ASTR 1040: Stars & Galaxies

Whirlpool Galaxy M51

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Lecture 11 Tues 2 Oct 2018
zeus.colorado.edu/astr1040-toomre

Logistics

- Read Chap 15.1: Properties of Stars with care, then 15.2: Patterns among Stars
- Mid-Term Exam 1 returned, with answers and grade boundaries
- Homework #4 also returned graded, answers
- Observatory #5 this Thur 4 Oct, by signup, need to complete first project

Topics for Today

- How to classify other stars?
- Vital work by Annie Jump Cannon in devising a sensible "spectral sequence" for stars
- Why temperature and spectral lines are closely linked in classifying stars O B A…M
- Cecilia Payne-Gaposhkin and the "Saha" equation to predict spectral line strengths
- Roadmap to the stars: Hertzsprung-Russell (H-R) diagram

So did we really love this exam?

RESULTS FROM FIRST MID-TERM EXAM

FIRST MID-TERM EXAM

- Grade boundaries, based on 110 points (graded on a "curve"):

- If 97/110 (88%) or over, A's [35%]
- 85/110 (77%) or over, B's [44%]
- 74/110 (67%) or over, C's [21%]

Also +, plain, and – within these ranges

Go through answer sheet – and talk to us if do not understand our choices. Keep exam + answers for future review (comp final)

REMINDER

Devising the strange temperature code

- Original classification of spectra (1890) was:

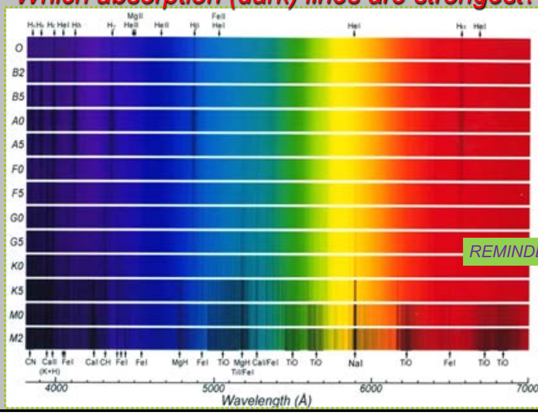
  A = strongest hydrogen feature

  B = less strong hydrogen …C, D, etc.

- Annie Jump Cannon realized that a different sequence made more sense (~1910)

→ O B A F G K M !!

Which absorption (dark) lines are strongest?



REMINDER

Spectral Classification: O B A F G K M

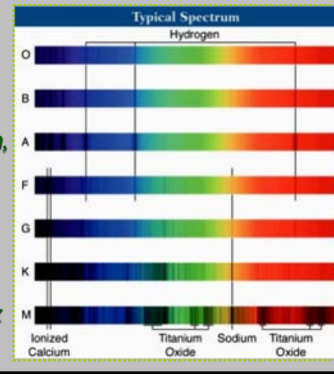
Which ABSORPTION lines are strongest

Hottest stars: O B
ionized helium only

Hot stars: A F helium, hydrogen

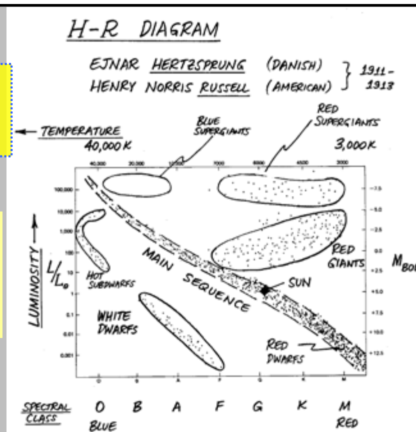
Cooler stars: G
hydrogen, heavier atoms

Coolest stars: M
molecules, (complex absorption bands)



Hertzsprung-Russell (H-R) Diagram

Luminosity (magnitude) vs Spectral class (temperature)



H - R Namesakes

Ejnar Hertzsprung

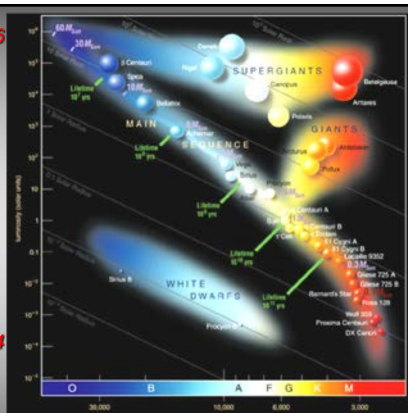
Henry Norris Russell

Luminosity

(solar units)

10^6

10^{-4}



40,000 ← Temperature 3,000

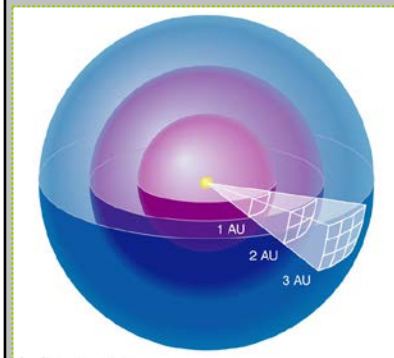
Most Basic Problem in Astronomy

Star of given APPARENT BRIGHTNESS could be either

A. very luminous star far away
B. low luminosity star closer by

Need to know the DISTANCE to the star

Inverse Square Law of Brightness



Apparent Brightness ≈ L_o / (distance)^2

Stellar Luminosity

- What we measure: APPARENT BRIGHTNESS

  or how bright it appears to us here on Earth

- What we want to know: (absolute) LUMINOSITY

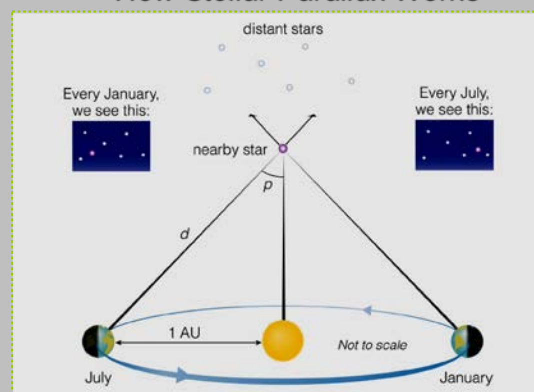
  or how much energy is emitted (joules/sec or watts)

- Need to know DISTANCE to the star

Parallax – to determine distance

- Measure the apparent movement of stars over a year
- Movement is caused by Earth's movement around the Sun
- Closer objects will move more than farther objects

How Stellar Parallax Works



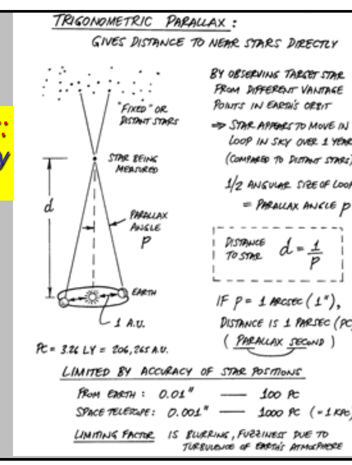
Class self-demo of parallax

- Your nose is the Sun
- Your left eye is the Earth in January
- Your right eye is the Earth in June

Watch the apparent motion of your thumb against a distant reference point (repeat at arm's length)

Which "move" more -- closer or farther objects?

Stellar Parallax: measuring nearby distances


TRIGONOMETRIC PARALLAX:
GIVES DISTANCE TO NEAR STARS DIRECTLY

"FIXED" OR DISTANT STARS
STAR BEING MEASURED
d
PARALLAX ANGLE p
EARTH
1 A.U.

BY OBSERVING TARGET STAR FROM DIFFERENT VANTAGE POINTS IN EARTH'S ORBIT
⇒ STAR APPEARS TO MOVE IN LOOP IN SKY OVER 1 YEAR (COMPARED TO DISTANT STARS)

1/2 ANGULAR SIZE OF LOOP = PARALLAX ANGLE p

DISTANCE TO STAR $d = \frac{1}{p}$

IF p = 1 ARCSEC (1"), DISTANCE IS 1 PARSEC (PC) (PARALLAX SECOND)

PC = 3.26 LY = 206,265 A.U.

LIMITED BY ACCURACY OF STAR POSITIONS
FROM EARTH: 0.01" — 100 PC
SPACE TELESCOPE: 0.001" — 1000 PC (= 1 KPC)

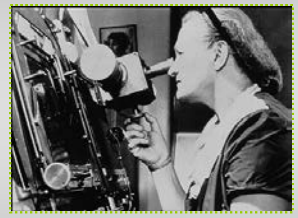
LIMITING FACTOR IS BLURRING, FUZZINESS DUE TO TURBULENCE OF EARTH'S ATMOSPHERE

Best parallax measurers:
Hipparcos satellite 1989-1993
GAIA satellite Dec 2013 →

- Space measurements not affected by atmosphere
- Measurement made many times until accurate to ~0.001 arcsec (Hipparcos →1,600 light years)
- 100,000 stars mapped; 2.5 million lesser accuracy
- GAIA: 10 micro-arcsec, billion stars; 10,000+ ly

Cecelia figured out WHY stellar spectra are so different: TEMPERATURE

- She showed that SURFACE TEMPERATURE is the big factor (not composition)
- She used the newly-devised SAHA EQUATION, estimating how many electrons remain attached to atoms as temperature is changed (or the level of ionization)



Cecelia Payne-Gaposchkin
(Harvard PhD thesis 1925)

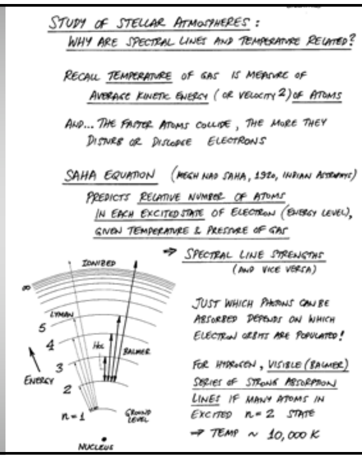
O B A F G K M → decreasing temperature

Why temperature and spectral lines are linked?

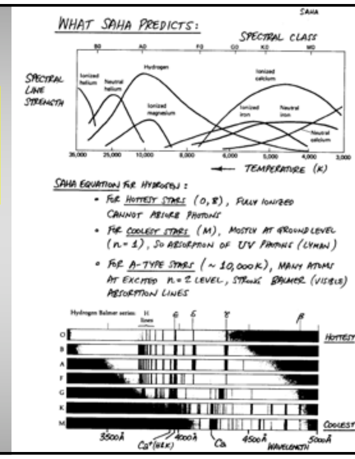
SAHA gives the answer:

can estimate "population of different energy levels" in H, He …

and ionization (continuous crash, bang, relax, do it again)



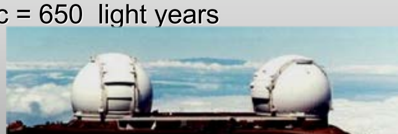
SAHA predicts spectral line strengths with temperature



Puzzle Clicker: Stellar Parallax

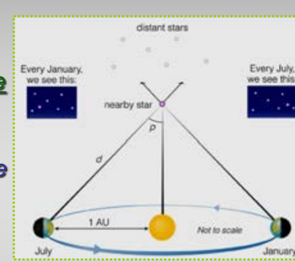
- The biggest ground-based telescopes with adaptive optics can measure stars positions with accuracies of about 0.05 arcsec. How far away could they map the positions of stars via parallax?
- A. 2 pc = 6.5 light years
- B. 20 pc = 65 light years
- C. 200 pc = 650 light years

B.



Parallax

- **B.** maximum distance is set by the accuracy with which you can measure positions in the sky (space does better than ground)



Distance (pc) =
1 / 0.05 arcsec
= 20 pc = 65 ly

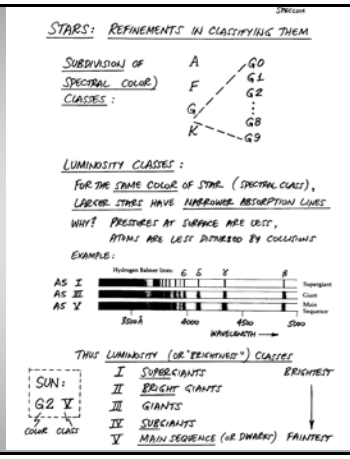
d (in parsecs) = 1 / p (in arcsec)

Further refinements:

DECIMAL SUBDIVISION

LUMINOSITY CLASSES
how narrow are absorption lines

Sun is:
G2 V
COLOR CLASS



STARS: REFINEMENTS IN CLASSIFYING THEM

SUBDIVISION OF SPECTRAL (COLOR) CLASSES:

A
F
G — G0, G1, G2, ⋮, G8, G9
K

LUMINOSITY CLASSES:

FOR THE SAME COLOR OF STAR (SPECTRAL CLASS), LARGER STARS HAVE NARROWER ABSORPTION LINES

WHY? PRESSURES AT SURFACE ARE LESS, ATOMS ARE LESS DISTURBED BY COLLISIONS

EXAMPLE:

THUS LUMINOSITY (OR "BRIGHTNESS") CLASSES

I SUPERGIANTS — BRIGHTEST
II BRIGHT GIANTS
III GIANTS
IV SUBGIANTS
V MAIN SEQUENCE (OR DWARFS) — FAINTEST

SUN: G2 V (COLOR, CLASS)

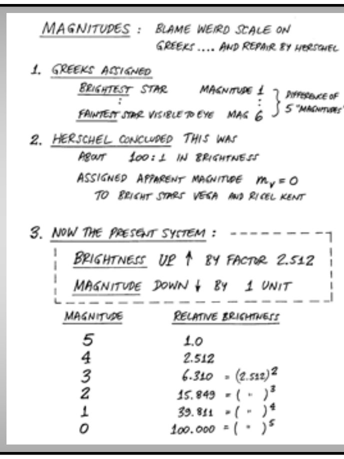
Magnitudes: Apparent vs Absolute

- Giving measures to stellar luminosities
- Built on choices made by Greeks!

Stellar MAGNITUDES

Weird system: brighter is smaller magnitude, even negative!

Of cultural importance, even if a bit confusing (secret society!)



MAGNITUDES: BLAME WEIRD SCALE ON GREEKS .... AND REPAIR BY HERSCHEL

1. GREEKS ASSIGNED
   BRIGHTEST STAR — MAGNITUDE 1
   ⋮
   FAINTEST STAR VISIBLE TO EYE — MAG 6
   } DIFFERENCE OF 5 "MAGNITUDES"

2. HERSCHEL CONCLUDED THIS WAS ABOUT 100 : 1 IN BRIGHTNESS
   ASSIGNED APPARENT MAGNITUDE $m_V = 0$ TO BRIGHT STARS VEGA AND RIGEL KENT

3. NOW THE PRESENT SYSTEM:
   BRIGHTNESS UP ↑ BY FACTOR 2.512
   MAGNITUDE DOWN ↓ BY 1 UNIT

MAGNITUDE	RELATIVE BRIGHTNESS
5	1.0
4	2.512
3	6.310 = $(2.512)^2$
2	15.849 = $(\,\cdot\,)^3$
1	39.811 = $(\,\cdot\,)^4$
0	100.000 = $(\,\cdot\,)^5$

Measuring BRIGHTNESS

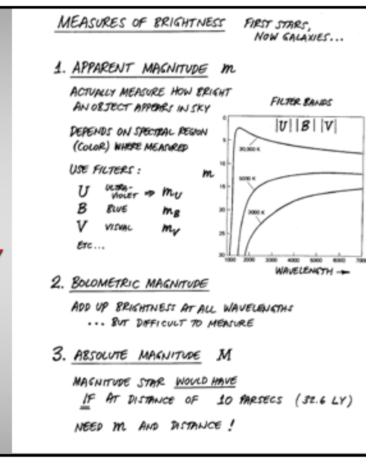
magnitudes

m

apparent mag: what looks like in sky

M

absolute mag: what would look like if at 10pc distance (LUMINOSITY)



MEASURES OF BRIGHTNESS — FIRST STARS, NOW GALAXIES...

1. APPARENT MAGNITUDE m
   ACTUALLY MEASURE HOW BRIGHT AN OBJECT APPEARS IN SKY
   DEPENDS ON SPECTRAL REGION (COLOR) WHERE MEASURED
   USE FILTERS:
   U — ULTRA-VIOLET ⇒ m_U
   B — BLUE — m_B
   V — VISUAL — m_V
   ETC...

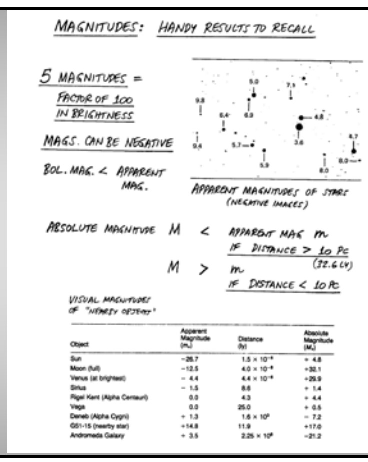
2. BOLOMETRIC MAGNITUDE
   ADD UP BRIGHTNESS AT ALL WAVELENGTHS ... BUT DIFFICULT TO MEASURE

3. ABSOLUTE MAGNITUDE M
   MAGNITUDE STAR WOULD HAVE IF AT DISTANCE OF 10 PARSECS (32.6 LY)
   NEED m AND DISTANCE!

(Slightly) screwy world of MAGNITUDES

IF can estimate distance, then can determine M given m

M = m if at distance 10pc



MAGNITUDES: HANDY RESULTS TO RECALL

5 MAGNITUDES = FACTOR OF 100 IN BRIGHTNESS

MAGS. CAN BE NEGATIVE

BOL. MAG. < APPARENT MAG.

APPARENT MAGNITUDES OF STARS (NEGATIVE IMAGES)

ABSOLUTE MAGNITUDE M < APPARENT MAG m IF DISTANCE > 10 Pc (32.6 LY)

M > m IF DISTANCE < 10 Pc

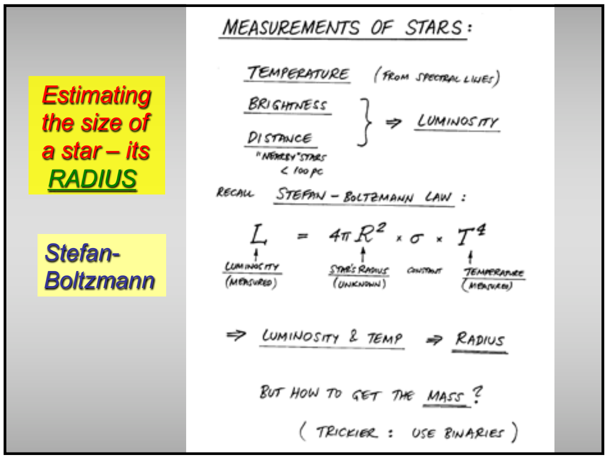
VISUAL MAGNITUDES OF "NEARBY OBJECTS"

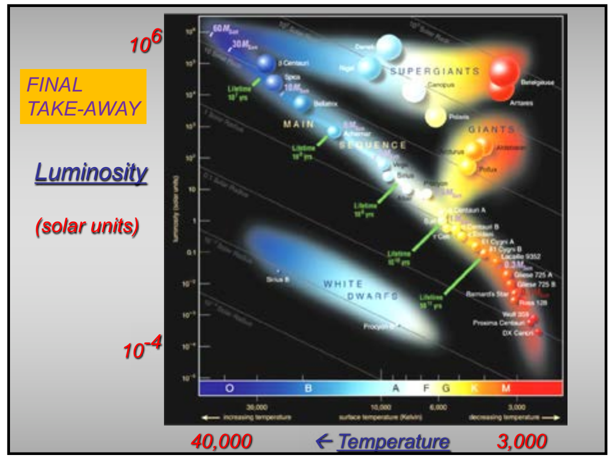
Object	Apparent Magnitude (m_v)	Distance (ly)	Absolute Magnitude (M_v)
Sun	−26.7	1.5×10^{-5}	+ 4.8
Moon (full)	−12.5	4.0×10^{-8}	+32.1
Venus (at brightest)	− 4.4	4.4×10^{-6}	+29.9
Sirius	− 1.5	8.6	+ 1.4
Rigel Kent (Alpha Centauri)	0.0	4.3	+ 4.4
Vega	0.0	25.0	+ 0.5
Deneb (Alpha Cygni)	+ 1.3	1.6×10^3	− 7.2
G51-15 (nearby star)	+14.8	11.9	+17.0
Andromeda Galaxy	+ 3.5	2.25×10^6	−21.2

Clicker: Stellar puzzle B.

- Two stars, Antony and Cleopatra, are both of spectral class M3, and of the same apparent brightness (magnitude) in the sky. Cleopatra shows narrow absorption lines in her spectrum, Anthony broad ones. Which star must be far more distant?

- A. Antony
- B. Cleopatra


Estimating the size of a star – its RADIUS
Stefan-Boltzmann
MEASUREMENTS OF STARS:
TEMPERATURE (FROM SPECTRAL LINES)
BRIGHTNESS
DISTANCE
"NEARBY" STARS < 100 pc
⇒ LUMINOSITY
RECALL STEFAN – BOLTZMANN LAW:
$L = 4\pi R^2 \times \sigma \times T^4$
LUMINOSITY (MEASURED)
STAR'S RADIUS (UNKNOWN)
CONSTANT
TEMPERATURE (MEASURED)
⇒ LUMINOSITY & TEMP ⇒ RADIUS
BUT HOW TO GET THE MASS?
(TRICKIER: USE BINARIES)


FINAL TAKE-AWAY
Luminosity
(solar units)
10^6
10^{-4}
SUPERGIANTS
MAIN
SEQUENCE
GIANTS
WHITE
DWARFS
O
B
A
F
G
K
M
40,000
← Temperature
3,000