A First Gaia look at the inner halo*

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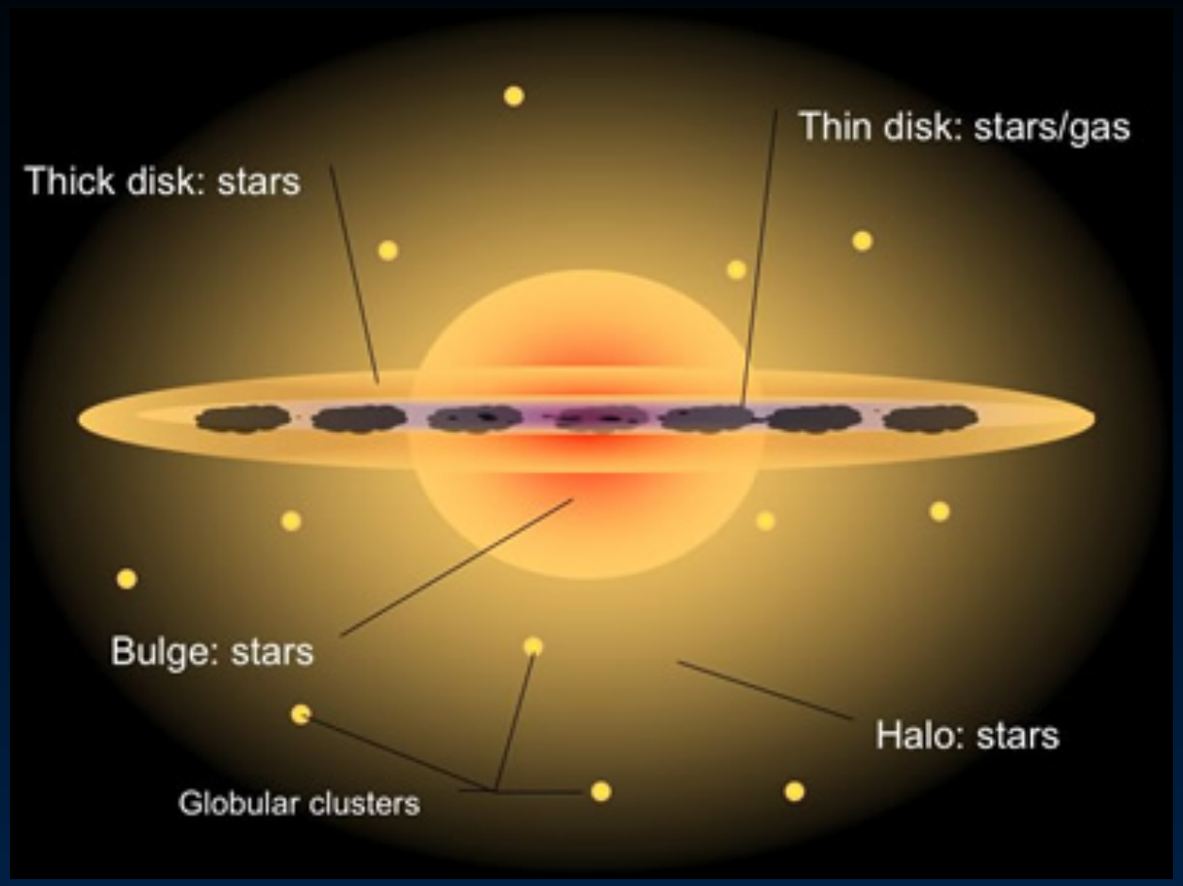
IoA, Cambridge

Vasily Belokurov, Denis Erkal, Sergey Koposov, Carlo Nipoti, Filippo Fraternali

***Iorio et al., 2017, submitted, arXiv:1707.03833**

Why study the Halo?



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Disc 6×10^{10} **Msun**
Bulge 10^{10} **Msun**
Stellar Halo 10^{9} **Msun**

Lightest component of the MW!

- Relic of the Galactic formation
- Trace the Galactic potential

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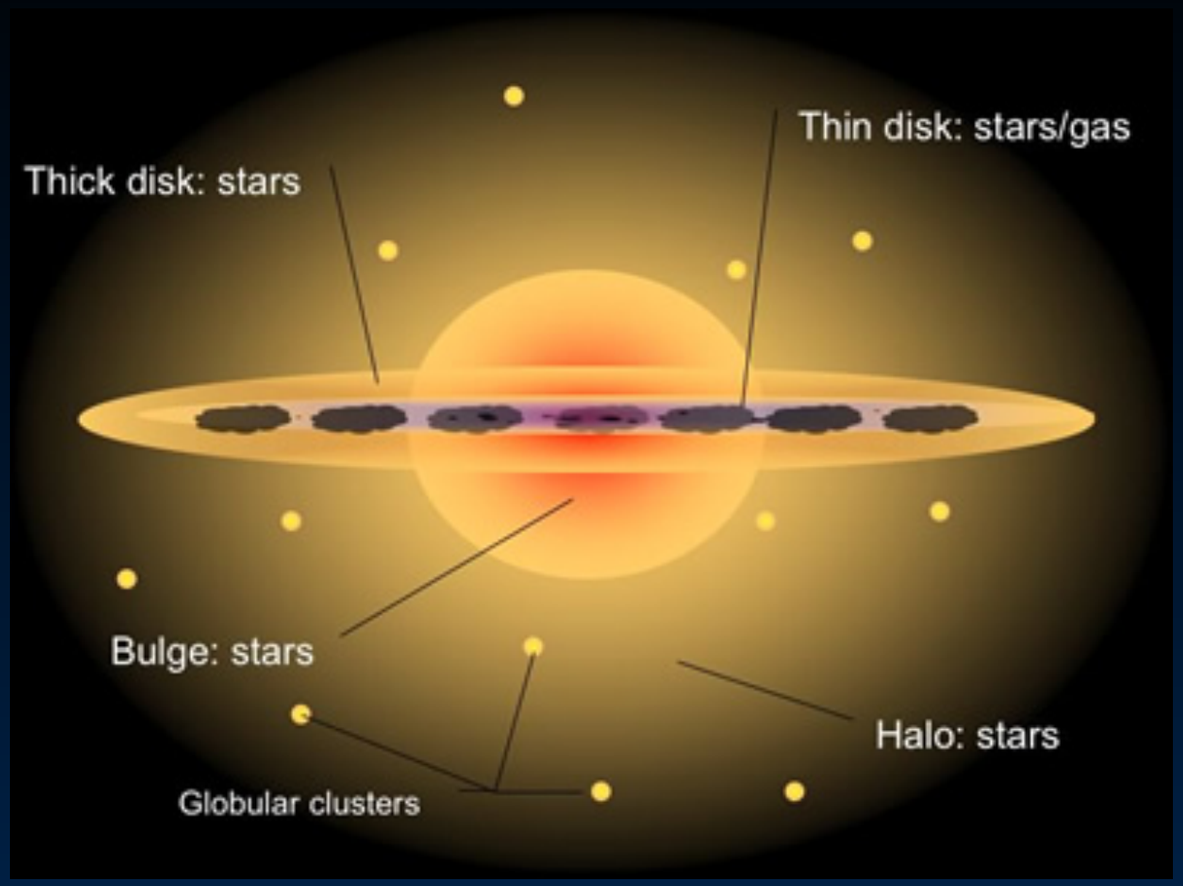

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How?

- Counting of Halo Tracers: **e.g. RRLyrae**
  - PopII stars
  - Known absolute magnitude

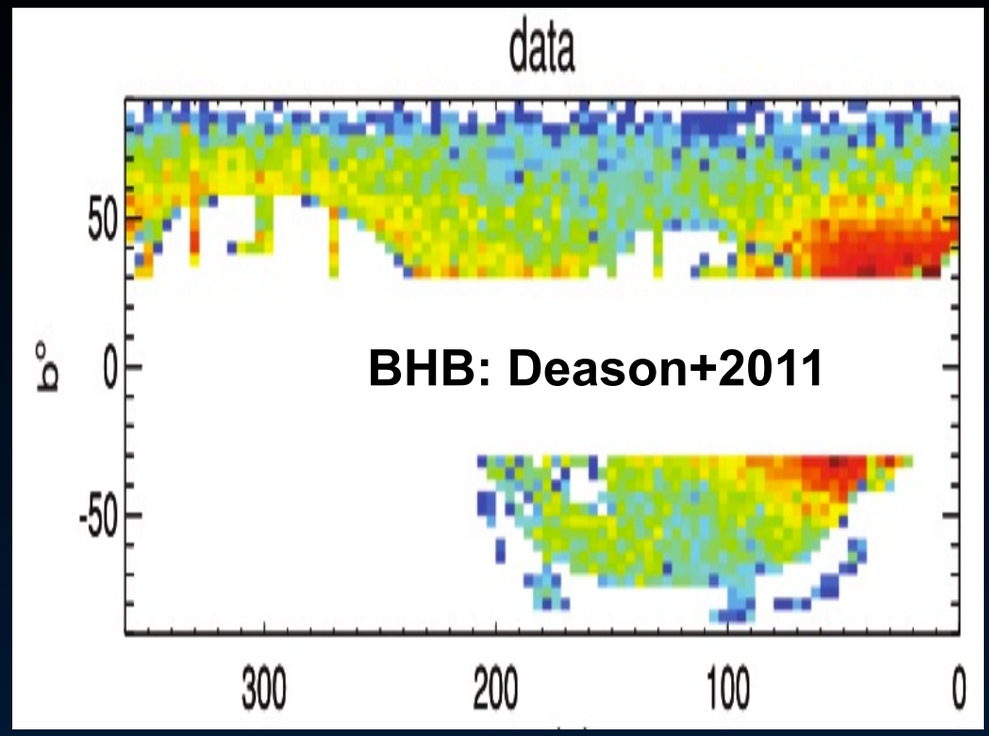
Star-counting results, so far:

Different tracers:

- K-Giants (e.g. Xue+15)
- BHB (e.g. Deason+11, Das+16)
- RRL (e.g. Sesar+10)

Halo properties:

- Power Law $\rho \propto \mathrm{m}^{-\alpha}$ $\alpha \approx 2-4$
- Oblate $q \approx 0.4-0.8$



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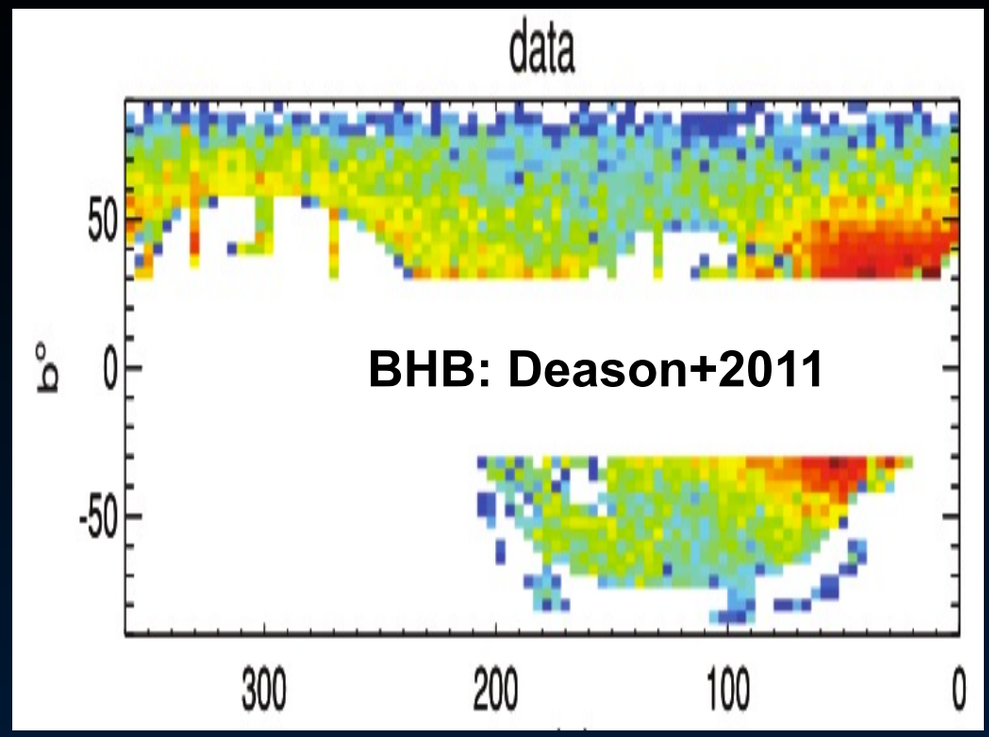
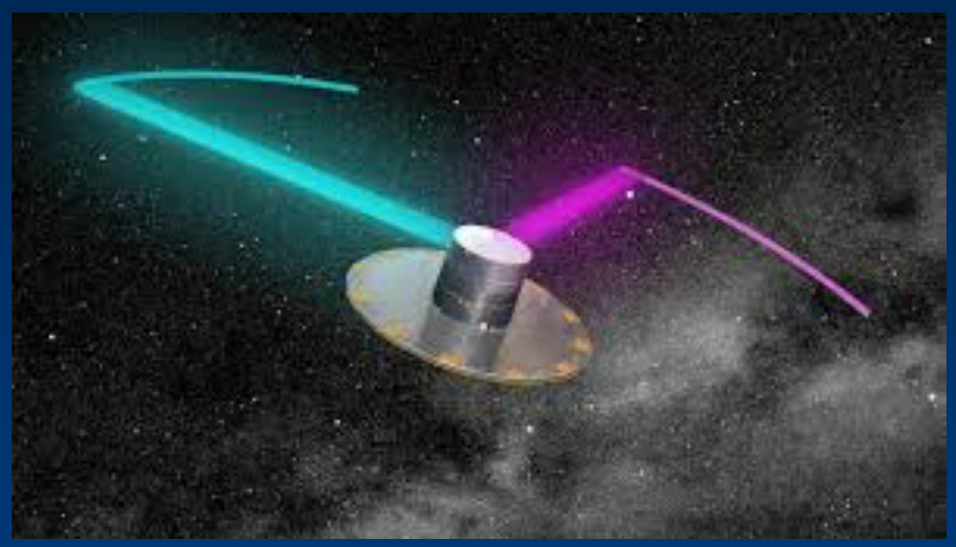


Only gross agreement and partial sky coverage..

The Gaia Revolution

Gaia is a formidable all sky variable machine



…. but RRLs available at the end of the missions (>2020)

Exploiting DR1

Photometry in DR1

- G-band mean mag.
- Mean Flux in *G* band
- Std Flux in *G* band

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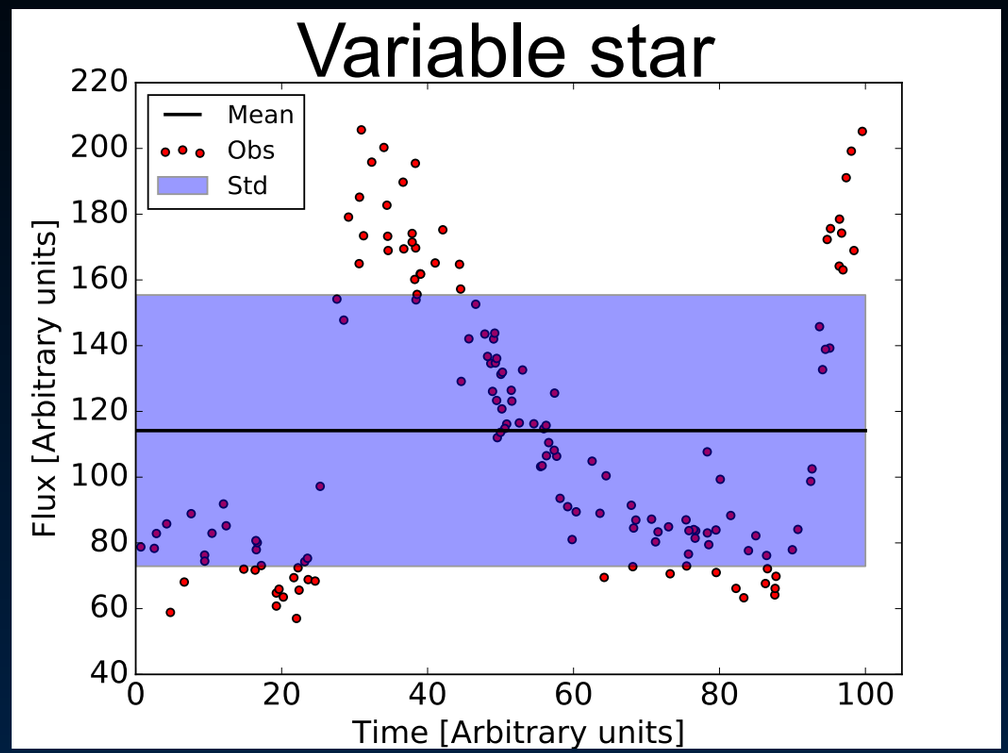

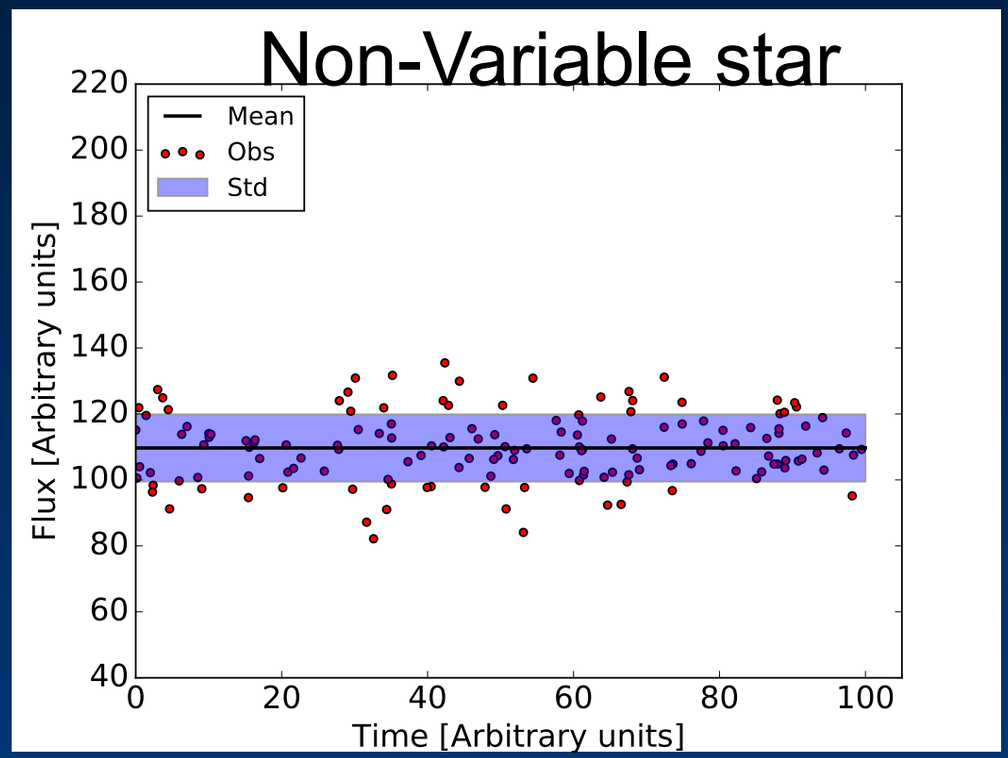

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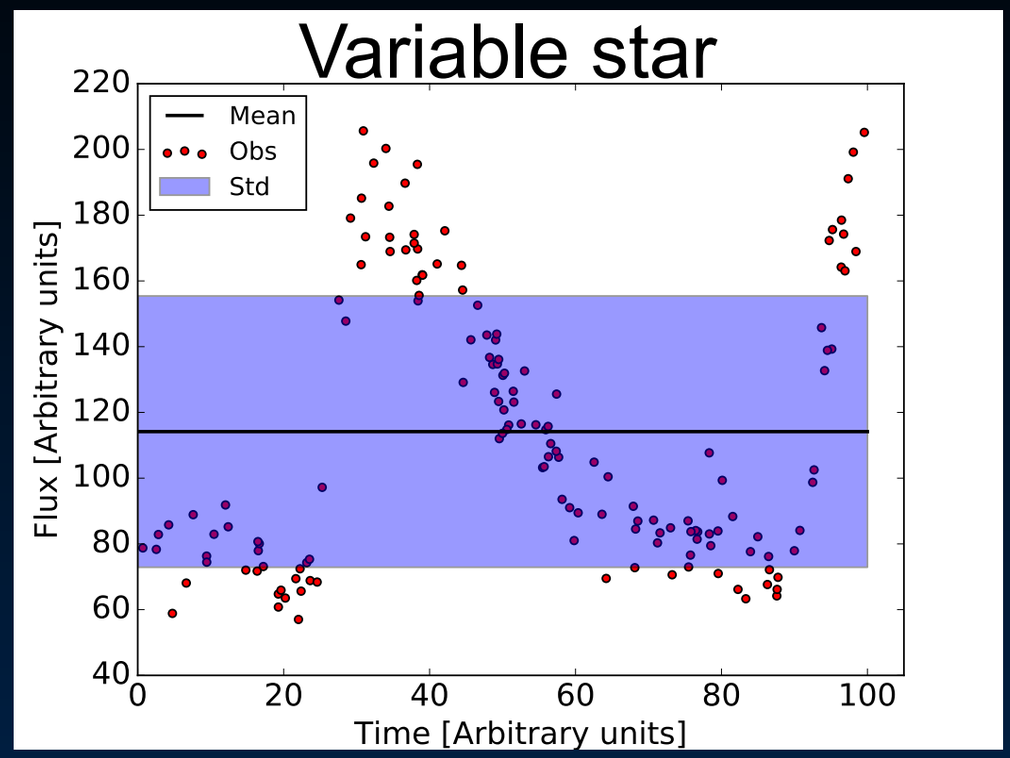
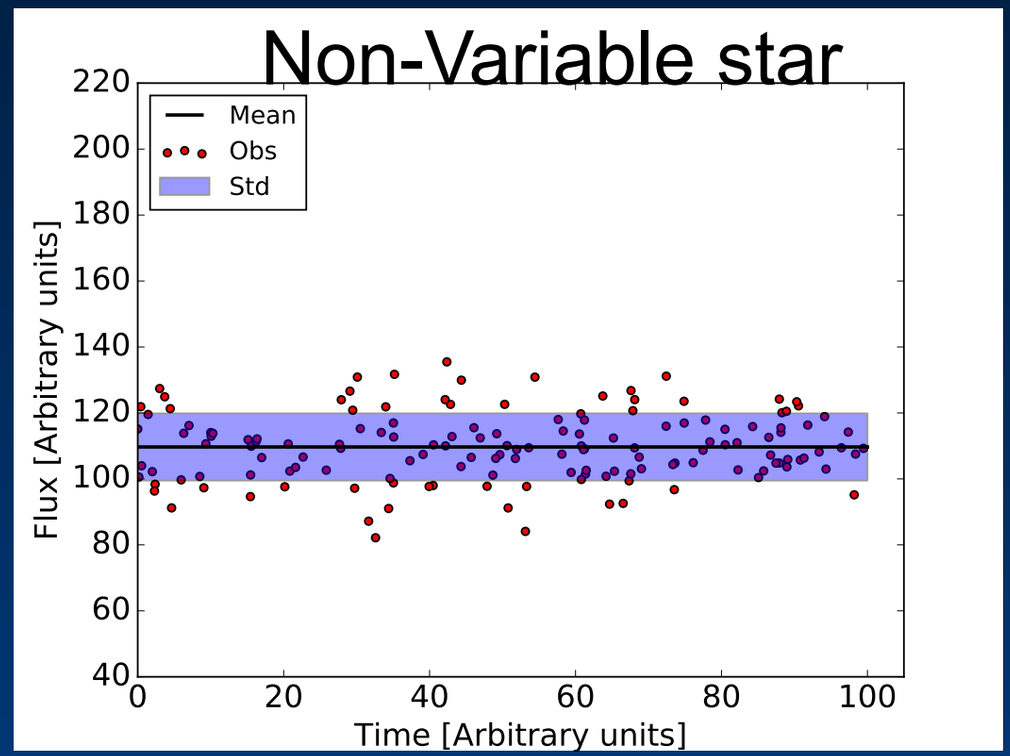
Belokurov+17, Deason+17

$$\mathrm{AMP} = \log\left(\sigma_F F^{-1} \sqrt{N_{obs}}\right)$$

large → **Variable**

small → **Non-Variable**





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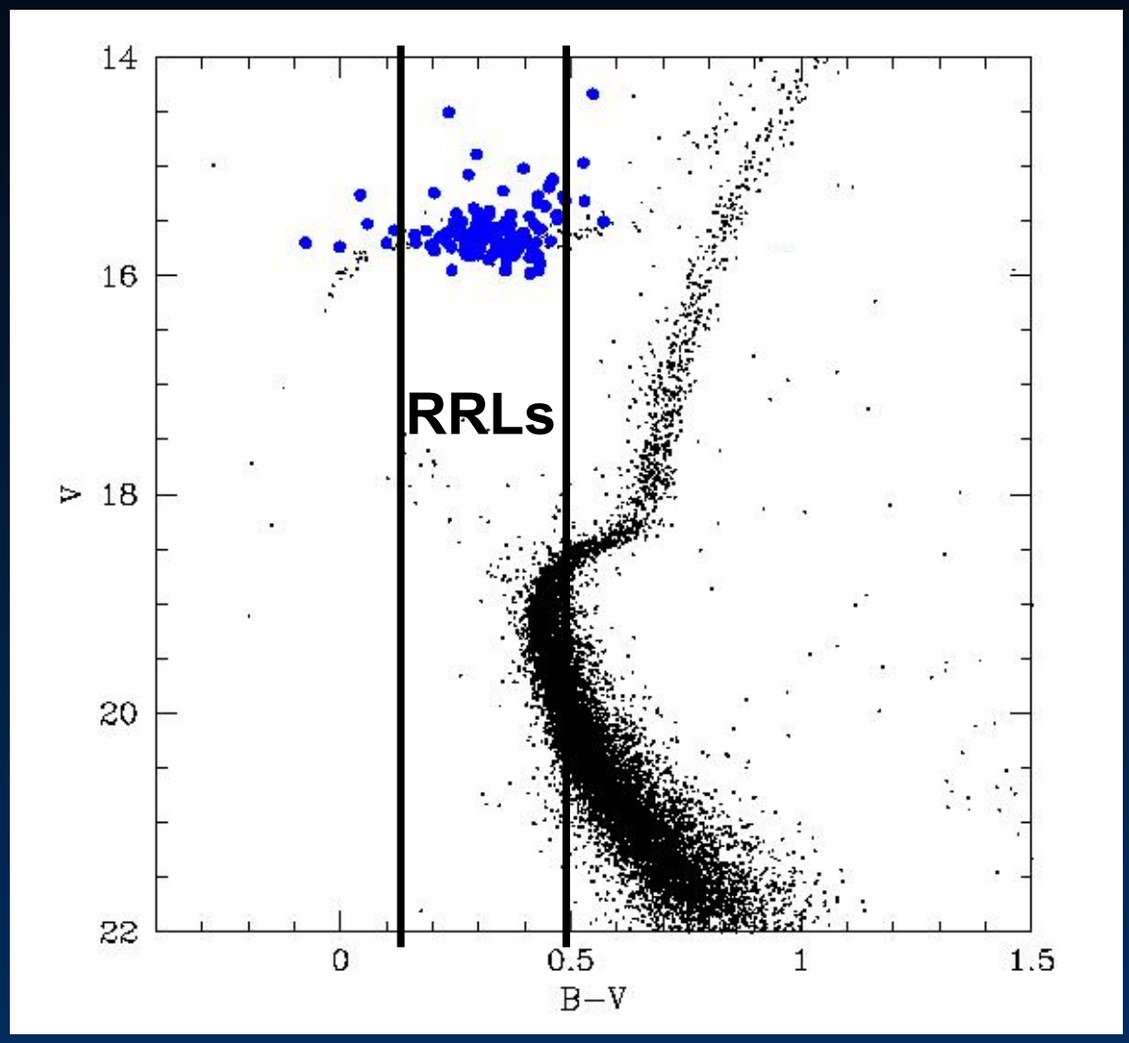


AMP alone is not enough…
we need a colour!

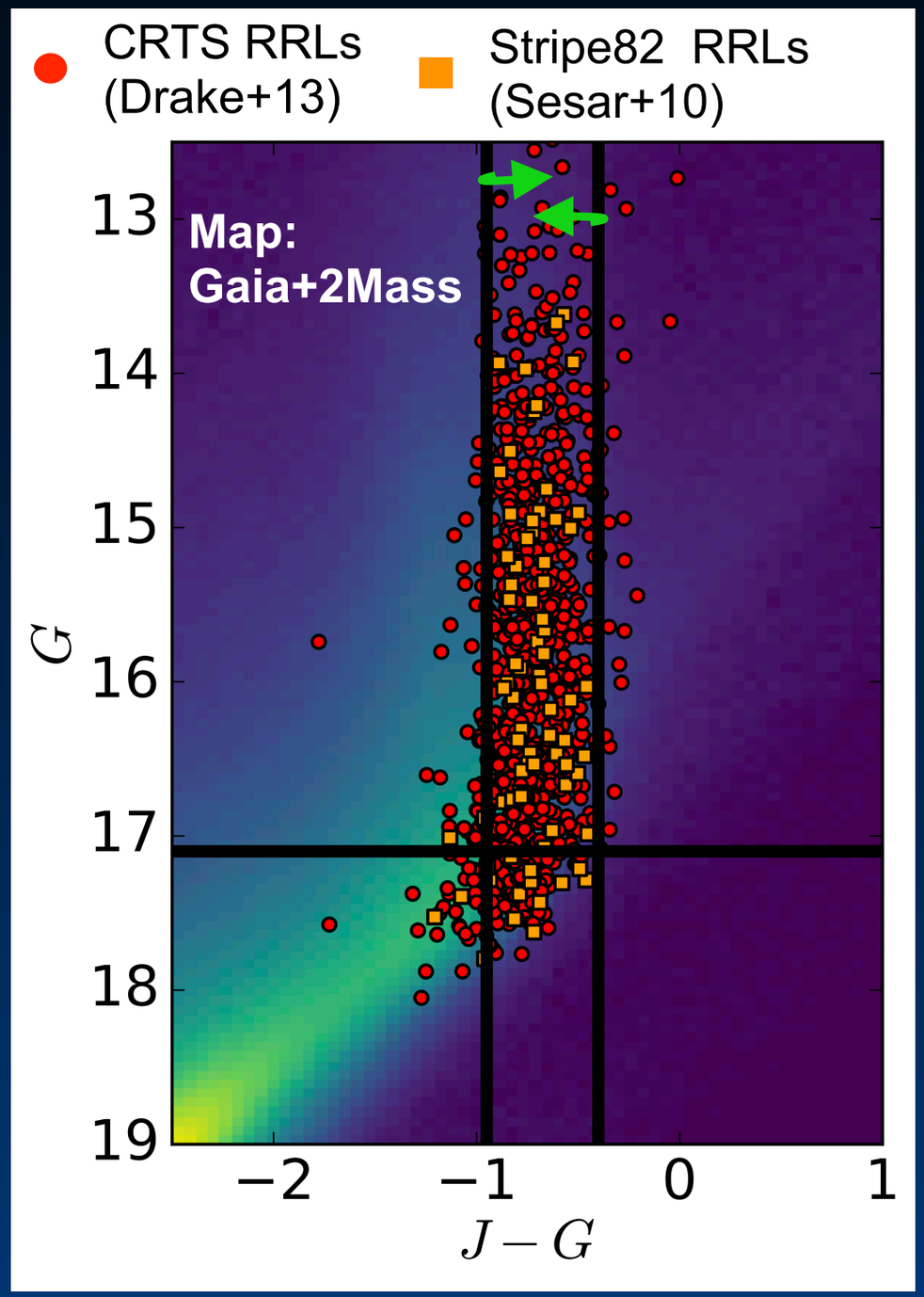
Cross-match with 2MASS!

Final sample

Selection Cuts (Driven by Bona Fide RRLs)

- -0.95<*J**-*G**<-0.4 **'Colour Cut'**

*Magnitude corrected for dust extinction using E(B-V) from Schlegel+98



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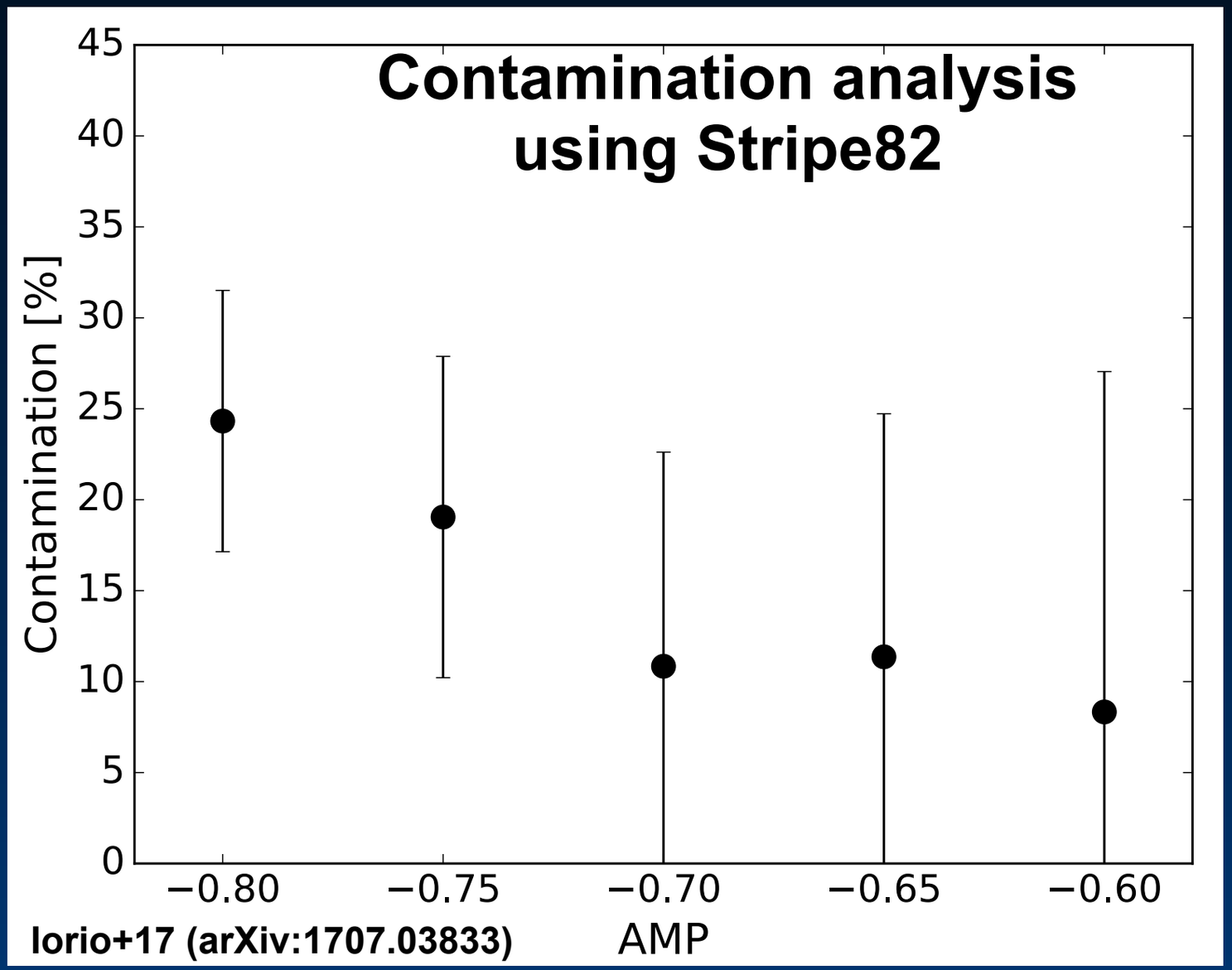

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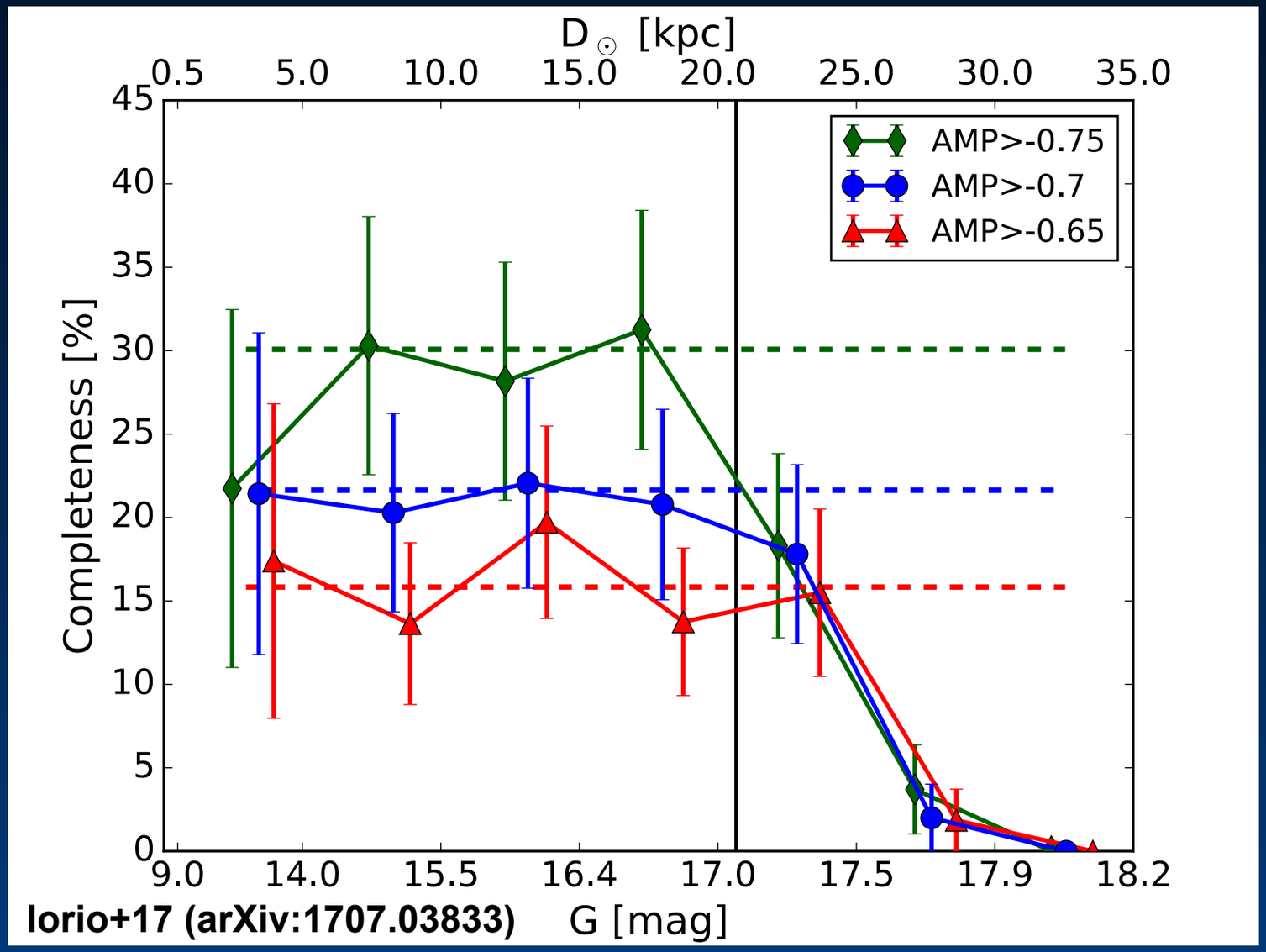

Iorio+17 (arXiv:1707.03833)

Completeness analysis using Stripe82

Not so complete…

….but we don't care

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- |b|>10°

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85% of the stars has E(B-V)<0.25

1% of the stars has E(B-V)>0.8

Final sample

From sky to physical coordinates

$$(\mathrm{l},\mathrm{b},G) \longrightarrow \mathrm{D}_{\odot}(M_G) \longrightarrow (\mathrm{X}_g,\mathrm{Y}_g,\mathrm{Z}_g)$$

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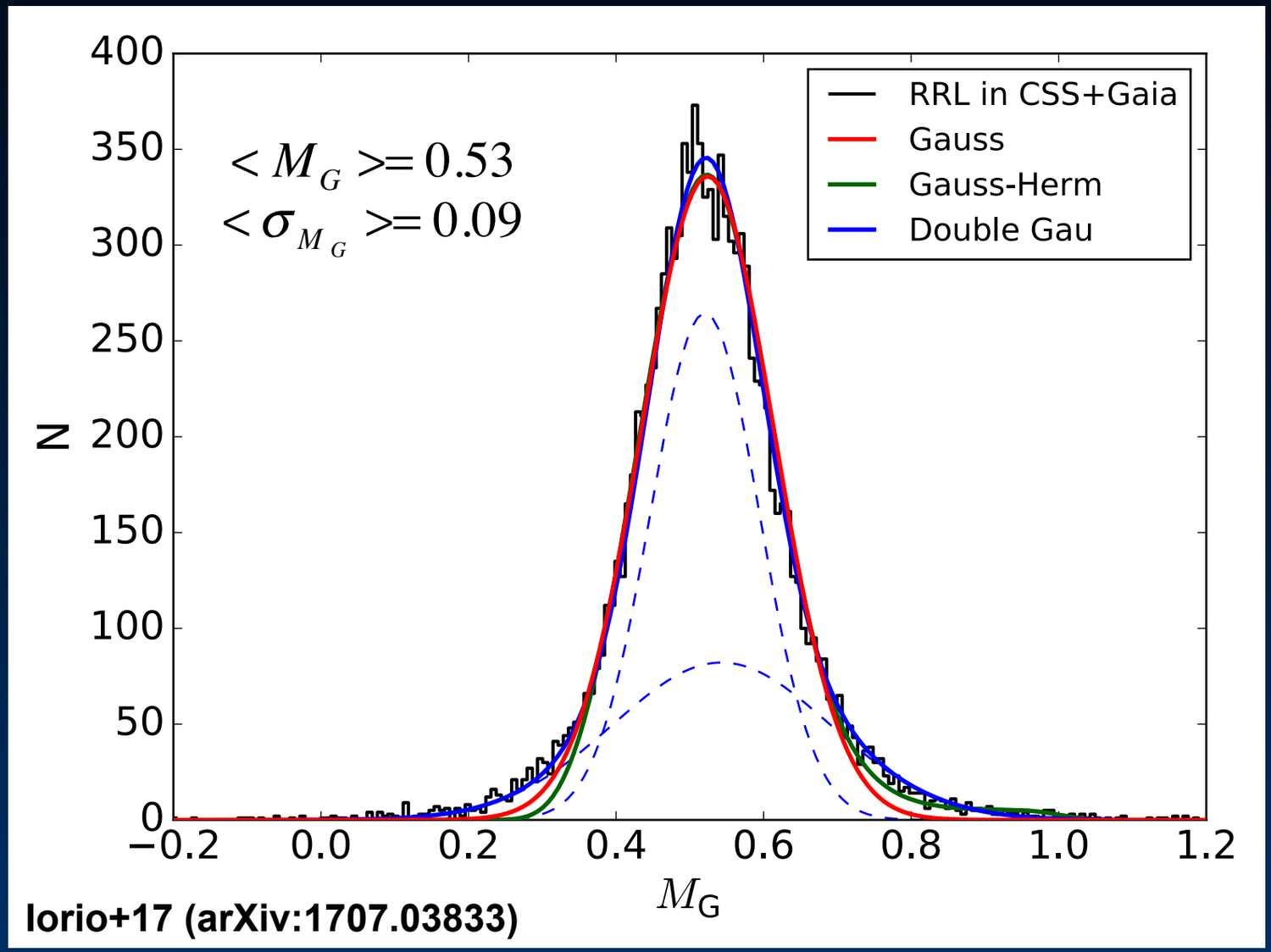

- **Little spread around median**

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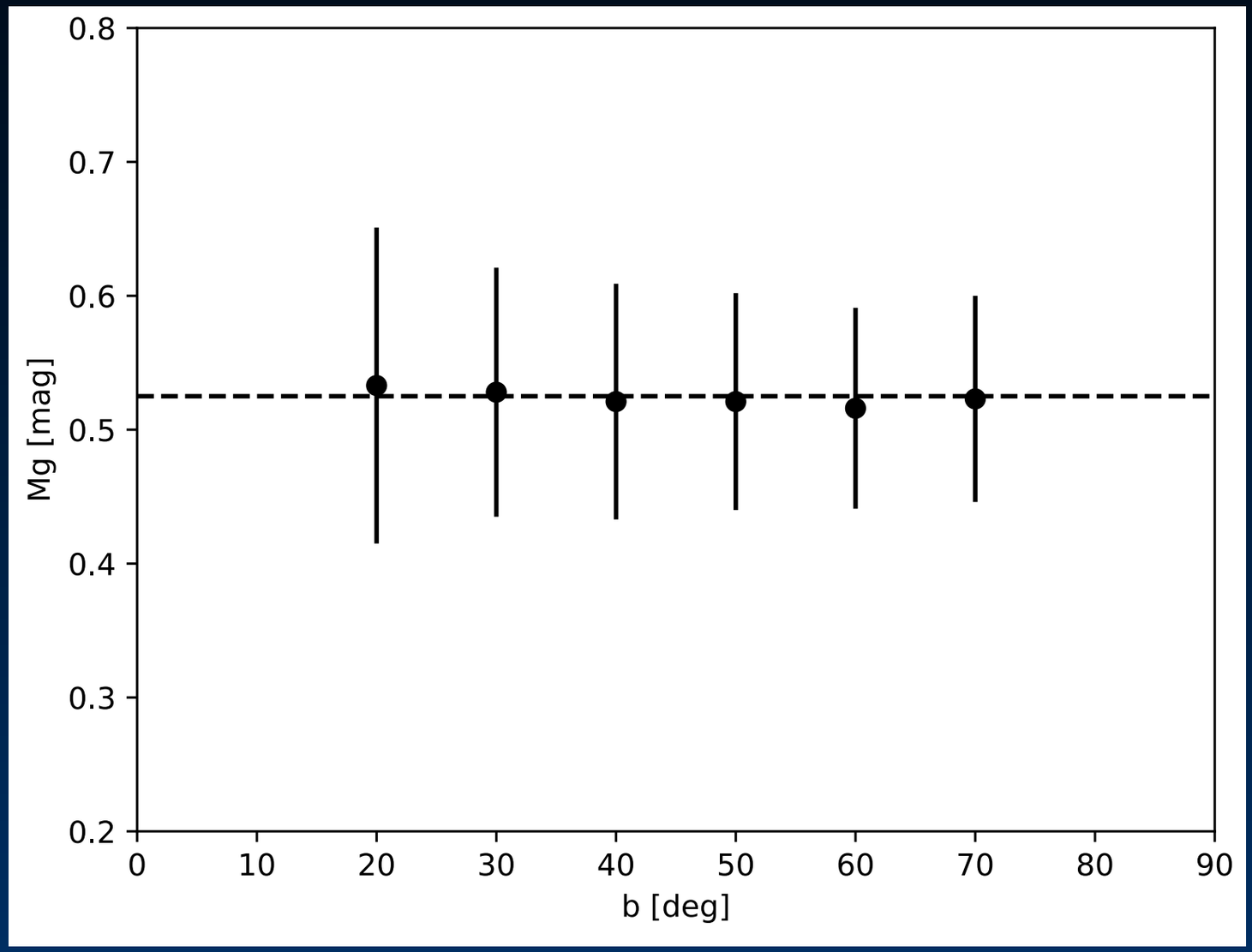

- **Little spread around median**
- **M_G distribution almost constant with b**

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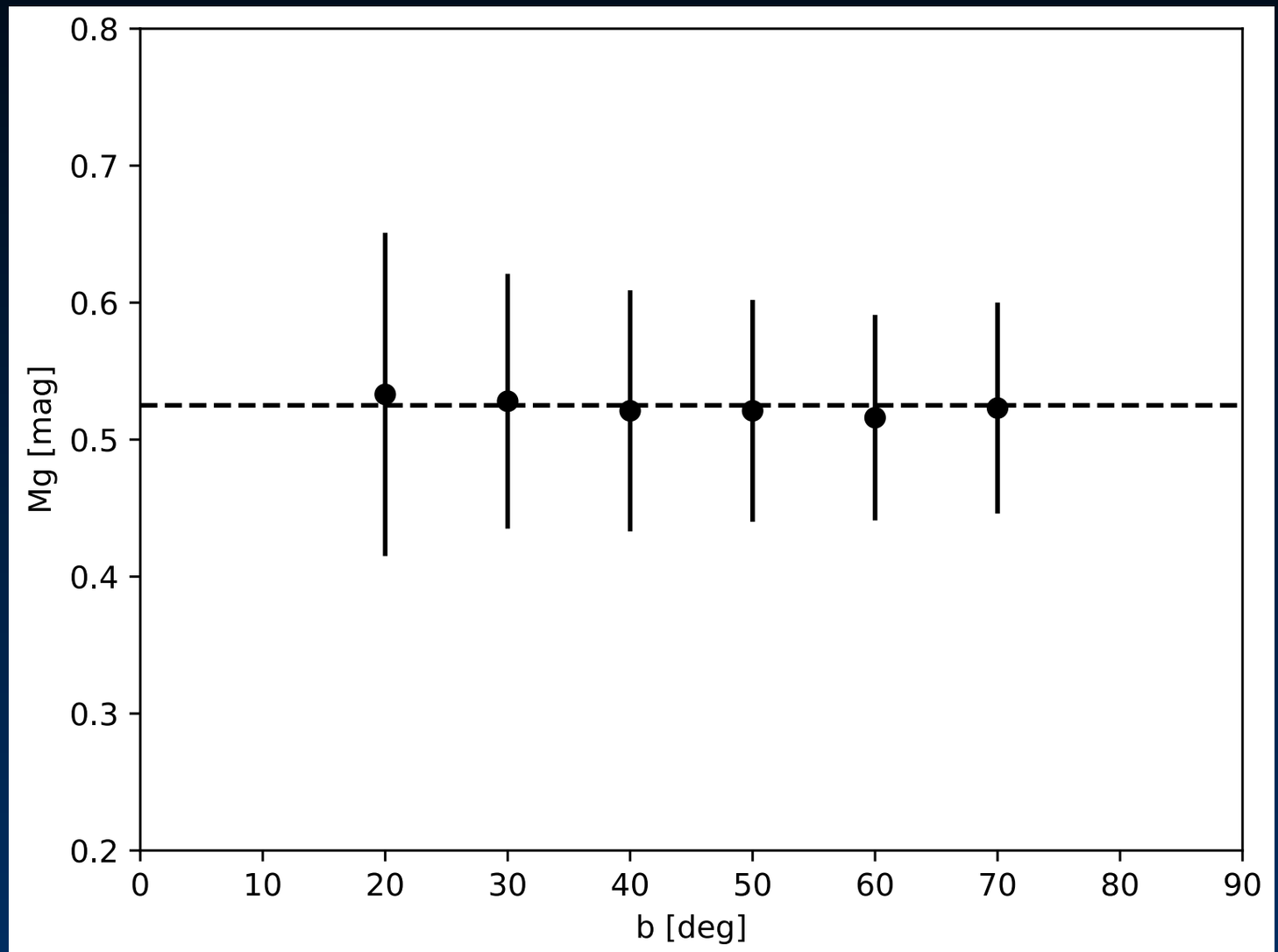

- Little spread around median

M_G=0.53 for all the stars

- M_G distribution almost constant with b

Final sample

Properties

about 22000 stars
Contamination < 10%
Completeness 20%

$$D_{\odot} \approx 0.5 - 20 \text{ kpc}$$

$$D_G \approx 1 - 28 \text{ kpc}$$

Sampled Vol. fraction:

$$f_V^{tot} \approx 50\%$$

Previous works < 20%
(e.g. Deason+11)

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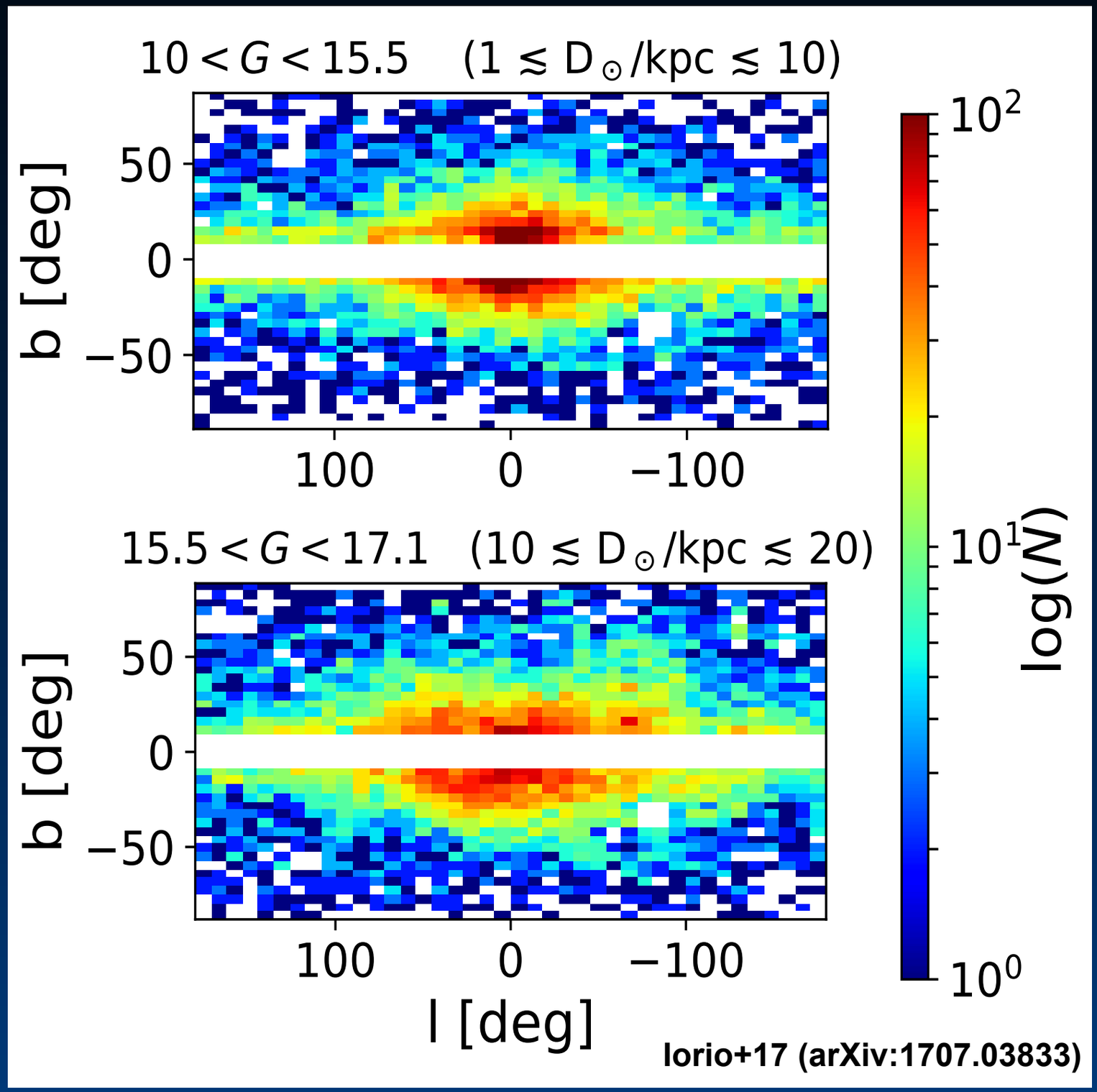
Sky distribution

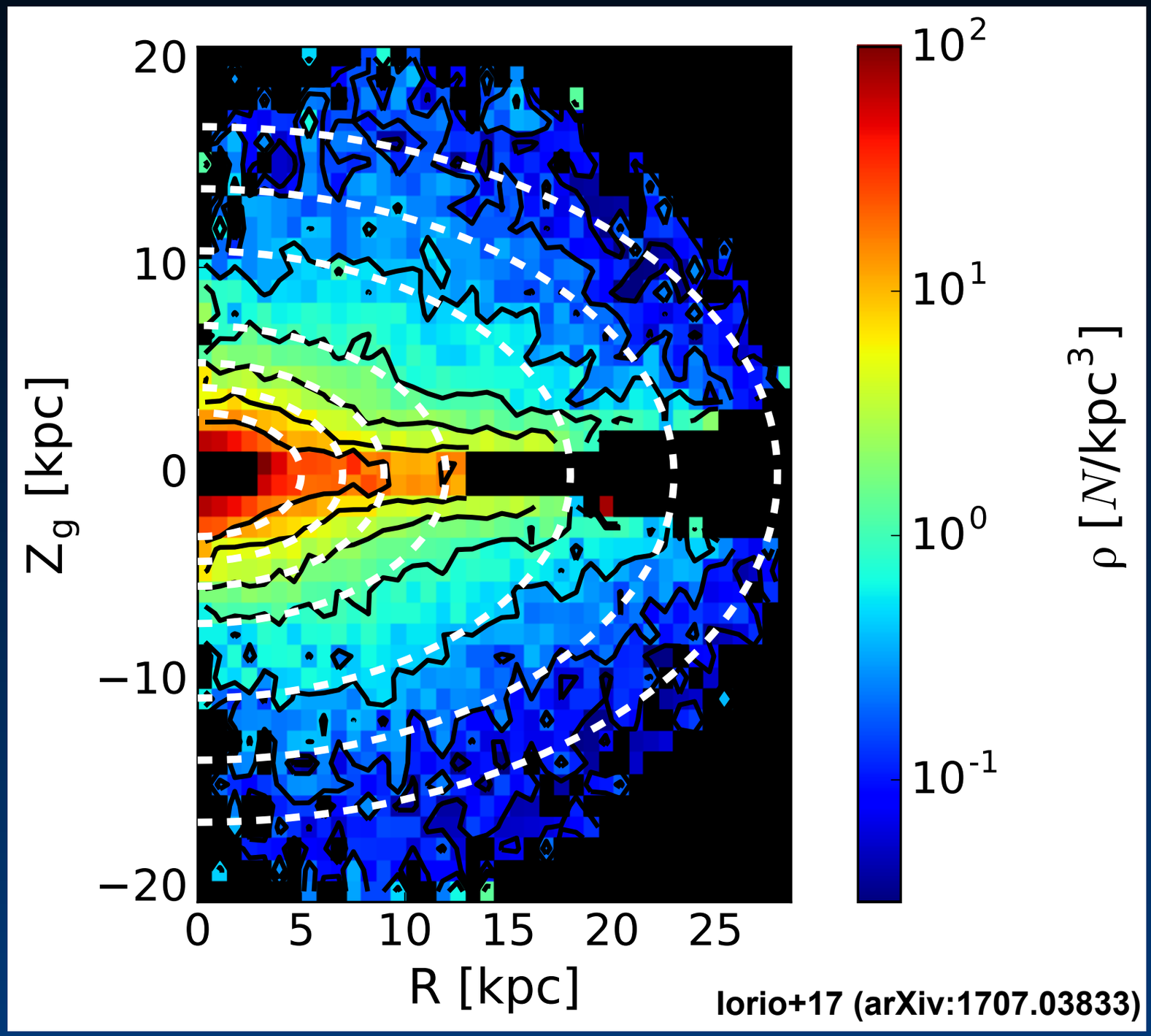


Iorio+17 (arXiv:1707.03833)

Exploring the Halo

Density in the RZ plane

- Disky at low Z
- Ellipsoidal at high Z

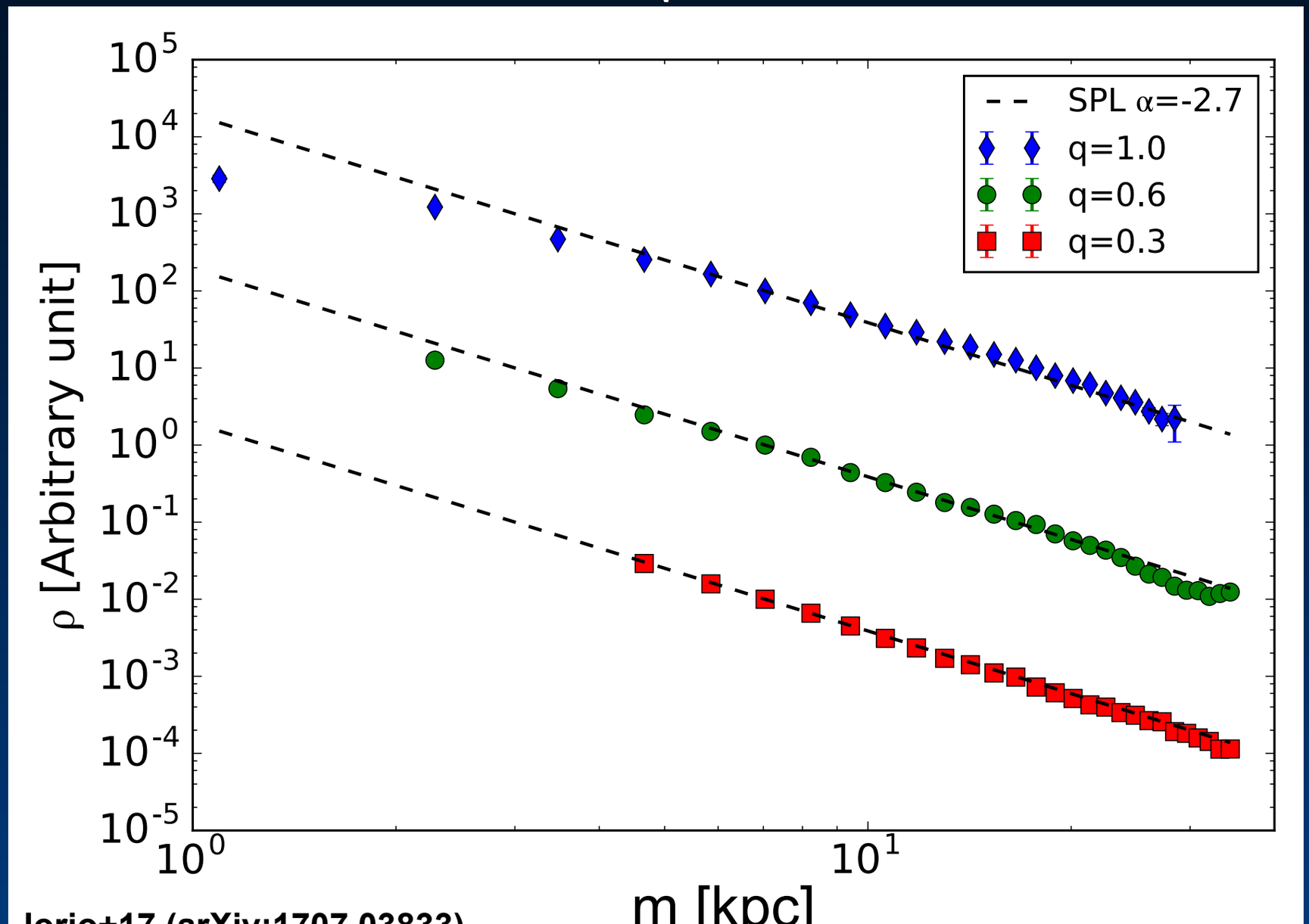


Exploring the Halo

Density profile

Assumption: Density stratified on ellipsoids

$$\rho = \rho(\mathrm{m}) \qquad \mathrm{m}=\sqrt{x^2 + p^{-2}y^2 + q^{-2}z^2}$$



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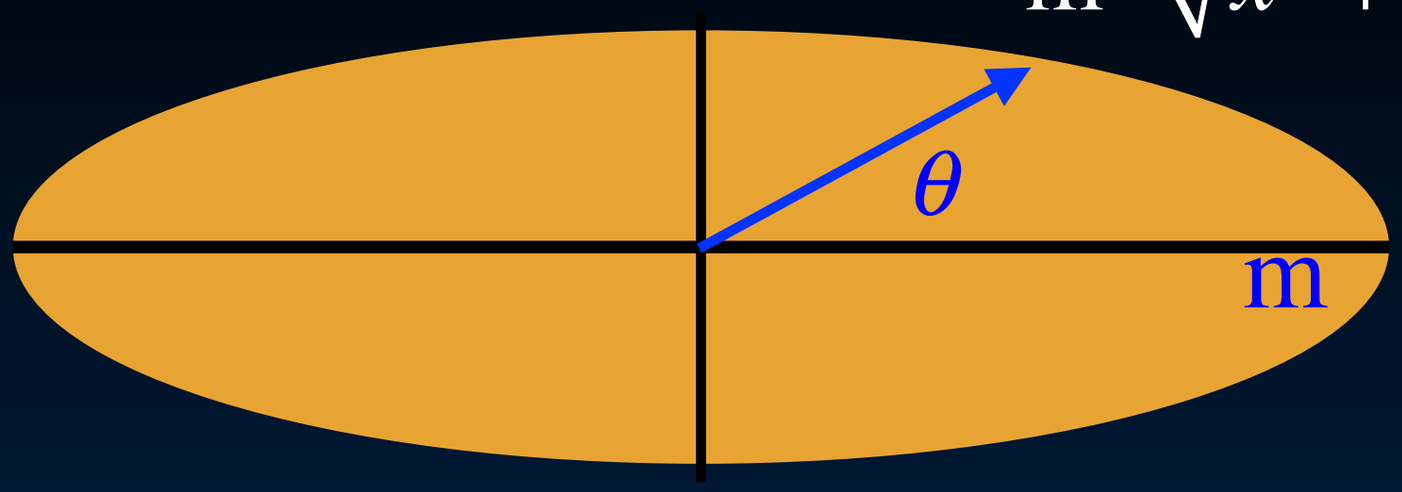
Flattening

$$\rho = \rho(m)$$



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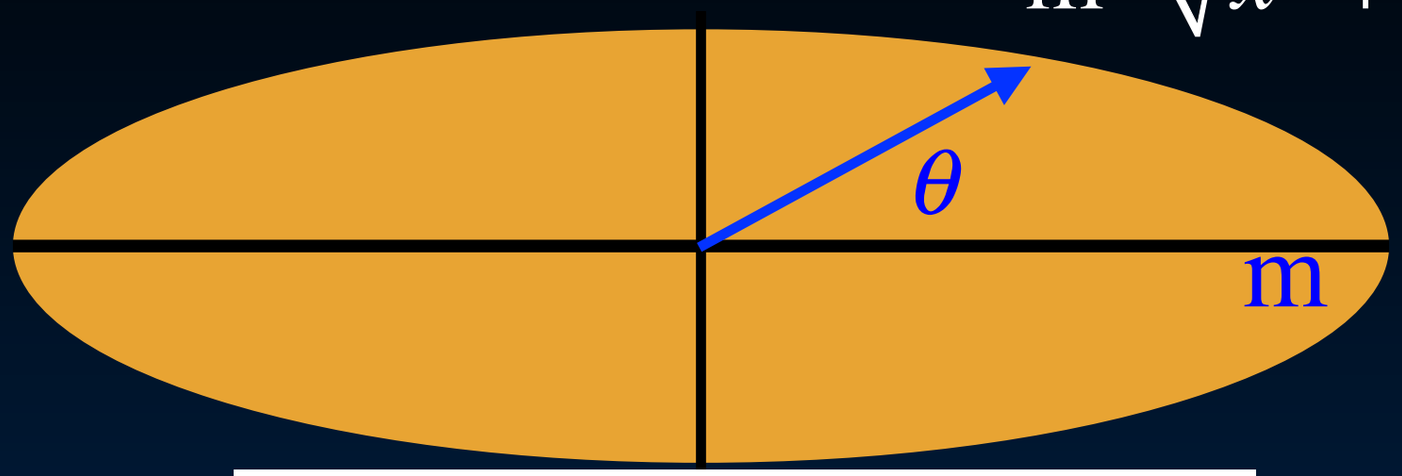
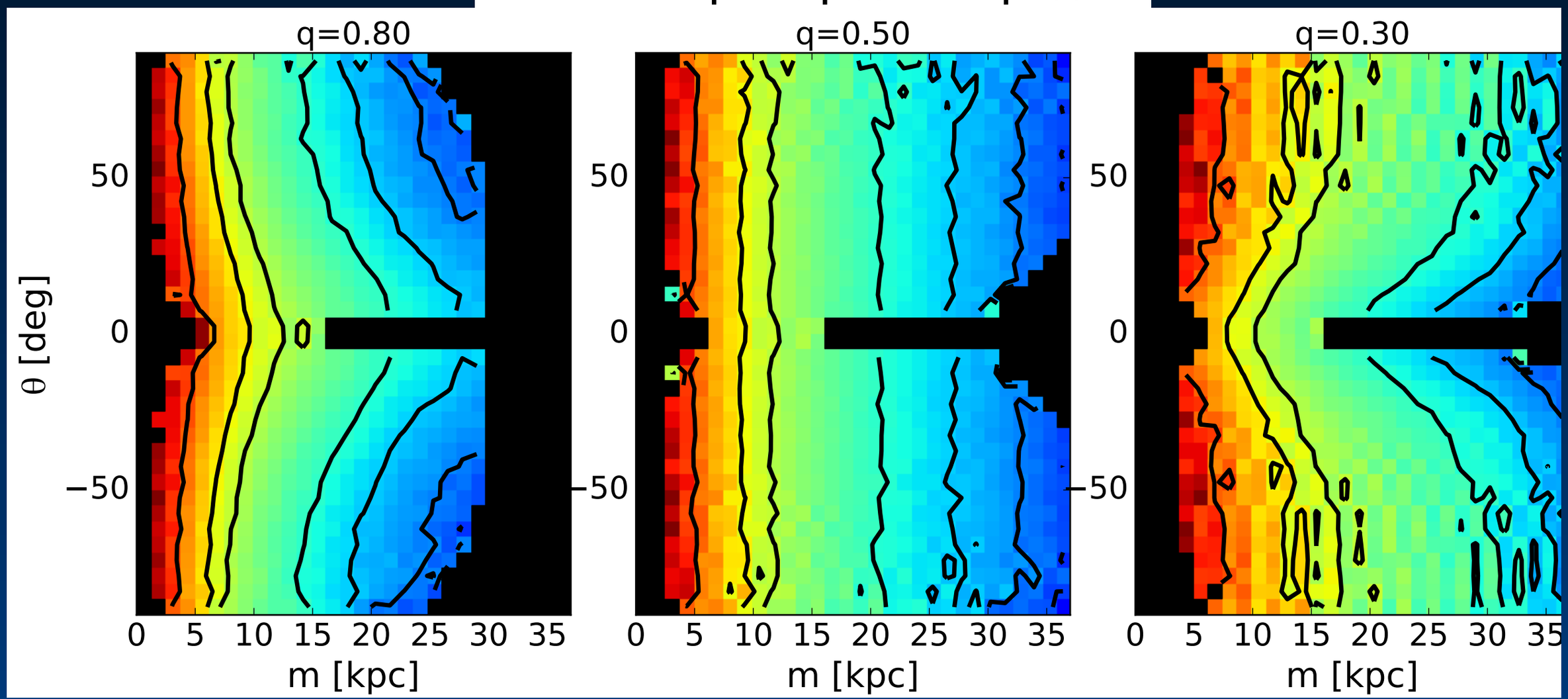


Mock sample: q_{true}=0.5 p_{true}=1



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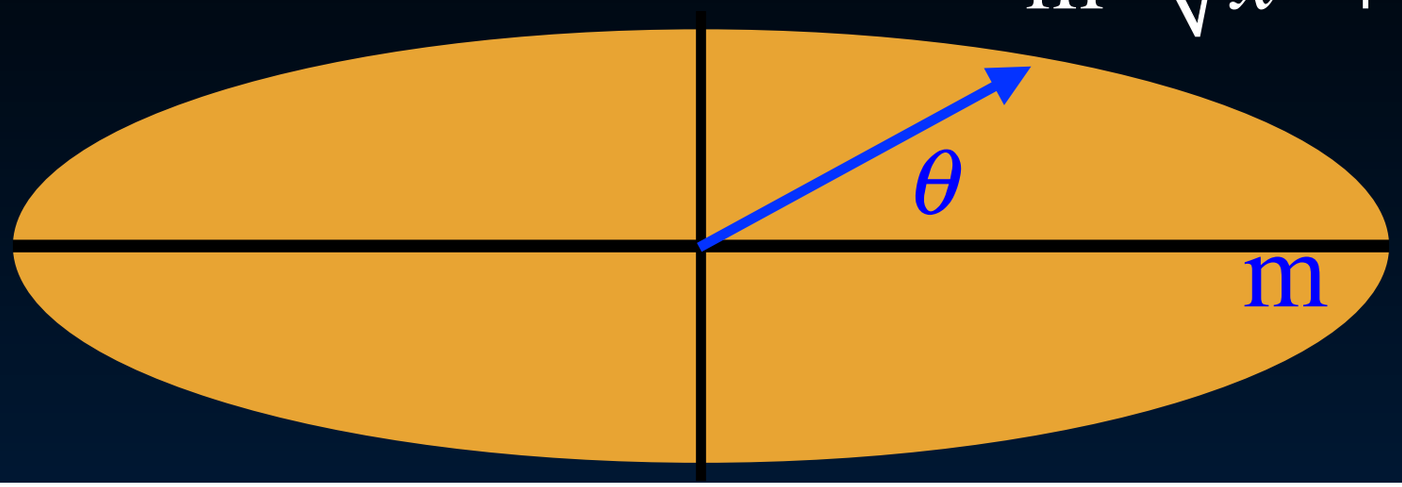

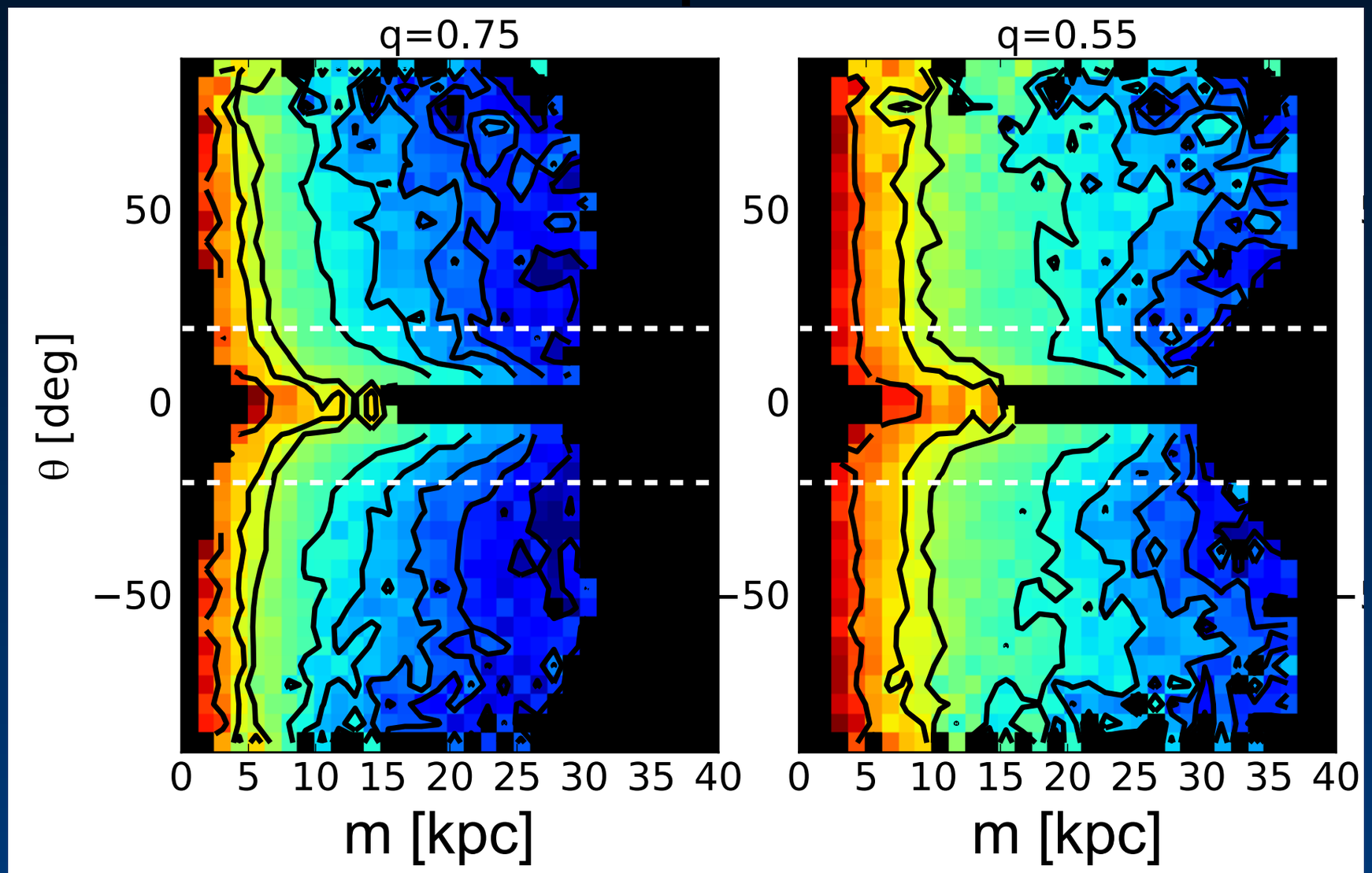

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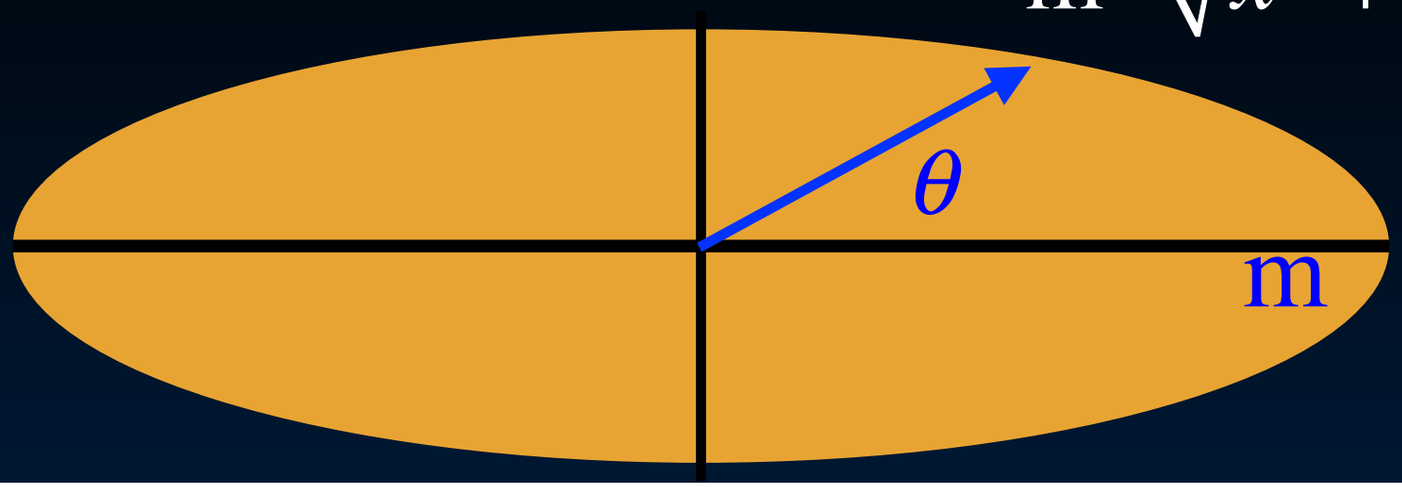

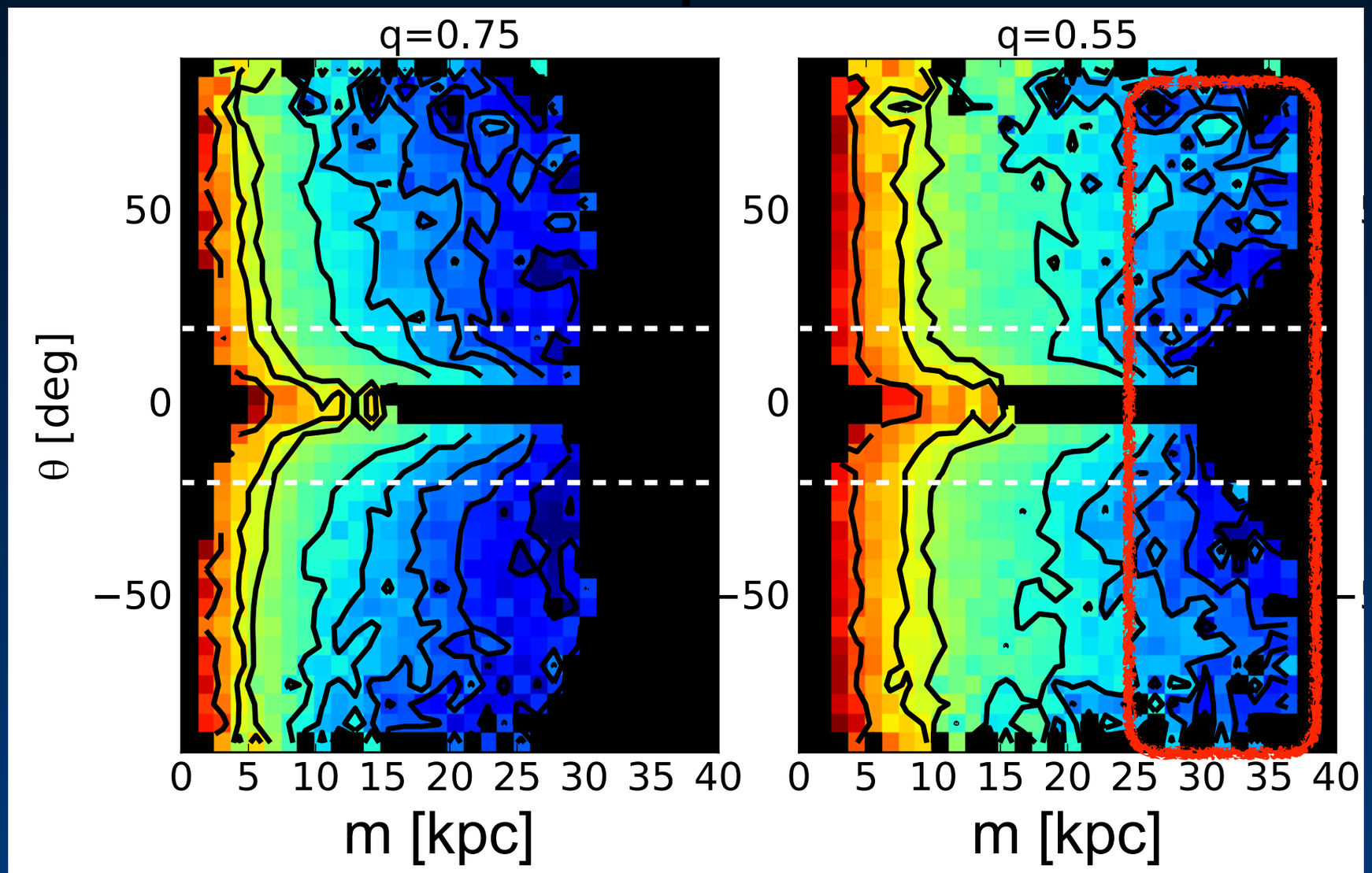

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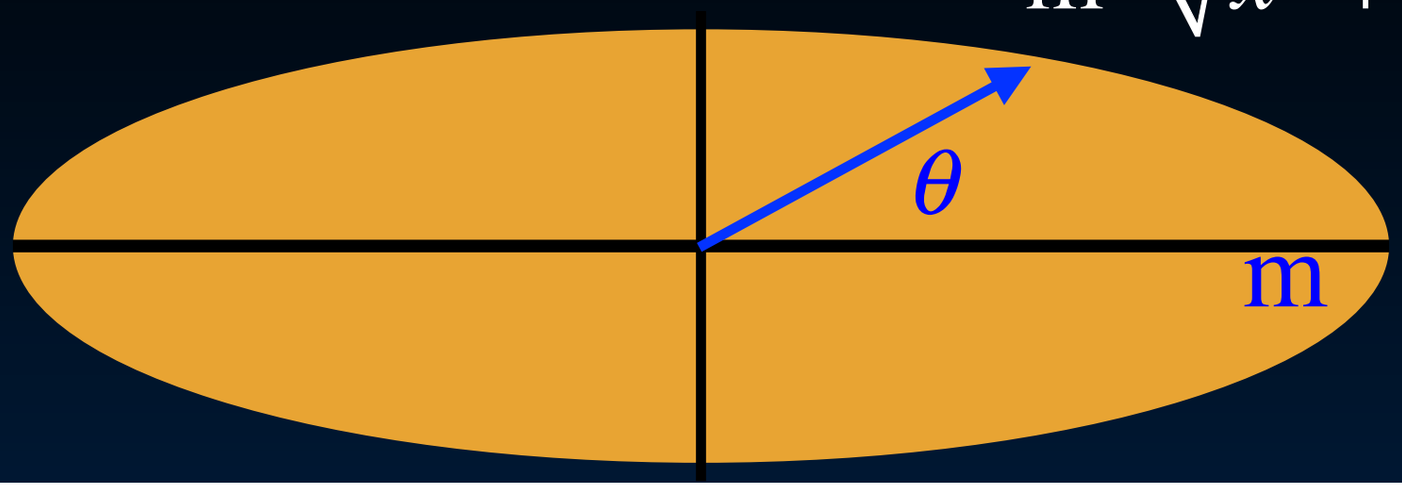

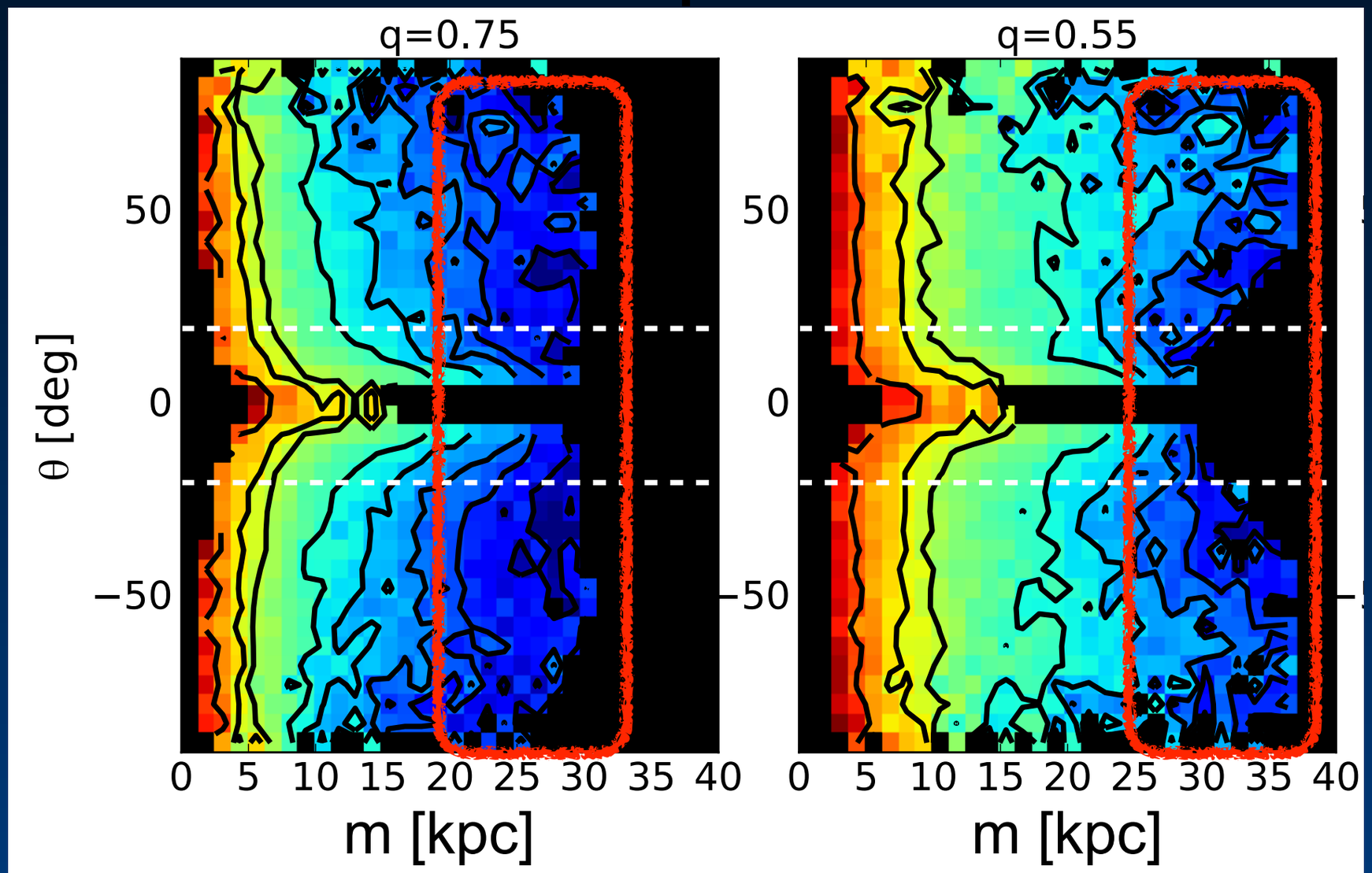

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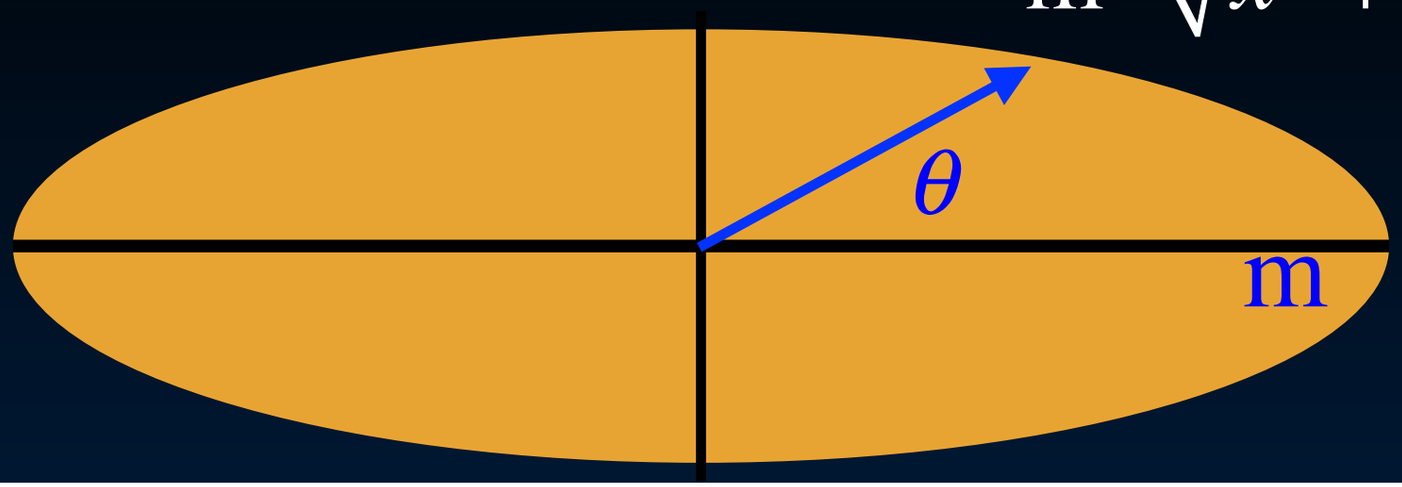
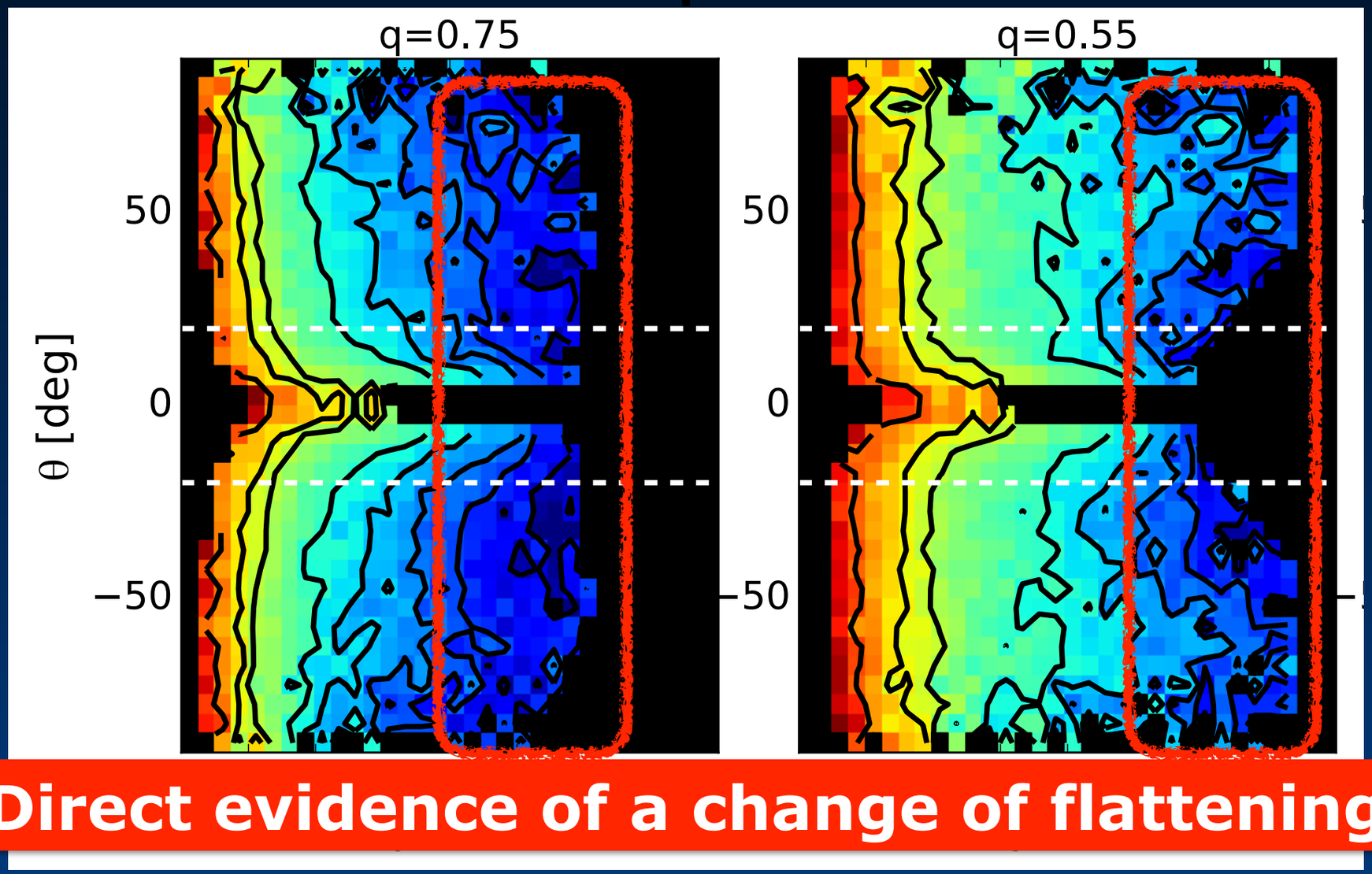


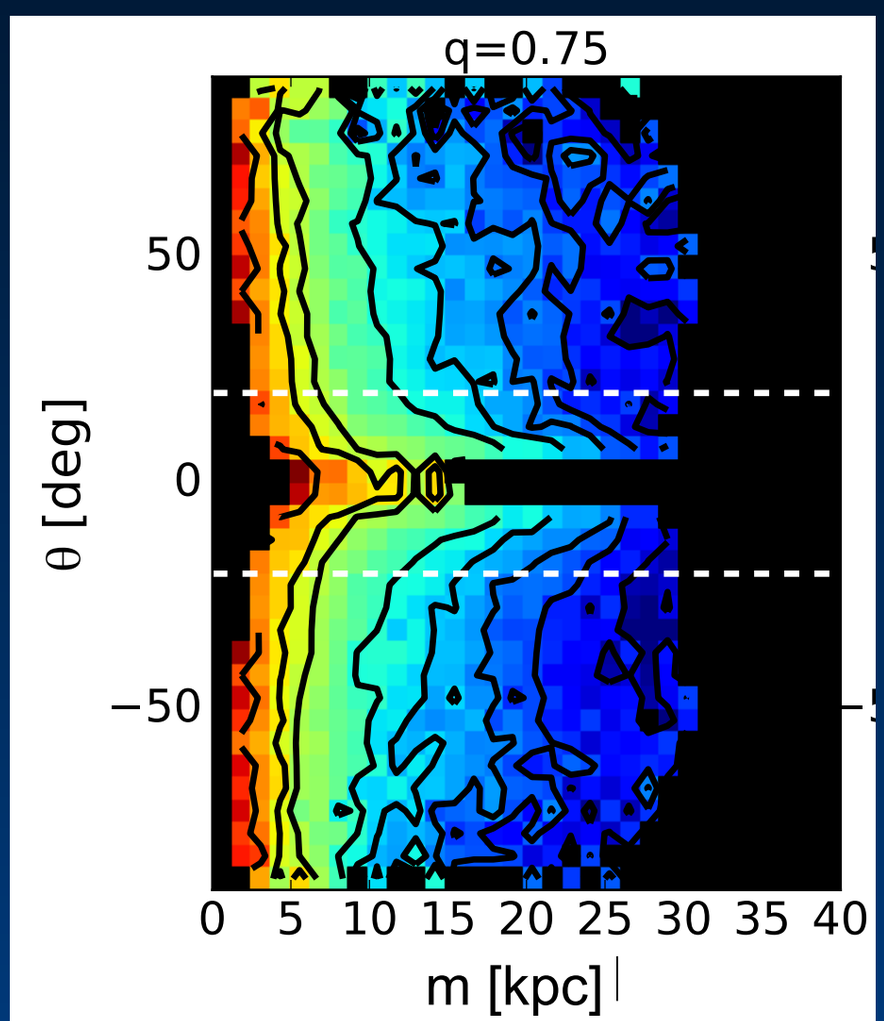


Direct evidence of a change of flattening

Exploring the Halo

MCMC Likelihood sampling

- Exclude the disky structure $|\theta| > 20^\circ$



- about half of RRLs in our sample
- No due to disc cont. (Rd=2.6, zd=0.2)

Maybe Monoceros (e.g. Juric+08) or related to Gaia DR1 problems at low latitude

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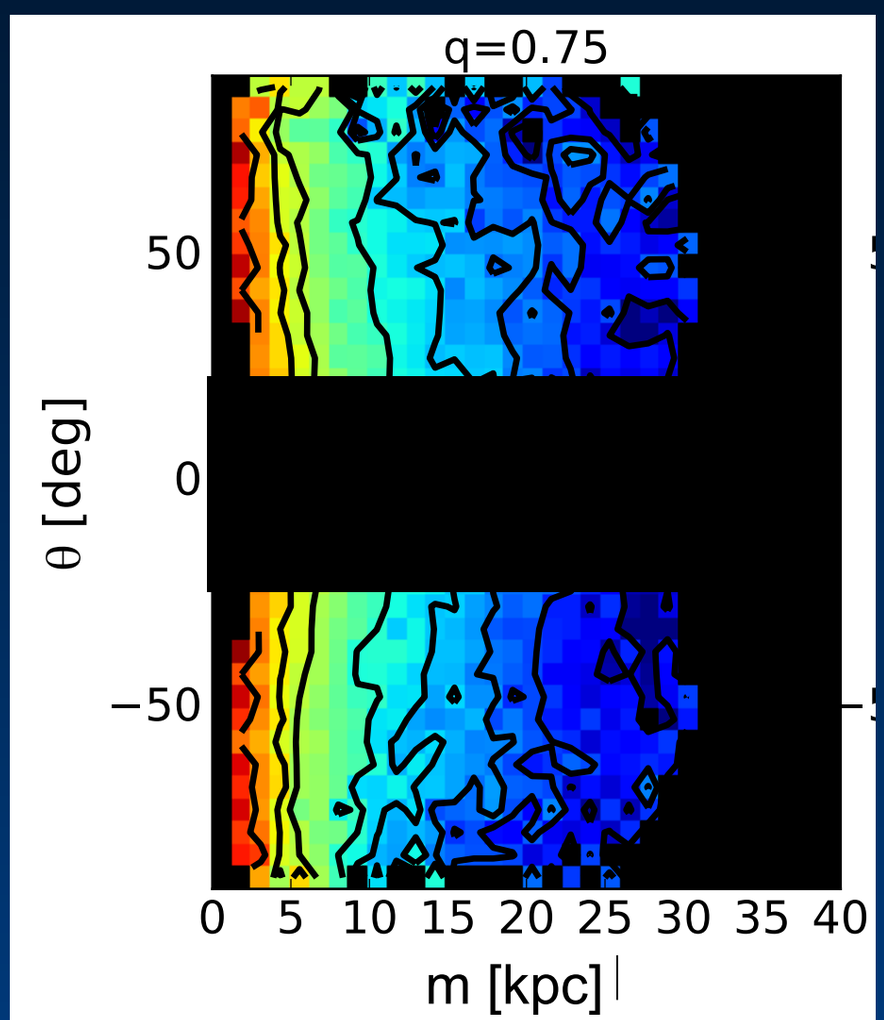

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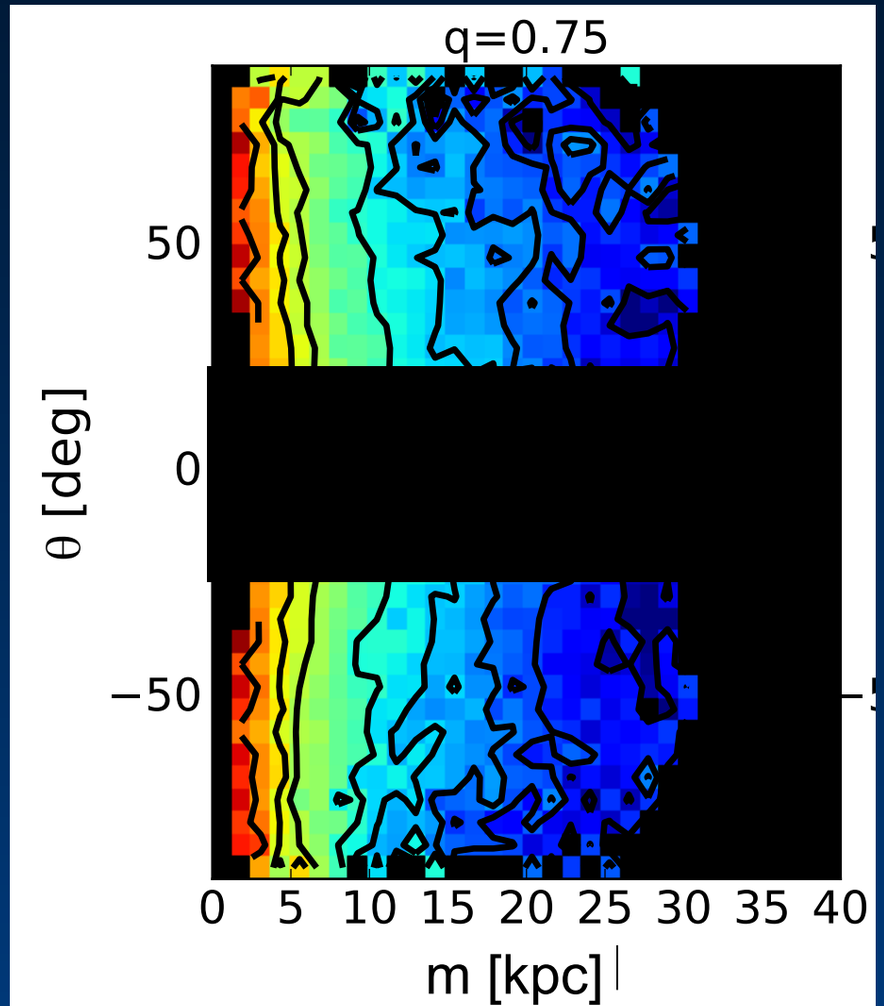
MCMC Likelihood sampling

- Exclude the disky structure $|\theta| > 20^\circ$
- Halo model

Halo recipes



- Density
  - Single Power Law
  - Double Power Law
  - Broken Power Law
  - Core Power Law
  - Einasto
- Shape
  - Spherical
  - Axisymmetric
  - Triaxial
  - Tilted
  - Off-set
  - Varyng q

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MCMC Likelihood sampling - Main results

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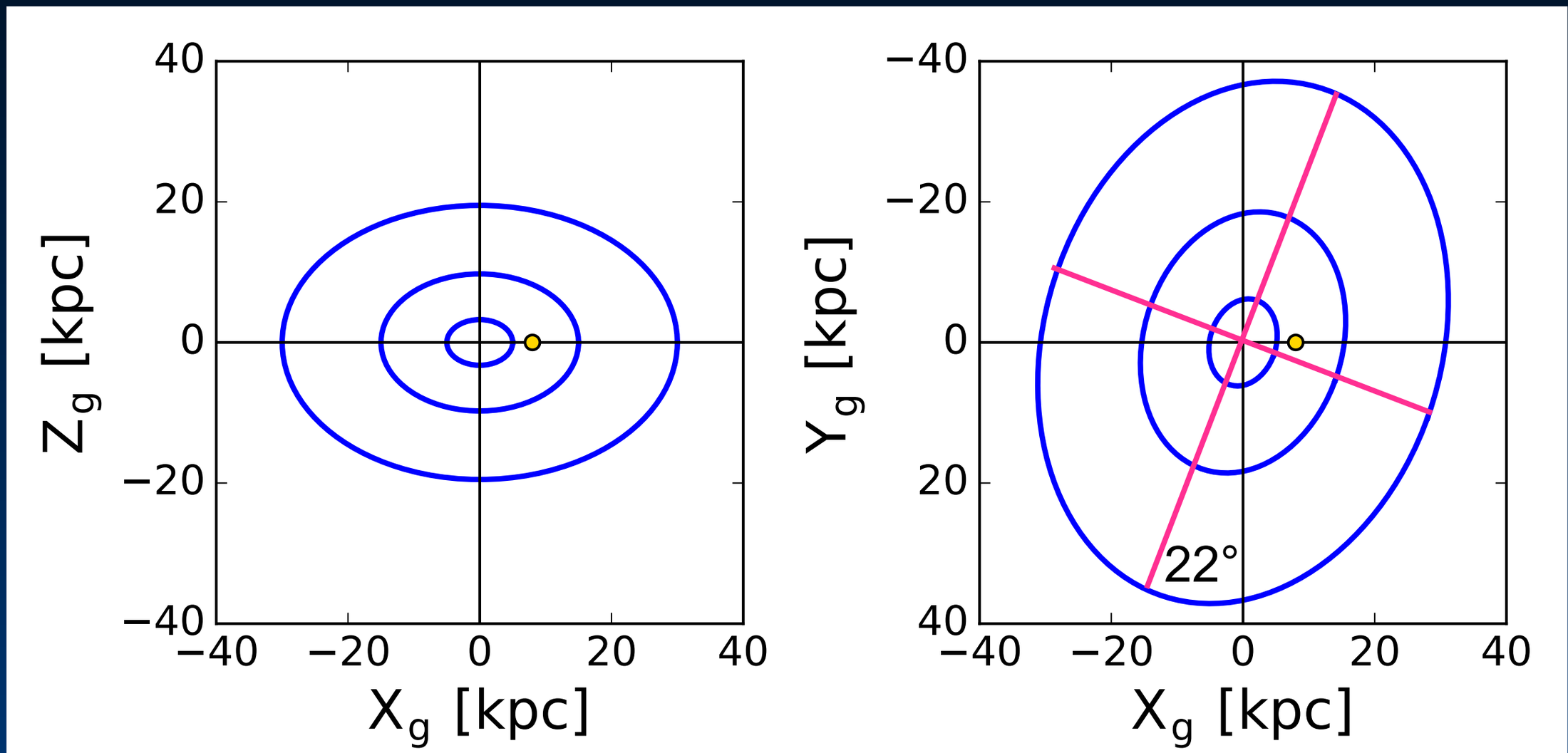

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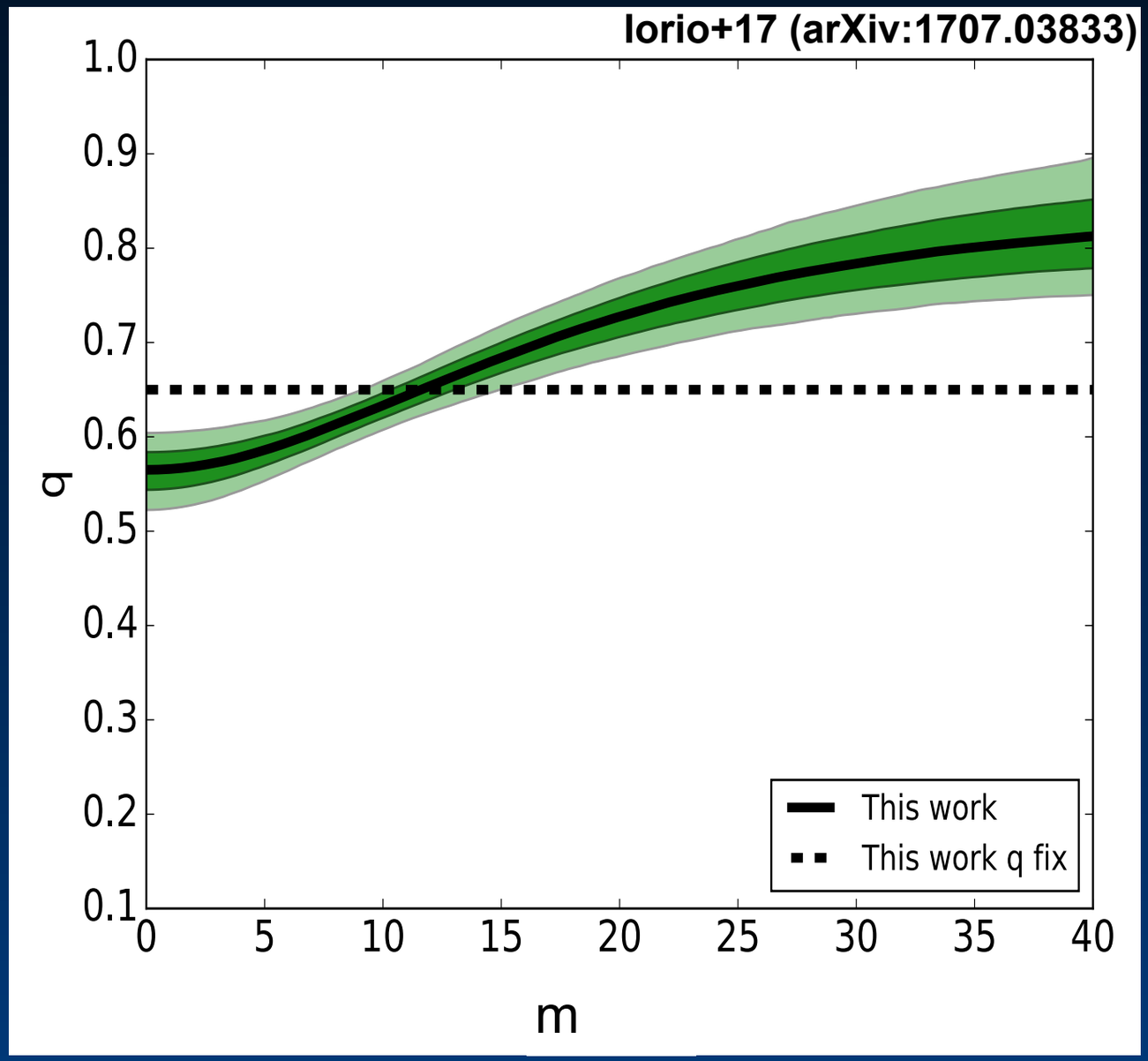

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- **Triaxial:** flattening along Z (q=0.6), elongation along Y(p=1.3)
- **q increasing** with m
- No significant **off-set** (d_{offset}) wrt GC or **tilt** wrt G. plane

$$\text{tilt} < 6^{\circ}$$

$$d_{\text{offset}} = 0.43 \pm 0.07 \text{ kpc}$$
$$X_{\text{offset}} = 0.39 \pm 0.05 \text{ kpc}$$

Compatible with uncertainties
in Sun dist. wrt GC

McMillan+10

Conclusions

First analysis of RRLs in the inner halo (Rg<28 kpc) using Gaia data*:

- Density is a Single Power Law $\rho \propto \mathrm{m}^{-2.95}$
- The halo is Triaxial and highly flattened along Z $(\mathrm{q} \approx 0.6)$
- Flattening changes with radius becoming more spherical

GAIA DR2 expected for April 2018

- Release of Gaia colors!
- Get rid of 2MASS

Extend this analysis up to 90 kpc!

Thank you for your attention!

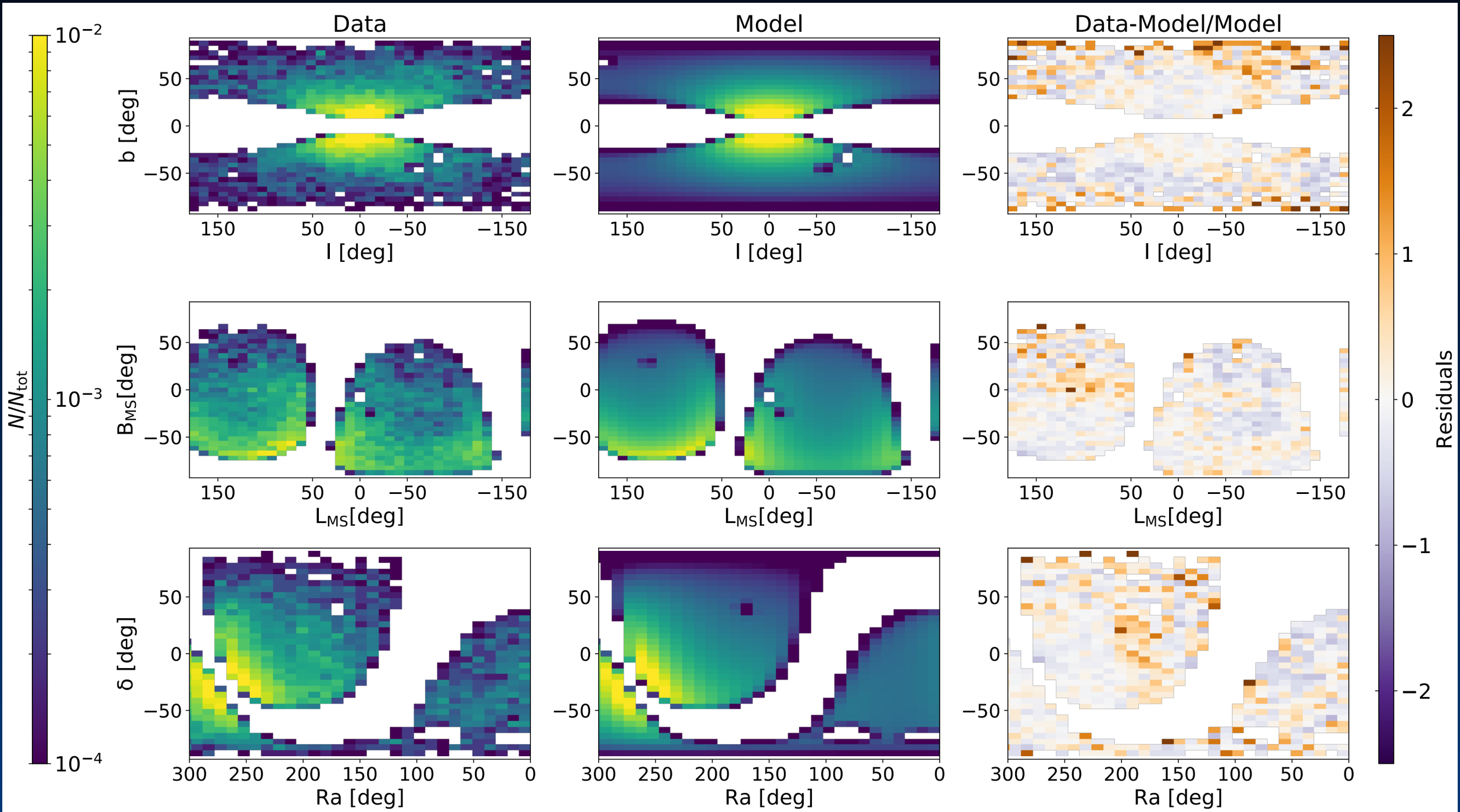
***Iorio et al., 2017, submitted, arXiv:1707.03833**

EXTRA

Exploring the Halo

MCMC Likelihood sampling - Main results

$$\rho = m^{-2.95} \qquad \mathrm{p} = 1.25 \qquad \mathrm{q} = 0.56 \rightarrow 0.82$$



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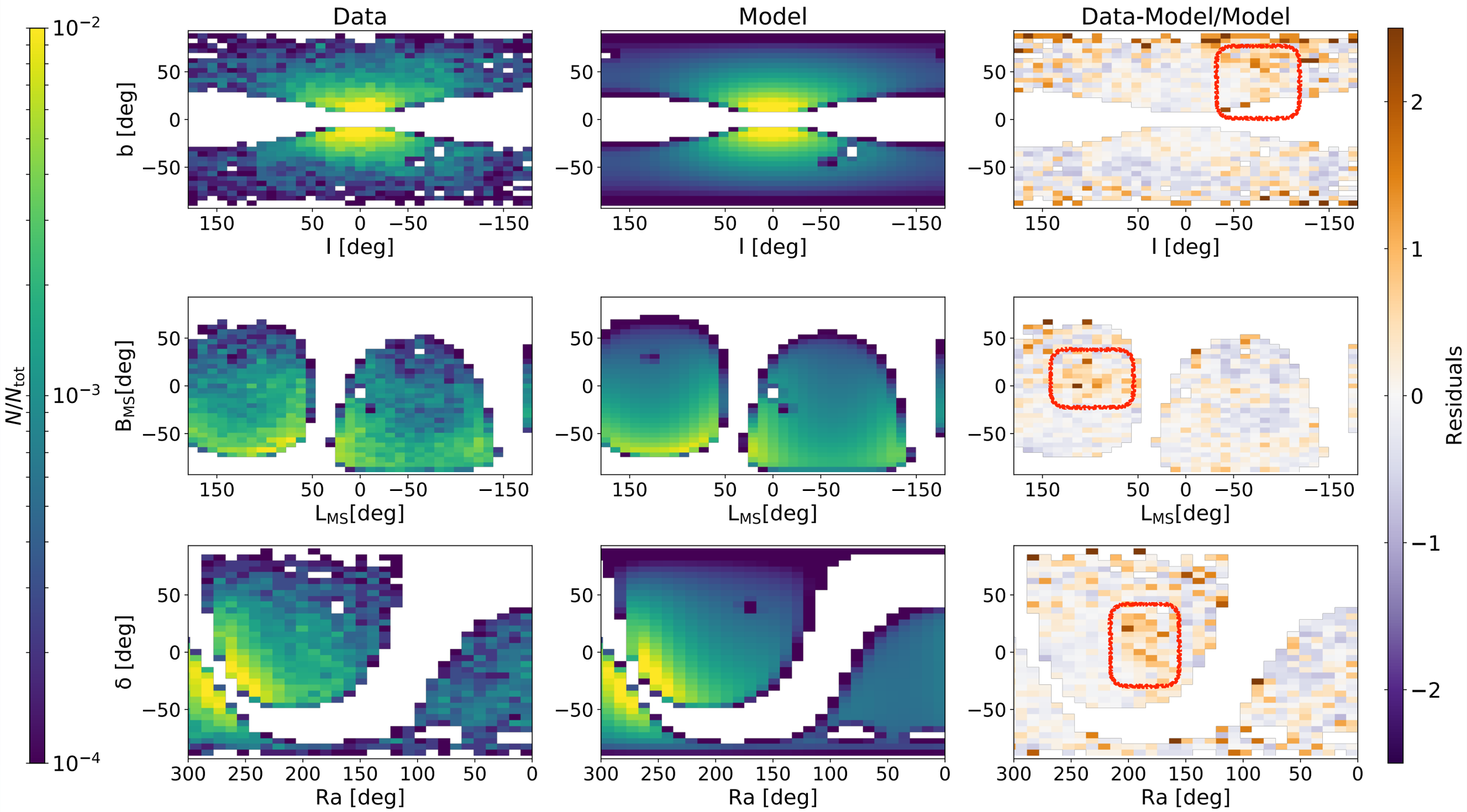
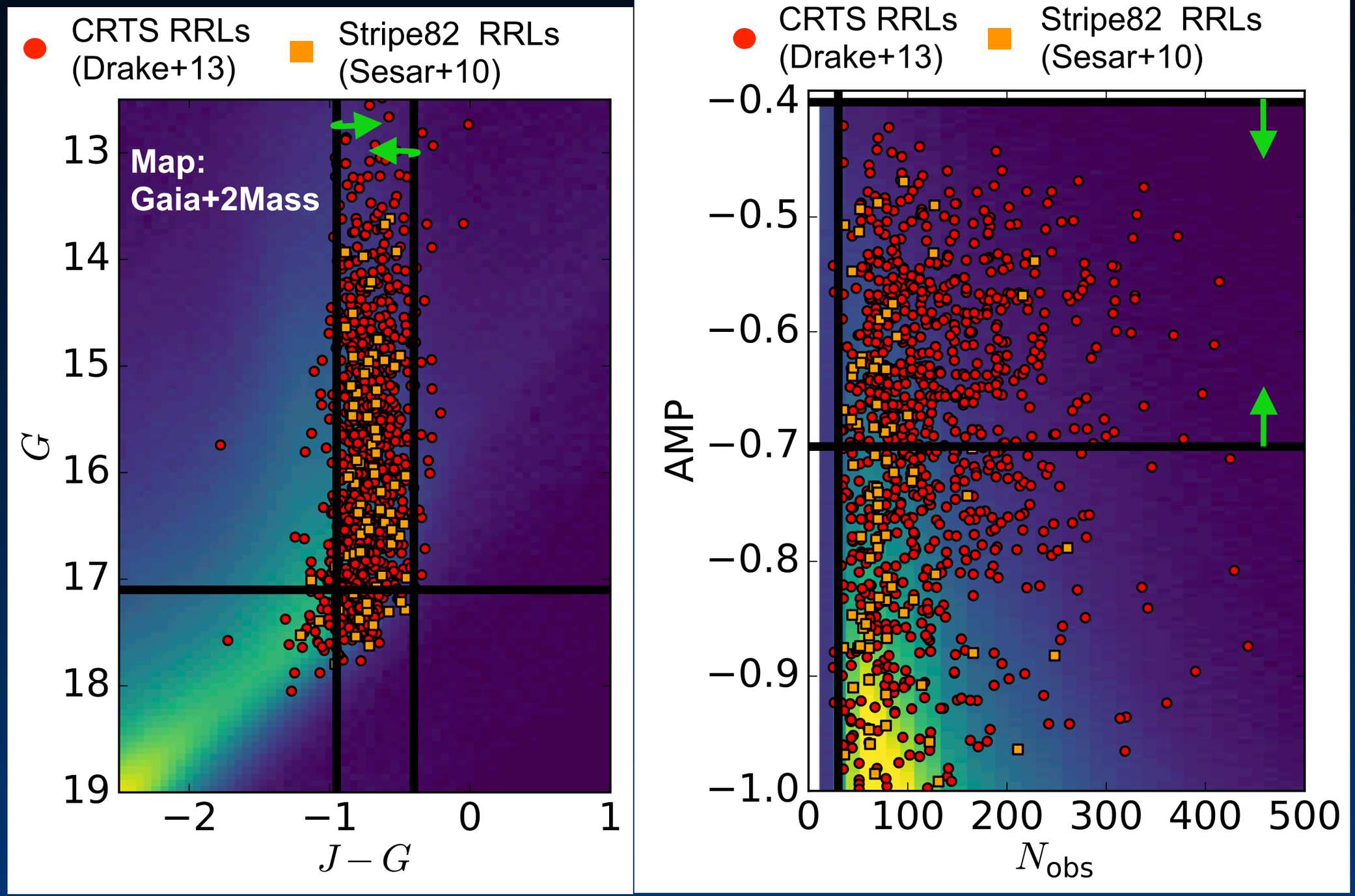
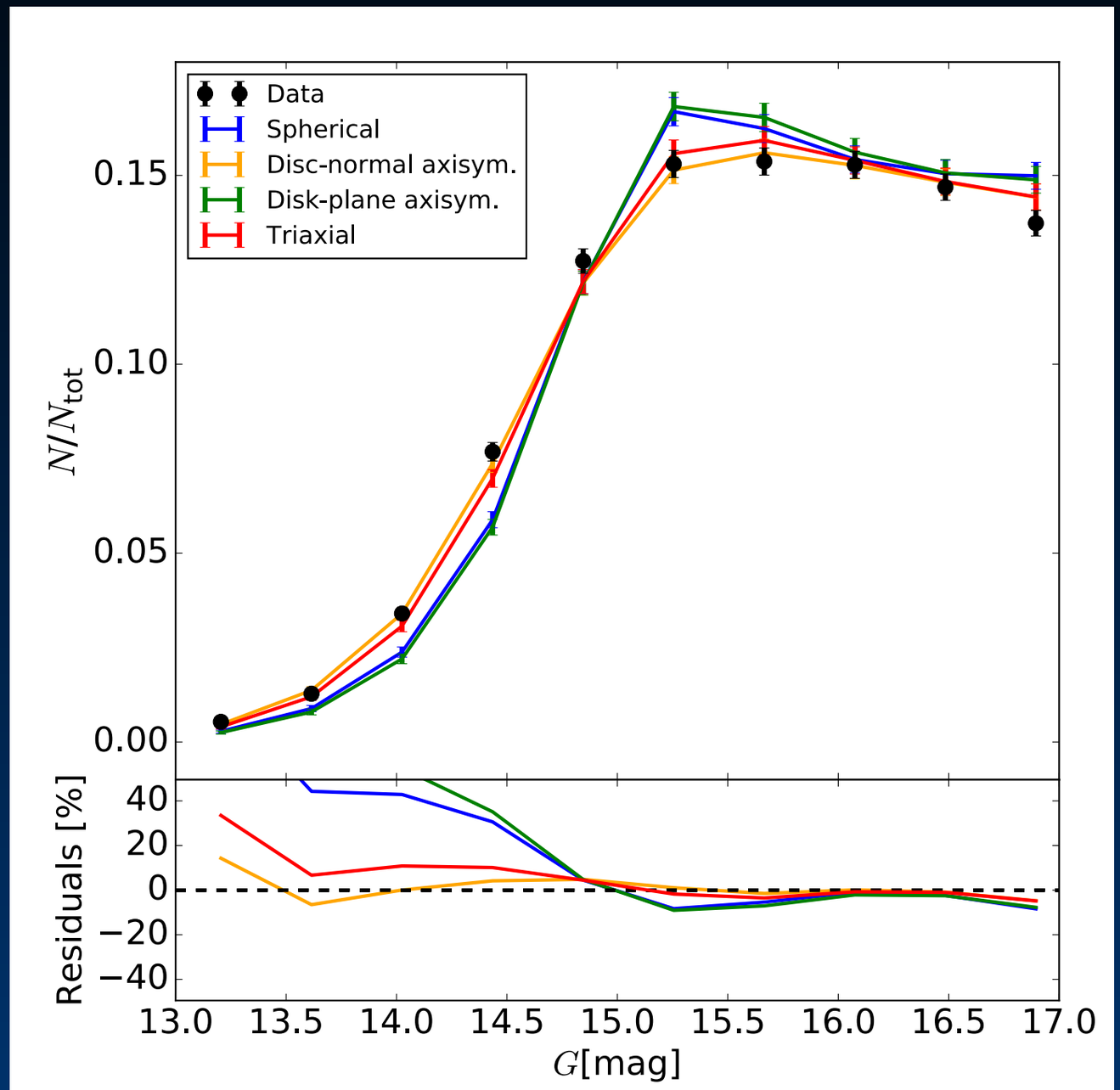


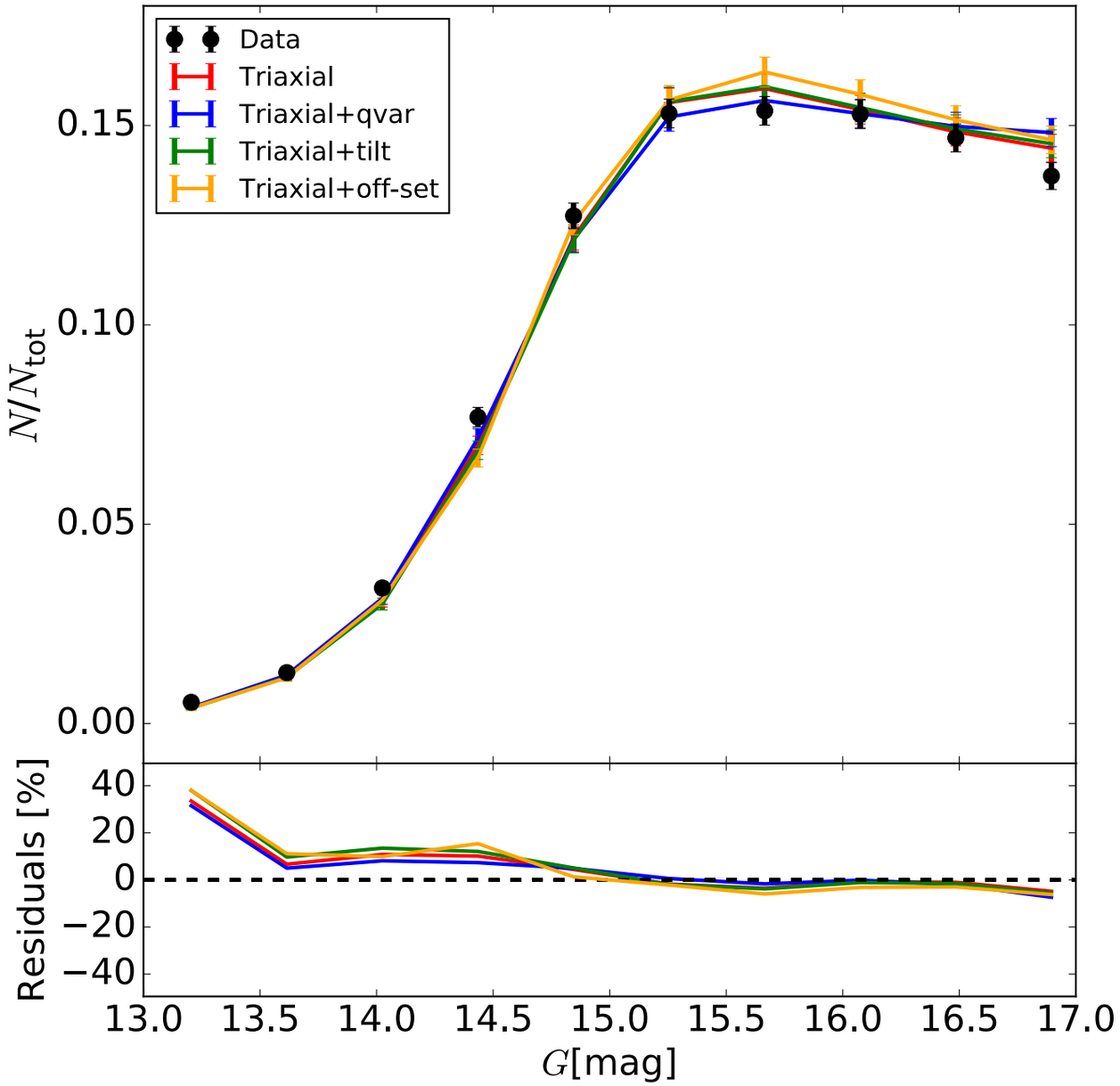
Iorio+17 (arXiv:1707.03833)

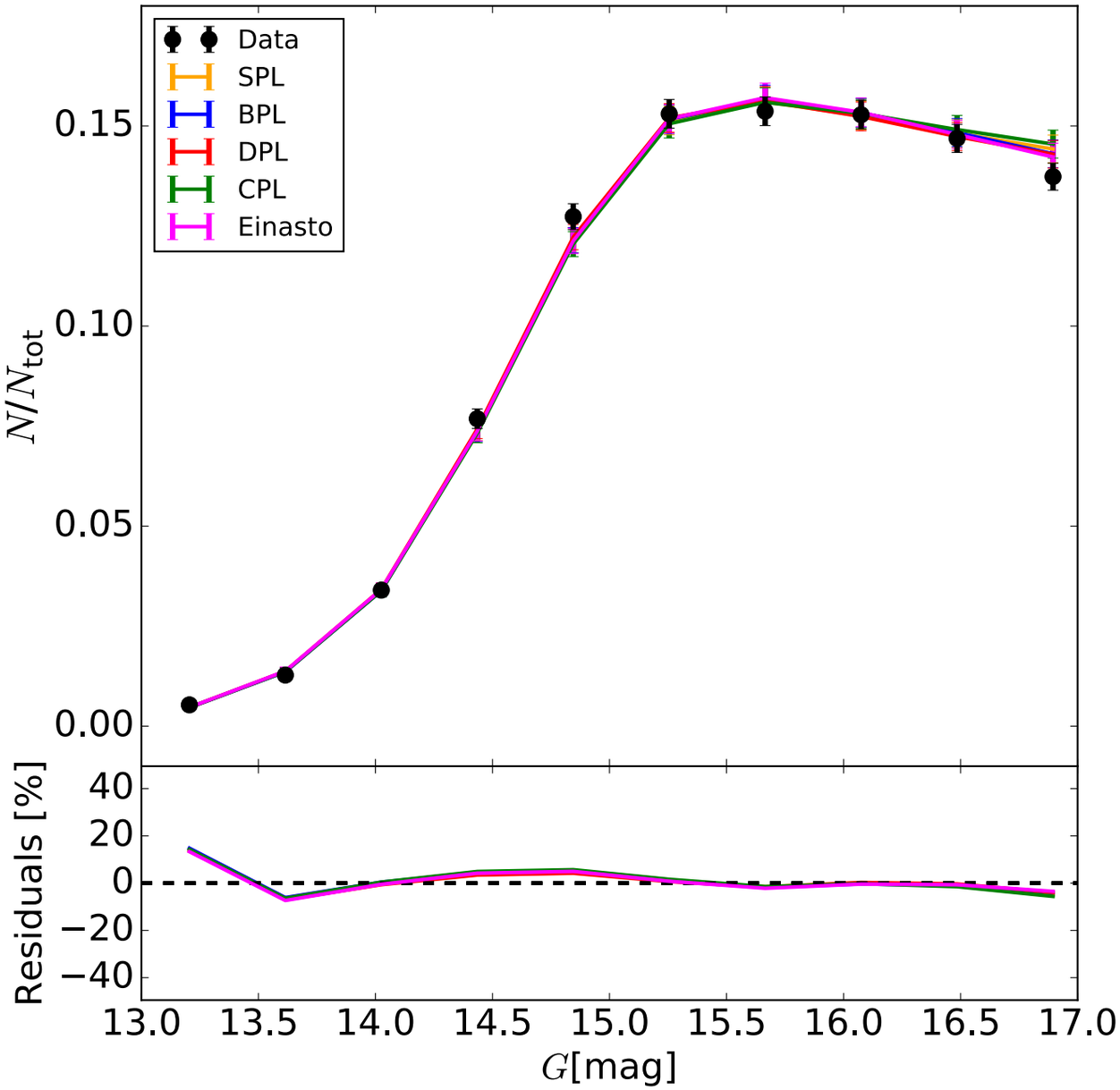

CRTS RRLs
(Drake+13)
Stripe82 RRLs
(Sesar+10)
Map:
Gaia+2Mass
G
J − G
13
14
15
16
17
18
19
−2
−1
0
1
CRTS RRLs
(Drake+13)
Stripe82 RRLs
(Sesar+10)
AMP
N_obs
−0.4
−0.5
−0.6
−0.7
−0.8
−0.9
−1.0
0
100
200
300
400
500

Exploring the Halo

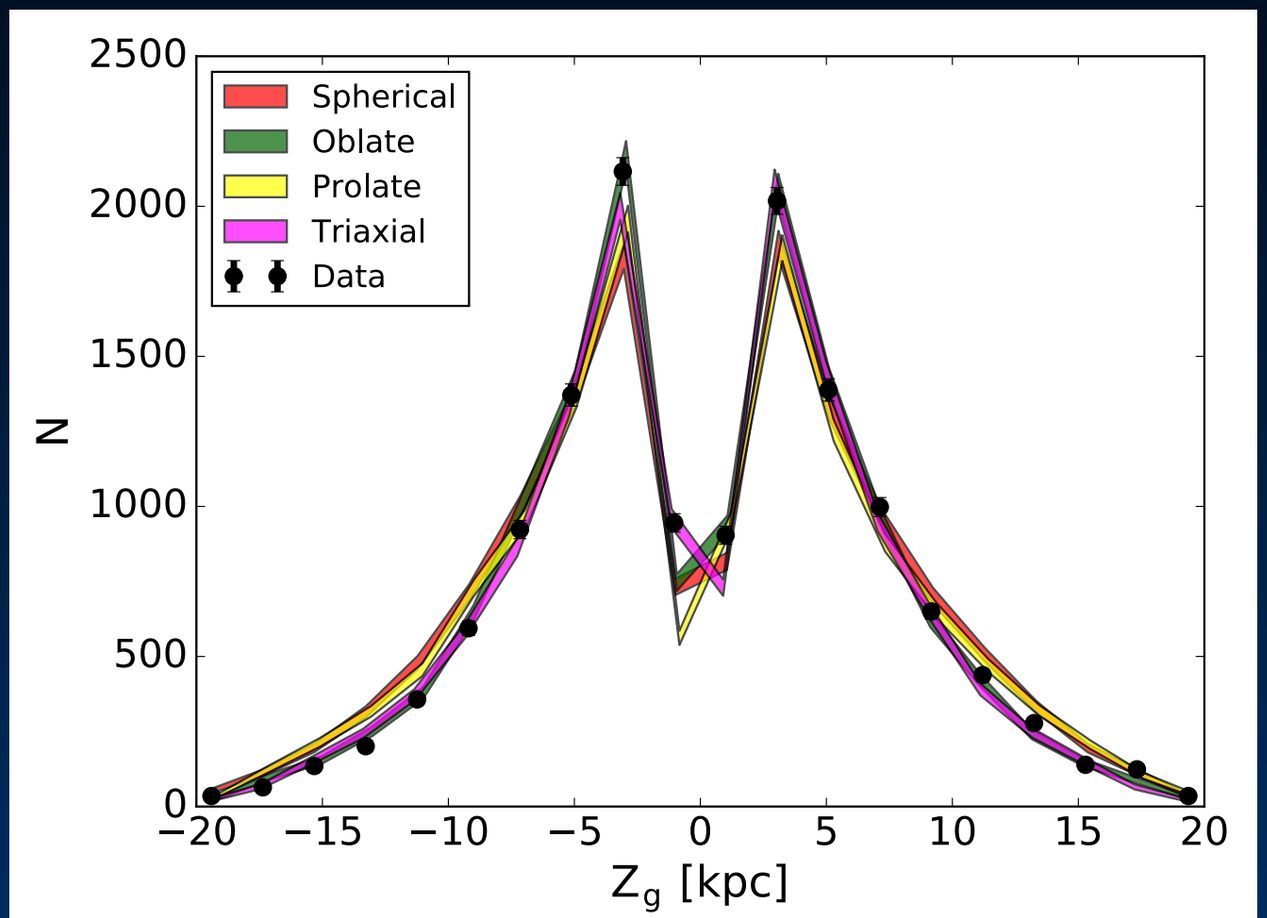


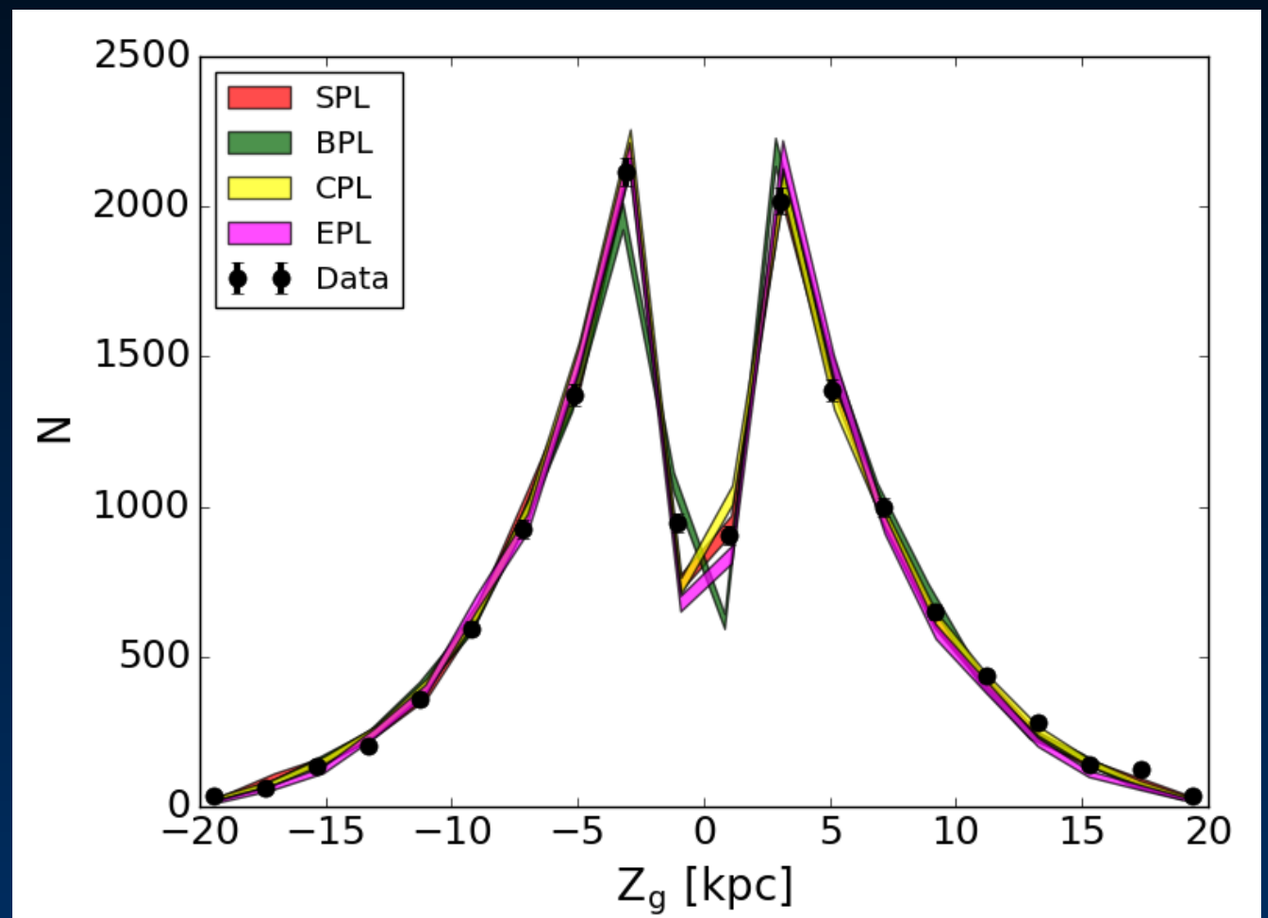
G distribution





Z distribution

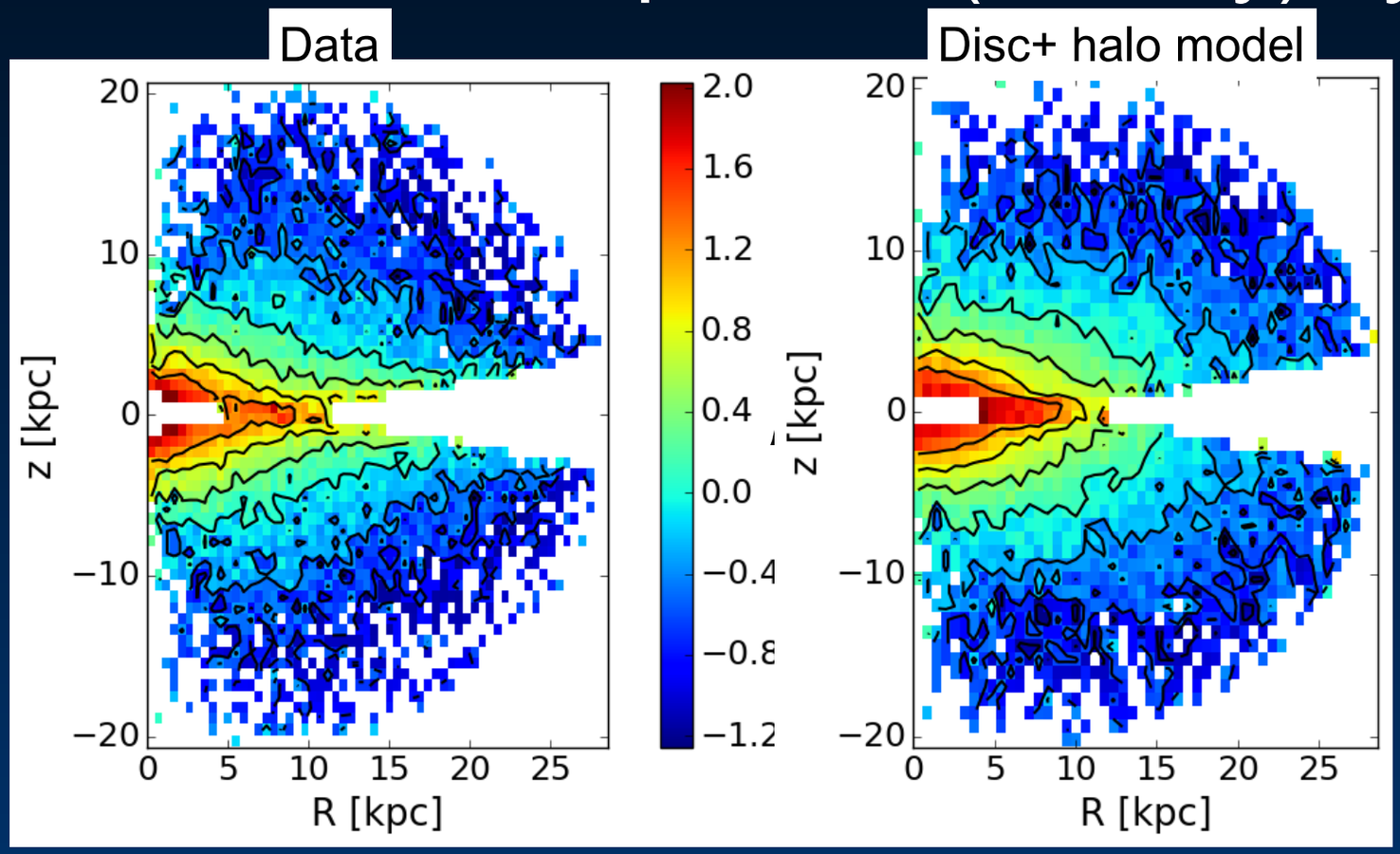


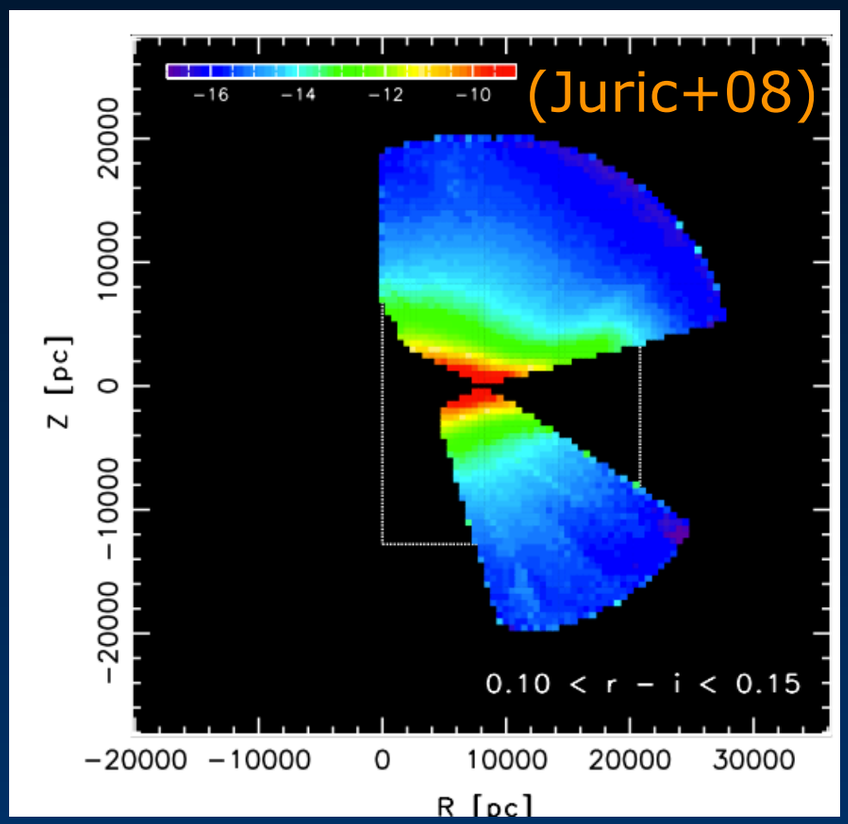


Structures

Structures - Low Latitude

- Extended disky feature
- It contains about half of RRLs in our sample
- It cannot be explained (entirely) by the Galactic disc





It could be Monoceros (e.g. Juric+08) or related to Gaia DR1 problems at low latitude

Structures

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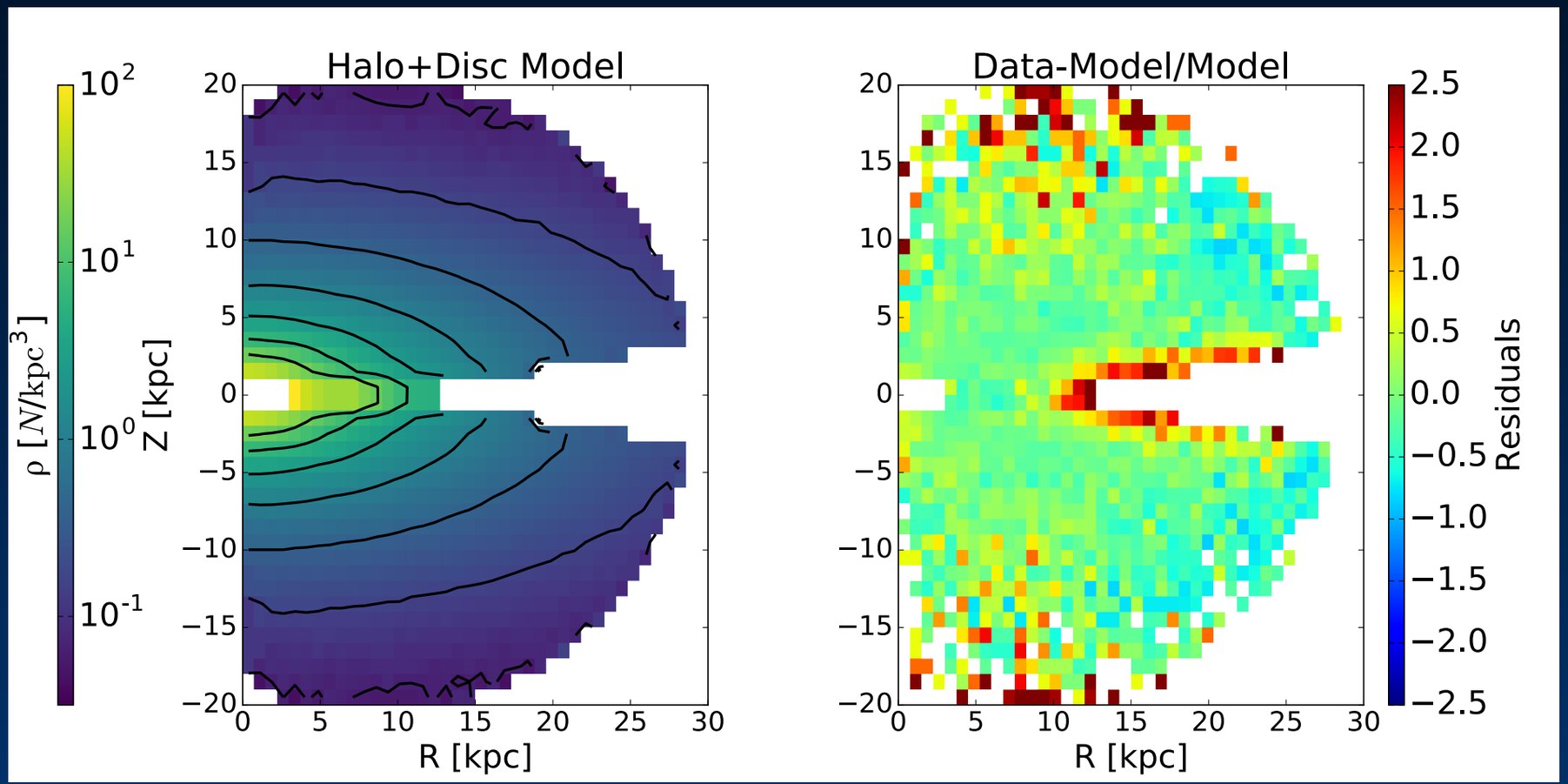

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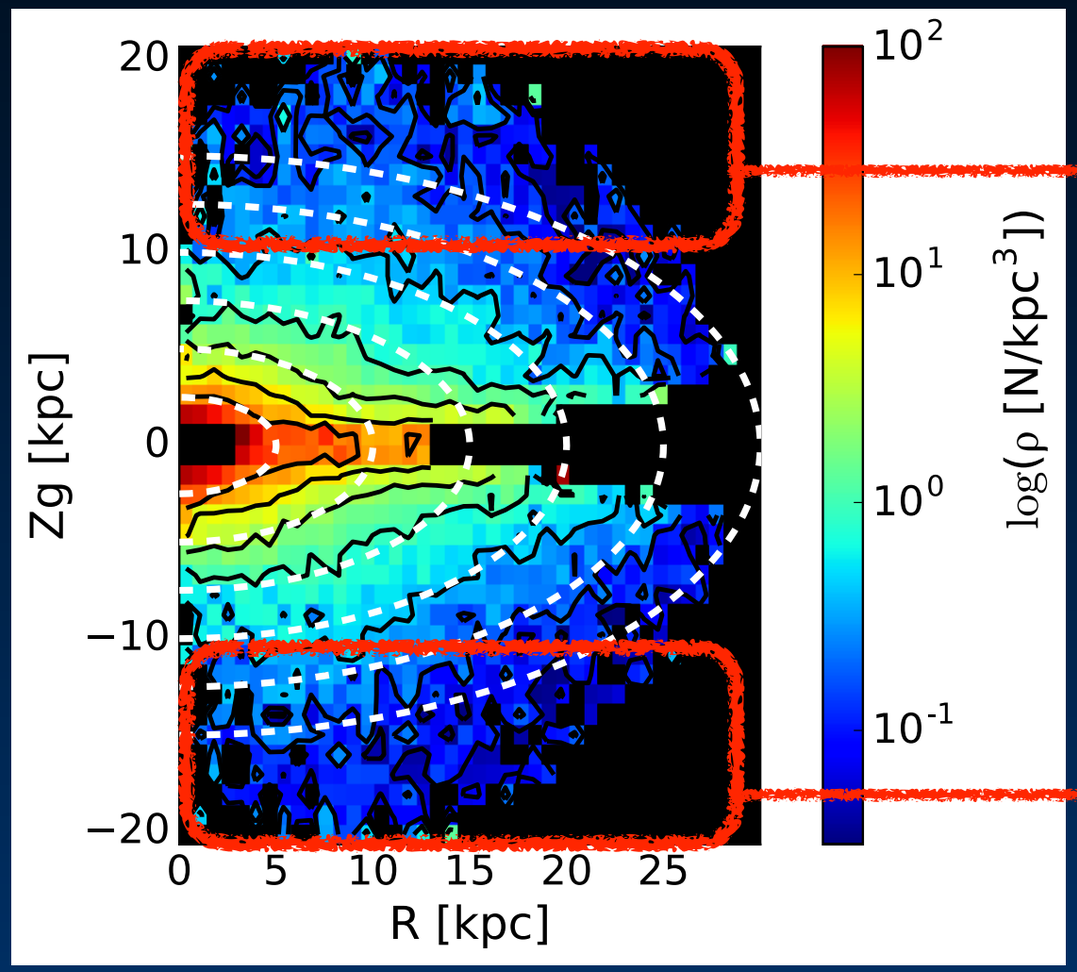
Structures

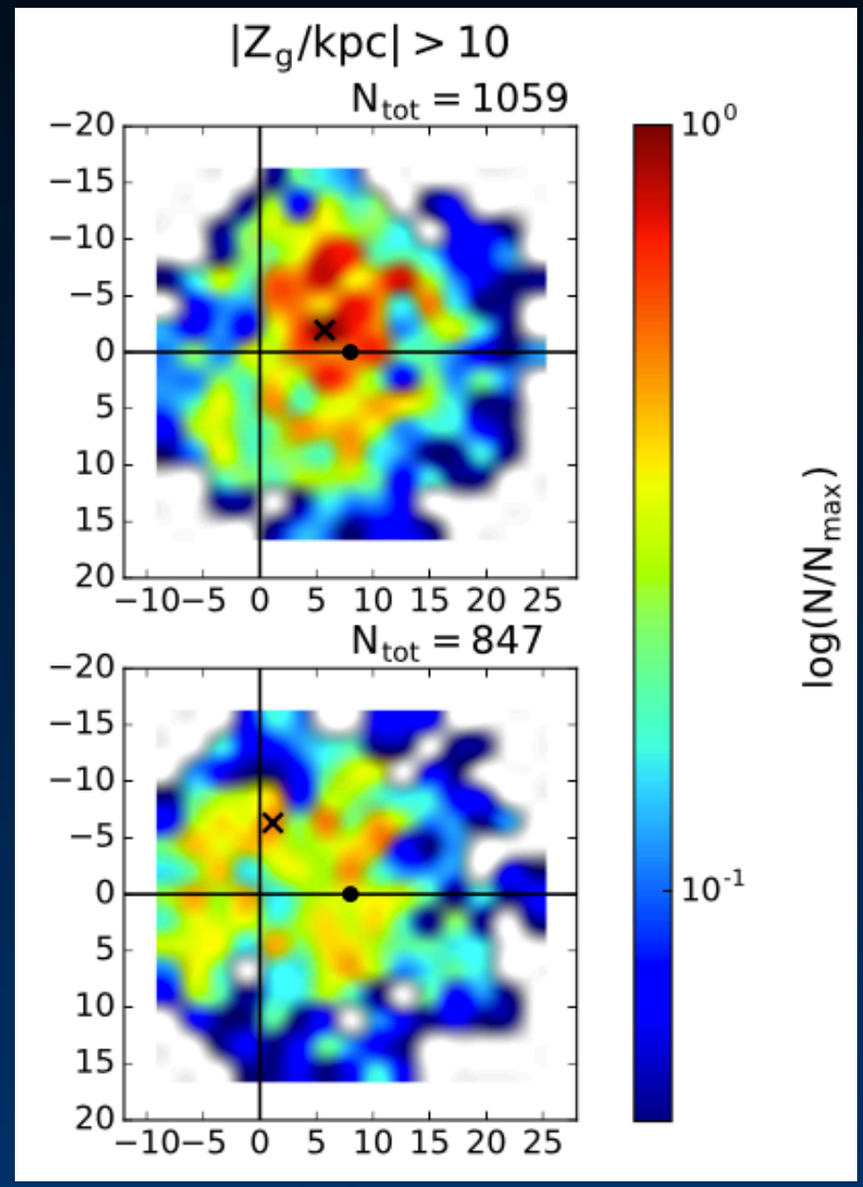
Structures - High Latitude

- Overdensity at very high-latitude



Yg

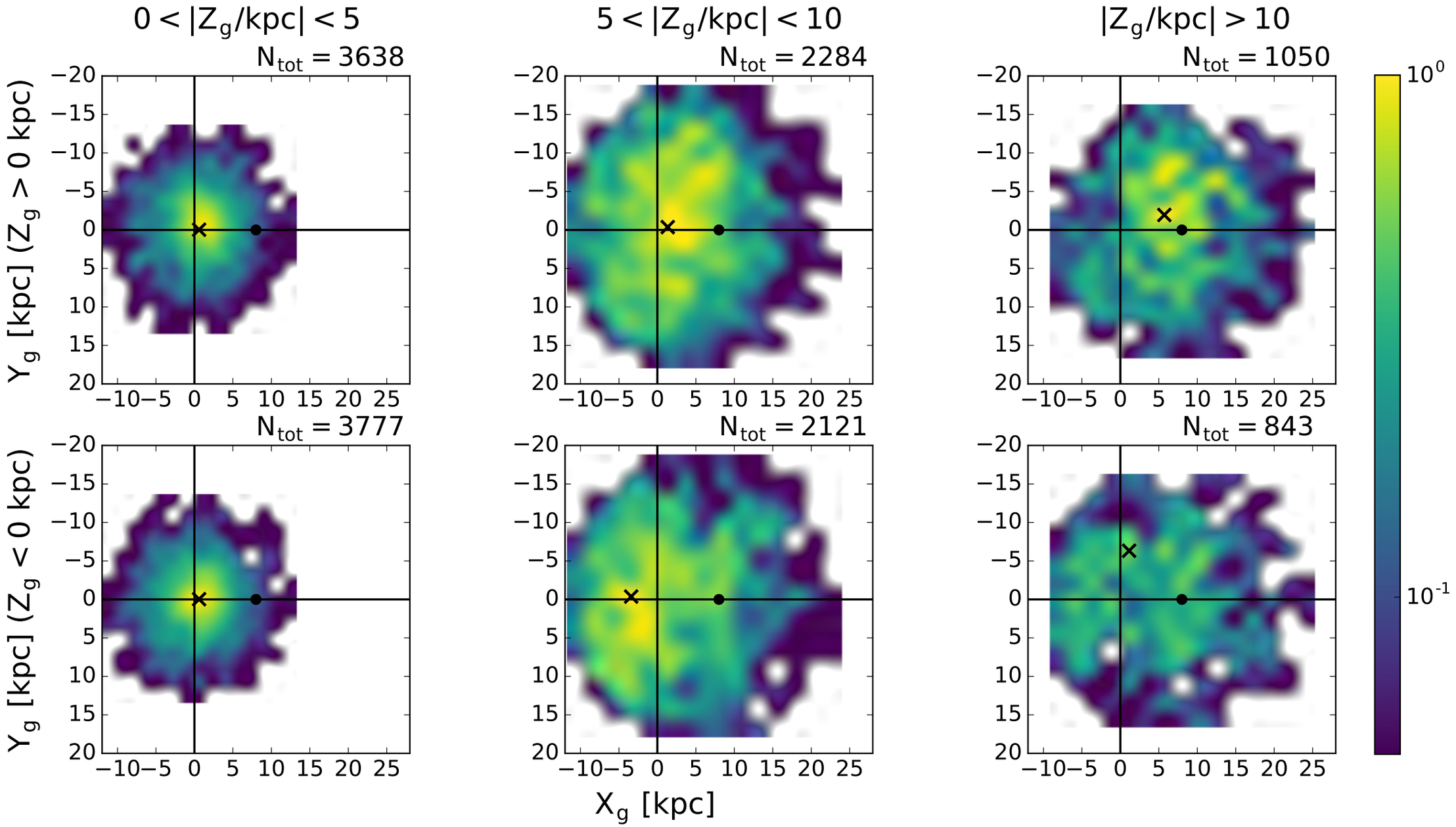
Yg



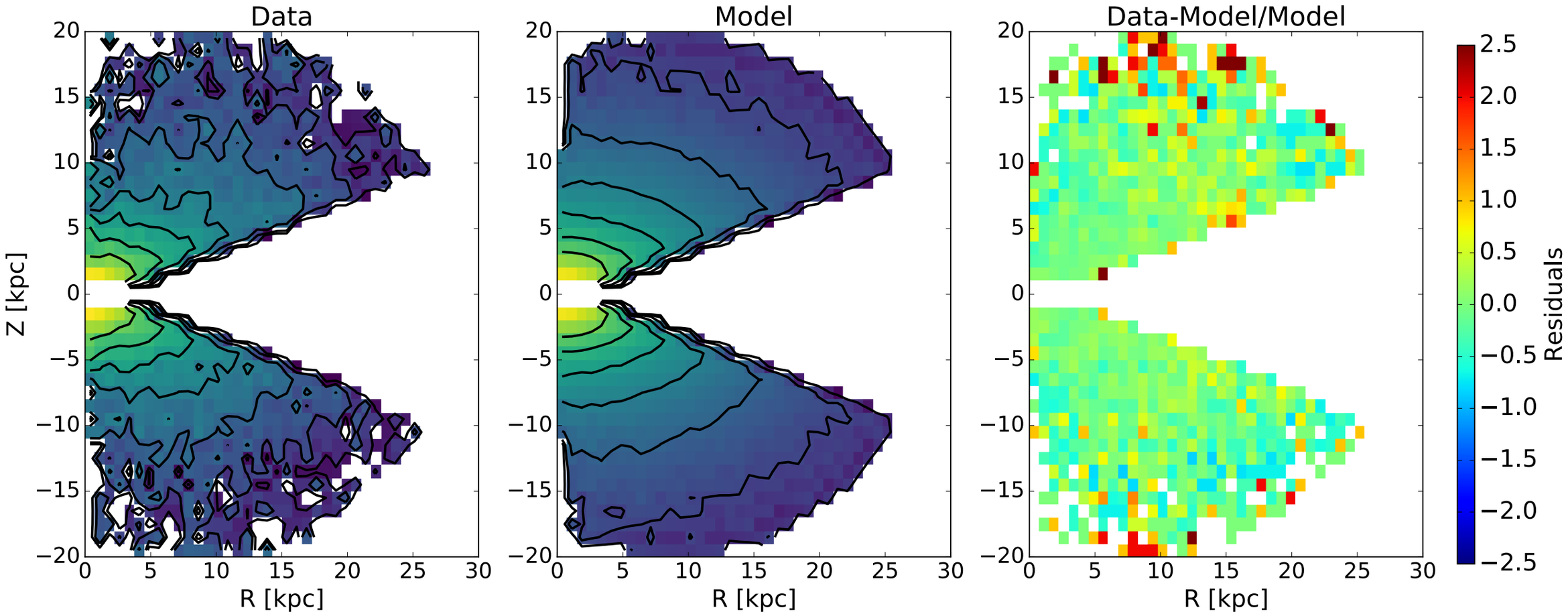
Xg

It is likely related to the Virgo Overdensity (Bell+08)

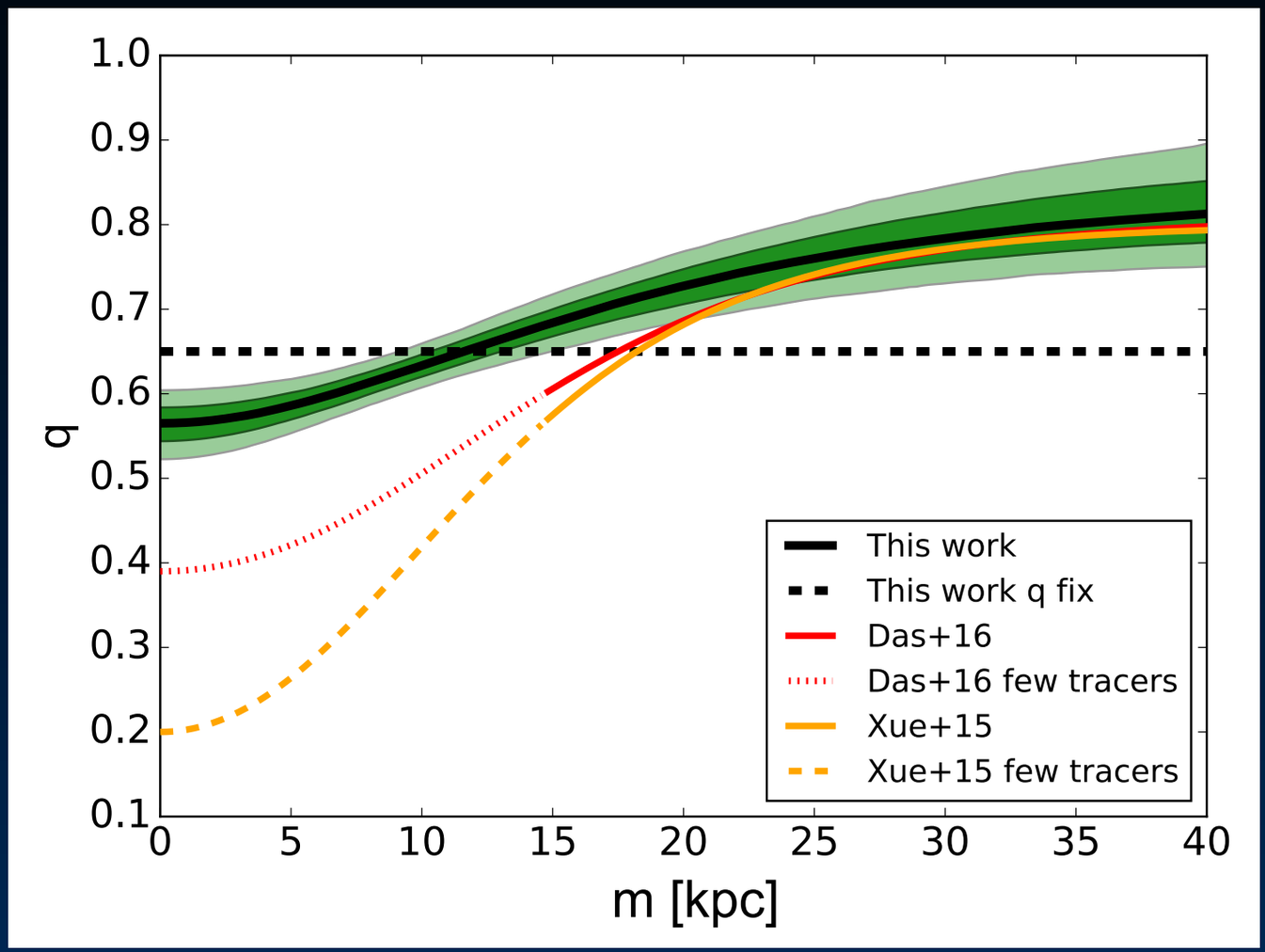
Z-Slab


0 < |Z_g/kpc| < 5
N_tot = 3638
5 < |Z_g/kpc| < 10
N_tot = 2284
|Z_g/kpc| > 10
N_tot = 1050
N_tot = 3777
N_tot = 2121
N_tot = 843
Y_g [kpc] (Z_g > 0 kpc)
Y_g [kpc] (Z_g < 0 kpc)
X_g [kpc]
10^0
10^-1
log(N/N_max)

Rz Residuals

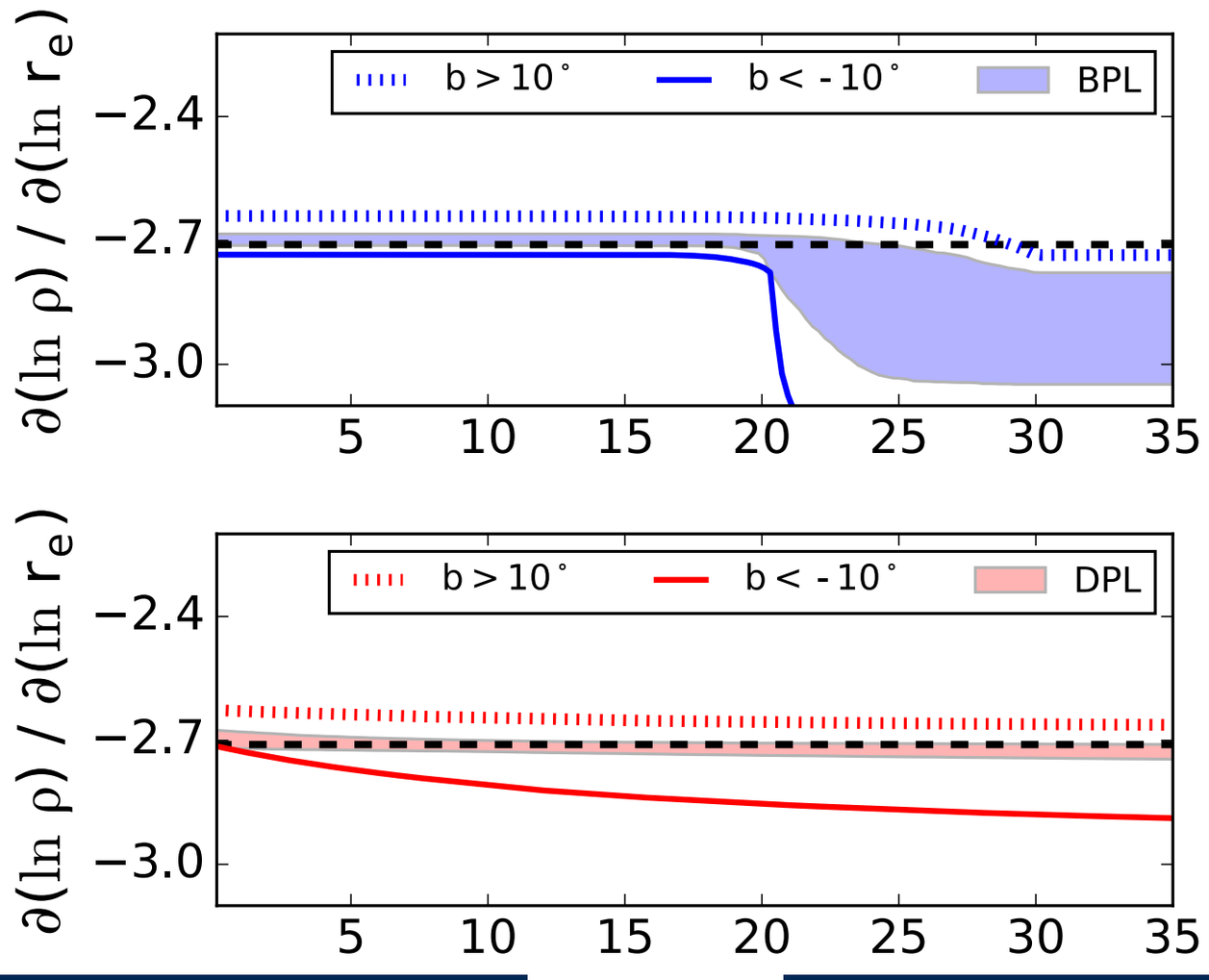


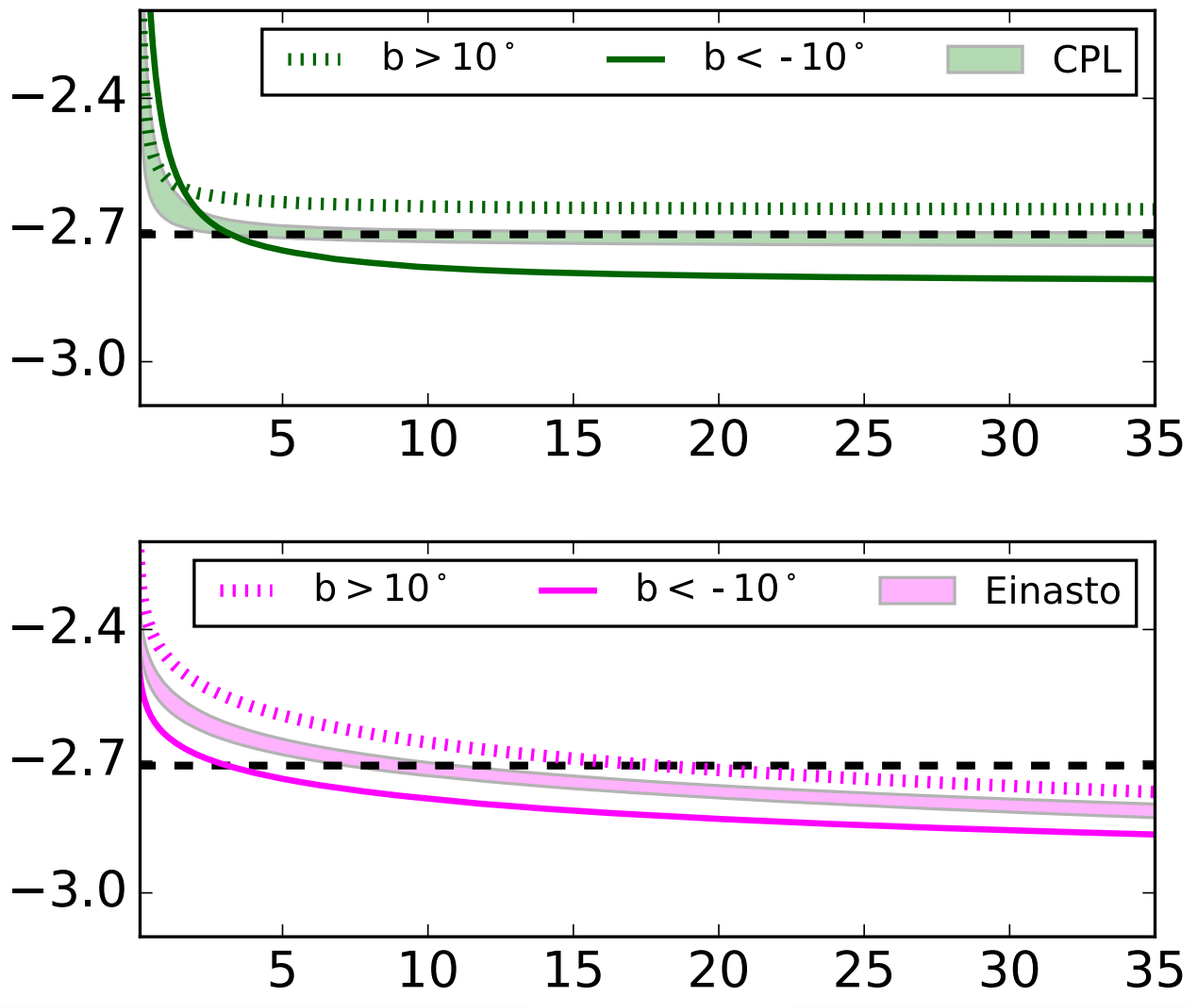
Flattening: previous works



$$q(r_e) = q_\infty - (q_\infty - q_0)\mathrm{Exp}\left[1 - \frac{\sqrt{r_e^2 + r_{eq}^2}}{r_{eq}^2}\right]$$

Dens models

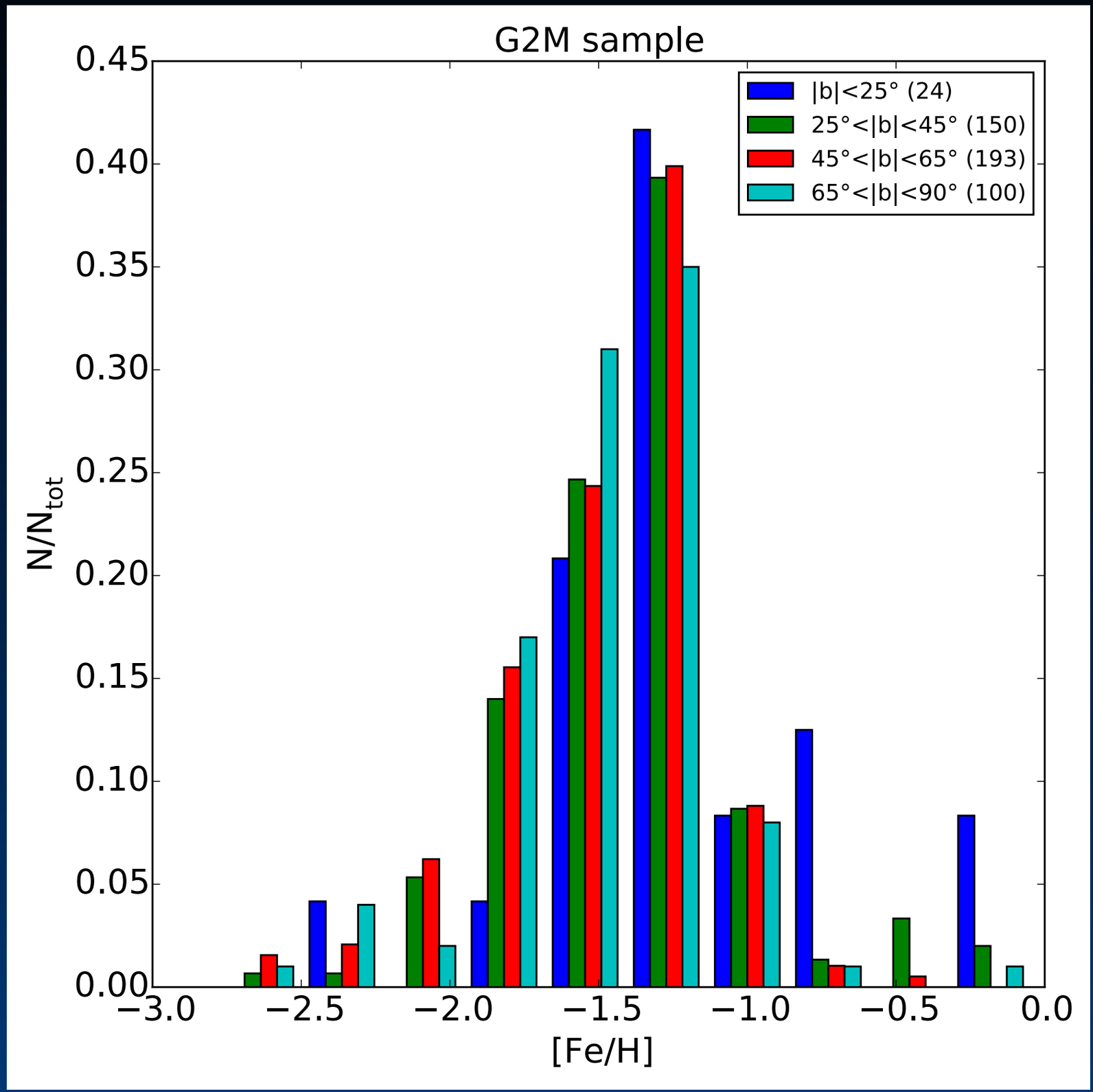

b > 10˚
b < -10˚
BPL
∂(ln ρ) / ∂(ln r_e)
−2.4
−2.7
−3.0
5
10
15
20
25
30
35


b > 10˚
b < -10˚
CPL
−2.4
−2.7
−3.0
5
10
15
20
25
30
35

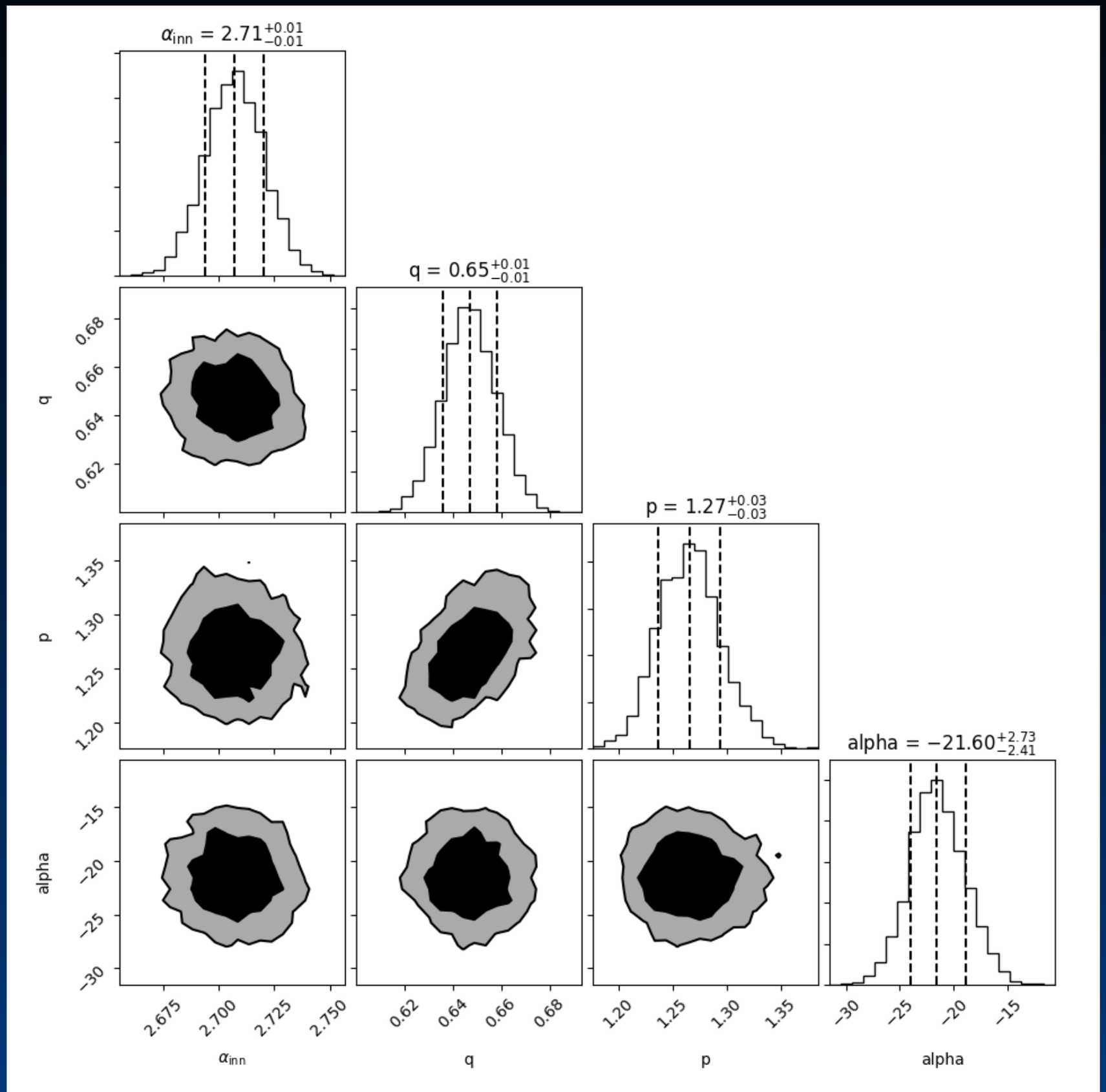
b > 10˚
b < -10˚
DPL
∂(ln ρ) / ∂(ln r_e)
−2.4
−2.7
−3.0
5
10
15
20
25
30
35
m [kpc]

b > 10˚
b < -10˚
Einasto
−2.4
−2.7
−3.0
5
10
15
20
25
30
35
m [kpc]

Metallicity distribution



Corner Plot


$\alpha_{inn} = 2.71^{+0.01}_{-0.01}$
q = $0.65^{+0.01}_{-0.01}$
p = $1.27^{+0.03}_{-0.03}$
alpha = $-21.60^{+2.73}_{-2.41}$
q
p
alpha
α_{inn}
0.62
0.64
0.66
0.68
1.20
1.25
1.30
1.35
2.675
2.700
2.725
2.750
−15
−20
−25
−30