

ALMA Science Highlights and Future Capabilities

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ESO ALMA Programme Scientist



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)

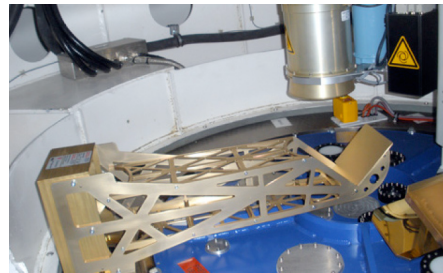
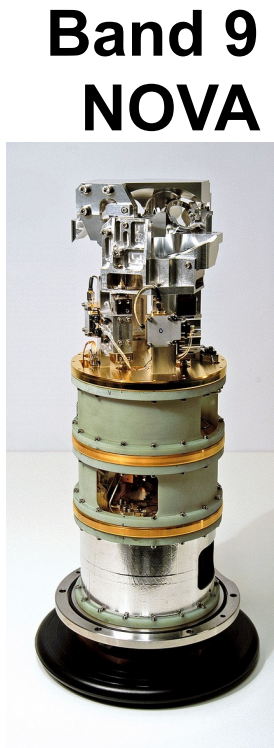


ALMA Frequency Bands Usage

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

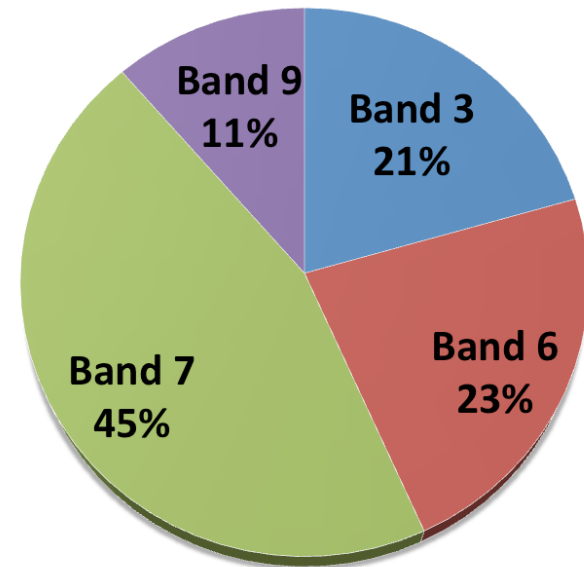


**Band 7
IRAM**



**WVR
OMNISYS**

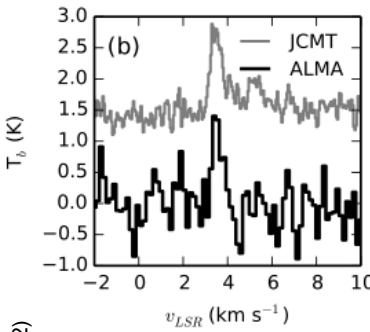
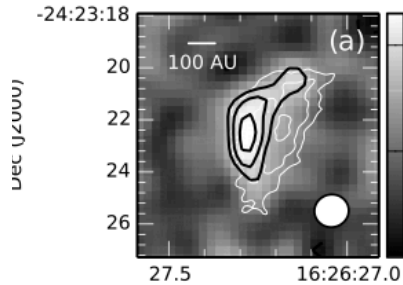
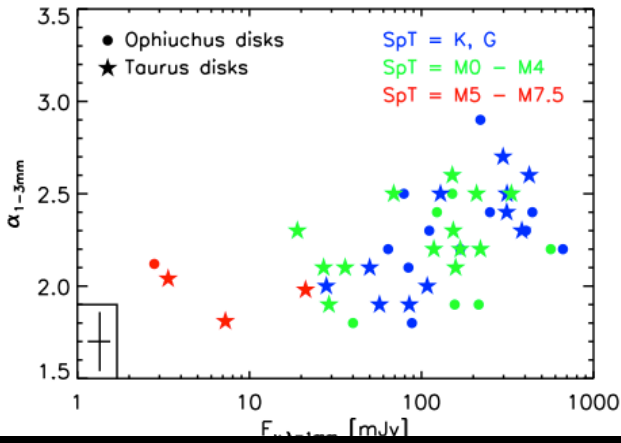
ALMA Cycle 0 Band Usage



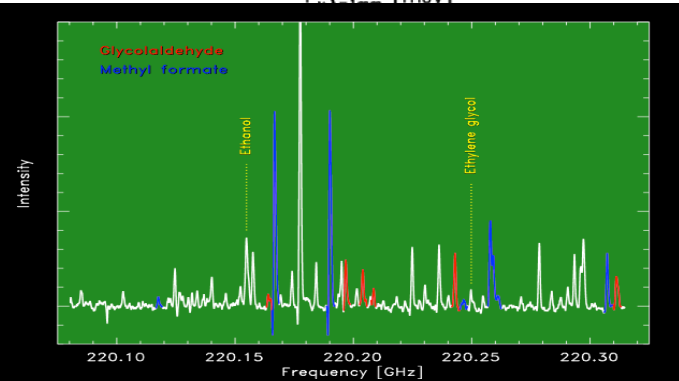
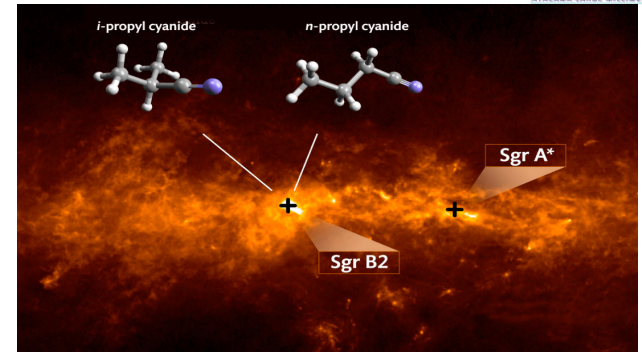
**Phase Correction
SW - U Cambridge**

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

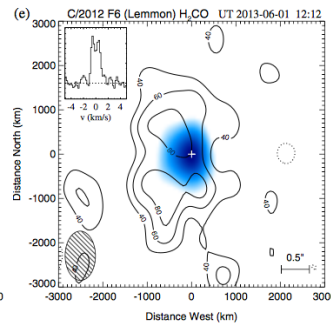
(Ricci et al. 2012; 2014)



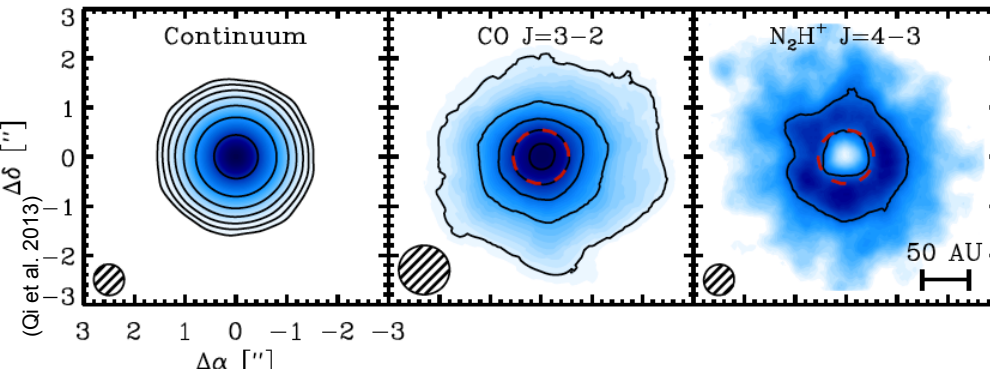
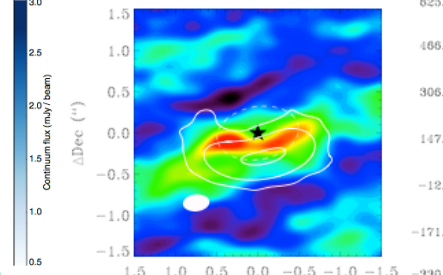
(Friesen et al. 2014)



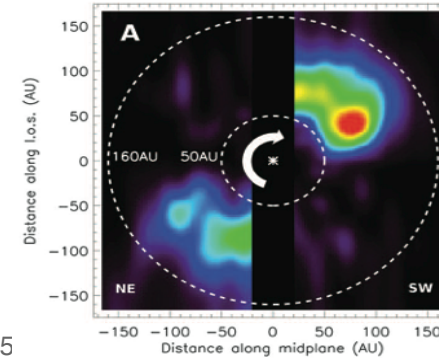
(Jorgensen et al. 2012)



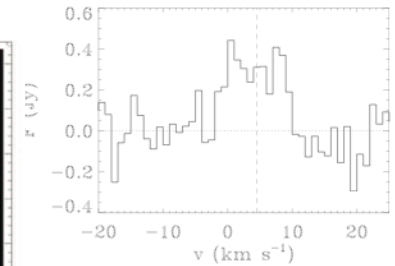
(Cordiner et al. 2014)



(Qi et al. 2013)



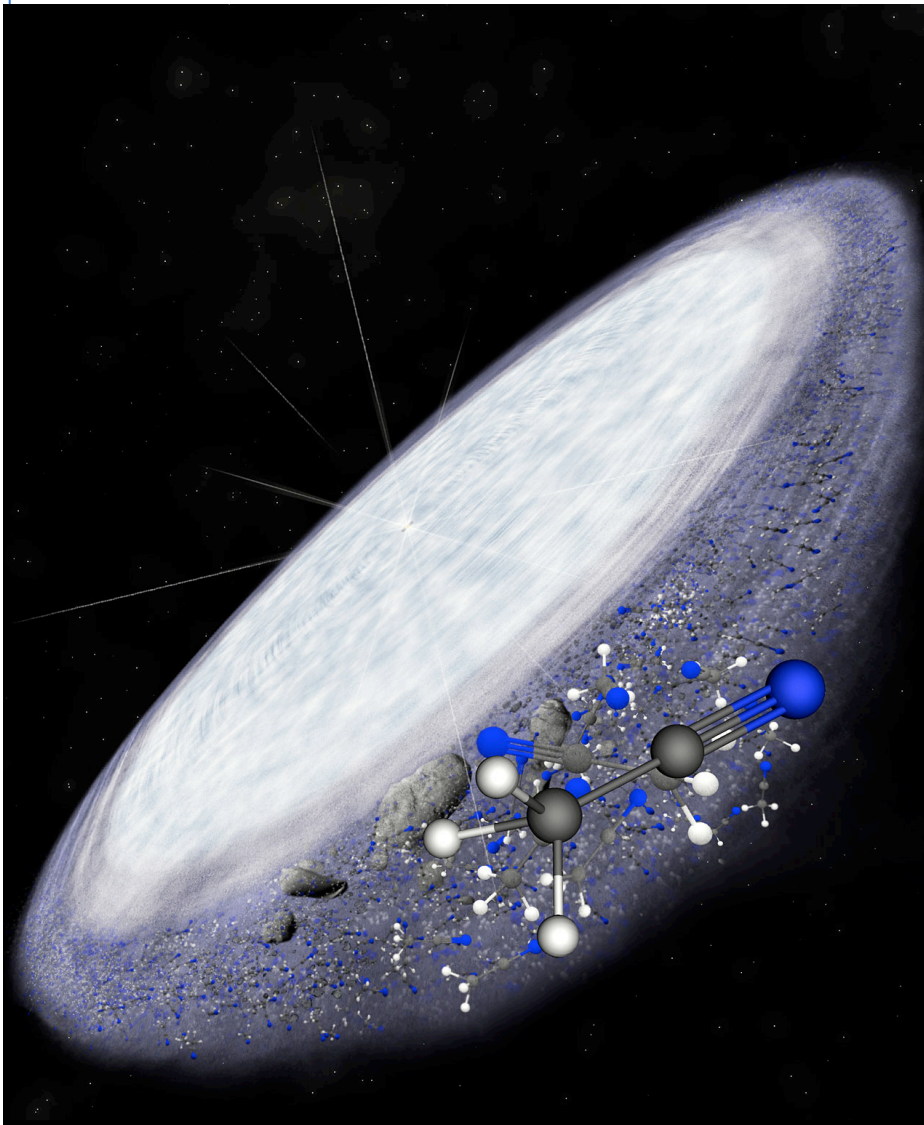
15



(van der Marel et al. 2013/2014)

(Dent et al. 2014)

Complex molecules in protoplanetary disks



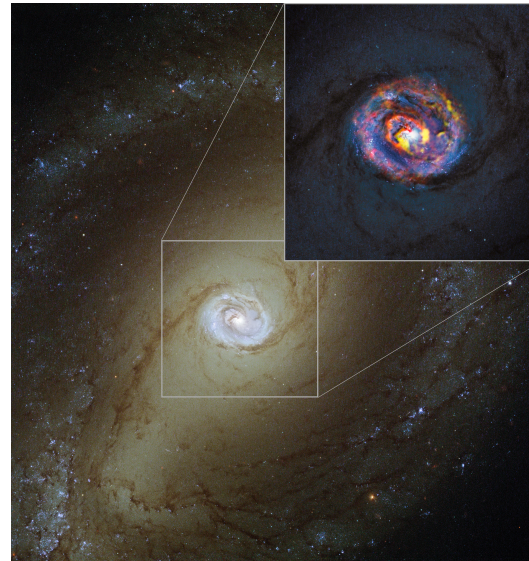
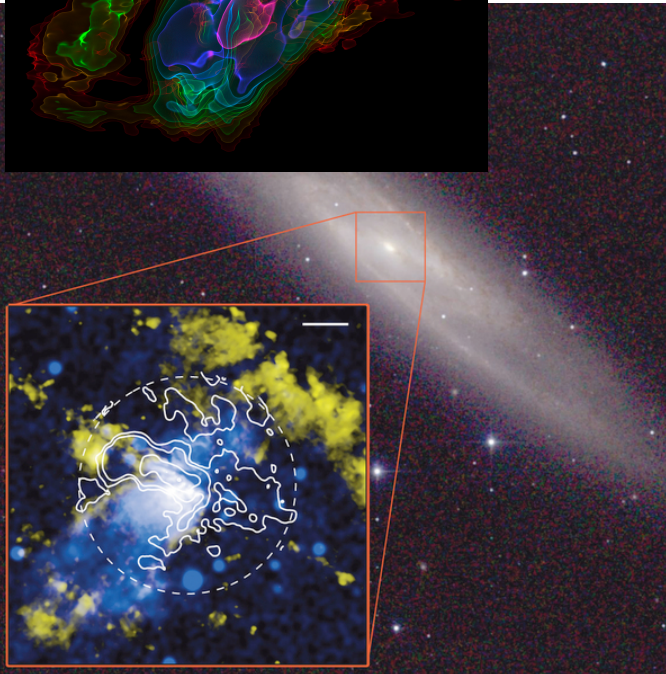
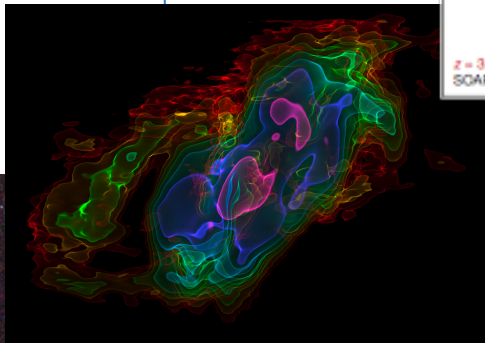
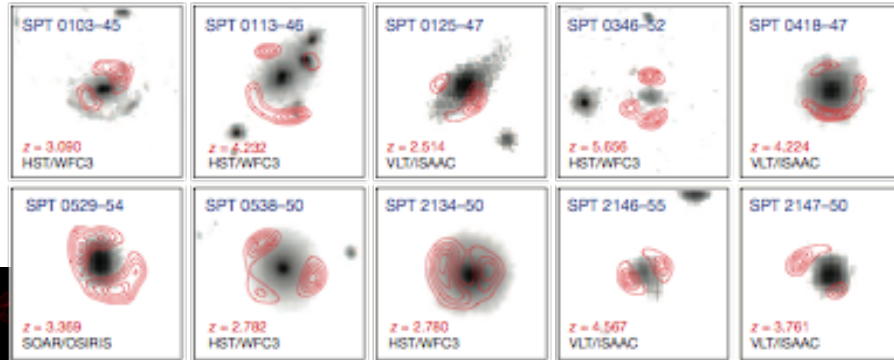
(Oberg et al. 2015)

- 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

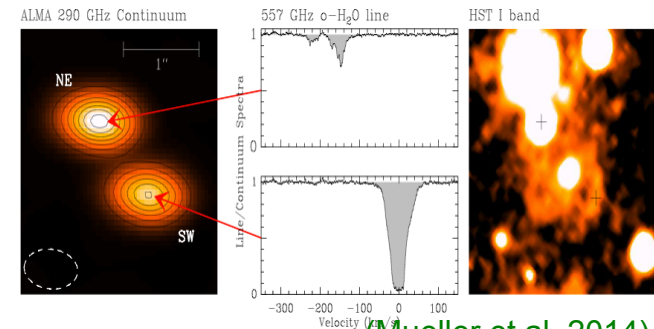
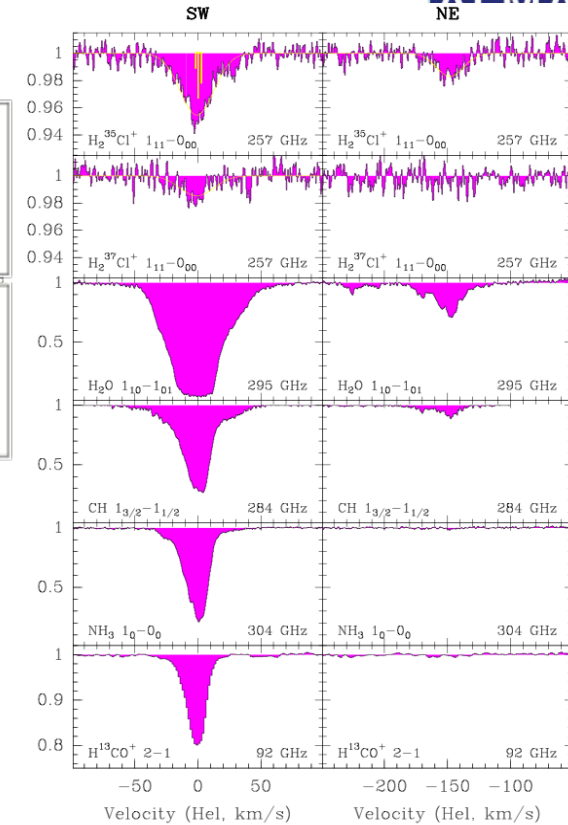
Galaxies, high redshift Universe

Feedback, Chemistry

(Vieira et al. 2012)



(Combes et al. 2013)



(Mueller et al. 2014)

(Bolatto et al. 2013)

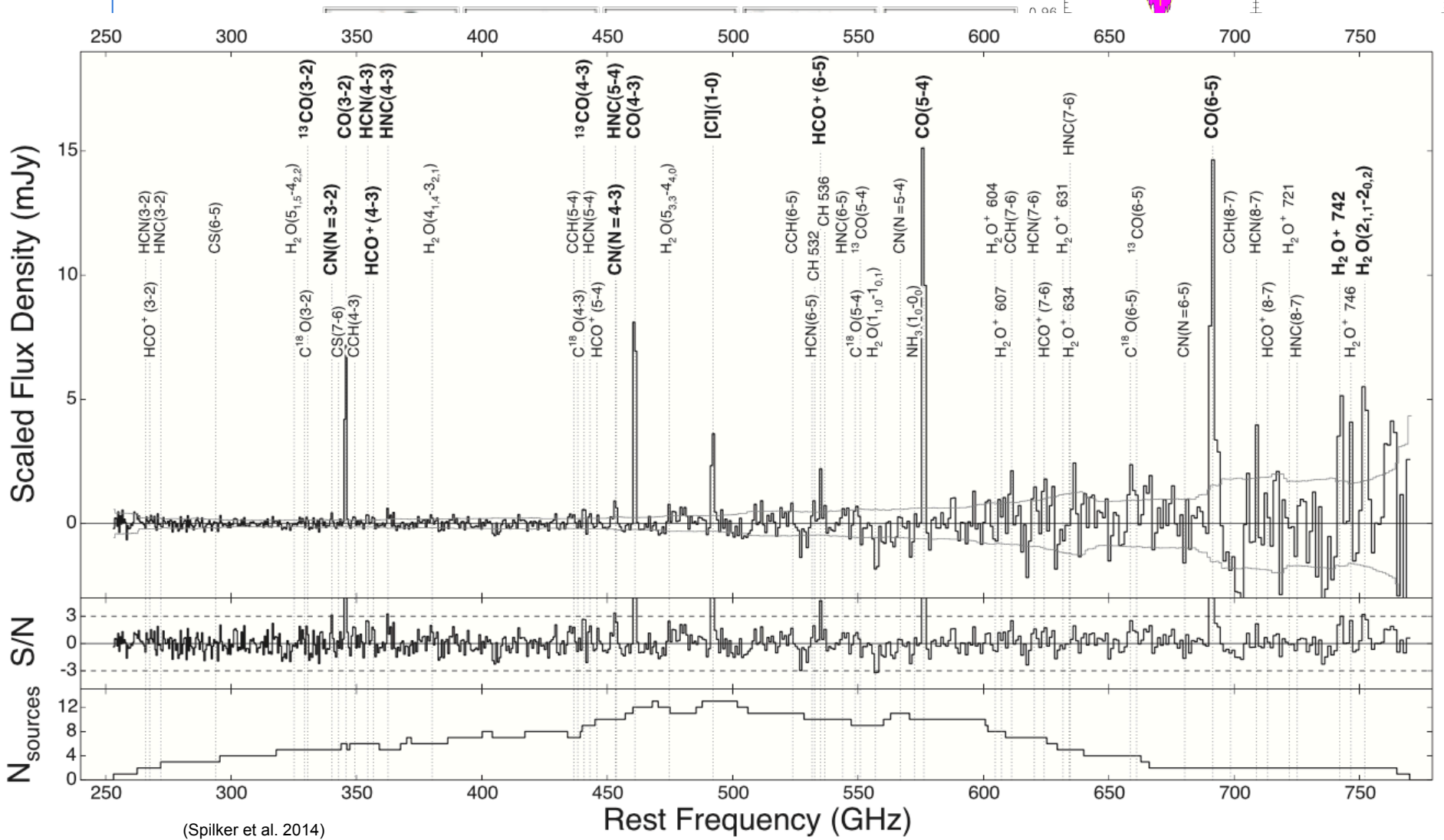
and future capabilities, 13 Apr 2015



Galaxies, high redshift Universe



Feedback, Chemistry



(Spilker et al. 2014)

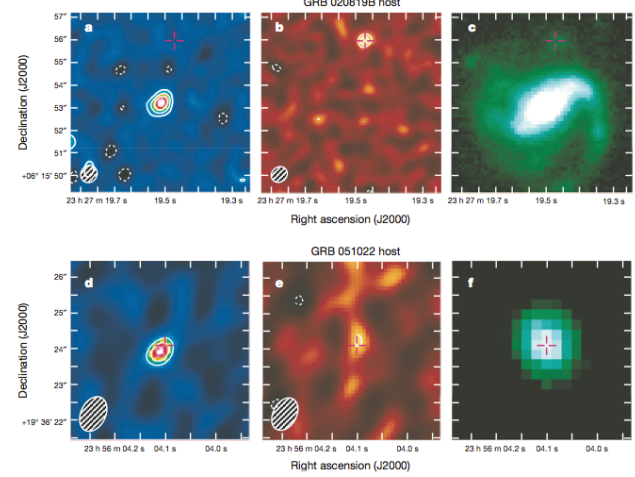
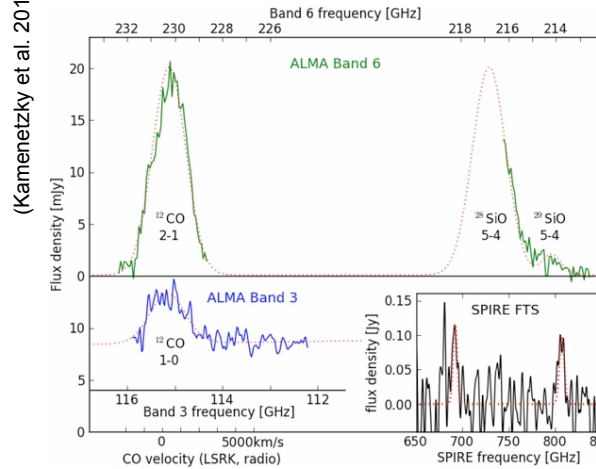
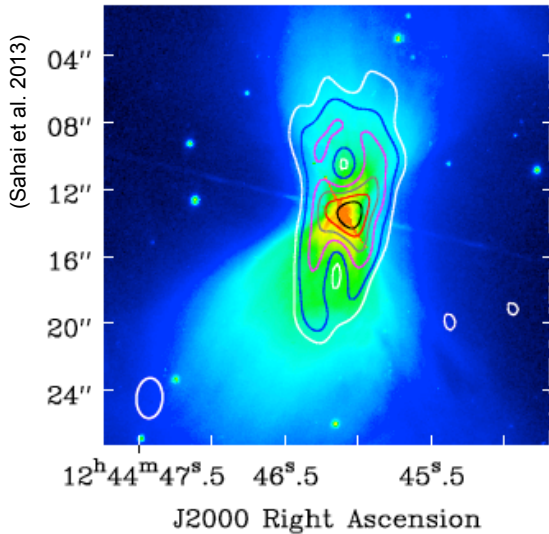
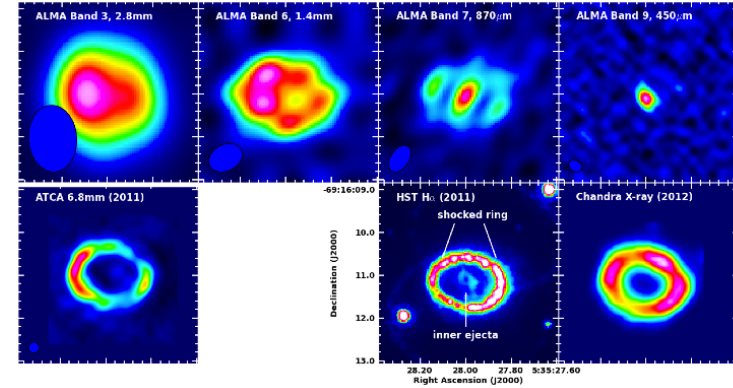
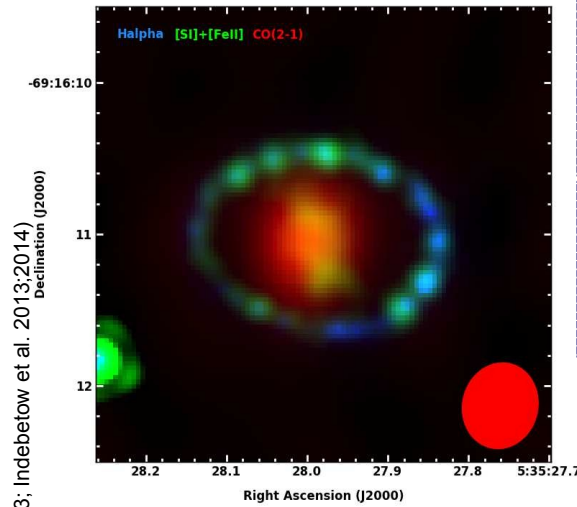
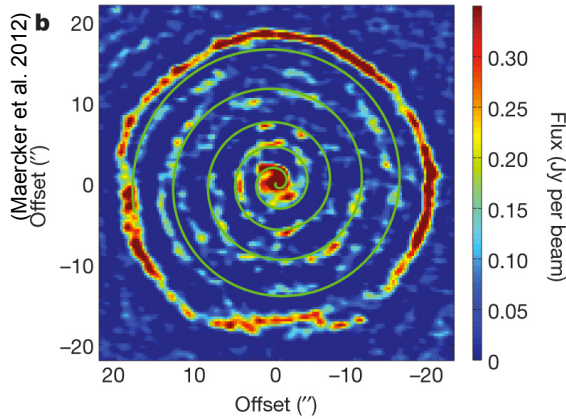
(Bolatto et al. 2013)

and later capabilities, for the ETC



Enrichment of the ISM

■ Late stages of stellar evolution, supernovae, GRBs

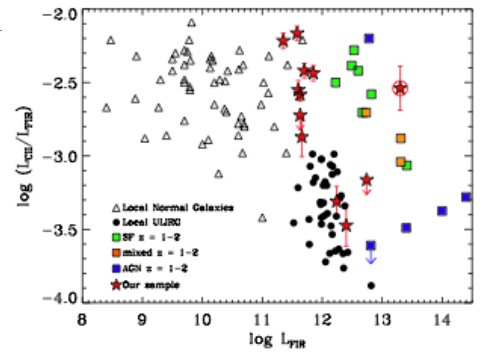
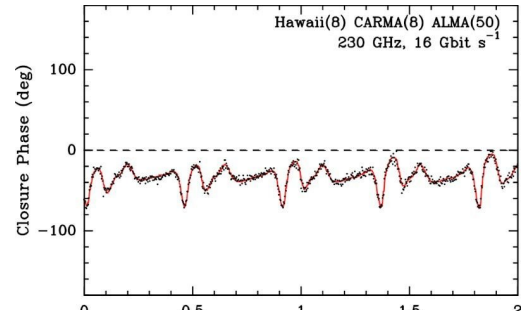
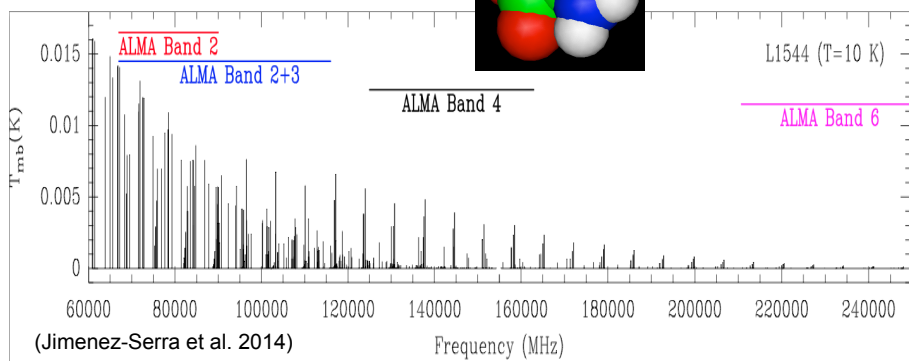
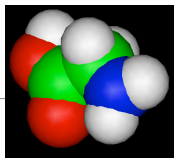
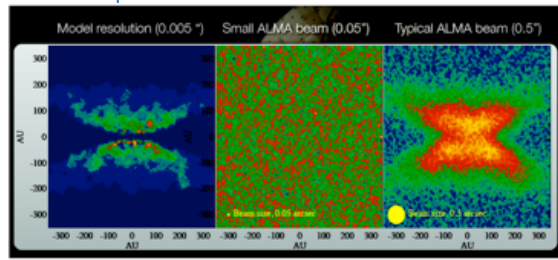
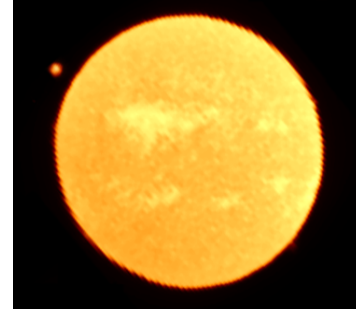


(Hatsukade et al. 2014)

and future capabilities, 13 Apr 2015

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)

(Doleman et al. EHT project)

(Rigoupolou et al. 2014)

6/22/2014

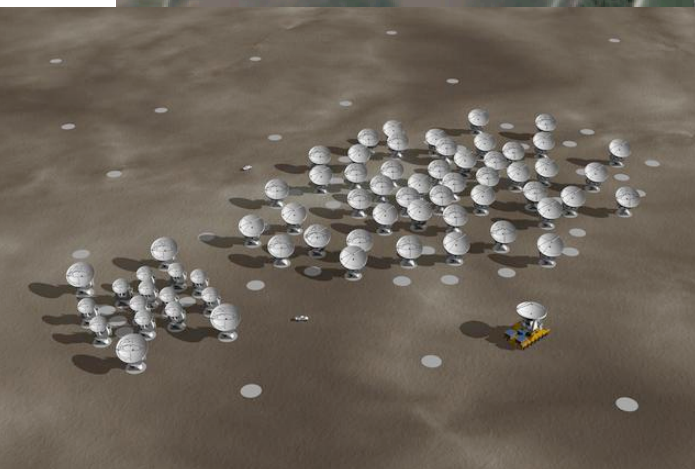
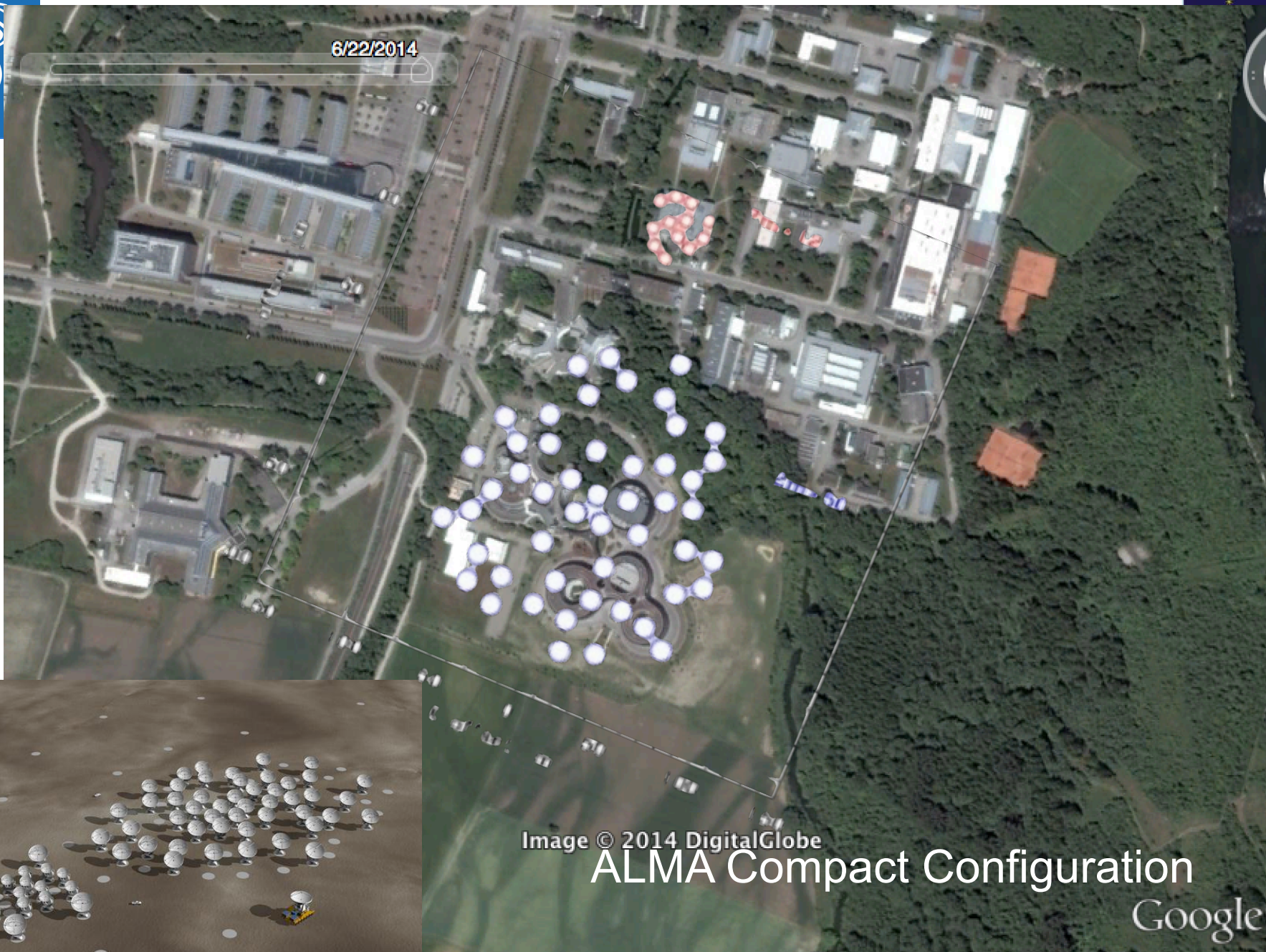
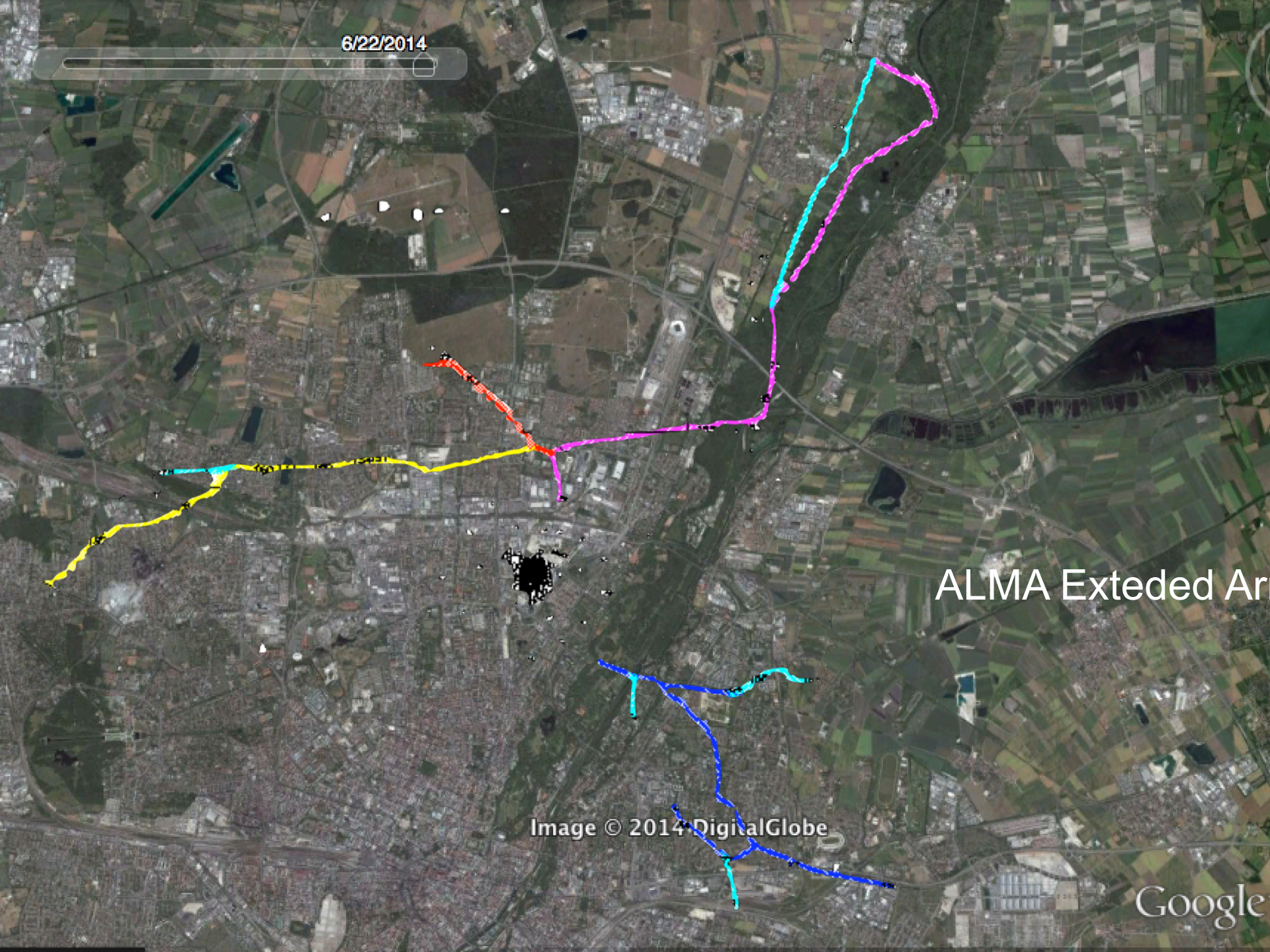


Image © 2014 DigitalGlobe

ALMA Compact Configuration

Google

6/22/2014



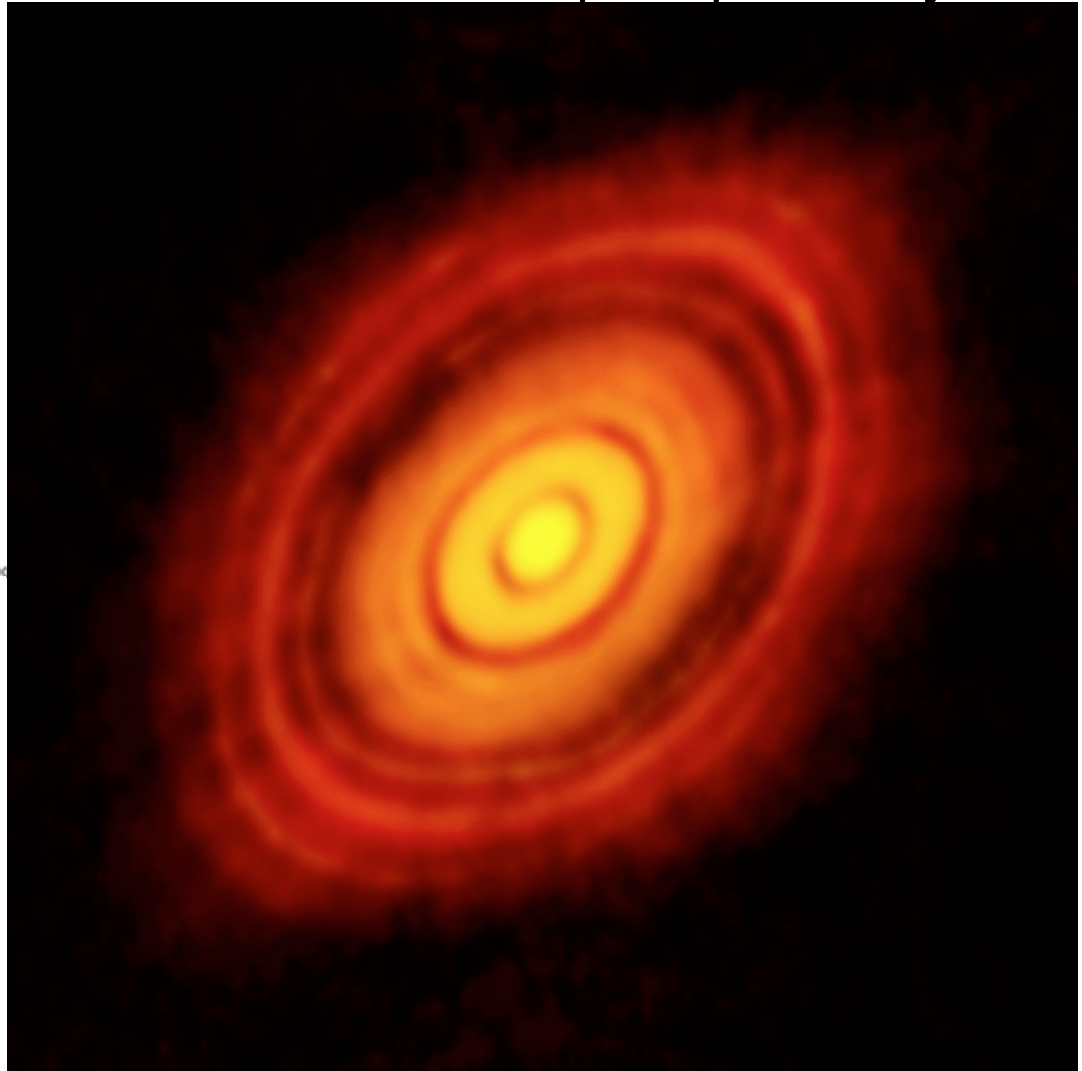
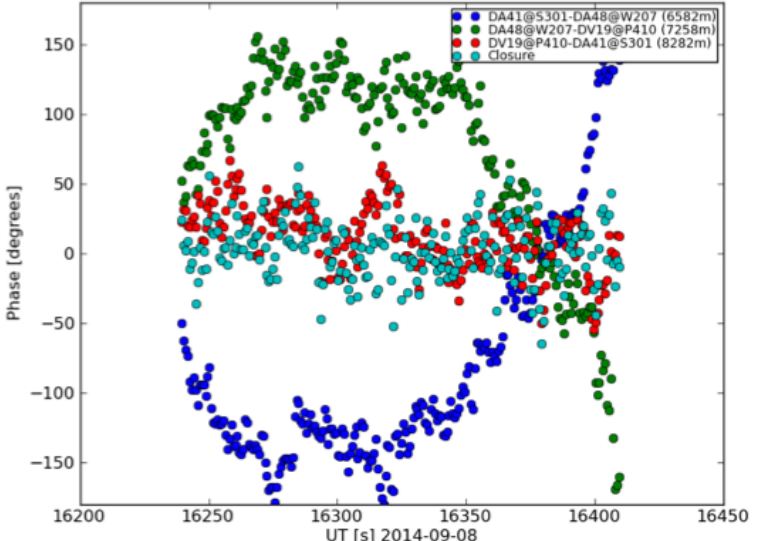
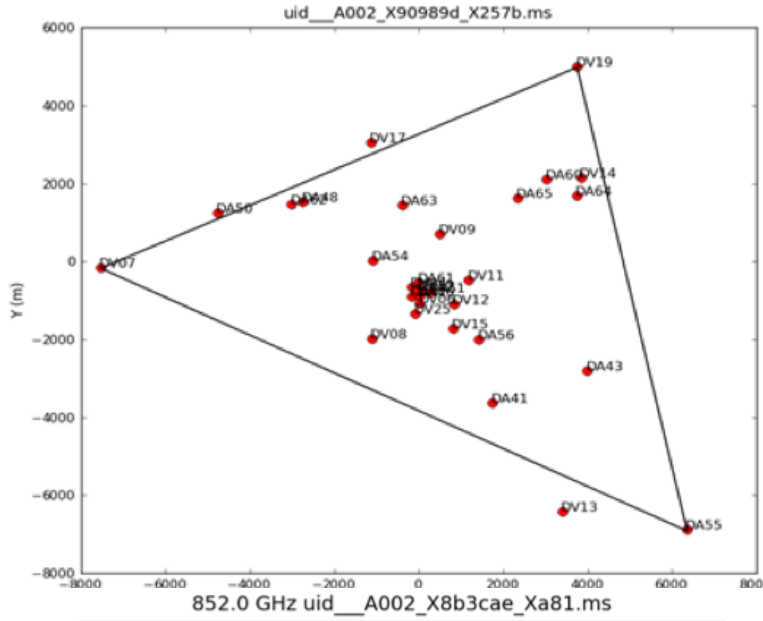
ALMA Extended Ar

Image © 2014 DigitalGlobe

Google

A glimpse of ALMA future capabilities

■ Long Baselines Campaign - Sep-Nov 2014 HL Tau protoplanetary disk

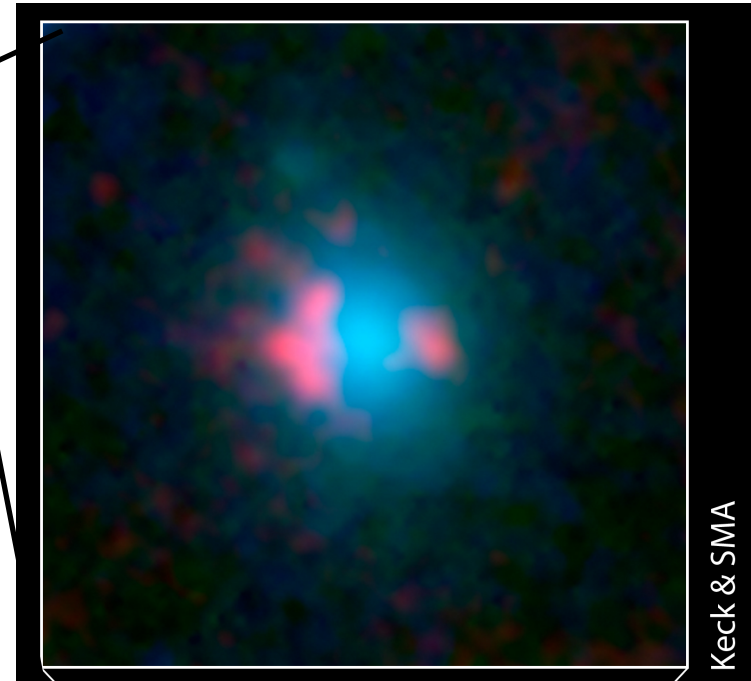
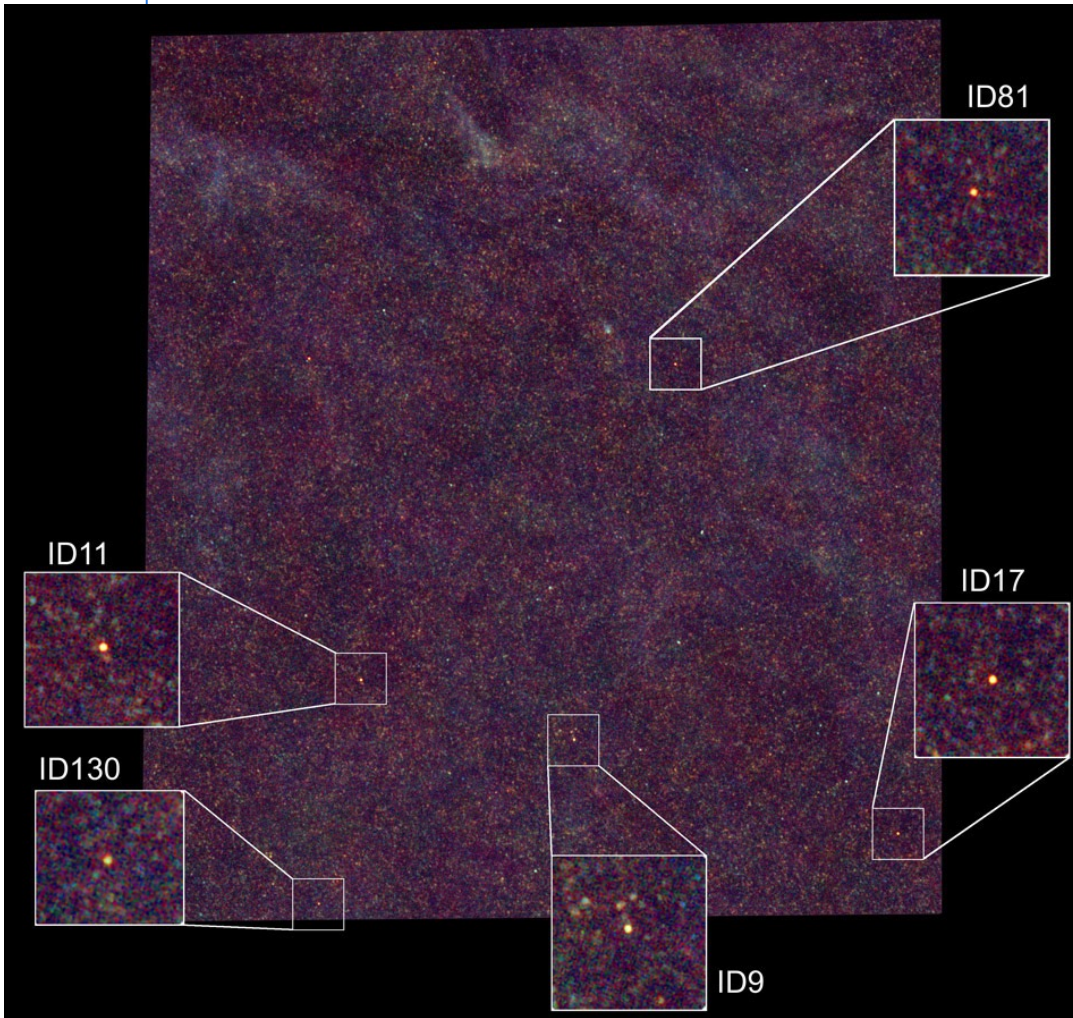


capabilities, 13 Apr 2015

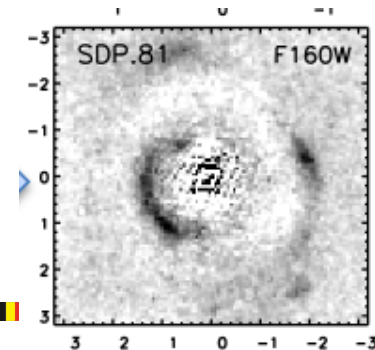
A glimpse to ALMA future capabilities

■ Long Baselines Campaign - Sep-Nov 2014

SDP 81 - Lensed SMG



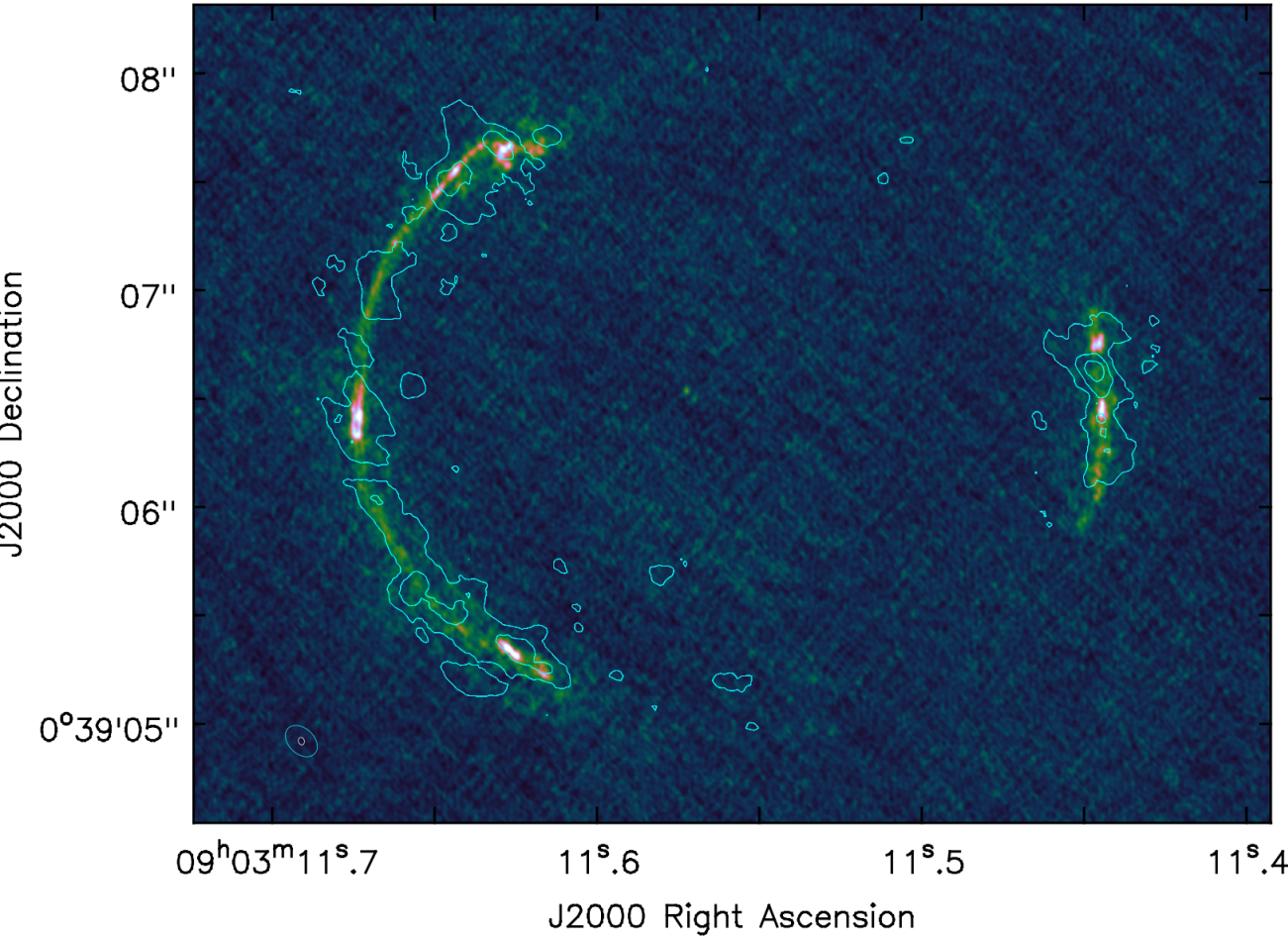
Negrello+2010;2015



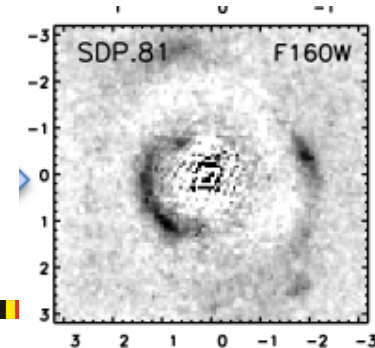
HATLAS
Eales+

A glimpse to ALMA future capabilities

■ Long Baselines Campaign - Sep-Nov 2014 - SDP 81 - Lensed SMG
 ALMA SV - SDP.81 - 1mm continuum & CO (8-7)



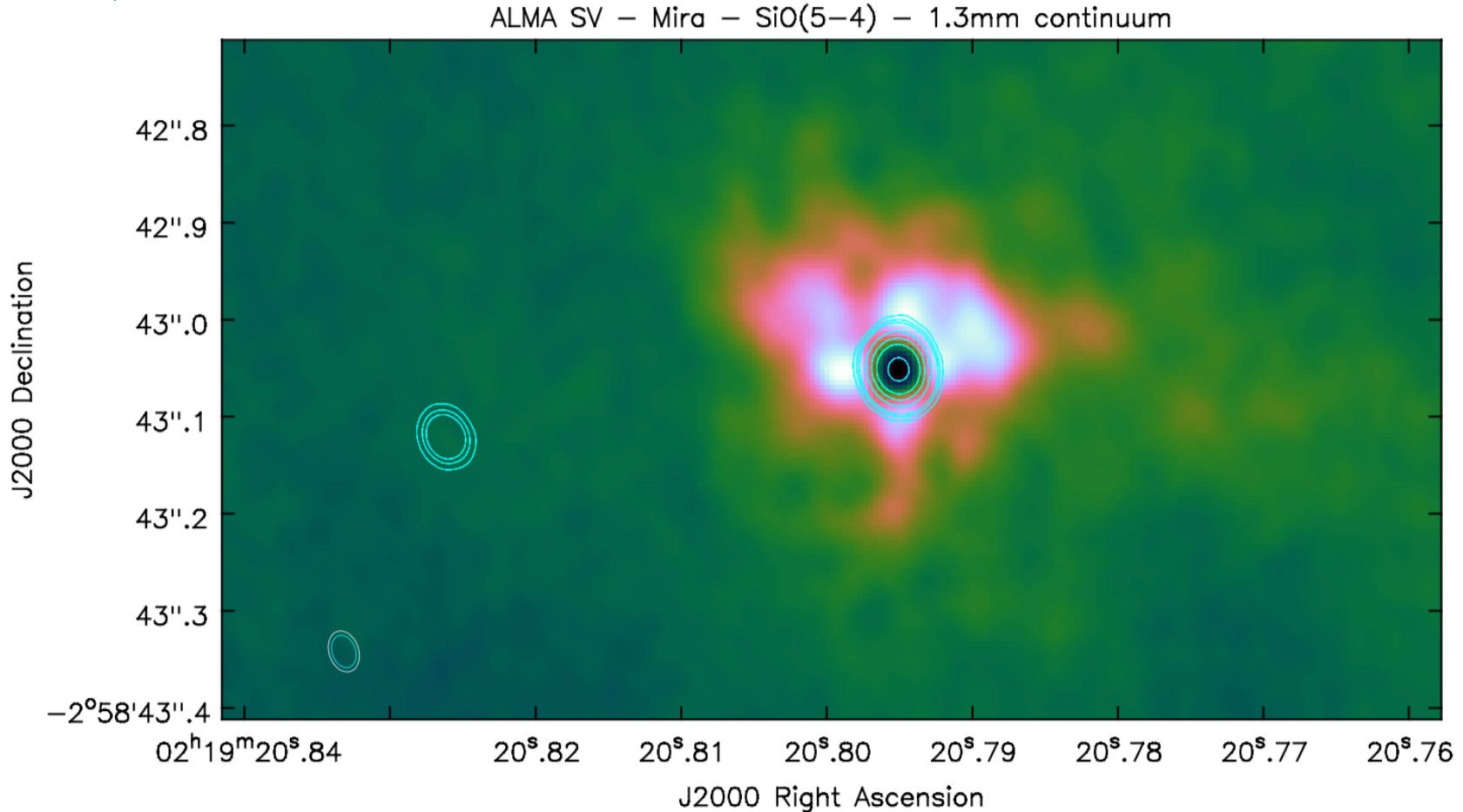
Negrello+2010;2015



HATLAS
Eales+

A glimpse to ALMA future capabilities

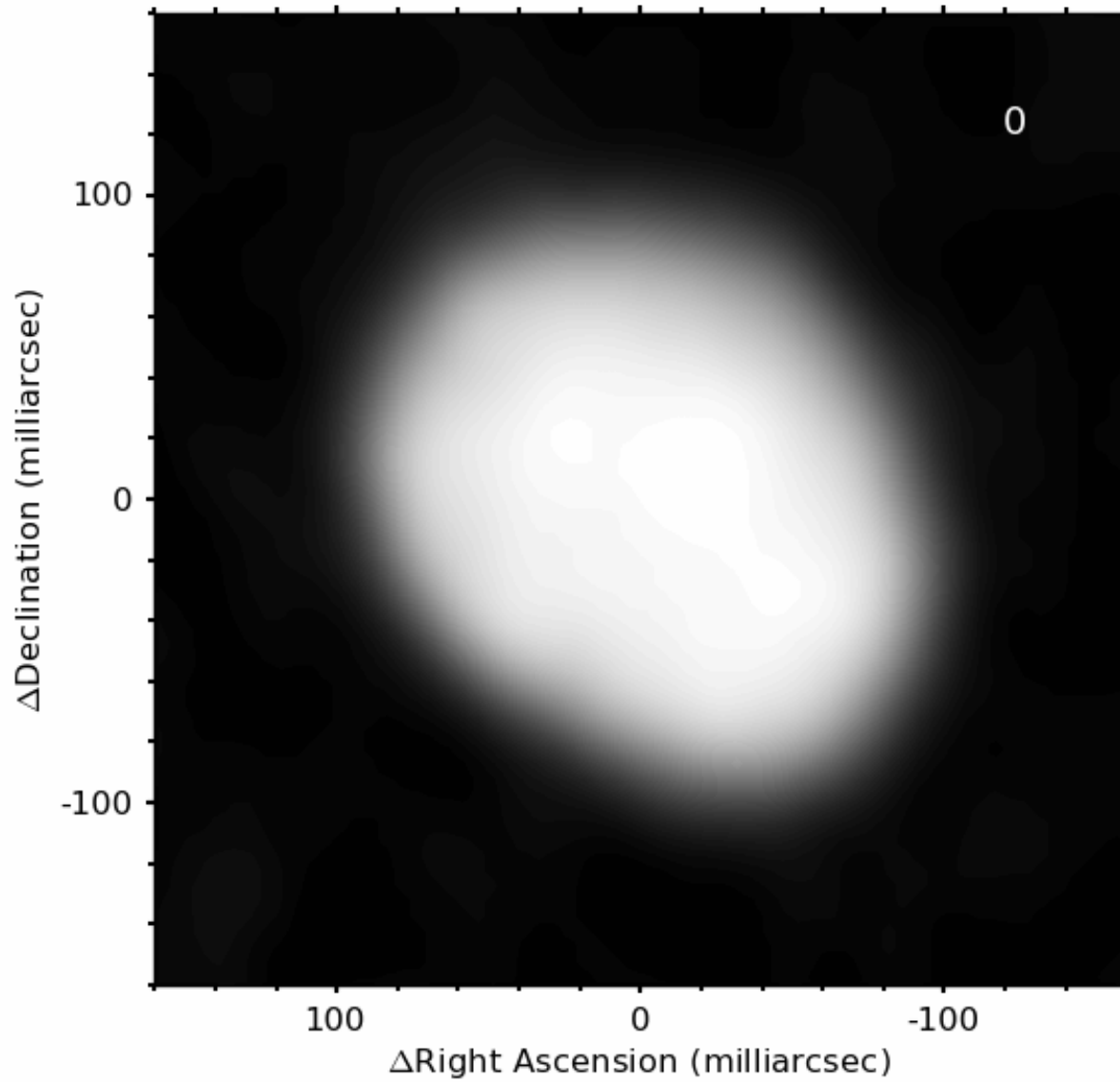
■ Long Baselines Campaign - Sep-Nov 2014 - **Data Public Today**
MIRA - AGB star



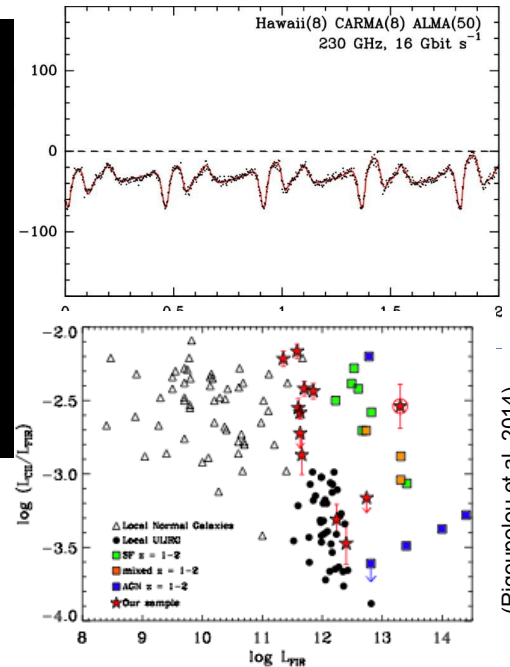
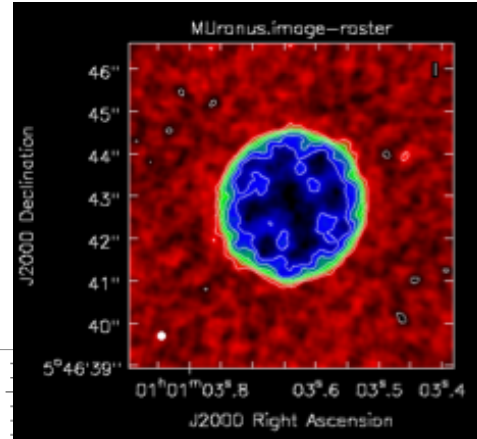
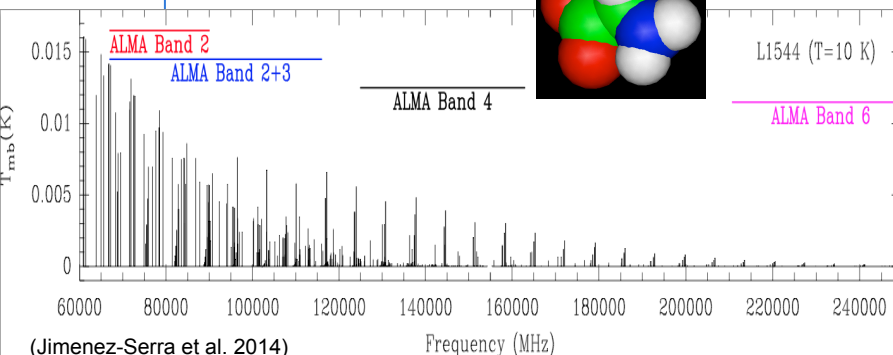
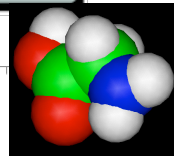
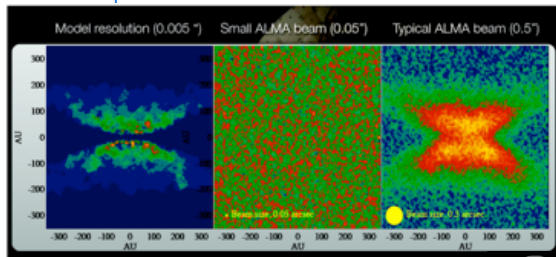
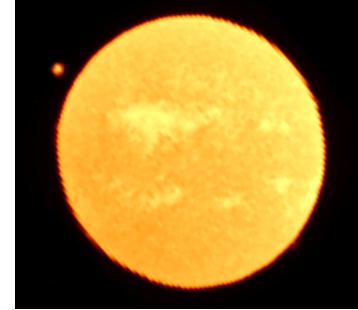
A glimpse of ALMA future capabilities

■ Long Baselines Campaign - Sep-Nov 2014

Juno



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- Chemistry of Complex Organic Molecules and Water
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 - Full sensitivity, mmVLBI



(Doleman et al. EHT project)

(Rigoupolou et al. 2014)

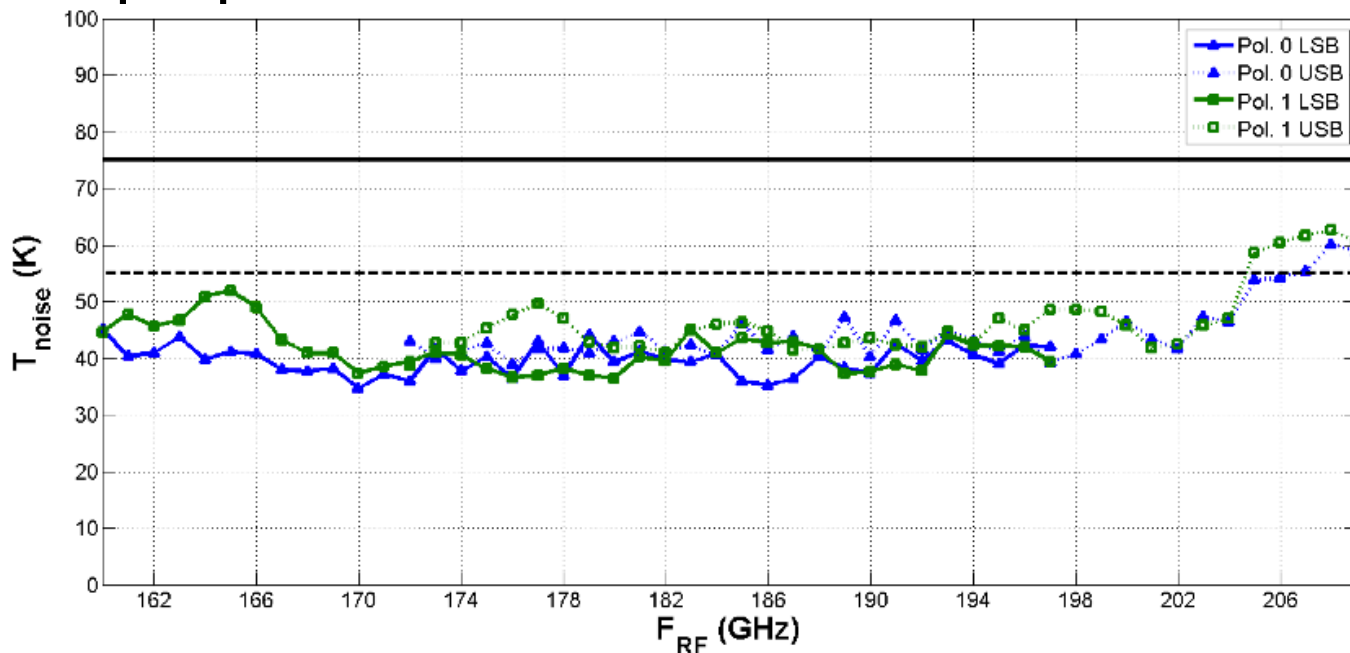
- Top priority: complete commissioning of the baseline ALMA-trilateral program
 - Full polarization, reach the target overall efficiency, full zero spacing capabilities, solar modes

- 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

Upcoming: Band 5

- First cartridges arriving at the beginning of next year
 - NOVA-OSO/GARD consortium, WCA from NRAO
- First cartridge meets (tightened) specs with margin
 - Continuing with pride a tradition of EU built cartridges
- Setting up the AIVC group in Chile
- One preproduction receiver installed on APEX



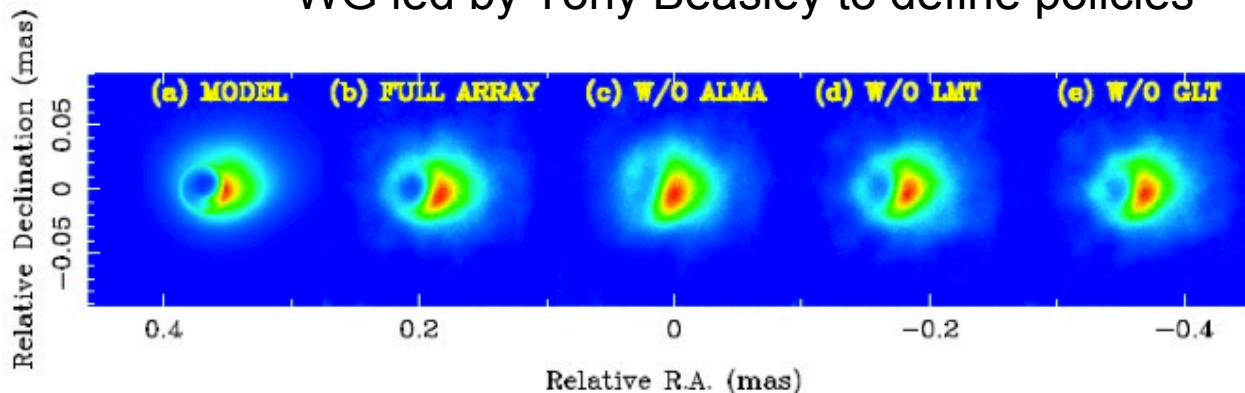
Upcoming: mmVLBI

■ APP project makes steady progress

- H-maser installed successfully, new frequency standard, rubidium kept as backup
- Software acceptance Q2 2015
- First global tests planned for Q2 2015

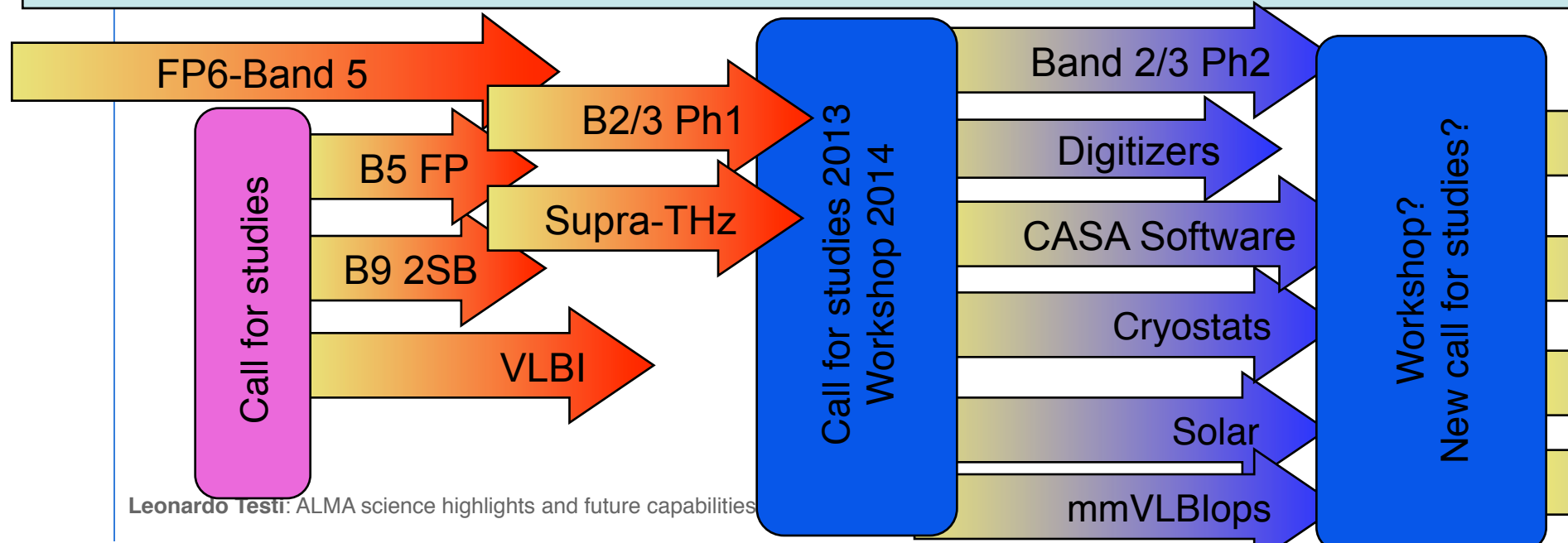
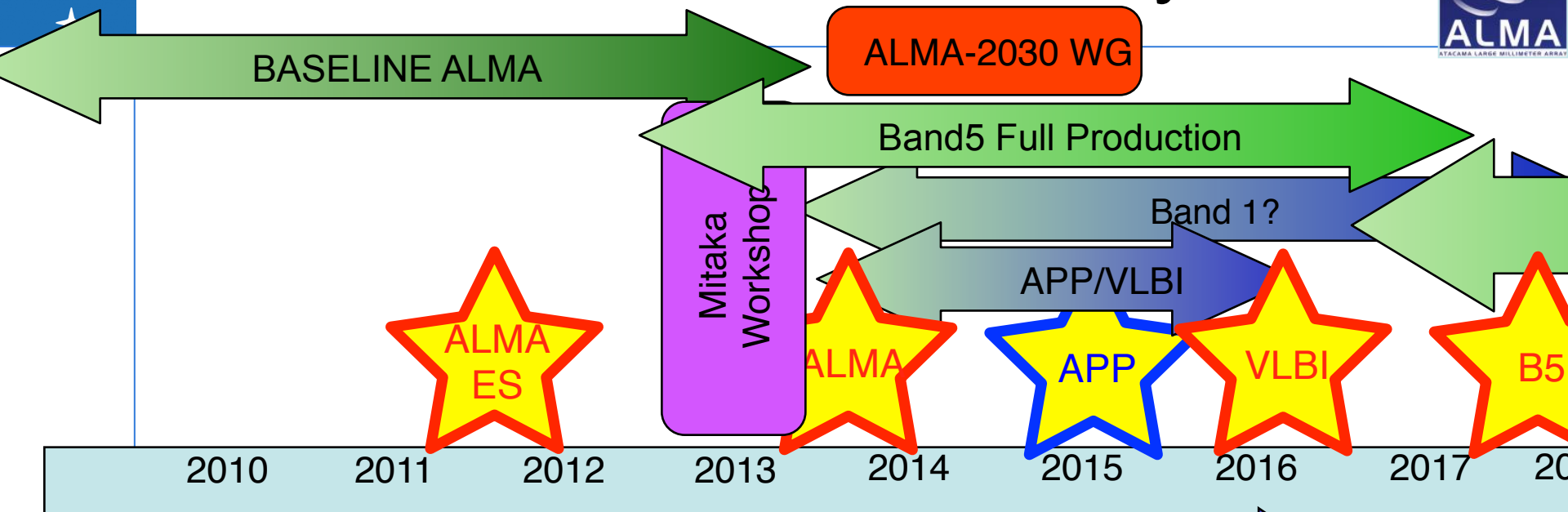
■ Towards a facility model for mmVLBI

- ALMA-GMVA study running, led by MPIfR
- Workshop in Bologna: Jan 22-23, 2015
 - Followed by ASAC/Board discussion
 - WG led by Tony Beasley to define policies





Timeline summary



ALMA 2030 effort

- Led by ALMA Science Advisory Committee
 - Survey of leading facilities in the 2020s
 - Major science drivers in the 2020s and role of ALMA
 - ALMA development pathways

- Final version March 2015

Major Science Themes in the 2020-2030 Decade

Executive Summary

ALMA was designed to address many science questions in the broad area sometimes bundled under the umbrella question: "How does the Universe work?" This includes areas in which the submillimetre band has traditionally advanced knowledge, such as the physics and chemistry of the ISM, the formation of stars and disks, the structure and evolution of galaxies and AGN. ALMA also has the potential to contribute to the highest profile areas of astrophysics, namely the search for life elsewhere, and placing constraints on fundamental physics.

PATHWAYS TO DEVELOPING ALMA

A document to inform the scientific discussions leading to the development of a roadmap for improvements in ALMA

Final version

ALMA DEVELOPMENT WORKING GROUP REPORT

Alberto Bolatto -- Chair, ASAC
Chair, General Coordination

Stuart Corder -- Deputy Director, JAO
Reliability & Efficiency lead

Daisuke Iono -- EA Project Scientist
Resolution, FOV, and Imaging Quality & Calibration lead

Leonardo Testi -- EU Project Scientist
Sensitivity, Spectral Coverage, and Flexibility lead

Alwyn Wootten -- NA Project Scientist
Simultaneous Frequency Coverage, and Usability lead

Options for 2020s and beyond

■ Larger bandwidths and better receivers

- Datarate/data volume increase
- Aim to cover full bands instantaneously

■ Longer baselines

- Brightness sensitivity issues, ideally linked to sensitivity increase

■ Increased wide field mapping speed

- Panoramic detectors for interferometry (!)
- Datarate/datavolume

■ The role of Archive will be more prominent than today

- 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