

Recap of last time

Photometry: Measuring light intensity

- Magnitude: Brightness measurement in a single filter
- Color: Difference of two magnitudes, sensitive to temperature

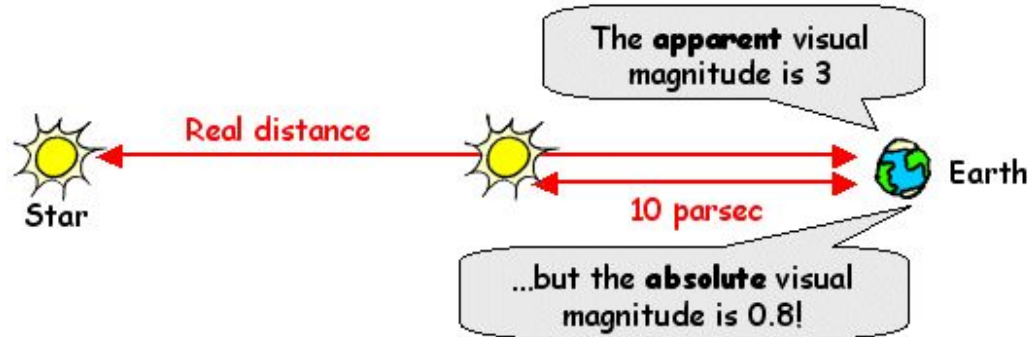
Astrometry: Measuring positions and motions (6D!)

- First 4 dimensions: Positions and velocities on the plane of the sky
- 5th dimension (distance): Derived from parallax measurements
- 6th dimension (radial velocity): Must be measured from spectra

Before we start with spectroscopy, a few extra details →

Absolute and apparent magnitudes

Objects have intrinsic brightnesses (**luminosity**), but their distance affects how bright or faint they appear to us here on Earth.



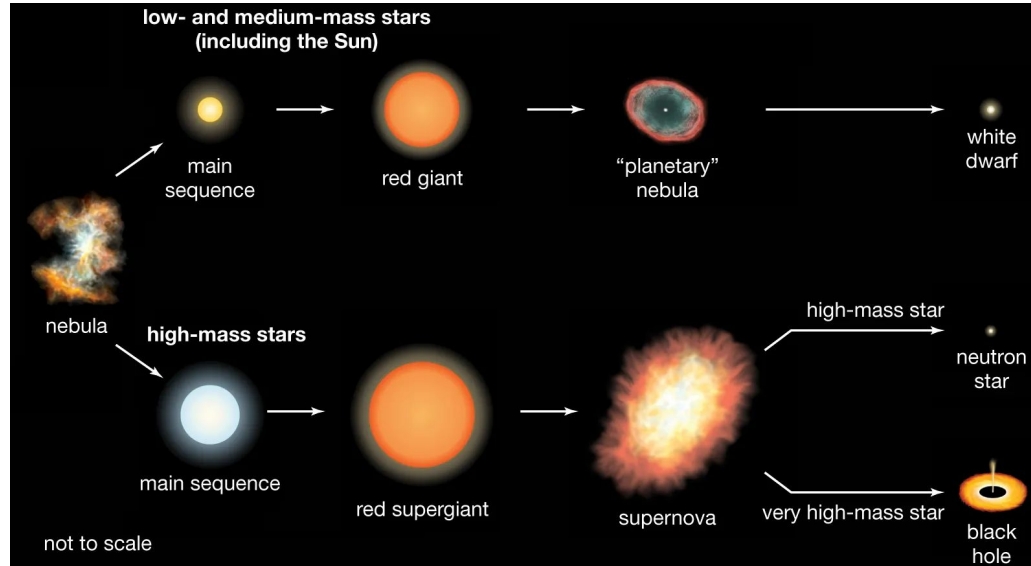
Absolute magnitude (M):
Brightness if the object were placed at 10 pc

Apparent magnitude (m):
What we measure on Earth

$$m - M = 5 \log \left(\frac{d}{10} \right)$$

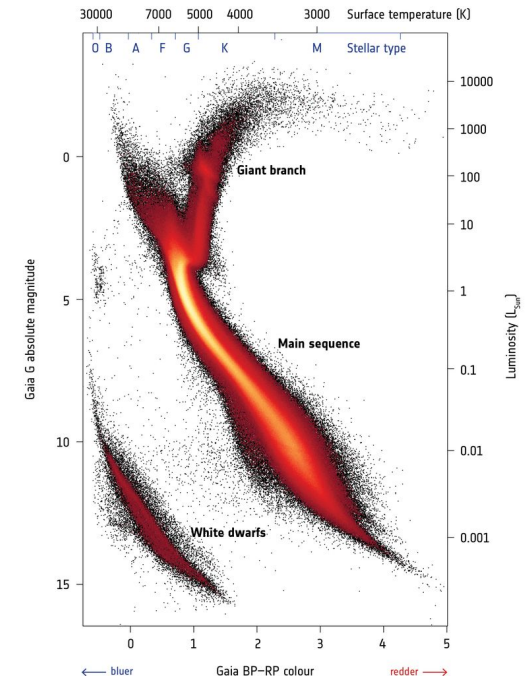
distance (pc)

Color-magnitude diagrams



CMDs allow us to distinguish the different stages of stellar evolution just with photometric information

→ GAIA'S HERTZSPRUNG-RUSSELL DIAGRAM



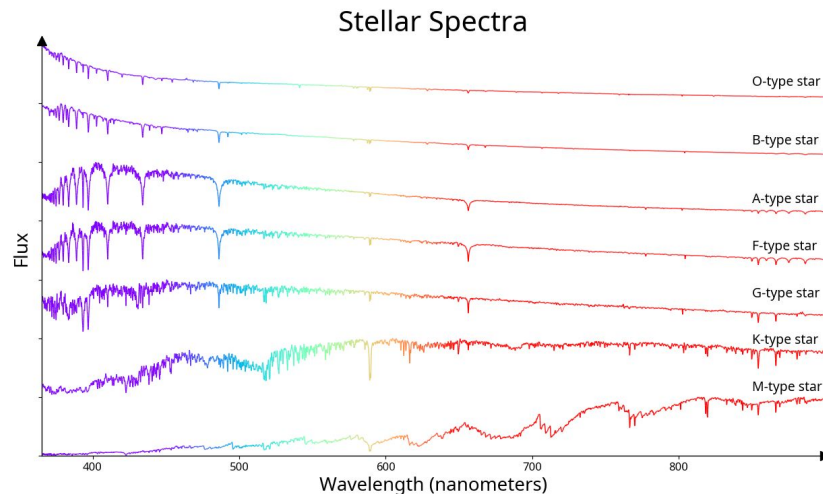
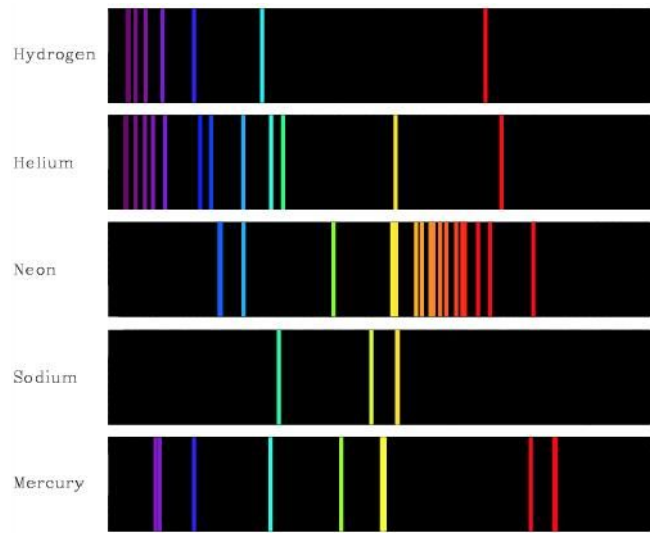
Spectroscopy

ASTR 2910 ★ Week 8

What is a spectrum?

Measurement of the flux (# photons/time) received at different wavelengths.

Spectral lines correspond to specific energy transitions within atoms. Each element on the periodic table has a unique spectral “fingerprint.”



Continuous light source

Cloud of gas

Light

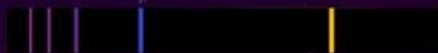
CONTINUOUS SPECTRUM

Spectrum that contains **all wavelengths** emitted by a hot, dense, light source



EMISSION SPECTRUM

Shows **colored lines** of light emitted by glowing gas

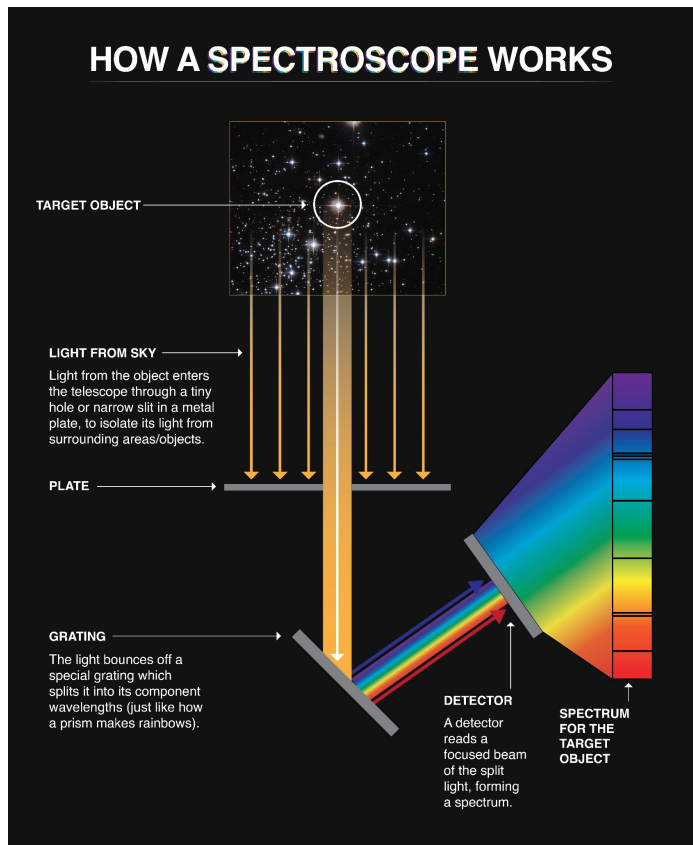


ABSORPTION SPECTRUM

Shows **dark lines or gaps** in light after the light passes through a gas

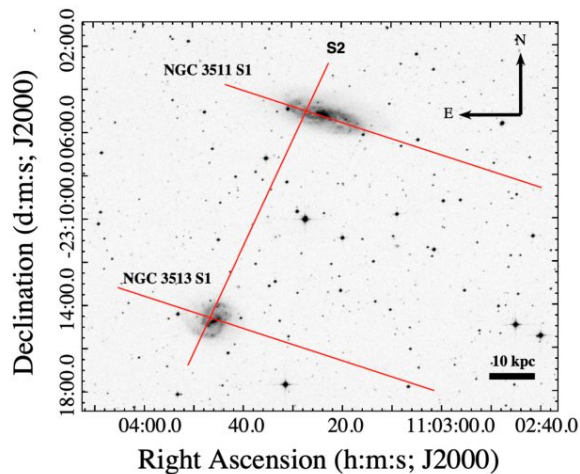


How do we get spectra?



Light enters through slit → split up by diffraction grating or prism → recorded by detector

Different gratings have different wavelength ranges and resolutions.



Slits are narrow, but have different lengths; some are long enough to lie across whole galaxies!

What information does a spectrum give us?

- Chemical composition
- Surface gravity
- Radial velocity
- Temperature
- And more...



Hard to get with photometry!

Stellar spectra tell you the composition of the star's atmosphere

“Integrated” spectra of galaxies tell you about the stellar populations and the activity level of the central black hole

Spectra of diffuse objects (e.g. planetary nebulae) can tell you what they are/how the gas was heated

Metallicity and abundances

PERIODIC TABLE OF ELEMENTS (FOR ASTRONOMERS)

1 H Hydrogen 1.008	2 He Helium 4.003																
3 Li Lithium 6.941	4 Be Beryllium 9.012																
11 Na Sodium 22.990	12 Mg Magnesium 24.305																
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.88	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.630	33 As Arsenic 74.922	34 Se Selenium 78.971	35 Br Bromine 79.904	36 Kr Krypton 83.799
37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.94	43 Tc Technetium 98.906	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.414	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.757	52 Te Tellurium 127.6	53 I Iodine 126.905	54 Xe Xenon 131.29
55 Cs Cesium 132.905	56 Ba Barium 137.327	57 La Lanthanum 138.905	58 Ce Cerium 140.12	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.24	61 Pm Promethium 144.913	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.50	67 Ho Holmium 164.930	68 Er Erbium 167.259	69 Tm Thulium 168.934	70 Yb Ytterbium 173.054	71 Lu Lutetium 174.967	72 Hf Hafnium 178.49
73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.967	80 Hg Mercury 200.59	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium 209	85 At Astatine 210	86 Rn Radon 222	87 Fr Francium 223	88 Ra Radium 226	89 Ac Actinium 227	90 Th Thorium 232
91 Pa Protactinium 231	92 U Uranium 238.029	93 Np Neptunium 237	94 Pu Plutonium 244	95 Am Americium 243	96 Cm Curium 247	97 Bk Berkelium 247	98 Cf Californium 251	99 Es Einsteinium 252	100 Fm Fermium 257	101 Md Mendelevium 258	102 No Nobelium 259	103 Lr Lawrencium 262	104 Og Oganesson 284				

Metallicity (Z)

- Amount of elements heavier than H
- Often reported as $[Fe/H]$: ratio of iron to hydrogen, normalized to the value in the Sun (so $[Fe/H]_{\odot} = 0$)

Abundances (for any element X)

- Amount of that element that is present in a given object
- Usually reported as $[X/Fe]$ (also normalized to solar values)

How do we get that information?

Stronger lines = more of that element

Other properties come from fitting the width of lines, determining the position of the lines (redshift/blueshift), etc.

In essence: fitting complicated models

GALAH

GALAH = **GAL**actic **A**rchaeology with **HERMES** =

- High-resolution spectroscopic survey
- Running since 2013
- Main science goal: Survey one million stars in the Milky Way to trace its history
- DR4 (October 2024): ~917,000 stars
- Provides spectra and derived properties, including over 30 (!) elemental abundances



Let's explore some GALAH data!