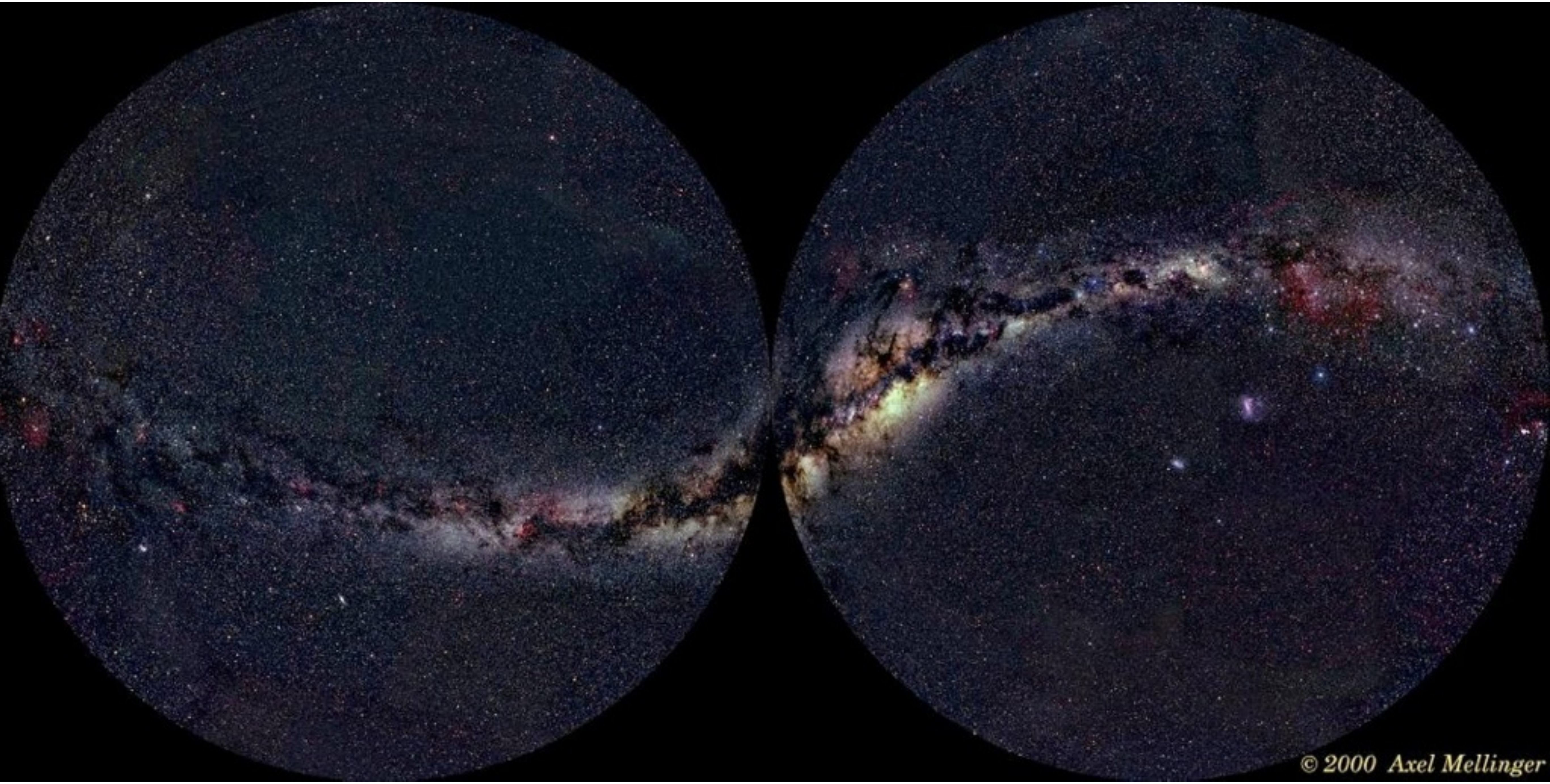
ALMA: alla scoperta dell’Universo freddo

Leonardo Testi
ESO ALMA Programme Scientist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Aur
Cep
Lyr
Oph
Sco
Lup
Cen
Ant
CMi
Cyg
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Cas
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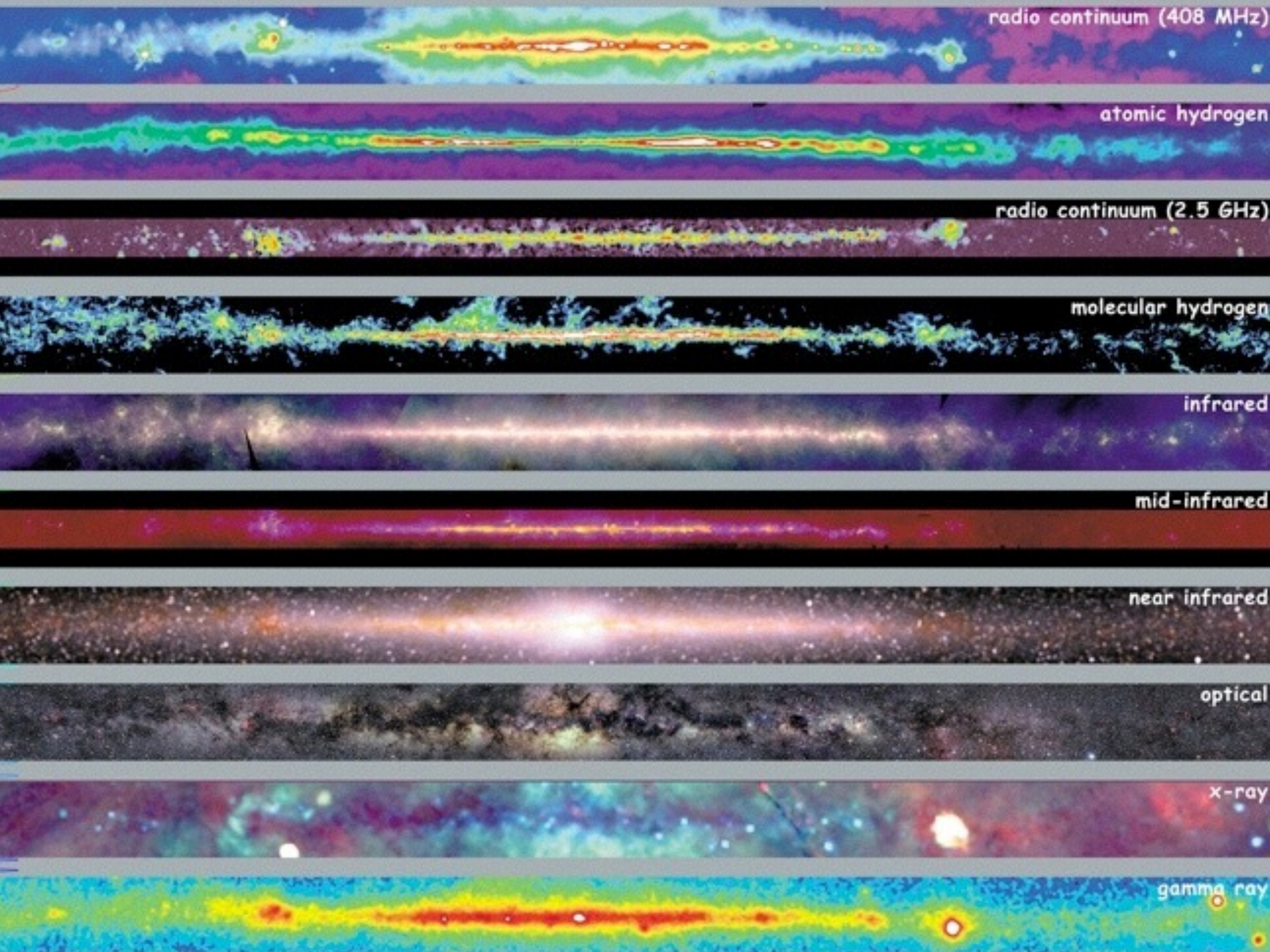
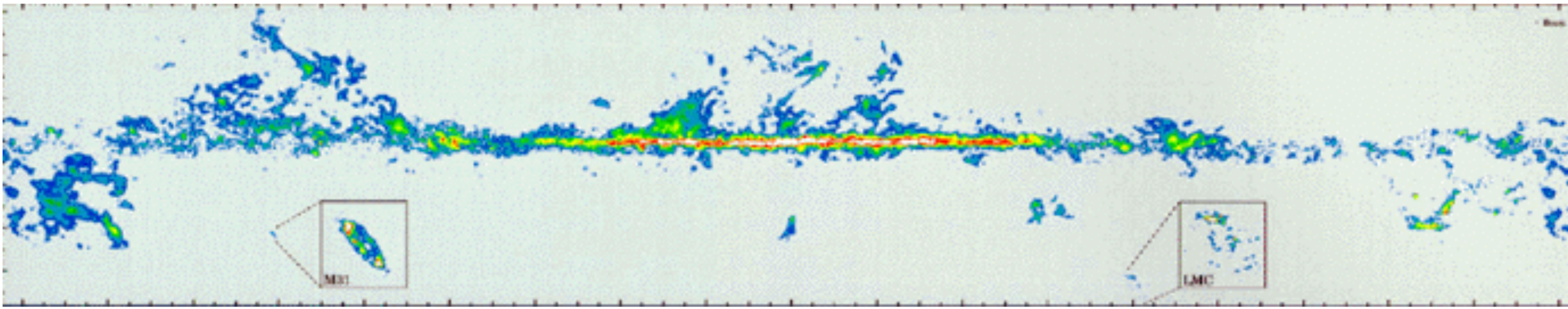
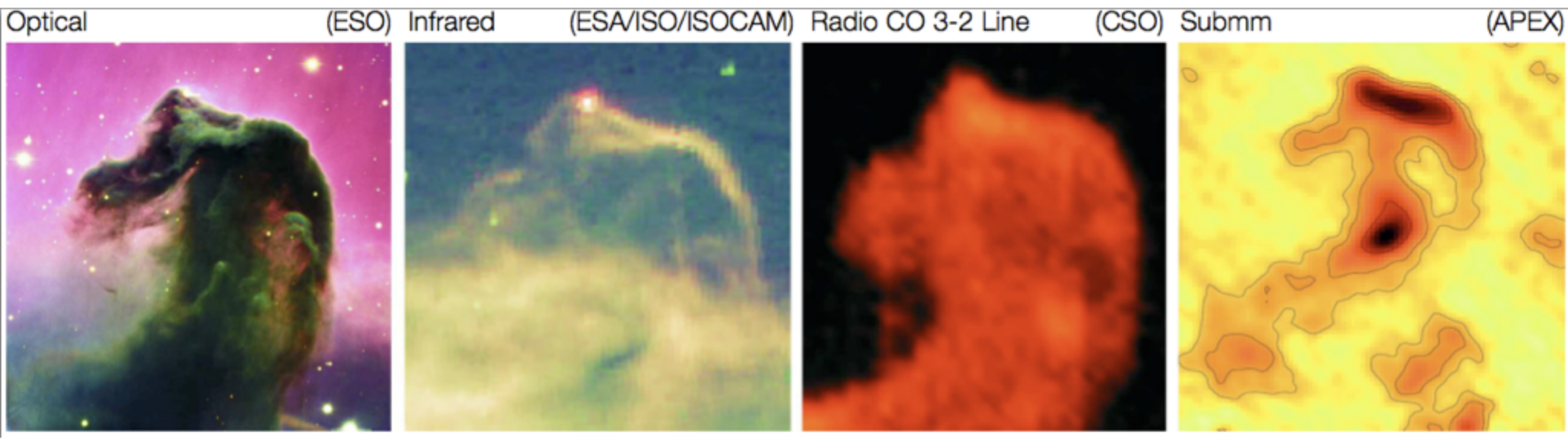

radio continuum (408 MHz)
atomic hydrogen
radio continuum (2.5 GHz)
molecular hydrogen
infrared
mid-infrared
near infrared
optical
x-ray
gamma ray

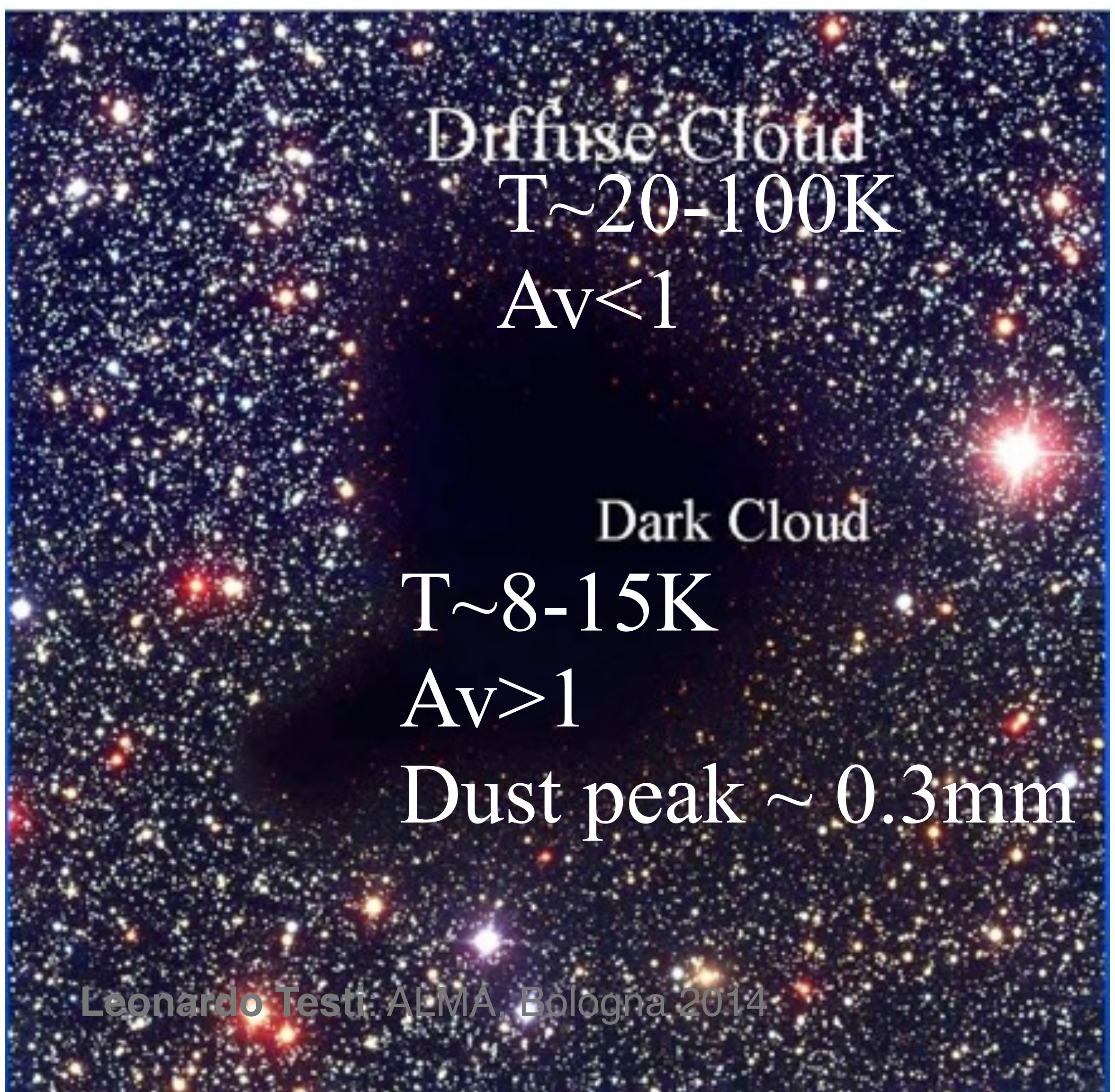
Molecular clouds and star formation

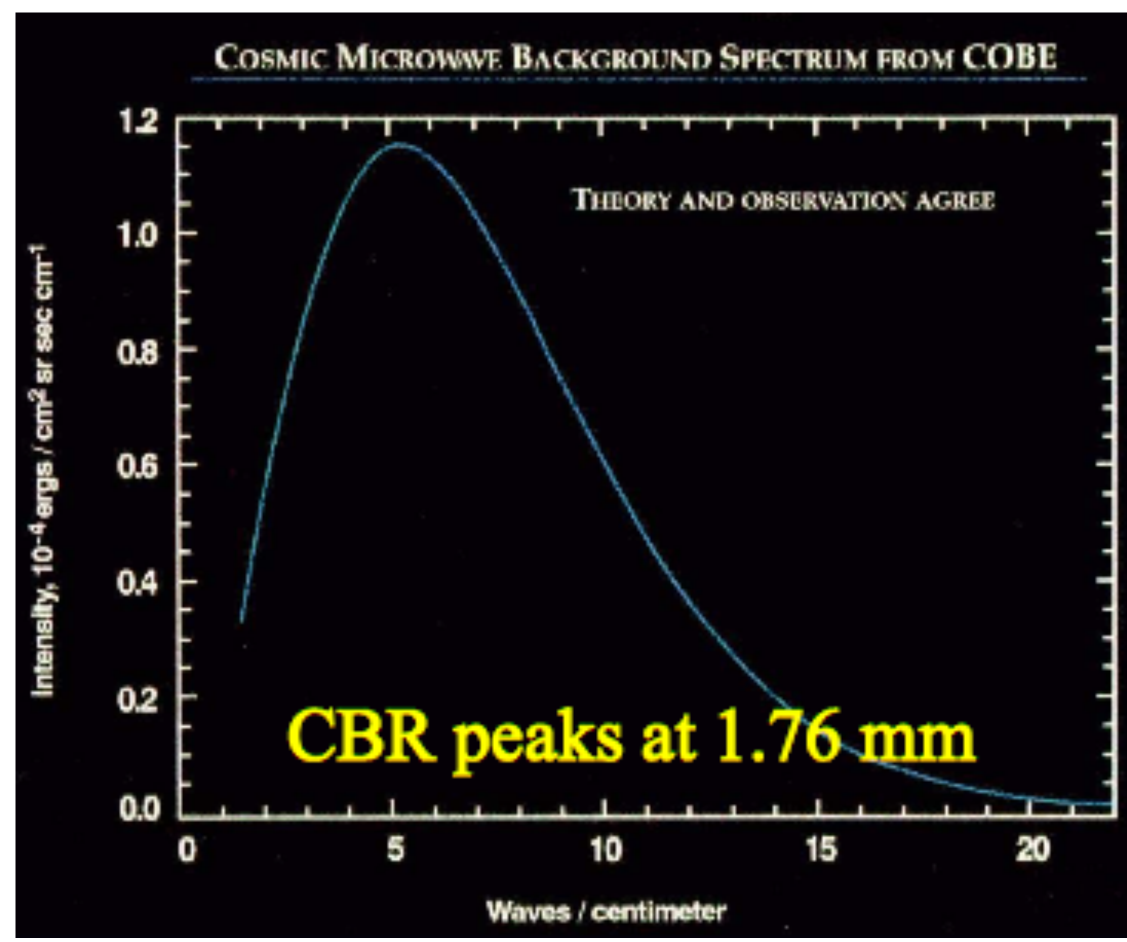




Millimeter wavelengths: thermal continuum

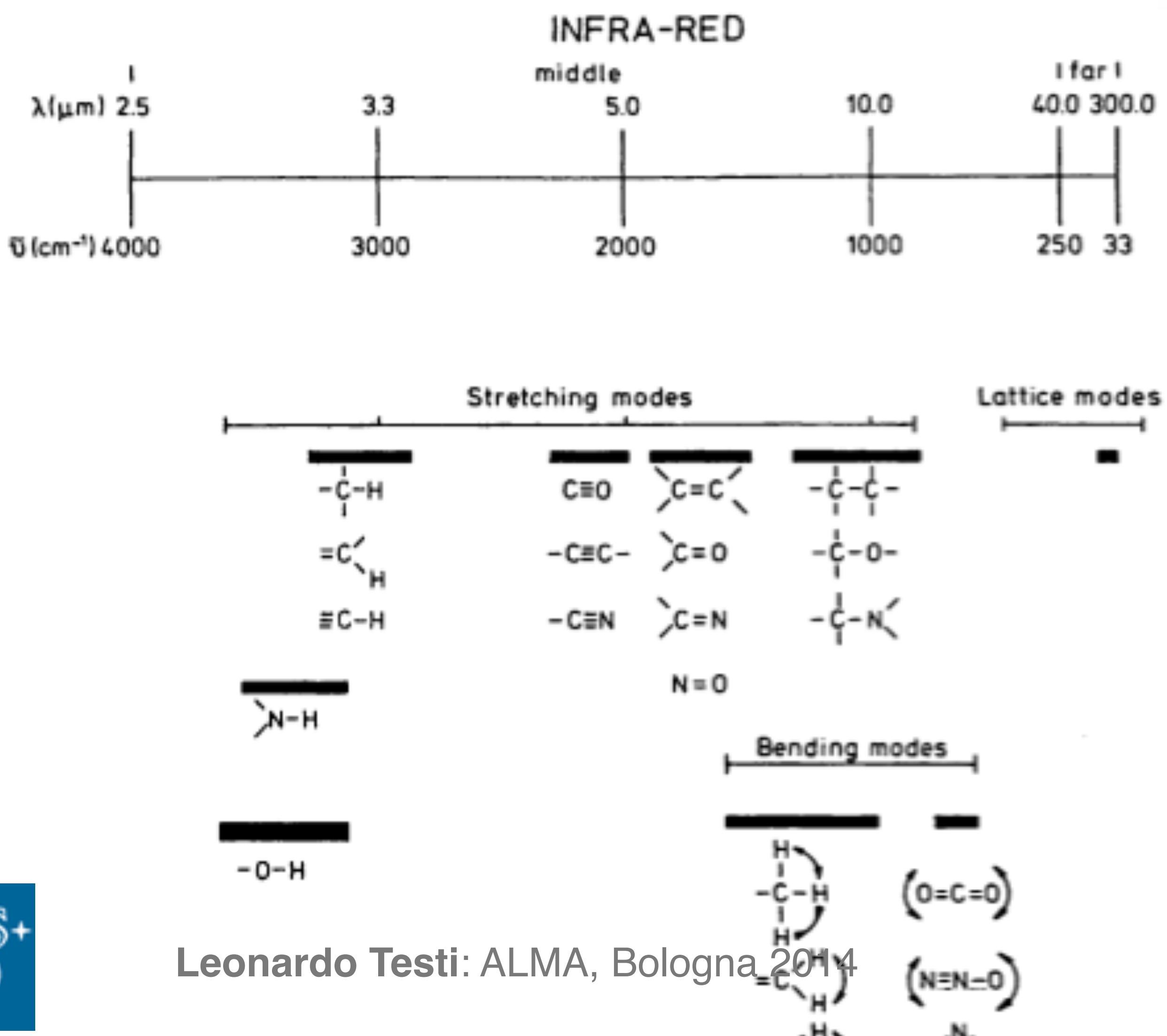
- Thermal emission:
  - near-IR & visible: hot matter 1000K-100000K
  - Far-IR & millimeter: cold matter 3K-100K
  - BB: $\lambda_m = hc/3kT \sim 0.5/T$ cm   Dust: $\lambda_m = hc/(3+\beta)kT \sim 0.3/T$ cm

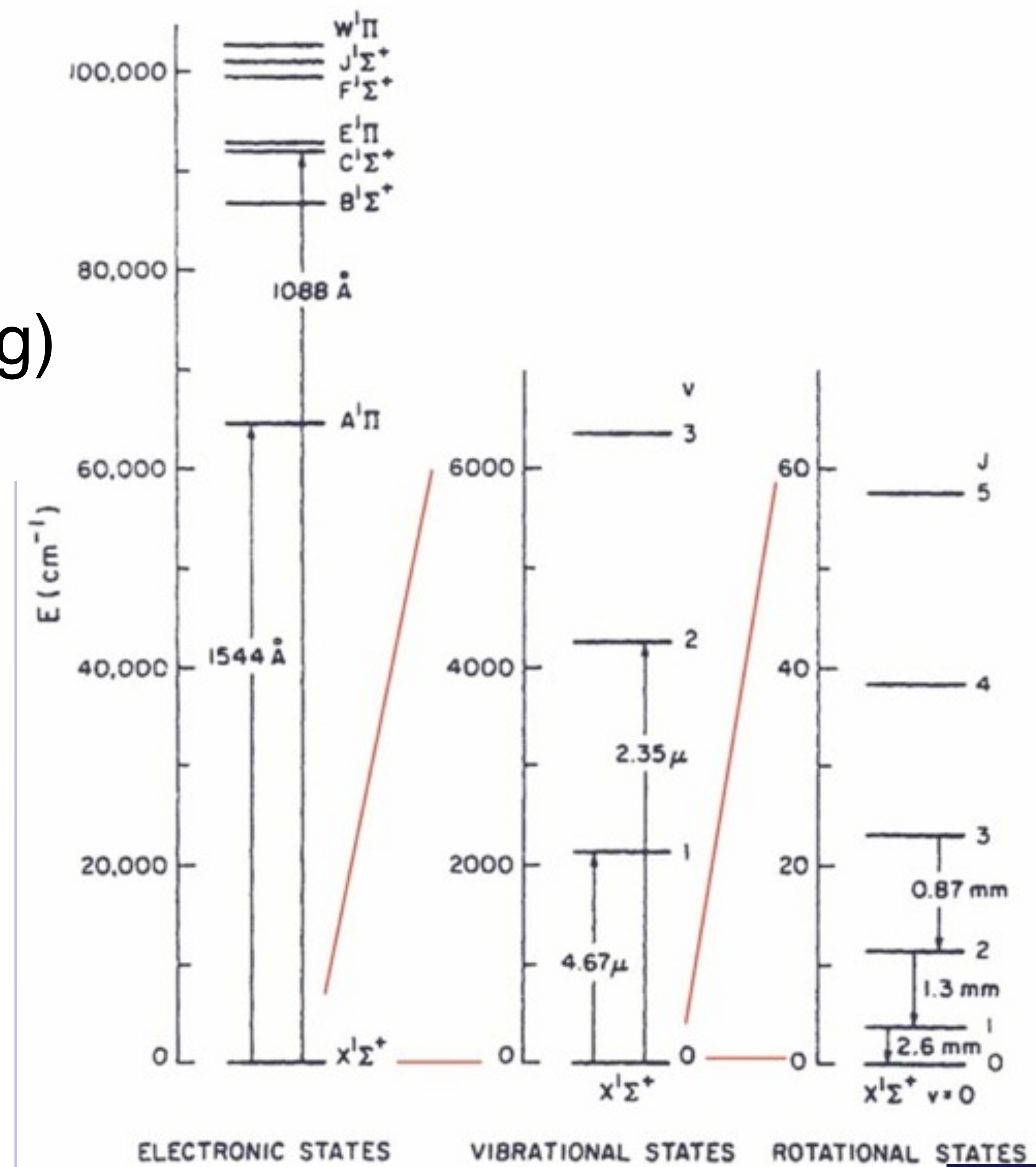




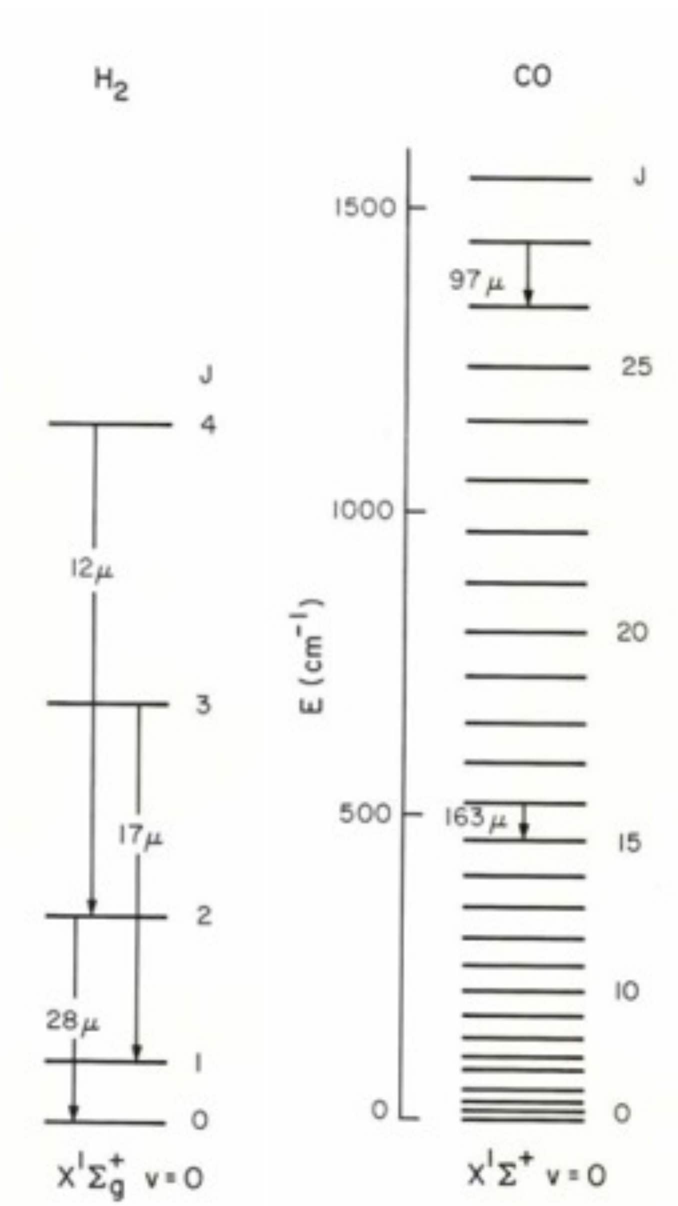
Molecular line emission

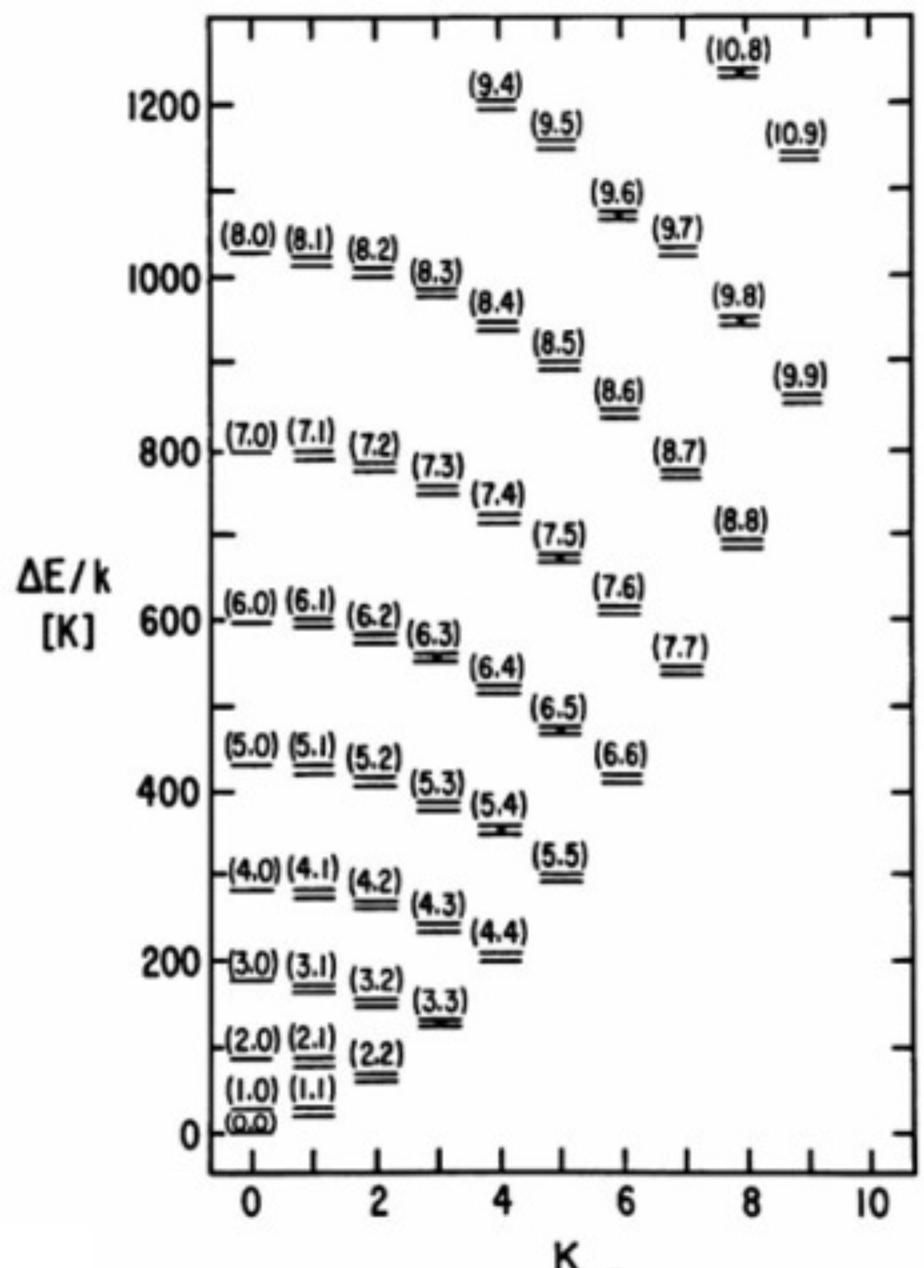
- Molecular lines:
  - Rotation
  - Vib (Stretching and Bending)
  - Electronic

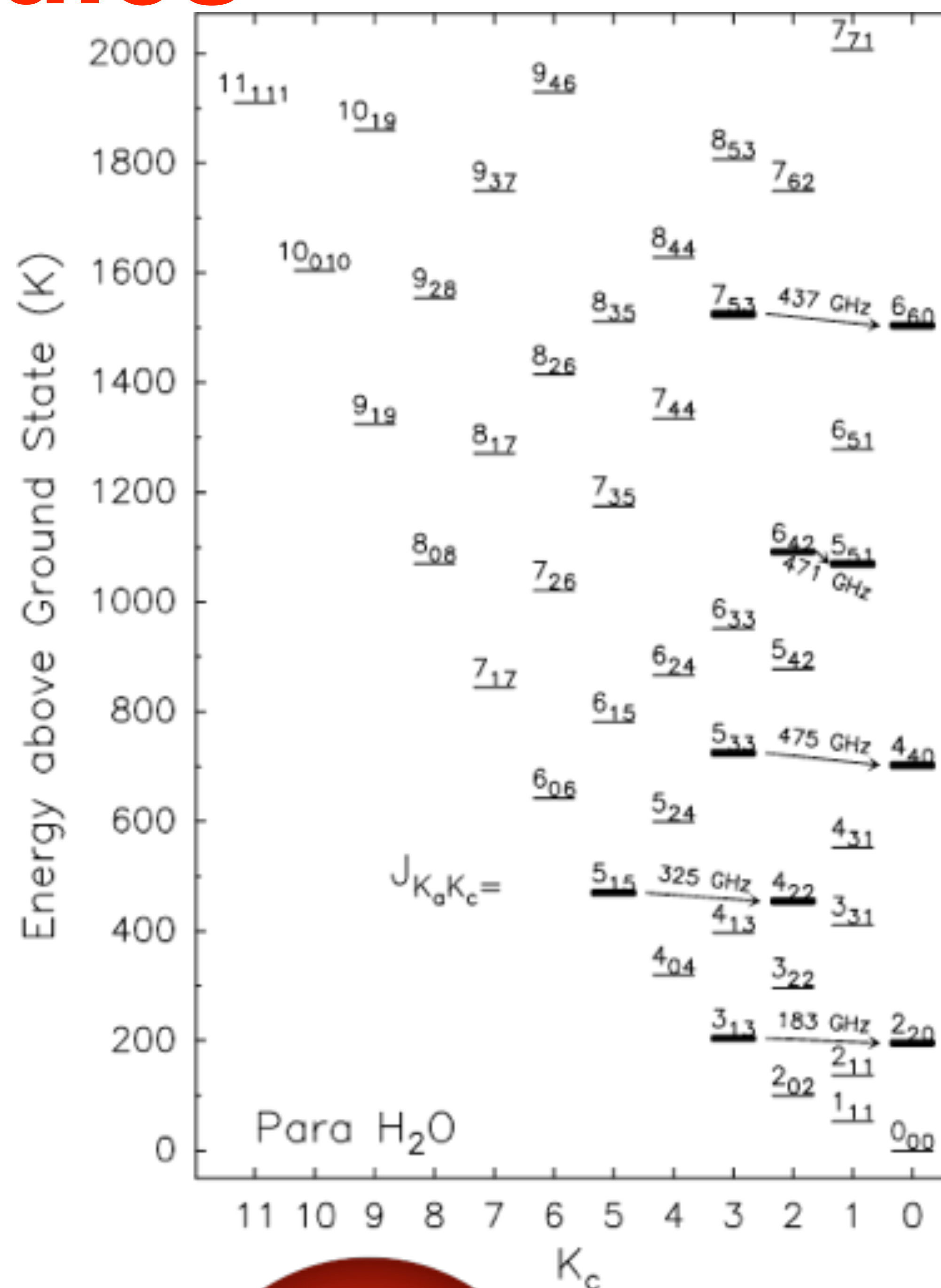


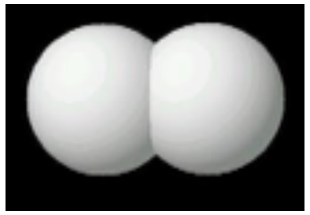


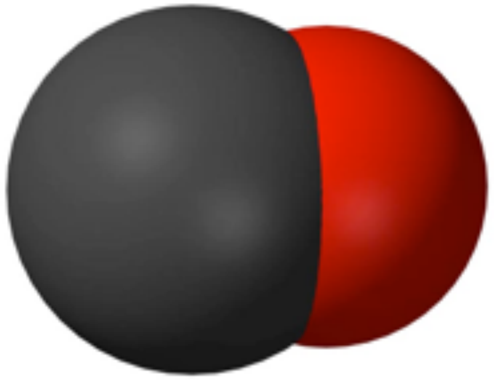
Examples of simple Astrophysically relevant molecules

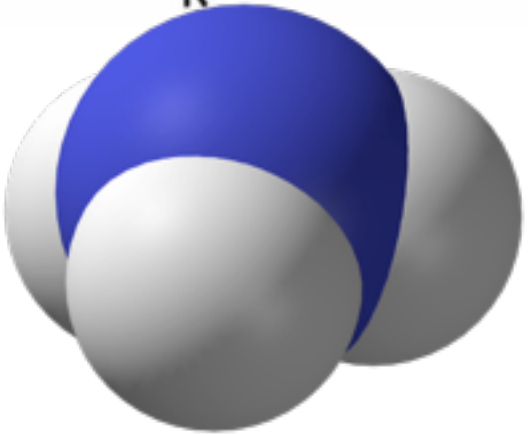


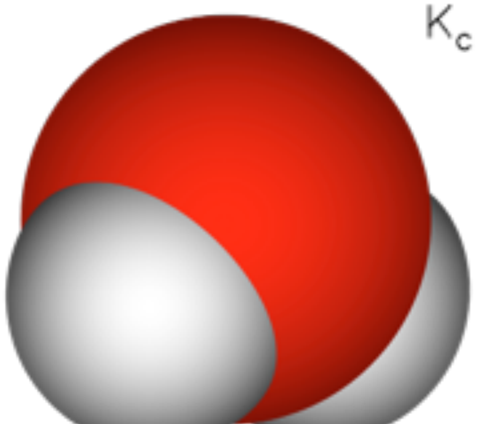


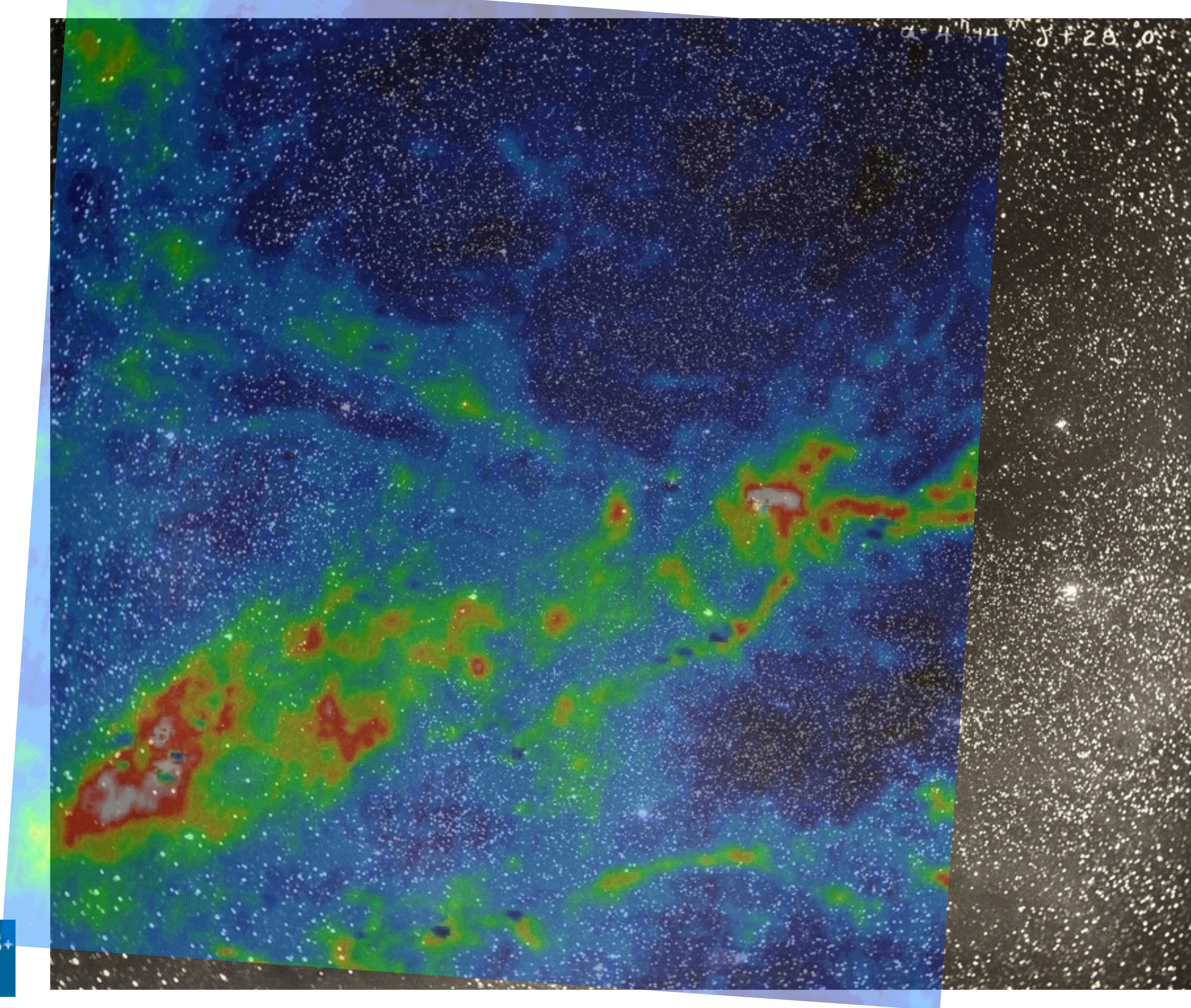


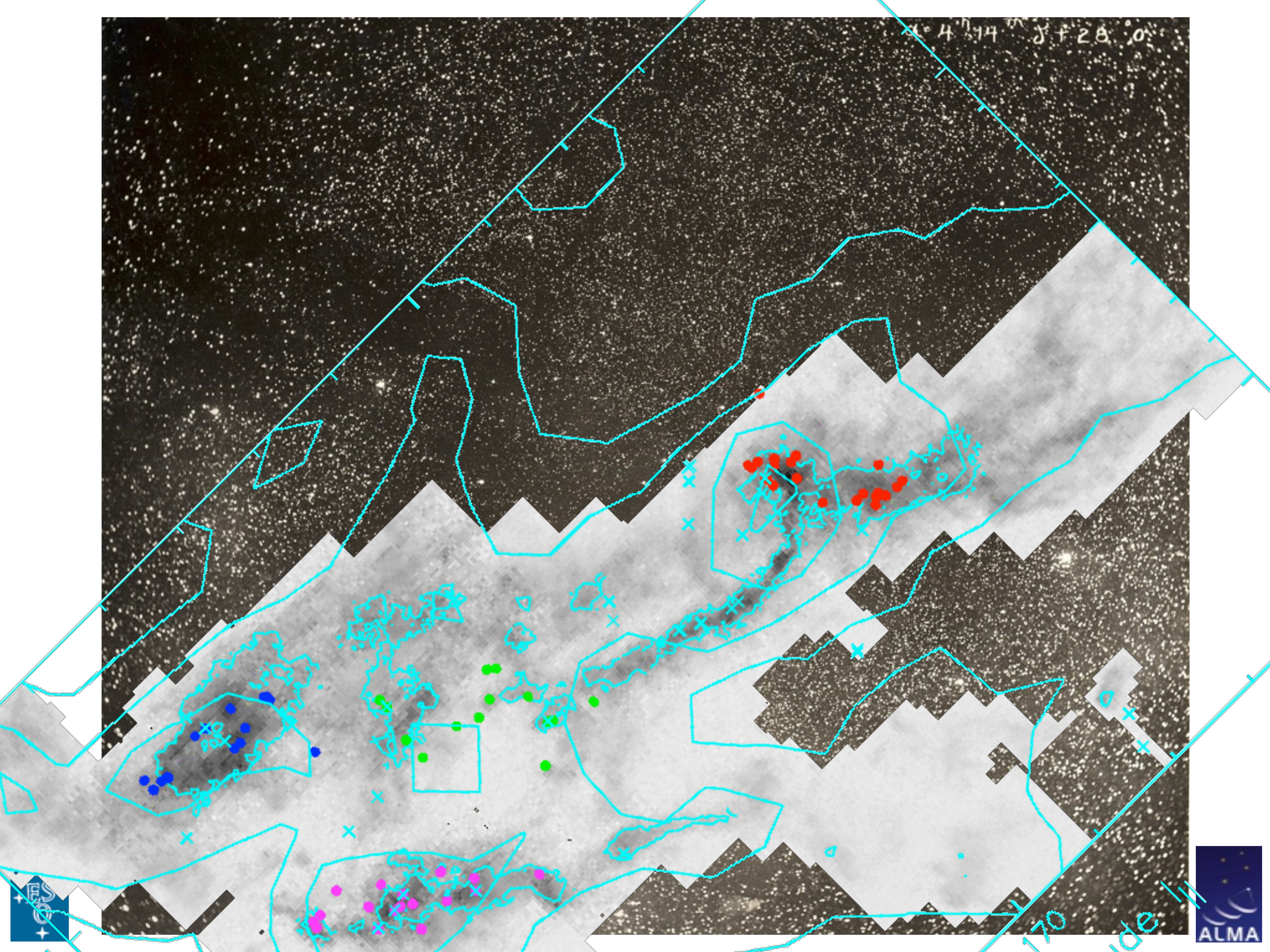




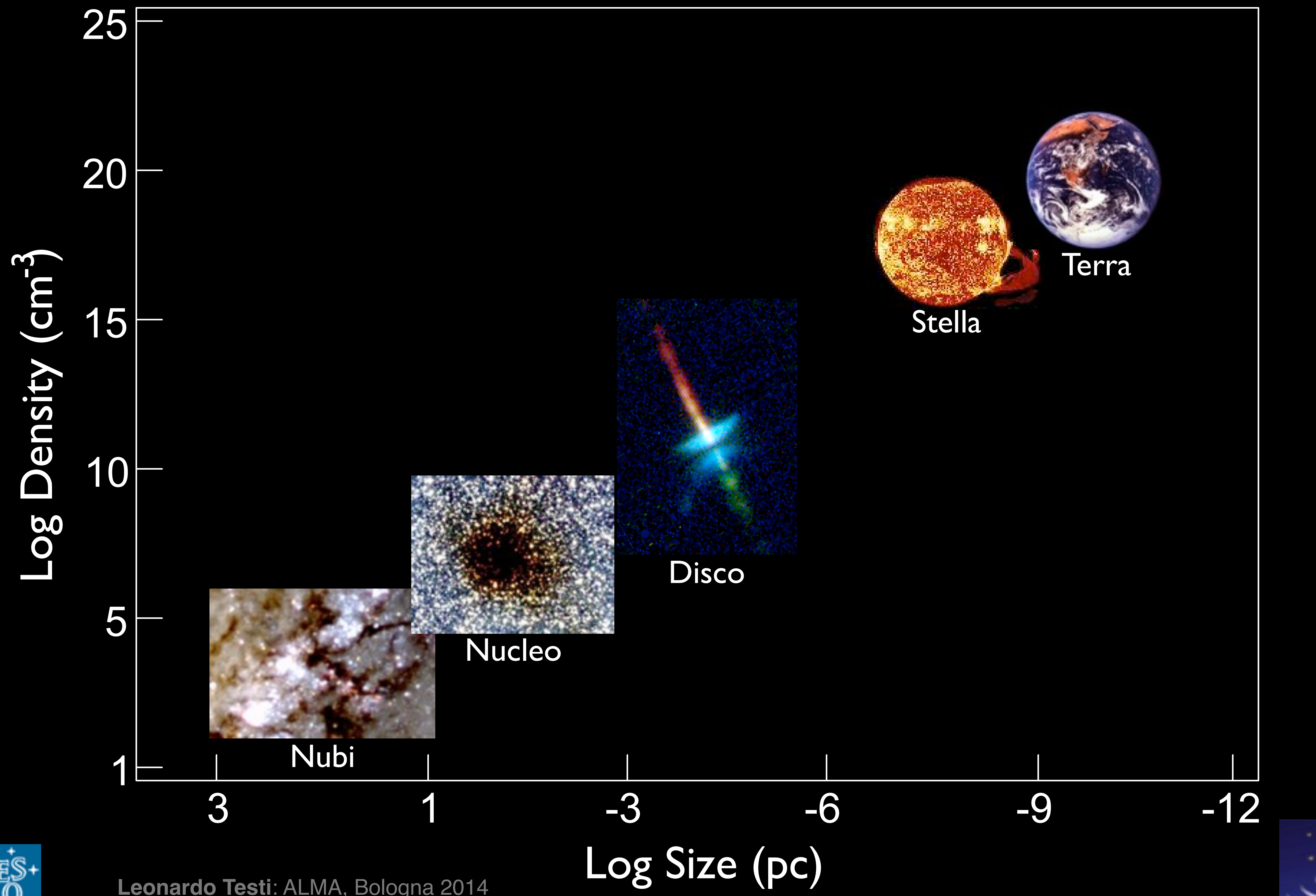





α 4h44m δ +28°0'


170

From clouds to stars and planets

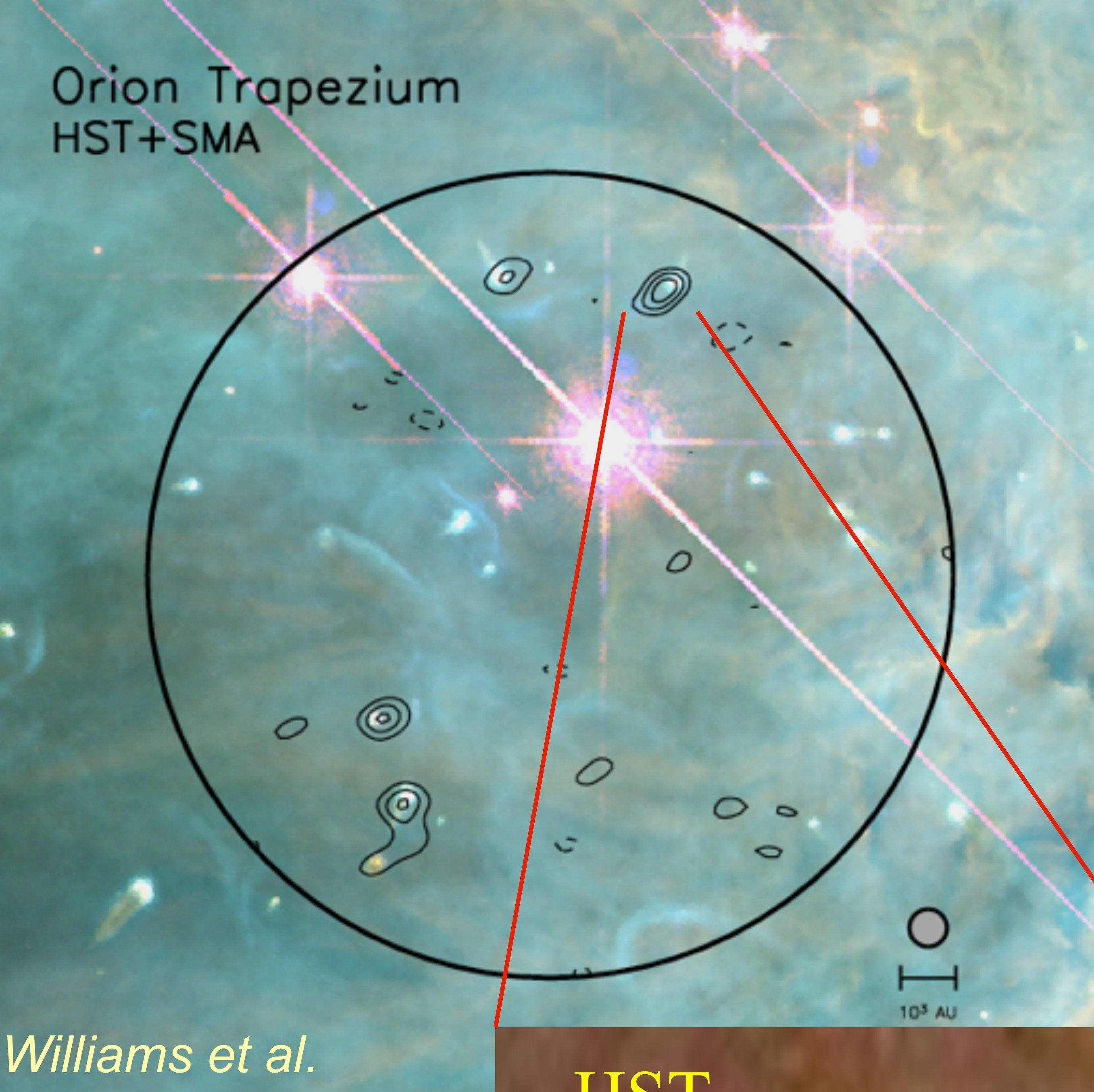


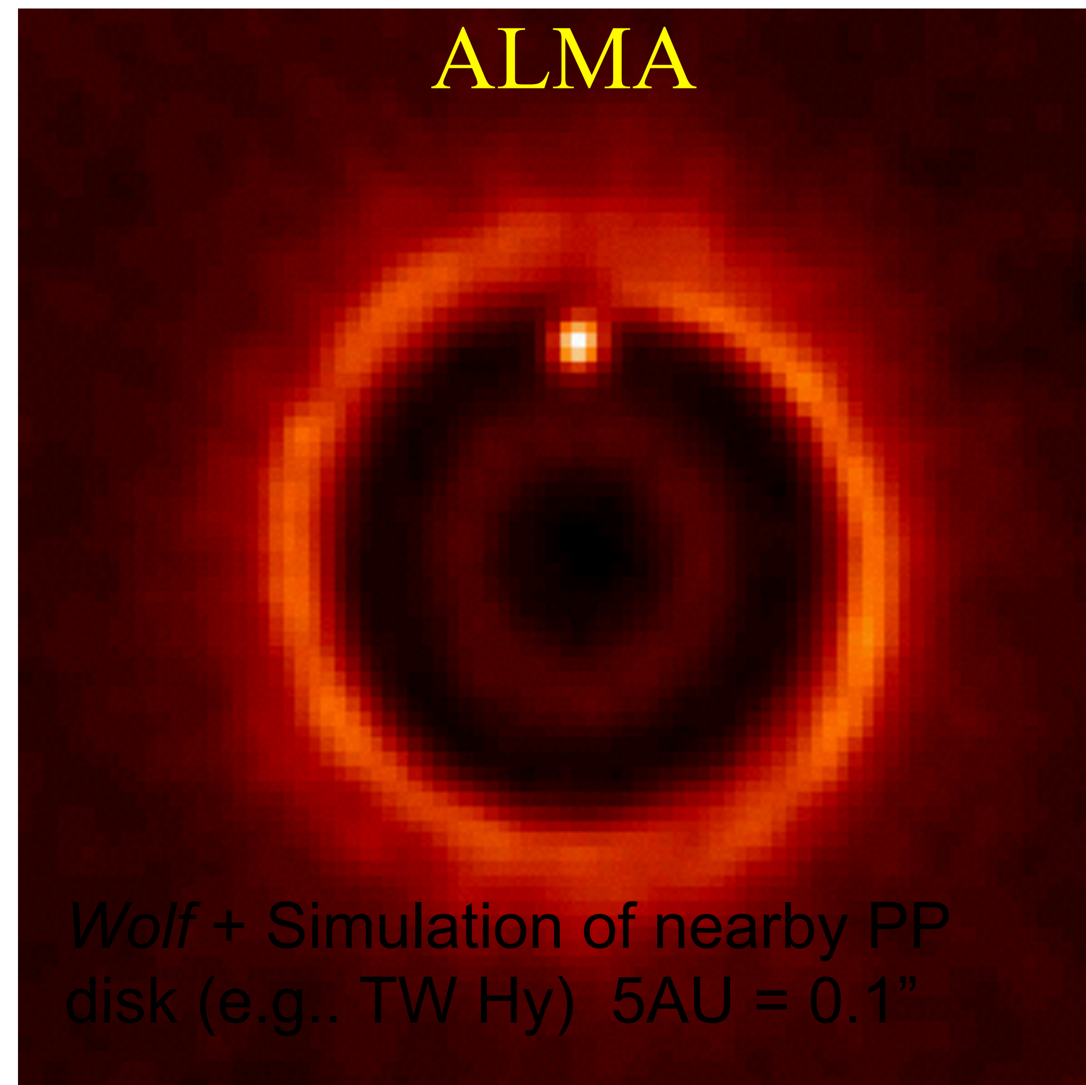
Planet Formation

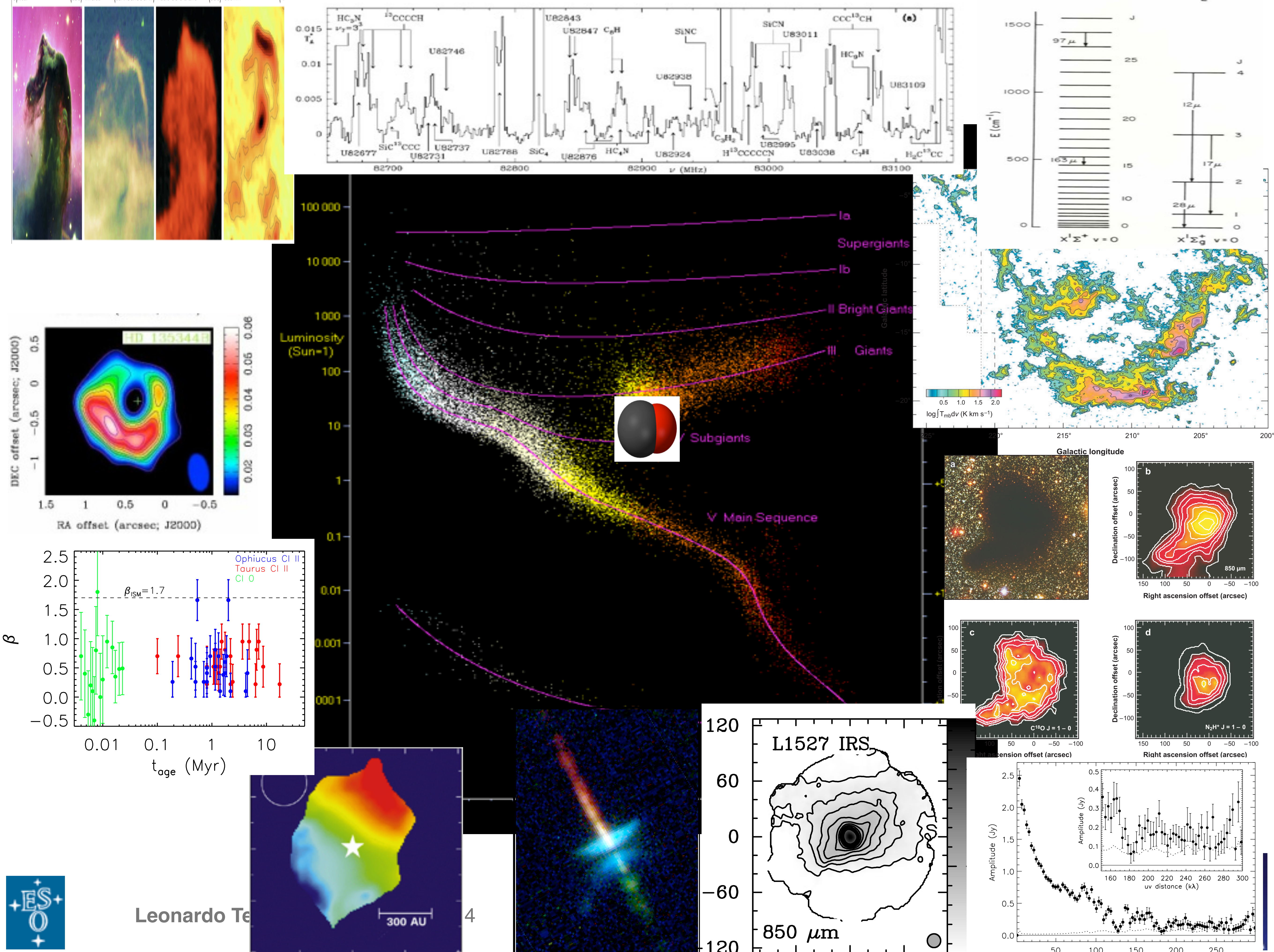
SIMULATION:

$M_{planet} / M_{star} = 1.0\ M_{Jup} / .5\ M_{sun}$

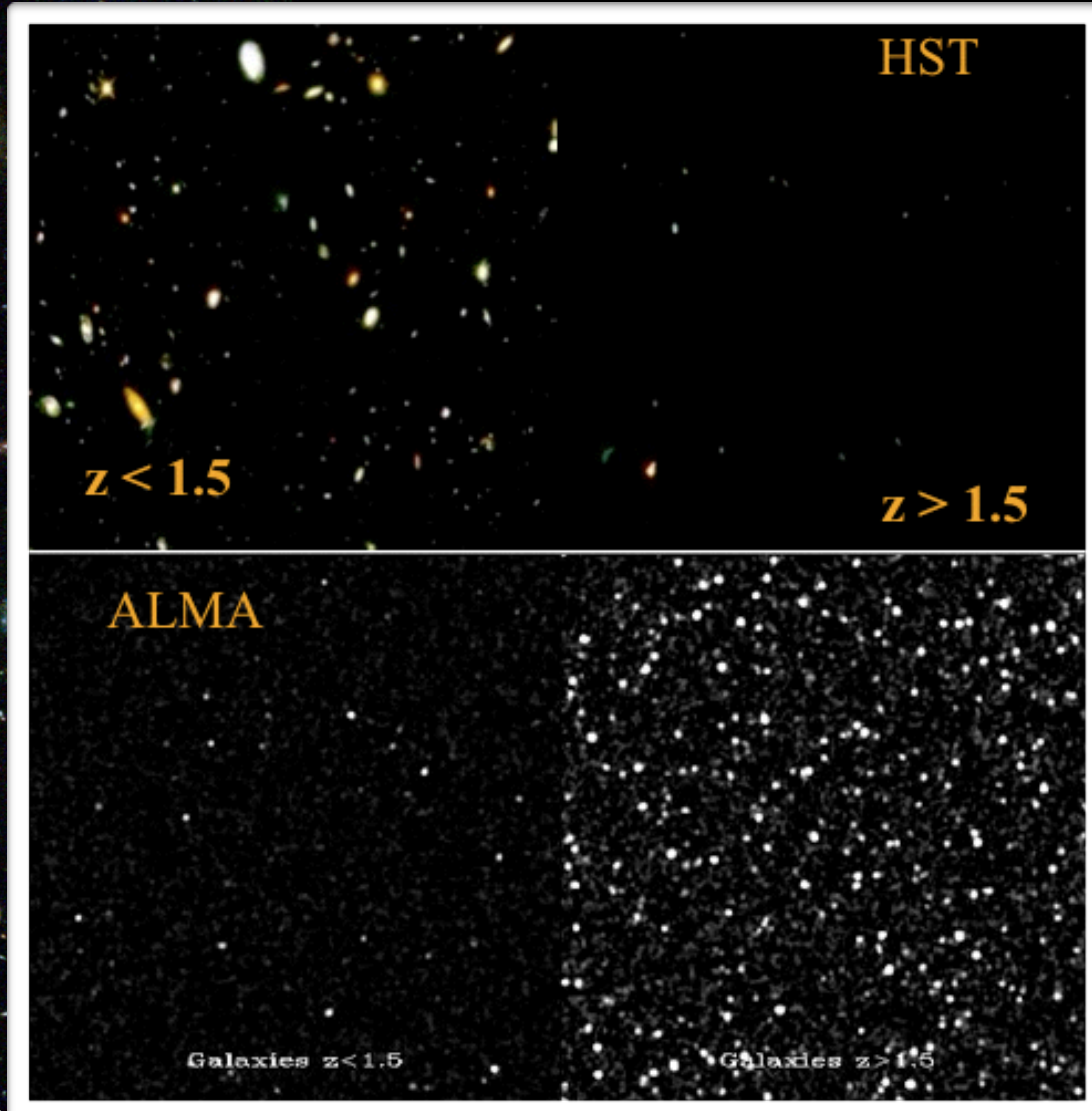
- Orbital radius: 5AU
- Distance: 50pc from Sun



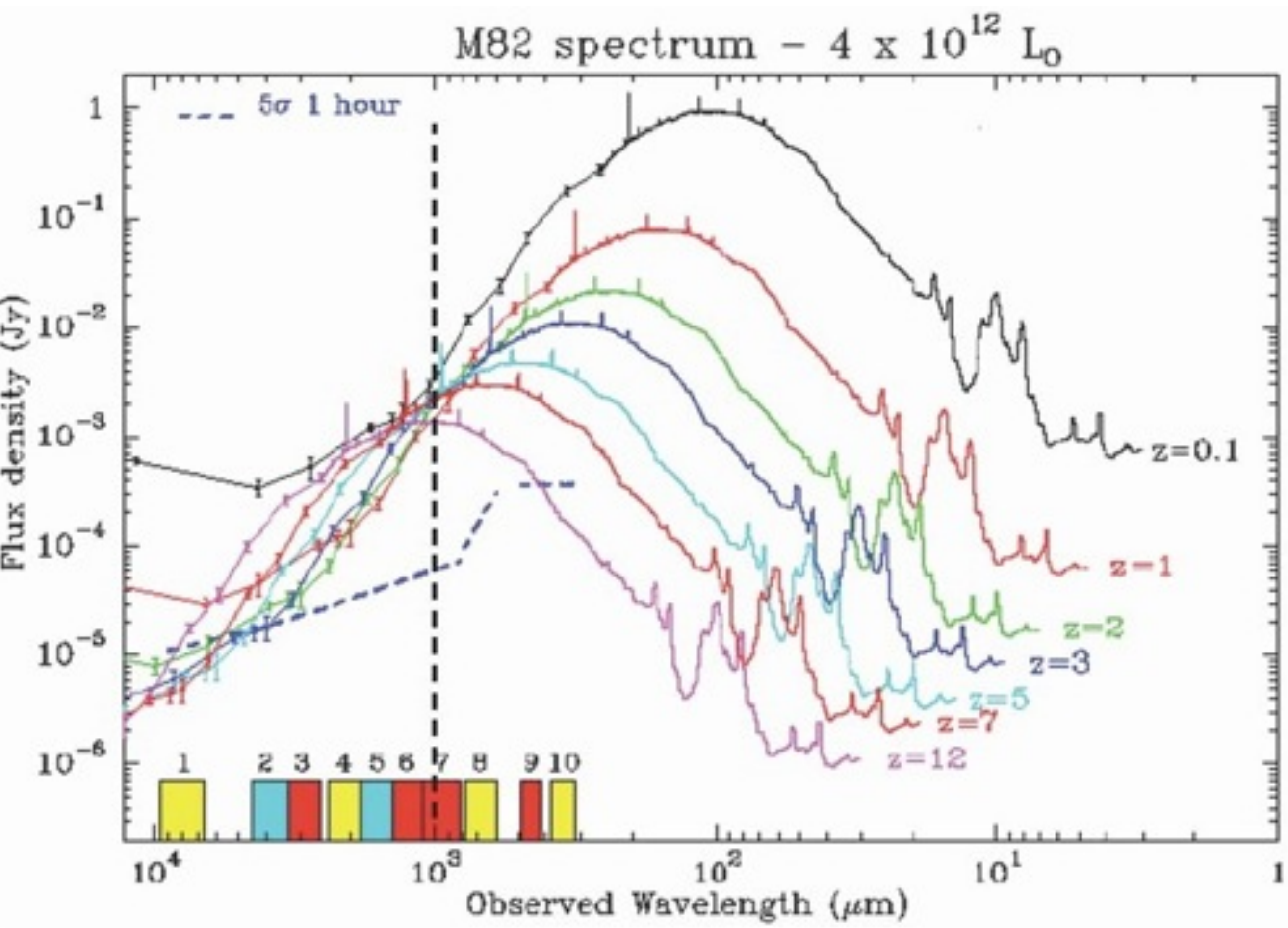


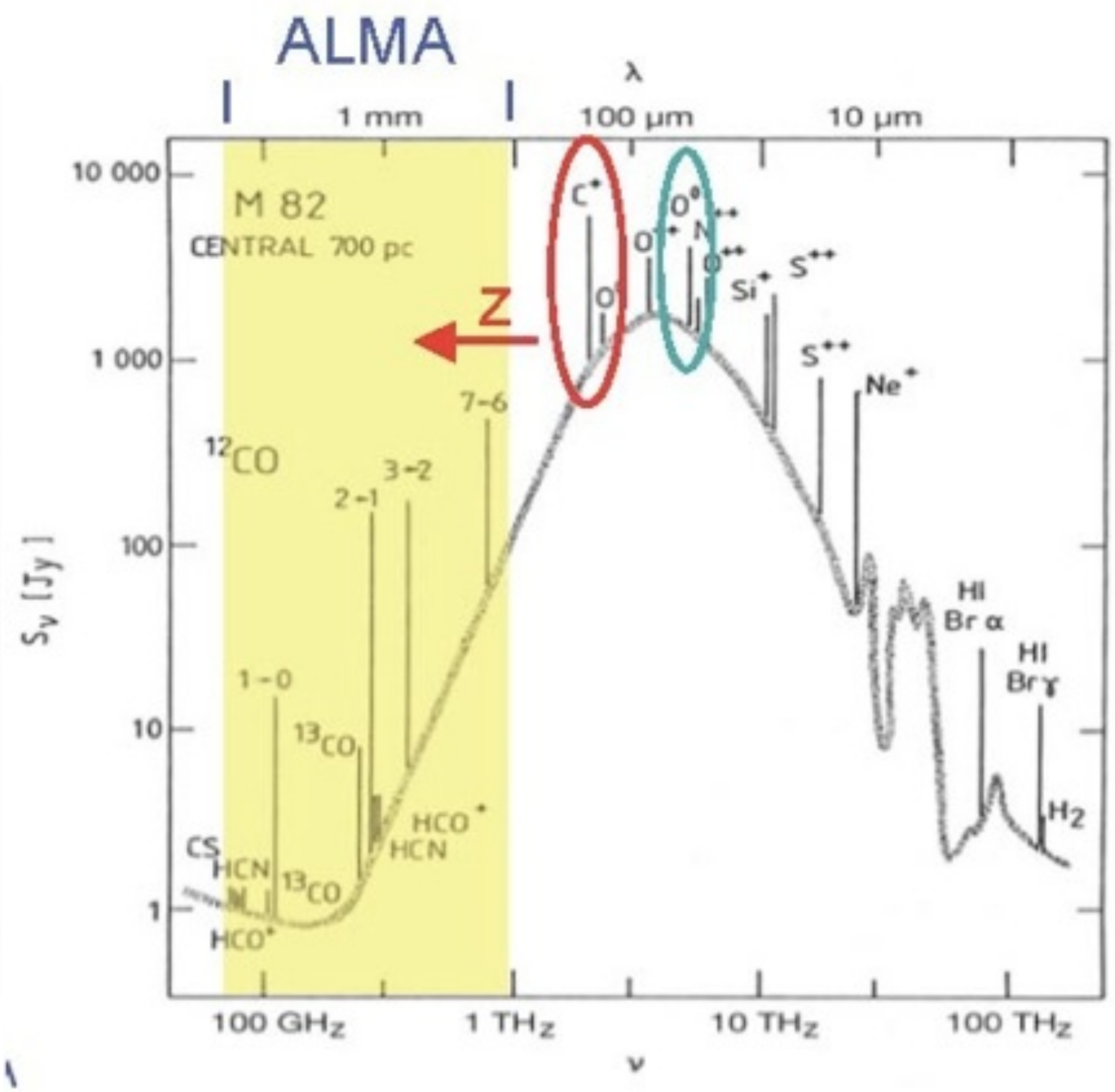

HD 135344B
DEC offset (arcsec; J2000)
RA offset (arcsec; J2000)
Luminosity (Sun=1)
Ia
Supergiants
Ib
II Bright Giants
III Giants
Subgiants
V Main Sequence
Ophiucus Cl II
Taurus Cl II
Cl 0
$\beta_{ISM}=1.7$
β
t_{age} (Myr)
300 AU
L1527 IRS
850 μm
Galactic longitude
Right ascension offset (arcsec)
Declination offset (arcsec)
Amplitude (Jy)
uv distance (kλ)

The Early Universe

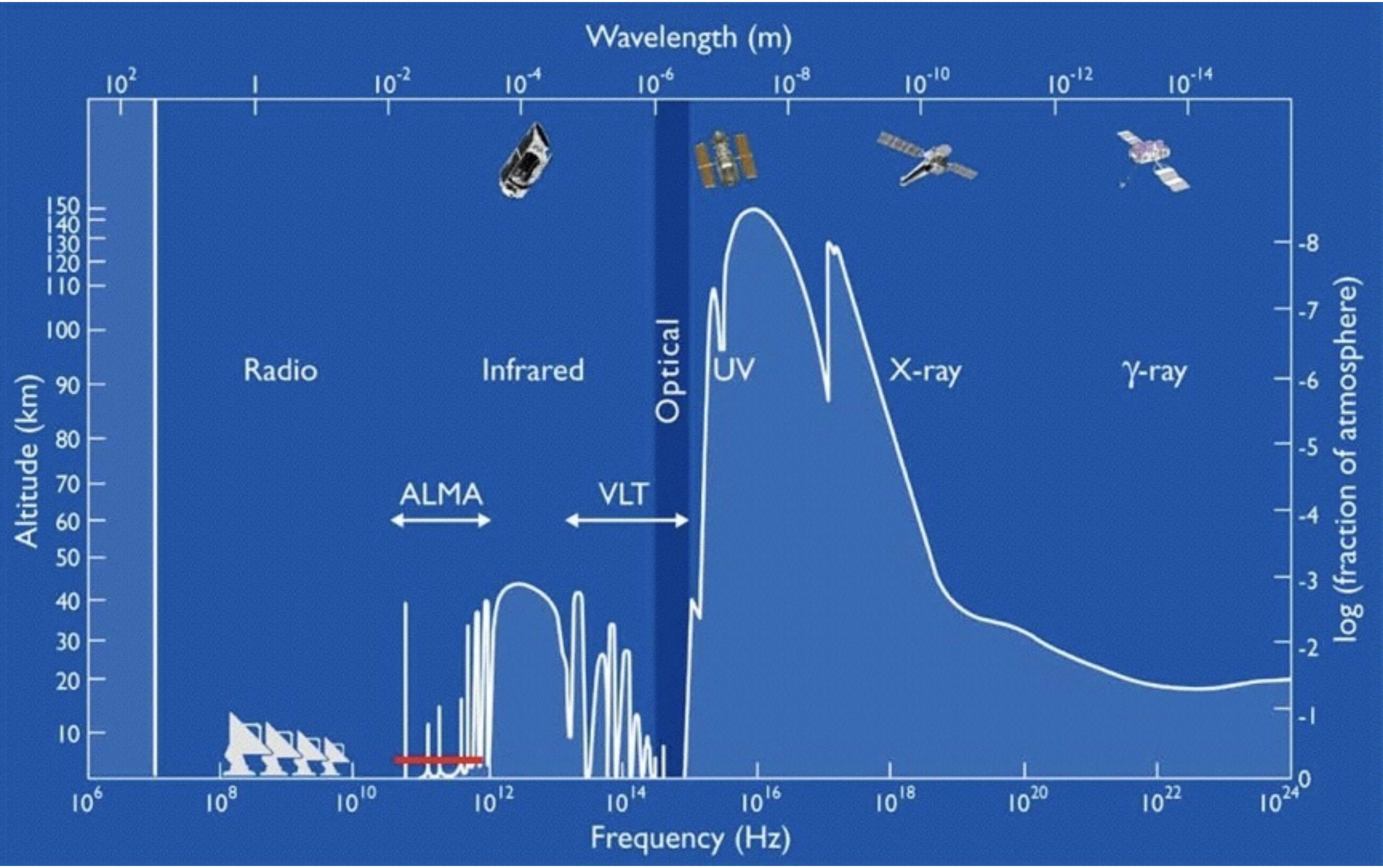


History of Galaxies



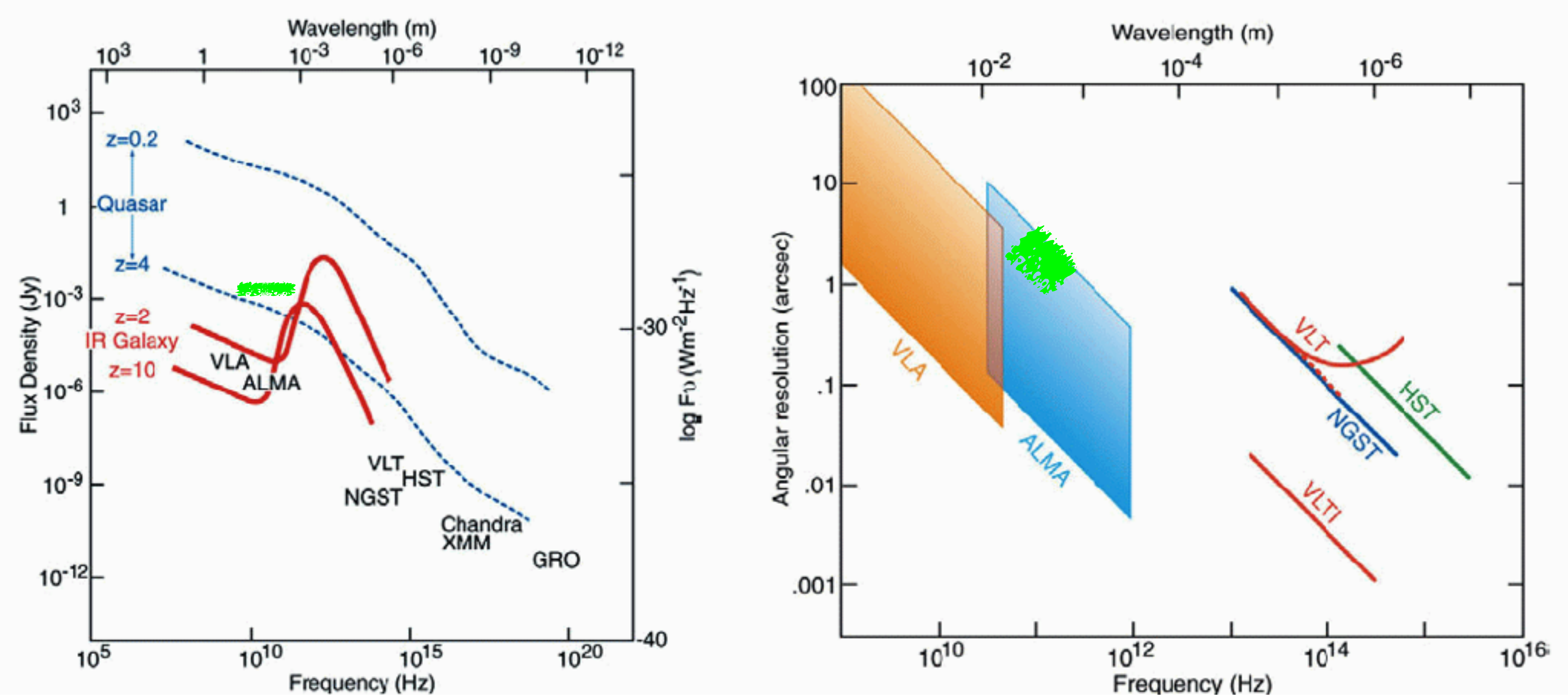


- Measuring redshift (and more) using CO, [CII] or [OI]



Wavelength (m)
10^2
1
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
Altitude (km)
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
Radio
Infrared
Optical
UV
X-ray
γ-ray
ALMA
VLT
log (fraction of atmosphere)
-8
-7
-6
-5
-4
-3
-2
-1
0
10^6
10^8
10^{10}
10^{12}
10^{14}
10^{16}
10^{18}
10^{20}
10^{22}
10^{24}
Frequency (Hz)

(Sub)mm facilities of the 1990s



Coming together for ALMA

LSA

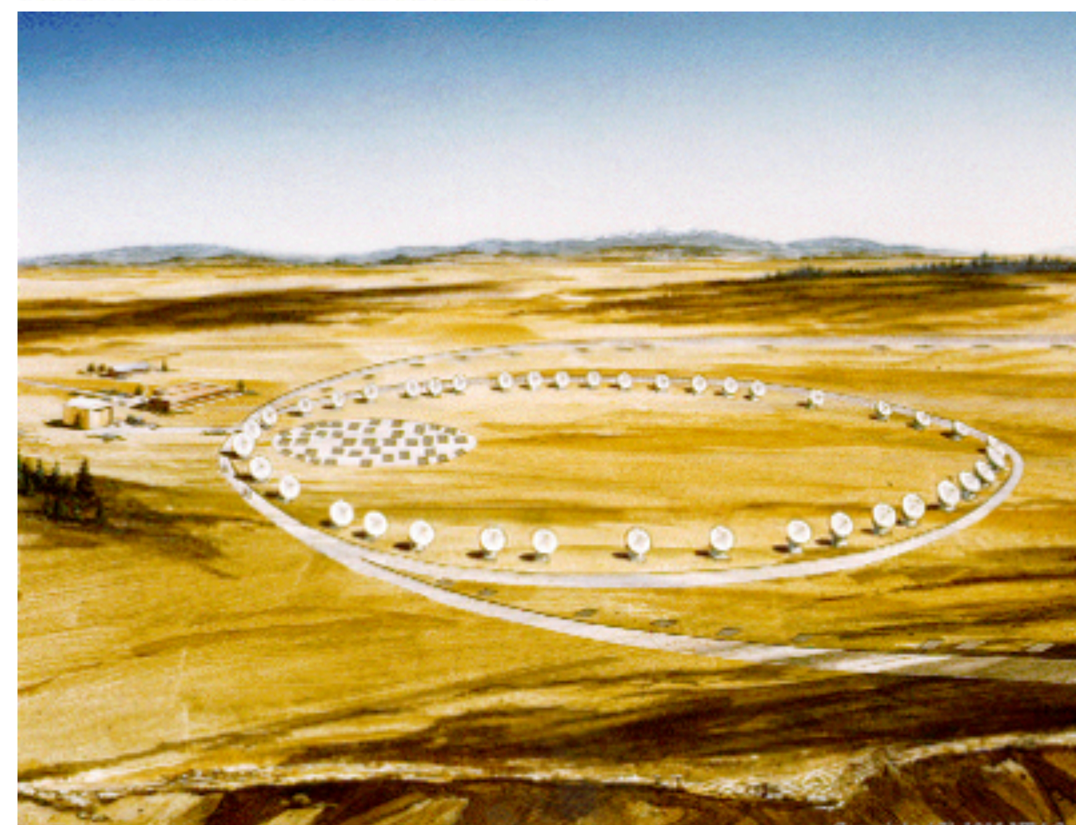
(1988)

MMA

(1982)

LMA

(1983)



June 1997: In Charlottesville, at the National Radio Astronomical Observatory headquarters, ESO and NRAO sign a resolution to develop a common project: ALMA is born.

Convergence to a common project:
Europe: expansion to the submm → high altitude site, reduction of the antenna diameter and collective area
U.S.: recognition of the importance of collective area → larger dishes

Difficulties:
Feasibility of 12m submm dishes?
Organizational challenges: USA-Europa-Chile-...

The trilateral project:
Japan joined the project in 2003 bringing additional and unique capabilities to the observatory

RESOLUTION

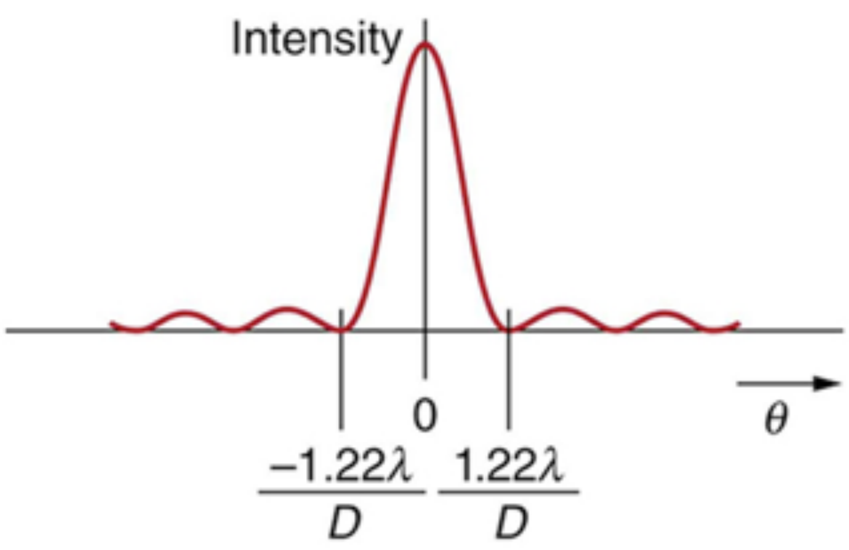
Whereas the development of millimeter-wavelength astronomy has shown the potential of large millimeter interferometric arrays for revealing the origin and evolution of stars and planetary systems, of galaxies, and of the Universe itself; the communities in the United States and Europe have proposed the construction of the Millimeter Array (MMA) and the Large Southern Array (LSA), respectively; and there is an opportunity through cooperation to achieve more than either community planned; we, as the observatories responsible for these projects and with the support of our communities, resolve to organize a partnership that will explore the union of the LSA and MMA into a single, common project to be located in Chile. Specifically, this partnership will study the technical, logistical, and operational aspects of a joint project. Of particular importance, the two antenna concepts currently under consideration will be studied to identify the best antenna size and design or combination of sizes to address the scientific goals of the two research communities. In doing so we will work through our observatories, utilizing the expertise in millimeter astronomy resident in research groups and institutions in our communities. Finally, we recognize that there are similar goals for millimeter astronomy in Japan, and cooperative activities with that project will continue.

R. Giacconi	P. Vanden Bout
European Southern Observatory	National Radio Astronomy Observatory

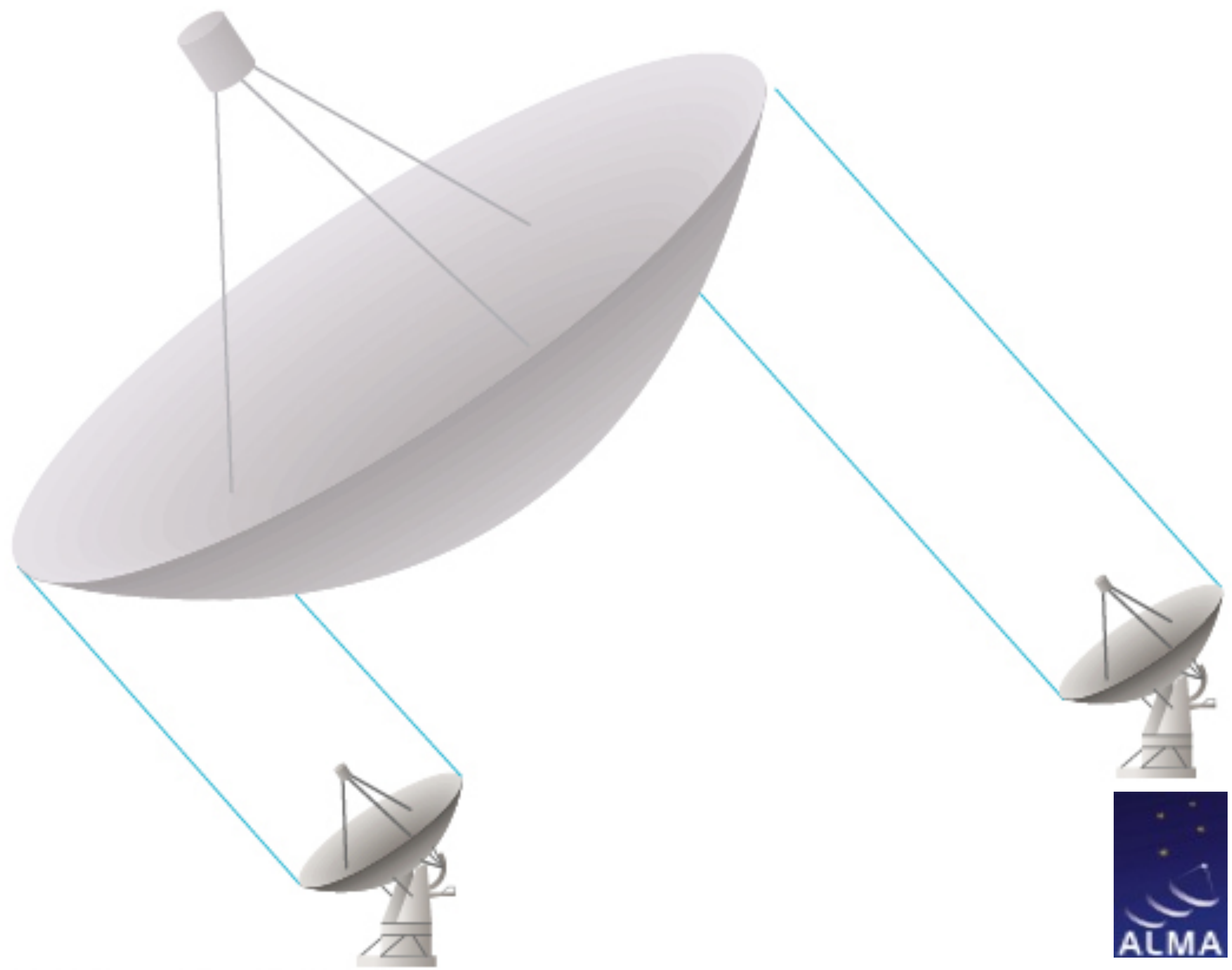
26 June 1997

Angular resolution

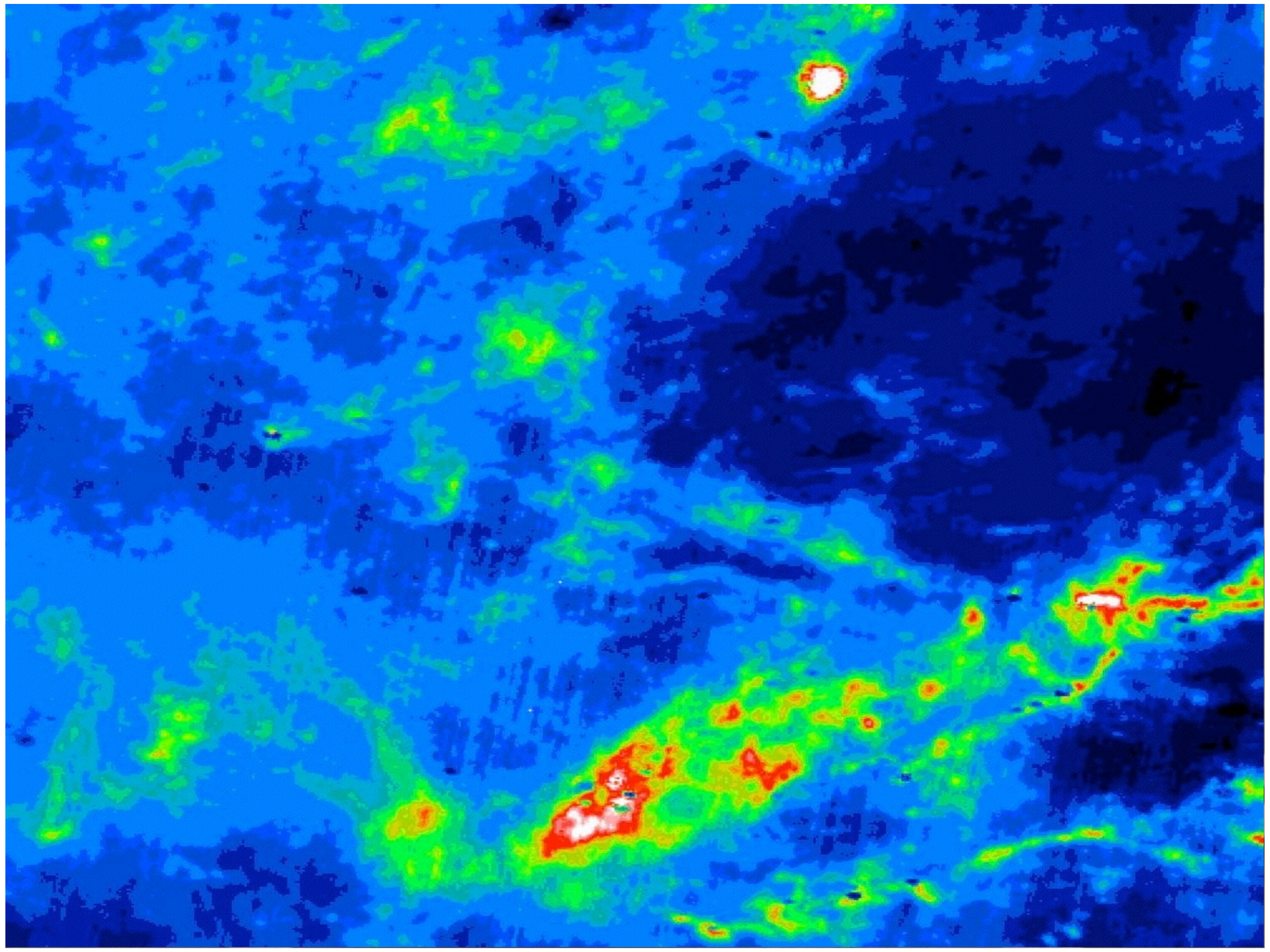
- Diffraction limit: ~1.22*lambda/D => 1mm/30m~8”
- 8” > 1000 AU @ 140pc (Sun-Neptune ~ 30AU)
- Sun-Jupiter ~ 5AU => 0.035” => >~7km @1mm
- Sun-Earth = 1AU => 0.007” => ~17km @0.5mm



(a)

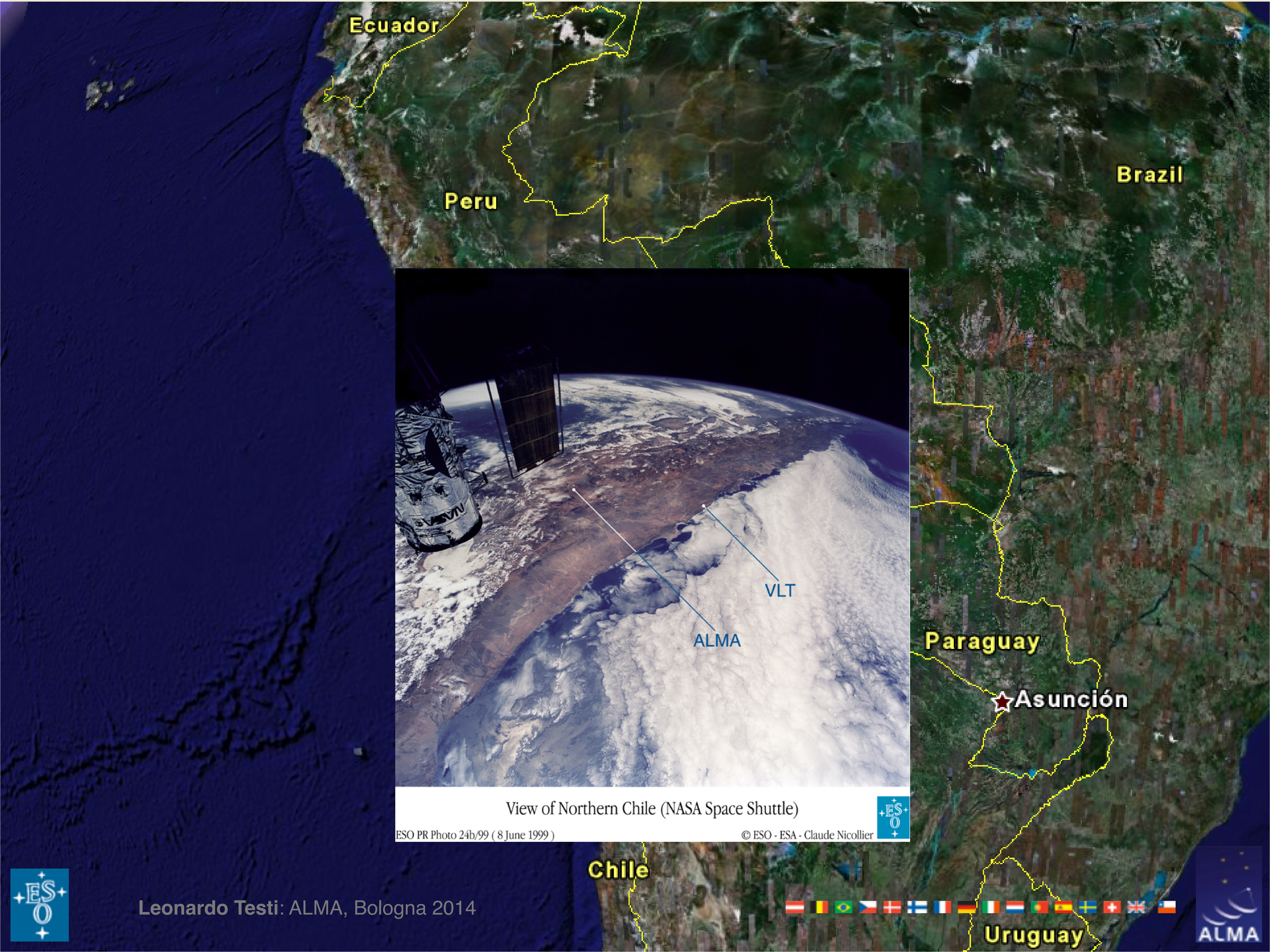


Atacama Large Millimeter Array



- At least 50x12m Antennas
- Frequency range 30-1000 GHz (0.3-10mm)
- 16km max baseline (<10mas)
- ALMA Compact Array (4x12m and 12x7m)

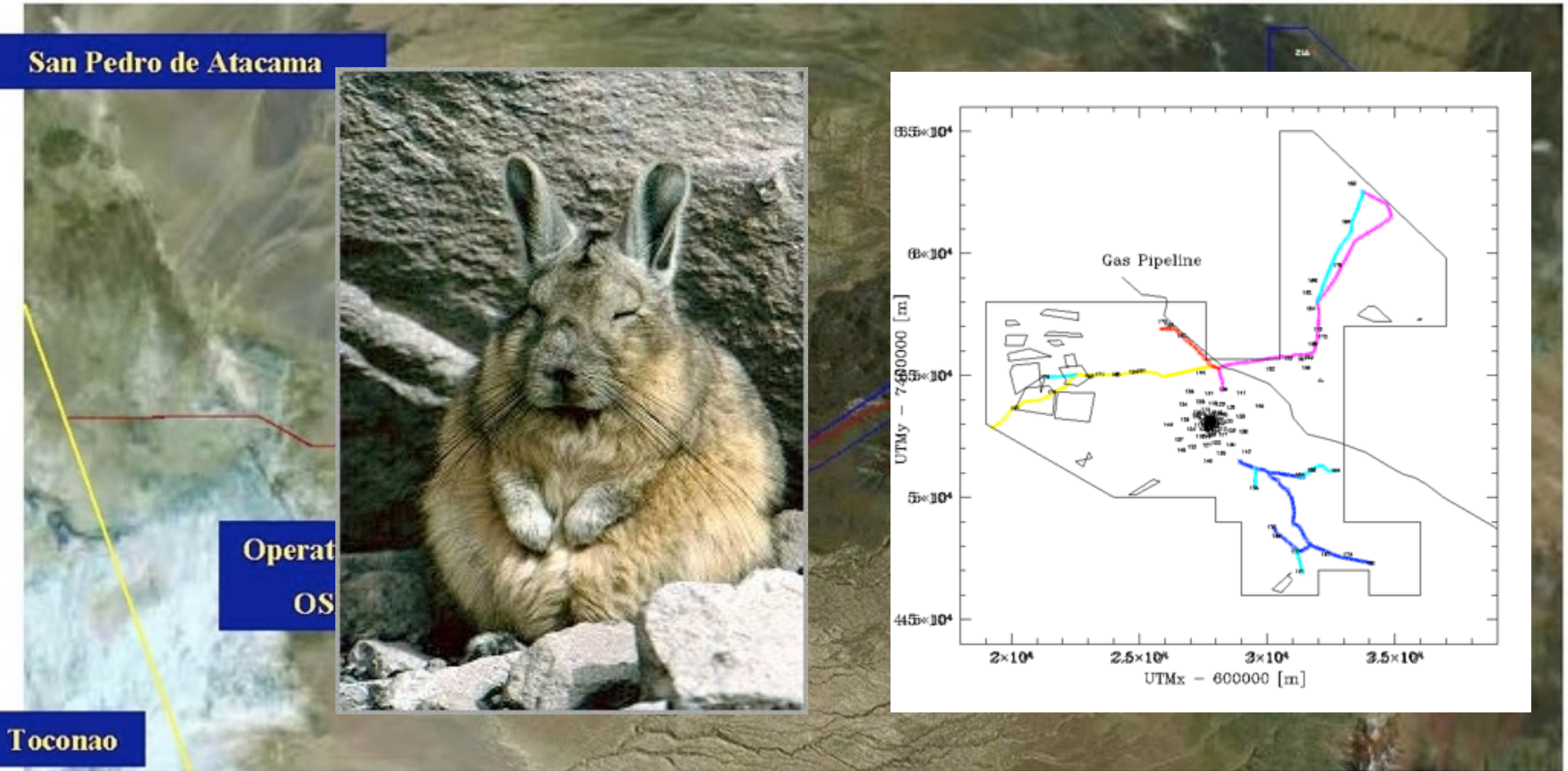
1. **Detect and map CO and [C II] in a Milky Way galaxy at z=3 in less than 24 hours of observation**
2. **Map dust emission and gas kinematics in protoplanetary disks**
3. **Provide high fidelity imaging in the (sub)millimeter at 0.1 arcsec resolution**



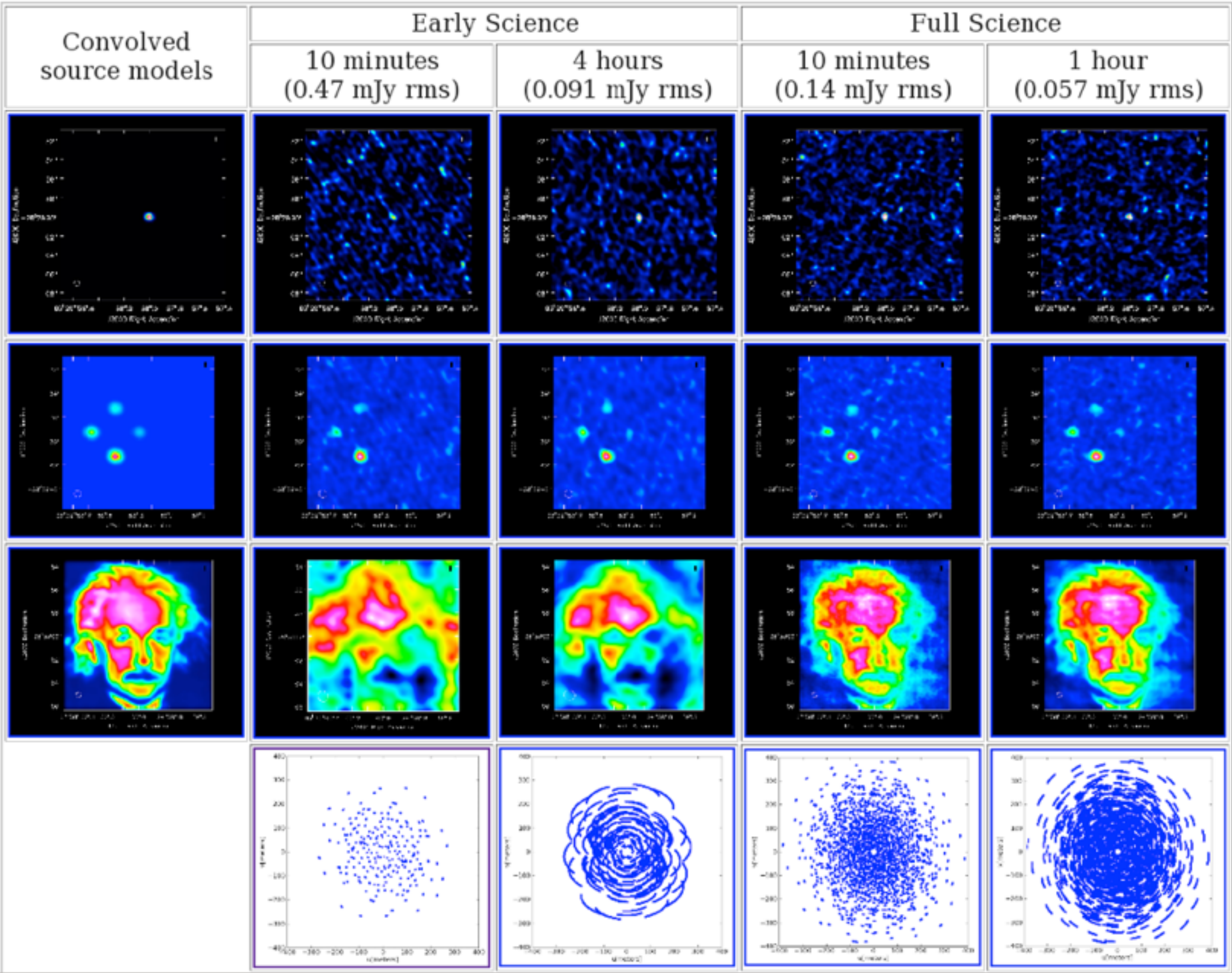
View of Northern Chile (NASA Space Shuttle)

ESO PR Photo 24b/99 (8 June 1999)

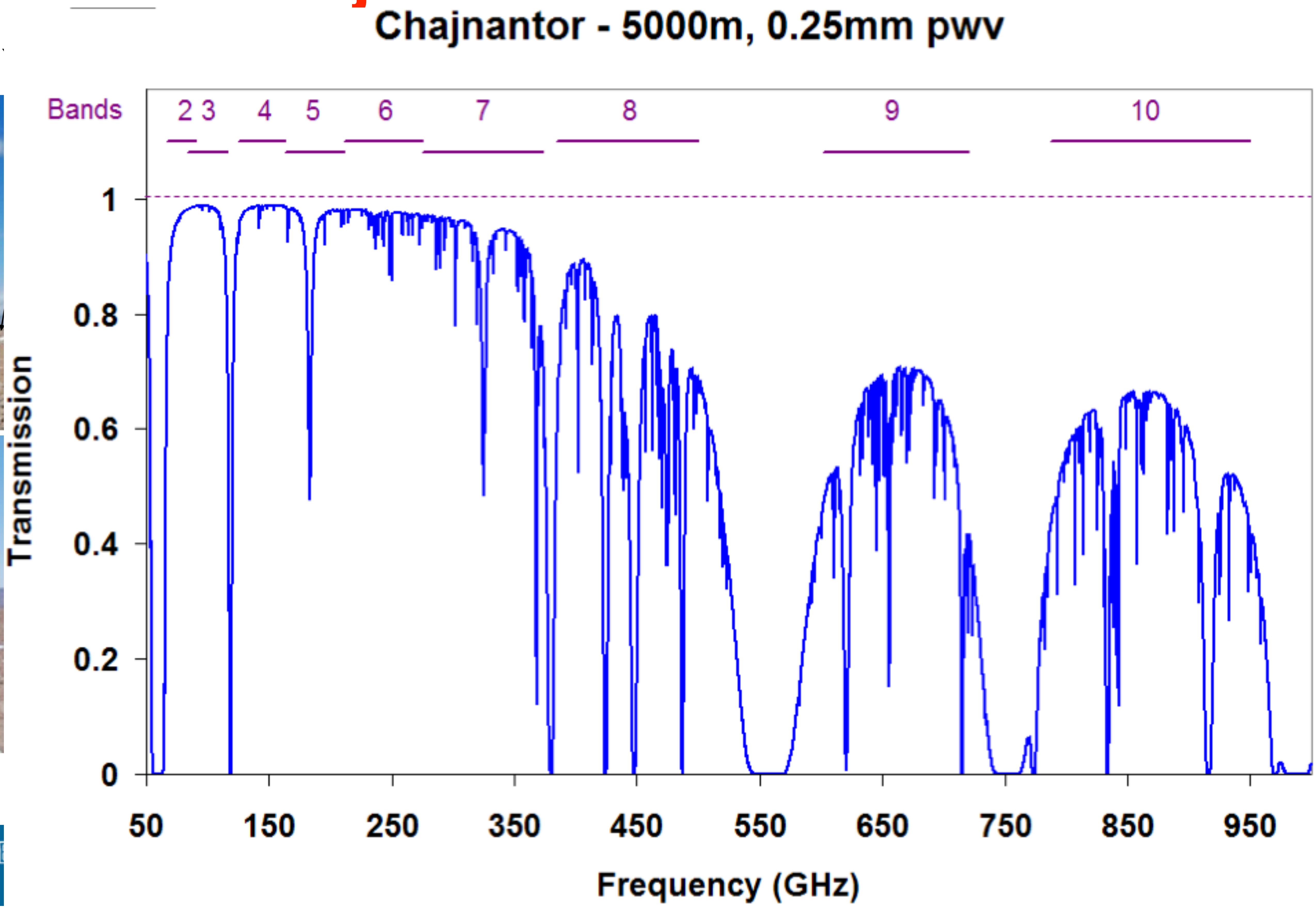

San Pedro de Atacama,
Atacama Desert, Chile


San Pedro de Atacama
Toconao
Gas Pipeline
UTMx − 600000 [m]
2×10⁴
2.5×10⁴
3×10⁴
3.5×10⁴

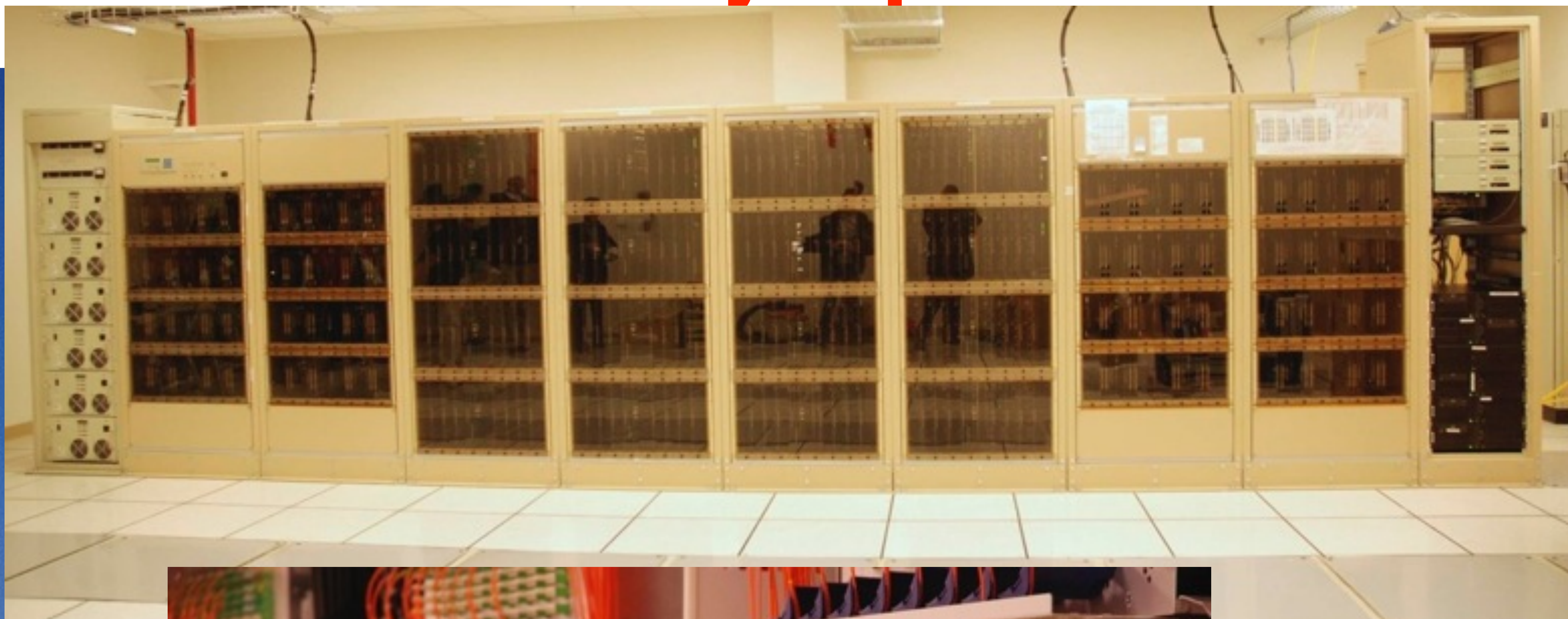
ALMA - Image Fidelity

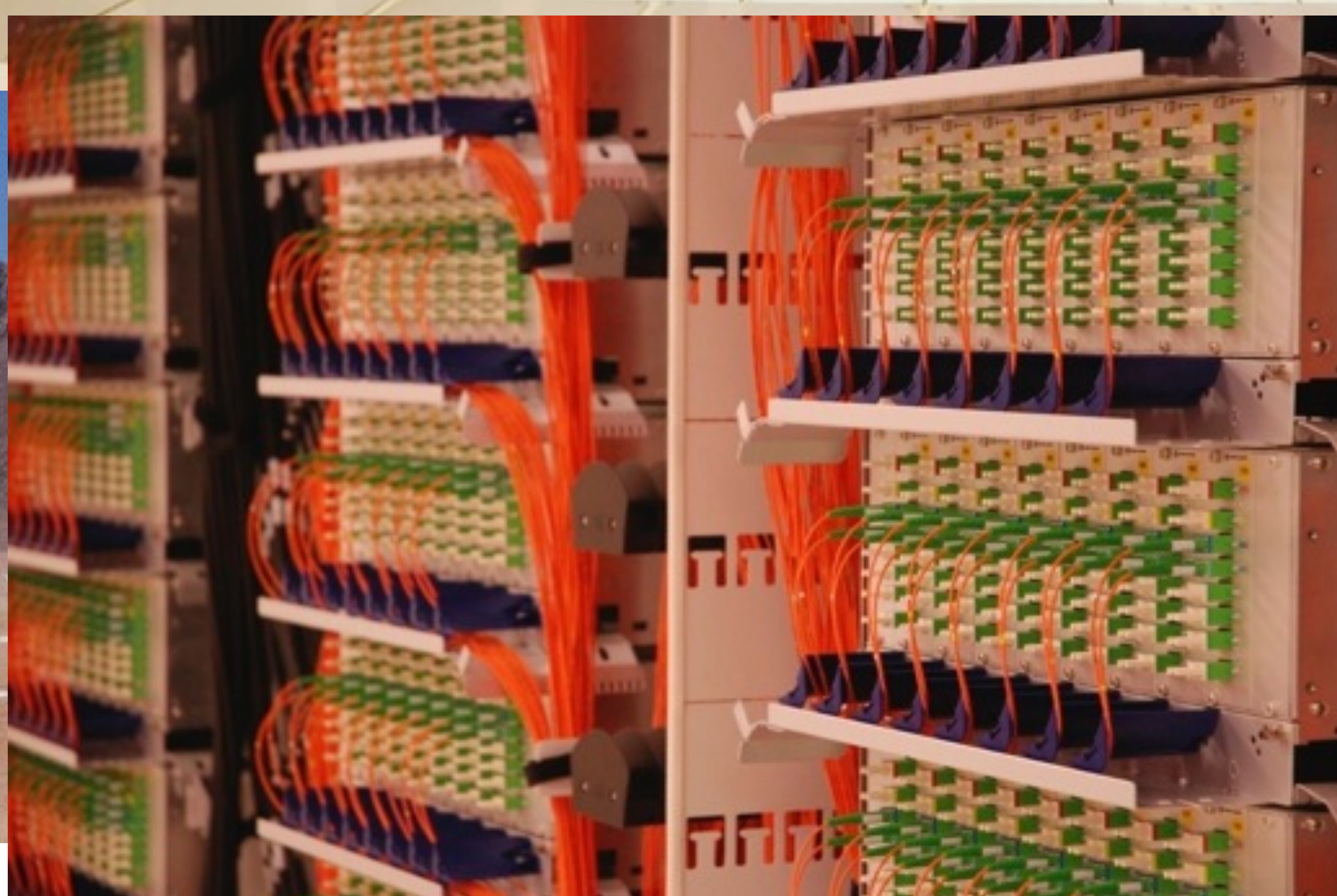


Chajnantor Plateau - 5000m



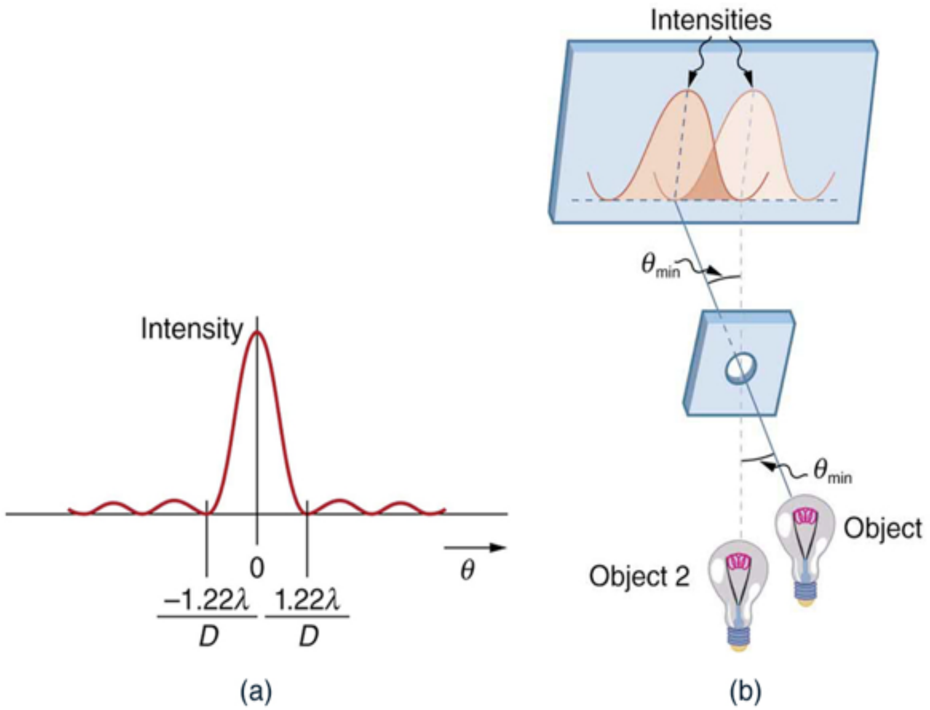
Array Operations Site

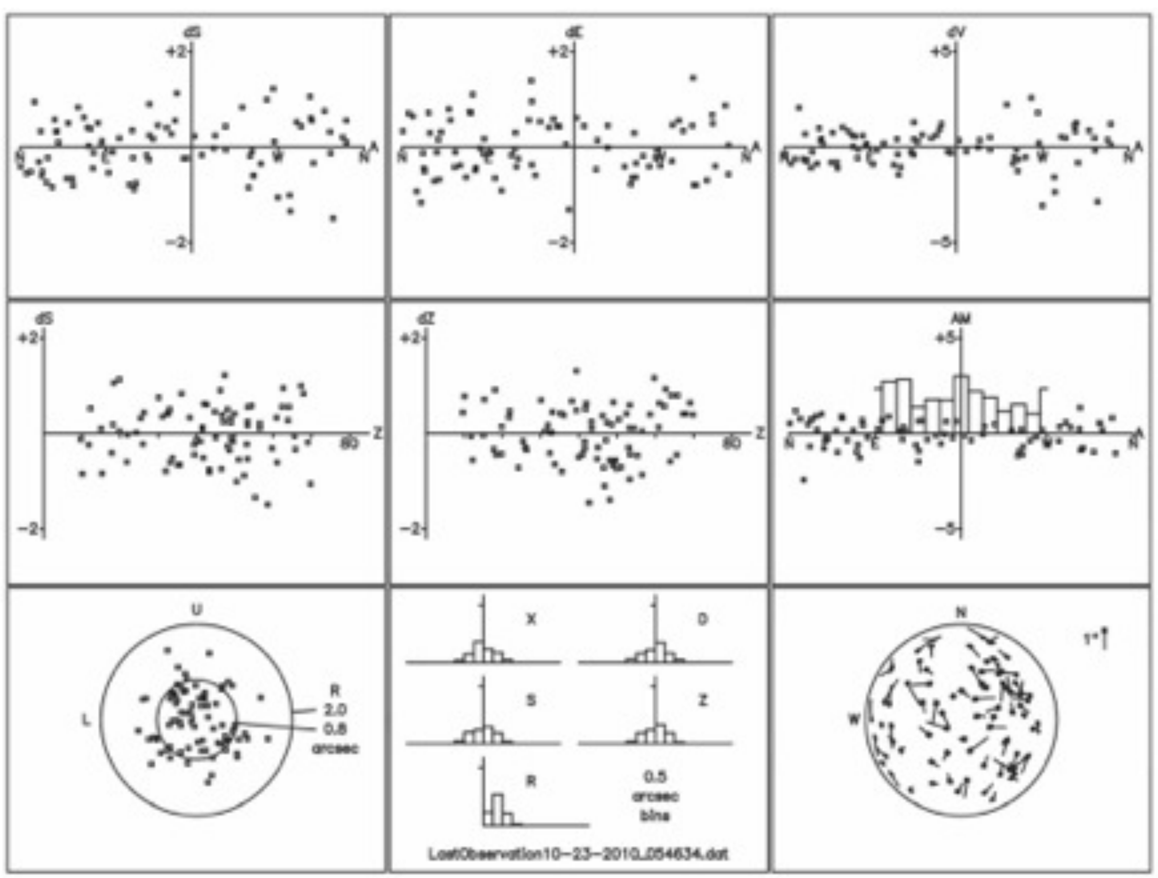


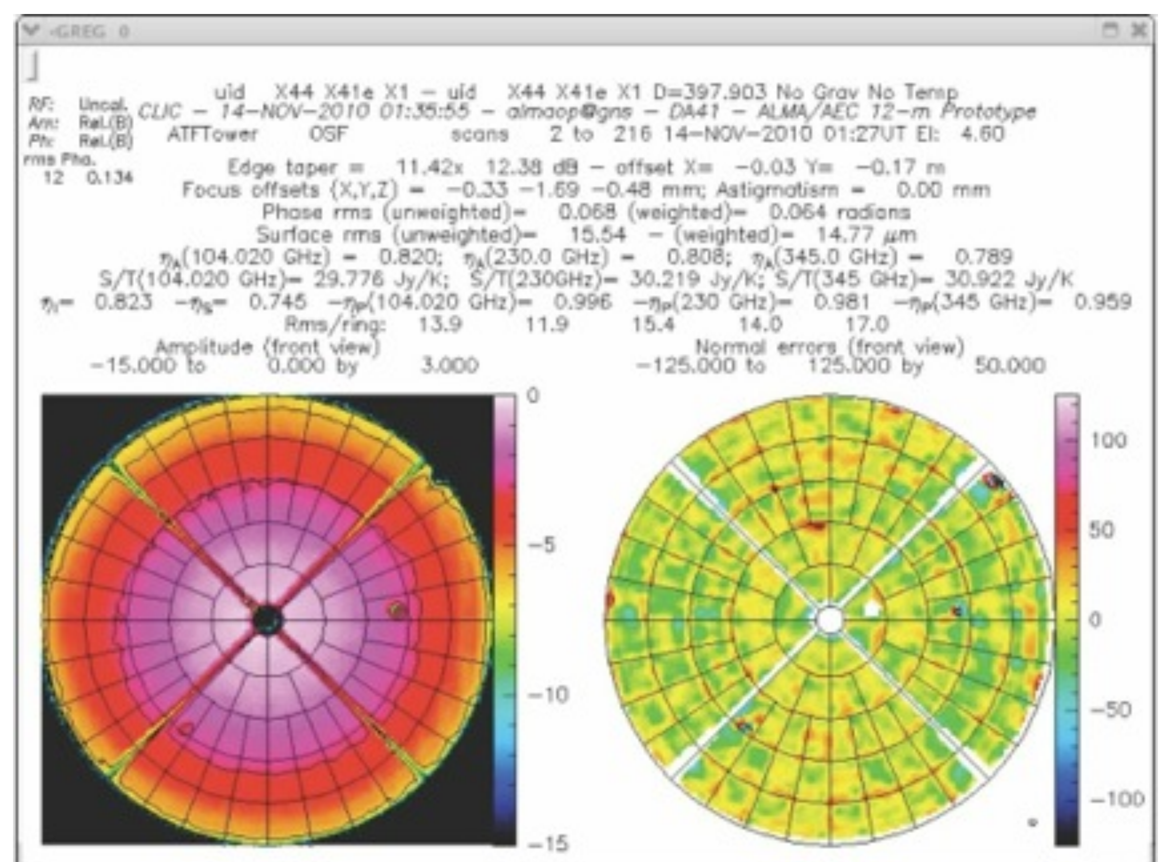


Antenna performances

- Excellent dynamical and optical performances of all antenna types
- Good results for very stringent potinting tests (well within specs)
- Excellent results from surface setting
- Now exploring long term stability

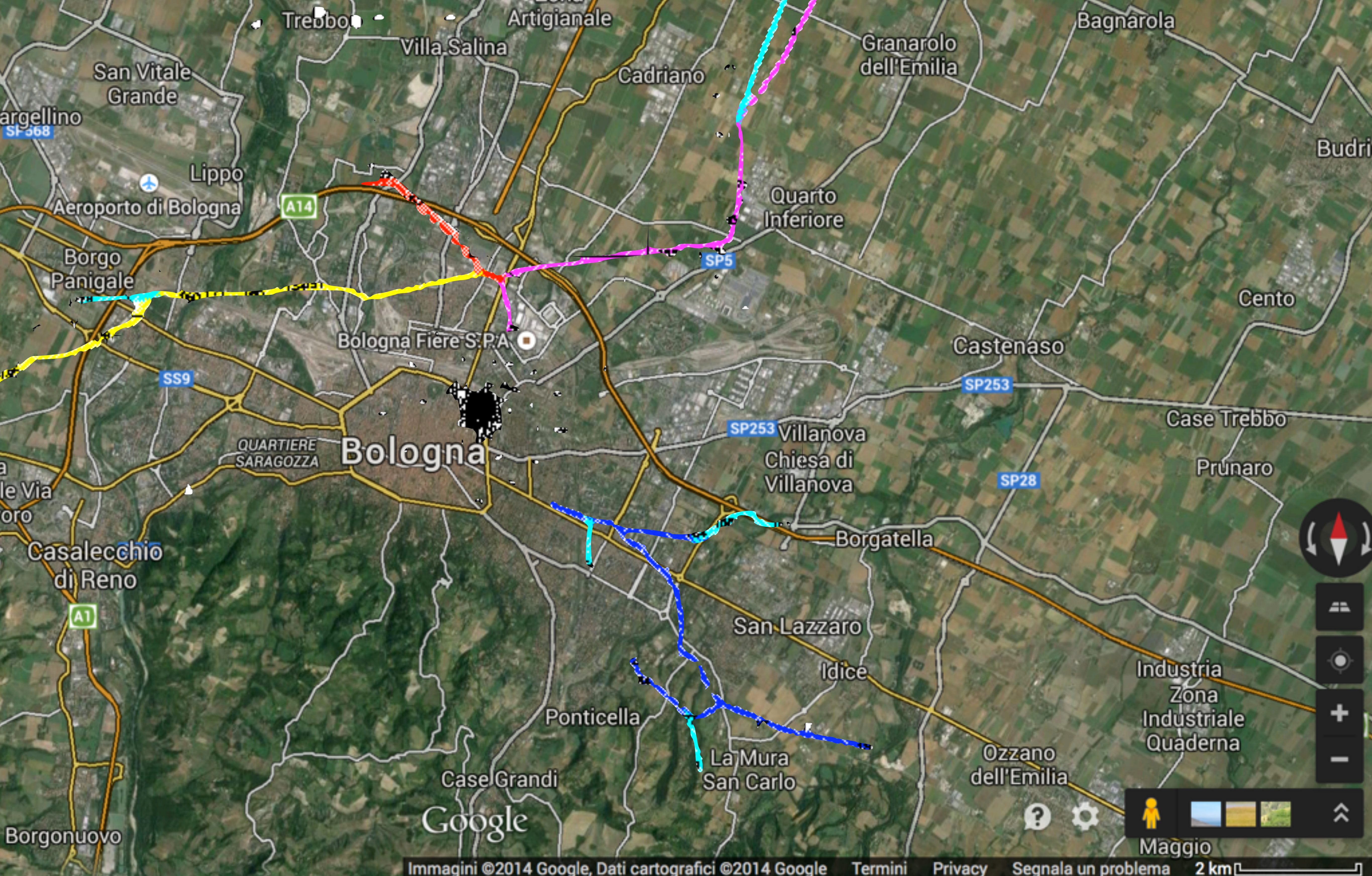






First antenna at 5000m

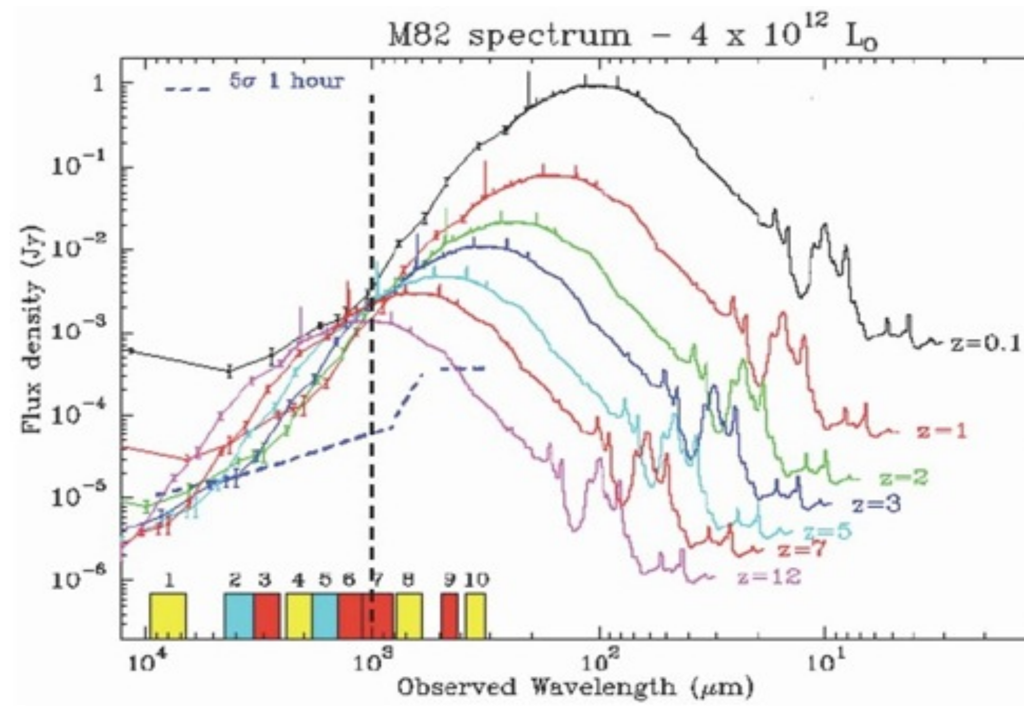
ALMA Compact Configuration



ALMA Exteded Array

ALMA Early Science

- ALMA Early Science C0, C1 & C2
  - 30-70% of the total number of antennas
  - Maximum separation 3km
  - Already the most powerful submm observatory
- Enormous pressure to use ALMA worldwide
  - Requests for 9 times the available time
  - Top 8% science projects selected (ESO)



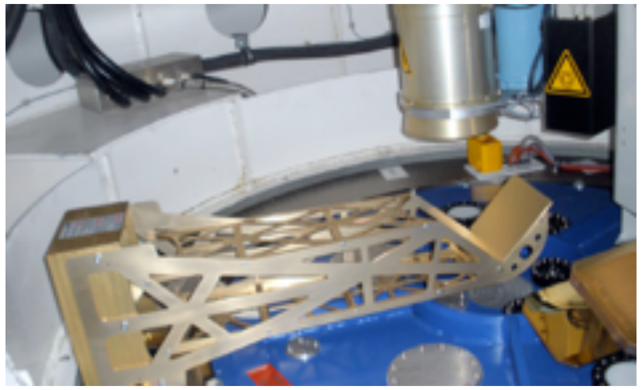
ALMA Science Programme

ALMA Frequency Bands Usage

- ALMA is a Sub-millimeter Observatory
- Thanks to the Site and the Water Vapour Radiometers

Band 7
IRAM

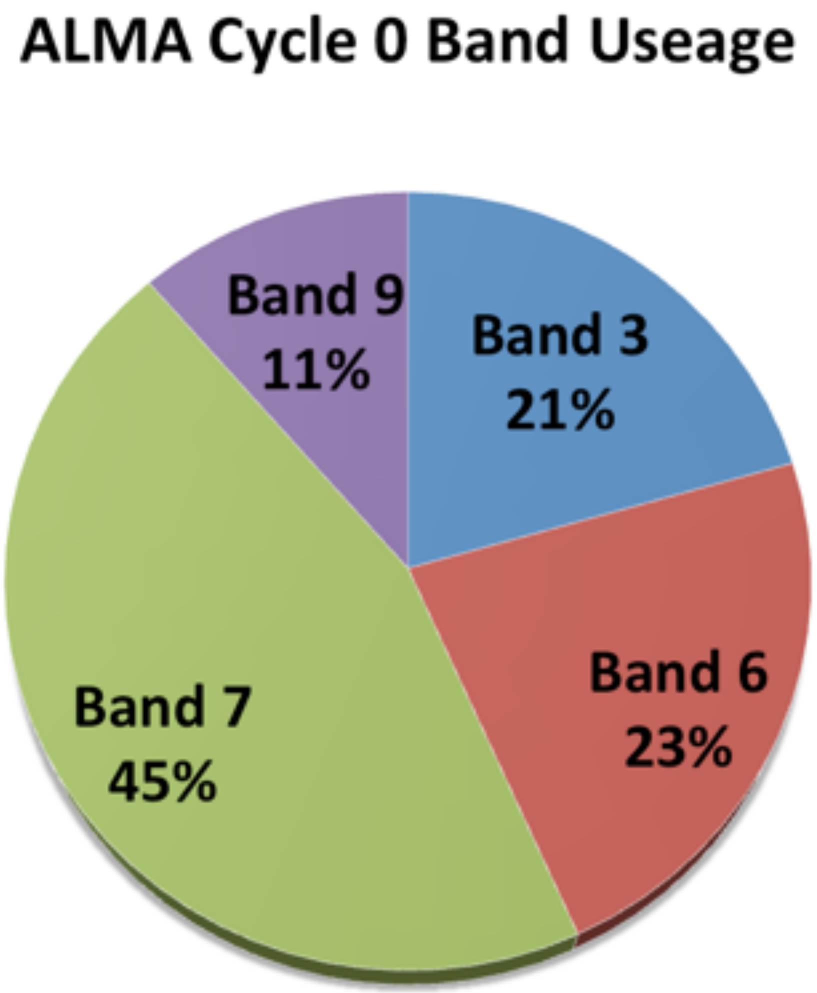
Band 9
NOVA



WVR
OMNISYS

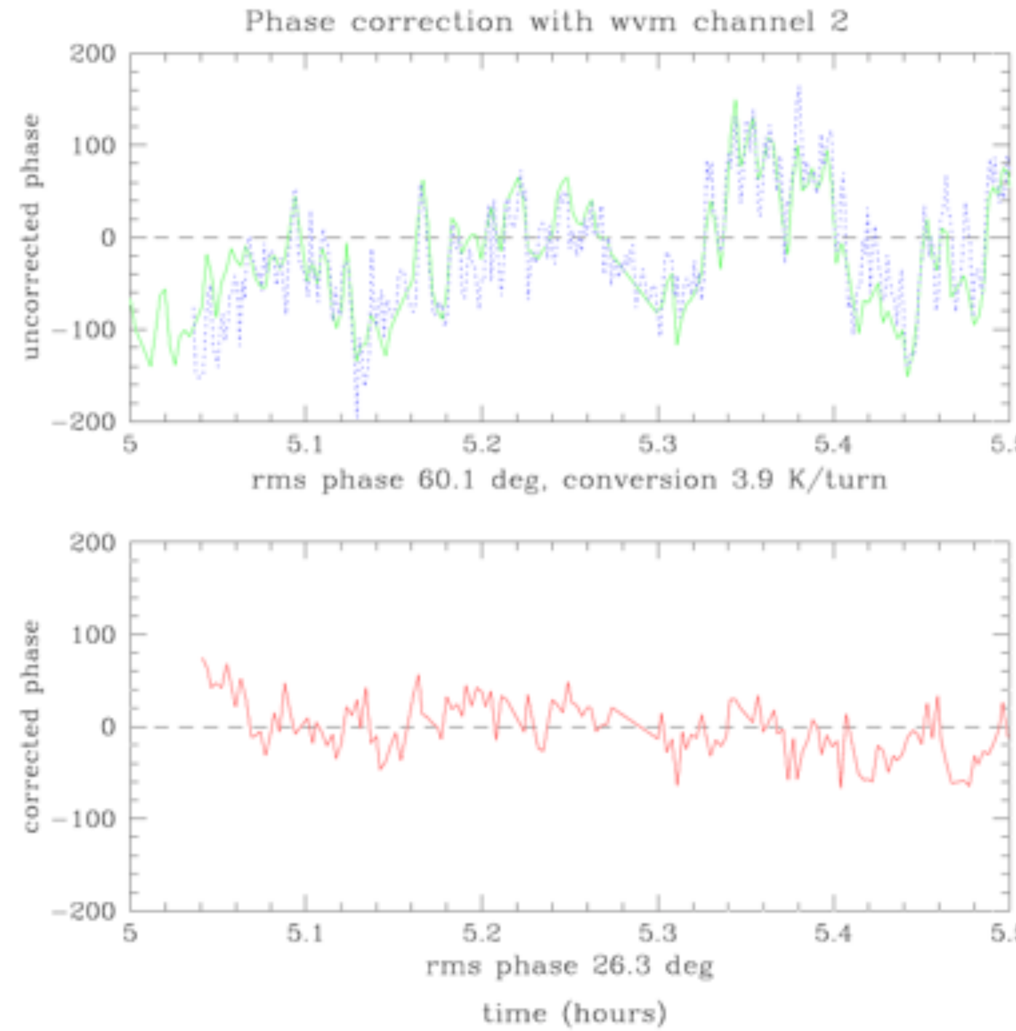
SIXTH FRAMEWORK PROGRAMME

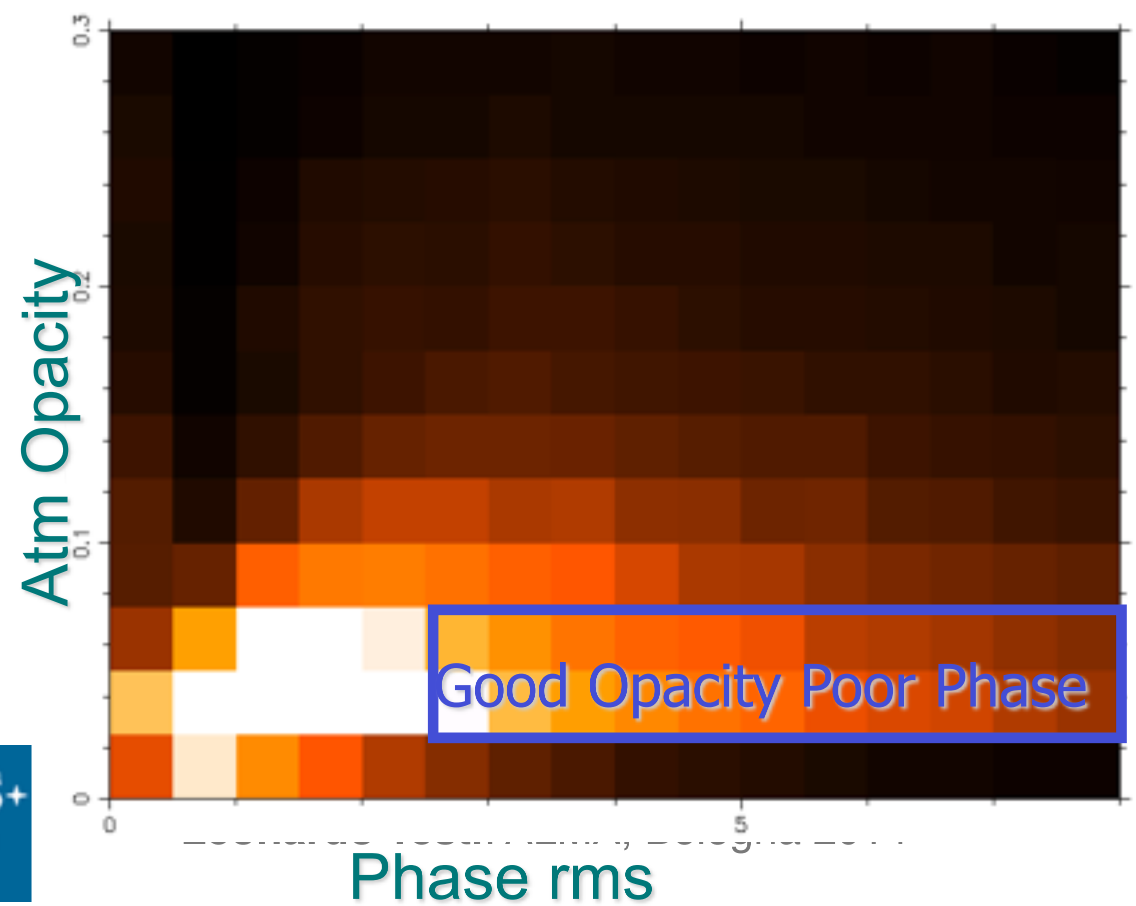
Phase Correction
SW - U Cambridge



Water Vapour Radiometers

- All ALMA antennas will be equipped with water vapour radiometers observing the 183GHz atmospheric water line.



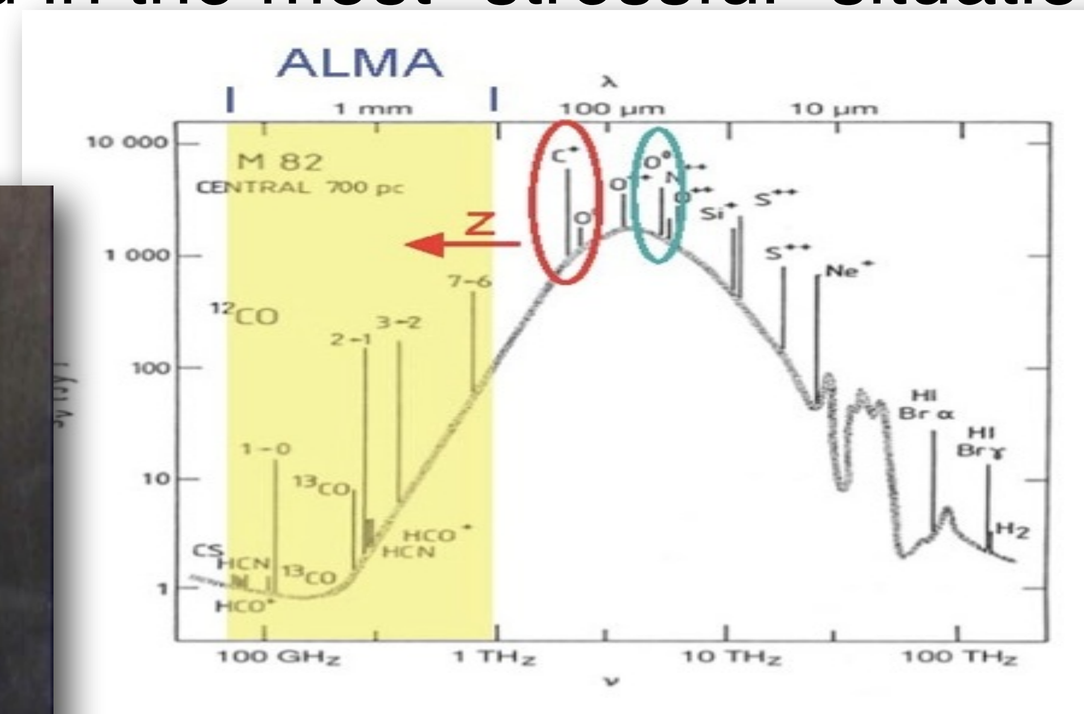


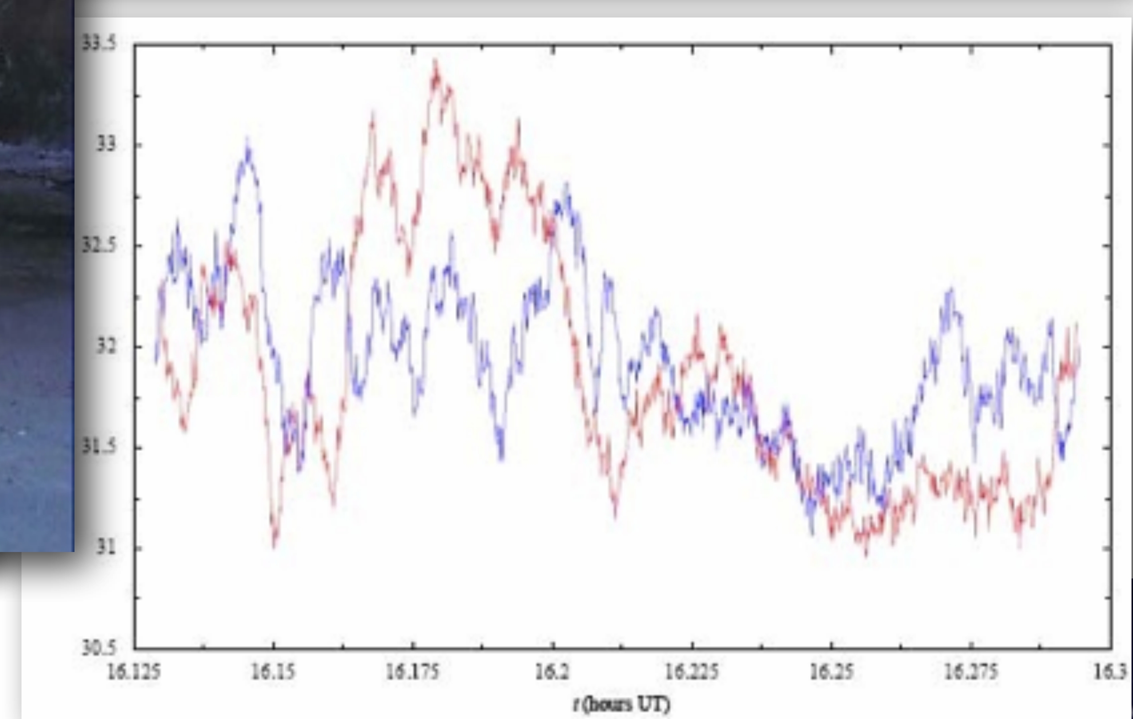
WVRs track phase on 1s timescales along the same path (within 3-10 arcmin) as the astronomical signal from the source (complementary to fastswitching: ≥10s and few degs)

-Improve Sensitivity and Fidelity
-Allow to increase switch time

WVR correction

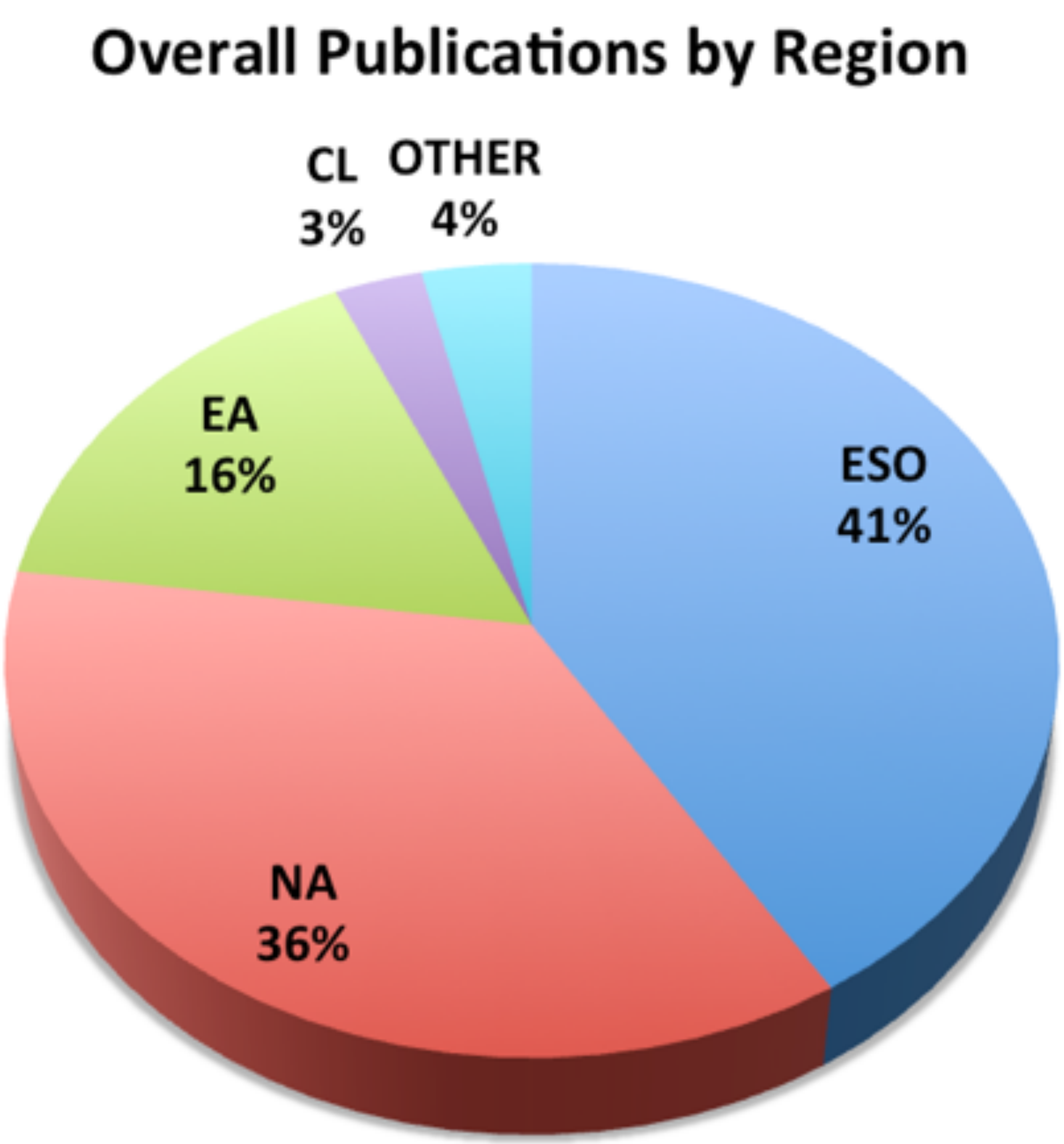
- Successful testing at Onsala, OSF, AOS and real life operations
- Correction very promising, to be tested in the most “stressful” situation

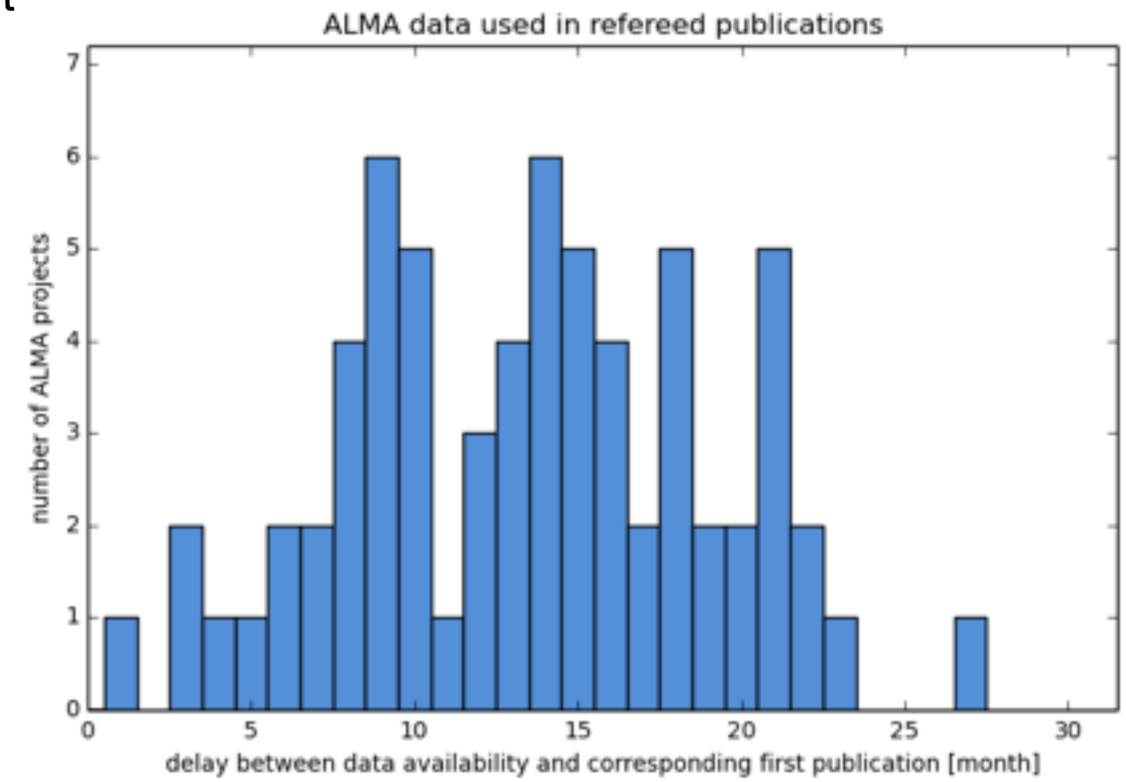


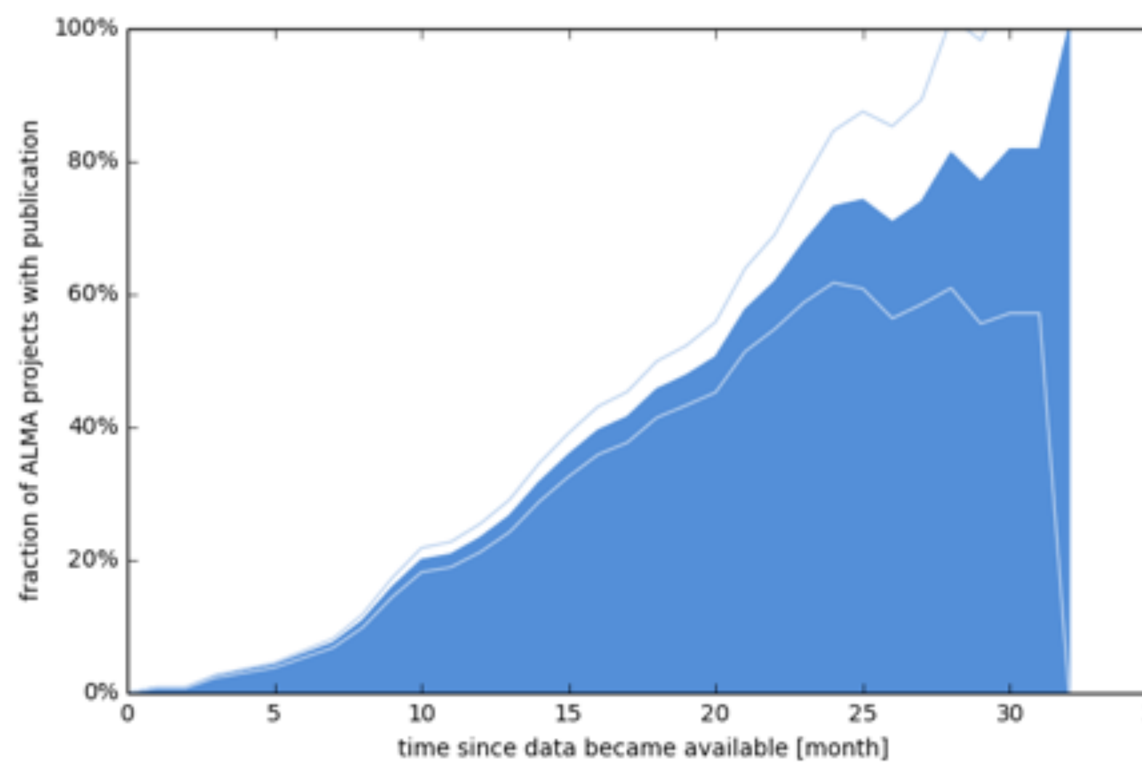


ALMA Publications

- Only refereed papers
  - Collected data as of **October, 2014** from telbib.eso.org (many thanks to ESO, NRAO, NAOJ librarians!)
  - Only printed papers on refereed journals appear on the list
- Database
  - 138 refereed publications (more now)
  - High fraction of high impact publications (7%)







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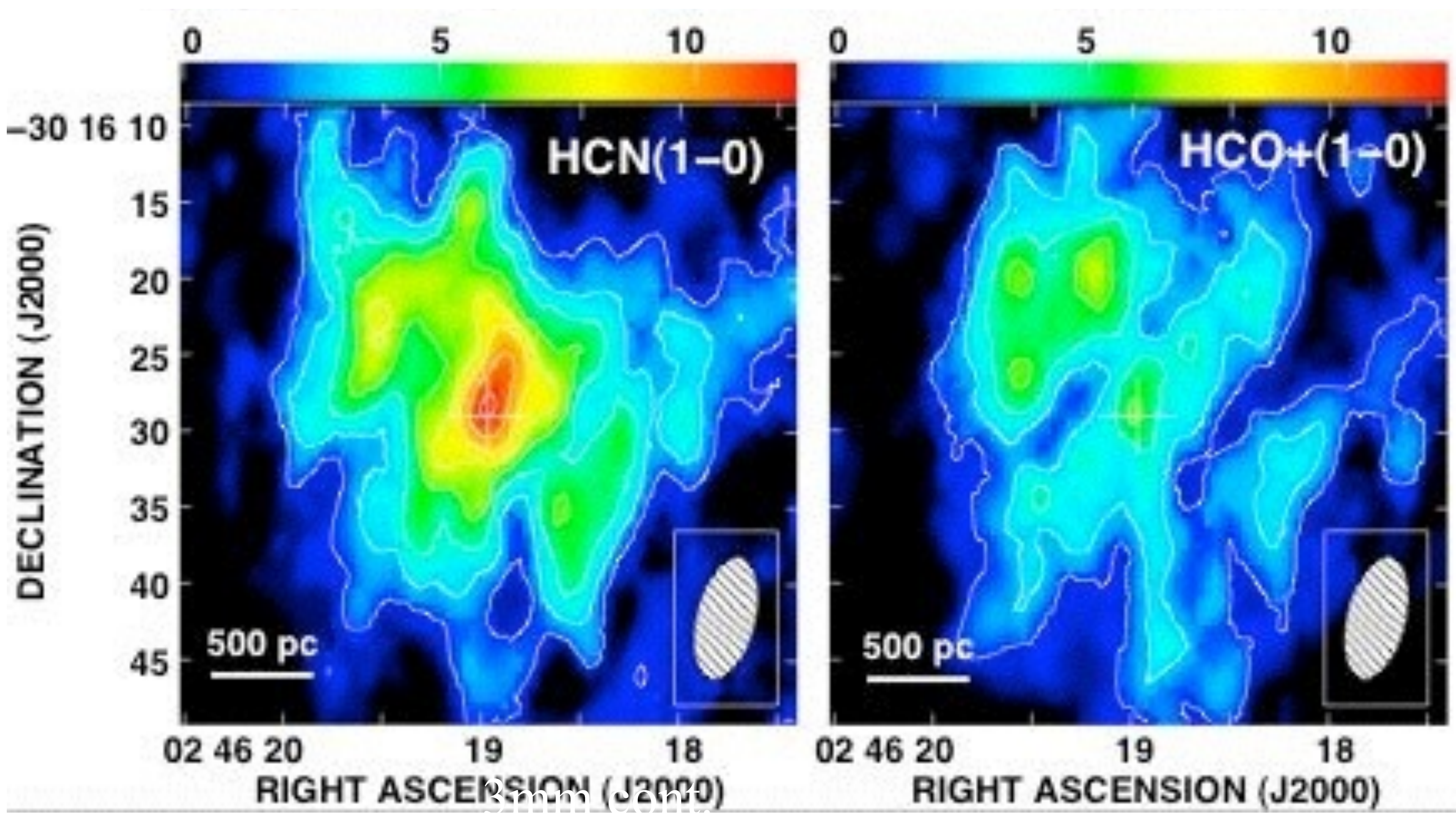
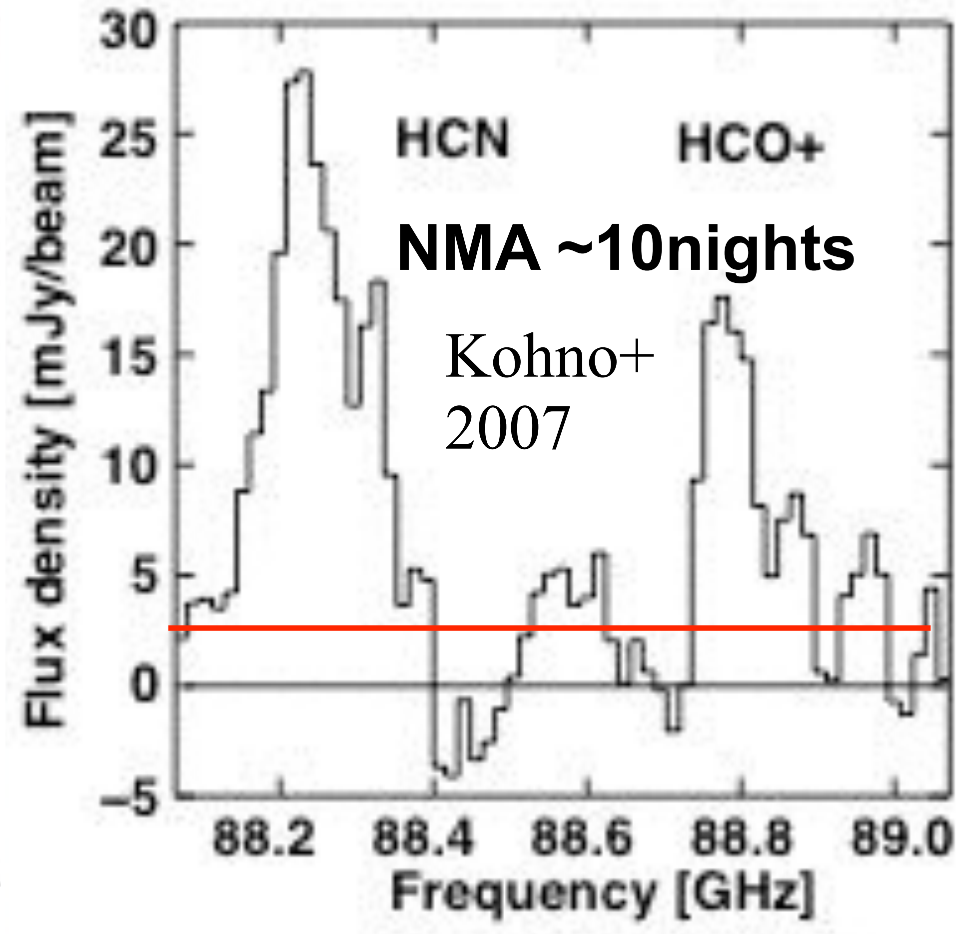
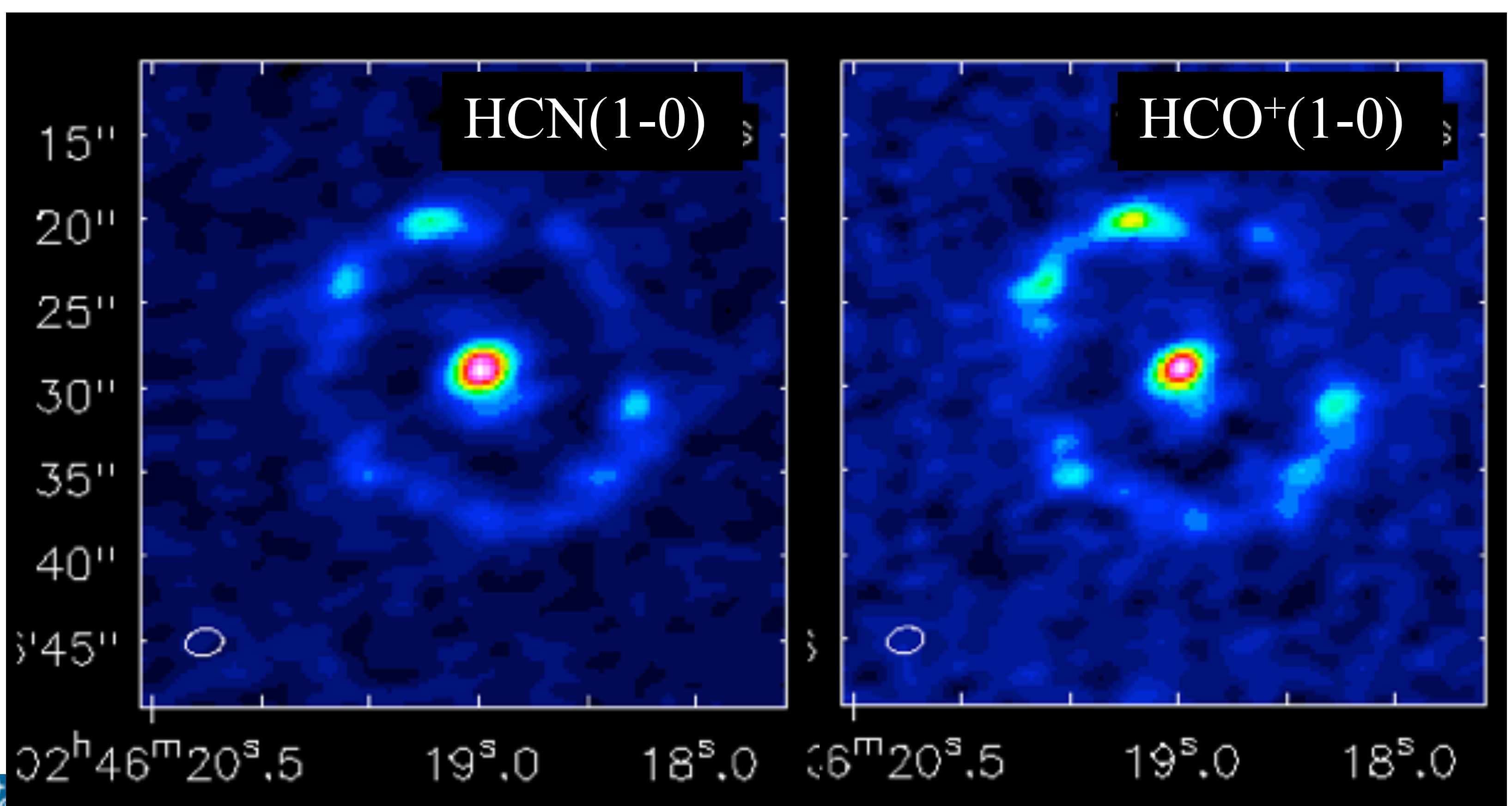
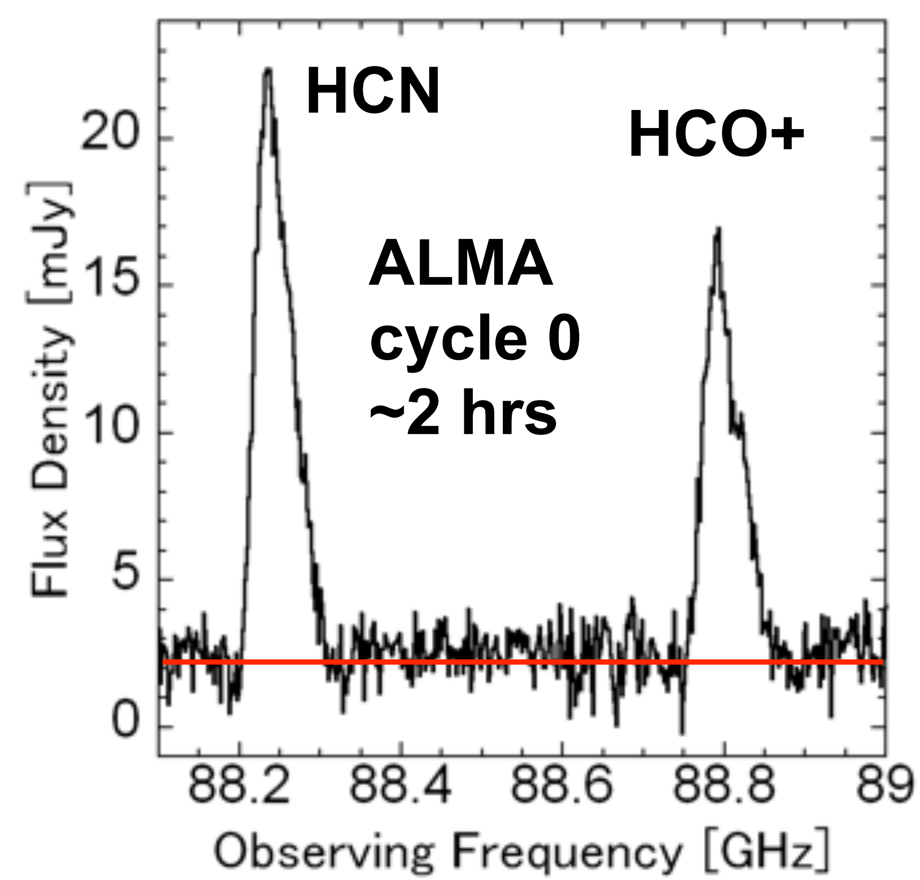




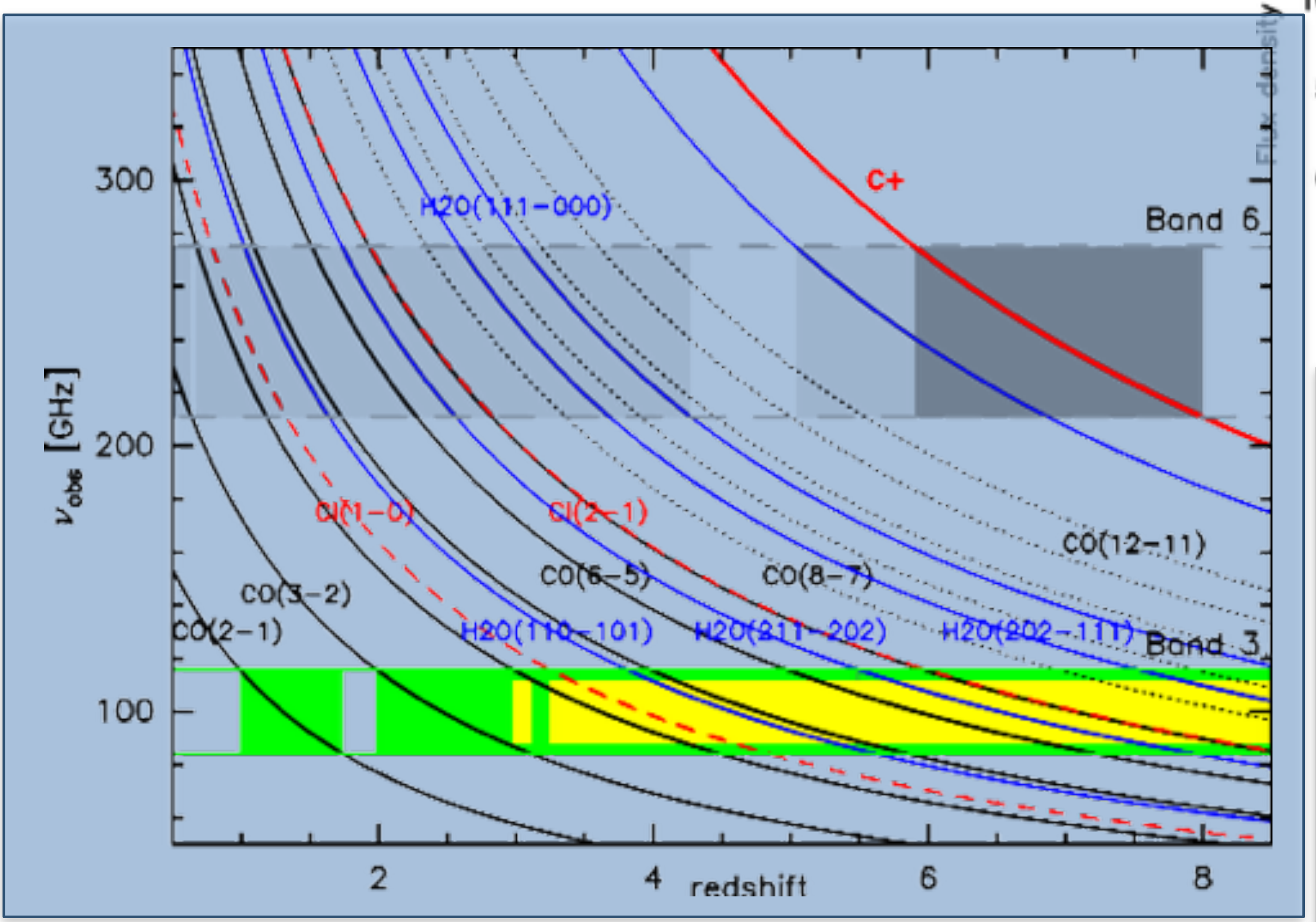


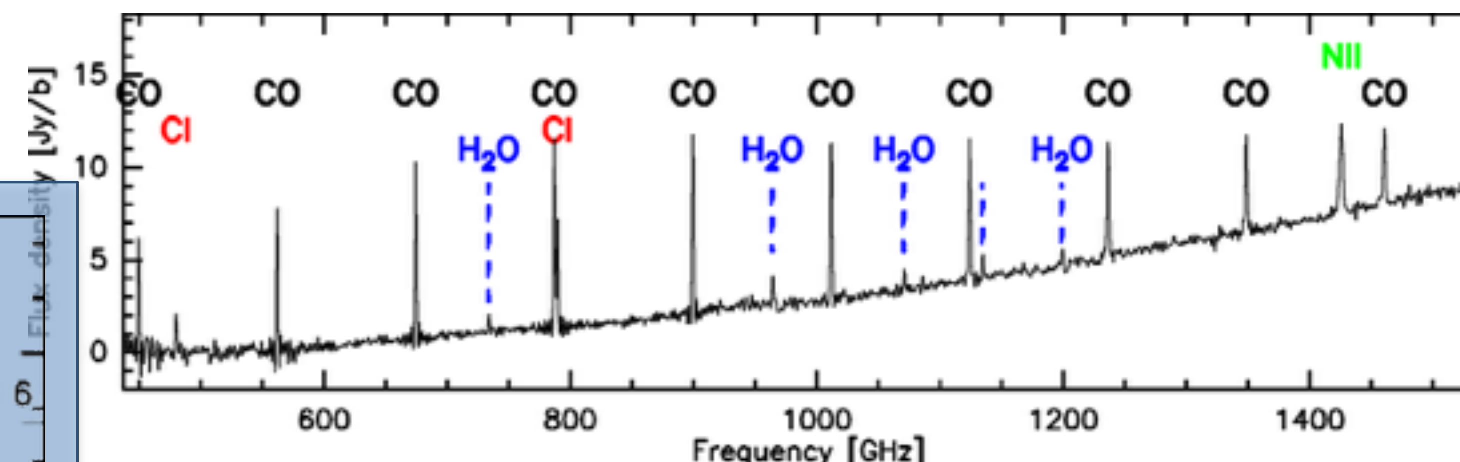


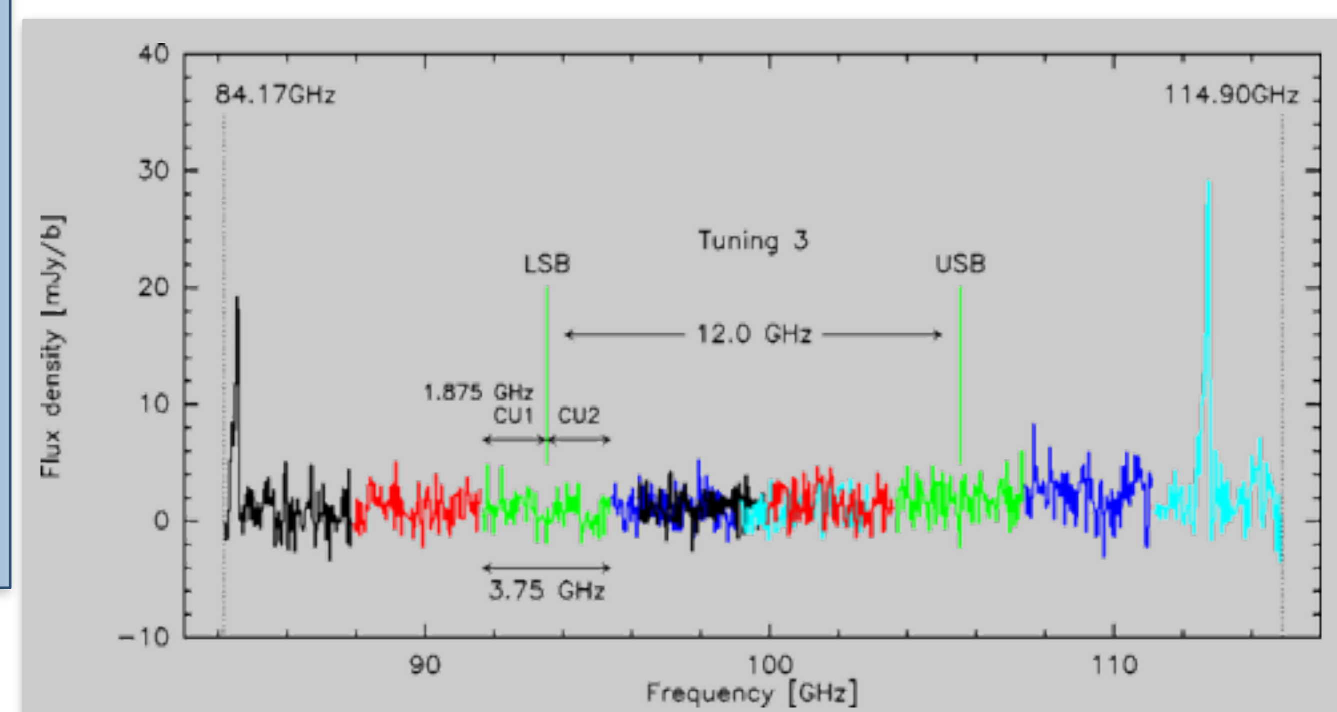
ALMA cycle 0 program (PI. K. Kohno)

The first ALMA redshift survey

- SPT submillimetre galaxies; B3 spectral survey
  - Vieira et al. 2013; Weiss et al. 2013; …

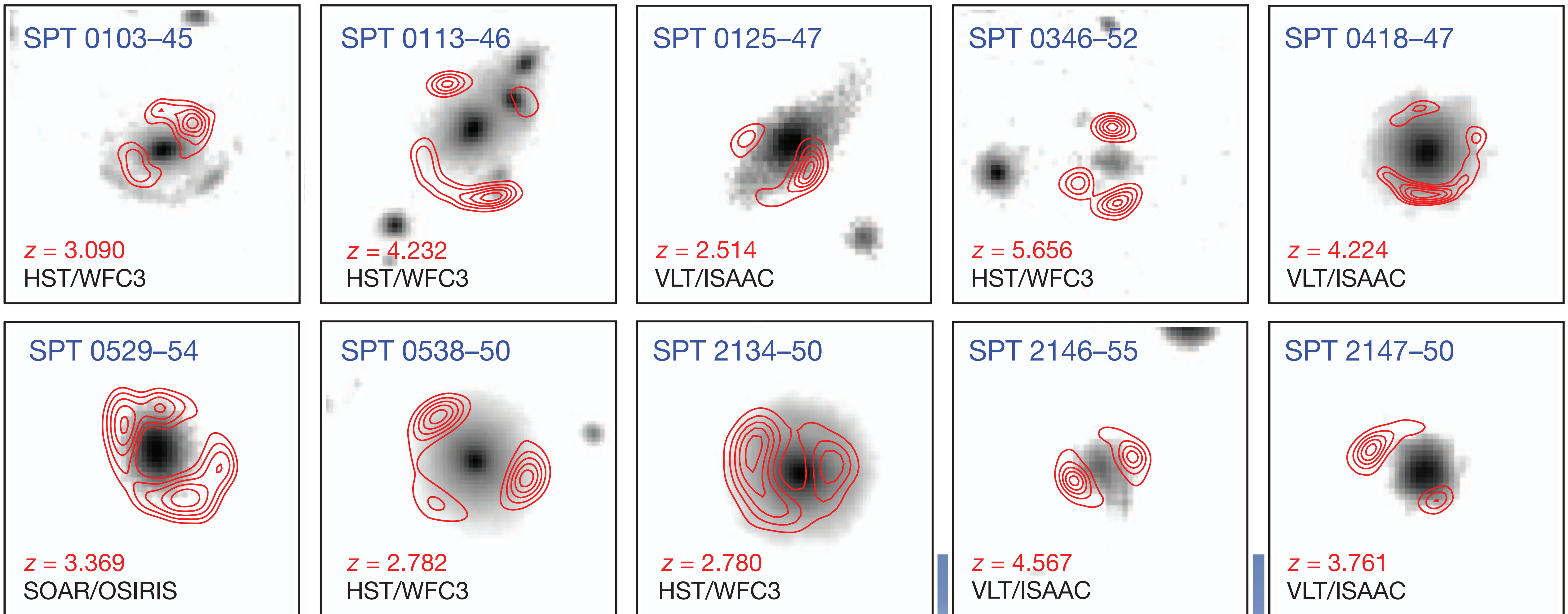


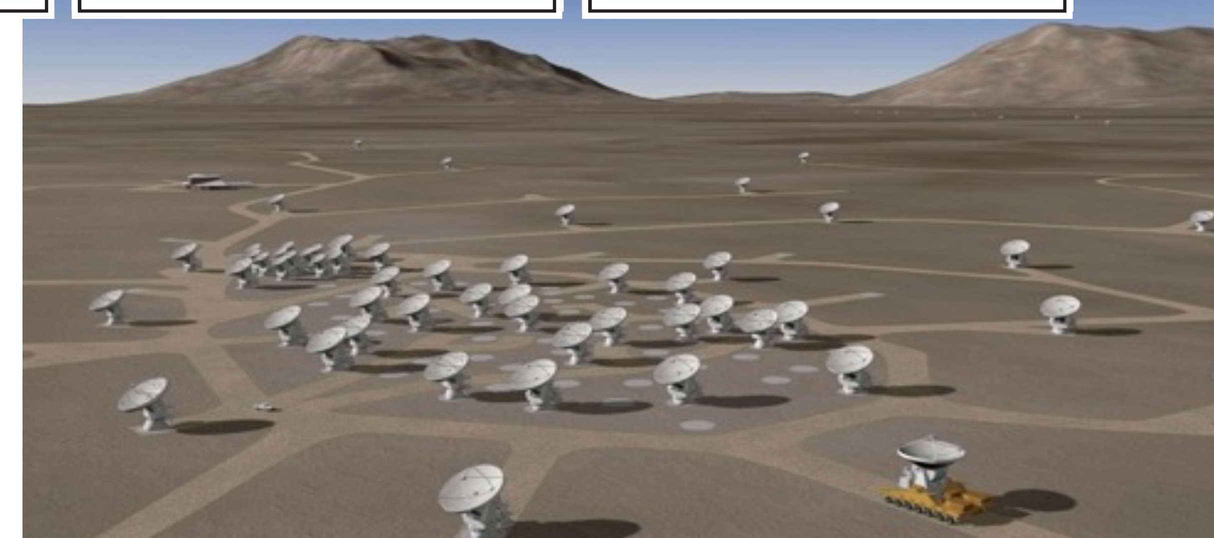




The first ALMA redshift survey

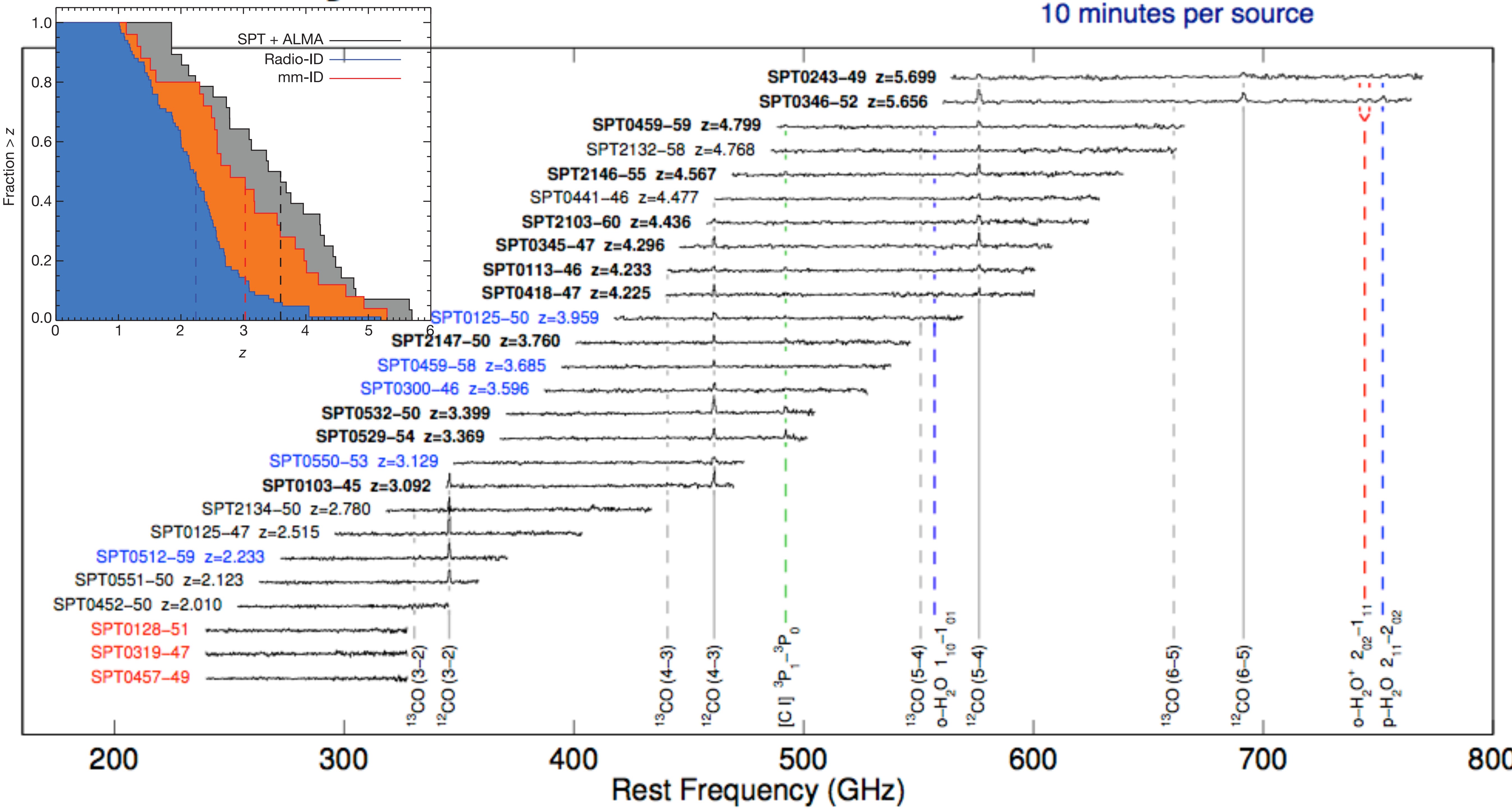
- SPT submillimetre galaxies; B3 spectral survey
  - Vieira et al. 2013; Weiss et al. 2013; …





First spectroscopic redshift survey with ALMA

ALMA Cycle 0 Band 3
100 GHz compact configuration
26 sources
5 tunings in the 3 mm band
10 minutes per source



Bold = unambiguous redshift from ALMA

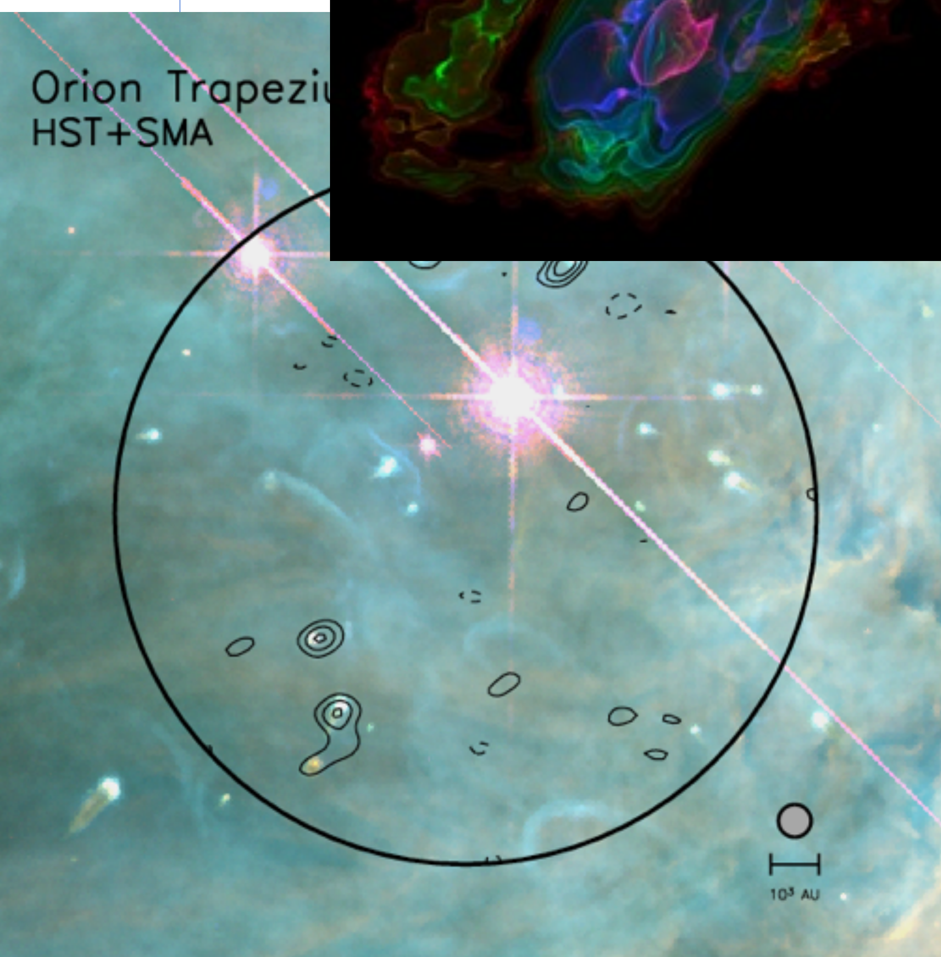
black = single lines with ALMA, confirmed with C+ or CO(1-0) with APEX or ATCA

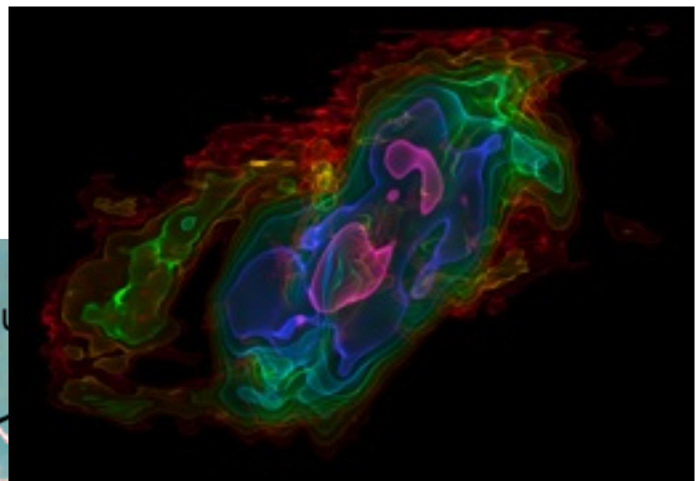
blue = single line detected with redshift, most likely redshift from photo-z

red = no line detected

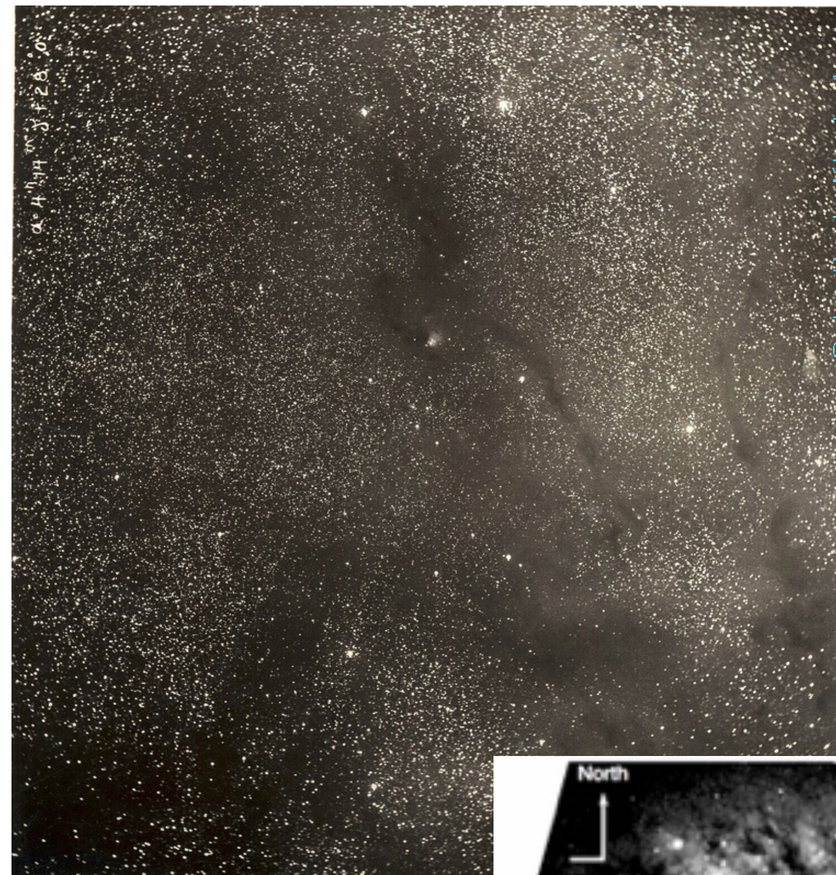
Starbursts and AGN

- AGN fueling and feedback
- Star formation feedback

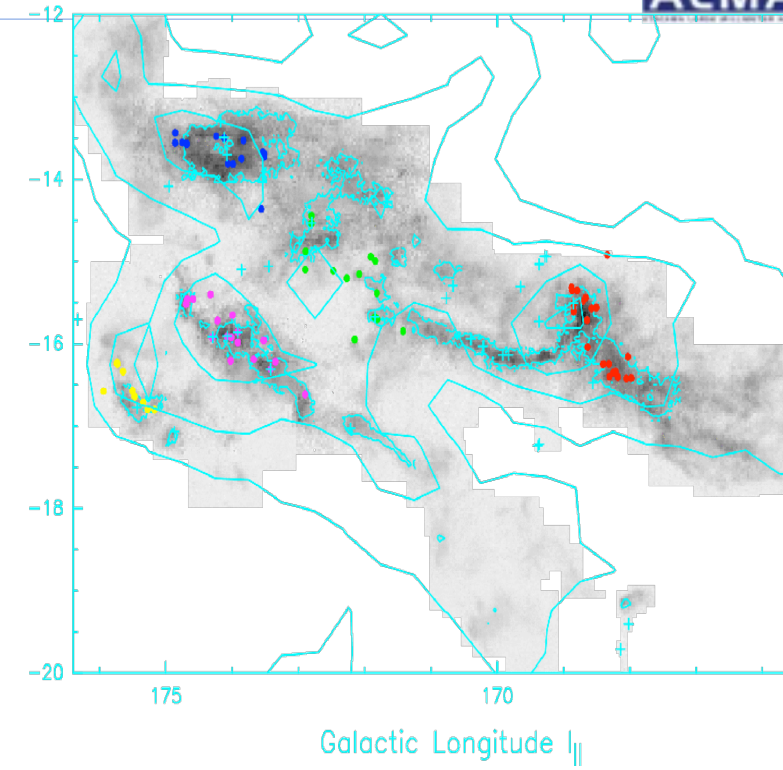




(Bolatto et al. 2013)

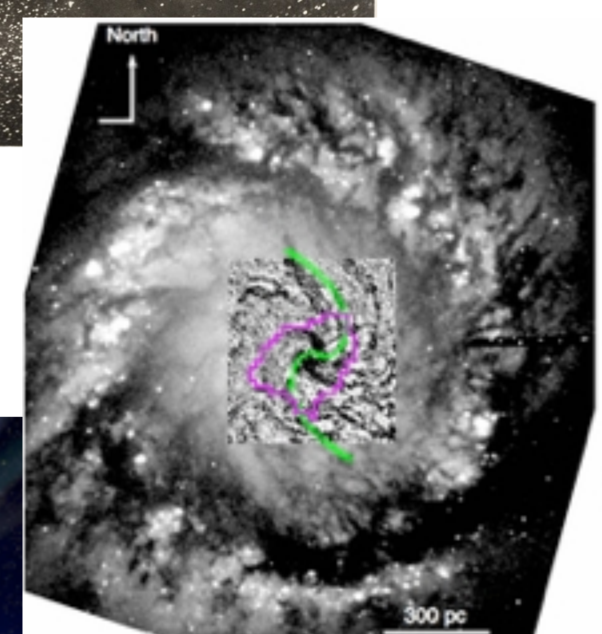


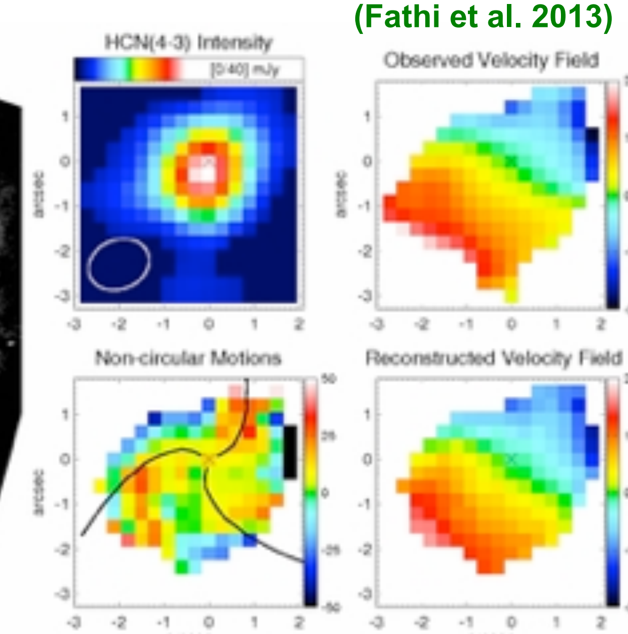
(Combes et al. 2013)

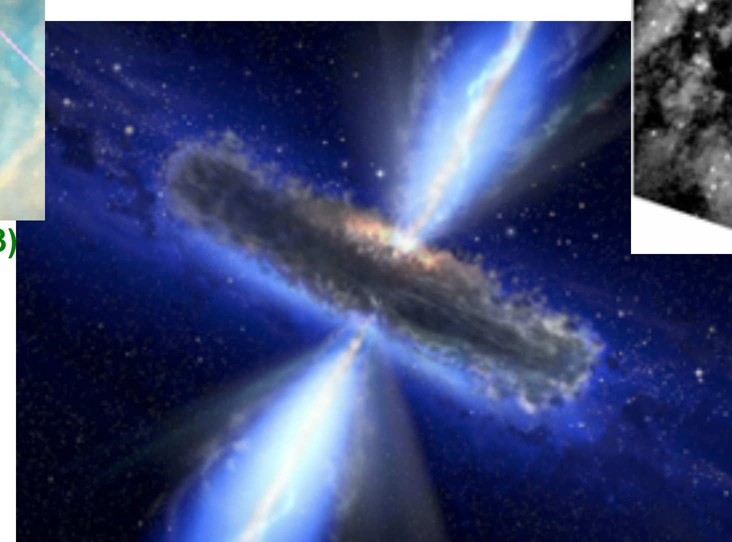


(Garcia Burillo et al. 2014)

(Fathi et al. 2013)

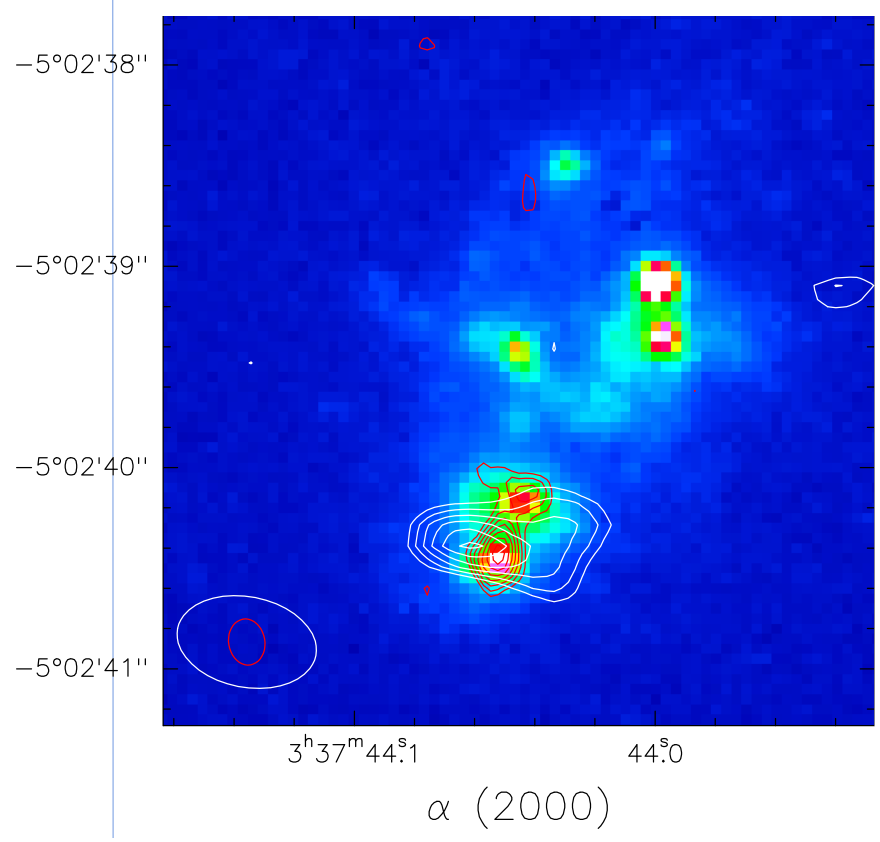




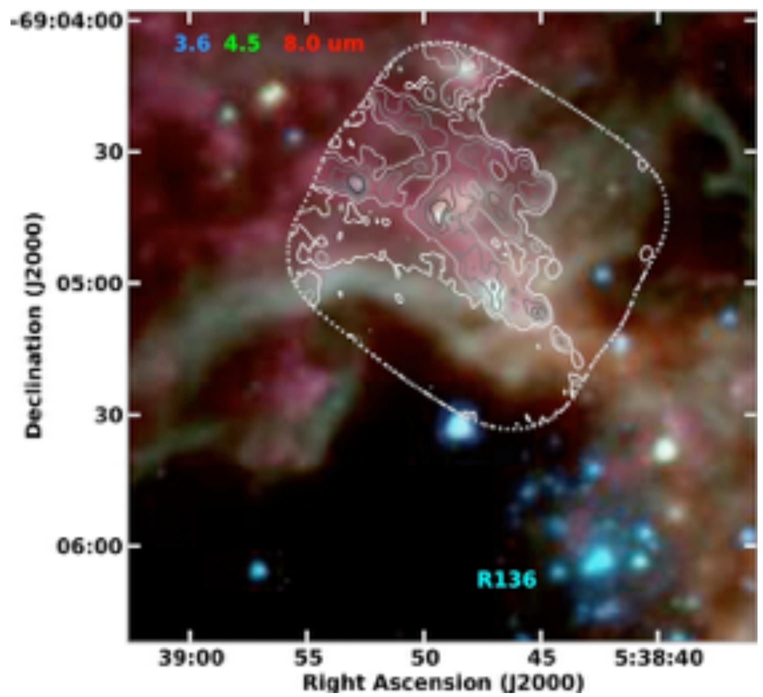


Chemistry and structure of the ISM

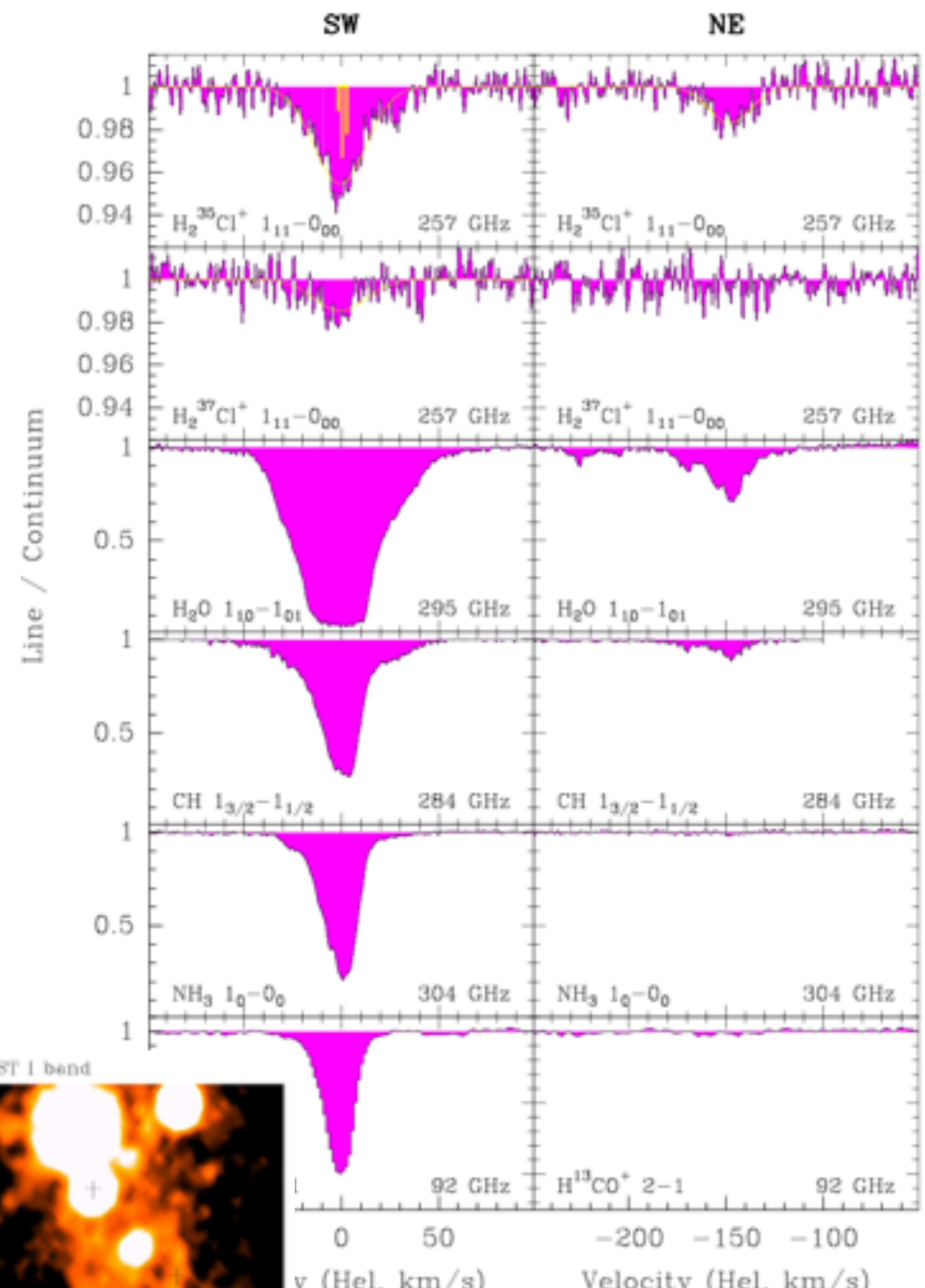
- Detailed analysis of extragalactic ISM

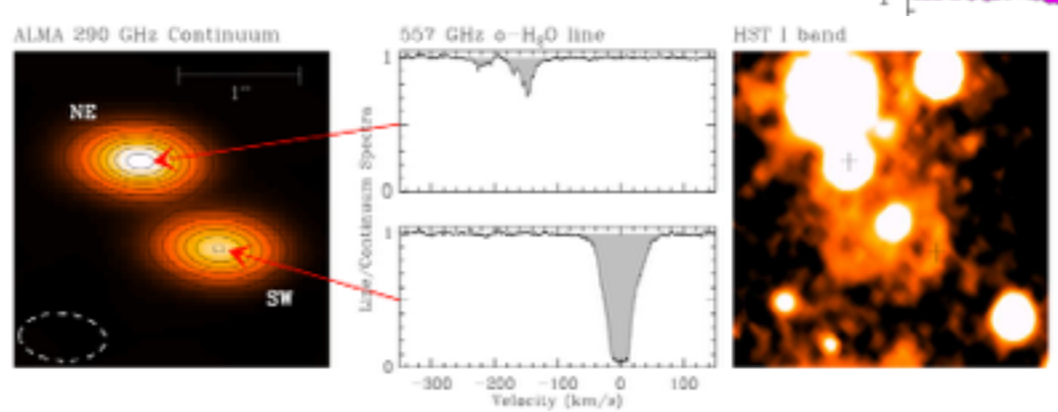


(Hunt et al. 2013)

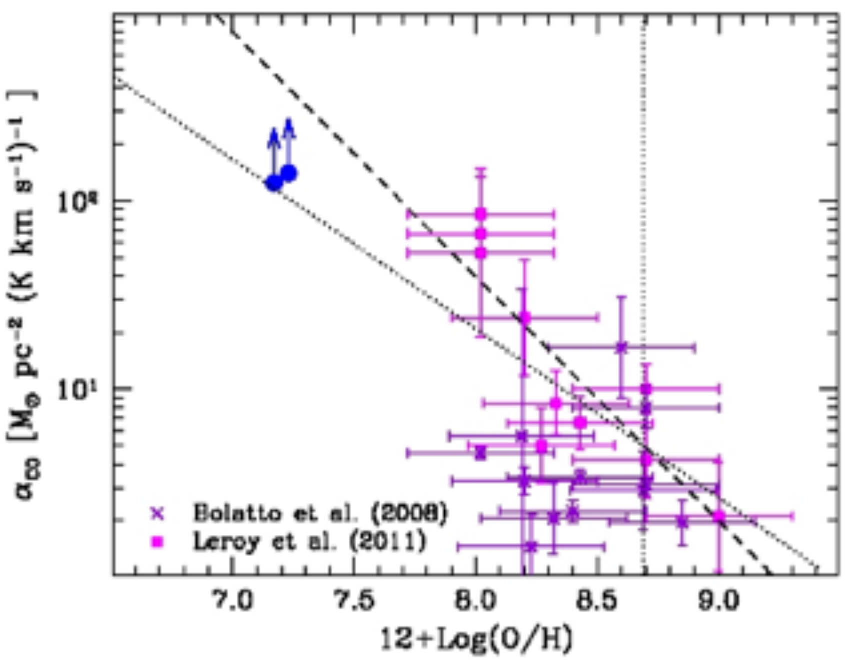


(Indebetouw et al. 2013)



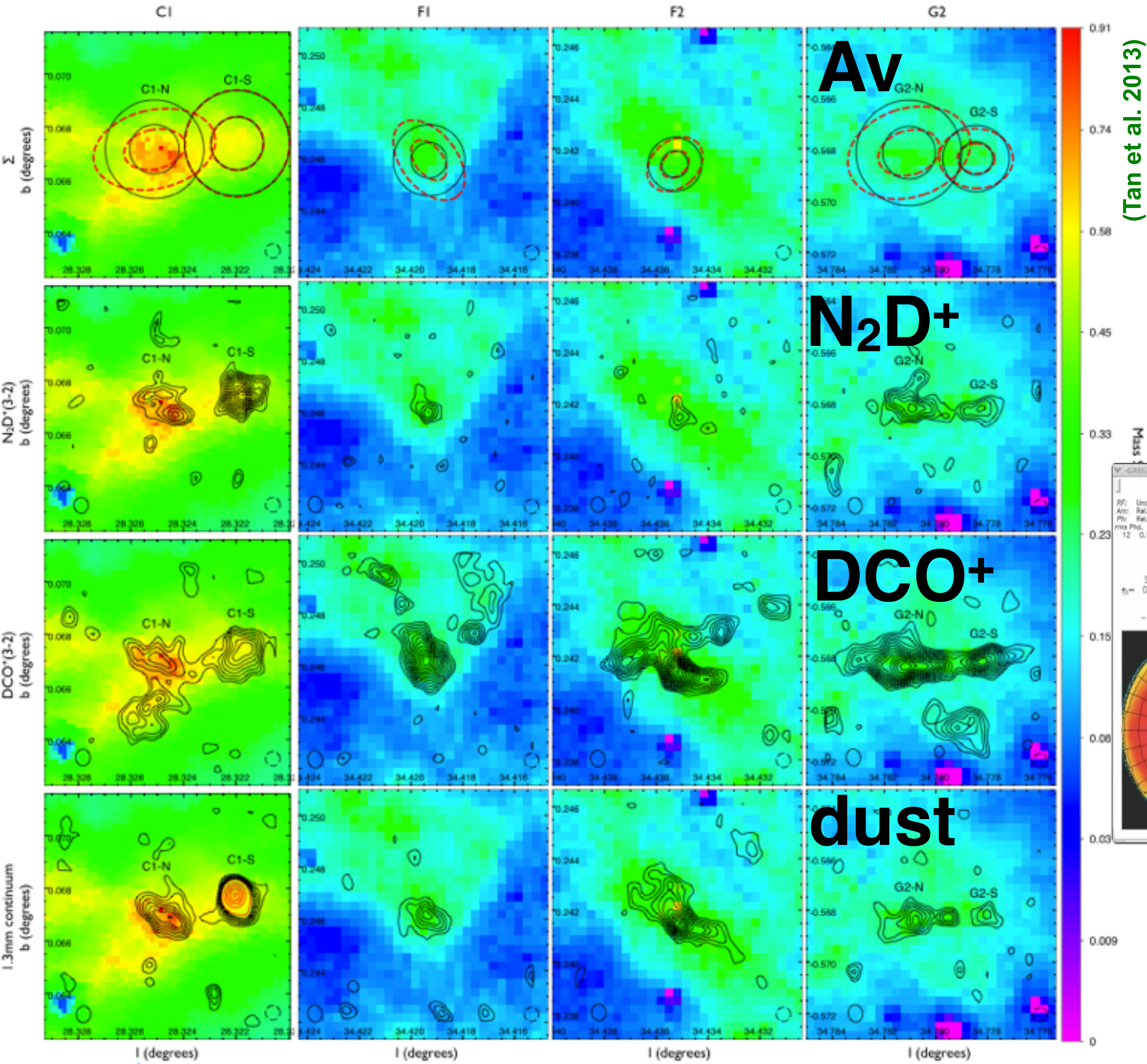


(Mueller et al. 2014)



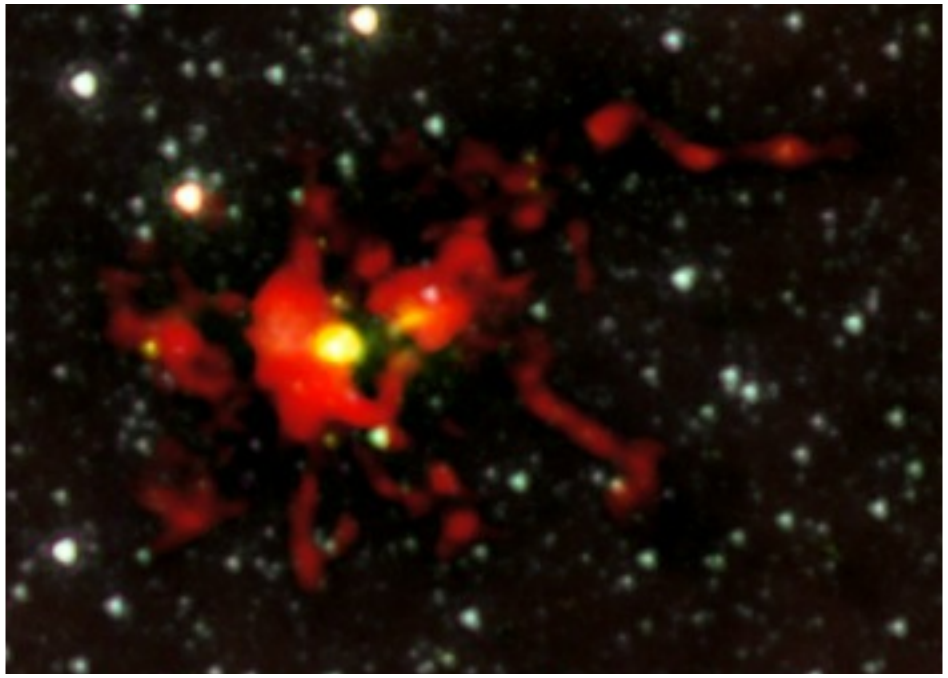
High mass star formation

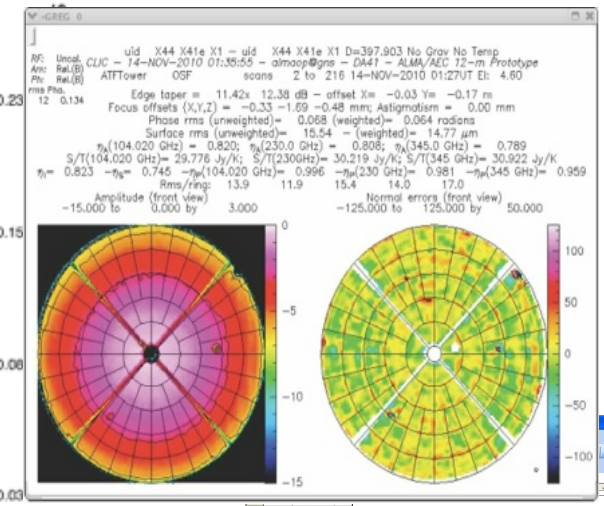
- From filaments to clouds and stars

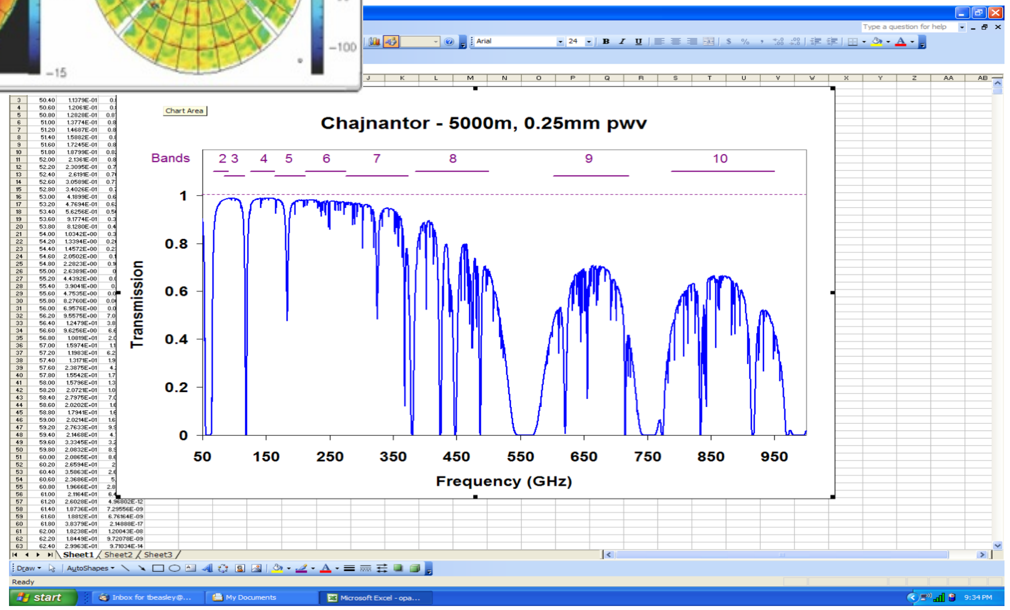


(Tan et al. 2013)

(Peretto et al. 2013)





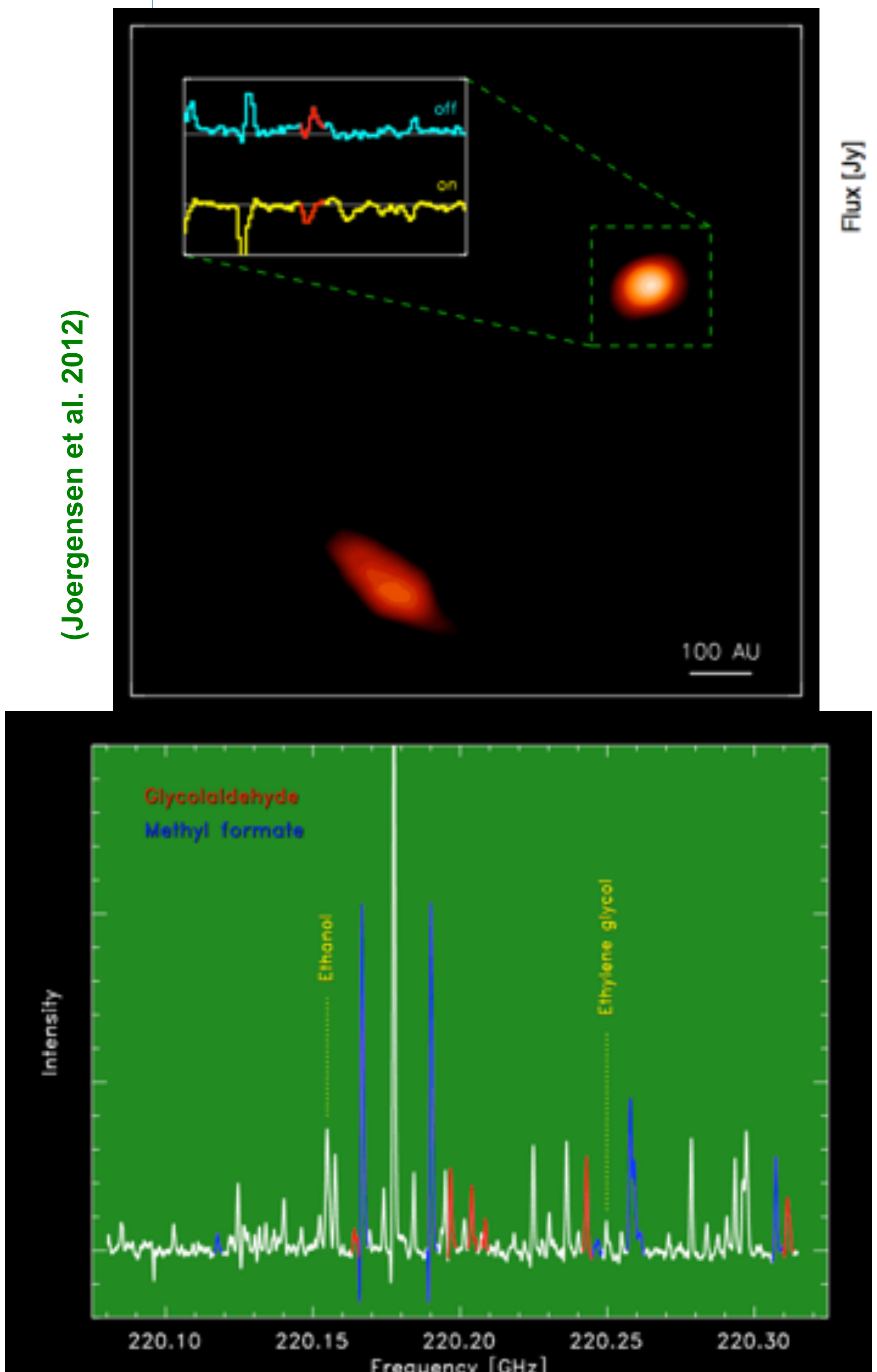


(Sanchez-Monge et al. 2013)

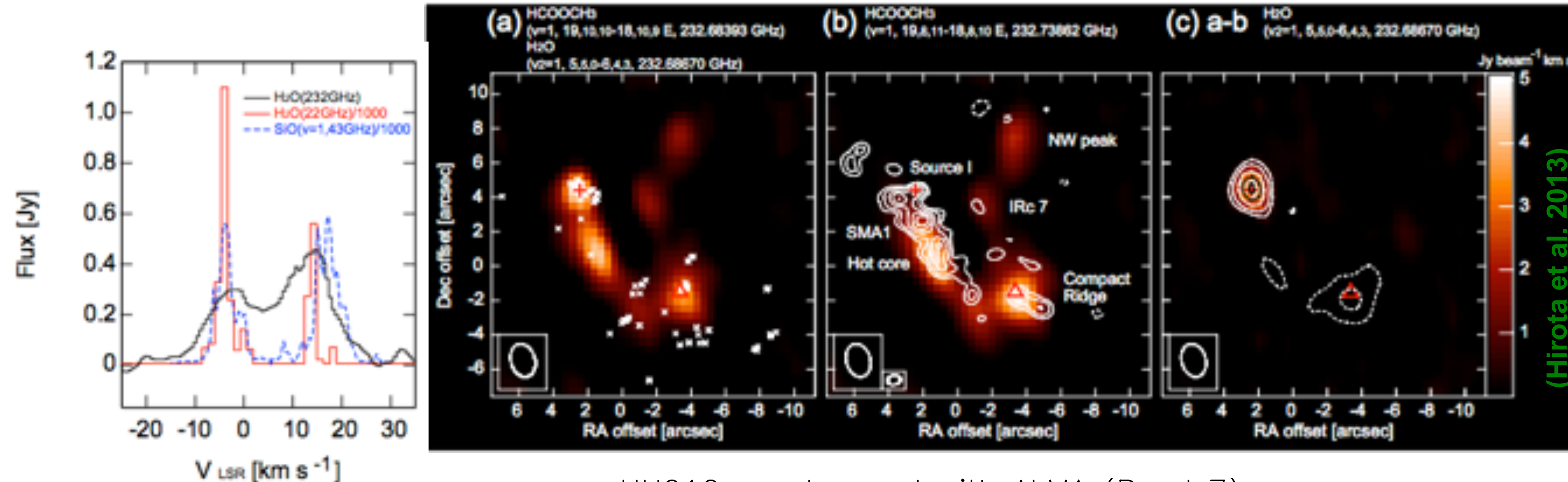
Leonardo Testi: ALMA, Bologna 2014

Complex organic molecules

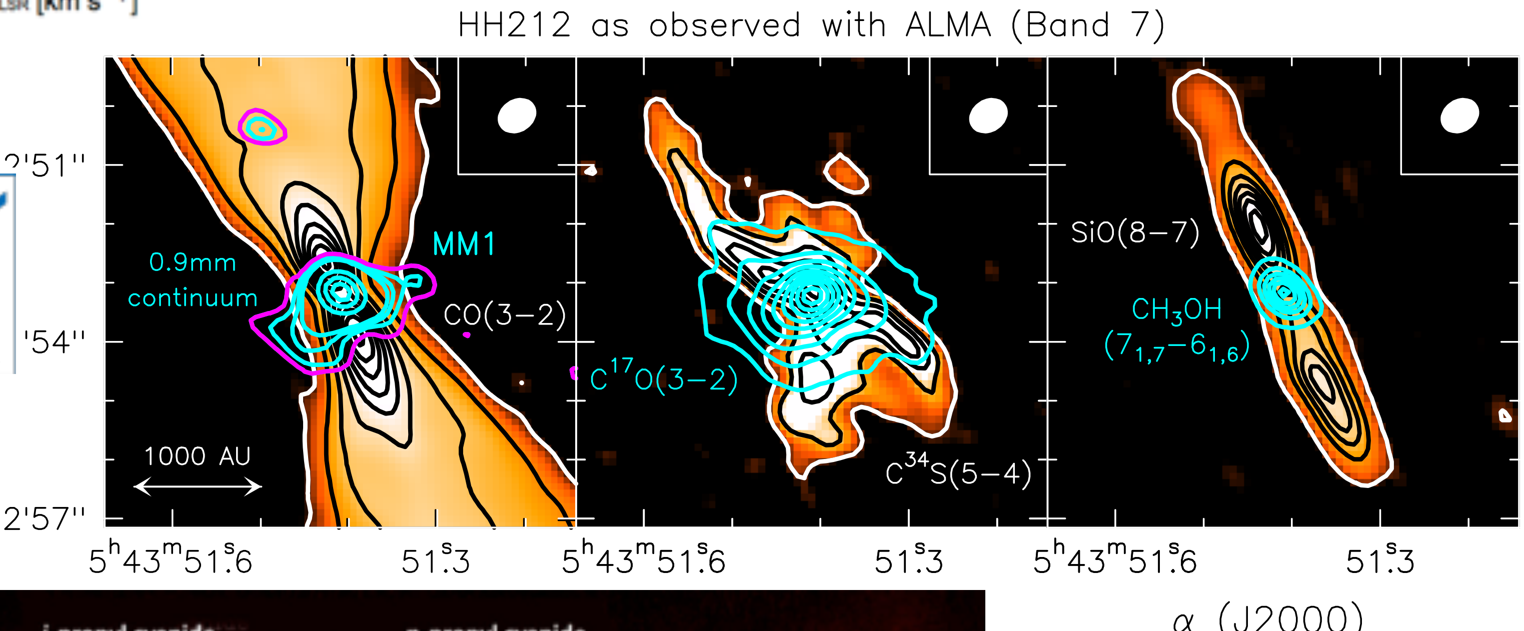
- Complex organic molecules in young solar analogs



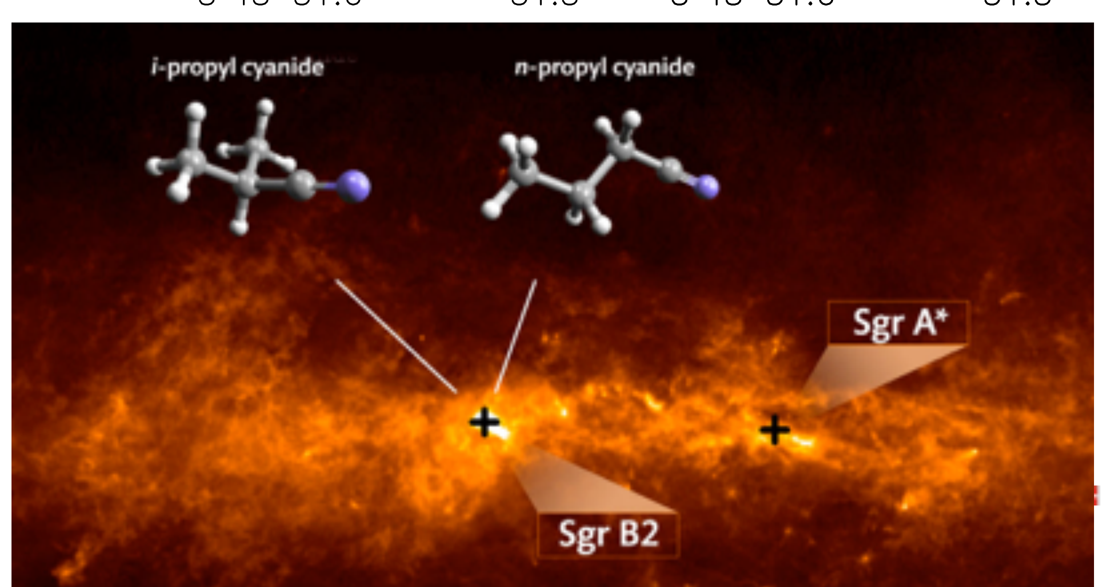
(Joergensen et al. 2012)



(Hirota et al. 2013)

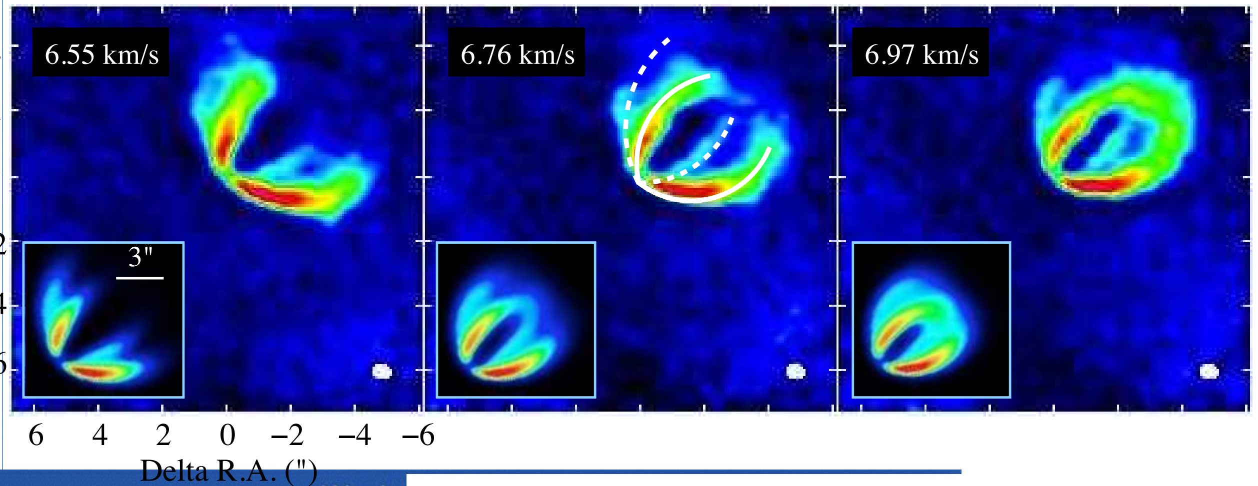


(Codella et al. 2014)

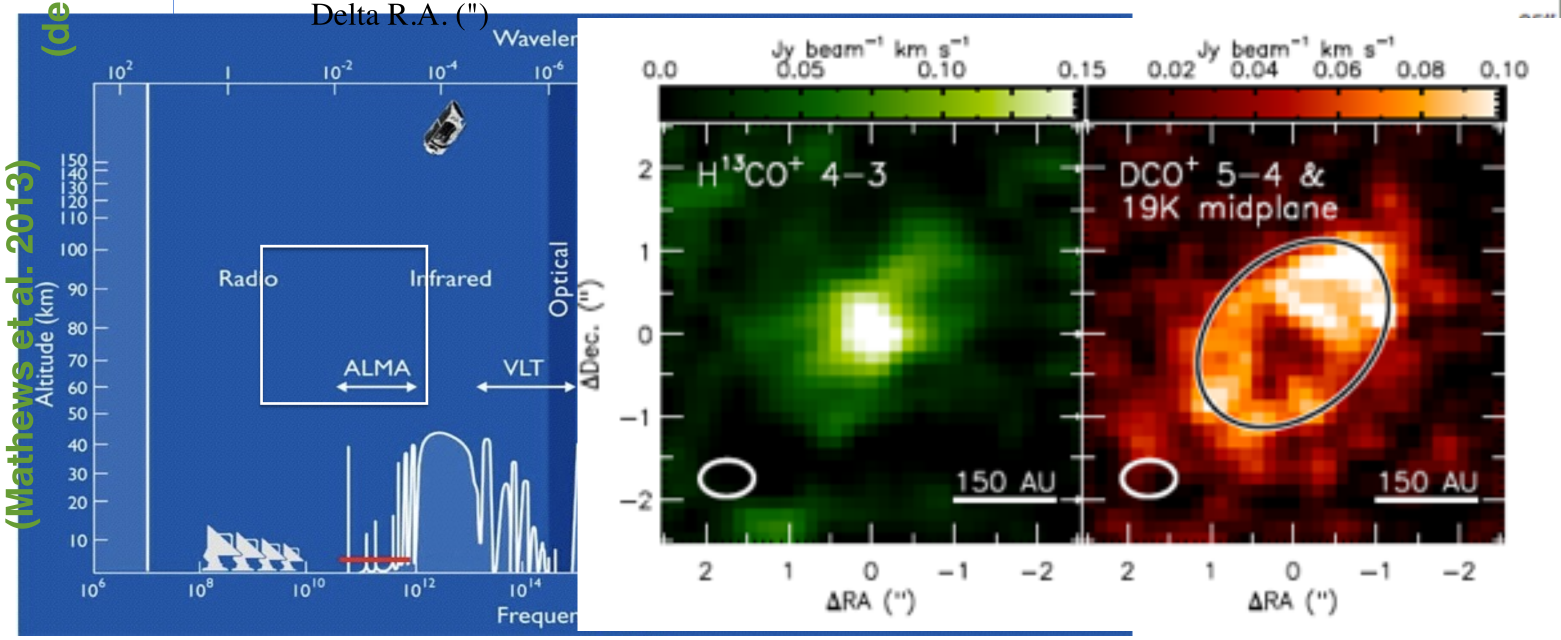


Protoplanetary disks: chemistry

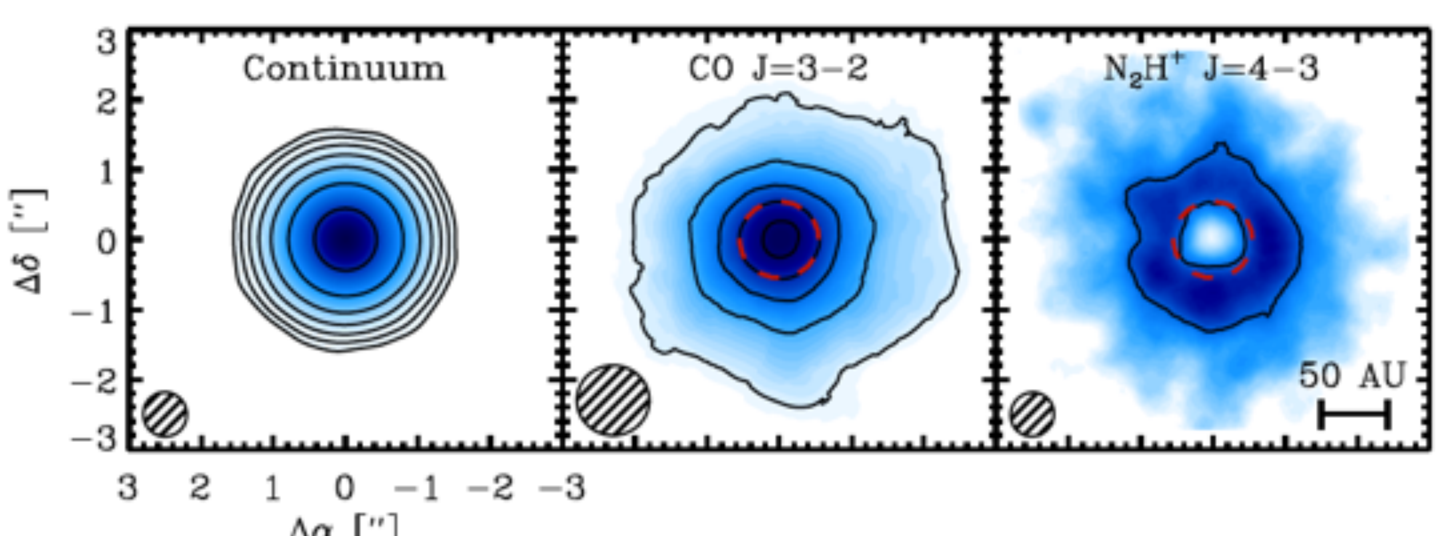
- Sharp chemical transitions and snow lines



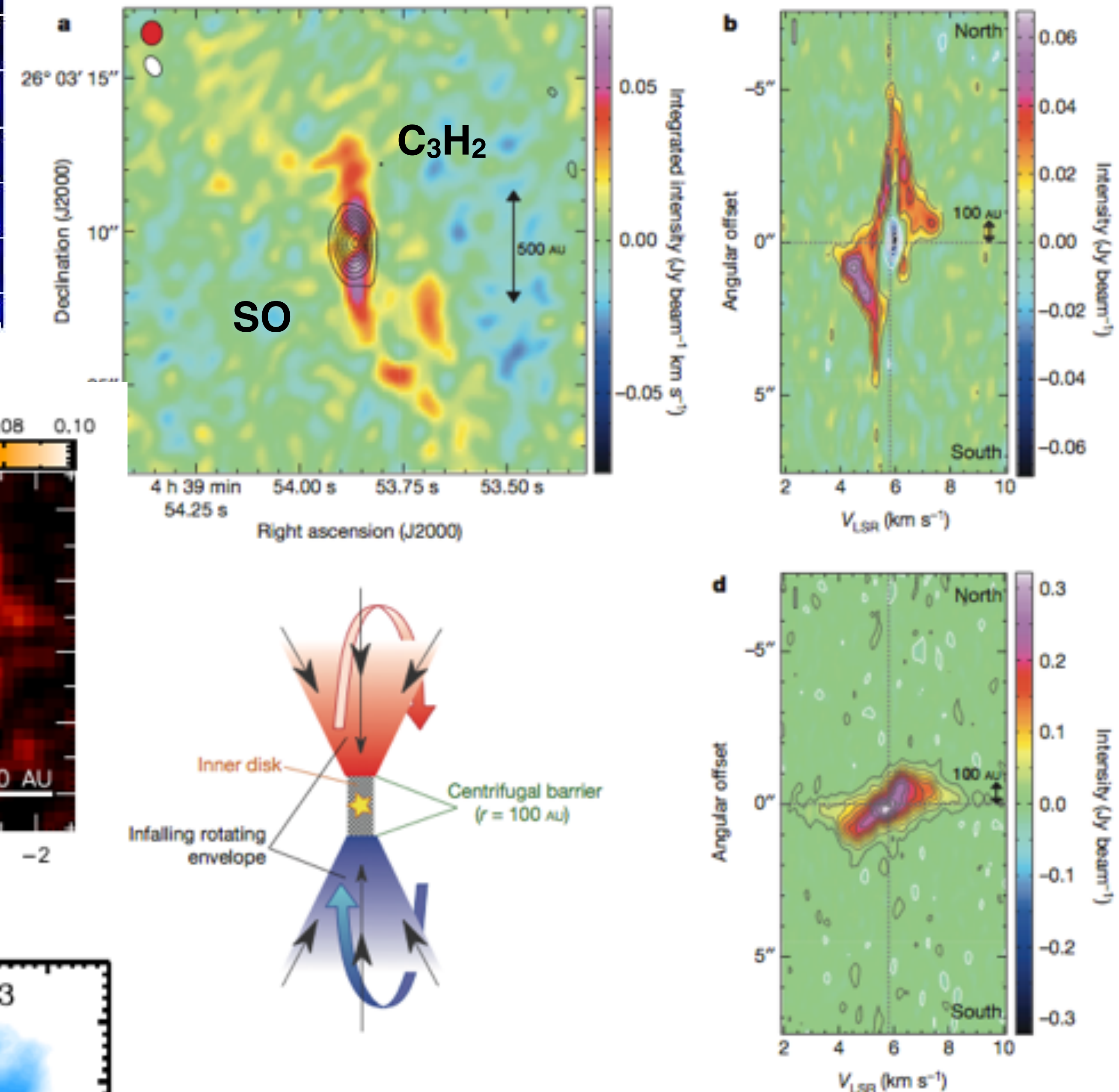
(de Gregorio Monsalvo et al. 2013)



(Mathews et al. 2013)



(Qi et al. 2013)

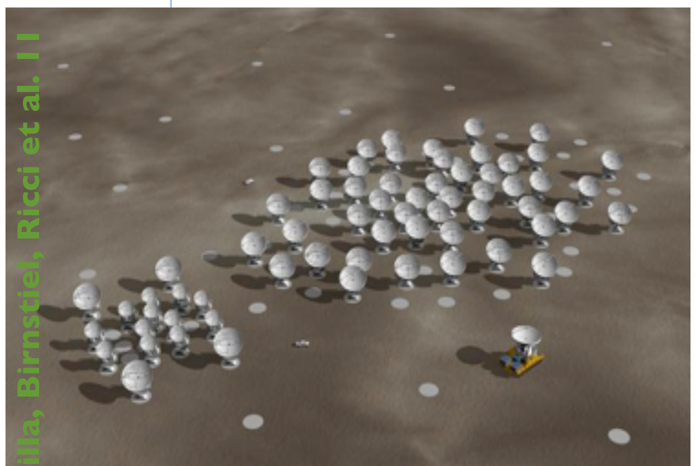


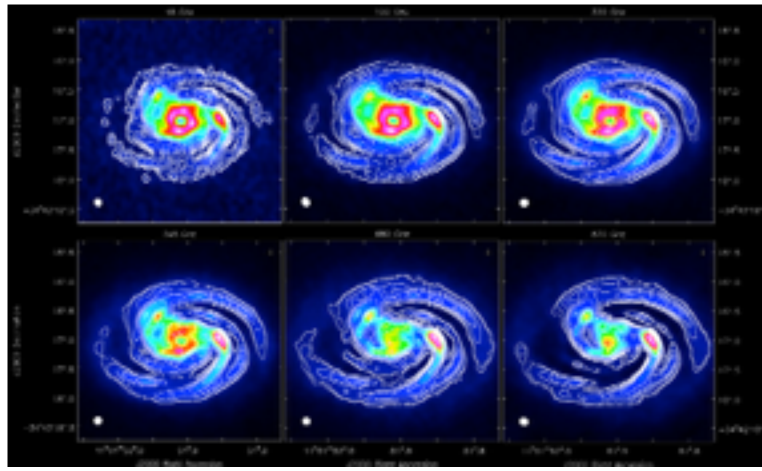
(Sakai et al. 2014)

Protoplanetary disks: planet formation

- Assembly of solids and disk-planet interaction

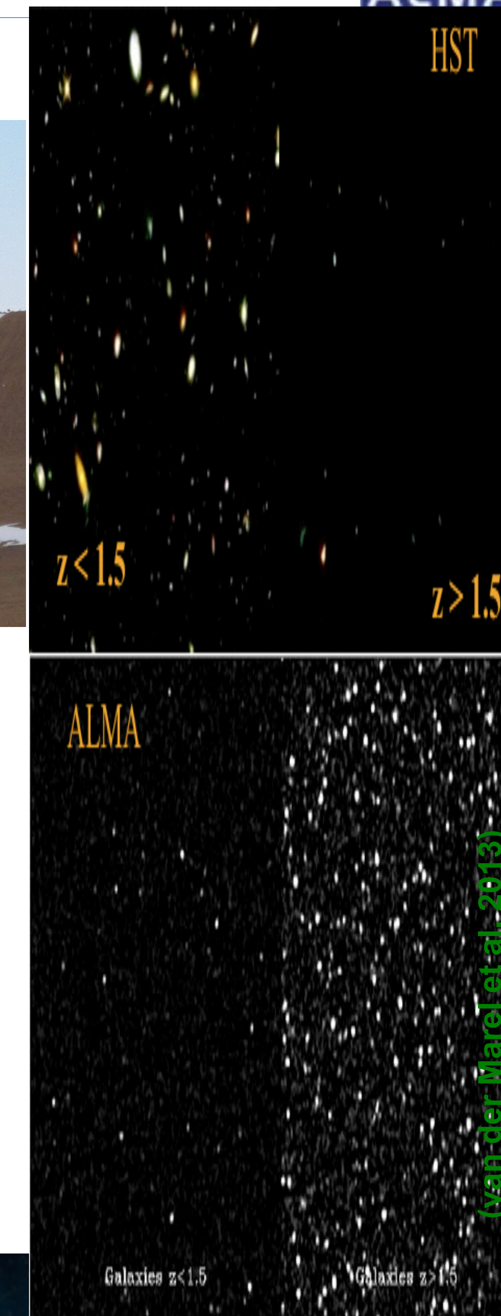
(Pinilla, Birnstiel, Ricci et al. 11)





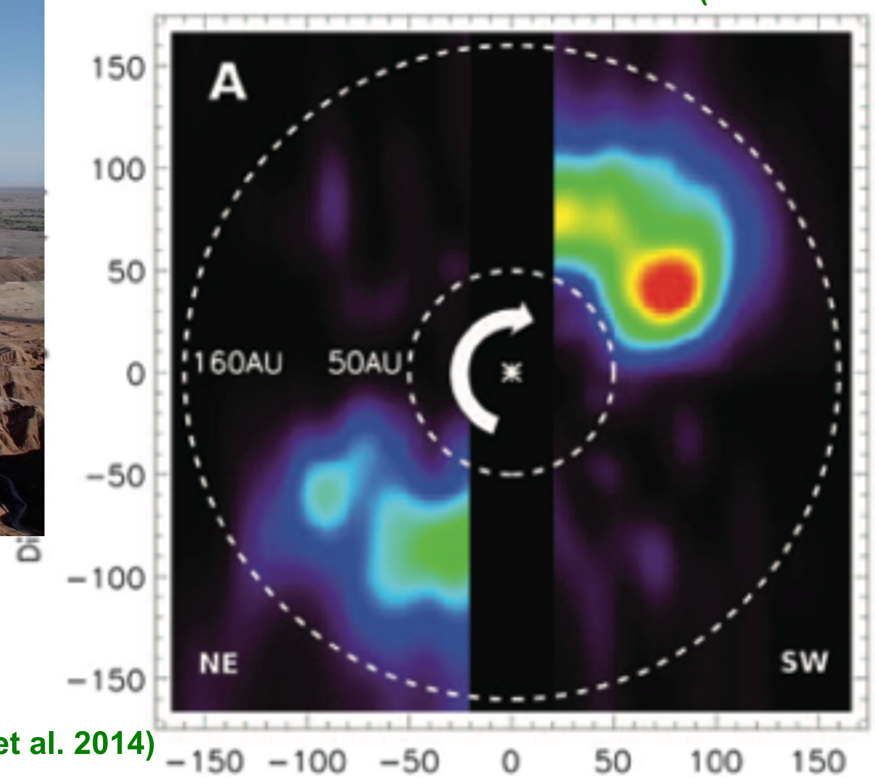
(Cossins, Lodato, Testi 2010; Dipierro, Lodato, Testi 2014)

(Ricci et al. 2013, 2014)



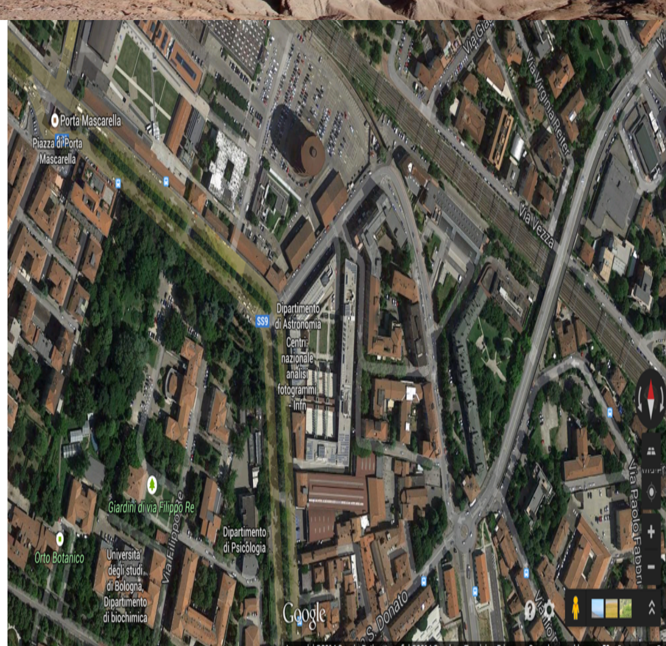
(van der Marel et al. 2013)

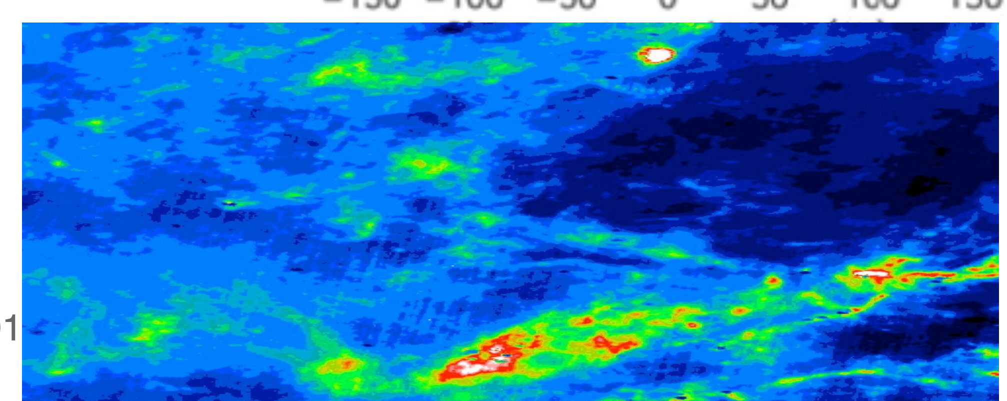
(Fukagawa et al. 2013)

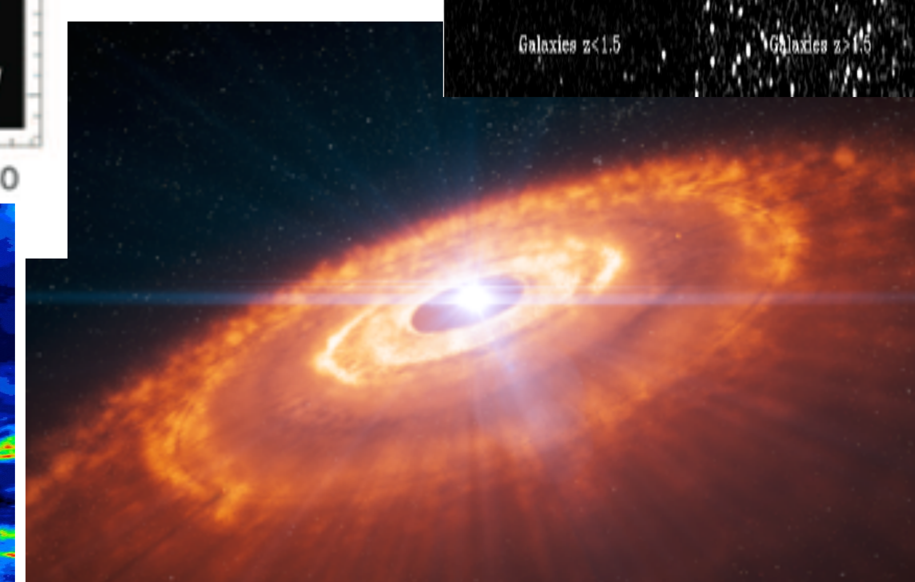


(Dent et al. 2014)

(Casassus et al. 2013)



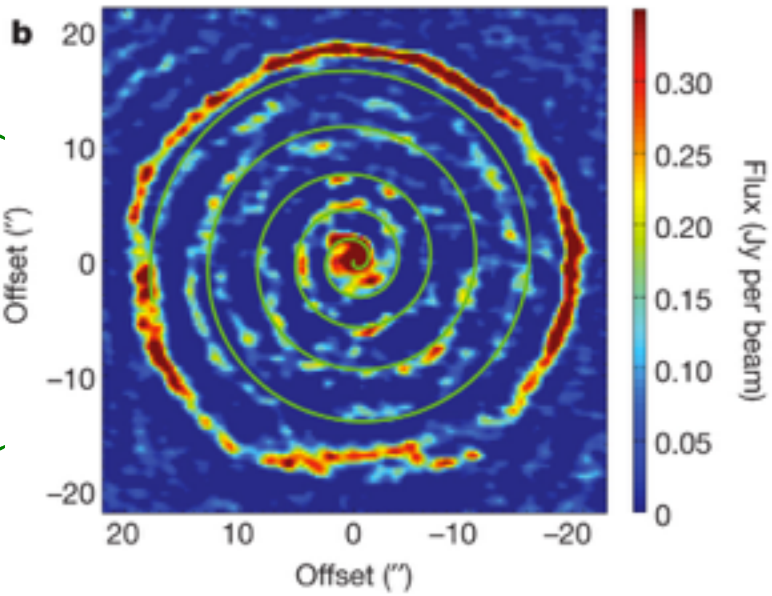




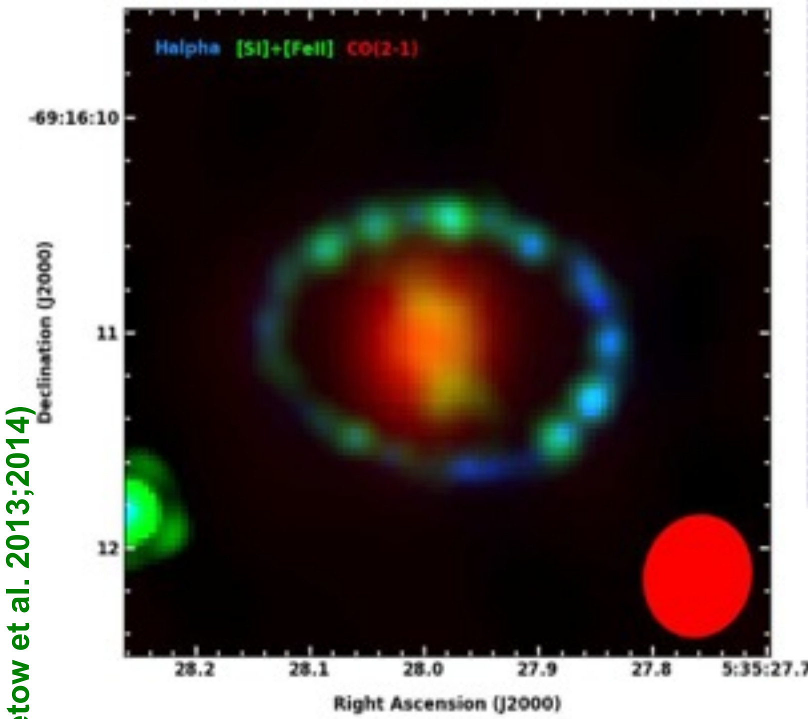
Enrichment of the ISM

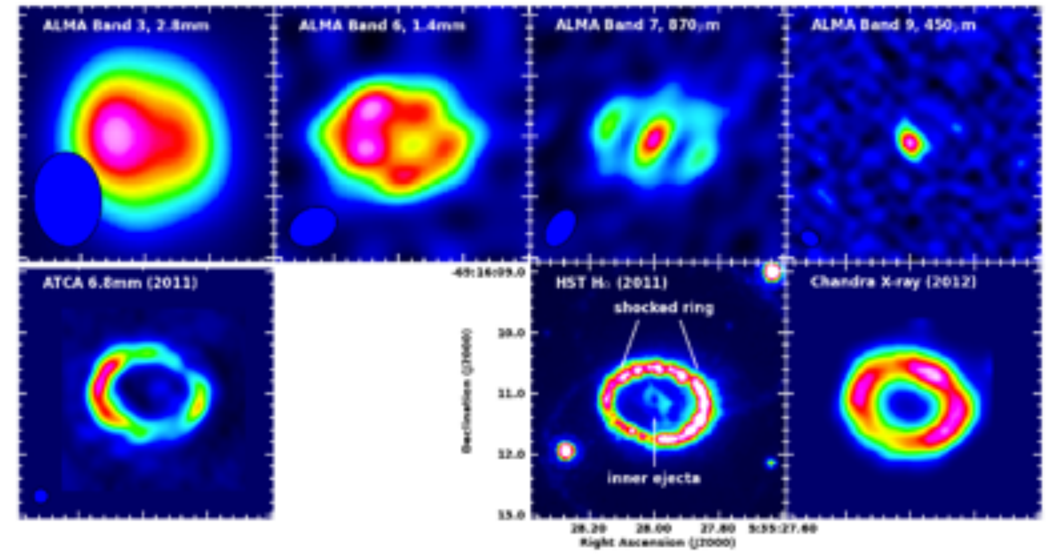
- Late stages of stellar evolution, supernovae, GRBs

(Maercker et al. 2012)

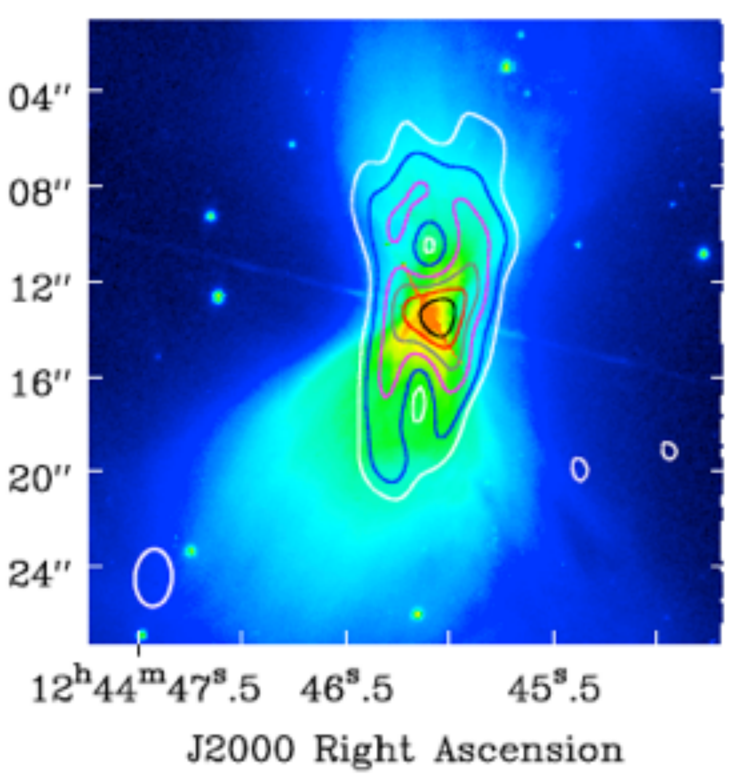


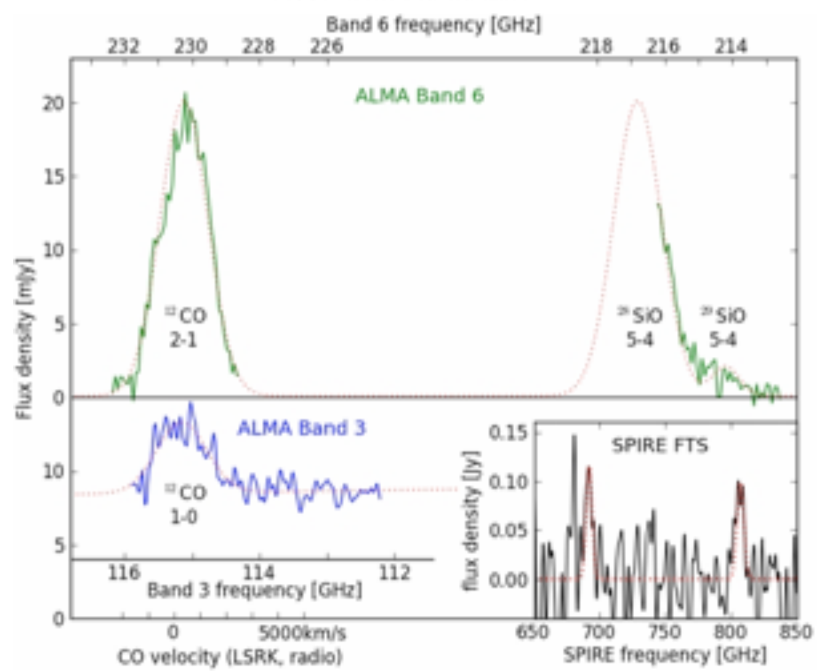
(Kamenetzky et al. 2013; Indebetow et al. 2013;2014)



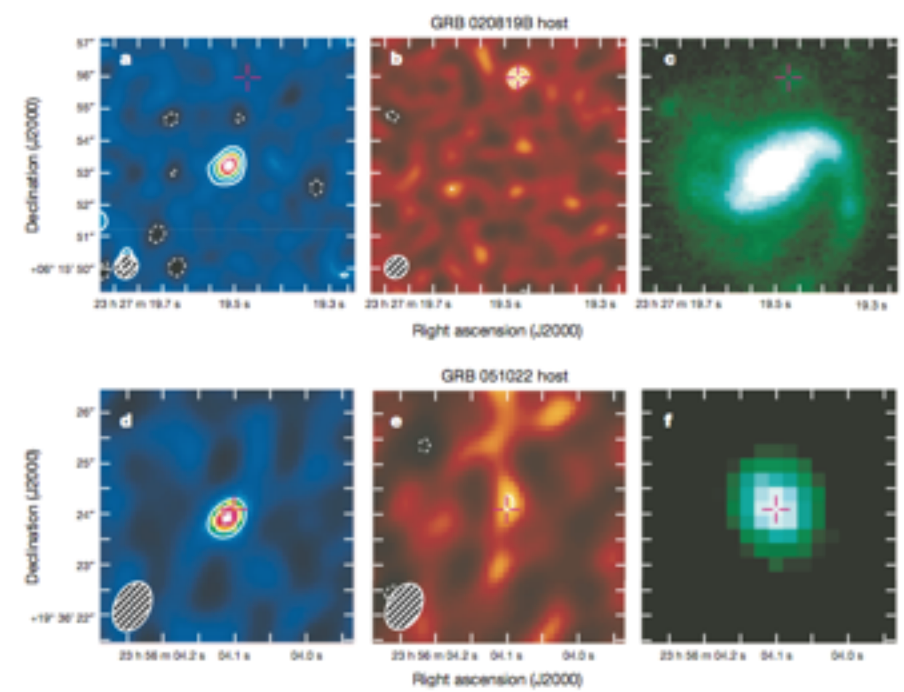


(Sahai et al. 2013)



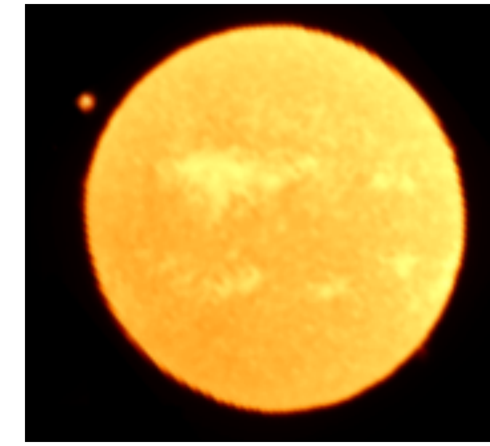


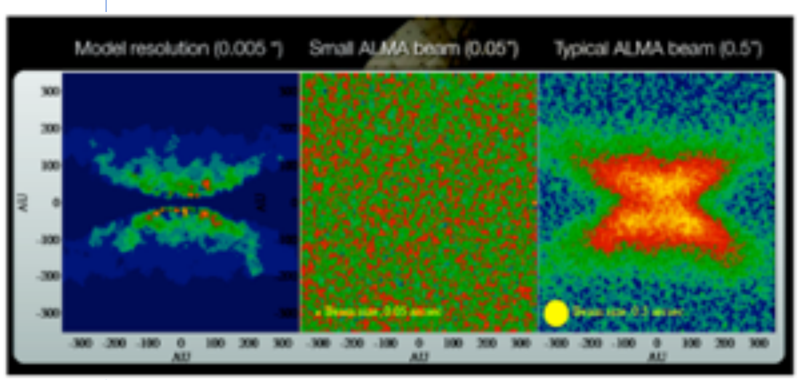
(Hatsukade et al. 2014)



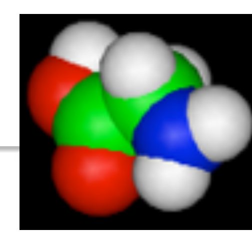
Science Priorities for the Future

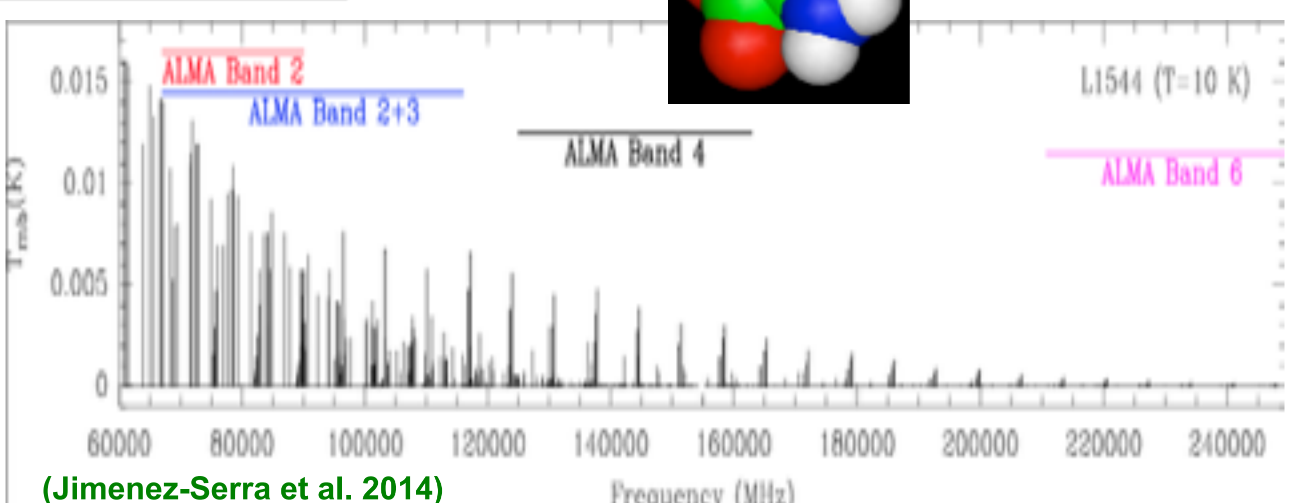
- Resolve planet formation in protoplanetary disks
  - ➢ Full sensitivity (antennas) and angular resolution (baselines)
- Statistical census of Star Formation at high-z
  - ➢ Full sensitivity, efficient spectral scans
- Chemistry of Complex Organic Molecules and Water
  - ➢ Full sensitivity, full frequency coverage, spectral flexibility
- Resolve Event Horizon of Supermassive Black Holes
  - ➢ Full sensitivity, mmVLBI



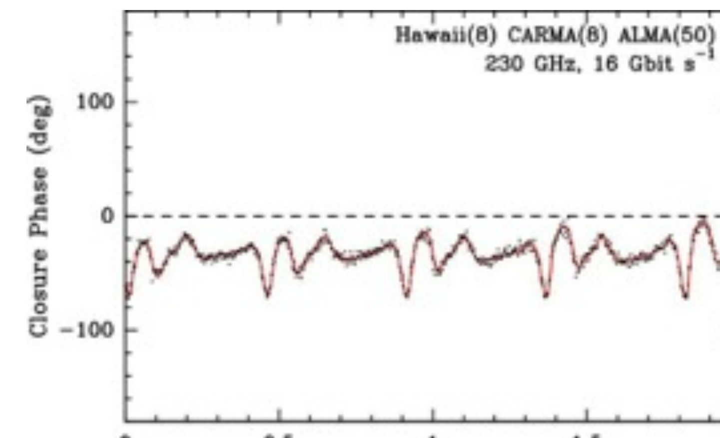


(Brinch et al. 2012)





(Jimenez-Serra et al. 2014)

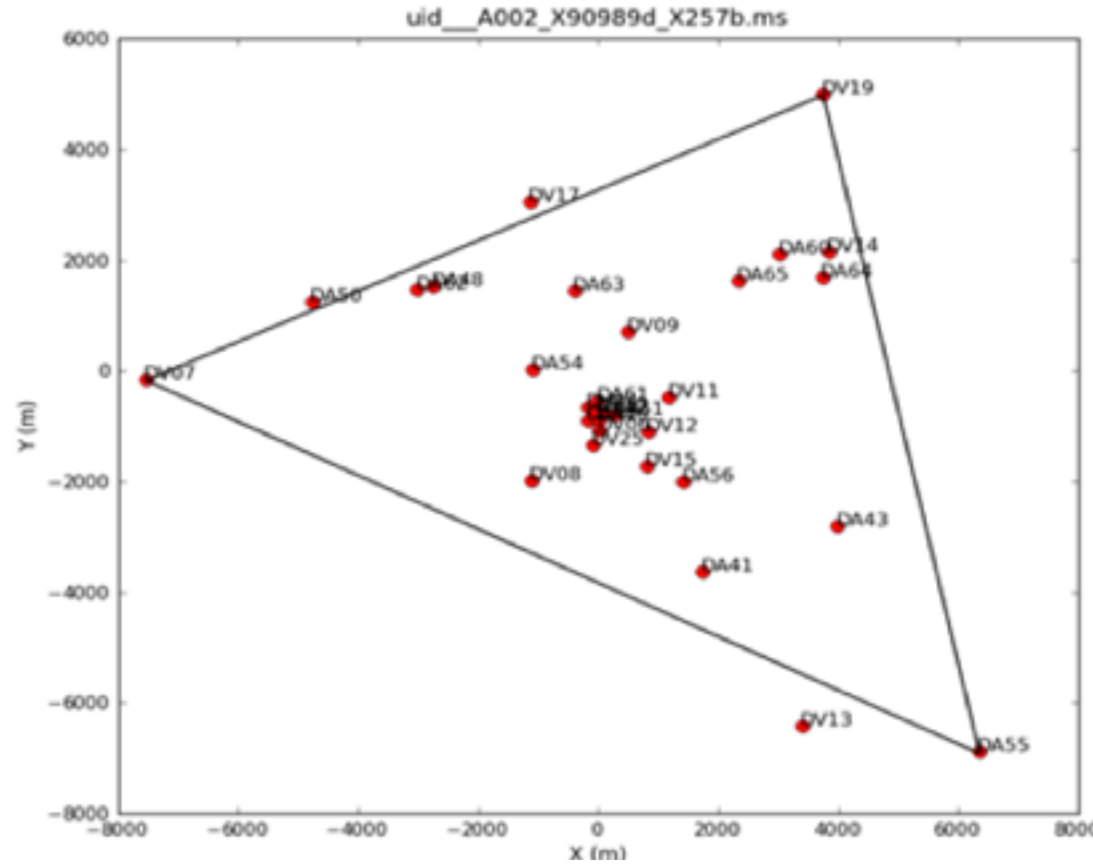


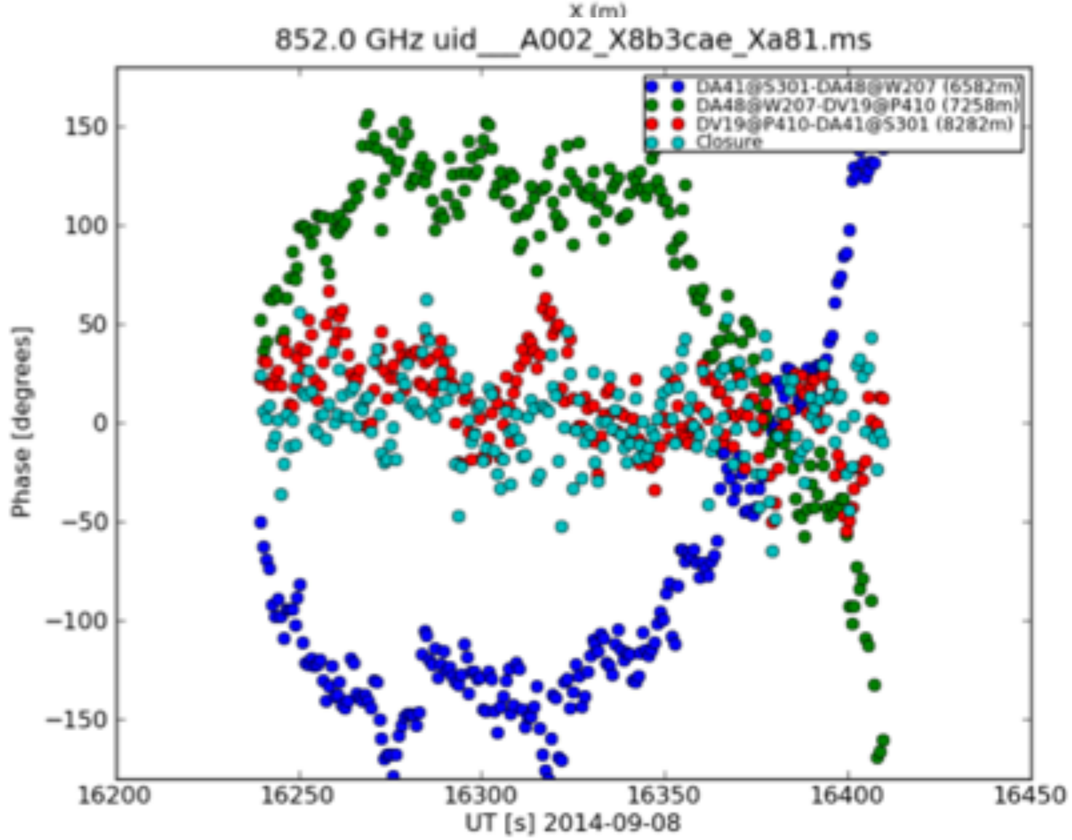
(Doleman et al. EHT project)


(Rigoupolou et al. 2014)

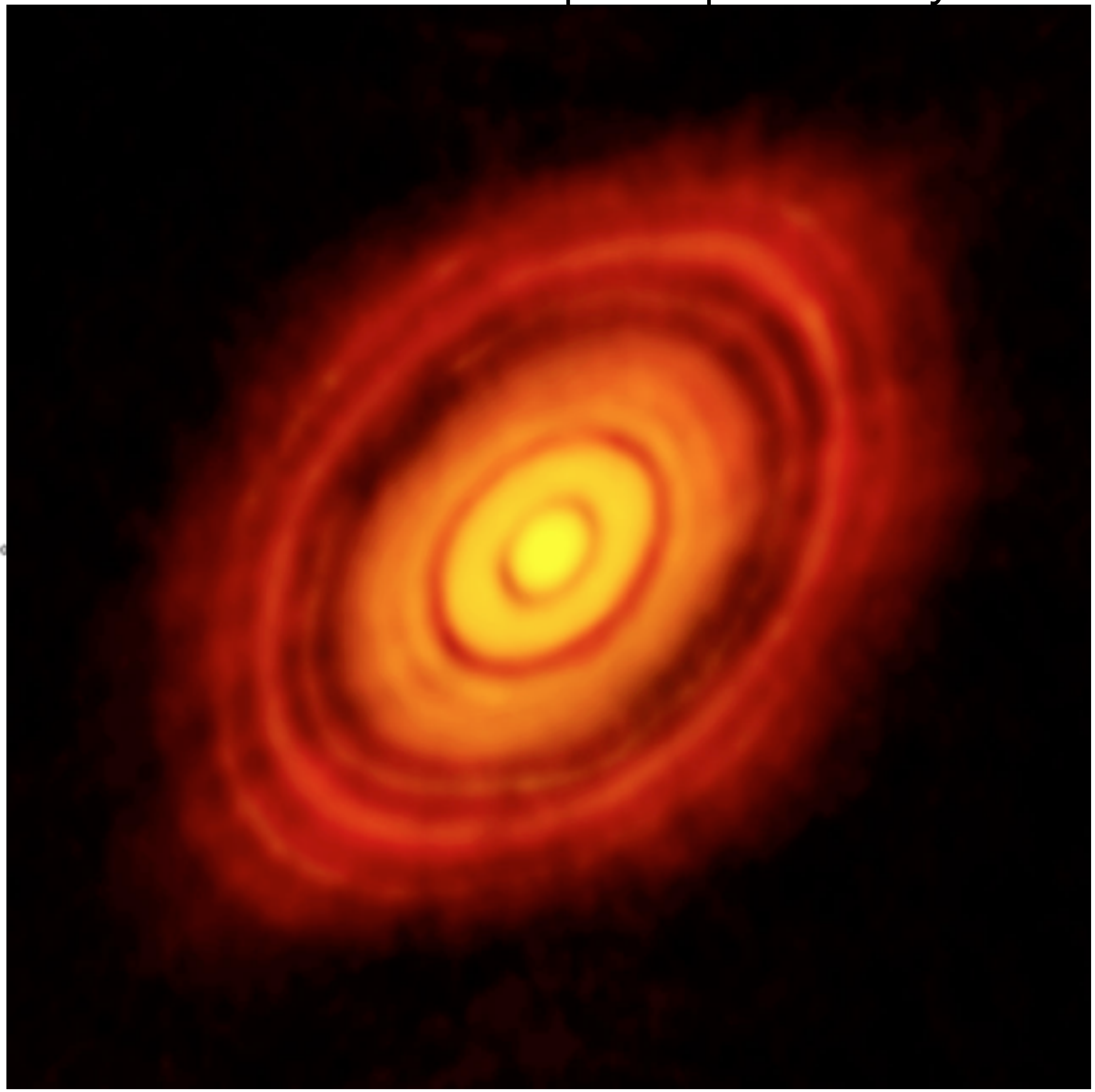
A glimpse to ALMA future capabilities

- Long Baselines Campaign - Sep-Nov 2014

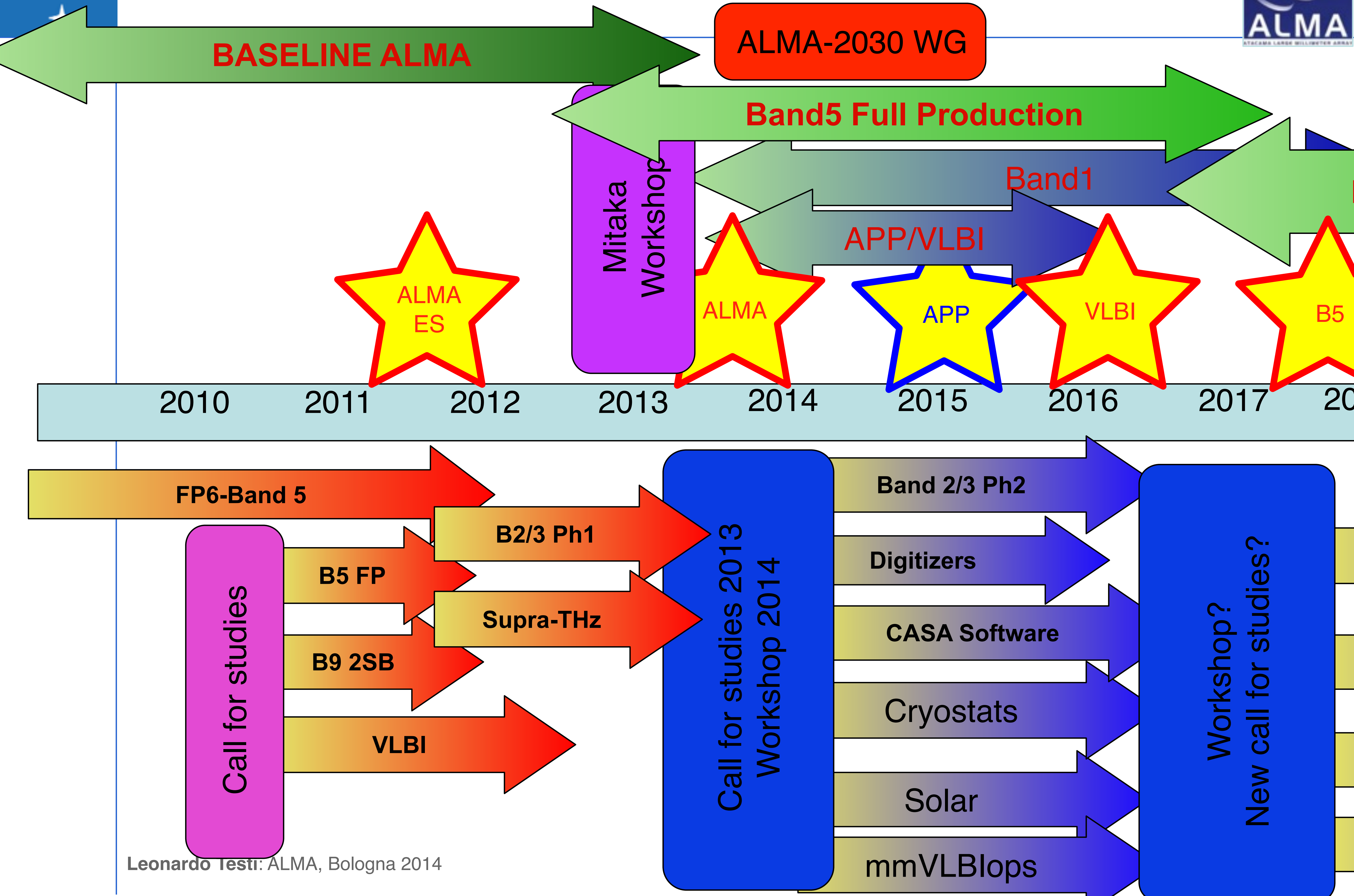




HL Tau protoplanetary disk



Timeline summary



iALMA

- Progetti Premiali 2012 - Sviluppo infrastruttura italiana di supporto a ALMA

- i+something=iSomething

- i(nstant) S(uccess)

  (© E. Bressert)

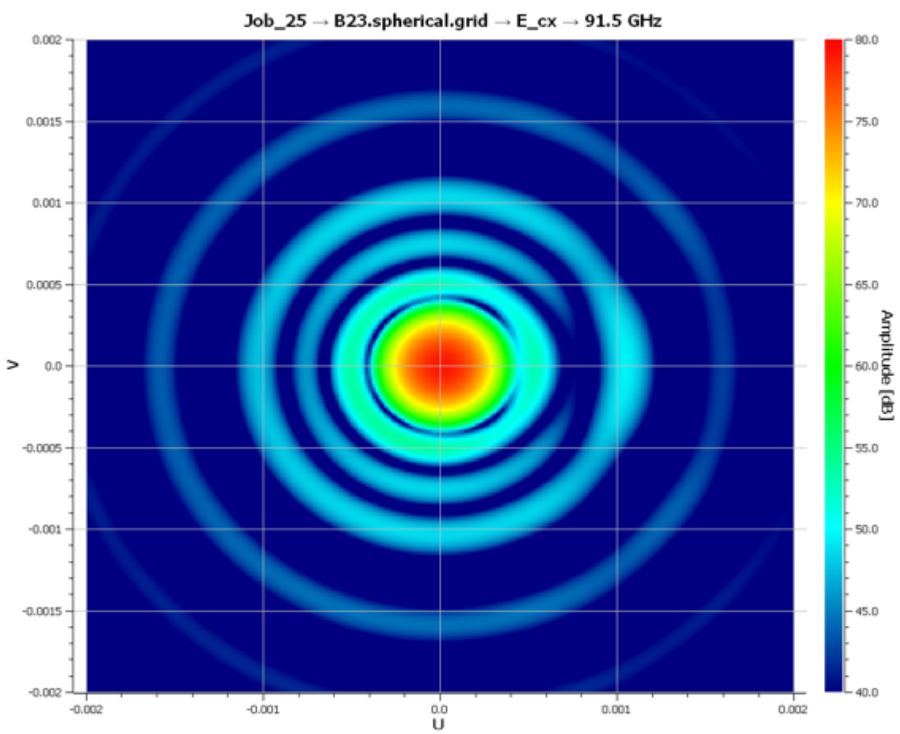
Science and Technology in Italy for the upgraded ALMA Observatory - iALMA

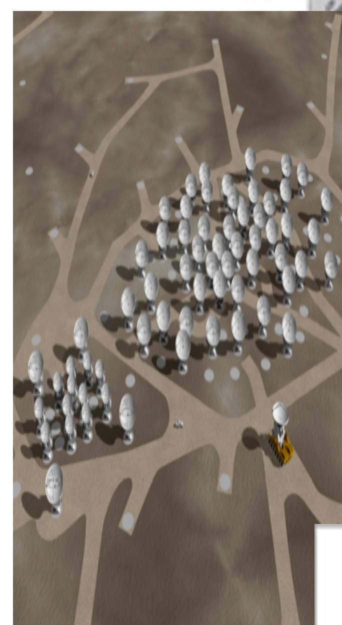
Science and Technology in Italy for the upgraded ALMA Observatory - iALMA

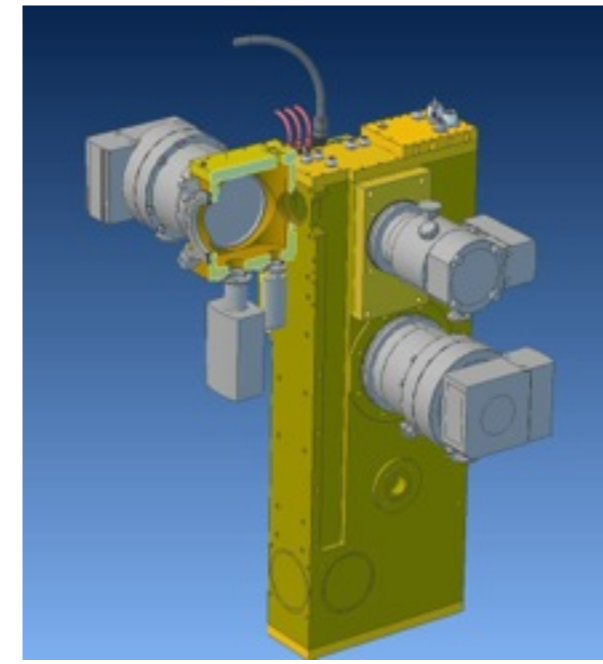
Linea di intervento:

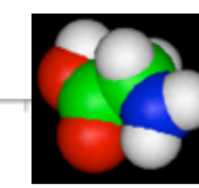
N.3: Programmi e/o progetti legati al potenziamento delle infrastrutture di ricerca esistenti che abbiano una valenza europea ed internazionale, anche in termini di impatto e che permettano di consentire la migliore partecipazione italiana ai programmi europei congiunti. Sono pertanto favorite quelle infrastrutture che: si autofinanziano almeno in parte attraverso servizi o altri progetti di ricerca; fanno parte di una rete europea; fanno parte di un ERIC (European Research Infrastructure Consortium) o sono in procinto di divenirlo; coinvolgono altre organizzazioni pubbliche o private distribuite sul territorio nazionale; non hanno già altre fonti di finanziamento in corso del MIUR per la stessa annualità e tipologia di spesa o siano ad esse complementari.

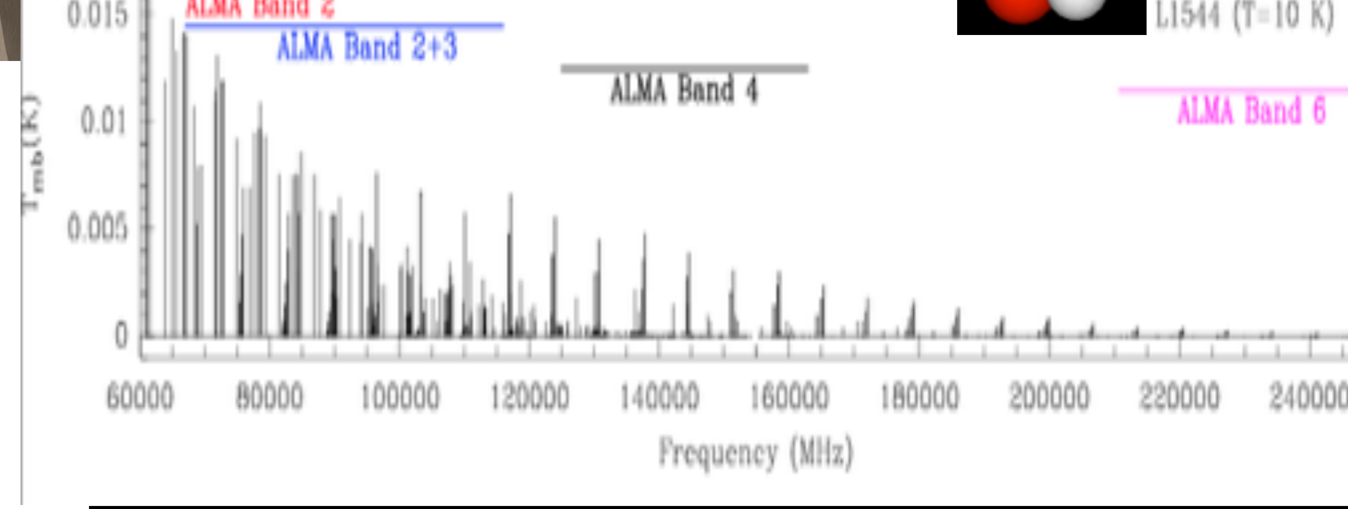
iALMA - Science and Technology











Testi – Progetto

The Science Case for ALMA Band 2

G. A. Fuller[1] C. De Breuck[2] S. Longmore[3] J. Wagg[4] L. Hunt[5] C. Cicone[6] P. Caselli[7] S. Viti[8] I. Jimenez-Serra[2] D. Vergani[9] S. Ramstedt[10] A. Richards[1] A. Avison[1] V. Casasola[11] M. Massardi[8] F. Costagliola[12] L. Testi[2] M. Beltran[13]

Science & Training

(Beltran - Arcetri, Gregorini - UniBo)

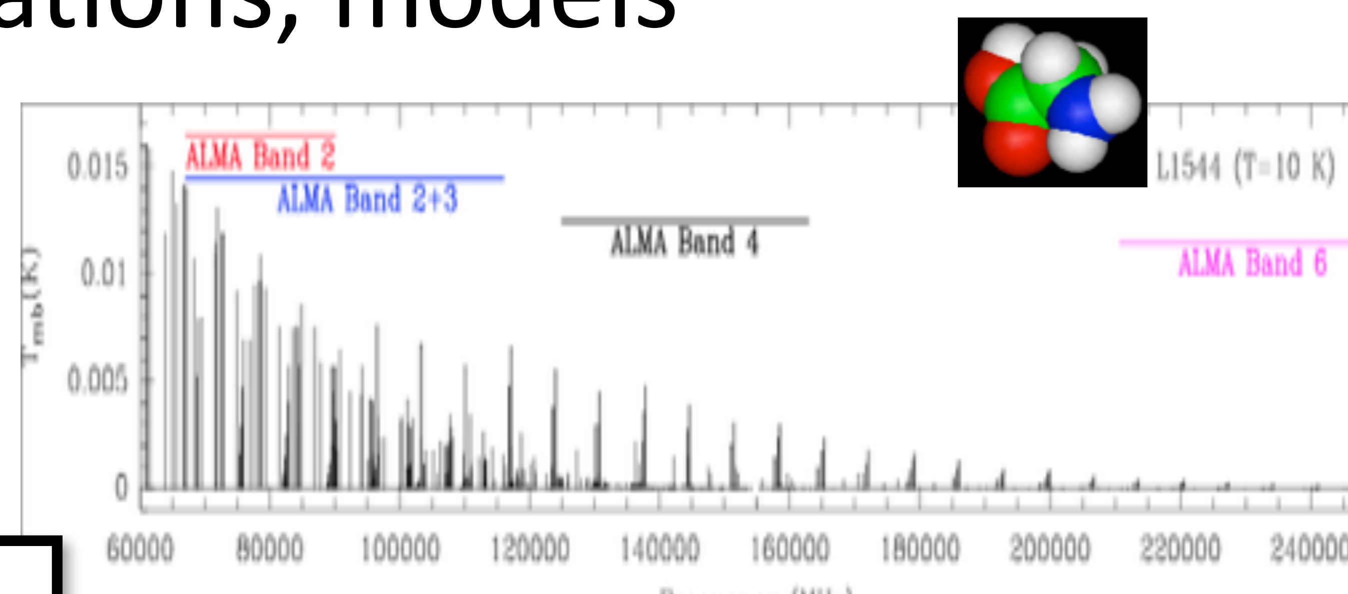
1. ALMA Band 2+3 Science Case (Fuller+)
2. COMs with ALMA & SKA (Codella+/Testi+)
3. 3 Students and 2 Postdocs selected
4. Lecture series, observations, models

Protoplanetary disks and the dawn of planets with SKA

L. Testired[*1,2,3], L. Perez[4], I. Jimenez-Serra[2], M. Hoare[5], A. Boley[6], T. Bourke[7], J.R. Brucato[1], P. Caselli[8], C. Chandler[4], C. Codella[1], A. Isella[9], J. Lazio[10], M.E. Palumbo[11], L. Podio[1], A. Remijan[4], J. Tarter[12], D.J. Wilner[13]
[1] *INAF-Osservatorio Astrofisico di Arcetri, Firenze, Italy;* [2] *European Southern Observatory,*

Complex organic molecules in protostellar environments in the SKA era

C. Codella[1], L. Podio[*1], F. Fontani[1], I. Jiménez-Serra[2], P. Caselli[3], C. Ceccarelli[4], M.E. Palumbo[5], A. López-Sepulcre[6,4], M.T. Beltrán[1], B. Lefloch[4], J.R. Brucato[1], S. Viti[7], L. Testi[2,1]
[1] *INAF, Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, 50125 Firenze (Italy);* [2] *ESO, Karl*



(Jiménez-Serra et al. 2014)

The Science Case for ALMA Band 2

G. A. Fuller[1] C. De Breuck[2] S. Longmore[3] J. Wagg[4] L. Hunt[5] C. Cicone[6] P. Caselli[7] S. Viti[8] I. Jimenez-Serra[2] D. Vergani[9] S. Ramstedt[10] A. Richards[1] A. Avison[1] V. Casasola[11] M. Massardi[8] F. Costagliola[12] L. Testi[2] M. Beltran[13]

Long term benefits for Italy

- Training + Laboratory + Receivers
  - Effective engagement in ALMA Science and Development
  - Benfits spreading to the Italian community at large
- Development of Italian ARC node in Bologna
  - Better support for the Italian community to use ALMA
  - Develop possible synergies with support of Italian radio telescopes (SRT and EVN as facilities for It users)
  - Develop possible synergies with the future user support concepts for SKA
- Receiver/hw development
  - Involvement of Italian industry
  - Synergy with SRT (indirectly SKA) receivers

Summary

- ALMA is ramping up from Early Science towards Full Science Operations
- The results from Science Verification and ALMA Cycle 0 & 1 are transformational
- ALMA Capabilities in Cycle 2 are a factor of several more powerful, and will continue to grow
- ALMA has an ambitious development plan and is developing the scientific vision for ALMA2030
- Italy is fully engaged in ALMA science and development through INAF

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