

# *Mapping the Reddening and Extinction towards the Galactic Bulge from Panchromatic Photometry of RR Lyrae Light Curves*

A.Saha

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Frye, Josh Bloom, Adam Miller, Brad Cenko, Mario Juric, David Nidever

...

# Why a new Bulge time domain study?

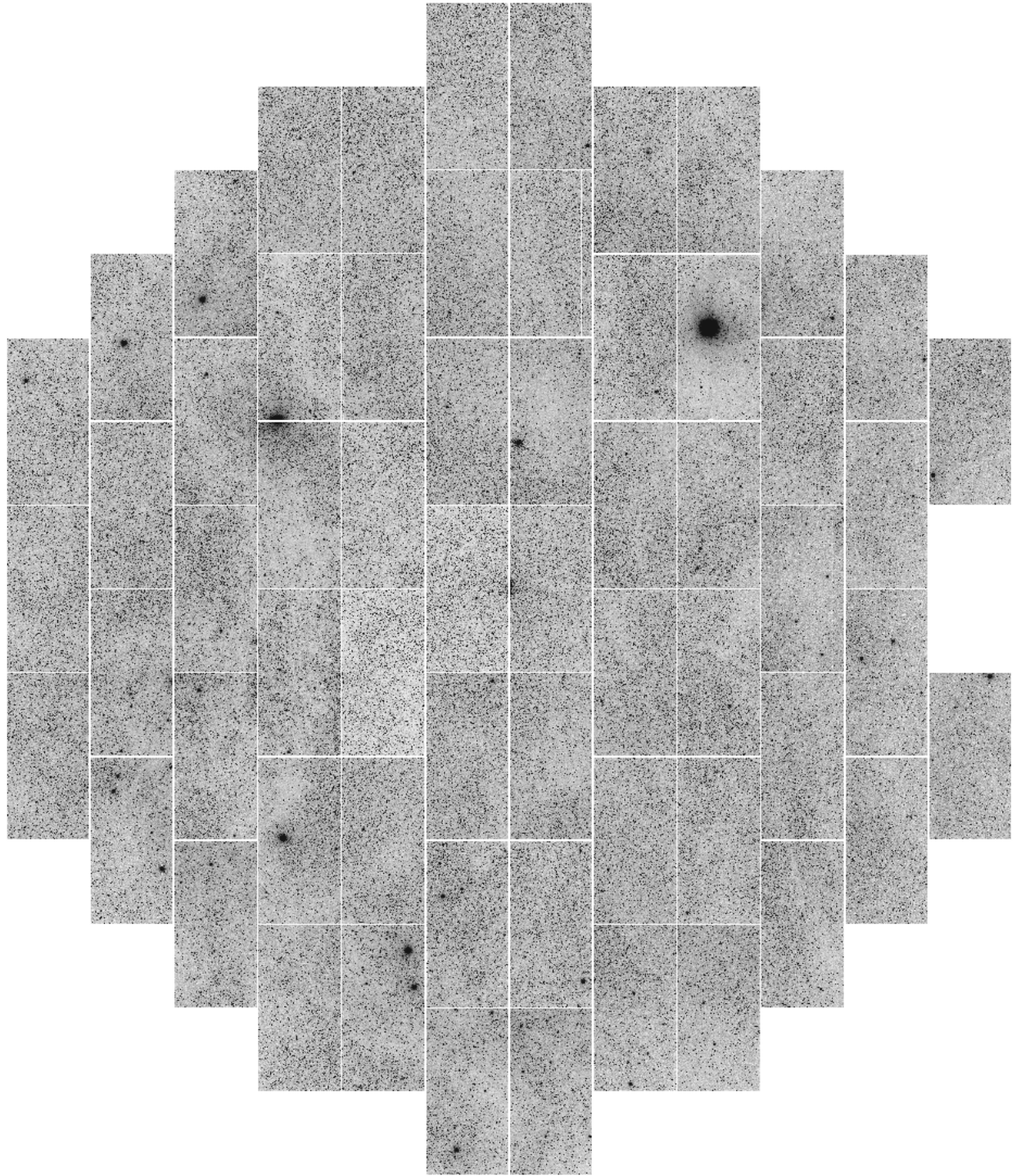
- Use RR Lyrae for reddening and extinction map
  - Get multi-color information not in OGLE
  - **Get dereddened extinction free CMDs / Hess diagrams**
  - **Use reddened RR Lyrae for structural investigation of the bulge**
- Get experience with LSST like data in very crowded fields
  - Similar depth and passbands
- De-reddened variable stars of all types
  - Useful for training “broker” for LSST.

# 3 road blocks to a bulge Hess diagram

- ✓ Extreme crowding for ground observations
  - Incompleteness issues are also hard, but can be modeled
- ✓ Differential reddening on scales of 1 arc-minute
- X Separation of foreground disk stars
  - Must await proper motions

u band image 300s  
Baade's window

Note intricate structure in  
Reddening with scales less  
Than 1 arc-minute!





1 Chip area

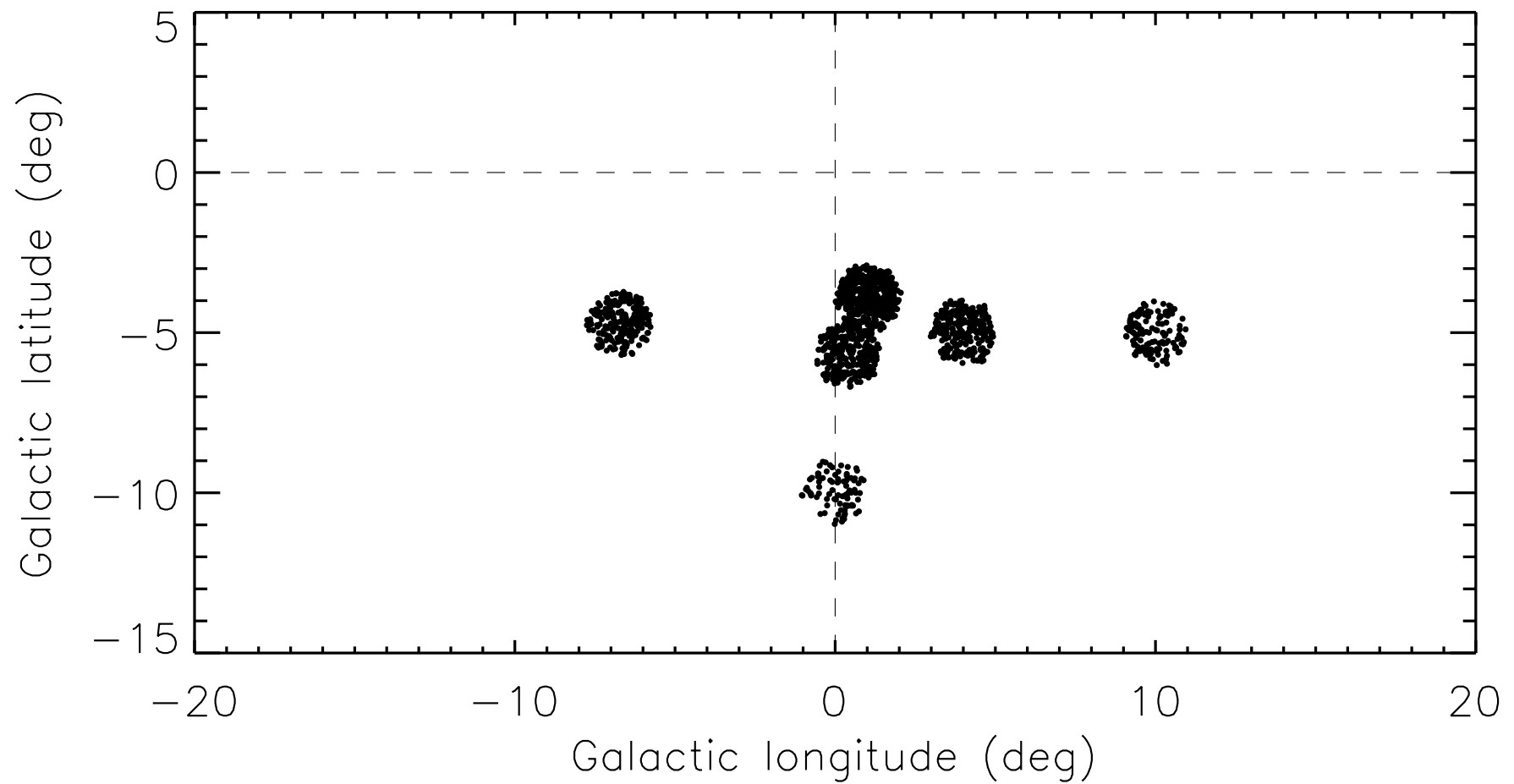


~4 sq arcmin



~1000 stars per square arc-min  
mean closest neighbour distance: ~2 arc-sec

# Field Positions in Galactic Coordinates

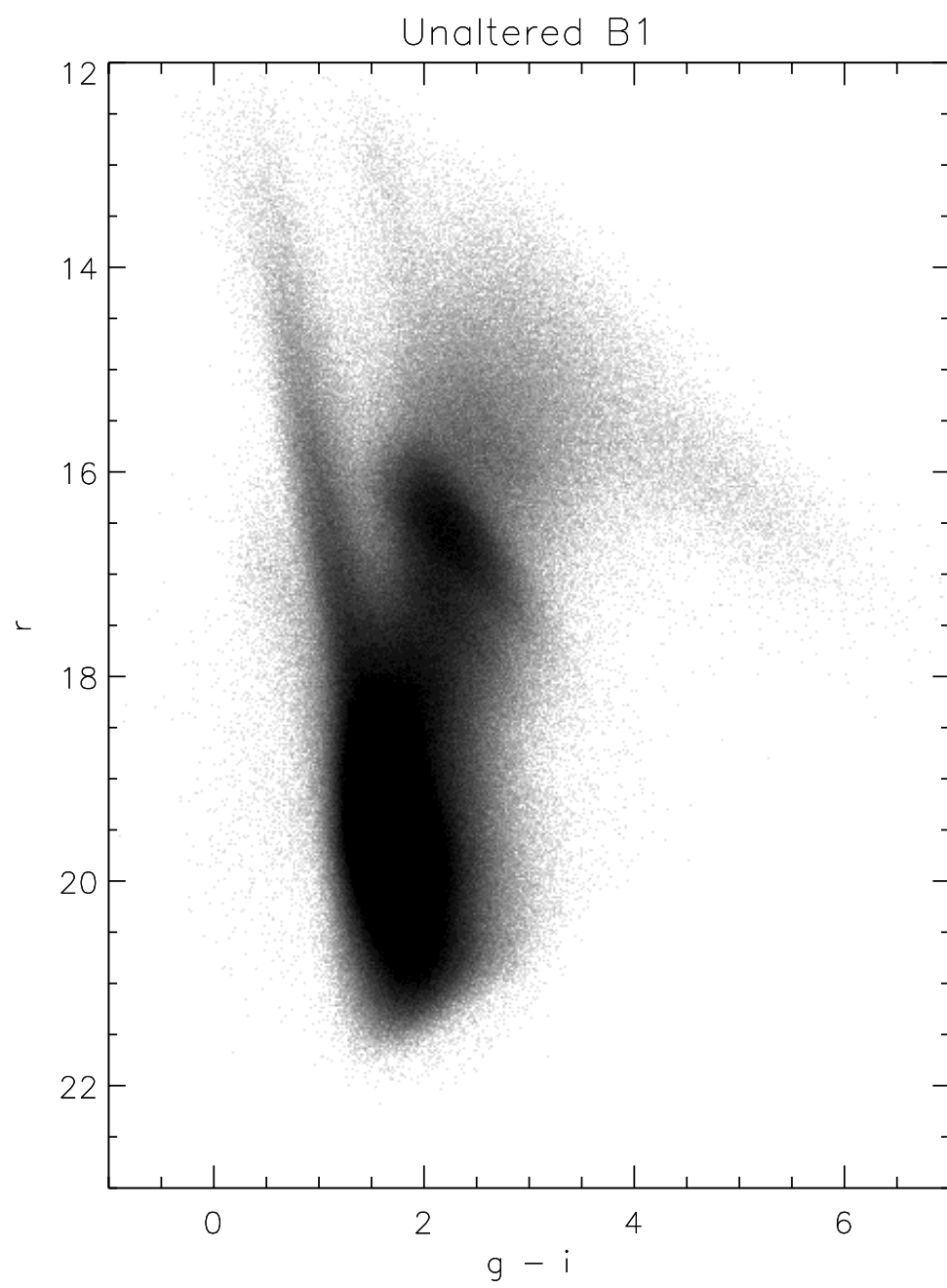


# The Observations

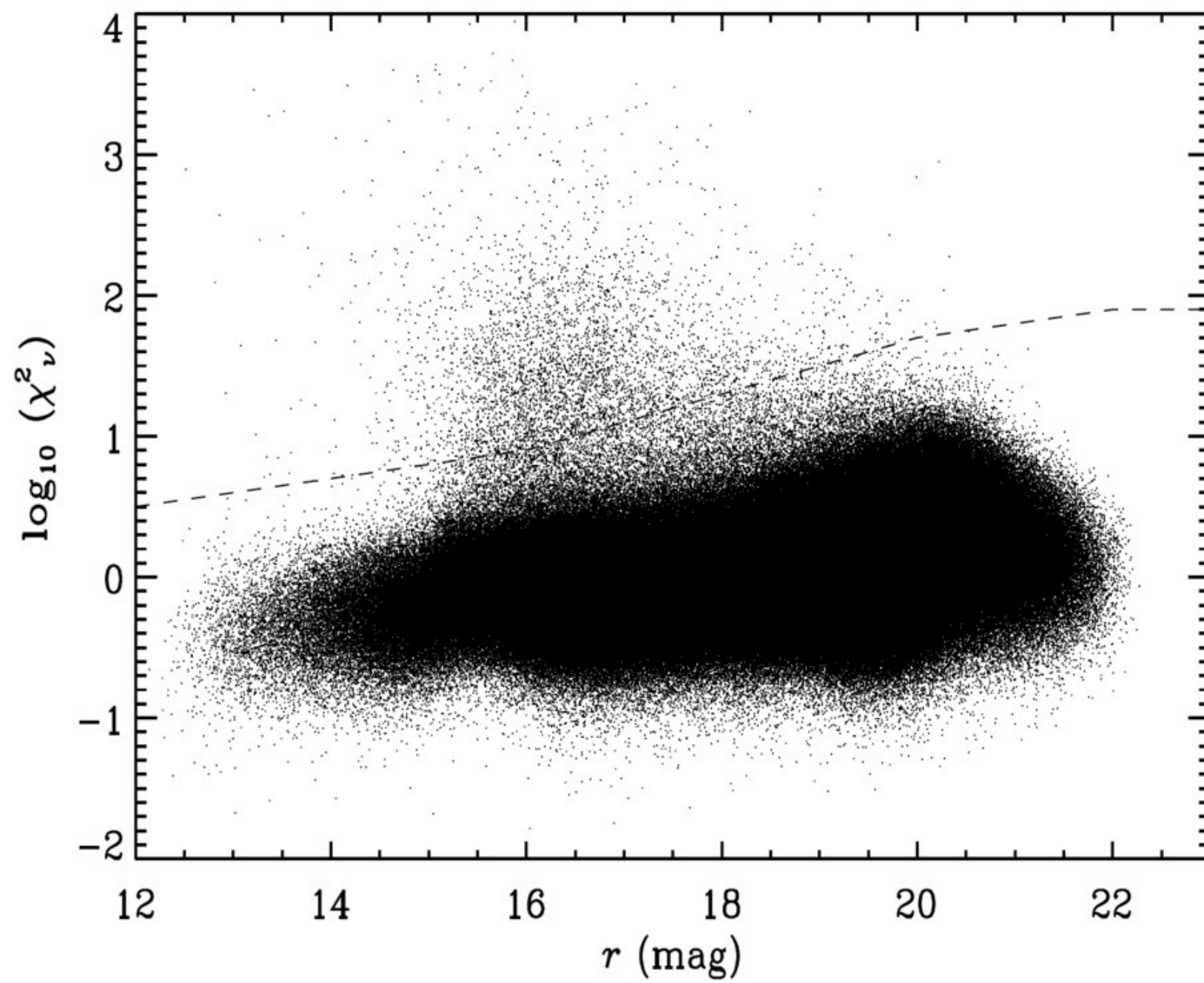
- 6 fields:
  - 2 fields near Galactic center: Baade's window and Blanco's windows
  - 1 field 5 degrees along the 'near side' of bar
  - 1 field 10 degrees along the 'near side' of bar
  - 1 field 10 degrees along 'far side' of bar
  - 1 field 10 degrees south of Galactic center
- Cadence:
  - Repeat visits 4 times a night
  - 3 runs: May, June, Aug (2013) with 3, 4, and 3 nights length
  - extra epochs in i and z during moon-lit nights in June
  - short cadence shallow exposures in March 2015

# Data Crunching

- Approx 60x5 images per field
- 6 fields
- Approx 7M stars per field
- *Photometry of approx 18 billion stellar images*
- *Tripped on > 25000 putative variables*
  - *Period analysis → visualize light curves*
  - *Light curve analysis*
  - *Selection of RR Lyrae → ~ 500 ab-type RRLyrae in Baade's window field*







# INTRINSIC *UBV* COLORS OF RR LYRAE STARS\*

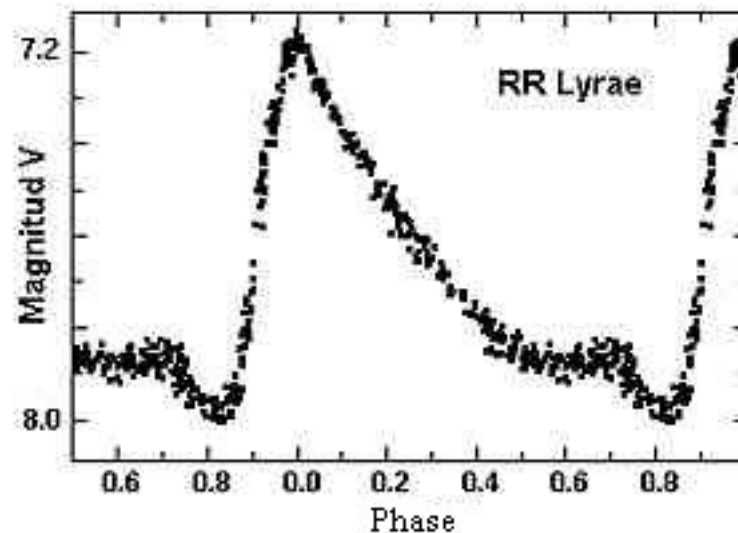
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*Received May 17, 1965; revised September 20, 1965*

## ABSTRACT

Photoelectric observations on the *UBV* system of more than one hundred Bailey type *a*, *b* RR Lyrae stars were obtained to investigate the color indices near minimum light. It is shown that for most purposes of galactic research  $B - V$  and  $U - B$  may be treated as constant in the phase interval  $0.5 < \phi < 0.8$ . The  $U - B$  index during this interval is correlated with the metallic-line blanketing derived from high-dispersion spectrograms, and is used to find a line-free index,  $(B - V)_c$ . A period versus  $(B - V)_c$  relation is found for those variables in the galactic caps and, combined with observations from stars at lower latitudes, is used to obtain a cosecant reddening law. A  $B - V$  excess at the poles of 0.03 mag. is adopted. From this, intrinsic *UBV* colors and individual color excesses are derived for the RR Lyrae stars. The probable error of an intrinsic color is only 0.01 mag. Applications to the determination of interstellar reddening and stellar populations are discussed.



# Sturch's rule

$$E(B-V) = (B-V)_{\phi=(0.5 \text{ to } 0.8)} + 0.0122 \Delta S \\ - 0.00045(\Delta S)^2 - 0.185P - 0.356$$

(gives results good to  $\sim 0.01$  mag in  $E(B-V)$  !!)

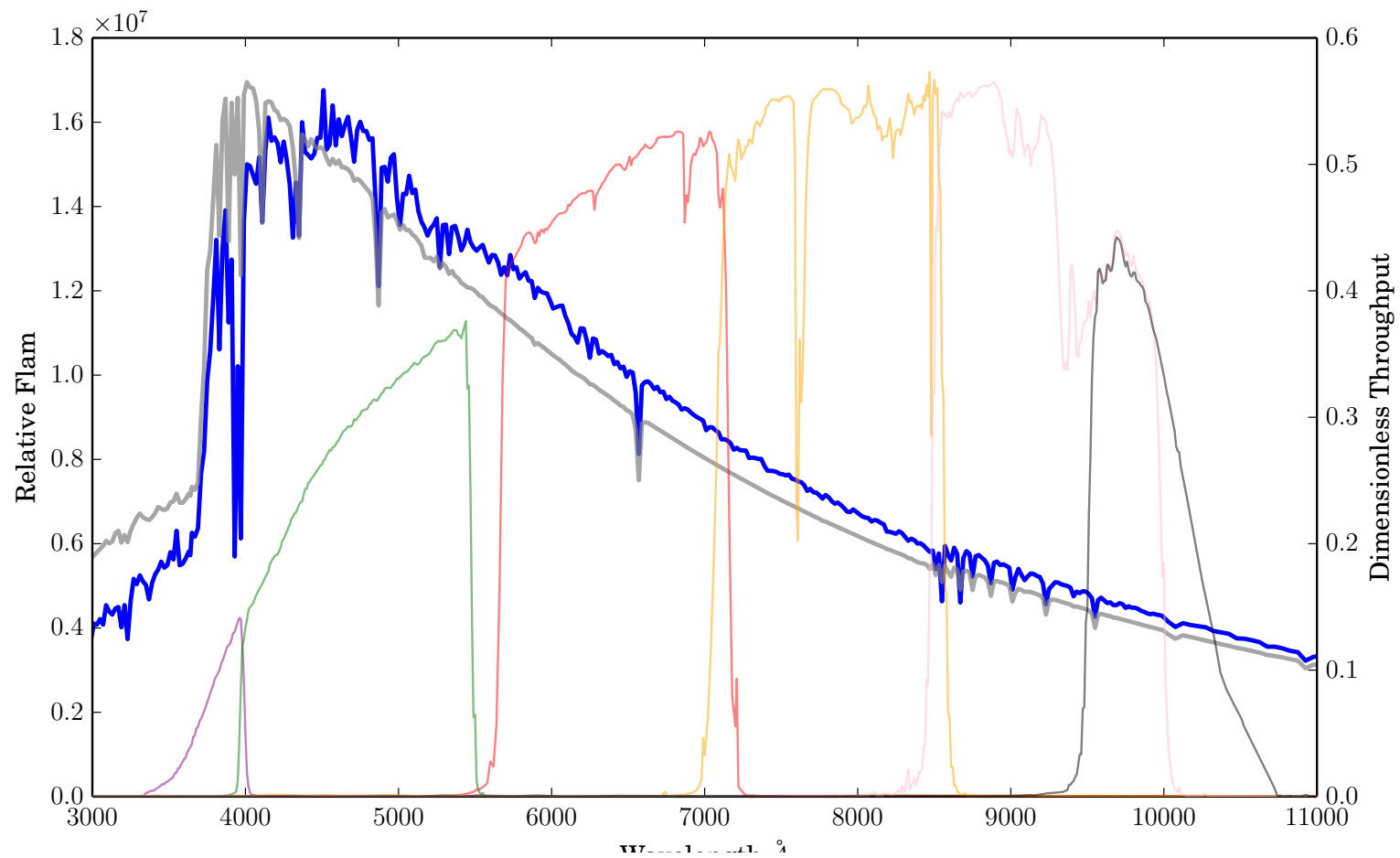
BUT ---You (may) have to know metallicity!

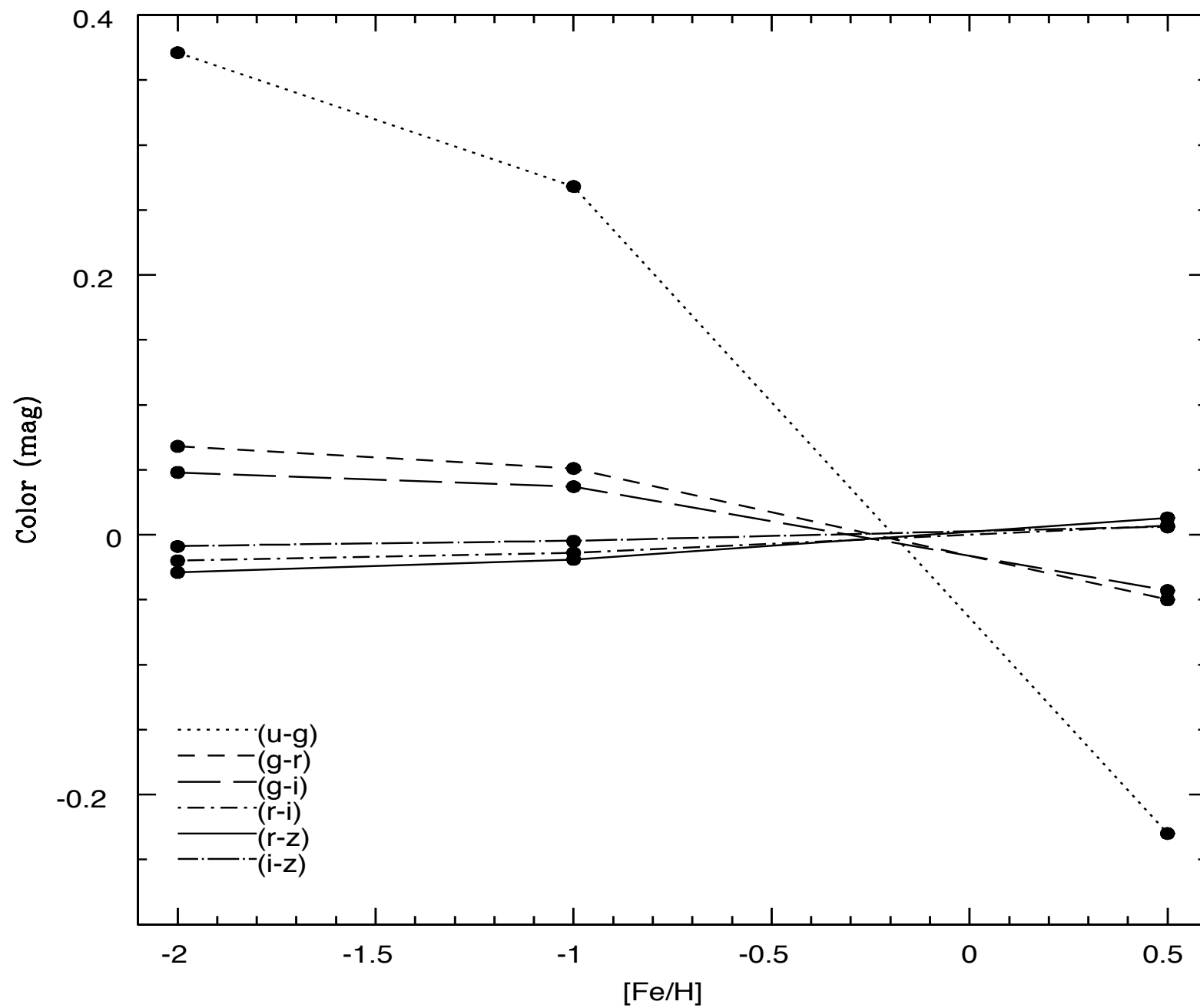
SDSS colors g-r, r-i, r-z, and i-z are progressively freer of line blanketing.

***In any case we have to recalibrate in the native DECam system***



# DECam passbands















- The ***combination*** of being standard candles and standard “crayons”, both to within a few percent, is very powerful as a diagnostic not only of reddening, but of the **reddening law**.

A partial solution to Baade’s lament ?

# THE ASTRONOMICAL JOURNAL

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## Absolute Magnitudes and Colors of RR Lyrae Stars in DECam Passbands from Photometry of the Globular Cluster M5

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# Metallicity Effects

- Walker & Terndrup 1991, ApJ 378, 119

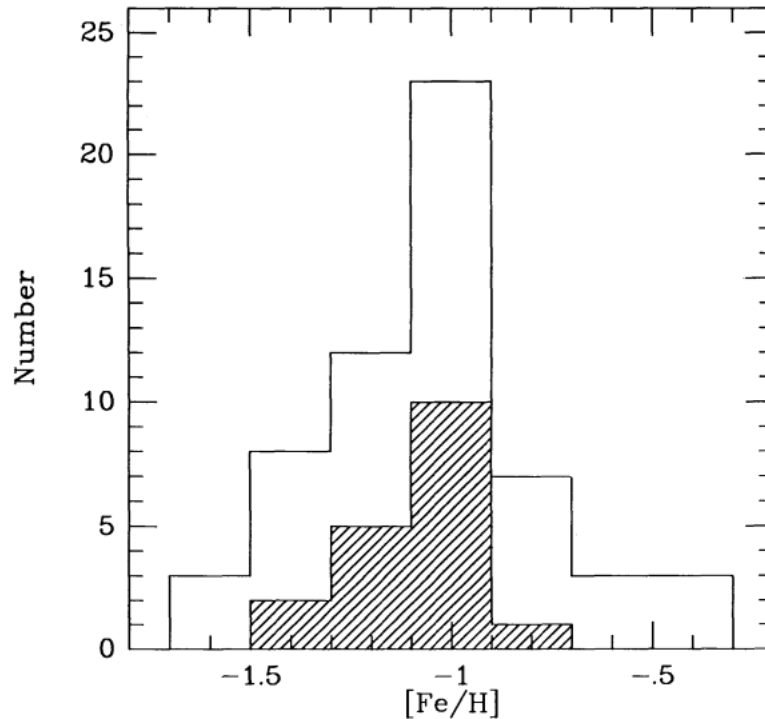
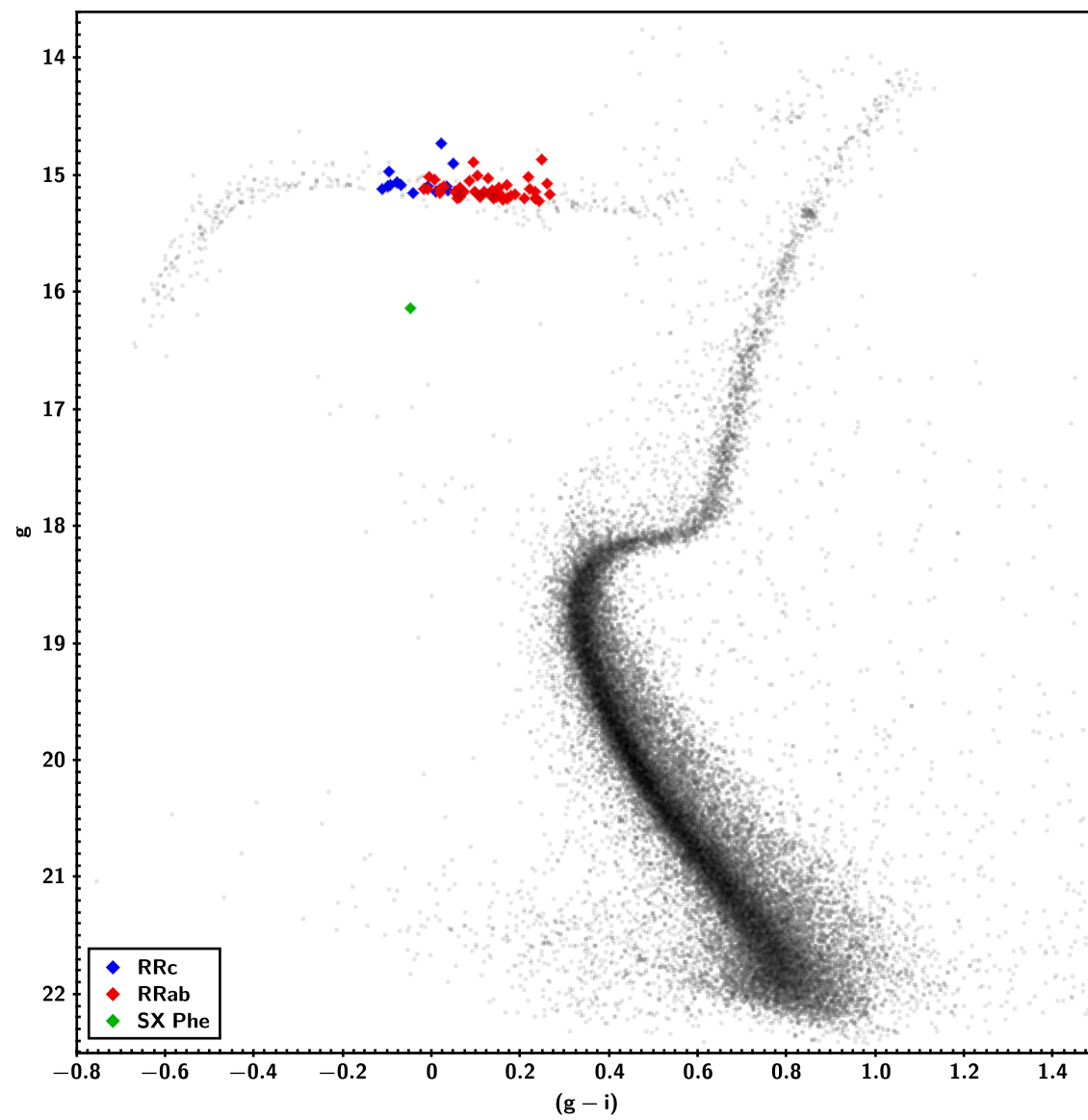


FIG. 7.—Histogram of the abundances determined for the BW RR Lyrae stars. The RRc stars are shaded.

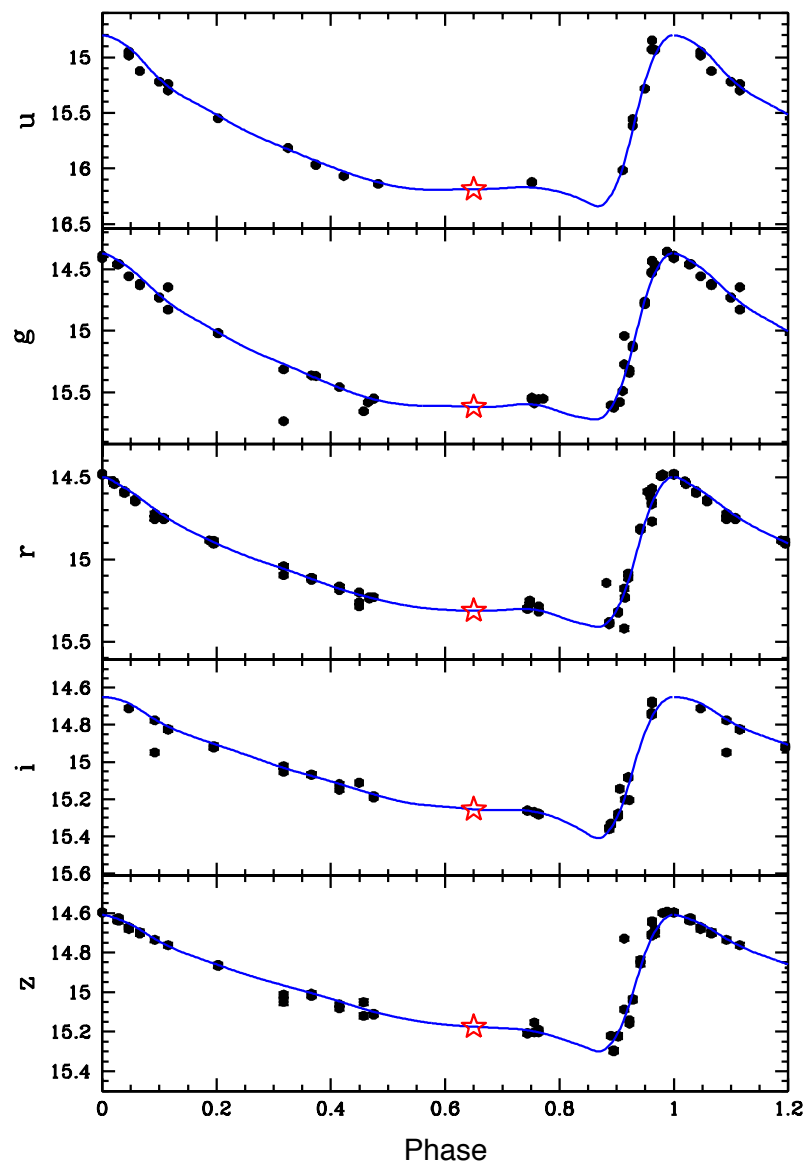
M5 metallicity –

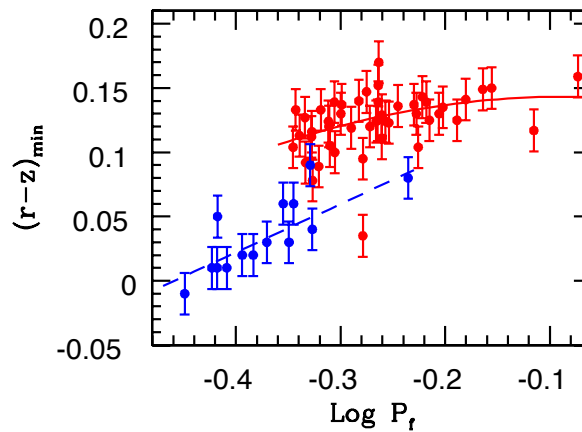
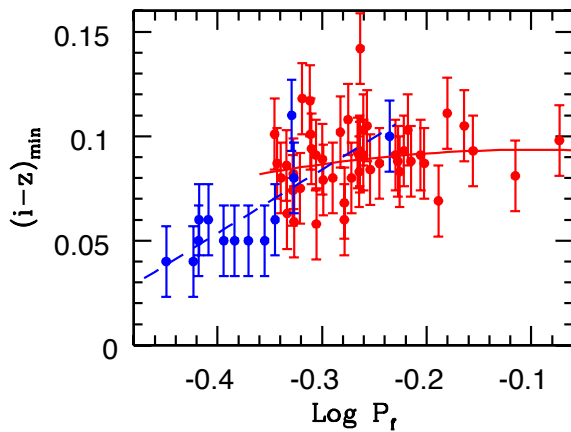
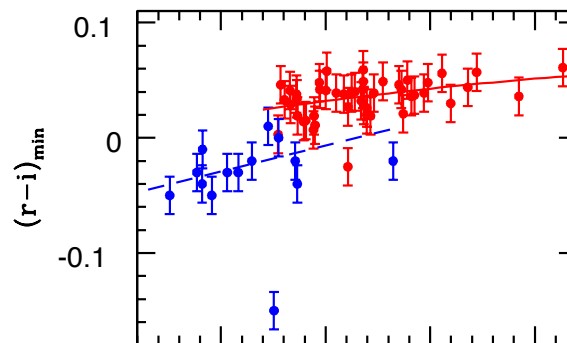
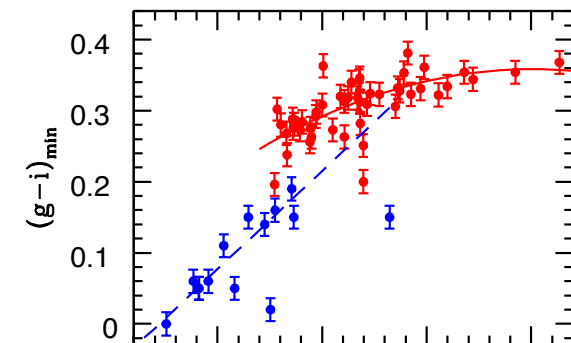
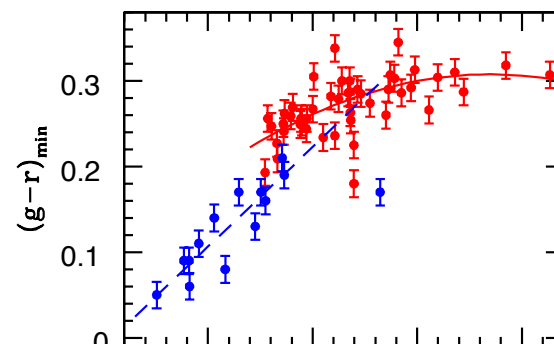
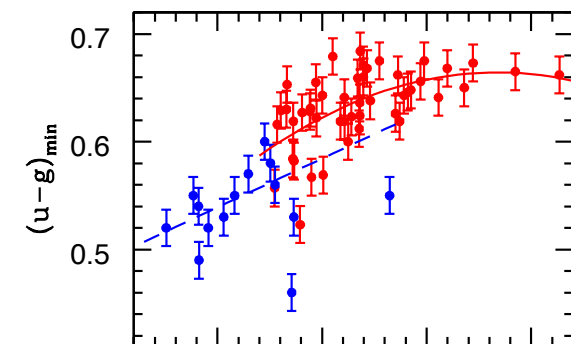
values in literature range  
between:

$$[Fe/H] = -1.1 \text{ to } -1.3$$



ID=59529    Period=0.50249 d





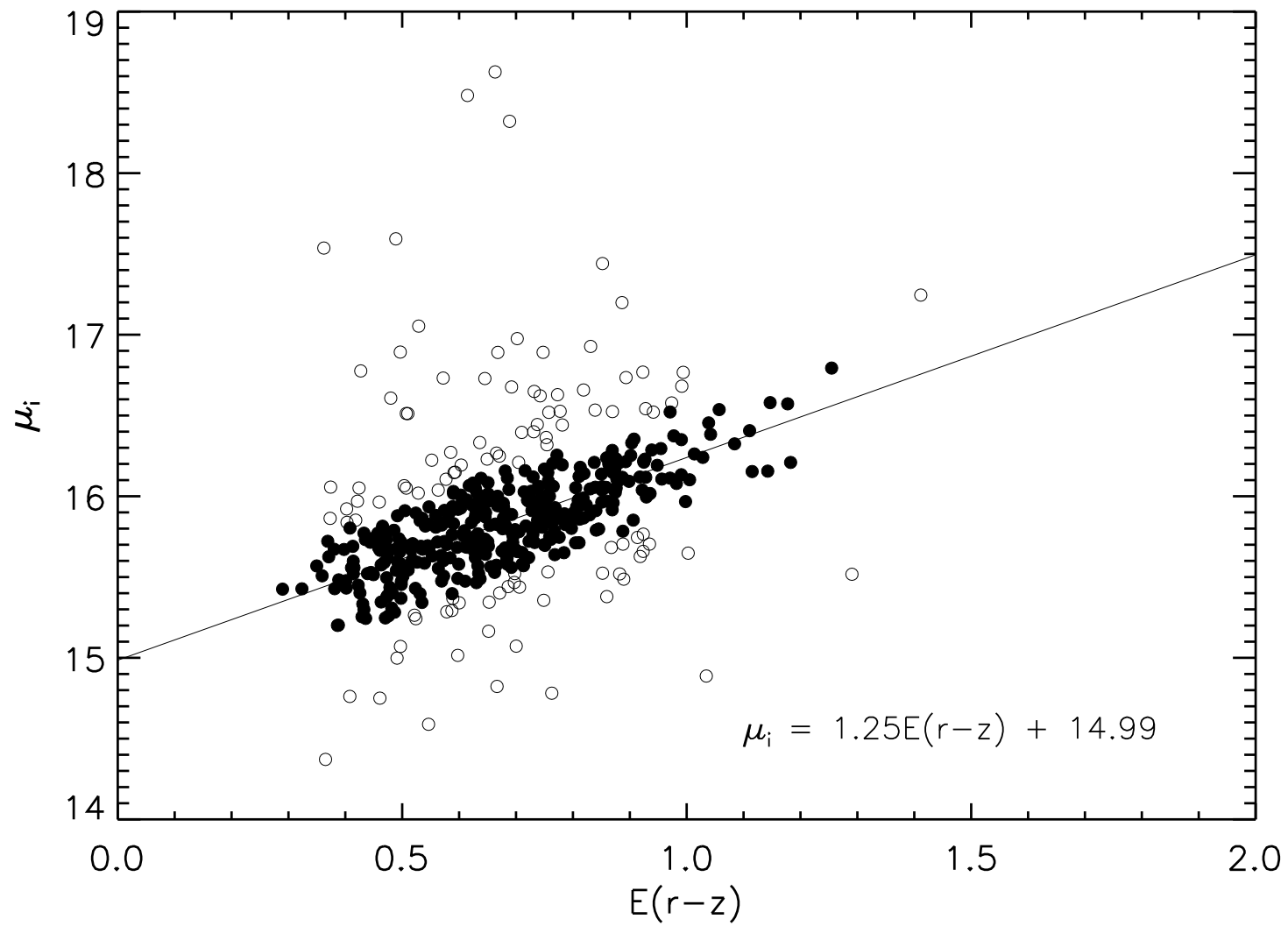
**For R Rab:**

$$\sigma_{(r-z)} = 0.013$$

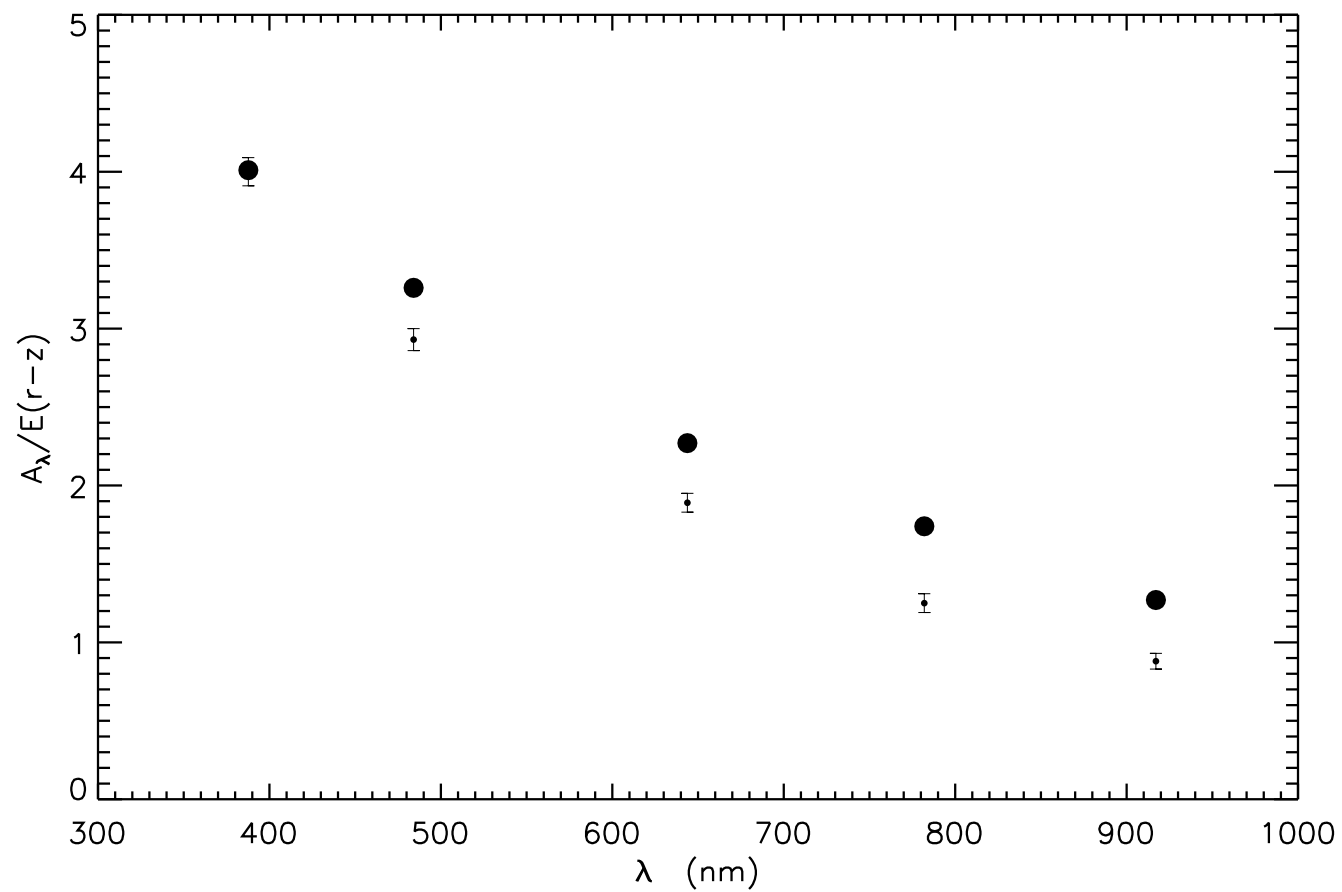
$$\sigma_{(g-i)} = 0.027$$

$$\sigma_{(u-g)} = 0.057$$

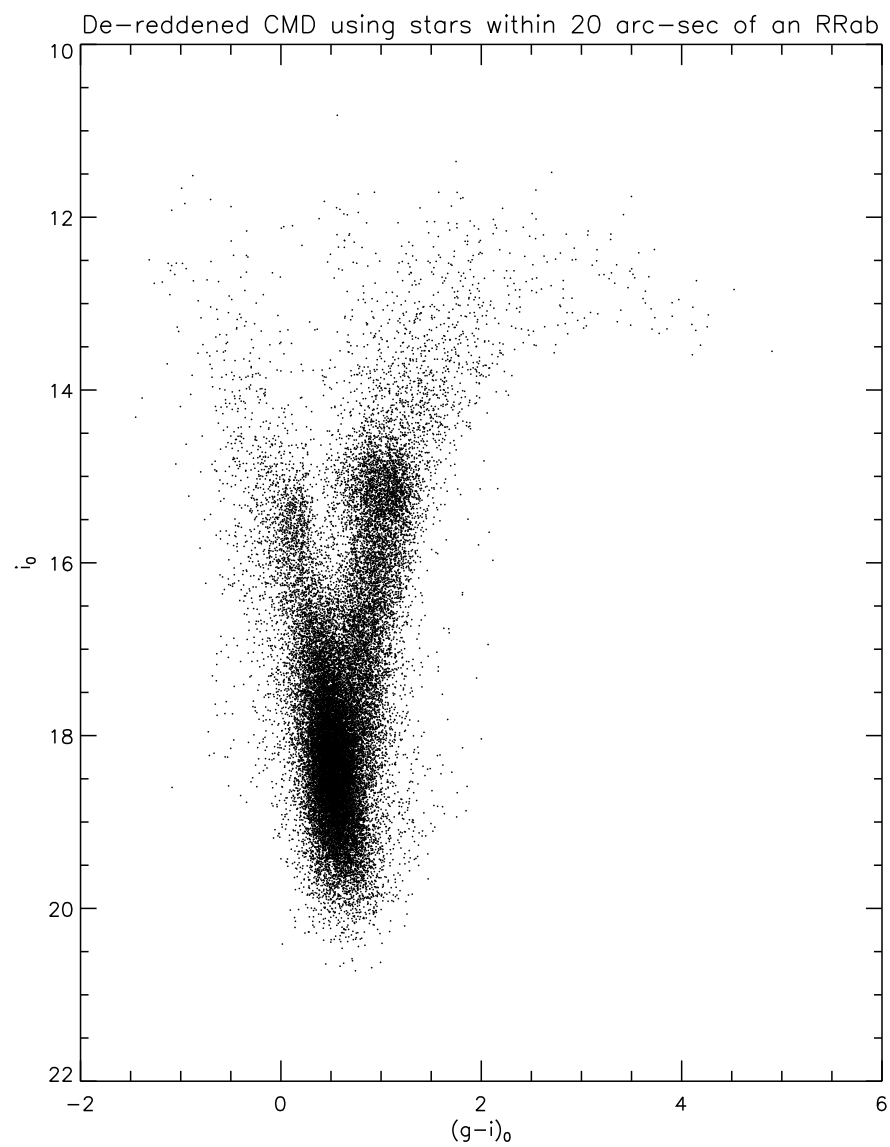




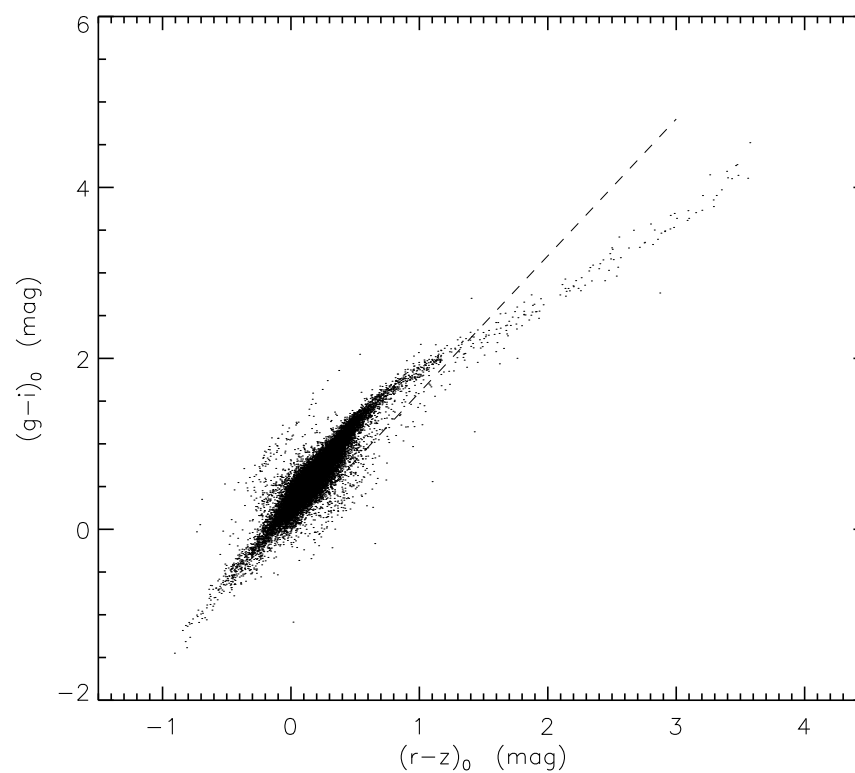
# Reddening Law towards Baade's Window



# CMD from stars around the RRLs



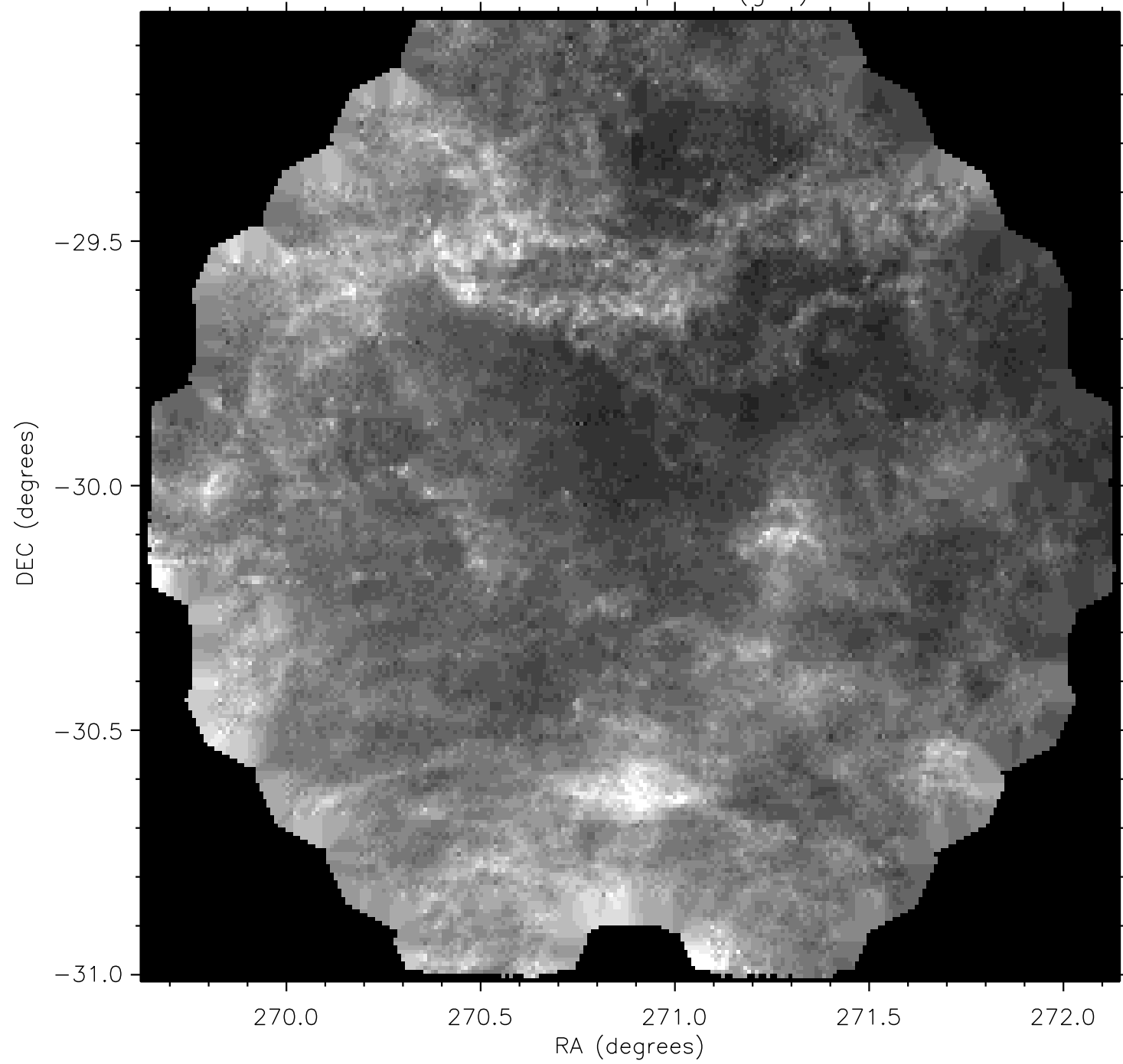
# Correlate CC diagram with itself



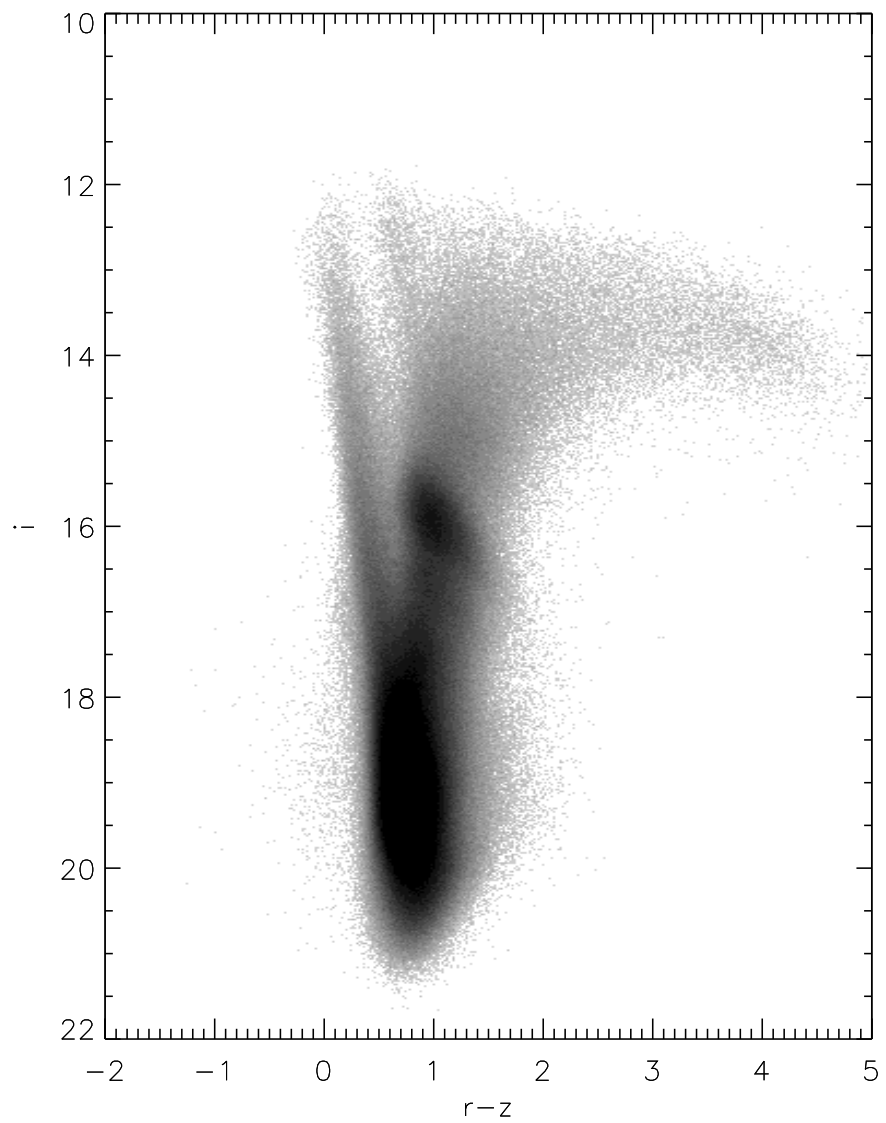
# Dereddening Full Field

- Make dereddened g-i vs r-z color color diagram in 30'' x 30'' cell around each RR Lyrae star, using RR Lyrae extinction/reddening and accumulate.
- For each 30'' x 30'' cell in the field, what extinction brings its C-C diagram to match dereddened C-C diagram?
- Using this extinction map with 30'' granularity, compile dereddened CMD with all stars.

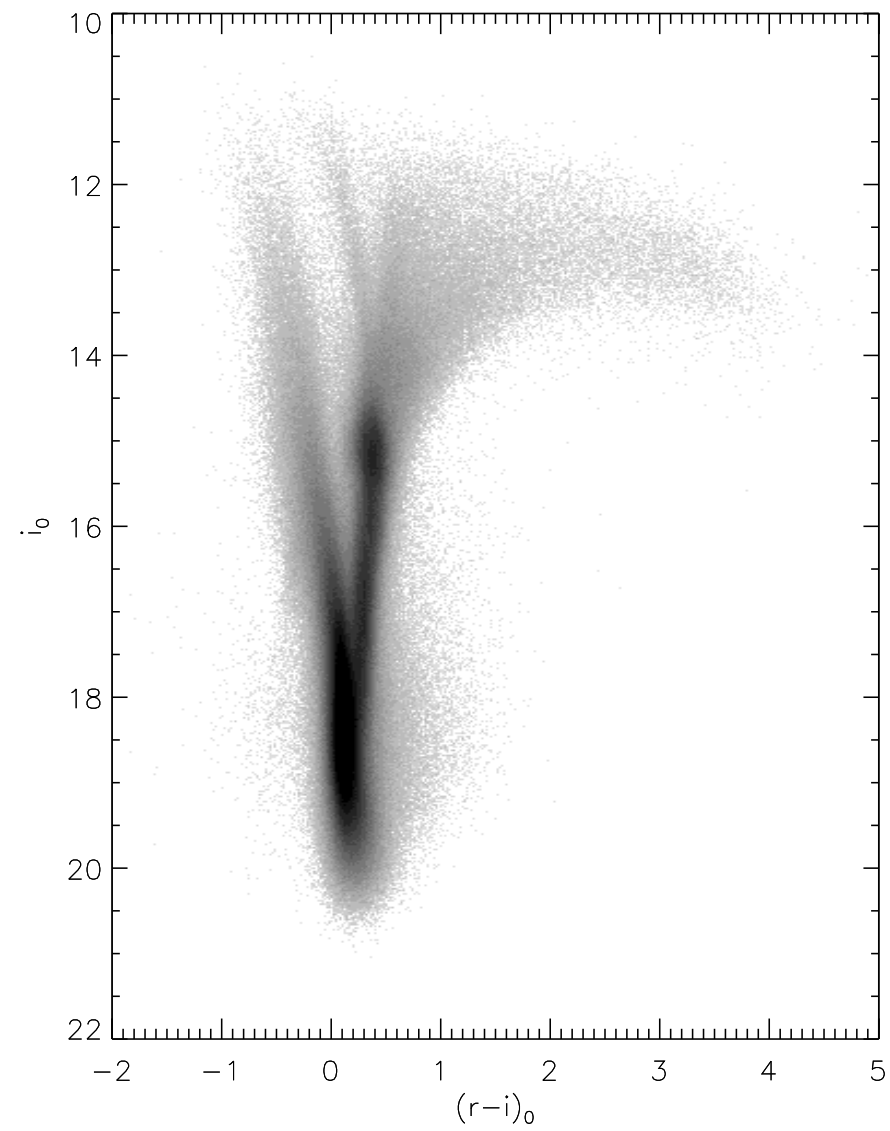
Field B1: Map of  $E(g-i)$

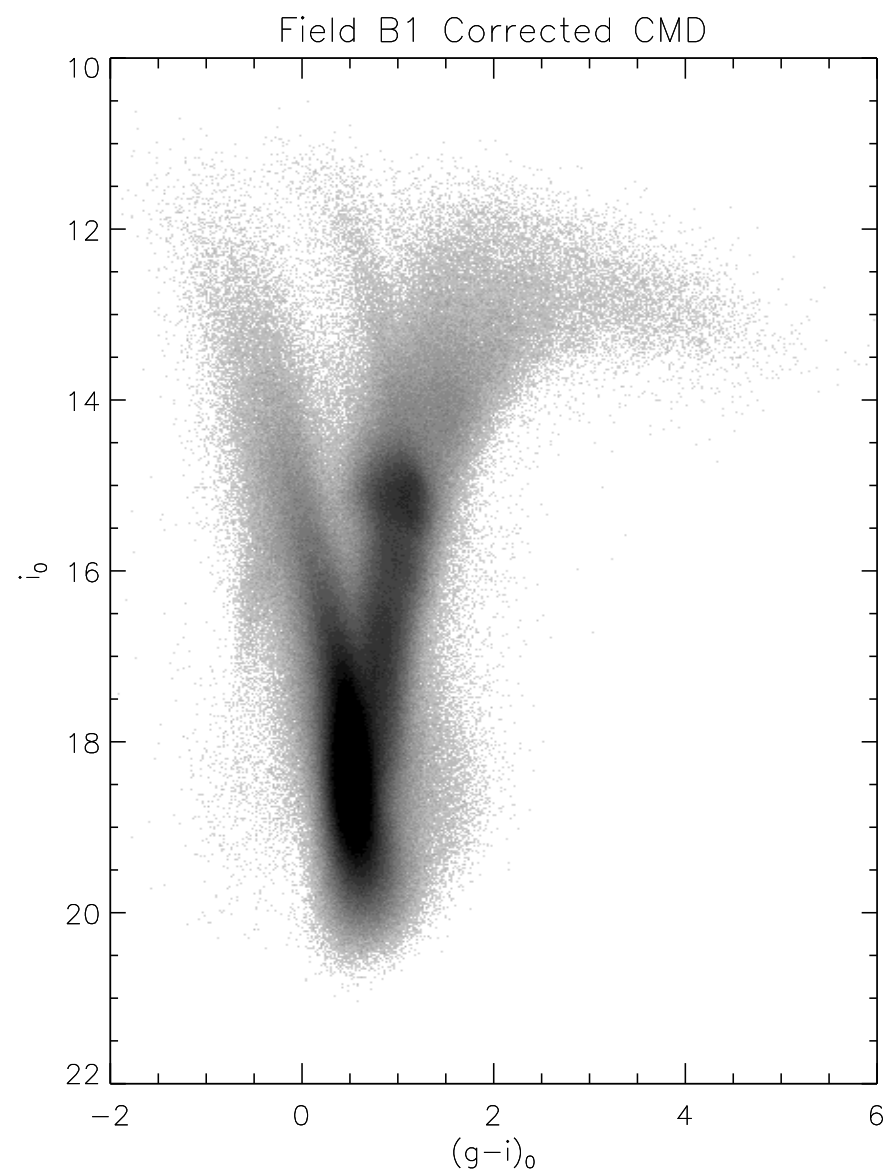
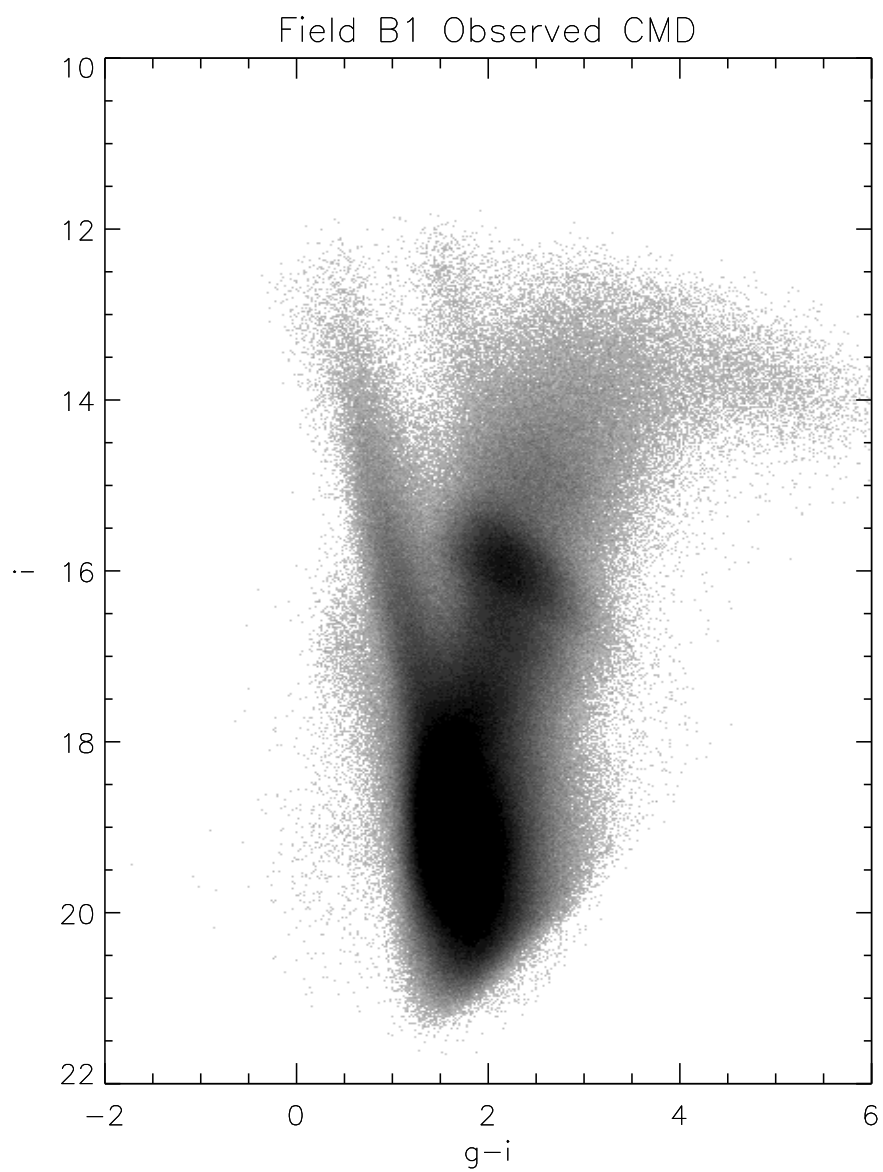


Field B1 Observed CMD

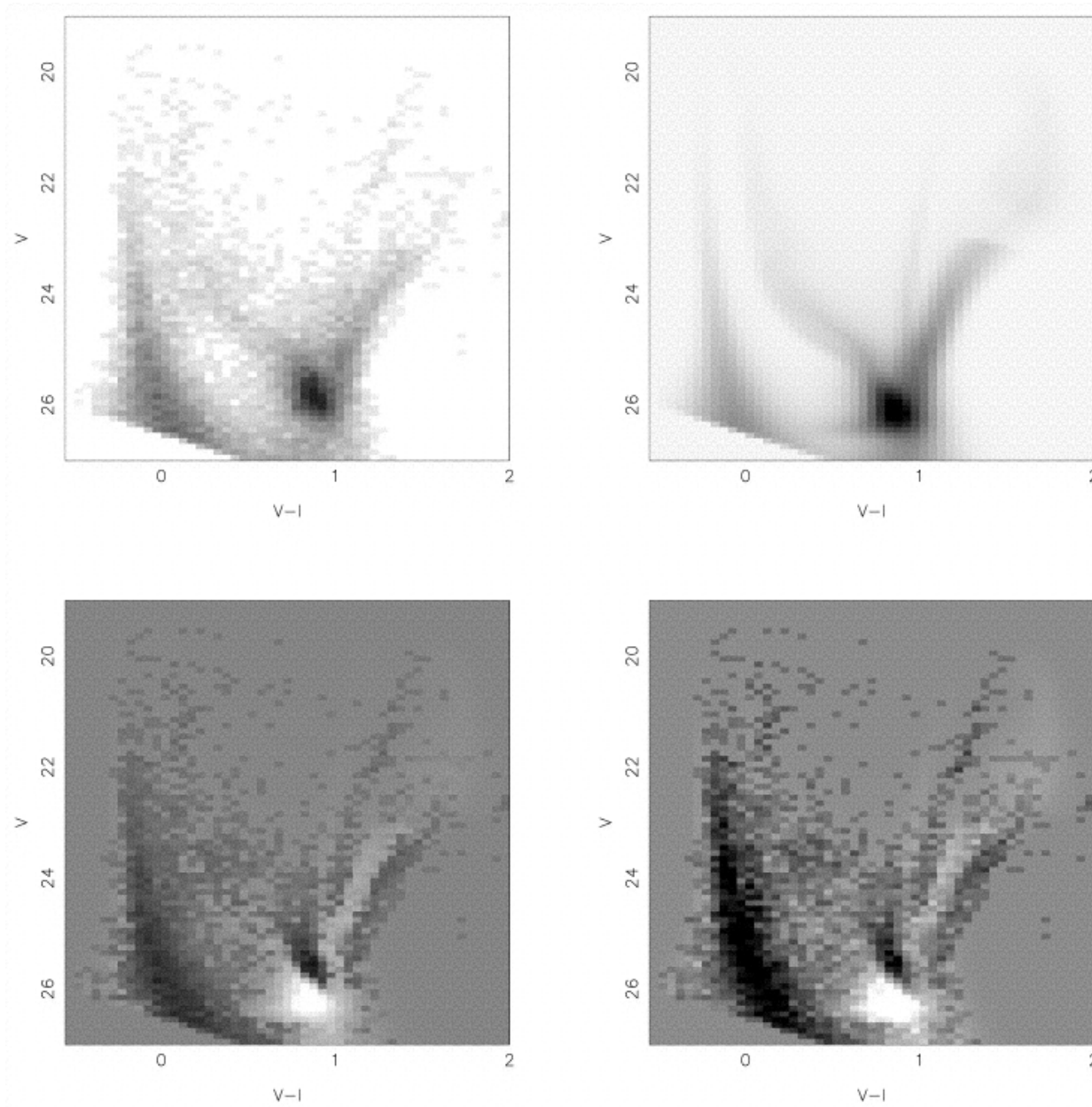


Field B1 Corrected CMD





## Sextans - A

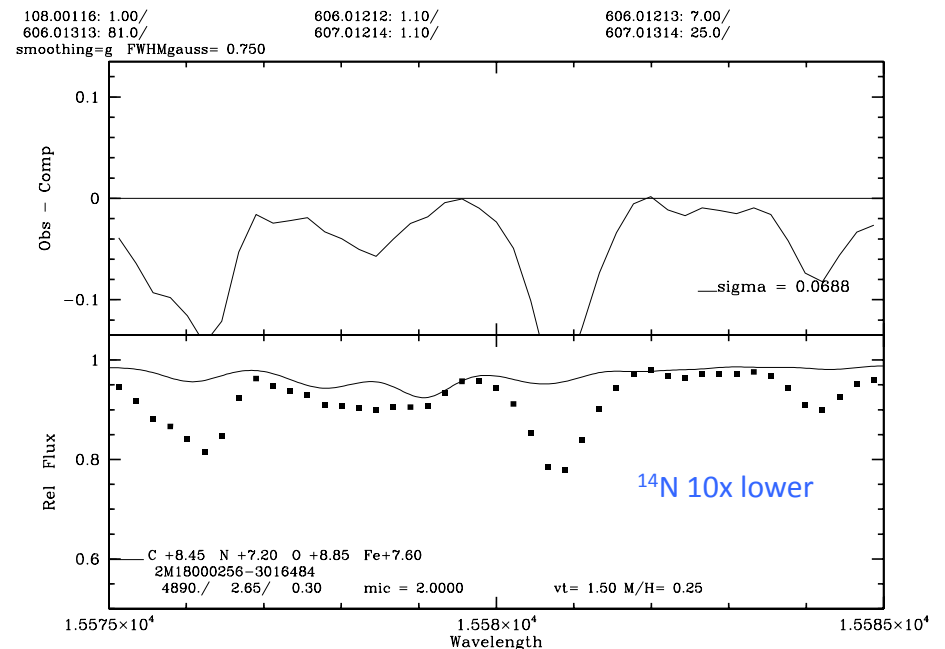
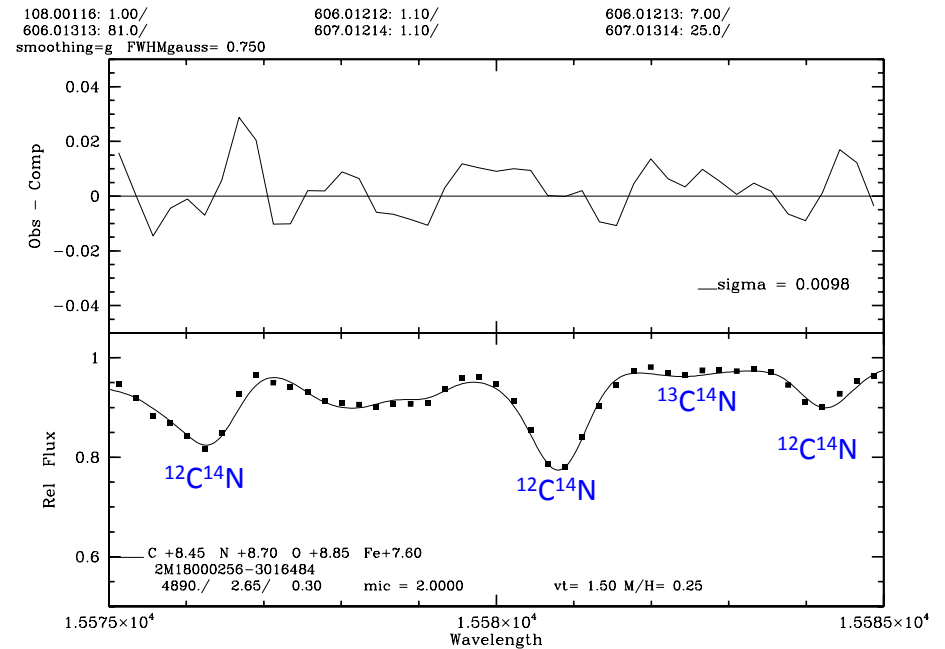




# APOGEE RESULT from Verne Smith

(1 of 12 stars matched in APOGEE)

- 2M18000256-3016484
- APOGEE spectra:  $\lambda 1.51 - 1.70 \mu\text{m}$
- $R=22,400$
- $T_{\text{eff}}=4890\text{K}$   $\text{Log } g=2.65$
- $[\text{Fe}/\text{H}]=+0.3$
- Carbon and Oxygen abundances from CO and OH
- Nitrogen abundances from CN
- $^{14}\text{N}$  very abundant
- $^{12}\text{C}/^{14}\text{N}= 0.55$  which is a function of red giant mass  $\rightarrow \sim M > 2.5 M_{\text{Sun}}$
- No evidence of peculiar initial C and N abundances, i.e.,  $[\text{C}+\text{N}/\text{Fe}] \sim 0.0$
- Signature of 1<sup>st</sup> dredge-up in a metal-rich intermediate-mass red giant



# Next Steps

- Population synthesis to match Hess diagram for giant stars (completeness is a serious but solvable issue)
- Compare de-reddened Hess diagrams of different fields
- Wait for GAIA (DRx ??) to remove foreground stars: especially clean up the “main sequence blue plume”.
- What other variables are there (fainter than OGLE)?
  - Informs automatic variable star characterization for use with LSST alert stream, especially re: multi-band data
  - Training set for ANTARES

