

WHY DOES SUN NOT COLLAPSE?

- GRAVITY AT SURFACE
 $\approx 30 \times \text{EARTH'S}$
- GAS NOT SOLID

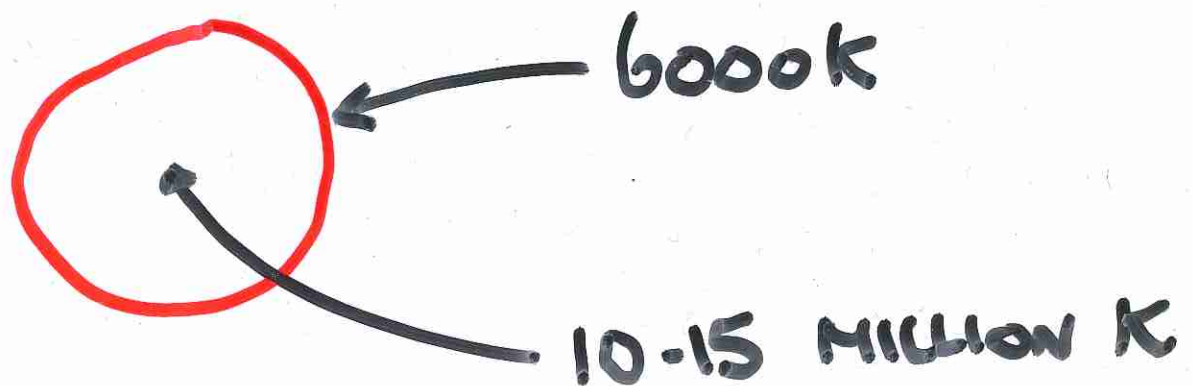
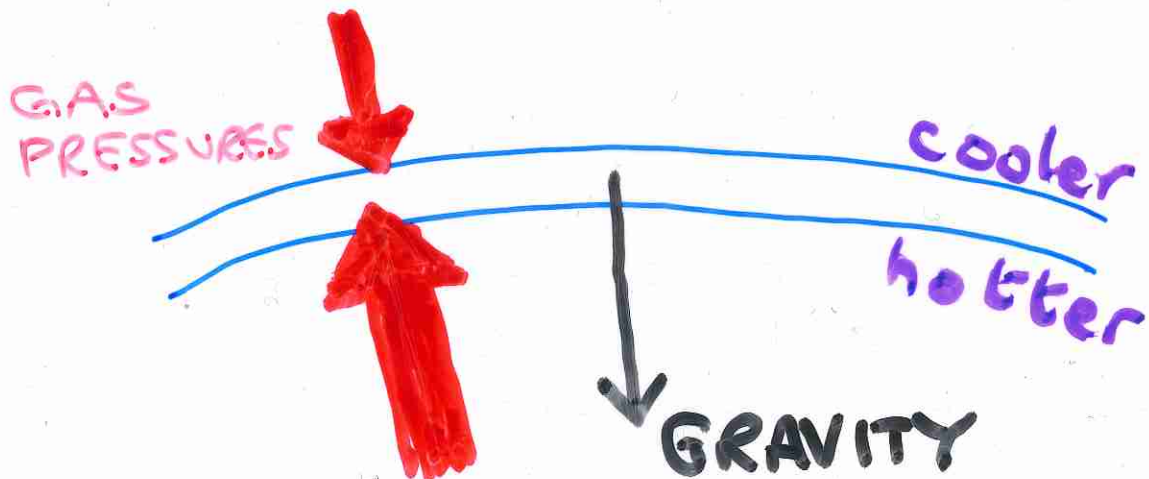
SHOULD COLLAPSE IN
A FEW MINUTES!

WHY NOT?

GRAVITY MUST BE
OPPOSED BY

THE SUN

A LAYER IN THE SUN



HYDROSTATIC EQUILIBRIUM

GAS PRESSURE IN STARS

OFTEN NOT ALWAYS

THERMAL (DEPENDS ON TEMP.)

THERMAL GAS PRESSURE

— PARTICLES

— ATOMS, MOLECULES, IONS,
ELECTRONS

$$P \propto \text{No.} \times \text{Temp.}$$

— PHOTONS

$$P \propto (\text{Temp.})^4$$

DEGENERATE ELECTRONS

P INDEPENDENT of T

IS HYDROSTATIC EQUILIBRIUM
FOR EVER? NO!

HEAT MUST FLOW FROM
HOT CENTER TO COOL
EXTERIOR. THIS COOLS
INTERIOR, DROPS GAS PRESSURES,
SUN COLLAPSES UNLESS...
SUN POSSESSES AN ENERGY
SOURCE RUNNING AT 10-15 MILLION
DEGREES (THERMAL
EQUILIBRIUM)

IS HYDROSTATIC + THERMAL
EQUILIBRIUM FOR EVER?

NO!

THE ENERGY SOURCE MUST
BE FINITE.

WHEN EXHAUSTED, GRAVITY
WINS - FOR A WHILE!

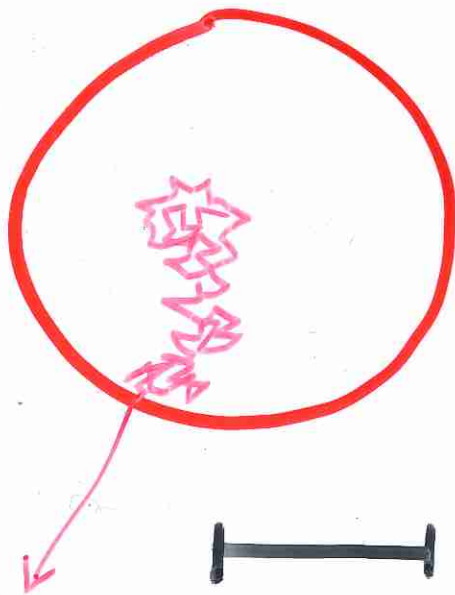
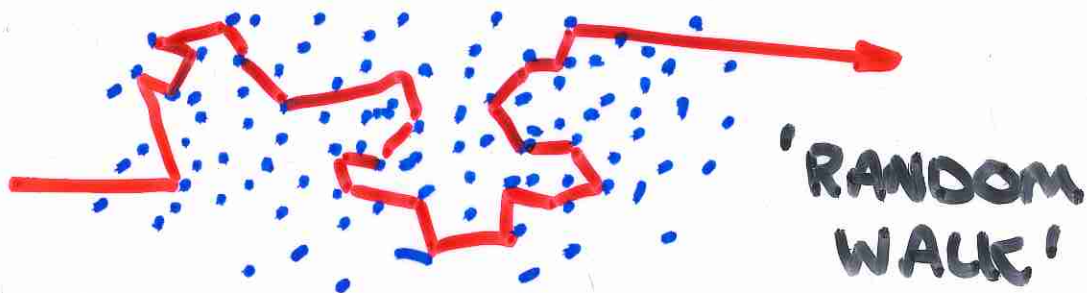
MAIN SEQUENCE STARS
MUST EVOLVE

LIFETIME DEPENDS ON
TEMPERATURE/MASS AND
RATE OF HEAT LEAKAGE

ENERGY TRANSPORT IN STARS

1. RADIATION (AS PHOTONS)

PHOTON'S FLIGHT IMPEDED BY
MATTER



ENERGY TAKES
~ MILLION YRS
TO ESCAPE !

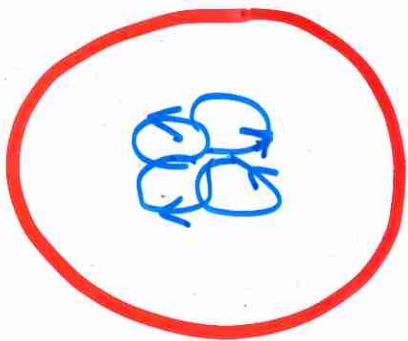
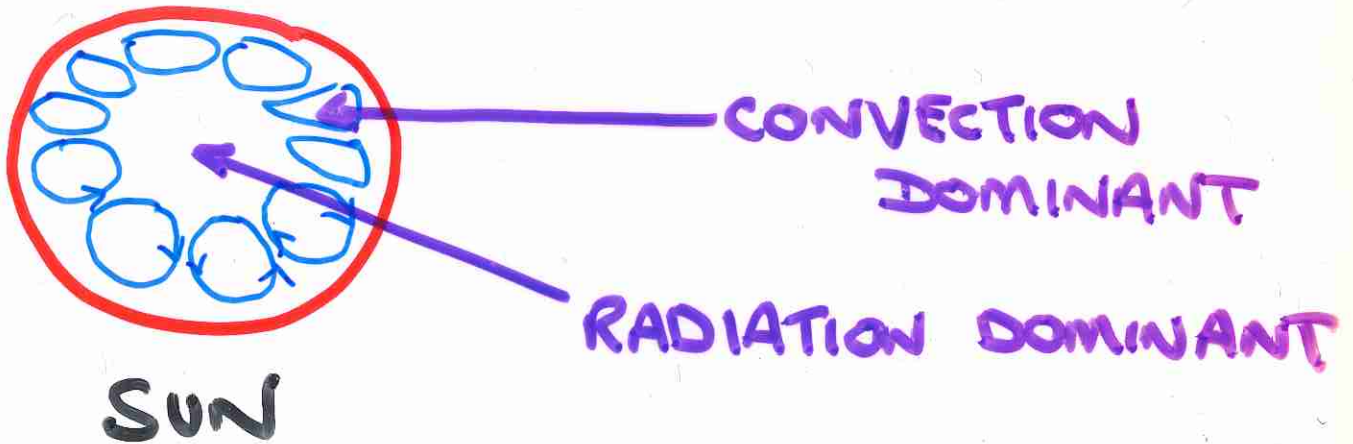


2 1/2 LIGHT
SECONDS

2. CONVECTION

FLOW/CIRCULATION OF GAS

HOT GAS RISES / COOL GAS SINKS



MASSIVE
MAIN SEQ. *

3. CONDUCTION

PARTICLE $\leftrightarrow$ PARTICLE COLLISION
TRANSFER ENERGY

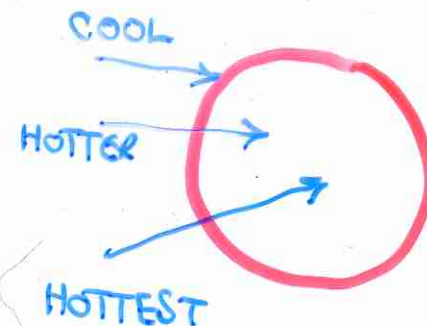
GENERALLY SLOW IN STARS

BUT - - - -

MAIN SEQUENCE STARS

- COLLAPSE UNDER GRAVITY postponed
BY THERMAL { GAS } PRESSURES
{ PHOTON }

- ENERGY FLOW FROM CORE TO
SURFACE must occur

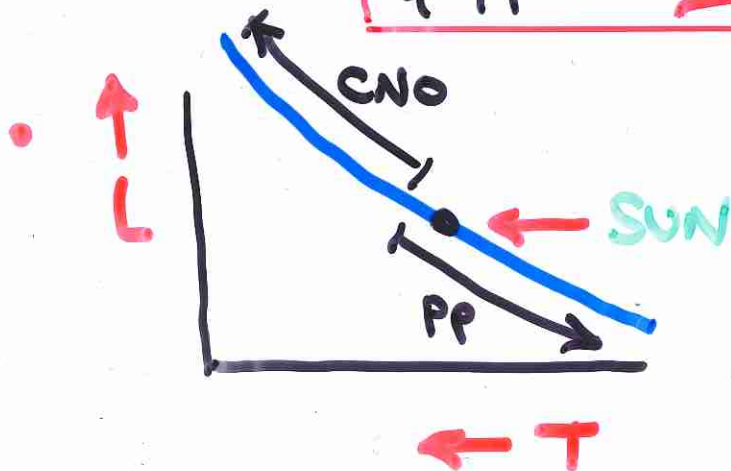


- ENERGY REPLACED BY FUSION OF



H-"BURNING" IN STARS

- PROTON-PROTON CHAIN (FIG ~~8-15~~ 8-15)
- CNO-CYCLES (FIG ~~11-13~~ 11-13 for CN-CYCLE)
- BOTH ARE A CHAIN/CYCLE OF ONE-ON-ONE NUCLEAR FUSION REACTIONS WITH NET EFFECT :



- HOW IS THE ENERGY SUPPLIED?

- PHOTONS (γ -RAYS)

DIRECT FROM
REACTIONS

POSITRON
ANNIHILATION



- KINETIC ENERGY

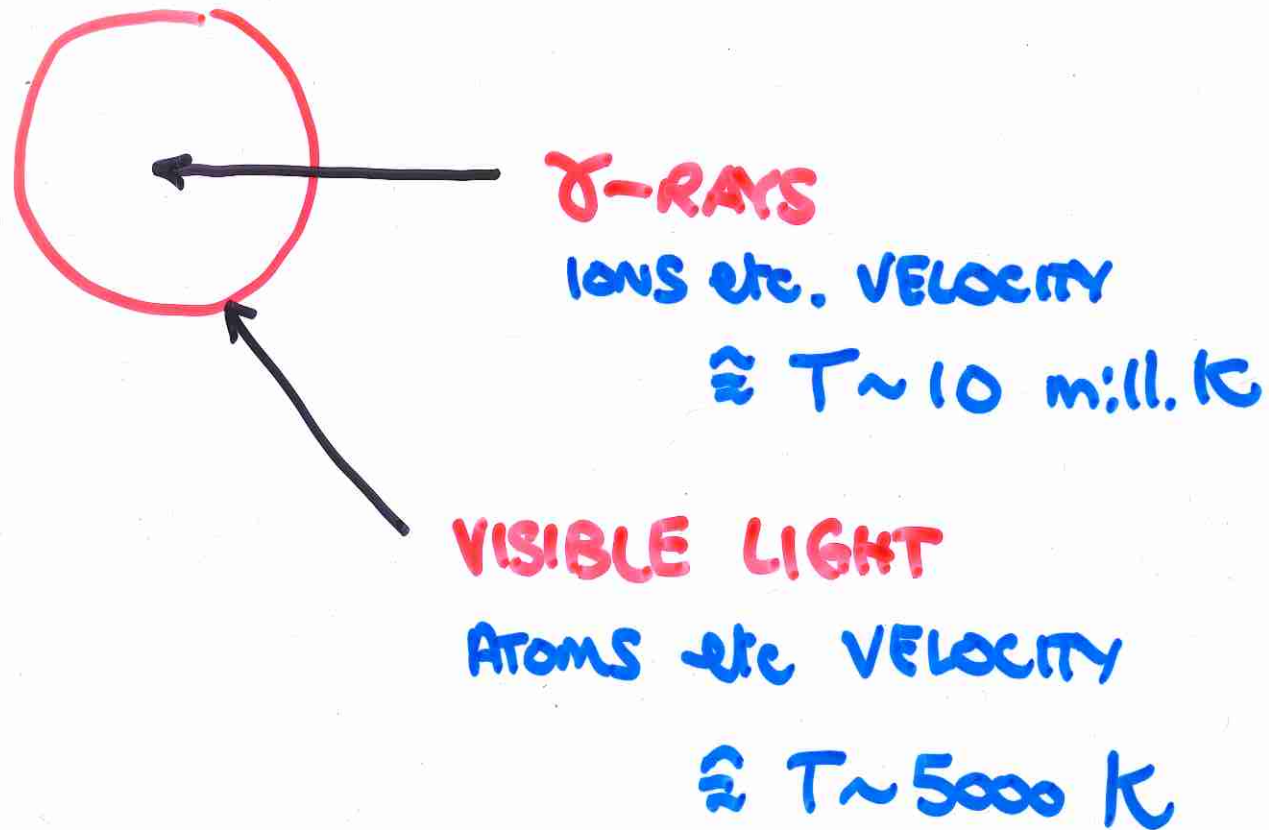
REACTION PRODUCTS FLY APART
AND SET NEIGHBOURING IONS....
IN MOTION

- NEUTRINOS

ESCAPE STAR. $\therefore$ NO HEATING OF CORE

SUN: $\sim 3\%$ ENERGY LOSS VIA ν 's.

- CONTINUOUS EXCHANGE OF ENERGY
BETWEEN PHOTONS AND ATOMS/IONS/ELECTRONS



THE END IS NIGH!

- HYDROGEN SUPPLY IS LIMITED
- HELIUM 'BURNS' BUT AT $T \sim 200$ MILL. K
NOT AT 10 MILL. K
- $\therefore$ MAIN SEQUENCE STAR MUST EVOLVE
- SUN CAN 'BURN' $4H \rightarrow He$ FOR
10 BILLION YEARS

NEUTRINOS

- "little neutral one", postulated in 1930s by ENRICO FERMI
- not detected directly until ~1950
- NO ELECTRICAL CHARGE
- "NO" MASS
- ALMOST NO INTERACTION WITH MATTER

SOLAR NEUTRINO EXPERIMENTS

- SOLAR NEUTRINOS RAIN ON EARTH IN VERY LARGE NUMBERS
 - 10^{12} PER SECOND THROUGH OUR BODIES
- BUT NEUTRINOS HAVE "NO" INTERACTION WITH MATTER - THAT'S WHY THEY CAN ESCAPE FROM THE SUN.
- CRITICAL PROBE OF CONDITIONS IN SUN'S CORE TODAY AND ~~IN THE PAST~~
A WAY TO TEST THEORIES OF NEUTRINOS

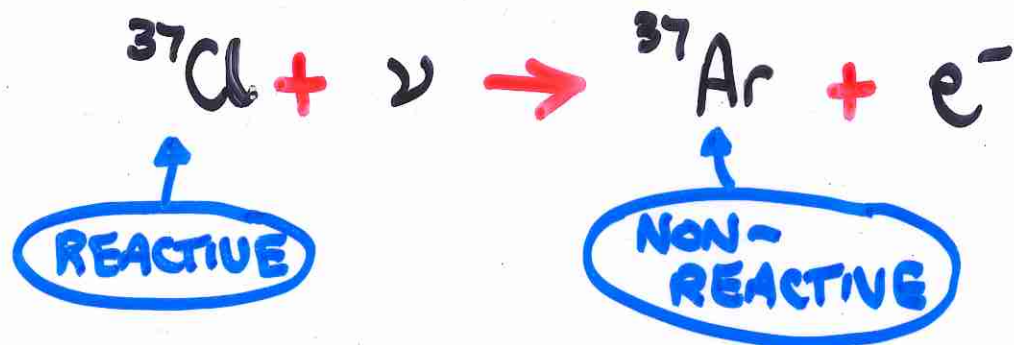
SOLAR NEUTRINO DETECTORS

- HOMESTAKE GOLD MINE (S. DAKOTA)
CLEANING FLUID TANK (100,000 GALLONS)
- KAMIOKANDE SALT MINE (JAPAN)
VAST TANK OF WATER
- SAGE (^{UNDER} CAUCASUS, RUSSIA) • GALLEX (^{UNDER} ALPS, ITALY)
TONS OF GALLIUM (A YEAR'S PRODUCTION)
- SUDBURY (CANADA)
TONS OF HEAVY WATER
- COMPLEMENTARY RATHER THAN REDUNDANT EXPTS

• HOMESTAKE (FIG ⁸⁻¹⁷ ~~1-17~~)

- 100,000 GALLONS OF PERCHLOROETHYLENE
(C_2Cl_4)

- VERY VERY OCCASIONALLY



- FLUSH TANK ONCE A MONTH TO
COLLECT ~ 30 Ar ATOMS AND
'COUNT' THEM WITH A GEIGER COUNTER

- THEN CAN ESTIMATE NEUTRINO
FLOW THROUGH THE TANK

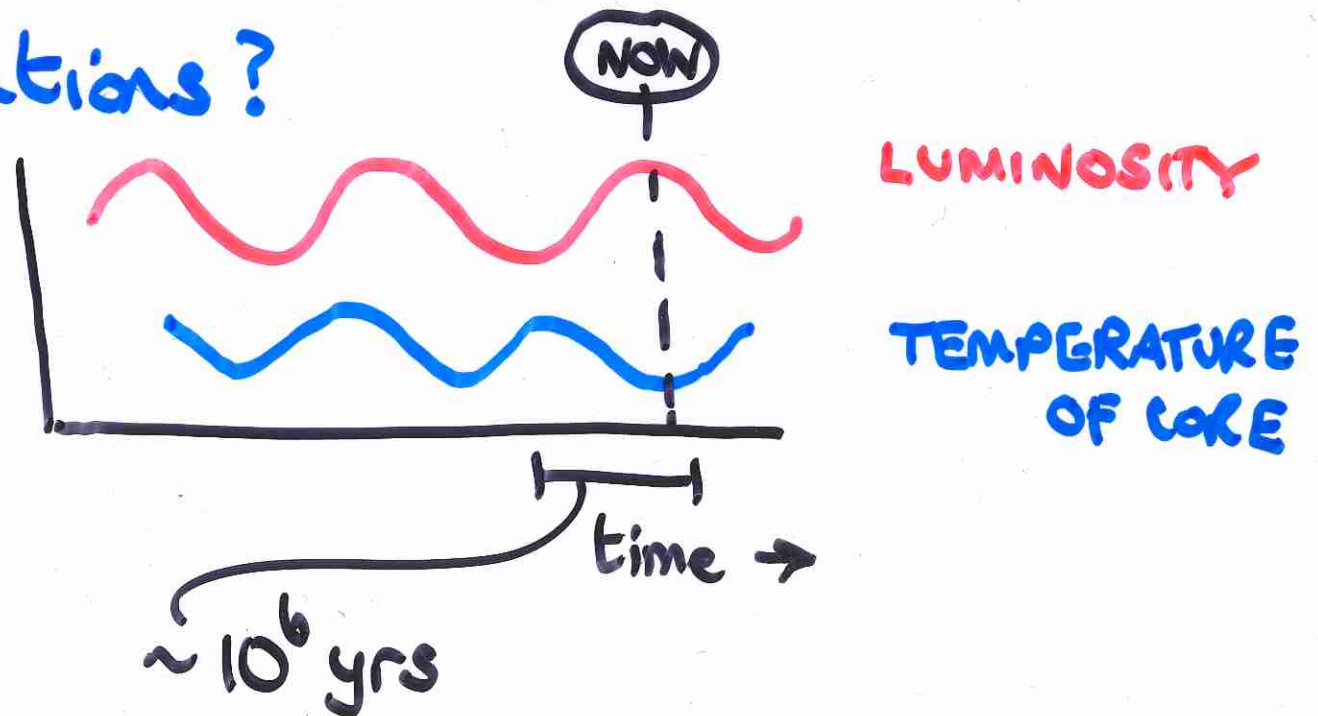
RESULT = ?

- SUN EMITS NEUTRINOS BUT AT A RATE
~ $1/2$ to $1/3$ THAT EXPECTED FROM OUR
MODELS OF THE SUN

"NO SNU5 IS BAD NEWS"

SOLUTIONS TO THE SOLAR NEUTRINO PROBLEM?

- PROTON-PROTON CHAIN?
 - nuclear experiments / theory checked / rechecked
- SOLAR MODEL INCORRECT?
 - surface composition and interior (initial) composition different?
 - oscillations?



- NEUTRINO PHYSICS

- THREE FAMILIES

- ELECTRON, MU, & TAU

- SUN EMITS ELECTRON NEUTRINOS

- EXPERIMENTS PRESENTLY DETECTED FIRST ELECTRON NEUTRINOS ONLY

- SUPPOSE ELECTRON ν  IN FLIGHT

- THEN WILL COUNT FEWER ELECTRON ν THAN PREDICTED

- SUDBURY /HEAVY WATER/ TO THE RESCUE  (FIG 8-17)

MAIN SEQUENCE PHASE

- REPRESENTS 80-90% OF TOTAL LIFETIME OF A STAR
- MS STARS RUN ON $4\text{H} \rightarrow \text{He} + \text{ENERGY}$, AN 'EFFICIENT' ENERGY SOURCE (0.7% of H MASS TO ENERGY)
- SUBSEQUENT NUCLEAR FUELS ARE LESS EFFICIENT, e.g.,
 $3\text{He} \rightarrow {}^{12}\text{C} + \text{ENERGY}$ (0.06% of He MASS TO ENERGY)
- LOW MASS STARS BURN He AT HIGHER LUMINOSITY THAN THAT AT WHICH THEY BURN H.

MAIN SEQUENCE STARS

$$L \propto M^4$$

$$\text{SEEDS} \\ L \propto M^{3.5}$$

$$\text{LIFETIME} \propto \frac{\text{FUEL SUPPLY}}{\text{RATE OF CONSUMPTION}}$$

$$\propto \frac{M}{L} = \frac{M}{M^4}$$

$$\propto \frac{1}{M^3}$$

CHECKING STELLAR EVOLUTION USING STAR CLUSTERS (SEGS 12-3)

- OPEN CLUSTERS

100 - 1000 STARS IN DISK OF GALAXY

YOUNG TO OLD

- GLOBULAR CLUSTERS

1,000,000⁺ STARS IN HALO OF GALAXY

OLD (~15 BILLION YRS)

- ASSUMPTION

IN A GIVEN CLUSTER ALL STARS ARE
OF SAME AGE AND SAME INITIAL COMPOSITION
STARS HAVE DIFFERENT MASSES

THEN, COMPARISONS OF CLUSTERS OF
DIFFERENT AGES WILL SHOW HOW
STARS OF DIFFERENT MASSES EVOLVE

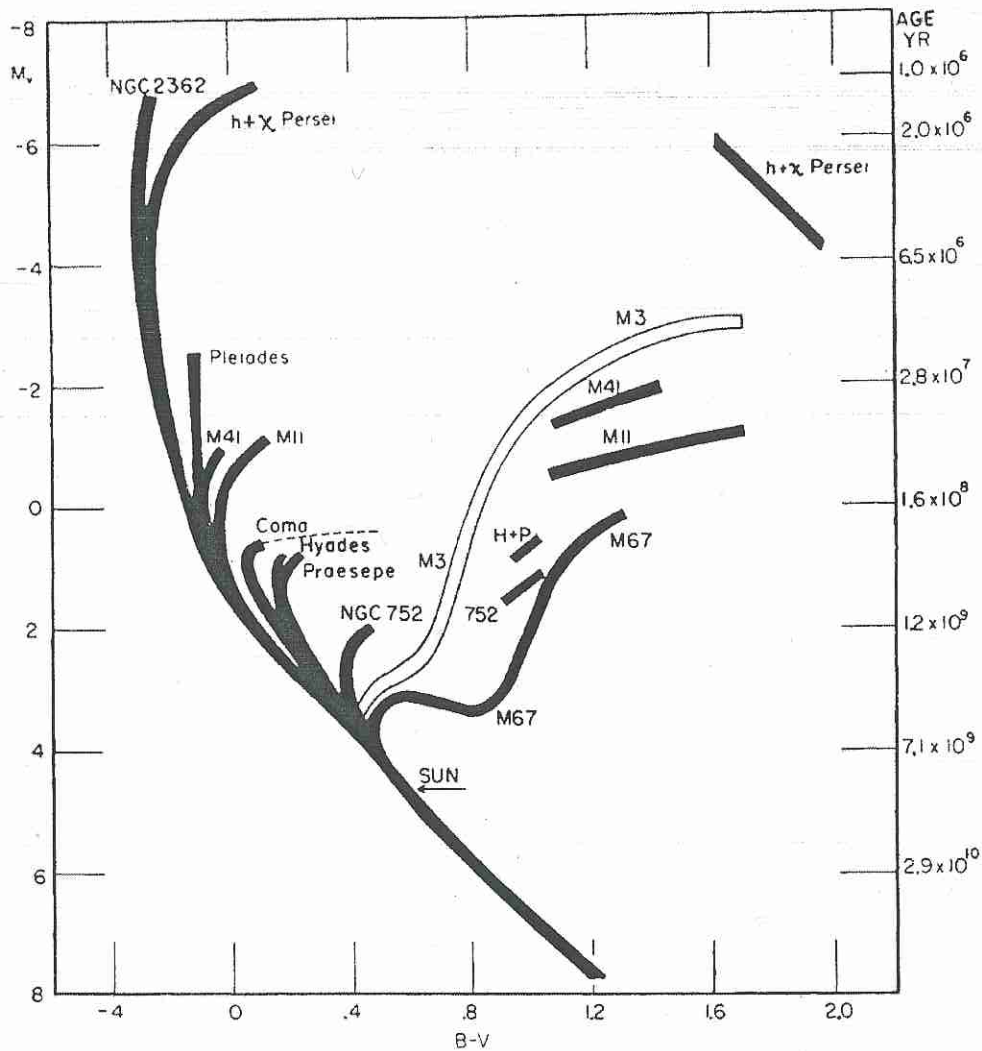
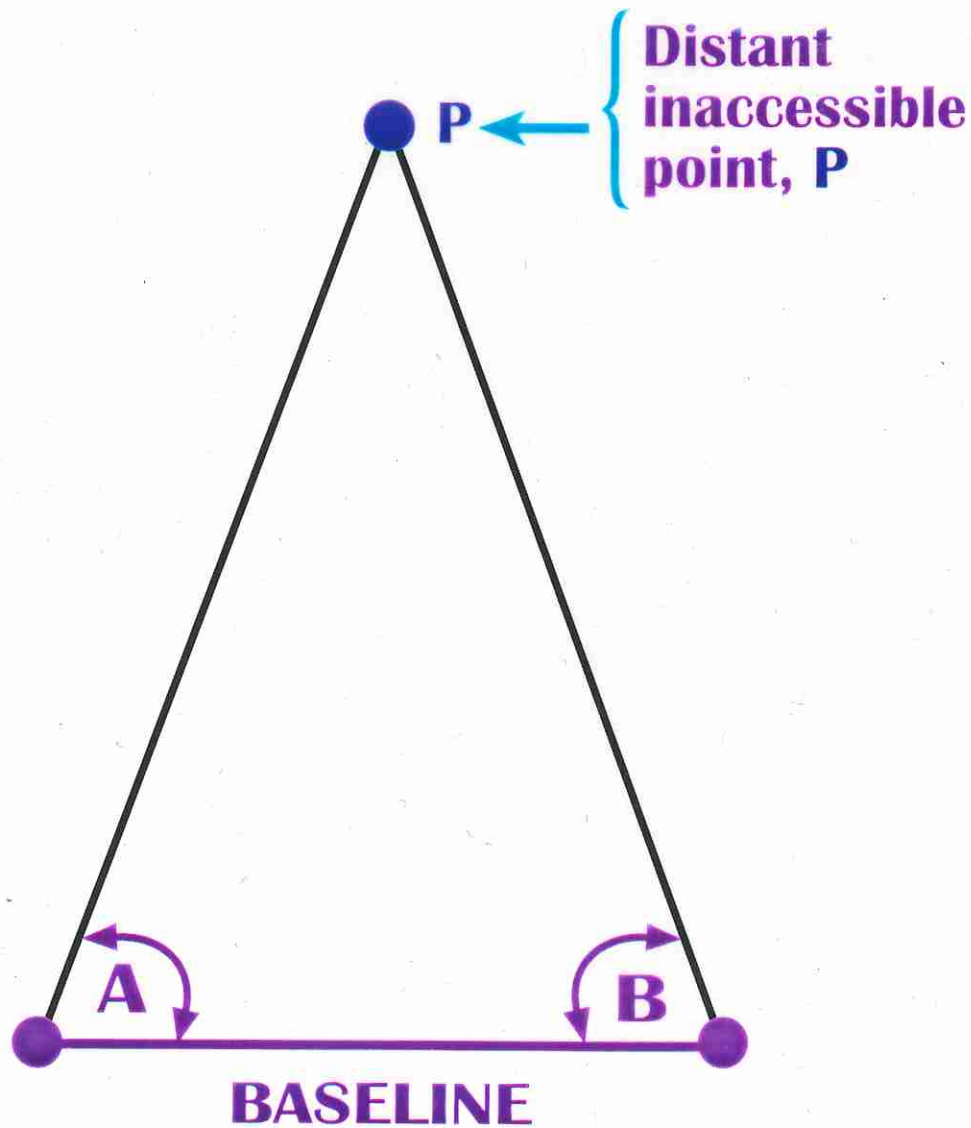


FIGURE 1 — A composite color-magnitude diagram of ten galactic clusters and one globular cluster. Ages corresponding to the various main sequence termination points are given along the right hand ordinate.

[4] II, 1 - Sandage 1 - p. 2

SURVEYOR'S METHOD

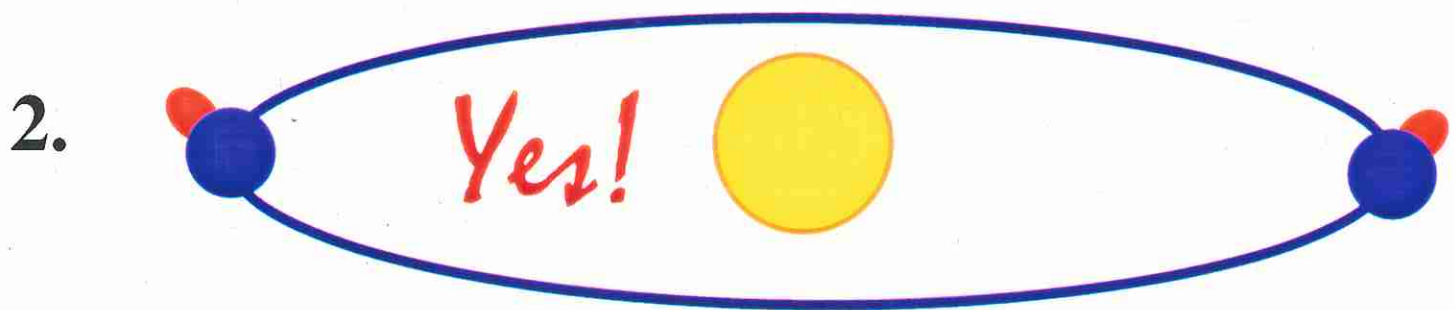
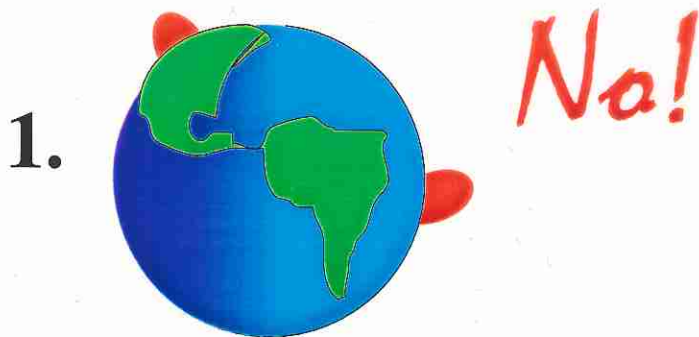


- Measure baseline
- Measure angles A and B
- Construct the *unique* triangle: then, you know distance to P



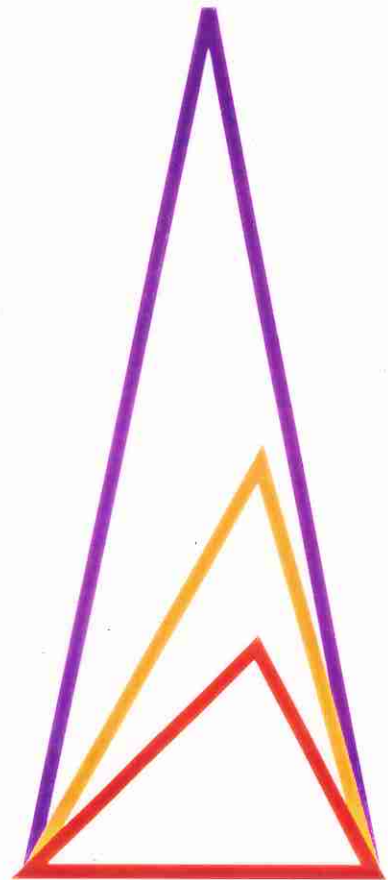
Distances to Stars?

Distances » Earth's size

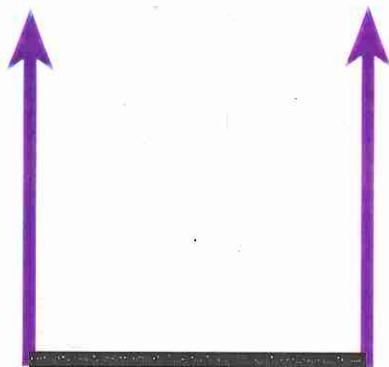


Distances still » Earth-Sun distance **but**
method works for nearest 100–1000
stars

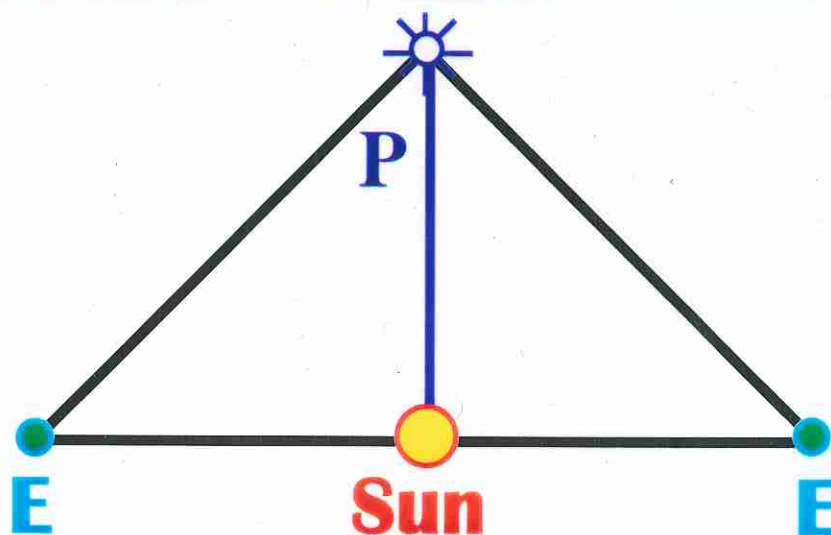
Method fails when
Distance » Baseline



Then, Angles **A** and **B** are
 $\approx 90^\circ$ **AND** $\approx$ Equal



Where do lines meet?



P = Parallax = 1/2 (the angle at star)

Distance in parsecs

$$= \frac{1}{\text{Parallax (in seconds of arc)}}$$

1 parsec = 3 1/4 light years
= 206, 265 A.U.

Abbreviations

1 parsec = 1pc
1000 pc = 1 Kpc
1,000,000 pc = 1 Mpc

HIPPARCHOS!

TELESCOPE IN SPACE

→ MUCH MORE ACCURATE
PARALLAXES

- WHY MORE ACCURATE?
- WHY IS THE GAIN IN
ACCURACY IMPORTANT?