The distribution of stars in space

Working hypothesis (first proposed in 1950s):

four stellar populations in the Galaxy

-- thin disk

-- thick disk

--bulge/bar

-- halo

(See discussion in Binney and Merrifield Ch10 intro)

In order to decide whether stars fit into a few simple categories which can be related to different formation histories, we need good measurements of

- age
- spatial density distribution
- kinematics
- metal abundance

.... for an unbiased sample of stars.

Age is by far the hardest ……

Age measurement for stellar clusters

Q: how can we use our knowledge of stellar evolution to estimate the age for a star cluster?

Age measurement for stellar clusters

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Compare cluster color-magnitude diagram with isochrones derived from evolutionary tracks from stellar models. Turnoff point is particularly useful here

Ages from clusters

- Q: which is harder to determine an age for, a young or an old cluster?

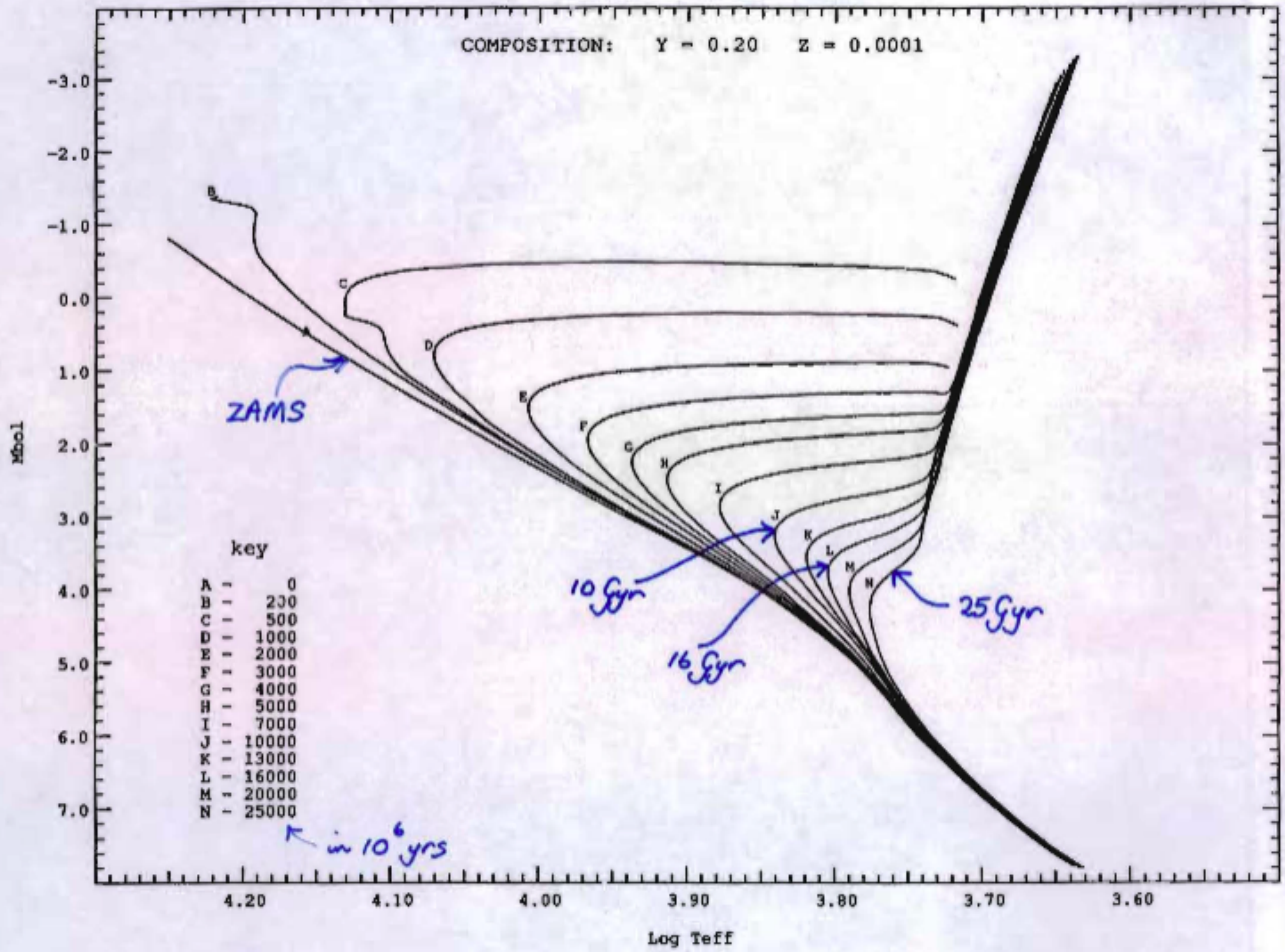
Ages from clusters

Q: which is harder to determine an age for, a young or an old cluster?

Old clusters are generally harder, because evolutionary tracks become closer together as the cluster ages.

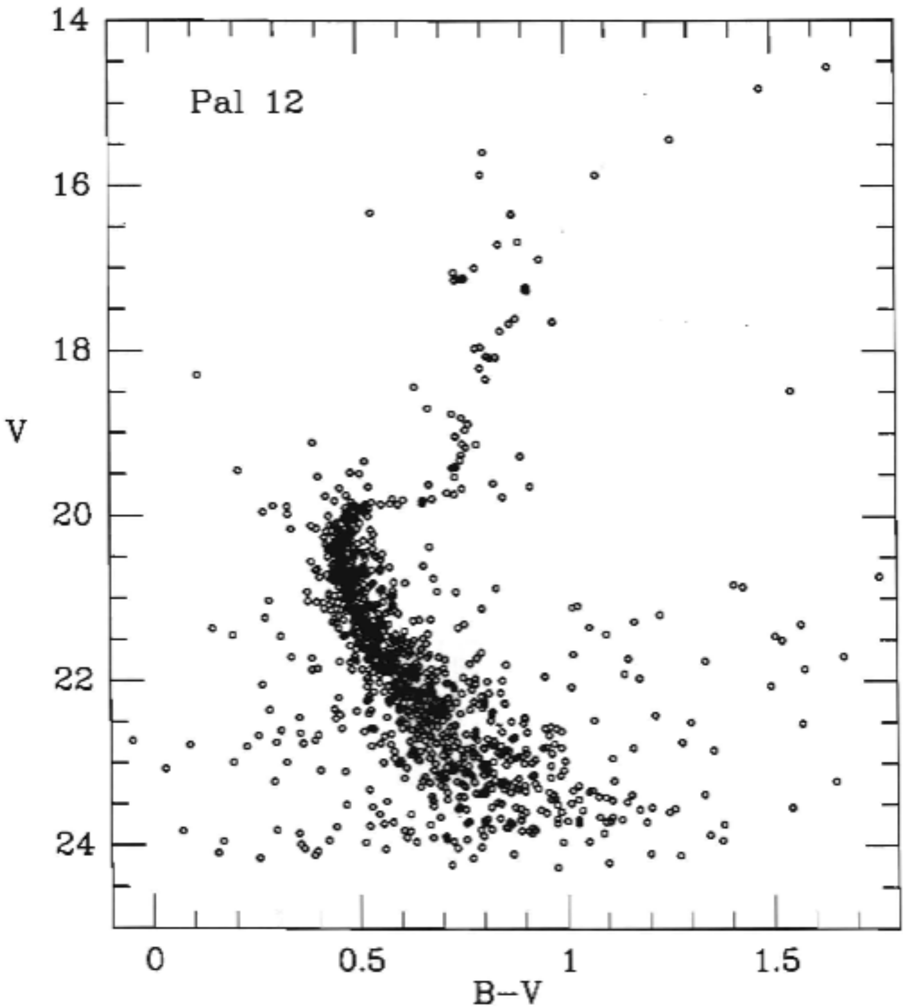
However, note that young clusters may have problems with reddening, pre-main sequence stars, etc

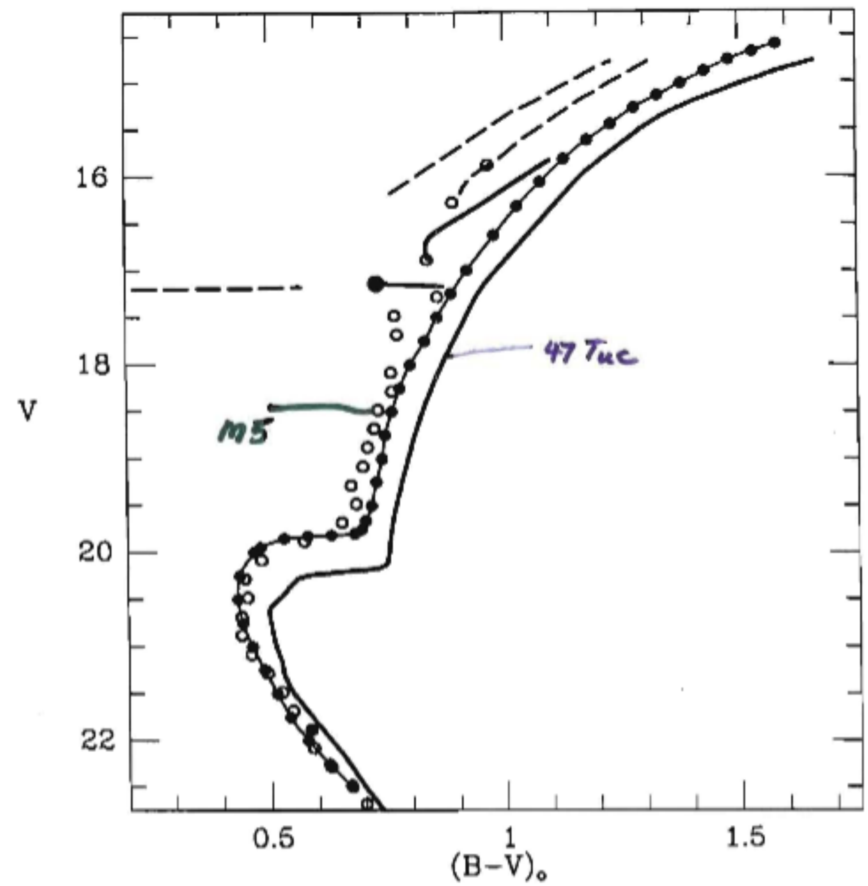
Yale isochrones (1987)



- Globular clusters are measured to have very old ages; altho' absolute ages are very difficult to measure, their ages are comparable with a Hubble time

- There are a few clusters (Pal 12, Rup 106, etc) that are clearly younger by ~ 3 Gyr or more


Pal 12
V
B−V
14
16
18
20
22
24
0
0.5
1
1.5


47 Tuc
M5
V
(B−V)₀
16
18
20
22
0.5
1
1.5

Cluster color-magnitude diagram

V, $B-V$

↓ distance, reddening

M_V, $(B-V)_0$

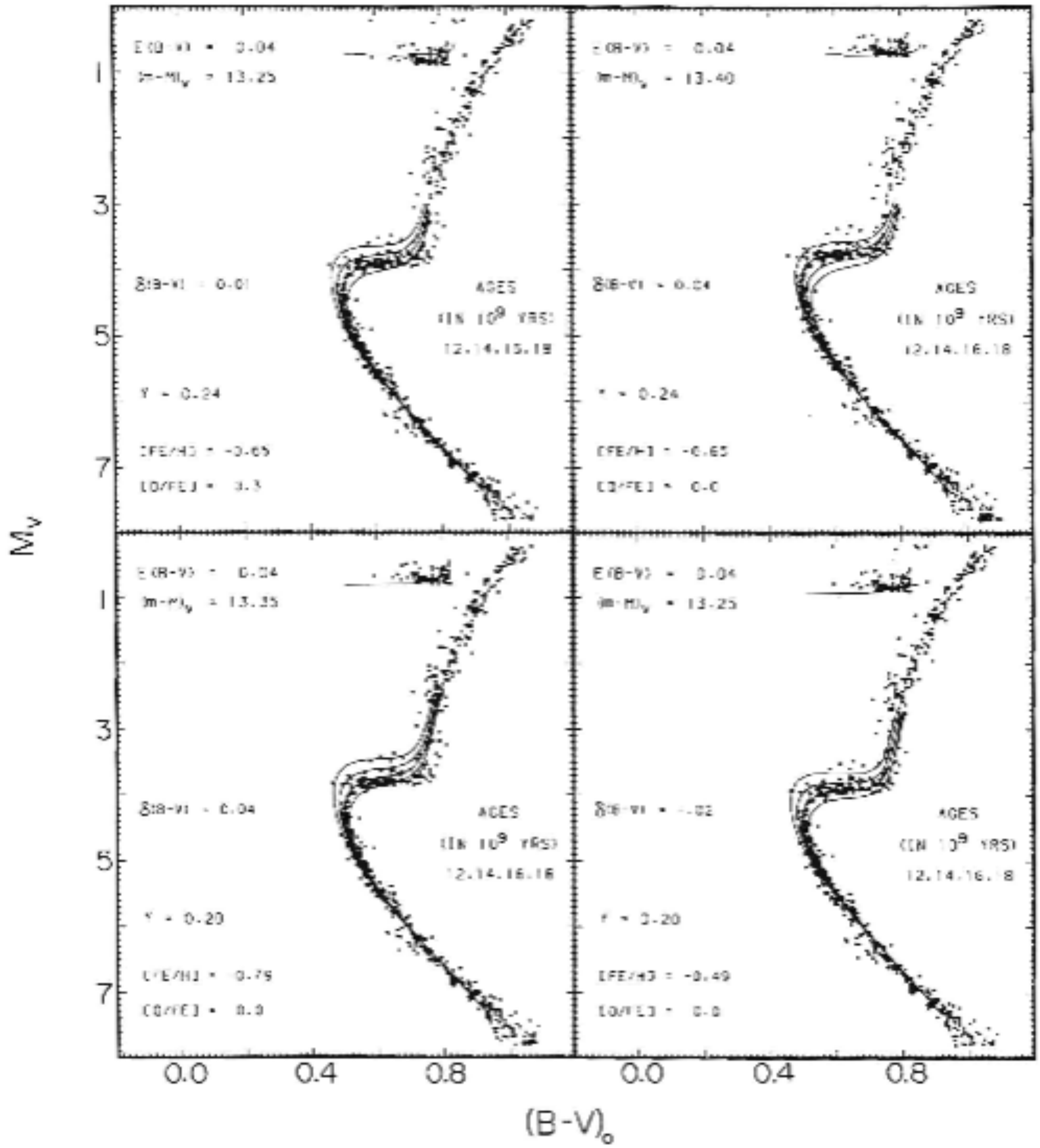
↓ stellar atmosphere model [Fe/H] [O/Fe]

M_{bol}, T_{eff}

↓ stellar interior model

Mass, age

: excellent CCD photometry



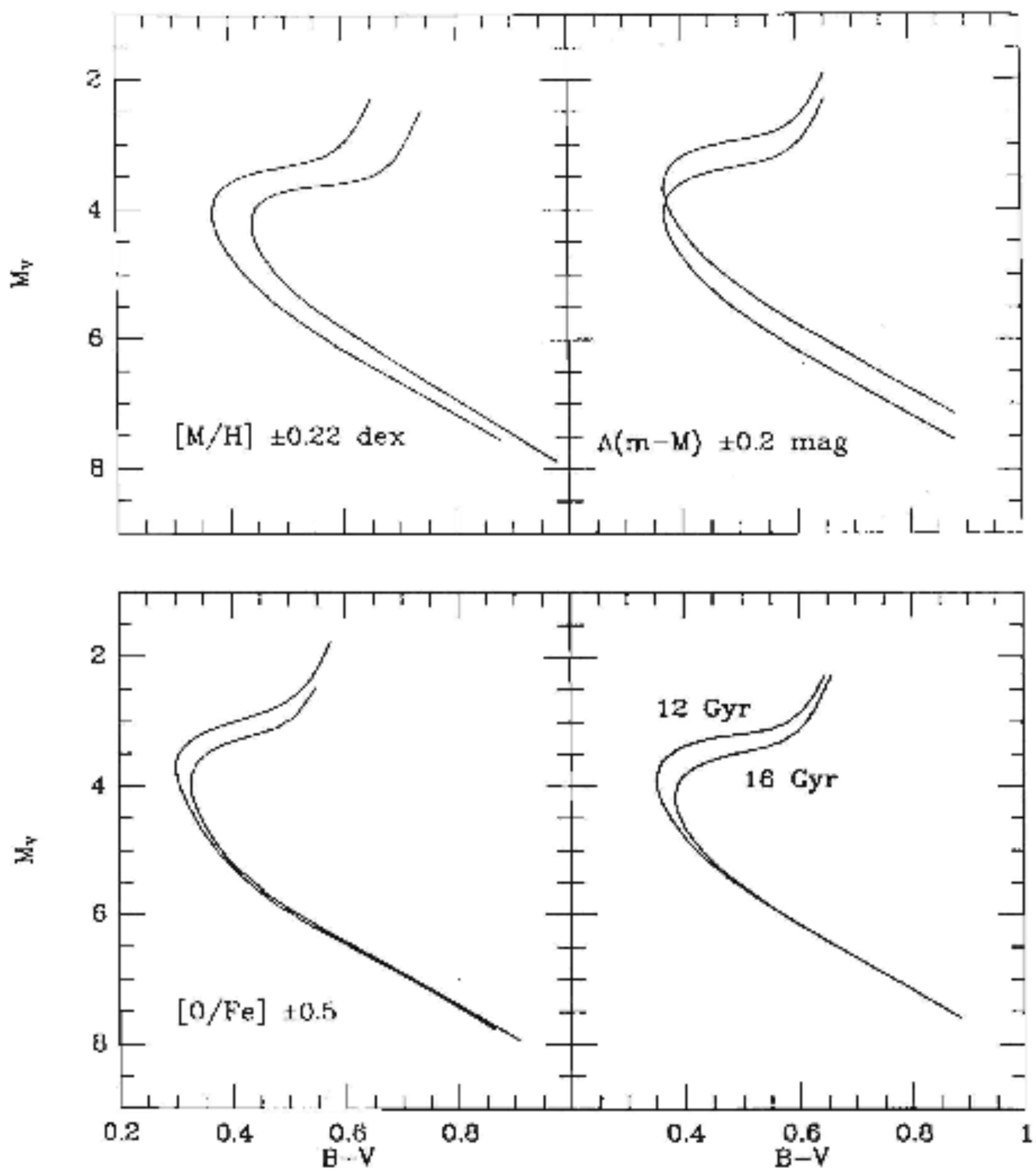


FIG. 1—The four panels show the effects of varying the labelled parameters with all other parameters held constant. The amount of the variation of any one parameter is chosen to be the ±1σ values typical for a well observed cluster.

Bolte 1990

AGES FROM WHITE DWARF COOLING

Well suited for old populations (why?)

Once nuclear burning stops and a star forms a white dwarf, it continues to cool. Physics of cooling is relatively simple.

This gives an independent check on cluster ages from turnoff colors.

Q What do you need, as well as the cooling sequence, in order to work out the age of a cluster if you know the luminosity of the faintest white dwarf ?

Q What do you need, as well as the cooling sequence, in order to work out the age of a cluster if you know the luminosity of the faintest white dwarf?

-> Main sequence, RGB and AGB lifetimes


Planetary
nebula
region
H burning
shell
extinguished
mass loss
AGB
HB
giant branch
PN shell expands
no longer visible
He burning
shell
extinguished
WD
region
→ cooling
main sequence

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THE WHITE DWARF COOLING SEQUENCE OF NGC 6397[1]

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ABSTRACT

We present the results of a deep *Hubble Space Telescope* (*HST*) exposure of the nearby globular cluster NGC 6397, focussing attention on the cluster's white dwarf cooling sequence. This sequence is shown to extend over 5 mag in depth, with an apparent cutoff at magnitude F814W ~ 27.6. We demonstrate, using both artificial star tests and the detectability of background galaxies at fainter magnitudes, that the cutoff is real and represents the truncation of the white dwarf luminosity function in this cluster. We perform a detailed comparison between cooling models and the observed distribution of white dwarfs in color and magnitude, taking into account uncertainties in distance, extinction, white dwarf mass, progenitor lifetimes, binarity, and cooling model uncertainties. After marginalizing over these variables, we obtain values for the cluster distance modulus and age of $\mu_0 = 12.02 \pm 0.06$ and $T_c = 11.47 \pm 0.47$ Gyr (95% confidence limits). Our inferred distance and white dwarf initial-final mass relations are in good agreement with other independent determinations, and the cluster age is consistent with, but more precise than, prior determinations made using the main-sequence turnoff method. In particular, within the context of the currently accepted ΛCDM cosmological model, this age places the formation of NGC 6397 at a redshift $z \sim 3$, at a time when the cosmological star formation rate was approaching its peak.

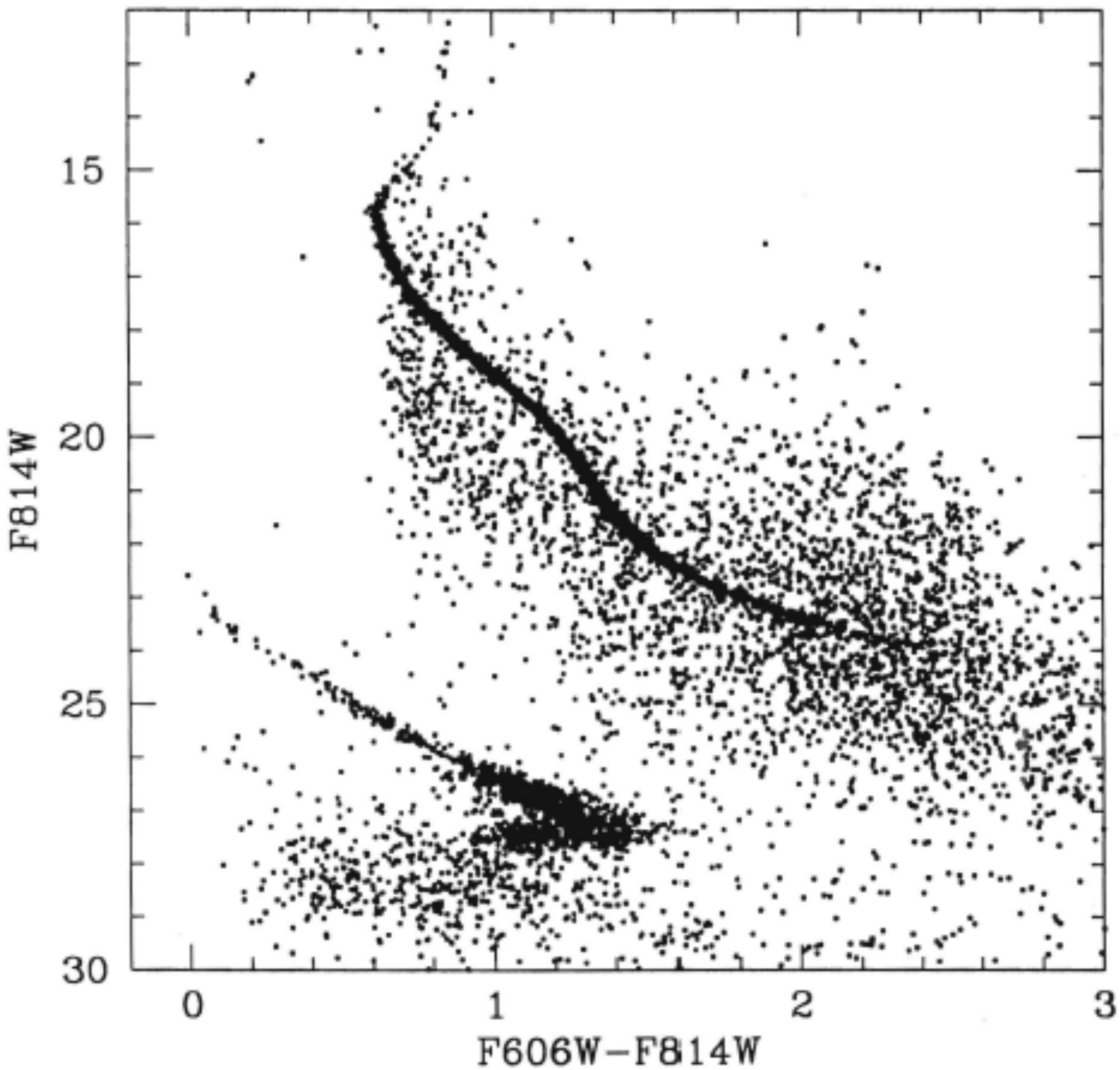

Fig. 1.—ACS color-magnitude diagram for our field in NGC 6397. All real point sources are shown (so the extended galaxy population is not shown). Prominent features include a cluster main sequence, a clear main-sequence turnoff, and a clear white dwarf cooling sequence. Most important is the clear evidence for a sharp decline in the number of white dwarfs at magnitudes greater than F814W = 27.6. The detectability of sources at fainter magnitudes is evident from the

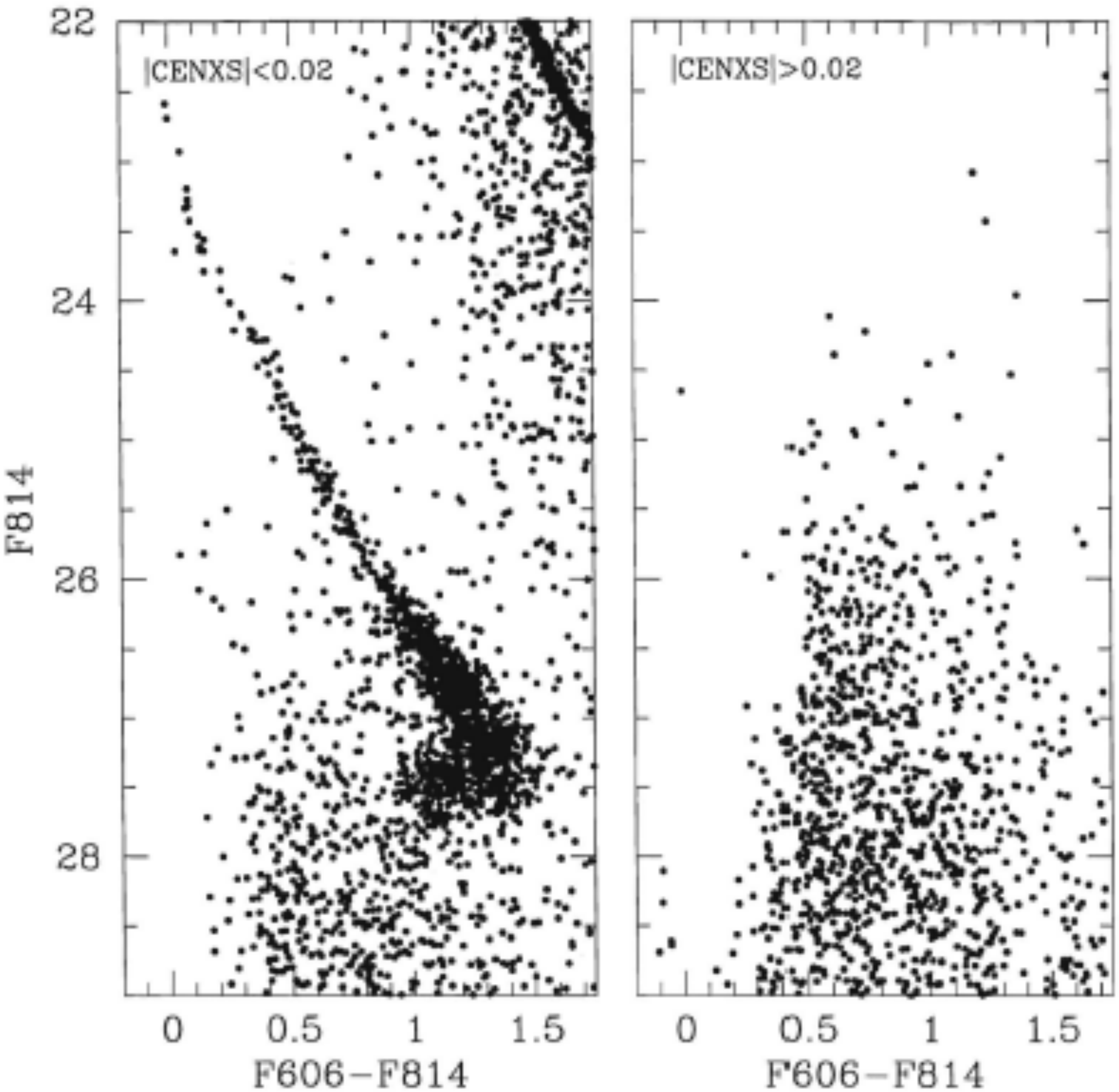

Fig. 2.—*Left*: Point sources in the region of the color magnitude diagram that encloses the white dwarf population. *Right*: The full population of extended sources in the same region—this is the background galaxy population.

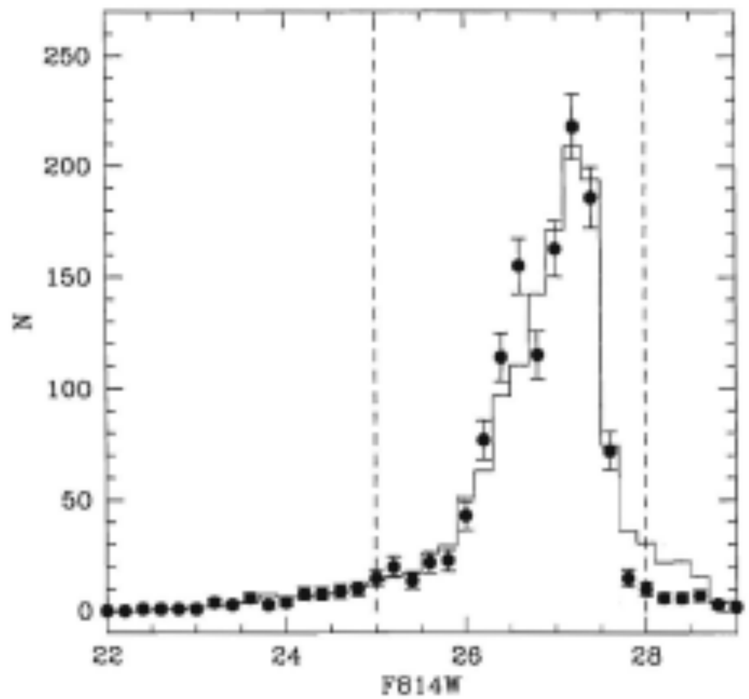

Fig. 12.—Filled circles are the observed luminosity function. The solid histogram shows the model population, which includes both model white dwarfs and our estimate of the residual galaxy contamination per bin. The fitting region is delineated by the vertical dashed lines.

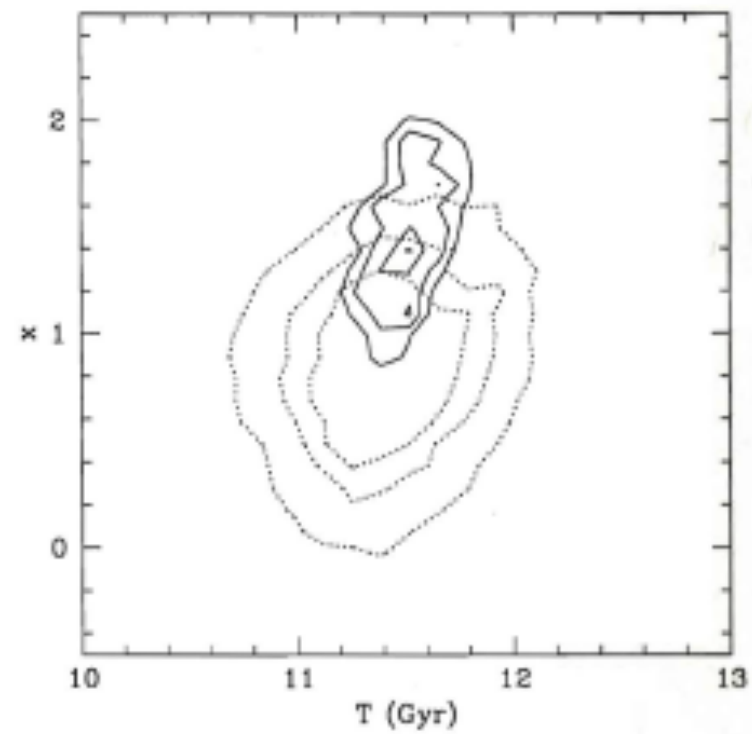

Fig. 13.—Solid contours are the confidence intervals for the Hess diagram fit but now using the [Fe/H] = −2 models from Dotter & Chaboyer. The dotted contours indicate the same but using the luminosity function.