ALMA Science Highlights

ALMA Town hall meeting at SNU
2019 March 21

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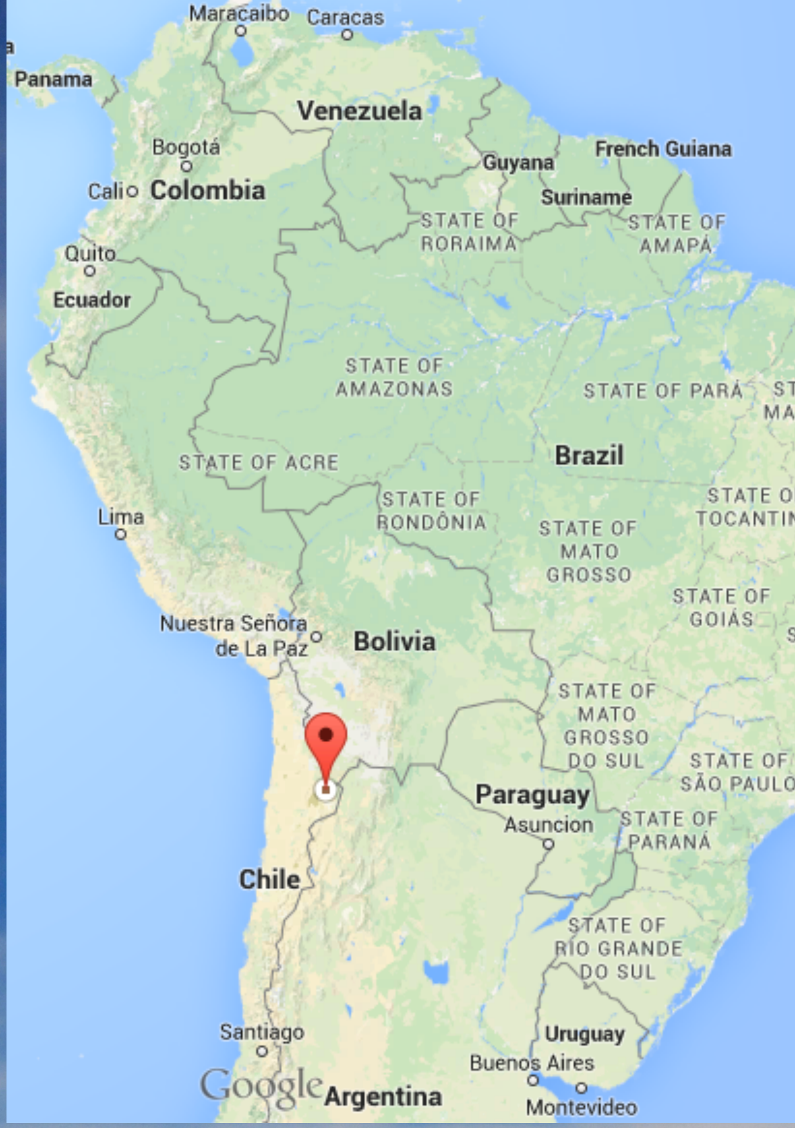
Atacama
Large
Millimeter/submillimeter
Array

- The largest ground-based astronomical facility
- 50 12-m, 12 7-m, 4 12-m = 66 antennas
- ~5000 m in altitude, Chajnantor plateau, Chile
- East Asia, Europe, North America, & Chile



ALMA full Operation's Specifications

	Specification
Number of Antennas	*50×12 m (12-m Array), plus 12×7 m & 4×12 m (ACA)*
Maximum Baseline Lengths	*0.16 - 16.2 km*
Angular Resolution (")	*~0.2" × (300/ν GHz) × (1 km / max. baseline)*
12 m Primary beam (")	*~20.6" × (300/ν GHz)*
7 m Primary beam (")	*~35" × (300/ν GHz)*
Number of Baselines	*Up to 1225 (ALMA correlators can handle up to 64 antennas)*
Frequency Coverage	*All atmospheric windows from 84 GHz - 950 GHz (with extension to ~30 GHz when Bands 1 and 2 are deployed)*
Correlator: Total Bandwidth	*16 GHz (2 polarizations × 4 basebands × 2 GHz/baseband)*
Correlator: Spectral Resolution	*As narrow as 0.008 × (300/ν GHz) km/s*
Polarimetry	*Full Stokes parameters*

Level one science goals

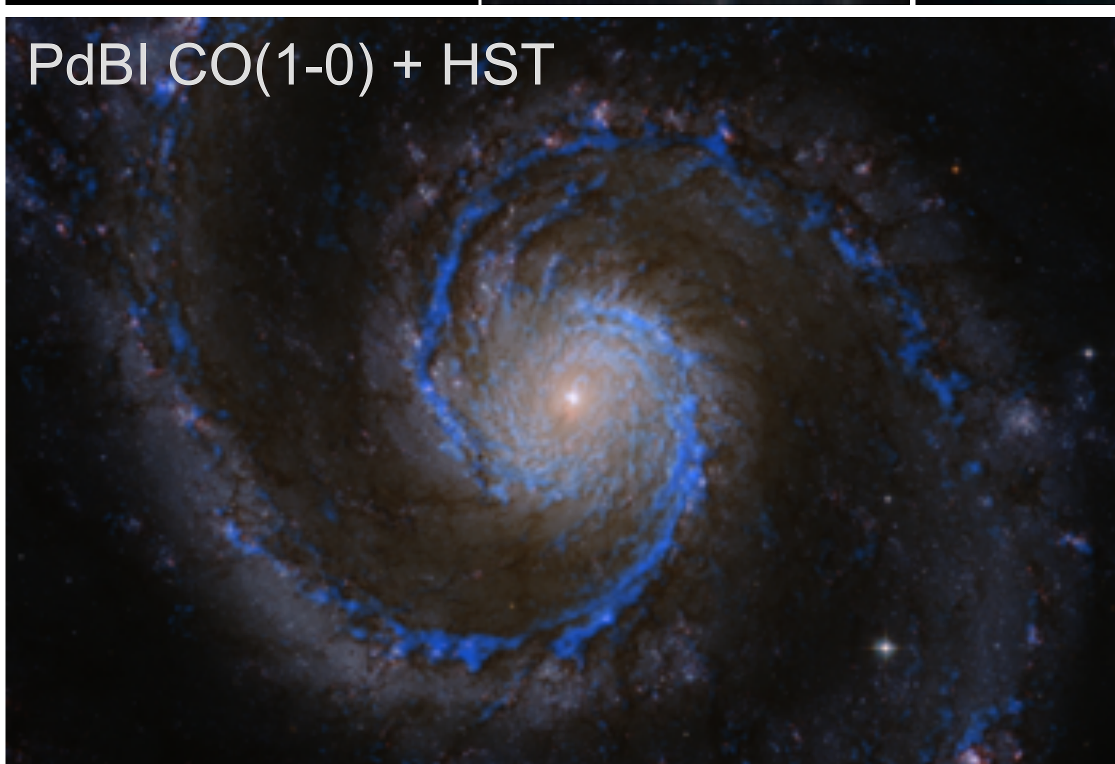
While ALMA will revolutionize many areas of astronomy, the technical requirements of ALMA were driven by three Level One Science Aims:

I. The ability to detect spectral line emission from C+ in a normal galaxy like the Milky Way at a redshift of $z = 3$, in less than 24 hours of observation.

II. The ability to image gas kinematics in a solar-mass protostellar/protoplanetary disk at a distance of 150 pc (roughly, the distance of the star-forming clouds in Ophiuchus or Corona Australis), enabling one to study the physical, chemical, and magnetic field structure of the disk and detect the tidal gaps created by planets undergoing formation.

III. The ability to provide precise images at an angular resolution of $0.1''$. Here the term "precise image" means an accurate representation of the sky brightness at all points where the brightness is greater than 0.1% of the peak image brightness. This requirement applies to all sources visible to ALMA that transit at an elevation greater than 20 degrees.

Why (sub)mm & ALMA?



Schinnerer et al. (2013)

galaxy = dark matter + stars + **ISM**

ISM = gas (H I, H II, H_2, He, C, N, O;
atoms + **molecules**)
+ dust (PAH, **grains**)

submm: extinction-free probe for
~1000 spectral lines from inter- &
circum-stellar medium and dust

From Y. Yang's slides

Galaxy Spectral Energy Distribution

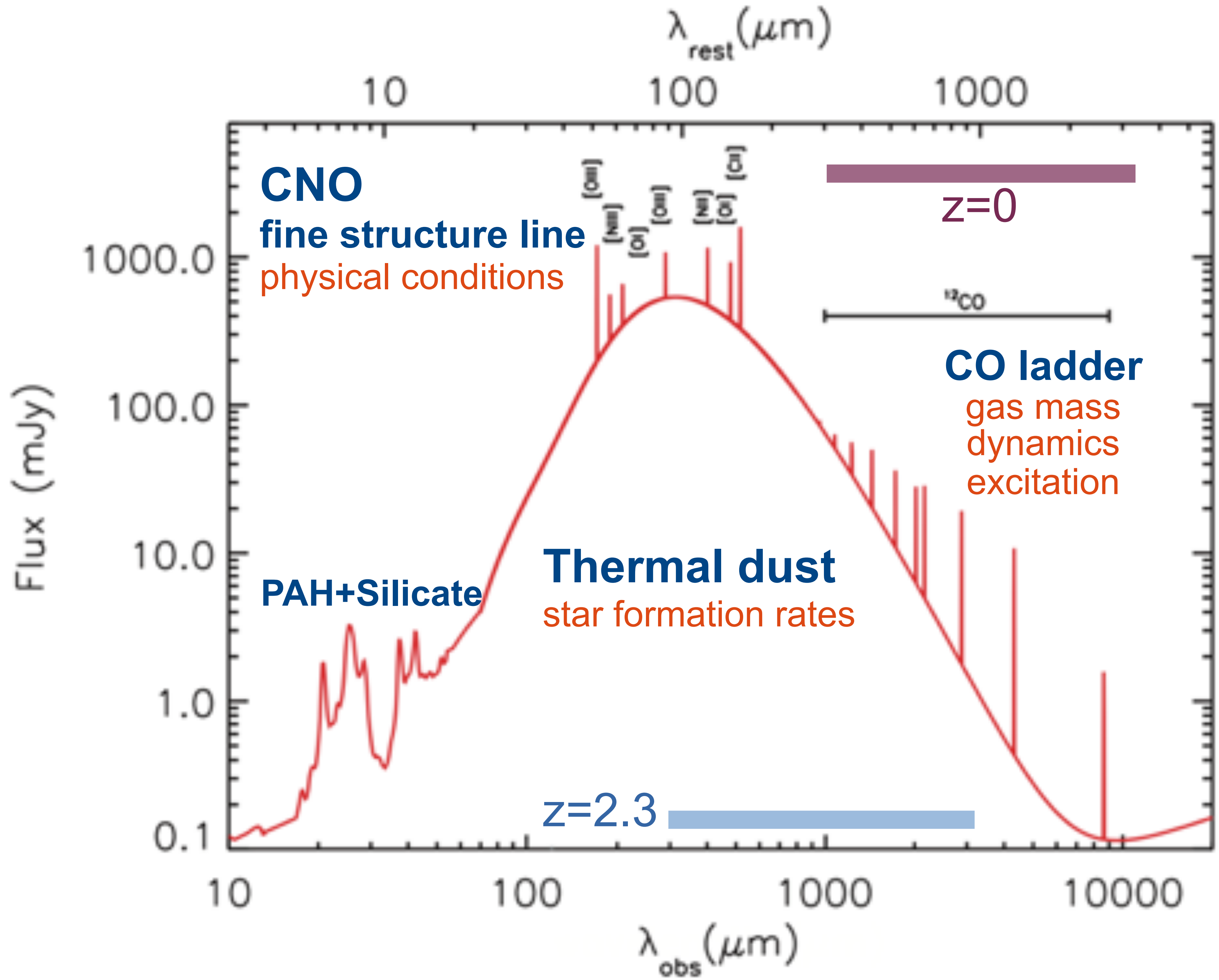


Figure from D. Riechers

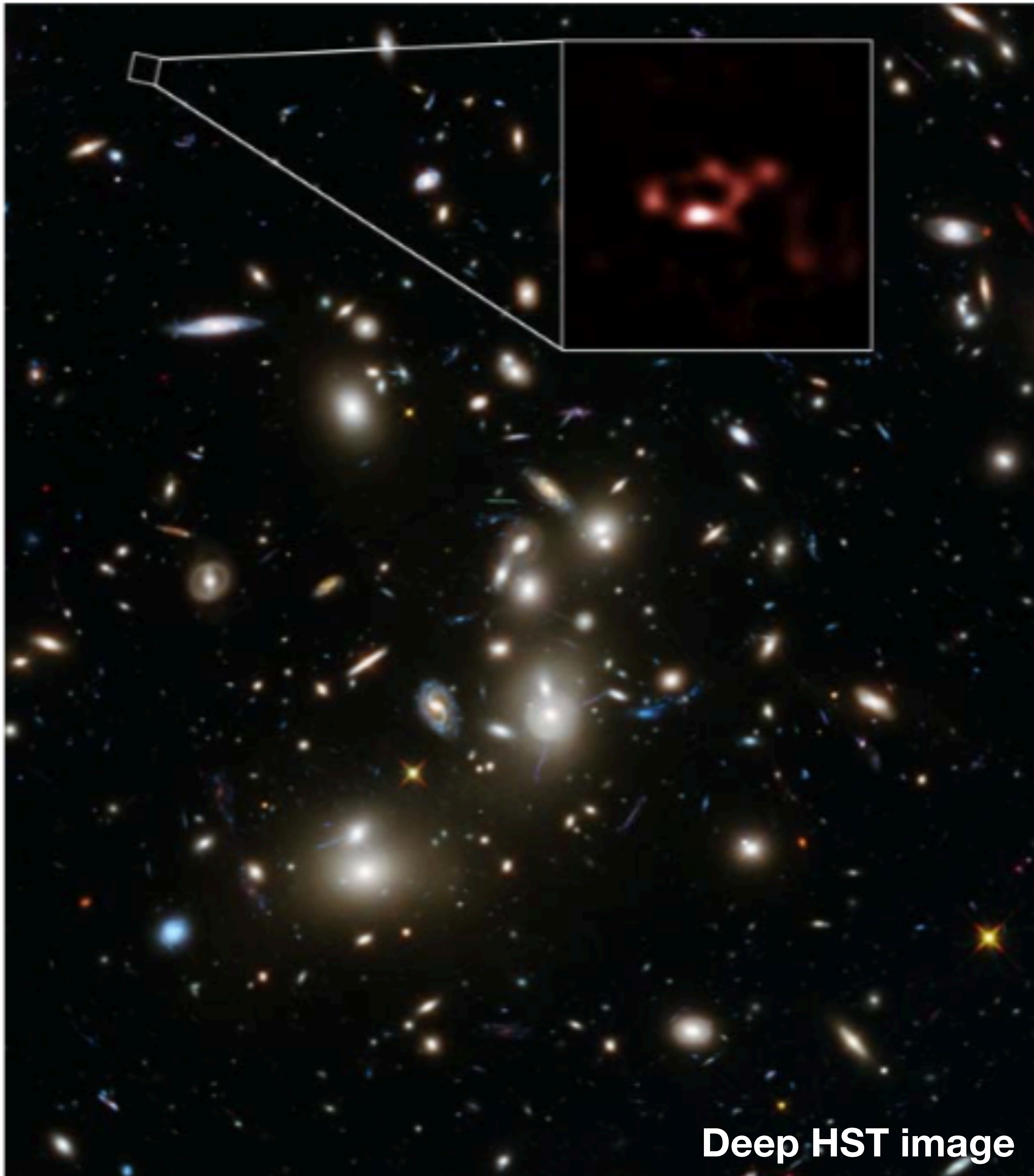
From Y. Yang's slides

Sciences

- Dust & Gas
  (physical/chemical property probes)
- Galactic targets
  ISM, YSOs, Sun (stars), evolved stars
- External galactic targets

Dust rich galaxy at z=8.38

- Laporte et al. 2017
- HST image of the galaxy cluster Abell 2744
- ALMA image of the z=8.38 gravitationally-lensed galaxy A2744_YD4 (Band 7)
- The galaxy at the 600 Myr old universe (200 Myr after re-ionization) is rich in dust: ~6 M $M_\odot$

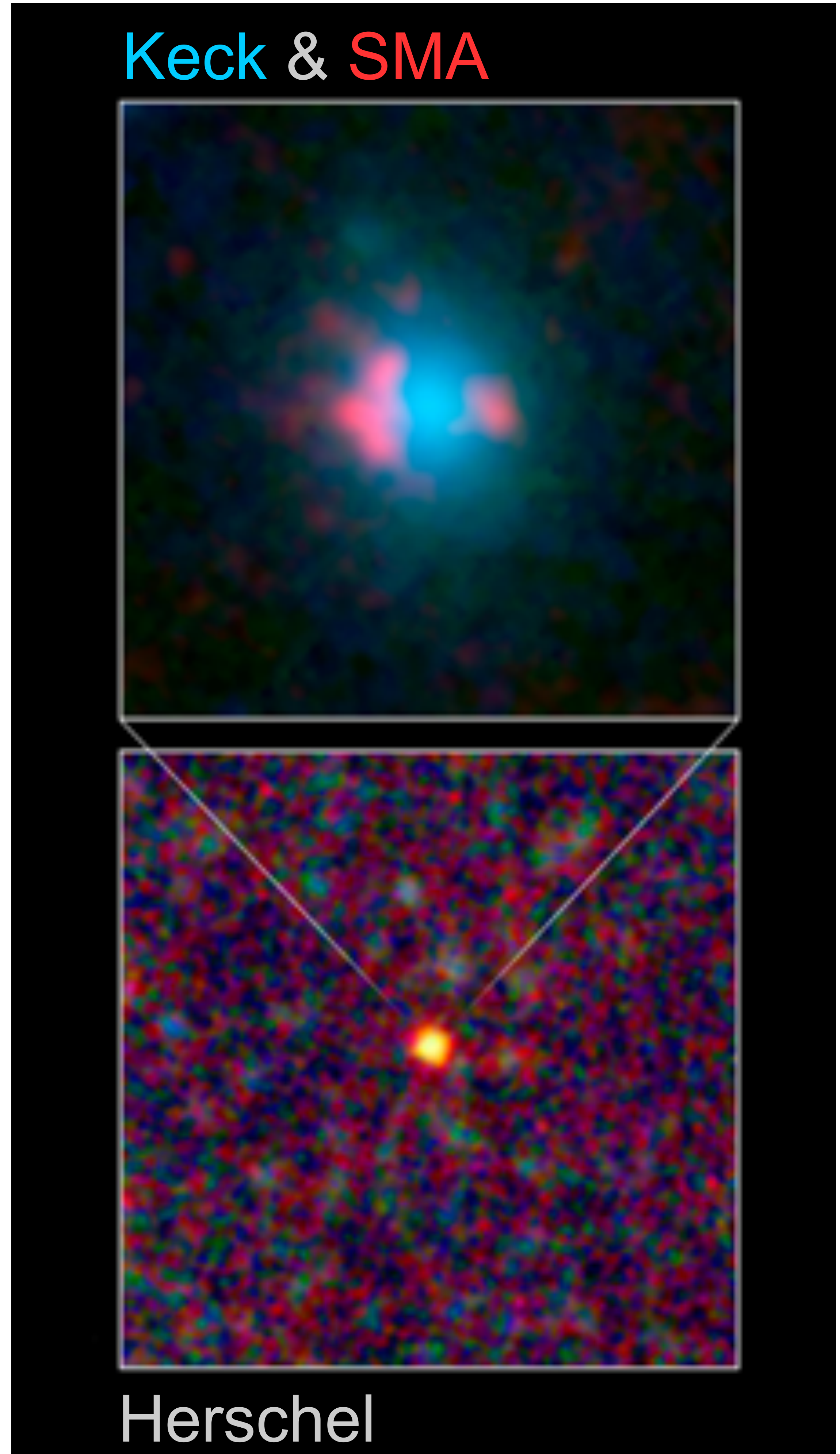


Probing ISM in 180 pc scales at z=3

- SDP.81
  Lensed active star-forming galaxy, z=3.042

- Lens: massive foreground galaxy, z=0.299 (blue: HST)

- ALMA (ALMA Partnership et al. 2015)
  - 0.023” resolution
  - dust & CO



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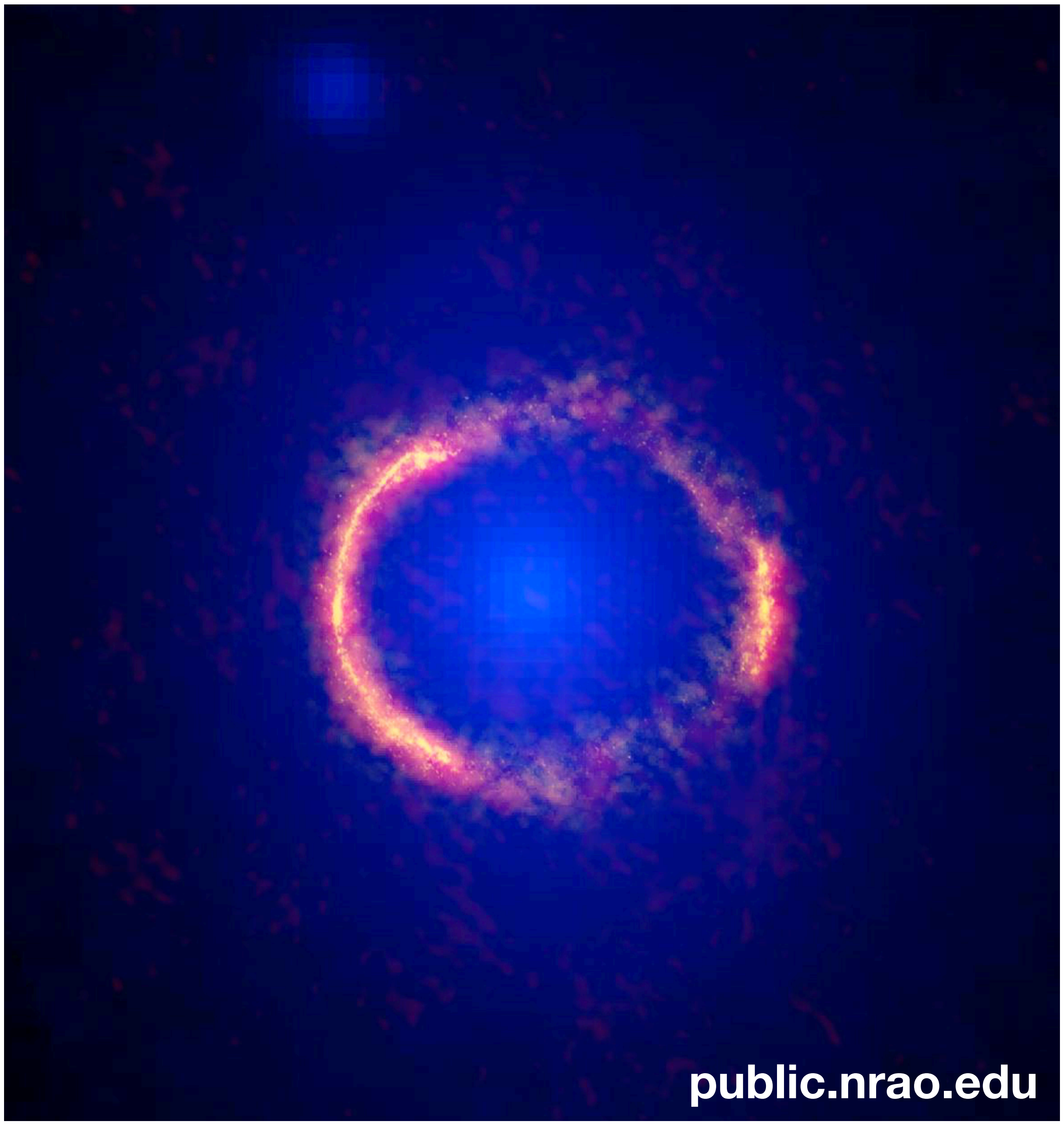
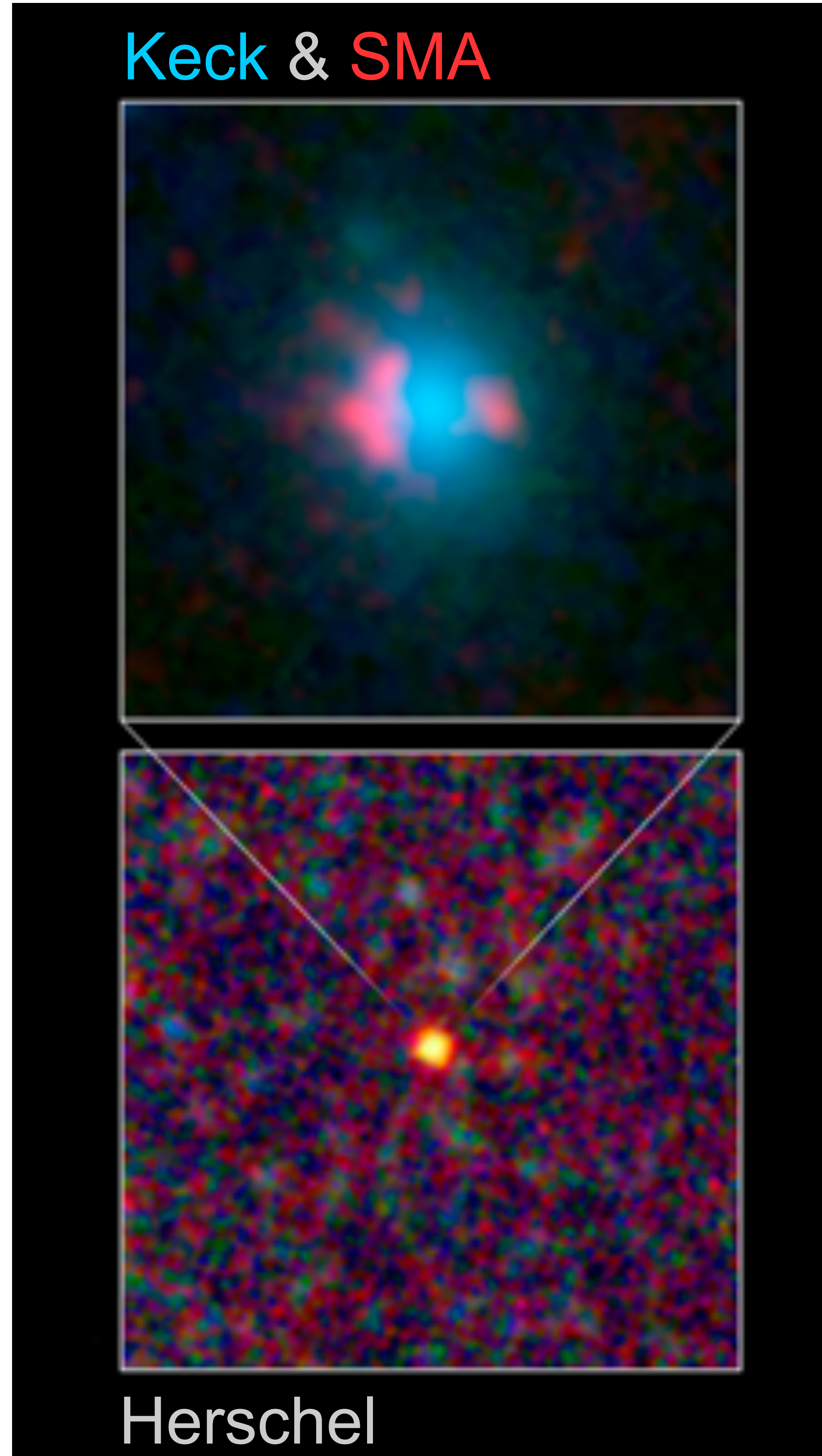
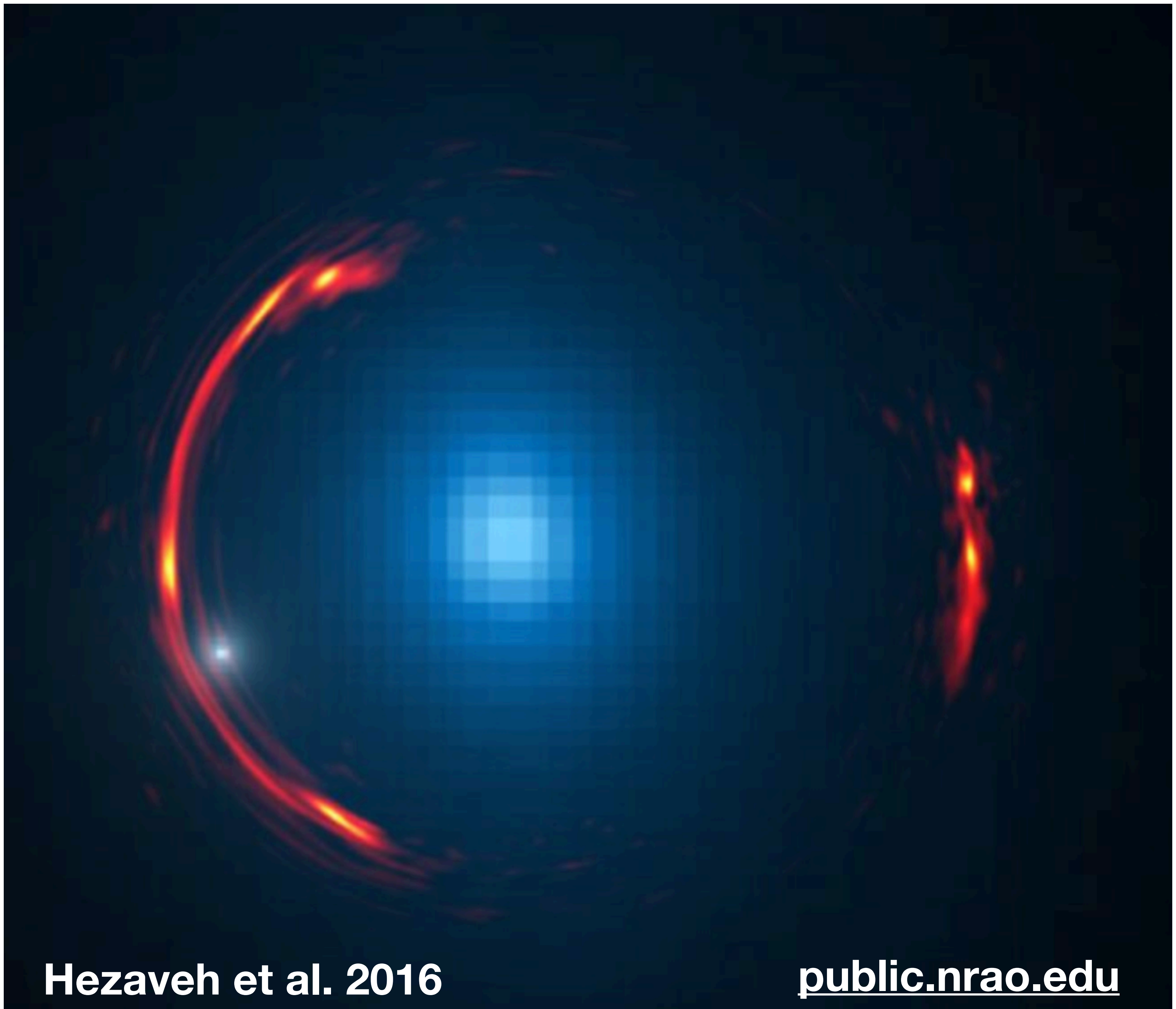




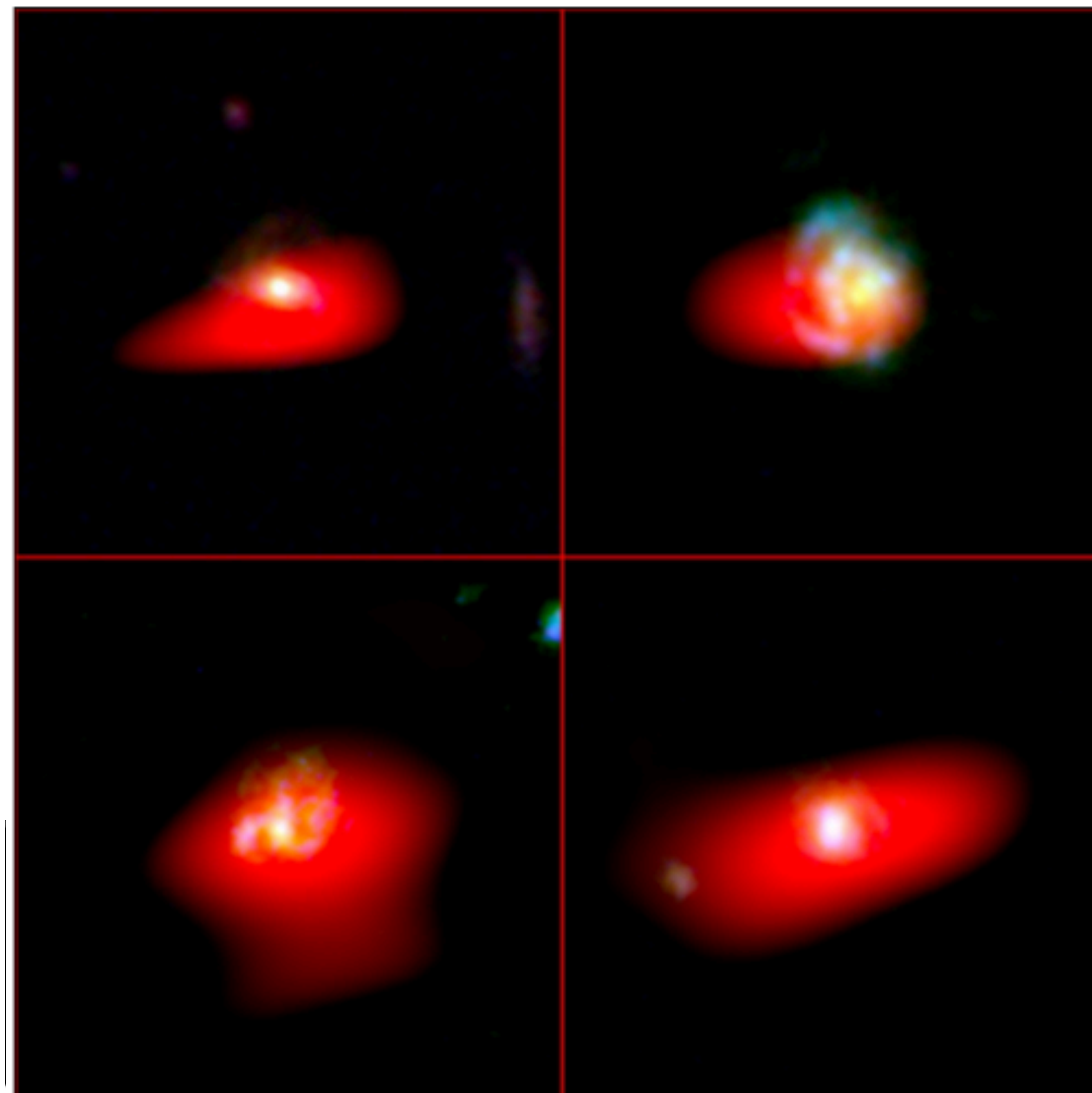
Dwarf dark galaxy
hidden in ALMA gravitational lens image



Milky-way-like progenitor galaxies at z=1.2-1.3

- Papovich et al. 2016
- Incredibly rich in molecular gas

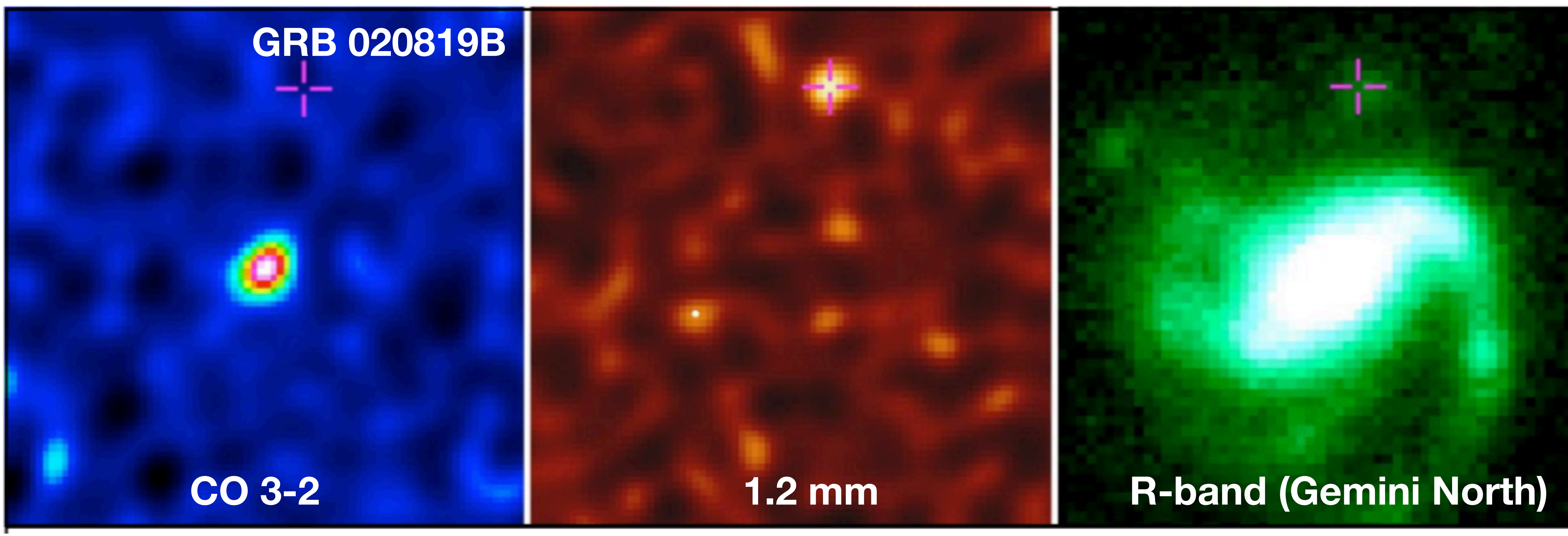
  CO 3-2 in red
  HST



GRB & host galaxy

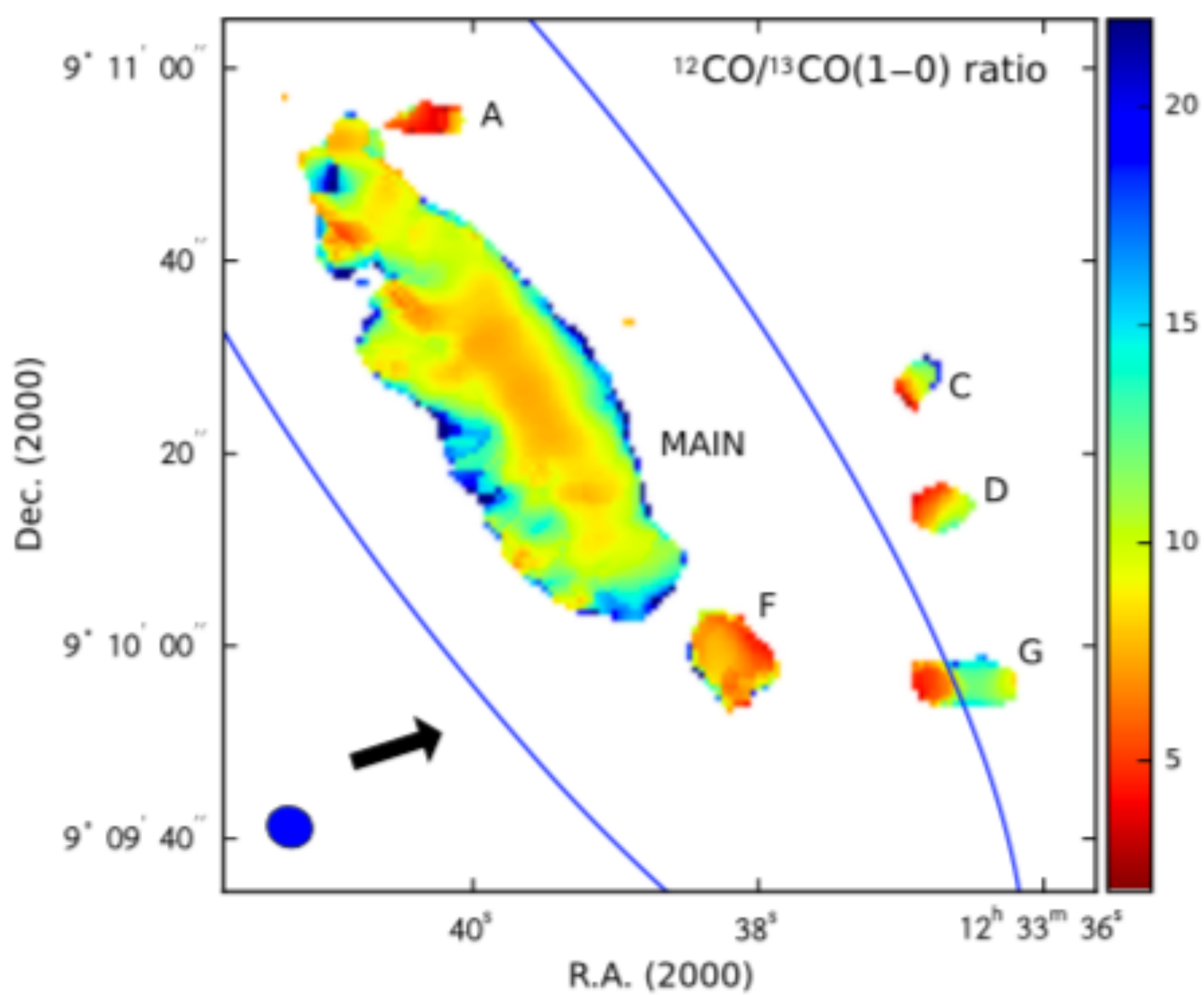
- First detection of CO from GRB hosts (z=0.4)
- Against expectations:
  Gas rich host galaxy
  Dust rich GRB

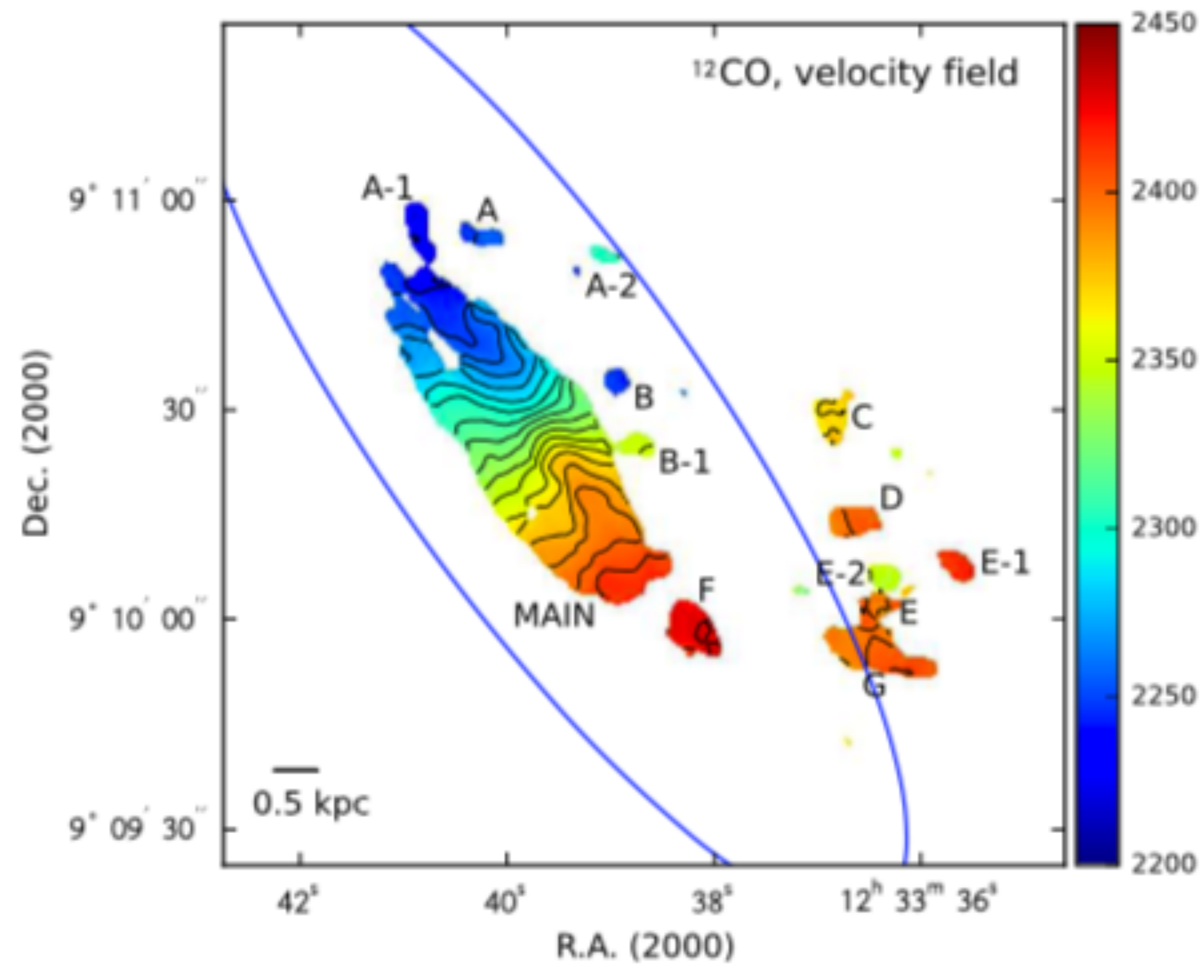
Hatsukade et al. 2014



Nearby galaxies

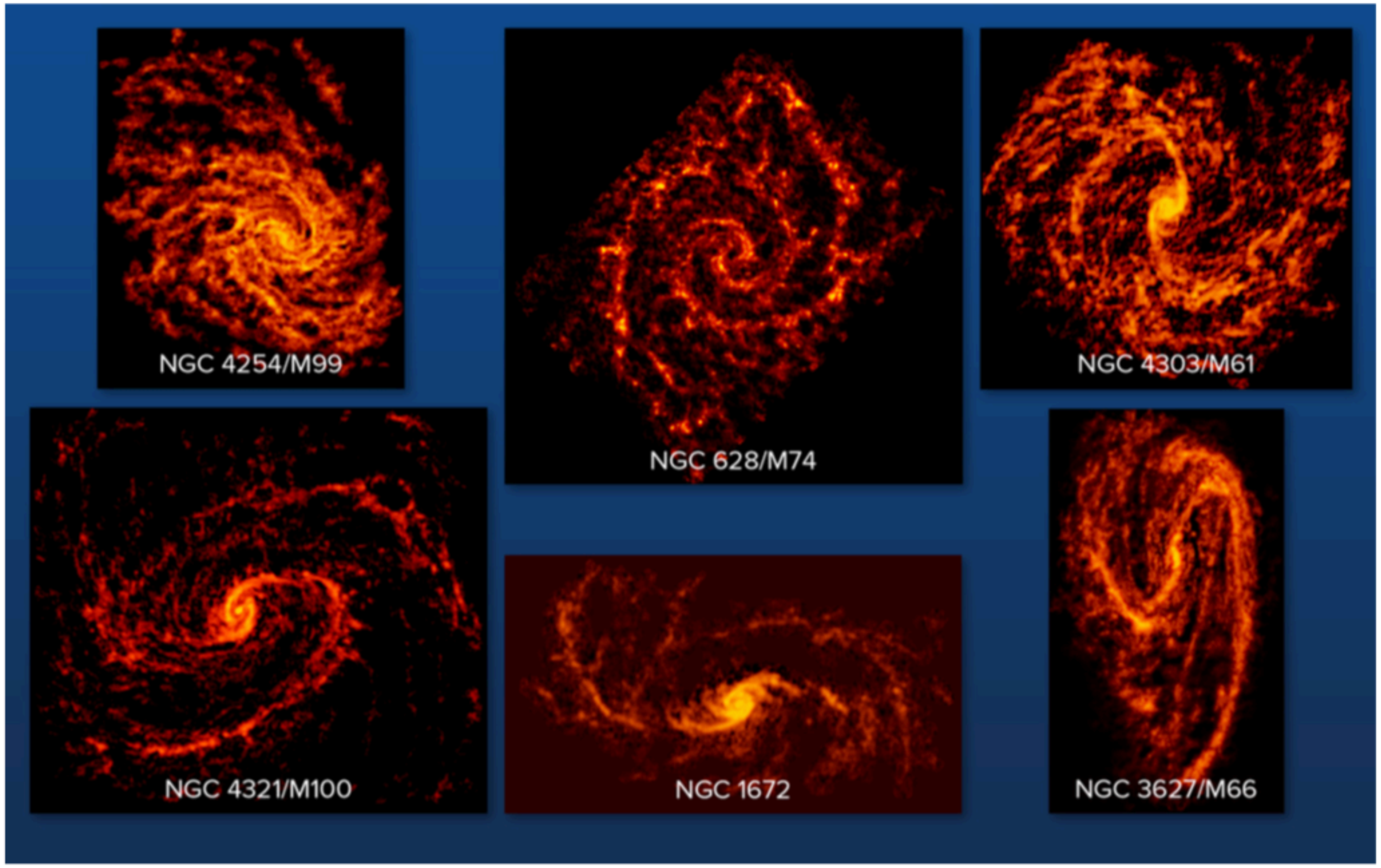
- Bumhyun Lee & Aeree Chung 2018
- NGC 4522: Virgo spiral galaxy with active ram pressure stripping
- ALMA Band 3 observations
  ^{13}CO detected: heavy elements from the galactic disk



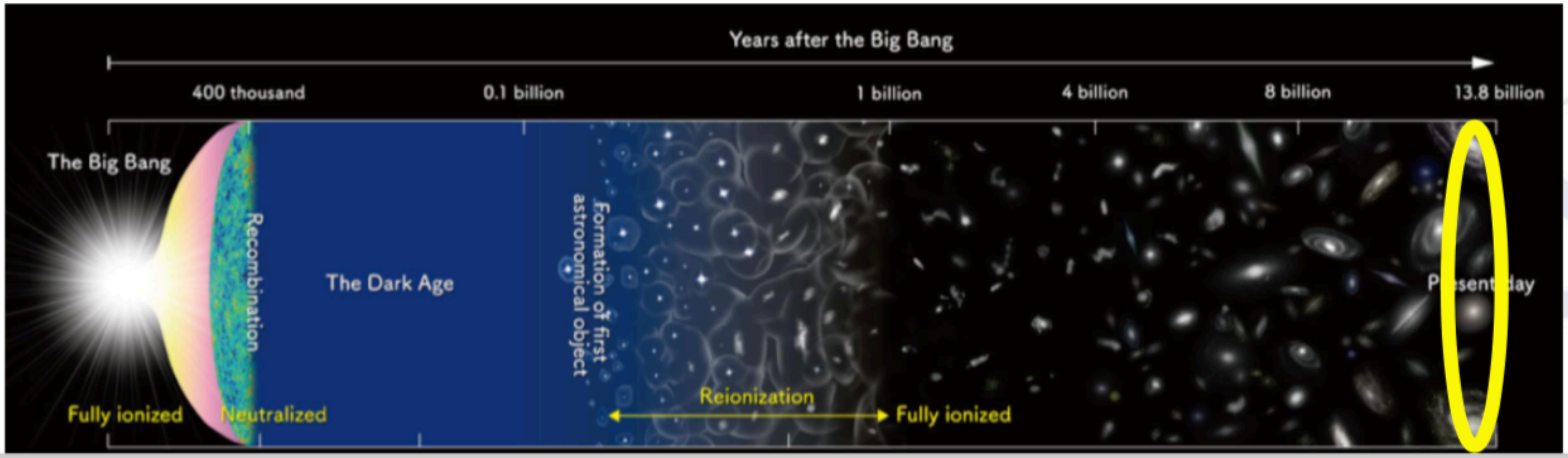


From J. Carpenter's slides

Atacama Large Millimeter/submillimeter Array
In search of our Cosmic Origins



Schinnerer et al. 2019
Cycle 5 Large Program
Press release at 2019 AAS



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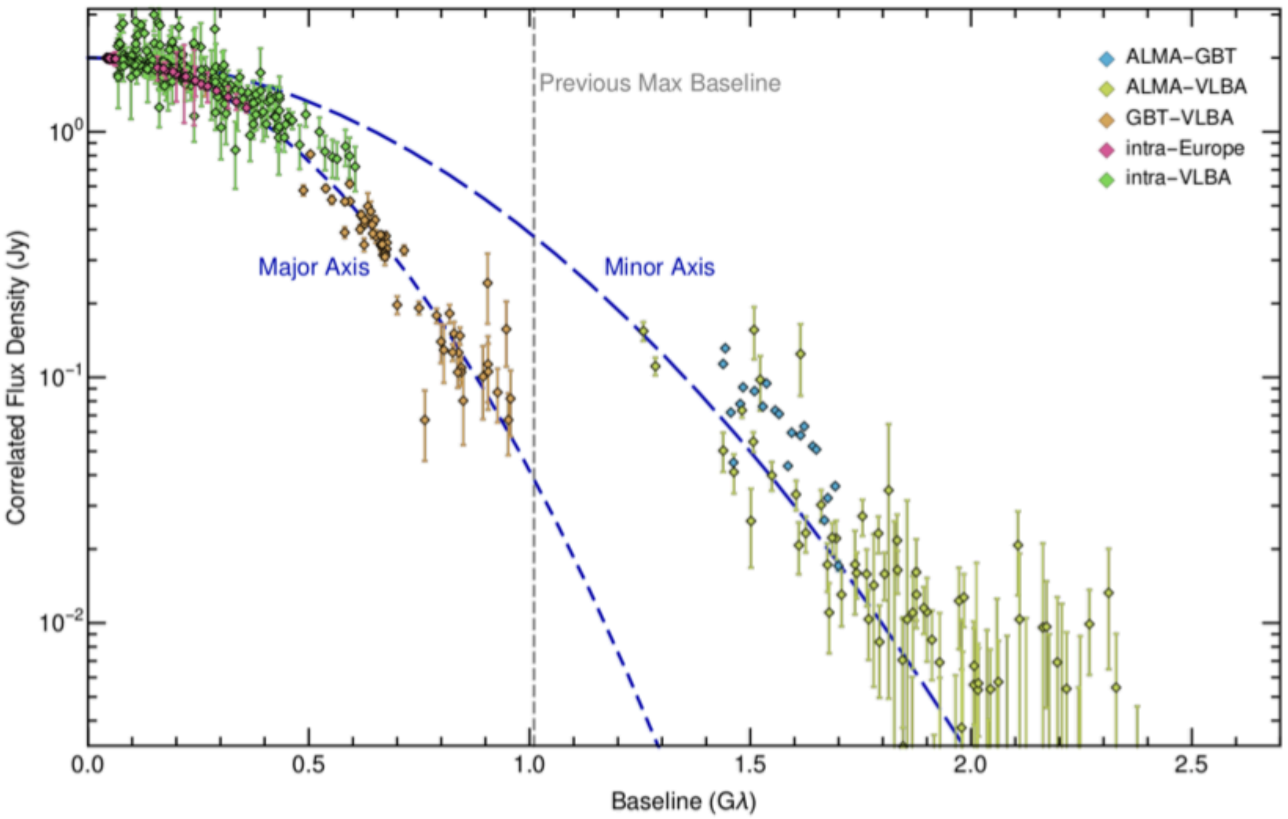
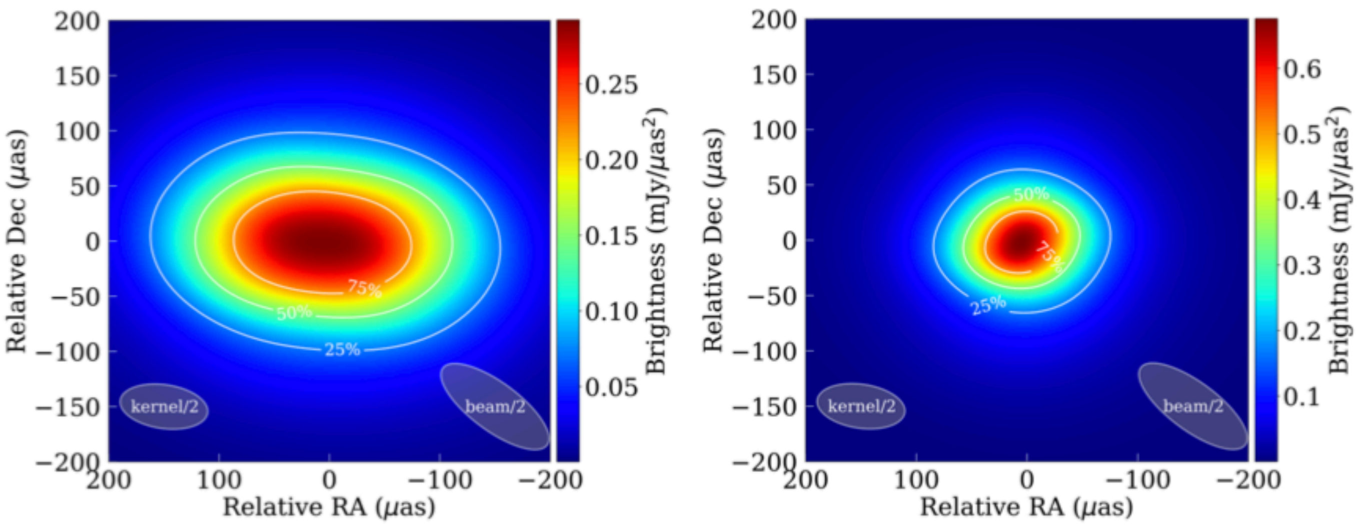
First 3mm ALMA VLBI Results



Reconstructed images



ALMA+GMVA images of Sgr A* at 86 GHz

- θ~87 μas
- unscattered source structure:
  major axis~120 μas (12 x Schwarzschild radius)
  symmetric morphology

Issaoun et al. (2019)

From J. Carpenter's slides

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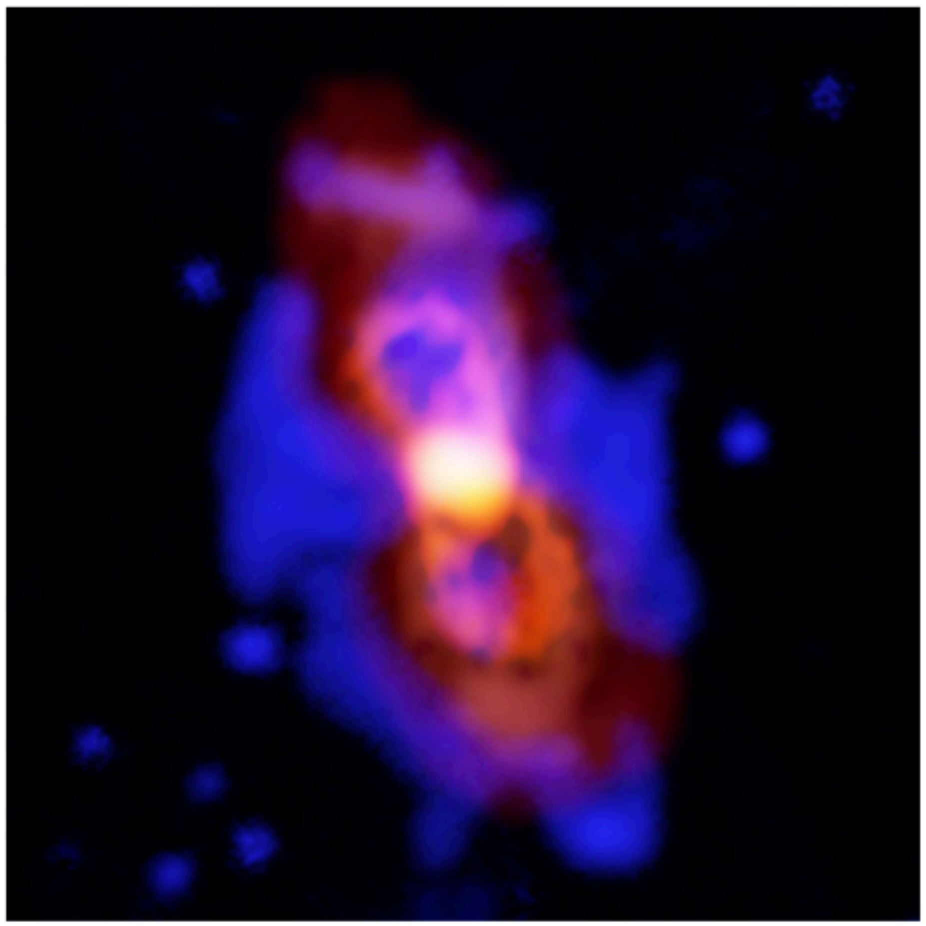
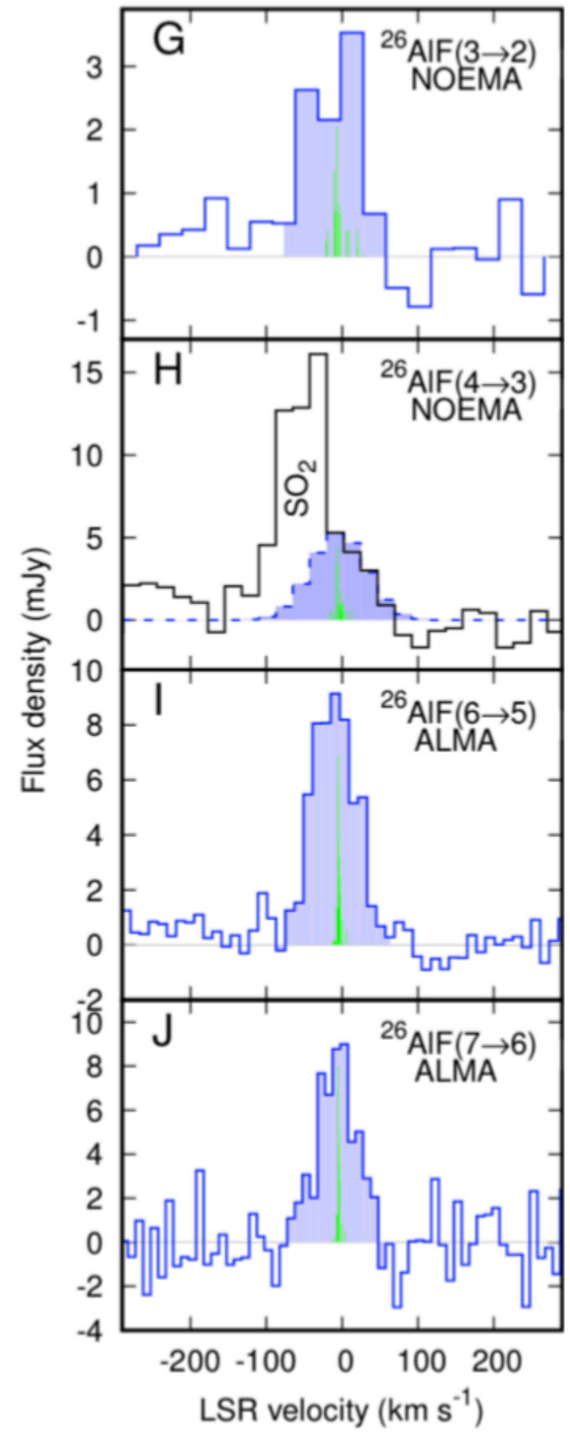
Origin of radioactive ^{26}Aluminum: First Band 5 publication



Orange: ALMA image of ^{27}Al
Blue: Optical image from Gemini



- CK Vul formed from the collision of two stars **(remnant of stellar merger)**
- First direct determination of the origin of ^{26}Al
- However, most of the ^{26}Al must be produced in other type of objects

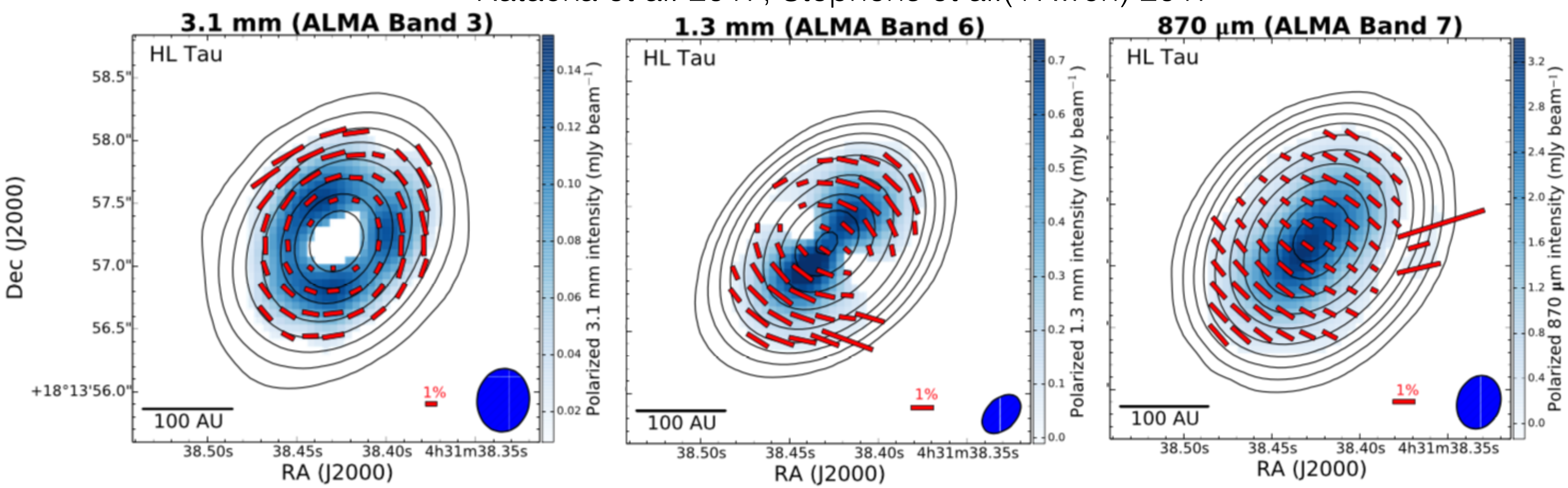
Kaminski et al. (2018)

Various Polarization Mechanisms

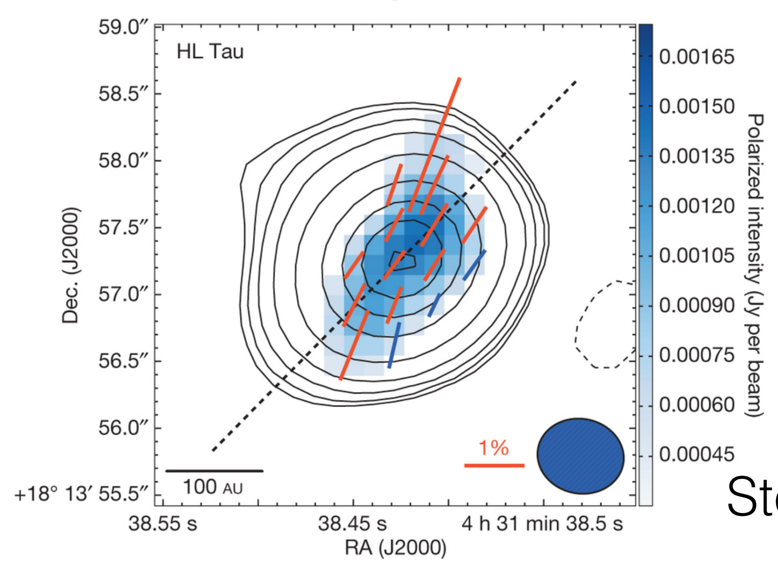
in Protoplanetary disks

Magnetically aligned dust grains => various mechanisms

Kataoka et al. 2017, Stephens et al.(+Kwon) 2017

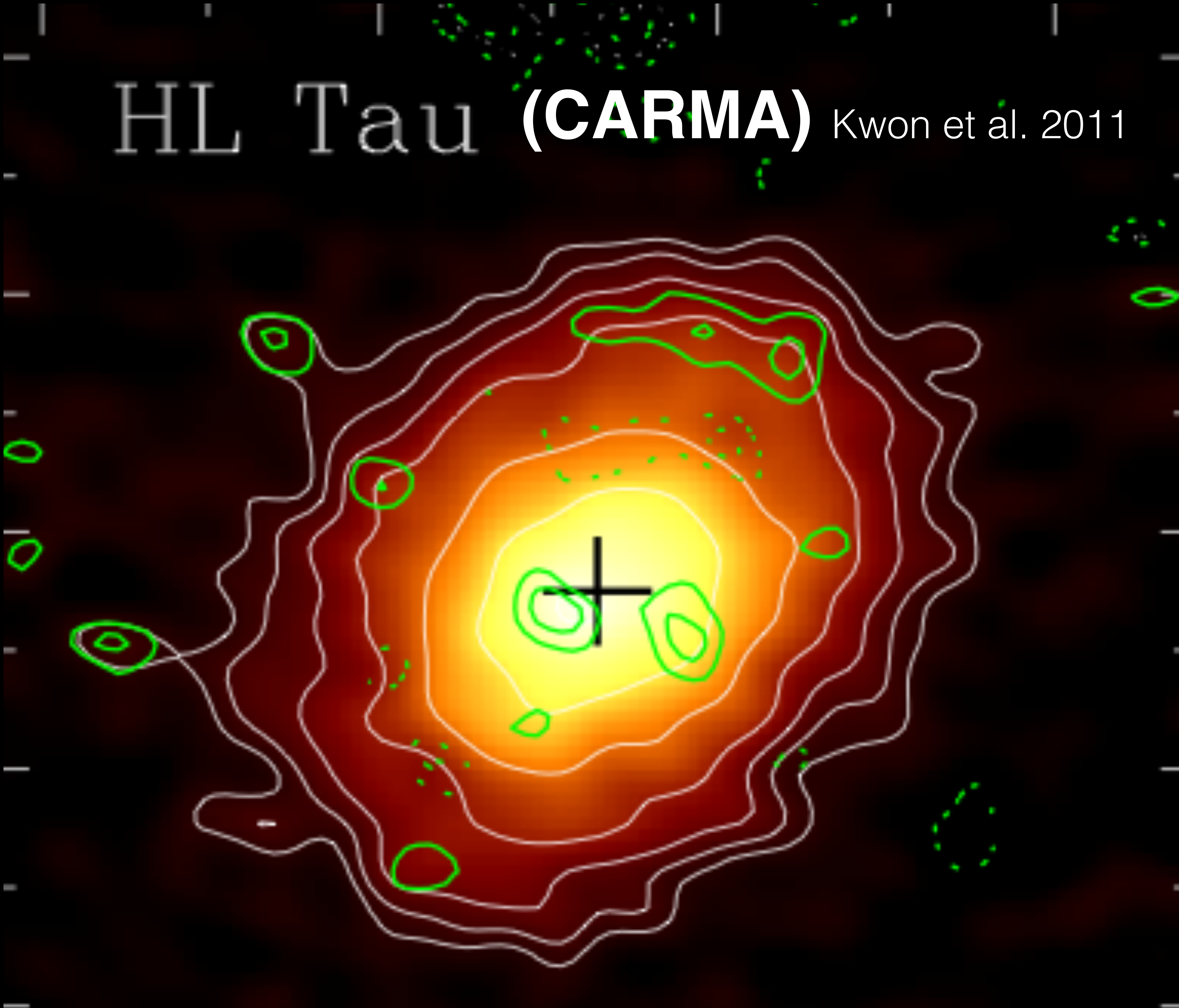


Radiation alignment

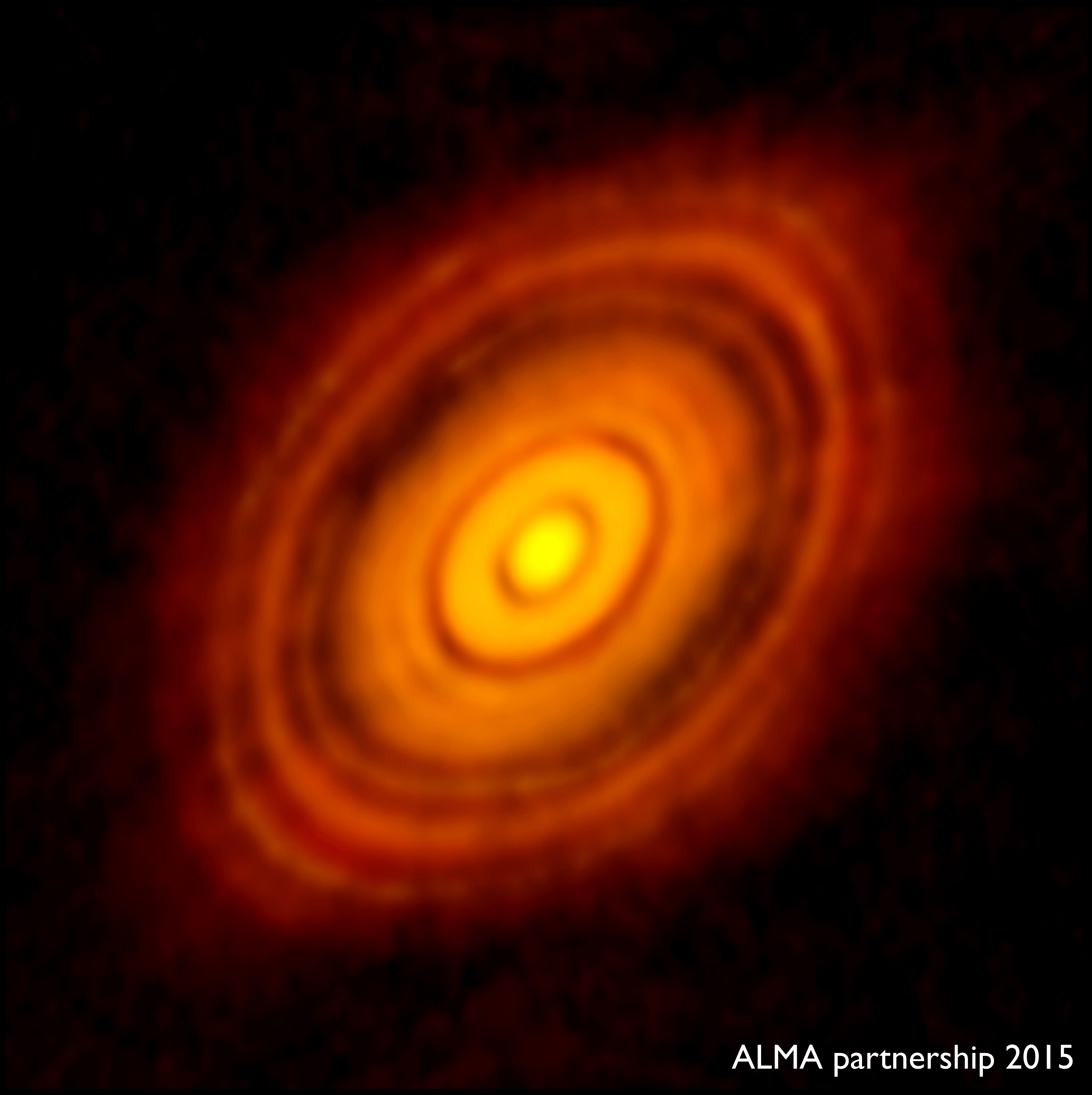


Self-scattering

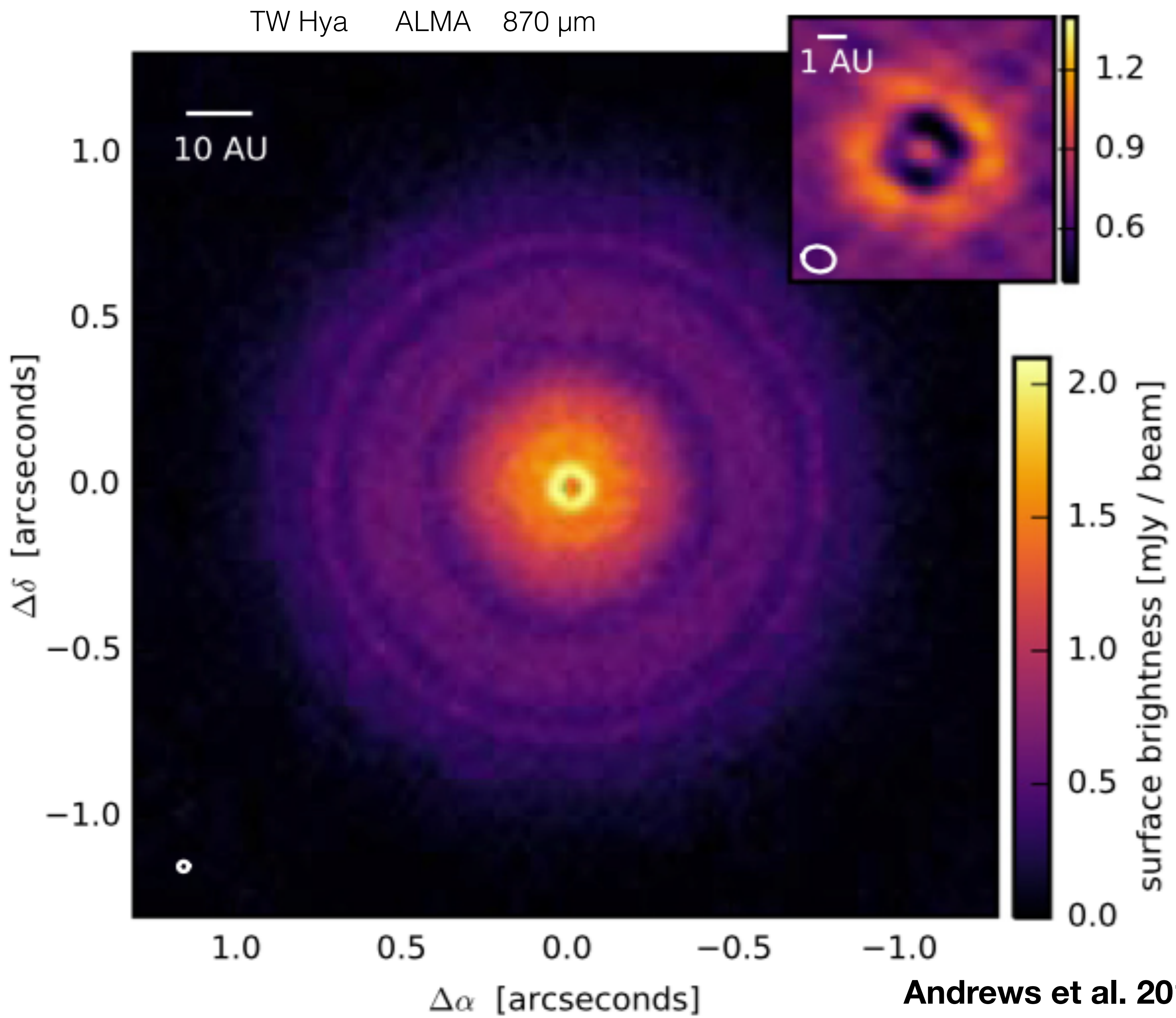
Stephens et al.(+Kwon) 2014


HL Tau
(CARMA)
Kwon et al. 2011

HL Tau (ALMA)



Protoplanetary disks TW Hya (d~54 pc)



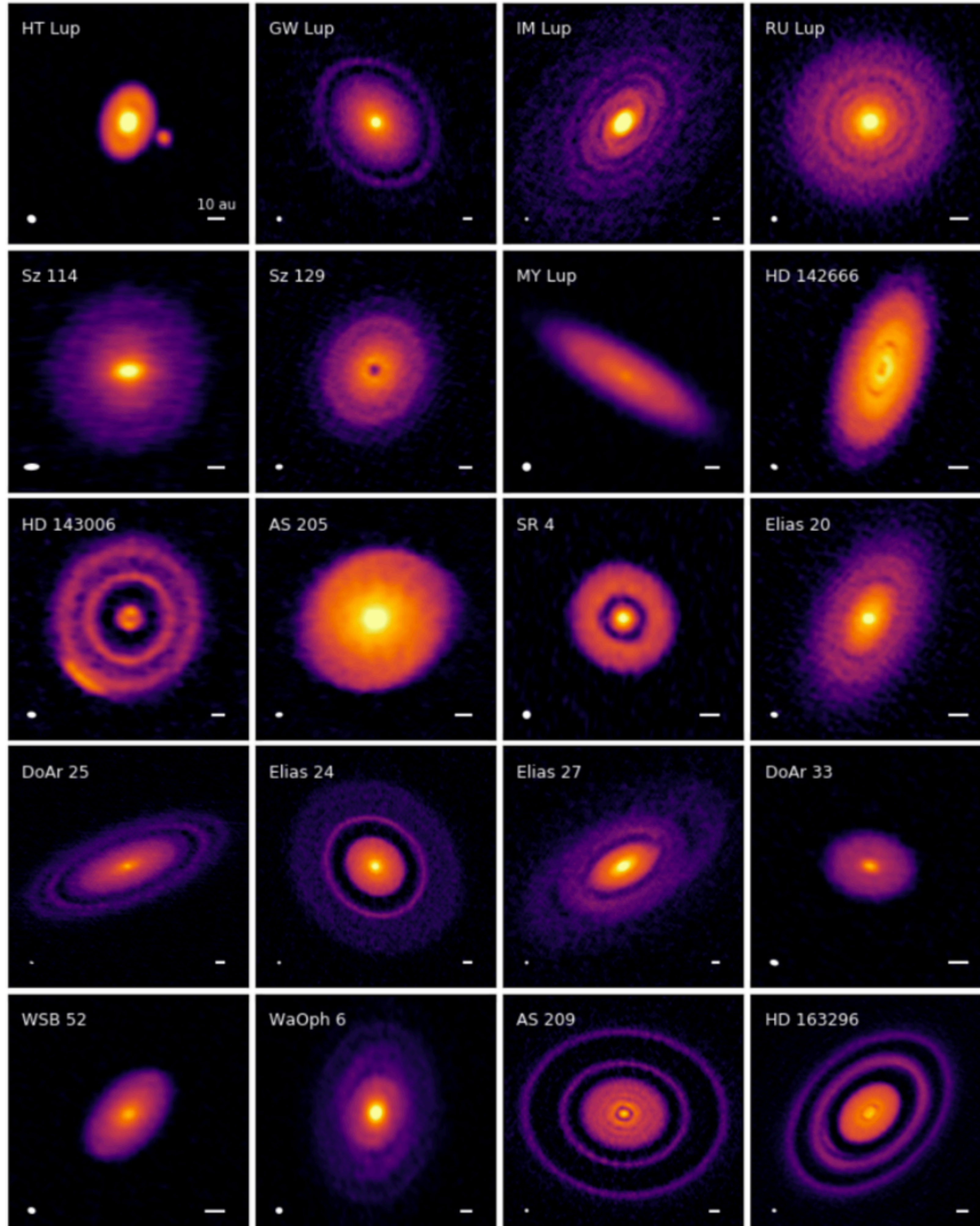
Andrews et al. 2016

DSHARP

Disk
Substructures at
High
Angular
Resolution
Project

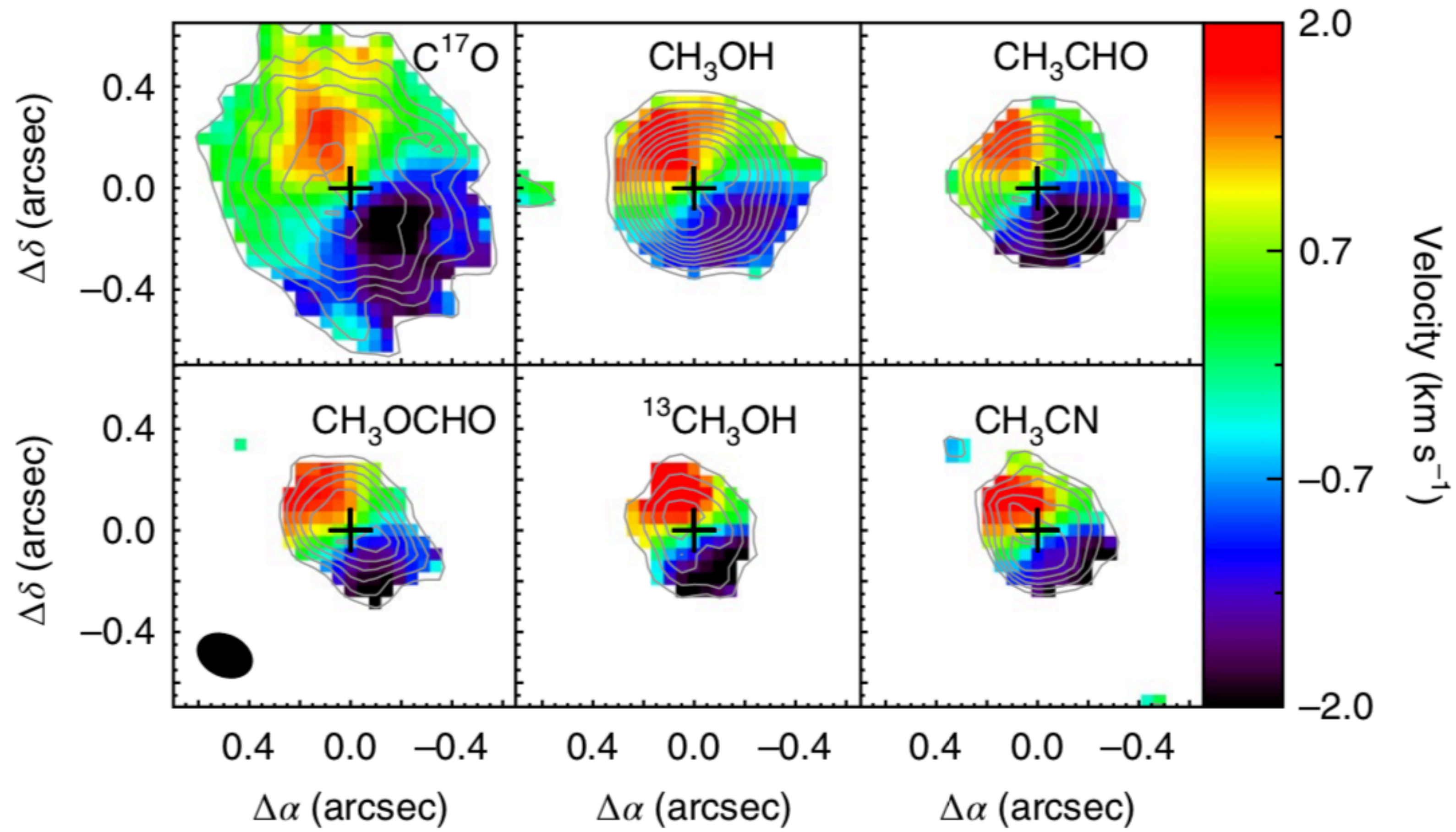
Sean Andrews et al. 2018:
10 ApJL papers,
posted at astro-ph
on Dec. 12, 2018

0.035” (5 au scales)
Band 6



COMs in V883 Ori

- Jeong-Eun Lee et al. 2019
- Protoplanetary disk with the snow line outward by an outburst (sudden increase of luminosity)



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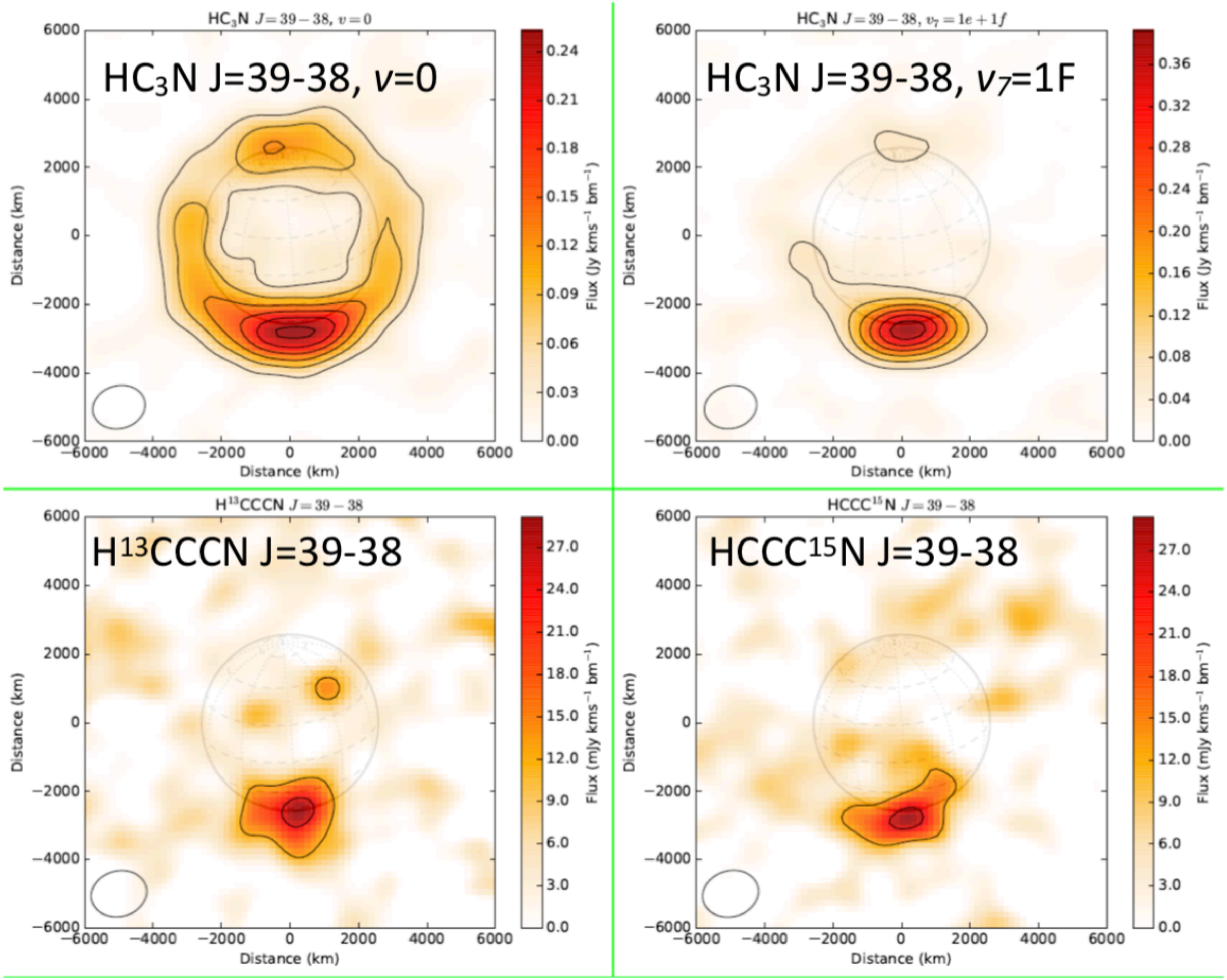
Titan's Atmosphere



- Obtained during Titan's solstice (southern winter)
- HC_3N enhanced over the south pole
- Consistent with photochemical loss of HC_3N from the summer hemisphere with production/transport to the winter pole

Cordiner et al. (2018)

Summary

- External galactic sciences
- Galactic sciences

ALMA!