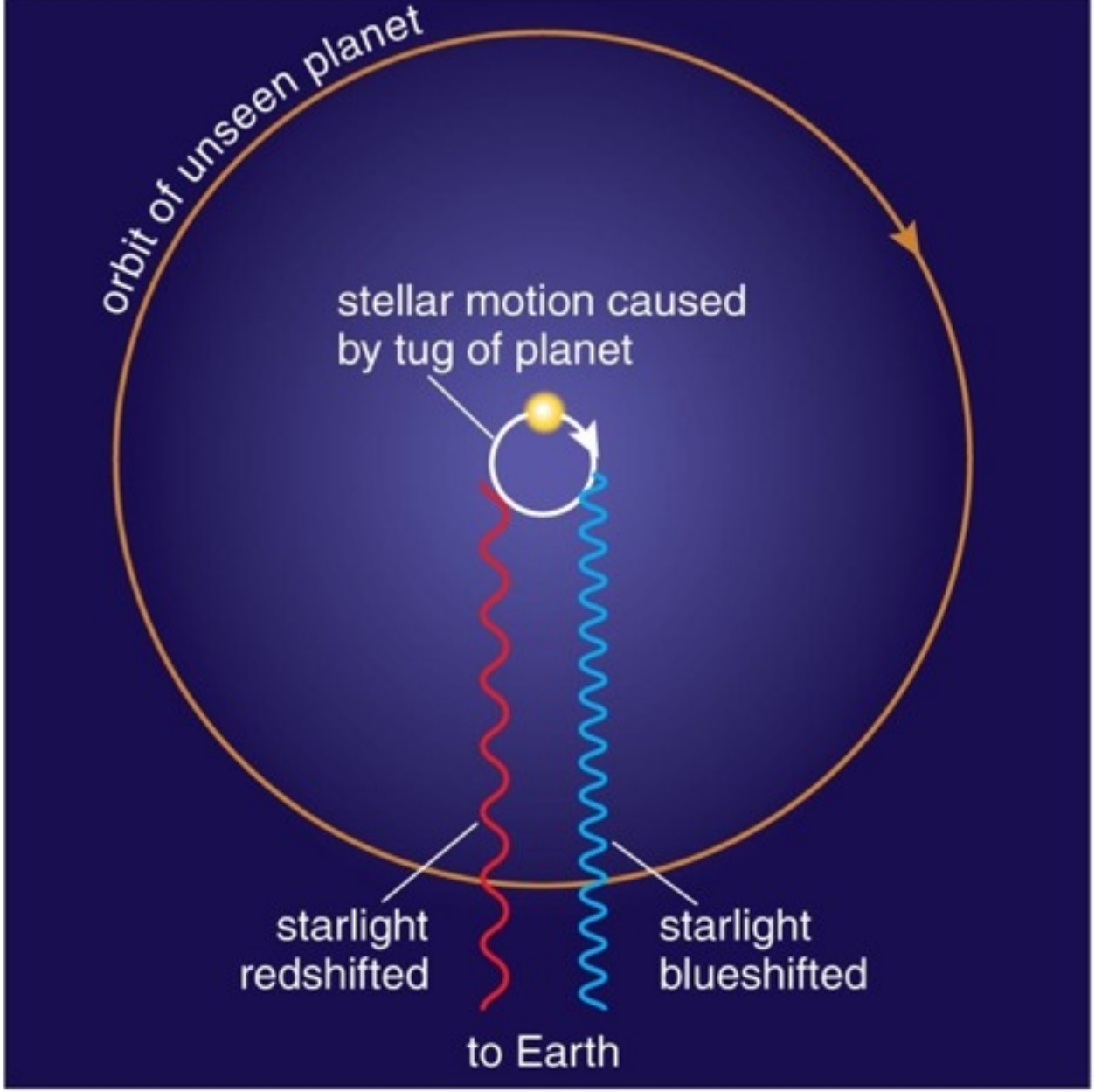
Today

- Doppler Effect & Motion
  - Extrasolar Planets
- Telescopes
- Our Star, the Sun

Next Homework
due in one week

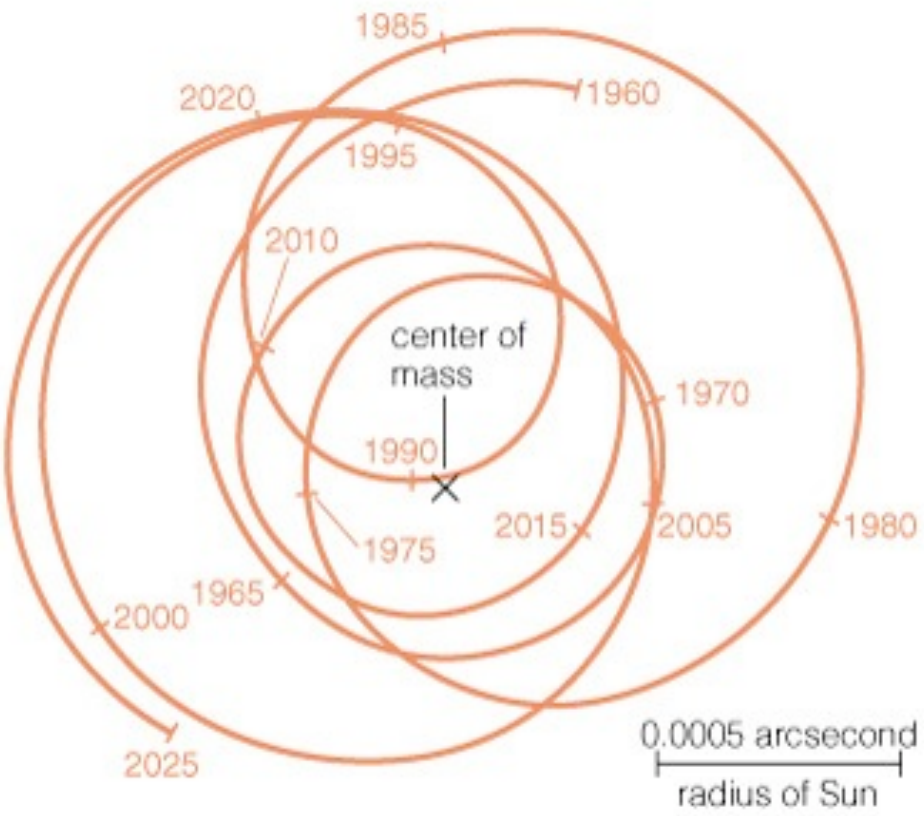
Doppler Application

- Extrasolar planets

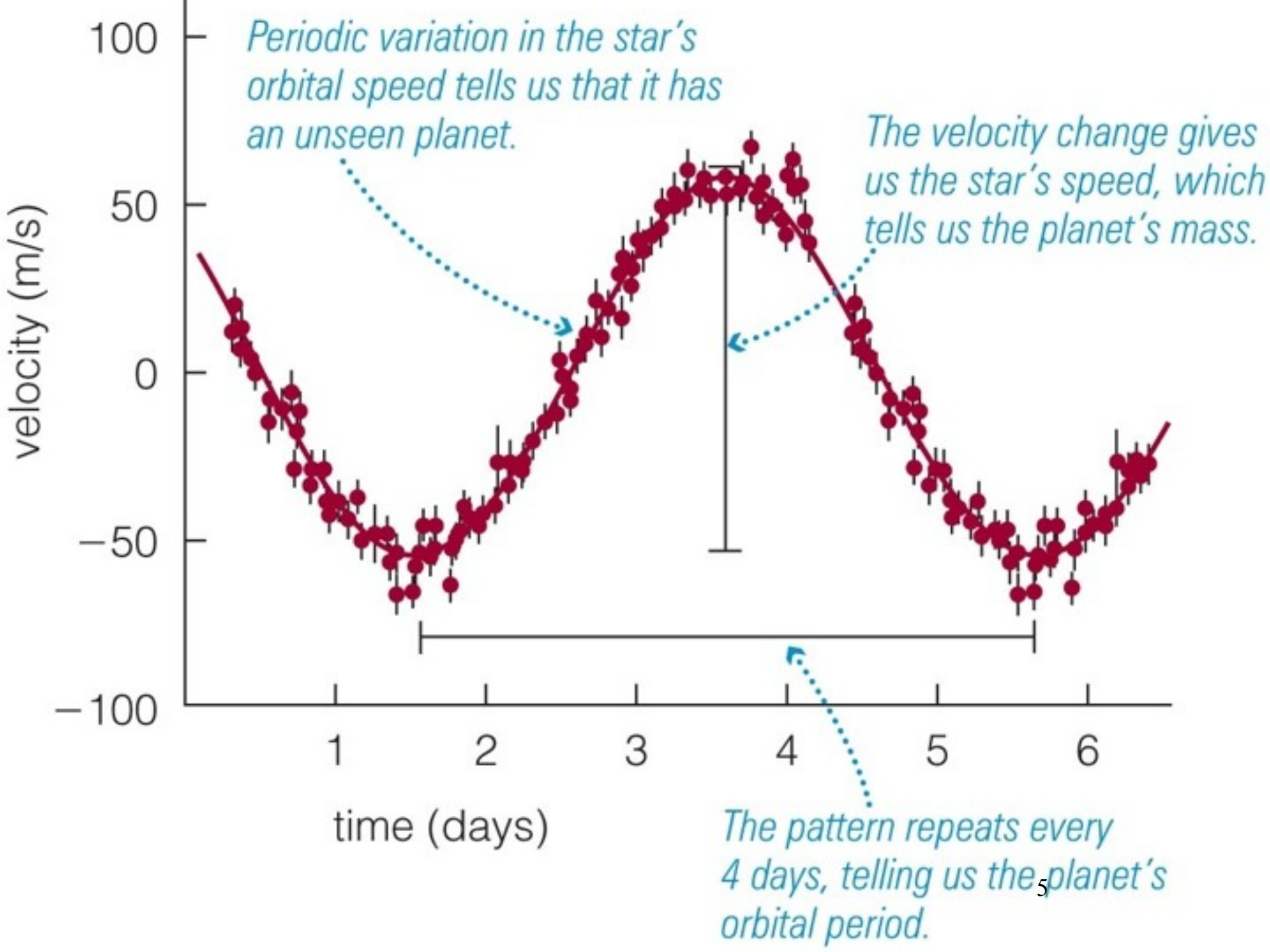


a Doppler shifts allow us to detect the slight motion of a star caused by an orbiting planet.

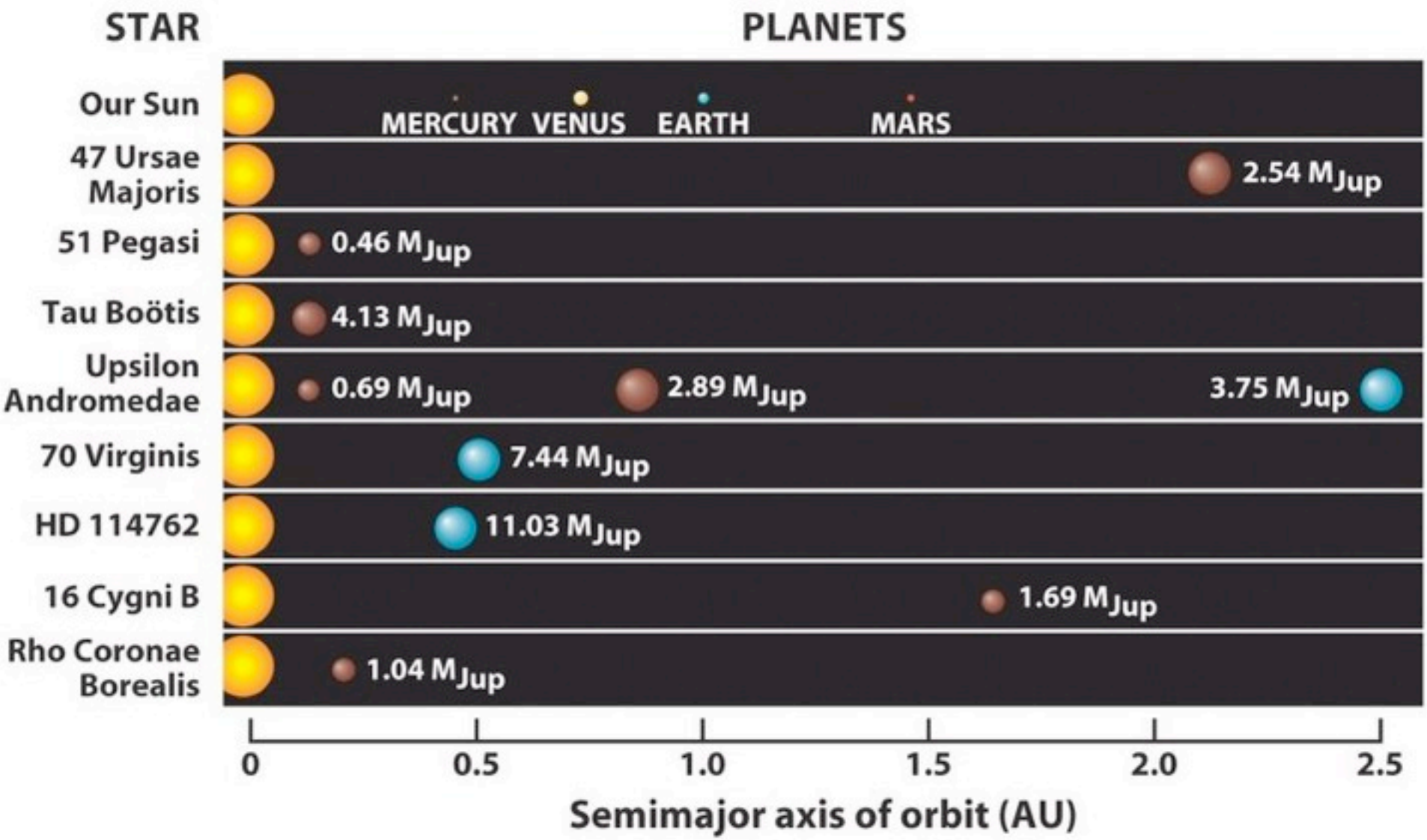
Gravitational Tugs

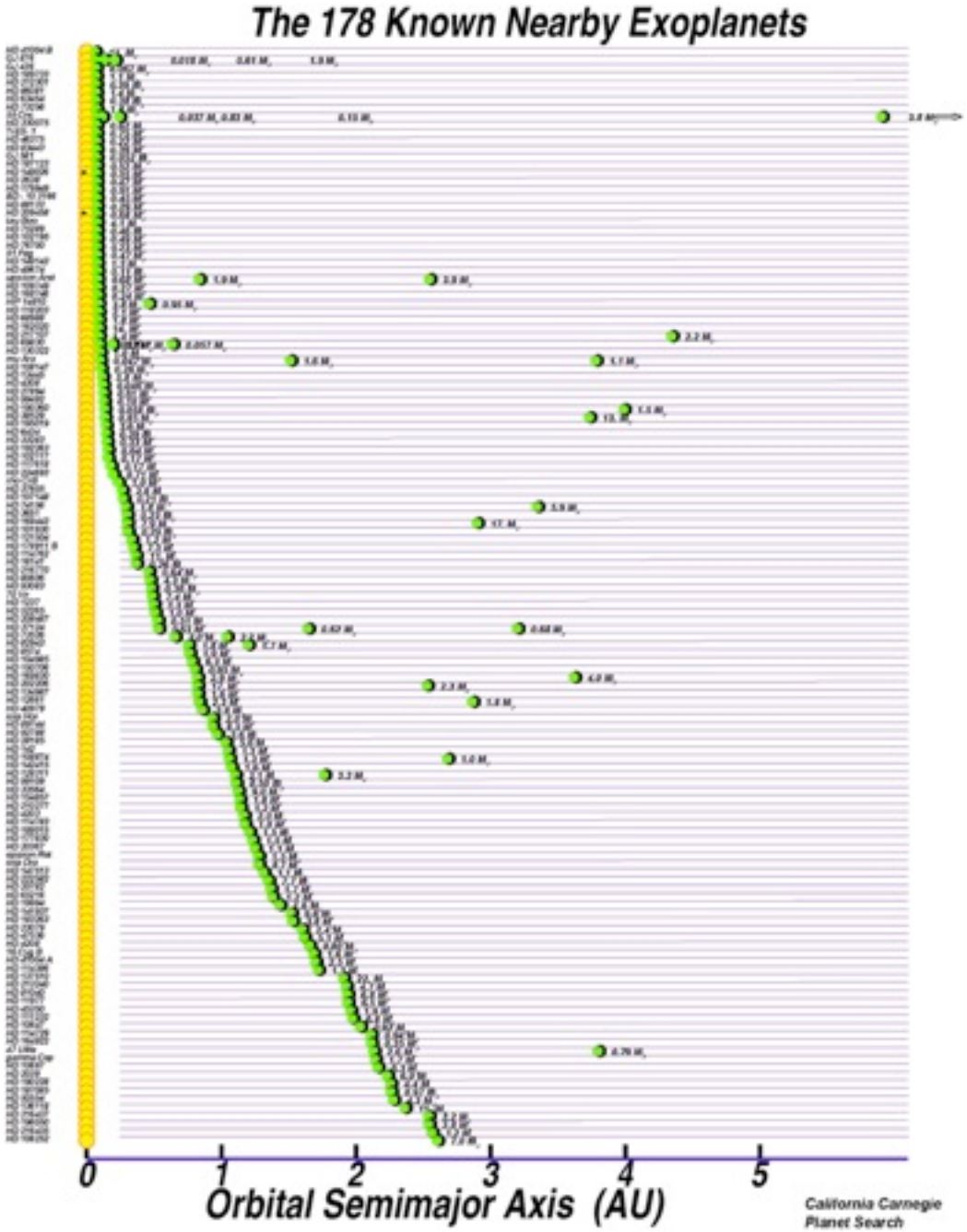


- The Sun's motion around the solar system's center of mass depends on tugs from all the planets.


Periodic variation in the star's orbital speed tells us that it has an unseen planet.
The velocity change gives us the star's speed, which tells us the planet's mass.
The pattern repeats every 4 days, telling us the planet's orbital period.
velocity (m/s)
100
50
0
−50
−100
1
2
3
4
5
6
time (days)

Planets around other stars

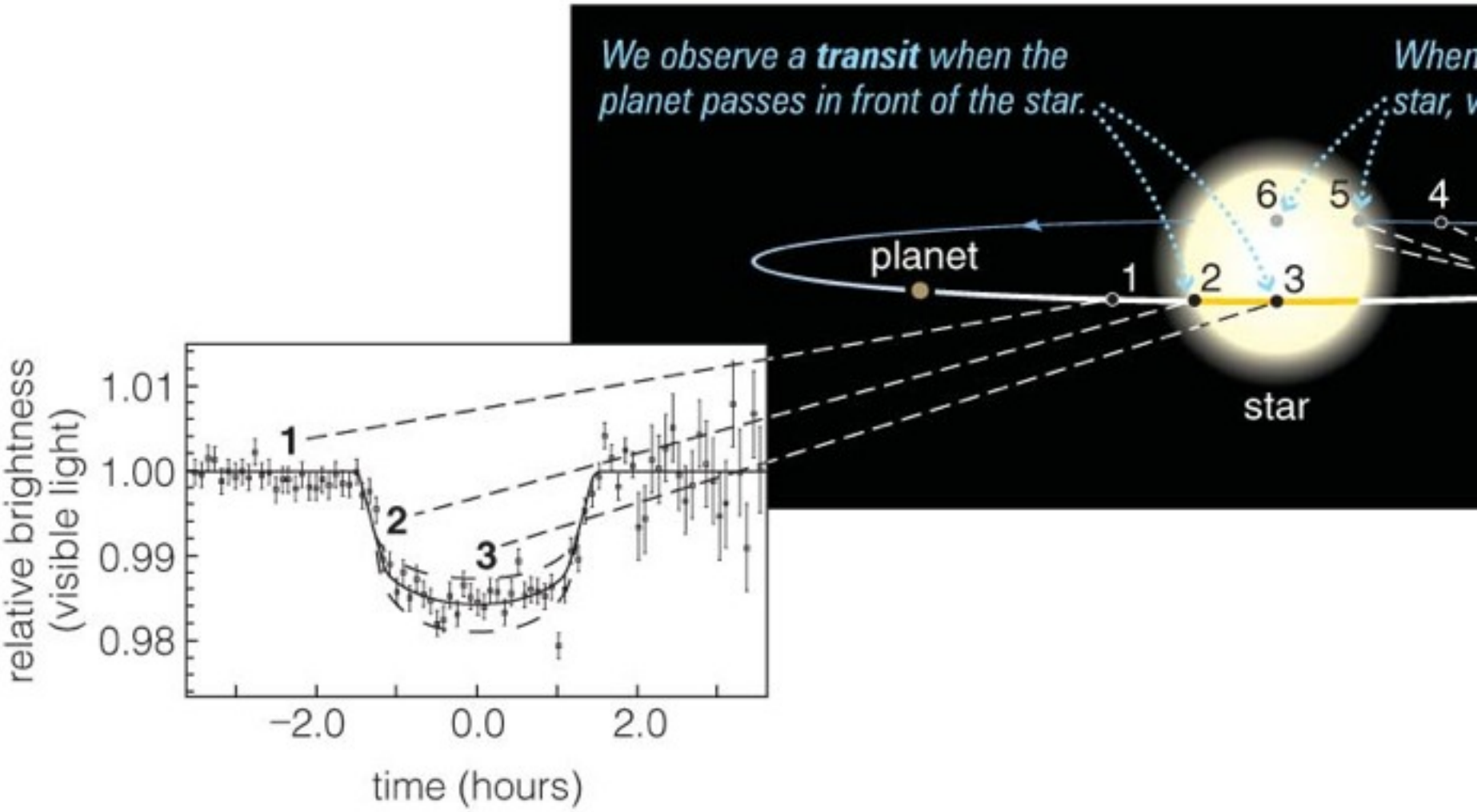


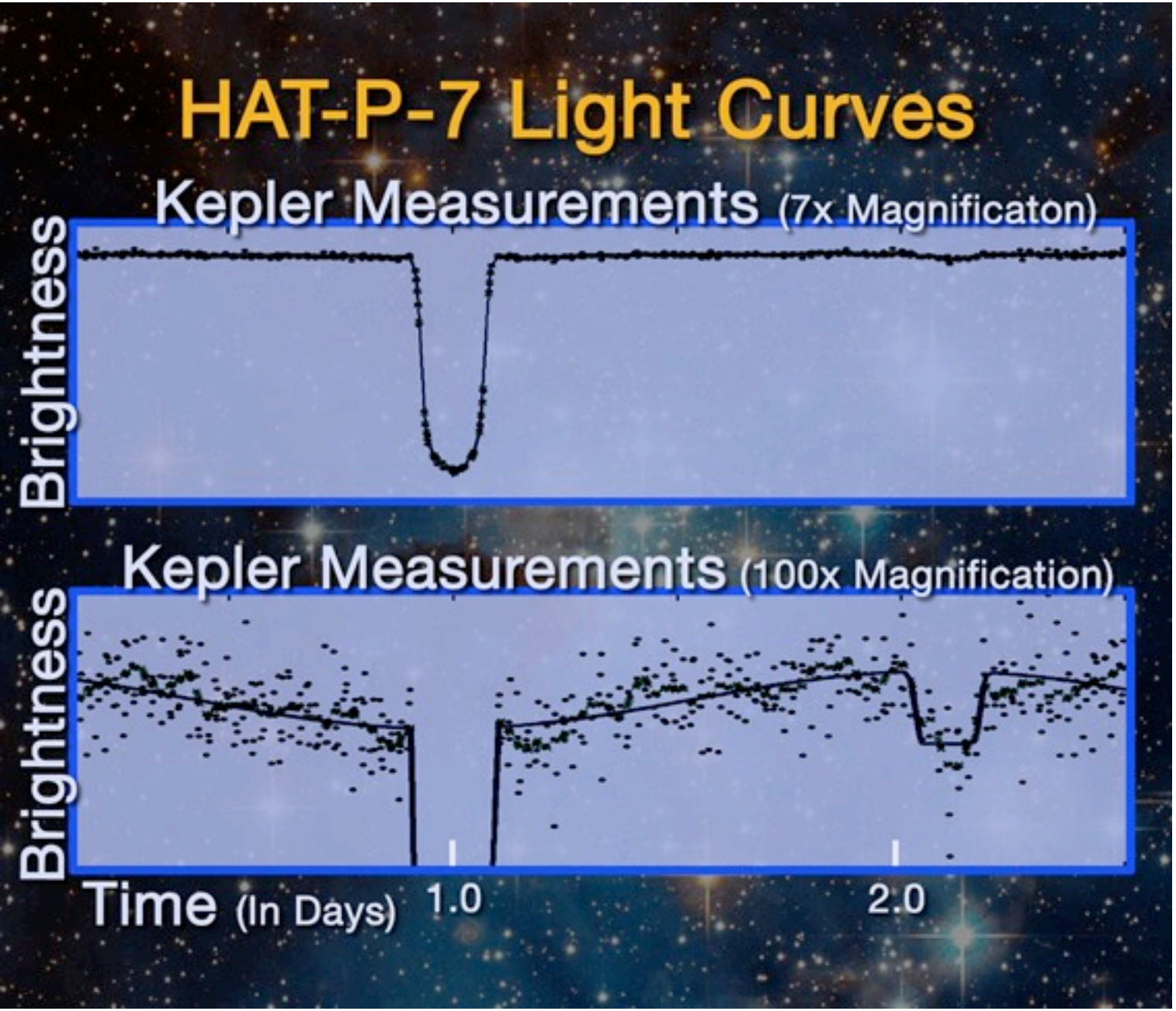


More being discovered all the time!

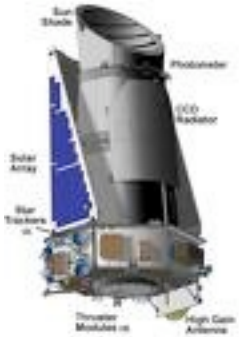
> 360 to date

Some planets detected via the Doppler effect have been confirmed by transit observations:





NASA Kepler mission



Phase variations detected!

Telescopes

- Telescopes collect more light than our eyes ⇒ **light-collecting area**
- Telescopes can see more detail than our eyes ⇒ **angular resolution**
- Telescopes/instruments can detect light that is invisible to our eyes (e.g., infrared, ultraviolet)

Bigger is better

1. Larger light-collecting area

   can see fainter things

2. Better angular resolution

   can see smaller things

Bigger is better

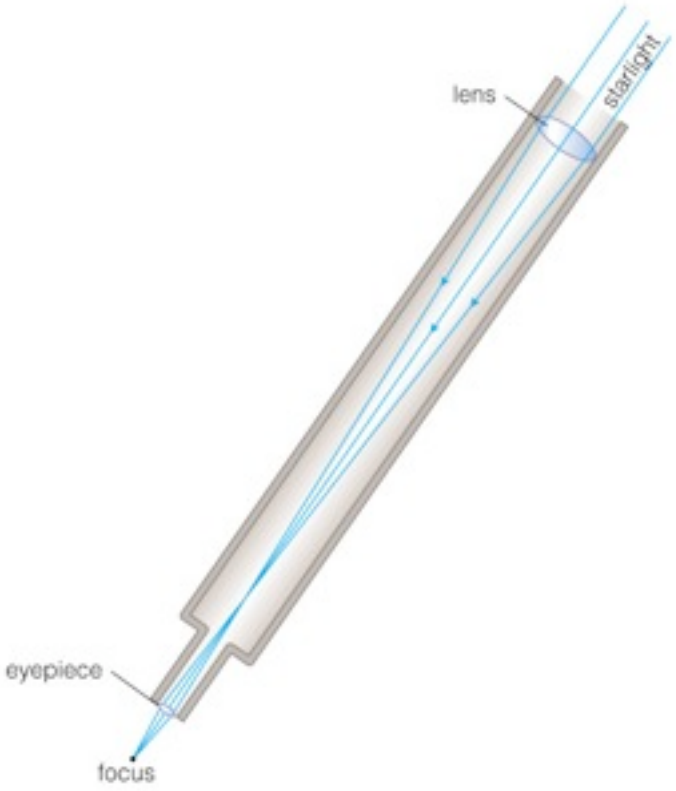
For a telescope with mirror of diameter D,

can see fainter: $b^{-1} \propto D^2$

with higher resolution: $\theta \propto \frac{\lambda}{D}$

Basic Telescope Design

- Refracting: lenses

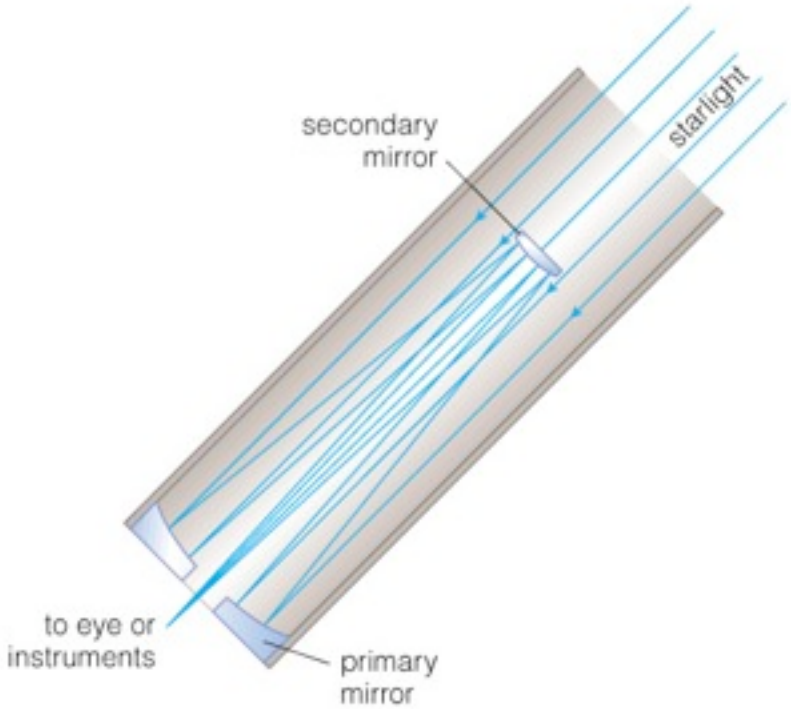


Refracting telescope

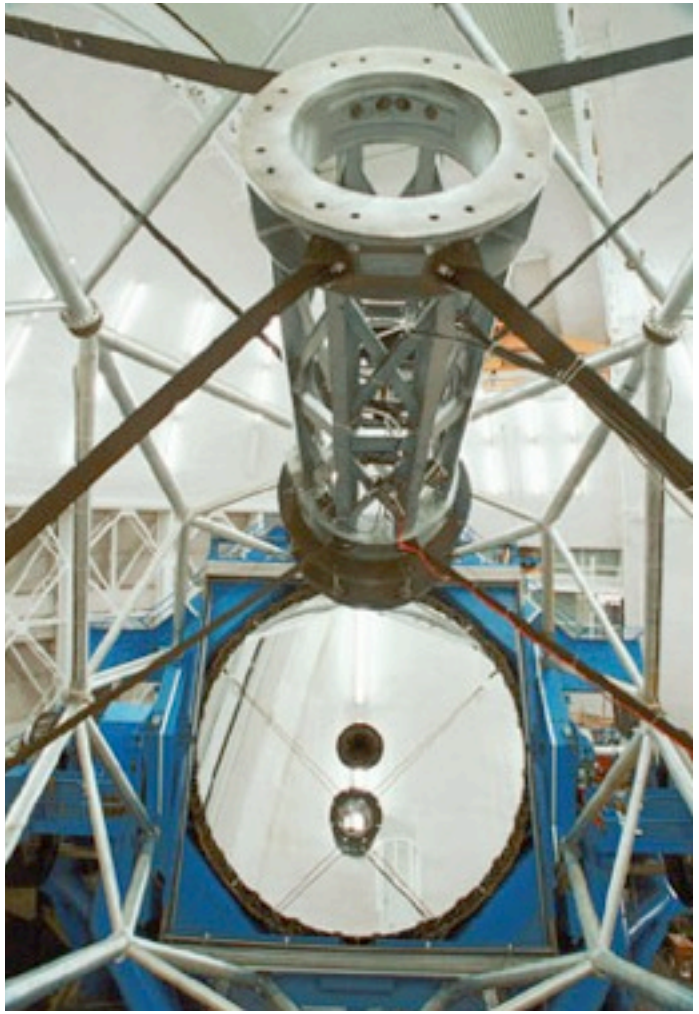
Yerkes 1-m refractor

Basic Telescope Design

- Reflecting: mirrors
- Most research telescopes today are reflecting



Reflecting telescope



Gemini North 8-m

Different designs for different wavelengths of light

Radio telescope (Arecibo, Puerto Rico)

Longer wavelengths need larger “mirrors”

Interferometry

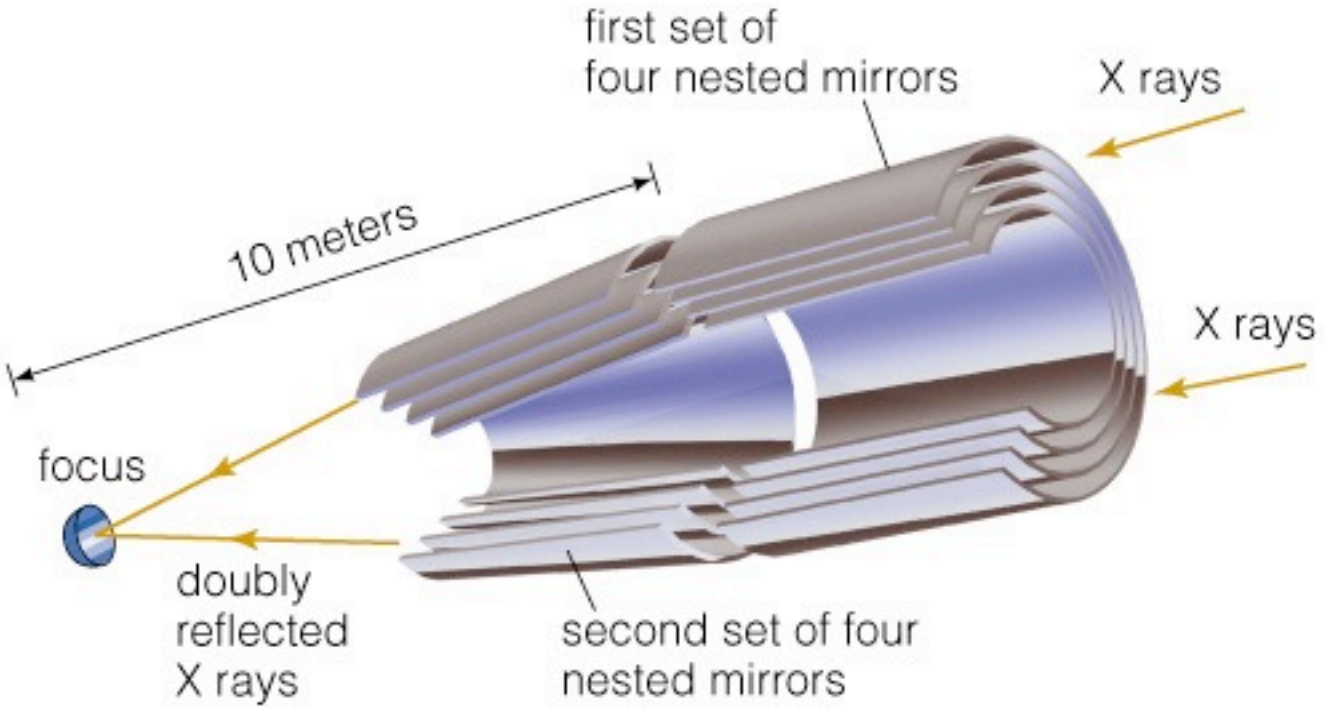
- This technique allows two or more small telescopes to work together to obtain the *angular resolution* of a larger telescope.

Very Large Array (VLA), New Mexico

Very Large Array (VLA), New Mexico

angular resolution of a telescope this size

X-ray telescope: “grazing incidence” optics



Mirror elements are 0.8 m long and from 0.6 m to 1.2 m in diameter.

b

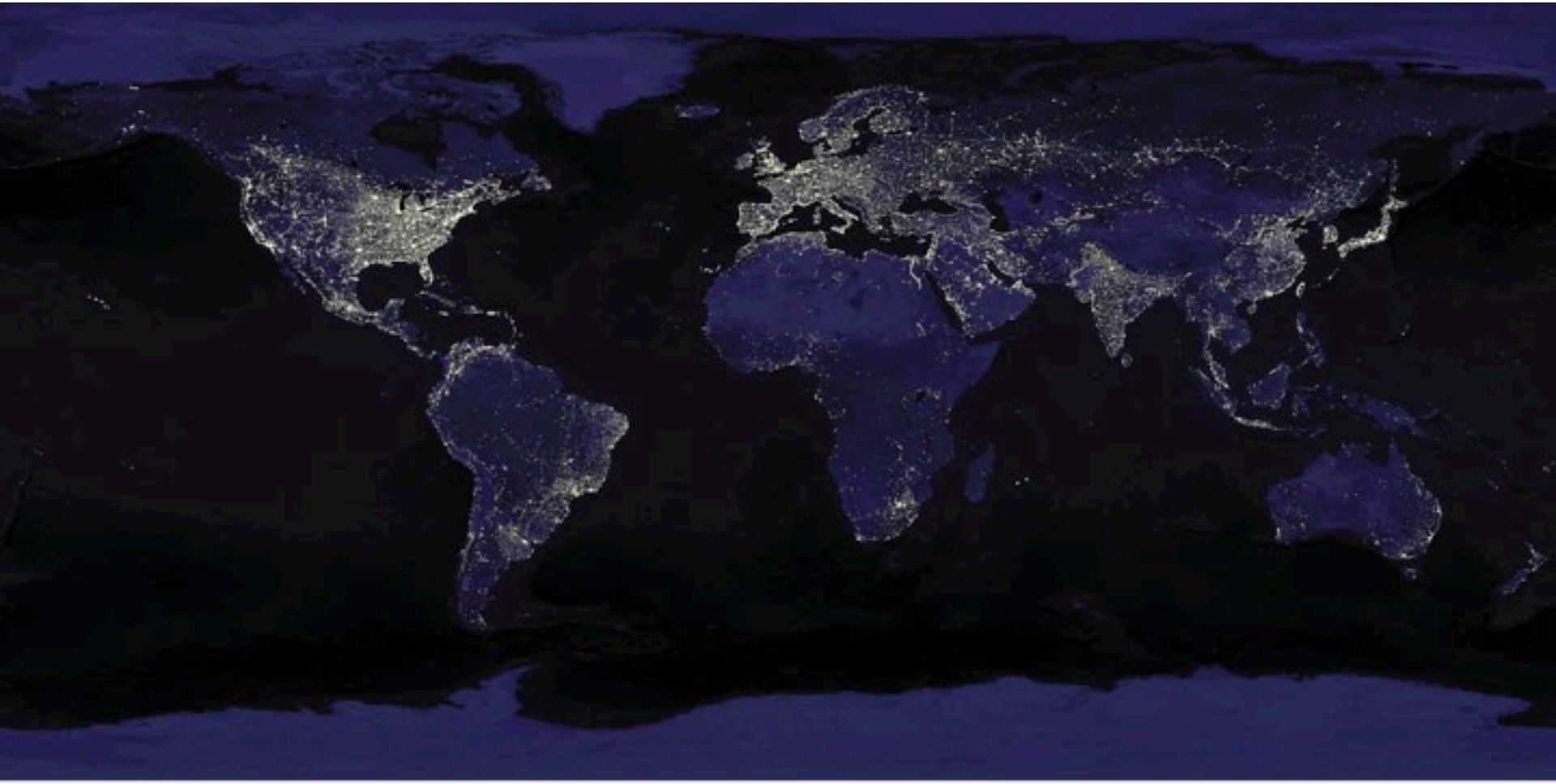
Advantages of telescopes in space

Hubble

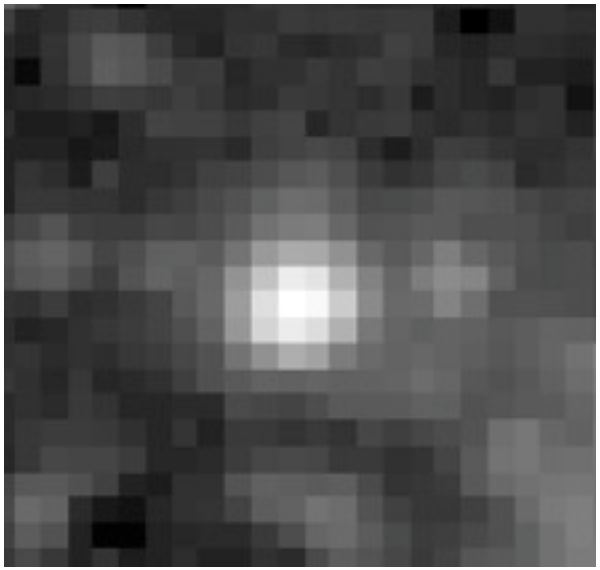
Chandra

Observing problems due to Earth's atmosphere

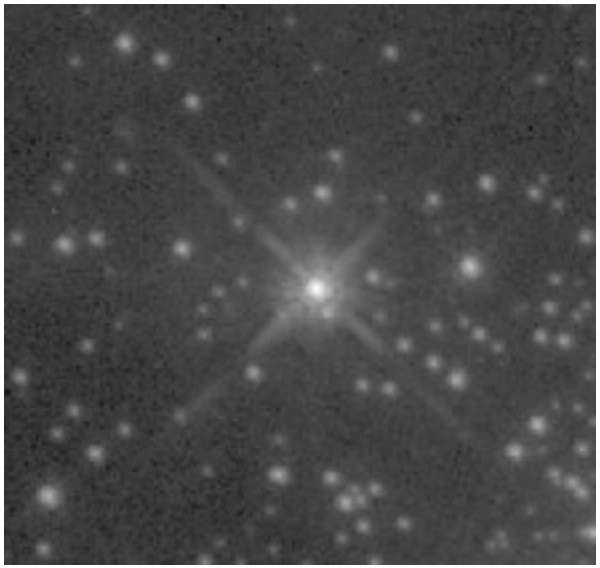
1. Light Pollution



2. Atmospheric Turbulence causes *twinkling* ⇒ blurs images (called "seeing" by astronomers).



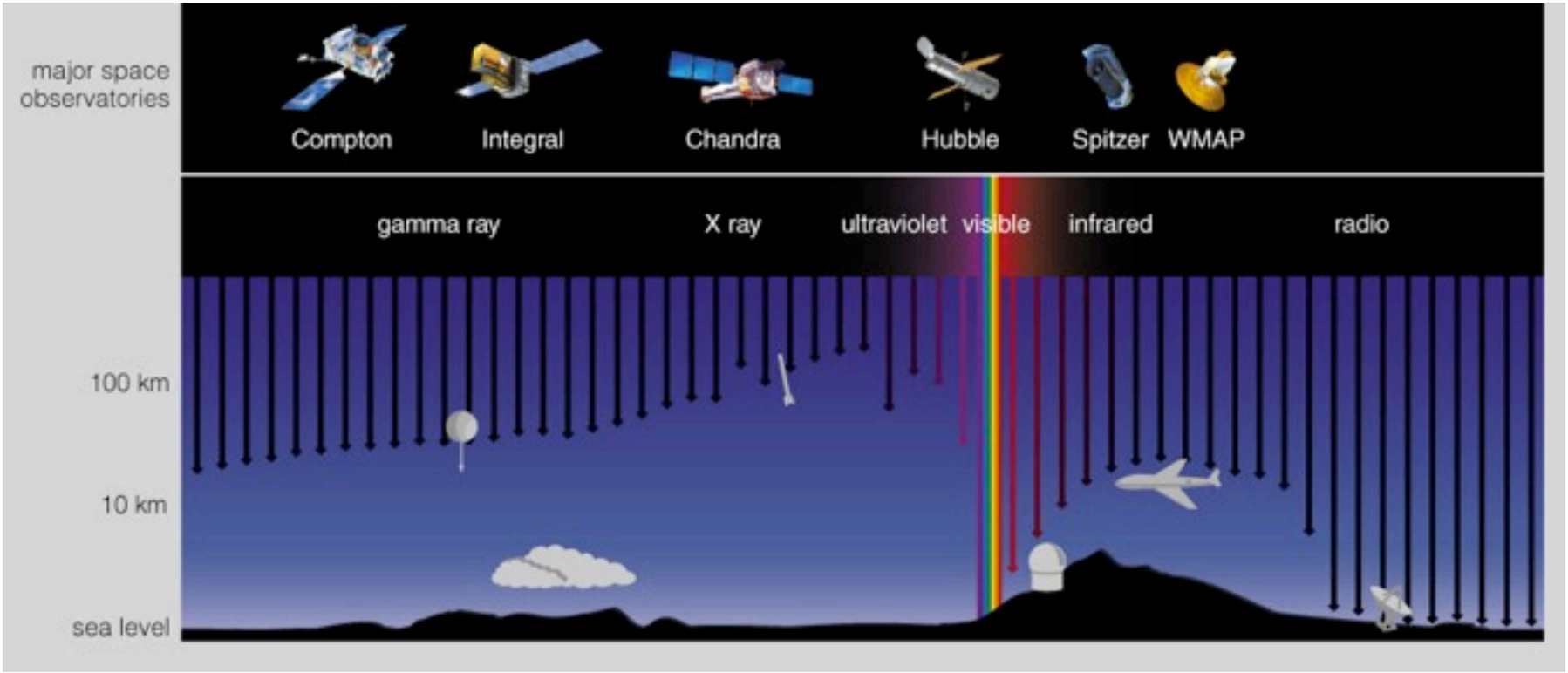
Star viewed with ground-based telescope



View from Hubble Space Telescope

3. Atmosphere absorbs most of EM spectrum, including all UV and X ray and most infrared.

Kepler

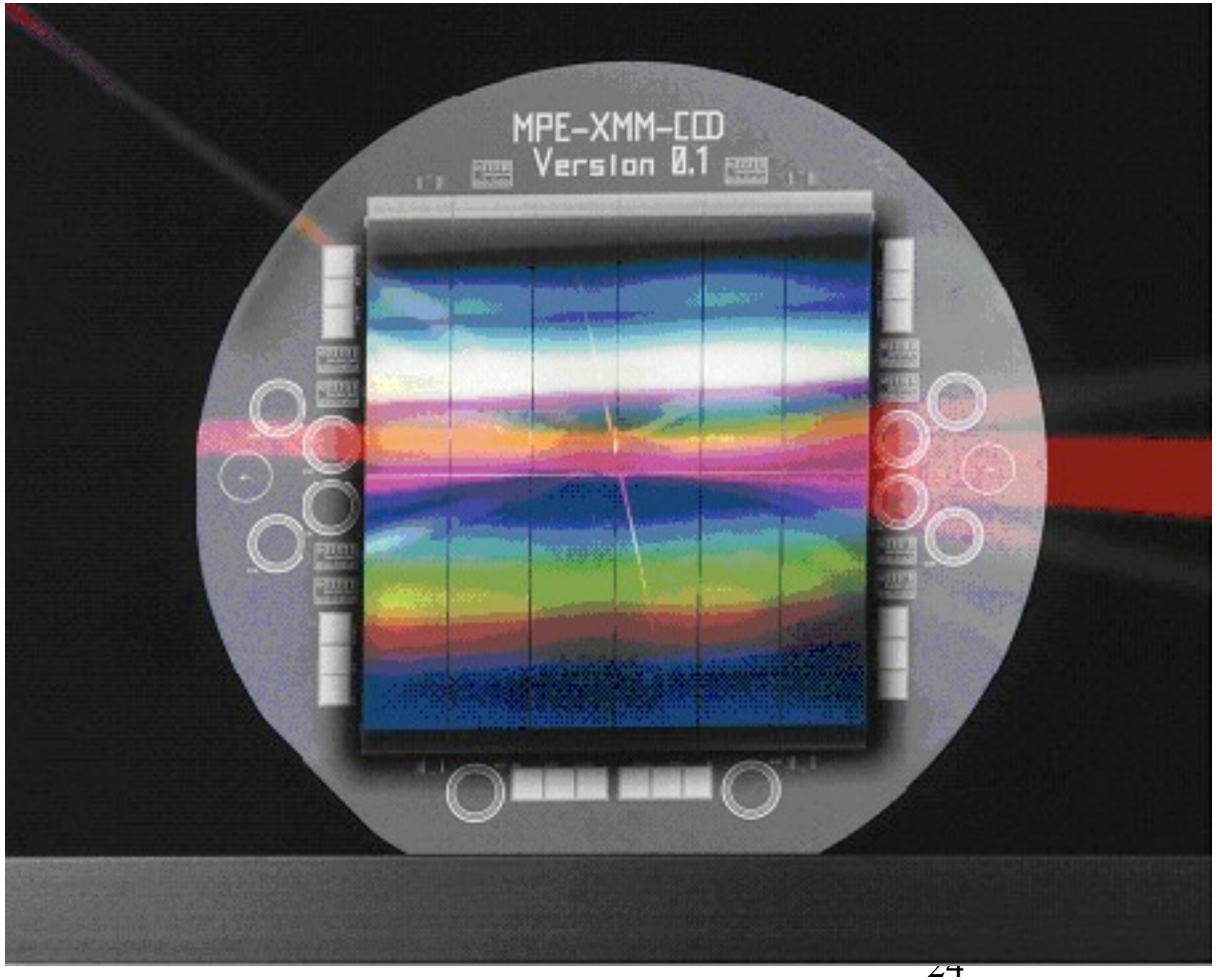


Telescopes in space solve all 3 problems.

Chandra X-ray Observatory

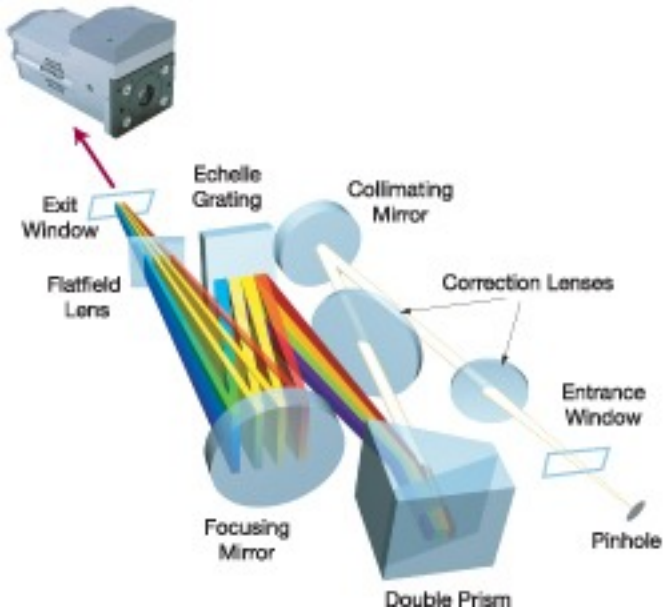
Instruments

- Cameras

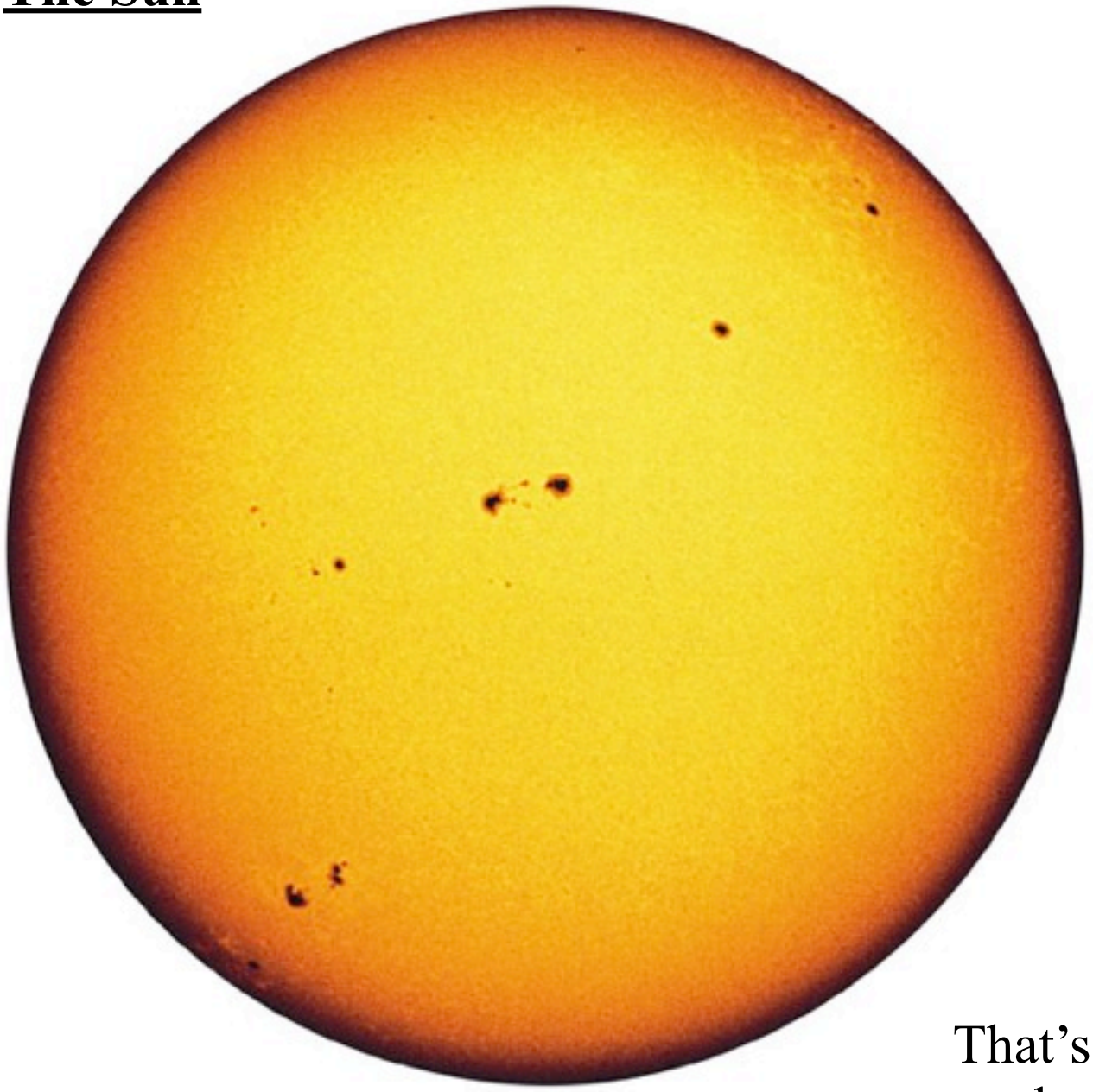


Instruments

- Spectrographs



The Sun



Radius:

6.9×10^8 m

(109 times Earth)

Mass:

2×10^{30} kg

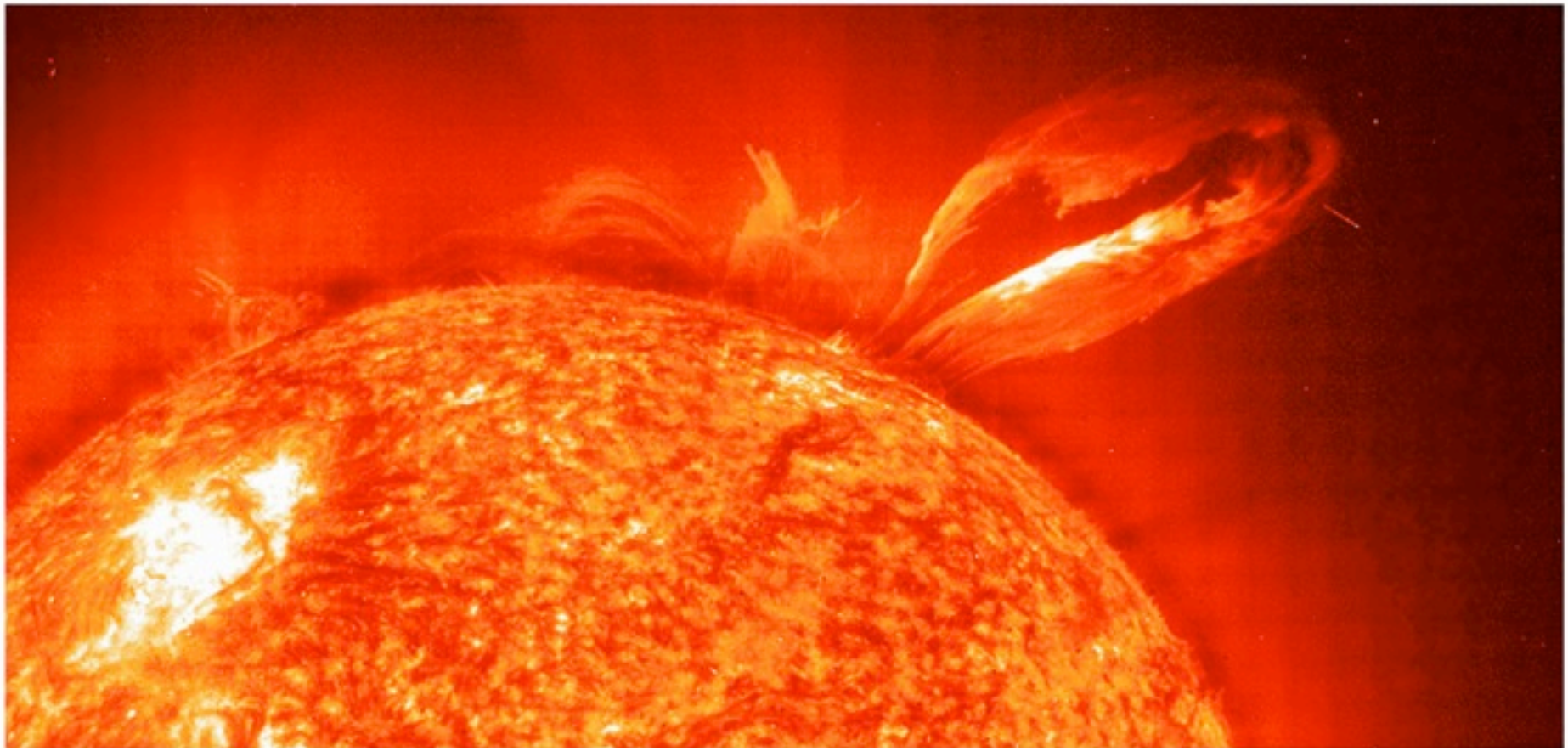
(1,000 Jupiters;
300,000 Earths)

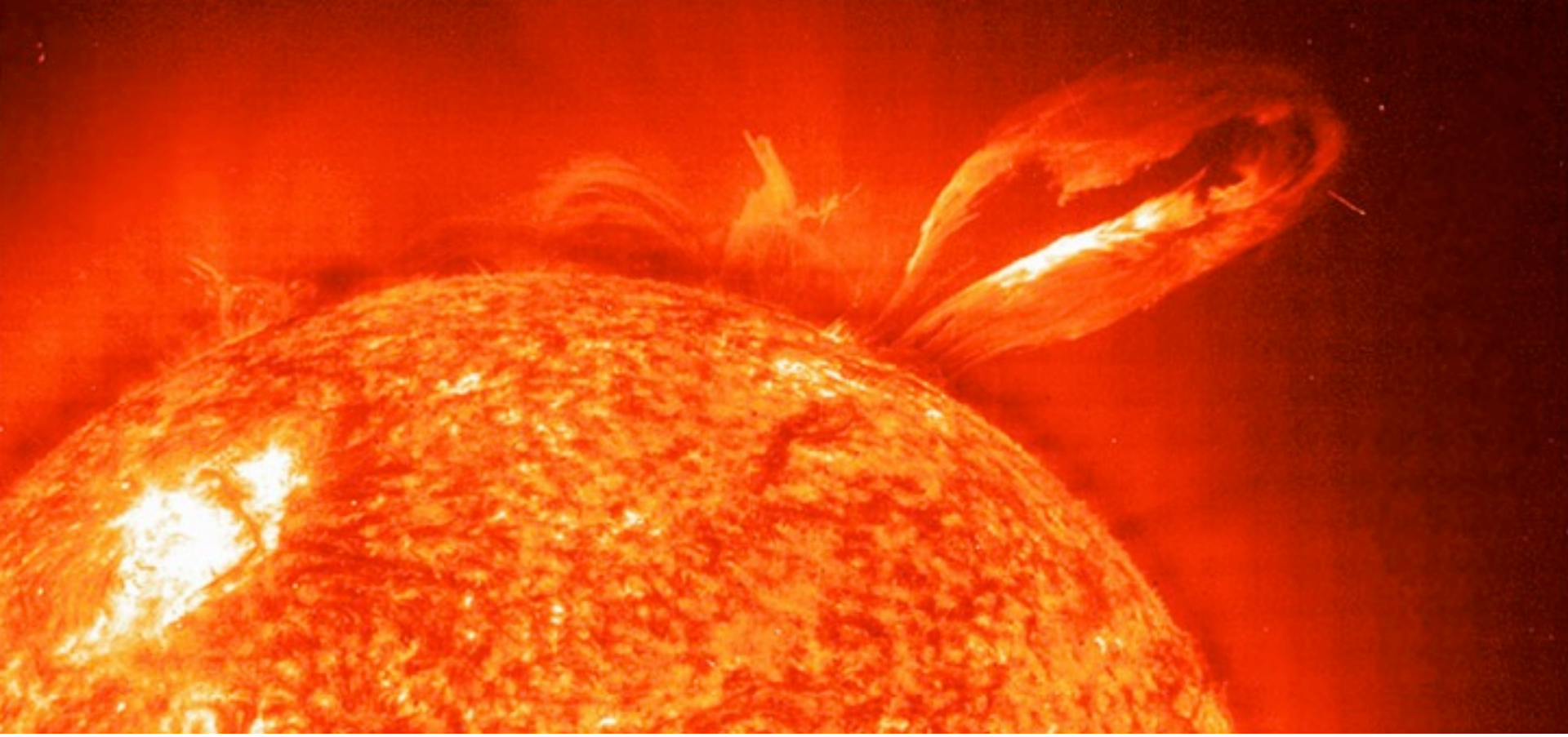
Luminosity:

3.8×10^{26} watts

That's about a billion big nuclear bombs every second

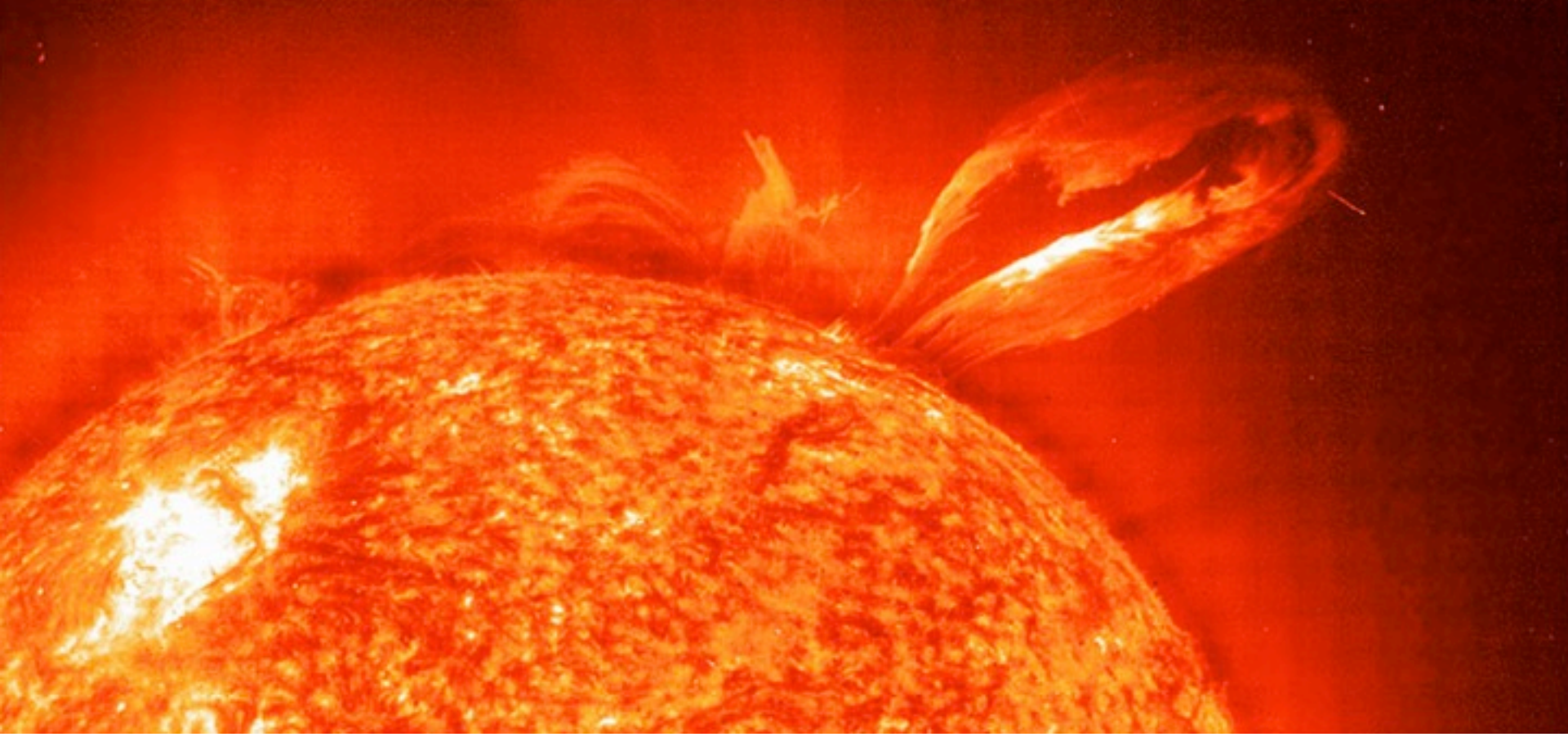
Why does the Sun shine?





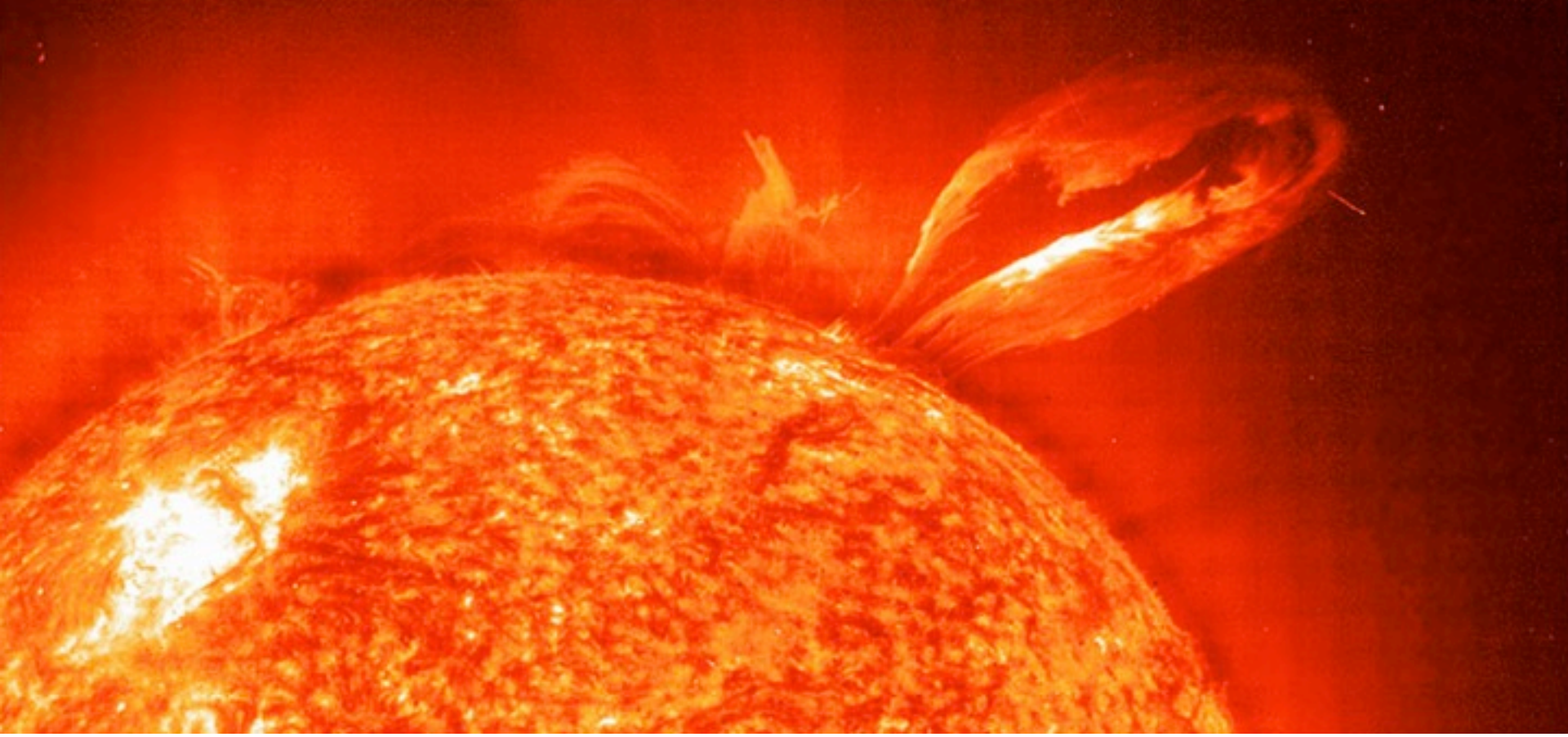
Is it on FIRE? … NO! ...not enough energy, not enough oxygen

$$\frac{\text{Chemical Energy Content}}{\text{Luminosity}} \sim 10{,}000 \text{ years}$$



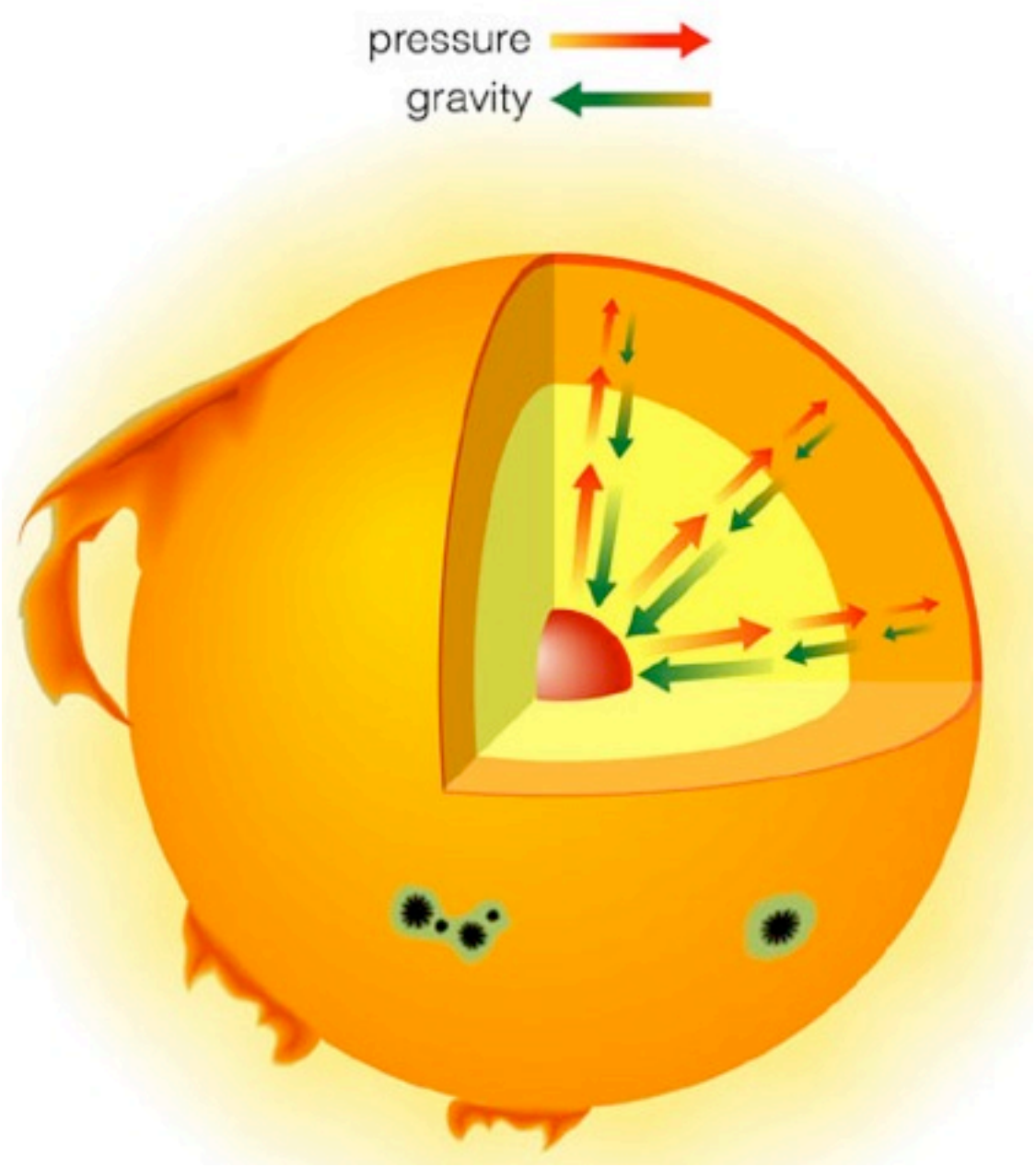
Is it CONTRACTING? … NO!

$$\frac{\text{Gravitational Potential Energy}}{\text{Luminosity}} \sim 25 \text{ million years}$$



It is powered by NUCLEAR ENERGY!

$$\frac{\text{Nuclear Potential Energy}}{\text{Luminosity}} \sim 10 \text{ billion years}$$



Stars are stable: pressure balances gravity.

Hydrostatic equilibrium:

Energy released by nuclear fusion in the core of the sun heats the surrounding gas. The resultant pressure balances the relentless crush of gravity.