Where are We Going

- How to build up the galaxies we observe from what we know about stars !
- Next presentation: read 2003MNRAS. 341...33 Kauffmann, G et al (1287 citations) and take a look at Tinsley,B. ApJ 151 547, 1968) and discuss what are the assumptions that allow one to convert optical spectra into stellar mass and constraints on the star formation history of a galaxy. Focus on sec 1,2 , 5.4, 7 and 8 (this is a long and detailed paper !)
- Laura Lenkic (IF I

How to Calculate Your Own Star

- arXiv:1509.06775 **grayStar3** - gray no more: More physical realism and a more intuitive interface - all still in a WWW browser C. Ian Short

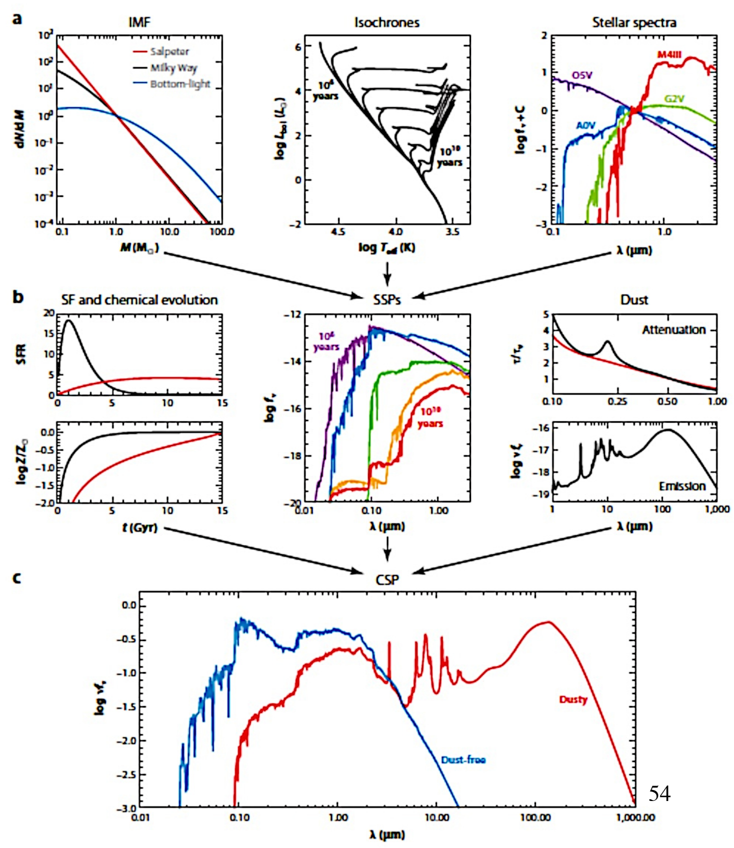
- The goal of the openStar project is to turn any WWW browser, running on any platform, into a virtual star equipped with parameter knobs and instrumented with output displays that any user can experiment with using any device for which a browser is available. .... The code integrates scientific modeling in JavaScript with output visualization HTML. The user interface is adaptable so as to be appropriate for a large range of audiences from the high-school to the introductory graduate level. The modeling is physically based and all outputs are determined entirely and directly by the results of in situ modeling, giving the code significant generality and credibility for pedagogical applications.
- gS3 also models and displays the circumstellar habitable zone (CHZ) and allows the user to adjust the greenhouse effect and albedo of the planet. In its default mode the code is guaranteed to return a result within a few second of wall-clock time on any device. The more advanced user has the option of turning on more realistic physics modules that address more advanced topics in stellar astrophysics.
- gS3 is a public domain, open source project and the code is available from www.ap.smu.ca/~ishort/grayStar3/ and is on GitHub. gS3 effectively serves as a public library of generic JavaScript+HTML plotting routines that may be recycled by the community.

This Time

- Age of a SSP
- SSP spectra as a function of time
- Initial Mass Function (IMF)
- Composite spectra of galaxies

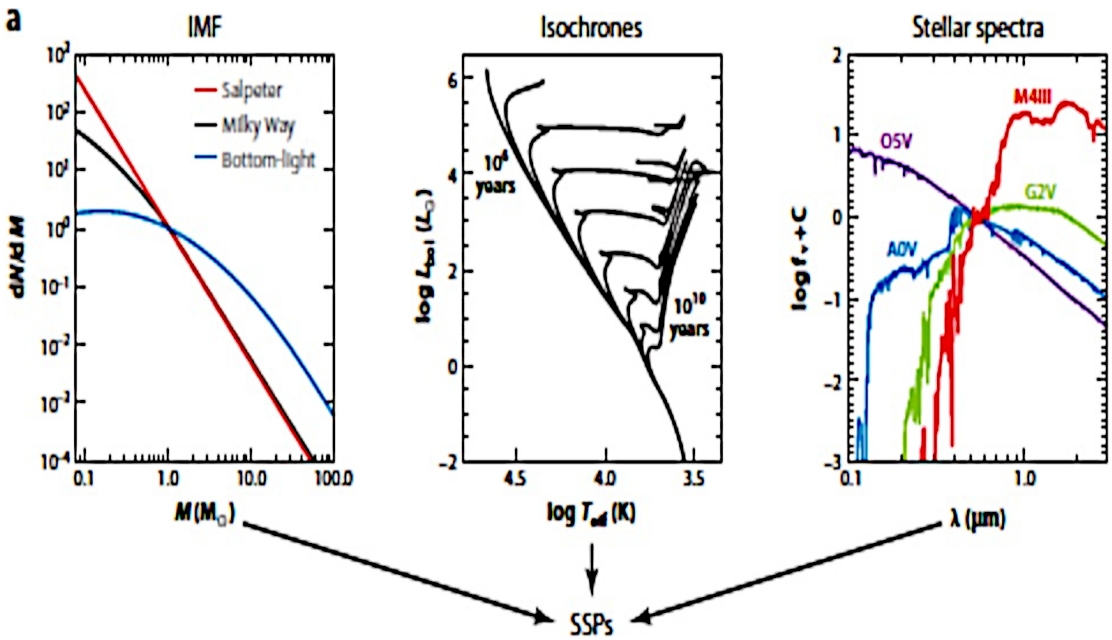
What is the Process – Conroy 2013

MBW sec 10.3



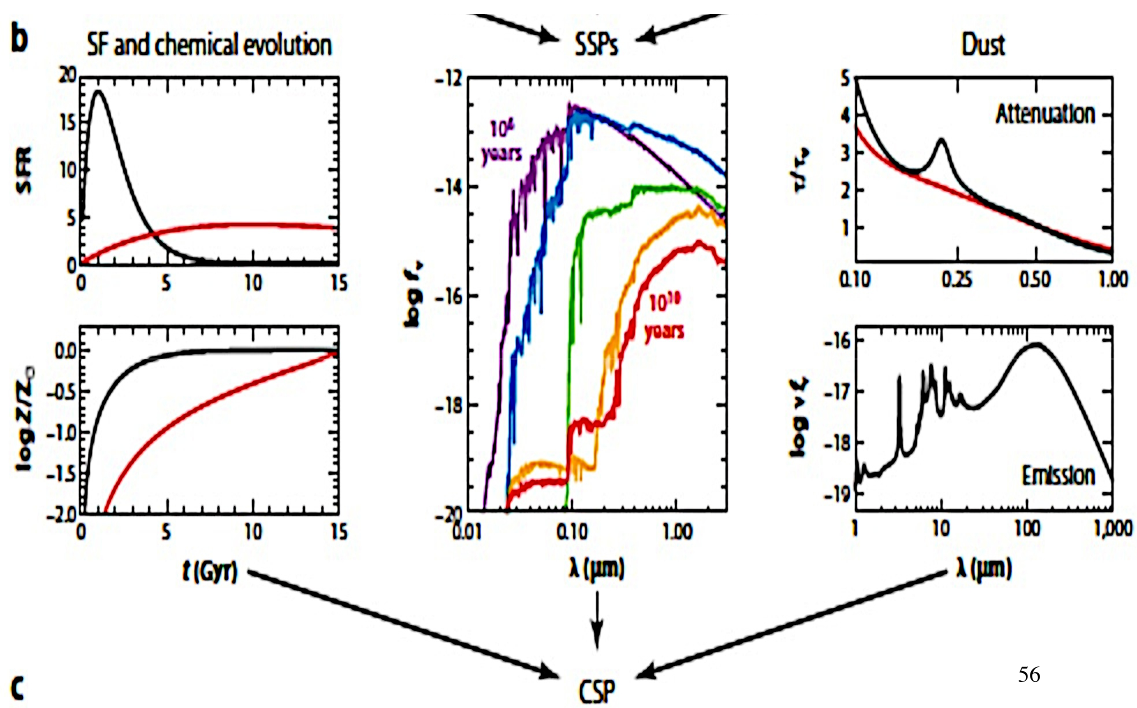
What is the Process –MWB sec 1.3 Conroy 2013

Taking stellar models and data and constructing a galaxy spectrum



What is the Process –MWB sec 1.3 Conroy 2013

Dust will be discussed later



What is the Process –MWB

sec 1.3 Conroy 2013

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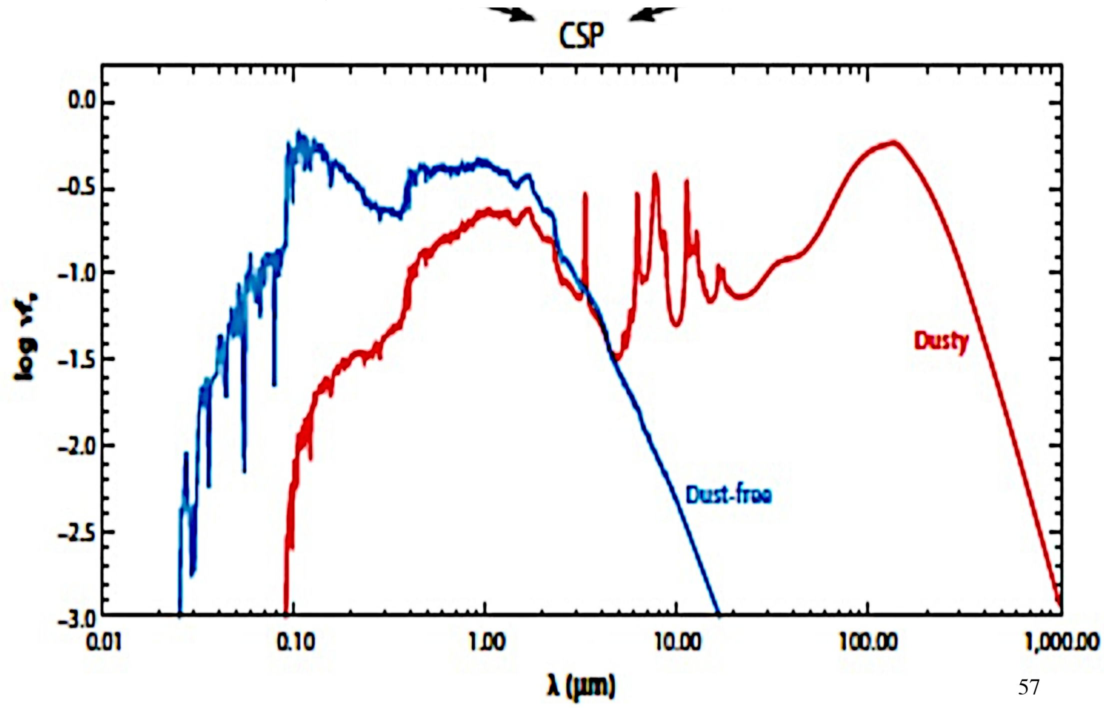

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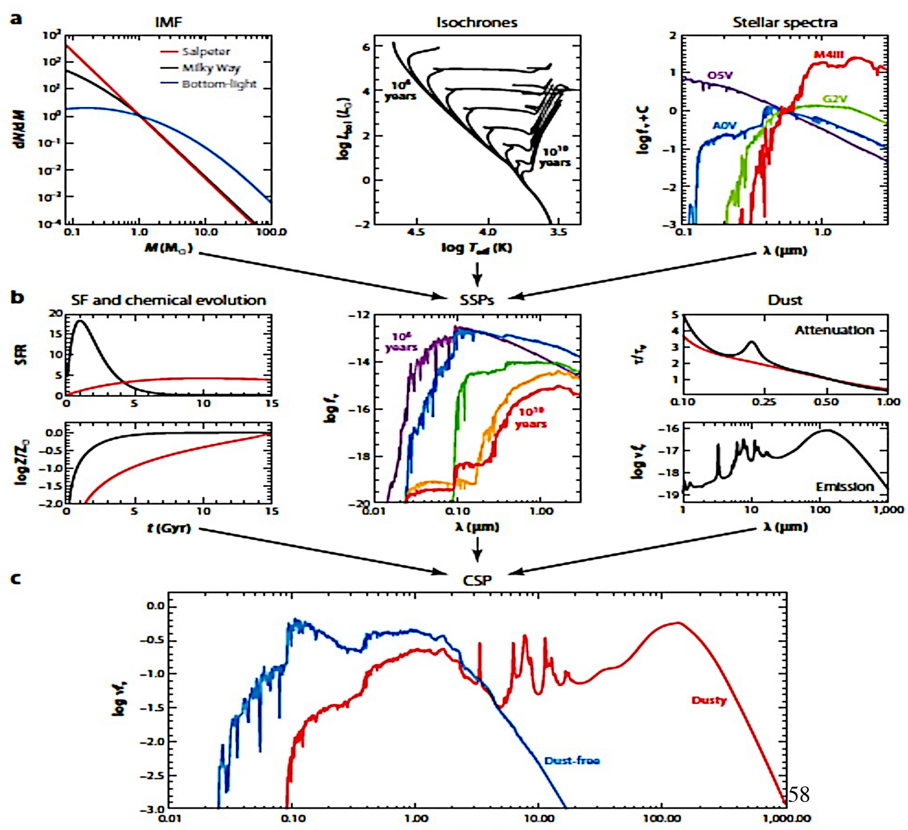
What is the Process – MWB sec 1.3 Conroy 2013



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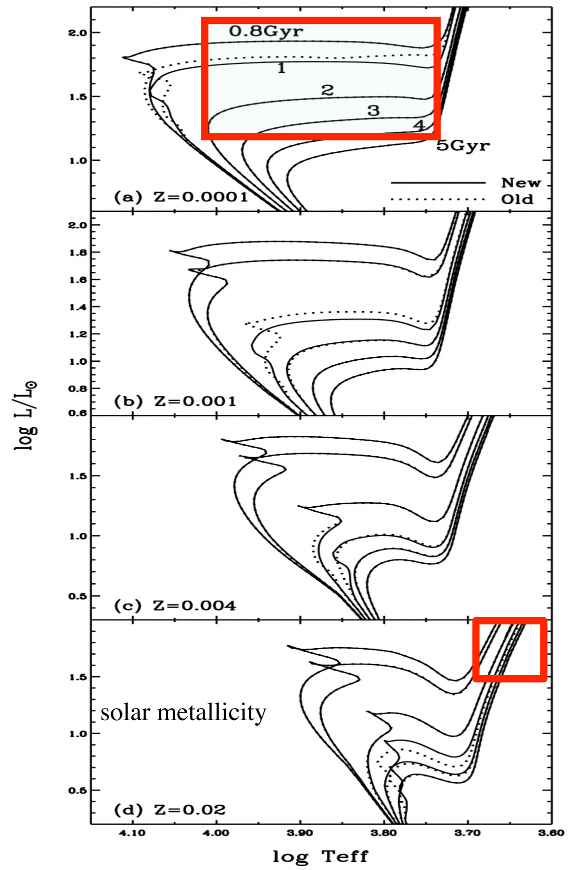
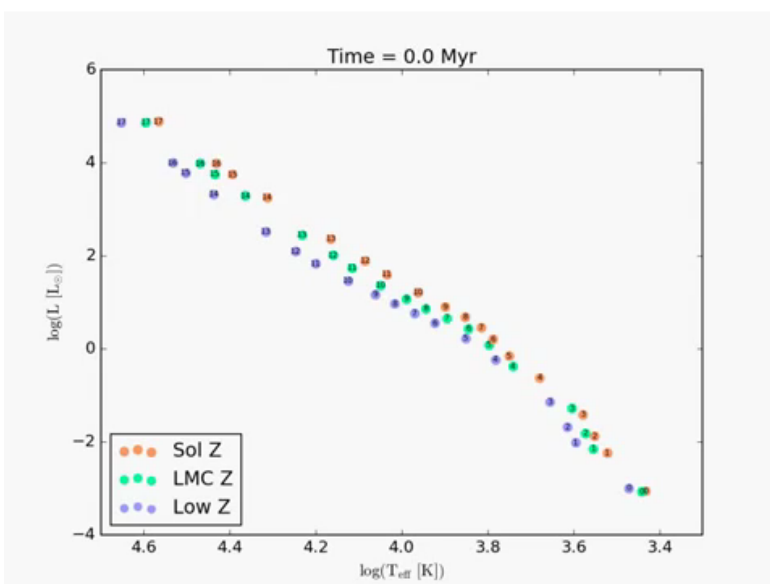
Theoretical Isochrones

- These lines are the positions of stars from a SSP as a function of the age of the system - in the temperature/ luminosity plane **if** no new stars are born
- The shape depends on the metallicity of the stars (Demarque et al 2004)

- One can determine the '*age*' of the system by fitting an isochrone (if one has data for individual stars) or by calculating some average property (color/spectrum) averaging over the isochrone - <u>degeneracy problems with age and metallicity are obvious</u> -
- notice stars 'pile up' on the red giant branch (dominate luminosity of old systems)

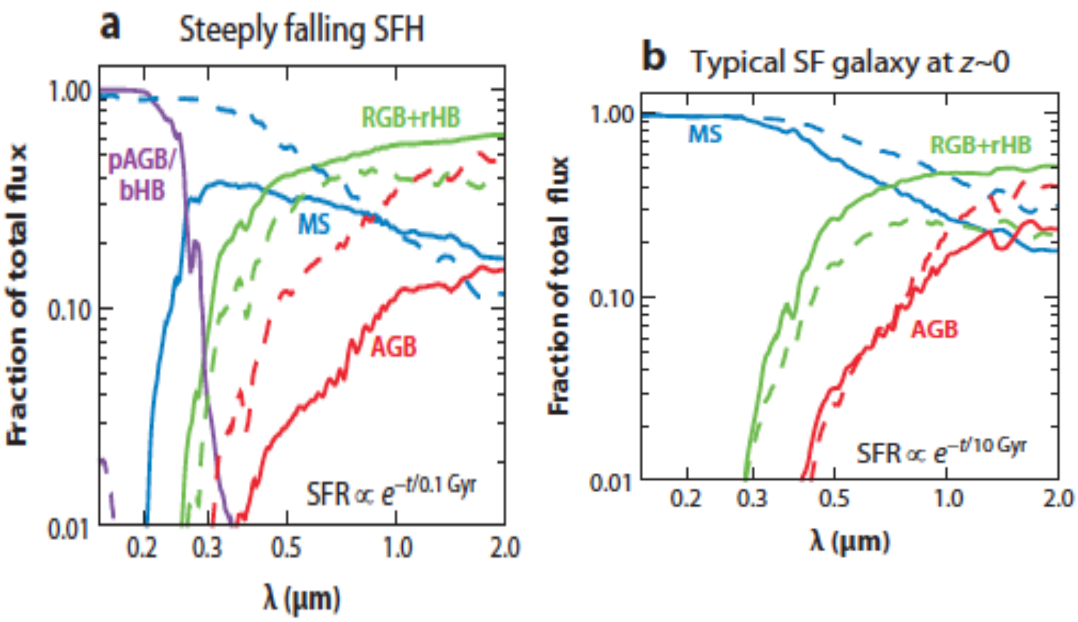


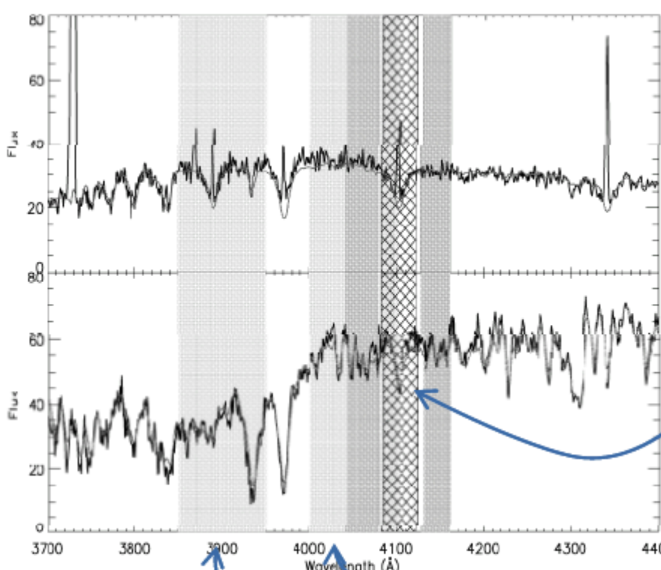
Isochrones-Laura Lenkic



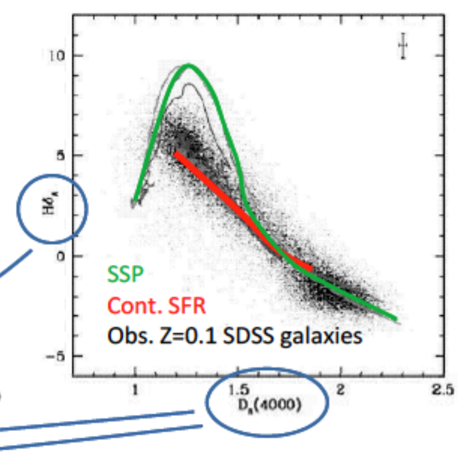
Effects of Different Star Formation Histories on Galaxy Spectra- Conroy 2013

13 Gyr solid lines, 1 Gyr dashed lines





Signatures of Stellar Evolution



- Hδ vs D(4000)- distinguish SSP vs continuous star formation- features in **summed** stellar spectra (see Kauffmann 2003)

- The Flux at one wavelength=

$$\iiint f_{\lambda}(M,Z,t)\ \psi(t,Z)\ n(M)\ dM\ dZ\ dt$$

- n(M) - the stellar IMF
- ψ(t,Z) - the star formation history
- fλ(M,Z,t) - stellar library, complicated…
- Critical assumptions
  - Universally-applicable stellar IMF which we *know* and how the star formation rate evolves

How to Use this Information

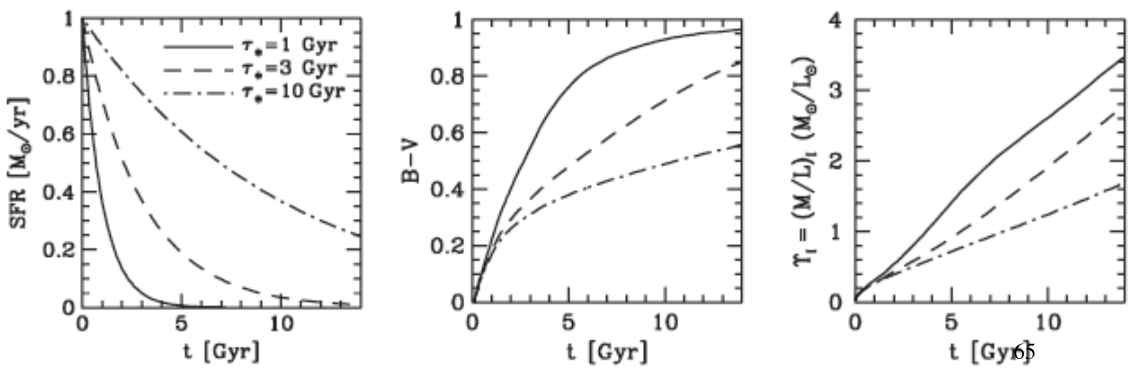
- ‘Integrated’ Stellar Populations

Crucial since only 10-100 Galaxies have resolved stars

- What can we say about stellar mass, metallicity, star formation history age– for low z galaxies can resolve 'parts' of the galaxy, for most distant objects 'whole' galaxy
- Data
  - images
  - colors, or ‘many colors’, i.e the ‘spectral energy distribution’ (SED) (R=5 spectrum)
  - Spectra (R=2000) (integrated or spatially resolved spectra or long slit)
- It is not possible to invert the data to derive the desired parameters.
- Process:
  - assume stellar formation history and IMF- generate isochrones
  - use stellar library to calculate spectra/colors
  - iterate and see if it converges

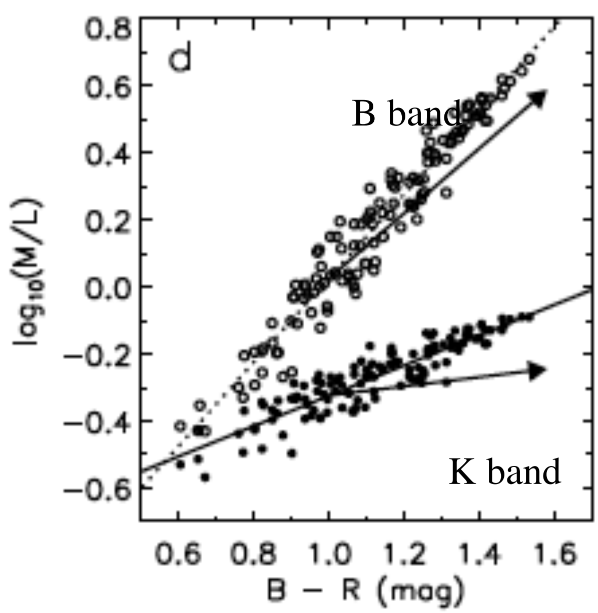
Effect of Star Formation History on Colors and Luminosity of a SSP (fig 10.9 of MBW)

- Left panel 3- different star formation histories
  - solid 1 Gyr e-folding time
  - dash 3 Gyr
  - -dash-dot .. 10 Gyr
- Middle panel B-V colors
- Right Panel mass to light ratios



M/L(Mass to Light) Indicators

- Some colors are very sensitive to M/L
  - correlation between stellar M/L and the optical colors
- For a composite population one has to make a lot of assumptions: SF vs time law, chemical evolution model, SSP model, etc etc- color is basically ratio of how much SF now to how much in the past
- Such techniques can be applied to large samples due to availability of huge data sets of photometric data -

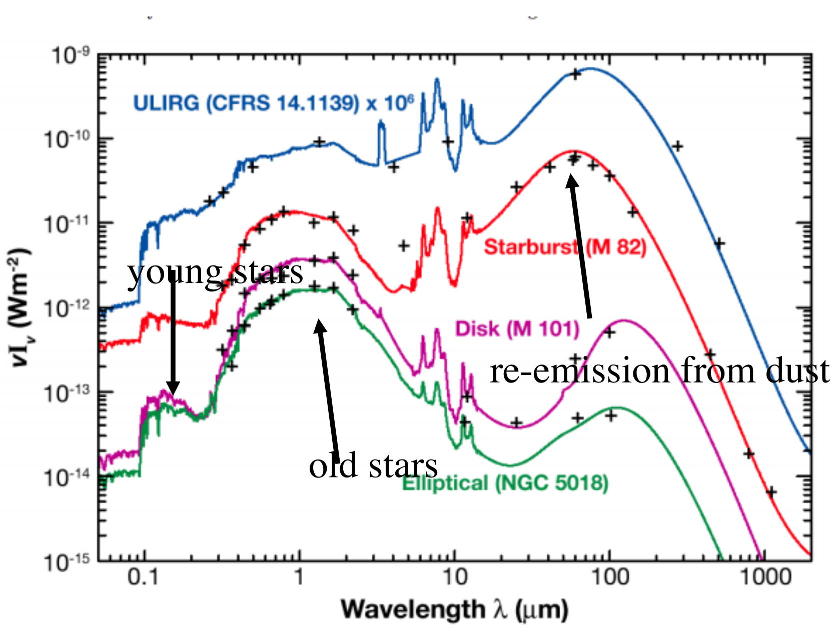


Color Magnitude Diagrams

- Need to measure individual stars- only possible in local group
- <u>But Very powerful</u>
  - If get to main sequence turn off for old stars
    - Star formation history
      - Resolution good for recent star formation, worse for ancient times
  - If you don't get to main sequence turn off (more distant objects)
    - Some SFH information remains but tricky to do well because it's all post-main sequence based

- However for the vast majority of galaxies just have integrated spectra/ color images
  - New data with spatially resolved spectra (IFUs)- e.g MANGA (more later) sub-divide galaxy into ~100 places (~1 kpc) for 10,000 (!!) galaxies

Put it All Together Into A Galaxy

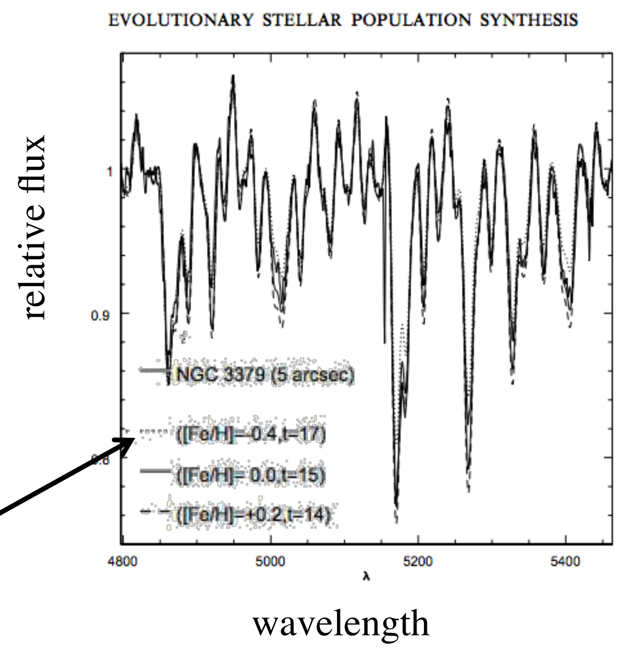


- Even some ellipticals have dust

http://hubblesite.org/newscenter

Summary Spectra of Galaxies see MWB sec 10.3.2-10.3.6

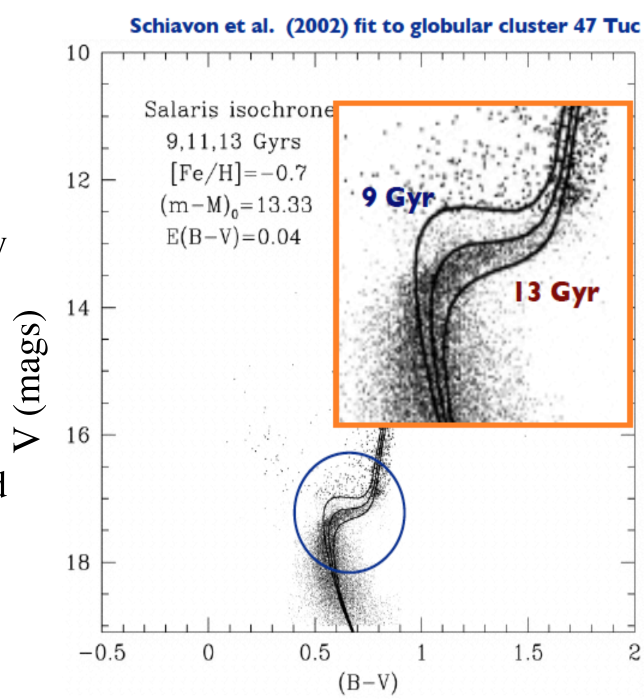
- Almost all the energy radiated by 'normal' (not AGN) galaxies is due to stars (either direct or reprocessed)
- However the stellar spectra is a triple integral over
  - IMF
  - star formation history
  - stellar library
- furthermore the observed spectrum is often strongly effected by dust
- Also there is a <u>'age/metallicity' degeneracy</u>; for much of the optical band spectra young, metal-rich populations strongly resemble old, metal-poor populations
  - NEED to get AGES



Vazdekis 1999

Age Dating a SSP

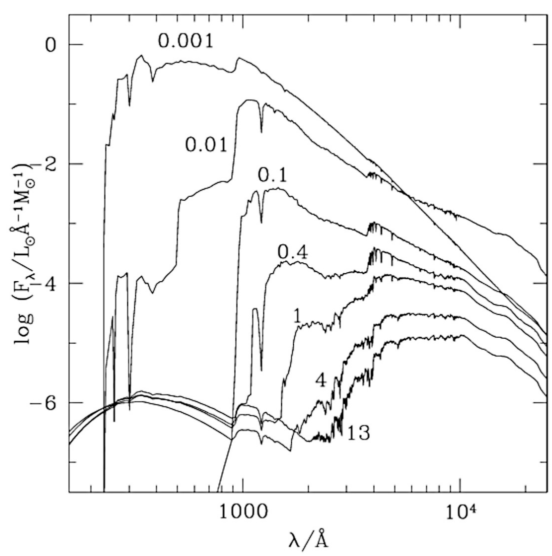
- Globular clusters can be well approximated by a SSP and are frequently chemically homogenous
- With precision photometry ages can be well estimated by measuring the location of the 'turn-off'- e.g. when the star leaves the main sequence.
  - (because stars at same distance, can use observed brightness, V, instead of absolute luminosity)



Color

Galaxy Spectra

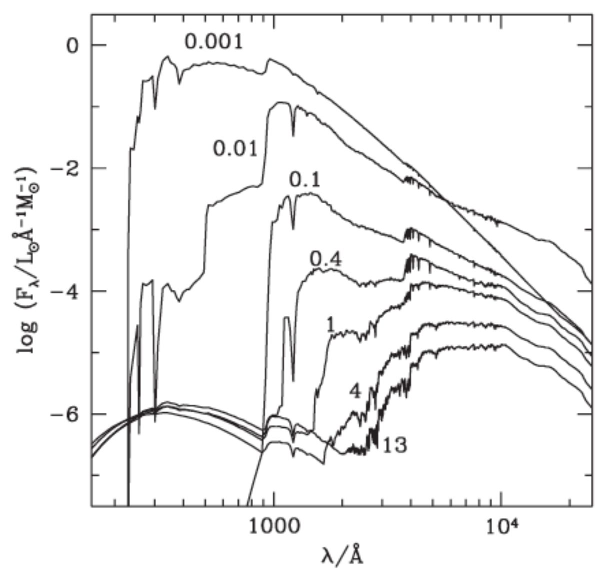
- Of course the galaxy spectrum is the sum of the stars, weighted by their luminosity.
- The spectra changes radically with the age of the system (MBW fig 10.5) and weakly with chemical composition
- After a ~fewx10^9 yrs stars on the red giant branch dominate the ~1μ flux;
  - stars on the red giant branch have a narrow range of parameters for a large range in mass; good estimator of mass in stars (discussion in sec 10.3.3 MBW)



Theoretical spectrum of a SSP with a Saltpeter IMF and solar metallicity at a variety of ages 0.001-13 Gyrs

Spectra of Co-Eval Population

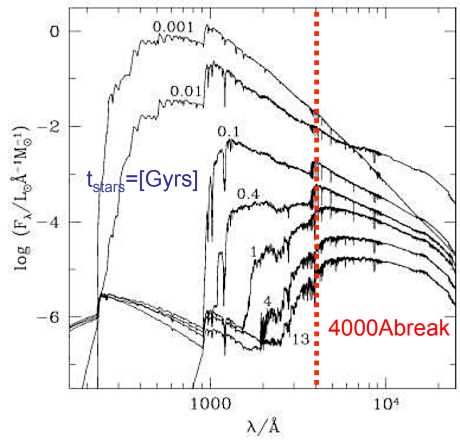
- MBW sec 10.3
- This takes a given IMF for a SSP and calculates the broad band spectrum of the stars at a variety of times.
- Notice the critical time ~200Myr when there are no more ionizing photons.
- Also notice that the ~2μ flux is almost independent of age

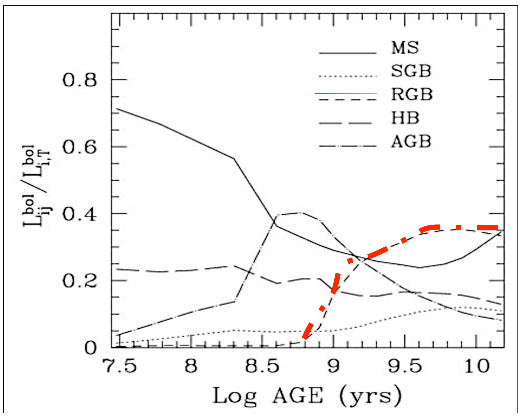


).5. The predicted spectra of a coeval stellar population at ages 0.001, 0.01, 0.1, 0.4, 1, 4.

Luminosity and Colors Changes of a SSP

- As SSP ages the relative luminosity due to different parts of the H-R diagram changes
  - young systems MS dominated by massive stars
  - Older systems(>2Gyrs)-dominated by red giant branch
  - If star formation is a continuous process which stars produce most of the luminosity and where most of the stellar mass lies can be quite different





Spectral energy distribution UV-IR of a SSP as it ages

Notice the enormous changes in the UV and blue

A slow fading in the IR

Age Dating A SSP

- the colors of a SSP can be calculated as a function of age (for a given metallicity) (See MBW pg 473)
- Notice the weak change in color vs age after ~3Gyrs, but the strong change in M/L_V and weak change in M/L_K
- **All this depends on the IMF !**

- ***why? please explain why these plots look like they do.***