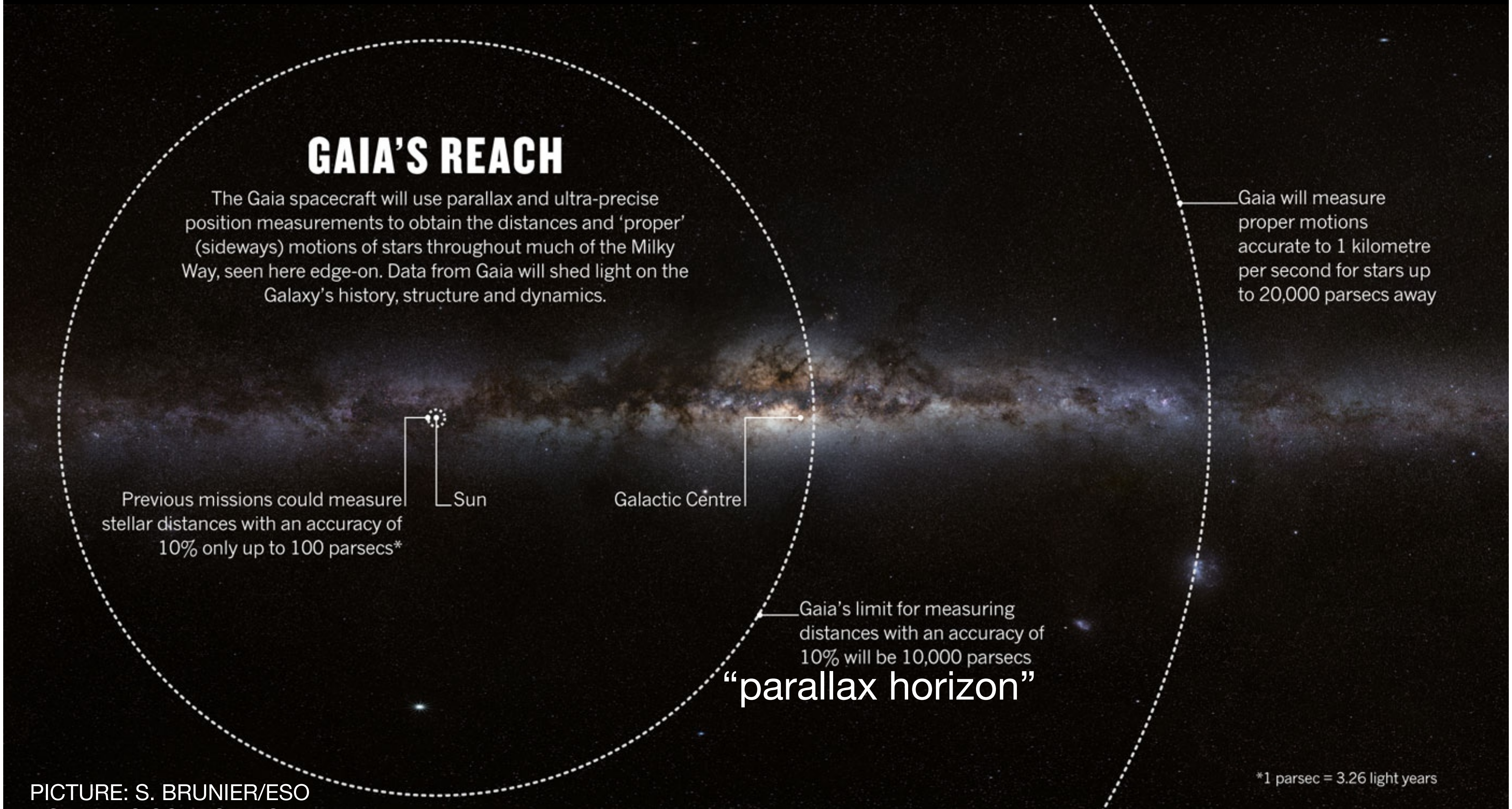
4MOST Gaia RRLyrae Survey (4GRoundS)

Anke Arentsen, Giuseppina Battaglia, Michele Bellazzini, Paolo Bianchini, Gisella Clementini, Benoit Famaey, Alessia Garofalo, Vanessa Hill, Rodrigo Ibata, Khyati Malhan, Nicolas Martin, Alessio Mucciarelli, Giacomo Monari, Lorenzo Posti, Arnaud Siebert, Asa Skuladottir, Antonio Sollima, Guillaume Thomas, Chris Wegg, Zhen Yuan

UNIVERSITÉ DE STRASBOURG
CNRS INSU Observer & comprendre
Observatoire astronomique de Strasbourg
European Research Council
Established by the European Commission



PICTURE: S. BRUNIER/ESO
GRAPHIC SOURCE: ESA

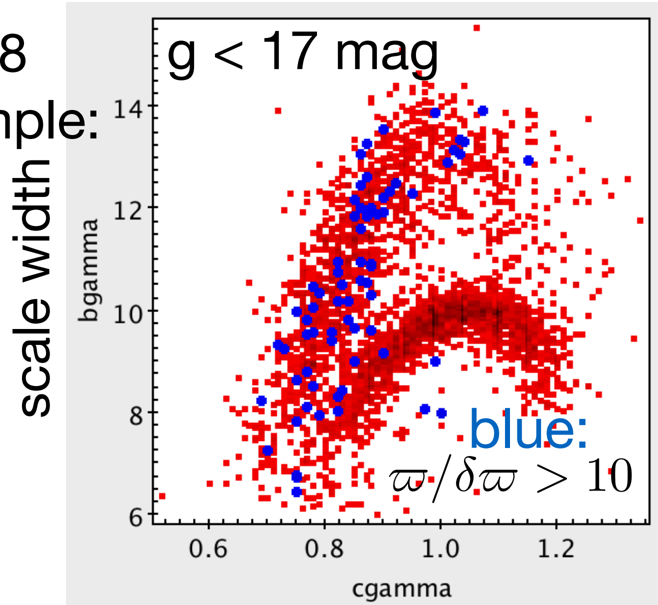
What tracers should we use for distant populations?

RGBs ? BHBs ? RRLyrae ?

Tracers of the distant Galaxy

- RGBs:
  - Easy RVs and chemistry.
  - But relatively poor distances (~26%, Thomas+ 2019), especially for metal-poor stars.
- BHBs:
  - Harder RVs than for RGBs
  - Photometric confusion with Blue Stragglers
  - Significant spread in M_g (Deason+ 2011)
- RRLyrae:
  - Easily identified from photometry (excellent contrast)
  - **Distances** can be **measured well**: uncertainty ~3% (Sesar+ 2017)
  - Seen in populations down to [Fe/H] ~ -2.9 (Hansen+ 2011)
  - Only present in **old** stellar populations (>~ 10 Gyr)

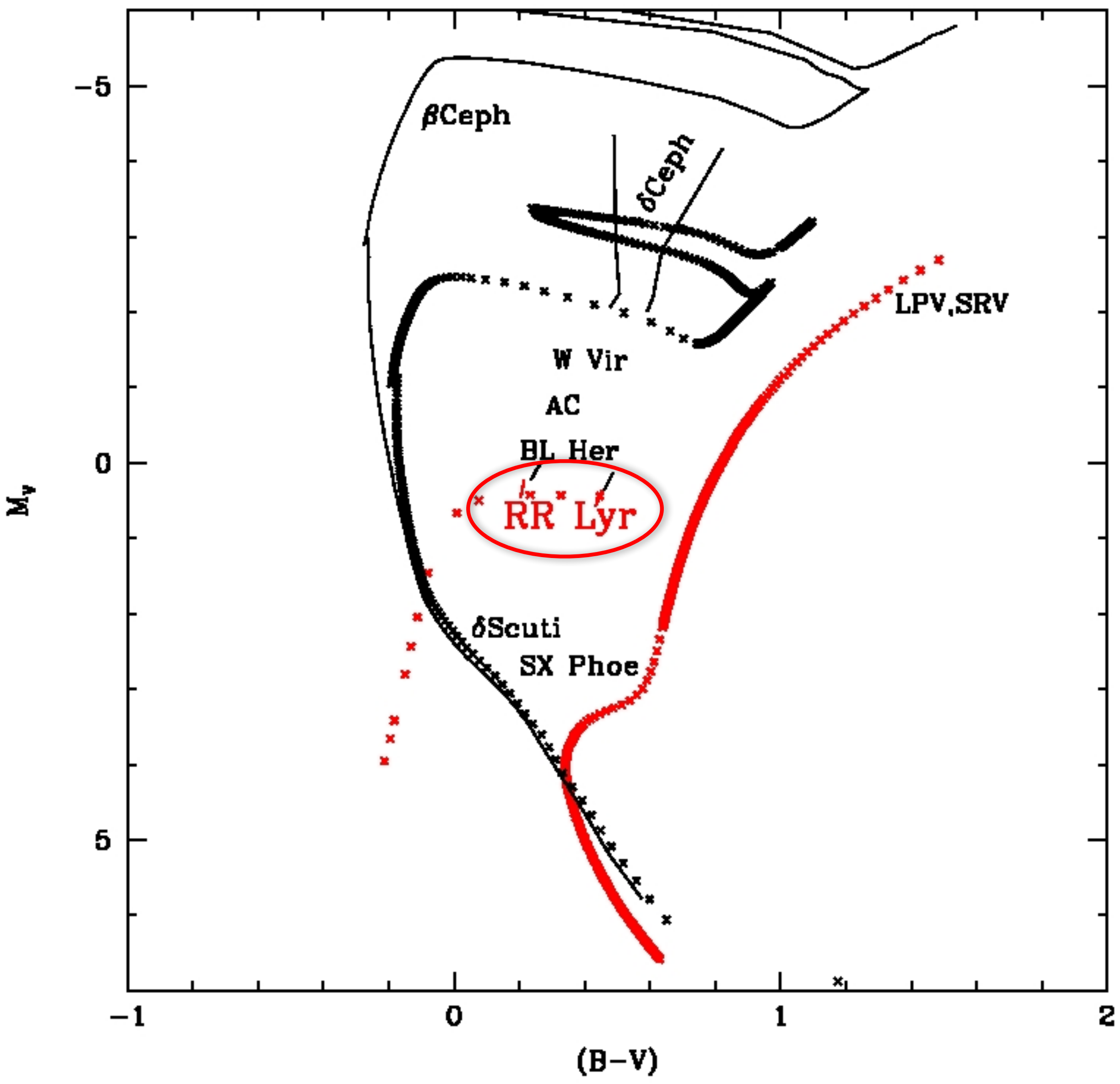
Xue+ 2008
BS/BHB sample:



line shape

… but variable

RR Lyrae: general properties



low mass Helium burning A-F giants, on the **Horizontal Branch**

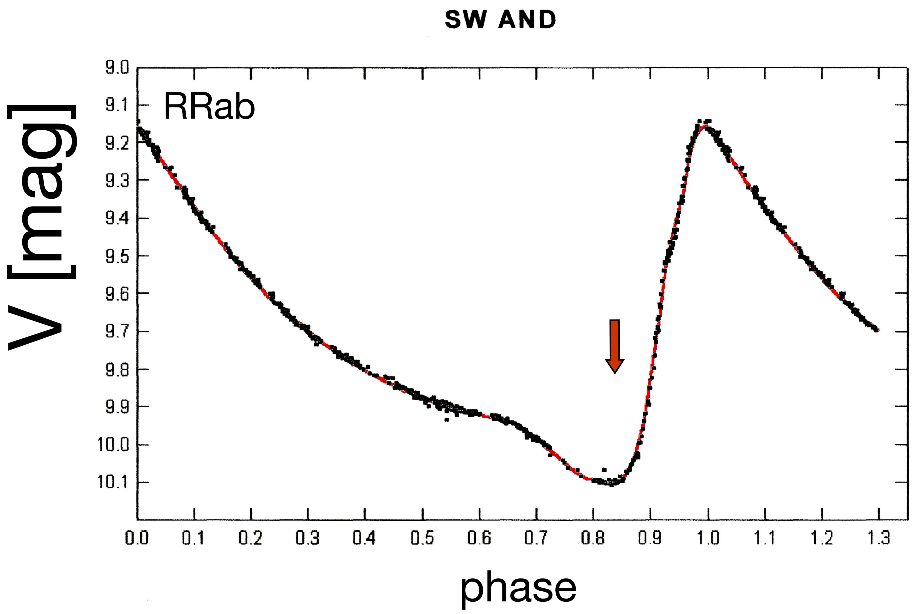
Most abundant class of pulsating stars in the Milky Way
found both in the field and in GCs

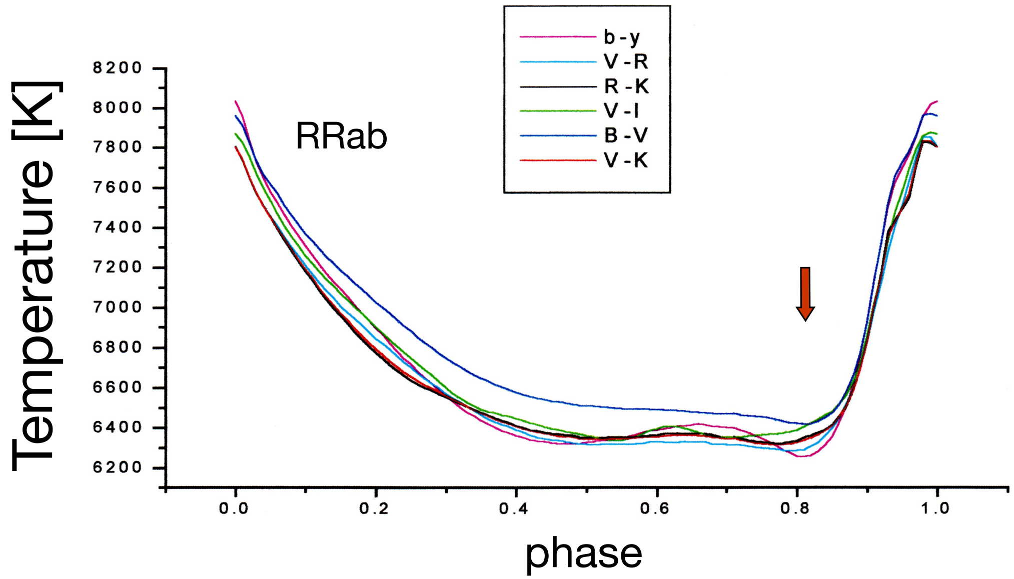
The V amplitude range:
~ 0.2 to ~ 1.8 mag

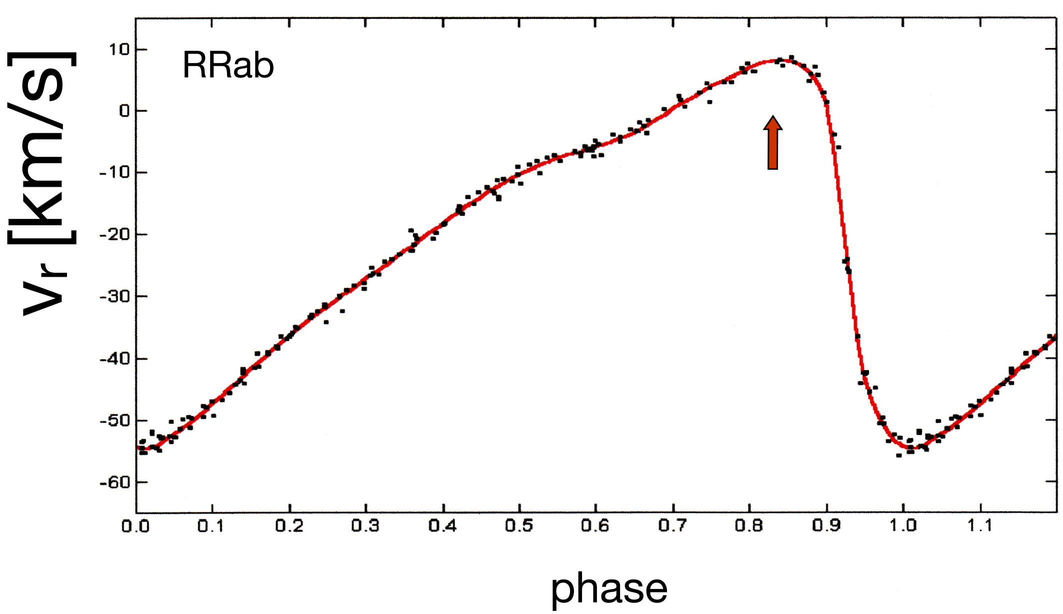
P ranges from:
~ 0.2 d to ~ 1.0 d

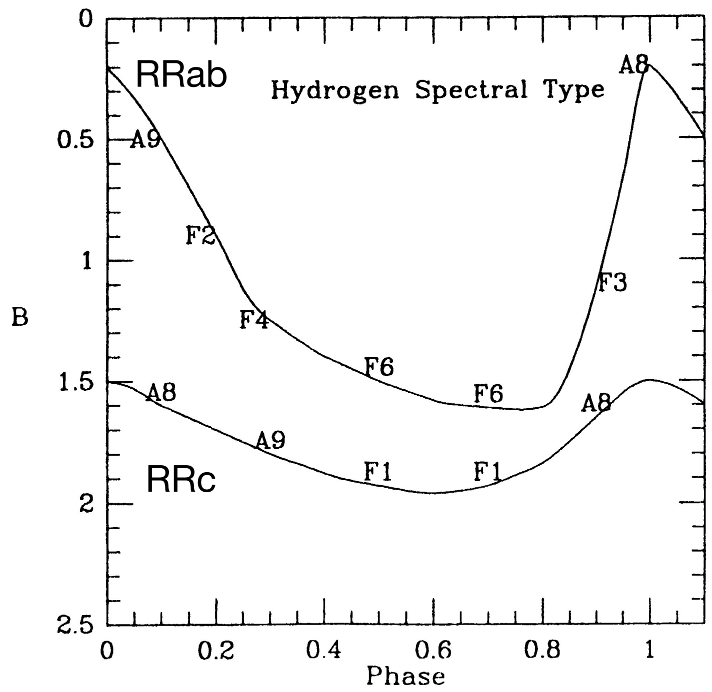
Pulsation in two radial modes:
Fundamental mode
(RRab type; ~0.4< P <1.0 d)
First Overtone
(RRc type; 0.2 < P < ~0.45 d)

Variation of the light, radial velocity, temperature and spectral type of an RR Lyrae star during the pulsation cycle

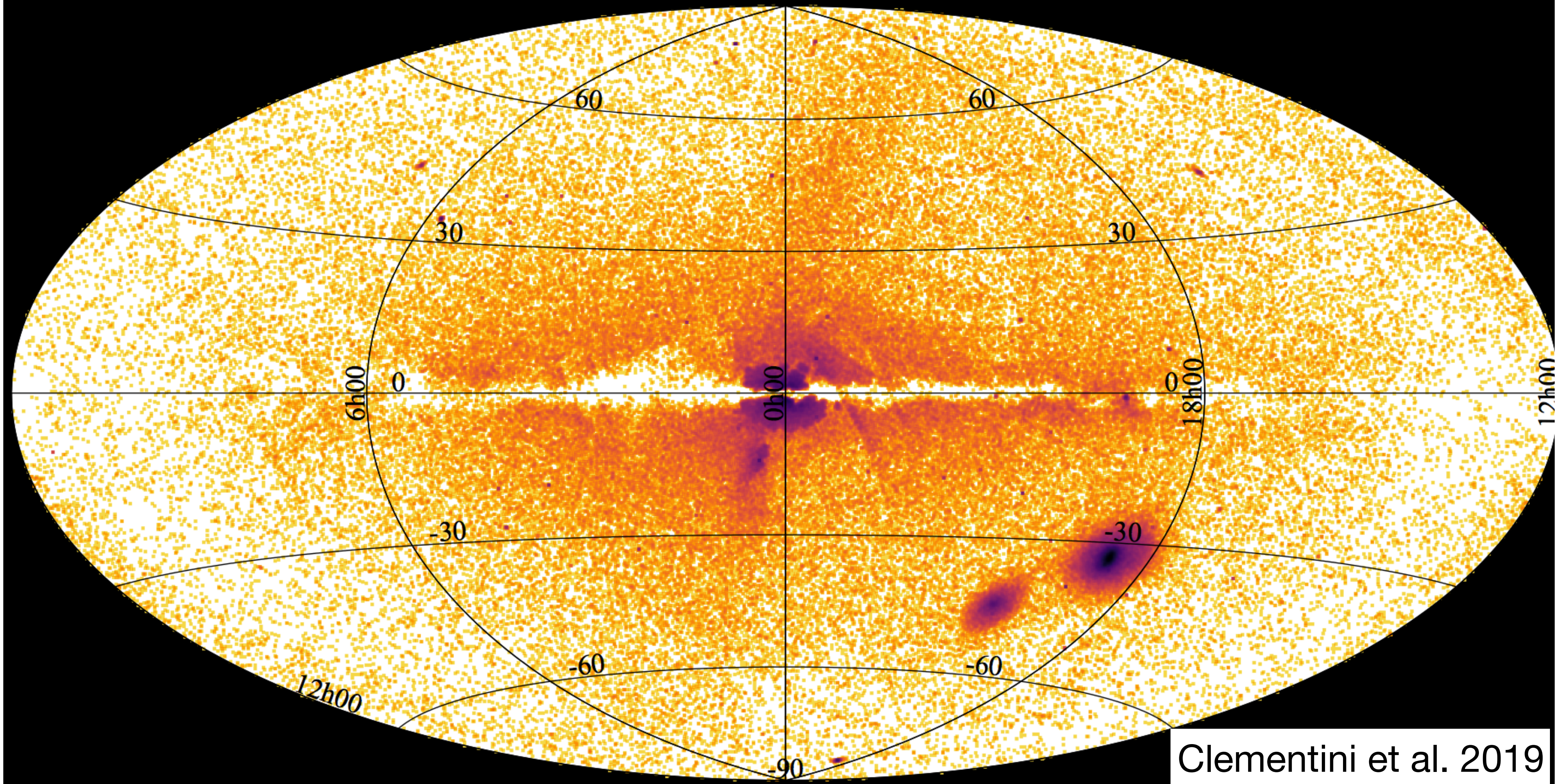








Gaia DR2 Sky in RR Lyrae Stars



Gaia DR2: 228,904 (candidate) RR Lyrae (Holl et al. 2018), confirmation and full characterization (periods, amplitudes, mean magnitudes, Fourier parameters) for **140,784**, interstellar absorption for **54,272** of them and photometric metal abundances for **64,932** (Clementini et al. 2019).

… but much more to come!

Gaia Third Data Release

Larger number of observations : **34 months in DR3, ~ 40 measurements**

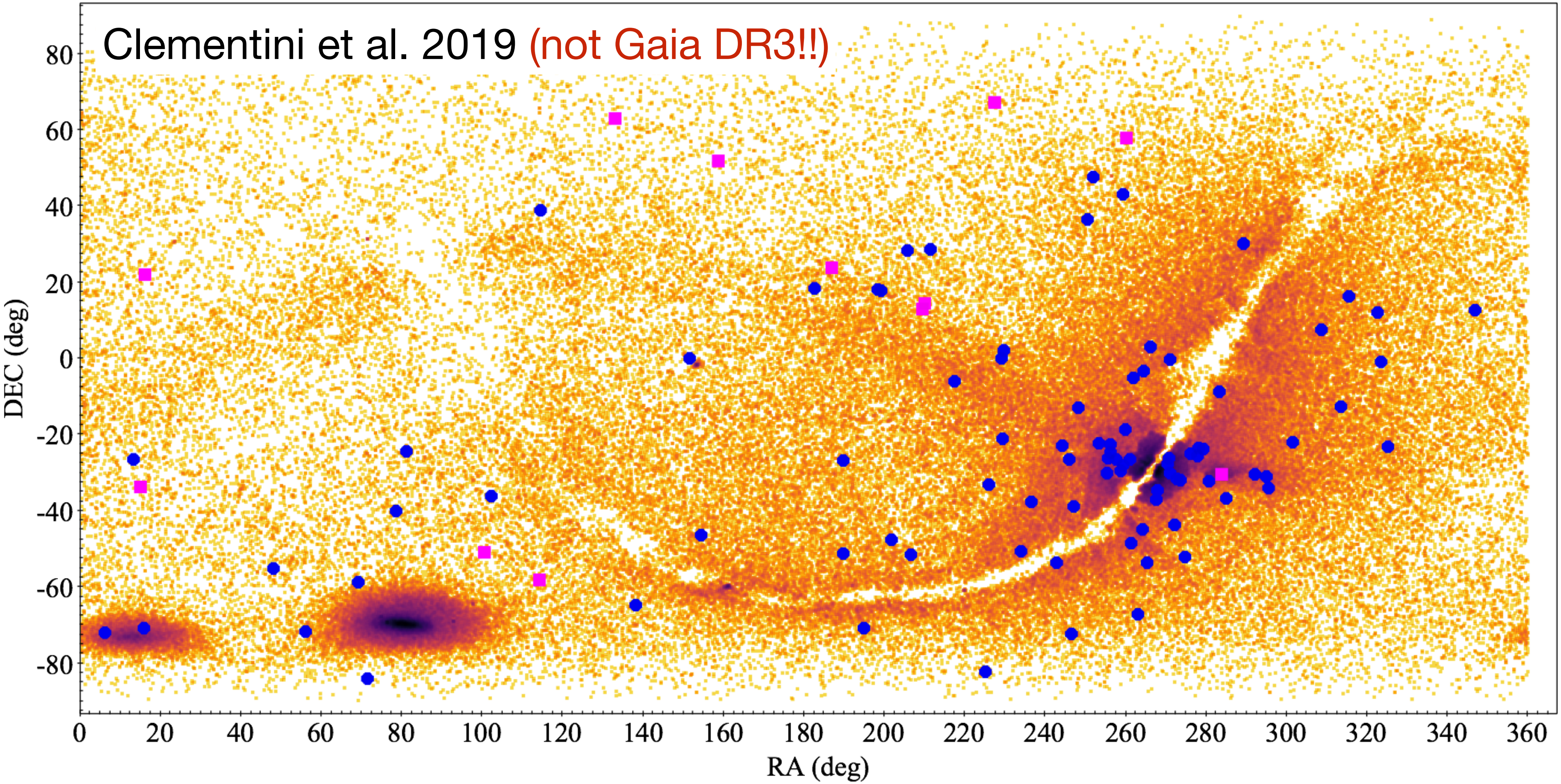
EDR3: End of 2020

- Improved astrometry (positions, parallaxes and proper motions)
- Improved photometry (integrated G, G_{BP}, G_{RP})

DR3: second half of 2021

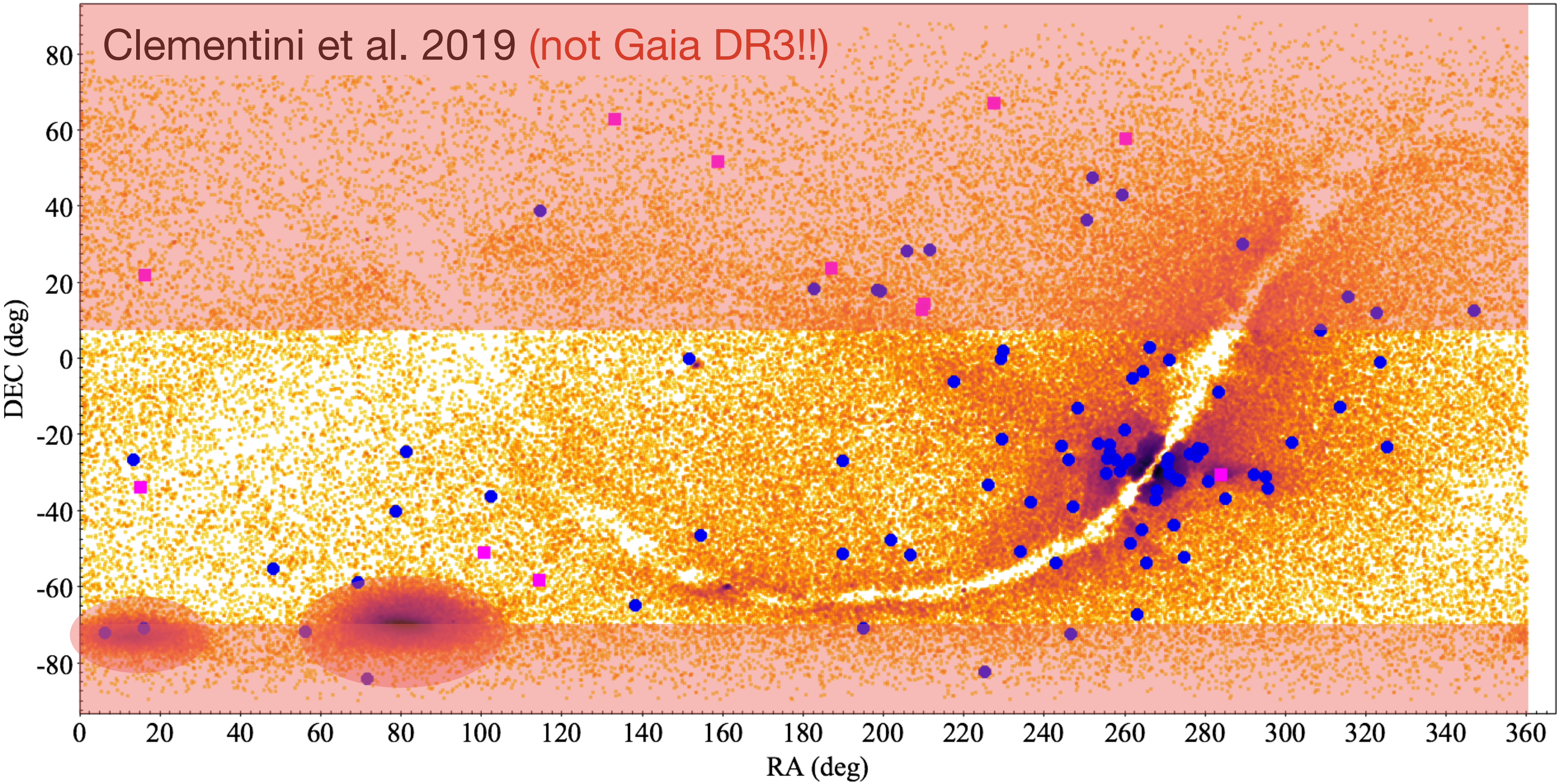
- Object classification and astrophysical parameters, together with BP/RP spectra and/or RVS spectra they are based on, for spectroscopically and (spectro-)photometrically well-behaved objects.
- Mean radial velocities (significantly more due to fainter magnitude limit)
- **Variable-star classifications together with the epoch photometry (5-10 million variable stars of different types) and RVS radial velocity curves for about 700 RR Lyrae stars with G< 14 mag.**
- Solar-system results with preliminary orbital solutions and individual epoch observations
- non-single stars
- Astrophysical parameters (based on spectra)
- Quasars and Extended Objects results
- Gaia Andromeda Photometric Survey (GAPS)

Gaia DR3: Given the increased number of epochs and the longer temporal coverage of DR3 (34 months), the number of RR Lyrae stars confirmed and fully characterized is expected to reach at least 180,000 - 200,000 stars.



Note - (eventually) superb follow-up photometry with LSST & Euclid.

Gaia DR3: Given the increased number of epochs and the longer temporal coverage of DR3 (34 months), the number of RR Lyrae stars confirmed and fully characterized is expected to reach at least 180,000 - 200,000 stars.

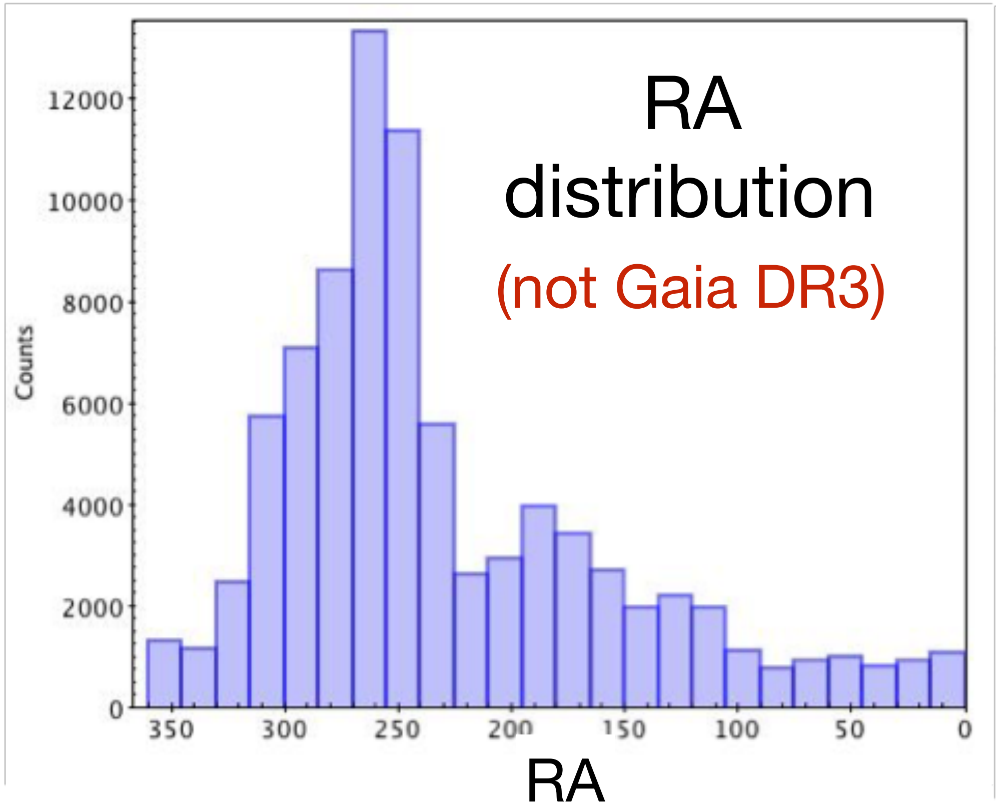


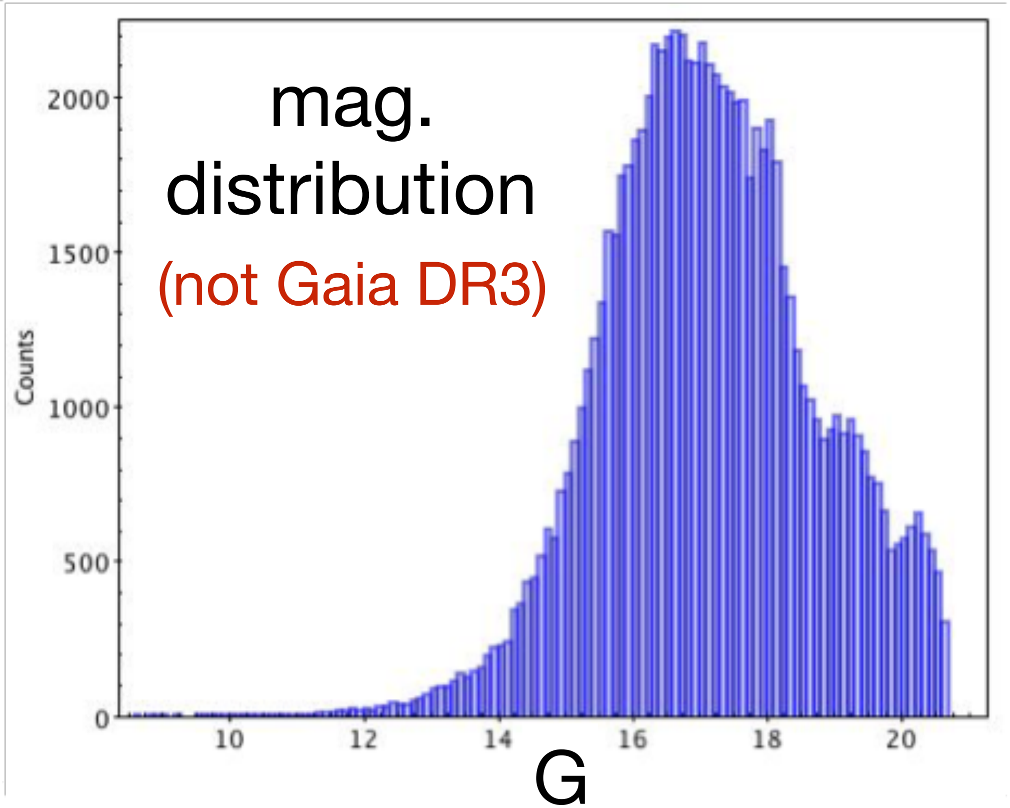
Note - (eventually) superb follow-up photometry with LSST & Euclid.

4GRoundS request:

100,000 hrs

- Approximately 100,000 stars to G=20.7 at -70° < δ < 5° outside of the MCs (>15° from the LMC and >10° from the SMC)
- low resolution required
- target density: ~5 per square degree
- due to radial velocity variability, exposure times < ~30 min.
- repeats if possible at random phase (no cadence required)
- **Measurements of**: radial velocity (S/N>5), metallicity (S/N > 10; G<19.5), abundances (S/N>30; G<17.5)
- post-facto phase corrections (phase from Gaia+LSST+4MOST+ML?)



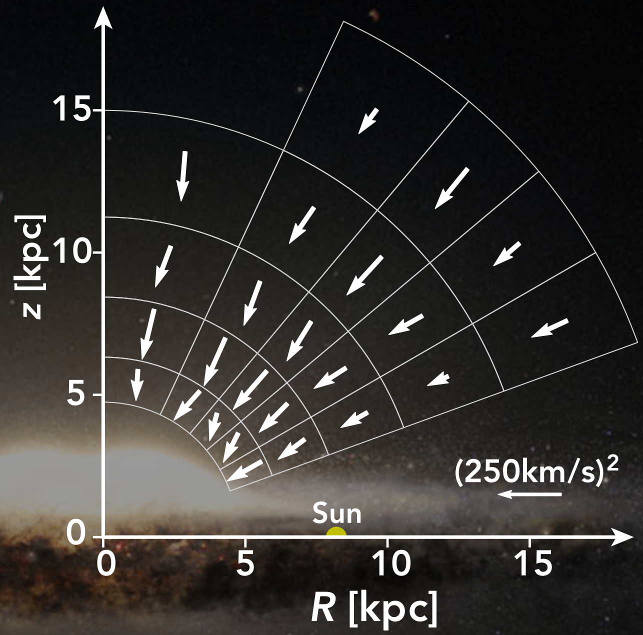


Some of our scientific aims with 4MOST GRoundS

- Dynamical mass modelling of the outer Galaxy
- Old stellar streams in the outer Galaxy
- Search for low-mass satellites
- Global halo asymmetry due to the arrival of the LMC
- Distant disk
- Bulge/halo decomposition
- Spatial variations in kinematic coherence through the halo

The Distribution of Dark Matter

2D: *The gravitational force field measured from RR Lyrae*



WEGG *et al* MNRAS (2019)

Using Gaia proper motions measured kinematics and forces in the halo

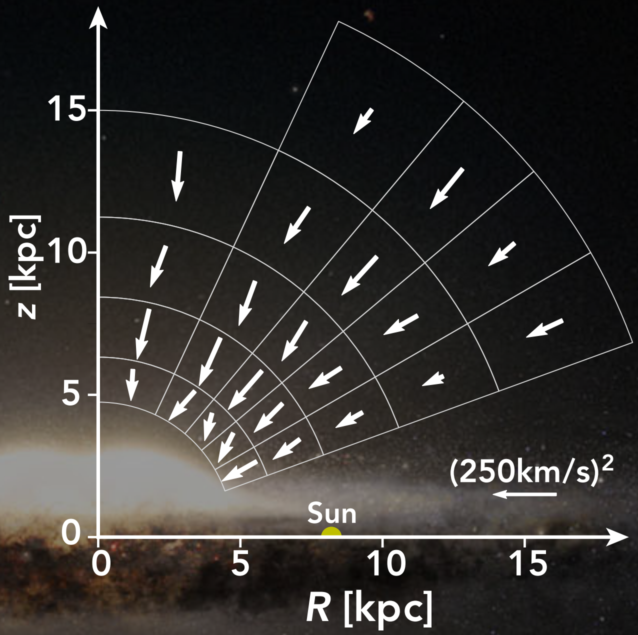
Dark matter is surprisingly spherical. Axis ratio: $q = 1.00 \pm 0.09$

Exciting! ΛCDM simulations generally predict $q \approx 0.8$

Shows power locked in Gaia data — but only beginning: 2D and limited number of stars

The Distribution of Dark Matter

3D: ***Gaia astrometry in concert with ground-based spectra***



Measurement was in 2D because Gaia didn't measure radial velocities for these stars. With radial velocities for these stars we can make the measurement more accurate and ***extend to 3D***

4GRoundS community survey will add radial velocities for these RR Lyrae

WEAVE will do the same in the north. Both hemispheres are necessary

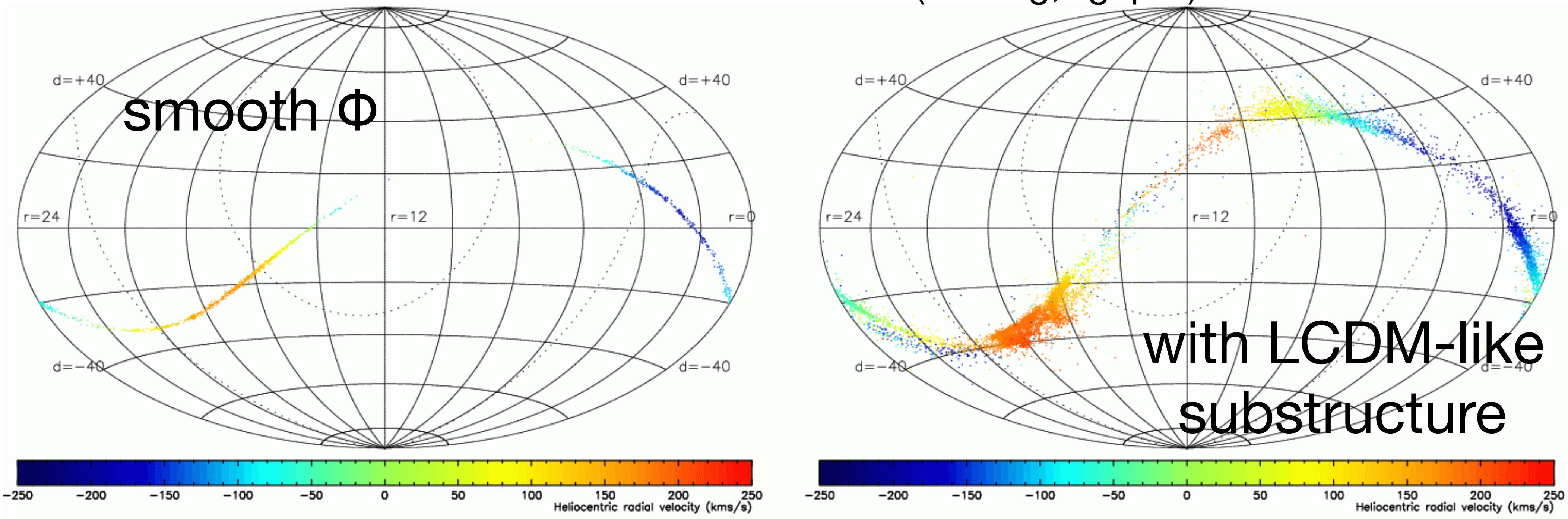
Expected Key Results

Non-parametric measure of the Milky Way's dark matter distribution in 3D
Compare to simulations — does dark matter behave as expected?

Exploring the dark sector with streams

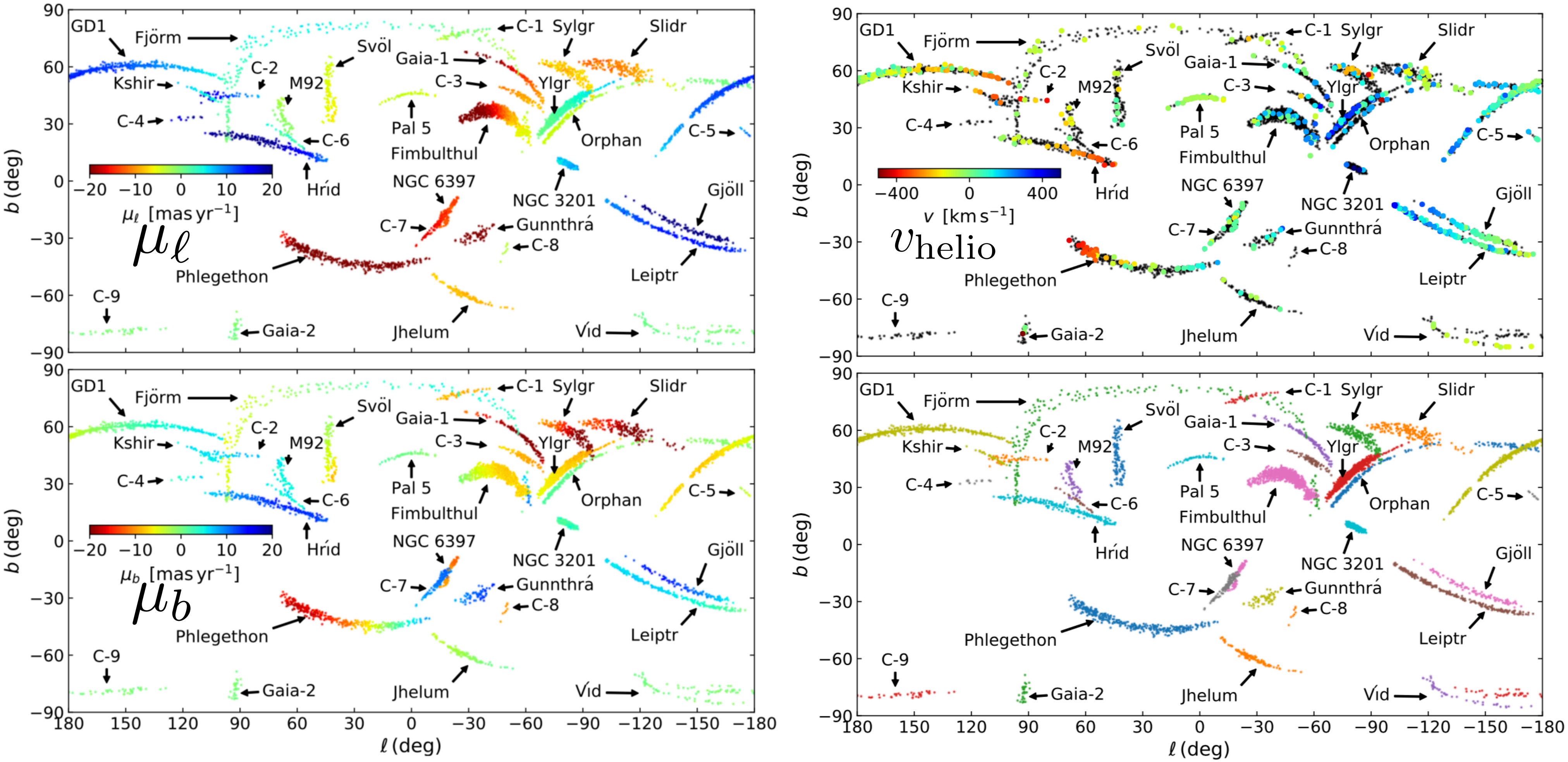
Streams:

- direct probe of global acceleration field
- do not need to assume equilibrium dynamics.
- retain memory of previous interactions (e.g. with sub-halos, disk, bar, satellites, etc)
- trace the buildup of the Galaxy
- also work as seismometers (heating, “gaps”):



RI, Lewis, Irwin, Quinn (2002) ; Johnston et al. (2002) ; Dalal & Kochanek (2002)
Carlberg et al. (2012), Erkal et al. (2016); RI, Thomas, Famaey, Malhan, Monari (2020)

STREAMFINDER high-resolution survey
(UVES & ESPaDOnS follow-up of Gaia DR2)



With 4GroundS & Gaia DR3, DR4: extend search to larger distances

Accurate distances would make the streams hugely more powerful…

4GRoundS Summary

- The driving scientific ambition of 4GRoundS is to reveal the six-dimensional structure of the outer Galaxy using a uniquely powerful tracer
- RRLyrae are important because they yield excellent distances and belong to the oldest Galactic populations
- We aim to study the dark matter distribution and the kinematic response of star streams and the stellar halo to the clumpiness of dark matter sub-haloes