STELLAR STRUCTURE AND EVOLUTION

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TO GET TO KNOW *YOU*

PLEASE, WRITE THIS PERSONAL INDEX CARD:

- 1) You name (or how you preferred to be addressed)
- 2) what is your greatest strength as a student and/ or as a person overall?
- 3) is there anything that you would like to share with me, that I need to know about you that I would otherwise not know?
- 4) what do you most want to learn from this class? or what topic are you most curious to know from this course?
- 5)Please, send me a selfie or pic of yourself by email emr@strw.leidenuniv.nl (with Luis and Ann-Sofie in cc) with your name on the email subject

STELLAR STRUCTURE AND EVOLUTION

TO GET TO KNOW MY COURSE

LOGISTICS

ROOMS, ETC..

- HL 414 BUT for Feb. 6 ==> de Sitter Zaal
- My Office 539 (please, on appointment after being to TA)
- Ann-Sofie's office 451. **Office hour: Thursdays 15-17)**
- Luis's office 551. **Office hour: Monday 10:00-12:00)**
- *Computer Lab* for assignment

MOTIVATIONS

Stars are fundamental bricks of Astronomy:

1.Building blocks of galaxies =>**Cosmology**

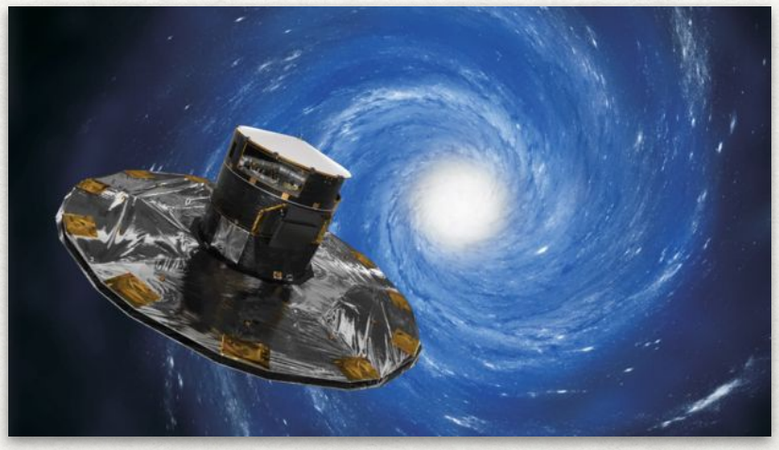
2.Site for planet formation =>**Extra-solar planet, Solar physics**

3. They produce the ``metals" life is made of (e.g. 99% human body made of oxygen, carbon, hydrogen, nitrogen, calcium, and phosphorus) **=>Astro-chemestry/Astro-biology**

4.Path to (stellar and super massive) black hole formation

5.Path to compact objects **4+5 => High energy astrophysics + GW**

In addition, *golden time* for stellar astronomy with ESA mission *Gaia*



COURSE DESCRIPTION

12 LECTURES, FIRST HALF

- 30/1: ***Introduction:*** basics concepts and motivations
- 6/2: (in De Sitter!) ***Fundamental stellar structure equations***: a matter of equilibrium!
- 13/2: ***Equations of state*** *(esp. Polytropic stars)*
- 20/2: ***Energy transport through the star***
- 27/2: ***Nuclear processes as source of a star's energy***
- 6/3: ***Stellar models:*** we now have all the bricks to build a star!

MID TERM GOAL: TO KNOW STELLAR STRUCTURE

COURSE DESCRIPTION

12 LECTURES, SECOND HALF

- 13/3: ***Stellar evolution: basics and overall pictures***

THIS IS THE RIGHT TIME FOR THE ASSIGNMENT

- 20/3: ***Formation, Pre-Main and Main sequence phase*** (very brief on the complex phenomenon of star formation)
- 27/3: ***Post-Main Sequence evolution to helium burning (HB) phase***
- 3/4: ***Late (after HB) evolution of low and intermediate mass stars (< 8 Msun)***
- 10/4: ***Late evolution of massive mass stars (>8 Msun, further burning cycles)***
- 24/4: ***Stellar explosions and remnants of massive stars***

WRITTEN EXAMINATION ON THE 8 MAY 2017

ASSIGNMENT

COMPULSORY FOR FINAL EXAM, WEIGH 20% OF FINAL GRADE

- ***2 tasks:***

  1. *numerically simulate and study the entire evolution of a star of a given mass using the code MESA*

  2. *Write a comprehensive but concise report*

- *Anne-Sofie and Luis will be helping you to understand the code and code set-up in a Computer Lab class around the 20 of March*

- *Around two weeks to perform the tasks*

- *If failing, you will get a second chance*

All the details will be given in March

FINAL EXAMINATION

8 MAY

- admission upon successful assignment
- written exam
- type questions: mix of definitions + conceptual questions (reasoning)
- no ``no'' or ``yes'' answers but arguments and formulae should be given in support of a statement
- a sheet of relevant formulae will be given
- result weigh 80% of the final grade

An example will be given in March

STUDY MATERIAL

- **Mainly following Prof. Polls' notes: http://www.astro.ru.nl/~onnop/education/stev_utrecht_notes/**
- Further reading:
- ``Theory of Stellar Structure and Evolution" by Dina Prialnik
- ``Stellar Interiors" by Hansen, Kawaler & Trimble
- http://home.strw.leidenuniv.nl/~nielsen/SSE17/SSE17.html

NOTES+CH 1 IN PRIALNIK

BASICS

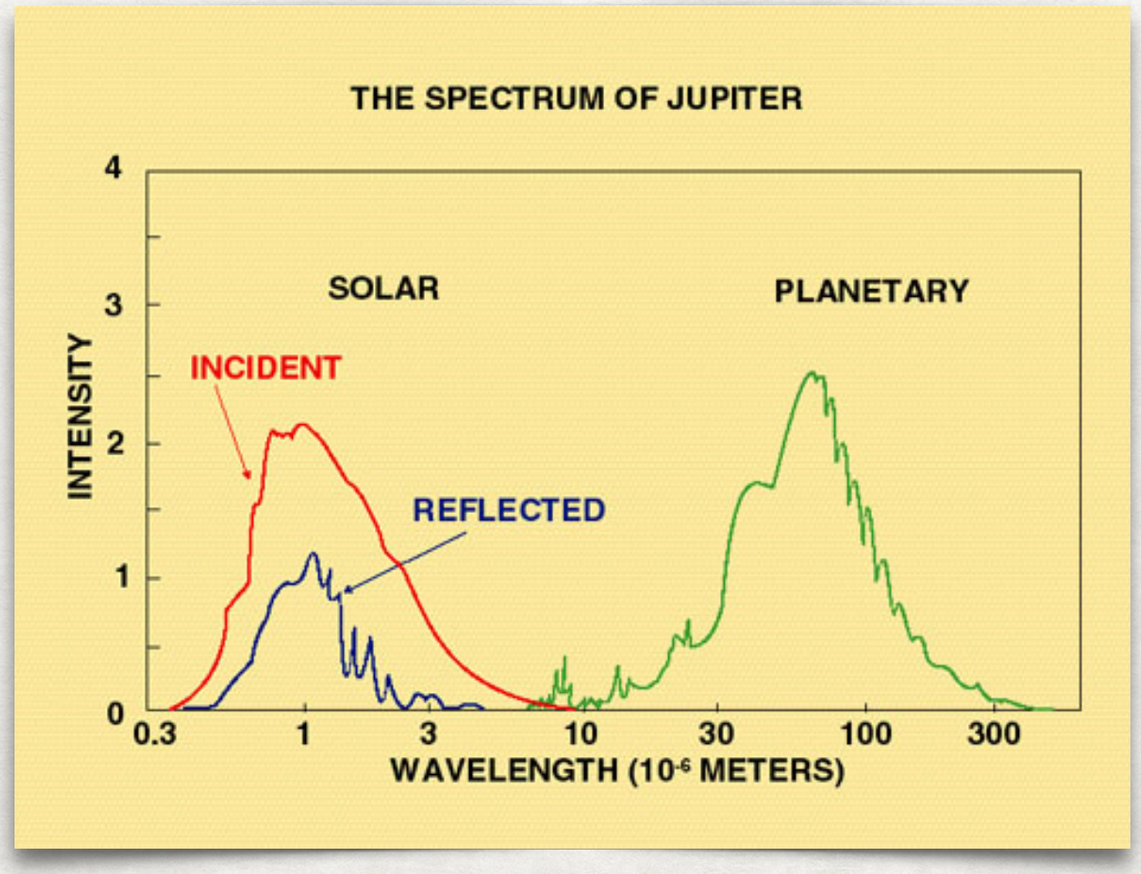
On slides you will find mainly figures…

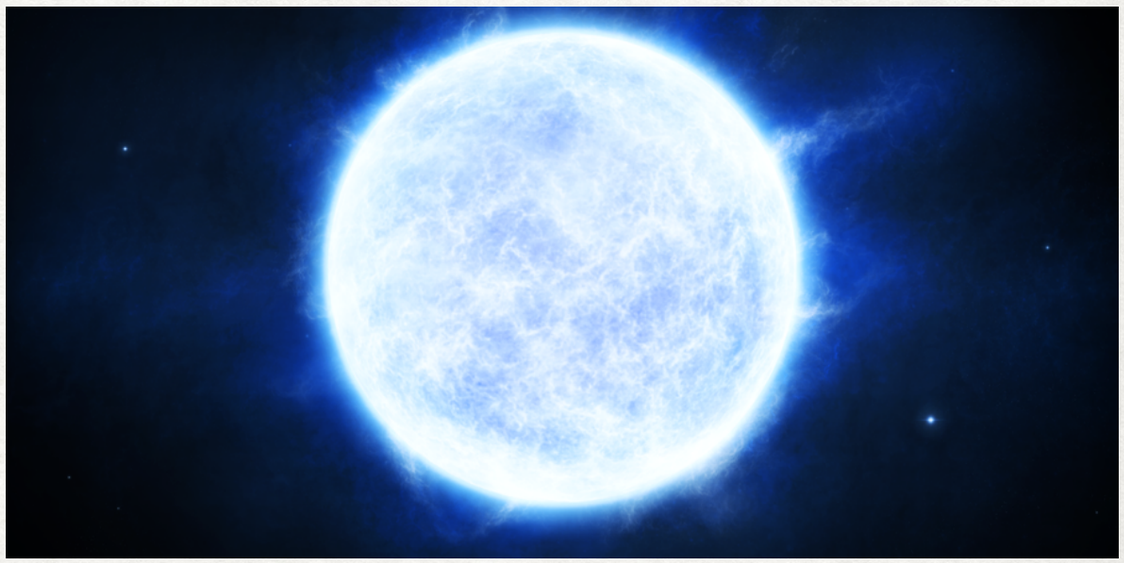
A STAR

A (CELESTIAL) BODY THAT SATISFIES TWO CONDITIONS:

★ (a) it is bound by self-gravity ==> (quasi) spherical because gravity is a spherically symmetric force field

★ (b) it radiates energy supplied by an internal source ==> planet, comets, moon shine by reflected light so they are not ``stars”





EVOLUTION

- As a star nuclear burns inside or releases gravitational energy ==> Star *evolves* in structure and composition

"Death"
- self gravity (a) is overwhelmed and star blow apart
- internal supply of energy (b) exhausted

Most stars end their lives by a combination of shedding of mass and exhaustion

"Birth" ? we will touch upon briefly, the course will some that a) and b) are already in place

ON BLACKBOARD

THE FOLLOWINGS

- Fundamental properties
- Stellar surface observations
- a few stellar interior messengers
- Stellar evolution observations

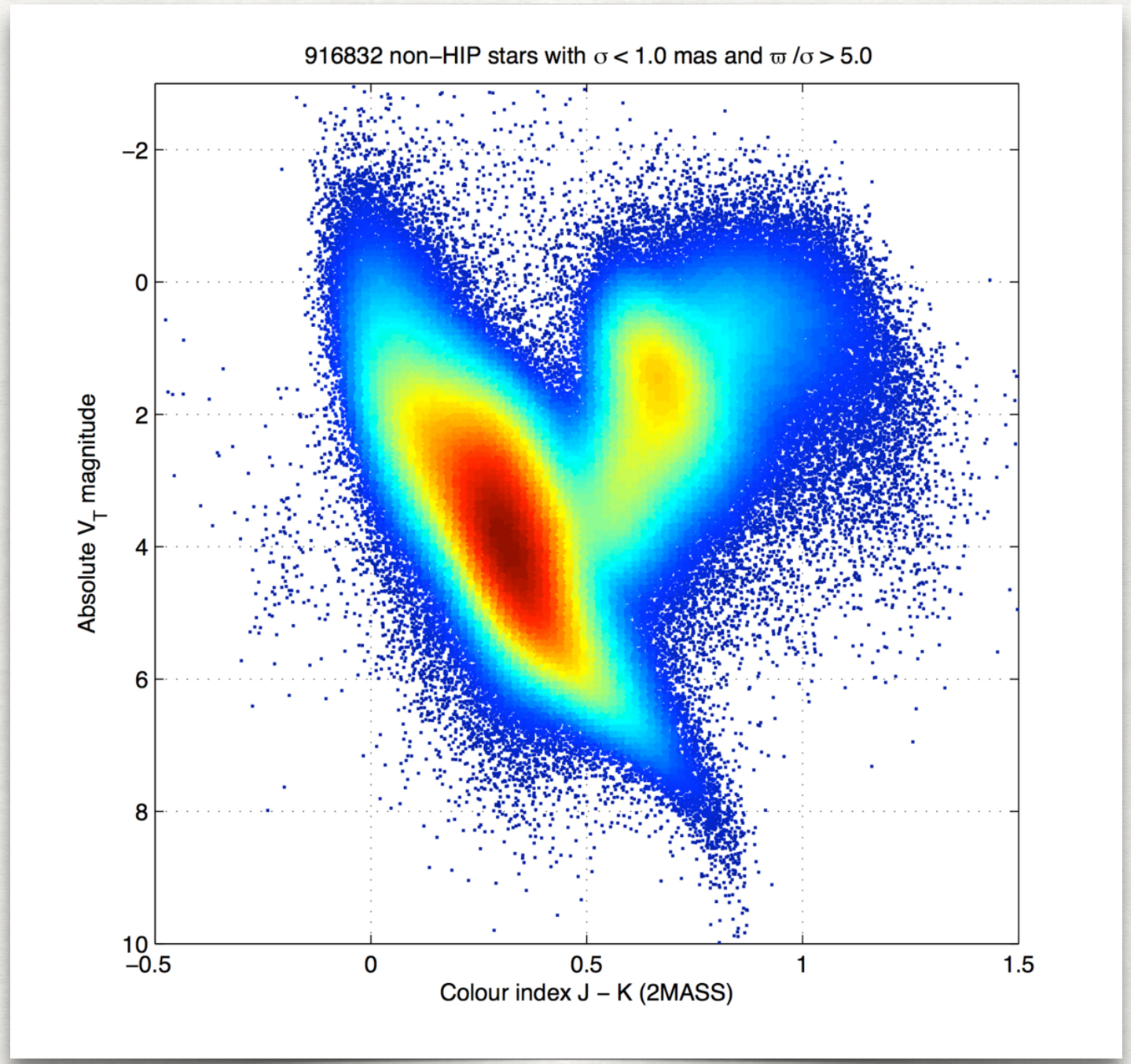
THE HERTZSPRUNG-RUSSEL DIAGRAM

H-R in short…

- INVENTED SIMULTANEOUSLY BY EJNAR HERTZSPRUNG (1911) AND HENRY NORRIS RUSSEL 1913
- FUNDAMENTAL TOOL FOR UNDERSTANDING STELLA EVOLUTION
- X-AXIS: DECREASING SURFACE TEMPERATURE (OR RELATED QUANTITIES)
- Y-AXIS: LUMINOSITY (OR RELATED QUANTITIES)
- EACH POINT = A STAR
- IMPORTANT TO SELECT THE SAMPLE:
  - VOLUME LIMITED SAMPLE
  - MAGNITUDE LIMITED SAMPLE
  - CLUSTERS

OBSERVERS TYPICALLY: MAGNITUDE VERSUS COLOUR

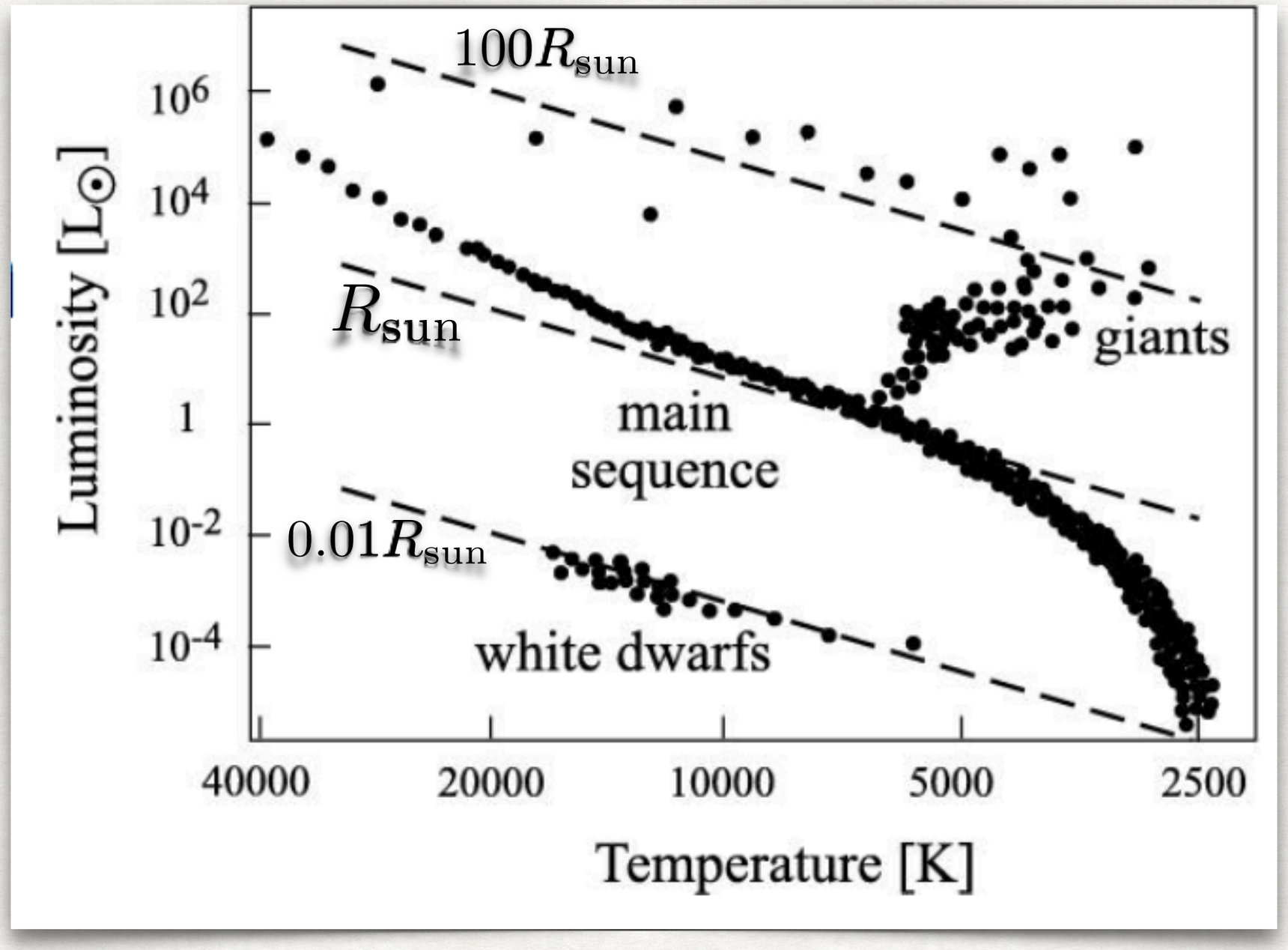
FIRST GAIA H-R DIAGRAM



NOTE: only some combinations of L and T_{eff} are possible

A THEORETICIAN'S VIEW: L VS T_{EFF}

STARS AT DIFFERENT LIFE STAGES CLUSTER



$$\log(L) = 4 \times \log(T_{\text{eff}}) + 2 \times \log(R) + A$$

STELLAR CLUSTERS ARE CLEANER (?)

``SIMPLE POPULATION" SCENARIO: SAME DISTANCE, METALLICITY, AGE

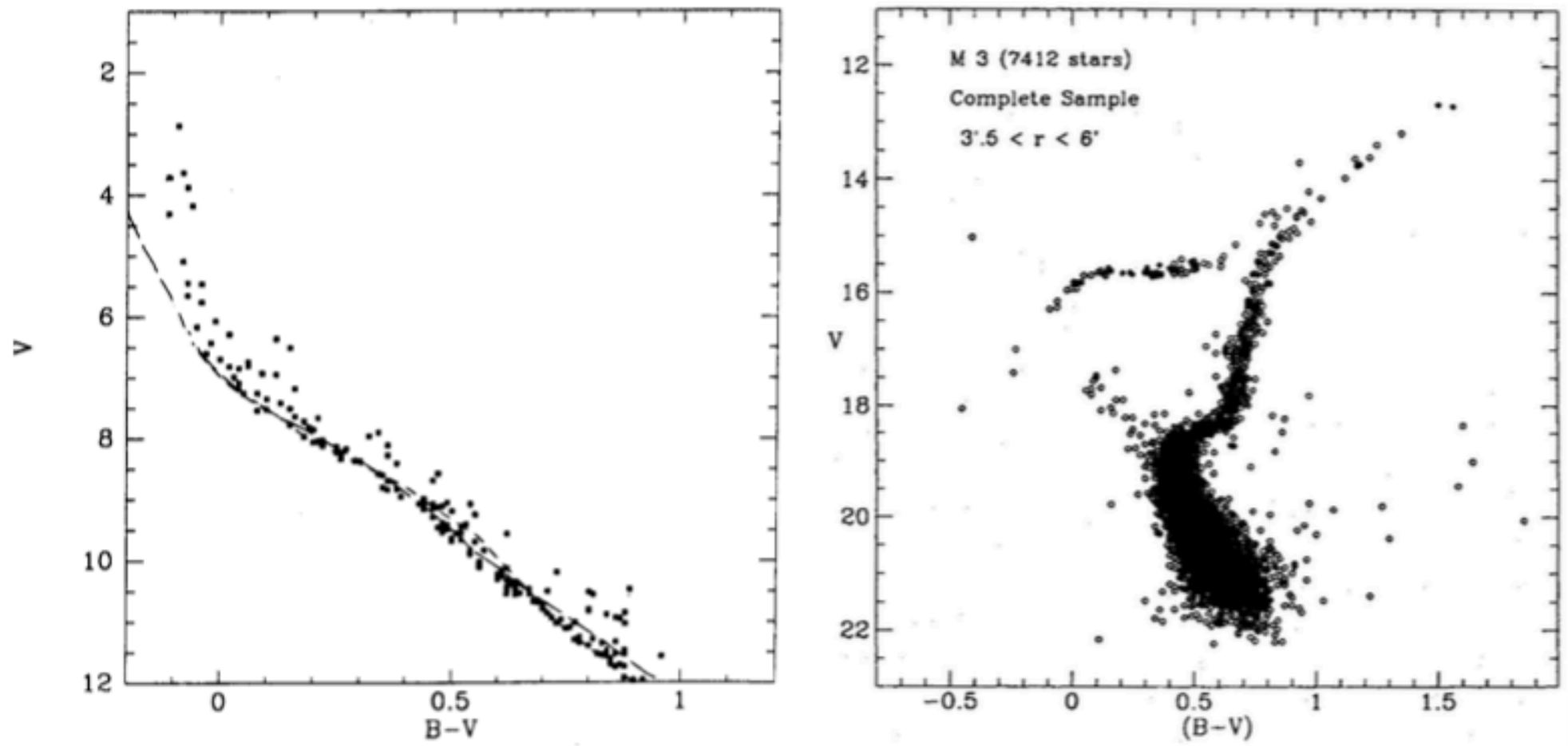


Figure 1.2. Colour-magnitude diagrams of a young open cluster, M45 (the Pleiades, left panel), and a globular cluster, M3 (right panel).

Hotter more luminous stars evolve faster off the main sequence

CORRELATIONS TO BE EXPLAINED BY THEORY

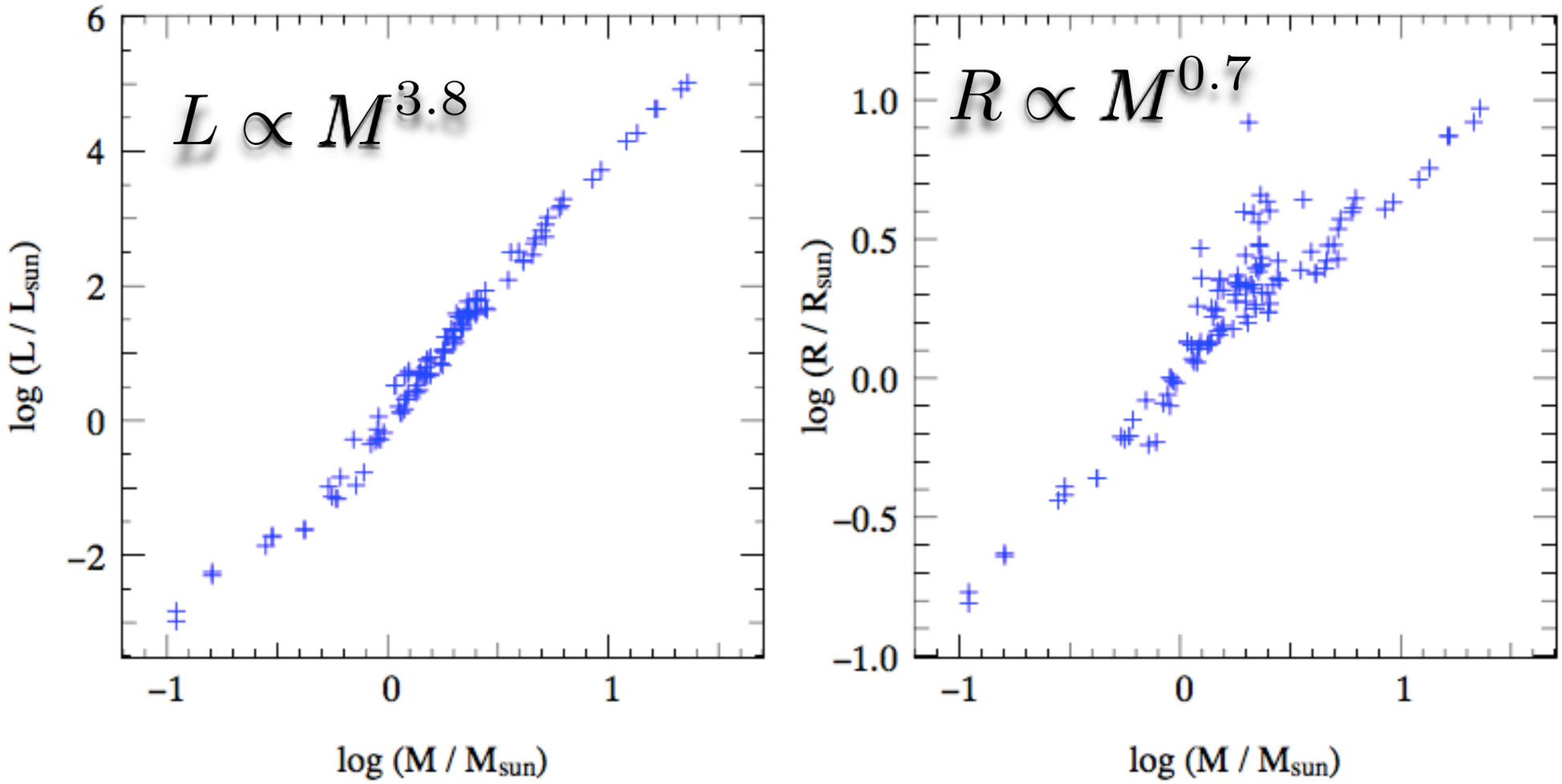


Figure 1.3. Mass-luminosity (left) and mass-radius (right) relations for components of double-lined eclipsing binaries with accurately measured M, R and L.

For main sequence stars with ~1 Solar mass

STELLAR POPULATIONS

- PoP III: first generation of stars from primordial gas. IMF debated but generally thought that may be quite massive ~100 Msun

- PoP II: Second generation $Z << Z_{sun}$: those of low mass (10^{10} yr old) have survived and can be observed in our Galactic Halo: fossils for “Galactic Archeology”.

- PoP I: $Z \sim Z_{sun,}$ lifetime < 10^{9} yr