Hypervelocity stars and the LMC

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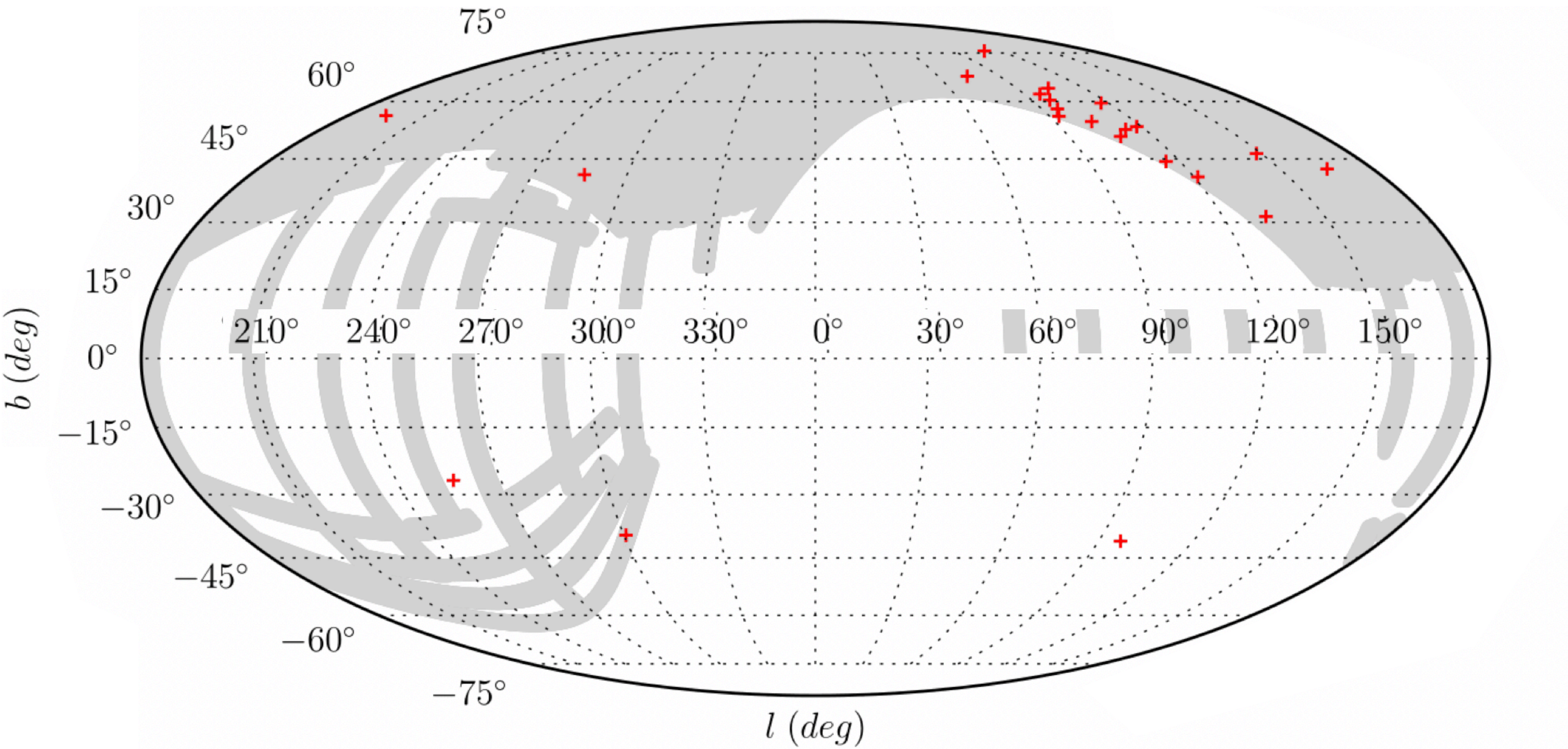
Outline

- HVS3 - A hypervelocity star from the LMC
- The effect of the LMC on the Milky Way
- The effect of the LMC on hypervelocity stars

HVS orbits with Gaia DR2

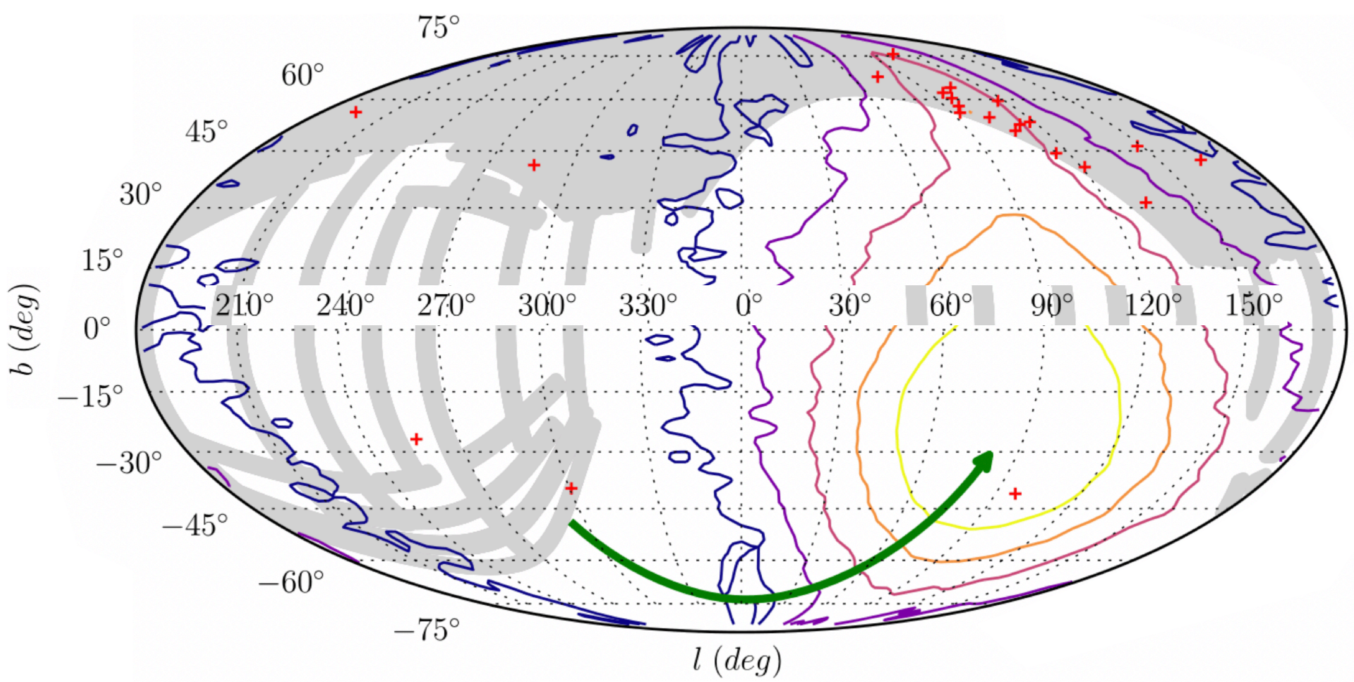
Hypervelocity stars are anisotropic

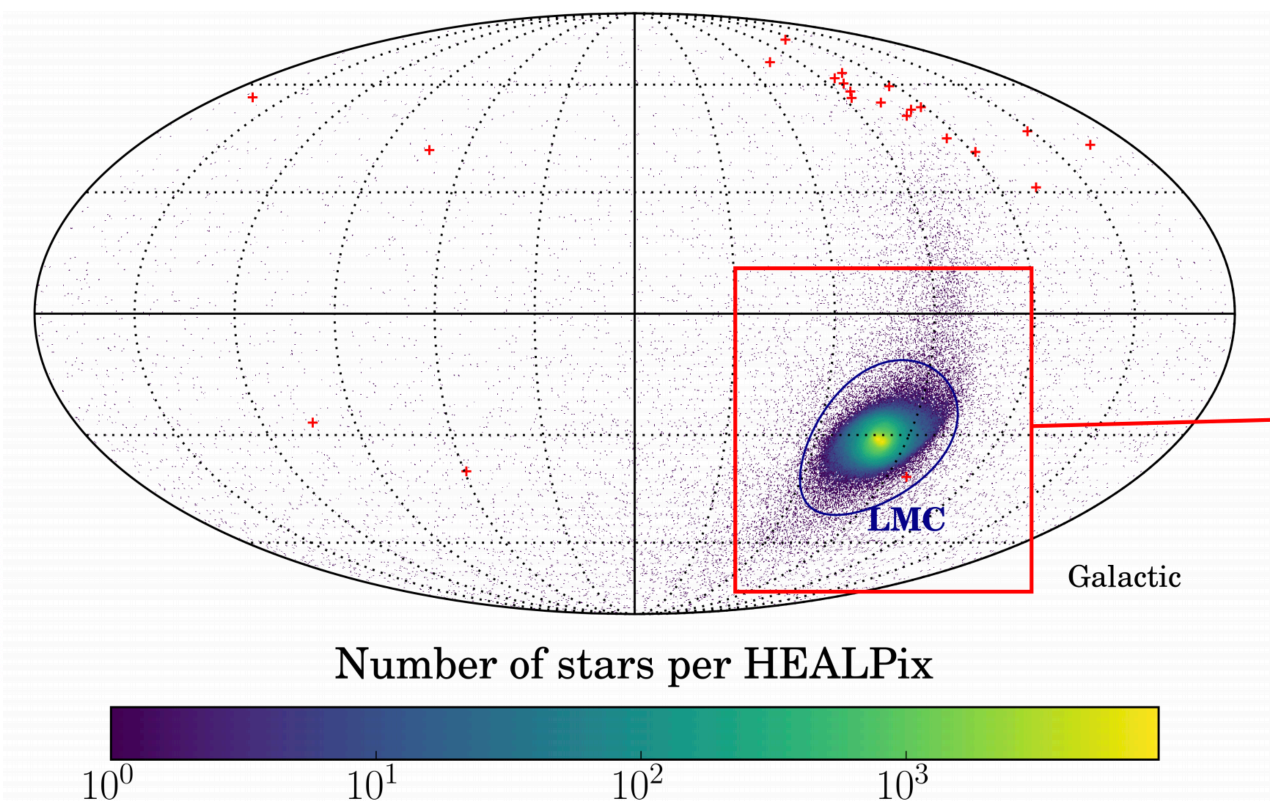


HVS orbits with Gaia DR2

Hills mechanism from LMC

Runaway stars from LMC



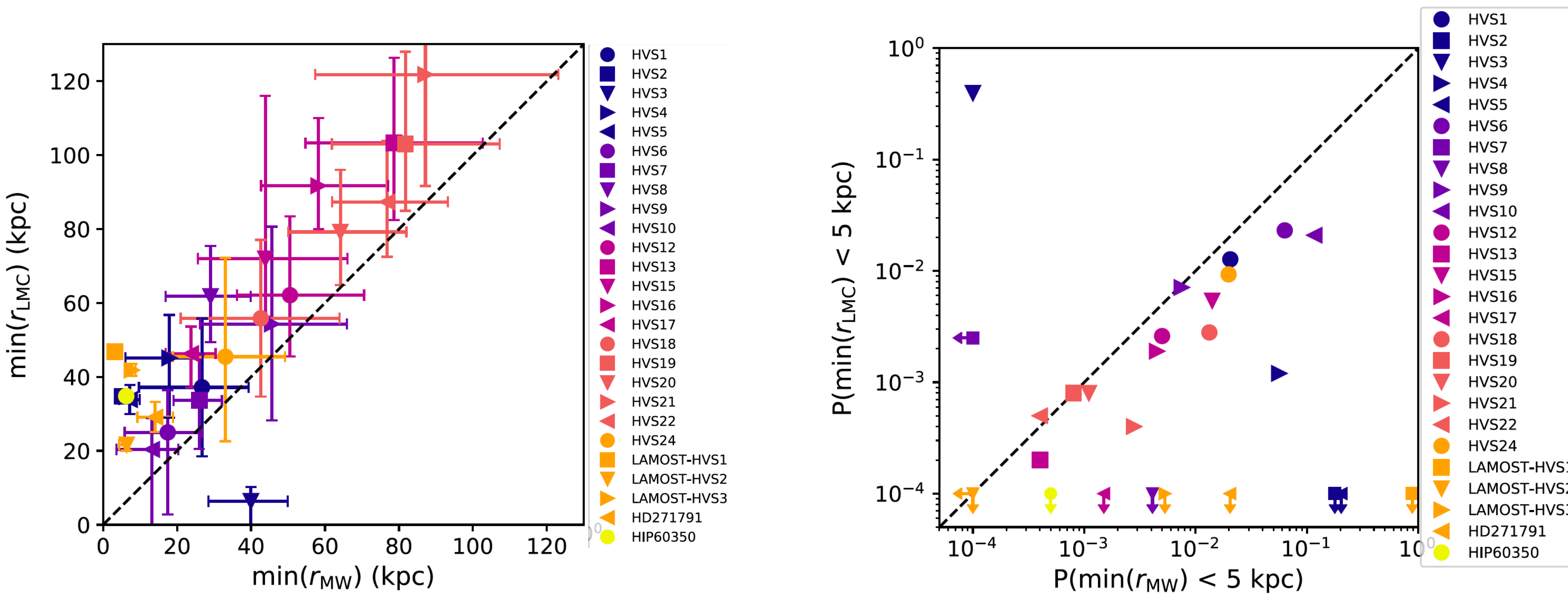


Boubert & Evans 2016

Boubert, Erkal et al. 2017

HVS orbits with Gaia DR2

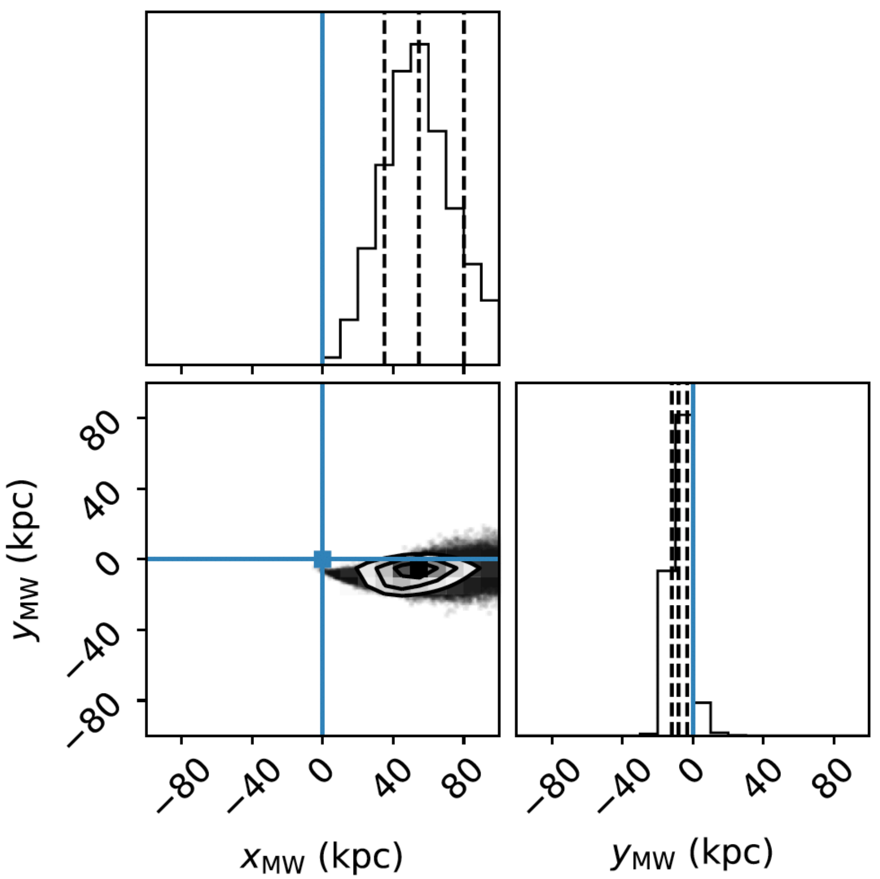
- Integrate orbits back in combined presence of Milky Way and LMC

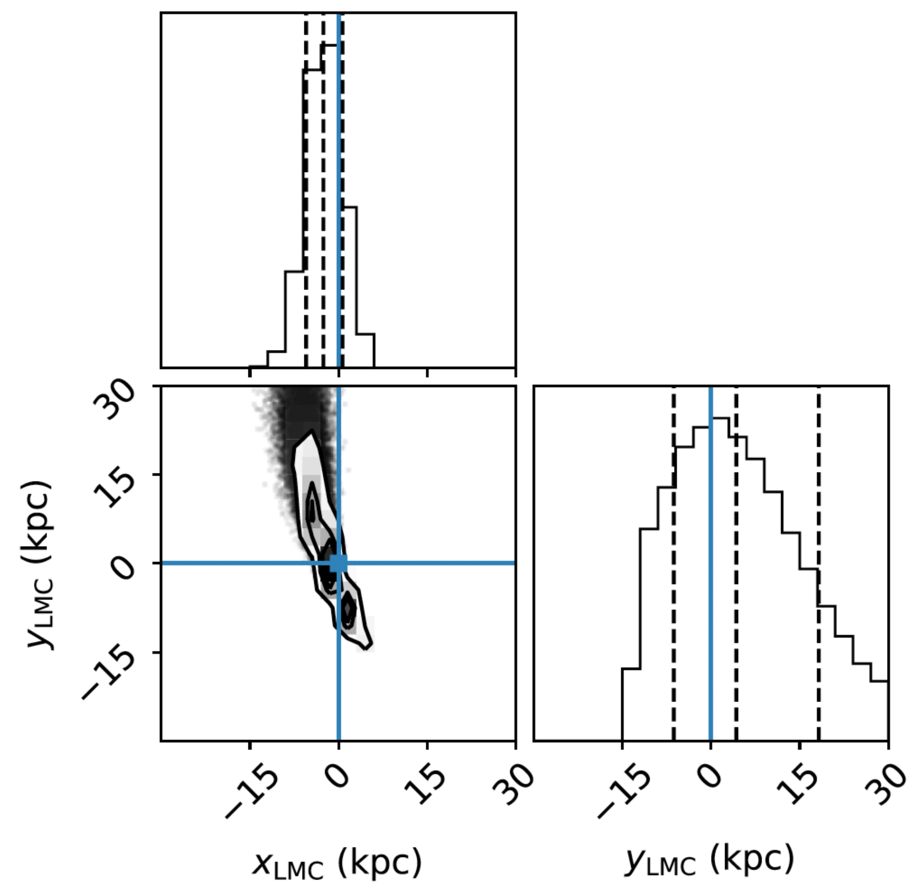


Erkal et al. 2019a

HVS3

- Check passage through Milky Way plane and LMC plane
- Consistent with origin in the very inner part of the LMC

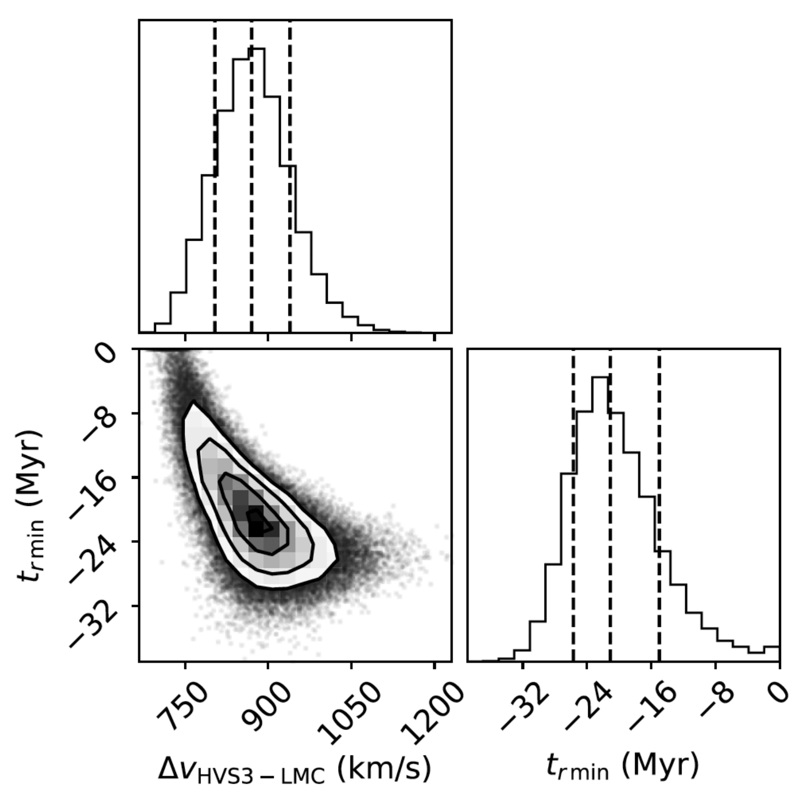




Edelmann et al. 2005, Gualandris & Portegies Zwart 2007, Brown et al. 2010, Brown et al. 2015

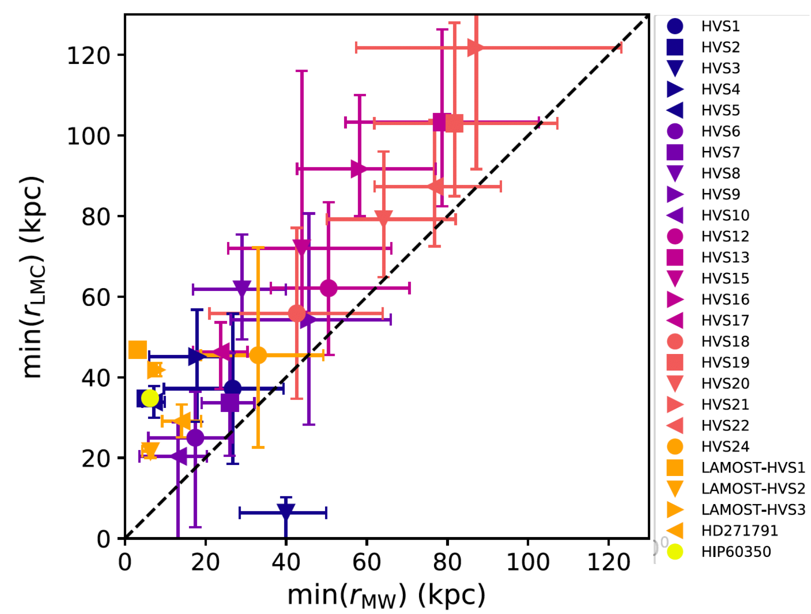
HVS3

- ~8 $M_\odot$ star (lifetime ~35 Myr)
- ~870 km/s ejection velocity, 21.1 Myr flight time
- Need a 4×10^3 - 10^4 $M_\odot$ blackhole in LMC to eject this
- Too fast to be a runaway, even with LMC disk rotation

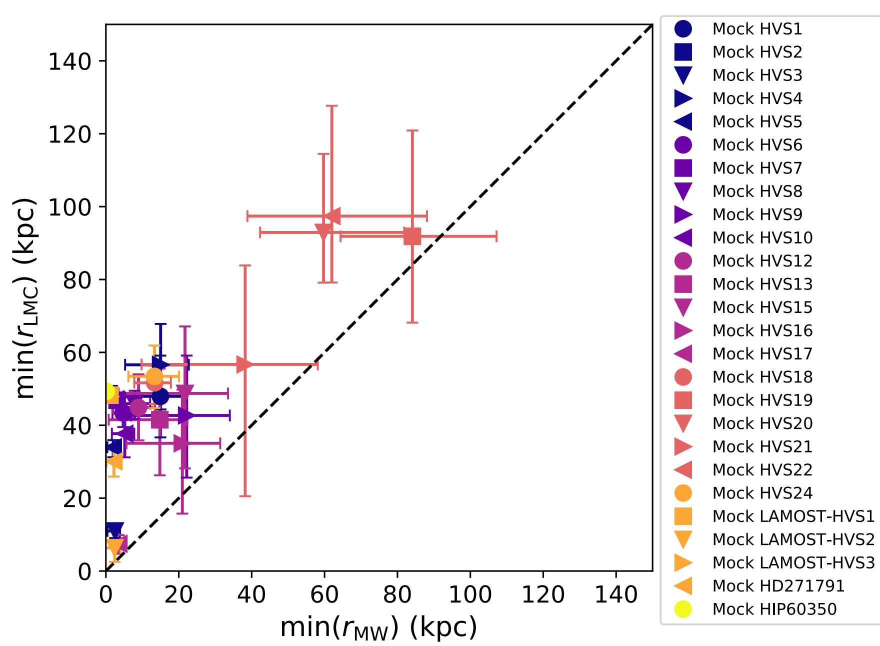


HVS3 - mock tests

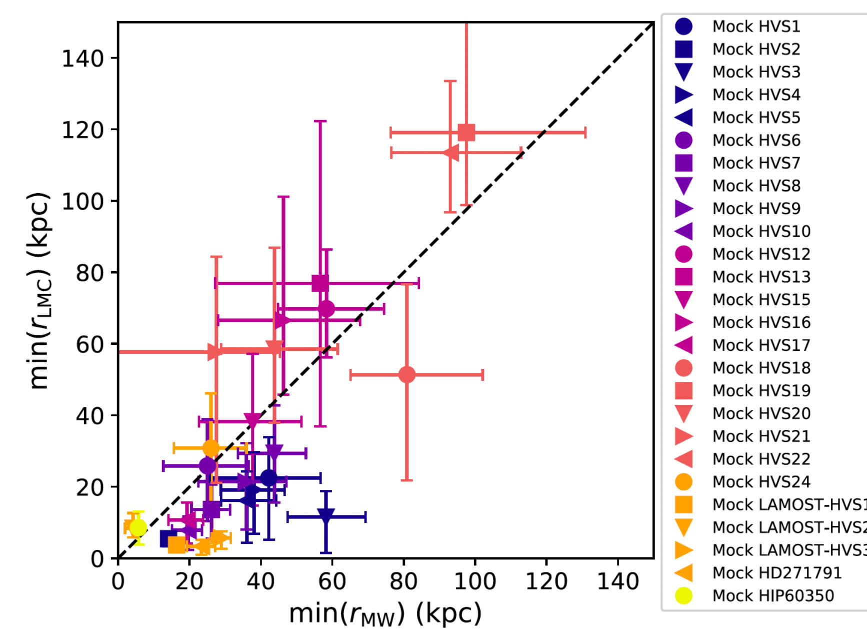
Gaia DR2 orbits



Mocks from MW



Mocks from LMC



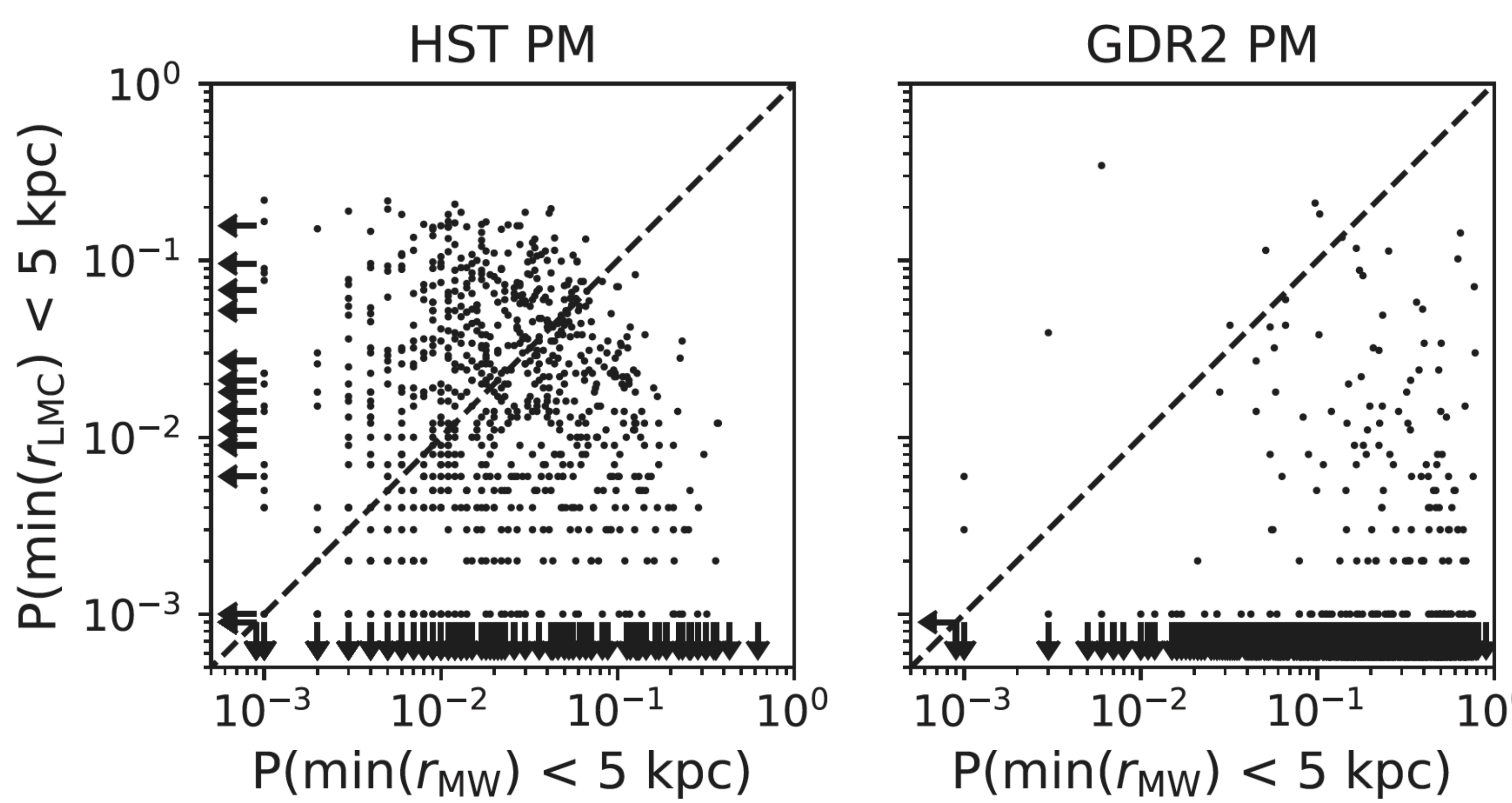
Most of these HVSs do not come from the LMC

Other LMC HVSs: Hattori et al. 2018

HVS3 - mock tests

- Gaia DR2 accuracy was critical for understanding HVS3
- High misclassification probability with HST proper motions (Brown et al. 2015)
- With Gaia DR2, only ~1/1000

Mocks from MW



Outline

- HVS3 - A hypervelocity star from the LMC
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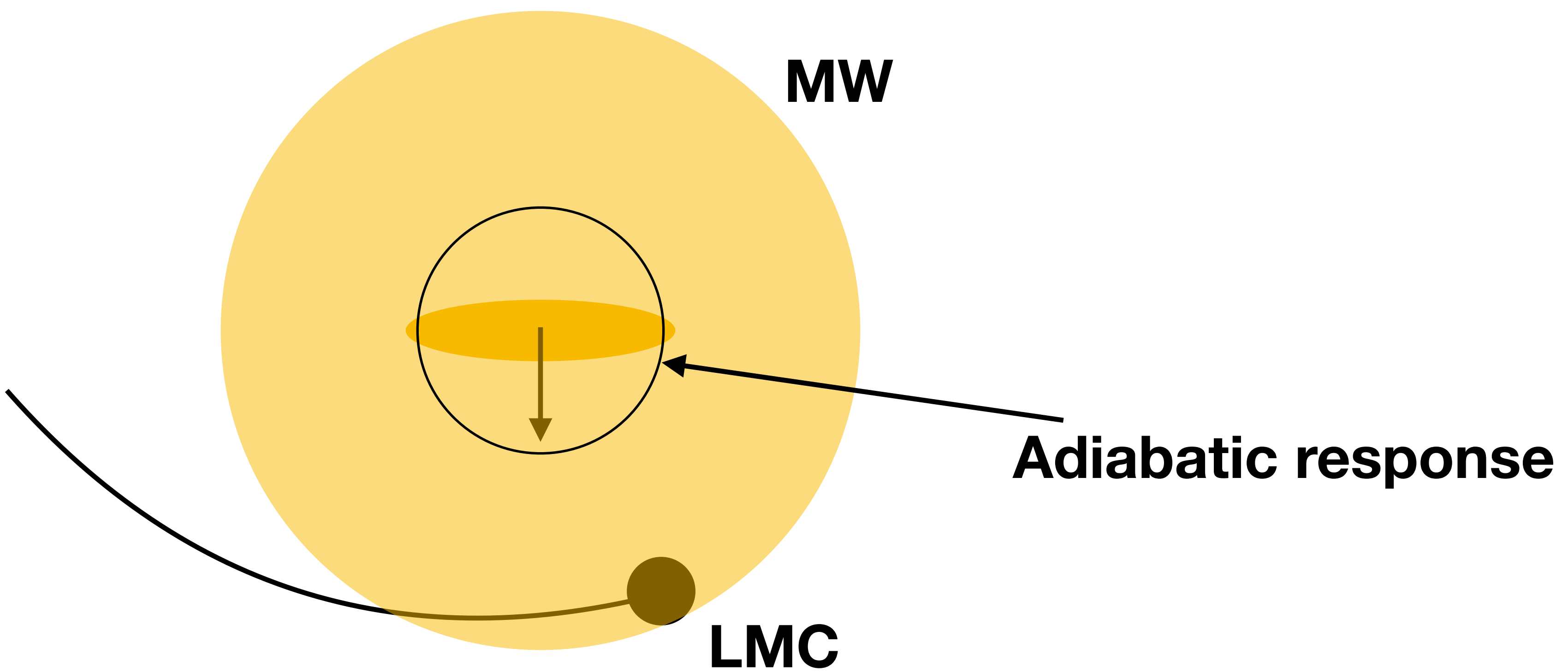
Effect of the LMC on the Milky Way

- The LMC is massive:
  - Believed to be on first infall with SMC (Kallivayalil et al. 2013): **M_{LMC} >~ 10^{11} $M_\odot$**
  - Affects timing argument with M31, nearby Hubble flow (Penarrubia et al. 2016): **$M_{LMC} = 2.5 \times 10^{11}\ M_\odot$**
  - Deflects tidal streams around the Milky Way (Erkal et al. 2019b): **$M_{LMC} = 1.4 \times 10^{11}\ M_\odot$**
  - Group infall with 7 dwarf satellites suggests large LMC mass (Erkal & Belokurov 2019): **$M_{LMC} > 1.2 \times 10^{11}\ M_\odot$**

Effect of the LMC on the Milky Way

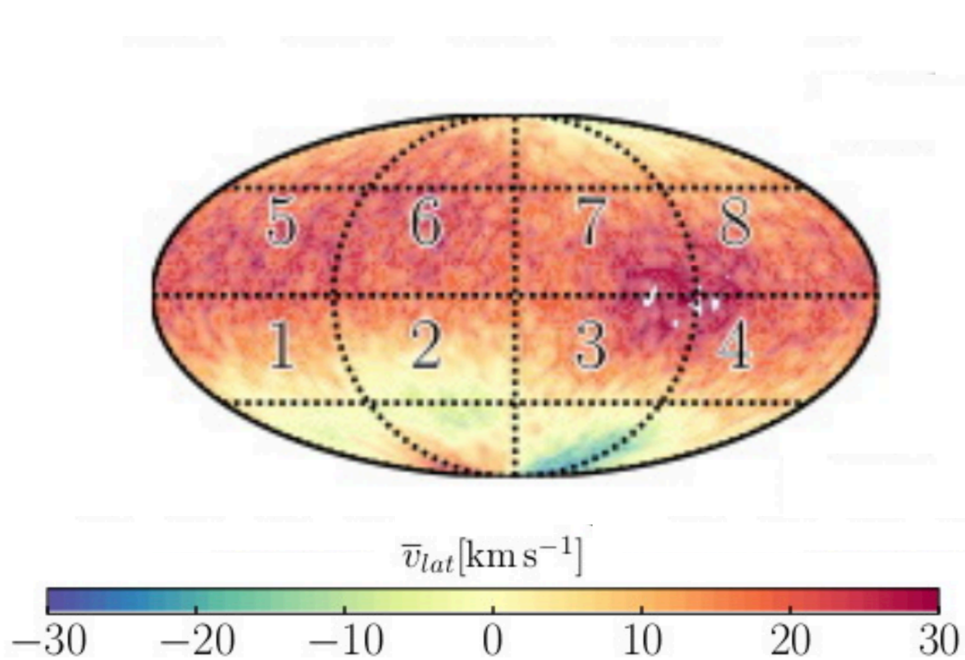


1) LMC pulls the inner part of the Milky Way down
2) LMC effect is weaker in the outer parts of the Milky Way
3) LMC directly affects stars on its past orbit

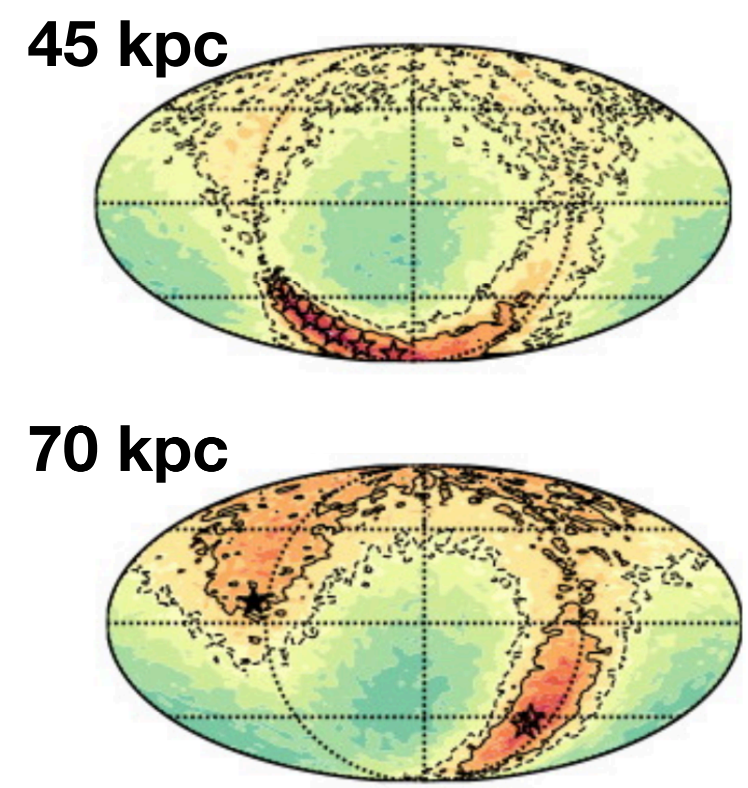
Effect of the LMC on the Milky Way

- This means the outer parts of the Milky Way will roughly be moving upwards relative to us

Predicted upward motion of stellar halo



Wake behind LMC

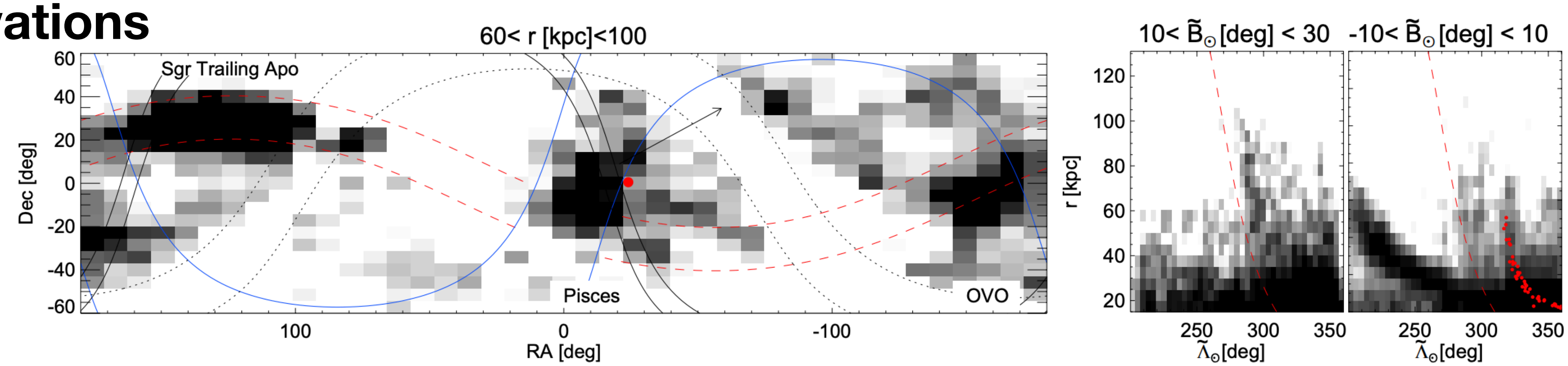


Garavito-Camargo et al. 2019

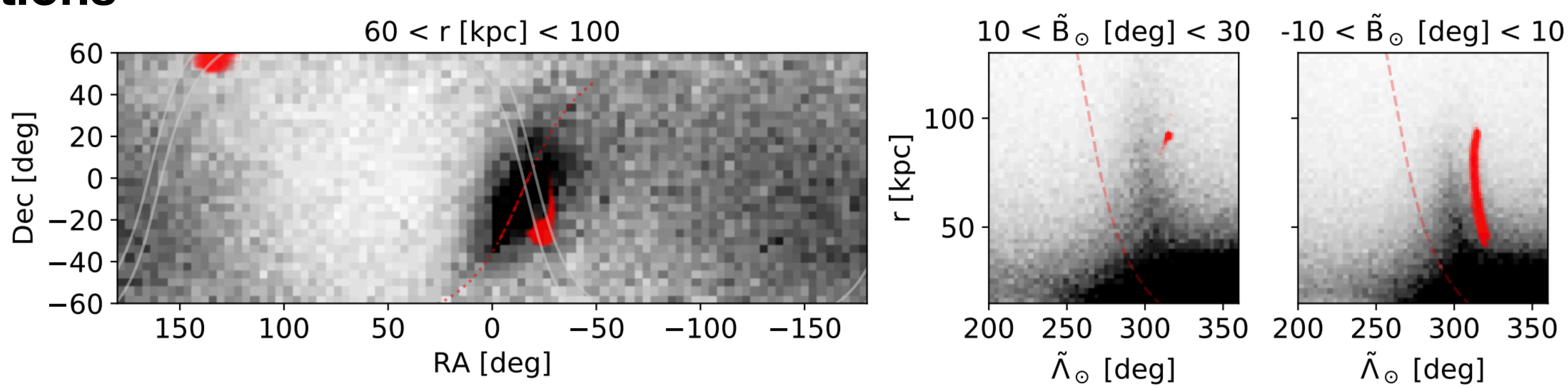
Effect of the LMC on the Milky Way

- We see the wake in the data

Observations



Simulations

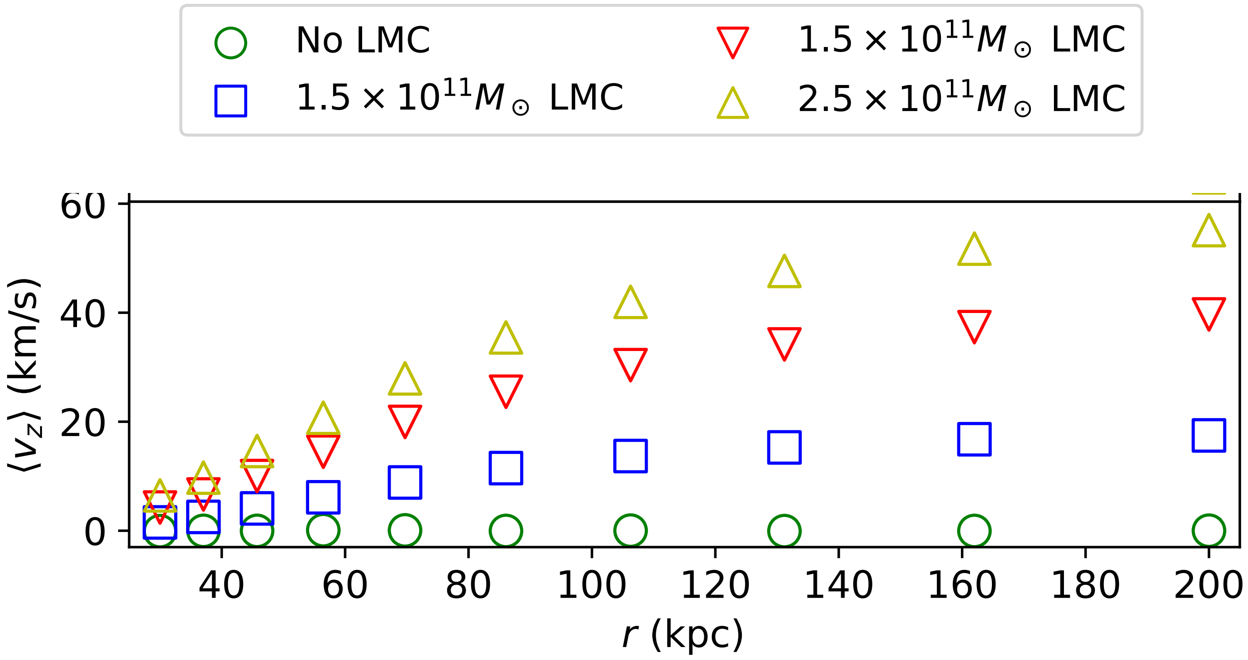


Belokurov, Deason, Erkal et al. 2019

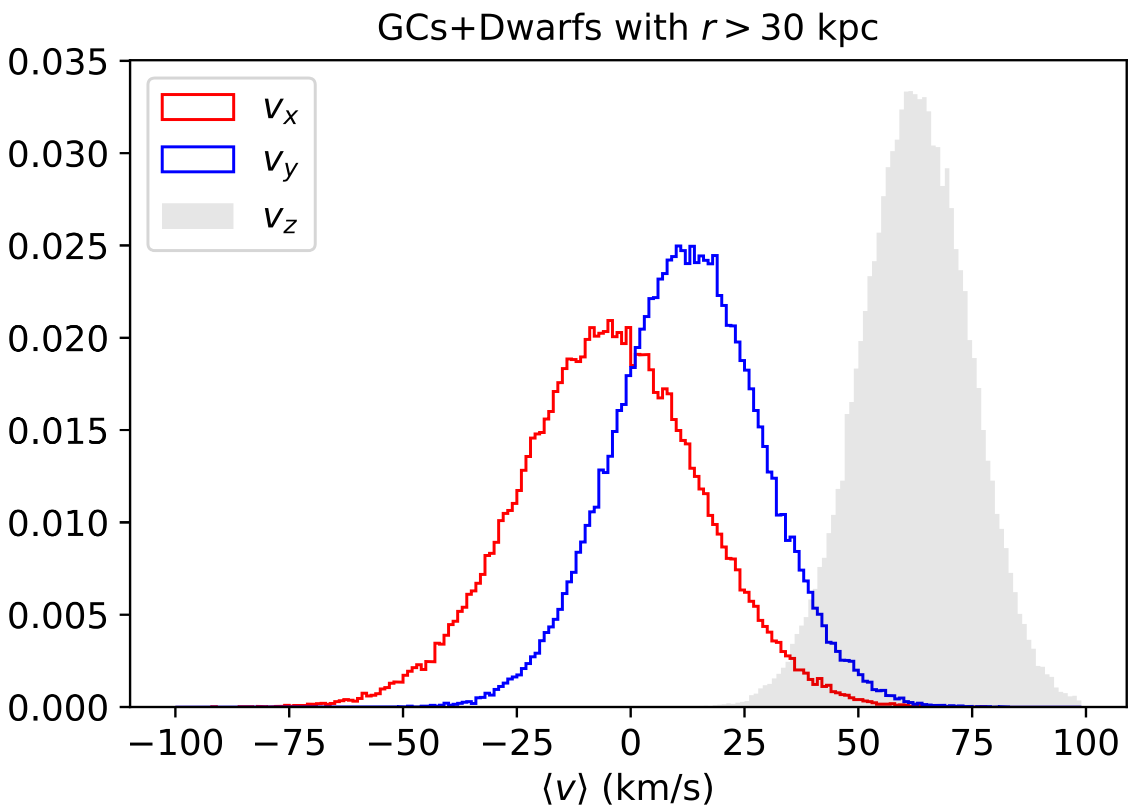
Effect of the LMC on the Milky Way

- We see velocity offsets in the data

Simulations



Observations



Tracers in the outer parts of the Galaxy seem to be moving upwards

Erkal et al. in prep

Effect of the LMC on hypervelocity stars

- So… what does this do to the hypervelocity stars?
- HVS were ejected from a Milky Way with a different velocity and position
- This means the HVSs will not point back to the galactic centre

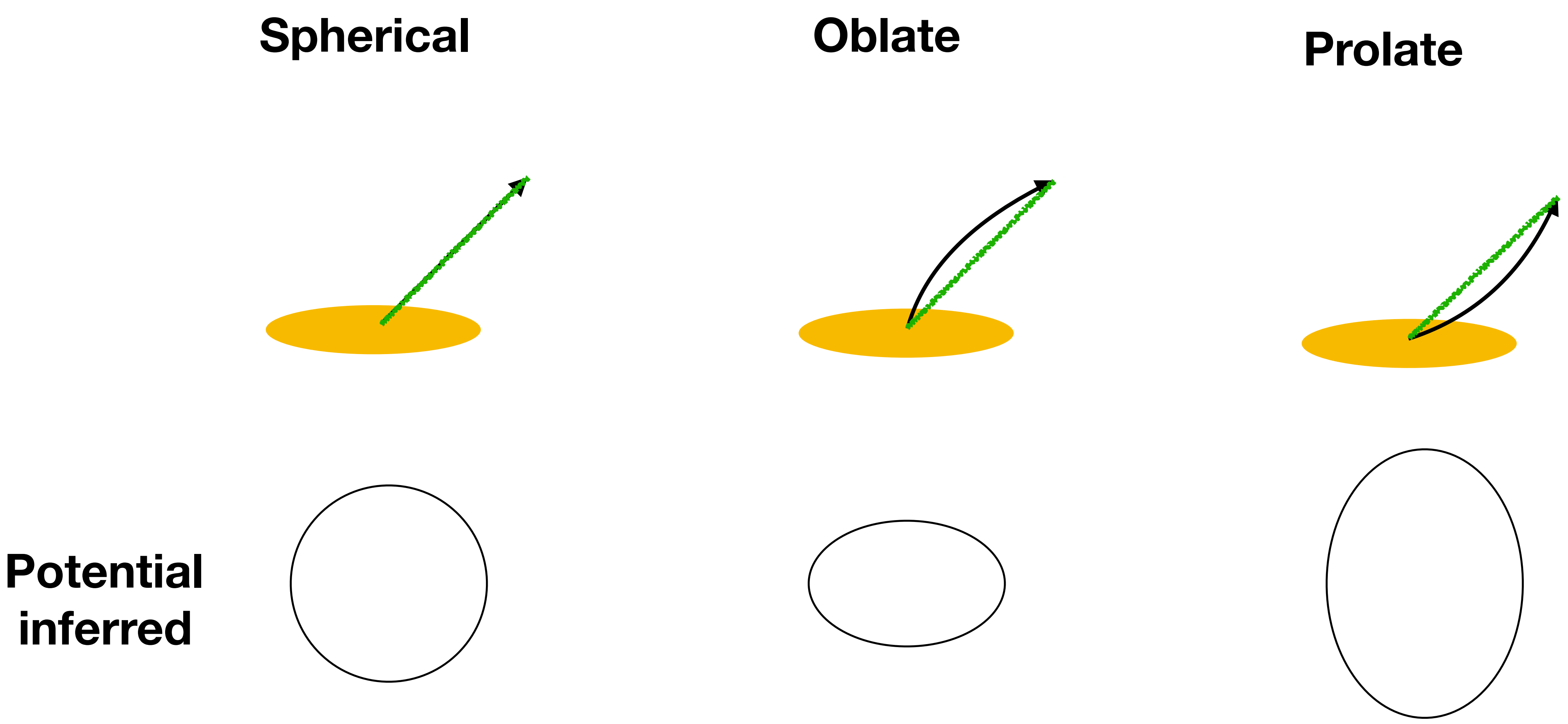
Kenyon et al. 2018

Boubert & Erkal in prep.

Effect of the LMC on hypervelocity stars

- Setup
  - HVS from Milky Way centre via Hills mechanism (Bromley et al. 2006)
  - Consider massive stars (2-4 $M_{\odot}$) over last 1 Gyr
  - Milky Way potential from *galpy* (Bovy 2016)
  - LMC mass of 1.5×10^{11} $M_{\odot}$, 2.5×10^{11} $M_{\odot}$
  - Only considering unbound stars

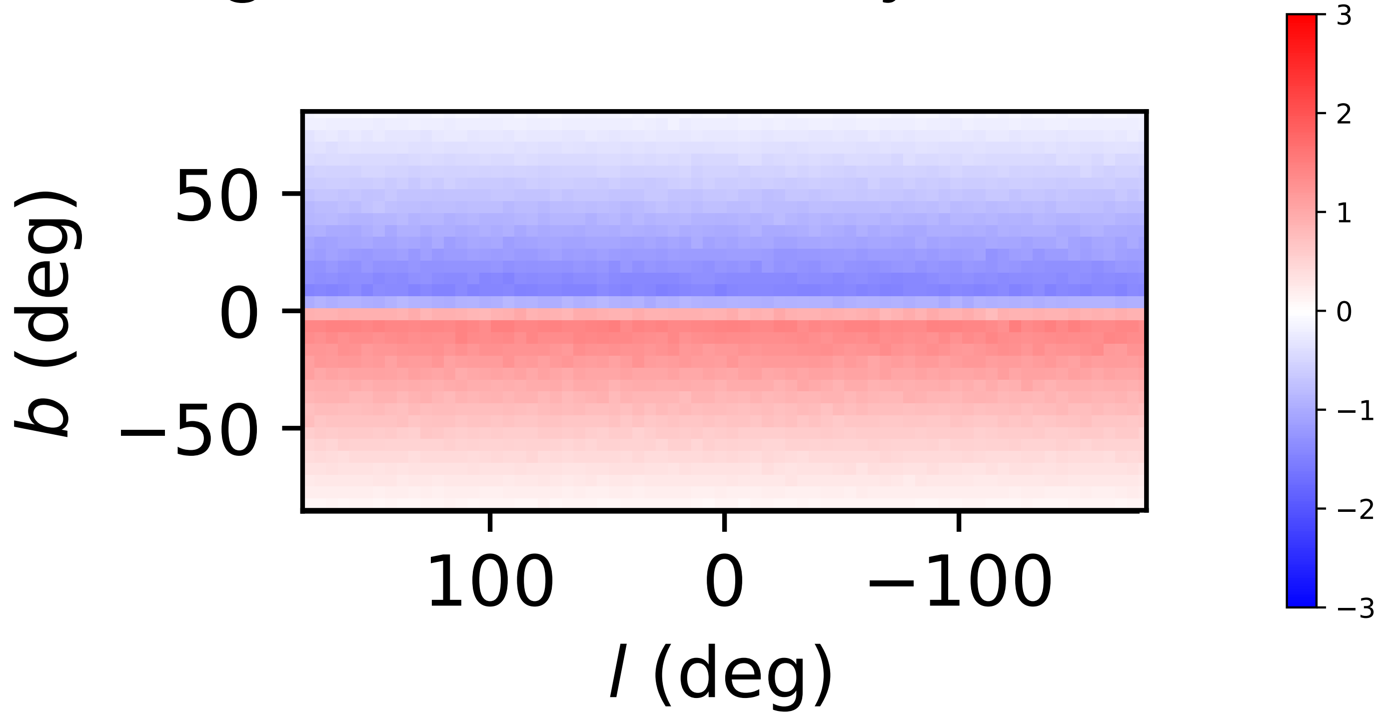
Effect of the LMC on hypervelocity stars



Compare radial direction with velocity to measure flattening

Effect of the LMC on hypervelocity stars

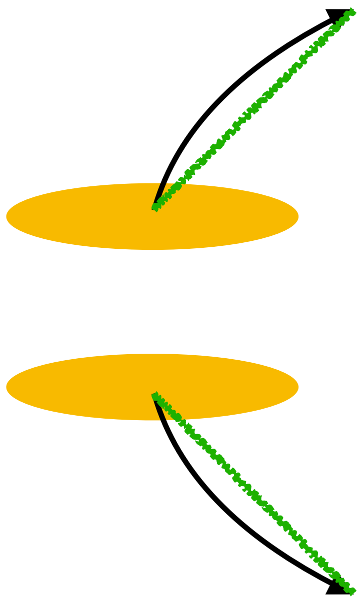
Mean misalignment of velocity and radial direction



Deflected upwards

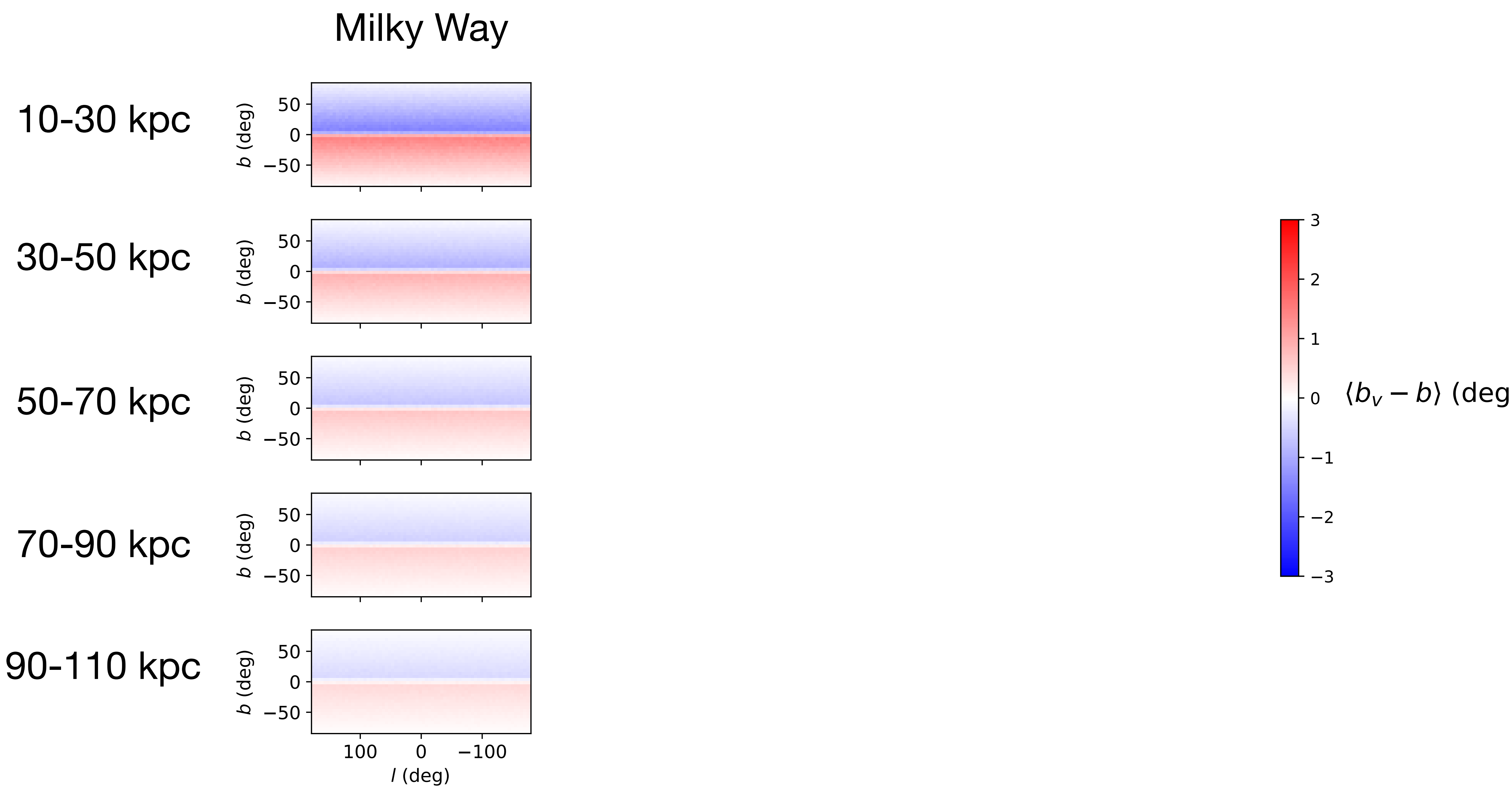
Deflected downwards

10-30 kpc

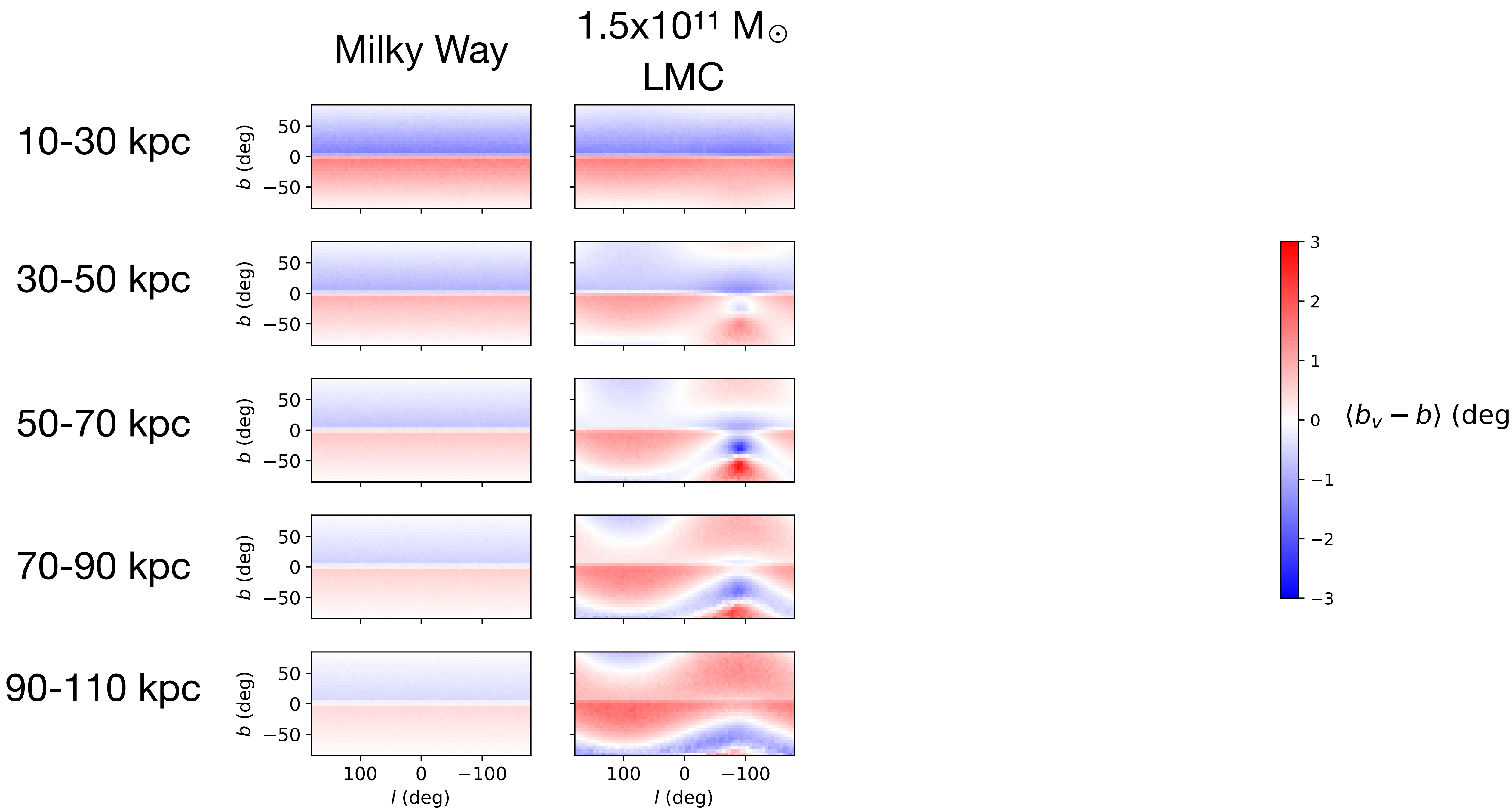


Oblate potential due to the disk

Effect of the LMC on hypervelocity stars

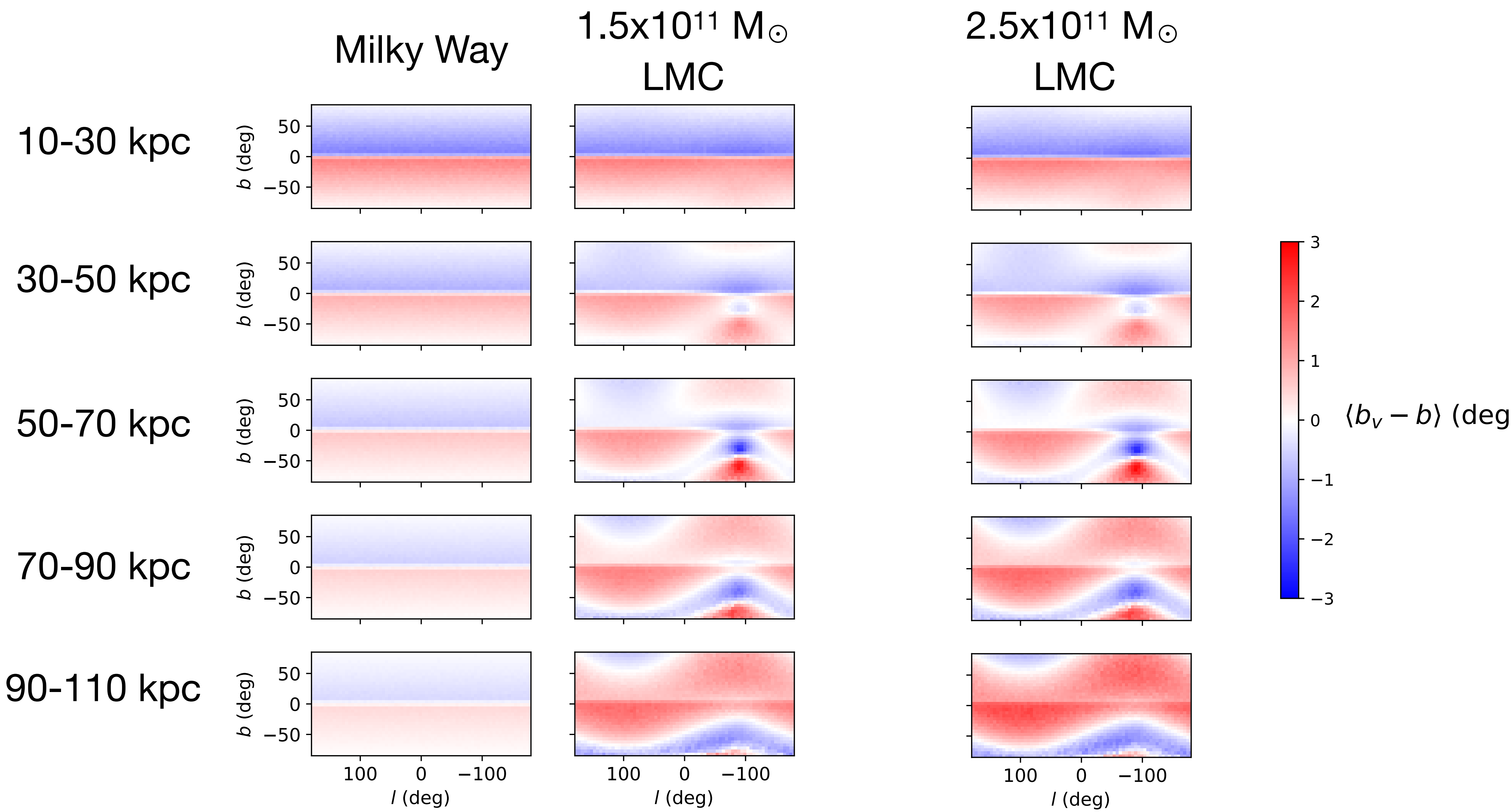


Effect of the LMC on hypervelocity stars



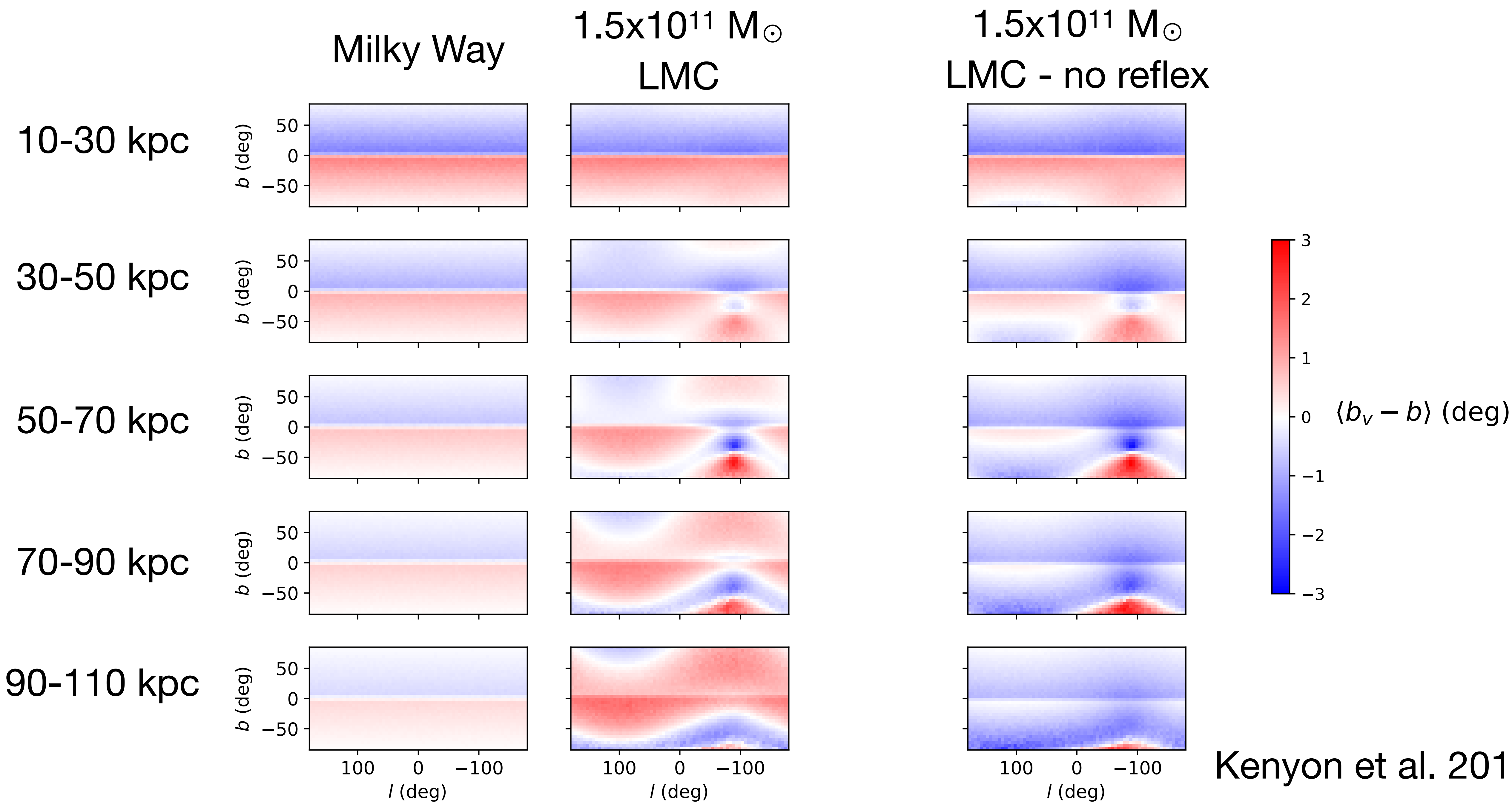
LMC is important beyond ~30 kpc

Effect of the LMC on hypervelocity stars



Increasing the LMC mass increases the deflection

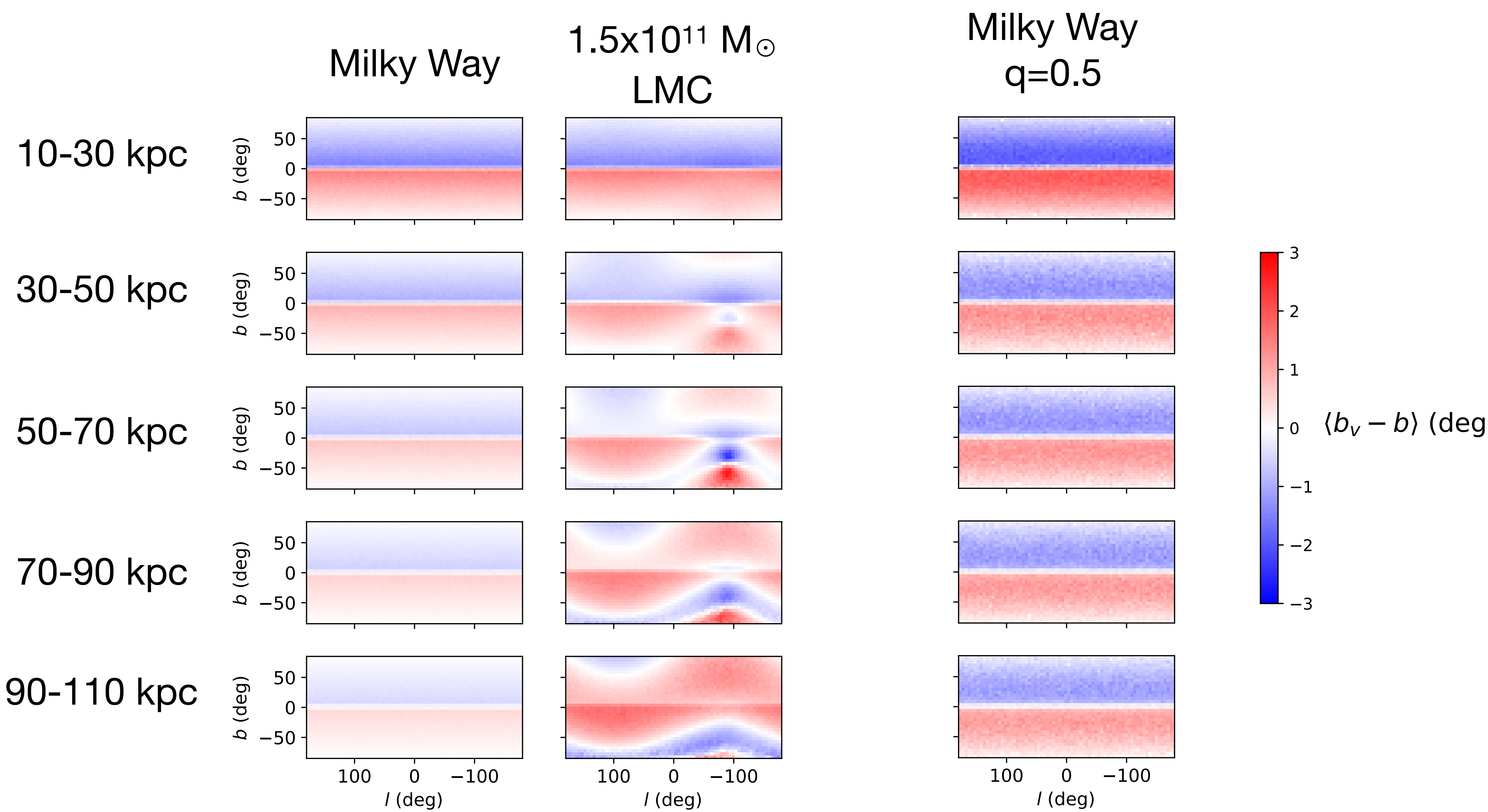
Effect of the LMC on hypervelocity stars



Kenyon et al. 2018

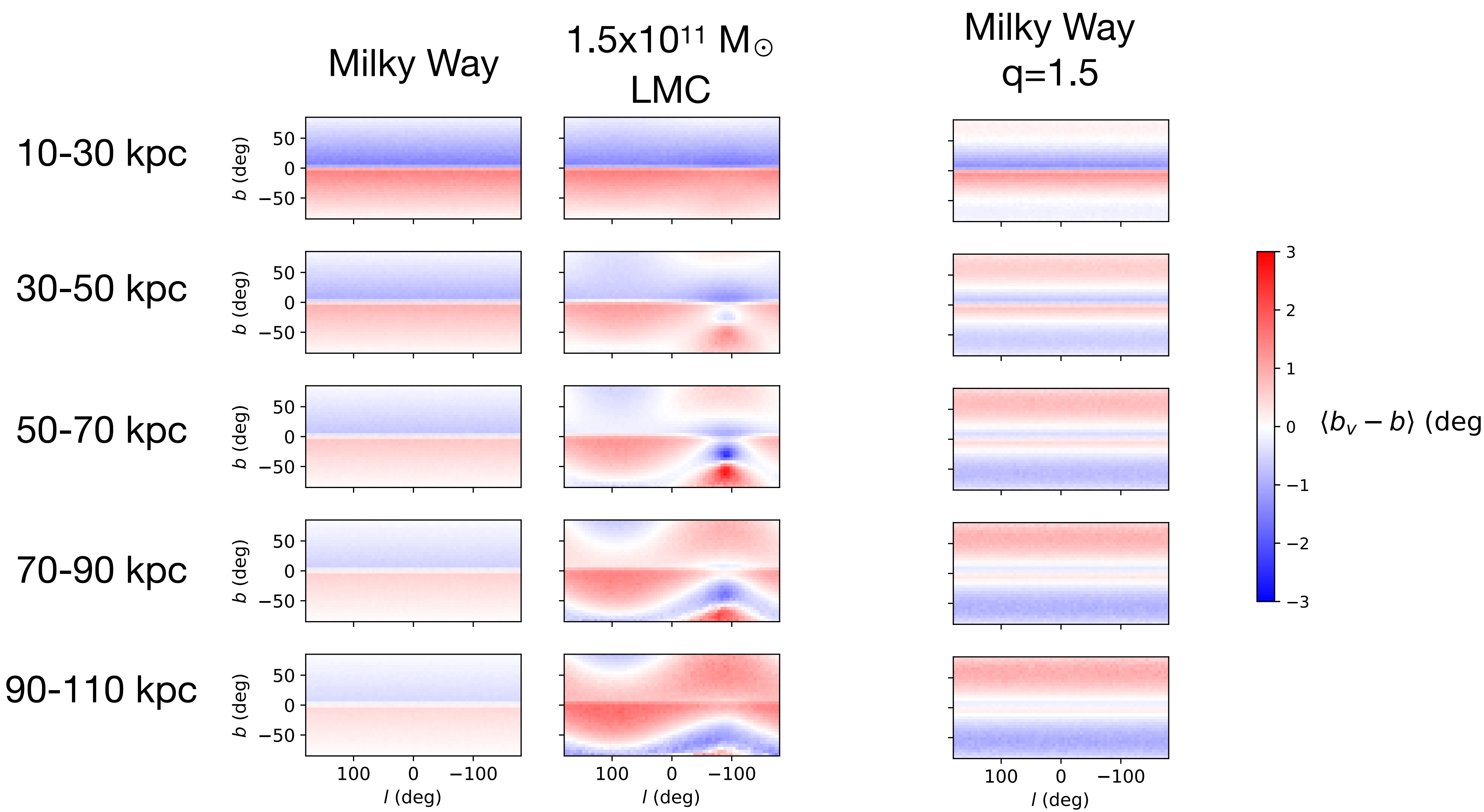
Including LMC with fixed Milky Way goes the wrong way

Effect of the LMC on hypervelocity stars



LMC has larger effect than q=0.5 halo in parts of the sky

Effect of the LMC on hypervelocity stars



LMC has larger effect than q=1.5 halo in parts of the sky

Conclusions

- HVS3 comes from the LMC - ejected at ~870 km/s
- Compatible with Hills mechanism and an LMC blackhole mass of 4×10^3-10^4 $M_\odot$
- The LMC is massive and has a large effect on (nearly?) everything in the outer part of the Milky Way
- LMC can deflect HVSs by ~3 degrees (~5 kpc at 100 kpc)
- LMC has larger effect than expected shape of the halo (can masquerade as q~0.5 or q~1.5)