Variable Stars in the Gaia era classical variables: RRL, T2C, δ Cep, Mira

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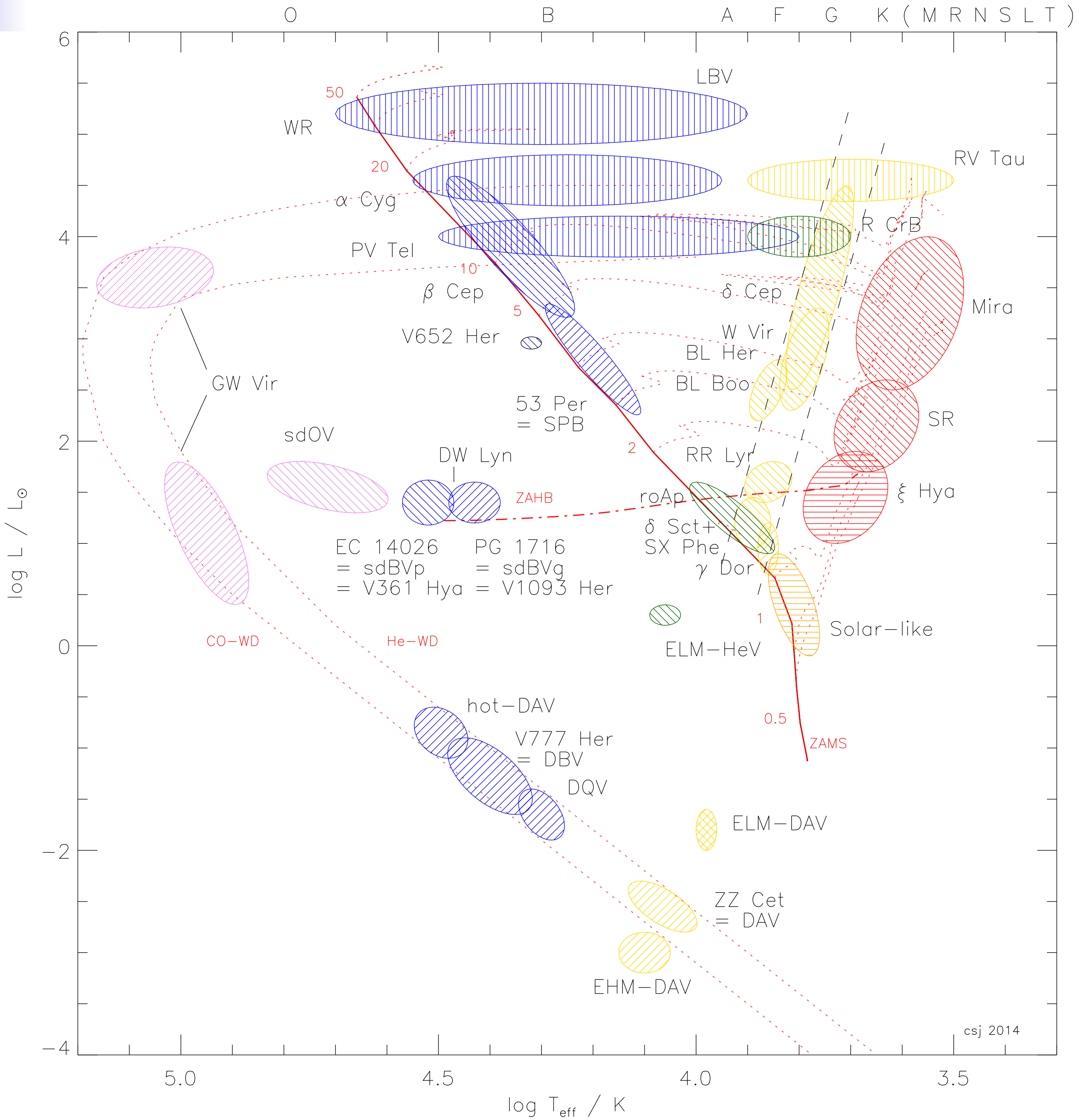
Overview Talk

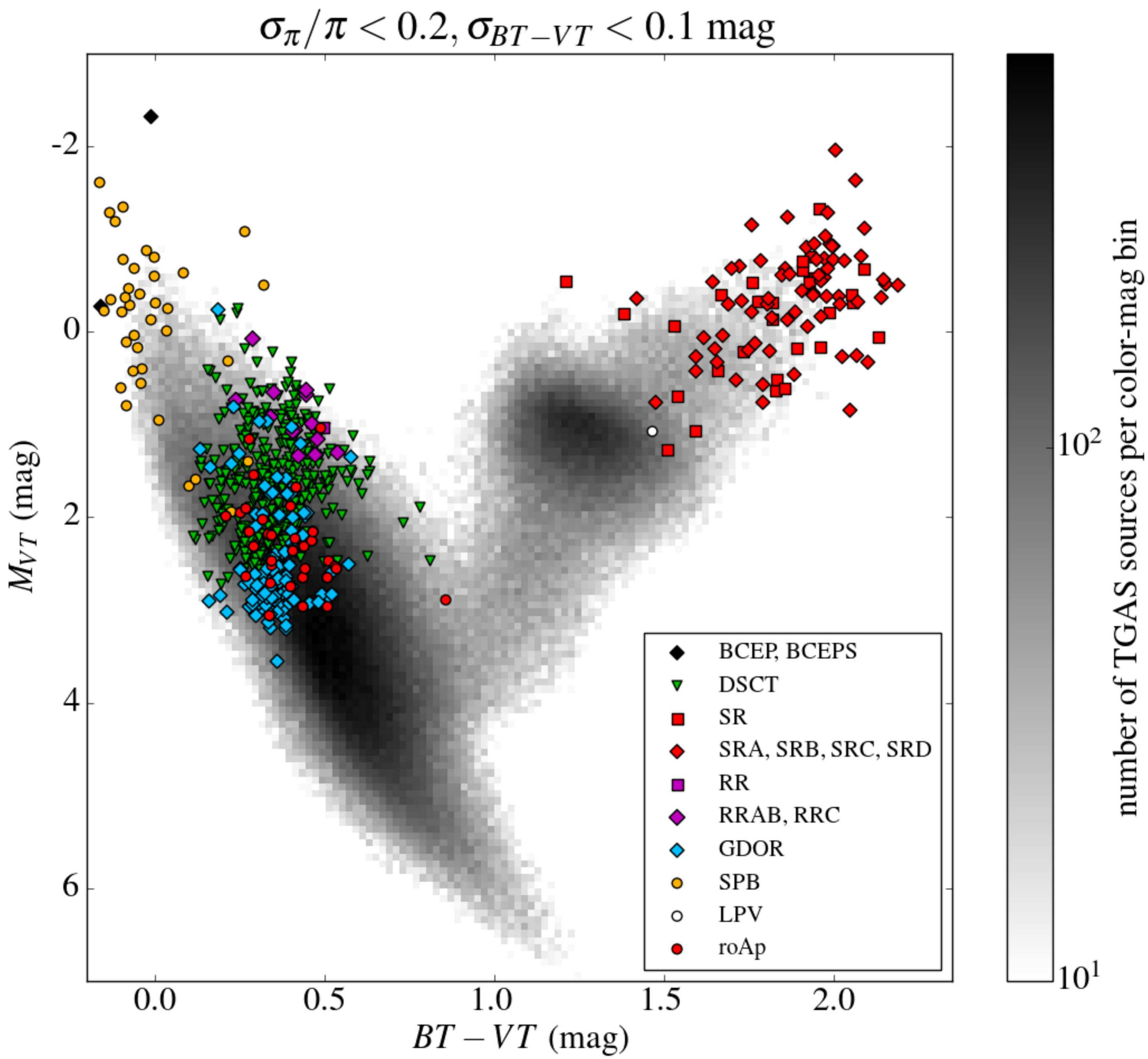
- Introduction
  - What and Where ?
- PLZ-relation
  - Galactic Structure
  - Calibration of the Distance Scale
- Hipparcos $\Rightarrow$ HST $\Rightarrow$ GDR1 $\Rightarrow$?

Where are they ?



(from Jeffery, Saio, 2016, MNRAS, 458)

Where are they ?

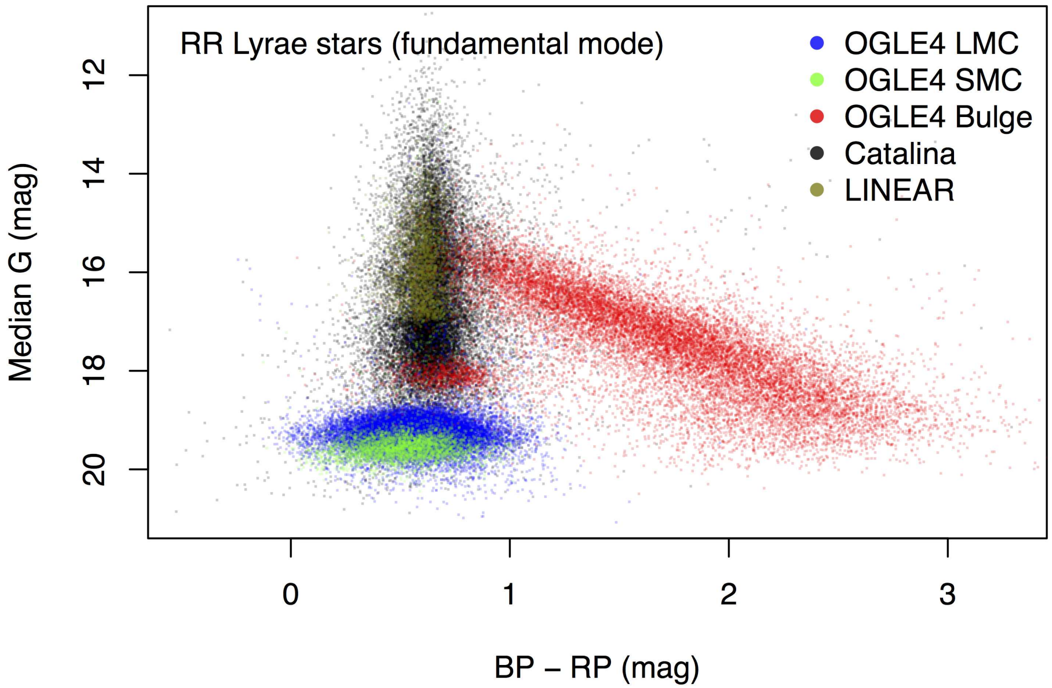


Eyer et al. (1704.0158)

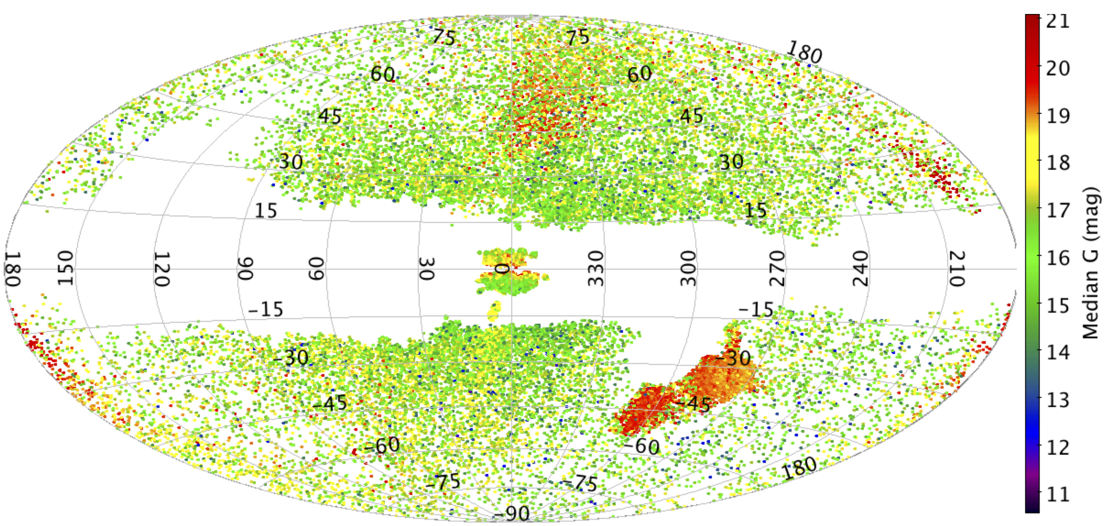
Classical Variables

- Mira (o Cet)
  1596: David Fabricius
  1638: Johannes Holwarda determined a period
  1662: Johannes Hevelius named it "The Wonderful"
- RR Lyrae
  Pickering et al. (1901, ApJ 13), Williamina Fleming
  ".....in which the variation is so great that it is obvious to the most inexperienced observer."
- δ Cep
  1784: John Goodricke dicovered it to be variable
- Type-II Cepheids
  BL Her (1 - 4d) : ?
  W Vir (4-20d): Eduard Schönfeld 1866
  RV Tau (20-70d): Lidiya Tseraskaya 1905
  (R Sct 1795 by Edward Pigott (η Aql in 1784))

Galactic Structure

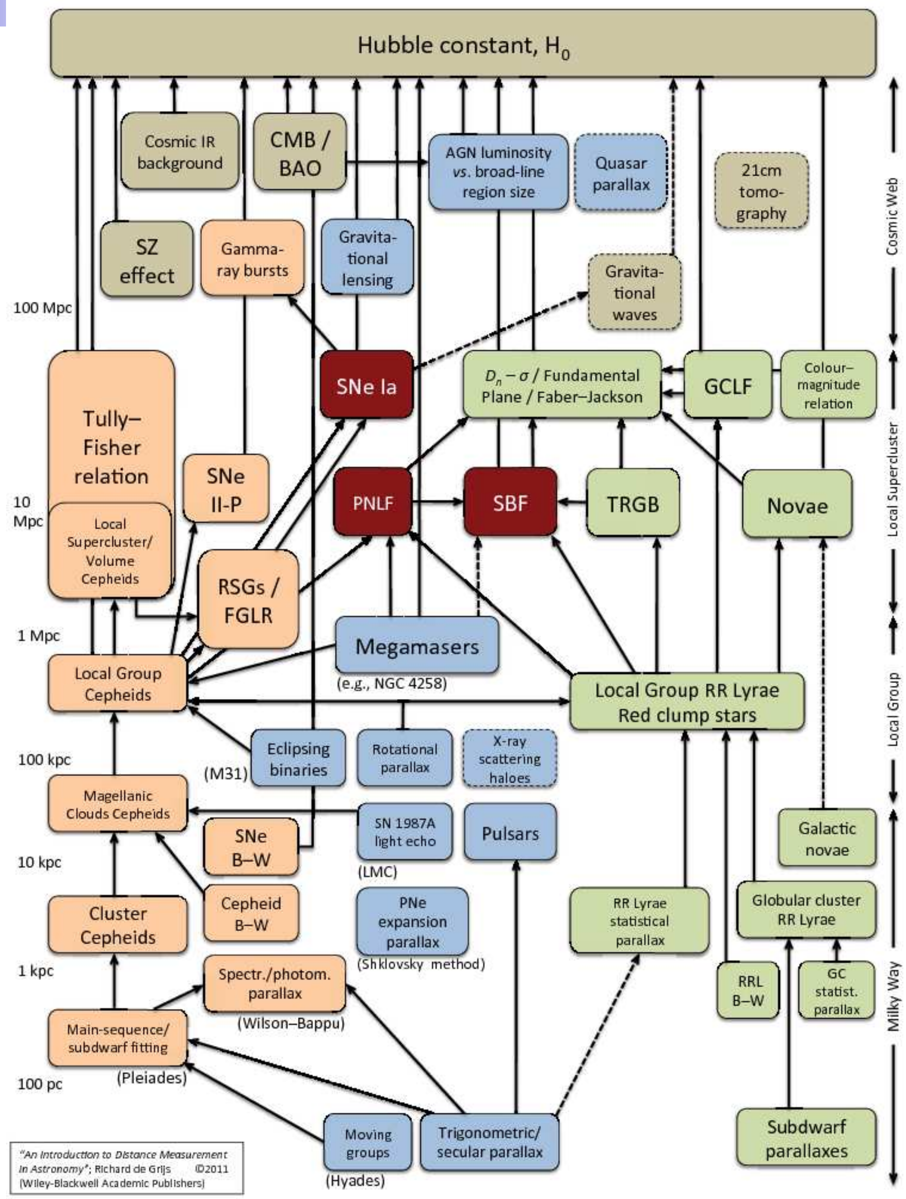


"Pulsating stars to study galactic structures" (IoW March 2017)



71 464 RRab

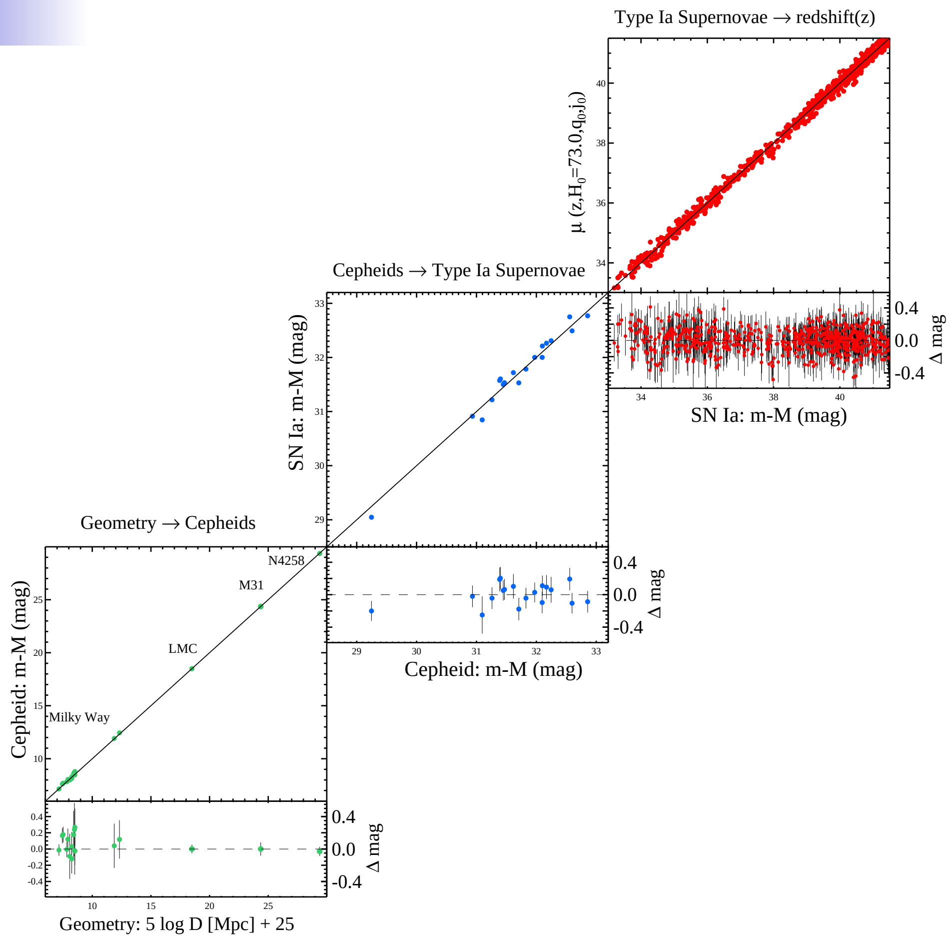
Distance Scale

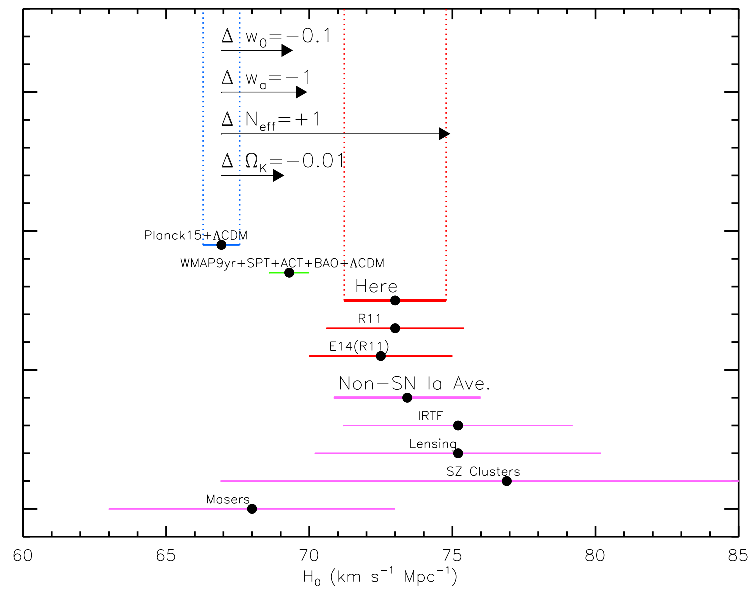


Riess et al. (2016)

$H_0 =$
73.0 ± 1.8 km s^{-1} Mpc^{-1}
(2.4%)

Local Calibration





"Tension" with 66.9 ± 0.7 km s^{-1} Mpc^{-1} from *Planck* + ΛCDM $\Rightarrow$ aim for 1% determination of H_0

PL-relations: RRL

Chaboyer (1999):

$M_{\rm V} = (0.23 \pm 0.04)([Fe/H] + 1.6) + (0.46 \pm 0.11)$

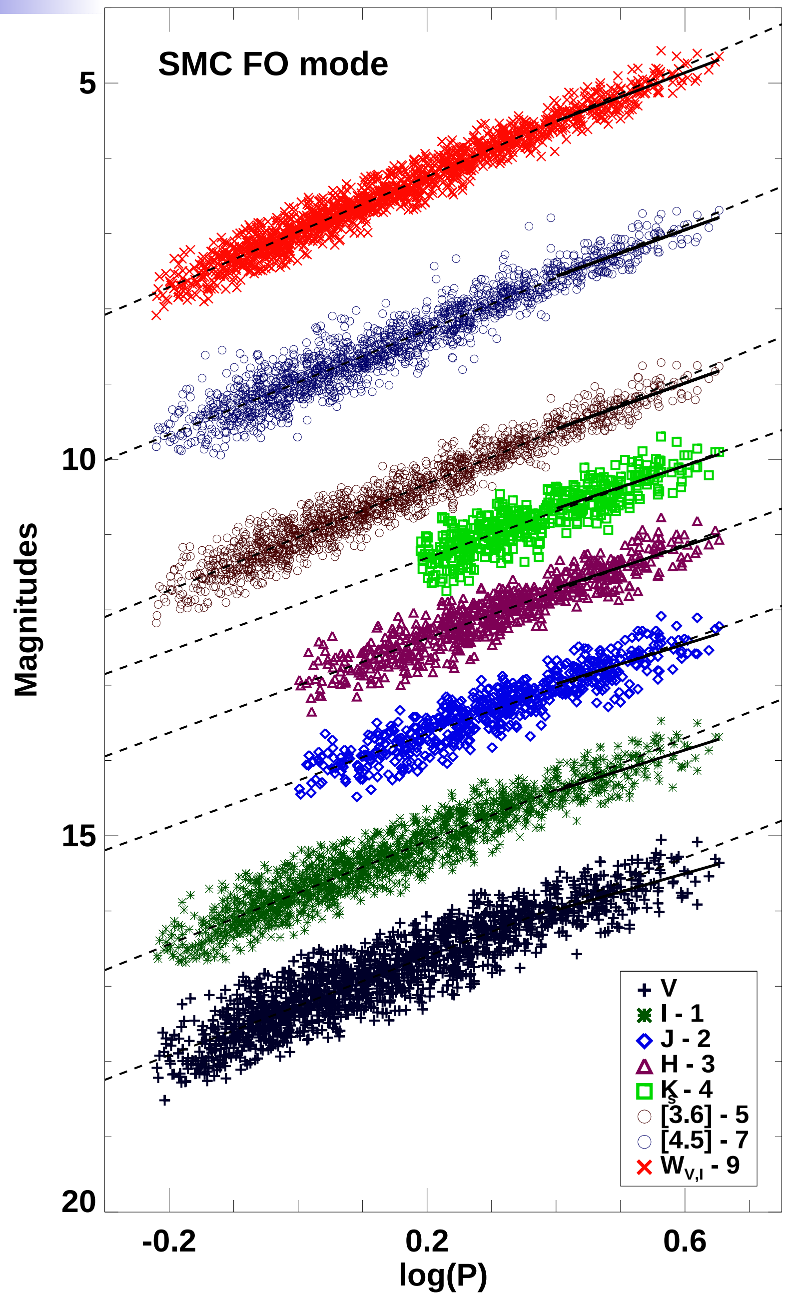
Muraveva et al. (2015, ApJ 807)
70 RRL, spectroscopic metallicities, period from OGLE, multi-epoch K from VMC
DM= 18.493 $\pm$ 0.008
(Pietrzyński et al. 2013 Nature 495) 8 dEBs

$M_{\rm K} = (-2.73 \pm 0.25) \log P + (0.03 \pm 0.07)[Fe/H] + (-1.06 \pm 0.01)$

5 Local RRL: (-1.25 ± 0.06)

Klein et al. (2014 MN 440): PL-relation in WISE
Neeley et al. (2015 ApJ 808): PL-relation in [3.6], [4.5]

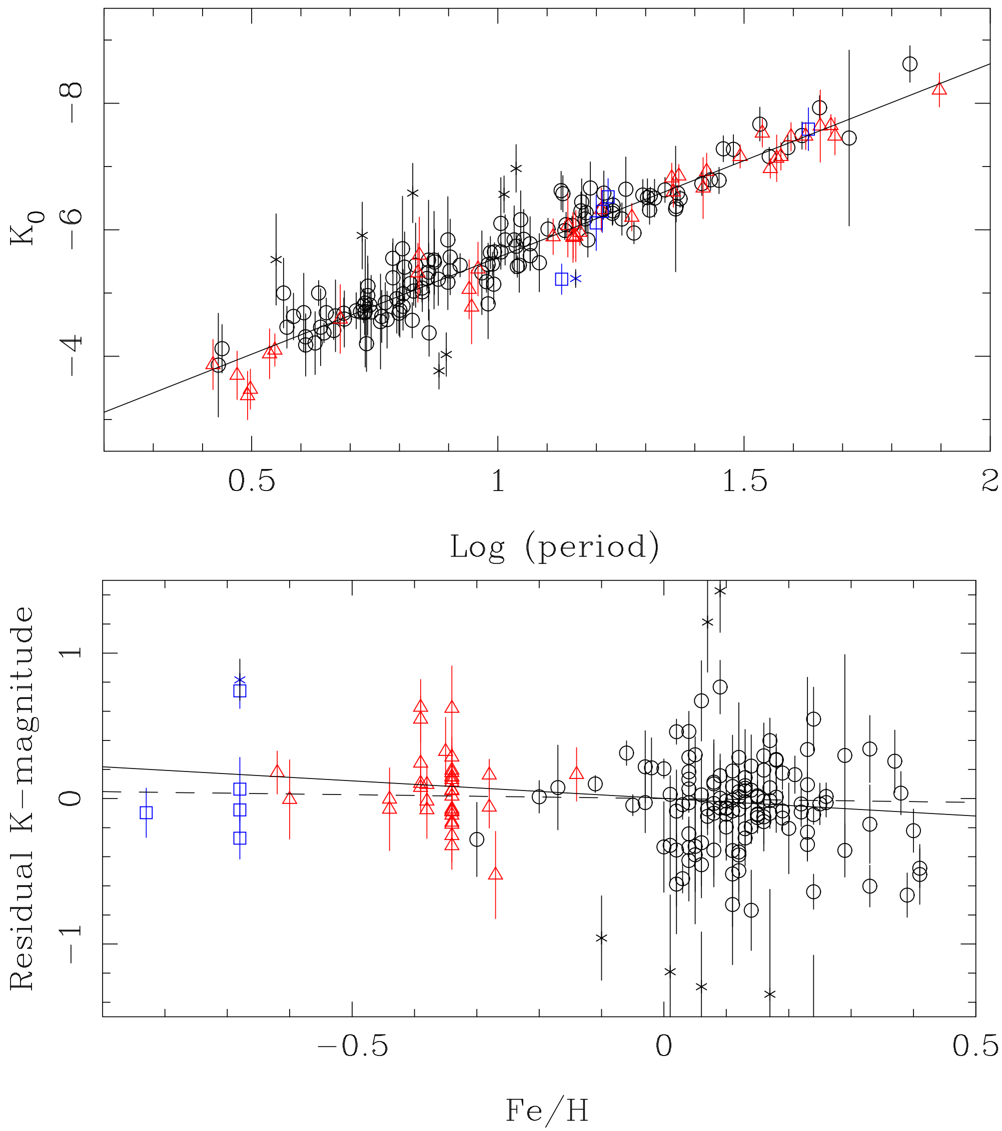
PL-relations: CEP



Bhardwaj et al.
(2016, MNRAS 457)

Issues:
Non-linear ?
(in BV;
Wesenheit, NIR-MIR not)
Metallicity dependent ?
(small, certainly in NIR-MIR)

PL-relations: CEP



Groenewegen et al. (2013 A&A 550)

$\gamma(V) = +0.23 \pm 0.11$

$\gamma(K) = -0.05 \pm 0.10$

Storm et al. (2011 A&A 534)

$\gamma(W_{\rm VI}) = -0.23 \pm 0.10$

$\gamma(K) = -0.10 \pm 0.10$

BW-method

p-factor !

Hipparcos $\Rightarrow$ HST $\Rightarrow$ GDR1

Hipparcos ($\sigma_\pi/\pi \lesssim 0.16$):
1 RR Lyrae, 2 Type-II, 10 Classical Cepheids, 8 Miras

RR Lyrae – T2C: Benedict et al. (2011 AJ 142)

Name	Type	$\pi \pm \sigma_\pi$ (HST)	$\pi \pm \sigma_\pi$ (Hipparcos)	$\pi \pm \sigma_\pi$ (GDR1)
RR Lyr	RRab	3.77 $\pm$ 0.13	3.46 $\pm$ 0.64	
UV Oct	RRab	1.71 $\pm$ 0.10	2.44 $\pm$ 0.81	
XZ Cyg	RRab	1.67 $\pm$ 0.17	2.29 $\pm$ 0.84	
SU Dra	RRab	1.42 $\pm$ 0.16	0.20 $\pm$ 1.13	
RZ Cep	RRc	2.54 $\pm$ 0.19	0.59 $\pm$ 1.48	
VY Pyx	BL Her	6.44 $\pm$ 0.23	5.01 $\pm$ 0.44	3.85 $\pm$ 0.28
κ Pav	W Vir	5.57 $\pm$ 0.28	6.52 $\pm$ 0.77	
KT Com	W Vir		5.50 $\pm$ 0.73	4.16 $\pm$ 0.66

RRab: 5782 GCVS, 217 GDR1, $\sigma_\pi/\pi \lesssim 0.16$: 9
CW: 271 GCVS, 44 GDR1, $\sigma_\pi/\pi \lesssim 0.16$: 2

Hipparcos $\Rightarrow$ HST $\Rightarrow$ GDR1

Benedict et al. (2007 AJ 133)
Riess et al. (2014, ApJ 785)
Casertano et al. (2016, ApJ 825)

Name	$\pi \pm \sigma_\pi$ (HST)	$\pi \pm \sigma_\pi$ (Hipparcos)	$\pi \pm \sigma_\pi$ GDR1
β Dor	3.14 ± 0.16	3.64 ± 0.28	
δ Cep	3.66 ± 0.15	3.81 ± 0.20	
FF Aql	2.81 ± 0.18	2.05 ± 0.34	1.64 ± 0.89
l Car	2.01 ± 0.20	2.06 ± 0.27	
RT Aur	2.40 ± 0.19	-0.23 ± 1.01	
T Vul	1.90 ± 0.23	2.31 ± 0.29	
Y Sgr	2.13 ± 0.29	3.73 ± 0.32	
X Sgr	3.00 ± 0.18	3.39 ± 0.21	
ζ Gem	2.78 ± 0.18	2.71 ± 0.17	
W Sgr	2.28 ± 0.20	2.59 ± 0.75	
SS CMa	0.348 ± 0.038		0.69 ± 0.23
SY Aur	0.428 ± 0.054		0.69 ± 0.25

DCEP: 632 GCVS, 289 GDR1, $\sigma_\pi/\pi \lesssim 0.16$: 1
(CK Cam: 1.56 ± 0.25 mas)

Hipparcos $\Rightarrow$ HST $\Rightarrow$ GDR1

Name	$\pi \pm \sigma_\pi$ (Hipparcos)
o Cet	10.91 $\pm$ 1.22
L_2 Pup	15.61 $\pm$ 0.99
R Car	6.34 $\pm$ 0.81
R Leo	9.01 $\pm$ 1.42
R Hya	8.24 $\pm$ 0.92
W Hya	9.59 $\pm$ 1.12
W Cyg	5.72 $\pm$ 0.38
R Cas	7.95 $\pm$ 1.03

Whitelock et al. (2008 MNRAS 386)

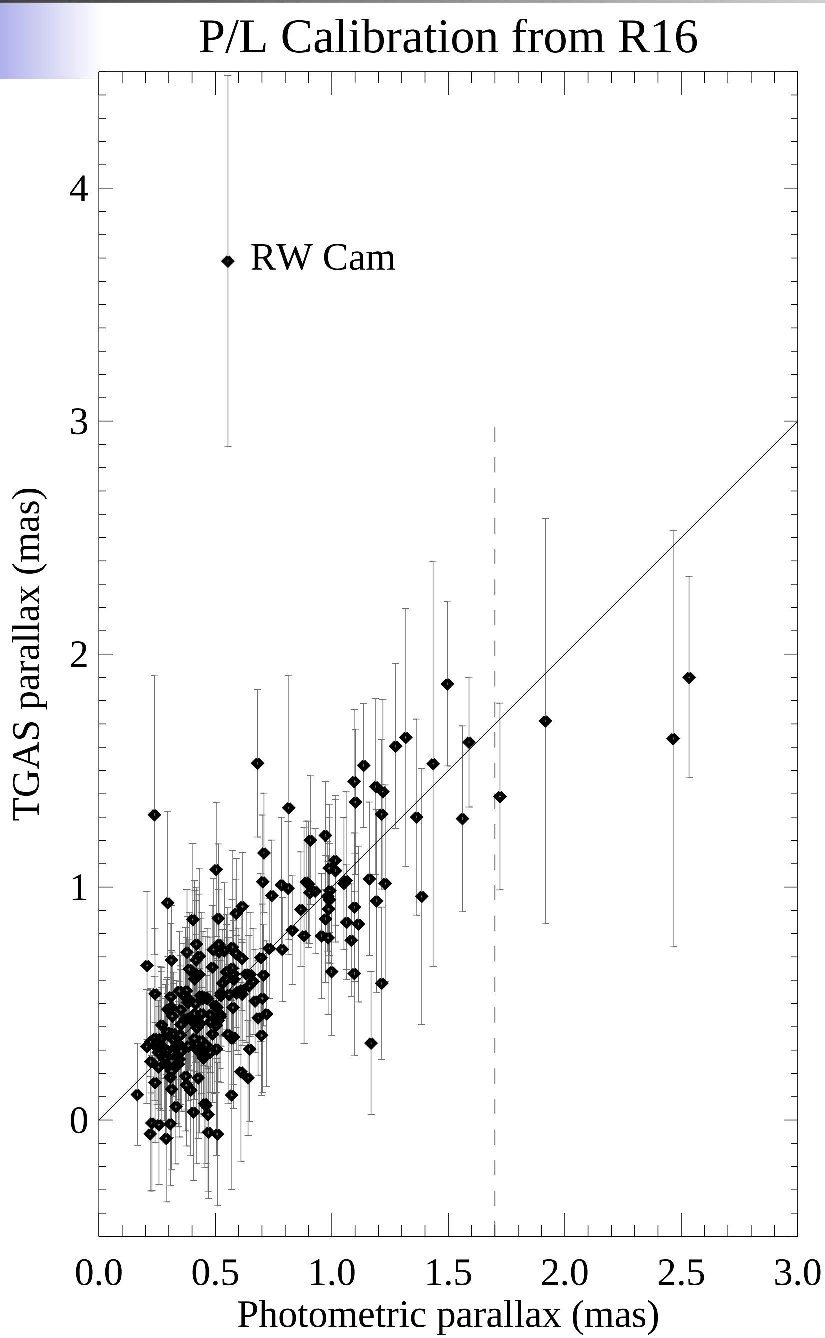
$10^{0.2\alpha} = \pi \cdot 10^{-0.2(\beta \log P + K_0)}$ ~ 180: $M_K = -3.51 \log P + 1.20$

500d Mira $M_K = -8.3$; 50d Cepheid $M_K = -7.9$

M + SRa+SRb: 10491 GCVS, 730 GDR1, $\sigma_\pi/\pi \lesssim 0.16$: 1

V375 And (2.91 ± 0.46 mas)

GDR1: Cepheids

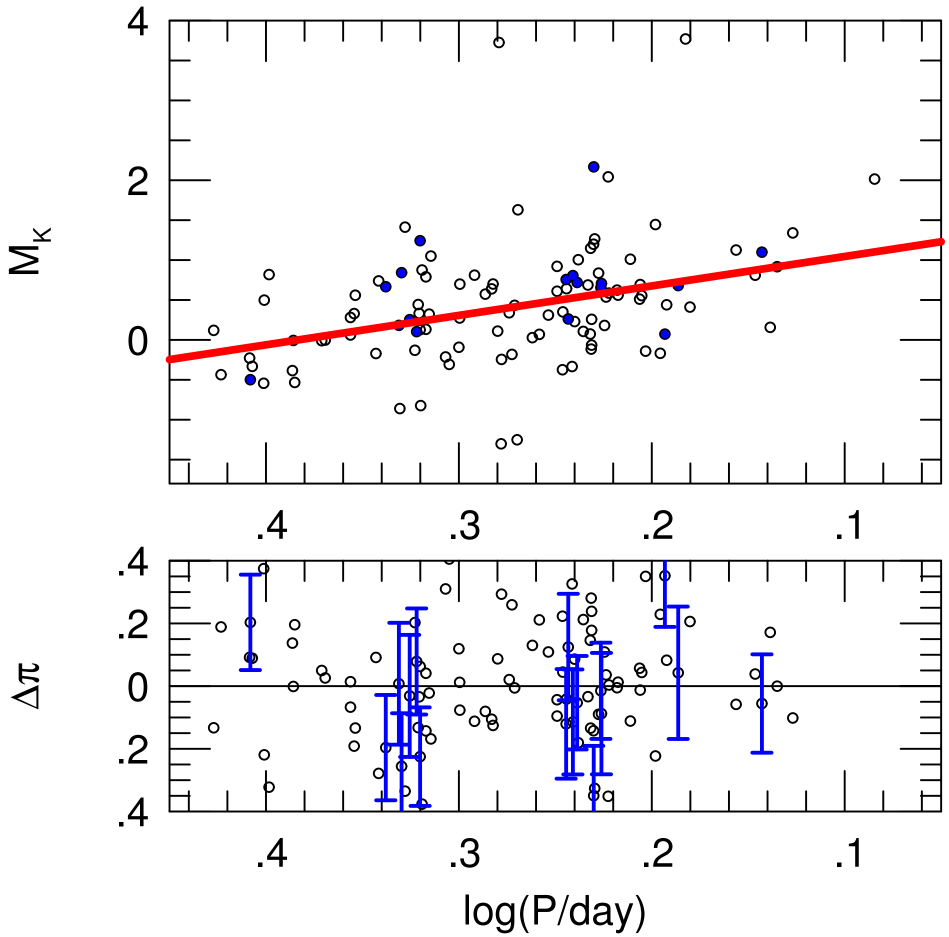


Casertano et al. (2017, A&A 599)
212 Cep from van Leeuwen et al. (2007), with $VIJK$

$$m_{\rm H} = m_{160} - 0.3861(m_{555} - m_{814})$$
$$M_{\rm H} = -2.77 - 3.26 \log P$$

"Our analysis suggests that the parallaxes of 9 Cepheids brighter than G = 6 may be systematically underestimated; trigonometric parallaxes measured with the HST FGS for three of these objects confirm this trend."

GDR1: RRL



Gould et al.
(arXiv: 160906315)

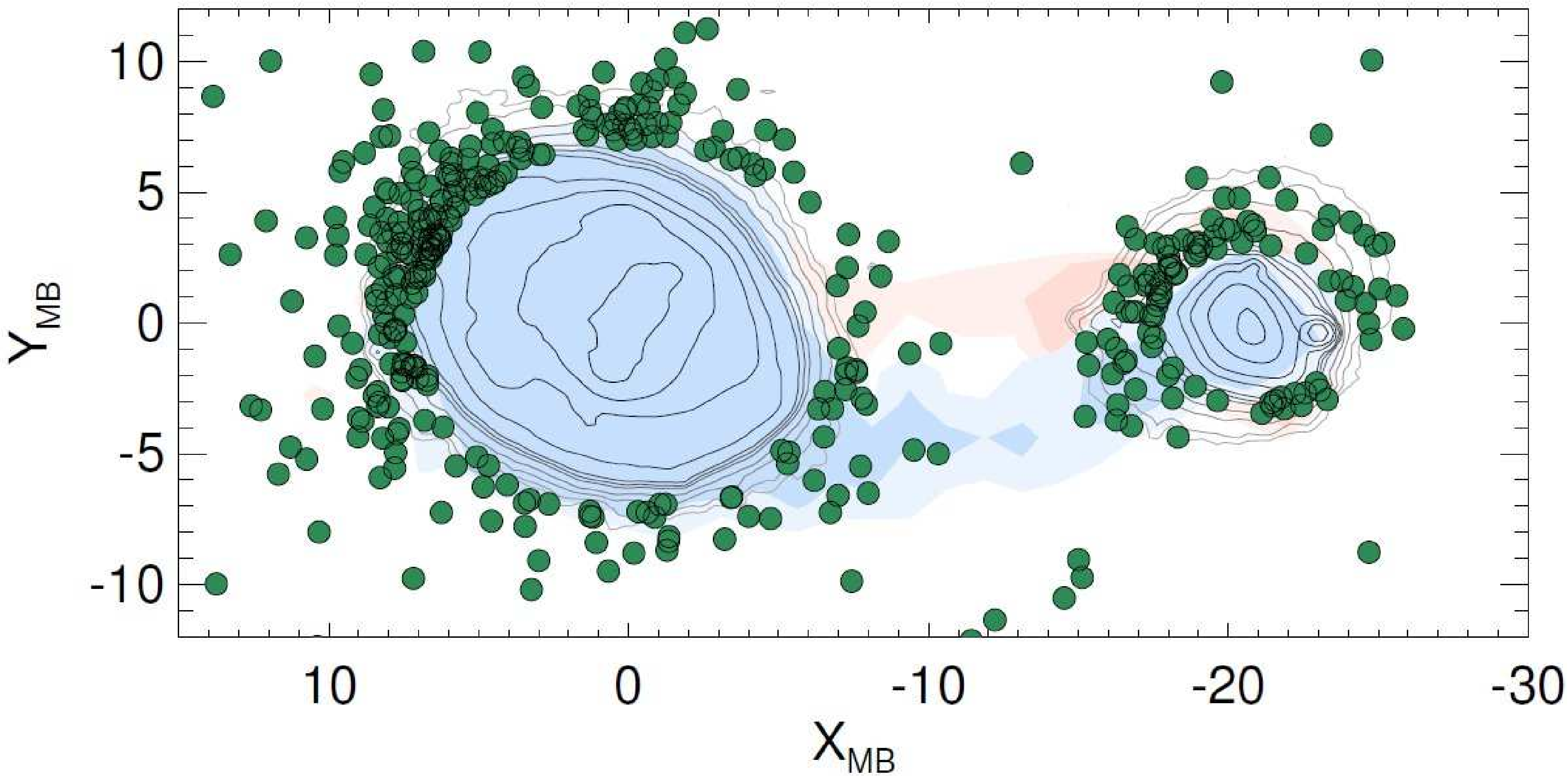
100 RRab single-epoch K

$$\pi = 10^{(K - A_{\rm K} - (\alpha + \beta \log P))/5}$$

$$\sigma_{\rm tgas}(\pi) = \sqrt{(A\sigma_{\rm int})^2 + \sigma_0^2}$$

GDR1: (A, σ_0) = (1.4, 0.2)
(1.1, 0.12)

GDR1: Miras



Deason et al. (2017 MNRAS 467)
Select LPVs/Miras based on 2MASS/WISE colours and
$A = \sqrt{N} \cdot \sigma_{\mathrm{F}} / F$
structure MC

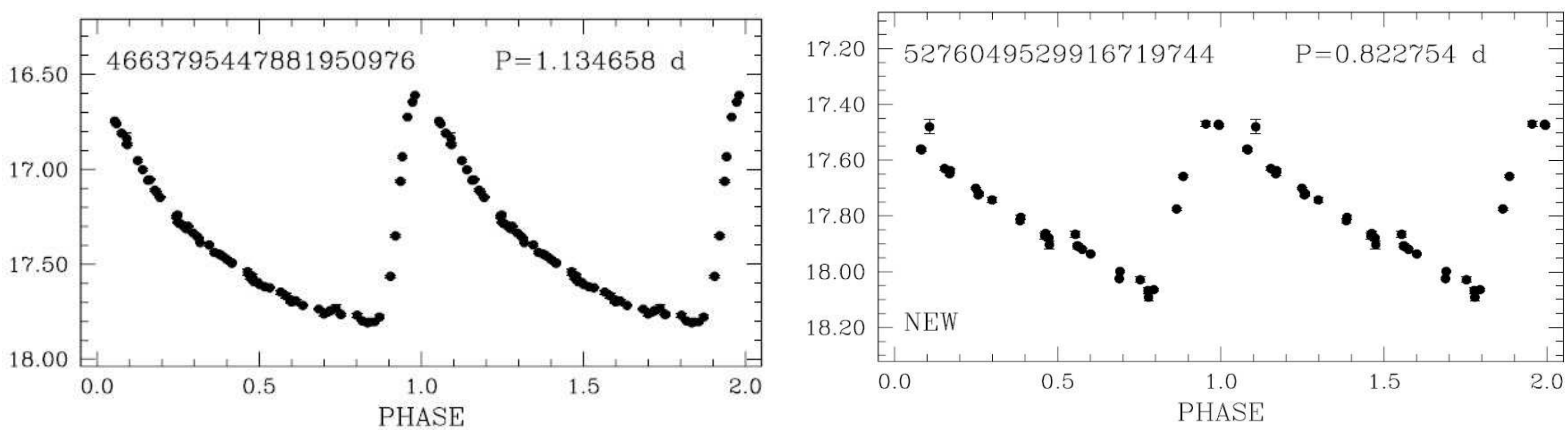
DR 1 → 2

Gaia Data Release 1

The Cepheid and RR Lyrae star pipeline and its application to the south ecliptic pole region*

G. Clementini[1,**], V. Ripepi[2], S. Leccia[2], N. Mowlavi[3], I. Lecoeur-Taibi[4], M. Marconi[2], L. Szabados[5], L. Eyer[3], L. P. Guy[4], L. Rimoldini[4], G. Jevardat de Fombelle[6], B. Holl[4], G. Busso[7], J. Charnas[4], J. Cuypers[8], F. De Angeli[7], J. De Ridder[9], J. Debosscher[9], D. W. Evans[7], P. Klagyivik[5], I. Musella[2], K. Nienartowicz[6], D. Ordóñez[4], S. Regibo[9], M. Riello[7], L. M. Sarro[10], and M. Süveges[4]

Clementini et al. (2016 A&A 595)



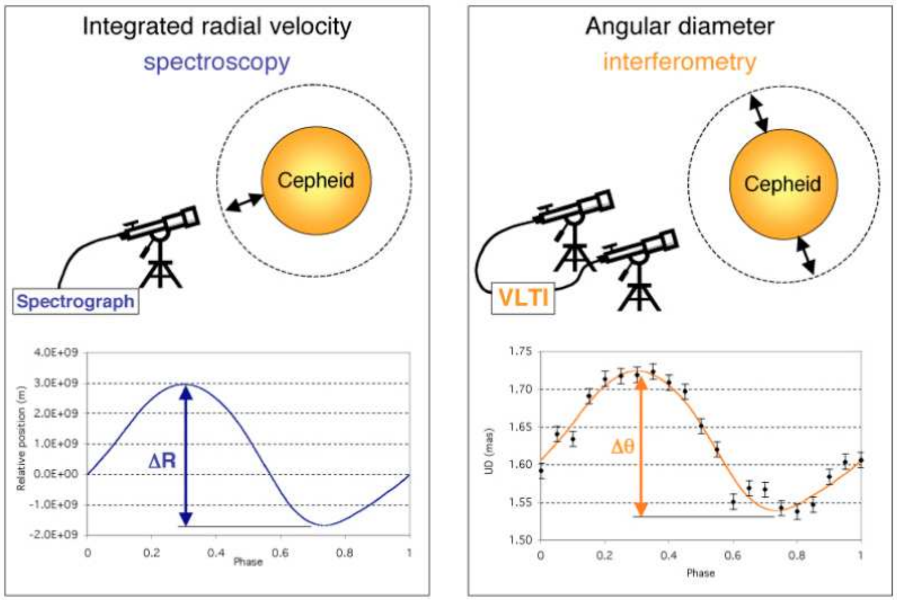
RRL: 2595 (343 New); DCEP: 558 (26);
AC: 16 (8); T2C: 25 (9)

GDR2+

- σ_π = 50 microarcsec in DR2
  (factor 5-6 better than TGAS solution).
- Time series of the G band, and the time series of integrated BP and RP bands.
  Goal: all-sky release and characterisation of RRL
  (20+ epochs) [decision in May]
- 2 000-8 000 Cepheids (Eyer&Cuypers 2000),
  9 000 (Windmark et al. 2011)
  70 000 RR Lyrae stars (Eyer&Cuypers 2000)
  200 000 LPVs (Eyer&Cuypers 2000)
- $T_{\rm eff}$, metallicity (RVS, spectrophotometry)

GDR2+

- Cepheids/RRL in Clusters
  δ Cep, ζ Gem
  (Majaess et al., 2012 ApJ 747, ApJ 748)
- Baade-Wesselink method

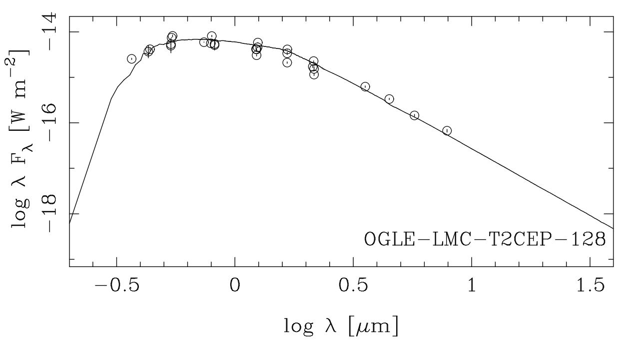


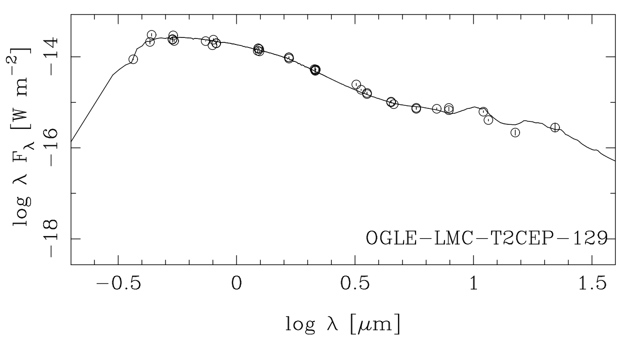
d [pc] = 9.305 **ΔR** [$R_\odot$] / **Δθ** [mas]

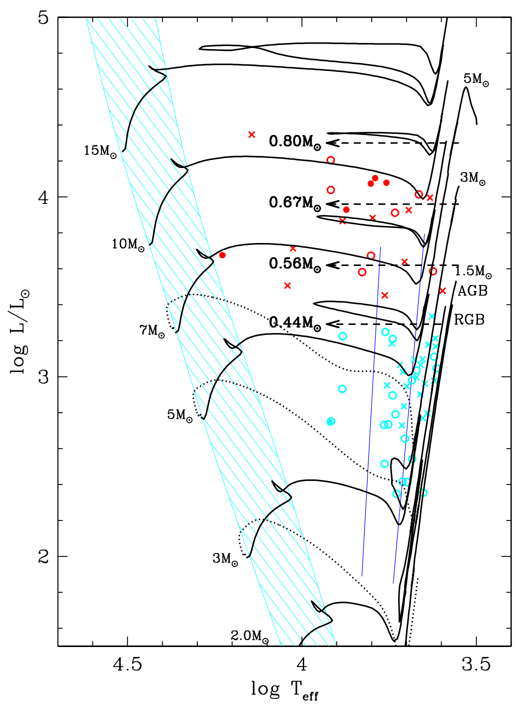
p-factor (Pierre Kervella on Friday)
Calibrating surface-brightness relations

GDR2+: Stellar Evolution

Barium stars, S-stars, CEMP (posters Ana Escorza, Shreeya Shetye, Sophie Van Eck, Alain Jorissen)
AN CEP, peculiar W Vir, RV Tau (post-AGB)







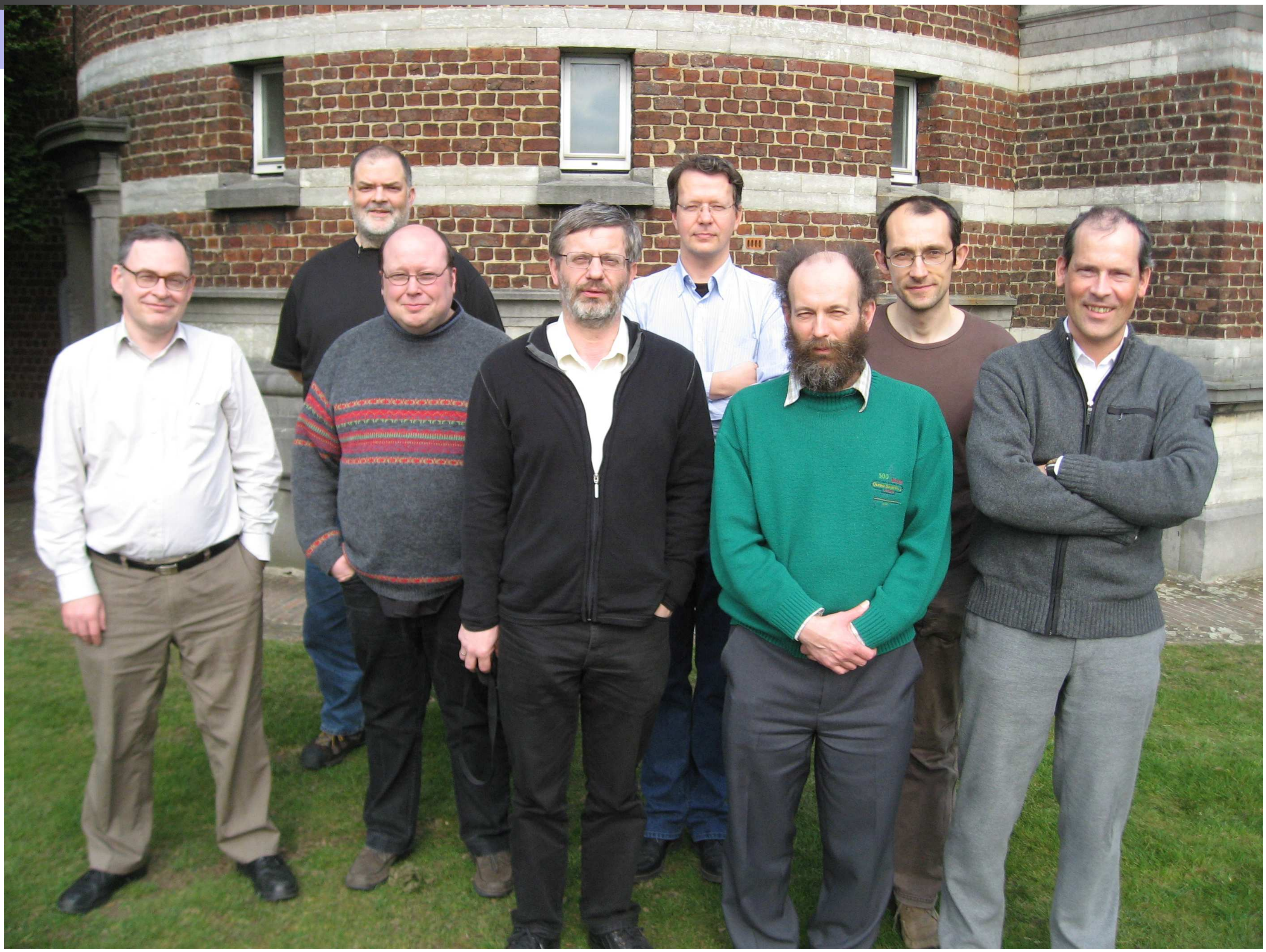
Kamath et al. (2016)
Groenewegen & Jurkovic (2017)
30 of 51 RV Tau have excess emission.
Surprise: 10% of all W Vir also have IR excess.
Luminosities of 200 - 800 $L_{\odot}$
dusty post-RGB objects

Conclusions

- GDR1 has indicated the potential in terms of Structure and Distance Scale
- Bright limit: linking Hipparcos/HST to Gaia

THE END

In Memoriam



Jan Cuypers (1956-2017)