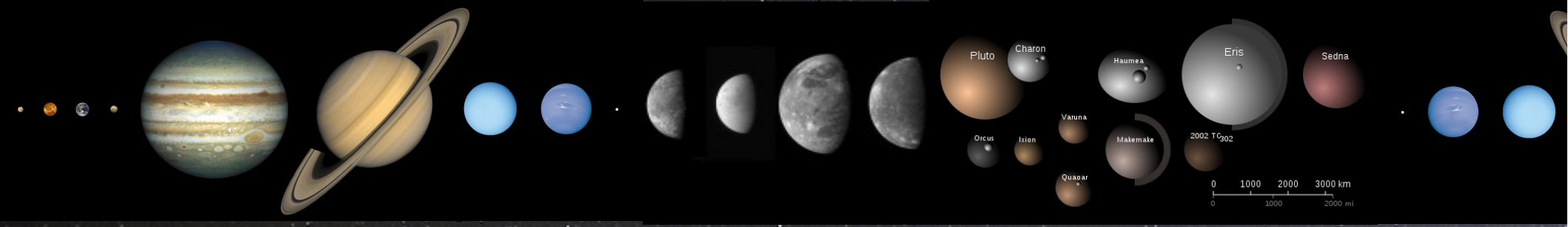
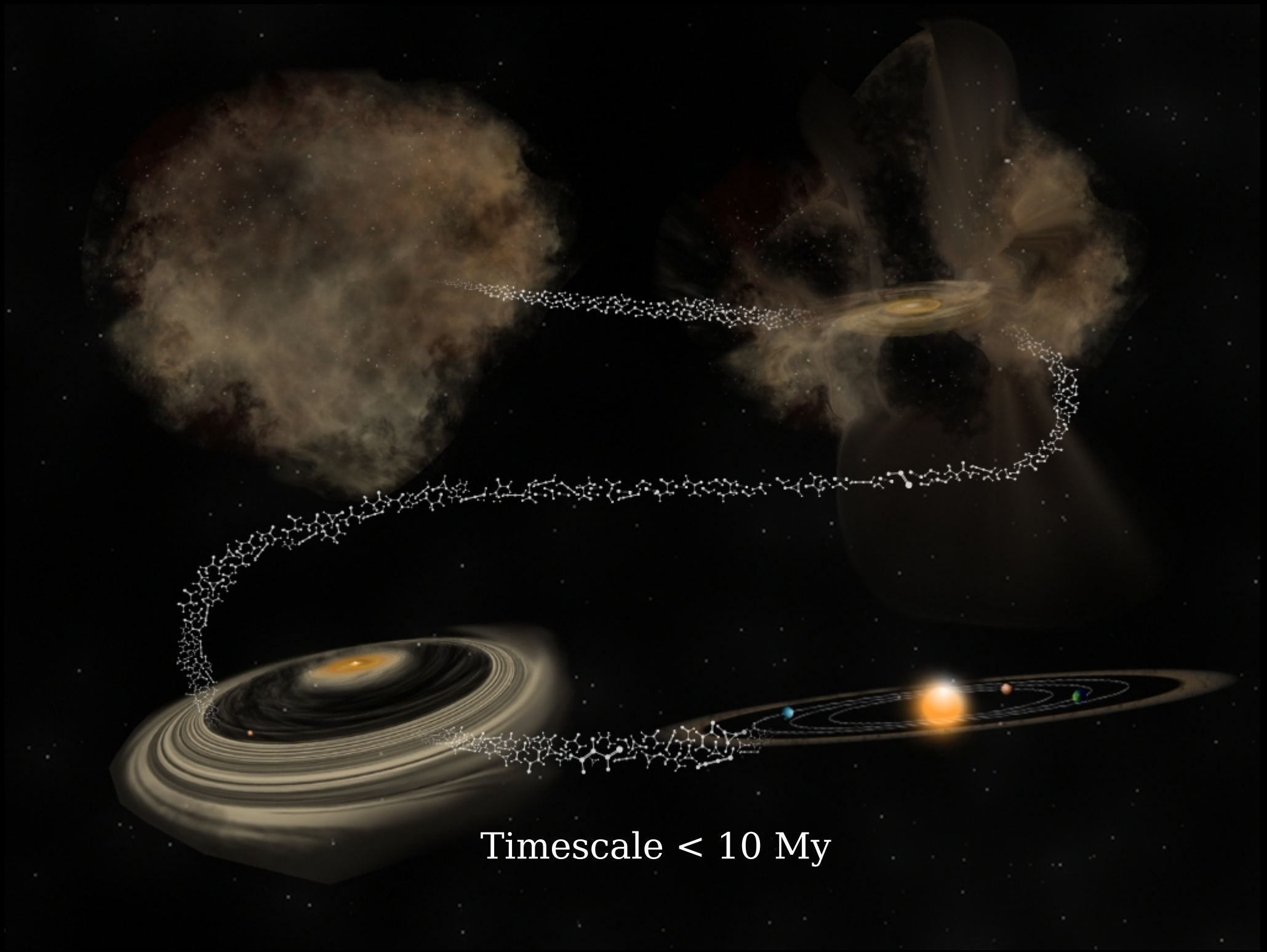


Exploring Our Solar System: Planets, Moons, and Small Rocky Bodies

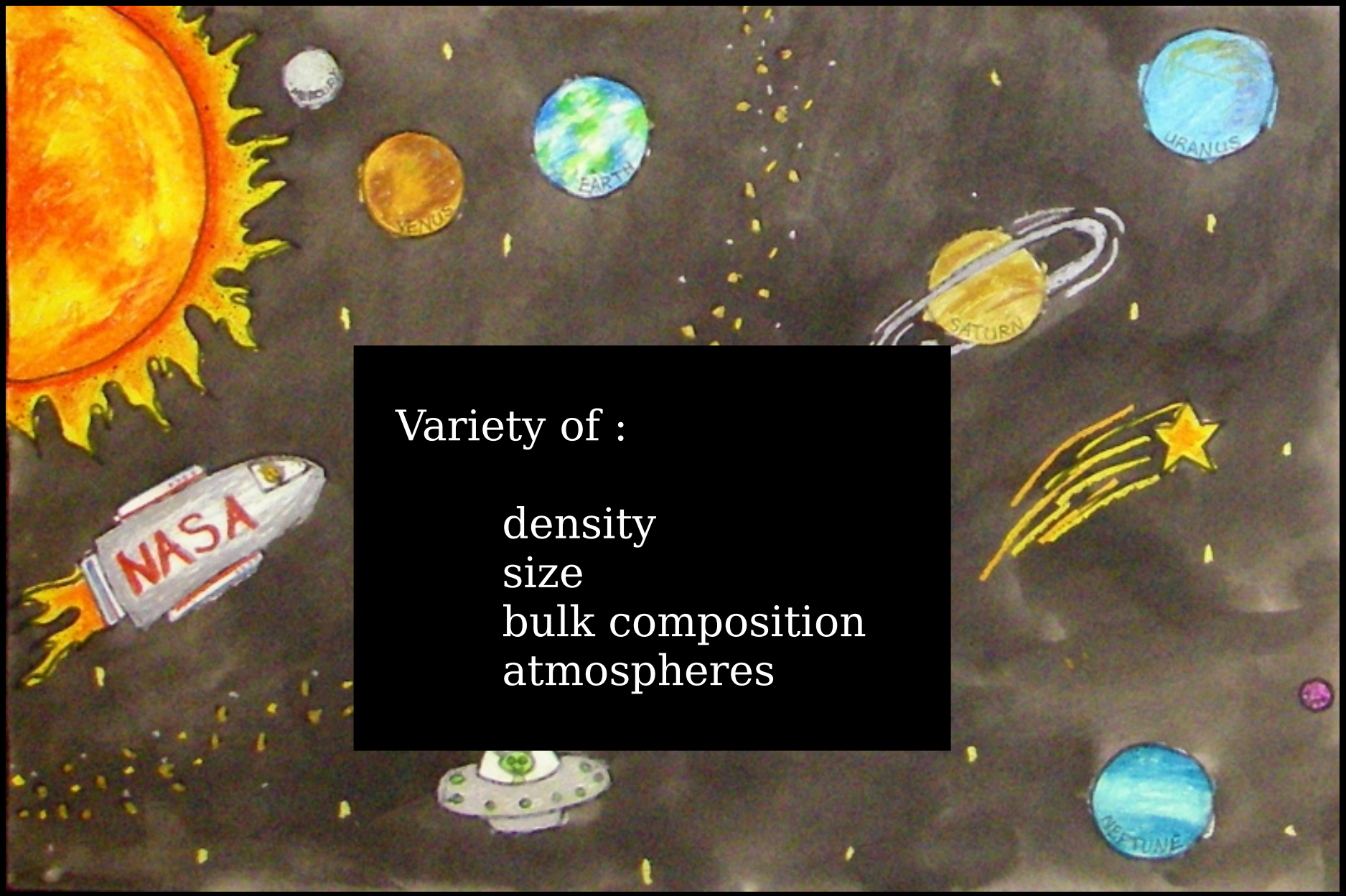
Arielle Moullet, NRAO

AAAS 2014 Meeting, Chicago


Timescale < 10 My

<u>* NOT TO SCALE</u>

http://mrsbrownart.com/



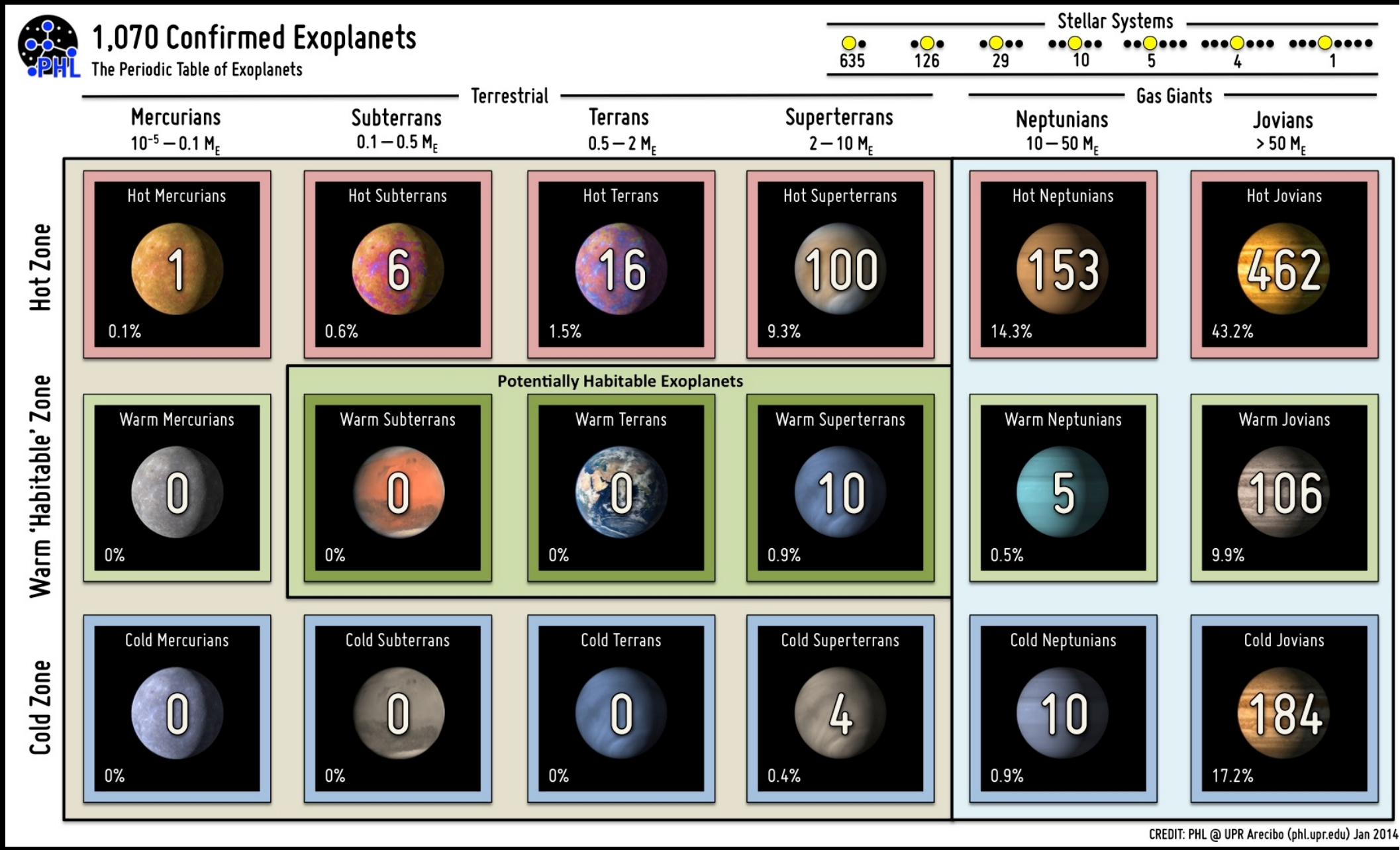
Variety of :

- density
- size
- bulk composition
- atmospheres

<u>* NOT TO SCALE</u>

http://mrsbrownart.com/

The Periodic Table of ExoPlanets



(PHL @ UPR Arecibo)

Solar system studies inform on:

- **<u>Protoplanetary physical and chemical conditions</u>**:
  Comets, Kuiper Belt Objects and chondrites,
  isotopic ratios, bulk densities

- **<u>Dynamics of late planetary system formation</u>**
  migration, mixing

- **<u>Planetary processes</u>**:
  seasonal cycles, gas escape, surface alteration, volcanism, …

- **<u>Evolution of individual bodies</u>**:
  climate, water content, organic chemistry

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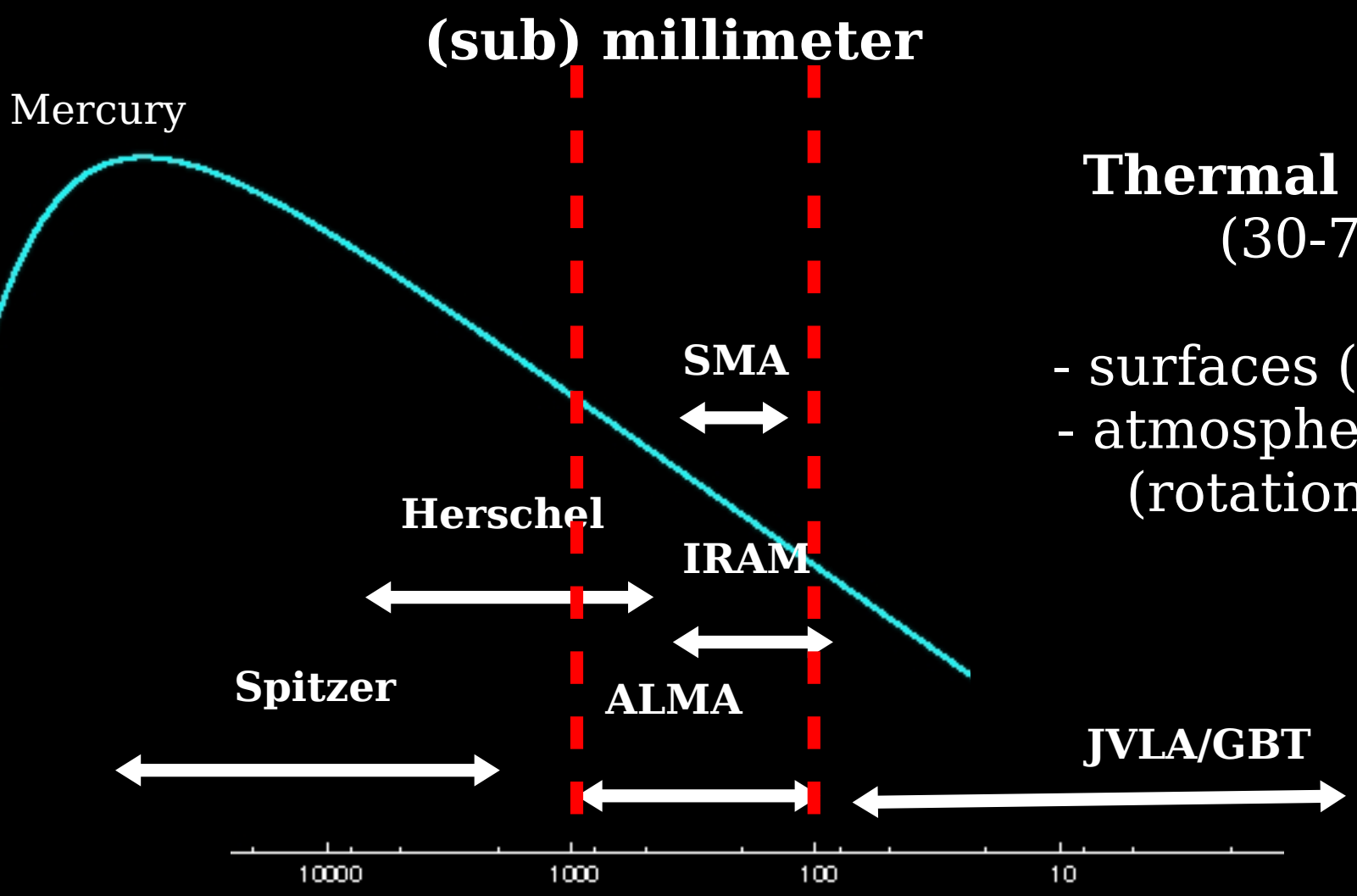
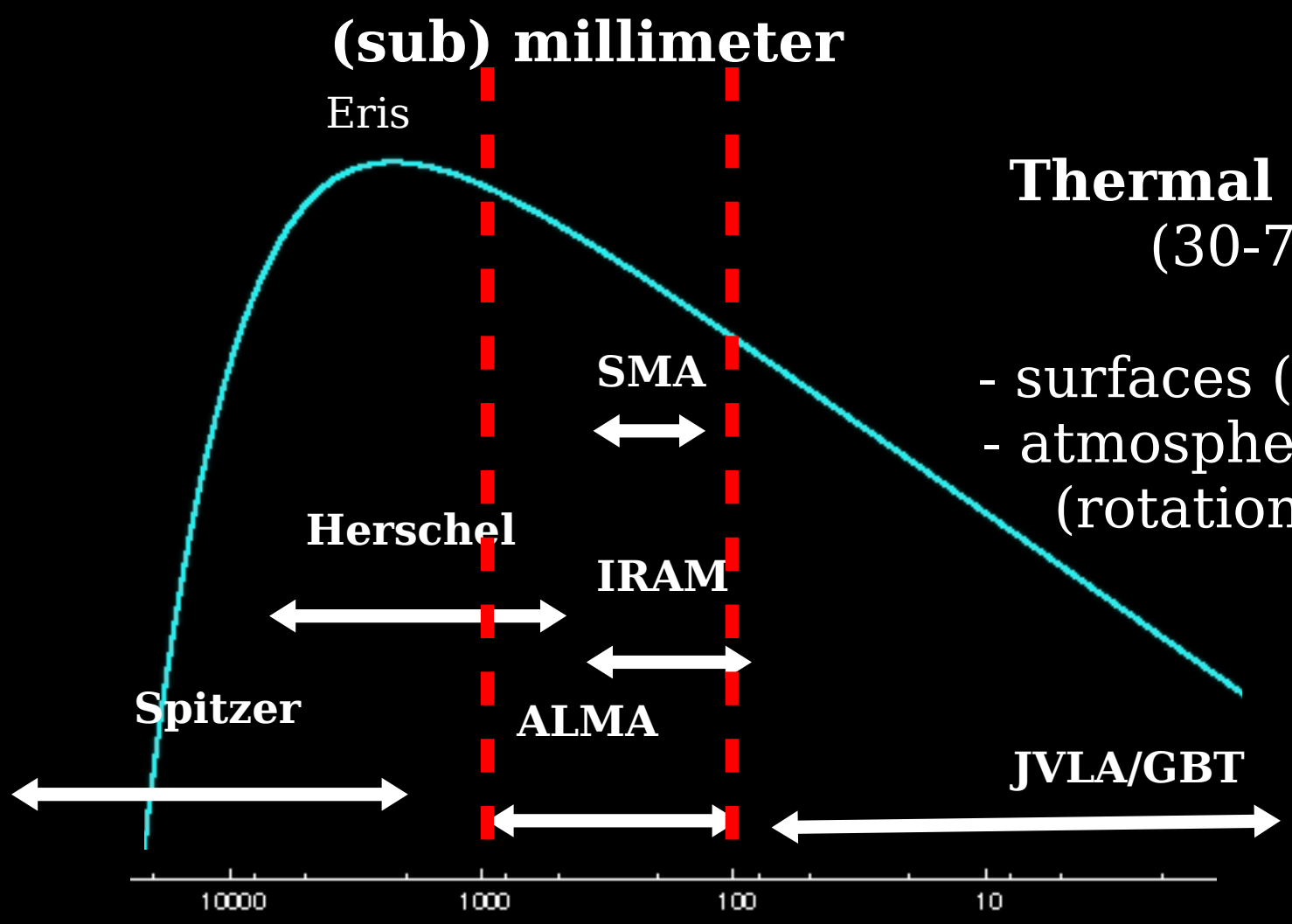
Solar System submm/cm radiation



Thermal emission
(30-700K)

- surfaces (continuum)
- atmospheres
  (rotational lines)

Solar System submm/cm radiation



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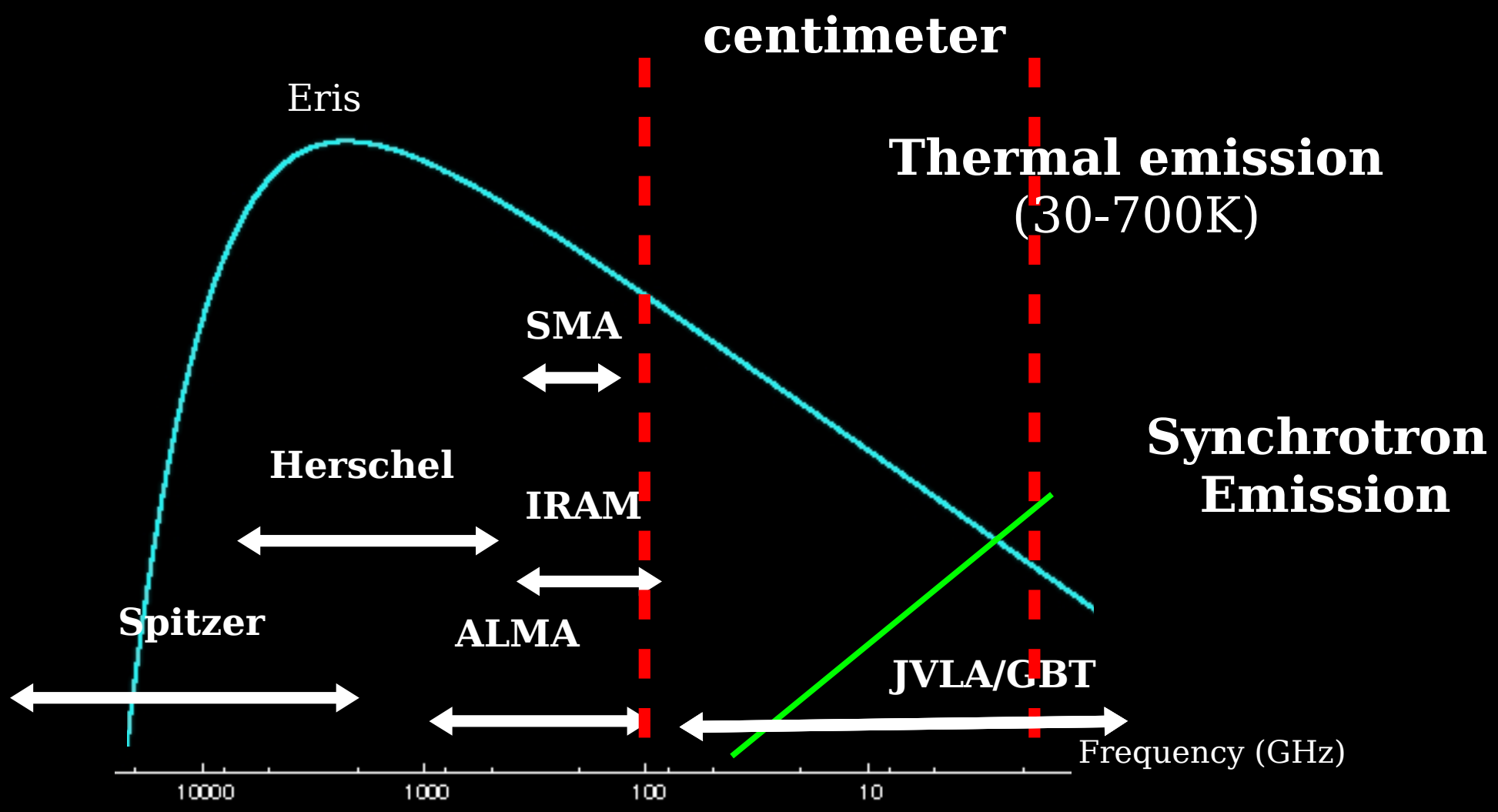
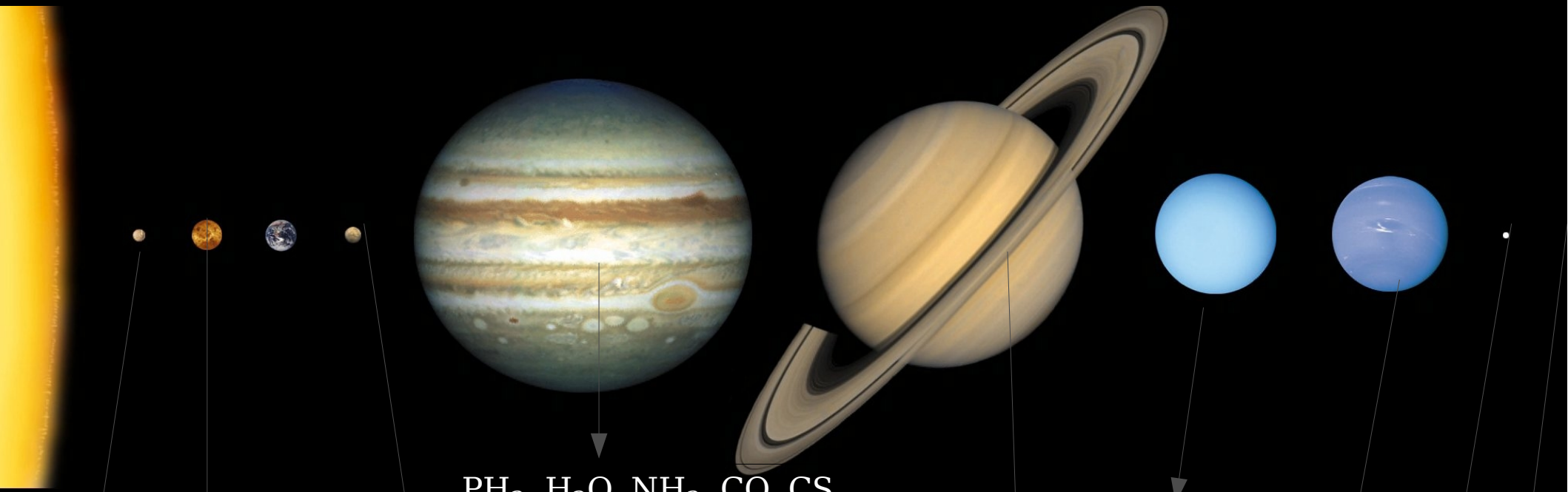


A wealth of ground-breaking results ...



Mapping CO,
Detection SO_2,
H_2O, HDO, SO
Mesospheric
dynamics

PH_3, H_2O, NH_3, CO, CS
detections, HCN mapping
Synchrotron mapping

<u>Io</u> : mapping SO_2, SO
Detection NaCl, KCl
Winds

Detection H_2O

Detection CO, HCN,
H_2O

Detection of 8 Kuiper
Belt Objects

Brightness
temperature
measurements

Mapping CO
Detection H_2O_2,
H_2O,HDO
Winds

Detection PH_3, CO,H_2O

<u>Titan</u> : Detection HCN,
CO, HC_3N, CH_3CN, H_2O
Winds

Comets
volatile composition

… and of new possibilities opened by ALMA and EVLA

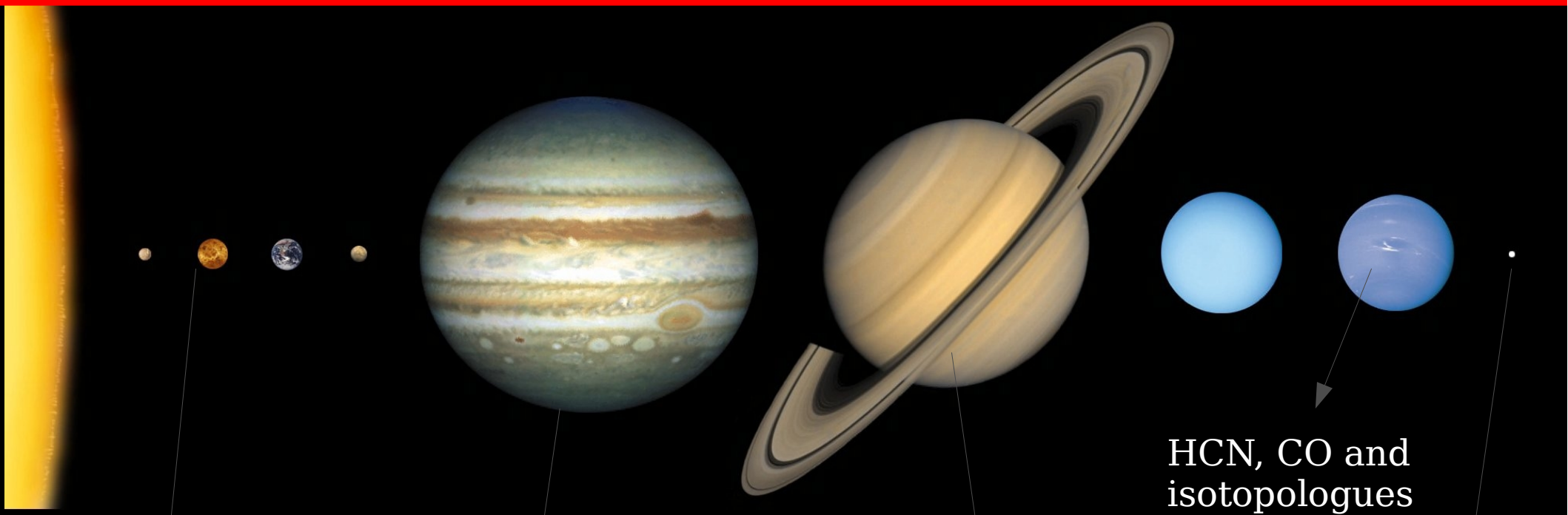
- **Sensitivity increase** : factor 3-40

  minor species detections, tenuous atmospheres, small and distant bodies

- **Spatial resolution**: factor 10-20 (ALMA)

  High-resolution mapping of planets, thermal mapping of large asteroids and KBOs

ALMA projects (Cycle 0/ Cycle 1)



Sulfur and HDO mapping, Chlorine species, winds

Io: chemistry, winds

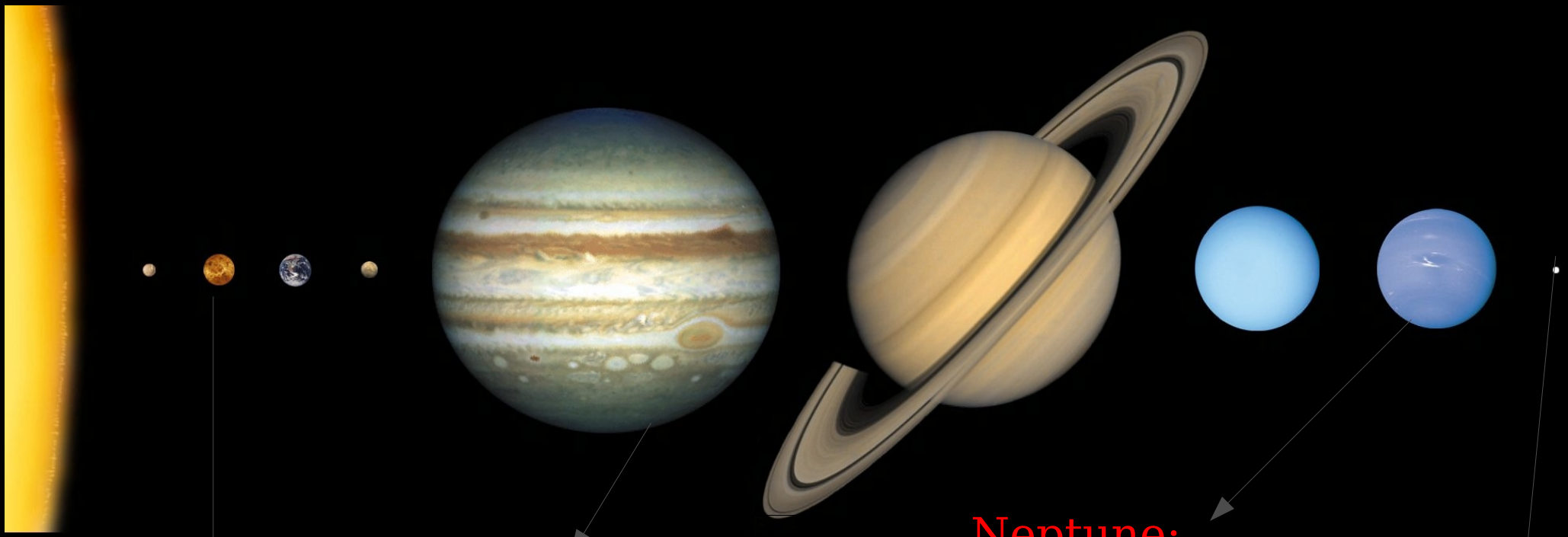
Storm CO and temp. mapping

Titan: nitrile detection and mapping, winds

HCN, CO and isotopologues

Medium-sized KBOs detection

Comets Lemon, ISON



Venus:

Mapping HDO

Io:

Mapping SO_2 and volcanic species

Neptune:

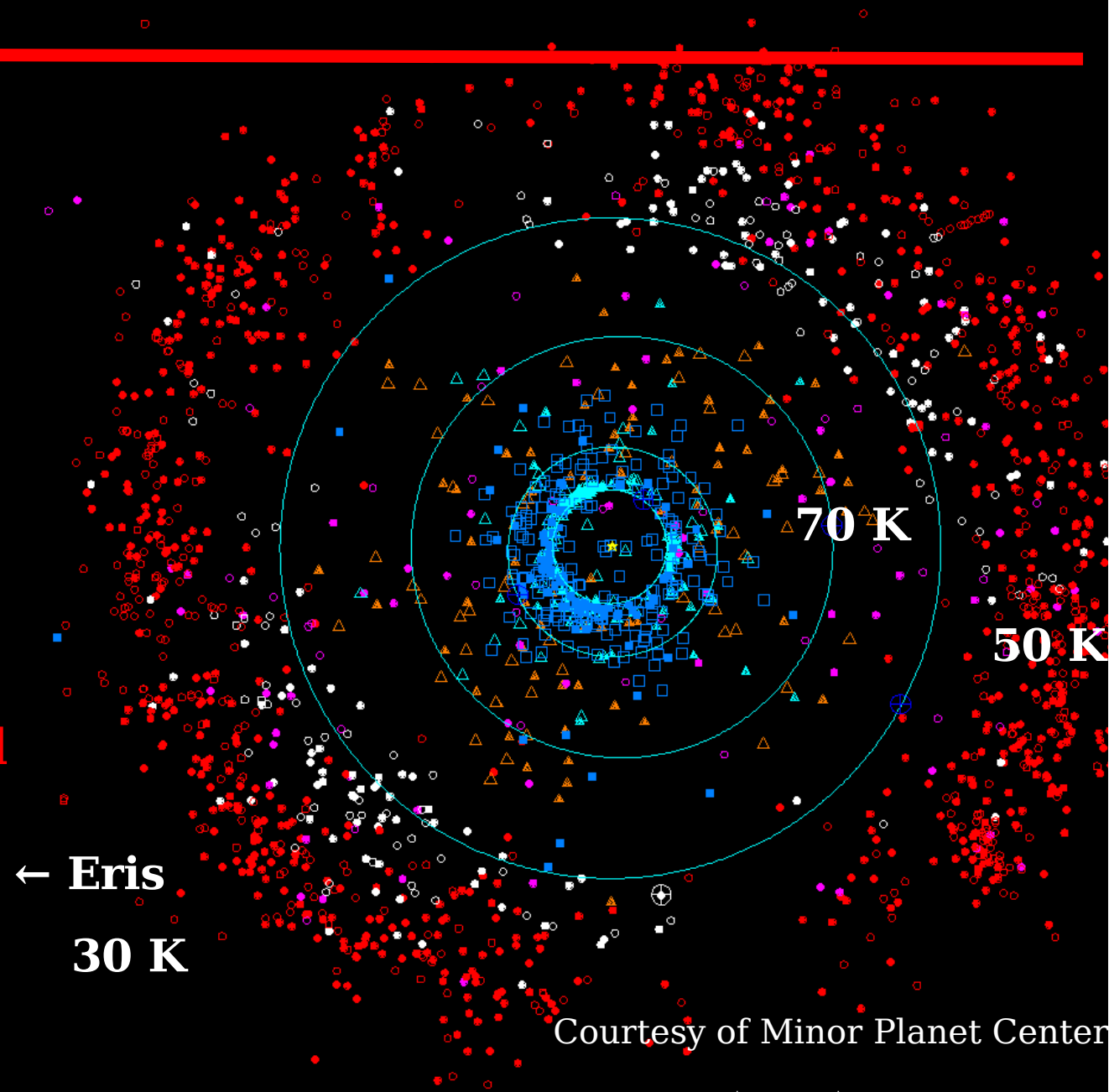
mapping disequlibrium species

Kuiper Belt Objects

Size and surface properties

The Kuiper Belt : A debris disk analog in our system

- >1500 'planetesimals' (30-3000 km)
- **Ice/rock** surfaces
- **Most pristine material** in the Solar System



Courtesy of Minor Planet Center

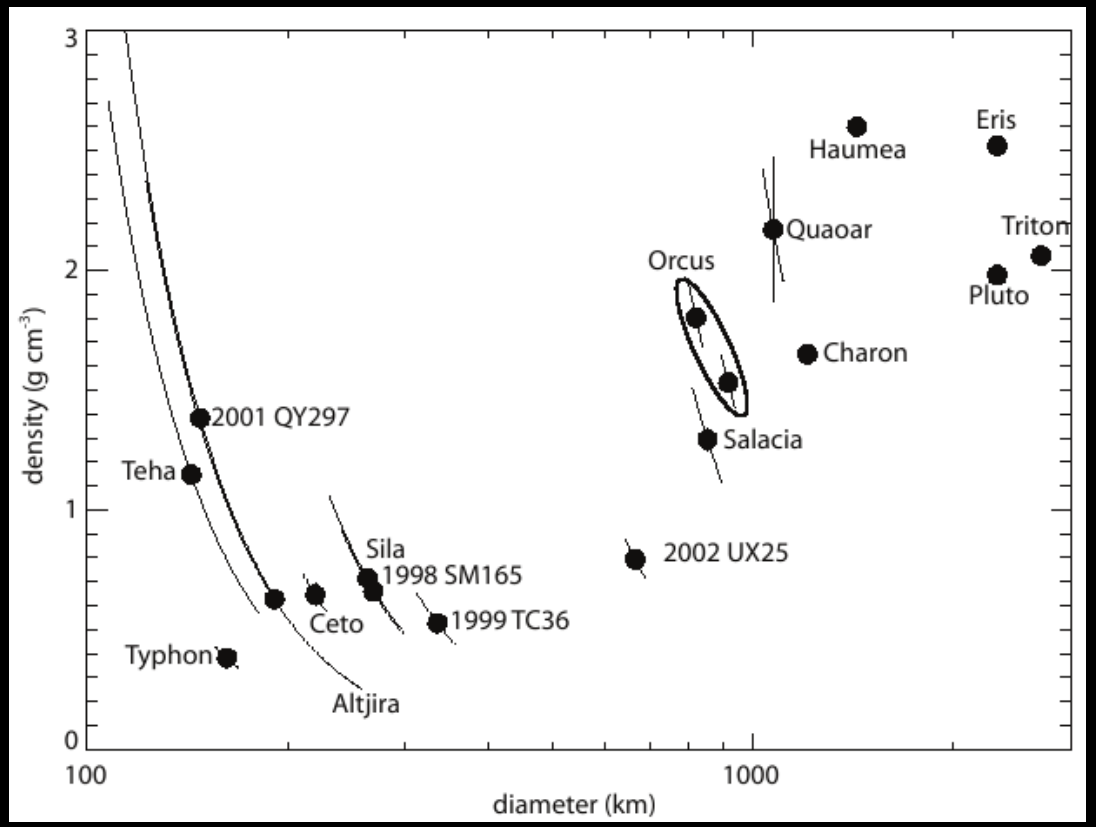
Size measurements

- Size distribution:

  collisional grinding and accretion processes in a planetesimal belt

- Density (ice to rock ratio):

  composition of the **protoplanetary disk**



Densities and diameters in the Kuiper Belt, Brown 2013

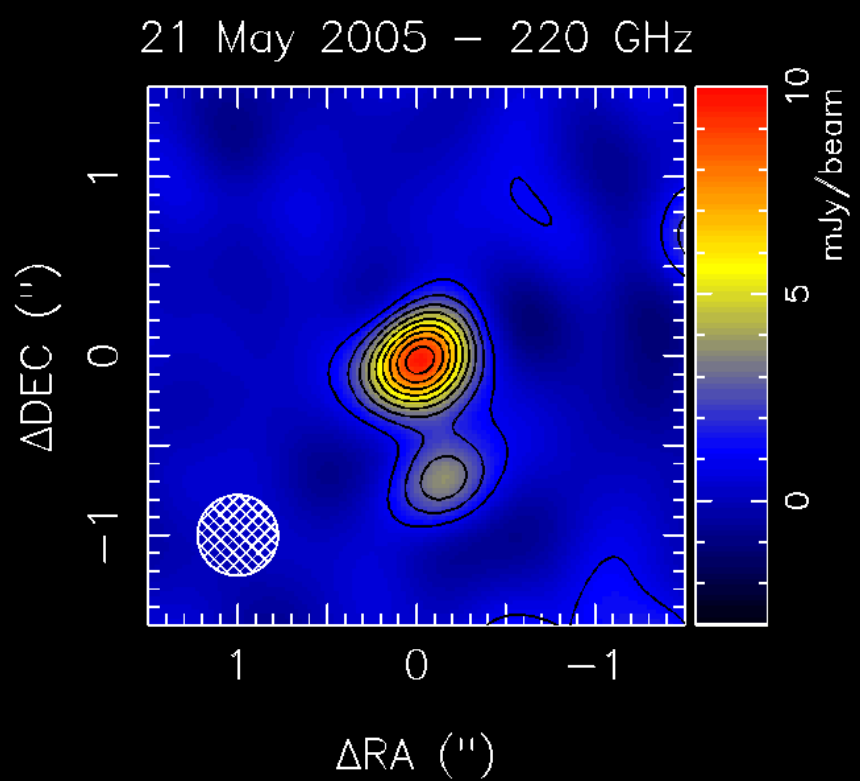
Multiple system imaging

Independent size /reflectance (albedo) constrain **multiple system formation:**

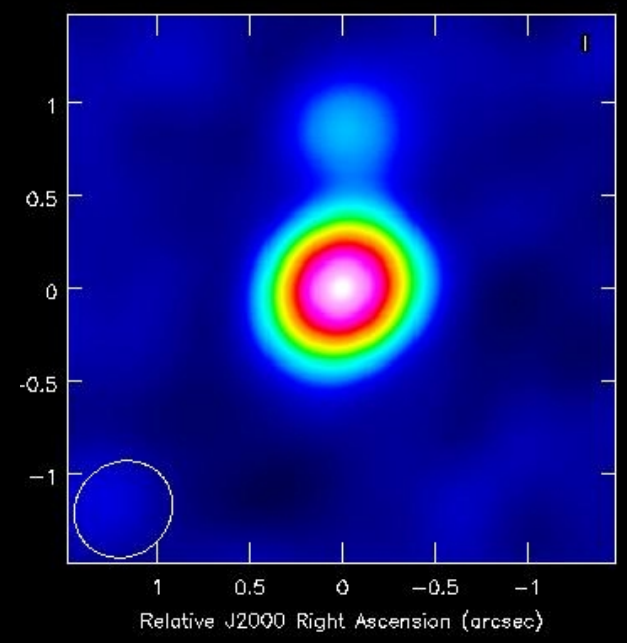
- planetesimals capture

- collision rate

Pluto/Charon system, SMA, Gurwell et al., 2005



Simulation *Haumea system, ALMA Band 7*



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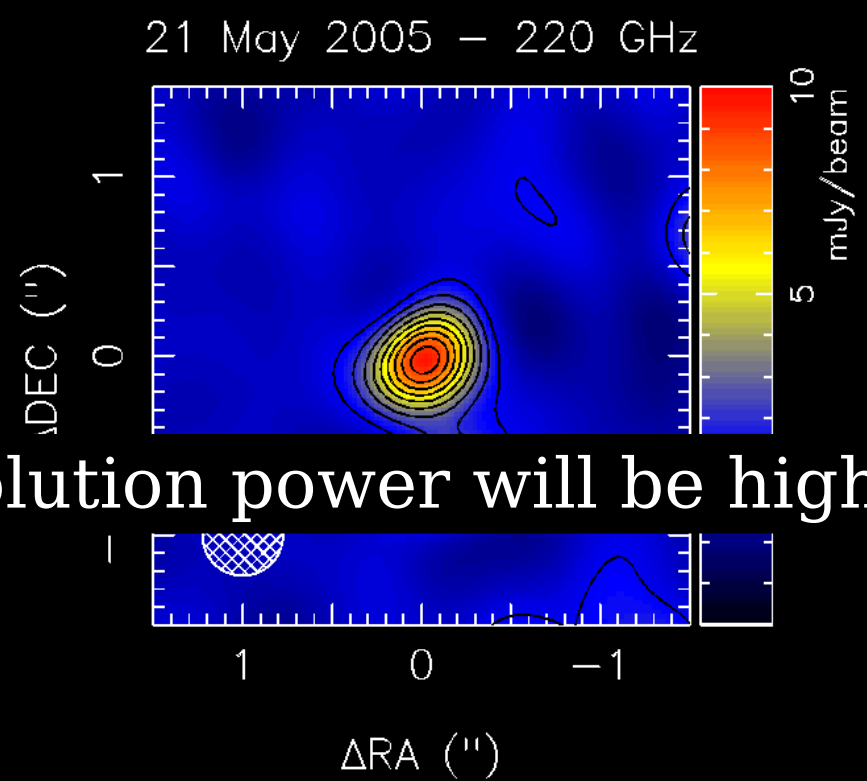
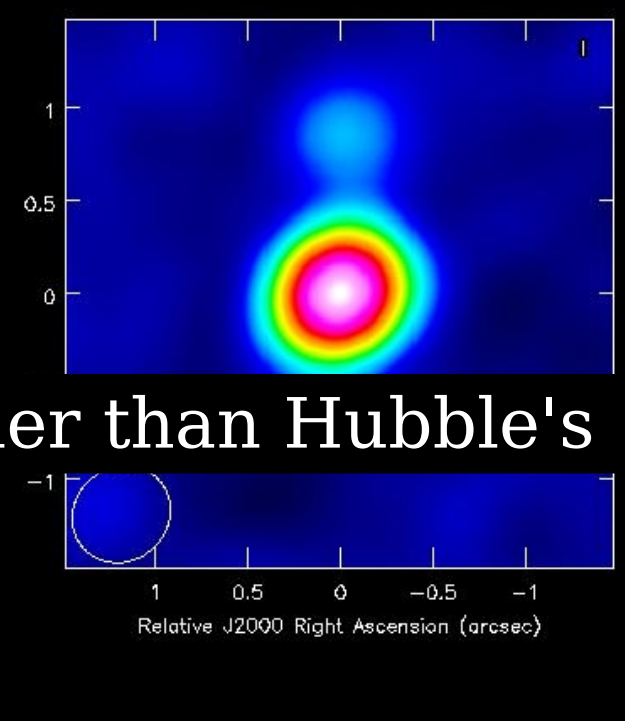
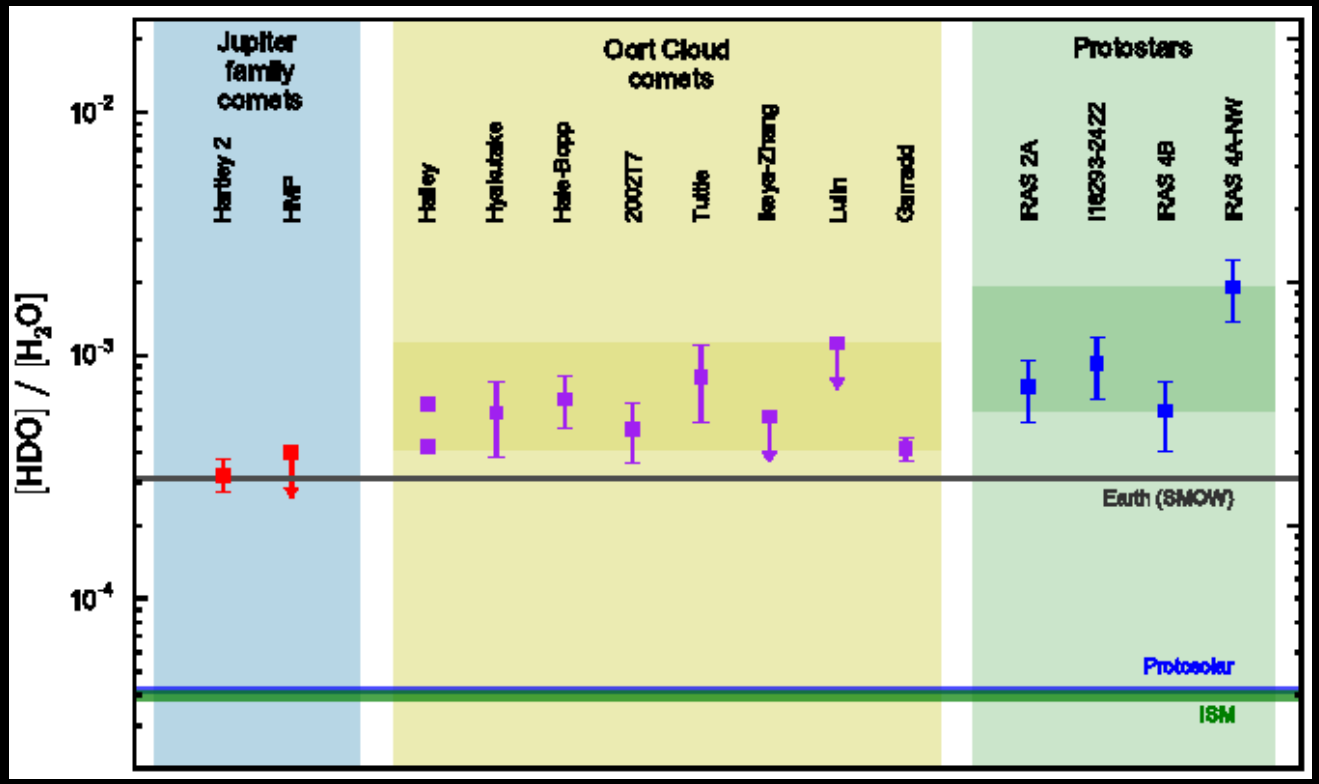




ALMA resolution power will be higher than Hubble's

Atmospheric composition: Internal end external sources

Water tracers (HDO, $H_2{}^{18}O$) and disequilibrium species:
indications of past and active sources



D/H ratio:

- retracing water origin/

- **chemical mixing**

Persson et al., 2013

Venus: water above clouds

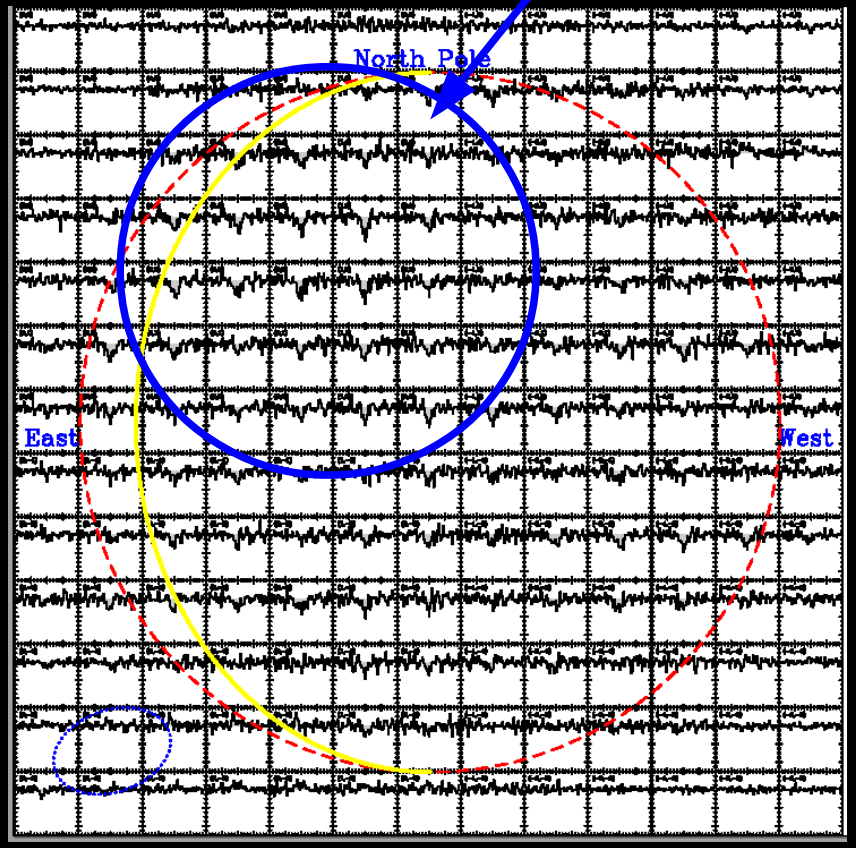
335.395 GHz HDO line map,
ALMA (PI. T. Encrenaz)

Ultimate source of water
volcanic or cometary

Water vapor product of
cloud evaporation:

$$H_2O + SO_3 \leftrightarrow H_2SO_4$$

Large temporal and spatial
variations detected with ALMA



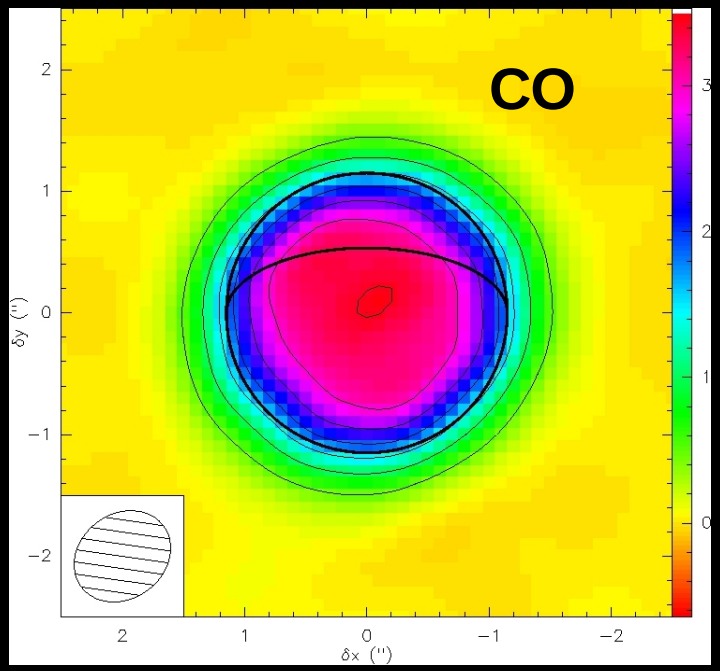
Neptune stratosphere

CO and HCN lines indicate abundance increase w altitude:

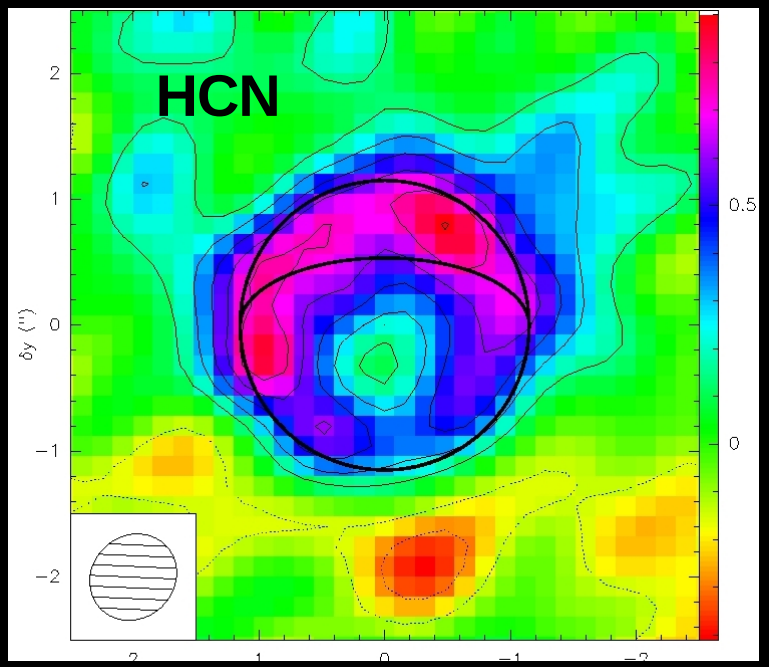
→ (partial) external origin

Mapping supports:

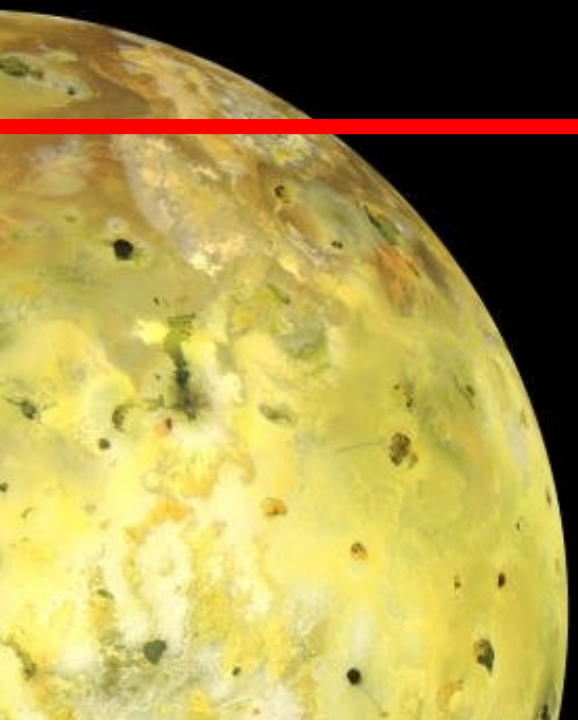
- continuous (non-equatorial) or ancient supply
- specific HCN destruction mechanism



Stratospheric lines mapping, SMA
Moullet et al., 2012



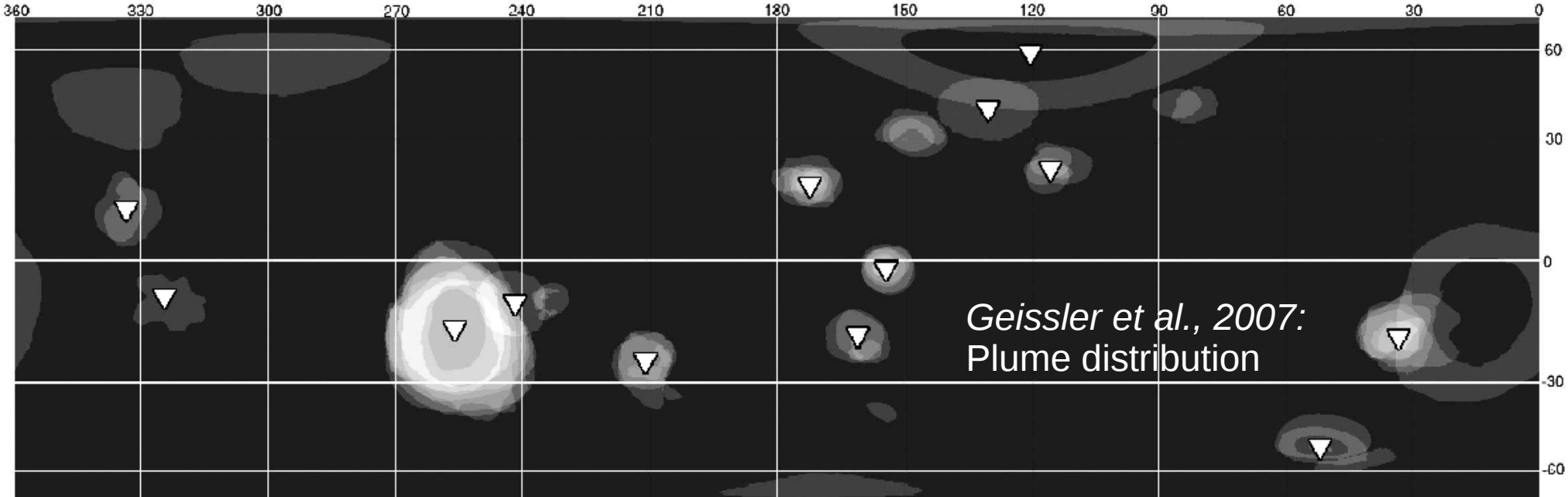
Characterizing unique worlds: Io, the volcanic moon



Strongest **volcanic activity** in solar system

SO_2 frost-covered surface

SO_2 atmosphere, tenuous (1-10nbar)

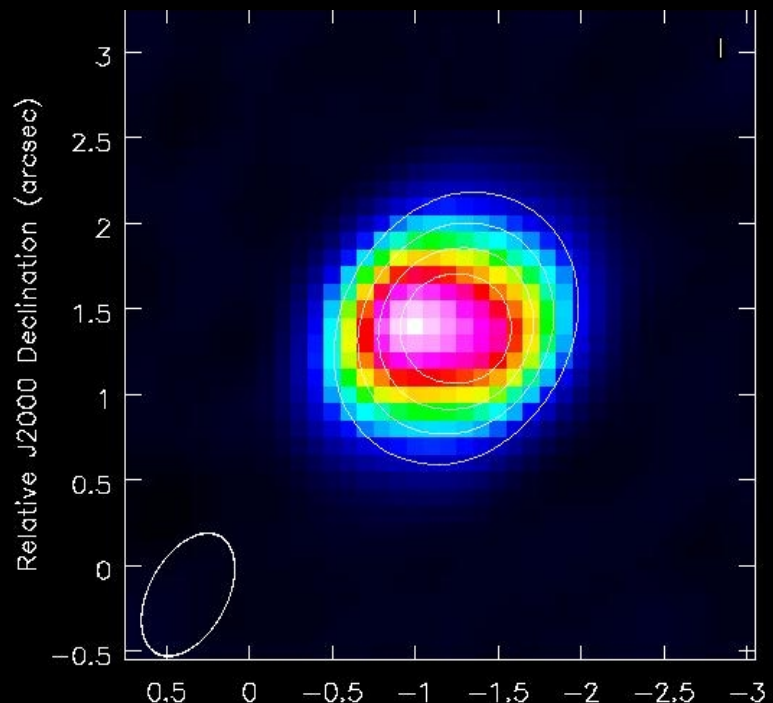


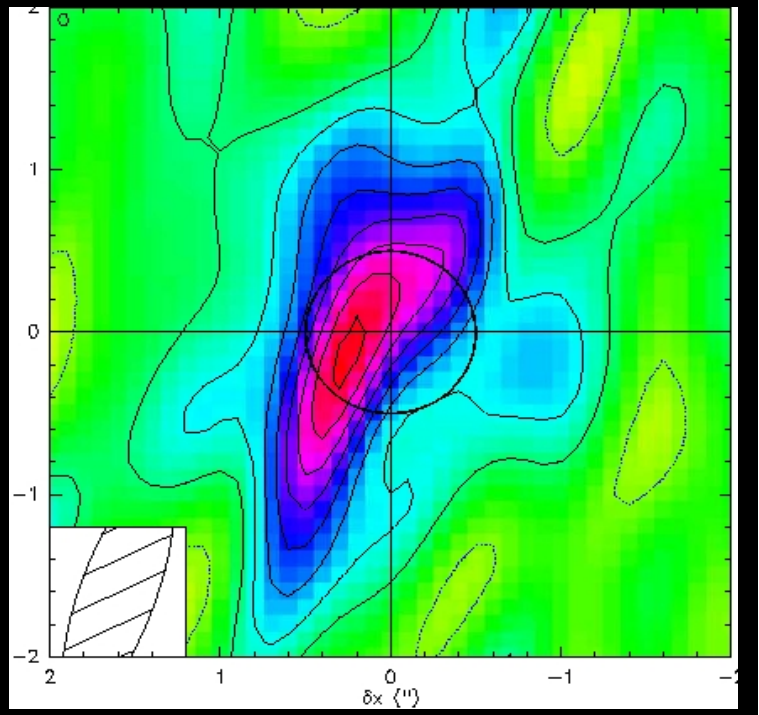
A sublimation-sustained SO_2 bulk atmosphere

Atmosphere beyond volcanic regions

Distribution consistent with frost maps

Steep latitudinal cutoff





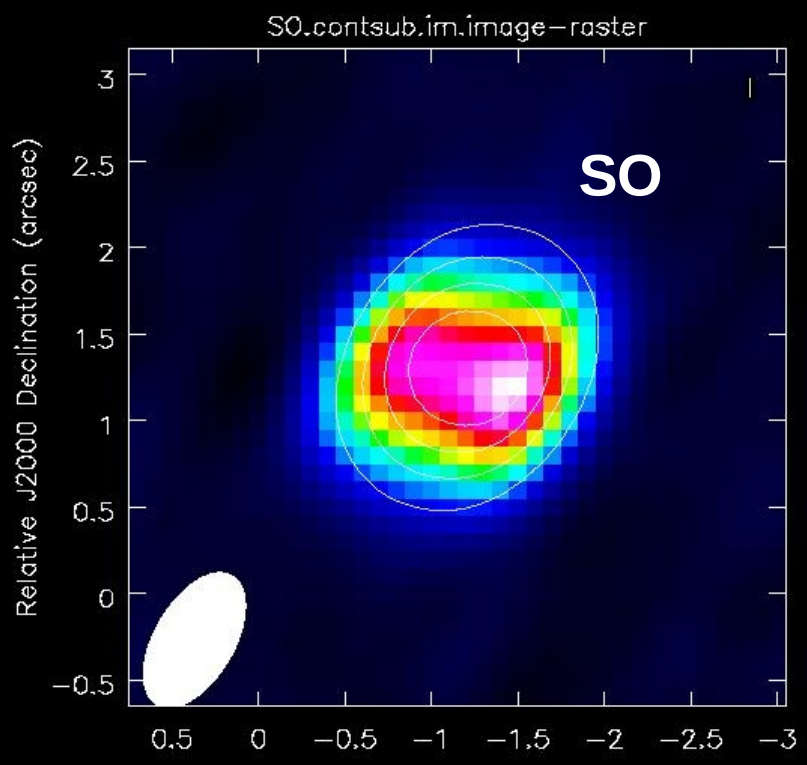
SO_2 integrated emission, IRAM-PdBI, Moullet et al., 2008

SO_2 integrated emission, ALMA, Moullet 2013

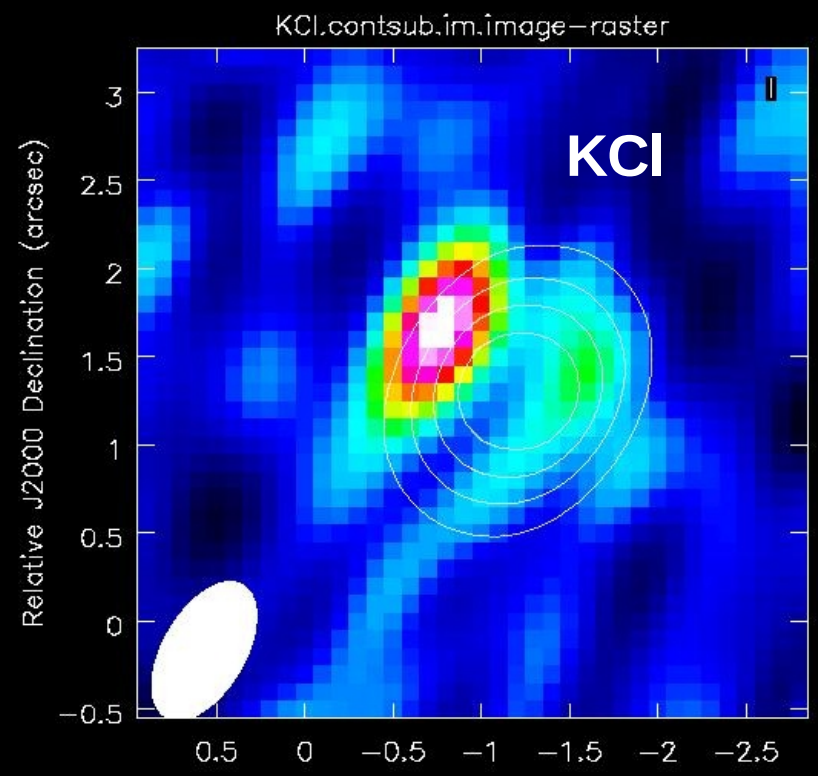
Identifying the volcanic contribution

Volcanic species (KCl, SO) trace **location of active volcanoes**

Different locations suggest different plume compositions

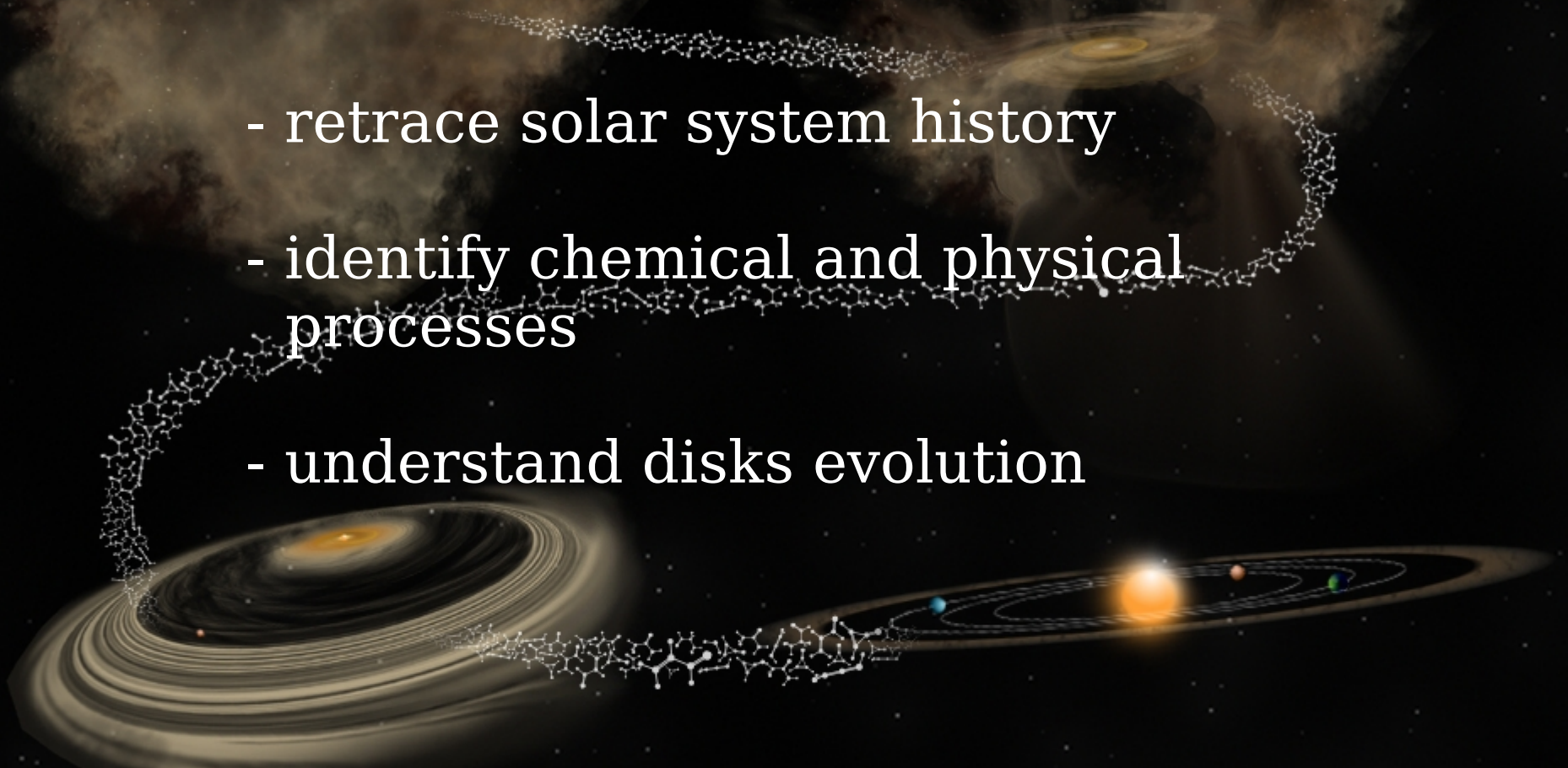


Atmospheric emission, ALMA, Moullet et al., 2013



Characterizing the properties of solar system bodies to:

- retrace solar system history
- identify chemical and physical processes
- understand disks evolution



The contribution of ALMA and EVLA is unique and essential!