# What can you observe with ALMA?

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A good starting point to learn what ALMA can do for you

https://science.nrao.edu/facilities/alma/didyouknow

Observing with ALMA - A primer

# A few examples

1. **Studying the Sun**
2. Studying the Solar system.
3. Studying proto-planetary disks.
4. Studying stellar-activity.
5. Studying High-Energy Astrophysics

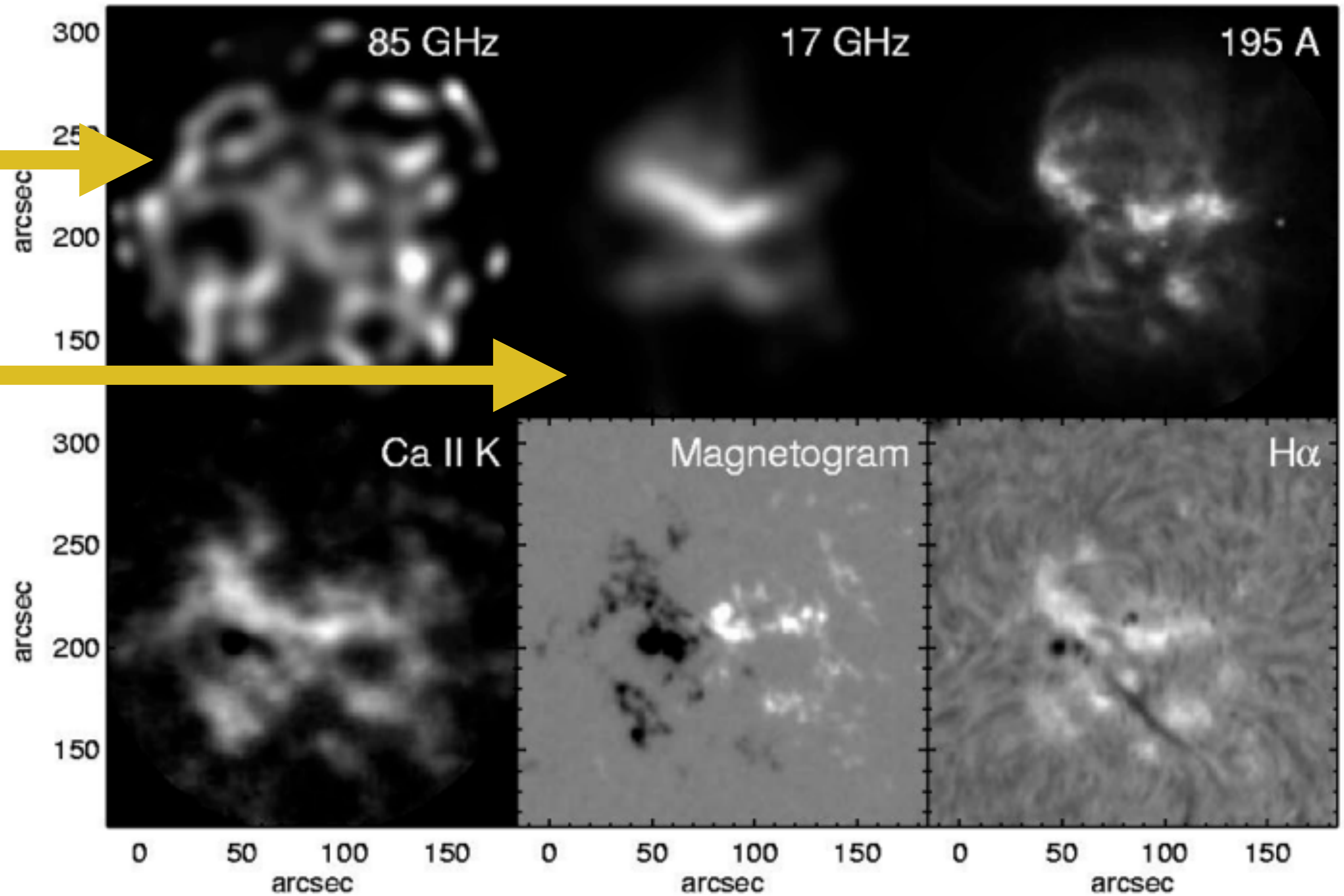
# 1. mm-wave observations of the Sun: Catching up with optical observations

https://arxiv.org/pdf/1601.00587.pdf

http://www.astro.gla.ac.uk/~eduard/solarALMA/presentations/White.pdf

BIMA image
10” resolution

VLA Image



# 1. ALMA unique capabilities in studying the solar chromosphere

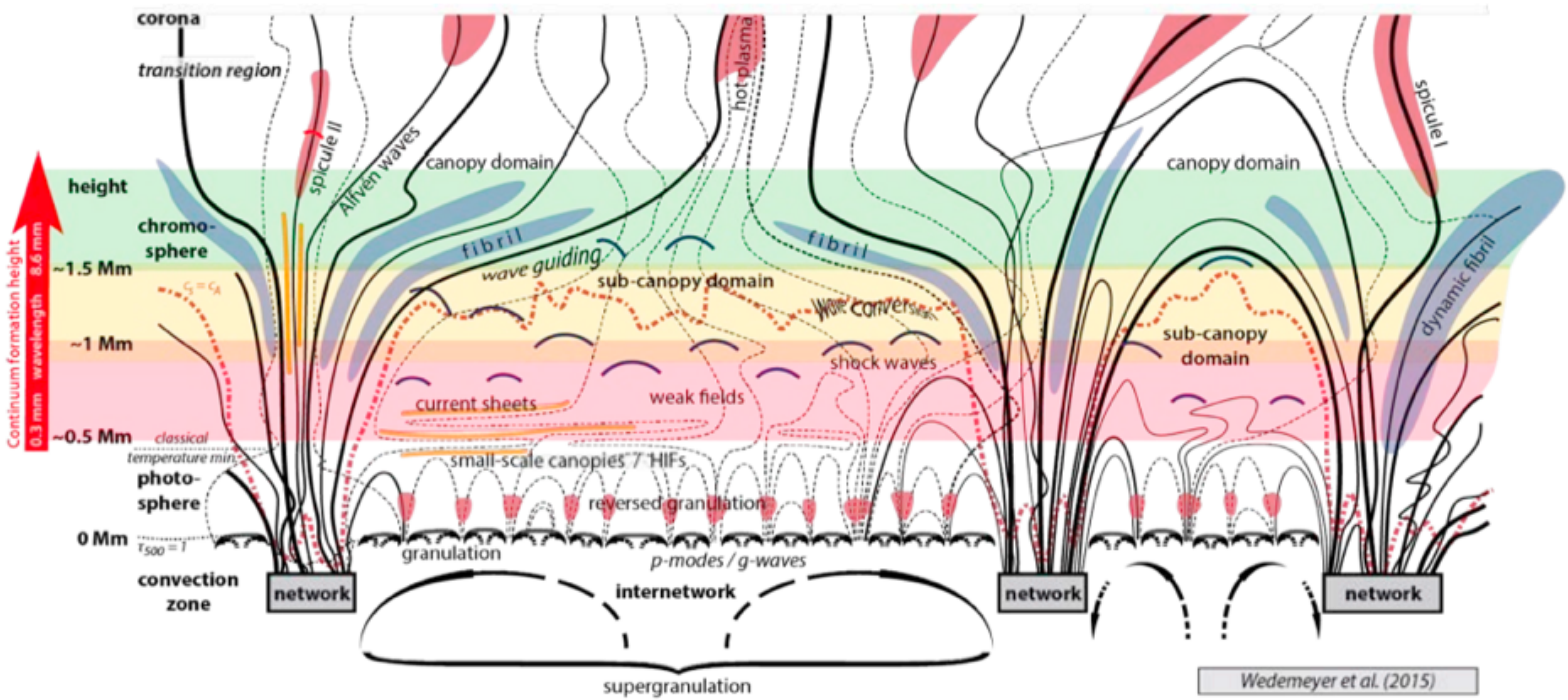



***Figure 4.3:*** *Schematic height structure of the solar atmosphere in quiet Sun regions ranging from the photosphere to the transition region and corona. The colored areas illustrate the chromospheric layers probed by ALMA at different wavelengths. From Wedemeyer et al. (submitted to SSRv).*

http://www.ssalmon.uio.no/

# 1. ALMA unique capabilities in studying the solar chromosphere

1. The continuum radiation at millimeter wavelengths probe the gas temperature in a rather narrow layer in the solar atmosphere.

2. The polarization provides a measure of the longitudinal magnetic field component in the same layer in the solar atmosphere.

3. The height of the probed atmospheric layer increases with the selected wavelength, enabling height scans through the solar atmosphere and tomographic techniques.

# 1. Fundamental questions in solar physics to be addressed with ALMA

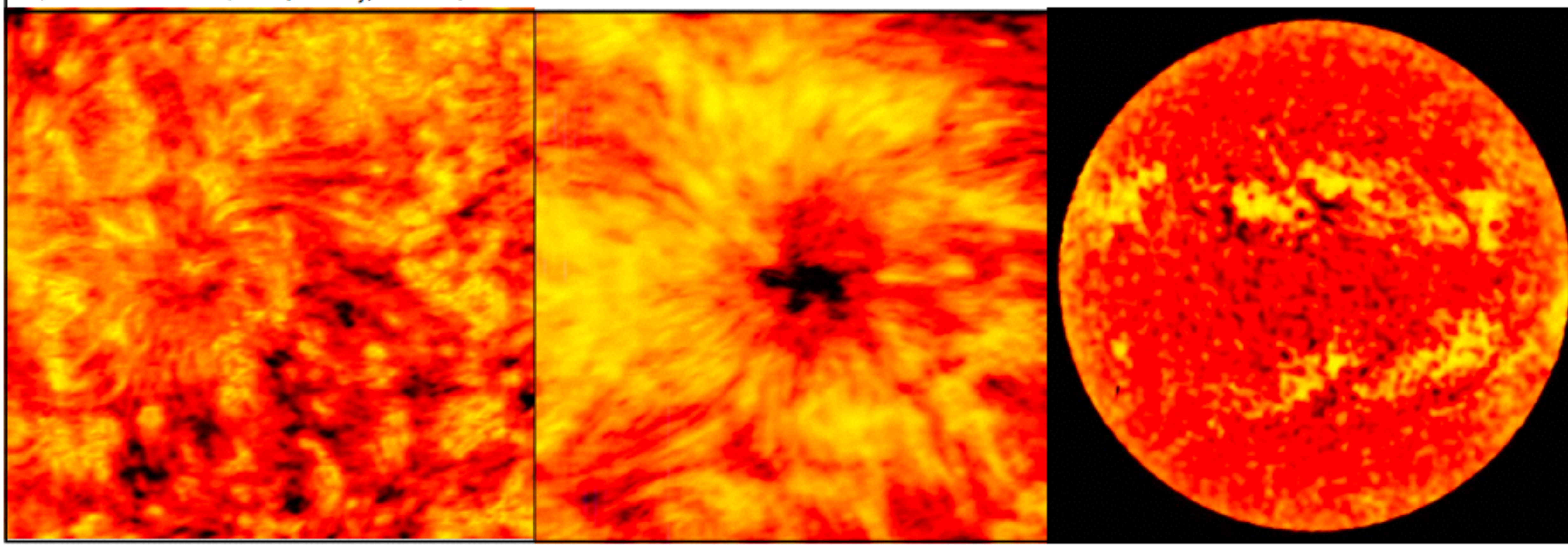
**Coronal and chromospheric heating:** ALMA has the potential to substantially contribute to solving the coronal/chromospheric heating problem by probing the 3D thermal structure and dynamics of the solar chromosphere, thus revealing the energy transport in the outer layers.

**Solar flares:** ALMA's ability to probe the thermal and magnetic state of flaring regions at high spectral, spatial and temporal resolution promises to deliver new key information about particle acceleration mechanisms and the source of the emission component at sub THz frequencies.

**Solar prominences:** ALMA is an ideal tool for probing the cool prominences plasma and addressing the many unanswered questions from the formation to the eruption of prominences.

# 1. Continuum Mapping of the Sun at Millimeter Wavelengths

Figure 26: *Images obtained by ALMA of a large sunspot on 18 December 2015 at 3mm (Band 3; left) and 1.25 mm (Band 6; center). Observations at shorter wavelengths (center) probe deeper into the solar chromosphere than longer wavelengths (left). Hence Band 6 observations map a deeper layer of the chromosphere that is closer to the visible surface (photosphere) of the Sun than Band 3 observations. The full map of the Sun (right) was taken at Band 6 using a single antenna of the TP array using a "fast-scanning" technique. (Credit: ALMA (ESO/NAOJ/NRAO)*



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1.2" resolution
at 100 GHz, or
900 km on the Sun

0.5" resolution
at 230 GHz, or
360 km on the Sun

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# 2. ALMA Observations of Solar System Objects

https://almascience.nrao.edu/alma-science/solar-system

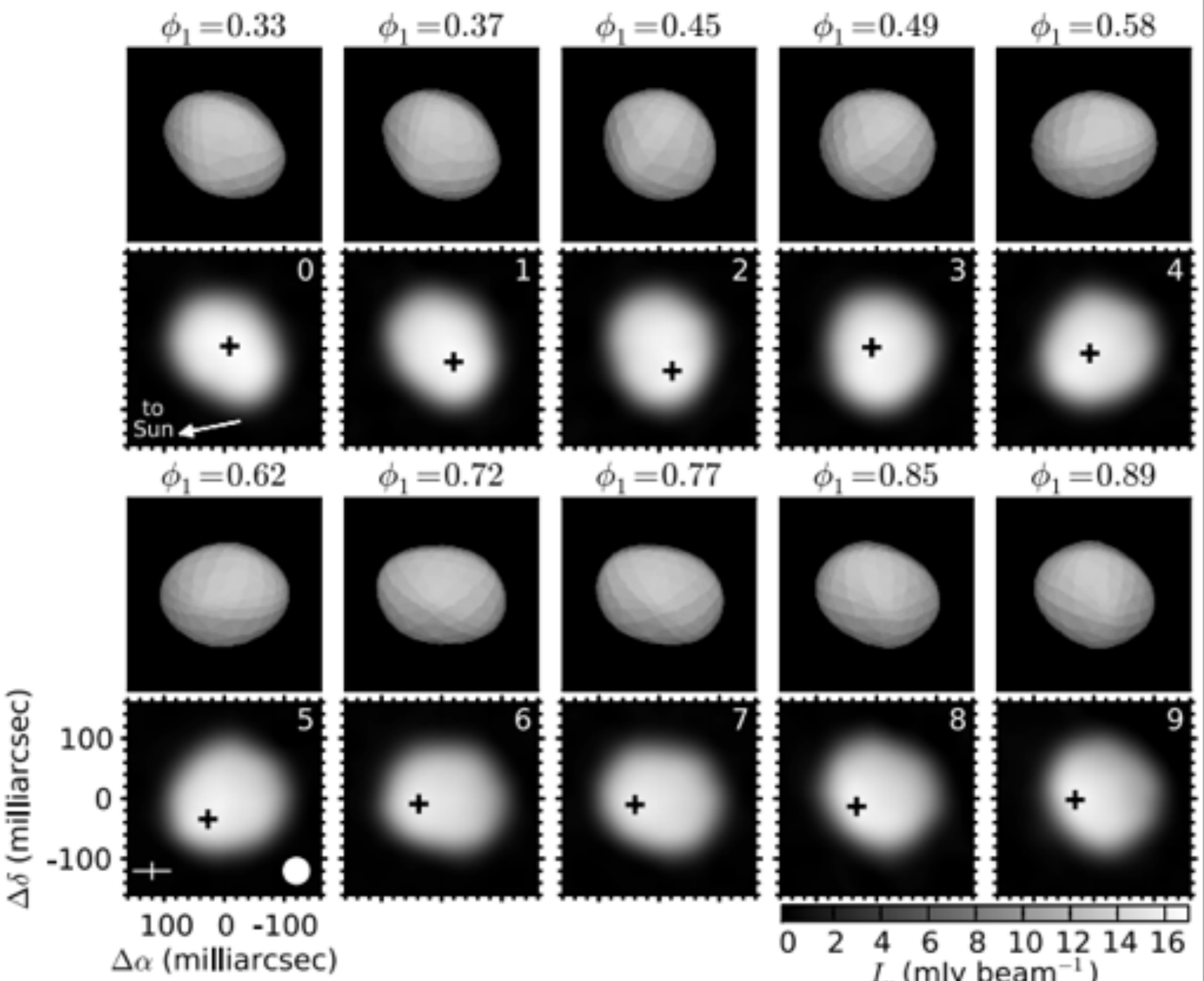



Figure 25: *Asteroid 3 Juno was observed in October 2014 during the commissioning period of the ALMA long baseline campaign. Over the course of the observations, the achieved resolution varied from 32 x 24 mas to 42 x 36 mas, differing mostly due to changes in phase stability as the observations spanned the transition from night through dawn and into daytime. The baselines used to achieve this resolution ranged from 26 m to 13 km. The observations spanned 10 epochs, covering 60% of the 7.2h rotation period. (Credit: ALMA Partnership et al., 2015, ApJ, 808, L2)*

ALMA observations measure the size and structure of asteroids.

ALMA observations are complementary to optical/IR adaptive optics observations and radar mapping.

Viikinkoski et al. 2015, A&A, 581, L3

# 2. ALMA Observations of Comets

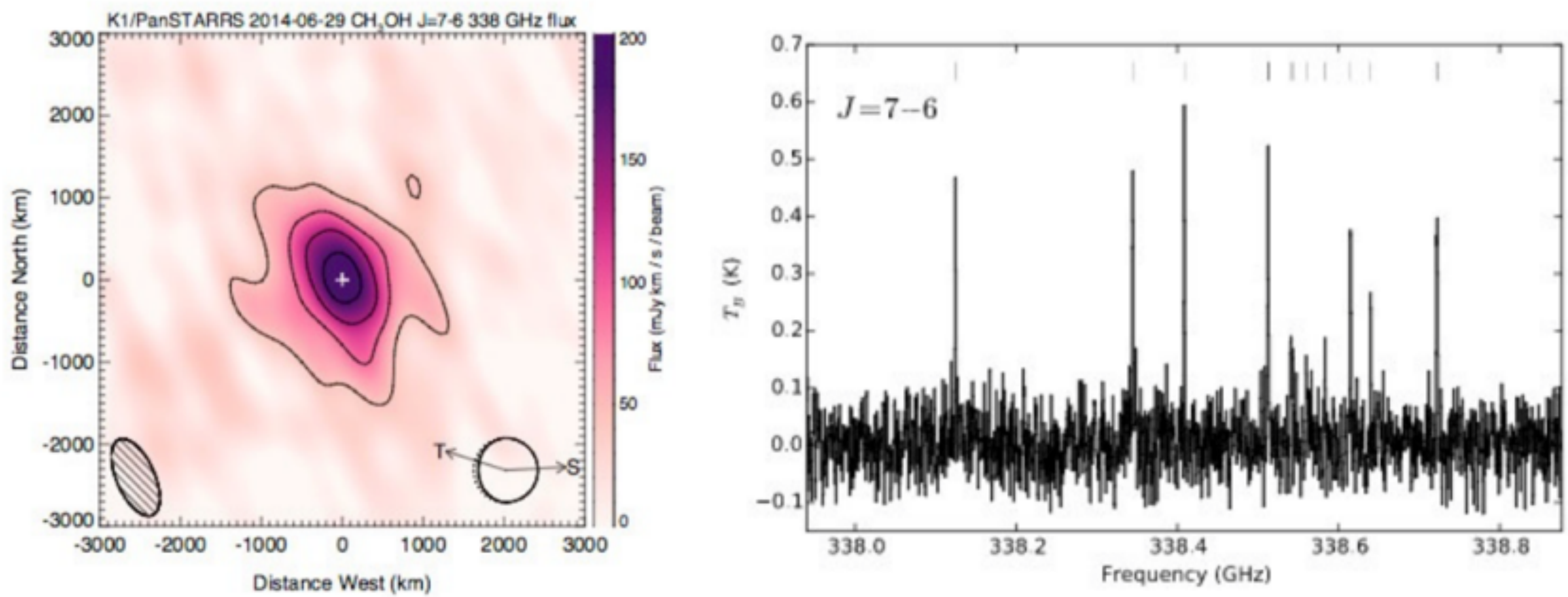
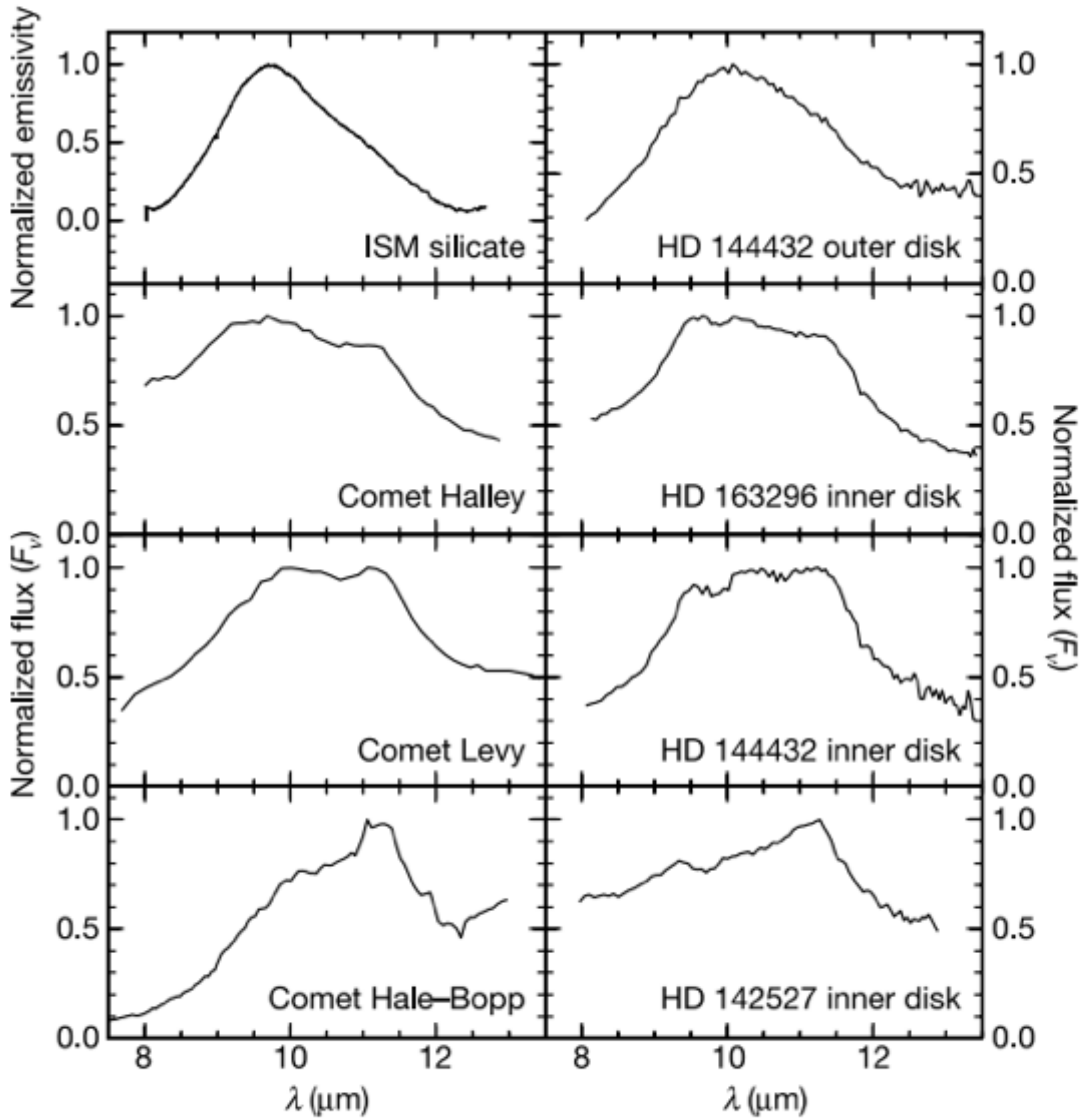



Image and spectrum of the comet C/2012 K1 (PanSTARRS) in the J=7-6 line of methanol, showing several transitions of the molecule. Cordiner et al. (2017a).

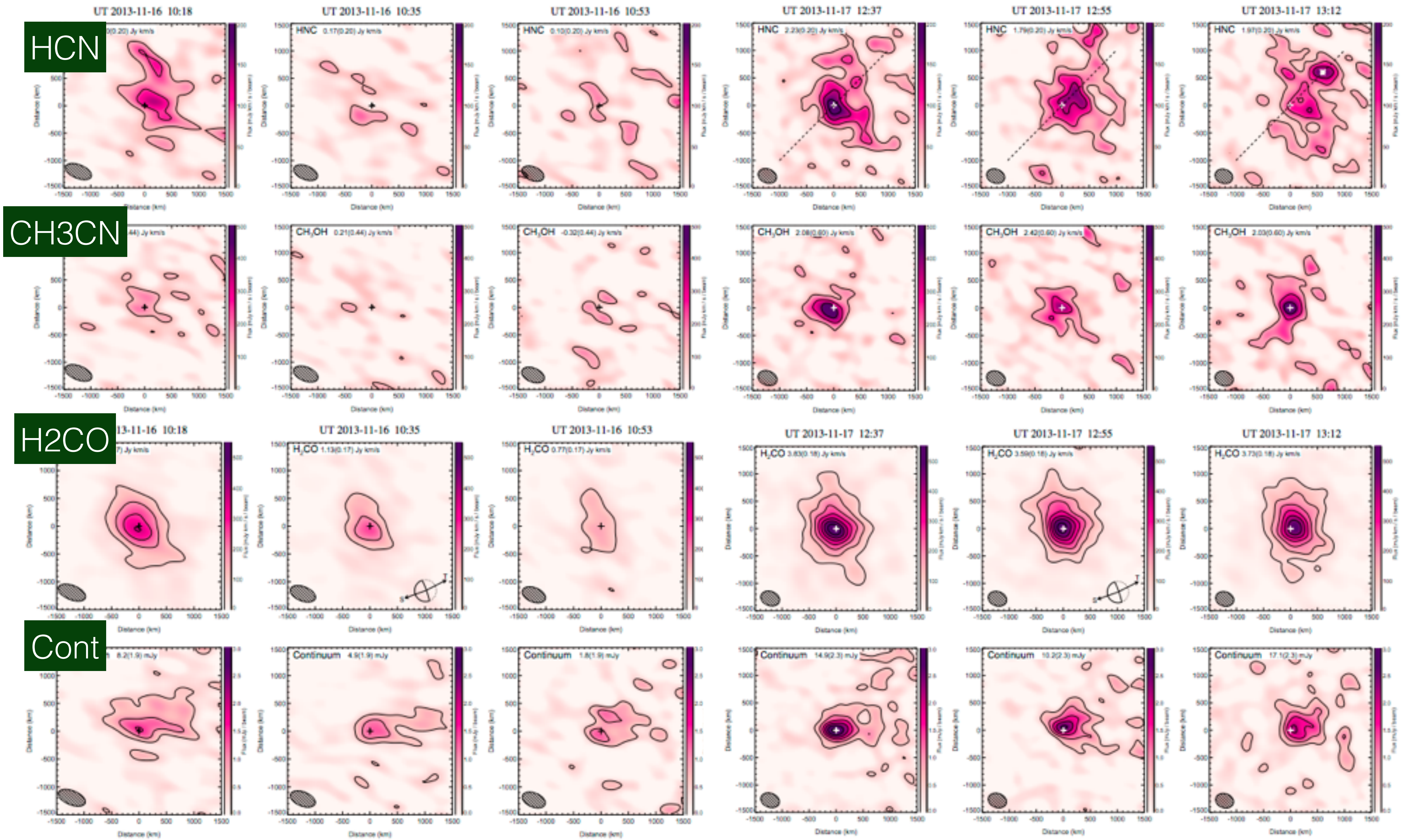
# 2. Comets: reservoir of pristine material



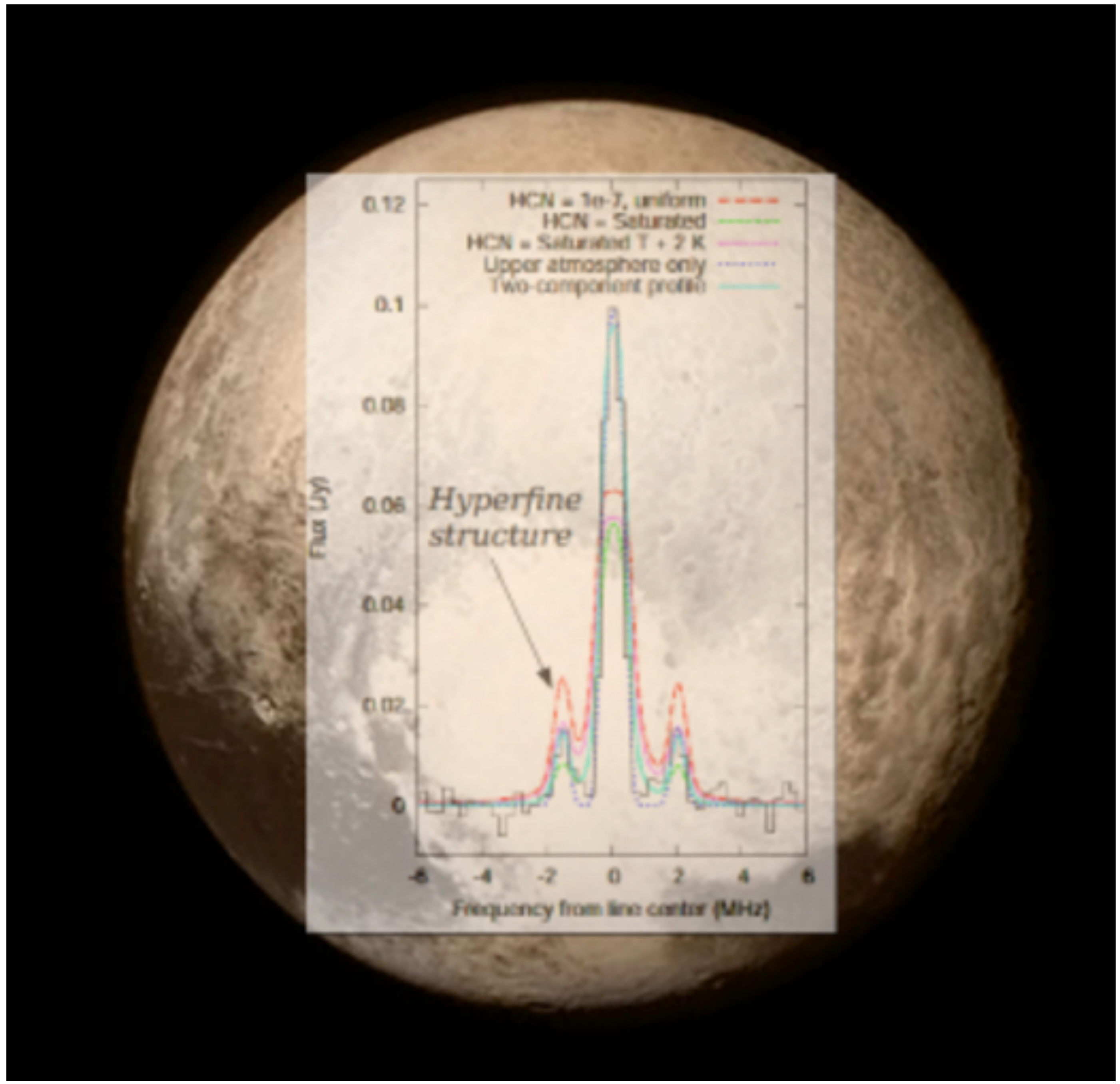

Van Boekel et al. (2004)

# 2. Comets: temporal variability

Cordiner et al. (2017b)



# 2. Detecting molecules the atmosphere of planets

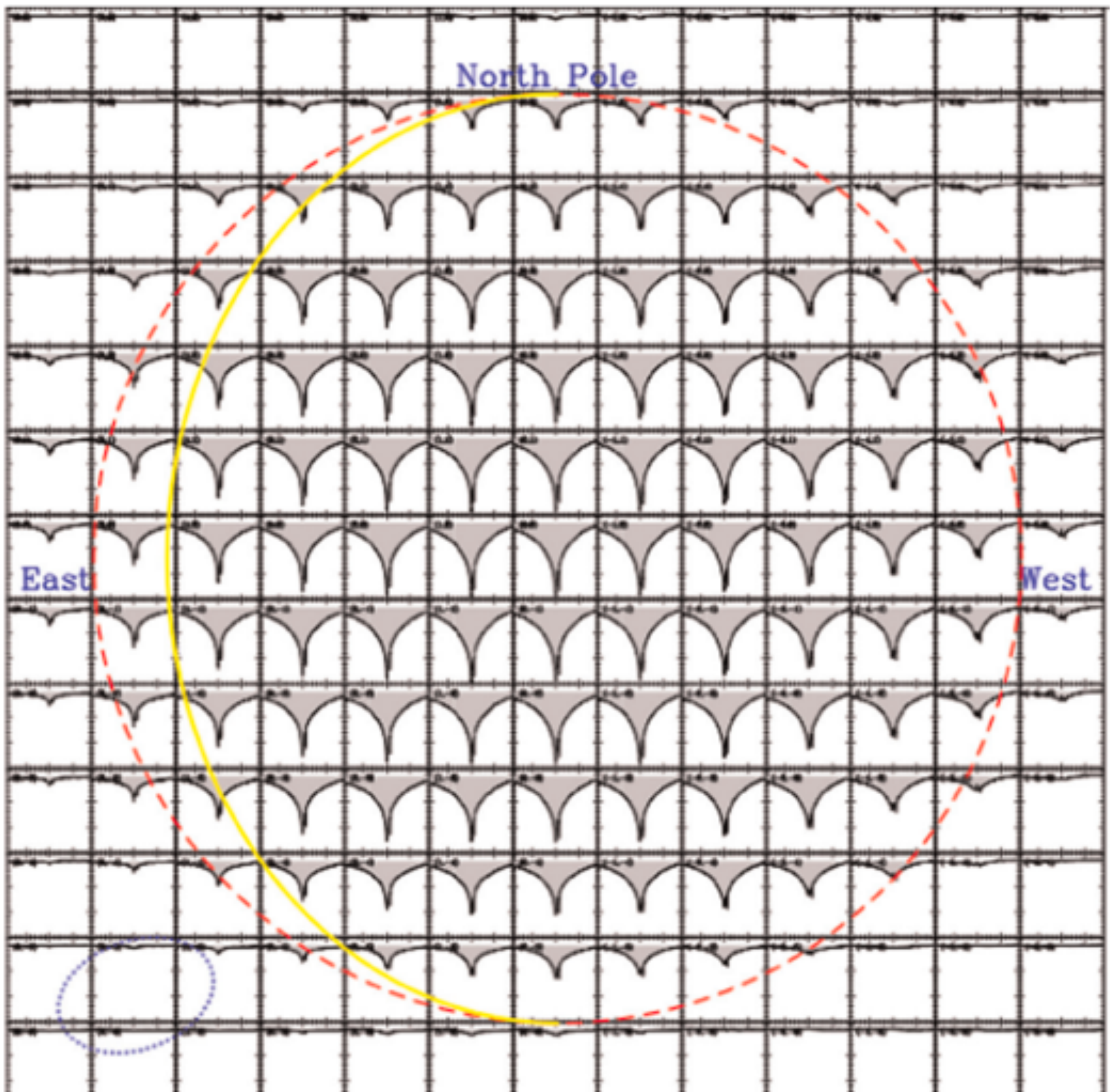


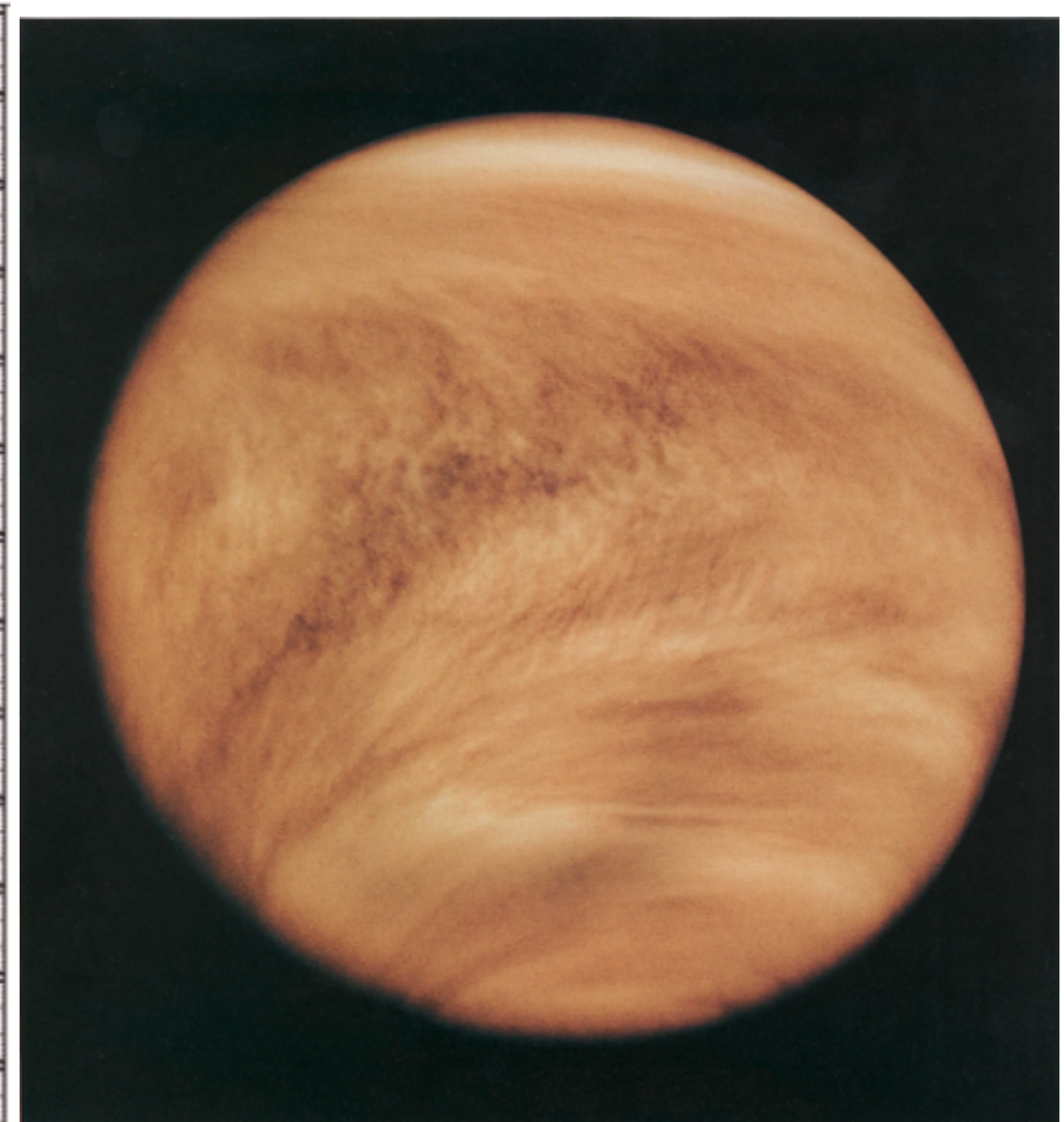

Lellouch et al. (2016) detected CO and HCN from Pluto using ALMA. From the CO profile, a thermal profile of the atmospheric temperature could be produced, showing that there is a well-marked temperature decrease above the 30-50 km stratopause;

# 2. Detecting molecules the atmosphere of planets

Spectral map of **CO** transition on Venus

Encrenaz et al. (2014)

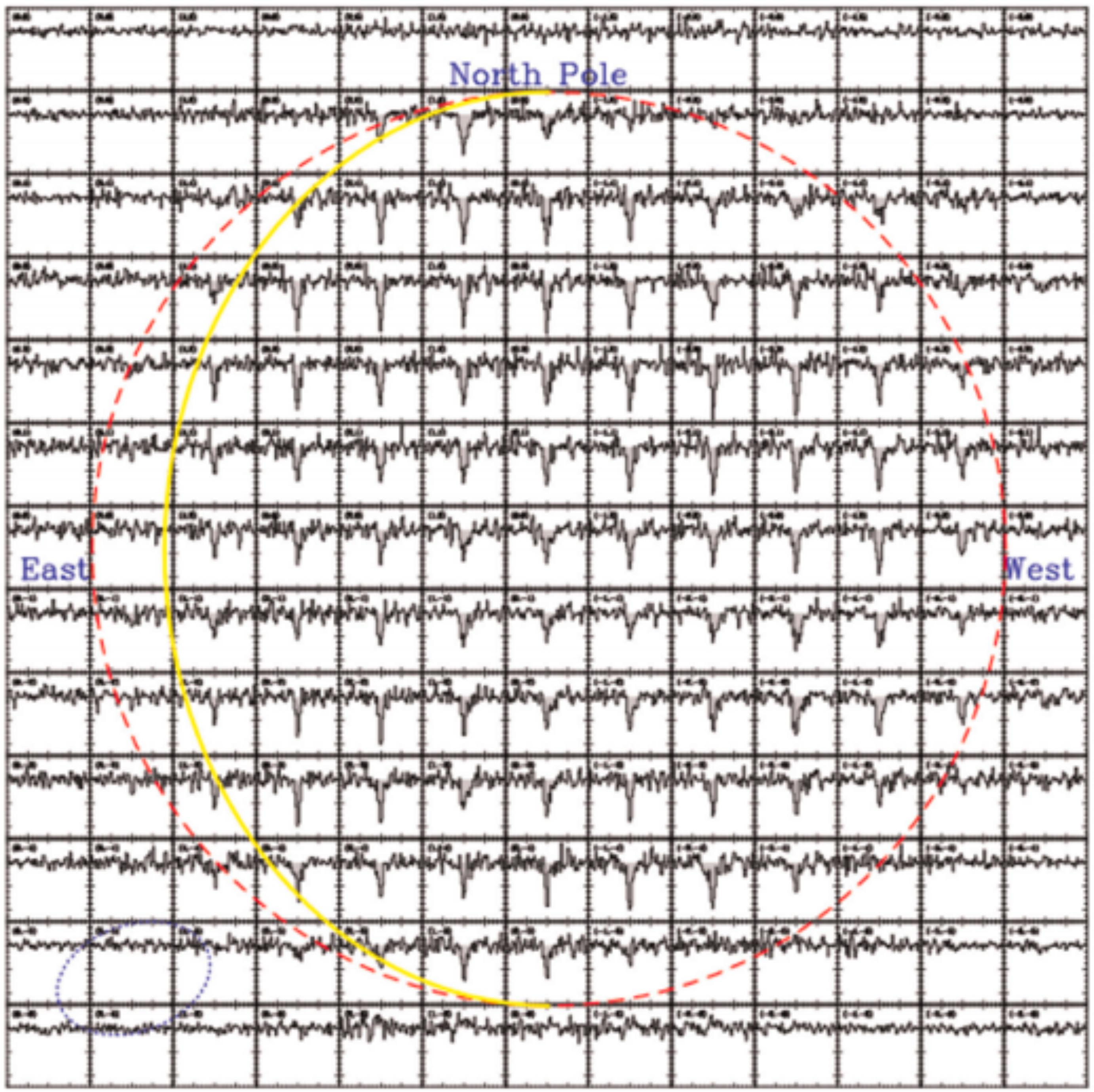


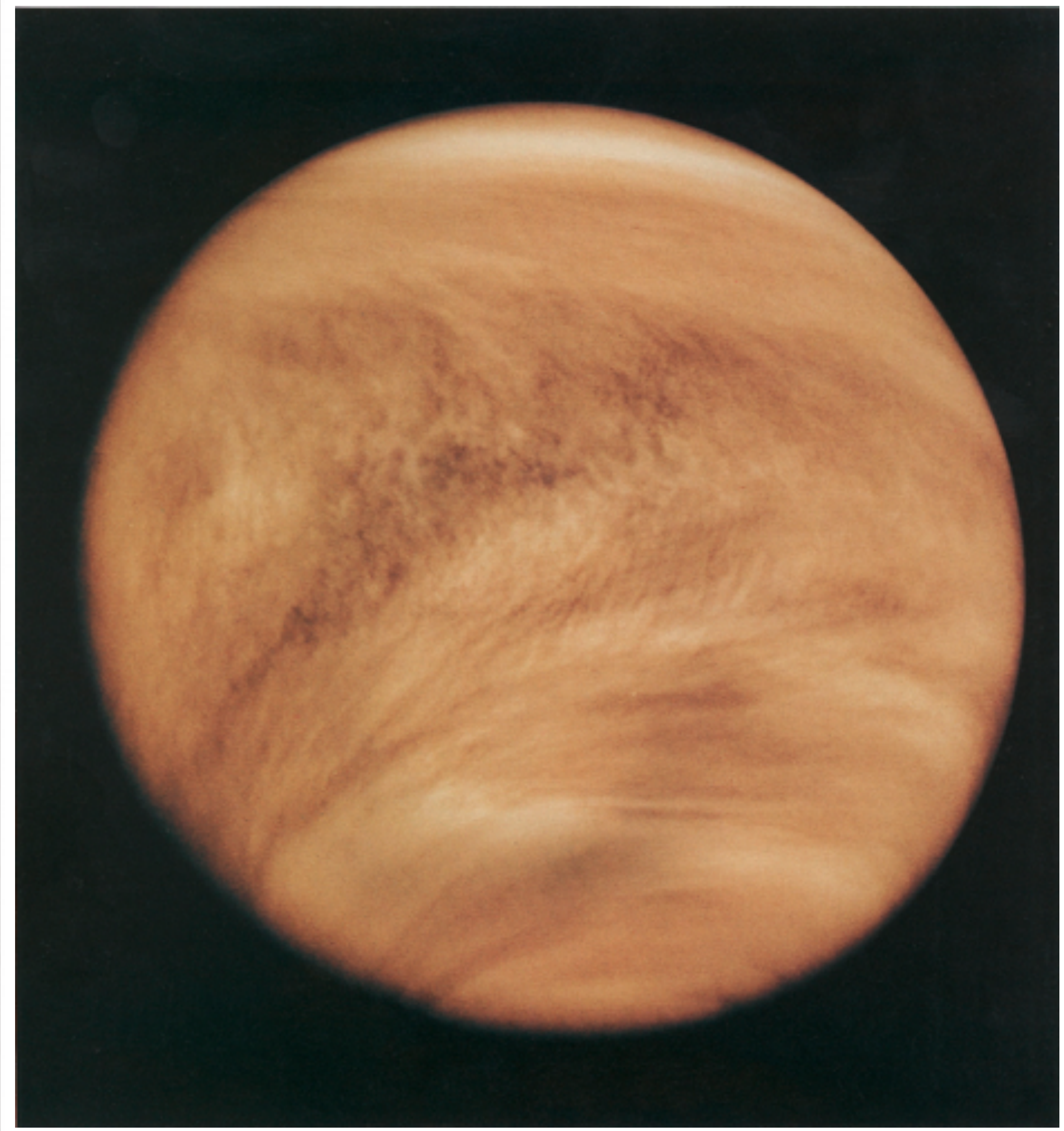



# 2. Detecting molecules the atmosphere of planets

Spectral map of **SO** transition on Venus

Encrenaz et al. (2014)



# 2. Thermal profile and composition of Venus atmosphere

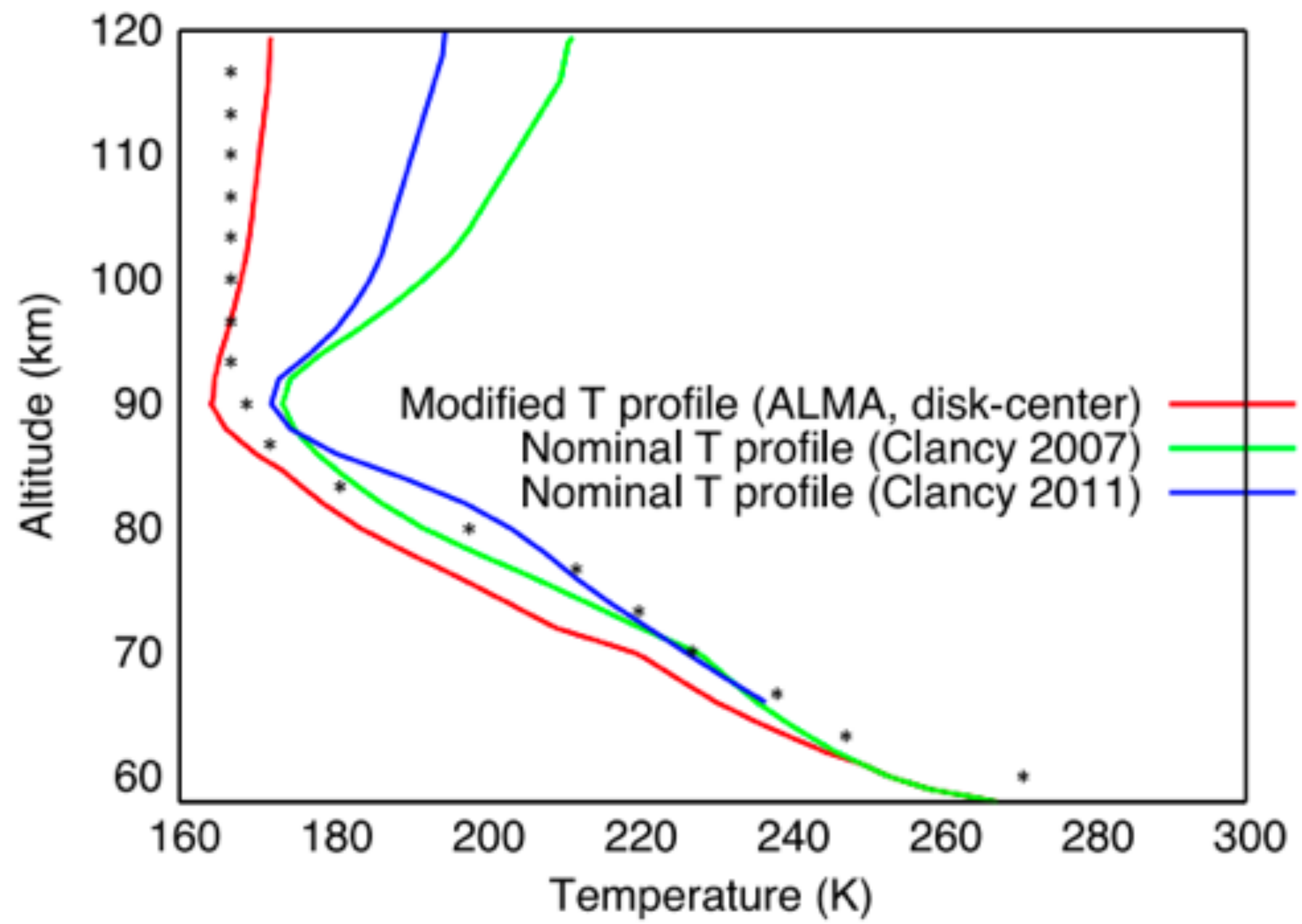



**Fig. 5.** The thermal profile (red line) inferred from the fit of the CO spectrum at the disk center assuming a nominal dayside vertical distribution of CO (Clancy et al., 2003). Nominal profiles retrieved by Clancy (2007, 2011), from dayside sub-millimeter data recorded in 2007 and 2011 respectively, are shown for comparison (green and blue lines). The VIRA profile retrieved on the dayside at low latitudes (Seiff et al., 1985) is indicated with black stars. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Encrenaz et al. (2014)

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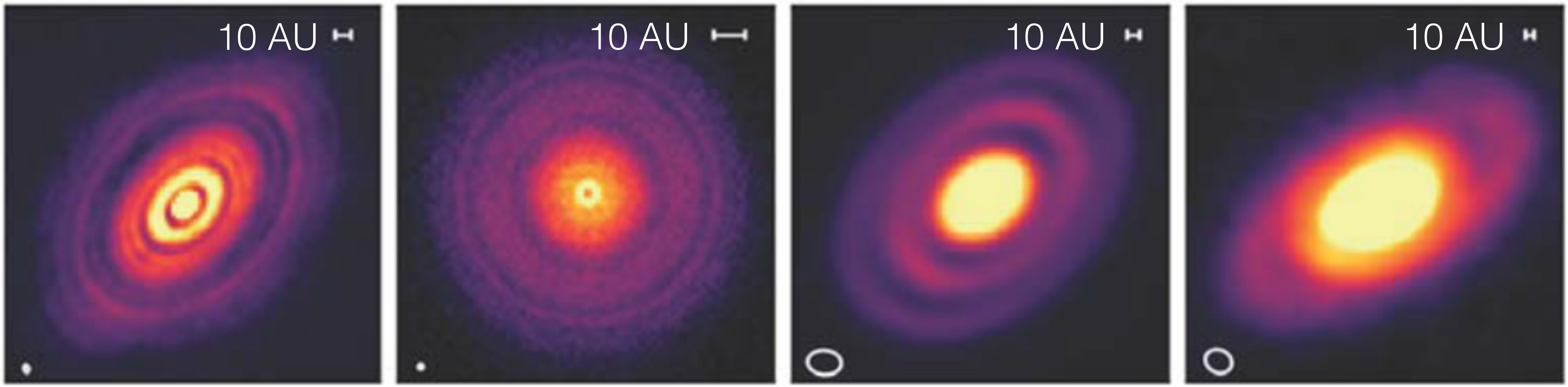
# Dust distribution

ALMA images of the dust emission at ~ 1 mm




ALMA observations achieve an unprecedented dynamic range resulting in the discovery of small-scale (< 30 AU) structures.

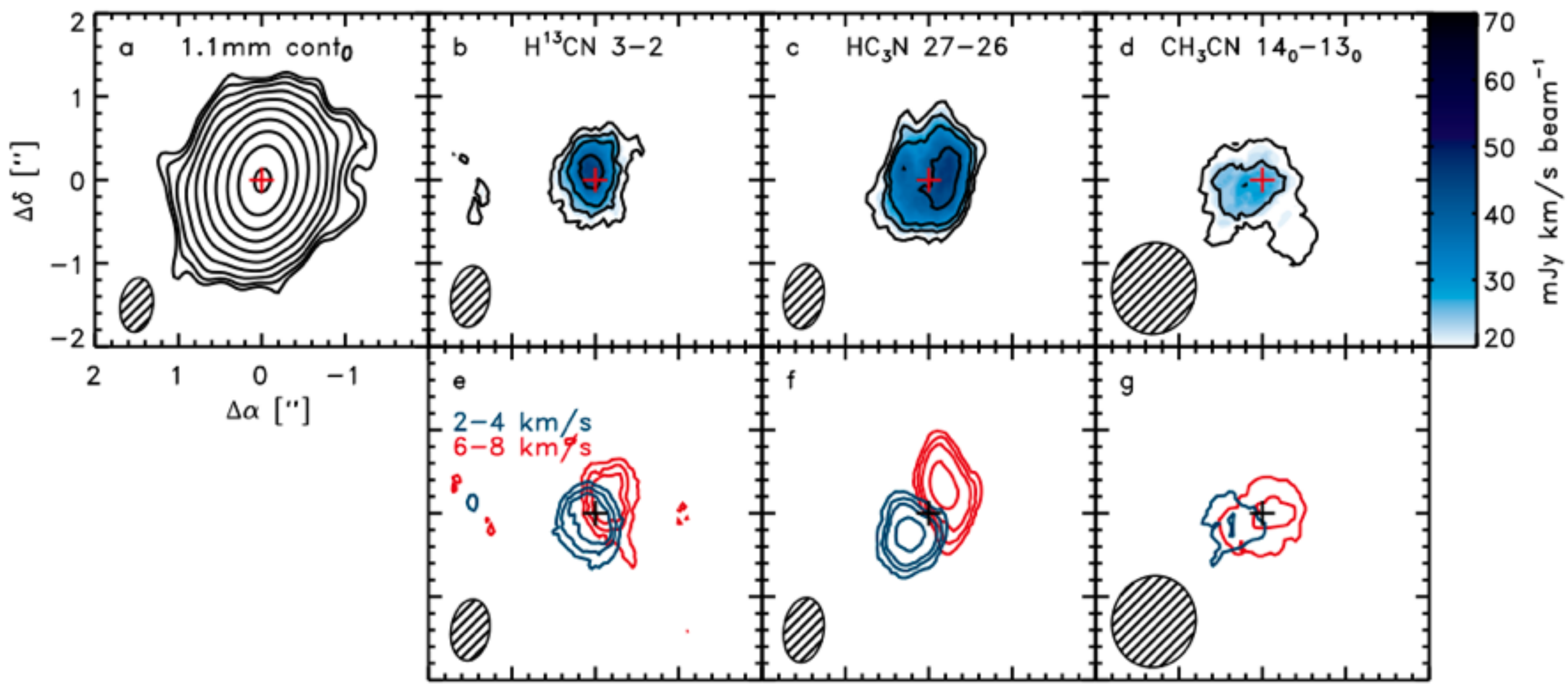
(ALMA partership 2015, Andrews et al. 2016, Isella et al. 2016, Perez et al. 2016)

# The cometary composition of a protoplanetary disk as revealed by complex cyanides*

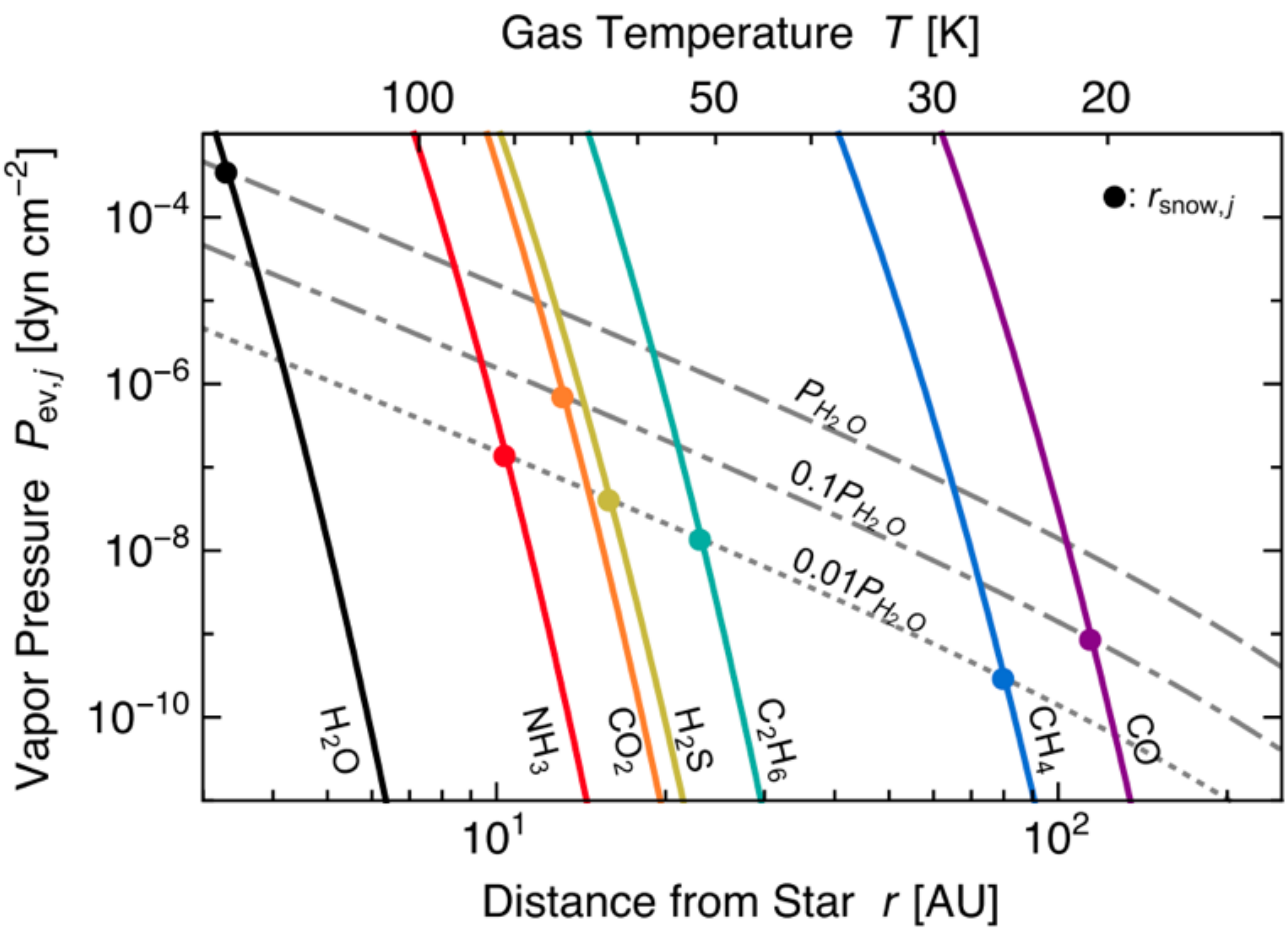
Karin I. Öberg[1], Viviana V. Guzmán[1], Kenji Furuya[2], Chunhua Qi[1], Yuri Aikawa[3], Sean M. Andrews[1], Ryan Loomis[1], David J. Wilner[1]

**Nature, 520, 7546, 198, 2015**

Detection of “large amount” of acetonitrile (CH3CN) in MWC 480. Evidence of chemical complexity similar to that observed in comets.

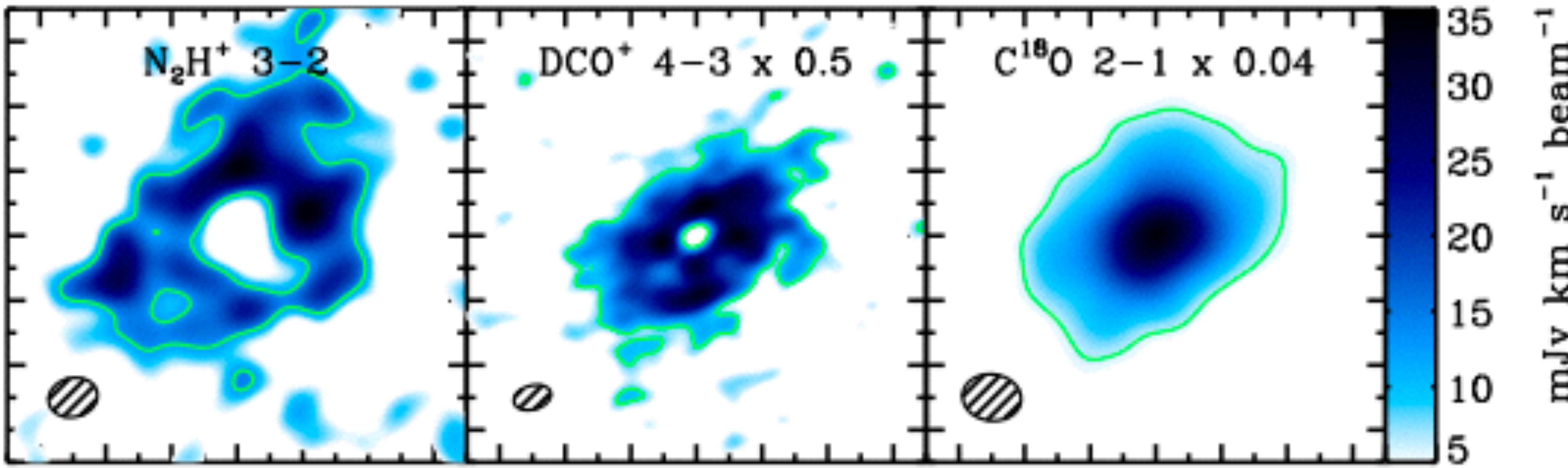


# Resolve the frost line of volatiles elements




Okuzumi et al. (2015)

# Resolving the CO frost line




Qi et al. (2015)

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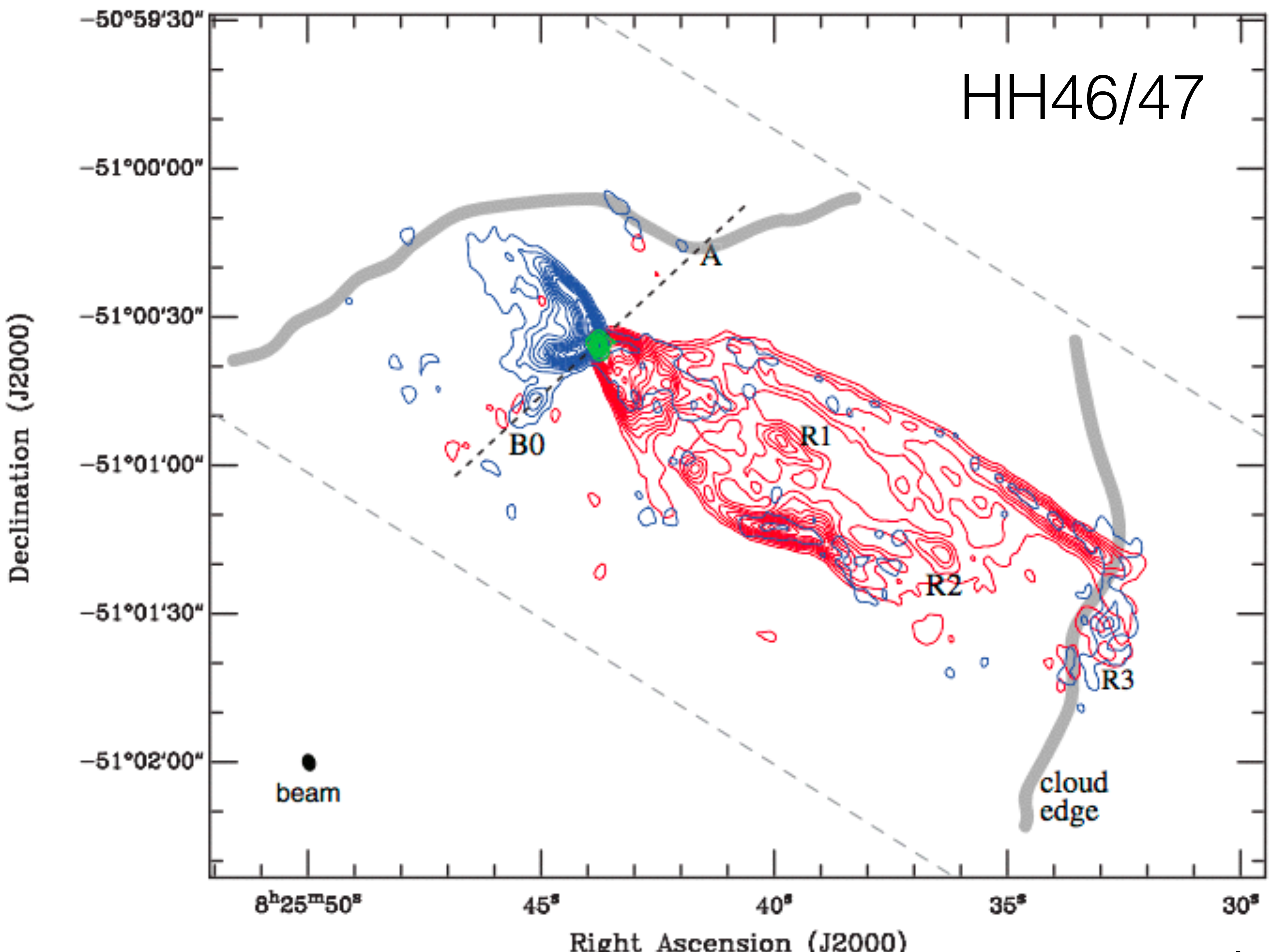
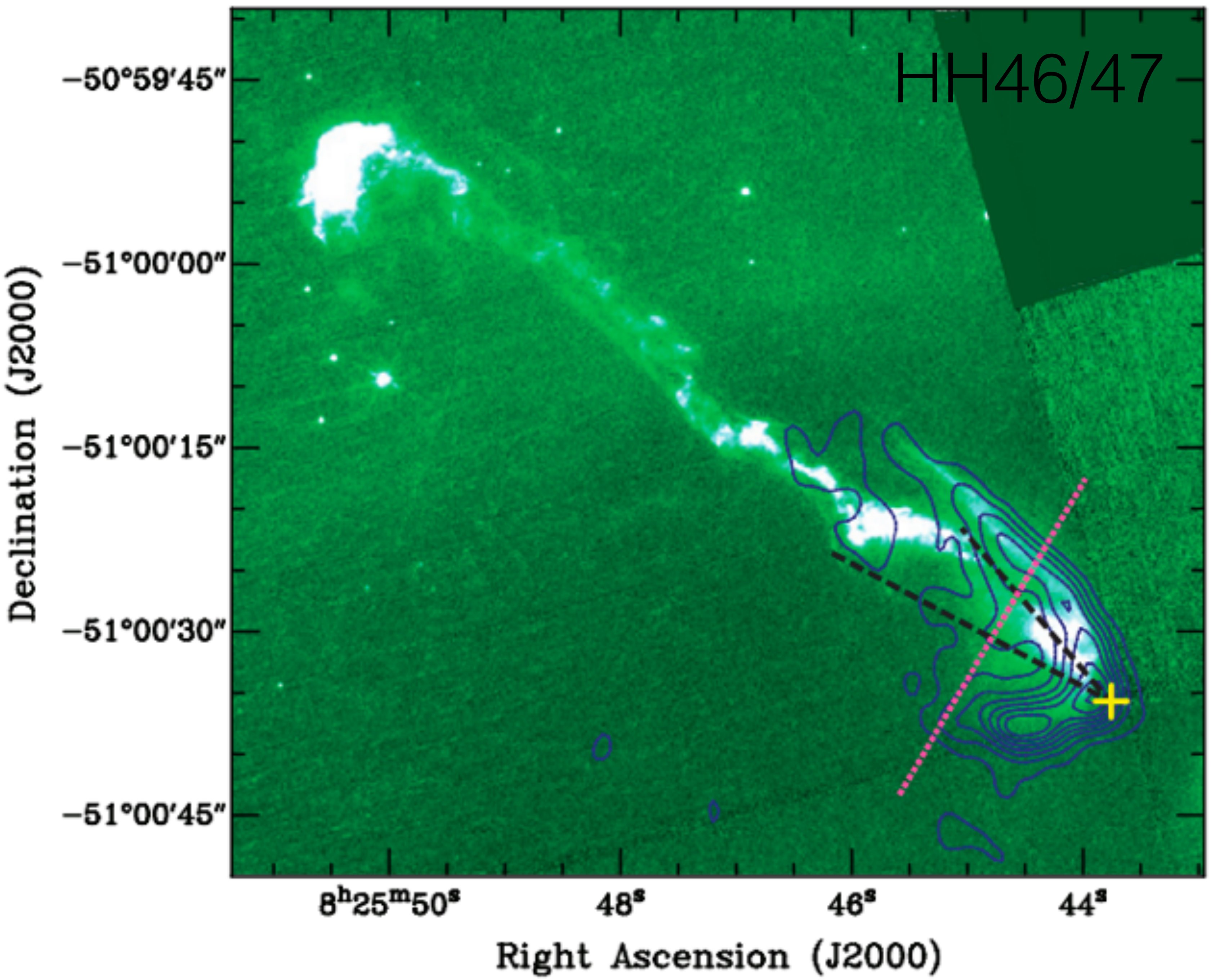
# Observations of molecular outflows




Arce et al. (2013)

# Observations of molecular outflows

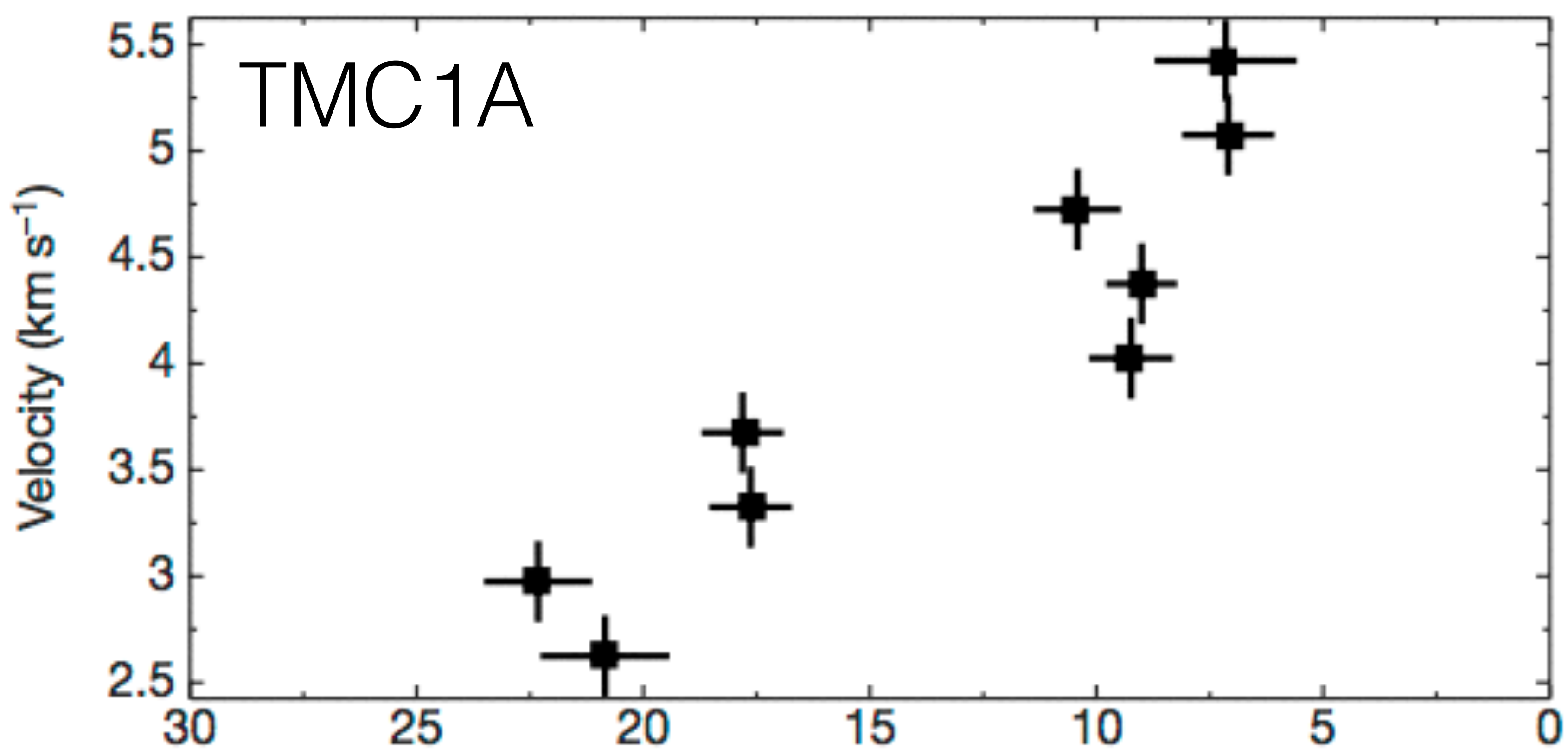



**Green: HST image in the SII filter Hartigan et al. (2011)**

Arce et al. (2013)

# Understanding the emission process

ALMA observations probes the outflow close to the star and show the presence of a disk wind




the disk wind launching point (AU)

Bjerkeli et al. (2016)

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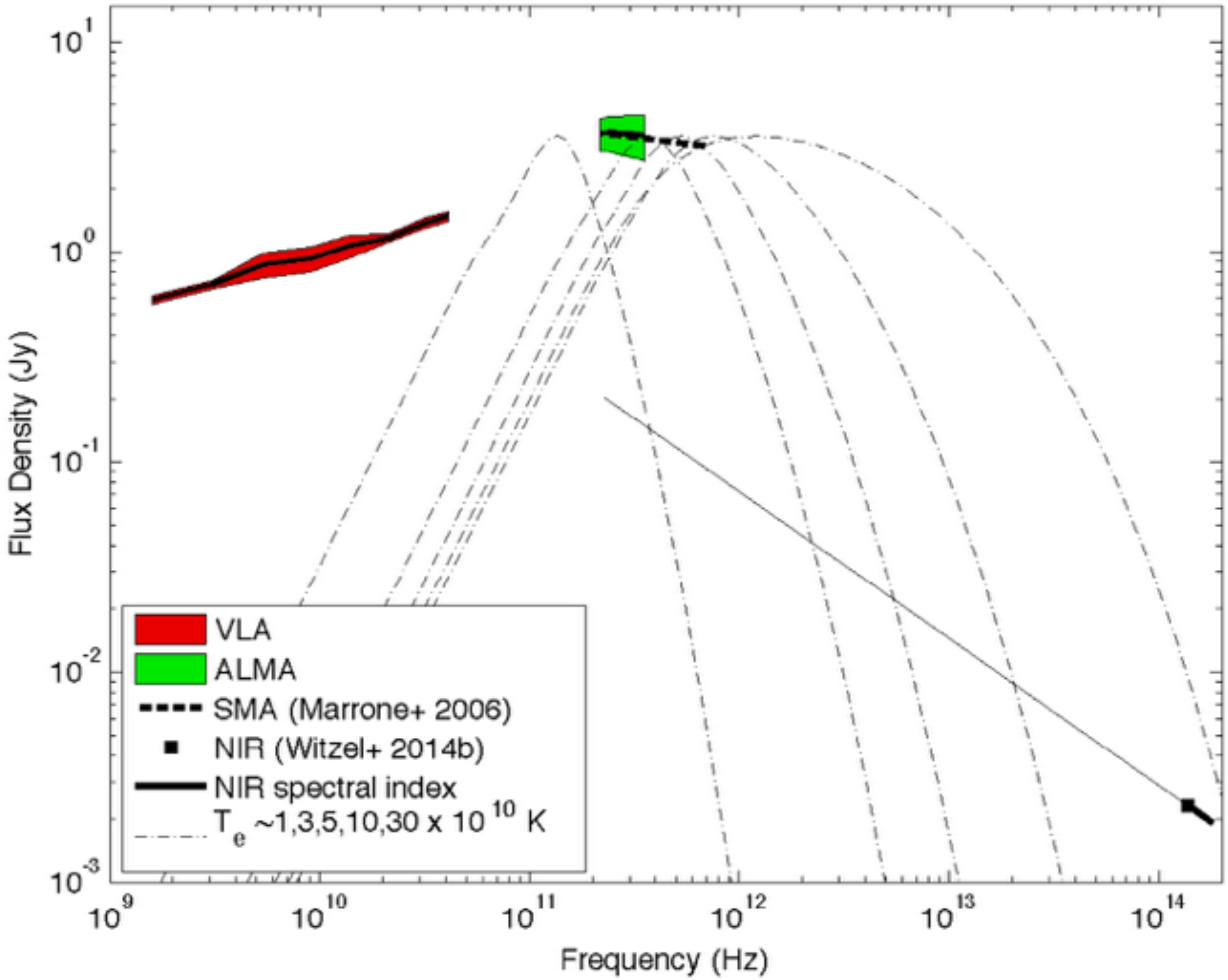
# Radio and Millimeter Monitoring of Sgr A*

no spectral break between 230 and 690 GHz



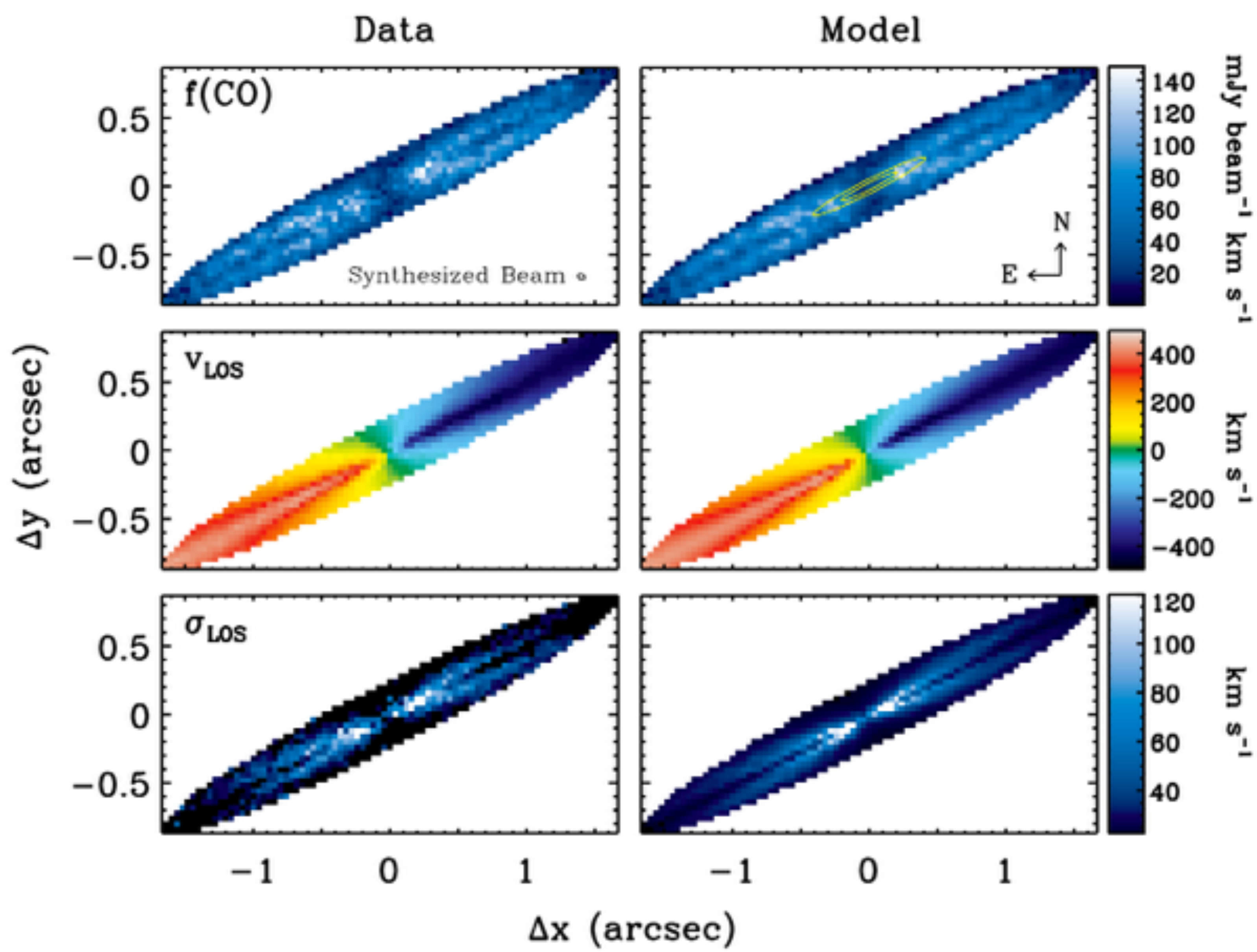

Bower et al. (2015)

# Measuring Black Hole Masses

**NGC 1332**

CO J=2-1
0.044” resolution
101’ on source

ALMA observation can resolve molecular line emission inside the gravitational radius of the BH and provide a precise estimate of the BH mass.




$$M_{\rm BH} = (6.64^{+0.65}_{-0.63}) \times 10^8\ M_\odot$$

Barth et al. (2016)

**ALMA is a fantastic resource and is much more accessible than what you might think.**

**HST oversubscription 4.5**
**ALMA oversubscription 4.1 (3.5 for NA)**

**If you have a good idea, give it a try!**