News and Reminders

Homework 6 - due now

End of semester proposal due dates:

- Proposal due: today
- Proposal review: Wednesday, Dec. 4
- Proposal review write-ups: Monday, Dec. 9

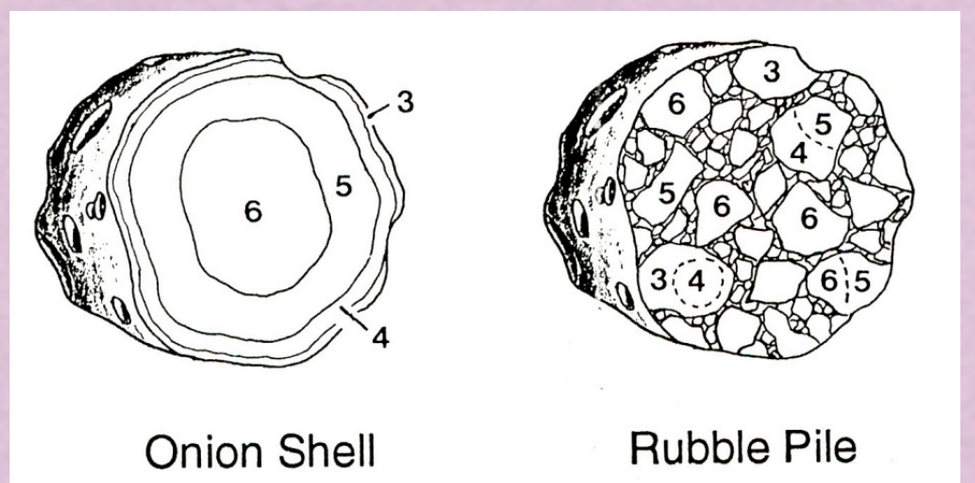
Bonus topics: magnetic fields and, time-permitting, life.

Please complete the **course evaluations**

Answers to Some of Your Questions

Question: at what mass does a body go from rubble-pile to differentiated?

Rubble pile asteroids are formed when an onion shell asteroid is shattered through a collision. If its size is in the 100's meters to kilometers range, it will re-accrete as a rubble pile asteroid.



Question: what is the timescale for the gas accretion part of giant planet formation?

0.2 - 1 Myr (depends on the orbital distance, surface density and core mass; also model-dependent)

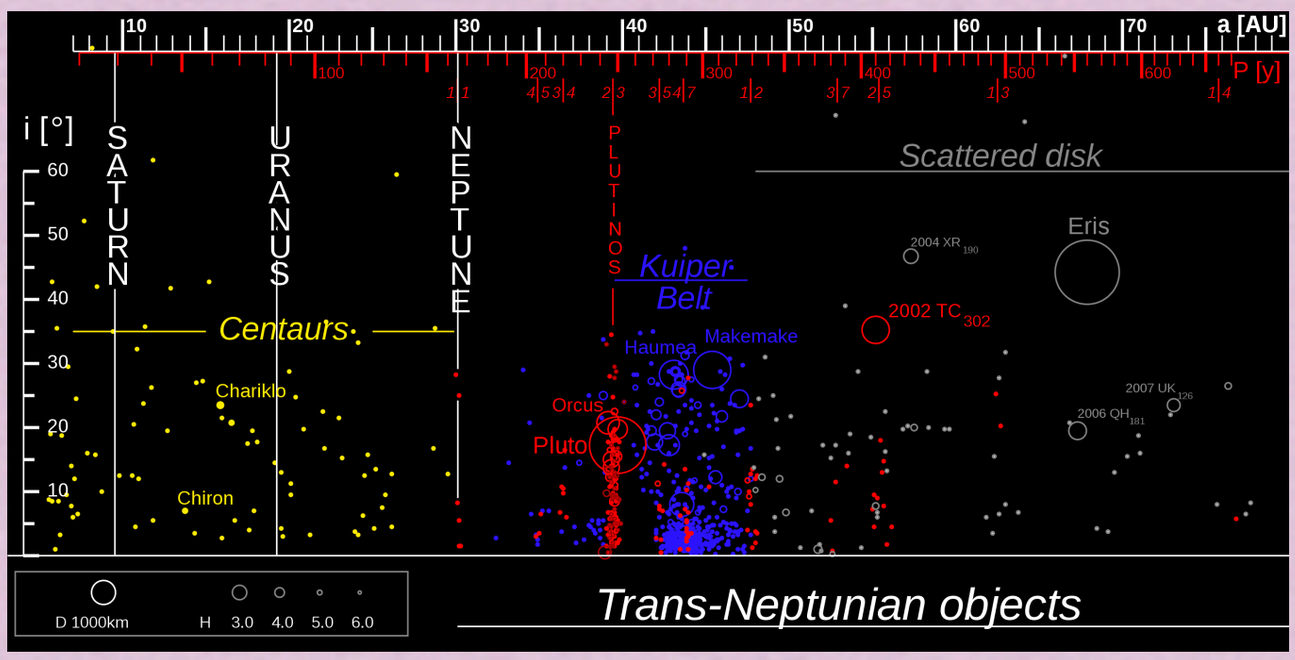
Question: what mass is the *initial* planet formed by disk instability?

Minimum initial mass 0.2 - 2 M_{Jup}

Minor Bodies

- **Main belt:** asteroids either depleted (i.e. 99.9% of original belt is gone) or implanted (by giant planet migration and resonances, and encounters/scattering)
  - asteroids remaining today are too small and spread out to coalesce into an embryo
  - evidence for implantation: Ceres likely comes from Jupiter-Saturn region and Vesta from terrestrial region

- The **Kuiper Belt** "hot" population and **Scattered Disk** objects were scattered by Neptune; the **Kuiper Belt** "cold" population" likely formed where it is today



- Other solids were scattered to what is now the **Oort cloud** (or ejected) by interactions with the giant planets (especially Jupiter)
  - however, it is also possible that much of the Oort cloud (up to ~1/3) could have been captured from free-floating debris or other nearby stellar disks)

Planetary Surfaces

The surfaces of the Solar System terrestrial planets likely assumed their current form after the planets formed and cooled.

Crater counting can be used to date planetary surfaces:

- many craters indicate an older surface
- few or no craters indicate a younger surface

Late Heavy Bombardment hypothesis:

Impact melts in lunar crater rocks indicate an increased impact flux are dated to 3.8 - 4.1 Gyr ago, suggesting a period of heavy cratering occurred a few 100 Myr after the formation of the Solar System.
But the lunar melt and lunar meteorite evidence has recently been found to be shaky, potentially eliminating the need for a LHB.

Moons

Giant Planets satellites:

- regular satellites have low-e prograde orbits in the equatorial plane of the planet — likely formed in a disk around the planet (made from outer portions of planet's envelope and/or material captured from the protoplanetary disk)
- irregular satellites are relatively small and have high-e, high inclination orbits outside those of the regular satellites - captured from heliocentric orbits
- Jupiter's moons decrease in density with increasing distance from Jupiter, while no such pattern is seen in Saturn's and the ice giants' moons; this is likely because Jupiter was much hotter when it formed, giving rise to its own temperature gradient within its circumplanetary disk

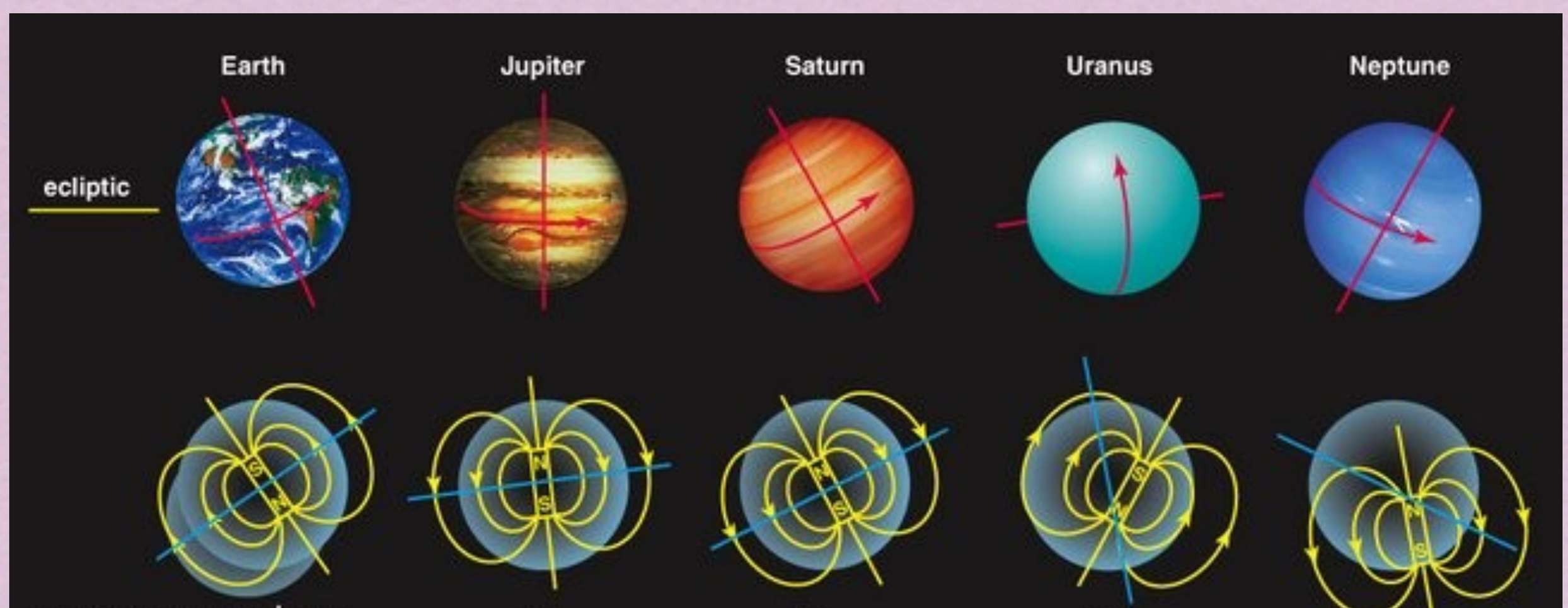
Earth's Moon:

- giant impact when Solar System was 200 Myr old

Mars' moons:

- Phobos and Deimos may have formed in a disk of planetesimals captured by Mars
- alternatively, they could have been captured

Solar System Magnetic Fields



	Earth	Jupiter	Saturn	Uranus	Neptune
Tilt of rotation axis	23°	3°	27°	98°	30°
Tilt of magnetic axis	12°	−10°	−0°	−59°	−47°
Offset of magnetic axis	8%	10%	5%	31%	55%
Field at equator	31,000 nT	428,000 nT	22,000 nT	23,000 nT	13,000 nT
Magnetosphere	10 R_{Earth}	65 $R_{Jupiter}$	20 R_{Saturn}	18 R_{Uranus}	25 $R_{Neptune}$

Detecting and Measuring Magnetic Fields

Solar System:

- Magnetometers on spacecraft (usually more sensitive and sophisticated than a compass)
- Radio emission
    - low-frequency emission (including aurorae, lightning and cyclotron maser emission)
    - synchrotron emission (higher-frequency)

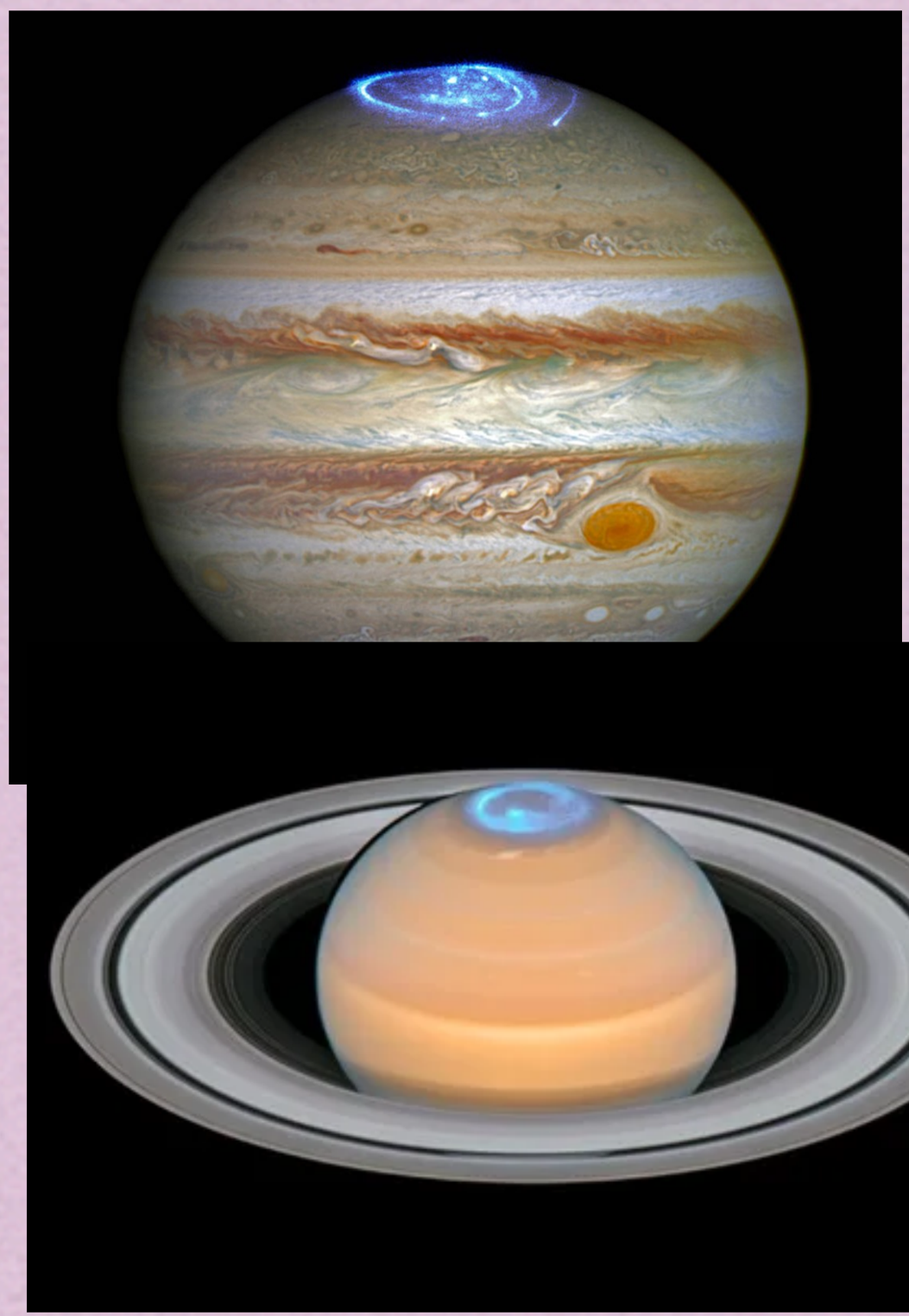
Detecting Magnetic Fields on Exoplanets

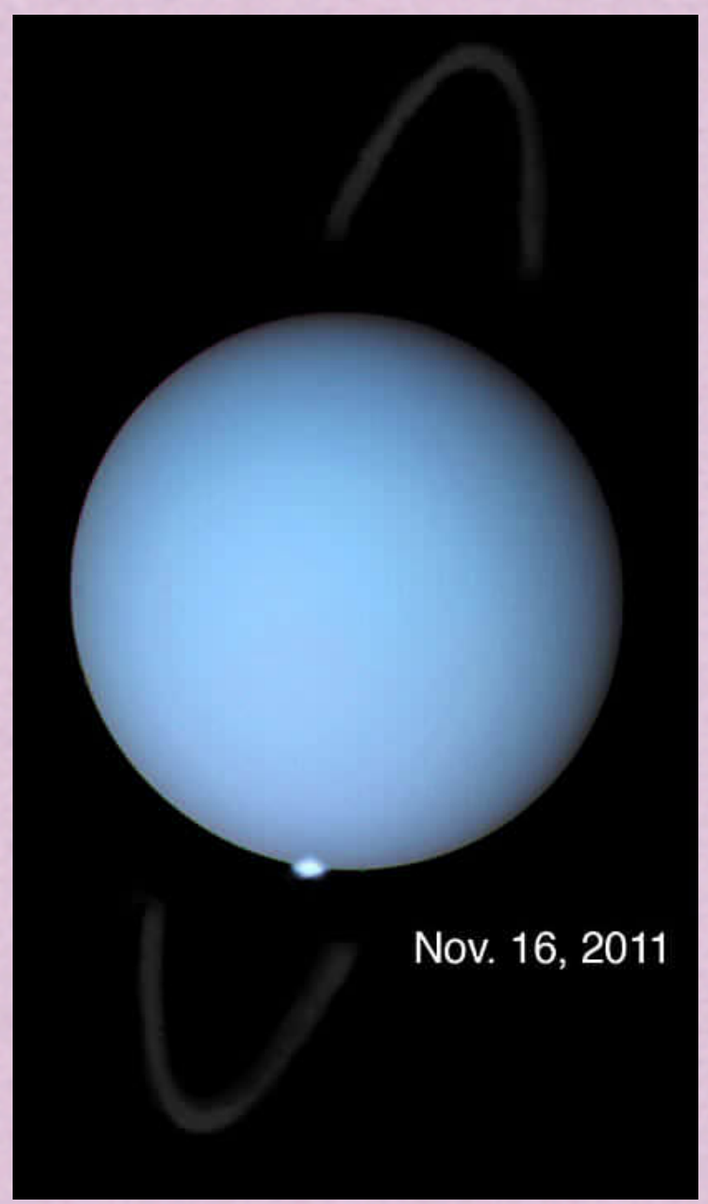
Table 2. Summary of exoplanet magnetic field measurement methods.

Method	Planet type	Information
Direct		
Exoplanet aurorae	all	local strength
He 1083 nm spectropolarimetry	transiting hot Jupiter	l.o.s. averaged strength
Radiation belt emission	all	dipole magnetic component
Indirect		
Star-planet interactions	close-in	magnetopause size
Ohmic dissipation	transiting hot Jupiter	
Magnetospheric bow shocks	transiting	magnetopause size
Atmospheric outflow transit spectroscopy	transiting close-in	strongly or weakly magnetized

Brain et al. (2024)

Aurorae in the Solar System



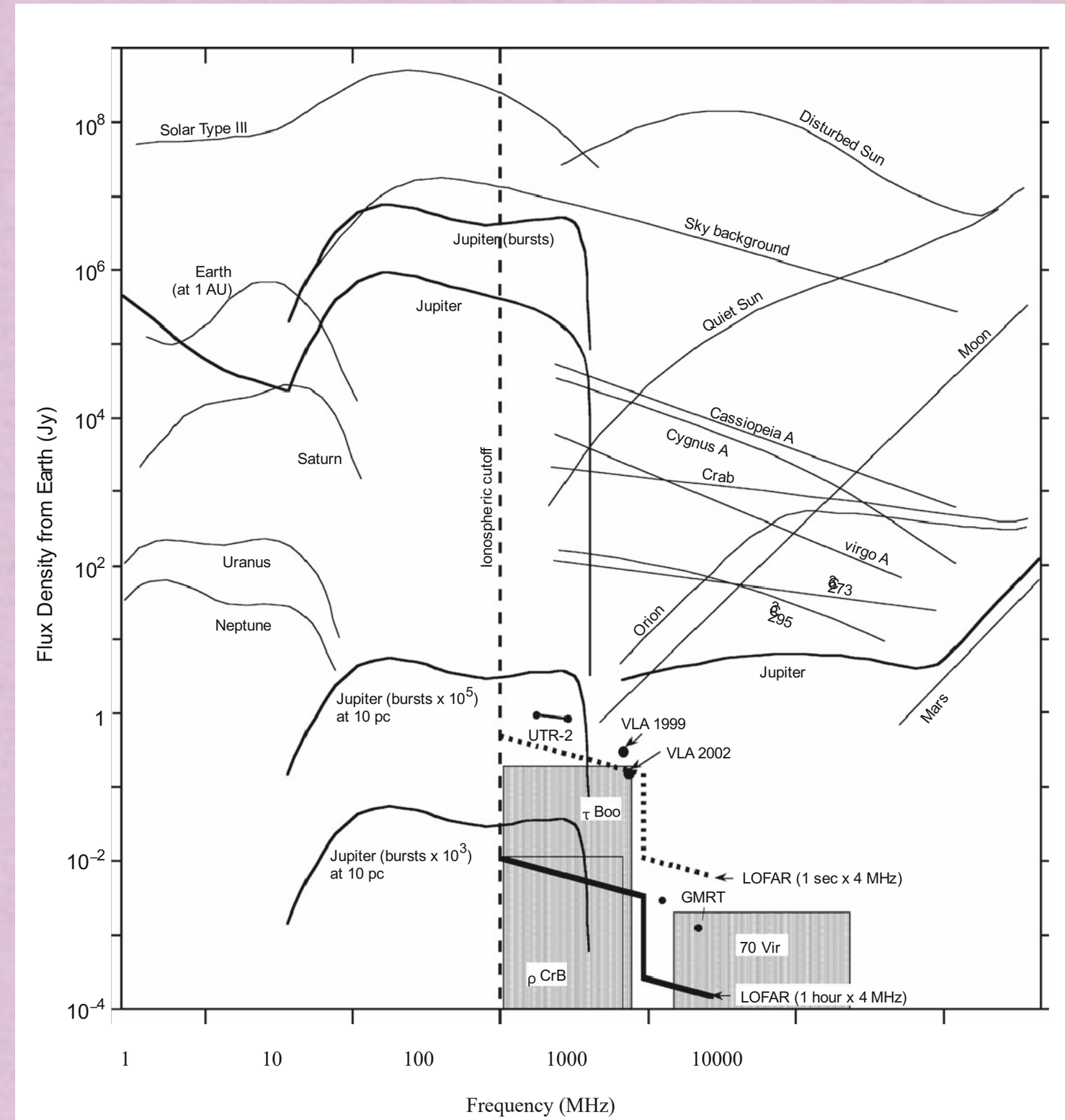


Detecting Magnetic Fields on Exoplanets

Aurorae:

- no detections on exoplanets so far
    - hot Jupiters may suffer from dense, plasma-filled magnetospheres that inhibit electron cyclotron maser emission
- however, detections have been made on brown dwarfs and low-mass M dwarfs

Detecting Magnetic Fields on Exoplanets



Zarka (2007)

Detecting Magnetic Fields on Exoplanets

Radiation Belt Emission (synchrotron emission):

for brown dwarfs, fainter than aurorae by a factor of a few -> could be challenging to detect in exoplanets, even with ngVLA