Today

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

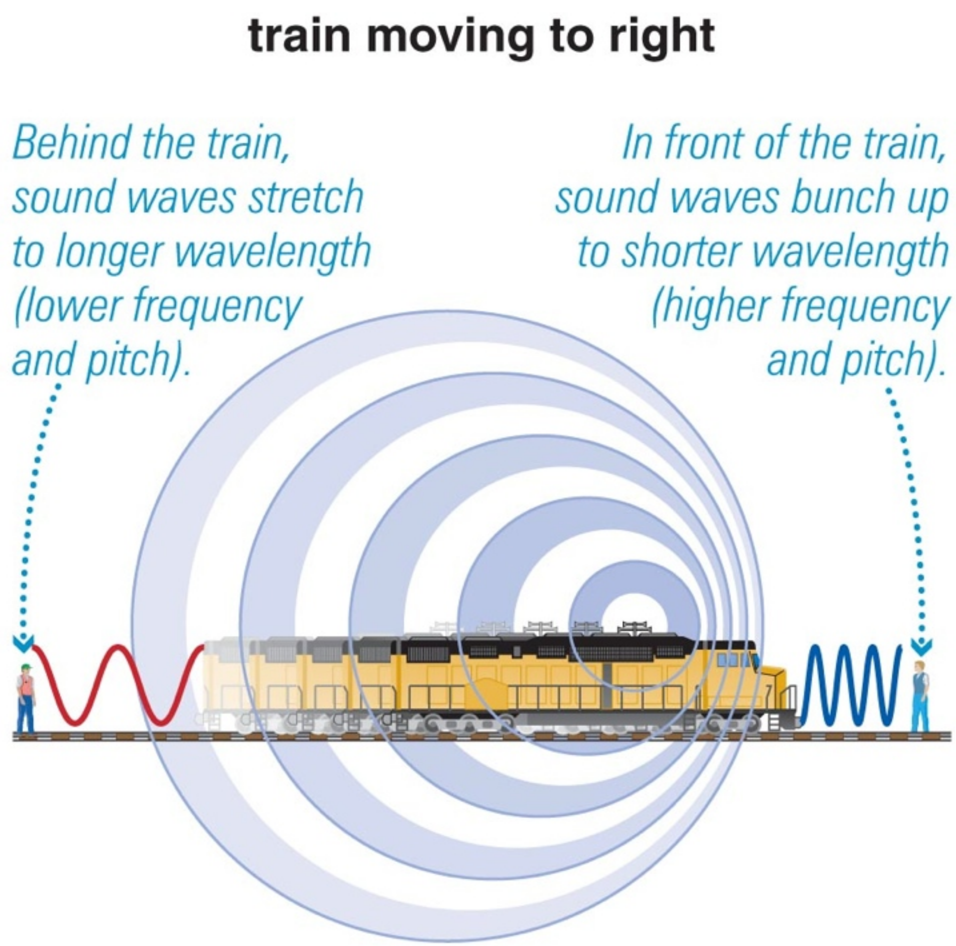
Extra credit (2 points)

- Spectral lines from atoms happen because of transitions of electrons. Name one of the two *other* types of transitions that can happen in molecules to produce lines

- Be sure to include your name and section number

- You may consult your notes, but do not communicate with anyone else

The Doppler Effect



b For a moving train, the sound you hear depends on whether the train is moving toward you or away from you.

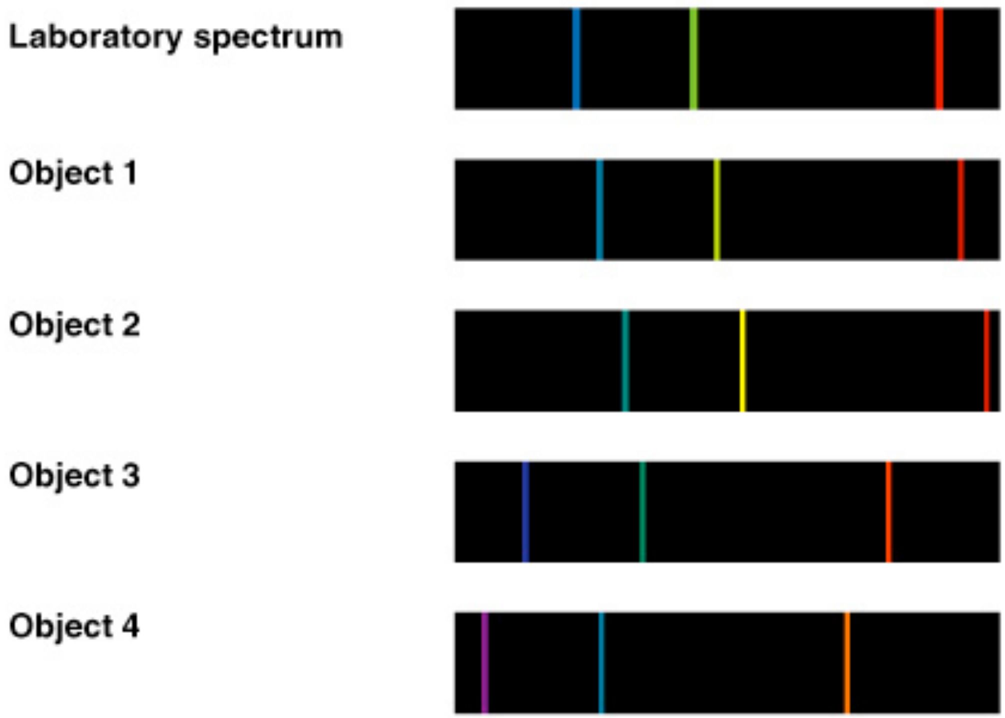
H2-41
doppler
ball

Doppler Effect for Light

- Motion away -> redshift
- Motion towards -> blueshift

$$\frac{\Delta\lambda}{\lambda} = \frac{\lambda_{obs} - \lambda_{em}}{\lambda_{em}} = \frac{v}{c}$$

Measuring the Shift



Stationary

Moving Away

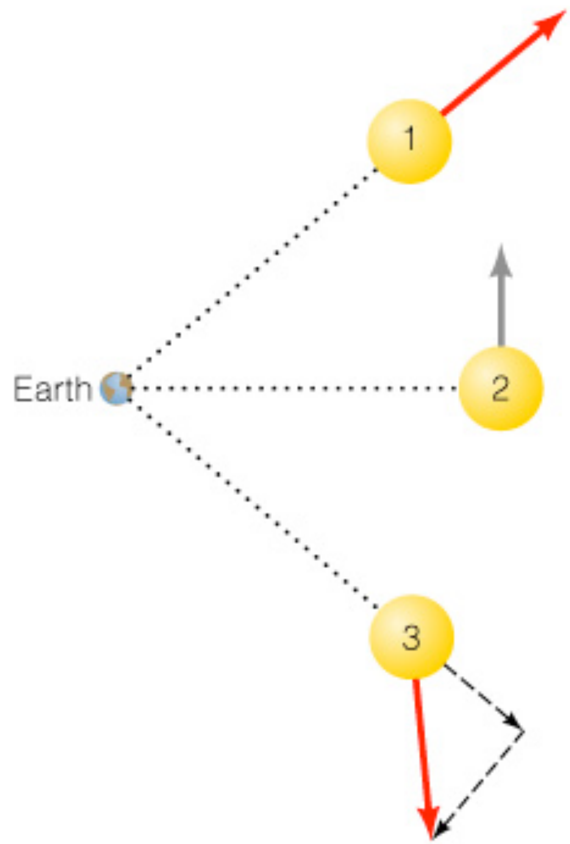
Away Faster

Moving Toward

Toward Faster

- We generally measure the Doppler effect from shifts in the wavelengths of spectral lines.

Doppler shift tells us ONLY about the part of an object's motion toward or away from us (along our line of sight).



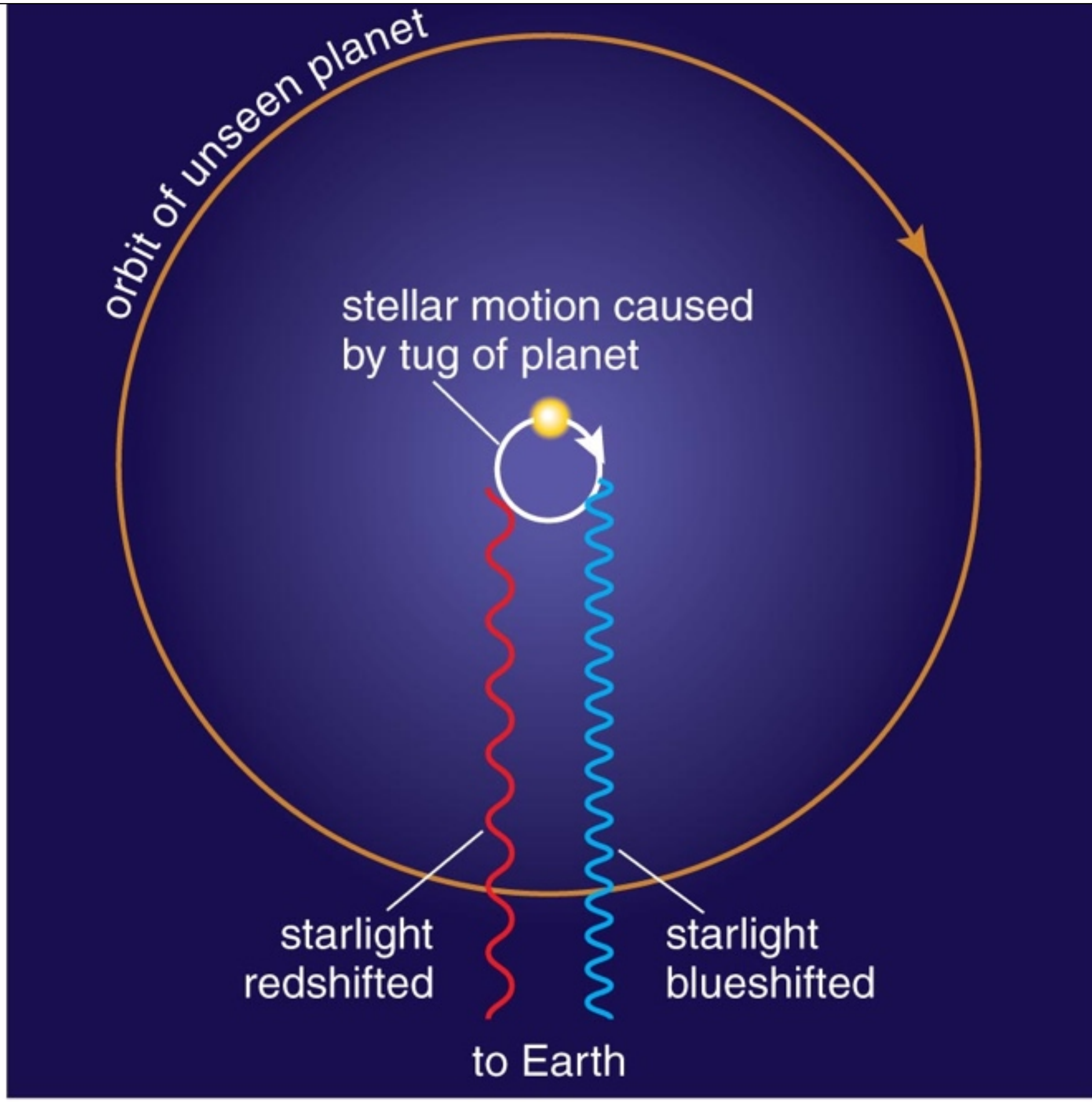
maximum doppler effect

no doppler effect

intermediate case

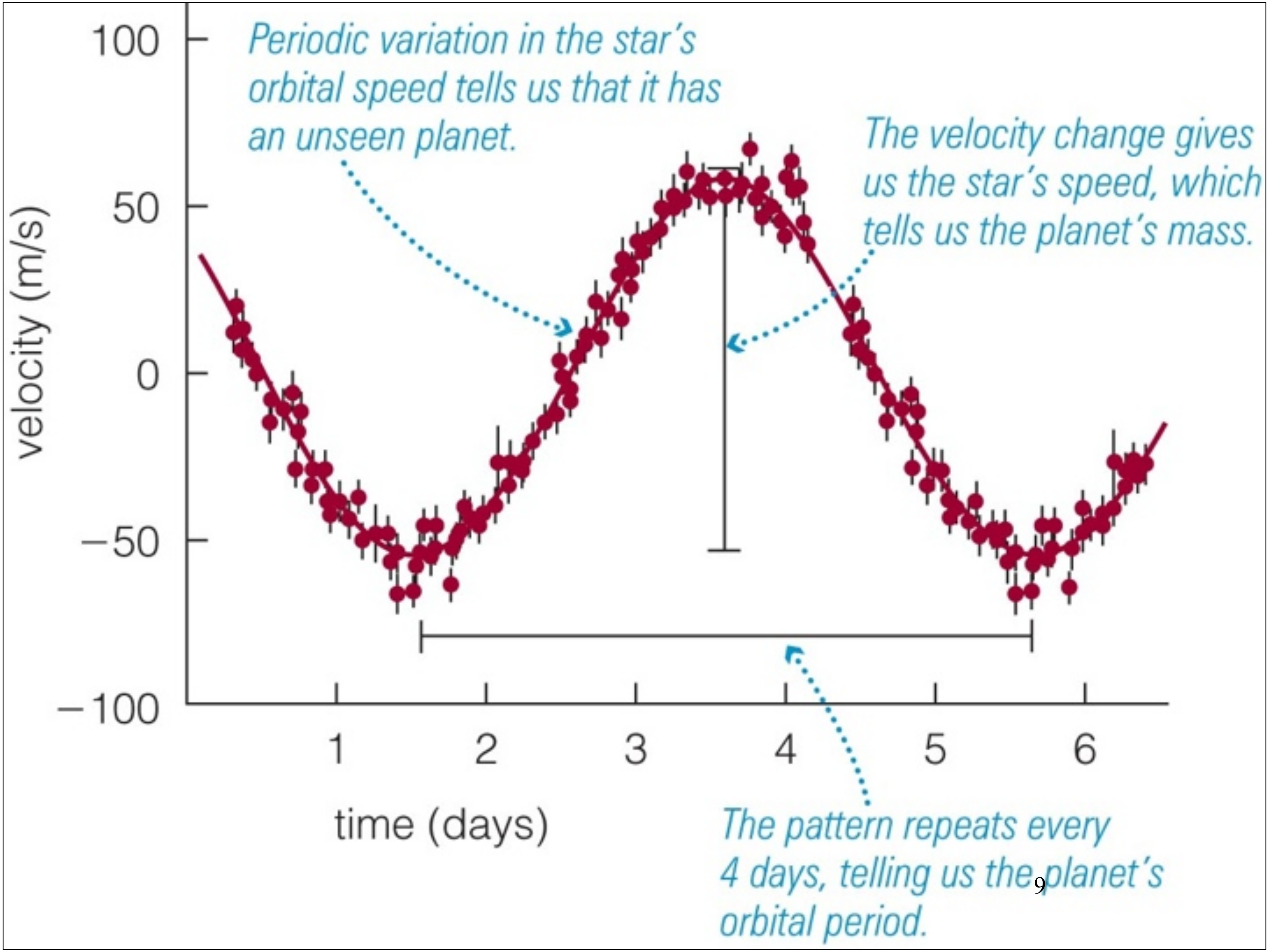
Doppler Application

- Extrasolar planets

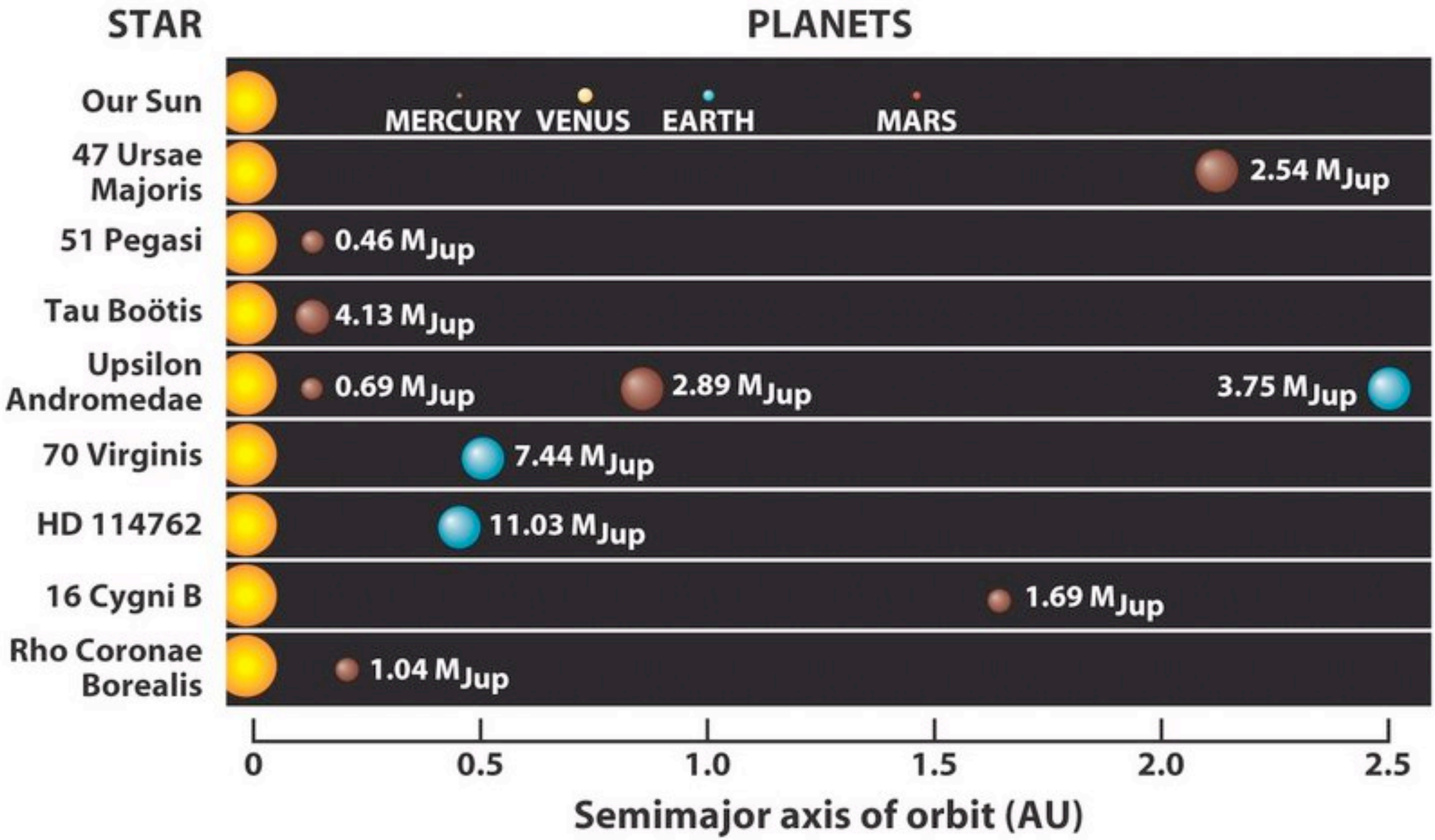


C1-01

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

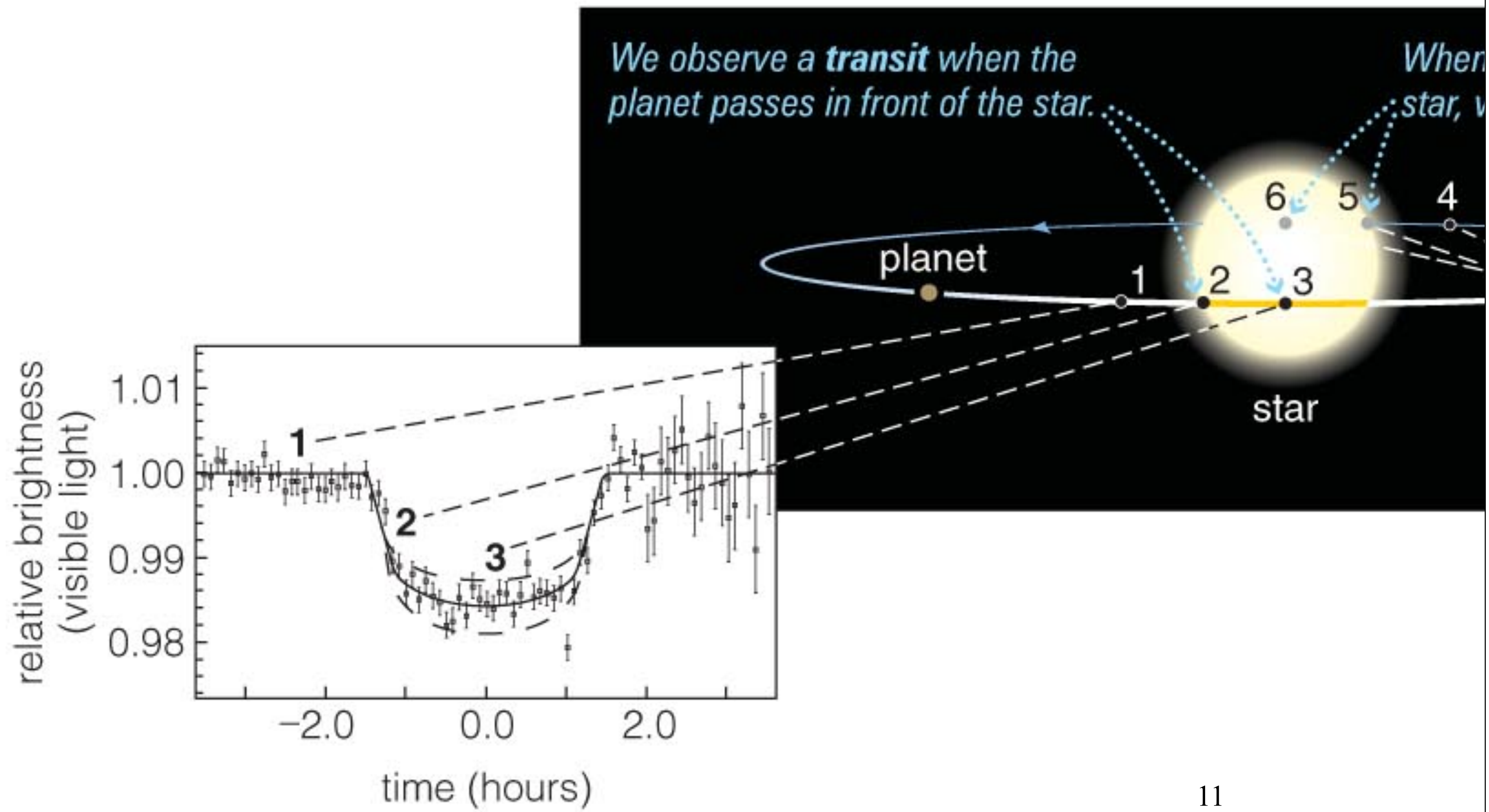

Periodic variation in the star's orbital speed tells us that it has an unseen planet.
The velocity change gives us the star's speed, which tells us the planet's mass.
The pattern repeats every 4 days, telling us the planet's orbital period.
velocity (m/s)
100
50
0
−50
−100
1
2
3
4
5
6
time (days)

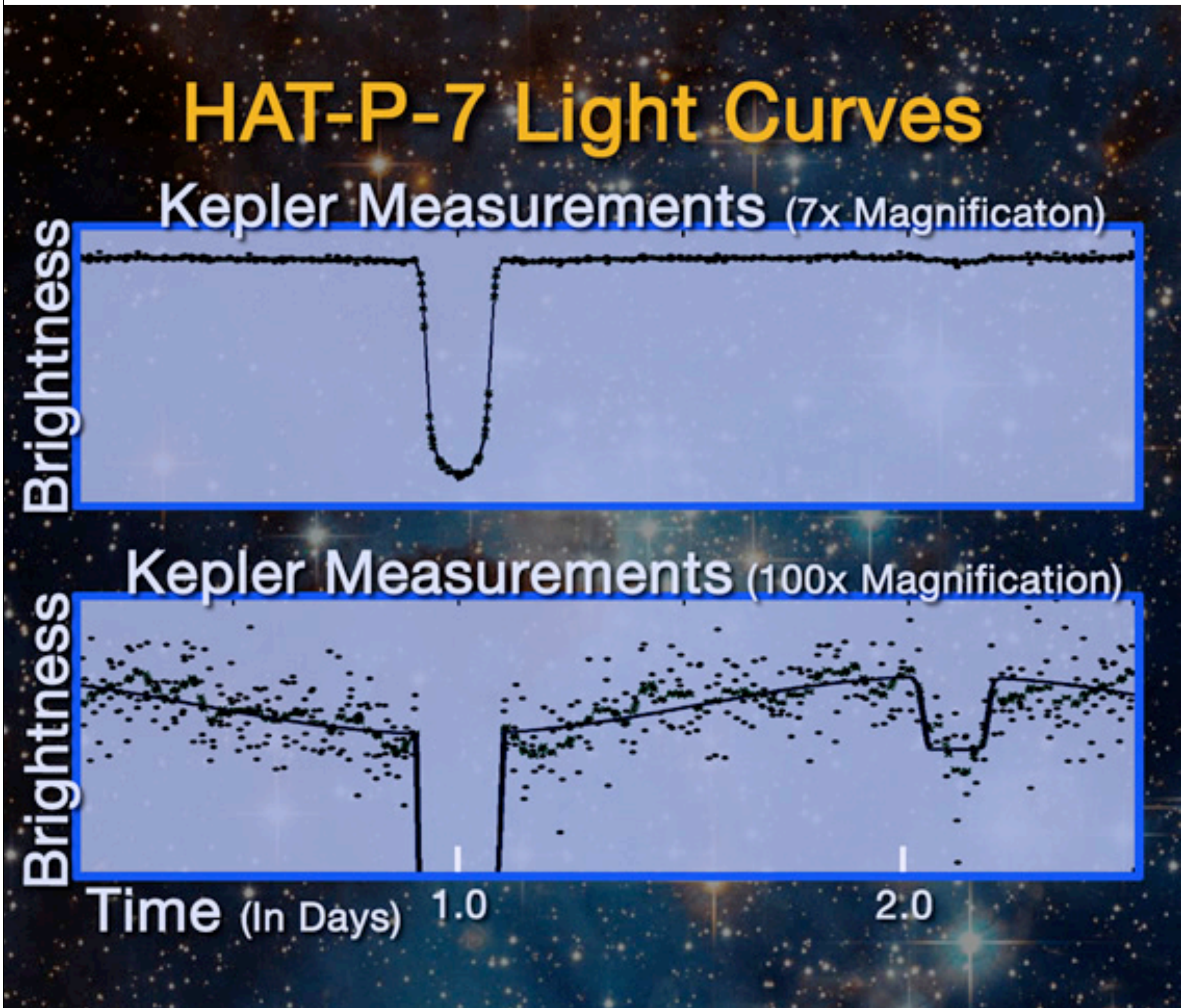
Example planets around other stars



More than 1000 detected!

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: $$\theta \propto \frac{\lambda}{D}$$

Light Collecting Area

The biggest optical telescope c. 1900 was 1 meter in diameter. The biggest telescope now is 10 meters in diameter. What is the ratio of collecting area?

A. 10 m has same collecting area

B. 10 m has 10x collecting area

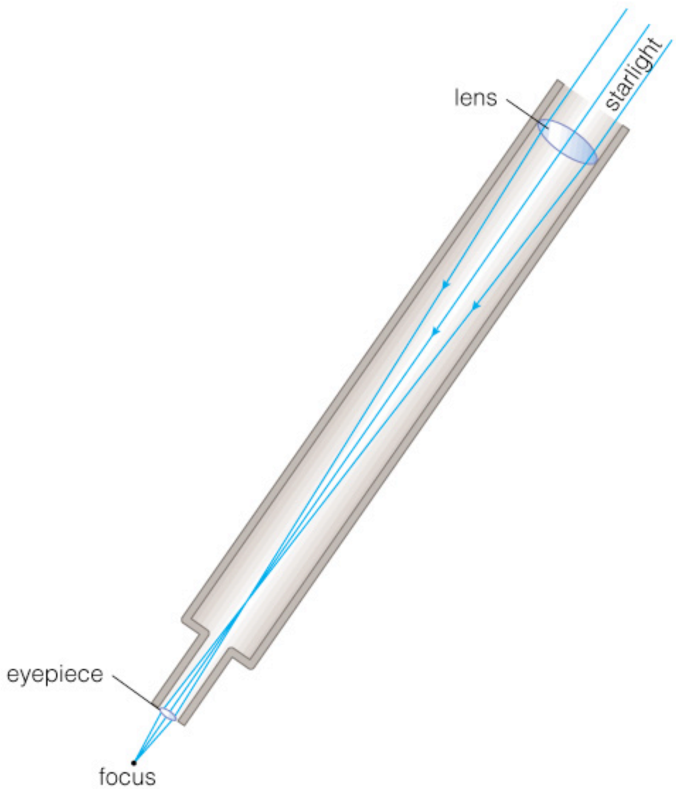
C. 10m has 100x collecting area

D. 10m has 1000x collecting area

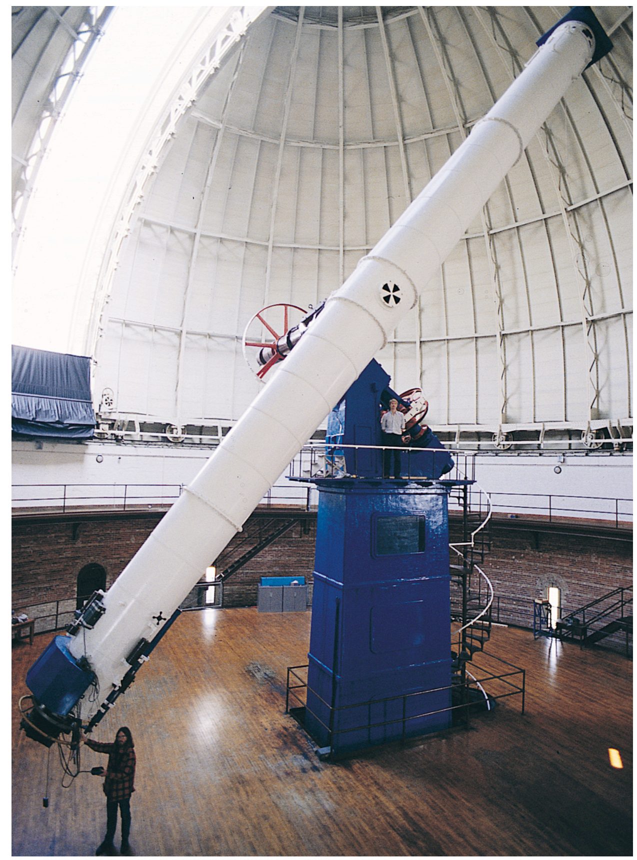
E. I don't know

Basic Telescope Design

- Refracting: lenses



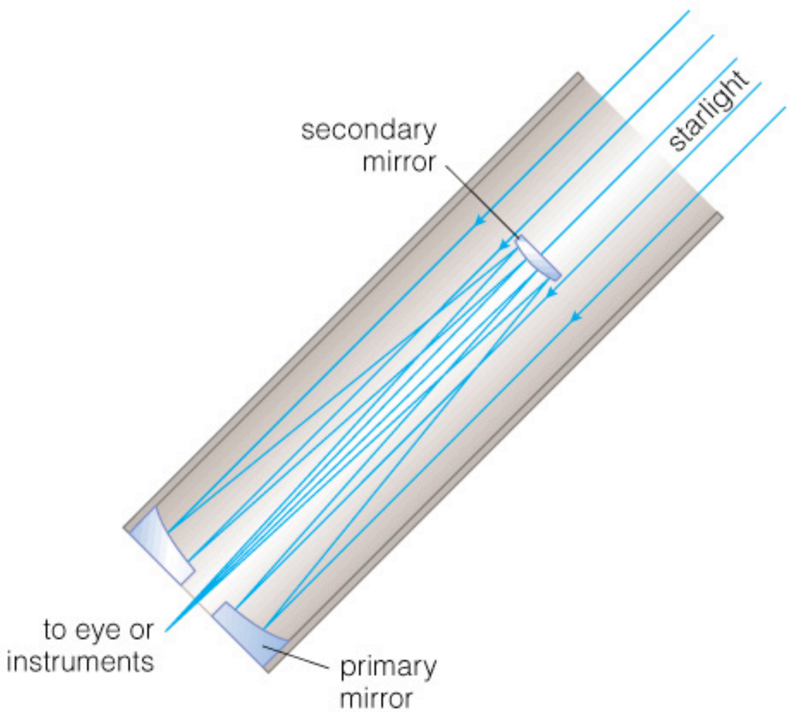
Refracting telescope



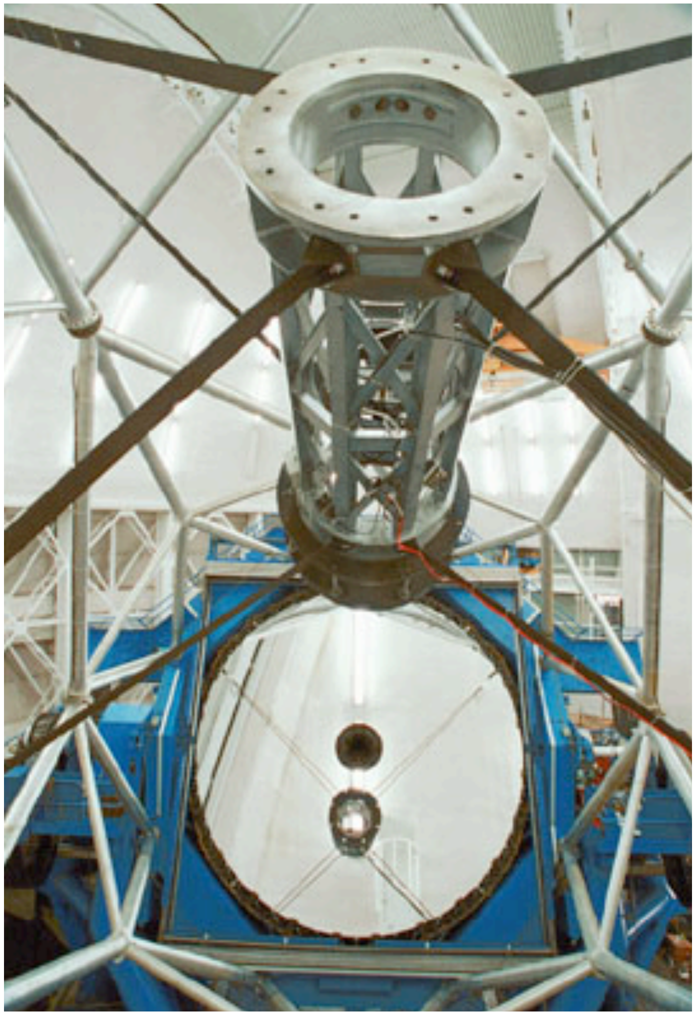
Yerkes 1-m refractor

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”

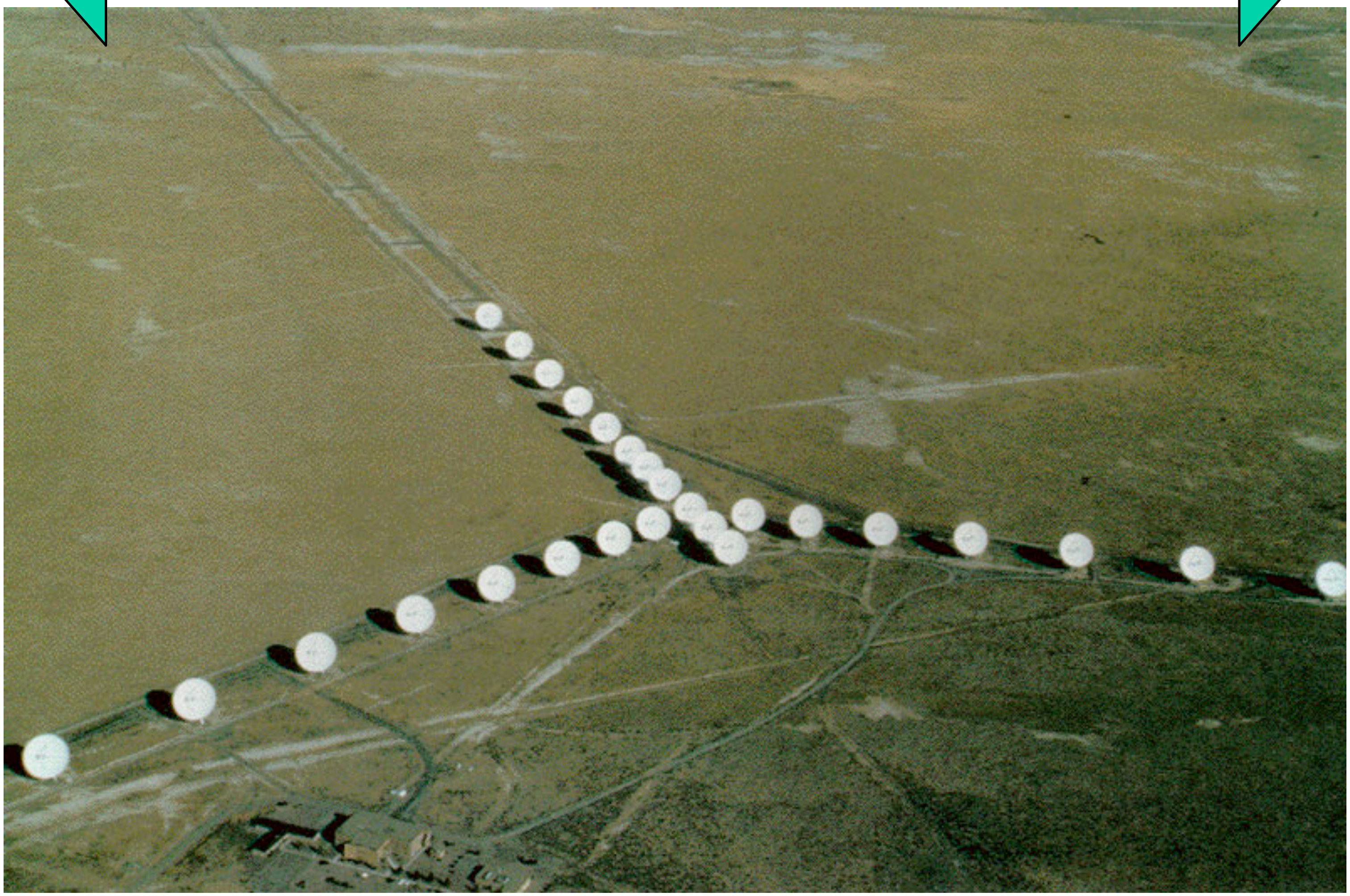
Interferometry

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

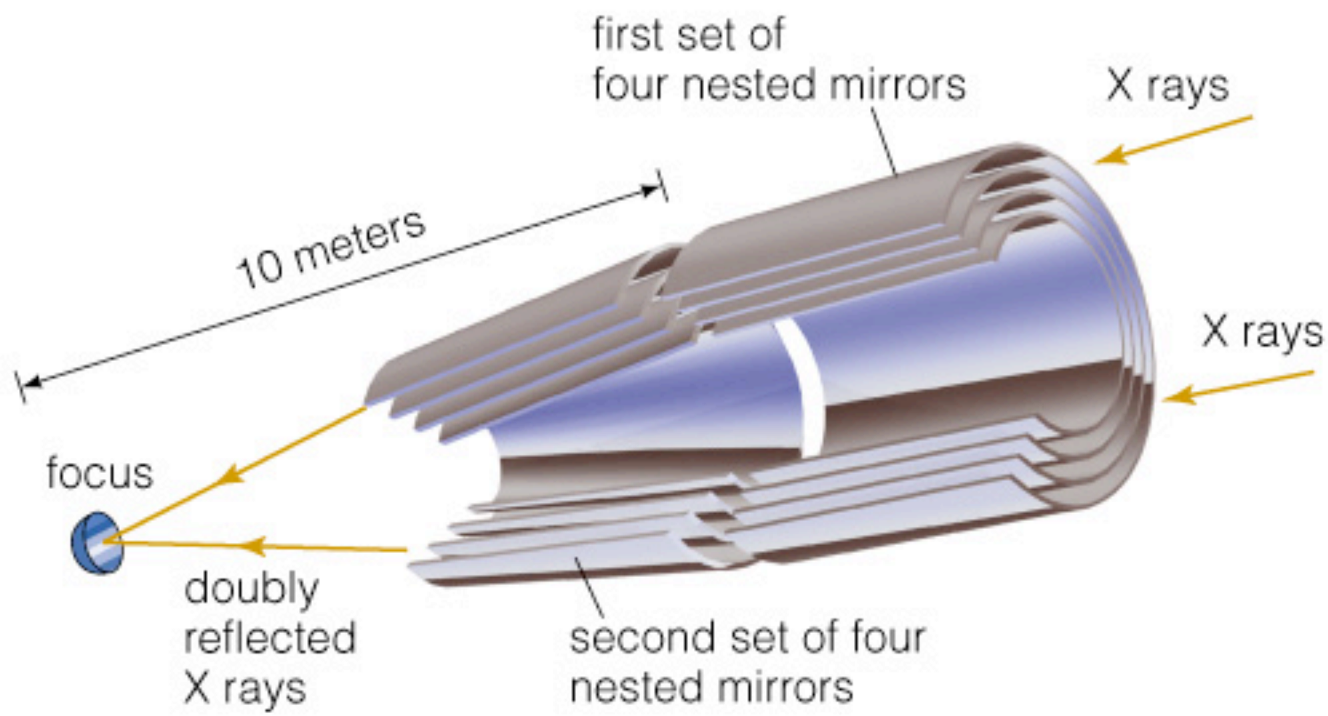
Very Large Array (VLA), New Mexico

Very Large Array (VLA), New Mexico

angular resolution of a telescope this size



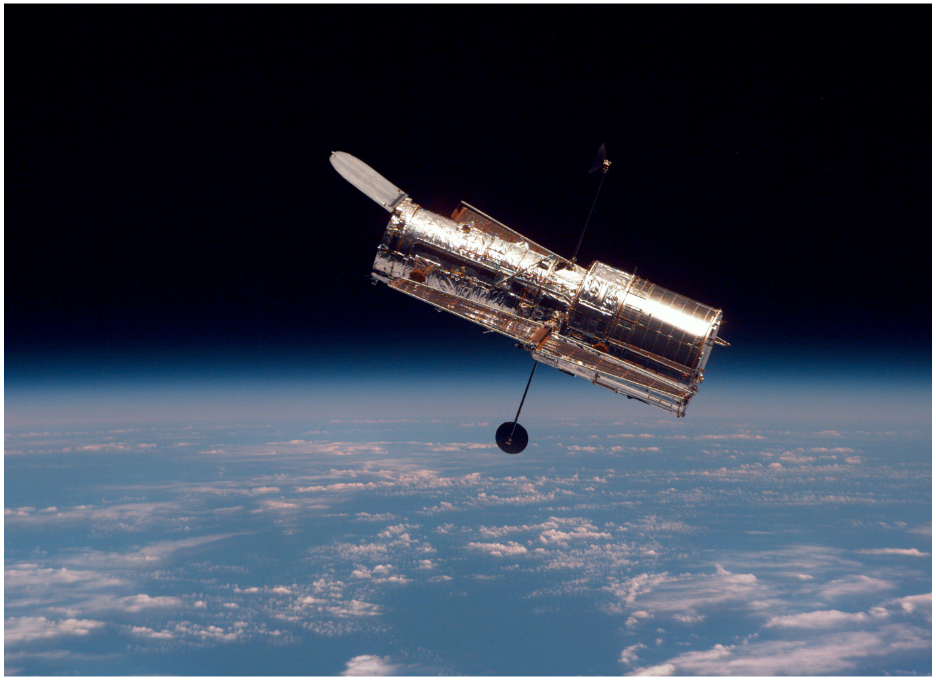
X-ray telescope: “grazing incidence” optics



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

b

Advantages of telescopes in space

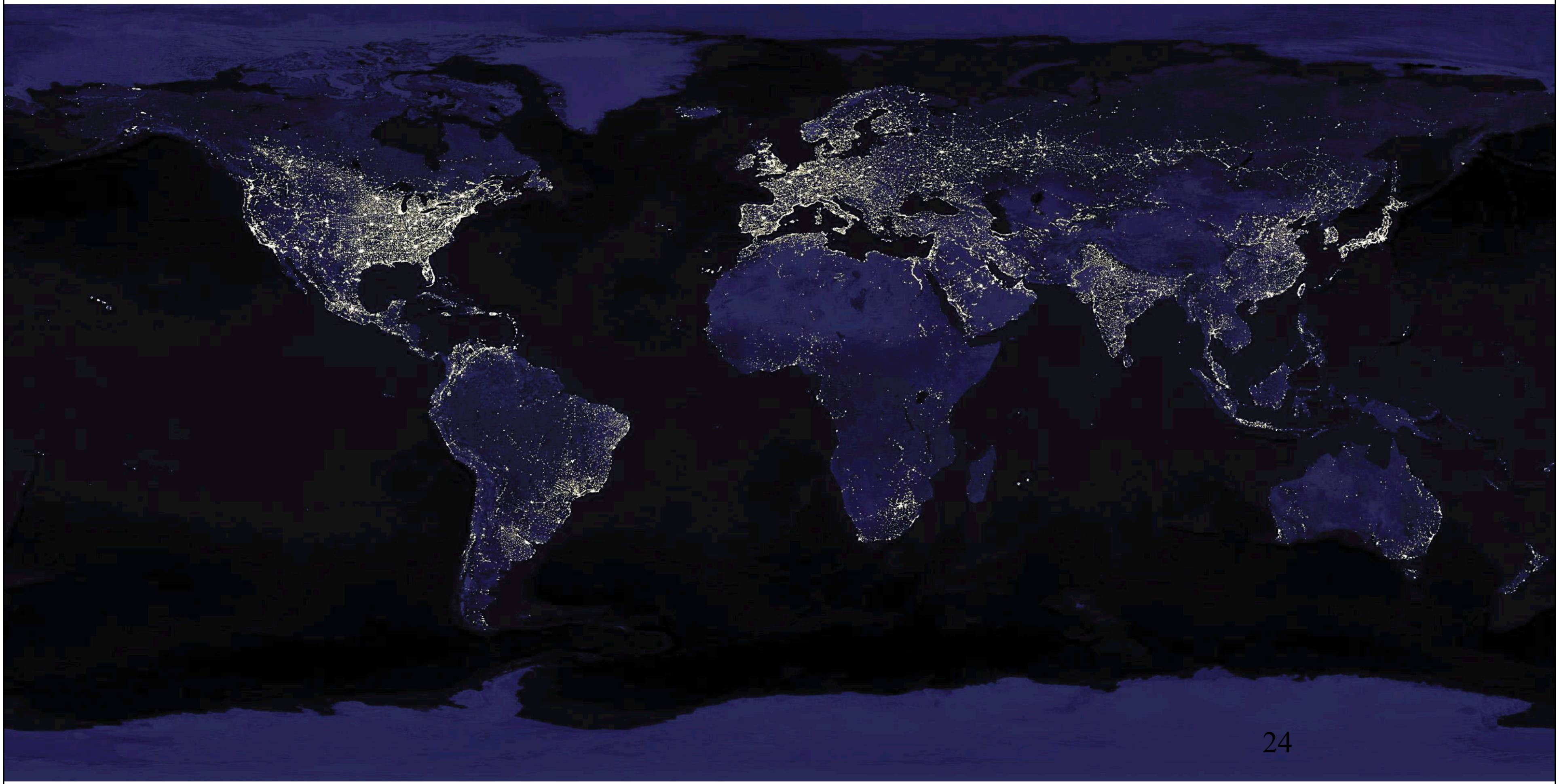


Hubble

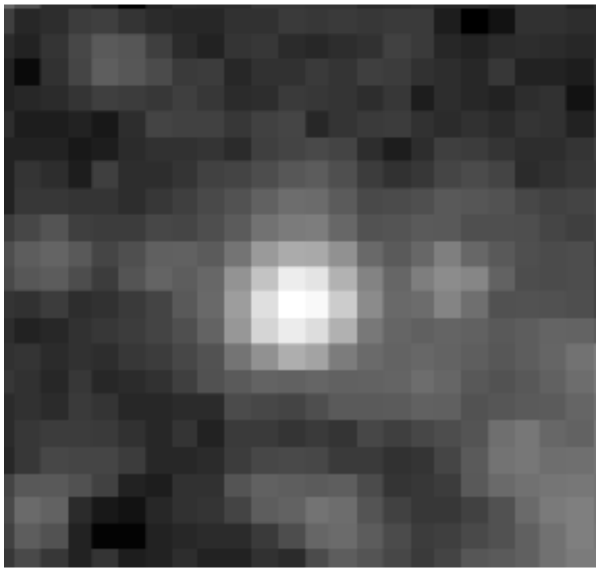
Chandra

Observing problems due to Earth's atmosphere

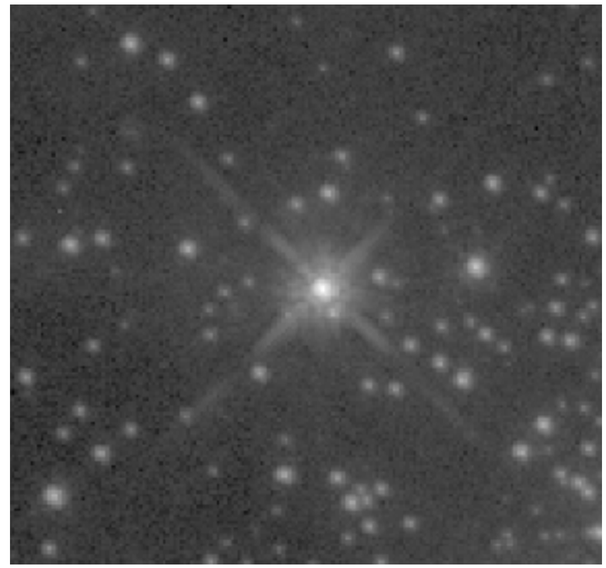
1. Light Pollution



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



Star viewed with ground-based telescope

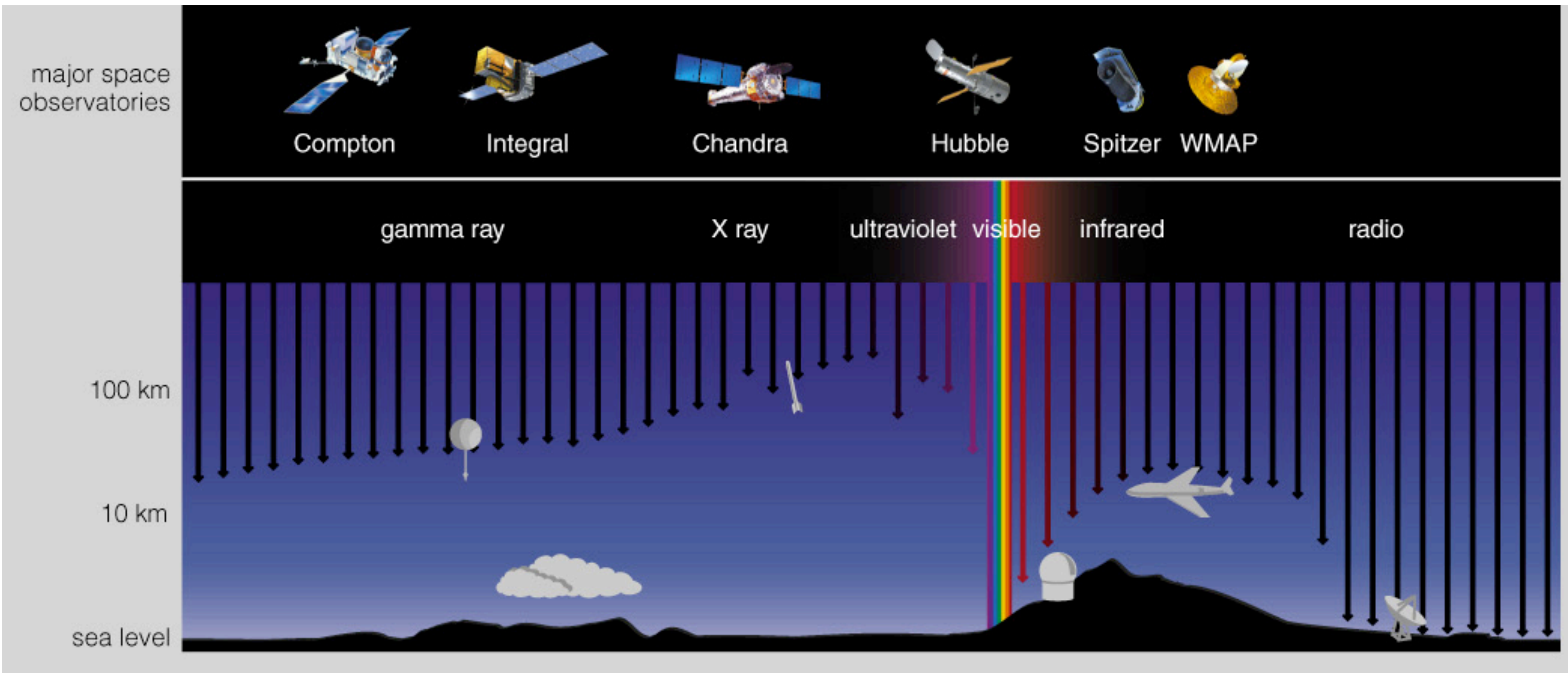


View from Hubble Space Telescope

E2-47/48 twinkling stars

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

Kepler

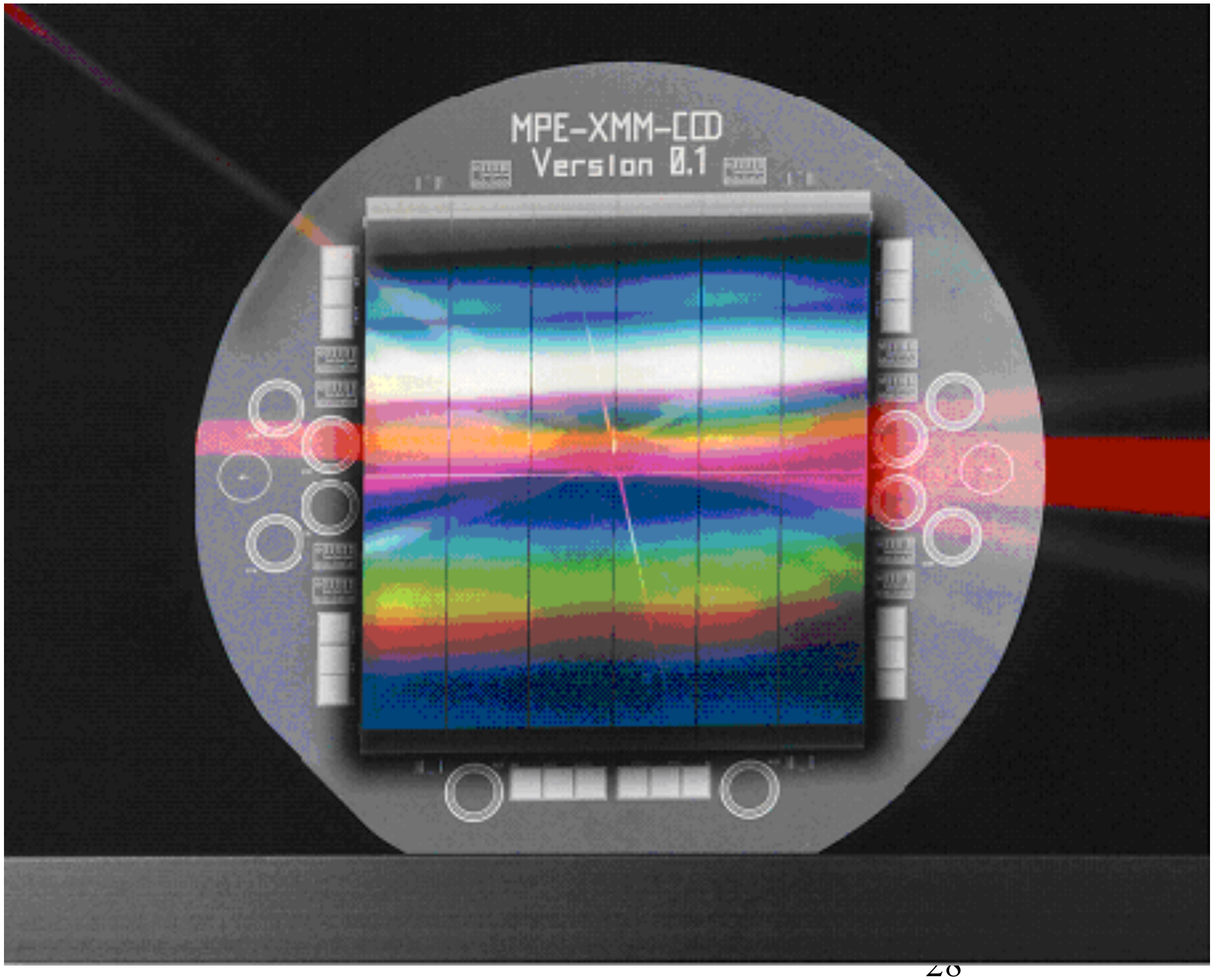


Telescopes in space solve all 3 problems.

Chandra X-ray
Observatory

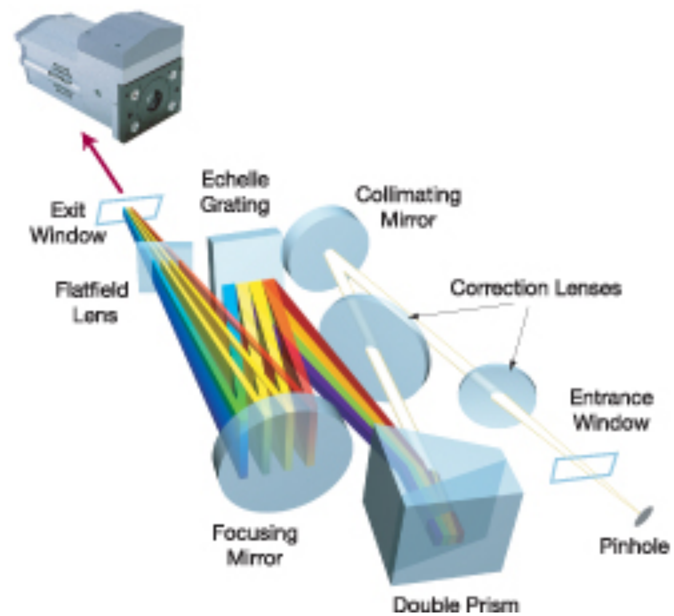
Instruments

- Cameras

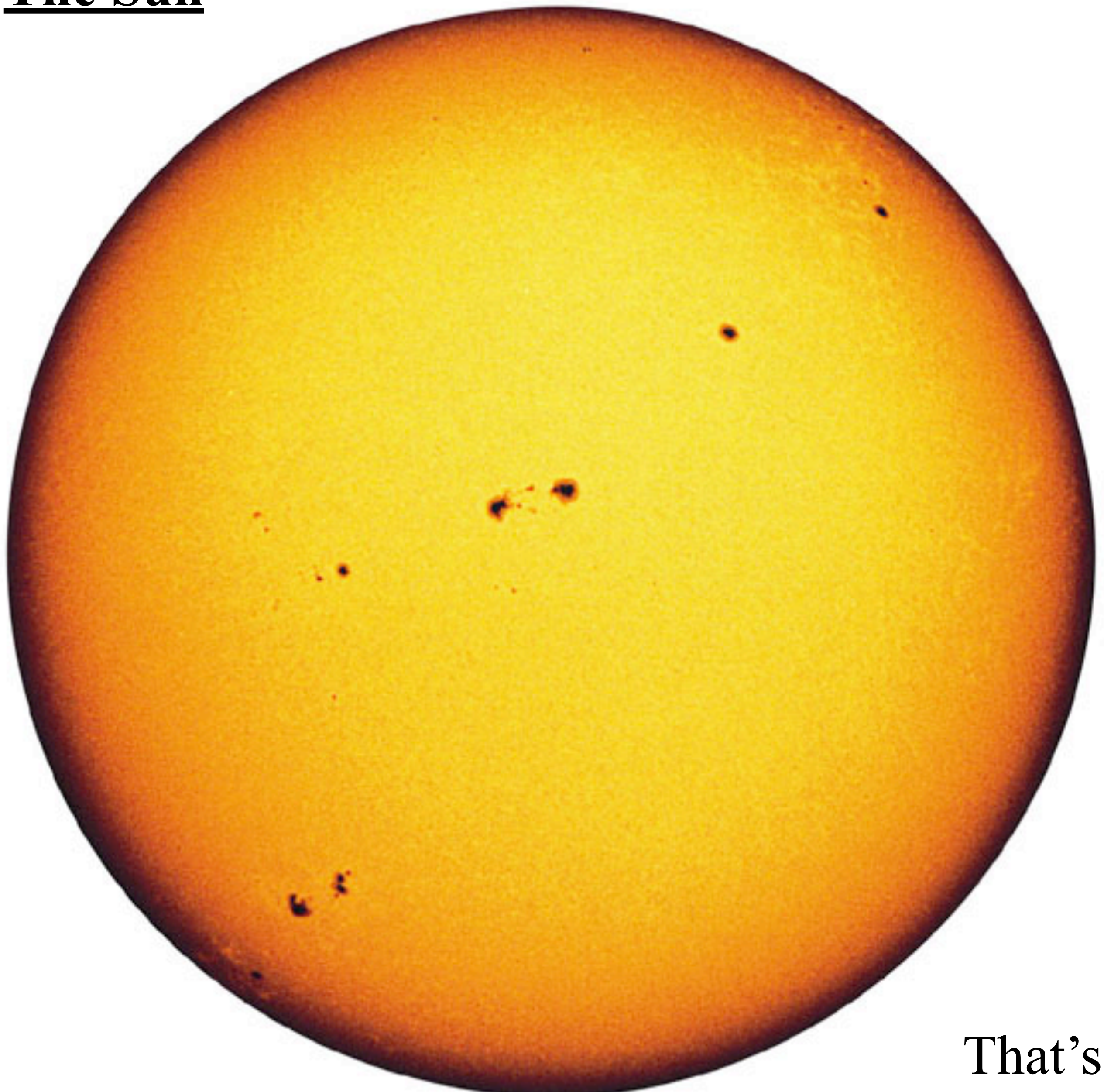


Instruments

- Spectrographs



The Sun



Radius:

6.9×10^8 m

(109 times Earth)

Mass:

2×10^{30} kg

(1,000 Jupiters;

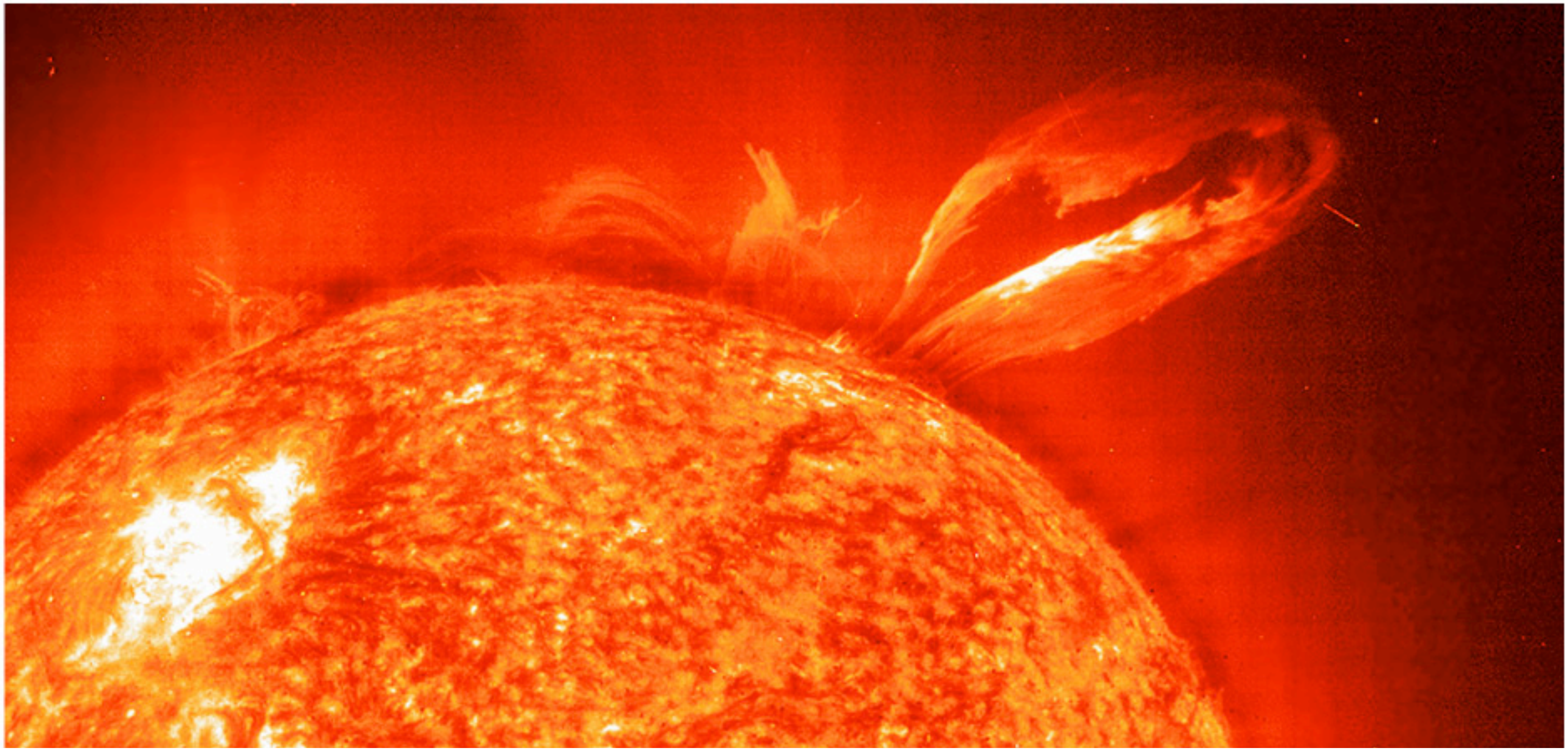
300,000 Earths)

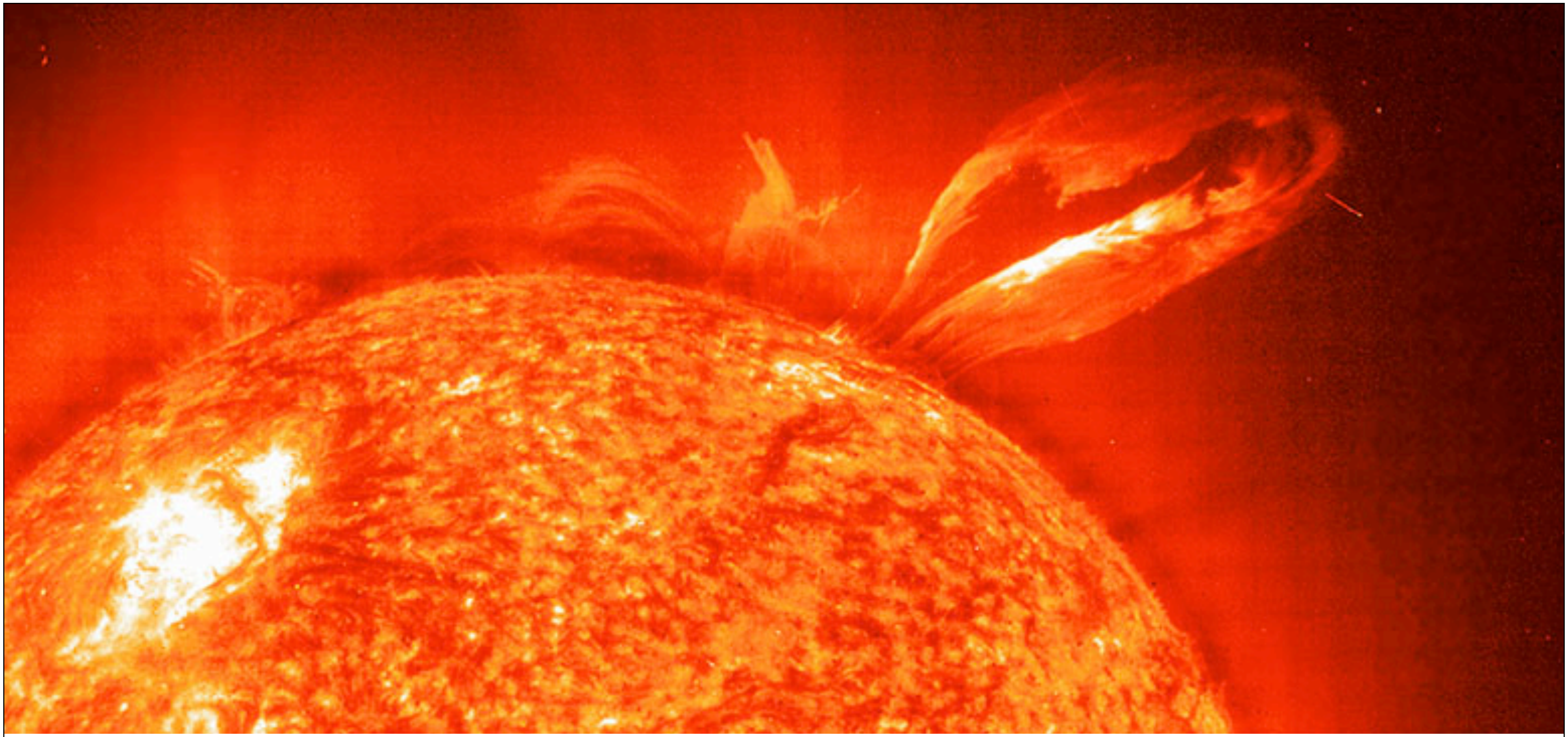
Luminosity:

3.8×10^{26} watts

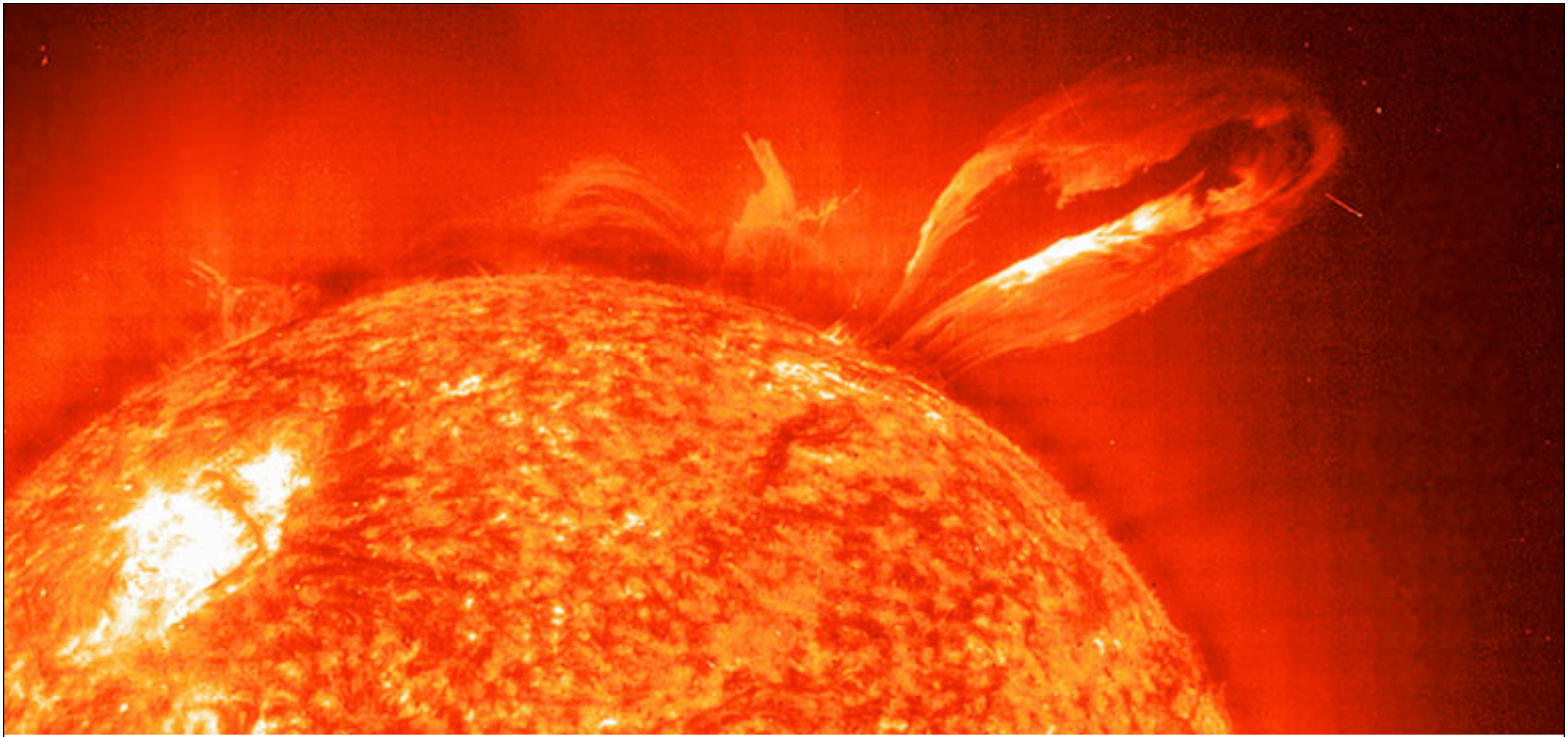
That's about a billion big nuclear bombs every second

Why does the Sun shine?



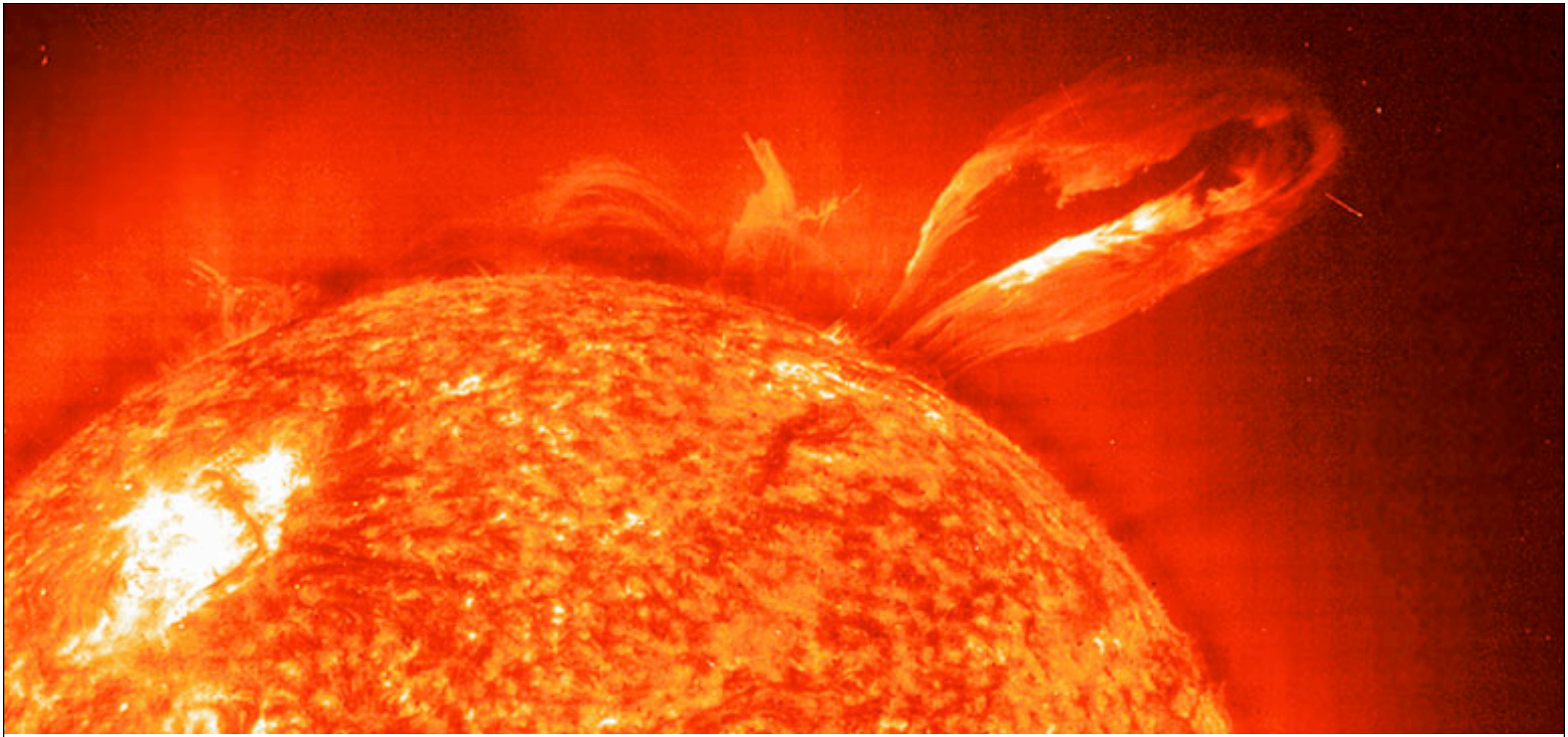


Is it on FIRE?



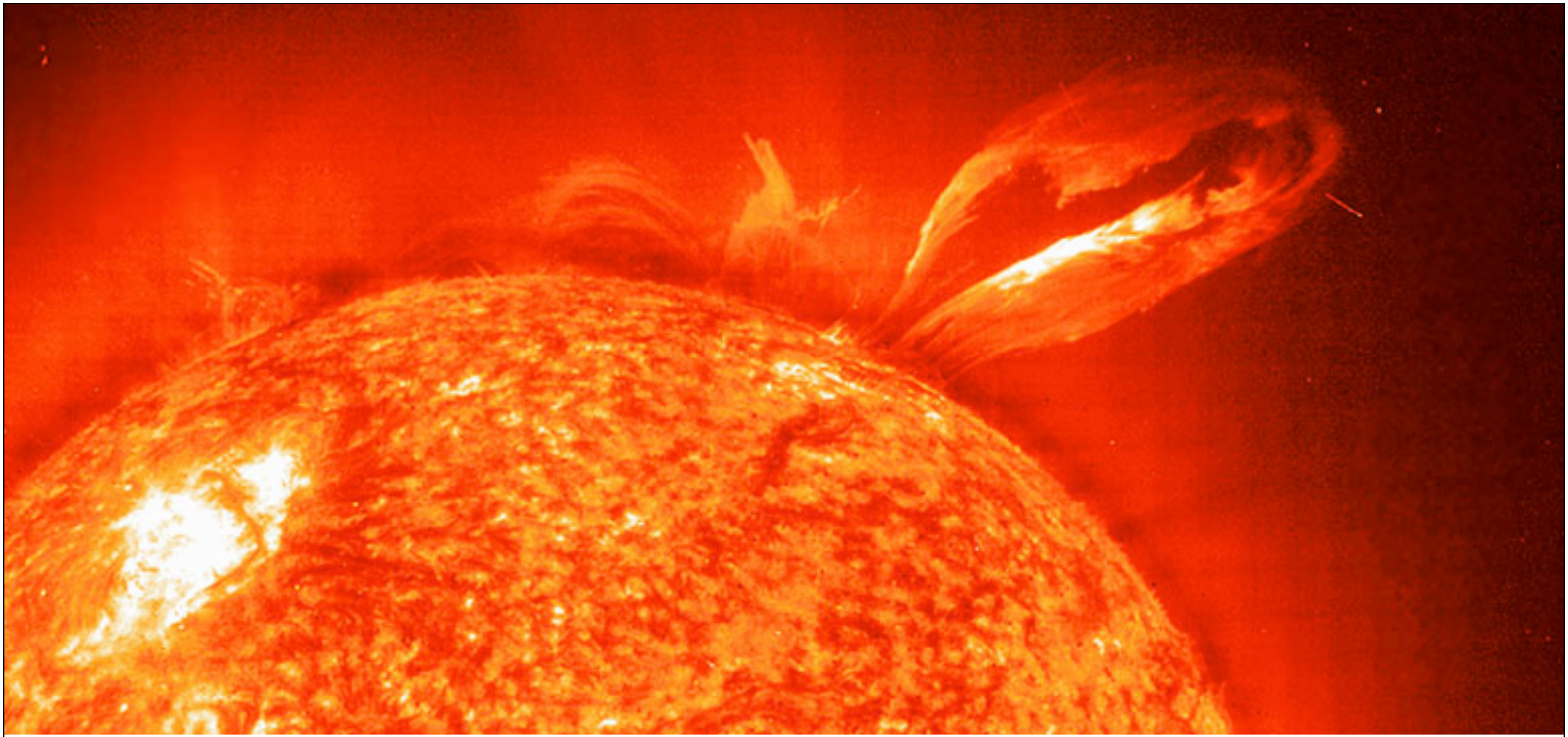
Is it on FIRE?

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

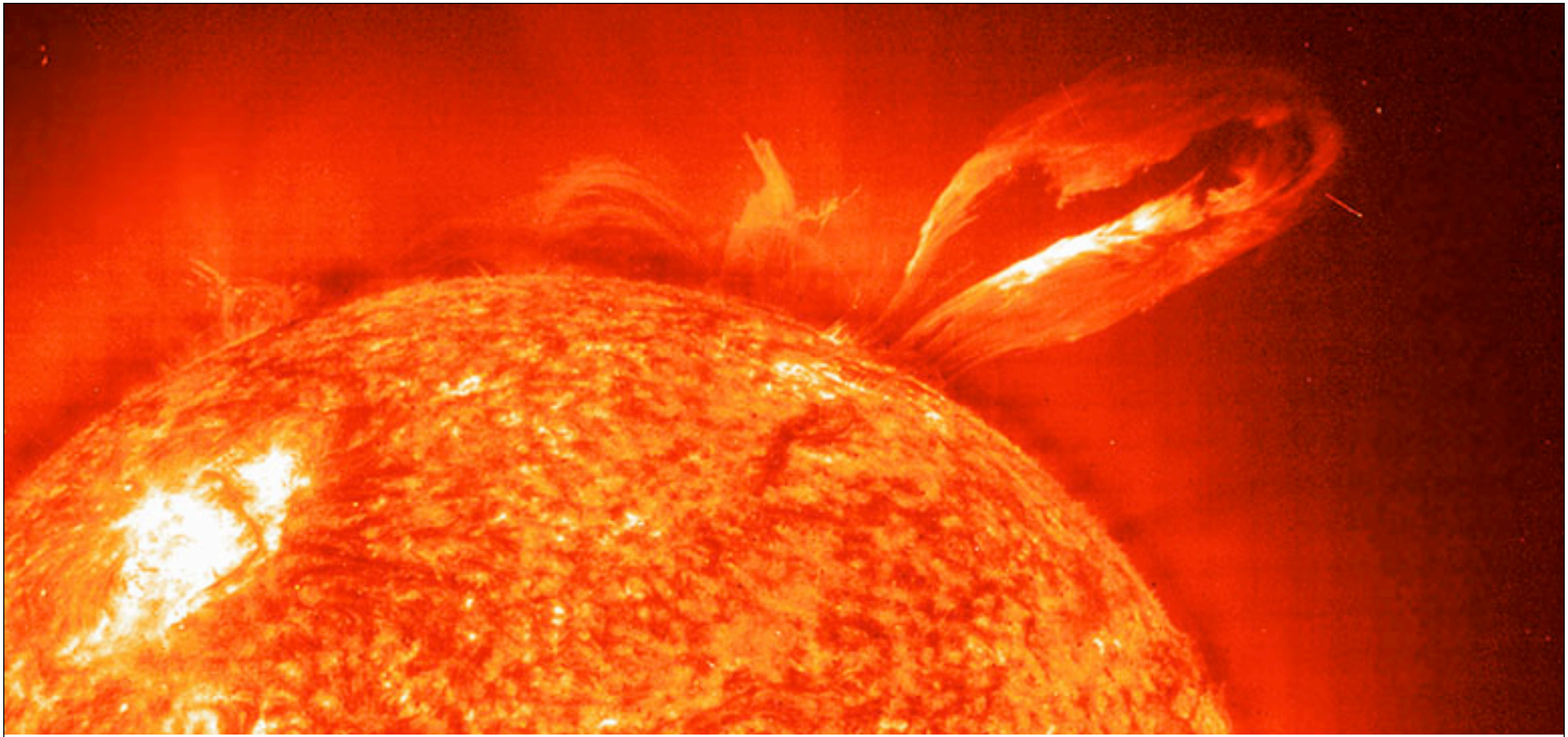


Is it on FIRE? … NO! ...not enough energy, not enough oxygen

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

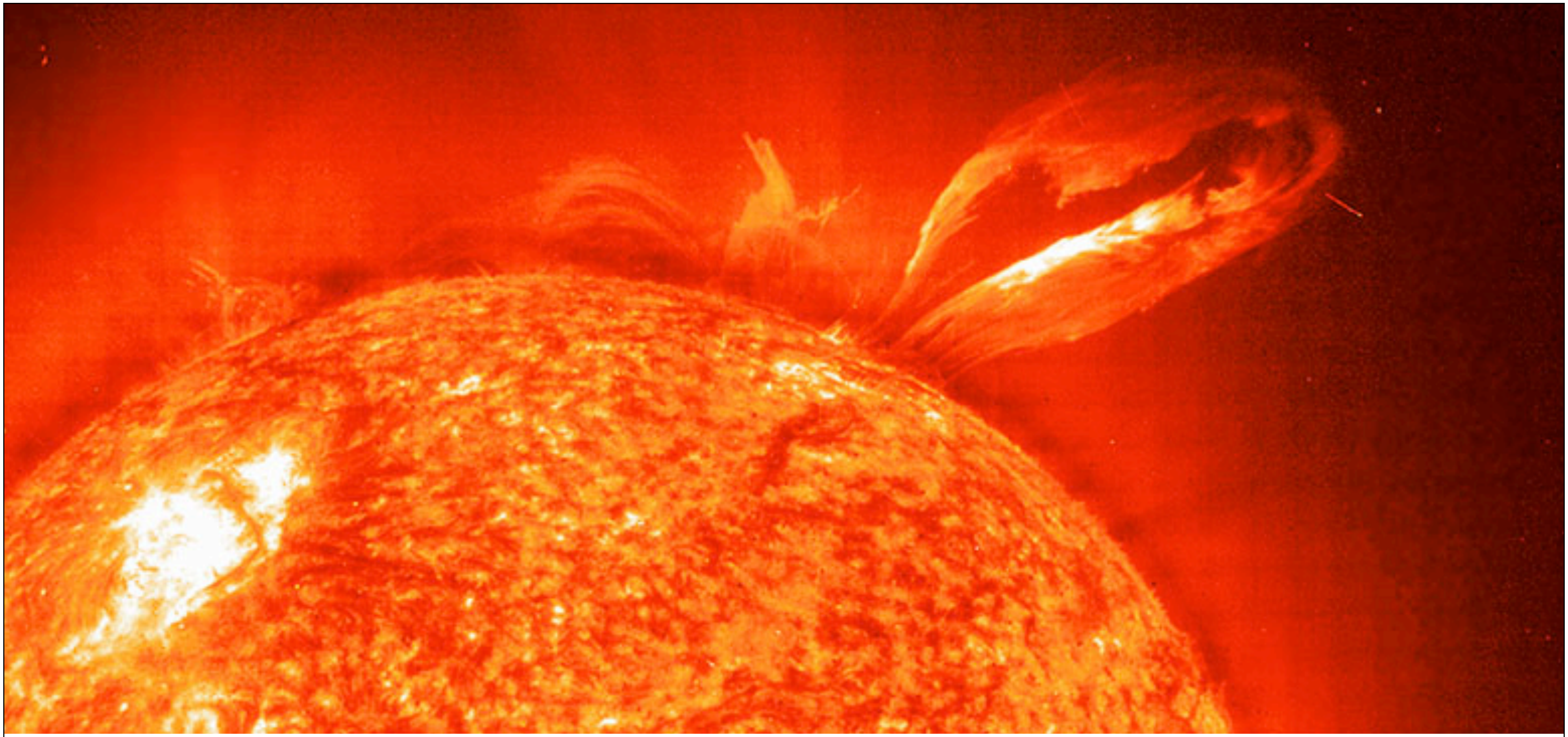


Is it CONTRACTING?



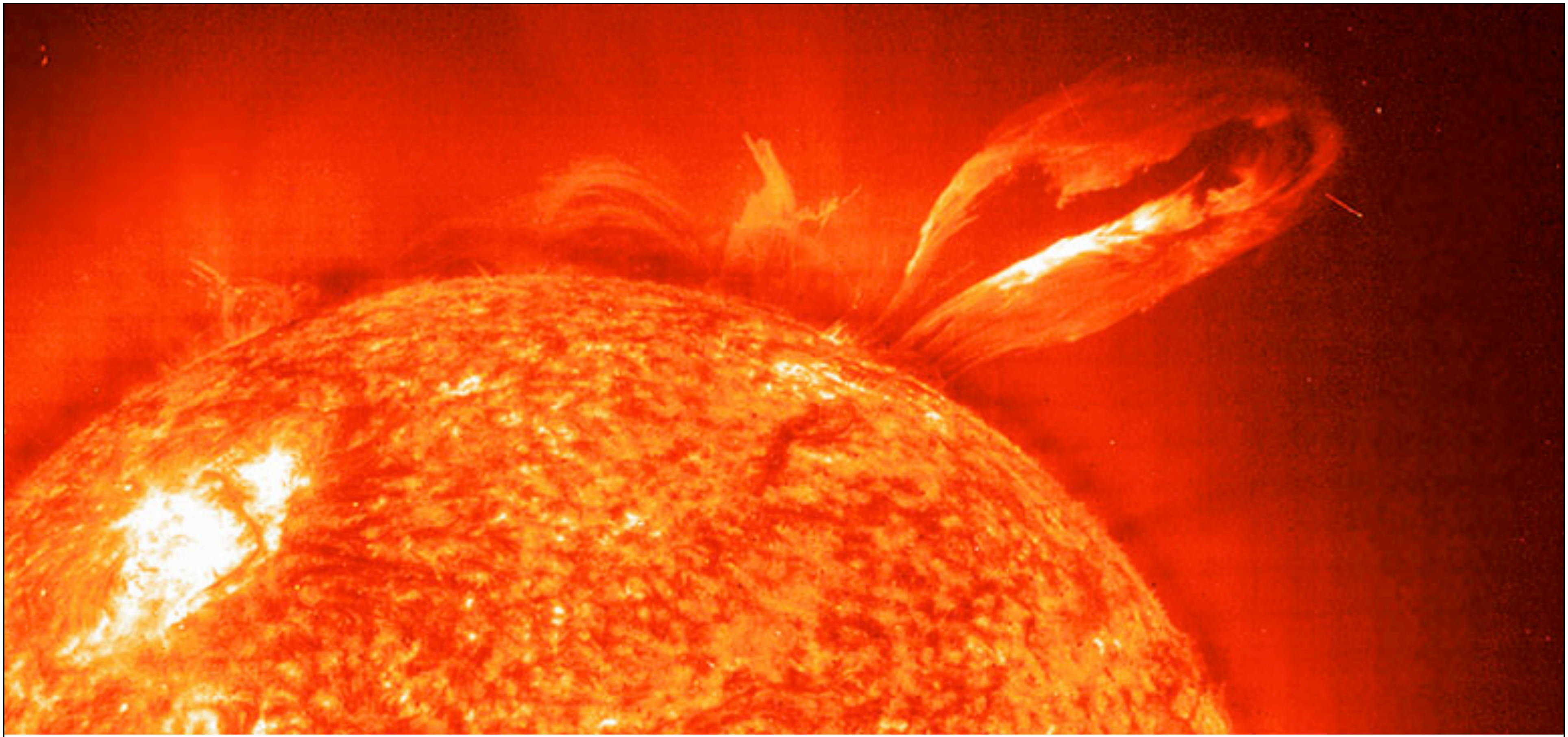
Is it CONTRACTING?

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



Is it CONTRACTING? … NO!

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



It is powered by NUCLEAR ENERGY!

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