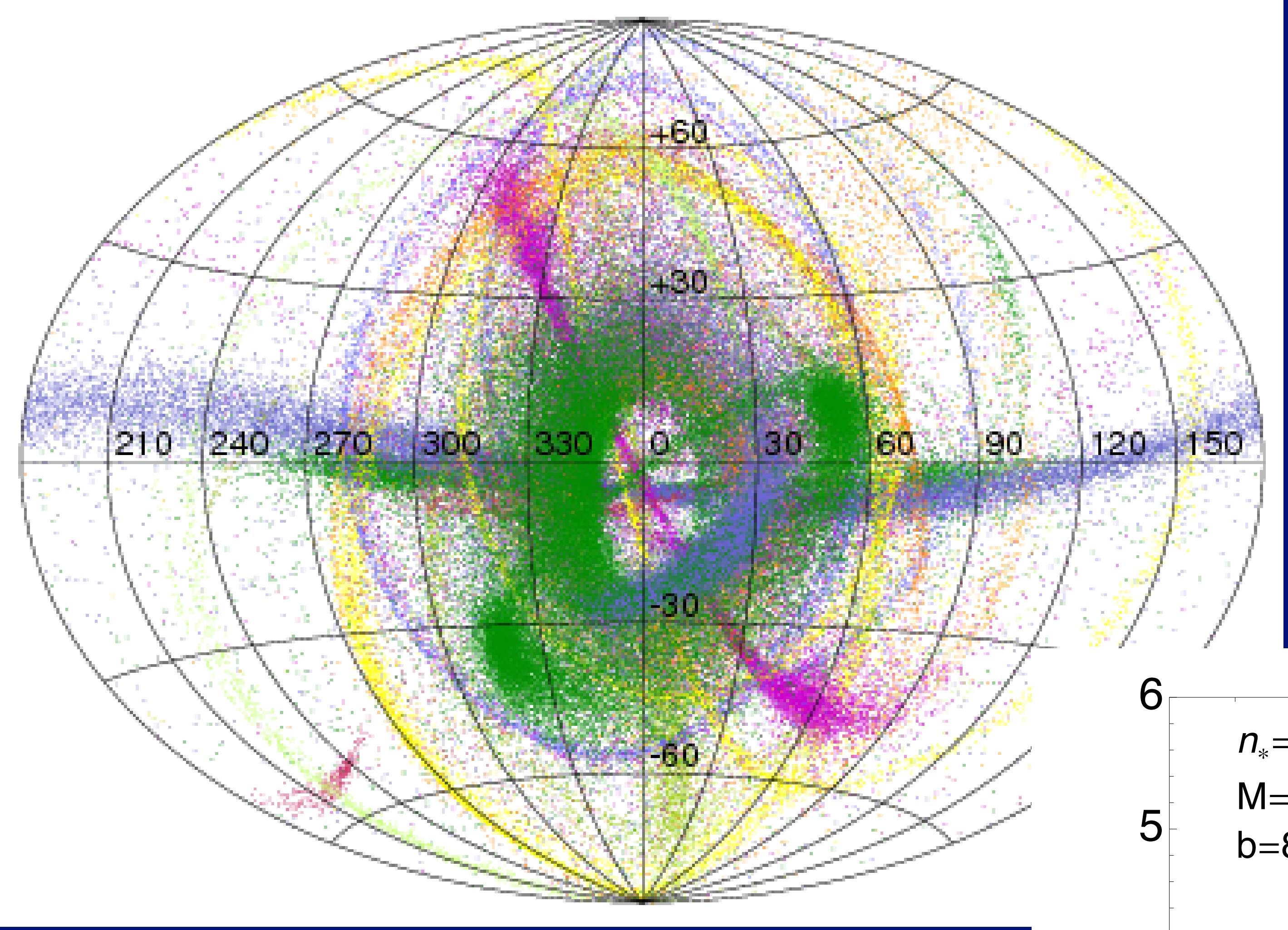
Inferring the Galactic gravitational potential with Gaia and friends

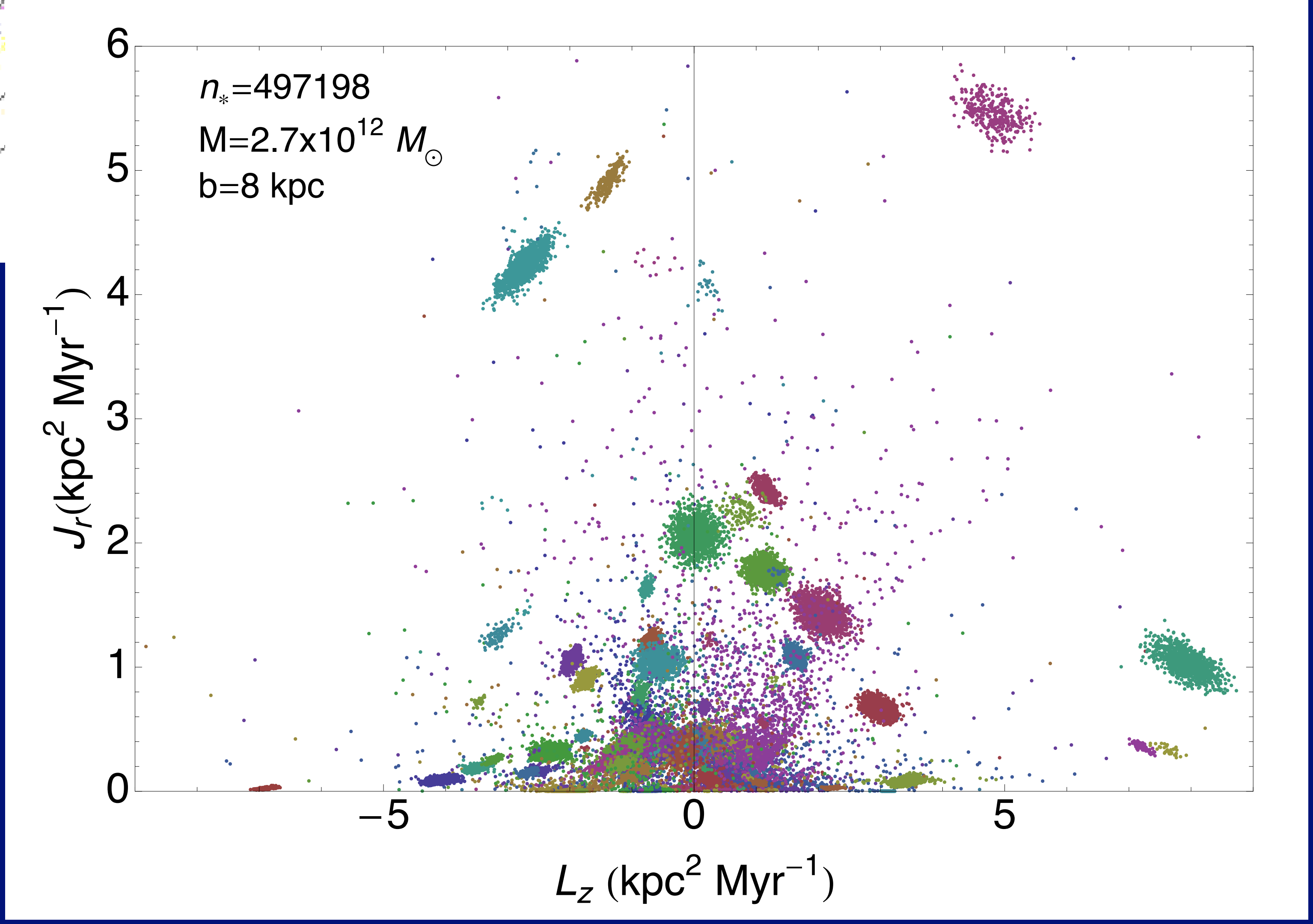
Robyn Sanderson
NSF Postdoctoral Fellow
Columbia University/NYU

The accreted stellar halo is clumpy in action space



View in Galactic coordinates

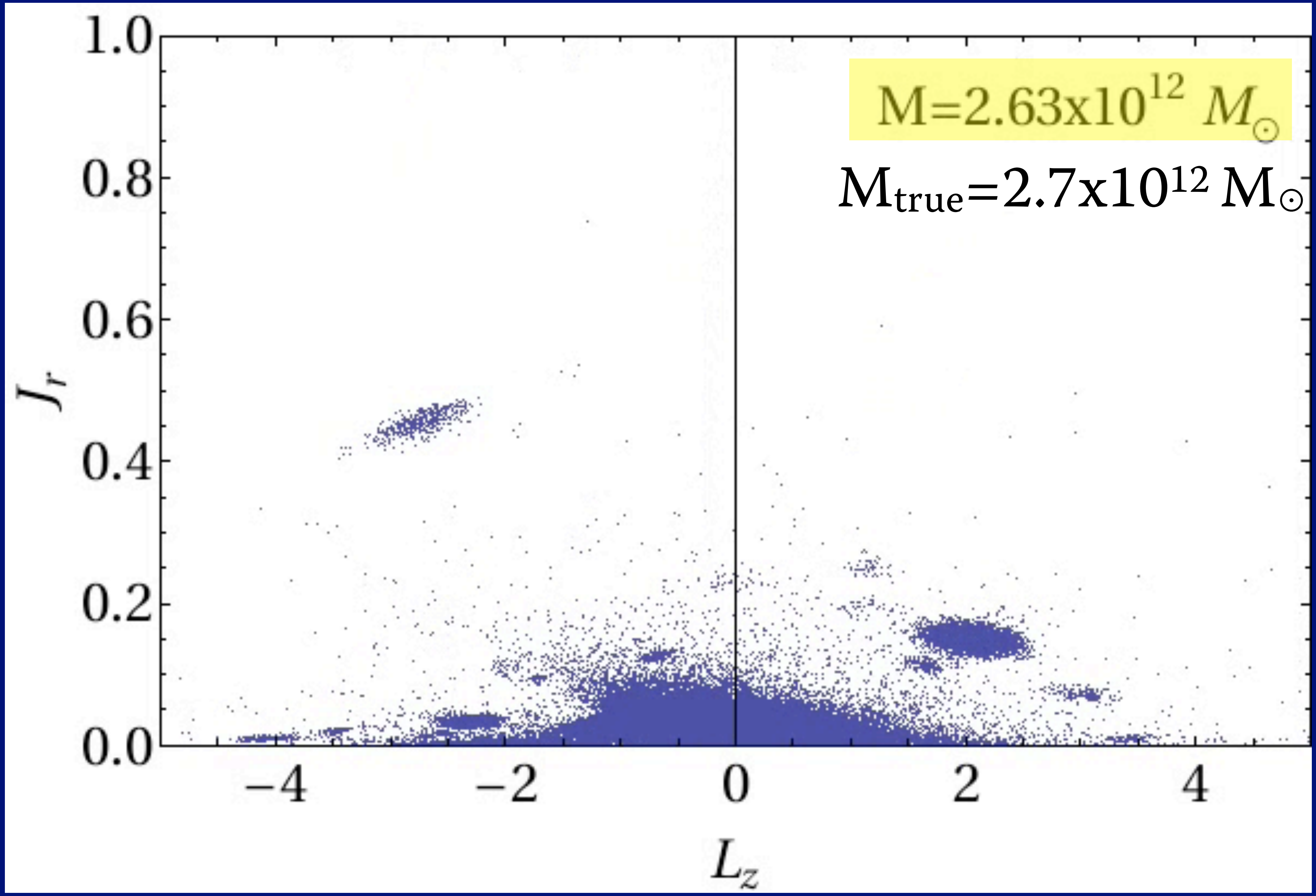
View in action space (using input potential)



Actions are most clustered in the correct potential

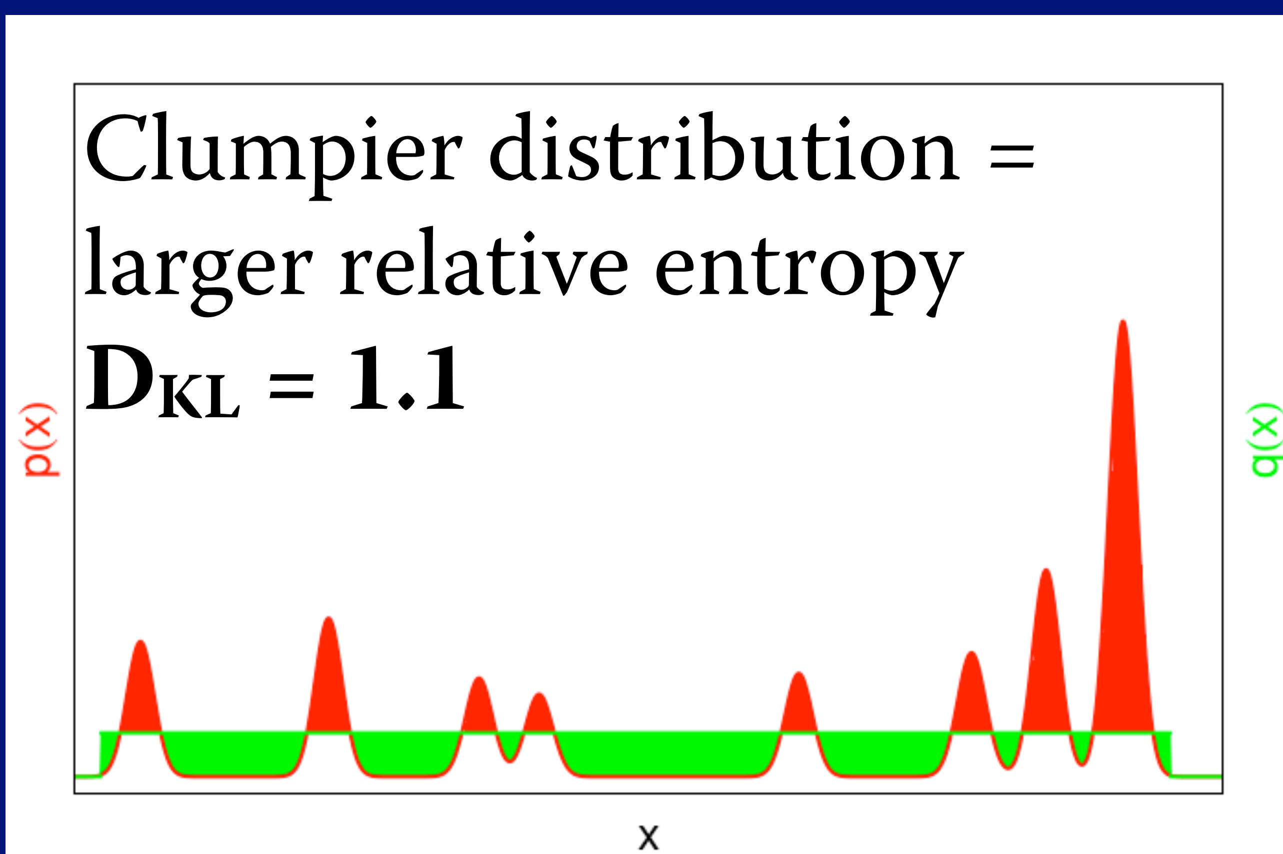
$$J_r = \frac{GM}{\sqrt{-2E}} - \frac{1}{2}\left(L + \sqrt{L^2 + 4GMb}\right)$$

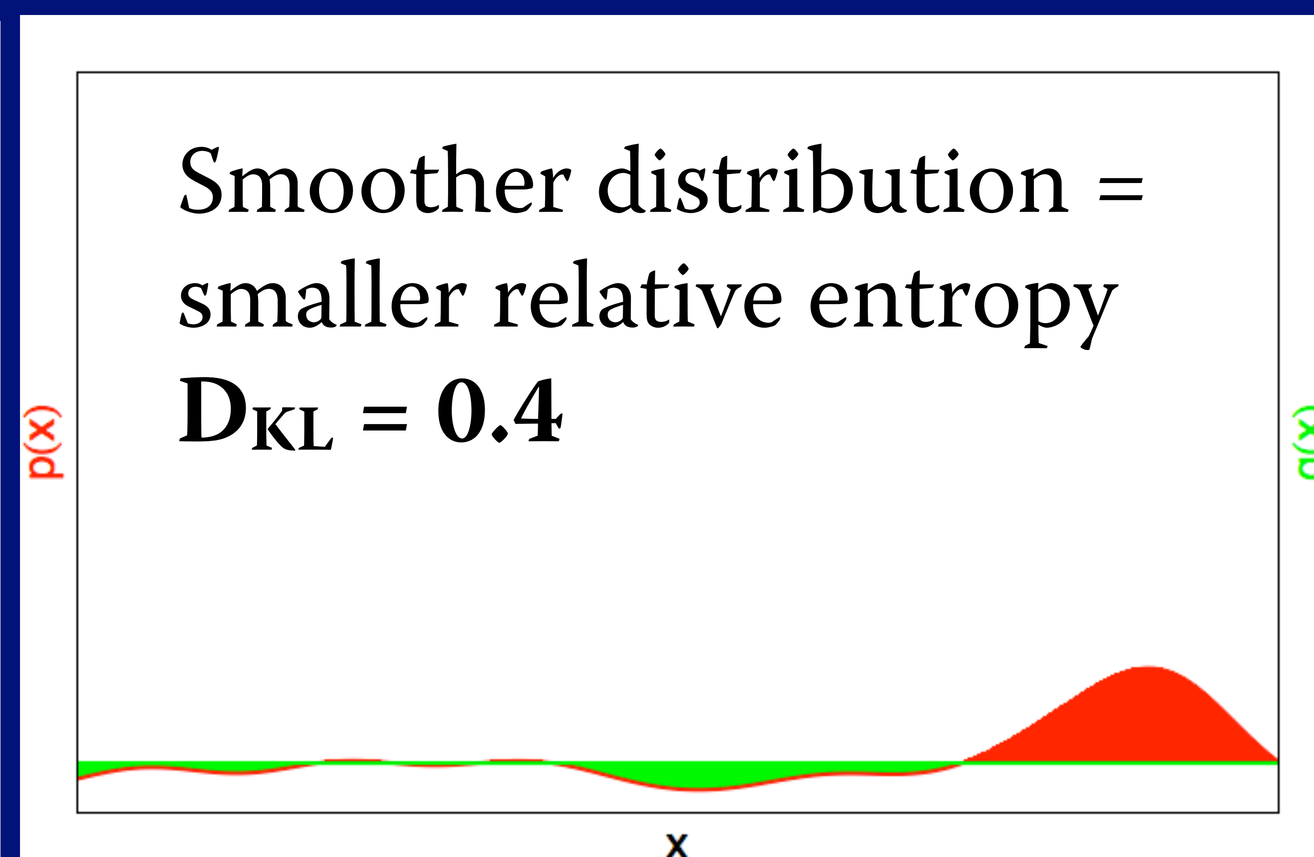
Potential parameters
Observations
Both



The Kullback-Leibler divergence measures clustering

$$D_{KL}(p||q) = \int \ln\left(\frac{p(x)}{q(x)}\right) p(x)dx$$





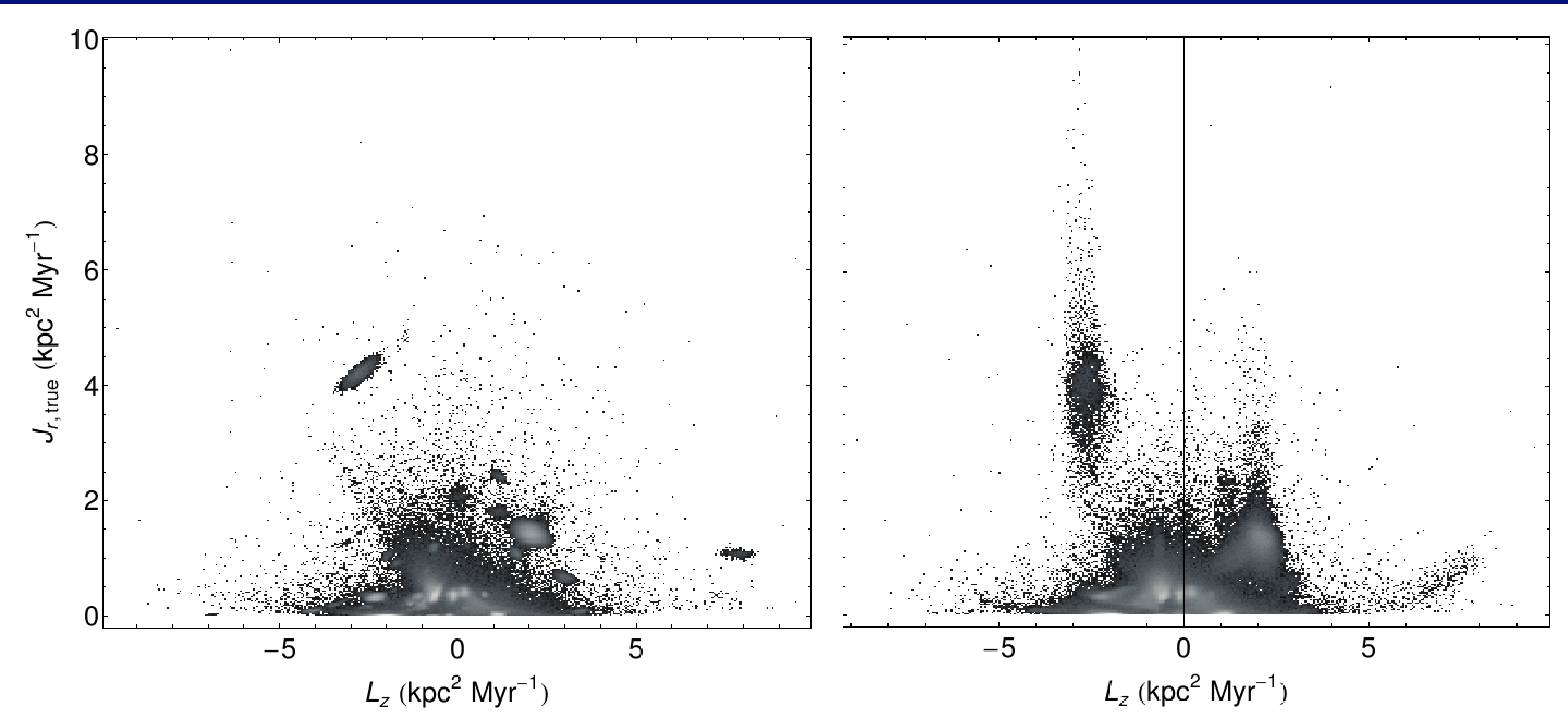
Testing the action-clustering method

1. Make a mock halo in a known potential (start with accreted component only)
2. "Observe" halo with Gaia
3. Find the potential that maximizes the KLD
4. Determine confidence intervals ("error bars")
5. Compare the answer to input values
6. Variations: incorrect/different functional forms, +smooth component, different error models, etc.

For details, see Sanderson, Helmi, & Hogg 2015, ApJ, 801, 98

Errors blur, but do not destroy the information

Without errors | With Gaia (pre-launch) errors

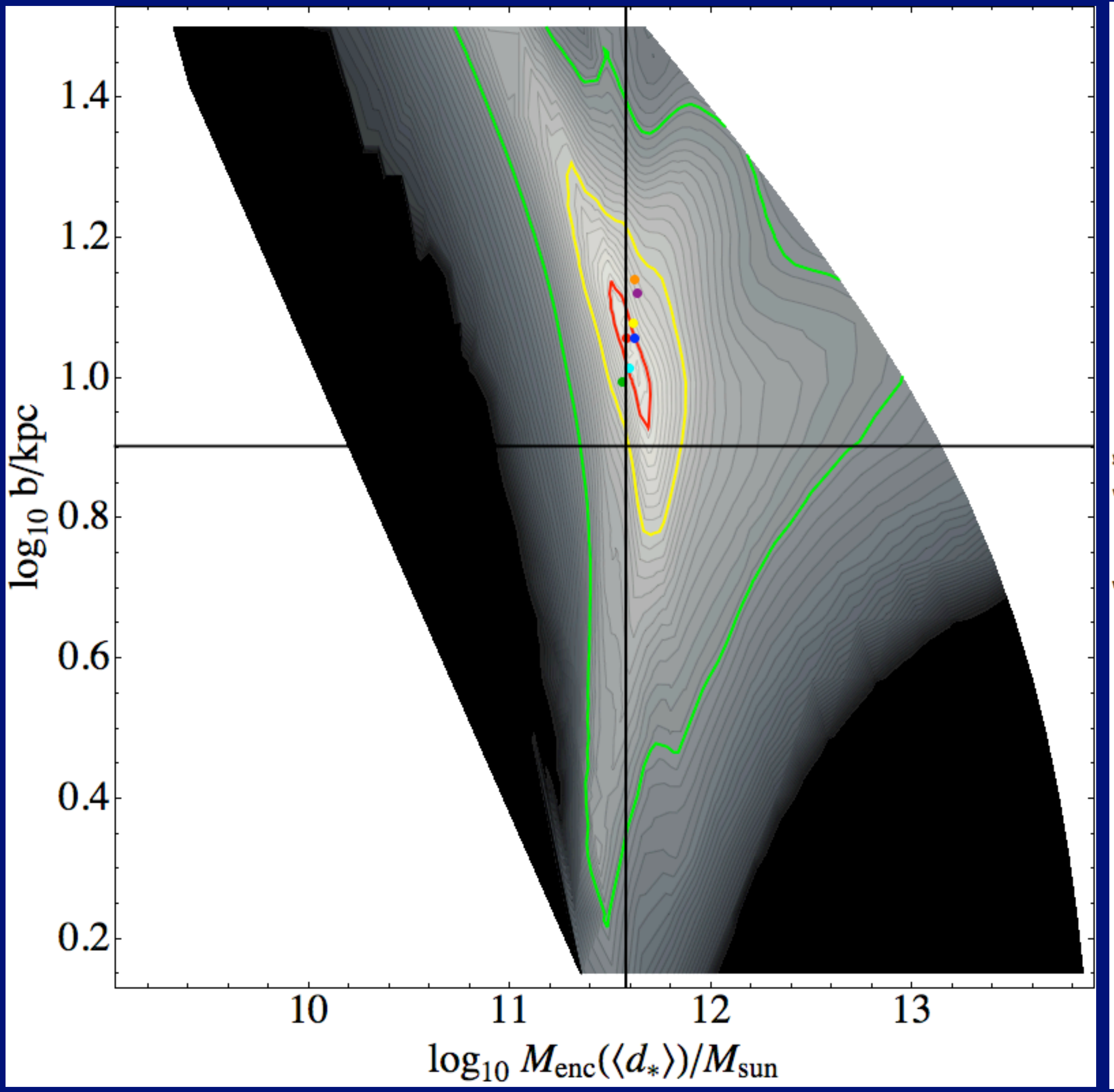


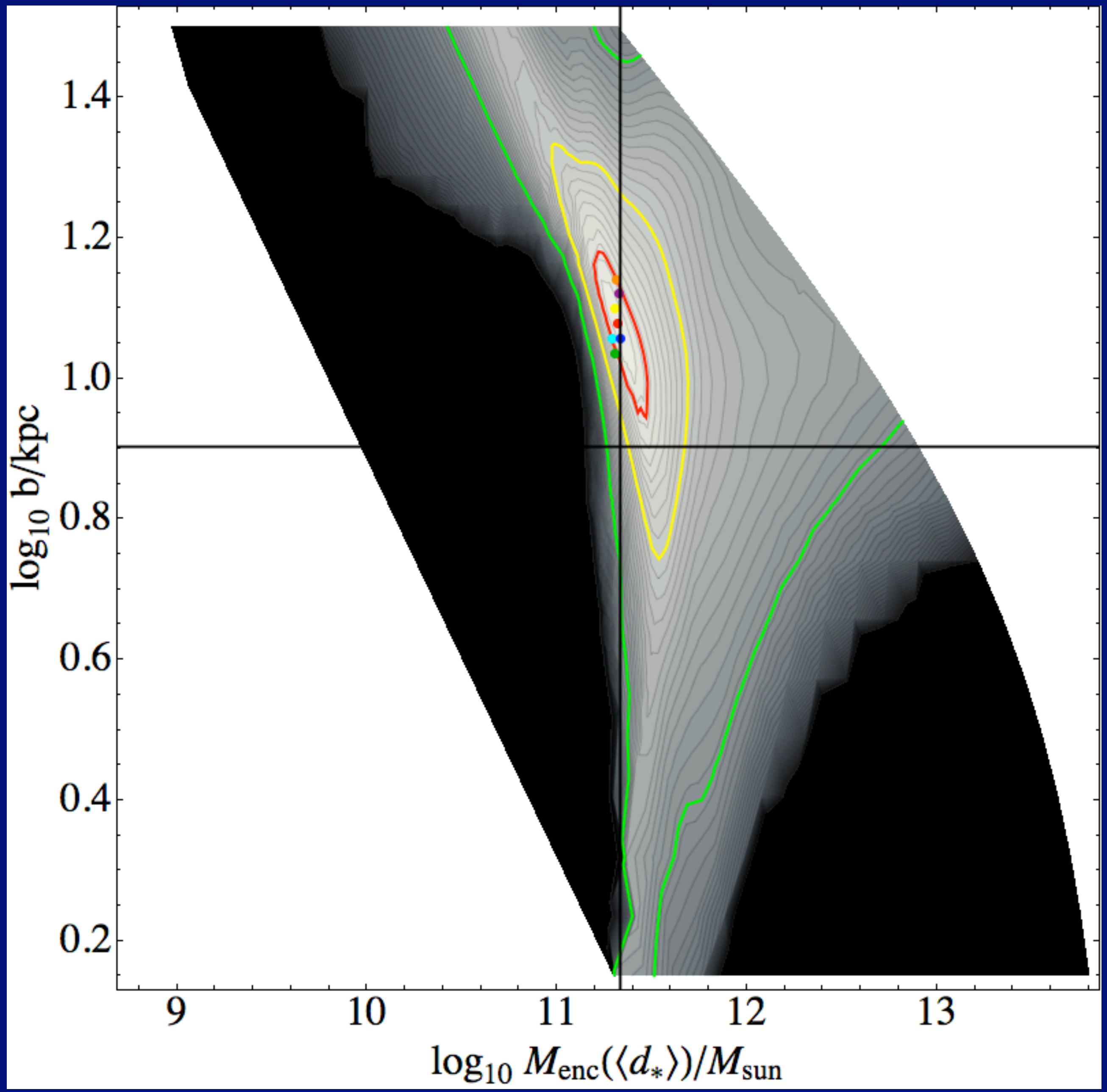
Sanderson, Helmi, & Hogg, 2015

Results of tests with a mock **isochrone** halo

Log$_{10}$ conditional probability

Without errors | With pre-launch Gaia errors





Sanderson, Helmi, & Hogg, 2015

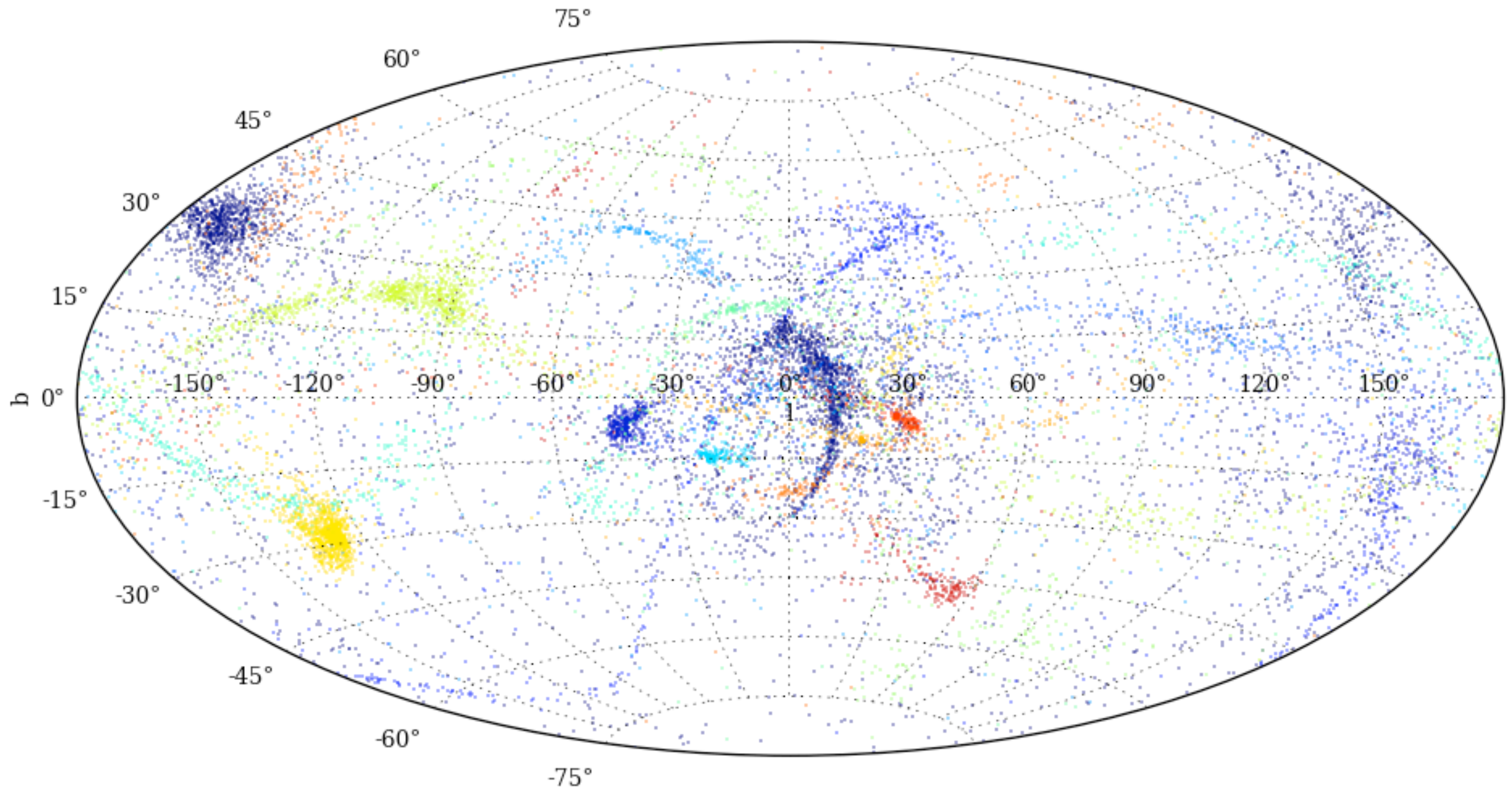
67, 95, 99% confidence equivalents

d_{GC}<20 kpc

Simulated stellar halo in cosmological potential

15 thin streams chosen by hand from tagged Aquarius halo Aq-A

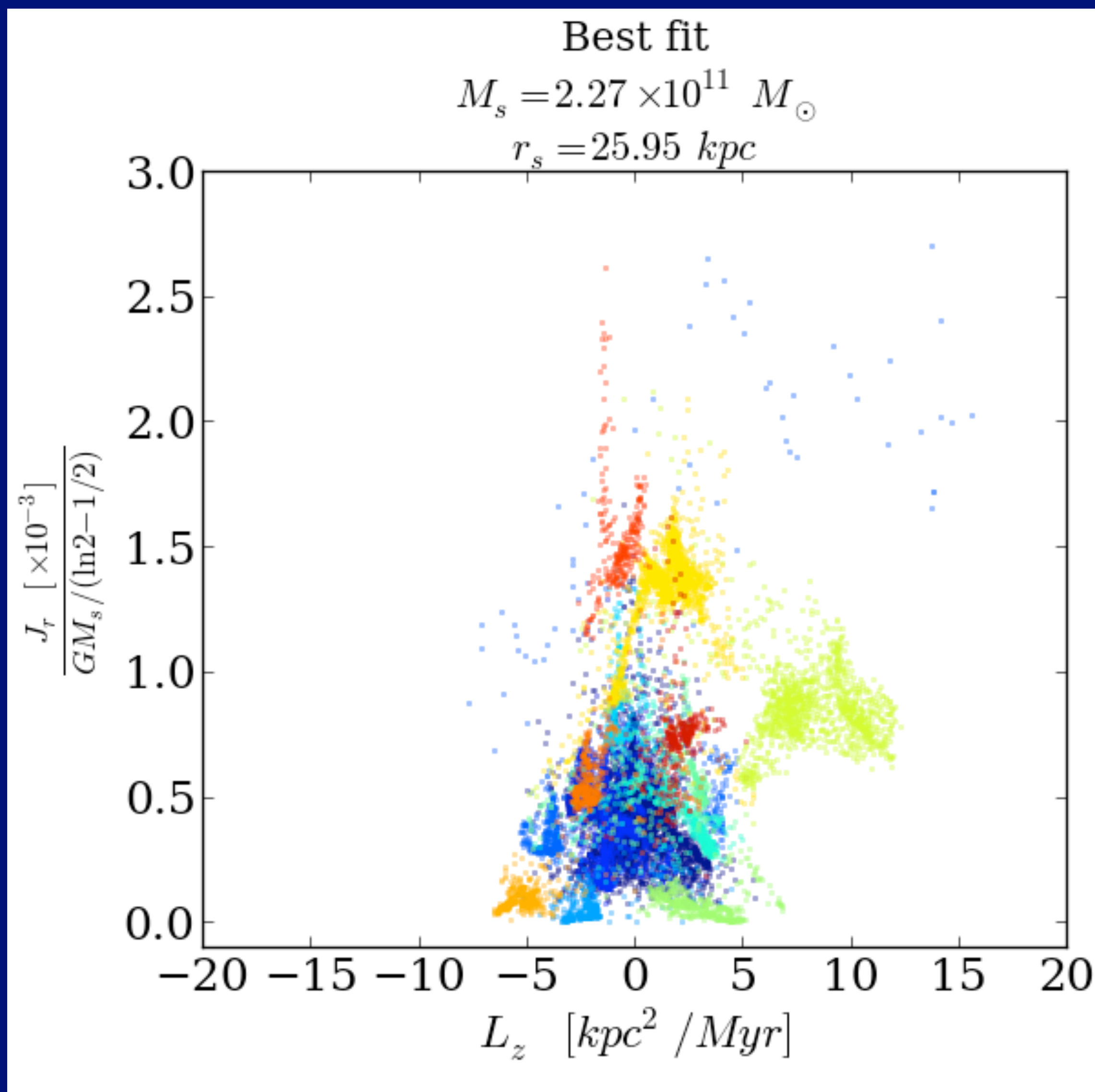
(Cooper+2010, Helmi+2011)

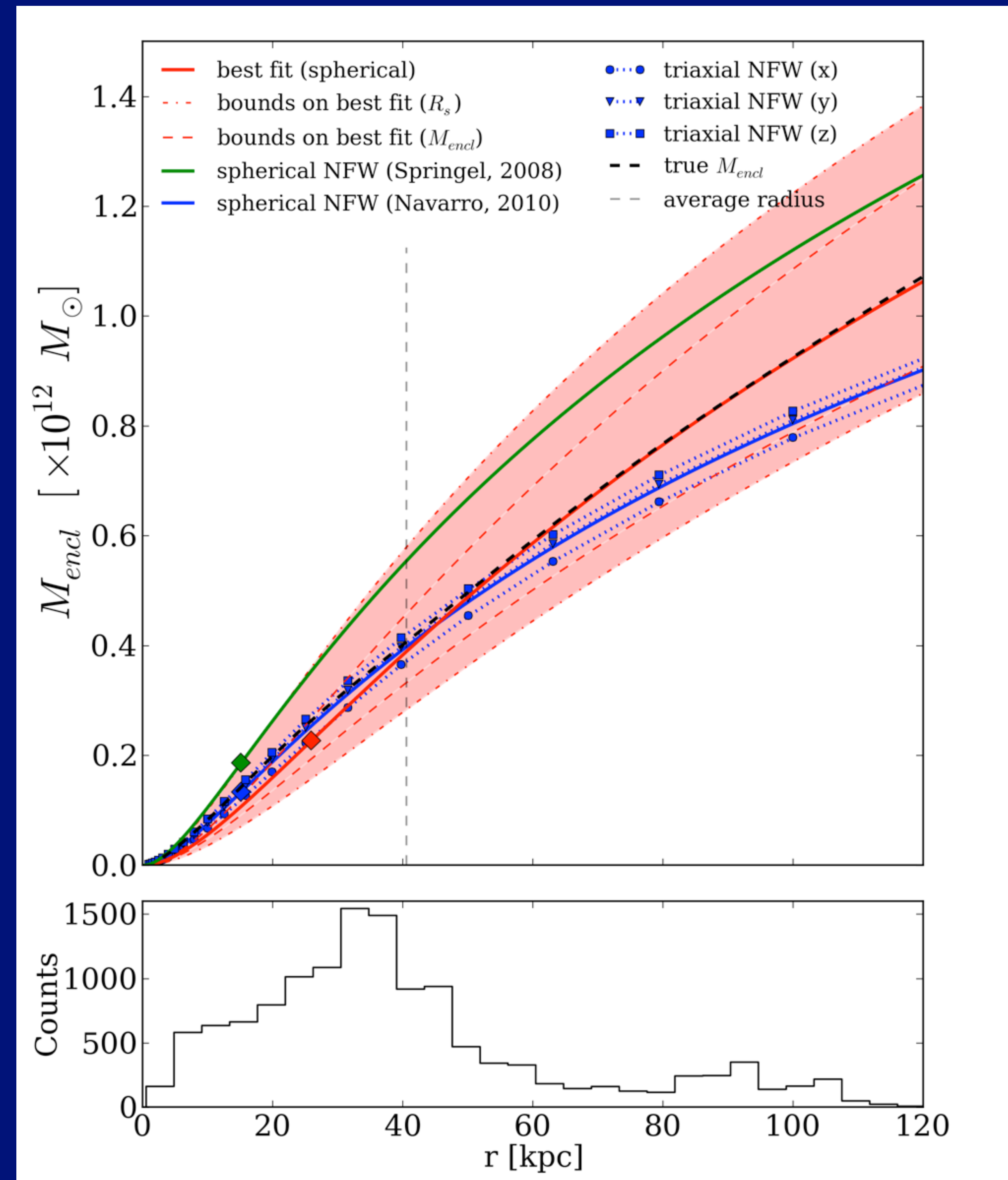


Sanderson, Hartke, & Helmi, in prep

Best-fit halo matches present-day mass profile

Model: smooth, spherical NFW



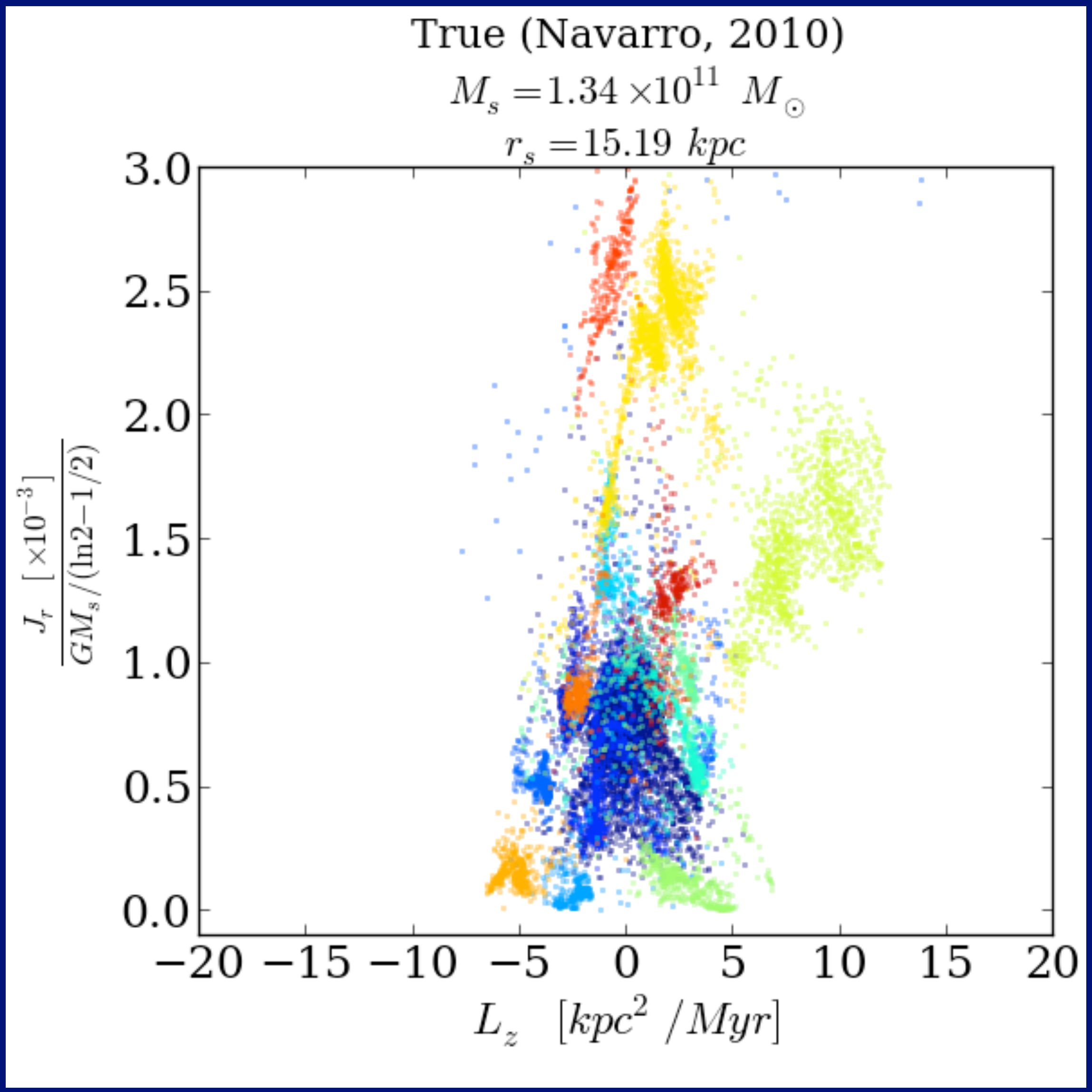


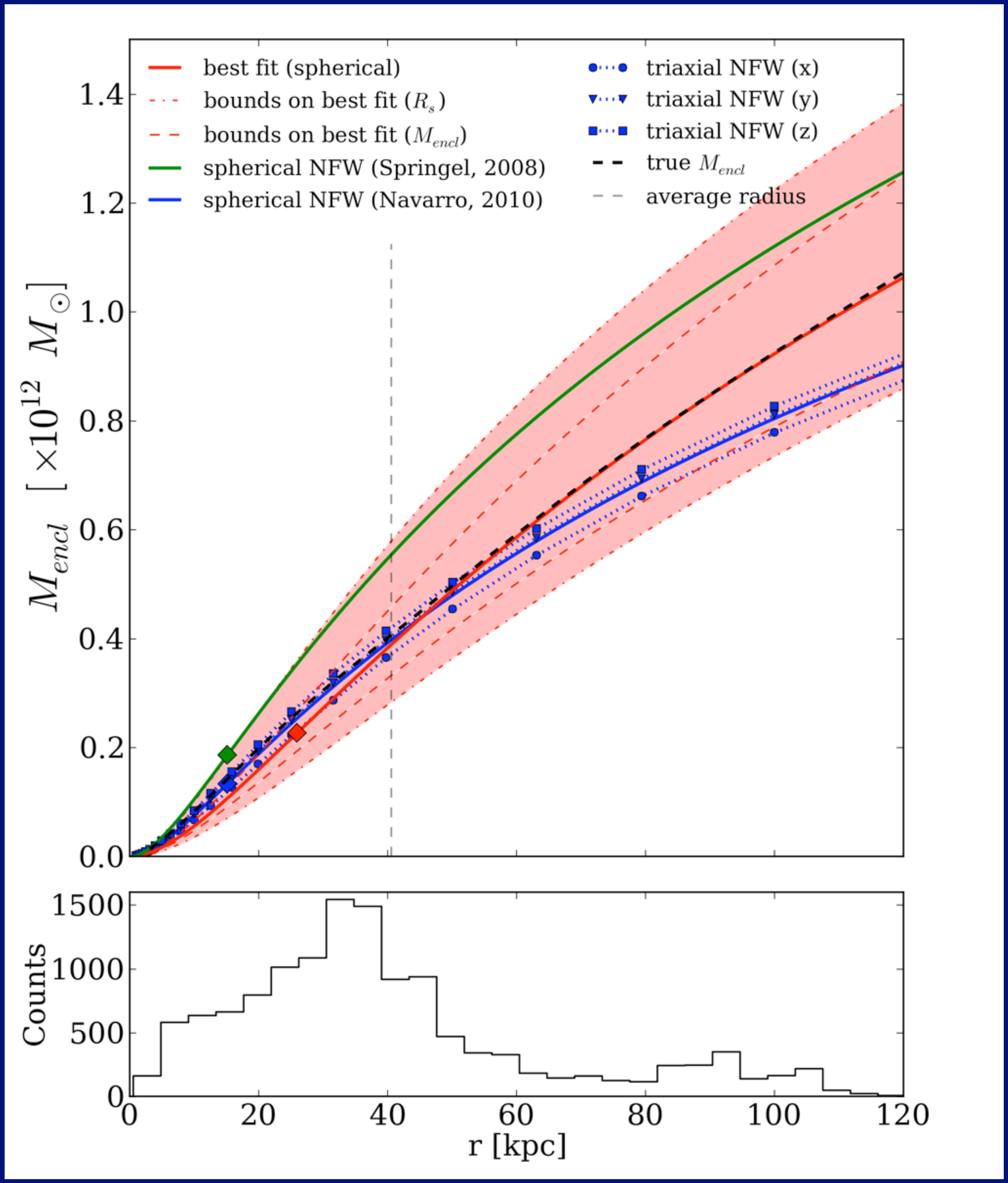
Membership info not used in fit

Sanderson, Hartke, & Helmi, in prep

Best-fit halo matches present-day mass profile

Model: smooth, spherical NFW





*Derived from (r_{-2}, ρ_{-2}) **of DM***

Sanderson, Hartke, & Helmi, in prep

SSS15, 15 April 2015

Follow-up observations

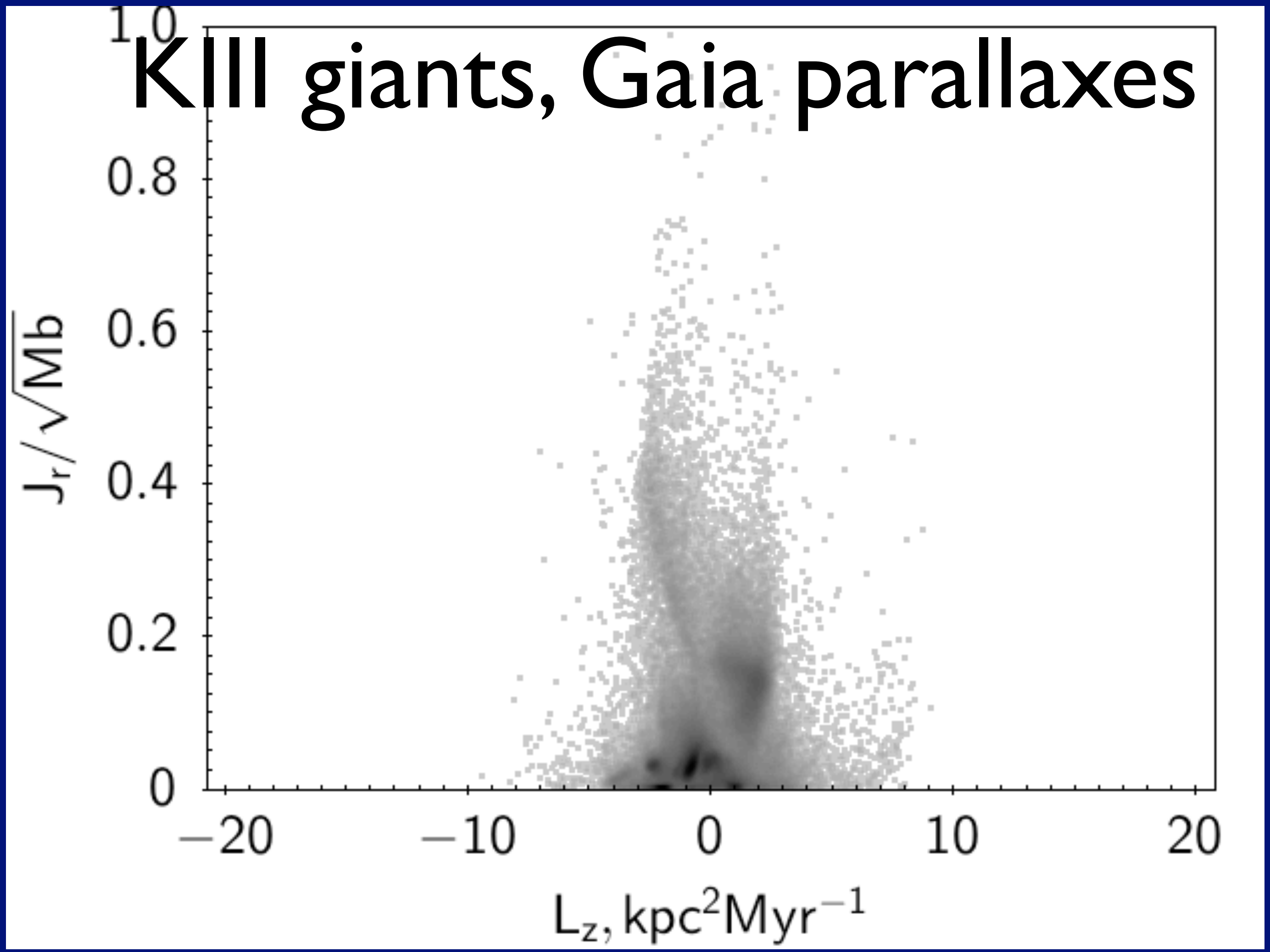
RVs

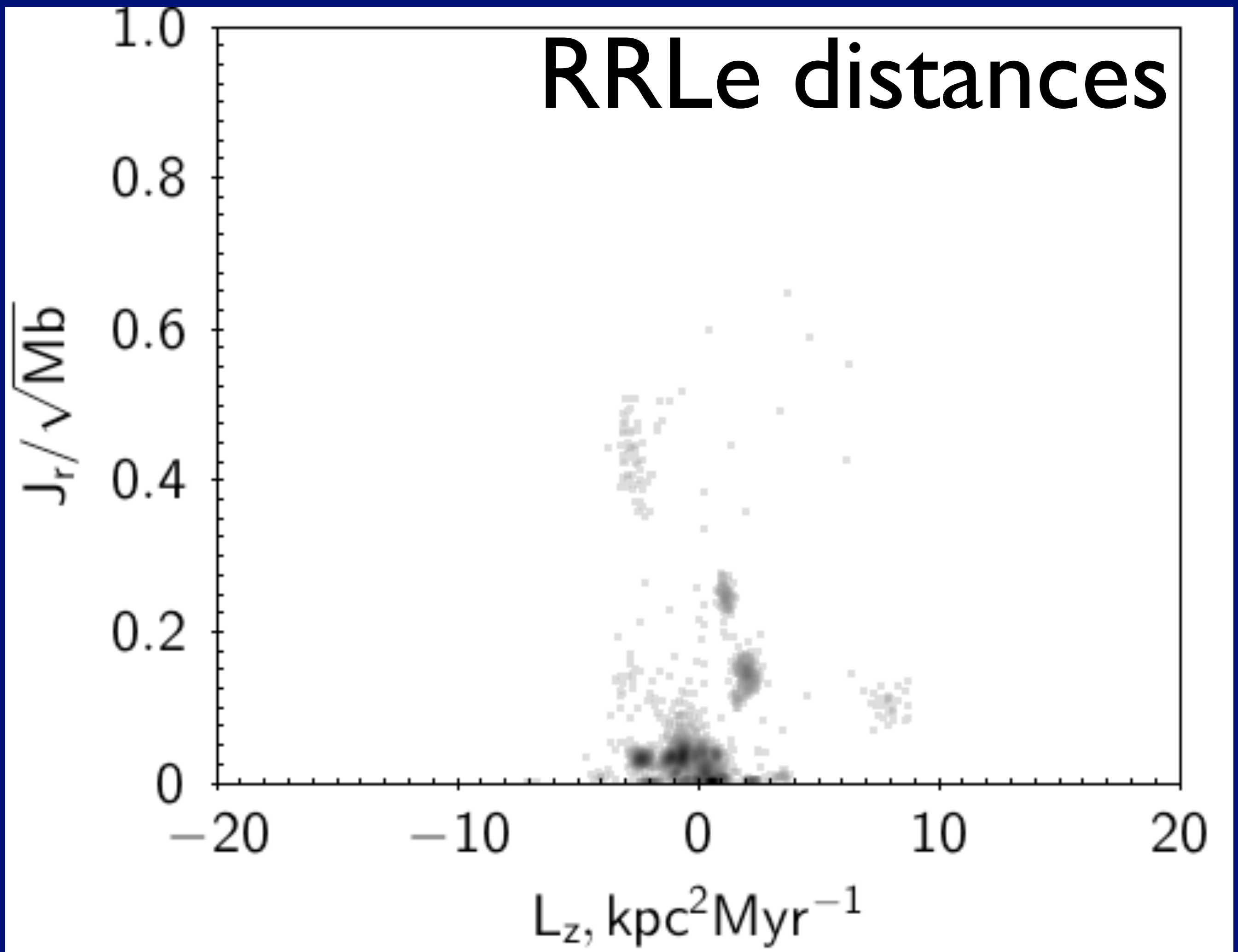
- **Northern Hemisphere**: WEAVE on William Herschel Telescope (INT/IAC, La Palma, Canary Islands)
- **Southern Hemisphere**: 4MOST on VISTA telescope in Chile (ESO, Cerro Paranal, Chile)
- 4m telescope with multiple-fiber instrument
- ~10^6 halo stars (per survey)
- RV errors <2 km s^{-1} to V=20-22
- Adds RVs to stars with Gaia proper motions
- 20% photometric distances

RR Lyrae

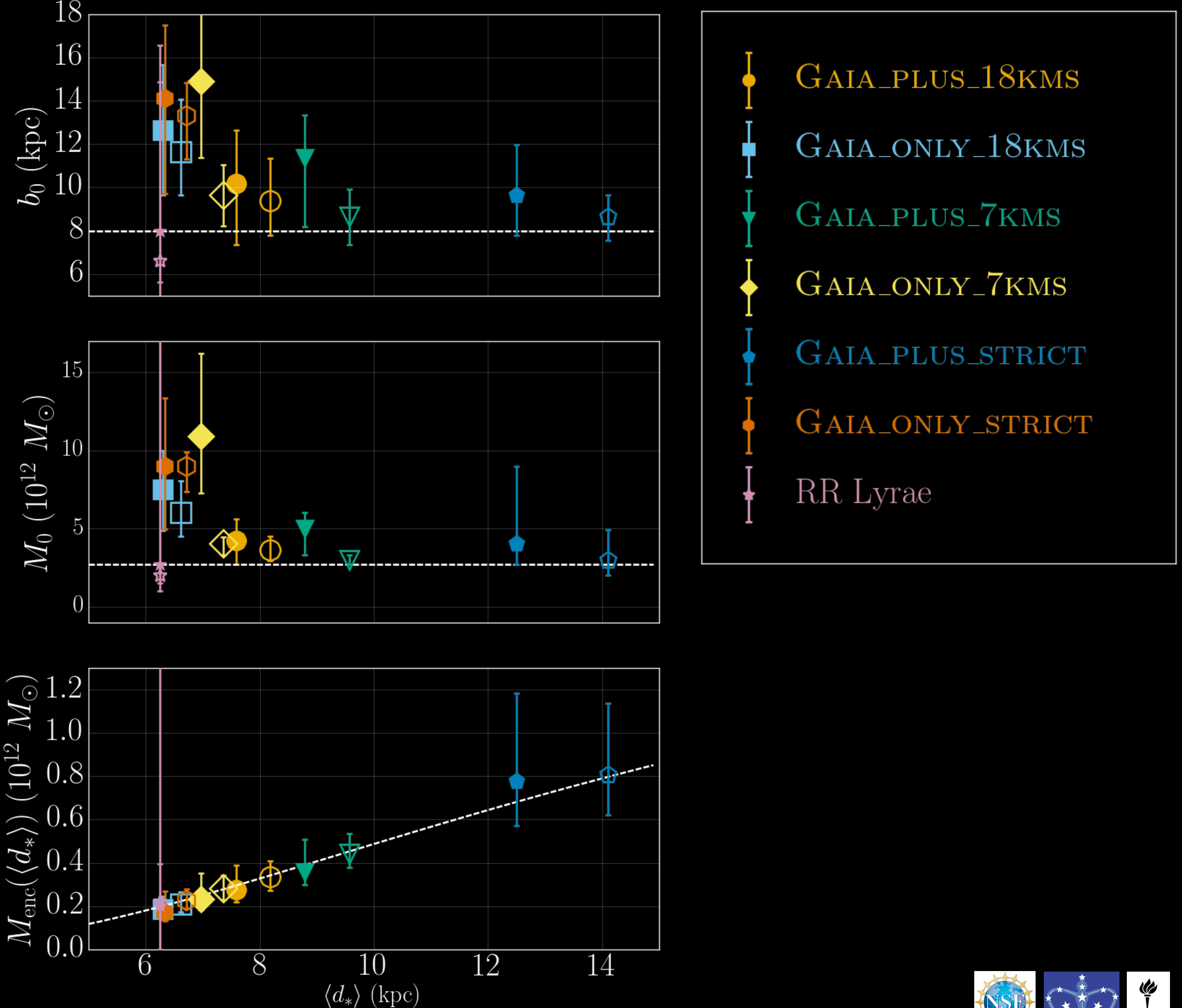
- **Distances** to 2%, RV errors 5-10 km s^{-1}

Improved distances increase information, but decrease sampling





Observations with larger average d_{GC} do better



Sanderson, in prep

SSS15, 15 April 2015

Advantages

- No need to assign membership of stars in streams (**membership probability is an output**)
- Robust to adiabatic time-evolution of host, substructure, some chaotic diffusion
- Can use any informative parameter (i.e. abundances)

Disadvantages

- Needs 6D phase space info
- **Not a forward model** (no way to treat uncertainties)
- Derailed by large (>50%) smooth component
- Limited to integrable potentials

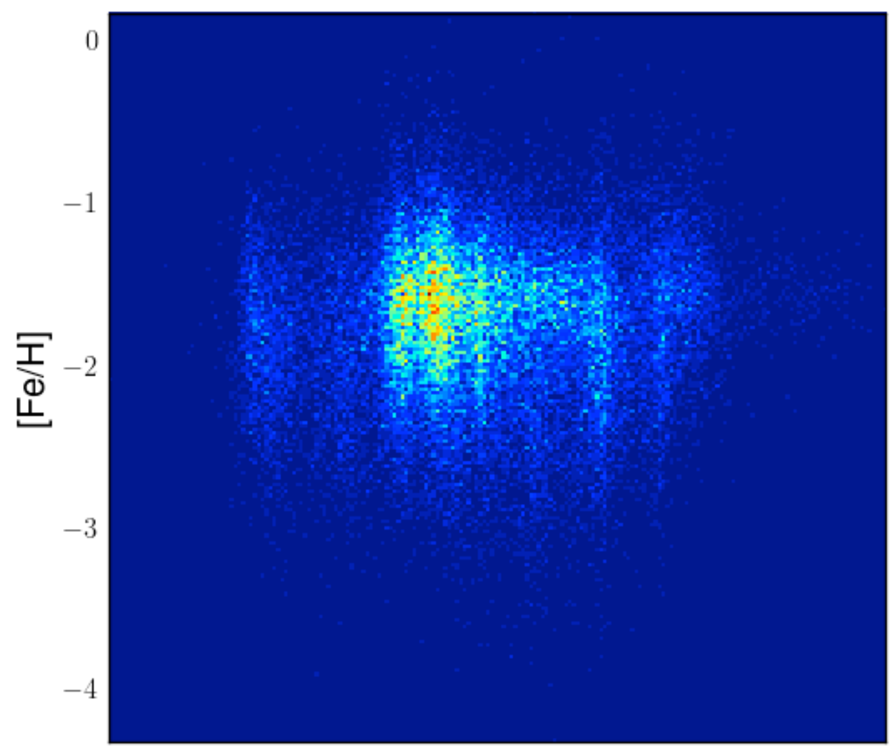
The takeaway

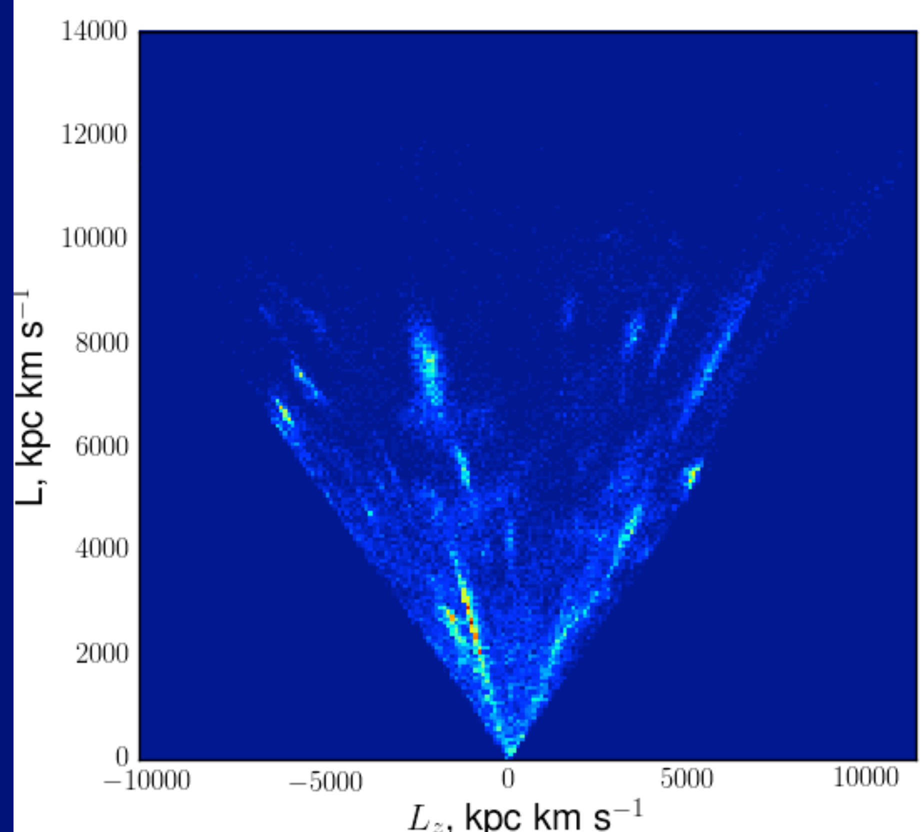
- Tidal streams are sensitive to the potential of the Galactic dark matter halo
- Streams form clumps in action space that still look clumpy at Gaia precision ($\delta\pi/\pi < 0.2$)
- Maximizing D_{KL} of action distribution **identifies the potential parameters**
- Relation between D_{KL} and posterior probability lets us set confidence intervals
- Expected number of MW streams is enough
- Stream membership info **not required**

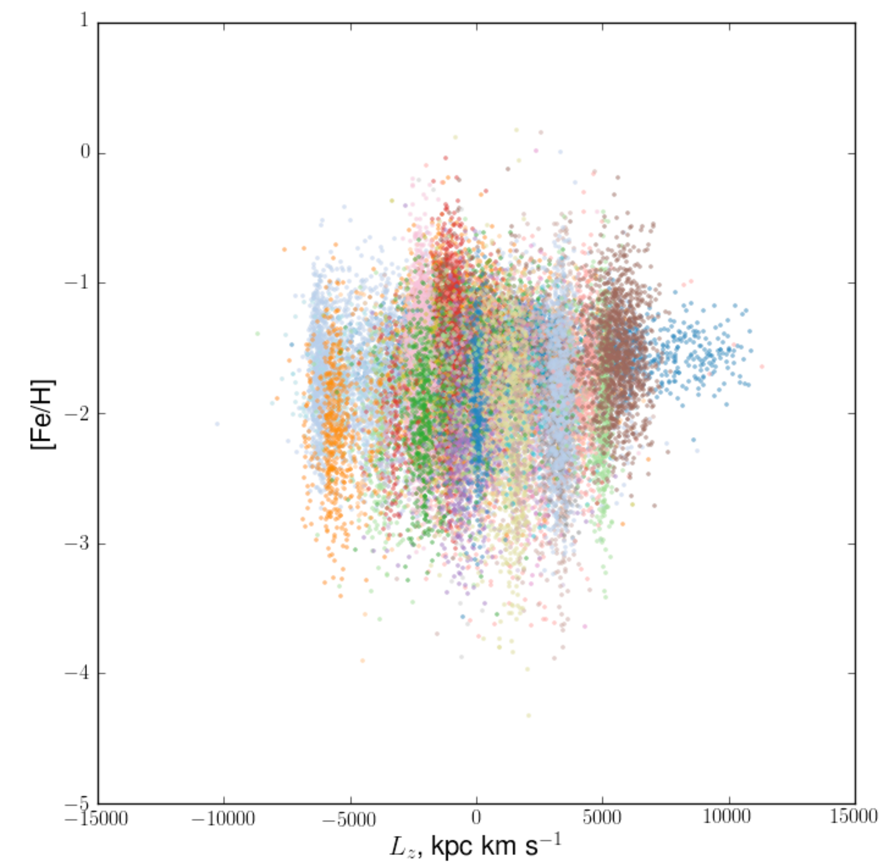
The future

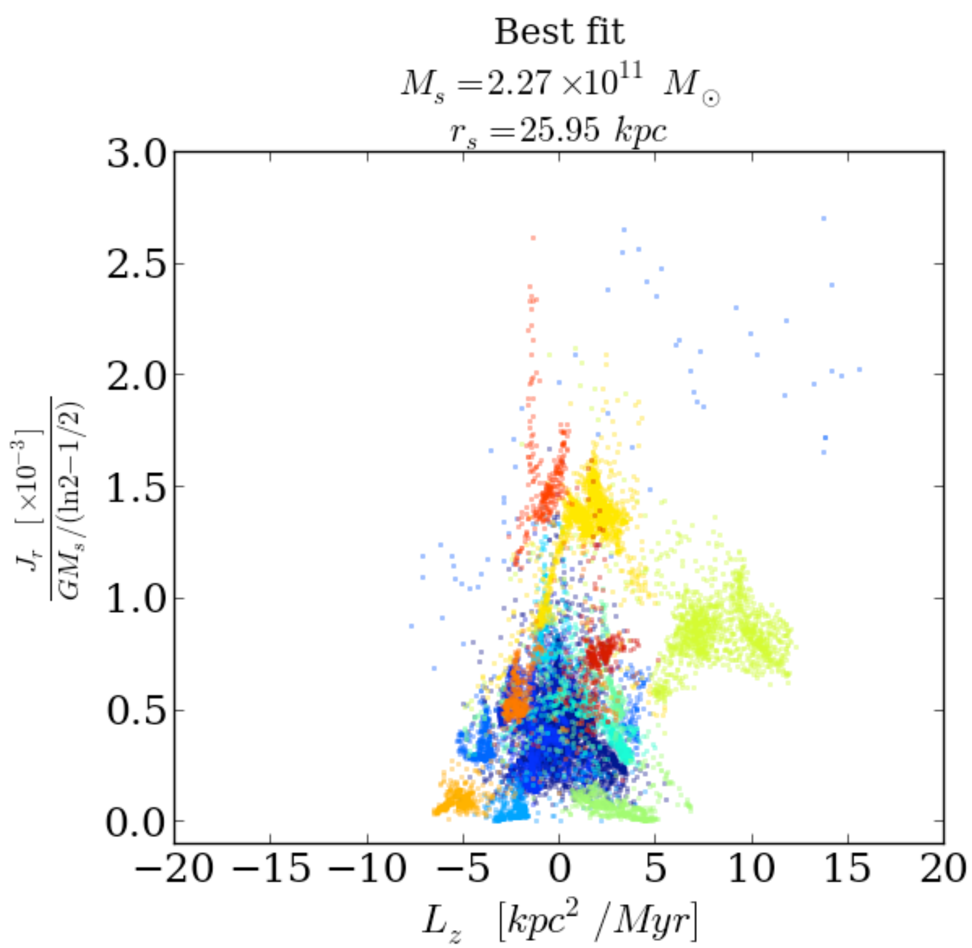
- **Metallicity/abundances as extra dimensions**
- More realistic potentials: flattening, triaxiality
- Halo-to-halo stochasticity
- Uses for the recovered action space

the **near** future









Metallicities and spreads from empirical relations of Kirby et al. (2011), **constant M/L**

$Z/Z_\odot$ might be better (e.g. Leaman 2012)