Ruprecht 147 – The Oldest Nearby Cluster

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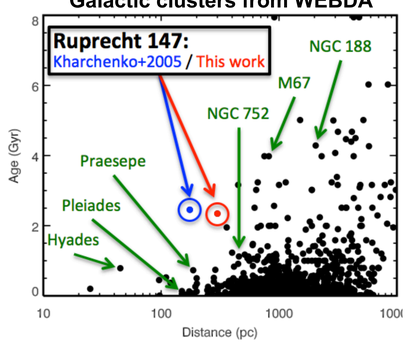
Summary: Ruprecht 147 is a hitherto unappreciated open cluster that holds great promise as a standard in fundamental stellar astrophysics. We have conducted a radial velocity survey of astrometric candidates with Lick, Palomar, and MMT observatories and have identified over 100 members, including 5 blue stragglers, 11 red giants, and 5 SB2 binaries. We estimate the cluster metallicity from spectroscopic analysis, using Spectroscopy Made Easy (SME), and find it to be [M/H] = +0. 08 ± 0. 03. We have obtained deep CFHT/MegaCam g′r′i′z′ photometry and fit Padova isochrones to the (g′ − i′) and 2MASS (J −K_S) CMDs, using the τ^2 maximum-likelihood procedure of Naylor (2009). We find best fits for isochrones at age t = 2. 5 ± 0. 25 Gyr, m – M = 7. 35 ± 0. 1, and A_V = 0. 25 ± 0. 05, with significant uncertainty from the unresolved binary population and possibility of differential extinction across this large cluster. At ~300 pc and an age of ~2.5 Gyr, Ruprecht 147 is by far the oldest nearby star cluster.

We have submitted our first paper to the *Astronomical Journal*, with co-authors Angie Wolfgang (UC Santa Cruz), John M. Brewer (Yale) and John A. Johnson (Caltech)

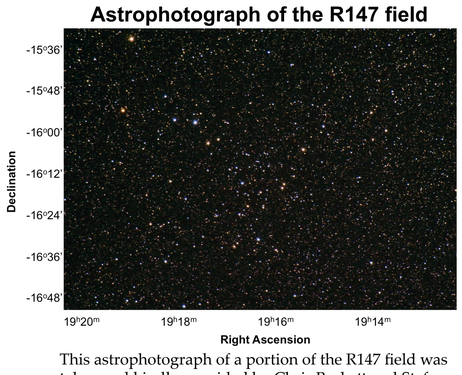
An old cluster, a new benchmark: We identify over 100 members

Galactic clusters from WEBDA



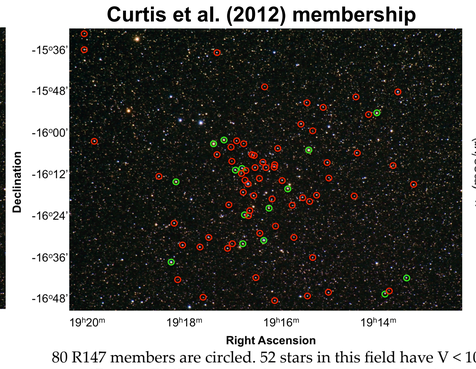
WEBDA lists an age for M67 at 2.5 Gyr, but we plot it at 4 Gyr according to Pichardo et al. (2012)

Astrophotograph of the R147 field



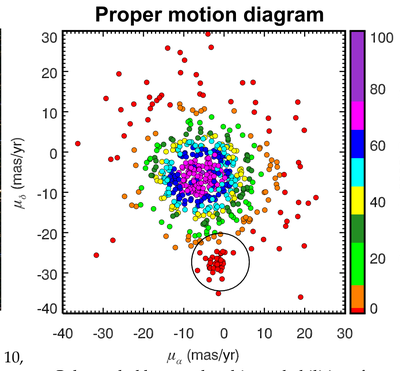
This astrophotograph of a portion of the R147 field was taken and kindly provided by Chris Beckett and Stefano Meneguolo of the Royal Astronomical Society of Canada.

Curtis et al. (2012) membership



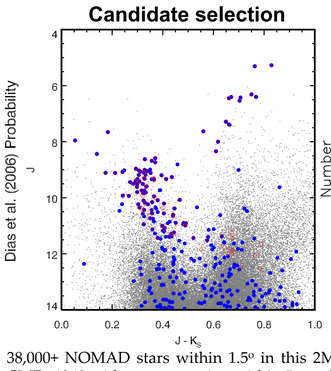
80 R147 members are circled. 52 stars in this field have V < 10, only 17 are in R147 (**green**). It is remarkable that Herschel correctly identified this cluster in 1830!

Proper motion diagram



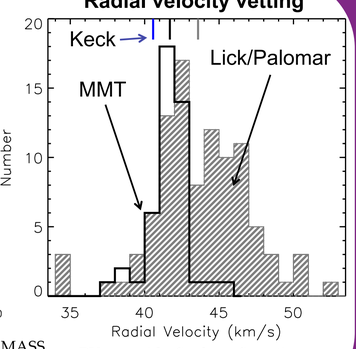
Color-coded by membership probabilities of Dias et al. (2006), which are clearly in error

Candidate selection



38,000+ NOMAD stars within 1.5° in this 2MASS CMD, 1348 with proper motion within 5 mas/yr of cluster mean (**blue**), and 108 R147 members (**red**)

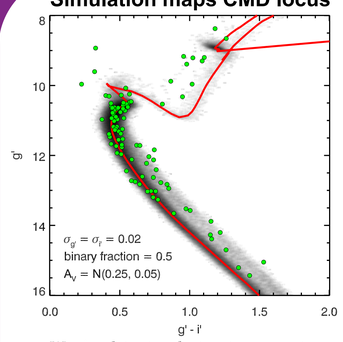
Radial velocity vetting



RVs provide final confirmation for cluster membership.

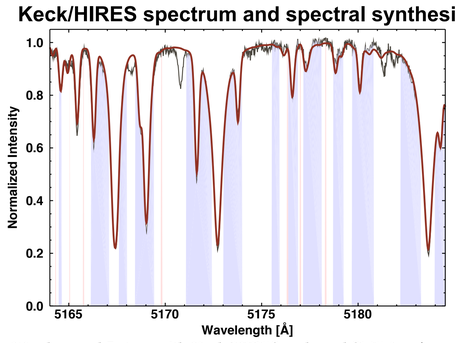
Composition, differential extinction and binarity

Simulation maps CMD locus



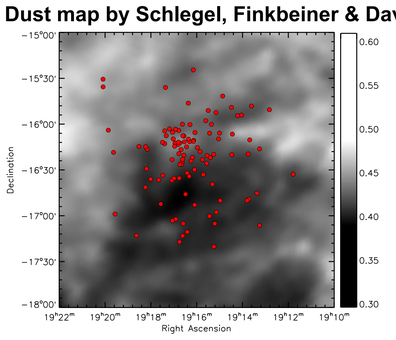
We simulate star clusters to map out regions of various likelihoods that members (**green**) can occupy on a CMD

Keck/HIRES spectrum and spectral synthesis



We observed 5 stars with Keck/HIRES and used SME (performed by John Brewer) to derive stellar properties, and determined the composition of R147 is [M/H] = +0.08, with zero α-enhancement.

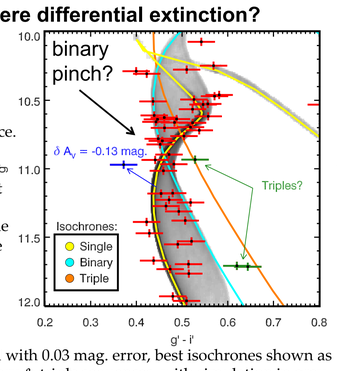
Dust map by Schlegel, Finkbeiner & Davis



The Schlegel et al. (1998) dust map shows cloud structures across the R147 field, with A_V varying from 0.3 to 0.5 magnitudes, assuming R_V = 3.1

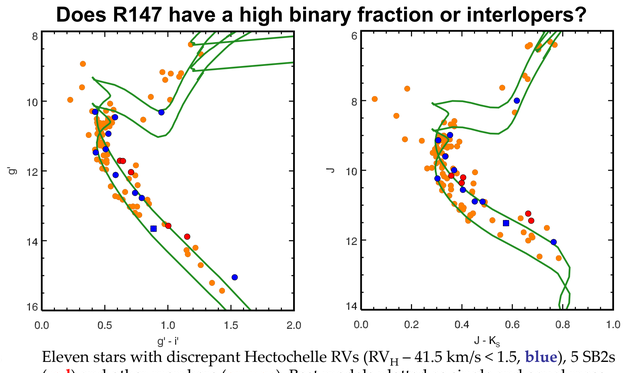
Is there differential extinction?

Blue symbol must be de-reddened by 0.13 mag. to place it on main-sequence. Interestingly, the A_V here from the dust map is 0.13 lower than the median value for the R147 field



Members plotted with 0.03 mag. error, best isochrones shown as single, equal binary & triple sequences, with simulation in gray assuming zero photometric error and no differential extinction

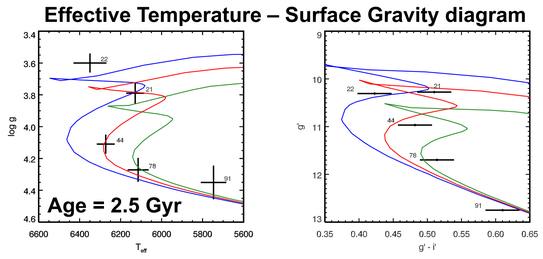
Does R147 have a high binary fraction or interlopers?



Eleven stars with discrepant Hectochelle RVs (RV_H – 41.5 km/s < 1.5, **blue**), 5 SB2s (**red**) and other members (**orange**). Best models plotted as single and equal mass binary sequences (**green lines**). Most are clustered around equal mass binary sequence, expected if binaries, but also if non-members. Need more RV epochs.

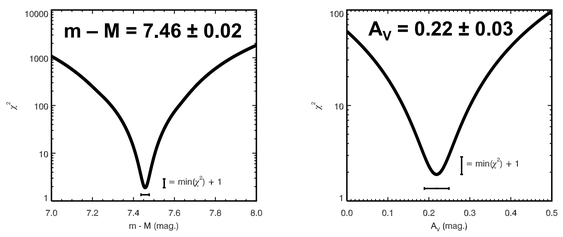
Inferring cluster properties with Padova isochrones

Effective Temperature – Surface Gravity diagram



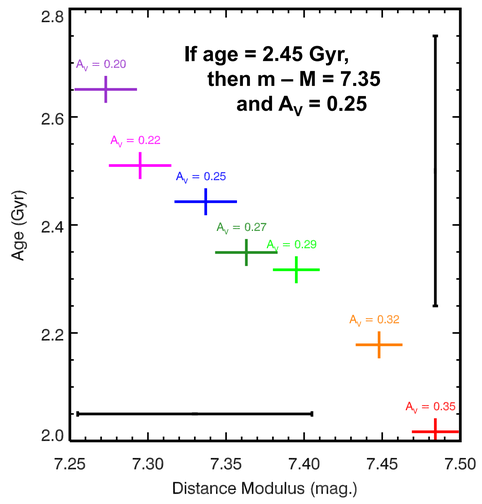
- T_{eff} and log-g for 5 stars with Keck/HIRES spectra
- SME analysis performed by John Brewer (Yale)
- A powerful fitting technique when m – M and A_V are unknown

Brute force fit for m – M and AV with a G0/2 dwarf



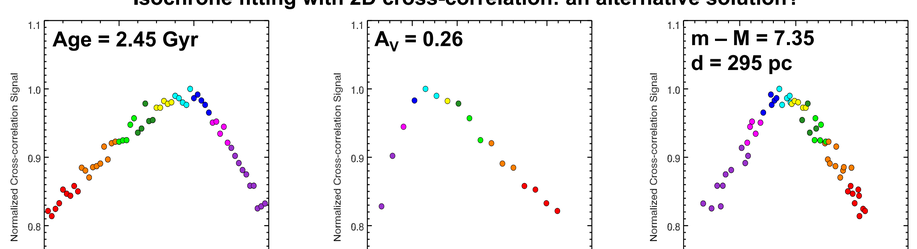
- CWW 91 is a G0/2 V, with T_{eff} and log-g from SME
- I queried the Padova model for photometric SED
- Then brute force X^2 fit for m – M and A_V

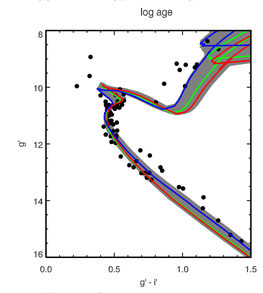
Isochrone fitting to broadband optical photometry With Tim Naylor's τ^2 maximum-likelihood method



- We ran τ^2 for A_V ranging from 0 to 0.5 mag.
- Without additional constraint, 2-band optical photometry alone cannot break degeneracy
- Error bars from T_{eff} – log-g fit establishes m – M and A_V range

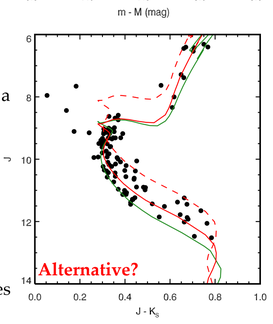
Isochrone fitting with 2D cross-correlation: an alternative solution?



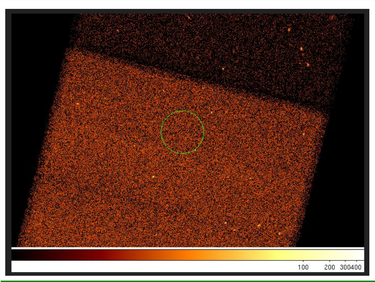


Alternative? Age = 3.4 Gyr, m – M = 7, A_V = 0.1

- Our preferred Padova model does not fit the optical CMD for the K dwarfs or red giants (left) although it does in NIR (right).
- We searched for an alternative solution using a 2D cross-correlation technique
  - Simulate clusters with different ages and compositions, bin the synthetic and real photometry, then cross-correlate the distributions. The location of peak signal provides the best m – M and A_V offsets
- We find the best age is consistent with our spectroscopic solution
- We identify an older model that better matches the optical CMD features, but is inconsistent with NIR CMD and spectroscopy



Summary and future work



Activity – Age – Rotation relations

- X-ray luminosities – Jason Curtis and Steve Saar
  Chandra observations complete!
- CaII H & K – Jason Curtis and Jason Wright
  MMT/Hectochelle, Keck/HIRES and Magellan/MIKE
- Hα activity – Jan Marie Anderson and Andrew West
- PTF rotation periods – Marcel Agüeros and Kevin Covey

Identification of faint membership

- Radial velocity survey of K and M dwarfs with Magellan/MIKE
  July 11 – 13, Jason Curtis, Steve Saar and Jason Wright
- Proper motion survey with CFHT/MegaCam to identify cool stars and white dwarfs. Propose next year?

Detailed abundance study

- Detailed abundance analysis of 30+ FGK dwarfs with Magellan/MIKE
  June 28 and July 8, Jason Curtis, Ivan Ramirez and Jason Wright

For a detailed discussion, please read J. L. Curtis, A. Wolfgang, J. T. Wright, J. M. Brewer & J. A. Johnson (2012), available on astro-ph, and hopefully soon in *AJ*.

Assuming Padova models, and neglecting model uncertainty in our error analysis, our paper derives the following properties for R147:

Age = 2.5 ± 0.25 Gyr **[M/H] = +0.08 ± 0.03**
m – M = 7.35 ± 0.1 **d = 300 ± 15 pc** **A_V = 0.25 ± 0.05**

References

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WEBDA: Mermilliod & Paunzen. 2003, A&A, 410, 511–518

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