Synergies with Rubin-LSST

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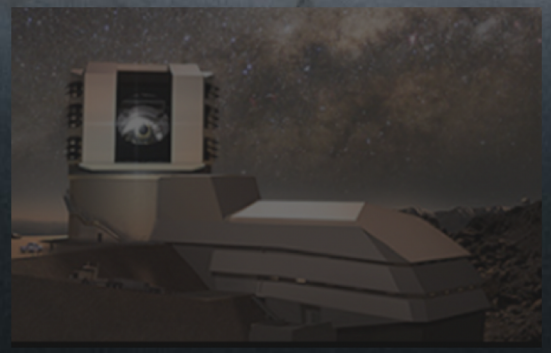
Gaia DPAC - CU7 (Variability Processing)

LSST - TVS and SMWLV SCs - In-kind project ITA-INA2 - S15



GaiaNIR:NEXT Generation Astrometric Mission

Bologna, January 17-18 2024

Layout of the talk

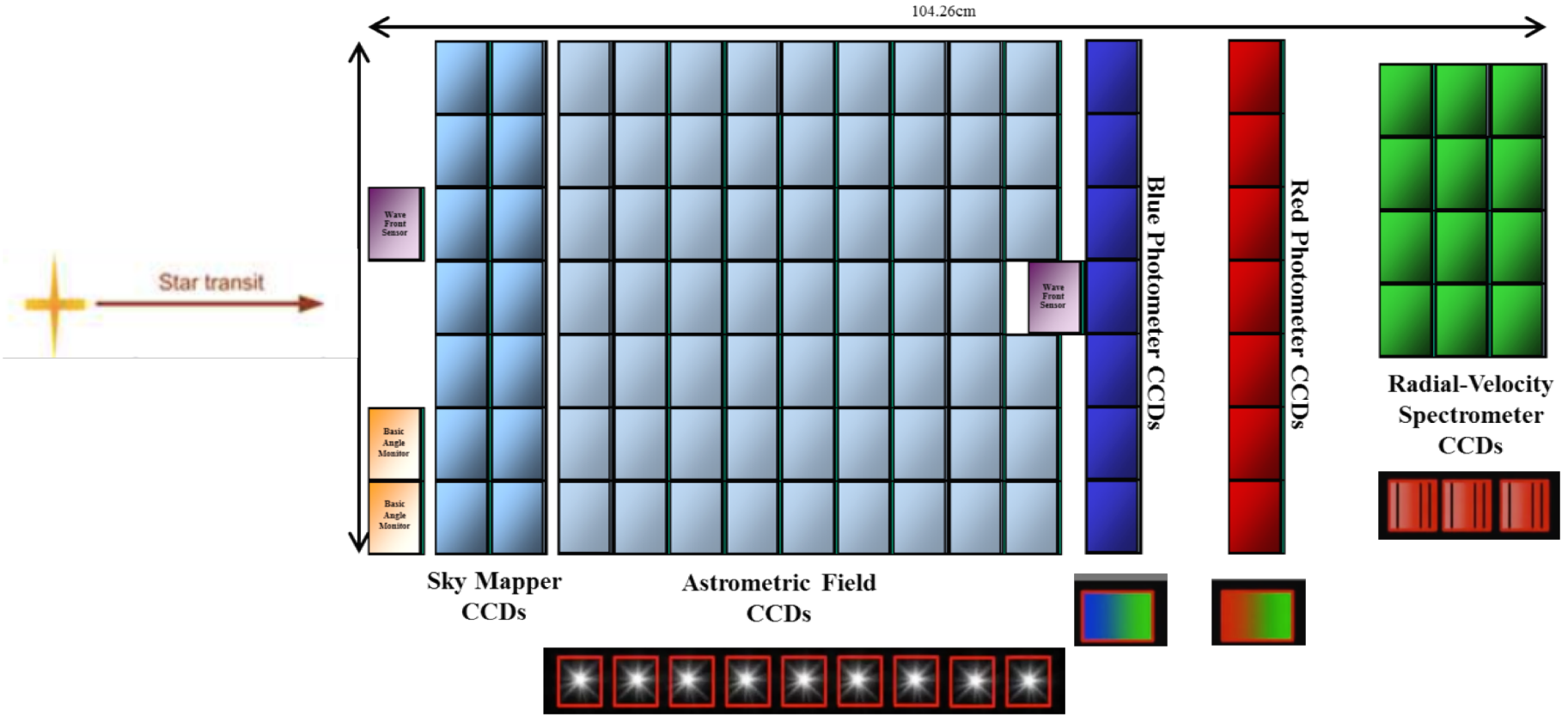
- Gaia vs LSST@VRO vs GaiaNir
- What Gaia can offer to LSST for variable sources
- What LSST can offer to GaiaNIR for variable sources

Gaia: 3 "Instruments" in 1

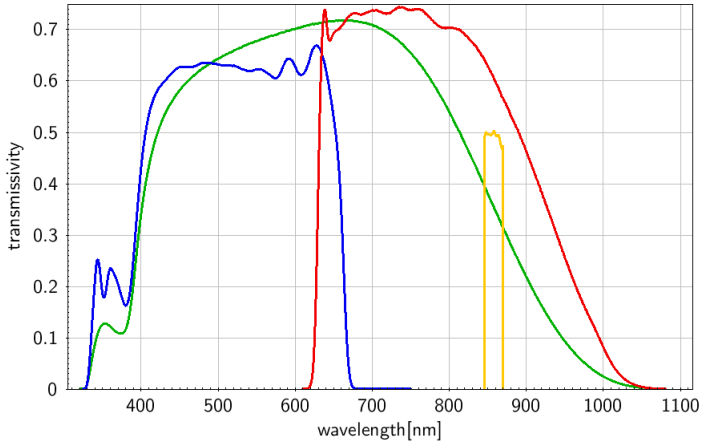
Astrometry, (Spectro)Photometry, Spectroscopy

G,	G_{BP},	G_{RP}	BP, RP,	RVS
330-1050 nm	330-680 nm	640-1050 nm	R~20-90	847-874 nm R=11,500

Gaia's focal plane



Gaia's passbands



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All Sky & Repeatedly: <N>~70 (G, G_{BP}, G_{RP}), ~40 (RVS) over 5 years

→ **Variable sources**

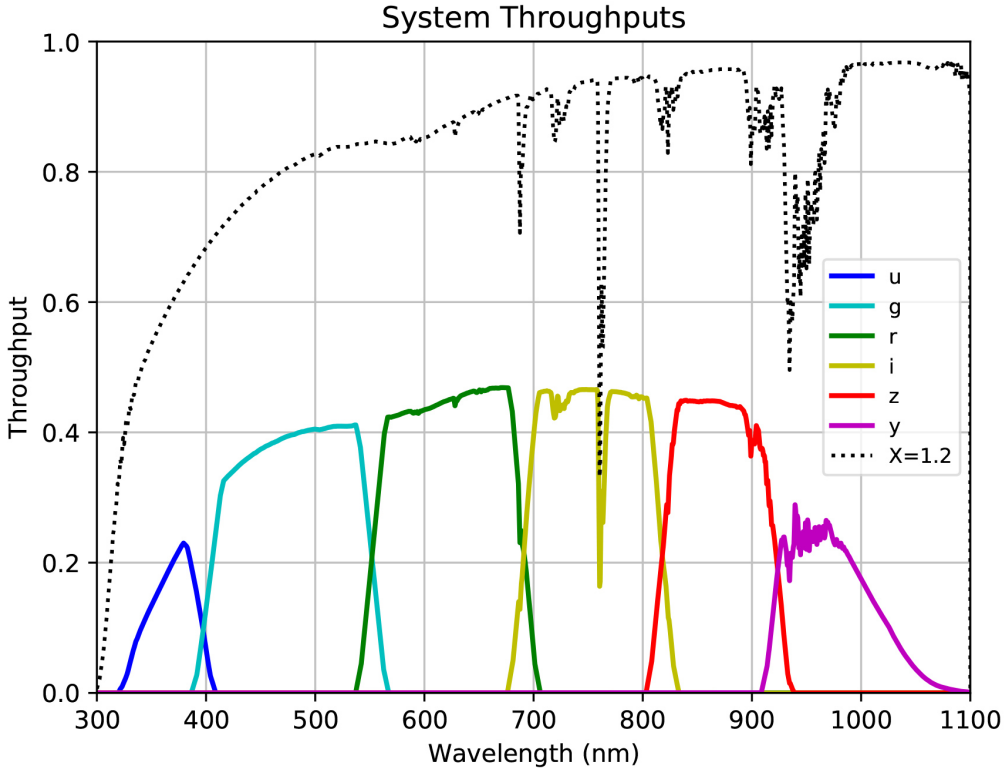
- Huge number of nearly **simoultaneous measurements** (for DR3 nearly one trillion CCD measurements) of all-sky sources down to a limiting magnitude **G~21** mag.
- Unprecedented astrometry
- Photometric precision reaching 1 mmag
- Systematic identification of all sky, variable sources of different types
- Incremental database and cyclic/iterative improved processing

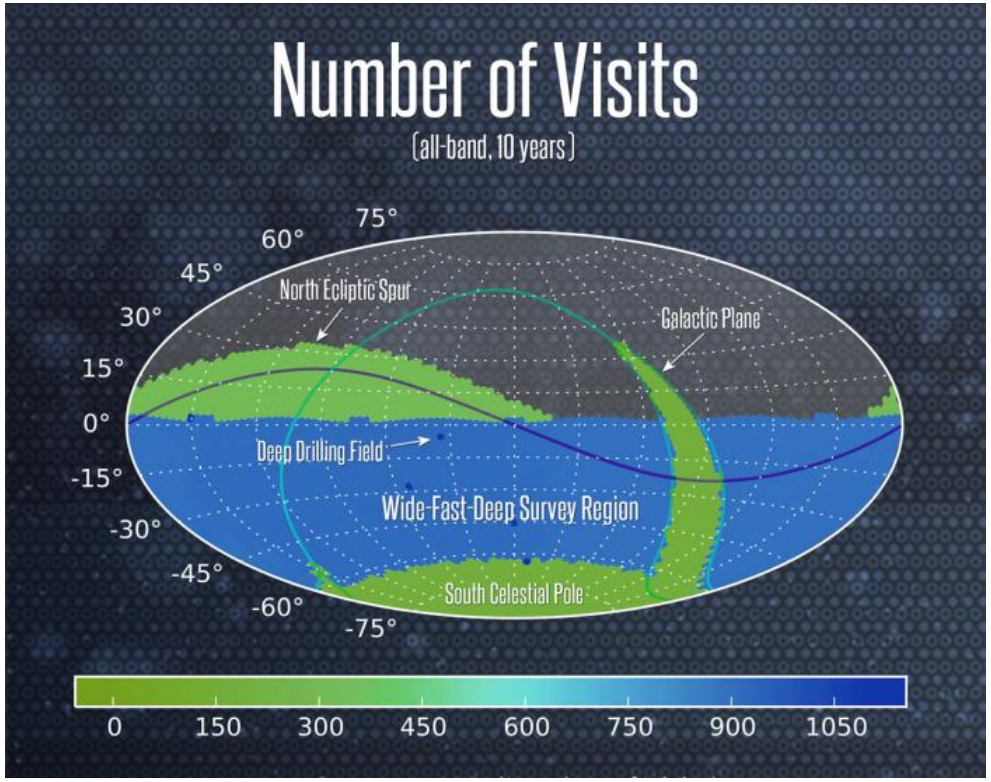
LSST @ V. Rubin Observatory

The Vera Rubin Observatory is a joint NSF and Department of Energy (DOE) funded observatory with an 8.4 m large-aperture, wide-field telescope, presently under construction on Cerro Pachón, Chile.

Over a ten-year period starting in summer 2025, Rubin will execute the Legacy Survey of Space and Time (LSST), an extremely deep (coadded depth ~27 mag) depth-limited survey of the entire Southern sky.

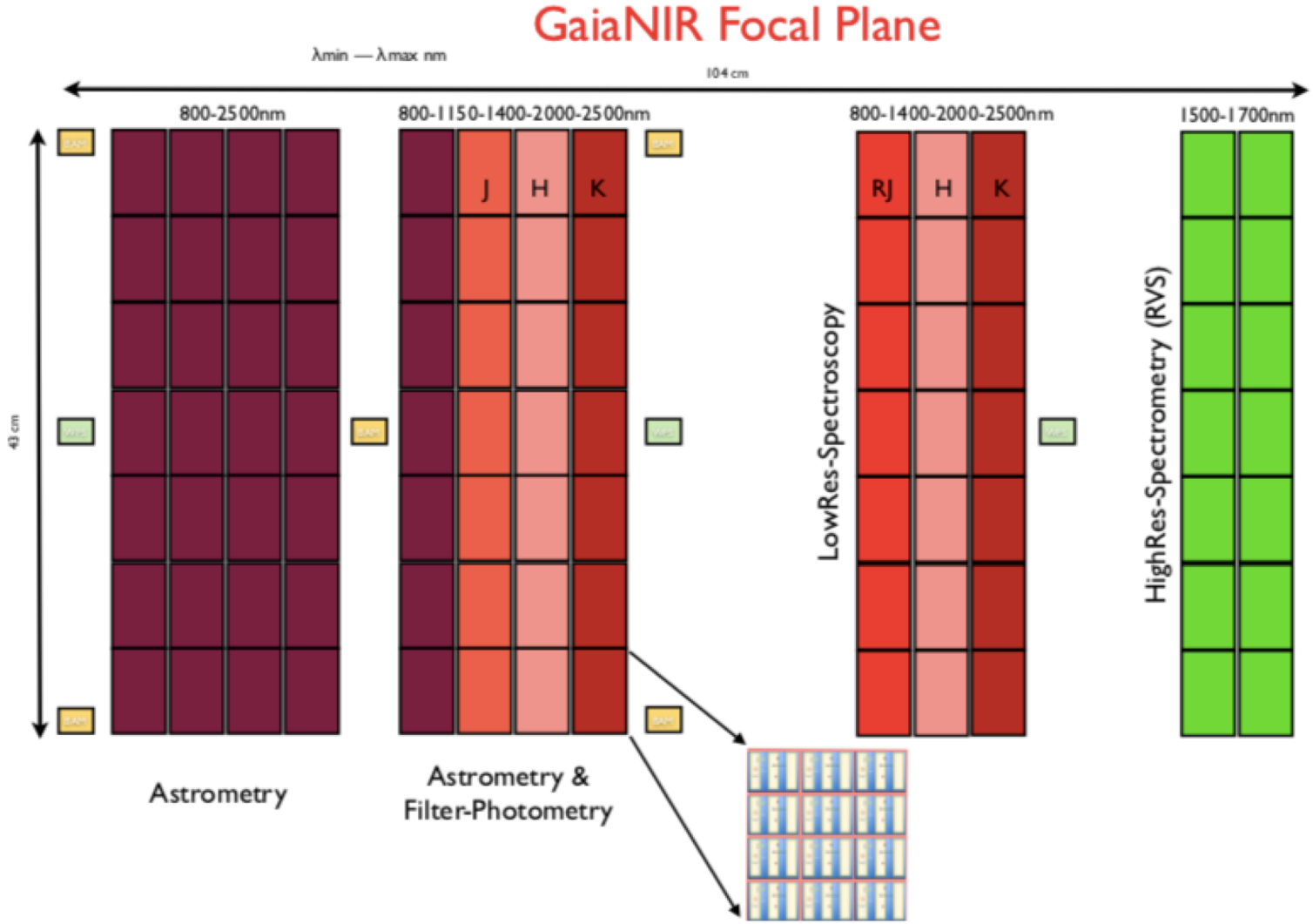
Enabled by its 9.6 square degree field of view, a 3.2 Gigapixel camera and a rapid observational cadence covering the sky every 3 nights in multiple bands (SDSS-*u*, *g*, *r*, *i*, *z*, *y*) and to single-exposure depths of r=24.5mag, the LSST is expected to collect 20 Tb data each night, concluding in a 60 petabyte data set and observations of 10 billion stars down to r ~ 27 as the legacy of the 10 yr survey.

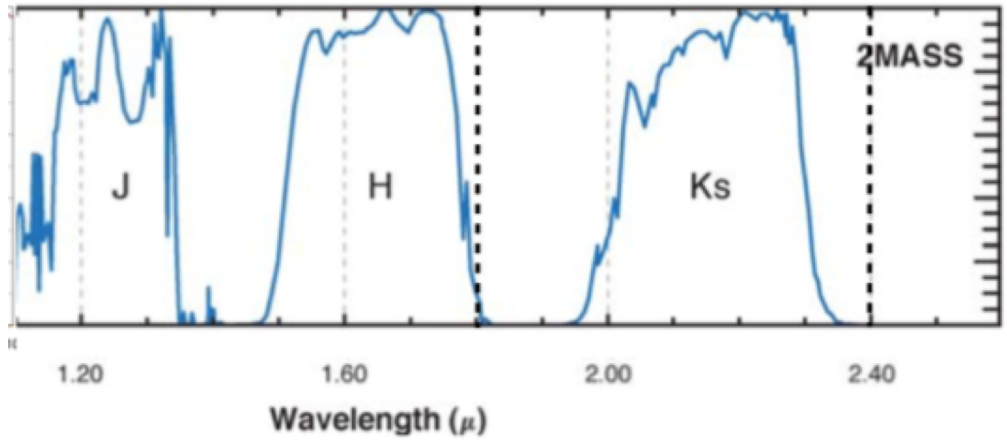




GAIANIR

A Gaia-like all-sky successor mission extending Gaia's astrometry, photometry and spectroscopy to the Near-InfraRed (NIR) with a wavelength cutoff in the K-band.





Gaia vs LSST vs GaiaNIR: filter passbands, limiting magnitudes

Gaia: 3 passbands

G	G_{BP}	G_{RP}
330-1050 nm	330-680 nm	640-1050 nm

G_{lim} ~ 21 mag

LSST: 6 passbands

SDSS-u, g, r, i, z, y

354.3 nm 477.0 nm 623.1 nm 762.5 nm 913.4 nm

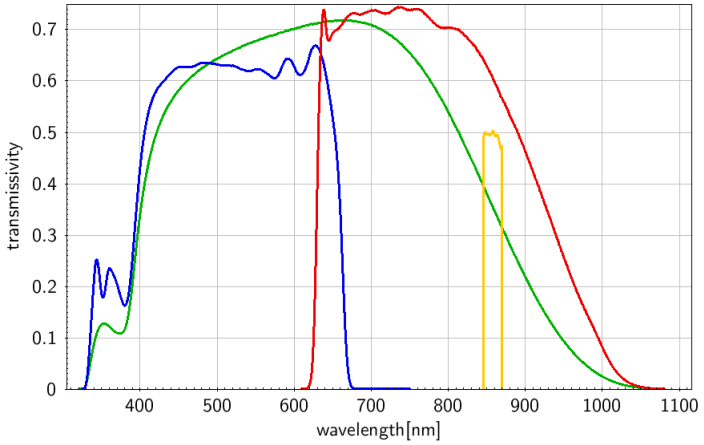
r_{lim} ~ 24.5 mag single exposure

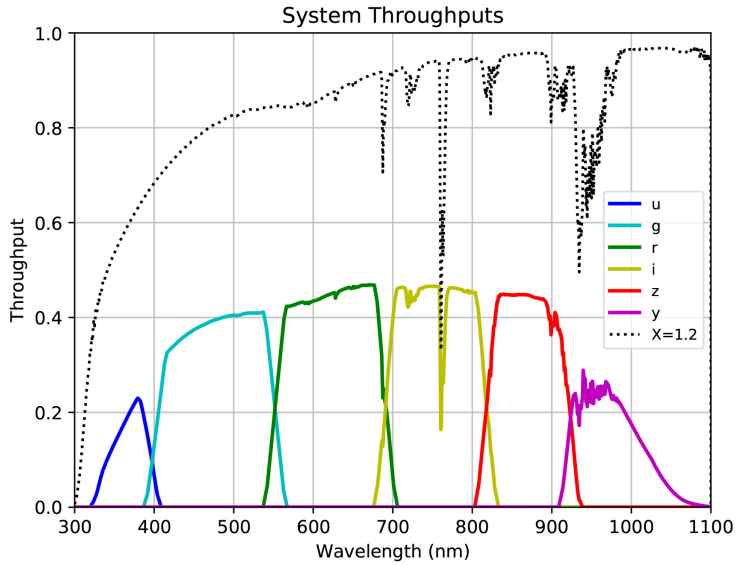
GaiaNIR: filter photometry in 3 passbands

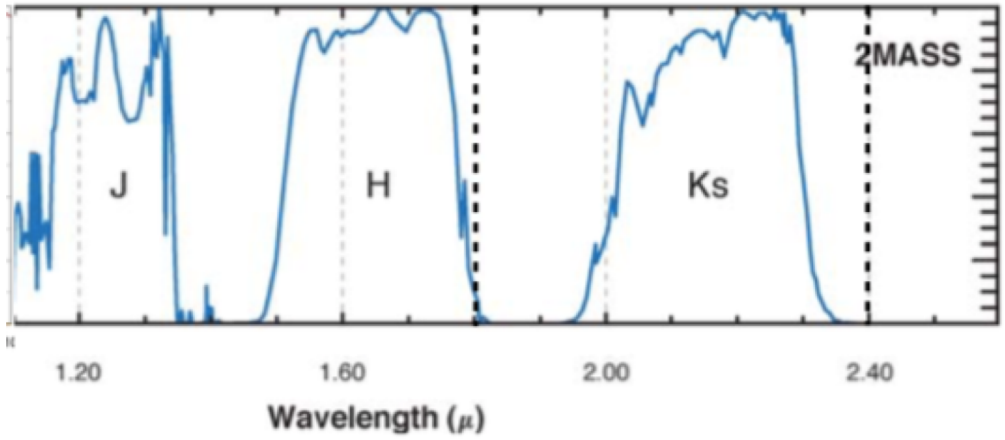
J, H, K

115-140 nm 140-190 nm 190-240 nm (K-band cutoff)

same as Gaia? 2-3 mag fainter?

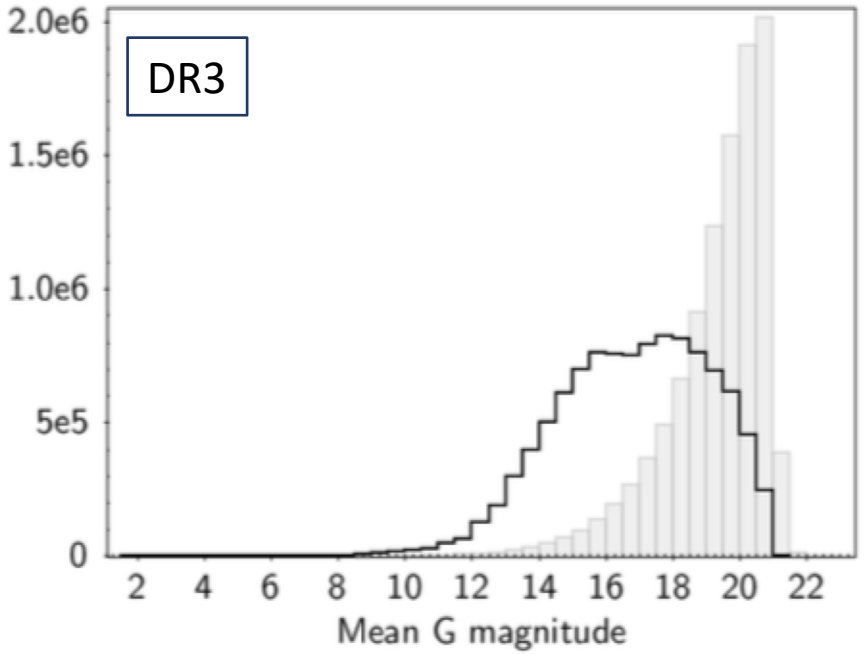




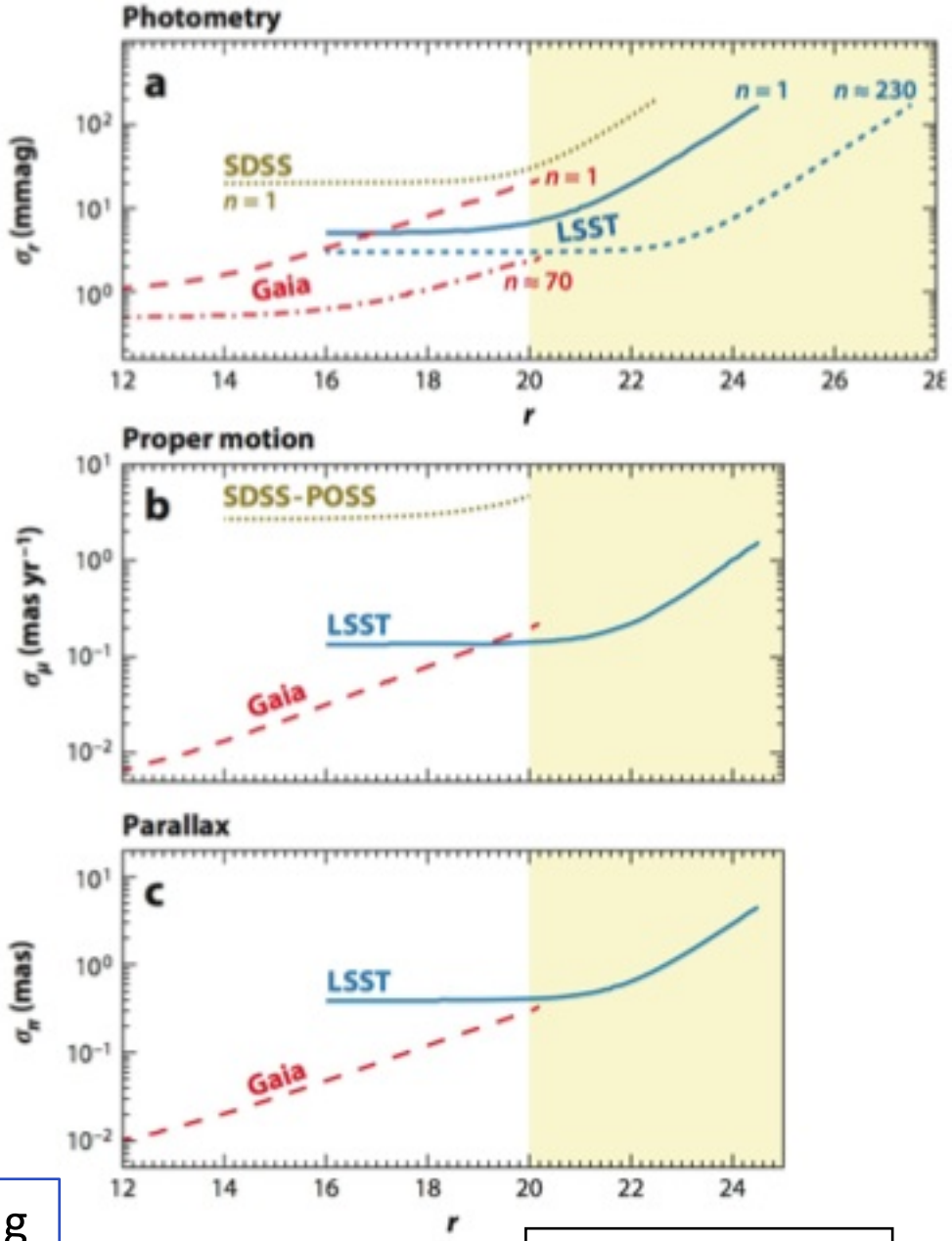


Overlap in spectral coverage between Gaia and LSST, but LSST reaching ~3.5 mag fainter in a single exposure, complementary with GaiaNIR

Synergies Gaia – LSST



Eyer et al. 2023



Ivezic et al. 2015

Gaia-LSST overlap of about 5 mag: $16 < r < 20.5\text{-}21$ mag

Overlap in spectral coverage between Gaia and LSST, but LSST reaching ~3.5 mag fainter in a single exposure, complementary with GaiaNIR

LSST will do good astrometry but with limited accuracy from the ground, obtaining parallax and proper-motion measurements of comparable accuracy, $\sigma_\pi \sim 0.6$ mas, $\sigma_\mu \sim 0.2$ mas yr^{-1}, to those of Gaia at its faint limit (G<20) and smoothly extending the error versus magnitude curve deeper by about 5 mag (Ivezić et al. 2015).

Thus, the LSST is anchored both in astrometry and photometry in the successful Gaia mission and is extremely complementary to GaiaNIR.

DR3 Variable Stars: Some statistics

Input data: 1.8 billion sources

Output: 10.5 million of variables (9.5 million variable stars + 1 million AGN/QSO)

24 variability types of which **11** with specific study, **35** variability subtypes

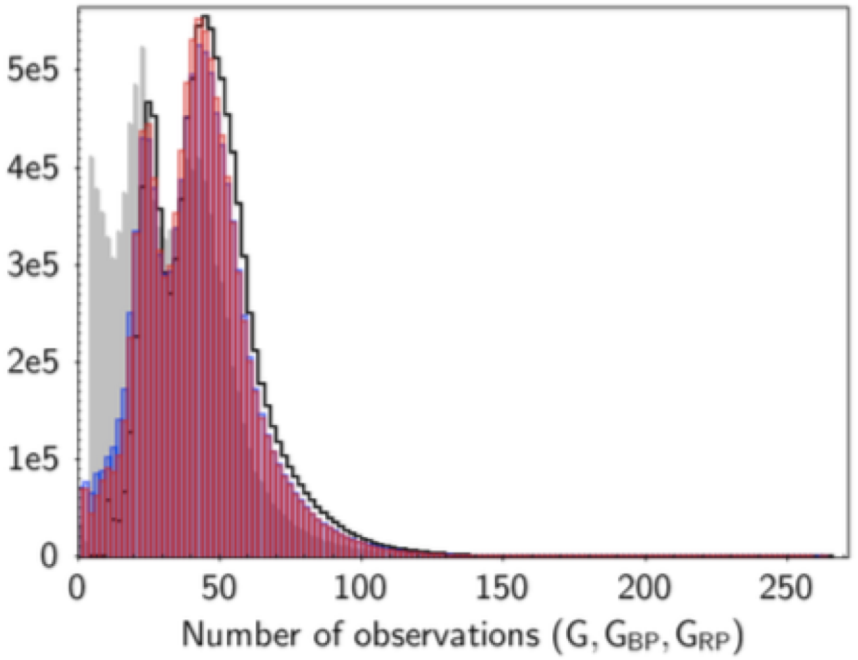


Fig. 1. Histogram of DR3 photometric FoV observations for the variables in the G (black), G_{BP} (blue) and G_{RP} (red) bands. The median numbers of measurements of G, BP and RP are 44, 40 and 41 though it extends up to 265 in the G band. In grey, we show the histogram of measurement numbers for the G magnitude of a random sample of 10.5 million stars. We see that the variability analysis favours a high number of measurements, as expected.

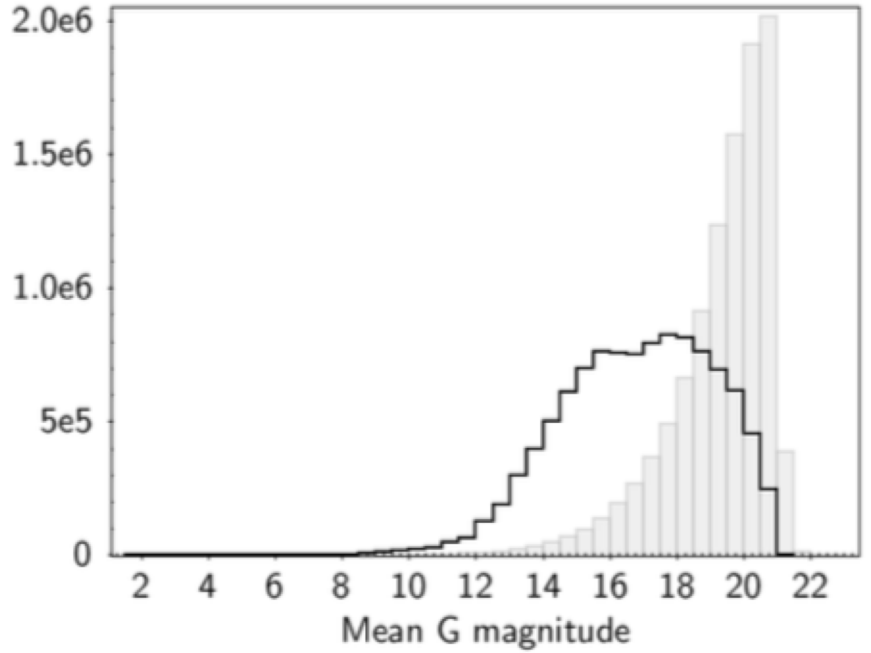


Fig. 2. Histogram of the mean magnitudes of the 10.5 million variable sources (black line). For comparison the histogram (grey) for a random selection of 10.5 million sources among the 1.8 billion.

Eyer et al. 2023

What Gaia can offer to LSST for variable sources

- Catalogues of variable sources of different types
  - source identification
  - multiband light (G, G_{BP}, G_{RP}) curves
  - attributes for different types of variables
  - catalogues of variables to train machine learning classifiers

- Software (for processing and validation)

Italian In-kind project S15

TITLE: Tools for classification, full characterization and validation of variable sources

INAF Team:
Gisella Clementini, INAF OAS Bologna (CL)
Vincenzo Ripepi , INAF OACN (Co-CL)
Alessia Garofalo, INAF OAS, Bologna
Massimiliano Gatto, INAF OACN, Naples
Tatiana Muraveva, INAF OAS, Bologna
A research fellow being recruited

Activity: Description

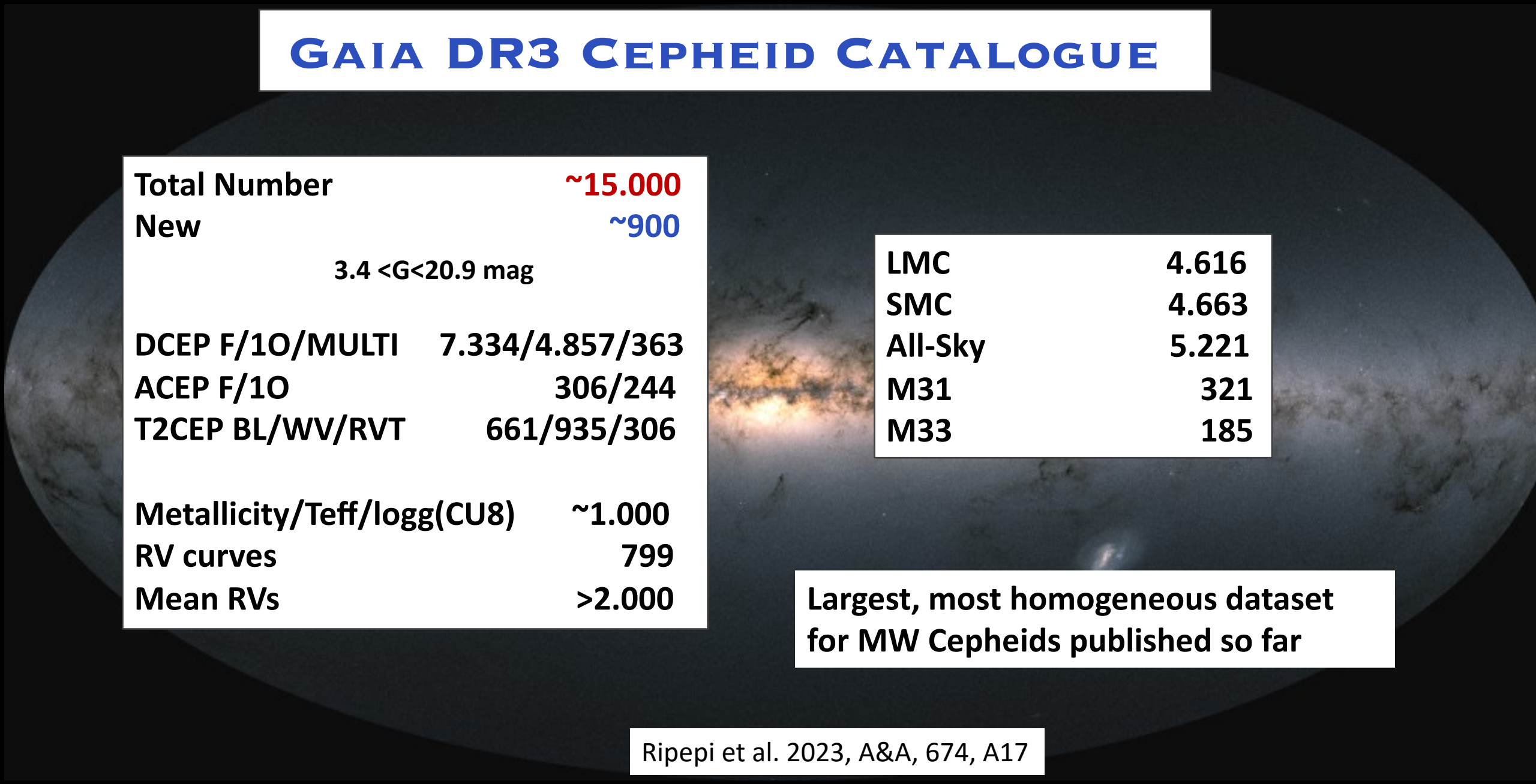
Our INAF team will contribute directable software development effort in the area of Rubin Transients and Variable Stars Science Collaboration, including machine/deep learning methods for prediction/classification tasks, tools for cross-matching with existing catalogues, analysis and validation of variable sources observed by the Rubin Observatory.

Catalogues of variable stars in Gaia DR3

- **10.5 million of variables** (9.5 million variable stars + 1 million AGN/QSO)
- Classification into **24 variability classes**, time series data for all of them
- Detailed **variability parameters** in dedicated tables for the following **11 classes**
  - Cepheids (15,021 objects);
  - Compact companions (6306 objects);
  - Eclipsing binaries (2,184,477 objects);
  - Long-period variables (1,720,588 objects);
  - Microlensing events (363 objects);
  - Planetary transits (214 objects);
  - RR Lyrae stars (271,779 objects);
  - Short-timescale variables (471,679 objects);
  - Solar-like rotational modulation variables (474,026 objects);
  - Upper-main-sequence oscillators (54,476 objects);
  - Active galactic nuclei (872,228 objects).

Gaia Data Release 3: Summary of the variability processing and analysis, **Eyer et al. 2023**, A&A, 674, A13

Gaia DR3 Cepheid Catalogue



Total Number	~15.000
New	~900
3.4 <G<20.9 mag	
DCEP F/1O/MULTI	7.334/4.857/363
ACEP F/1O	306/244
T2CEP BL/WV/RVT	661/935/306
Metallicity/Teff/logg(CU8)	~1.000
RV curves	799
Mean RVs	>2.000

LMC	4.616
SMC	4.663
All-Sky	5.221
M31	321
M33	185

Largest, most homogeneous dataset for MW Cepheids published so far

Ripepi et al. 2023, A&A, 674, A17

Gaia DR3 RR Lyrae Catalogue

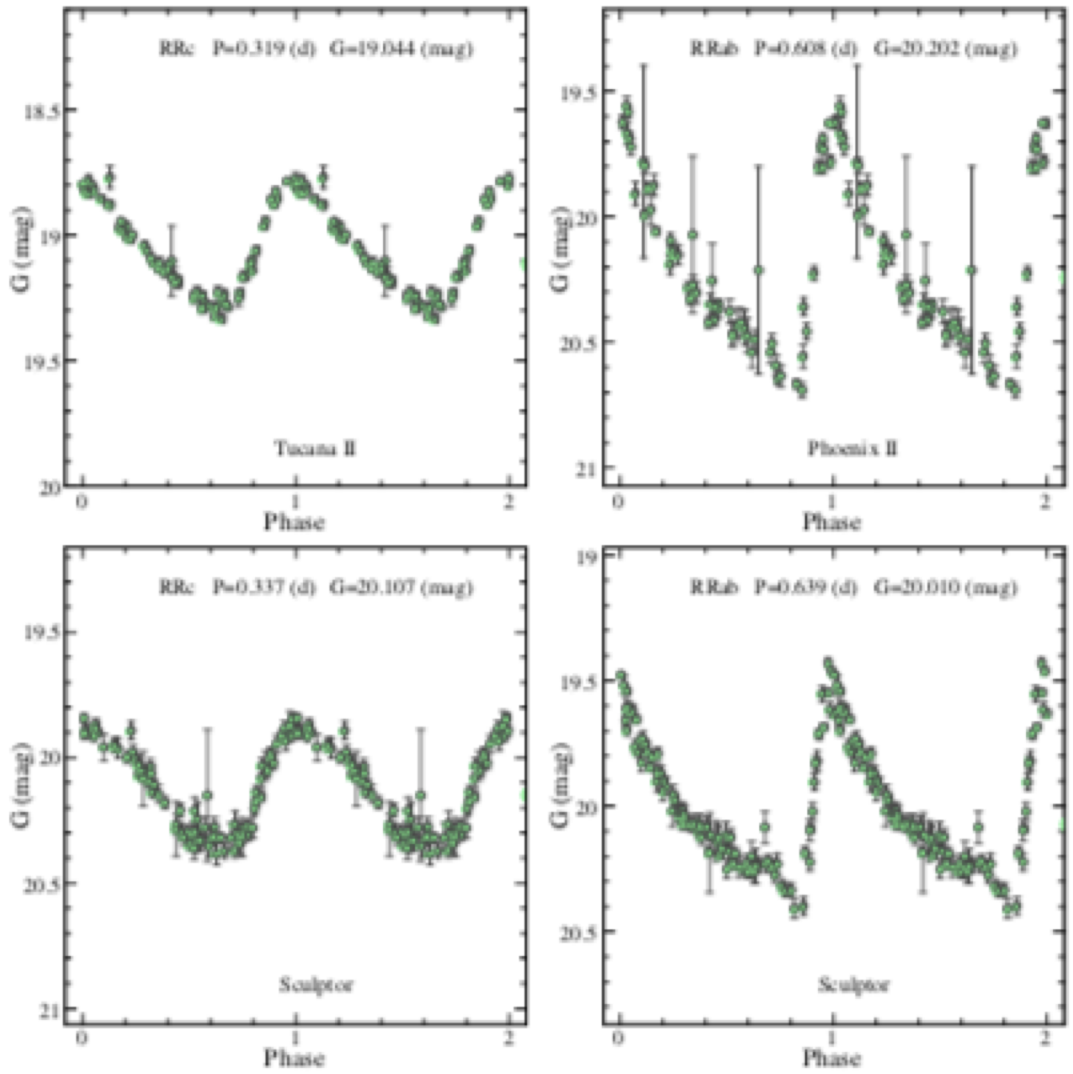
Total Number	270.905
Known	200.294
New	70.611
7.5 <G<21 mag	
RRab	174.947
RRc	93.952
RRd	2.006
Metallicity	133.559
G-absorption	142.660
RV curves	1.096
Mean RVs	5.096

LMC	31.379
SMC	4.788
All-Sky	234.738
95 Globulac Clusters	1.676
7 dSphs e 16 UFDs	1.114

Largest , most homogeneous and parameter-rich catalogue of all-sky RR Lyrae stars published so far

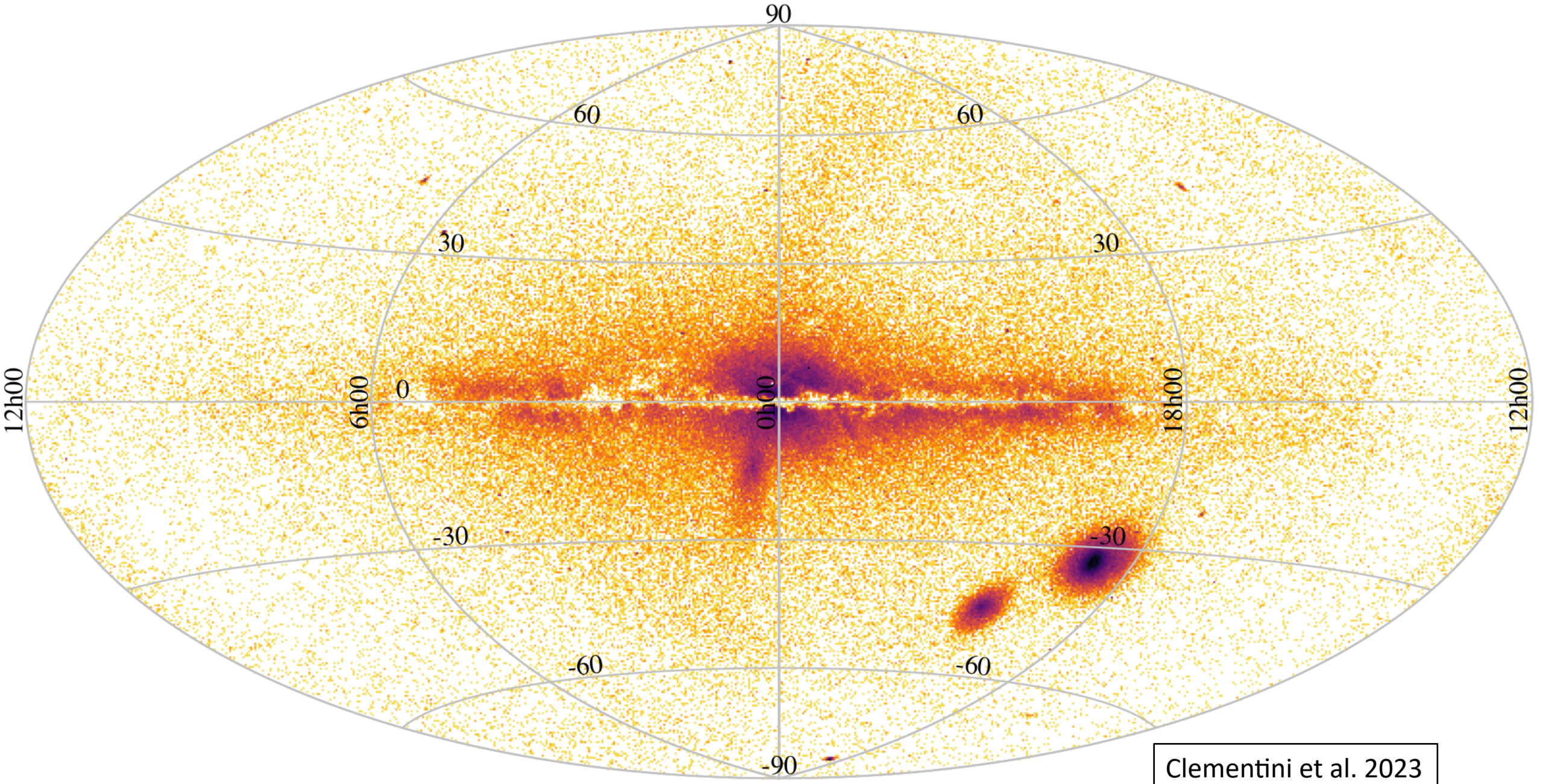
Clementini et al. 2023, A&A, 674, A18

G-band light curves at the f**aint** limit of Gaia



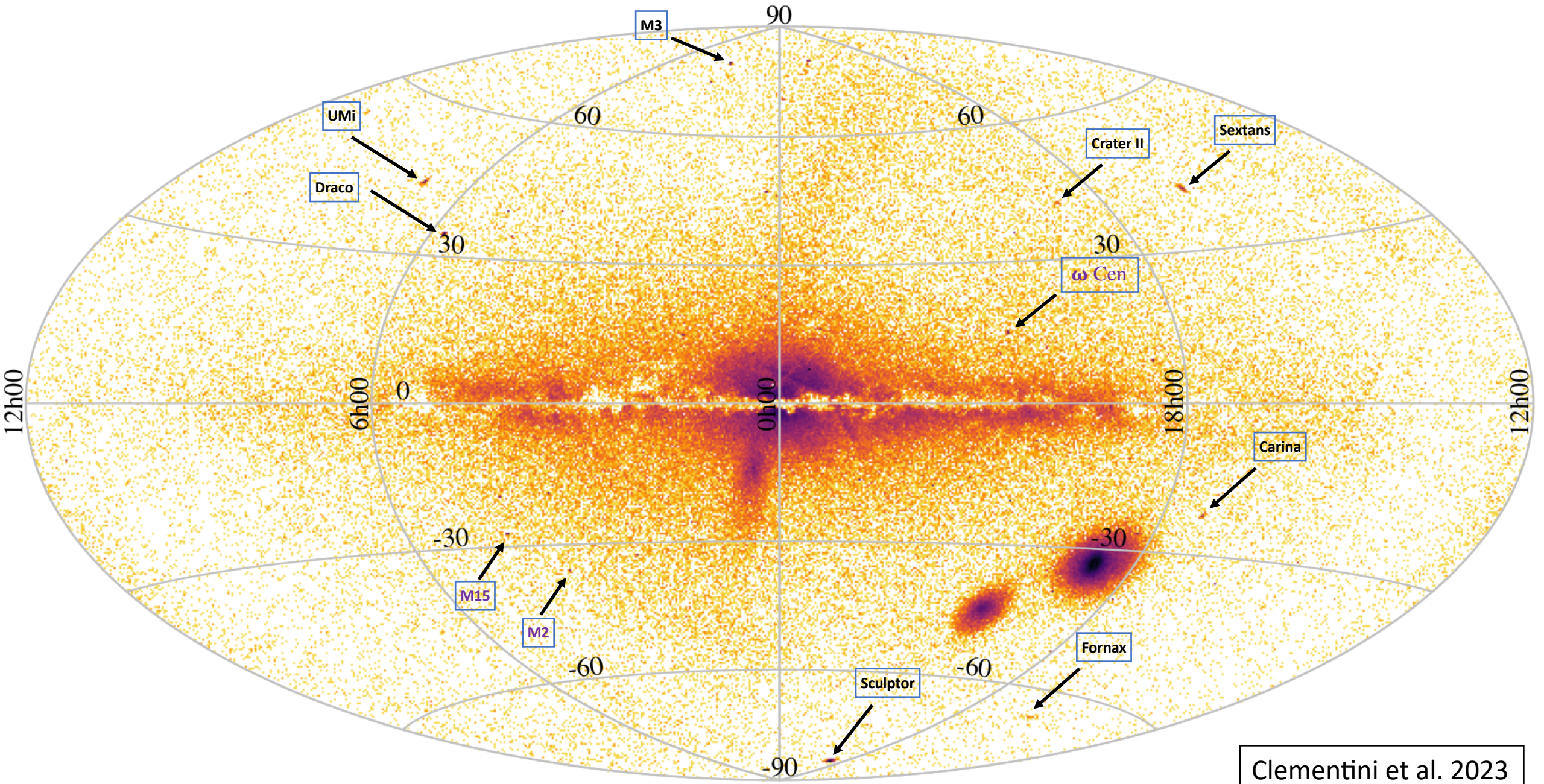
Clementini et al. 2023

RR Lyrae Stars in Gaia DR3: Sky Distribution



Clementini et al. 2023

RR Lyrae Stars in Gaia DR3



Clementini et al. 2023

What LSST can offer to GaiaNIR for variable sources

- Catalogues of variable sources of different types
  - source identification (down to *r* ~24.5 mag*)*
  - parallax measurements (although with large errors)
  - multiband light (SDSS filters) curves
  - attributes for different types of variables
  - catalogues of variables to train machine learning classifiers

Thank you