3D extinction mapping of the Milky Way with the Besançon Galaxy Model in the *Gaia* era

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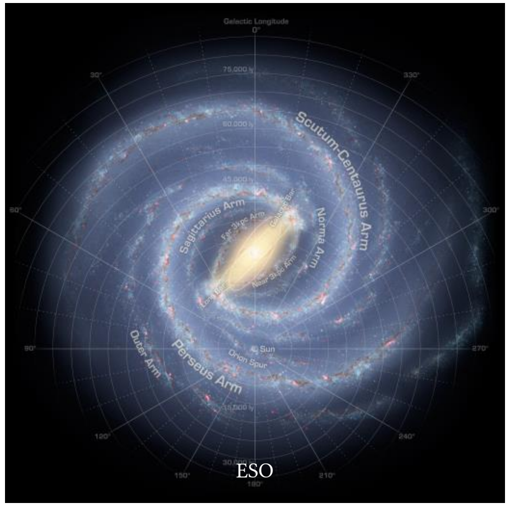
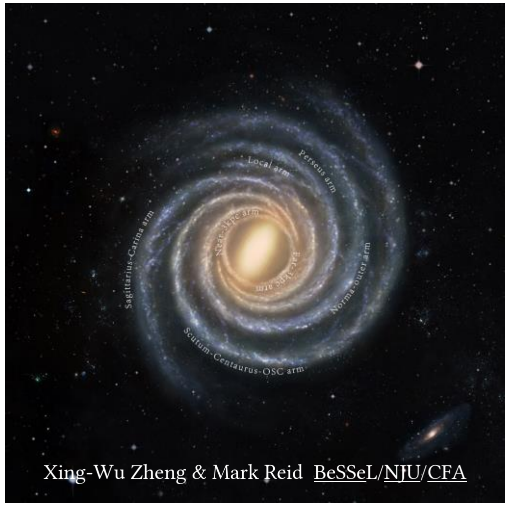
Colloque PCMI 2024
28 October 2024

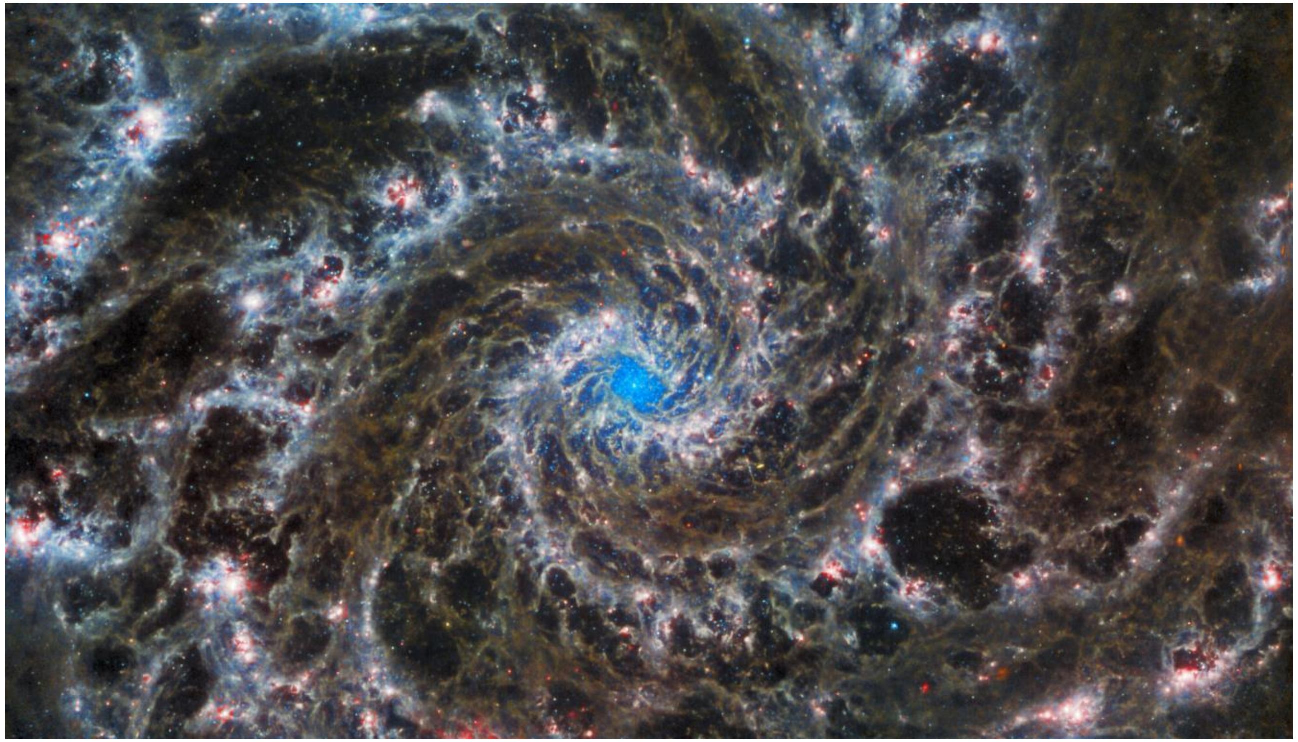
Context: The Milky Way

The MW structure

- What does the MW look like?
- What are the characteristics of the remarquable structures in the MW (bar, spiral arms, etc.)?
- What are the processes that link the ISM to stellar formation?
- Etc.







NGC 628 by the JWST

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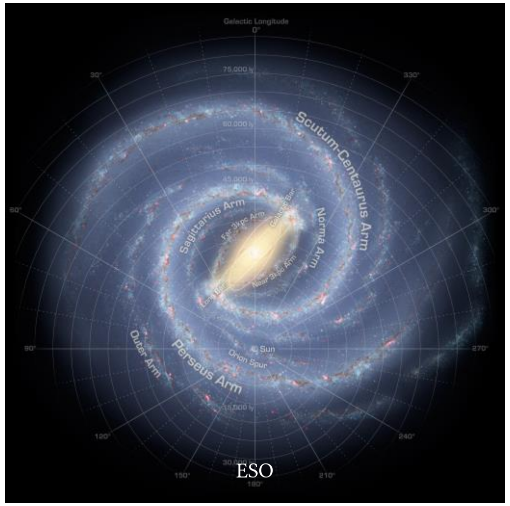

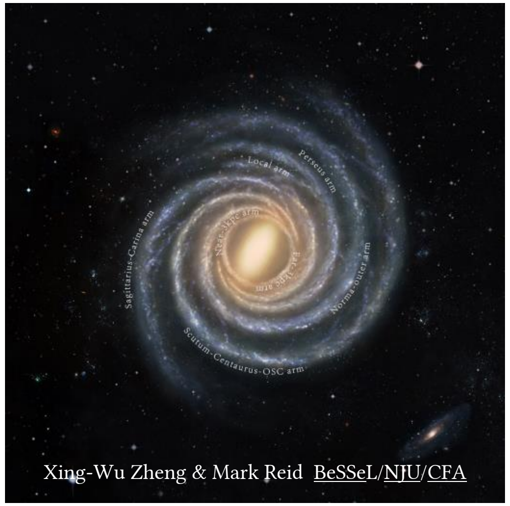

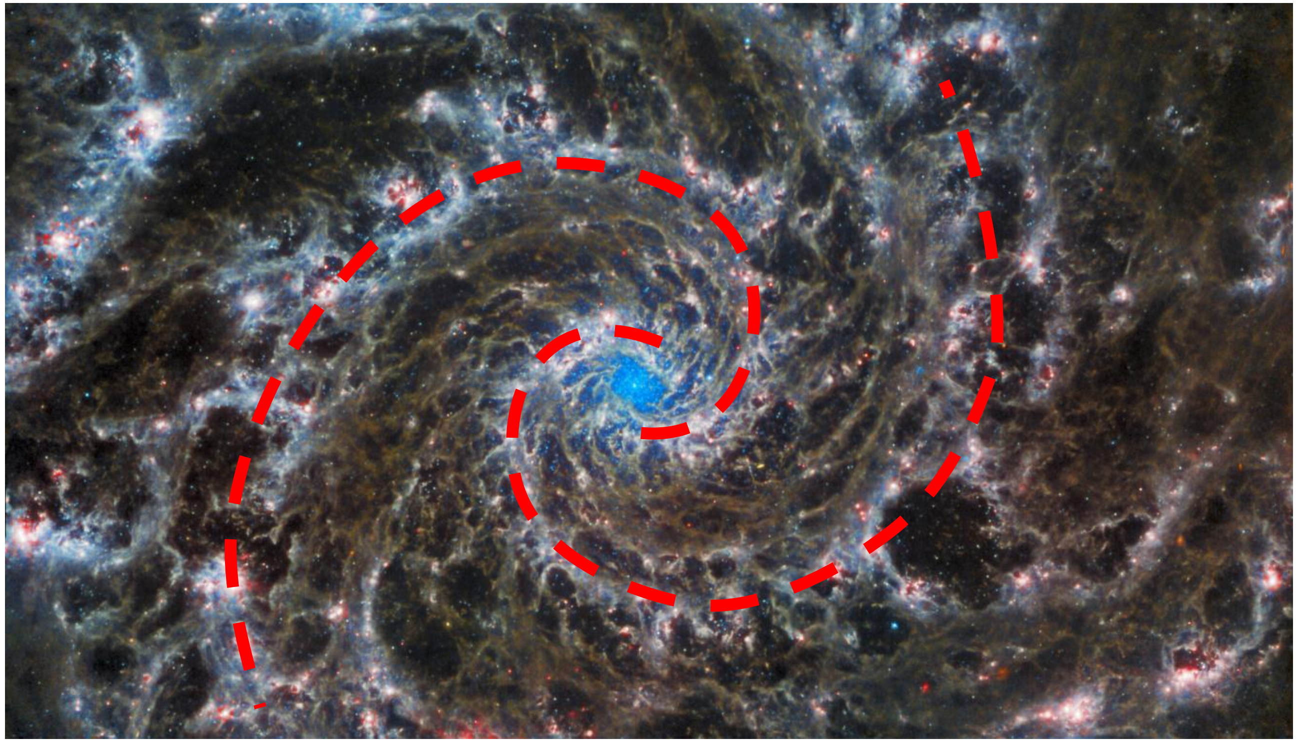

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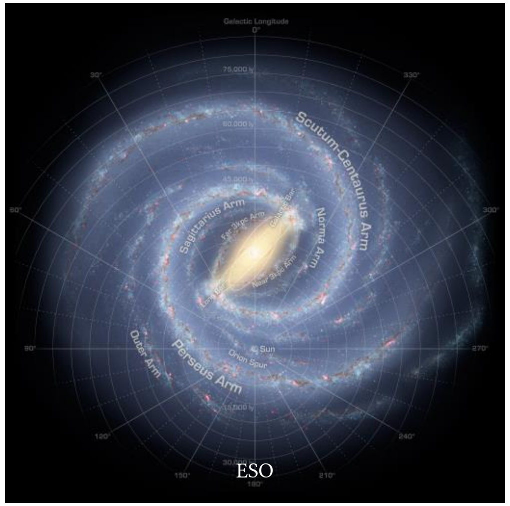

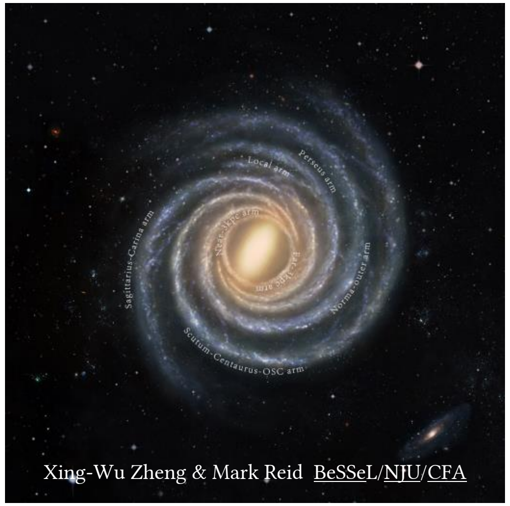

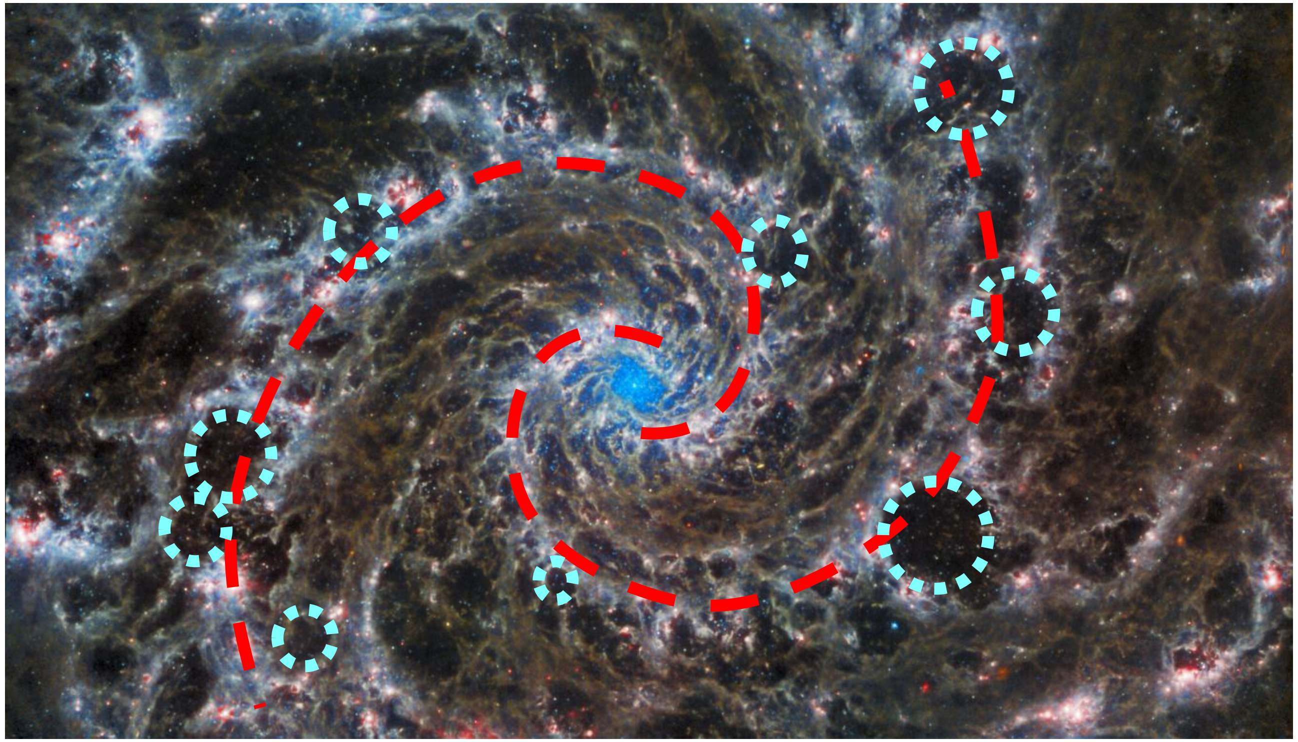

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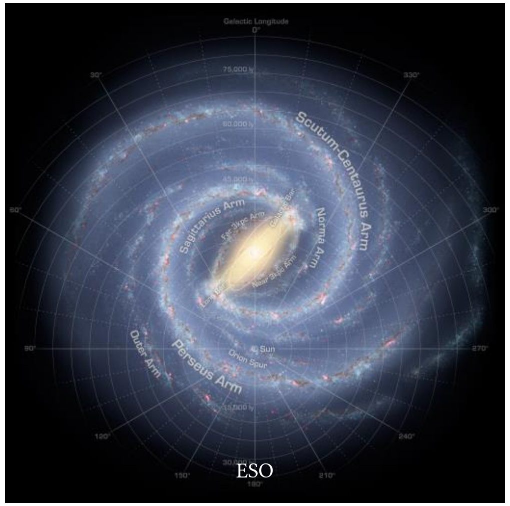

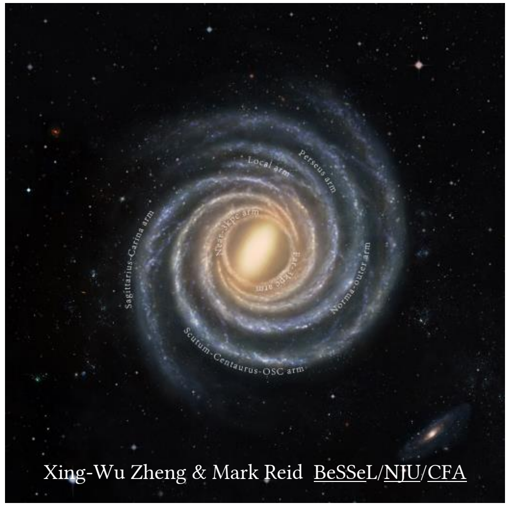

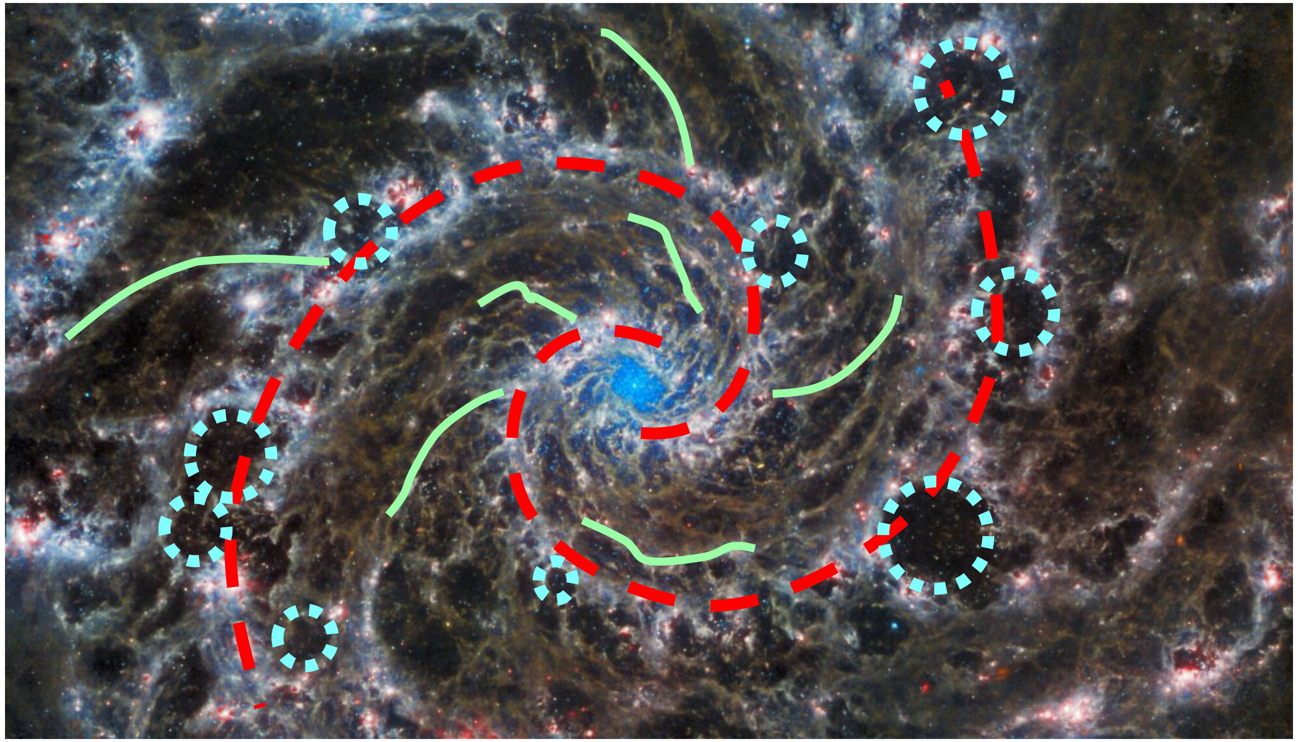

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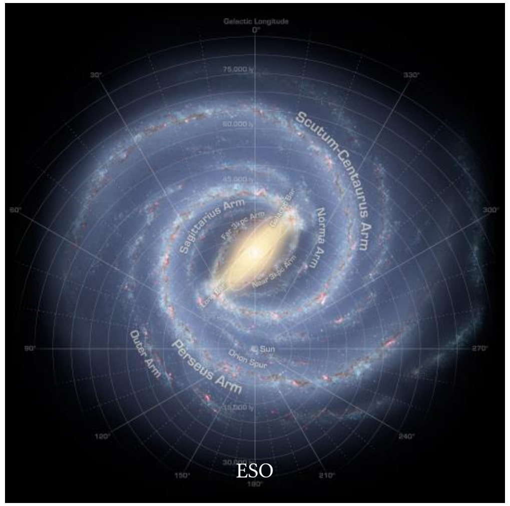

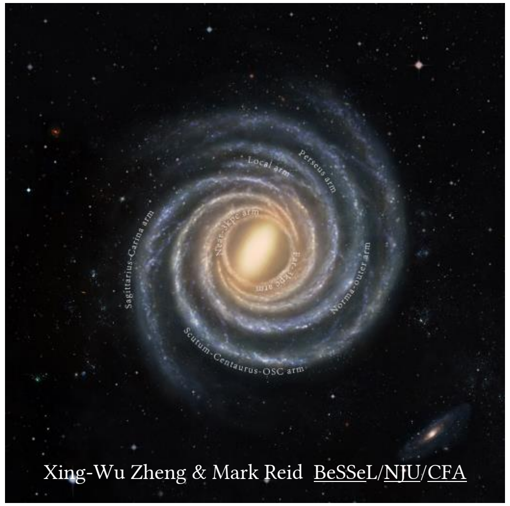

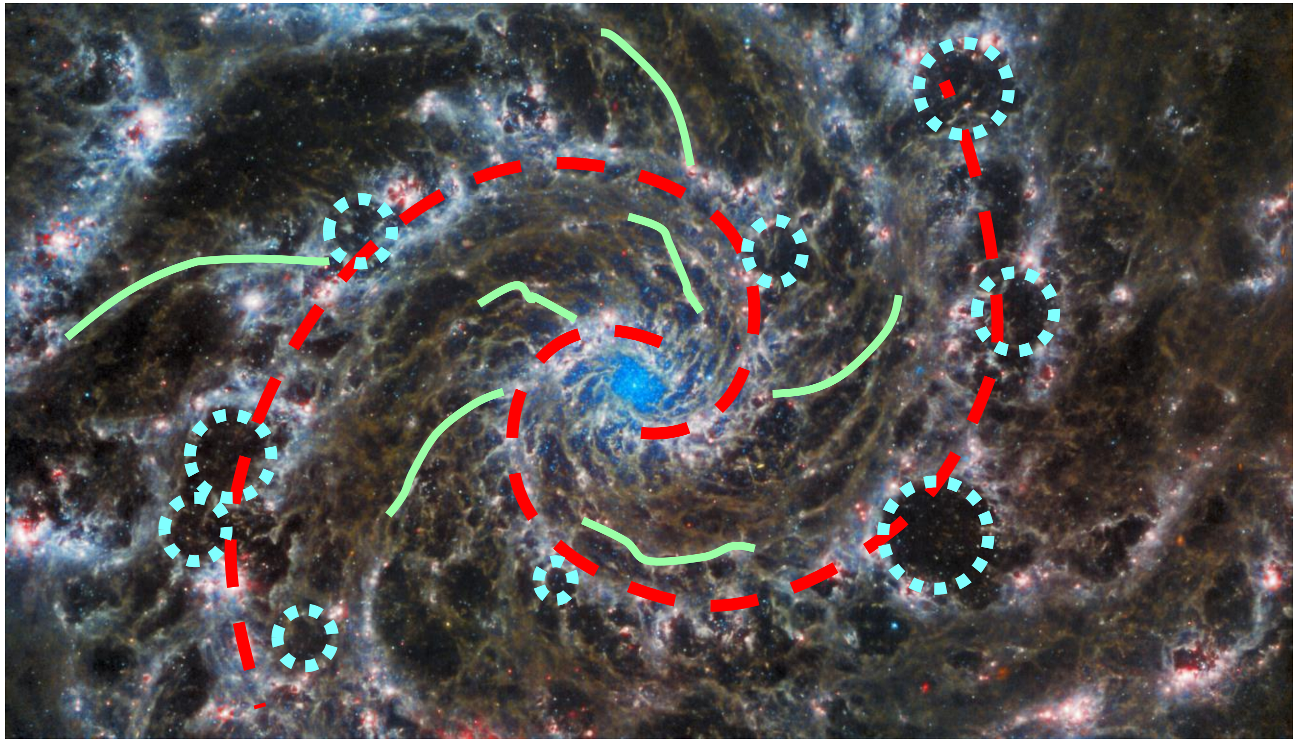

NGC 628 by the JWST

The MW ISM structure is not well known

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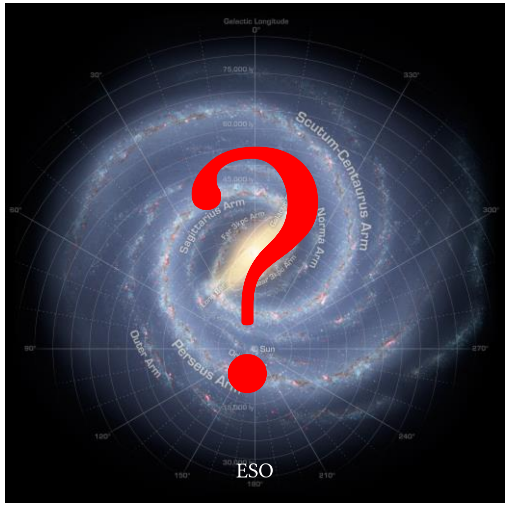

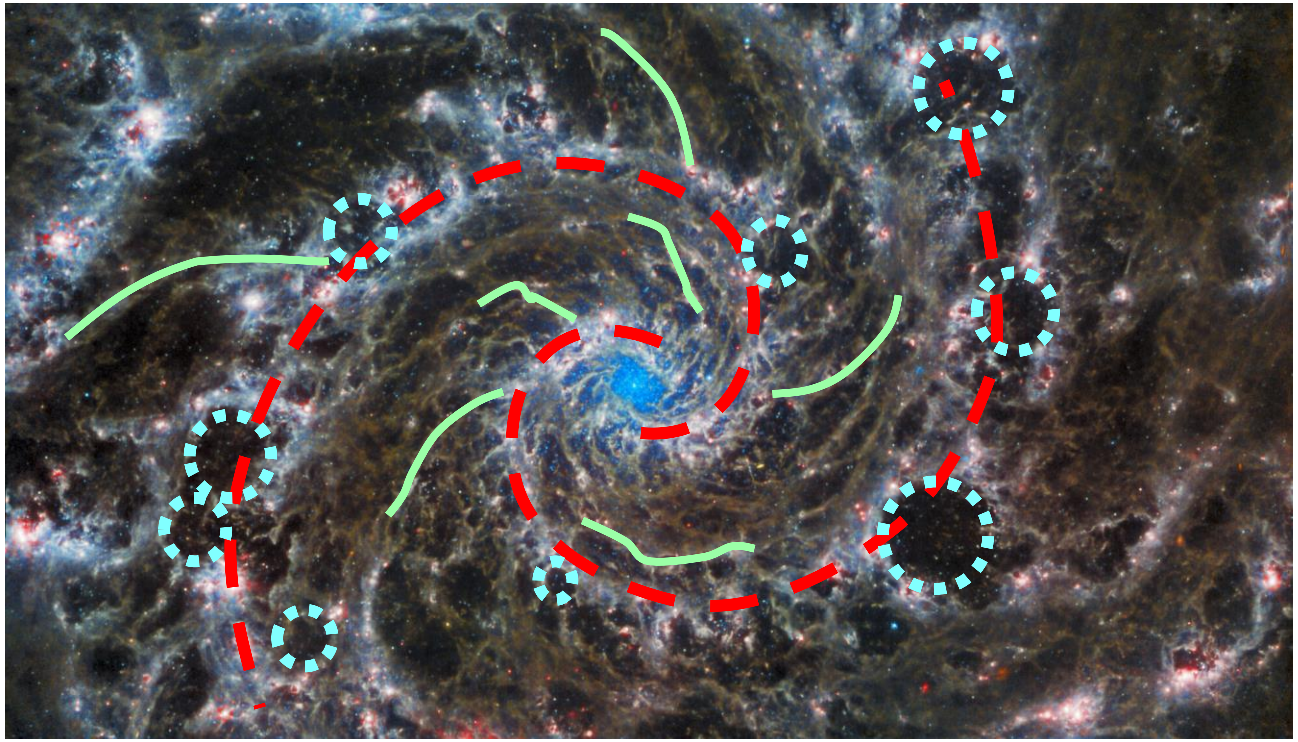

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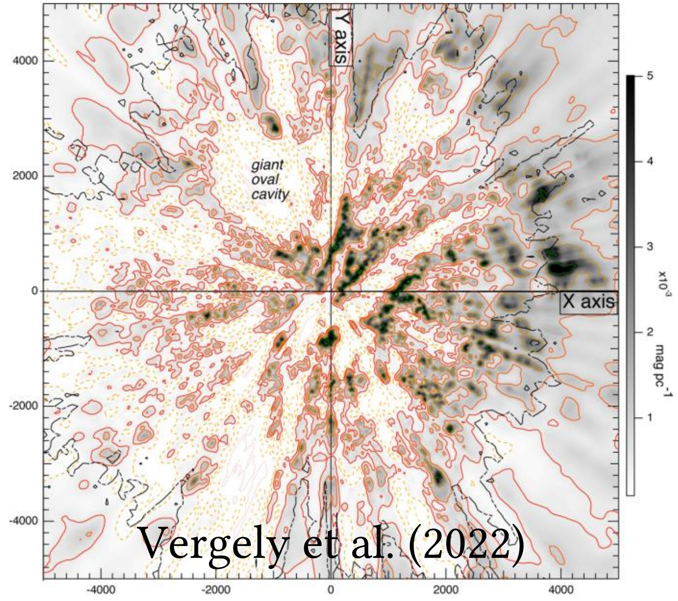
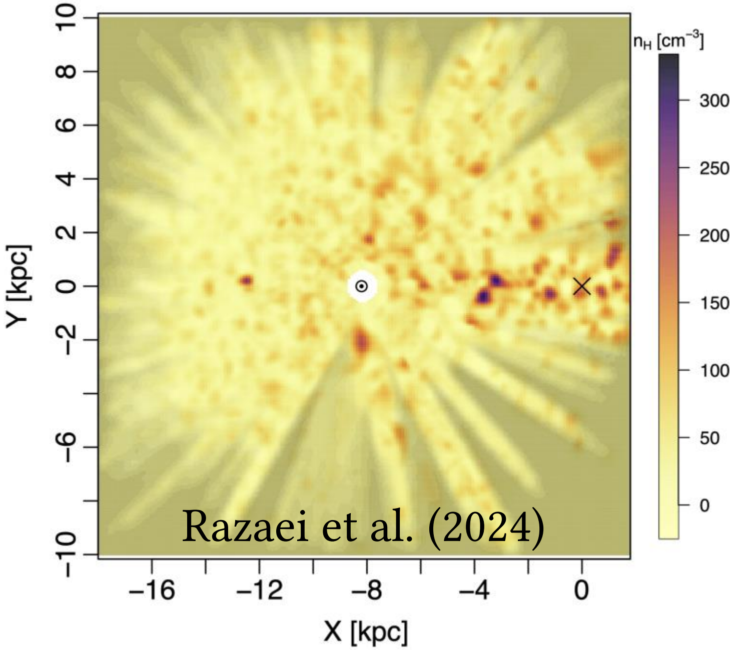
The MW ISM structure is not well known

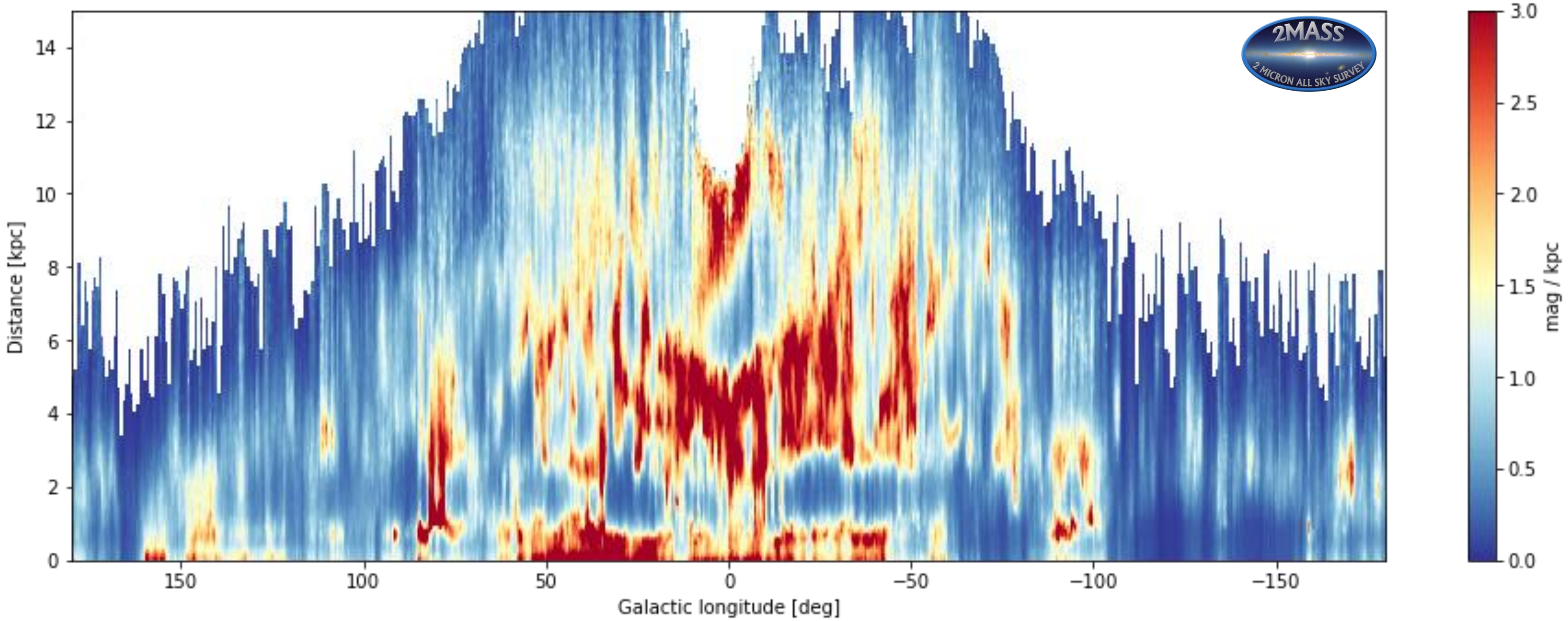
Context: 3D extinction maps



Vergely et al. (2022)



Razaei et al. (2024)



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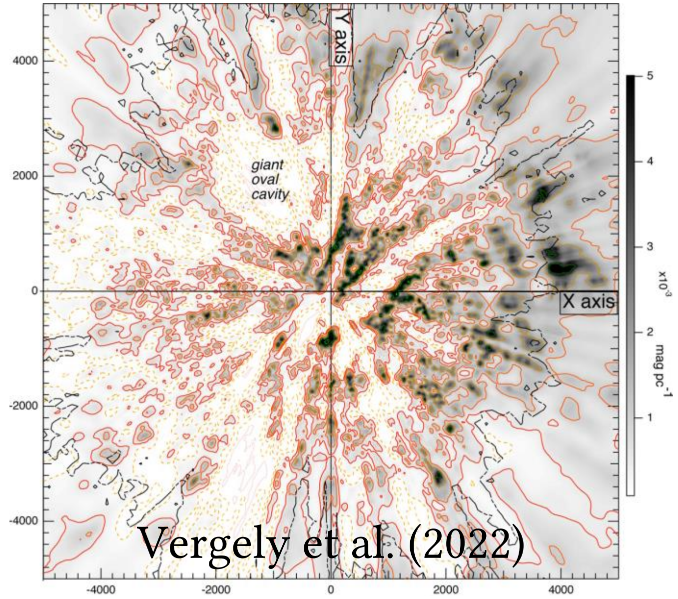

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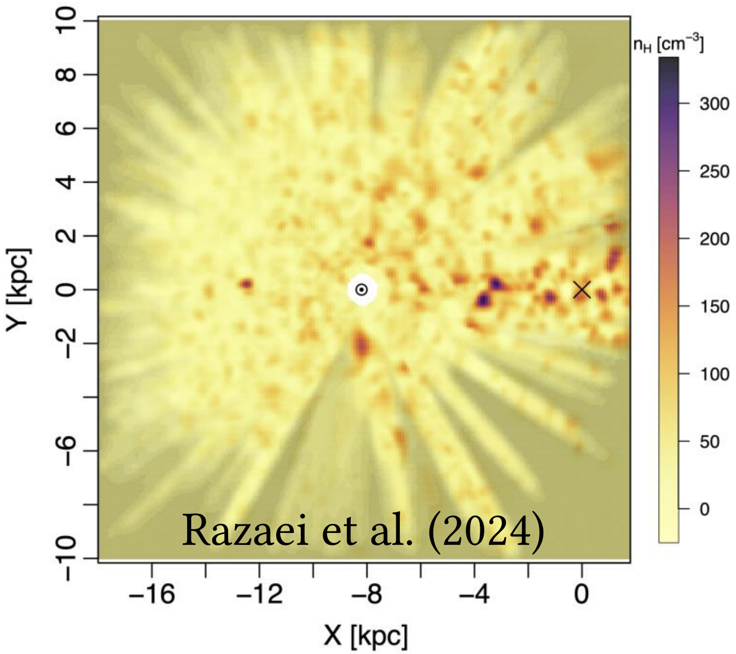

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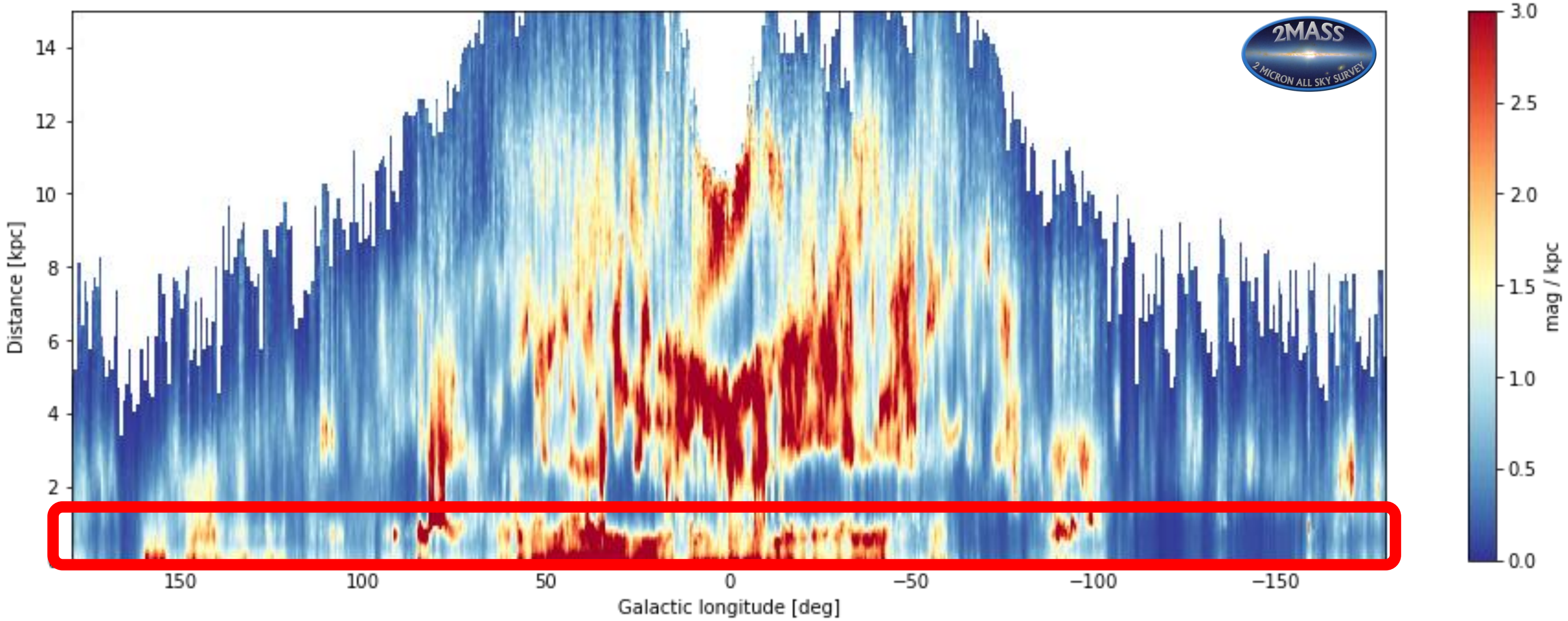
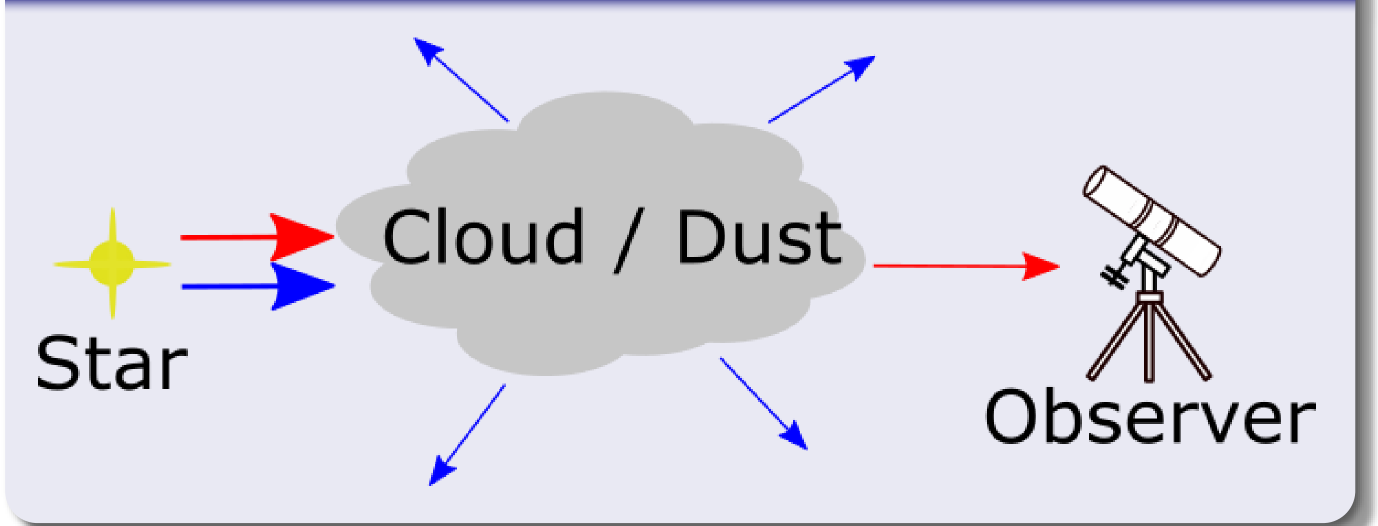


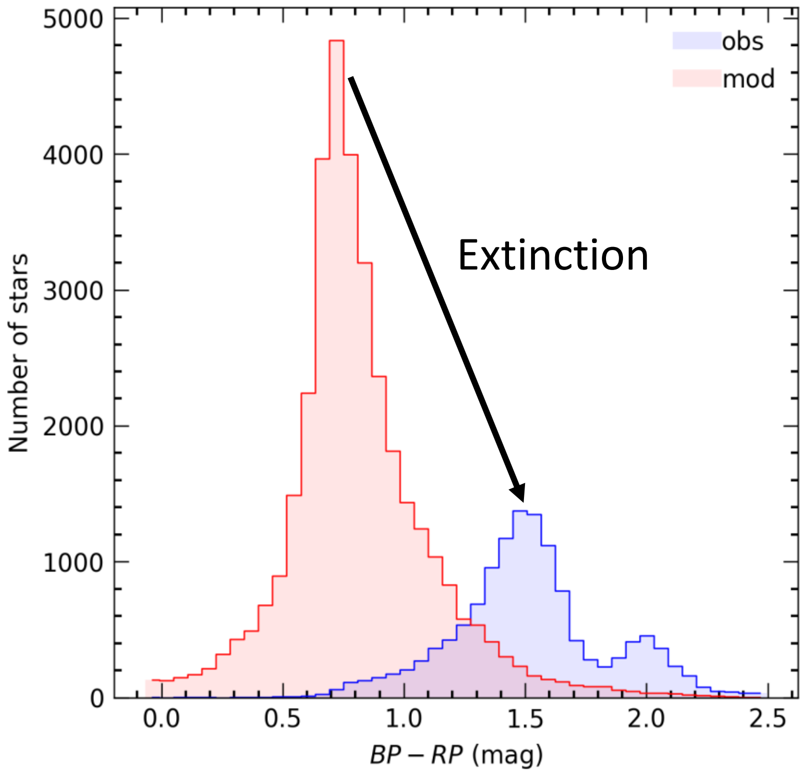
Marshall et al. (in prep.)

Can be improved!

Method: Interstellar Extinction ?

The interstellar extinction phenomenon

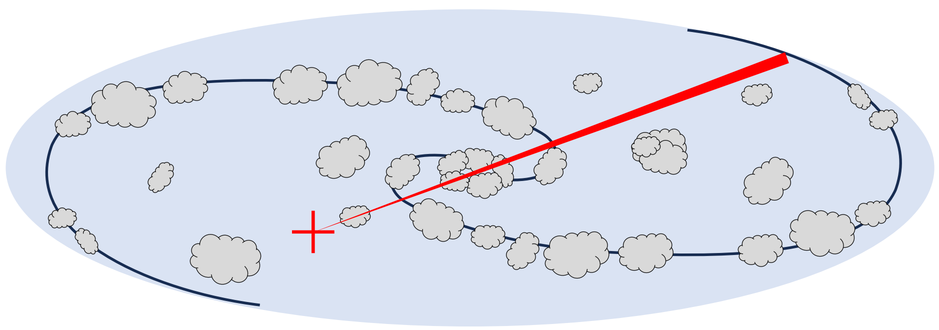


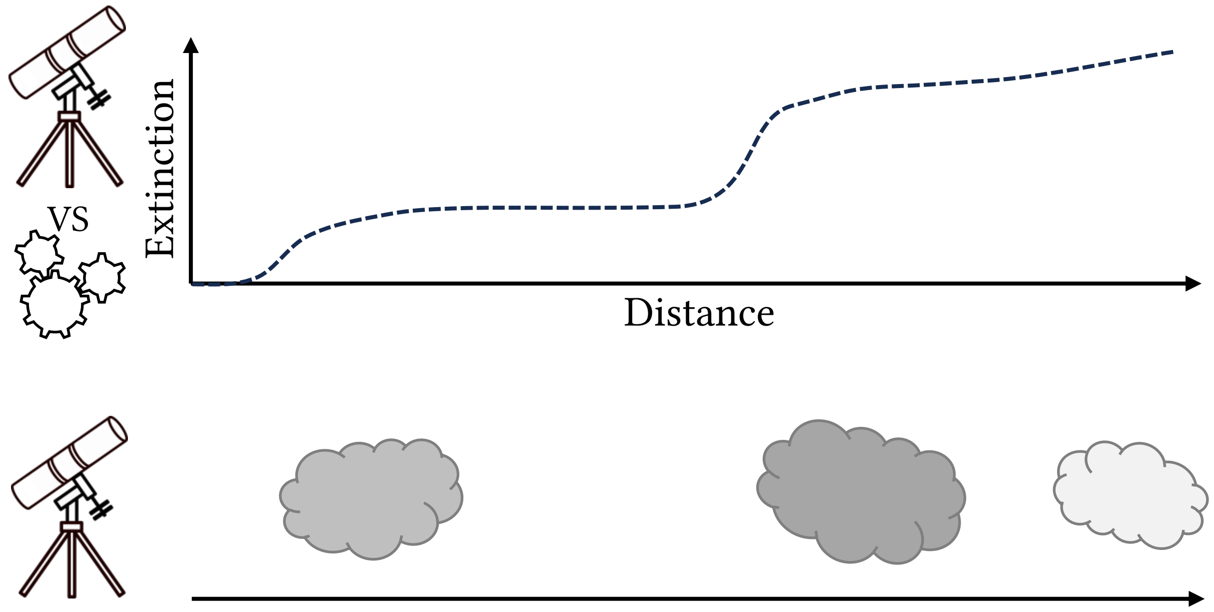


Method: How to measure Interstellar Extinction ? (1)

The Idea (Marshall et al. 2006)

Observations	−	Simulations	=	Extinction
↓		↓		
Real stars catalogue (Stars + **Extinction**)		Synthetic stars catalogue (Stars)		





Method: The Besançon Galaxy Model

Stellar population synthesis model

IMF

SFH

EVO TRACKS

...

BGM CATALOGUE
Stars photometry
Stars distances
...

3D extinction map

OBS CATALOGUE
Stars photometry
Stars parallaxes

History

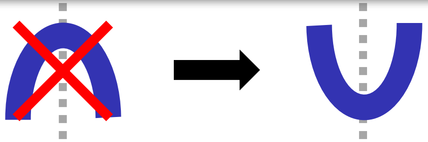
- Robin et al. (2003)
- Marshall et al. (2006) (3D extinction map)
- Czekaj et al. and Robin et al. (2014) (new evolutionary tracks, SFH and IMF)
- Lagarde et al. (2017) (new population synthesis code)
- Mor et al. (2018, 2019) (IMF, SFH)
- Robin et al. (2022) (fully self-consistent gravitational potential)

Method: *Gaia* DR3 and 2MASS

Gaia

- Parallaxes
- 3 photometric bands:
  - BP: 511 nm
  - G: 622 nm
  - RP: 777 nm

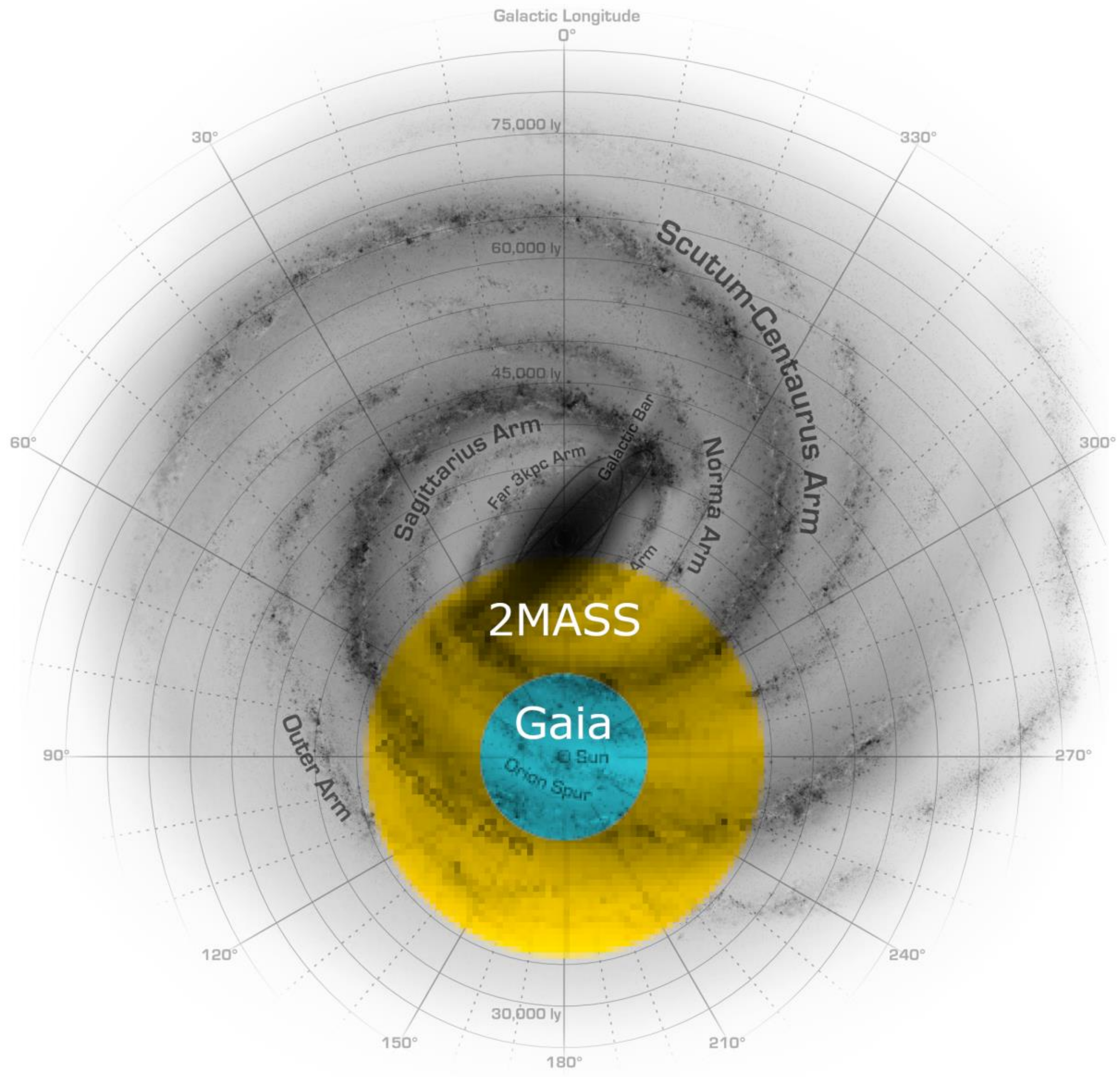
- 5 < G < 17 mag
- Relative parallax error < 20%



2MASS

- 3 photometric bands:
  - J: 1235 nm
  - H: 1662 nm
  - Ks: 2159 nm

- 10 < K < 16 mag

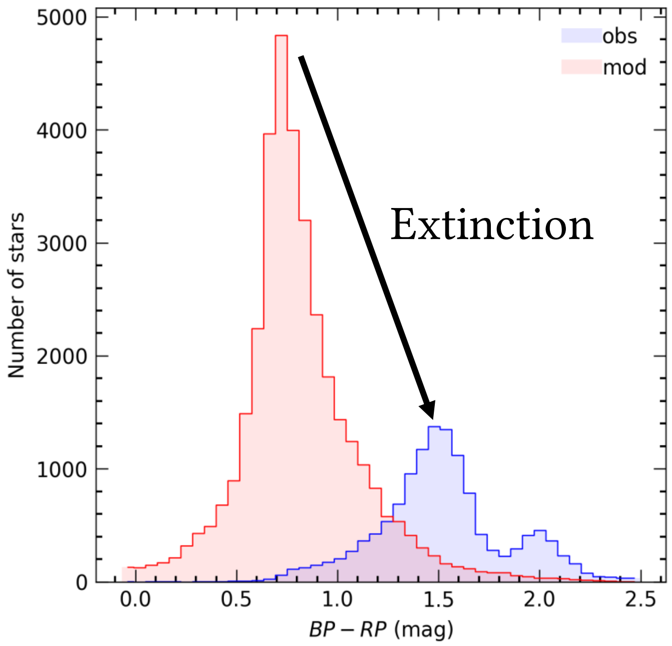


Adapted from ESO

Method: How to measure Interstellar Extinction ? (2)

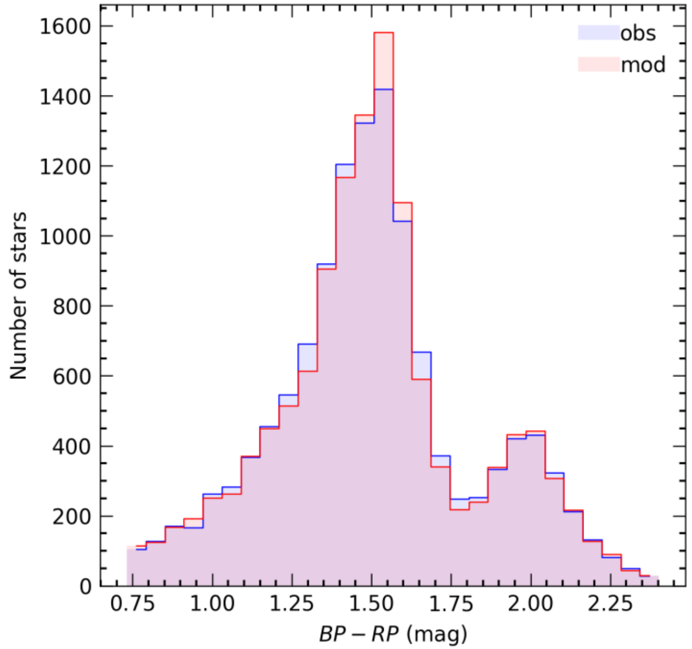
What we have

VS



What we want

VS



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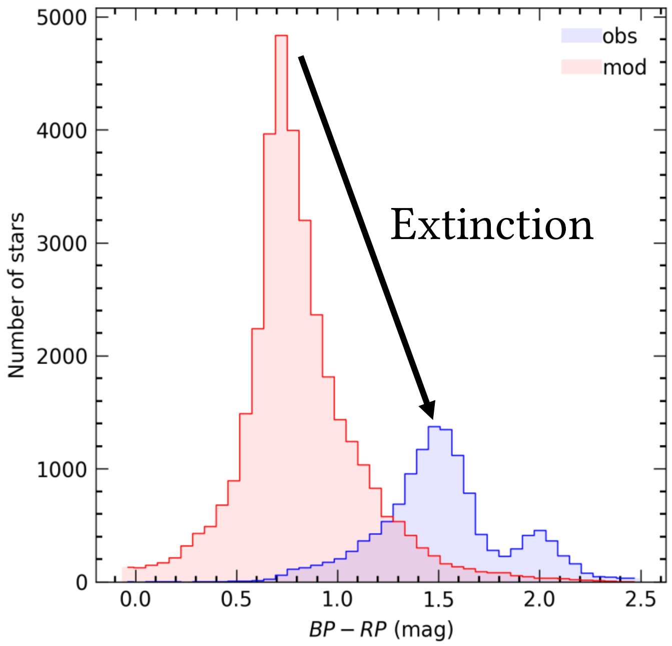

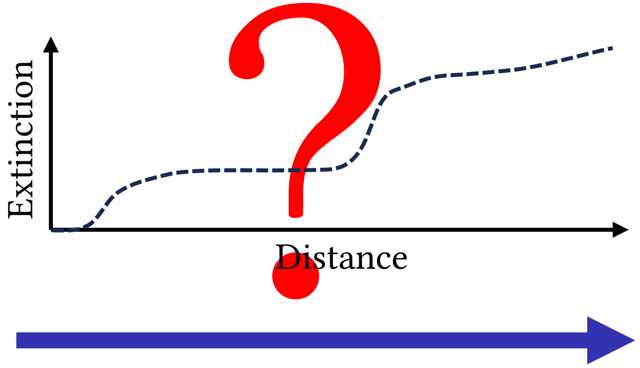

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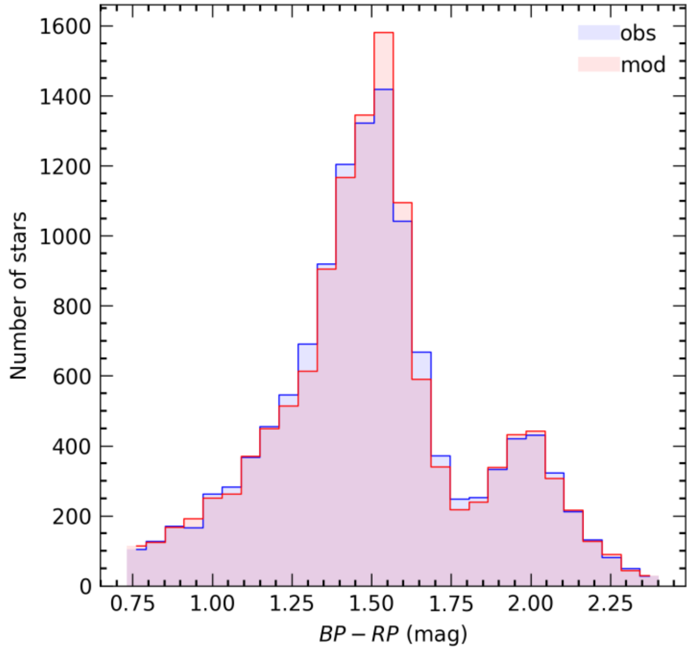


Method: PyRedLine

Redline (Marshall et al. in prep)

Custom MCMC

1 walker

PyRedLine

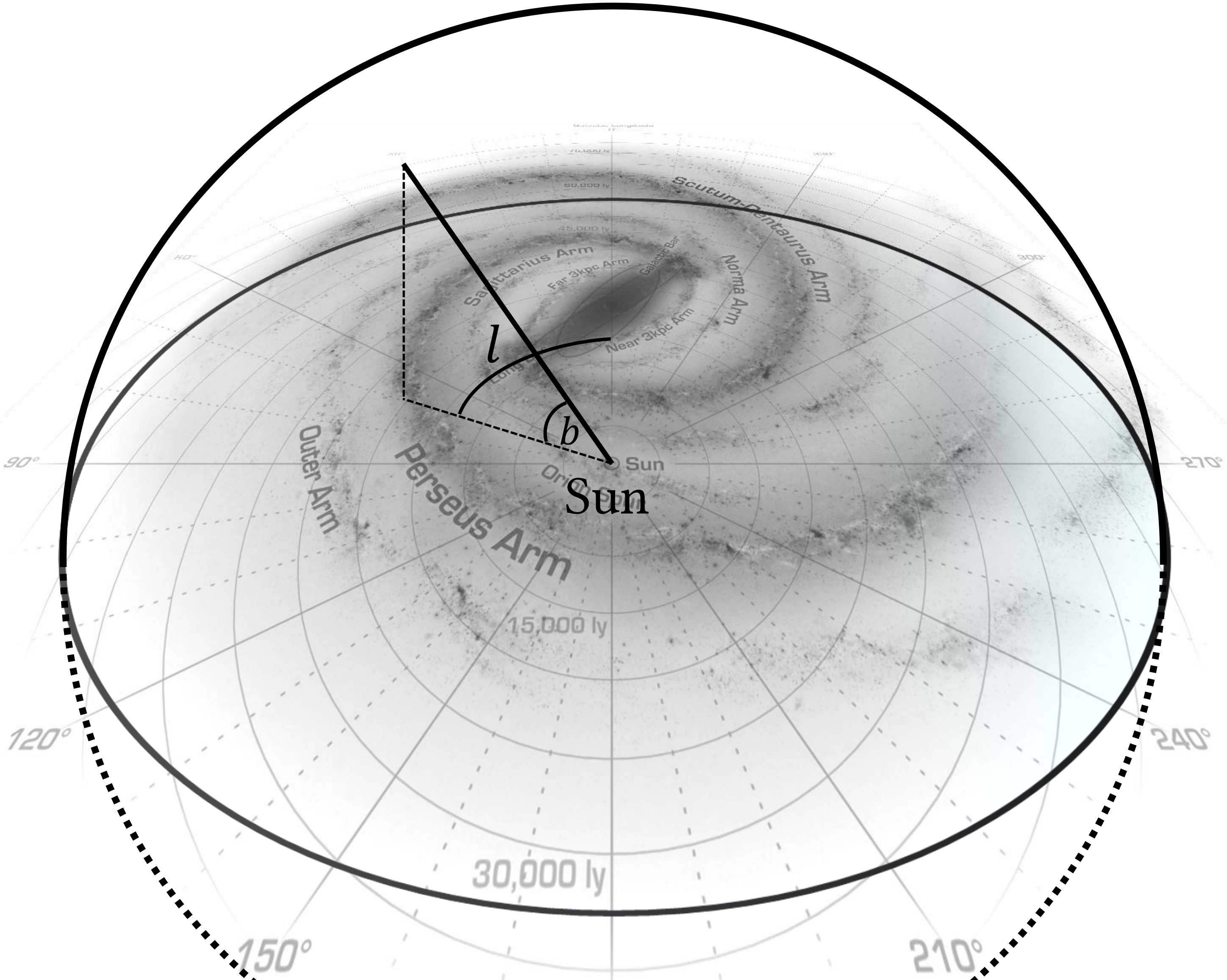
EMCEE

Foreman-Mackey et al. (2013)

- MCMC parameters: N $\times \frac{dA_0}{dr}$
- $M \times N$ walkers
- Fitzpatrick et al. (2019) with $R_v = 3.1$

Results: Vela C

Single line of sight



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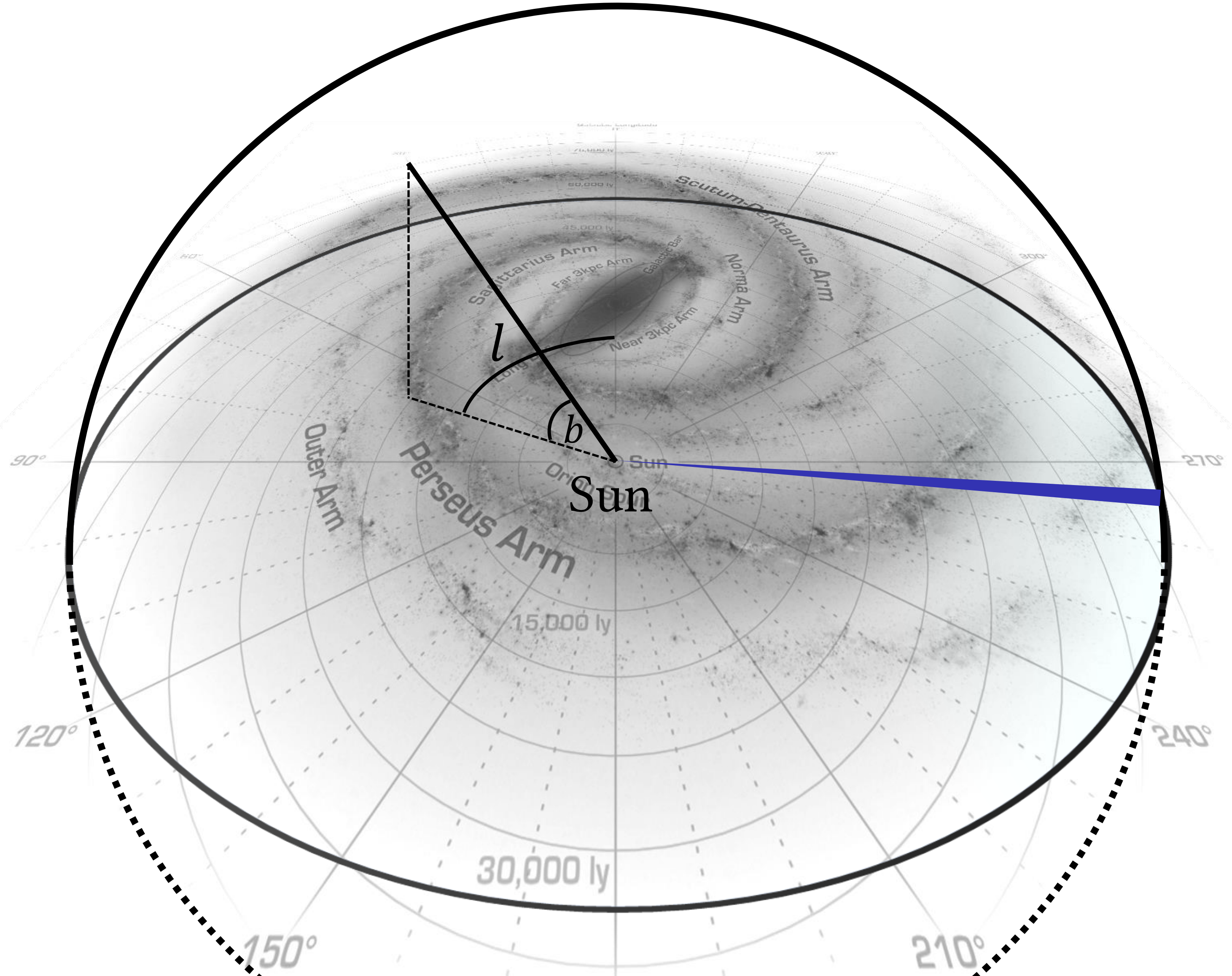
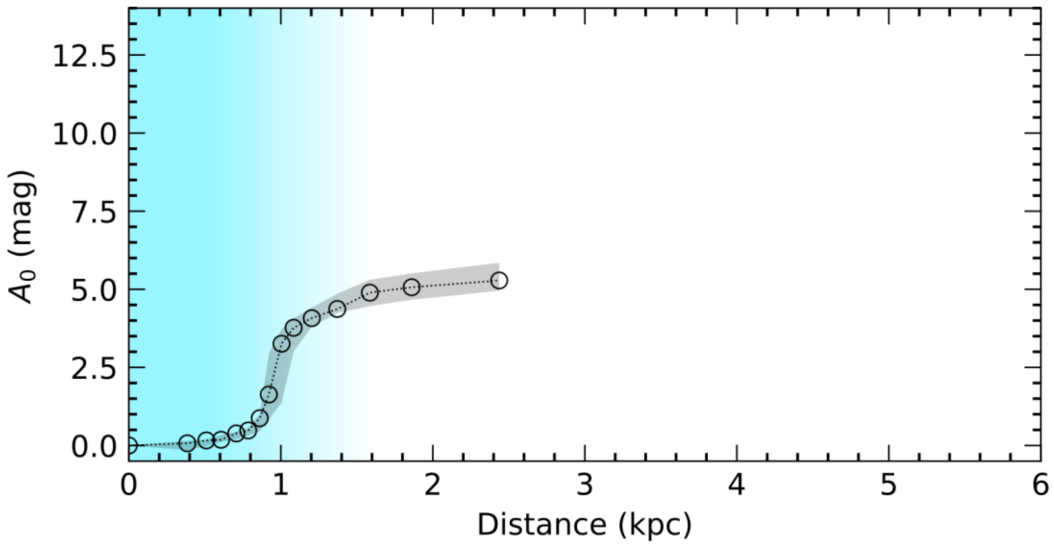
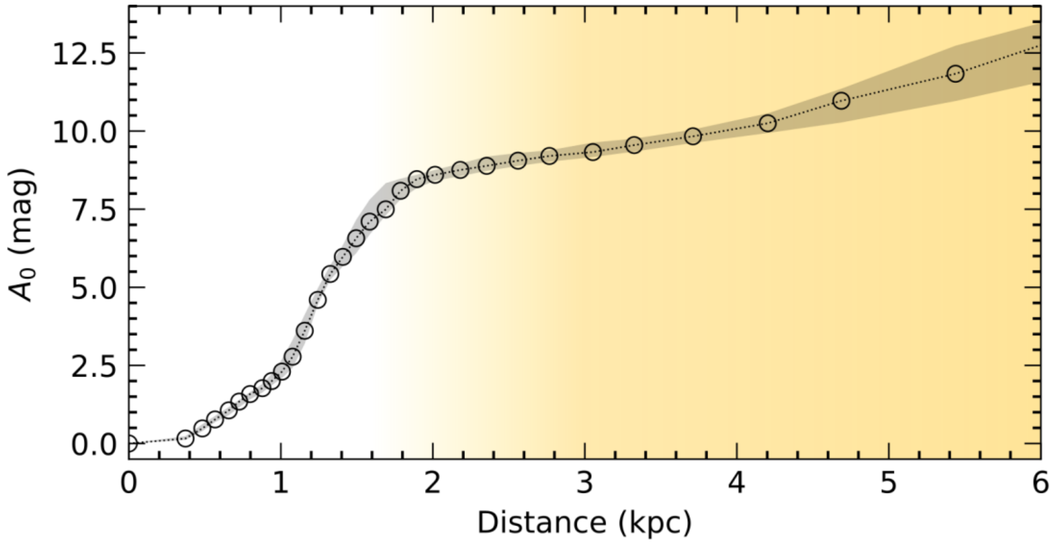


Results: Vela C

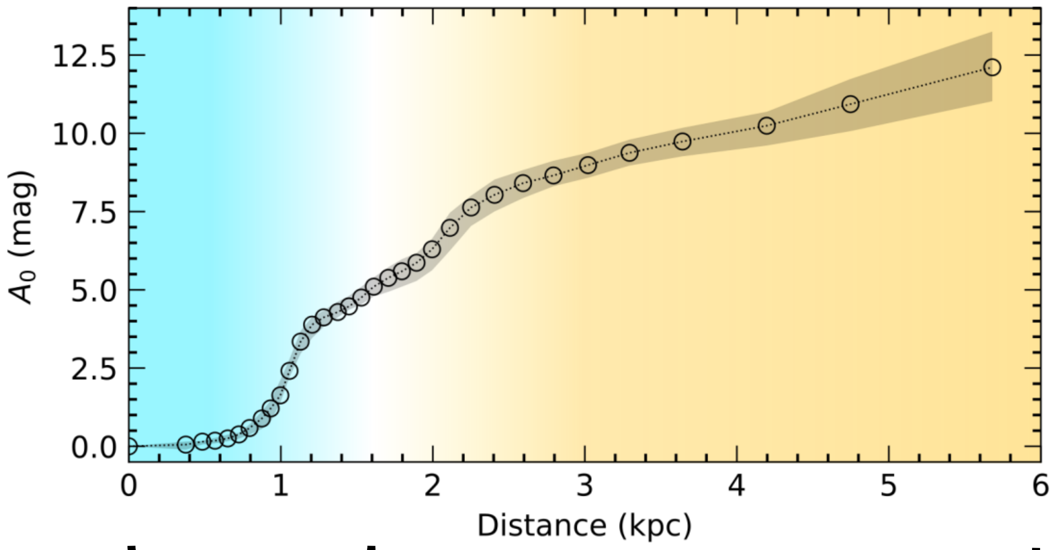
Gaia only



2MASS only



2MASS + *Gaia*



Gaia dominated 2MASS dominated

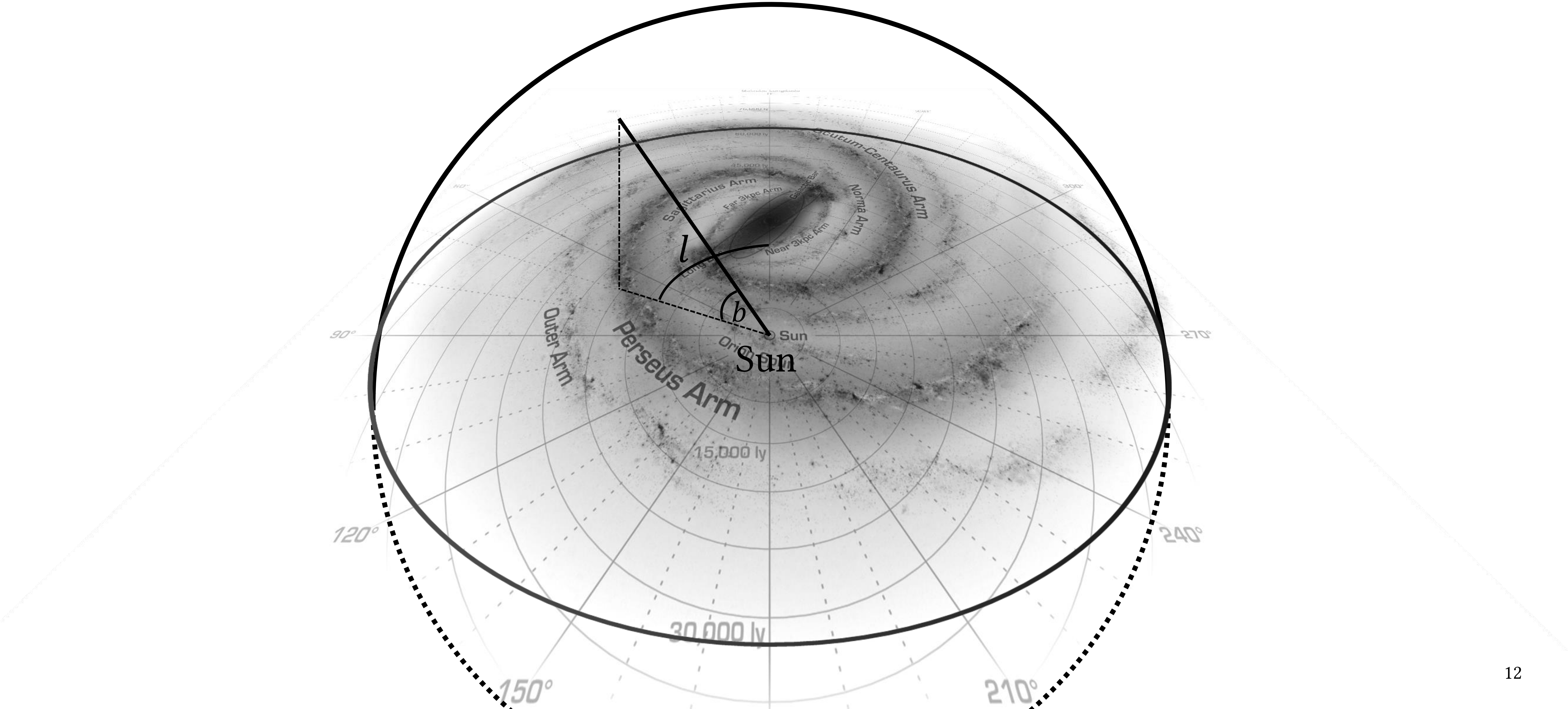
Vela C

l = 266.1°, b = 1°

~917 pc (Zucker et al. 2020)

Results: Carina arm region

3D mapping



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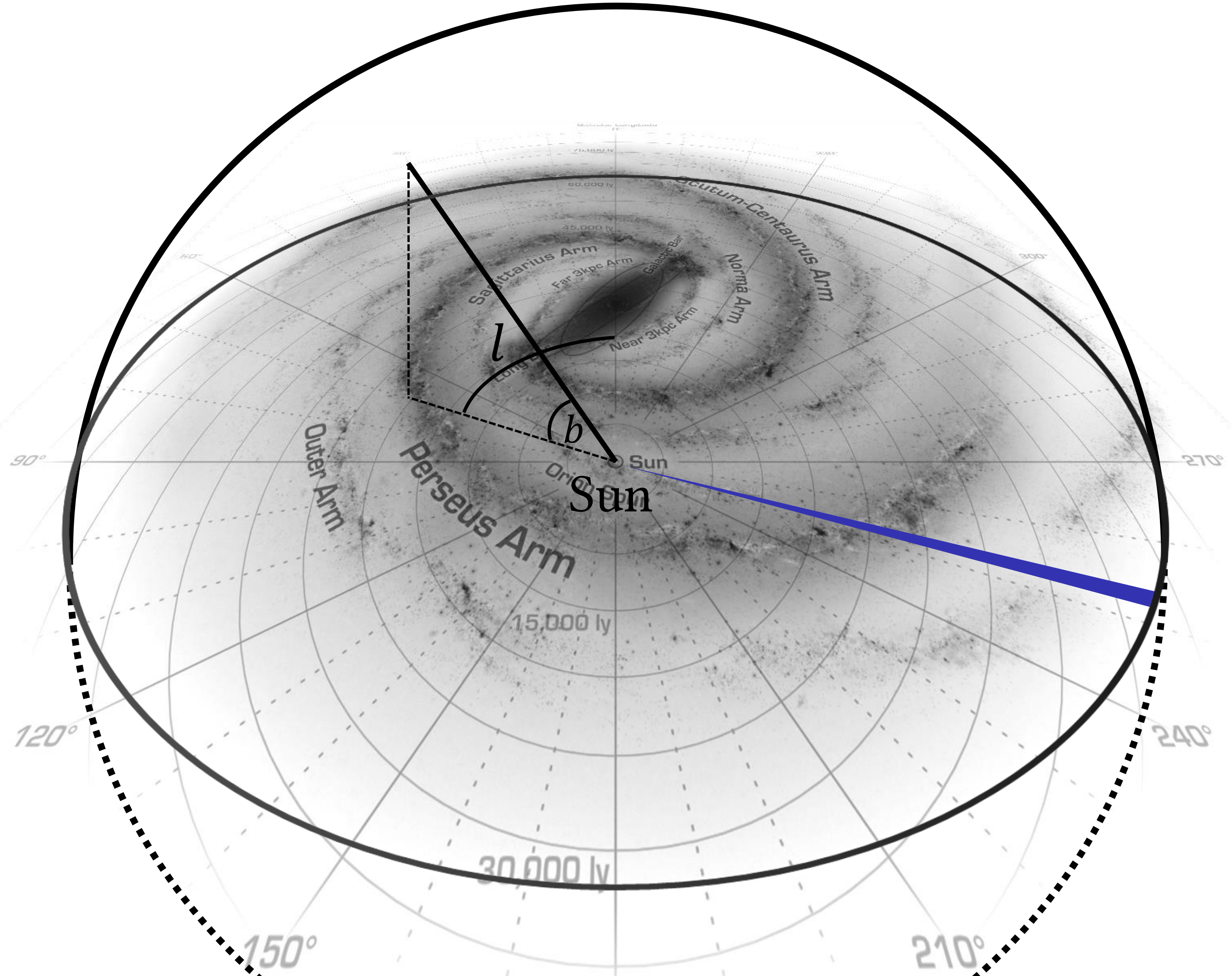

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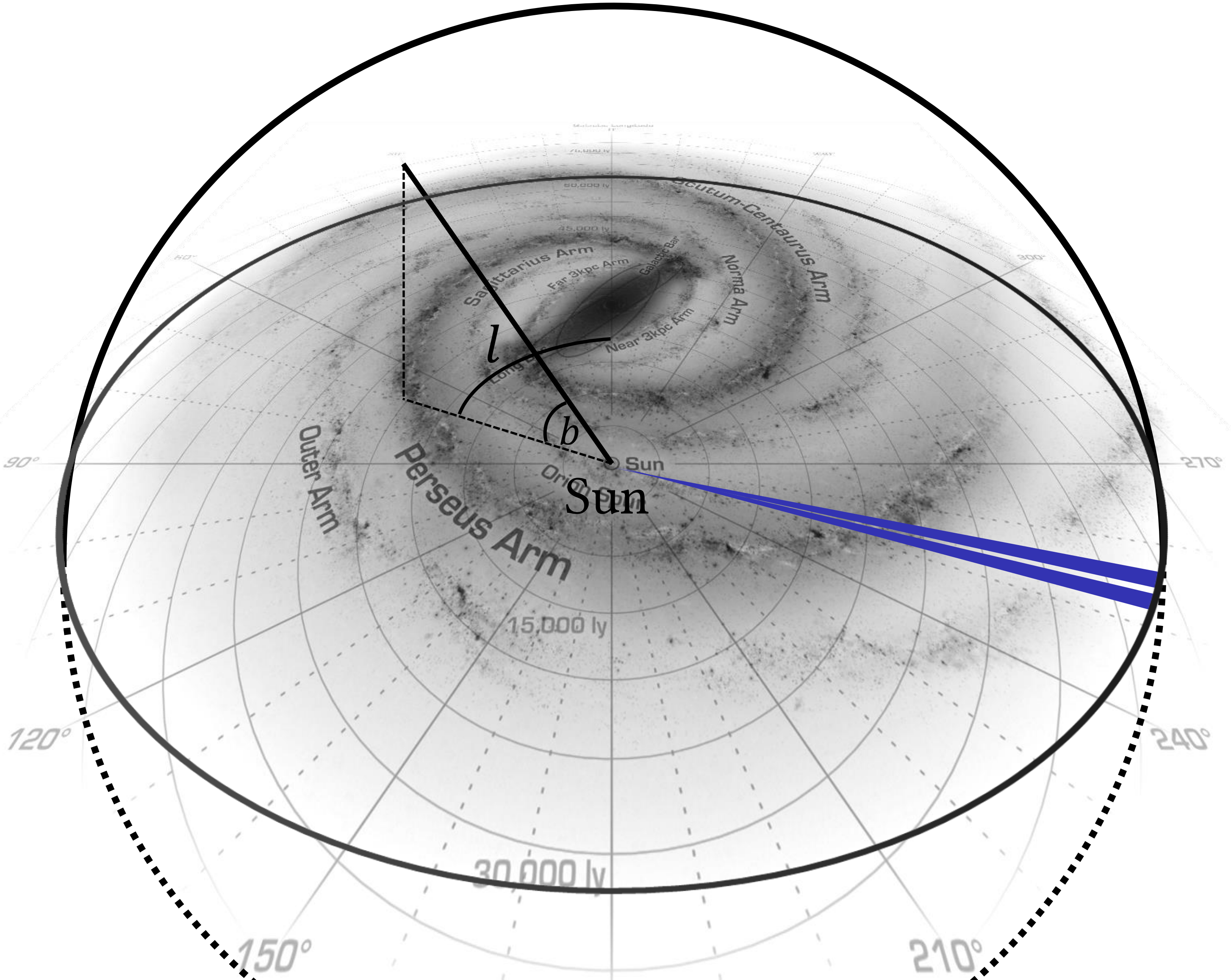

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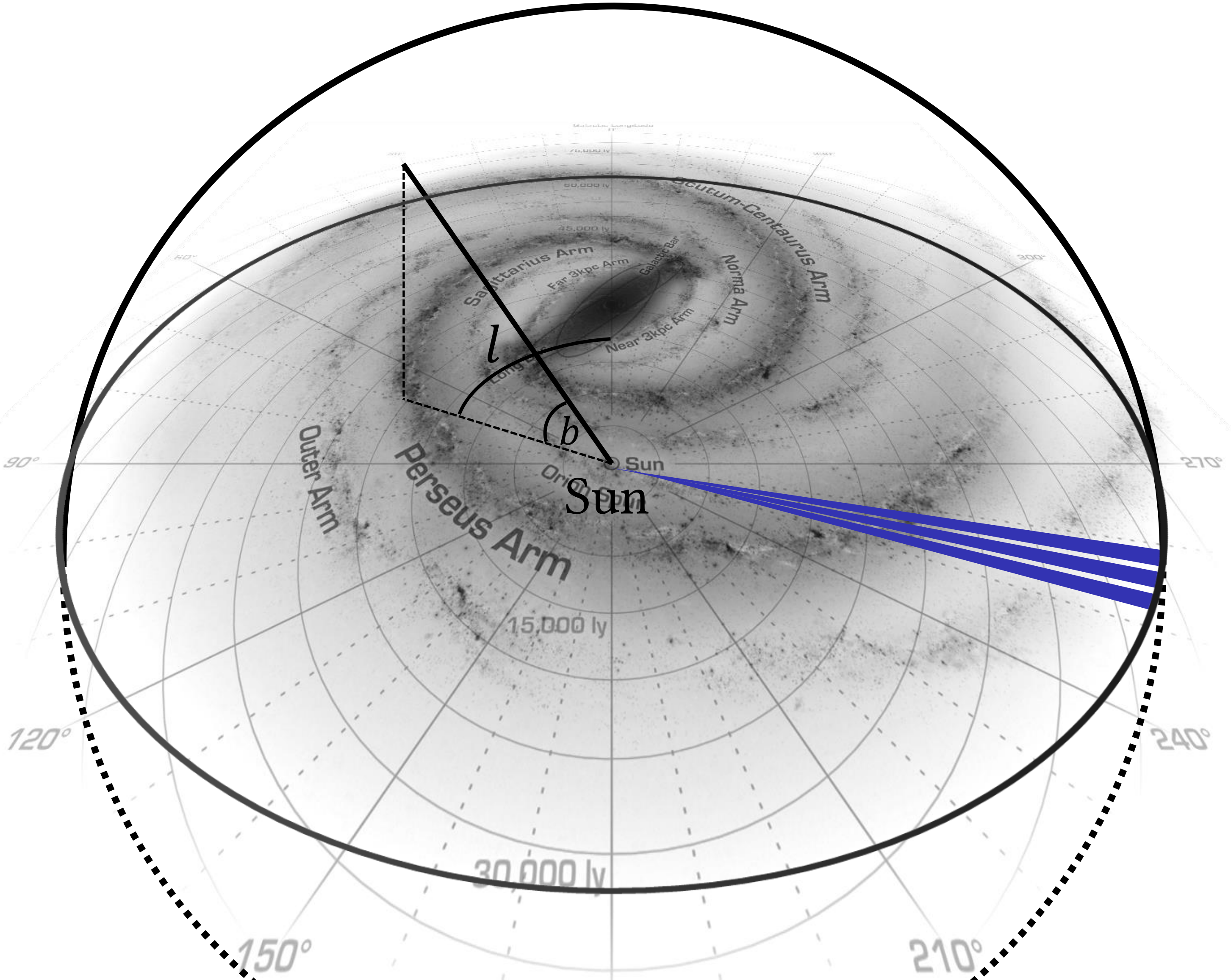

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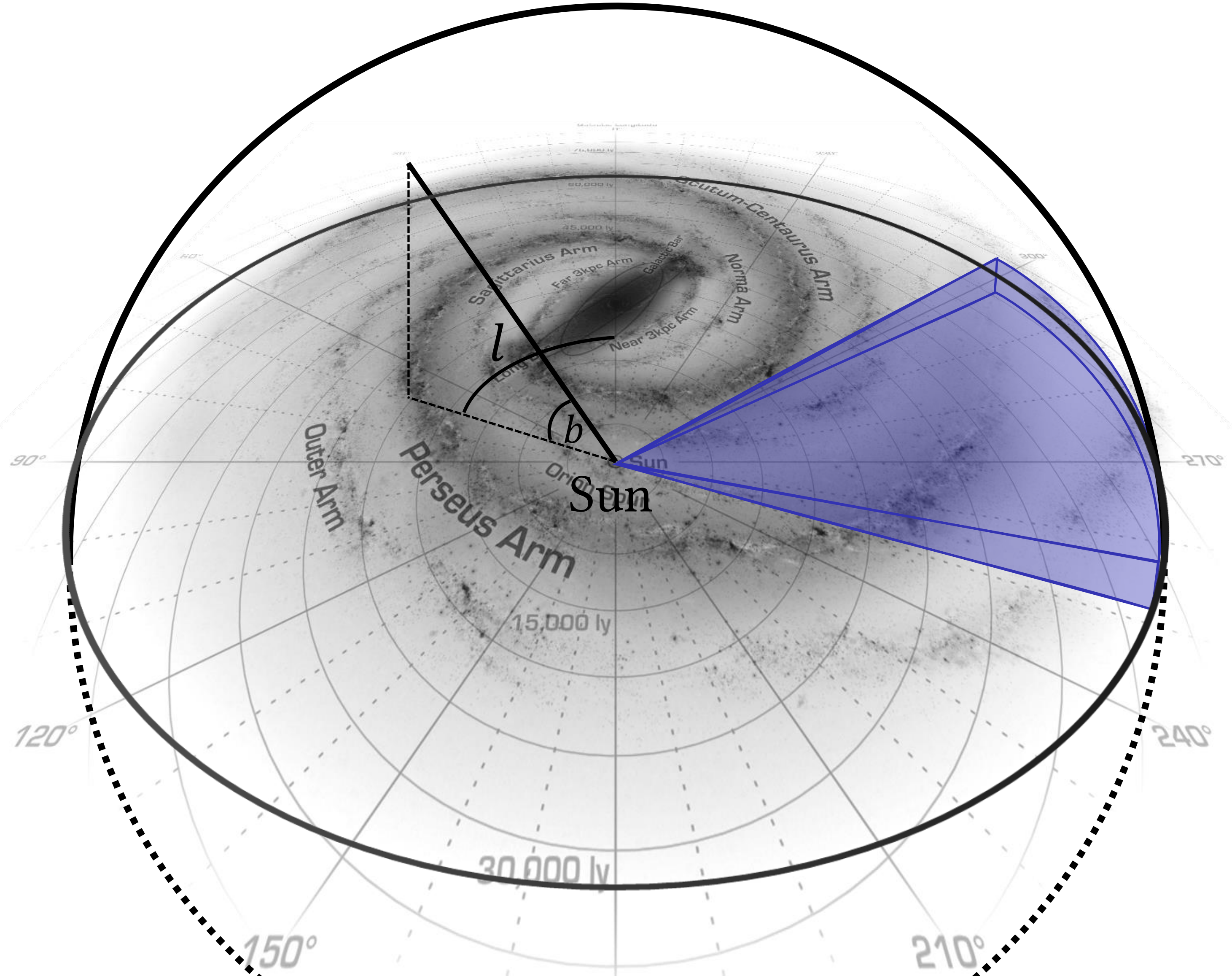
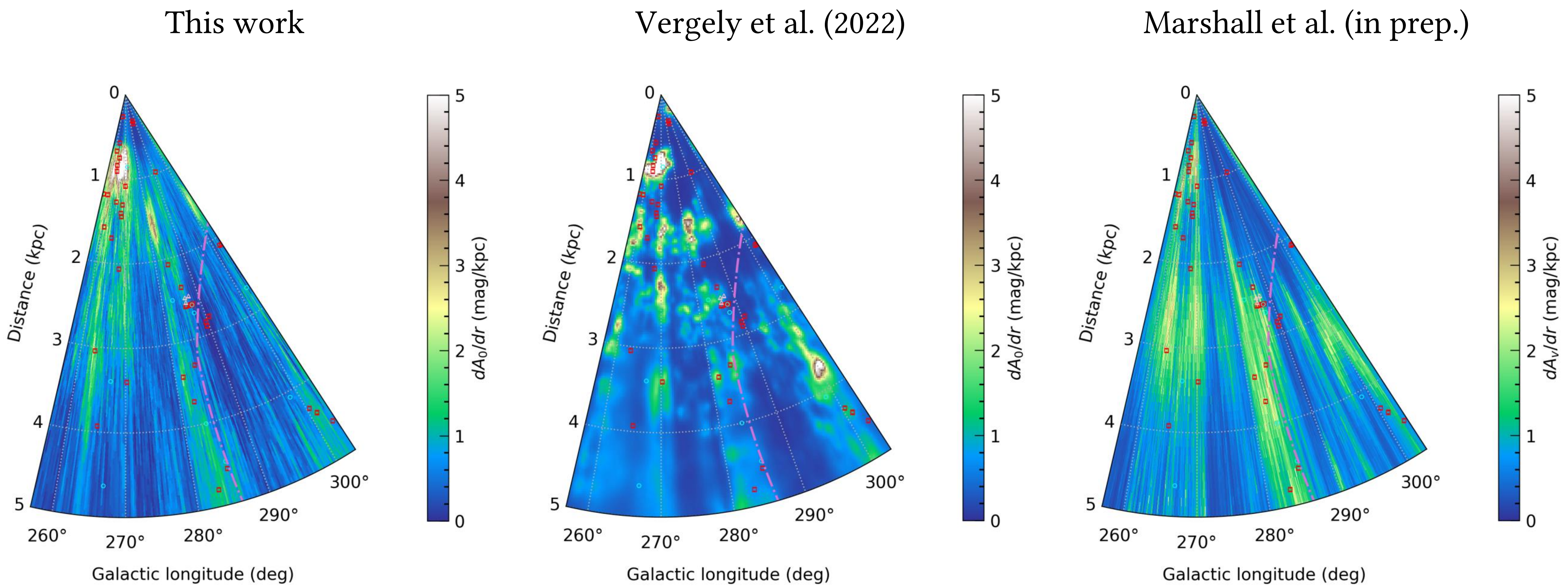


Results: Polar view of the Carina arm region

Carina arm region (5kpc)

GMC and HII from Hou & Han (2014)
MC by Zucker et al. (2020)
Carina arm model from Hou (2021)



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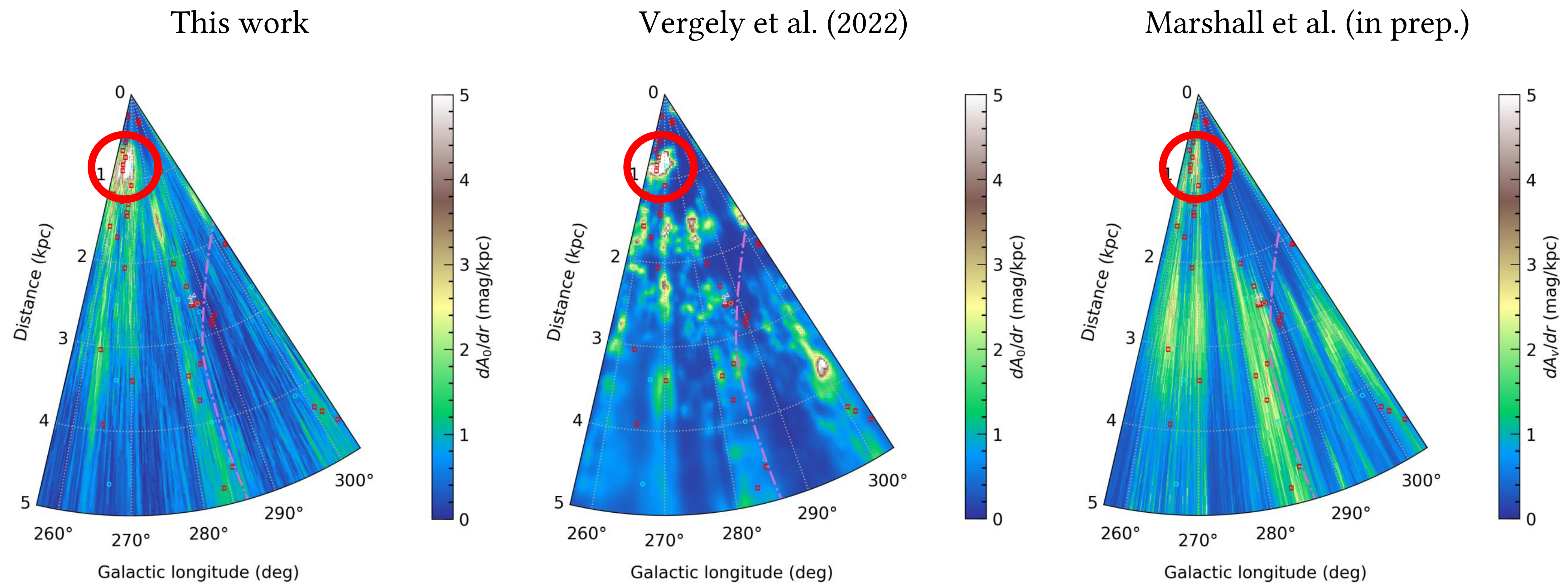

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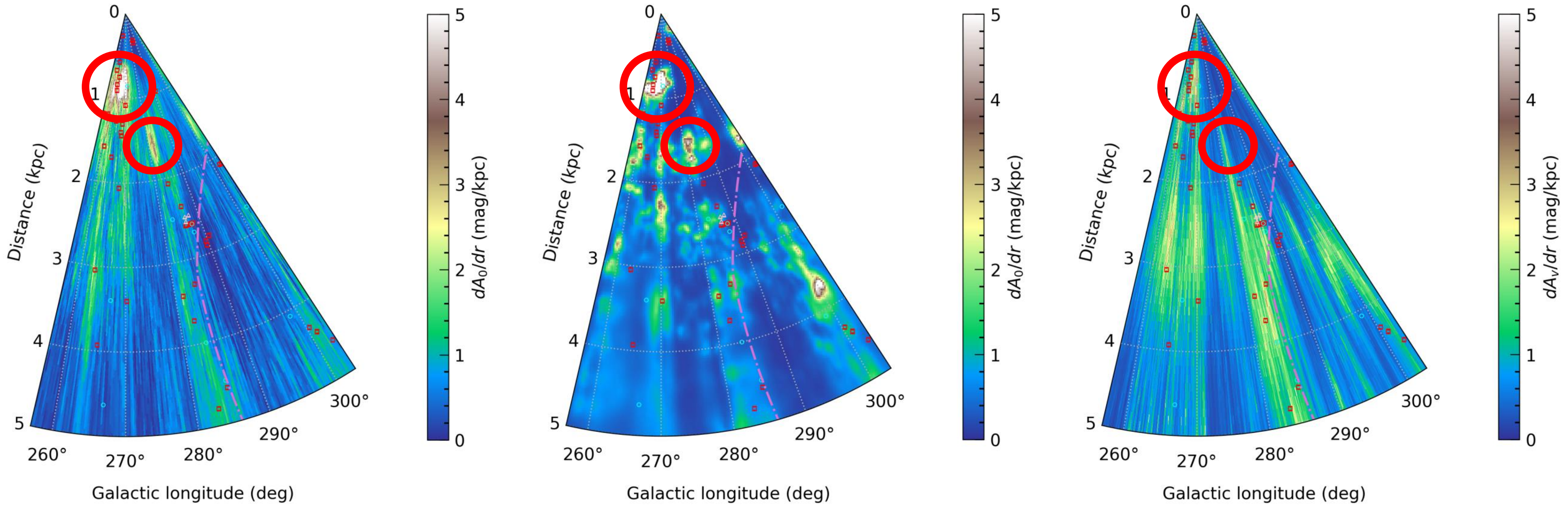

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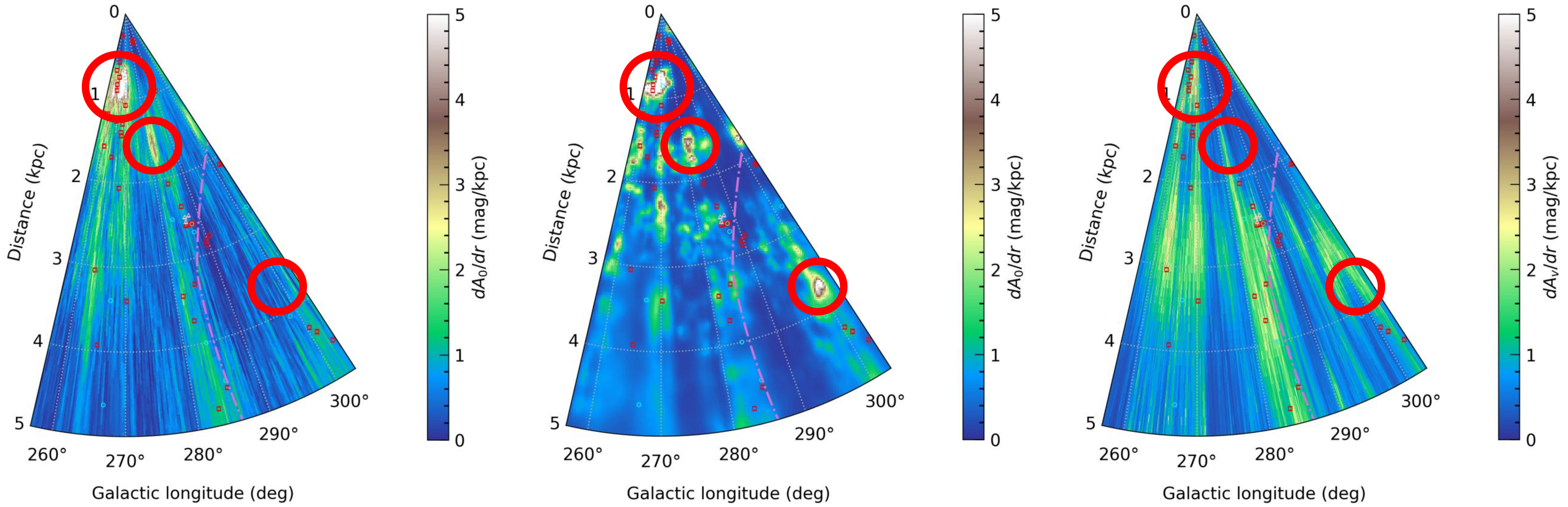

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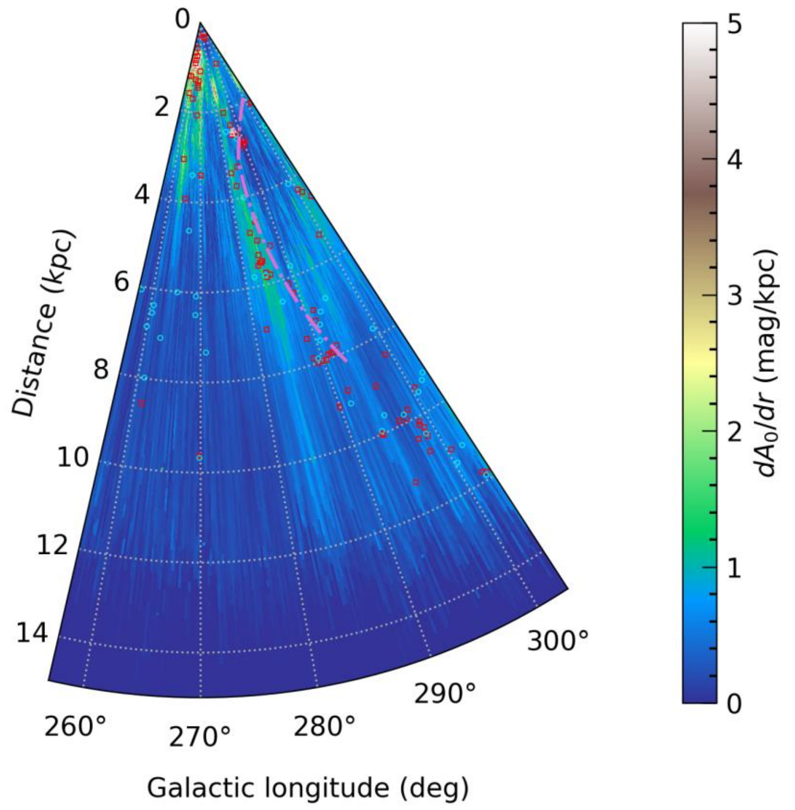
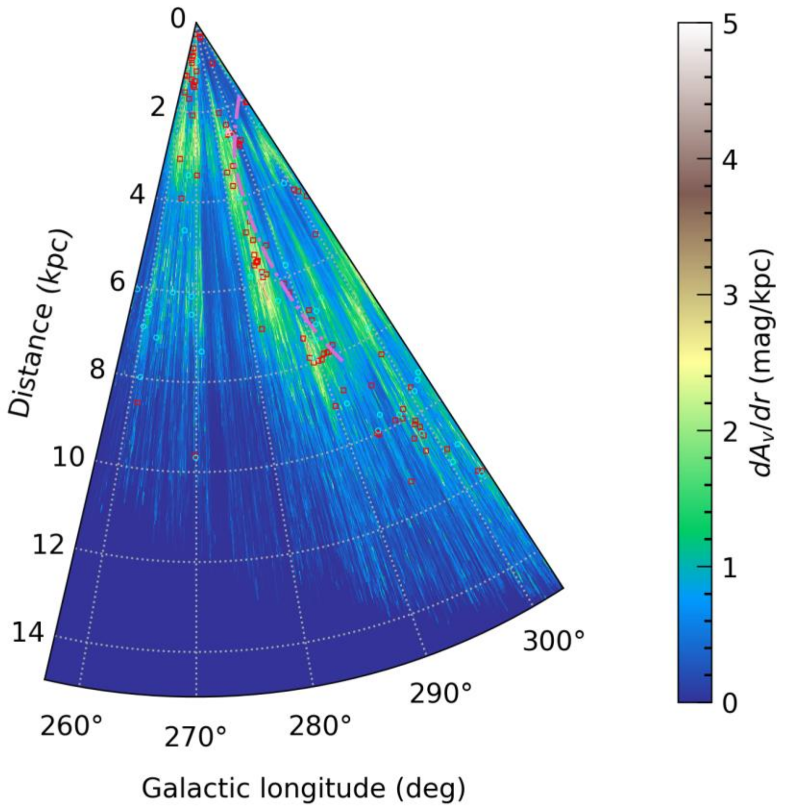
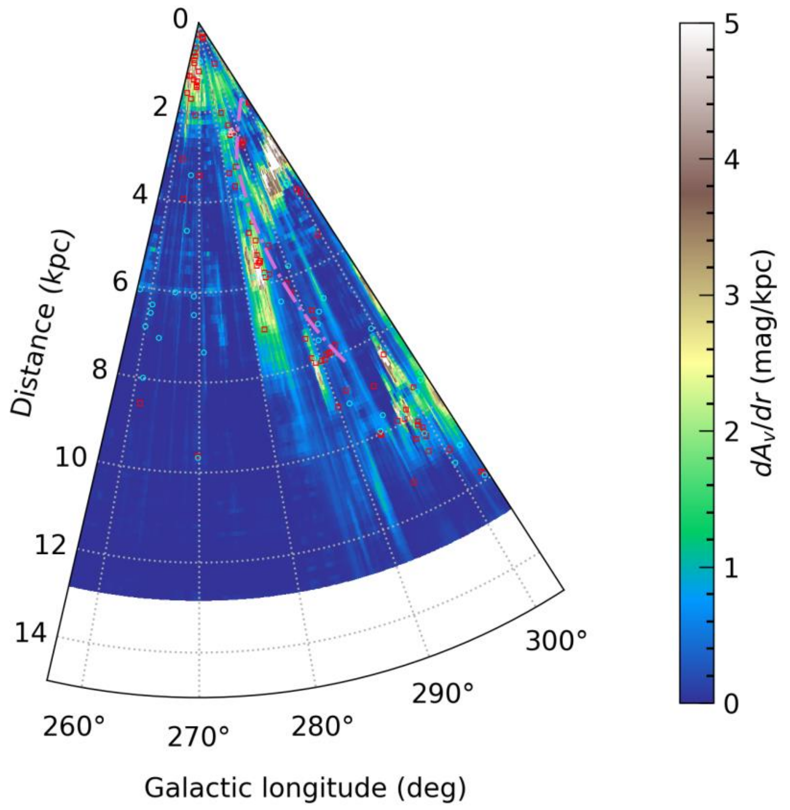


Marshall et al. (in prep)



Cornu et al. (2022)



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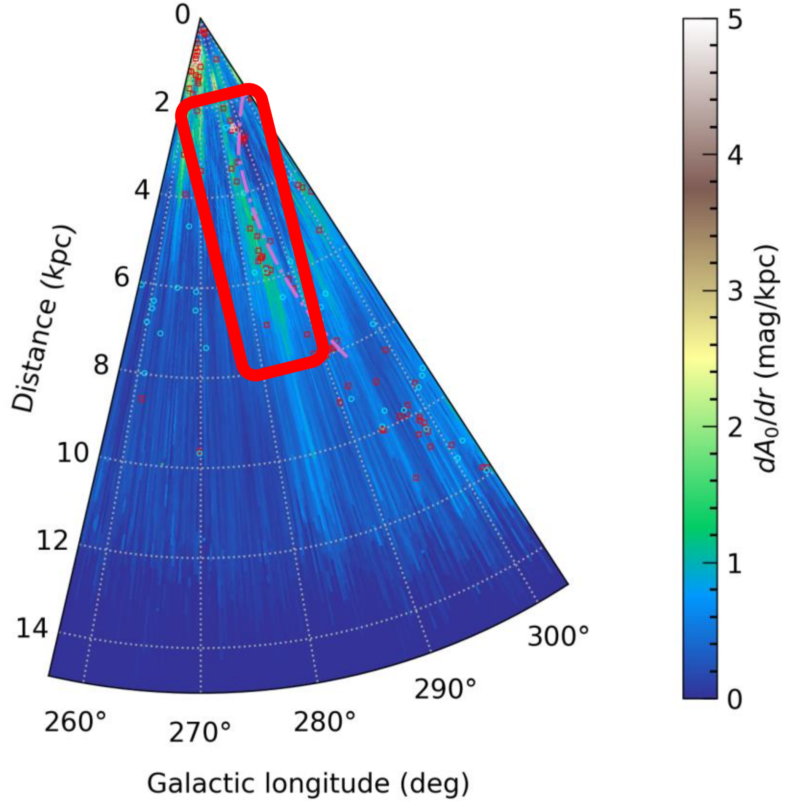

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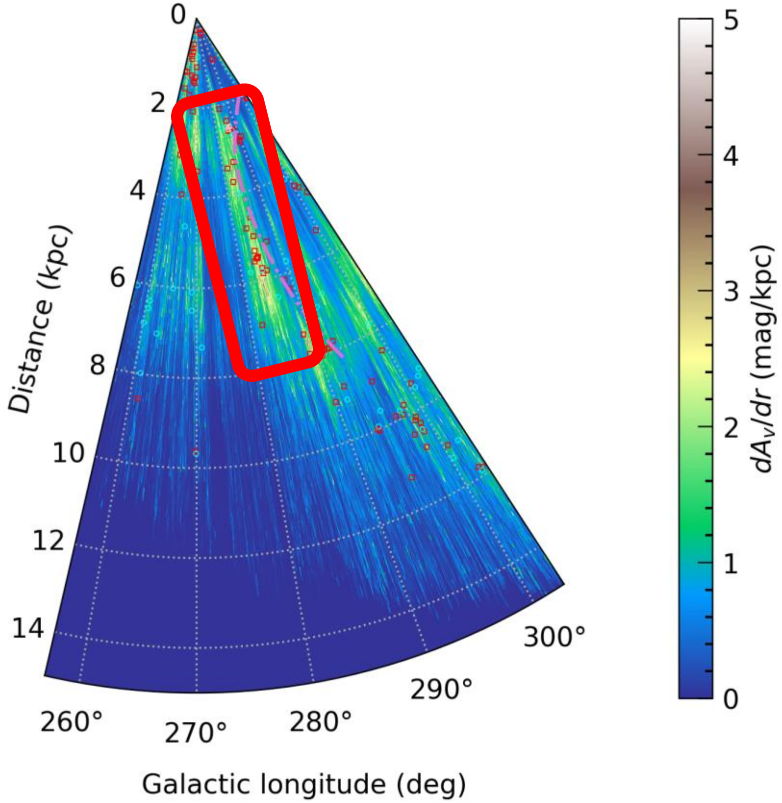

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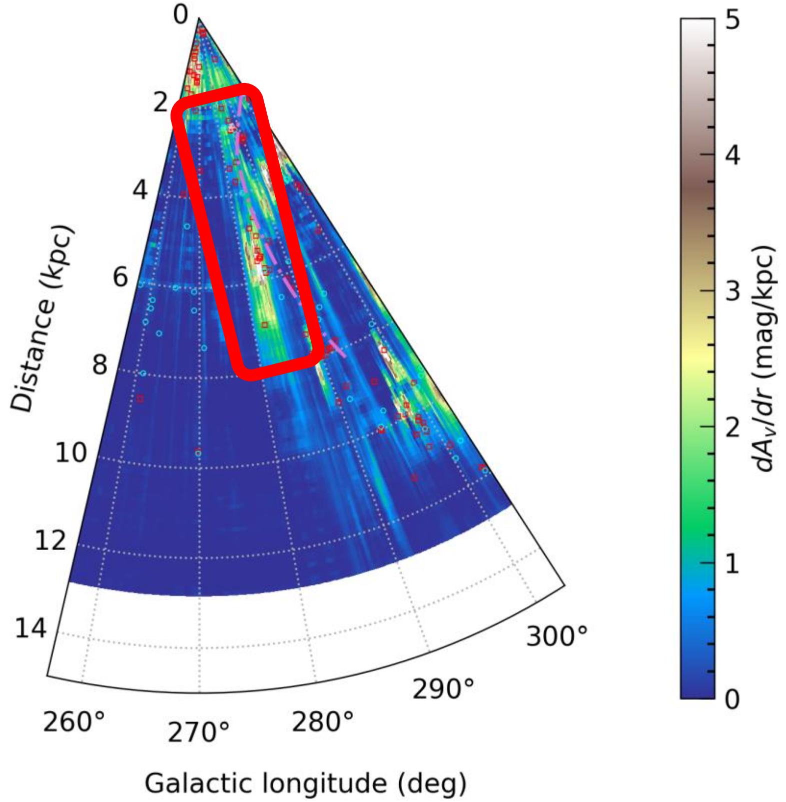

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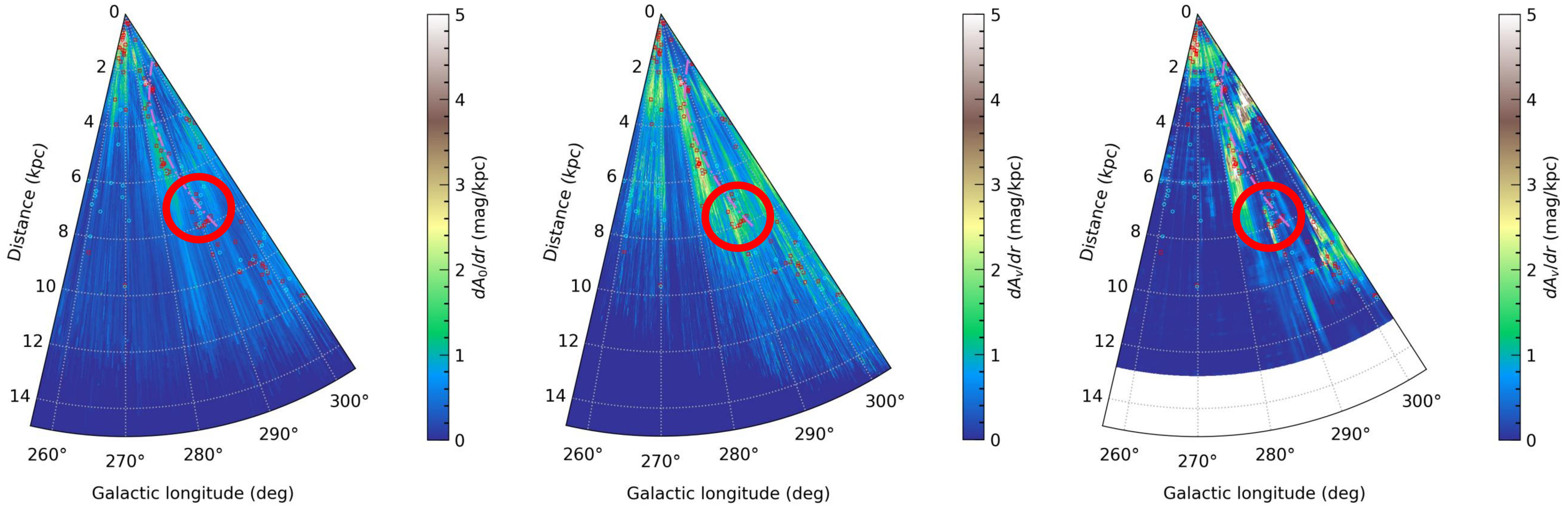
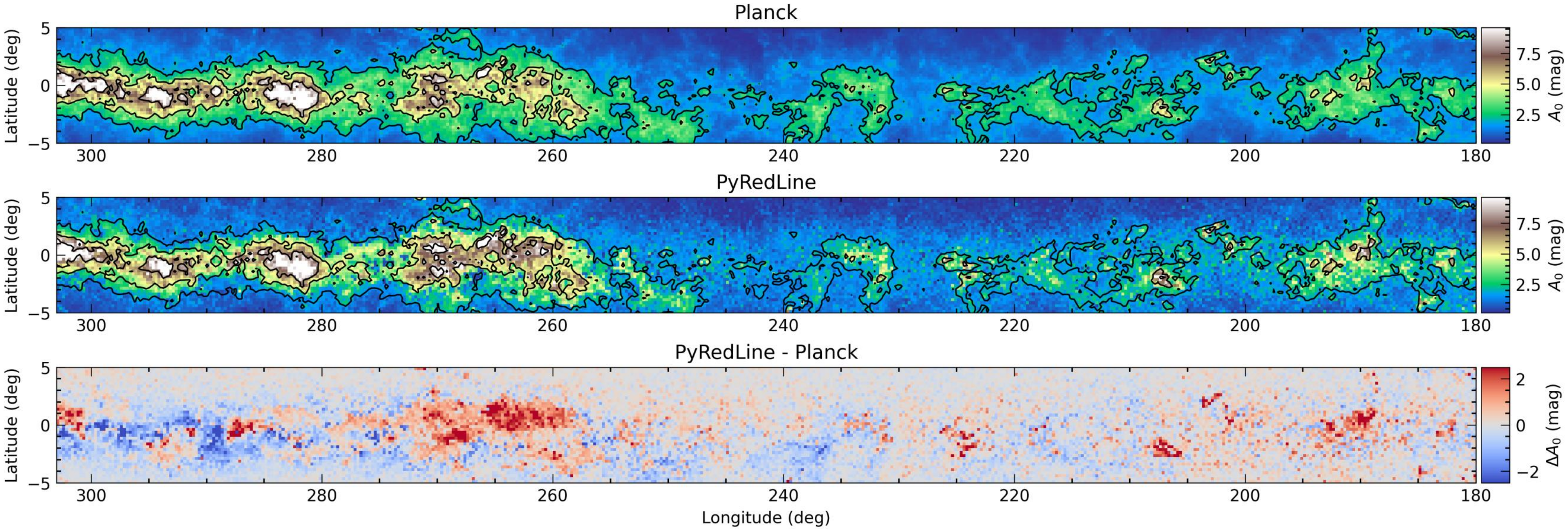


Results: Comparaison with Planck dust opacity

Planck vs PyRedLine



Temperature Gradient -> Underestimate in Planck dust opacity
Constant R_v -> Overestimate in PyRedLine

Conclusions

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No need for cross-match

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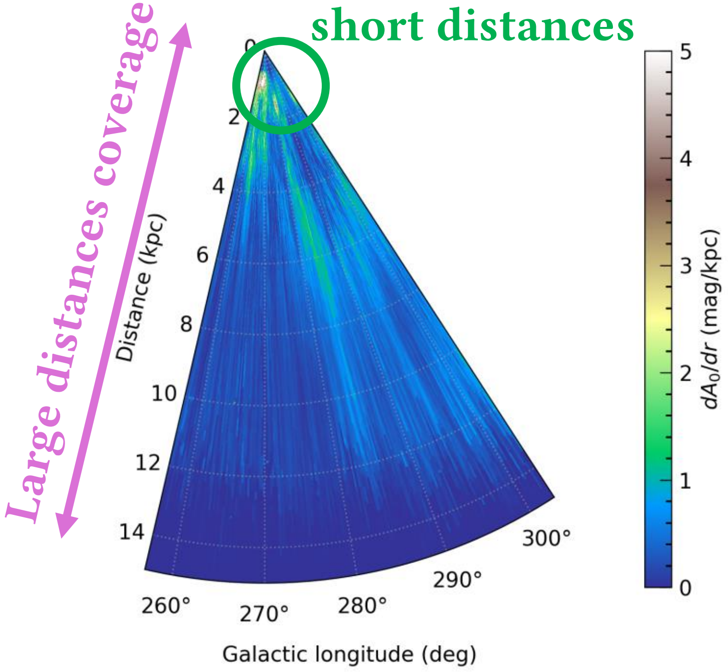
No need for cross-match

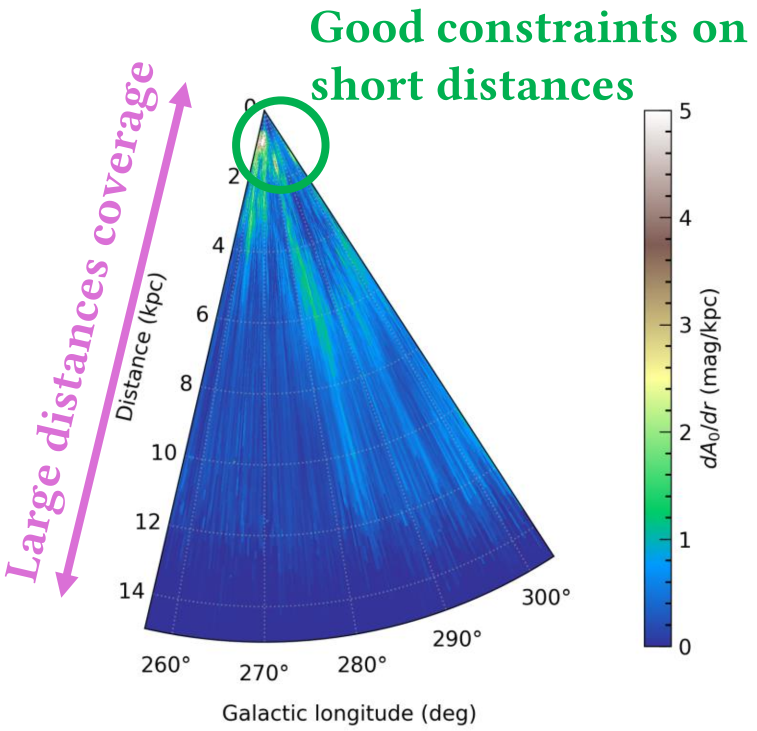
Good constraints on short distances



Conclusions

Gaia ∪ 2MASS

No need for cross-match

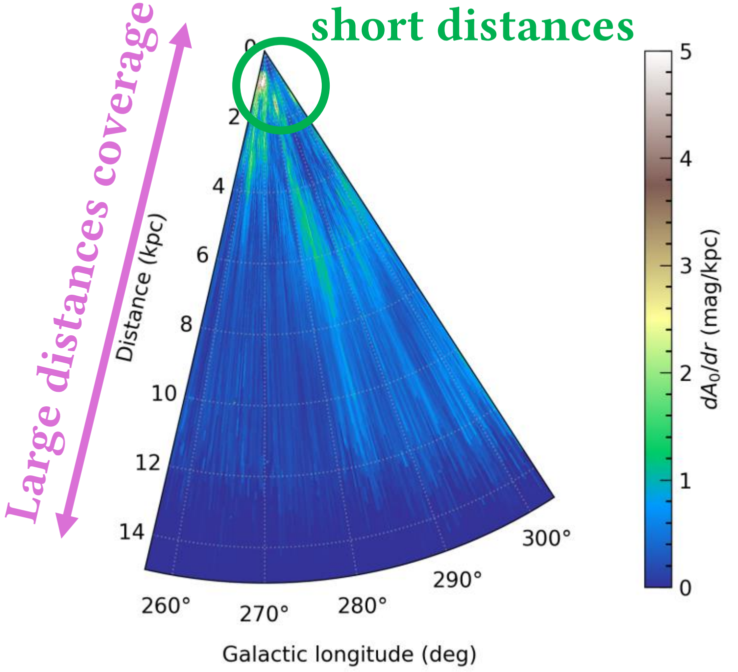


- Improvements under study:
  - Fractal structure of the ISM
  - Sub-pixel gradient of dust density for each LoS

Conclusions

No need for cross-match

Good constraints on short distances



- Improvements under study:
  - Fractal structure of the ISM
  - Sub-pixel gradient of dust density for each LoS

- Prospective:
  - Map the entire MW plane
  - Characterize dependences on the BGM
  - Use Spitzer data to probe larger distances in the central regions
  - Replace MCMC with Nested sampling
  - Hybridize our method with others (Leike et al. 2020, Vergely et al. 2022)
  - Add constraints using gas observations

Thank You!

Backup slides

Bayesian inference

$$P(y|x) \propto \mathcal{L}(x|y)P(y)$$

Likelihood

Poisson likelihood (Bienayme et al. (1987):

$$\mathcal{L} = \sum_i o_i \left[1 - \frac{m_i}{o_i} + \ln\left(\frac{m_i}{o_i}\right)\right]$$

Prior