White Dwarfs in Clusters

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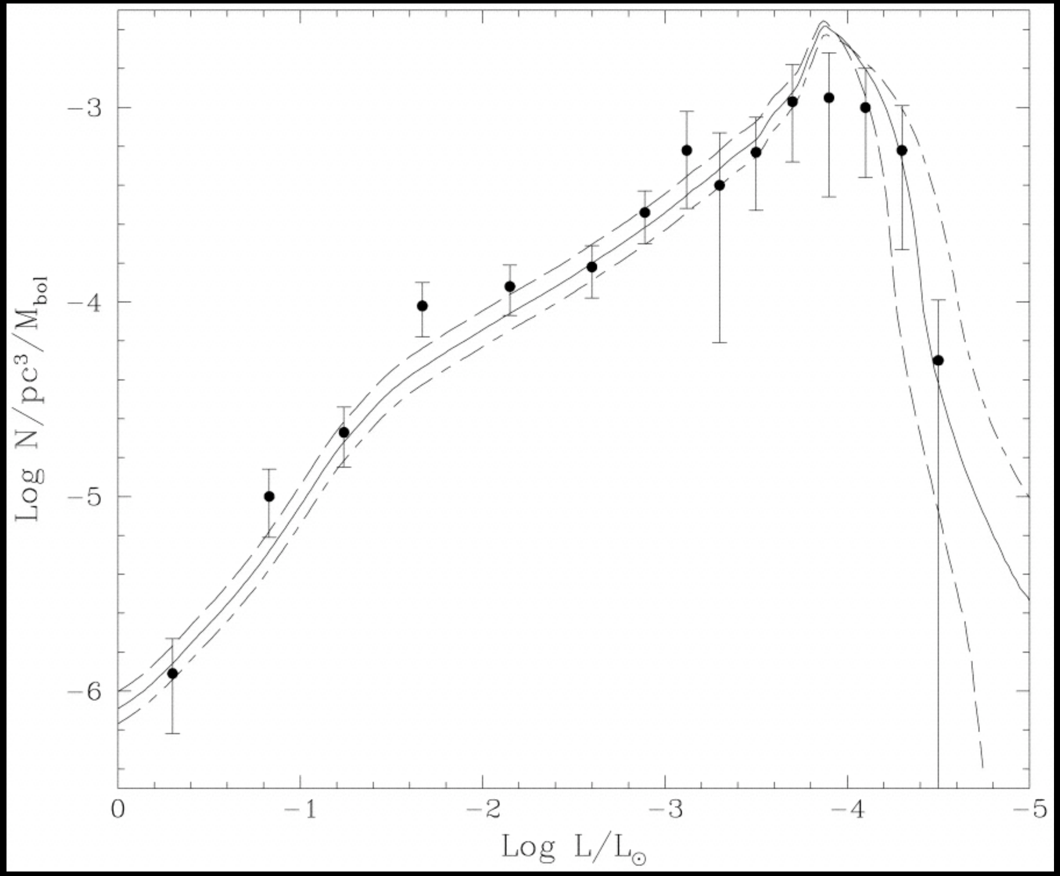
White Dwarfs provide two key pieces of information

- They are an important part of the mass budget
- They can provide an age estimate for the cluster independently of the main sequence turnoff

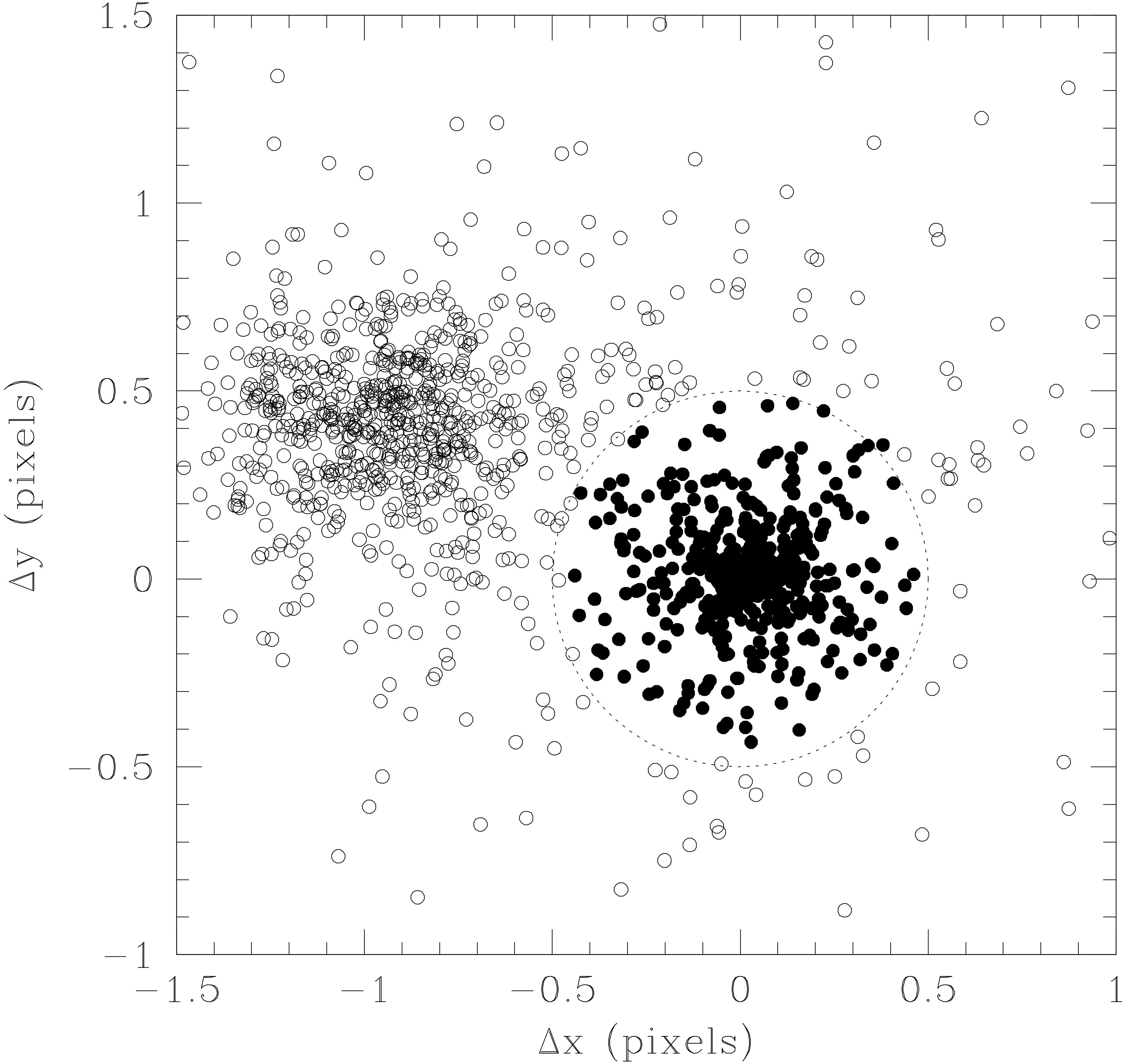


Winget et al (1987) ApJ 315, L77
Leggett et al (1998) ApJ 497, 294

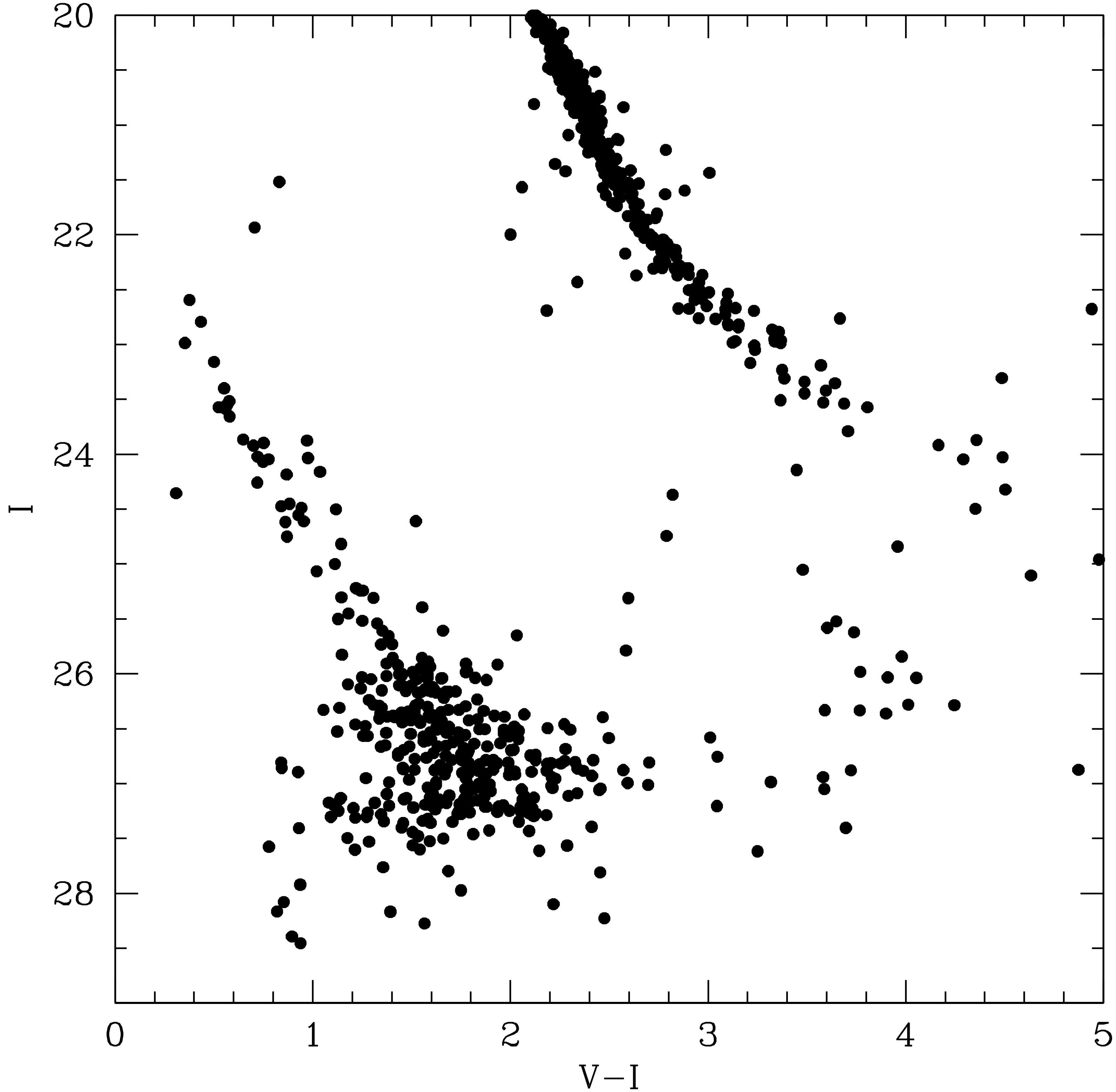
Messier 4

- Nearest Globular Cluster
- 123 HST orbits with WF/PC2
- proper motion separation

Richer et al (2002) ApJ 574, L151; Hansen et al (2002) ApJ 574, L155; Hansen et al (2004) ApJS 155, 551



1.5
1
0.5
0
−0.5
−1
−1.5
−1
−0.5
0
0.5
1
Δy (pixels)
Δx (pixels)



20
22
24
26
28
I
0
1
2
3
4
5
V−I

Messier 4 Results:

- Differential Age between M4 and the Galactic Disk using the default set of cooling models: (2002 paper)

Disk: 7.3 ±1.5 Gyr

M4: 12.7 ±0.7 Gyr

- Absolute Age constraint include model and observational systematics: (2004 paper)

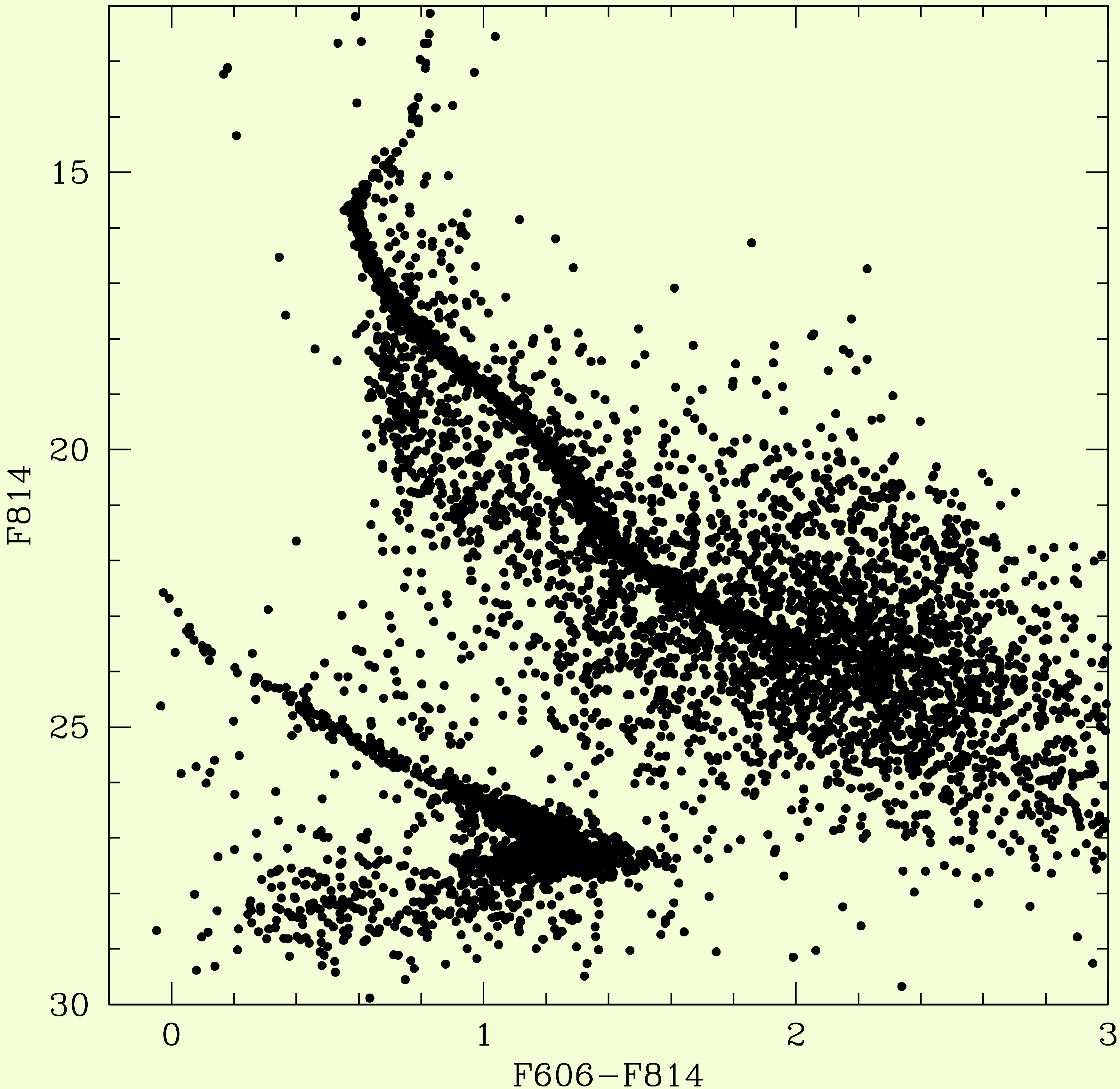
M4: > 10.3 Gyr (95% confidence)

NGC6397

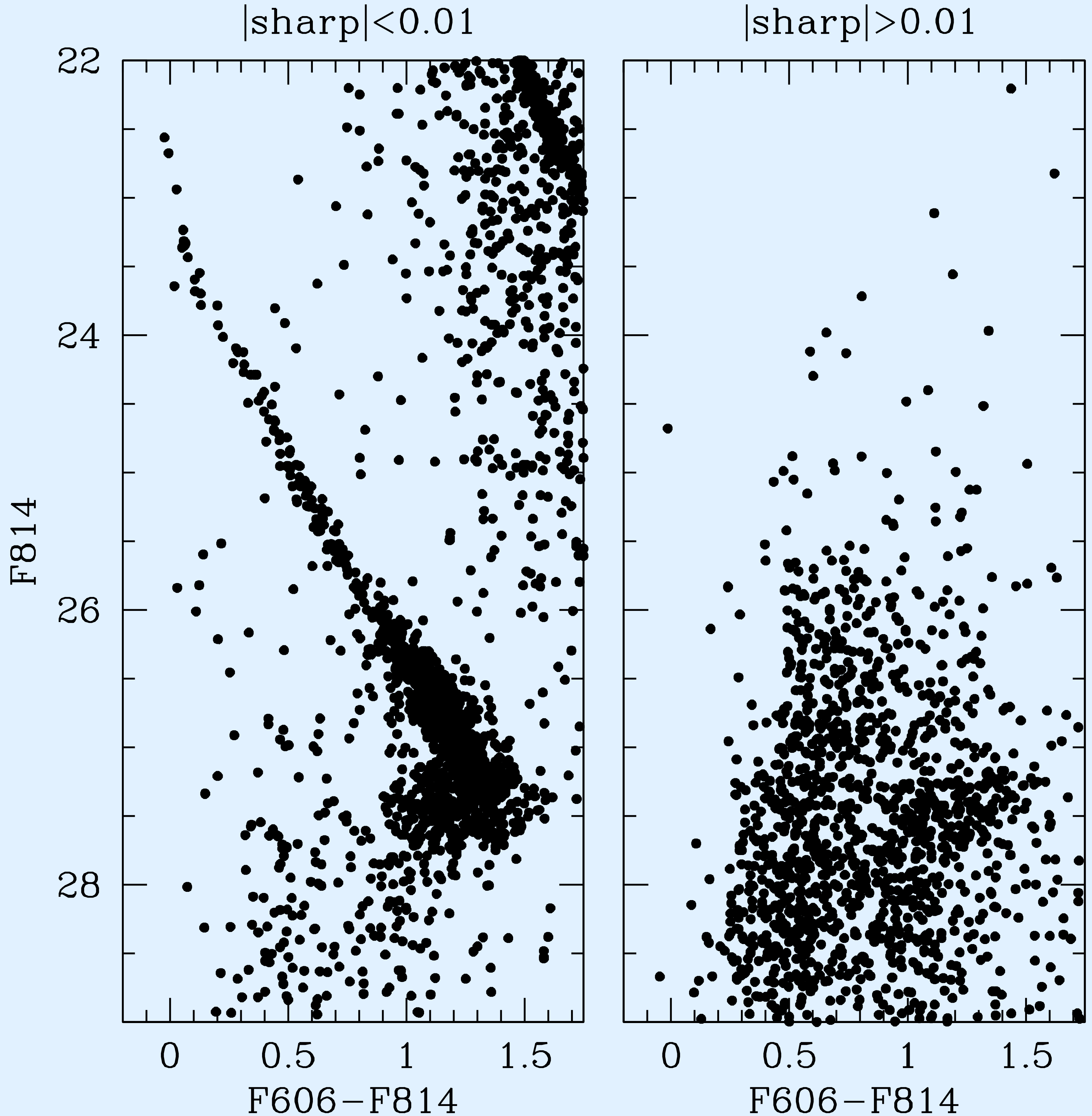
- Second closest cluster, but with less extinction than M4 - actually slightly better distance modulus in HST bands
- New instrument on HST: *ACS* - better image quality so better control of scattered light
- Better comparison with MSTO method
- Metal-poor : [Fe/H]=-2

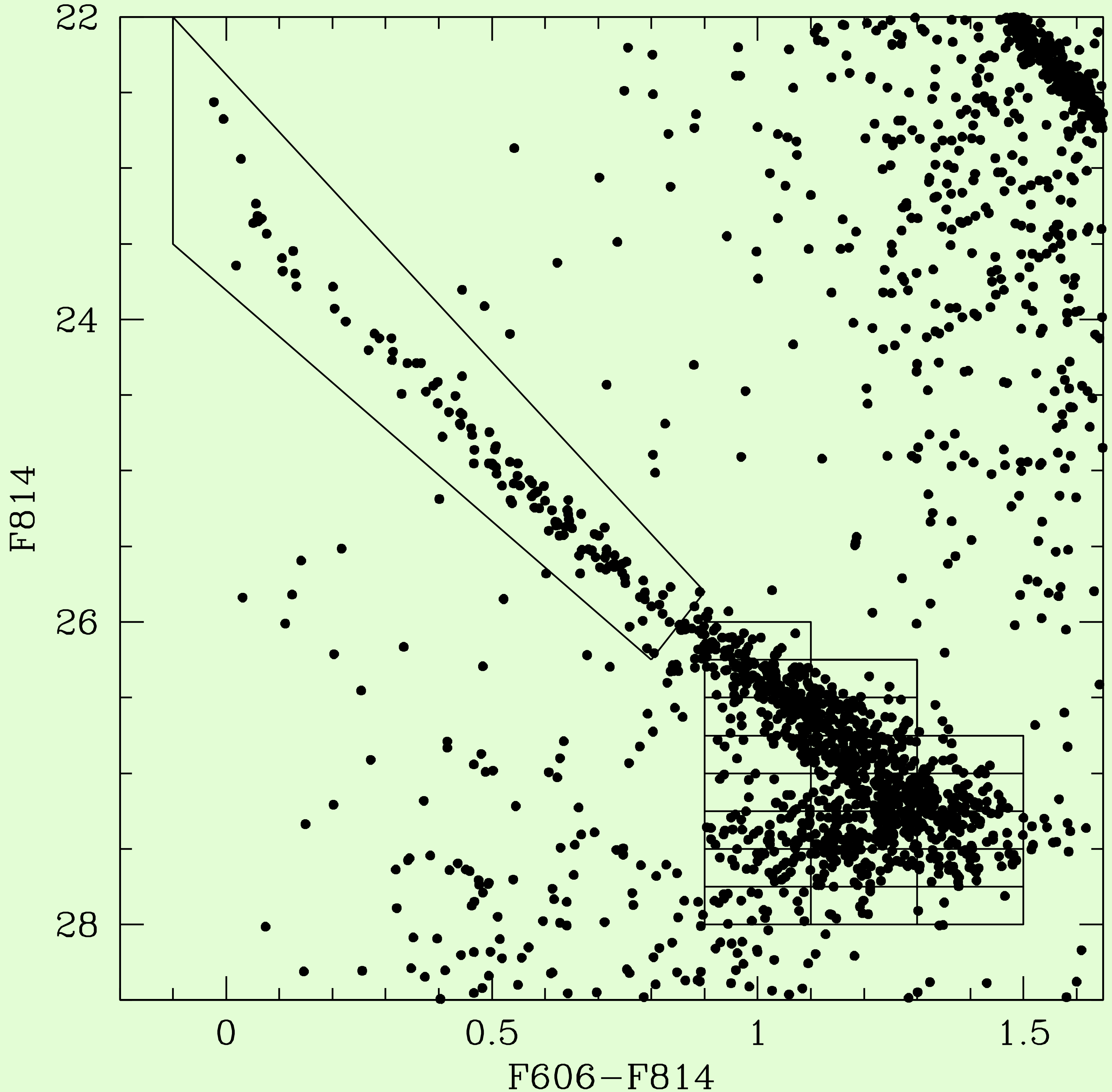
Observations of NGC 6397

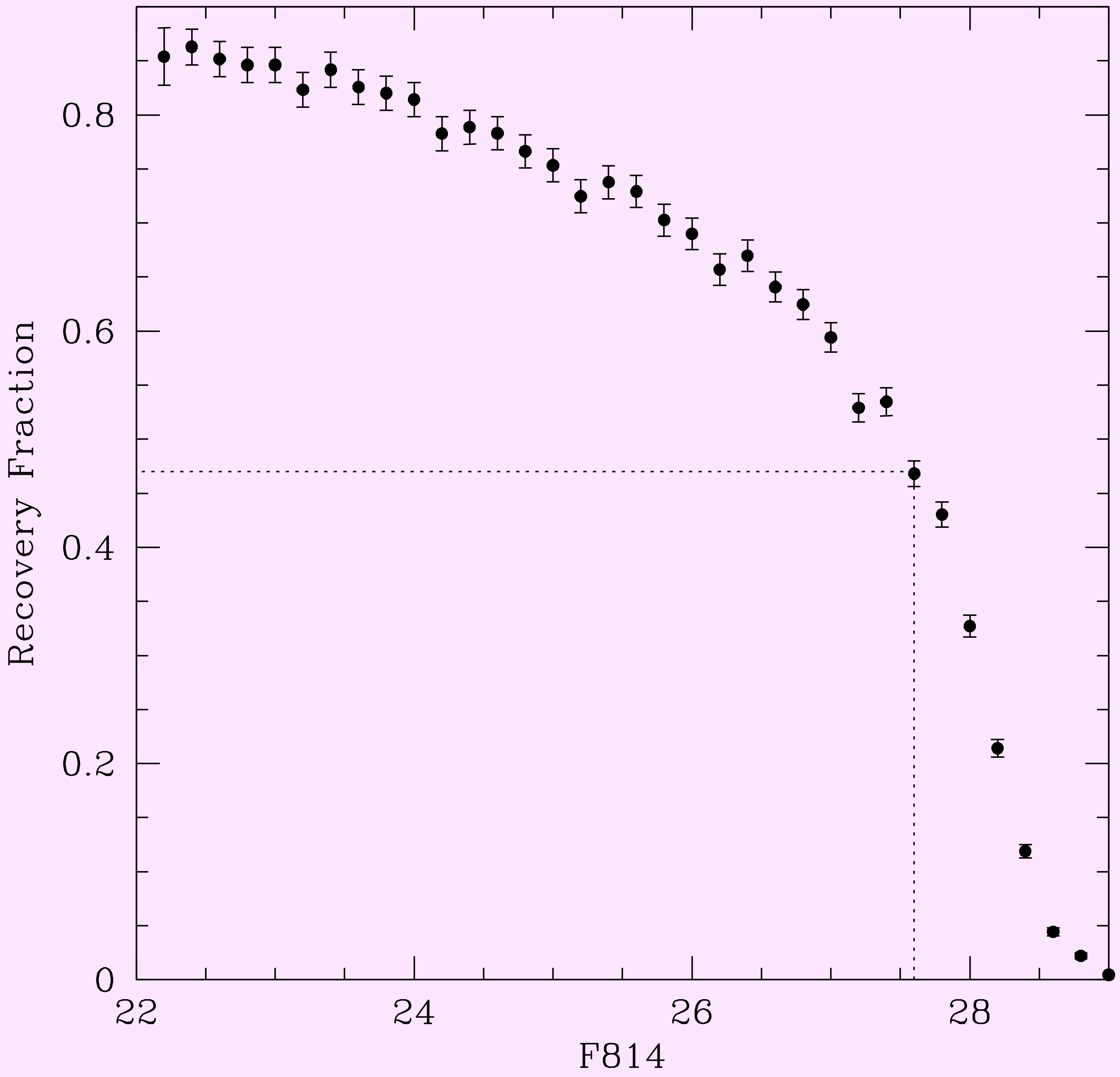
- 126 HST orbits in Cycle 13
- 252 F814 (I) frames and 126 F606 (V) frames
- short and long exposures – enables us to cover both bright and faint stars



F814
F606−F814
15
20
25
30
0
1
2
3


|sharp|<0.01
|sharp|>0.01
F814
22
24
26
28
0
0.5
1
1.5
F606−F814
F606−F814

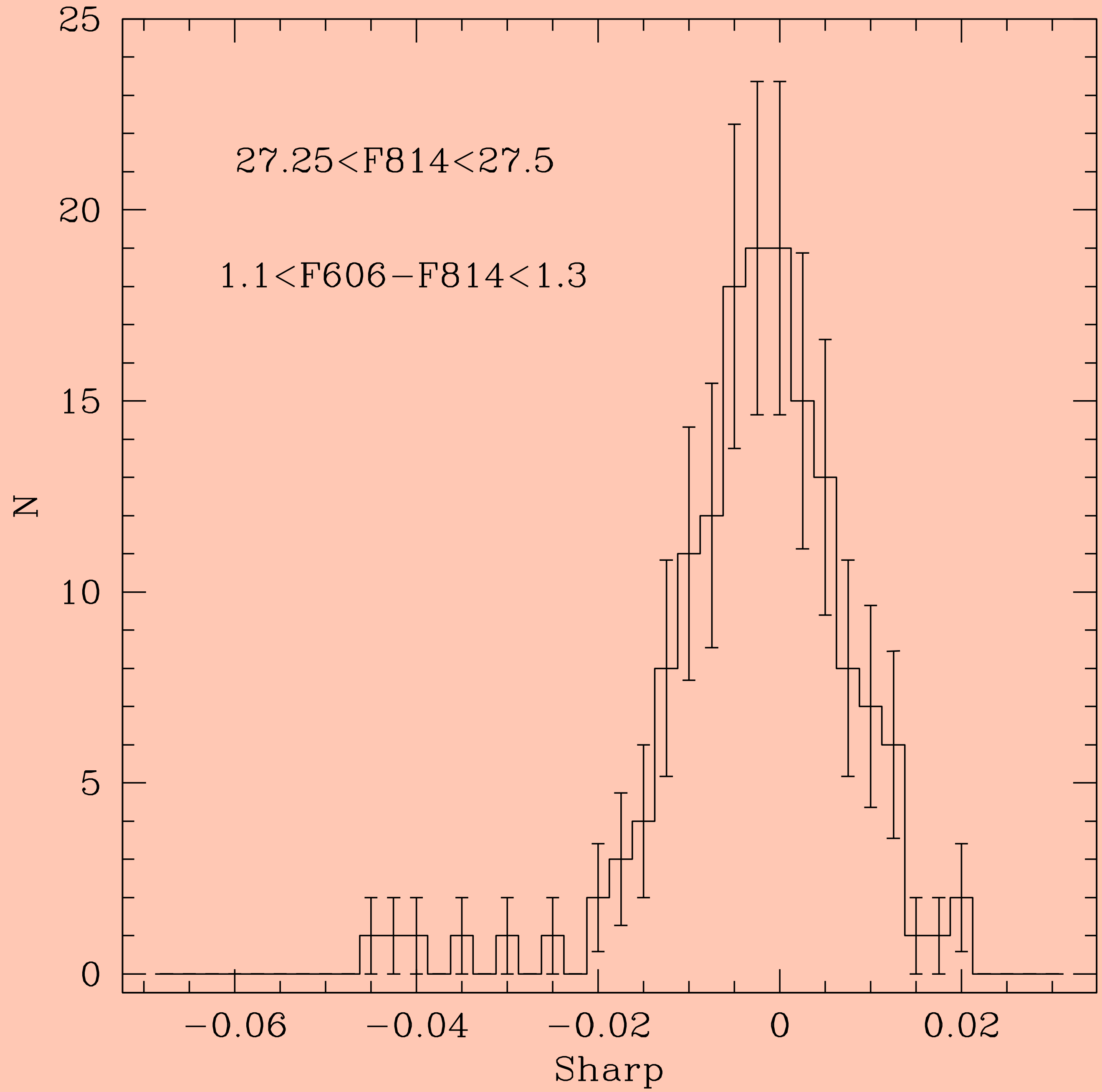

22
24
26
28
F814
0
0.5
1
1.5
F606−F814



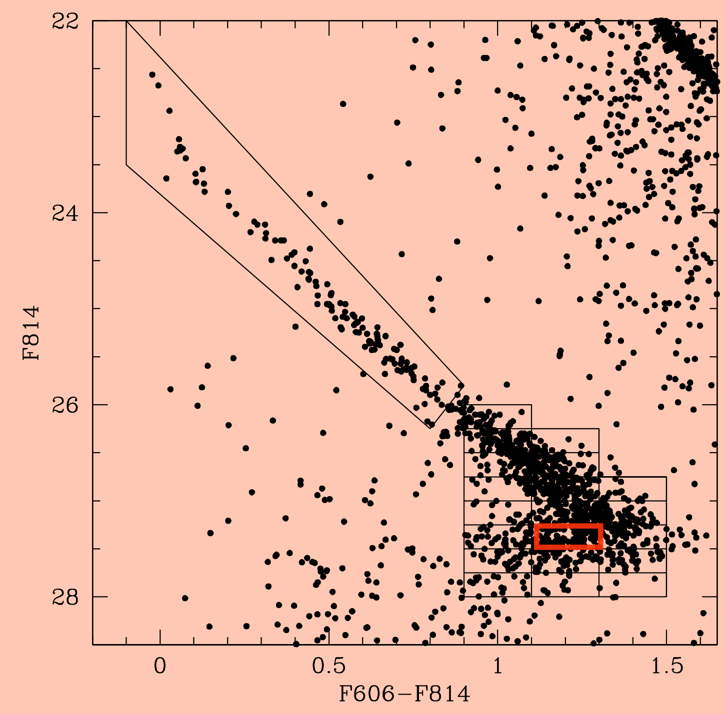
Recovery Fraction
0
0.2
0.4
0.6
0.8
22
24
26
28
F814

Modelling the Cooling Sequence

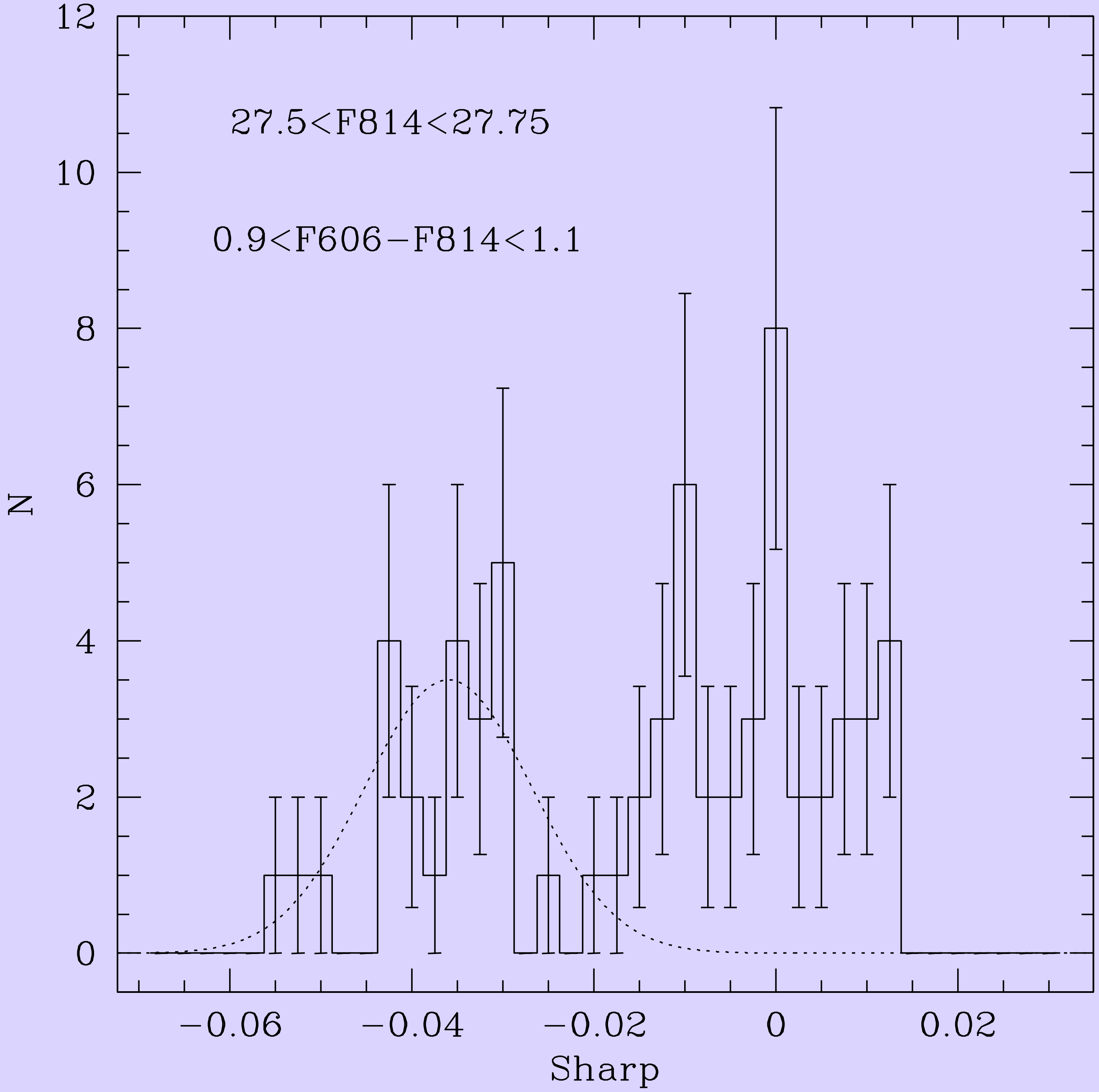
- Need to fit distance, extinction, radius at bright end
- Need to fit mass, temperature evolution at faint end
- Cooling models, mass function and initial-final mass relation imposes consistency between the two

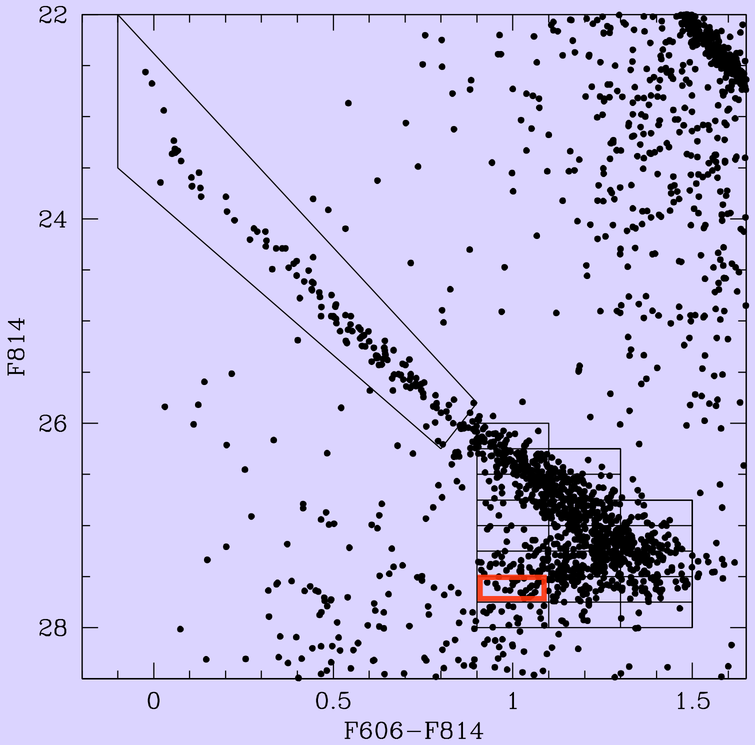


27.25<F814<27.5
1.1<F606−F814<1.3
N
Sharp
25
20
15
10
5
0
−0.06
−0.04
−0.02
0
0.02



F814
F606−F814
22
24
26
28
0
0.5
1
1.5


27.5<F814<27.75
0.9<F606−F814<1.1
N
Sharp
−0.06
−0.04
−0.02
0
0.02
0
2
4
6
8
10
12

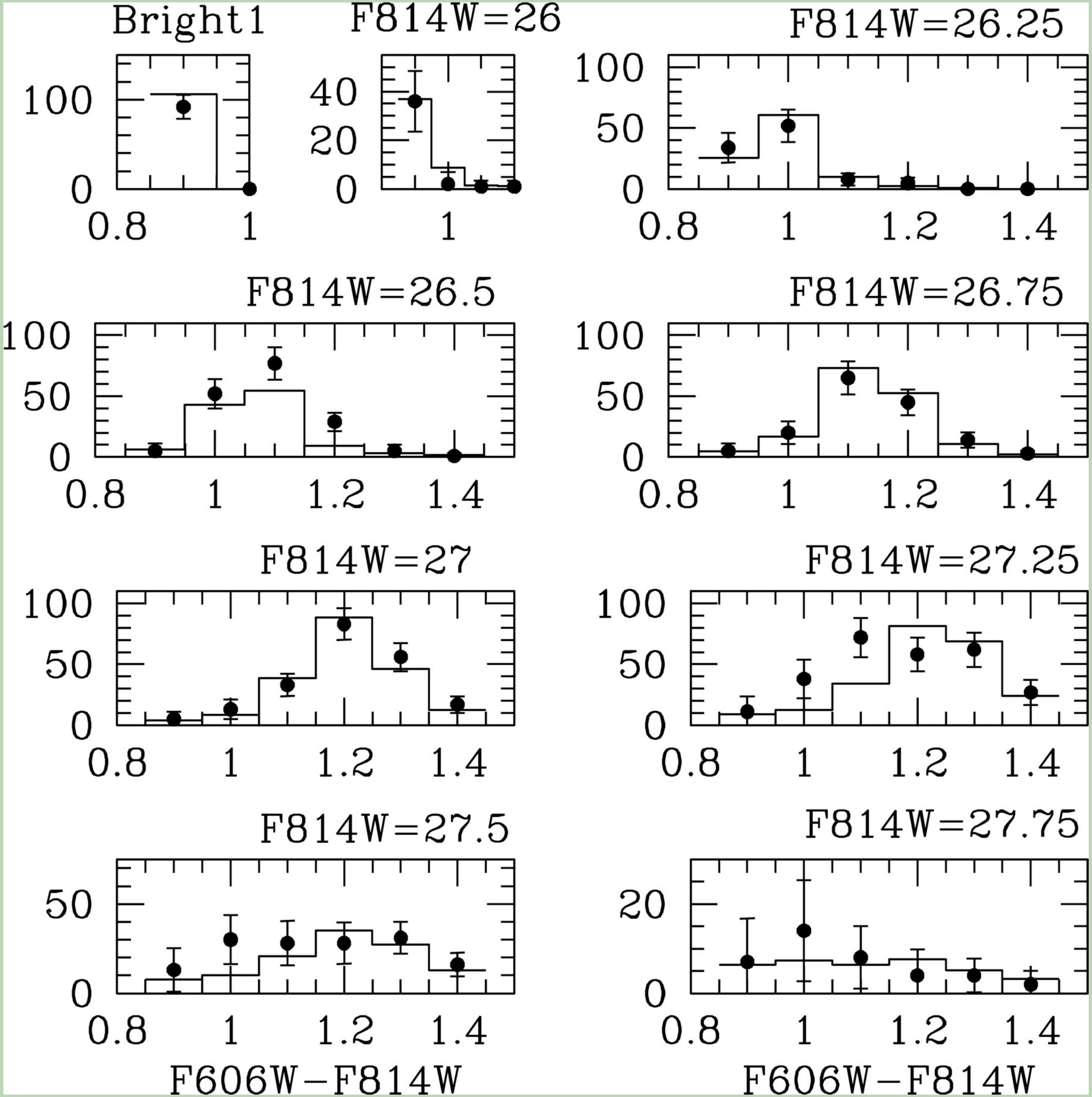

F814
F606−F814
22
24
26
28
0
0.5
1
1.5

Default Model:

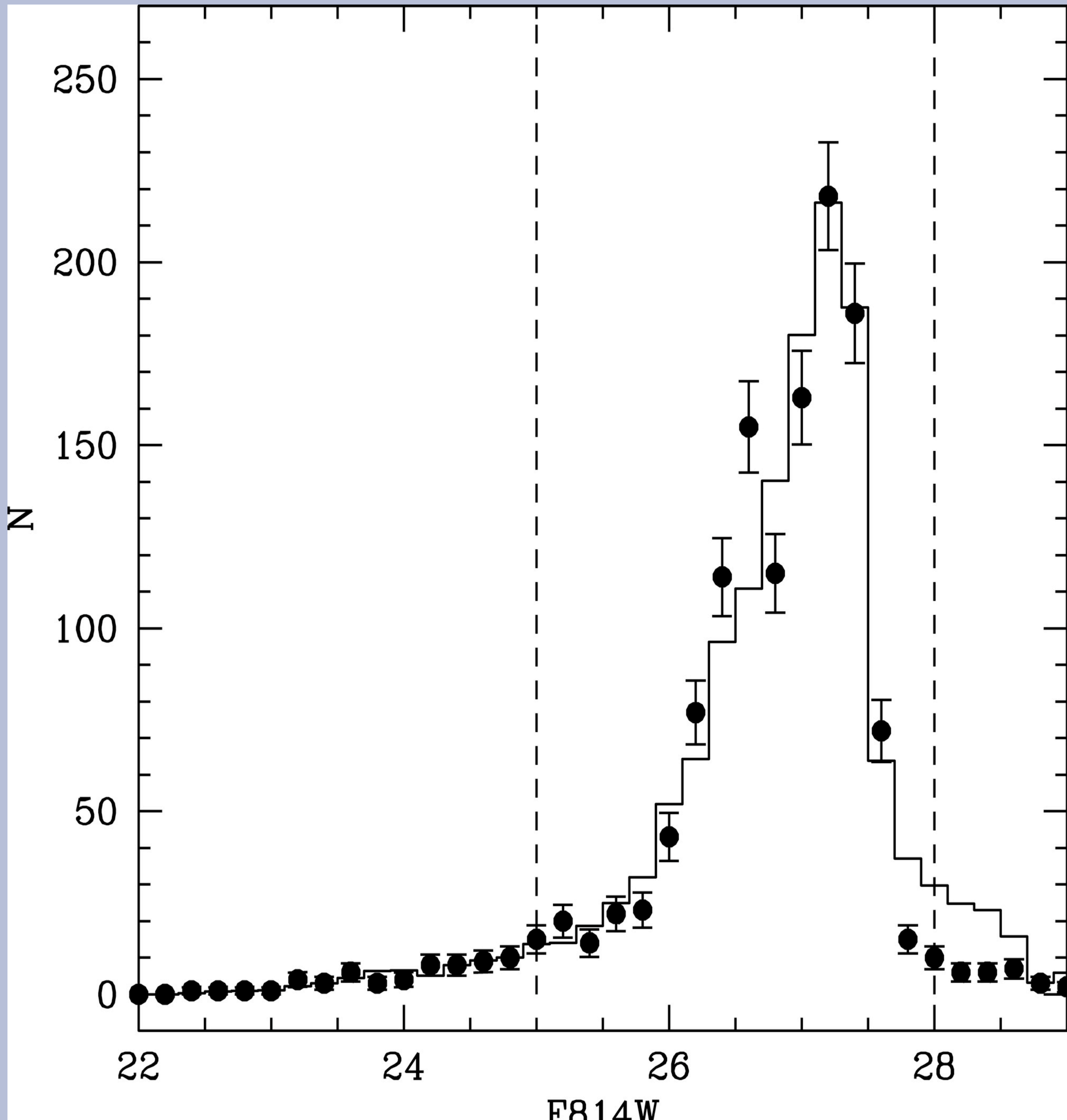
- Cooling models from Hansen (1999) ApJ 520,680
- Colours from Bergeron et al (1996) PASP 107, 1047
- Initial-final mass relation of the form

$$M_{wd} = \alpha e^{\beta(M - M_{TO})}$$

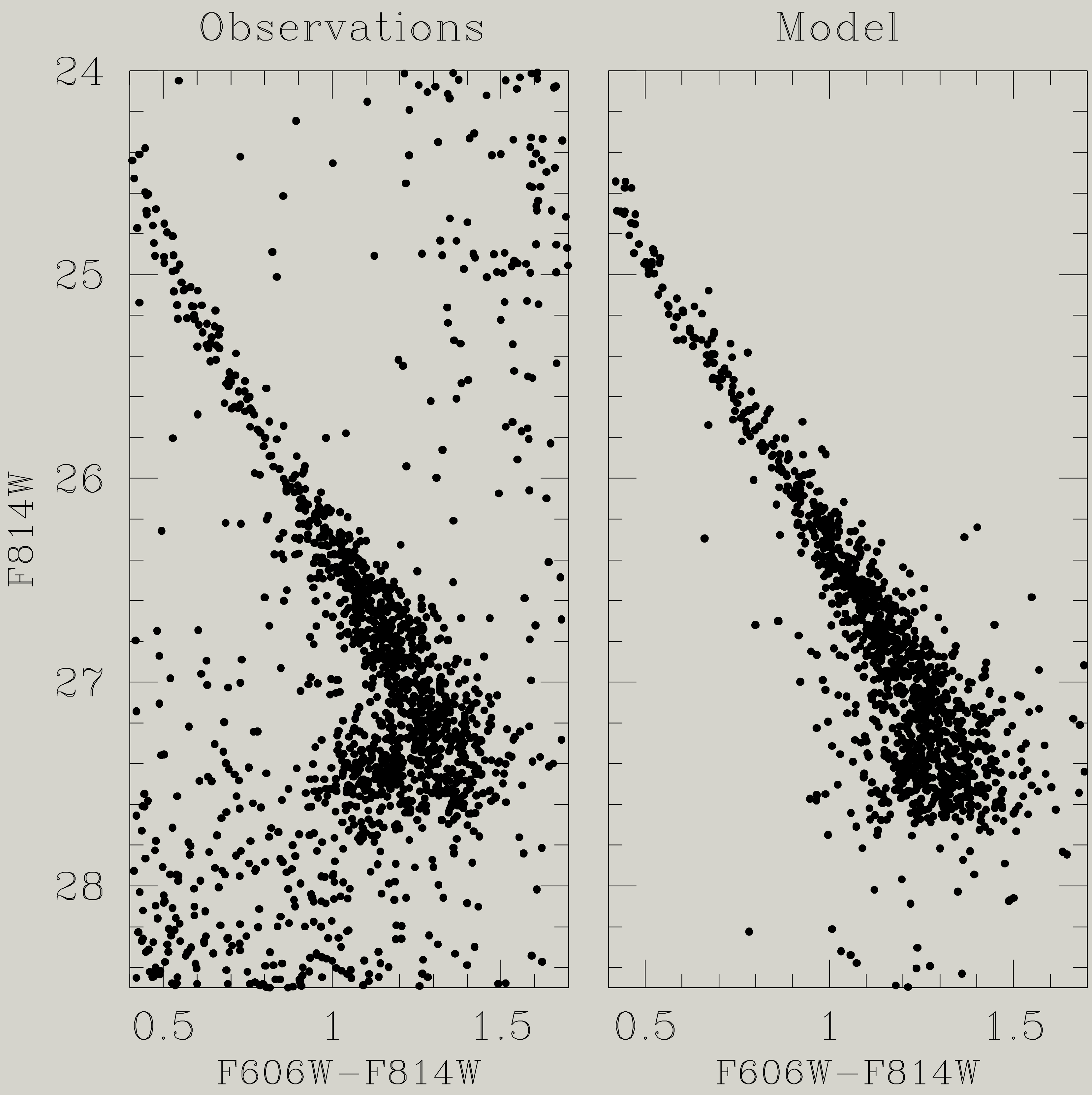
- Fit for distance, extinction, age, Mass function and IFMR

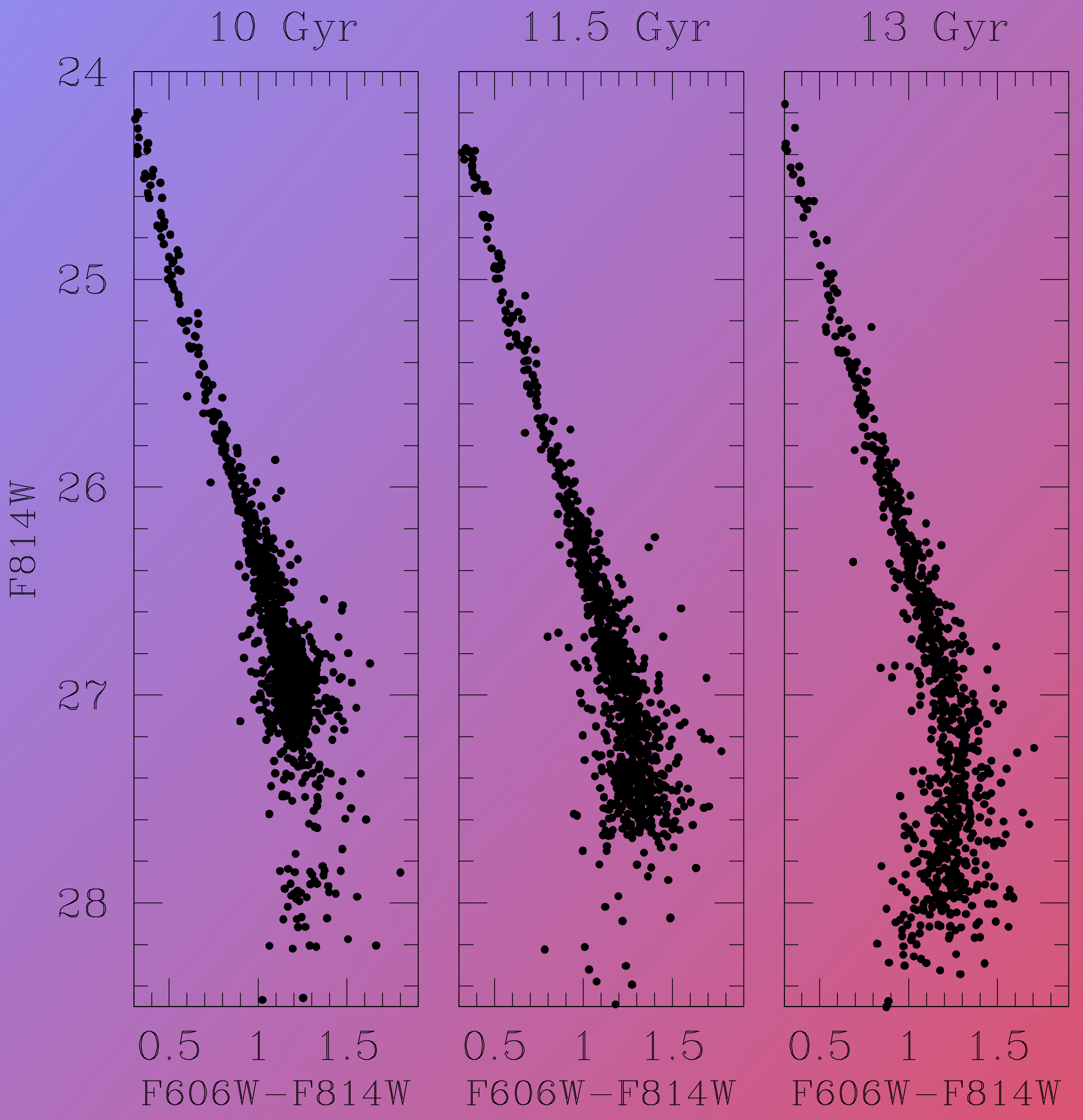


Bright1
F814W=26
F814W=26.25
F814W=26.5
F814W=26.75
F814W=27
F814W=27.25
F814W=27.5
F814W=27.75
F606W−F814W
F606W−F814W



250
200
150
100
50
0
N
22
24
26
28
F814W


Observations
Model
F814W
24
25
26
27
28
0.5
1
1.5
F606W−F814W
0.5
1
1.5
F606W−F814W


10 Gyr
11.5 Gyr
13 Gyr
F814W
24
25
26
27
28
0.5
1
1.5
F606W−F814W

A White Dwarf-based Age for NGC6397

11.47± 0.47 Gyr (95% confidence)

Distance modulus of 12.03± 0.06 agrees well with independent estimates

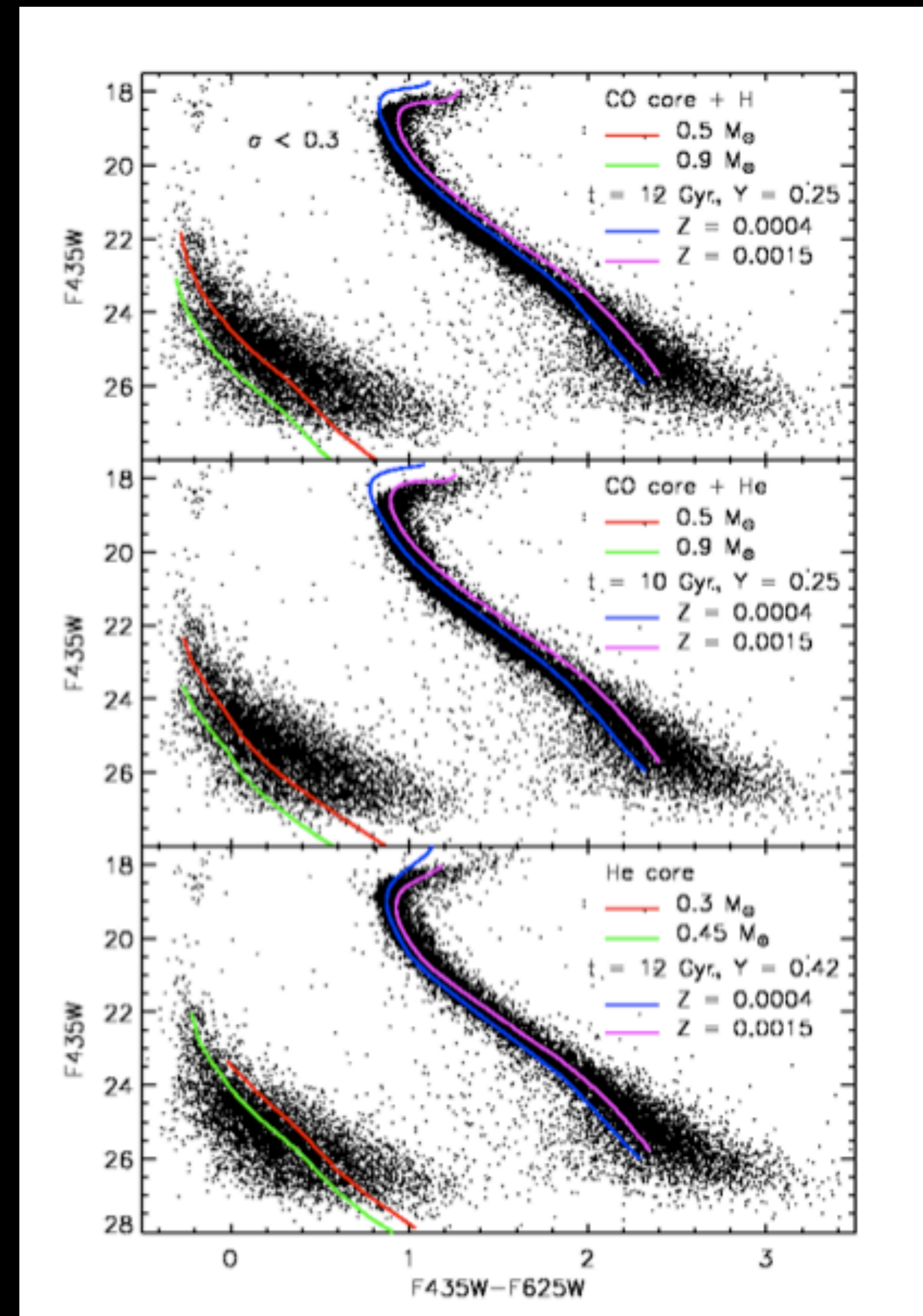
Colours from atmosphere models remain a systematic - Kowalski (2007) A&A 474, 491 finds an age about 0.5 Gyr older using his colours (and so do I if I use his colours)

Weird White Dwarfs in ω Cen

Calamida, Bono et al report an anomalous colour distribution in the bright white dwarf sequence.

Interpreted as an excess of low-mass He core white dwarfs (10%-80% depending on mass; field incidence is 2%)

Can abundance anomalies cause stars to skip He flash?



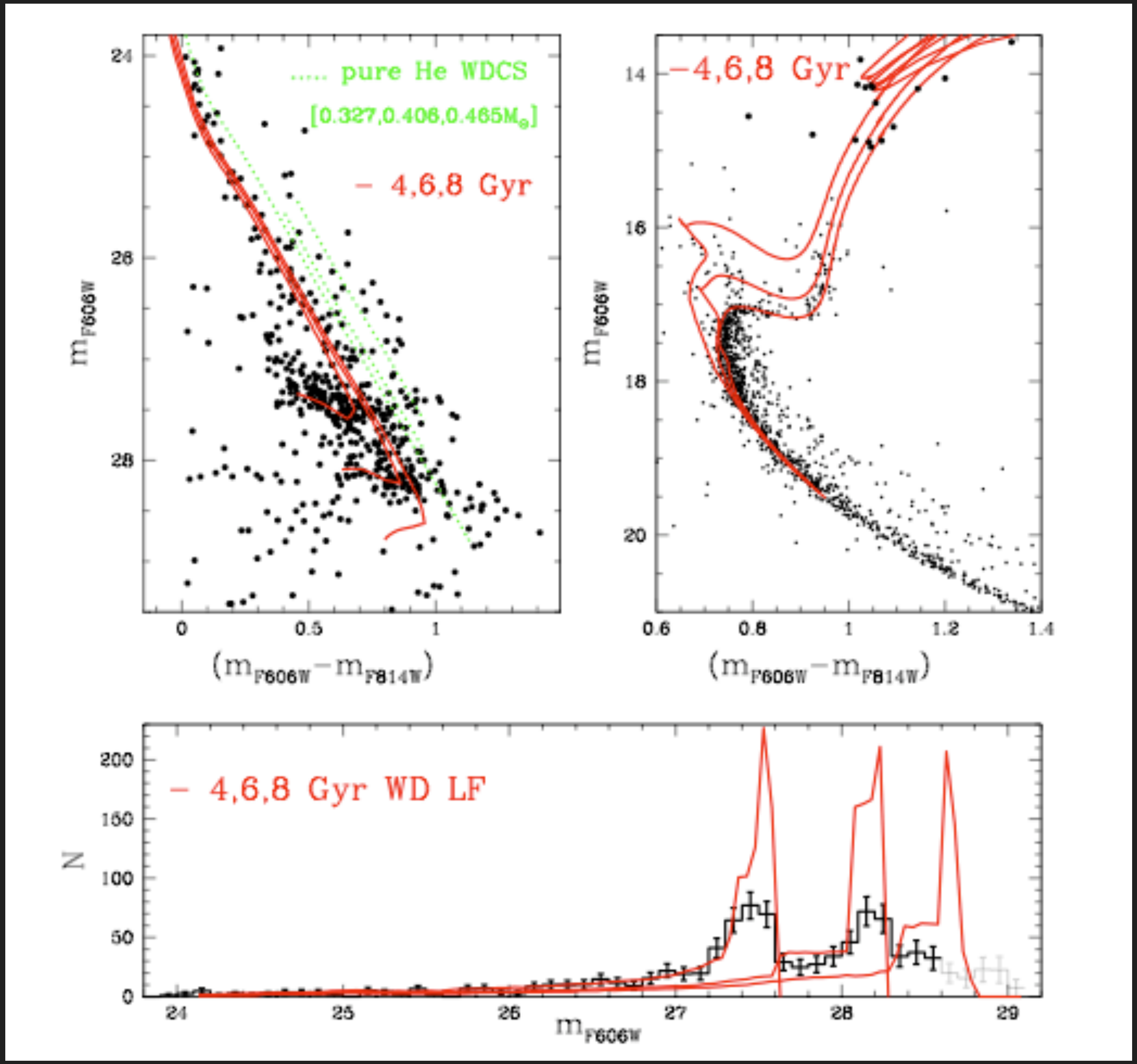
Calamida et al (2008) ApJ 673, L29

Weird White Dwarfs in NGC6791

Bedin et al identifiied a strange white dwarf luminosity function in the old, metal-rich open cluster NGC6791.

Luminosity function has multiple peaks, but a relatively normal main sequence turnoff.

Multiple solutions proposed - including He core white dwarfs and a large binary fraction.



Bedin et al (2008) ApJ 678, 1279

White Dwarf Kicks

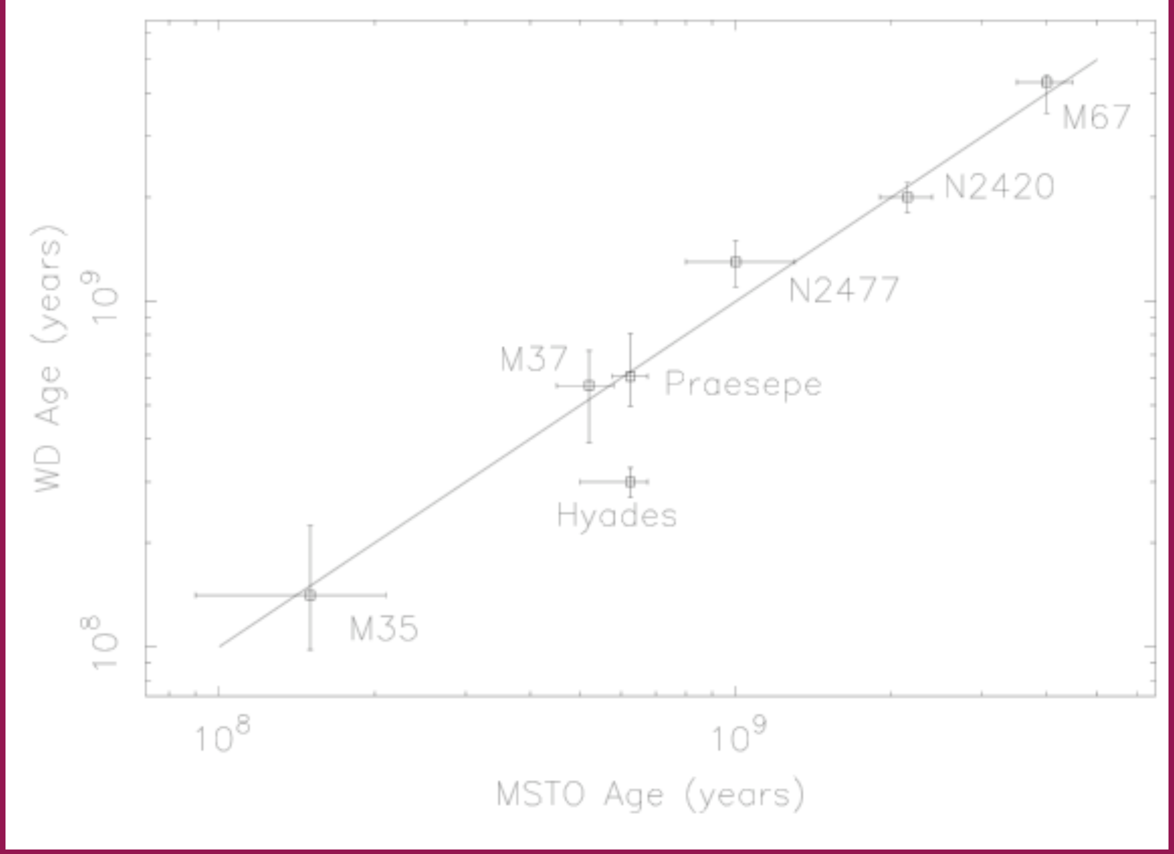
Is it really an impulsive kick or just asymmetric mass loss?

Crossing time ~ 1 pc/10 km/s ~ 10^5 years

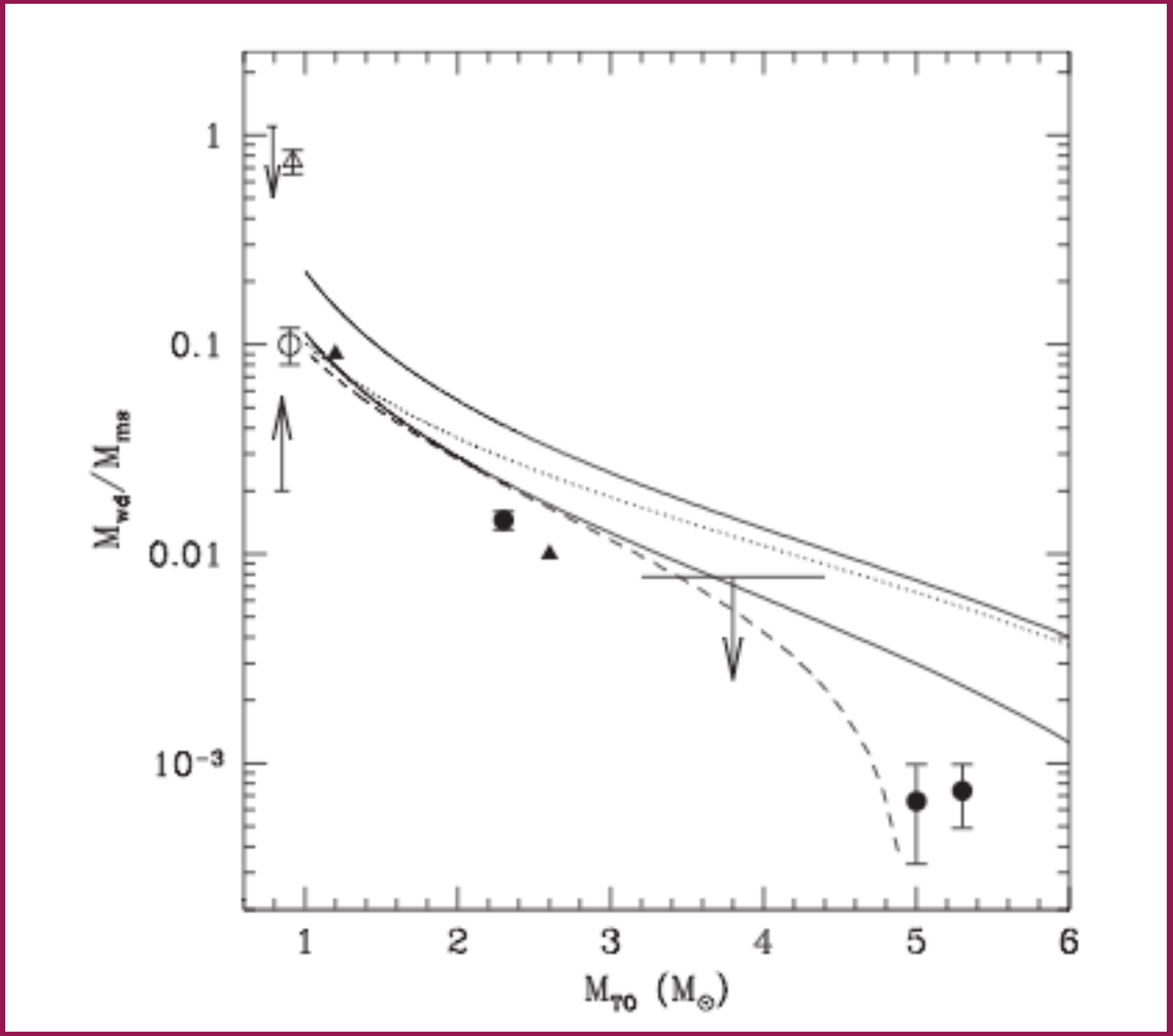
Based on Hurley models,

Core Helium Burning lasts 10^8 yr (Most mass loss occurs here)
First Ascent of AGB lasts 5×10^6 yr
Second Ascent of AGB lasts 10^5 yr

White Dwarfs in Open Clusters



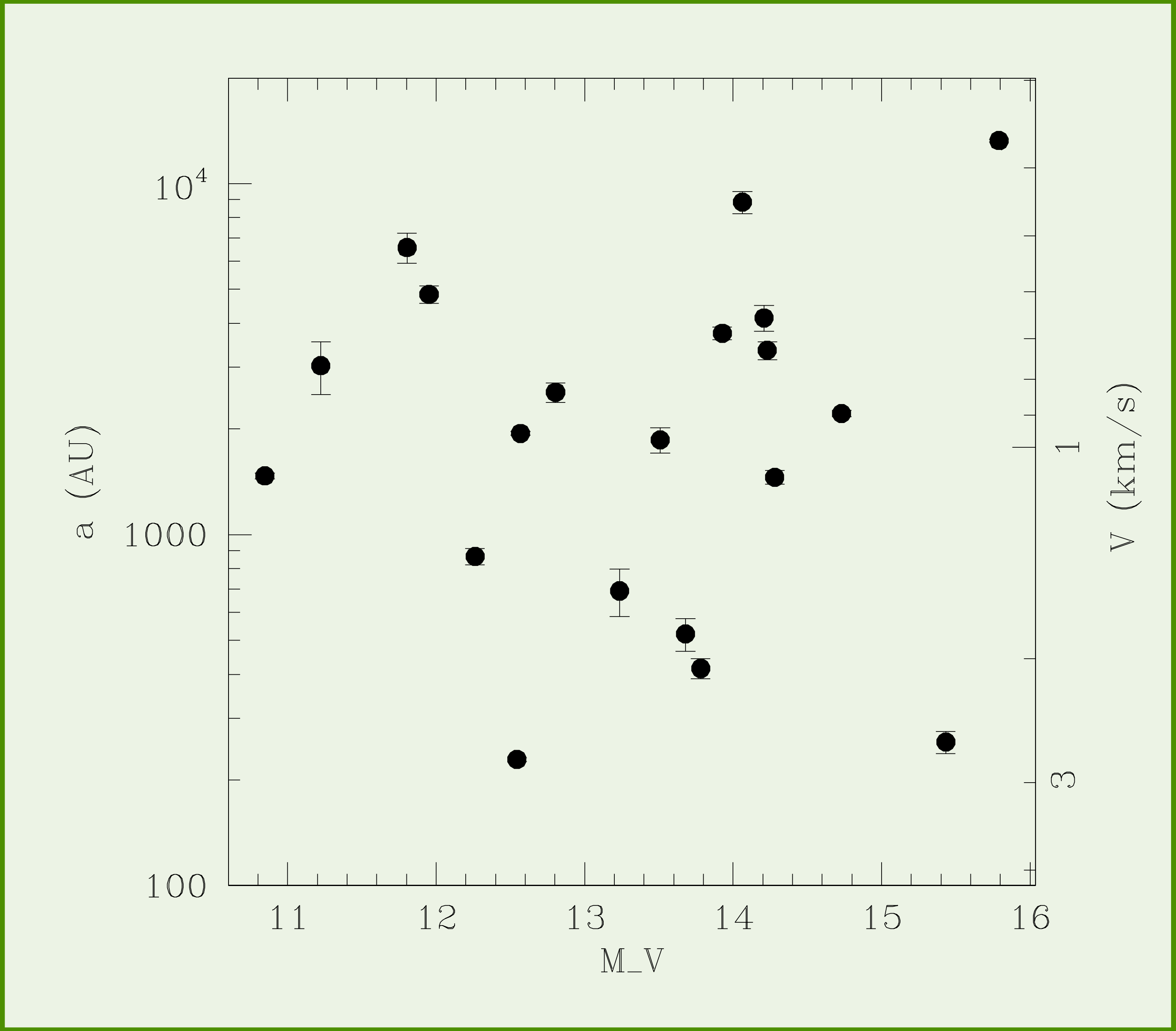
von Hippel (2005) ApJ 622, 565



Hansen (2004) Physics Reports, 399, 1

White Dwarf "deficit" relative to MS stars is seen in many clusters. Contributing factors are likely to be incompleteness (MS binaries)+uncertainty in upper cutoff + possibly kicks

Wide White Dwarf Binaries



Luyten's proper motion catalogue contains many white dwarfs in wide, common proper motion binaries. These should have been disrupted if white dwarfs got true kicks.

Sample from
Gould & Chaname (2004)
ApJS 150, 455

In calculating V, I've assumed a 1 solar mass star became a 0.5 solar mass white dwarf in each case