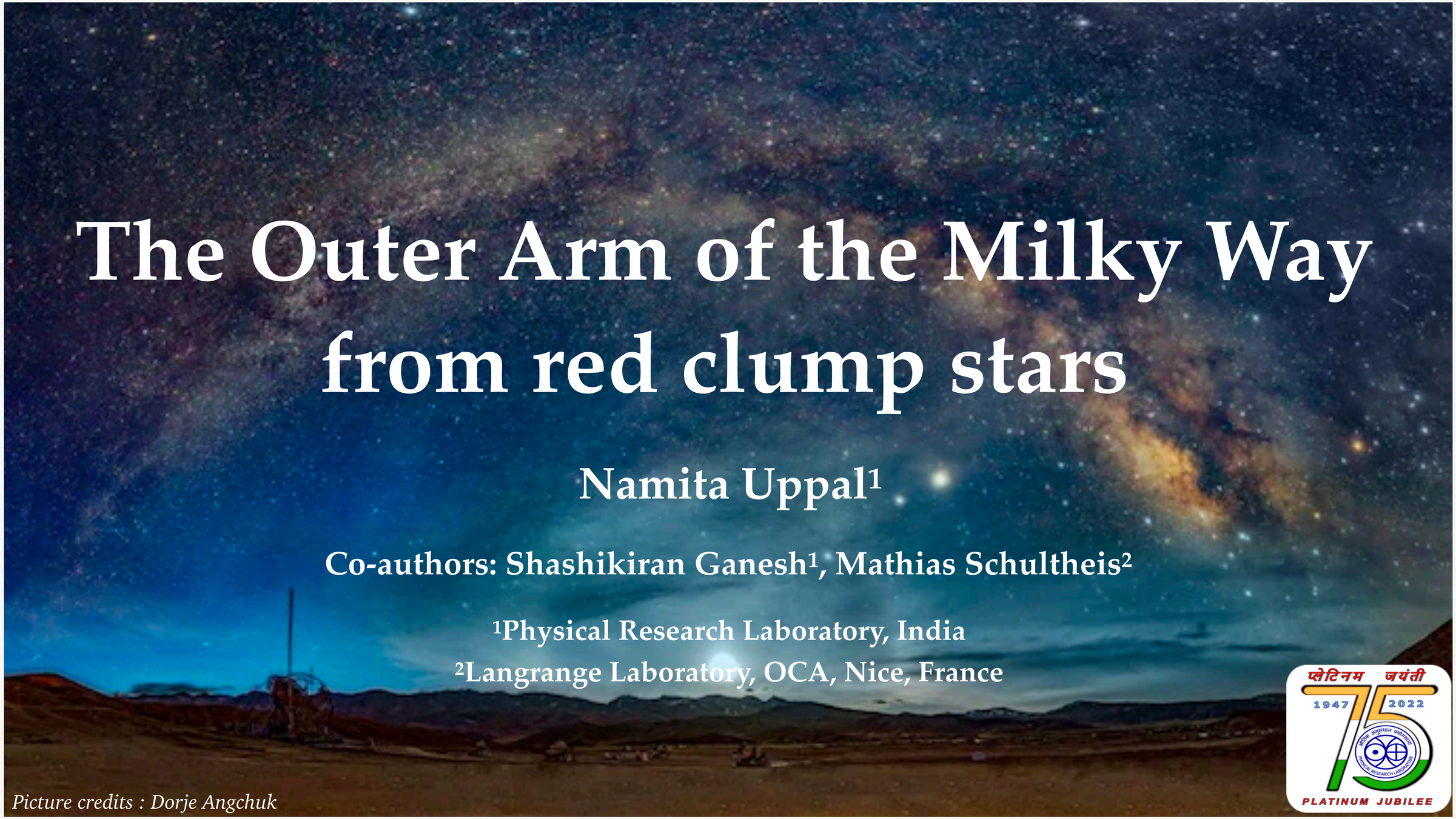


The Outer Arm of the Milky Way from red clump stars

Namita Uppal[1]

Co-authors: Shashikiran Ganesh[1], Mathias Schultheis[2]

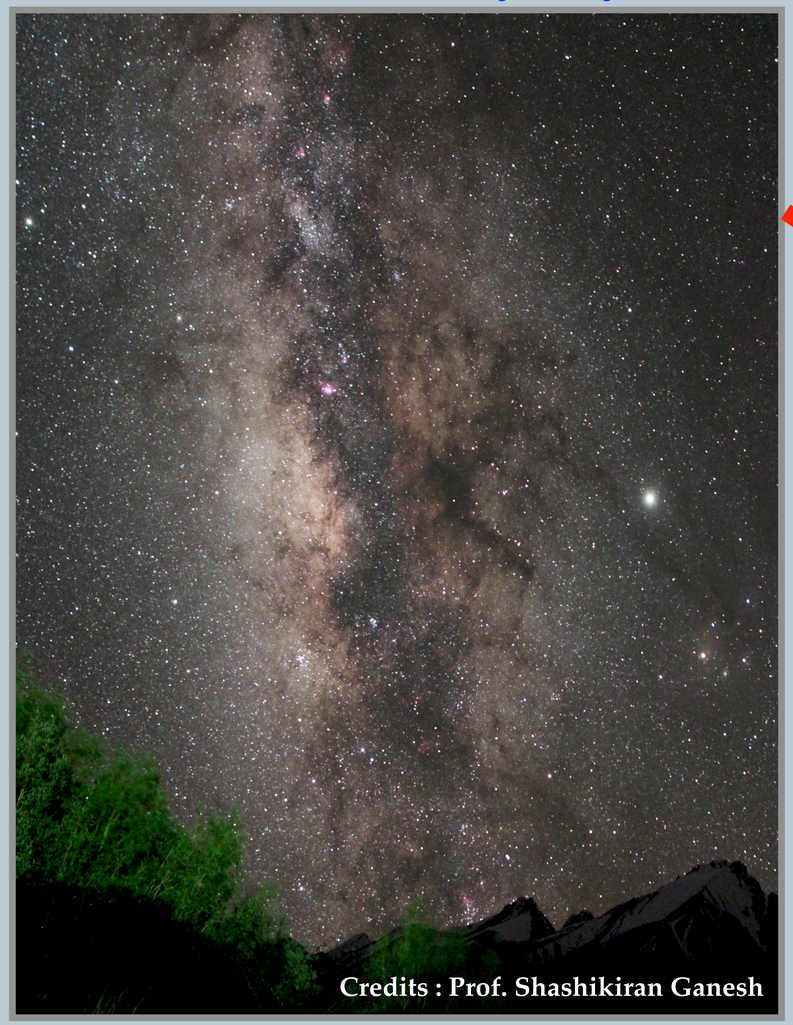
[1]Physical Research Laboratory, India

[2]Langrange Laboratory, OCA, Nice, France

Picture credits : Dorje Angchuk

3D picture of our home Galaxy Milky Way

Visual Milky Way



From: What we see

To: face-on view

Artistic impression

3D picture of our home Galaxy Milky Way

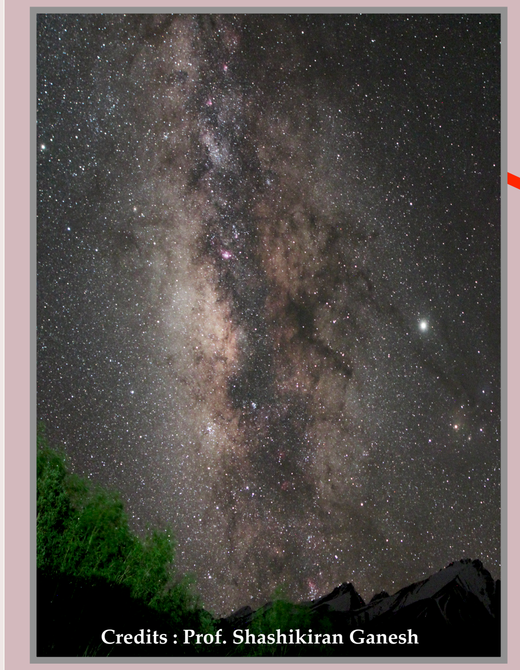
Problems

- Our position inside the Galaxy
- **Distance determination**
- Dust extinction in the optical.
- Distance ambiguities in longer wavelengths.

Requirements

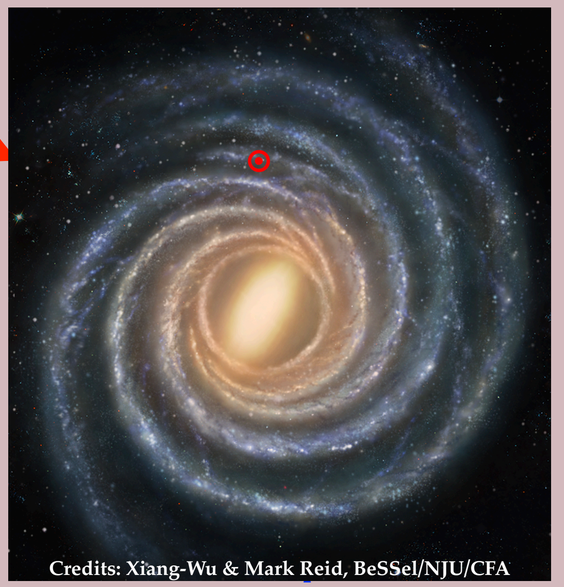
- Distance indicator stars.
- Numerously present in the Galaxy.
- Visible in longer wavelength, where extinction is relatively small.

Reality/ Actual View



From: What we see

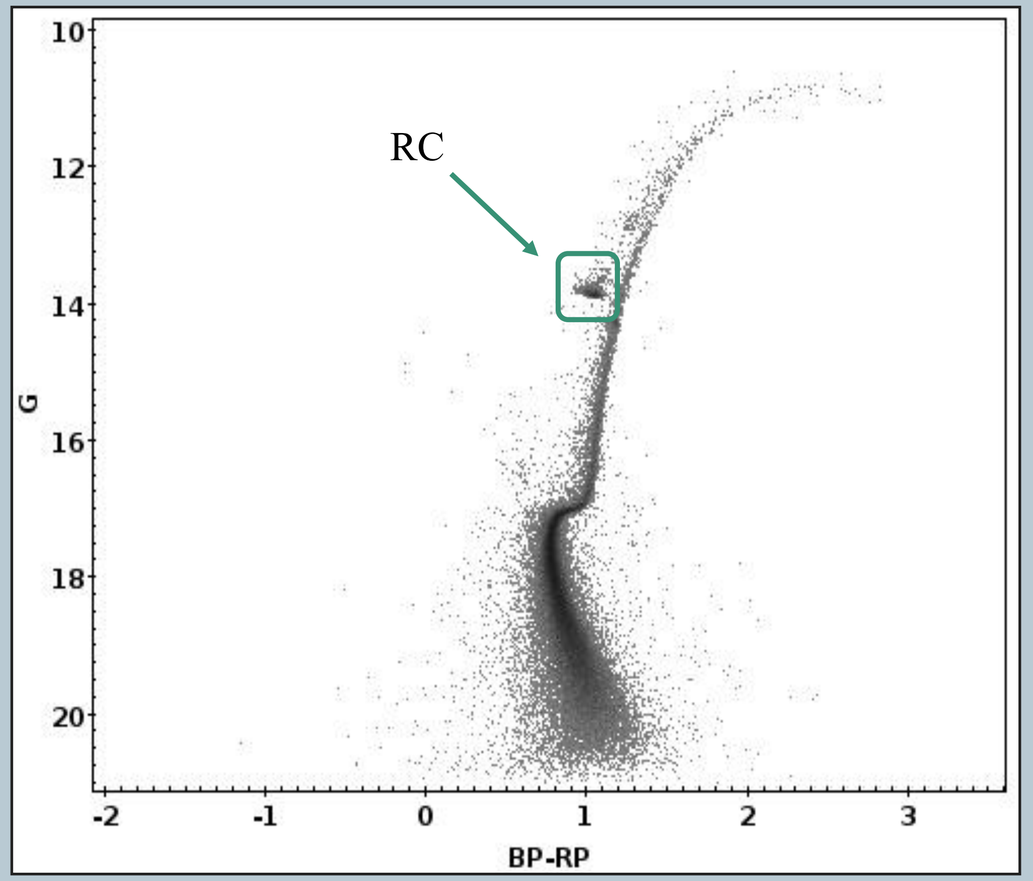
To: face-on view



Red clump stars

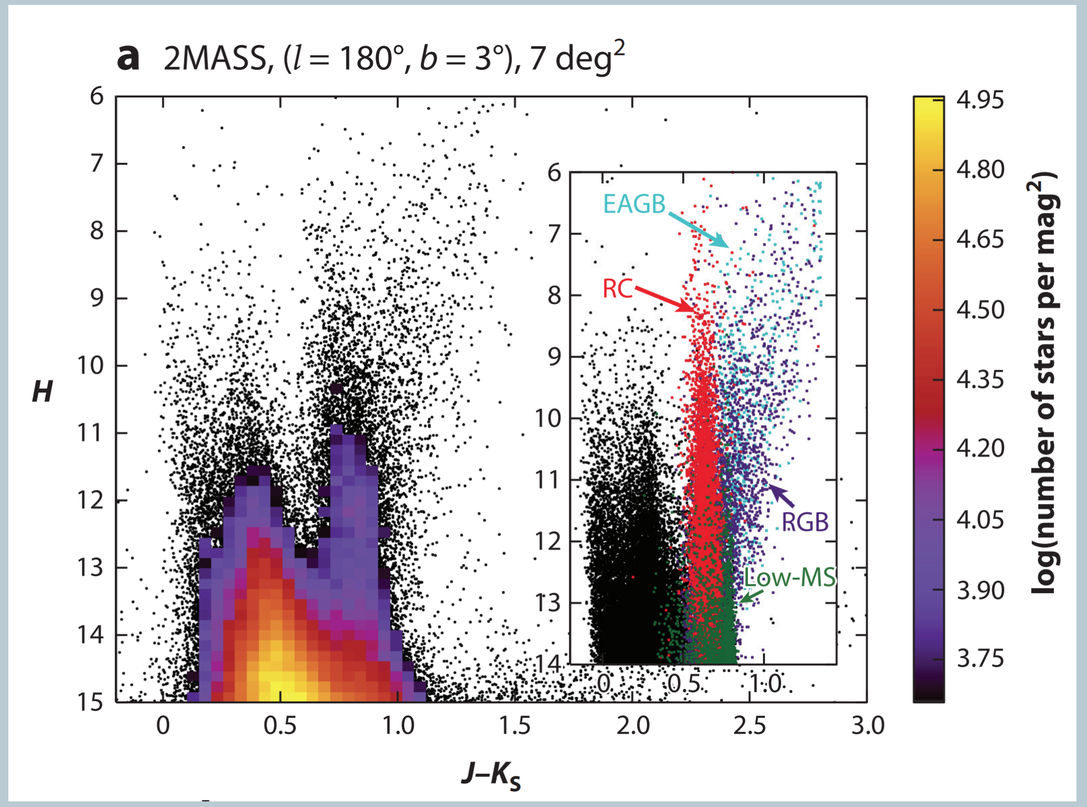
- **Low mass stars (M < 2$M_\odot$) -** numerously present in the Galaxy
- **K2 -type Giants**
- **Teff ~5000 K**
- **Metallicity ~ -0.6 dex to 0.4 dex.**
- **Absolute magnitude** $M_G = 0.495 \pm 0.009$
- **Intrinsic color** $(G_{BP} - G_{RP})_0 = 1.22 \pm 0.04$
- **Life span ~ 0.1 Gyr**

NGC104 cluster



Red clump stars

- **Low mass stars (M < $2M_{\odot}$) -** numerously present in the Galaxy
- **K2 -type Giants**
- **Teff ~5000 K**
- **Metallicity ~ -0.6 dex to 0.4 dex.**
- **Absolute magnitude** $M_G = 0.495 \pm 0.009$
- **Intrinsic color** $(G_{BP} - G_{RP})_0 = 1.22 \pm 0.04$
- **Life span ~ 0.1 Gyr**



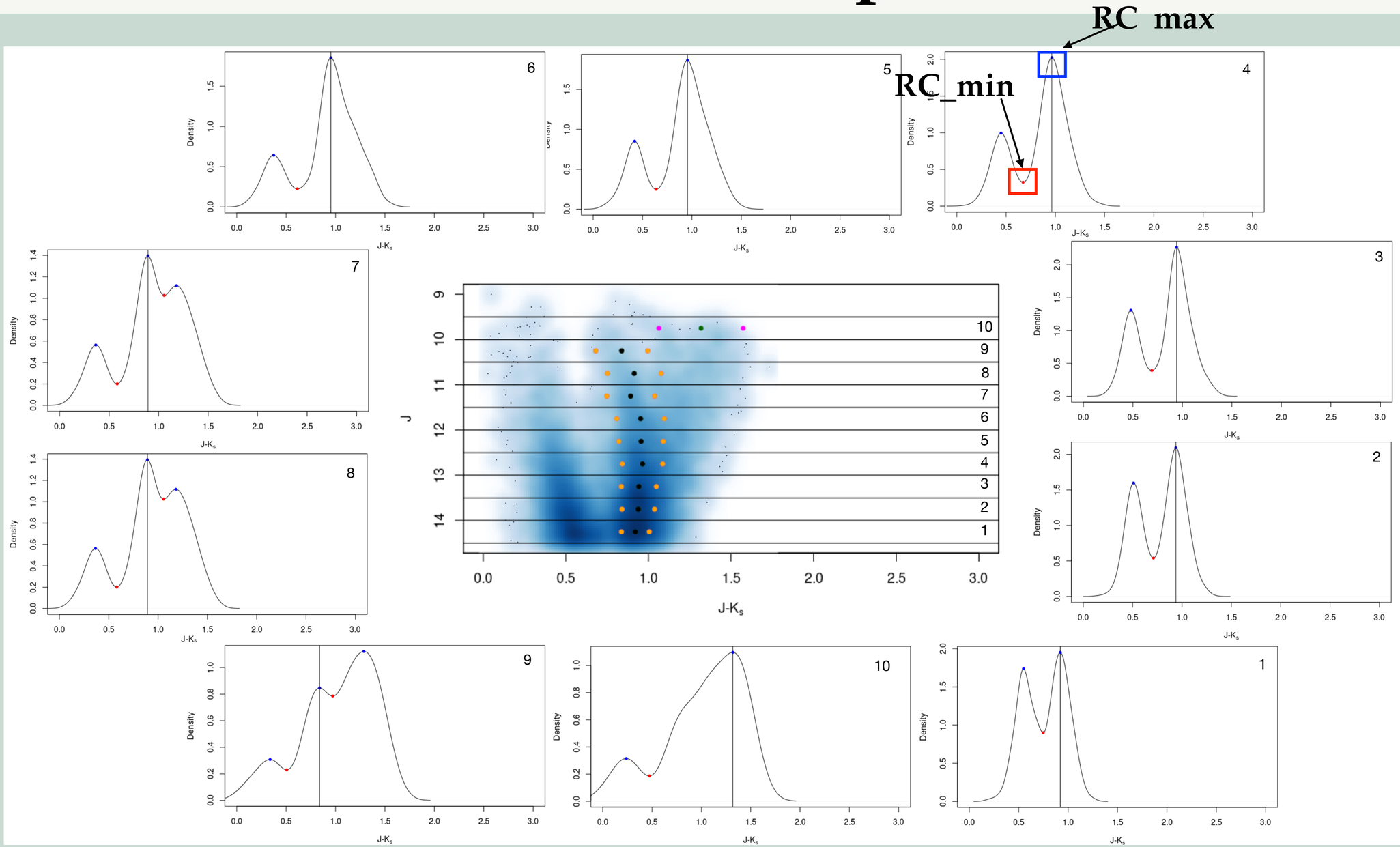
Léo Girardi (2016)

Extraction of red clump stars

$\ell = 45°$

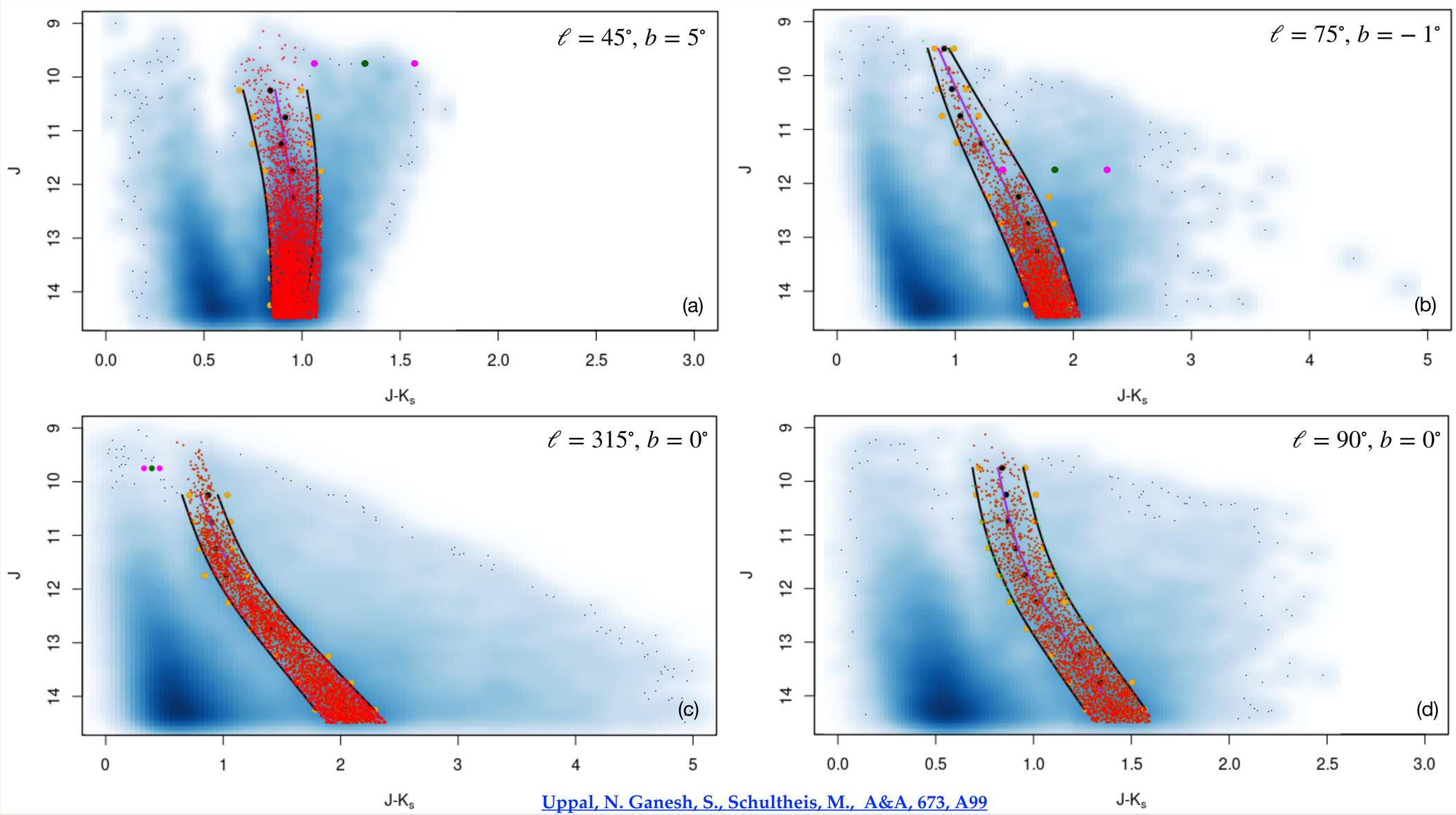
$b = 5°$

$1° \times 1°$



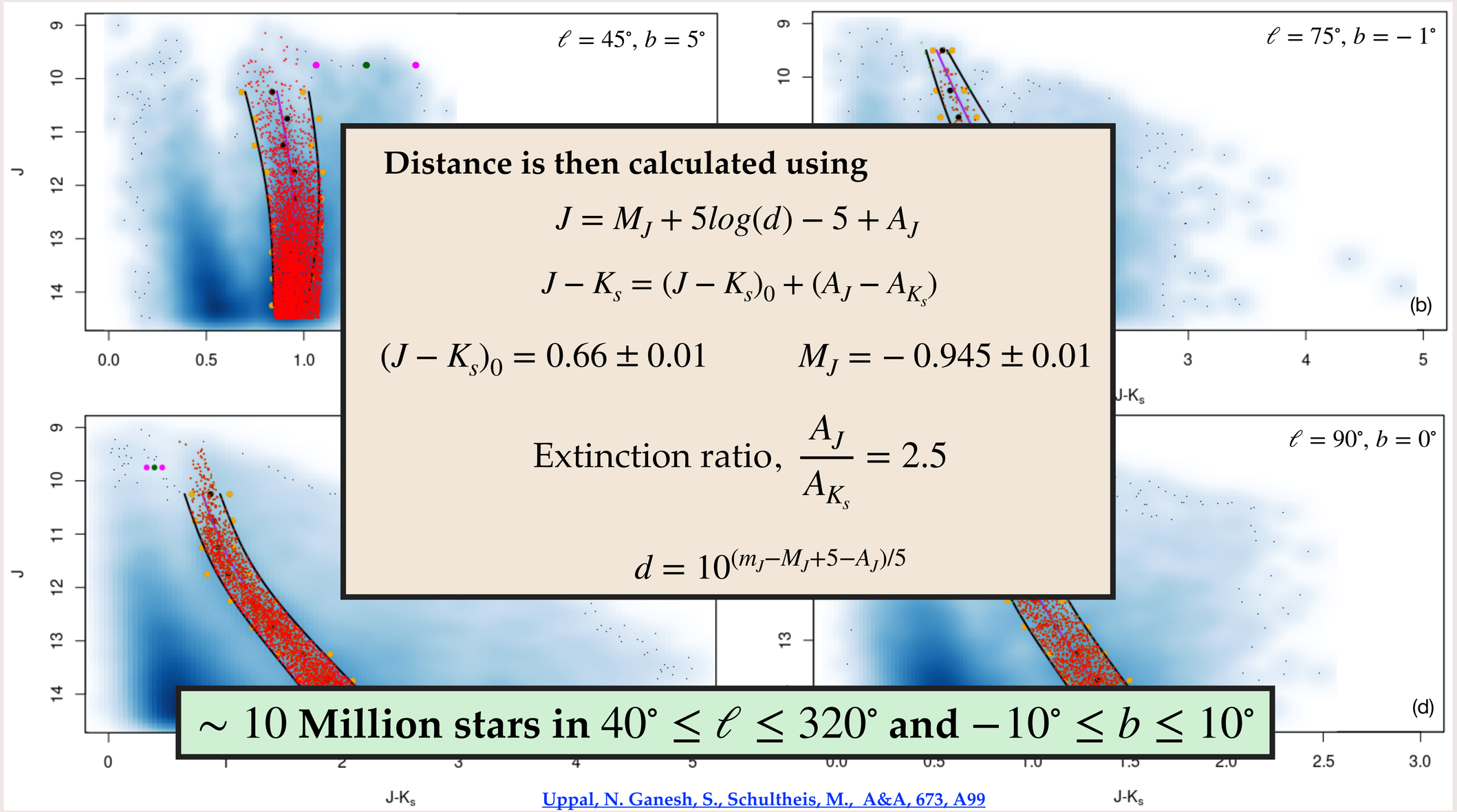
Uppal, N. Ganesh, S., Schultheis, M., A&A, 673, A99

Extraction of red clump stars



Uppal, N. Ganesh, S., Schultheis, M., A&A, 673, A99

Extraction of red clump stars



Distance is then calculated using

$$J = M_J + 5log(d) - 5 + A_J$$

$$J - K_s = (J - K_s)_0 + (A_J - A_{K_s})$$

$$(J - K_s)_0 = 0.66 \pm 0.01 \qquad M_J = -0.945 \pm 0.01$$

$$\text{Extinction ratio, } \frac{A_J}{A_{K_s}} = 2.5$$

$$d = 10^{(m_J - M_J + 5 - A_J)/5}$$

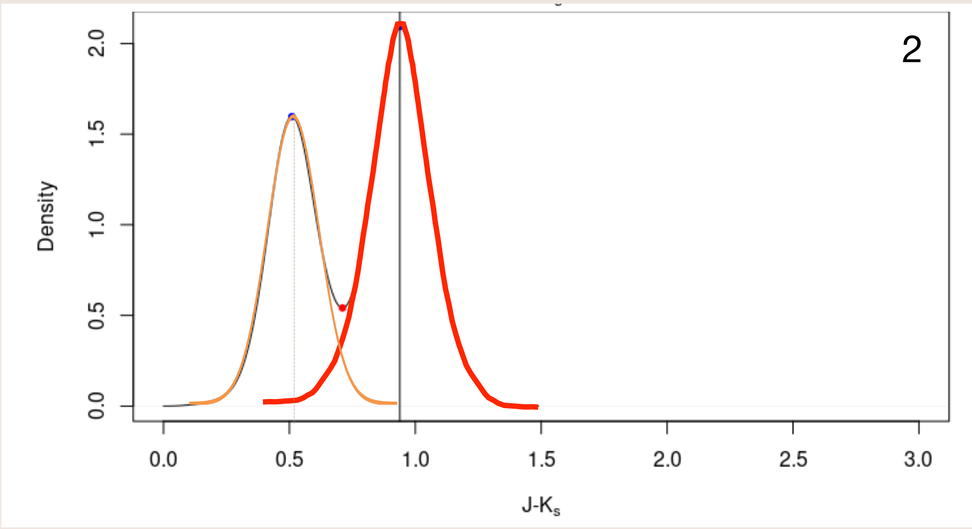
$\sim$ 10 Million stars in $40° \leq \ell \leq 320°$ and $-10° \leq b \leq 10°$

Uppal, N. Ganesh, S., Schultheis, M., A&A, 673, A99

Completeness & Foreground Contamination

Completeness

- 1σ region is decided to select pure sample and reduce contamination.
- For a gaussian distribution 1σ implies 66.5% probability.
- 34% will be missing.
- Increasing to 2σ or 3σ will increase the contamination.



Contamination

- Foreground stars - good Gaia parallax / distance.

(Distance - Bailer Jones+ 2021)

10.3 million Gaia crossmatch

| Gaia dis - our dis | > 1.5 kpc

for sources having Gaia dis error < 10%

14-15% contamination

These sources removed from our list

8.8 million RC stars

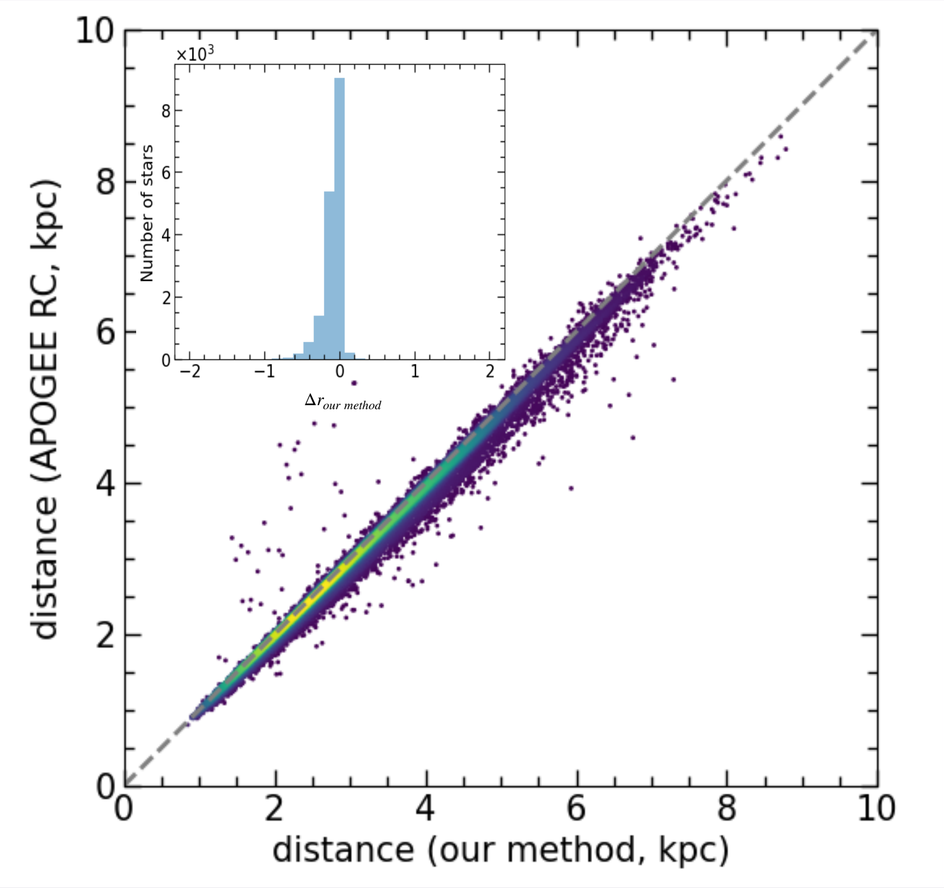
Distance comparison

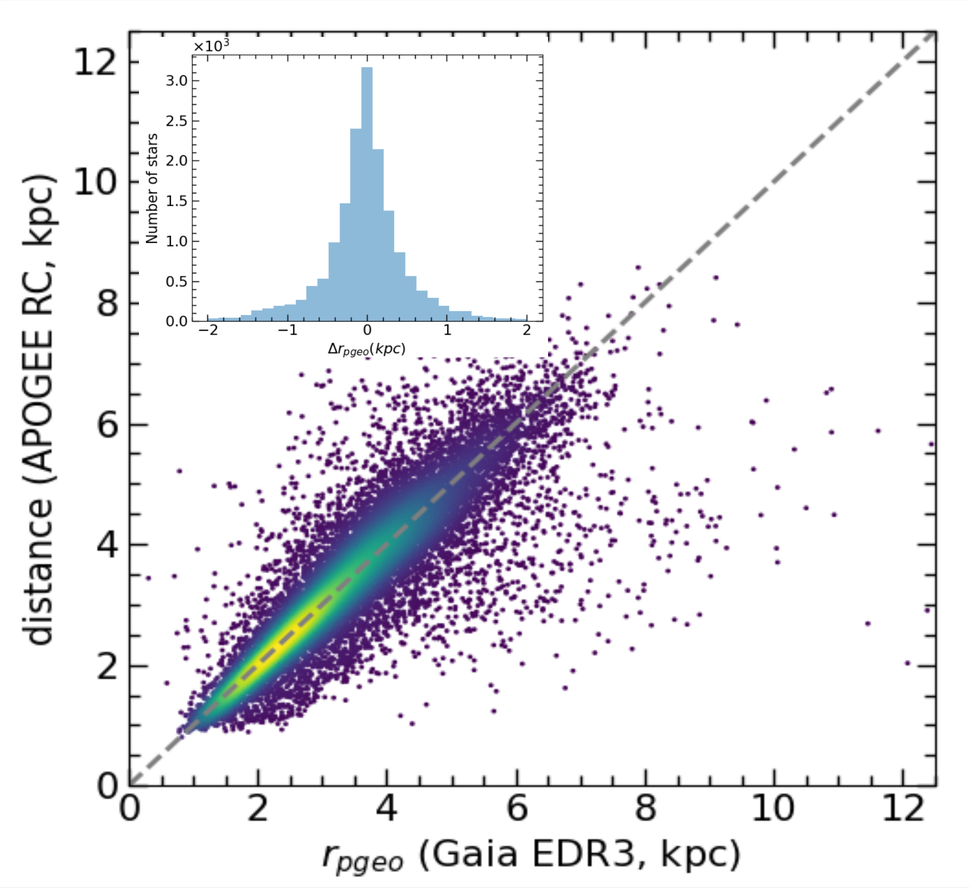
Gaia Collaboration et al. (2022)

(Andrae et al. 2022)

rpgeo - best out of rgeo, rpgeo (Gaia EDR3), dis (Gaia DR3)

(Bailer-Jones et al. 2021)





Uppal, N. Ganesh, S., Schultheis, M., A&A, 673, A99

Results : Detection of Outer arm

Overdensity map

$$\Delta_\Sigma = \frac{\Sigma(X,Y)}{<\Sigma(X,Y)>} - 1$$

Following Poggio+2021

$\Sigma(X,Y)$ local density at (X,Y), bandwidth = 0.5 kpc

$<\Sigma(X,Y)>$ mean density, bandwidth = 2 kpc

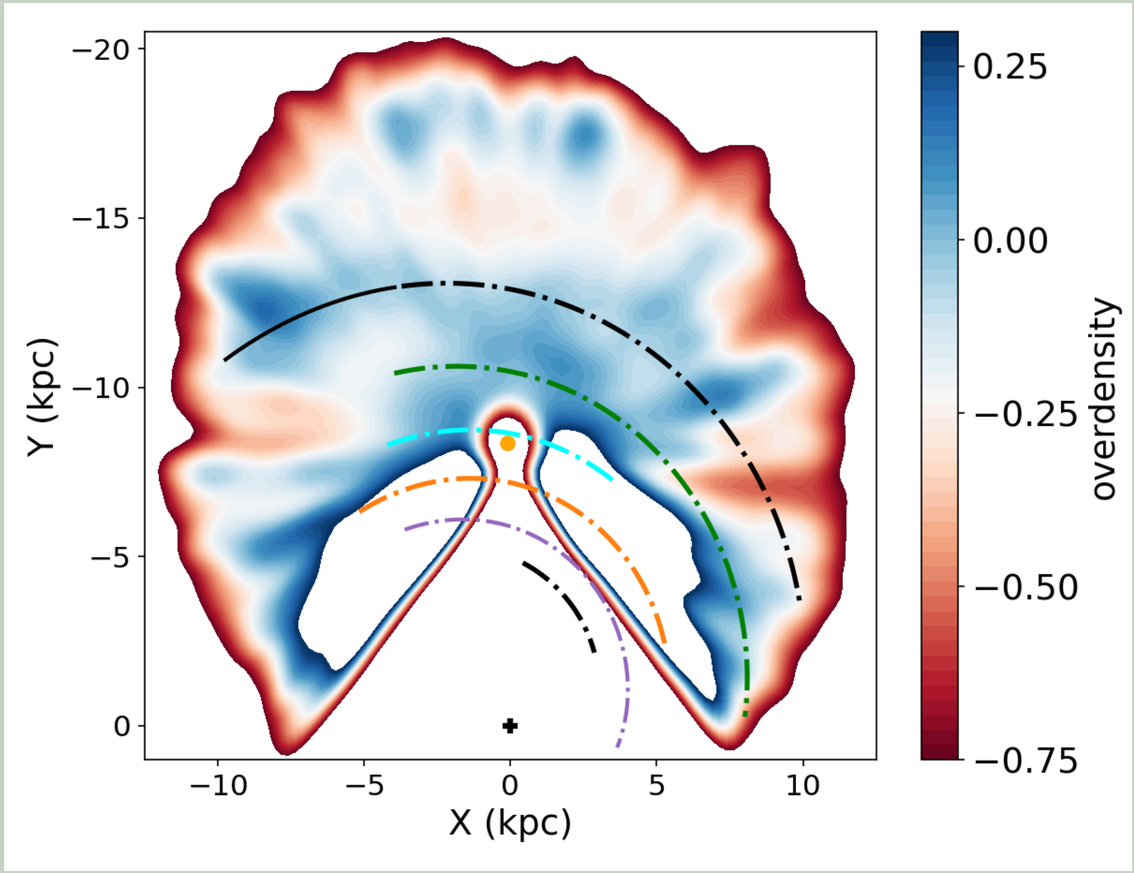
Scutum arm **Local arm**

Sagittarius arm **Perseus arm**

Castro-Ginard et al.(2021)

Norma-Outer arm

Reid et al. (2019)



Uppal, N. Ganesh, S., Schultheis, M., A&A, 673, A99

Results : Detection of Outer arm

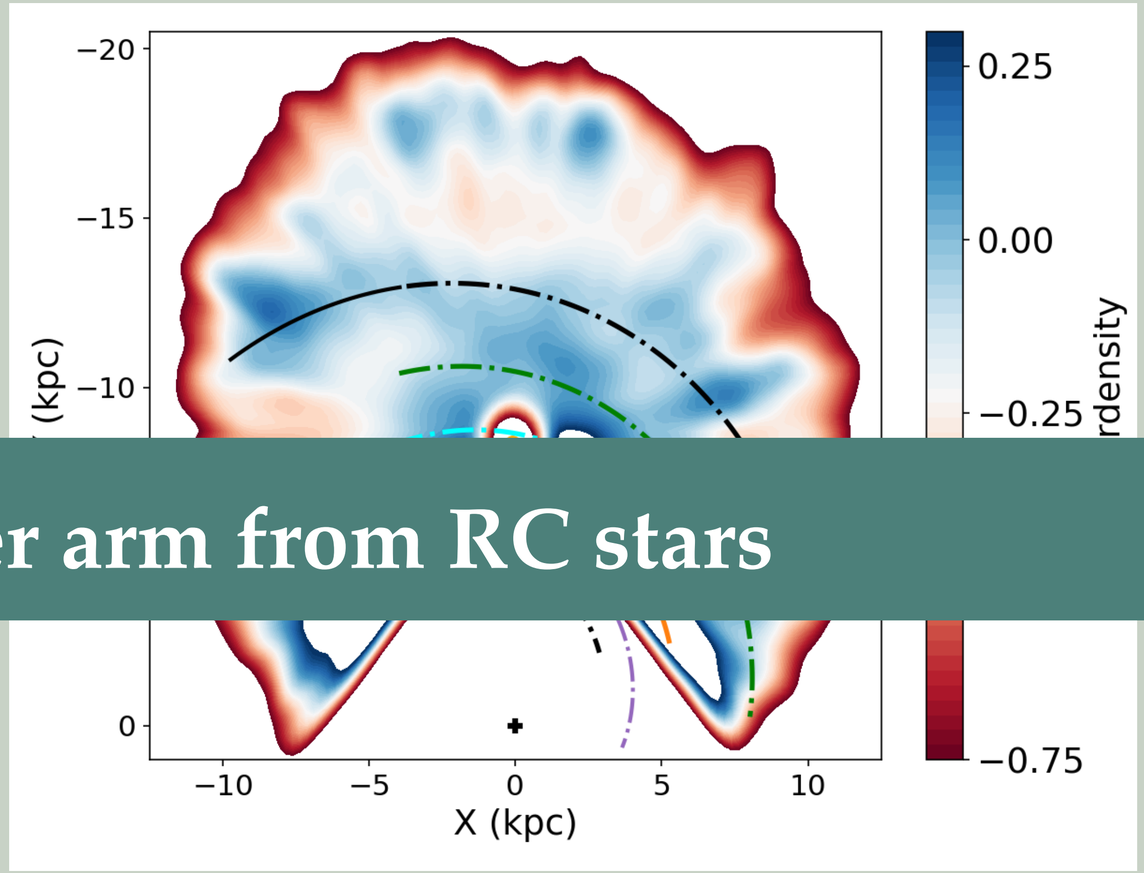
Overdensity map

$$\Delta_\Sigma = \frac{\Sigma(X,Y)}{<\Sigma(X,Y)>} - 1$$

Following Poggio+2021

$\Sigma(X,Y)$ local density at (X,Y), bandwidth = 0.5 kpc

$<\Sigma(X,Y)>$ mean density, bandwidth = 2 kpc



Uppal, N. Ganesh, S., Schultheis, M., A&A, 673, A99

Detection of Outer arm from RC stars

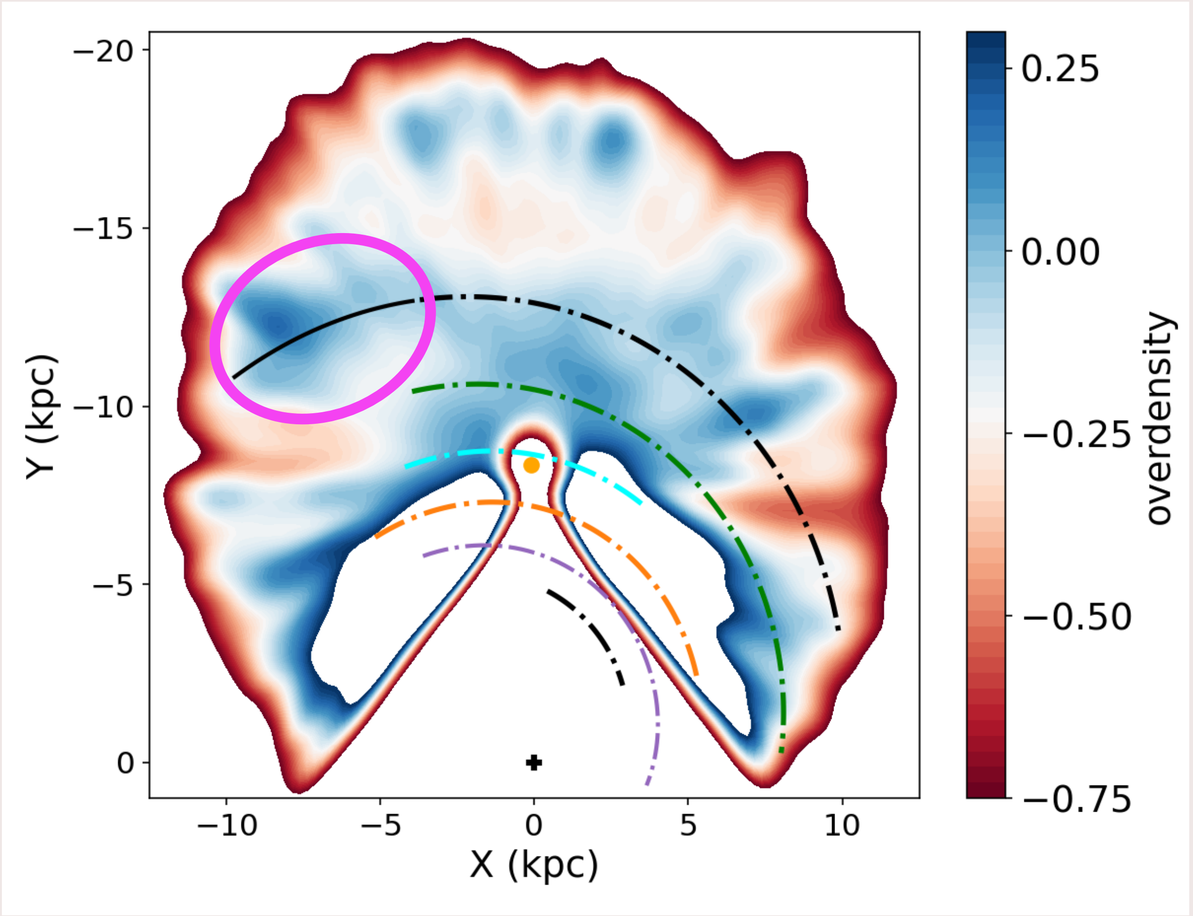
Sagittarius arm **Perseus arm**

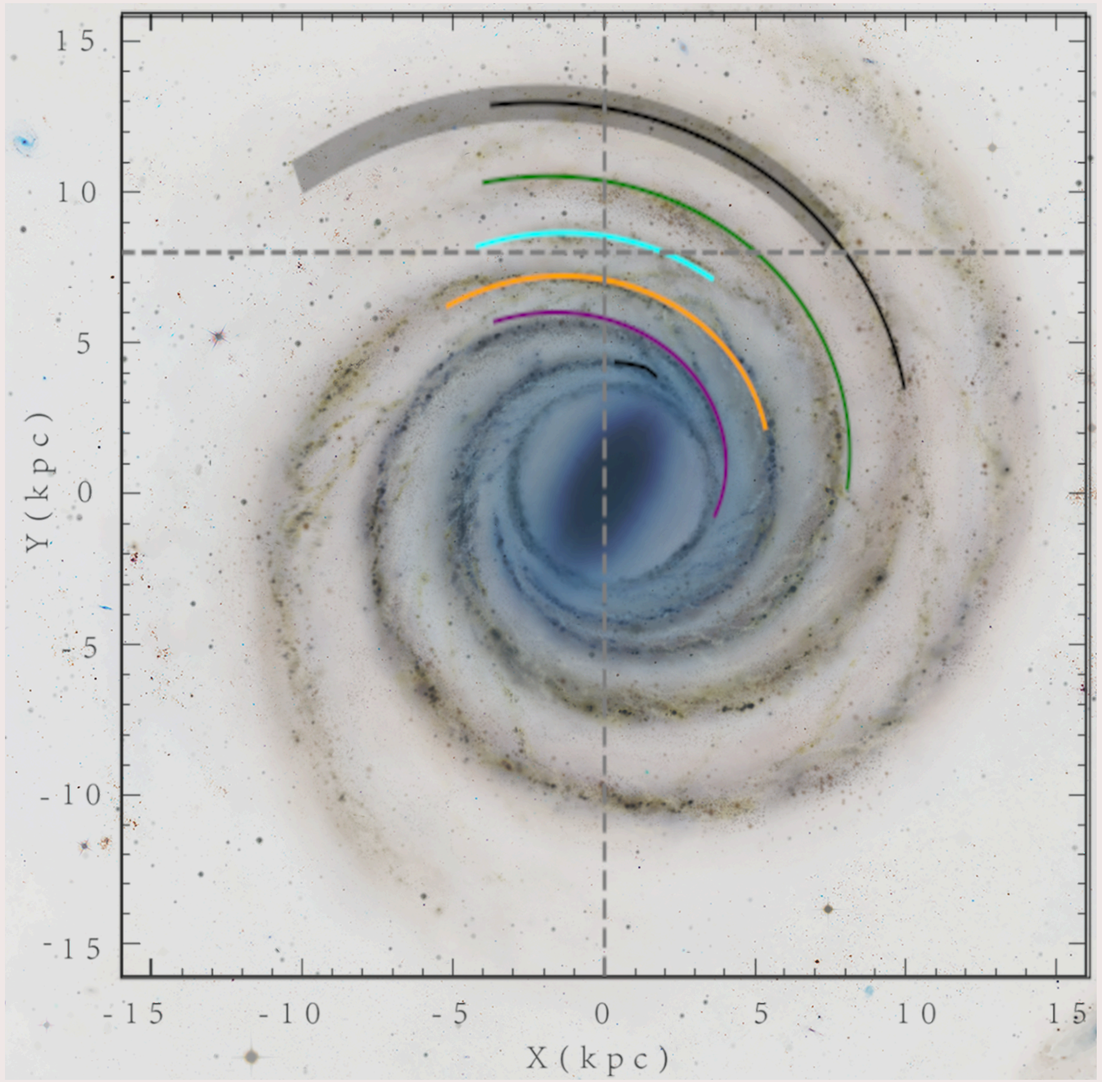
Castro-Ginard et al.(2021)

Norma-Outer arm

Reid et al. (2019)

Results : Detection of Outer arm



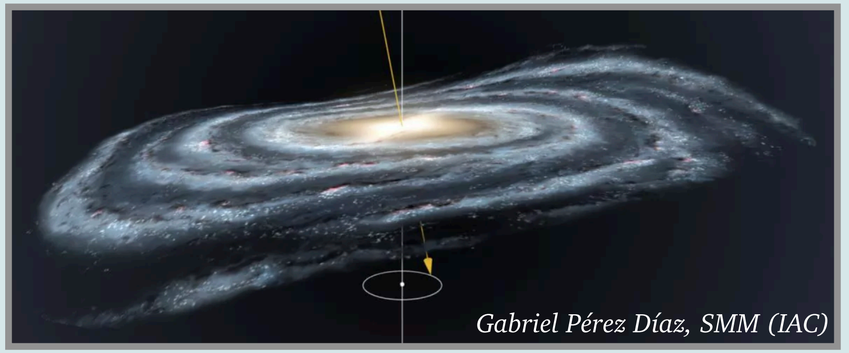


New detection : ~ 6 kpc long extension of Outer arm

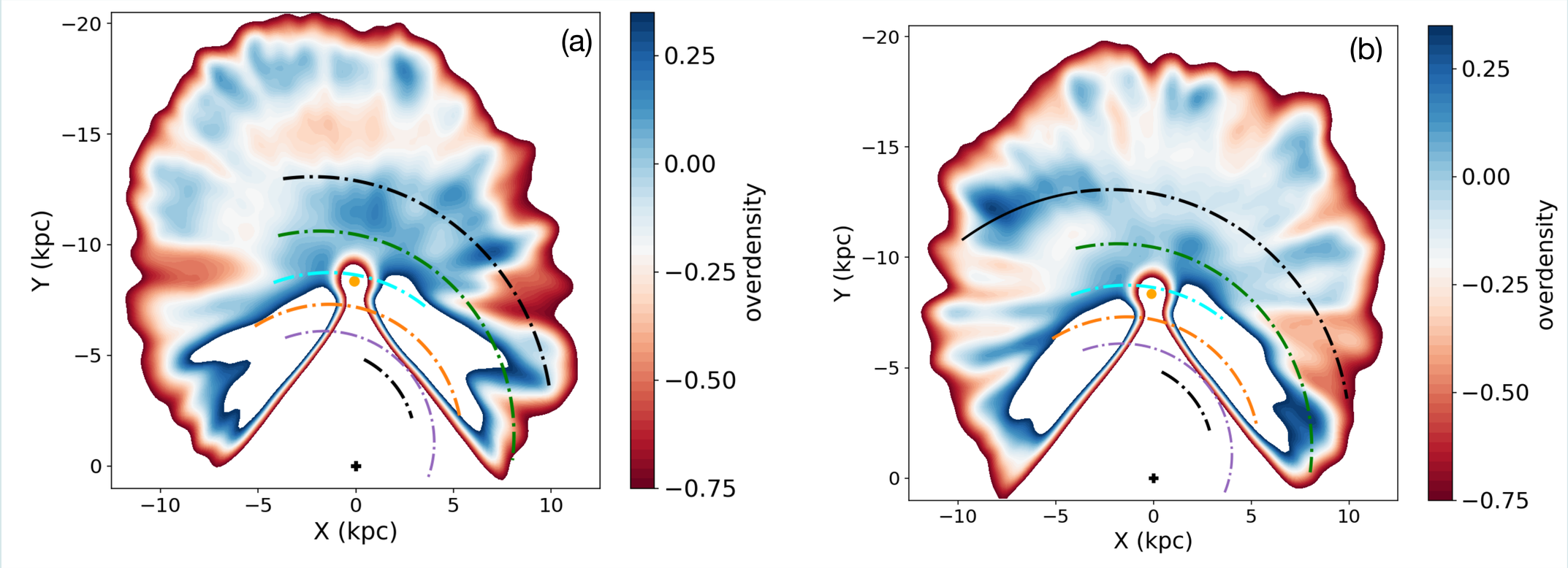
Results : Warping of Spiral arms

★ RC overdensity in $Z > 0$ is tracing a part of outer arm present in $\ell < 180^{\circ}$ and in $\ell > 180^{\circ}$ for $Z < 0$.

★ Signature of spiral arm warping.



Uppal, N. Ganesh, S., Schultheis, M., A&A, 673, A99



भौतिक अनुसंधान प्रयोगशाला
PHYSICAL RESEARCH LABORATORY

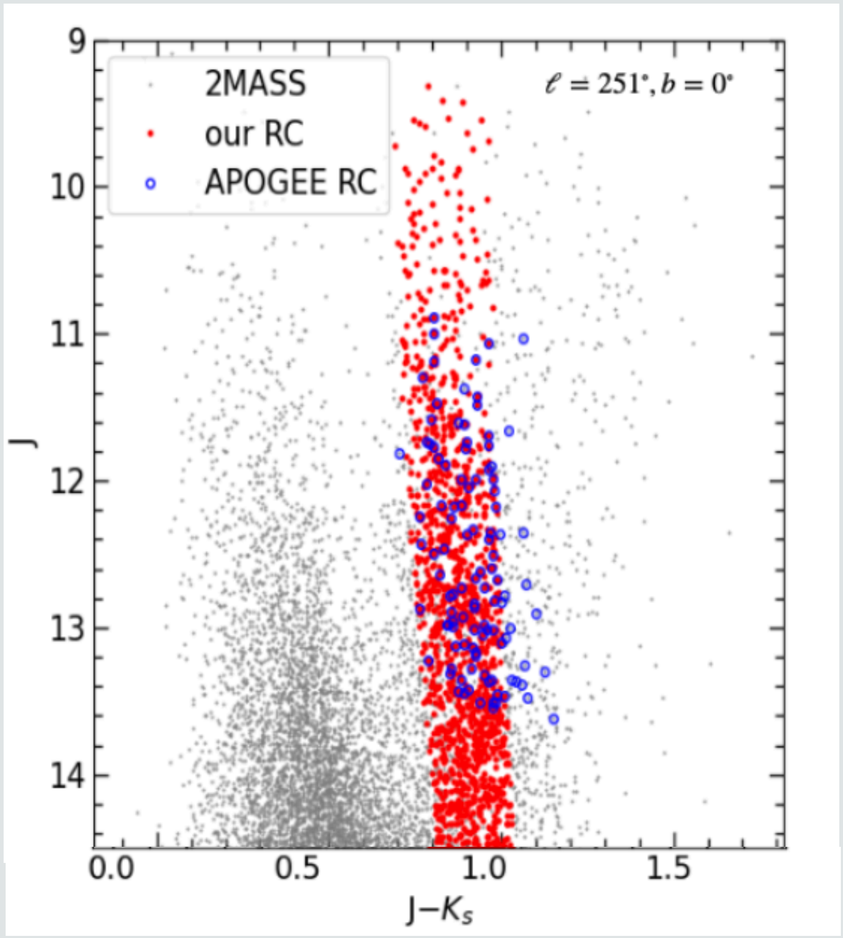
Thank You

Catalog Validation

APOGEE value added RC catalog

Bovy et al., 2014

82% matched with our catalog

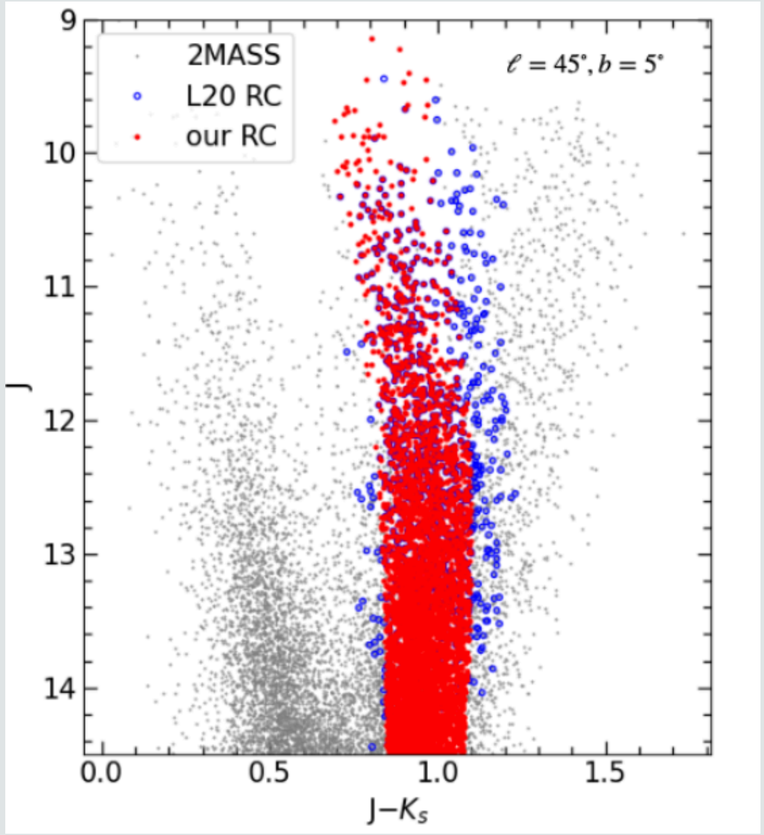


Lucey et al., 2020 RC catalog

Tier 1 - 20% contamination , 25% completeness

Tier 2 - 33% contamination , 94% completeness

Crossmatched

Tier 1 - 85%

Tier 2 - 71%