

Today

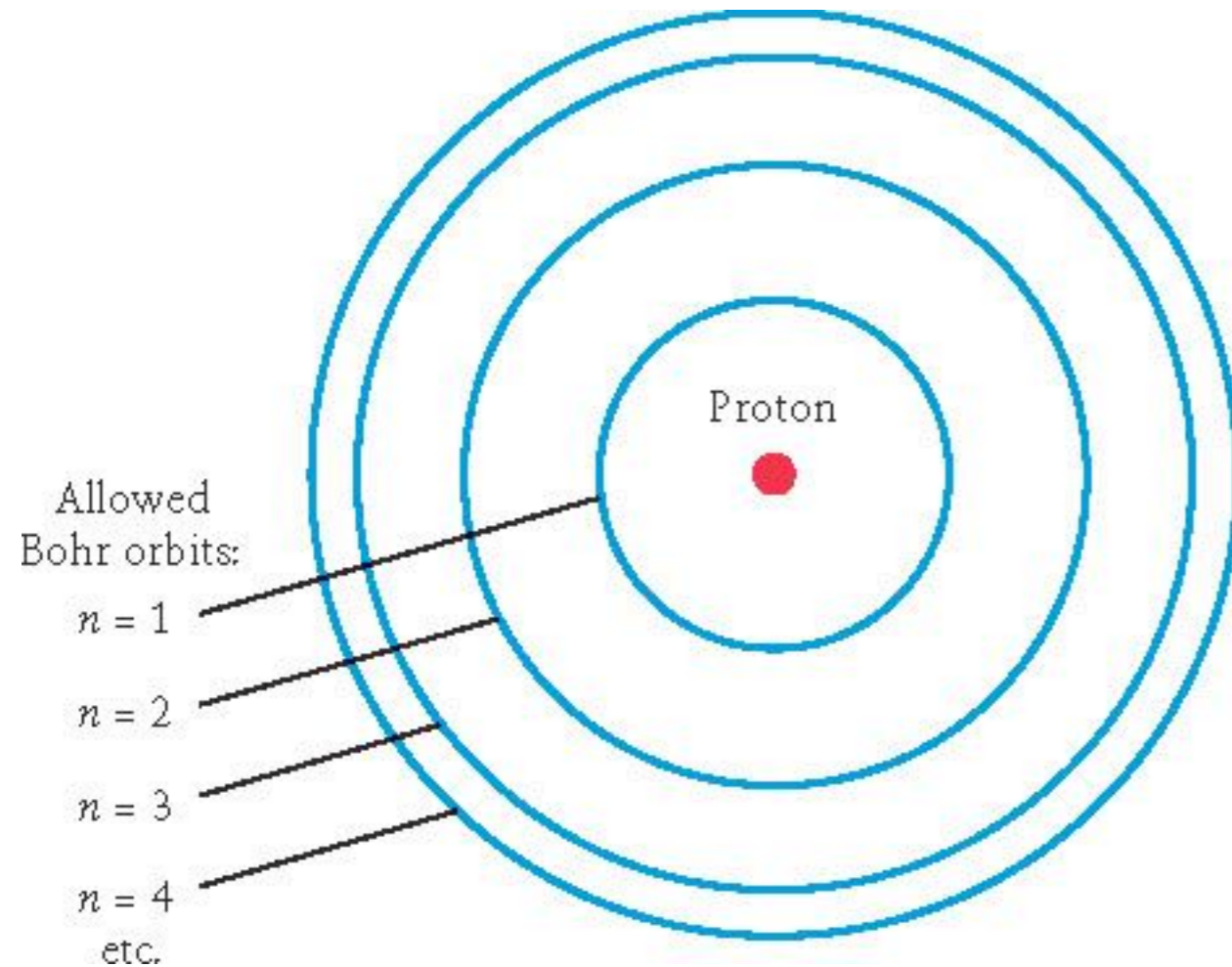
- Emission & Absorption lines
measuring elemental abundances
- Doppler Effect
measuring motion
- Telescopes
technology to measure with
- Solar System Overview
what's out there?

Next time

- Homework 3 Due



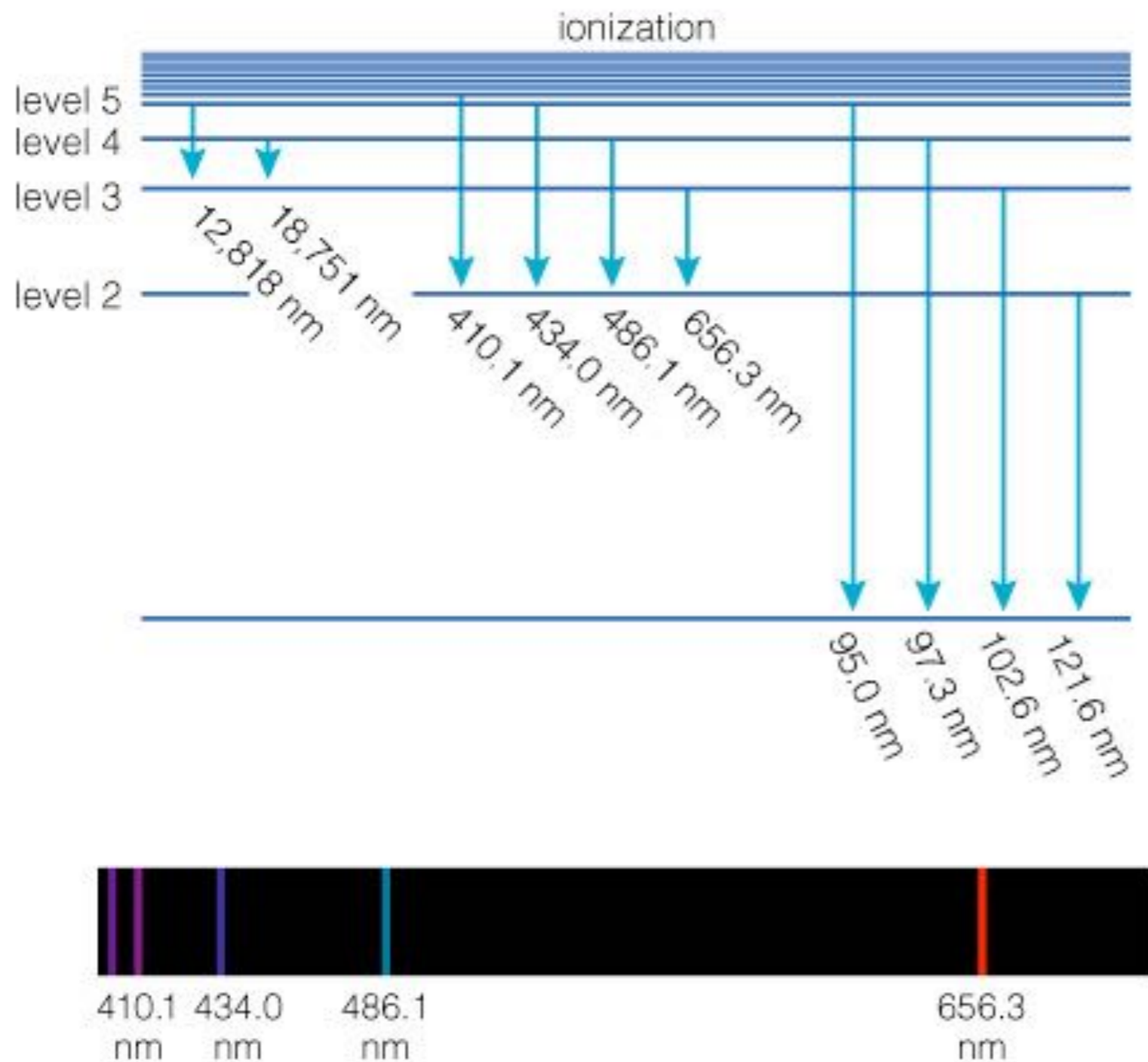
Chemical Fingerprints



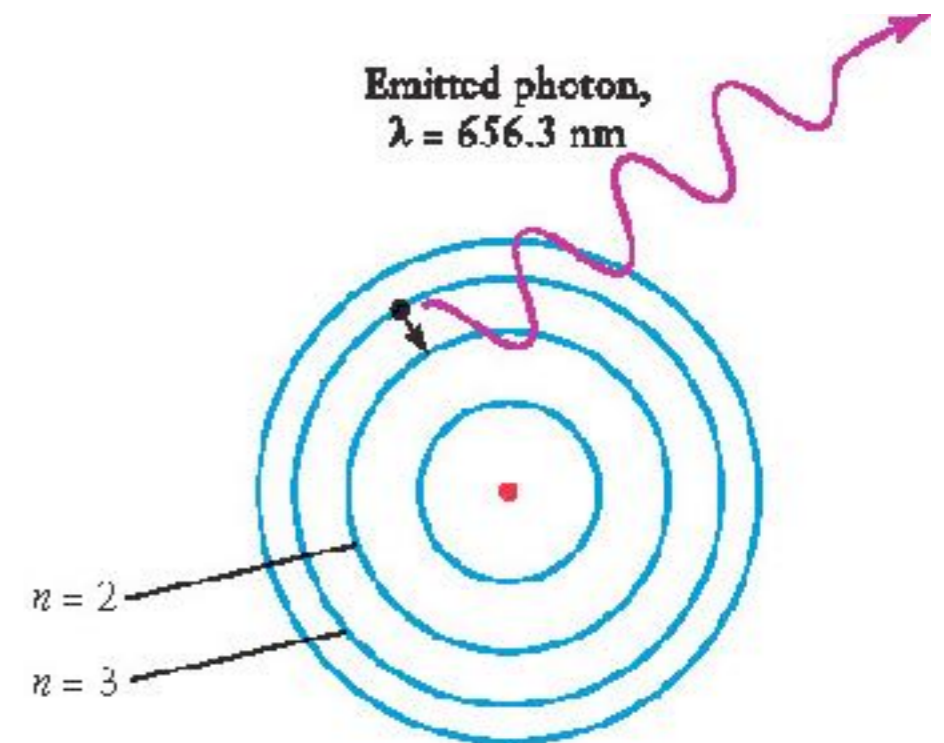
Energy levels of hydrogen

- Each type of atom has a unique set of energy levels.
- Each transition corresponds to a unique photon energy, frequency, and wavelength.

Chemical Fingerprints



- Downward transitions produce a unique pattern of emission lines.

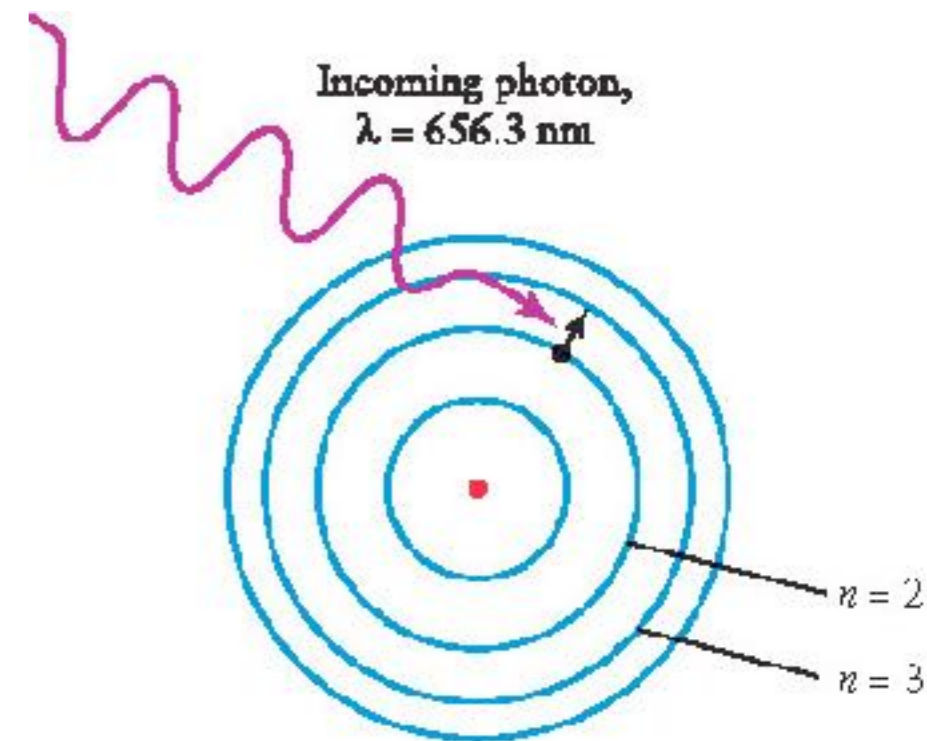
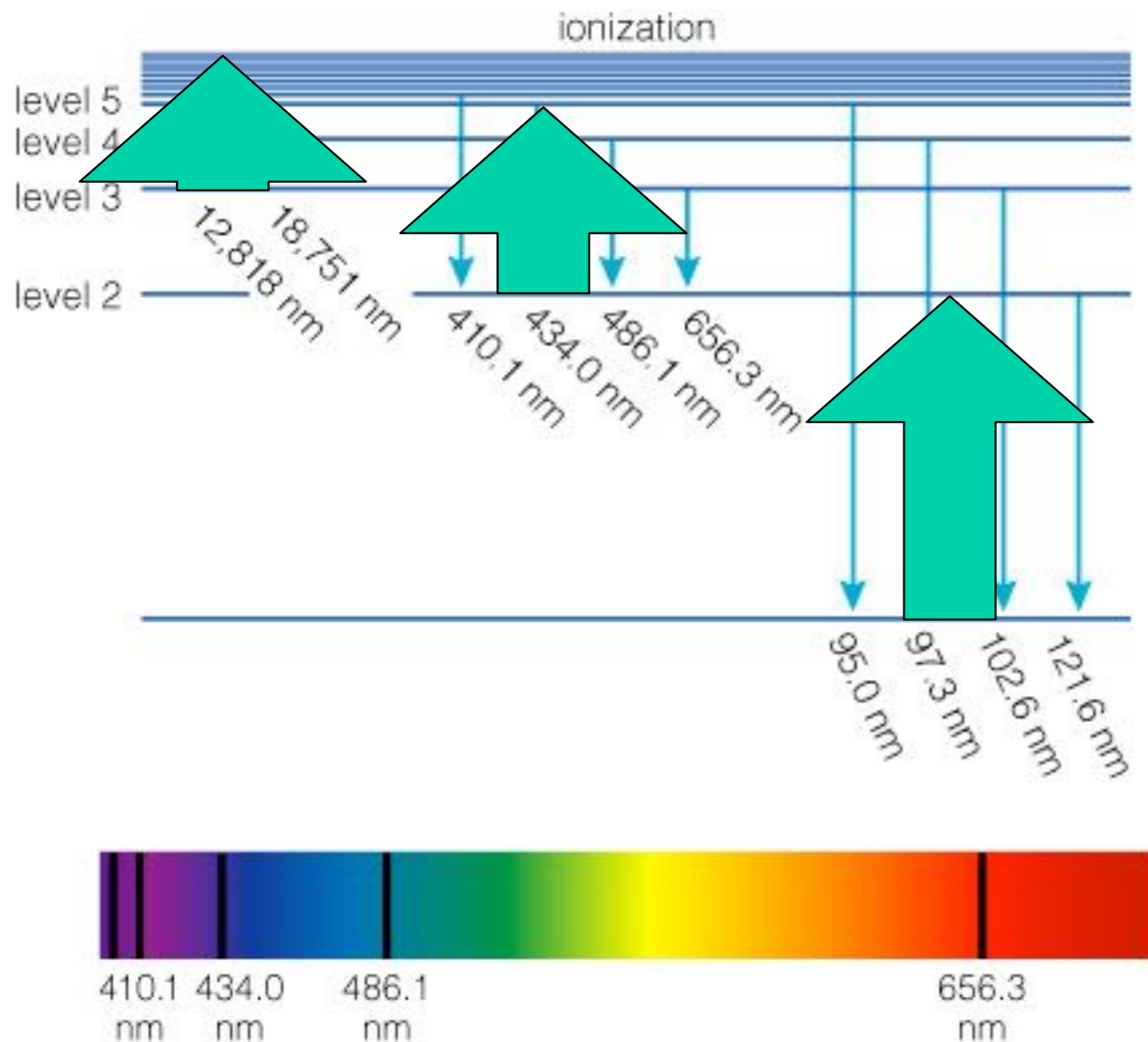


(b) Electron falls from the $n = 3$ orbit to the $n = 2$ orbit; energy lost by atom goes into emitting a 656.3-nm photon

bit

Chemical Fingerprints

- Atoms can absorb photons with those same energies, so upward transitions produce absorption lines.



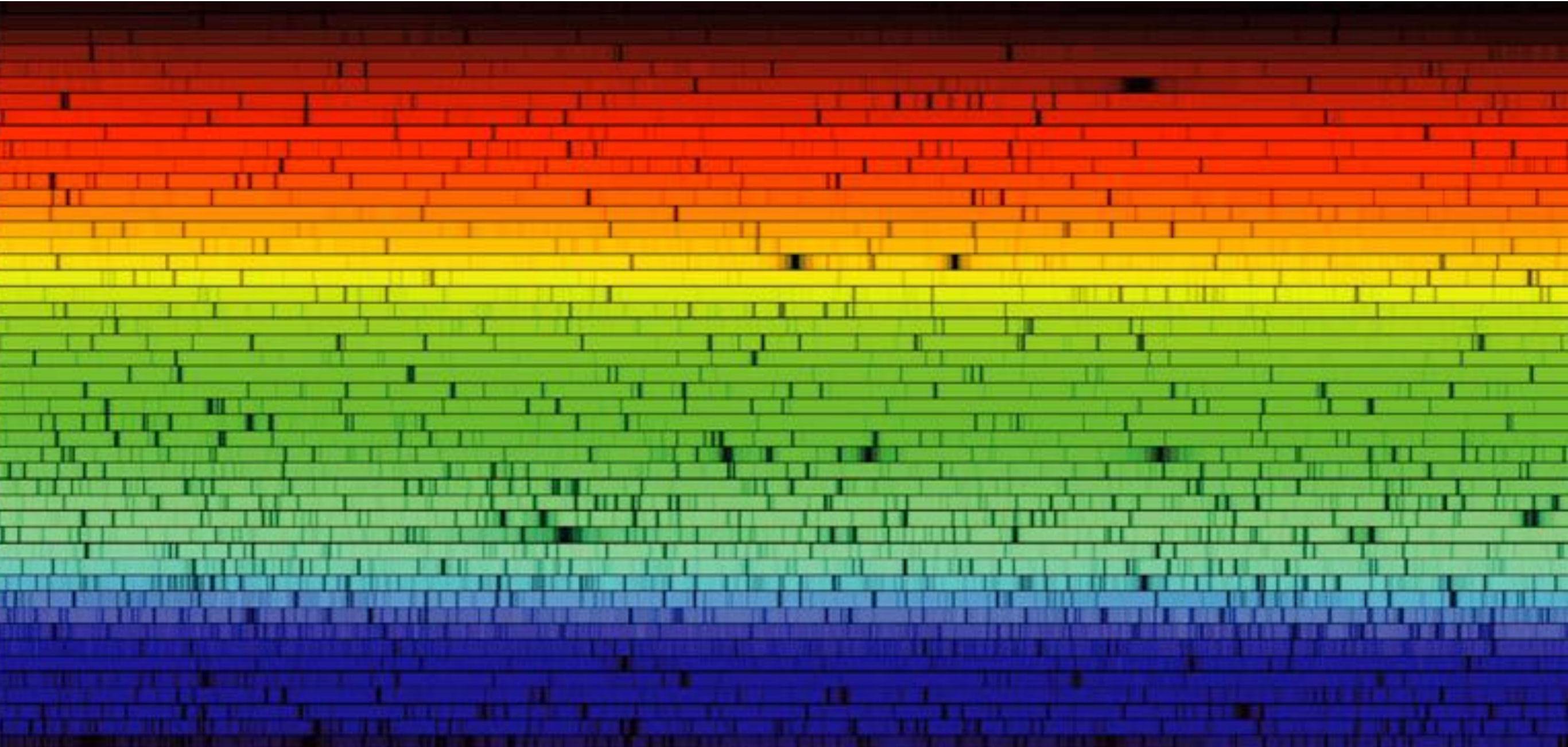
(a) Atom absorbs a 656.3-nm photon; absorbed energy causes electron to jump from the $n = 2$ orbit up the $n = 3$ orbit

Chemical Fingerprints



- Each type of atom has a unique spectral fingerprint.

Example: Solar Spectrum



All the dark regions are absorption lines due to all the elements in the sun's atmosphere. The strengths of the lines tell us about the sun's composition and other physical properties like temperature and surface gravity.

Solar composition

- 73% Hydrogen
- 25% Helium
- 2% everything else
 - “metals”

Periodic Table of the Elements

| | | | | | | | | | | | | | | | | | |
|----------------------|-----------------------|-----------------------|-----------------------|--------------------------|------------------------|------------------------|-----------------------|-----------------------|------------------------|-----------------------|-------------------------|-------------------------|-----------------------|--------------------------|-----------------------|---------------------|---------------------|
| 1 H Hydrogen | 2 He Helium | | | | | | | | | | | | | | | | |
| 3 Li Lithium | 4 Be Beryllium | 5 B Boron | 6 C Carbon | 7 N Nitrogen | 8 O Oxygen | 9 F Fluorine | 10 Ne Neon | | | | | | | | | | |
| 11 Na Sodium | 12 Mg Magnesium | 13 Al Aluminum | 14 Si Silicon | 15 P Phosphorus | 16 S Sulfur | 17 Cl Chlorine | 18 Ar Argon | | | | | | | | | | |
| 19 K Potassium | 20 Ca Calcium | 21 Sc Scandium | 22 Ti Titanium | 23 V Vanadium | 24 Cr Chromium | 25 Mn Manganese | 26 Fe Iron | 27 Co Cobalt | 28 Ni Nickel | 29 Cu Copper | 30 Zn Zinc | 31 Ga Gallium | 32 Ge Germanium | 33 As Arsenic | 34 Se Selenium | 35 Br Bromine | 36 Kr Krypton |
| 37 Rb Rubidium | 38 Sr Strontium | 39 Y Yttrium | 40 Zr Zirconium | 41 Nb Niobium | 42 Mo Molybdenum | 43 Tc Technetium | 44 Ru Ruthenium | 45 Rh Rhodium | 46 Pd Palladium | 47 Ag Silver | 48 Cd Cadmium | 49 In Indium | 50 Sn Tin | 51 Sb Antimony | 52 Te Tellurium | 53 I Iodine | 54 Xe Xenon |
| 55 Cs Cesium | 56 Ba Barium | 57 La Lanthanum | 58 Ce Cerium | 59 Pr Praseodymium | 60 Nd Neodymium | 61 Pm Promethium | 62 Sm Samarium | 63 Eu Europium | 64 Gd Gadolinium | 65 Tb Terbium | 66 Dy Dysprosium | 67 Ho Holmium | 68 Er Erbium | 69 Tm Thulium | 70 Yb Ytterbium | | |
| 87 Fr Francium | 88 Ra Radium | 89 Ac Actinium | 90 Th Thorium | 91 Pa Protactinium | 92 U Uranium | 93 Np Neptunium | 94 Pu Plutonium | 95 Am Americium | 96 Cm Curium | 97 Bk Berkelium | 98 Cf Californium | 99 Es Einsteinium | 100 Fm Fermium | 101 Md Mendelevium | 102 No Nobelium | | |

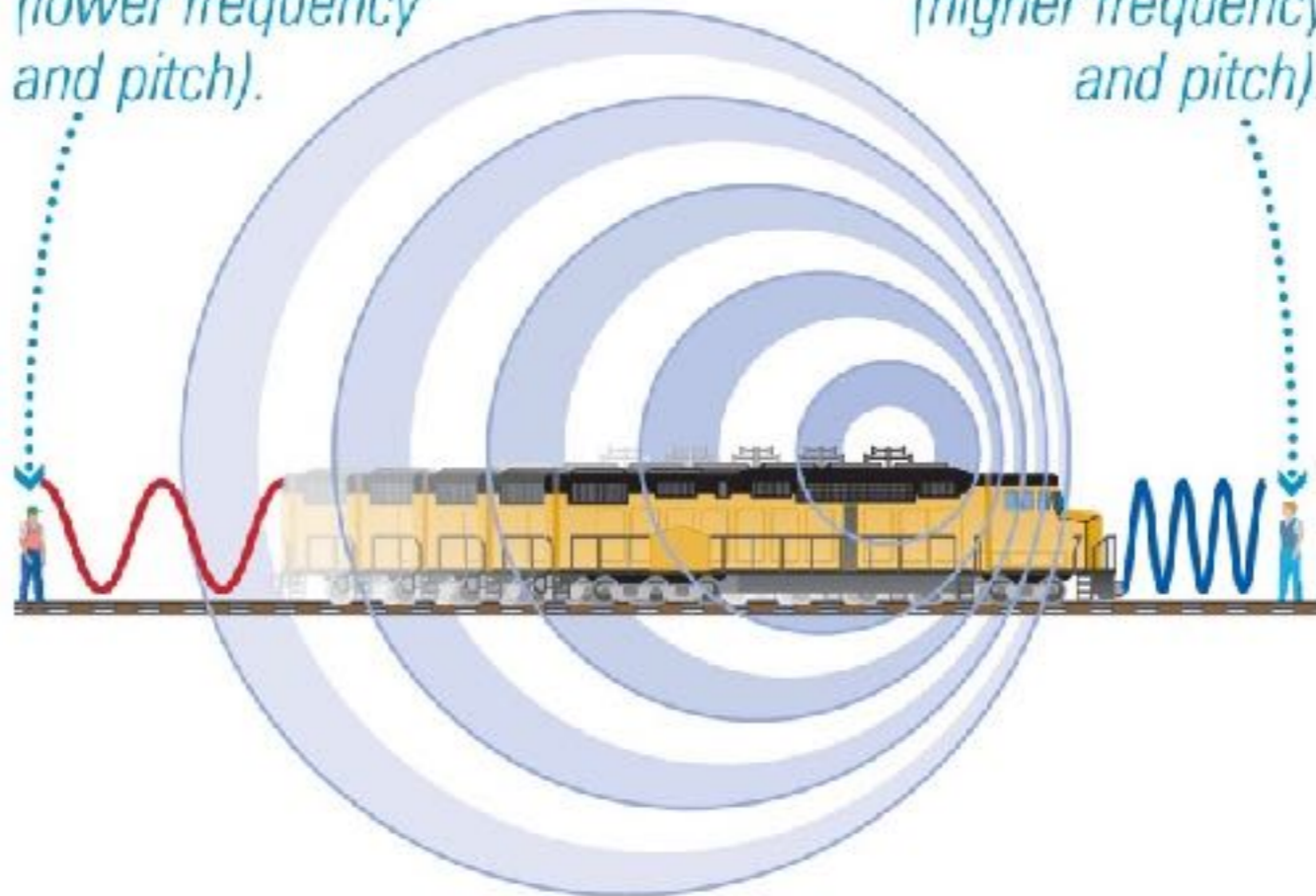
- Other stars similar
 - H & He most common stuff in the universe
 - Helium was *discovered* in the spectrum of the sun
 - nearly everything other element made by stars

The Doppler Effect

train moving to right

*Behind the train,
sound waves stretch
to longer wavelength
(lower frequency
and pitch).*

*In front of the train,
sound waves bunch up
to shorter wavelength
(higher frequency
and pitch).*



Doppler
ball

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

Doppler Effect for Light

- Motion away \rightarrow redshift
- Motion towards \rightarrow blueshift

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

v ← speed
 c ← speed of light

Measuring the Shift

Laboratory spectrum



Stationary

Object 1



Moving Away *redshift*

Object 2



Away Faster *redshift*

Object 3



Moving Toward *blueshift*

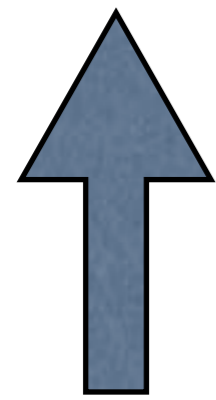
Object 4



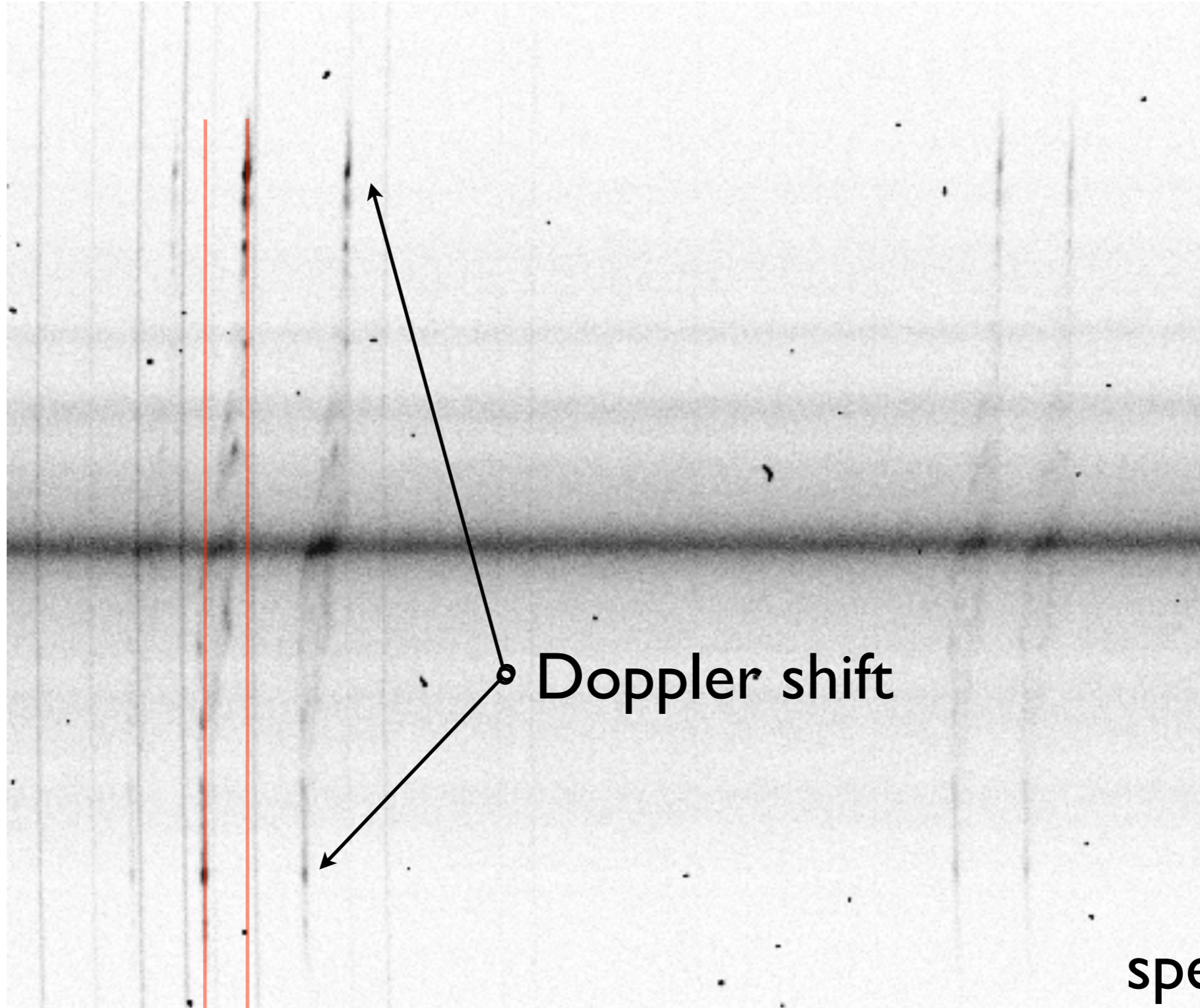
Toward Faster *blueshift*

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

Spectrum

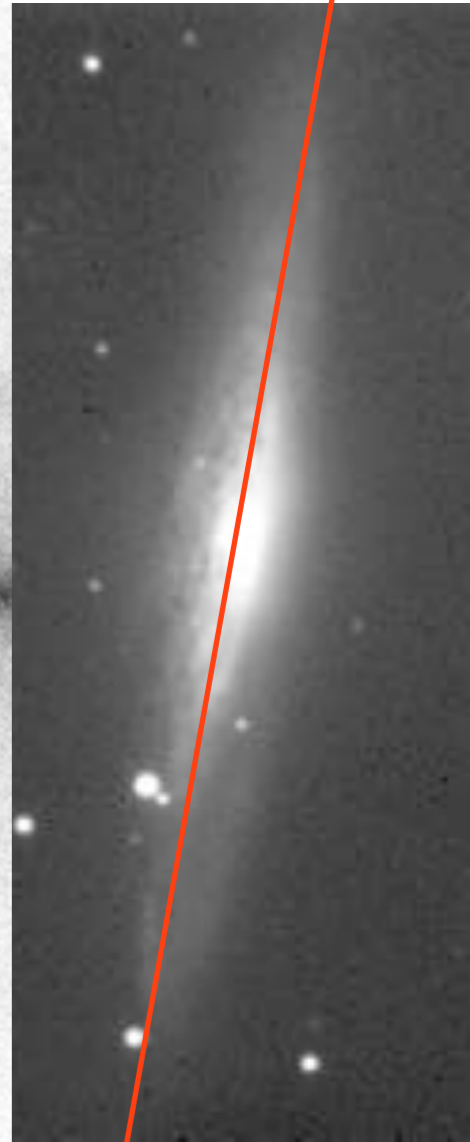
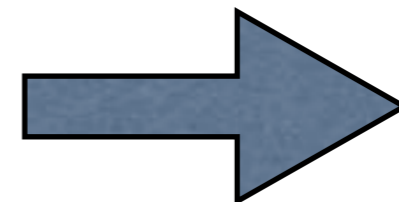


position along slit



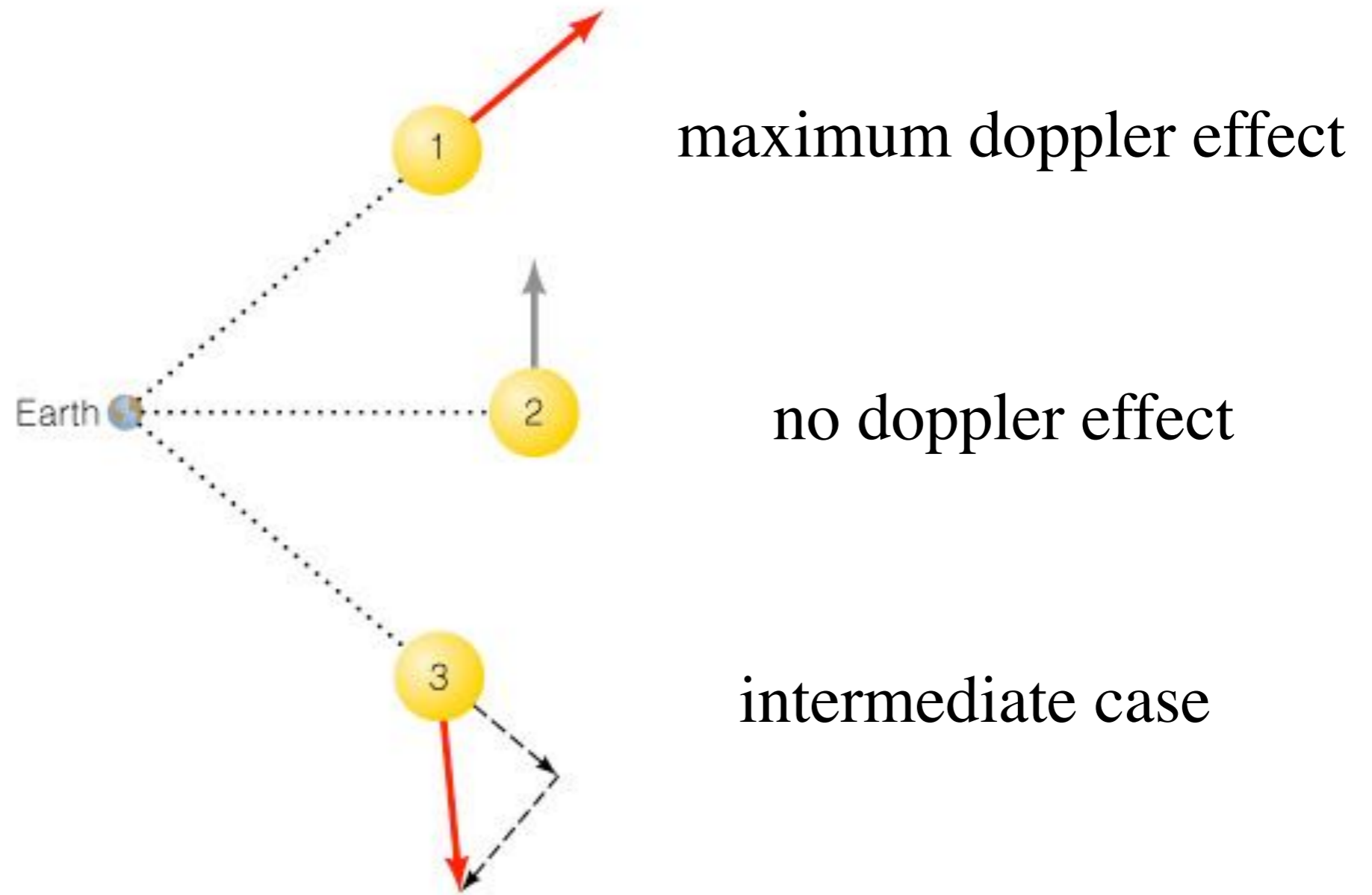
$\Delta\lambda$

wavelength



spectrograph slit

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



Telescopes

- Telescopes collect more light than our eyes \Rightarrow **light-collecting area**
- Telescopes can see more detail than our eyes \Rightarrow **angular resolution** (magnification)
- Telescopes/instruments can record light more sensitively than our eyes, and detect electromagnetic radiation 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

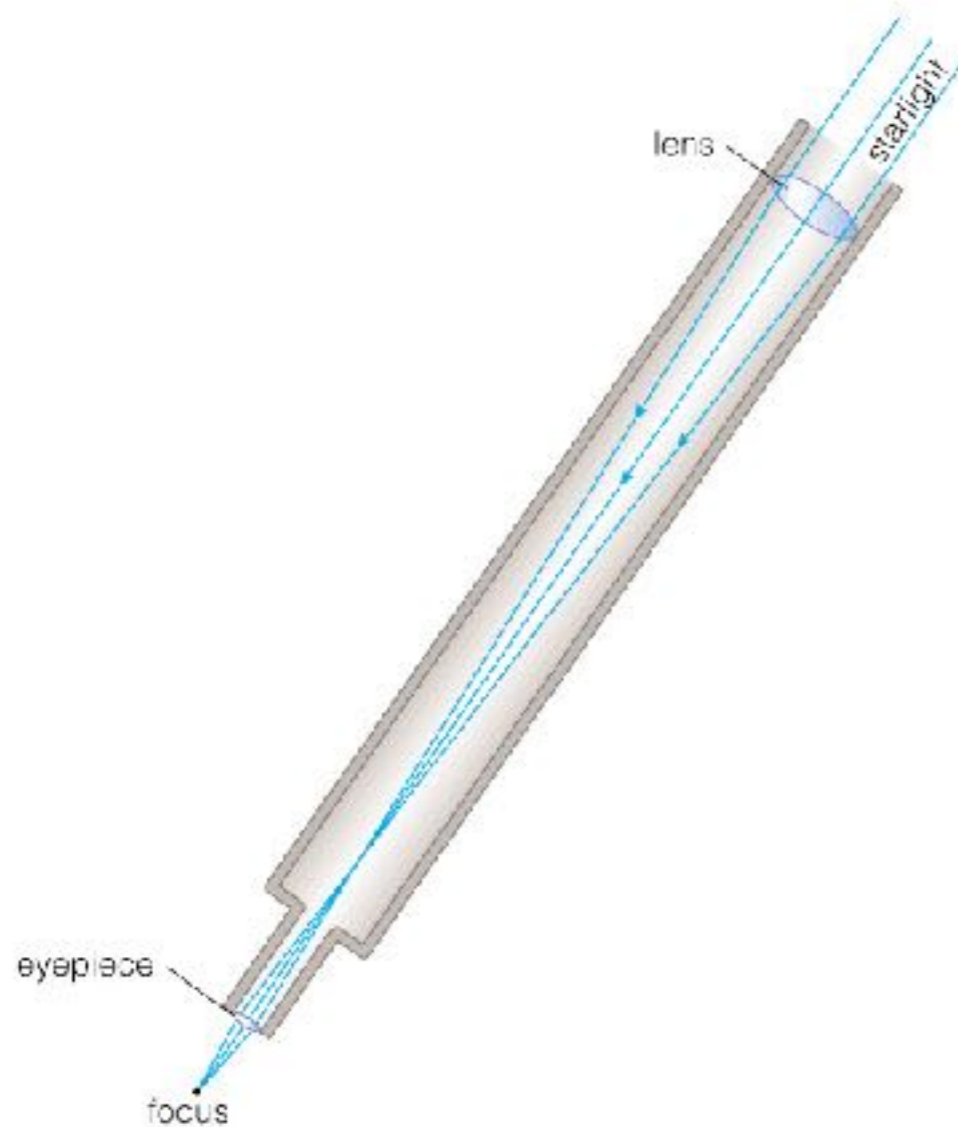
For a telescope with mirror of diameter D ,

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

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

Basic Telescope Design

- Refracting: lenses



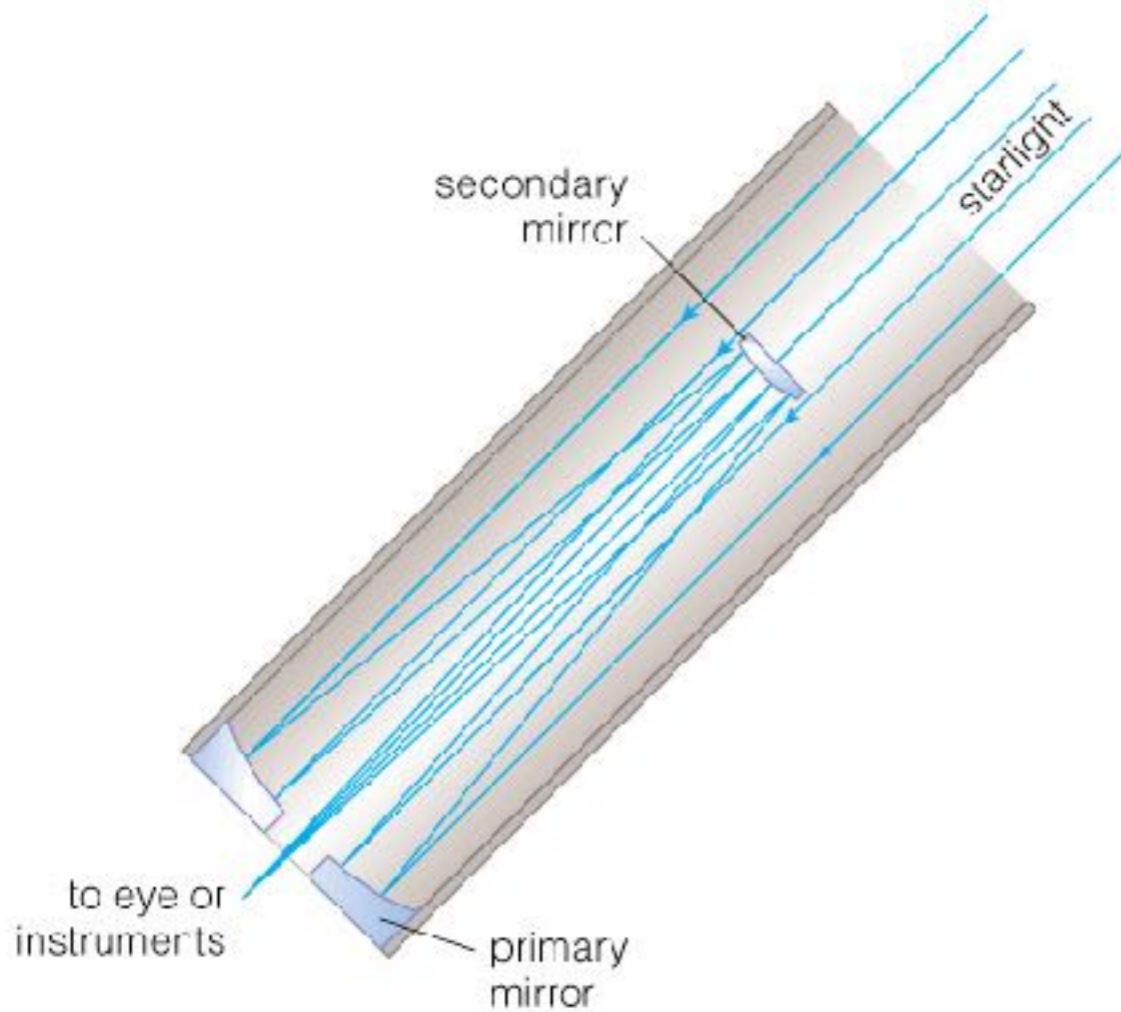
Refracting telescope



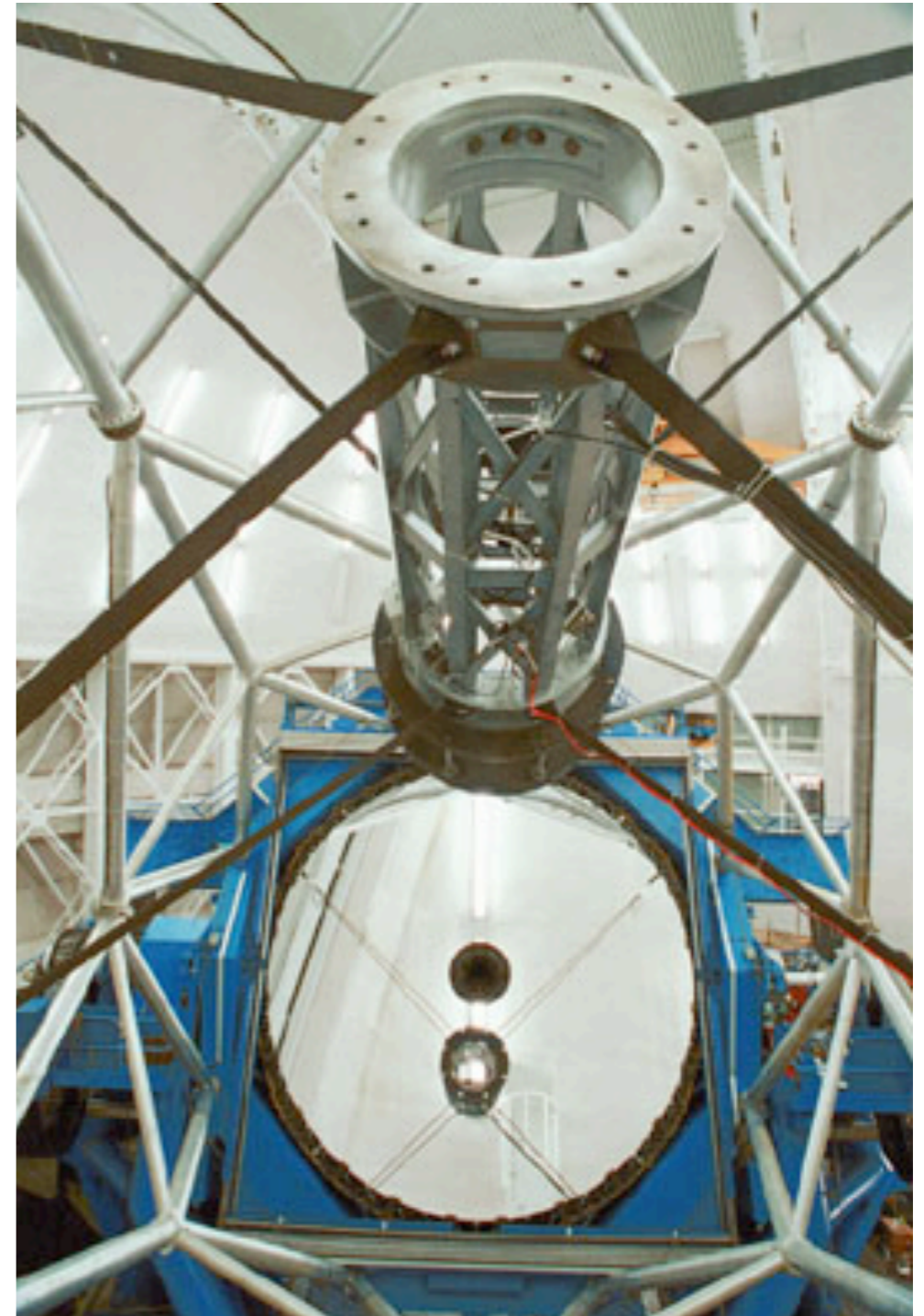
Yerkes 1-m refractor

Basic Telescope Design

- Reflecting: mirrors
- Most research telescopes today are reflectors



Reflecting telescope



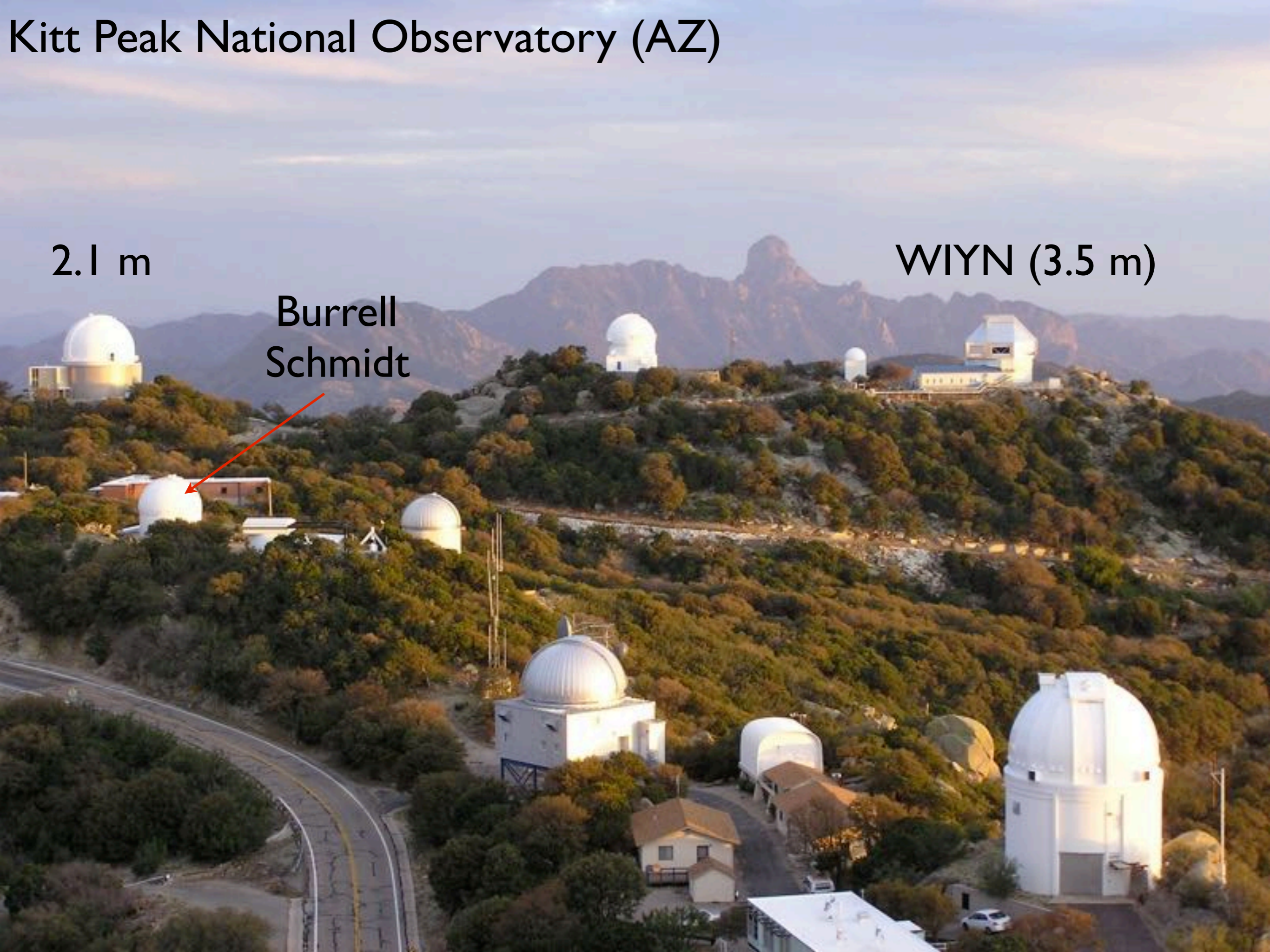
Gemini North 8-m

Kitt Peak National Observatory (AZ)

2.1 m

Burrell
Schmidt

WIYN (3.5 m)

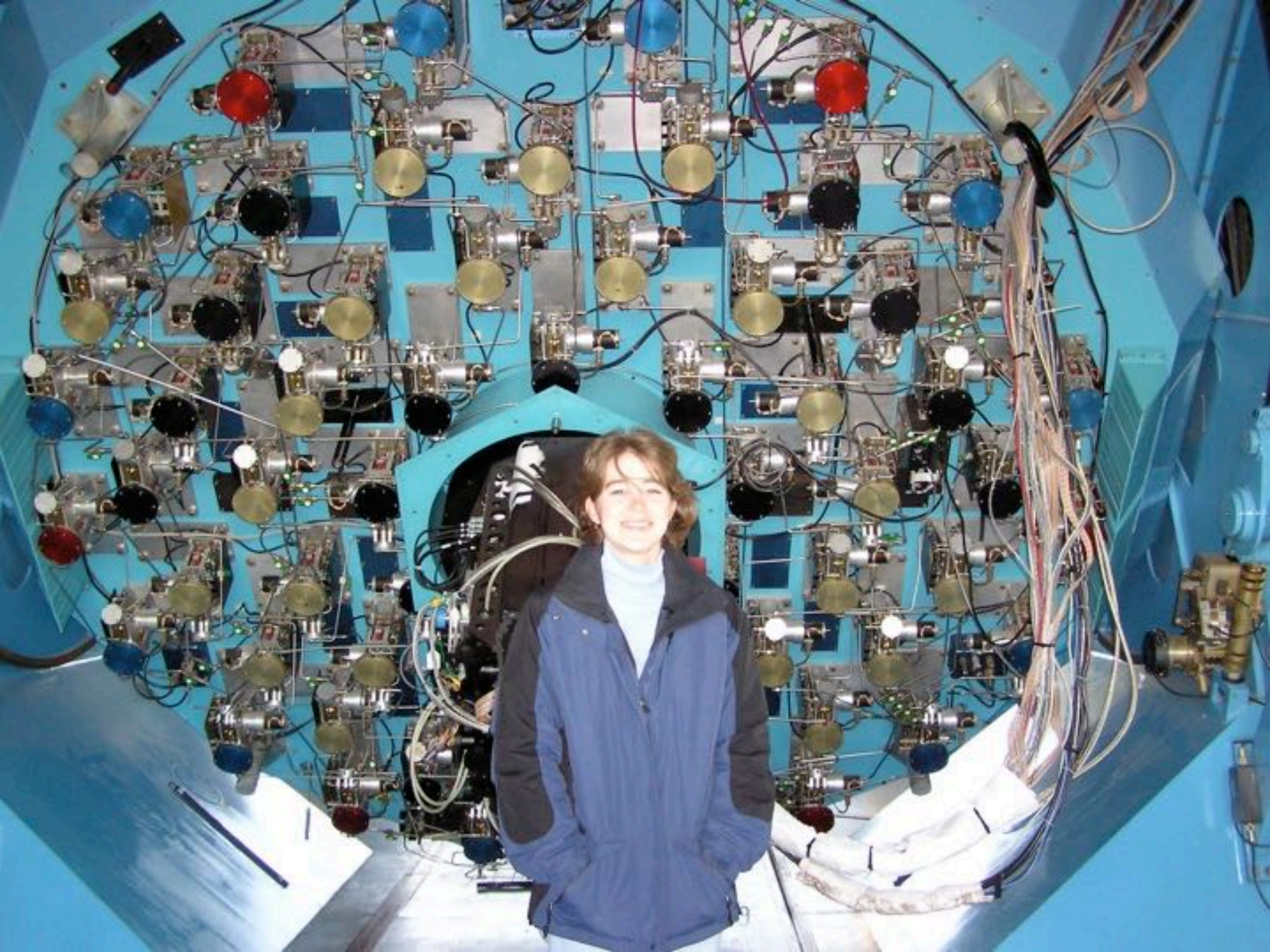


Burrell Schmidt



WIYN 3.5 m





Advantages of telescopes in space



Hubble

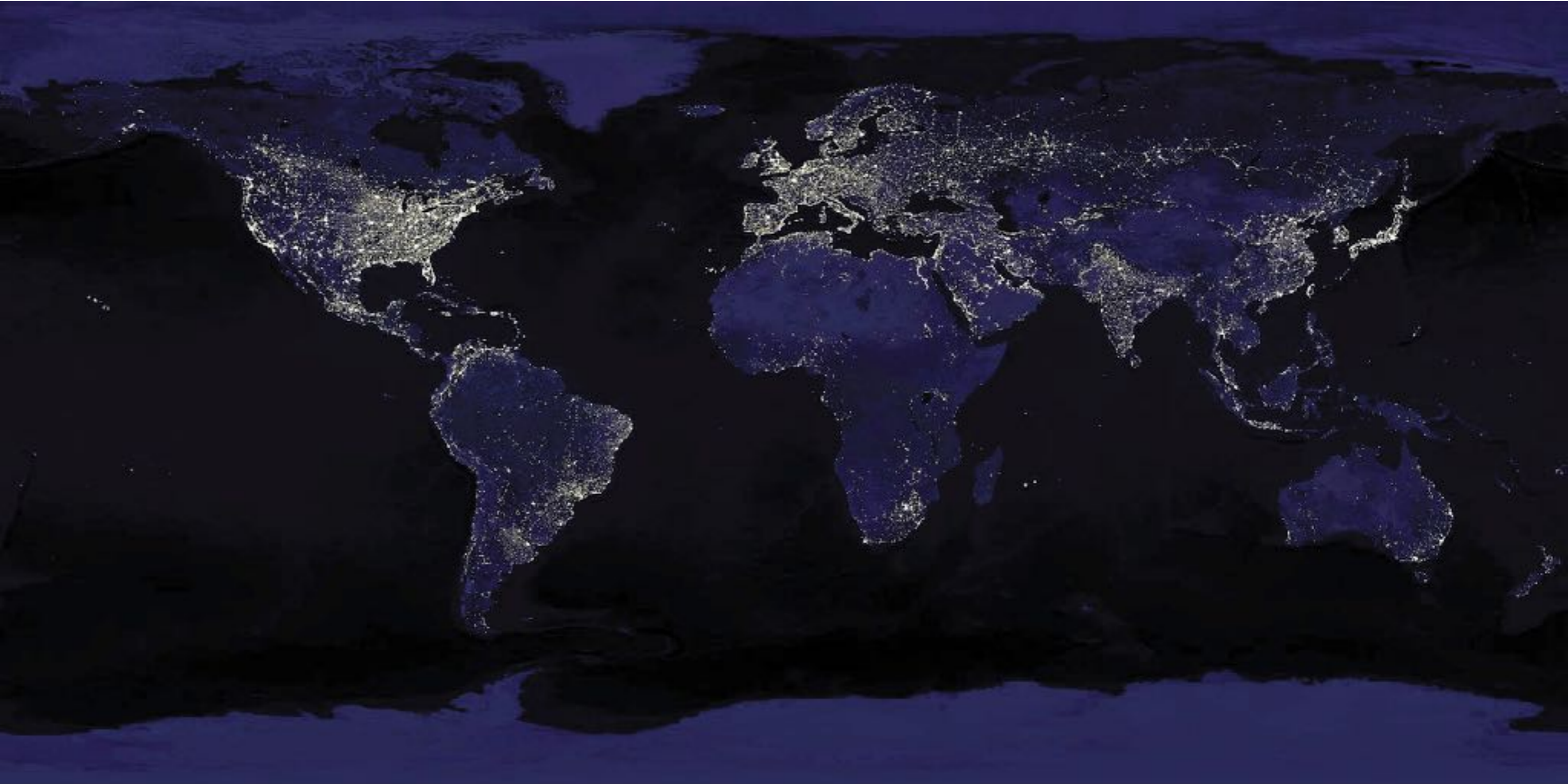


Chandra

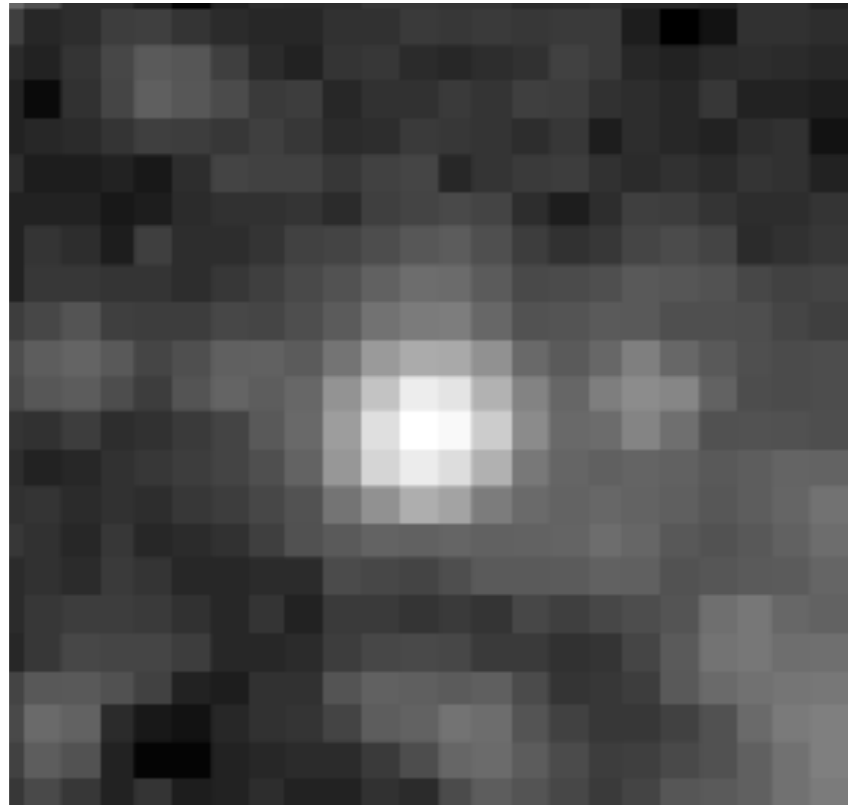
Fun fact: one of these pictures is real; the other is fake. Can you tell the difference?

Observing problems due to Earth's atmosphere

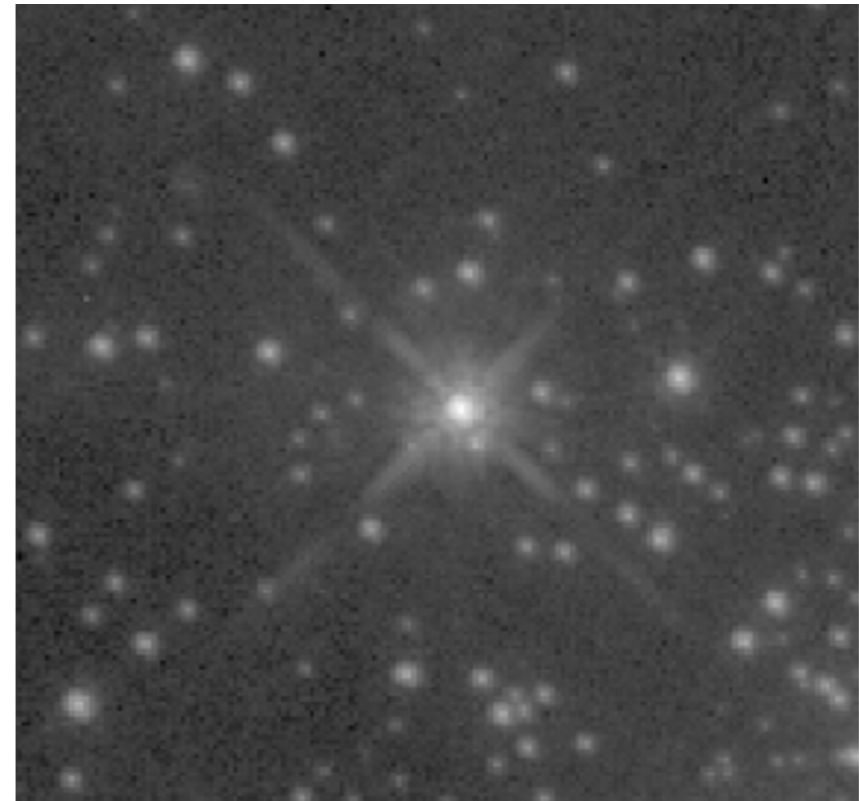
1. Light Pollution



2. Atmospheric Turbulence causes *twinkling* \Rightarrow blurs images (called “seeing” by astronomers).



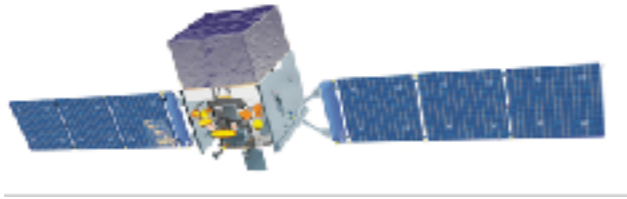
Star viewed with
ground-based telescope



View from Hubble
Space Telescope

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

Fermi



Herschel

major space observatories



Compton



Integral



Chandra



Hubble



Spitzer



WMAP

gamma ray

X ray

ultraviolet

visible

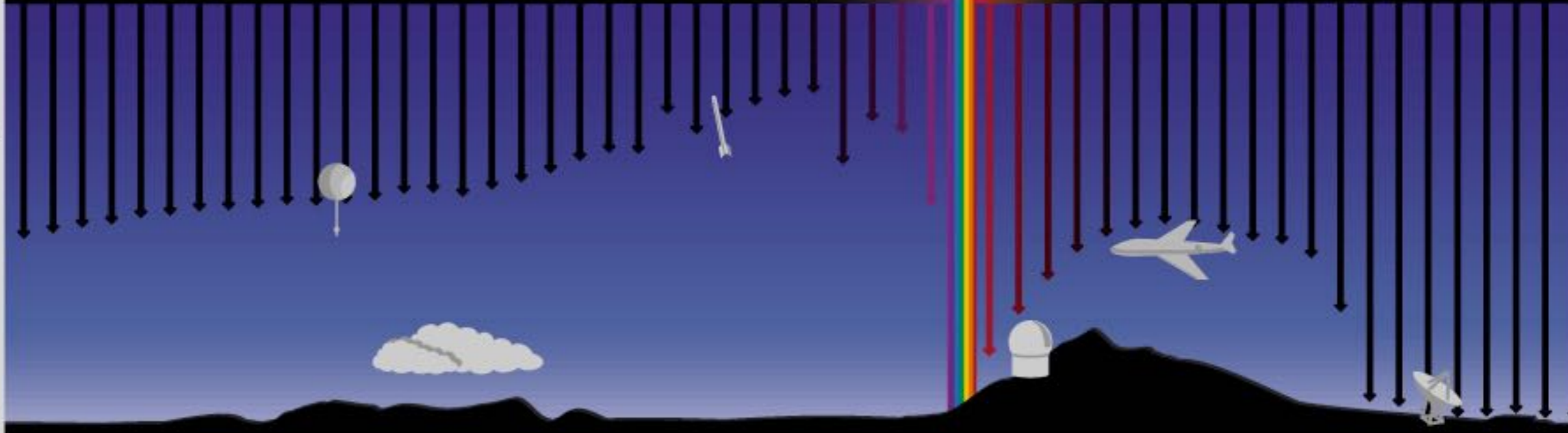
infrared

radio

100 km

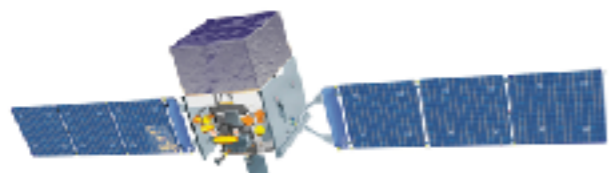
10 km

sea level



Telescopes in space solve all 3 problems.

Fermi



Herschel

major space observatories



Compton



Integral



Chandra



Hubble



Spitzer



WMAP

gamma ray

X ray

ultraviolet

visible

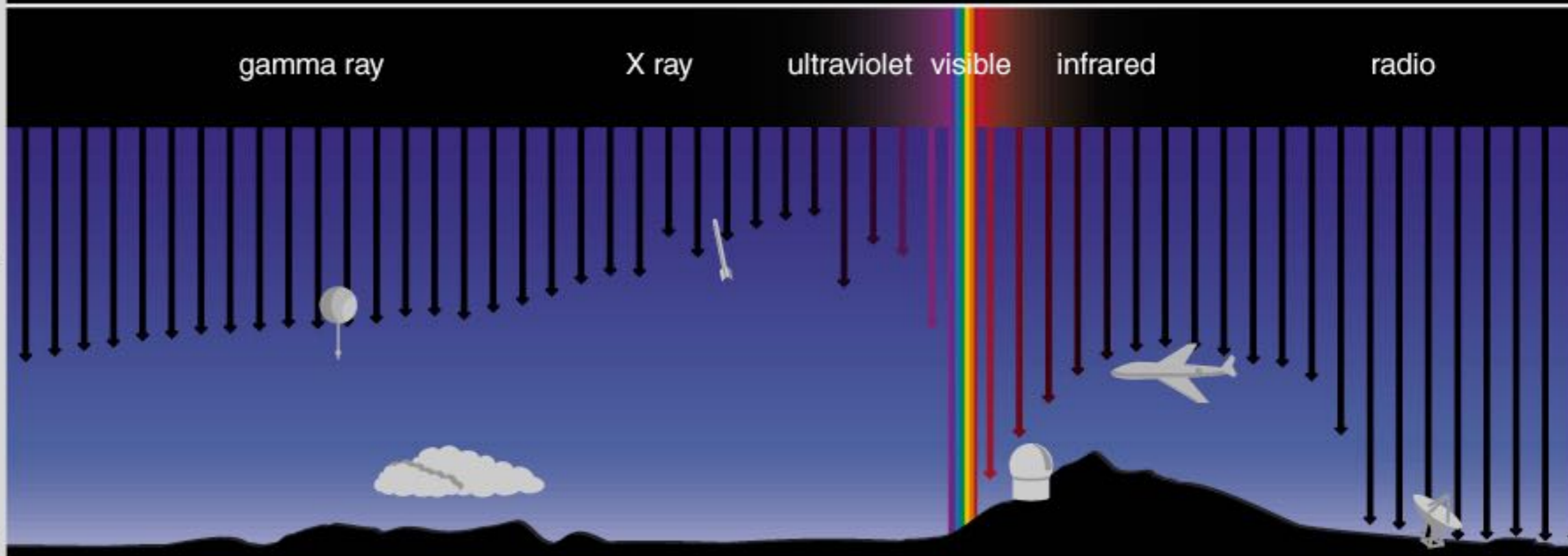
infrared

radio

100 km

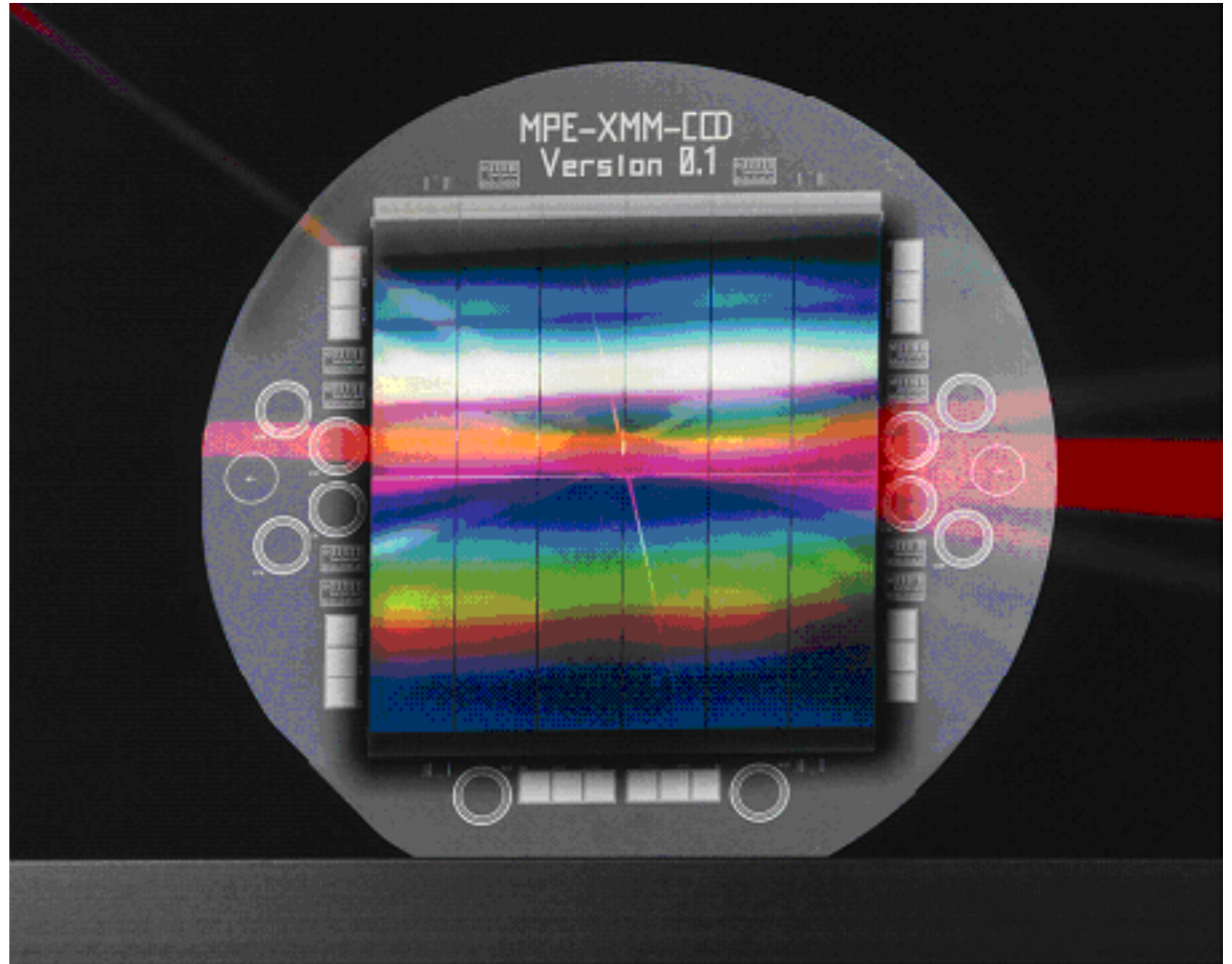
10 km

sea level

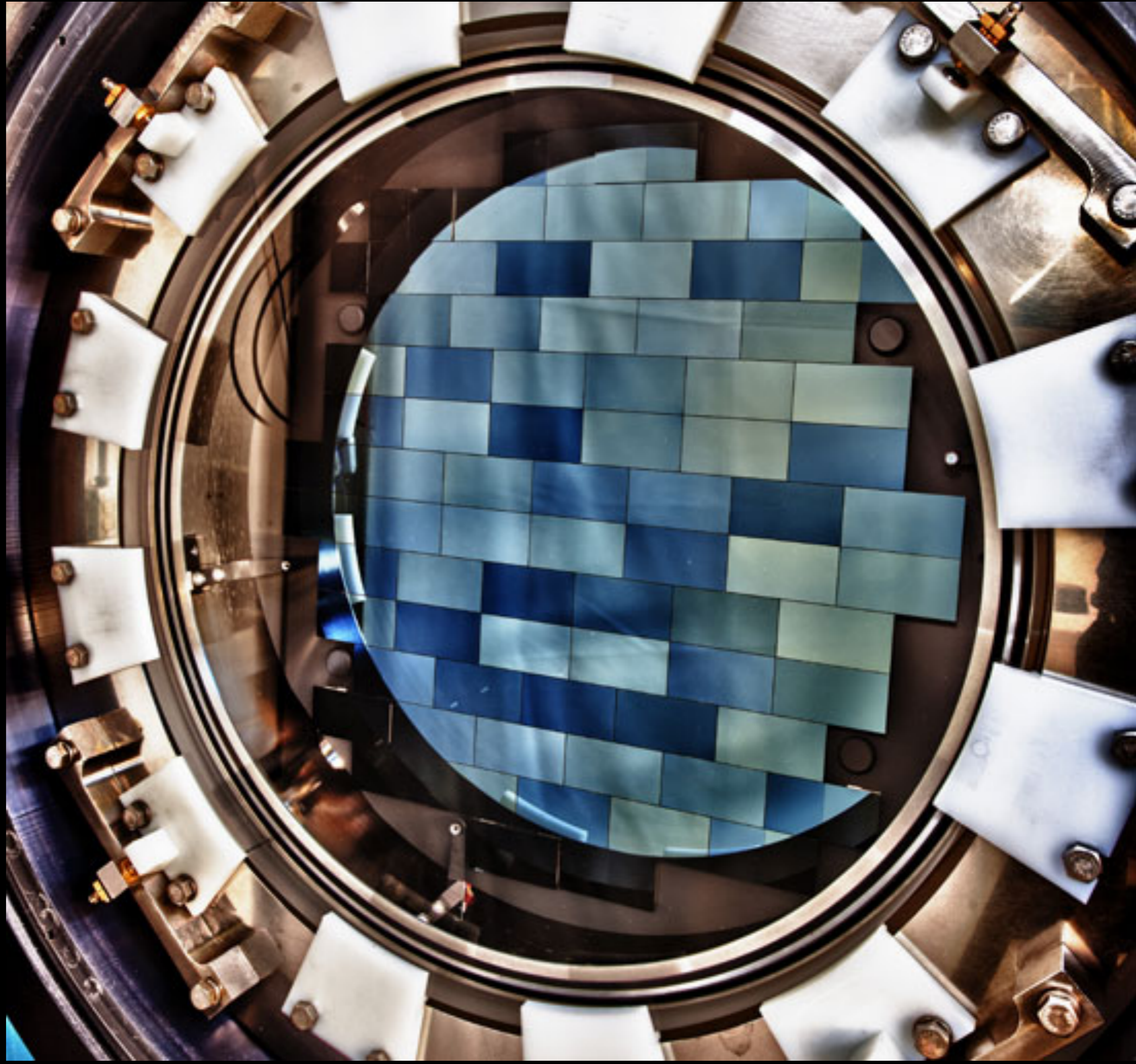


Instruments

- Cameras

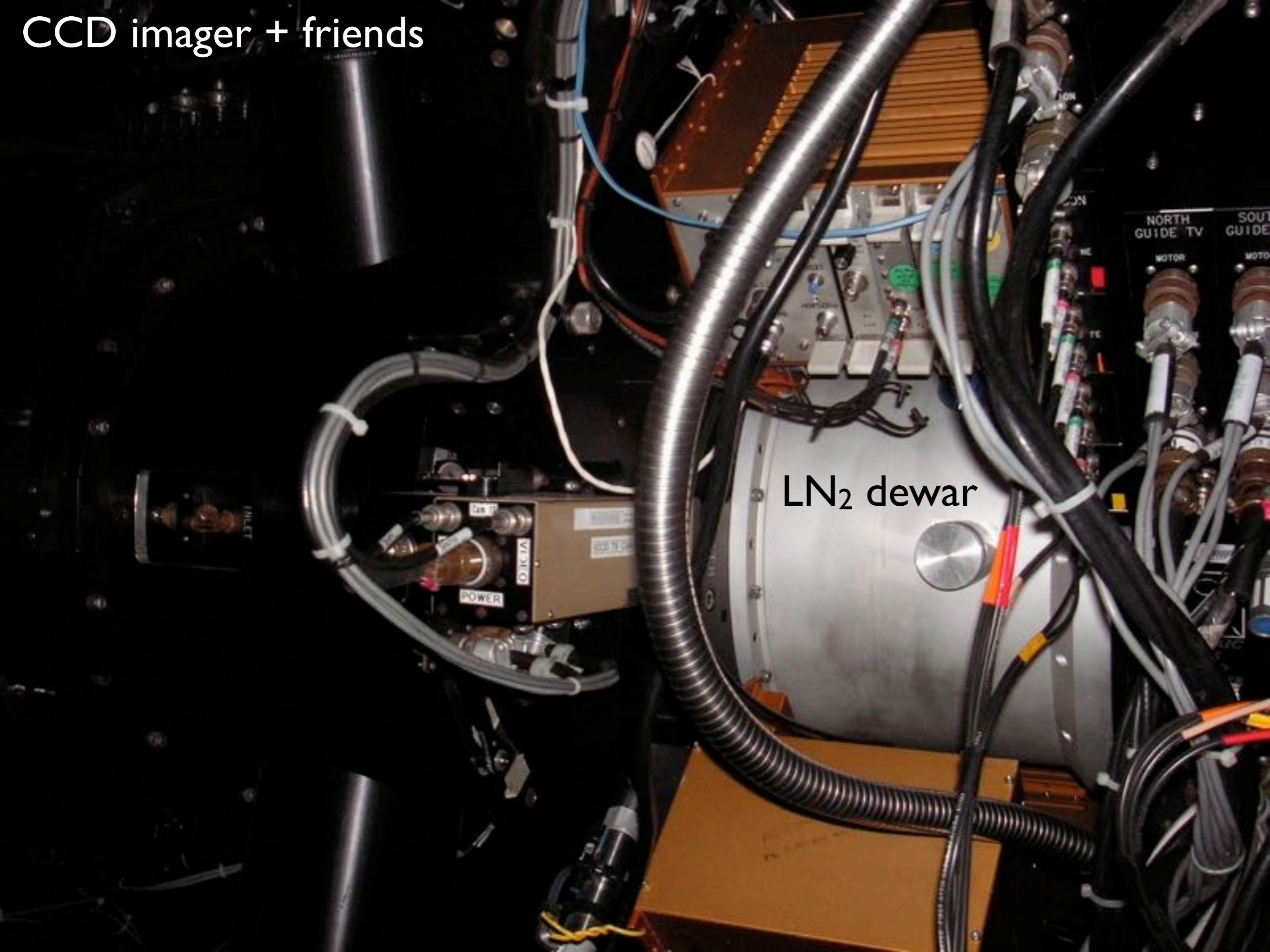


Dark Energy Camera
570 Megapixel

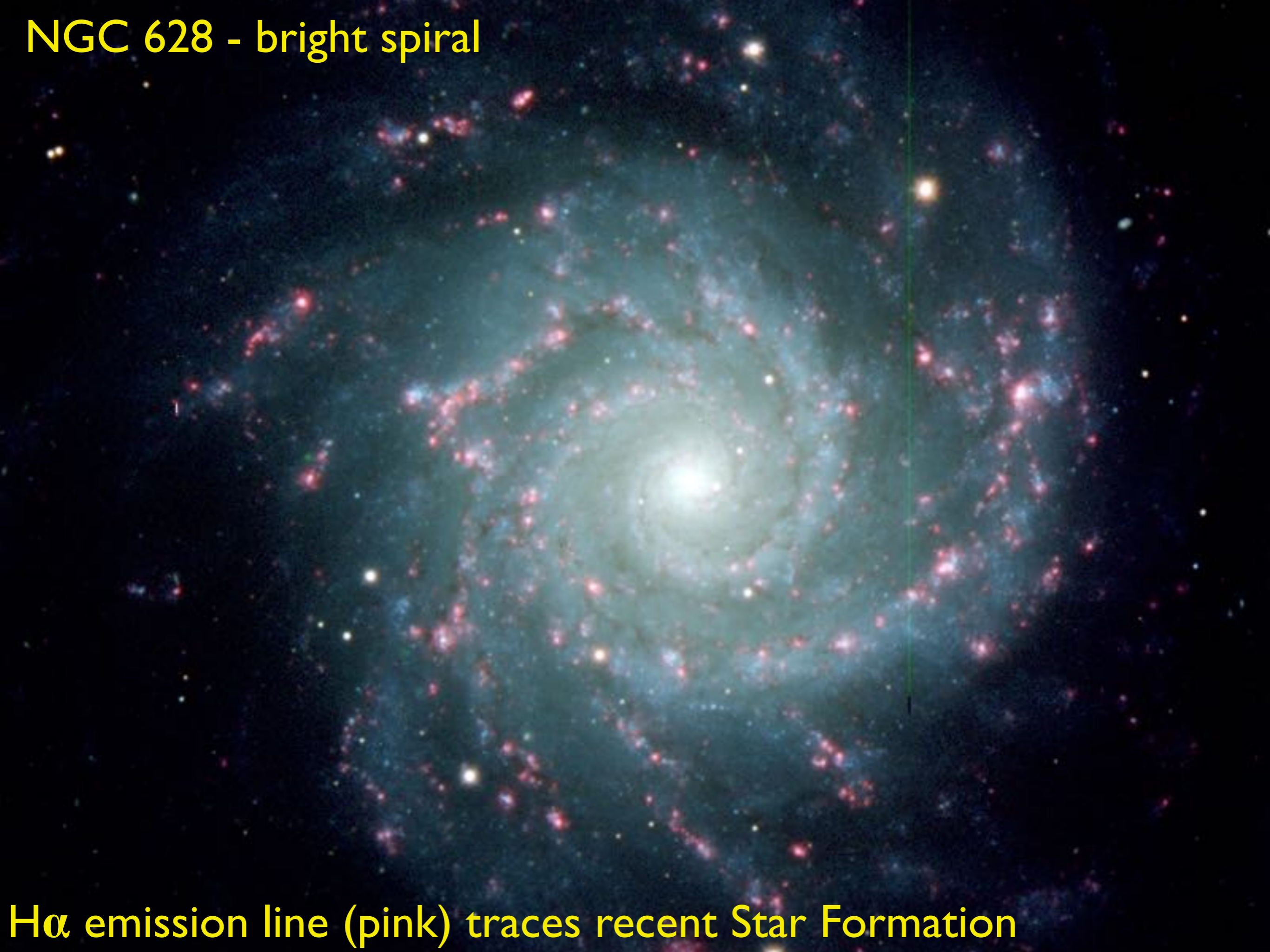


CCD imager + friends

LN₂ dewar



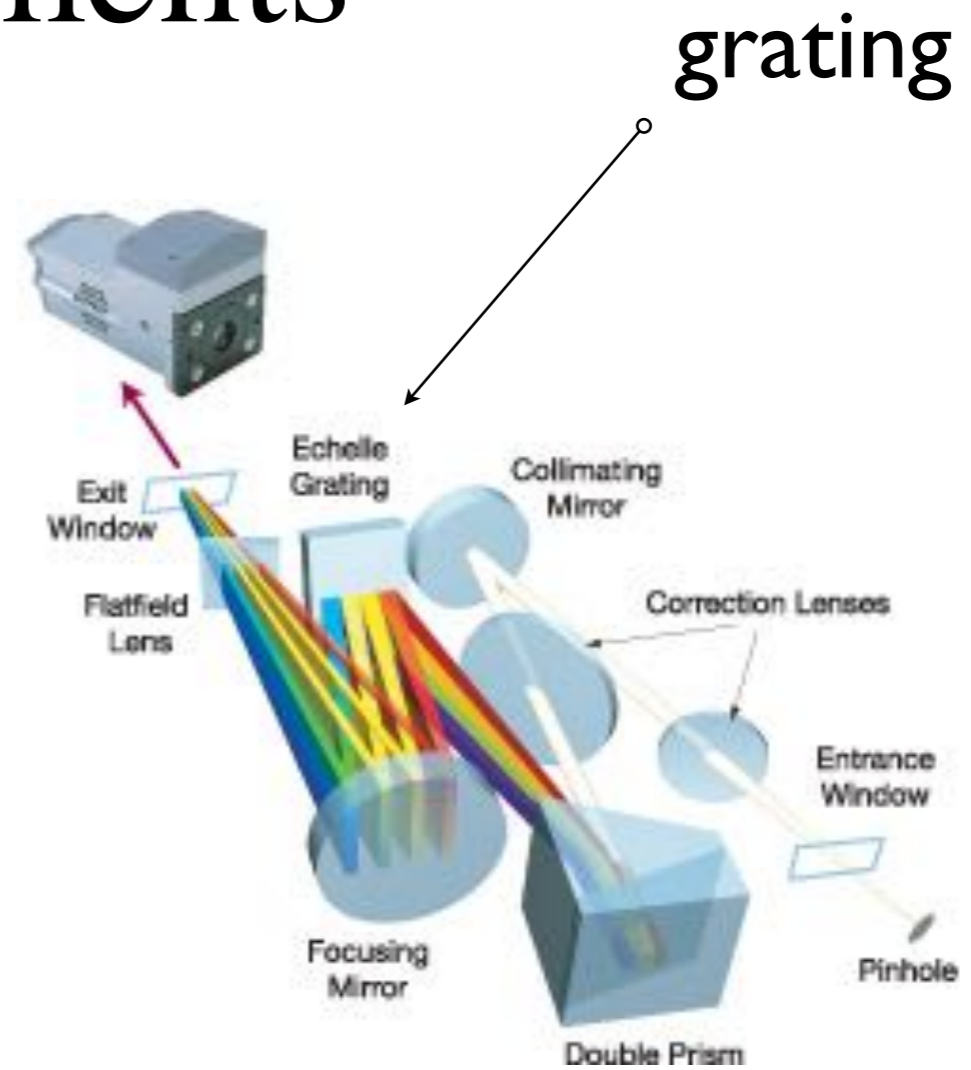
NGC 628 - bright spiral



H α emission line (pink) traces recent Star Formation

Instruments

- Spectrographs





spectrograph



grating

Contents of the Solar System

- The Sun
- Major Planets
 - Terrestrial: Mercury, Venus, Earth, Mars
 - Jovian planets: Jupiter, Saturn
 - Ice Giants: Uranus, Neptune

} Gas Giants
- Moons
- Dwarf Planets
 - KBOs/TNOs: Pluto, Quaoar, Eris, Sedna...
- Asteroids
 - KBO: Kuiper Belt Object
 - TNO: Trans-Neptunian Object

} same thing
- Comets
 - misc. dust, meteoroids, solar wind particles...