



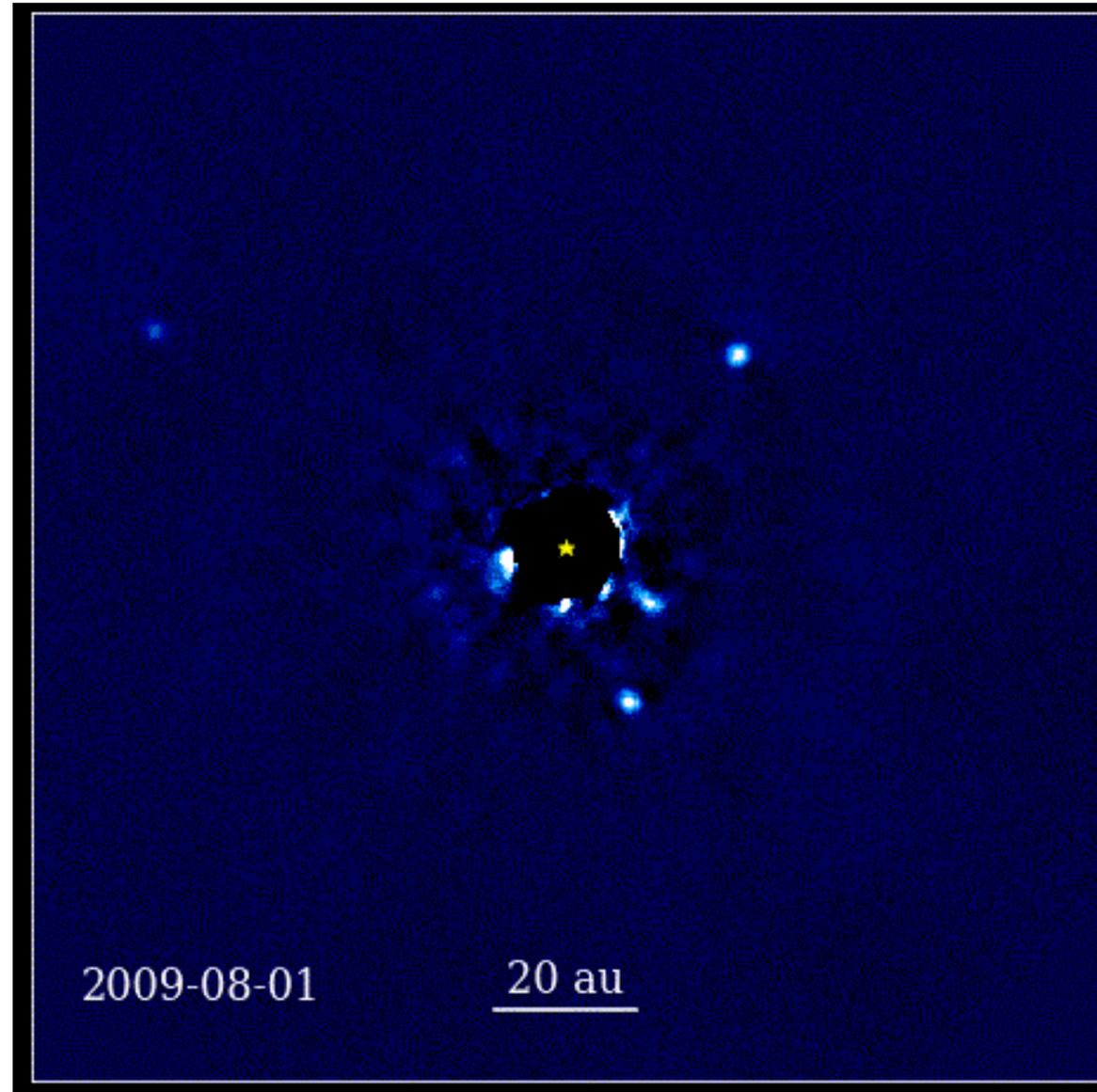
ASTR 620: Planetary Processes
Professor Eric Nielsen

Lecture 1: Logistics
Tour of the Solar System

Logistics

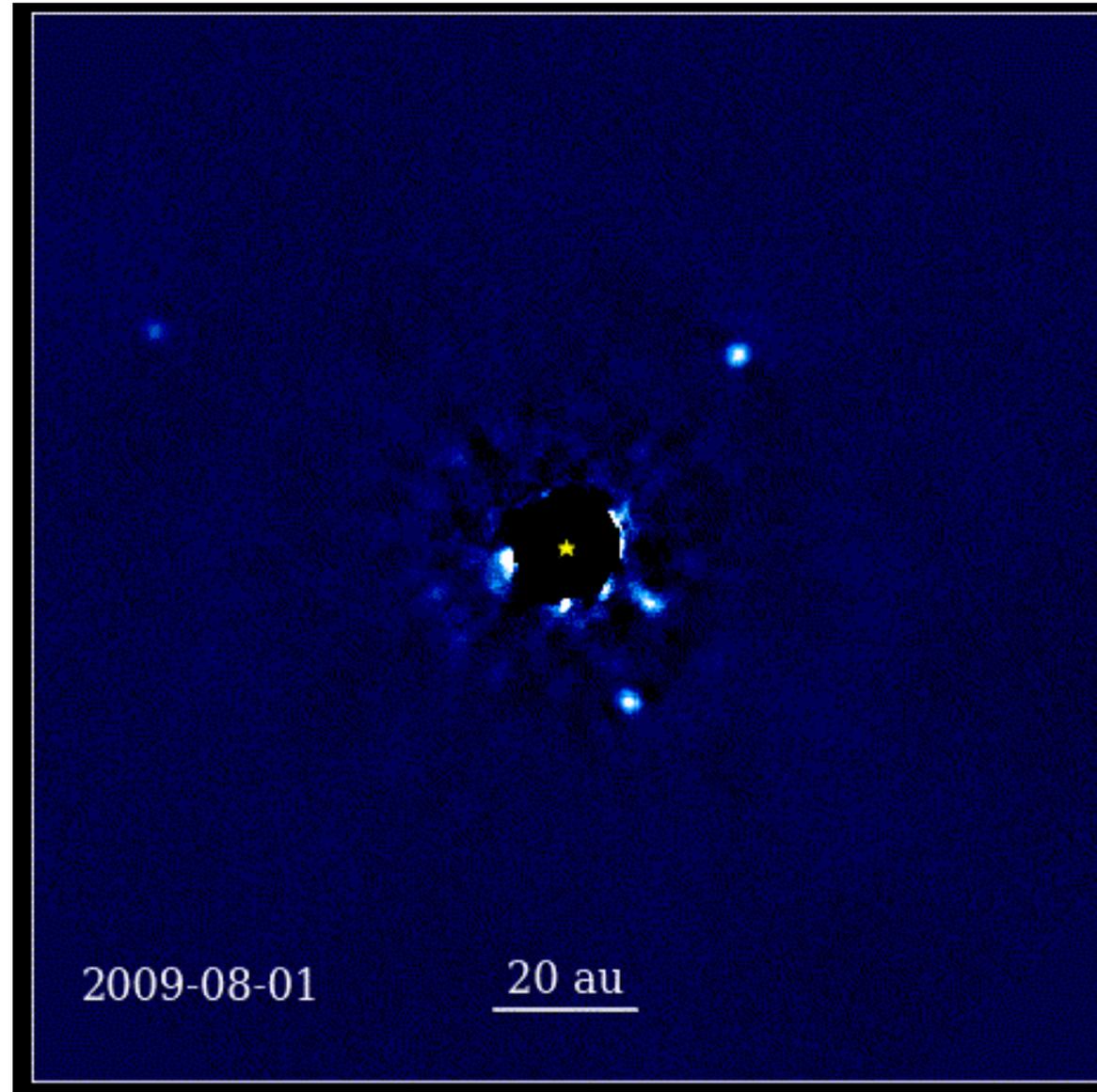
- Masks are encouraged
- No laptops, phones, or other electronic devices during class (I'll let you know in advance if we'll need laptops for an activity)
- Things you should bring to lecture each day:
 - something to take notes on (including extra paper if there's a writing assignment),
 - something to write with
 - your response card (will be handed out later in class)

Me



Movie from Jason Wang and Christian Marois

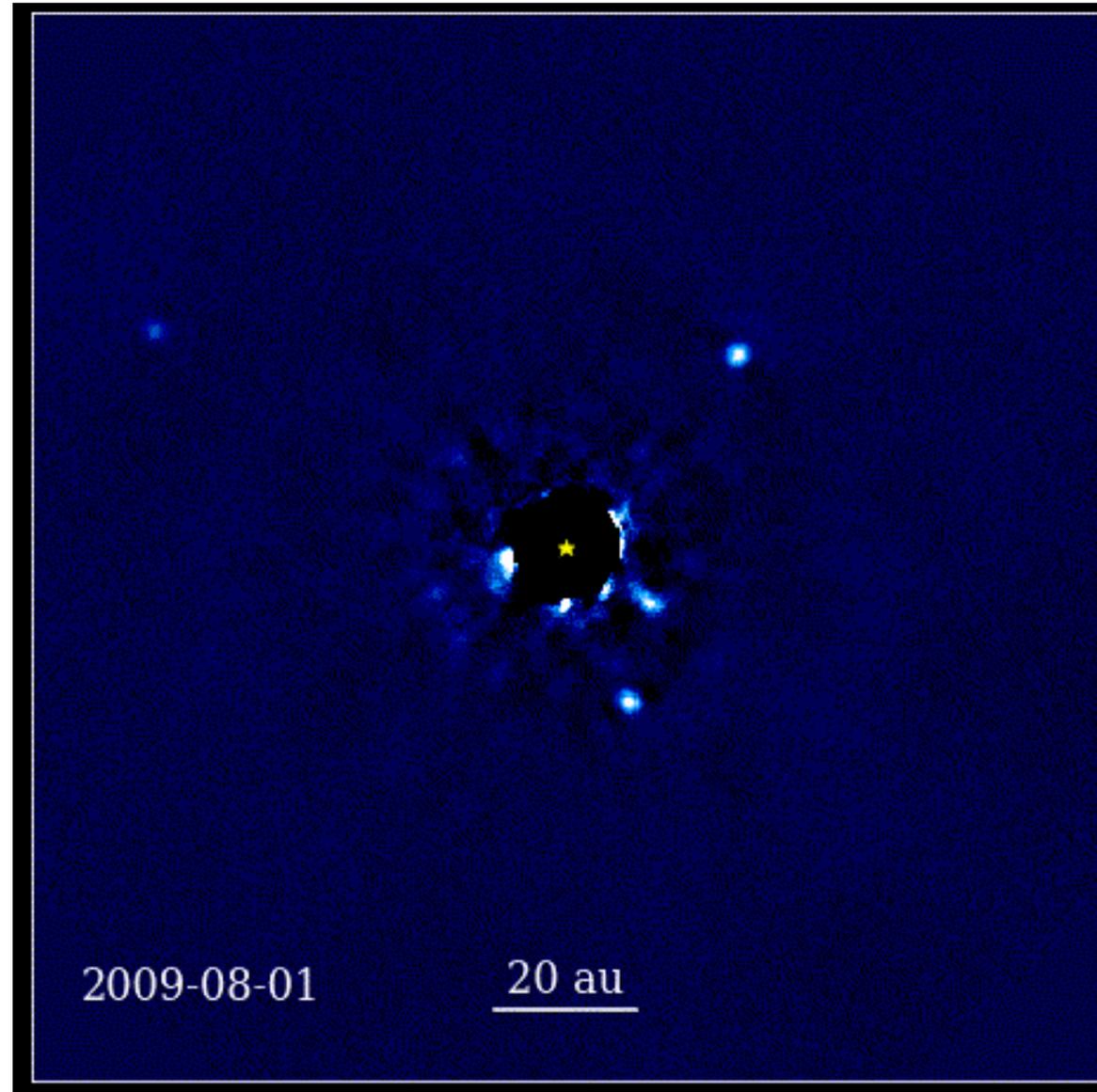
Me



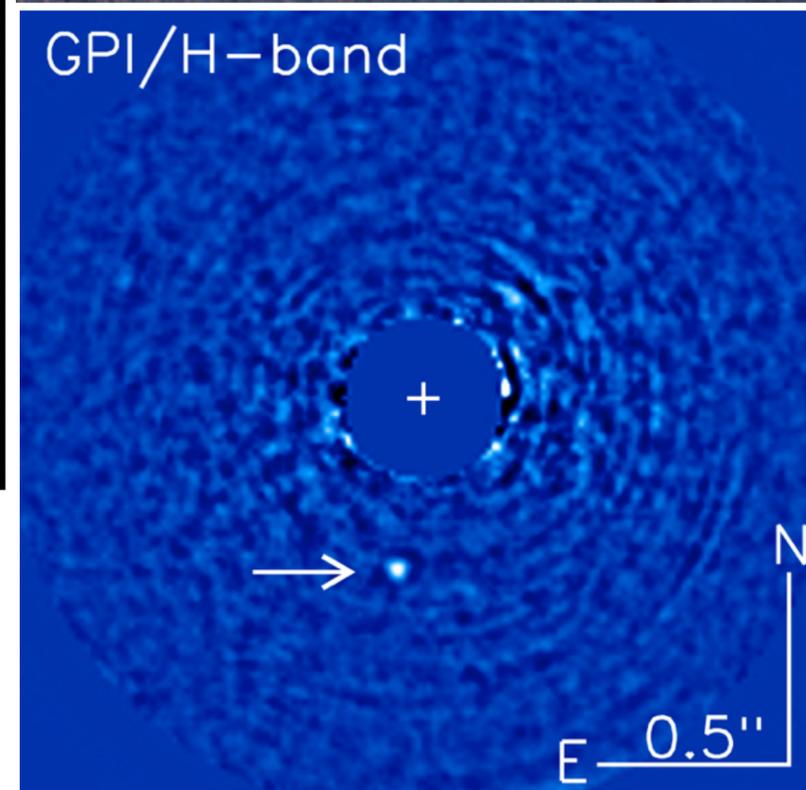
Movie from Jason Wang and Christian Marois



Me



Movie from Jason Wang and Christian Marois



Macintosh et al. 2015

Response Card

Response Card

- The answer to this question is “A”
 - (A) — A
 - (B) — B
 - (C) — C
 - (D) — D
 - (E) — E

Response Card

- A photographer drops her camera. She walks 1 mile South, then 1 mile West, then 1 mile North. She picks up her camera and takes a picture of a bear. What color is the bear?
 - (A) — blue
 - (B) — brown
 - (C) — white
 - (D) — black
 - (E) — purple

Response Card Question

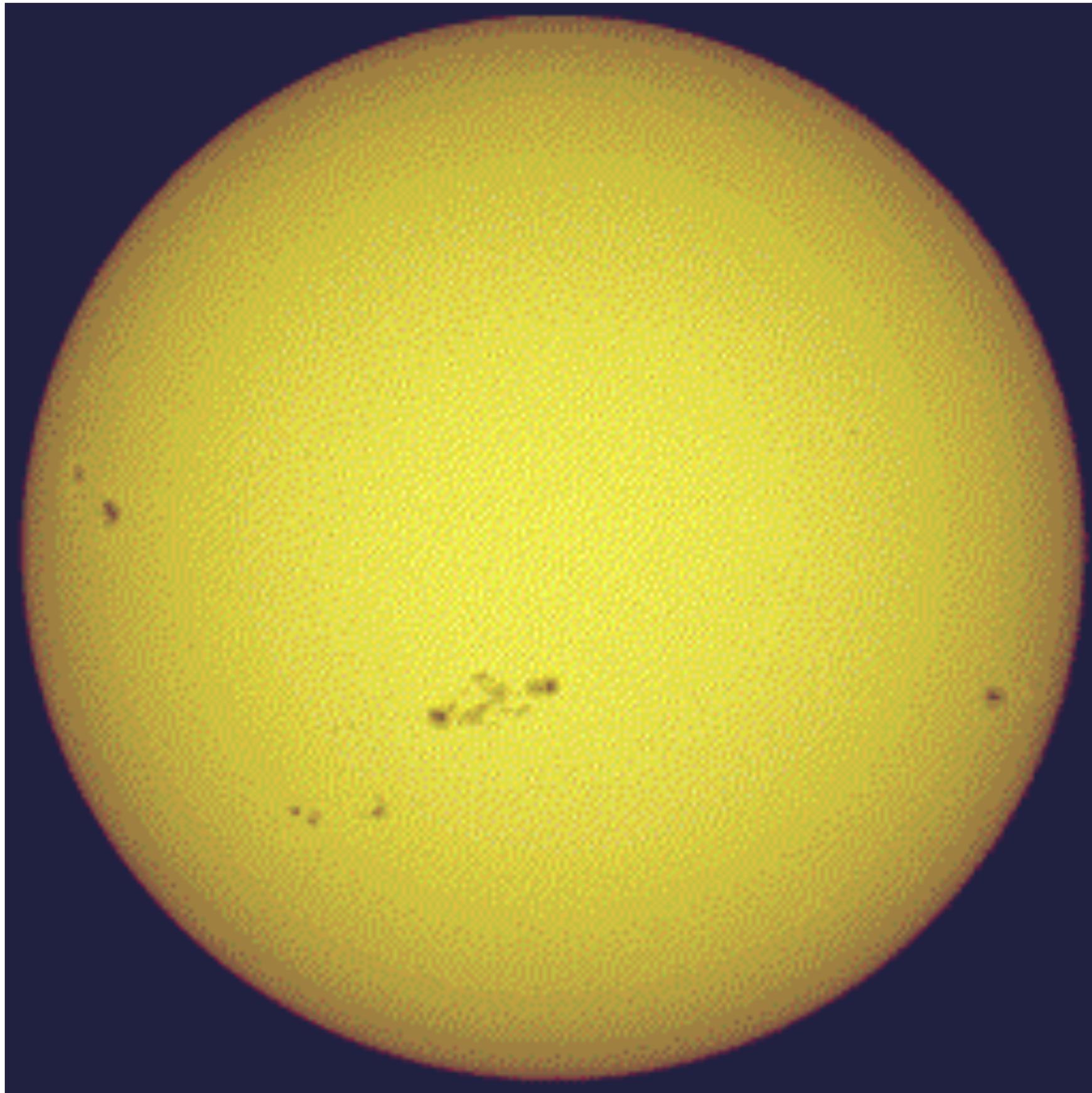
- Which object contains most of the mass in our Solar System?
 - (A) — Earth
 - (B) — Jupiter
 - (C) — Saturn
 - (D) — Neptune
 - (E) — Sun

Response Card Question

- Which object contains most of the angular momentum ($L = m \cdot v \cdot r$) in our Solar System?
 - (A) — Earth
 - (B) — Jupiter
 - (C) — Saturn
 - (D) — Neptune
 - (E) — Sun

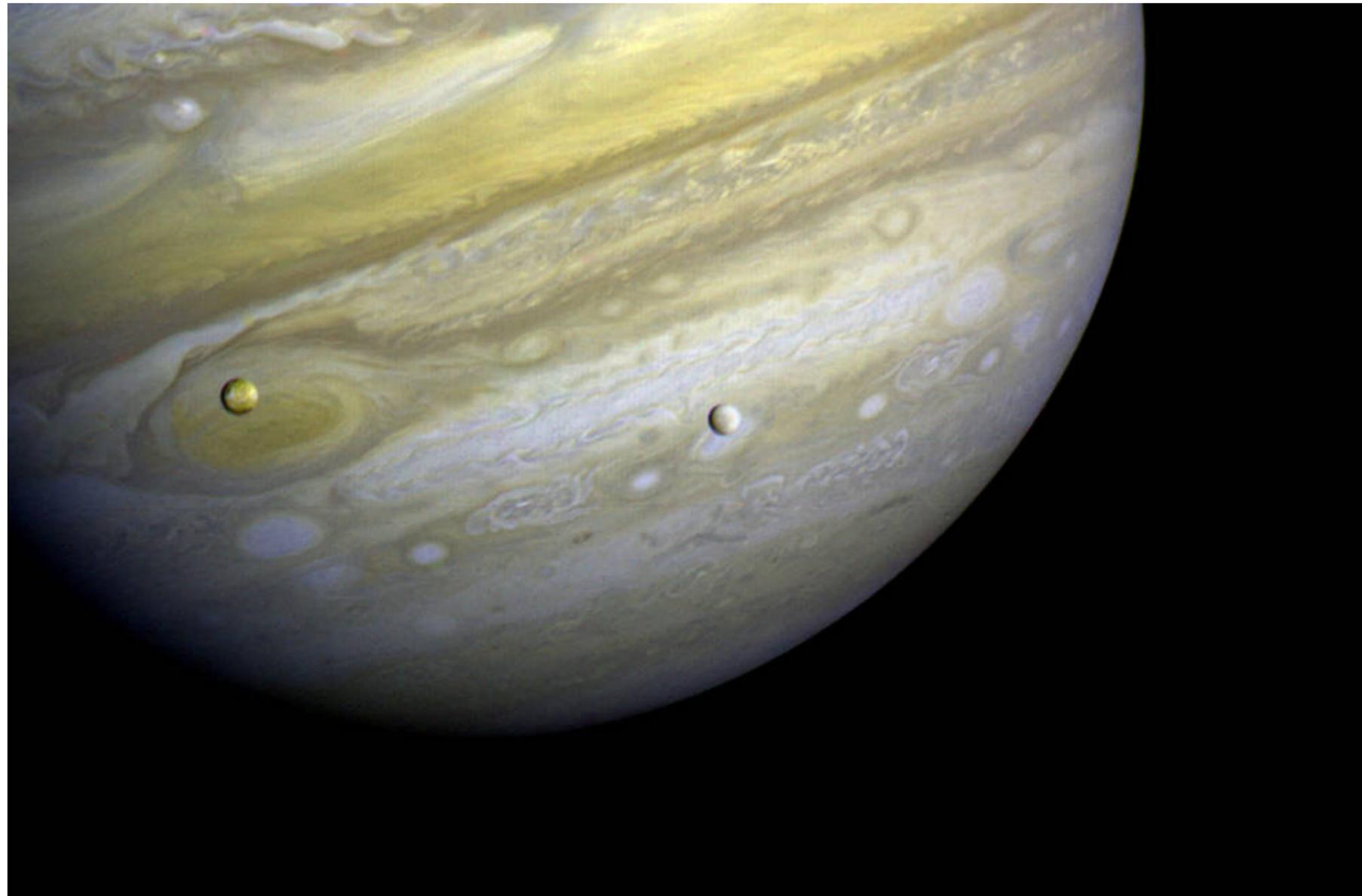
The Sun

- Contains 99.8% of the mass of the solar system
- Contains <2% of the angular momentum of the Solar System (most is in Jupiter's orbital motion)
- Plasma powered by nuclear fusion



Giant Planets

- Mass of Jupiter:
 - ~300 Earth masses
 - ~3 Saturn masses
 - ~20 Neptune masses
 - ~1/1000 Solar masses
- Gas giants (Jupiter, Saturn): mostly H and He
- Ice giants (Uranus, Neptune): H, He, H₂O, CH₄, NH₃
- All 4 have strong magnetic fields



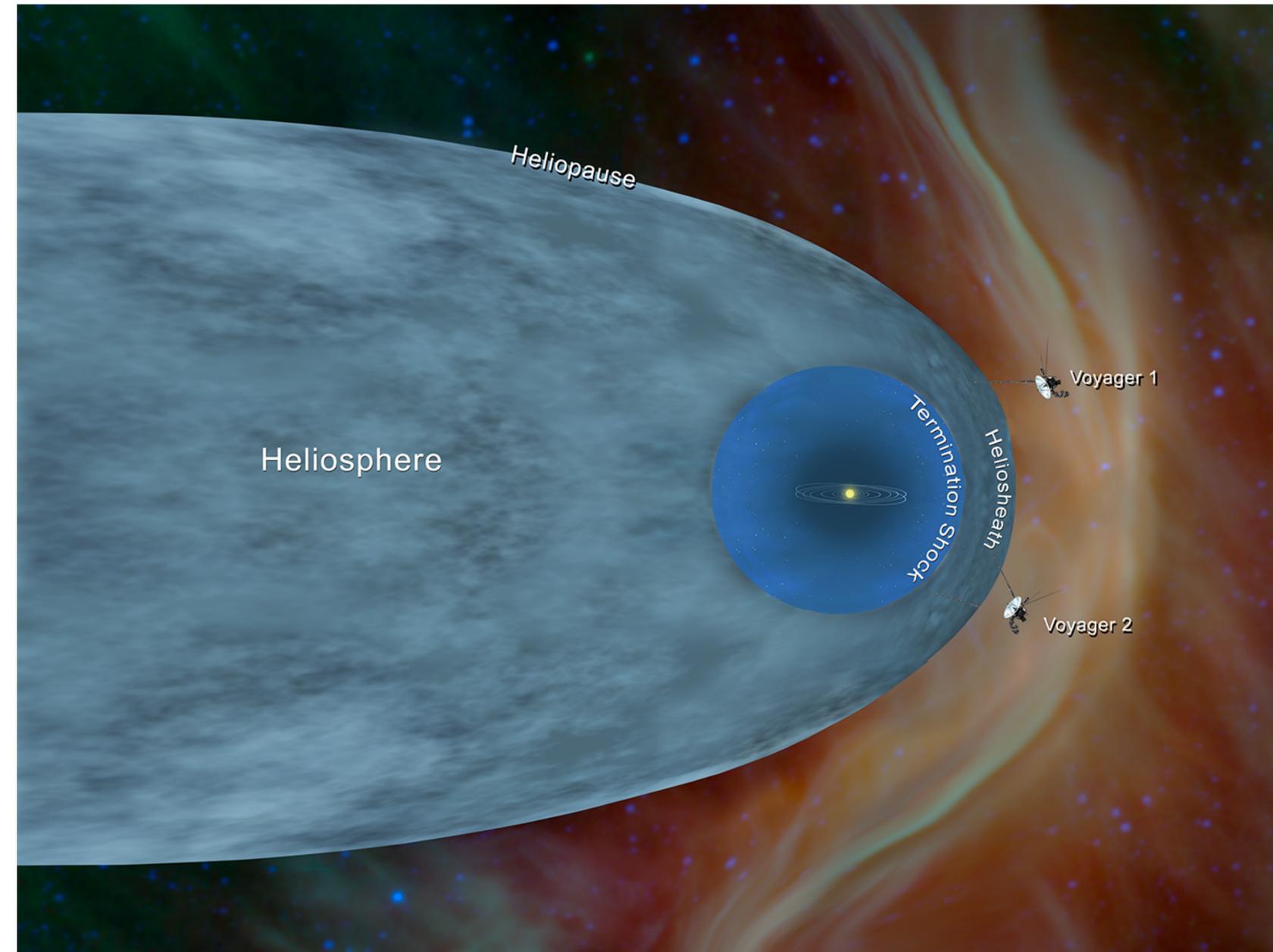
Solid Bodies

- Terrestrial planets: 2 larger, 2 smaller
- 7 large moons
- lots of dwarf planets
- lots of “small bodies” — asteroids, comets, small moons
- “other” — dust particles, ring particles



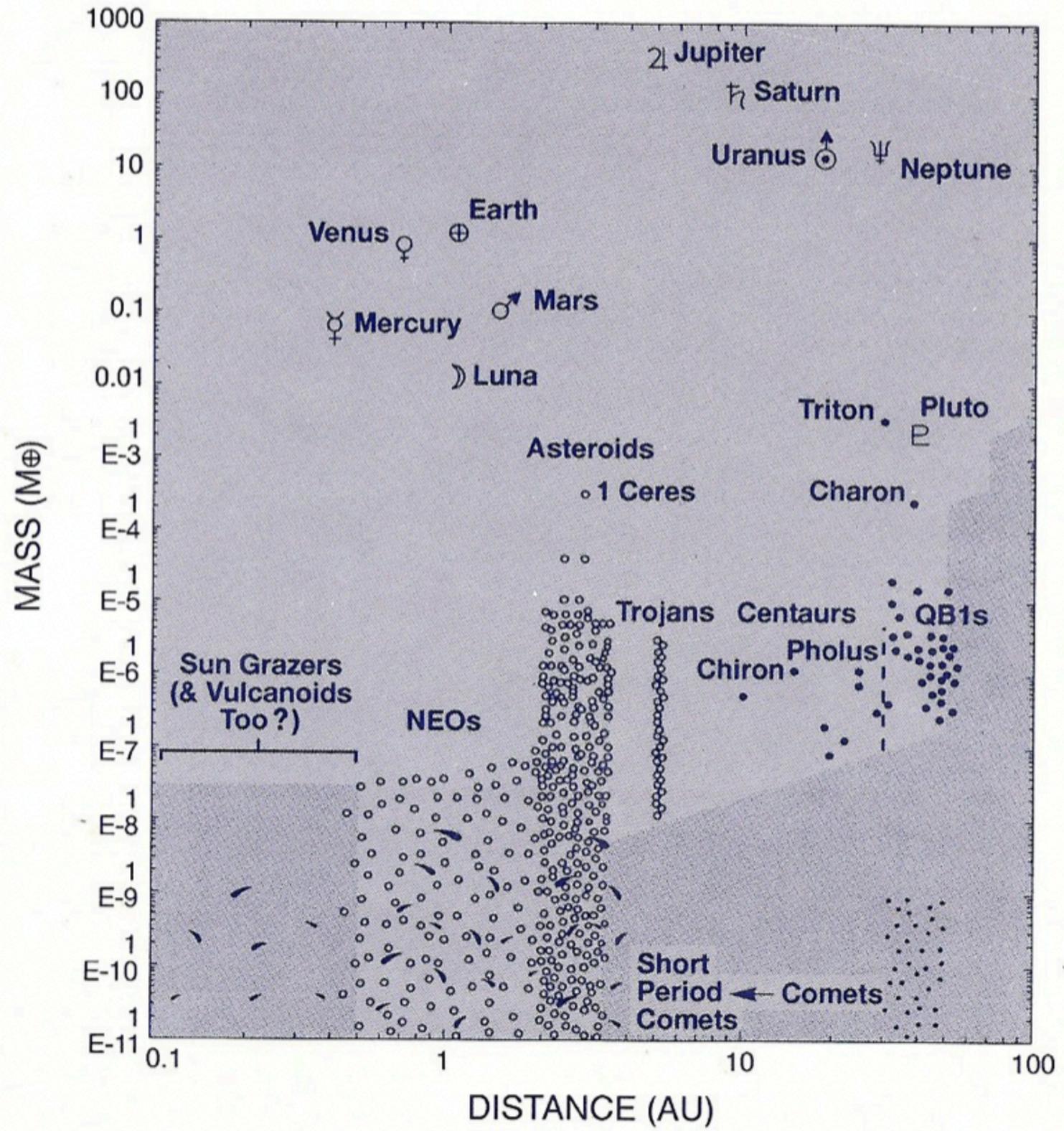
Heliosphere

- Region of space dominated by Sun's plasma and magnetic fields
- composed of solar wind protons and electrons
- moves through ISM at speed of ~ 26 km/s
- heliopause: ~ 100 - 200 AU upstream in solar wind
- note: there are objects "inside" the solar system that are outside the heliopause:
 - Sedna is on an eccentric orbit with aphelion of 900 AU



JPL/Caltech

COMPLETING THE INVENTORY OF THE SOLAR SYSTEM

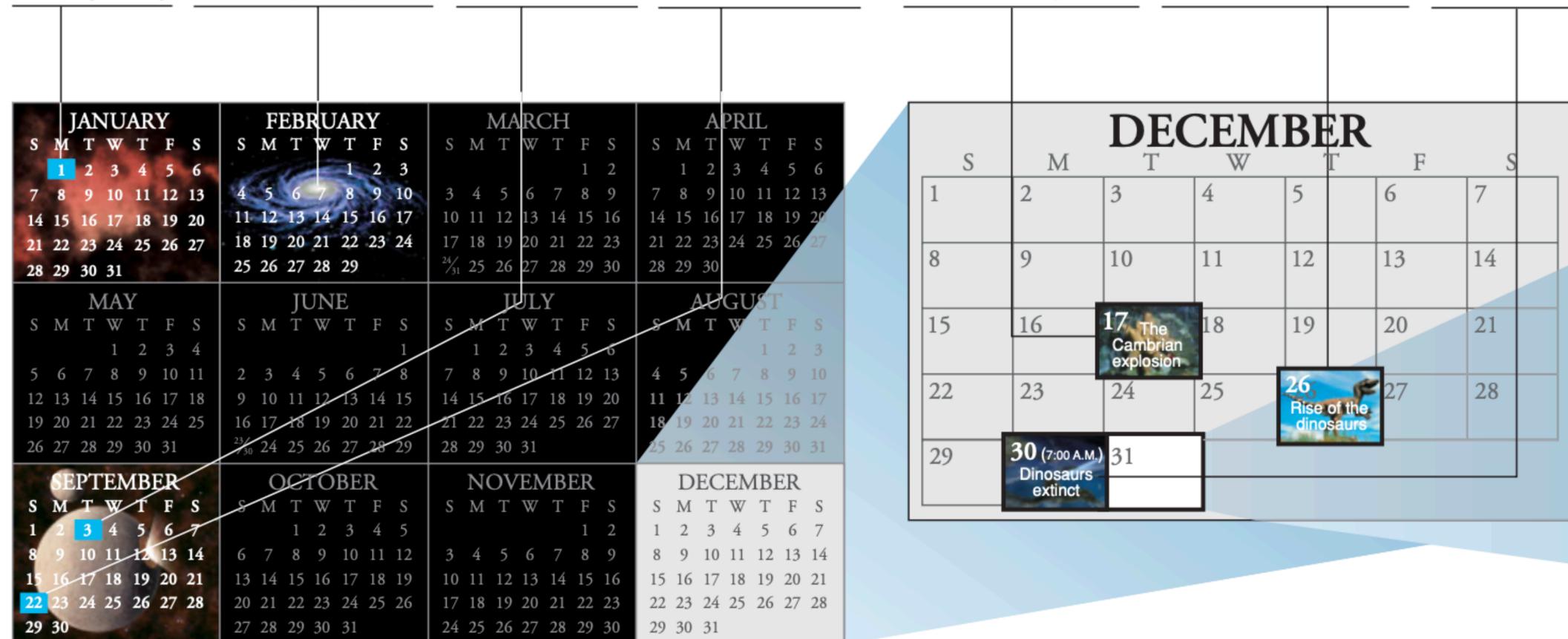


The Cosmic Calendar

- The universe is 13.8 billion years old
- To make sense of that number, let's create a scale model of time: compress those 13.8 billion years to a 1-year calendar
- Solar system forms 4.6 billion years ago

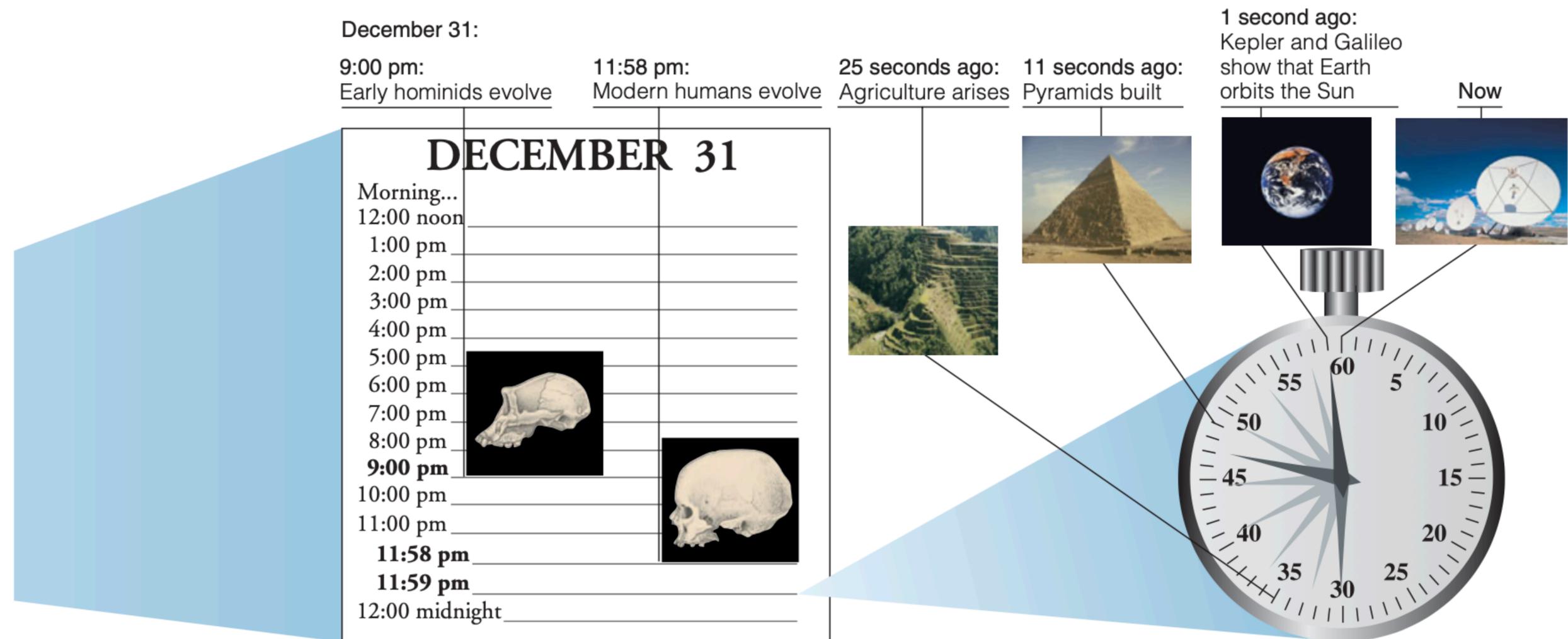
THE HISTORY OF THE UNIVERSE IN 1 YEAR

January 1: The Big Bang February: The Milky Way forms September 3: The Earth forms September 22: Early life on earth December 17: Cambrian explosion December 26: Rise of the dinosaurs December 30: Extinction of the dinosaurs



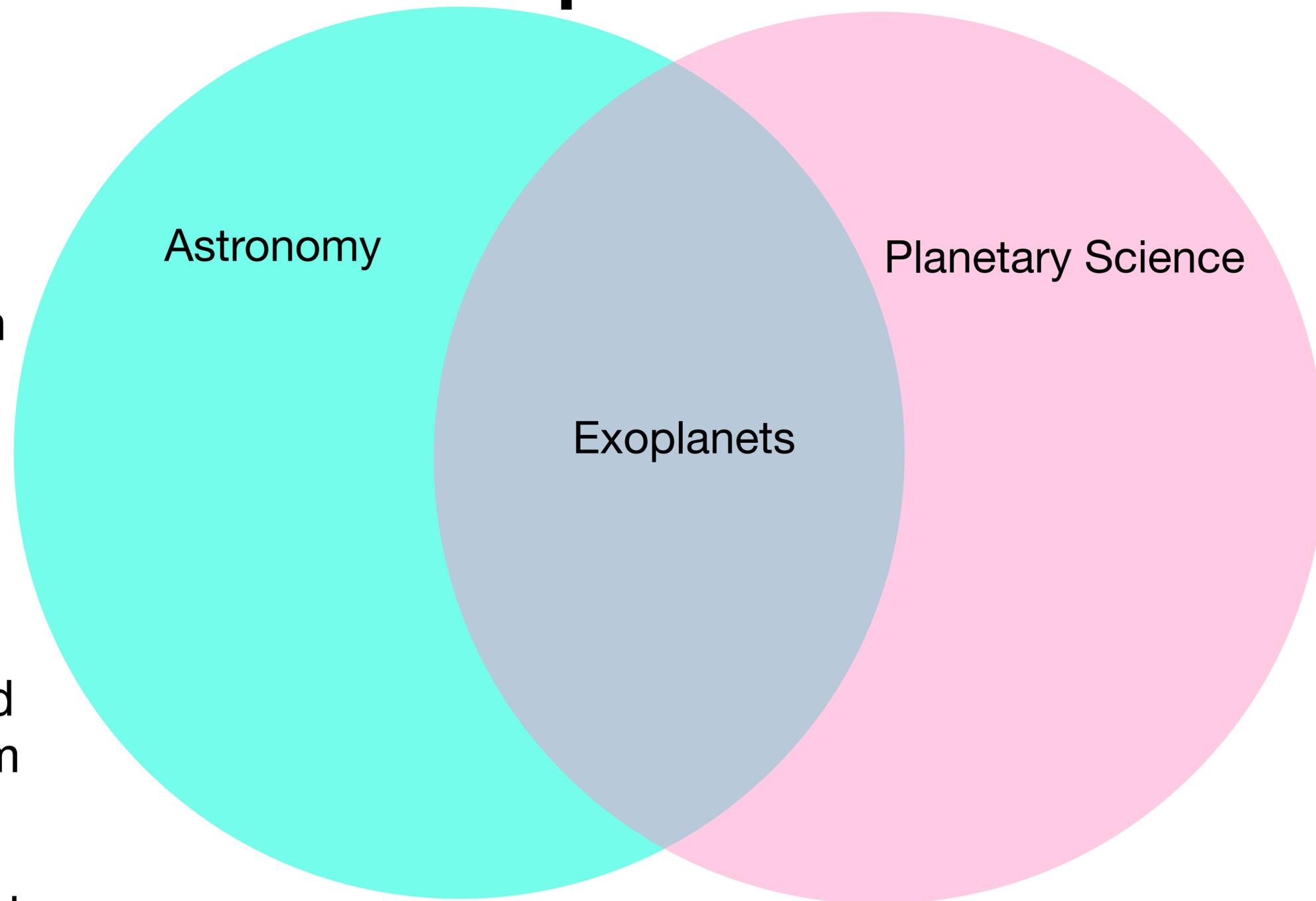
The Cosmic Calendar

- On this scale, most of human civilization is in the final seconds before midnight on December 31st



Planetary Science and Exoplanets

- We can learn about planets in our own solar system in great detail
 - But, sample size is small (one planetary system, one planet with abundant life...)
- We can learn about demographics and other configurations from exoplanets
 - But, in much less detail compared to planets in our own solar system
- Putting it all together, however, we can learn about how planets form and evolve



Observables: How do we know?

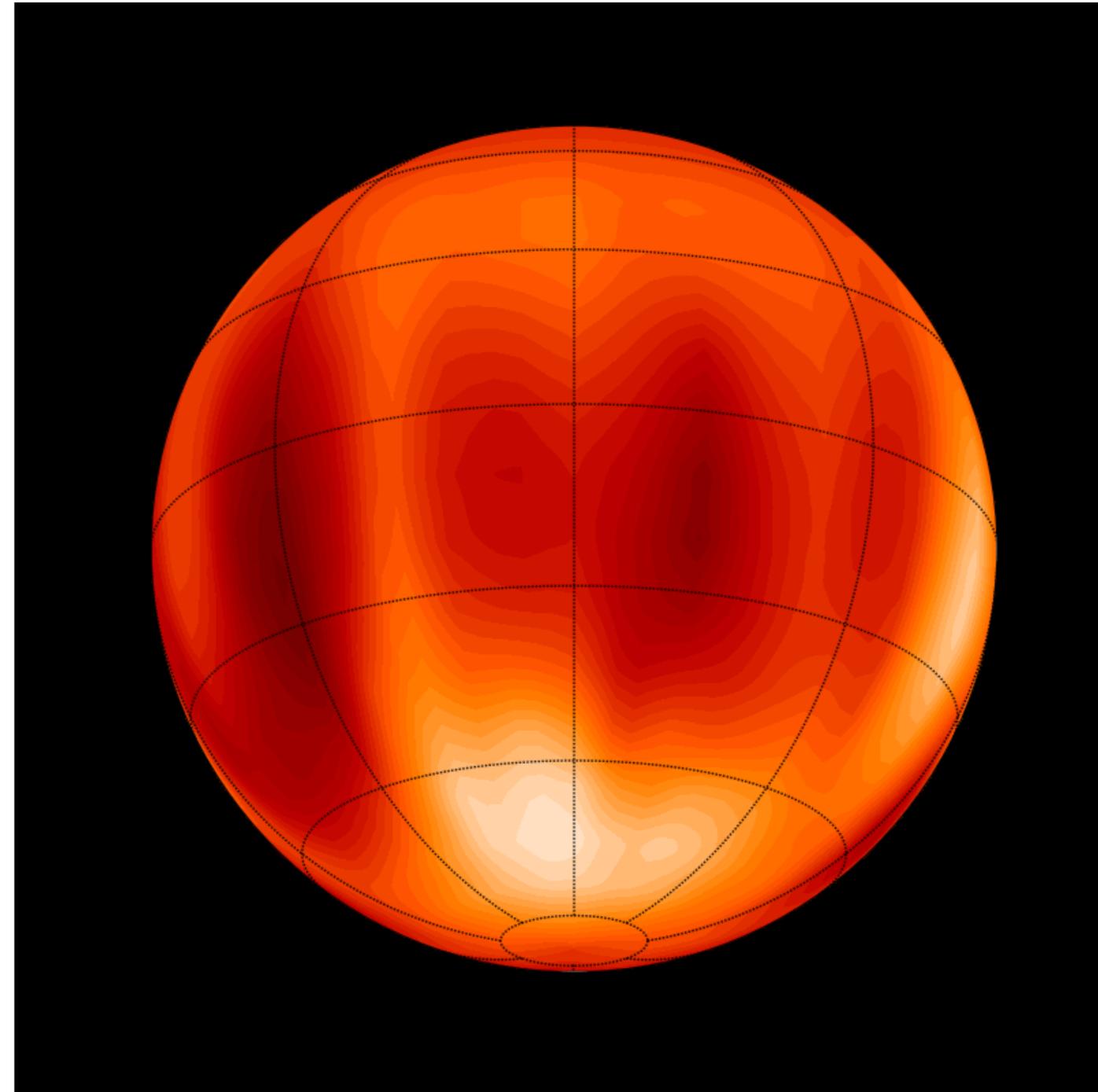
- Orbit
- mass, mass distribution
 - orbits of moons, spacecraft, perturbations on other planets
- size
 - angular size and distance, occultations, radar (if close)
- from mass and size: density (bulk composition), escape velocity (atmosphere?)

Planetary Fact Sheet - Metric

	MERCURY	VENUS	EARTH	MOON	MARS	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Mass (10 ²⁴ kg)	0.330	4.87	5.97	0.073	0.642	1898	568	86.8	102	0.0130
Diameter (km)	4879	12,104	12,756	3475	6792	142,984	120,536	51,118	49,528	2376
Density (kg/m ³)	5429	5243	5514	3340	3934	1326	687	1270	1638	1850
Gravity (m/s ²)	3.7	8.9	9.8	1.6	3.7	23.1	9.0	8.7	11.0	0.7
Escape Velocity (km/s)	4.3	10.4	11.2	2.4	5.0	59.5	35.5	21.3	23.5	1.3
Rotation Period (hours)	1407.6	-5832.5	23.9	655.7	24.6	9.9	10.7	-17.2	16.1	-153.3
Length of Day (hours)	4222.6	2802.0	24.0	708.7	24.7	9.9	10.7	17.2	16.1	153.3
Distance from Sun (10 ⁶ km)	57.9	108.2	149.6	0.384*	228.0	778.5	1432.0	2867.0	4515.0	5906.4
Perihelion (10 ⁶ km)	46.0	107.5	147.1	0.363*	206.7	740.6	1357.6	2732.7	4471.1	4436.8
Aphelion (10 ⁶ km)	69.8	108.9	152.1	0.406*	249.3	816.4	1506.5	3001.4	4558.9	7375.9
Orbital Period (days)	88.0	224.7	365.2	27.3*	687.0	4331	10,747	30,589	59,800	90,560
Orbital Velocity (km/s)	47.4	35.0	29.8	1.0*	24.1	13.1	9.7	6.8	5.4	4.7
Orbital Inclination (degrees)	7.0	3.4	0.0	5.1	1.8	1.3	2.5	0.8	1.8	17.2
Orbital Eccentricity	0.206	0.007	0.017	0.055	0.094	0.049	0.052	0.047	0.010	0.244
Obliquity to Orbit (degrees)	0.034	177.4	23.4	6.7	25.2	3.1	26.7	97.8	28.3	122.5
Mean Temperature (C)	167	464	15	-20	-65	-110	-140	-195	-200	-225
Surface Pressure (bars)	0	92	1	0	0.01	Unknown*	Unknown*	Unknown*	Unknown*	0.00001
Number of Moons	0	0	1	0	2	79	82	27	14	5
Ring System?	No	No	No	No	No	Yes	Yes	Yes	Yes	No
Global Magnetic Field?	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Unknown
	MERCURY	VENUS	EARTH	MOON	MARS	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO

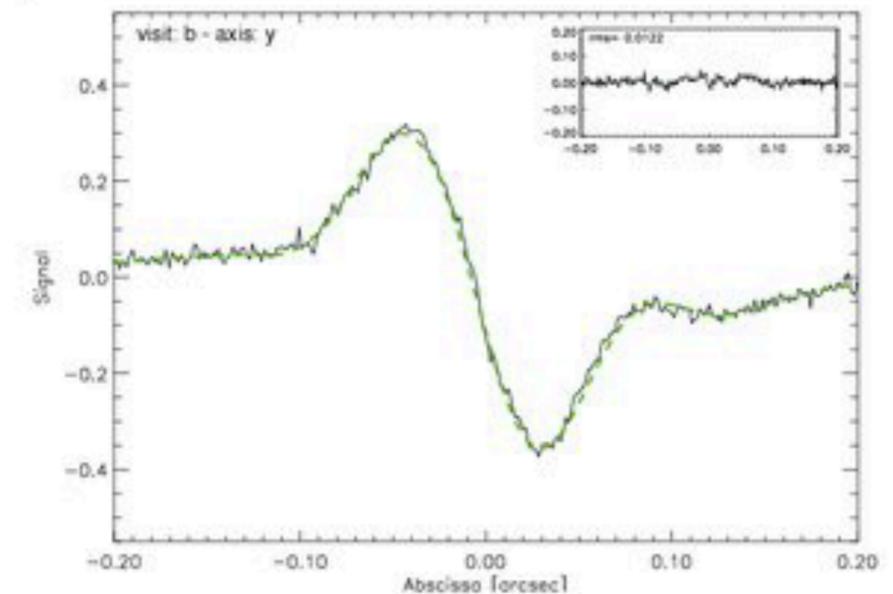
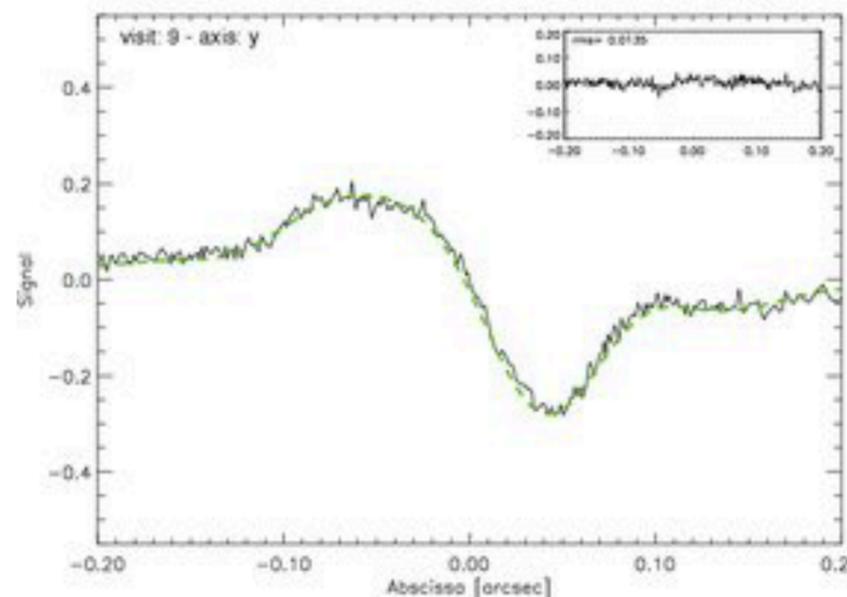
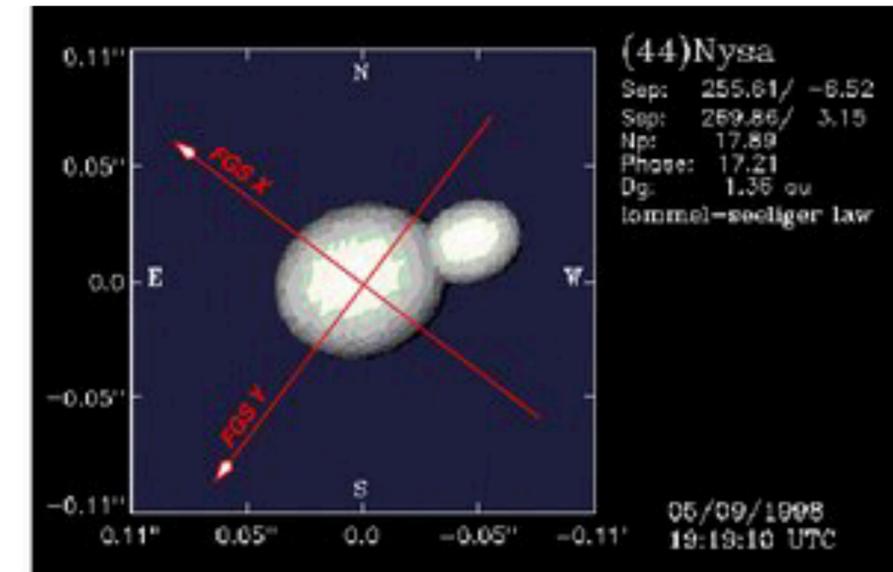
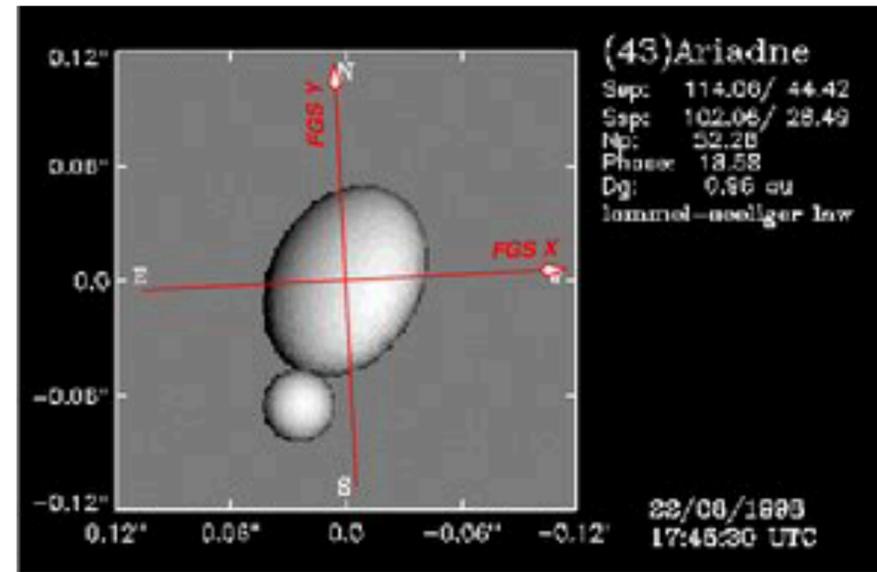
Observables: How do we know?

- Rotation
 - track markings as they move across disk
 - radio signals caused by trapped charged particles in planets' magnetospheres
 - light curves
 - measure Doppler shift across disk



Observables: How do we know?

- Shape
 - direct imaging
 - stellar occultations
 - radar
 - light curves



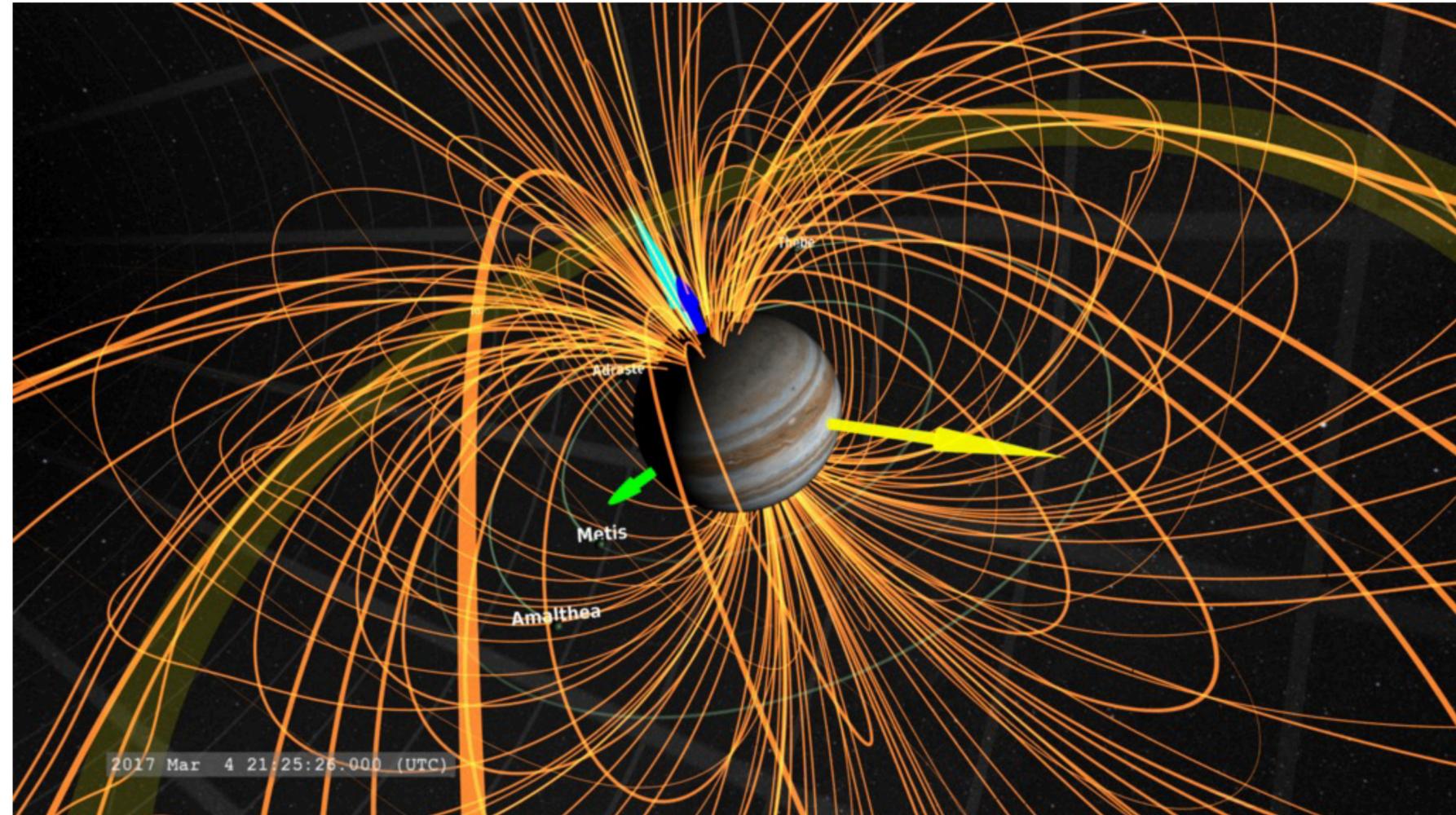
Observables: How do we know?

- Temperature
 - (internal heat, greenhouse effect, latitude/diurnal variations, etc)
 - direct in situ measurements
 - thermal IR (blackbody) spectrum



Observables: How do we know?

- Magnetic Field
 - magnetometer (in situ)
 - radiation produced by accelerating charged particles (aurorae, radio emissions)



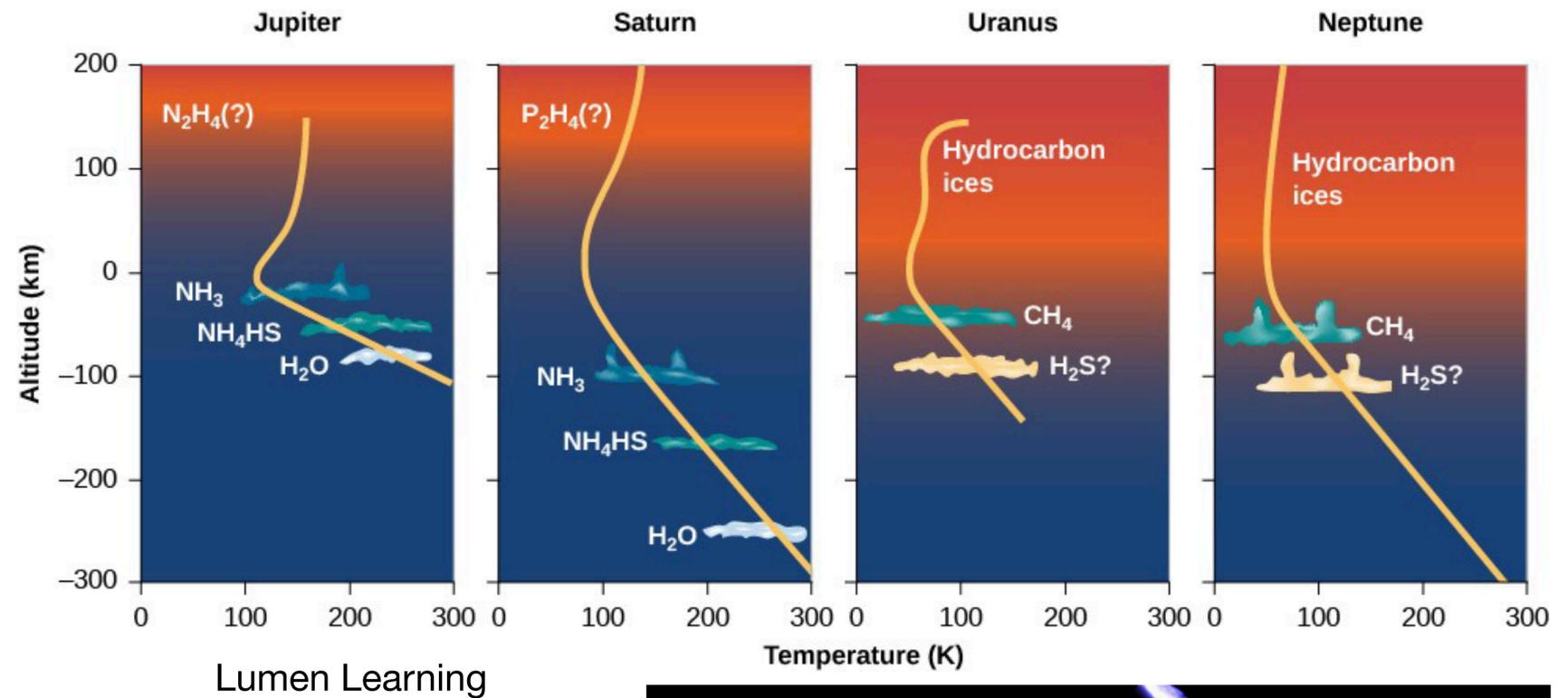
Observables: How do we know?

- Surface Composition
 - spectral reflecting measurements or IR spectra
 - radar reflectivity
 - X-ray or gamma ray fluorescence
 - surface samples (in situ or returned to Earth)
- surface structure
 - passive or active imaging (vary illumination, phase angle)

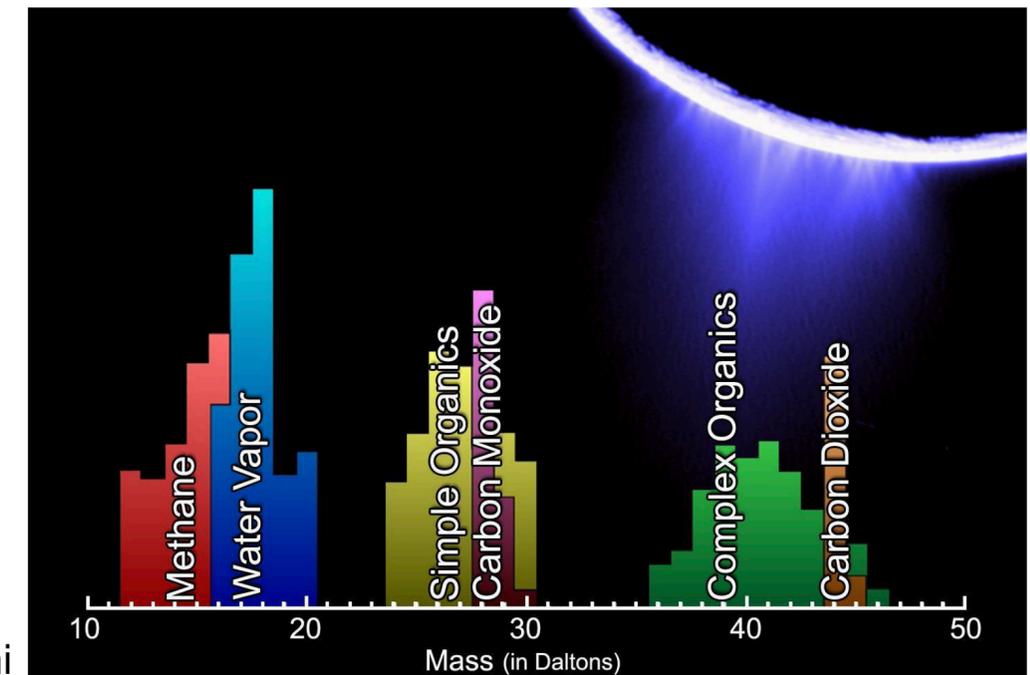


Observables: How do we know?

- Atmospheric composition and structure
 - spectral reflectance data, IR spectra
 - stellar occultations
 - atmospheric probes
 - mass spectrometers (in situ)



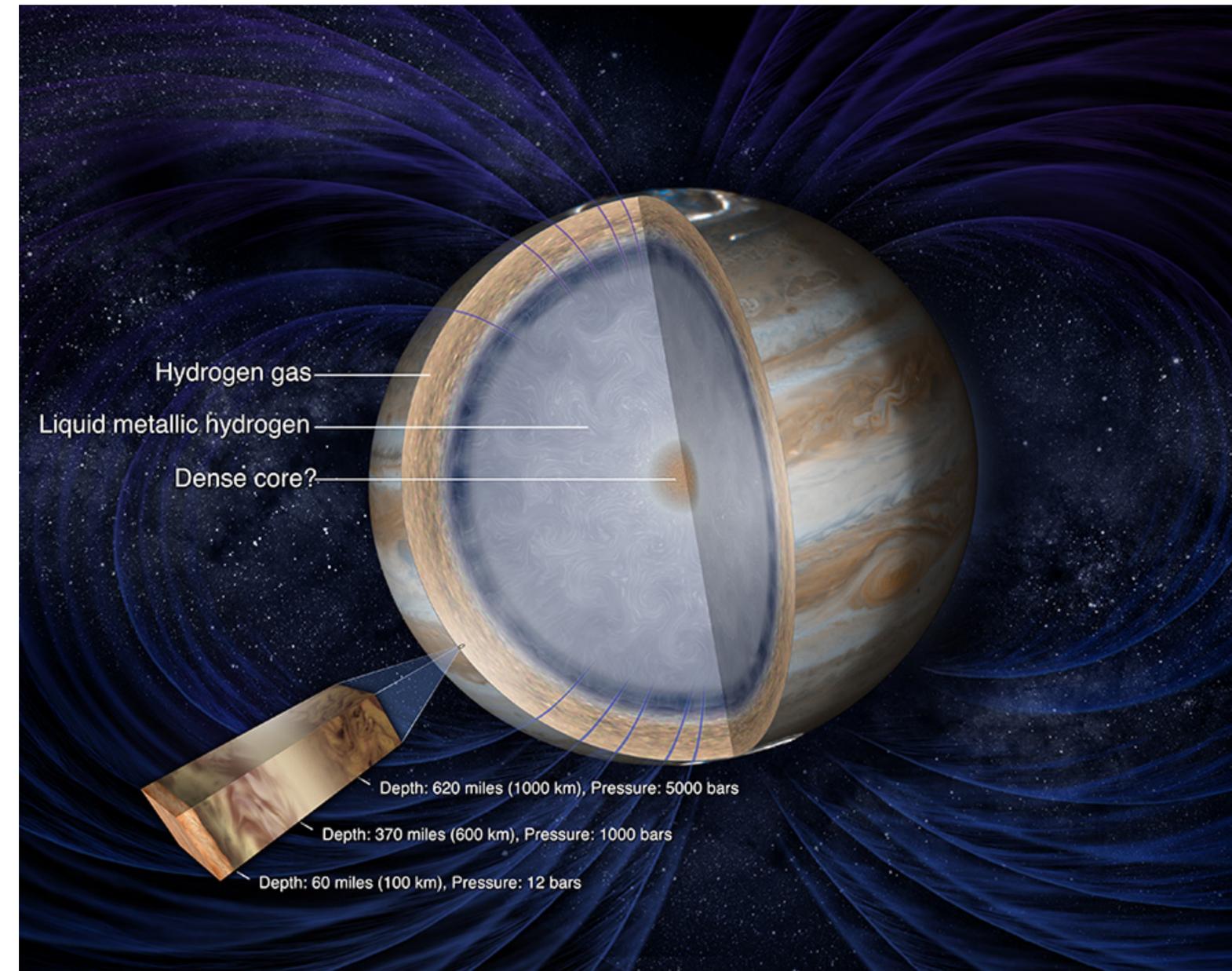
Lumen Learning



NASA/Cassini

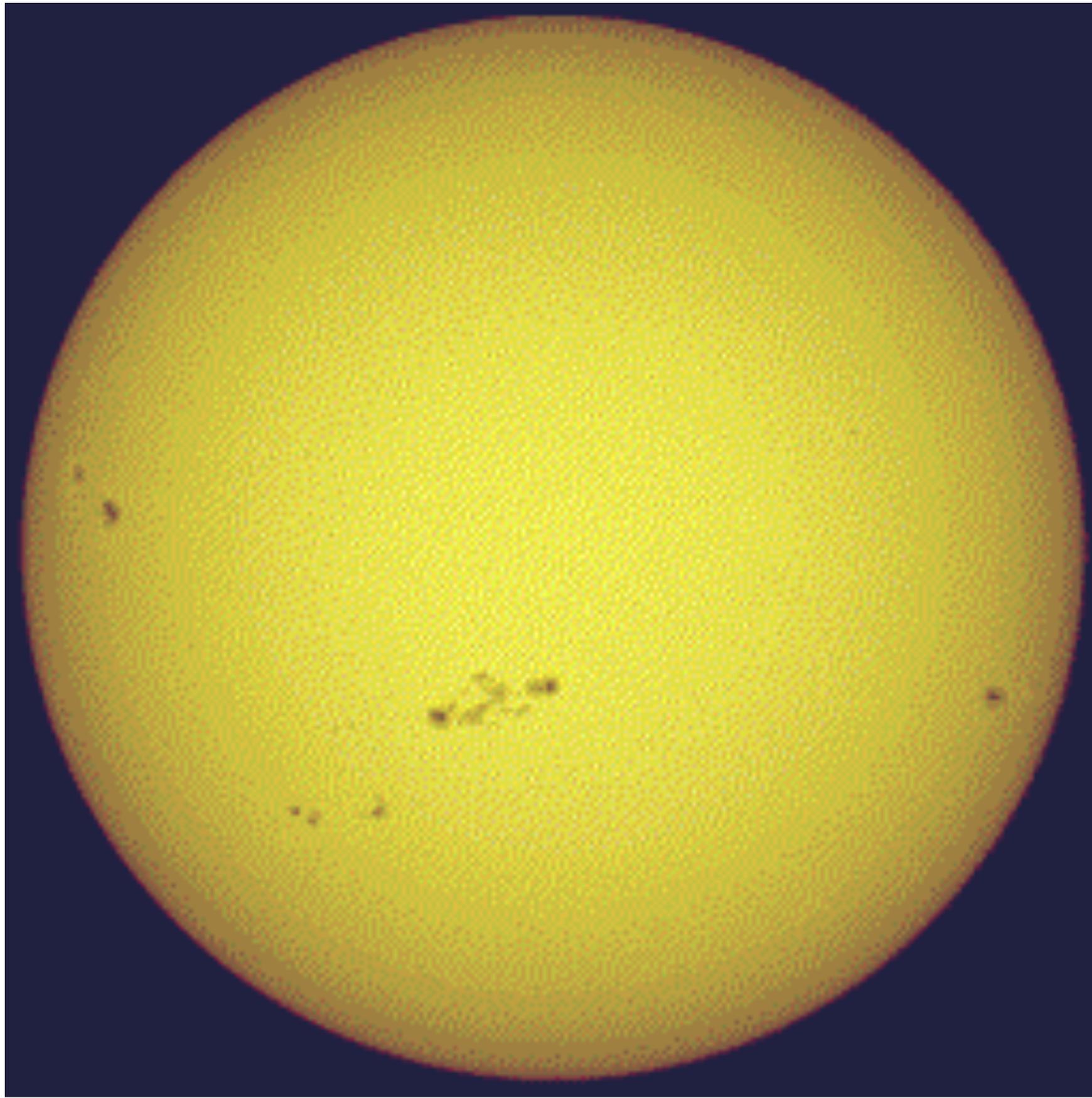
Inferences: How do we get...?

- Bulk composition
 - mass, size, laboratory data
 - mass, size, surface and atmospheric composition, orbital distance, initial (“cosmogenic”) abundances
- Internal structure
 - gravity field, rotation rate
 - seismometers?
 - surface geological process (volcanism, tectonism)



The Sun

- We won't spend a lot of time talking about the Sun (there are other grad classes for that)
- But, the Sun is the dominant influence over planetary:
 - motions
 - energy
 - weather
 - magnetospheres
- We will have to understand stellar properties, formation, and evolution

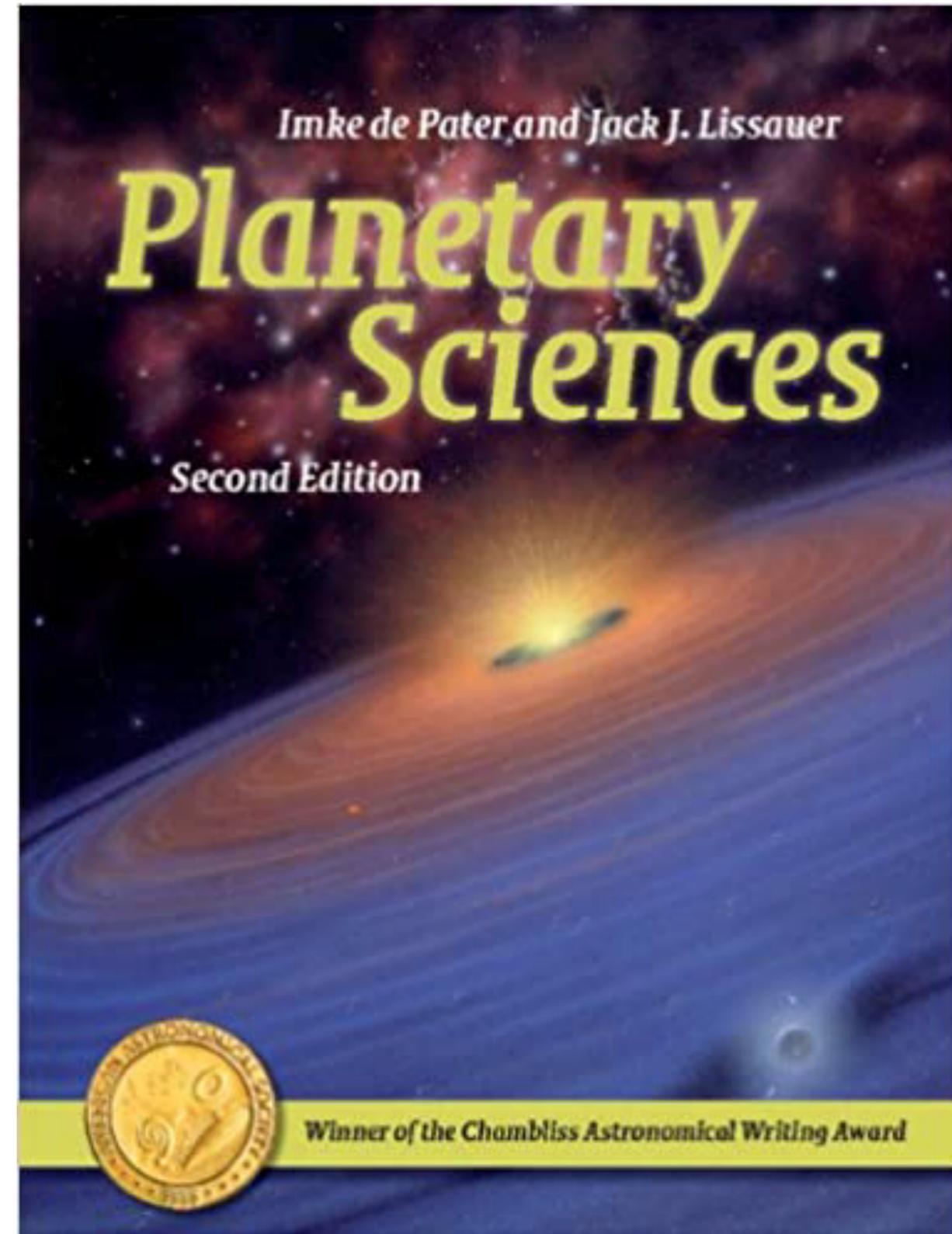


Break

05:00

Textbook

- Readings and some homework will be assigned from the textbook
- Either “second edition” or “updated second edition” is fine
 - try to avoid the first edition, it’s a bit out of date



Grading

The relative weights of these components will be used to calculate your final grade:

Course Component	%
Class Participation	5
In-Class Assignments	15
Homework	30
Midterm Exam	20
Final Exam	20
Project	10

Canvas will display your class grades based on this grading scheme, though keep in mind it will ignore categories where there are not (yet) items: for example, if the class project and final exam have not yet taken place, it will display your grade with respect to the 70% of the categories it has at least some entries for.

Important dates

- Wednesday, October 5 (10:30-11:45) in class — Midterm Exam
- Monday, December 5 (10:30-12:30) — Final Exam
- Exams will be in this room, closed-book, closed-note (an equation sheet will be provided)

Office Hours

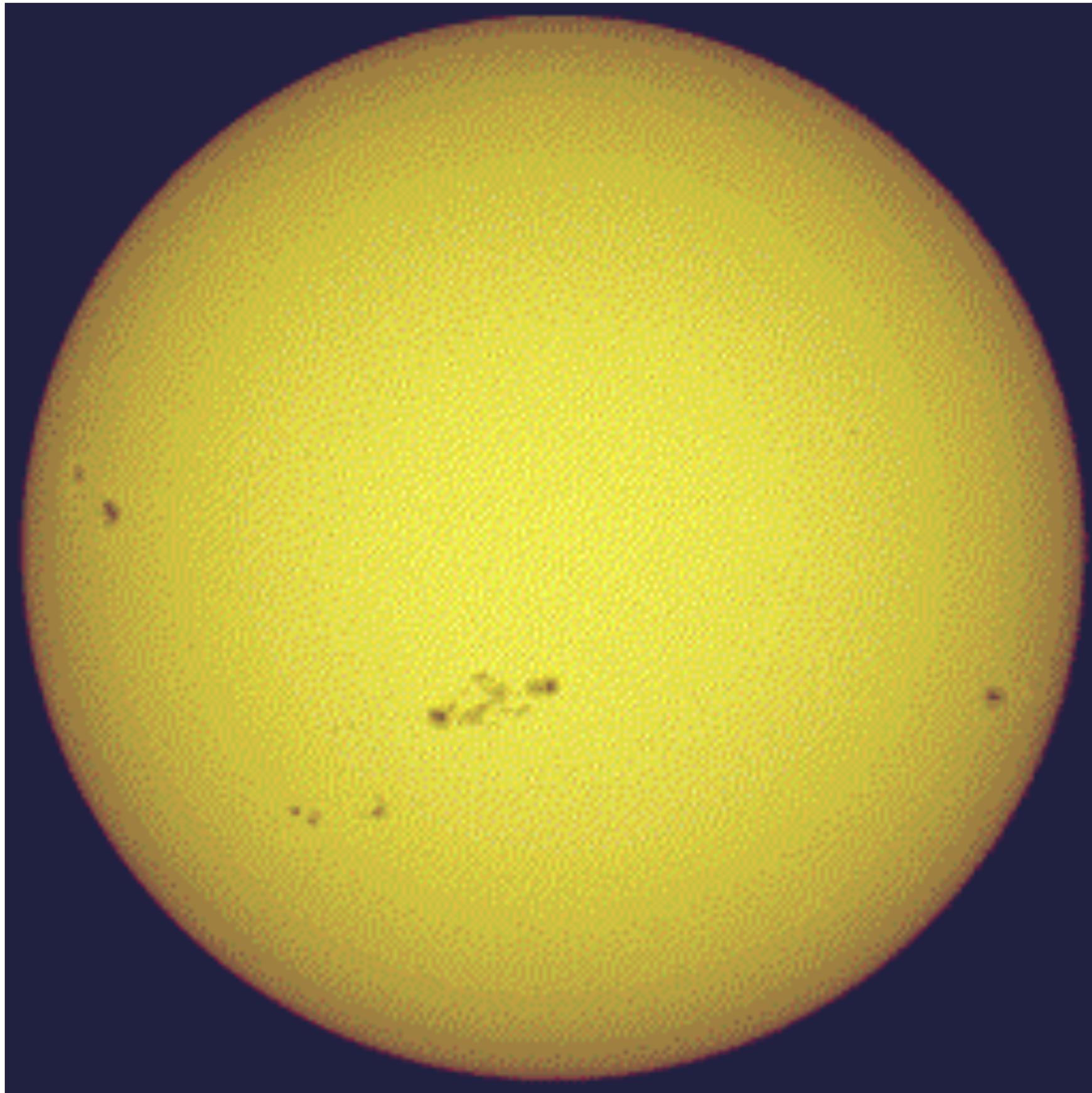
- Vote now!
- Options:
 - **Monday 4pm-5pm**
 - Tuesday 1pm-2pm
 - Wednesday 2pm-3pm
 - Wednesday 4pm-5pm
- Office hours and other course details available on the syllabus, on canvas

Order of Magnitude (OOM) Problems

- A lot of the time in astronomy, you will have to do exact calculations (including in this class!)
- But a very useful skill is to estimate the answer to within an “order of magnitude” (factor of 10)
- You each know a lot of physics and astronomy! This semester, we’ll talk about how to tap into that knowledge to quickly solve a range of problems, without books, calculator, laptop, or internet
- We’ll do some together, you’ll try some on your own, and the project near the end of the semester will be on order of magnitude problems

OOM: Neutrinos

- If I'm standing on Earth, and hold my hand up to the Sun, how many solar neutrinos pass through my hand every second?



Neutrinos

- What do I need to know?
 - Area of my hand: not 10 cm², not 1000 cm², let's go with 100 cm²
 - Distance to the Sun: 1 AU = 1.5 x 10¹³ cm
 - The Sun makes neutrinos while doing nuclear fusion, so the rate of neutrino production will be directly related to the rate of energy production
 - Luminosity of the Sun: 4 x 10³³ erg/s = 10³⁴ erg/s
 - How many neutrinos are made for each erg of energy made?
 - Fusion is turning 4H into 1 Helium-4, which converts about 1% of the mass into energy. The proton-proton chain makes a couple (4) neutrinos per Helium-4 atom
 - Energy per Helium-4: $mc^2 = (10^{-2} \times 4 \times m_p)c^2 = (10^{-2} \times 4 \times 2 \times 10^{-24} \text{ g})(3 \times 10^{10} \text{ cm/s})^2$
 - $= 10^{-2+1-24+1+20} = 10^{-4} \text{ erg / Helium-4}$

Neutrinos

- Area of my hand: 100 cm^2
- Distance to the Sun: 10^{13} cm
- Luminosity of the Sun: 10^{34} erg/s
- 10^{-4} erg / Helium-4
- 4 neutrinos / Helium-4
- neutrinos / erg = $4 / 10^{-4} = 10^5$
- neutrinos / second = $10^5 \times 10^{34} = 10^{39}$
- square centimeters of a sphere with a 1AU radius:
- $4 \times \pi \times r^2 = 10 \times (10^{13} \text{ cm})^2 = 10 \times 10^{26} \text{ cm}^2 = 10^{27} \text{ cm}^2$

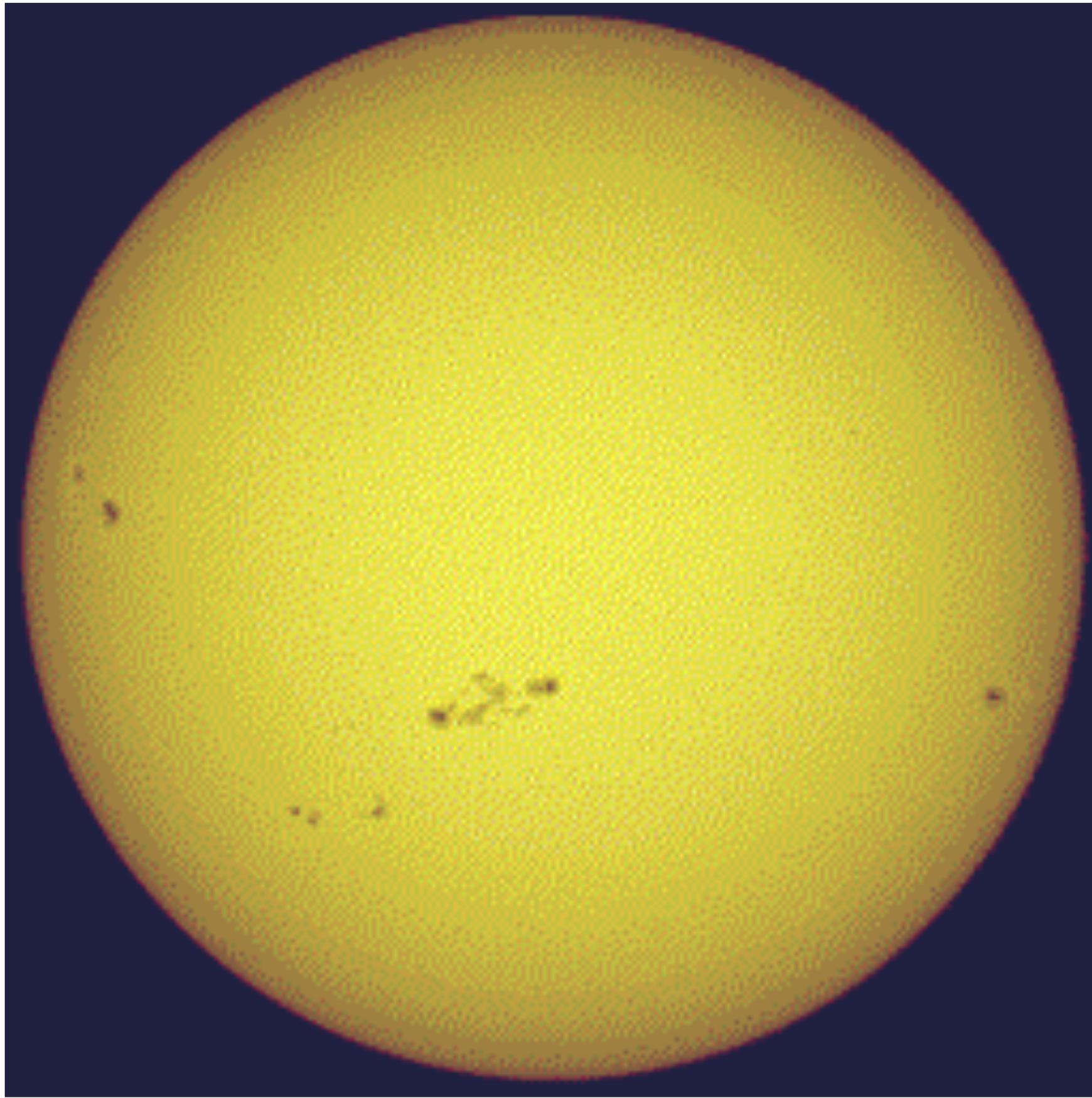
Neutrinos

- neutrinos / second = 10^{39}
- square centimeters of a sphere with a 1AU radius = 10^{27} cm²
- Neutrinos / second / square centimeter: $10^{39} / 10^{27} = 10^{12}$
- Neutrinos / second / hand = $10^{12} \times 10^2 = 10^{14} = 100$ trillion

In-class activity:

Solar Power

- (1) What fraction of all photons that leave the Sun's surface in 1 second hit the Earth?
- (2) What is the total energy (in erg/s or Watts) that we could capture from solar panels, if we coated the entire surface of the Earth in 100% efficient solar panels?
- (3) How much energy (in Watts) do you use (averaged over a single day)?
- (4) How many people like you could our solar-panel-covered-Earth support?



For next time

- Take a look at the class Canvas page
- Find a copy of the textbook (remember: either version of the 2nd edition works — NOT the first edition)
- Reading: de Pater & Lissaeuer Chaper 2, section 2.1.1-2.1.3