The structure of the Milky Way Galaxy at different scales

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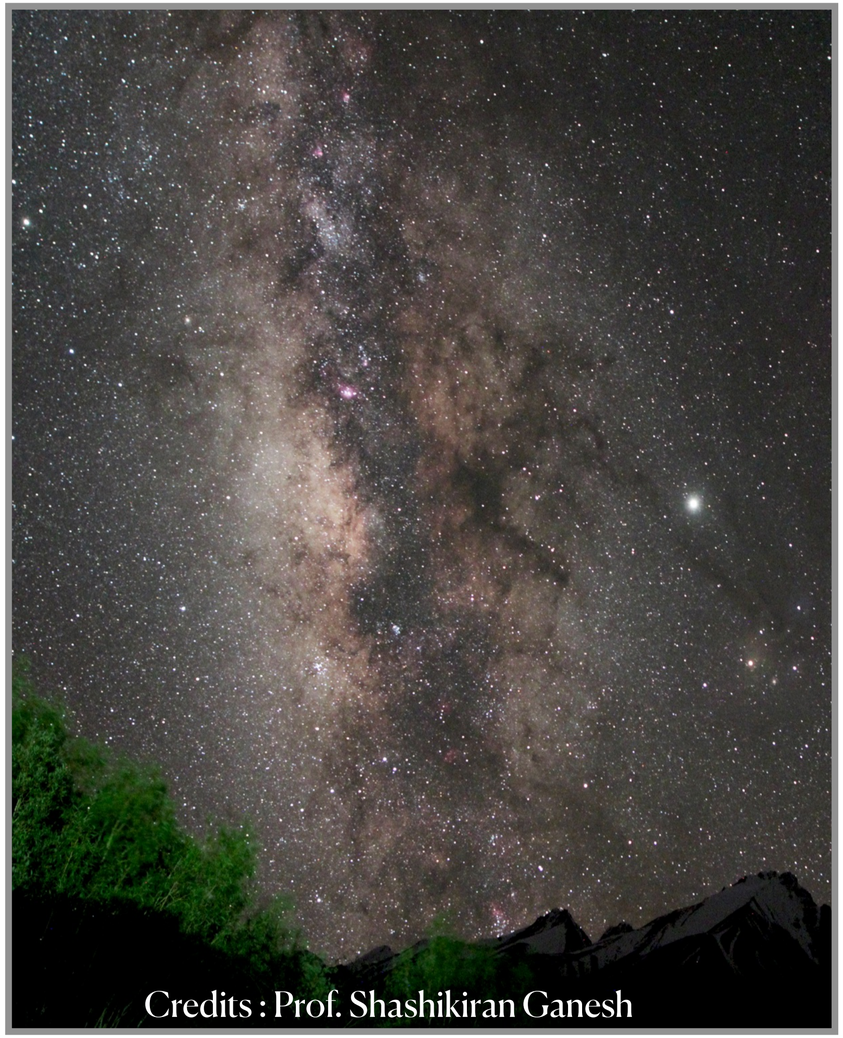
Introduction

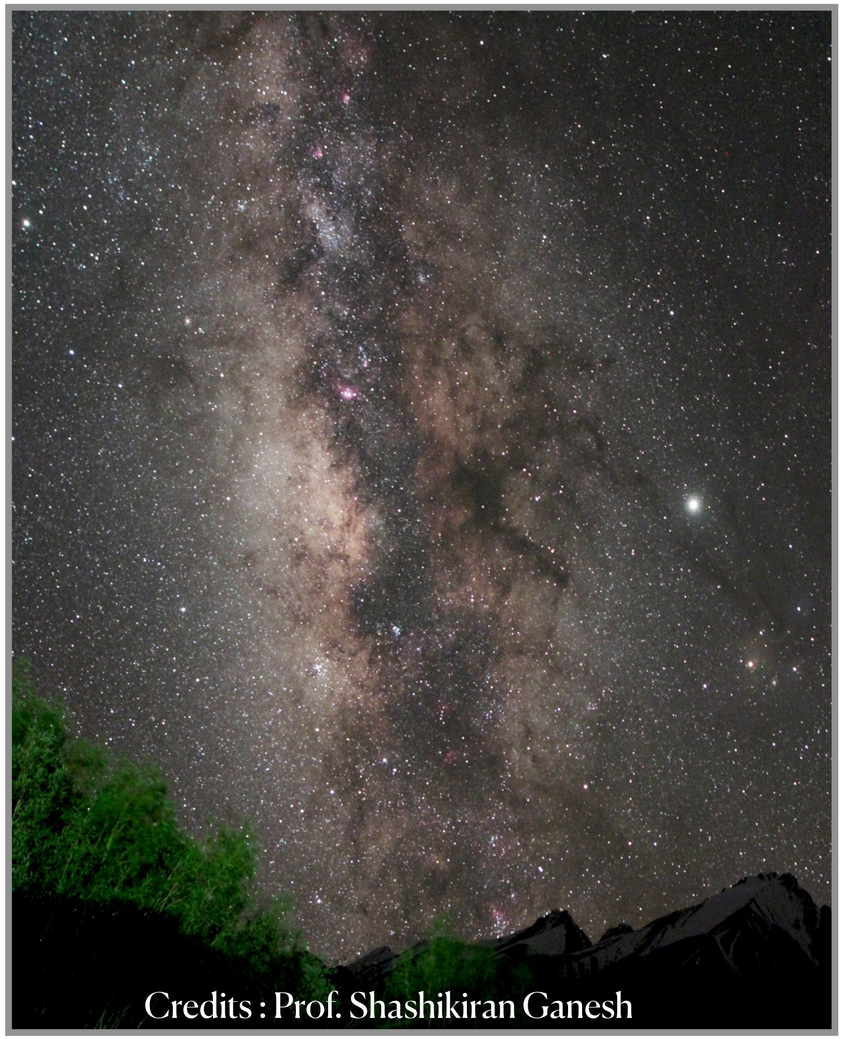
Visual Milky Way



From: What we see

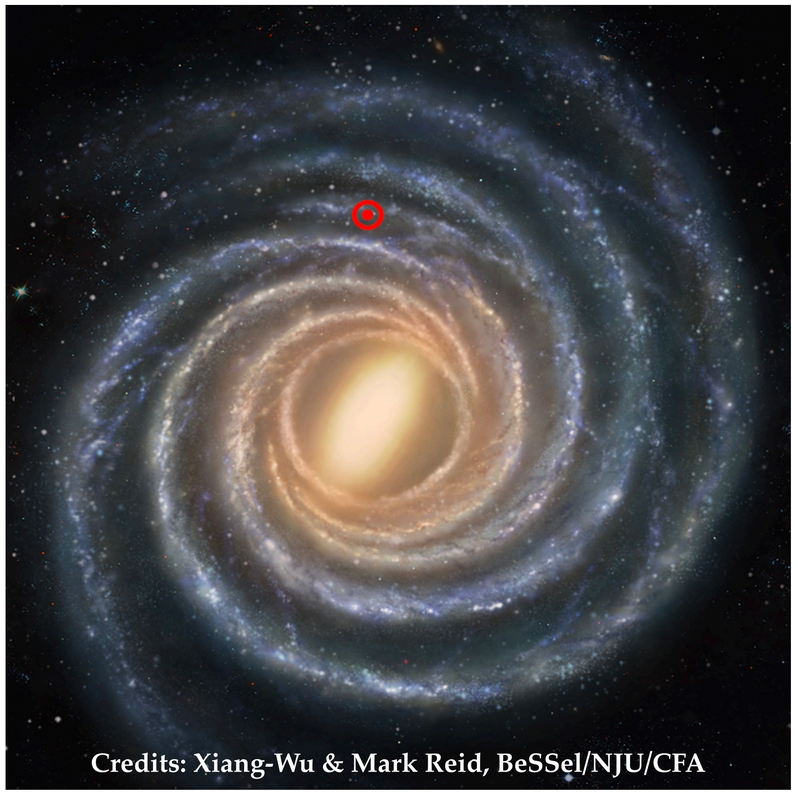
Introduction

Visual Milky Way



From: What we see

Artistic impression



To: face-on view

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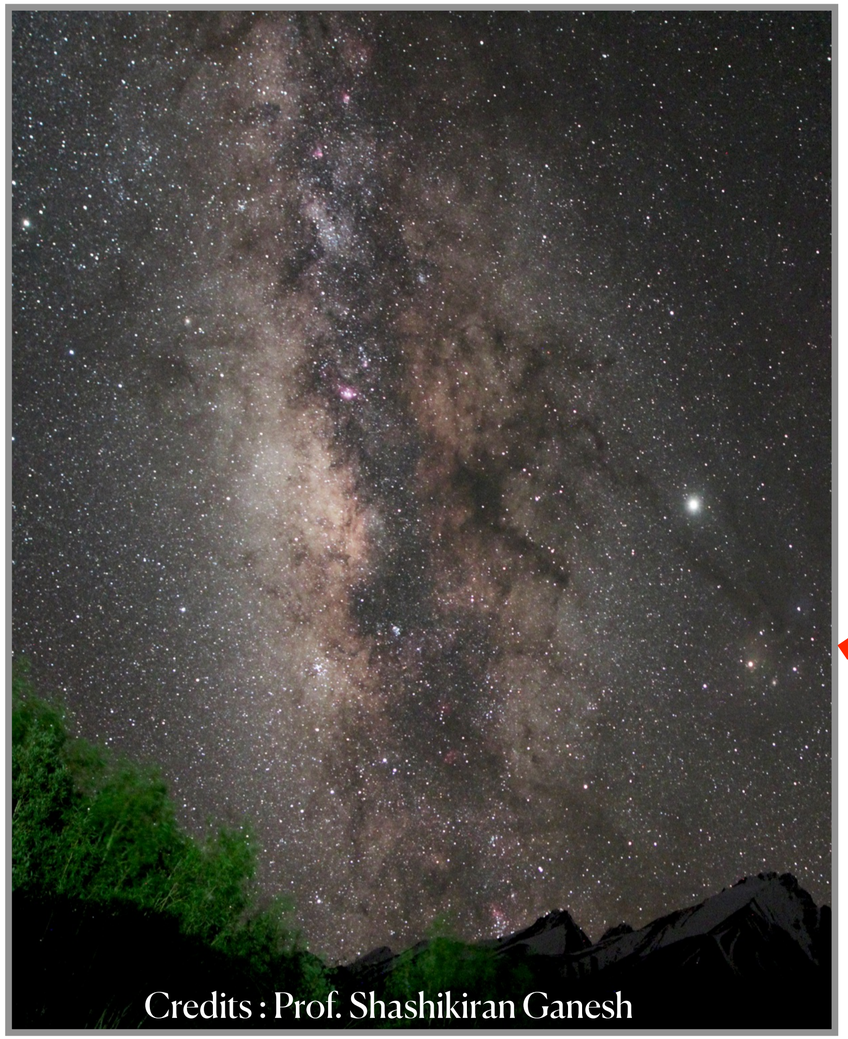

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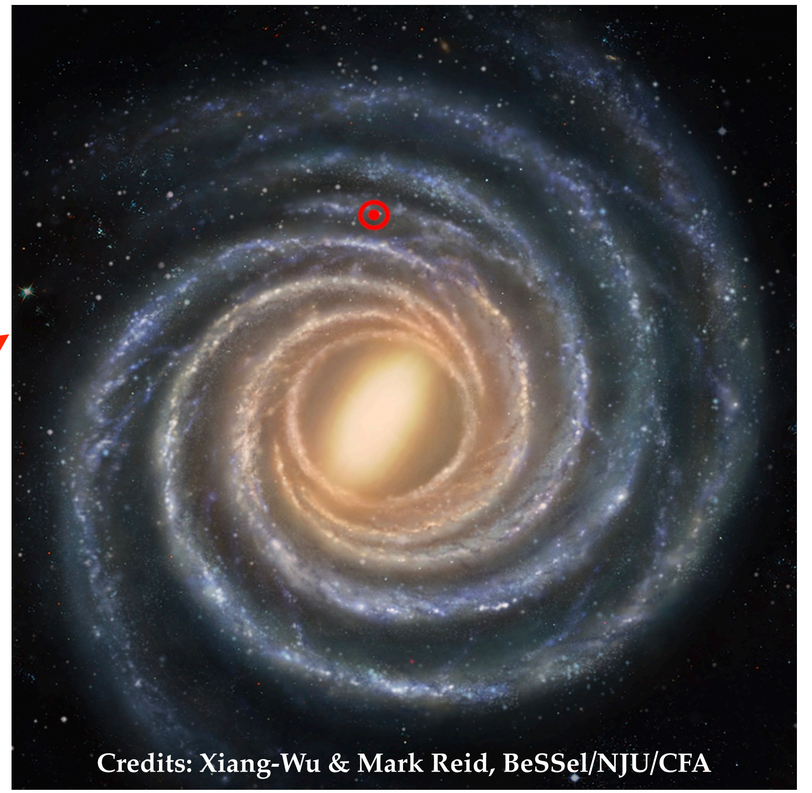
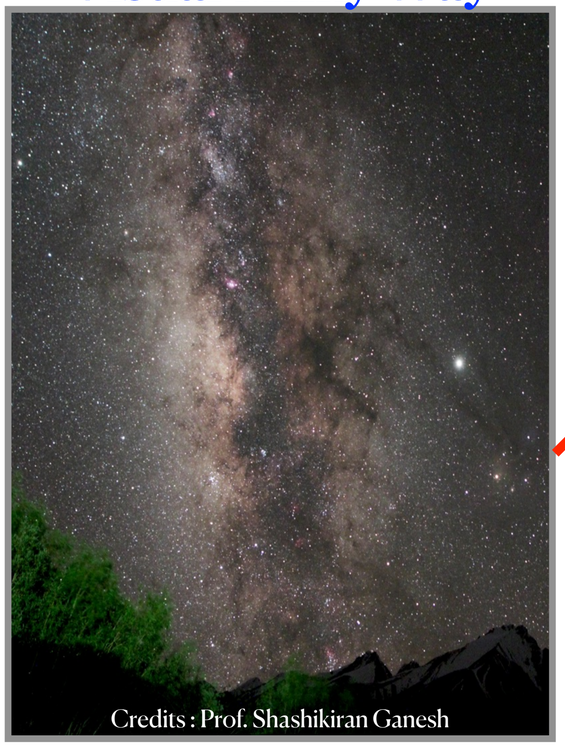


To: face-on view

Motivation

Visual Milky Way



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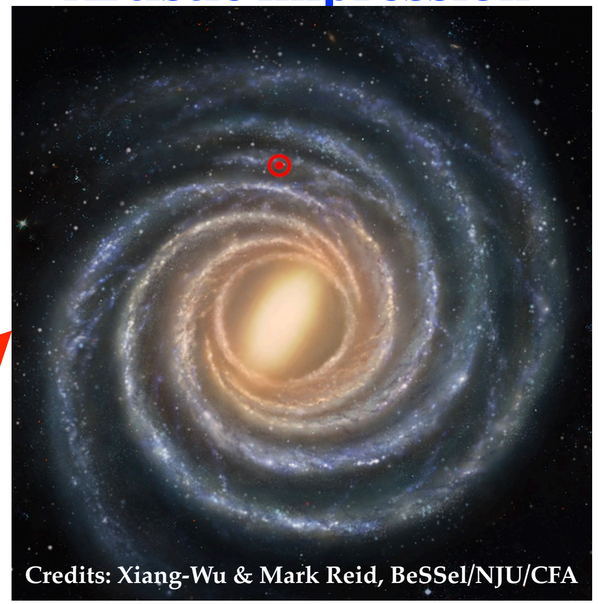


To: face-on view

- Tracing Material
  Stars/dust/gases

- <u>Requirements</u>
  Location
  Distance

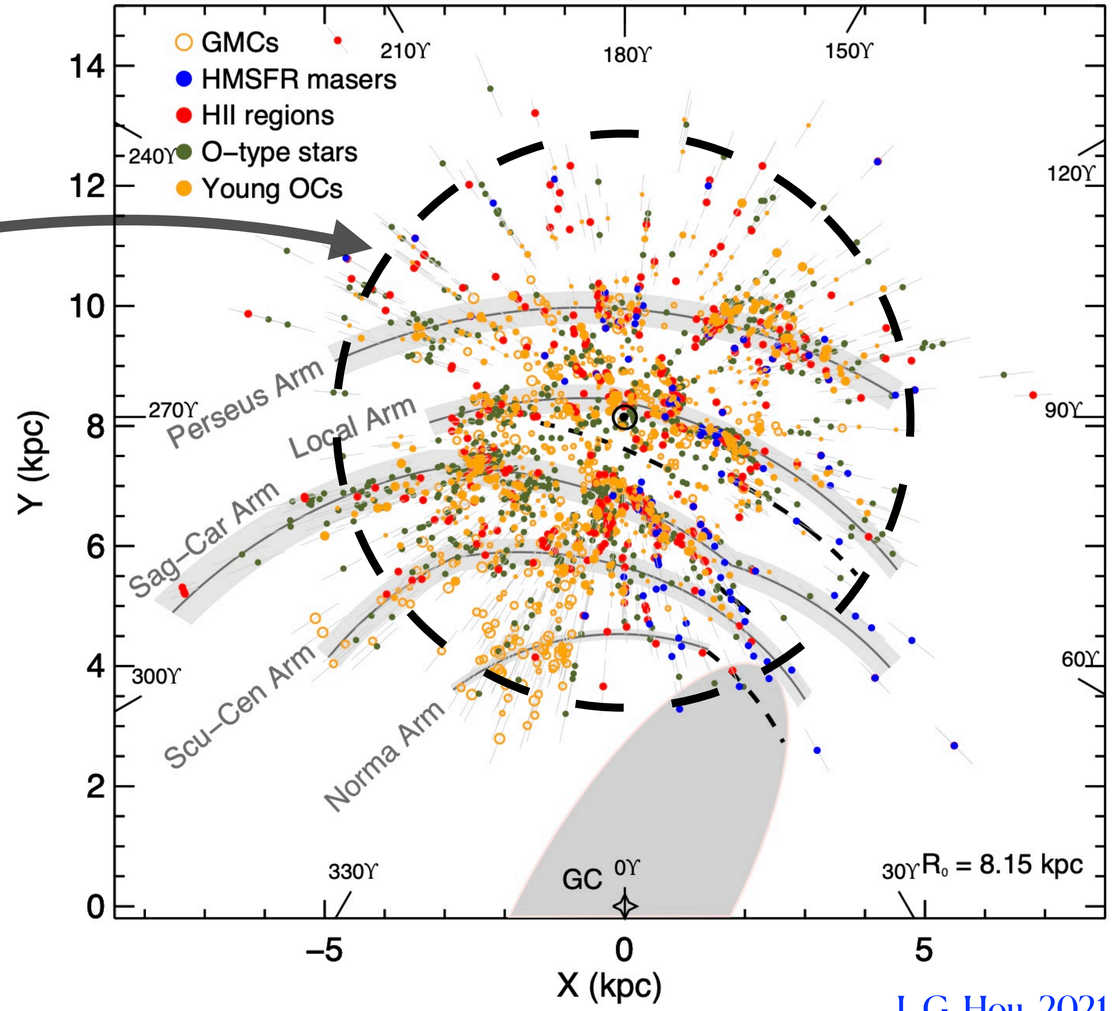
Gaia - space based mission - measure parallax
1.7 billion stars
<u>Revolutionize the field</u>

Motivation

Different tracers distributed in the face-on view of the Galaxy

- ✦ High dense region corresponds to spiral arms
- ✦ Only patches of arms are observed.
- ✦ Low number statistics.

Region covered in Gaia



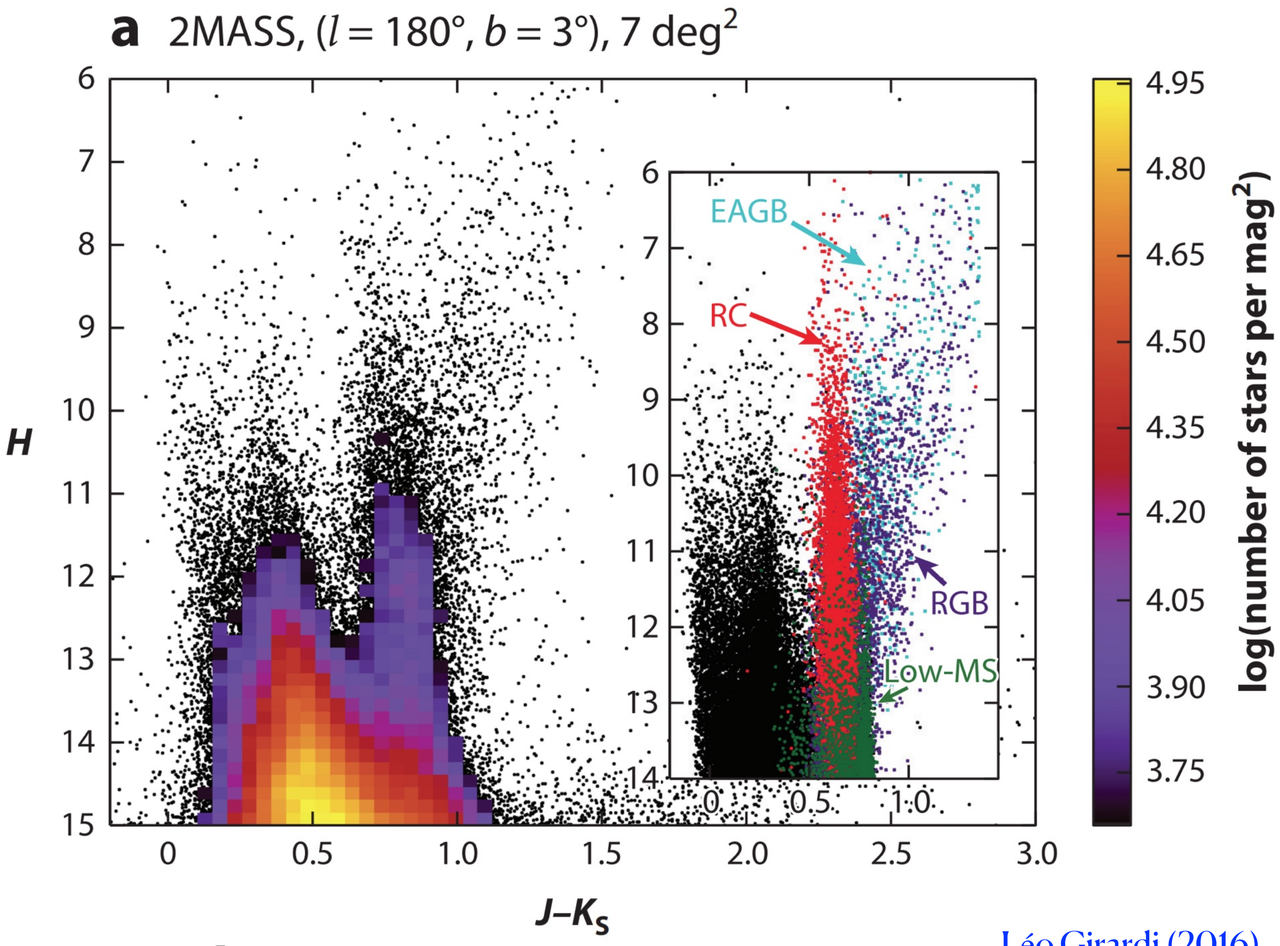
L.G. Hou, 2021

- Dominated by younger population
- Older population of stars - ?

  - Old disk structure
  - Evolution

Red clump stars: Selection

- **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**



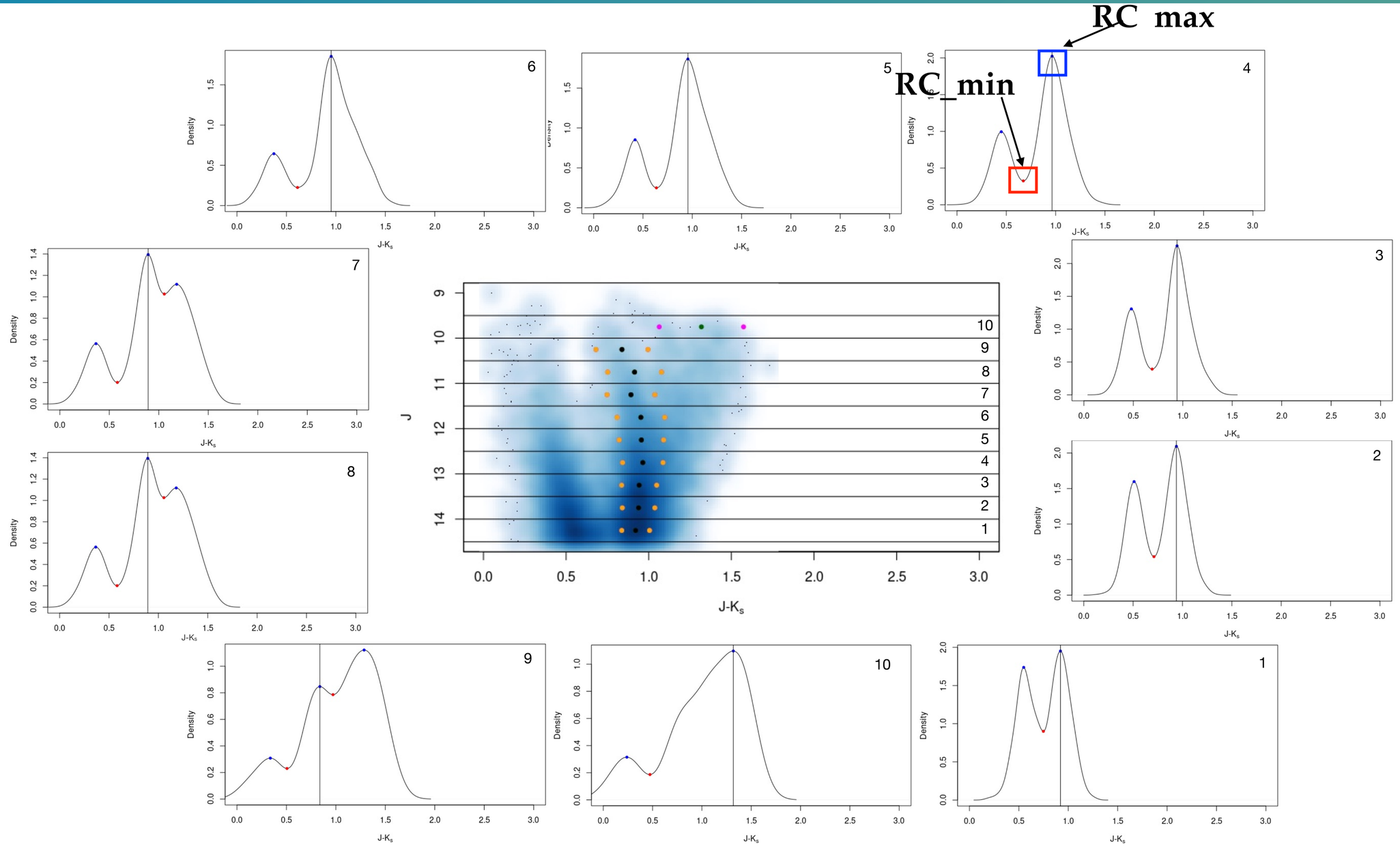
Léo Girardi (2016)

Red clump stars: Selection

$\ell = 45°$

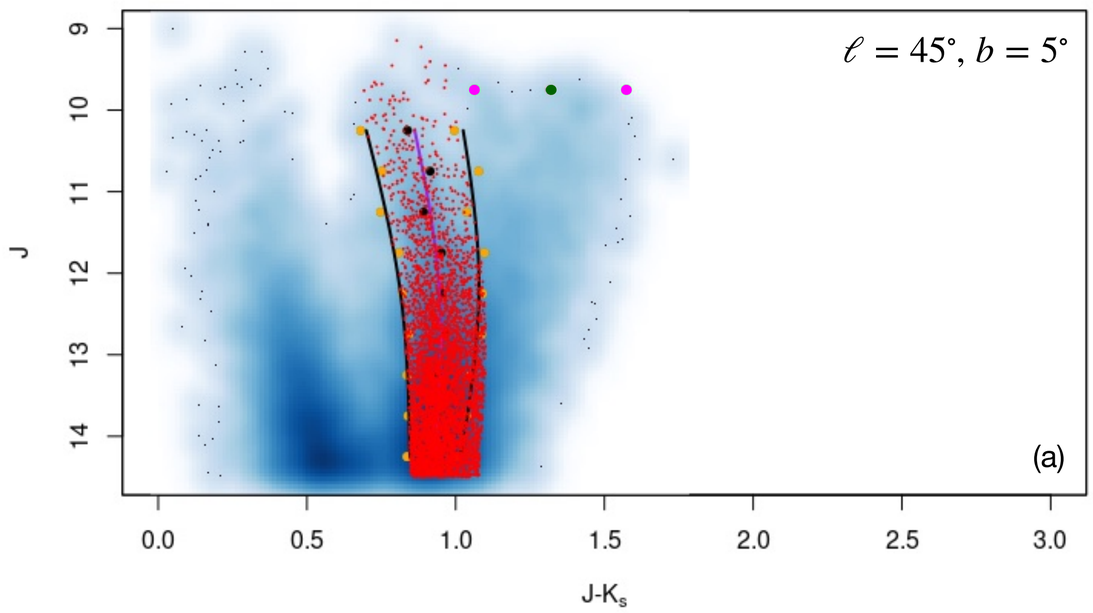
$b = 5°$

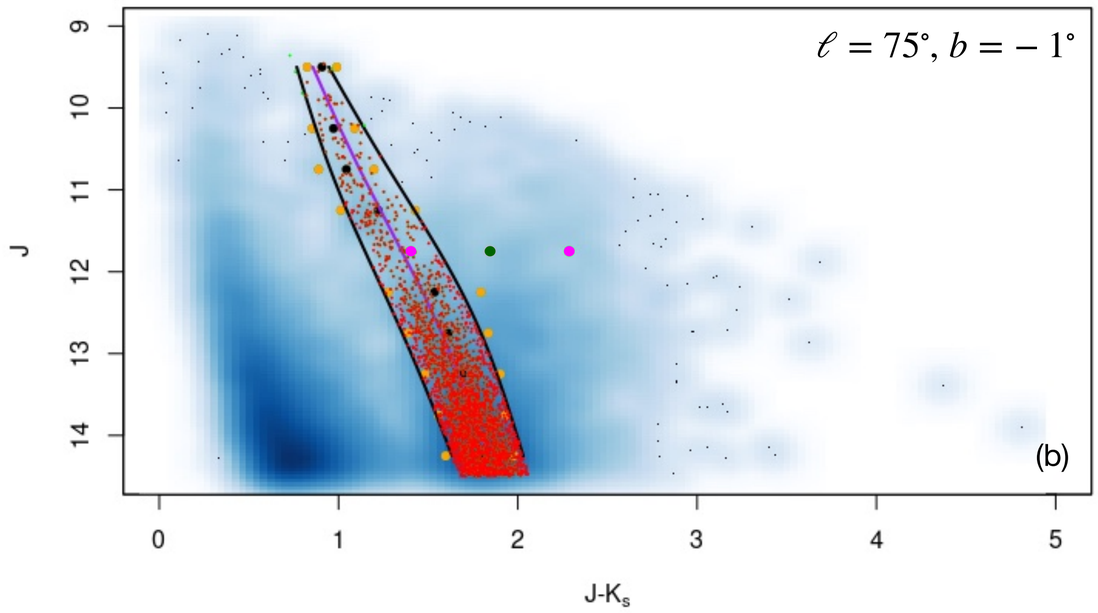
$1° \times 1°$

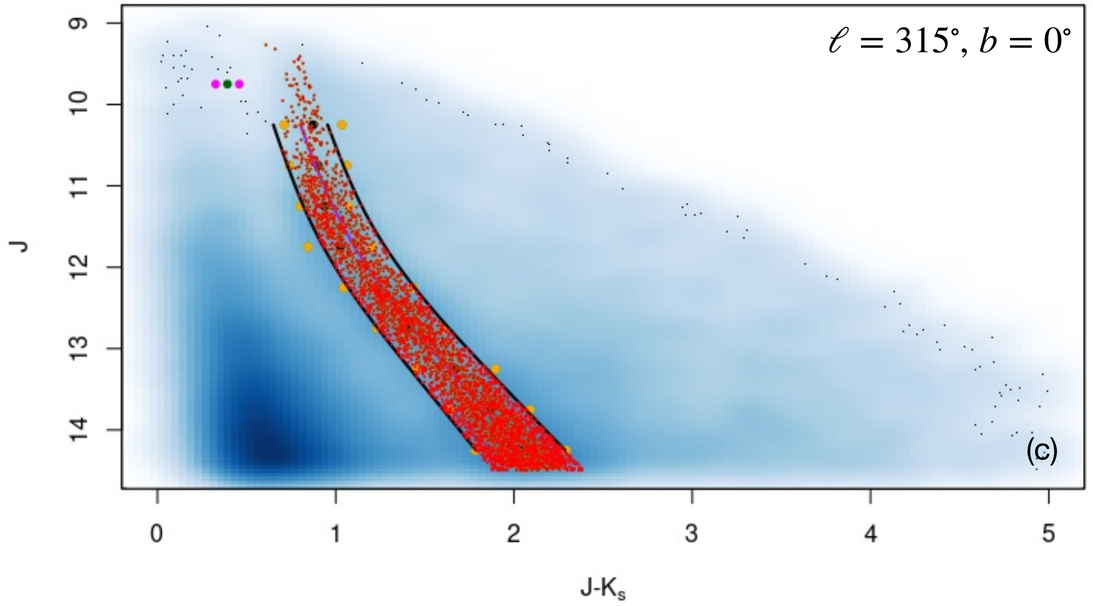


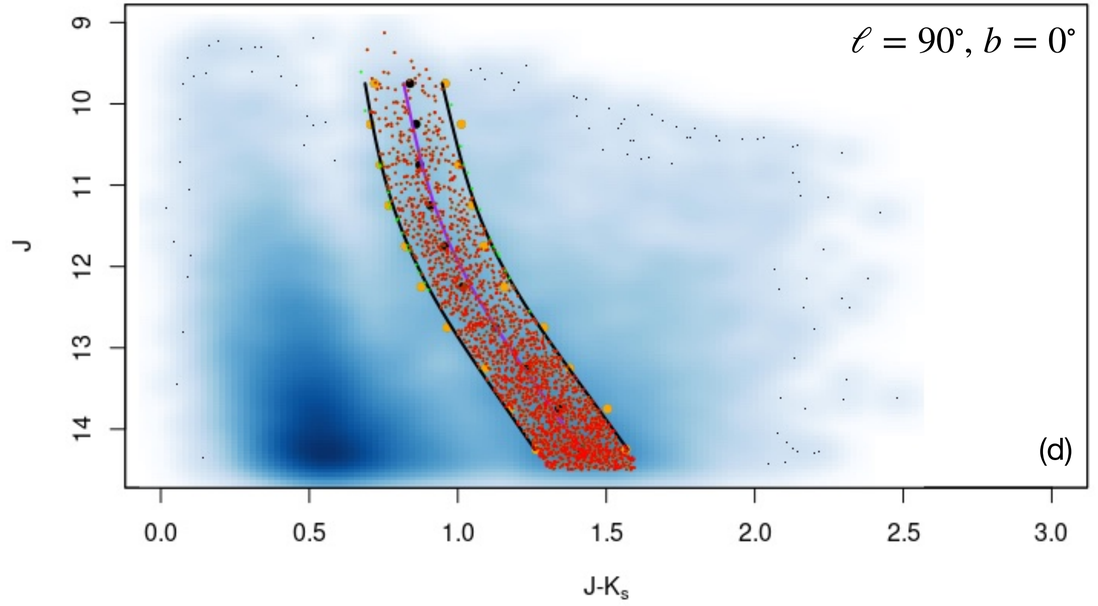
Uppal, N. Ganesh, S., Schultheis, M., 2023, A&A, 673, A99

Red clump stars: Selection









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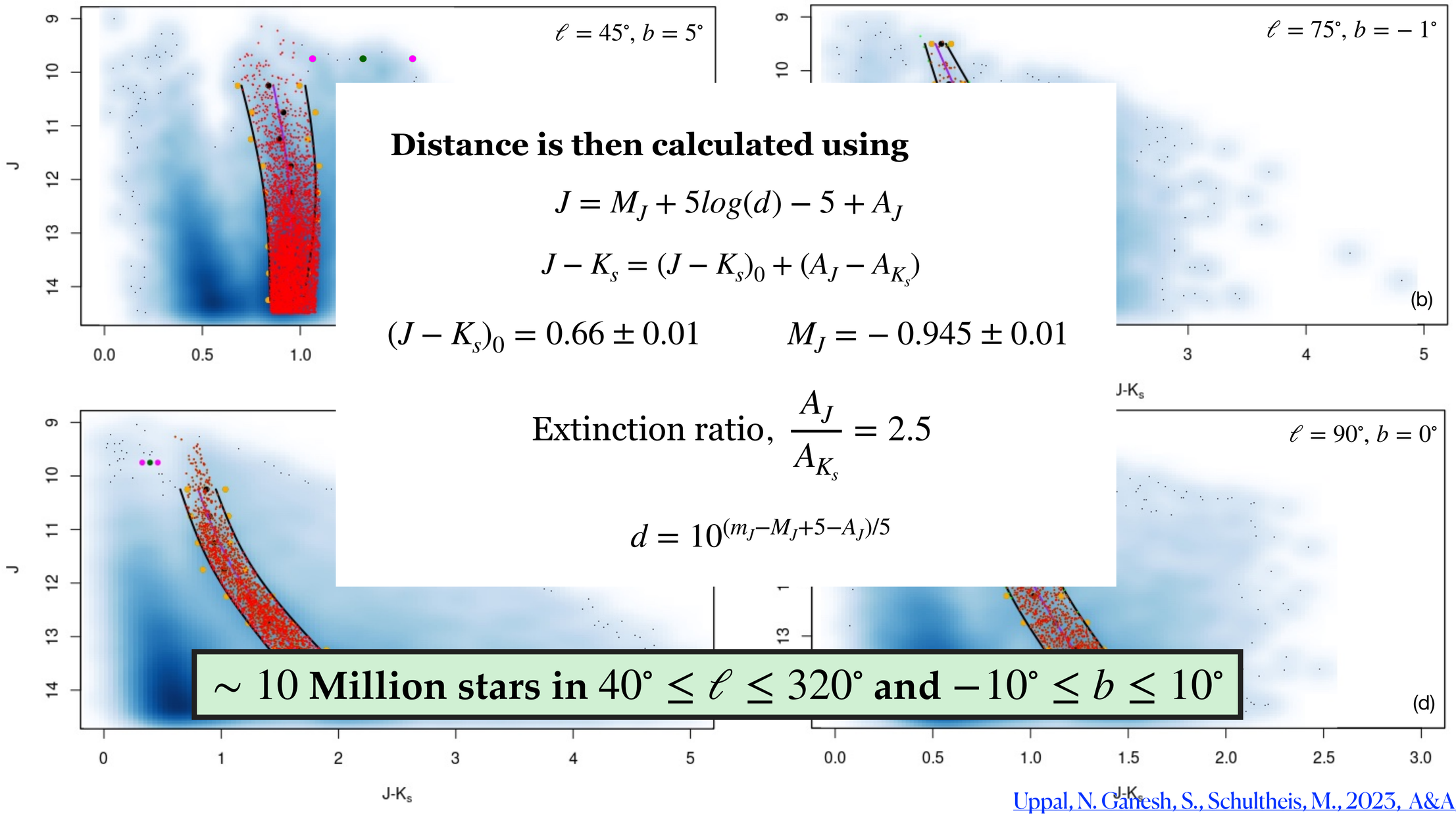
Red clump stars: Selection



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 $-10° \leq b \leq 10°$

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Red clump stars: Distribution

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

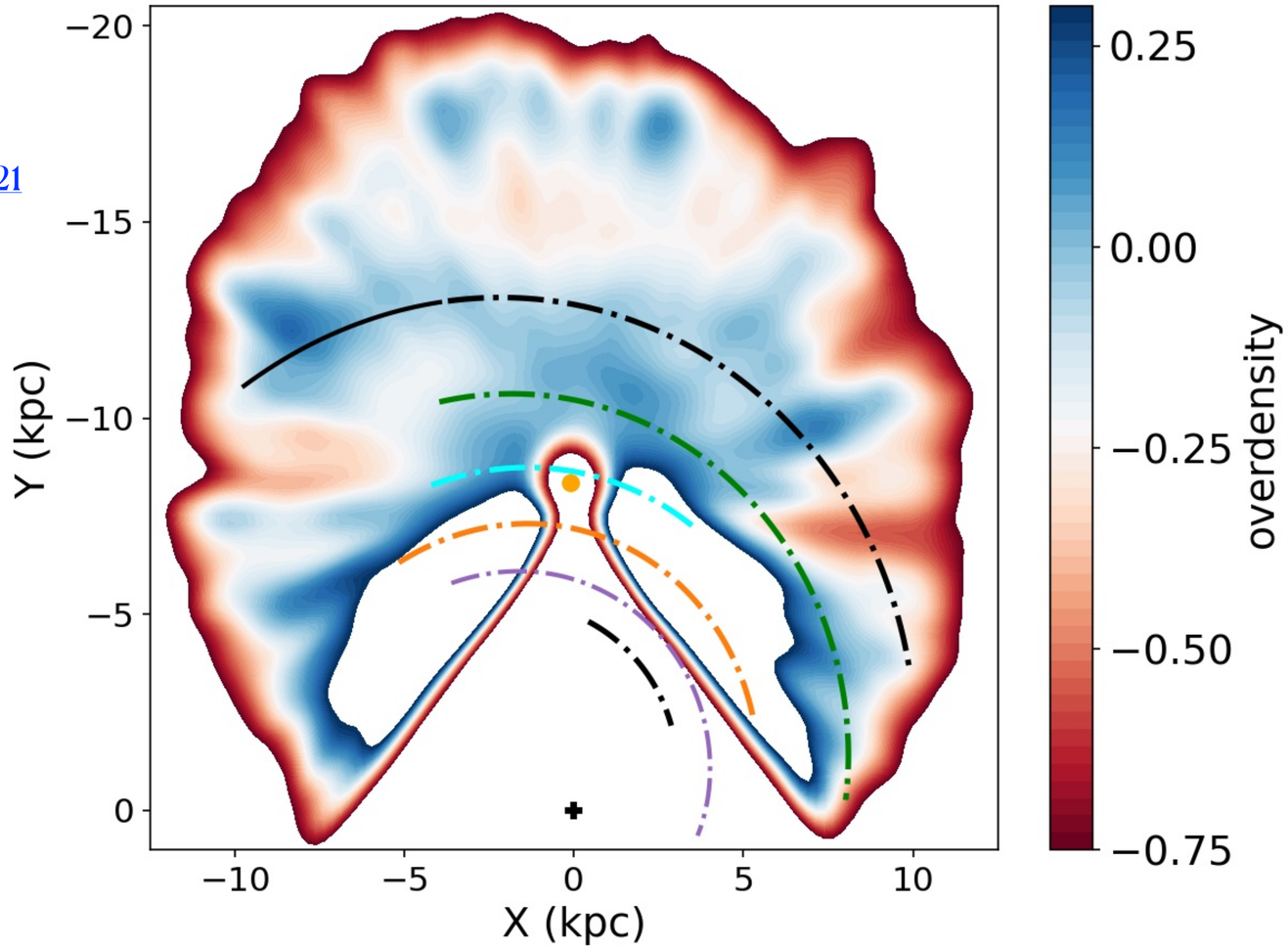
Scutum arm **Local arm**

Sagittarius arm **Perseus arm**

Castro-Ginard et al.(2021)

Norma-Outer arm

Reid et al. (2019)



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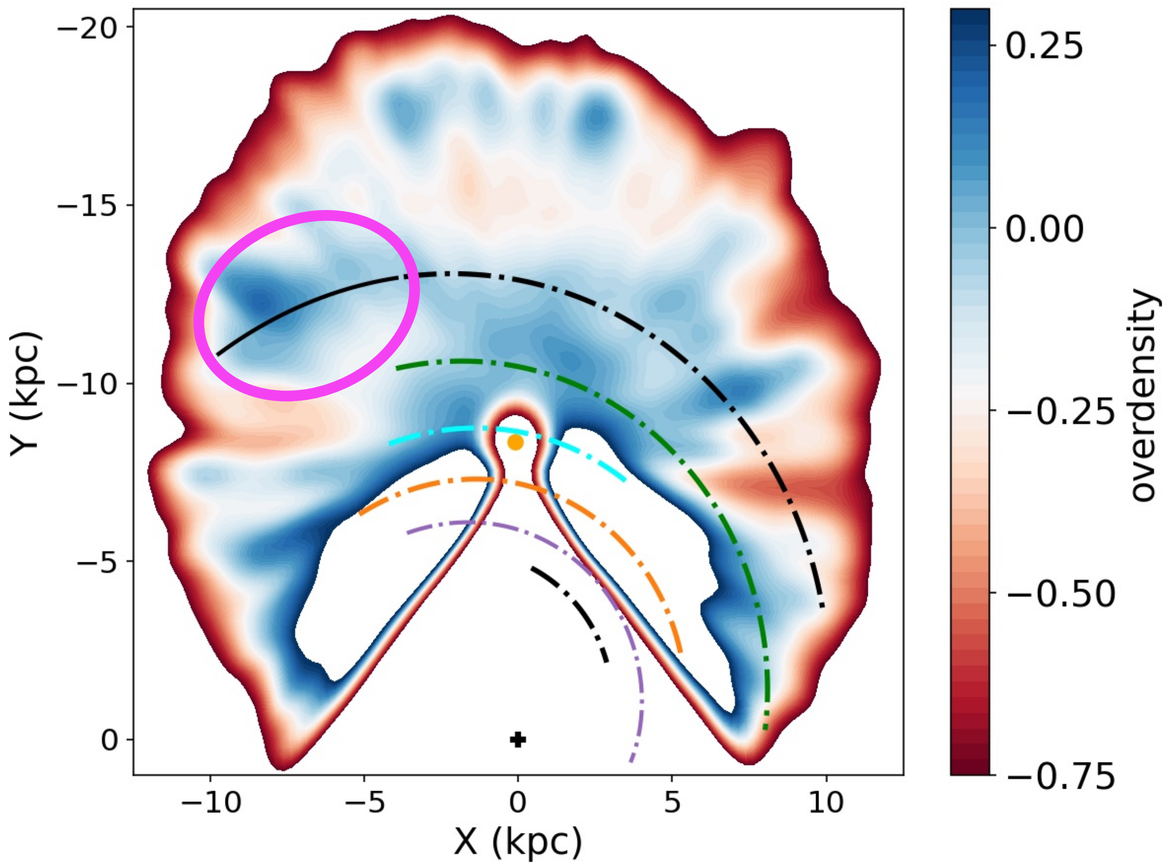

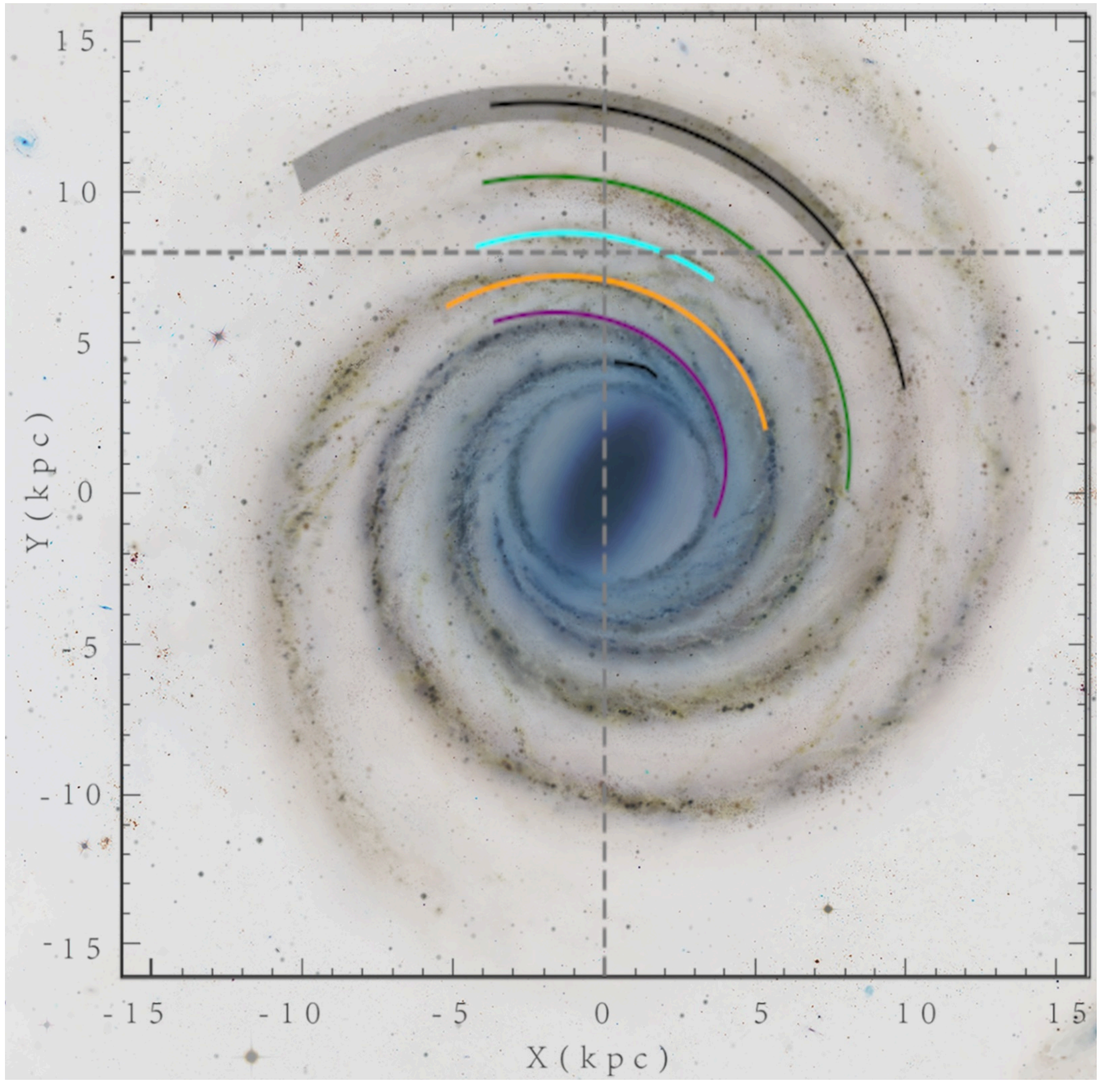

New detection : ~ 6 kpc long extension of Outer arm

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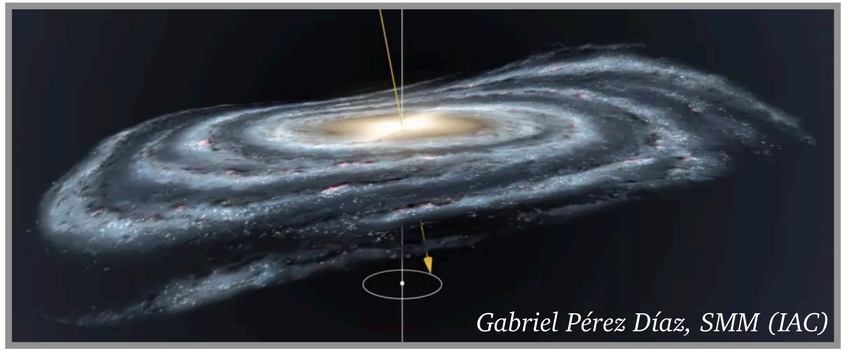
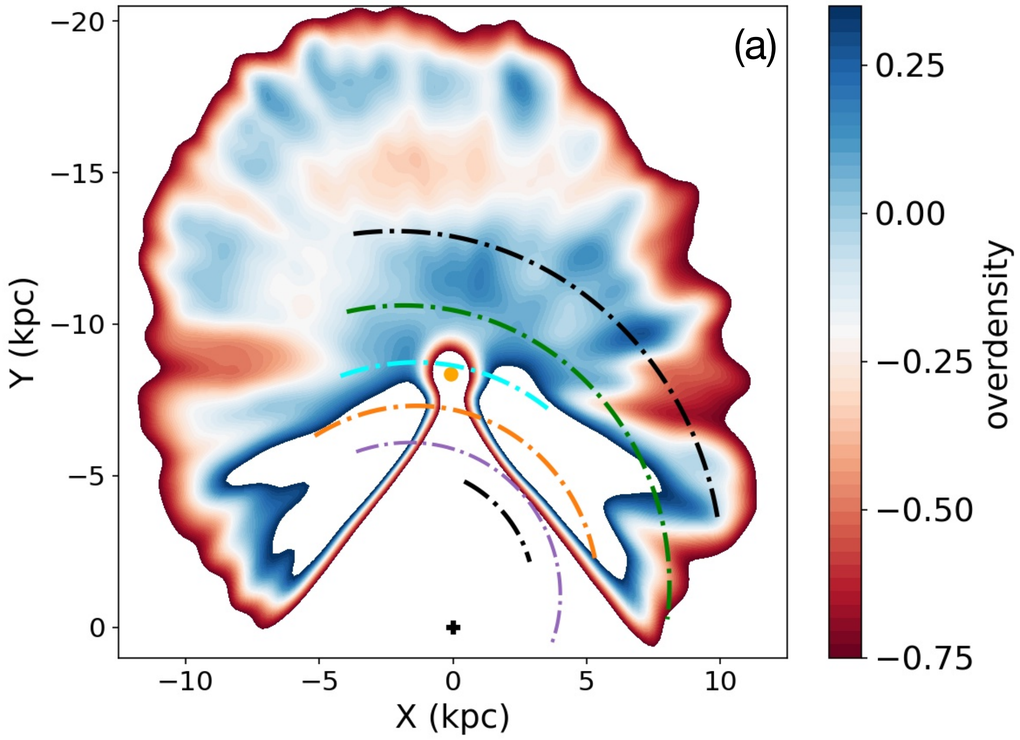
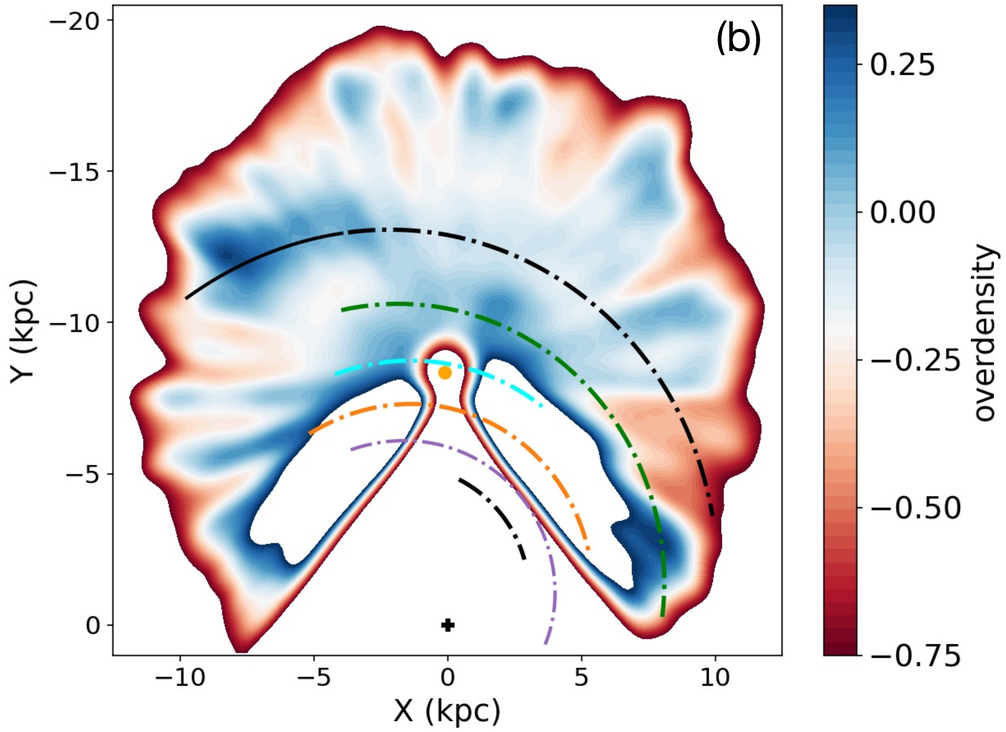
Red clump stars: Distribution

★ 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.







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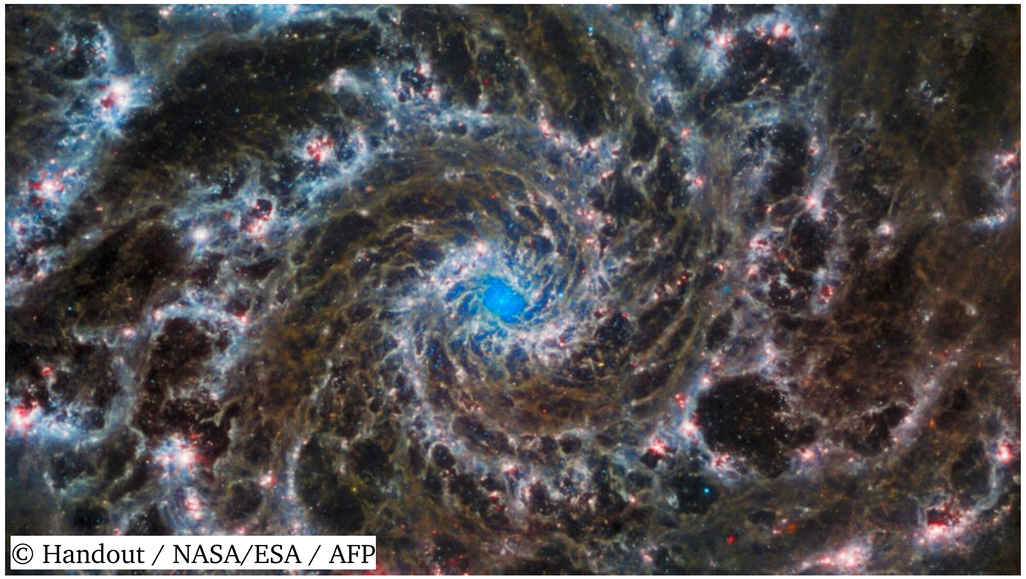
Dust Distribution: Motivation

Dust is highly confined to the structure of the Galaxy and give fine features.

M57 Spiral galaxy

MIR view



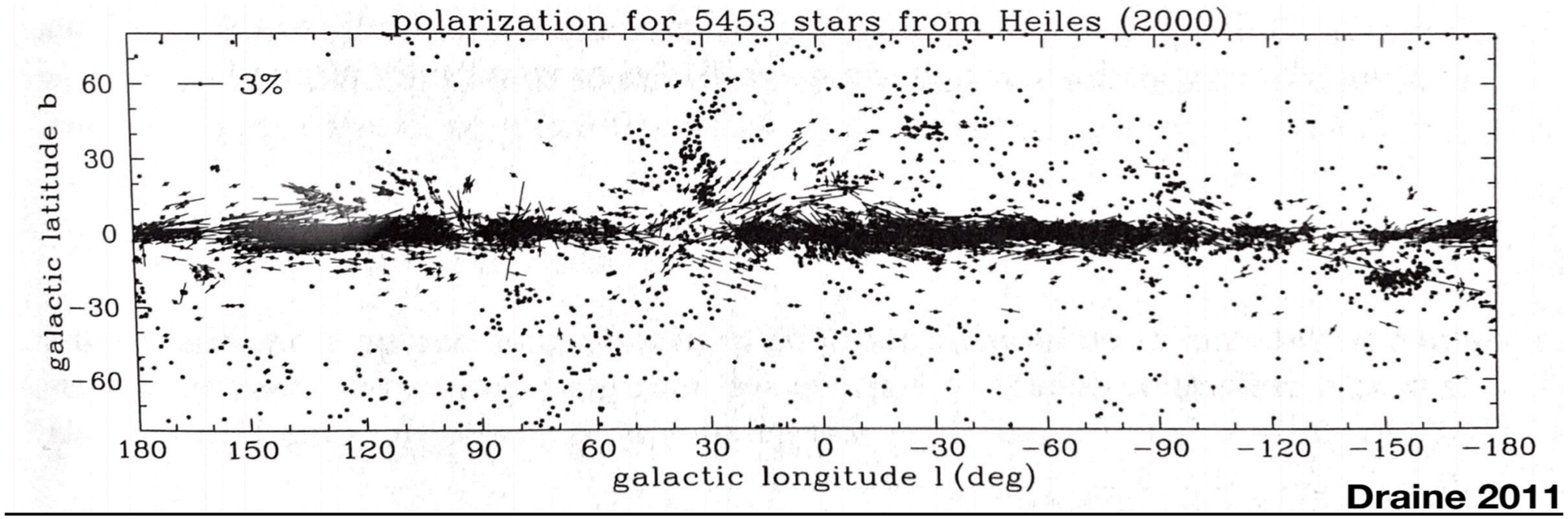
3D dust distribution is quite challenging due to difficulties in distance measurements.

Challenging in our Galaxy ⟶ **Properties of dust**

Dust Properties

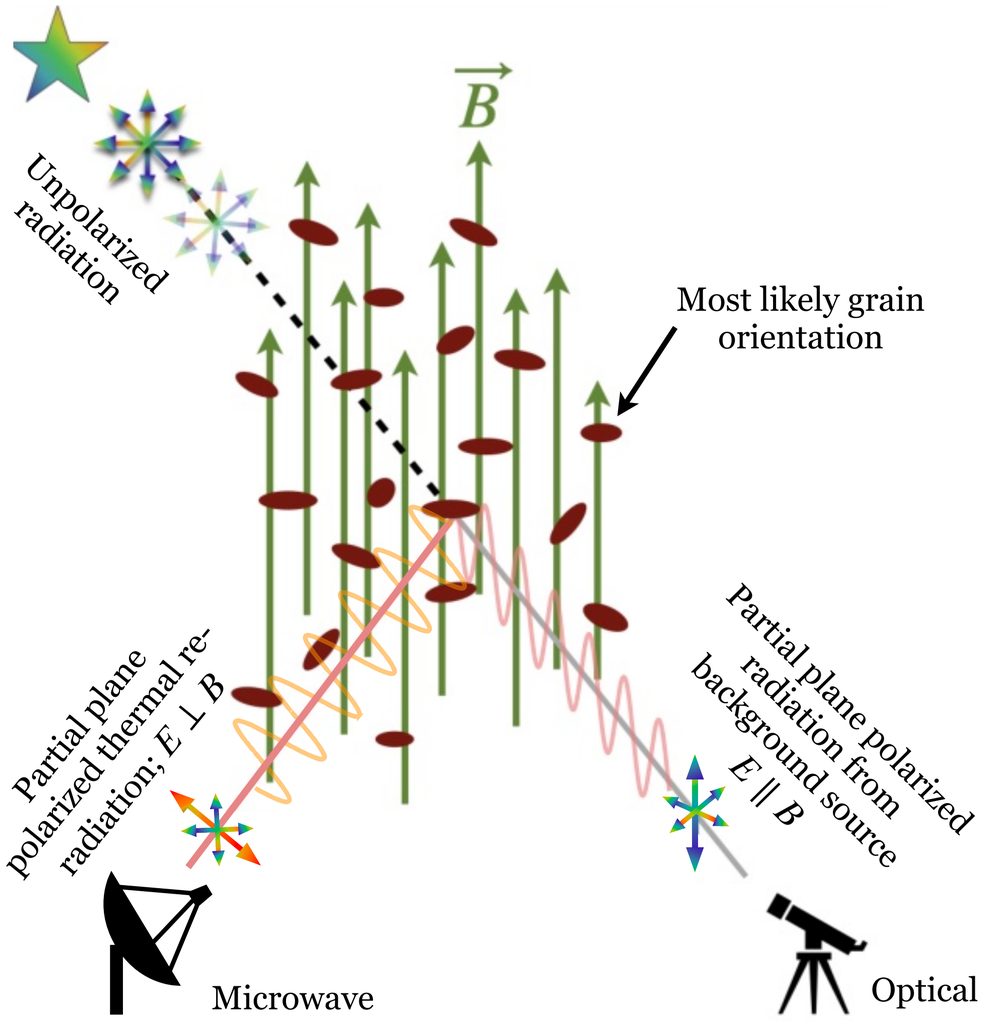
Extinction : Absorption & Scattering ← Derived quantity

Interstellar polarization : Differential Extinction ← Observed quantity



ISM polarization

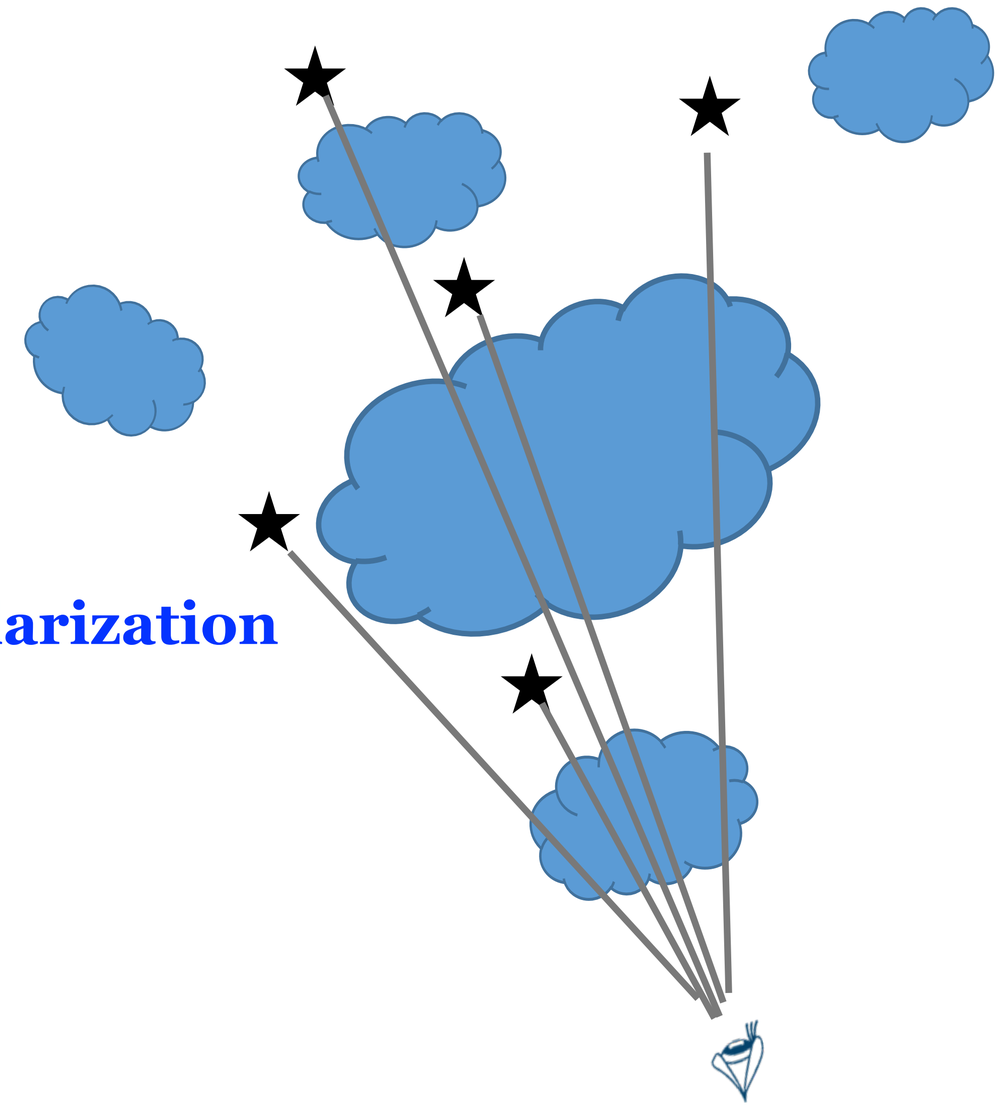
- Asymmetric grains
- Dichroic extinction
- Net alignment of anisotropy



ISM polarization

Polarization in combination with distance

- Similar orientation - **increase in degree of polarization**
- Different orientation - **decrease in degree of polarization**



Observations: Strategy

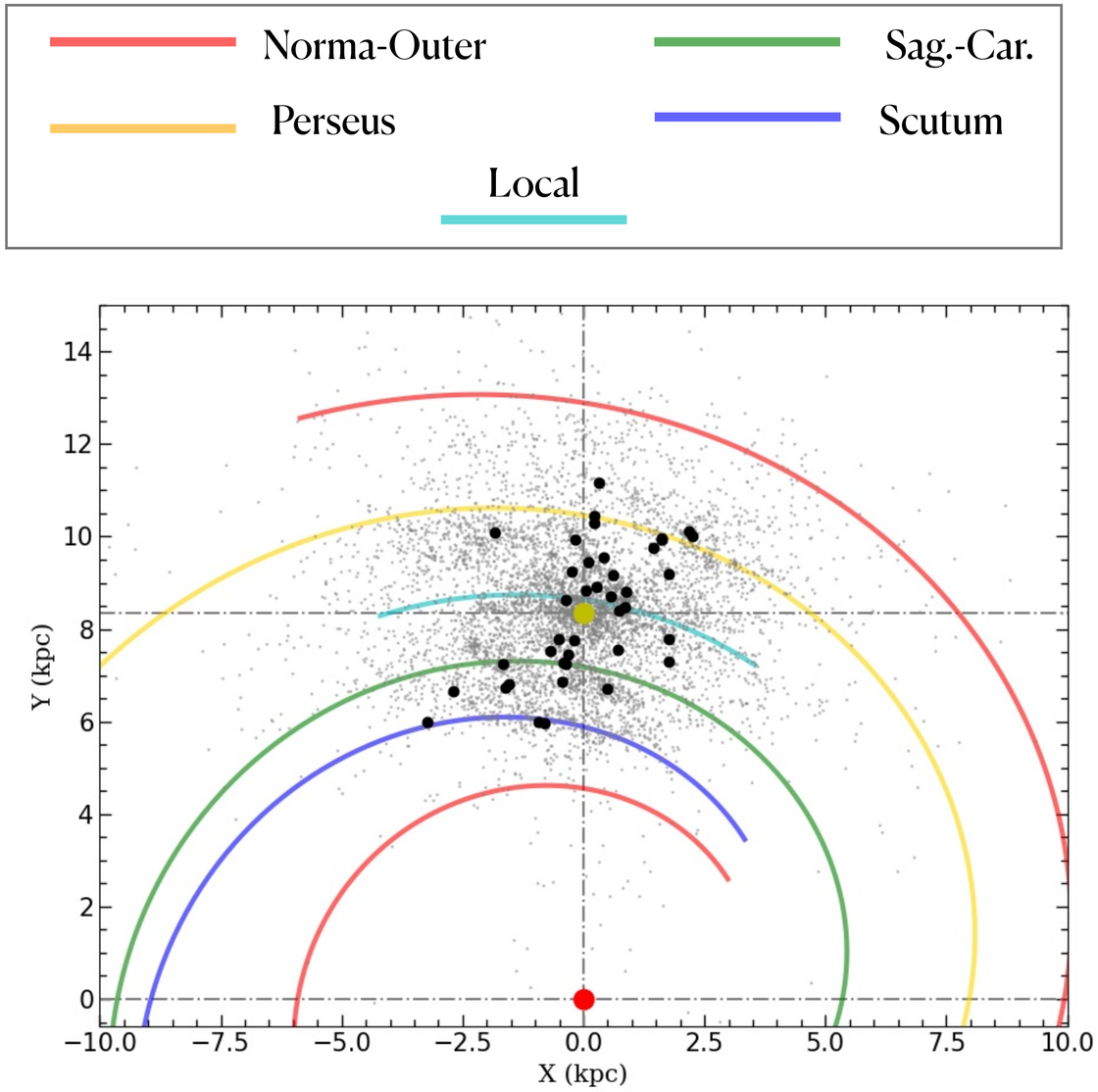
Galactic Open clusters

- ~7200 clusters known till now - Hunt et al., (2023).
- Only ~40 clusters have polarization observations
- Upto moderate distance. (< 3 kpc)

Select cluster in the same line of sight but at different distance

Selection of clusters

- Location
- Distance
- Brightness
- Size
- Number if members



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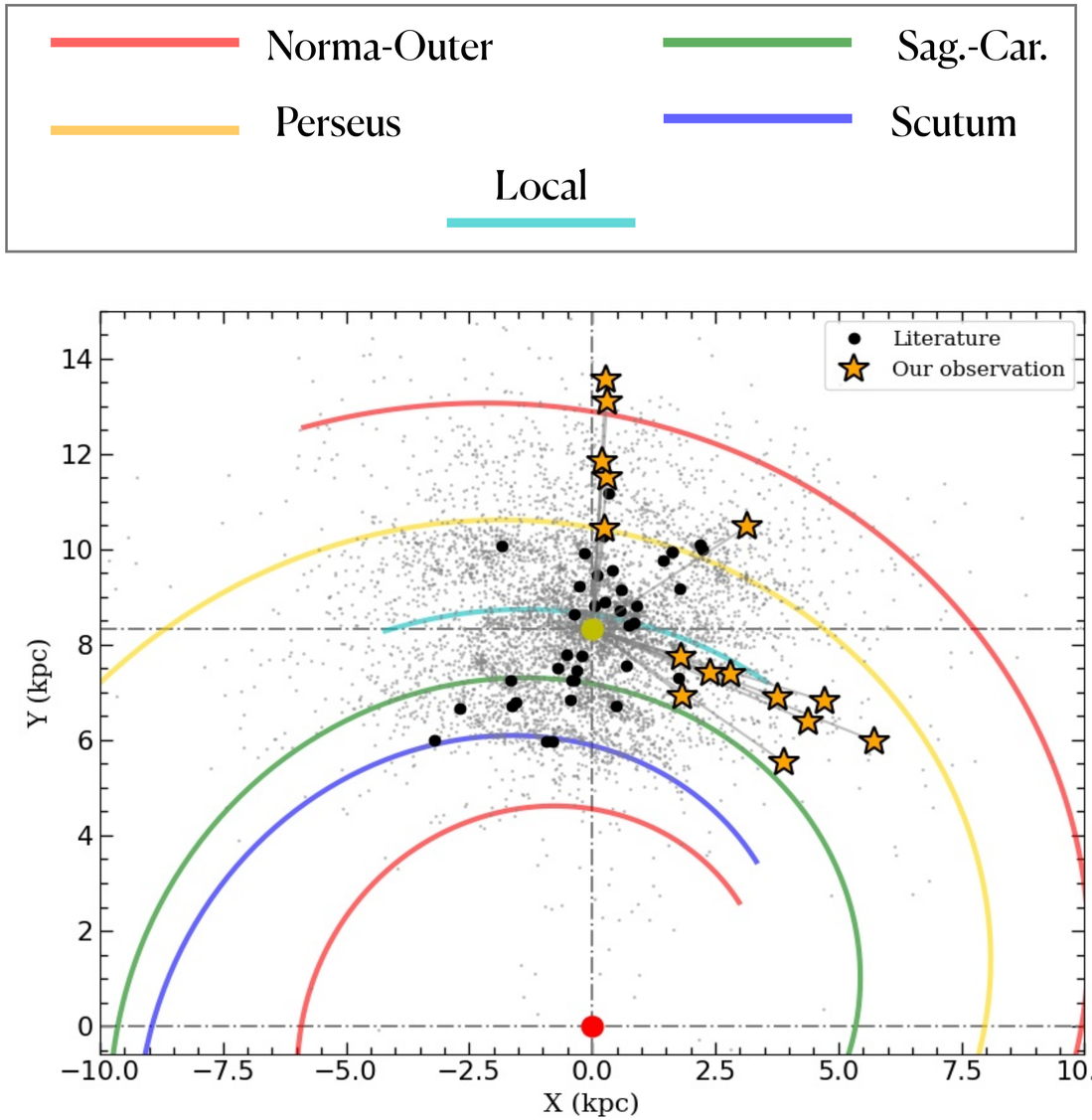
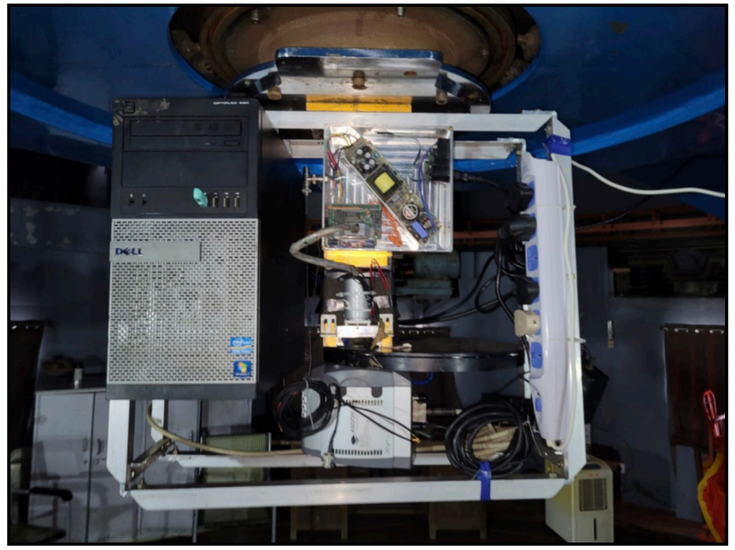
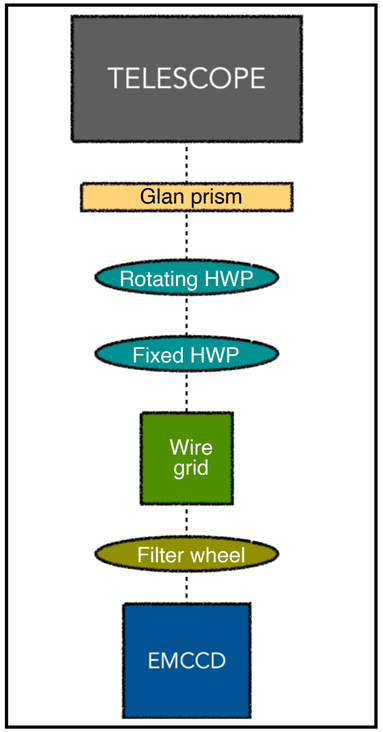


Obsesrvations





EMCCD based Polarimeter (EMPOL)

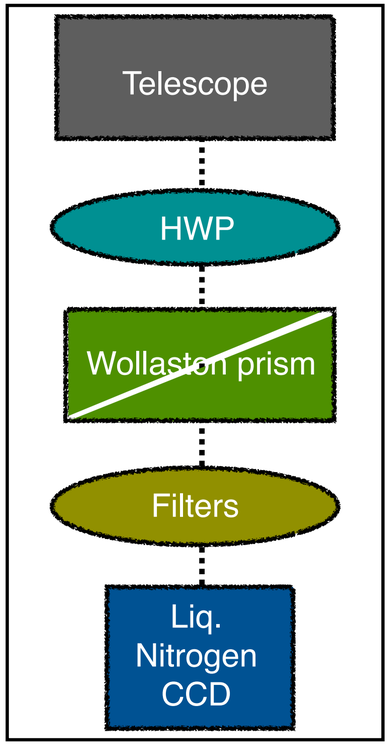
1.2 m telescope
Mount Abu, PRL

Regular observations : 3-4 nights per month

ARIES Imaging Polarimeter (AIMPOL)

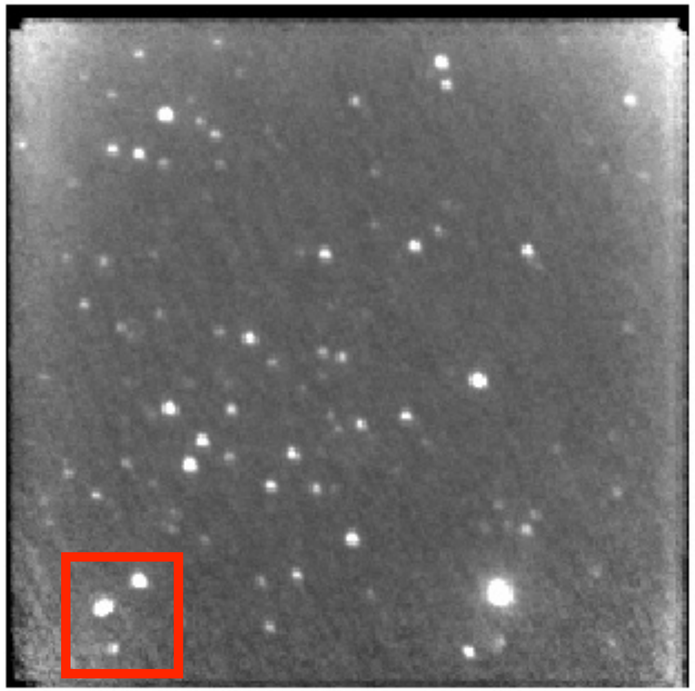
1.04 m Sampurnanand telescope
ARIES, Nainital

Proposal: Awarded ~ 13 nights in 3 observation cycle

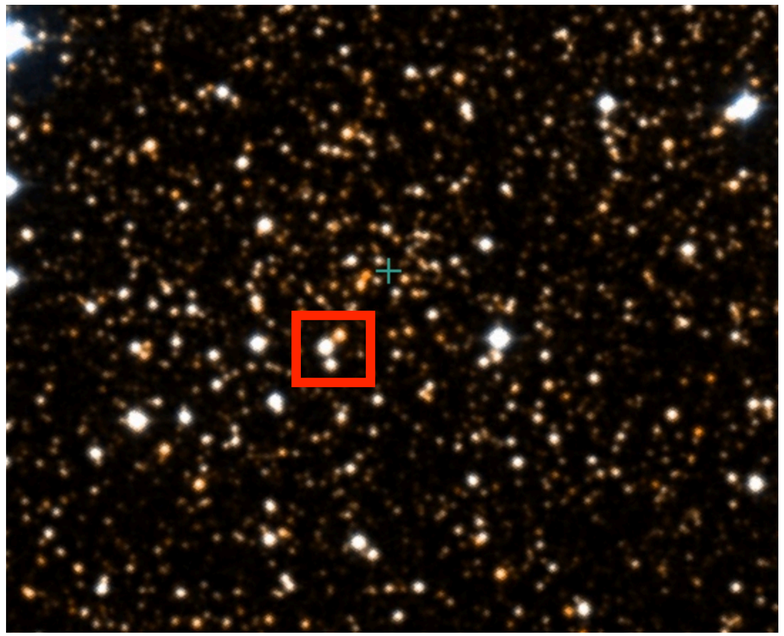


Observations

Kronberger 69, EMPOL image

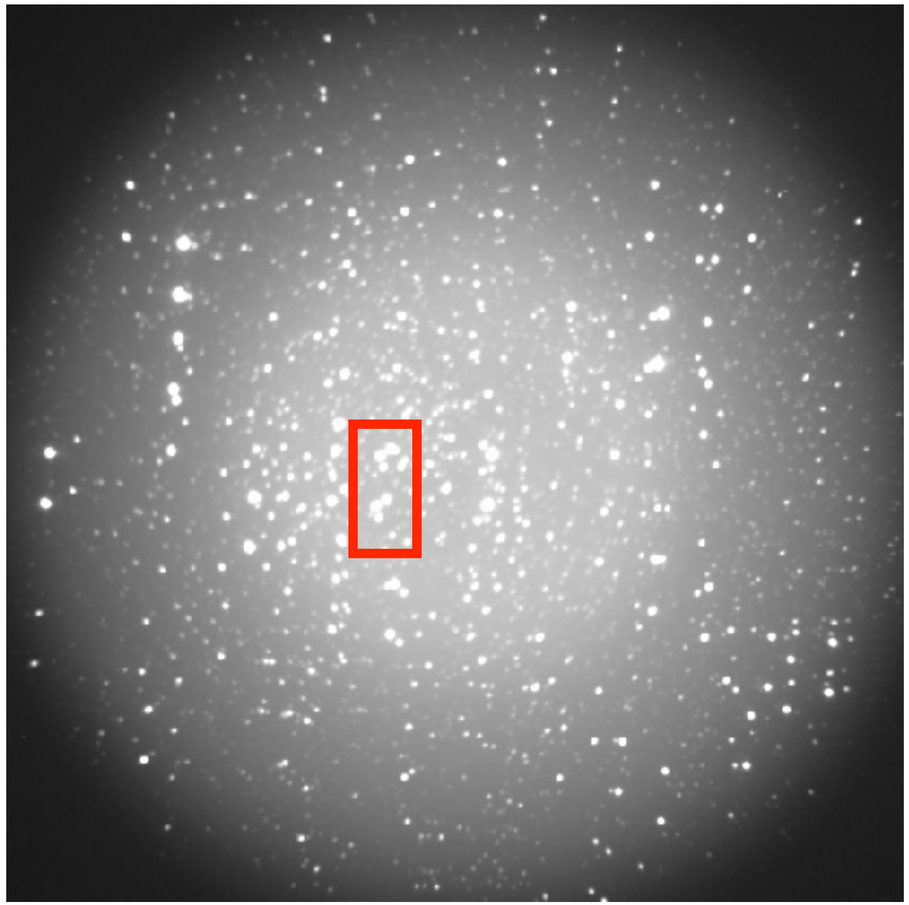


Kronberger 69, DSS2 R-band image



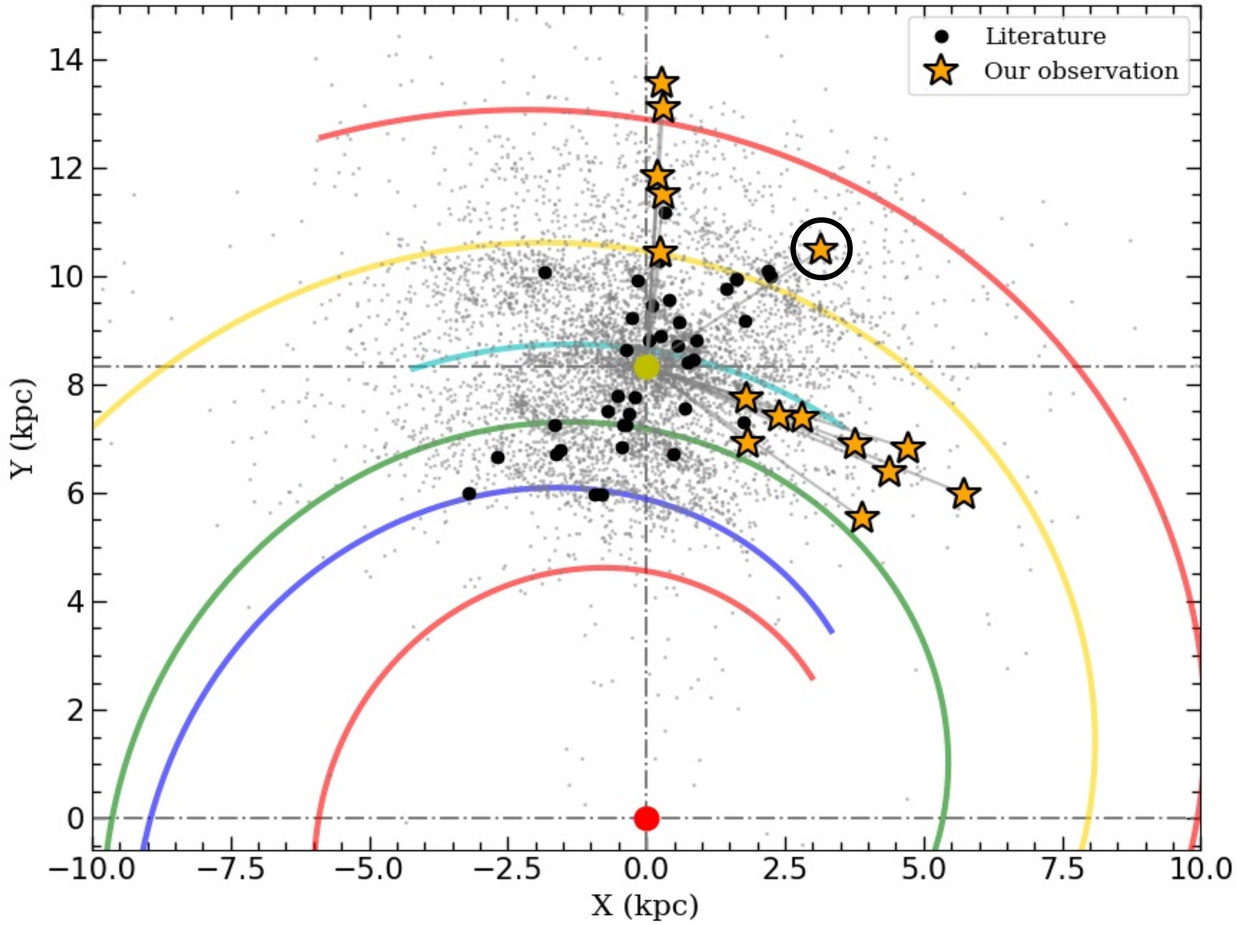
Developed Pipelines for automated data reduction from EMPOL as well as AIMPOL

Kronberger 69, AIMPOL image

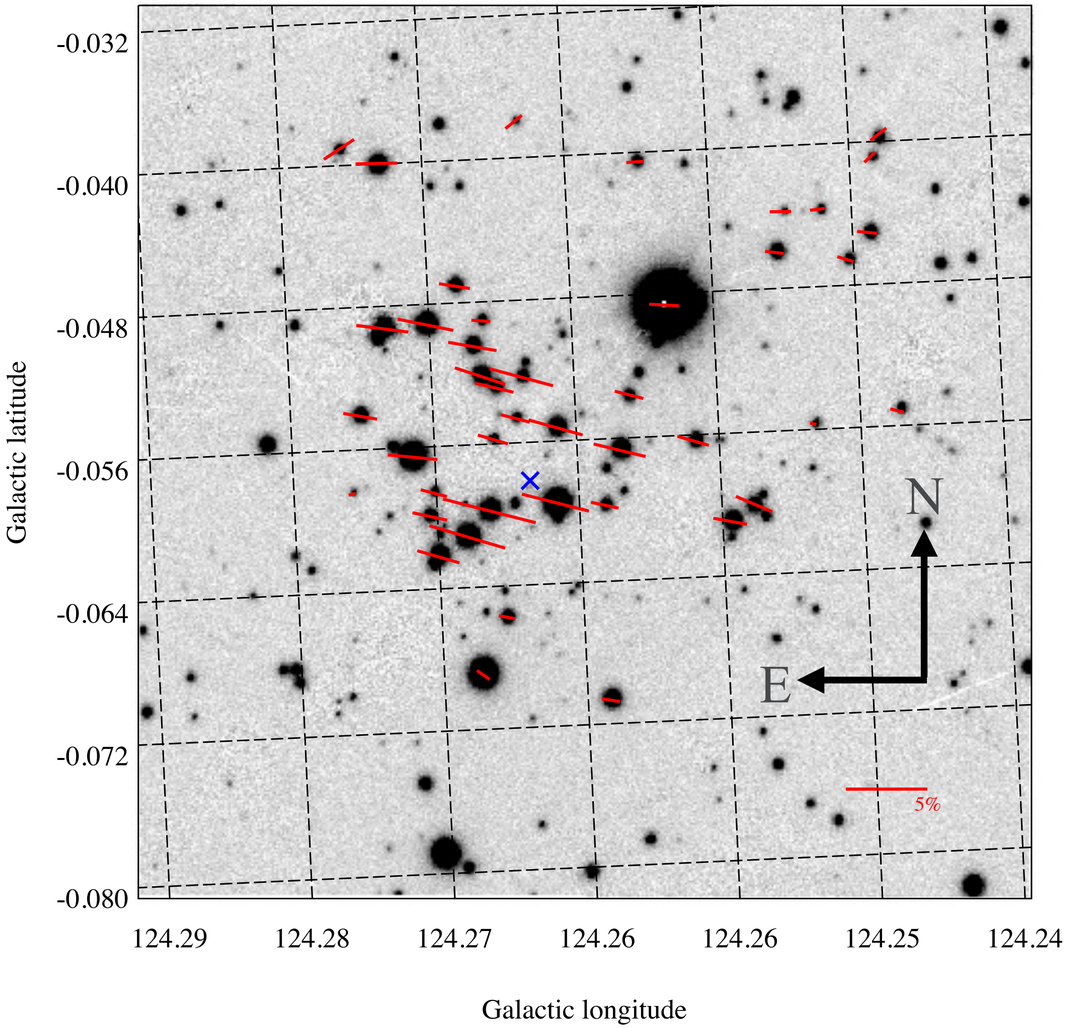


ISM polarization : Czernik 3

Using PRI's EMPOL



Uppal. N. et al. 2022, AJ



ISM polarization

Uppal. N. et al. 2022, AJ

- Jump in polarization and extinction

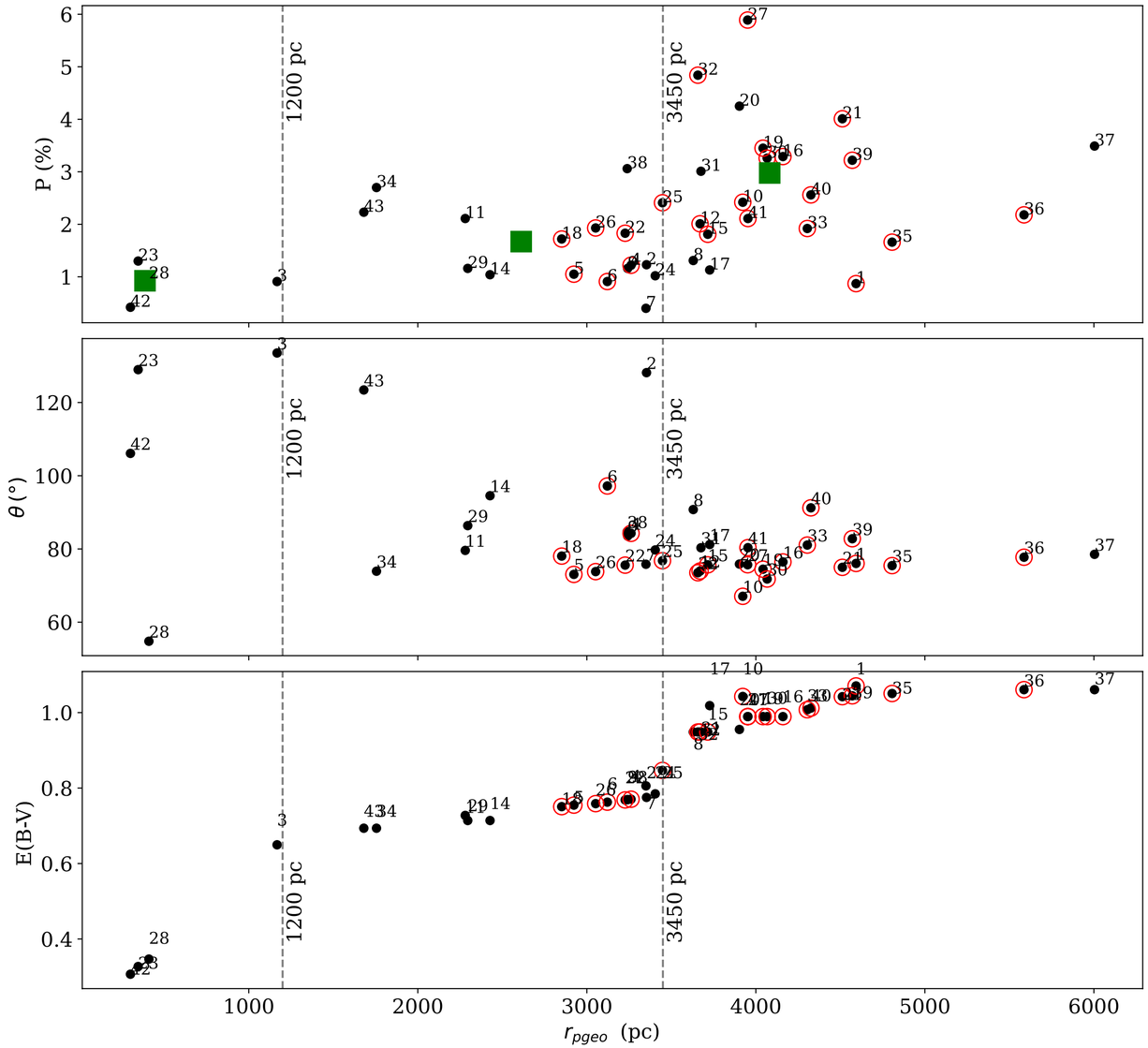
X-axis -> distance, from Gaia DR2 (Bailer Jones et al., 2018)

E(B-V)—>Extinction from Green et al., (2019)

~1 kpc and 3.4 kpc

At ~ 1 kpc => LDN 1306

Confirmed with the molecular data

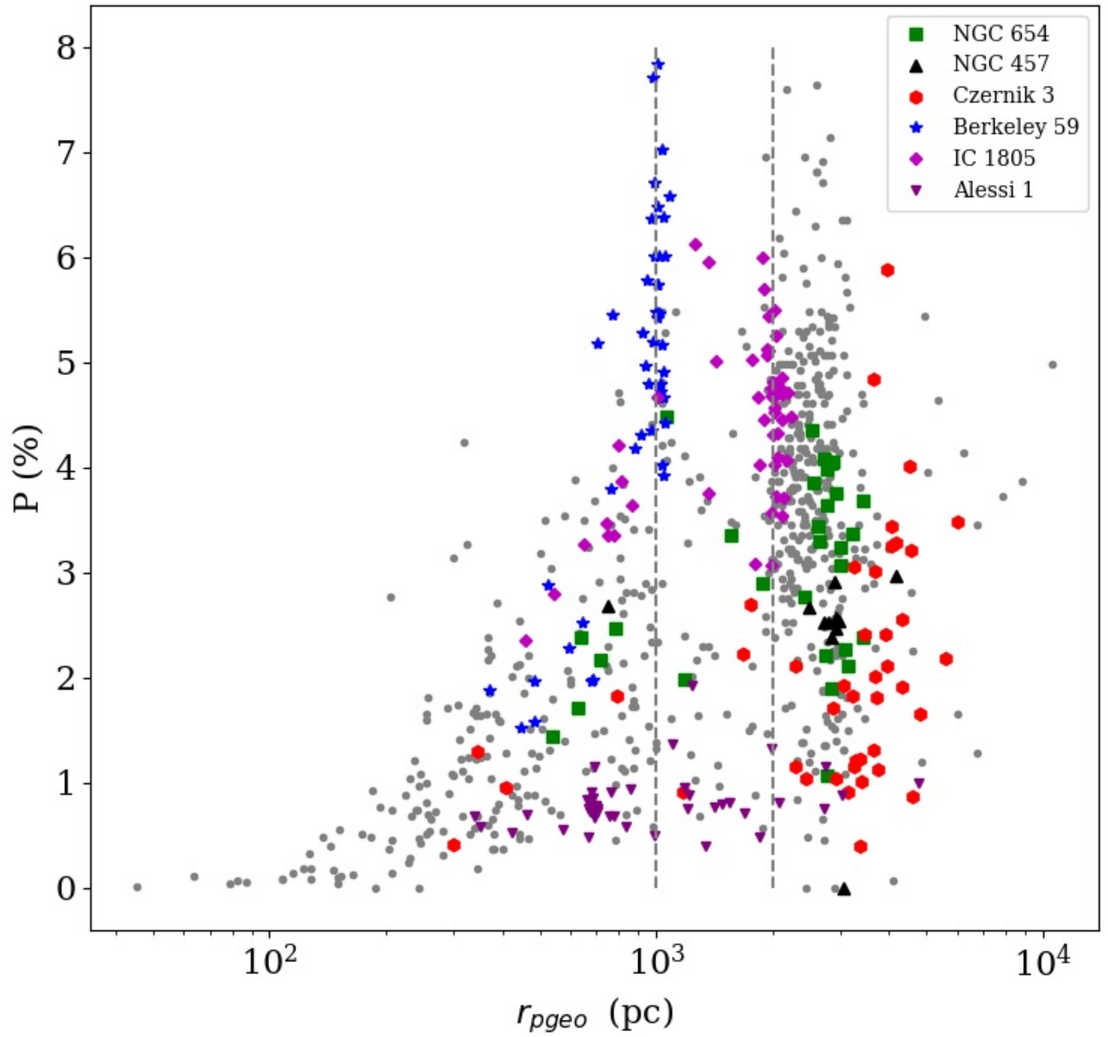


ISM polarization

Uppal. N. et al. 2022, AJ

- Clusters within 15° of Czernik 3
- Polarization uniformly increases till 1 kpc
- Polarization is approx same before and after 1-2 kpc gap.

Less dust content



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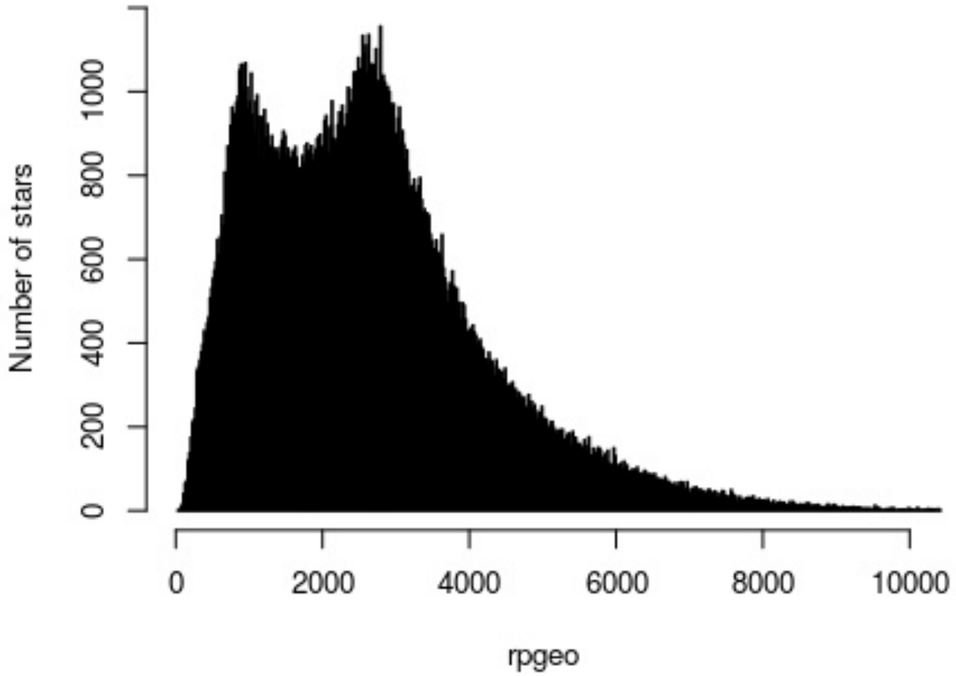
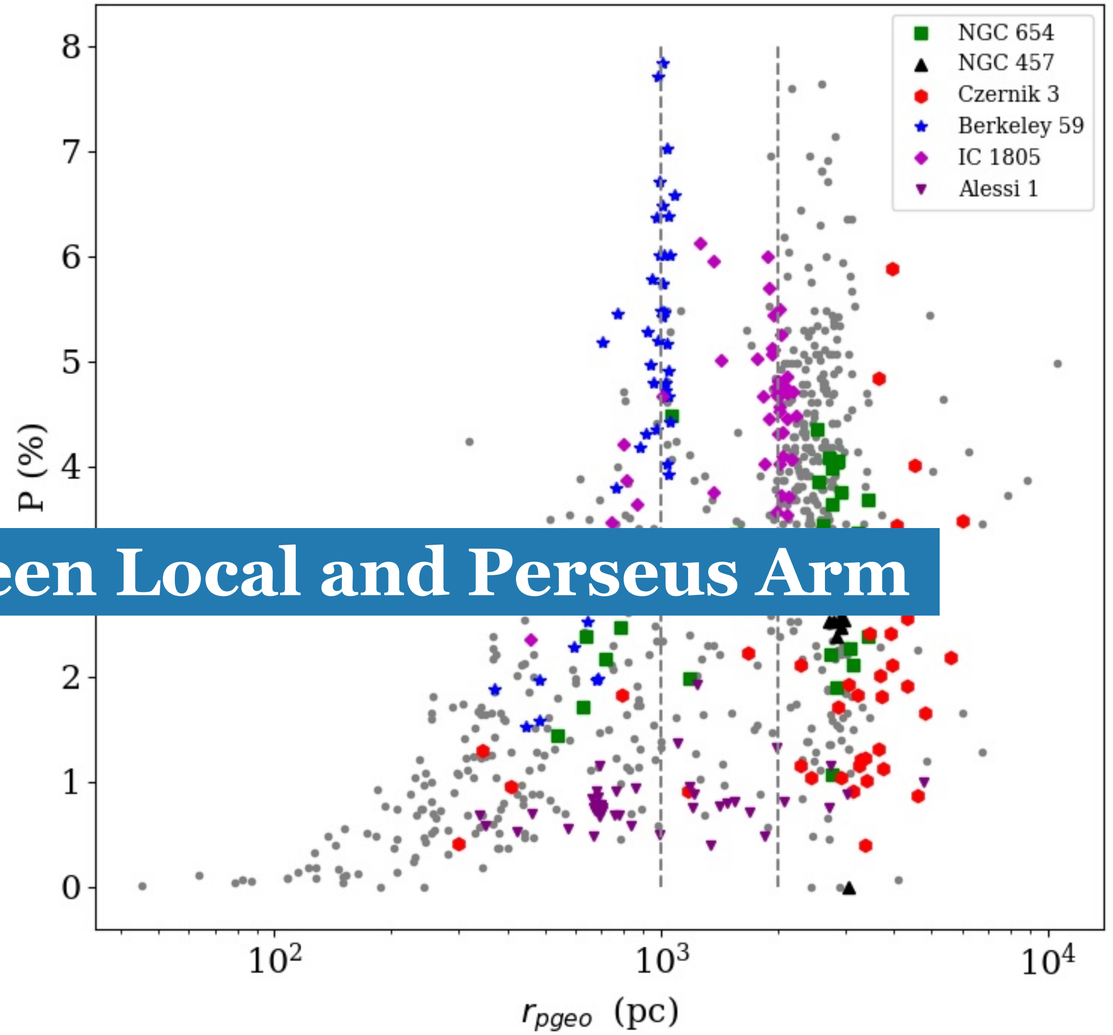




between Local and Perseus Arm

Stellar density dropped in 1-2 kpc gap

ISM polarization

Kinematic distances show high uncertainties

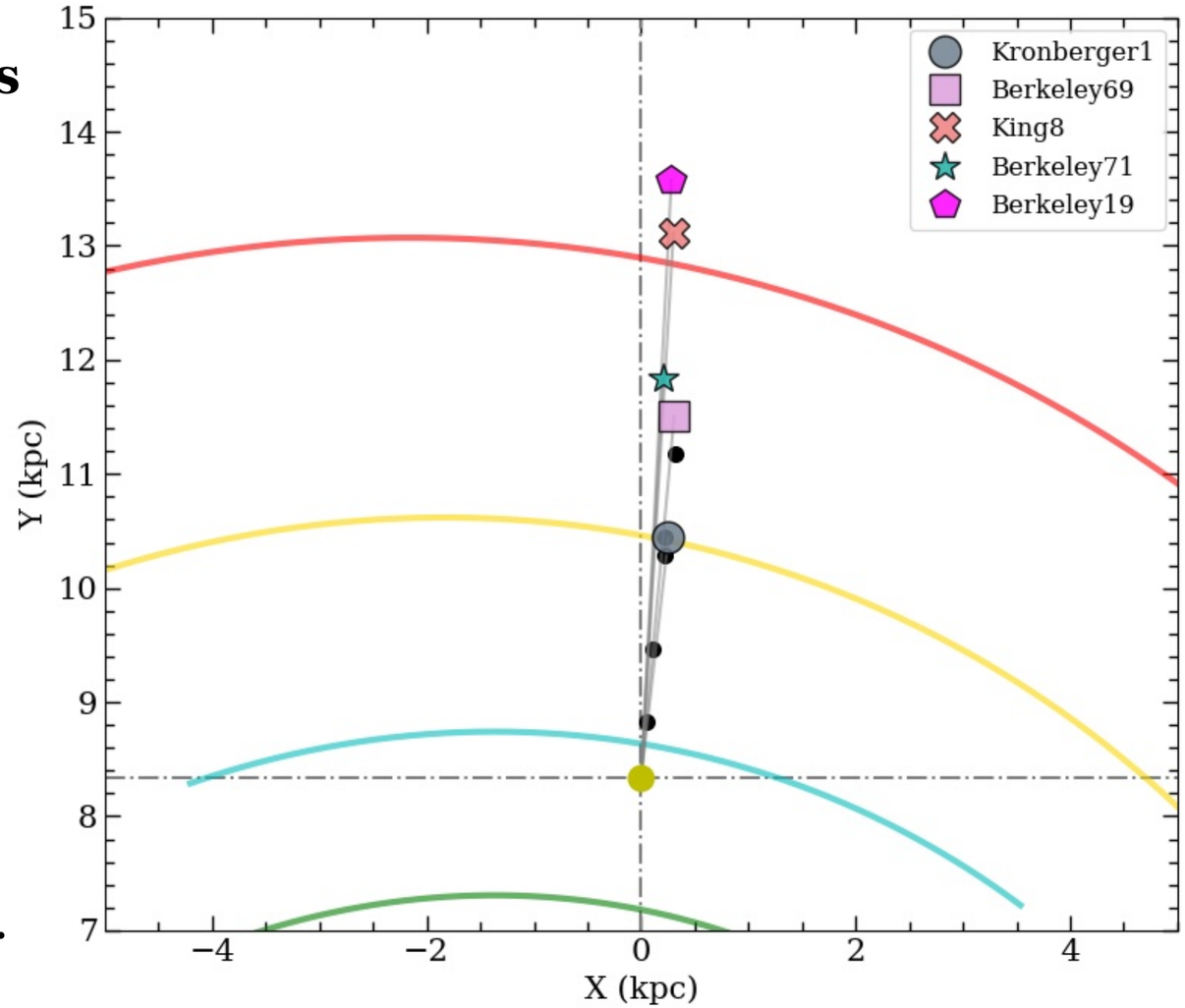
Polarization is the best possible way to trace the dust along the line of sight

Literature - 5 clusters but distance < 3 kpc

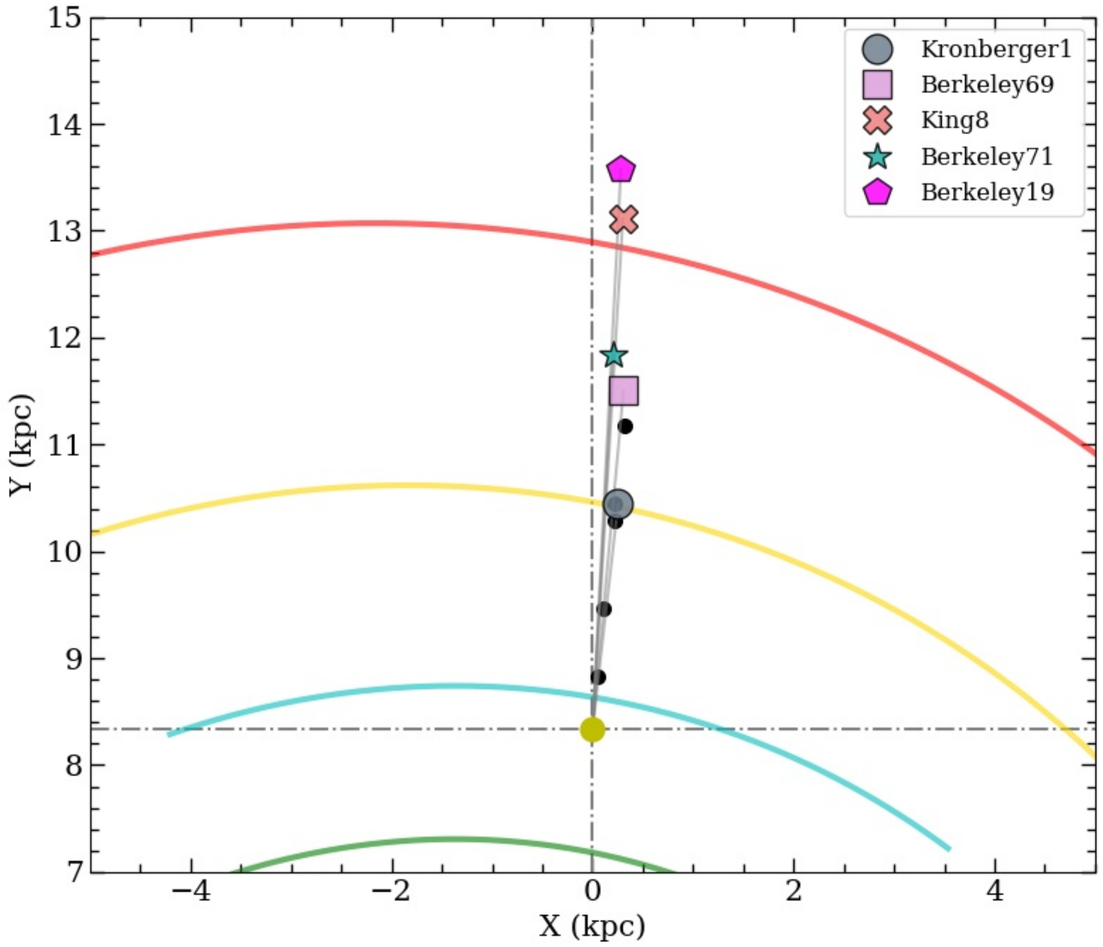
Our target - clusters in similar line of sight but different distance

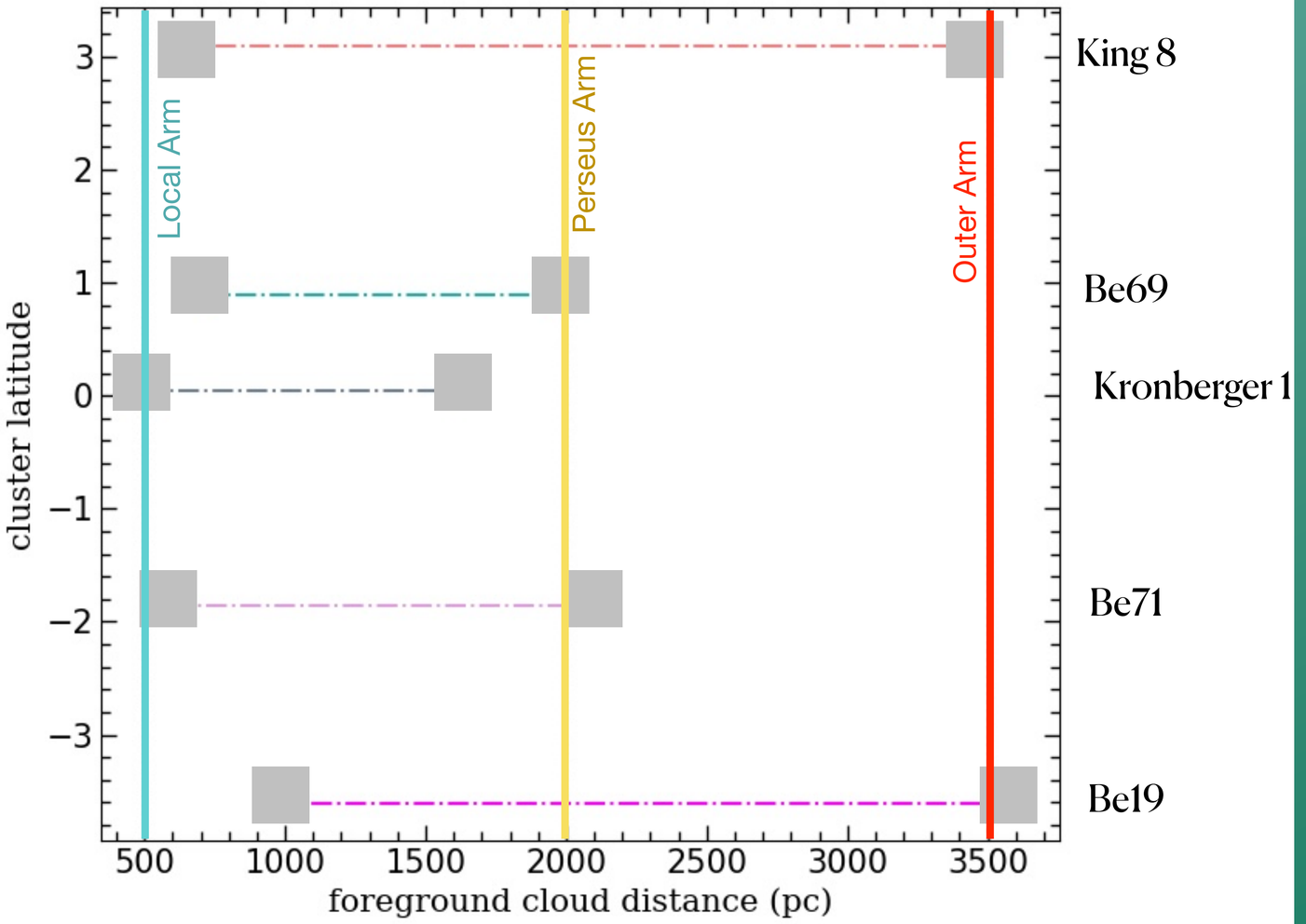
5 clusters

Results : More than 100 stars towards each cluster.

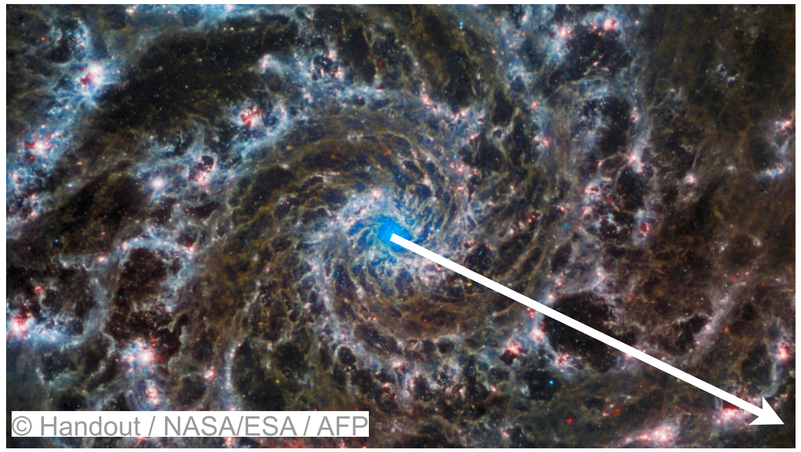


ISM polarization

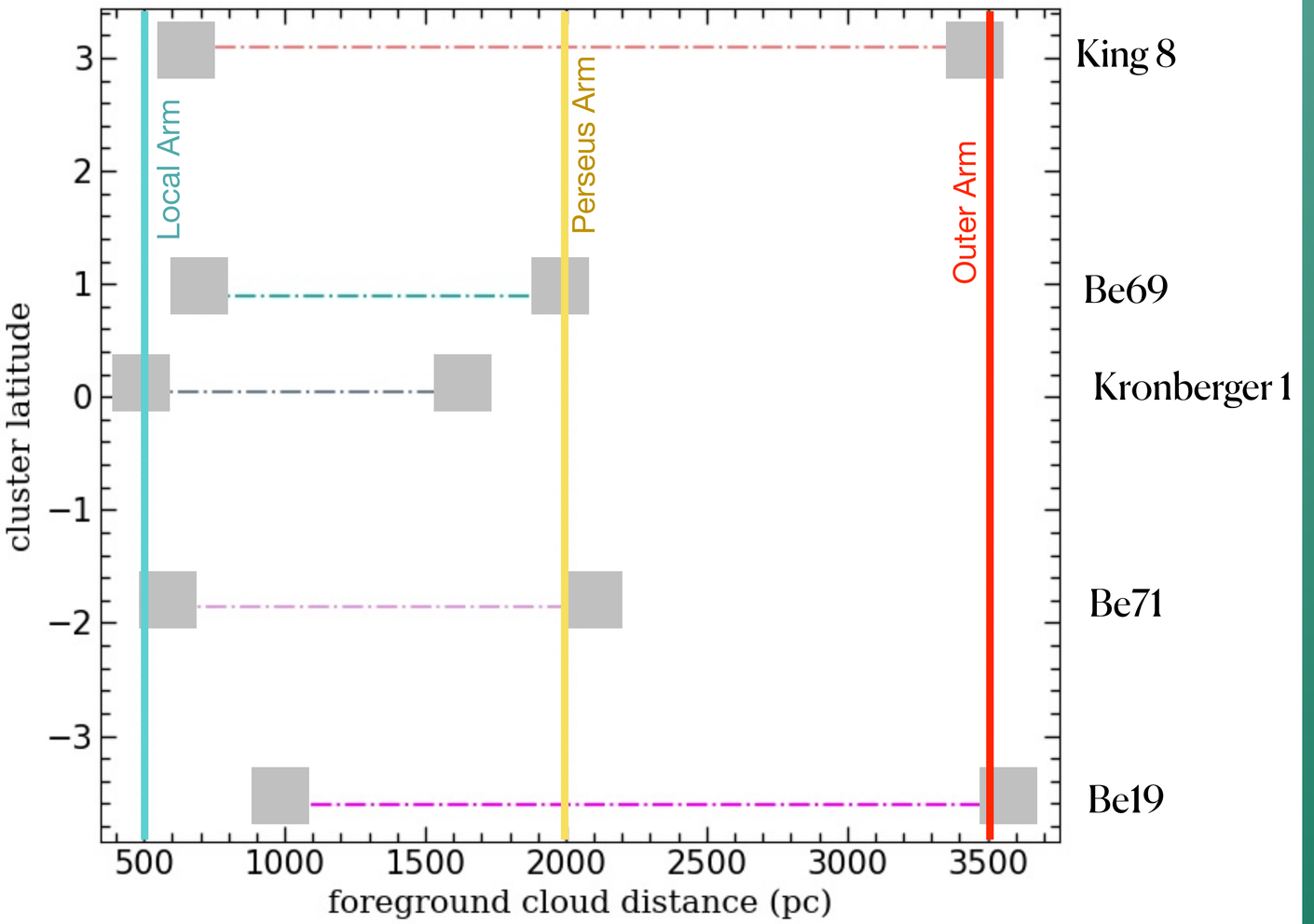




ISM polarization



Possibility 1: Low extinction window in Perseus arm



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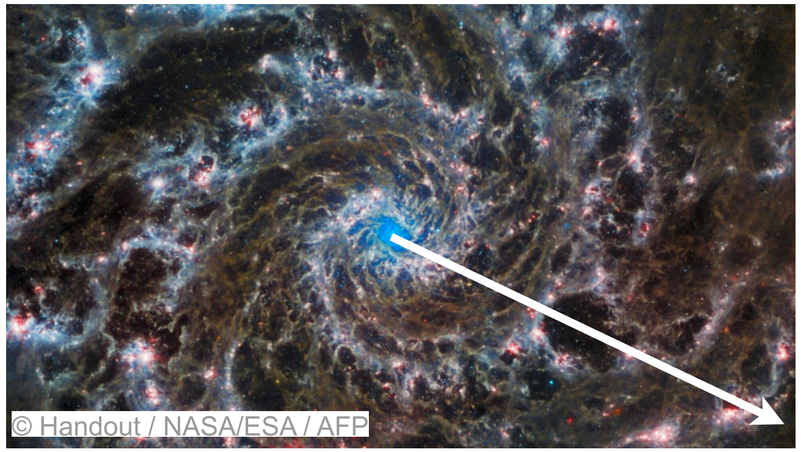
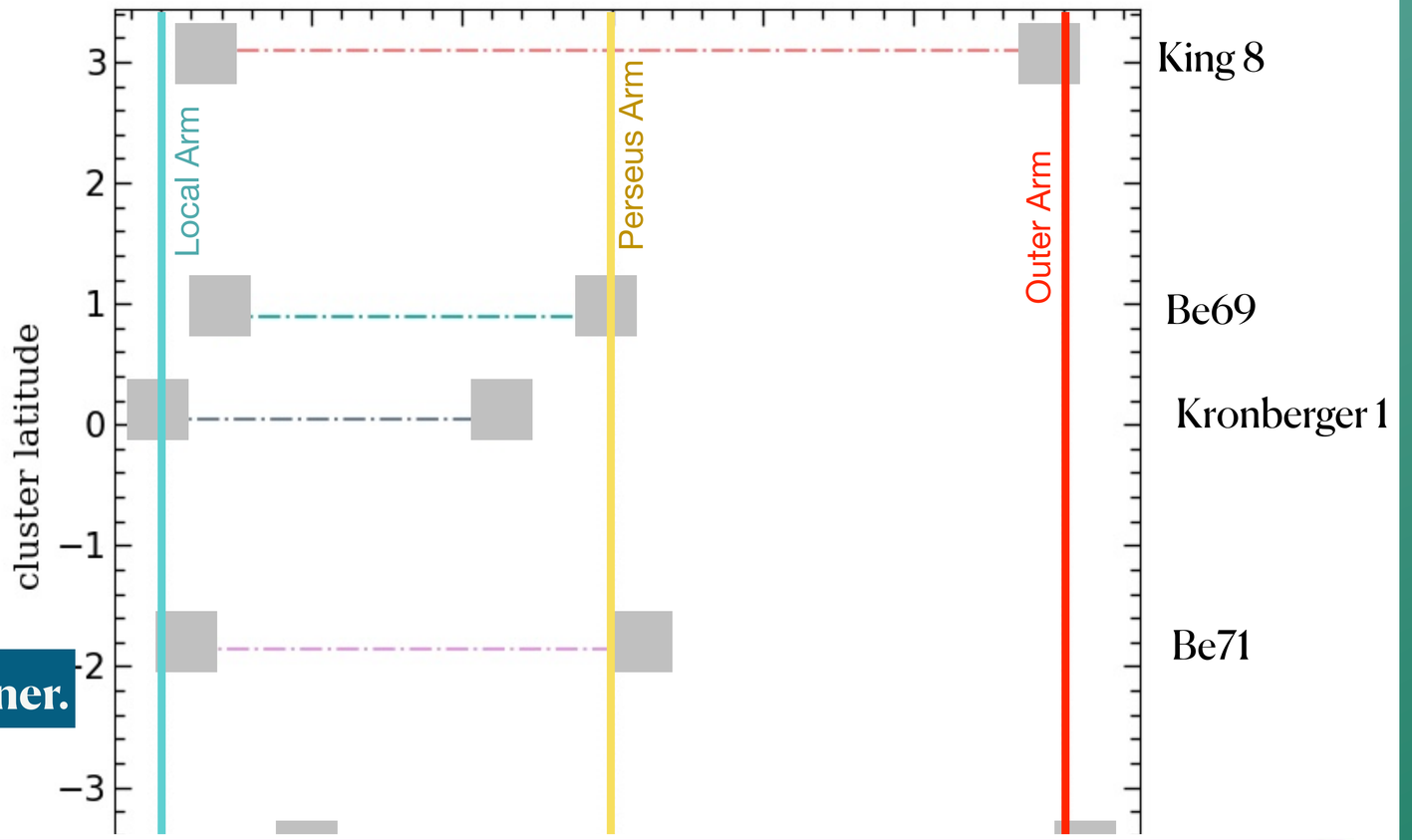
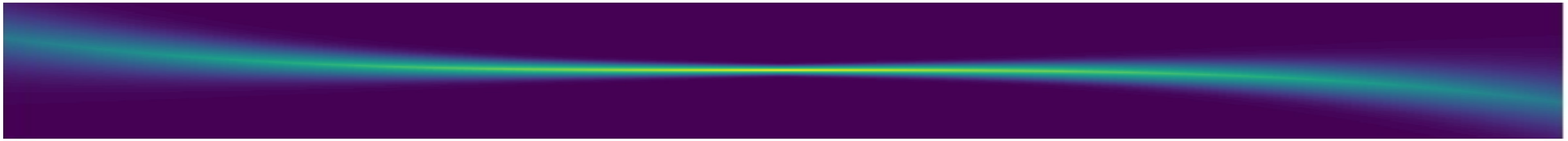


Possibility 1: Low extinction window in Perseus arm

Possibility 2: Outer Arm being more thicker than the inner.





ISM polarization

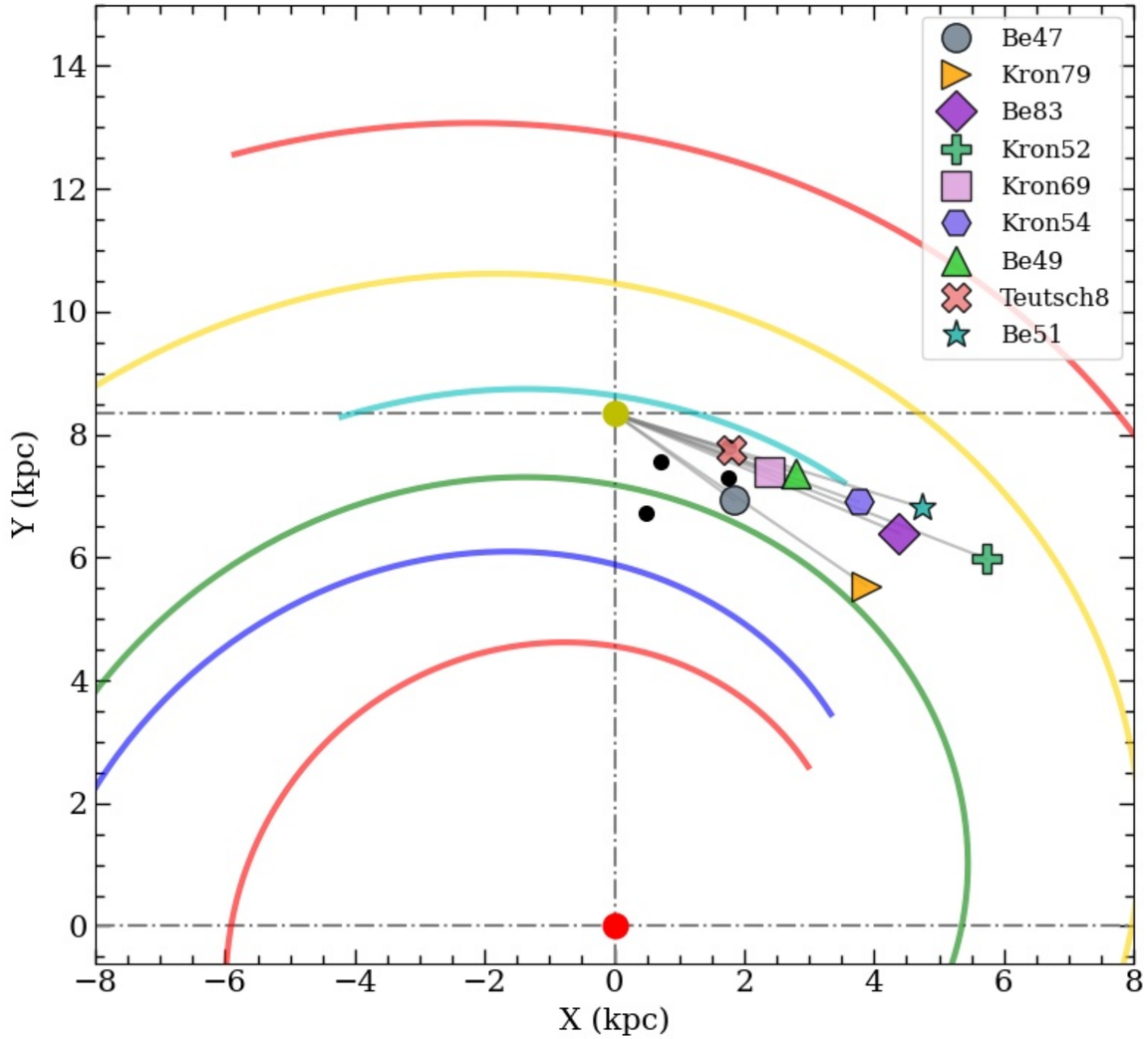
Line of sight radial to the spiral arm

Polarization observations in Literature - only 4 clusters

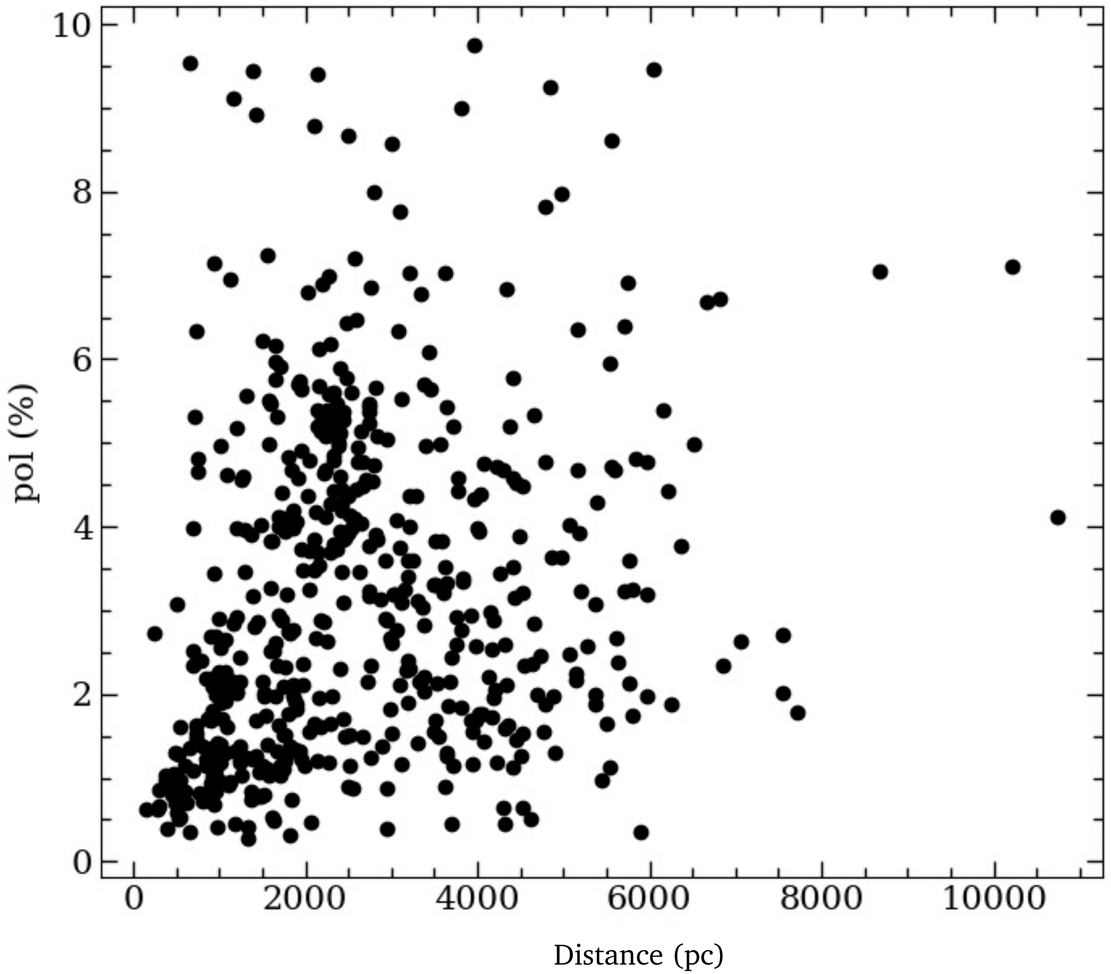
Our observations - 9 clusters

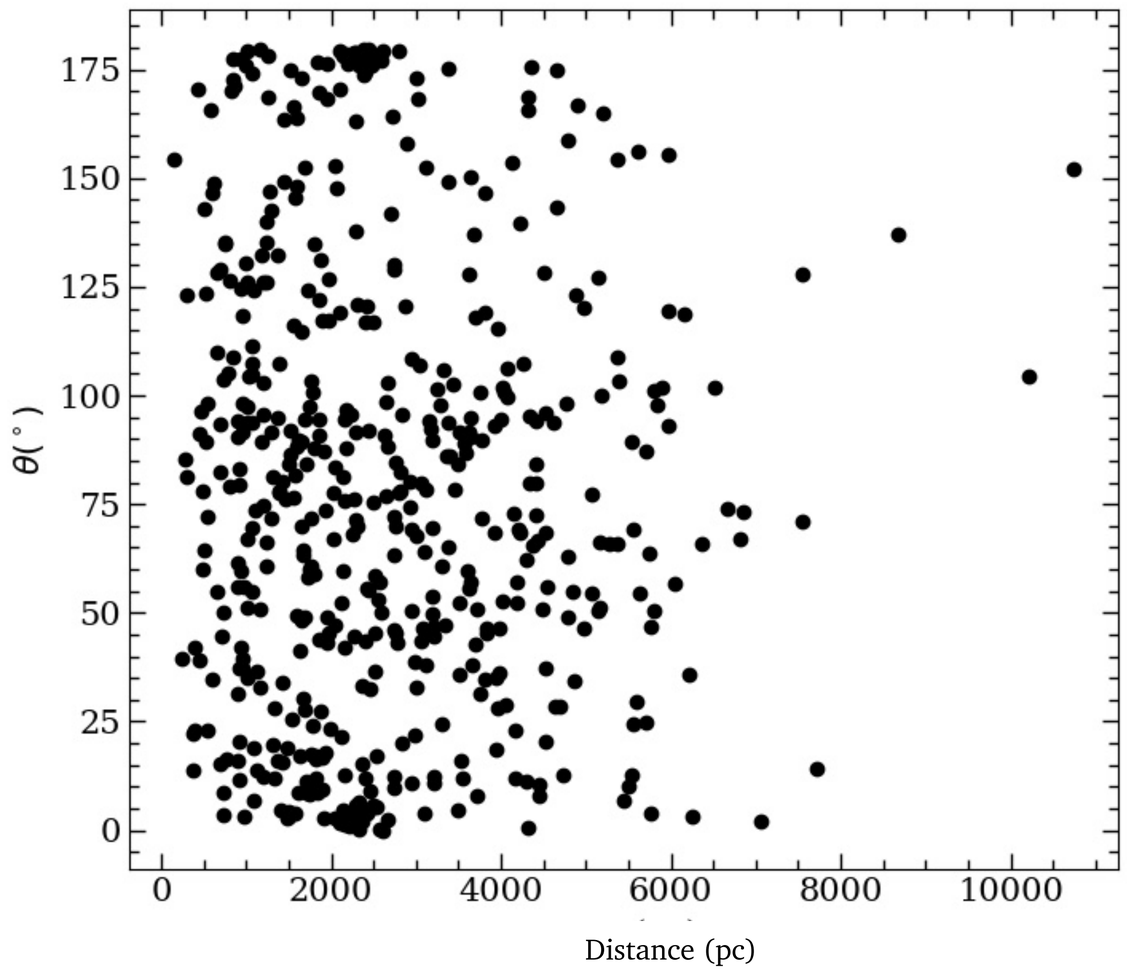
3 from AIMPOL

6 from EMPOL



ISM polarization





- Large scatter in polarization angle.
- Increase in degree of polarization with distance but large dispersion

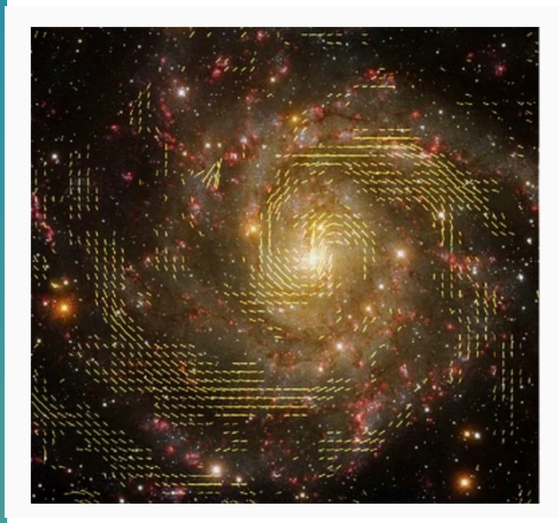
ISM polarization

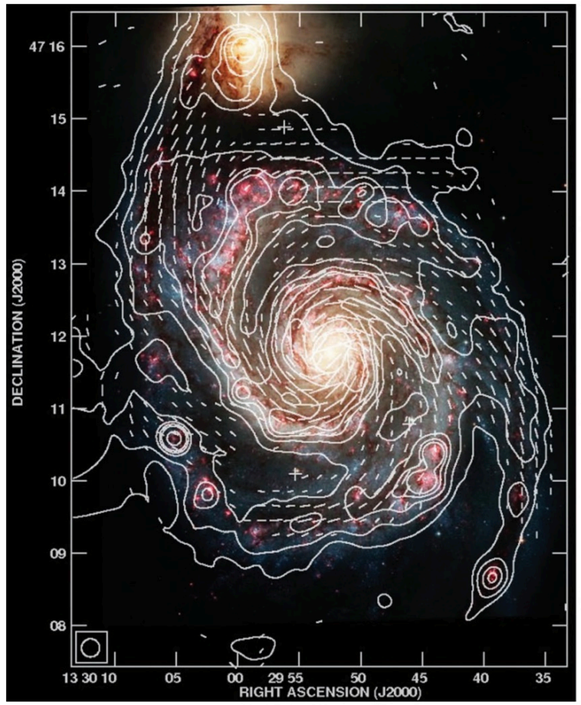
★ Patchy dust distribution

- Stars at same distance may not have same foreground dust layers

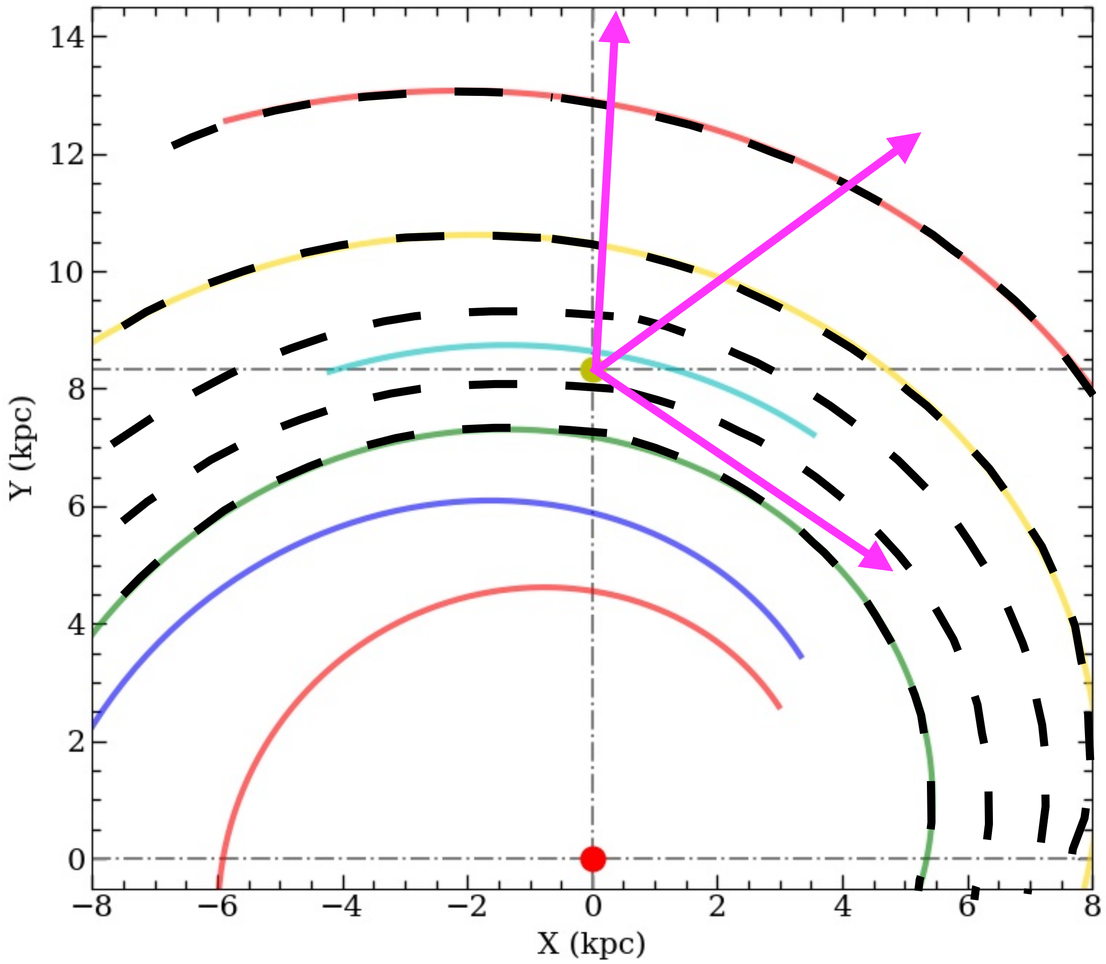
ISM polarization

★ **Magnetic field alignment along spiral arms**





Directions chosen in this thesis



Summary

- A complete understanding of the disk morphology require a systematic study of different populations.
- RC stars are good distance as well as structural tracers.
- Detected Outer arm of the Galaxy using RC stars with 6 kpc long extension.
- First observational evidence of warping of spiral arms.
- Dust distribution can be used to probe small scale structures.
- Polarization is an indirect and effective tool to trace large scale as well as small scale structures
- Indication of large scale magnetic field alignment.

Thank you