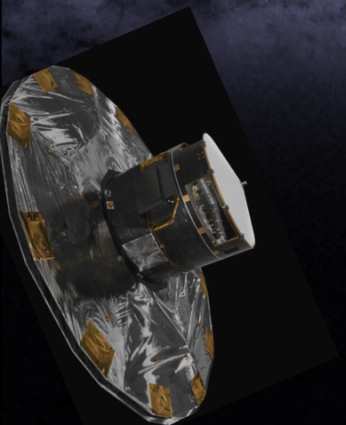
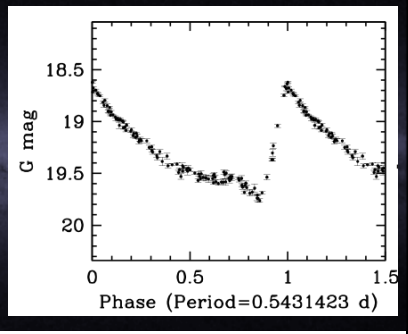
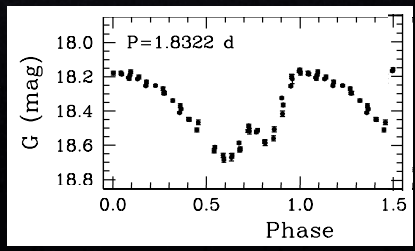
Cefeidi ed RR Lyrae osservate da Gaia

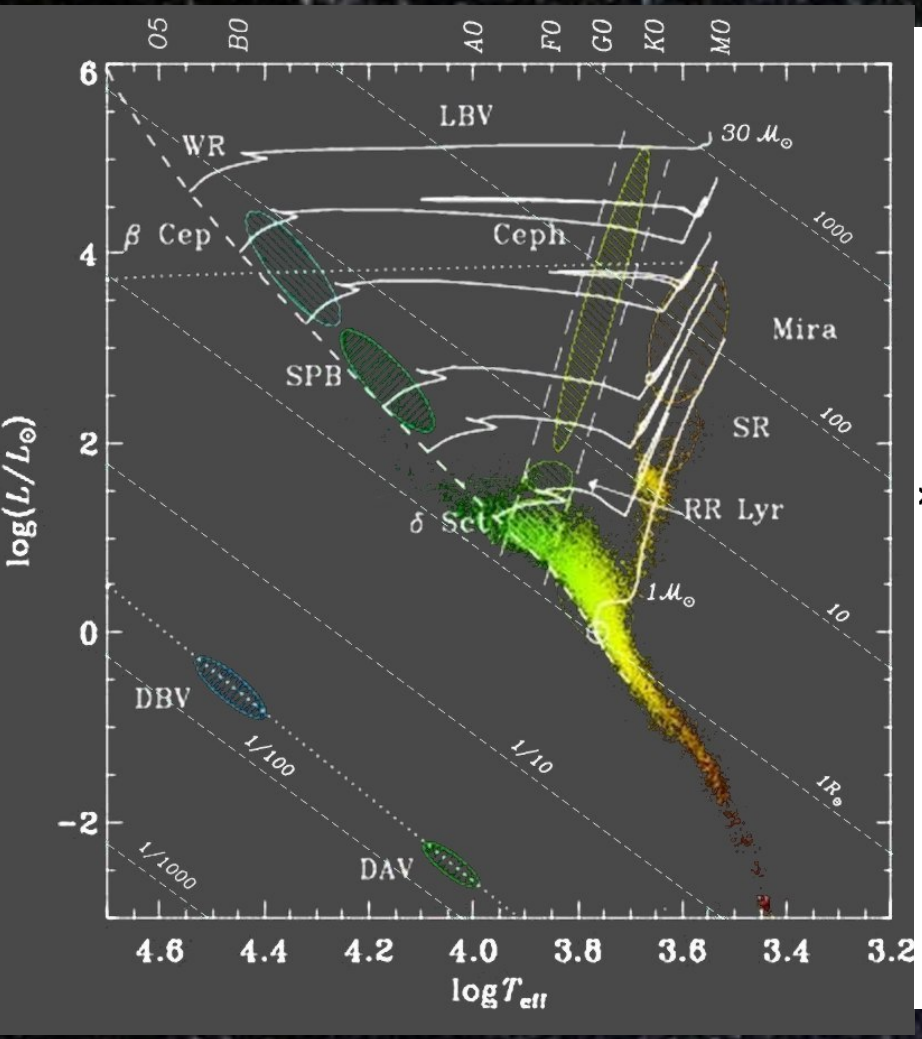


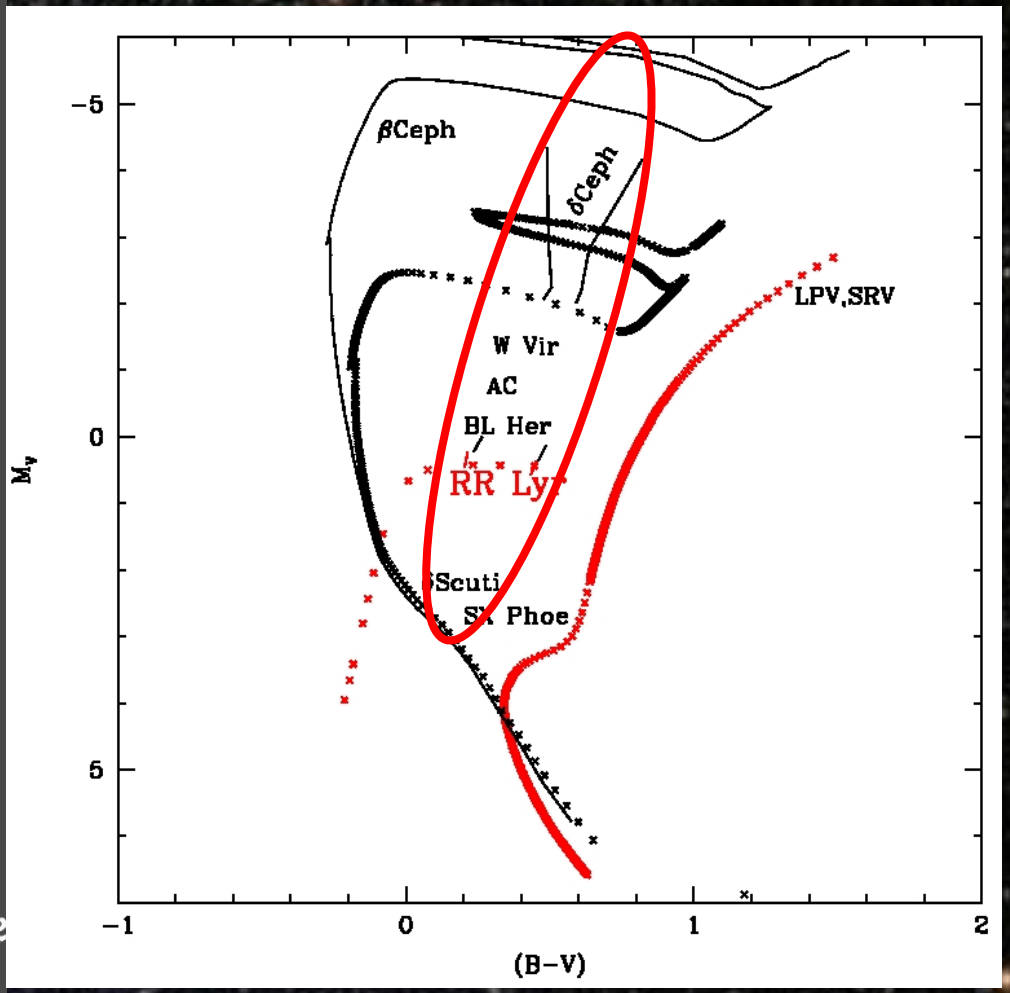




Meeting MA2- Bologna, June 15-16, 2016

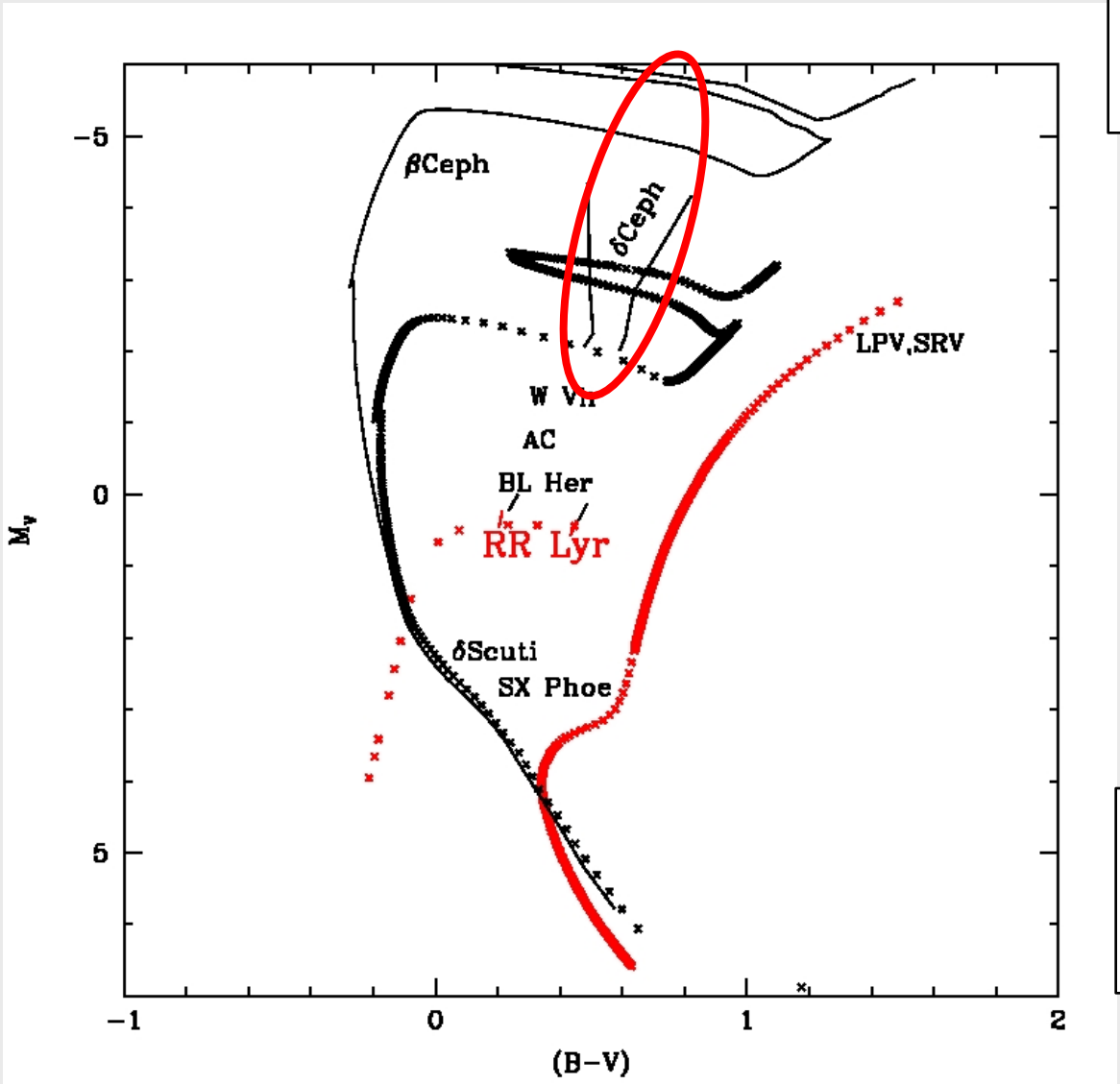
Cepheids and RR Lyrae stars in the HR diagram





Pulsating stars in the instability strip

Classical Cepheids: general properties



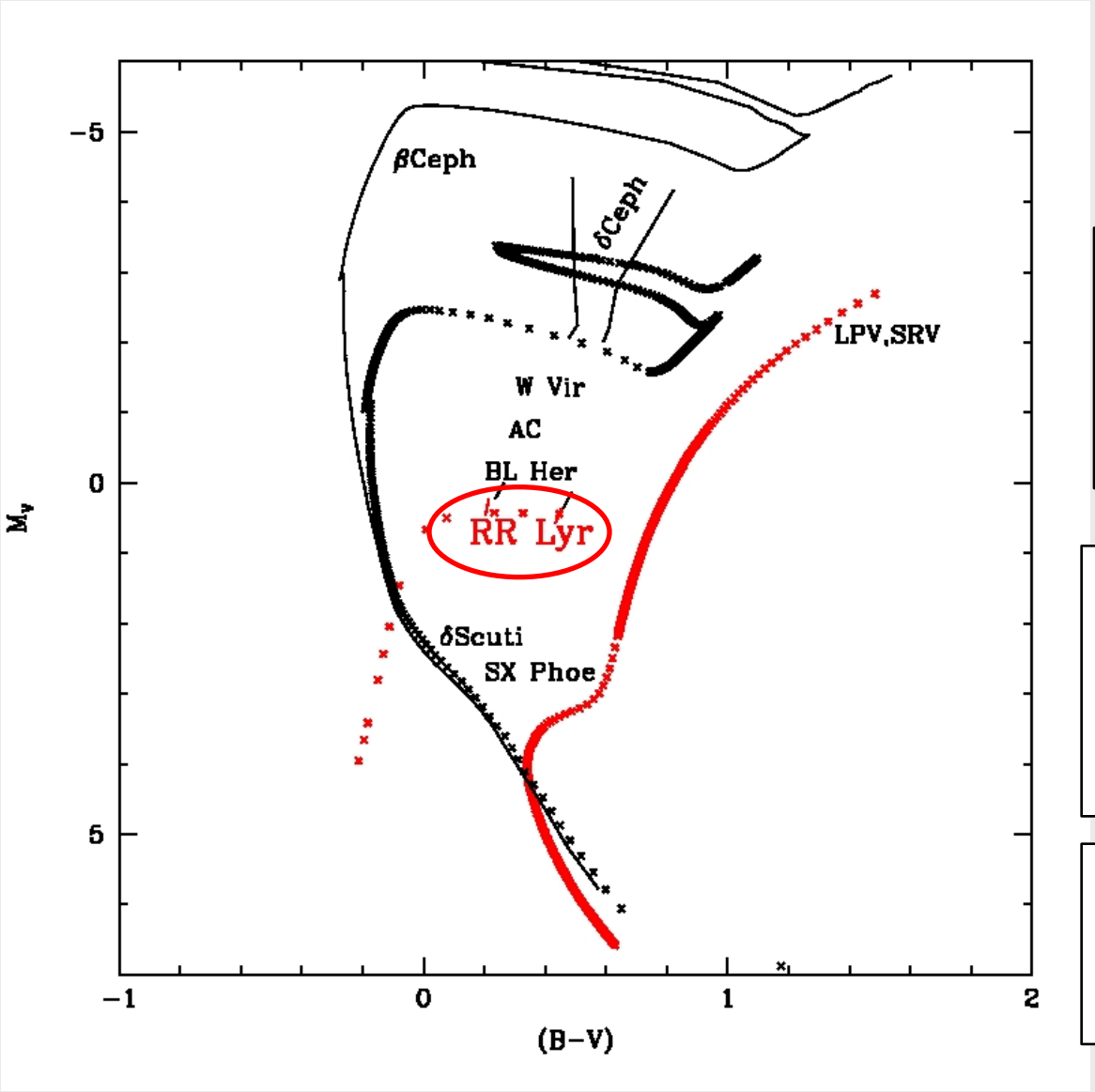
Classical Cepheids are yellow supergiant stars

1d < P < 100d
M_V from -2 to -7 mag
Population I
Evol. phase: Blue Loop

Primary standard candles in Pop I systems: PL, PLC & PW relations

Tracers of chemical and dynamical properties of young stellar populations

RR Lyrae: general properties

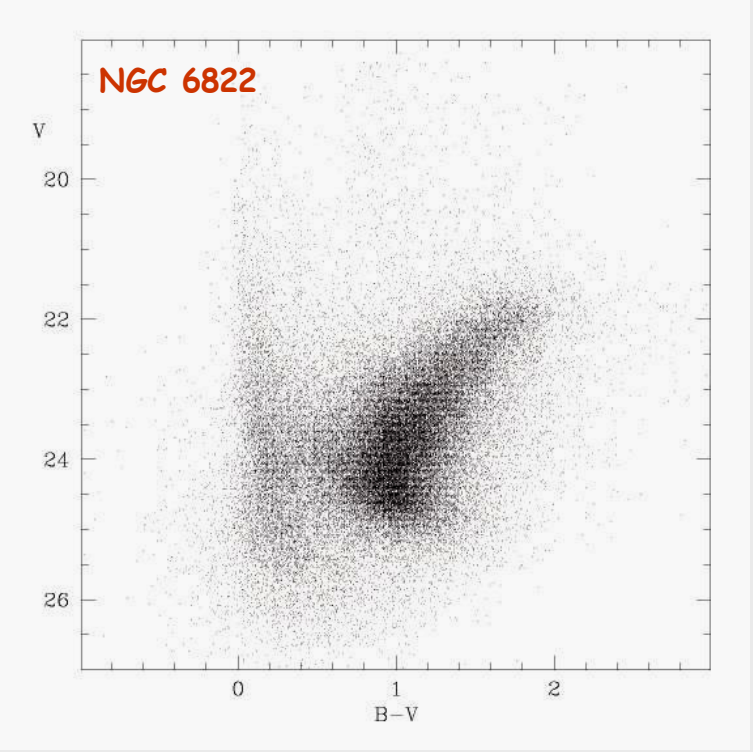


RR Lyrae are low mass He burning A-F giants

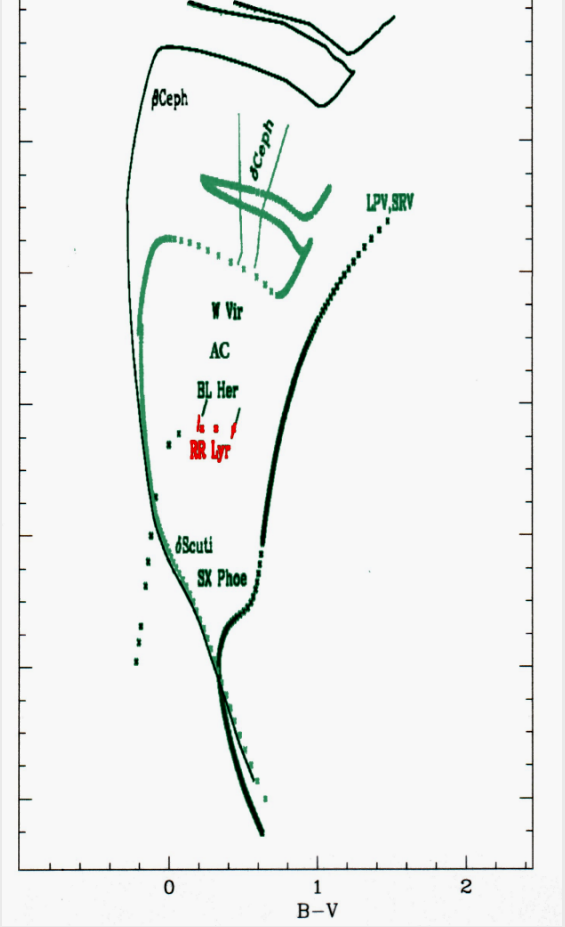
0.2 < P < 1.0 d
M_V from 0.0 to +1.0 mag
Population II
Evol. phase:HB

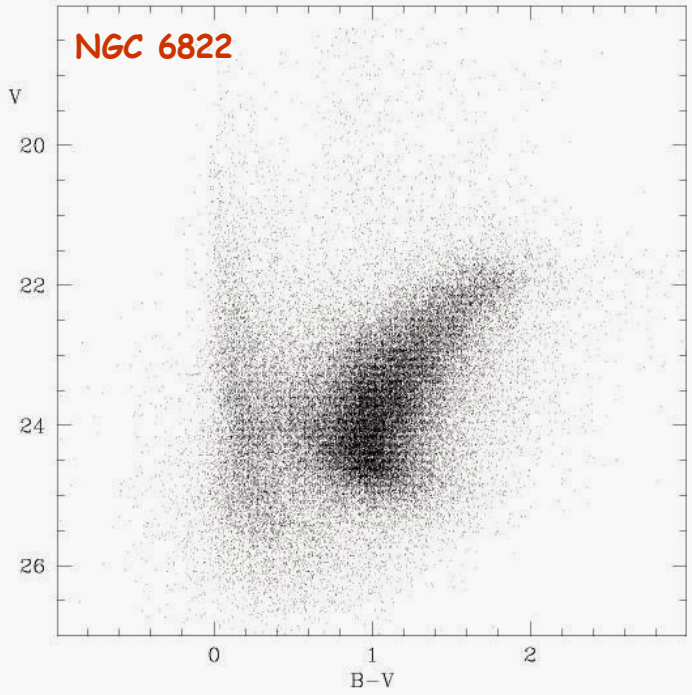
Primary standard candles in Pop II systems: M_V-[Fe/H] and PL_KZ relations

Tracers of chemical and dynamical properties of old stellar populations

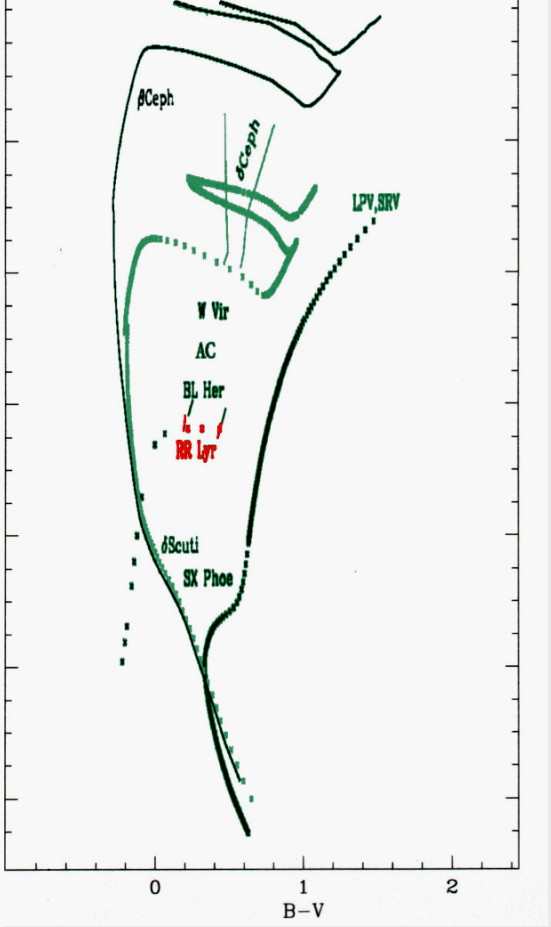


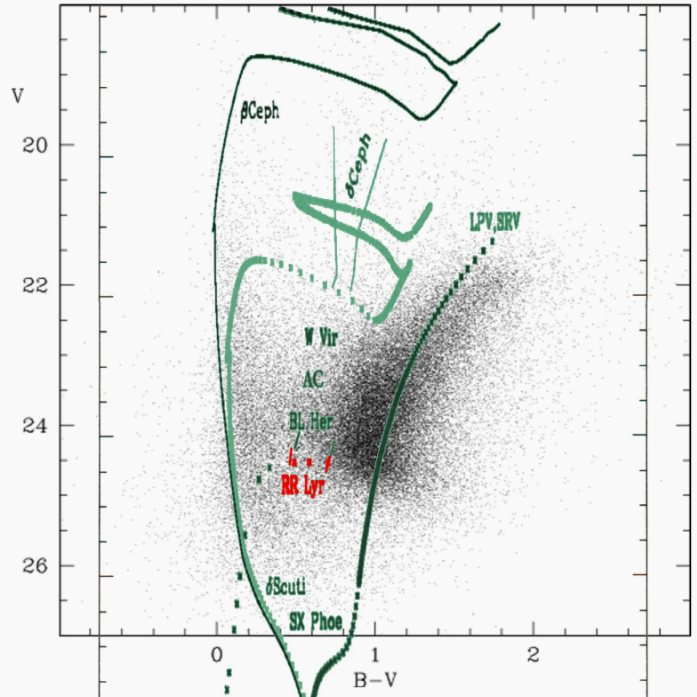
Observations vs Theory

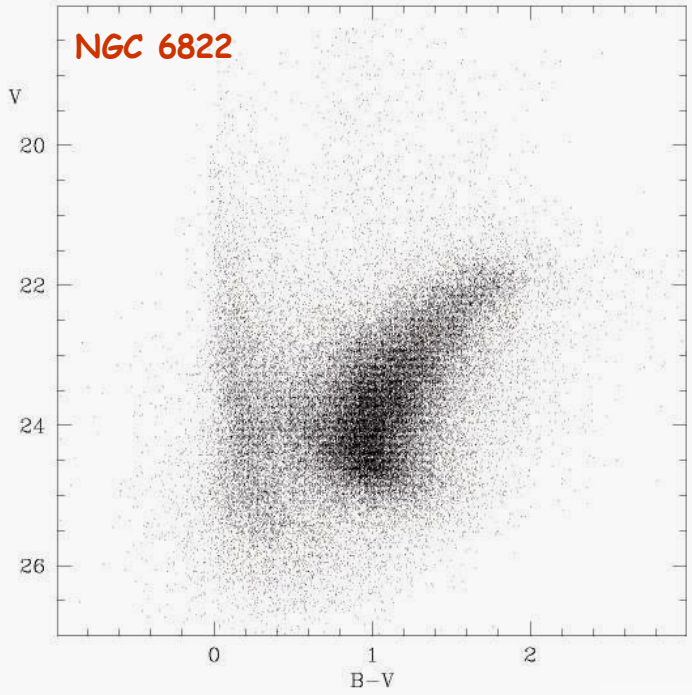




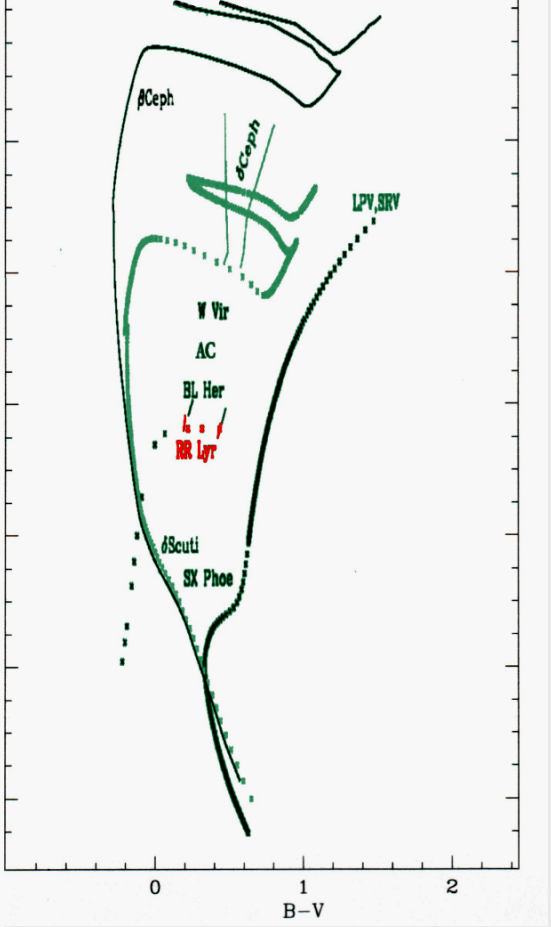
Observations vs Theory

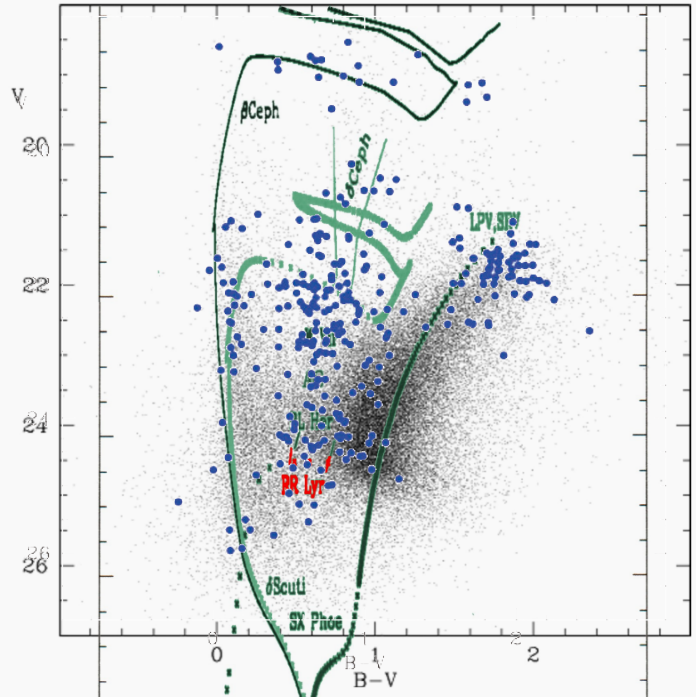






Observations vs Theory





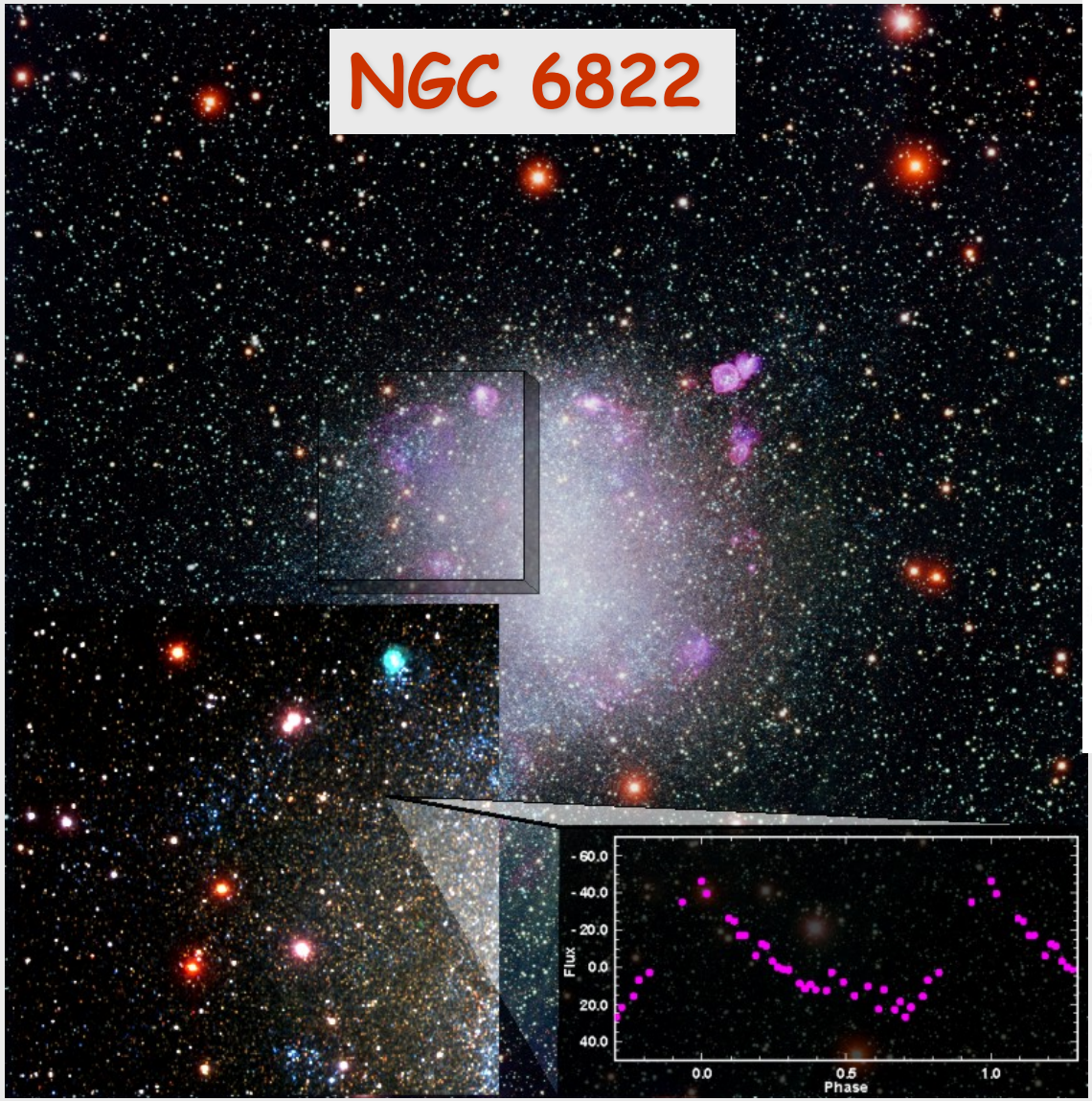
➢ Cepheids and RR Lyrae trace stellar populations of different age and chemical composition

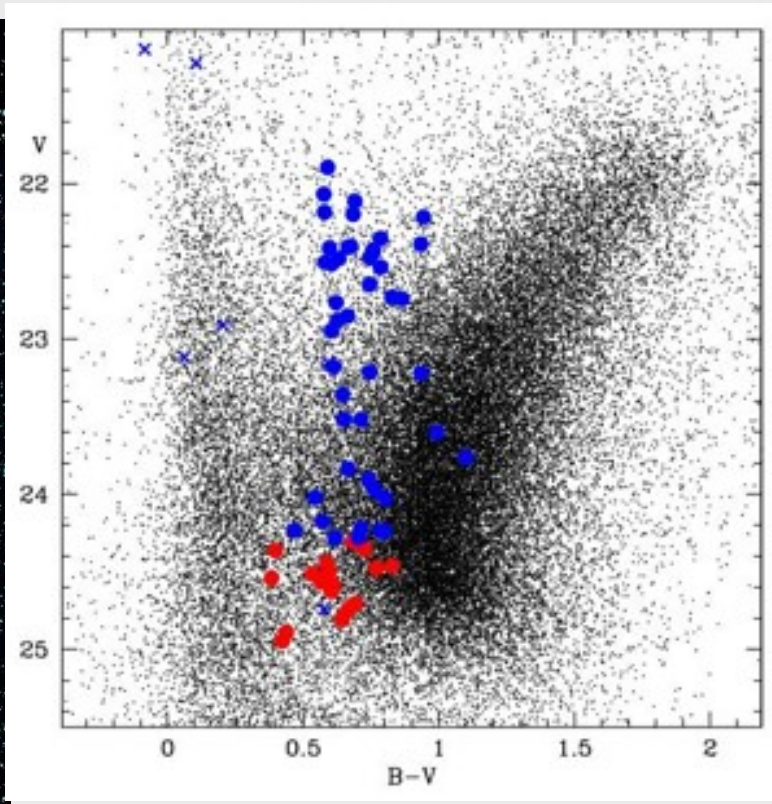
- young (t < 100 Myr) ⟹ Classical Cepheids
- intermediate age ⟹ Anomalous Cepheids
- old (t > 10 Gyr) ⟹ RR Lyrae, Pop II Cepheids

At the distance of M31 the turn-off of a 10 Gyr old stellar population is at V ~ 28-28.5 mag, the RR Lyrae are 3 mag brighter !

RR Lyrae stars have been found in "all" Local Group galaxies where they have been searched for →"all Local Group galaxies contain a very old population component, i.e. all nearby galaxies started to form stars just after they were formed". In other words there are **no truly young** galaxies in the Local Group.

- trace the different stellar generations in galaxies
- set the distance



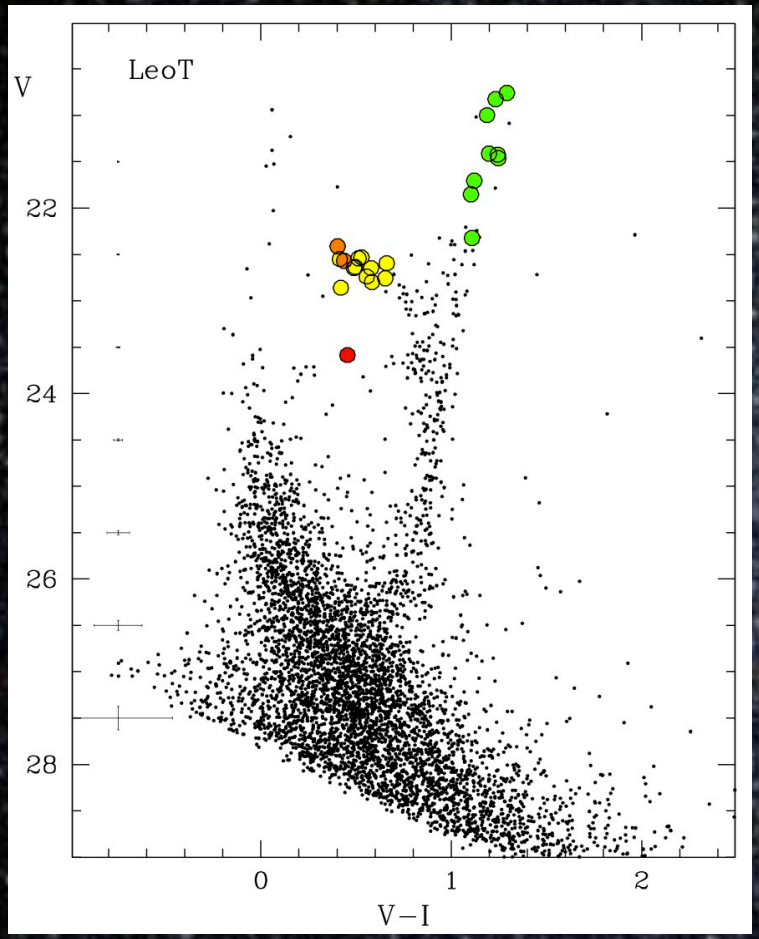


$V(RR) = 24.61 \pm 0.14$ mag

$\mu_{NGC6822} = 23.36 \pm 0.17$

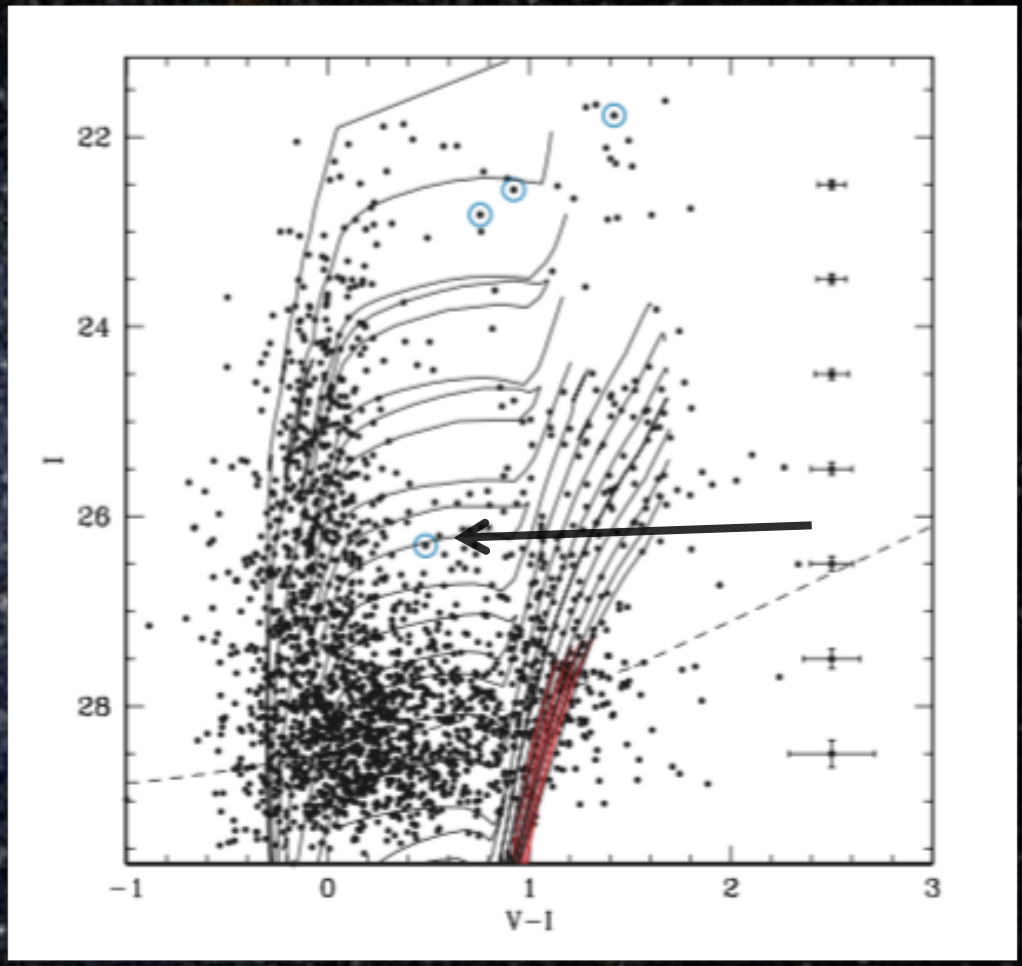
Clementini et al. 2003

- trace the different stellar generations in galaxies
- set the distance



Clementini et al. 2012

D ~ 400 kpc



Aloisi et al. 2007

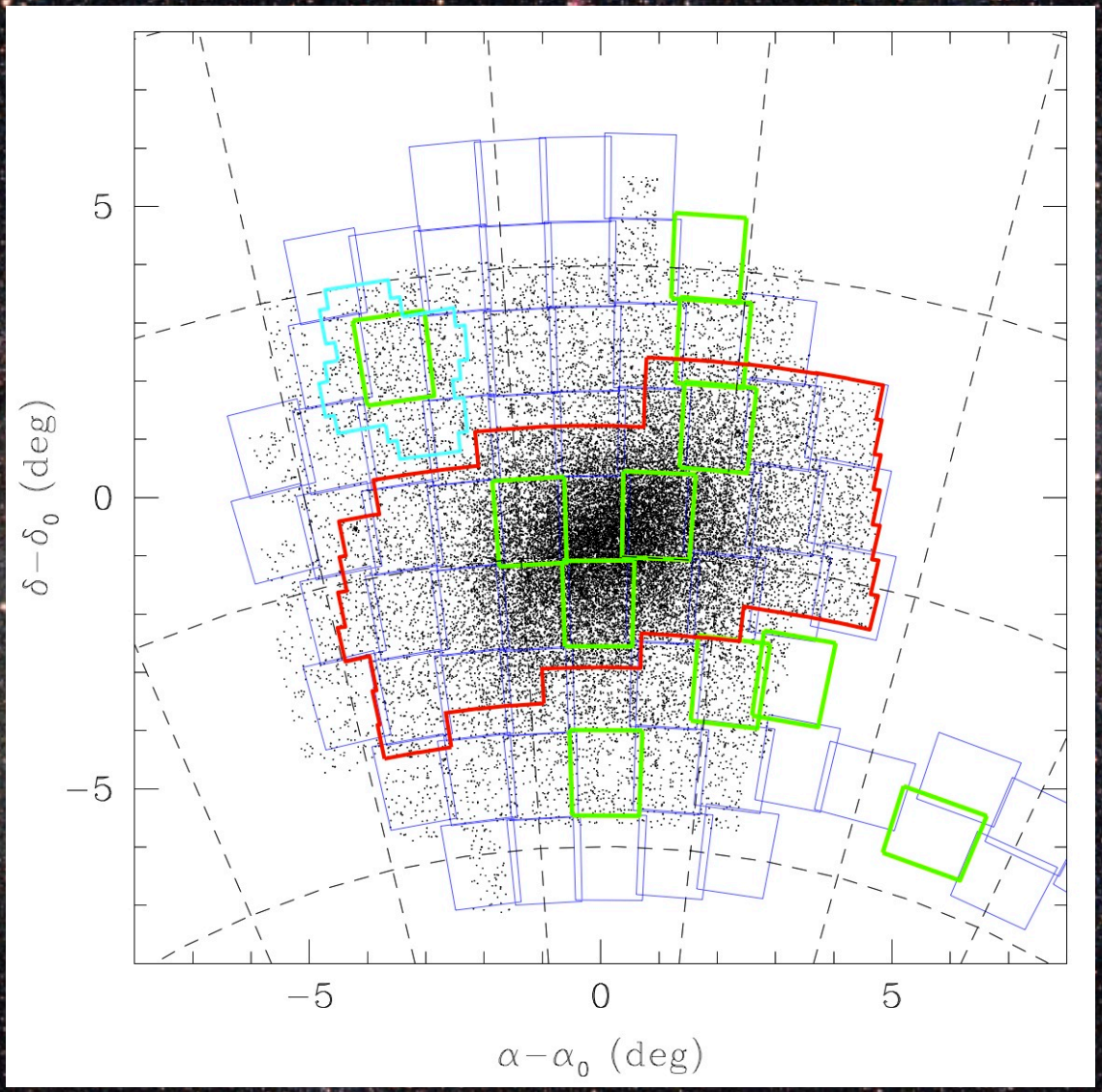
D ~ !8 Mpc

- **Pulsating variables map 3D structures, radial trends, halos & streams ⇒ hints on how galaxies have formed**

A local overdensity of RR Lyrae stars in the Galactic halo is the northen tidal stream left over by the Sagittarius dwarf spheroidal galaxy

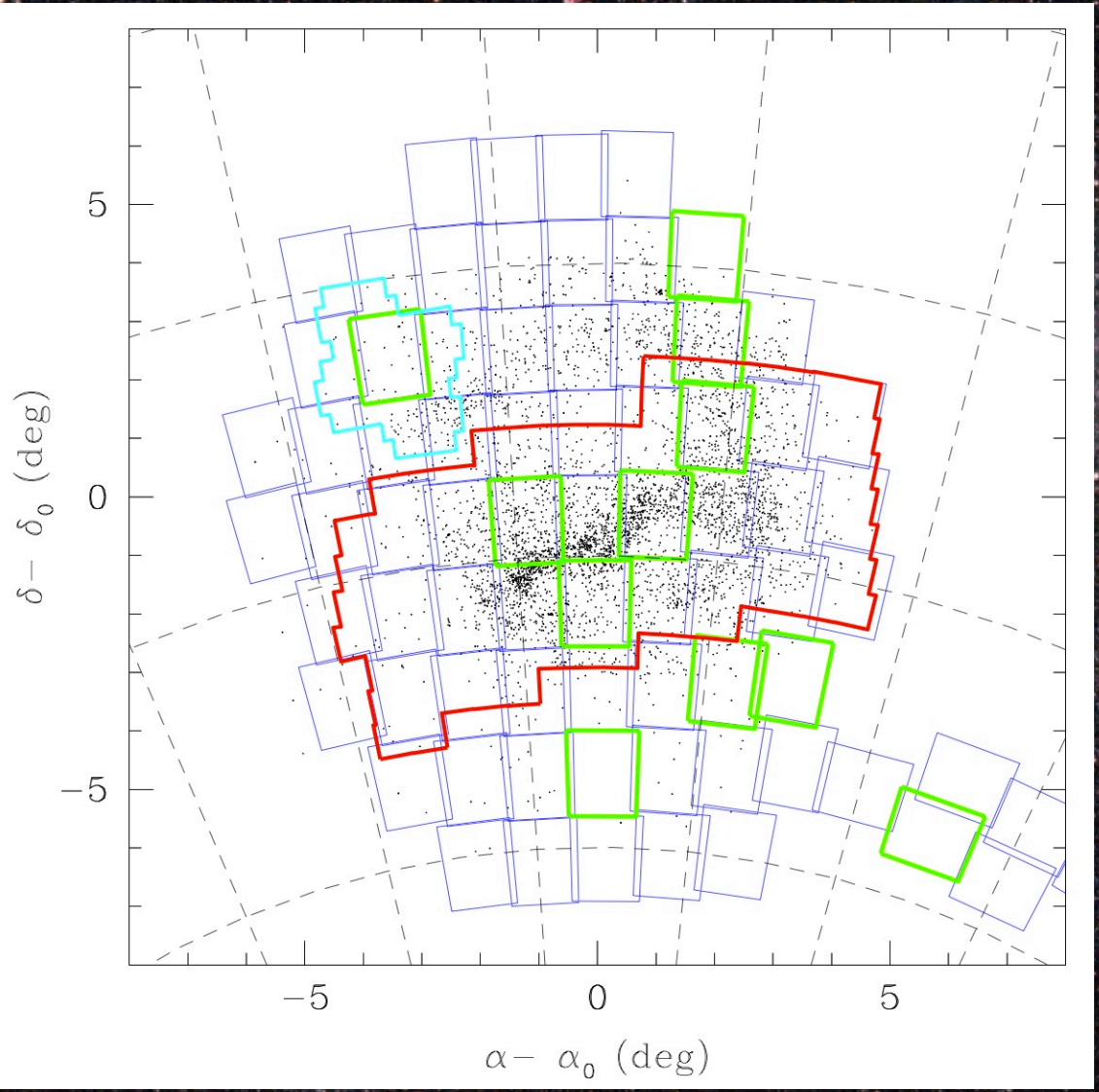
Classical Cepheids, RR Lyrae stars, (and "hot binaries") trace different substructures in the LMC

The LMC structure as traced by: RR Lyrae stars



Moretti et al. 2014

The LMC structure as traced by: Classical Cepheids

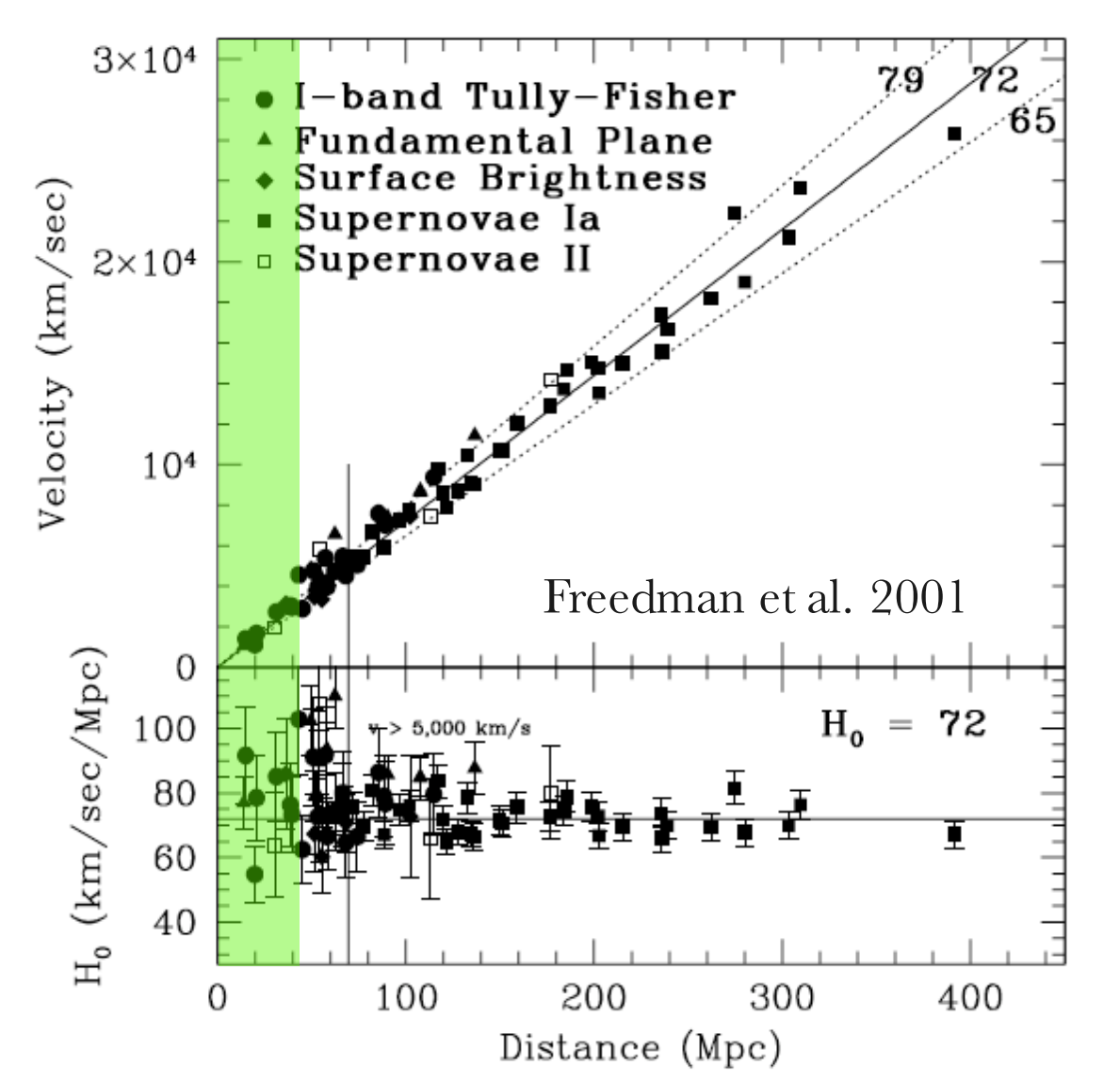


Moretti et al. 2014

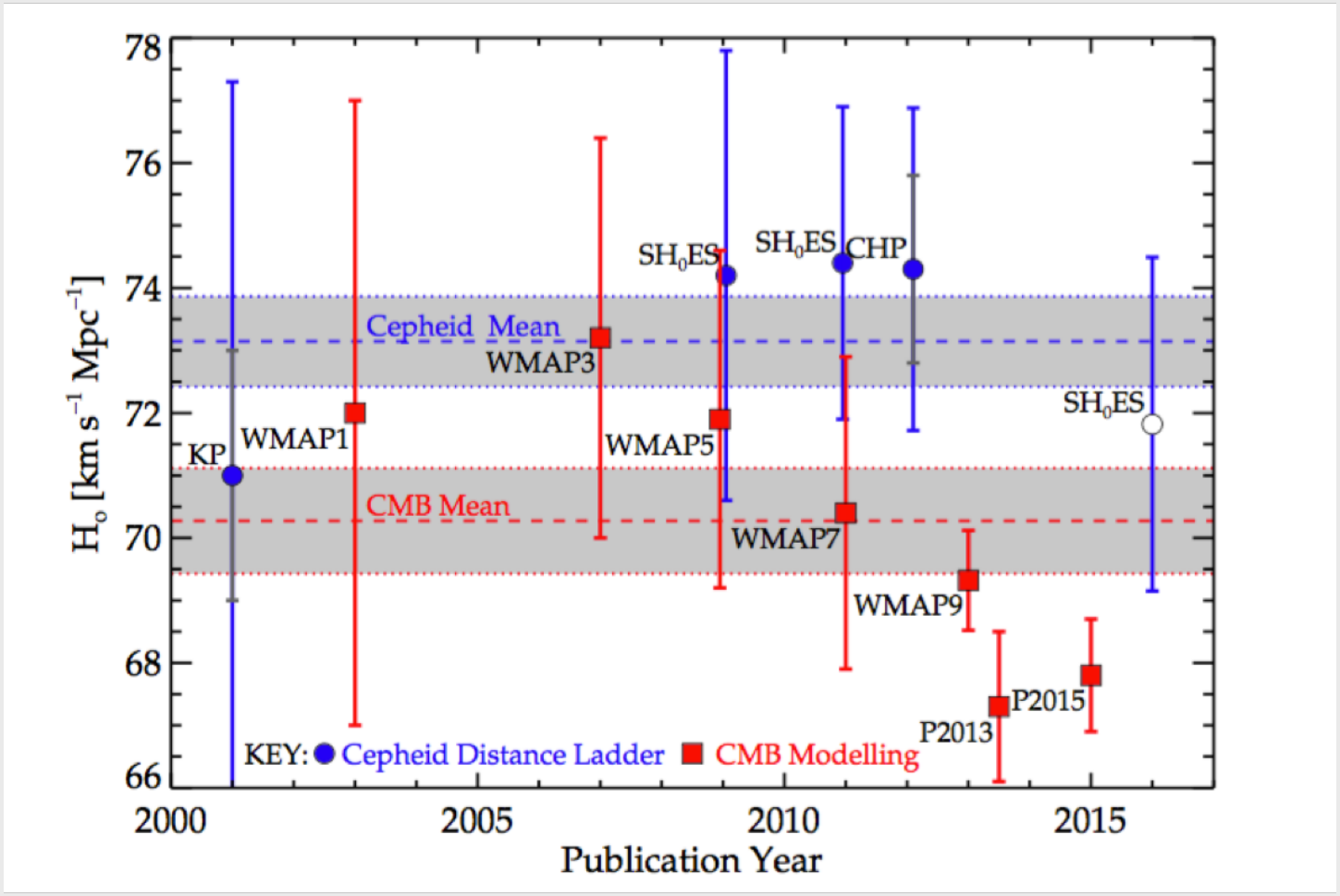
➢ distance scale ⇒ H_0

Most important standard candles in the Local Group (RR Lyrae stars, M_V-[Fe/H], PL_KZ relations) and beyond, up to 20-30 Mpc (Cepheids, PL, PLC,PW relations)
⇒ calibration of secondary indicators ⇒ measure of H_0

The secondary distance indicators are typically calibrated with the **Cepheid PL**



Recent determinations of H_0 using the **Cepheid distance ladder** and the **cosmic microwave background (CMB)** modelling with Planck



Beaton et al. 2016

$H_0 = 73.24 \pm 1.74$ km/sec/Mpc
Cepheids

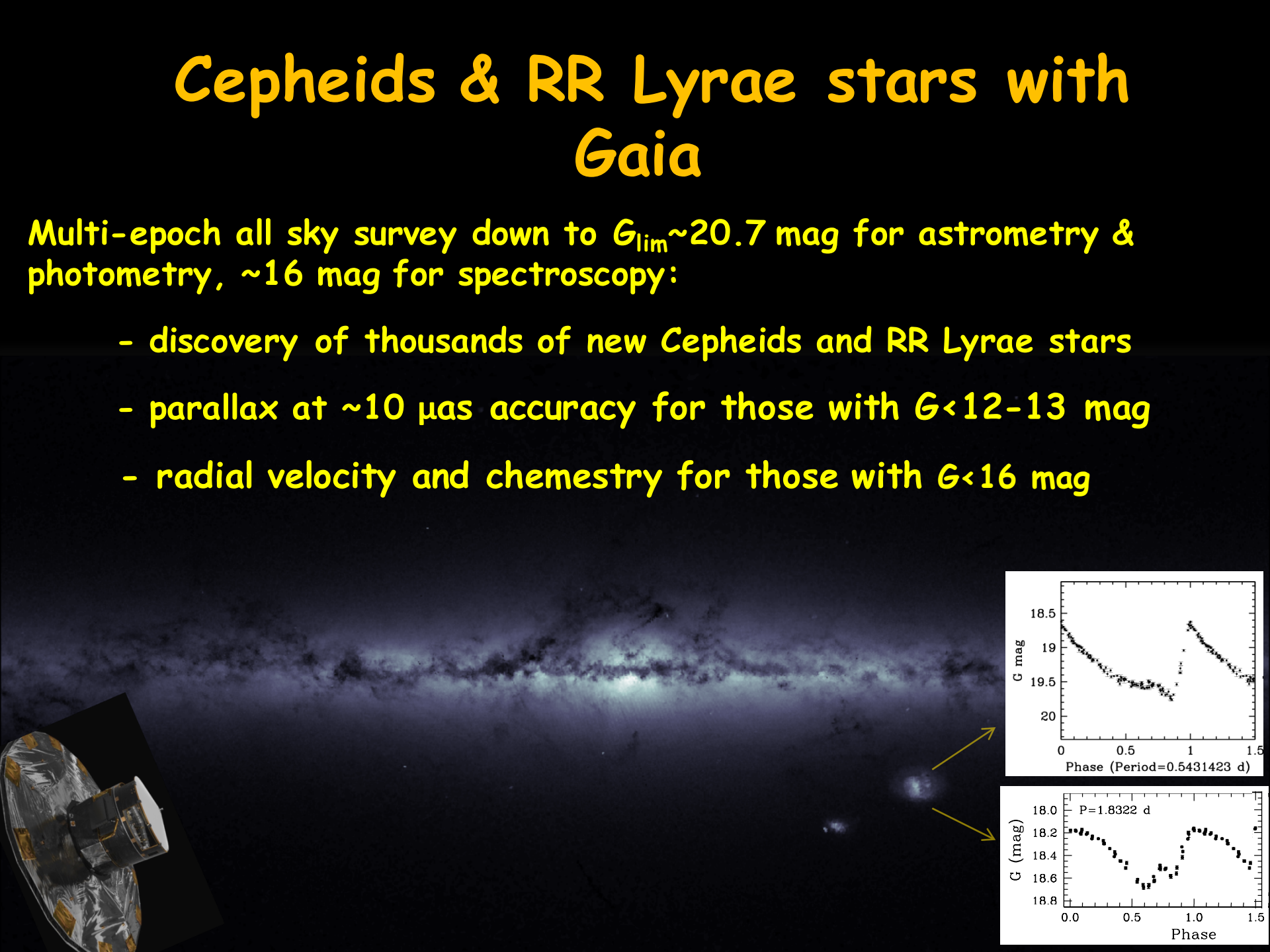
$H_0 = 66.93 \pm 0.62$ km/sec/Mpc
CMB

Riess et al. 2016

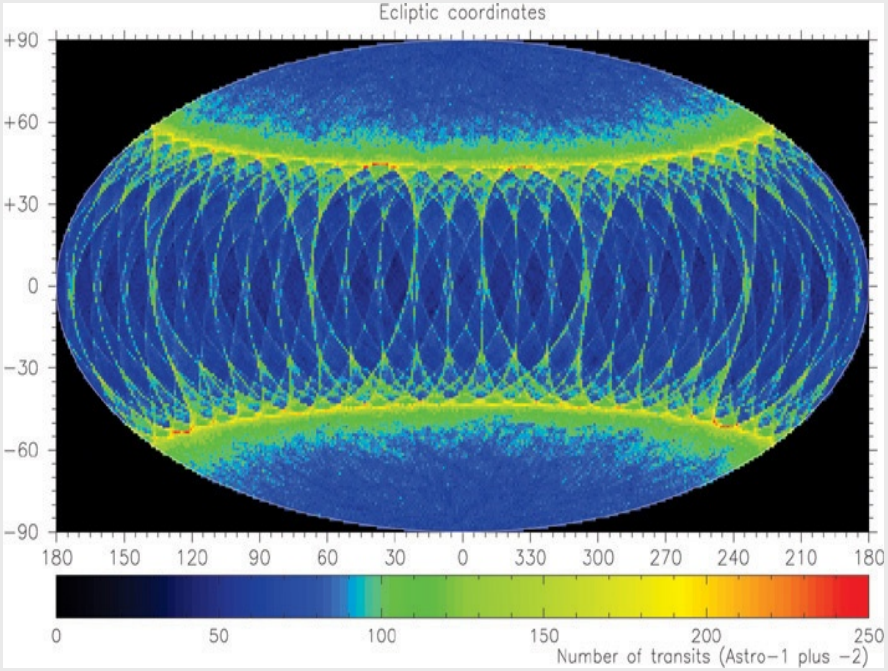
Cepheids & RR Lyrae stars with Gaia

Multi-epoch all sky survey down to G_{lim}~20.7 mag for astrometry & photometry, ~16 mag for spectroscopy:

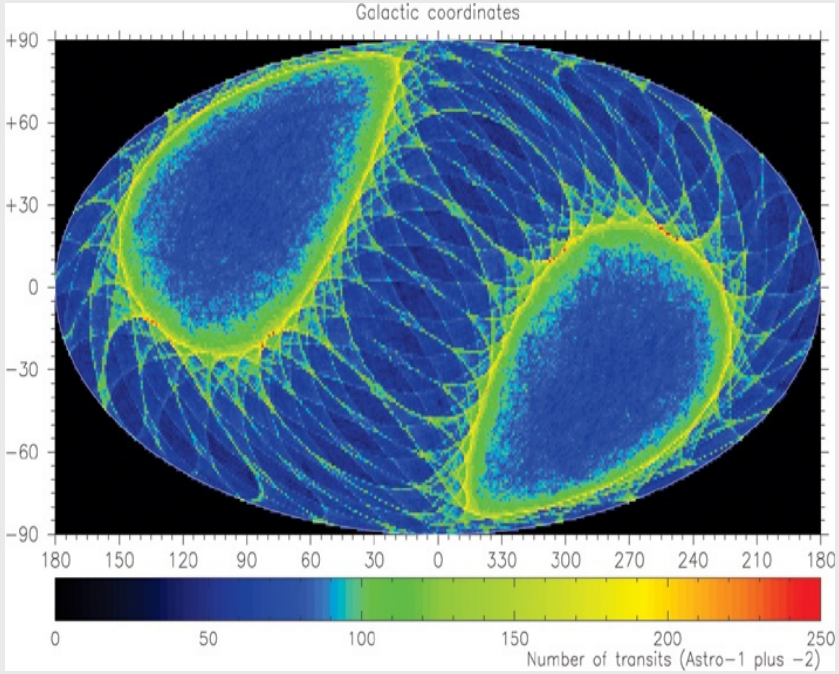
- discovery of thousands of new Cepheids and RR Lyrae stars
- parallax at ~10 μas accuracy for those with G<12-13 mag
- radial velocity and chemestry for those with G<16 mag



Transit maps



Ecliptic coordinates



Galactic coordinates

Each object observed 10 – 250 times

End of mission (5 yr) sky-average number of transits: ~ 70 (RV=40)
(max > 200 at $|\beta|$ = 45 $\pm$ 10 deg

- **Gaia photometry measurement concept: spectro-photometry (G ≤ 20.7 mag)**

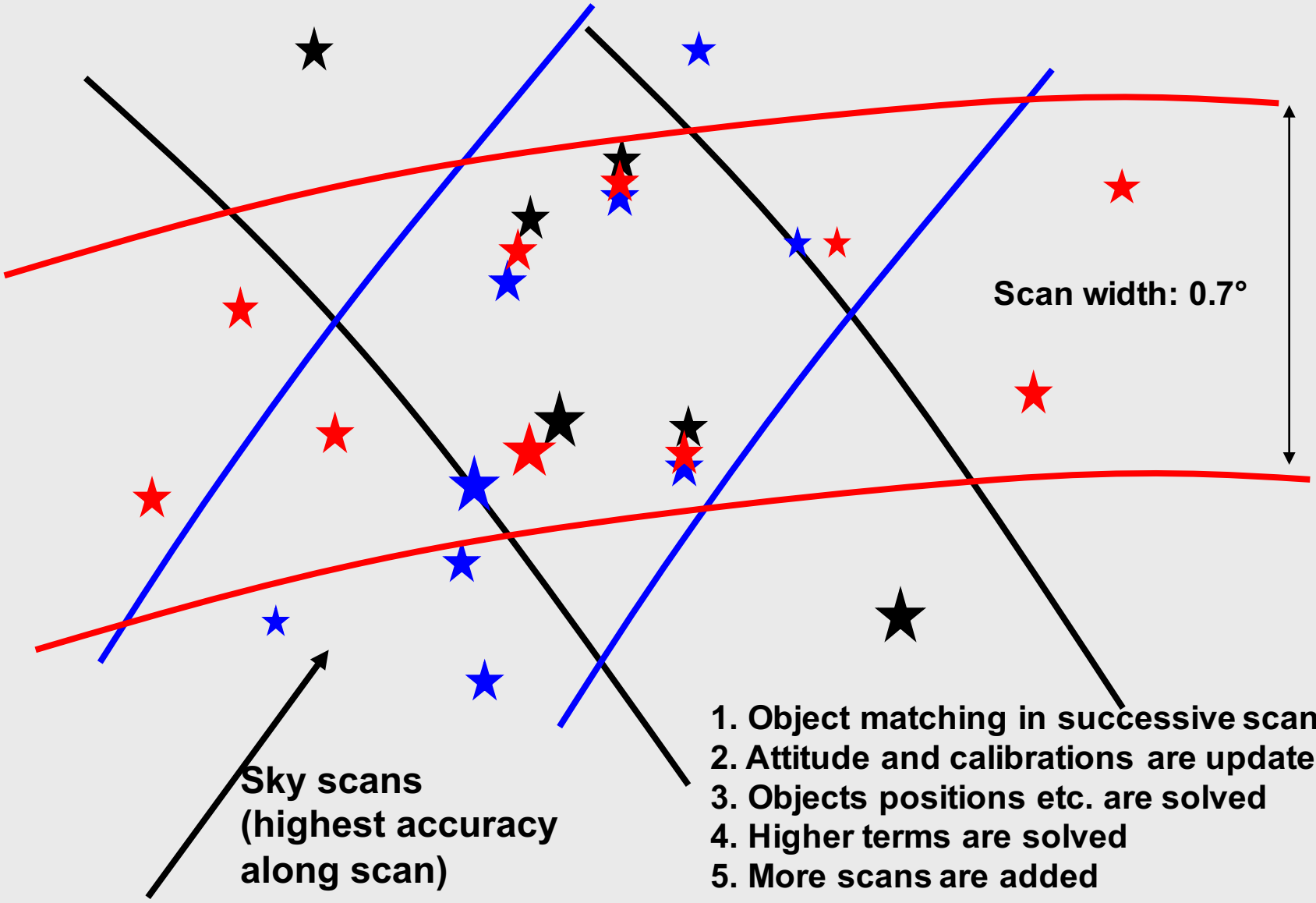
  - **Integrated:**
    - ➔ white-light (G-band, 330-1050 nm) from the Astrometric Field

  - **Dispersed:**
    - ➔ Blue (BP, 330-680 nm) & Red (RP, 640-1050 nm) low resolution spectra (R~20-90)

- **Gaia Radial-Velocity Measurement Concept (G ≤ 16.2 mag)**

  Slitless spectroscopy on Ca triplet (847–874 nm)
  Resolution 11,500

Astrometry: data reduction principles

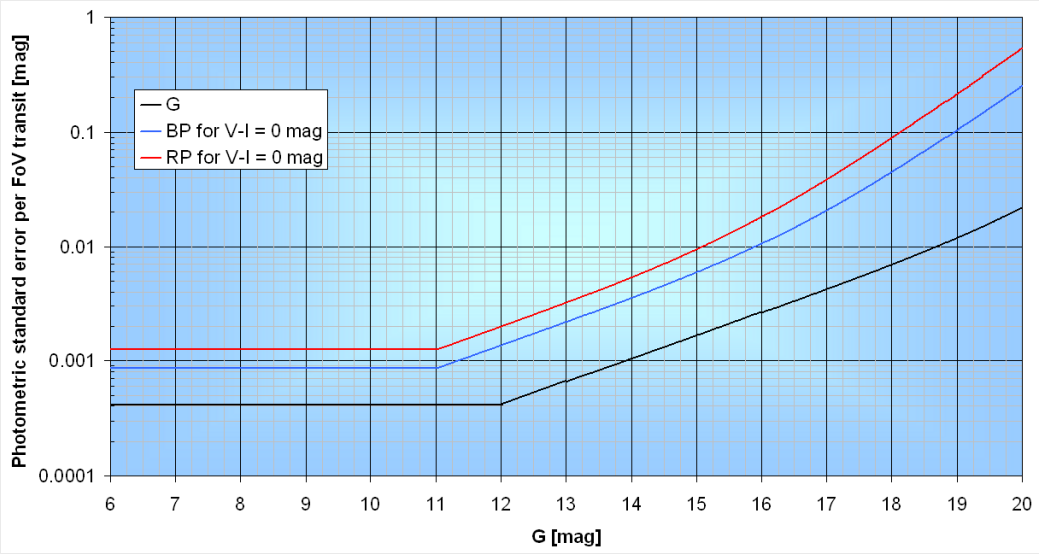


1. Object matching in successive scans
2. Attitude and calibrations are updated
3. Objects positions etc. are solved
4. Higher terms are solved
5. More scans are added
6. System is iterated (Global Iterative Solution)

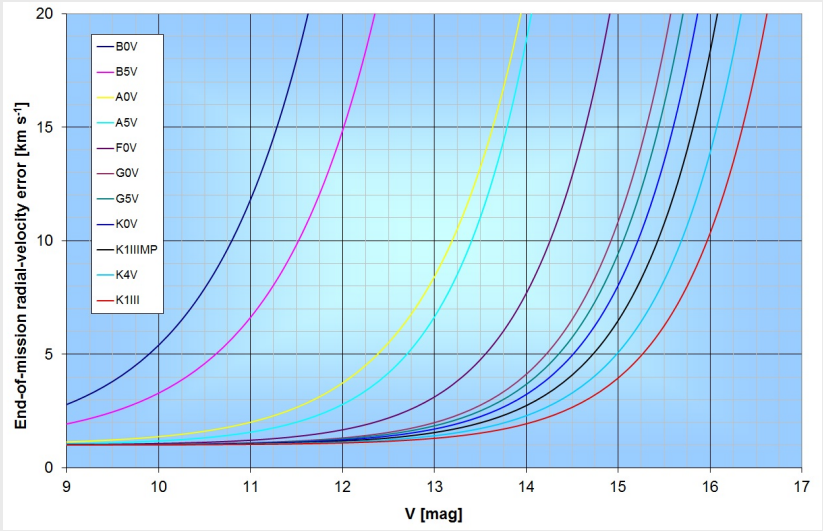
Figure courtesy Michael Perryman

Post-launch performances

G,BP,RP photometry



RVS



End-of-mission photometric standard errors of the integrated G-band, BP-band, and RP-band, in units of **milli-magnitude** (stray light included).

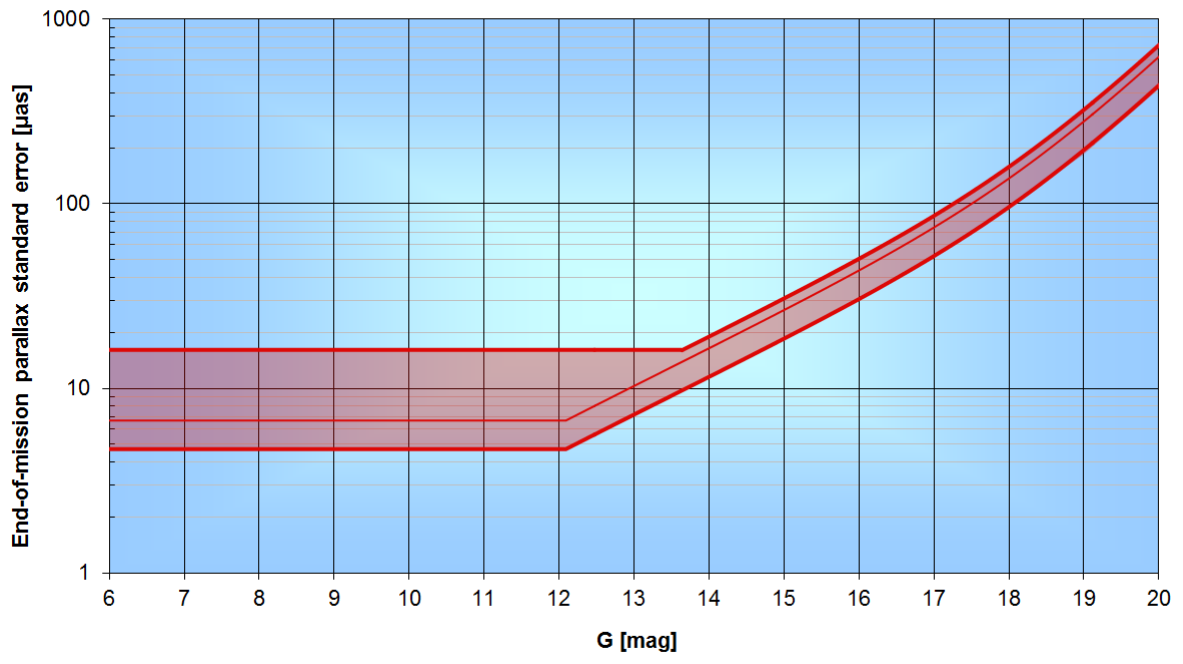
	B1V			G2V			M6V		
G [mag]	**G**	**BP**	**RP**	**G**	**BP**	**RP**	**G**	**BP**	**RP**
15	1	4	4	1	4	4	1	7	4
18	2	8	19	2	13	11	2	89	6
20	6	51	110	6	80	59	6	490	24

Predicted end-of-mission radial-velocity robust formal errors.

Spectral type	V [mag]	Radial-velocity error [km s^{-1}]
B1V	7.5	1
	11.3	15
G2V	12.3	1
	15.2	15
K1III-MP (metal-poor)	12.8	1
	15.7	15

De Bruijne et al. 2015, arXiv1502.00791

Post-launch astrometric performance



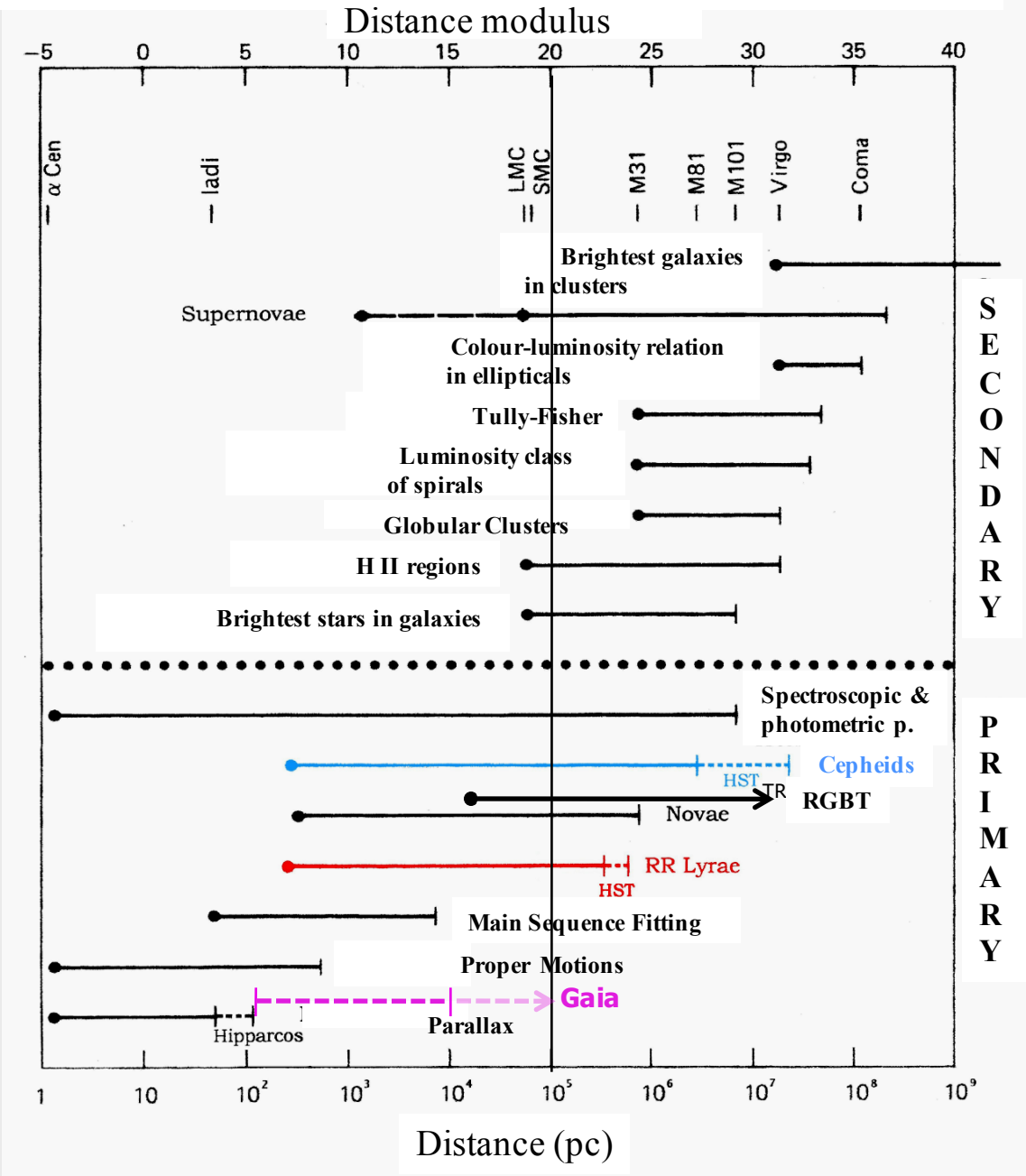
Sky-averaged, end-of-mission, astrometric standard errors, in units of **μas**, for position, parallax, and proper motion, as a function of Gaia G magnitude, for an unreddened G2V star (V-I=0.75 mag and V-G=0.16 mag).

G [mag]	3–12.09	13	14	15	16	17	18	19	20
σ_0 [μas]	5.0	7.7	12.3	19.8	32.4	55.4	102	208	466
σ_ϖ [μas]	6.7	10.3	16.5	26.6	43.6	74.5	137	280	627
σ_μ [μas yr^{-1}]	3.5	5.4	8.7	14.0	22.9	39.2	72.3	147	330

De Bruijne et al. 2015, arXiv1502.00791

Distance Ladder, Cepheids & RR Lyrae, Gaia

"Given the range spanned by the astronomical distances, the astronomical distance ladder is made by overlapping techniques and distance indicators, starting from the most closeby **that we can calibrate directly."**



RR Lyrae & Cepheids with Gaia

- **Census of Galactic Cepheids:**
  ~ 9000 Classical Cepheids
  ~ 2000 Type II Cepheids

- **Census of Galactic RR Lyrae:**
  ~70,000 in the MW halo
  ~ 15-40,000 in the bulge

- **Parallaxes**

  e.o.m. parallax accuracy: 10 μas for V < 12-13 mag - bright field variables
  17 - 140 μas for V_{HB} ~ 14-18 mag - RR Lyrae in globular clusters

  Within 1.5 kpc $\sigma\pi/\pi<1\%$, within 3 kpc $\sigma\pi/\pi<2.5\%$, $\sigma\pi/\pi\approx25$-30% at 10 kpc

  RR Lyrae in Globular Clusters with $\sigma\pi/\pi<1$

  ~7000 Galactic Cepheids with an error on the parallaxes less than 3%

  ⇒ trigonometric distances and absolute calibration via parallax of M_V-[Fe/H], and IR PLZ relations for RRLs and PL, PLC, PW relations for Cepheids

⇒ **DISTANCE LADDER** ⇒ **H_0 by means of Gaia's Cepheids & RR Lyrae**

- **Positions + proper motions**
  census of Cepheids & RRLs down to G~20.7 mag, spatial distribution, identification and tracement of structures, overdensities, streams, new satellites …. ⇒ **MW formation and assembling**

- **RVS metallicities:** metallicity distributions of young and old populations

- **Parallaxes + photometry + RVS radial velocities:** star physical parameters, tests of pulsation models, improvement of model input Physics …..

The distance scale: MW Cepheids

Only ~ 800 Galactic Cepheids are known – most are located in the Solar neighbourhood - expected number ~ 9000

400 Galactic Cepheids from David Dunlap DB
distance and magnitude ➔ Gaia predicted accuracy for parallax
15 @ d < 0.5 kpc
65 @ D < 1 kpc
165 @ d < 2 kpc

Presently, ~ 250 Cepheids with parallax & photometry
(10 with HST parallax)
only ~ 100 with $\sigma_\pi \leq 1$ mas (Hipparcos)

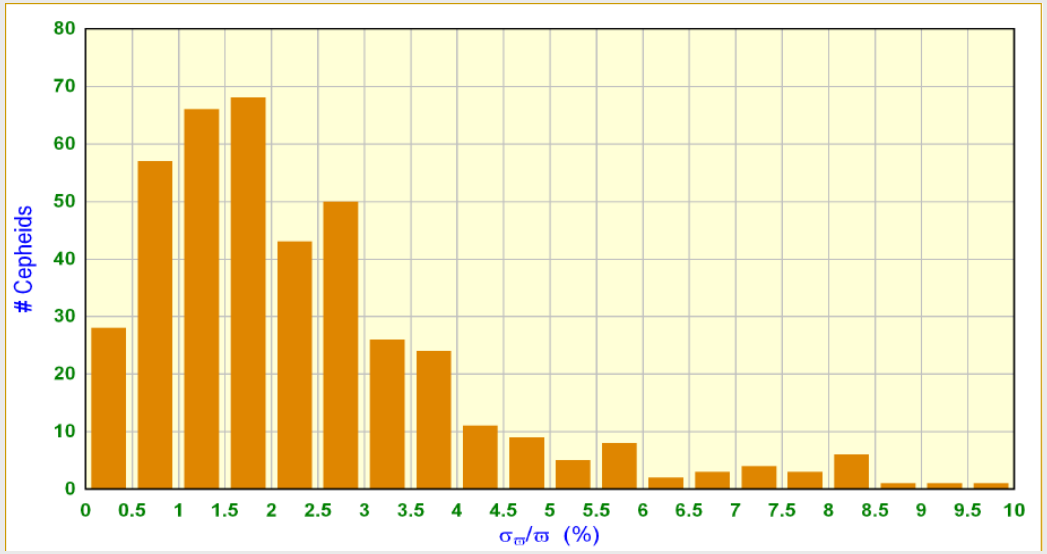


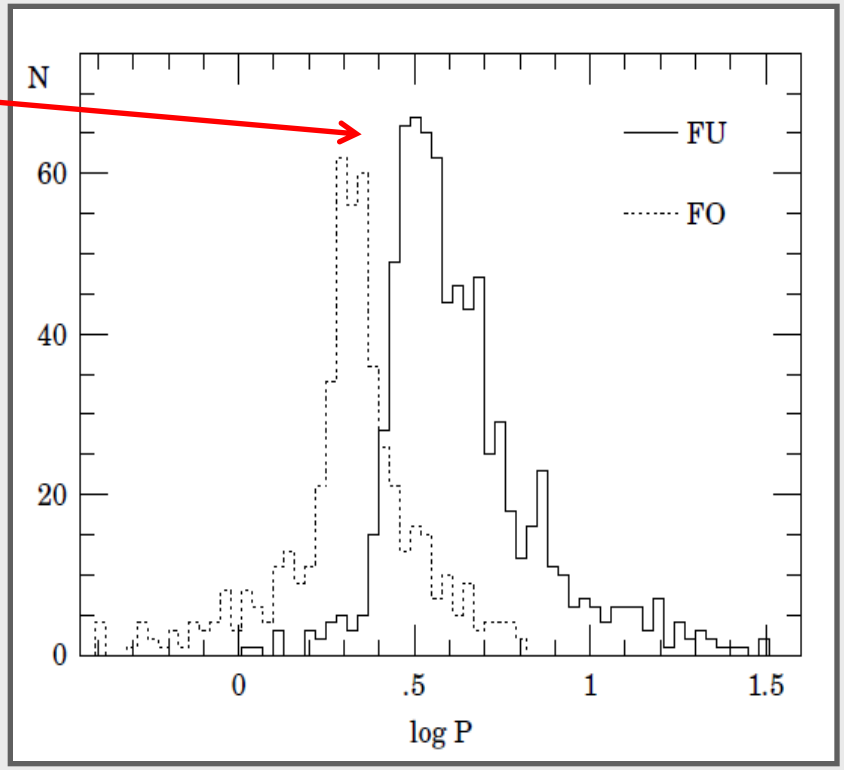
Figure courtesy A. Brown

Most (~ 3/4) Galactic Cepheids will have Gaia individual parallaxes to < 3%

The distance scale: MC Cepheids

Over 9500 Cepheids are known (from OGLE IV) and observable by Gaia in the LMC/SMC

600 Cepheids in the LMC (OGLE, Udalski et al. 1999)



The bulk of the distribution for fundamental LMC pulsators lies at Period = 3 – 5 days

Mv ~ -3 ➔ V ~ 15.8 – 16

➔ individual distances to ~ 150%

➔ mean of 400 to ~ 7-8 %

Cepheids with P ≥ 10 d

Mv ≤ ~ - 4.2 ➔ V ~ 14.5

individual distances to ~ 80%

Ultra-long period (> 100 d) Cepheids

Mv ≤ ~ - 7 ➔ V ~ 12

4 in LMC, 3 in SMC (Bird et al. 2009)

➔ **individual distances to ~ 45% (LMC) - 55% (SMC)**

➔ **direct (trigonometric) calibration of the cosmological distance scale**

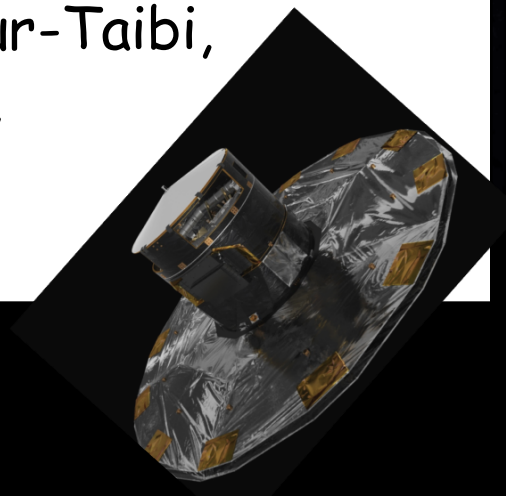
Gaia variability processing (CU7)

DPAC Coordination Unit 7 (CU7) – DPCG (Geneva)
L. Eyer (manager)

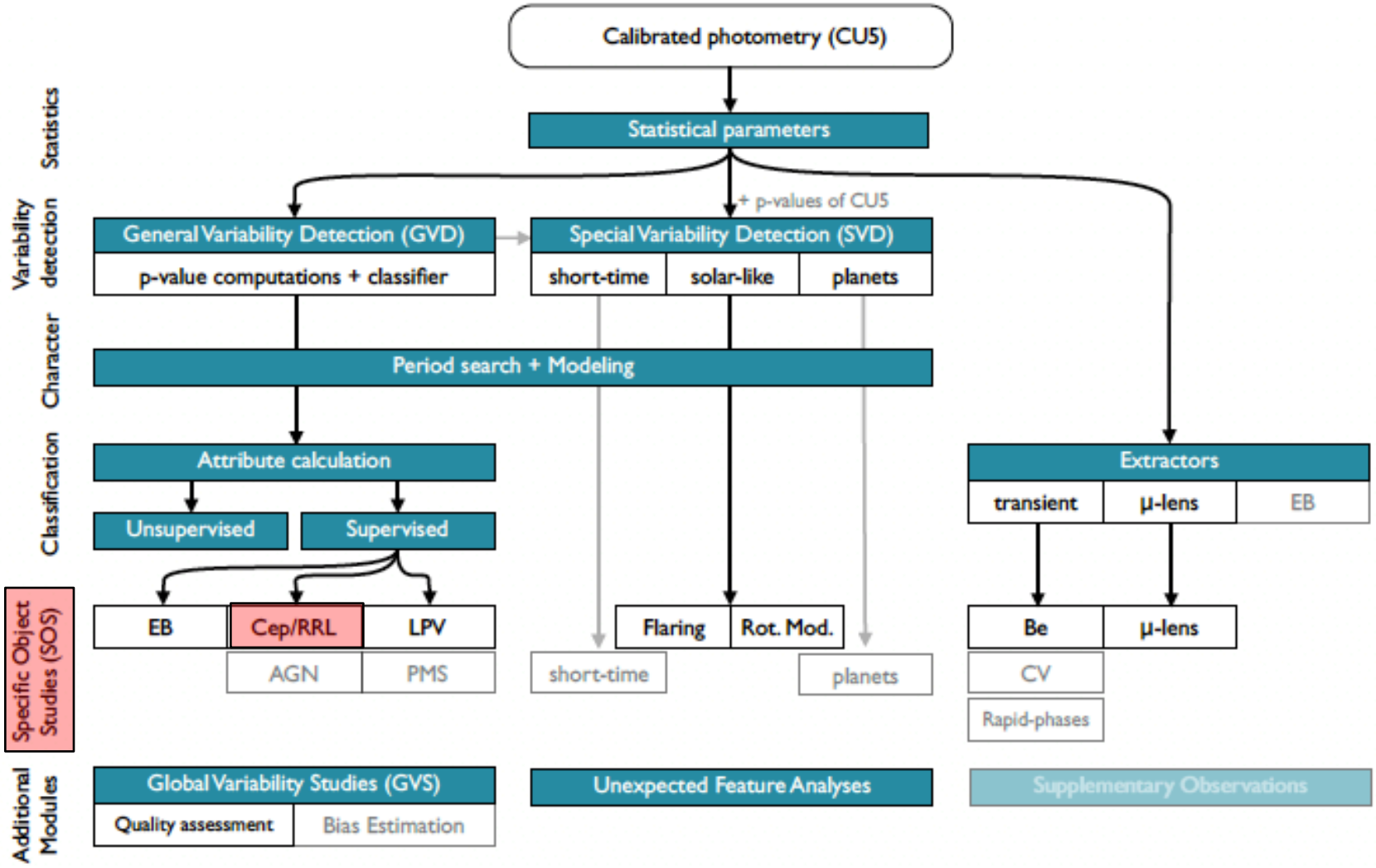
Cepheid & RRLyrae pipeline - **G. Clementini** (manager)

Team: **V. Ripepi, S. Leccia, M. Marconi, I. Musella (INAF-OACn),** L.Szabados (Konkoly Observatory)

+ **T. Muraveva (postdoc OABo), A. Garofalo (PhD OABo)**
+ 1-2 affiliated contributors & developers
+ support staff at DPCG (N. Mowlavi, I. Lecoeur-Taibi, L. Rimoldini, L. Guy, G. Jevardat de Fombelle, J. Charnas, ...)



CU7 processing chain

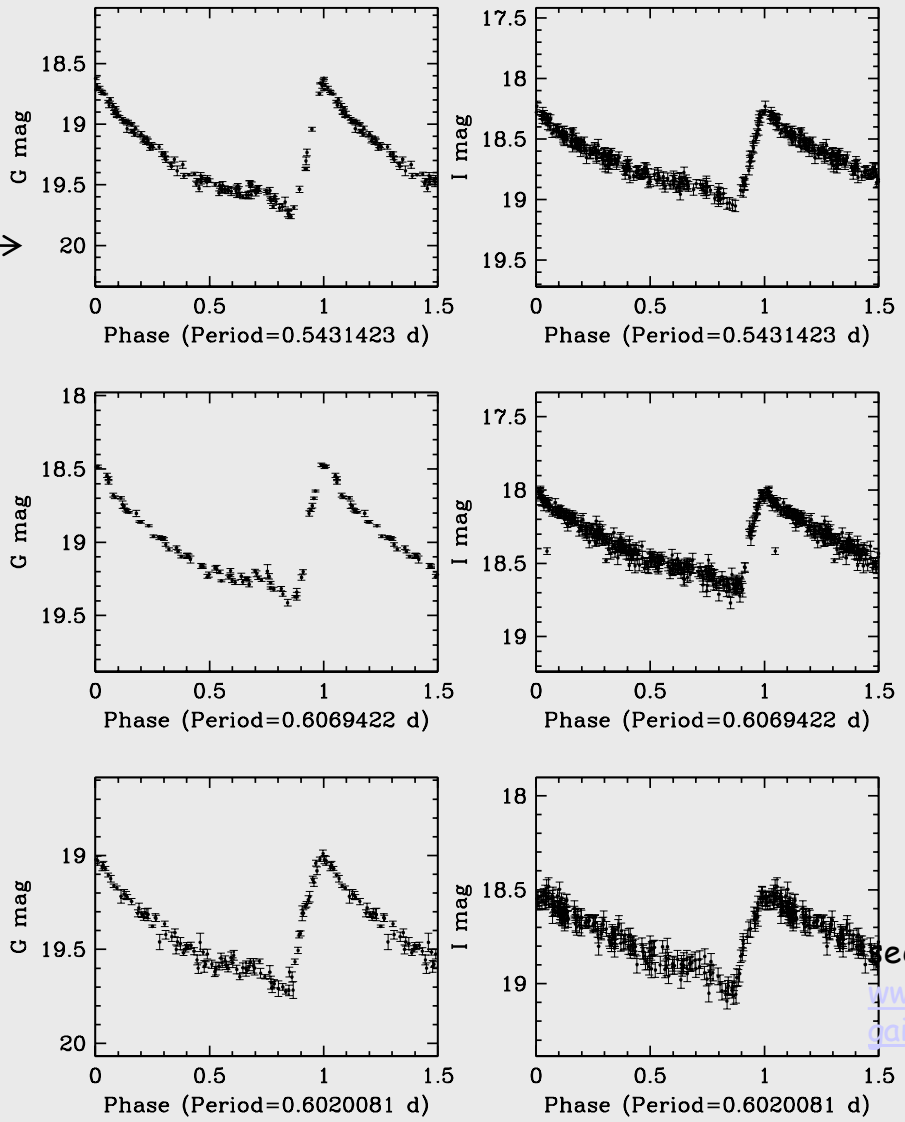


Courtesy of B.Holl

RR Lyrae stars in the LMC as seen by Gaia

http://www.cosmos.esa.int/web/gaia/iow_20150305

Gaia →



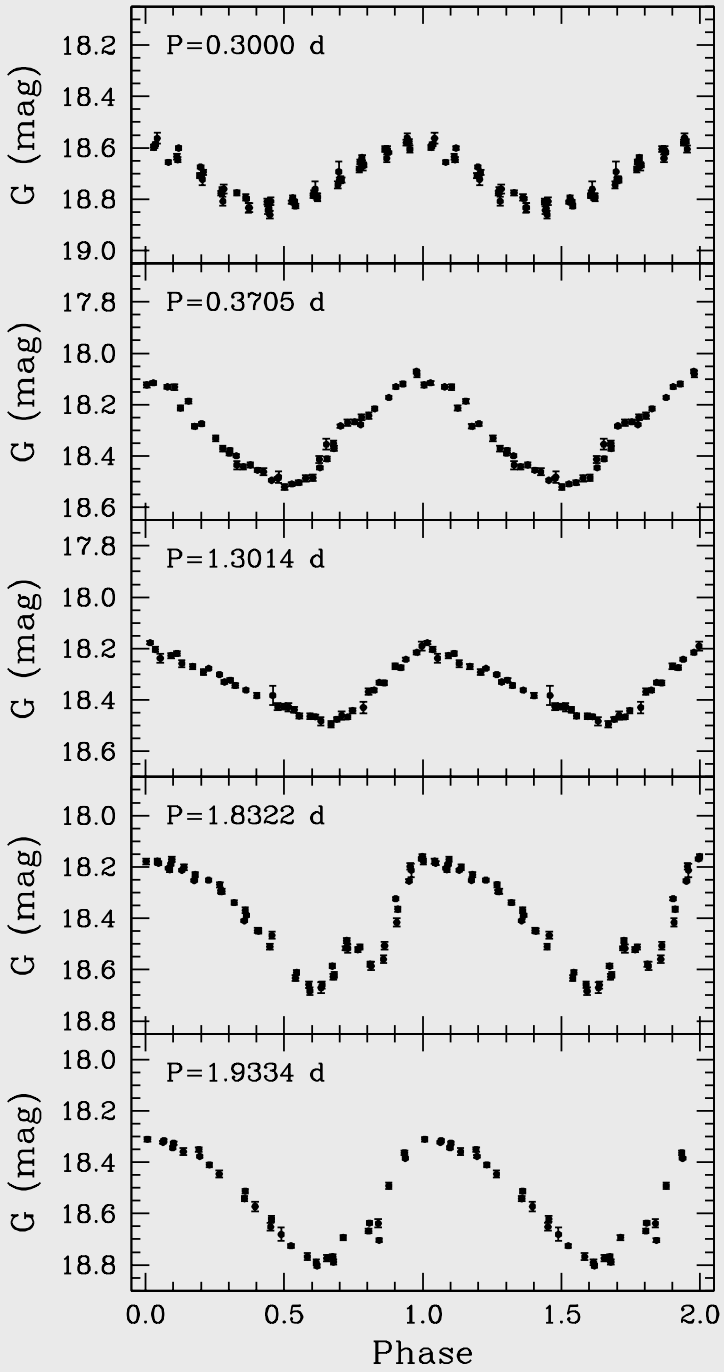
← OGLE IV

Gaia's IoW
March 5th, 2015

Credits: ESA/Gaia/DPAC/CU5/CU7/INAF-OABo **Gisella Clementini**, Dafydd Evans, Laurent Eyer, Krzysztof Nienartowicz, Lorenzo Rimoldini and the Geneva CU7/DPCG and **CU7/INAF-OACN** teams.

See also News Media INAF: www.media.inaf.it/2015/06/.../le-stelle-variabili-di-gaia

Left panels: G-band light curves of RR Lyrae stars in the Large Magellanic Cloud observed by Gaia during the EPSL scanning. *Right panels*: I-band light curves obtained for the same stars by the OGLE IV survey.



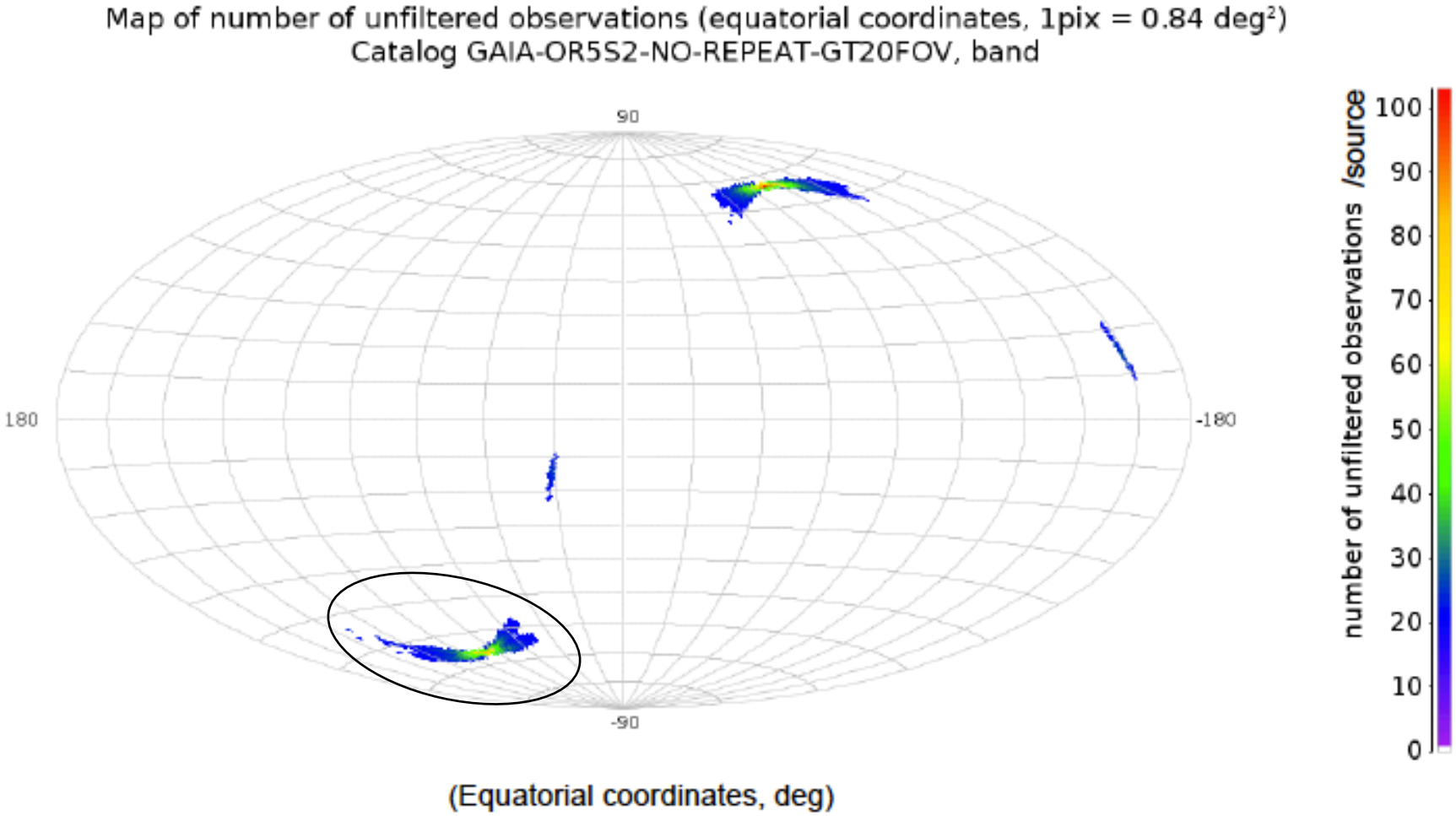
Short period/faint magnitude Cepheids in the LMC observed by Gaia

http://www.cosmos.esa.int/web/gaia/iow_20150528

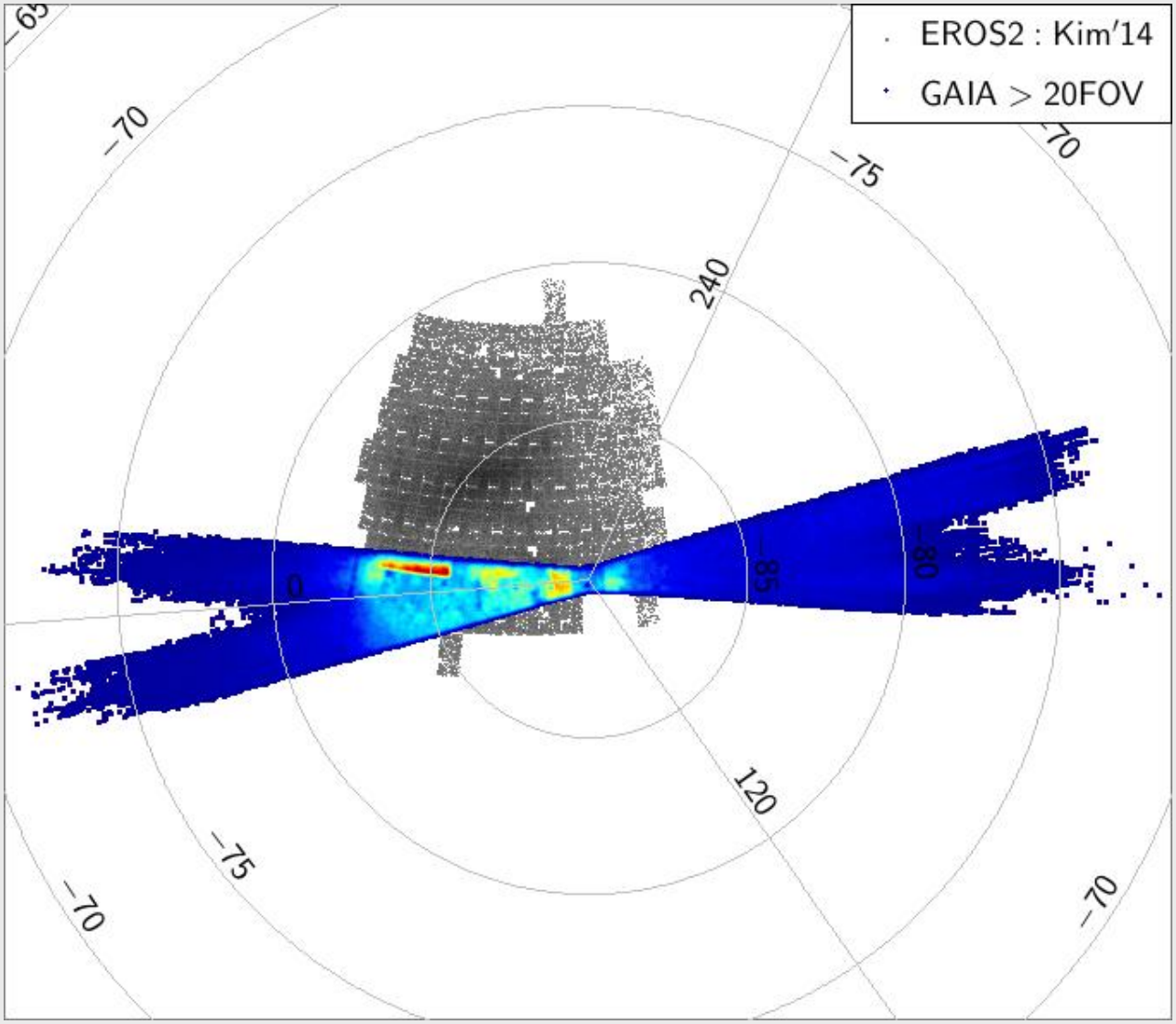
Gaia's IoW
May 28th, 2015

Credits: ESA/Gaia/DPAC/CU5/DPCI/CU7/INAF-OABo/INAF-OACn **Gisella Clementini, Vincenzo Ripepi, Silvio Leccia,** Laurent Eyer, Lorenzo Rimoldini, Isabelle Lecoeur-Taibi, Nami Mowlavi, Dafydd Evans, Geneva CU7/DPCG and the whole CU7 team.
The photometric data reduction was done with the PhotPipe pipeline at DPCI; processing data were received from the IDT pipeline at DPCE.

Mean number of obs/source (789K)



(courtesy of L.Rimoldini)

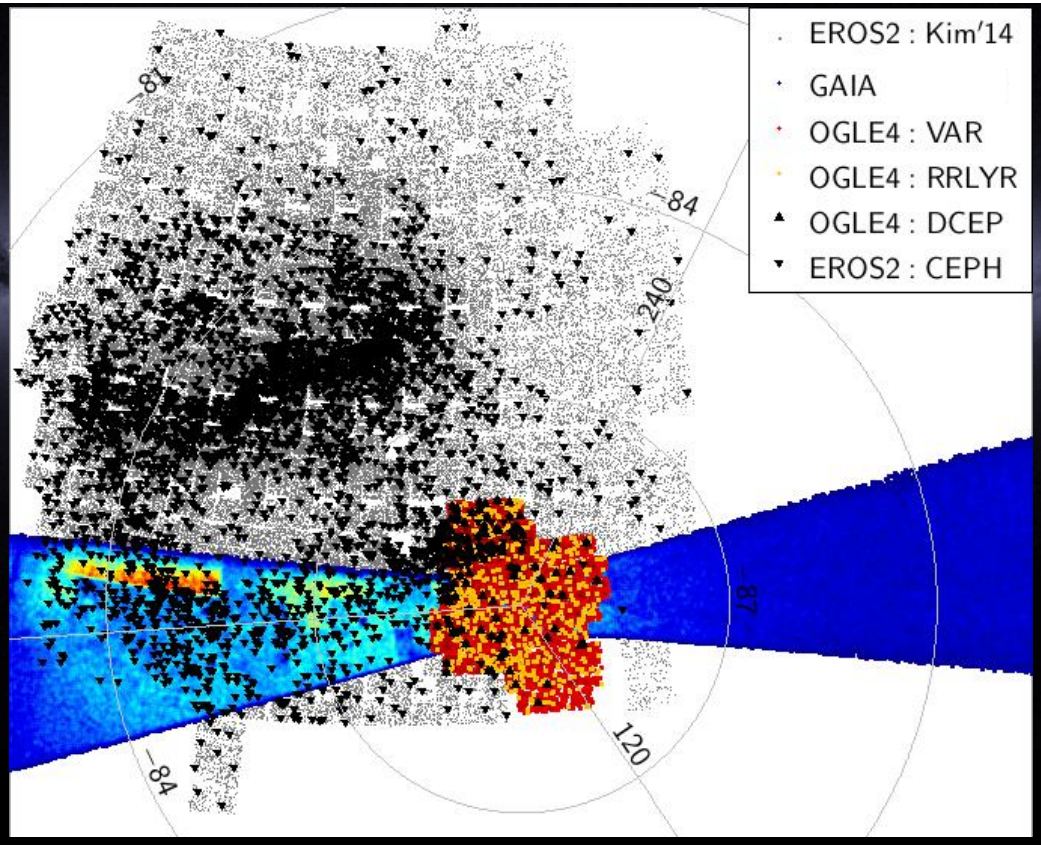


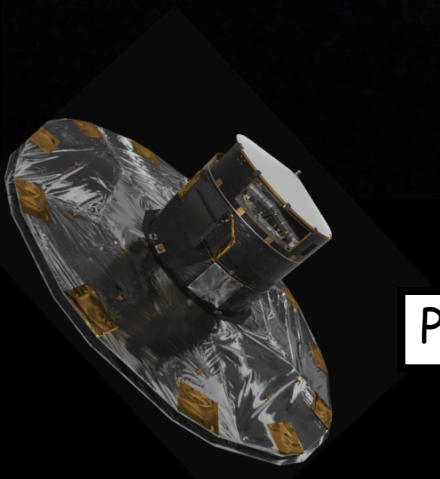
(courtesy of L.Rimoldini)

Gaia – Data Release 1

G-DR1: end of Summer 2016

- Positions and G magnitude (~all sky, single stars)
- **RR Lyrae & Cepheids in the South Ecliptic Pole (SEP; only > 20 transits)**
- **TGAS** for 2.0 millions stars in common between Tycho and Gaia catalogues





Preparing the release of the SEP RRLyrae & Cepheids

Synergies with other surveys

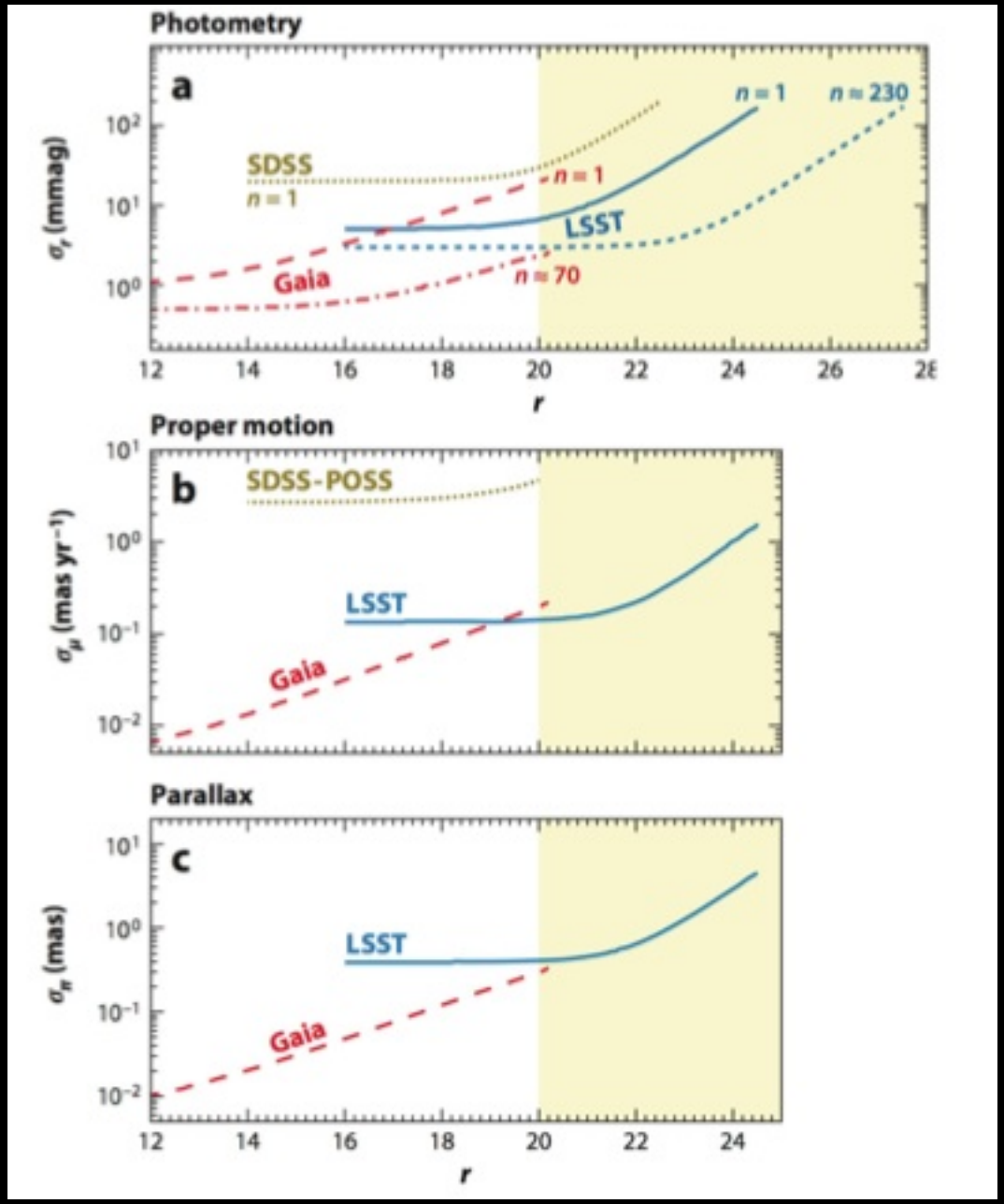
Gaia is an *all sky survey* with direct links/impact on other surveys:

1. Optical from the ground:
   OGLE, EROS, LINEAR, CATALINA, PTF, ASAS, PanSTARRS
   …. and in the future: LSST

2. Infrared from ground: 2MASS, VVV, VMC …
   and from space:
   WISE, CRRP + SMAHSH & Spitzer, …..

3. Need to complement Gaia RVS data for Cepheids & RR Lyrae stars:
   GES?, WEAVE, MOONS, 4MOST ….

Gaia & LSST



Ivezic et al. 2015

CRRP@Spitzer

PI: W. Freedman, 779h

SMHASH@Spitzer

PI: K. Johnston, 664h

CCHPII@HST

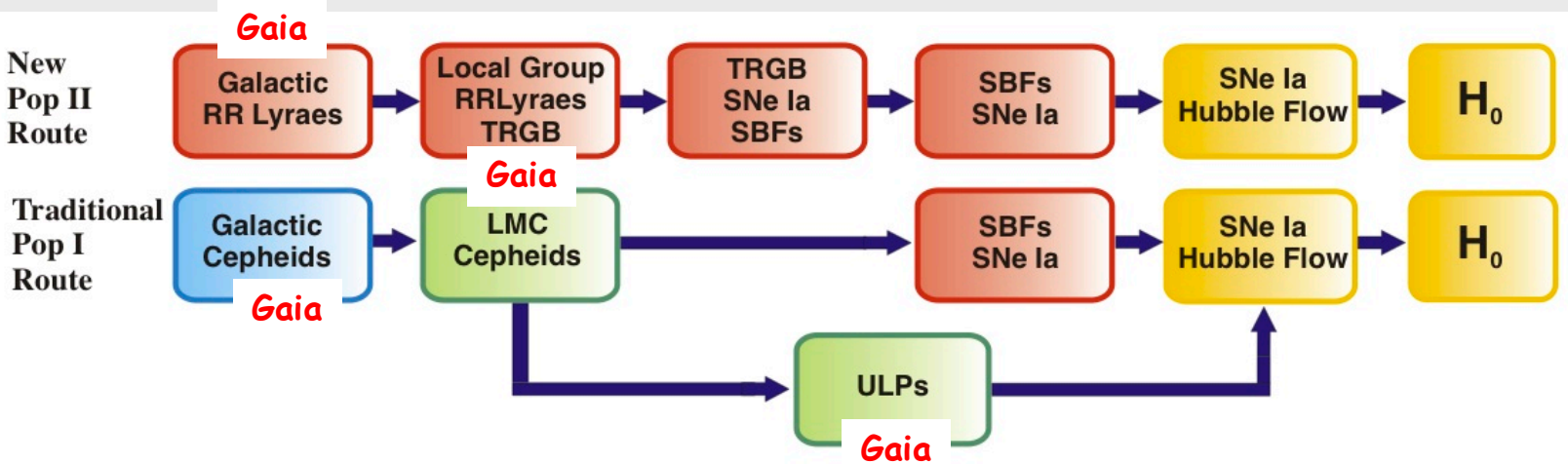
PI: W. Freedman, 132 orbits

G. Clementini, G. Bono (Co-Is)

Wide international collaborations: Wendy Freedman, Barry Madore, G. Preston, E. Persson, V. Scowcroft, J. Kollmeier, I. Thompson, A. Monson, M. Seibert (Carnegie Observatories, Pasadena, USA); van der Marel (Space Telescope Science Institute, Baltimore, USA); S. Majewski (University of Virginia, Charlottesville, USA); K. Johnston, G. Besla (Columbia University, New York, USA); D. Nidever (University of Michigan, Ann Arbor, USA); H.A. Smith (Michigan State University, East Lansing, USA); N. Kallivayalil (Yale Center for Astronomy & Astrophysics, New Haven, USA); C. Klein (University of California, Berkeley, USA); M. Marengo (Iowa State University, Ames, USA); M.R. Cioni (Leibnitz-Institut fur Astrophysik, Potsdam, Germany); D. Law (University of Toronto, Canada); A. Udalski, I. Soszynski, G. Pietrzynski (Warsaw University Observatory, Poland).

CCHP@HST

PI: W. Freedman, G. Clementini Co-I, 211 orbits requested in Cycle 24



EXCALIBUR'S – PRIN INAF 2014 (2015-early 2017), PI G. Clementini

Gaia data distribution

- **Final catalogue ~ 2022**
- **Intermediate data releases:**

  GDR1: End of summer 2016
  - Positions+G magnitude (~all sky, single stars)
  - SEP Cepheids & RR Lyrae stars
  - TGAS

  GDR2: Summer 2017
  - Radial velocities for bright stars
  - Two-band photometry
  - Full astrometry

- **Science alerts are released immediately**
- **No proprietary data rights**

To take home message:

Gaia e' una realta' concreta, pienamente in fase operativa e con la prima release di dati prevista per il Settembre 2016, sta entrando a pieno regime nella fase della scientific exploitation.

La comunita' scientifica INAF e' fortemente presente in Gaia con ruoli di leadership, spesso determinanti per il successo in certi settori della missione.

Per poter mantenere il ruolo acquisito in questi anni e poter sfruttare pienamente l'incredibile potenziale scientifico di Gaia in generale e nell'ambito della cosmologia che le variabili pulsanti permettono di fare bisogna attrarre giovani ricercatori verso questi settori di ricerca: … siamo una comunita' che sta invecchiando … senza riuscire a passare il testimone alle nuove generazioni.

Occorrono:

a) risorse per fare scientific exploitation di Gaia
b) la possibilita' di offrire posizioni a lungo termine/stabili
c) una maggiore sinergia con le universita' e i luoghi di formazione