An Extended View of the Pulsating Stars in the Carina Dwarf Spheroidal Galaxy

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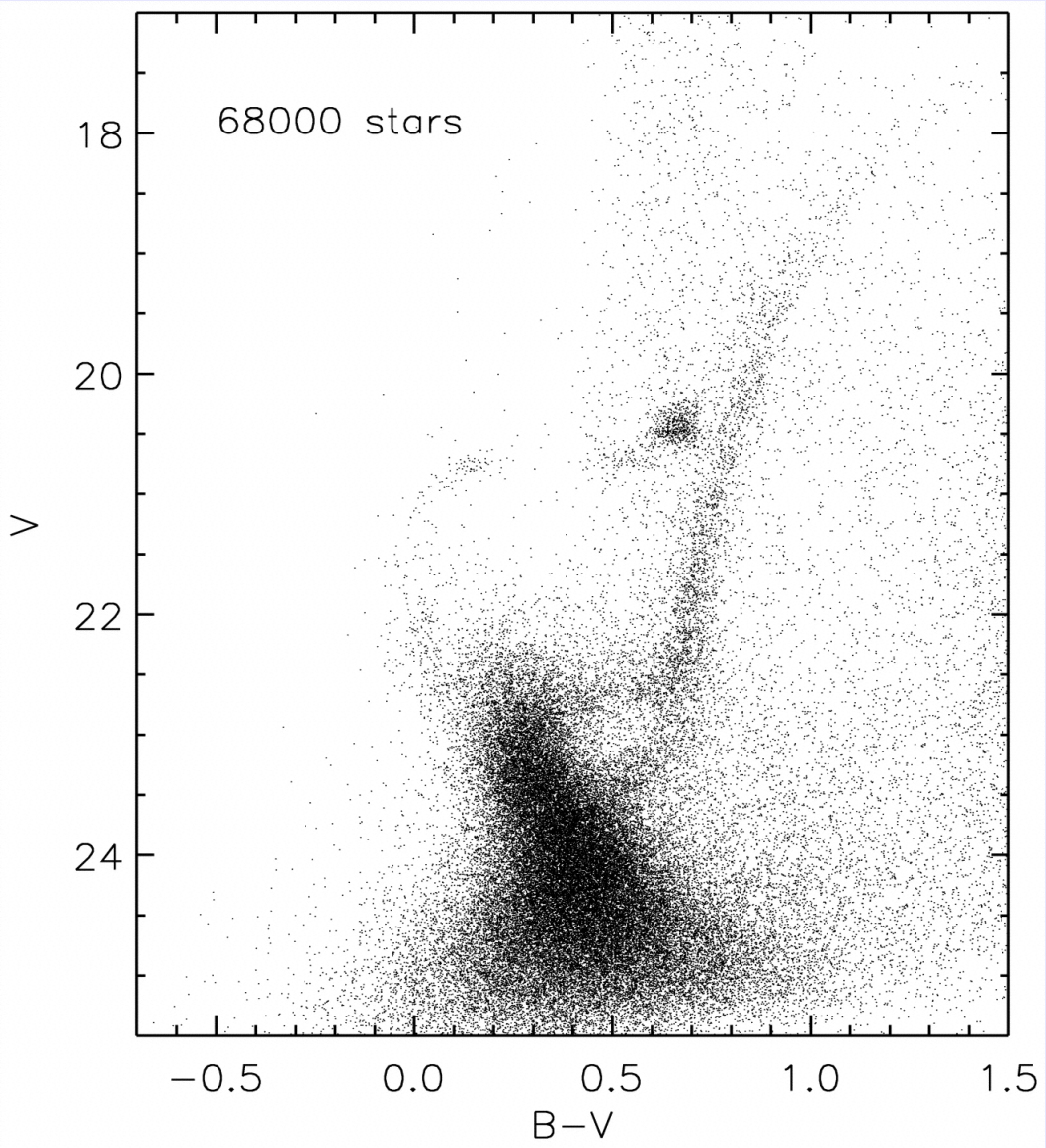
CMD from Monelli et al (2003)



- Southern galaxy
- ~100 kpc
- Multiple bursts of star formation at ~1, 5 and 11 Gyrs *(Smecker-Hane et al 1996, Monelli et al 2003)*
- Small metallicity spread *(Rizzi et al 2003, Bono et al 2010)*

The Carina Dwarf

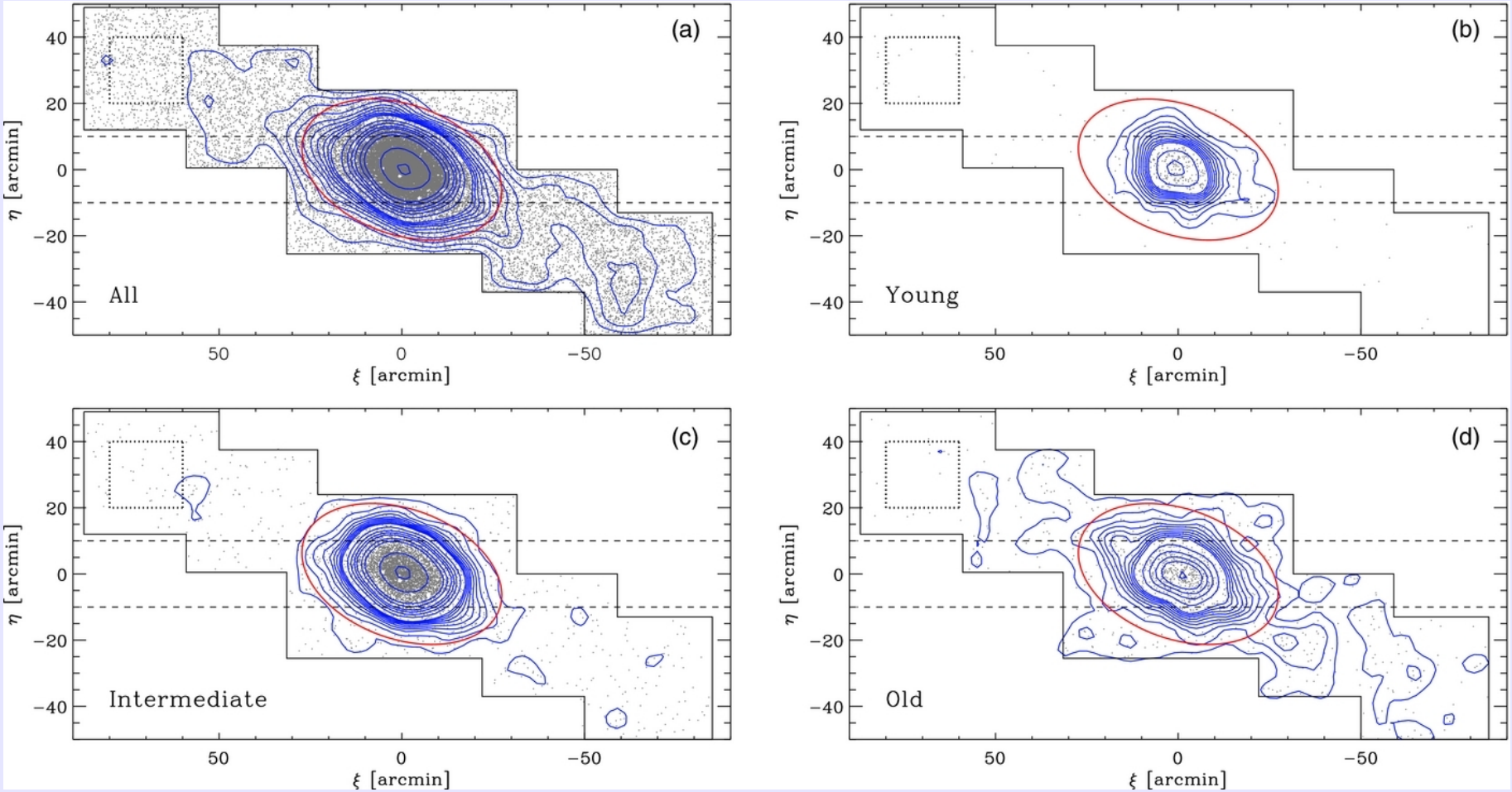


Figure from Battaglia et al (2012)

Extension and Age Gradient in Carina

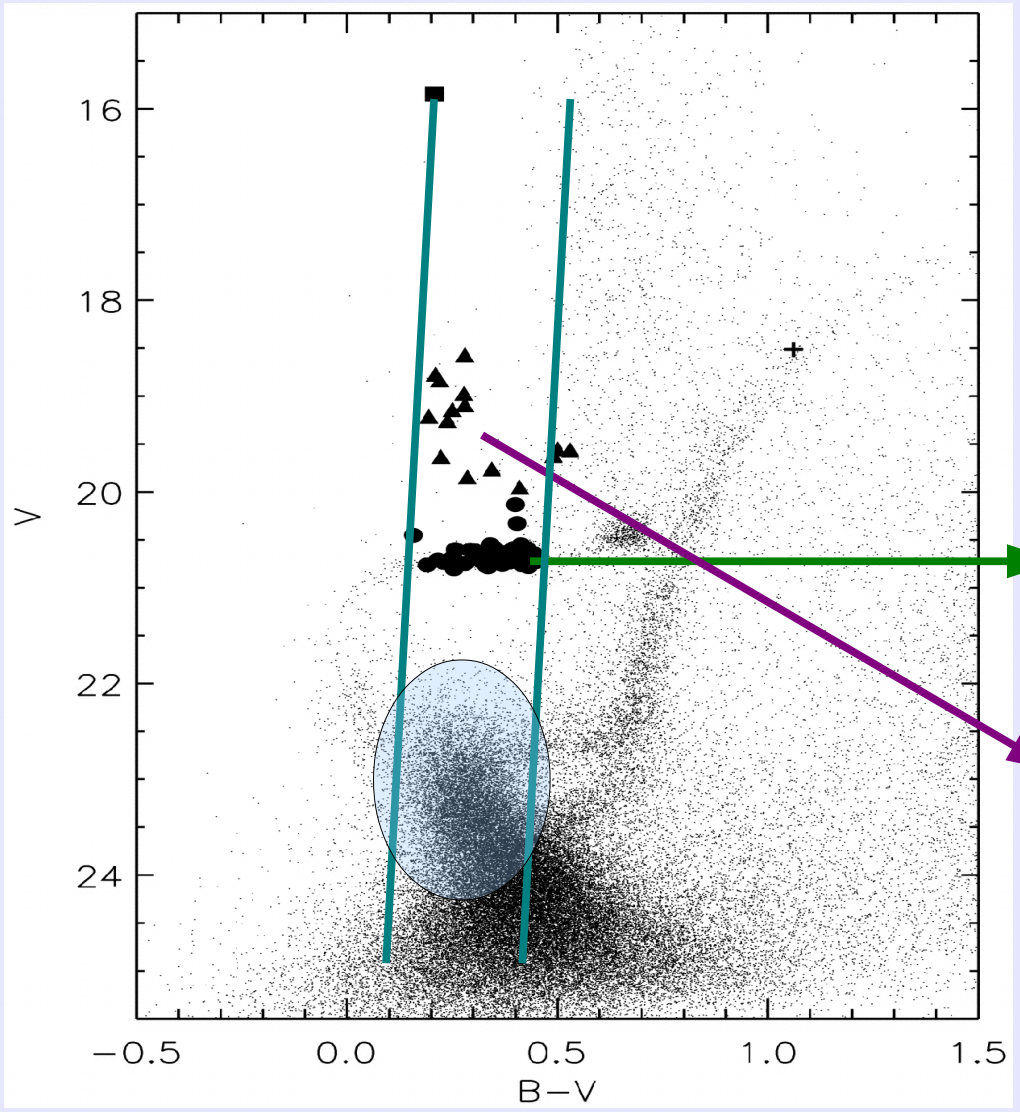


Figure from Dall'Ora et al (2003)

- Bright variables have been studied by Saha et al (1986) and then by Dall'Ora et al (2003)

RR Lyrae → old population

Anomalous Cepheids → Intermediate age population

Bright Variables in Carina

- Dwarf Cepheids: include SX Phe and δ Scutti (collective name is appropriate if the metallicity of the population is unknown)
- 20 dwarf cepheids were found in three small fields in Carina by Mateo et al (1998).
- Mateo et al (1998) speculated dwarf cepheids may be very numerous in this galaxy.

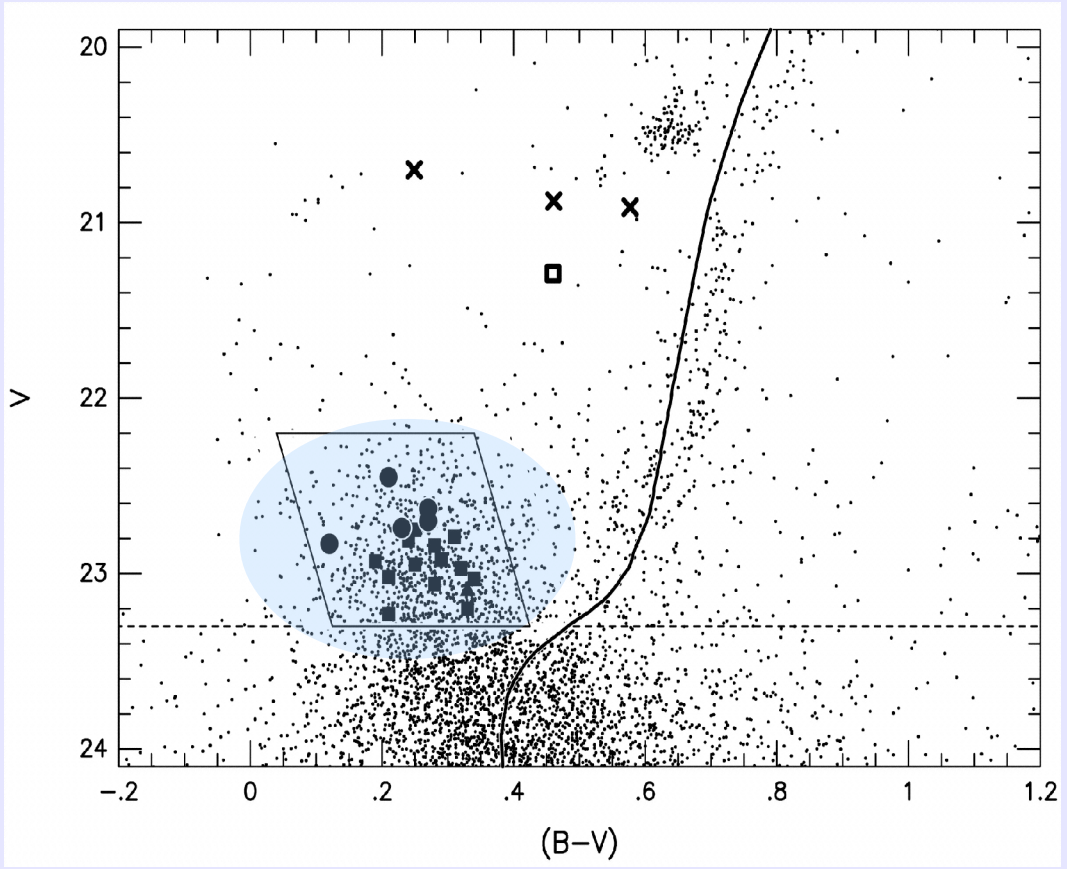


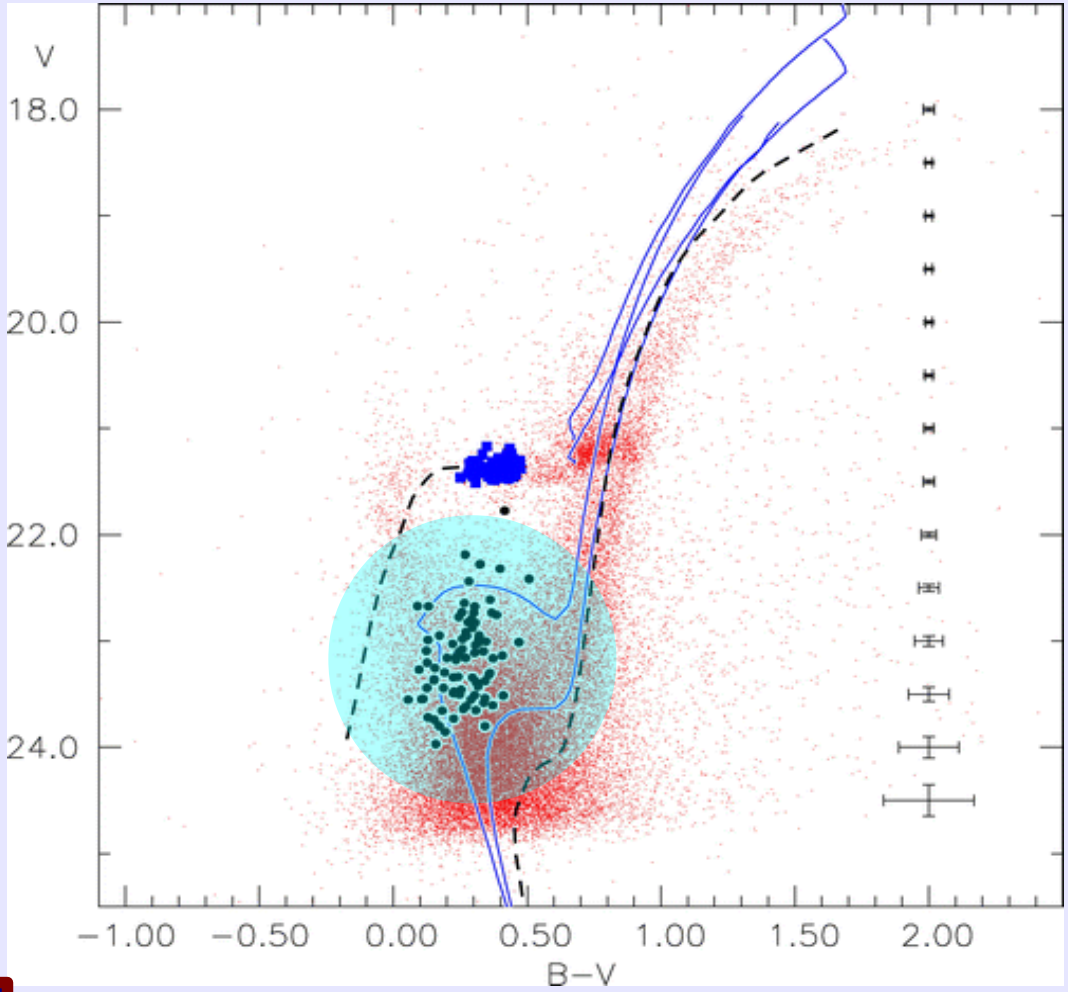
Figure from Mateo et al (1998)

Faint Variables

Why?

- Trace different stellar populations
- May be more numerous than RR Lyrae stars
- Standard candles
- Study frequency of these stars in different environments

→ **Dwarf Cepheids have been found in large numbers in only 3 extragalactic systems**



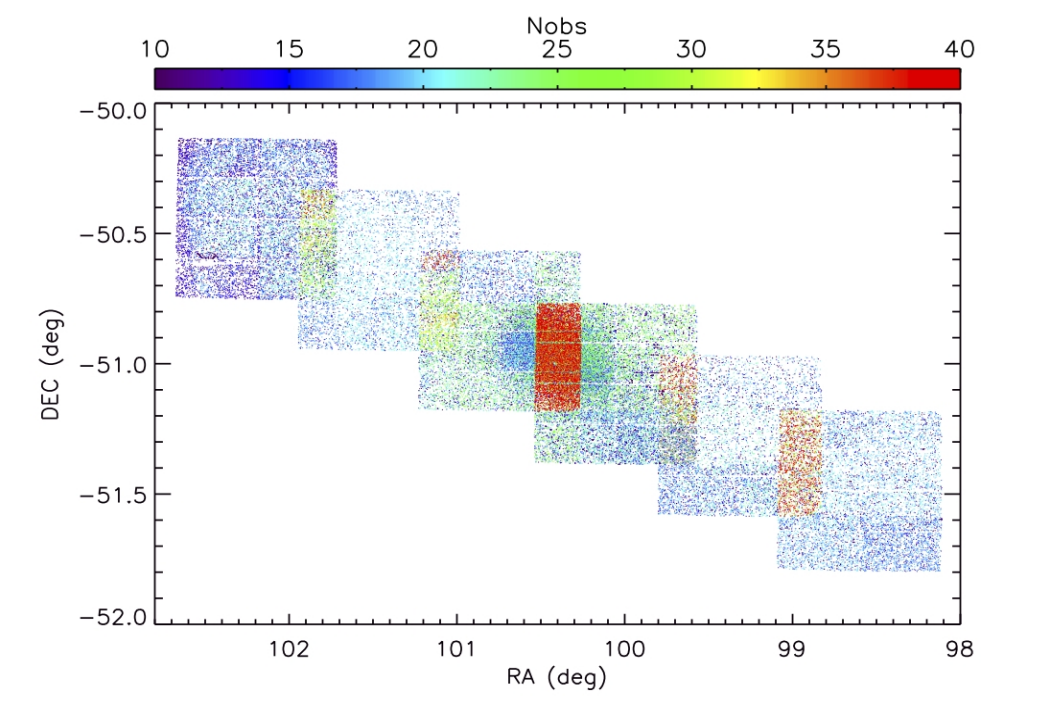
Variable stars in Fornax by Poretti et al (2008)

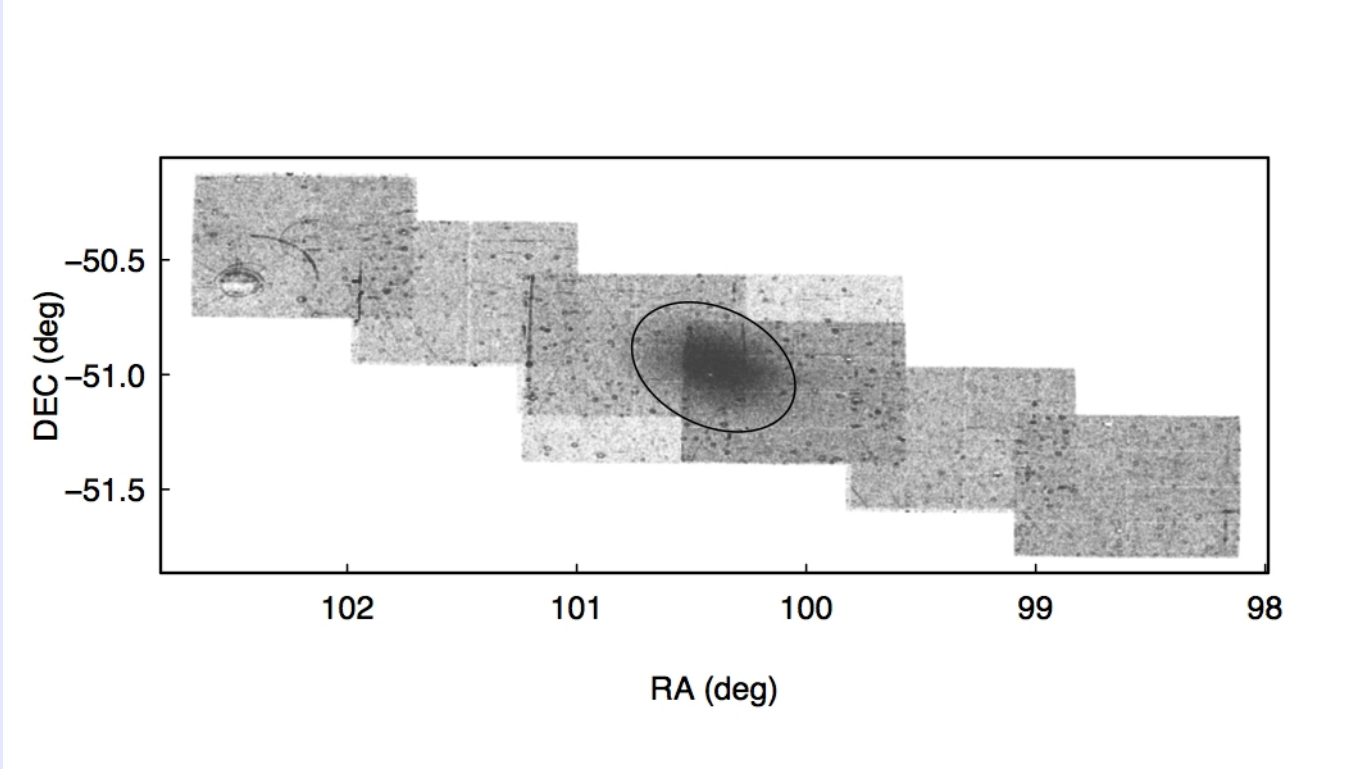
Observational Challenge:
- Faint stars
- Very short periods (<~1 hour)

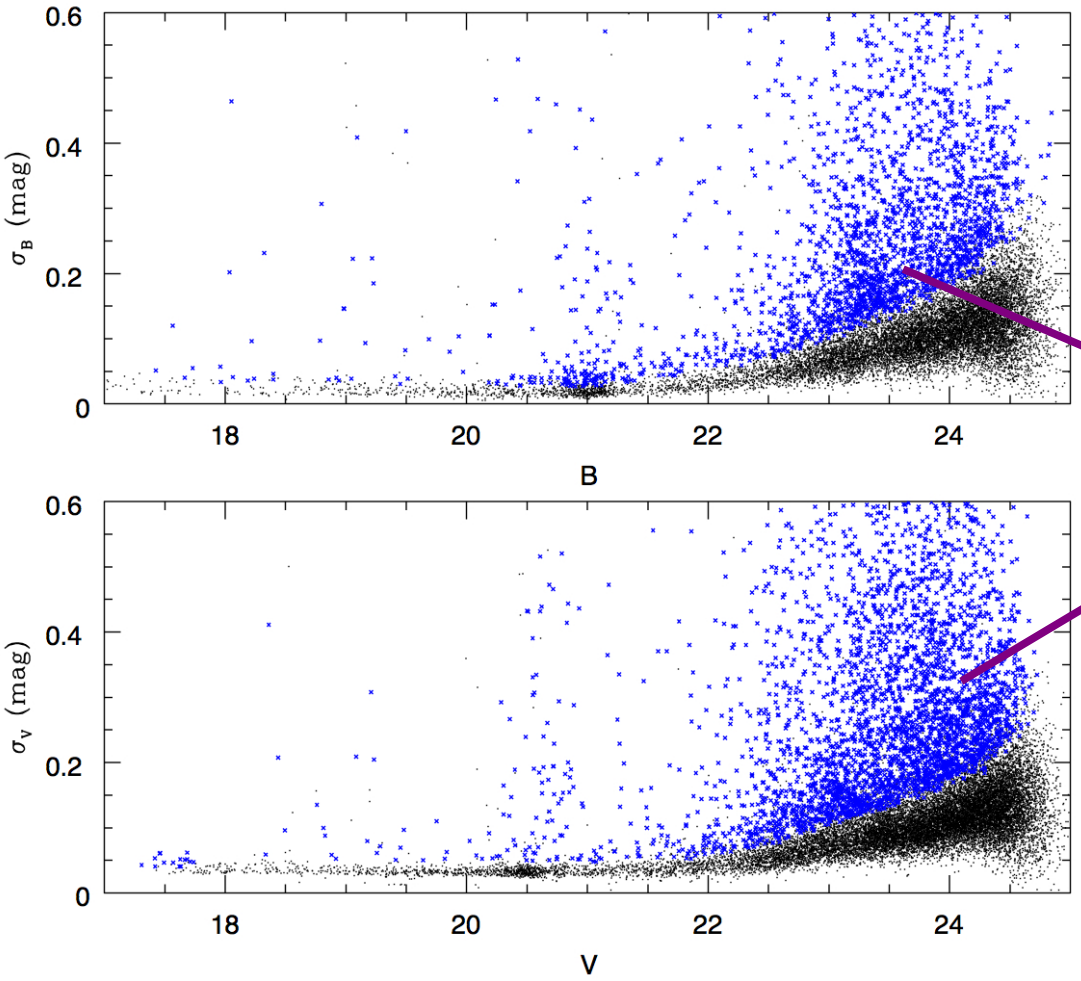
Dwarf Cepheids

Observations

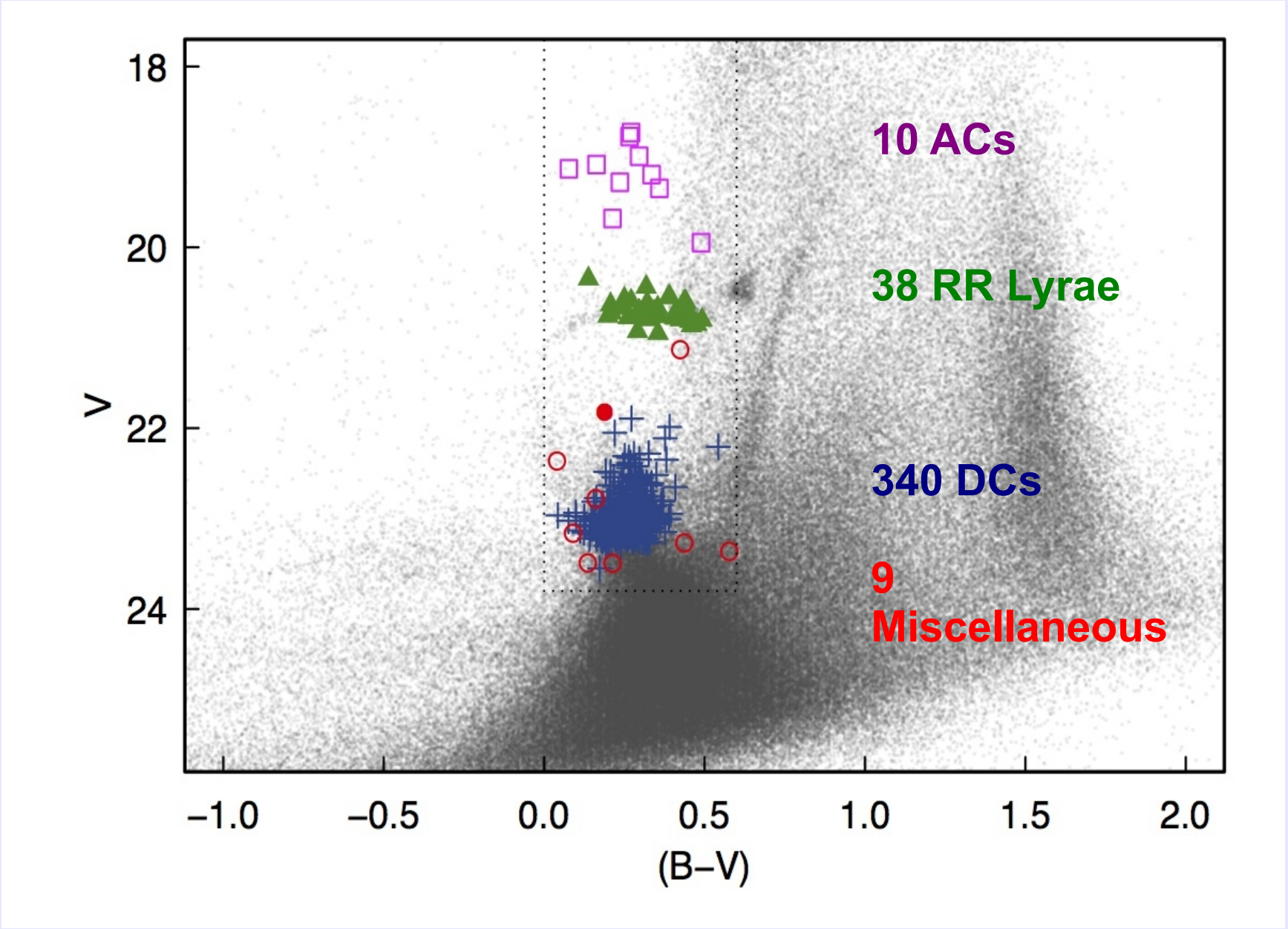
- CTIO Blanco Telescope + MOSAIC-II (December 2007)
- Continuous observations for ~3-4 hours in 2 nights
- Multi-epoch observations in B and V
- ~ 600s exposures



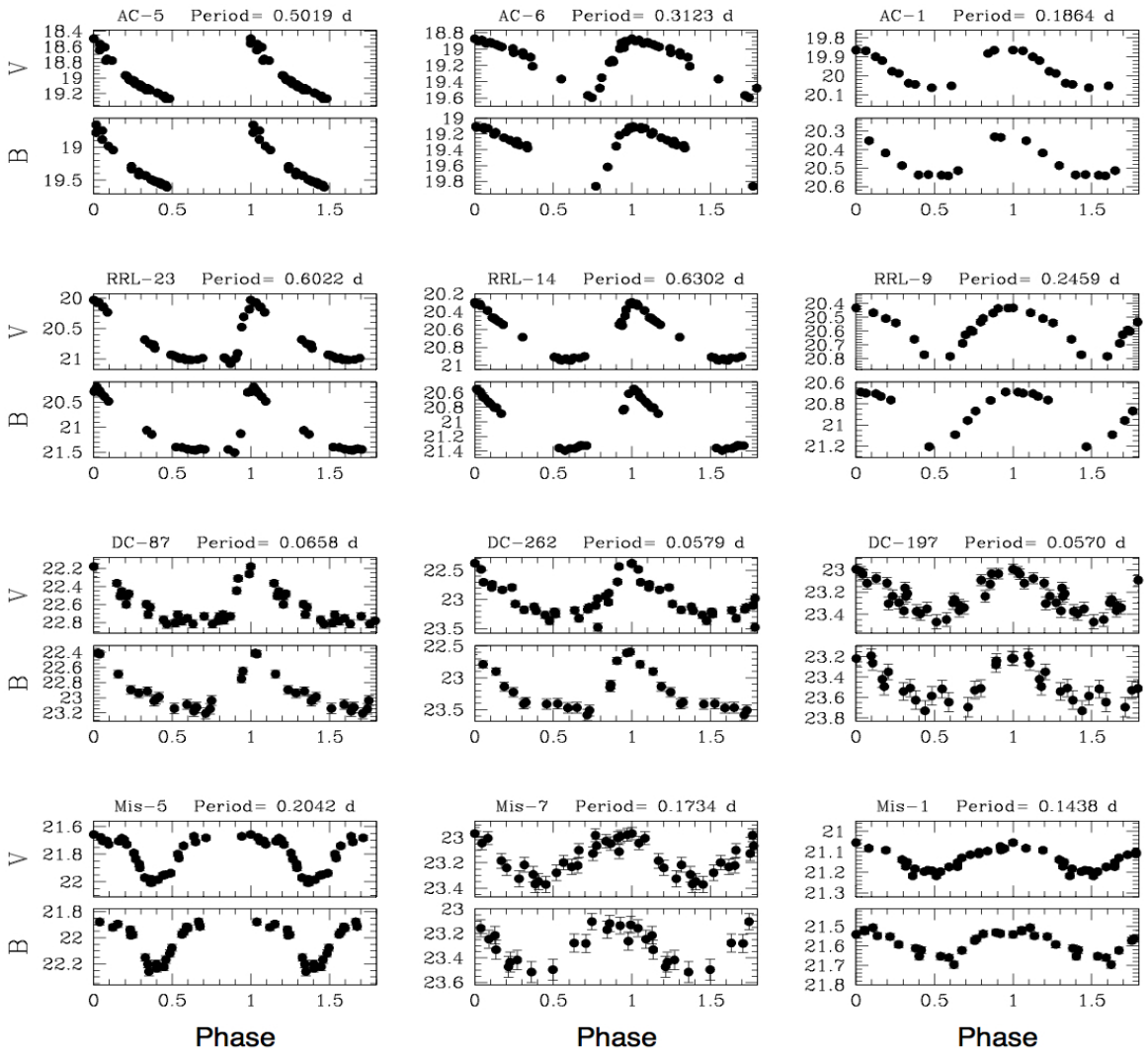




Variable stars



Periodic Variable Stars in Carina



Anomalous Cepheids

RR Lyrae stars

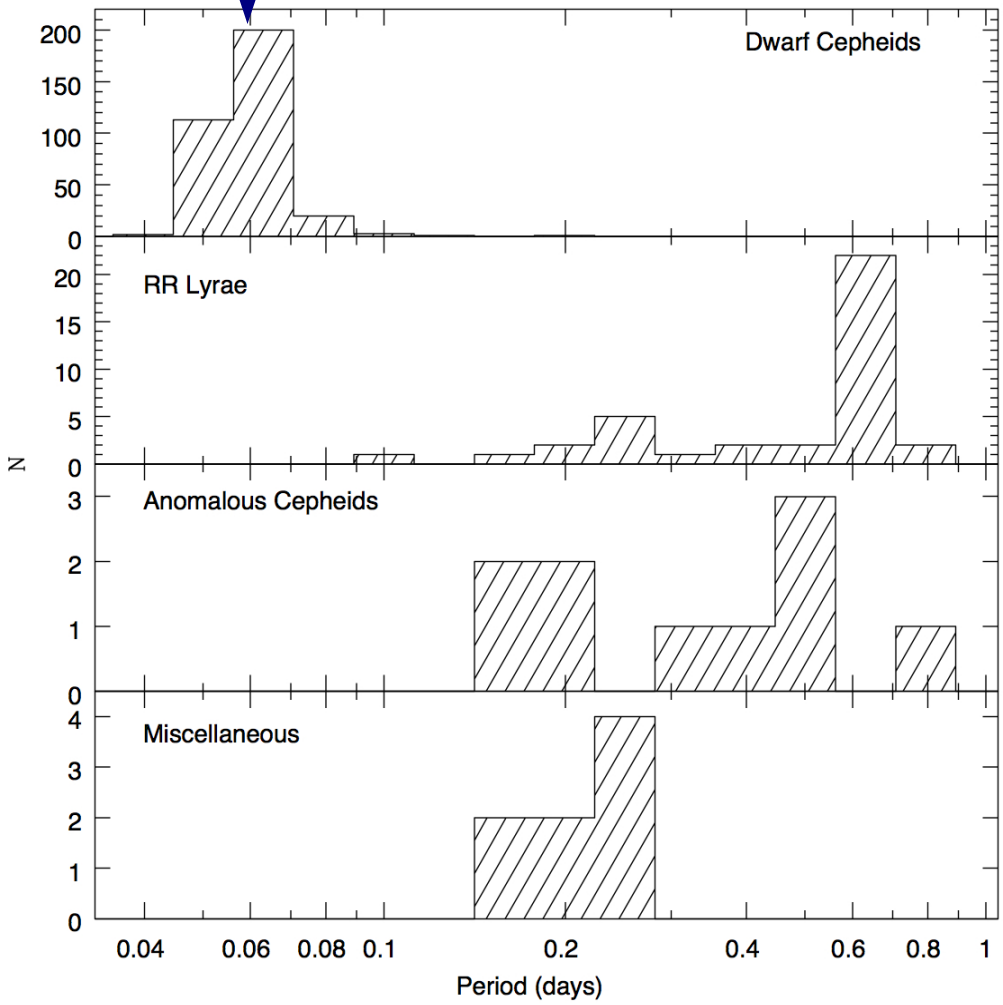
Dwarf Cepheids

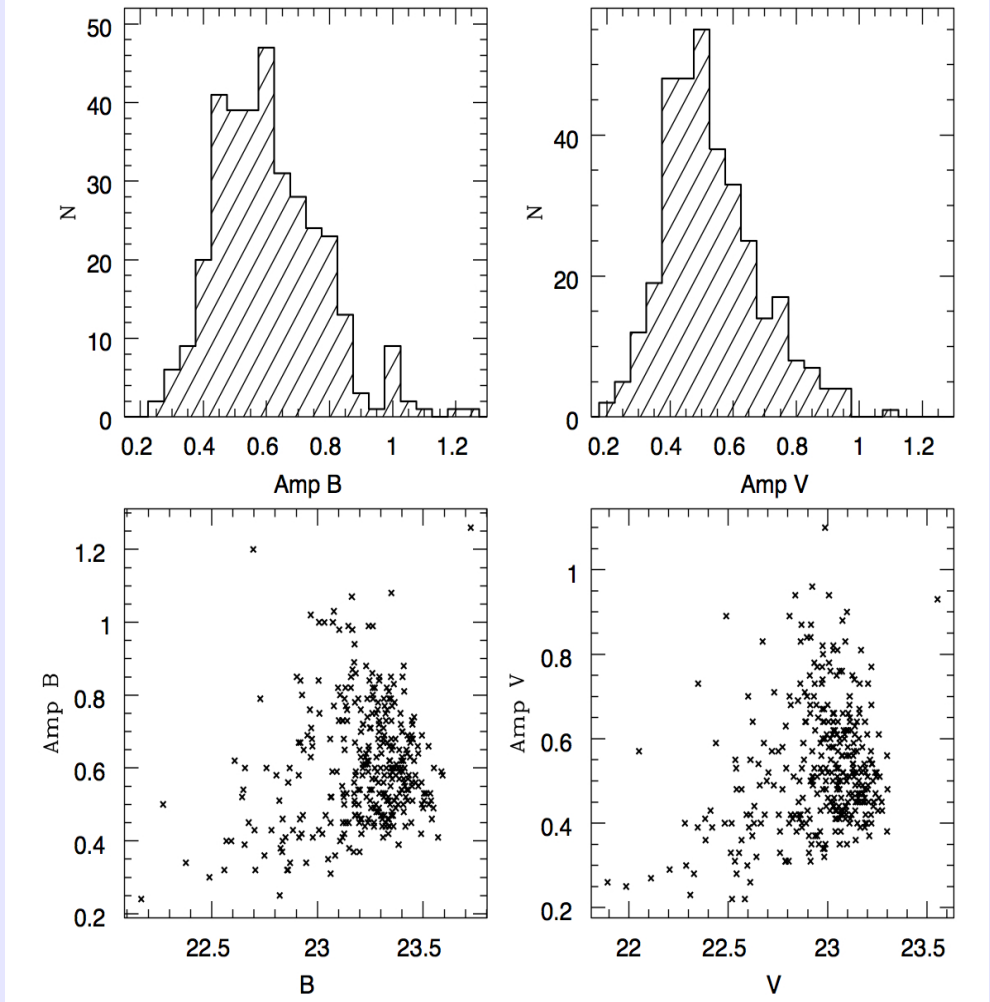
Miscellaneous

Examples of Light Curves

Very short periods.
Mean = 0.06 days

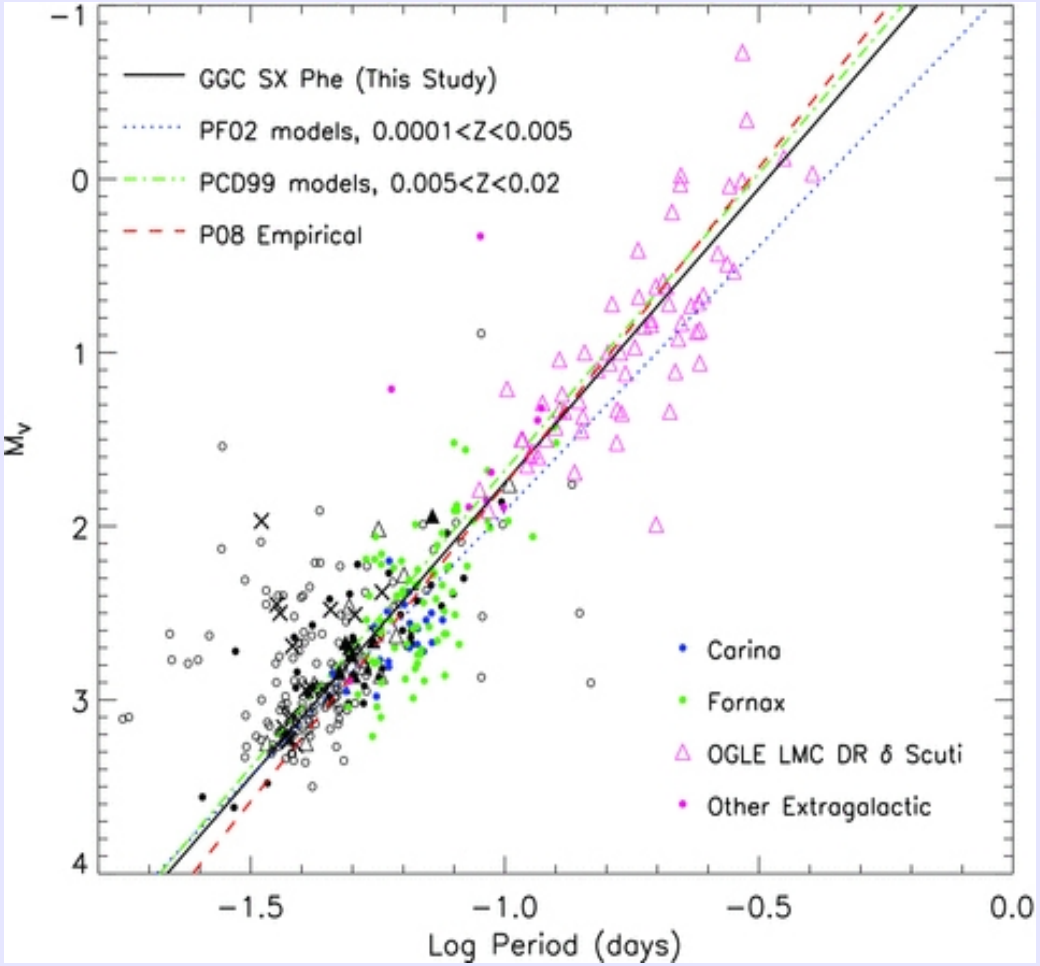
<Amp V> = 0.5 mags
< Amp B> = 0.6 mags
We may be missing some of the smaller amplitude variables at the faint end.





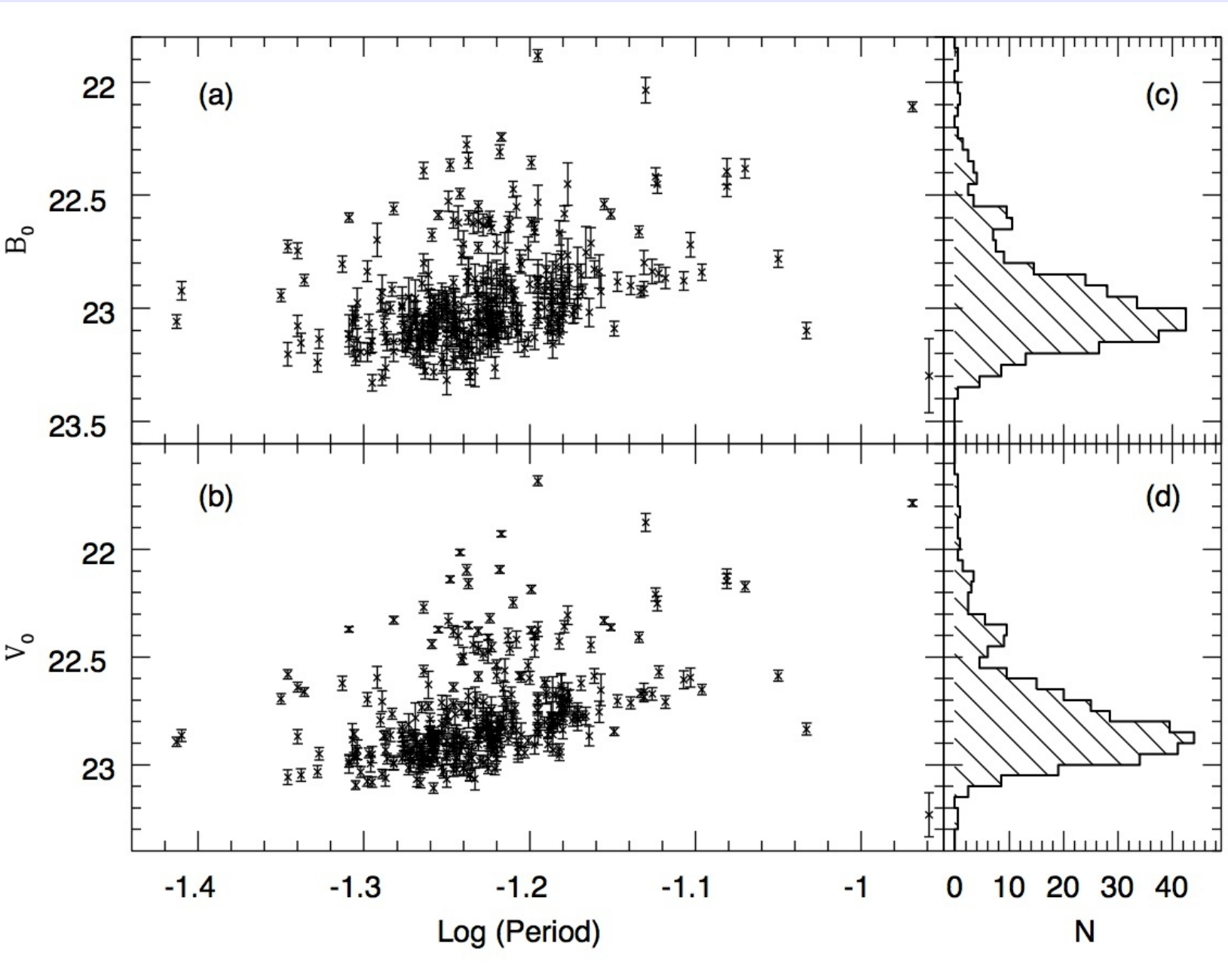
Properties of the Dwarf Cepheids

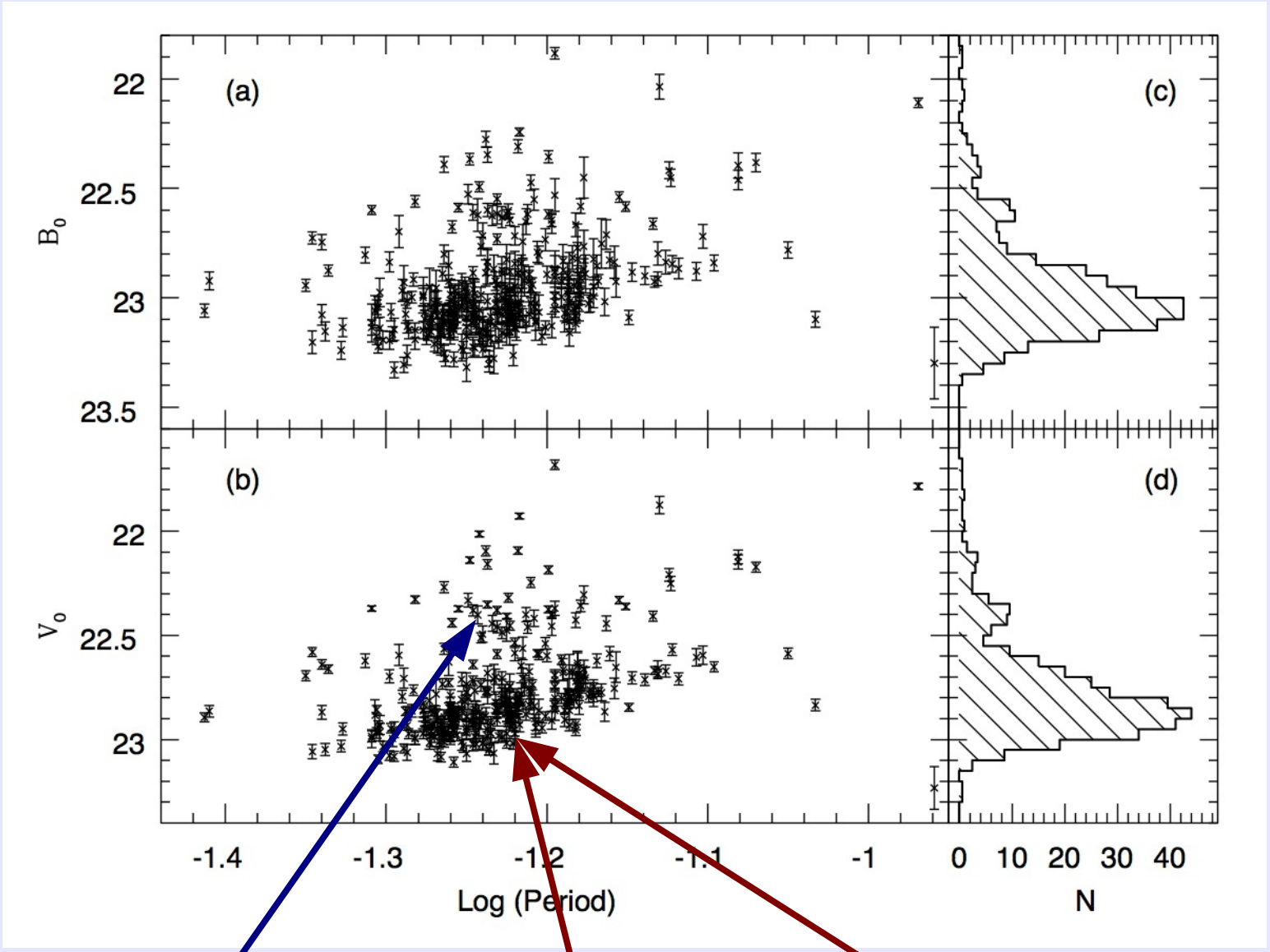
- Dwarf cepheid stars exihibit a P-L relationship
- Caution must be taken because there are different P-L relationships for F or FO pulsators
- Lately, some relationships independent of metallicity have been derived



P-L relationship for fundamental (F) pulsators.
Cohen & Sarajedini (2012)

Period – Luminosity Relationship


(a)
(b)
(c)
(d)
B_0
V_0
22
22.5
23
23.5
-1.4
-1.3
-1.2
-1.1
-1
Log (Period)
0
10
20
30
40
N


(a)
(b)
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(d)
B_0
V_0
22
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Log (Period)
0
10
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30
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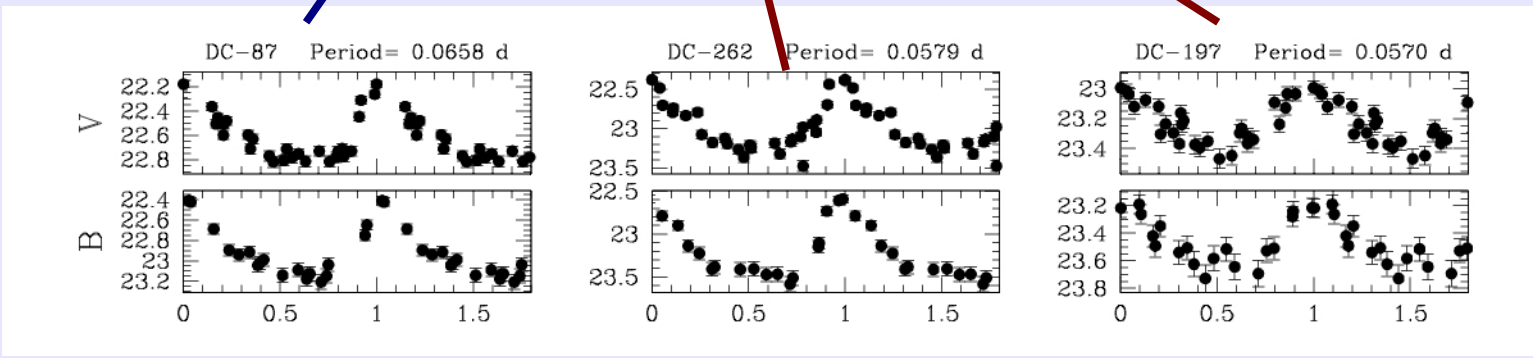
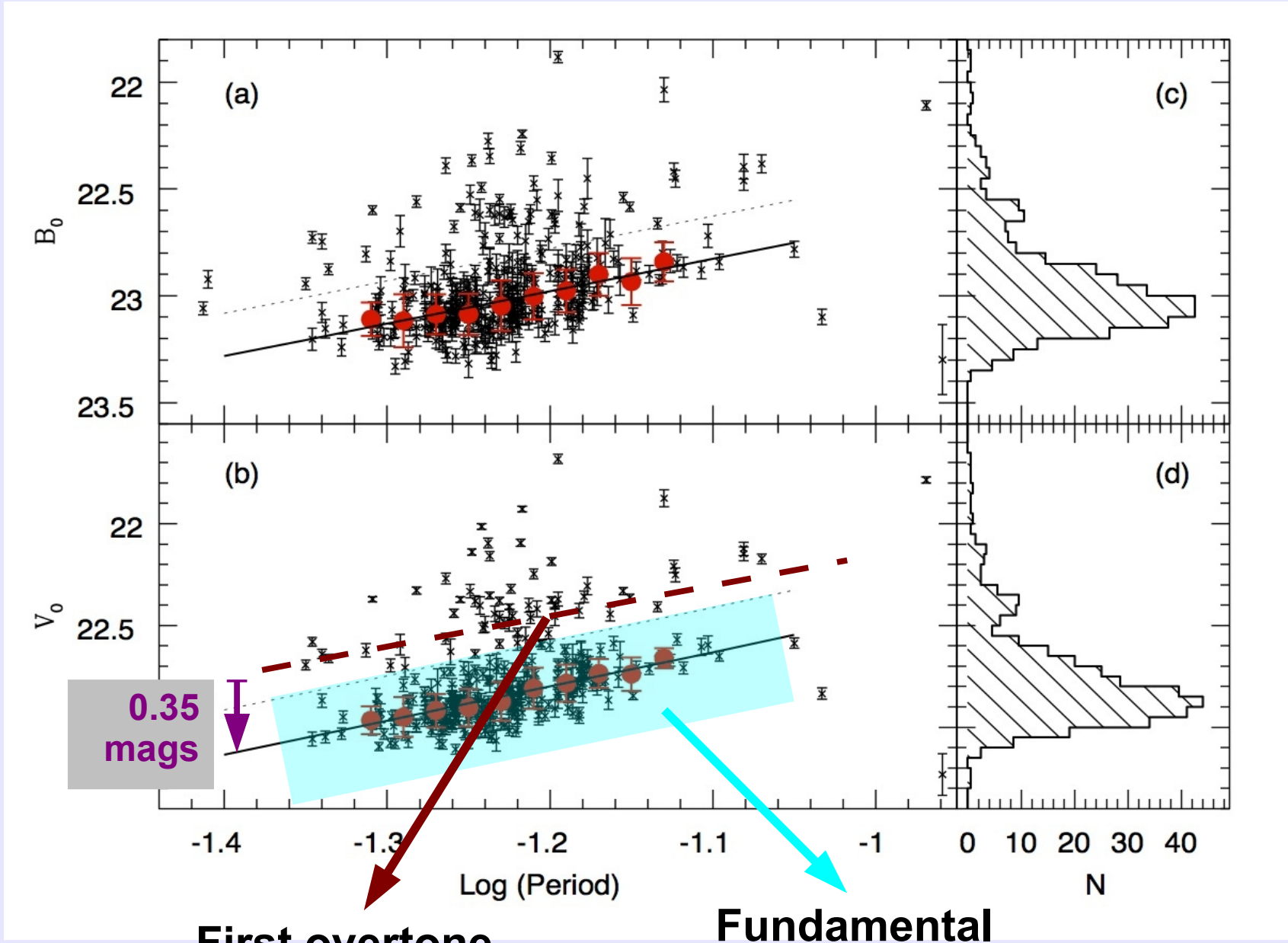
N


DC−87 Period= 0.0658 d
DC−262 Period= 0.0579 d
DC−197 Period= 0.0570 d
V
B
0
0.5
1
1.5


(a)
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B_0
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22
22.5
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-1.4
-1.3
-1.2
-1.1
-1
Log (Period)
0
10
20
30
40
N
0.35
mags
First overtone
Pulsators (FO)
Fundamental
Pulsators (F)

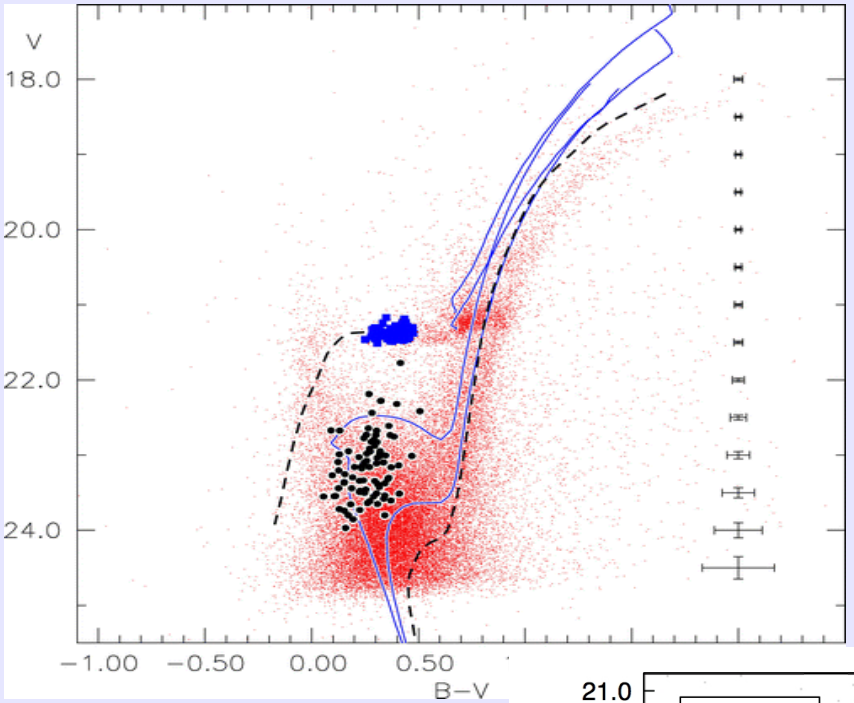
Dereddened Distance Modulus for Carina using different PL relationships for DC stars

PL relationship	[Fe/H]	μ_0	rms
Nemec et al. (1994)	-2.0	19.99	0.10
	-1.7	19.89	0.10
Poretti et al. (2008)	···	20.20	0.13
McNamara (2011)	-2.0	20.18	0.10
	-1.7	20.24	0.10
Cohen & Sarajedini (2012)	···	20.33	0.12

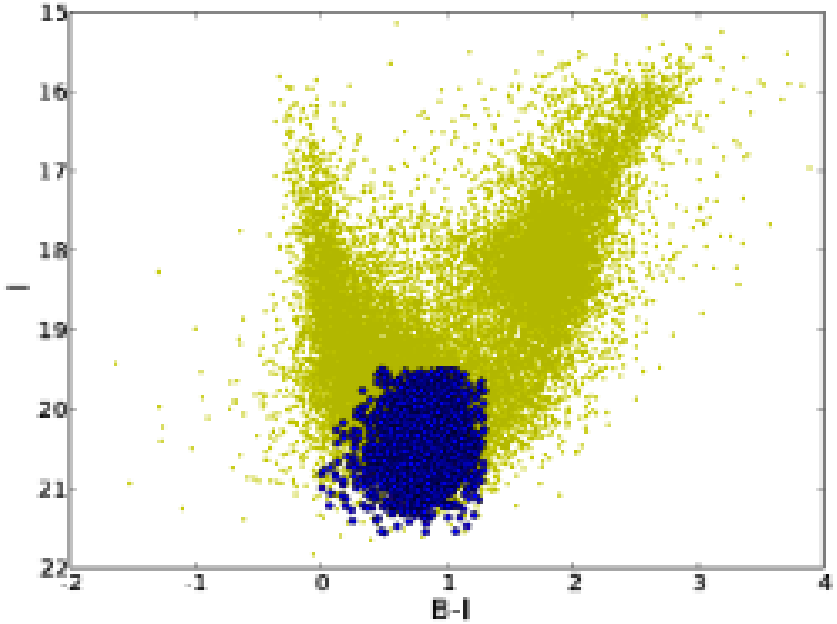
Average (for [Fe/H]=-1.7) = 20.17 +/- 0.10

RR Lyraes = 20.12 +/- 0.12 *(Dall'Ora et al 2003)*

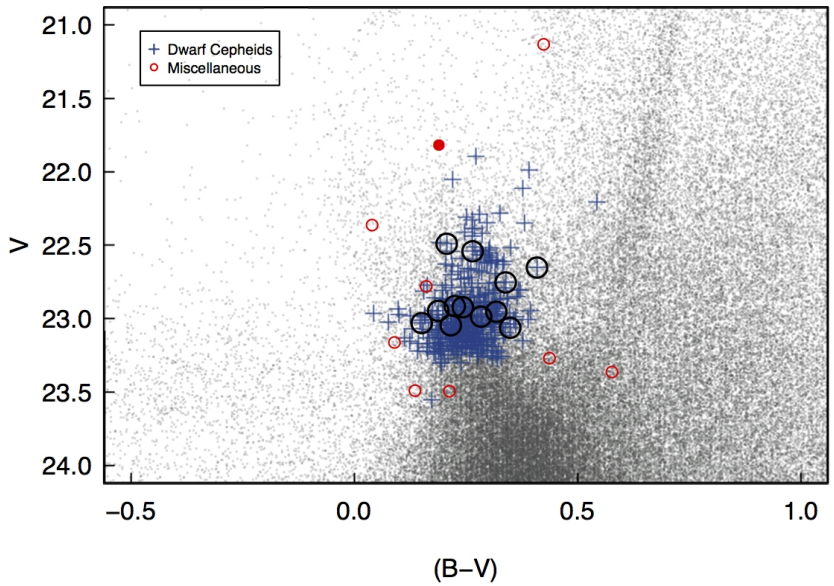
Distance Modulus



85 dwarf cepheids in Fornax
Poretti et al (2008)

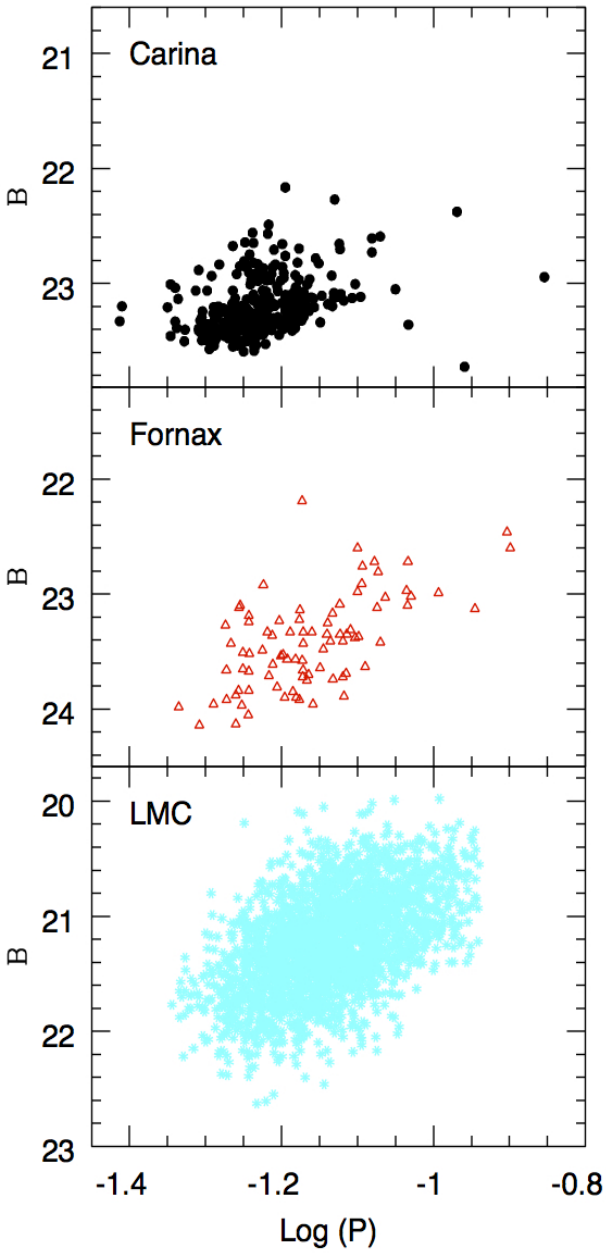


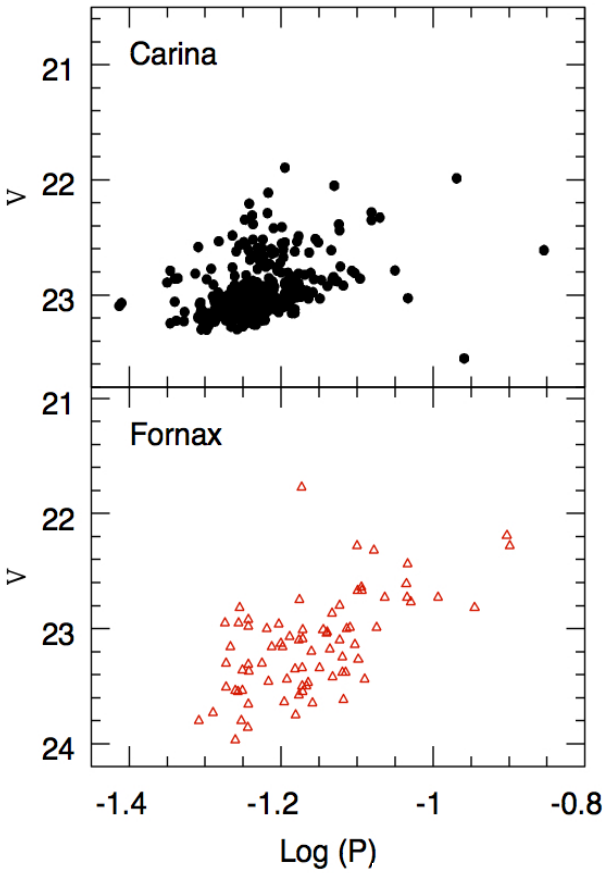
2,323 dwarf cepheids in the LMC
Garg et al (2010)



340 dwarf cepheids in Carina
Vivas & Mateo (2013)

Dwarf Cepheids in other extragalactic systems

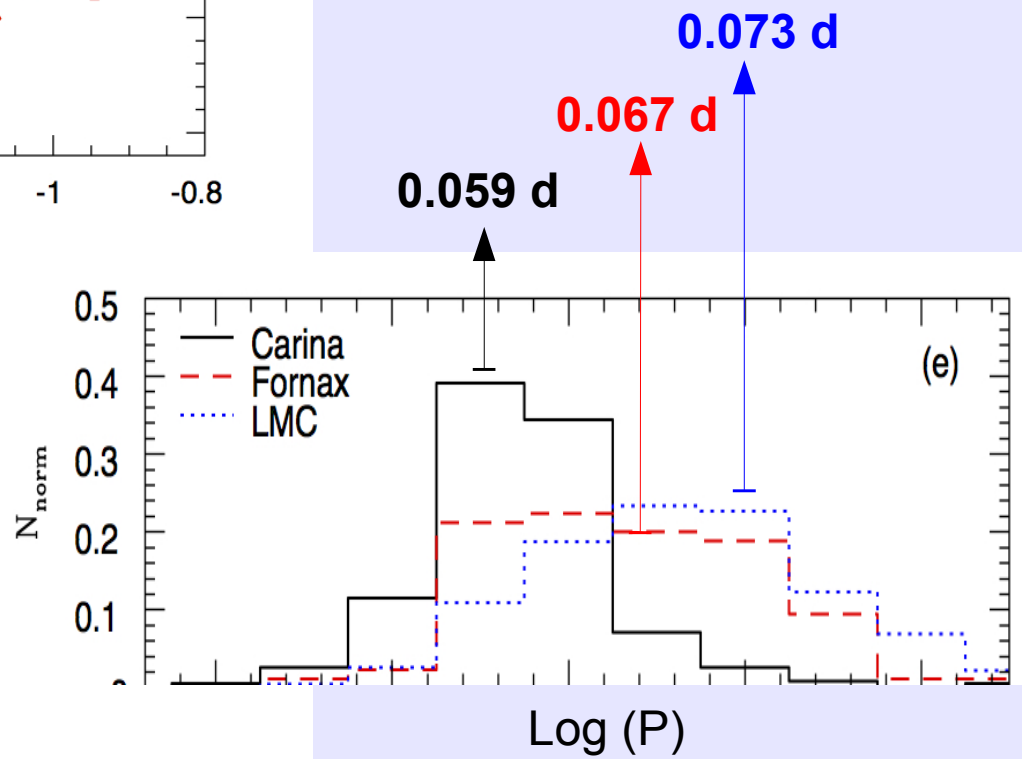


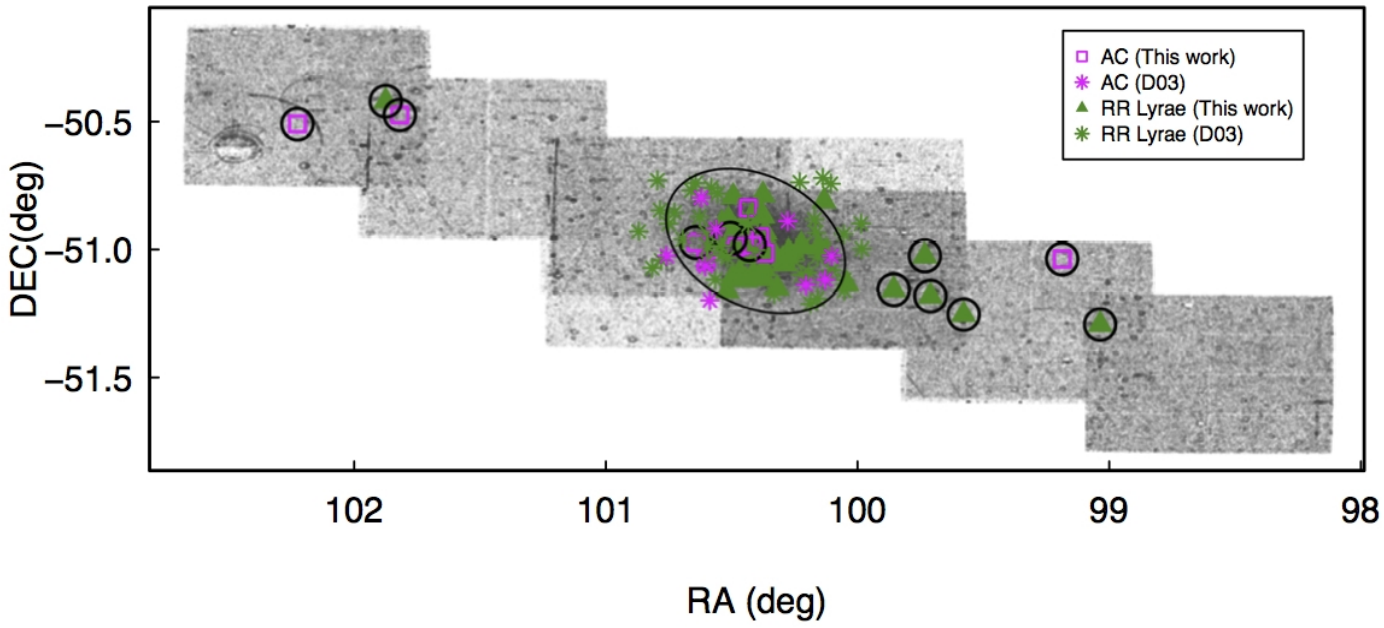


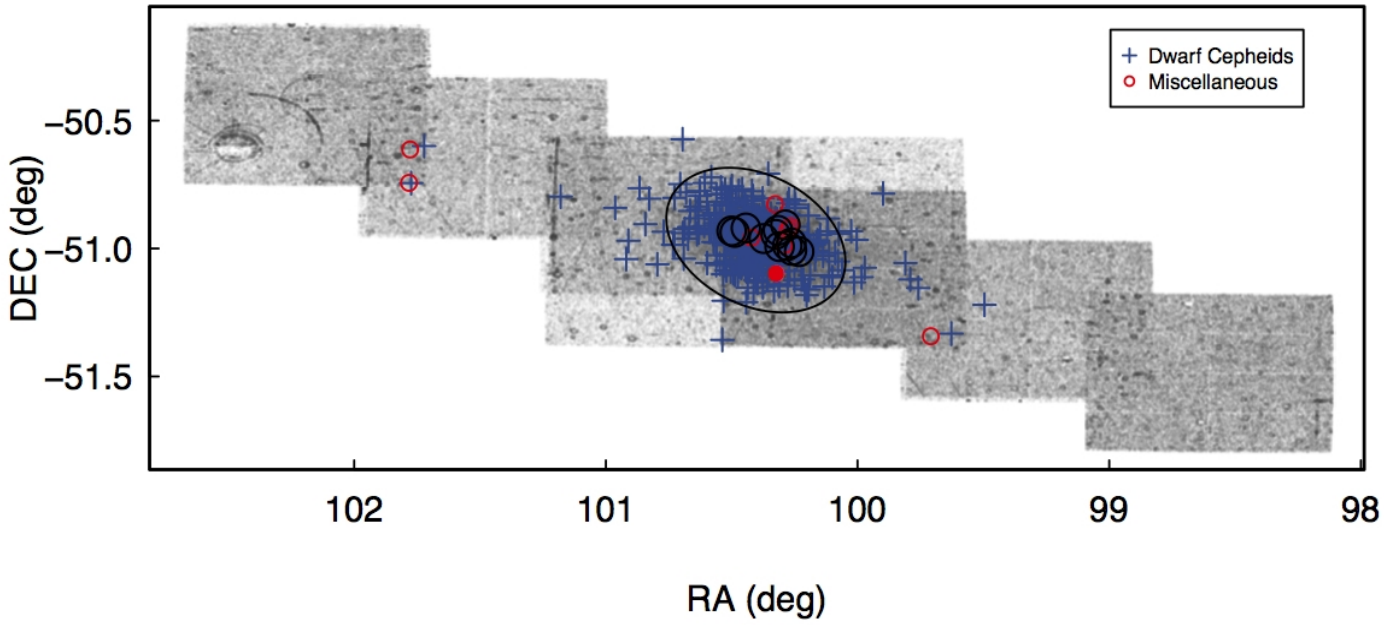
Differences:
1) Period distribution

2) Separation of F and FO modes

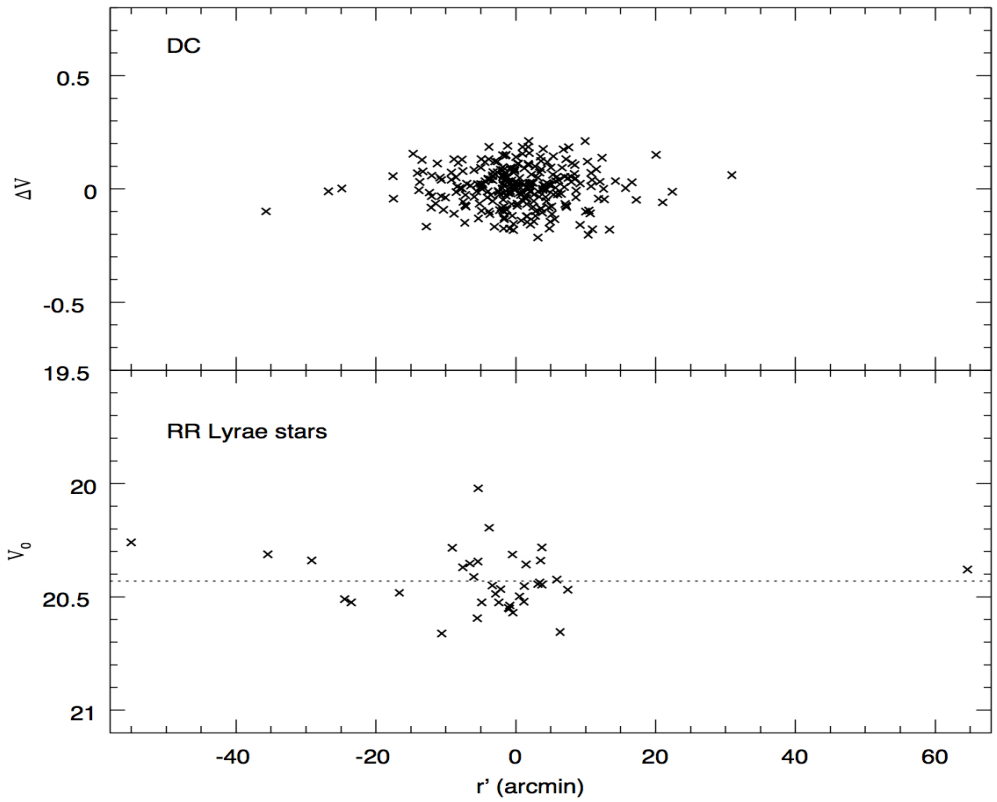
3) Slope of the P-L relationship







Spatial Distribution



Projected distance on the semi-major axis

$\Delta V = V_0 - V_F$

Difference of the extinction corrected magnitude to the magnitude predicted by the P-L relationship

No gradient is evident.

However, σd/d ~0.04 implies σd ~4 kpc at the distance of Carina.

Is there any line of sight effect along the galaxy?

- Carina is rich in dwarf cepheid stars, which may be a consequence of its prominent intermediate age population
  - There are 3-4 times more dwarf cepheids than RR Lyrae stars in this galaxy
- We have surveyed Carina up to ~ 3 times its tidal (King) radius, and found extra-tidal variables of all types.
  - Signatures of tidal disruption
  - This confirms results by Battaglia et al (2012) that both the old and intermediate-age population extends beyond it tidal radius

Conclusions

- The properties of the dwarf cepheids in Carina differ from those in Fornax and the LMC.
  - A small metallicity spread in the intermediate age population of Carina may be the main reason why the pulsation modes are separated in the P-L diagram. This would not be the case for Fornax.
- About 8% of the stars in the upper main sequence of Carina are dwarf cepheids
- Observations of dwarf cepheids in other extragalactic systems will shed light on the origin of these stars and their frequency in systems with different ages/metallicities