Big Q: What is the Nature of the Stars?
Can we ever know the `Physics of the Stars’?
(= astrophysics)

• Auguste Comte (1798-1857)

• founder of `Positivism’
  - real knowledge only due to hard facts, e.g., laboratory science, measurements

• claimed that we will never know the nature of the stars
  - distant stars are forever out of our reach
  - we cannot conduct laboratory experiments with them
Which questions would an astronomer have asked about the stars in the early 1800s?

• How far away are they (stellar distance scale)?

• What are the stars made of (stellar composition)?

• How massive are they?

• How long do they live (stellar lifetimes)?

• By what mechanism do they shine?

• Is the Sun just a (nearby) star?
  A: Yes, already widely believed (Descartes, Newton)
The Hunt for Stellar Parallax!

\[ d = \frac{1}{p} \]

- \( p \) = parallax in arcseconds
- \( d \) = distance to star in parsecs

(1 parsec = 3.26 light-years)
The Hunt for Stellar Parallax!
Measuring the Distance to the Stars

• Friedrich Wilhelm Bessel (1784-1864)
  • highly talented in astronomy and mathematics ("Bessel functions")
  • director of Königsberg Observatory
  • 1838: First stellar parallax
Q: How to select promising candidates?

- possible criteria:
  1) brightest stars
  2) most rapid proper motion

Bessel’s choice!
Stellar Motions on the Sky

- proper motion $\alpha 1/d$

Diagram showing the paths of nearby and distant stars with angles $\theta$ and $\phi$. Distant star is further away than the nearby star.
Q: How to select promising candidates?

- 61 Cygni: the `flying star’ (5 arcsec per year)
Great Success: First Stellar Parallax (1838)!

- Bessel: 61 Cygni
  - 1/3 arcsec → 10.3 Lightyears

- almost simultaneously:
  - Wilhelm Struve: Vega
  - Thomas Henderson: Alpha Centauri

Bessel’s heliometer
The True Brightness of the Stars

- what we measure: flux = energy/area (‘apparent brightness’)

- if distance (d) to star is known, can figure out true (intrinsic) brightness = Luminosity (L)

- \( L = 4 \times \pi \times d^2 \times \text{flux} \) (‘inverse-square law’)

\[ L = 4 \times \pi \times d^2 \times \text{flux} \]
What stuff are the Sun and stars made out of?

- scrutinize the light that we receive!
The Message of Starlight (Newton 1666)

• white light is composed of different colors!
The Spectrum of the Sun

• Joseph Fraunhofer (1787-1826)

• master optician and telescope builder

• 1814: Discovery of Spectral Lines in Solar Light (= ‘Fraunhofer lines’)

[Image of Joseph Fraunhofer]
The Spectrum of the Sun (1814)

- Fraunhofer lines: dark lines
What are the Spectral Lines?

- Heidelberg in 1850s and 60s:

- Gustav Kirchhoff (1824-87) and Robert Bunsen (1811-99)
  - discover the `Laws of Spectral Analysis’

- Robert Bunsen (`Bunsen burner’)

Gustav Kirchhoff (left) and Robert Bunsen.
What are the Spectral Lines?

• `Flame test’ (Spectral Analysis):
  - each chemical element has a distinct fingerprint!
What are the Spectral Lines?

- `Flame test’ (Spectral Analysis):
  - each chemical element has a distinct fingerprint!
What are the Spectral Lines?

• `Flame test’ (Spectral Analysis):
  - Kirchhoff/Bunsen discover new elements (Rubidium, Caesium)

Periodic Table: Dmitri Mendeleev (1869)
What are the Spectral Lines?

- dark lines = absorption lines
- bright lines = emission lines
What are the Spectral Lines?

Niels Bohr (1885-1962)

Bohr’s quantum model of the atom (1913)
What are the Spectral Lines?

- Bohr’s quantum model of the atom (1913):
  - emission and absorption lines!
Classifying the Spectra of the Stars
Classifying the Spectra of the Stars

- Father Angelo Secchi
  (Jesuit, 1818-78)

- first scheme to classify stellar spectra
Classifying the Spectra of the Stars

- great classification effort at Harvard College Observatory, beginning in 1880s
Classifying the Spectra of the Stars

• the `women computers’ of Harvard
Classifying the Spectra of the Stars

• Annie Jump Cannon (1863-1941)

• master classifier

• instrumental in publishing the *Henry Draper Catalogue*
  - 1918-24, ~225,000 stars:
    - each with spectral type and brightness
The Harvard Sequence of Spectral Types

Traditional mnemonic: “Oh, Be A Fine Girl, Kiss Me!”

- arranged in order of decreasing temperature on the surface of the star
Spectral Type and Temperature

- Red: lower Temperature, blue: higher T
Classifying the Spectra of the Stars
Chemical Composition of the Stars

• Cecilia Payne-Gaposchkin (1900-79)

• Harvard PhD 1925

• hydrogen and helium are most abundant elements in the universe!
Chemical Composition of the Stars

• measured strength of spectral line \((S) =\)
  
  abundance \((A) \times \) transition probability \((P)\)

- Metal lines (e.g., Ca):

\[ S = a \times P \]

- Hydrogen lines:

\[ s = a \times P \]

• Hydrogen is most abundant element!!!
Birth of Astrophysics (part 1)

• Measuring the Distance to the Stars:
  - Friedrich Wilhelm Bessel
  - 1838: First successful stellar parallax
  - 61 Cygni: 1/3 seconds of arc 10 lightyears
  - “the greatest triumph which astronomy has ever witnessed”
    (John Herschel)

• Figuring out the composition of the stars:
  - spectral analysis (absorption and emission lines)
  - Harvard classification: stars can be grouped according
    to spectral type (and thus surface temperature)
  - OBAFGKM
  - Hydrogen and Helium are most abundant elements in the
    Sun and the stars (Cecilia Payne)