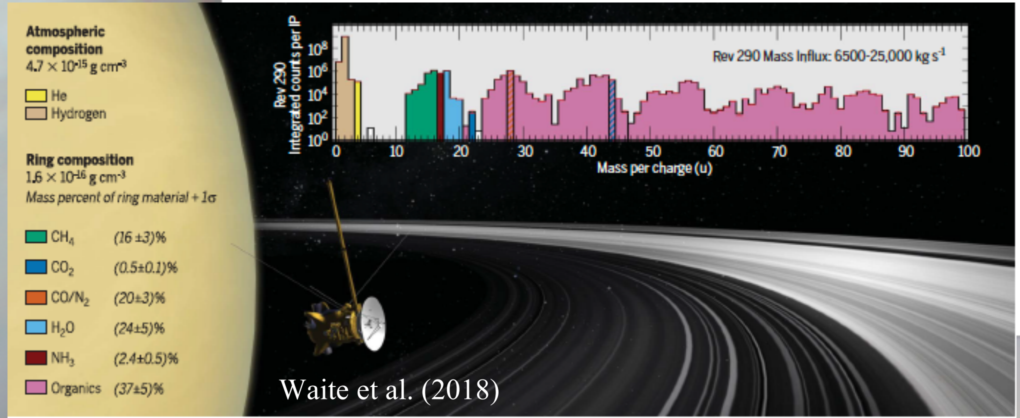


HCN with ALMA in 2017

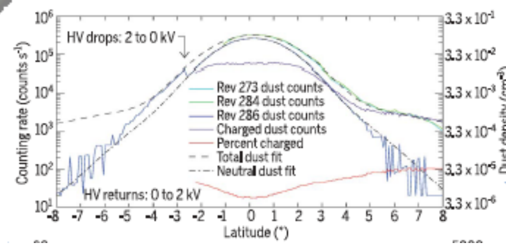
Cavalié et al.

Submillimetre Wave Instrument

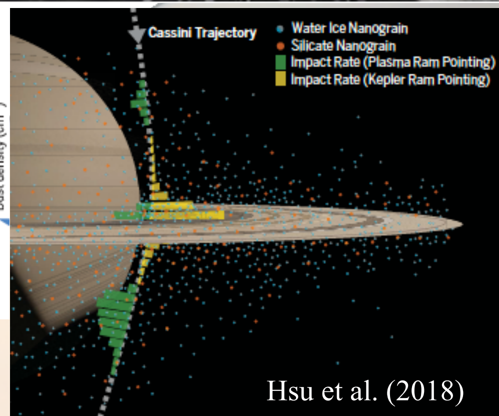
2) What species is ring rain delivering to Saturn's atmosphere ?



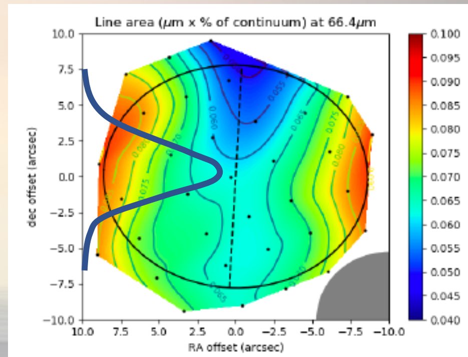
Waite et al. (2018)



Mitchell et al. (2018)



Hsu et al. (2018)



Herschel Cavalié et al.

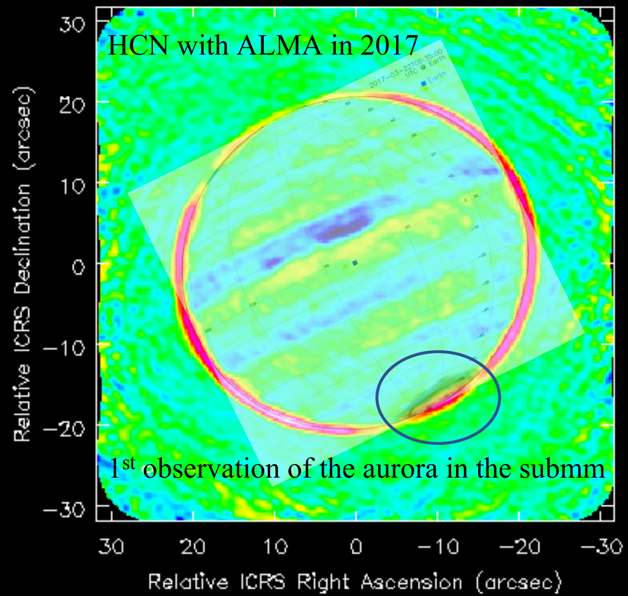
Observations of CO, HCN, CS and their isotopes, and new species with NOEMA

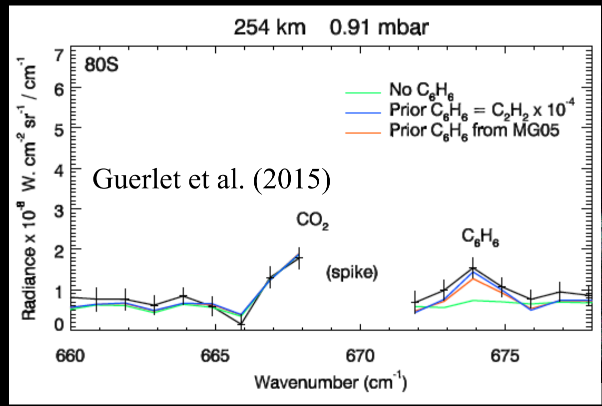
Long-term monitoring and chemical inventory in Jupiter and Saturn's atmospheres

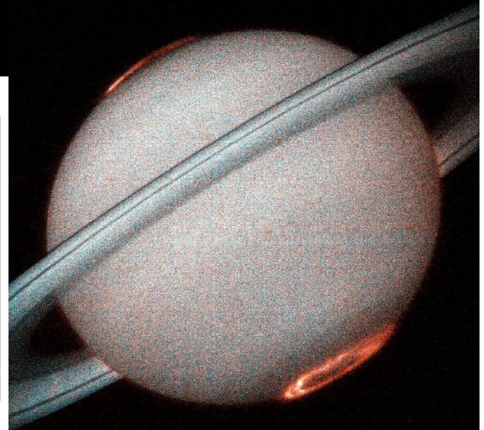
T. Cavalié, R. Moreno, T. Fouchet, E. Lellouch, V. Hue, S. Guerlet, M. Dobrijevic

l'Observatoire de Paris – LESIA

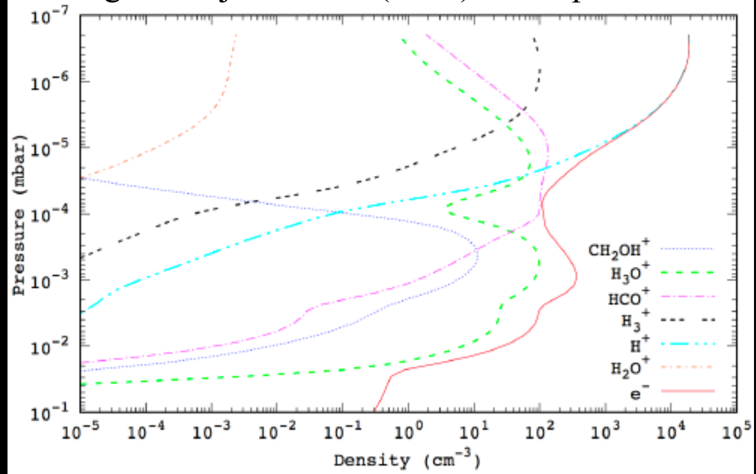
Chemical inventory in Jupiter’s and Saturn’s auroral regions

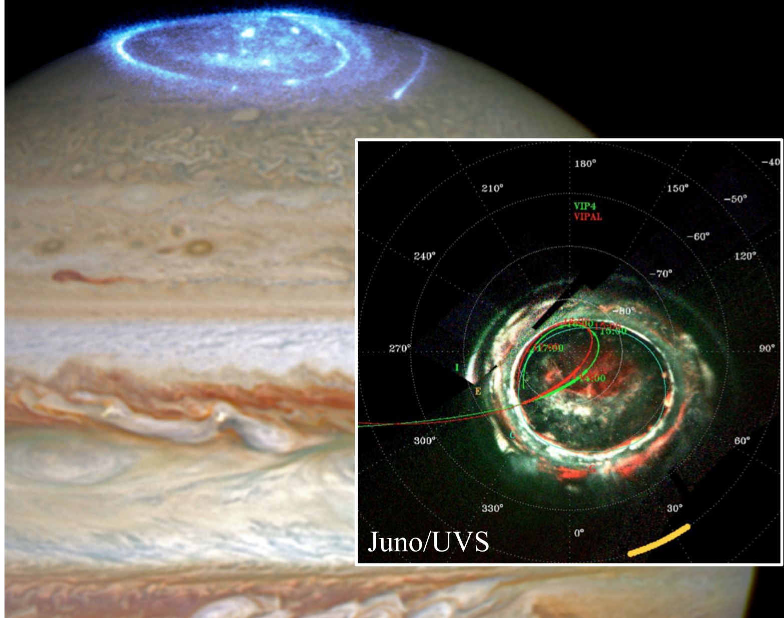






Development of ion-neutral chemistry models, e.g. Dobrijevic et al. (2019) for Neptune





Search for new species (incl. ions) in the auroral regions of Jupiter and Saturn with NOEMA

Long-term monitoring and chemical inventory in Jupiter and Saturn's atmospheres

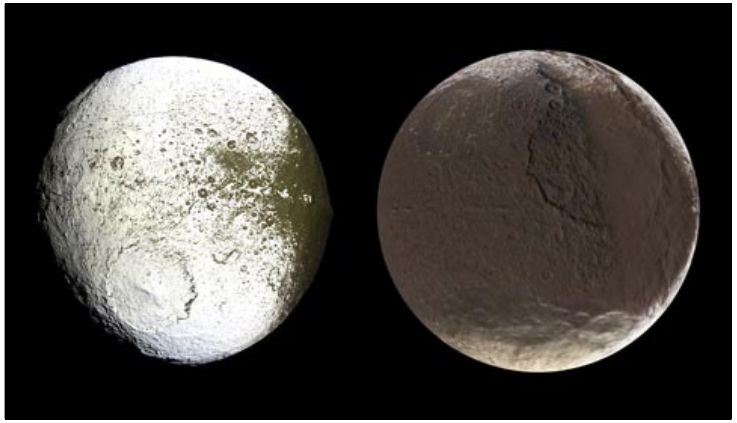
T. Cavalié, R. Moreno, T. Fouchet, E. Lellouch, V. Hue, S. Guerlet, M. Dobrijevic

Léa Bonnefoy & Alice Le Gall

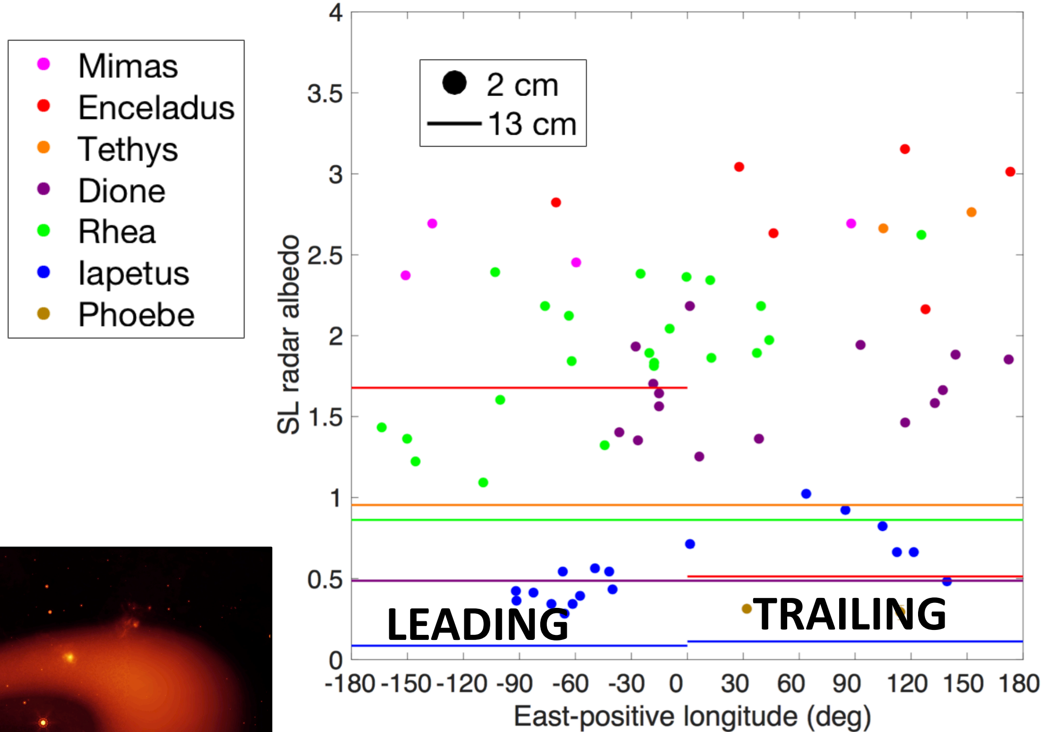
Probing the subsurface of Iapetus' two faces

Probing the subsurface of Iapetus’ two faces

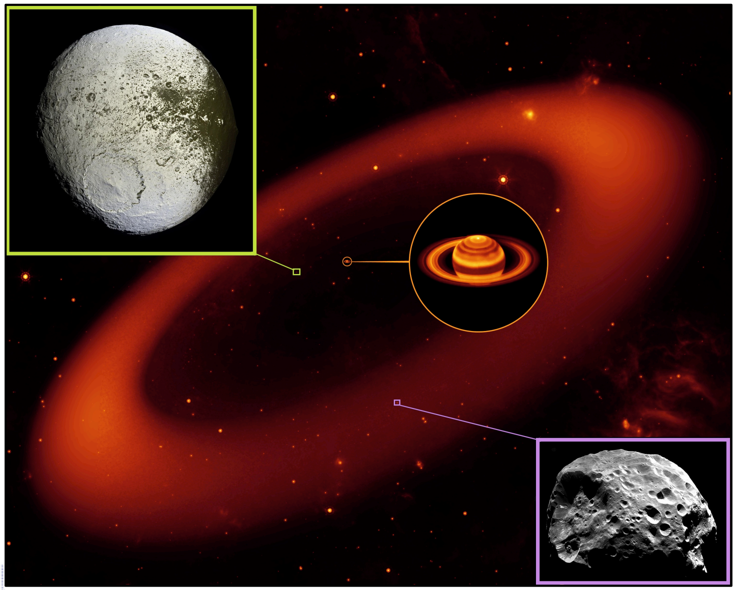
L. Bonnefoy, E. Lellouch, A. Le Gall, C. Leyrat, J.F. Lestrade, N. Ponthieu



Iapetus displays the most dramatic hemispheric two-tone coloration in the Solar System.



The leading side of Iapetus is progressively coated by non ice dark dust from the diffuse debris ring around Phoebe that crosses Iapetus orbit.



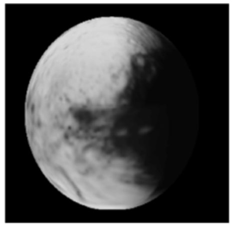
The dark layer is at least a few decimeters thick but no more than a few meters (Black et al., 2004; Ostro et al., 2006; 2010; Le Gall et al., 2014).

The nature of the contaminant is still unknown.

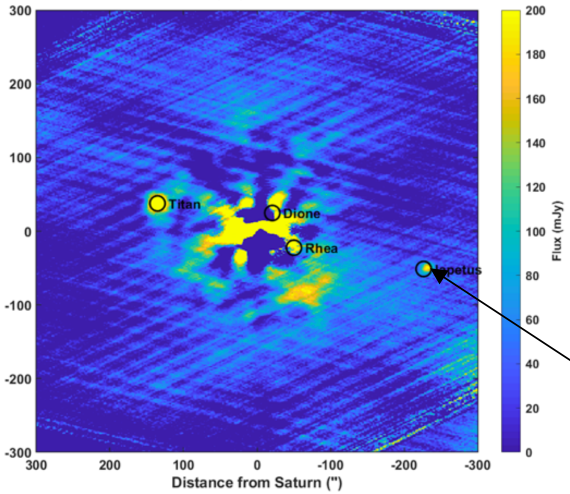
LATMOS l’Observatoire de Paris

We use NIKA2 to measure the disk-integrated thermal emission from the two hemispheres of Saturn's satellite Iapetus at 1.15 and 2.0 mm.

(a) May 28, 2018

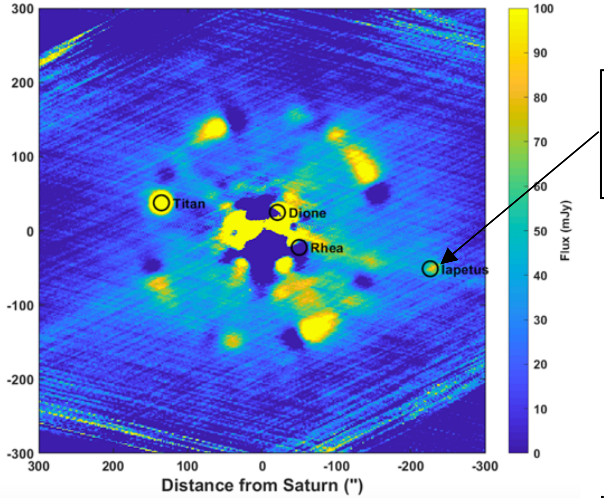


(b) 1 mm



117.6 mJy
T_b=68.6 K

(c) 2 mm



41.4 mJy
T_b=70.1 K

The overall goals of the project are to investigate :

(1) the nature and origin of the darkening agent on Iapetus' leading side,
(2) the vertical variations of the thermal and electrical properties of Iapetus' subsurface on its two faces,
(3) the diversity of icy regoliths in the Solar System

Brightness temperature T_b of Iapetus from VLA & Cassini