AST400A - Theoretical Astrophysics - Fall 2025, Steward Observatory

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Day 0 - August, 26, 2025

Agenda:

- Introductions (15m)
- Syllabus + Questions (15m)
- Lecture - Intro & orders of magnitude (30m)
- Questions (10m)
- Homework - Pre-course Survey here. Extra credit.

Introductions

1. Name
2. Research Interests or Current Research Project Topic
3. Topic you are most interested in learning more about in this course?
4. Hobbie(s) outside of astronomy?

Syllabus

Navigate to the syllabus here.

Communication

1. Slack
2. Email
3. D2L

Introduction

Based on notes following Chapter 1 of Pols Lectures here.

What is a star?

- Historical definition: *flickering light source in the sky with no intrinsic motion* (where flickering excludes planets, and no intrinsic motion excludes planets *and* other solar system objects such as comets and asteroids).
- More modern definition: *self-gravitating amount of gas that at some point is sufficiently hot for nuclear fusion.*

What determines the properties of a (single) star?

1. **Mass**
2. Chemical composition
3. Presence of other stellar companion(s)
4. Rotation
5. Magnetic fields

Discuss together (1min)

What is a star made of? Can you think of a star made of something else?

Cecilia Payne-Gaposchkin

She determined that stars were composed primarily of hydrogen and helium in her 1925 doctoral thesis.

- accurately relating the spectral classes of stars to their measured temperatures

Image Credit: Smithsonian Institution

Observations

- Photometry
- Spectroscopy
- Astrometry
- Asteroseismology (either through photometry or spectroscopy)
- Neutrinos

Some definitions

In astrophysics (and in stellar physics in particular) we still use quantities and units that have mostly a historical justification.

Let's explore some.

Parallax

The yearly apparent motion on the sky of stars (w.r.t. to farther stars that are too far to exhibit this behavior) due to the orbit of the Earth around the Sun is called **parallax**.

A commonly used unit of distance in astronomy is the *parsec* = distance of a star with a parallax of one arcsecond:

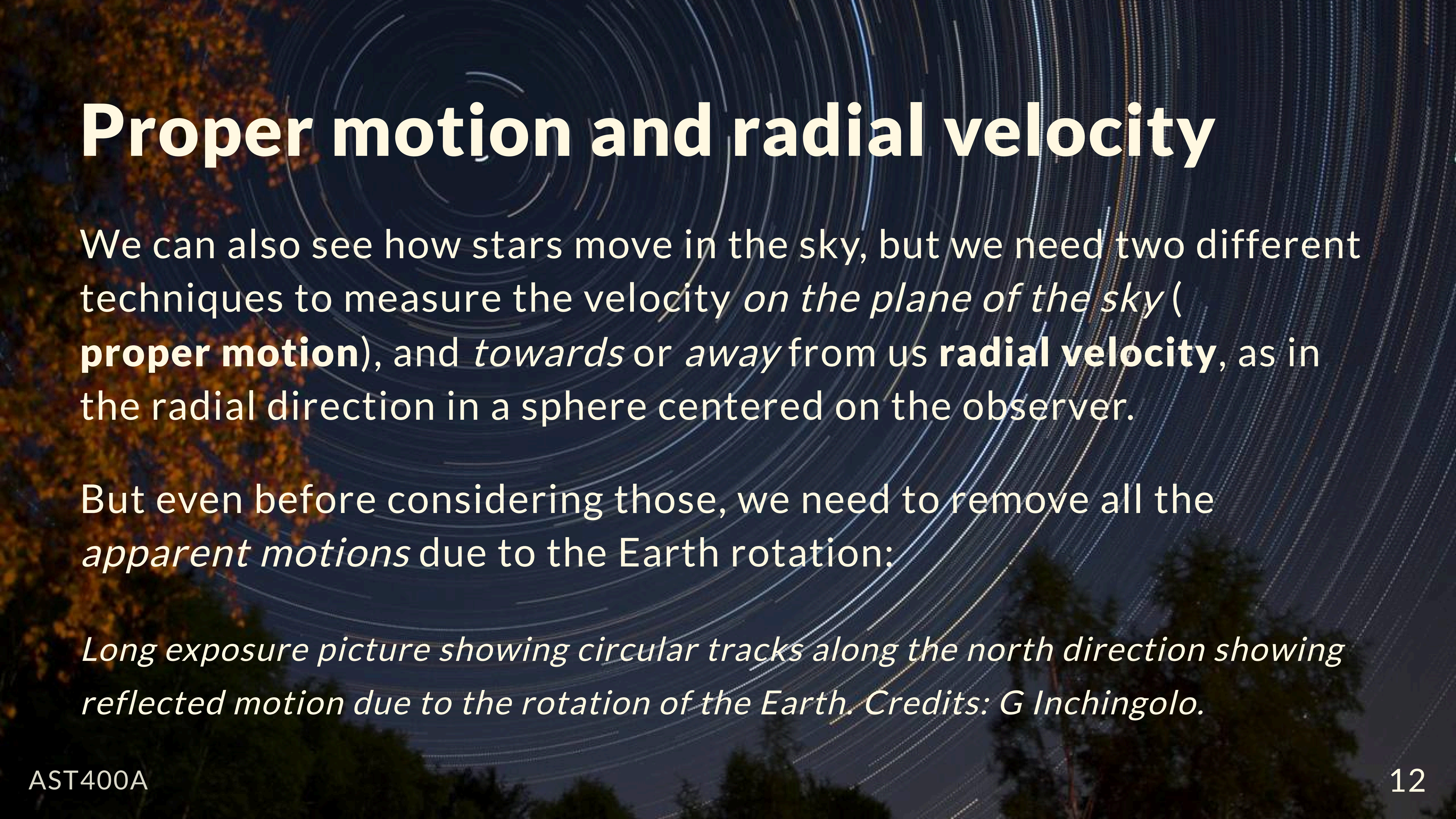
$$1 \ \mathrm{pc} \approx \ 3 \ \times \ 10^{18}\mathrm{cm} \ \approx \ 2 \ \times \ 10^{5}\mathrm{AU} \ \approx \ 3 \ \text{light years}$$

This is a measure of distance that can be used for stars with relatively small distances to the Solar system.

Proper motion and radial velocity

We can also see how stars move in the sky, but we need two different techniques to measure the velocity *on the plane of the sky* (**proper motion**), and *towards* or *away* from us **radial velocity**, as in the radial direction in a sphere centered on the observer.

But even before considering those, we need to remove all the *apparent motions* due to the Earth rotation:



Long exposure picture showing circular tracks along the north direction showing reflected motion due to the rotation of the Earth. Credits: G Inchingolo.

Magnitudes

The magnitude scale is a logarithmic scale first introduces by Hipparchus, who clearly was only able to do naked-eye observations. This explains why a logarithmic scale: the sensory responses are often logarithmic (see Weber-Fechner's law). The magnitude scale was formalized by Pogson 1856.

The magnitudes measure the energy flux from a point-like source (like a distant star) and it is a differential measure relative to some standard source.

Magnitudes

- More Hipparchus lore

$$m = -2.5 \log_{10}\left(\frac{\int T(\lambda) F_\lambda d\lambda}{\int T(\lambda) d\lambda}\right) + m_0 \ ,$$

m_0 is the reference magnitude, F_λ is the monochromatic flux of the source, and the factor of -2.5 is chosen so that the magnitudes measured this way roughly agree with Hipparchus.

An increase of 5 magnitudes corresponds to an increase in flux of a factor of 100

Magnitudes

- **bolometric** magnitude is the magnitude across all wavelengths for an idealized perfect detector. If the distance of a source is known, we can then infer its intrinsic luminosity from this.
- **apparent** magnitude m we defined above is a measure of the actual photon flux received from a source (e.g., a star) on Earth, but that of course depends on how far the source is from Earth (a candle in your hand has a higher apparent magnitude than Betelgeuse in the sky!).

Magnitudes

- **absolute** magnitude as the apparent magnitude a star would have if it were at a distance of 10 pc from the Sun, thus the relation between apparent magnitude m and absolute magnitude M is

$$M - m = -2.5 \log_{10} \left[\left(\frac{d}{10 \mathrm{pc}} \right)^2 \right]$$

where d is the distance, and it is assumed there is no absorption of light by the interstellar material.

Magnitudes

For the reference magnitude m_0 there are multiple choices. For instance, typically the star Vega (α Lyrae) is used as a standard and by definition its magnitude in U, B, and V band in the Vega-based magnitude system is zero. More details here.

Relevant physical scales

The star we can observe best is the closest one, the Sun ($\odot$), so a lot of quantities are scaled to those of the Sun in stellar physics and in astronomy more generally.

- Solar radius: $R_\odot = 6.957 \times 10^{10}$ cm $\approx\ 7\ \times\ 10^{10}$ cm $\approx\ 10^{11} cm$
- Solar mass: $M_\odot = 1.98 \times 10^{33}$ g $\approx\ 2 \times 10^{33}$ g
- Solar luminosity: $L_\odot = 3.82 \times 10^{33}$ erg s^{-1}
- Solar effective temperature: $T_\odot$ ≃ 5900K ≃ 6000K
- Solar metallicity: $Z_\odot \approx 0.0146 \approx\ 0.02$

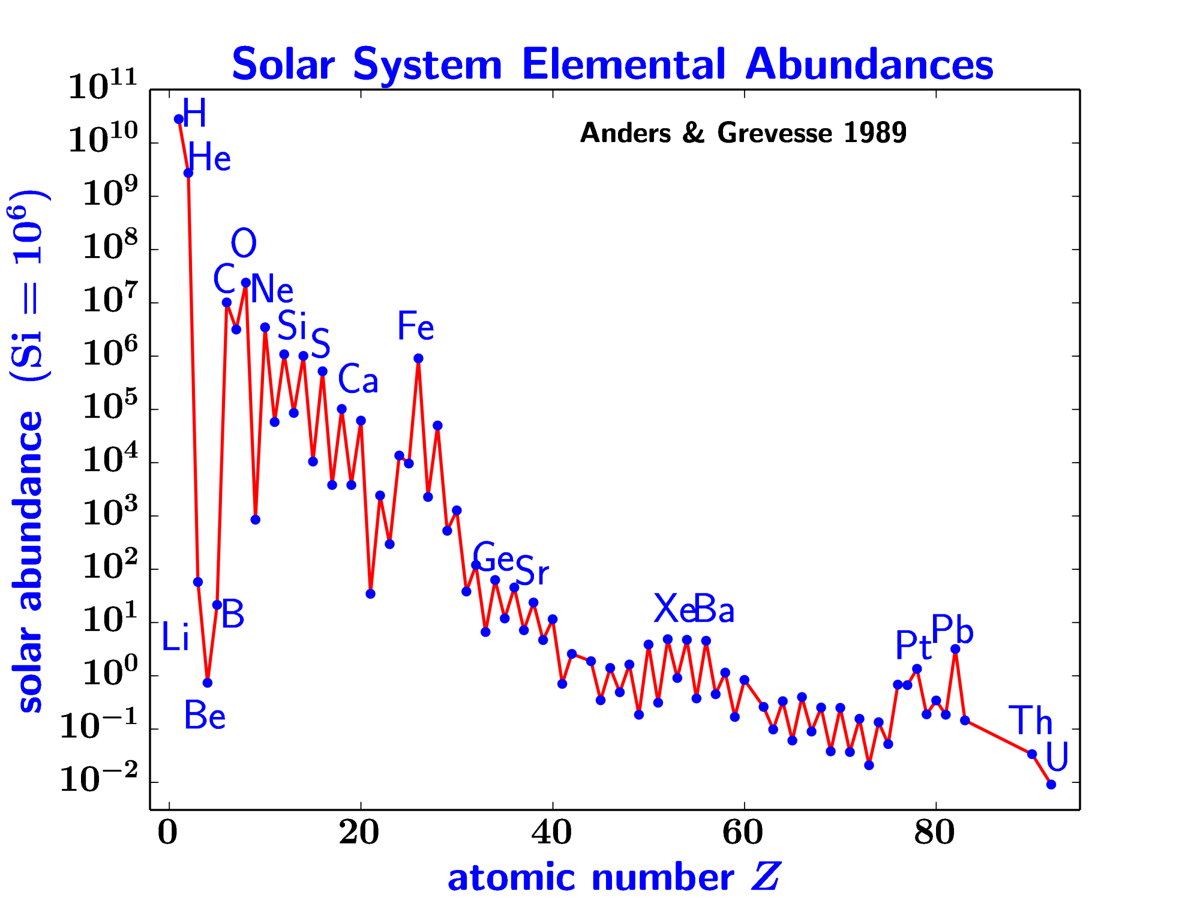
Metallicity

- the fraction by mass of gas that is *not* hydrogen nor helium. This includes many elements (e.g., C, N, O, Si) that a chemist would not call "metals". See here for an online periodic table of elements.

We assume that the distribution of metals scales with the Solar distribution.

Metallicity

- This shows the number of atoms normalized to 10^6 atoms of Silicon as a function of atomic number A.



Solar abundance pattern from Anders & Grevesse 1989.

Discuss projects

- Projects will cover topics that are important and or timely, but hard to fit in the main body of the course
- Occasion for you to dig deeper and teach to your peers
- You should look over the list of proposed topics here.
- You will be graded on the following:
  - written summary
  - oral presentation in class (again, with your peers!)
  - how you give feedback to others.

Homework 0

Due: End of day, Friday, August 29, 2025

- Pre-course survey here. Extra credit.
- Submit ranked list of topics to D2L. Ungraded.

How to be successful in this course

1. Show up, engage, and be respect each other.
2. Be patient.
3. Communicate.
4. Come to class ready to grow your knowledge everyday. Article on Growth Mindset.
5. We are here to help you reach your goals.