Observations radio-astronomiques millimétriques

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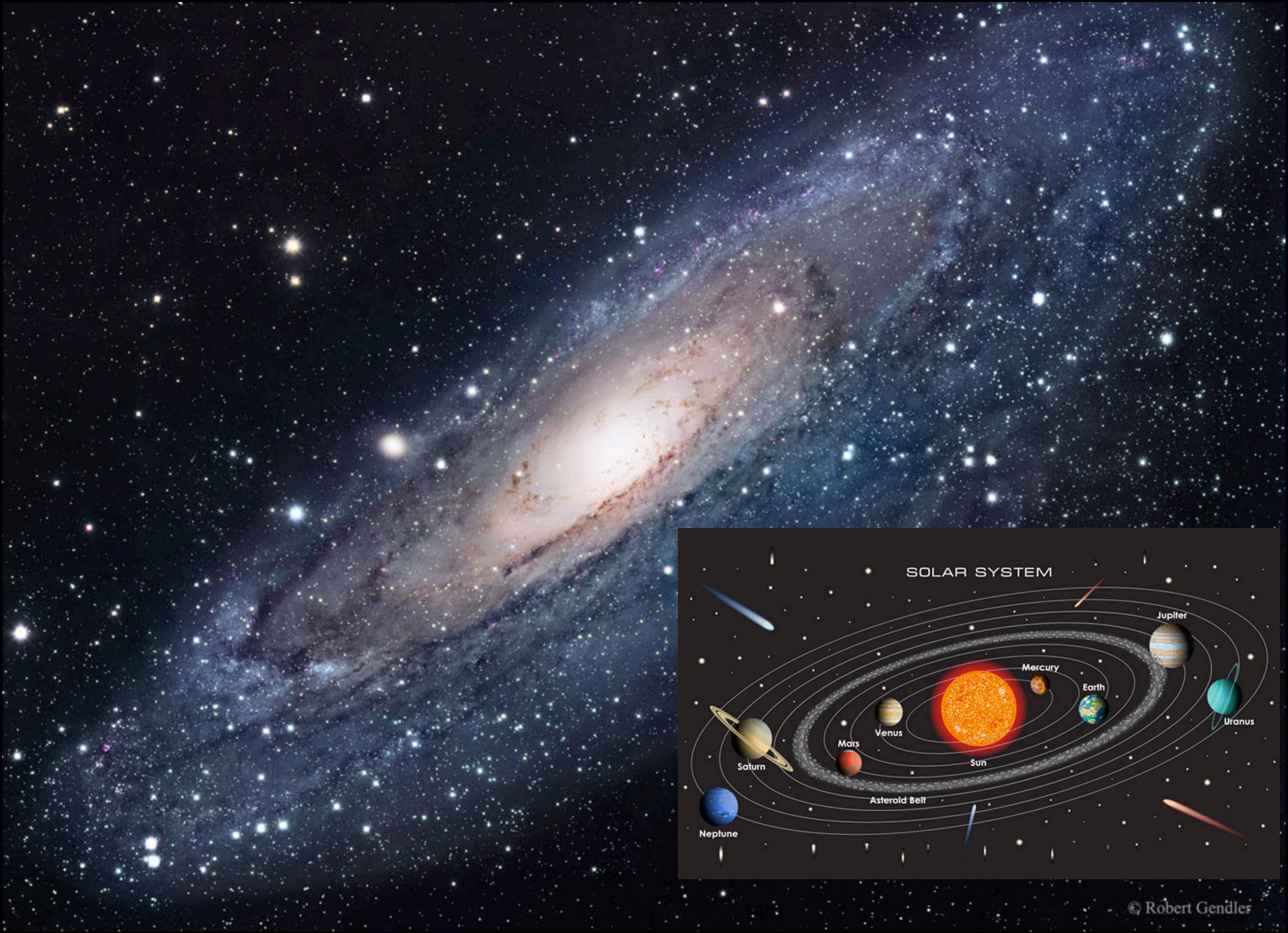
Outline

- **What do one observe in the mm ?**
- Telescopes / Interferometers
- French community

APOD - M31: The Andromeda Galaxy Image Credit & Copyright: Robert Gendler



APOD - M31: The Andromeda Galaxy Image Credit & Copyright: Robert Gendler

Hubble observations have taken advantage of gravitational lensing to reveal the largest sample of the faintest and earliest known galaxies in the universe. Some of these galaxies formed just 600 million years after the Big Bang (Frontier Fields. K. Hatek

Credits: ESA/NASA

PESSTO (the "Public ESO Spectroscopic Survey of Transient Objects")
Credit:
ESO/PESSTO/S. Smartt

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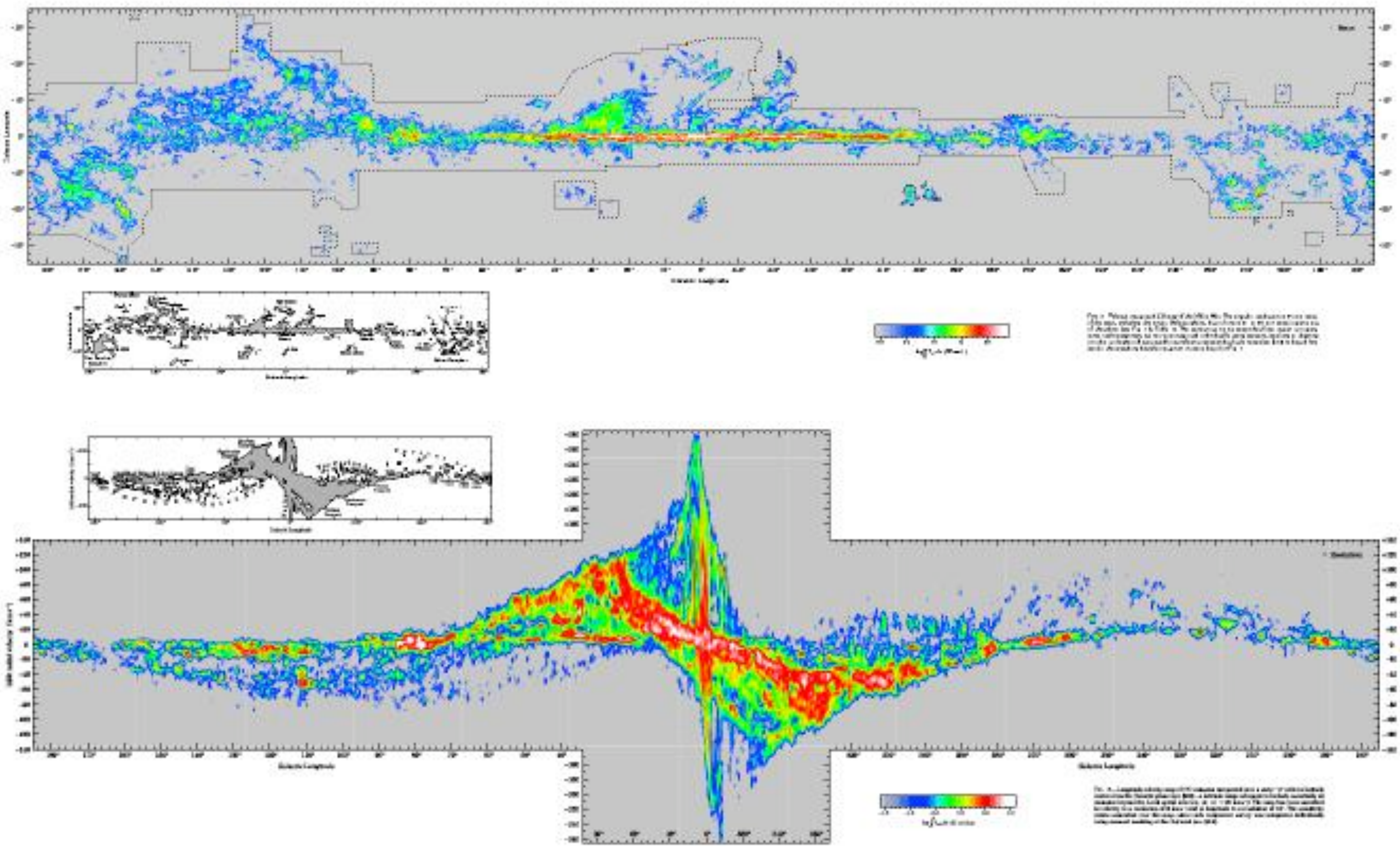
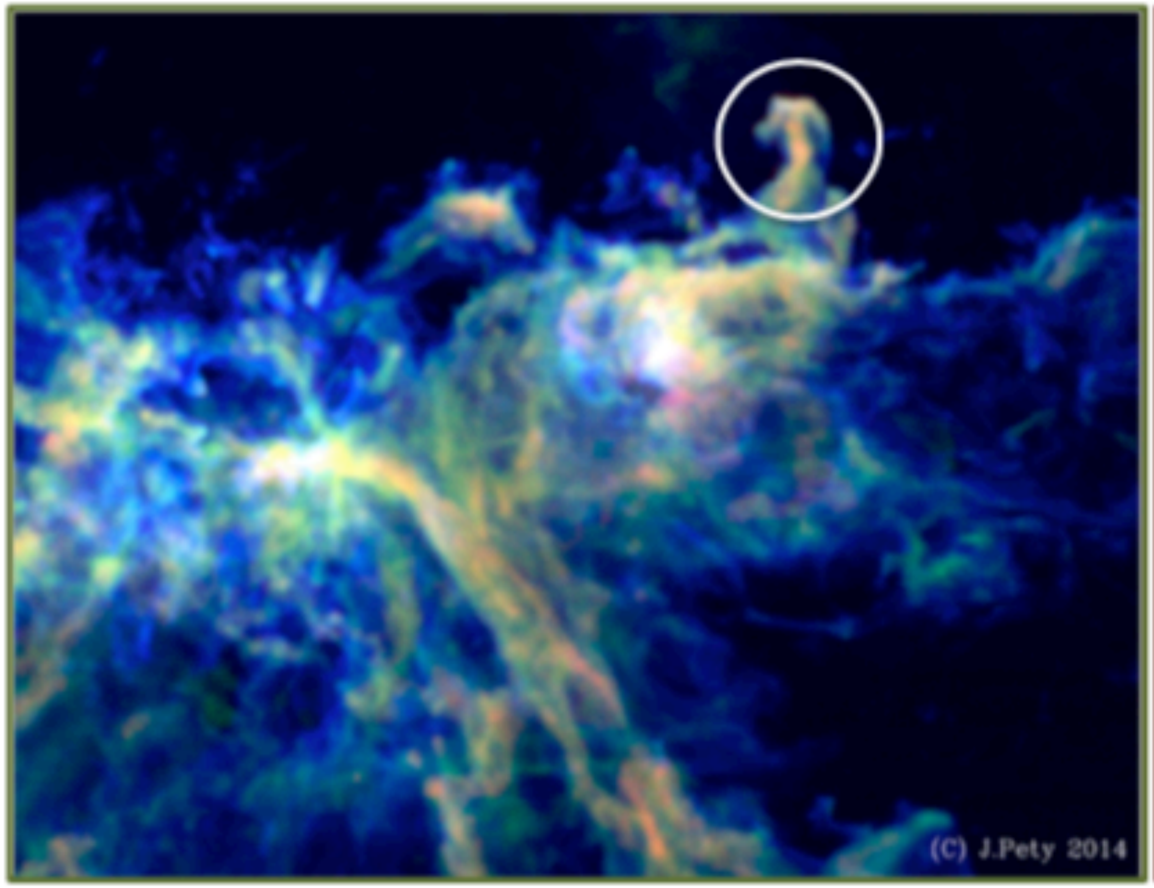
Credit:
ESO/PESSTO/S. Smartt

Molecular Line in the Milky Way



Credits : Dame et al.

Inter-stellar Medium



- visible = hot matter = stars/HII between 10^3 and 10^5 K
- millimeter = cold matter = dust/molecules between 10 and 100 K

⇨ stars are born in cold matter

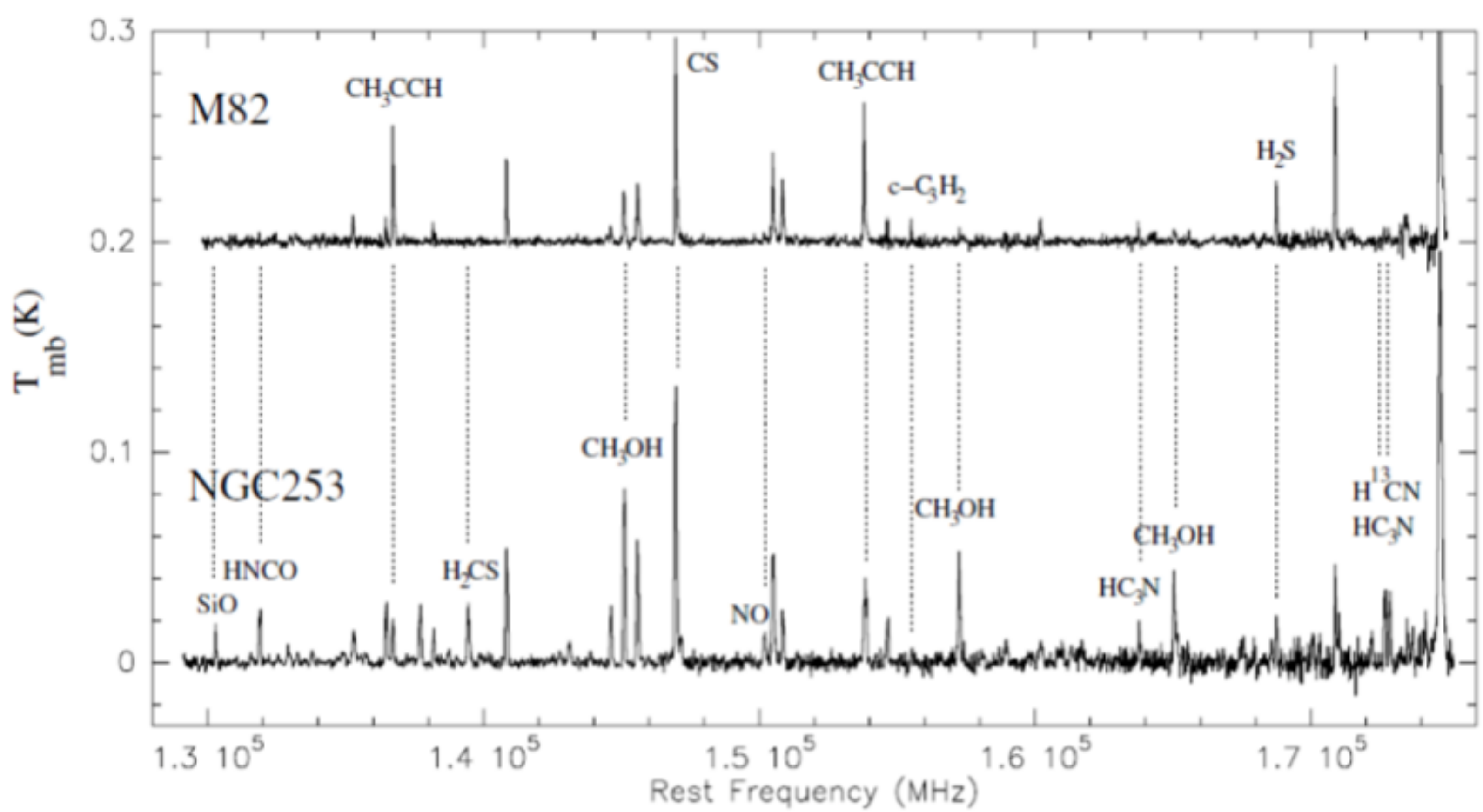
$$h\nu = kT$$
$$4.3\ \text{K} = 90\ \text{GHz} = 3\ \text{cm}^{-1}$$

Credits : R. Neri, IRAM X^{th} IRAM school

Molecular Line Emission in space

H and C						
C_2	C_{70}	CH_4	C_5H	C_2H_4	CH_2CHCH_3	$c{-}C_6H_6$
C_3	CH	C_2H	C_6H	$c{-}C_3H_2$	C_6H_2	$l{-}HC_6H$
C_5	CH^+	$c{-}C_3H$	C_7H	$l{-}C_3H_2$	CH_3C_2H	C_4H^-
C_{60}	CH_2	$l{-}C_3H$	C_8H	$l{-}C_4H_2$	CH_3C_4H	C_6H^-
C_{60}^+	CH_3	C_4H	C_2H_2	$l{-}HC_4H$	CH_3C_6H	C_8H^-
H_2	H_3^+					
H, C and O						
CO	OH	H_2O	H_2CO	$c{-}H_2C_3O$	CH_3O	CH_3CH_2OH
CO^+	OH^+	H_2O+	H_2COH^+	$c{-}C_2H_4O$	CH_3OH	CH_3CH_2CHO
CO_2	HCO	H_3O^+	$HCOOH$	HC_2CHO	CH_3CHO	CH_3COOCH_3
C_2O	HCO^+	HO_2	$HOCO^+$	CH_2CHOH	CH_3OCHO	CH_3OCH_3
C_3O	HOC^+	$HOOH$	CH_2CO	CH_2OHCHO	CH_3COOH	$(CH_3)_2CO$
O_2					$(CH_2OH)_2$	C_2H_5OCHO
H, C and N						
N_2	CN	HC_3NH^+	$HC_{11}N$	HC_2NC	CH_2CCHCN	CH_3CHNH
NH	C_3N	HC_3N	H_2CN	$HNCNH$	CH_3CN	CH_3CH_2CN
NH_2	C_5N	$l{-}HC_4N$	CH_2NH	$HNCHCN$	CH_3NC	$n{-}C_3H_7CN$
N_2H^+	HNC	HC_5N	CH_2CN	NH_2CN	CH_3NH2	CN^-
NH_3	HCN	HC_7N	HNC_3	NH_2CH_2CN	CH_3C_3N	C_3N^-
	$HCNH^+$	HC_9N	HC_2N	CH_2CHCN	CH_3C_5N	C_5N^-

Species containing S					H, C, O and N	
SH	SH^+	NS	H_2S	NO	$HNCO$	NH_2CHO
CS	SO	$HNCS$	HCS^+	N_2O	$HCNO$	$CNCHO$
C_2S	SO^+	$HSCN$	H_2CS	HNO	$HOCN$	CH_3CONH_2
C_3S	SO_2	OCS	CH_3SH			OCN^-
Species containing F, Al, K, Na, Cl, Si, P, Mg, Fe and Ti						
HF	$AlNC$	HCl	SiC	$c{-}SiC_2$	CP	$MgCN$
CF^+	$AlCl$	HCl^+	SiO	$c{-}SiC_3$	PO	$MgNC$
AlF		H_2Cl^+	SiN	SiC_4	PN	$FeCN$
AlO	KCN	KCl	SiS	$SiCN$	HCP	TiO
$AlOH$	$NaCN$	$NaCl$	SiH_4	$SiNC$	CCP	TiO_2
Deuterated species						
HD	HDO	D_2CO	C_2D	ND	N_2D+	D_2S
H_2D^+	D_2O	CH_2DOH	c-C_3HD	NH_2D	DCN	HDS
HD_2^+	DCO^+	CH_3OD	c-C_3D_2	NHD_2	DNC	$HDCS$
NH_3D^+	$HDCO$	CD_3OH	C_4D	ND_3	CH_2DCN	D_2CS



Molecular Line Emission in the ISM

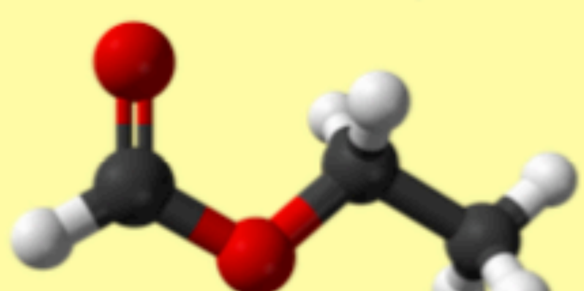
2 atoms	3 atoms	4 atoms	5 atoms	6 atoms	7 atoms	8 atoms	9 atoms	10 atoms	11 atoms	12 atoms	>12 atoms
H_2	C_3*	c-C_3H	C_5*	C_5H	C_6H	CH_3C_3N	CH_3C_4H	CH_3C_5N	HC_9N	C_6H_6*	$HC_{11}N$
AlF	C_2H	l-C_3H	C_4H	l-H_2C_4	CH_2CHCN	$HC(O)OCH_3$	CH_3CH_2CN	$(CH_3)_2CO$	CH_3C_6H	$C_2H_5OCH_3$?	C_{60}* 2010
AlCl	C_2O	C_3N	C_4Si	C_2H_4*	CH_3C_2H	CH_3COOH	$(CH_3)_2O$	$(CH_2OH)_2$	C_2H_5OCHO	n-C_3H_7CN	C_{70}* 2010
C_2**	C_2S	C_3O	l-C_3H_2	CH_3CN	HC_5N	C_7H	CH_3CH_2OH	CH_3CH_2CHO			
CH	CH_2	C_3S	c-C_3H_2	CH_3NC	CH_3CHO	H_2C_6					
CH^+	HCN	C_2H_2*	H_2CCN	CH_3OH	CH_3NH_2	CH_2OHCHO					
CN	HCO	NH_3	CH_4*	CH_3SH	c-C_2H_4O	l-HC_6H*					
CO	HCO^+	HCCN	HC_3N	HC_3NH^+	H_2CCHOH	CH_2CHCHO (?)					
CO^+	HCS^+	$HCNH^+$	HC_2NC	HC_2CHO	C_6H^-	CH_2CCHCN					
CP	HOC^+	HNCO	HCOOH	NH_2CHO		H_2NCH_2CN					
SiC	H_2O	HNCS	H_2CNH	C_5N							
HCl	H_2S	$HOCO^+$	H_2C_2O	l-HC_4H*							
KCl	HNC	H_2CO	H_2NCN	l-HC_4N							
NH	HNO	H_2CN	HNC_3	c-H_2C_3O							
NO	MgCN	H_2CS	SiH_4*	H_2CCNH (?)							
NS	MgNC	H_3O^+	H_2COH^+	C_5N^-							
NaCl	N_2H^+	c-SiC_3	C_4H^-								
OH	N_2O	CH_3*	HC(O)CN								
PN	NaCN	C_3N^-									
SO	OCS	PH_3 ?									
SO^+	SO_2	HCNO									
SiN	c-SiC_2	HOCN 2010									
SiO	CO_2*	HSCN									
SiS	NH_2	H_2O_2 2011									
CS	H_3^+*										
HF 2010	H_2D^+, HD_2^+										
HD	SiCN										
FeO ?	AlNC										
O_2 2011	SiNC										
CF^+	HCP										
SiH ?	CCP										
PO	AlOH 2010										
AlO	H_2O^+ 2010										
OH^+ 2010	H_2Cl^+ 2010										
CN^- 2010	KCN 2010										
SH^+ 2011	FeCN 2011										

Molecules in the ISM

Cologne Data Base for Molecular Spectroscopy (CDMS)

- H_2 is by far the most abundant but invisible @ mm-waves
- CO is visible in almost all mm-windows
- more than 200 molecules
- observations, laboratory, theory
- organic chemistry but also species with S,P,F,Cl,Fe,Si,...
- many cations (HCO^+, H_3O^+, ...) and few anions (CN^-)
- many radicals: CH, C_2H, OH, HCO, CN, ...

Ethyl-formate C_2H_5OCHO

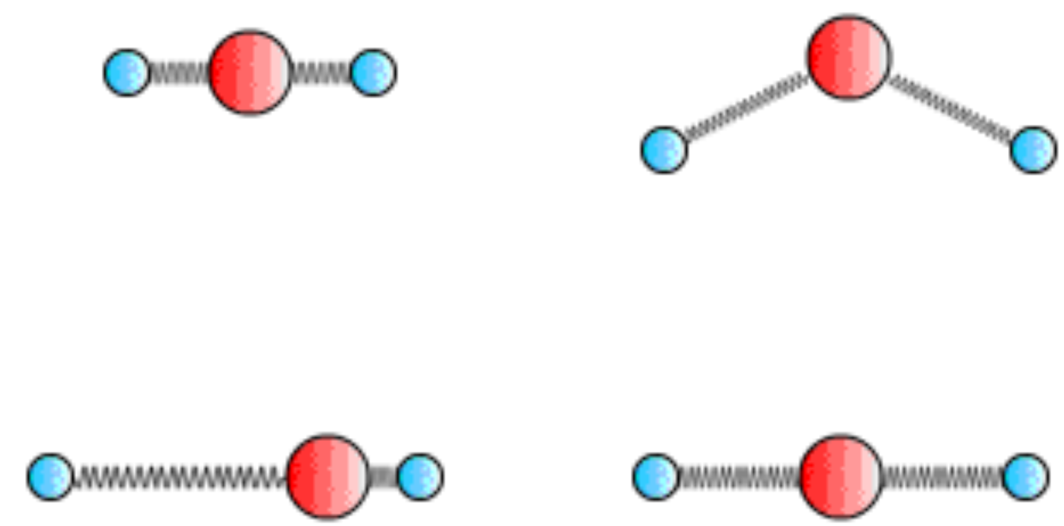


(Belloche et al. 2009 with the 30m)

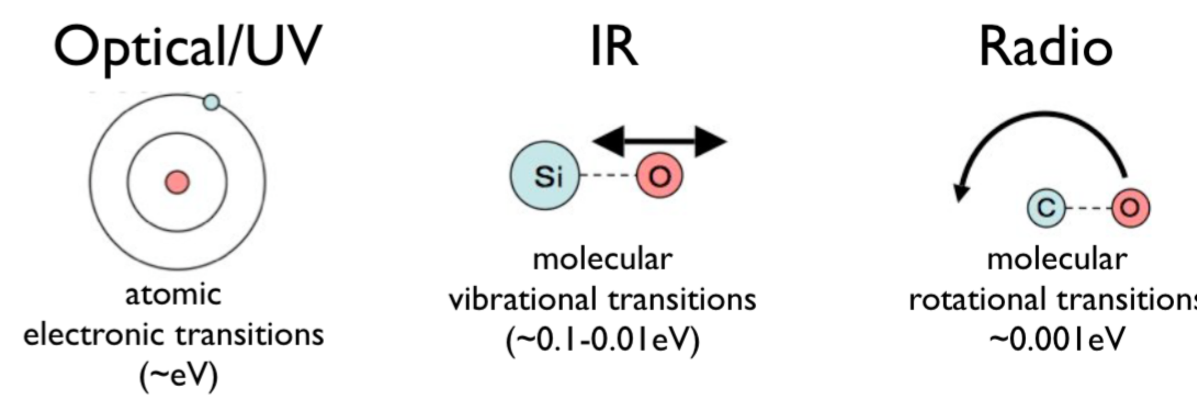
https://cdms.astro.uni-koeln.de/classic/molecules

Credits : R. Neri, IRAM Xth IRAM school

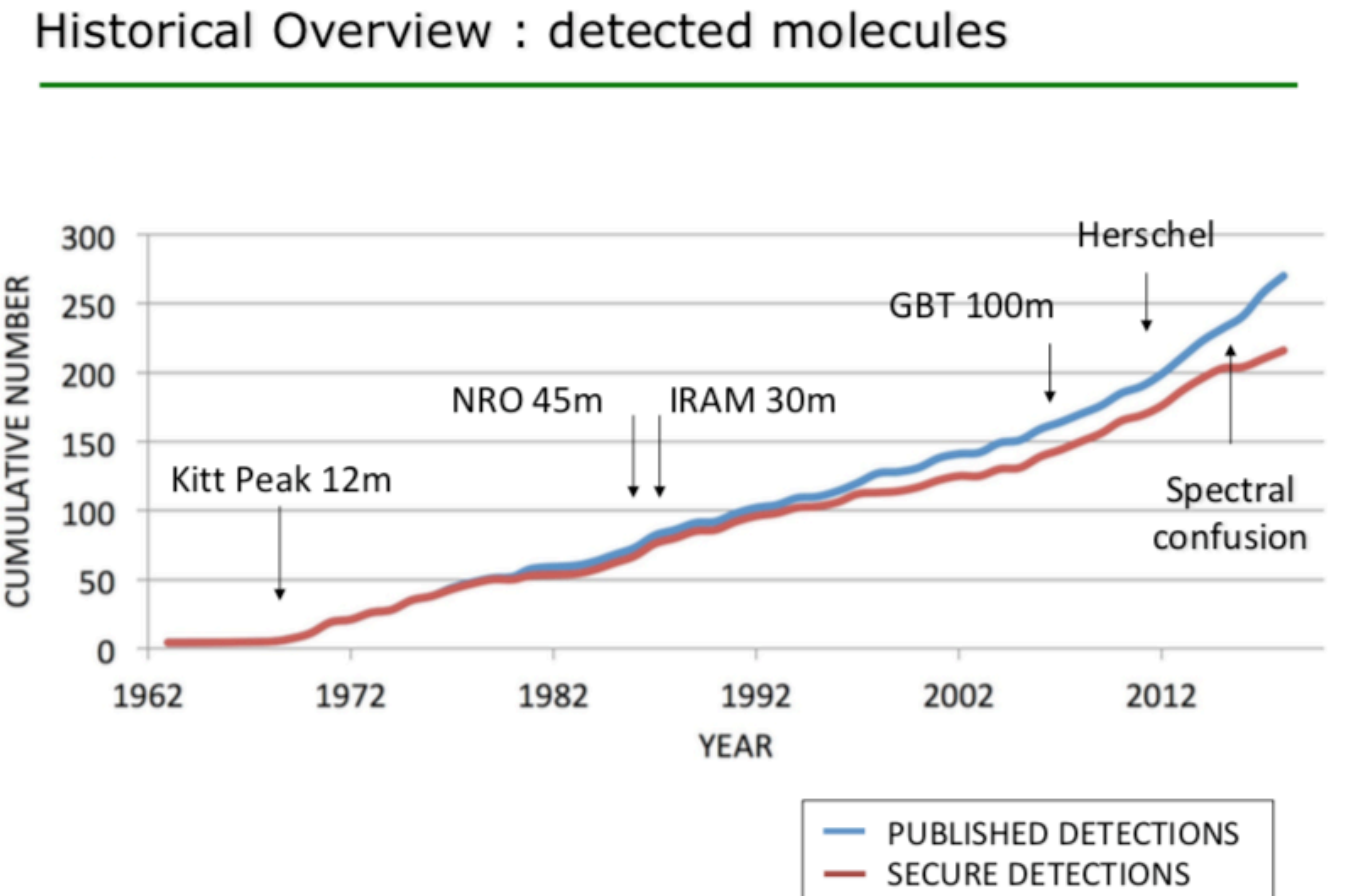
Molecular Line Emission space



- Most frequent molecules
  - Monoxide Carbon (CO)
  - Water (H2O), OH, HCN, HCO+, CS
  - Ammonia (NH3), Formaldehyde (H2CO)
- Rare Molecules
  - Alcohol,Sugar, …



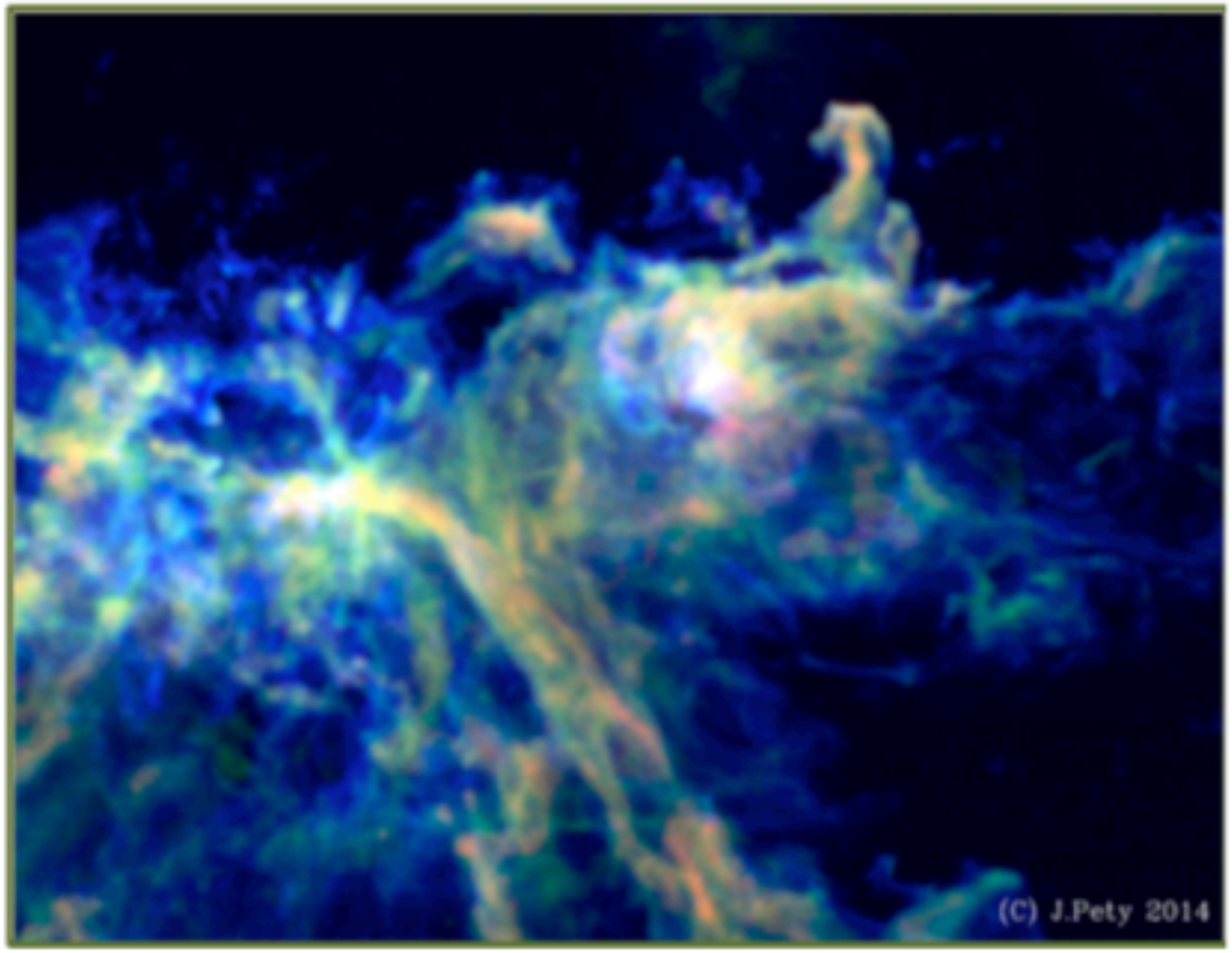
Molecular Line Emission in the ISM



Credits : R. Neri, IRAM Xth IRAM school

Emission Processes

- mm-astronomy deals with
  - continuum emission: free-free, dust, synchrotron, compton scattering, SZ, …
  - line emission: mostly molecules but also atoms
  - inter- stellar/galactic medium in various phases
    - matter in ionized, atomic, molecular state, dust grains, etc.
    - temperature, density of the matter



- HII regions $T \sim 10^4$K, $n = 10^1 - 10^6/cm^3$ e.g. H, He
- molecular clouds/cores $T \sim 10 - 10^3$K, $n \sim 10^2 - 10^8/cm^3$ e.g. ^{12}CO

Credits : R. Neri, IRAM Xth IRAM school

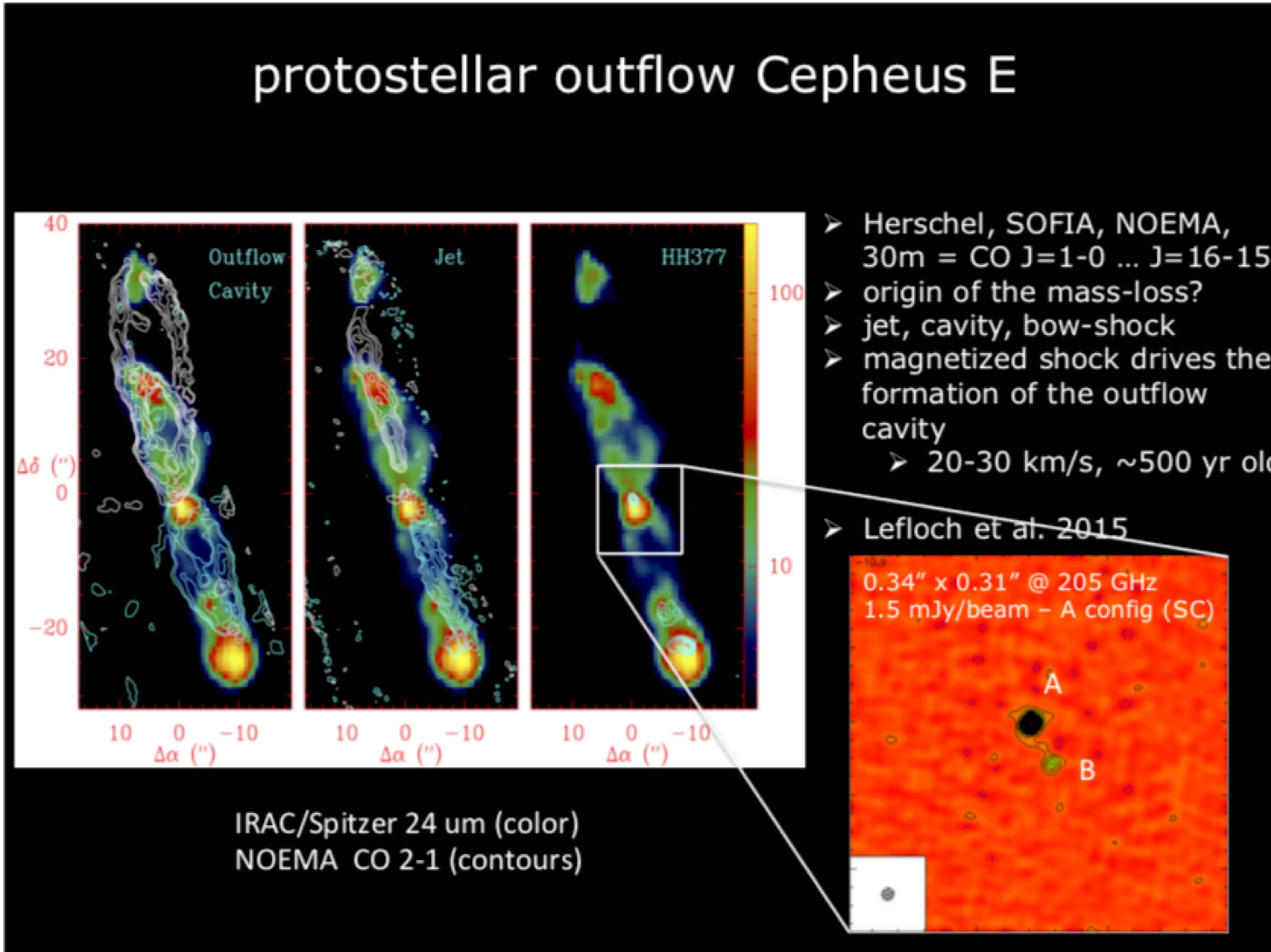
Where are the molecules ?

Joan Miró : Le disque rouge (1960)

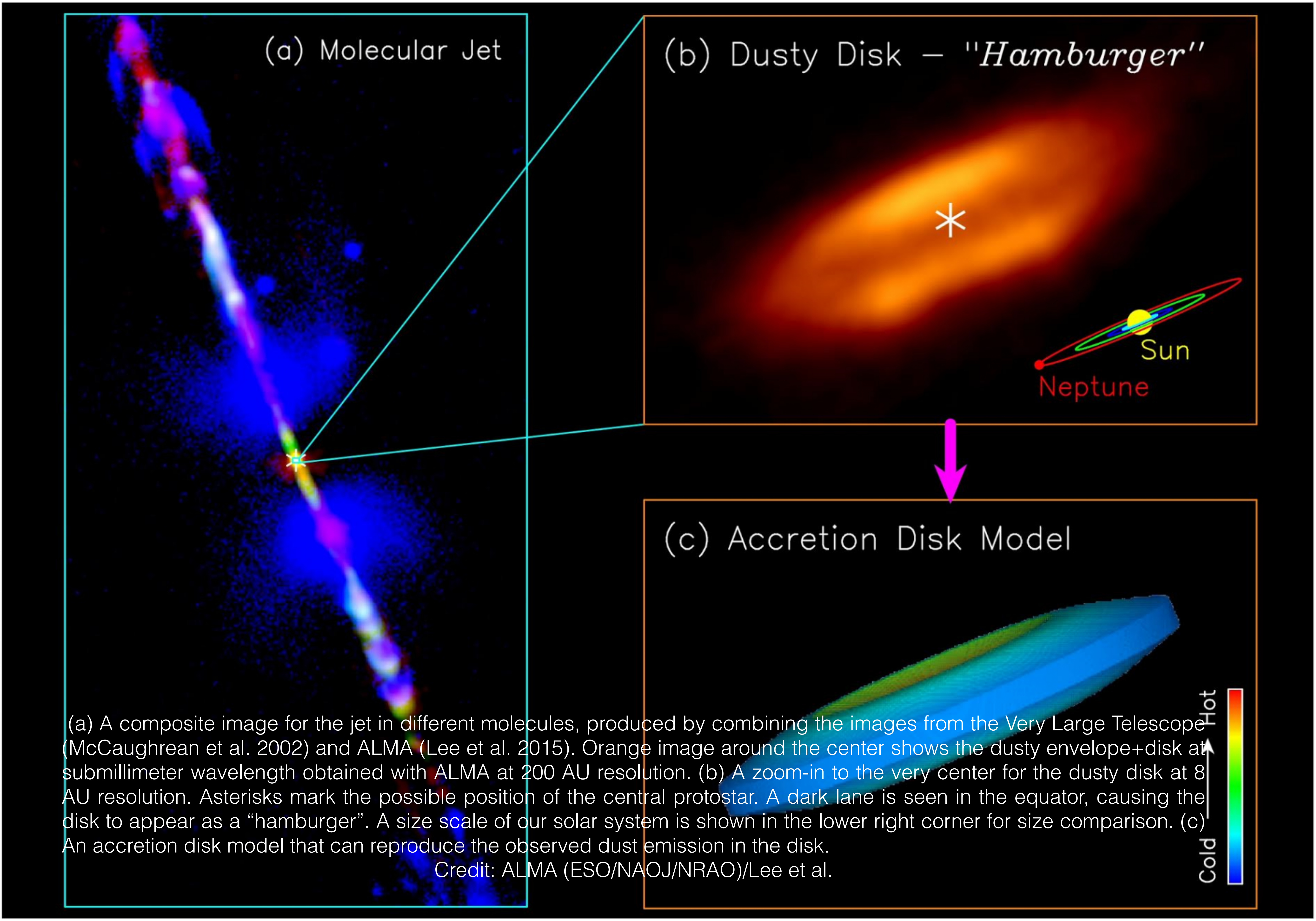
Molecules tracks different phases along the stellar life

Joan Miró : L'Etoile Bleue (1927)

Stellar Birth



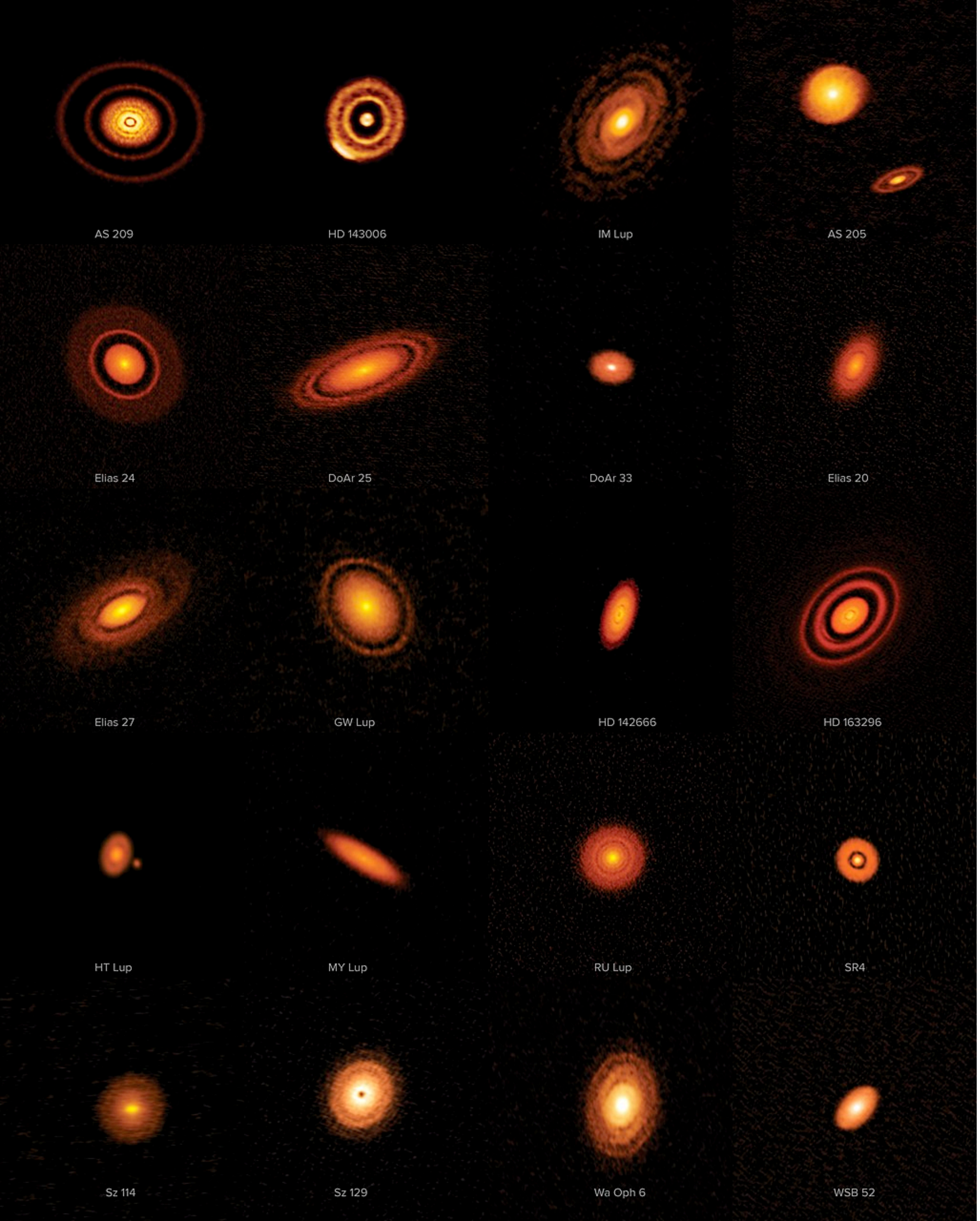
Credits : R. Neri, IRAM Xth IRAM school



(a) A composite image for the jet in different molecules, produced by combining the images from the Very Large Telescope (McCaughrean et al. 2002) and ALMA (Lee et al. 2015). Orange image around the center shows the dusty envelope+disk at submillimeter wavelength obtained with ALMA at 200 AU resolution. (b) A zoom-in to the very center for the dusty disk at 8 AU resolution. Asterisks mark the possible position of the central protostar. A dark lane is seen in the equator, causing the disk to appear as a “hamburger”. A size scale of our solar system is shown in the lower right corner for size comparison. (c) An accretion disk model that can reproduce the observed dust emission in the disk.

Credit: ALMA (ESO/NAOJ/NRAO)/Lee et al.

Proto-planetary disks
Planet formation and the cradle of life



Protoplanetary discs

ALMA Large Program (DSHARP) :
20 nearby protoplanetary discs to learn more about the earliest stages of planet formation.

Planetary systems are likely to have their origins in protoplanetary discs of gas and dust, which form around protostars in the early stages of their development.

DSHARP studies the process by which planets emerge from these diffuse discs when dust within a disc coalesces into planetesimals and the seeds of planets are formed.

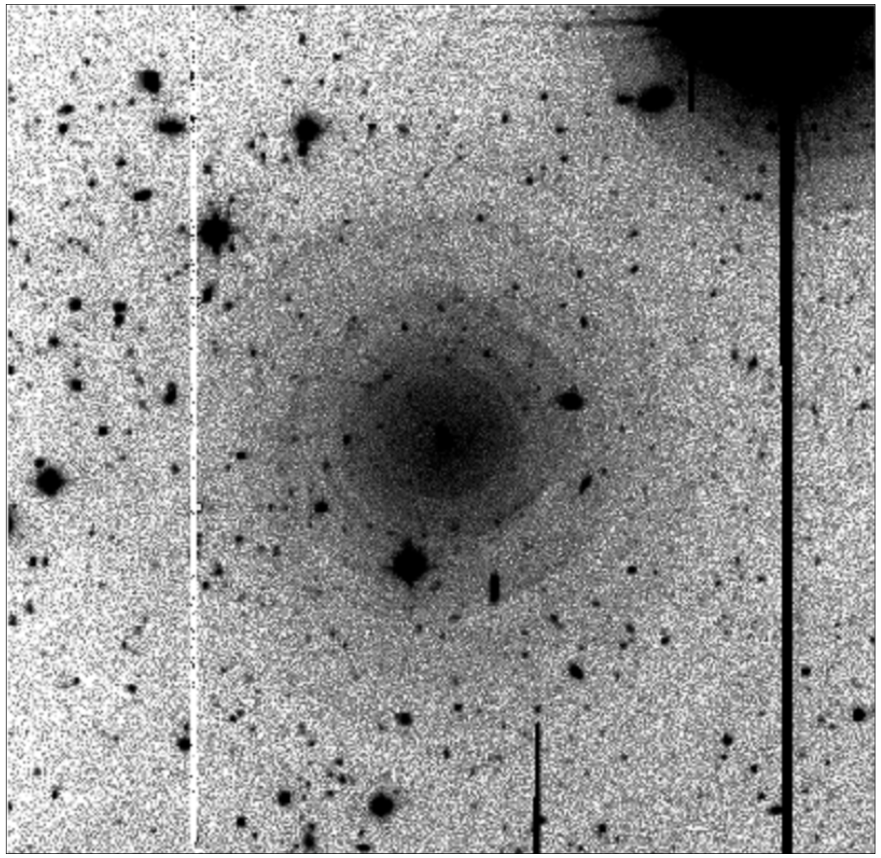
Next : to accurately predict what type of planetary system will evolve from any particular disc.

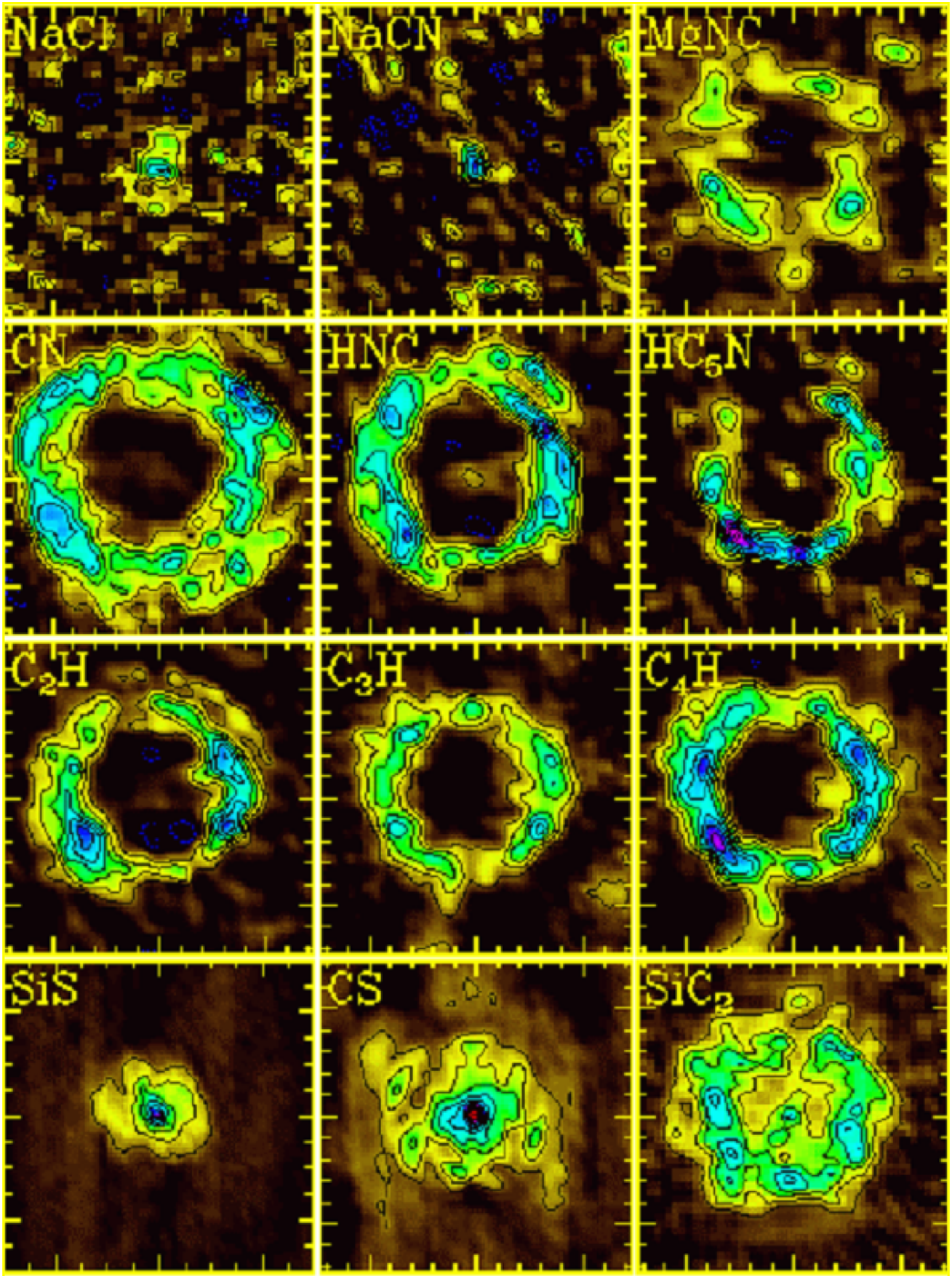
The death of stars
Matter recycling - molecular complexity

Evolved Stars

Red Giant evolved star:
Molecular gas wind

Optical



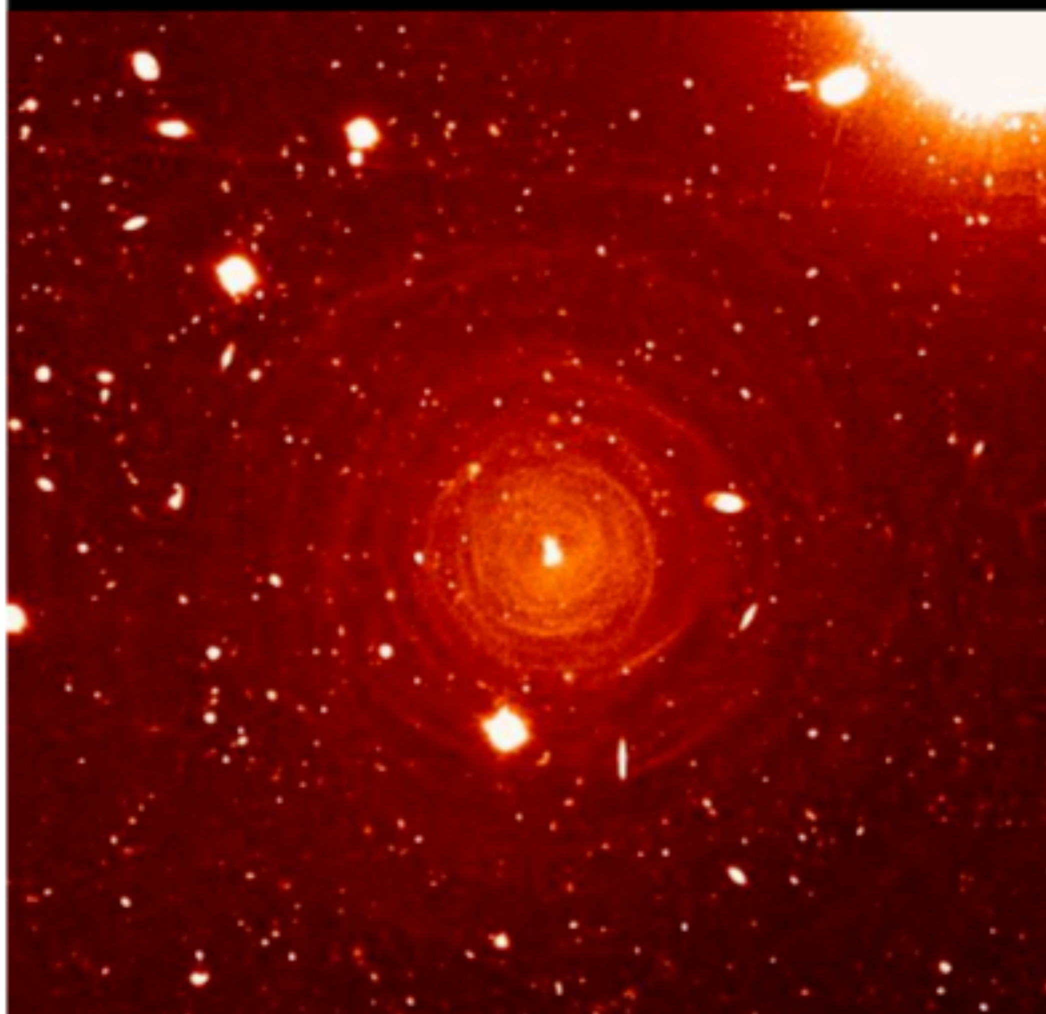


Molecular gas in the mm-band

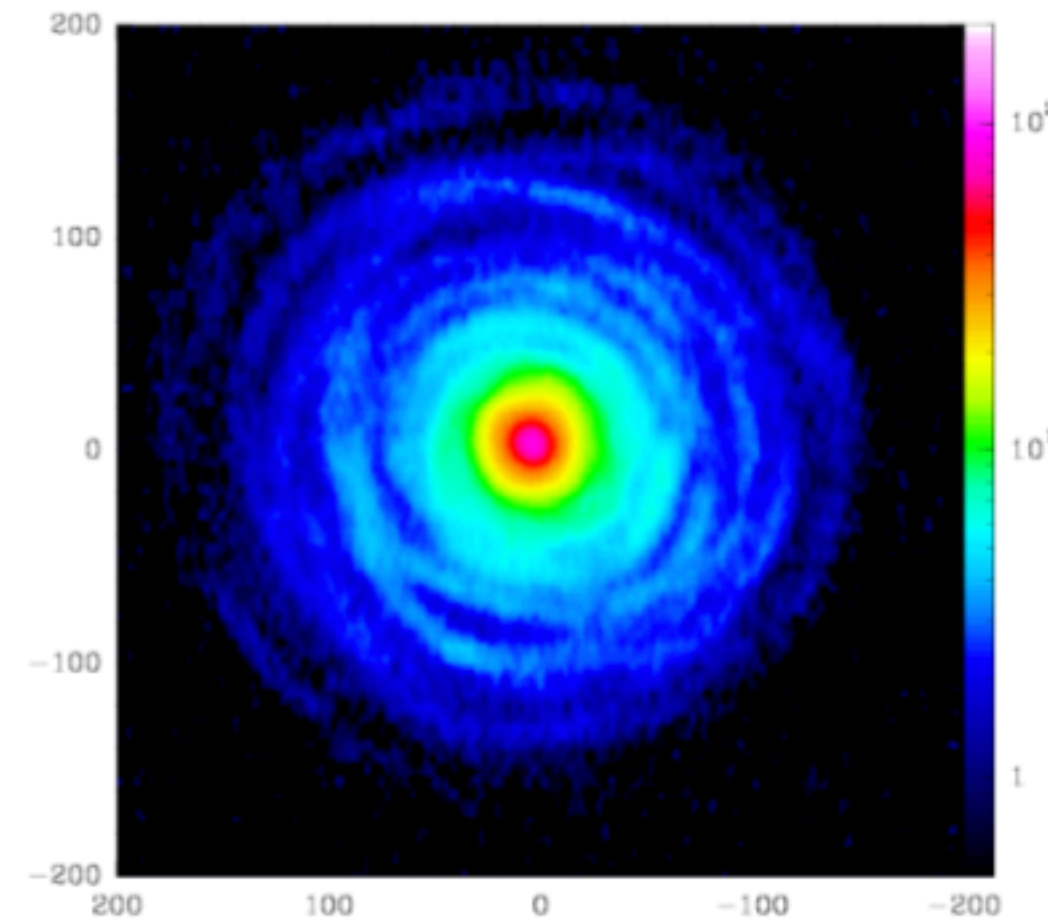
Stellar death

Recycling of gas and dust

Mass-loss of massive stars during the last stages of stellar evolution. Example: IRC+10216



Expelled circular dust shell during the last 8000 years. Optical image.
Expansion velocity ~15 km/s,
One expulsion every ~800 years



Expulsion of CO shells
Cernicharo et al. 2014

Credits : R. Neri, IRAM Xth IRAM school

Recycling gas and dust

The strange shape was probably created by a hidden companion star orbiting the red giant.

The interstellar medium

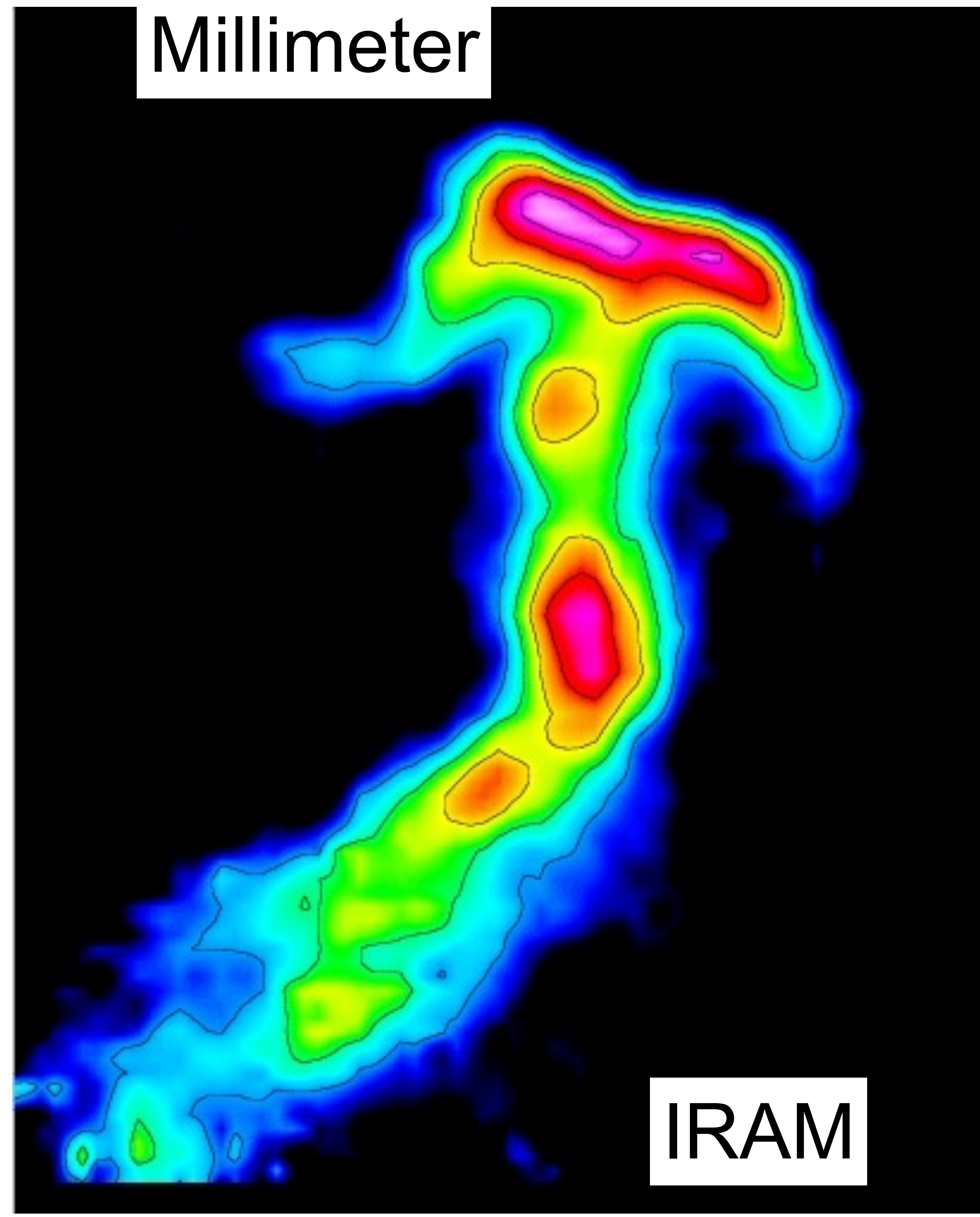
The star nursery

Joan Miro : Constellations (1940)

Optical vs mm-Observations

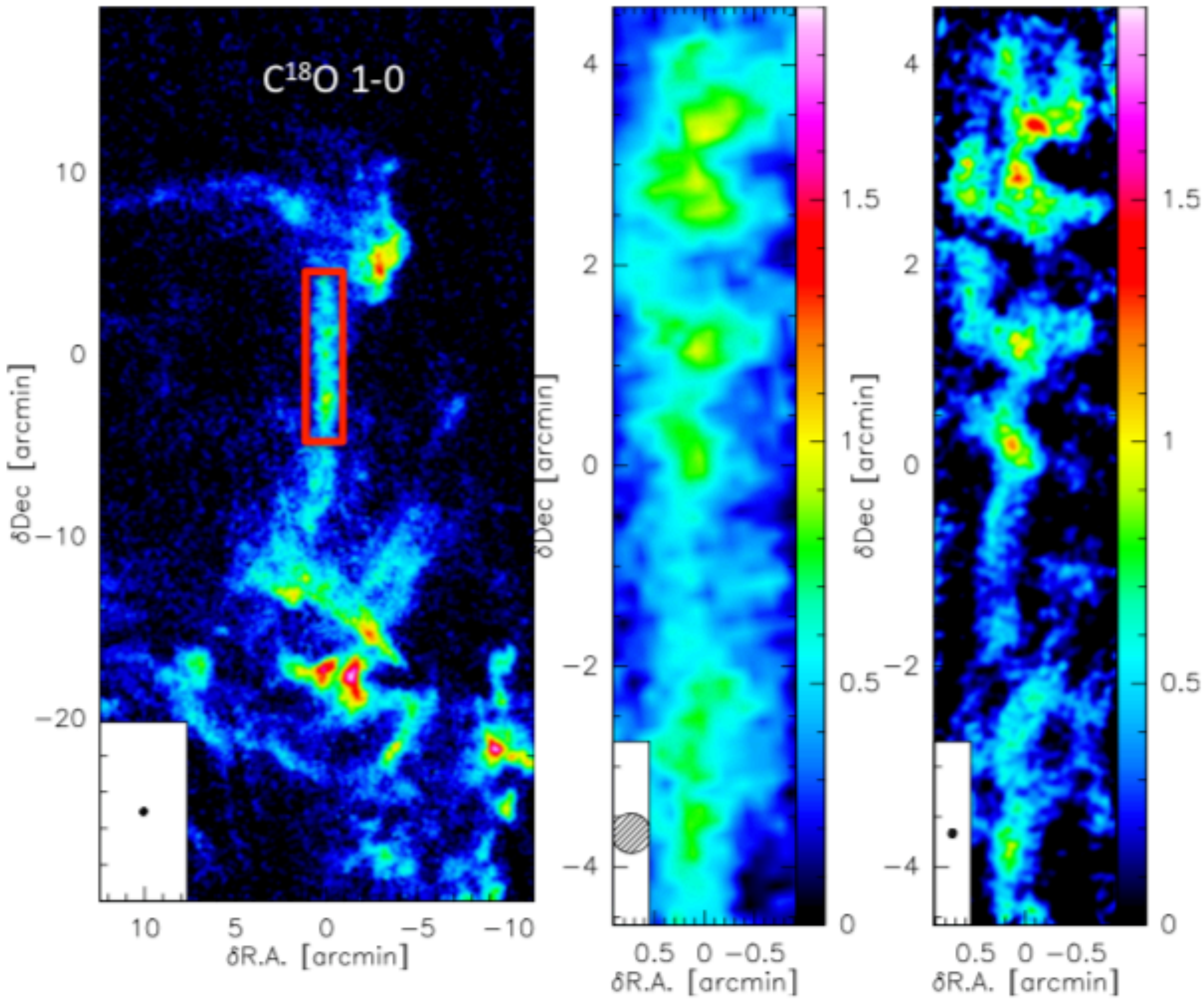
The Horsehead Nebula
(VLT KUEYEN + FORS 2)

ESO PR Photo 02a/02 (25 January 2002)

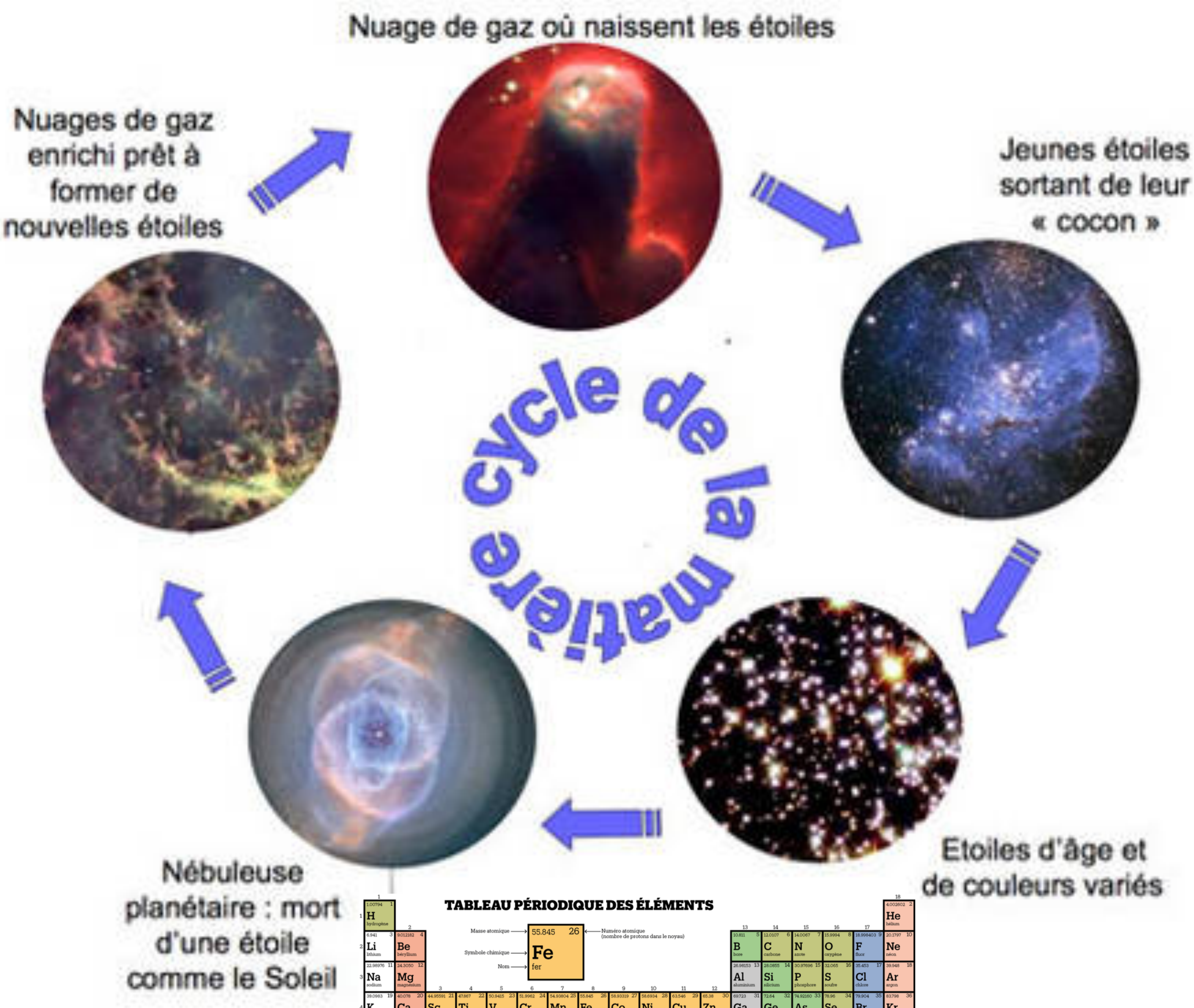


ISM

Filamentary structures in NGC 2024 - Jan Orkisz et al.
First light with NOEMA 10 antennas + IRAM 30-meter telescope



Credits : R. Neri, IRAM Xth IRAM school



Nuage de gaz où naissent les étoiles
Jeunes étoiles sortant de leur « cocon »
Etoiles d'âge et de couleurs variés
Nébuleuse planétaire : mort d'une étoile comme le Soleil
Nuages de gaz enrichi prêt à former de nouvelles étoiles
cycle de la matière

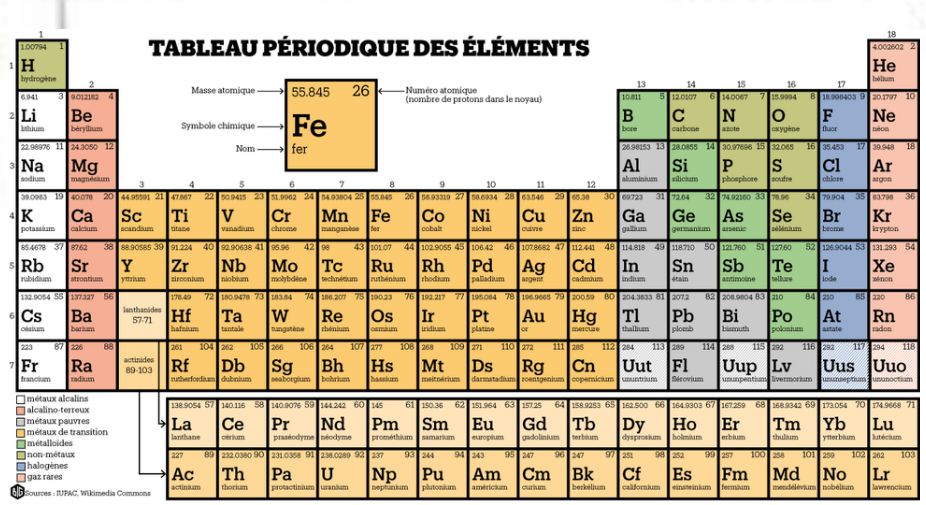
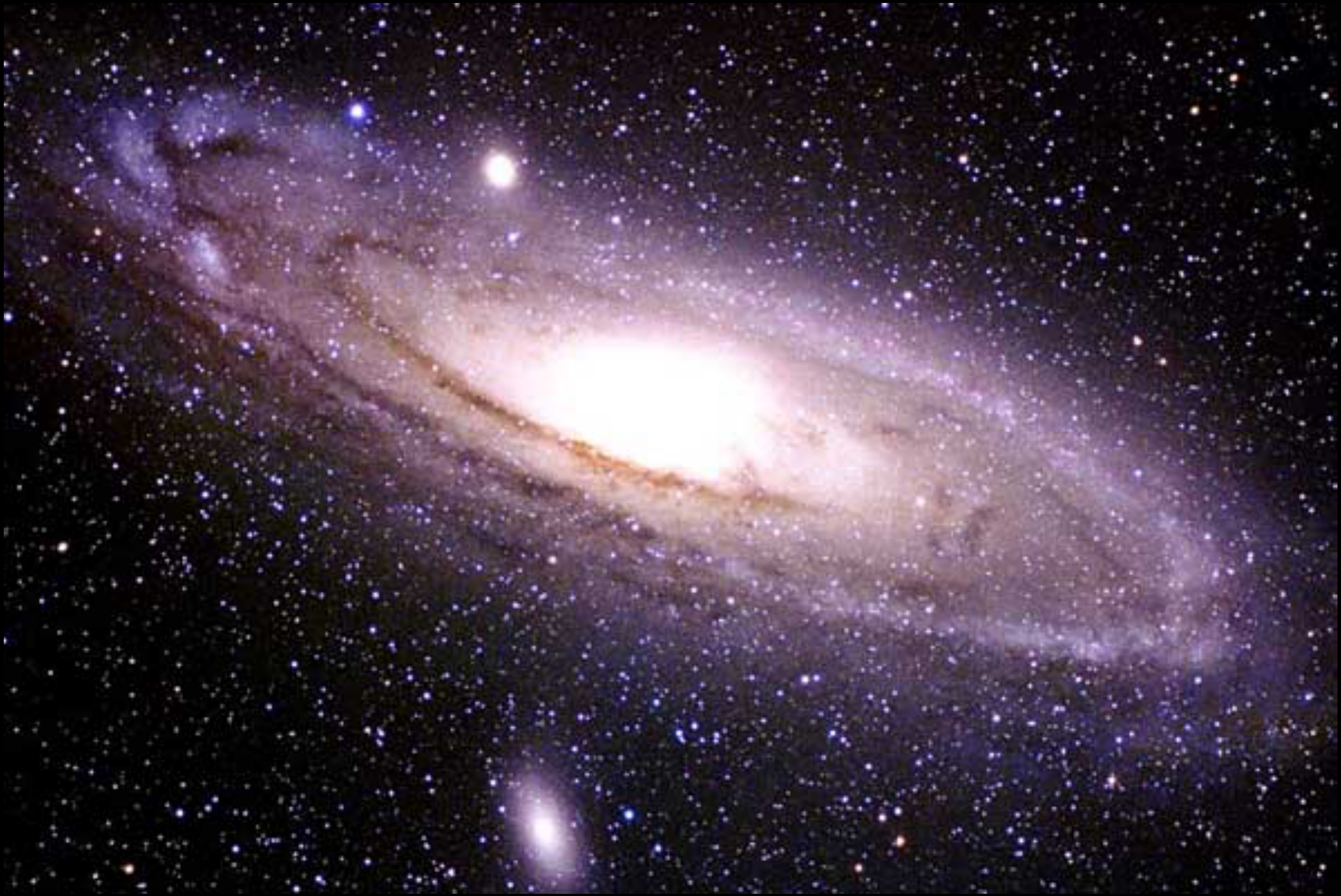
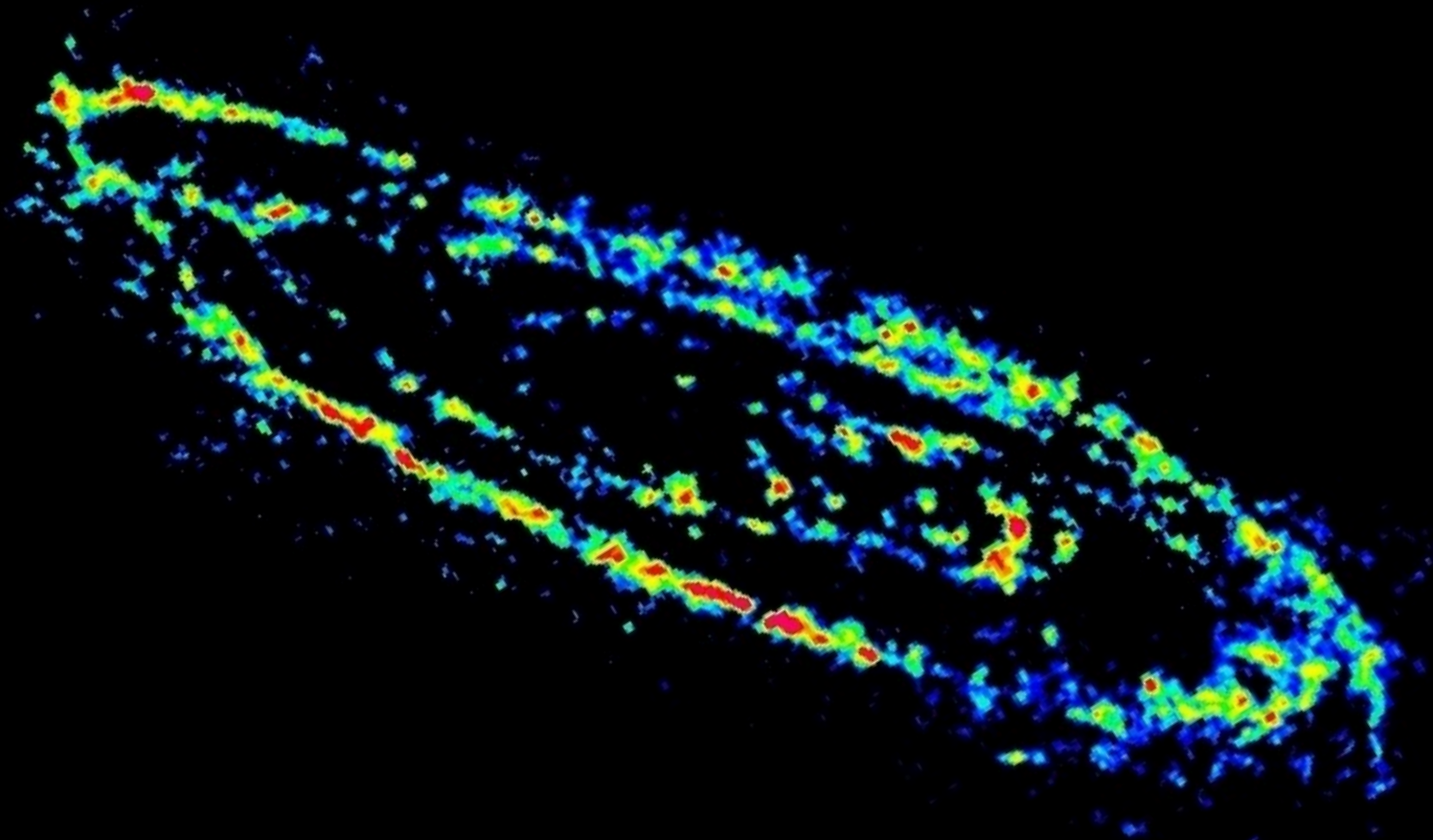
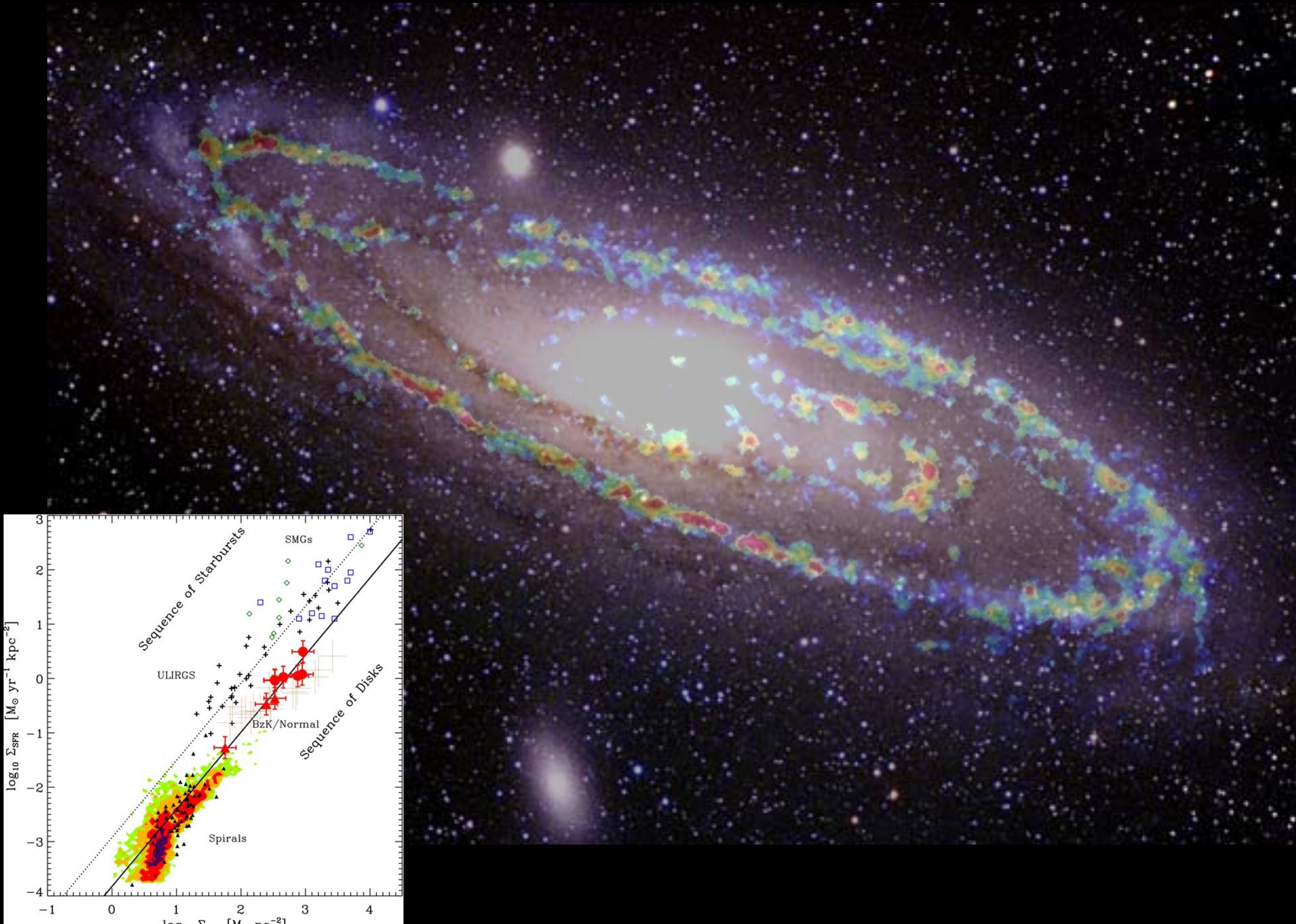


TABLEAU PÉRIODIQUE DES ÉLÉMENTS

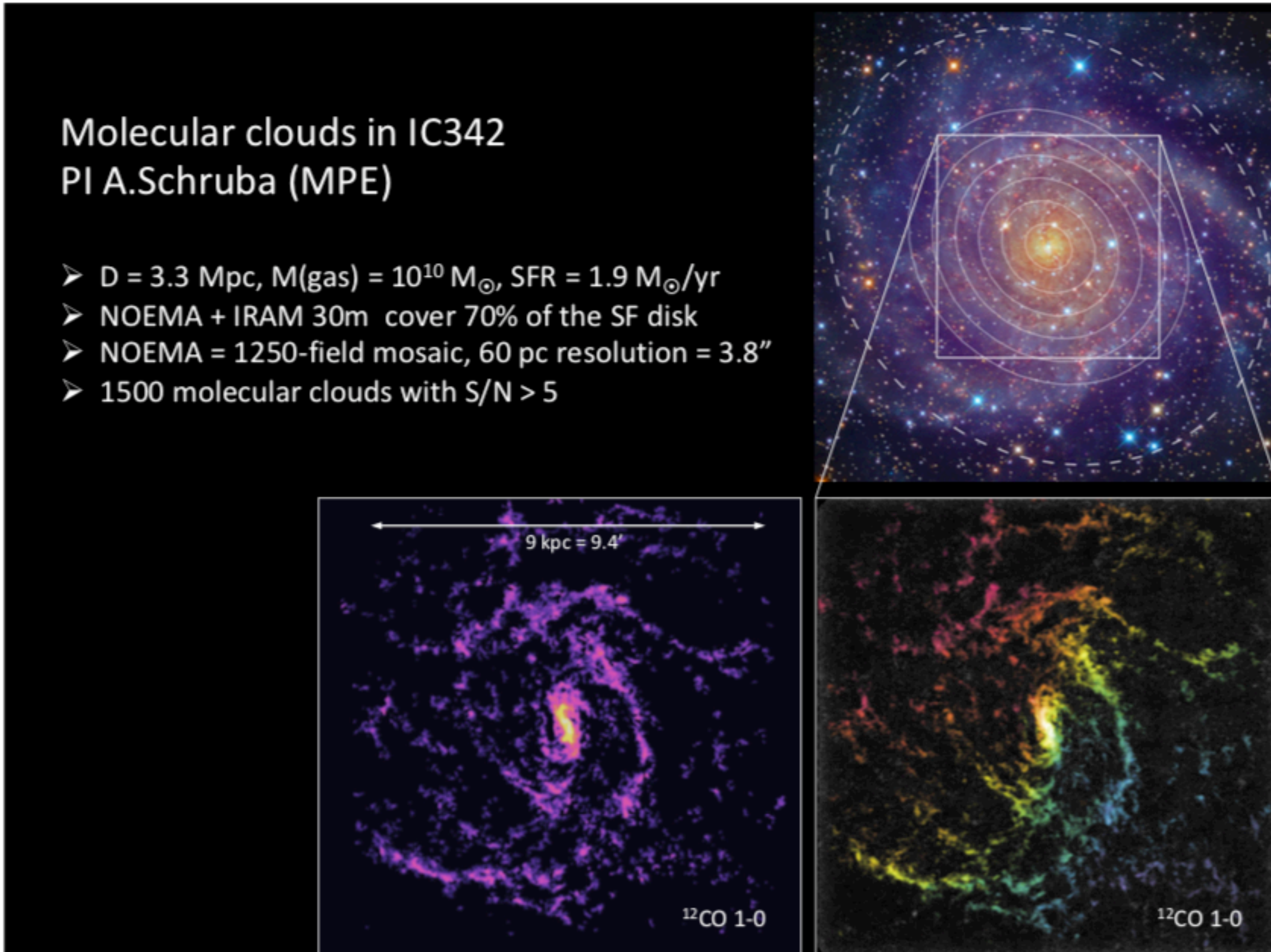






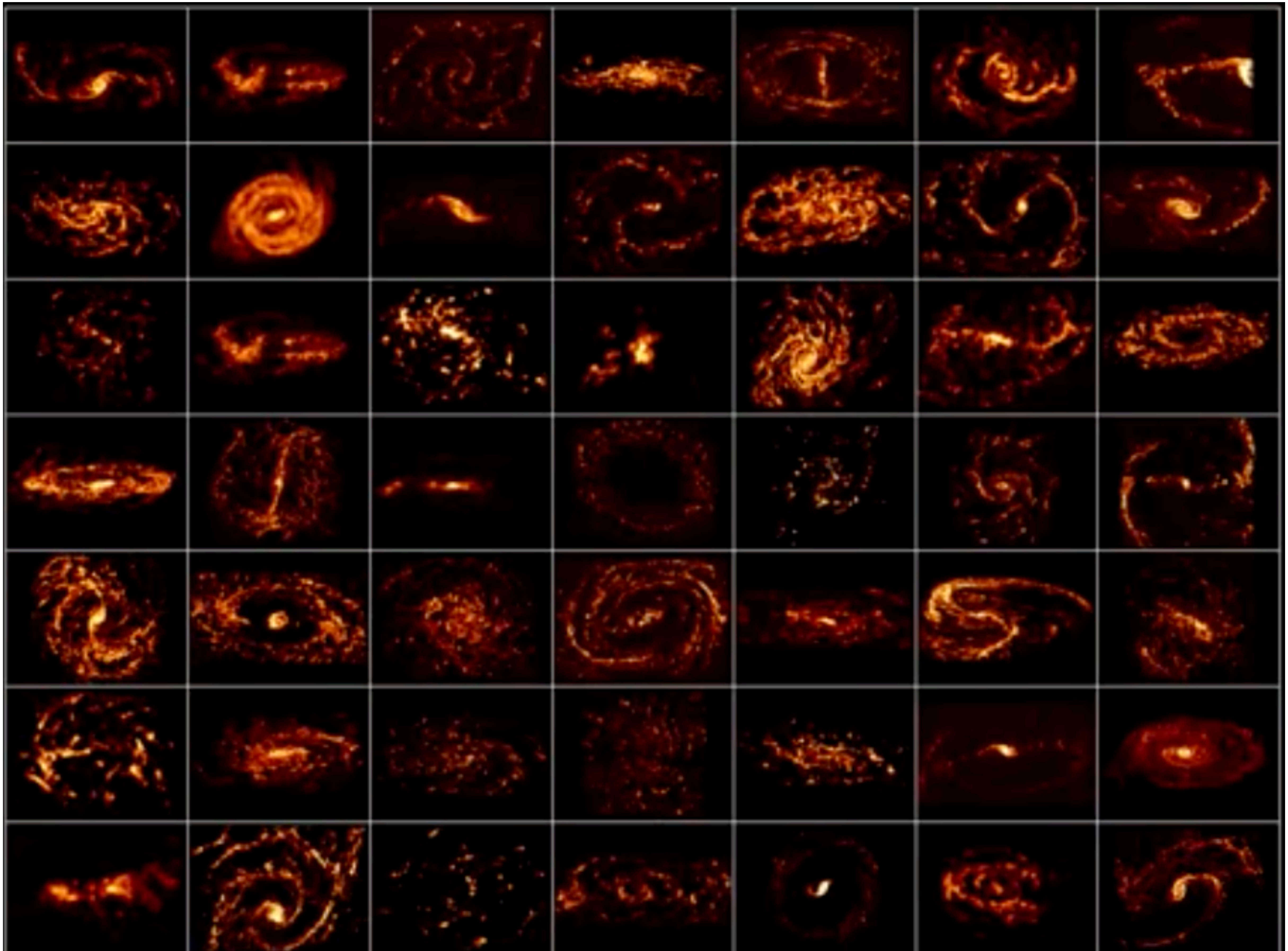
Sequence of Starbursts
SMGs
ULIRGS
BzK/Normal
Sequence of Disks
Spirals
log10 ΣSFR [M⊙ yr−1 kpc−2]
log10 ΣGas [M⊙ pc−2]
−1
0
1
2
3
4
−4
−3
−2
−1
0
1
2
3

Nearby galaxies



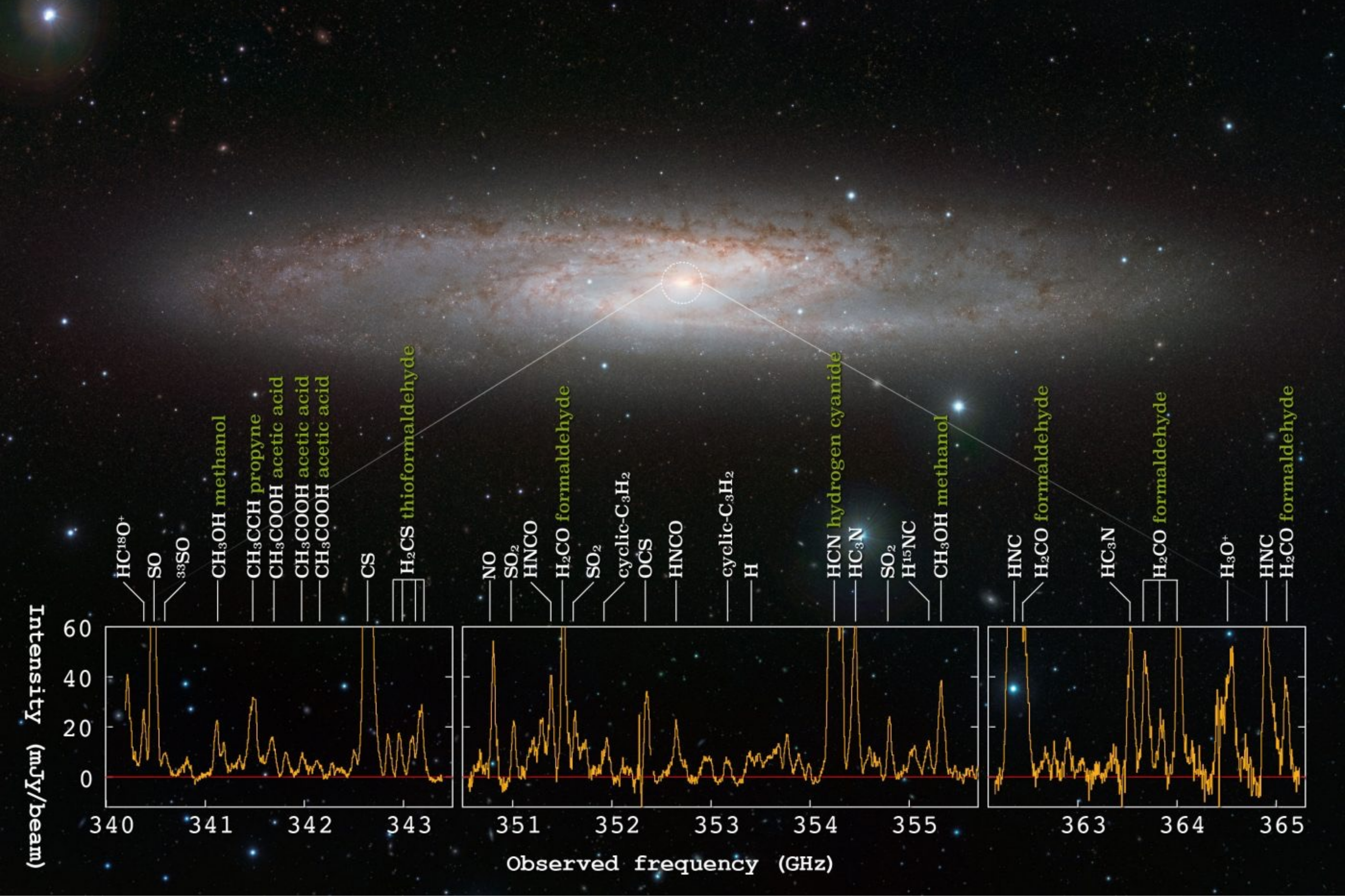
Credits : R. Neri, IRAM Xth IRAM school

PHANGS ALMA images



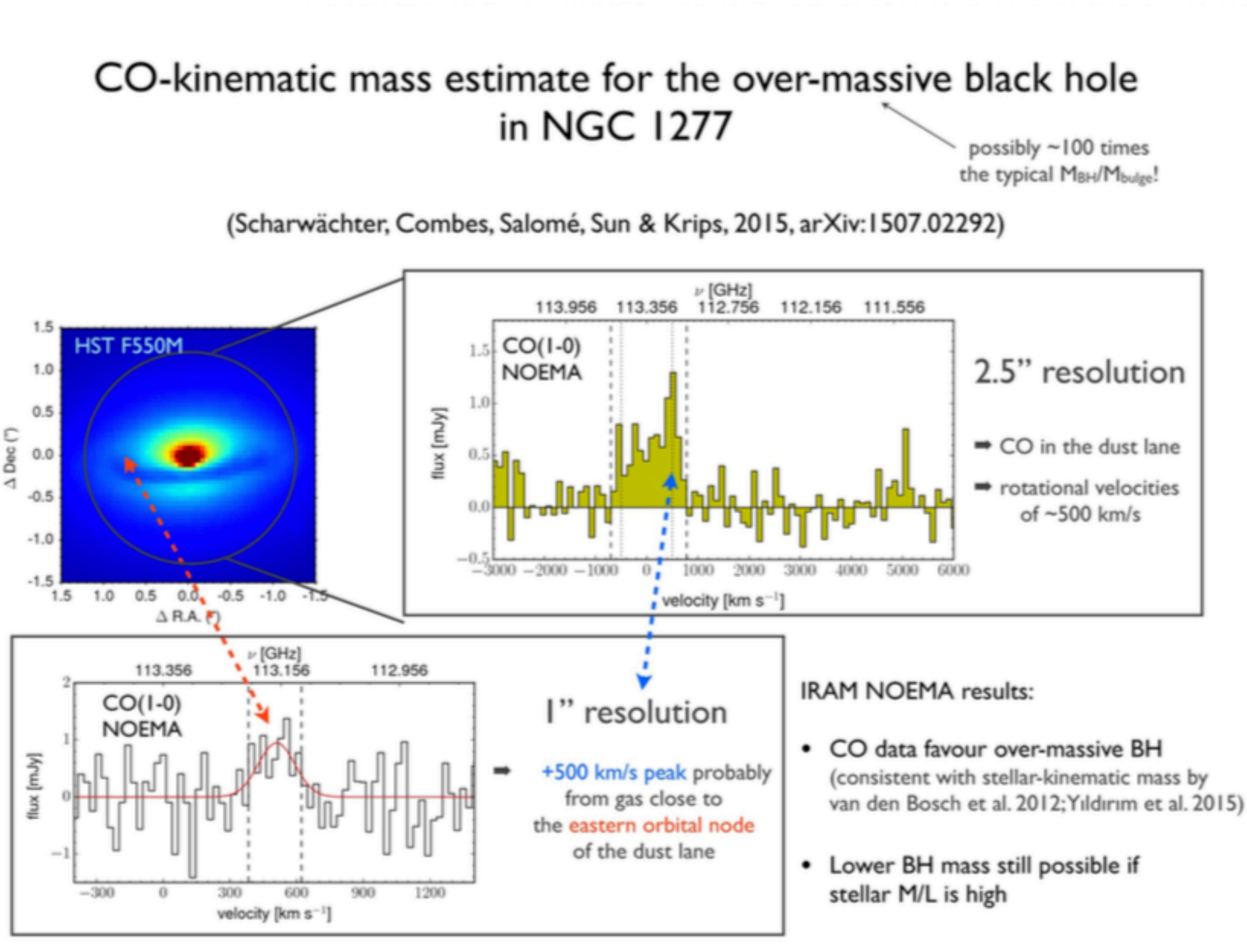
Credit: F. Santoro & A. Leroy/PHANGS/ALMA

The starburst galaxy NGC 253 and the radio spectra obtained with ALMA. ALMA detected radio signals from 19 different molecules at the center of this galaxy. Credit: ESO/J. Emerson/VISTA, ALMA (ESO/NAOJ/NRAO), Ando et al. Acknowledgment: Cambridge Astronomical Survey Unit



Black-Holes and Feedback

Weighting Black-Holes



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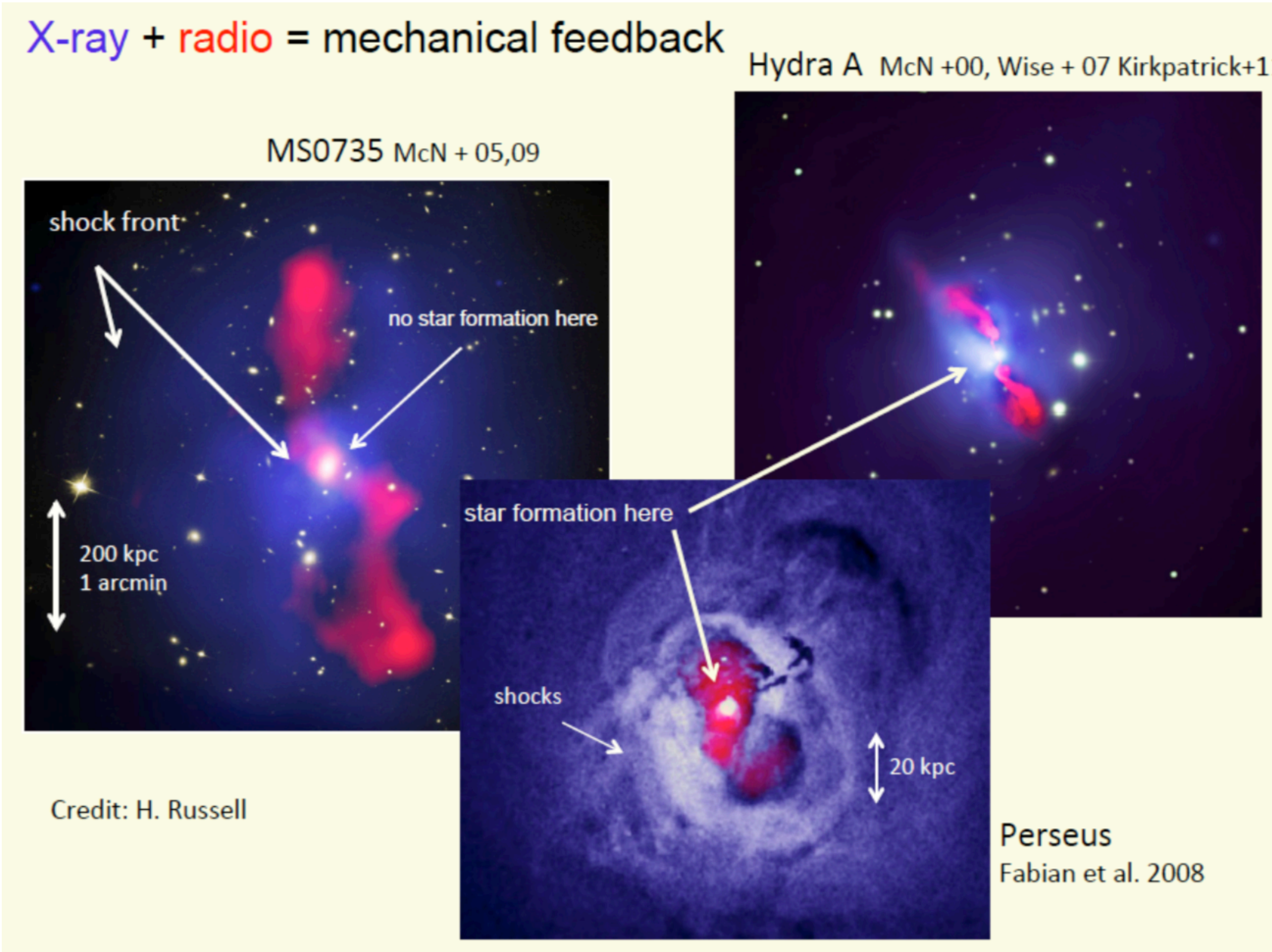
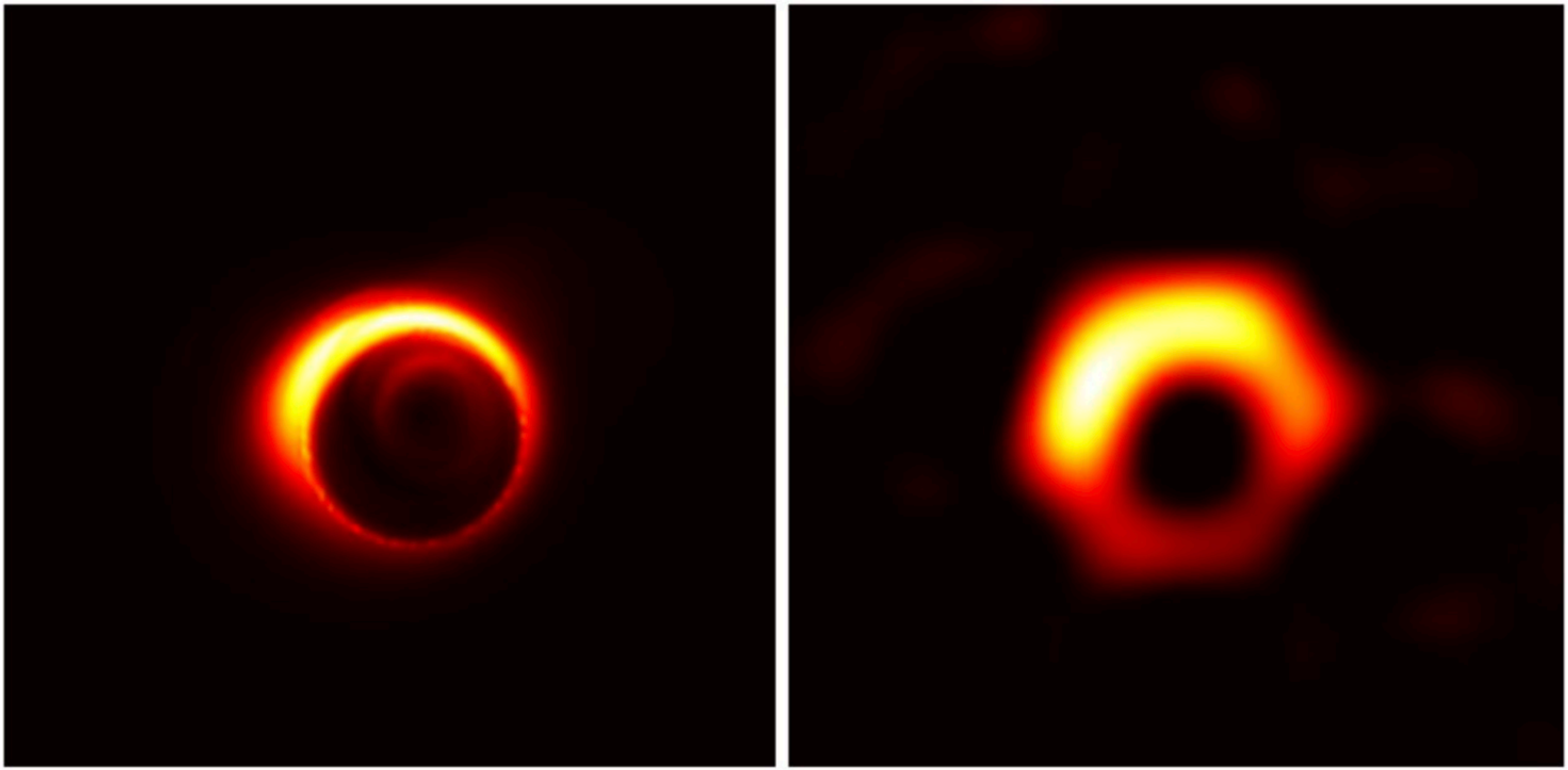
AGN-Feedback
(Black-Hole retro-action)

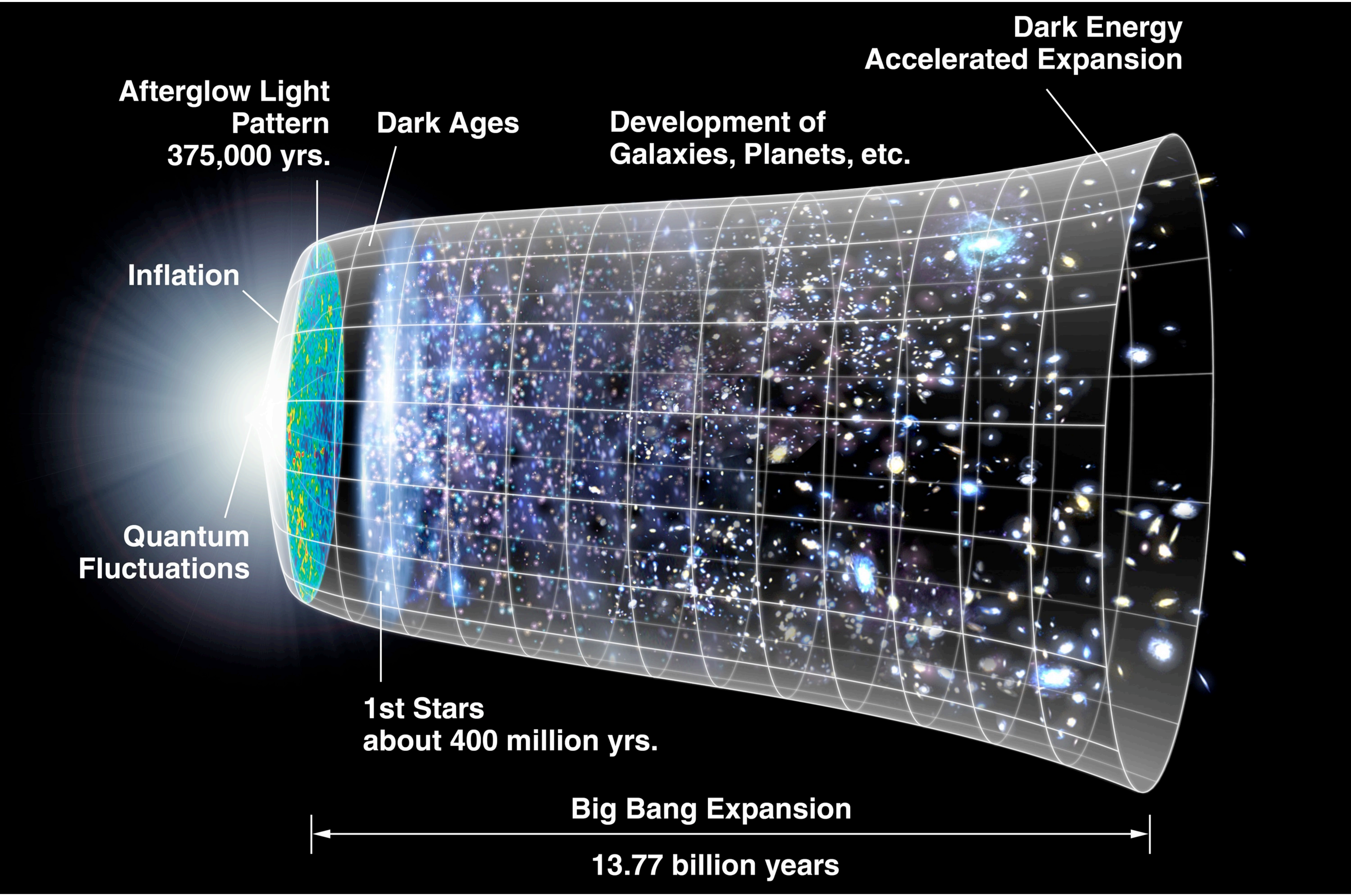


EHT (Event Horizon Telescope)
First image of a Black-Hole



A simulated image of the supermassive black hole at the centre of the M87 galaxy. The dark gap at the centre is the shadow of the black hole. Credit: Jason Dexter (left) and Kazunori Akiyama (right)

Primordial galaxies and Proto-clusters

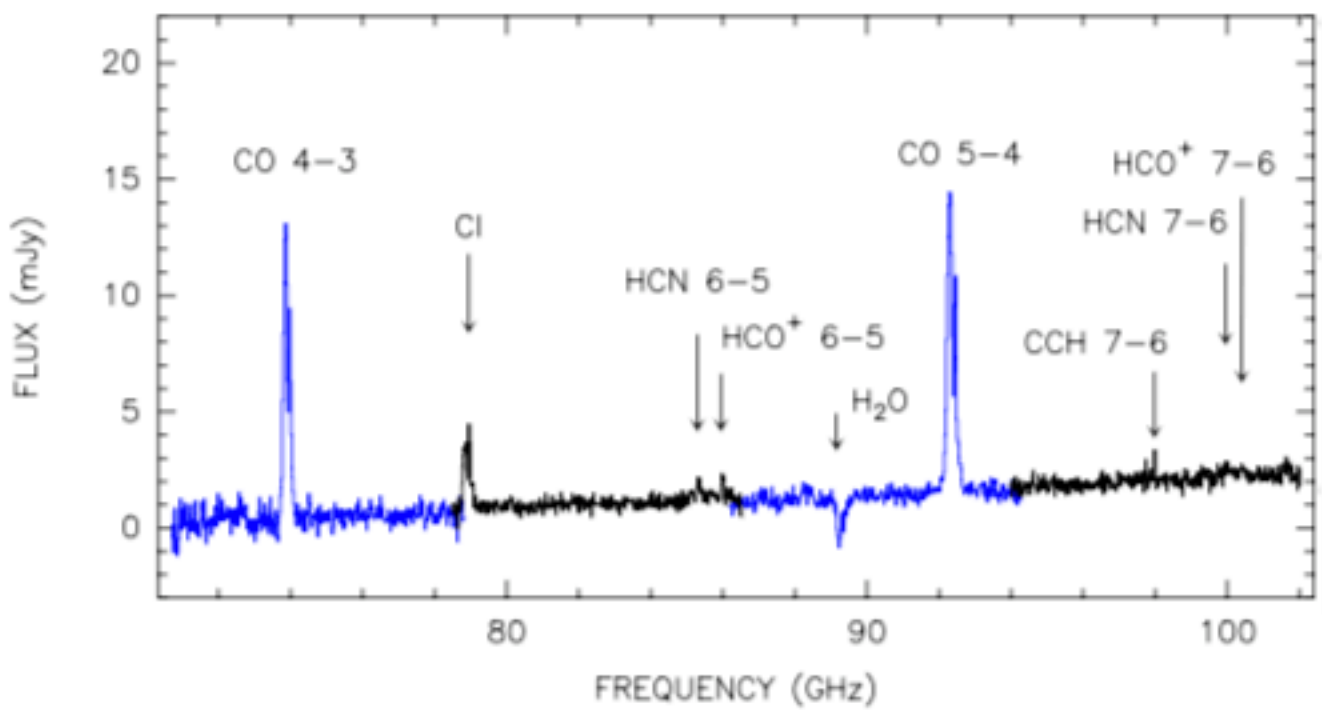

Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
375,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.77 billion years

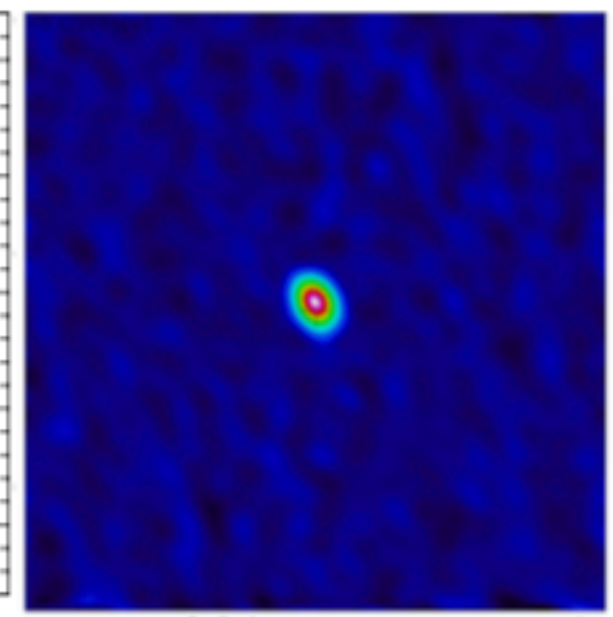
Molecules in primordial galaxies

wide-band spectroscopy with PolyFiX

- 7.2 hr on-source with nine antennas, two frequency setups
- continuum detected with a dynamic range 200:1
- detection of several transitions allows to determine the redshift

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

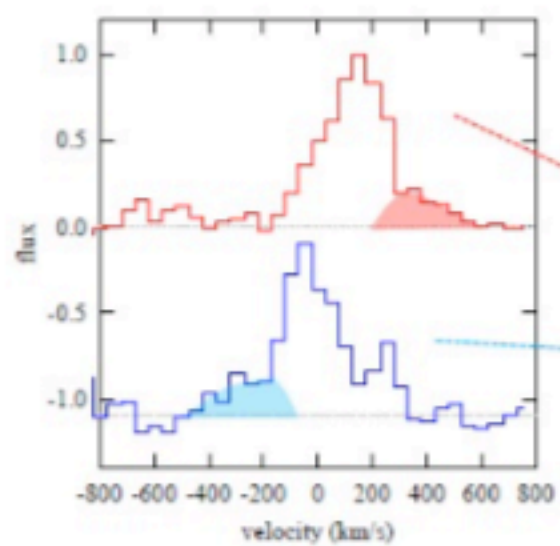


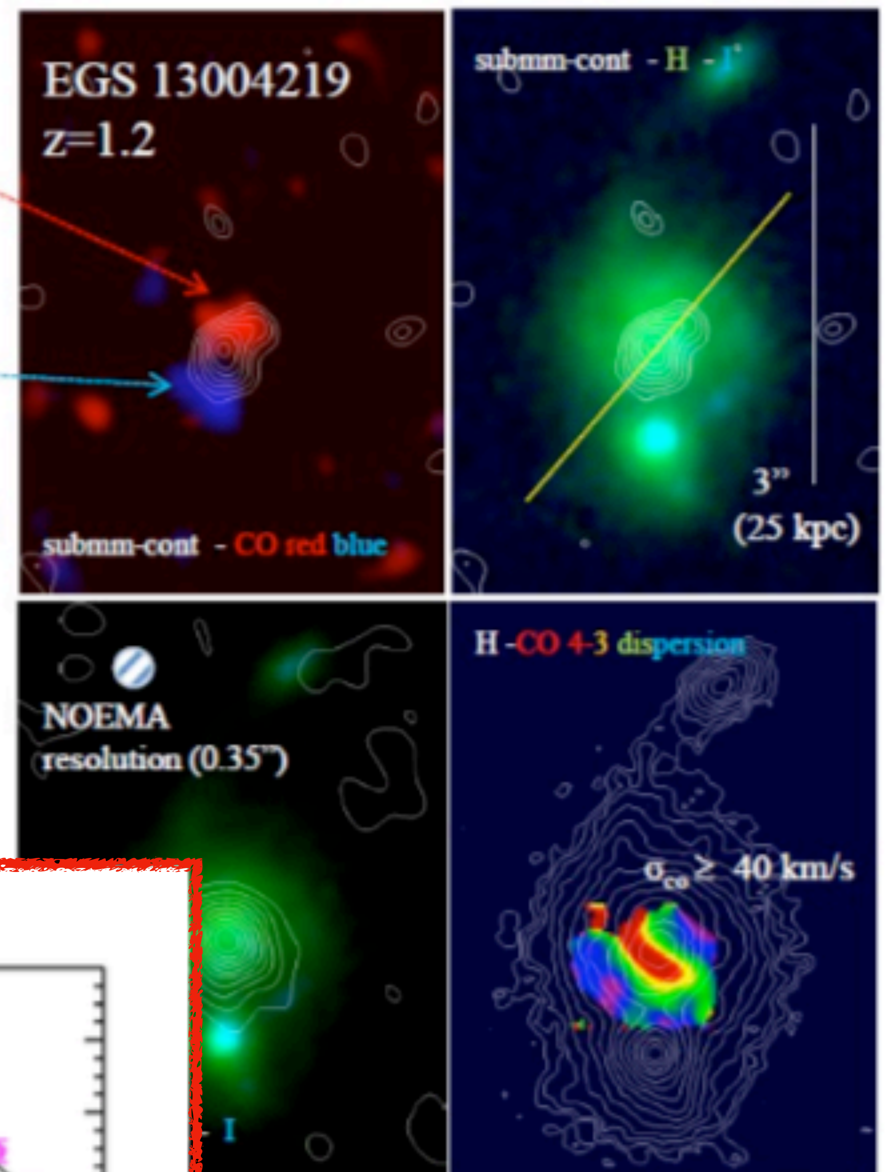


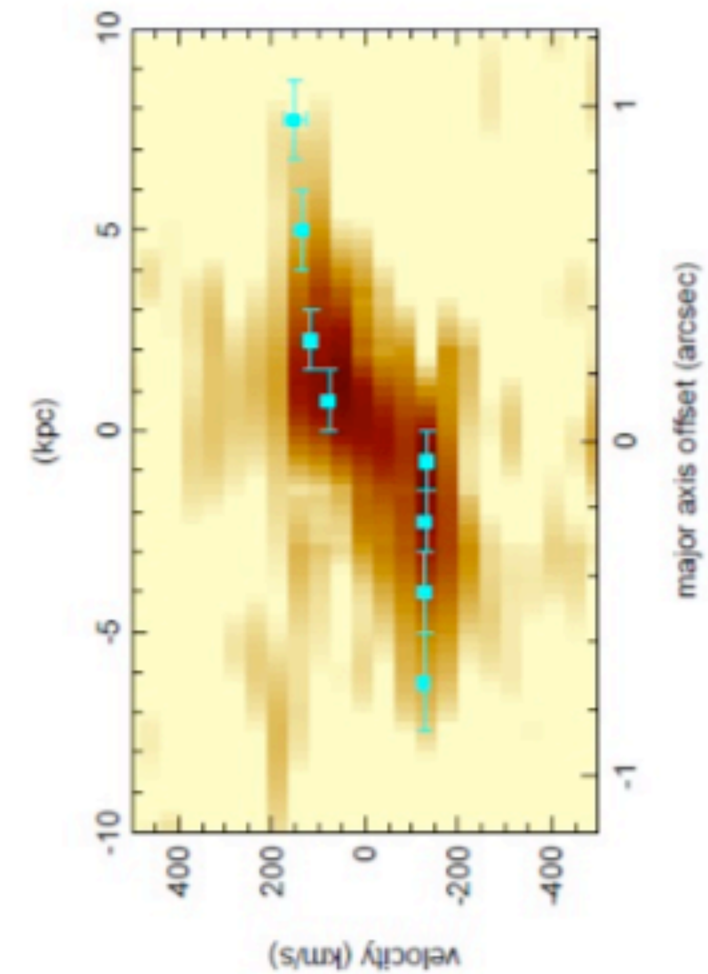
Credits : R. Neri, IRAM Xth IRAM school

Surveys of primordial galaxies

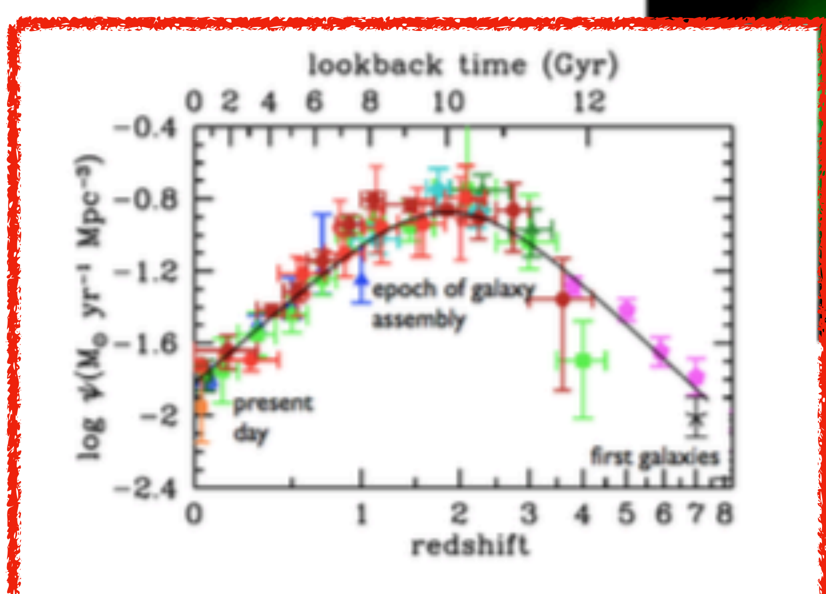
PHIBSS Cosmology Large Program 7/8 Ants





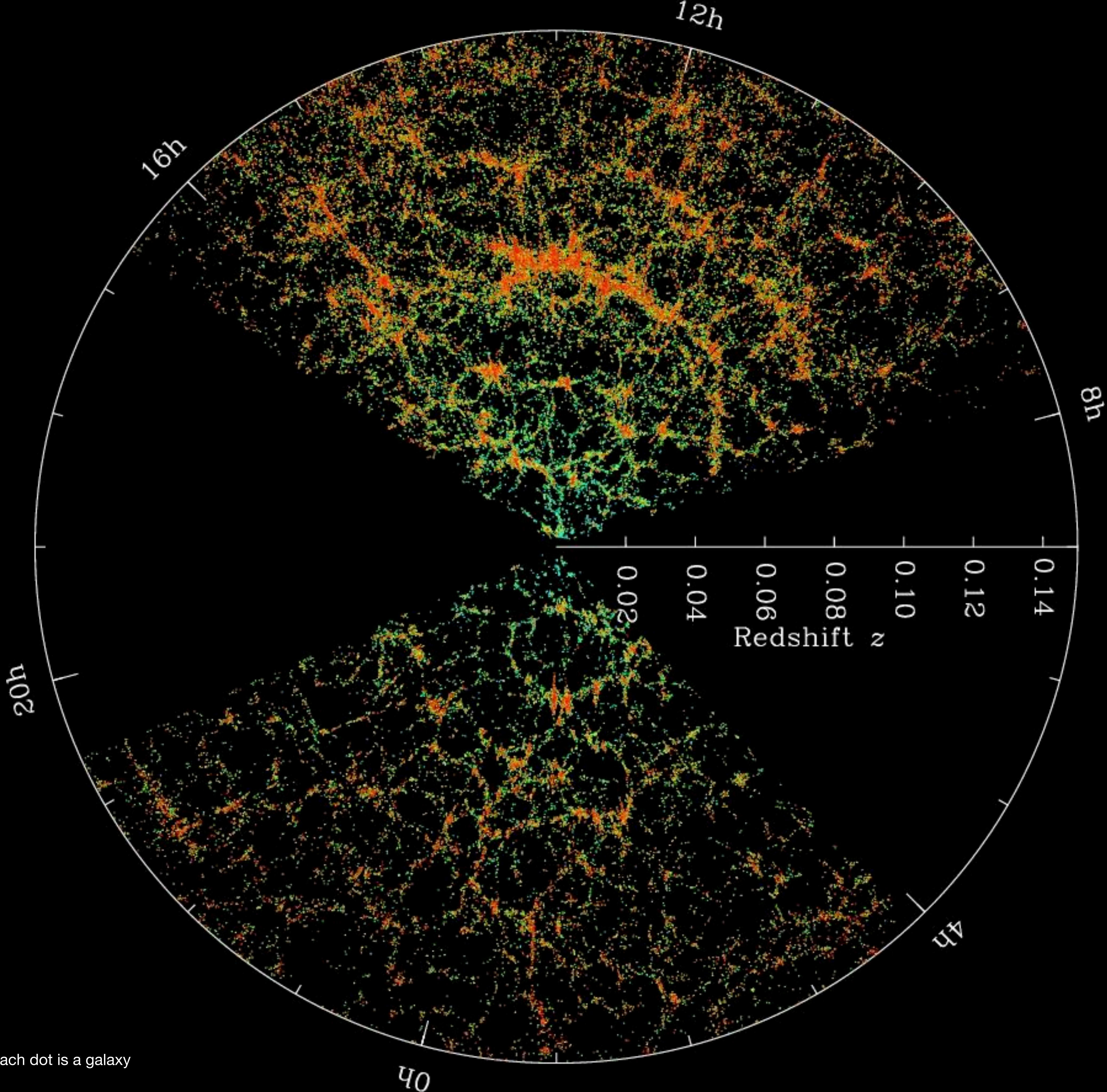


>1100 hr on-source time



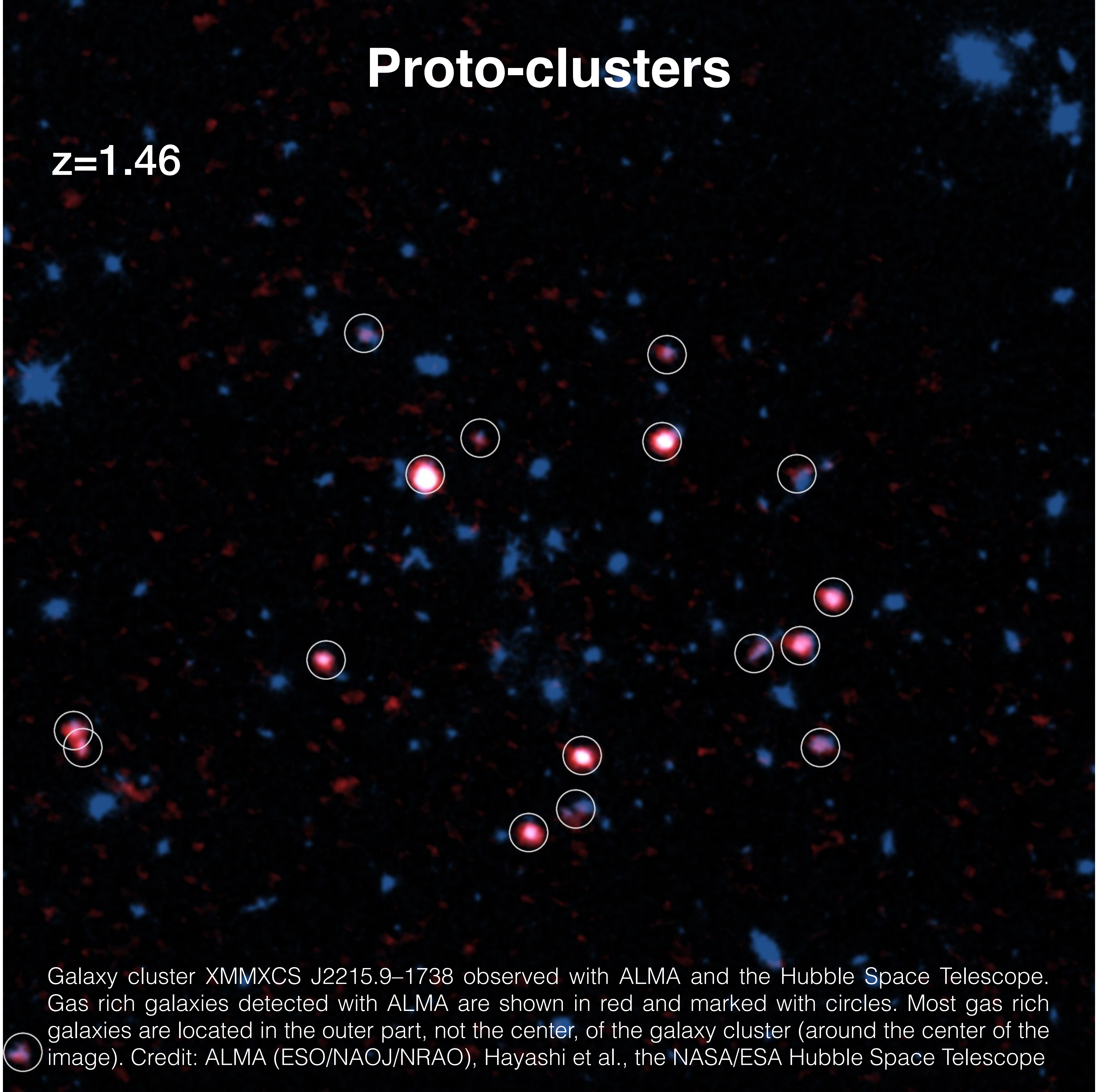
Tacconi, Combes, García-Burillo, Neri et al

Credits : R. Neri, IRAM Xth IRAM school



SDSS cosmic web. Each dot is a galaxy

Proto-clusters



Galaxy cluster XMMXCS J2215.9–1738 observed with ALMA and the Hubble Space Telescope. Gas rich galaxies detected with ALMA are shown in red and marked with circles. Most gas rich galaxies are located in the outer part, not the center, of the galaxy cluster (around the center of the image). Credit: ALMA (ESO/NAOJ/NRAO), Hayashi et al., the NASA/ESA Hubble Space Telescope

Telescopes

Historical Overview : some (sub)mm-Telescopes

- 1964: Haystack 37-m tel. (λ>6mm)
- 1965: Green Bank 140ft telescope (λ>6mm)
- 1969: Kitt Peak 36′/12m telescope (λ>1mm)
- 1970: Effelsberg 100m telescope (λ>3mm)
- 1982: Nobeyama 45m telescope (λ>2mm)
- 1984: IRAM 30m telescope (λ>0.8mm)
- 1988: CSO 10.4m telescope (λ>0.3mm)
- 1990: IRAM Plateau de Bure Interferometer (λ>0.8mm)
- 2000: GBT 105m telescope (λ>3mm)
- 2004: APEX (λ>0.3mm)
- 2006: LMT (λ>0.8mm)
- 2012: ALMA (λ>0.1mm)
- 2014: NOEMA (λ>0.8mm)

Credits : R. Neri, IRAM Xth IRAM school

Telescopes in the (sub)mm

- need for powerful instruments to observe astronomical targets up to the EoR (z=8)

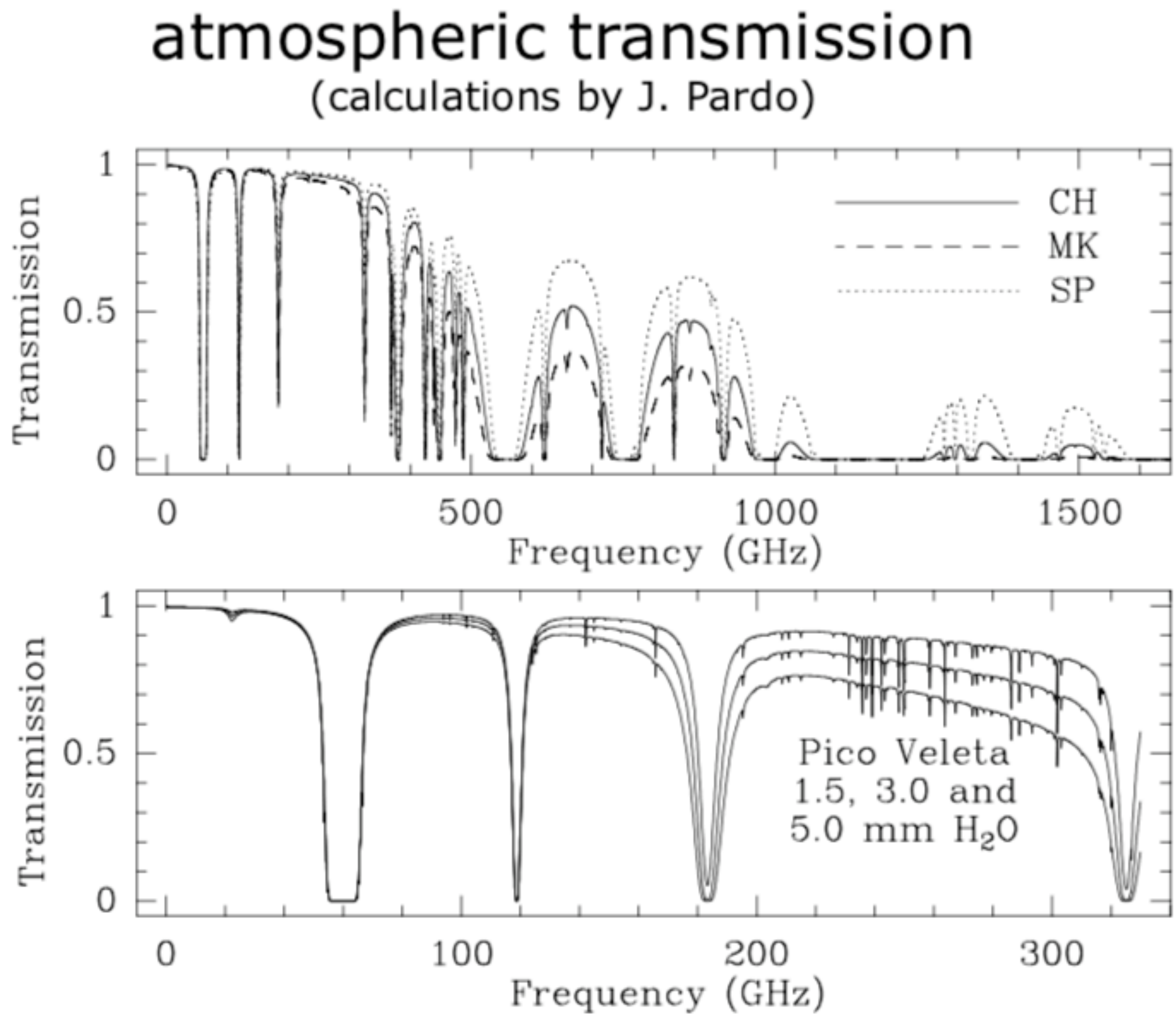
⇨ sensitivity and angular resolution
⇨ large telescopes e.g. ALMA, NOEMA/IRAM 30m
⇨ continuum and heterodyne receivers $R=10^7$-10^8

- water vapor reduces the ability to observe in the mm-range from the ground

⇨ high altitude sites i.e. above 2000m

Credits : R. Neri, IRAM Xth IRAM school

Telescopes in the (sub)mm

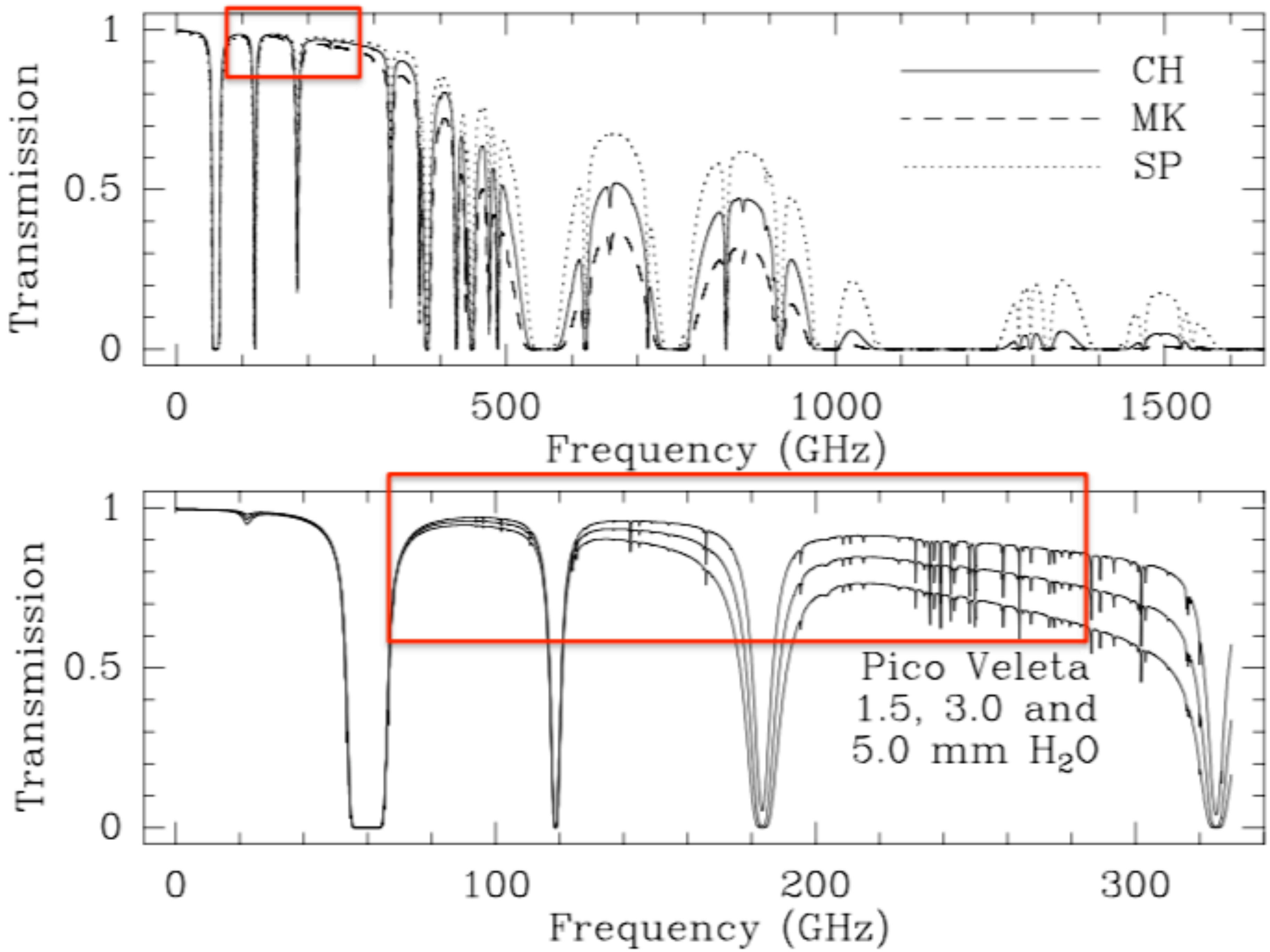


Credits : R. Neri, IRAM X[th] IRAM school

Telescopes in the (sub)mm

atmospheric transmission

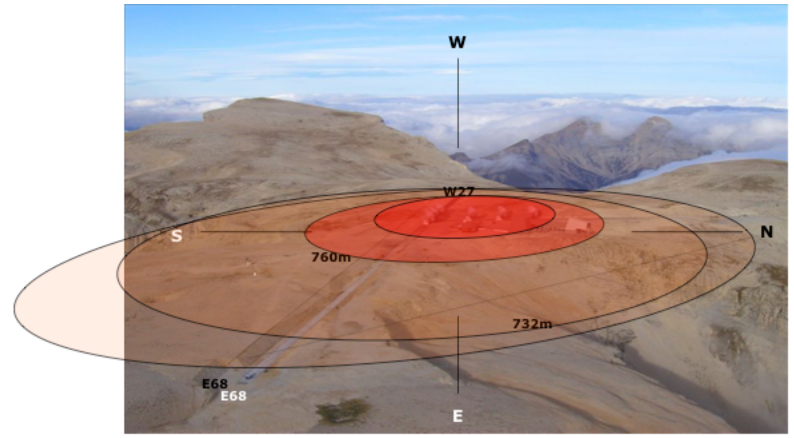
(calculations by J. Pardo)



Credits : R. Neri, IRAM X[th] IRAM school


IRAM NOEMA Interferometer **France**
IRAM 30-meter Telescope **Spain**
Submillimeter Telescope **USA**
Large Millimeter Telescope **Mexico**
Nobeyama **JAPAN**
– James Clerk Maxwell Telescope
– Submillimeter Array
USA
– Atacama Large Millimeter Array (ALMA)
– Atacama Pathfinder Experiment (APEX)
Chile
ATCA
Australia
South Pole Telescope **Antarctica**

Interferometers



Résolution = Lambda / D	**Résolution = Lambda / B**
D=Single antenna Diameter	B=Distance btw antennas

- high angular resolution
  - @ 230 GHz: 0.4″ with NOEMA10 > 0.2″ with NOEMA12
  - @ 350 GHz ~20 uas with VLBI (planned)

- large collective area
  - NOEMA12 = 50-meter antenna; ALMA45 = 80-meter antenna

- no need of reference sky position (gain of a factor √2 in sensitivity)
- flatter baselines, depend less on receiver/atmosphere stability
- field of view with many independent pixels ⇨ good noise statistics makes possible secure detections down to 4 sigma
- well suited for special observations e.g. polarimetry, SZ
- accurate source positions
- filter out extended (foreground/background) emission

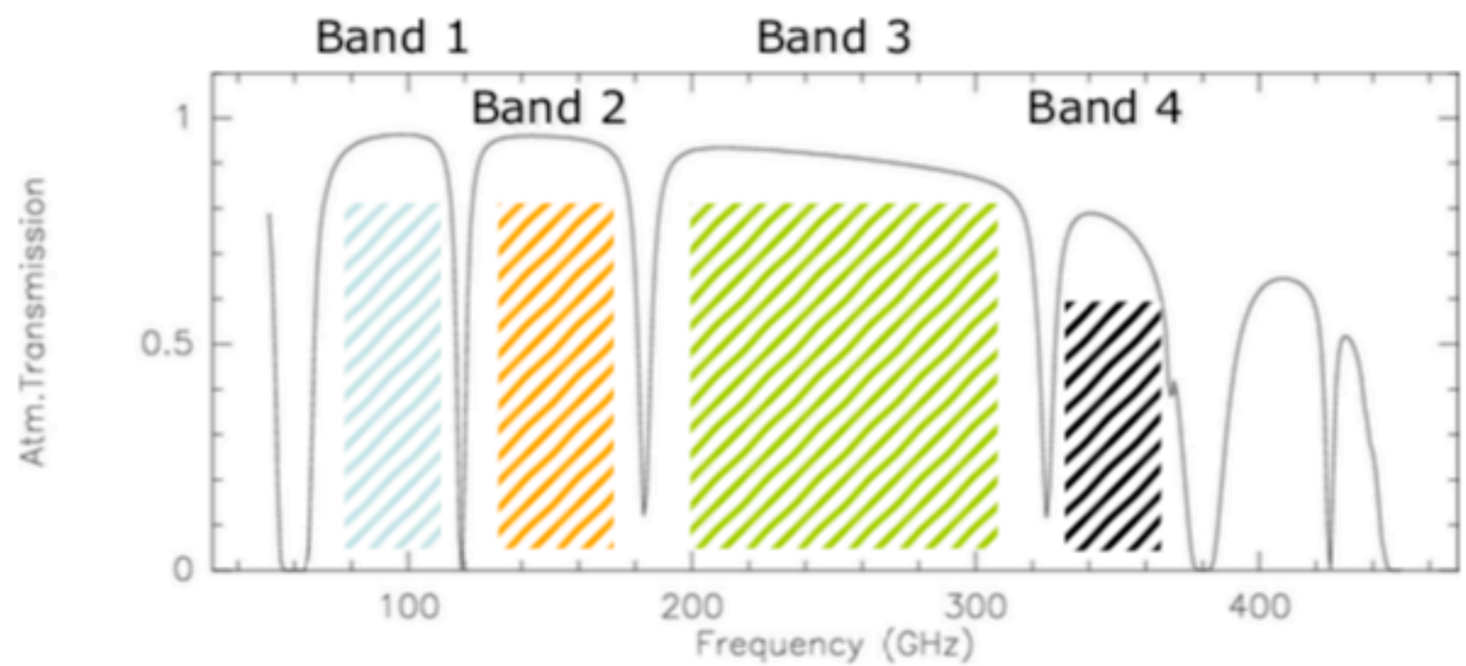
Credits : R. Neri, IRAM Xth IRAM school

Interferometers

Telescope	Altitude	Frequencies
EFFELSBERG 100m	320	<90 GHz
ATCA	240	<105 GHz
GBT	320	<115 GHz
NOEMA/IRAM 30M	2500/2800	< 380 GHz
SMA 8	4030	<700 GHz
LMT	4600	<350 GHz
ALMA 50	5000	<1000 GHz

Credits : R. Neri, IRAM X[th] IRAM school

Interferometers



3mm = 100 GHz   2mm = 150 GHz   1mm = 300 GHz   0.8mm = 350 GHz

Interferometer	Atmospheric window	Ang.Resolution
ATCA	3mm	1.6" @ 105 GHz
NOEMA	3mm, 2mm, 1mm, 0.8mm	0.4" @ 230 GHz
SMA	1mm, 0.8mm	0.5" @ 230 GHz
ALMA	3mm, 2mm, 1mm ⇨ Band 10	0.02" @ 230 GHz

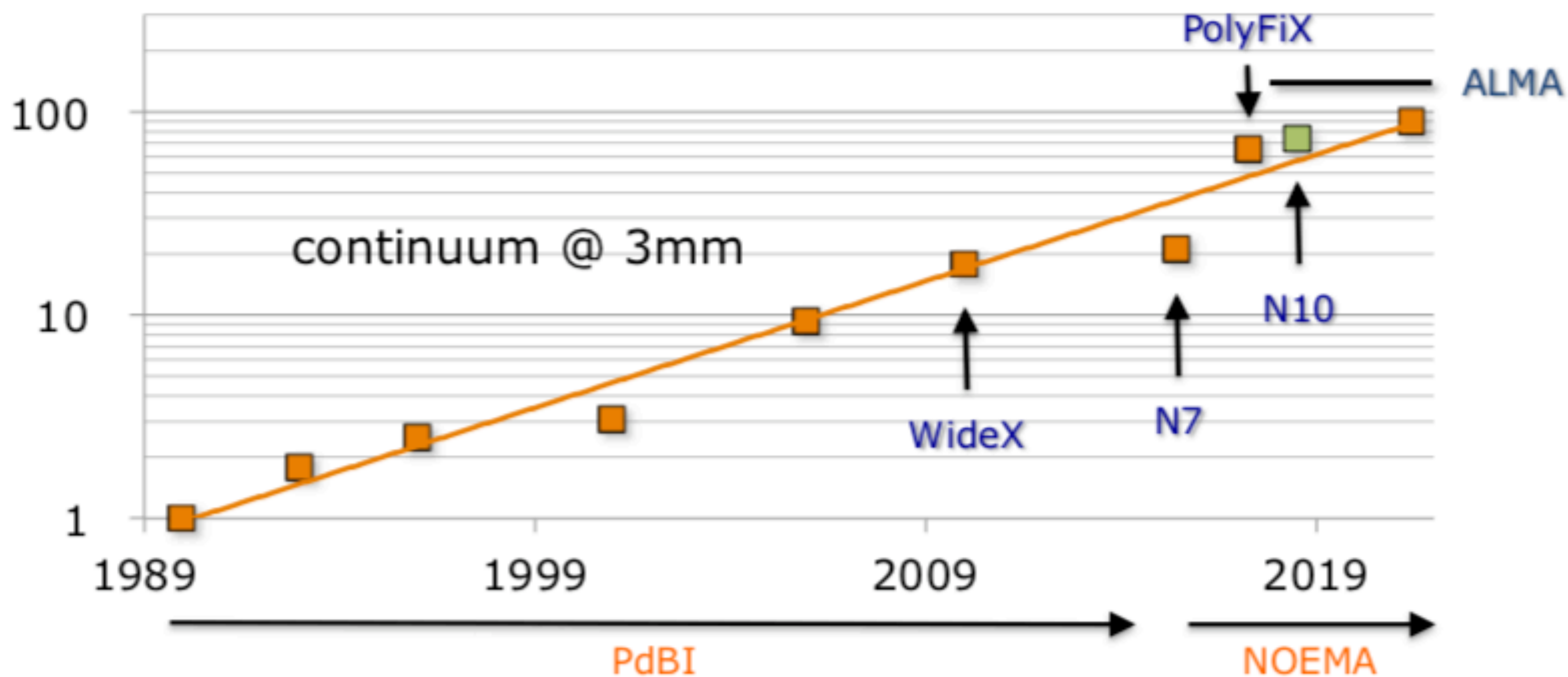
Large differences !

Credits : R. Neri, IRAM Xth IRAM school

Interferometers

- initial PdBI capabilities multiplied by orders of magnitude

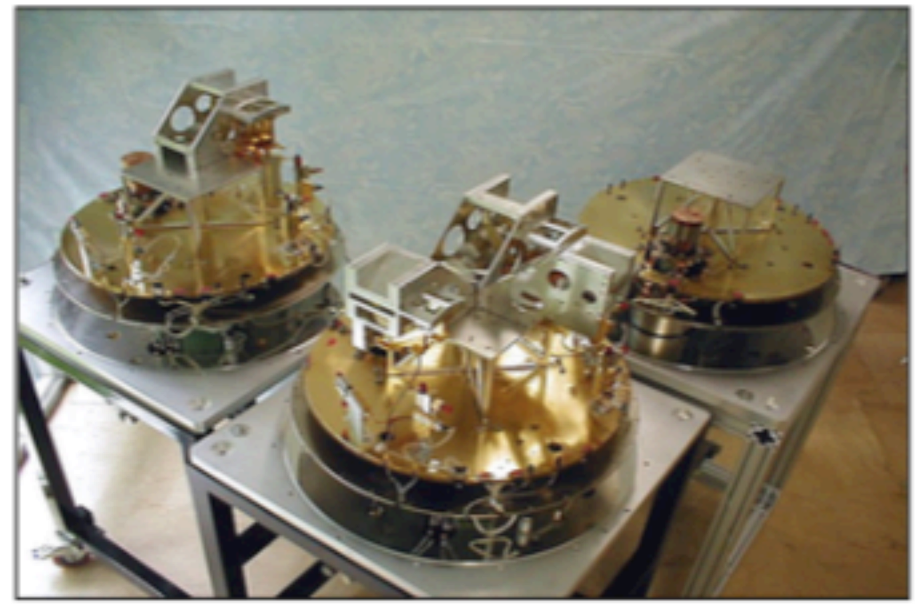
  100x cont. sensitivity, 7x line sensitivity ⇨ ALMA like sensitivities



NOEMA will reach >65% ALMA continuum sensitivity @ 3mm
>45 % ALMA line sensitivity @ 3mm

Credits : R. Neri, IRAM Xth IRAM school

IRAM (Fr/Ger/Sp)
Institut Radio-Astro millimetrique



- Telescope design (~30 um), construction and operation
- Receiver design and development e.g. ALMA Band7, MPS, AETHRA
- HS-digital backends + LO systems e.g. PolyFiX (2x 2x 8 GHz)

Credits : R. Neri, IRAM X^{th} IRAM school

IRAM Receivers

NOEMA state of the art receiver technology

- closed cycle cryocoolers ⇨ no liquid He refills
- SIS mixers ⇨ 8 GHz Band per polarization and sideband
  ⇨ USB and LSB operation (2SB)
- fully reflective optics ⇨ lower loss
- new design ⇨ higher density, better EMI control, simplified wiring
- in the near future tuneless mixers and LOs ⇨ simplified frequency tuning and switching

Credits : R. Neri, IRAM Xth IRAM school

IRAM Correlator

PolyFiX

- (32 GHz = 8 GHz x 2 sidebands x 2 polarizations) x 12 antennas
- data output = >140.000 spectral channels

Full 32 GHz band, 16000 x 2 MHz
AND
up to 128 spectral windows of 64 MHz, 1024 x 62.5 KHz

- 5-bit sampling = correlation efficiency close to 100%

Credits : R. Neri, IRAM Xth IRAM school

ALMA in a Nutshell...

- Angular resolution down to 0.015” (at 300 GHz)
- Sensitive, precision imaging 84 to 950 GHz (3 mm to 315 μm)
- State-of-the-art low-noise, wide-band receivers (8 GHz bandwidth)
- Flexible correlator with high spectral resolution at wide bandwidth
- Full polarization capabilities
- Estimated 1 TB/day data rate
- All science data archived
- Pipeline processing

Credits: Nienke van der Marel

ALMA in a Nutshell...

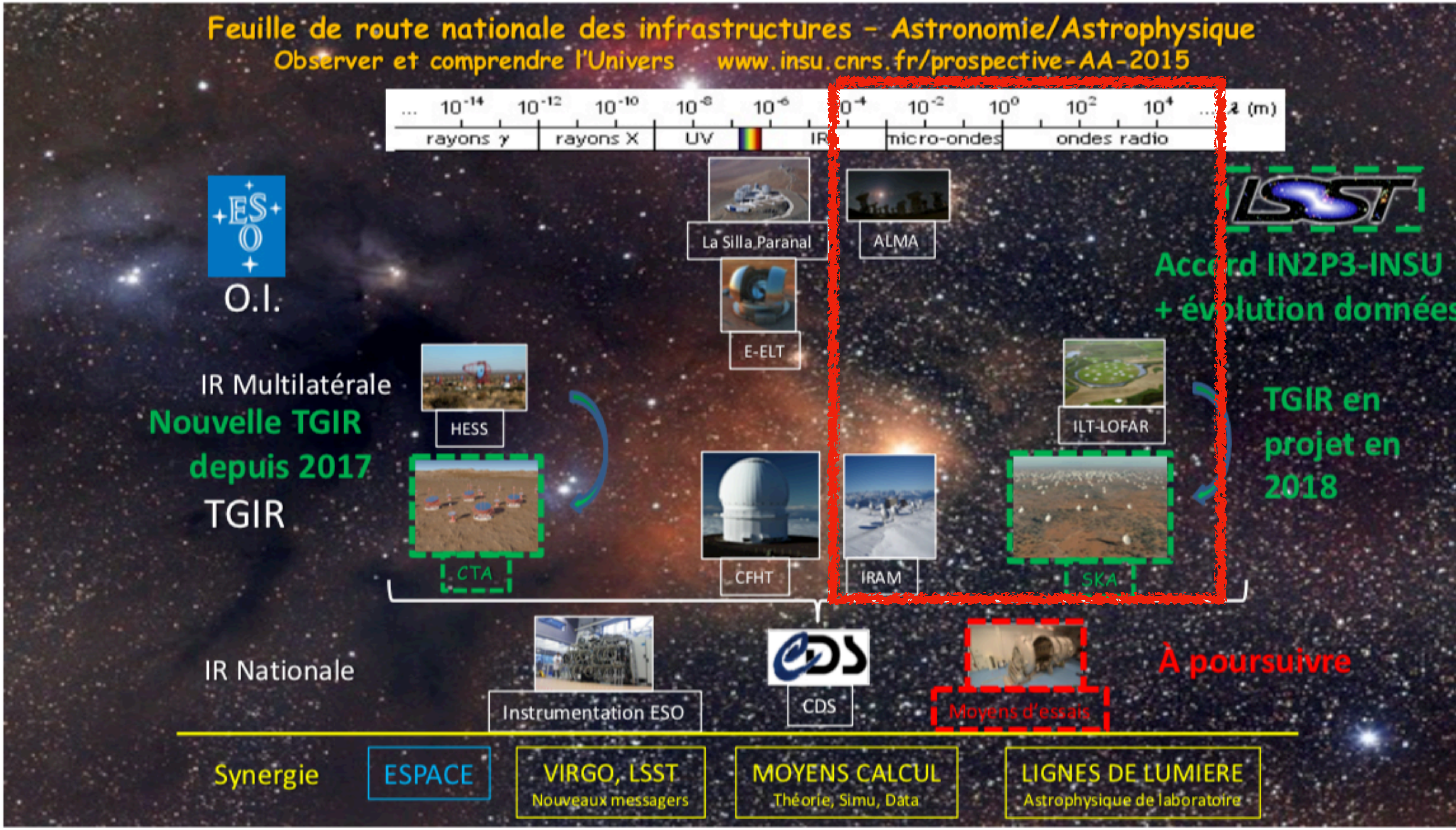
- Angular resolution down to 0.015” (at 300 GHz)
- Sensitive, precision imaging 84 to 950 GHz (3 mm to 315 μm)
- State-of-the-art low-noise, wide-band receivers (8 GHz bandwidth)
- Flexib
  bandv
- Full p
- Estim
- All sci
- Pipeline processing

Rich Archive of public data (2D + 3D)

- ESO : https://almascience.eso.org/asax/
- OP-viewer : http://artemix.obspm.fr/

Credits: Nienke van der Marel

TGIR



Credits : Guy Perrin (SF2A 2019)

INFRASTRUCTURES DE RECHERCHE : ASTRONOMIE ET ASTROPHYSIQUE

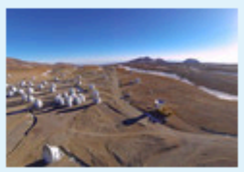
Lien Site Ministère

ASTRONOMIE ET ASTROPHYSIQUE

European Southern Observatory-ESO

L'ESO est une organisation intergouvernementale européenne dans le domaine de l'astrophysique au sol ; 15 états-membres, dont la France, contribuent en proportion de leur PIB. L'ESO construit et gère un ensemble de télescopes au sol installés au Chili, dont certains sont des infrastructures ESFRI...

Atacama Large Millimeter/Submillimiter Array-ESO-ALMA



ALMA est un observatoire astronomique installé au Chili, fruit d'un partenariat international avec l'ESO, dédié à l'observation de l'univers dans le domaine des ondes radio millimétriques et sub-millimétriques (30 Ghz - 1 THz) grâce à un réseau d'antennes au sol...

European Extremely Large Telescope-ESO E-ELT

Le E-ELT (European Extremely Large Telescope), dont le développement a commencé en 2015, est l'un des observatoires de l'ESO. Installé au Chili, il sera dédié à l'observation de l'univers dans le domaine visible/infrarouge...

La Silla & Paranal Observatory-ESO LSP

La Silla-Paranal est l'un des observatoires de l'ESO au Chili consacré à l'observation de l'univers dans le domaine visible et proche infrarouge. Il comprend le VLT (Paranal) avec une forte implication de la France dans les instruments MUSE et SPHERE, et les télescopes de 3,60 m et NTT (la Silla)...

Canada-France-Hawaii Telescope-CFHT

Le CFHT est un observatoire astronomique international (FR, CA , US) au sommet du volcan Mauna Kea, sur la grande île d'Hawaii. Il collecte avec une excellente qualité d'image la lumière visible et infrarouge émise par les galaxies, les étoiles, les planètes,...

Institut de RadioAstronomie Millimétrique-IRAM

L'IRAM, institut international (FR-DE-ES) met à disposition de la communauté scientifique deux observatoires dans le domaine des longueurs d'onde millimétriques et submillimétriques : antennes NOEMA pour la France (Plateau de Bure, vers Grenoble) et une antenne au Pico Veleta (Andalousie, Espagne)...

Centre de Données astronomiques de Strasbourg-CDS

Le CDS produit des services à forte valeur ajoutée, de référence pour la communauté astronomique internationale, SIMBAD, VizieR, Aladin et le service de cross-identification. C'est un acteur majeur de l'Observatoire Virtuel (OV) international, et le porteur des projets OV européens depuis 2006...

Instrumentation pour les grands télescopes de l'ESO-INSTRUM-ESO

INSTRUM-ESO concerne la réalisation par les moyens nationaux des instruments focaux des grands télescopes optiques de l'ESO, aujourd'hui pour les VLT/VLT-I du site de Paranal et dans le futur pour le European Extremely Large Telescope (E-ELT)...

High Energy Stereoscopic System-HESS

HESS est un réseau international de cinq télescopes situés en Namibie, consacré à l'astrophysique des très hautes énergies. Il détecte les photons gammas de l'ordre du Tera-Electronvolt à travers les cascades de particules générées dans l'atmosphère terrestre, et permet de remonter à leur origine...

International Low Frequency Radio Array Telescope - ILT-LOFAR FR

LOFAR est un réseau de stations de radioastronomie aux basses fréquences (10-270 MHz). Il s'intéresse à l'astrophysique, la planétologie et la cosmologie. Il est formé d'environ 50 stations centrées aux Pays-Bas et réparties à travers l'Europe. Le nœud français est situé à Nançay (région Centre)...

SRN l'Observatoire de Paris | PSL

Station de Radioastronomie de Nançay

Services Nationaux d'Observation (SNO)

ANO-2 : Instrumentation des grands observatoires au sol et spatiaux

Cette Action nationale d'observation porte sur la capacité des OSU de concevoir, exercer la maîtrise d'œuvre, réaliser et assurer le fonctionnement d'instruments (en particulier focaux) pour les infrastructures de recherche sol et les missions spatiales qui fournissent des données accessibles à l'ensemble de la communauté. Il s'agit de moyens lourds, ouverts à l'ensemble de la communauté française, ayant une visibilité internationale forte, et dont les données sont rapidement rendues publiques. Elle concerne également la fourniture de logiciels d'acquisition et de réduction de données. Cette Action nationale d'observation est structurée en deux volets :

- Instrumentation des télescopes, sondes et observatoires spatiaux
- Instrumentation des grands télescopes et interféromètres au sol

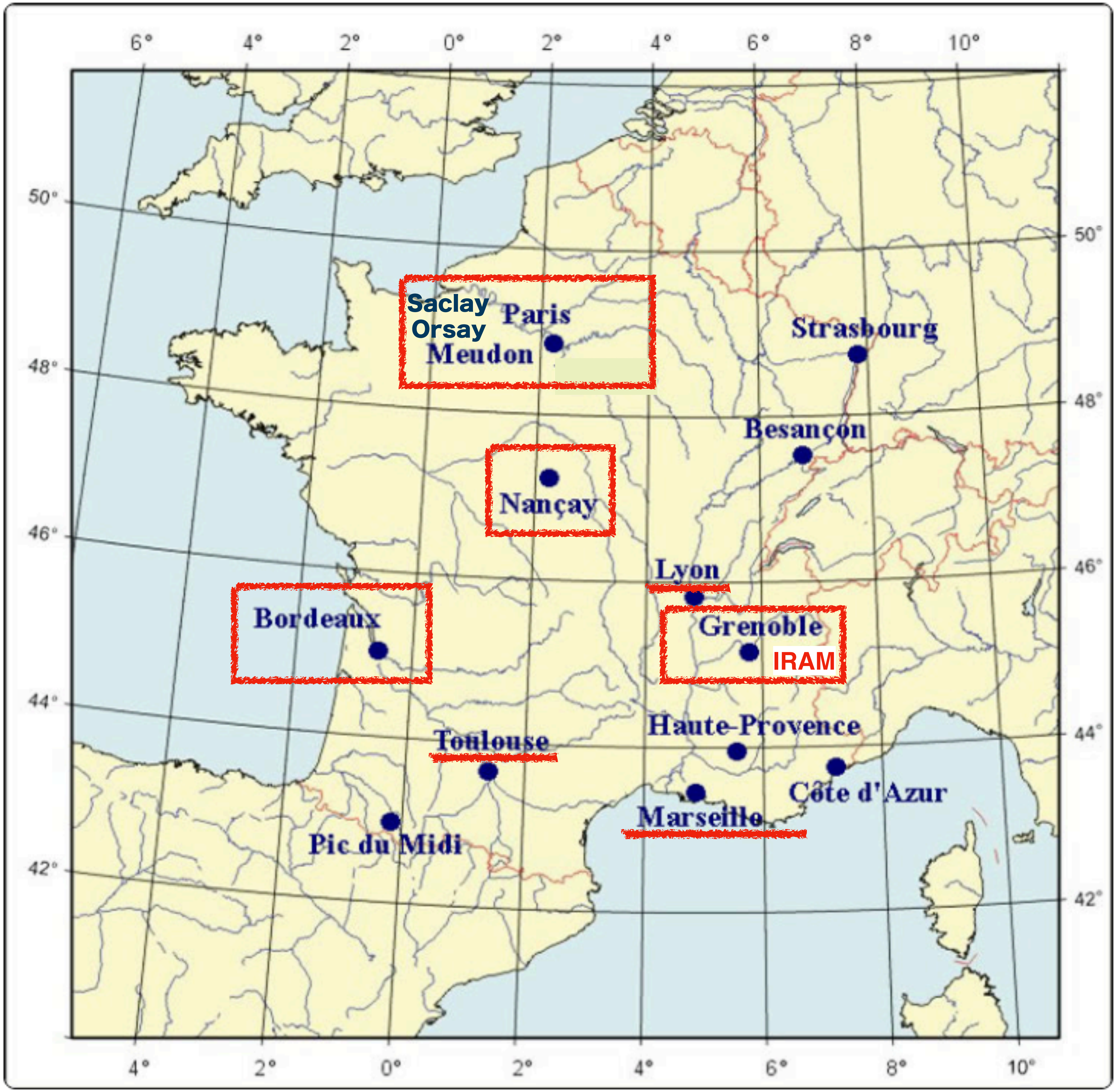
Obs. Paris	AA-ANO2	SO2_InstrumentationSpatiale	JUICE / RPWI
Obs. Paris	AA-ANO2	SO2_InstrumentationSpatiale	JUICE / SWI
Obs. Paris	AA-ANO2, AA-ANO3	SO2_InstrumentationSol	SKATE

ANO-3 : Stations d'observation

Les astronomes ont à leur disposition des moyens lourds nationaux ou internationaux dont la gestion est une tâche souvent exigeante, et qui n'a pas de retour direct en termes de publications. Pour reconnaître ce service à la communauté cette action comprend :

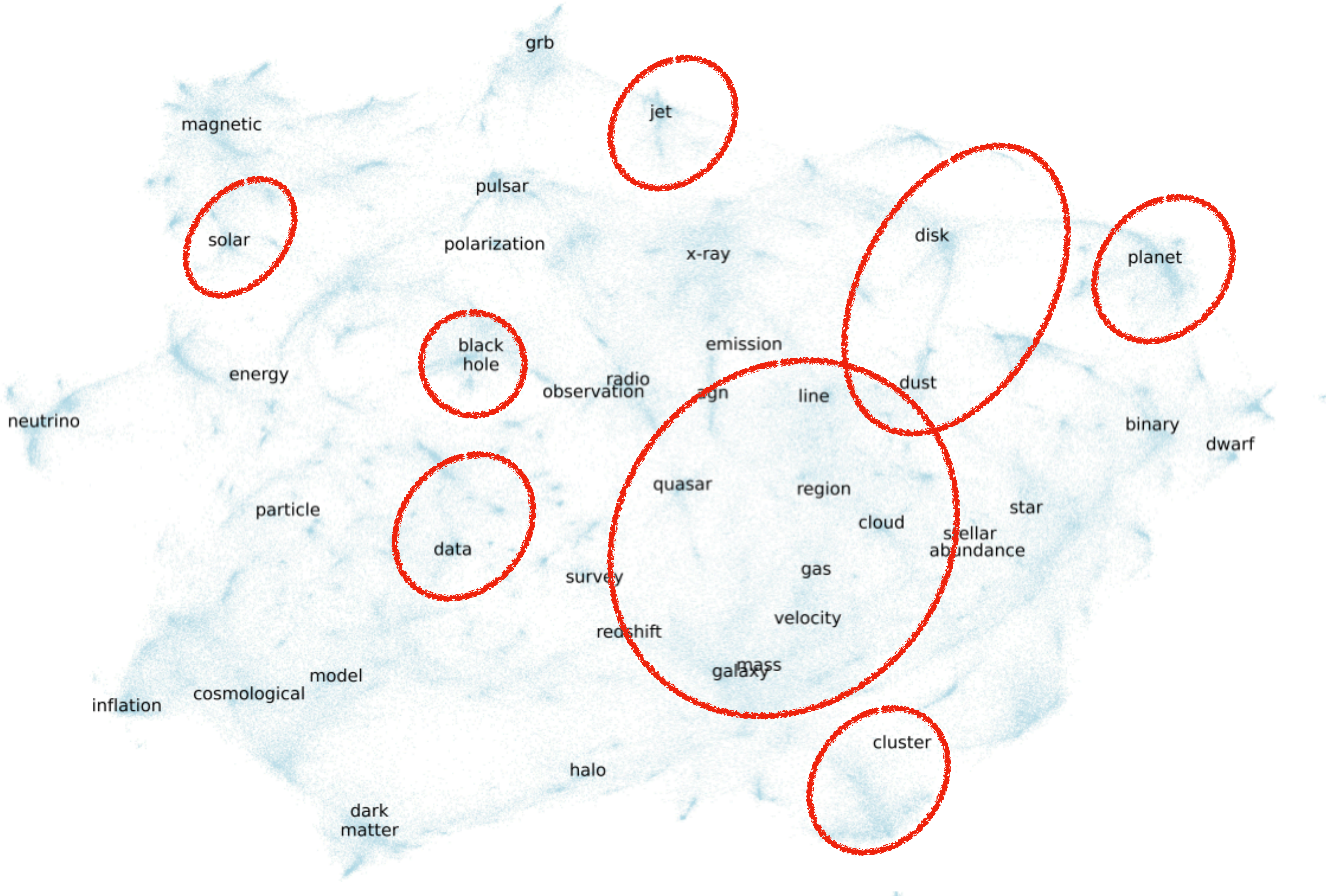
- La gestion des stations d'observation
- Les activités instrumentales qui leur sont propres
- L'opération des instruments après leur mise en service
- Les actions amont qui visent la qualification et la protection des sites d'observation existants et futurs (optique, radio…)

OSU coordinateur	Type de SNO	Sous-type de SNO	Nom du SNO
Obs. Paris	AA-ANO2, AA-ANO3	SO2_InstrumentationSol	SKATE
OASU	AA-ANO3		ALMA Regional Center
OASU	AA-ANO3		IRAM
Obs. Paris	AA-ANO3		Station de Radioastronomie de Nançay


Saclay
Orsay
Paris
Meudon
Strasbourg
Besançon
Nançay
Lyon
Grenoble
IRAM
Bordeaux
Haute-Provence
Toulouse
Côte d'Azur
Marseille
Pic du Midi

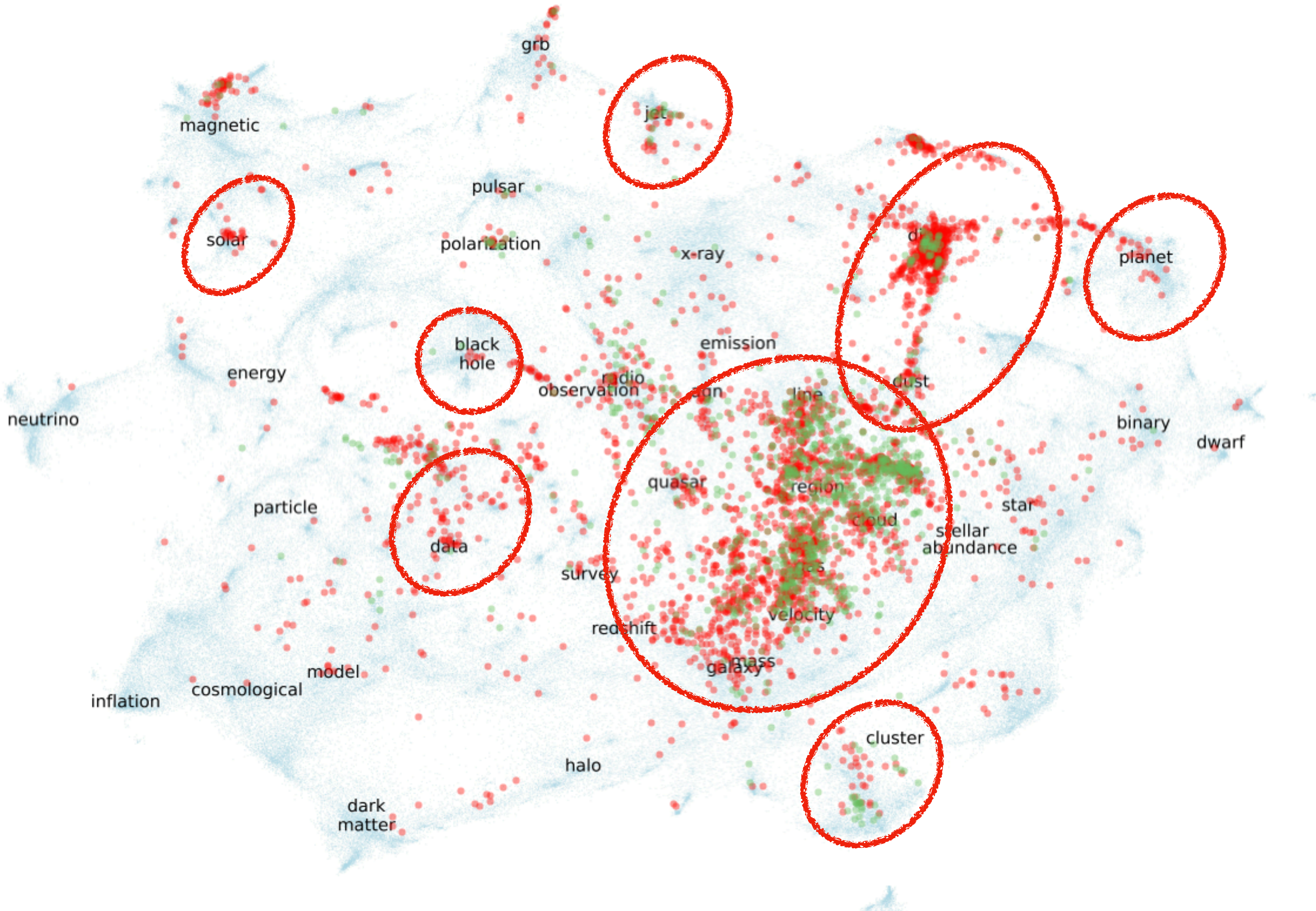
Carte IMCCE

Words: ALMA, IRAM



https://arxivsorter.org/stats/papermapper

Words: ALMA, IRAM



https://arxivsorter.org/stats/papermapper

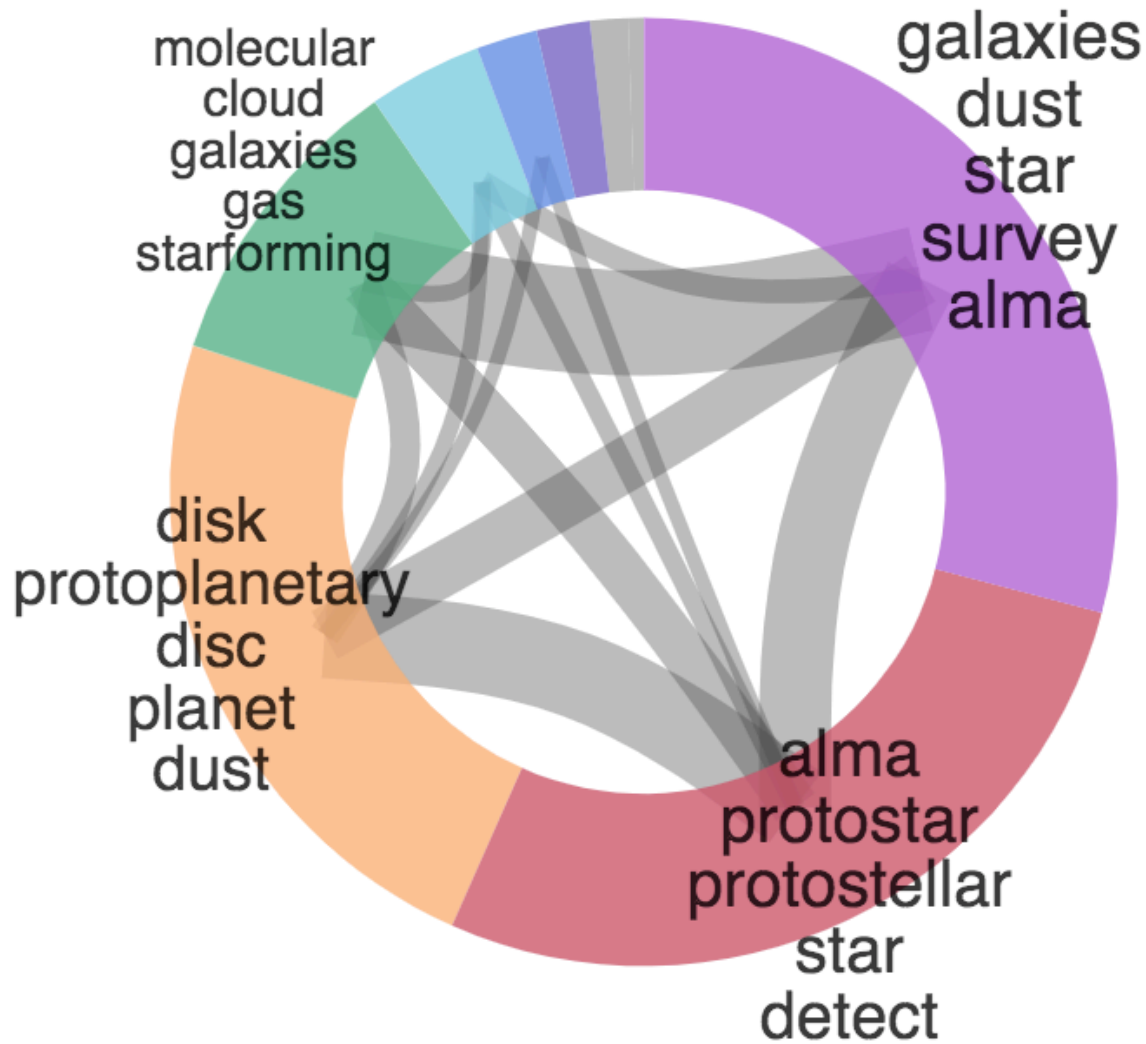
Publications

abstract:("millimeter" OR "submillimeter" OR "ALMA" OR "IRAM" OR "RADIO" OR "mm" OR "submm

Aff: France

[Link to ADS query "France"]

Your search returned **4,448** results



Aff: All

[Link to ADS query "ALL"]

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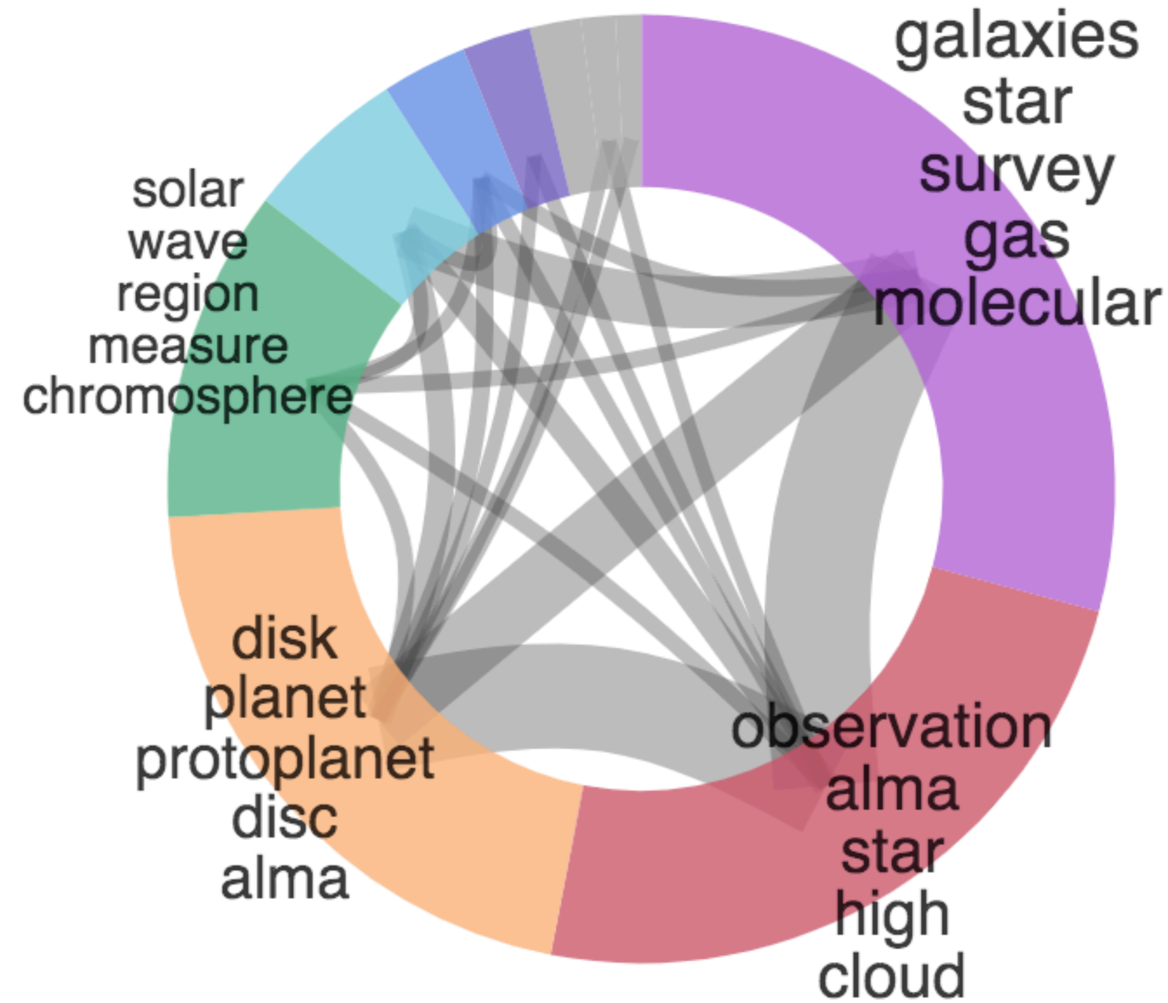


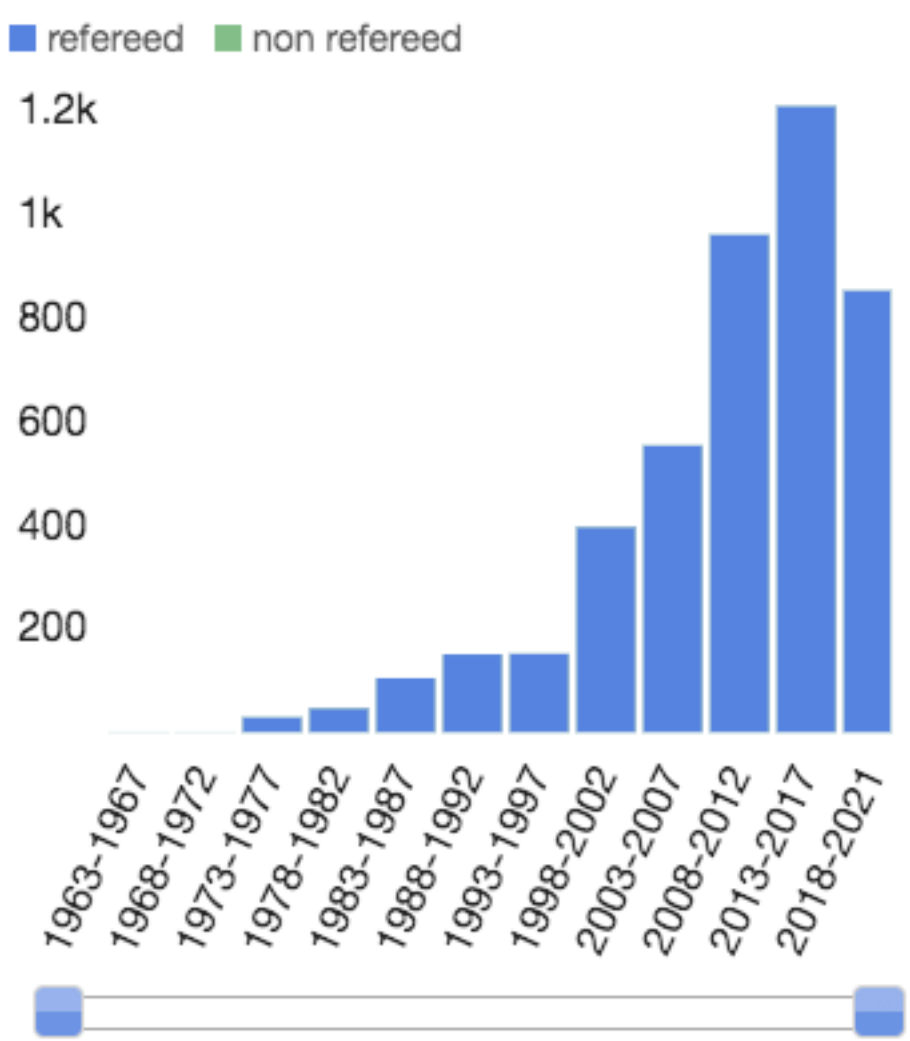
Publications

abstract:("millimeter" OR "submillimeter" OR "ALMA" OR "IRAM" OR "RADIO" OR "mm" OR "submm

Aff: France

Link to ADS query "France"

Your search returned **4,448** results



Limit results to papers from

1963 to 2021 Apply

Aff: All

Link to ADS query "ALL"

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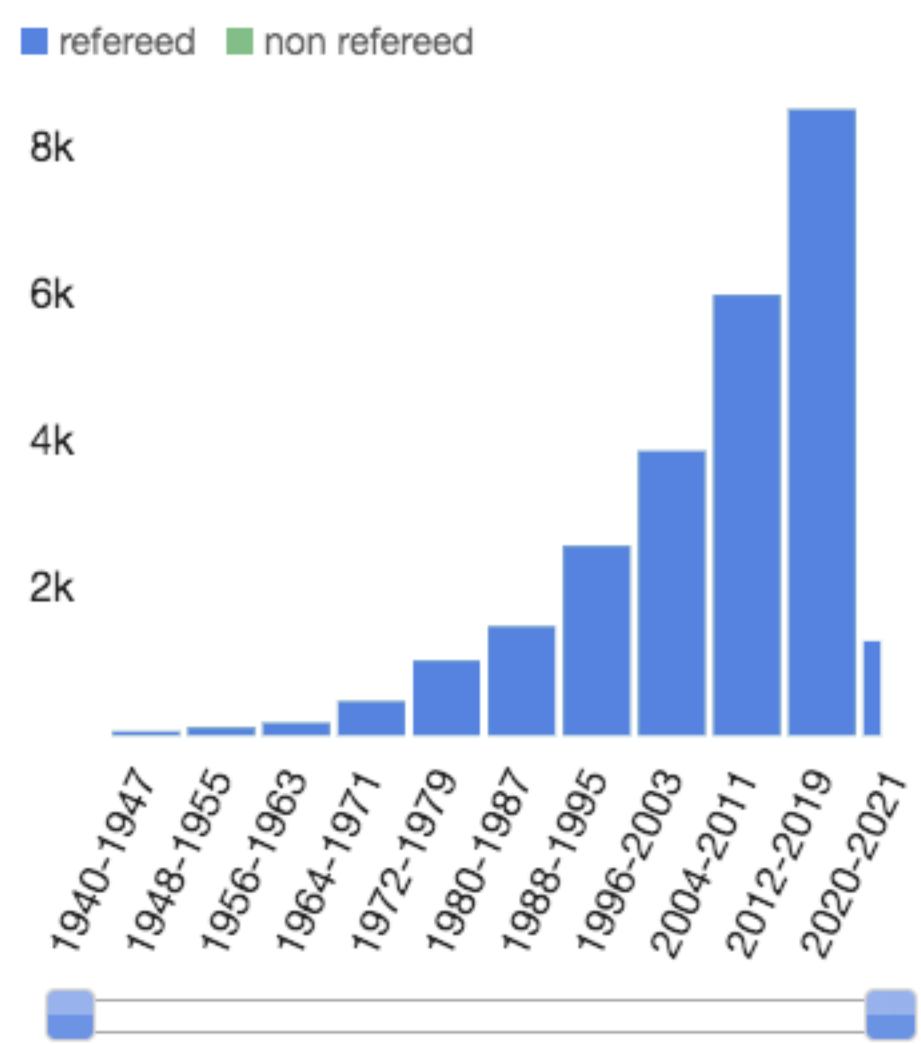
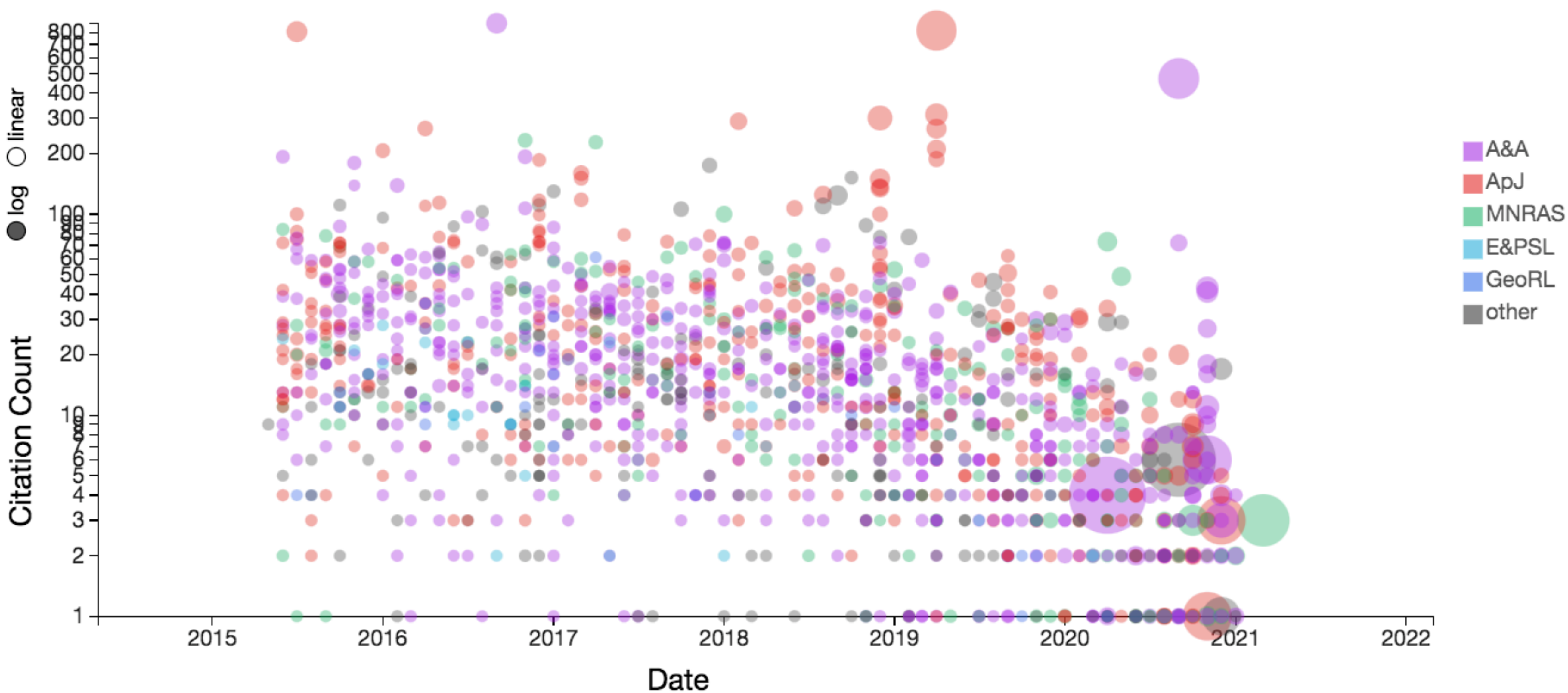


Limit results to papers from

1940 to 2021 Apply

Publications (France)

Link to ADS (France) here



Publications (France)

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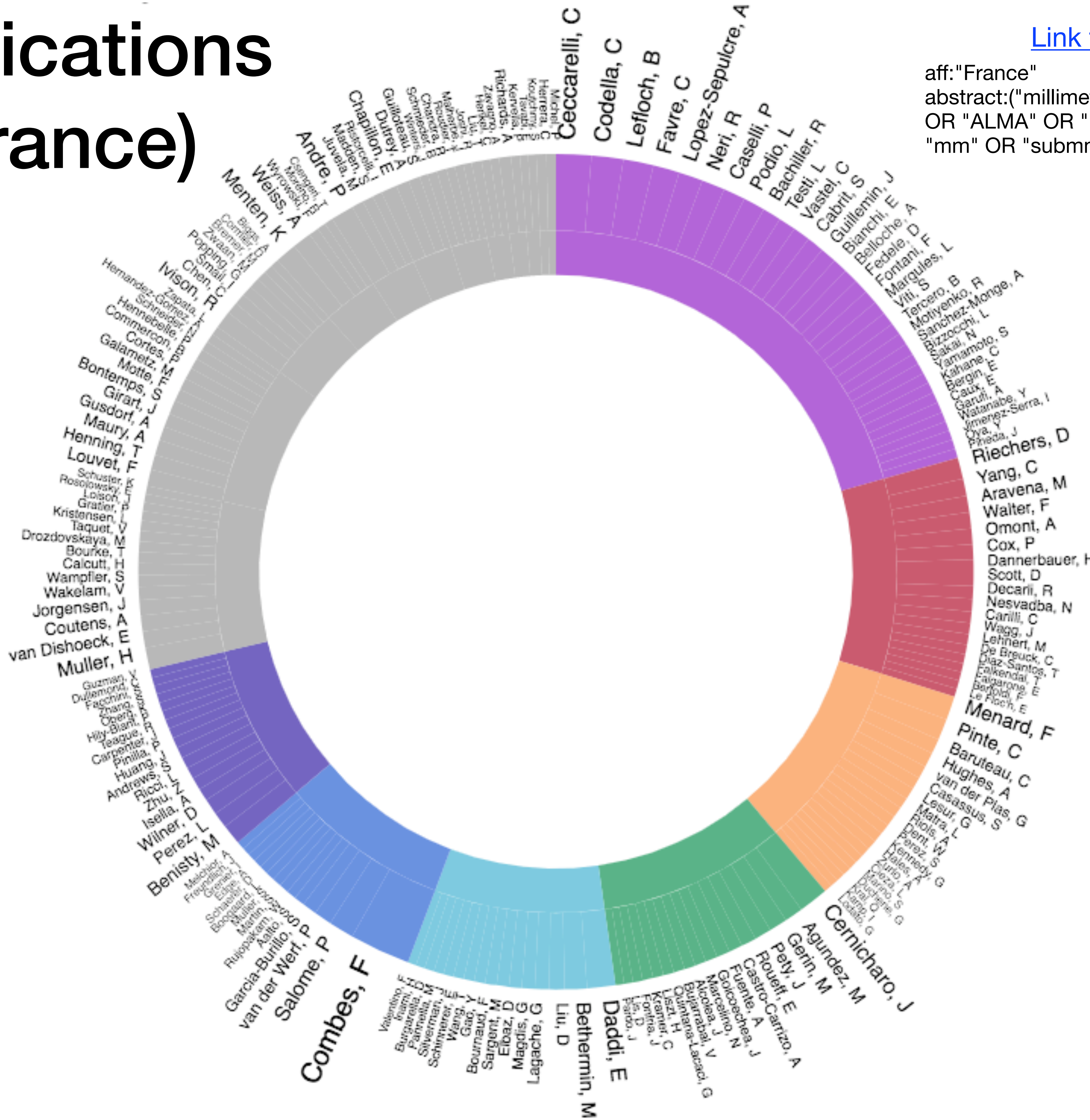

Publications (France)

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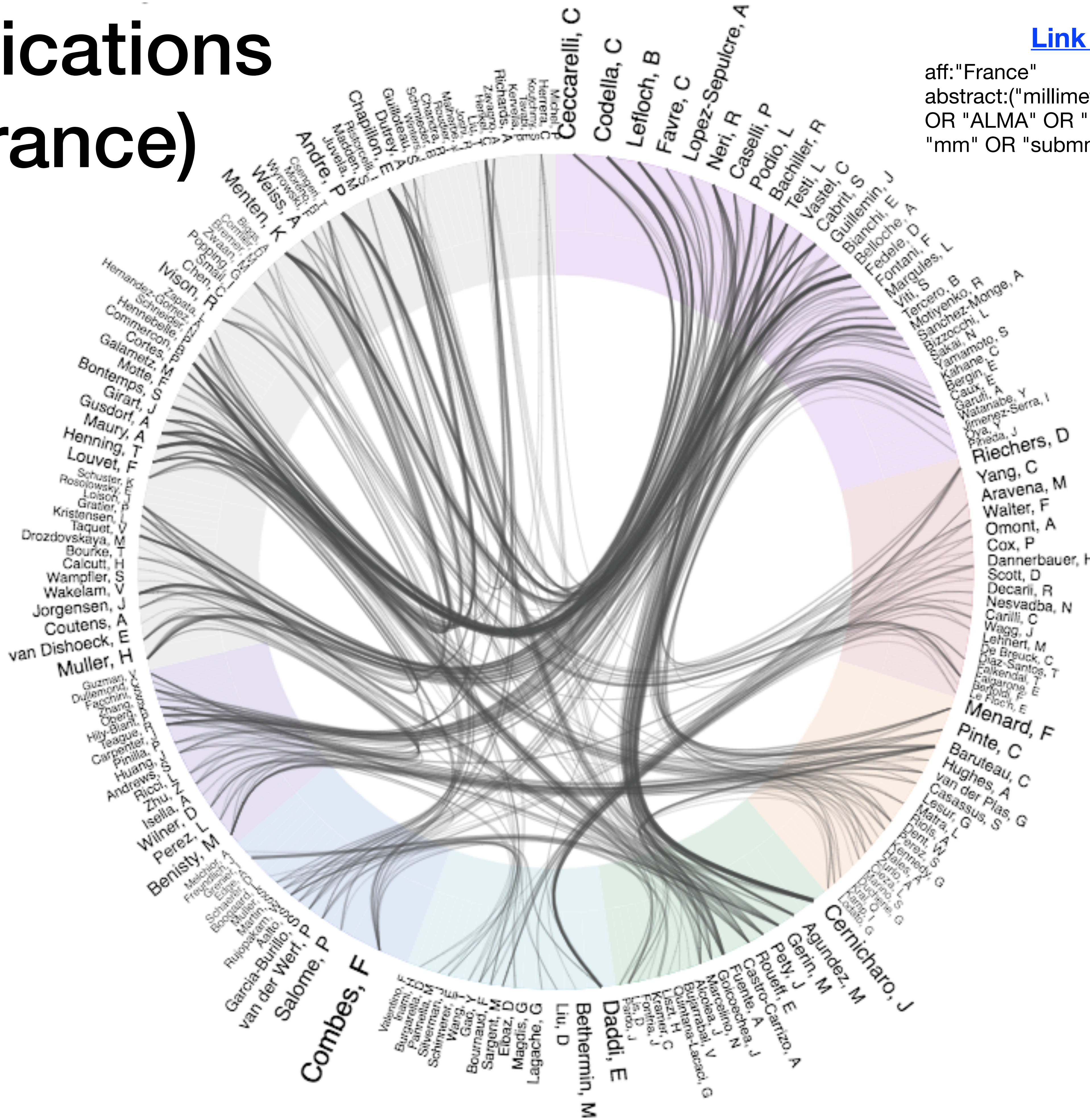

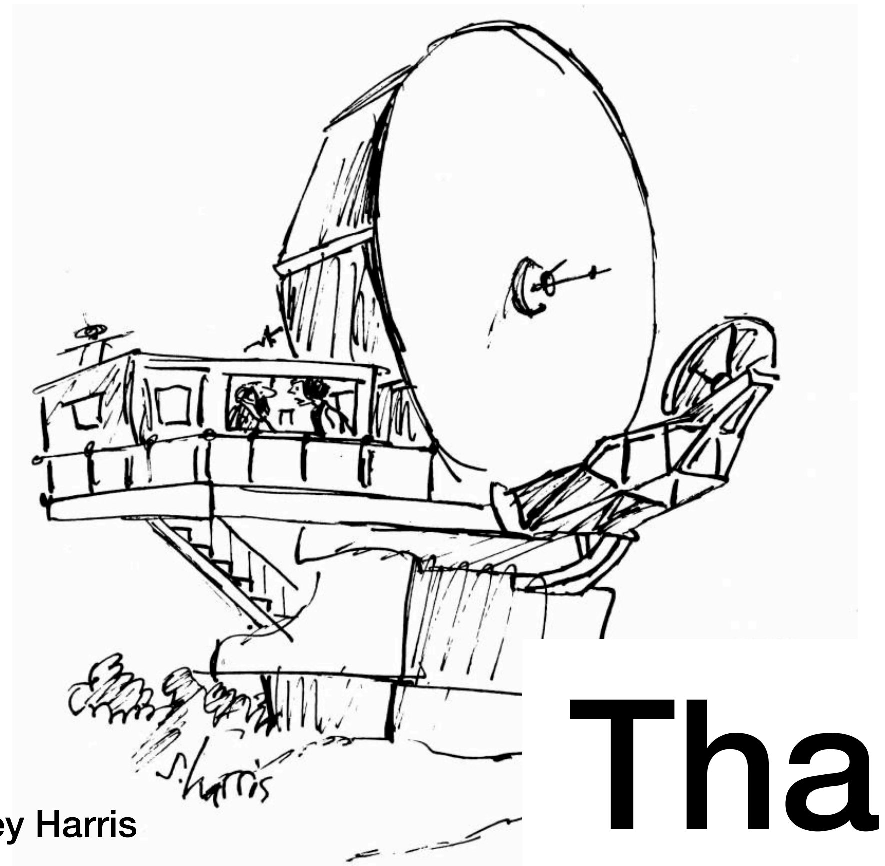

Sidney Harris

"WE SEEM TO BE PICKING UP BACKGROUND RADIATION FROM TWO SOURCES. WAS THERE ALSO A LITTLE BANG?"

Thanks !

All day long, a tough gang of astrophysicists would monopolize the telescope and intimidate the other researchers.

Gary Larson

LERMA l'Observatoire de Paris | PSL

LERMA UMR8112

Laboratoire d'Études du Rayonnement et de la Matière en Astrophysique et Atmosphères