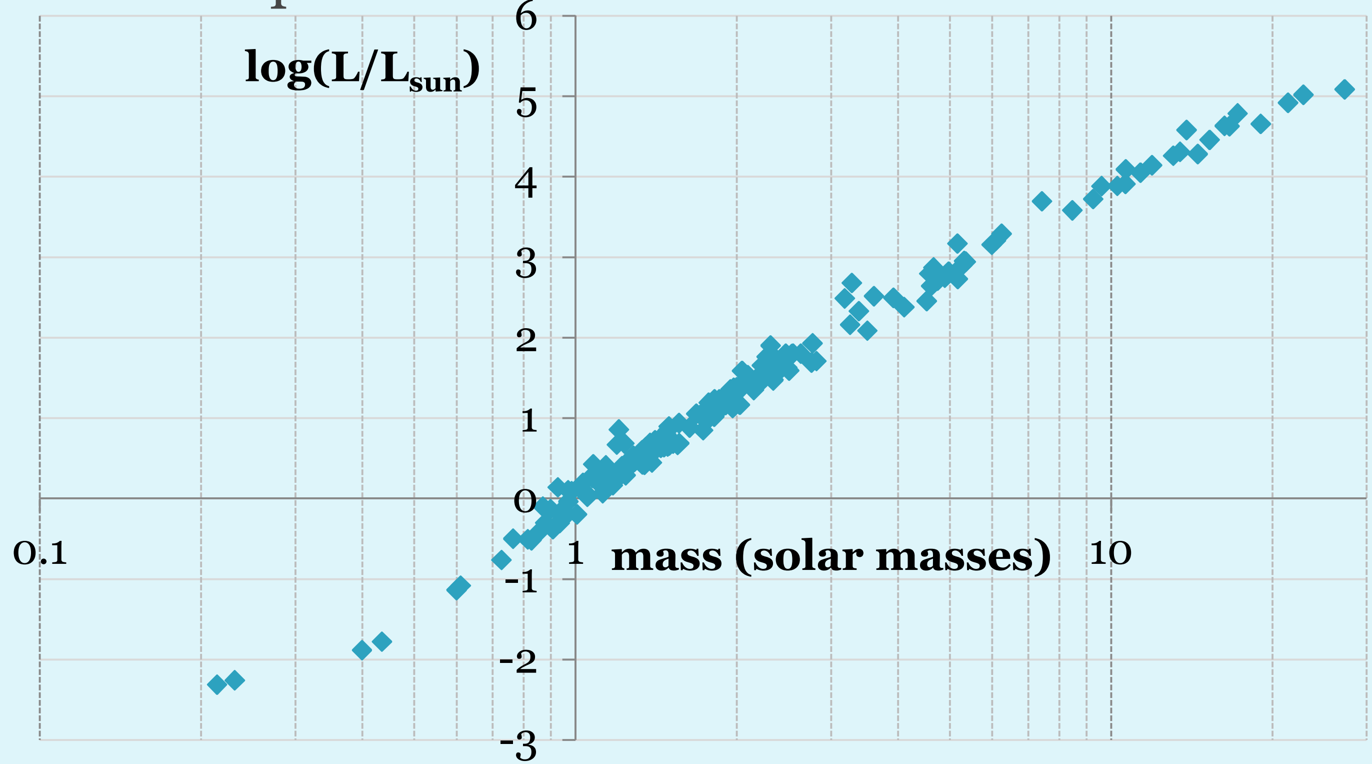
Stellar evolution and star clusters

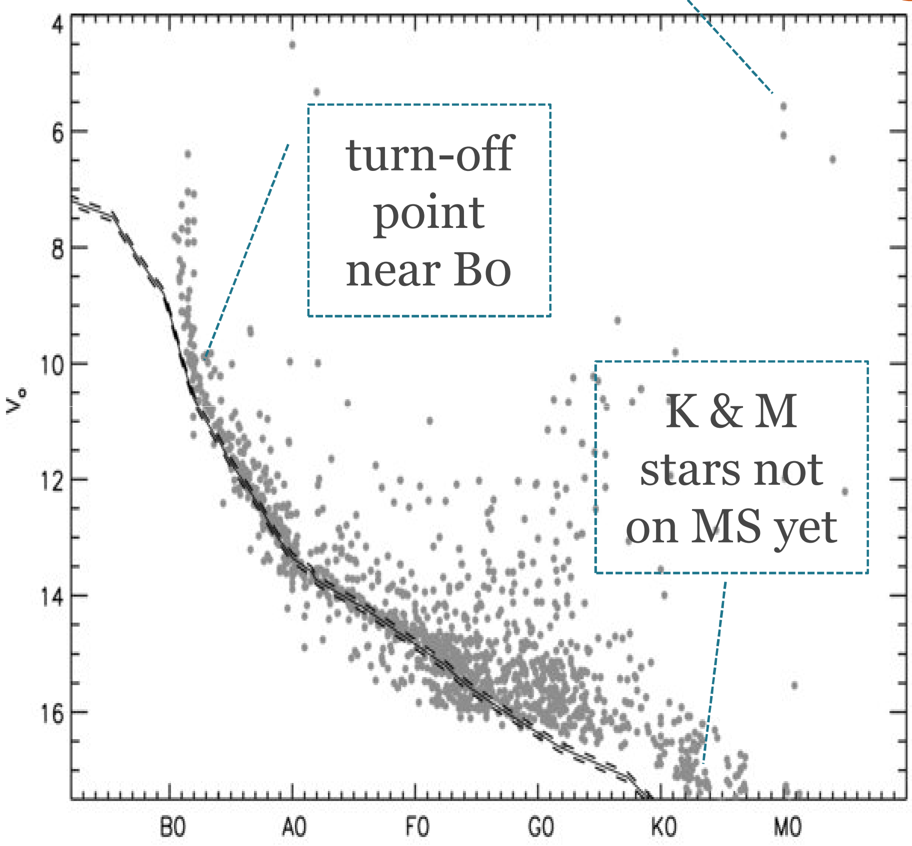
- Key variable is *mass* of star
  - directly measured only for binary stars, but it determines position on main sequence



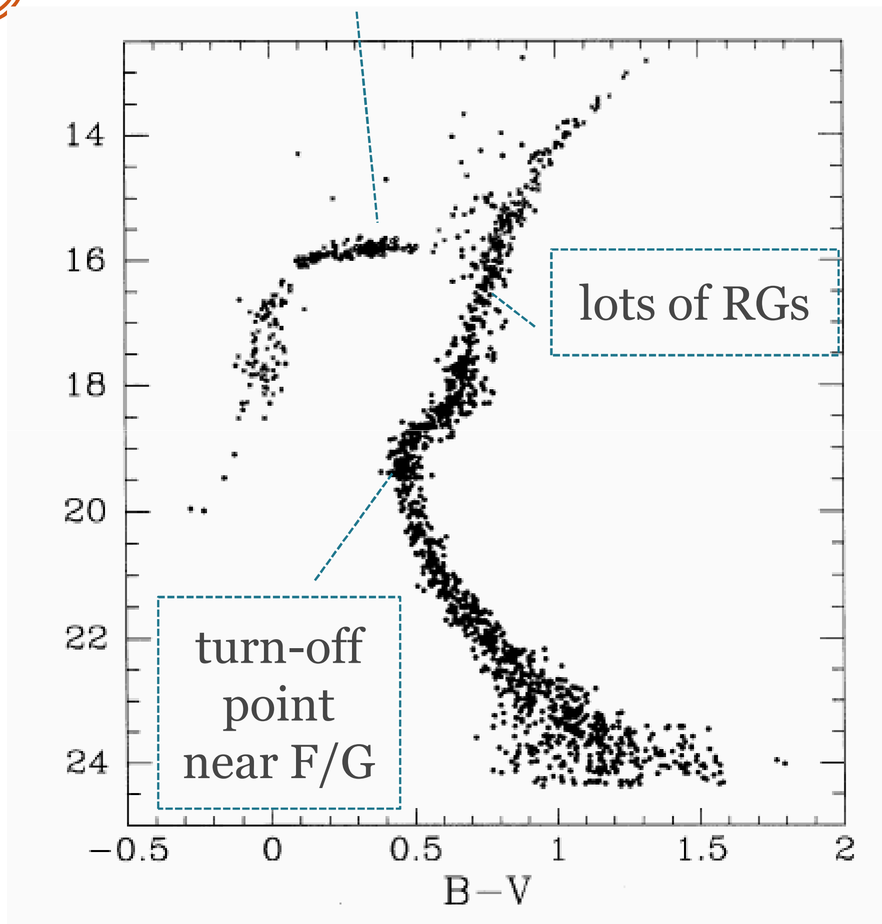
Cluster ages

- Main-sequence luminosity increases *much* faster than mass
  - therefore massive stars use up their fuel much faster
  - therefore their lifetimes on main sequence are much shorter
  - therefore age of cluster can be found from the location of the *top* of its main sequence
    - confirm this with the length and strength of the red giant branch: the longer the RGB and the further down it goes, the older the cluster
  - any HR diagram showing *both* a clear upper main sequence *and* a long red giant branch is not a single-age population
    - but in real HR diagrams don’t be fooled by scattered bad measurements/foreground stars

Examples

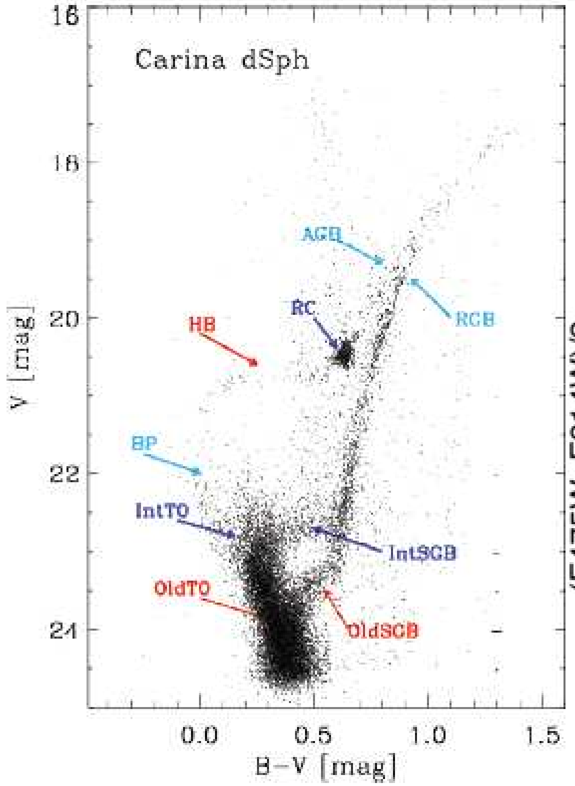


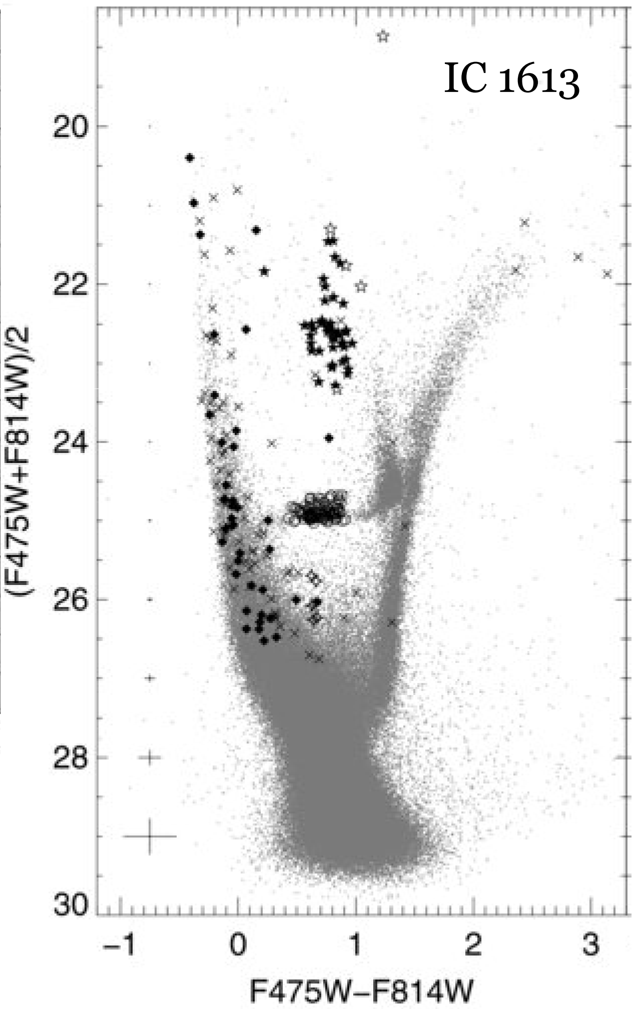
Very young cluster h & χ Persei

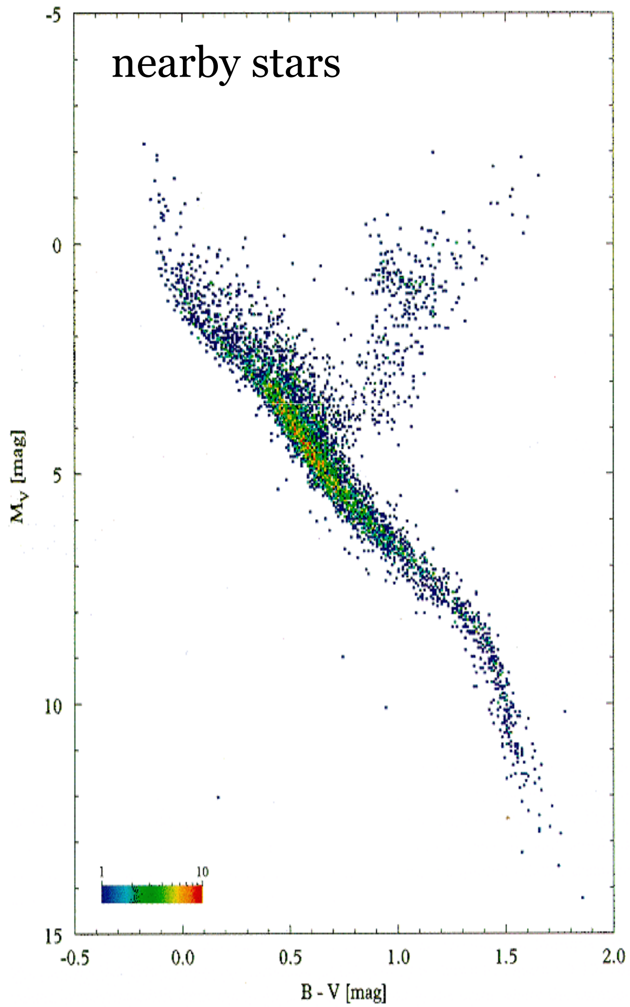


Globular cluster M15

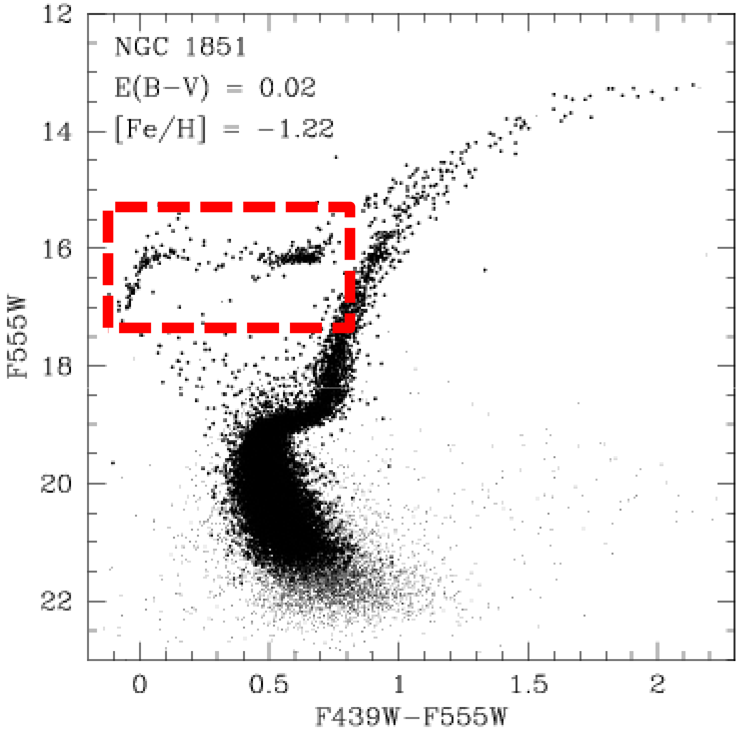
Examples

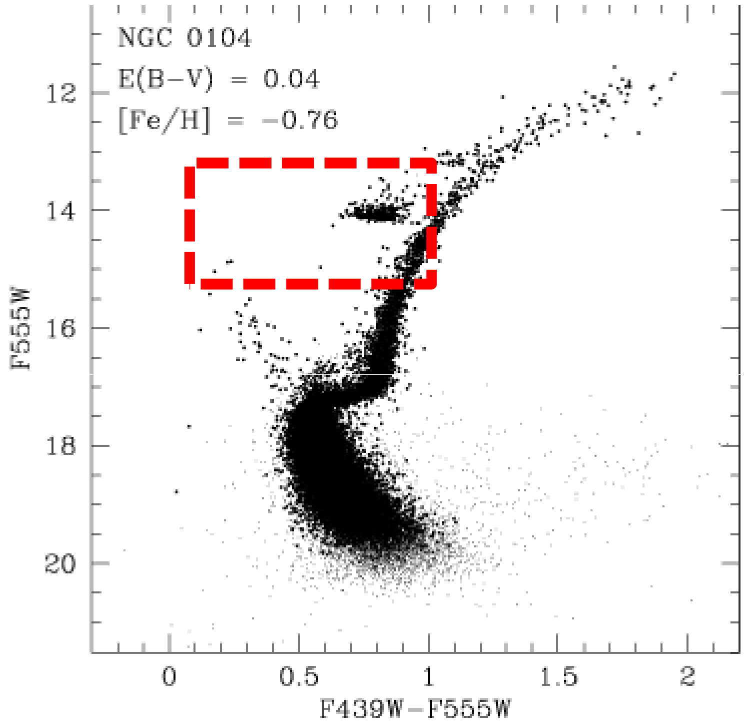

Carina dSph
AGB
RC
RGB
HB
BP
IntTO
IntSGB
OldTO
OldSGB
V [mag]
B−V [mag]
16
18
20
22
24
0.0
0.5
1.0
1.5


IC 1613
(F475W+F814W)/2
F475W−F814W
20
22
24
26
28
30
−1
0
1
2
3


nearby stars
M_V [mag]
B - V [mag]
-5
0
5
10
15
-0.5
0.0
0.5
1.0
1.5
2.0
1
10

Effect of heavy element content

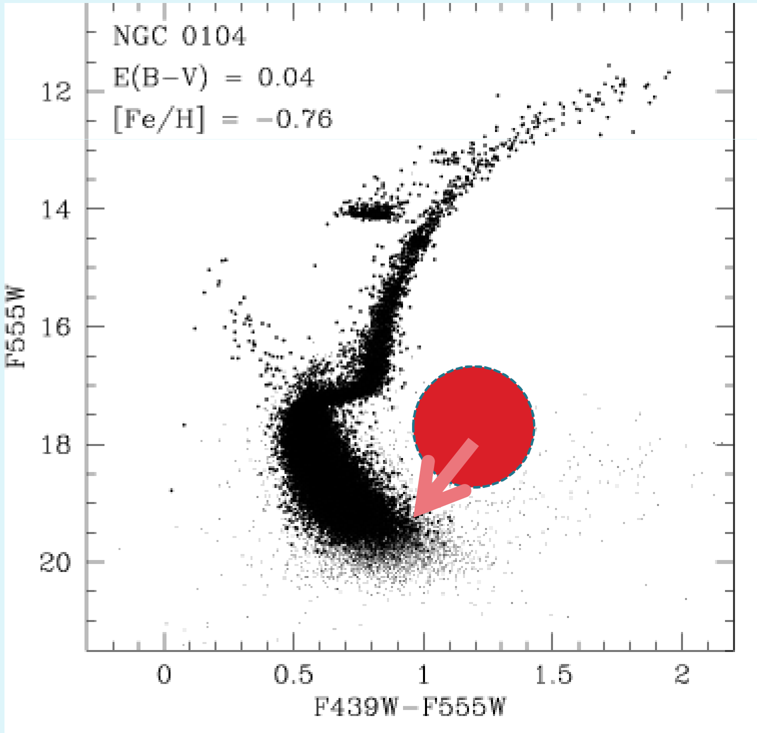




Horizontal branch extends further to the left for lower (initial) heavy element content

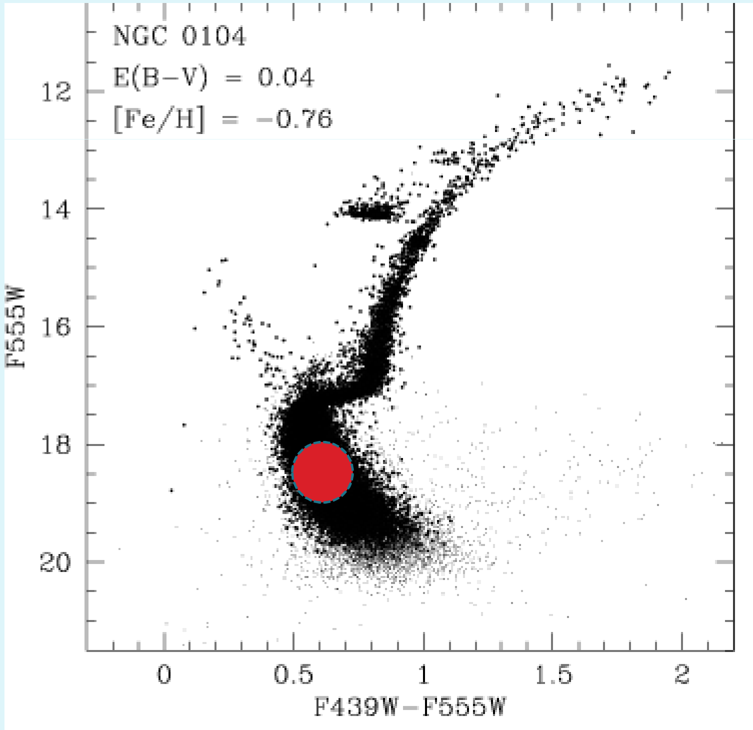
Stellar evolution

- Step 0: pre main sequence
  - gas cloud collapses under gravity
    - this will make it spin faster and form a disc (later planets)
    - lost gravitational potential energy is partly converted to internal heat and partly radiated away
    - star is large, cool and quite luminous
  - eventually core gets hot enough to fuse hydrogen
    - star has reached main sequence



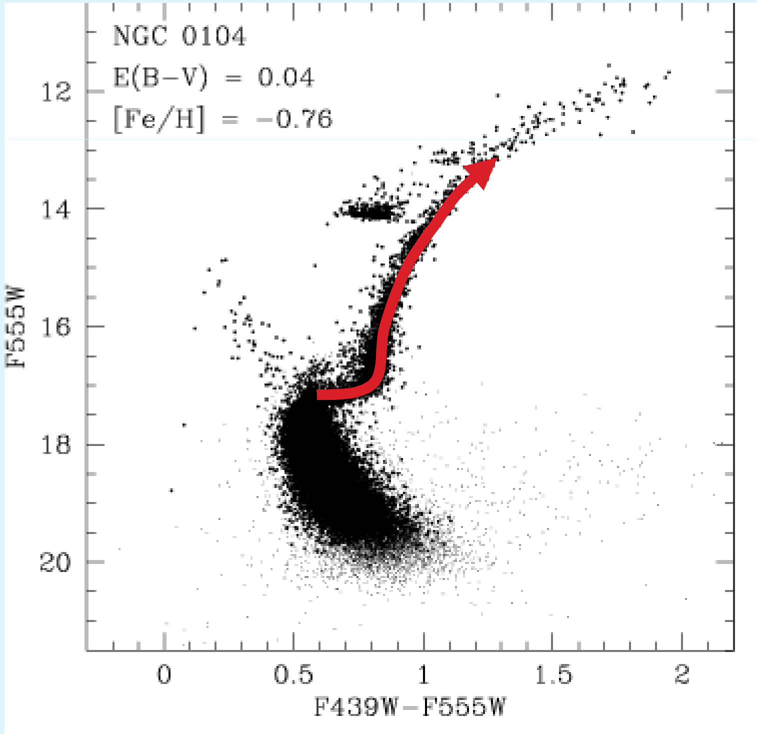
Stellar evolution

- Step 1: main sequence
  - fusing hydrogen to helium in core
    - star will spend ~90% of its lifetime here
    - luminosity and colour (surface temperature) depend on mass
    - more massive star will be hotter and much brighter ($L \propto M^{3.5}$ or so)
    - surface temperature and chemical composition can be determined from spectrum
  - eventually core hydrogen will run out



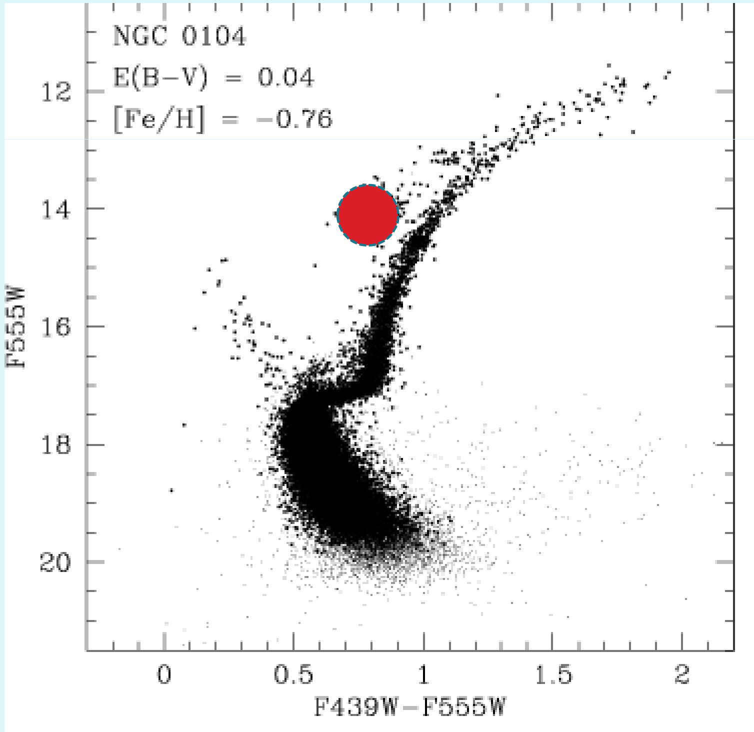
Stellar evolution

- Step 2: subgiant and red giant
  - fusing hydrogen to helium in shell around helium core
    - this is not a stable situation
    - H fusing shell gets hotter, generates more energy and pressure
    - star expands, cools and gets brighter
    - moves along subgiant branch and up red giant branch
  - eventually core helium gets hot enough to fuse
    - note star does **not** run out of H!



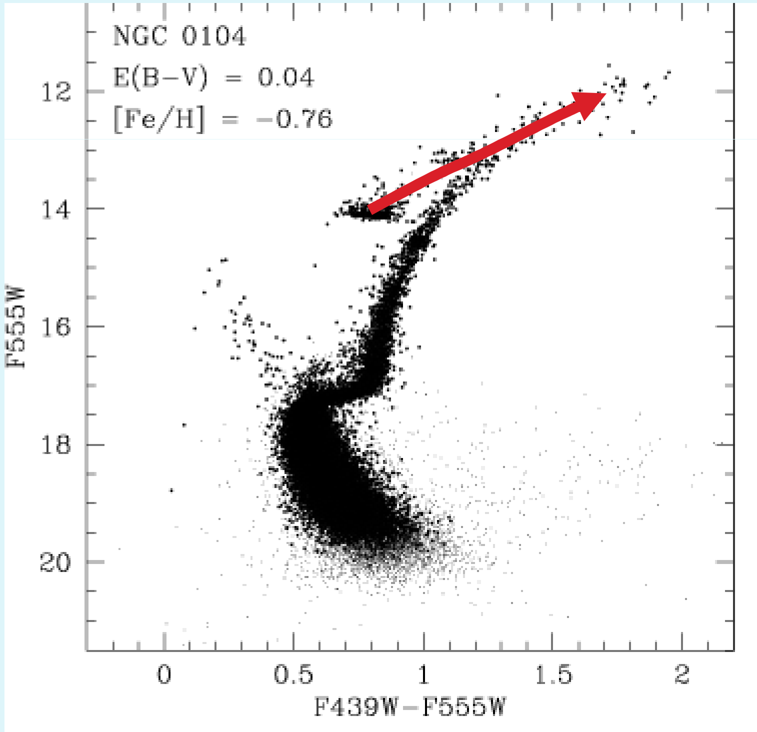
Stellar evolution

- Step 3: horizontal branch
  - fusing helium to carbon in core
    - position depends on (initial) heavy element content
    - lower-metallicity stars hotter
    - stable, but lasts <10% as long as main sequence because helium fusion is only 10% as efficient (and star is brighter now)
  - eventually core helium will run out



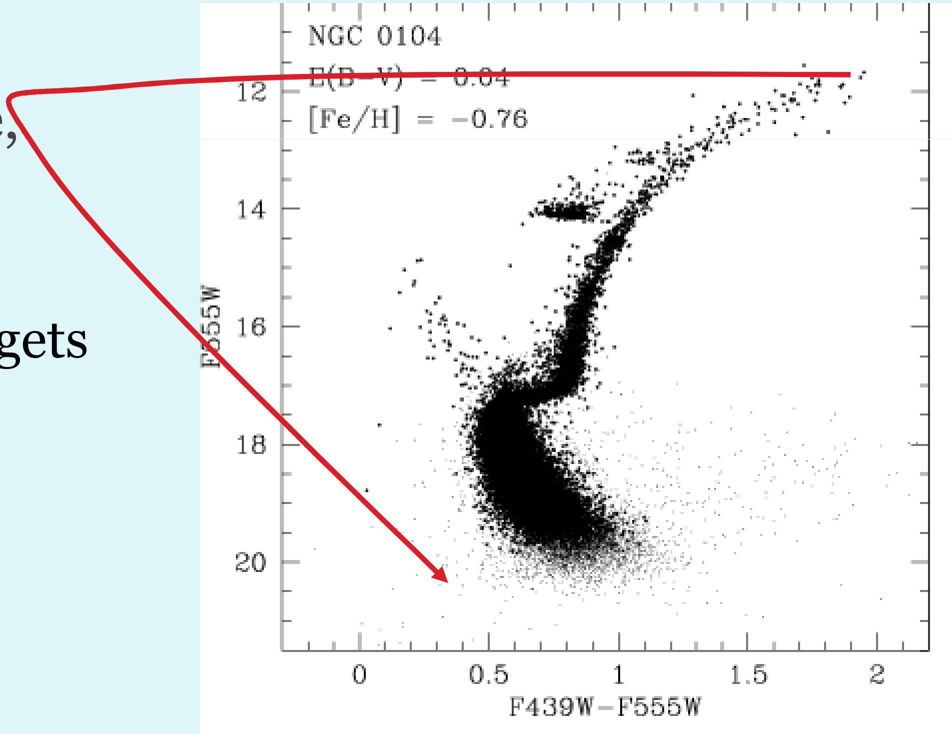
Stellar evolution

- Step 4: second red giant branch (asymptotic GB)
  - fusing helium to carbon in shell around carbon core
    - very unstable indeed
    - later, hydrogen fusion turns on again in second shell
    - very severe mass loss in stellar wind
  - eventually all outer layers are blown off, causing fusion to stop and leaving very hot carbon core



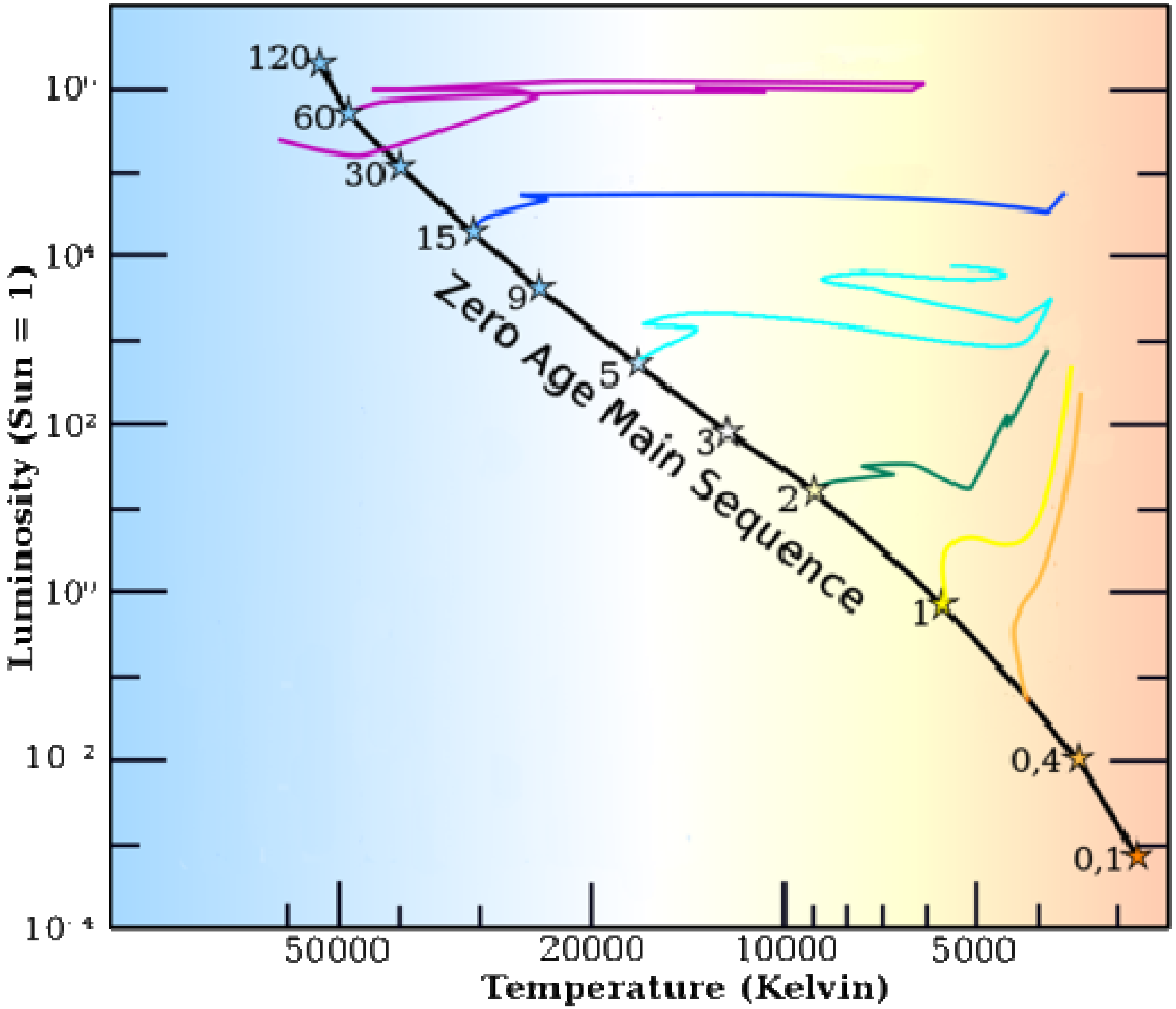
Stellar evolution

- Step 5: planetary nebula and white dwarf
  - carbon core will ionise and excite surrounding gas, making it glow
    - planetary nebula
  - gas will eventually dissipate, leaving behind small, hot white dwarf
    - which will just cool off as it gets older



Massive stars

- Differences from lower-mass (<8 solar masses)
  - much shorter lifetime
  - luminosity **does not change much** as they evolve (though colour does)
  - after He fusion, will repeat process with steadily heavier elements until iron core forms
  - iron fusion does not generate energy, so collapse of iron core is catastrophic
  - core produces neutron star or black hole, rest of star bounces off core to produce supernova explosion


Zero Age Main Sequence
120
60
30
15
9
5
3
2
1
0,4
0,1
Luminosity (Sun = 1)
10^4
10^2
50000
20000
10000
5000
Temperature (Kelvin)