

STELLAR POPULATIONS

INTRODUCED BY

WALTER BAADE

LOCATIONS

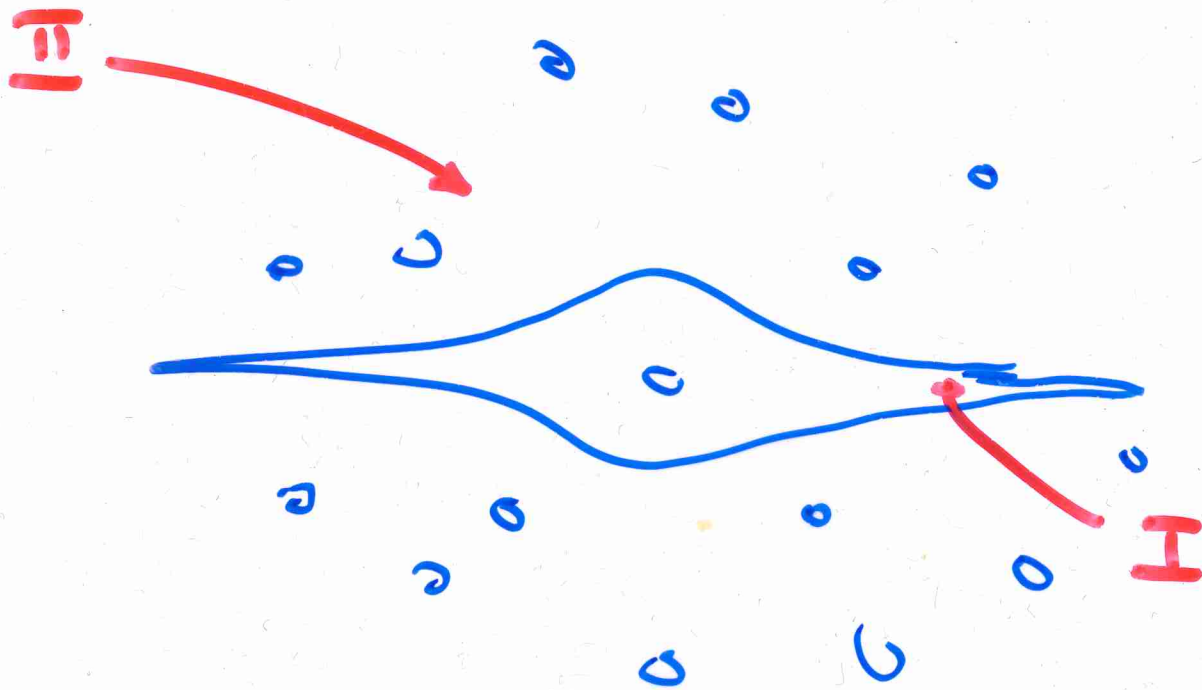
MOTIONS

CHEMICAL COMPOSITIONS

AGE

POP. I & II

LOCATION IN GALAXY



I IN DISK WITH GAS/DUST

II IN HALO

CHEMICAL COMPOSITIONS

I 'METAL' CONTENT $\sim$ SOLAR.

FROM $2 \times$ SOLAR TO $1/10$ SOLAR

II 'METAL' CONTENT $\ll$ SOLAR,

FROM $1/10$ TO $1/10000$ TO ? OF
SOLAR.

AGE

I

YOUNG TO MIDDLE AGED :

0 YRS TO 10 BILLION YRS

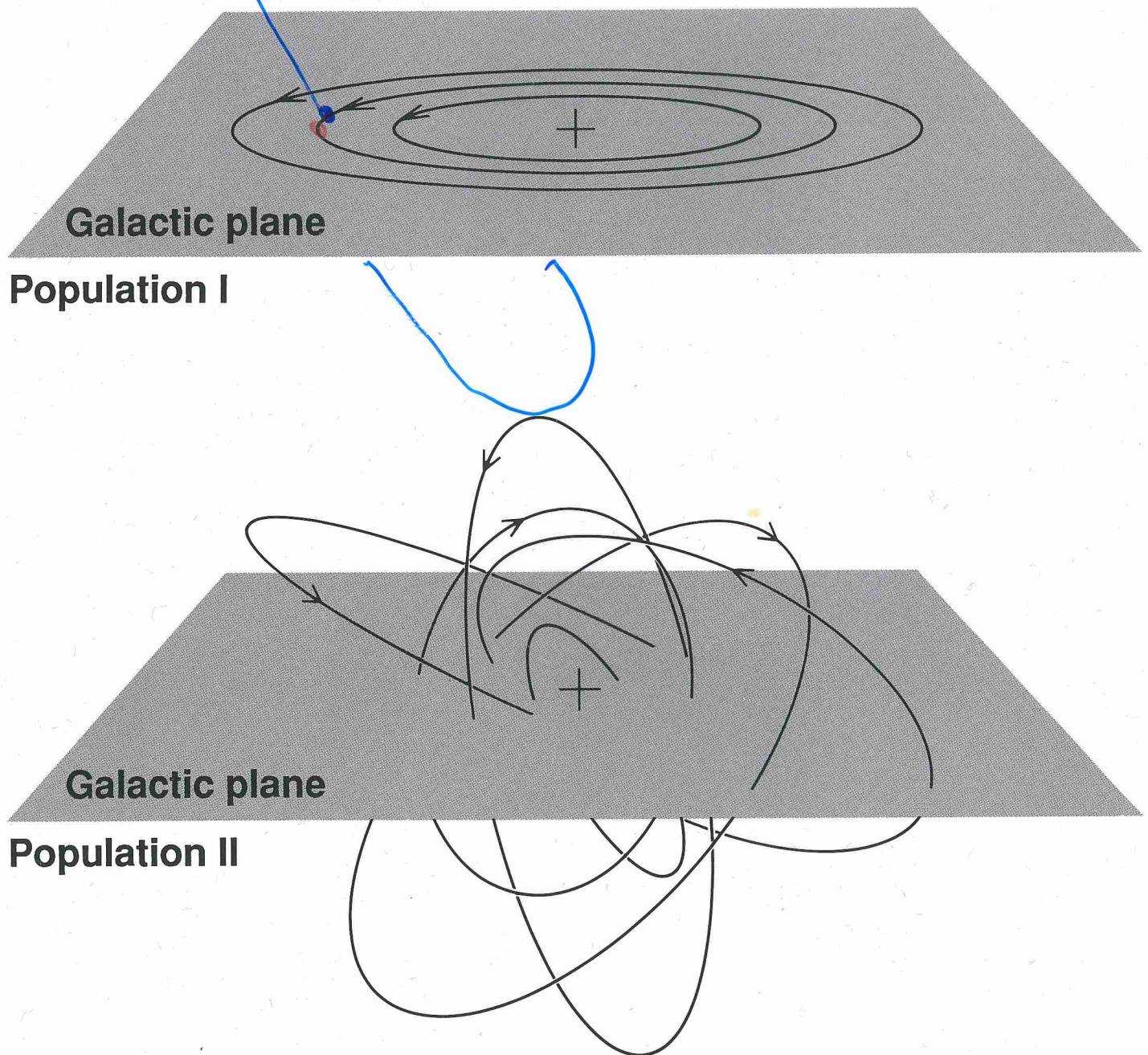
II

OLD - 15 BILLION YRS WITH

A SPREAD OF A FEW BILLION

YRS.

MOTIONS



POP II = HIGH VELOCITY STARS

Comparison of orbits of disk Population I and halo Population II stars

Pop. I or II ?

O STAR

GLOBULAR CLUSTER

H I CLOUD

H II REGION

SOLAR COMPOSITION F STAR

TYPE II SN

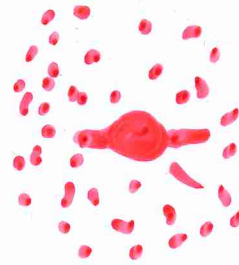
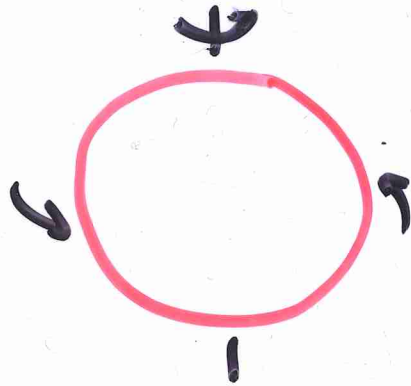
TYPE I SN

METAL-POOR M DWARF

METAL-RICH M DWARF

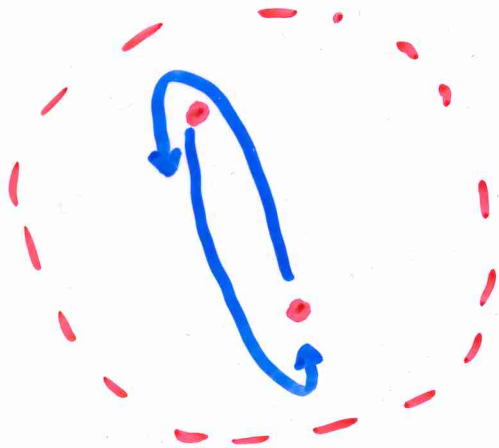
AN EXPLANATION?

- LARGE GAS CLOUD COLLAPSED QUICKLY UNDER ITS GRAVITY

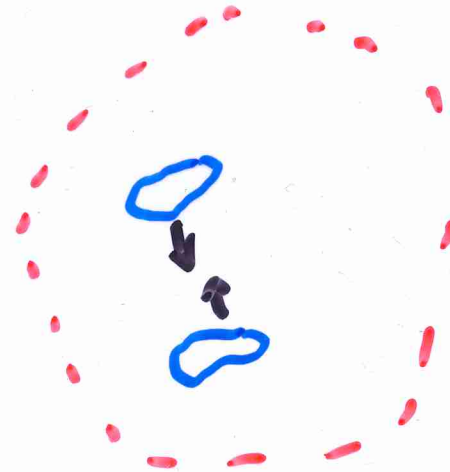


- COLLAPSE RAPID IN POLAR DIRECTIONS
- SLOWER IN EQUATORIAL DIRECTIONS

- GAS SETTLES INTO A DISK, BUT **NOT** STARS FORMED WHILE CLOUD WAS QUASI-SPHERICAL



NO COLLISIONS
OF STARS



CLOUDS COLLIDE
AND DISSIPATE
ENERGY

- WHY ARE POP. II (HALO) STARS METAL-POOR?
- WHY ARE ^{SOME} POP I (DISK) STARS METAL-NORMAL, OR METAL-RICH?
- WHY ARE HALO STARS REFERRED TO AS 'HIGH-VELOCITY' STARS?

* SEE SEEDS FOR OBJECTIONS TO THIS
 PICTURE pp ³⁴²⁻³⁴⁴ ~~345-348~~

GALAXY FORMED PARTLY BY ACCRETING
 SMALLER GALAXIES

THE DISTANCE SCALE [~~PYRAMID~~].

[LADDER]

- THE ASTRONOMICAL UNIT

- PLANET'S POSITIONS ON SKY

- ACCURATE RELATIVE DISTANCES

- RADAR TO ONE (OR MORE) PLANETS

- PRECISE EARTH-PLANET DISTANCES

- & → PRECISE MEASUREMENT OF THE AU

• TRIGONOMETRICAL PARALLAX

WITH BASELINE OF TWO AU

— FROM GROUND : $d \sim 200 \text{ pc}$

— FROM SPACE

HIPPARCOS : $d \sim 1000 \text{ pc}$

GAIA (new) : $\sim 10,000 \text{ pc}$

A REVOLUTION!

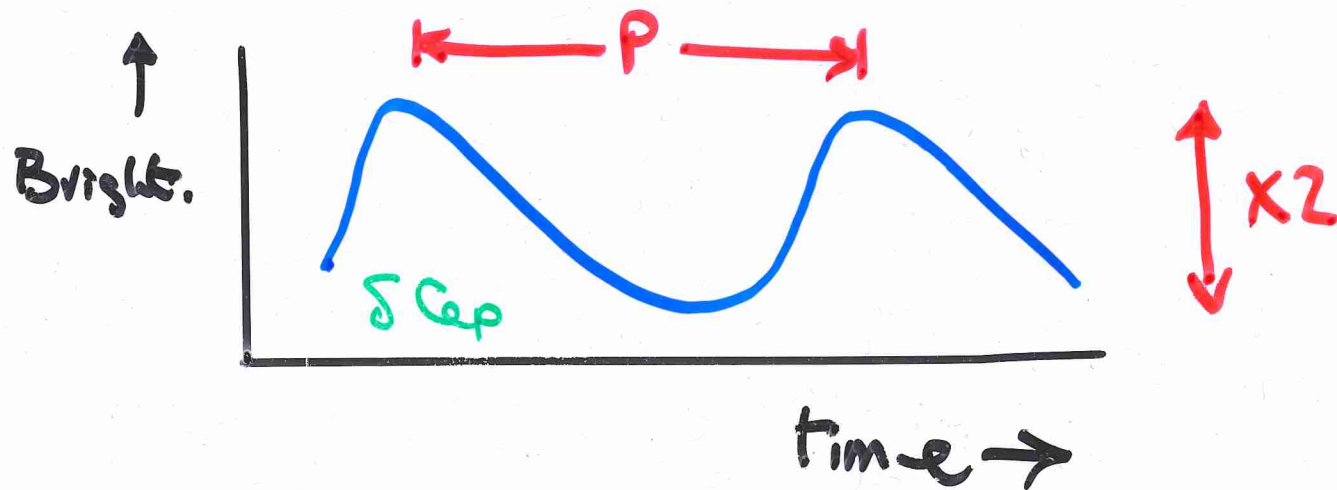
- LARGER VARIETY OF STARS
incl. CEPHEIDS
- TOTAL SPACE MOTIONS

SPECTROSCOPIC PARALLAX

- MAIN SEQUENCE FITTING
 - TRIG. PARALLAX NEEDED TO DEFINE MAIN SEQUENCE
 - THEN WITHIN GALAXY AND TO NEAREST GALAXIES (DUST!) WITH LUMINOUS STARS

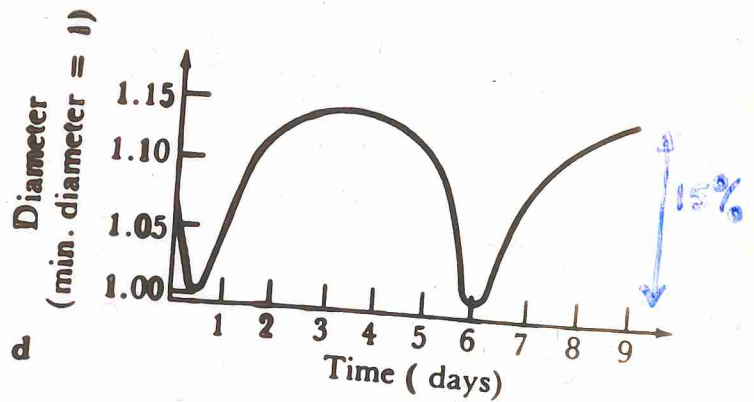
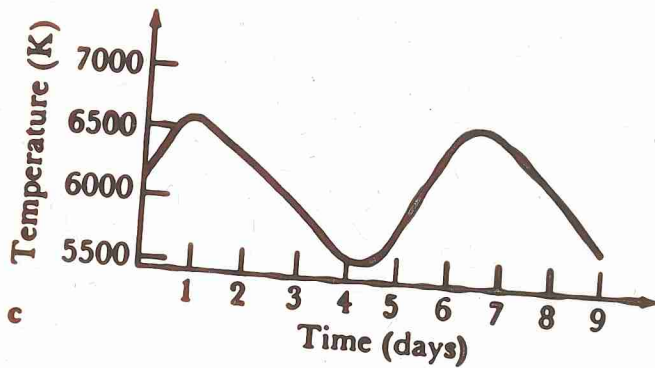
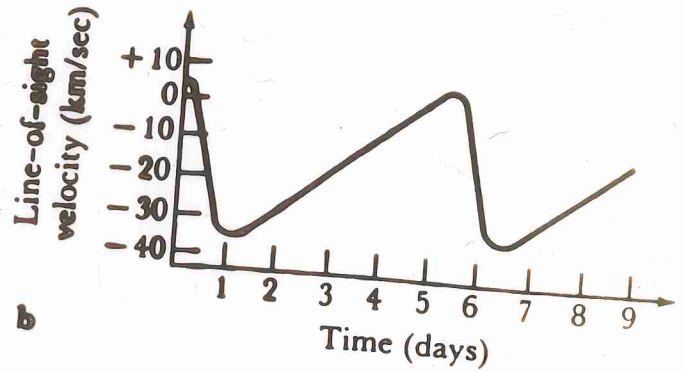
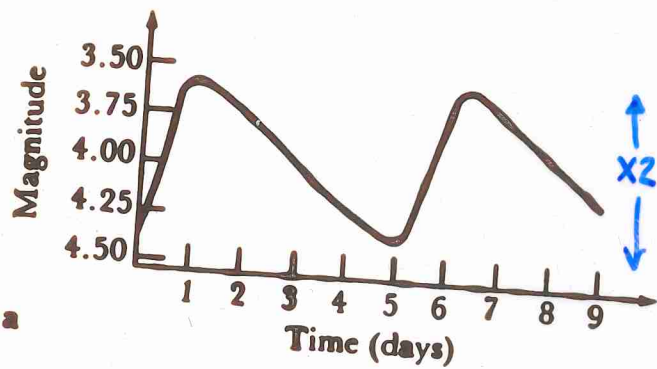
CEPHEID VARIABLES

- named for δ Cephei
- variability discovered by John Goodricke (deaf + dumb, 19 yrs old, died at 21y, in 1786)

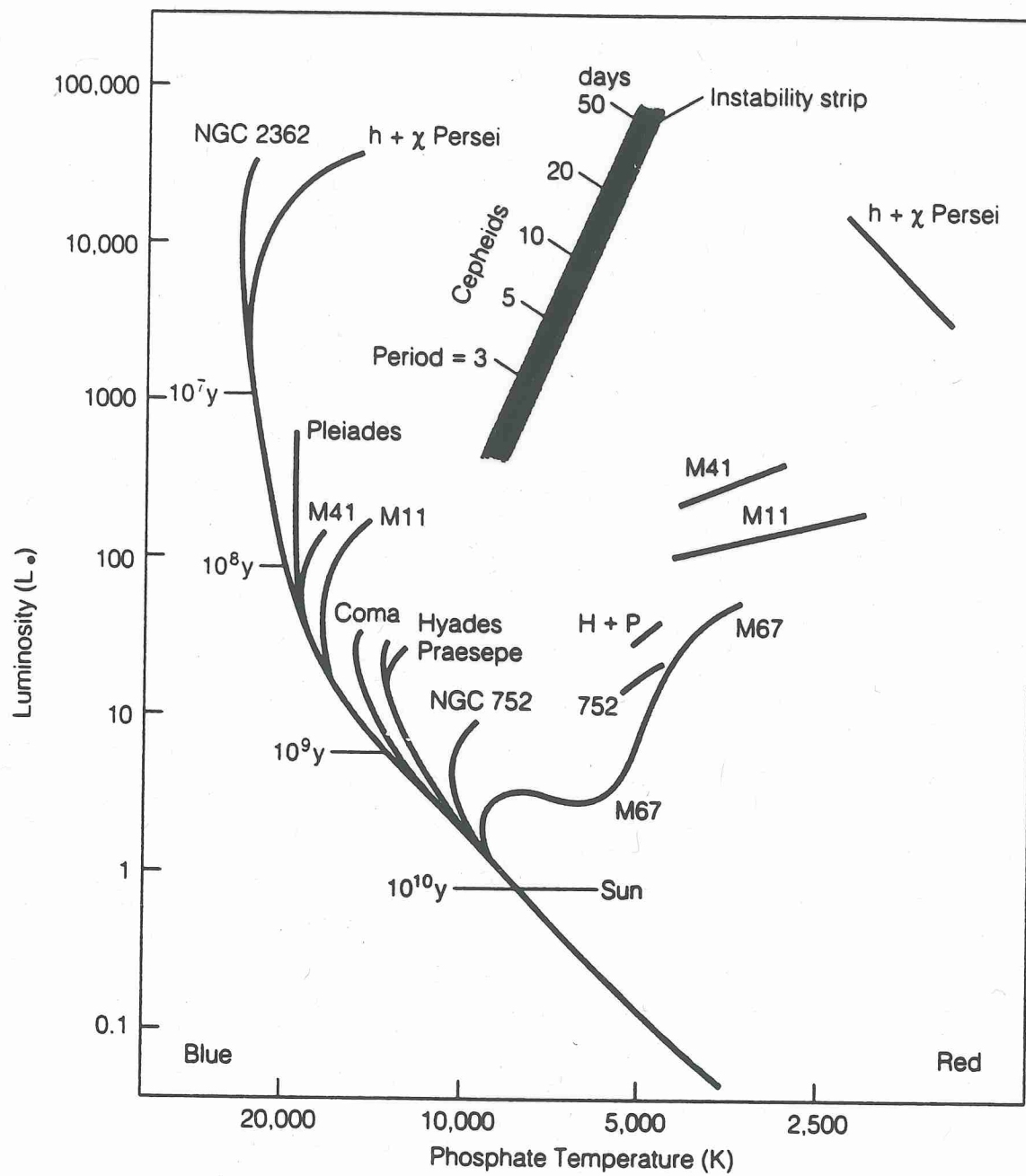


$$P = 5.4 \text{ days}$$

- ~1000 known in our Galaxy



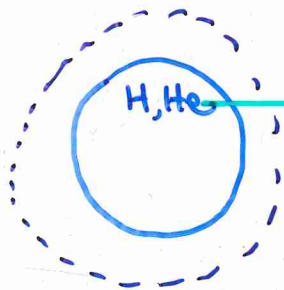
δ Cephei



CEPHEID PULSATION

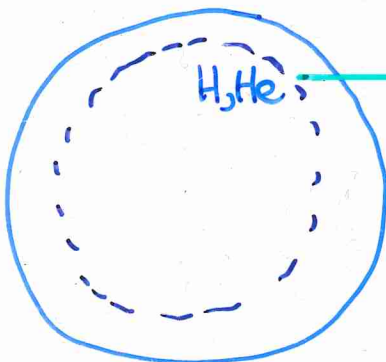
EDDINGTON (1941) H, He IONIZATION
ACTS AS A VALVE

VALVE IN OUTER LAYERS
NOT IN CORE WHERE
NUCLEAR REACTIONS RUN
UNPERTURBED



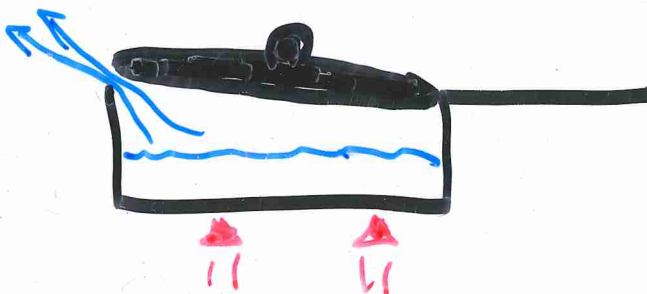
H, He ABSORB PHOTONS
ARE IONIZED

$T \uparrow$ Pressure $\uparrow$
STAR EXPANDS



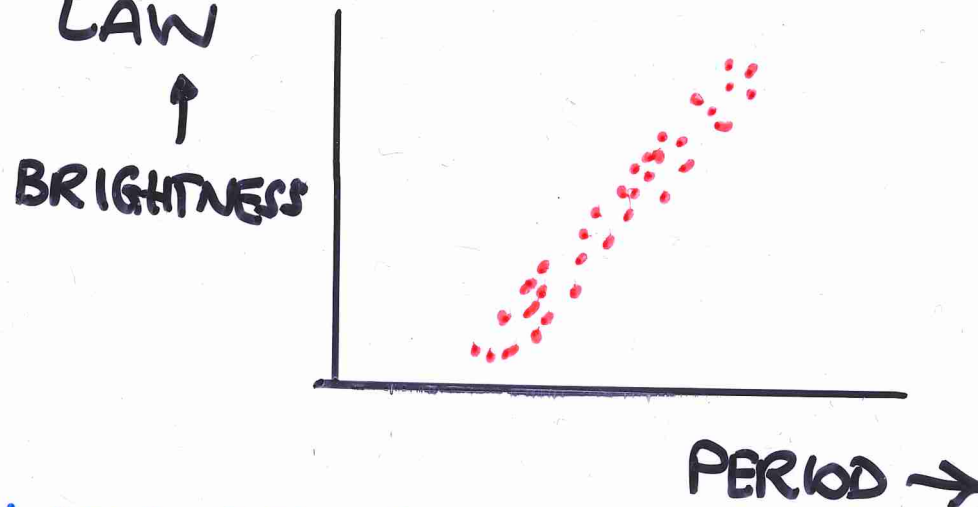
H, He IONIZED
PHOTONS ESCAPE MORE
EASILY

$T \downarrow$ Pressure $\downarrow$
STAR CONTRACTS



PERIOD - LUMINOSITY LAW : DISCOVERY

- OBSERVATIONS [PHOTOGRAPHS] OF THE MAGELLANIC CLOUDS → DISCOVERY OF CEPHEIDS
- HENRIETTA LEAVITT NOTED BRIGHTNESS VS PERIOD LAW



AHA! THE LADY DECLARED

- GALACTIC-LIKE CEPHEIDS but MUCH FAINTER
- CLOUDS LIKELY STELLAR CONGREGATION AT SAME GREAT DISTANCE

∴ THERE IS A LUMINOSITY - PERIOD LAW
FOR CEPHEIDS (POPULATION I $\neq$ POP. II)

BUT HOW DO WE ESTABLISH THIS FOR
GALACTIC CEPHEIDS?

• TOO FEW WITH ACCURATE
STELLAR PARALLAXES

{ HIPPARCOS
GAIA

• USE OPEN CLUSTERS WHOSE
DISTANCES ARE FOUND FROM
MAIN SEQUENCE FITTING
BUT GAIA (soon!)

STEP 1 : IDENTIFY THOSE FEW ^{YOUNG} CLUSTERS
CONTAINING A CEPHEID

STEP 2 : OBSERVE CLUSTER TO CONSTRUCT
ITS H-R DIAGRAM

STEP 3 : CALCULATE SPECTROSCOPIC PARALLAX
(CLUSTER DISTANCE) OF CLUSTER
VIA MAIN SEQUENCE FITTING

DUST?

STEP 4 : REPEAT FOR ALL CLUSTERS
FOUND IN STEP 1

RESULT

ABOUT 10 CEPHEIDS FROM OPEN
CLUSTERS DEFINE THE
PERIOD-LUMINOSITY LAW

- WHY ARE CEPHEIDS SO IMPORTANT?

- HIGH ABS. LUM.

∴ VISIBLE TO GREAT DISTANCES
incl. NEARBY GALAXIES

- OBSERVATIONS OF BRIGHTNESS (& COLOR) SUFFICE.

- P-L RELATION NOW WELL CALIBRATED & THEORETICALLY UNDERSTOOD.

- WHY ARE CEPHEIDS SO RARE?

- MASSIVE STARS ARE RARE

- CEPHEIDS IN RAPID PHASE OF EVOLUTION (HERTZSPRUNG GAP NOT MAIN SEQUENCE)

DISTANCES TO GALAXIES (CONTAINING CEPHEIDS)

NOW TO ~ 15 Mpc WITH HST

→ WHY?

BRIGHTEST ~~BLUE/RED~~ STARS

$\sim 10^6 L_{\odot}$

$\sim 100 L_{\odot}$ of
av. Ceph.

$\sim 10 L_{\odot}$ of
longest P
Ceph.

OBSERVATION

MOST LUM. BLUE/RED S'GIANTS

$\approx$ SAME L IN ALL NEARBY
GALAXIES

ASSUMPTION

SAME TRUE OF MORE
DISTANT GALAXIES

WORRY

IS ASSUMPTION VALID?

LUMINOUS STARS UNSTABLE

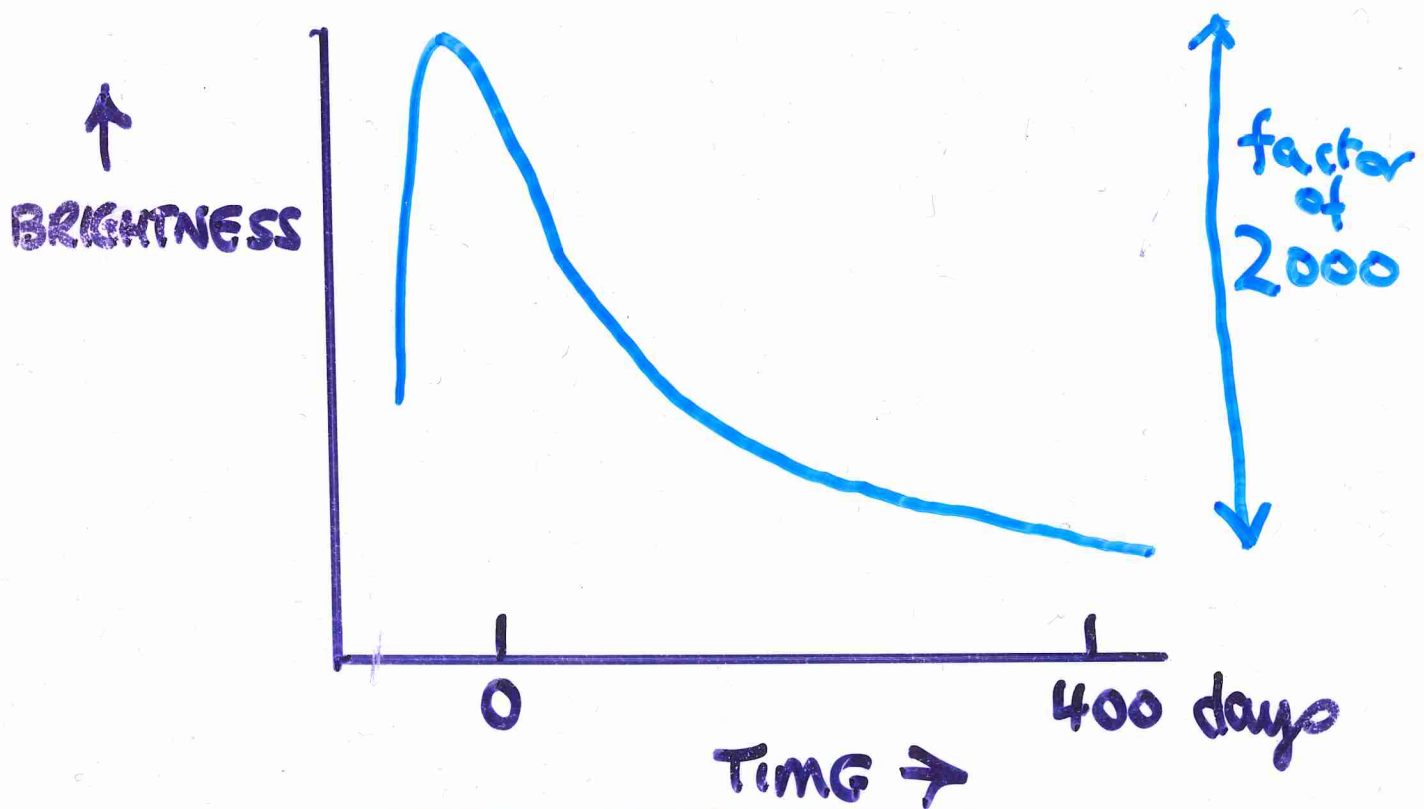
$\rightarrow$ MASS LOSS via WINDS;
METAL CONTENT?

SUPERNOVAE

$\sim 10^{10}$ to $10^{11} L_{\odot}$ at PEAK LIGHT

$\therefore$ VISIBLE IN V. DISTANT GALAXIES

OBSERVATION } as before
ASSUMPTIONS }

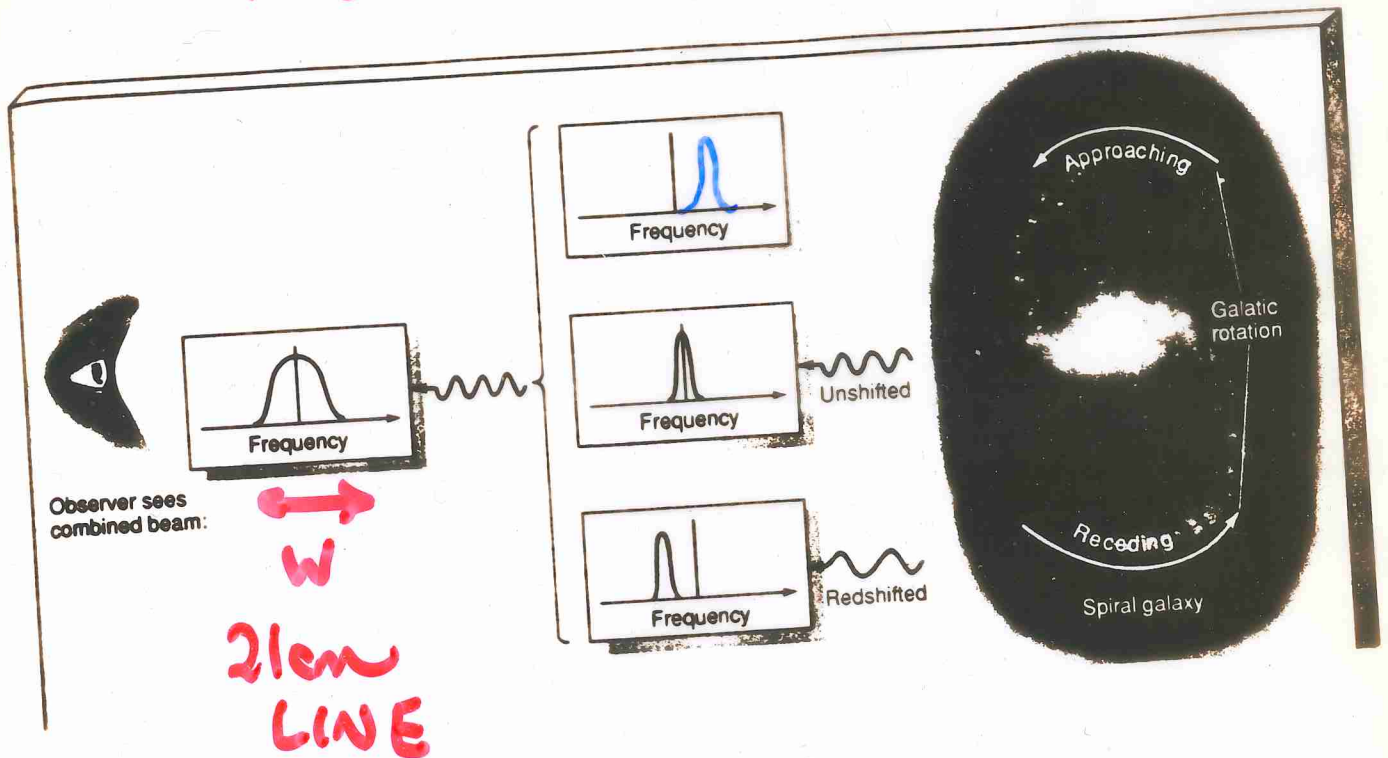


TYPE Ia SN $\equiv$ POP. II

TYPE II SN $\equiv$ POP. I

! →
MORE LUMINOUS
MORE
UNIFORM

TULLY-FISHER RELATION



W related to MASS of GALAXY

L " " " "

OBSERVATION

NEARBY GALAXIES $\rightarrow$ W-L CORRELATION

etc.

BRIGHTEST ~~GALAXY~~ IN CLUSTER

GALAXIES OCCUR IN CLUSTERS

EMPIRICAL 'FACT': BRIGHTEST
GALAXY IN A CLUSTER $\approx$
CONSTANT/UNIFORM LUMINOSITY.
 $L \sim 10 \times \text{OUR GALAXY} \sim 10^{11} L_{\odot}$

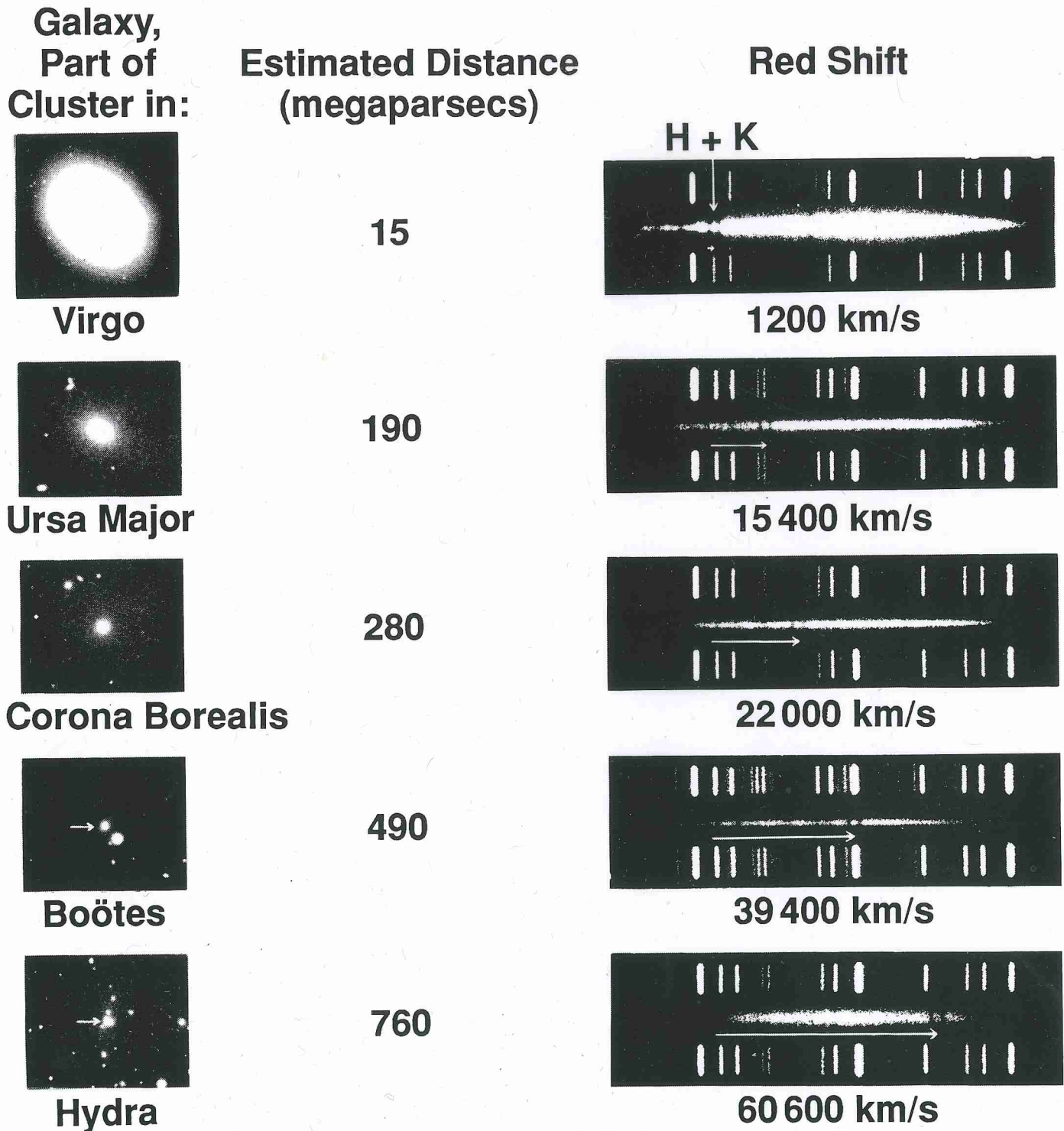
OBSERVATION } as before.
ASSUMPTION }

EXPANSION OF THE UNIVERSE

- DISCOVERED IN 1920s by EDWIN P. HUBBLE
- OBSERVATION: RADIAL VELOCITY OF RECESSION PROPORTIONAL TO DISTANCE



Relation Between Red Shift and Distance for Remote Galaxies



Red shifts of remote galaxies

$$V = H_0 D \quad \text{where}$$

$H_0 \equiv$ HUBBLE'S CONSTANT

$$\approx 70 \text{ km/sec/Mpc}$$

IS THIS A DISTANCE INDICATOR?

- INTERPOLATION = OK BUT WATCH FOR LOCAL DEVIATIONS
- EXTRAPOLATION — NEED MODEL UNIVERSE TO PREDICT EXPANSION AT LARGE LOOK-BACK TIMES

- IF A GALAXY HAS A RADIAL VELOCITY OF $+4200 \text{ km/s}$, HOW FAR AWAY IS IT?

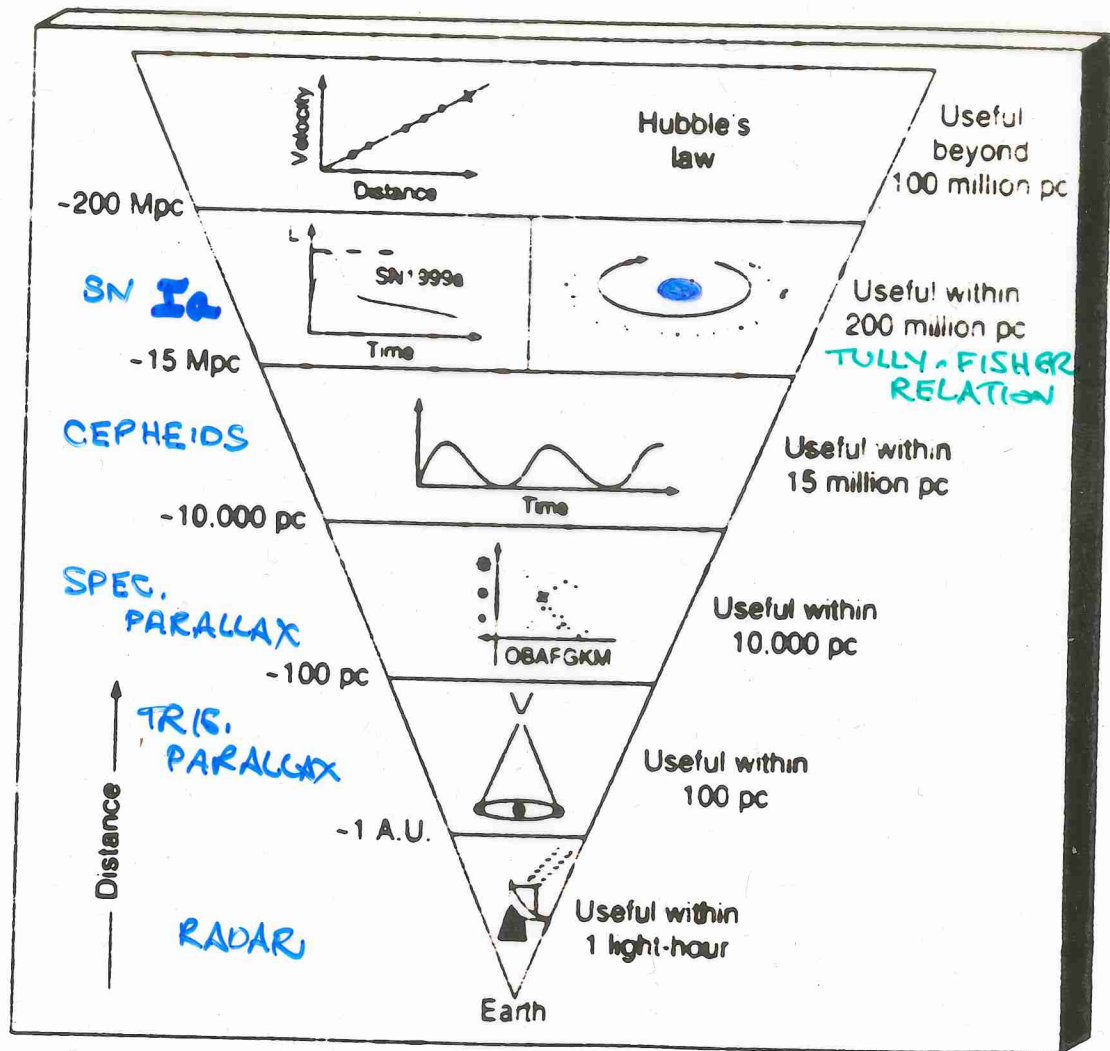
ASSUME $H_0 = 50, \text{ or } 70, \text{ or } 100 \text{ km/s/Mpc}$

- A GALAXY IS AT 3500 Mpc , WHAT IS ITS RADIAL VELOCITY?

ASSUME $H_0 = 50, \text{ or } 70, \text{ or } 100 \text{ km/s/Mpc}$

- WHAT IS THE LOOK-BACK TIME TO THIS GALAXY?

$1 \text{ pc} = 3.3 \text{ lyr.}$



DISTANCE LADDER

TODAY

RADAR



AU



TRIG PARALLAX



SPEC PARALLAX



CEPHEID P-L



SN Ia

+ TULLY · FISHER

H_0 AND time = zero

DISTANCE LADDER

TOMORROW [?]

RADAR → TRIG. PARALLAX
(GAIA)

UNDERSTANDING

✓ GEOMETRY

↓
CEPHEID P.L.

✓ PHYSICS

↓
SN Ia
+ TULLY - FISHER

? NOT
YET

↓
H₀ AND $t_{\text{time}} = \text{ZERO}$

? MODEL
OF
UNIVERSE