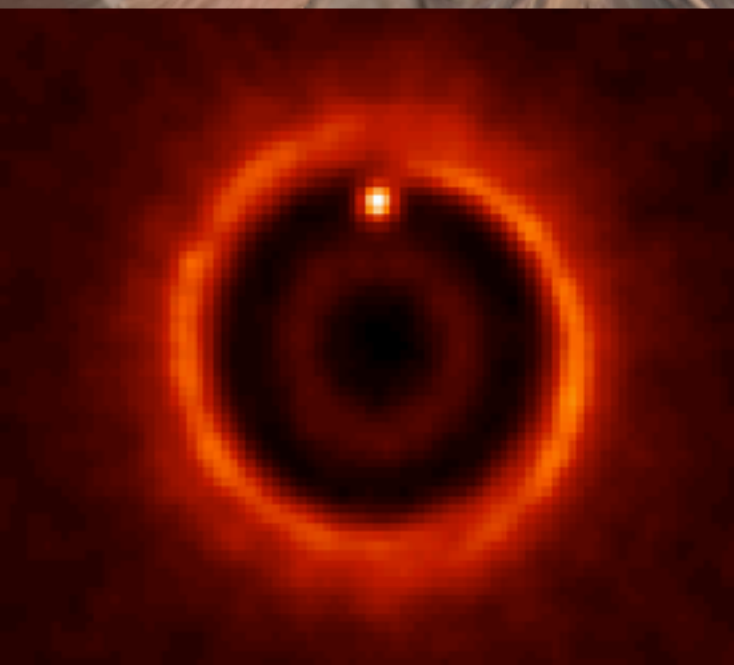
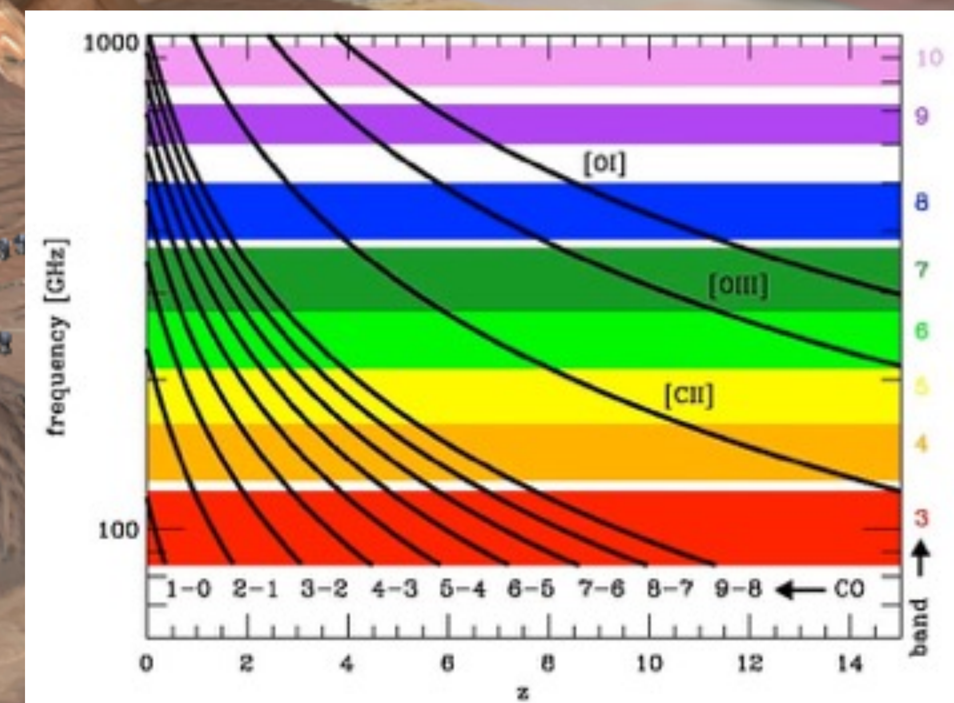
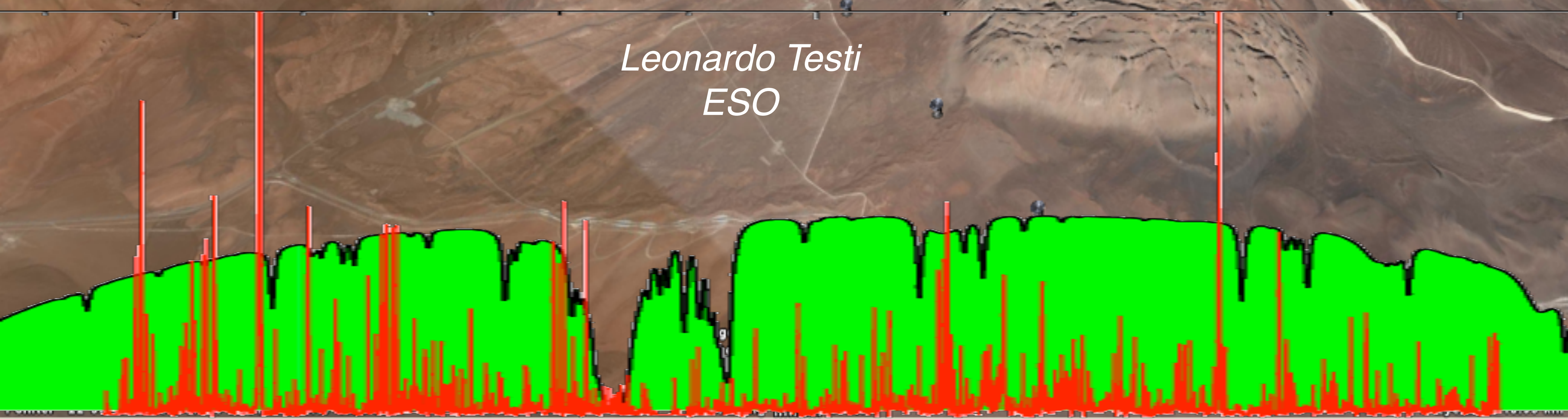
ALMA Introduction

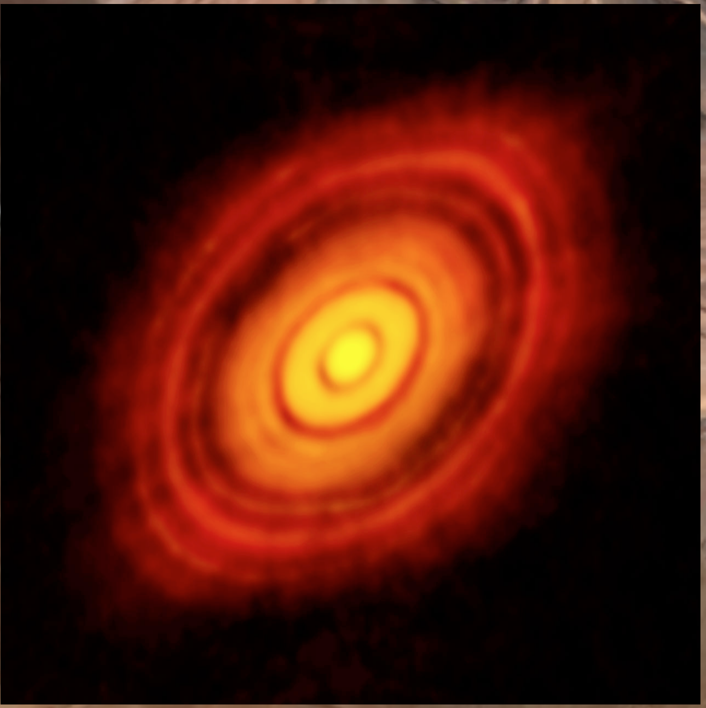


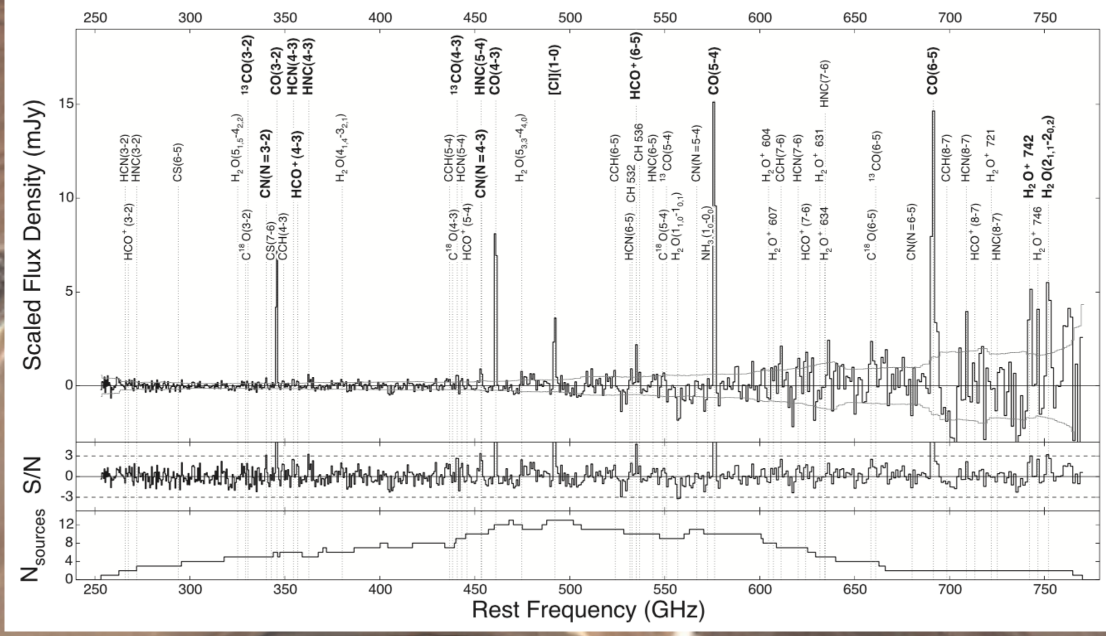


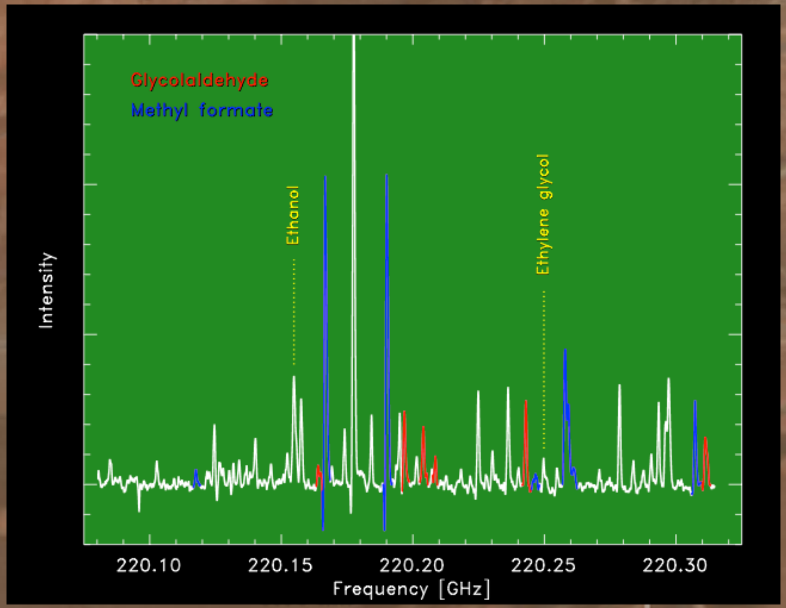
Leonardo Testi
ESO



ALMA Introduction







Leonardo Testi
ESO

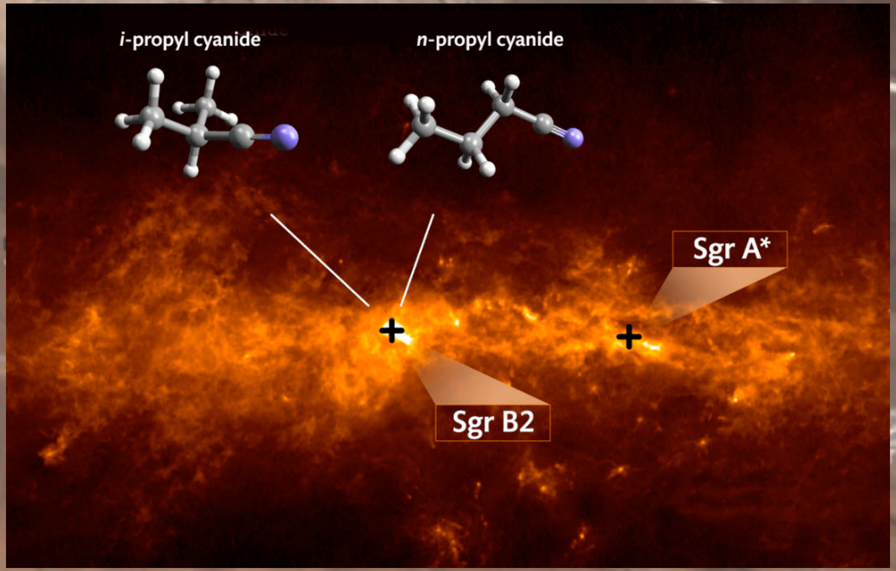
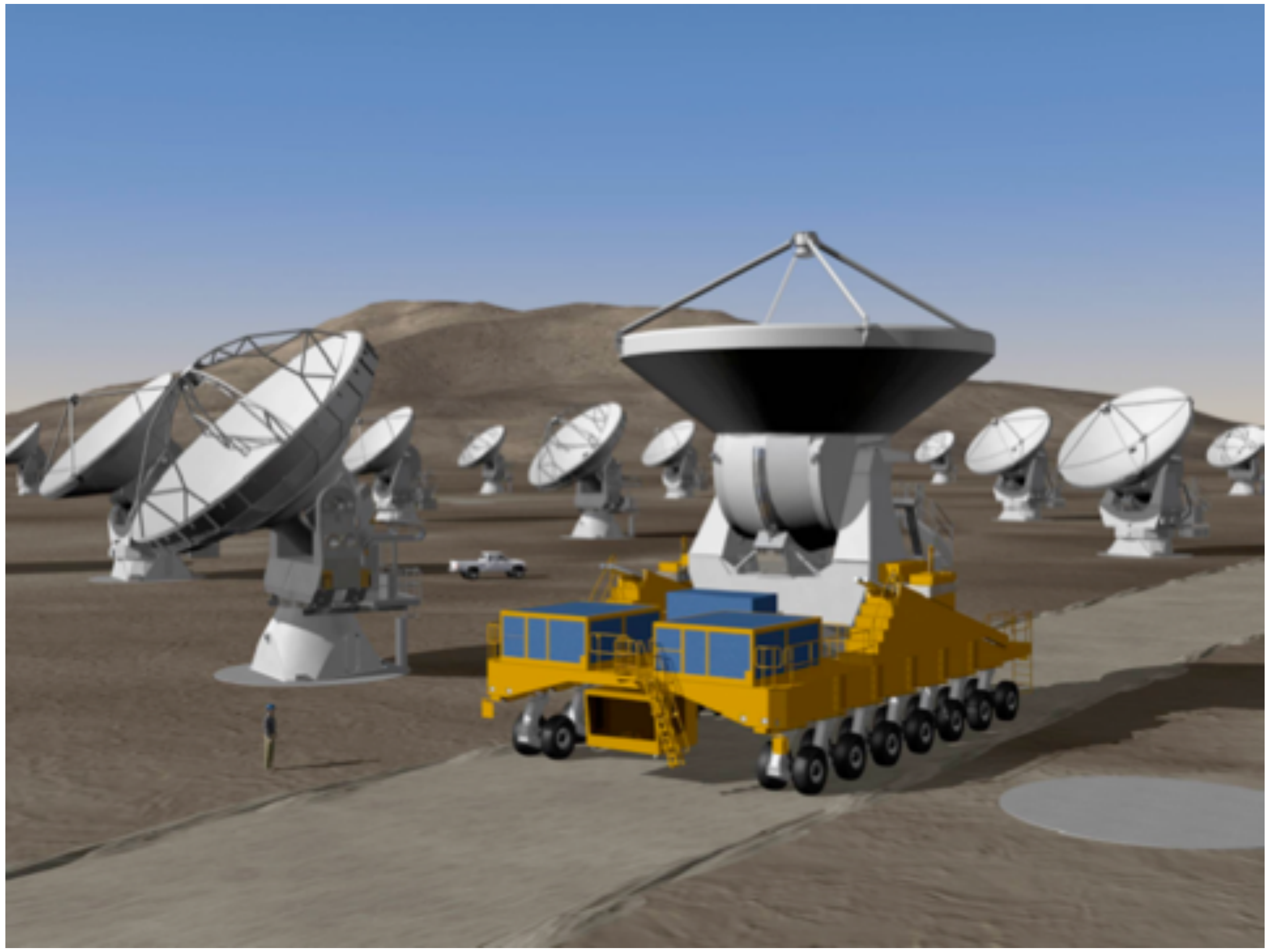


Image © 2007 DigitalGlobe
Image © 2007 TerraMetrics
© 2007 Europa Technologies

Pointer 22°59'45.21" S 67°43'16.81" W elev 4927 m Streaming ||||||||| 100% Eye alt 18.99 km

Atacama Large Millimeter Array

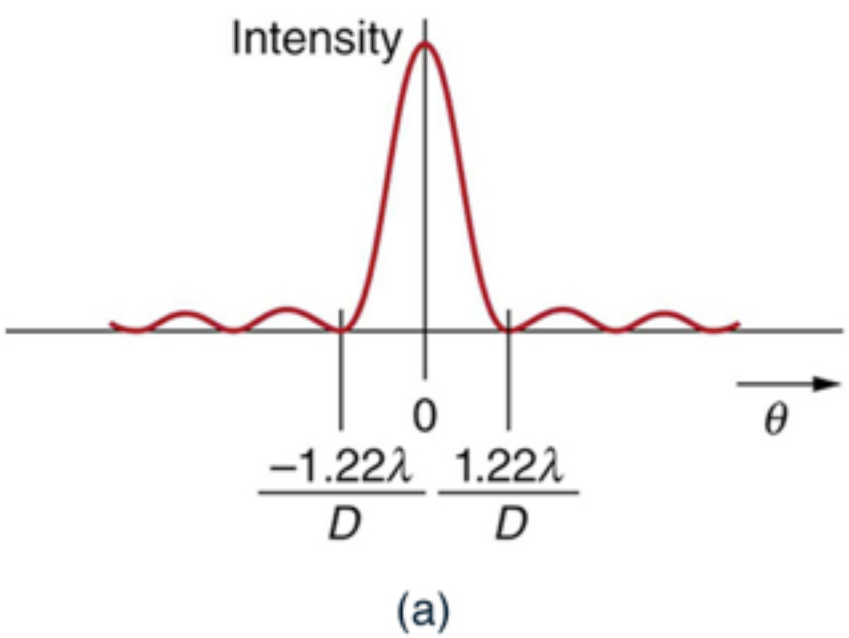


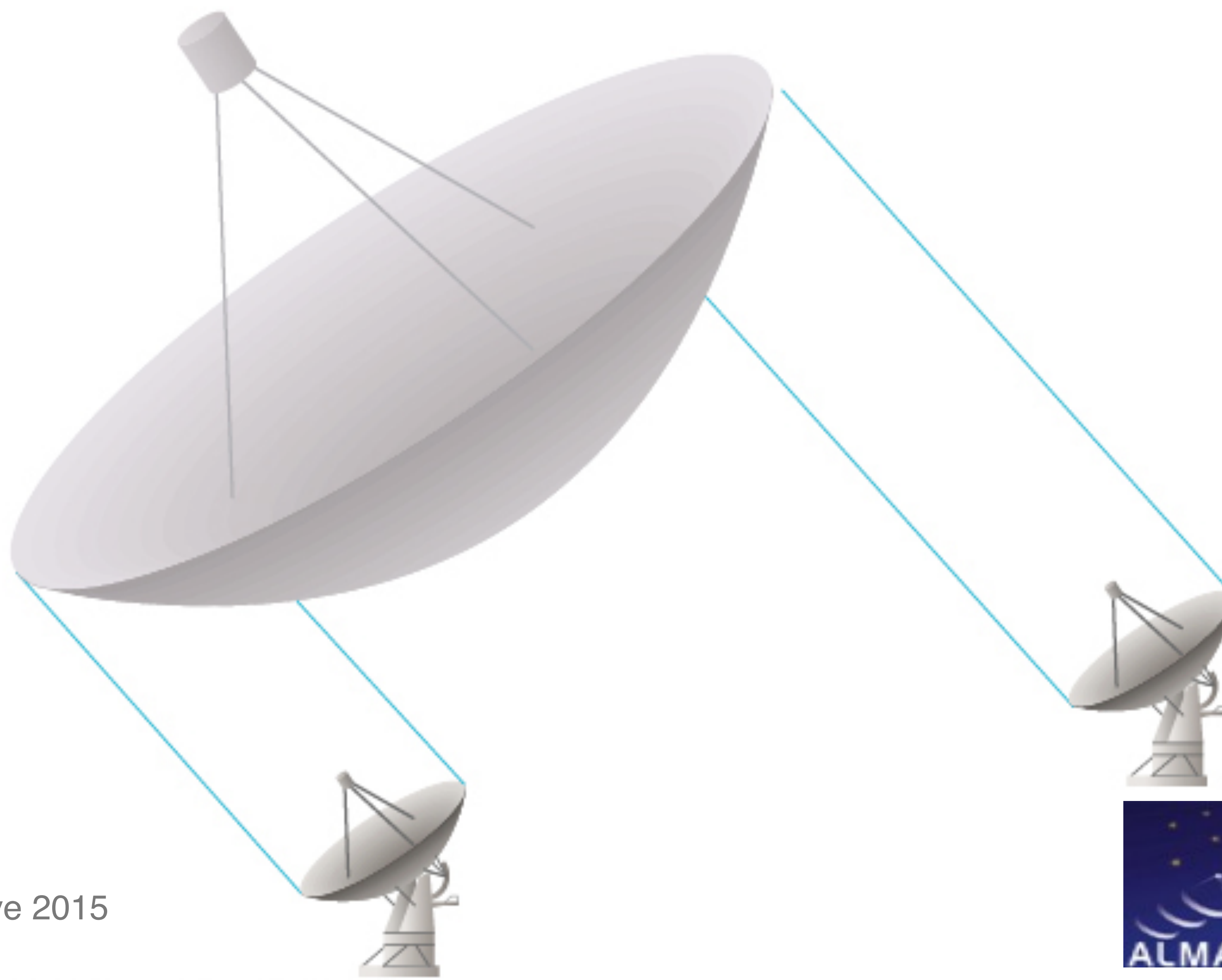
- At least 50x12m Antennas
- Frequency range 30-1000 GHz (0.3-10mm)
- 16km max baseline (<10mas)
- ALMA Compact Array (4x12m and 12x7m)

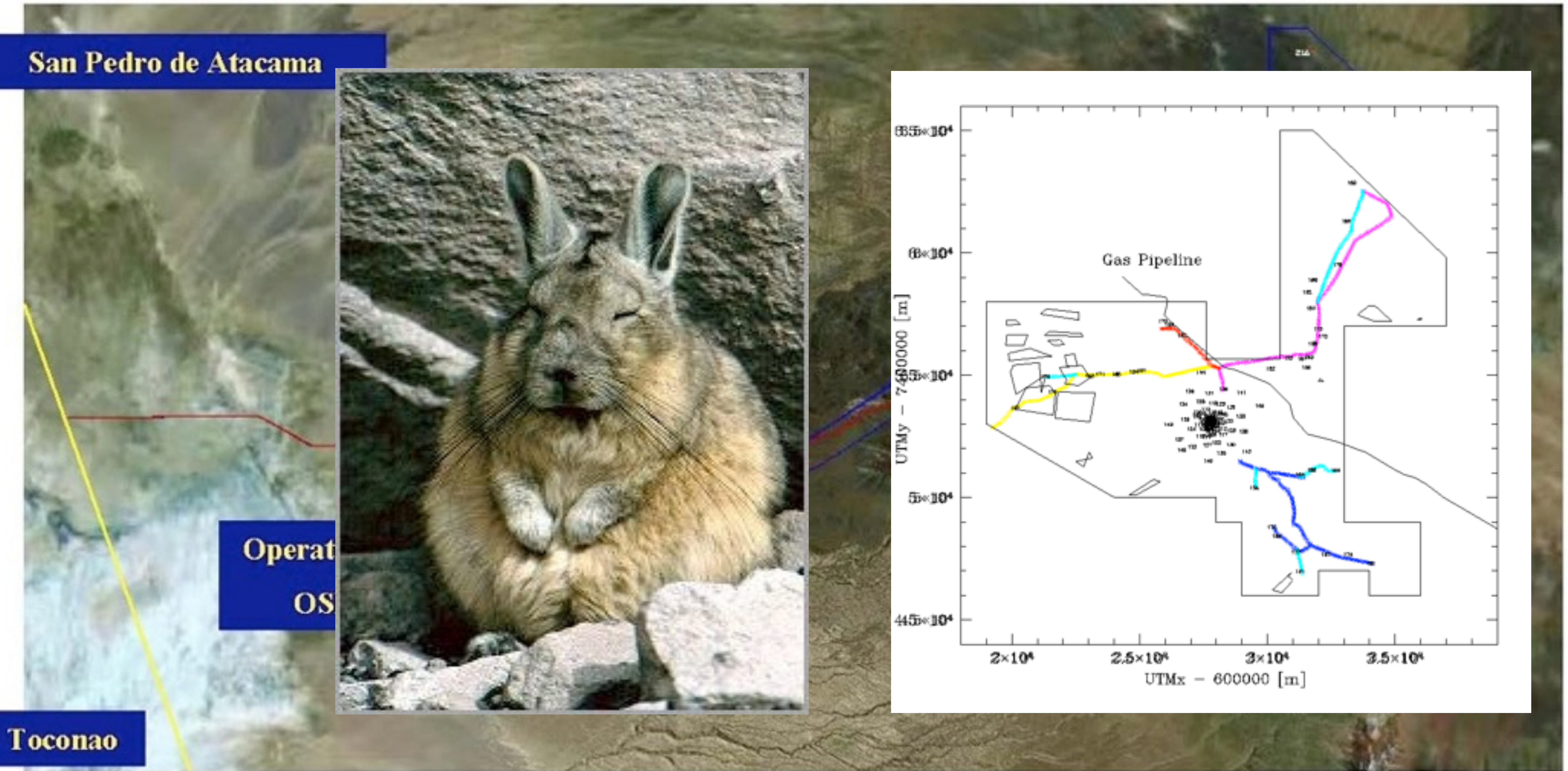
1. **Detect and map CO and [C II] in a Milky Way galaxy at z=3 in less than 24 hours of observation**
2. **Map dust emission and gas kinematics in protoplanetary disks**
3. **Provide high fidelity imaging in the (sub)millimeter at 0.1 arcsec resolution**

Angular resolution

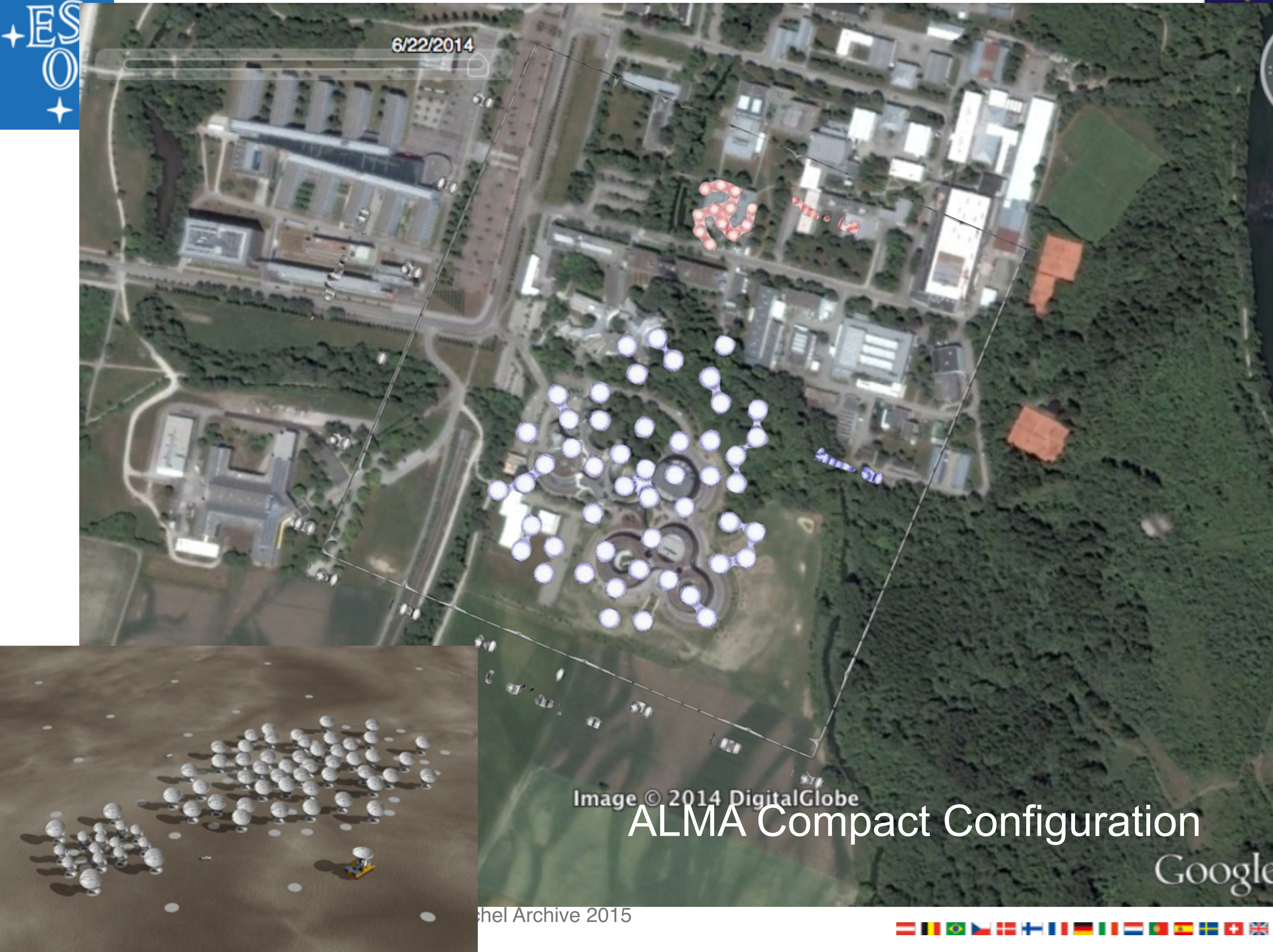
- Diffraction limit: ~1.22*lambda/D =>   1mm/30m~8”
- 8” > 1000 AU @ 140pc (Sun-Neptune ~ 30AU)
- Sun-Jupiter ~ 5AU => 0.035” => >~7km @1mm
- Sun-Earth = 1AU =>   0.007” =>   ~17km @0.5mm



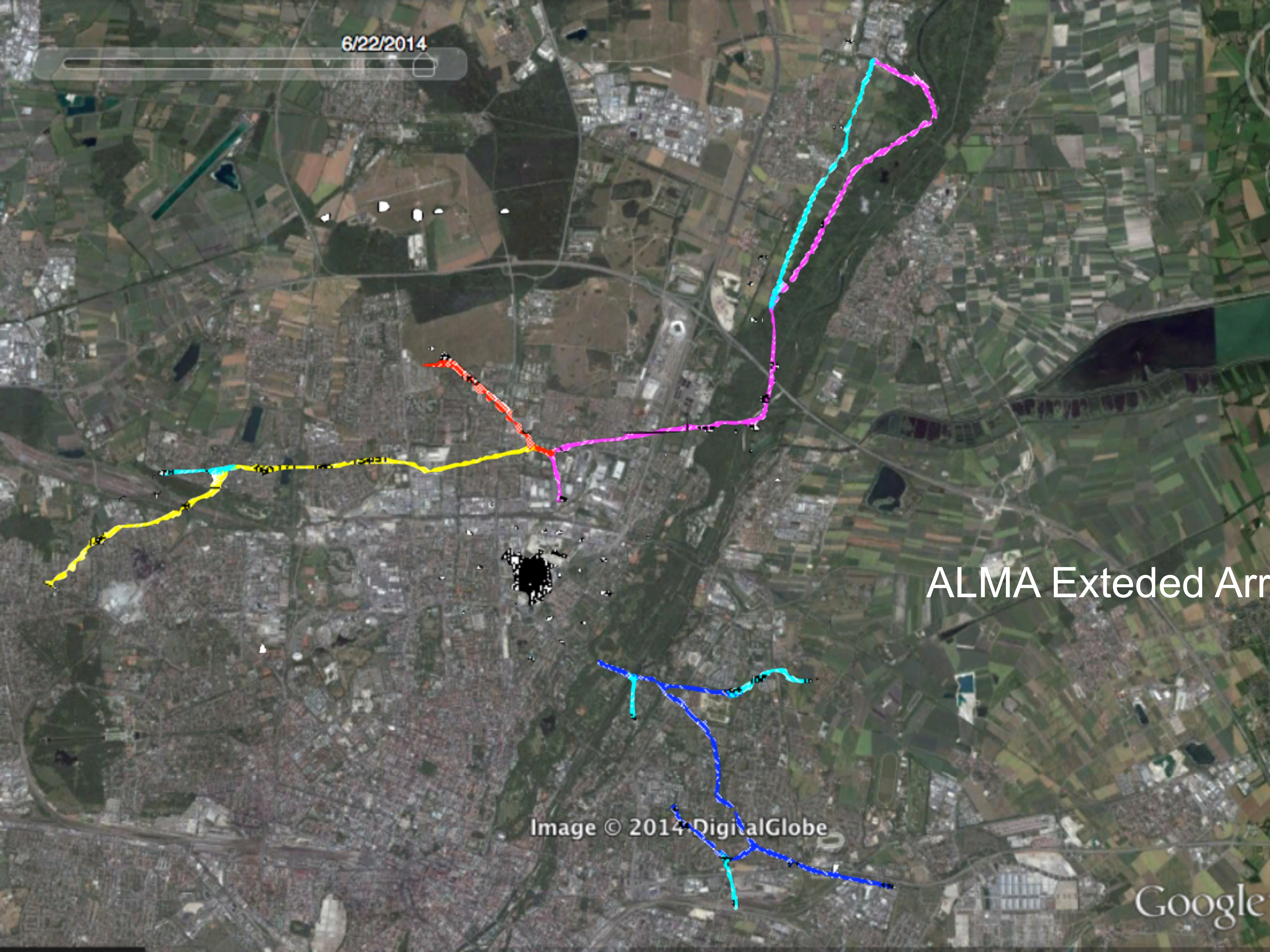




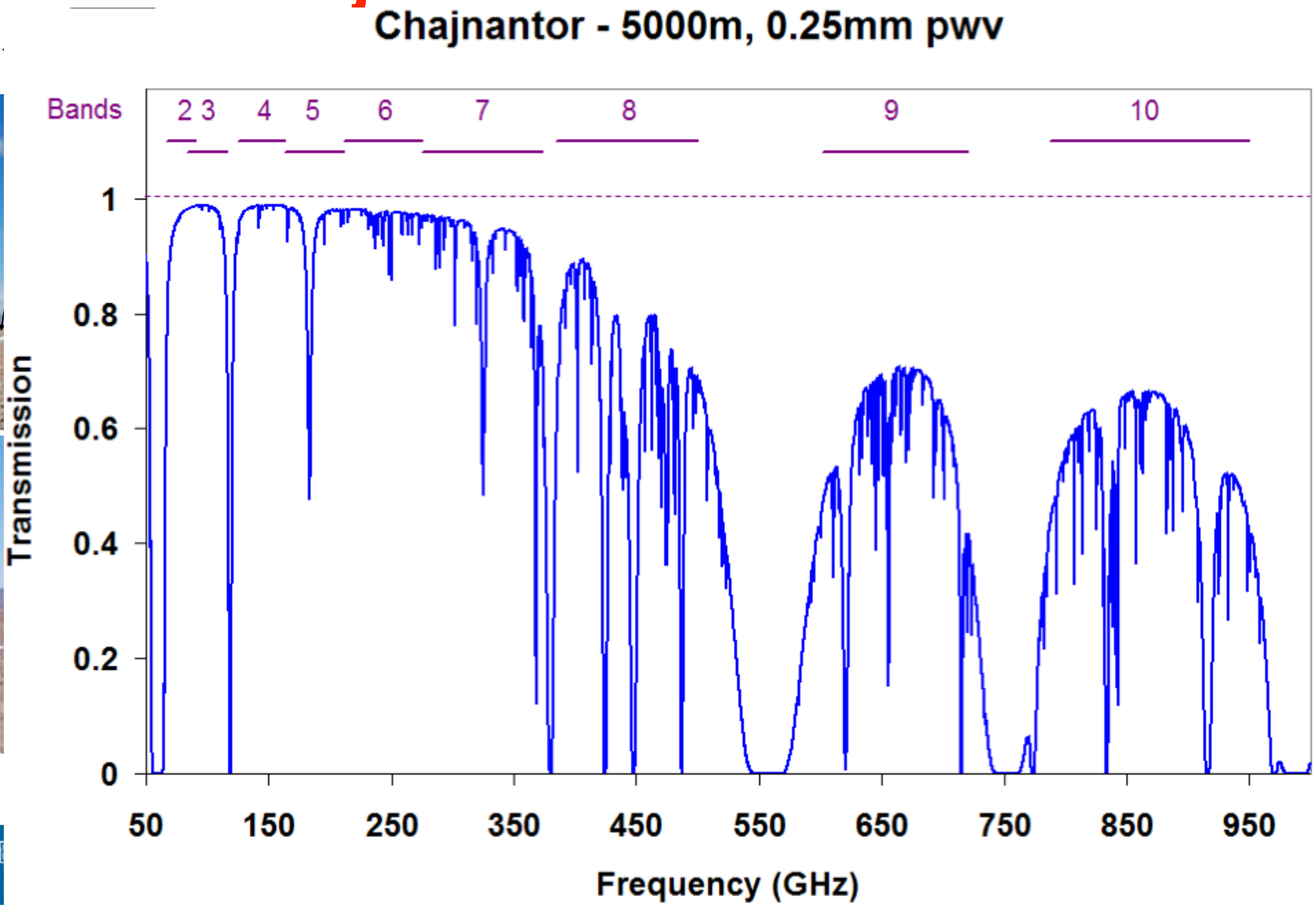
San Pedro de Atacama
Operat
OS
Toconao
Gas Pipeline
UTMy − 7400000 [m]
UTMx − 600000 [m]
2×10⁴
2.5×10⁴
3×10⁴
3.5×10⁴



ALMA Compact Configuration

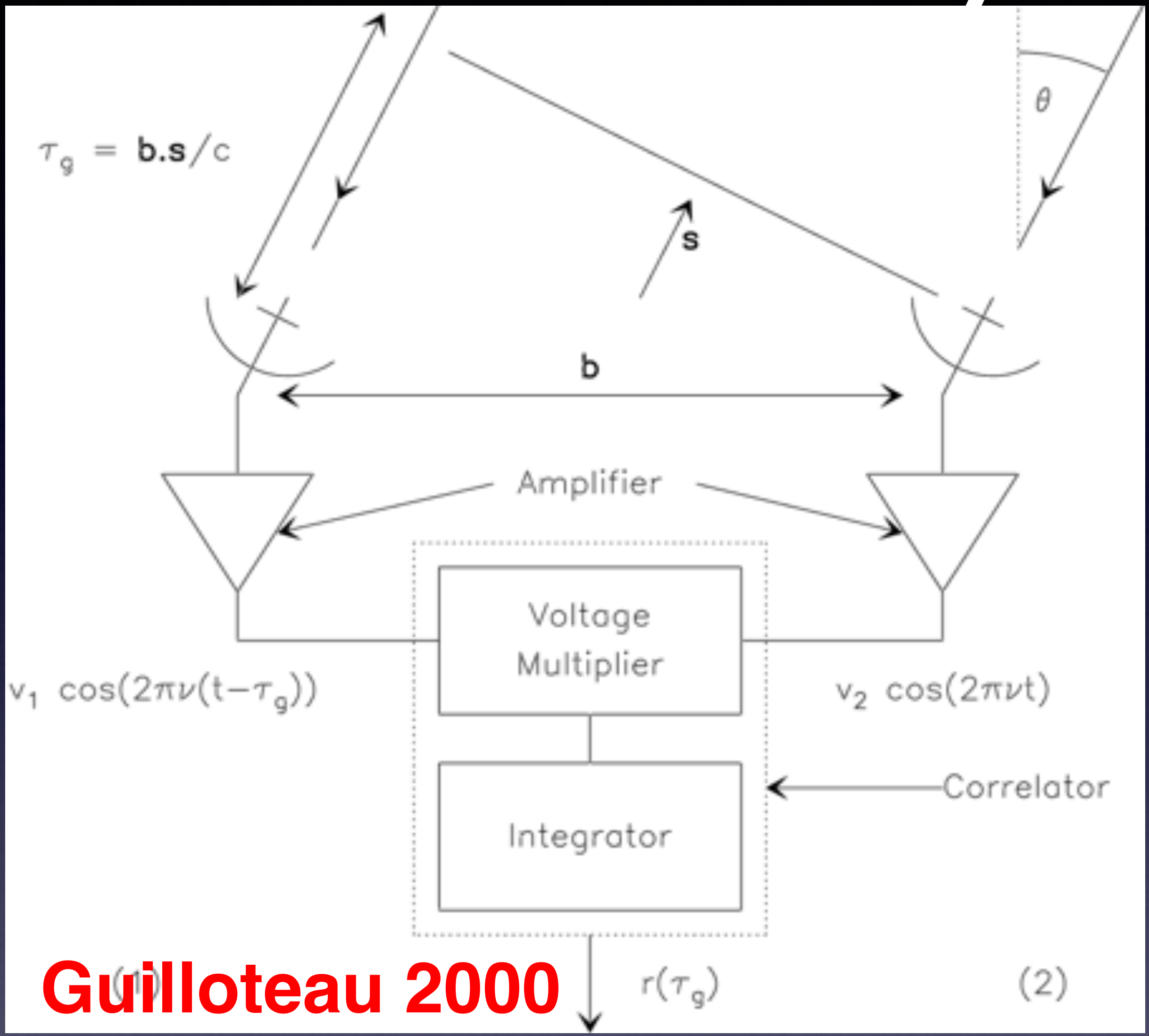

6/22/2014
ALMA Exteded Arr
Image © 2014 DigitalGlobe
Google

Chajnantor Plateau - 5000m



Small digression on interferometry

- Interference pattern of the signal from two antennas separated by a baseline b
- After correction for the optical path delay each pair of antennas measure the fringe visibility corresponding to the baseline b (as seen from the source)



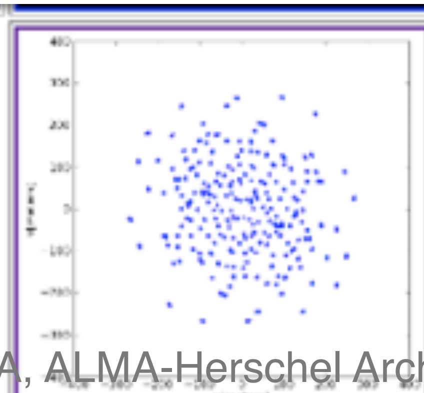
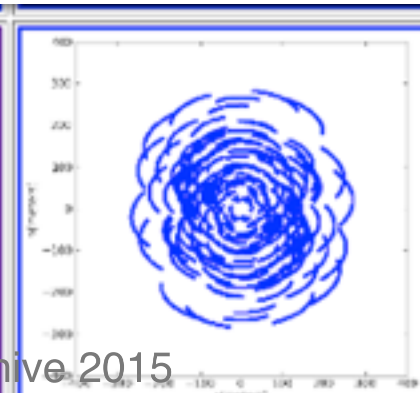
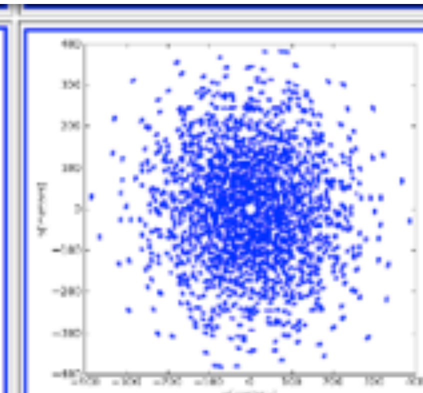
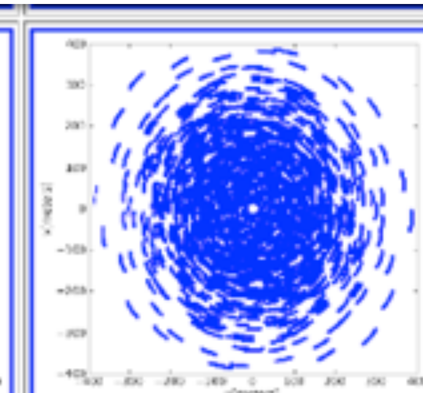
Guilloteau 2000

$$\boxed{\mathrm{V}(\mathrm{u},\mathrm{v}) = \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} \mathrm{P}(x,\mathrm{y})\mathrm{I}(x,\mathrm{y})\exp(-2i\pi\,(ux+vy))\mathrm{dxdy}}$$

(x,y)=Sky (u,v)=baselines plane V(u,v)=Measured visibility

P(x,y)=Antenna power pattern I(x,y)=Brightness distribution on Sky

ALMA - Image Fidelity

Convolved source models	Early Science		Full Science	
	10 minutes (0.47 mJy rms)	4 hours (0.091 mJy rms)	10 minutes (0.14 mJy rms)	1 hour (0.057 mJy rms)
				

ALMA - Image Fidelity

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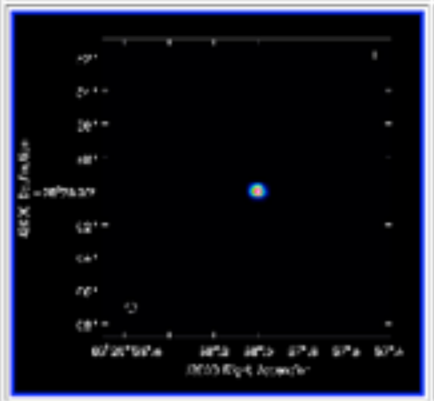	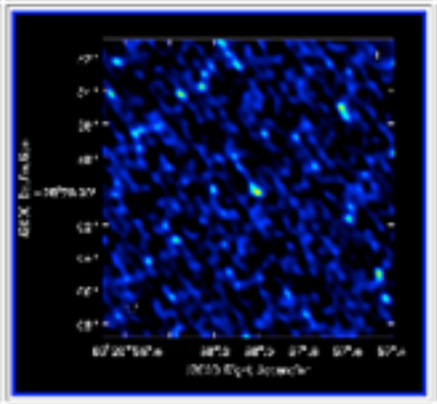	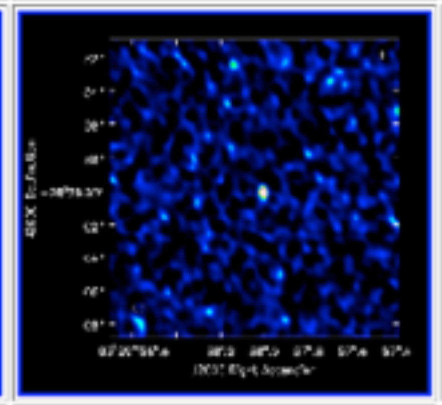	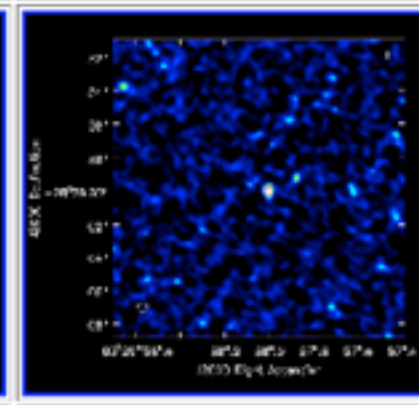	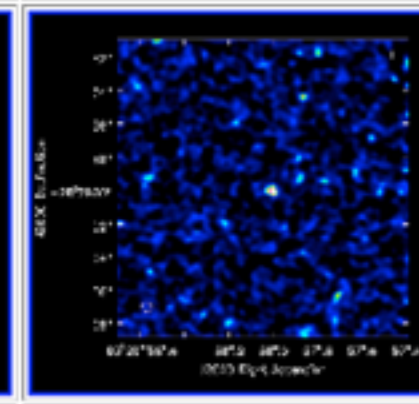
	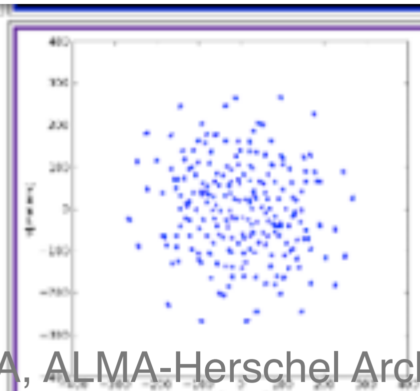	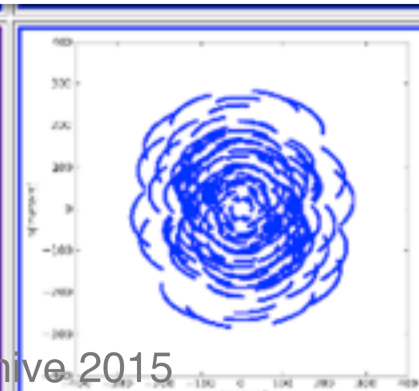	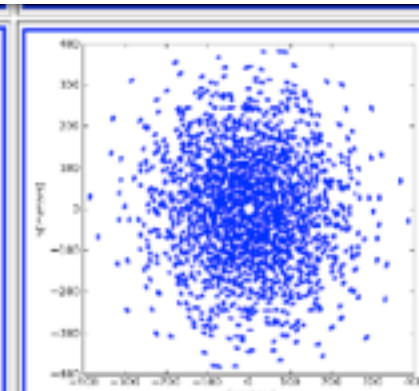	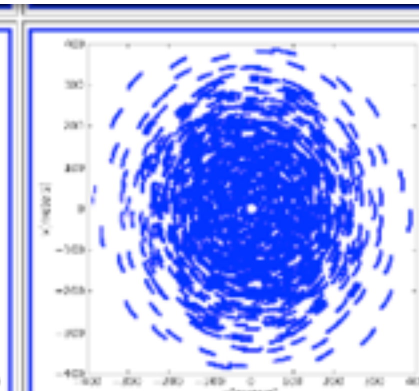

ALMA - Image Fidelity

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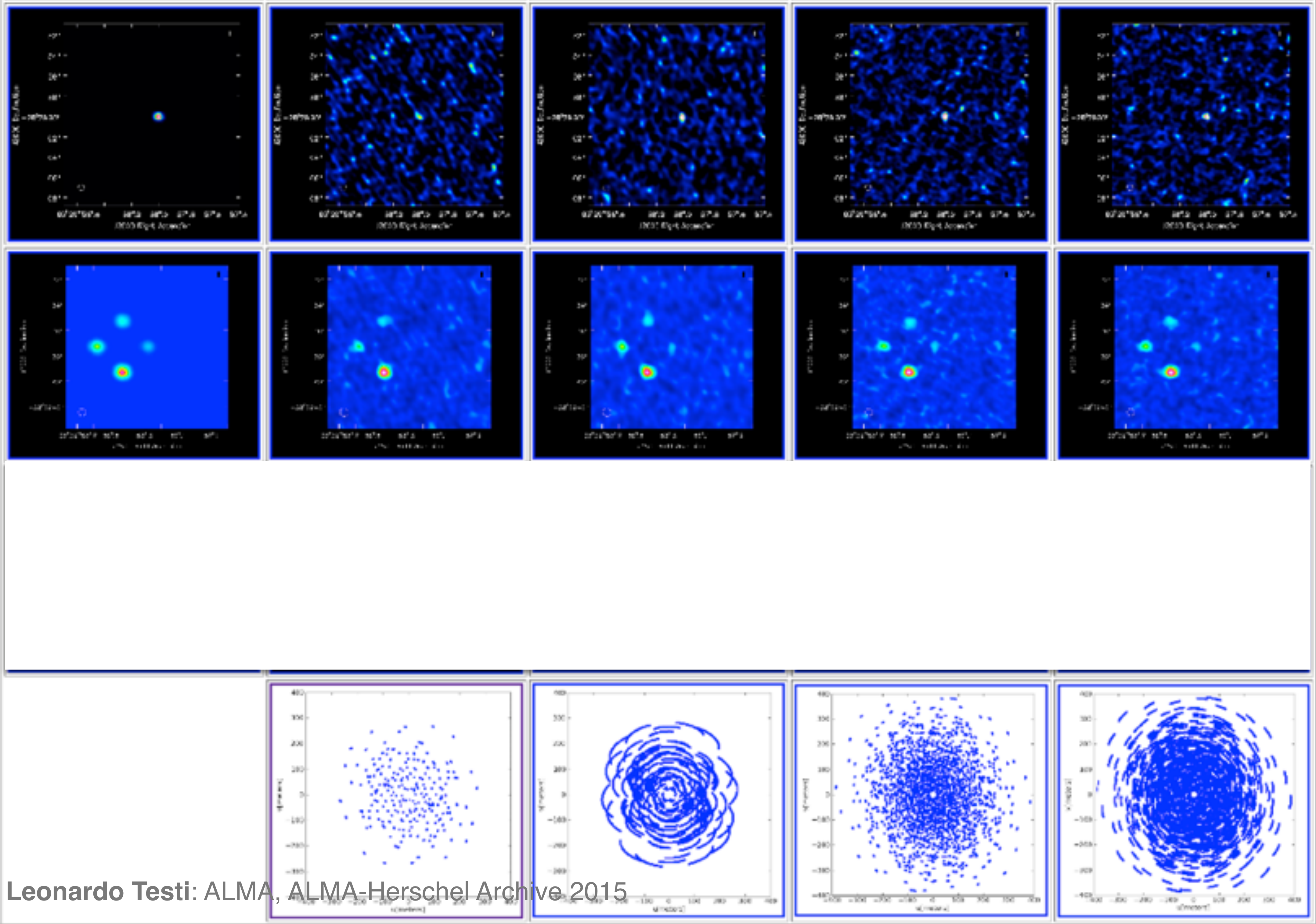
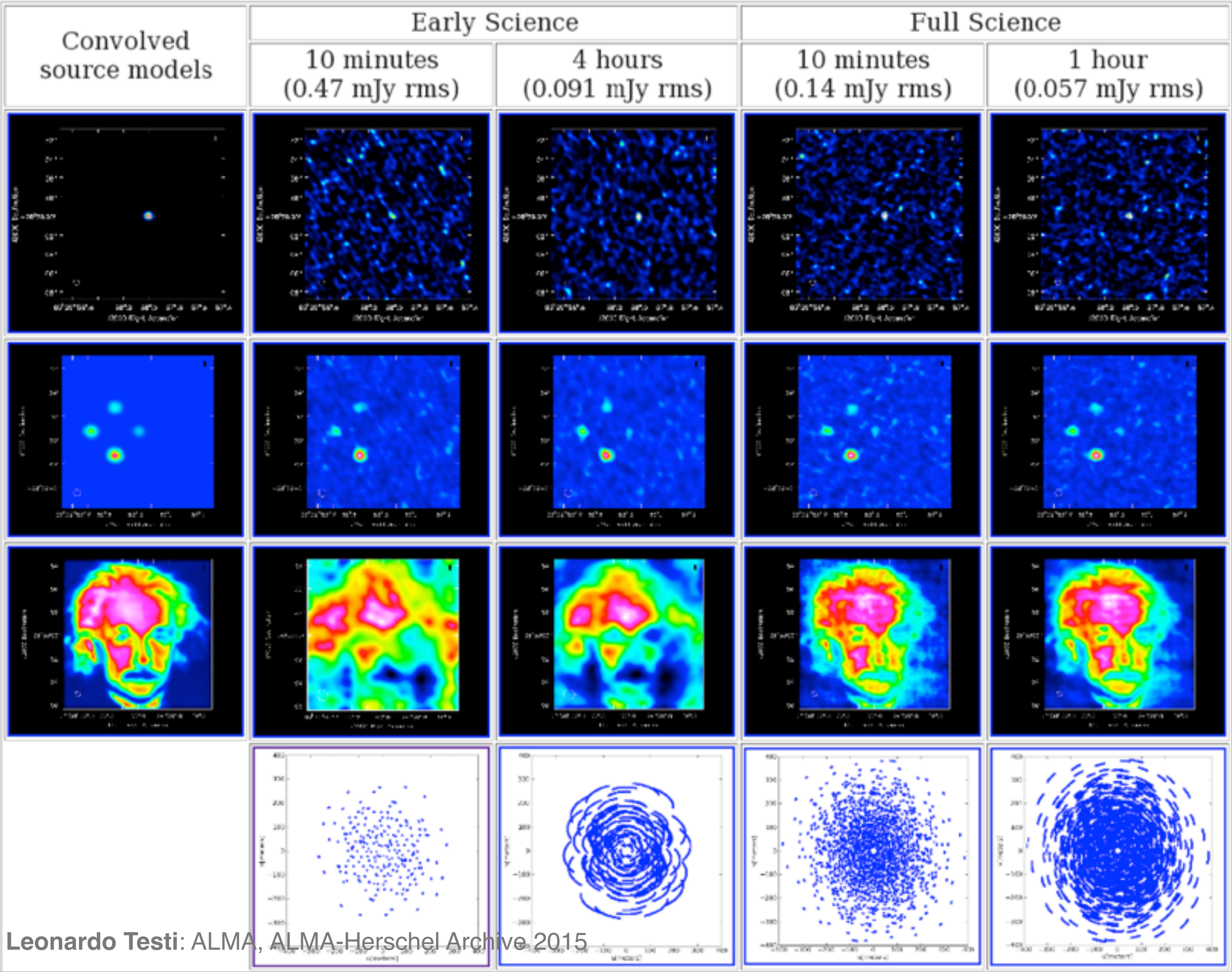


ALMA - Image Fidelity



ALMA Early Science

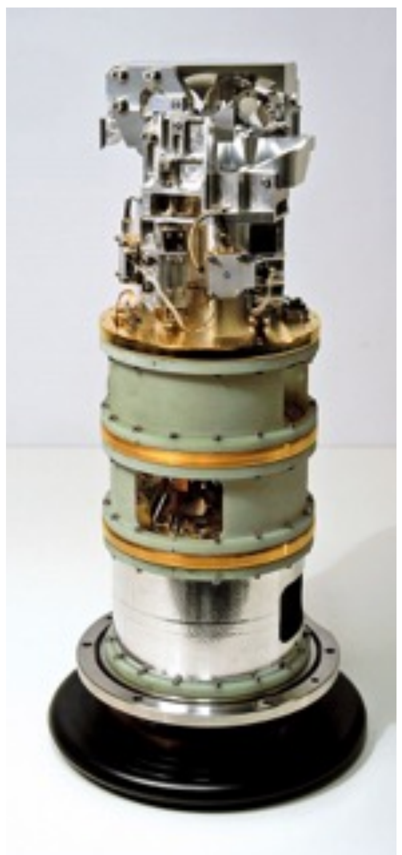
- ALMA Early Science C0, C1 & C2
  - 30-70% of the total number of antennas
  - Maximum separation 3km
  - Already the most powerful submm observatory
- Enormous pressure to use ALMA worldwide
  - Requests for 9 times the available time
  - Top 8% science projects selected (ESO)

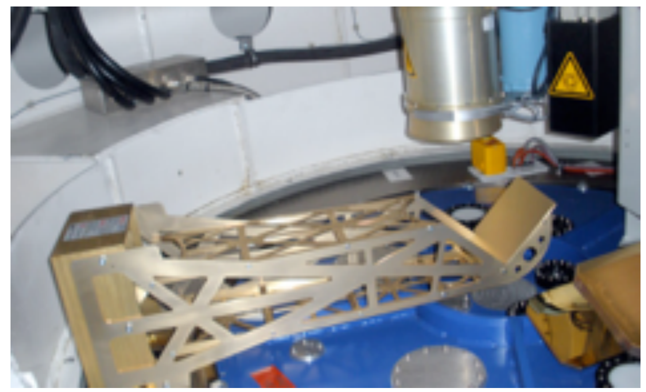
ALMA Frequency Bands Usage

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

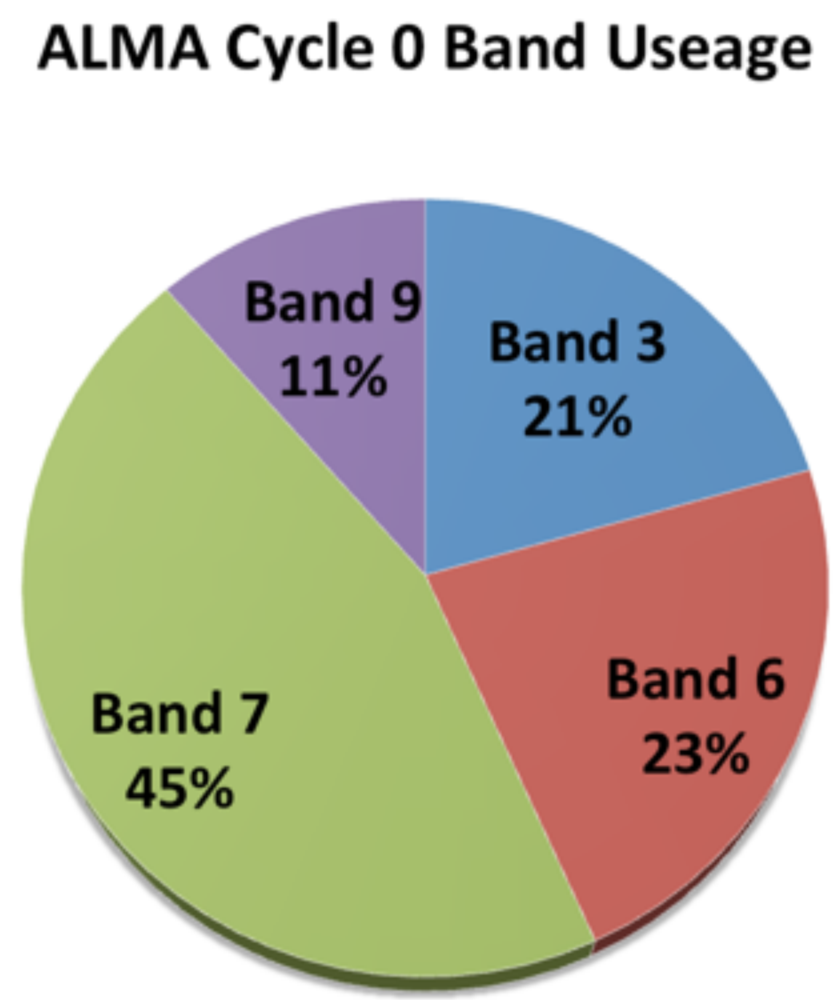
Band 7
IRAM

Band 9
NOVA



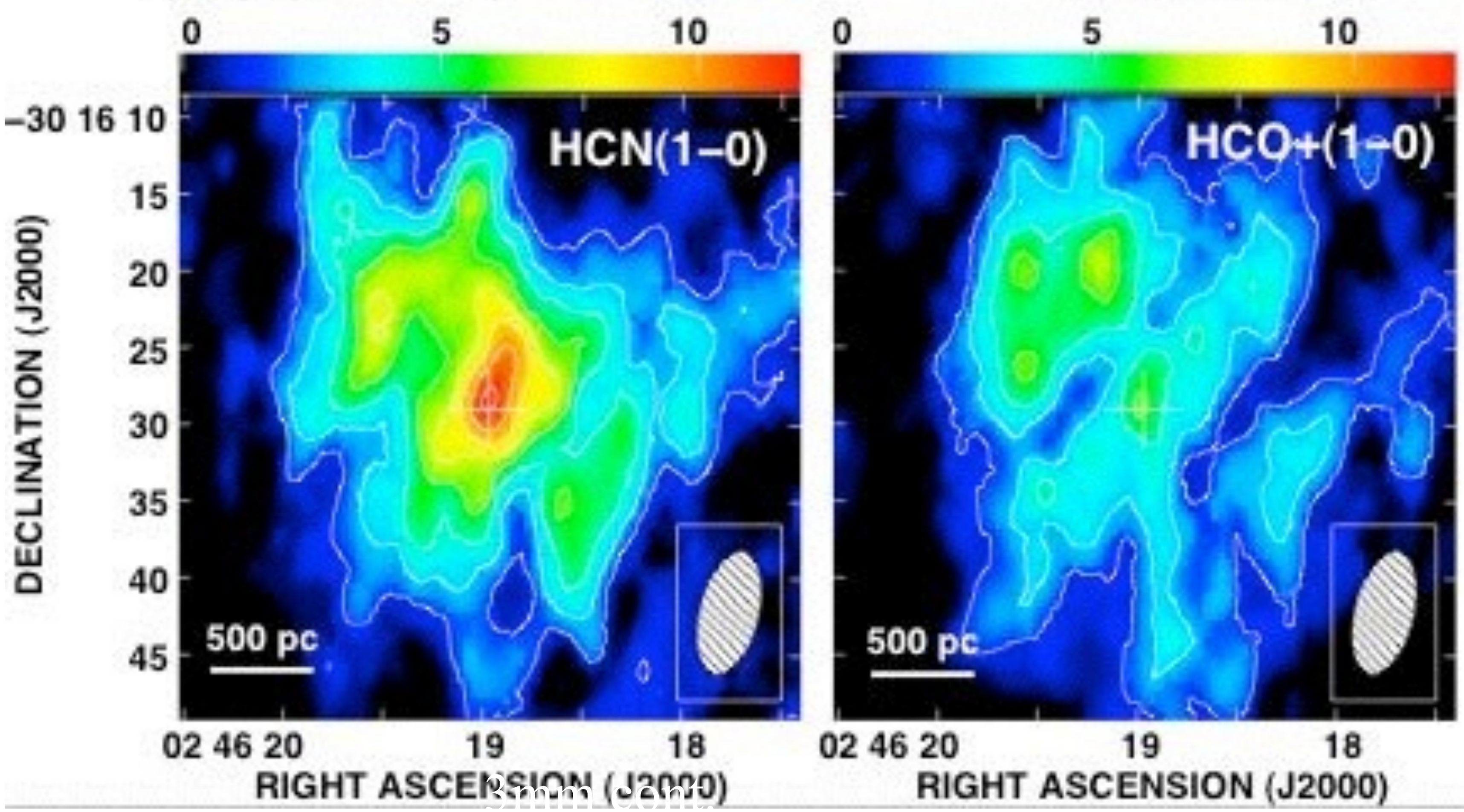


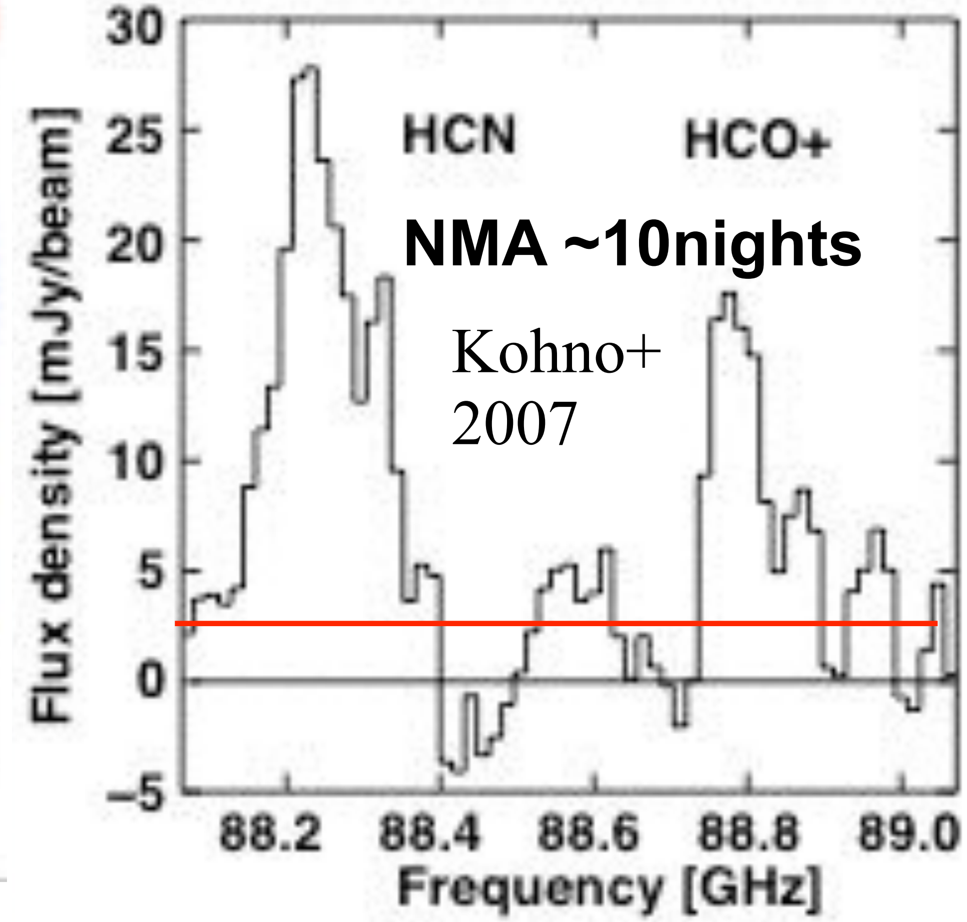
WVR
OMNISYS

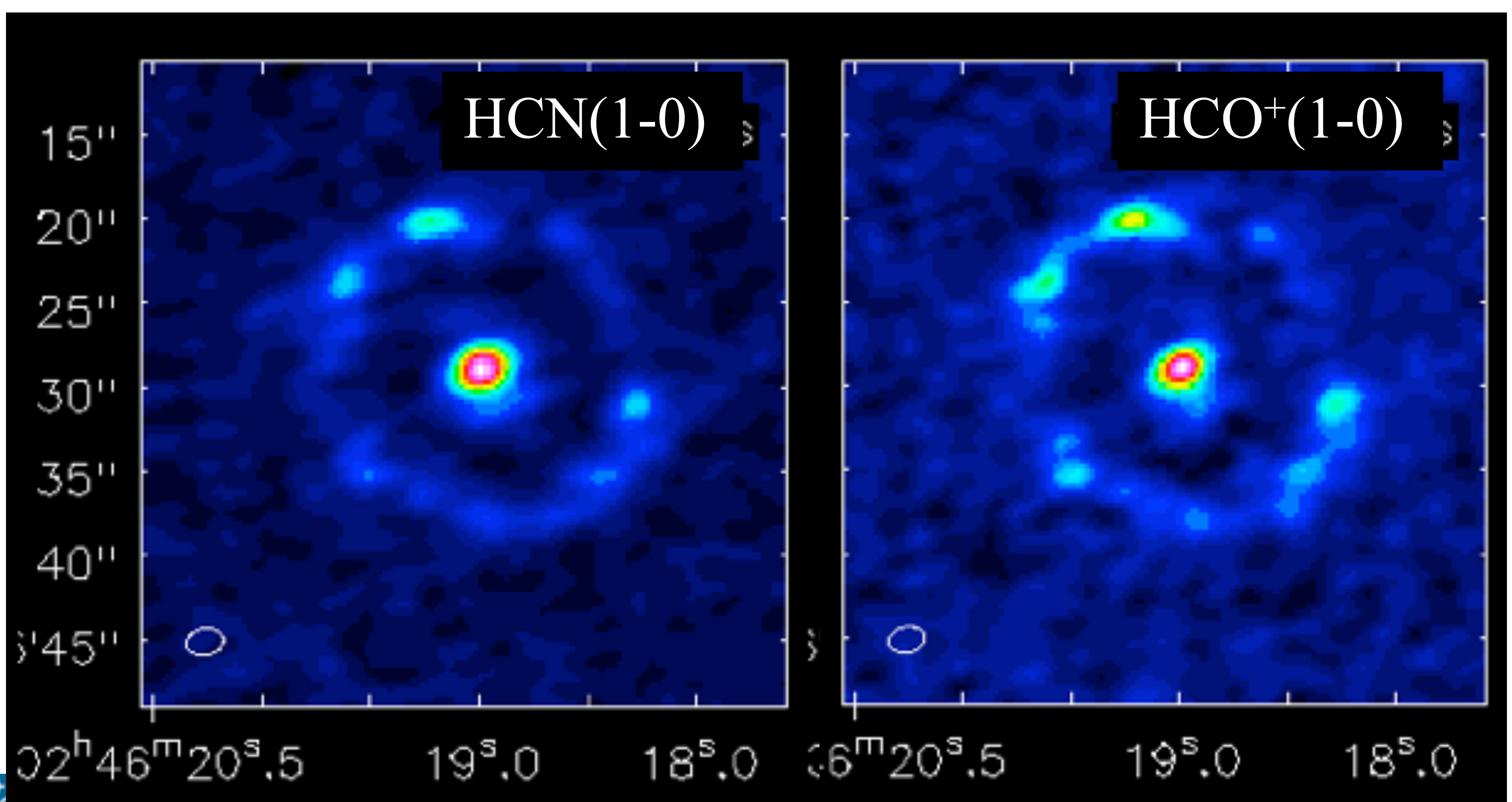


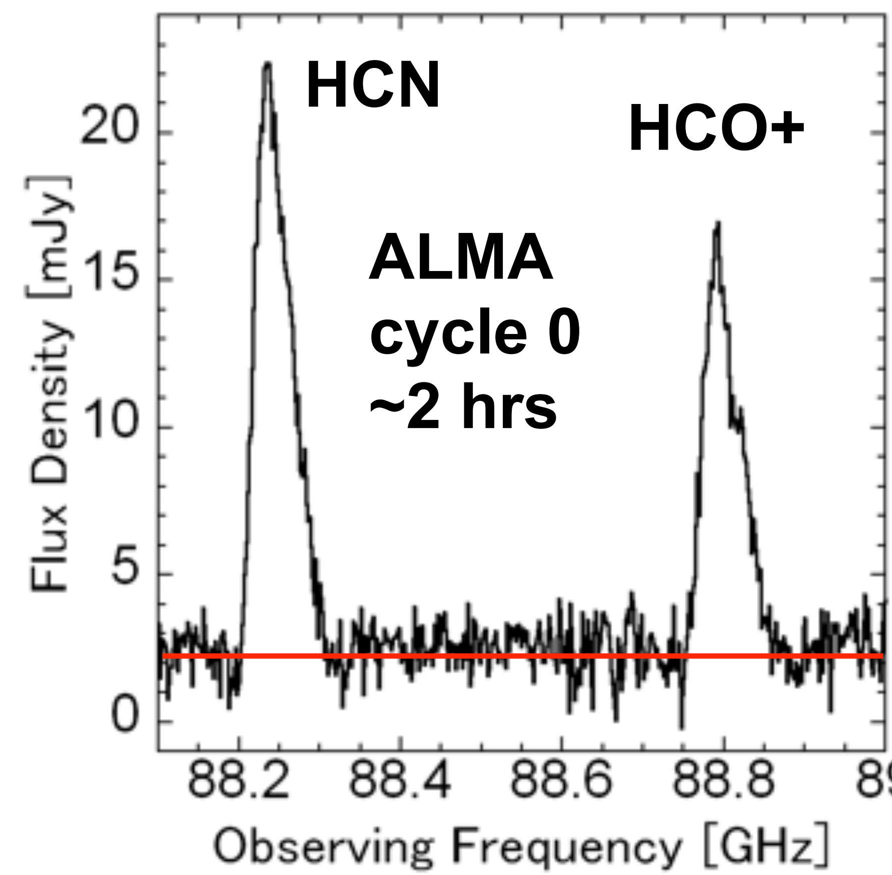
SIXTH FRAMEWORK PROGRAMME

Phase Correction
SW - U Cambridge



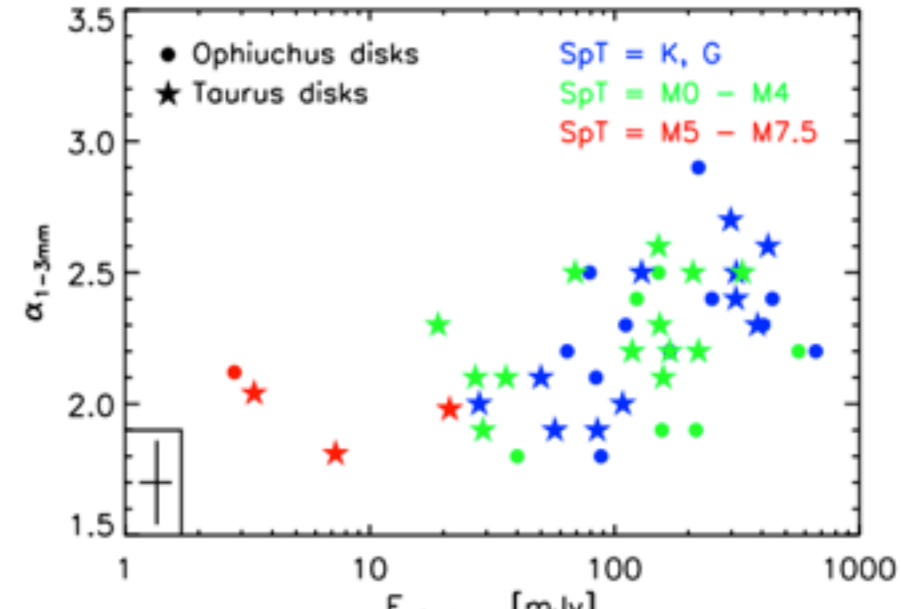




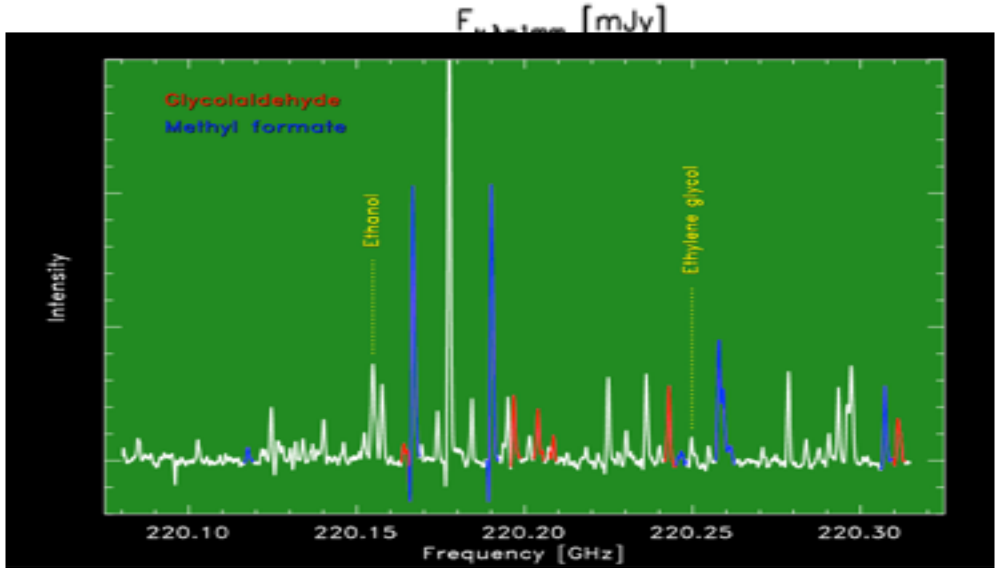


ALMA cycle 0 program (PI. K. Kohno)

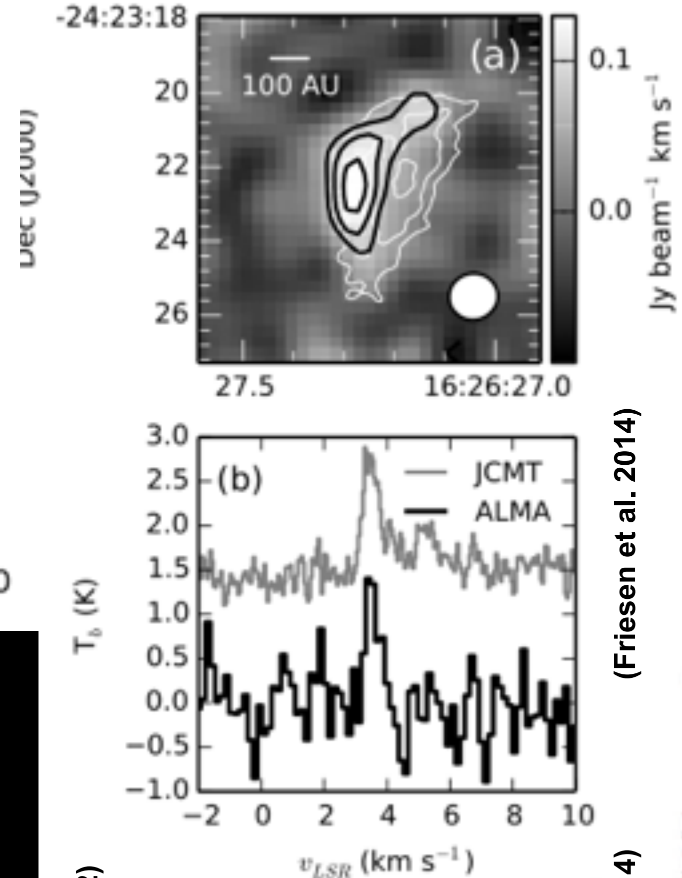
Disks and star formation: evolution, planet formation, chemistry, surveys coming



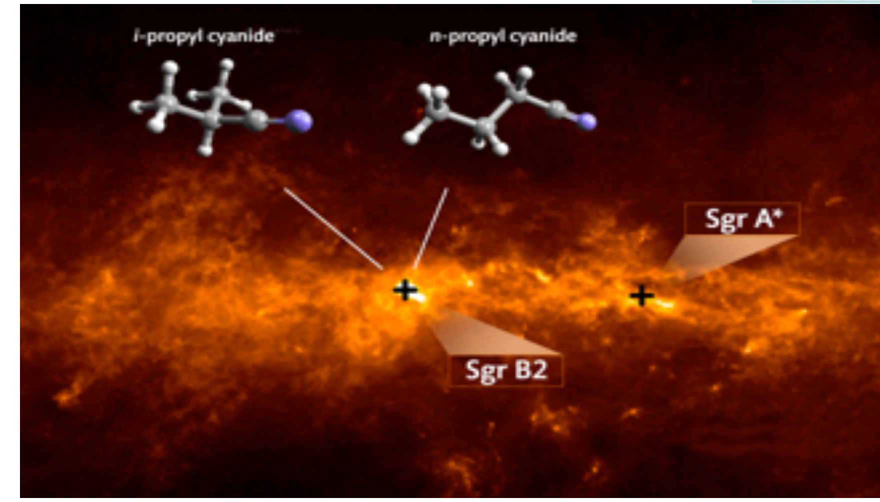
(Ricci et al. 2012; 2014)



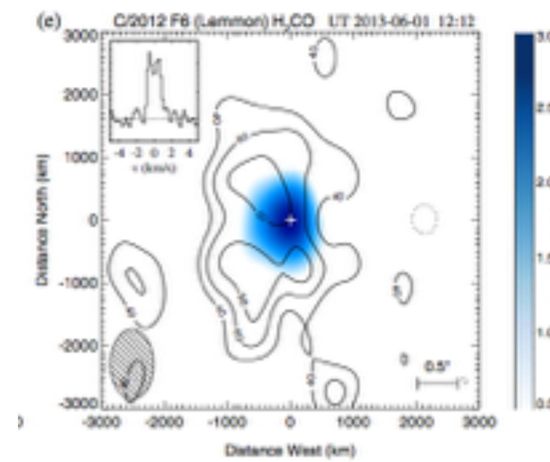
(Jorgensen et al. 2012)



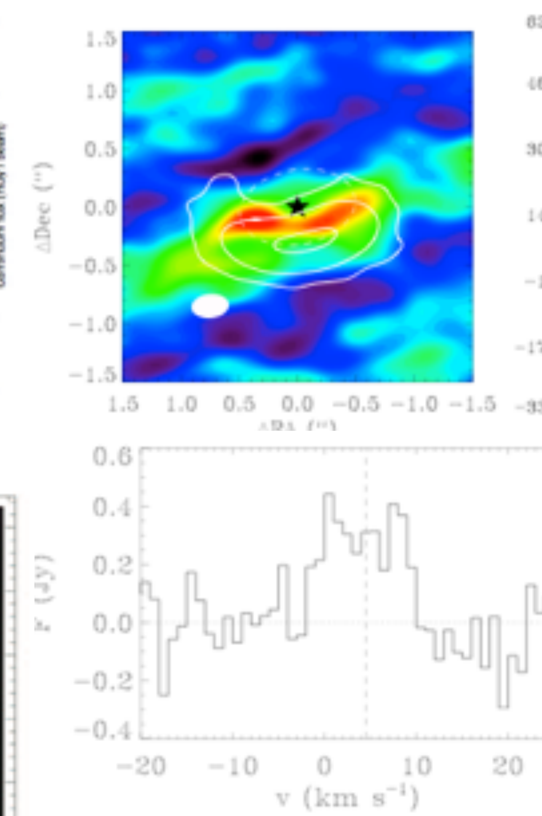
(Friesen et al. 2014)



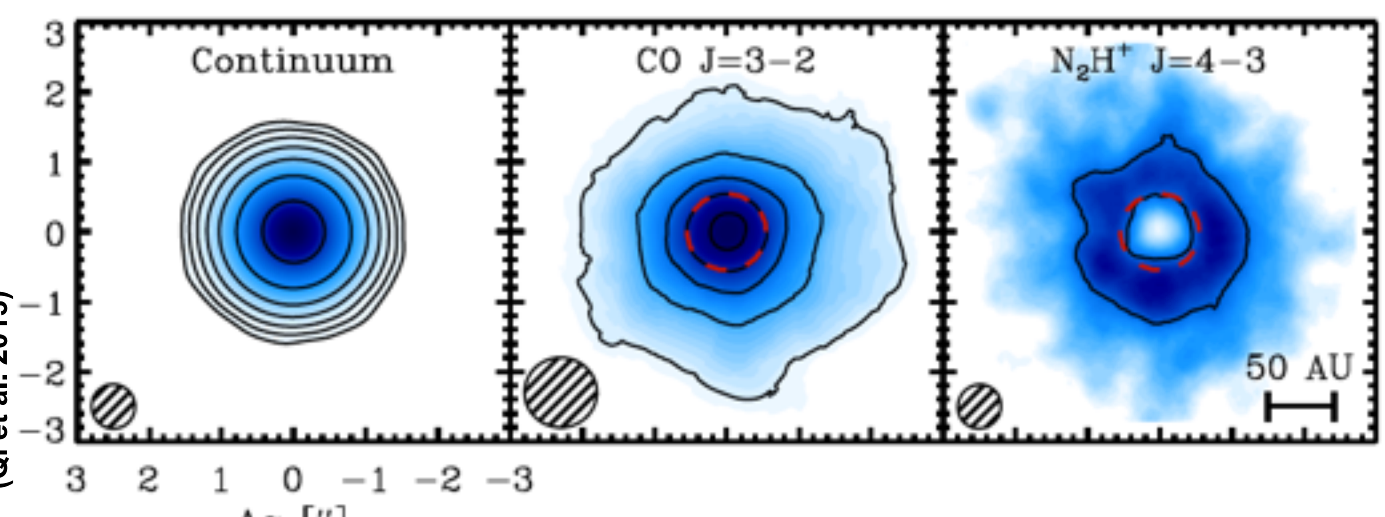
(Belloche et al. 2014)



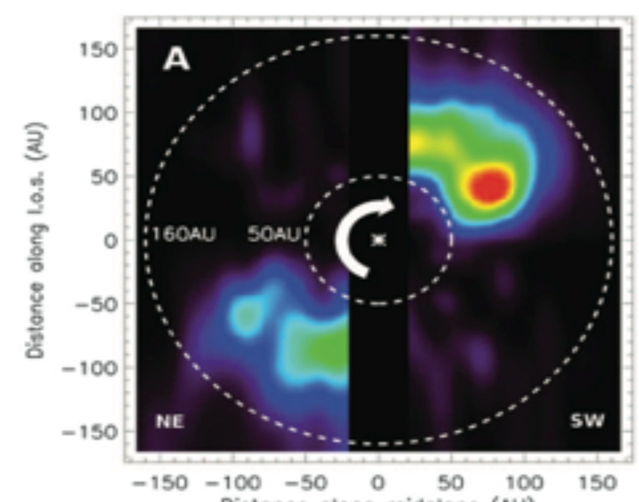
(Cordiner et al. 2014)



(van der Marel et al. 2013/2014)

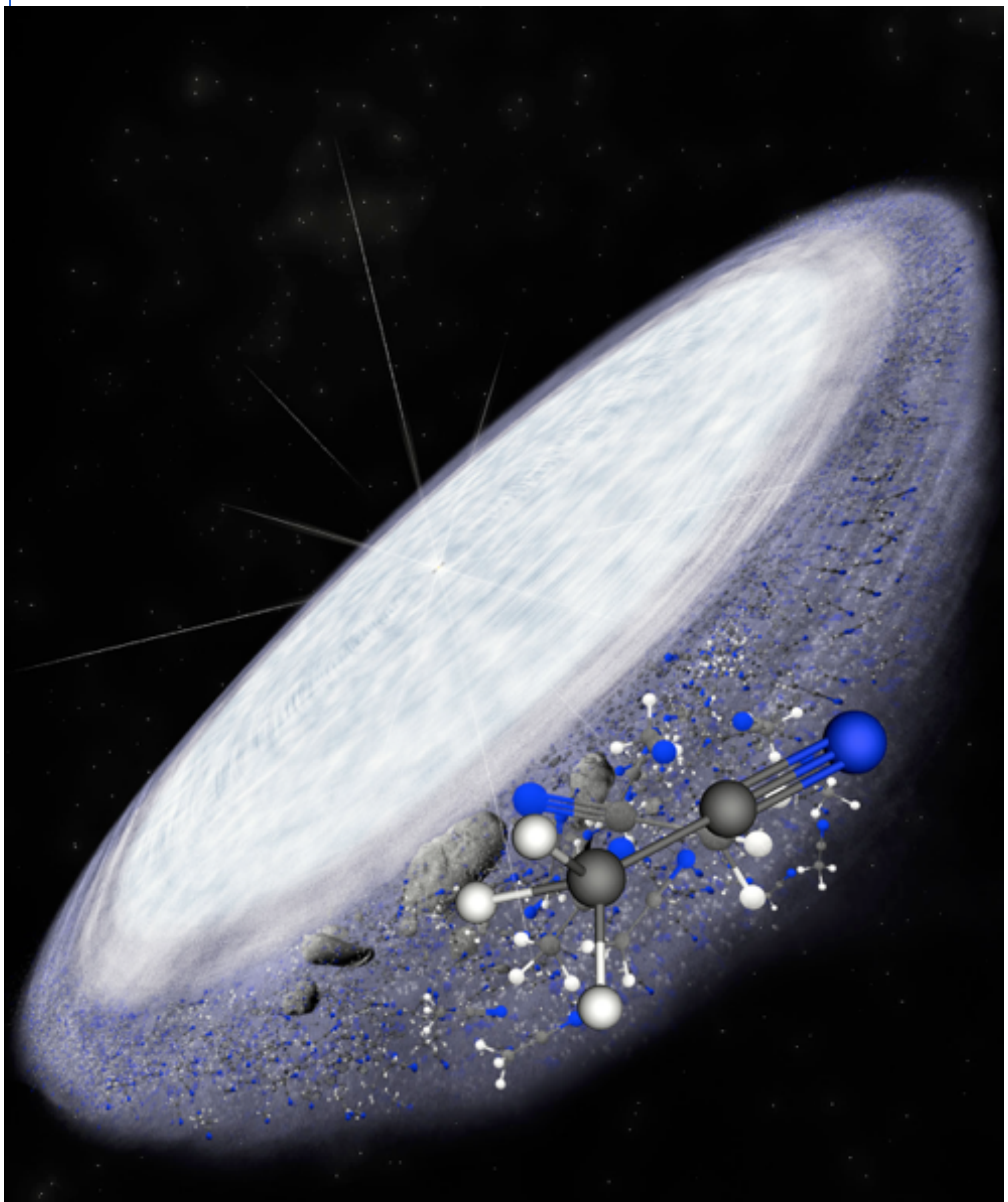


(Qi et al. 2013)



(Dent et al. 2014)

Complex molecules in protoplanetary disks

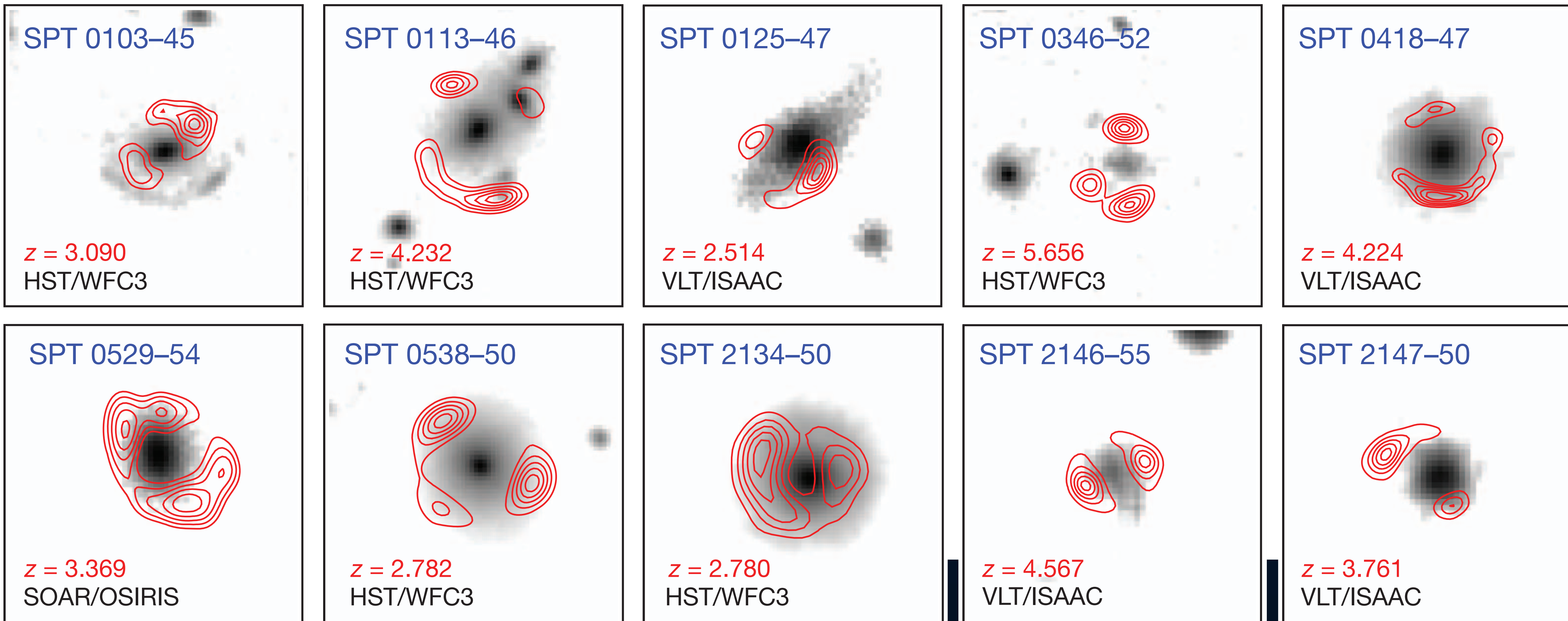


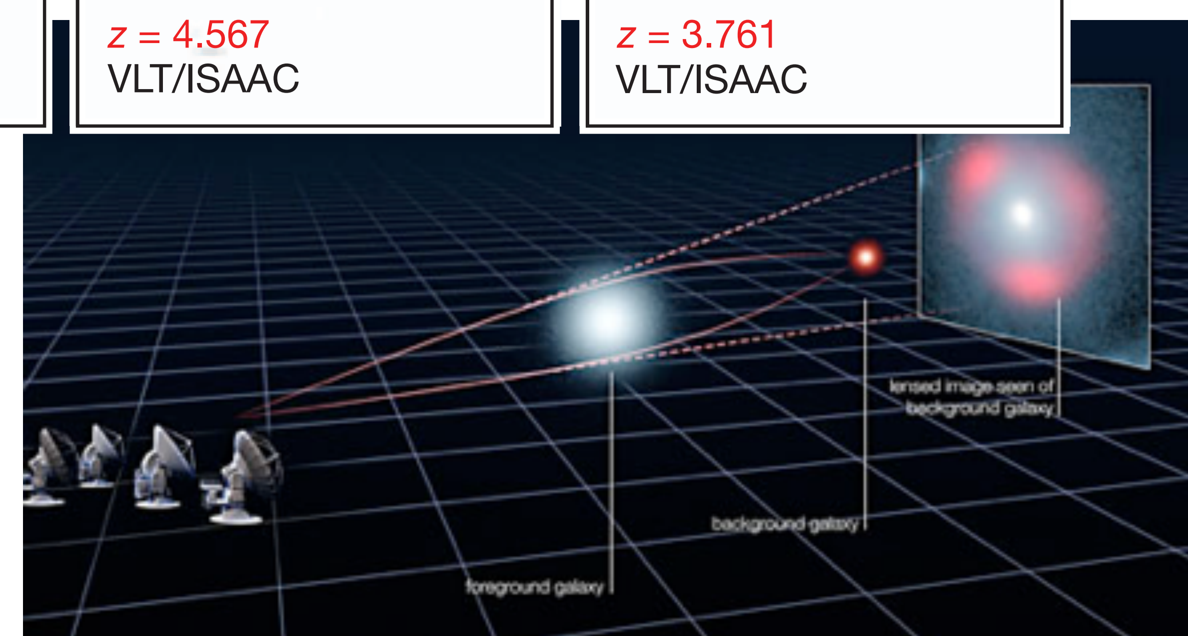
(Oeberg et al. 2015)

- First detection of complex molecules in disks
  - ➢ CH_3CN
  - ➢ (also HCN and HC_3N)
- Abundance similar to comets in SS
  - ➢ COMs accompany simpler volatiles in protoplanetary disks
  - ➢ The rich chemistry of the primordial SS is not unique

The first ALMA redshift survey

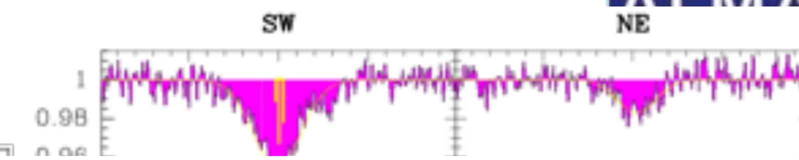
- SPT submillimetre galaxies; B3 spectral survey
  - Vieira et al. 2013; Weiss et al. 2013; …

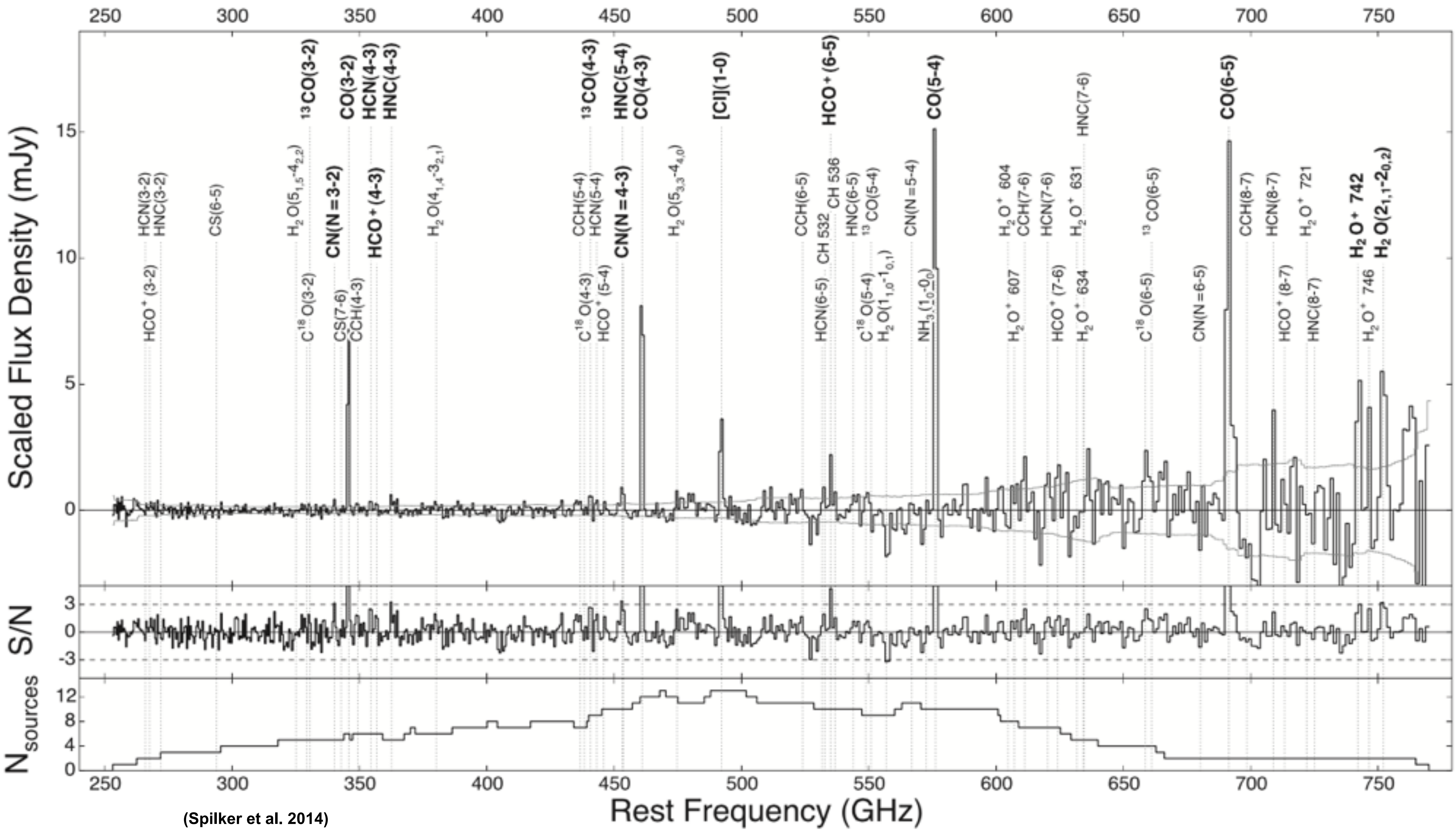




Galaxies, high redshift Universe

- Feedback, Chemistry





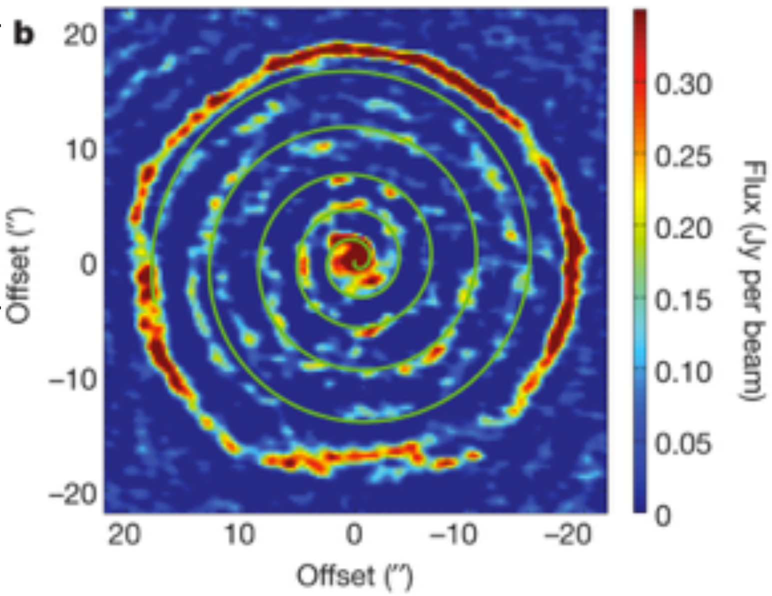
(Spilker et al. 2014)

(Bolatto et al. 2013)

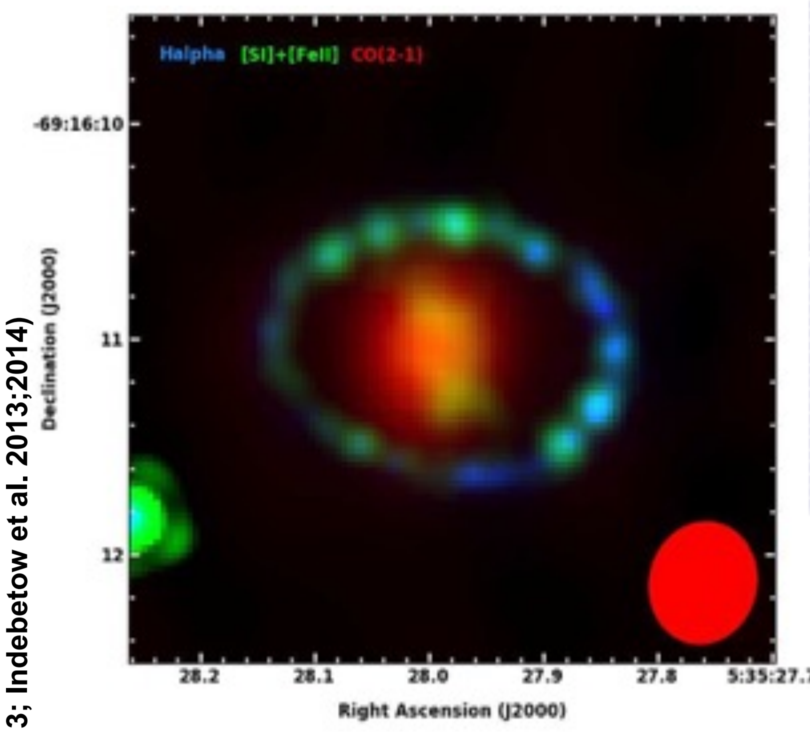
Enrichment of the ISM

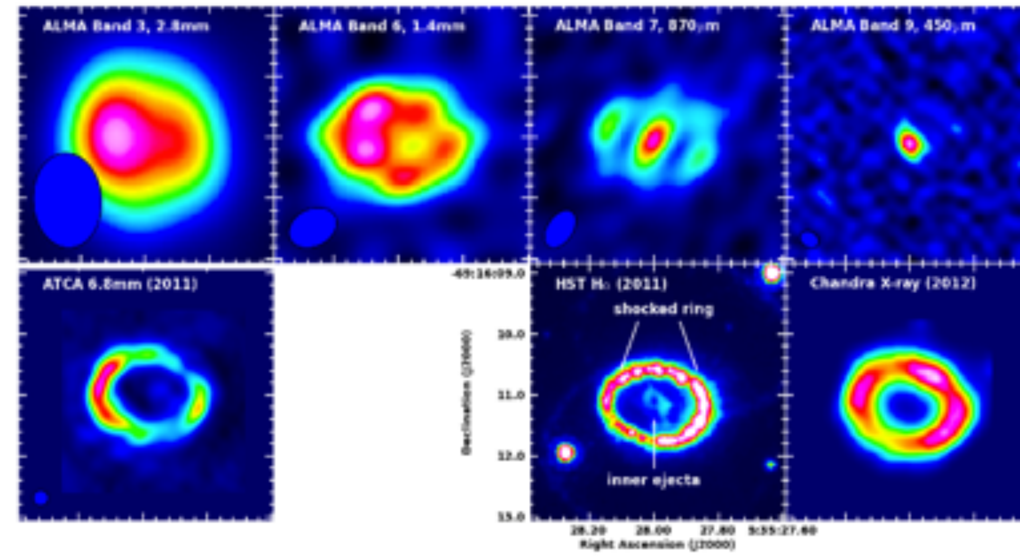
- Late stages of stellar evolution, supernovae, GRBs

(Maercker et al. 2012)

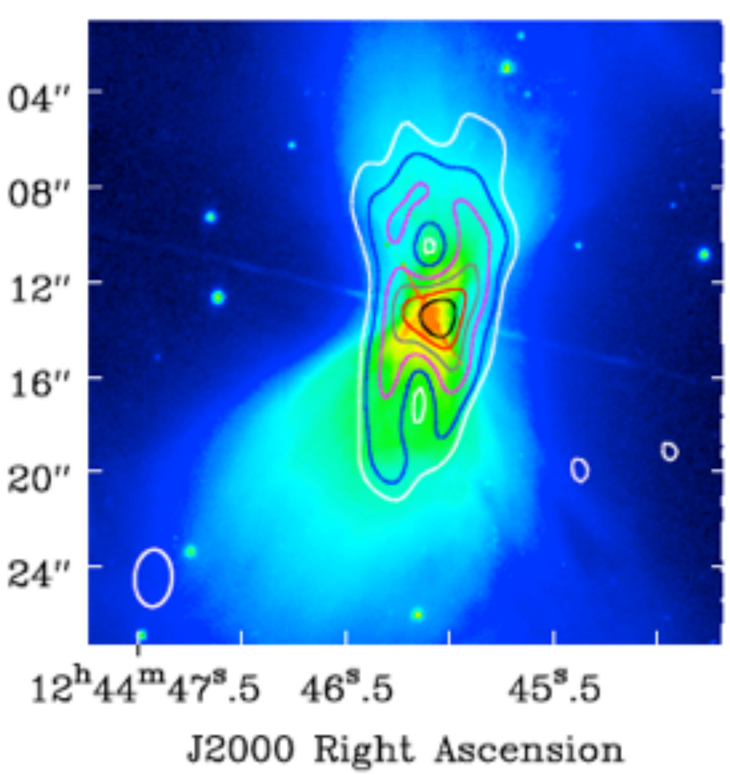


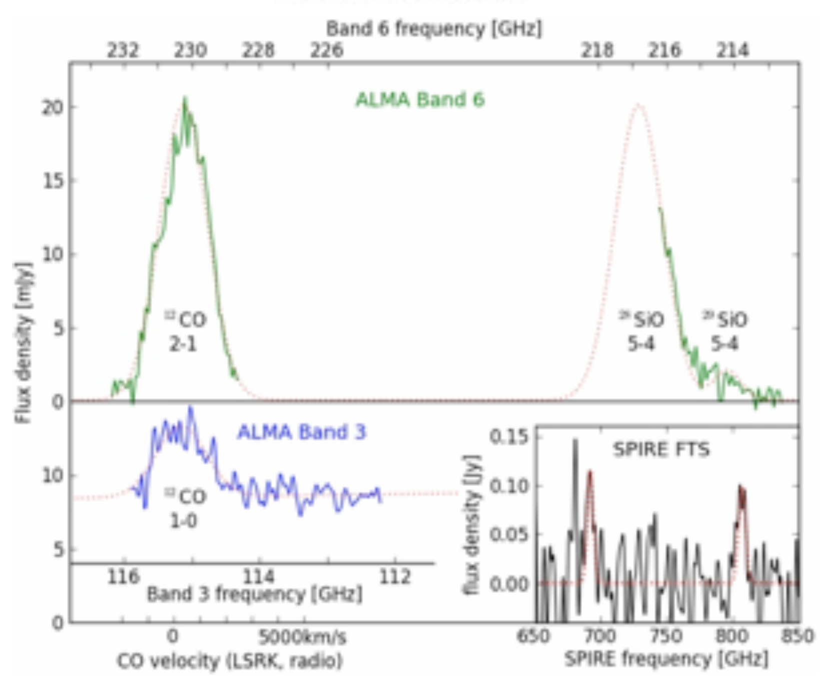
(Kamenetzky et al. 2013; Indebetow et al. 2013;2014)

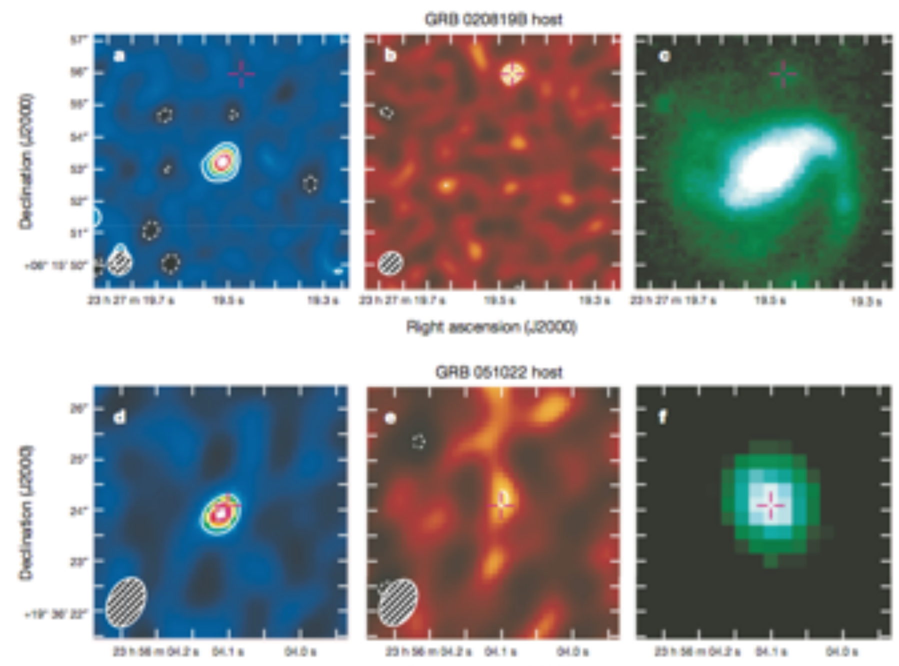




(Sahai et al. 2013)

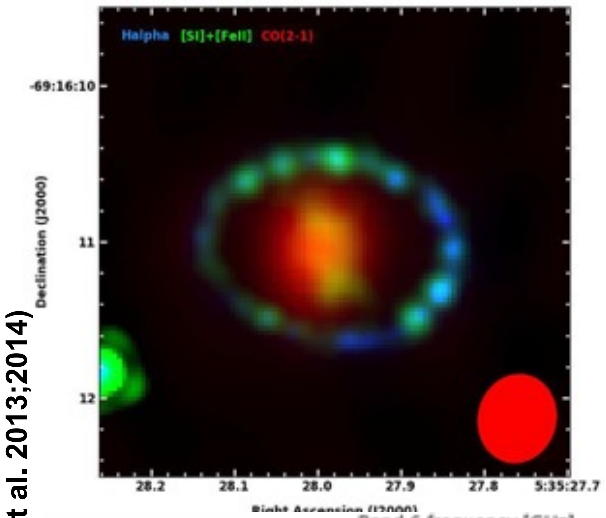




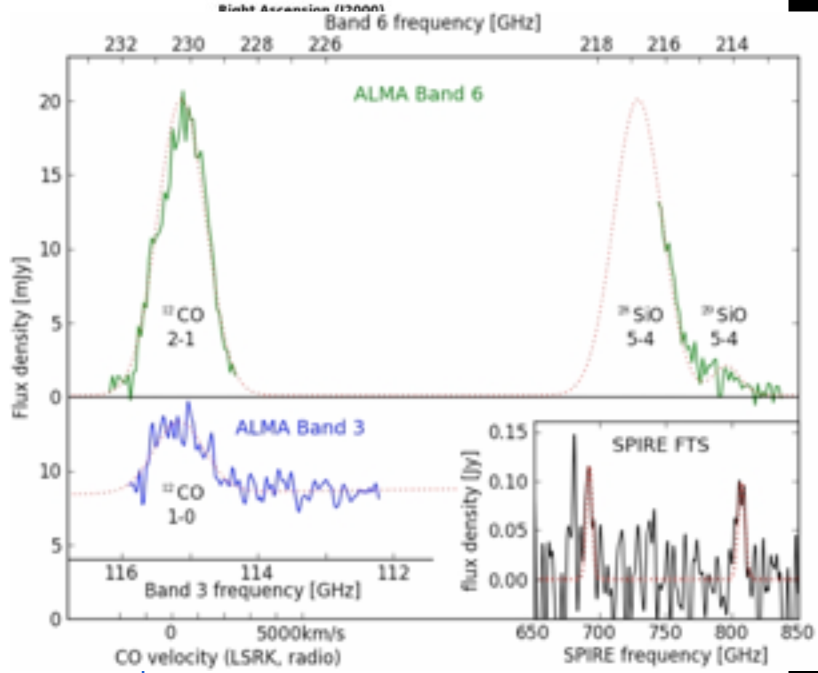


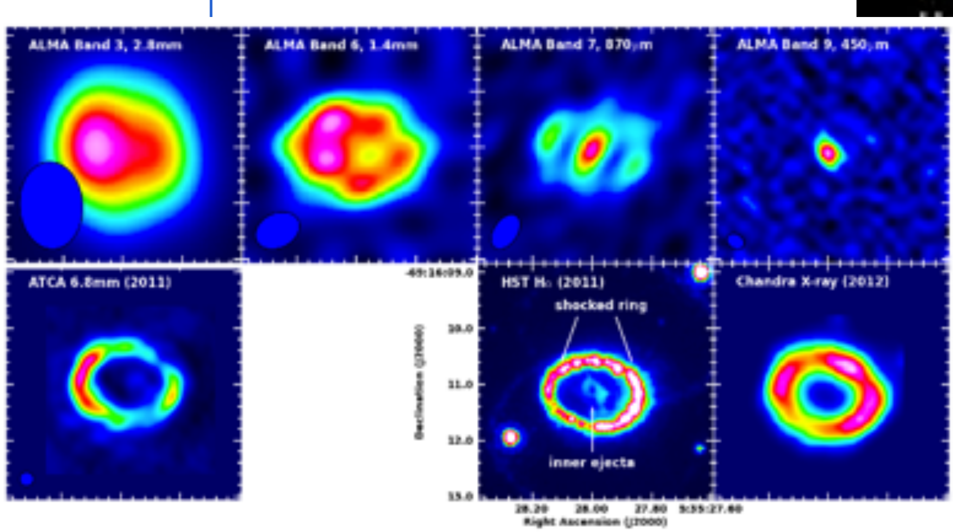
(Hatsukade et al. 2014)

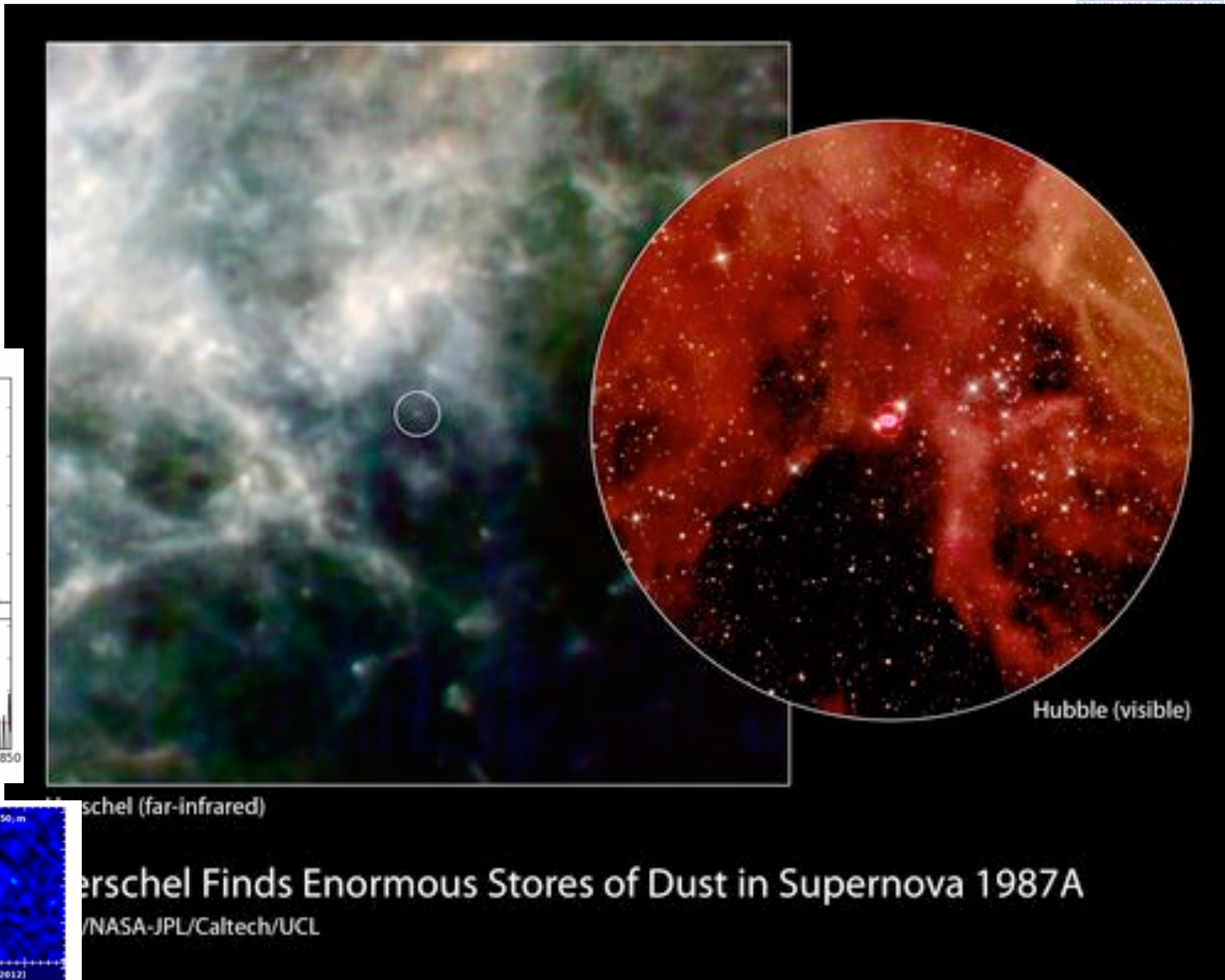
SN1987A



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

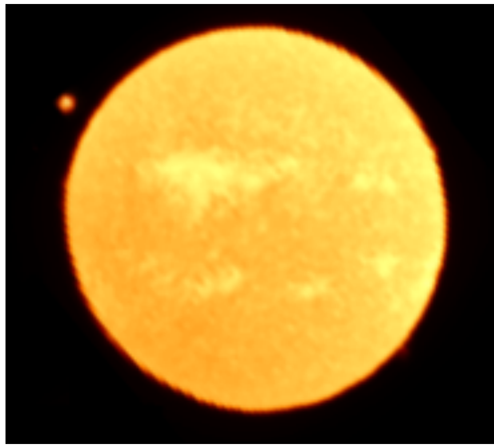


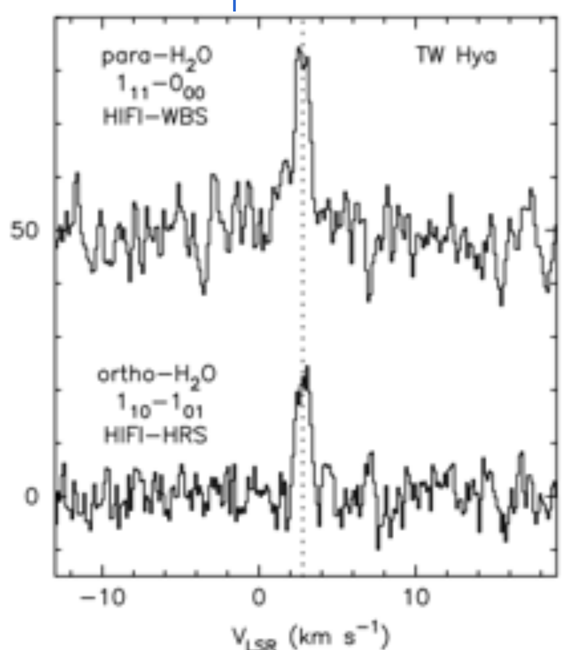




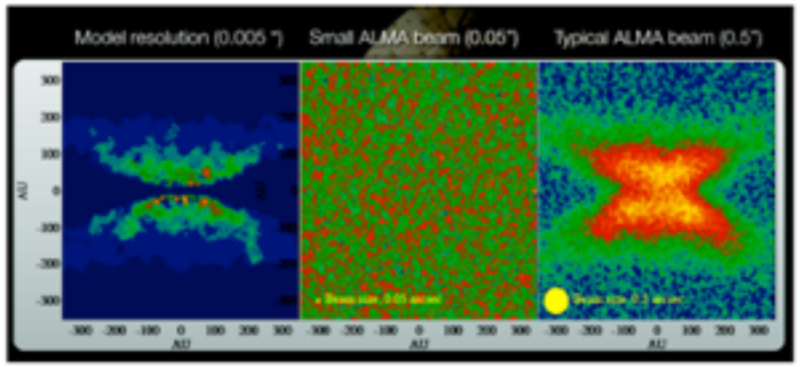
Science Priorities for the Future

- 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

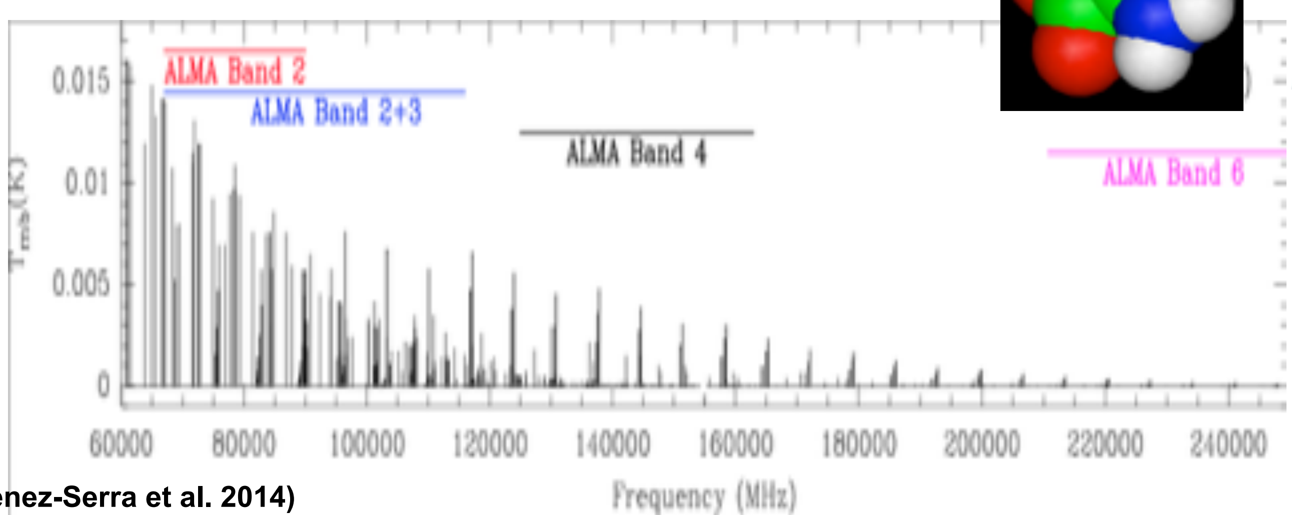




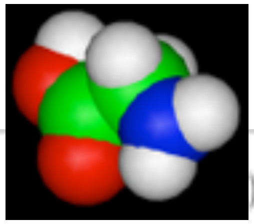
(Hogerheijde et al. 2011)

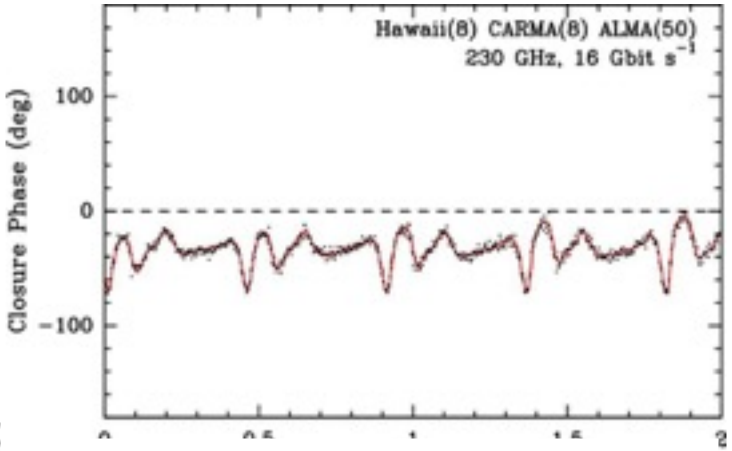


(Brinch et al. 2012)

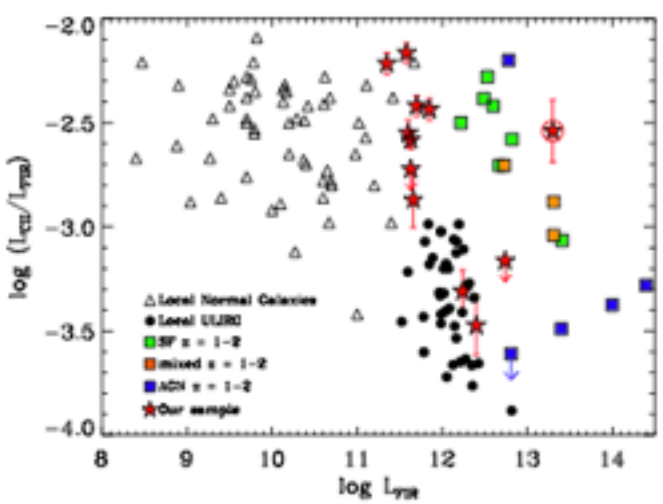


(Jimenez-Serra et al. 2014)





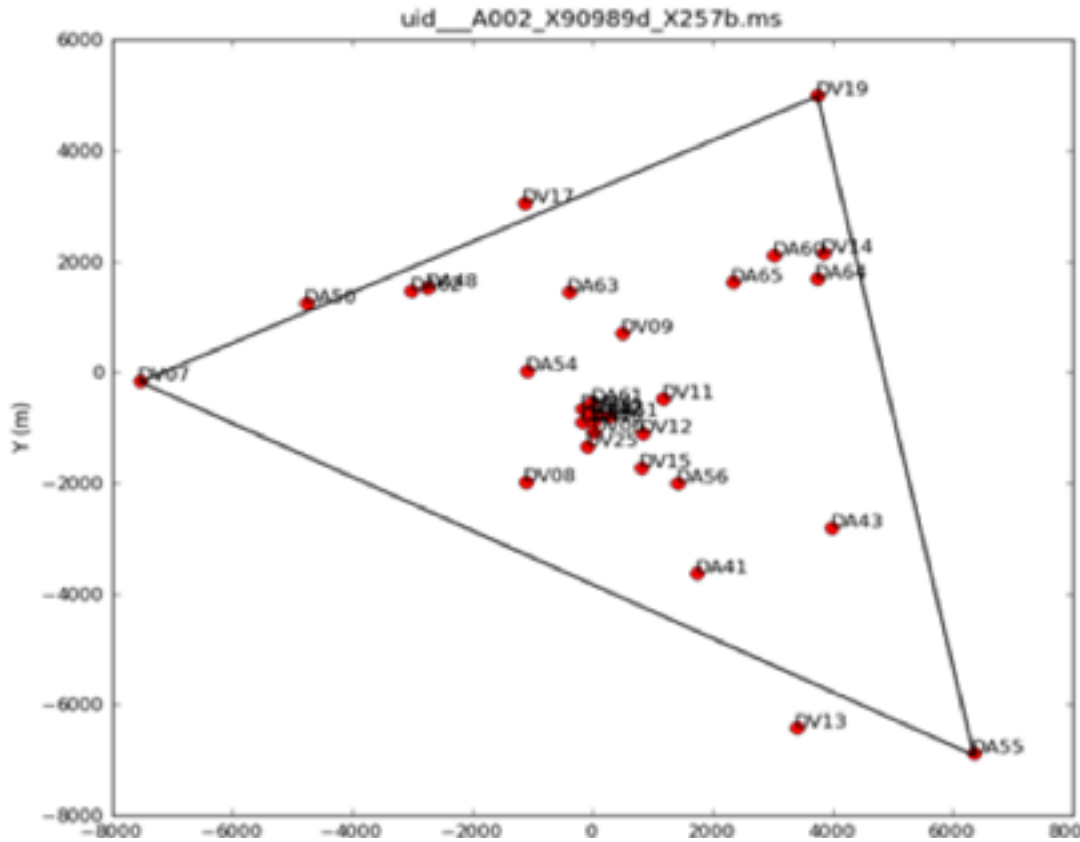
(Doleman et al. EHT project)

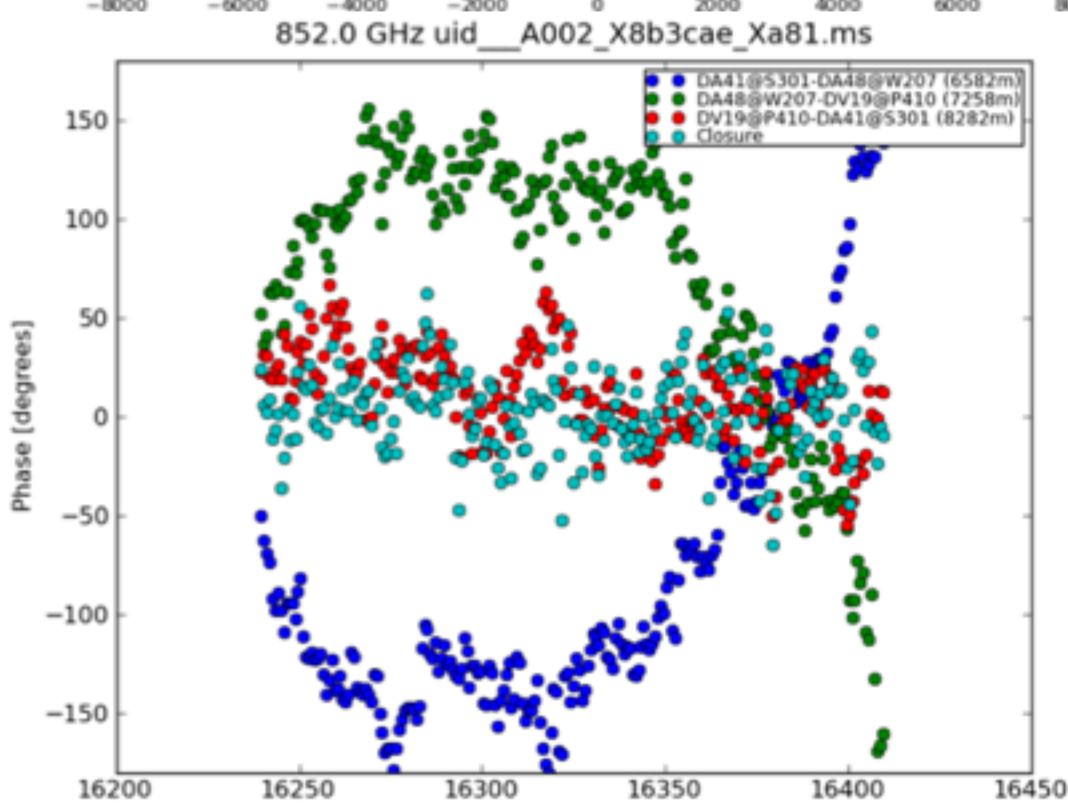


(Rigoupolou et al. 2014)

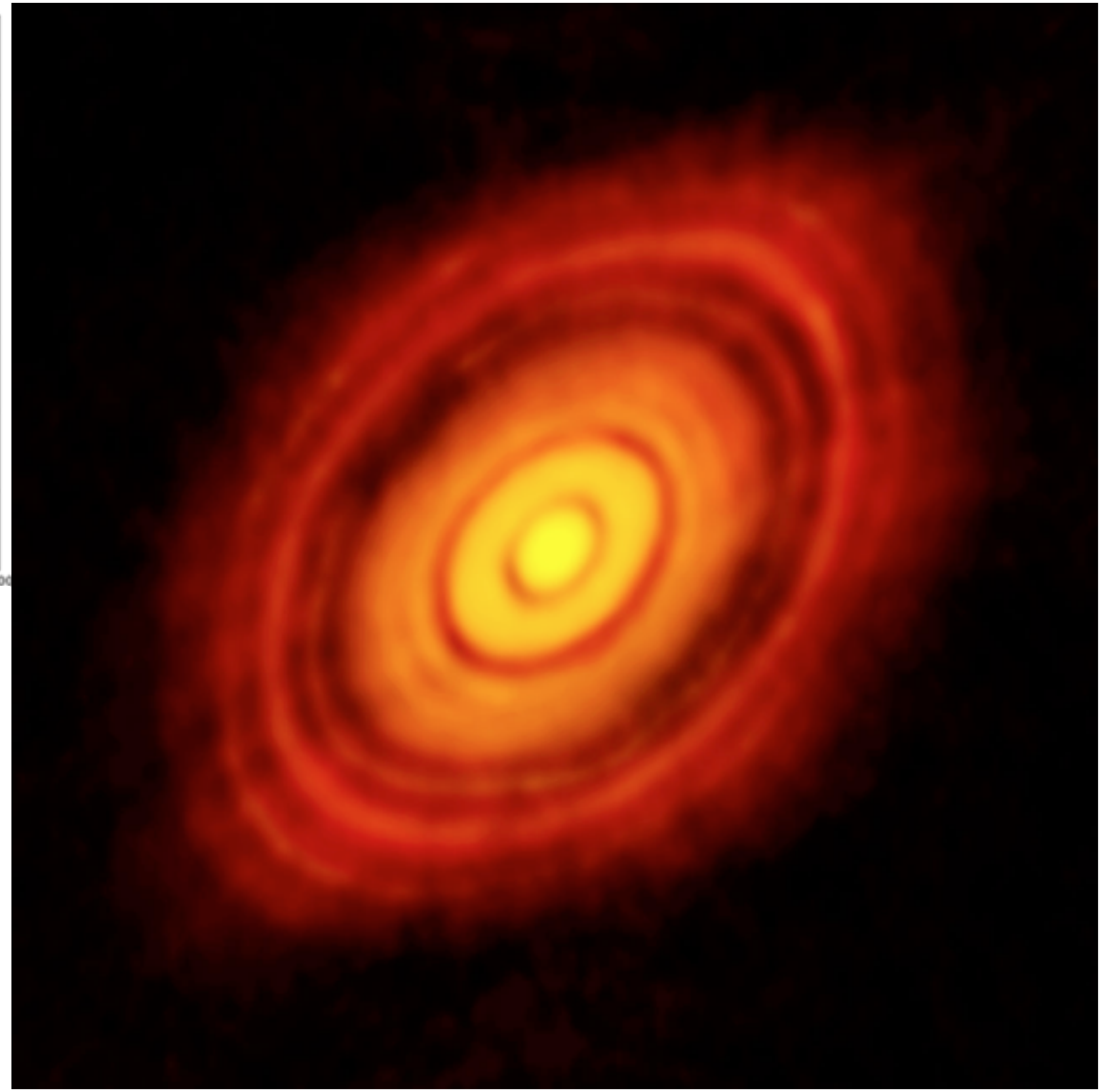
A glimpse of ALMA future capabilities

- Long Baselines Campaign - Sep-Nov 2014





HL Tau protoplanetary disk



A glimpse to ALMA future capabilities

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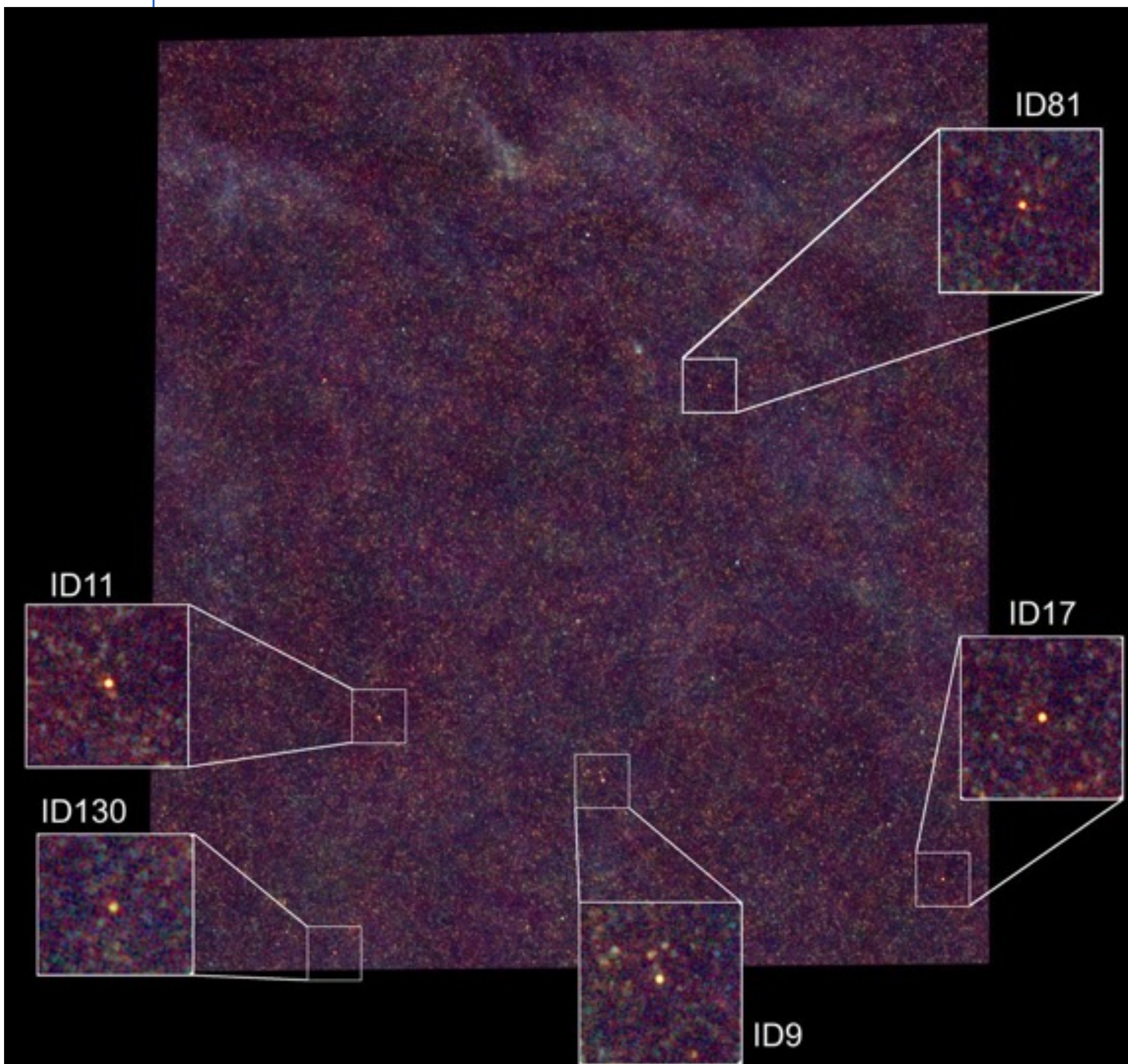
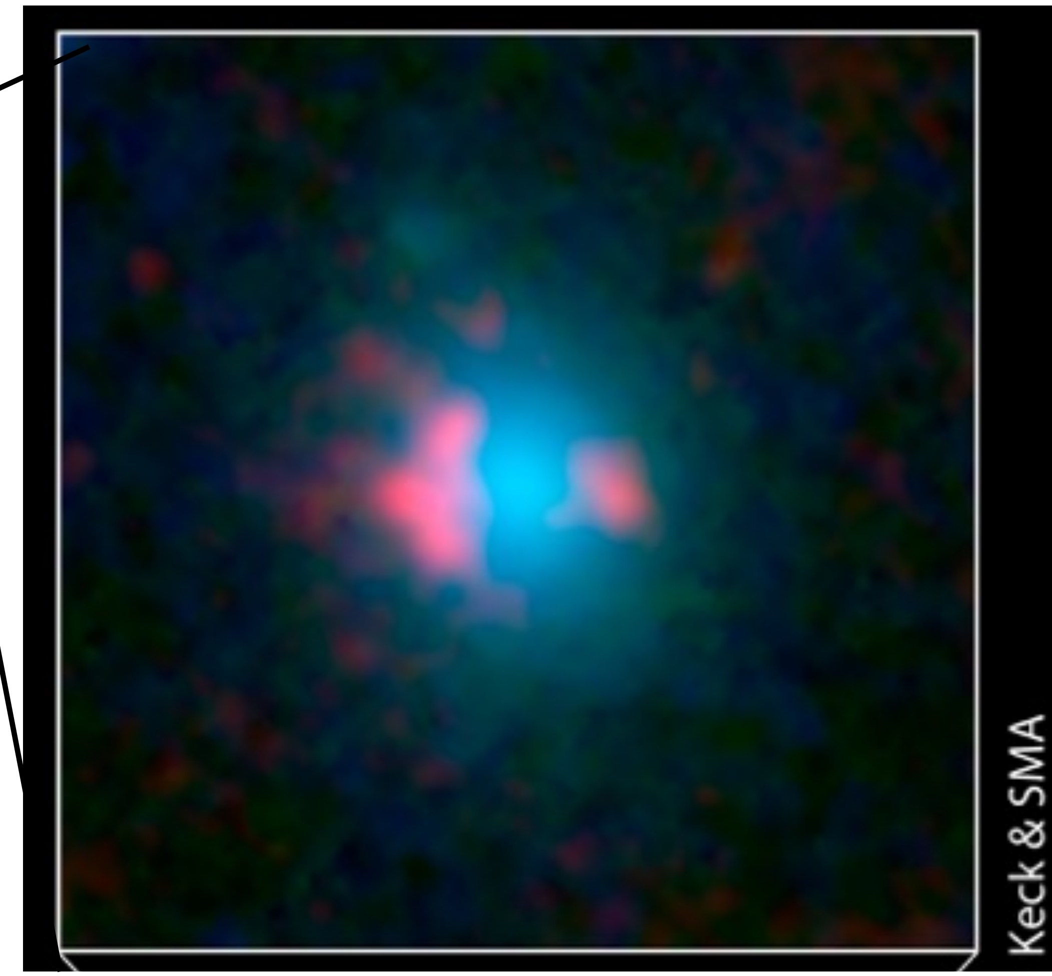
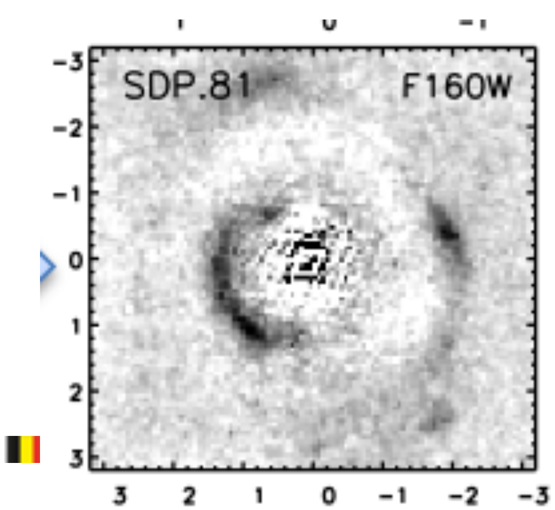
SDP 81 - Lensed SMG



HATLAS
Eales+

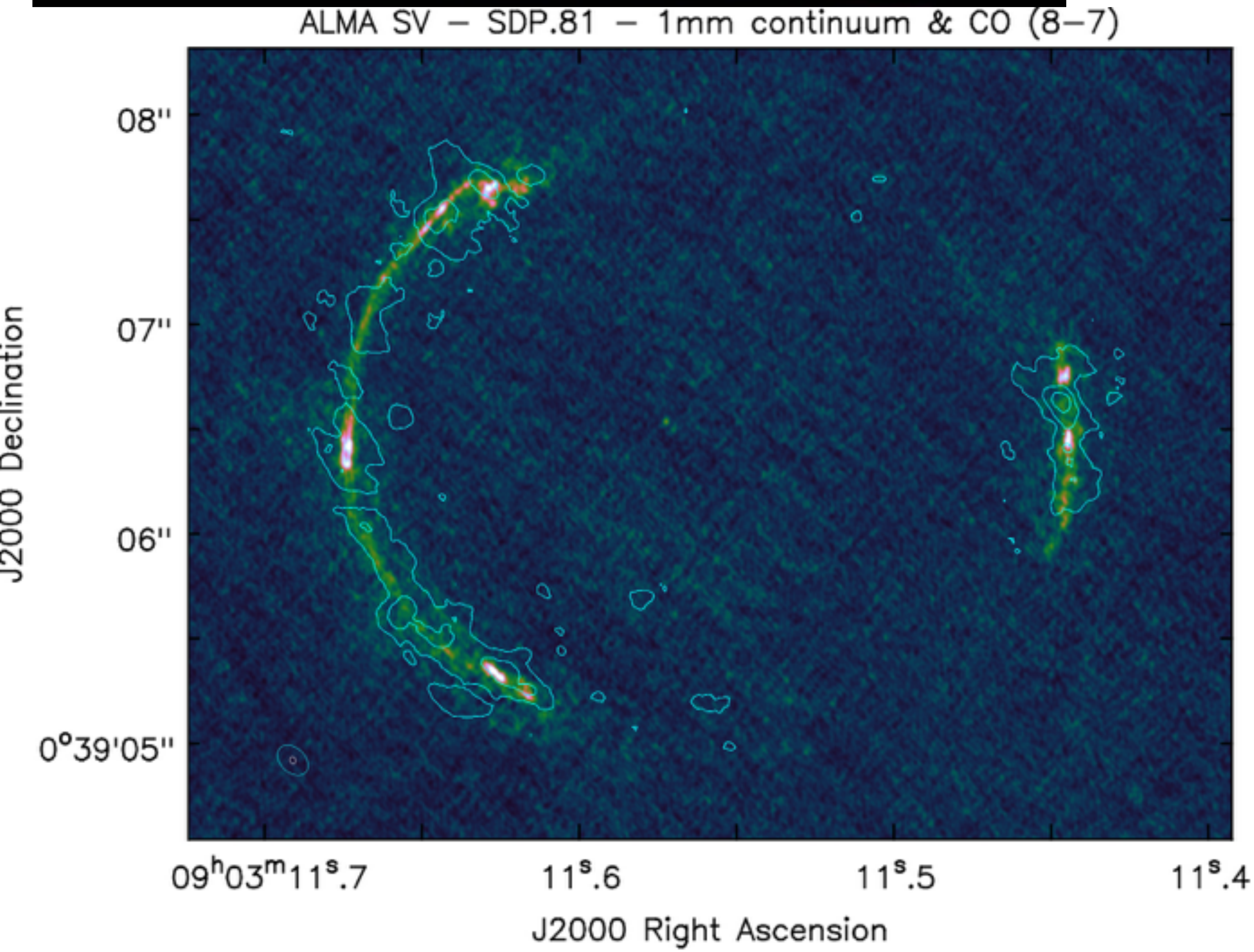


Negrello+2010;2015

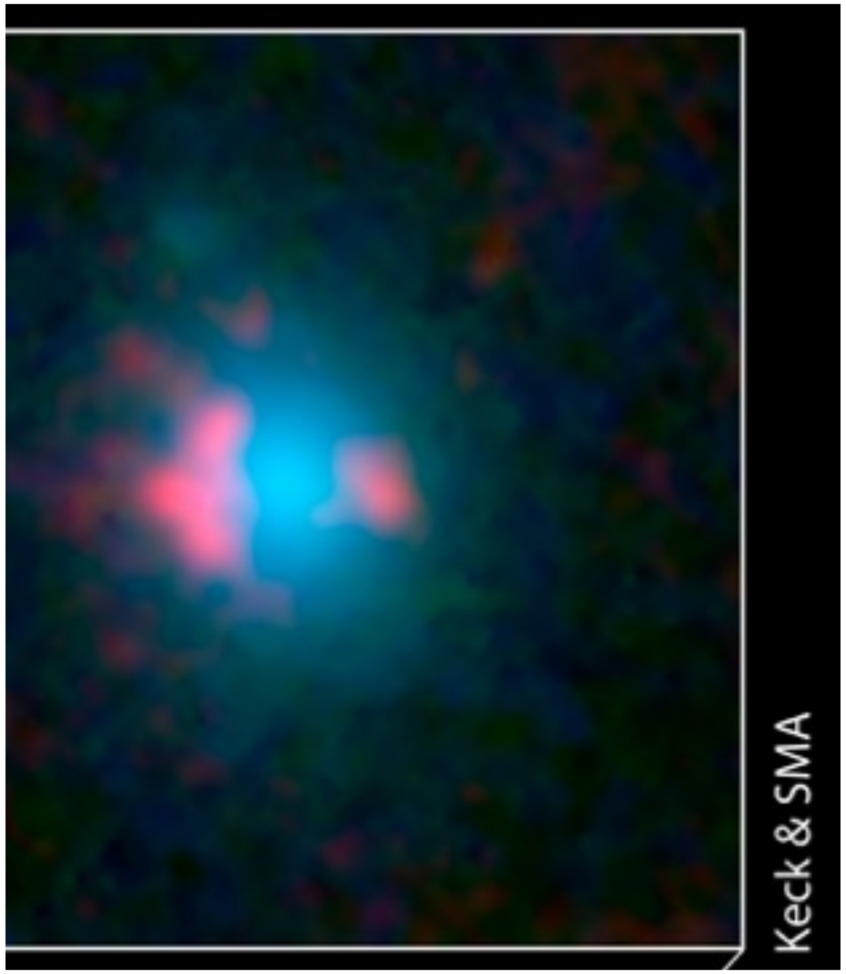


A glimpse to ALMA future capabilities

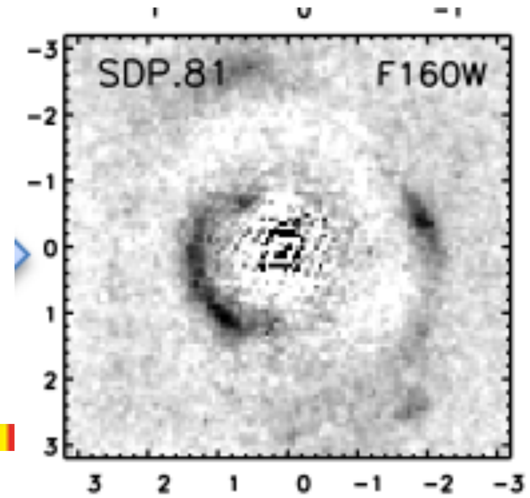
- Long Baselines Campaign - Sep-Nov 2014 -



SDP 81 - Lensed SMG



Negrello+2010;2015



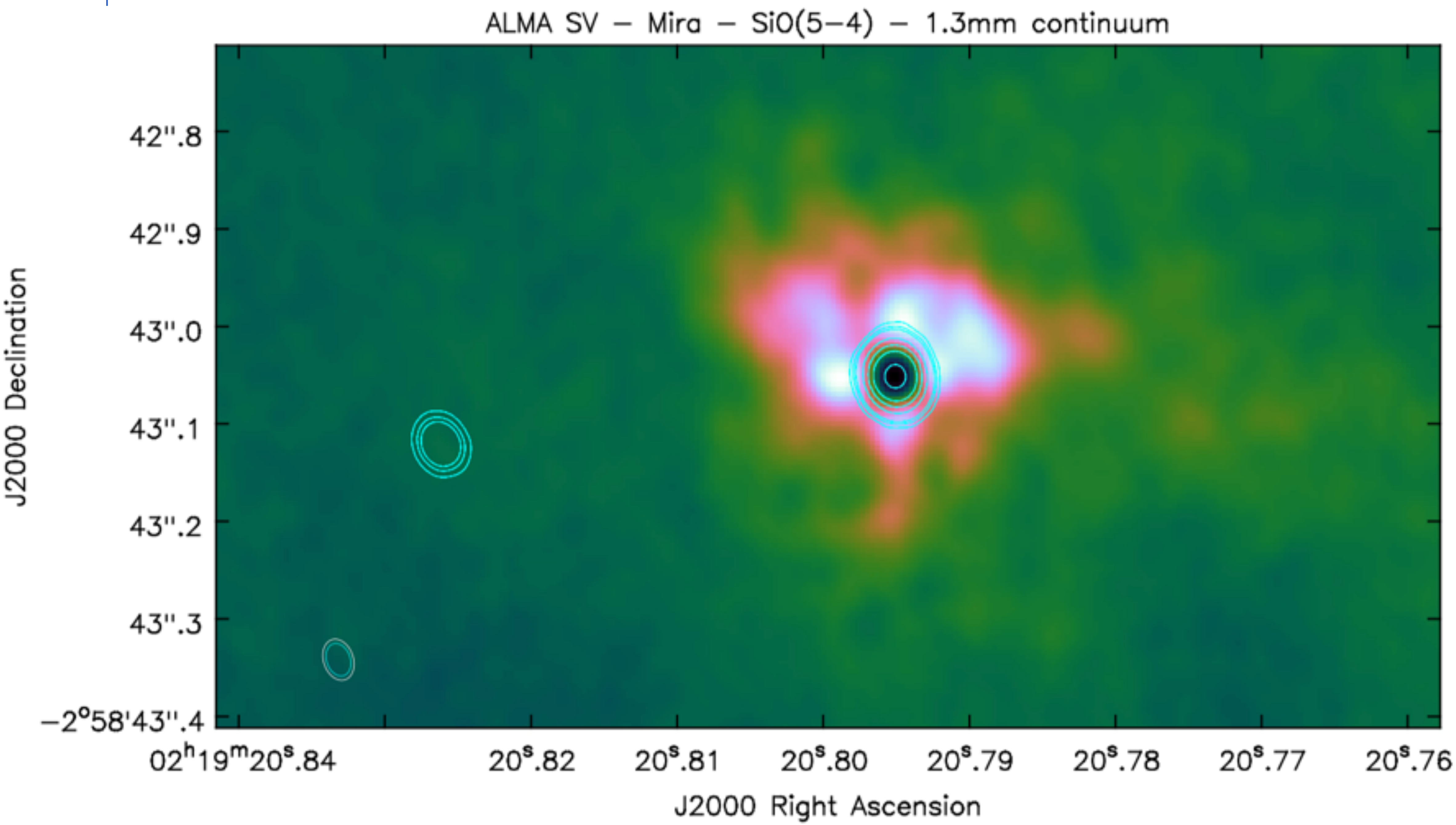
HATLAS

Eales+

A glimpse to ALMA future capabilities

- Long Baselines Campaign - Sep-Nov 2014 - **Data Public Today**

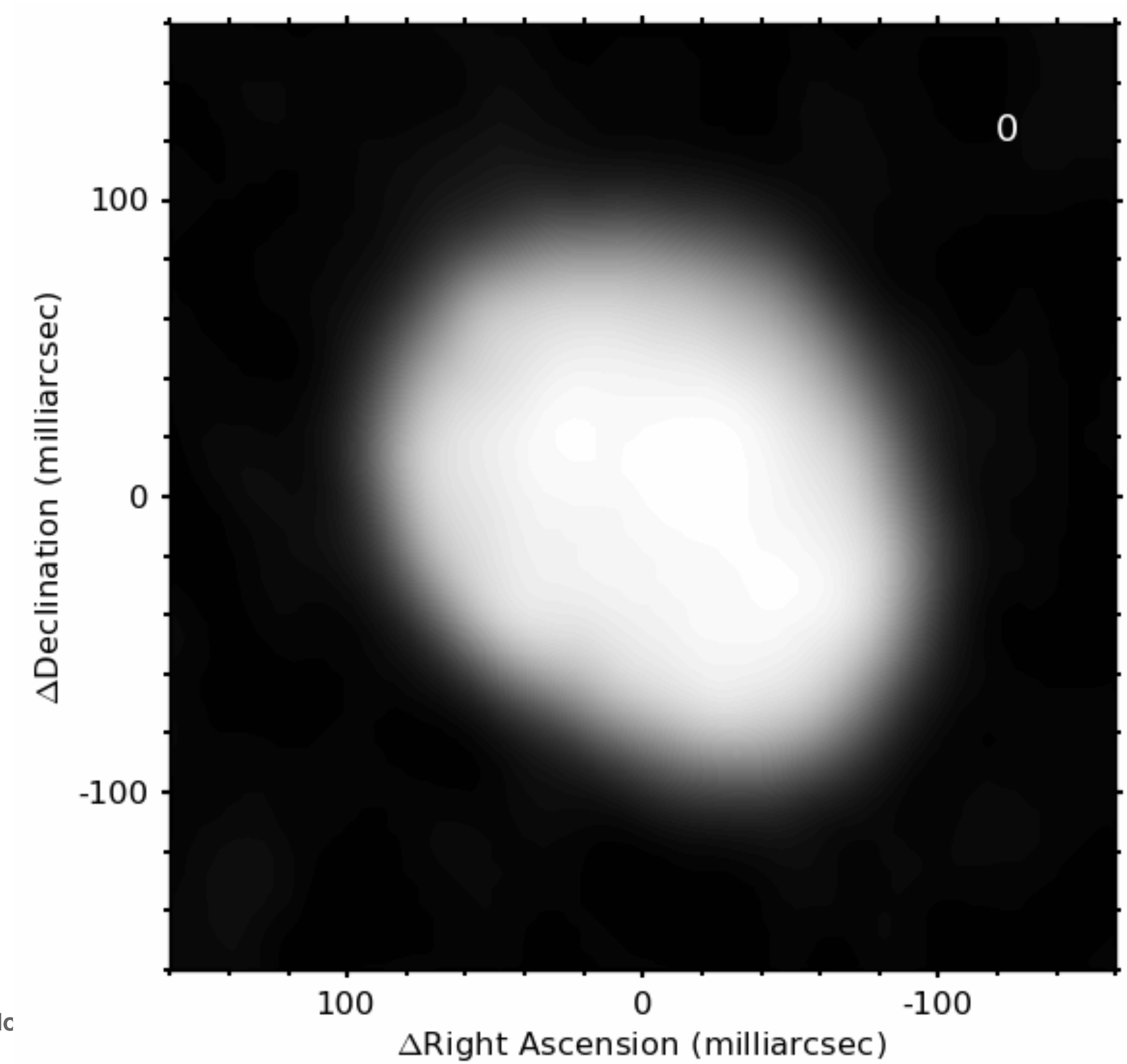
MIRA - AGB star



A glimpse of ALMA future capabilities

- Long Baselines Campaign - Sep-Nov 2014

Juno



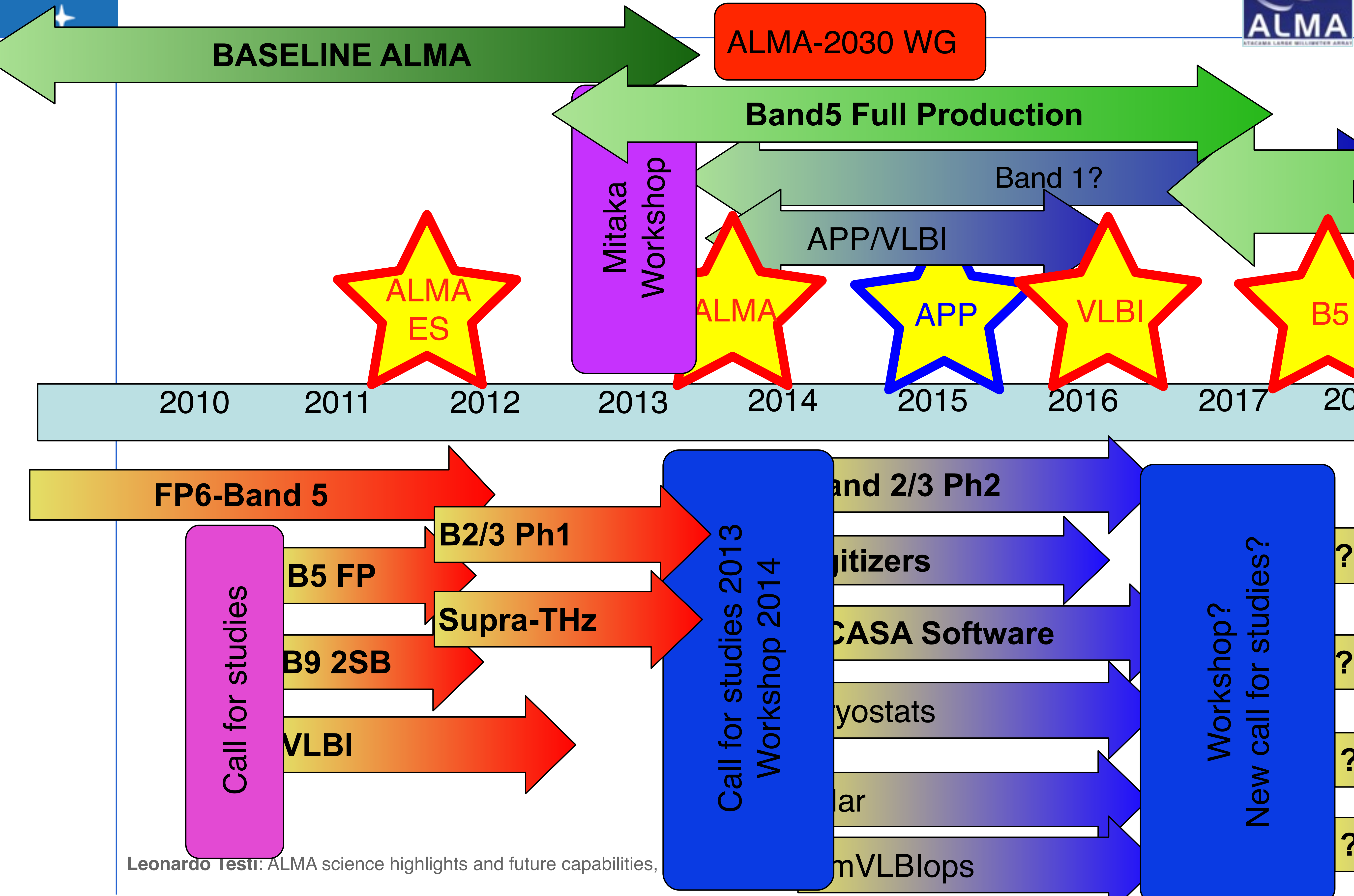
Timeline and near-/mid-term strategy

- Top priority: complete commissioning of the baseline ALMA-trilateral program
  - Full polarization, reach the target overall efficiency, full zero spacing capabilities, solar modes

- Recovery as part of the early development plan of science-critical capabilities descoped before 2005, revisit and develop key technologies
  - Bands 5, 1 and 2, mmVLBI, subarrays, data analysis software, data rates
  - Where possible deploy more advanced technologies/capabilities
  - Develop new ideas/technologies for future developments

- Develop a scientific vision for ALMA in 2030
  - Science questions, complementary facilities, pathways for development

Timeline summary



Options for 2020s and beyond

- <u>Larger bandwidths and better receivers</u>
  - Datarate/data volume increase
  - Aim to cover full bands instantaneously
- <u>Longer baselines</u>
  - Brightness sensitivity issues, ideally linked to sensitivity increase
- <u>Increased wide field mapping speed</u>
  - Panoramic detectors for interferometry (!)
  - Datarate/datavolume
- <u>The role of Archive will be more prominent than today</u>
  - Code to data => results to users

Outlook on Cycle 4

N.B.: These are all goals (some low risk, some somewhat higher)

- Improved Spectral Scans
- Spectral line I,U,Q Stokes
- mmVLBI
- Solar Observing
- OTF Interferometry (mapping speed, better uv reconstruction)
- Several technical improvements: correlator linearity and modes, 90deg switching, single dish continuum, B9/10 sideband separation, V-stokes, full baselines length, subarrays

Summary

- ALMA is ramping up from Early Science towards Full Science Operations. The results from Science Verification and ALMA Cycle 0, 1 & 2 are transformational
- Key improvements for Cycle 3 will be long baselines, Band 10 and better stability/efficiency. Large Programmes and mmVLBI on track for Cycle 4, Solar observing may also make it. Band 5 on track for Cycle 5.
- Short-medium term upgrades being developed consistently with science priorities
- Science driven R&D relevant for long term upgrades
- Option for a large single dish to be developed