ALMA Science Highlights

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Credits: NRAO, M. MacGregor

Atacama Large Millimeter/submillimeter Array
Expanded Very Large Array

What Can We Observe in the Radio?

Sun	coronal mass ejections, magnetic field activity
Solar System	atmospheres, astrometry, composition, KBOs
Star-Forming Regions	dust and gas environment, kinematics (infall, outflows, jets), protoplanetary disks, cores, chemistry, feedback
Exoplanets	direct imaging, gaps in disks, kinematics
Pulsars	neutron star physics, pulse morphology, gravity, ISM probe
Galactic Structure	spiral arms, bars, global atomic/molecular gas properties
Nearby Galaxies	molecular/atomic gas content and kinematics, dynamics of galaxies at high resolution, (obscured) star formation, gas properties
Galaxy Groups and Clusters	atomic and molecular gas across systems, star formation efficiency, kinematics, dynamical mass measurements
Black Holes	mass measurements, kinematics
High Redshift Galaxies	extragalactic background light, source counts, star formation history and efficiency, evolution of gas content
Cosmology	H_0 measurement, SZE

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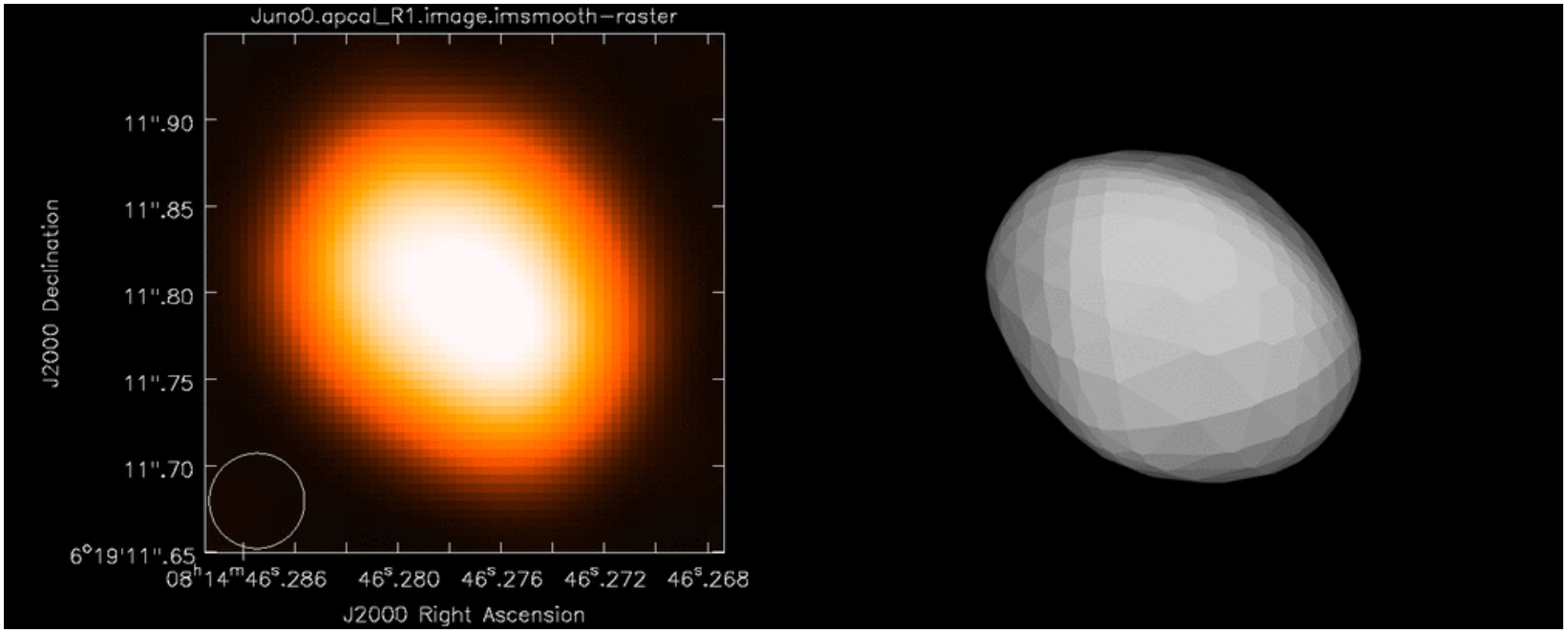
ALMA Images Juno

Science Verification observations in Band 6 (1.3 mm, 233 GHz)

Five consecutive executions over 4.4 hours

Beam size ~0.04″ x 0.03″ (~60 x 45 km)



(ALMA Partnership, Hunter et al. 2015; Model from Durech et al. 2010, 'Database of Asteroid Models from Inversion Techniques')

ALMA Detects Organics on Pluto

CO(3-2) and HCN (4-3) detected in atmosphere

Lines probe abundances and temperature of Pluto's atmosphere

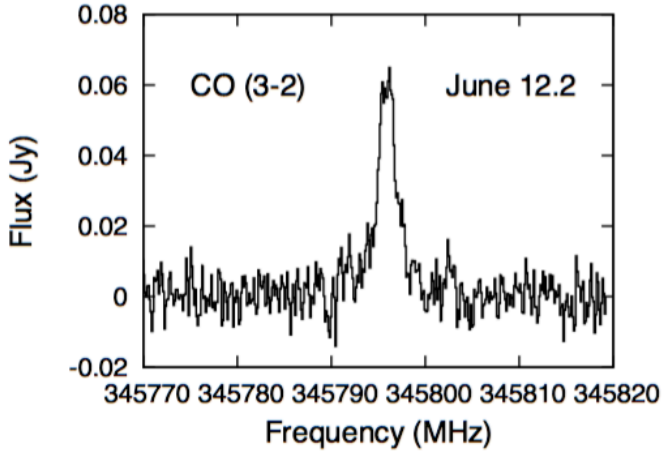
Dayside temperature profile shows decrease (i.e., mesosphere)

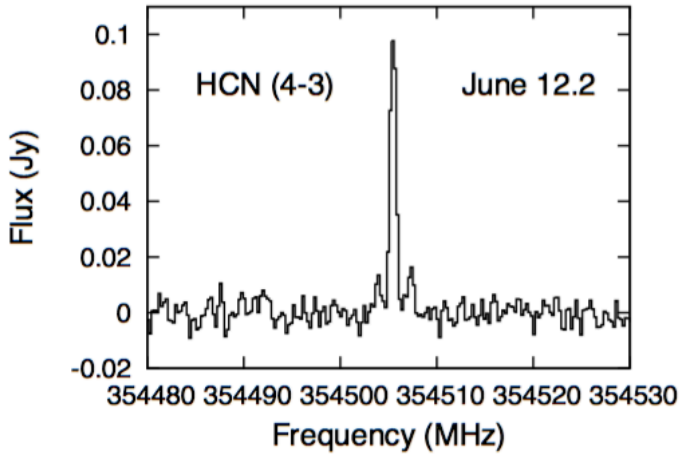
Above the 30-50 km stratopause, with T= 70 K at 300 km

In agreement with New Horizons solar occultation data

HCN line shape implies high abundance in upper atmosphere

Suggests a warm (>92 K) upper atmosphere (450 – 800 km)





Lellouch et al. (2016)

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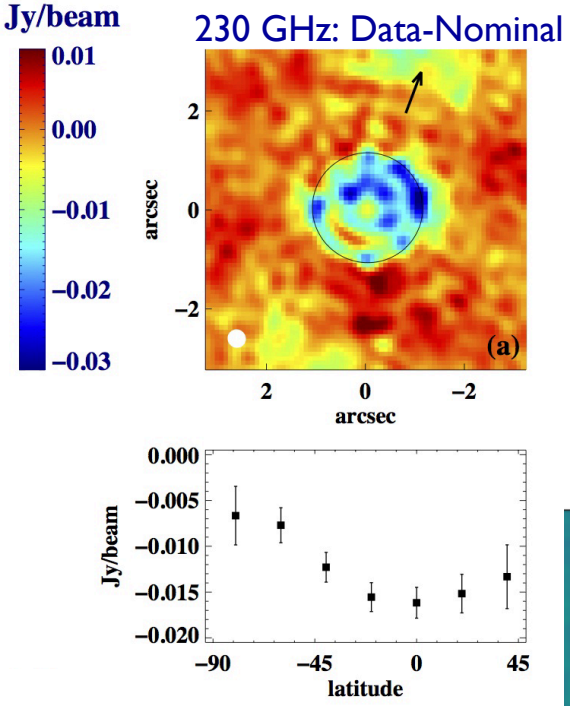
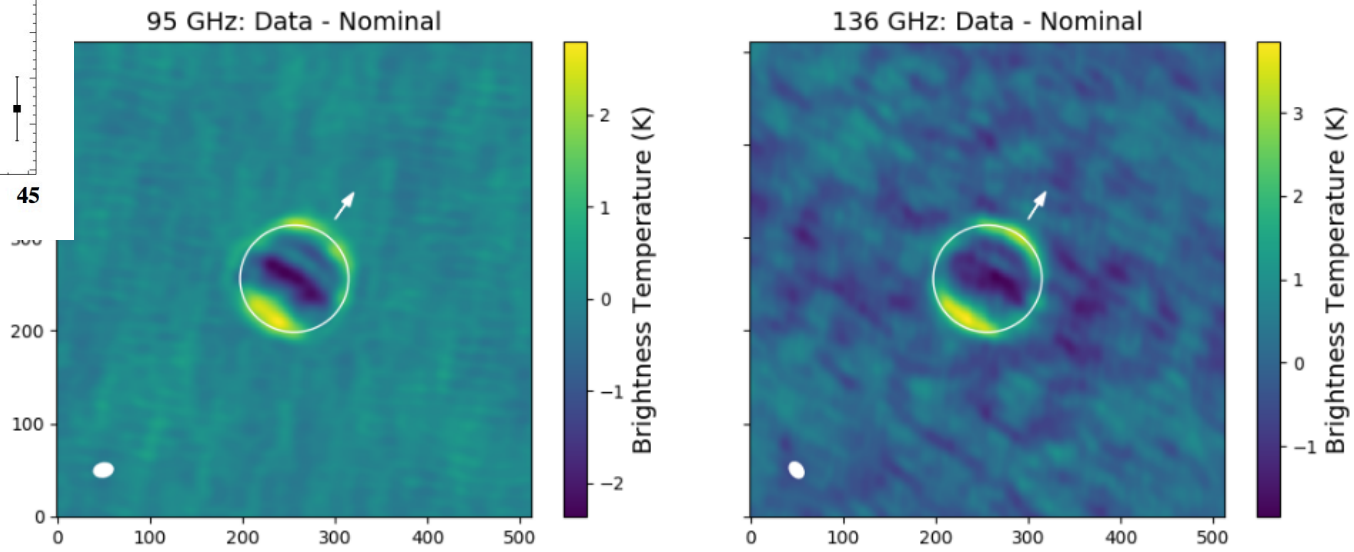
Disequilibrium Species on Neptune



CARMA: Luszcz-Cook+ 2013

- Measure Neptune's Bulk Composition
- Trace Atmospheric Circulation
- *Other ALMA projects I'm working on: comet impacts on Uranus, bulk composition of Uranus, origin of sulfur species on Io*



ALMA: Tollefson, Luszcz-Cook, + (preliminary)

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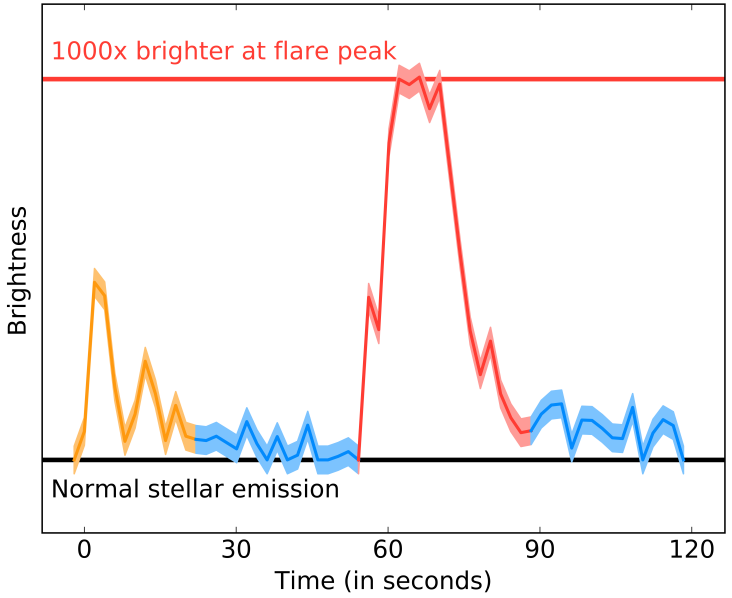
Detection of a Flare from Proxima Cen

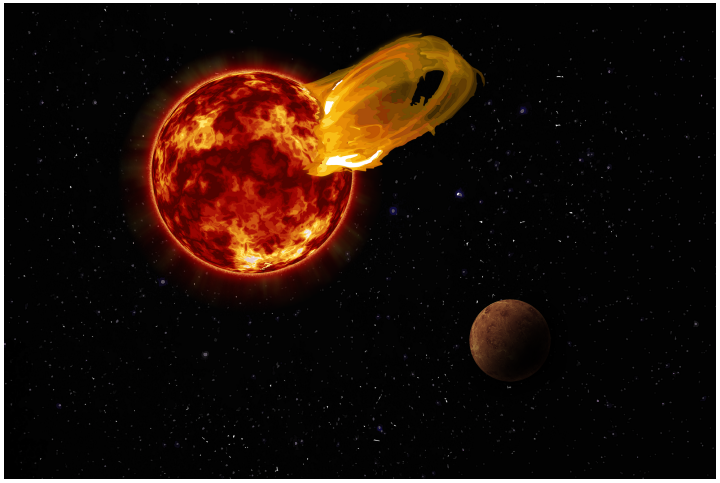
ALMA 12-m and ACA observations at 1.3 mm

Star underwent a significant flaring event, brightening by a factor of 1000

10x brighter at peak than solar flares observed at millimeter wavelengths
Also observe change in polarization and spectral index during the flare

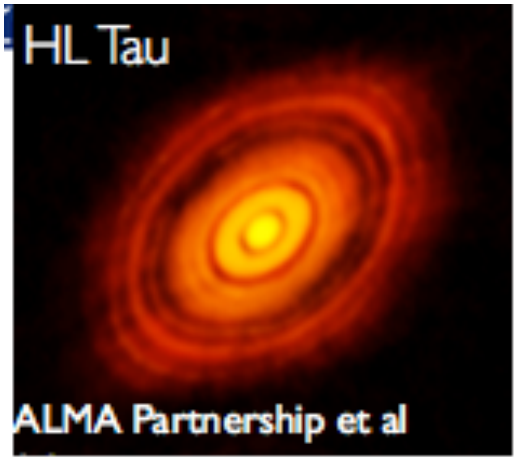
Disproves hypothesis of multiple dust belts in the system

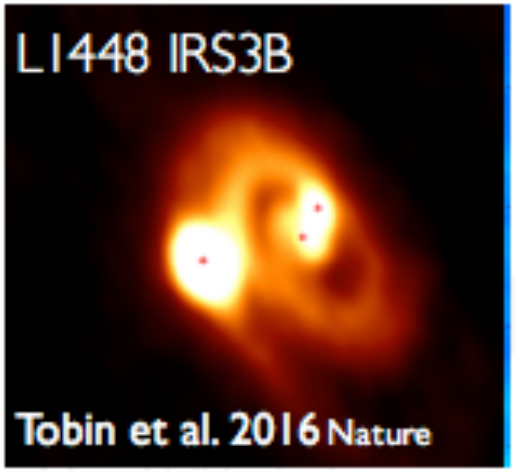


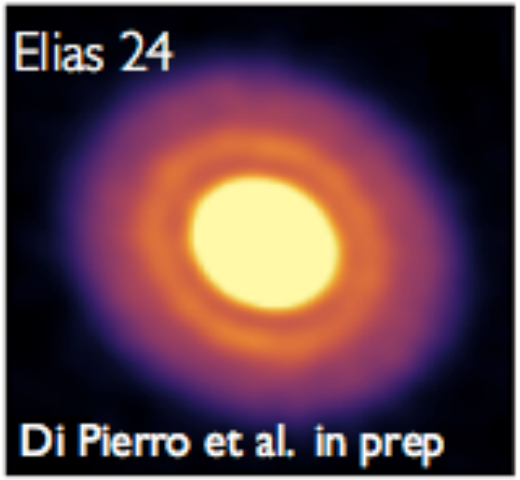


MacGregor et al. (2018)

Protoplanetary Disks: With ALMA







Composite image courtesy J. Carpenter / A. Wootten (ALMA / NRAO)

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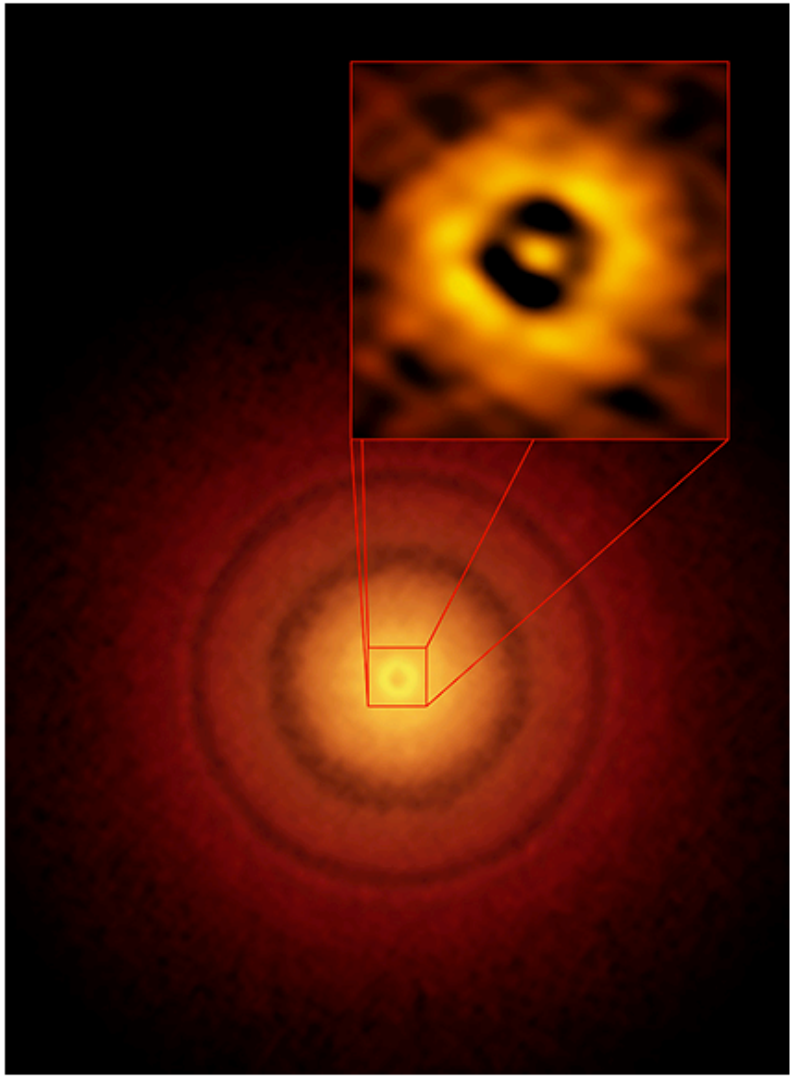
ALMA Images TW Hya

Imaged in Band 7 (870 microns)

Young (10 Myr-old) system at 175 light years

Series of concentric ring-shaped substructures (1-6 AU wide)

Narrow dark annulus located only 1 AU from the star
Could indicate interactions between the disk and young planets



Andrews et al. 2016

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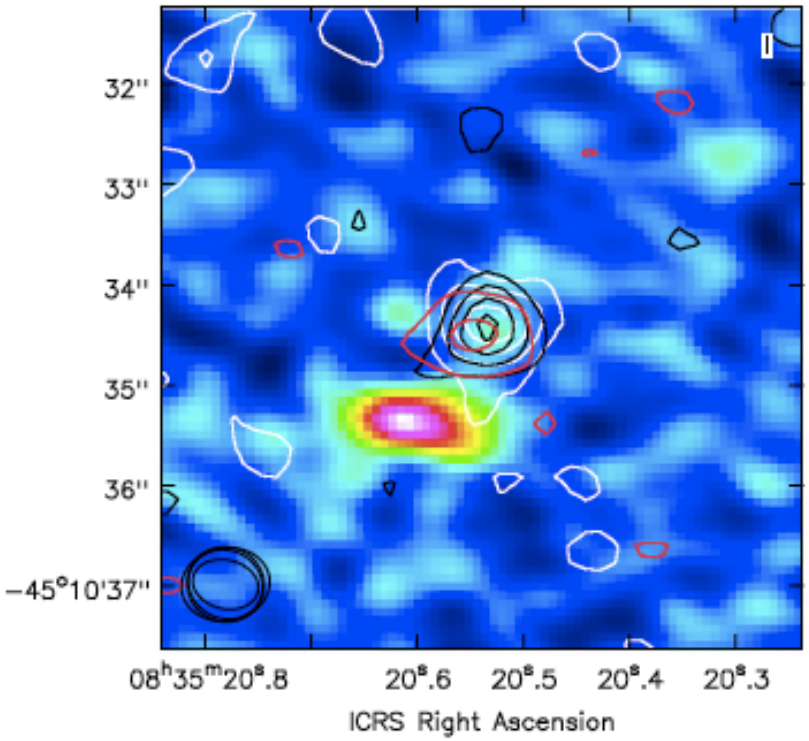
ALMA Images Vela Pulsar

ALMA Development Study results on pulsar observations will appear soon

Detections in non-time resolved mode made of Vela Pulsar, SgrA* magnetar, and Crab Pulsar

- Vela pulsar detected in Bands 3, 4, 6, 7
- Extended structure in Band 7 may be counter jet protruding from pulsar

Allows array to be used as a single receiving station for VLBI



Magnani et al. 2017

ALMA Bands 3,4,6 (colored contours) on Band 7 image

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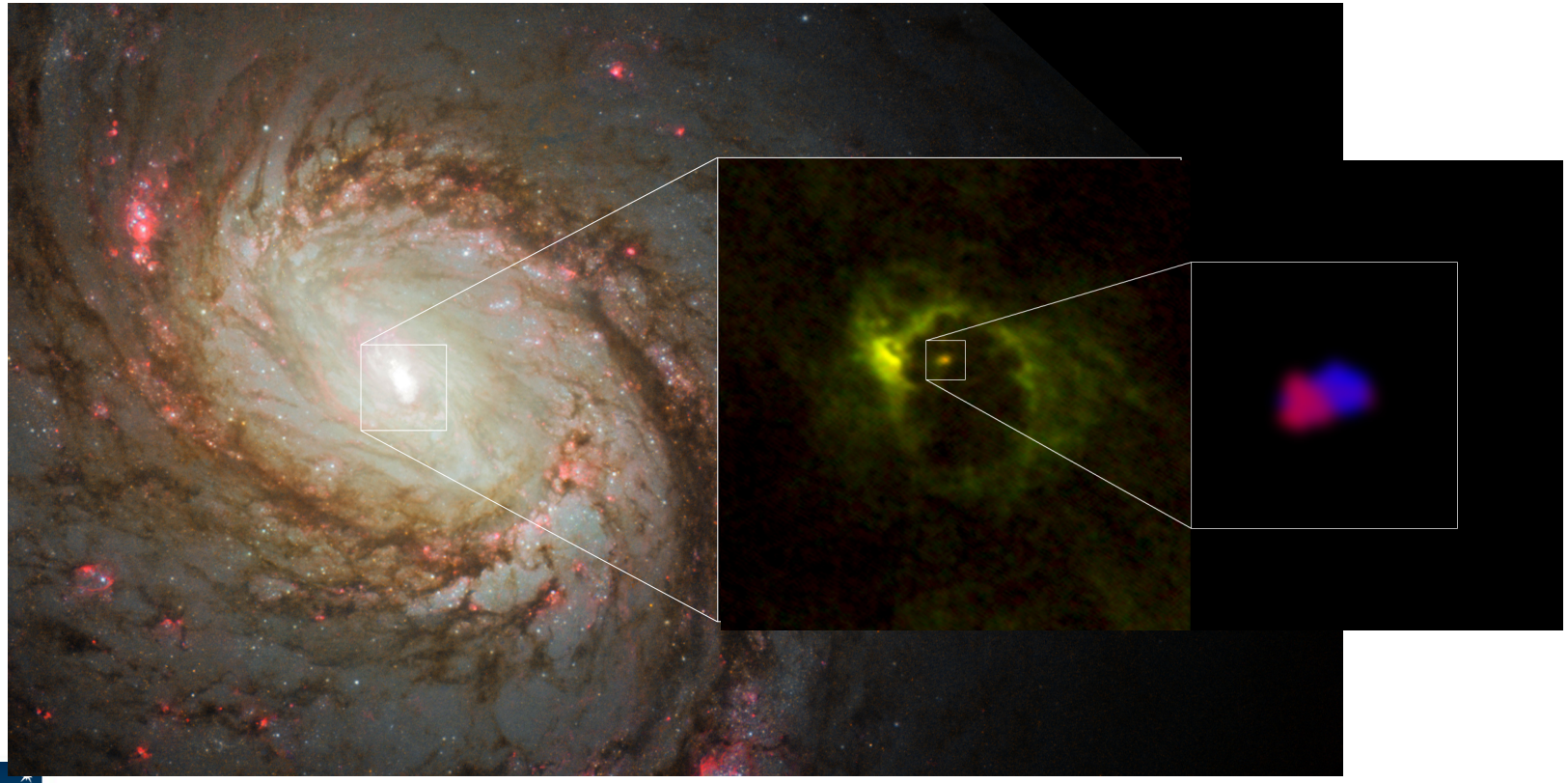
Dense Torus around an AGN

- Rotating dusty gas torus observed around an active galactic nucleus (AGN) in spiral galaxy M77



Imanishi et al. 2018

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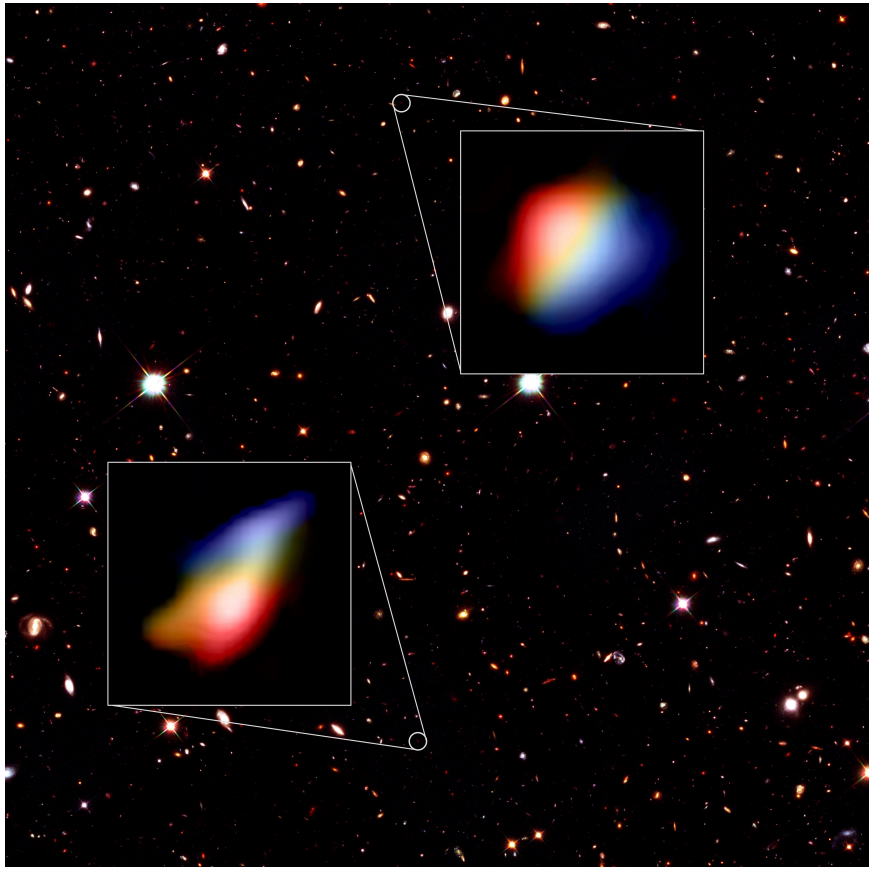
Very Early Galaxies

- Rotation detected in two galaxies at redshift of 6.8 (800 million years after Big Bang)
- Only 1/5 mass of Milky Way
- Clear velocity gradient suggests rotation-dominated disks, akin to galaxies observed 2Gyr later



Smit et al. 2018

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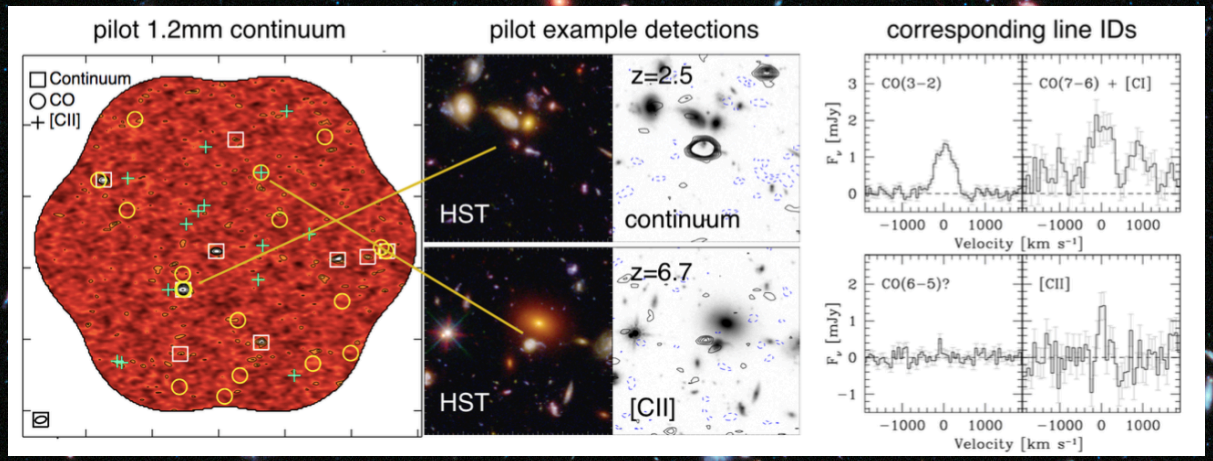
ALMA Deep Fields

Large volume surveys for cold gas throughout the Universe

ASPECS is the first line deep field, involving full frequency scans of Band 3 and 6 in the Hubble UDF

- 21 candidate line galaxies detected
- CO emission at z = 1 to 5, [CII] at z > 6
- 9 dust continuum sources at 1.2 mm



See papers by Walter, Decarli, Aravena

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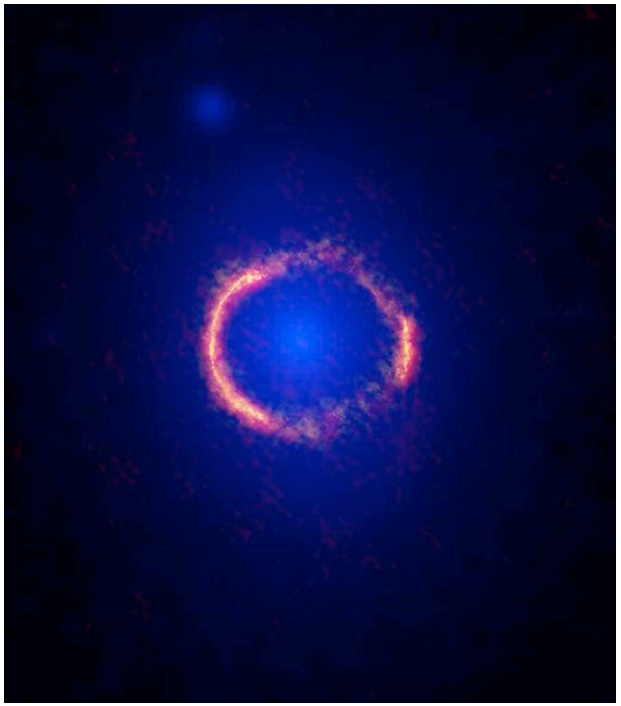
Gravitational Lensing, hidden dark galaxies

Hezaveh et all (2016) show ALMA's potential to advance understanding of dark matter substructures

ALMA's SDP.81 observations are analyzed to detect a subhalo with a mass of $10^{8.96\pm0.12}\ M_{sun}$

Consistent with theoretical expectations



Blue: HST/WFC3 F160W data shows lensing elliptical at z~0.3

Red: ALMA Bands 4/6/7 combined emission.

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More Cool ALMA Science

- **Find a list of published ALMA papers** at: http:almaobservatory.org/en/science-at-jao/articles-a-publications
- **Check out example Science Cases** in the *ALMA Primer*
- **Browse recent results** at: http://www.almaobservatory.org/en/press-release

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