From Nearby Stars to Distant Galaxies – ALMA – TMT Synergies

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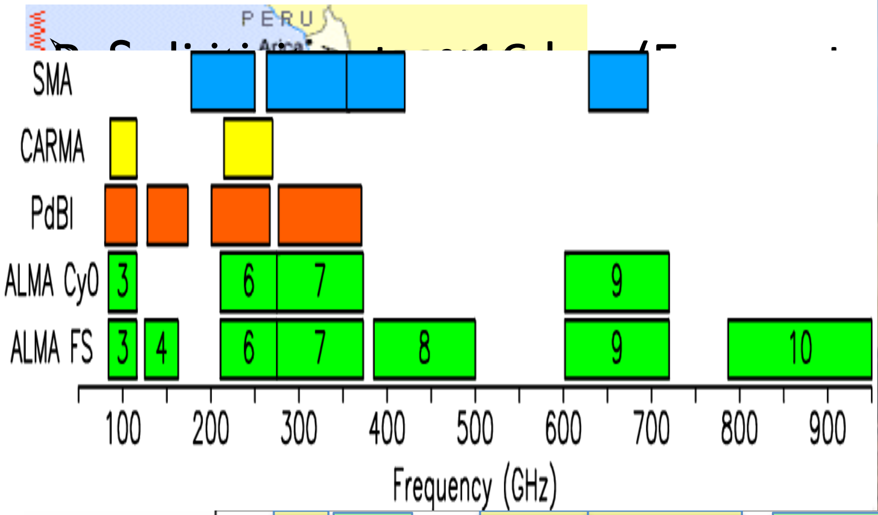
Atacama Large Millimeter/submillimeter Array

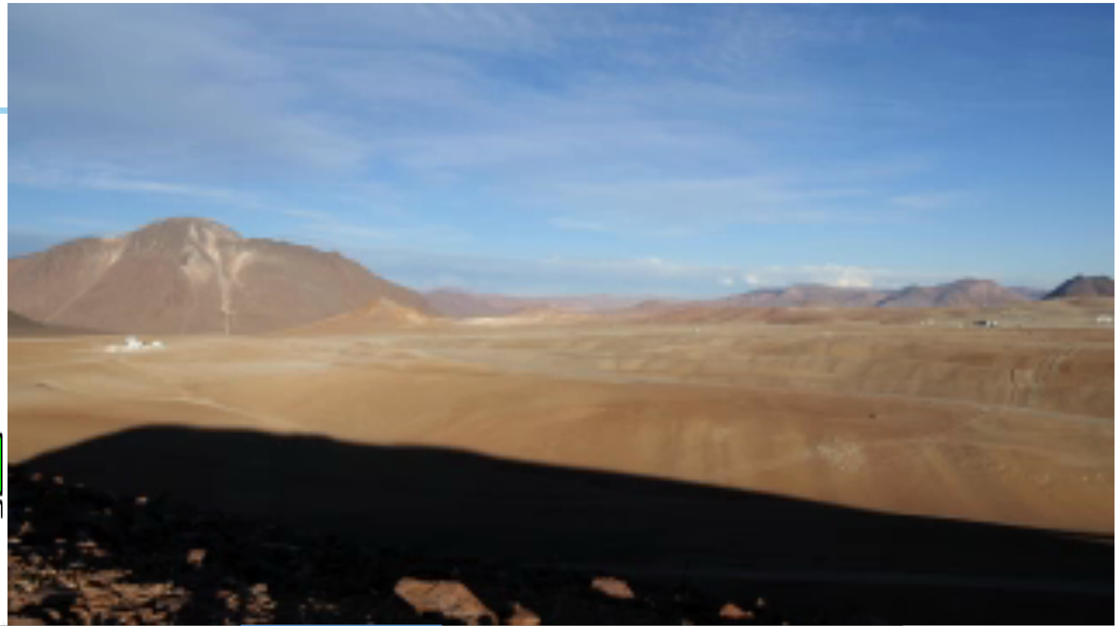
Karl G. Jansky Very Large Array

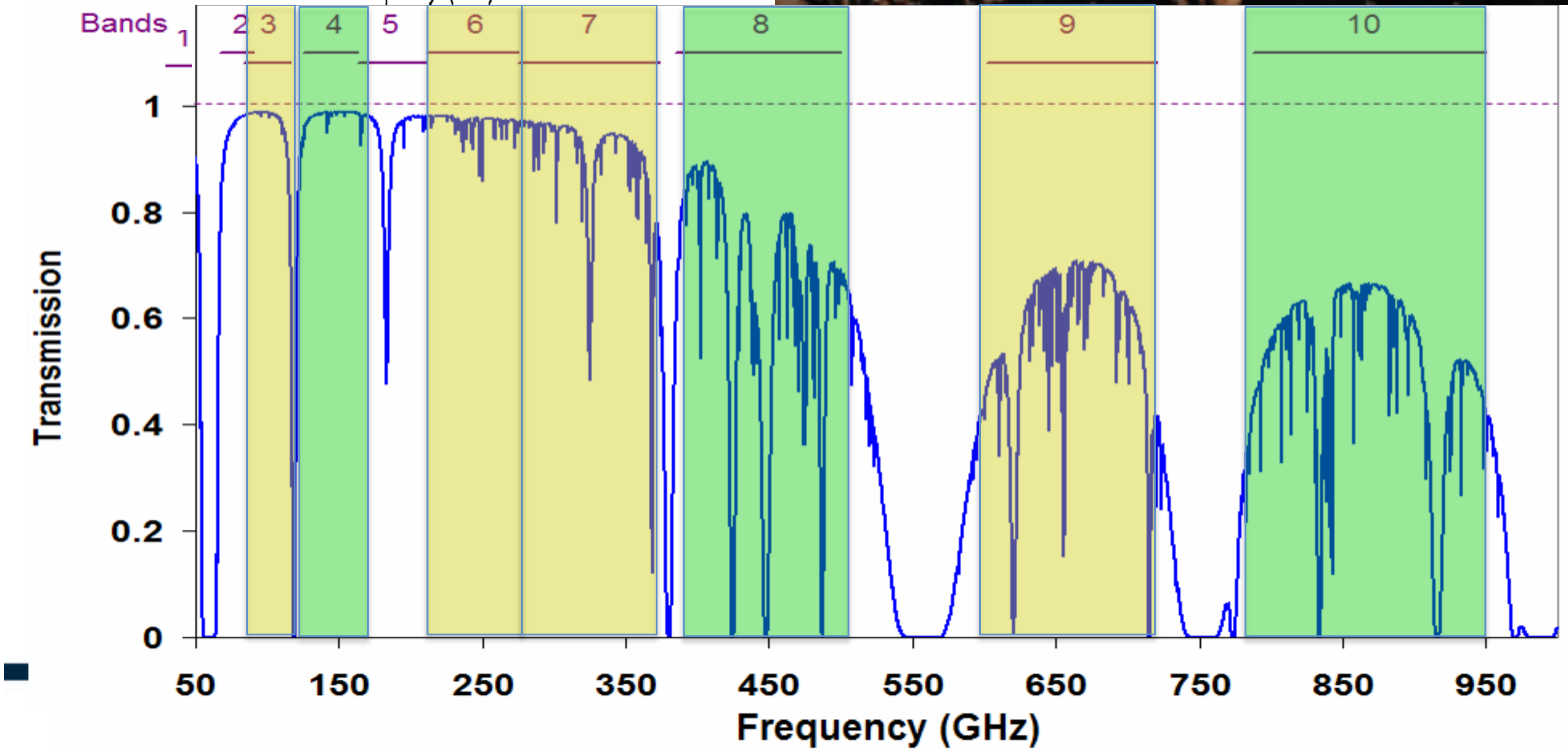
Robert C. Byrd Green Bank Telescope

Very Long Baseline Array

ALMA Overview







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ALMA & TMT

	FIR – submm- mm - cm	*Optical – NIR – mid IR*
	ALMA	**TMT**
Wavelength (current)	**315 μm – 3529 μm**	**0.3 μm – 2.5 μm**
Goal (eventual)	**187 μm – 9677 μm**	**0.3 μm – 28 μm**
Angular Resolution	**8 mas * λ/400μm * 10 km / B_{char}**	**8.3 mas * λ/1μm**
Spectral Resolution	**R = 3191 -- 2.7 x 10^7**	**R = 10 – 10^5**

	ALMA	**IRIS (0.8-2.5 μm) NFIRAOS**	**WFOS (0.3-1 μm) Seeing-limited**	**IRMS (0.8-2.5 μm) NFIRAOS**
Field of view	6”-74” + mosaics	3” (IFU) 17” (imaging)	➢ 40 sqarcmin ➢ >500” slits	2’ (46 slits)
Spectral Resolution	3191 --2.7e7	>3500 5-100 (imaging)	1000-5000 >7500 @0.75”	4660 @0.16” slits
Angular Res	8mas – 4”	8mas at 1μm	~0.2 “	

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ALMA & TMT

	FIR – submm- mm - cm	*Optical – NIR – mid IR*
	ALMA	**TMT**
Wavelength	315 µm – 3529 µm	0.3 µm – 2.5 µm

Continuum

Optical – Stellar

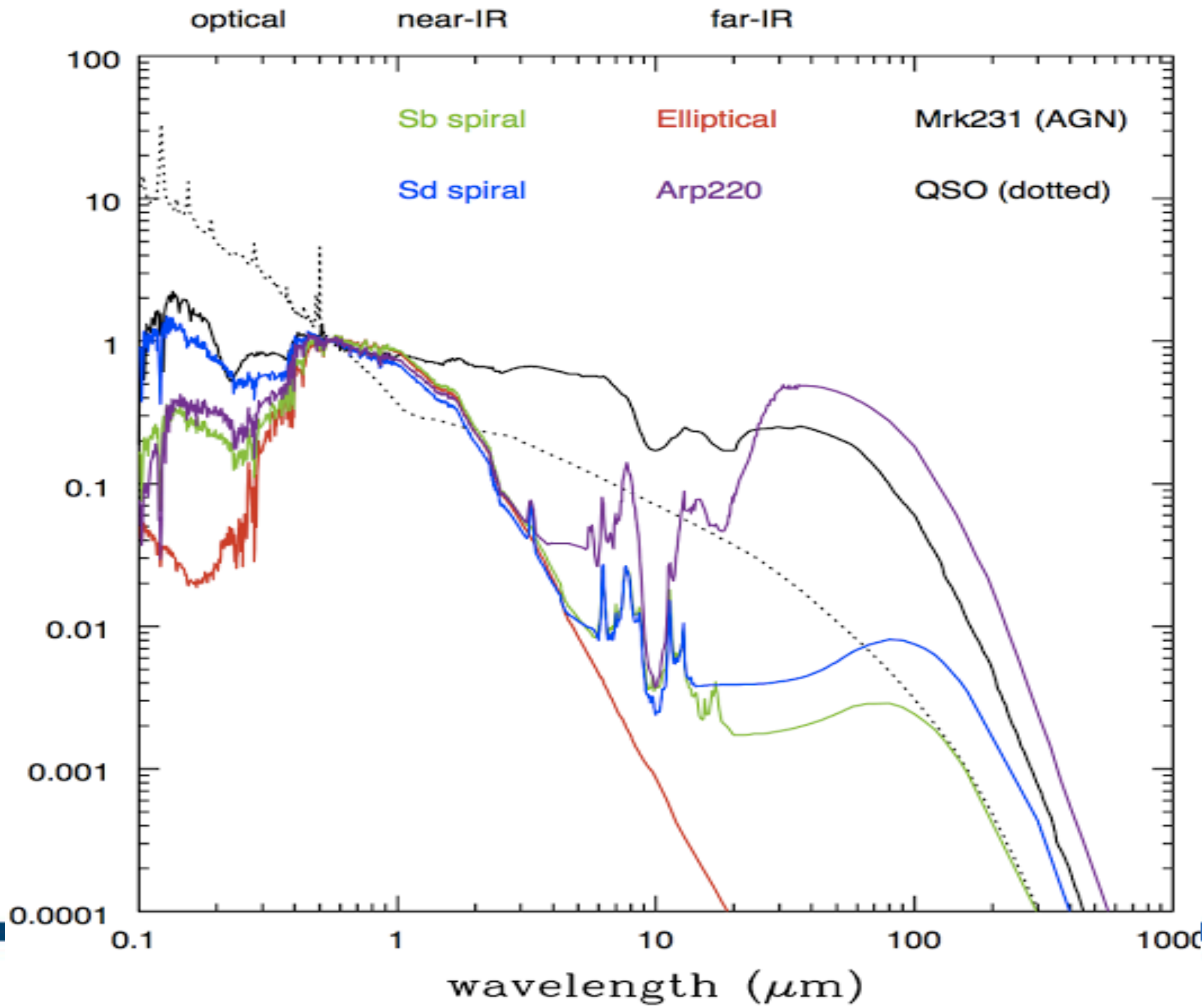
NIR – Stellar -> dust

MIR - dust

FIR – dust

Mm – Dust / thermal

Radio – Synchotron / thermal



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ALMA & TMT

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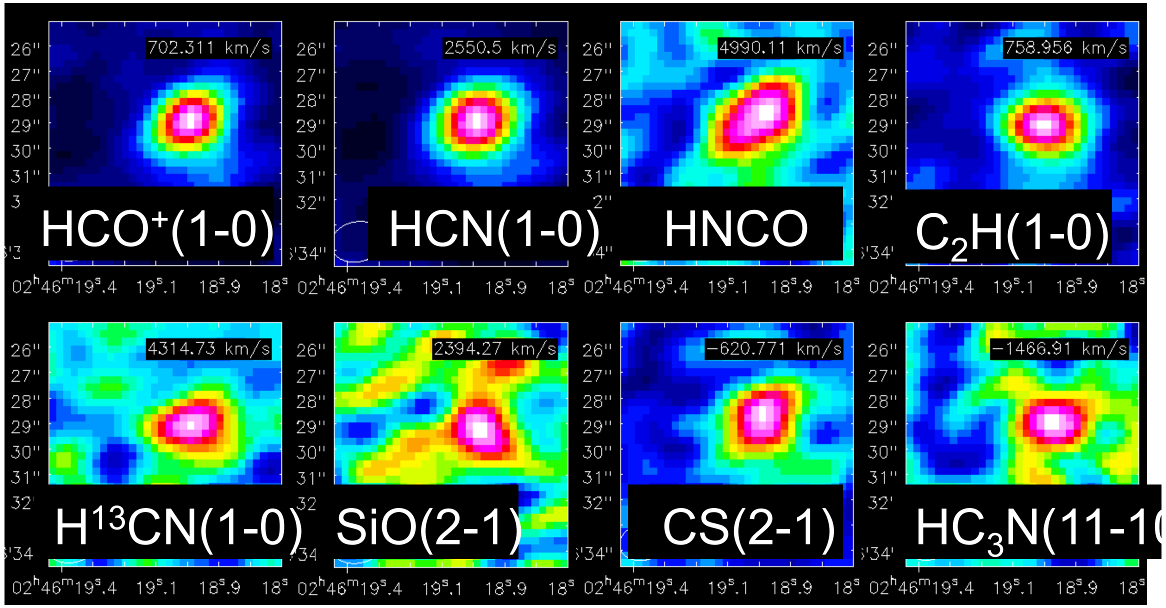
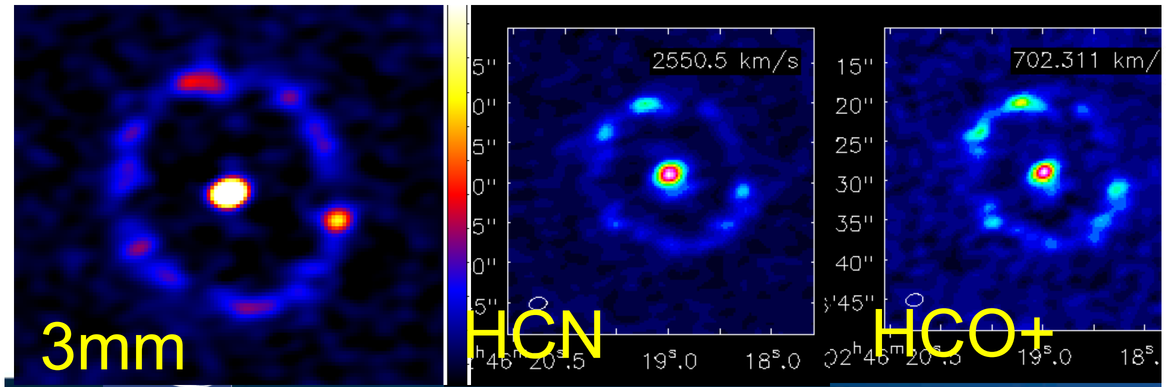


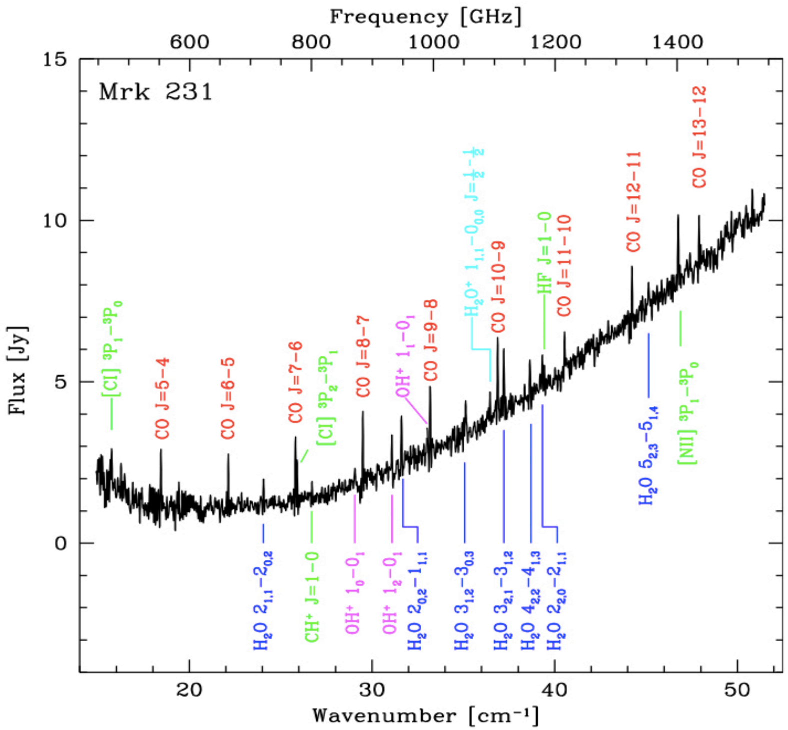
Molecules in NGC 1097

Cycle 0: Kohno,

Cycle 1: Sheth

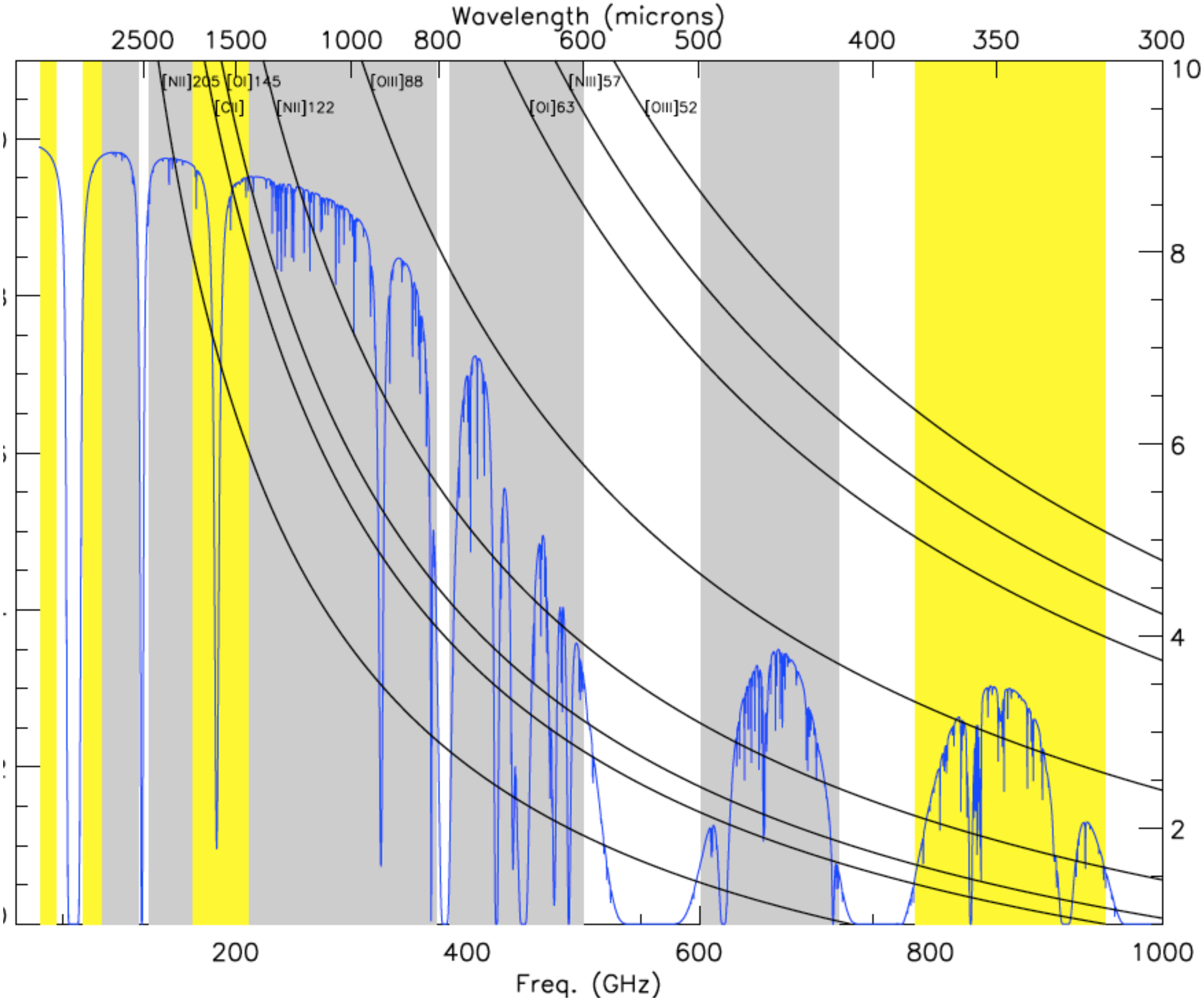
Izumi et al. 2014; Onishi et al. 2014





ALMA & TMT

https://github.com/brisbind/ALMA_linez



Courtesy
Drew Brisbin

ALMA & TMT

ALMA

TMT: Stars, star formation, metallicity, ionization, hot dust, atoms & molecules (eg. PAH, H_2)

ALMA: Stars (Hydrogen recomb), star formation (molecular gas, dust), metallicity (CII, OII, NII, etc.), cold dust, atoms + molecules

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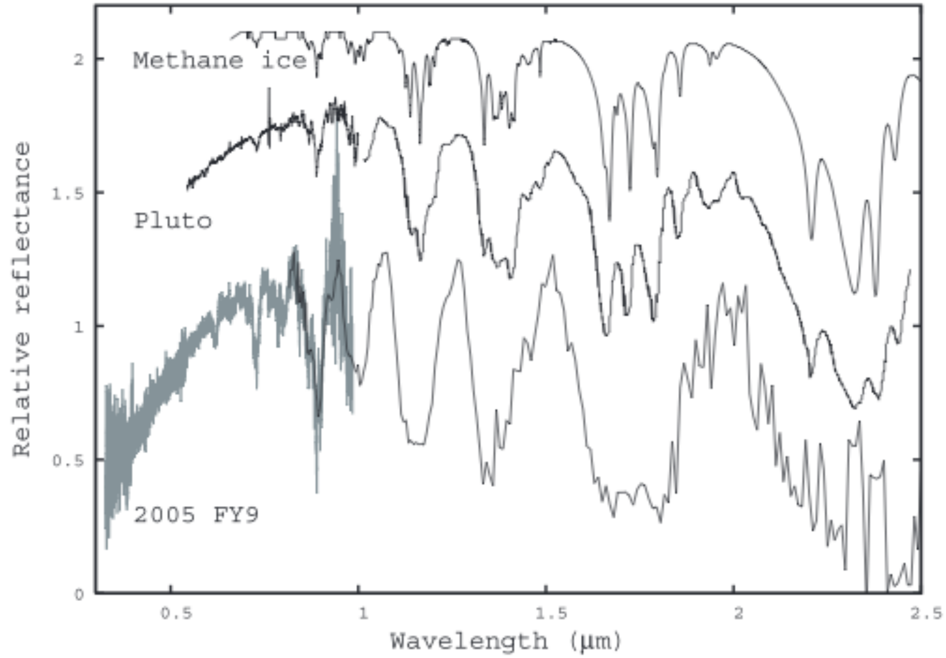
ALMA & TMT Synergy: Solar System

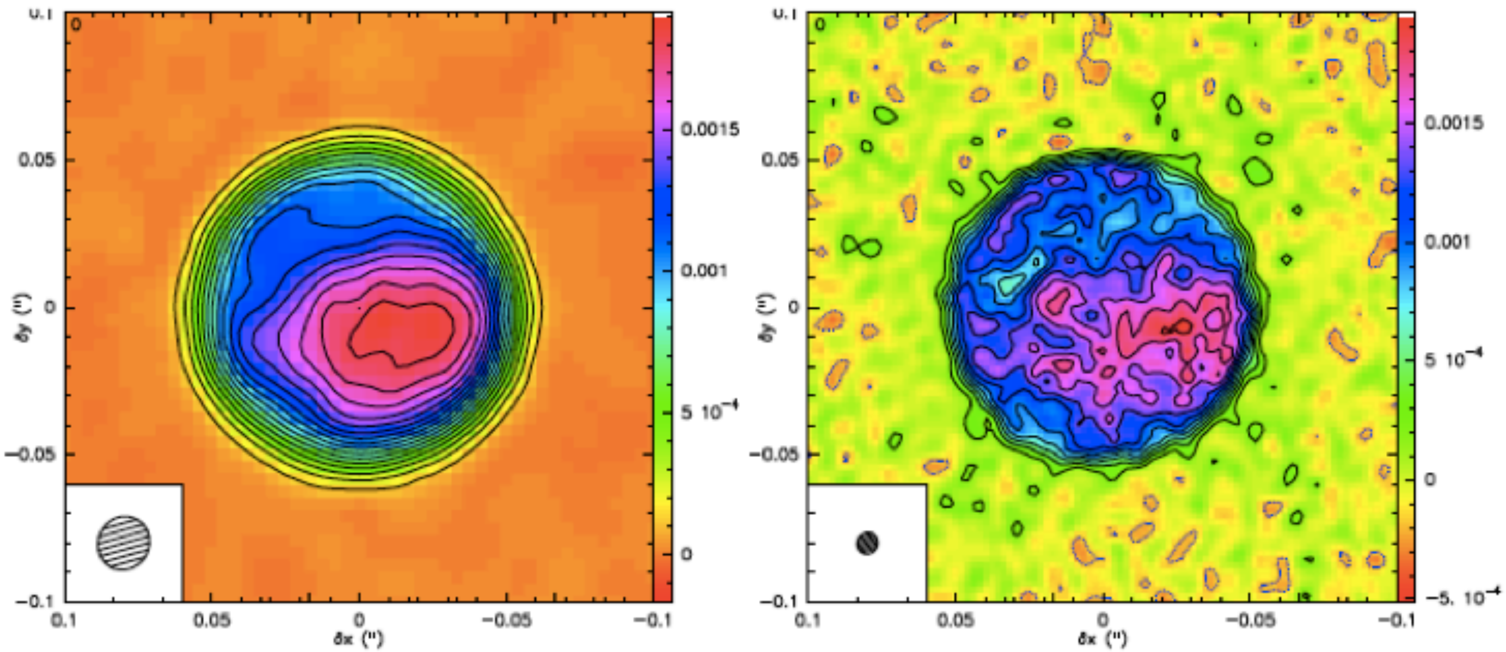


Compositional and dynamical studies of KBO and TNOs

NIR spectrum of Pluto + TNO (Licandro et al. 2006)

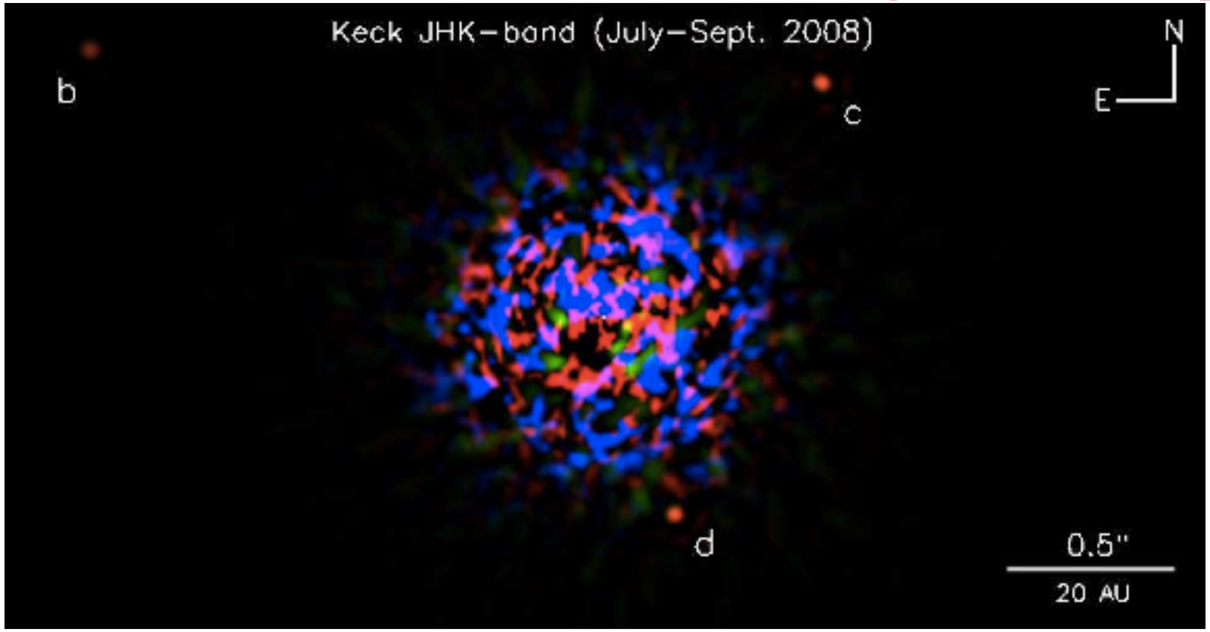
Simulated Pluto map w/ full ALMA in 4hrs and 4 km/s baselines (Cycle 3)

350 + 850 GHz, (courtesy A. Moullet)



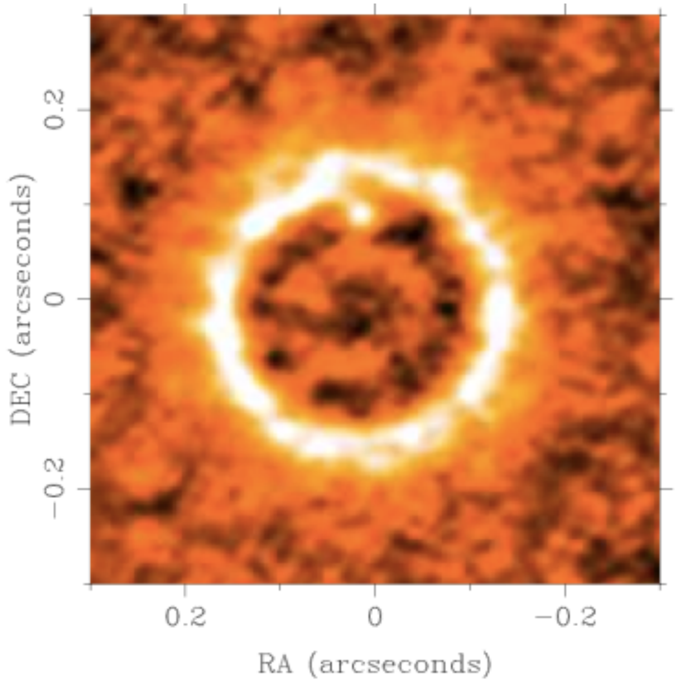
ALMA & TMT Synergy: Exoplanets

ALMA



Detection+ characterization of extra solar planets

HR 8799 Keck JHK Jul-Sep 2008, Marois et al. 2008



Proto-Jupiter at 5AU around a 0.5 $M_\odot$ at 50pc (Burton et al. using model by Wolf & D'Angelo)

- Directly detect forming giant planets (condensations) in protoplanetary disks.
- Directly detect very young giant planets to ~50 pc in a reasonable (~few hrs time)
- Indirectly detect the presence of giant planets around nearby stars using astrometry.

ALMA & TMT Synergy: Planet Formation

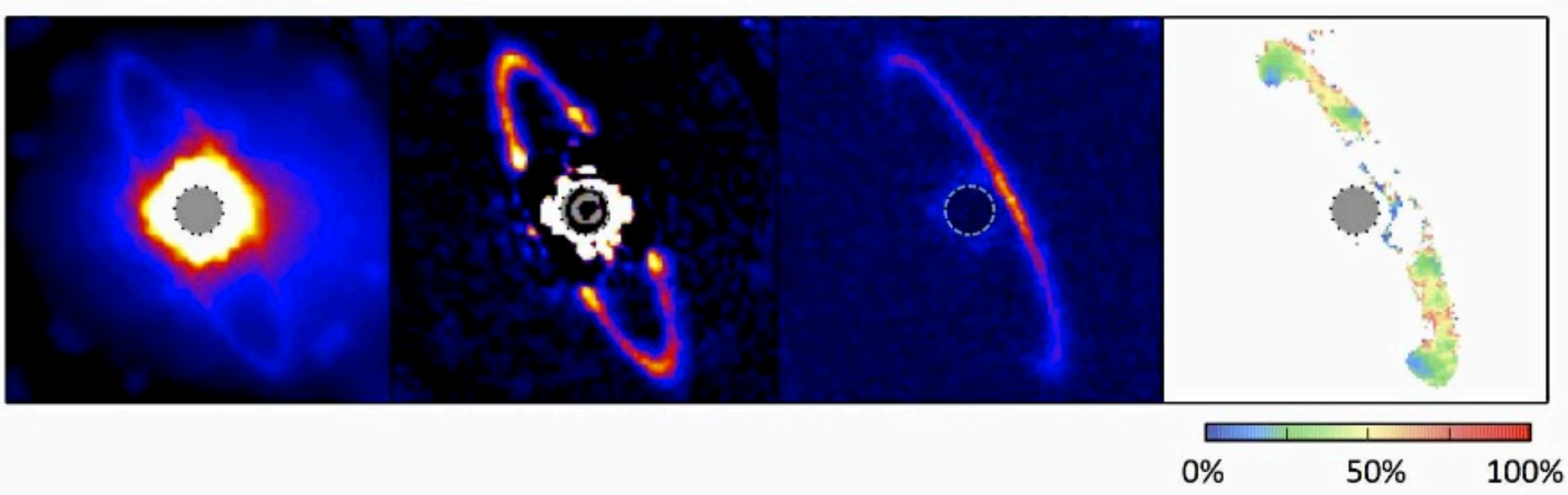
ALMA

Total Intensity

PSF-subtracted total instensity

Polarized intensity

Polarization fraction



- Circumstellar disk around HR 4796A
- K1 band (1.2-2.19 μm) , ~2x2" FOV shown
- Perrin et al., 2014 ApJ,. (1407.2495)

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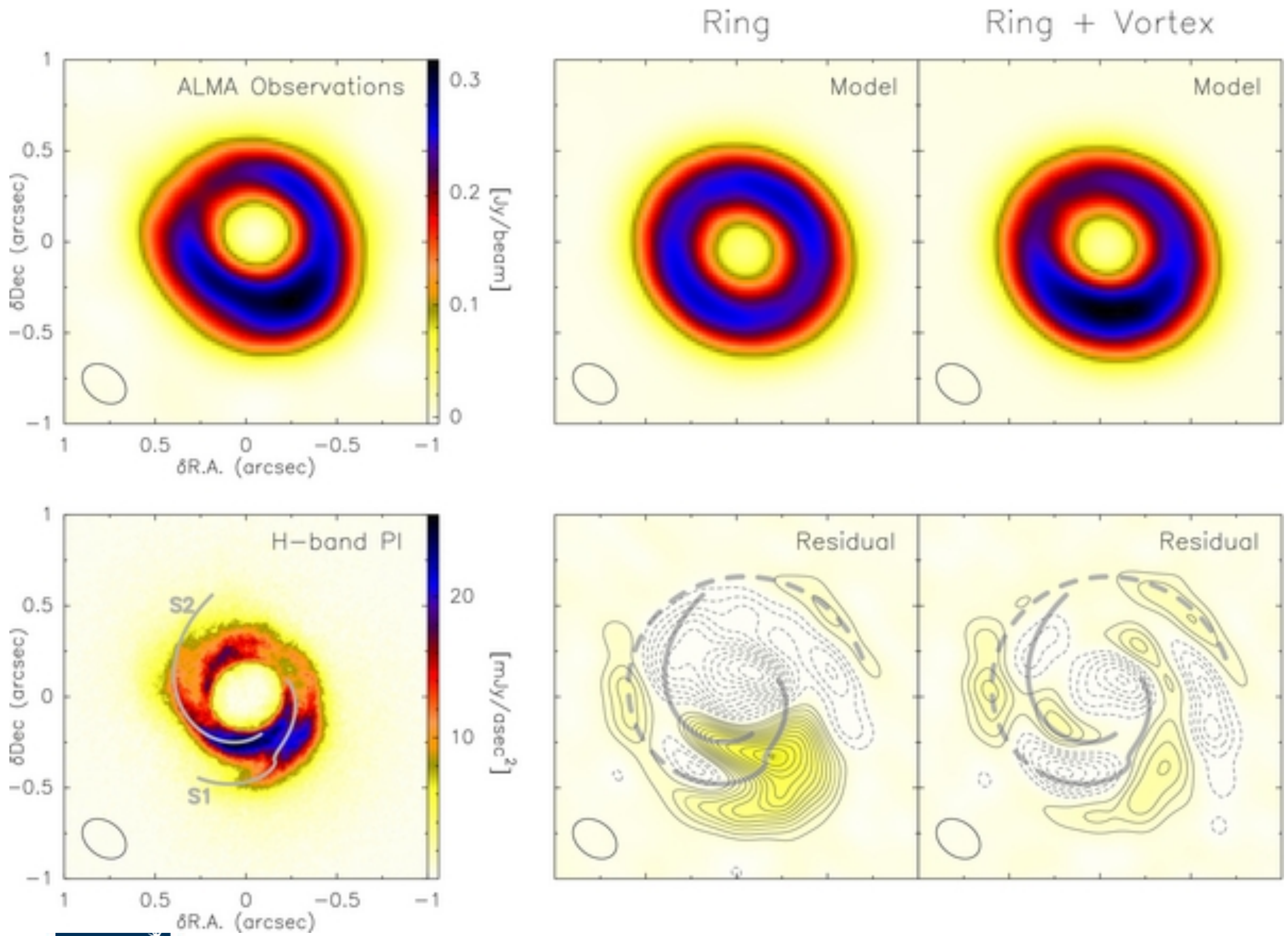
ALMA & TMT Synergy: Planet Formation



Transitional disk around SAO 206462

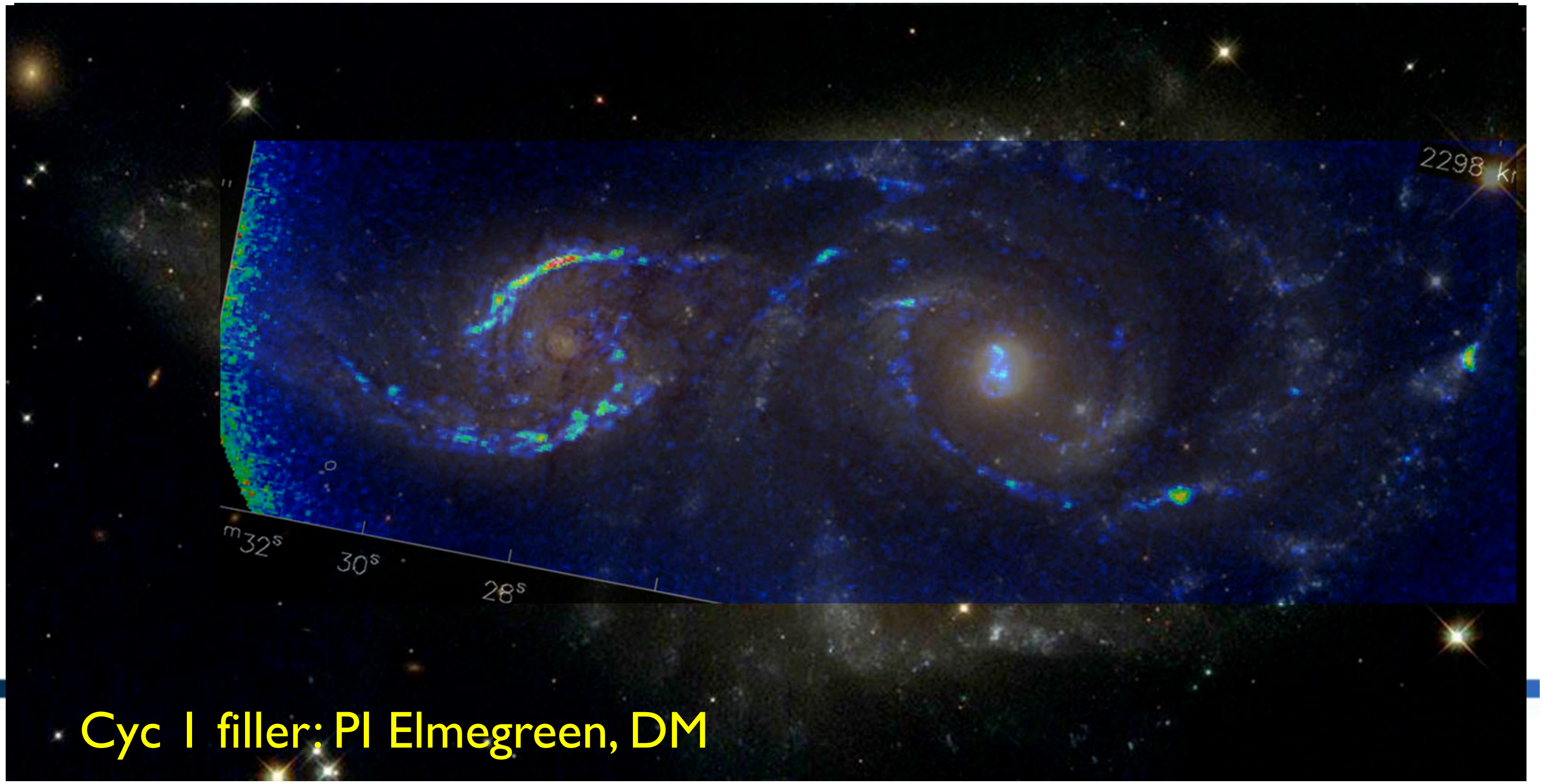
430 μm, 0.3" x 0.2"

Perez et al. 2014 ApJL

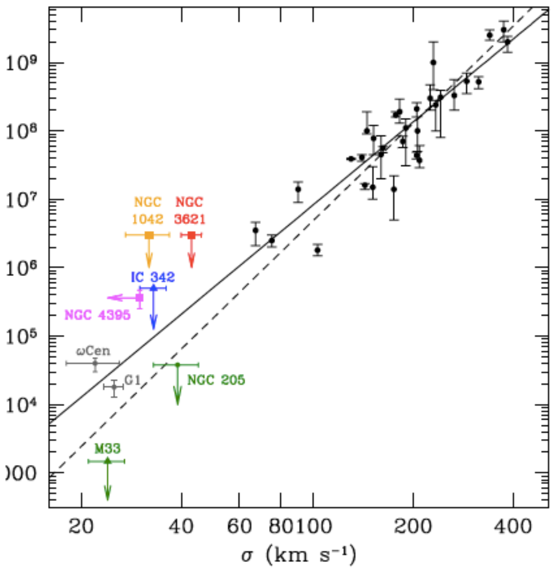
ALMA & TMT Synergy: Star Formation

Star formation properties in star clusters: timescale of star formation and efficiencies, initial cluster mass function (ICMF), initial mass function, multiplicity and kinematics

ALMA offers ability to directly measure the gas and dust in which stars are born to understand SFE, cluster dissolution rates from environment to environment + KINEMATICS!

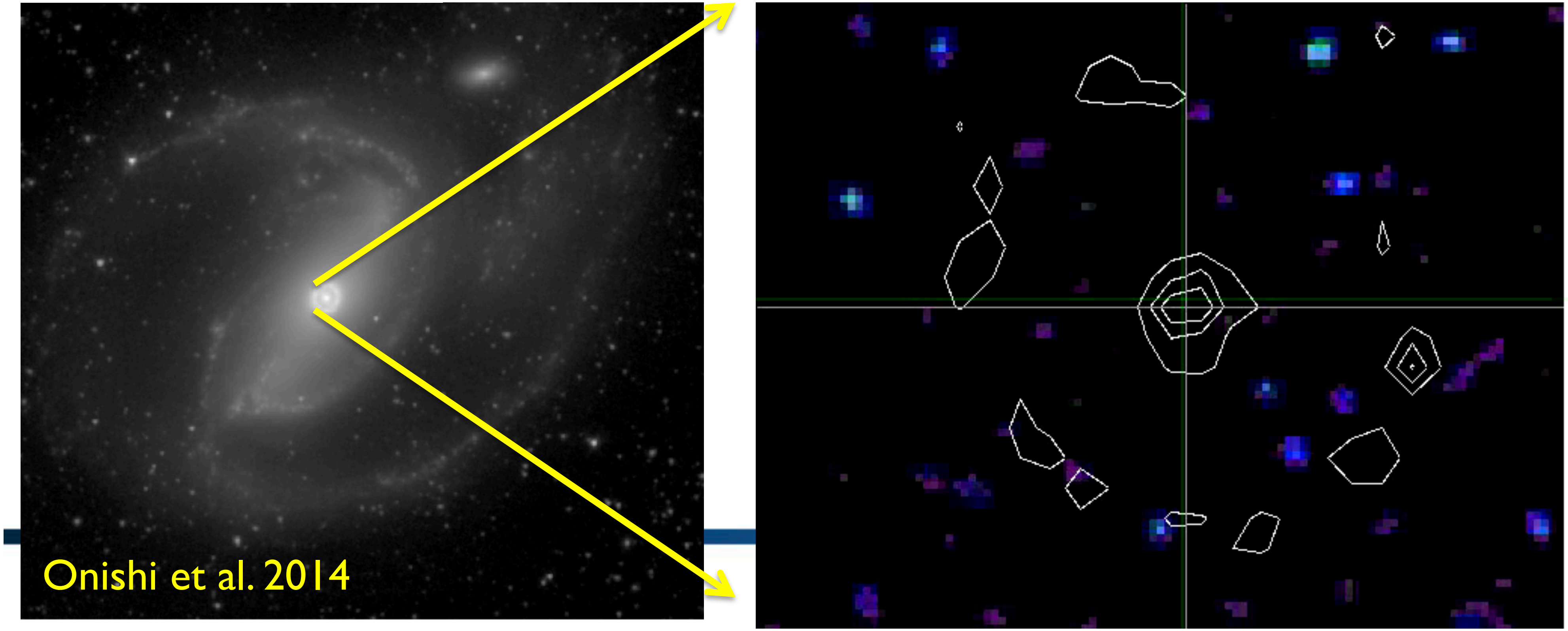


ALMA & TMT Synergy: Black Hole Mass



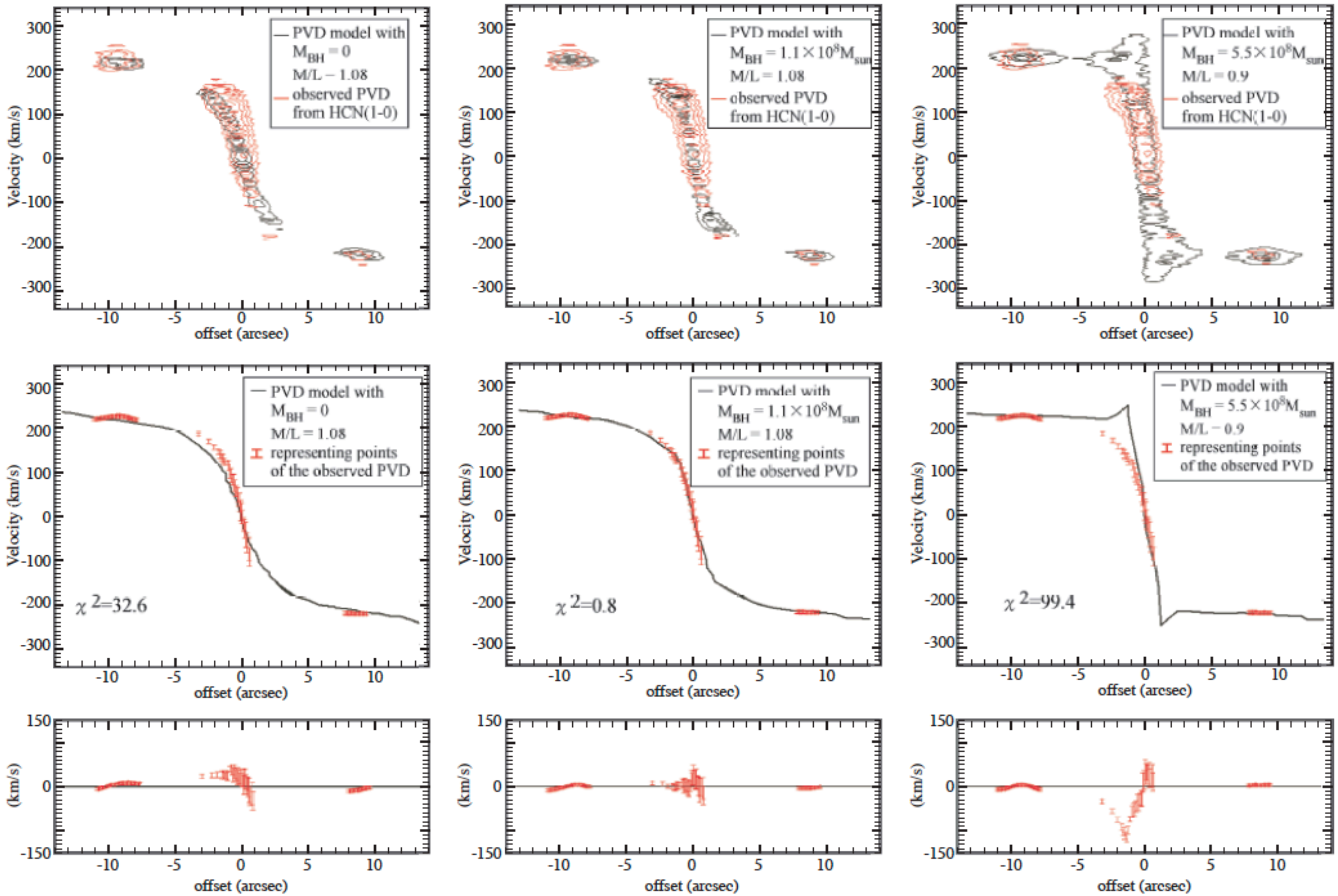
Large phase-space regime to be explored with TMT's higher sensitivity and angular resolution for low and high mass black holes.

ALMA offers ability to independently measure black hole masses. Very high spectral resolution + angular resolution – direct measurement of BH mass. Possible now!



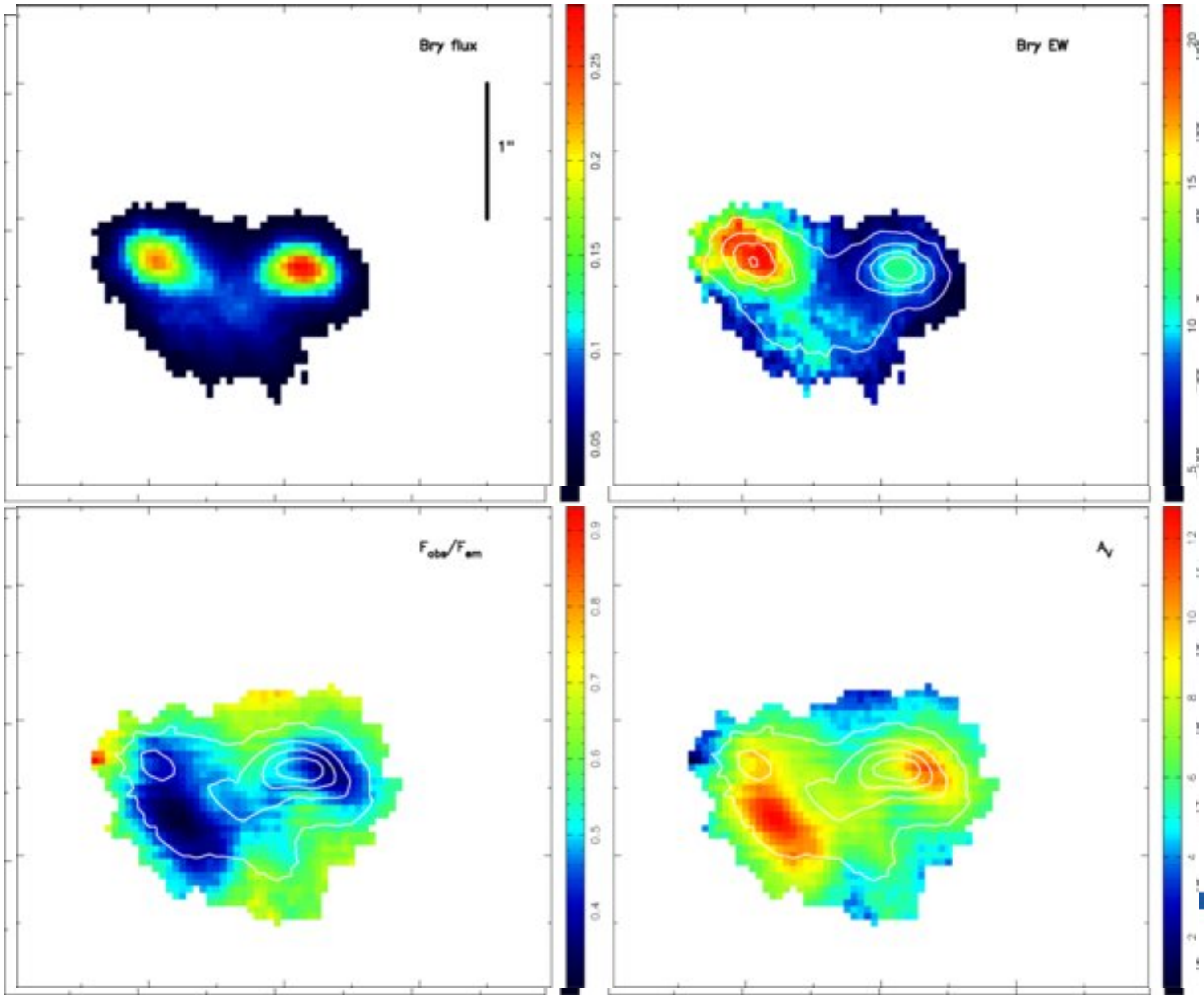
ALMA & TMT Synergy: Black Hole Mass

Onishi et al. 2014



ALMA & TMT Synergy: Galaxy Nuclei

Arp 220 stellar kinematics from CO absorption bandhead ($\lambda > 2.3\ \mu m$)



FOV = 3x3"

$\Lambda \sim 1.45 - 2.45\ \mu m$

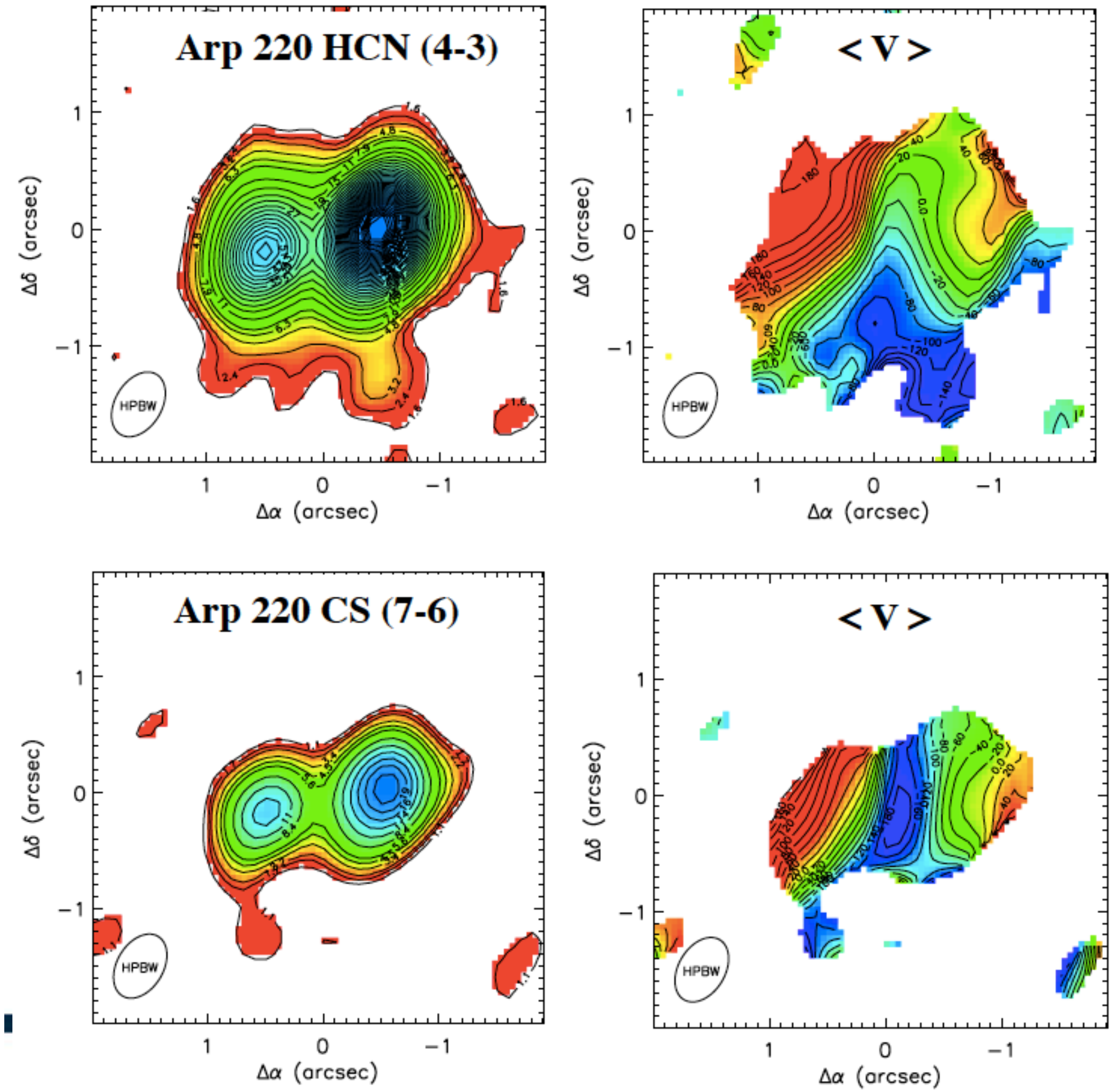
TMT will be able to observe fainter and more distant galaxies

Engel et al. 2011 ApJ

ALMA & TMT Synergy: Galaxy Nuclei

ALMA

Arp 220 dust morphology and gas kinematics from ALMA



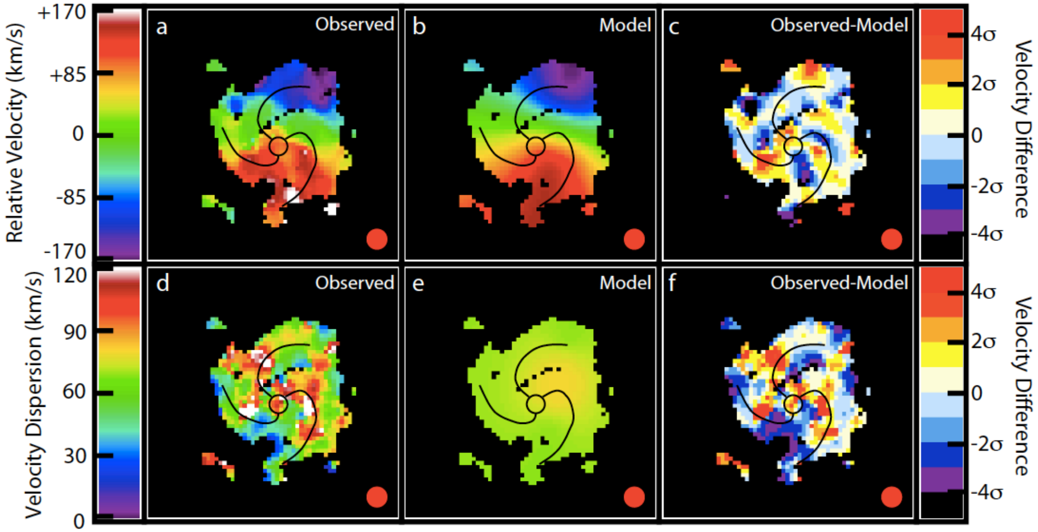
ALMA and TMT will have complementary angular resolution

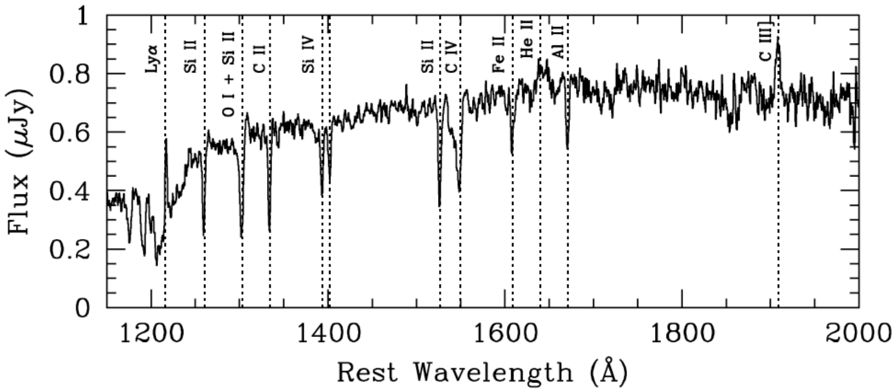
ALMA and TMT will explore dynamics of galaxy nuclei, and SF in extreme environments

Wilson et al. 2014
Scoville, KS et al. 2014

ALMA & TMT Synergy: Galaxy Formation: 1 < z < 5

ALMA





Law et al. 2012a,b

Enormous progress has been done observing rest-frame optical spectra + 2-D kinematics using Keck, LRIS and OSIRIS.

IRMS: rest optical properties of high-z galaxies; 2' FOV, 2.4" slits

WFOS: 20', multiple targets

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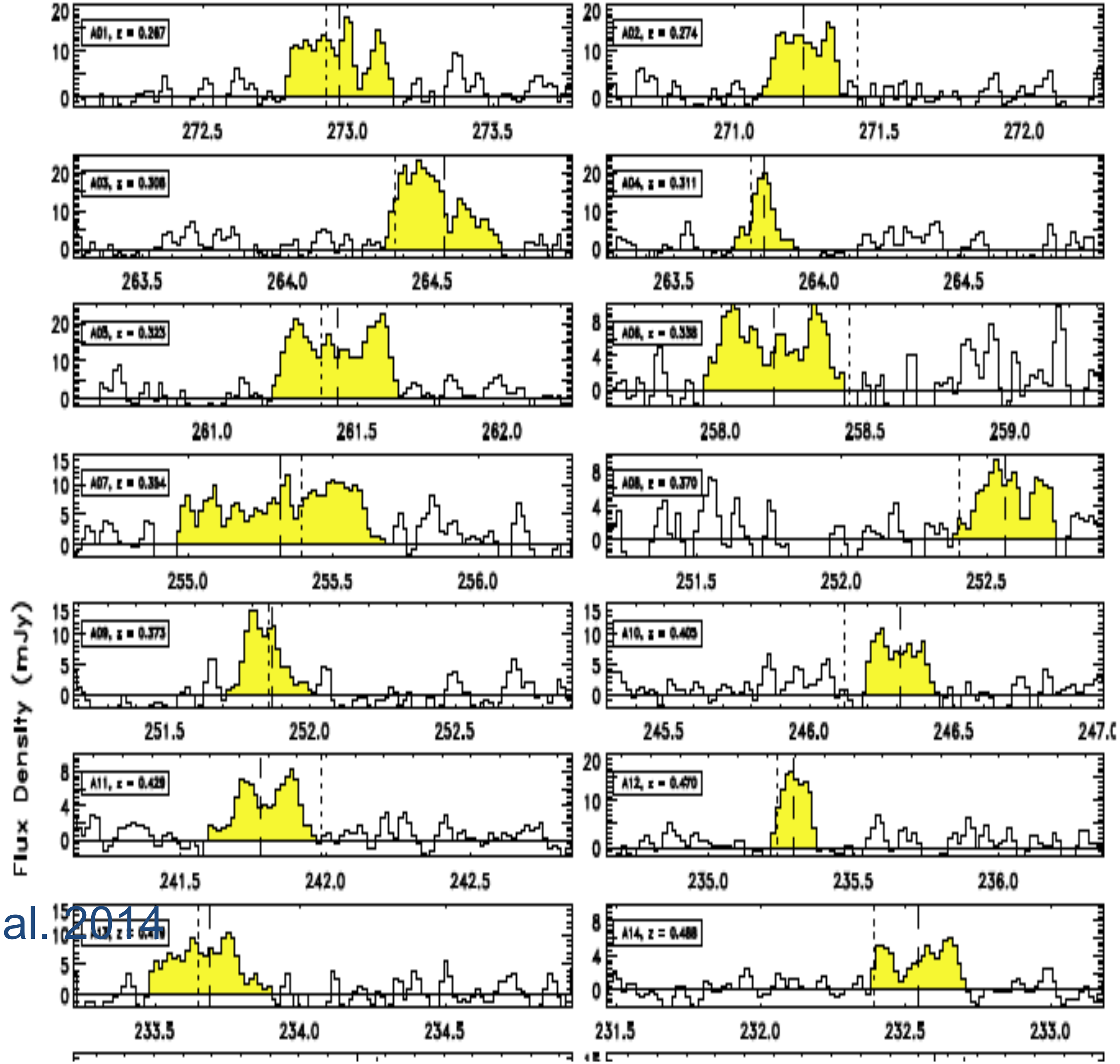
ALMA & TMT Synergy: Galaxy Formation: 1 < z < 5

ALMA

ALMA Cyc 1 – 20 LIRGs at z < 1 in just 10-30 mins per target.

At higher z..



Scott, KS et al. 2014

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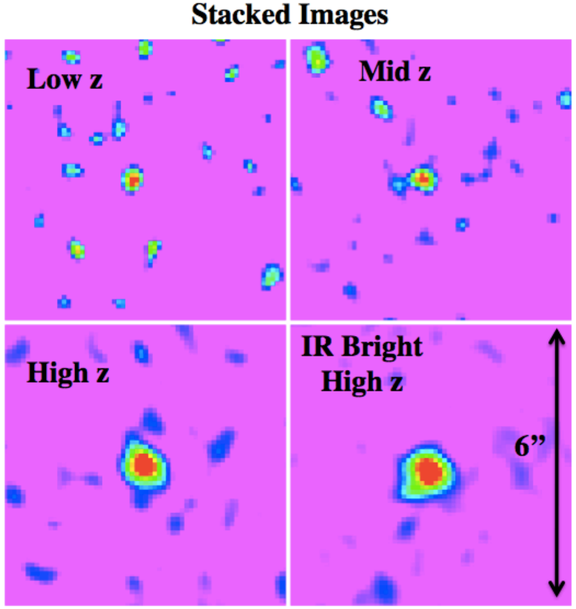
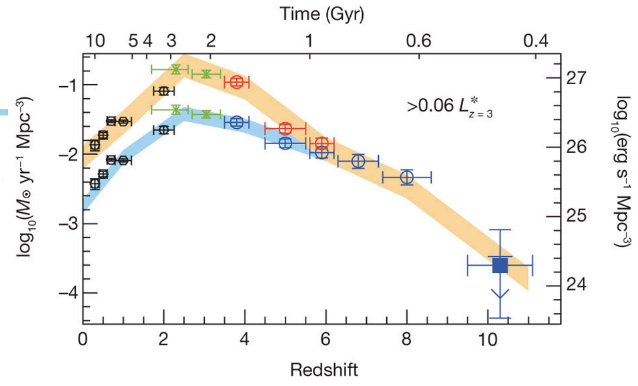
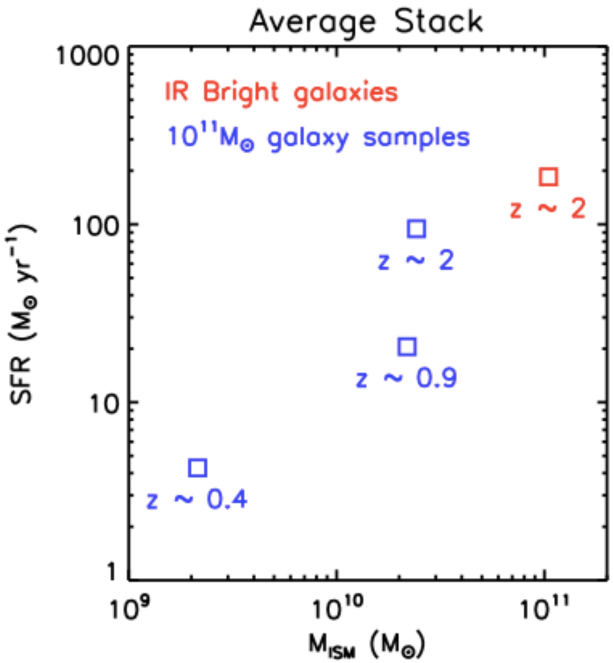
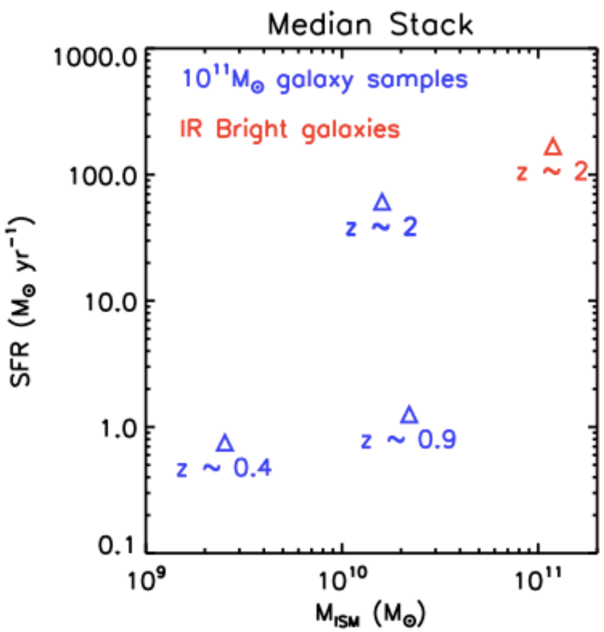
ALMA & TMT Synergy: High-z





- Molecular gas– critical for understanding the SFR density evolution and assembly of disks.
- May be most efficient using dust measurements because of large ALMA bandwidth.





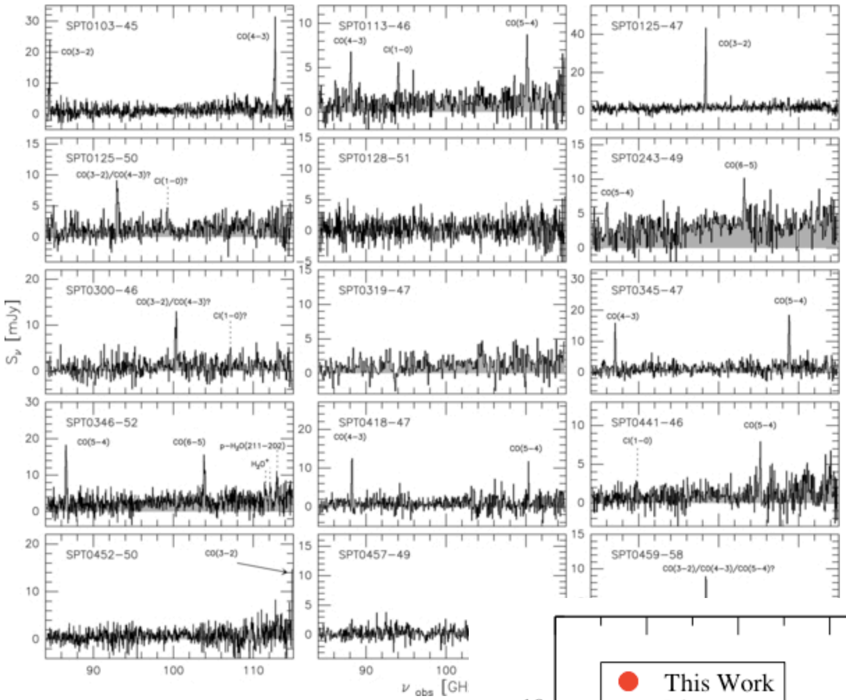
Scoville et al. 2014

ALMA & TMT Synergy: High-z

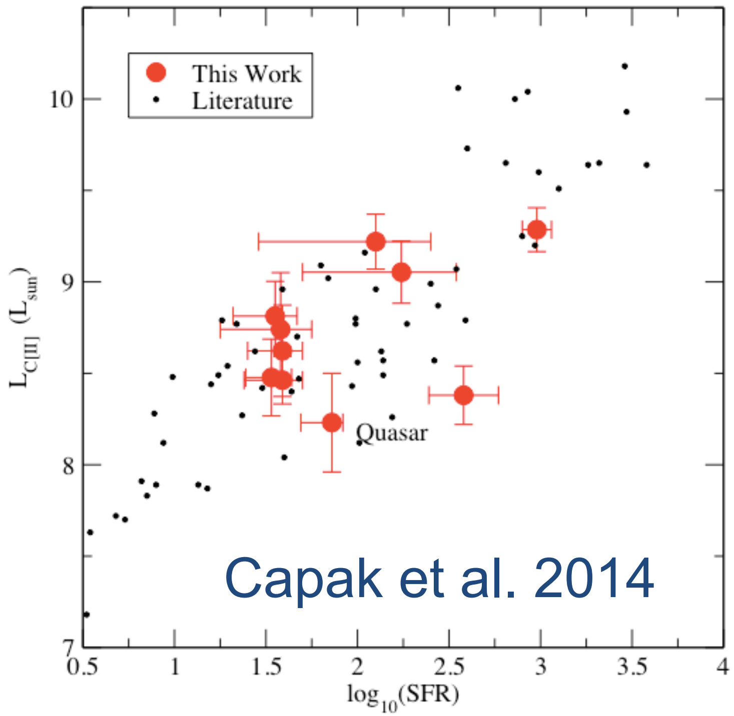
ALMA

Molecular gas reservoir – critical for understanding the SFR density evolution and assembly of disks.

Gas measurements require longer int times but can sample all redshifts using molecular and atomic lines!

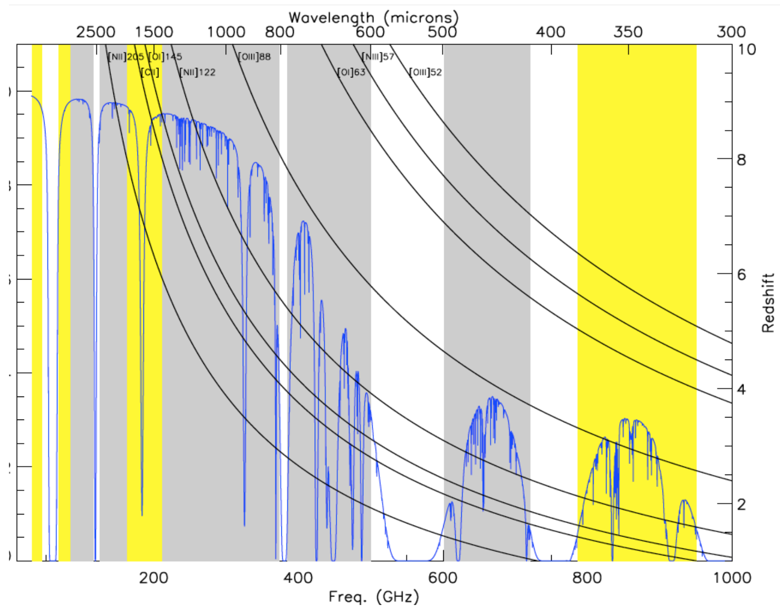


Vieira et al.



Capak et al. 2014

Brisbin et al.



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ALMA & TMT Synergy Summary

ALMA

- The next decade will see a new era of "Great Observatories"
- The combination of TMT, ALMA and JWST will be extremely powerful and synergistic leading to transformational science in all areas of astrophysics.
- TMT and ALMA will provide extremely high angular resolution data ~ 10 mas!
- The depth of TMT and ALMA will allow us to probe new parameter space: higher sensitivity → fainter, more distant objects in a reasonable amount of time.
- TMT → Near to mid-IR complementary to ALMA
- Combination of the distribution of star light, dust and gas and kinematics will address a vast range of astrophysics questions!

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