

Planets, moons and asteroids

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With many contributions from Mark Gurwell, CfA



In its first decade, SMA demonstrated sub-mm interferometry, paving the way to ALMA

SMA projects uniquely contributed to characterize planets, moons and asteroids



Ceres, Vesta:
rotational lightcurve

Io: atmosphere
mapping (SO_2 , SO ,
 NaCl)

Titan: CO , HCN
nitriles mapping

Broadband CO
spectroscopy
Continuum map
 CO and HCN
mapping

Moons: polarization
maps

CO mapping

Wind mapping

Triton:
Atmosphere
exploration

Wind mapping,
 CO/HDO , surface
mapping

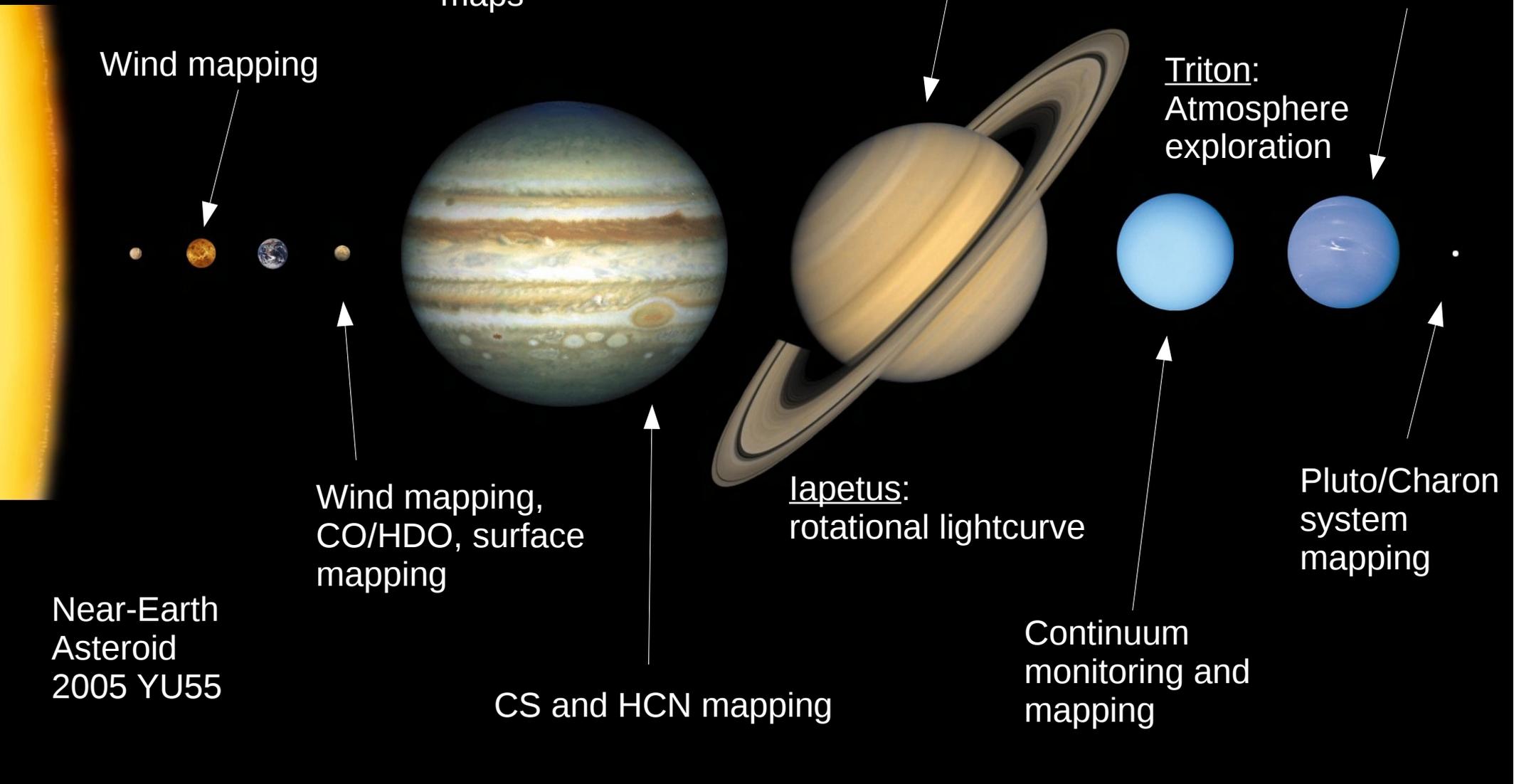
Iapetus:
rotational lightcurve

Pluto/Charon
system
mapping

Near-Earth
Asteroid
2005 YU55

CS and HCN mapping

Continuum
monitoring and
mapping



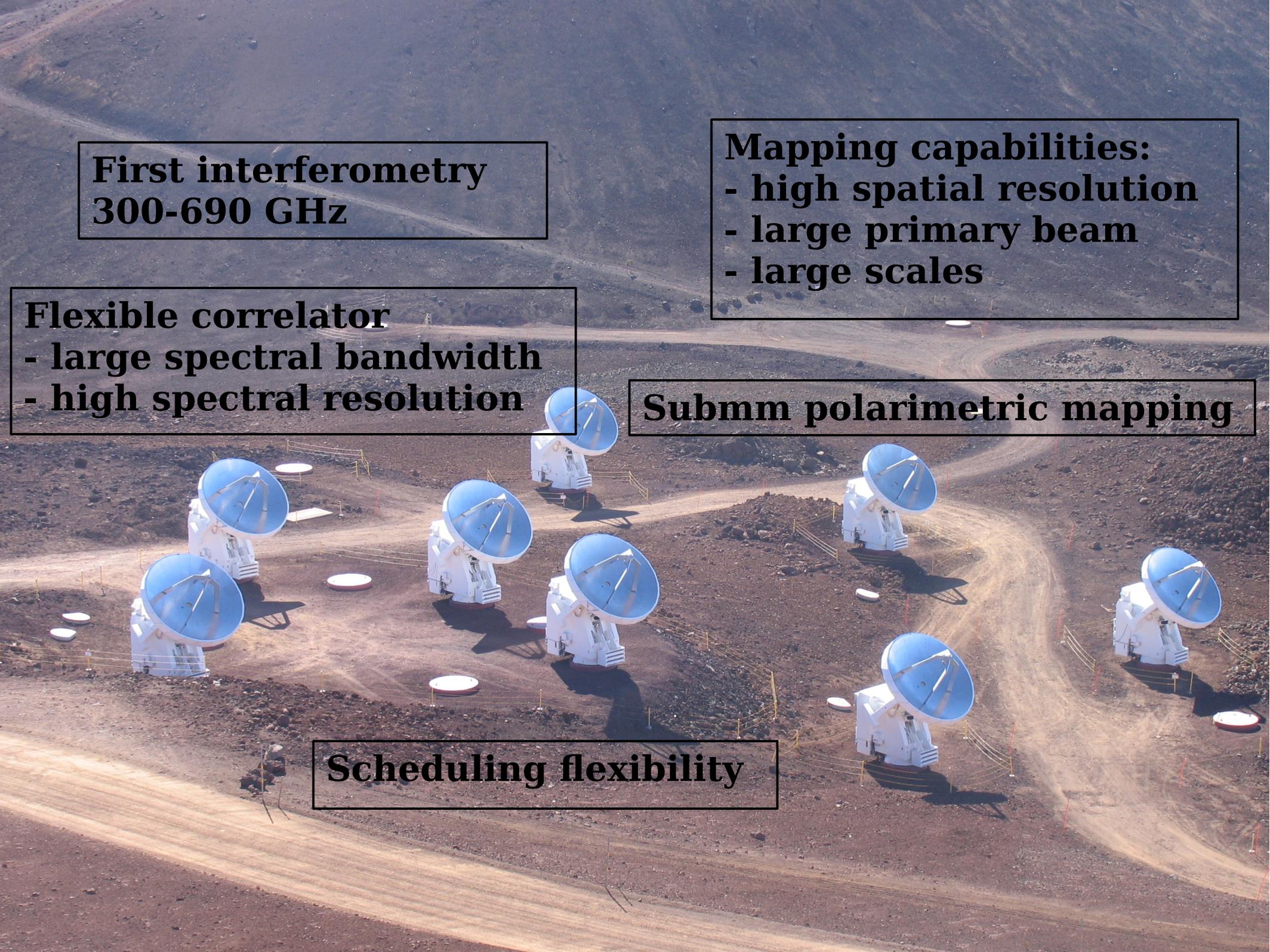
**First interferometry
300-690 GHz**

Mapping capabilities:
- high spatial resolution
- large primary beam
- large scales

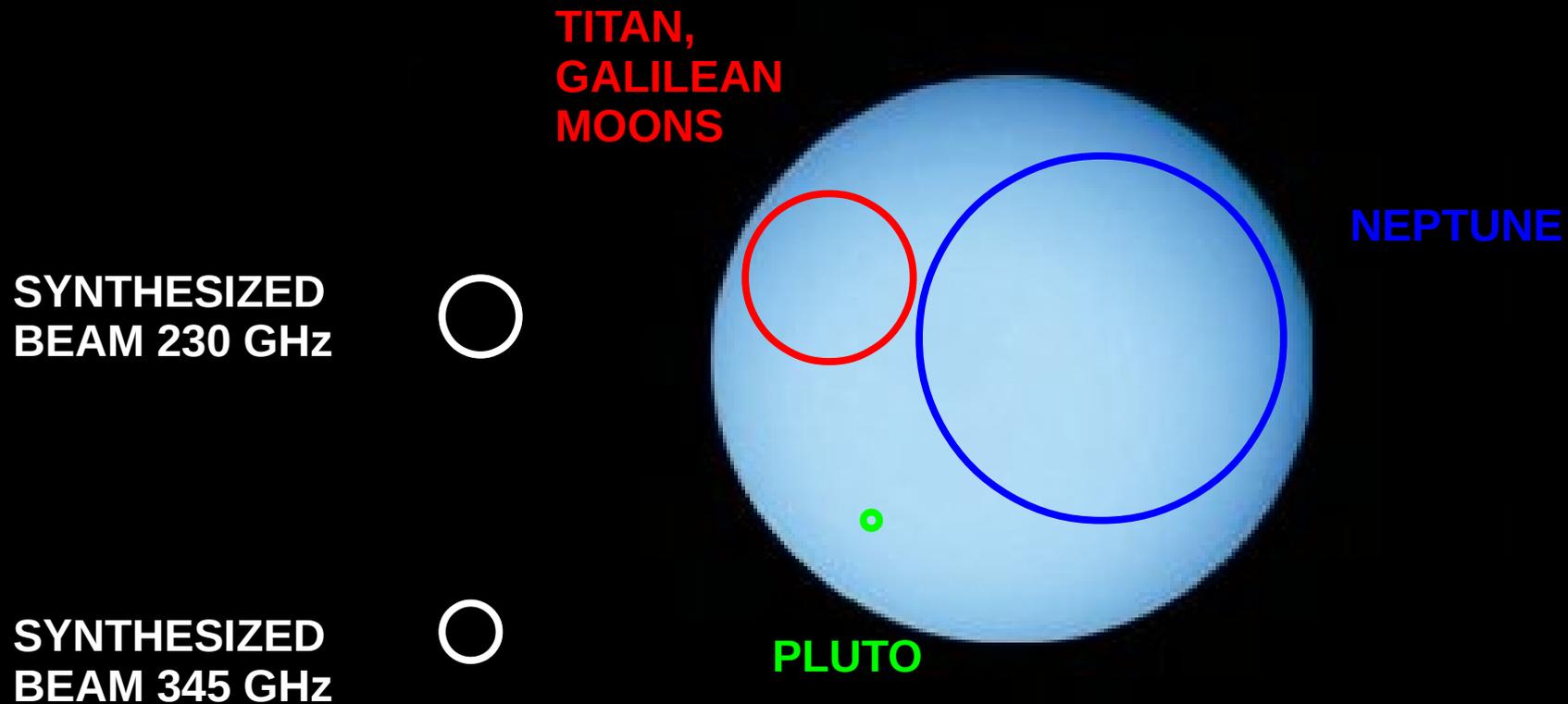
Flexible correlator
- large spectral bandwidth
- high spectral resolution

Submm polarimetric mapping

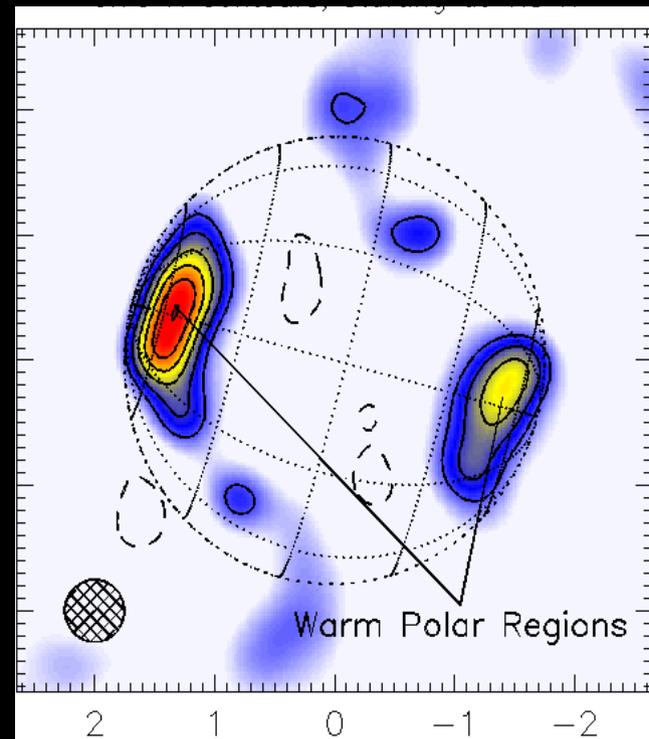
Scheduling flexibility



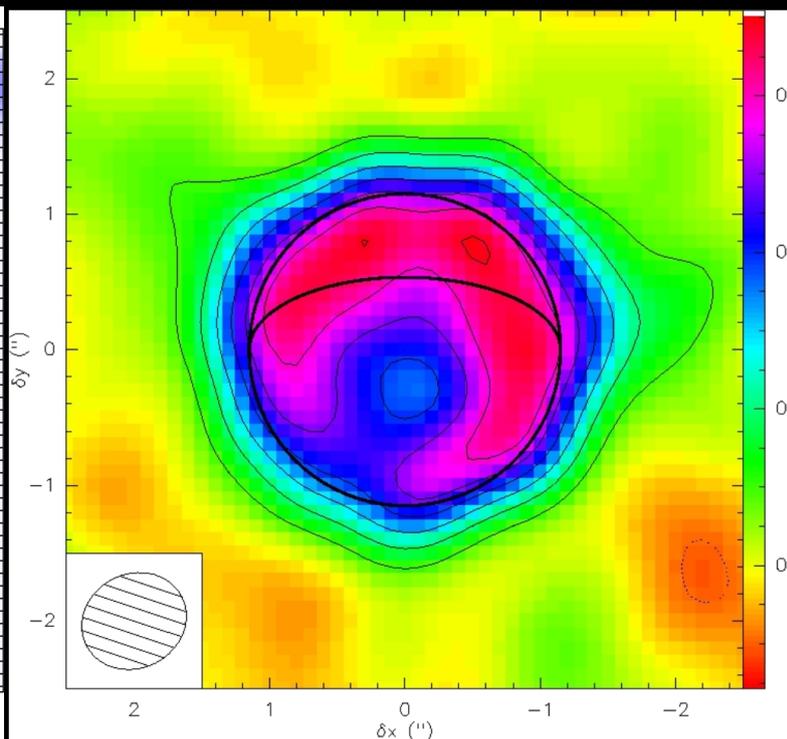
High-resolution imaging



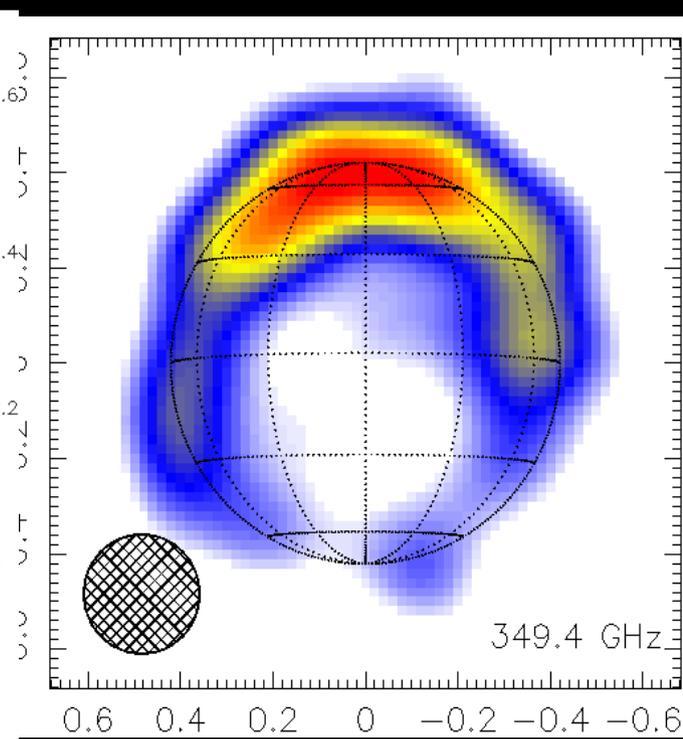
High-resolution imaging



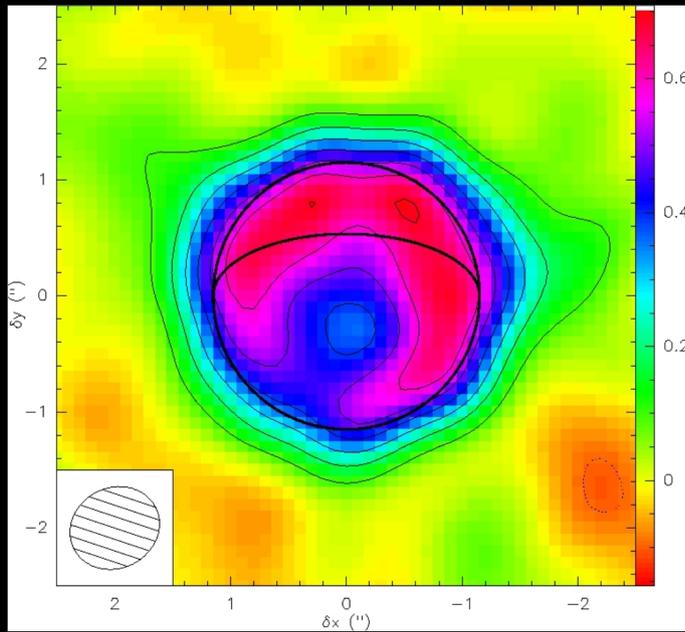
URANUS - continuum
(Hofstadter, 2006)



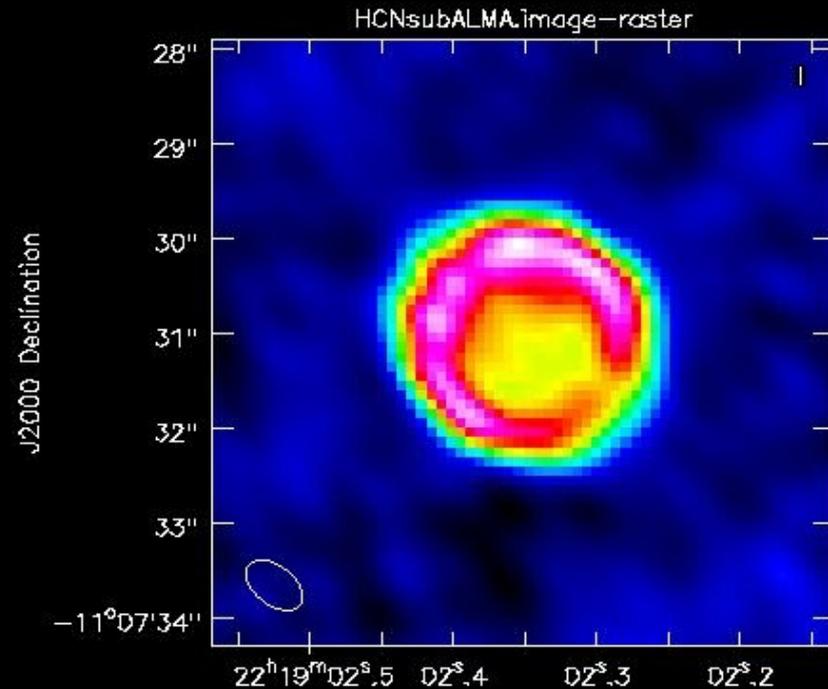
NEPTUNE - HCN
(Moulet, 2010-2012)



TITAN - CH_3CN
(Gurwell, 2009)



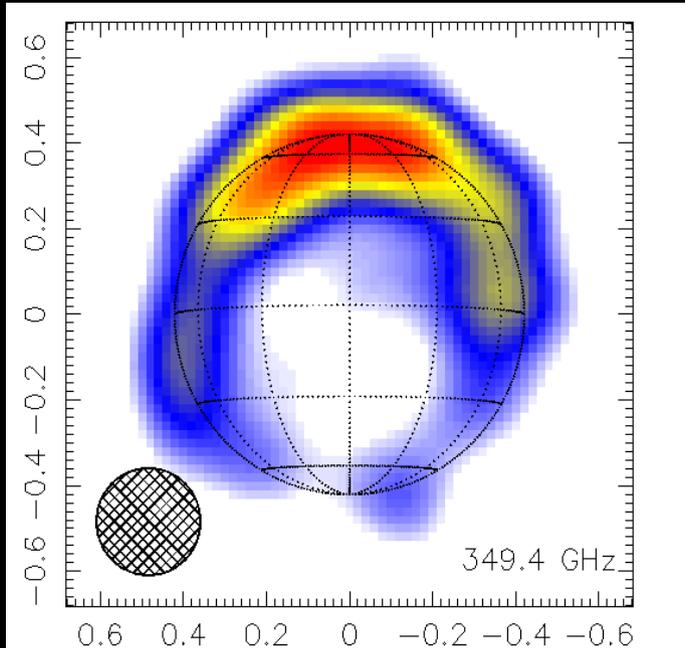
NEPTUNE HCN / SMA
(Moulet, 2010-2012)



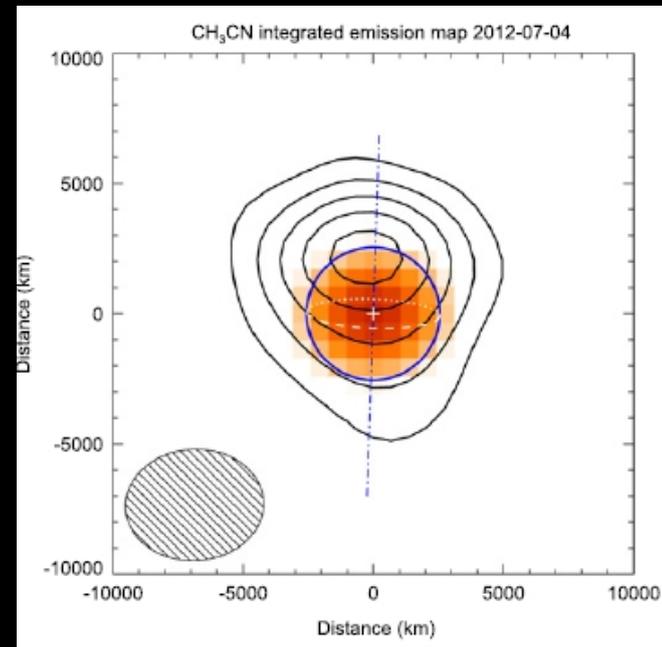
NEPTUNE HCN / ALMA
(Archival data, 2012)

Depletion of HCN at Southern latitudes, stable over years

- Enhanced **photolysis** at South latitudes?
- Summer to Winter **seasonal circulation**?
- Signature of **upwelling branch** (cooling) of local cyclone?



TITAN - CH₃CN/ SMA
(Gurwell, 2009)



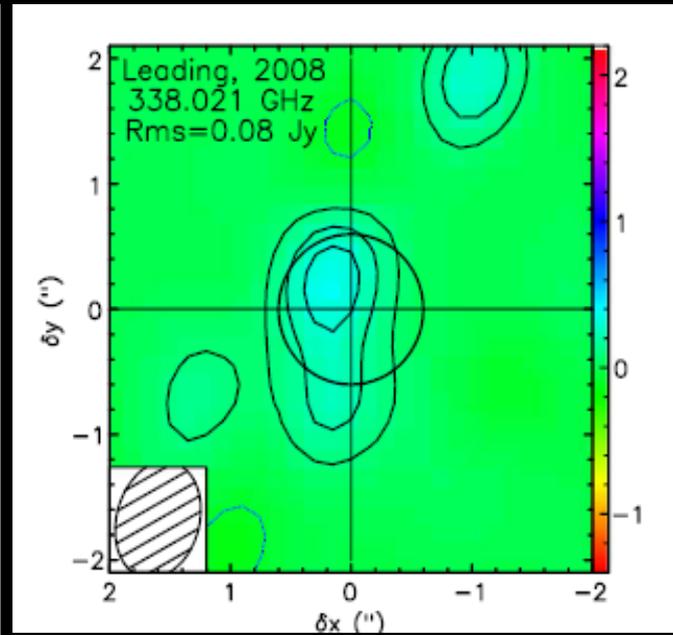
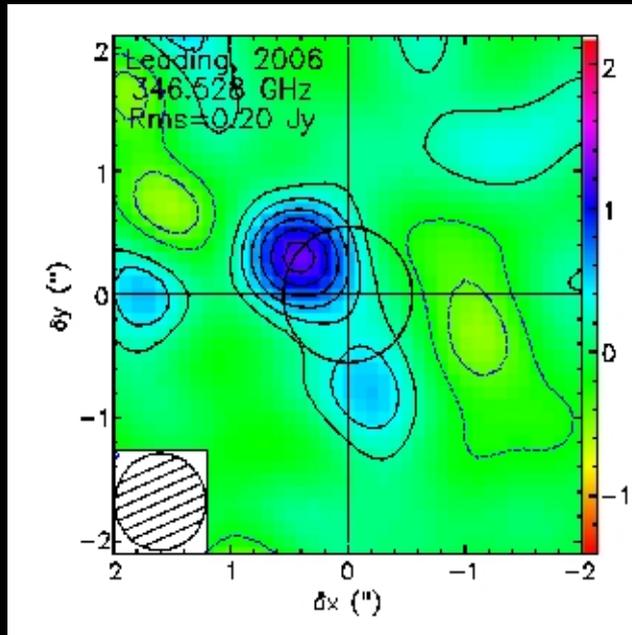
TITAN - CH₃CN / ALMA
(Cordiner et al, 2014)

CH₃CN concentrated at high North latitudes during equinox

- CH₃CN may concentrate there during Winter
- **Long chemical lifetime** → subsistence at Northern latitudes even after seasonal transport to South starts

SO

NaCl



IO - SMA
(Moulet et al, 2010)

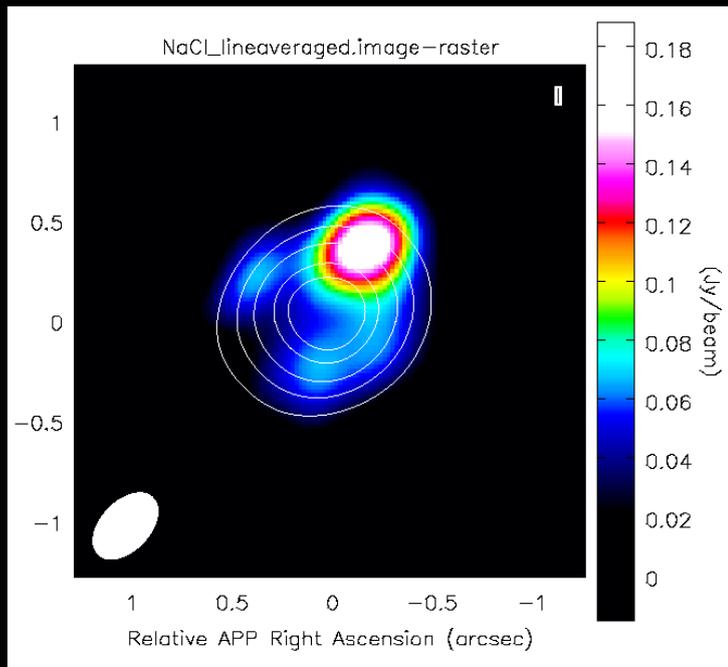
First mapping of minor species in Io's atmosphere:

- **Less extended** emission than sublimation-sustained bulk SO_2 atmosphere: different sources
- SO: photochemistry and plume outgassing
- **NaCl: plume outgassing**

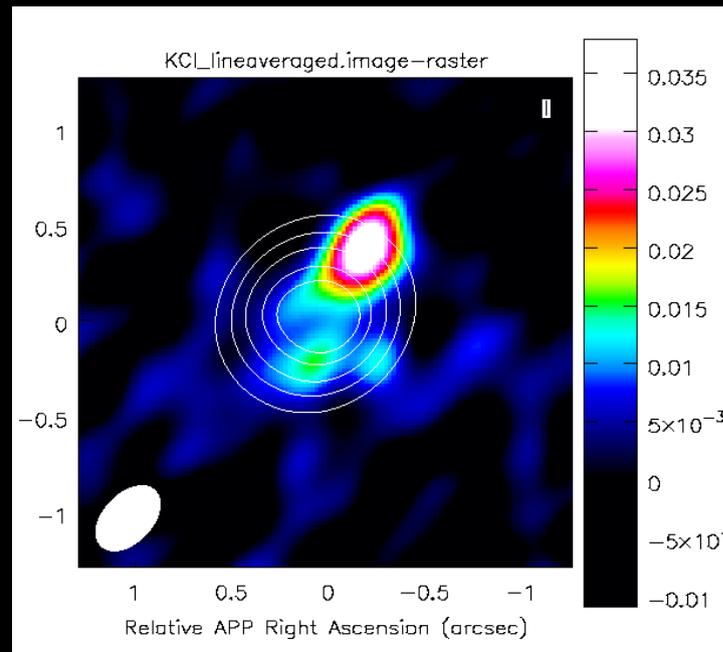
Expanding the study to other minor species with ALMA:

- Alkali volcanic species (KCl, NaCl) trace **location of active volcanoes**

NaCl



KCl



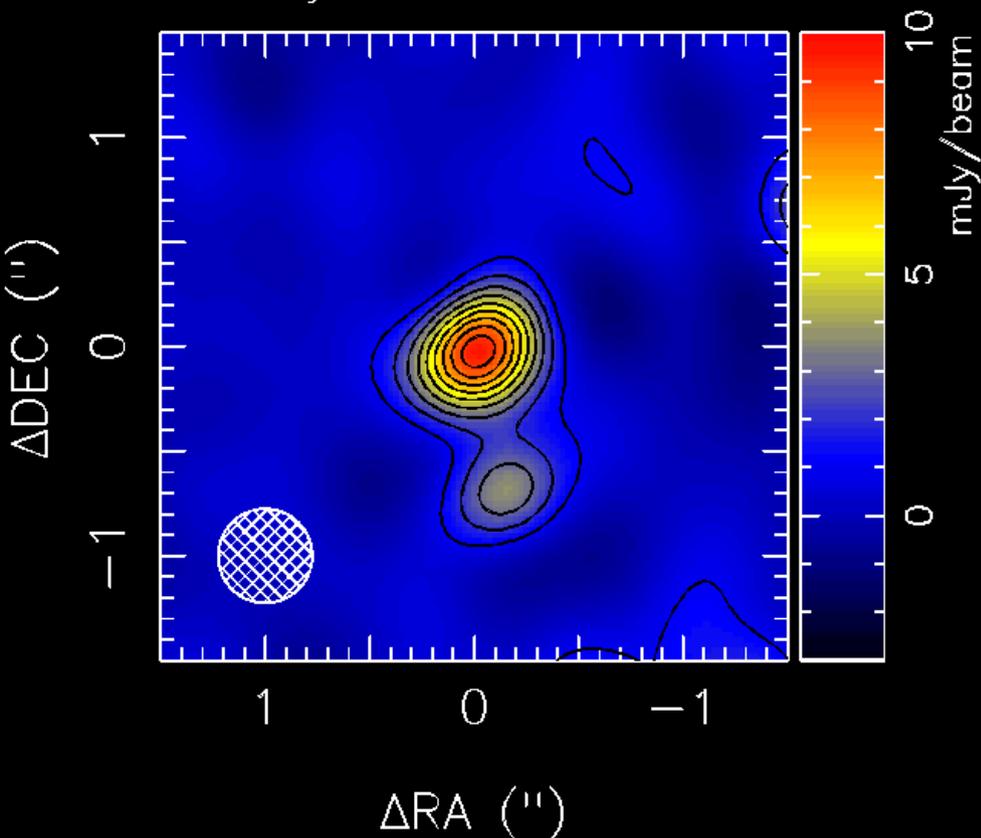
IO - ALMA
(Moulet et al, 2015)

PLUTO/CHARON

(Gurwell et al, 2005)

**First resolved thermal image
of the system**

21 May 2005 – 220 GHz



Pluto: $T_B = 37 \pm 2.3$ K

Charon: $T_B = 49 \pm 8$ K

Mean surface temperature:
41 K / 54 K - **consistent with
albedo / latent heat models**

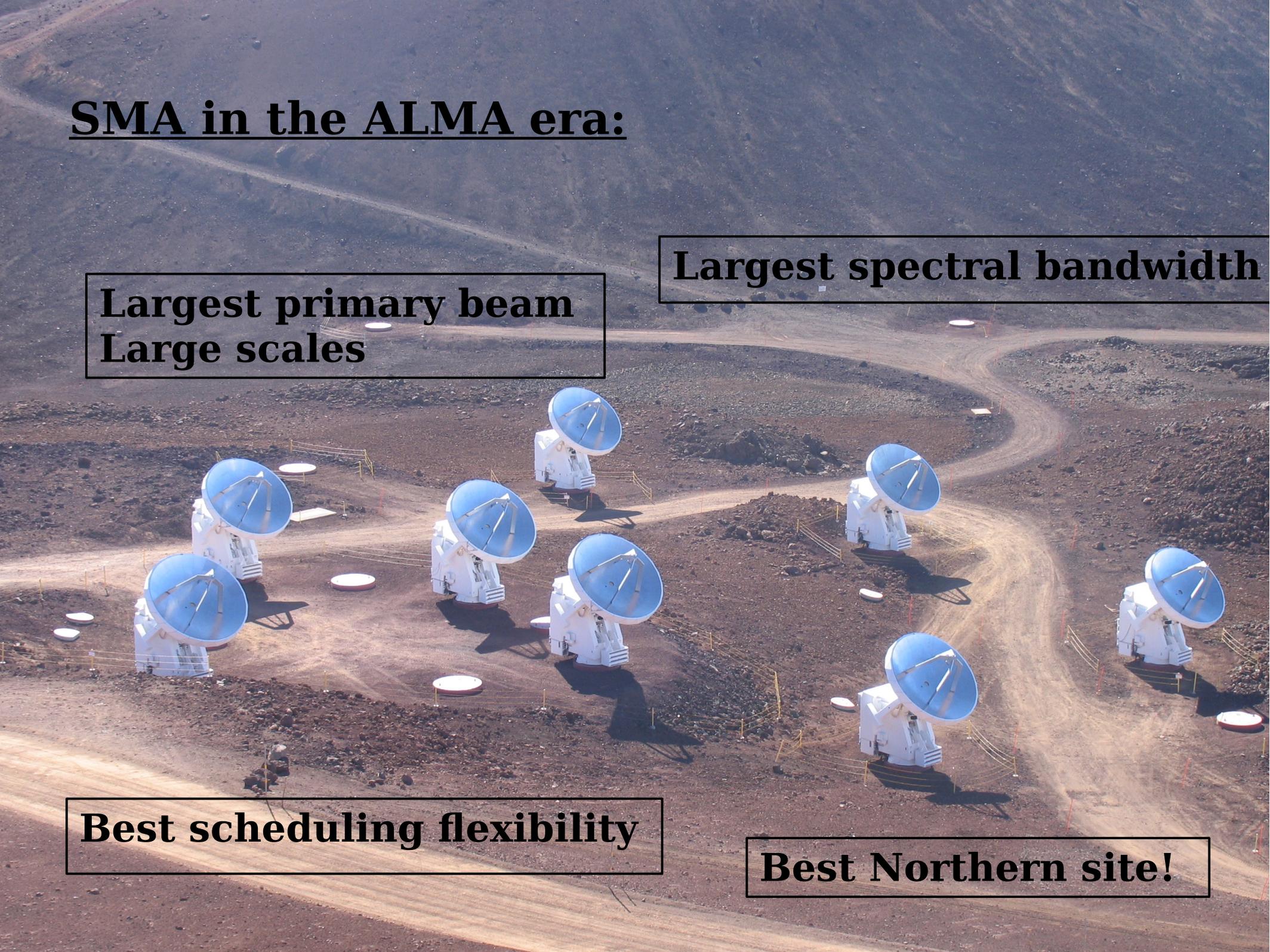
SMA in the ALMA era:

**Largest primary beam
Large scales**

Largest spectral bandwidth

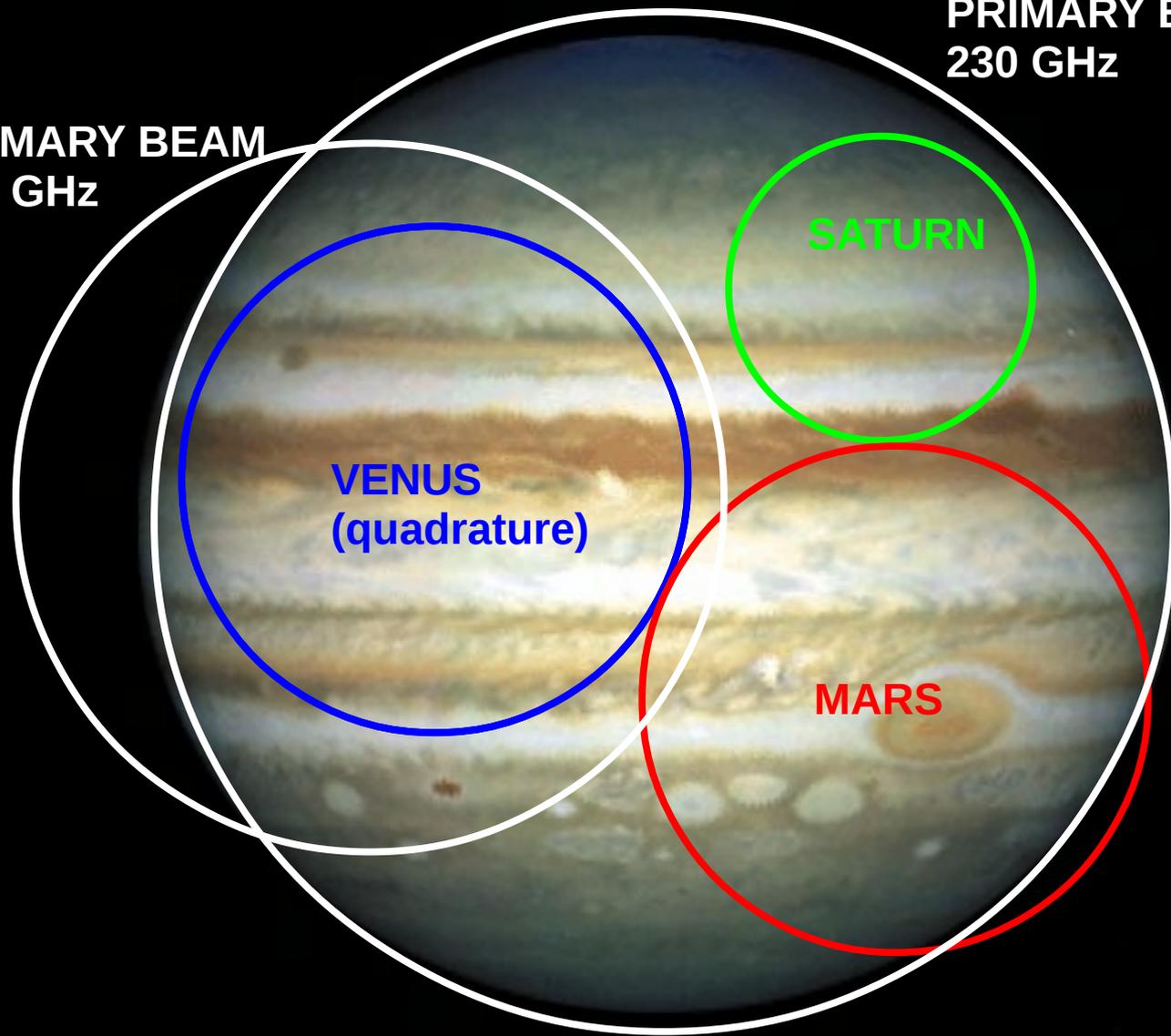
Best scheduling flexibility

Best Northern site!



**PRIMARY BEAM
345 GHz**

**PRIMARY BEAM
230 GHz**



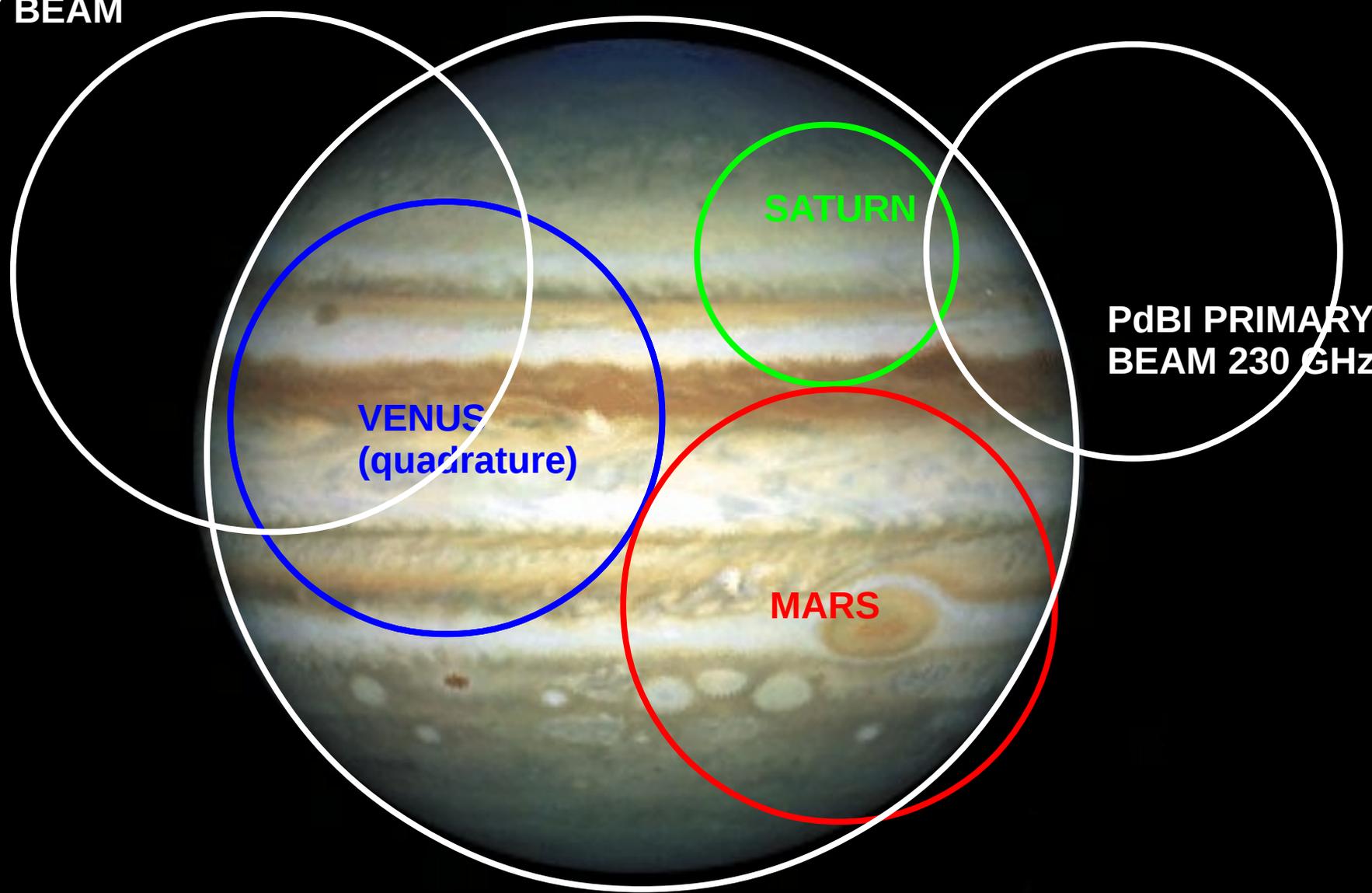
SATURN

**VENUS
(quadrature)**

MARS

ALMA 12m
PRIMARY BEAM
230 GHz

SMA PRIMARY
BEAM 230 GHz



PdBI PRIMARY
BEAM 230 GHz

VENUS
(quadrature)

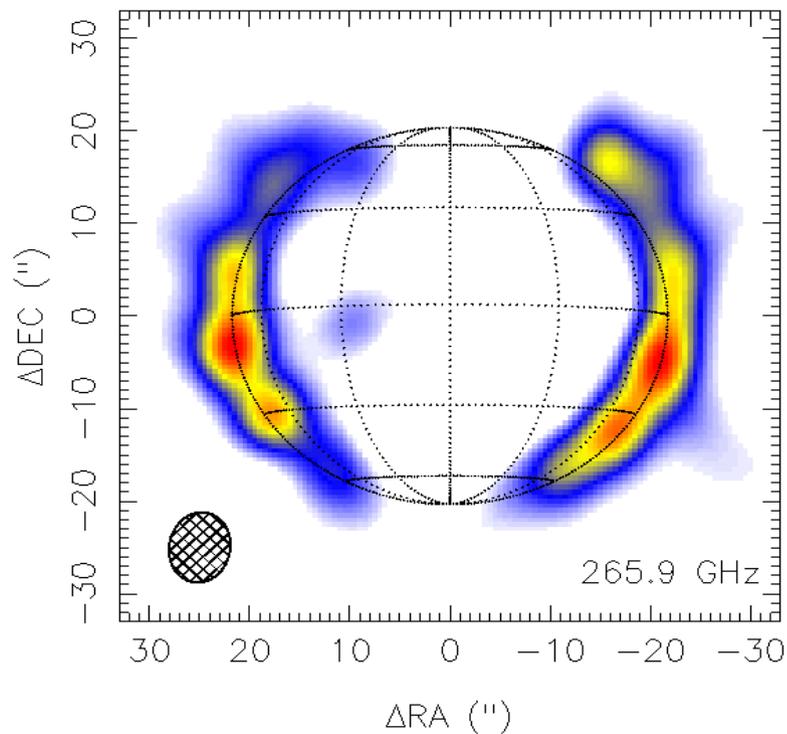
SATURN

MARS

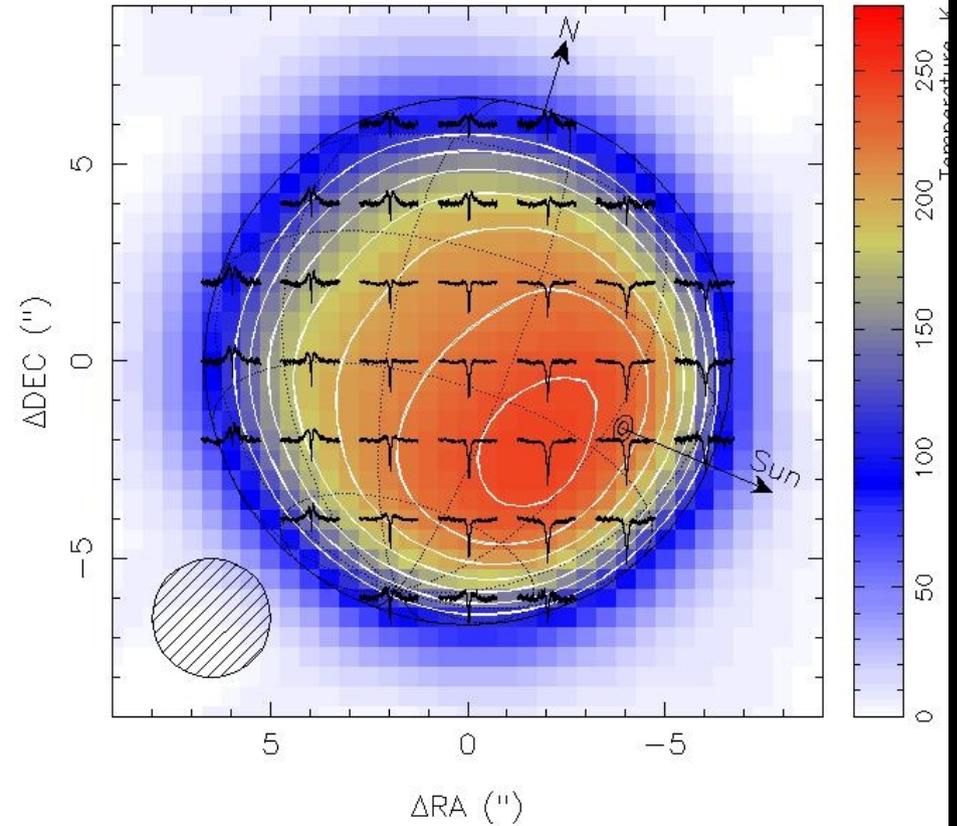
**SMA captures 2x larger scales than ALMA 12-m
(filters out >12" at 230 GHz)**

Large-scale mapping

Jupiter HCN(3-2) Integrated Emission [SMA: 28 April,



JUPITER - HCN
(Moreno, 2007)



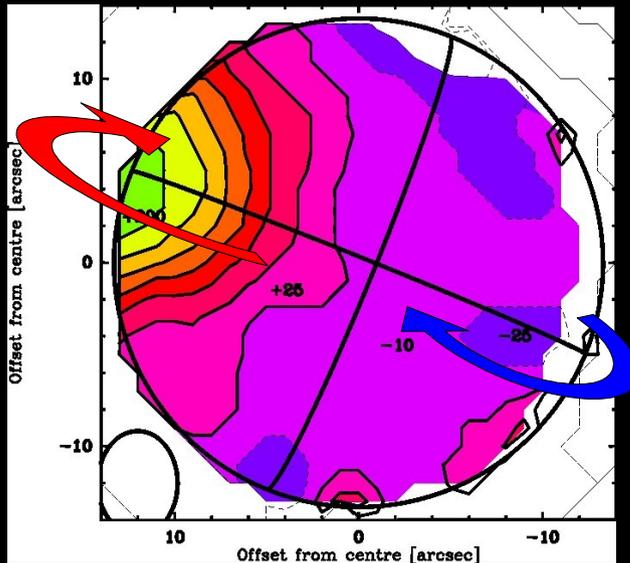
MARS - CO
(Gurwell, 2004)

VENUS CO(2-1)

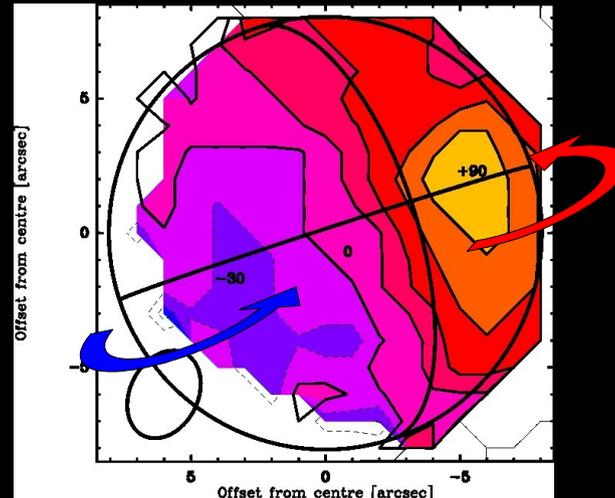
(PIs Gurwell, Sagawa)

Mapping of mesospheric
(~90 km) wind field

Quadrature East



Quadrature West

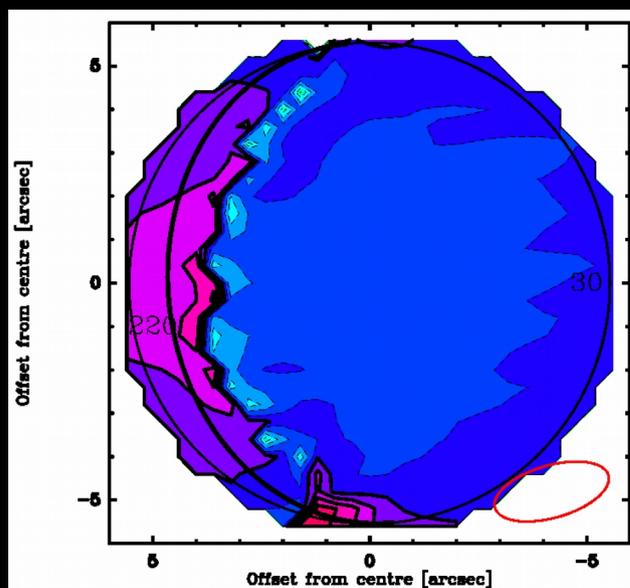


Venus ~ 22" :
SMA adequate for
morning/evening
phases (and ~ night)

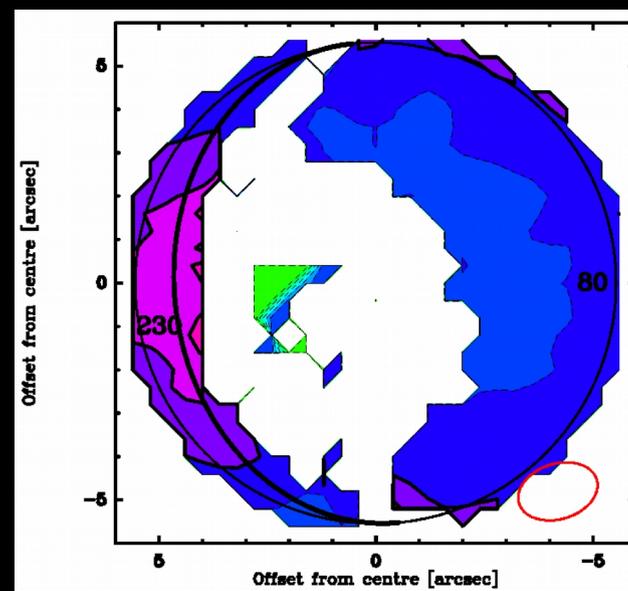
- **Subsolar-to-antisolar wind** dominating
- Possible zonal retrograde jet at night near equator

Trends confirmed by **ALMA dayside maps** (PI Encrenaz)

- **dominant SSAS wind** ($V_{\text{ter}} = 211/245 \text{ m/s}$)
- zonal retrograde wind in an equatorial band ($V_{\text{equ}} = 50/30 \text{ m/s}$)

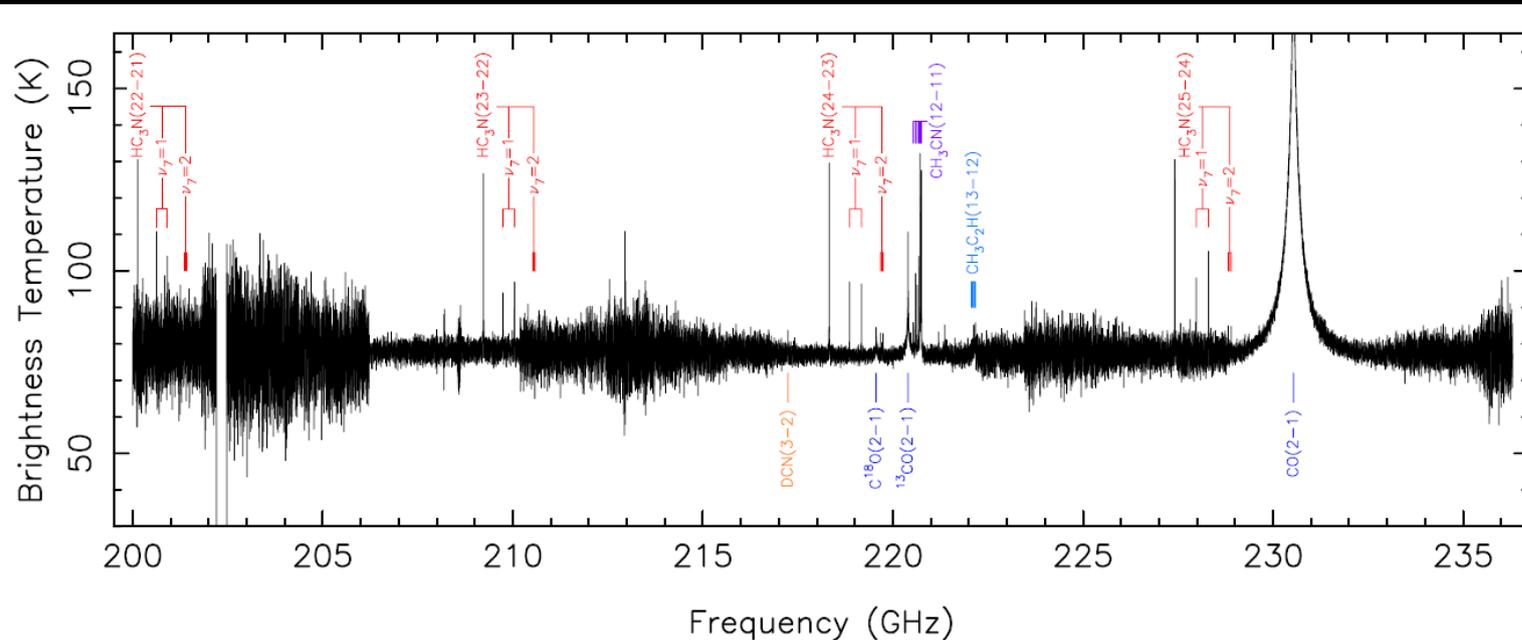


Doppler-shift map, Nov 14th, 2011



Doppler-shift map, Nov 15th, 2011

Spectral grasp: line searches

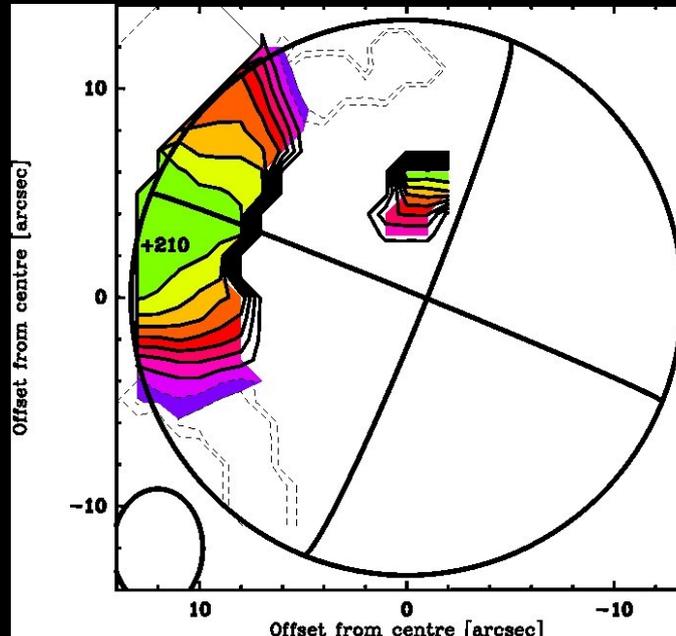
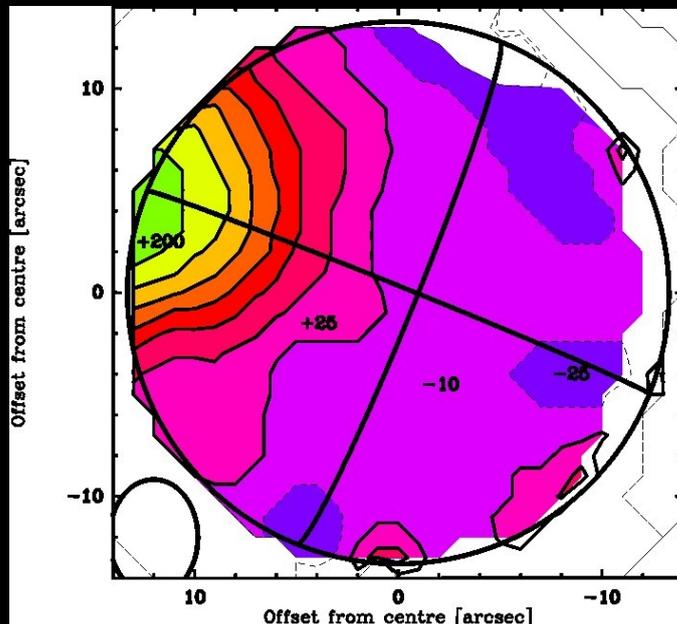


TITAN
(PI Gurwell):
100 datasets!

- 32 GHz instantaneous bandwidth/ receiver: fast spectral surveys on chemically rich atmospheres

Spectral grasp: instantaneous vertical profiles

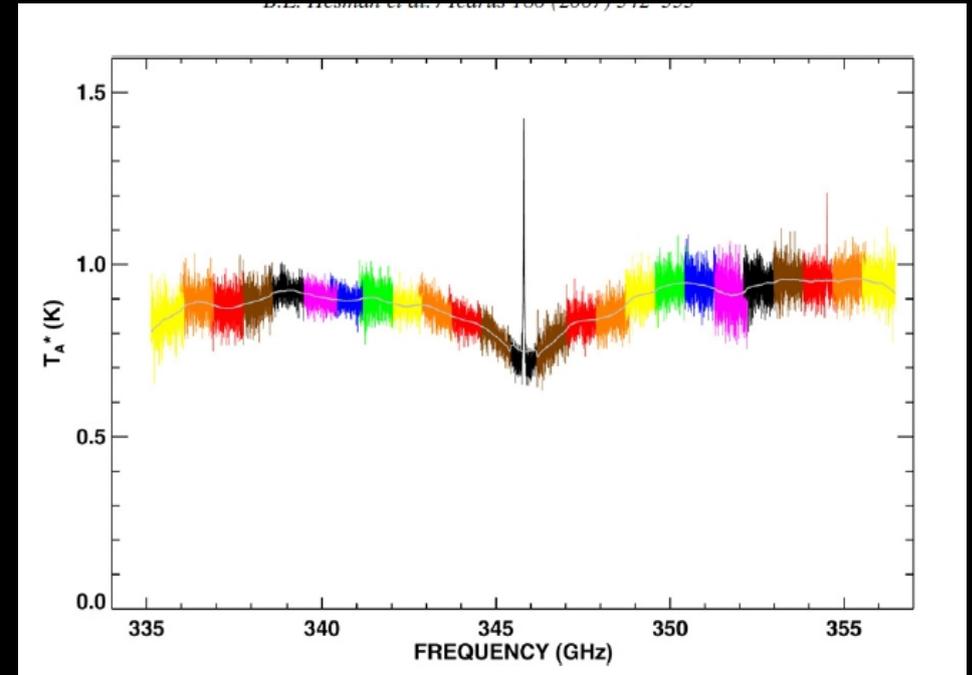
- Instantaneous mapping of different transitions/isotopologues:
 - **wind field at different probed altitudes**
 - vertical temperature profiles



VENUS
CO(2-1)/CO(3-2)
(PI Sagawa)

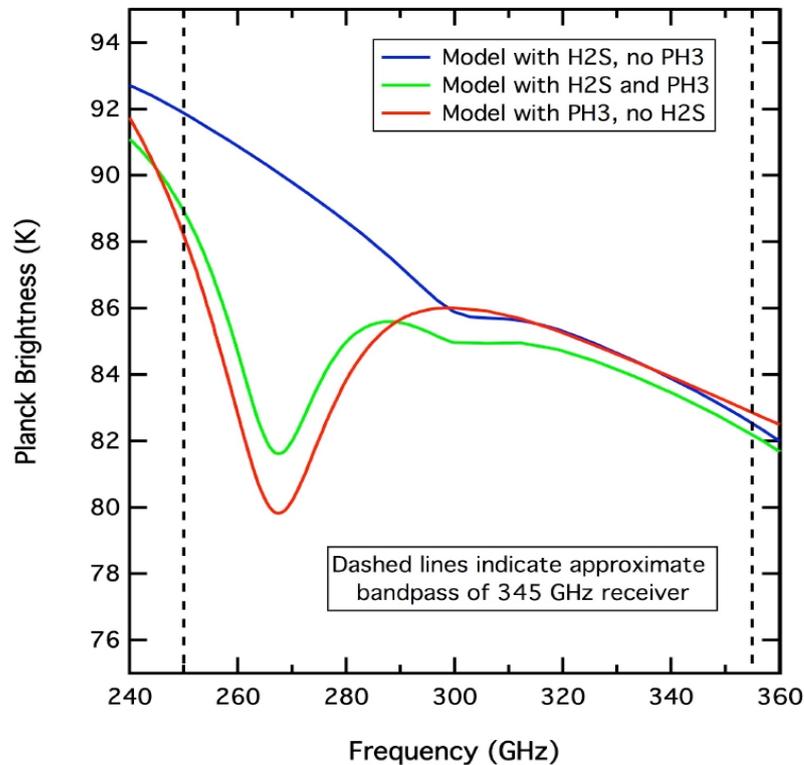
Spectral grasp: pressure-broadened lines

- Tropospheric CO pressure-broadened Voigt profiles: 10s of GHz wide!
- Informs on temperature/abundance profile in tropospheres/stratospheres



Neptune's CO (-32) spectrum
observed at JCMT
(Hesman et al., 2007)

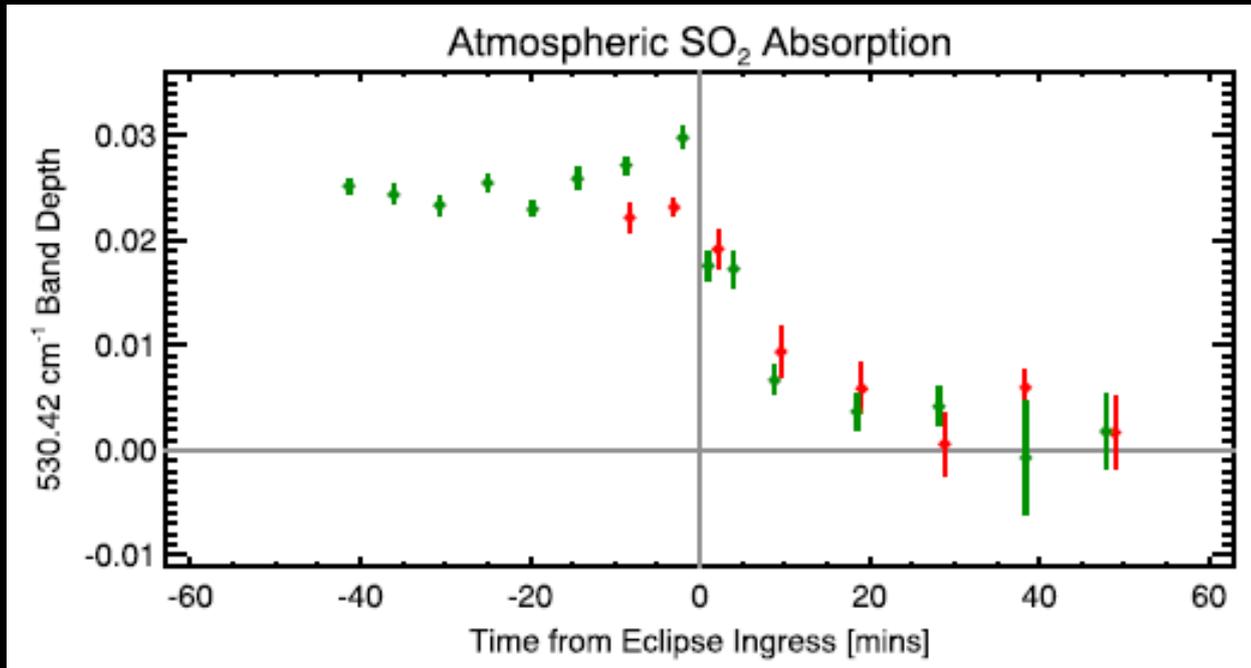
Spectral grasp: collisionally-induced absorption lines



- High-pressures induce short-lived dipolar momentum in molecules: very wide absorption
- Unique information on **phosphine, ammonia, H₂S, ...** at depth in giant planets

Uranus's model spectrum
(courtesy M, Hofstadter)

Scheduling flexibility: short-term phenomena

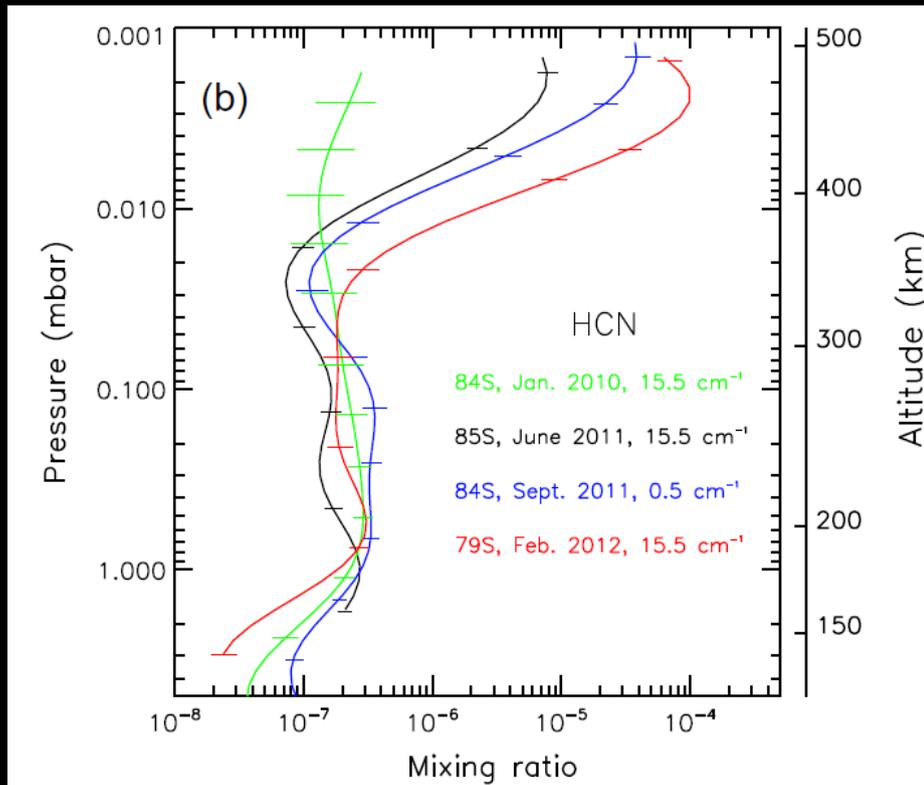


SO₂ IR-band variation on Io during an eclipse, Tsang et al., 2016

- Mutual eclipses
 - thermal inertia
 - temperature-driven changes
- Wind pattern changes (Venus)
- Volcanic/plume activity

Hour(s)-long phenomena need tight time-constraints

Scheduling flexibility: long-term monitoring



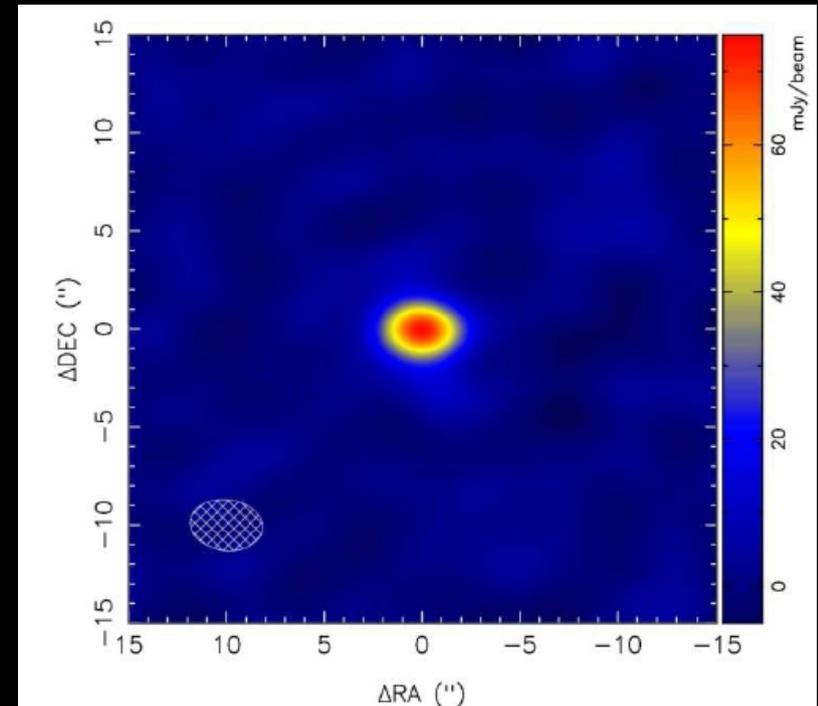
- Seasonal patterns
- Orbital variations
- Storms/vortexes

**Observing time availability
on months/years-long
timescales**

HCN seasonal variation in Titan's upper atmosphere, Vinatier et al., 2015

Scheduling flexibility: ToO

- Near Earth Asteroid approaches
- Cometary impacts
- Coordinated multi-wavelengths/
space-missions observations



NEA 2005 YU₅₅ - SMA (1.3 mm)
Muller et al, 2013

Need rapid response and data processing!

SWARM and the great scheduling flexibility of the SMA make it the best instrument for several specific Solar System projects.

Further planned upgrades in those areas will keep the SMA critical role in the field and its complementary to ALMA.

