Open clusters as observational isochrones

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Isochrones

- Isochrones are an end-product of at least three interacting models:
  - Stellar evolution
  - Stellar structure
  - Stellar atmospheres
- Through stellar atmospheres the models are “translated” to observational quantities
  - Dependencies are mass, age, composition
  - Secondary dependency: rotation, duplicity

Interdependencies

- The models describe relations between bolometric magnitudes and mass, chemical composition, age
  - How are these relations calibrated?
- Relied on cluster HR diagrams for the differential effects
  - And on assumptions about relations between HR diagrams of clusters of different age and chemical composition
  - One distance calibration: the Hyades

H.L.Johnson, 1957, ApJ

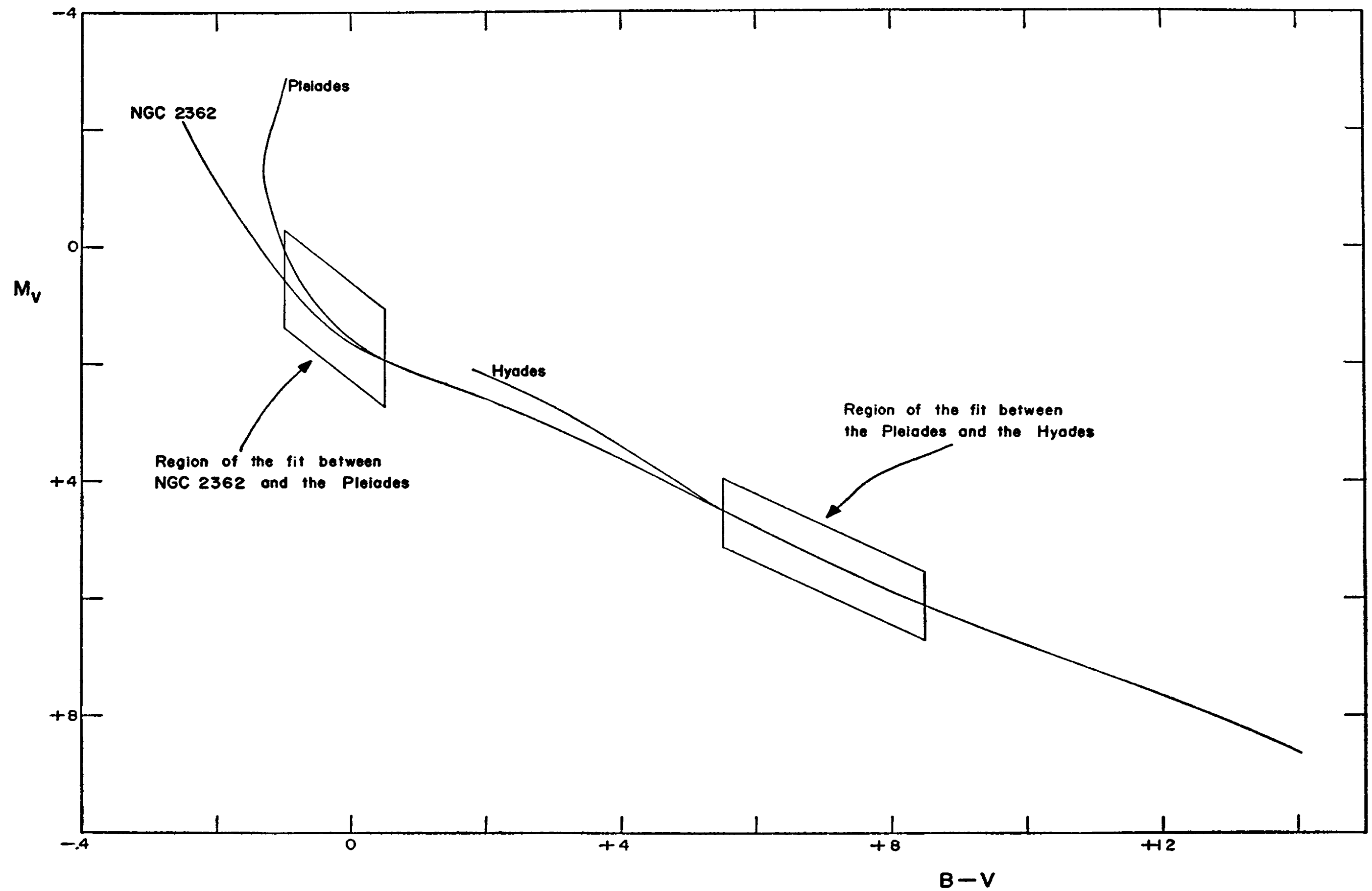


FIG. 3.—The standard initial main sequence, showing the regions of the fits between the clusters

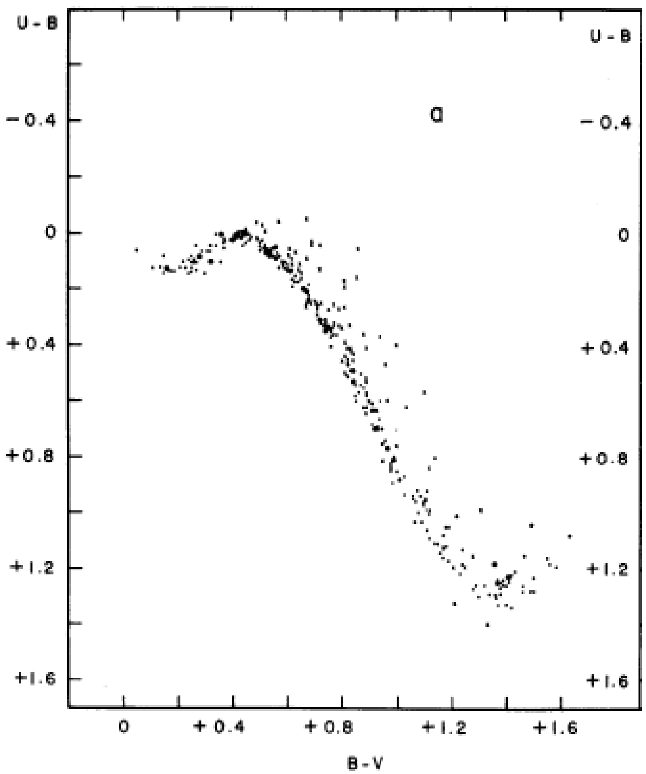
Johnson's main sequence

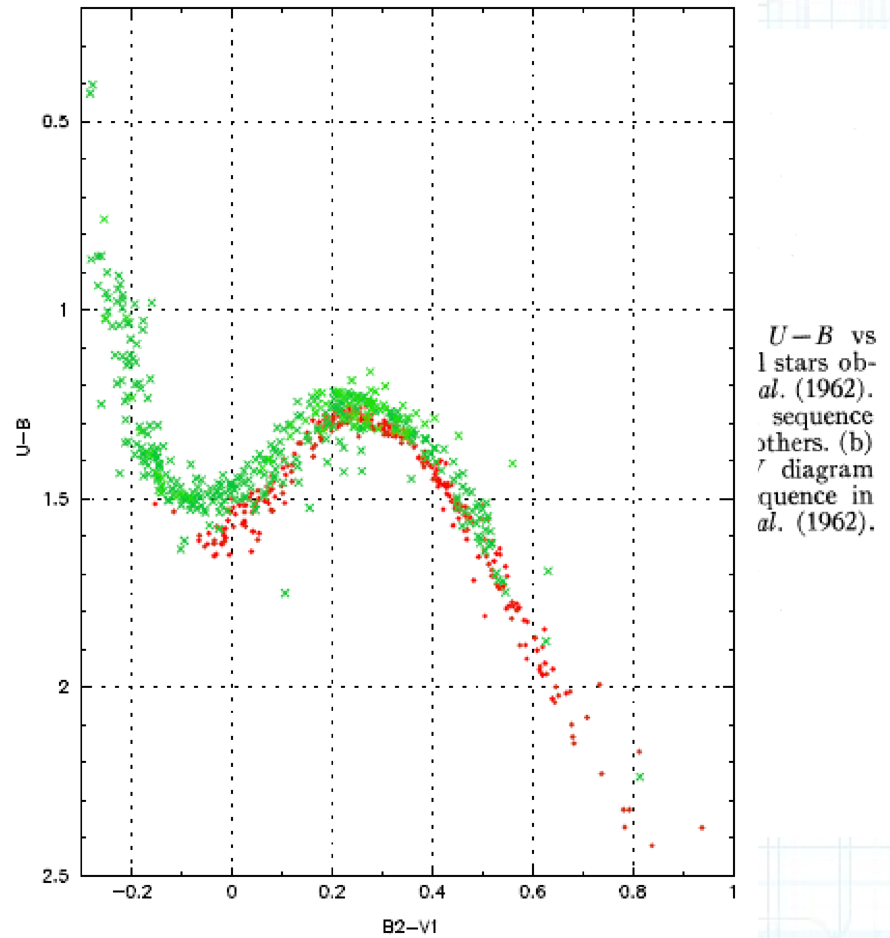
- Dominated cluster-distance determinations for more than 40 years
  - Both directly and indirectly
    - Directly through transformation to other photometric systems
    - Indirectly through repeating the basic assumptions made
- As is often the case, initial assumptions are rapidly forgotten when applying “calibrations”

Assumptions

- The main-sequence position was (and still often is) assumed to depend almost entirely on chemical composition
  - It was difficult to use any other assumption, as this could not be verified from data
  - Accurate absolute parallax-based distances for clusters were not available
    - Best distance estimate available was for the Hyades, convergent-point based
    - Estimates in the 1950s were still wrong by 0.3 magnitudes

The first sign of trouble





W.van Altena, 1966, AJ: The Hyades anomaly

Chemical composition differences?

- For 40 years the “anomaly” was attributed to differences in chemical composition
  - Despite this being inconsistent with spectroscopic observations
- The difference in (B-U) is equivalent to the c1 parameter in Strömgren photometry
  - Study by Crawford (1975, AJ) on calibration of F stars
    - Showed character of c1 variations
    - These are to do with luminosity

D.L.Crawford, 1975, AJ

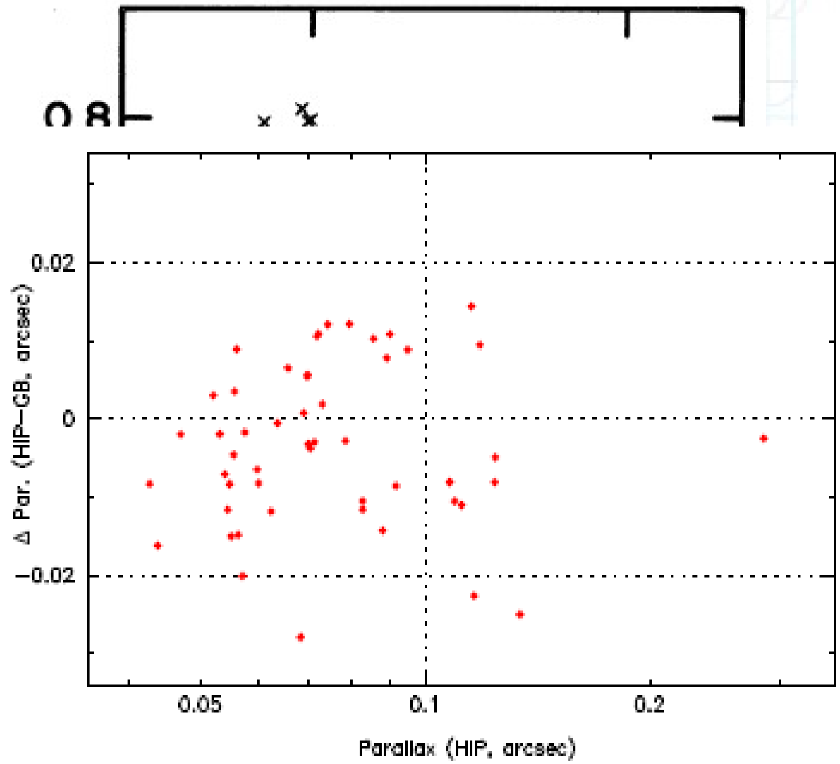


Fig. 3. A comparison between the ground-based parallax values as used by Crawford (1975) and parallaxes for the same stars as obtained from the new Hipparcos reduction. The comparison shows a systematic difference of 3.4 mas and a noise on the ground-based parallaxes of 10 mas.

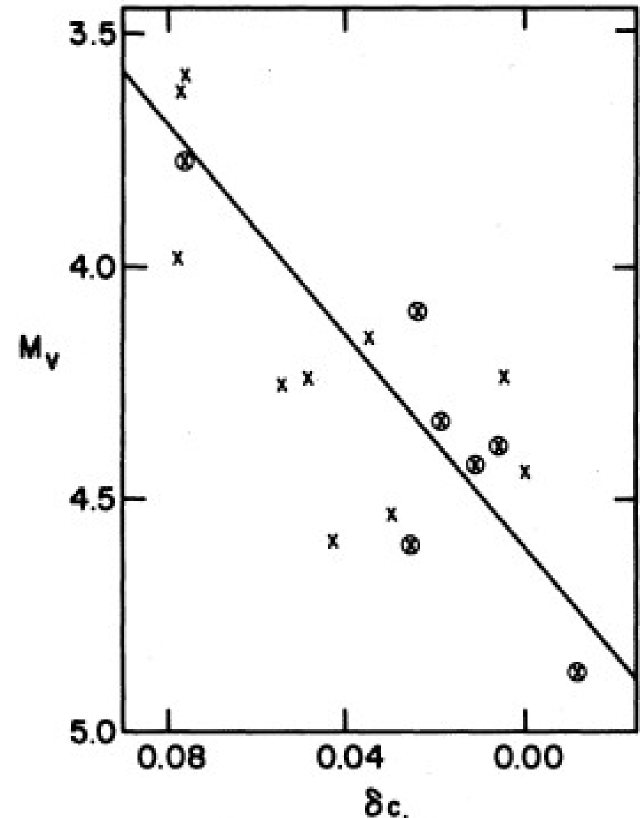
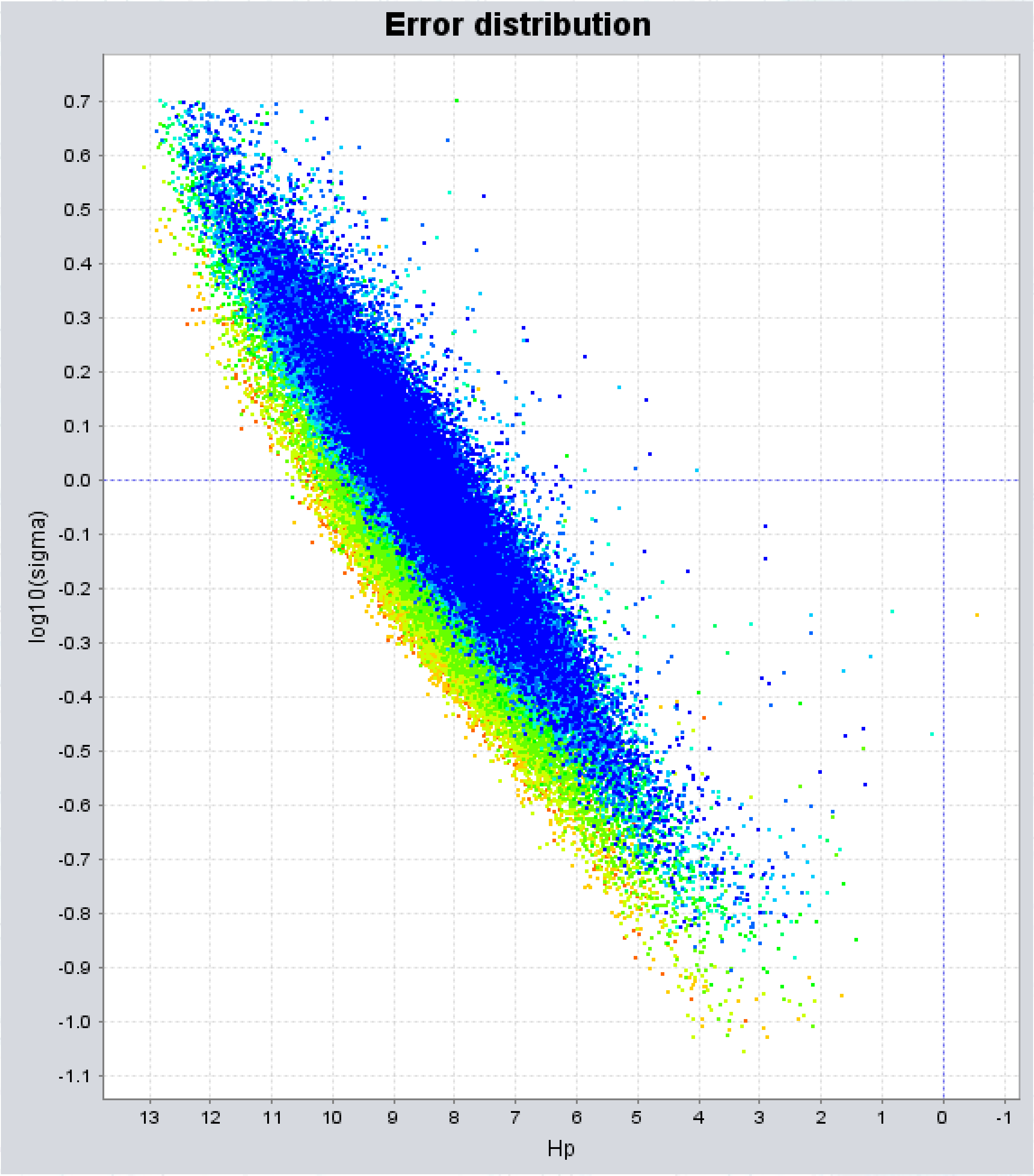


FIG. 15. The M_V vs δc_1 relation for the F-type stars in group 1. e slope of the line drawn is $f=11.2$. ⊗ denotes those stars with ·0.1 arcsec.

The Hipparcos data



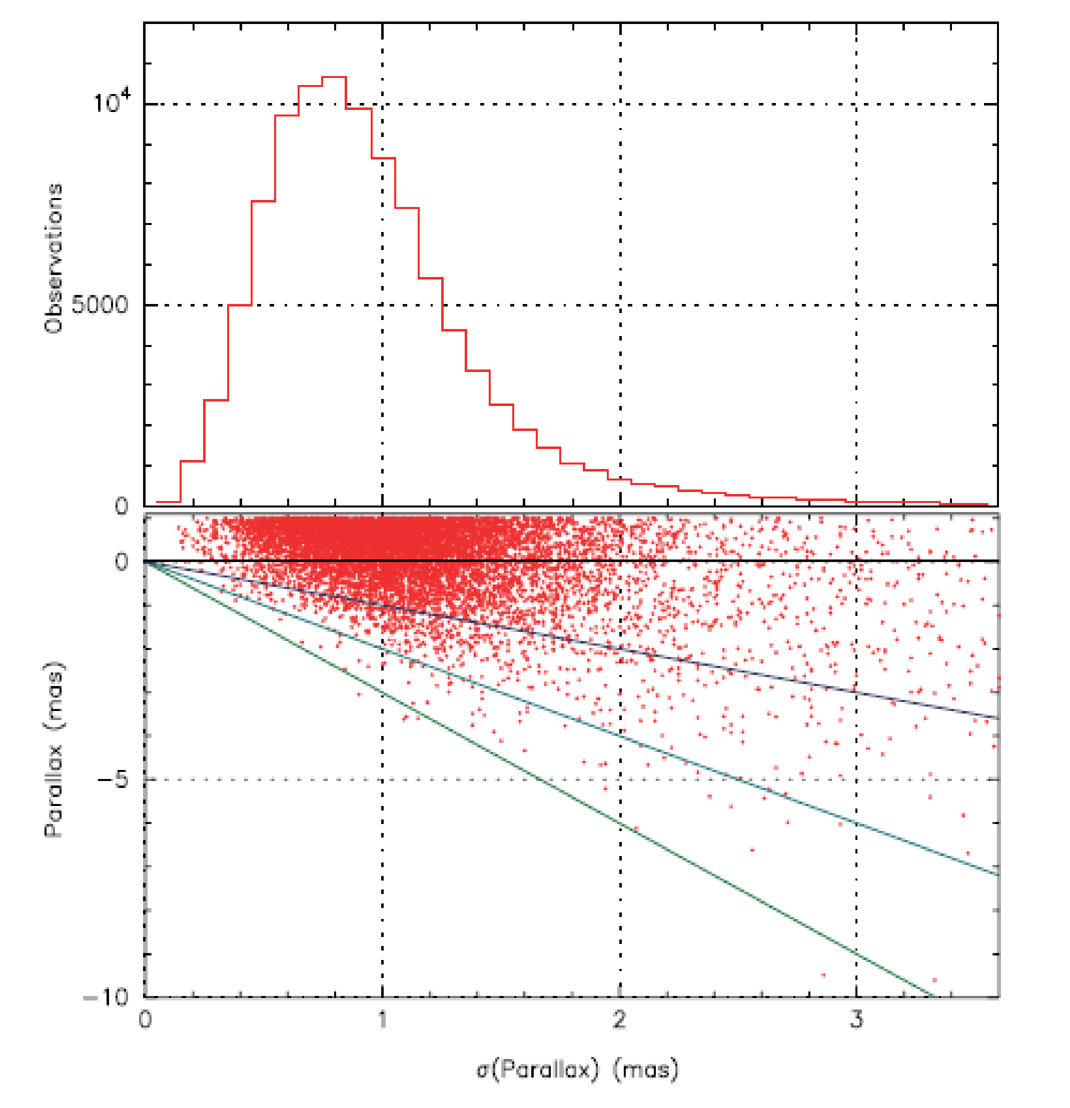
New reduction:
30000 stars with parallax accuracies better than 10%

Increase by more than 30% wrt original reduction

Colours represent ecliptic latitude

Red-> poles
Blue-> plane

Verification new reduction



Parallax errors and negative-parallax distribution

1 σ

2 σ

Absolute, not relative parallax

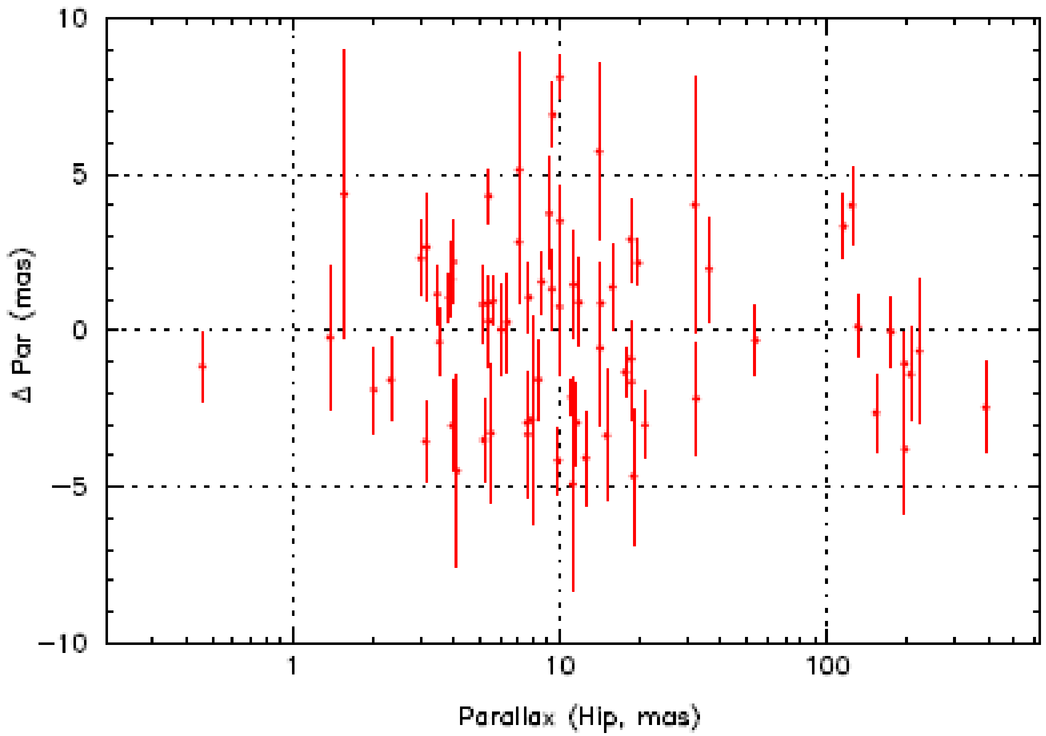
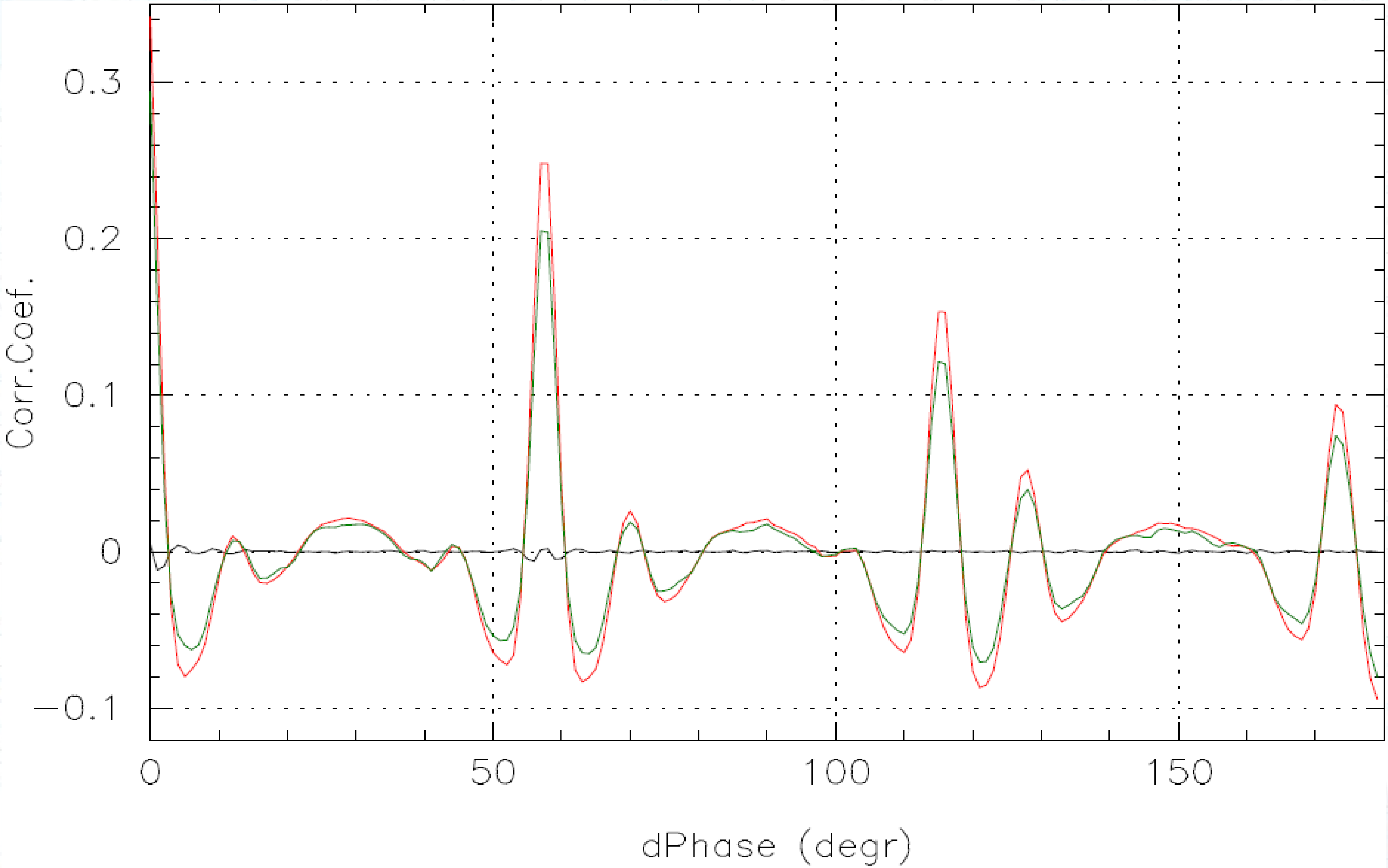


Fig. 4. Differences between MAP-based and Hipparcos parallaxes for 71 stars. The error bars contain the contributions of the formal errors on the Hipparcos parallaxes and the precisions as given for the MAP data.

Calibration noise about 2.4 mas

Important for cluster parallaxes



Using Hipparcos data

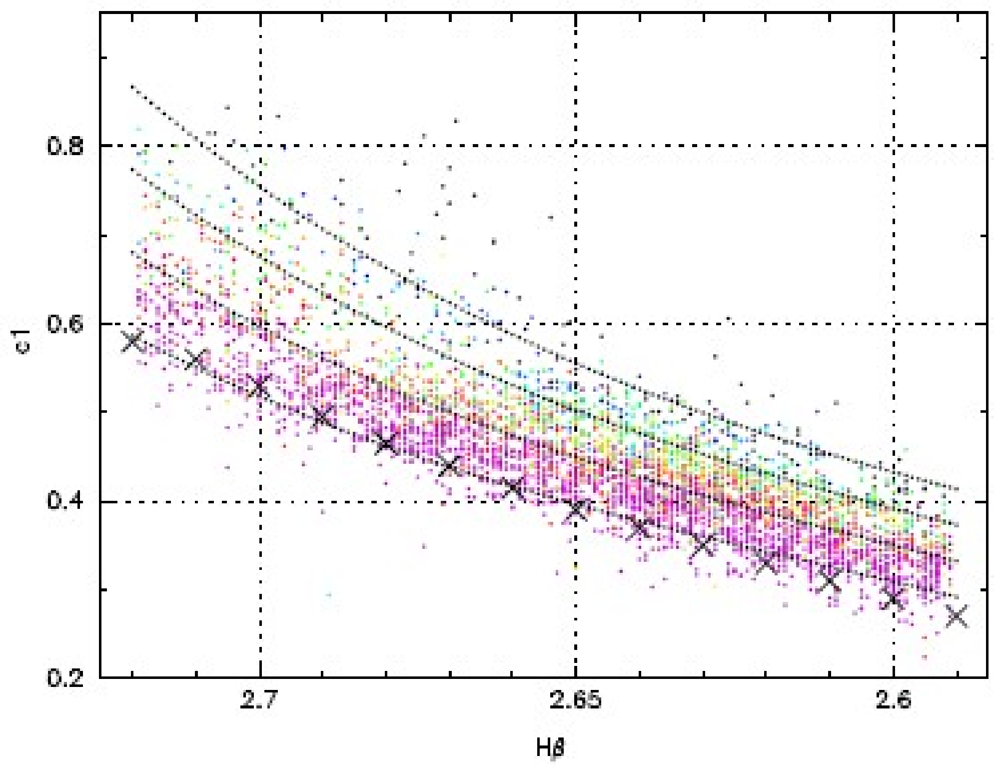


Fig. A.1. The relation between Hβ and c_1 in the Strömgren system for nearby F type stars with parallax errors below 10 per cent. The curved lines of black dots represent from bottom to top the calibration relation at Δv values of 1.2, 0.2, -0.8 and -1.8 magnitudes. The crosses show the calibration relation determined and used by Crawford (1975).

The luminosity relation

$d\beta \equiv (H\beta - 2.64) \cdot 10$ ($d\beta$ thus ranges from -0.5 to $+0.8$), and
$\Delta v \equiv v - v_0(b - y) + 0.75$:

$$\begin{aligned} c_1 = {} & (0.4370 \pm 0.0007) + (-0.049 \pm 0.010)\,\Delta v \\ & + (0.2205 \pm 0.0029)\,d\beta + (-0.032 \pm 0.003)\,\Delta v\, d\beta \\ & + (0.086 \pm 0.007)\,d\beta^2 + (-0.029 \pm 0.007)\,\Delta v\, d\beta^2 \\ & + (0.060 \pm 0.013)\,d\beta^3, \end{aligned} \tag{A.2}$$

Remaining standard deviation: 0.029 magn.

Based on 271 F stars with parallax errors<10%

The relation with log(g)

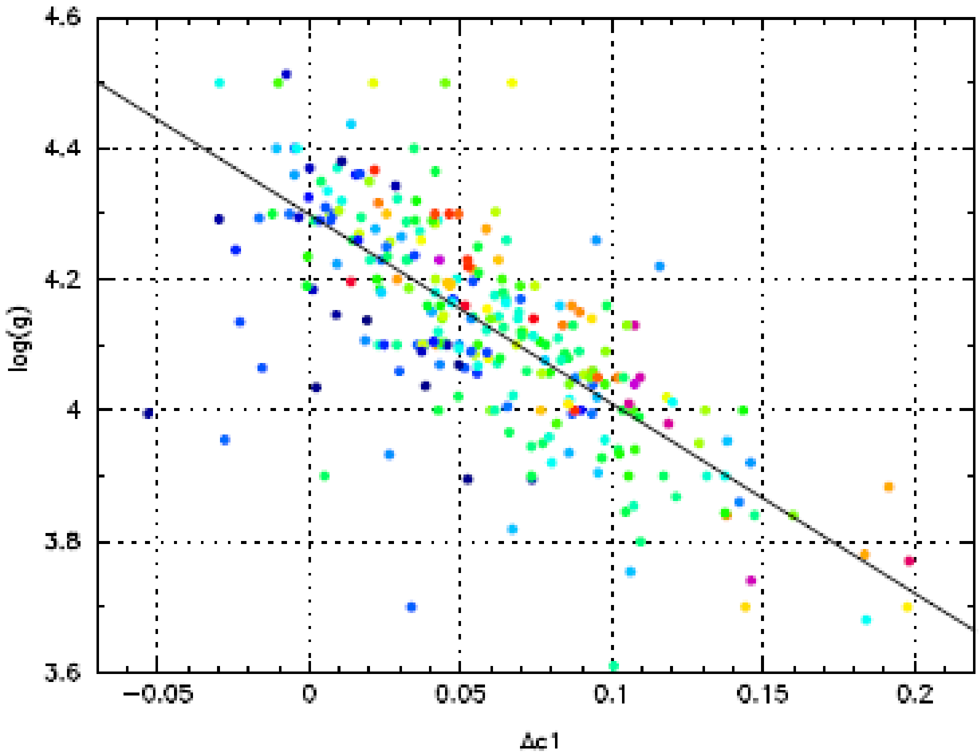


Fig. A.5. The relation between Δc_1 and log g for 271 F stars of luminosity types III, IV and V. The diagonal line is the calibration curve.

How about metallicity?

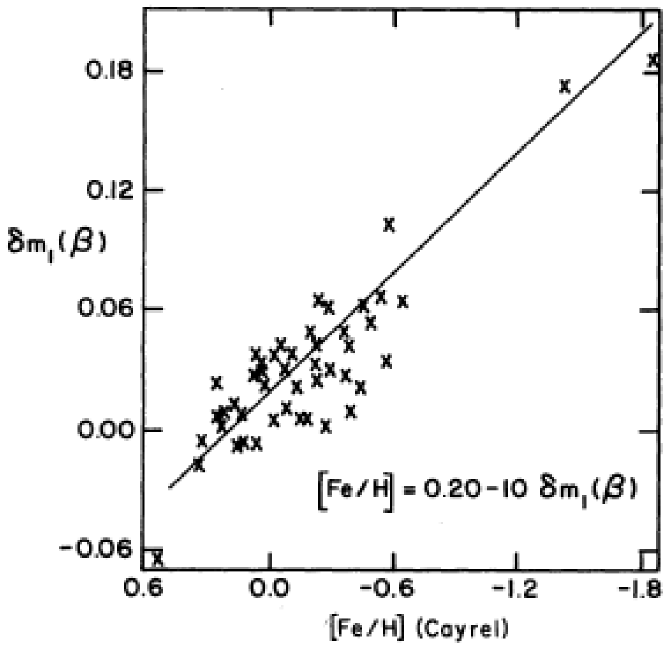


FIG. 17. The $\delta m_1(\beta)$ vs [Fe/H] (Cayrel) relation.

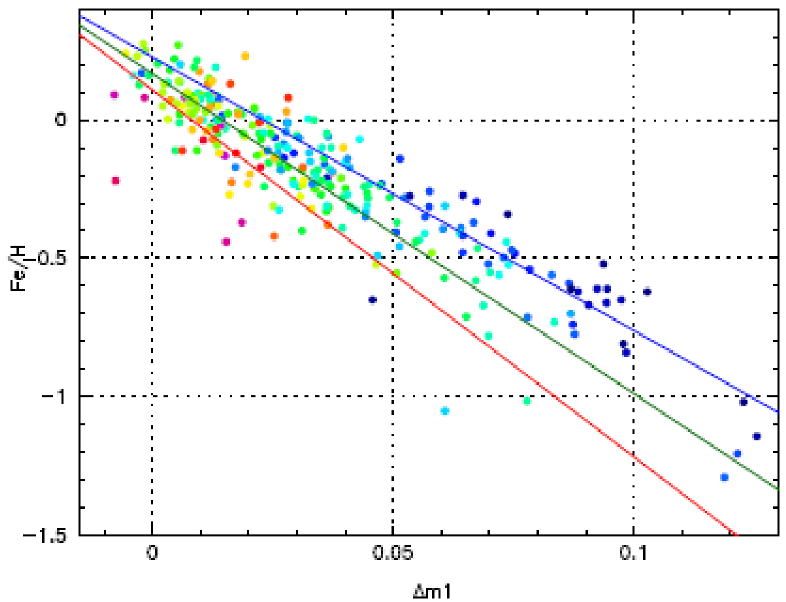
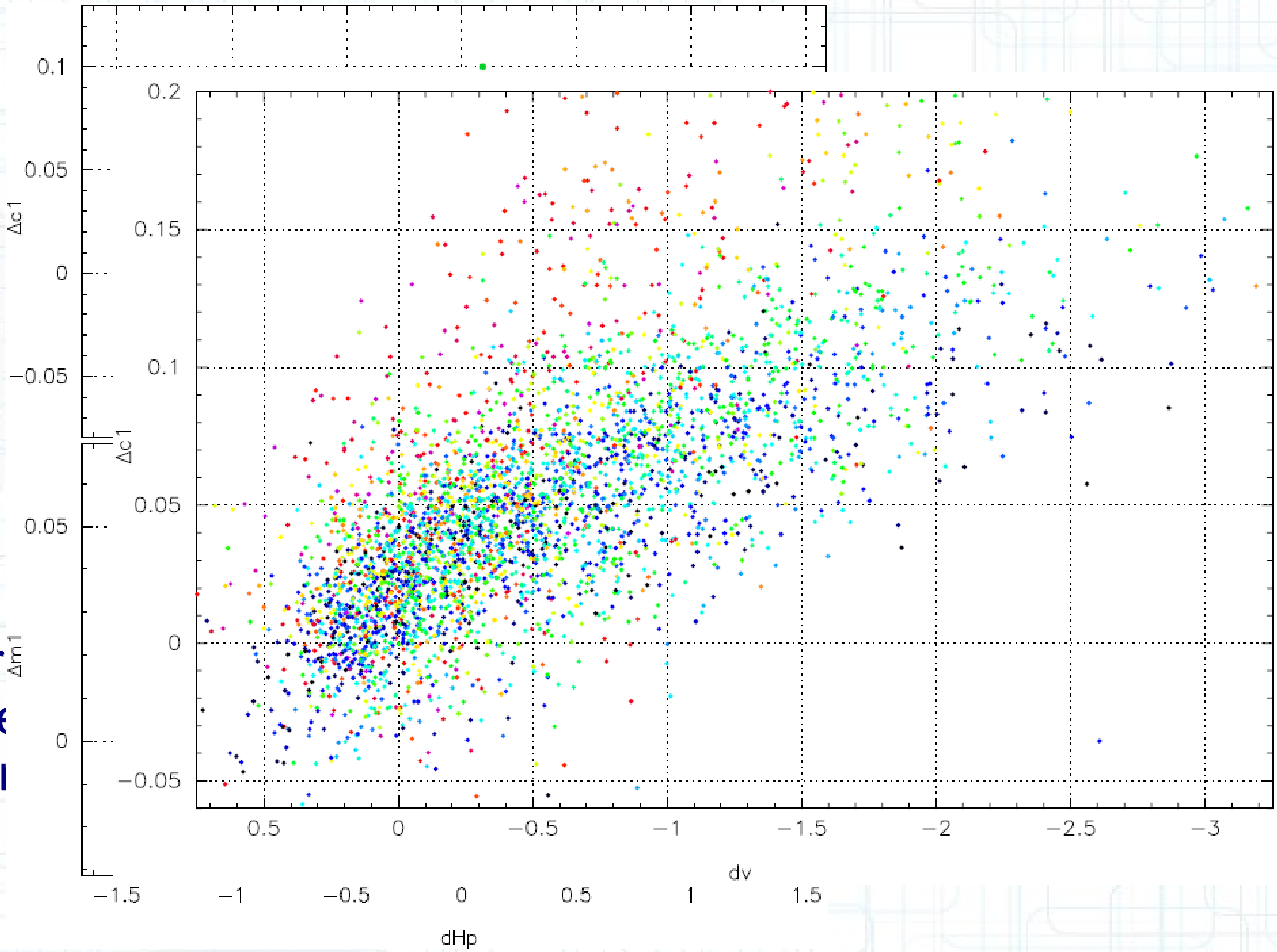


Fig. A.4. The relation between Δm_1 and Fe/H for 271 F stars. The calibration for $H\beta = 2.60,\ 2.65,\ 2.70$ is shown by the diagonal lines, with the lowest value of $H\beta$ as the top line.

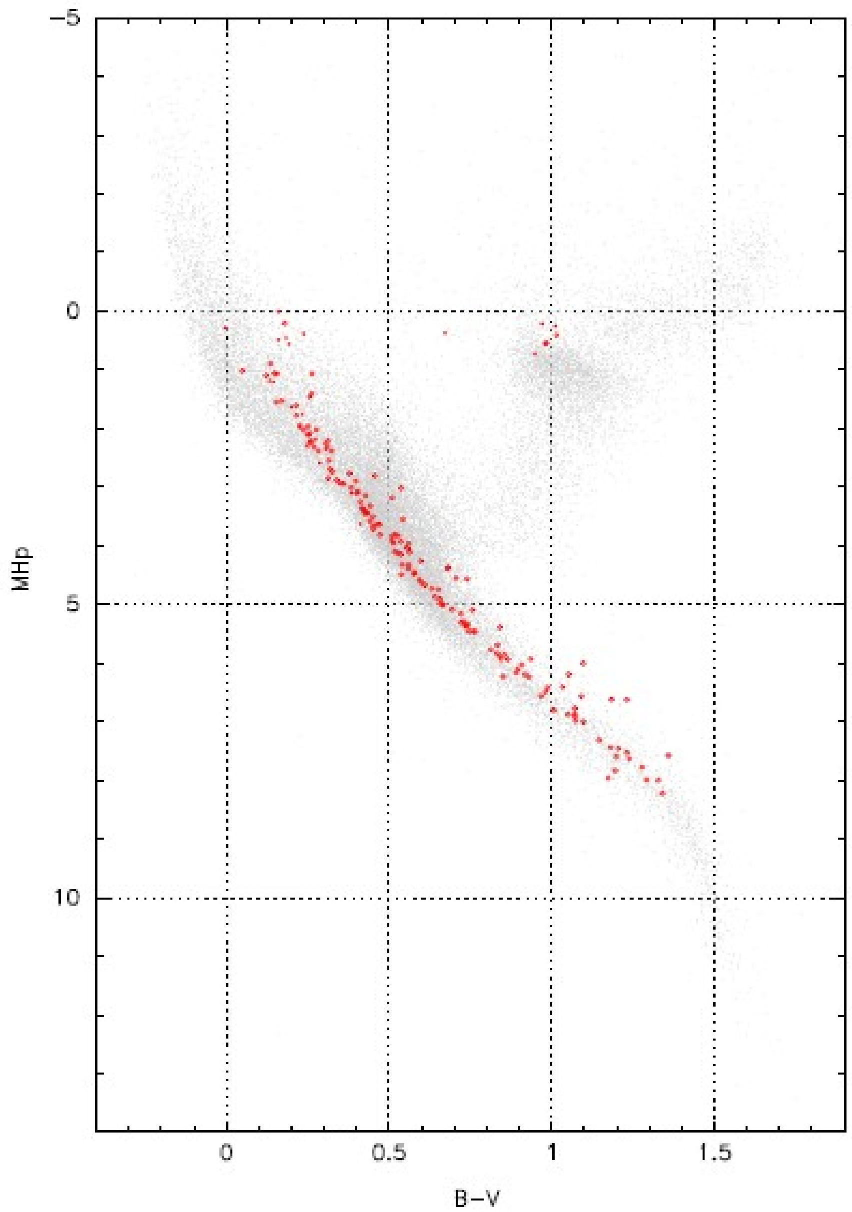
$$\mathrm{Fe/H} = (0.179 \pm 0.012) + (-0.119 \pm 0.038)\,\mathrm{d}\beta + (-11.21 \pm 0.38)\,\Delta m_1 + (-3.37 \pm 1.05)\,\Delta m_1\,\mathrm{d}\beta, \quad \text{(A.9)}$$

$\sigma = 0.1$

Luminosity calibration



For ... olde ... thai ... ious ... gn.

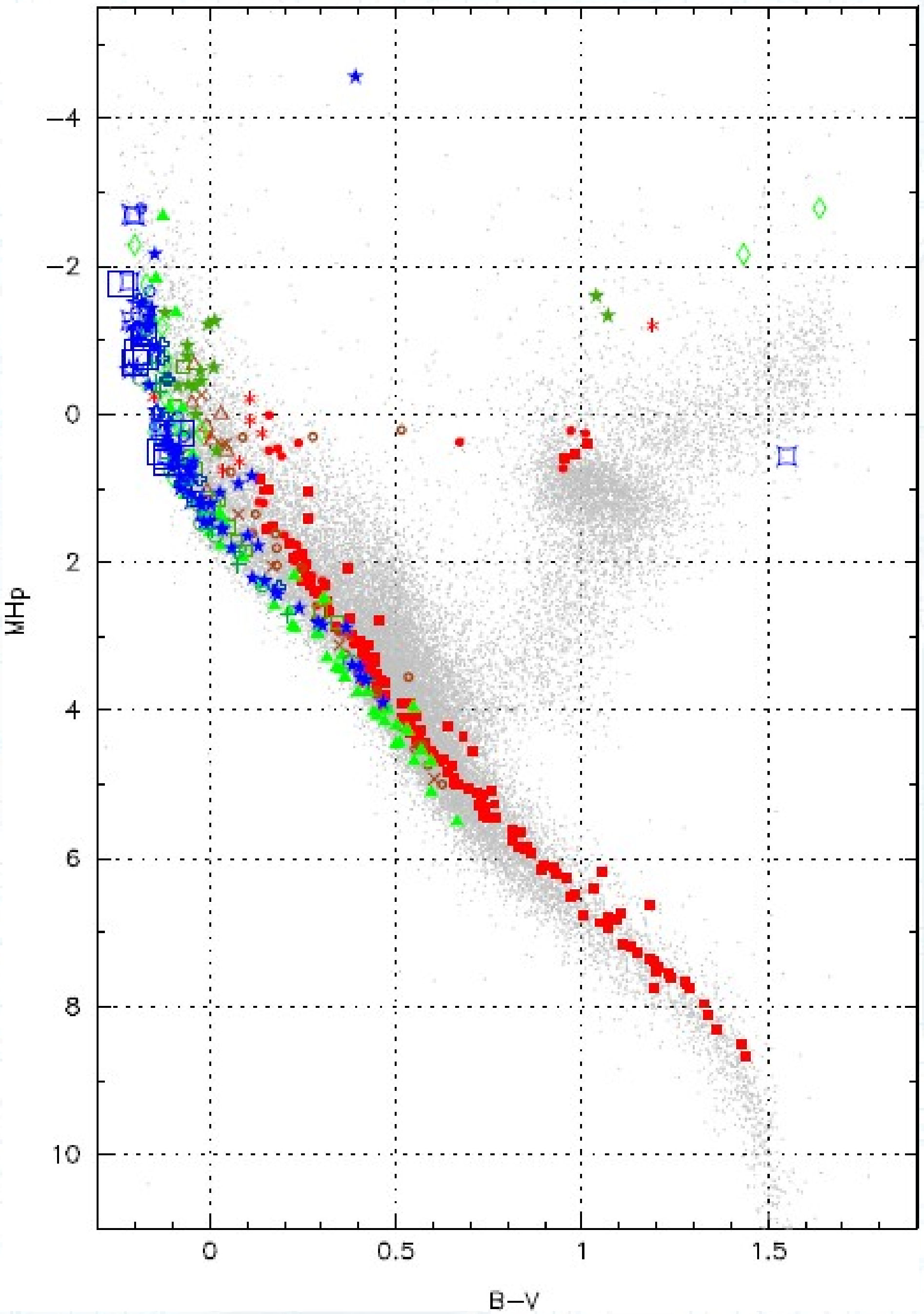


HR Diagrams for Hyades and Praesepe

Background:

30000 single stars with parallax errors <10%

Distance moduli entirely parallax-based



log(Age)

8.9

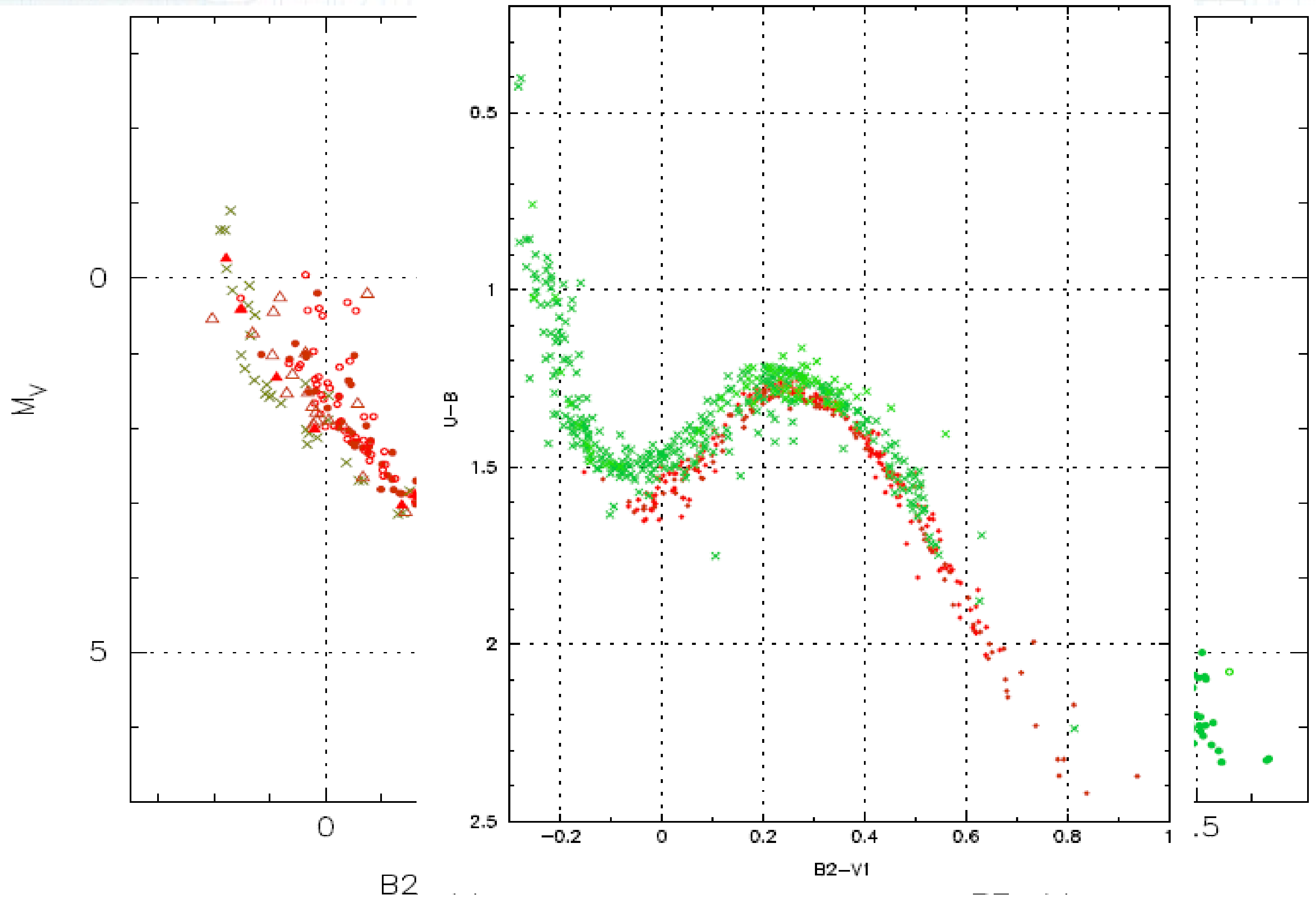
8.7

8.2

7.8

7.5

Using Geneva photometry



Distance moduli

- All distance moduli are parallax-based
  - Accuracies range from 0.02 to 0.15 magn.
- Reddening corrections are small
  - Have been applied when derived independently from main-sequence fitting
- Ref: FvL, 2009, A&A 497, p209
- Field stars: FvL, 2007, A&A 474, p653

This is only the start

- Gaia data will add several orders of magnitude in information
  - At source-accuracies typically 10 to 20 μas, cluster parallaxes accuracies can in principle reach 1 μas and better
    - Equivalent to 0.001 mag at 500 pc
    - Depth resolution till about 300 pc

Clusters seen by Gaia

- <1kpc of the order of 300 to 400 clusters
  - And a couple of OB associations
  - Age range log(t): 6.0 to 9.6
  - Many clusters still need confirmation
  - New clusters are expected too
- Membership from proper motions and parallaxes
- Photometry for all stars
  - Broadband as well as low resolution spectral
  - High-resolution spectra for all brighter stars

Gaia is important for clusters

- Provides unbiased selection of cluster members
  - Not just the easy-to-study core
    - Also the low density halo
    - Different populations in core and halo
    - Affects luminosity function studies
- At 1kpc, faintest stars still abs.12.5 magn (-redd.)
  - Wide and homogeneous HR diagram coverage

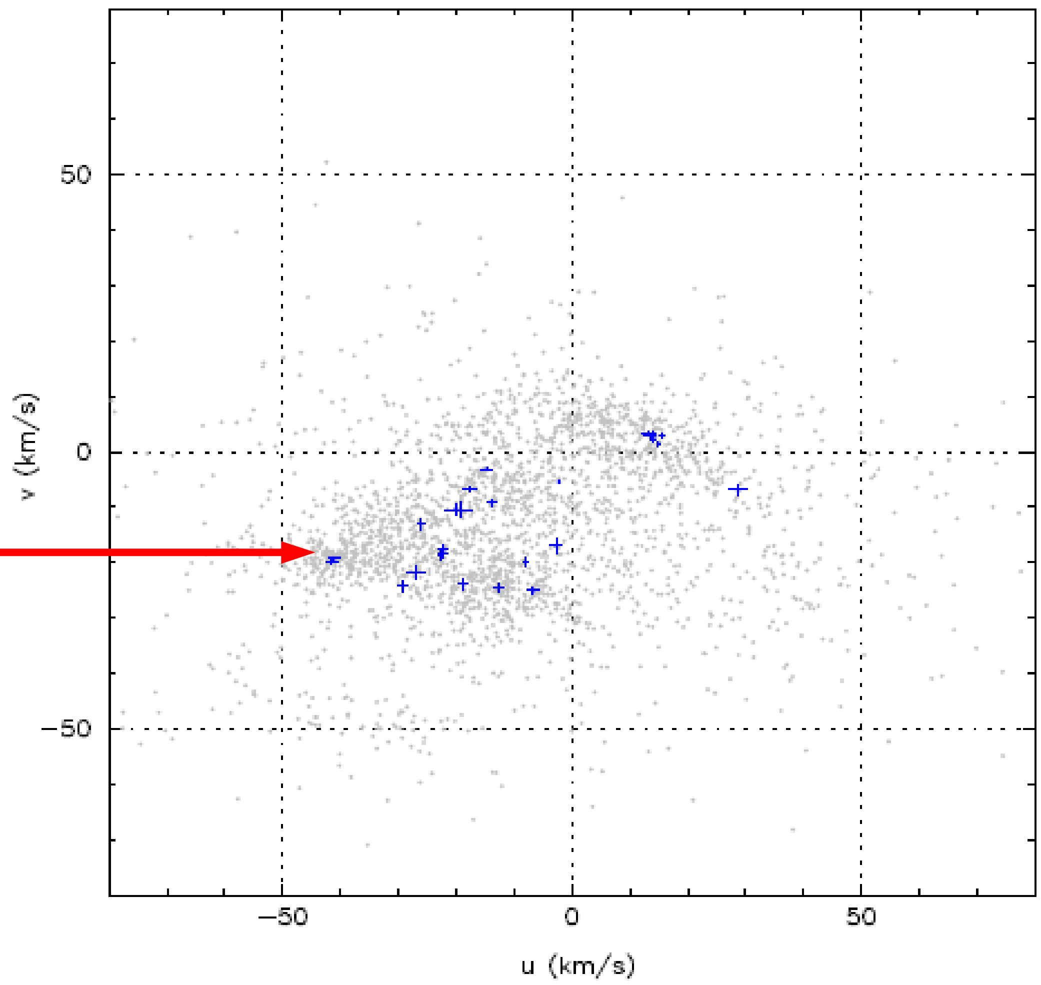
HR Diagram coverage

- Extended to younger clusters from OB associations to older open clusters
  - Also a few globular clusters will have accurate parallax-based distance moduli
- Additional information from galactic dynamics
  - 3D velocity vector of each cluster will be accurately measured
  - Shows links between clusters
  - Shows trails of “lost” members

Dynamic links between clusters

A & F stars within 125 pc

Hyades & Praesepe

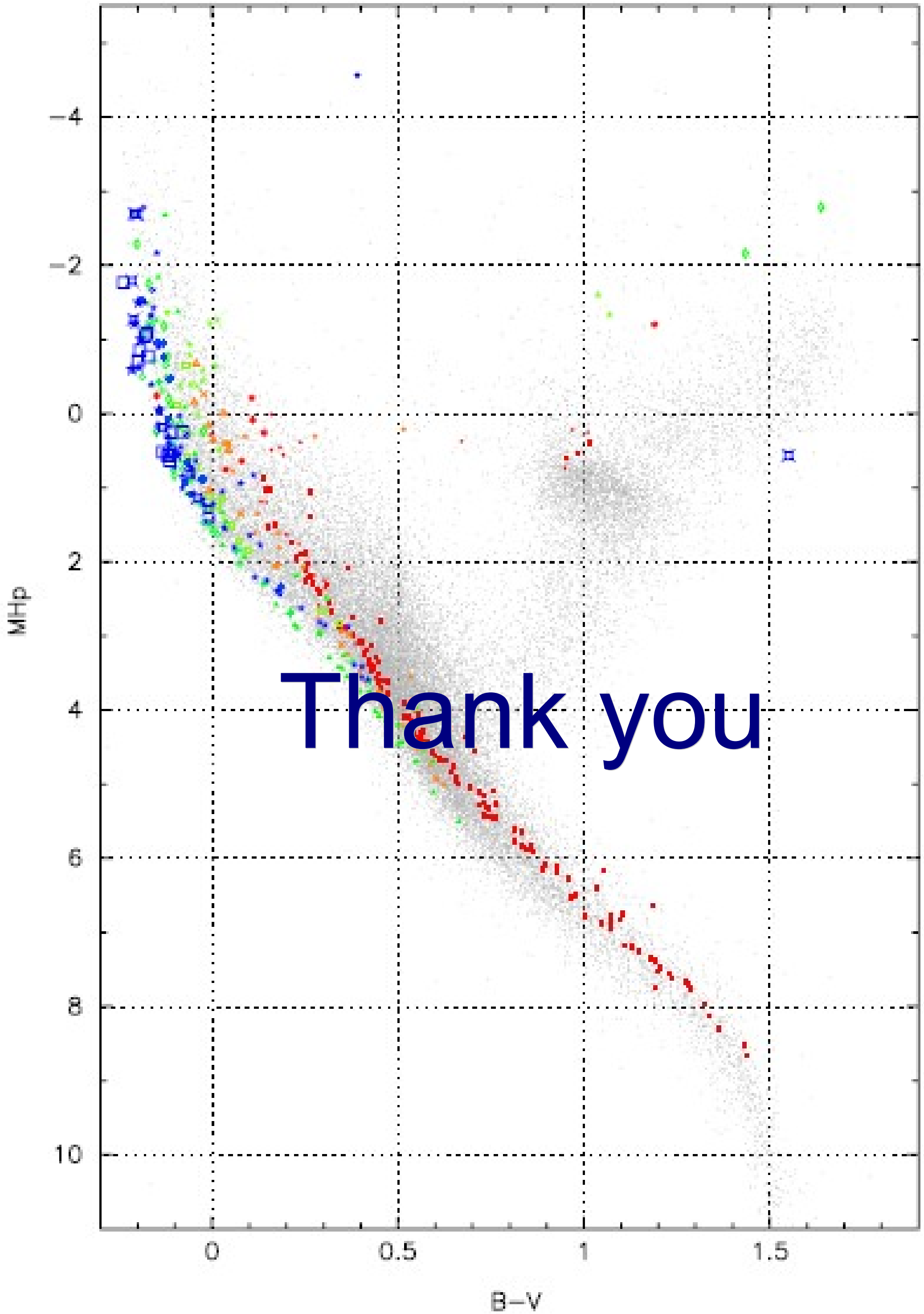


Conclusions

- Parallax-based distance determinations for open clusters have become reality with the Hipparcos mission data
  - In particular following the improvements from the new reduction
- The first observational isochrones show general confirmation of theoretical isochrones, but there are differences
  - In particular for age group around 100 MY

Conclusions

- The Gaia data will dramatically extend and improve upon this picture
  - More than 10 times more clusters
  - For each cluster a few hundred stars
  - Wider range in age coverage
  - Inclusion of globular clusters
- Remaining difficulties:
  - Reddening, sometimes differential
  - Cluster dispersion, few old open clusters



Thank you

The Pleiades "problem"