Stellar Populations - Lecture 1

RUSSELL SMITH

Rochester 333

russell.smith@durham.ac.uk

http://astro.dur.ac.uk/~rjsmith/stellarpops.html

Scope and Aims

What is "Stellar Populations" ?

* Properties of stellar systems (galaxies, star clusters) arising from <u>regularities</u> in their stellar content.

* The interface between "stellar astronomy" and "galaxy astronomy" / cosmology.

* A vital connection point between "theory" and "observation"

Aims of the course

* To give you a summary of Stellar Population models, in particular their ingredients, limitations and applications.

* Course is intended for students in neighbouring fields - who need some appreciation of how "stellar pops" relates to their area.

Course Outline

I.

*   **Resolved stellar populations**

    Ingredients of population models: tracks, isochrones and the initial mass function. Effects of age and metallicity. Star cluster colour-magnitude diagrams.

II.

*   **Colours of unresolved populations**

    Population synthesis. Simple stellar populations. The age/metallicity degeneracy. Beyond the optical. Surface brightness fluctuations.

III.

*   **Spectra of unresolved populations**

    Spectral Synthesis. Empirical and theoretical stellar libraries. Line indices. Element abundance ratios.

IV.

*   **Additional topics: chemical evolution and stellar masses**

    Abundance ratios, nucleosynthesis and chemical evolution. Stellar mass estimation: methods, uncertainties and limitations.

Stellar evolution reminder
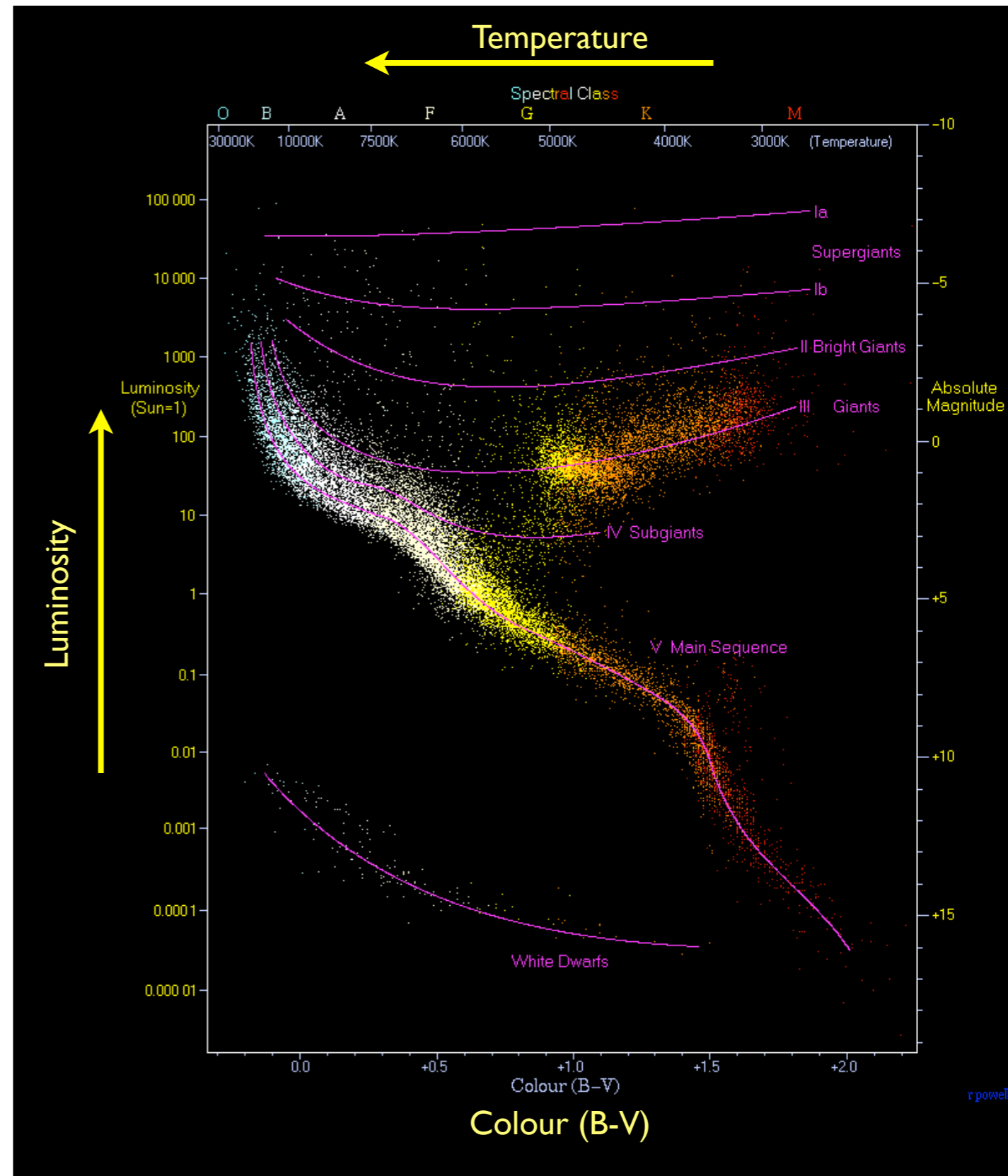
HERTZSPRUNG-RUSSELL DIAGRAM

Plots luminosity of stars, versus their temperature.

Stars populate distinct regions of this plane, corresponding to particular evolutionary phases.

Terminology:

HRD is "theory" plane: temperature vs bolometric luminosity.

CMD (colour-magnitude diagram) is its empirical analogue.

Stellar evolution reminder

MAIN SEQUENCE (MS)

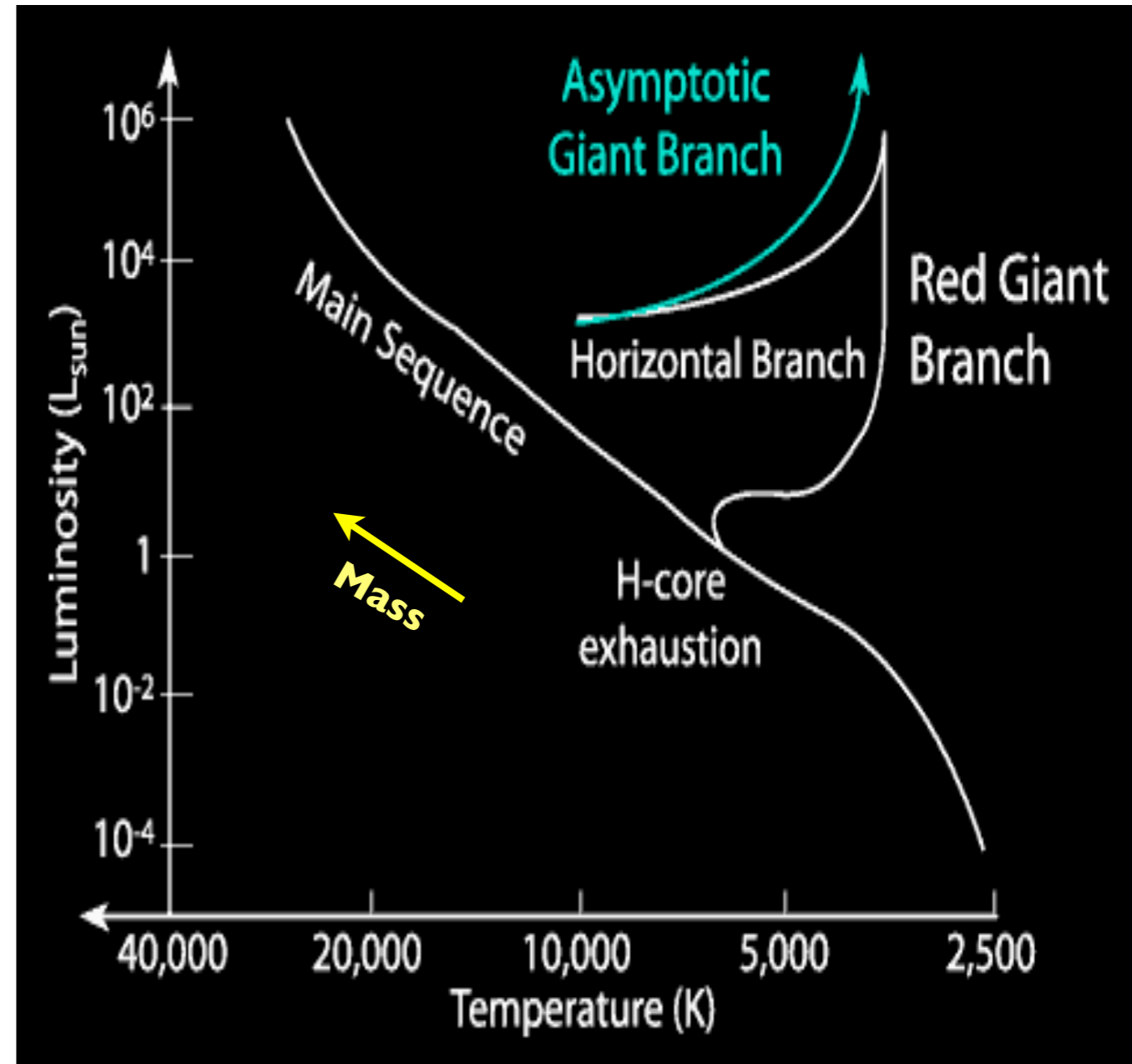Core hydrogen burning phase. Longest phase of evolution.

TURN-OFF

Hydrogen exhausted in core, start of "interesting" evolution.

RED-GIANT BRANCH (RGB)

Hydrogen burning in shell around inert helium core. Growth of He core.

RGB TIP

End of RGB phase: core massive and hot enough to ignite He-burning (the "helium flash")

Stellar evolution reminder

HORIZONTAL BRANCH (HB)

Core He burning. Details depend on metallicity and on mass-loss in the RGB phase.

ASYMPTOTIC GIANT BRANCH (AGB)

He burning in shell around inert C/O core. Complicated mass-dependent evolution from here on.

WHITE DWARF SEQUENCE (WD)

Low-mass stars eject envelope and leave inert C/O core which cools as a WD.

SUPERNOVAE

Massive stars explode as SNe.
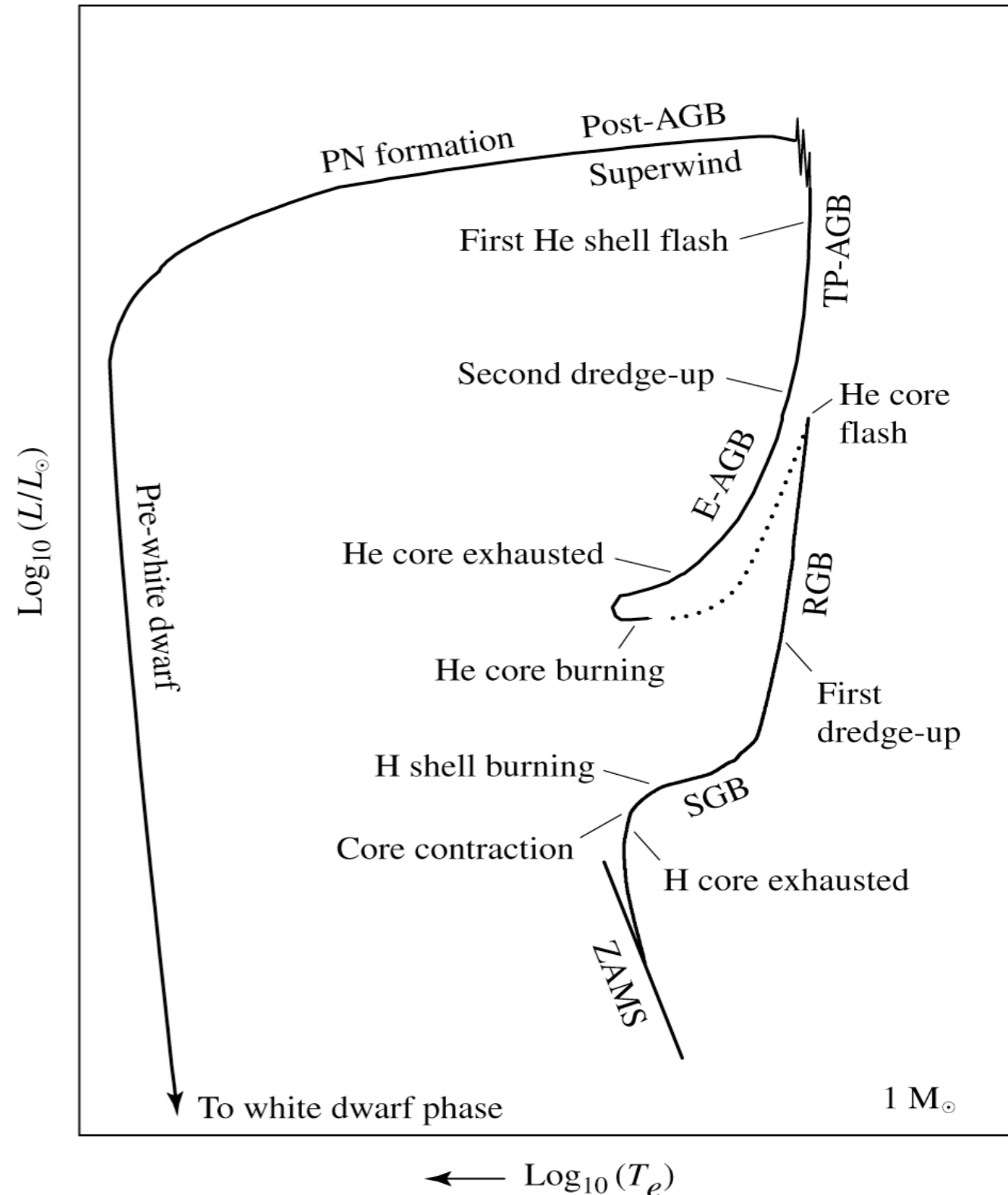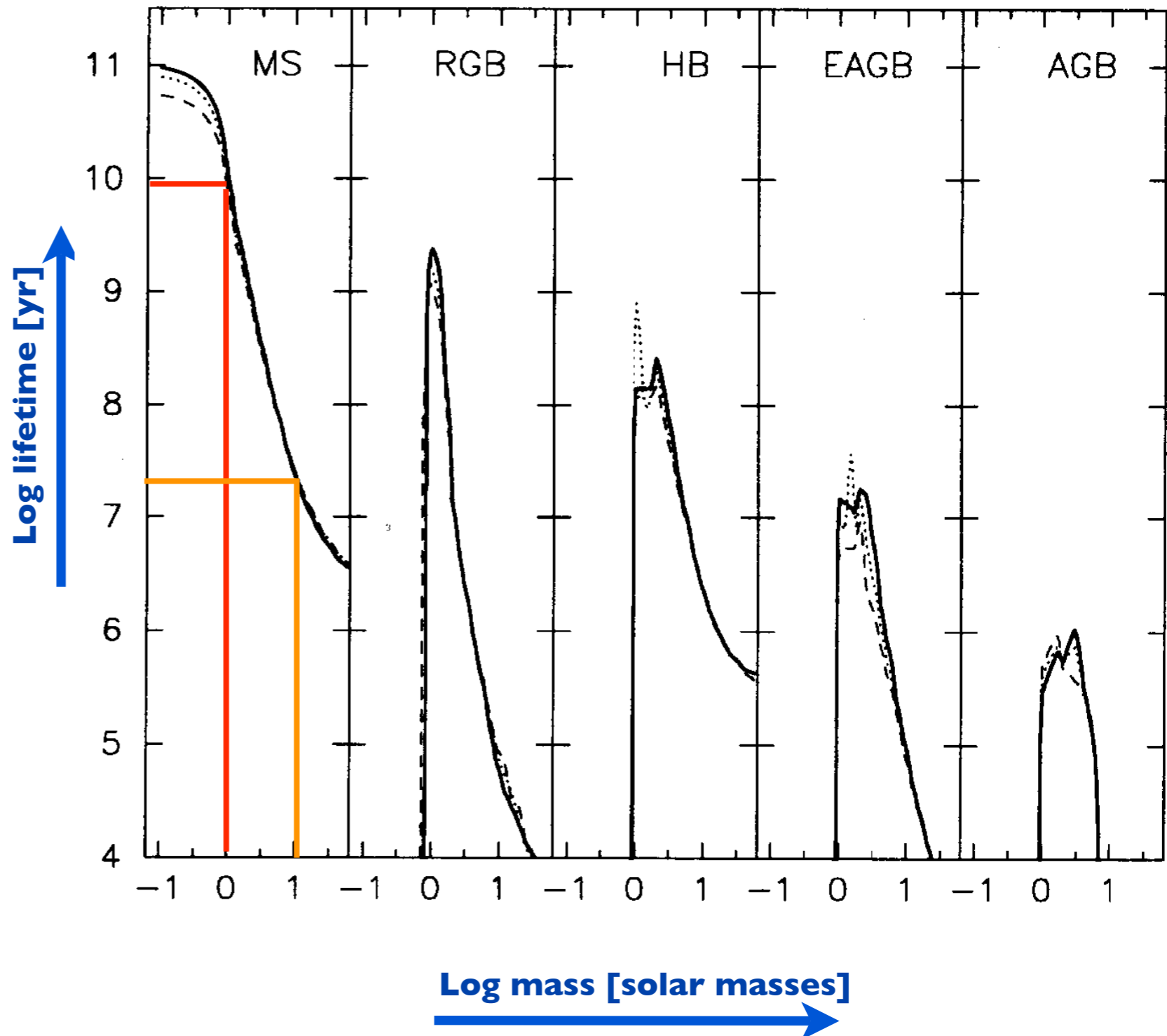
Stellar Evolution Reminder

MASS-DEPENDENT LIFETIMES

Lifetime in each evolutionary phase depends sensitively on initial mass.

MS lifetime is $\sim 10^{10} (M/M_{sun})^{-2.5}$ yrs: so 10 Gyr at 1 solar mass, but only ~ 20 Myr for 10 Msun.

Subsequent phases shorter-lived.

Below ~ 0.9 Msun, the MS lifetime is longer than age of Universe!

Mass-vs-lifetime relation is one of the crucial tools for age-dating populations.

Log lifetime [yr]

Log mass [solar masses]

TRACKS

"Tracks" are trajectories of individual stars in the HRD.

Stellar evolutionary tracks are tables describing the evolving properties:

luminosity,

temperature,

evolving mass, etc

as a function of initial mass (and initial chemical composition).

In detail, the tracks are computed from stellar evolution models (Padova, Geneva, BaSTI etc).
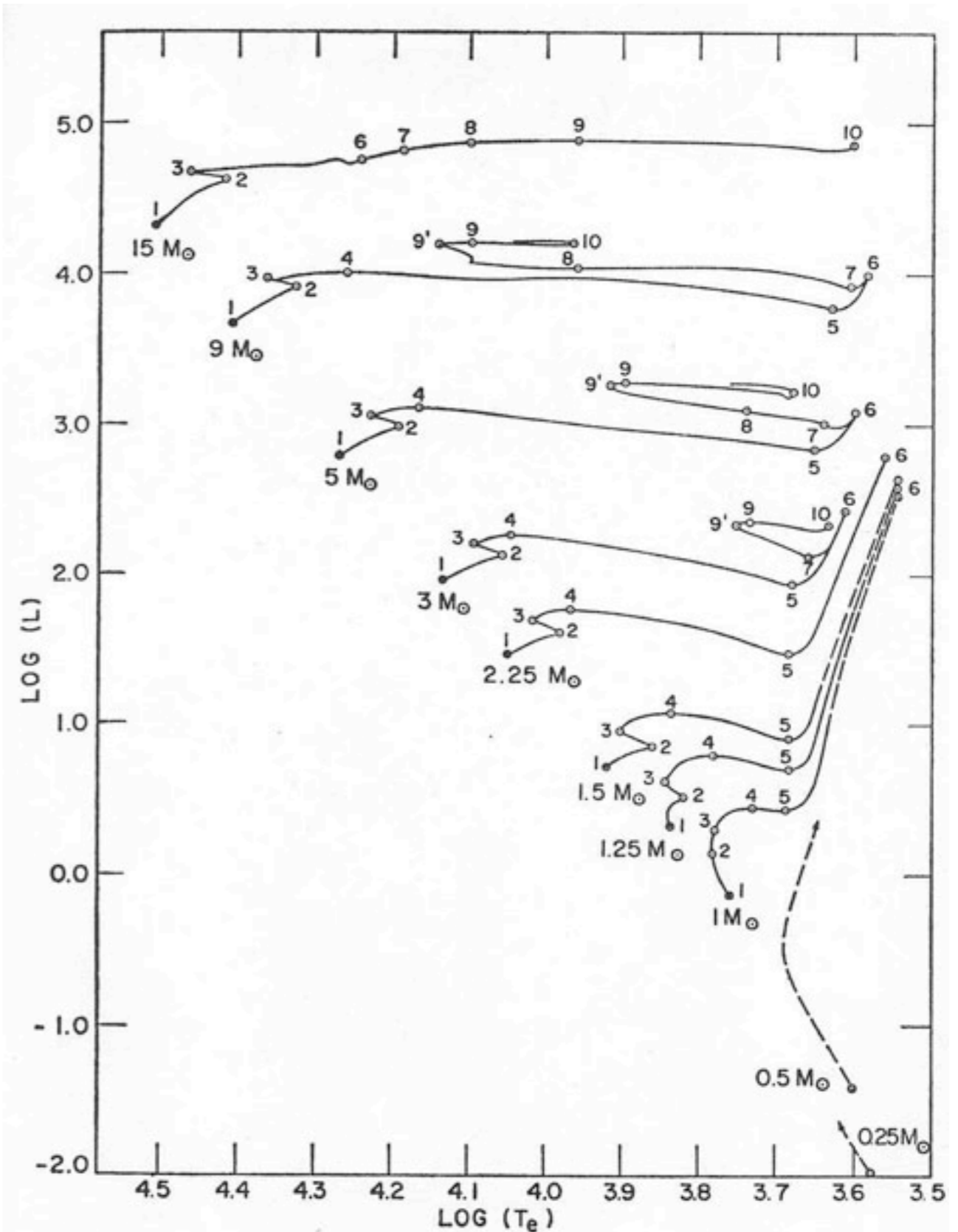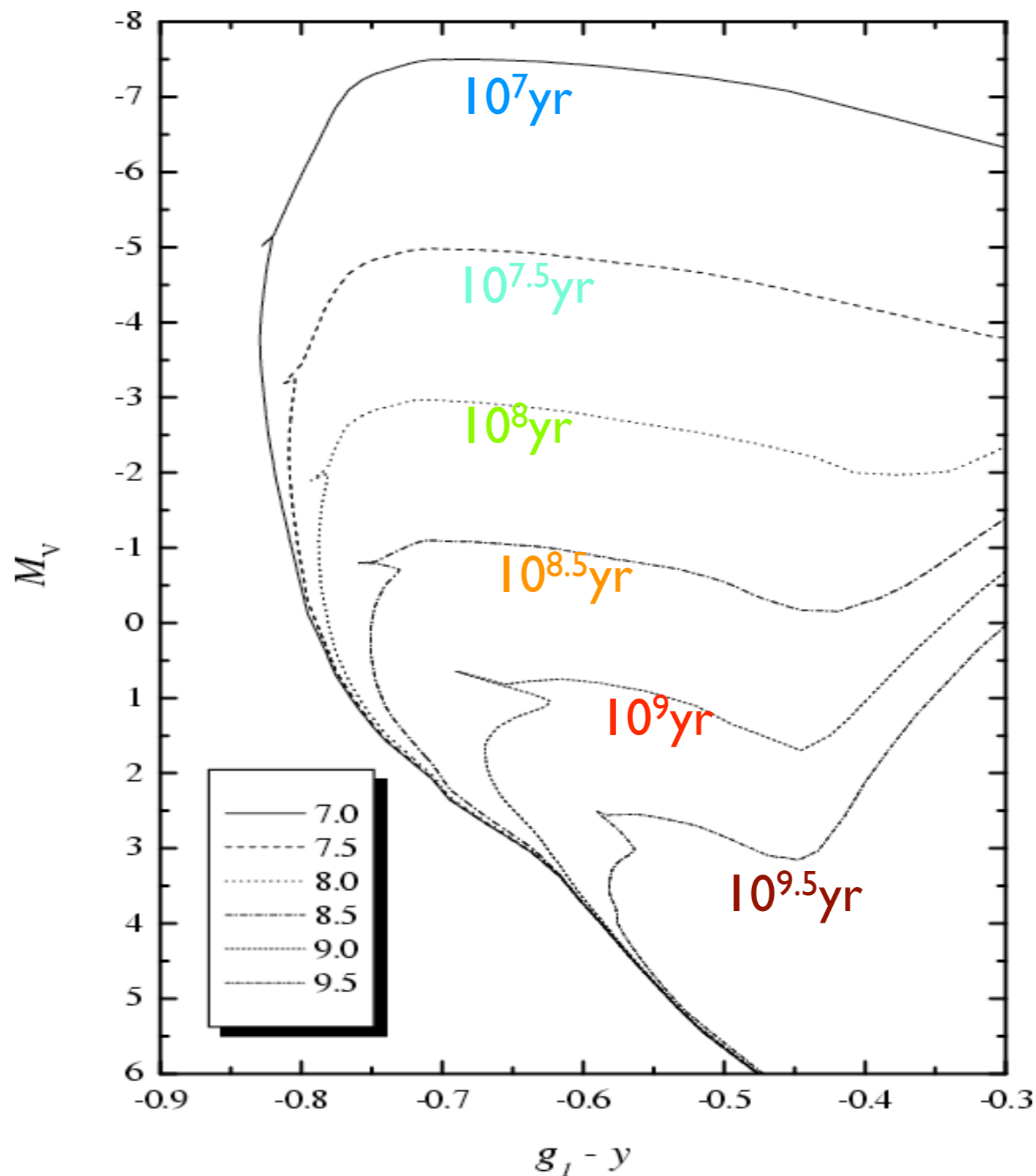
ISOCHRONES

"Isochrones" are loci on the HRD populated by stars of a given time since formation, for a range of different masses.

Formed by picking a common "time" point from the track for each stellar mass.

Snapshot of a "simple" stellar population.
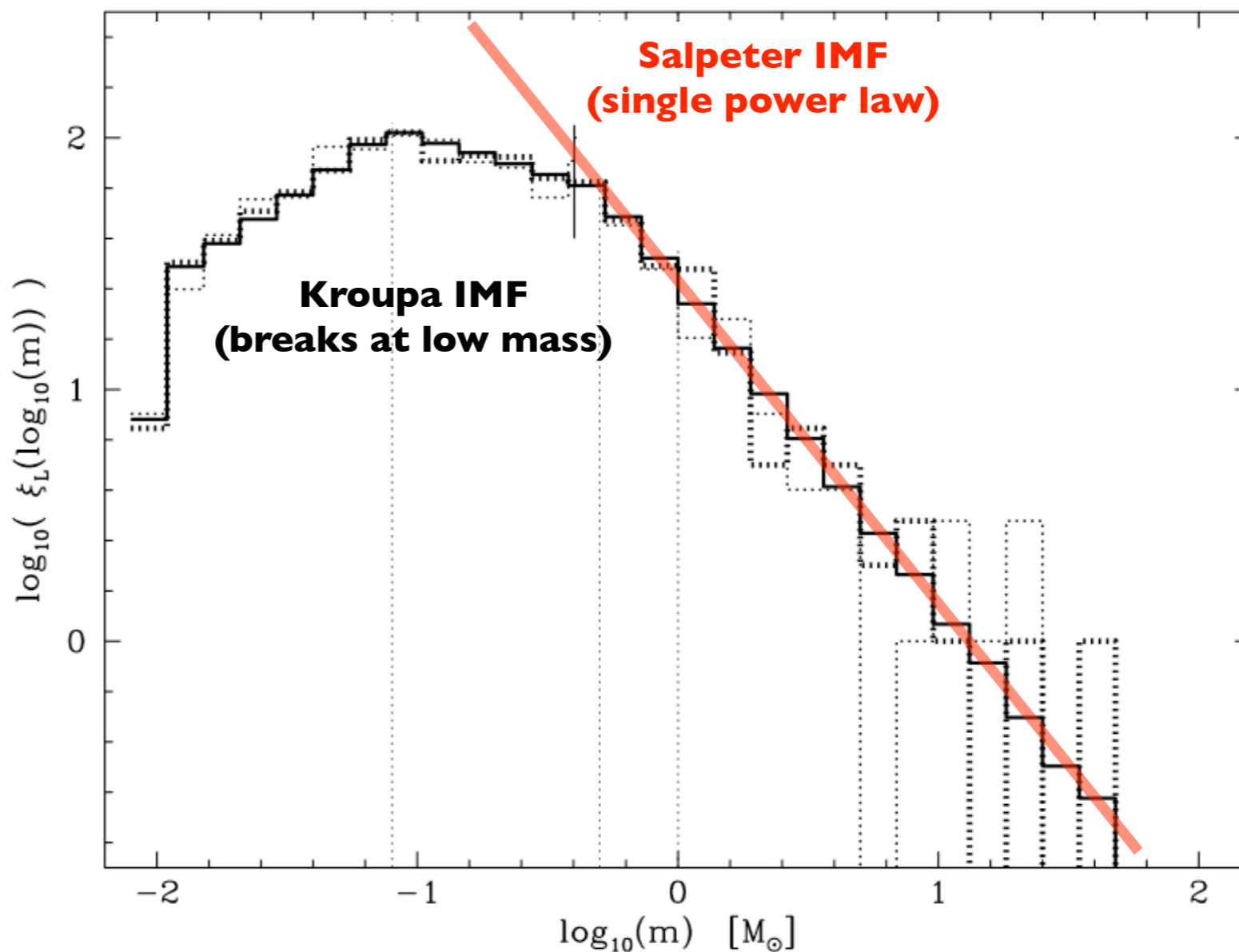
Tracks & Isochrones

INITIAL MASS FUNCTION

How many stars formed per unit mass?

Determines number of stars expected at each point along isochrone.

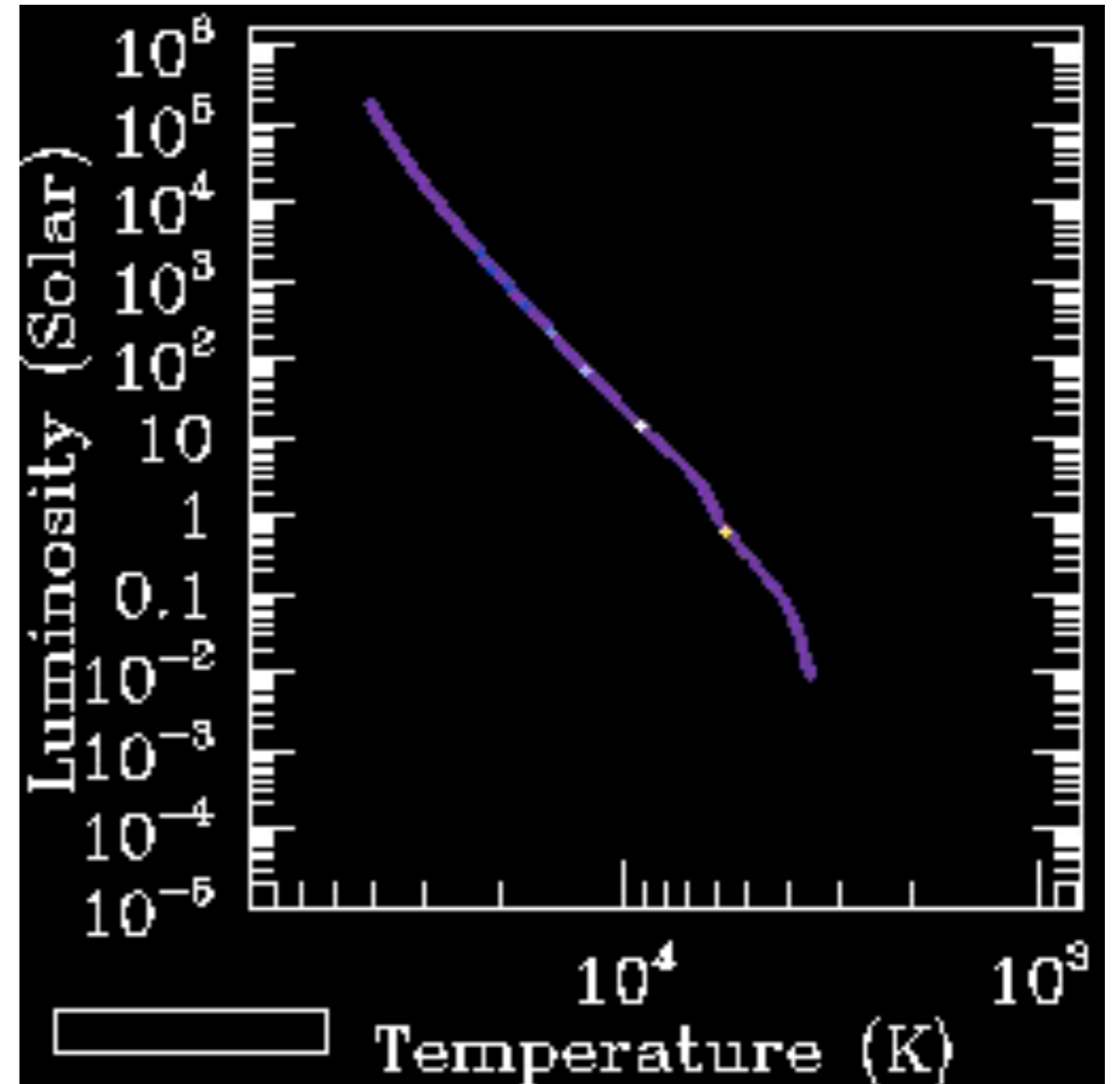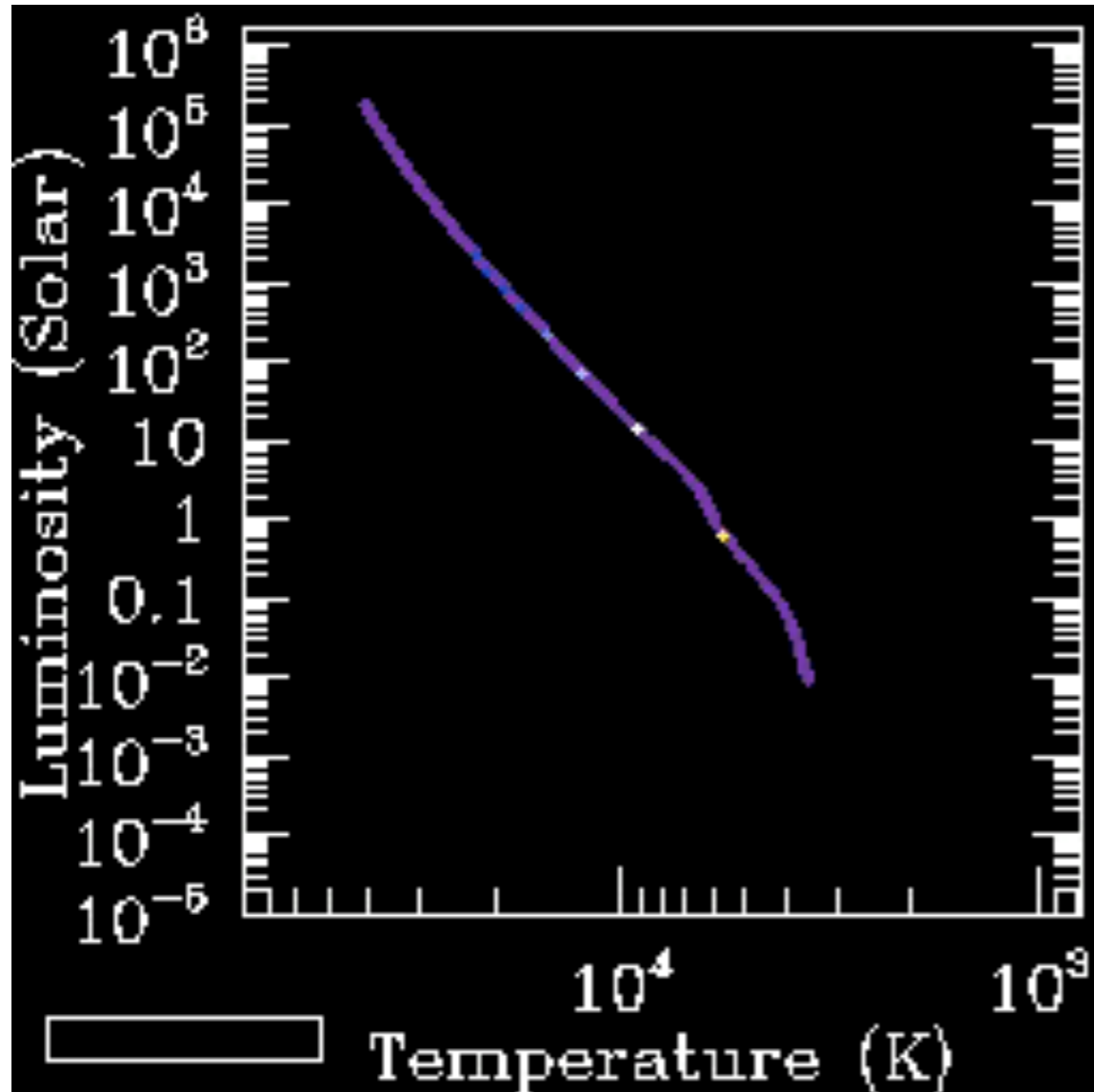Constrained from detailed observations of star-forming regions in the MW.

Applied to wide range of environments beyond MW!

Salpeter IMF
(single power law)

Kroupa IMF
(breaks at low mass)

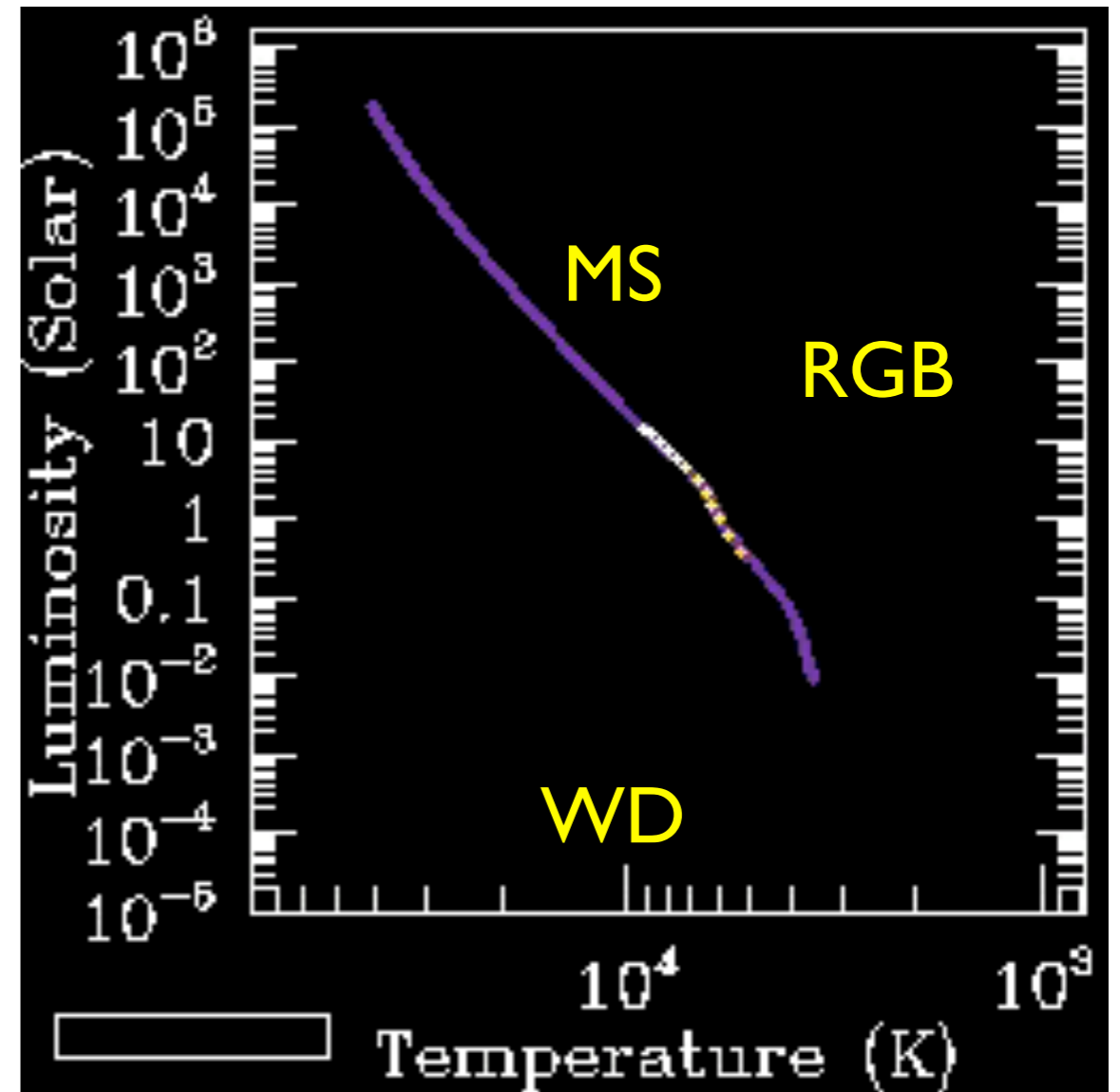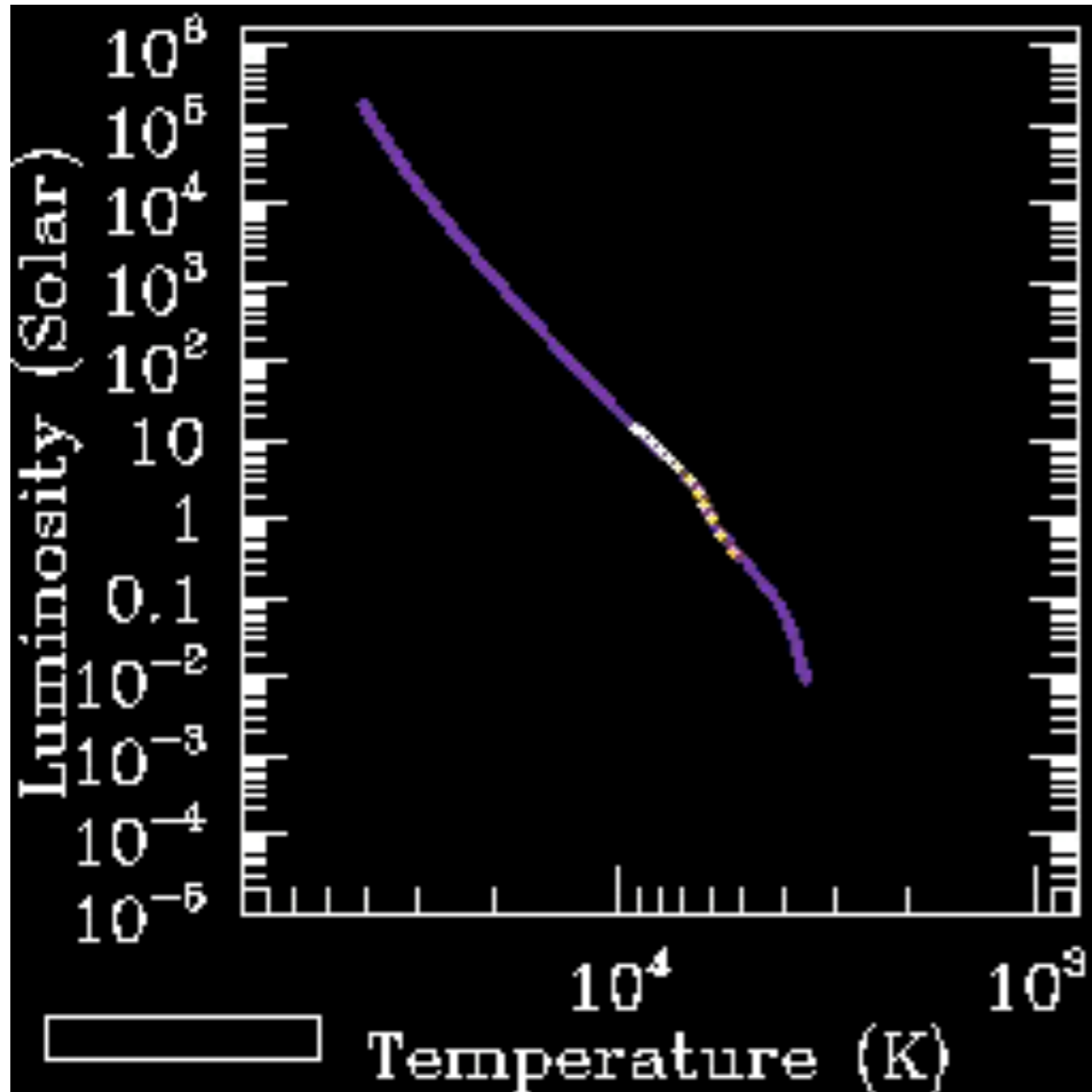Kroupa (2002)

Stellar evolution movies

Evolutionary tracks for 1-8 Msun
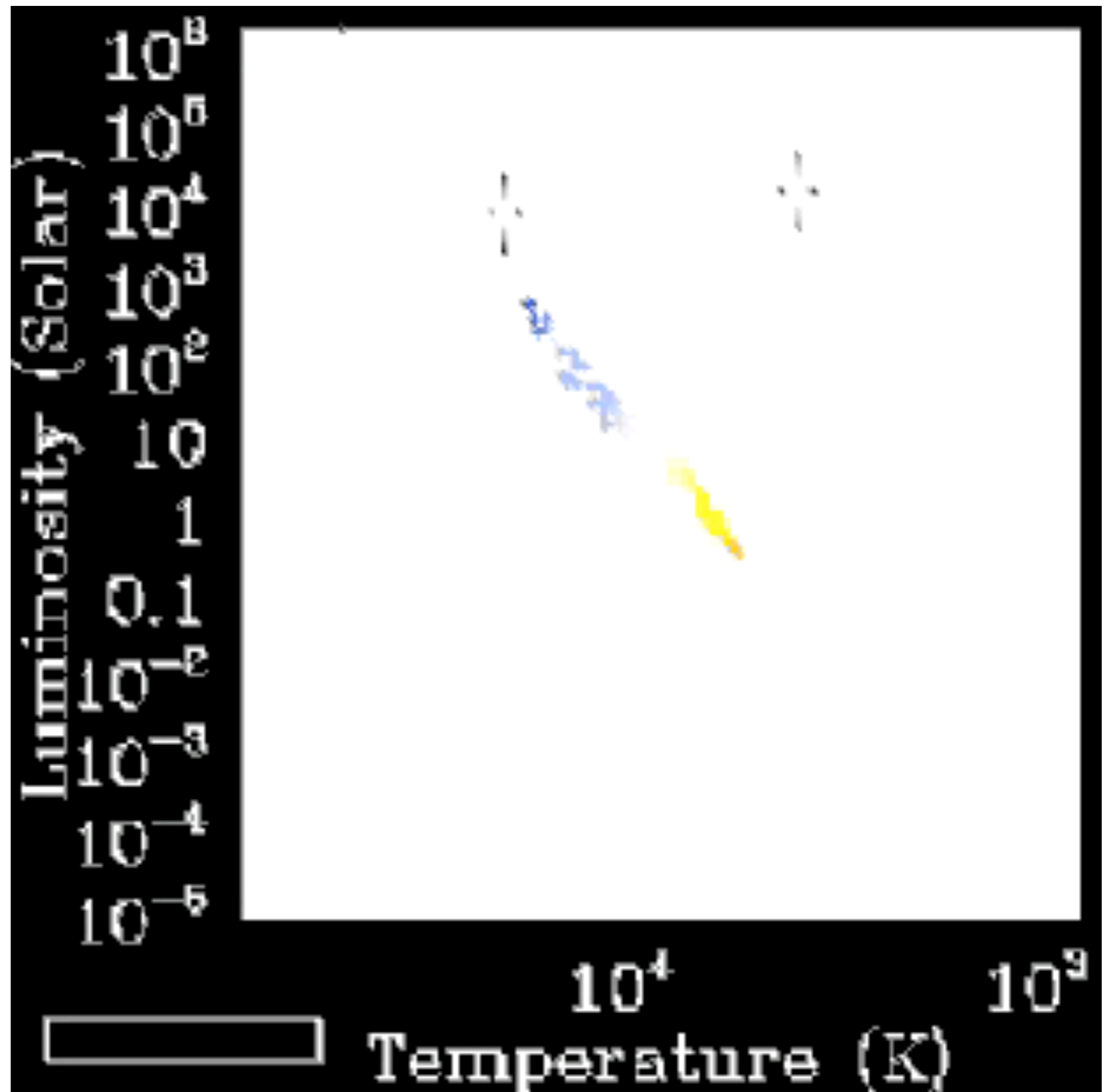
Stellar evolution movies

Lower masses: 0.9-2.0 Msun

Stellar evolution movies

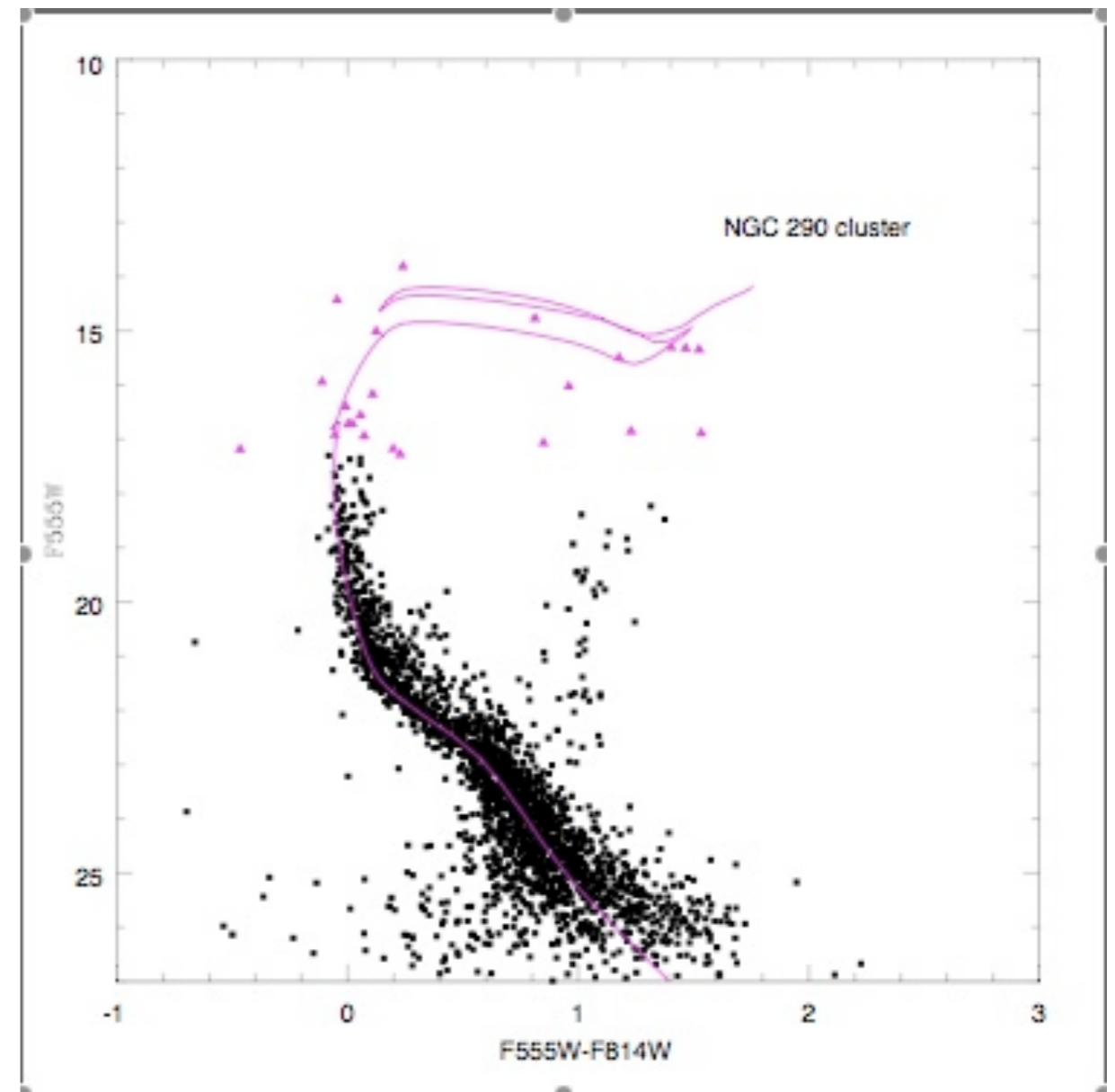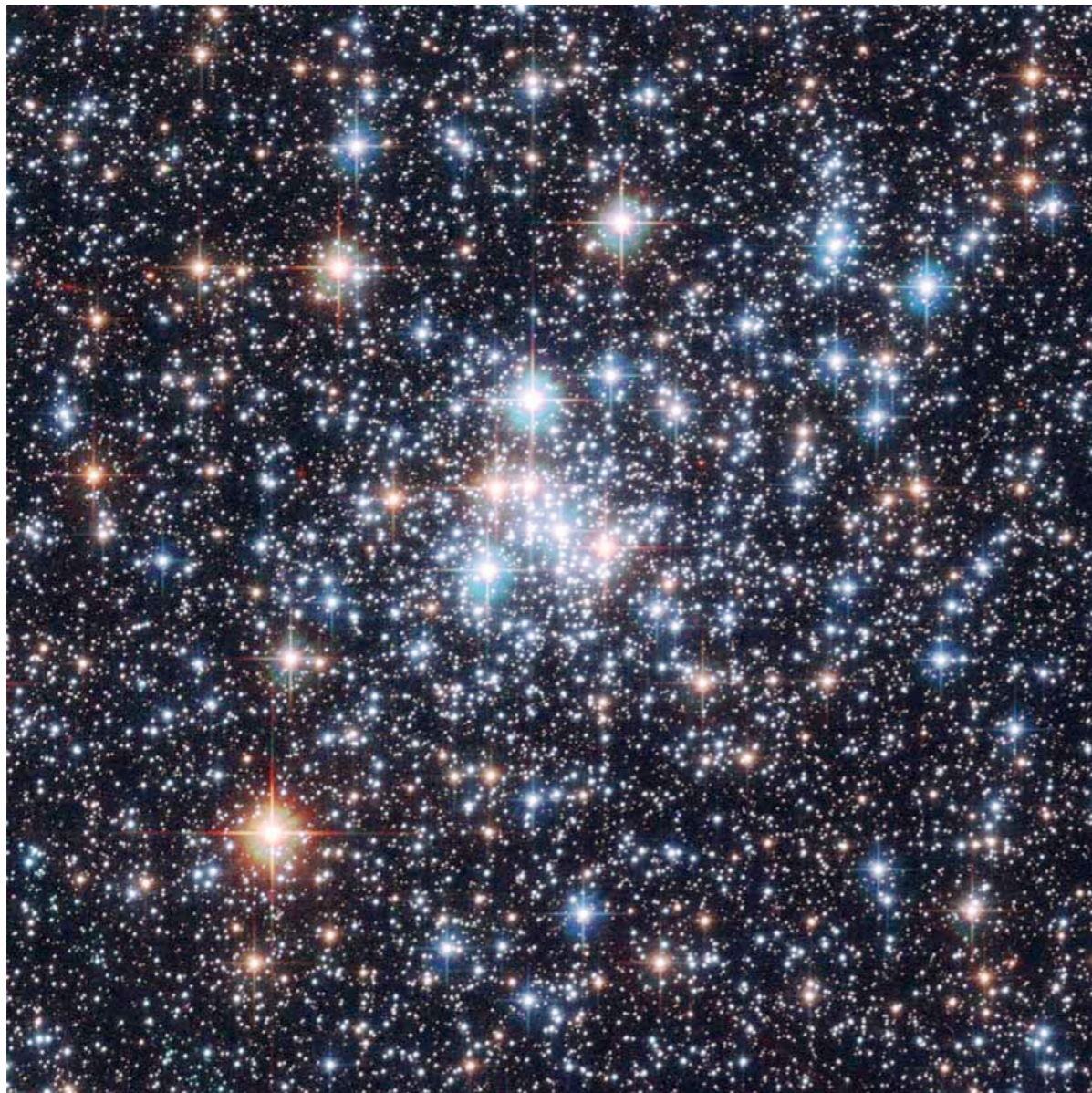1000 stars forming in a single burst. Note the SNe and PNe!

Lowest masses (<0.9 Msun) not shown: they don't evolve off the within a Hubble Time.

Observed star cluster CMDs

OPEN CLUSTERS

MS dominant, few RGB or other evolved stars. Only few 100s or 1000s of stars.

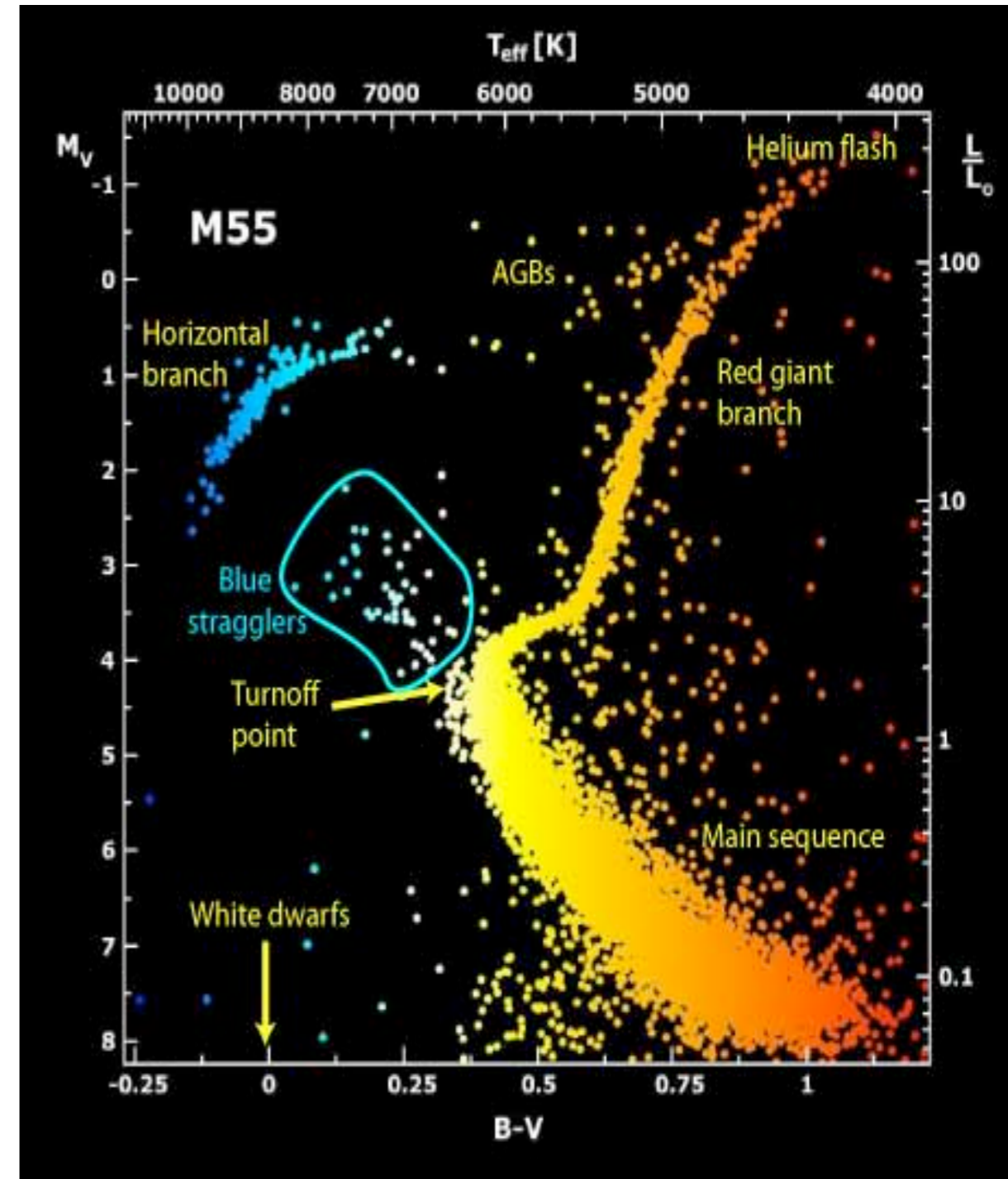**NGC 290 in the Small Magellanic Cloud (Chiosi & Vallenari 2007)**

Observed star cluster CMDs

GLOBULAR CLUSTERS

De-populated upper MS. Strong RGB and HB.

1,000s to 100,000s of stars.

Simple Stellar Population (SSP)

THE SIMPLEST STELLAR POPULATION MODEL

A burst of star-formation at a given time: all stars have the same age.

All stars form with the same initial chemical composition: a single "metallicity".

The distribution of initial masses is given by some functional form, e.g. power law $N(M)\,dM \propto M^{-x}\,dM$. Commonly assume x=2.35, the "Salpeter IMF", over M=0.1-100 M_{sun}.

Modern studies in the MW show fewer low mass stars than in Salpeter, e.g. Kroupa IMF (but these make little contribution to the total light).

USEFUL BECAUSE...

For stellar systems without much recent SF (GCs, elliptical galaxies) the SSP is probably a good approximation.

More complex systems can be modelled using combinations of SSPs.

Theoretical isochrones vs data

ISOCHRONE FITTING

The classic tool for "resolved stellar populations".

First need to predict observable quantities, i.e. colours

COLOUR TRANSFORMATIONS

Need to translate physical parameters (Teff, logg) to observed colours (e.g. B-V, J-K), based on theoretical stellar atmospheres (or empirical libraries).
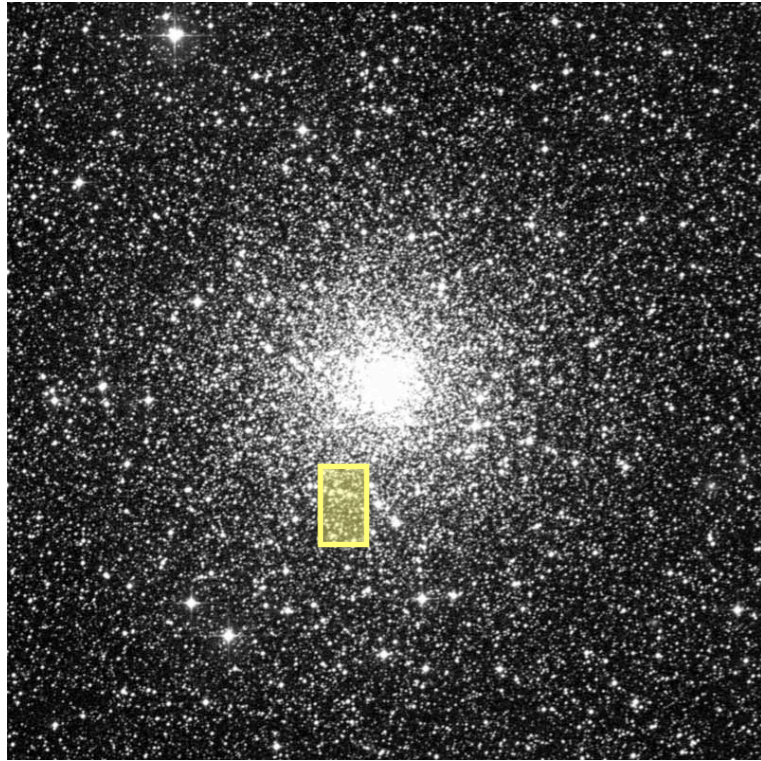
Sometimes called "bolometric corrections".

M92 (Dotter et al. 2009)

Empirical
DM=14.65
E(B-V)=0.04
[Fe/H]=-2.3
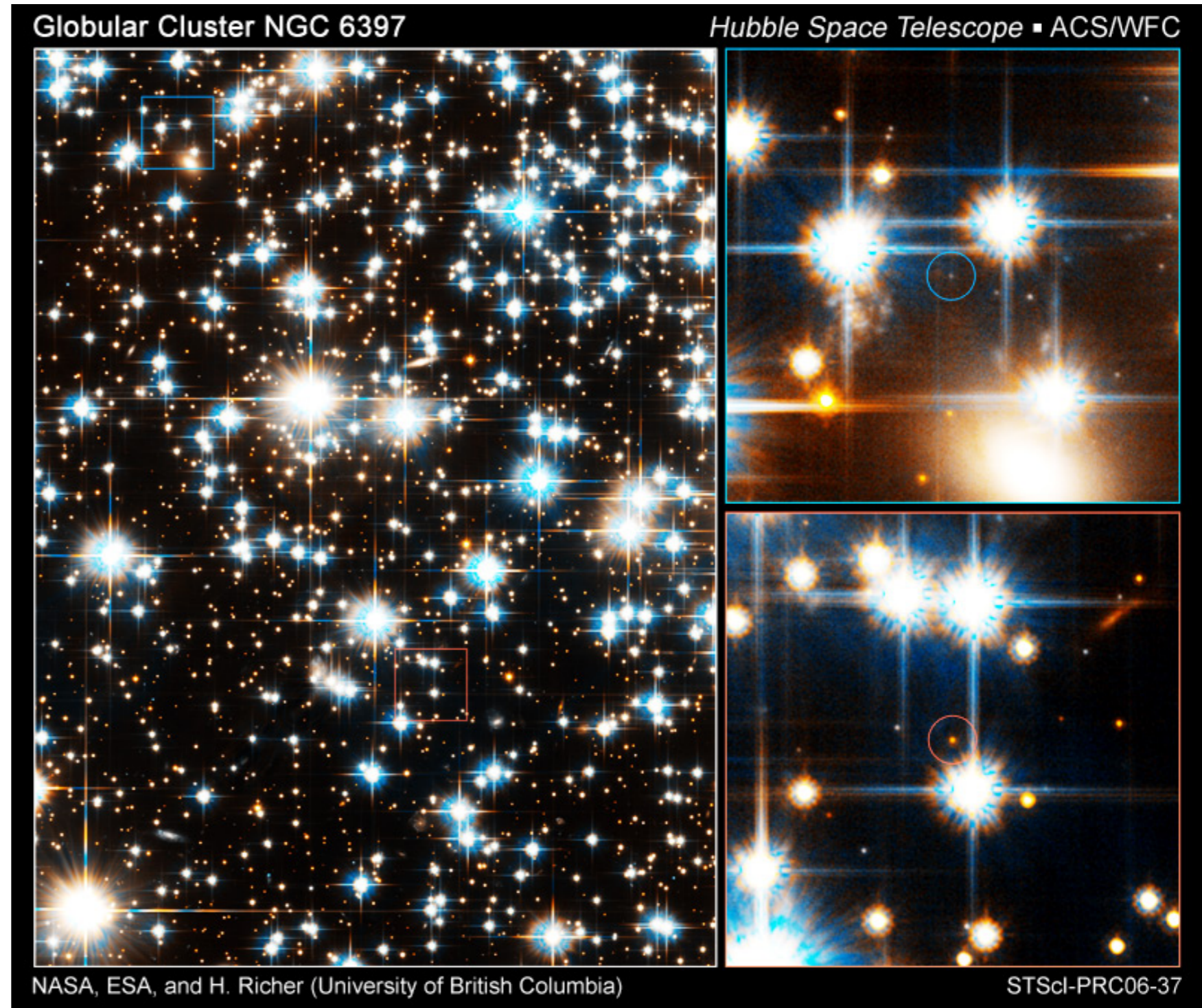[α/Fe]=0.4
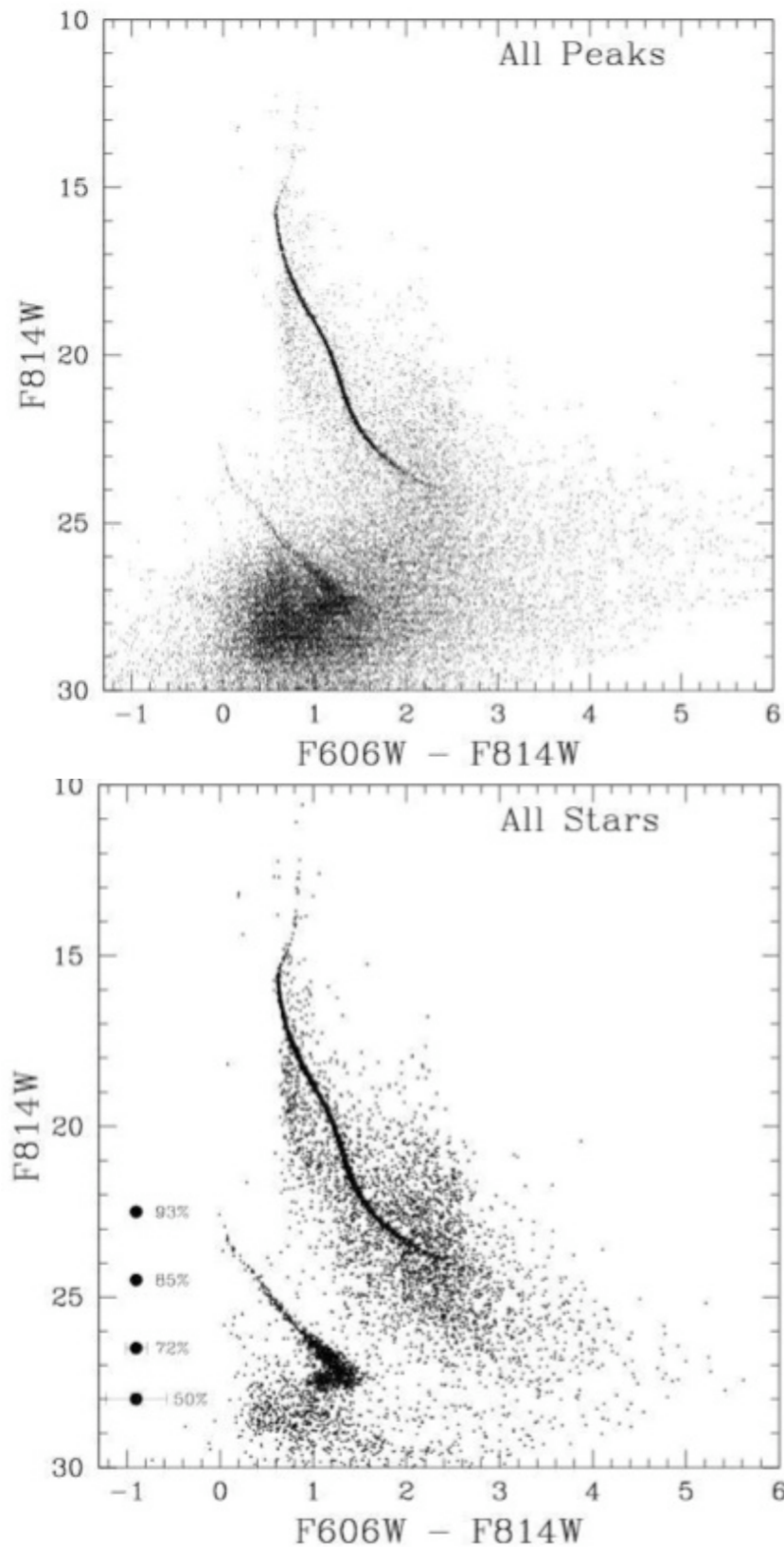13.5 Gyr
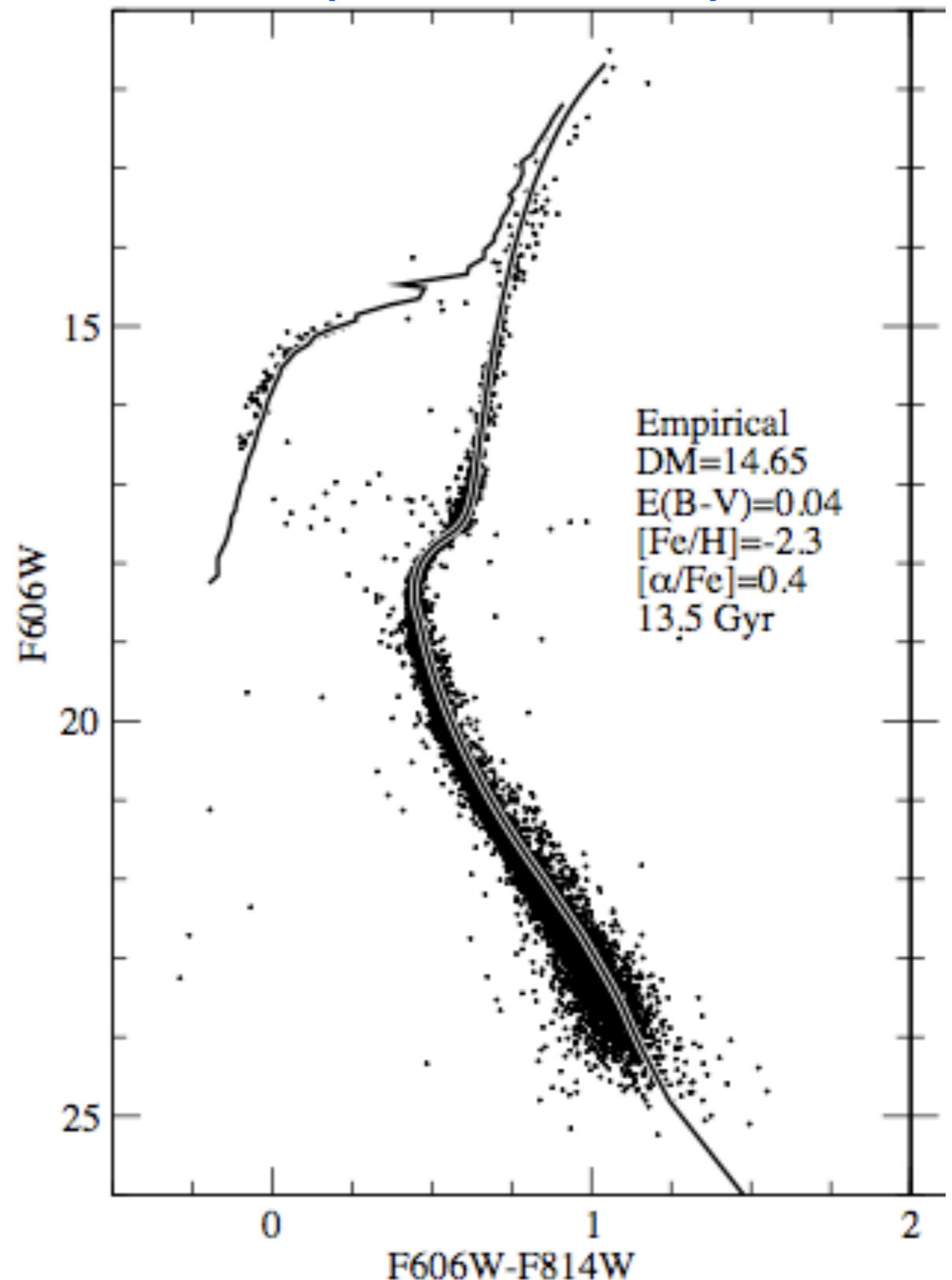
Observational example

NGC 6397

Richer et al. (2007)

126 orbits of HST/ACS imaging on outskirts of a globular cluster.

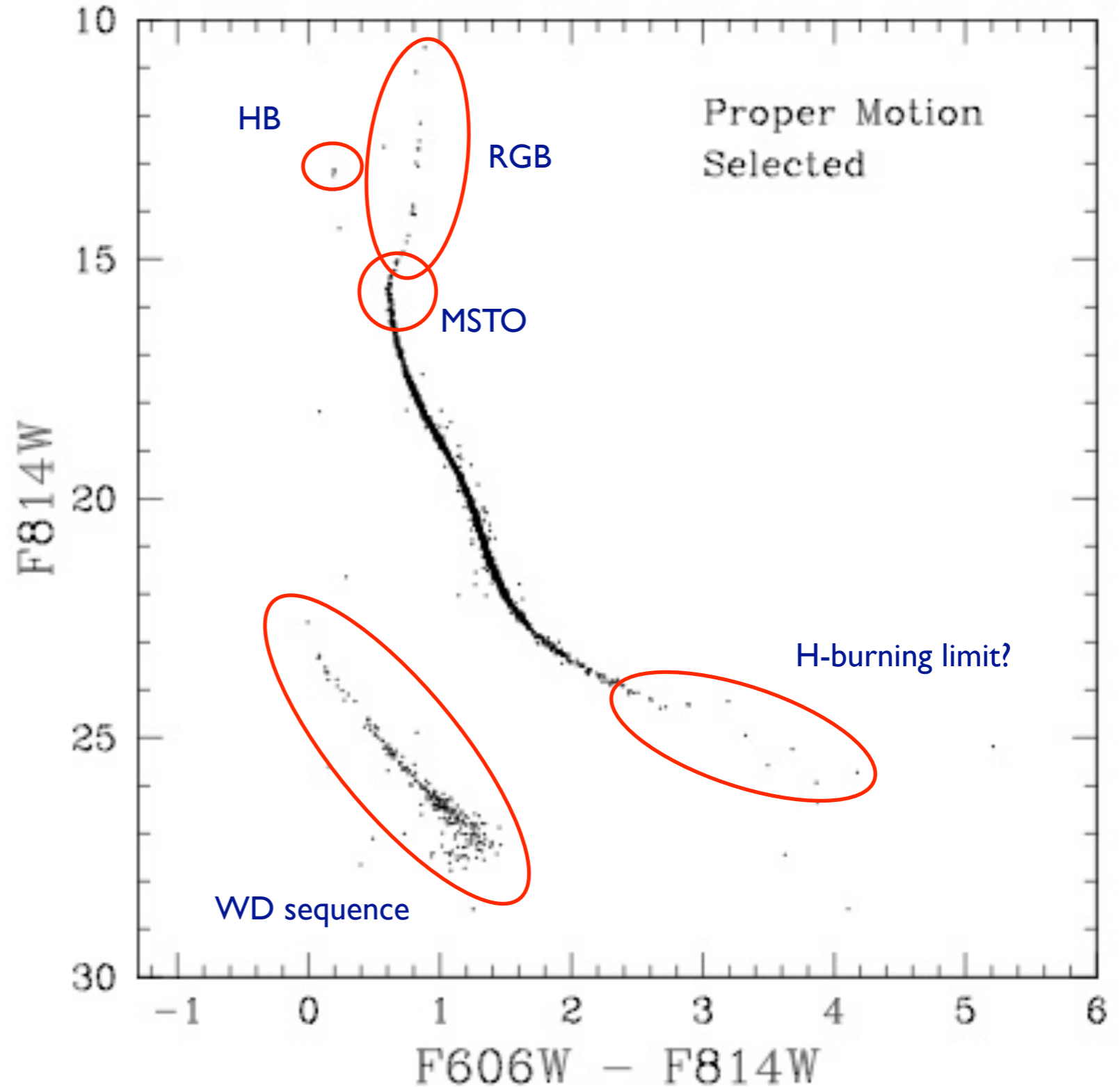Also proper motions to reject any non-cluster-members.

Globular Cluster NGC 6397 — Hubble Space Telescope • ACS/WFC

NASA, ESA, and H. Richer (University of British Columbia)

STScI-PRC06-37

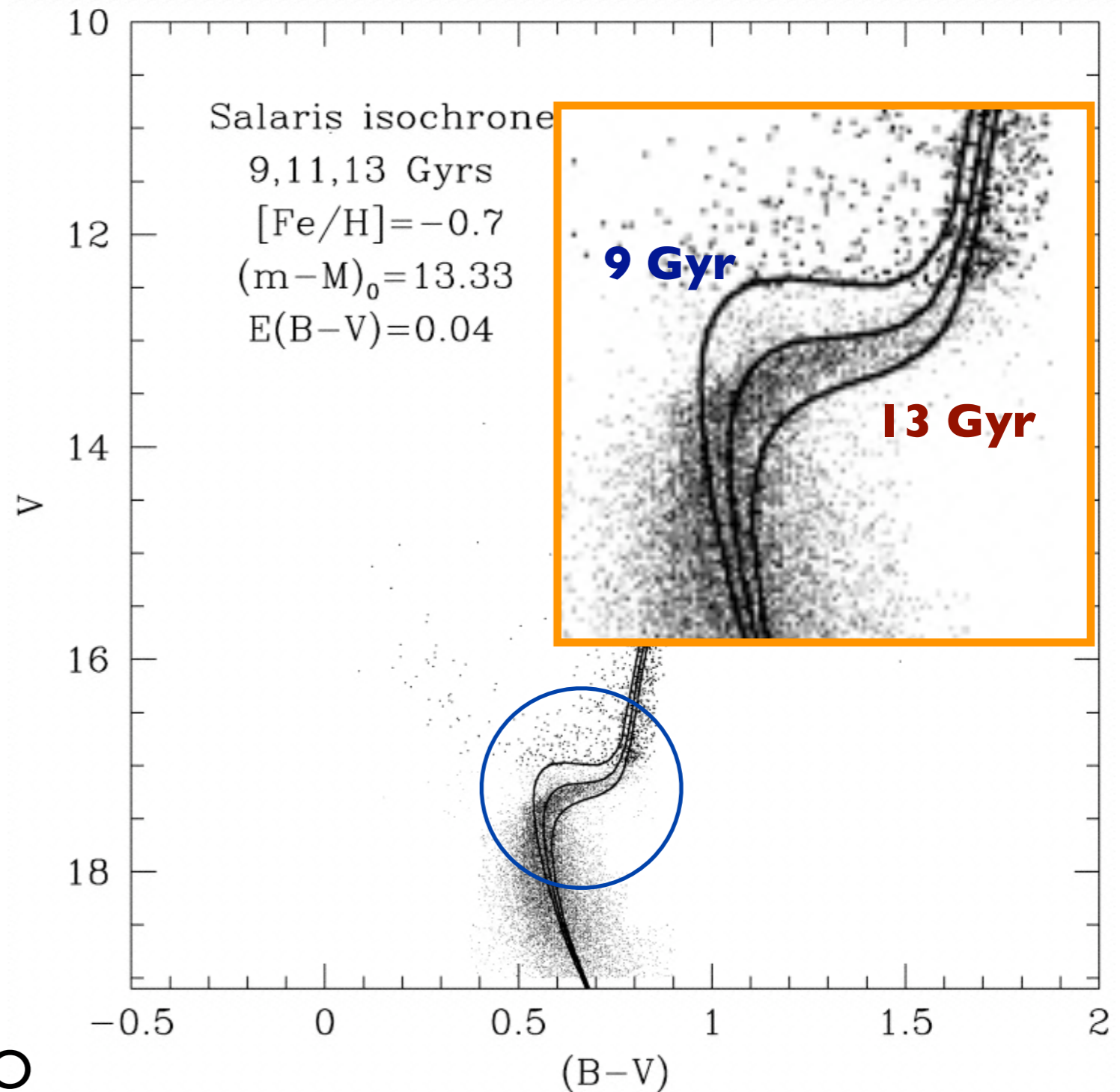# Observational example

NGC 6397 (Richer et al. 2007)

Theoretical isochrones vs data

Stellar evolution as a clock

MS lifetime versus mass relation: luminosity (and colour) of stars at TO depends on time since formation.

Schiavon et al. (2002) fit to globular cluster 47 Tuc

Salaris isochrone
9,11,13 Gyrs
$[Fe/H] = -0.7$
$(m-M)_0 = 13.33$
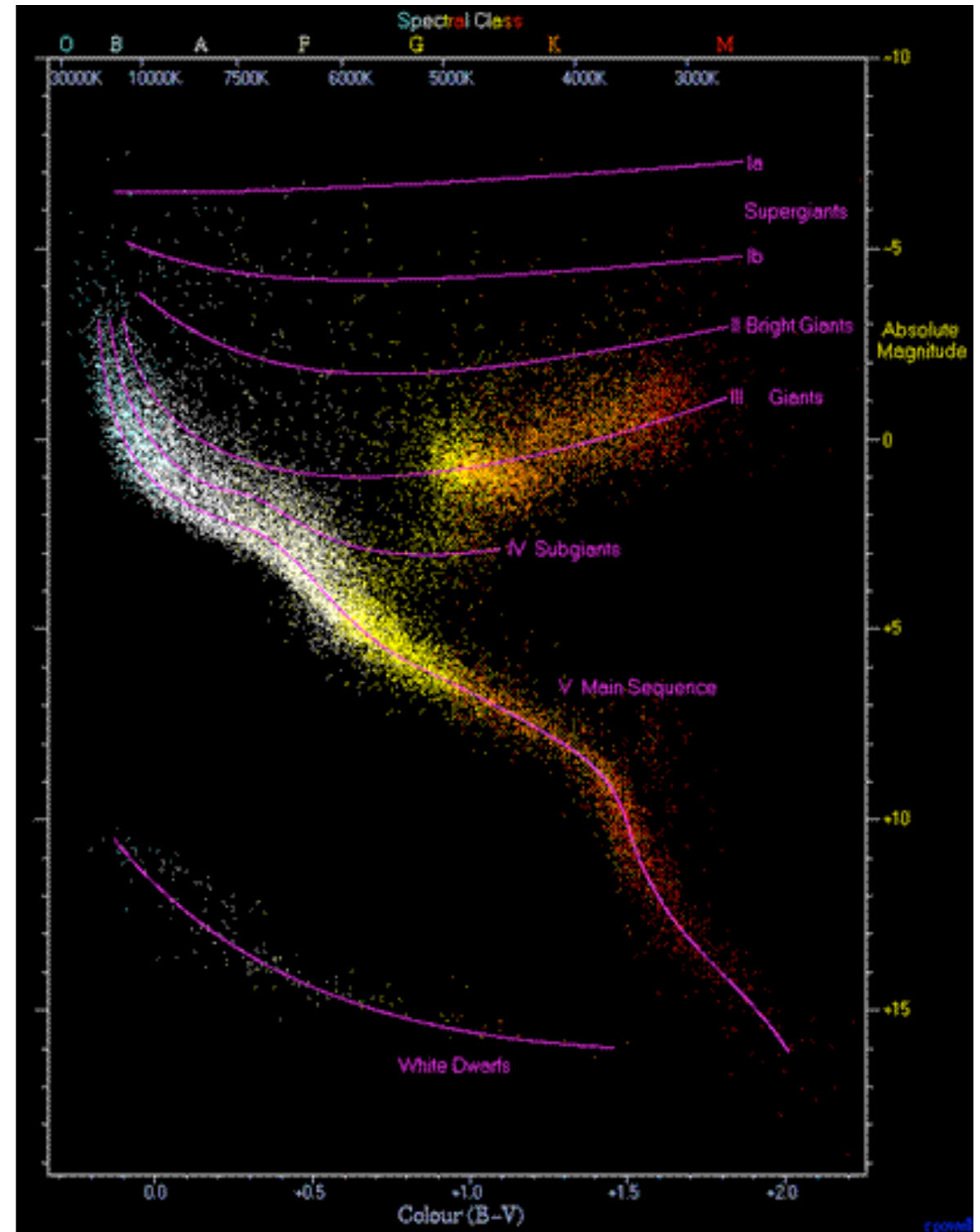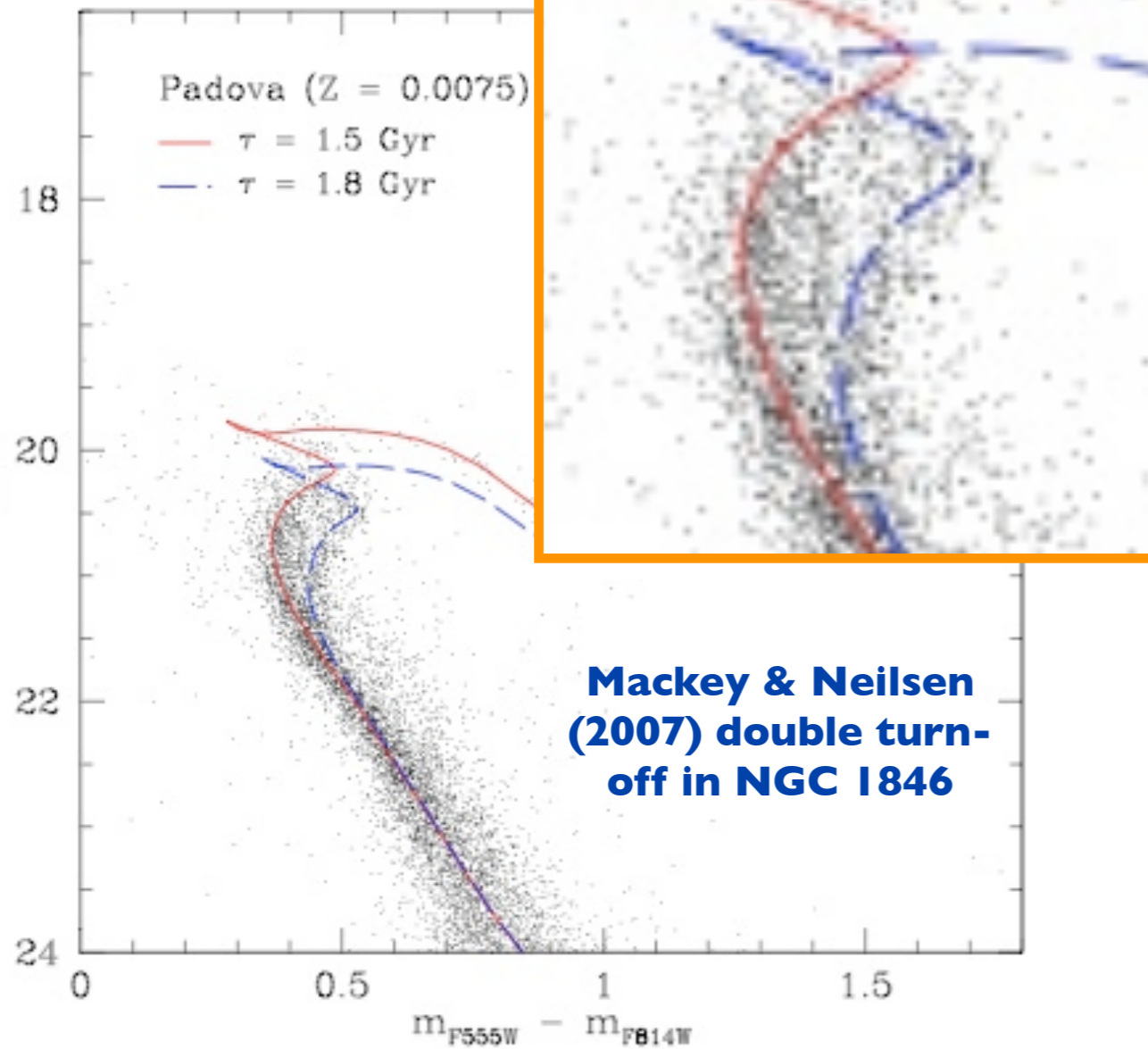$E(B-V) = 0.04$

9 Gyr

13 Gyr

More complicated CMDs

MULTIPLE AGES

In general, stellar systems may have extended formation histories (continuous star-formation, or multiple bursts). Multiple turn-offs.

Mackey & Neilsen (2007) double turn-off in NGC 1846

solar neighbourhood : continuous star-formation history
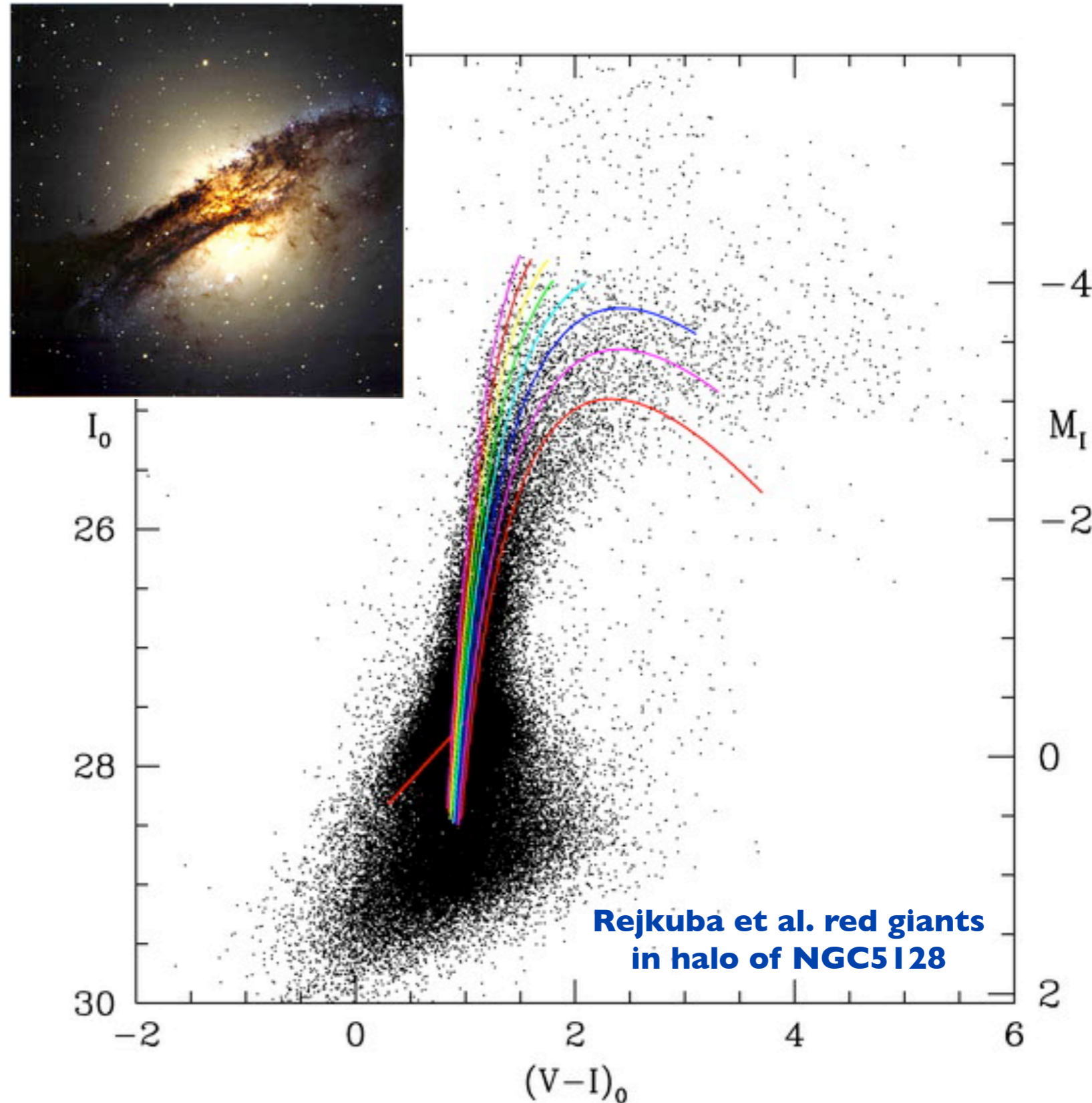
MULTIPLE METALLICITIES

In general there might be a mix of different metallicities.

Chemical composition of ISM varies with time (e.g. enrichment from supernovae).

RGB position depends on metallicity, so the RGB is broadened by any metallicity spread.

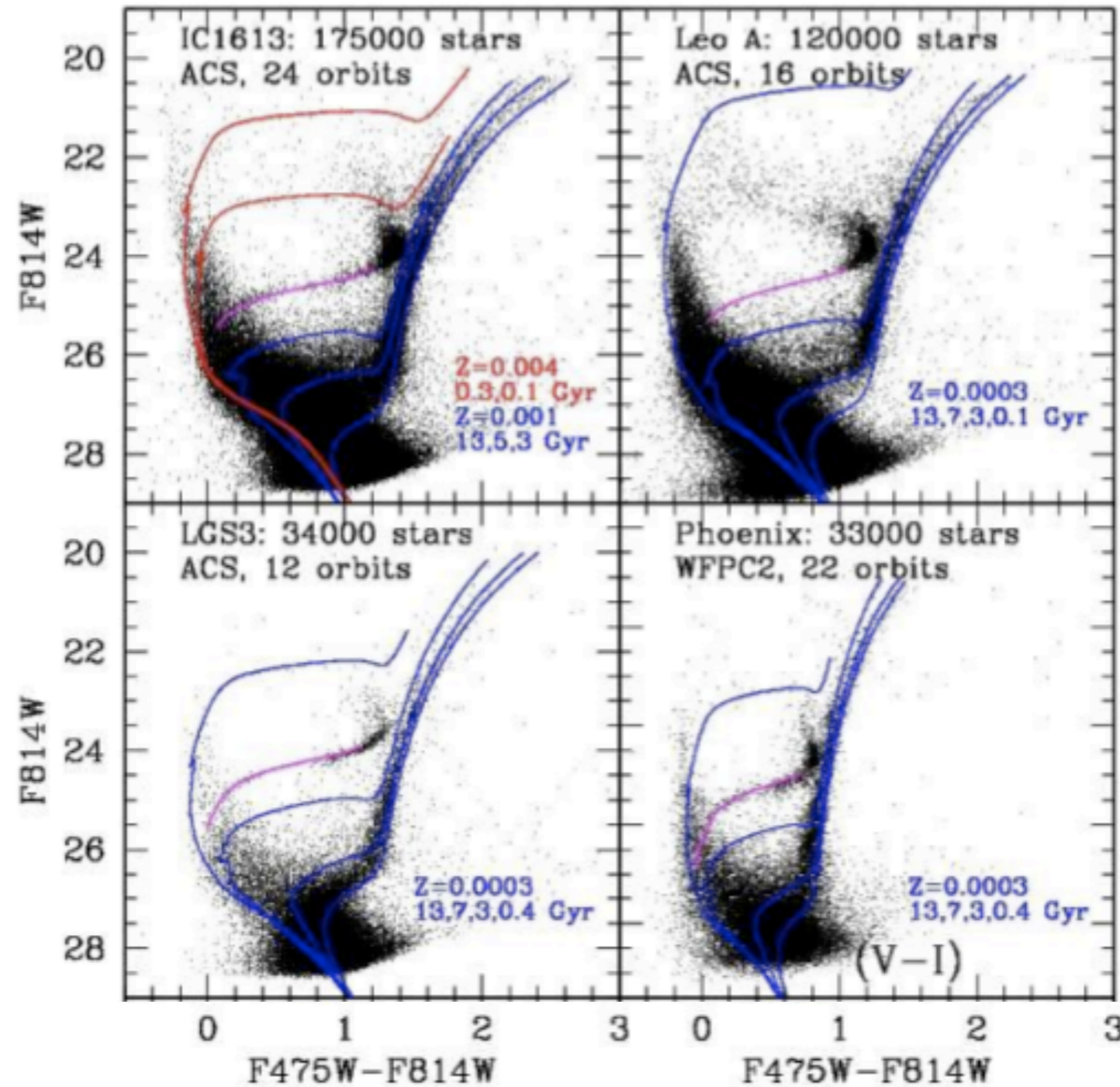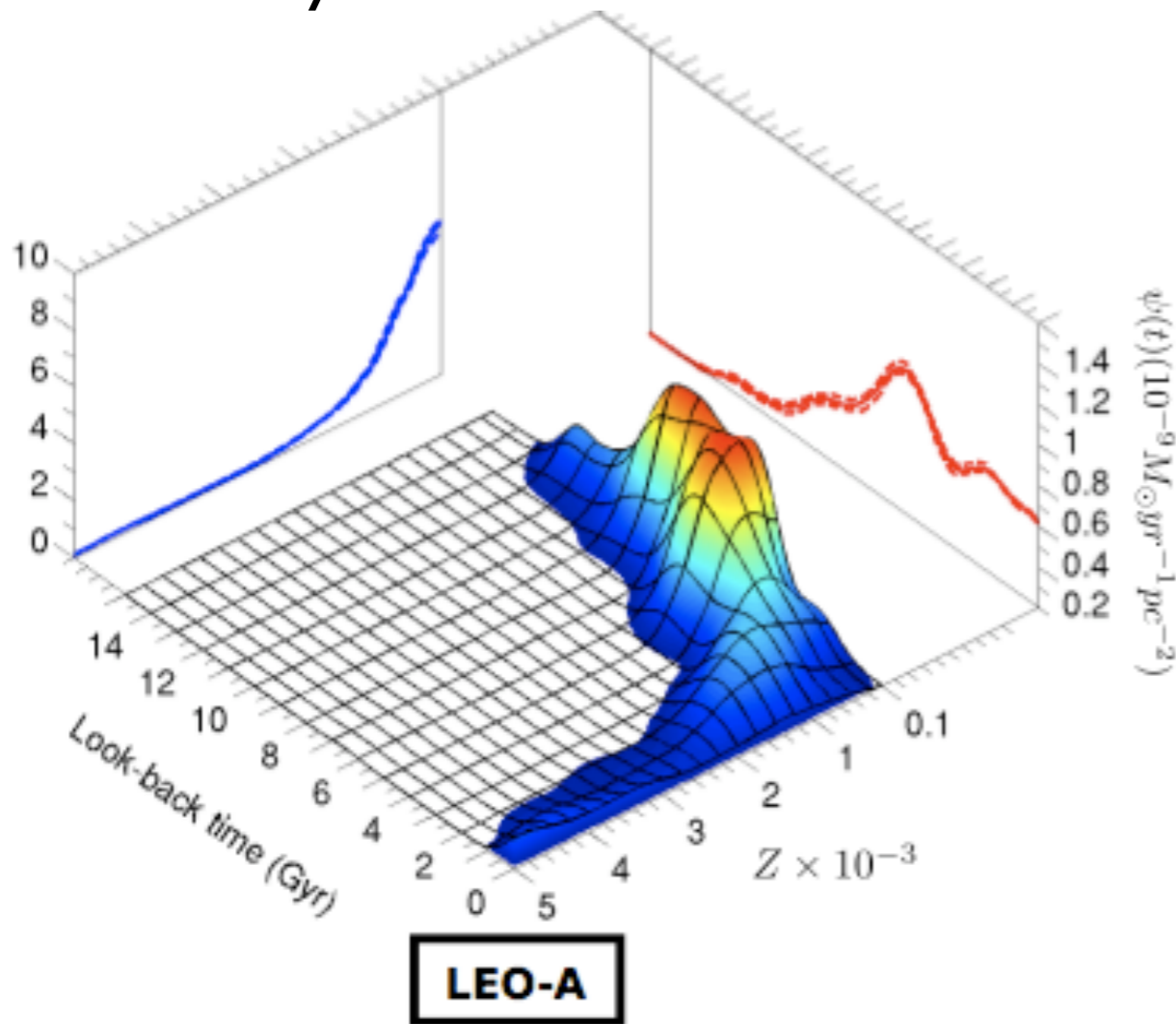**Rejkuba et al. red giants in halo of NGC5128**

More complicated CMDs

General methods for fitting multiple populations in resolved populations.

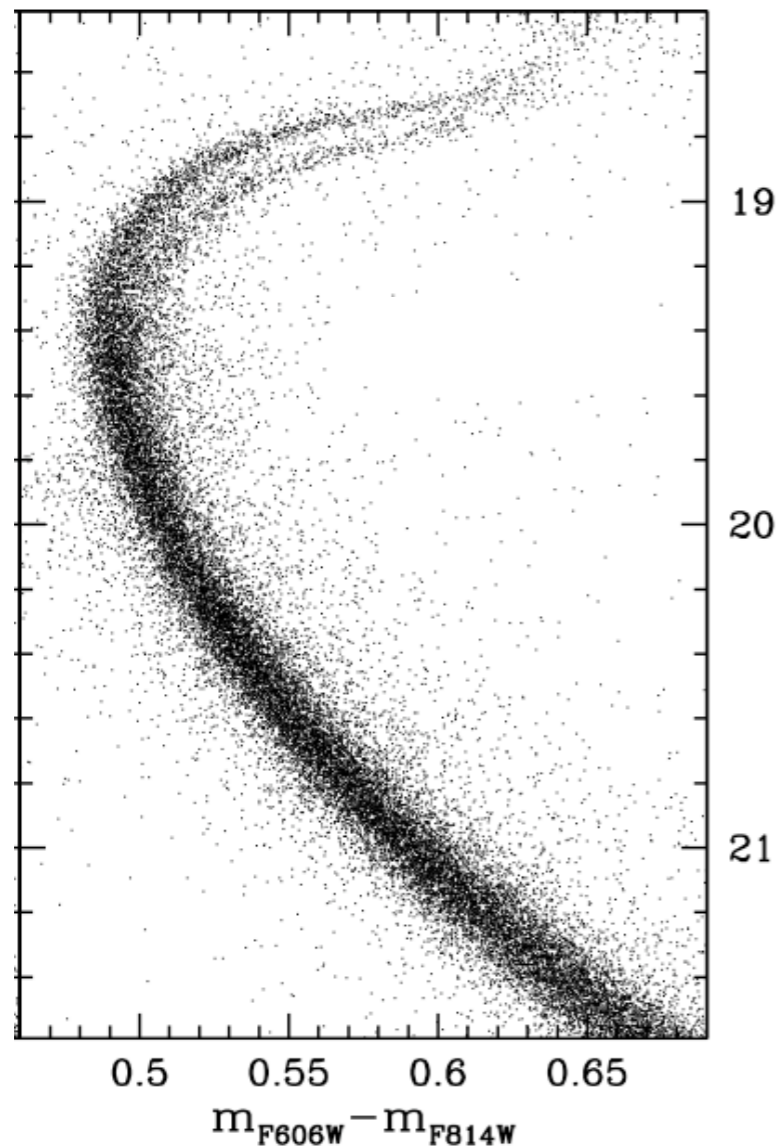Can aim to recover fraction of stars formed on a grid of age and metallicity.

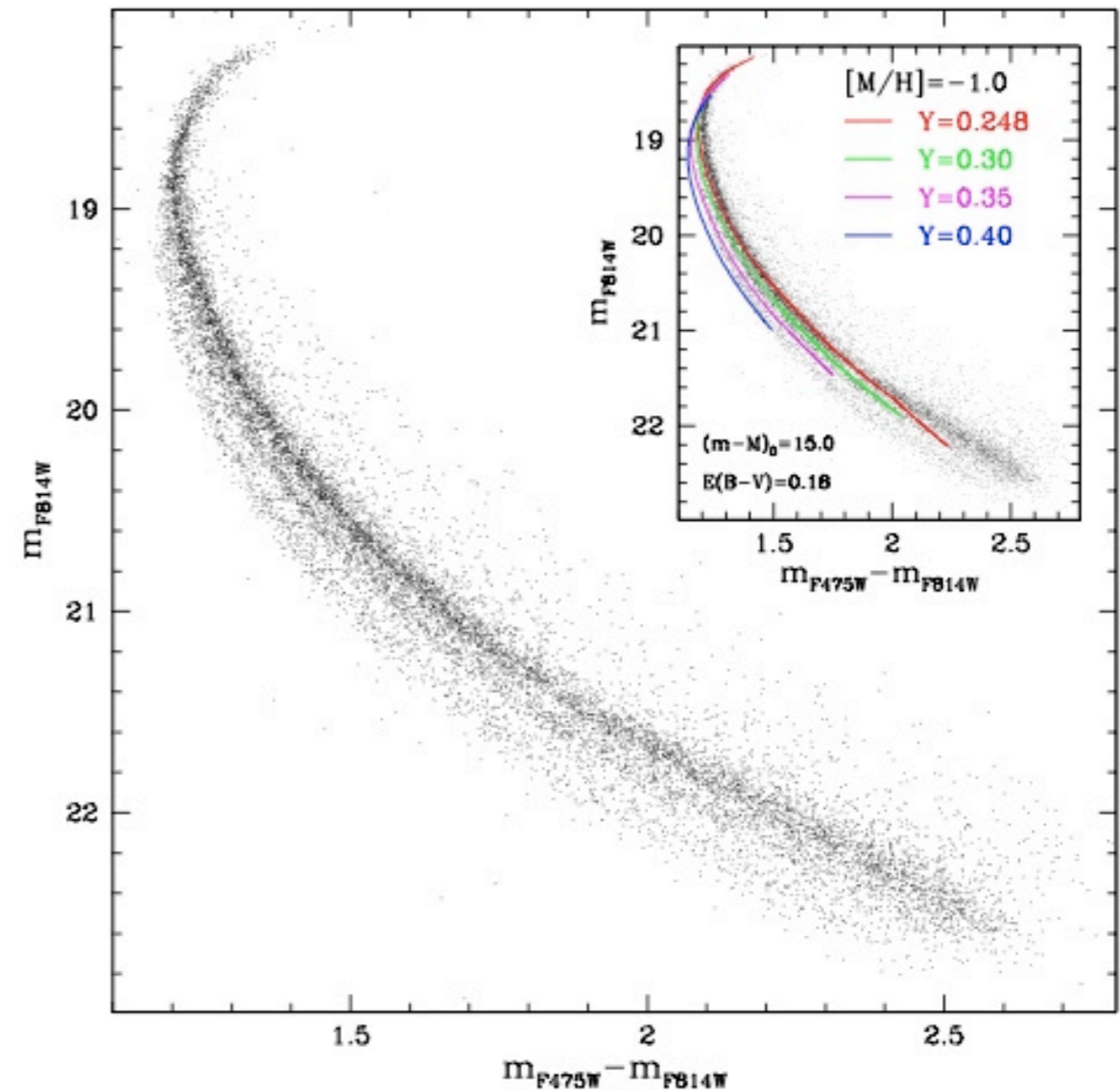**Gallart et al. (2007)**
Local Group Dwarf Galaxies

CMD Exotica

Milone et al. (2007)

NGC2808 Piotto et al. (2007)

Multiple main sequence in NGC 2808, Omega Cen; double SGB in NGC 1851, ...

In some cases, appears some of the stars formed with enhanced Helium abundance.

Implies that even some globular clusters are not true SSPs

CMD Exotica

BLUE STRAGGLER STARS

Why have these stars not evolved off the main sequence like others o similar mass?

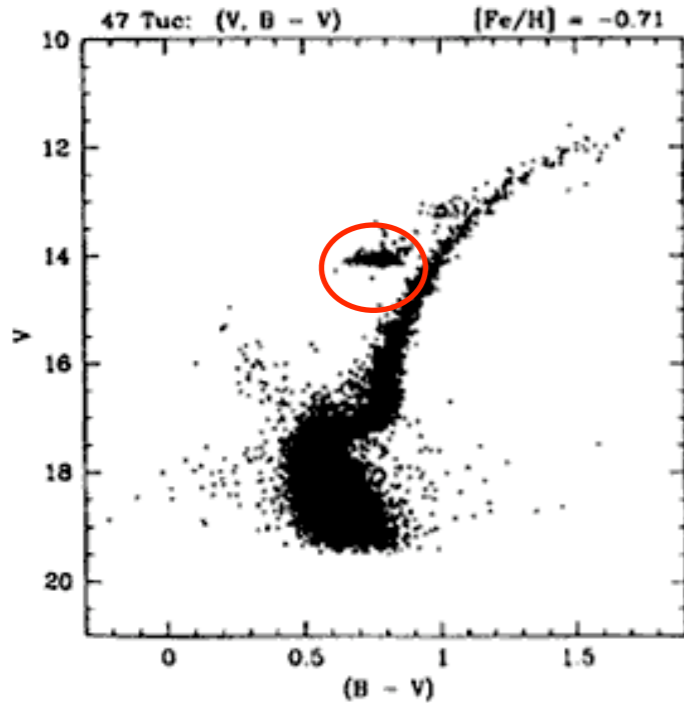Not thought to be young, but rather "delayed" evolution.

Most likely explanation is mass transfer in <u>binary star</u> systems: "stellar re-fuelling".

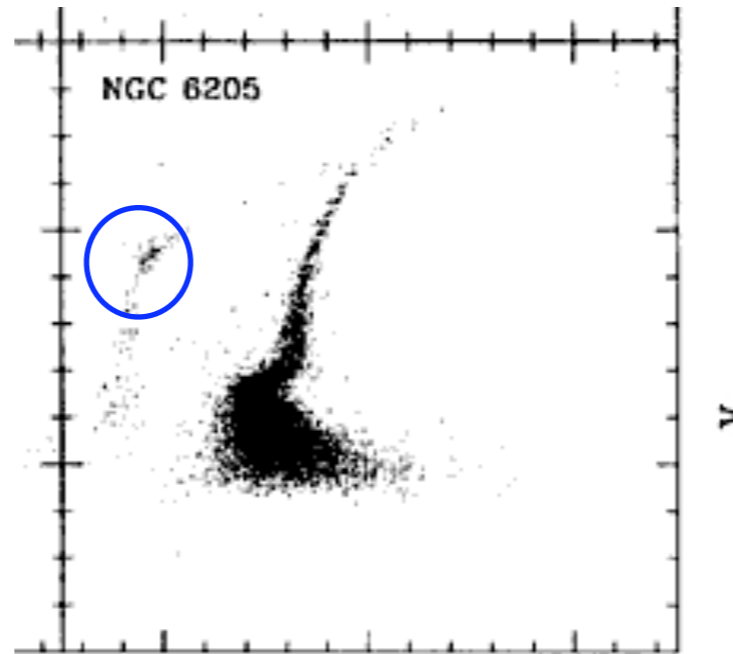We have no idea how to predict from first principles the number of BS stars formed...

M30: r<130"
9507 stars

△ HB
● Bright RGB/AGB
□ Faint RGB/SGB
× BSS
· MS
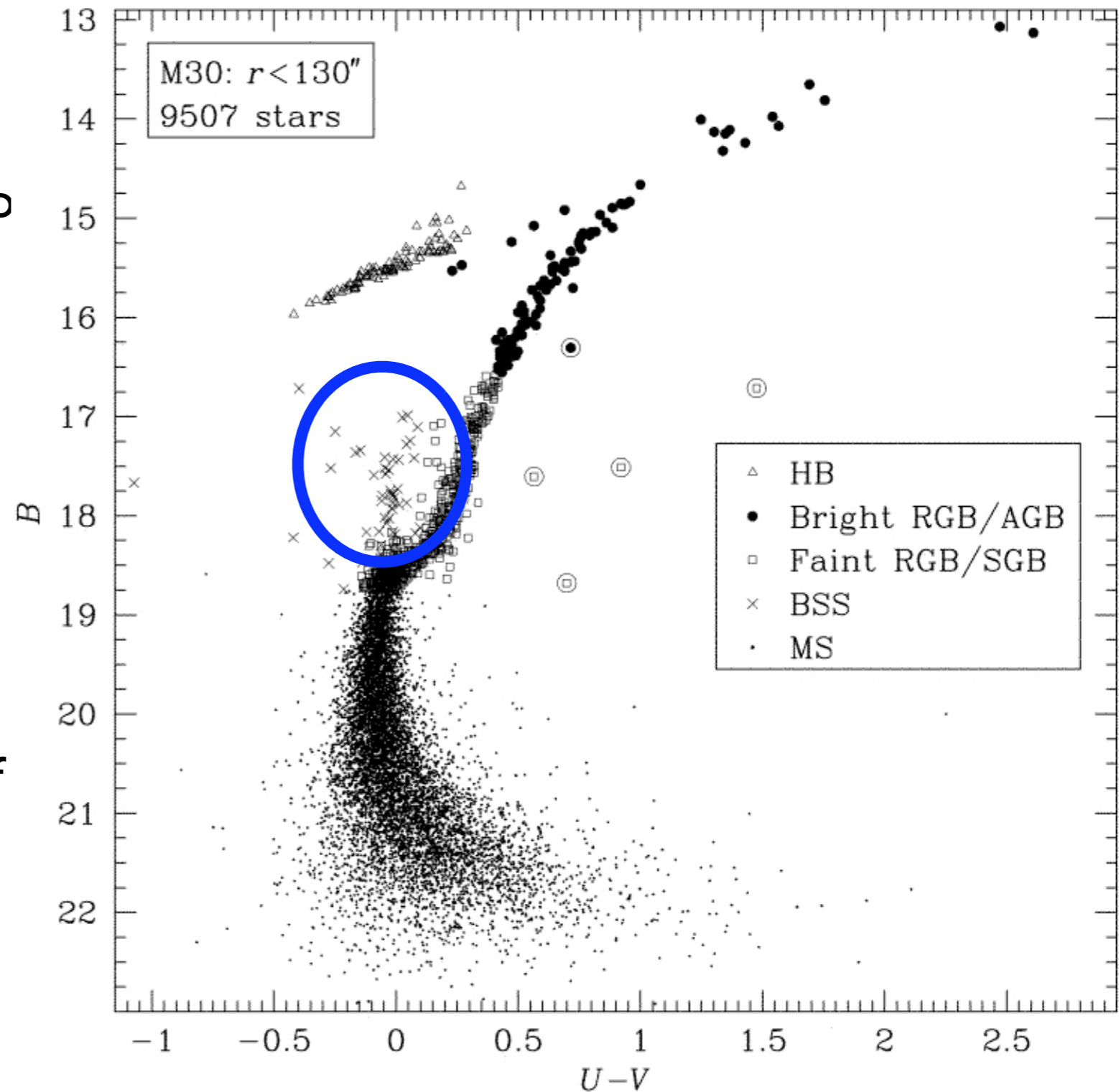
M30, Guhathakurtha et al (1998)

CMD Exotica

Classic High-Fe/H "Red Clump"

Classic Low-Fe/H Blue HB

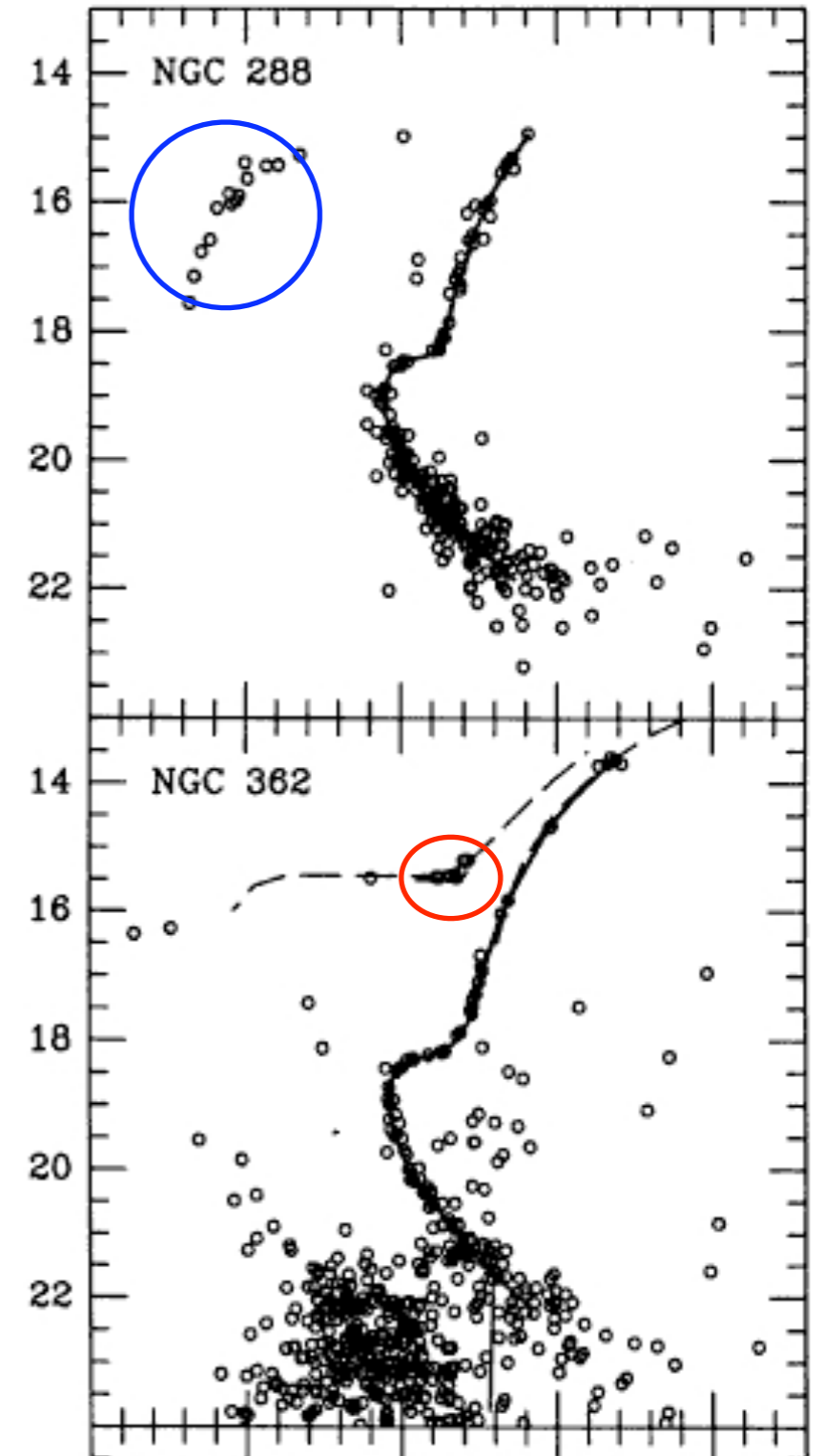
NGC 288

NGC 362

Famous "2nd parameter" pair with
same Fe/H but very different HB

HORIZONTAL BRANCH MORPHOLOGY

Temperature of HB stars depends on how much mass was lost on the RGB. Difficult to model.

The temperature distribution on the HB in globular clusters depends on mostly on their metallicity.

But some differences not attributable to metallicity: what is the "second parameter" that determines HB form at given Fe/H?
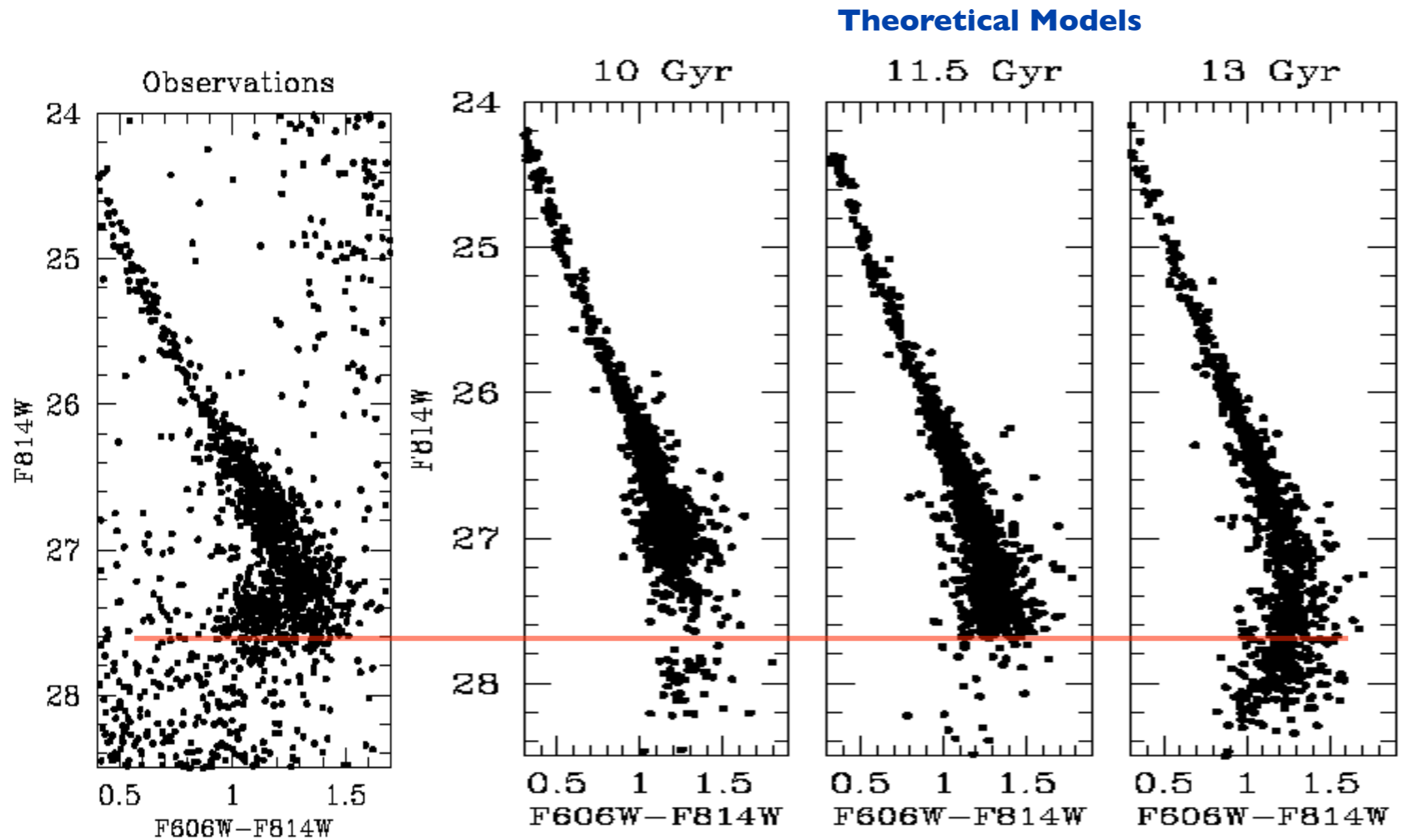
CMD exotica

Age estimates from cooling sequence of white dwarfs.

Theoretical Models

Observations   10 Gyr   11.5 Gyr   13 Gyr

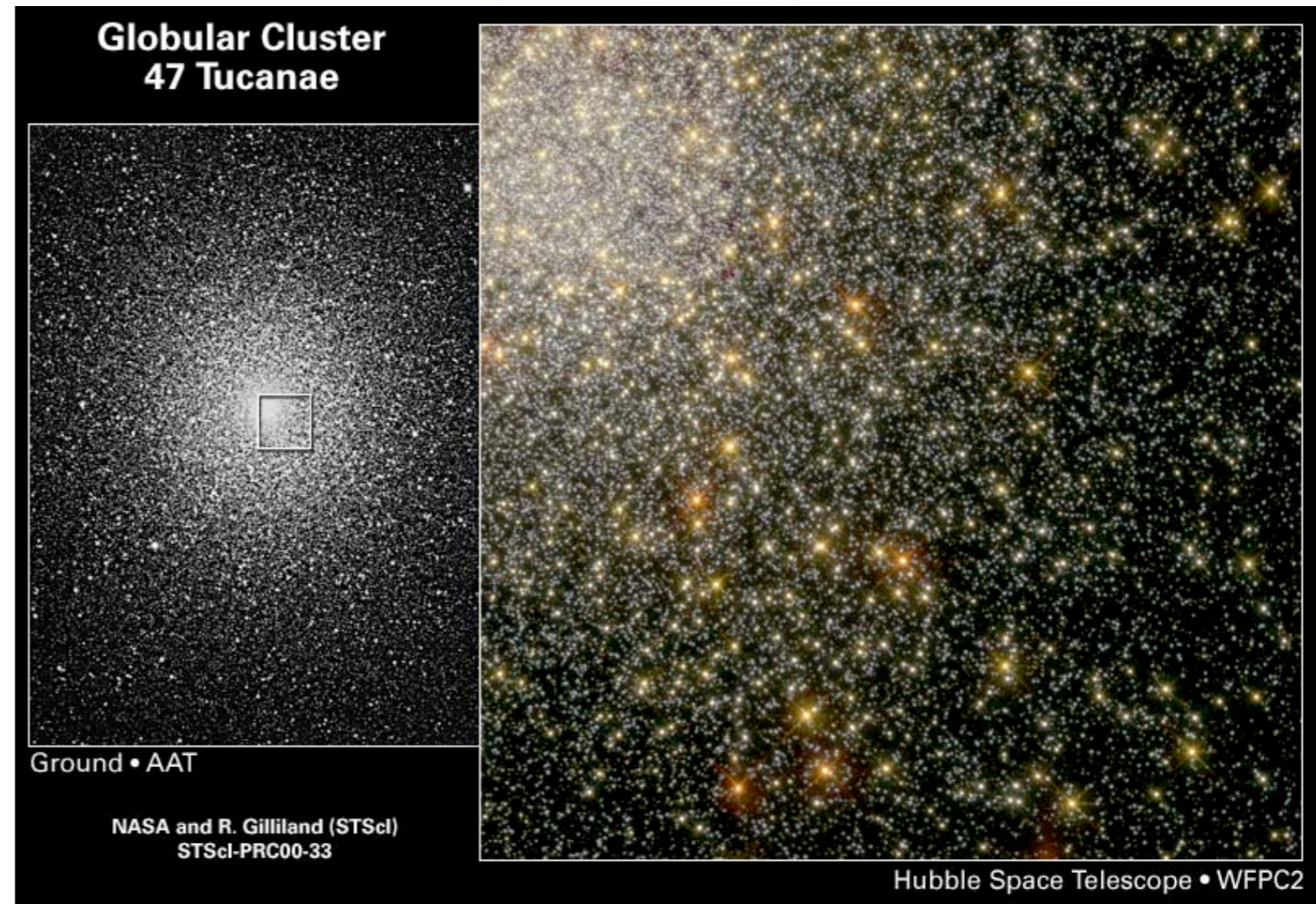**Hansen et al. (2007) WD sequence in globular cluster NGC6397**

Current limitations

Resolved SP studies are crucial test of stellar evolution and the foundation of our knowledge of galaxy stellar content.

But it is observationally challenging due mostly to crowding.

Even with HST, we can only resolve populations beyond the RGB for objects in (or very near) the Local Group of galaxies.

But the Local Group contains NO ellipticals. (Nearest are NGC5128 and Maffei I - wouldn't want to generalize from either!)

Globular Cluster
47 Tucanae

Ground • AAT

NASA and R. Gilliland (STScI)
STScI-PRC00-33

Hubble Space Telescope • WFPC2

NGC 5128

Maffei I

Resolved Stellar Populations: Summary

Review of stellar evolution.

Population model inputs: tracks, isochrones and the initial mass function.

(We will meet these again in the next section.)

Observed cluster colour magnitude diagrams.

Isochrone fitting methods: ages, metallicities

(We can learn a lot from this kind of data, if we can get it.)

More complicated cases & exotica.

(These may be more common than we would like to think.)

Practical limitations.

(Resolved studies cannot fairly sample the population of galaxies.)

To go beyond the resolved populations in and near the LG, we need to understand how to learn about unresolved stellar pops.

END OF LECTURE I