Introduction to ASTR 565

Stellar Structure and Evolution

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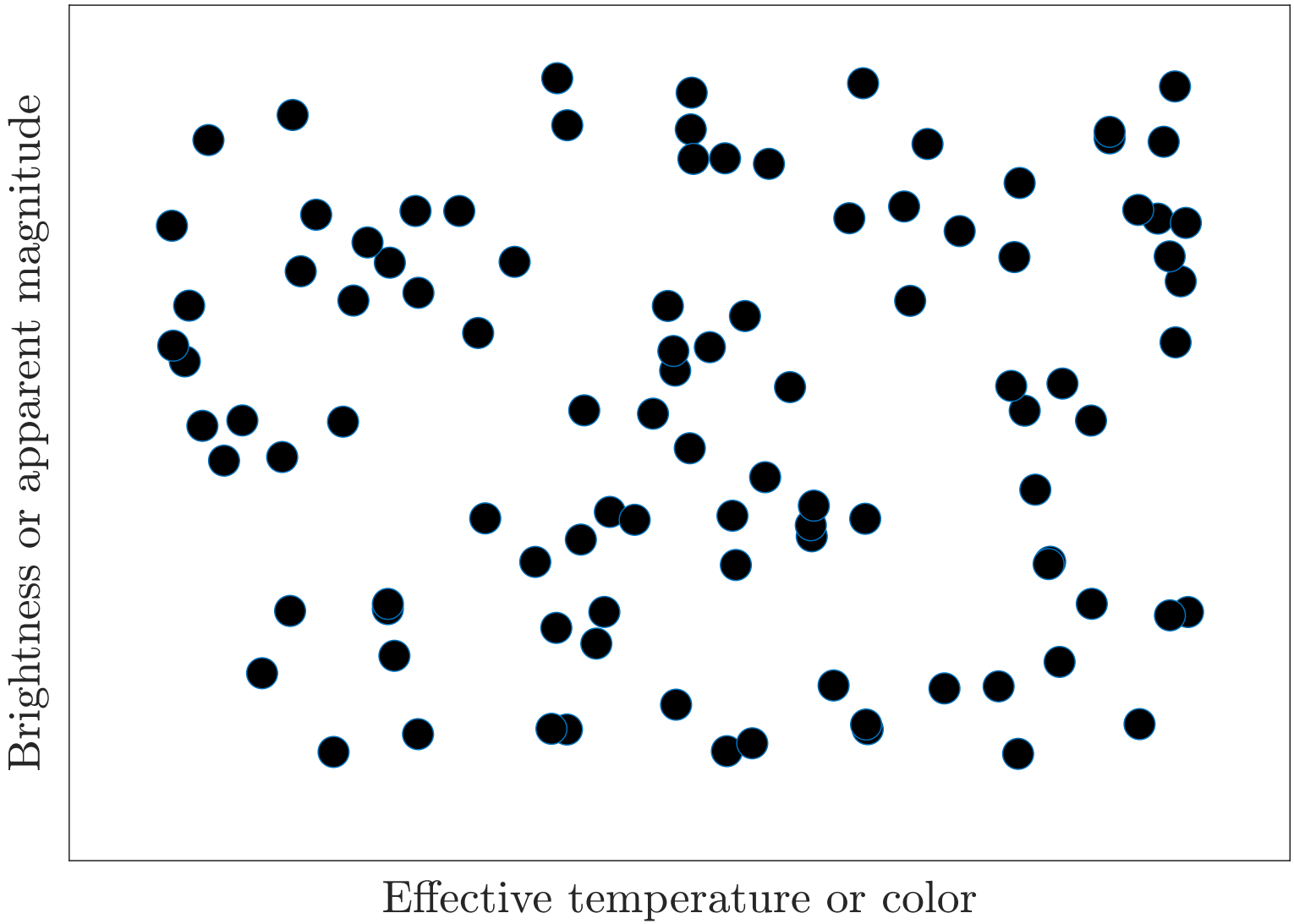
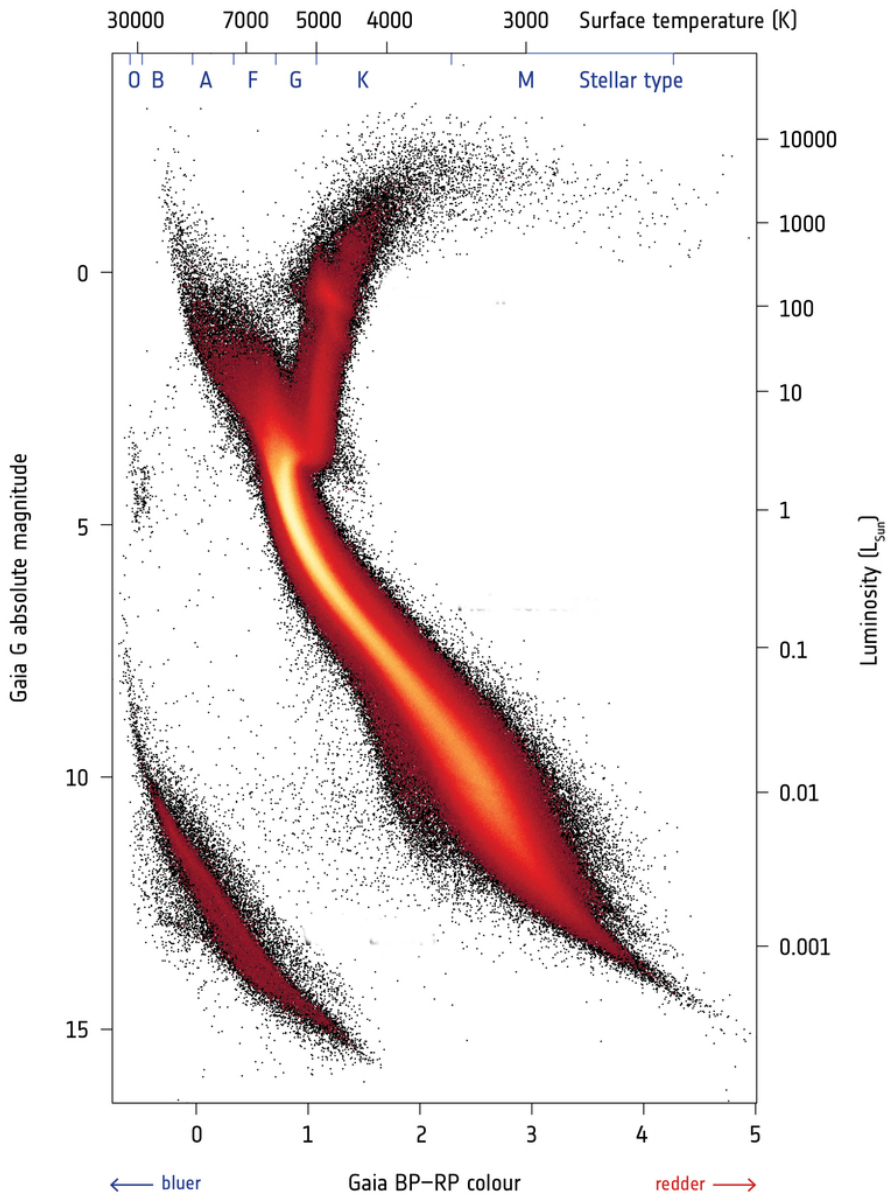
Outline

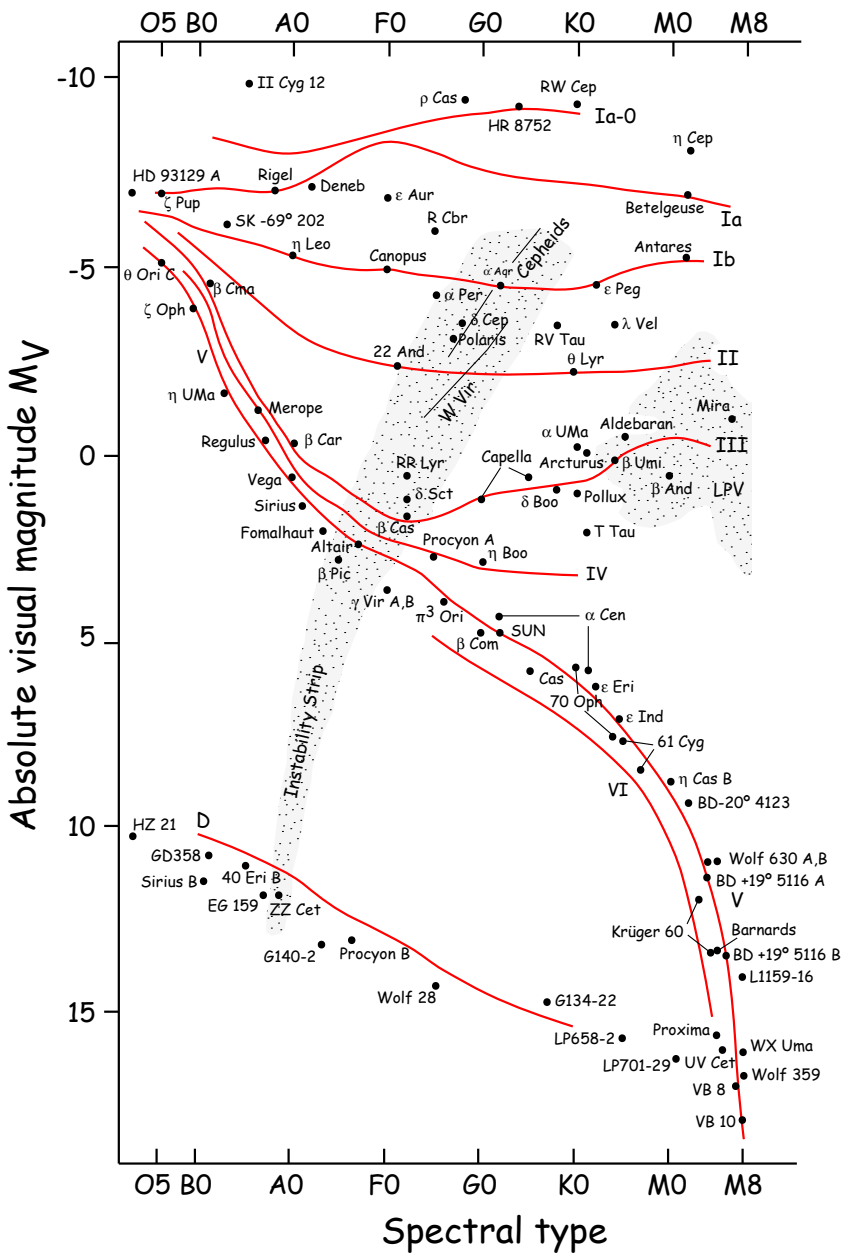
Order in the H-R Diagram!!



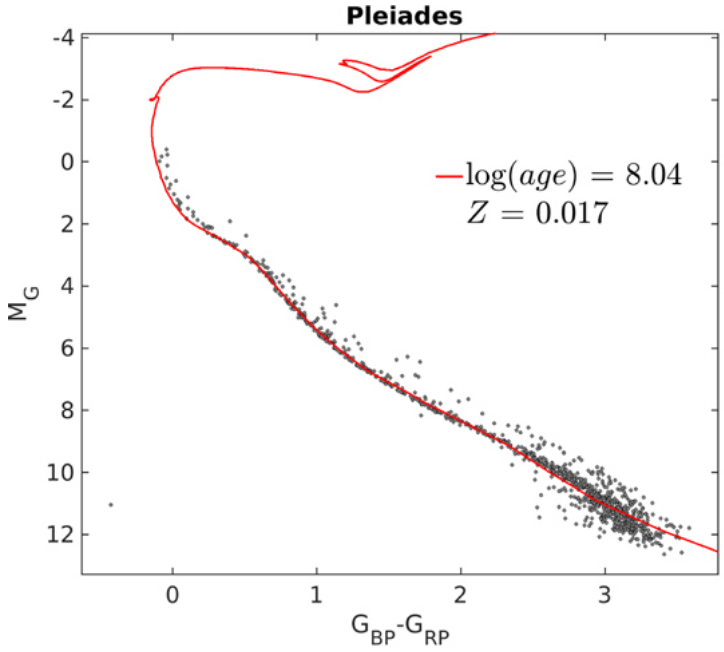
Motivation: Understanding the H-R Diagram

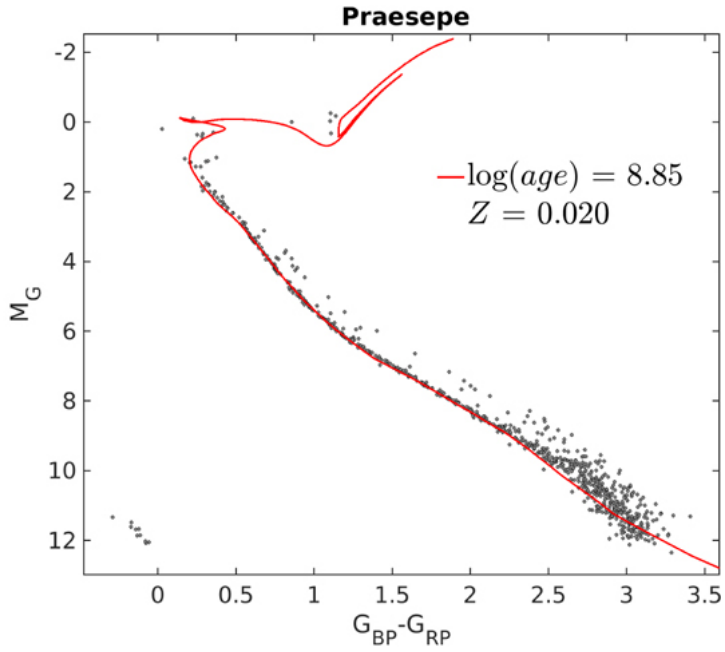


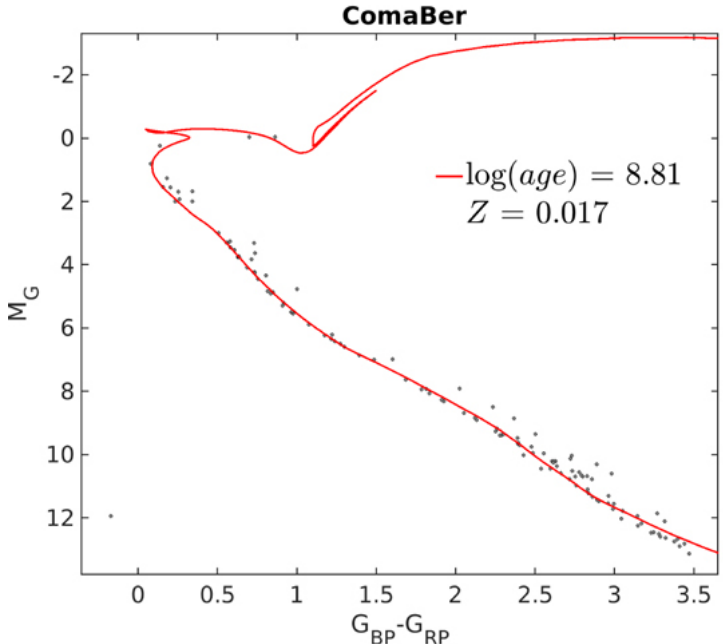
H-R Diagram (2)

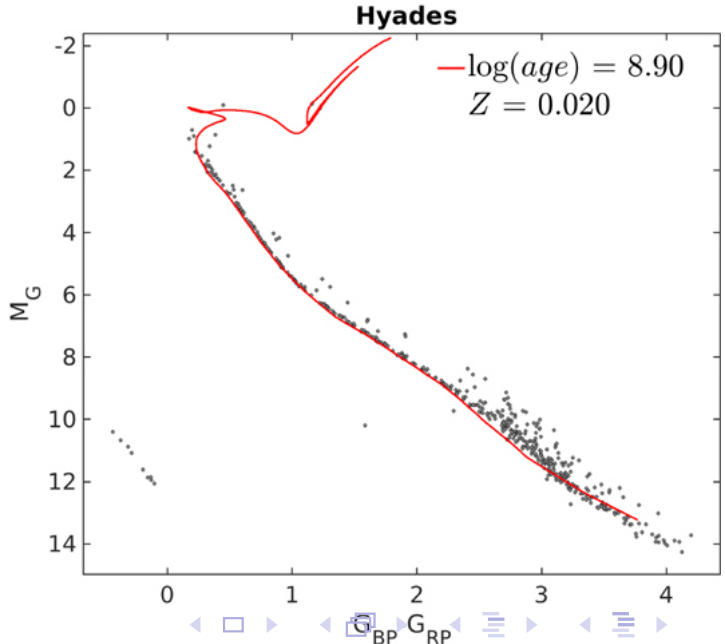

O5 B0 A0 F0 G0 K0 M0 M8
-10
-5
0
5
10
15
Absolute visual magnitude M_V
Spectral type
II Cyg 12
ρ Cas
RW Cep
HR 8752
Ia-0
η Cep
HD 93129 A
Rigel
Deneb
ε Aur
ζ Pup
Betelgeuse
Ia
SK -69° 202
R Cbr
η Leo
Canopus
Cepheids
α Aqr
Antares
Ib
θ Ori C
β Cma
α Per
ε Peg
ζ Oph
δ Cep
λ Vel
Polaris
RV Tau
22 And
θ Lyr
II
V
W Vir
η UMa
Merope
Mira
α UMa
Aldebaran
Regulus
β Car
III
RR Lyr
Capella
Arcturus
β Umi
Vega
δ Sct
δ Boo
Pollux
β And
LPV
Sirius
Fomalhaut
β Cas
T Tau
Altair
Procyon A
η Boo
β Pic
IV
γ Vir A,B
π3 Ori
α Cen
SUN
β Com
Cas
ε Eri
70 Oph
ε Ind
61 Cyg
Instability Strip
η Cas B
VI
BD-20° 4123
HZ 21
D
GD358
Wolf 630 A,B
Sirius B
40 Eri B
BD +19° 5116 A
V
EG 159
ZZ Cet
Krüger 60
Barnards
G140-2
Procyon B
BD +19° 5116 B
L1159-16
Wolf 28
G134-22
LP658-2
Proxima
WX Uma
LP701-29
UV Cet
Wolf 359
VB 8
VB 10

H-R Diagram (3)

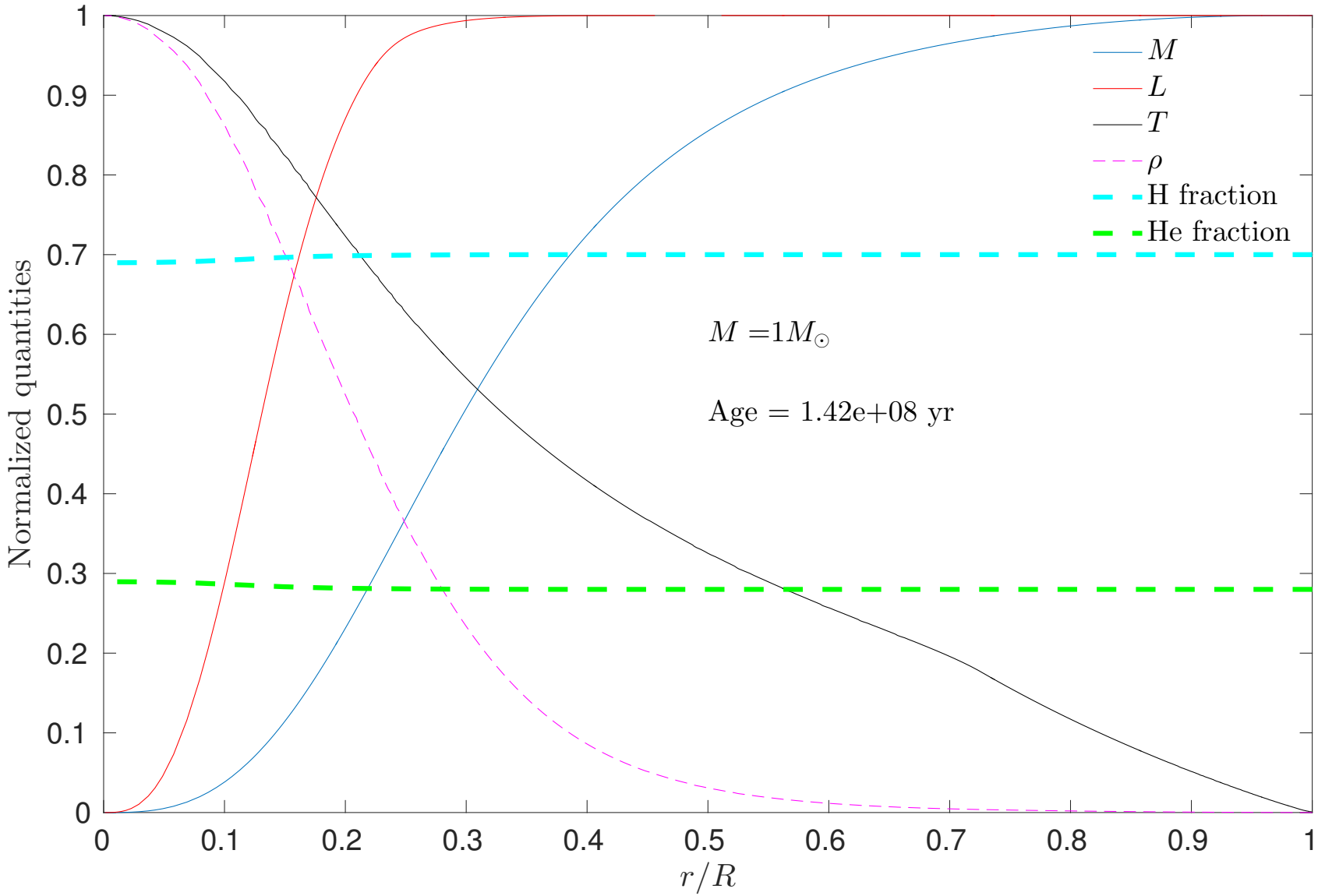

Pleiades
$\log(age) = 8.04$
$Z = 0.017$
M_G
G_{BP}-G_{RP}


Praesepe
$\log(age) = 8.85$
$Z = 0.020$
M_G
G_{BP}-G_{RP}

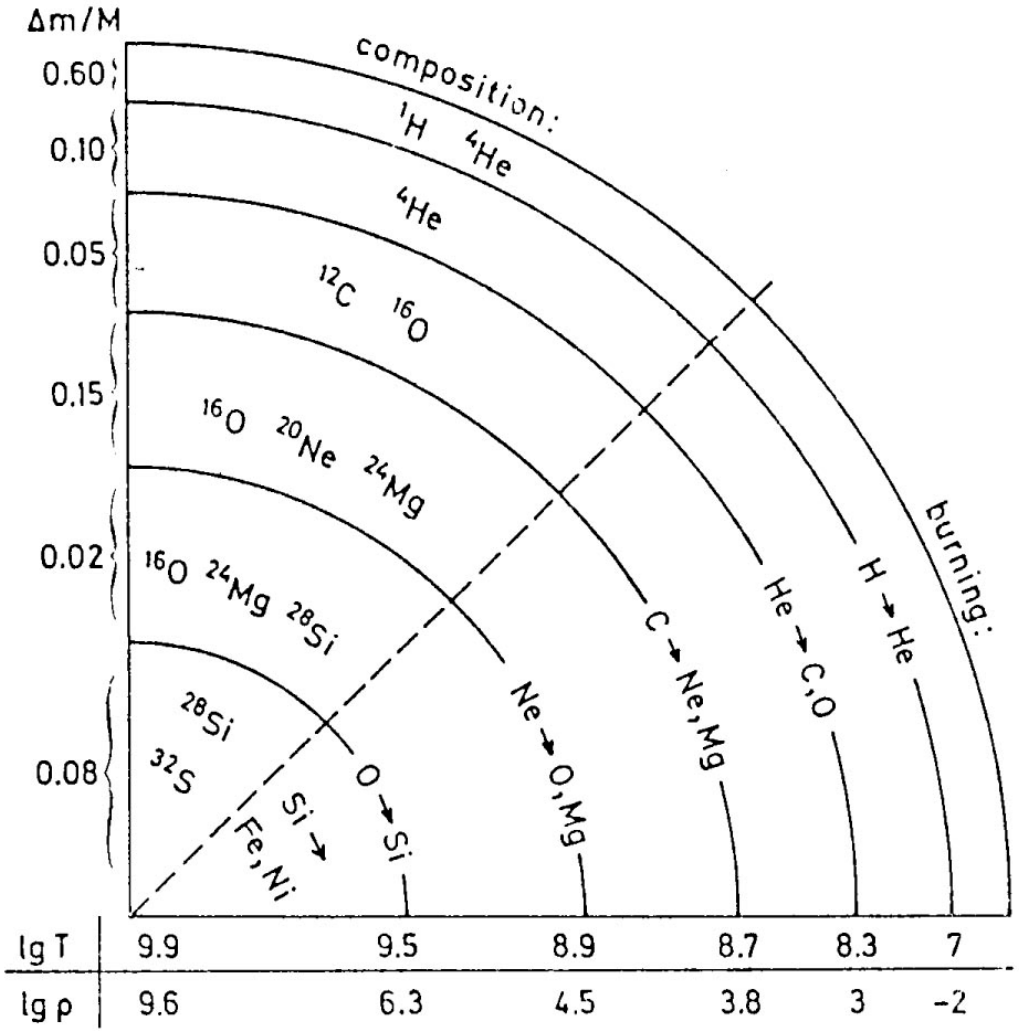

ComaBer
$\log(age) = 8.81$
$Z = 0.017$
M_G
G_{BP}-G_{RP}


Hyades
$\log(age) = 8.90$
$Z = 0.020$
M_G
G_{BP}-G_{RP}

Basic structure - highly non-linear solution



Massive-star nuclear burning



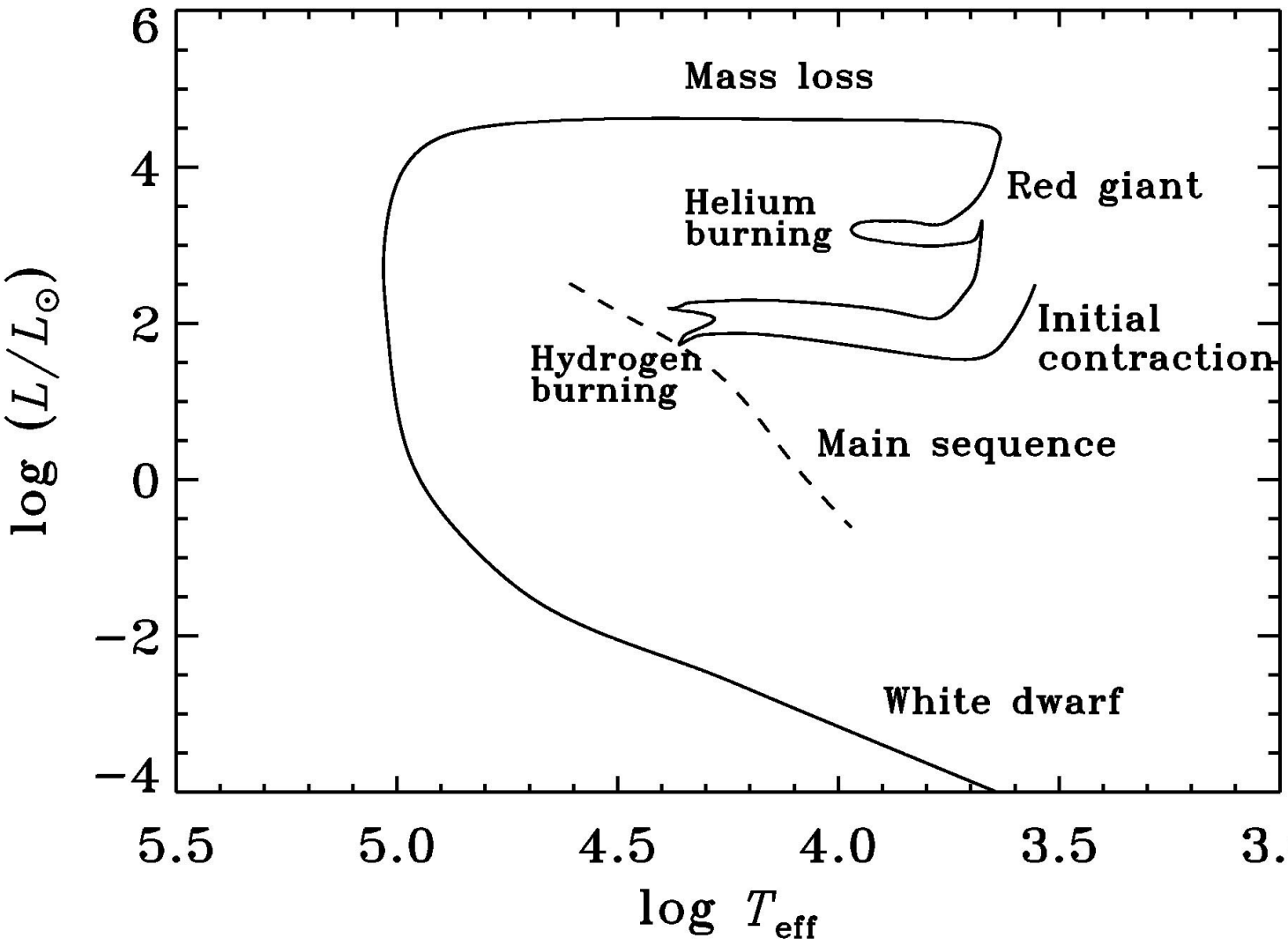
Topics: what does a star look like inside?

- Nuclear interactions
- Hydrogen burning, T dependence, neutrinos
- Equation of state (ideal gas, degenerate gas)
- Hydrostatic equilibrium
- Polytrope solutions to basic equations
- Transport: radiation, conduction, and convection
- Convectively stable and unstable regions
- Opacity
- MESA

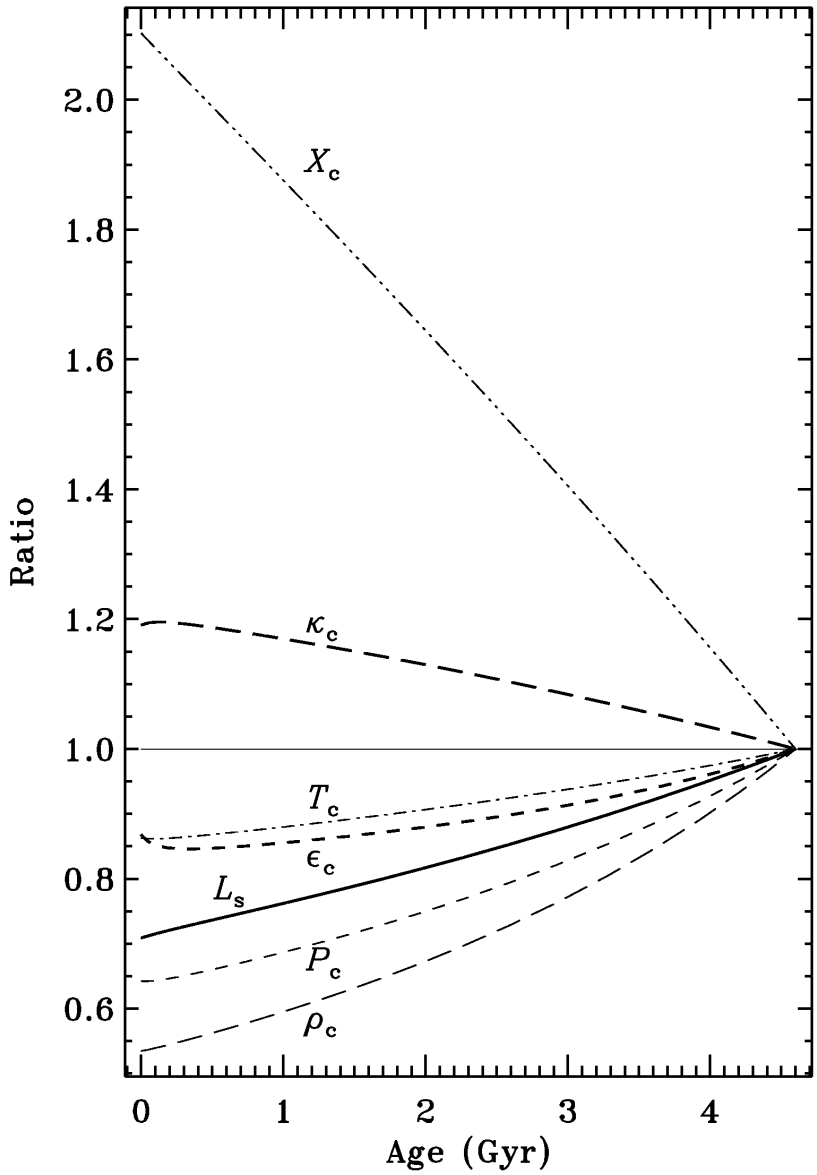
What parameters are in play?

- Mass
- Composition (He + metals)
- Opacity calculations
- Mixing length of convection
- Overshoot of convection
- Chemical diffusion, radiative levitation
- Rotation (primordial, mixing, structure)
- Mass loss
- Magnetic fields (primordial vs. generated)

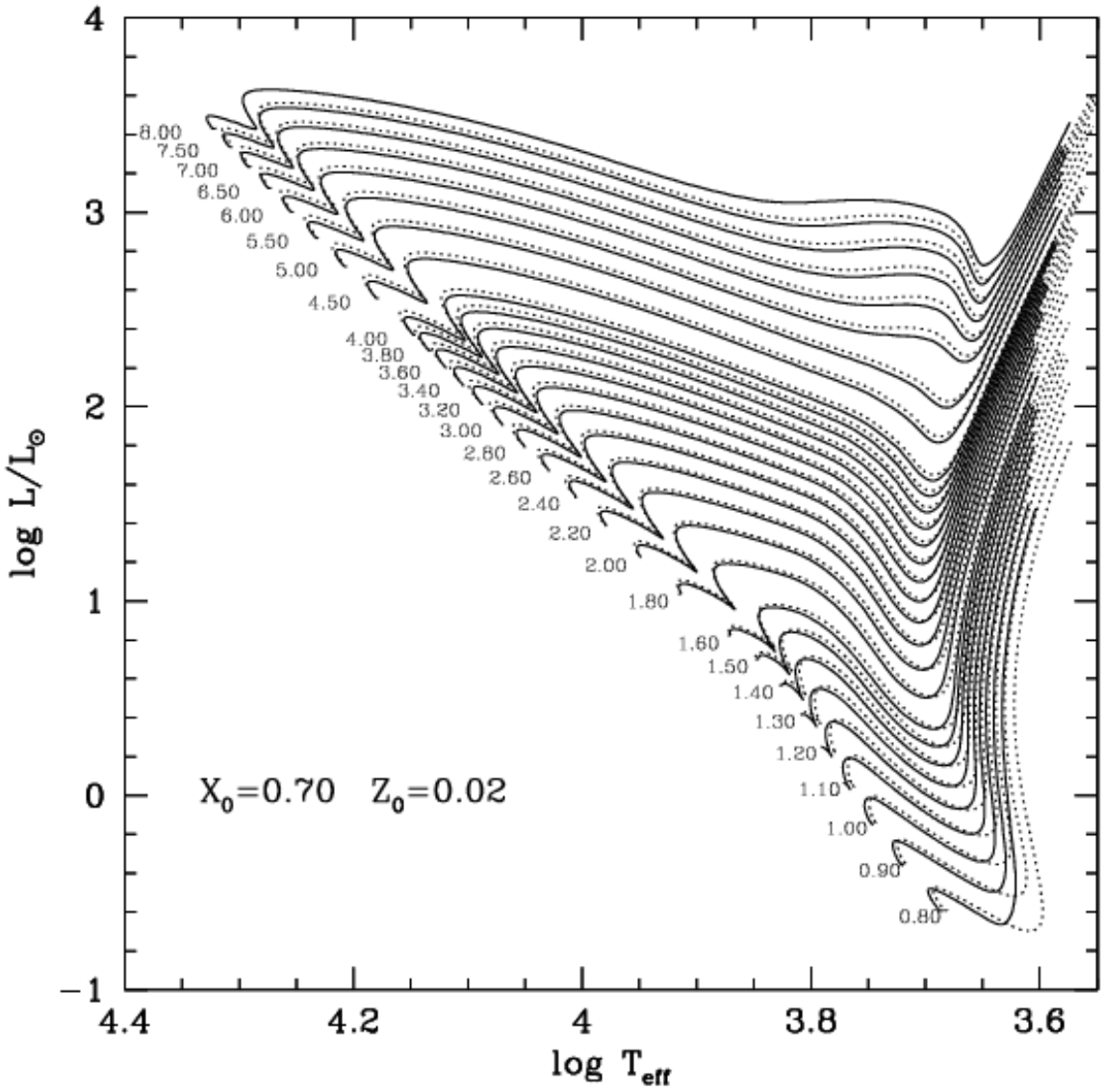
Evolution - surface and interior changes



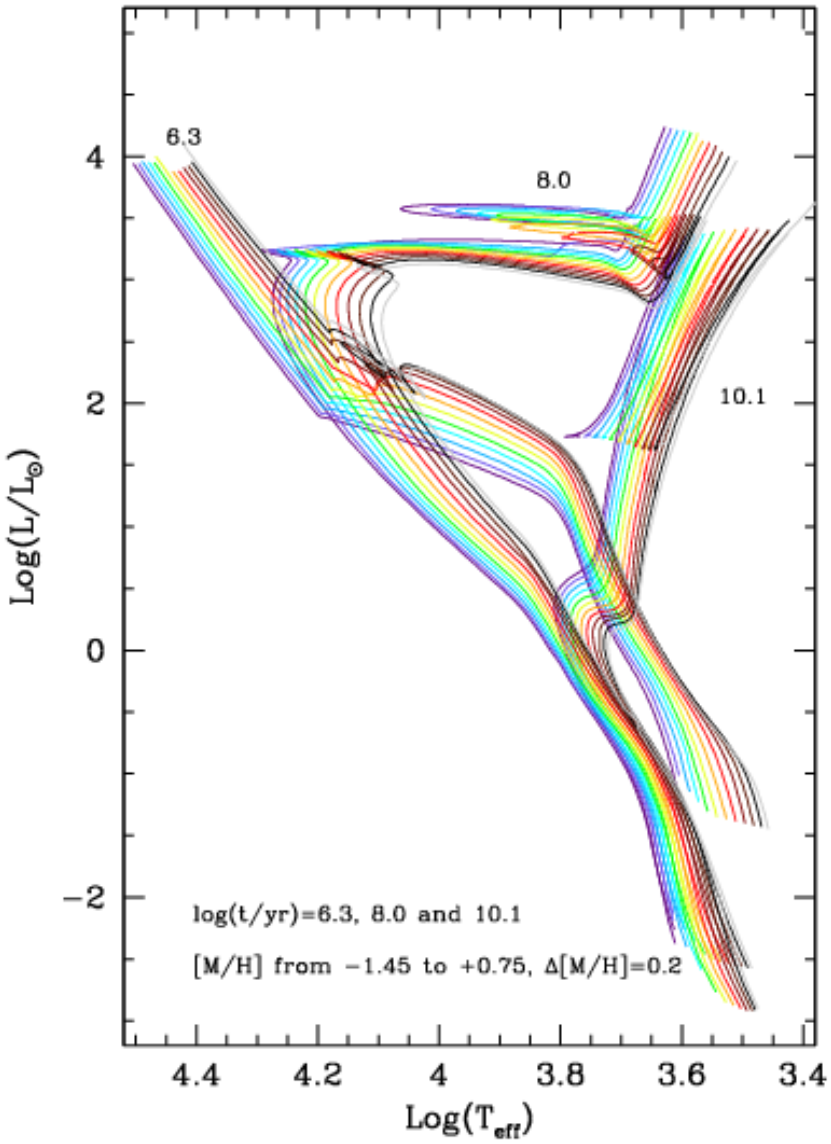
Solar properties over time



H-R diagram and mass



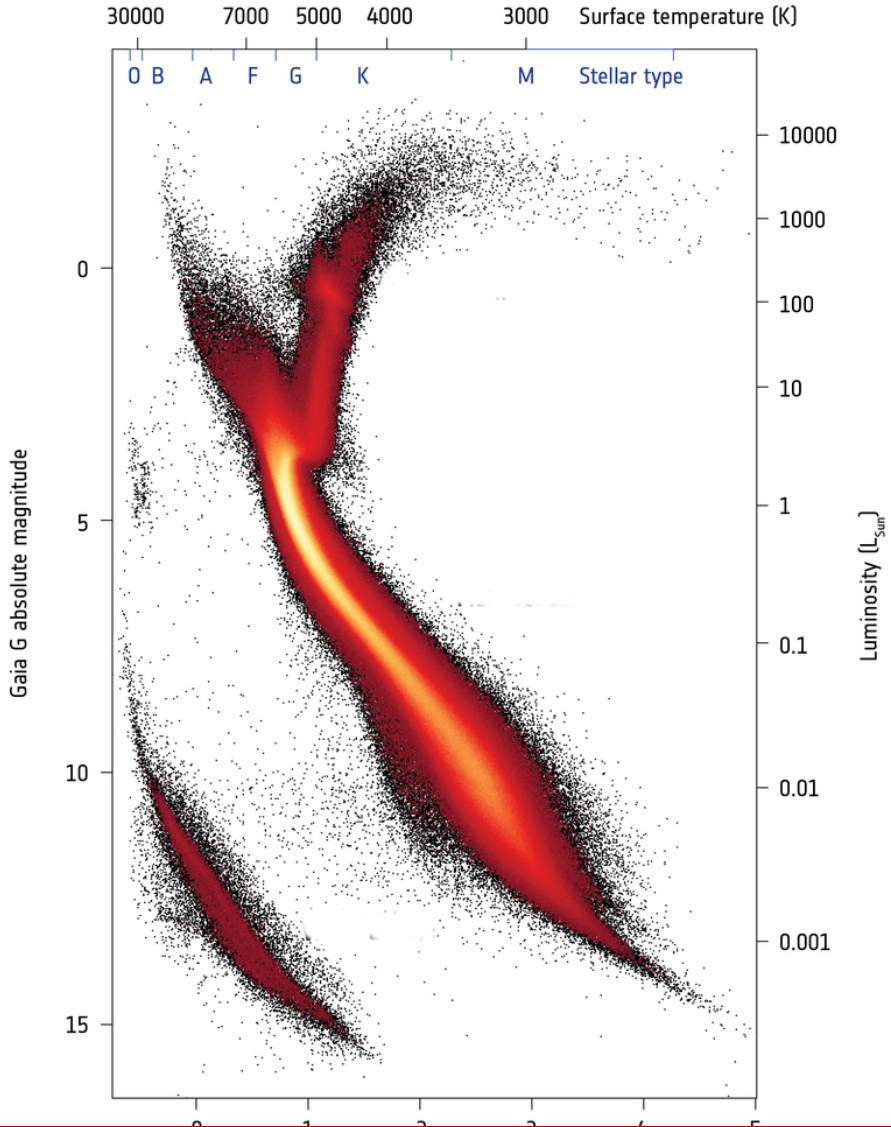
H-R diagram and isochrones



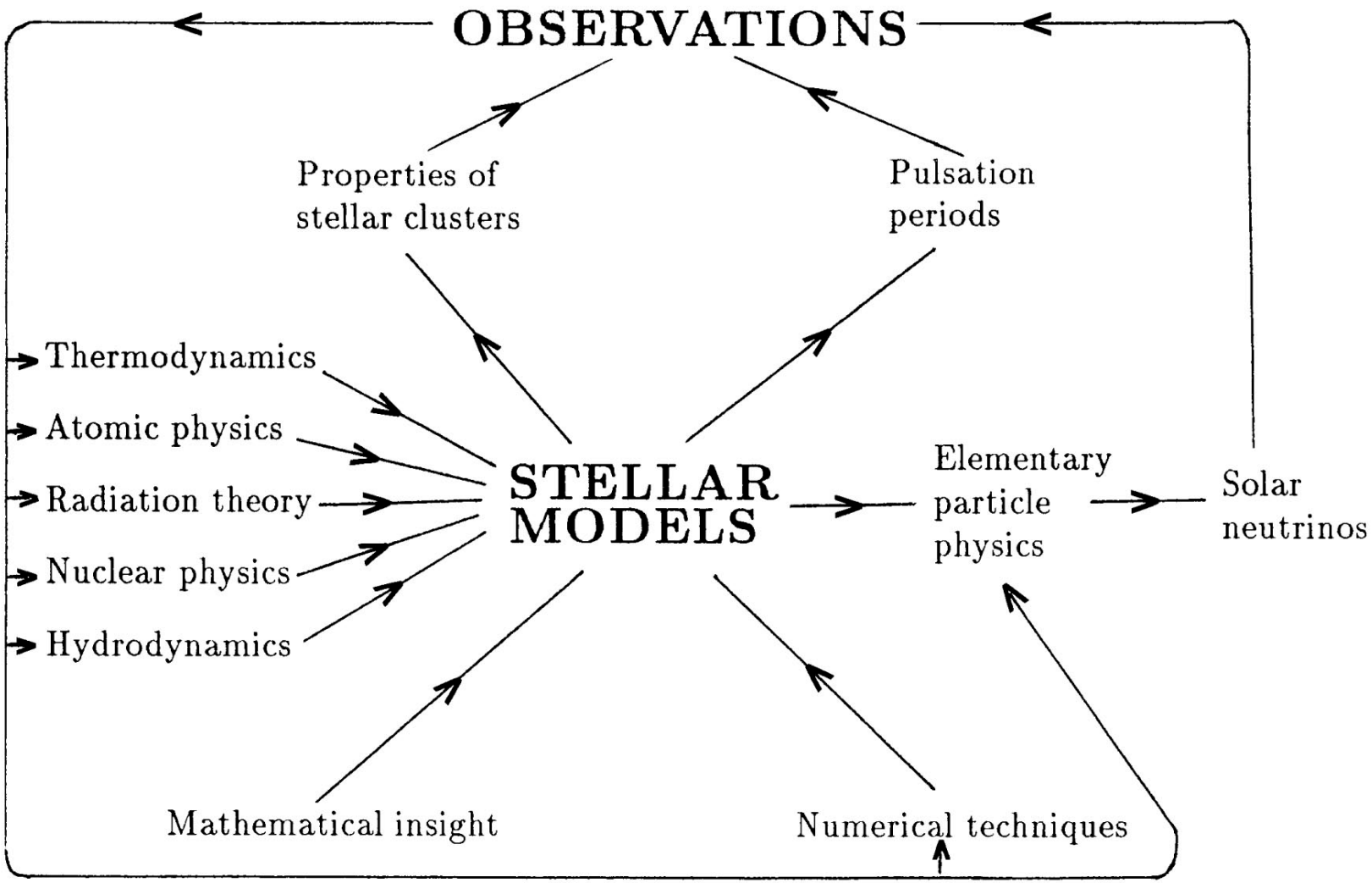
Topics: what changes take place in a star over time?

- Main sequence, homology relations
- Schönberg-Chandrasekhar limit, or core mass
- Subgiant and RGB properties
- Helium burning
- Horizontal branch, thermal pulses
- Nebulae, Supernovae
- Compact objects
- Instability strip
- MESA

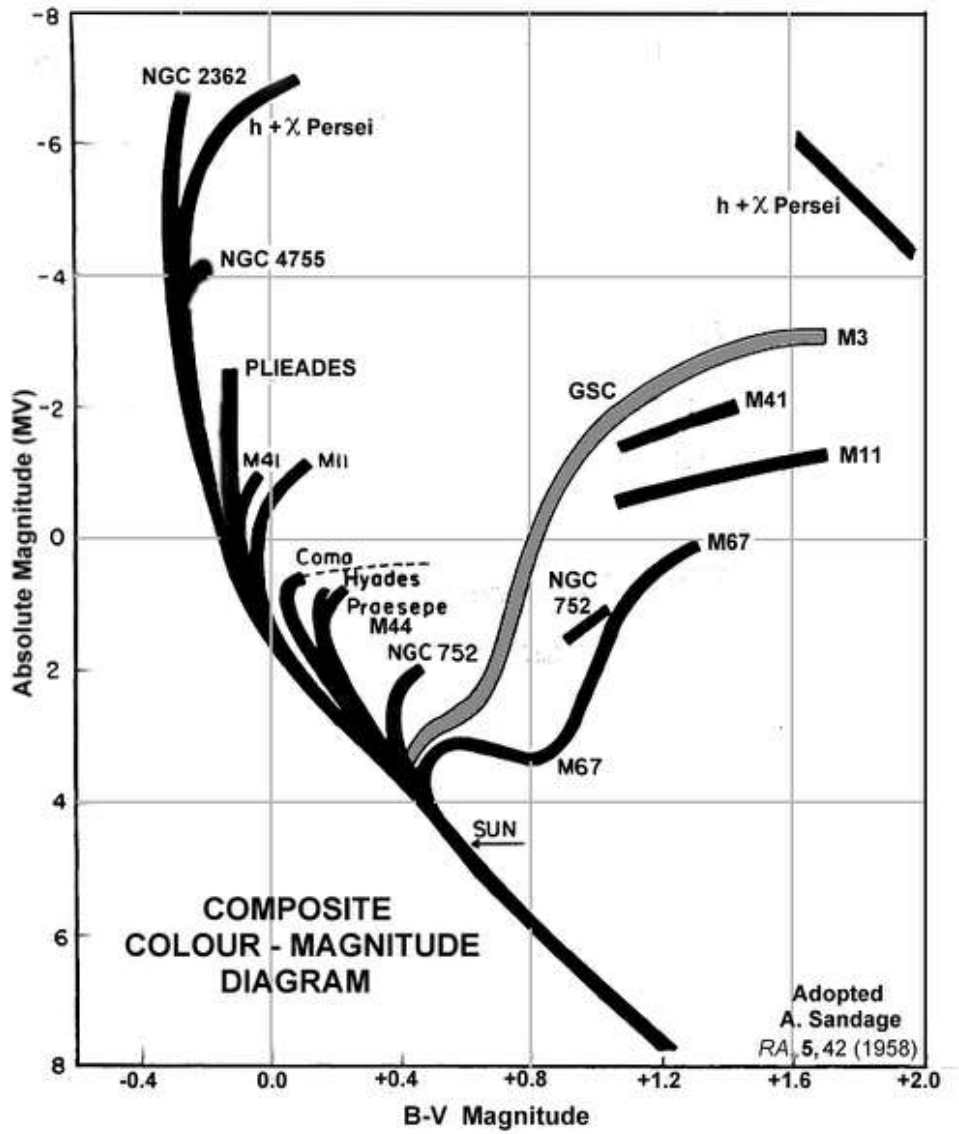
Motivation: Understanding the H-R Diagram



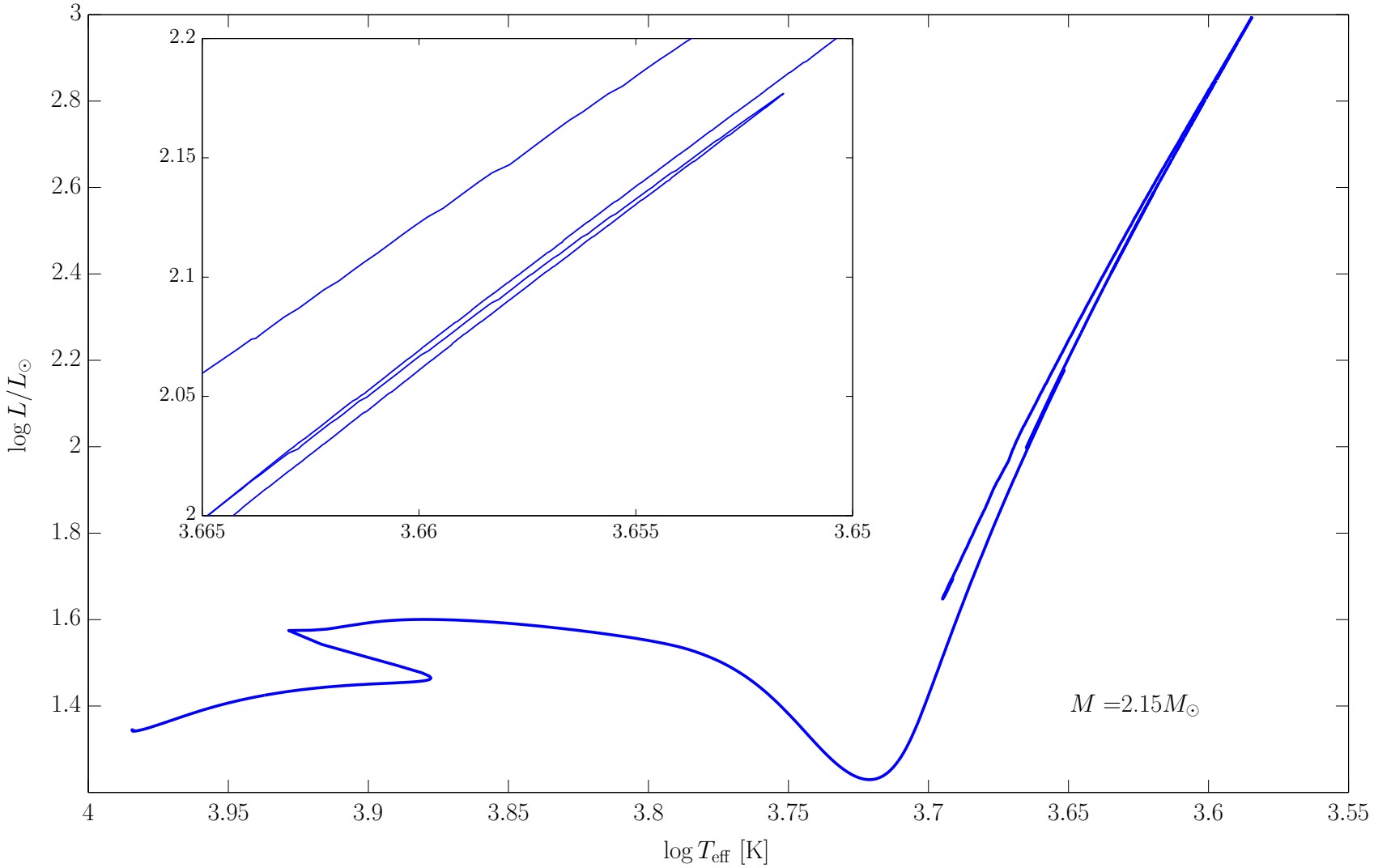
Connection to observables



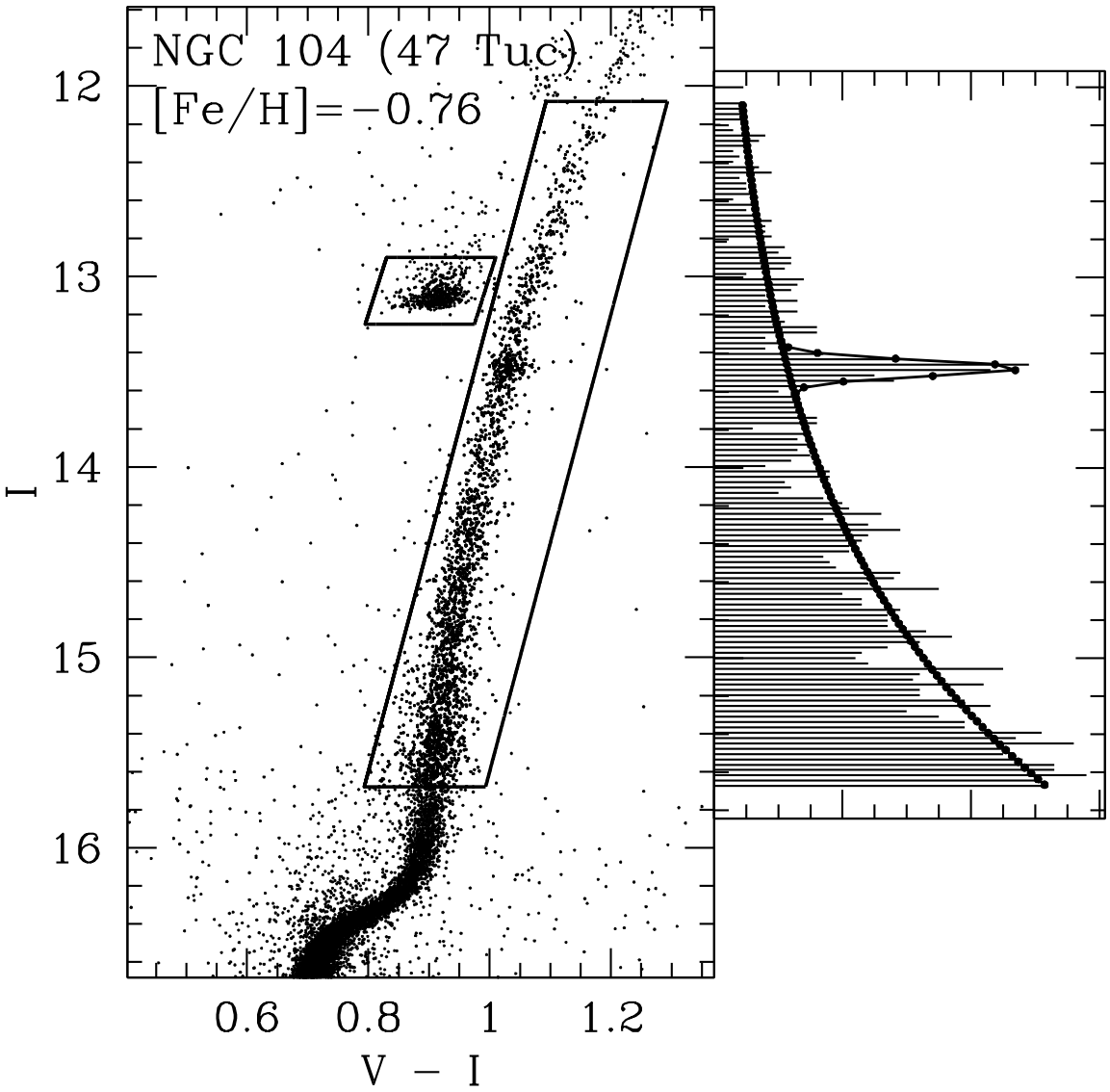
Populations: Open clusters $\longrightarrow$ ages



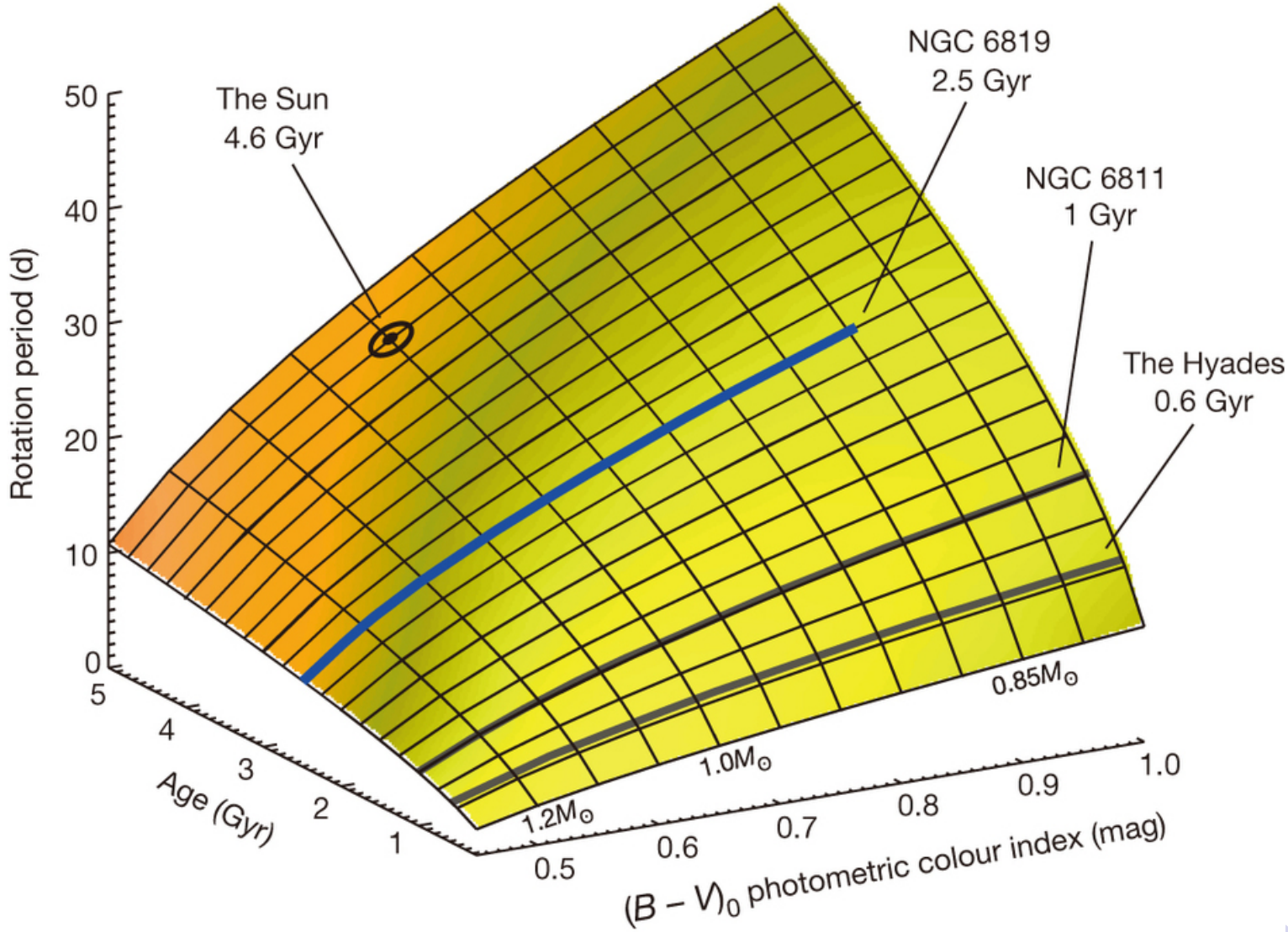
Populations: RGB luminosity bump modeled



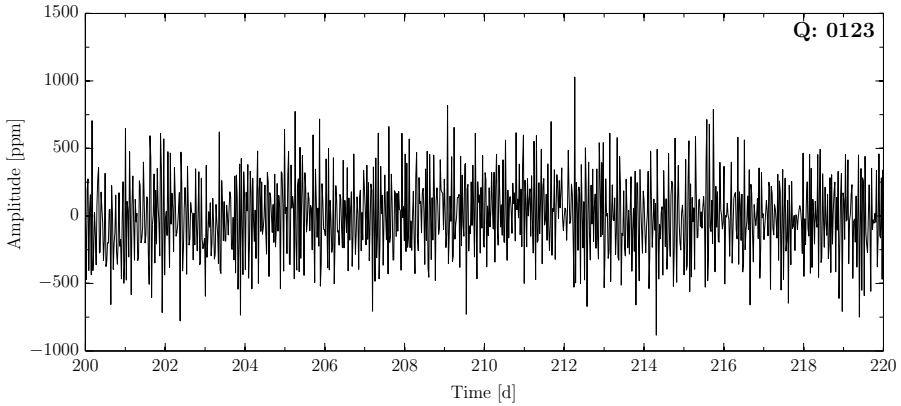
Populations: bump measured (GC He abundance, etc.)

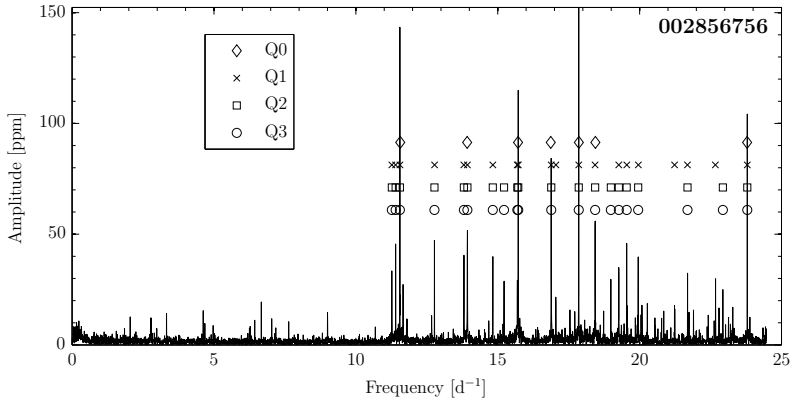


Rotation: ages (gyrochronology)



Asteroseismology: mass and radius



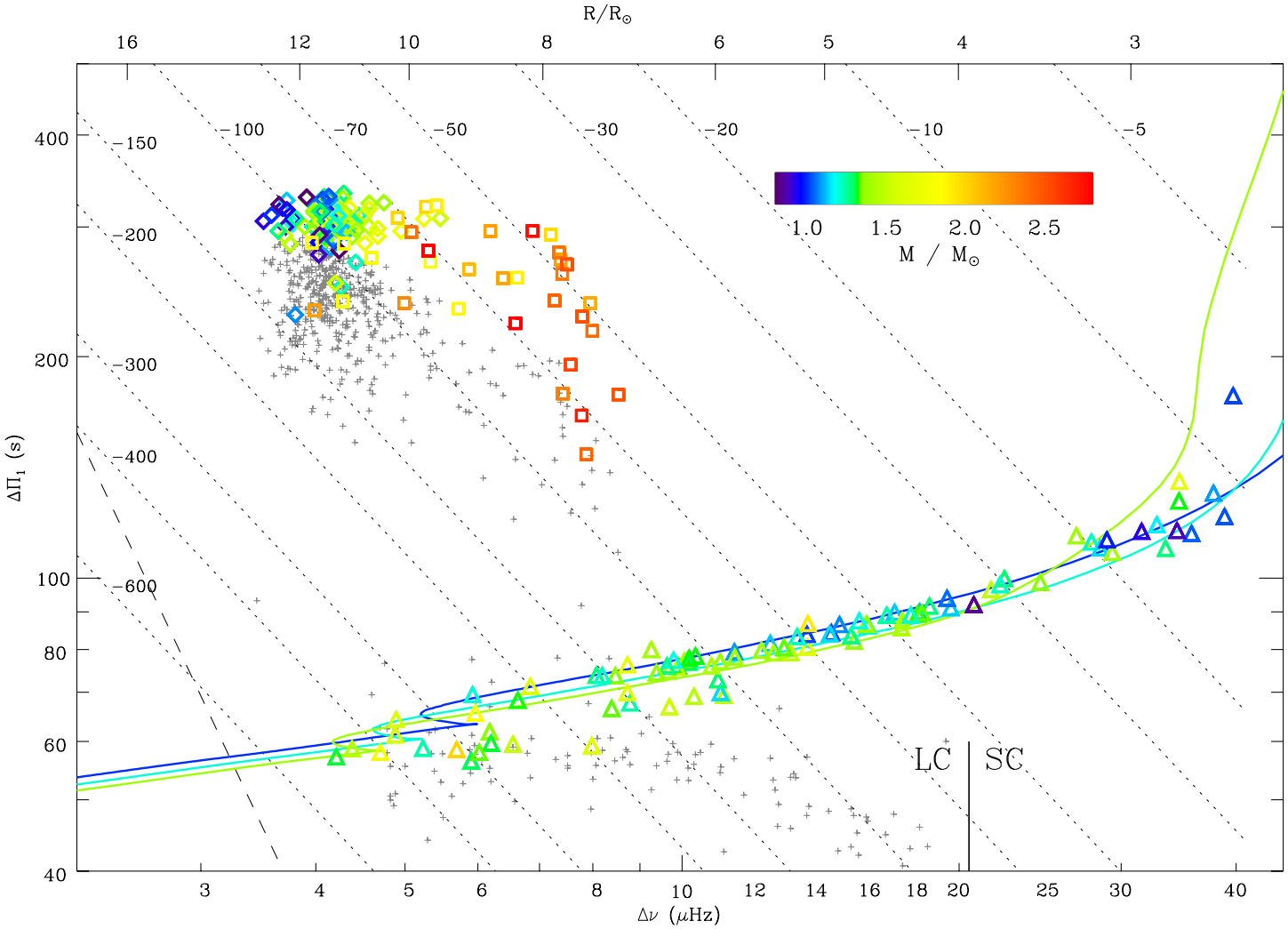


$$\frac{M}{M_\odot} = \left(\frac{\nu_{\rm max}}{\nu_{\rm max,\odot}}\right)^3 \left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{-4} \left(\frac{T_{\rm eff}}{T_{\rm eff,\odot}}\right)^{3/2}$$

$$\frac{R}{R_\odot} = \left(\frac{\nu_{\rm max}}{\nu_{\rm max,\odot}}\right) \left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{-2} \left(\frac{T_{\rm eff}}{T_{\rm eff,\odot}}\right)^{1/2}$$

- Consequence of our deep understanding of stellar structure

Asteroseismology: evolutionary state, age



Anomalies and other keys for astrophysics

- ZAHB/RGB luminosity at tip (cosmology)
- Cepheid pulsations (cosmology)
- Binaries (CMD, mass)
- Blue stragglers (cluster TO, mergers, mass transfer)
- Blue horizontal branch stars in GCs (mass loss, metallicity, binarity?)

Things we probably won't cover

- Star formation
- Rotation (angular momentum transport)
- Magnetic fields (dynamo)
- Mixing and diffusion
- Mass loss, stellar winds
- Binarity, mass transfer
- Pulsation driving
- Numerical techniques

Details

- Course homepage
- Syllabus
- Canvas app (or using browser)
- MESA

Assignment

- Read the syllabus carefully
- Read the MESA overview, and see if you can get the code to run
- If you can't get things going by tonight, send me an email!
- Complete first assignment for next week, Computer Problem 0