Probing the evolution of stellar systems

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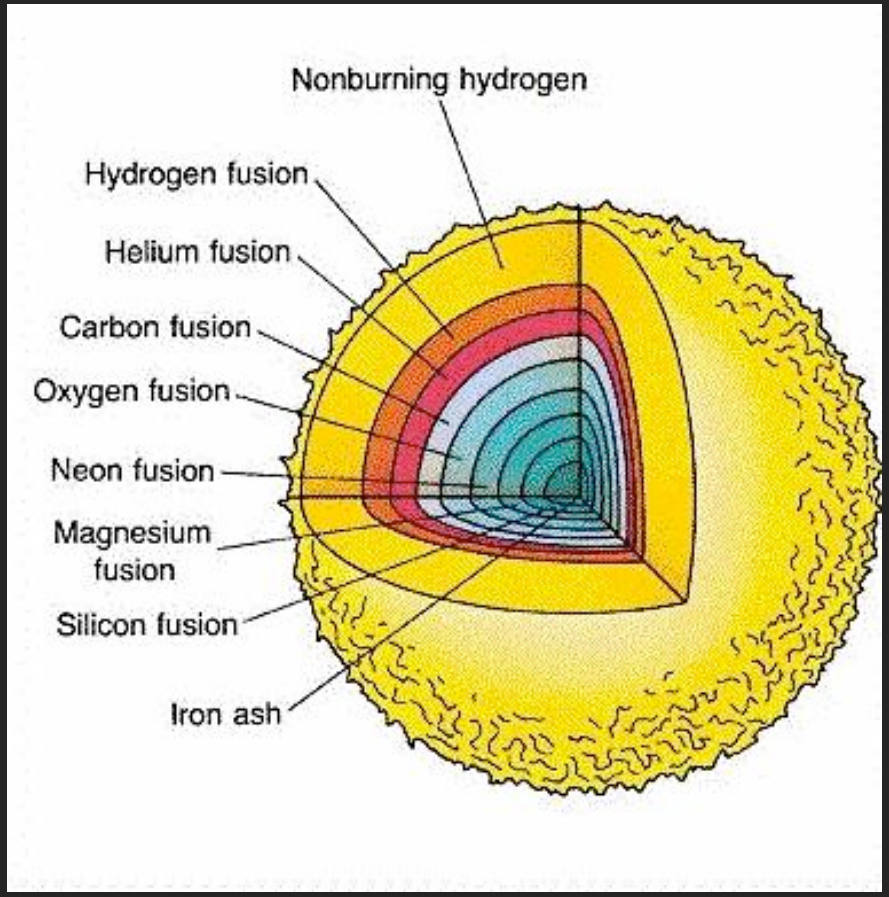
The lives of stars : fighting against gravity

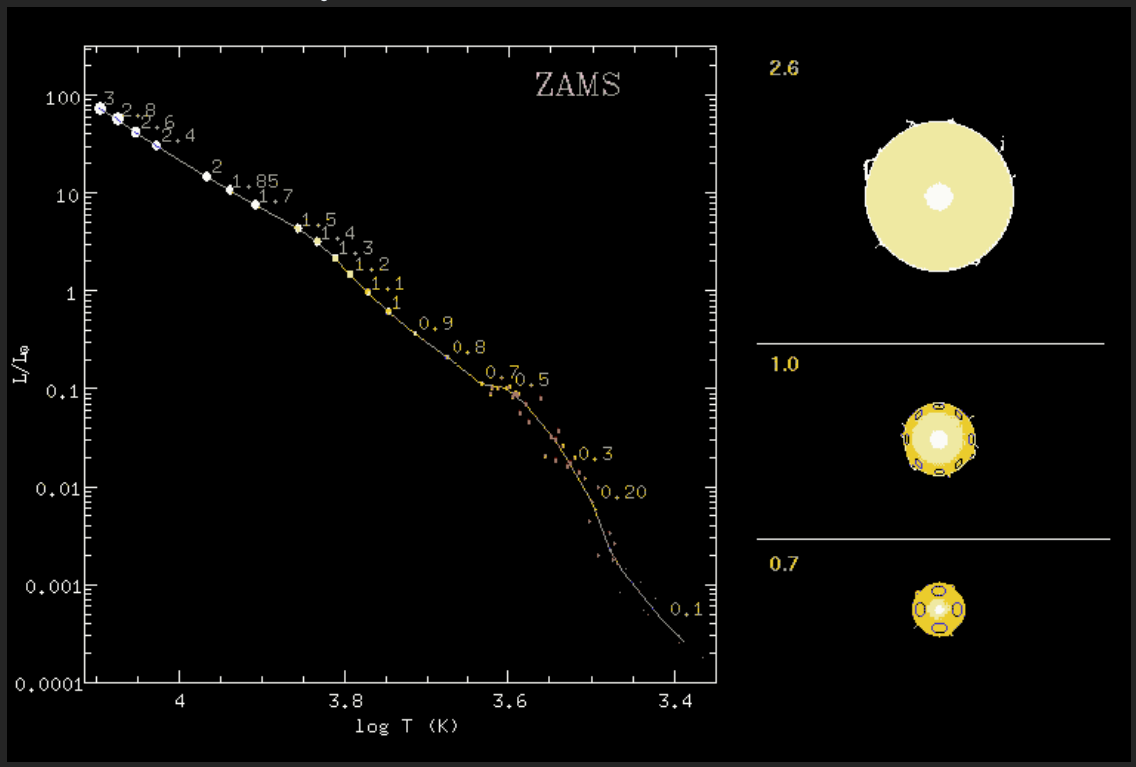
- Defining parameter :
  Mass

- To avoid implosion stars must generate energy from fusion reactions

- The stages of stars are determined by the type of fuel left:
  hydrogen, helium, carbon etc



The complicated lives of stars



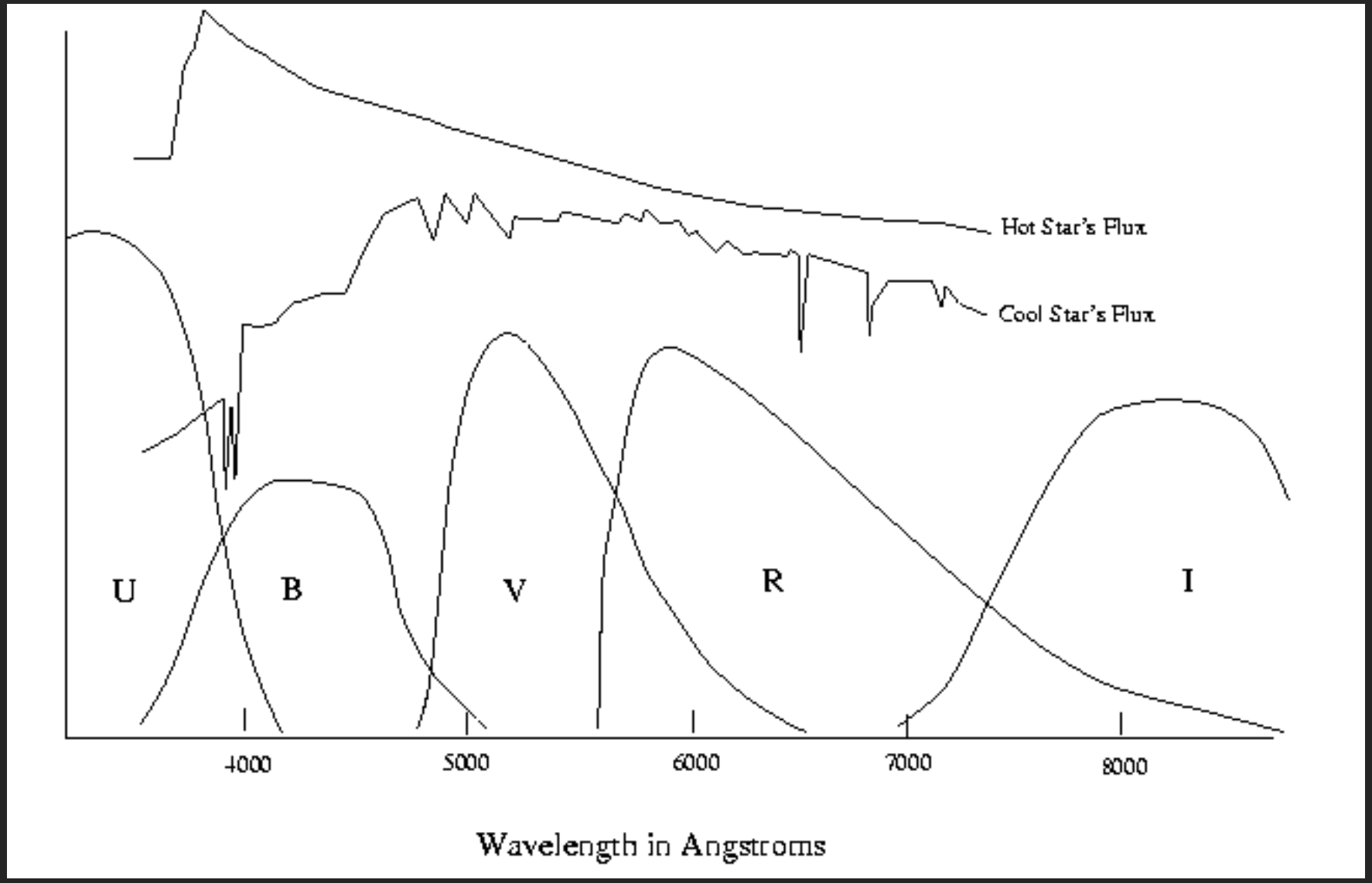
… but, after some time they run out of fuel

White dwarf (≤8 $M_\odot$)

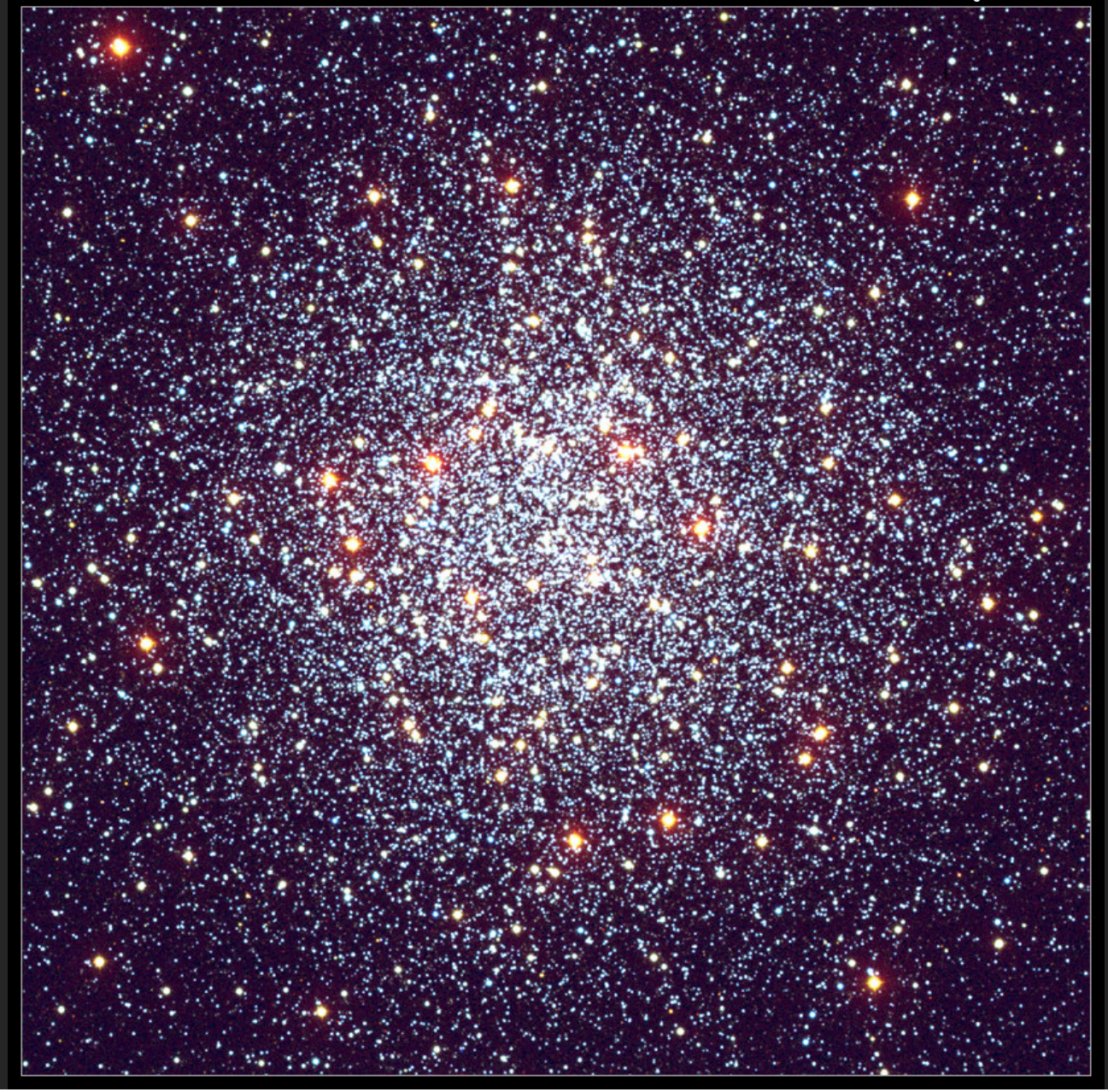
Supernova (≥8 $M_\odot$) → Neutron star (M~1.4-3.0 $M_\odot$)

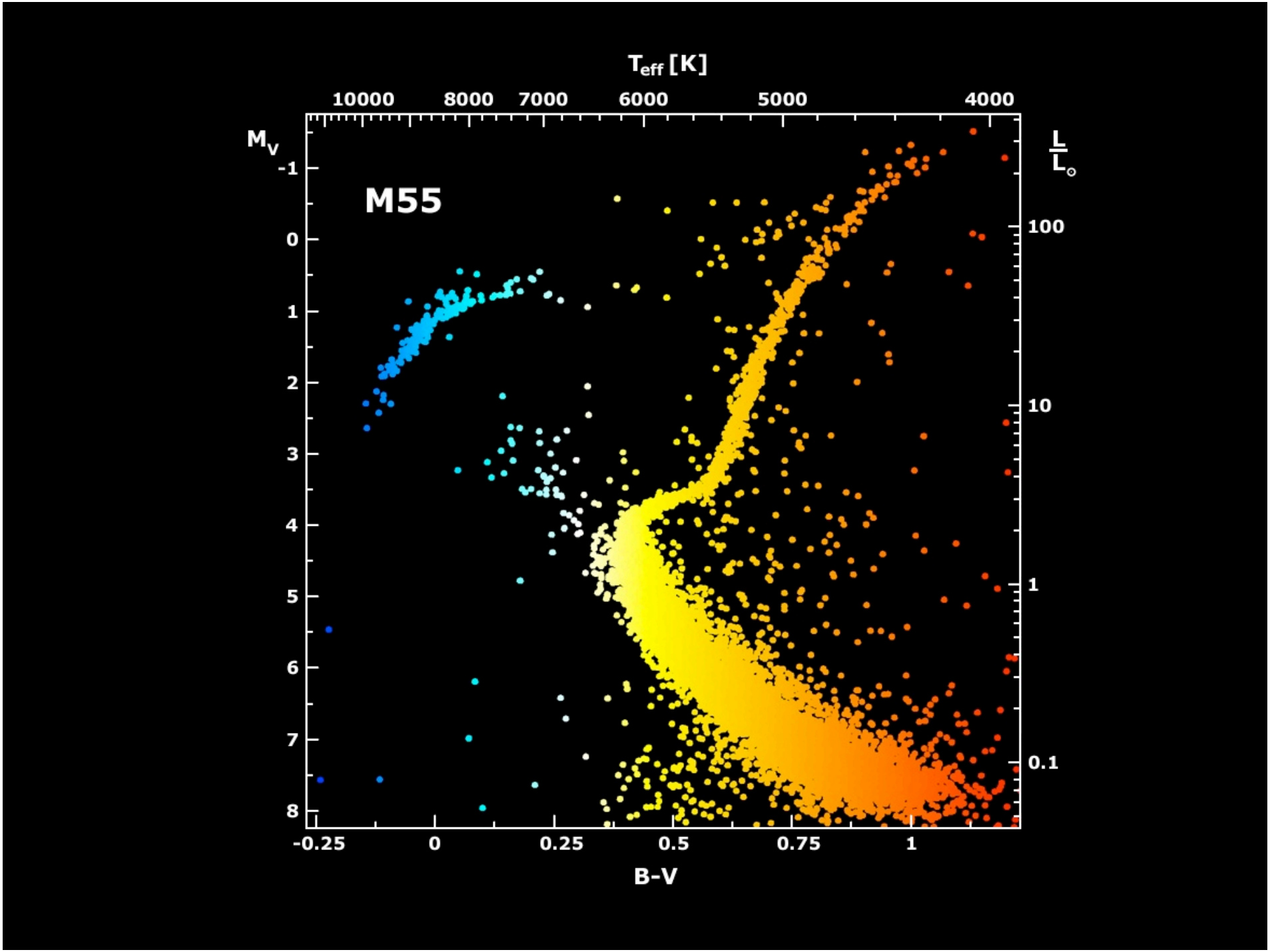
→ Black-hole (M >3.0 $M_\odot$)

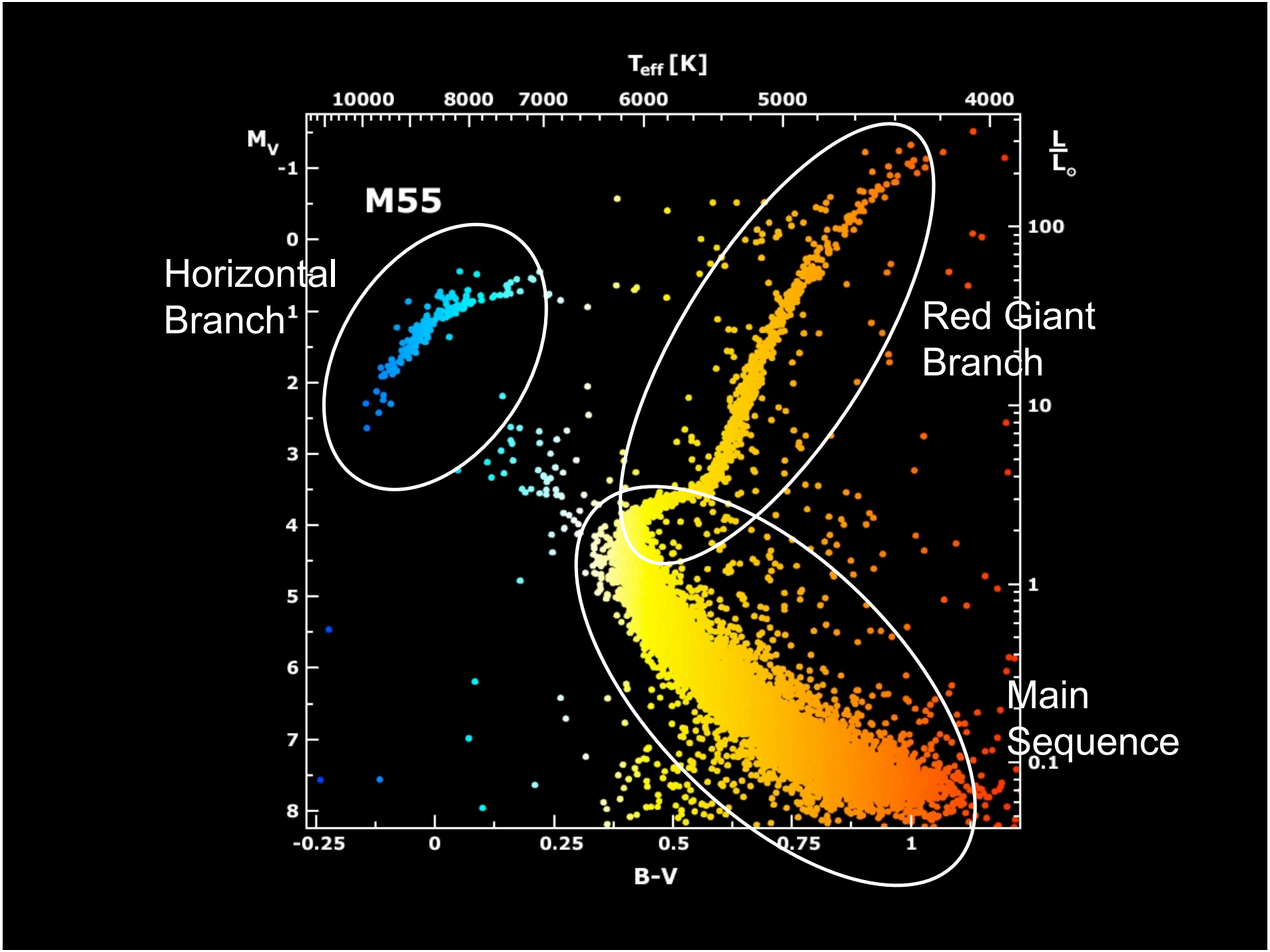
Basic tool : Photometry



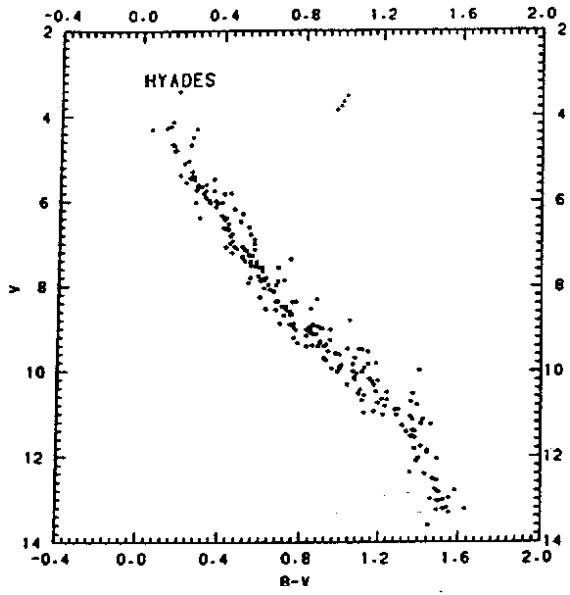
Basic tool : Photometry

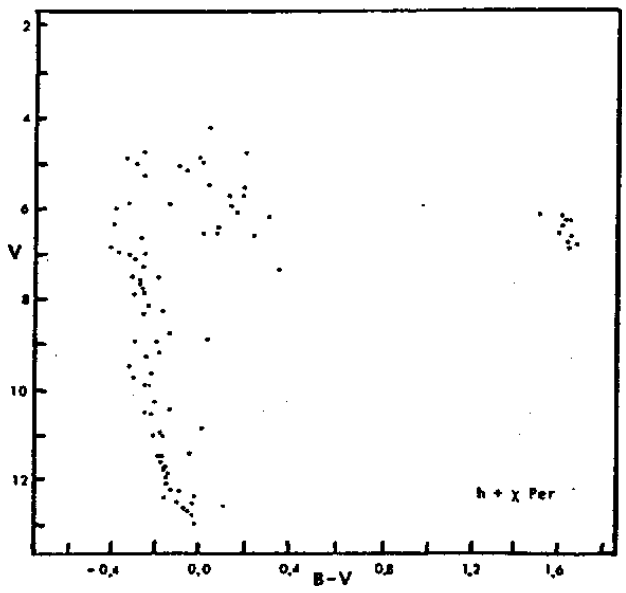


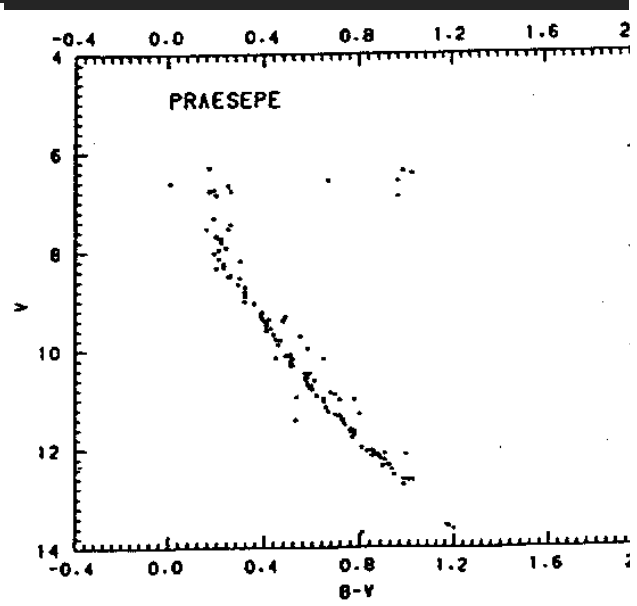

M55
T_{eff} [K]
10000
8000
7000
6000
5000
4000
M_V
-1
0
1
2
3
4
5
6
7
8
$\frac{L}{L_\odot}$
100
10
1
0.1
-0.25
0
0.25
0.5
0.75
1
B-V

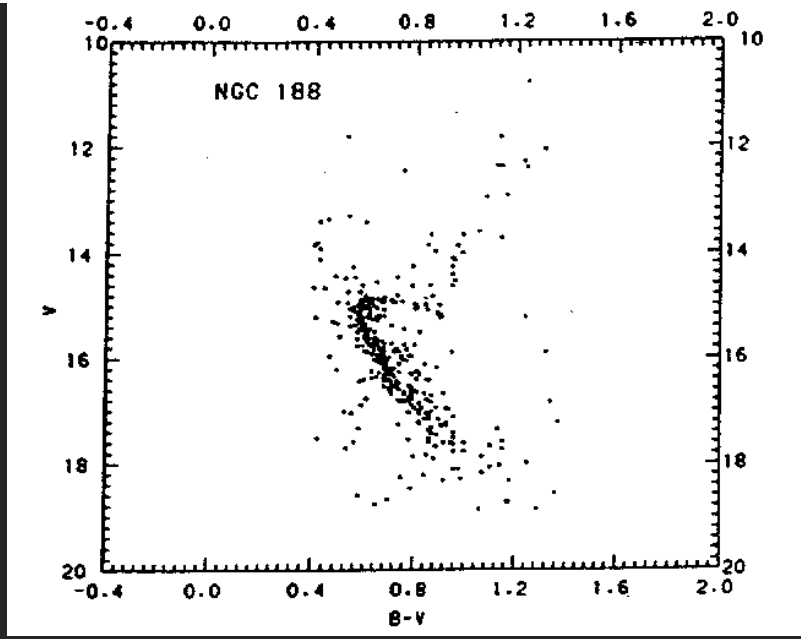

T_{eff} [K]
10000
8000
7000
6000
5000
4000
M_V
-1
0
1
2
3
4
5
6
7
8
$\frac{L}{L_\odot}$
100
10
1
0.1
M55
Horizontal Branch
Red Giant Branch
Main Sequence
-0.25
0
0.25
0.5
0.75
1
B-V

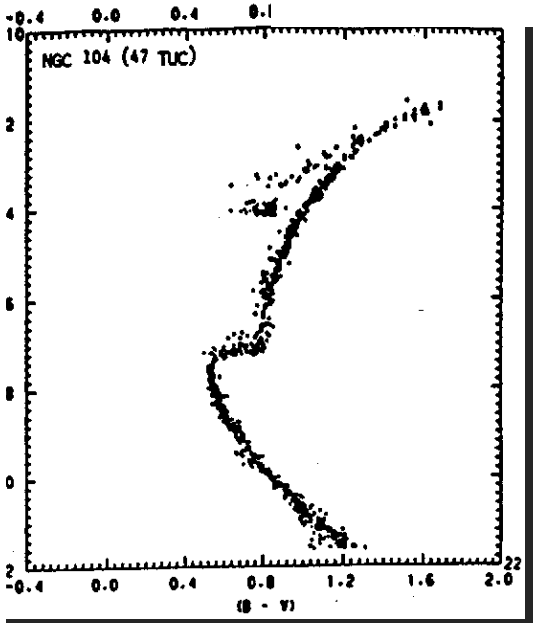
CMDs : Simple cases



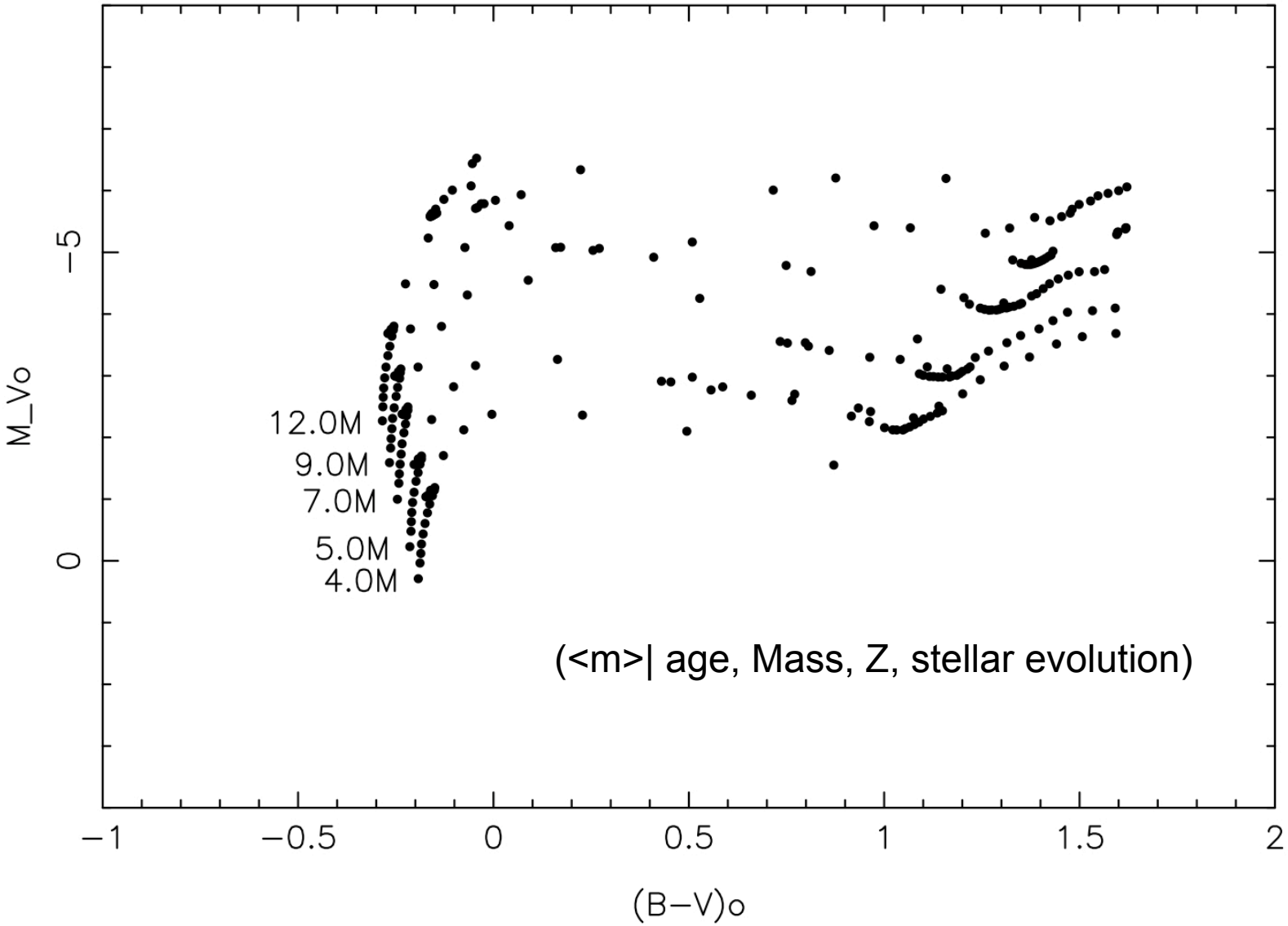






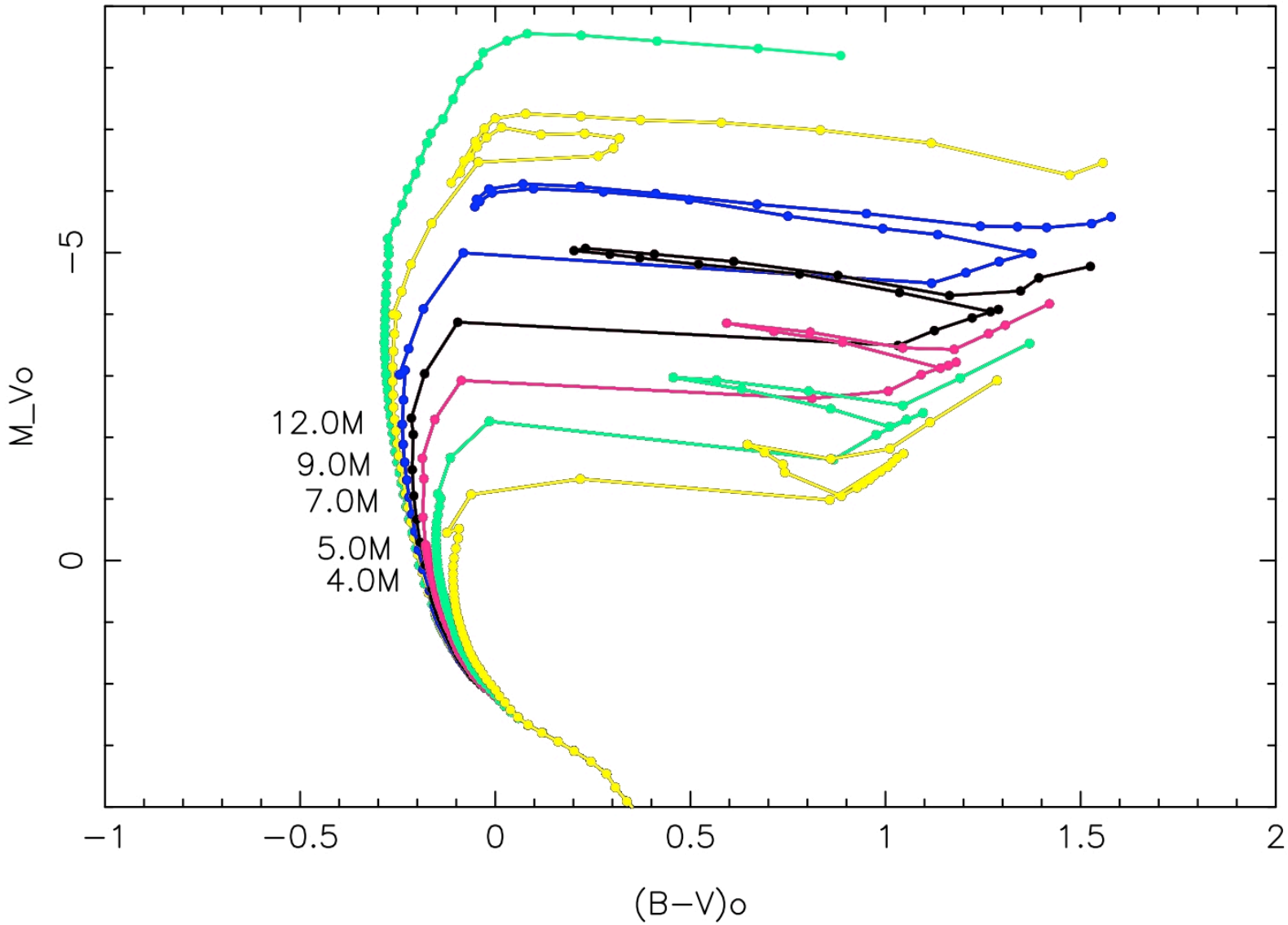


The tools : Stellar Tracks

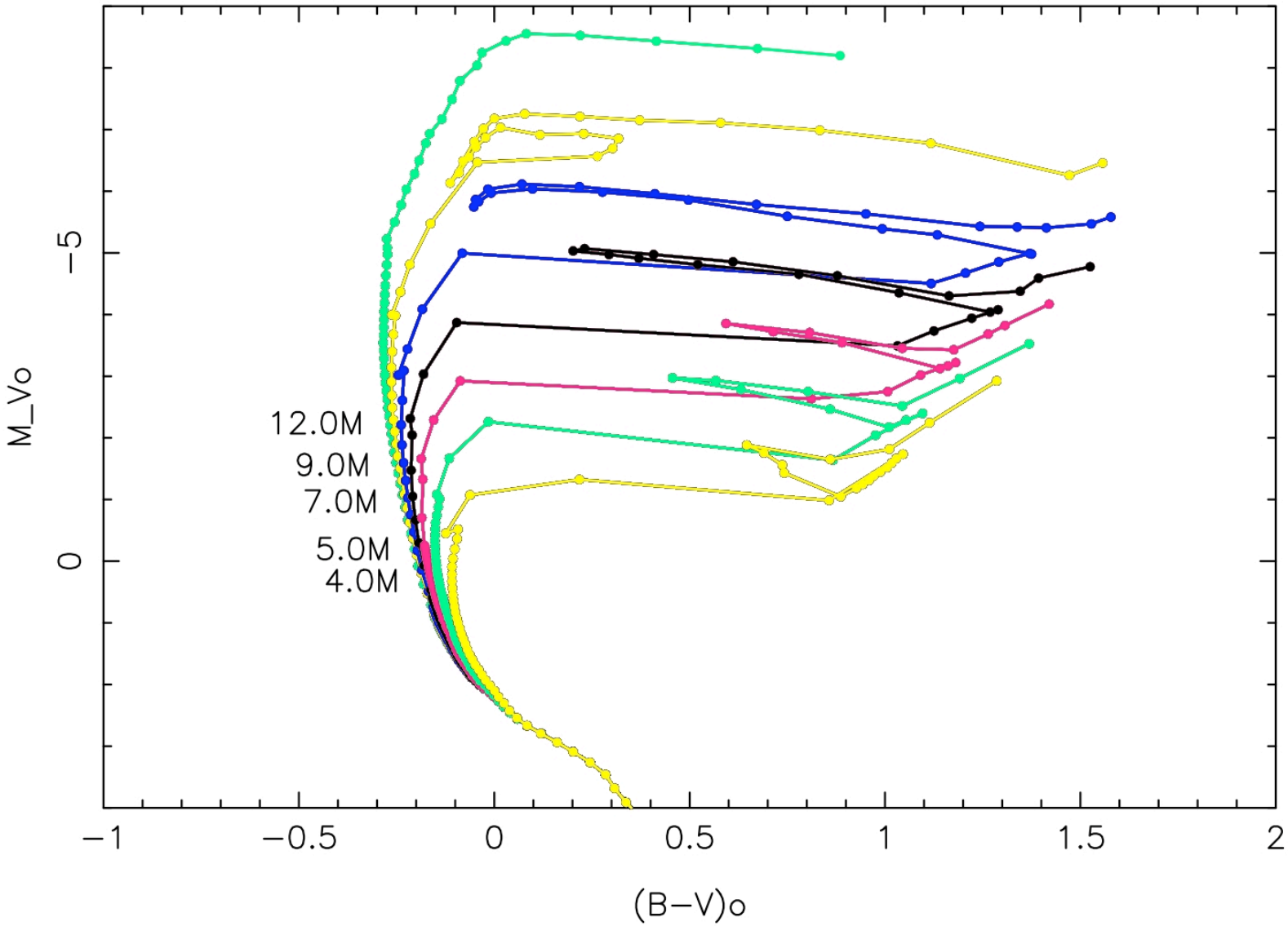


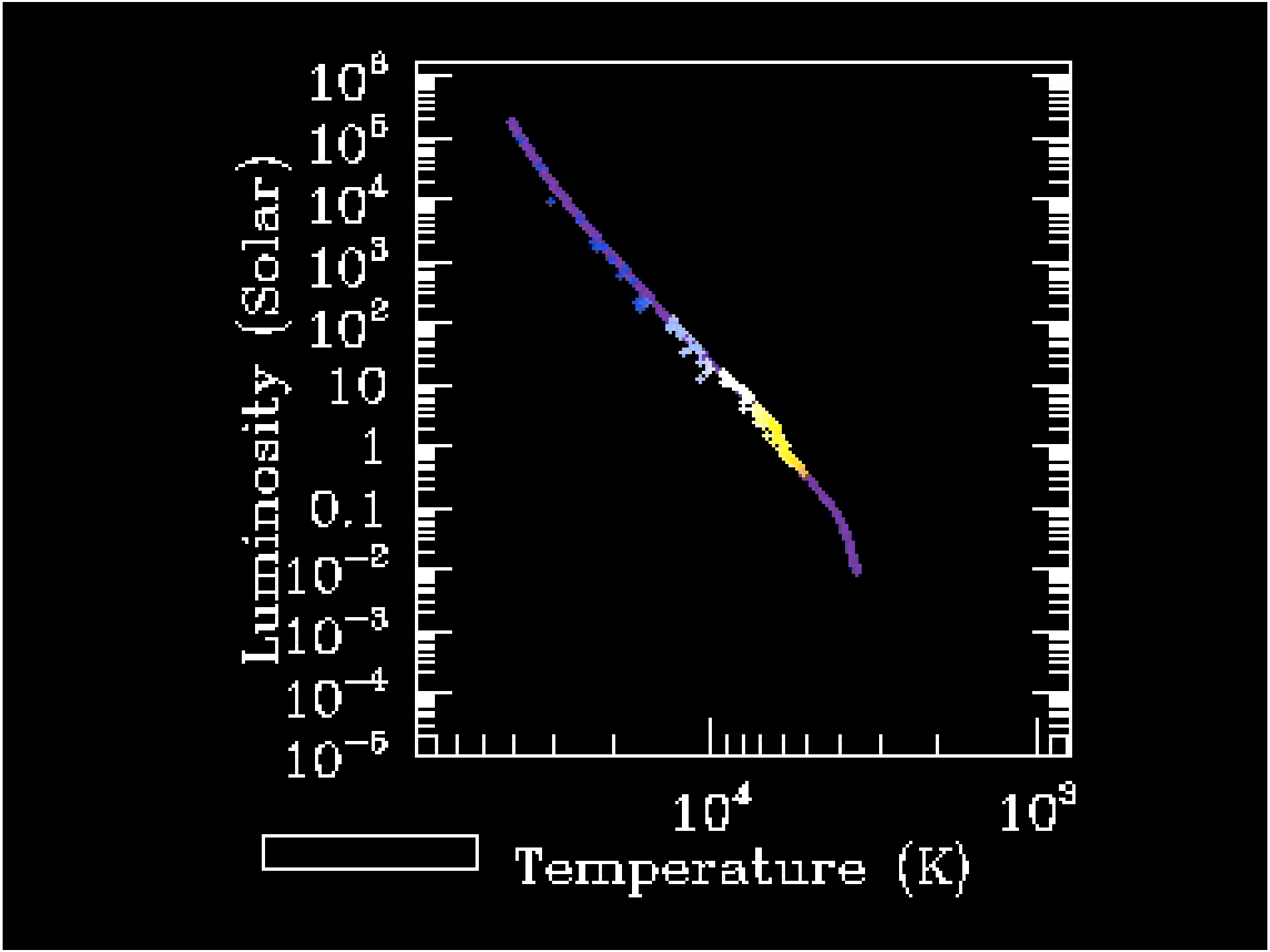
(<m>| age, Mass, Z, stellar evolution)

The tools : Isochrones



The tools : Isochrones




Luminosity (Solar)
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
10
1
0.1
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{4}
10^{3}
Temperature (K)

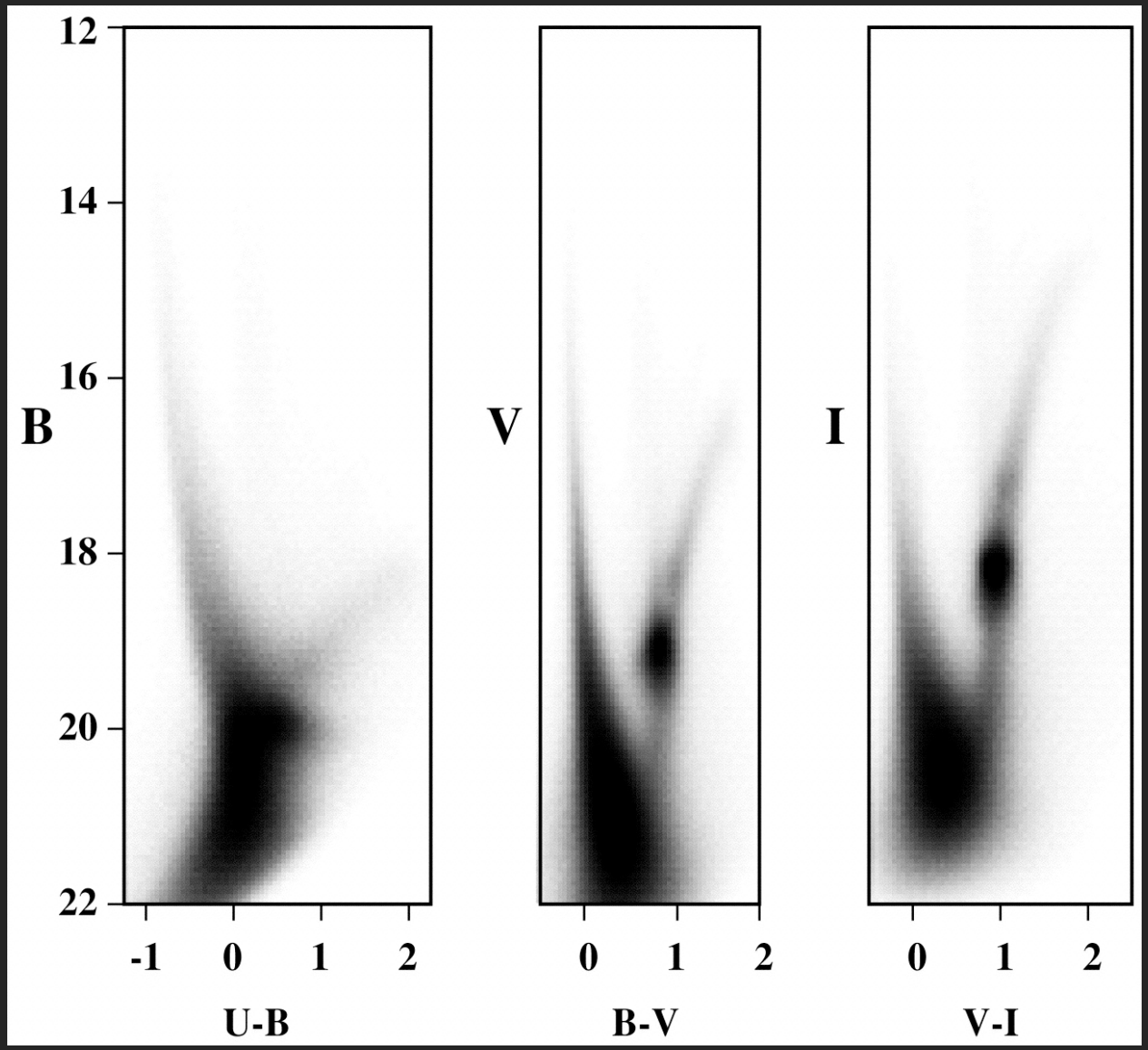
The recipe

- Assume a star-formation scenario (model)
- Take some isochrones (calibration)
- Weight them by the IMF : $N \propto M^{-\Gamma}$
- Mix them
- Simulate (include observational biases)
- Compare with observed CMD

Analogy with X-rays

- Isochrones ≡ RMF
- Detection probability ≡ ARF

The "standard method"



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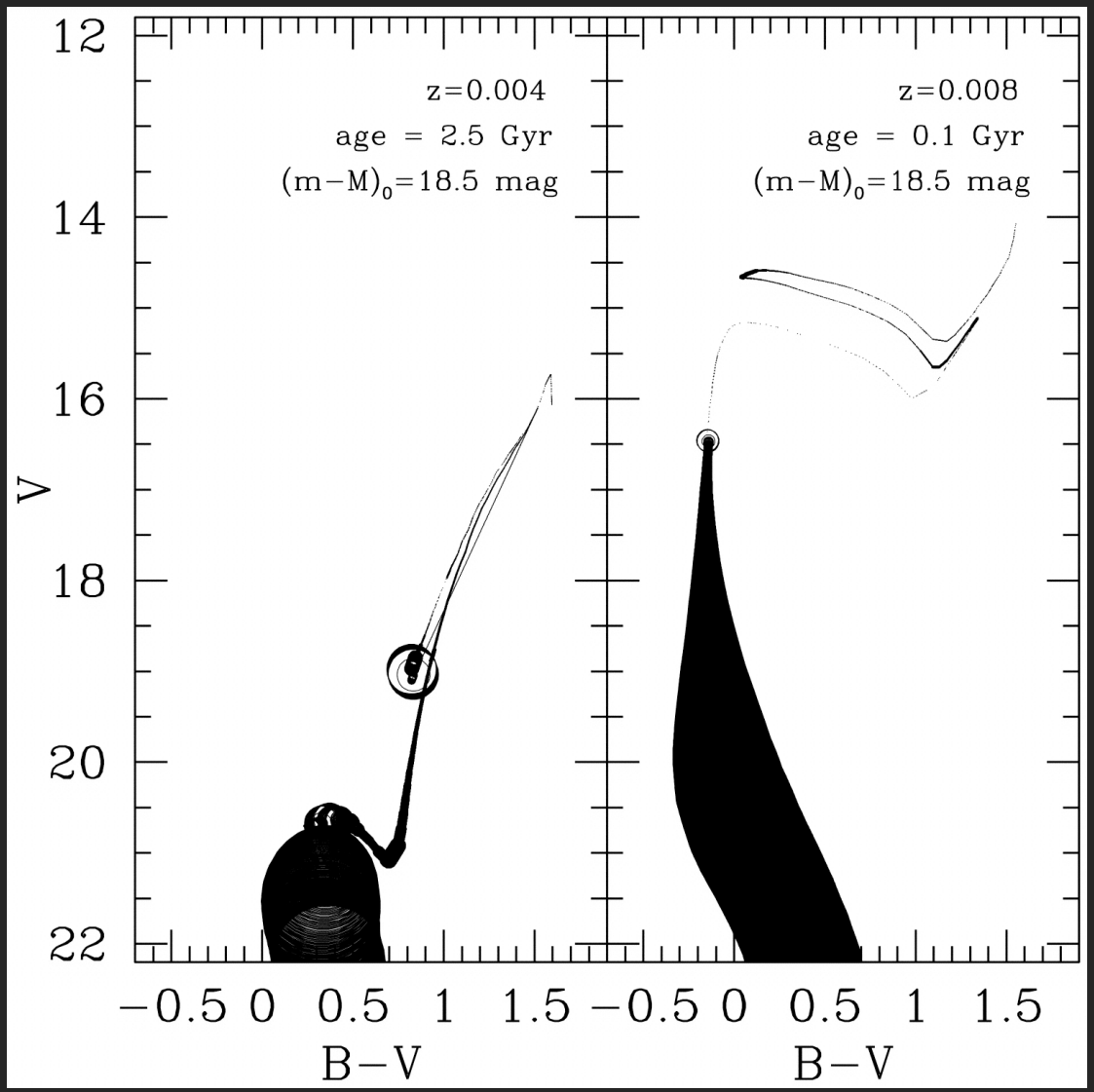
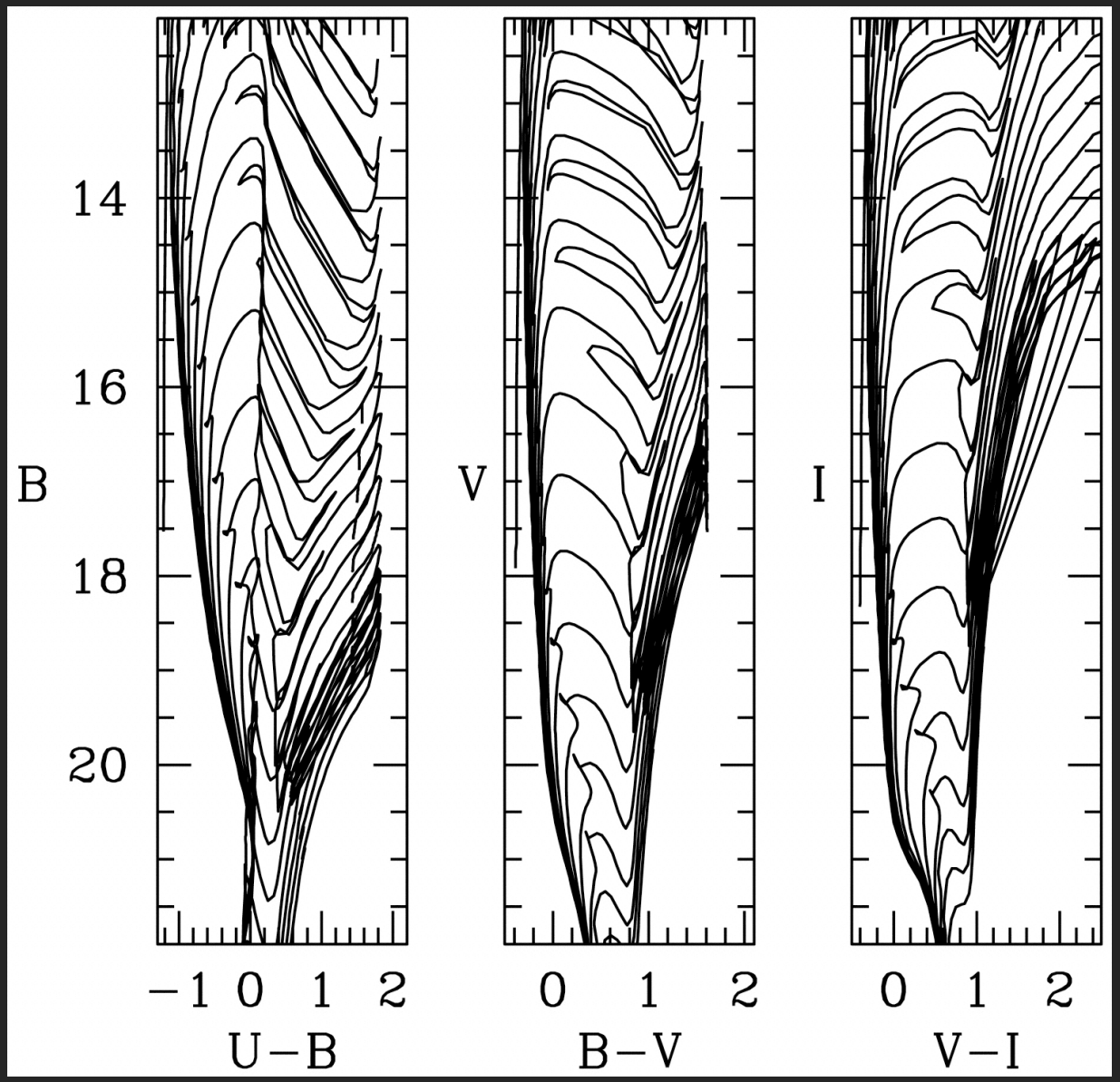


The "standard method"



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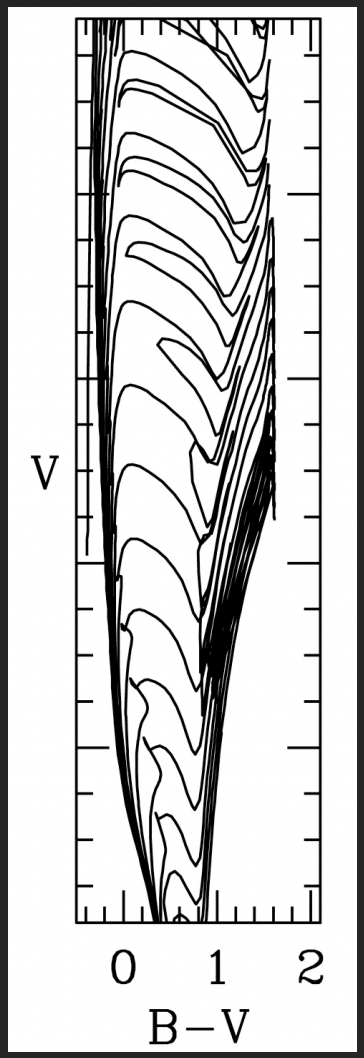
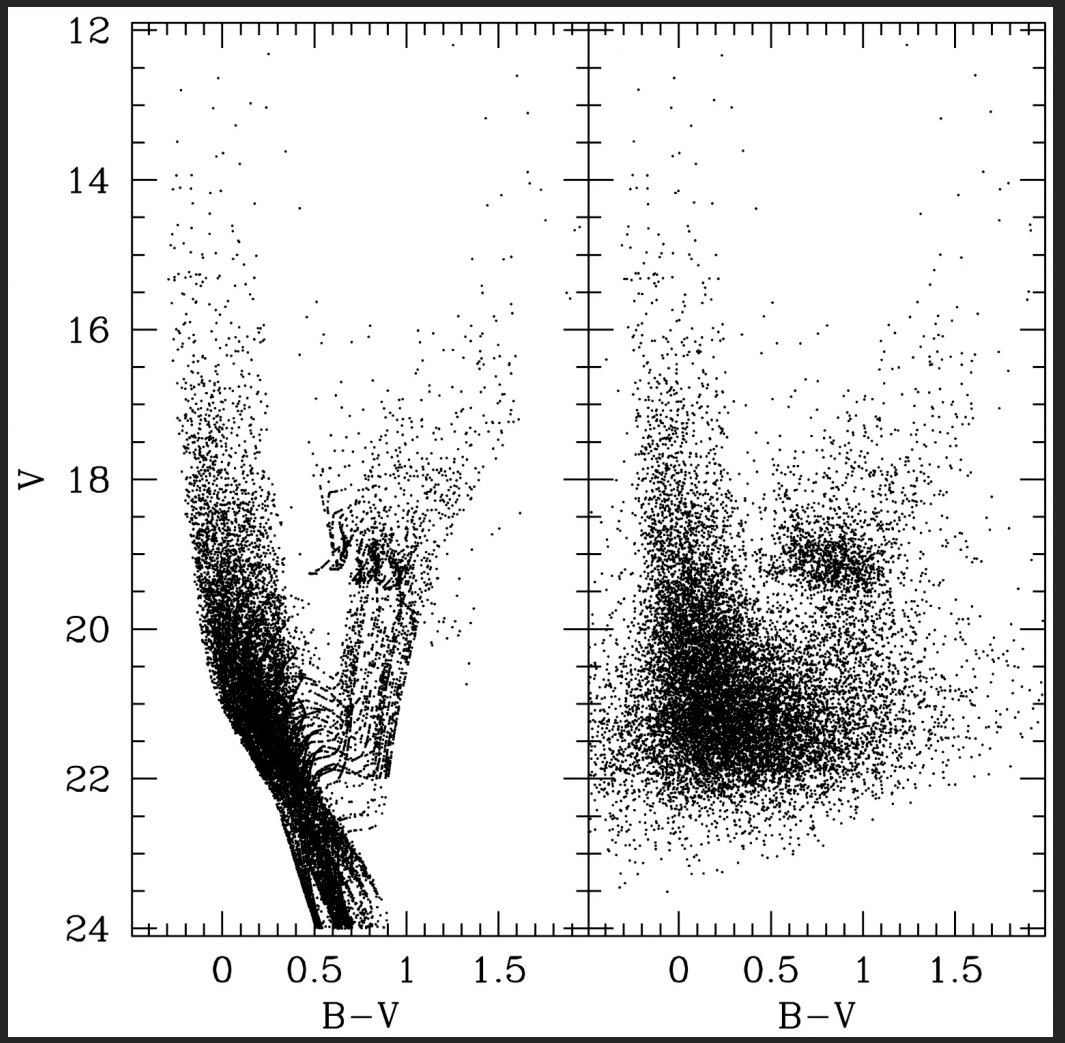
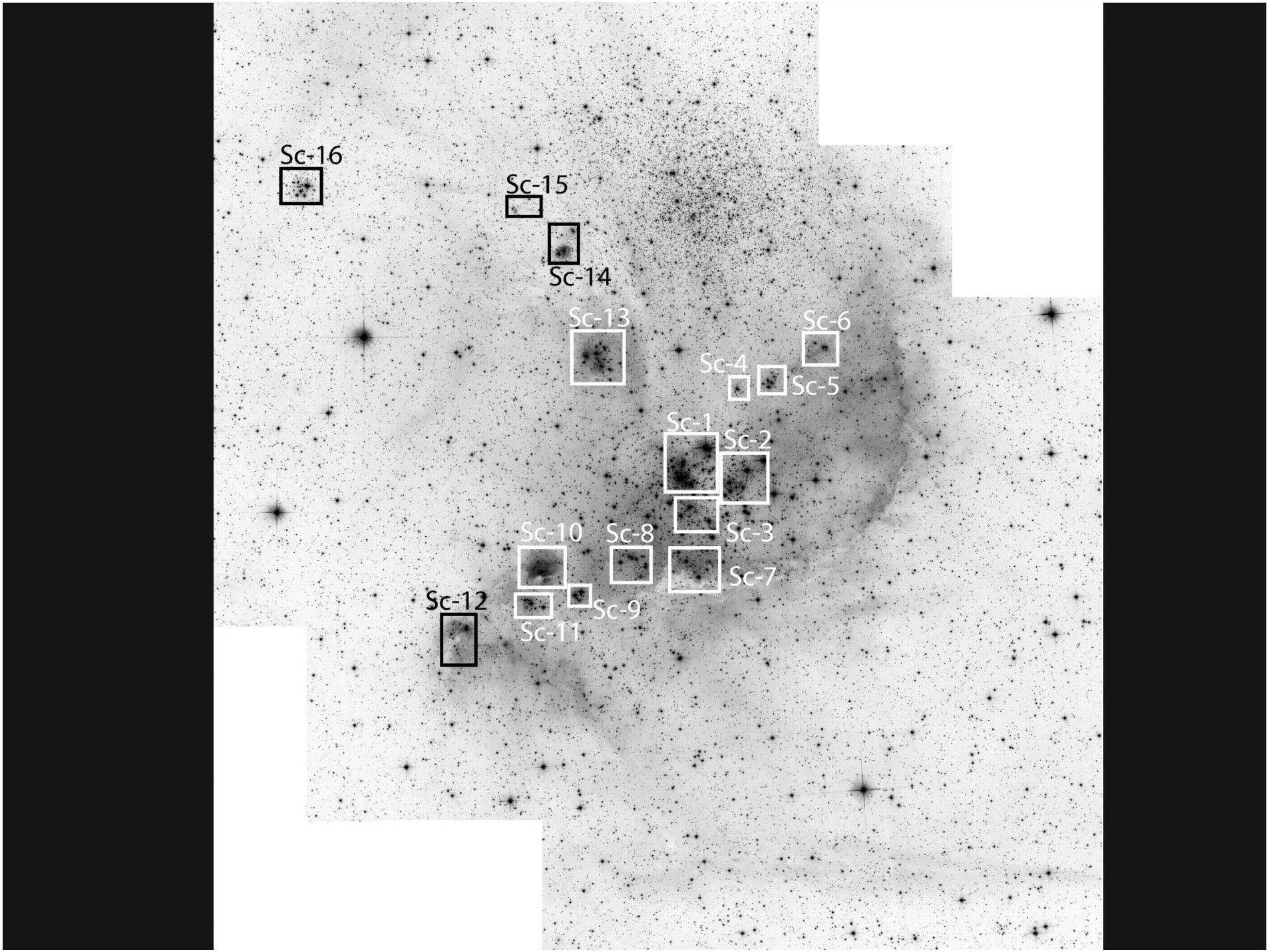


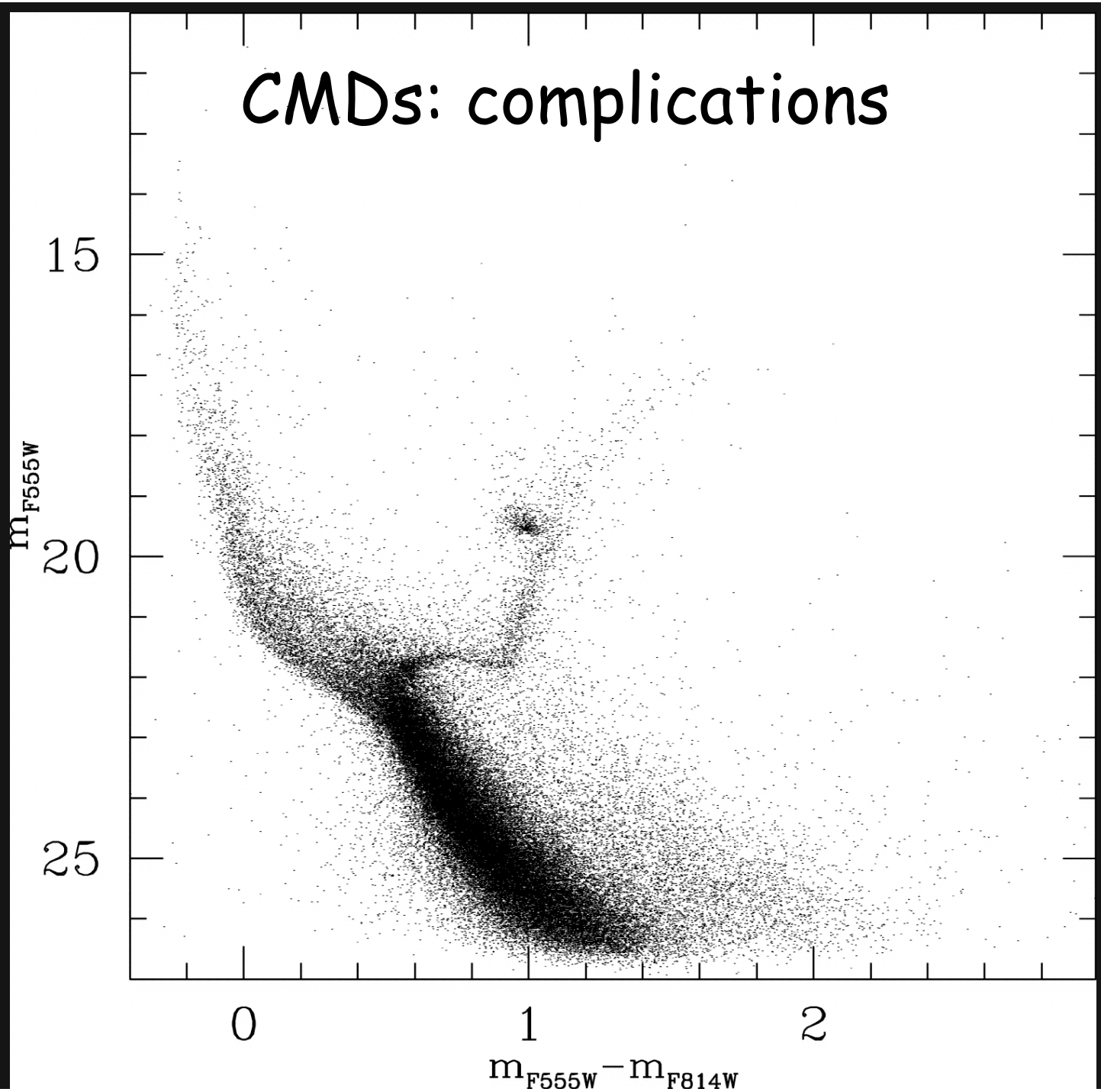


Complications

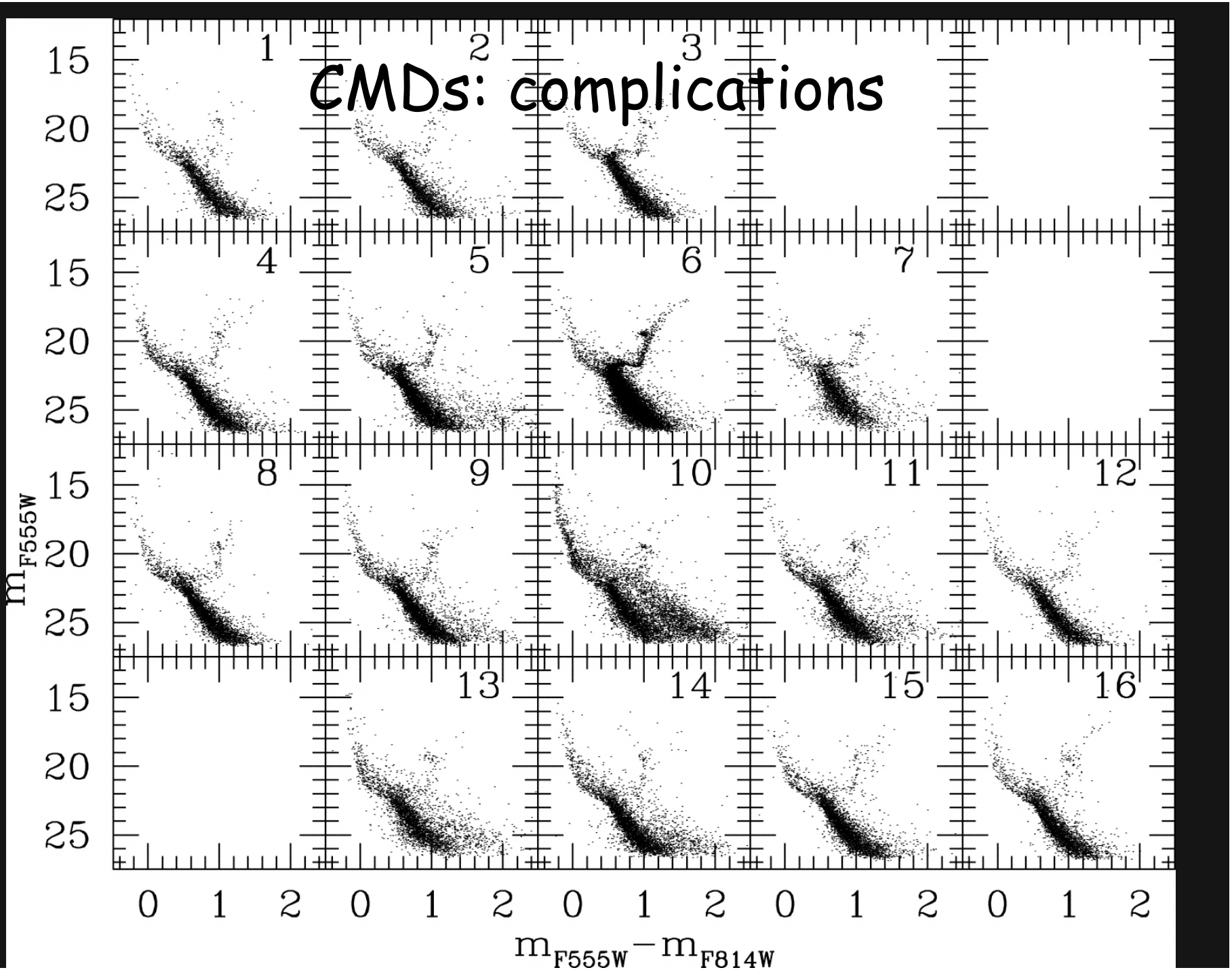
- Incompleteness
- Multiple populations
- Uncertainties on isochrones


Sc-16
Sc-15
Sc-14
Sc-13
Sc-6
Sc-4
Sc-5
Sc-1
Sc-2
Sc-3
Sc-10
Sc-8
Sc-7
Sc-12
Sc-9
Sc-11

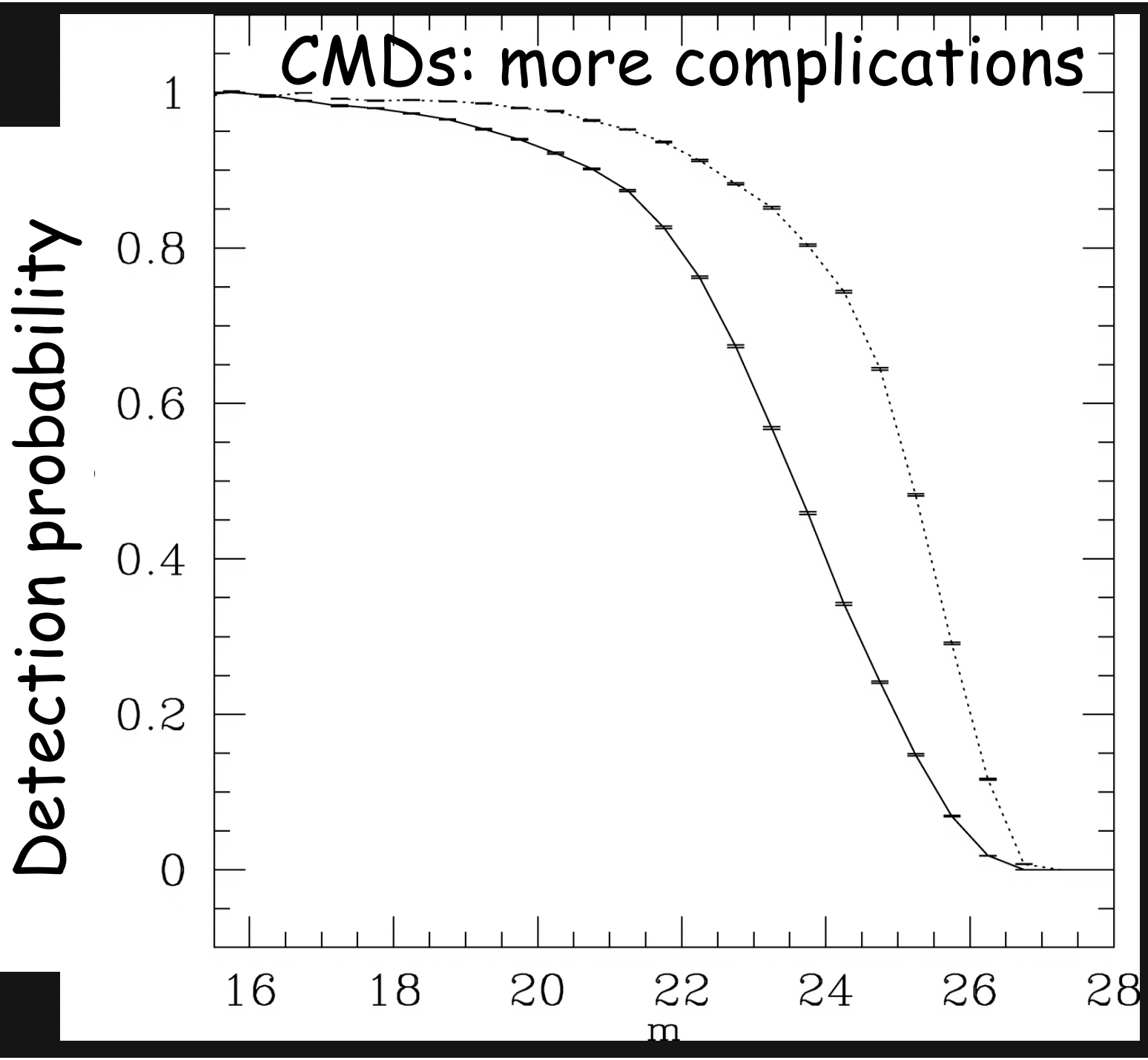
CMDs: complications



CMDs: complications



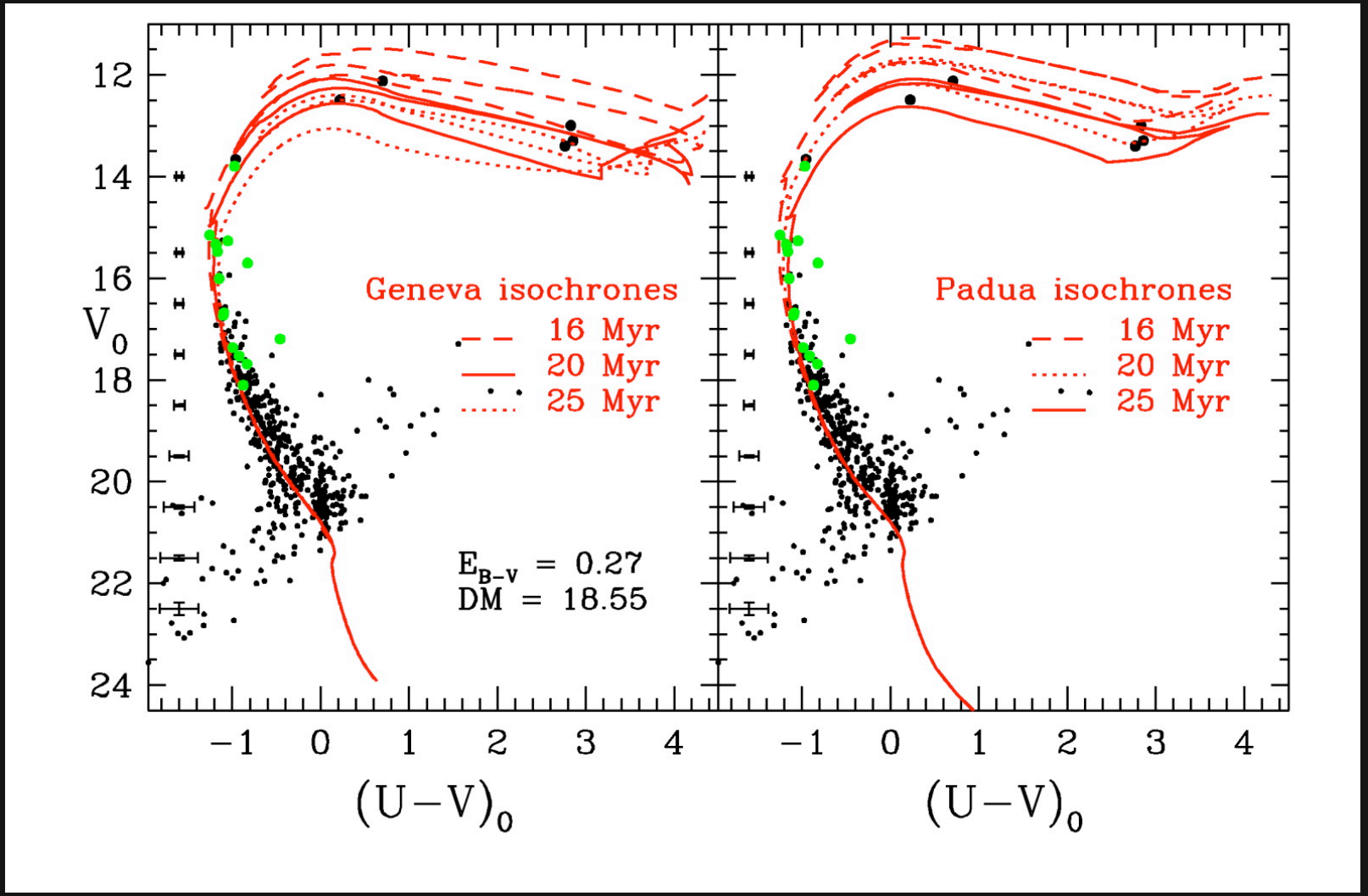
CMDs: more complications



Problems with standard method

- Gaussian statistics (as usually…)
- χ^2 fits
- All stars have equal weight
- Complex mixture problem with several free correlated parameters
- Several different sets of isochrones

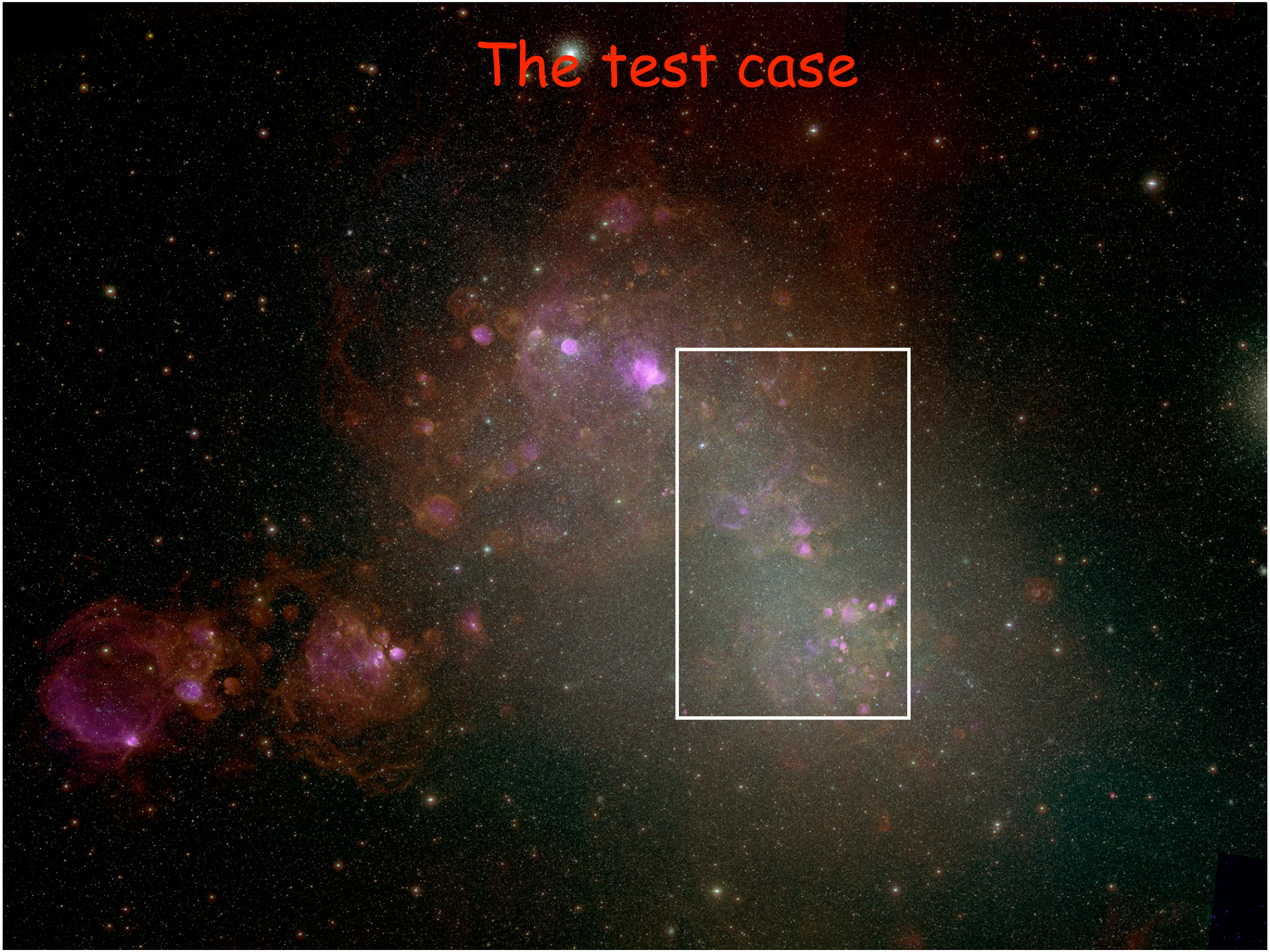
The link with cal. uncertainties



A new method

- Estimate the likelihood that each data point comes from a given isochrone
- Find the likelihood for all points
- Advantages
  - Easily generalized to n-dimensions
  - Easily estimate effect of different isochrones
  - Proper statistical treatment of uncertainties
  - Can include correlated uncertainties and data augmentation for missing data
- Can treat as mixture problem

The test case



The test case

- Nearby galaxy (60 kpc)
- Recent star-formation (a bit complex)
- … but can observe very deep and set good constraints on star-formation