Constraining Milky Way models with action clustering

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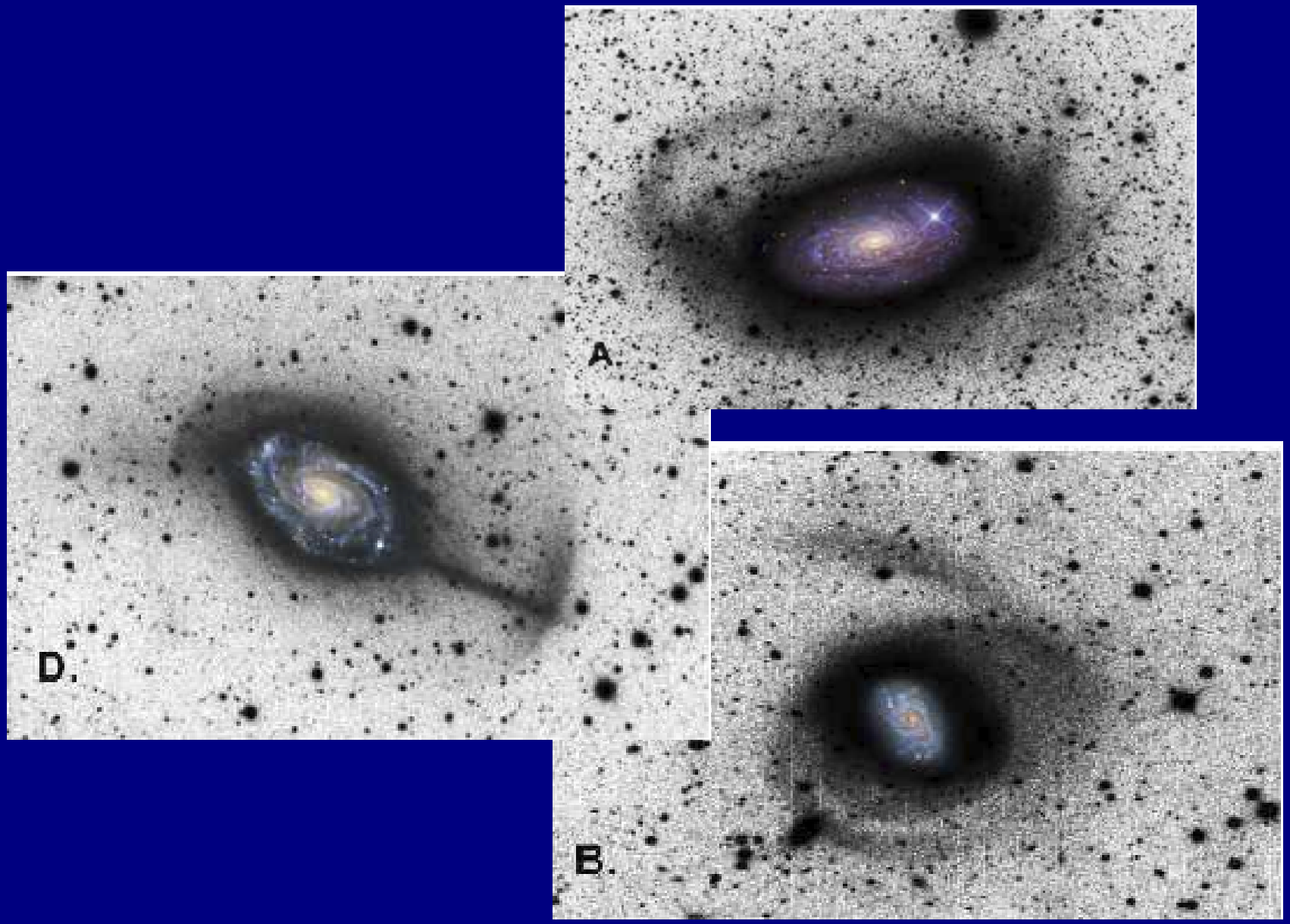
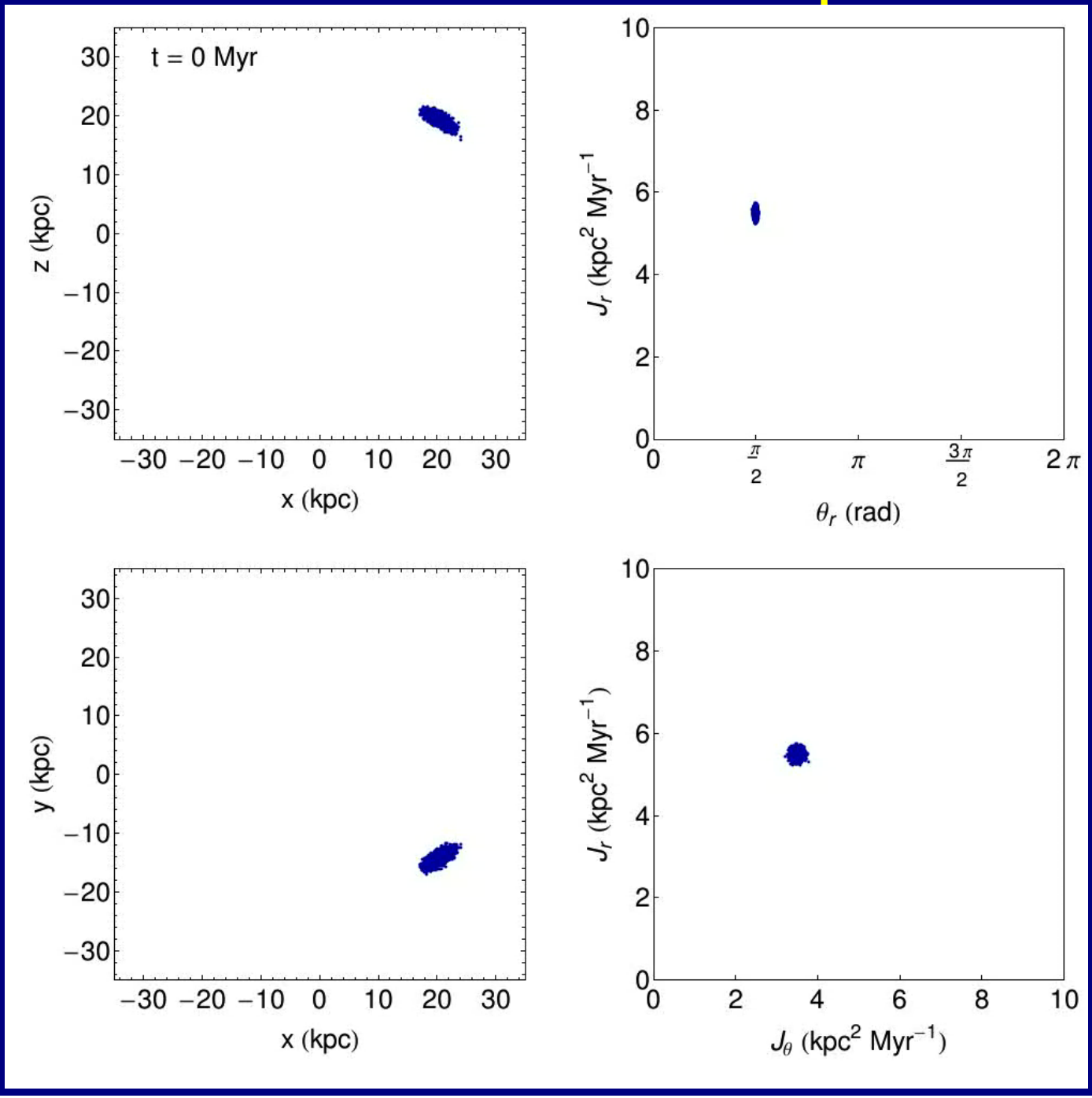
Tidal streams: keys to the dark Milky Way



Martinez-Delgado et al. 2010

Tidal streams in AA space



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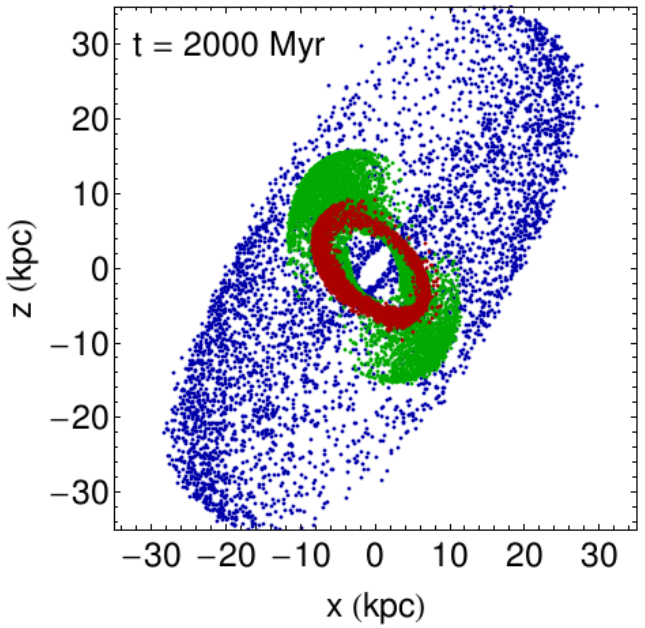
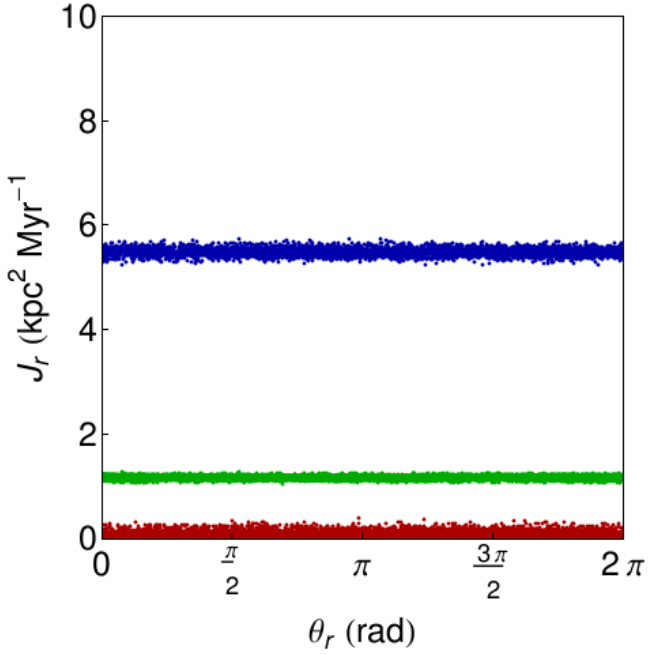
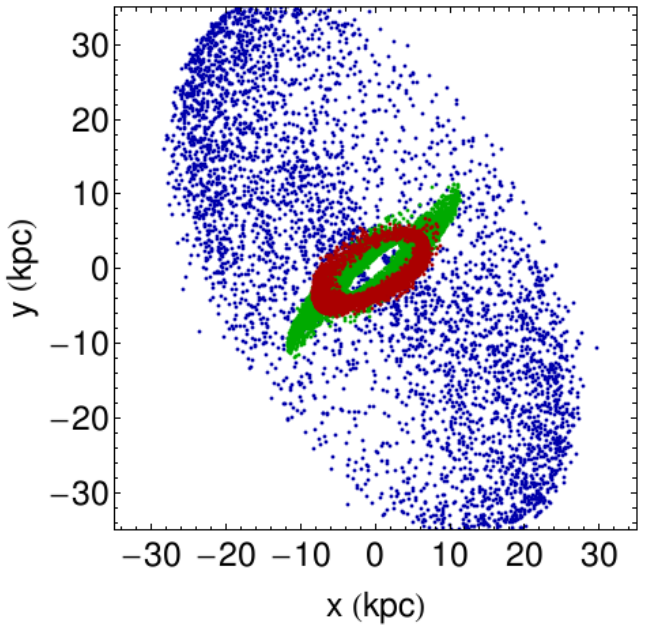
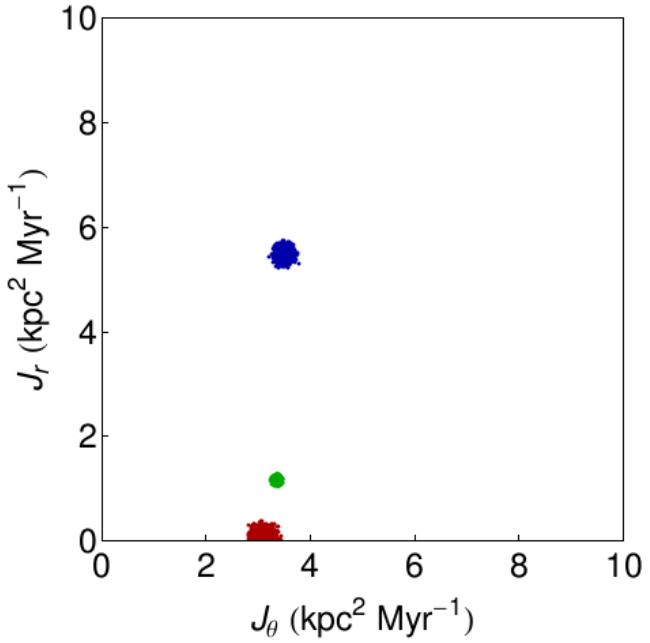




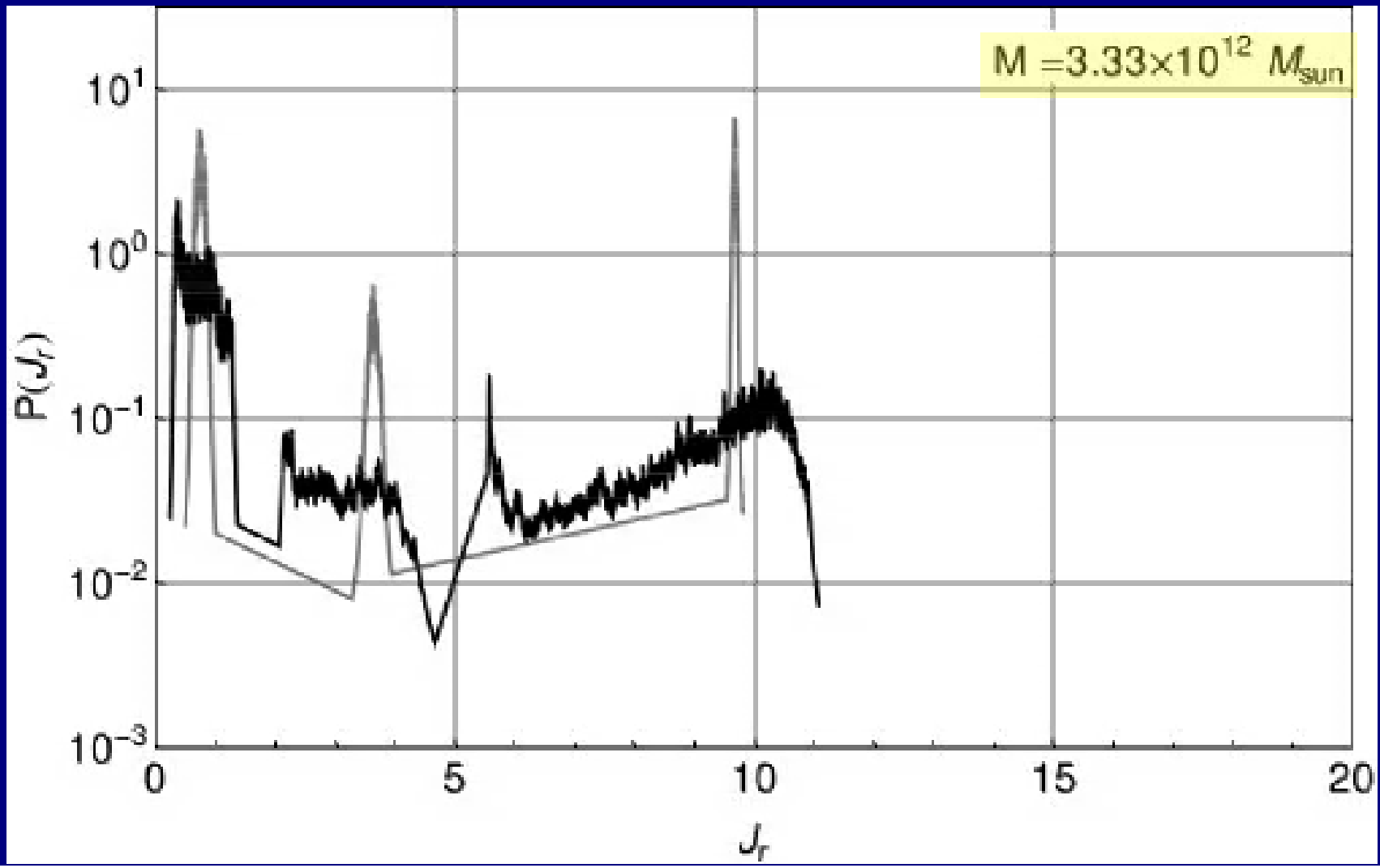




Actions are most clustered in the correct potential

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

Potential parameters
Observations
Both



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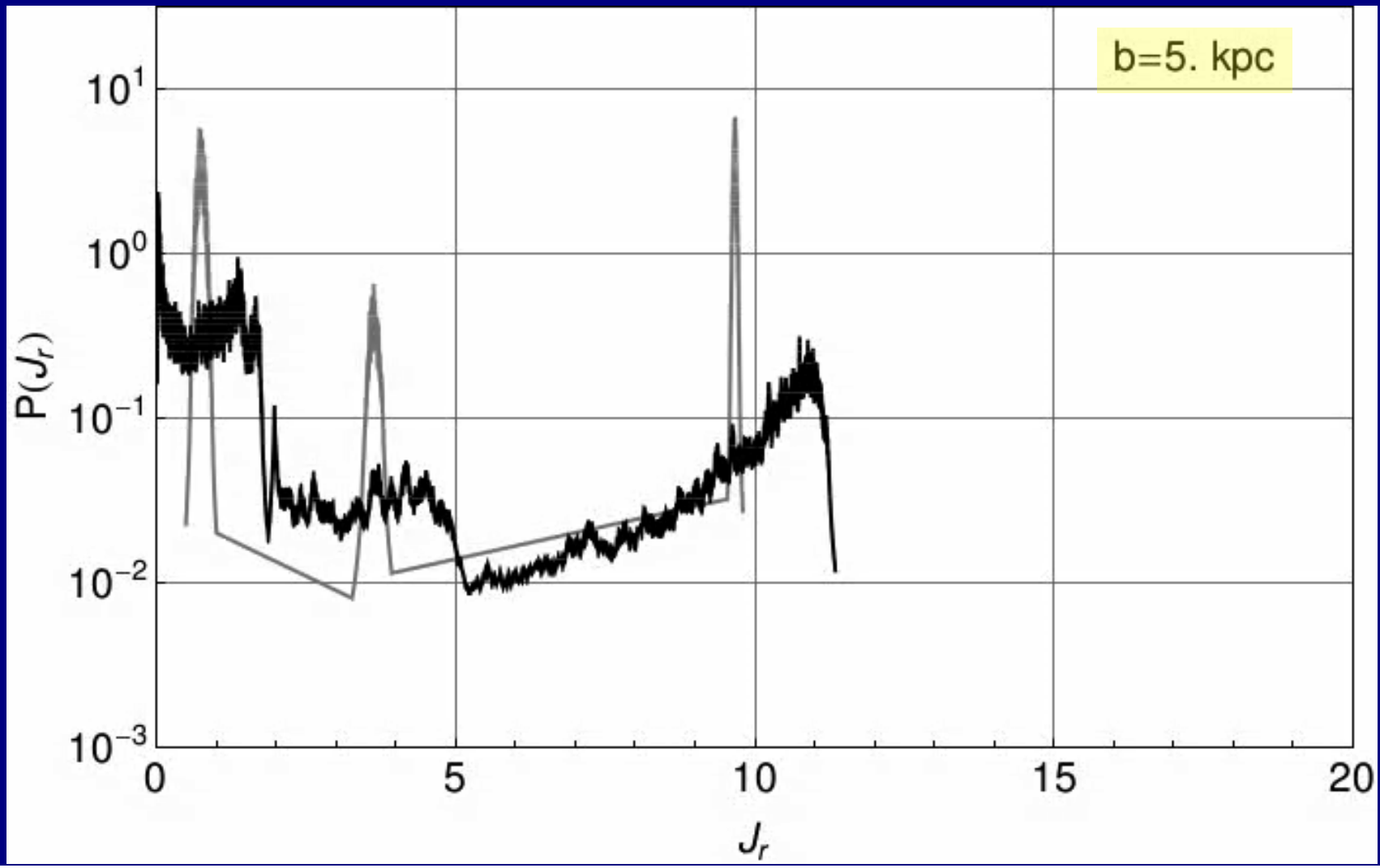
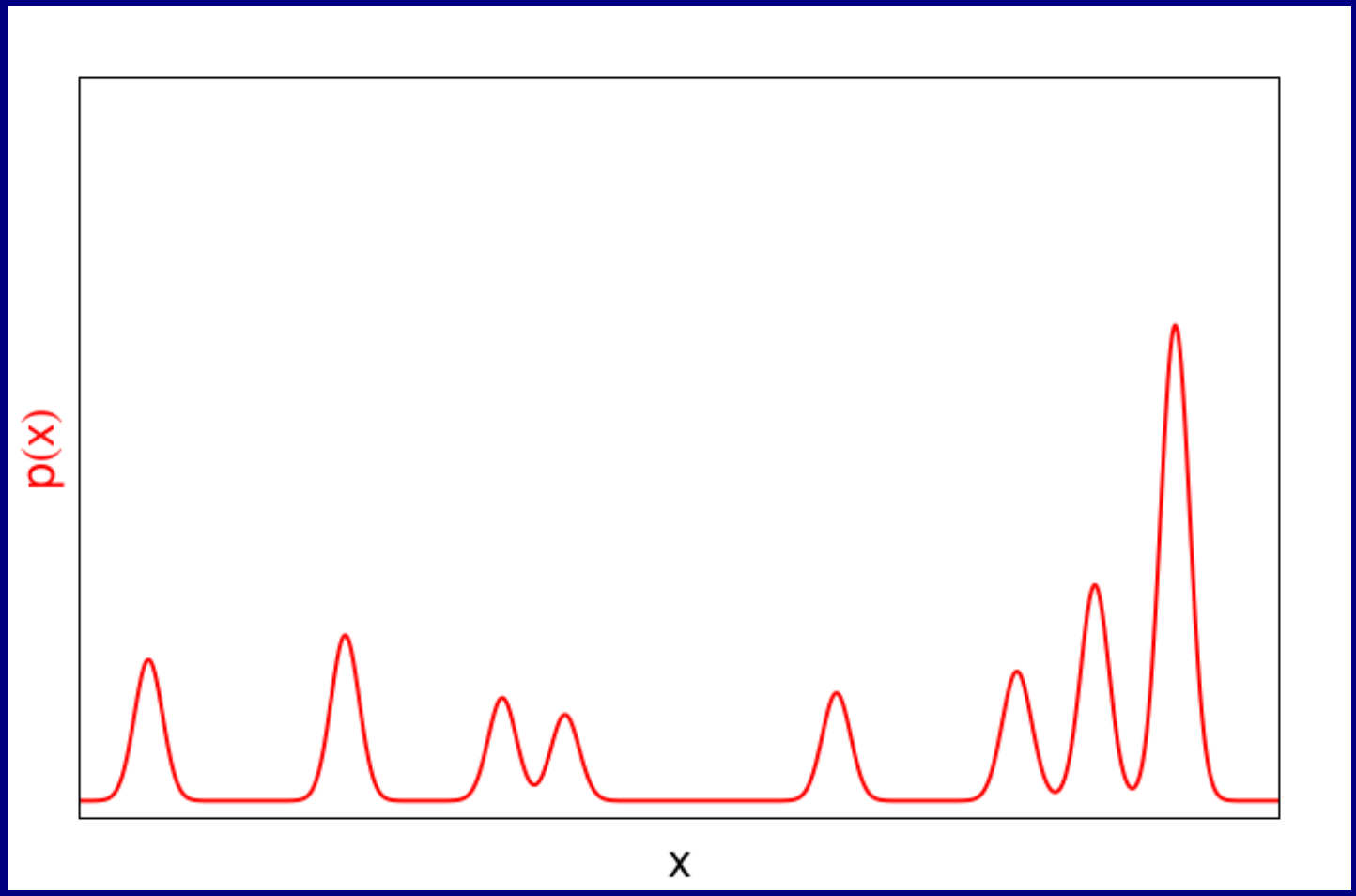


Clustering measurements: the Kullback-Liebler divergence



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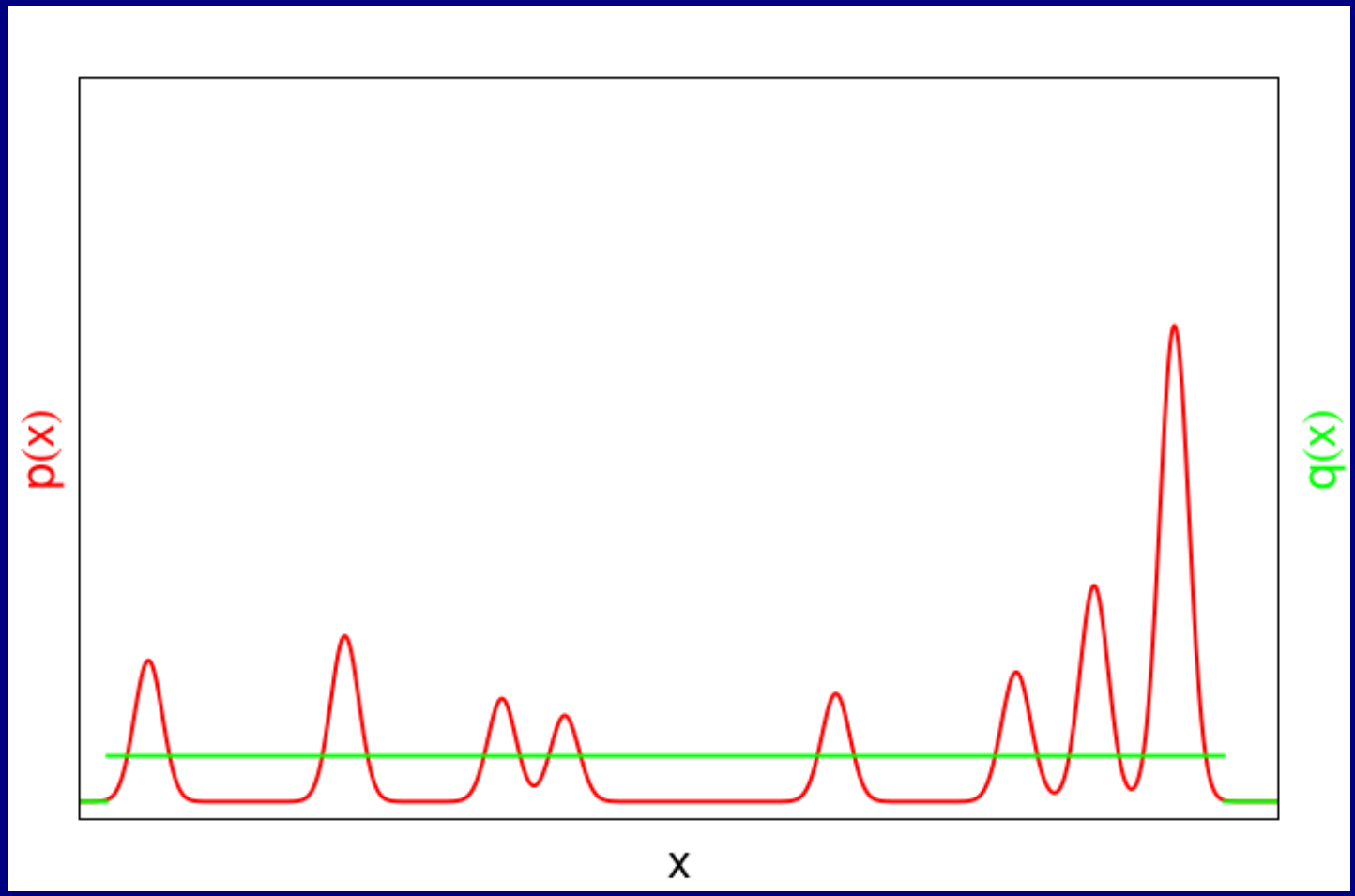

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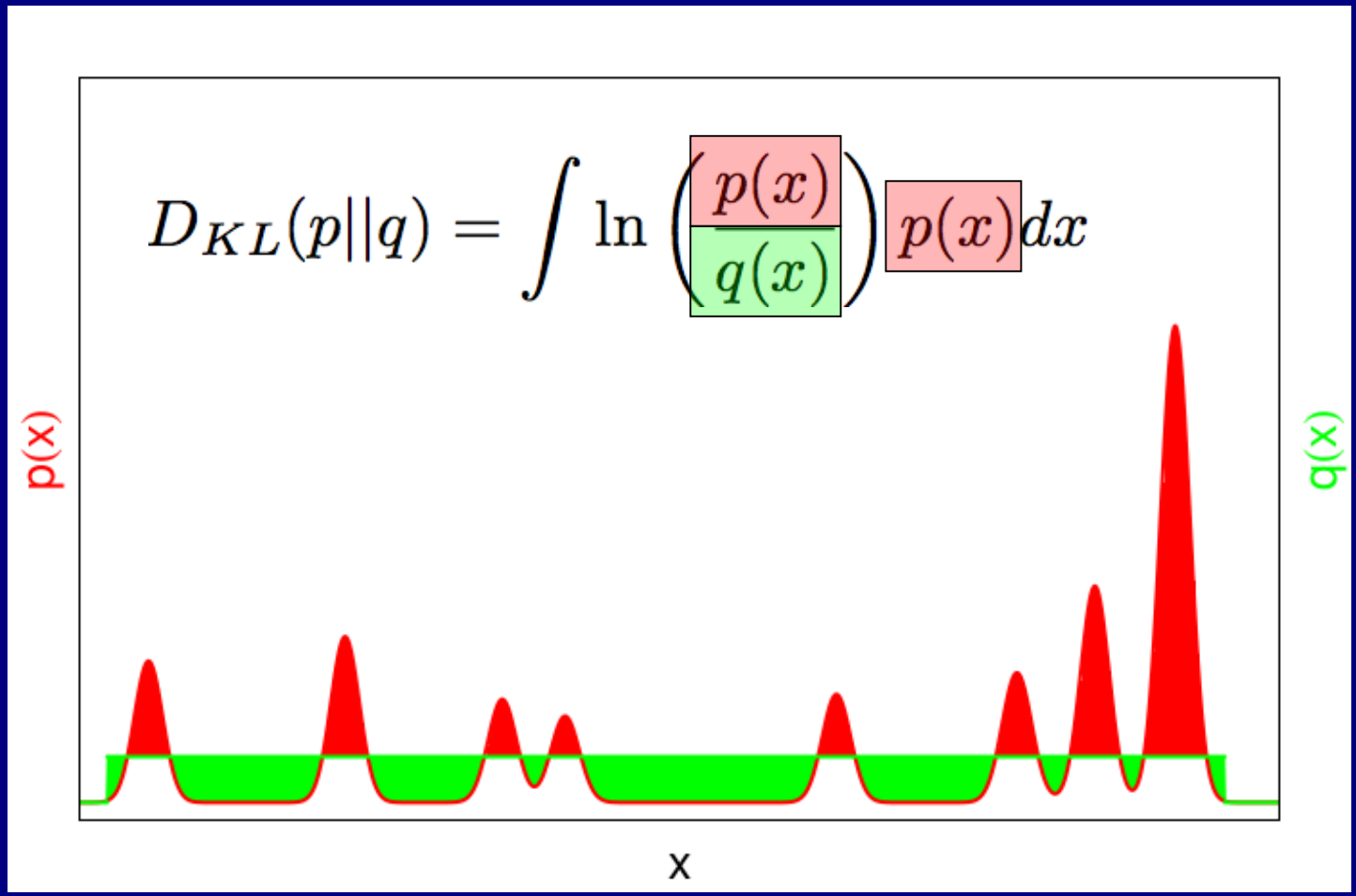

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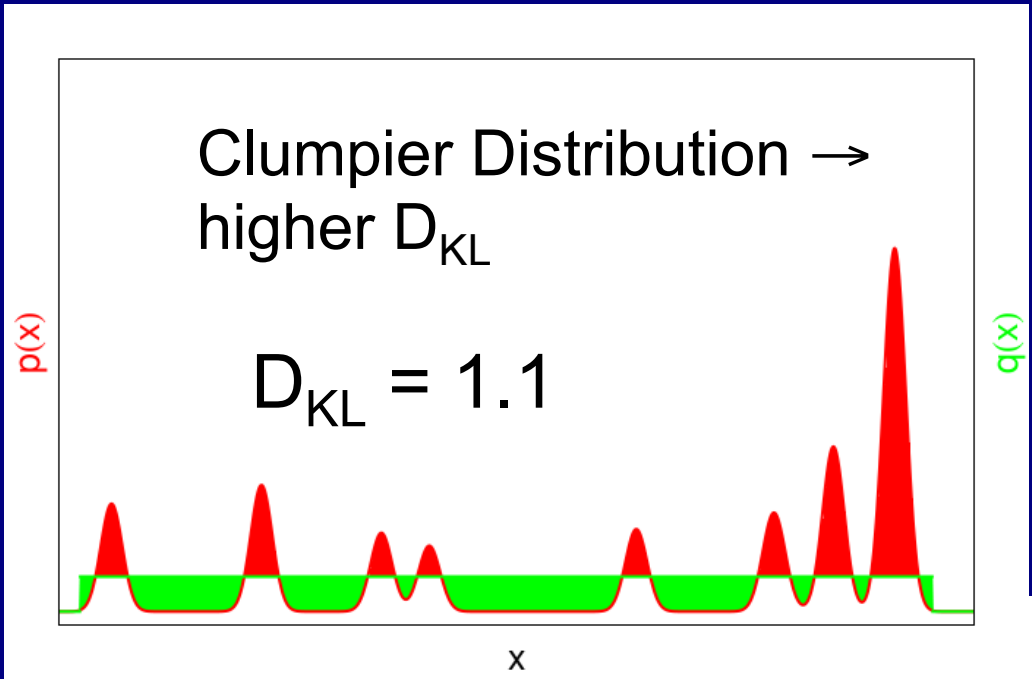
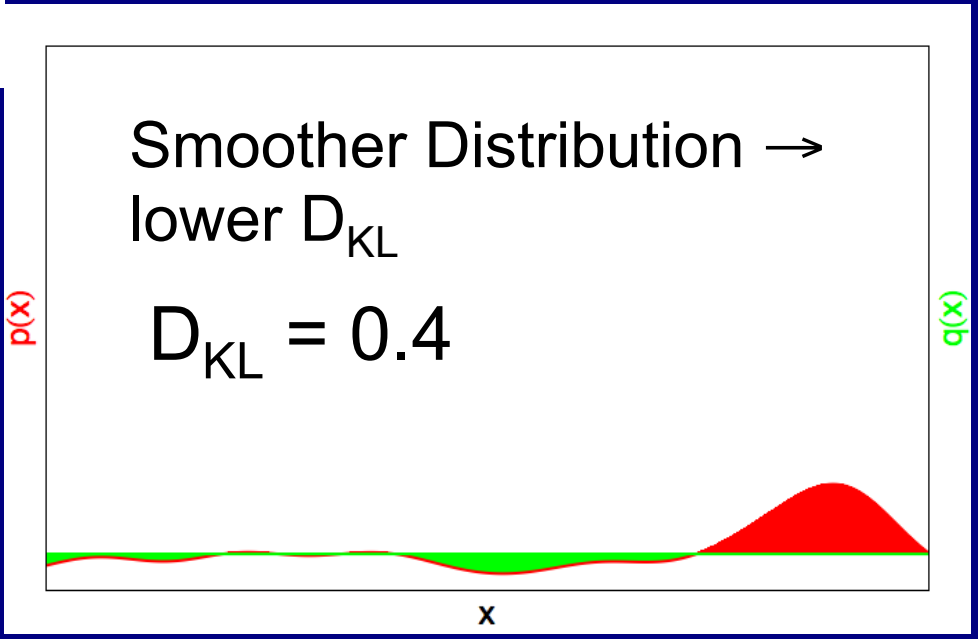
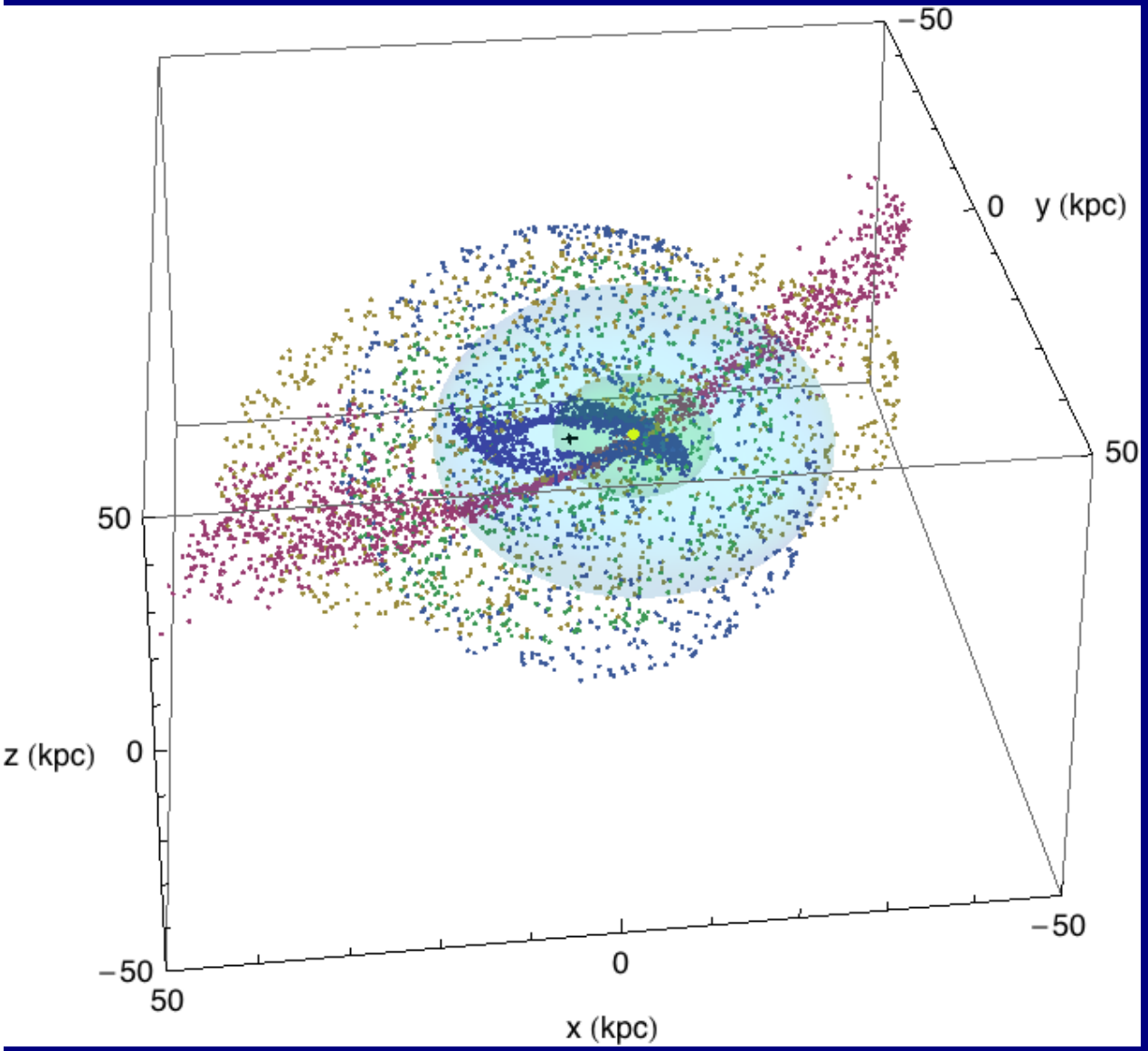




Performance with perfect measurements



Initial "satellites":
σ_r : 0.5-4.5 kpc
σ_v : 10-40 km/s

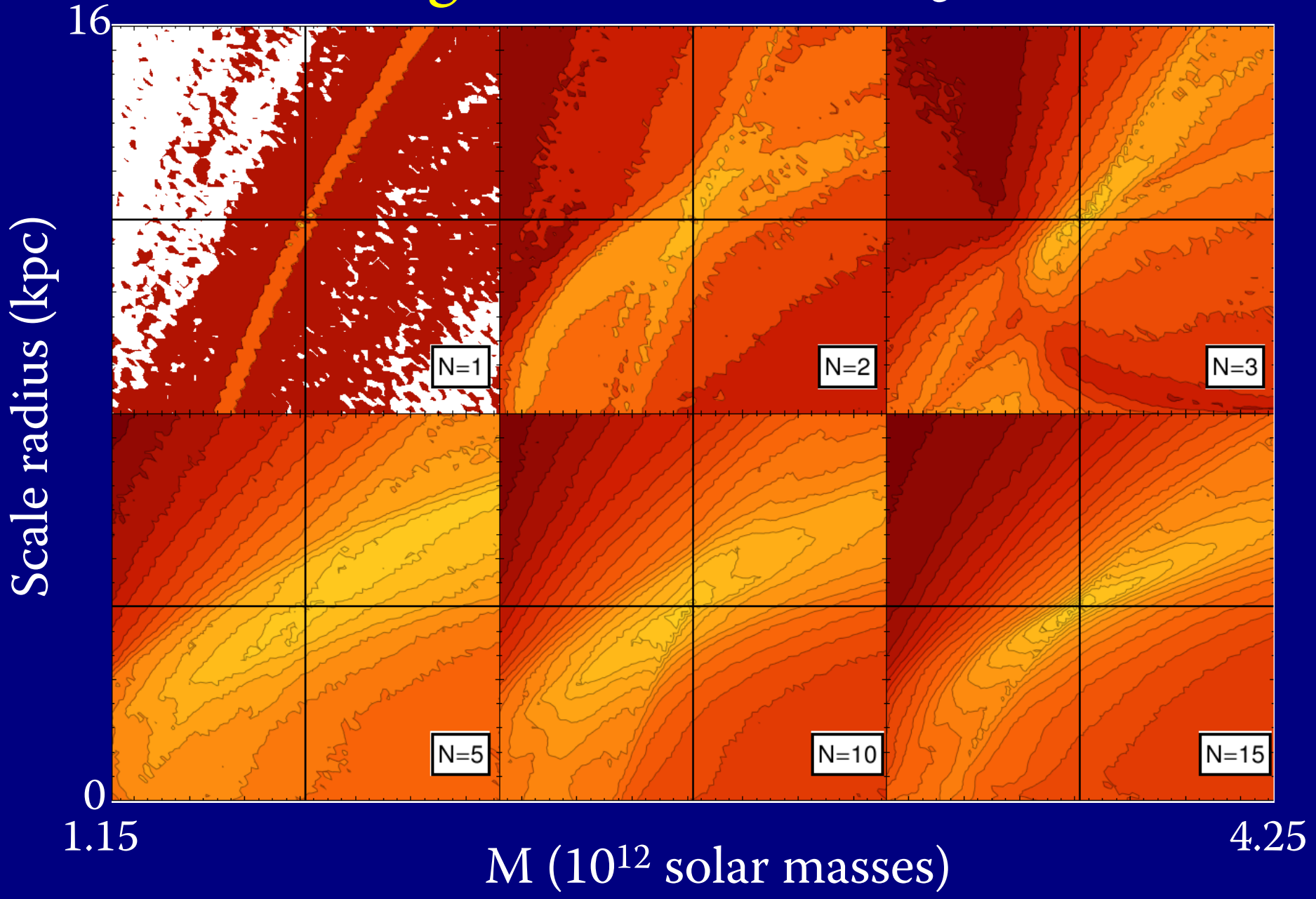
Orbital pds: 20-70 Myr
Stream ages: 500-5000 Myr

Sun GC

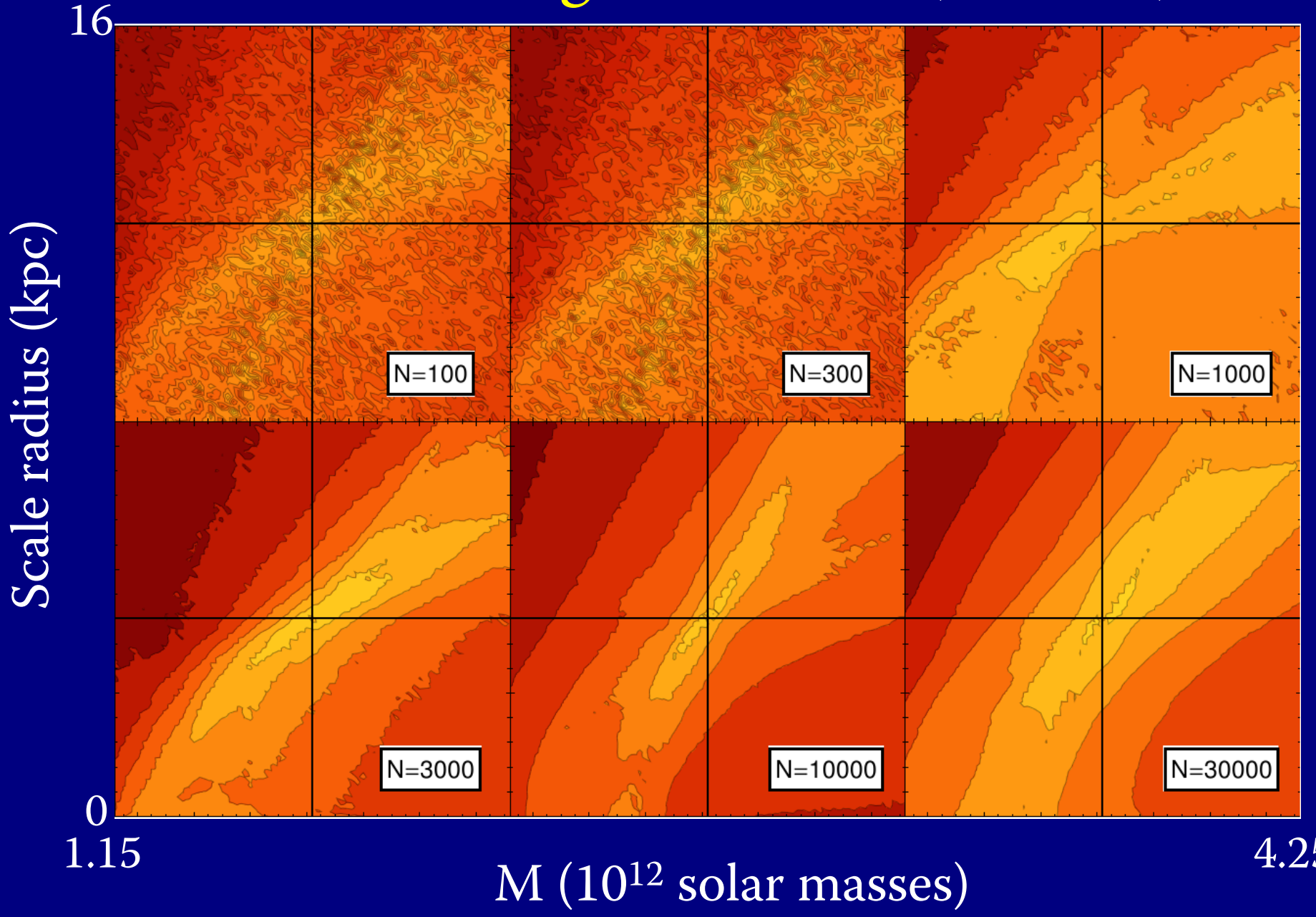
10 kpc from Sun

25 kpc from Sun

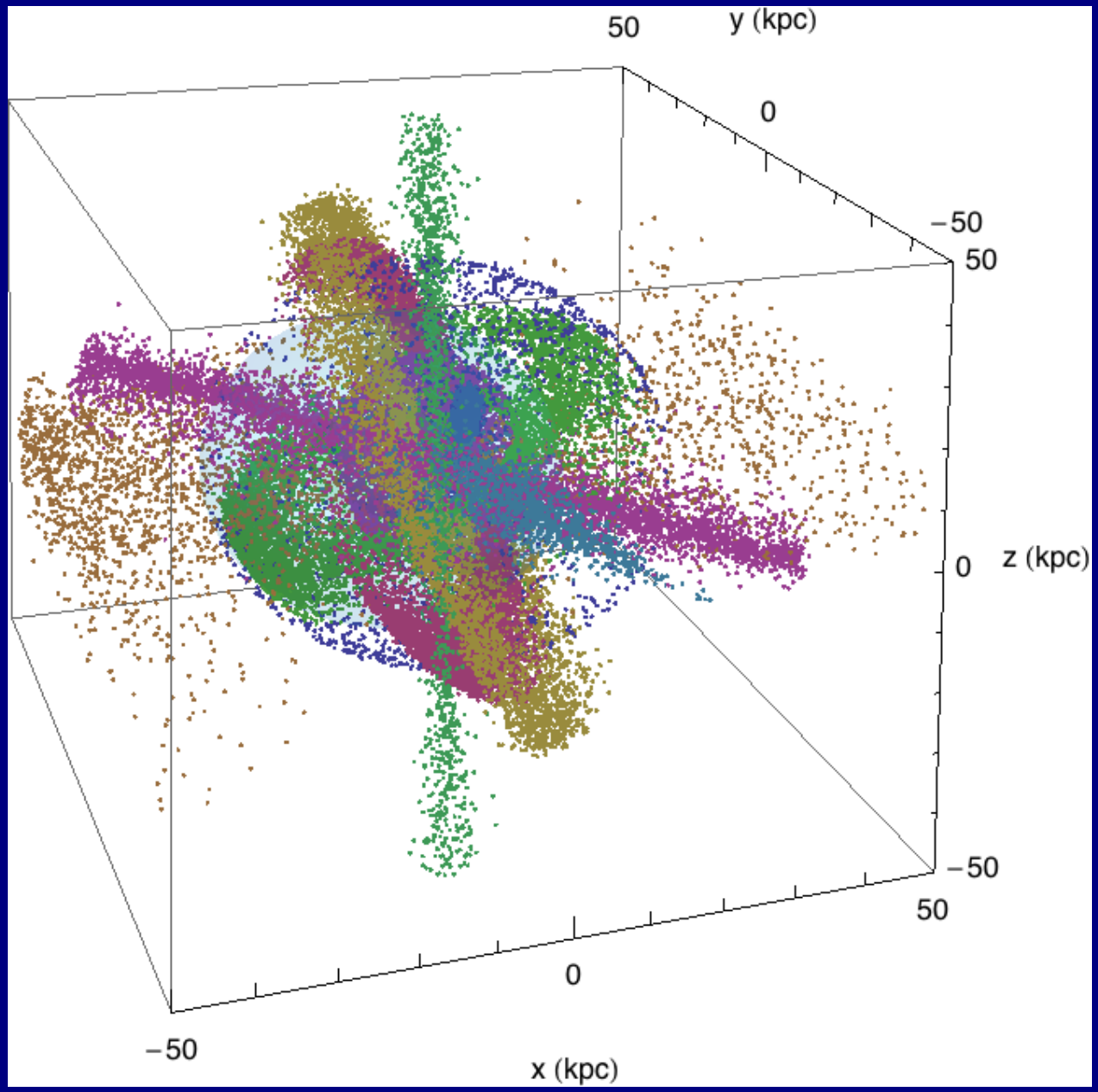
Effect of adding more streams (avg. 1000 stars each)



Effect of adding more stars (5 streams)



Including observational errors



- Ten “satellites”
- Avg. 5000 stars each
- Randomly chosen orbits & ages
- Isochrone potential
- Convolved with Gaia/4MOST error models
- Includes Gaia photo parallaxes
- No RA/Dec cuts

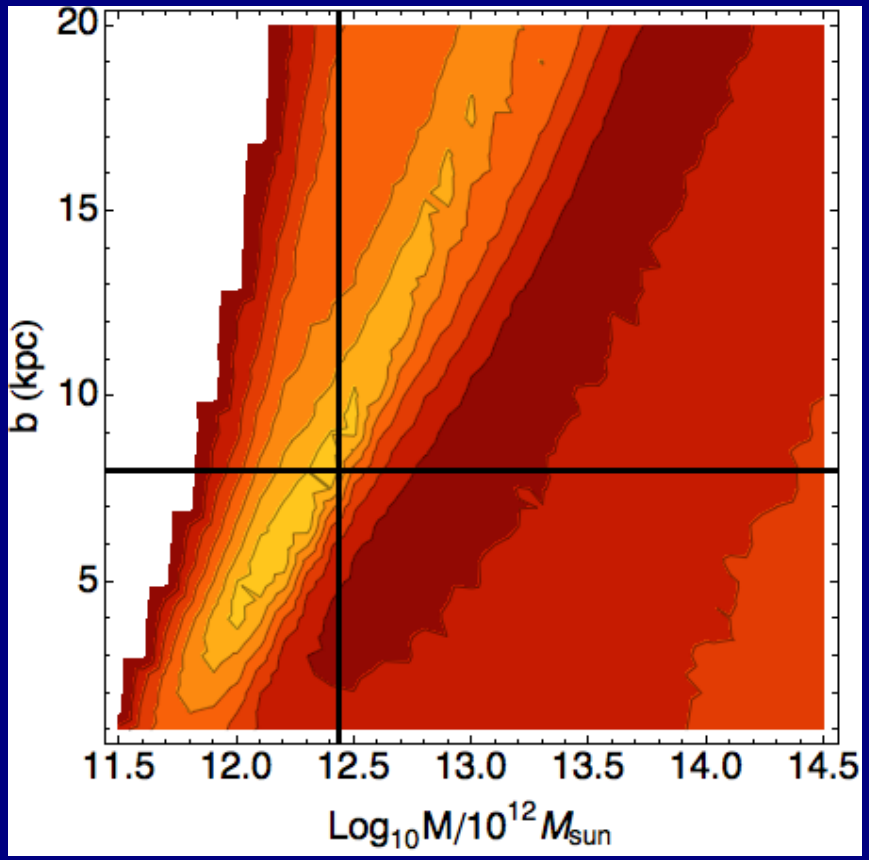
The effect of improved RVs

% of stars with $\sigma_\pi/\pi < 0.2$
that also have $\sigma_{RV} < 10$ km/s

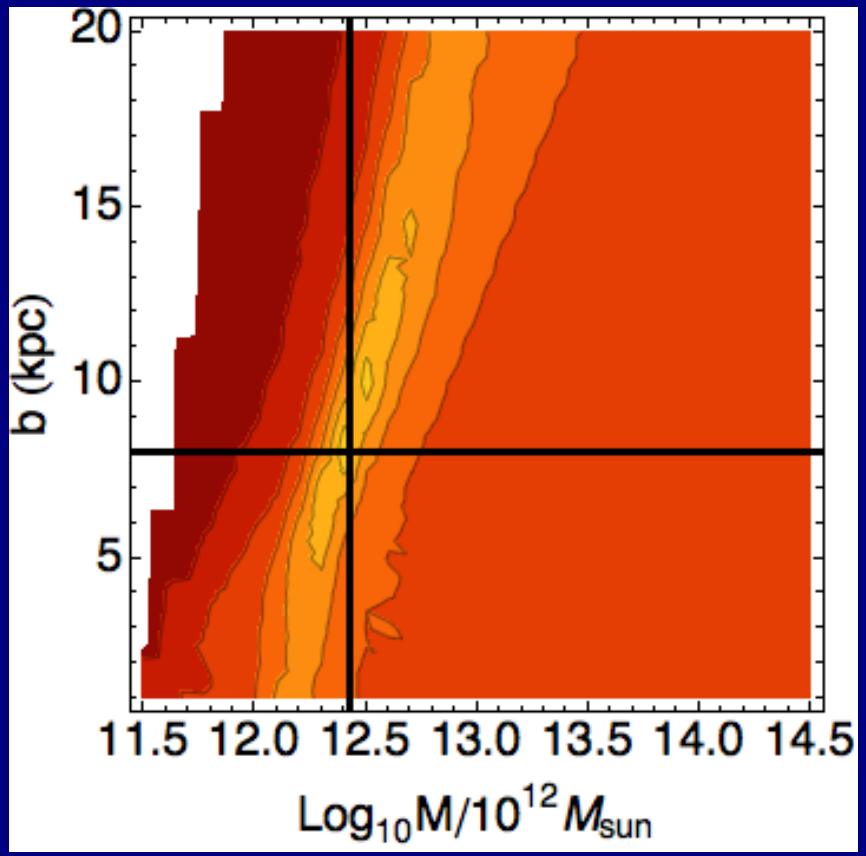
Stellar mag	Gaia only	Gaia + 4MOST
"Red giants" ($M_V = 1$)	60%	100%
"MSTO" ($M_V = 4.5$)	2%	100%

The effect of improved RVs

For RED GIANTS ($M_V = 1$)



Gaia only



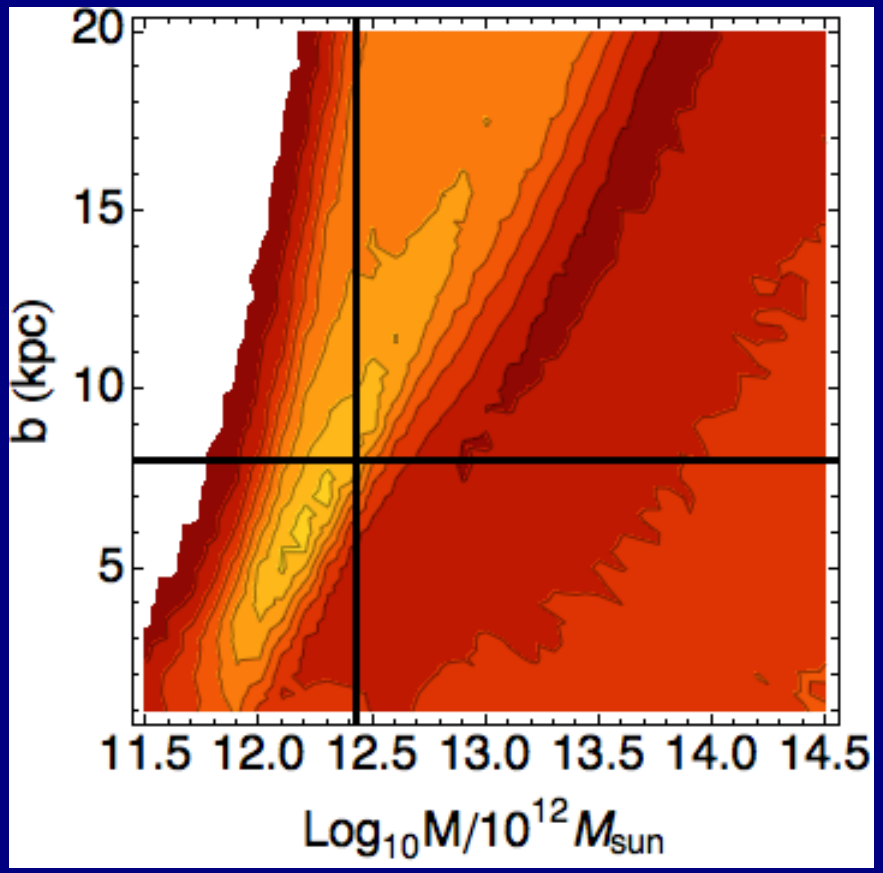
With 4MOST RVs

The effect of improved RVs

For MSTO (M_V = 4.5)

Not enough stars left!

Gaia only



With 4MOST RVs

Conclusions

- Action clustering can be used to constrain the mass and shape of a potential
- number of streams > number of stars per stream
  - Resolve degeneracies between parameters
  - Clumpier underlying distribution provides more contrast
- Gaia photo parallax errors may be sufficient
- *Existence* of 4MOST RVs >> accuracy (dist error dominates)

  ⇒ sky coverage >> spectral resolution
- More stars = better constraints:
  - Find more streams
  - Larger distances = better total mass measurement
  - Pick best data in each stream

Review of action-angle coordinates

- Canonical transformation for bound orbits

$$(q,p) \rightarrow (\theta, J) \qquad H(q,p) \rightarrow H(J)$$

- Angles increase linearly with time

$$\theta = \theta_0 + \Omega(t - t_0) \qquad \Omega \equiv \frac{\partial H}{\partial J}$$

- Actions are
  - Constants of motion
  - Adiabatic invariants
  - Potential-dependent

$$J = \text{const for } \frac{1}{H}\frac{\partial H}{\partial t} \ll \Omega$$

Outline

- Review of action-angle variables
- Tidal streams in action space
- How to measure clustering
- Proof of principle
- Effect of Gaia proper-motion errors
- Impact of 4MOST improved RVs