Disc kinematic substructure beyond the solar neighbourhood

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the Netherlands

A. Helmi and the RAVE collaboration

Ringberg Meeting, 12th April 2012
Dynamics meets Kinematic Tracers

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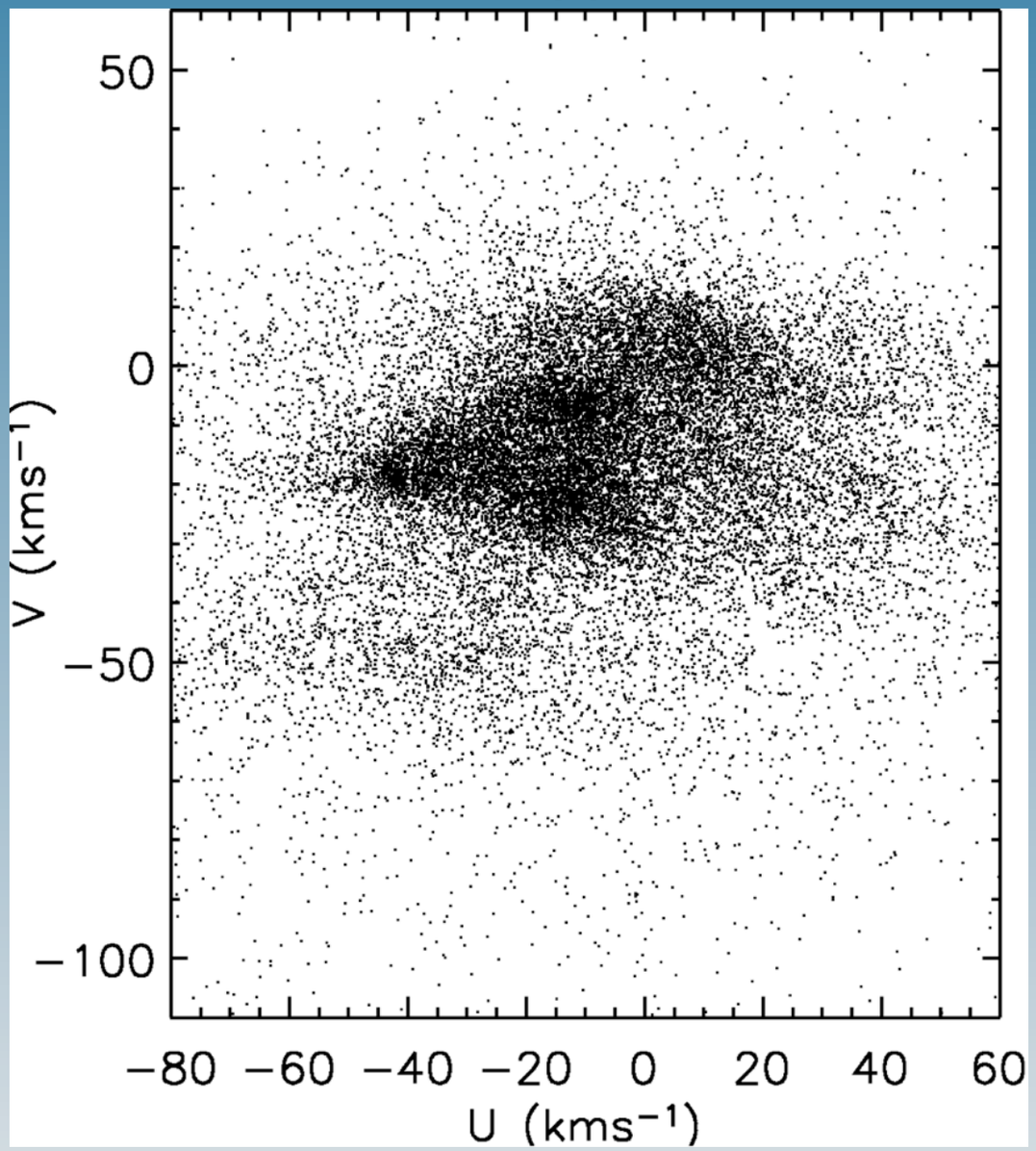
Introduction

Velocities of stars in the solar neighbourhood (~150 pc)

Hipparcos + Geneva-Copenhagen



Discovery
- Proctor 1869
- Eggen (1950-2000)

Hipparcos era
- Chereul et al. 1998
- Dehnen 1998

With radial velocities
- Asiain et al. 1999
- Skuljan et al. 1999
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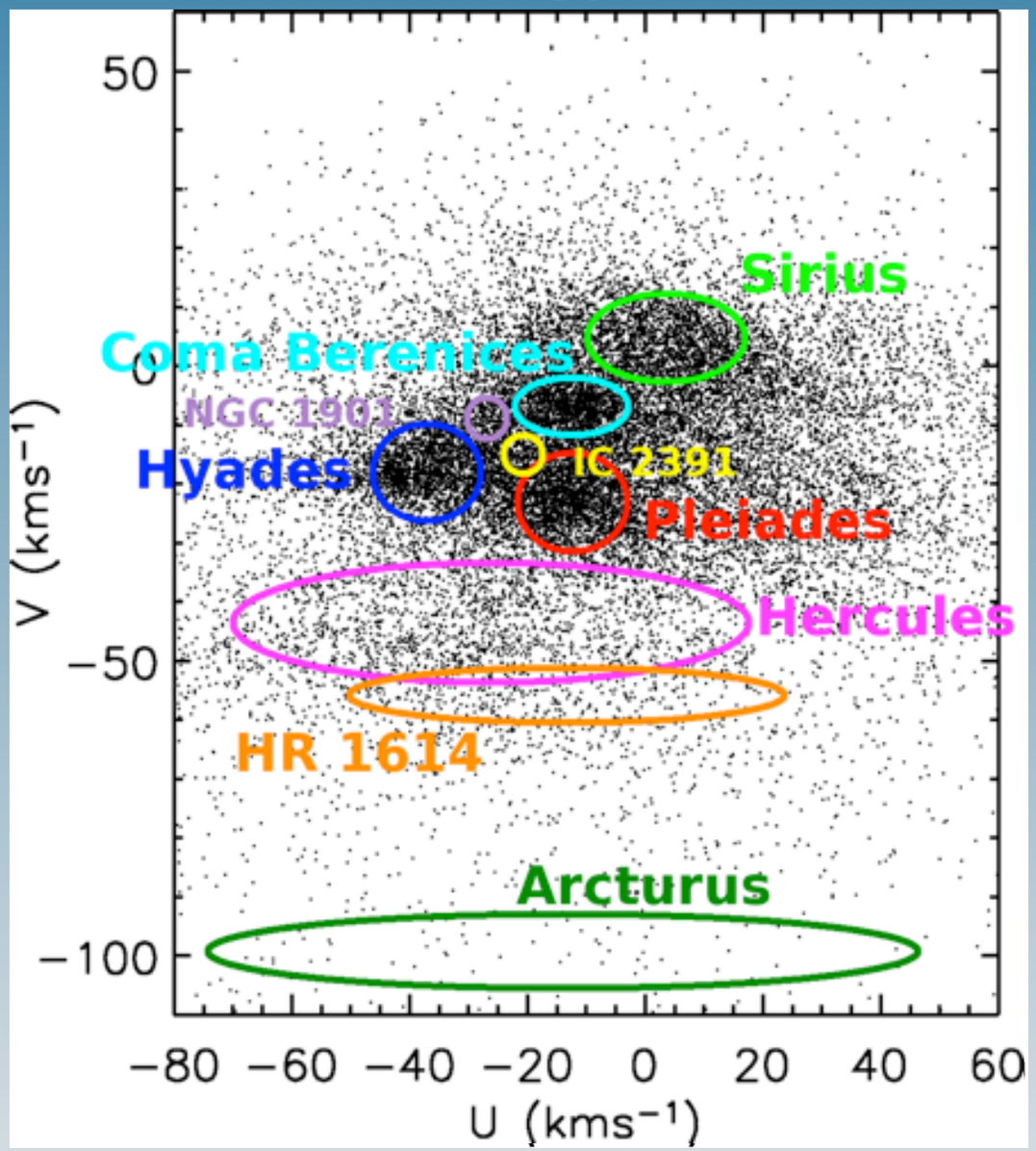

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Origin of the kinematic groups

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- Disruption of a stellar cluster

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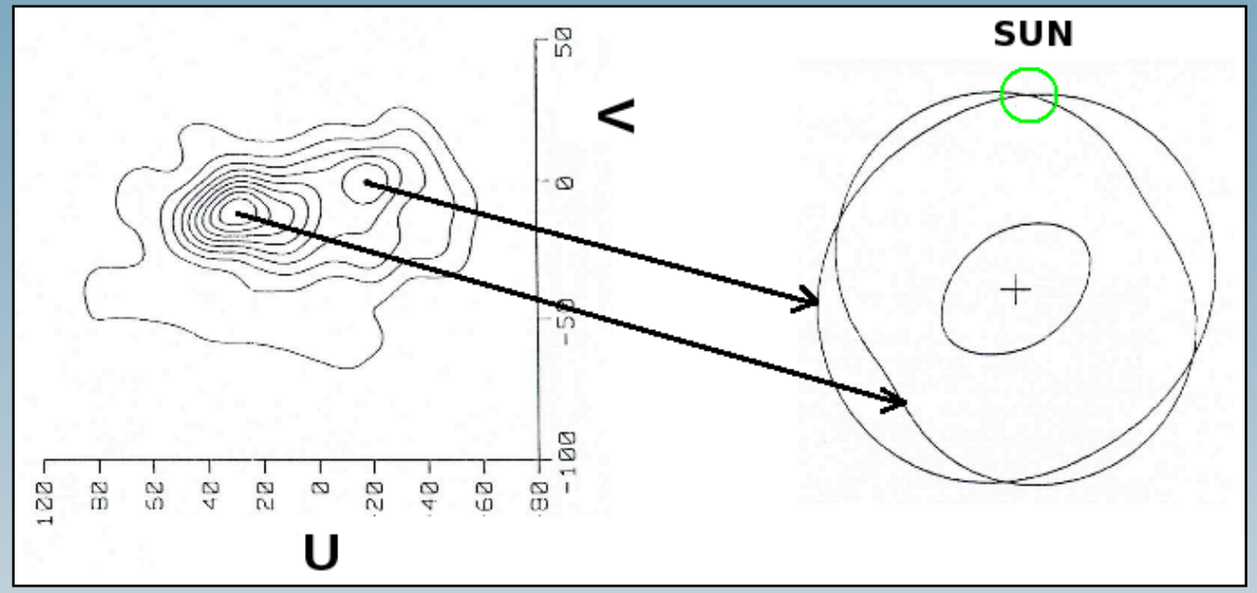
- Orbital and resonant effects of the MW spiral arms and bar

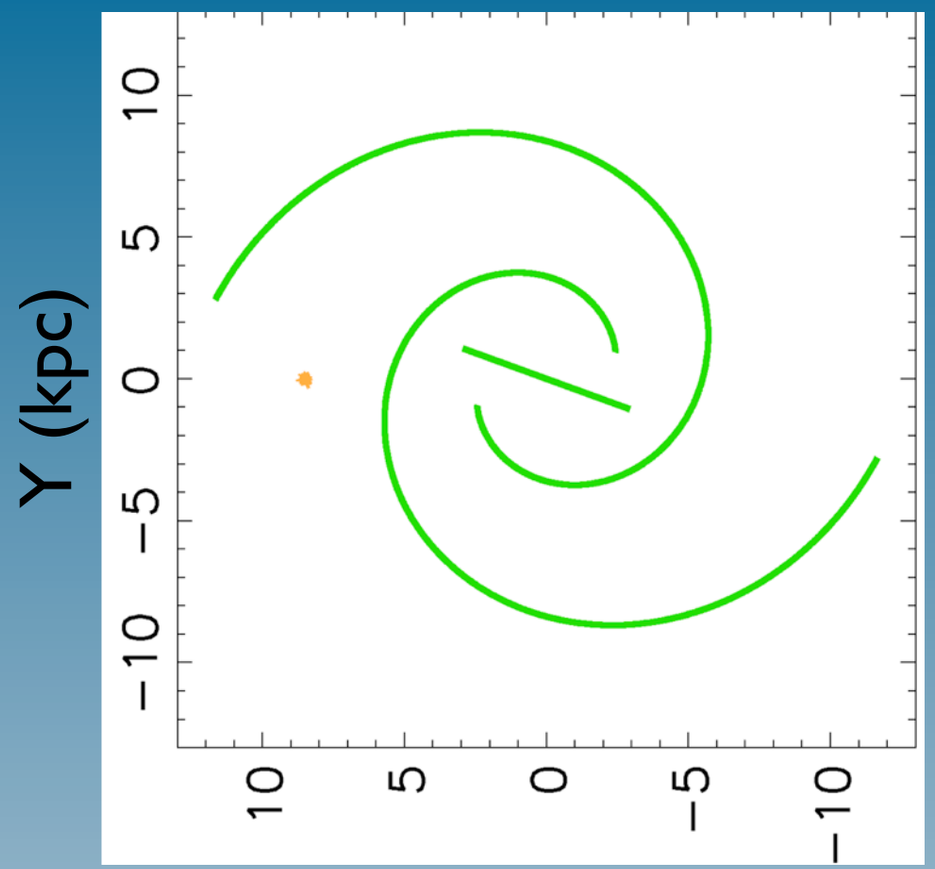


Kalnajs 1991

Dehnen 2000
Fux 2001
Quillen & Minchev 2005
Chakrabarty 2007
Antoja et al. 2009, 2011

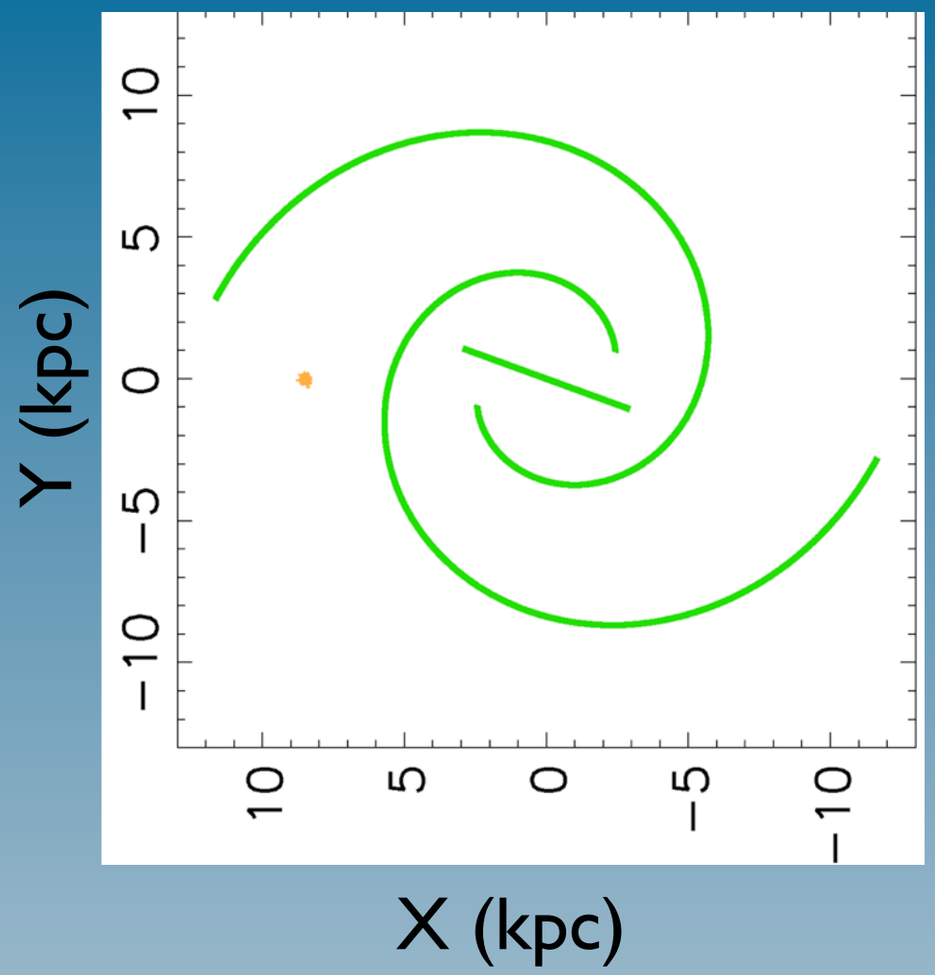
Hercules, Hyades, Pleiades, Sirius, Coma Berenices, Arcturus

Degeneracy!



Outline:

- Models: orbital effects on the disc kinematics
- RAVE: study of the kinematic groups across the disc



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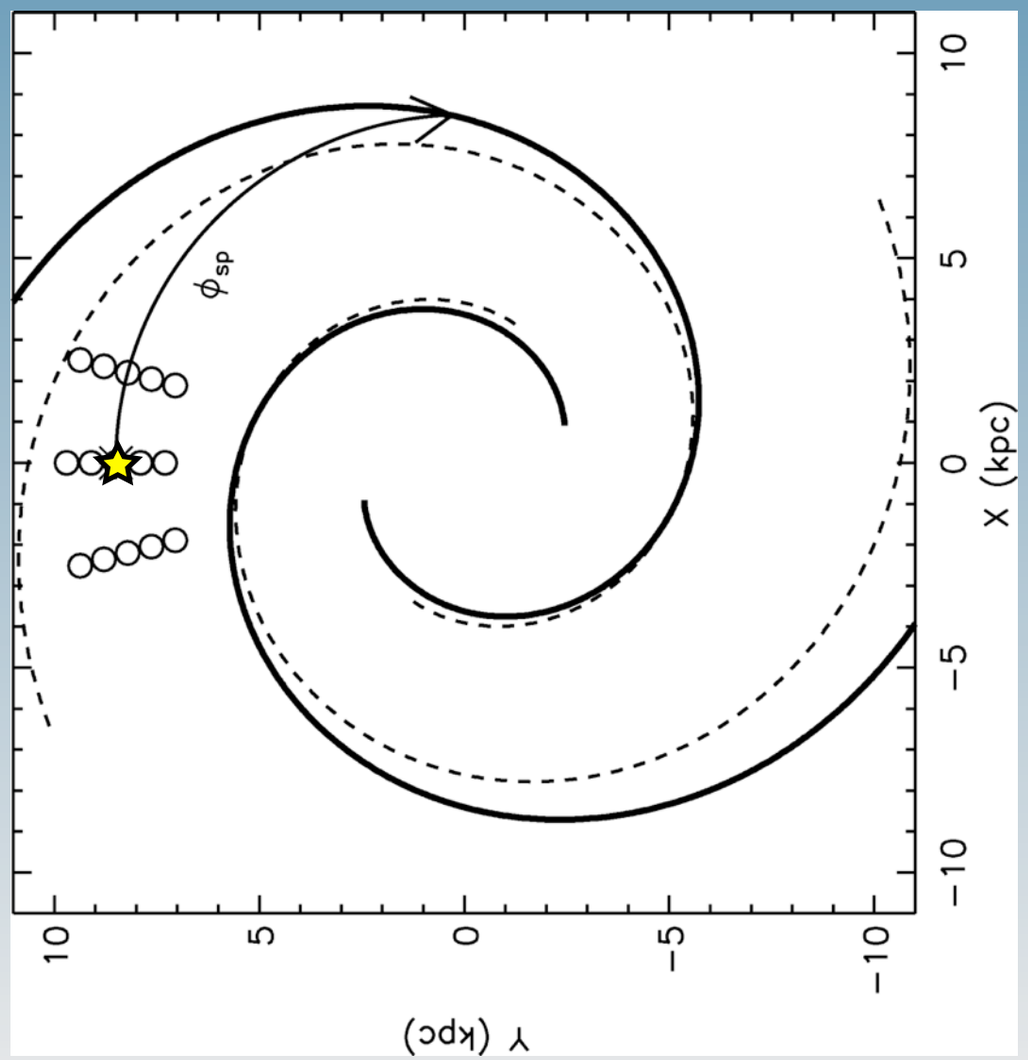
Spiral structure in the MW

Test particle simulations

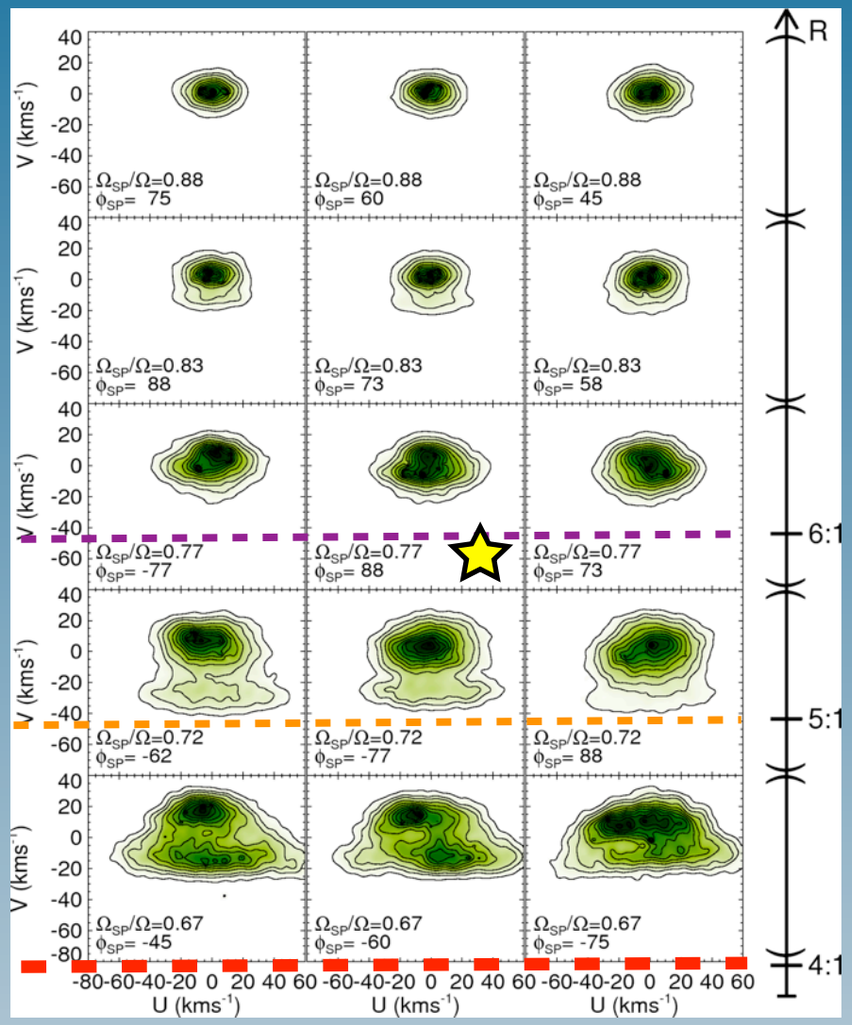
PERLAS model
(Pichardo et al. 2003)
Superposition of small pieces of mass distribution

Property		Value or range
Number of arms	m	2
Scale length	R_Σ (kpc)	2.5
Locus beginning	R_{sp} (kpc)	2.6/3.6
Pitch angle	i (°)	15.5/12.8
Relative spiral phase	$\phi_{sp}(R_\odot)$ (°)	88/60
Pattern speed	Ω_{sp} ($\mathrm{km\,s^{-1}kpc^{-1}}$)	15–30
Density contrast	A_2	0.14–0.23
Density contrast	K	1.32–1.6



Different pattern speed

Ωsp=20 km/s/kpc



Antoja et al. 2011

- Kinematic response to the spiral arms is strong and depends on disc position
- Significant changes: ~0.6 kpc in radius, ~2 kpc in azimuth
- Strong effects: close to the 4:1 inner resonance
- Where do we find more substructure? It depends on the pattern speed

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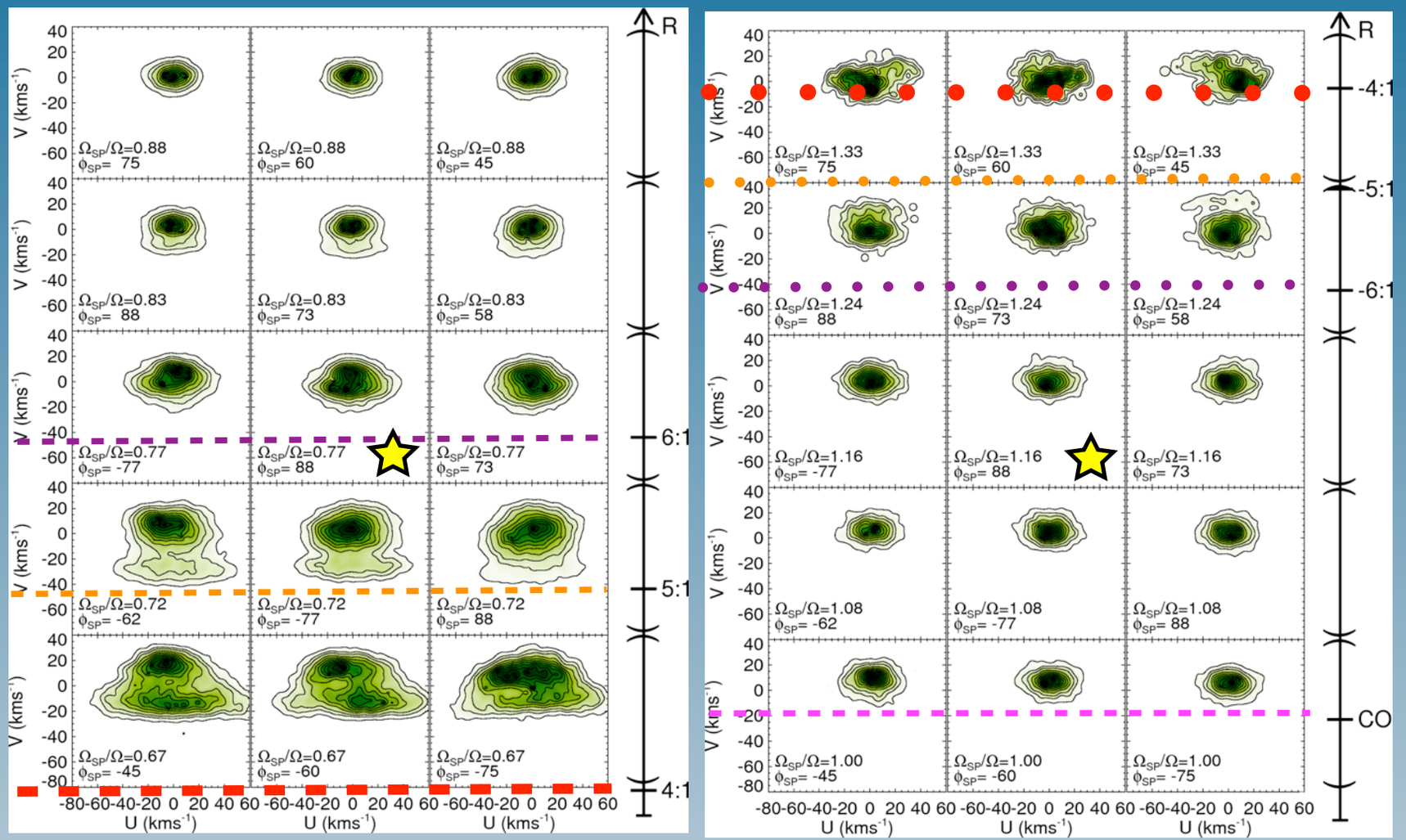
Ωsp=20 km/s/kpc

Ωsp=30 km/s/kpc



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Bar effects: a model for Hercules

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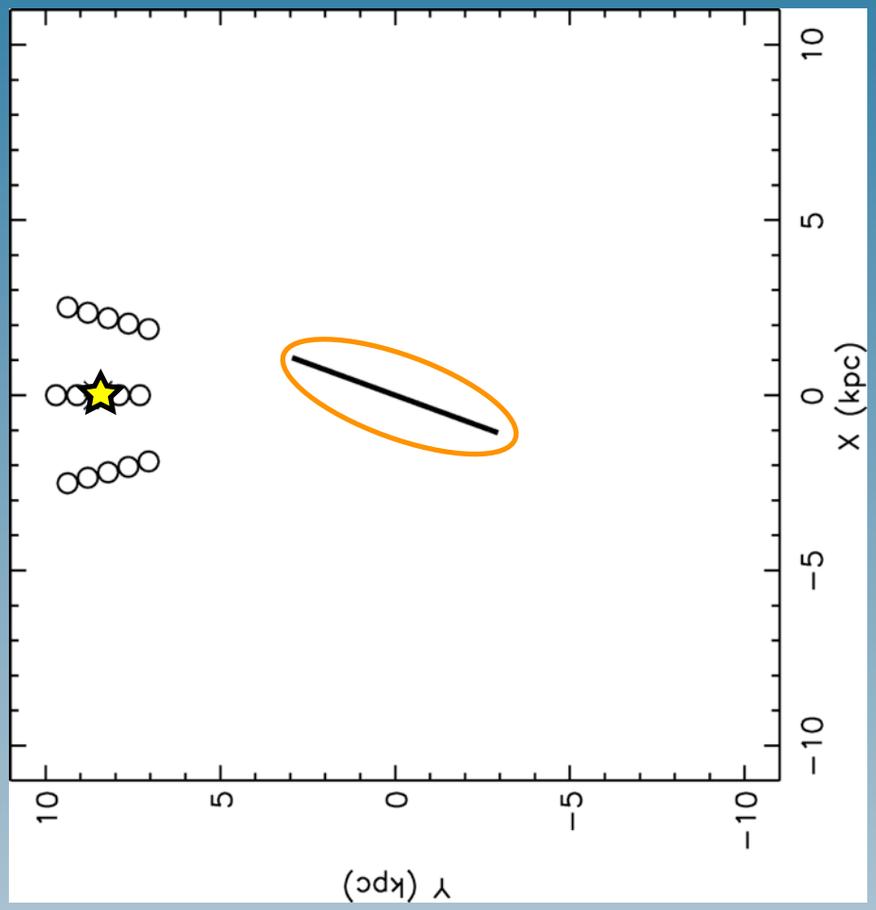

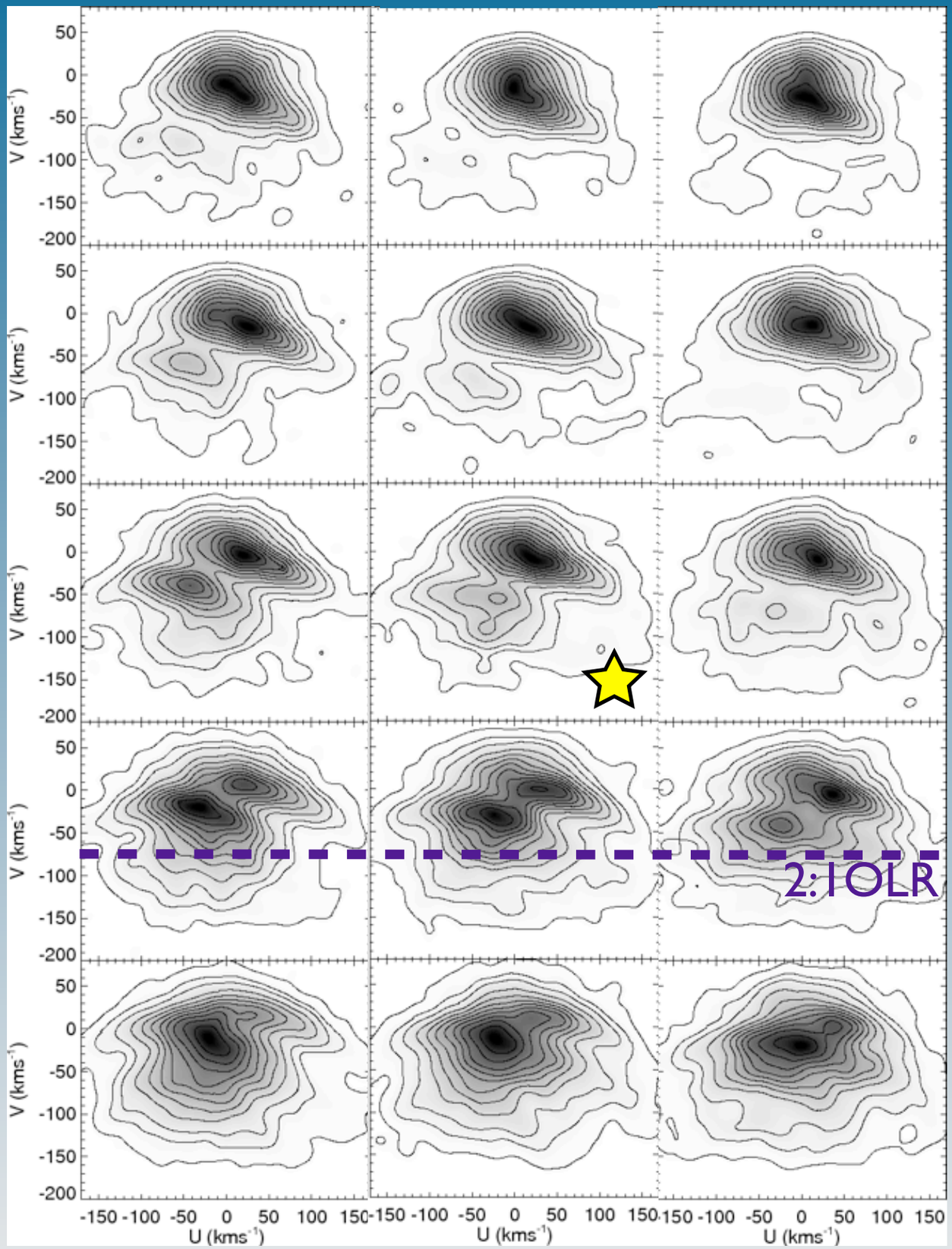

- Hercules moves to lower azimuthal velocities for larger Galactocentric radius

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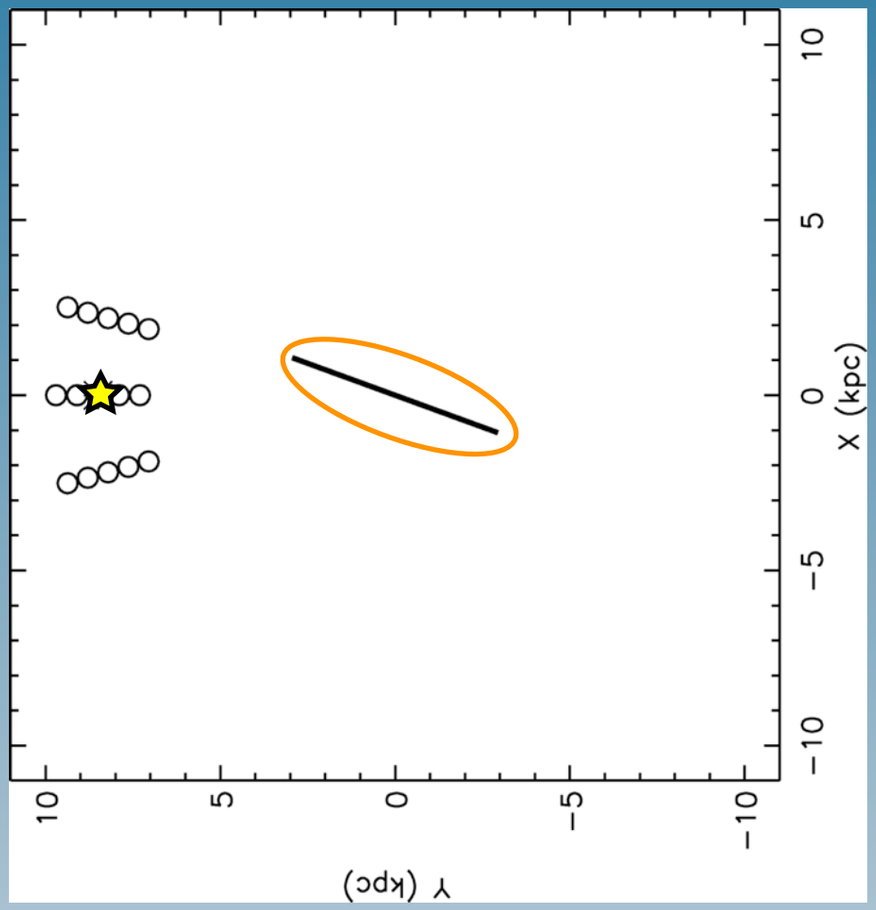


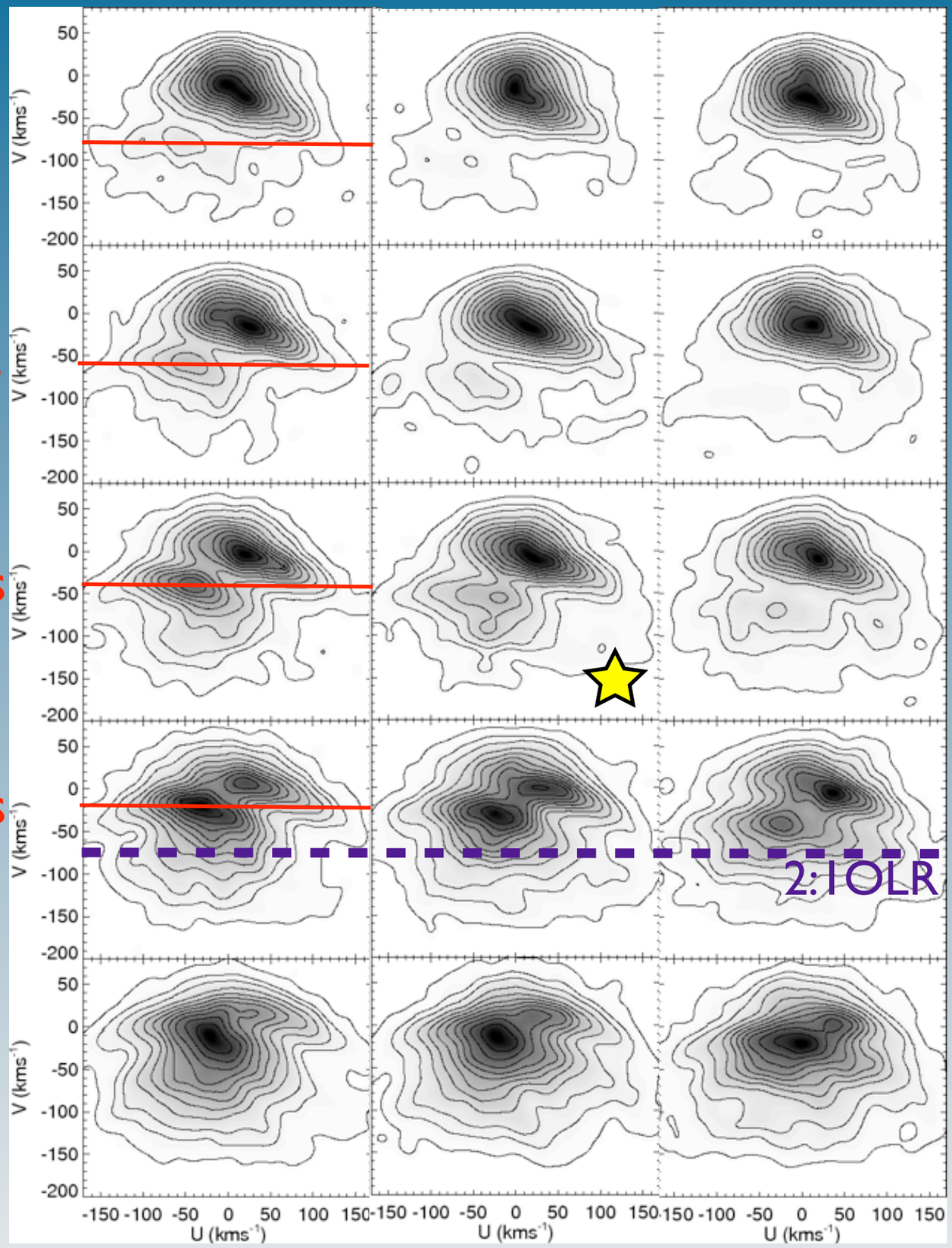
-80 km/s

-60 km/s

-40 km/s

-20 km/s

?



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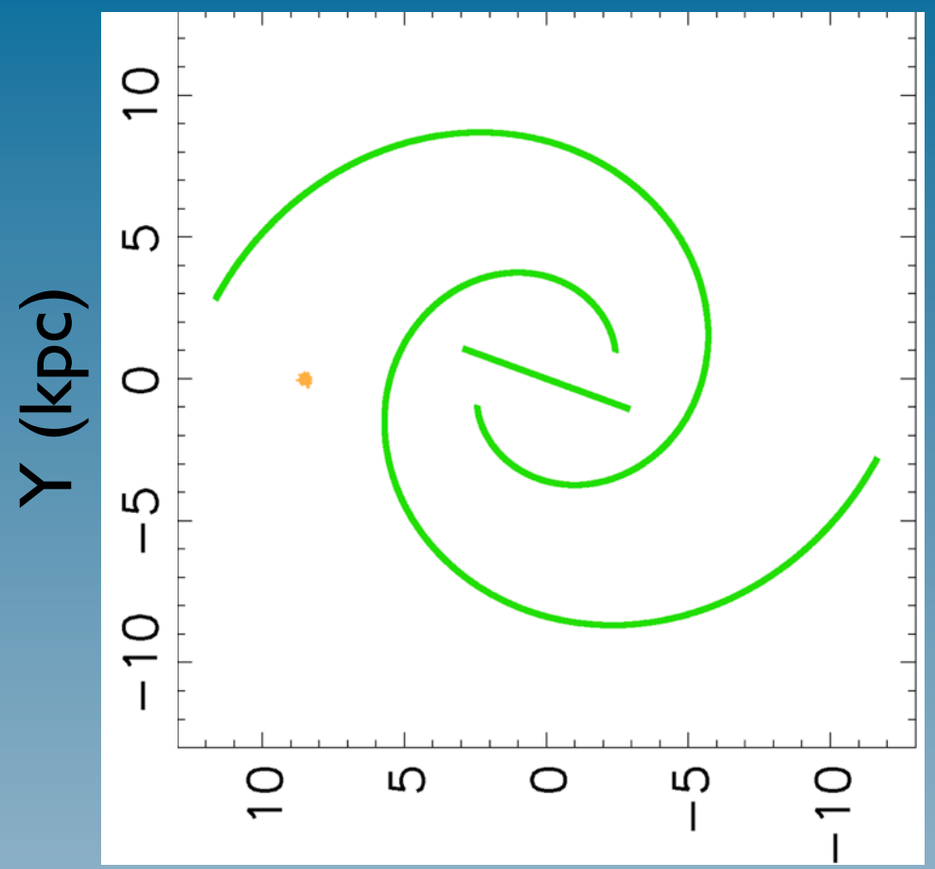

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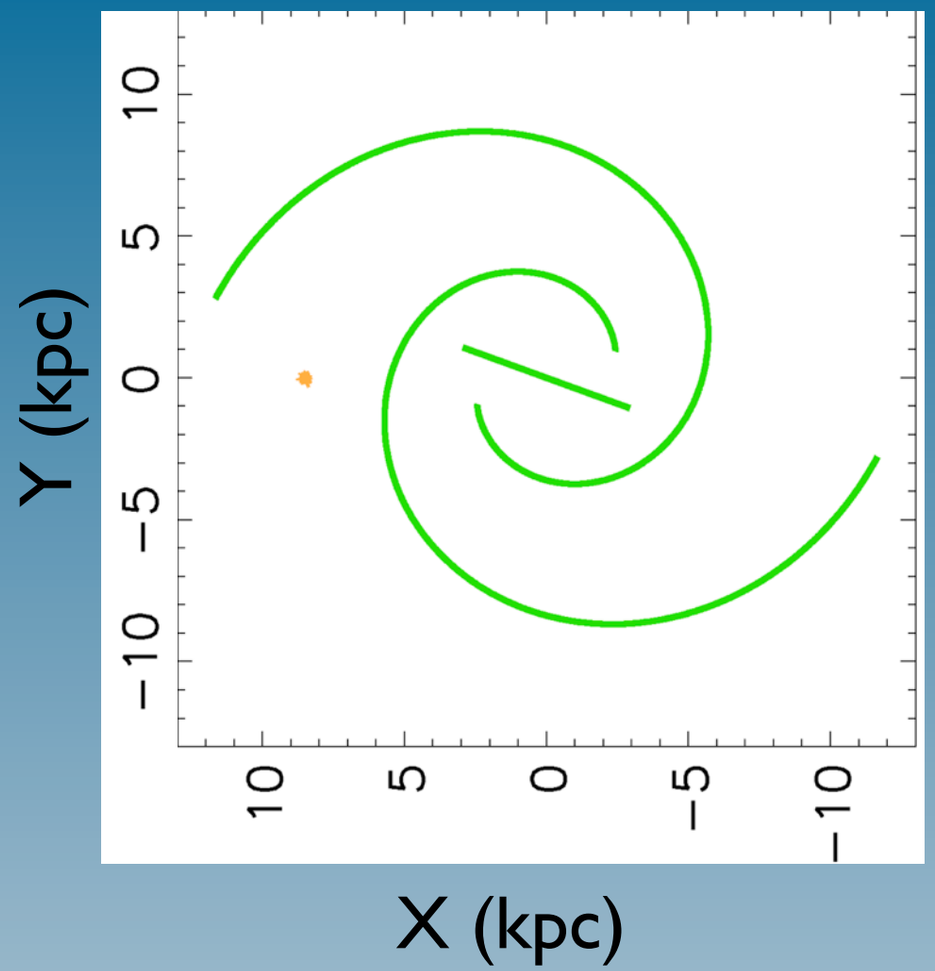

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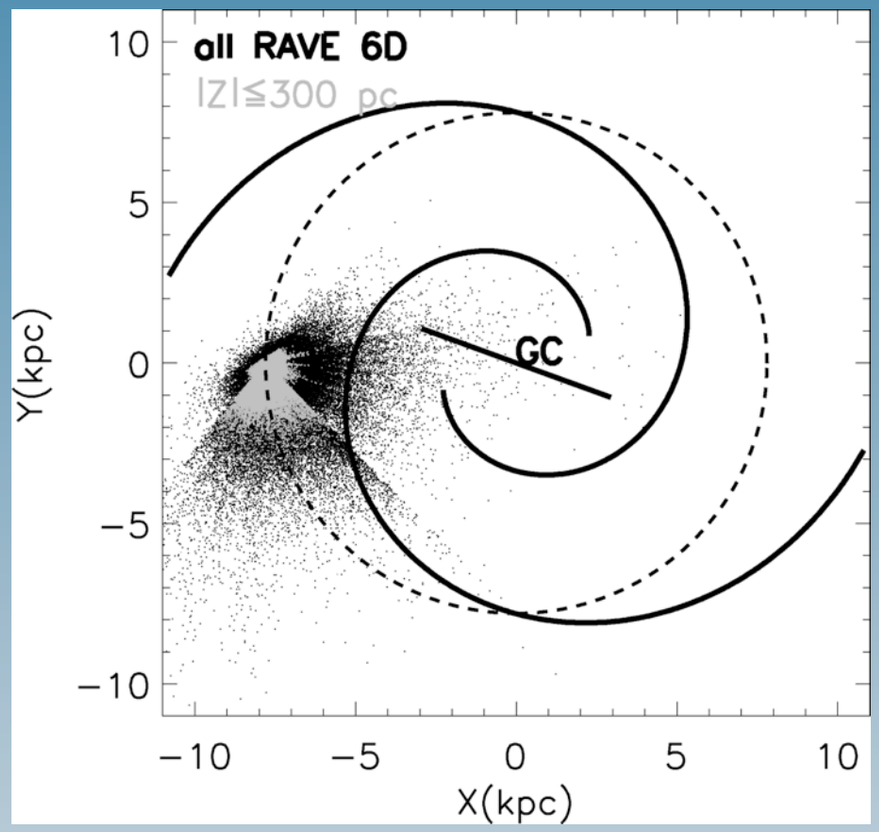
RAVE sample

- multi-fiber spectroscopic survey
- DR3 (Siebert et al. 2012): 500000 spectra, e_{VR}~2km/s
- Proper motions: UCAC2, PPMX
- Spectro-photometric distances: Burnett & Binney 2010

- 6D phase space for 200000 stars
- |Z| ≤ 300 pc:

6D phase space for 100000 stars



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- To be considered:
  - Assume: $R_\odot$, v_c (R), $U_\odot$, $V_\odot$
  - Low number of stars
  - Errors in velocity

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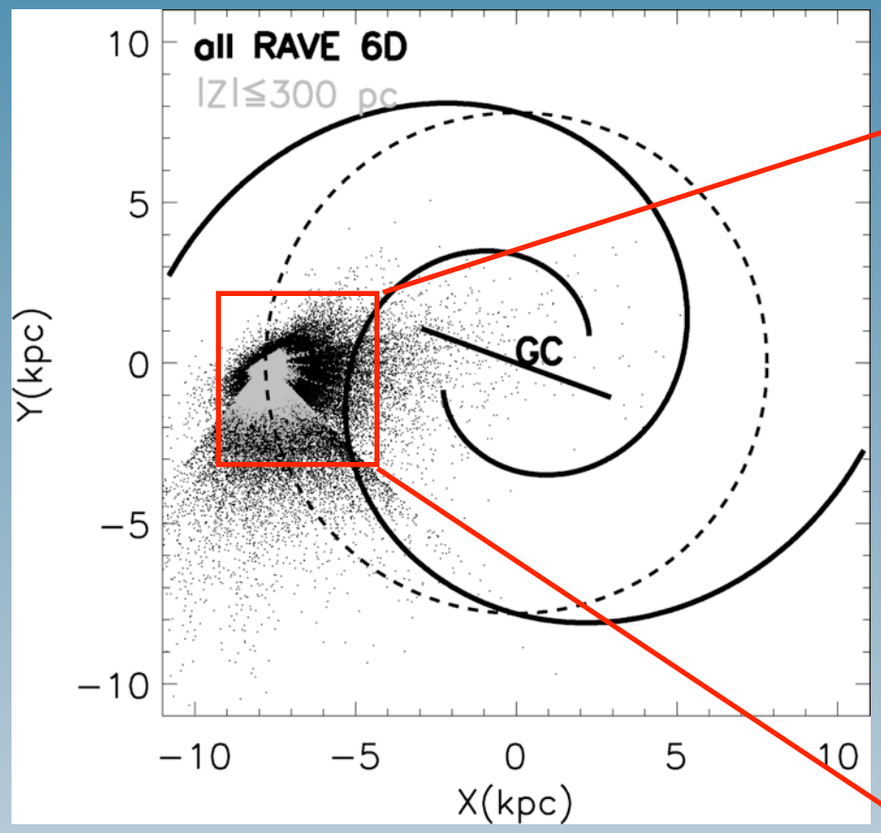

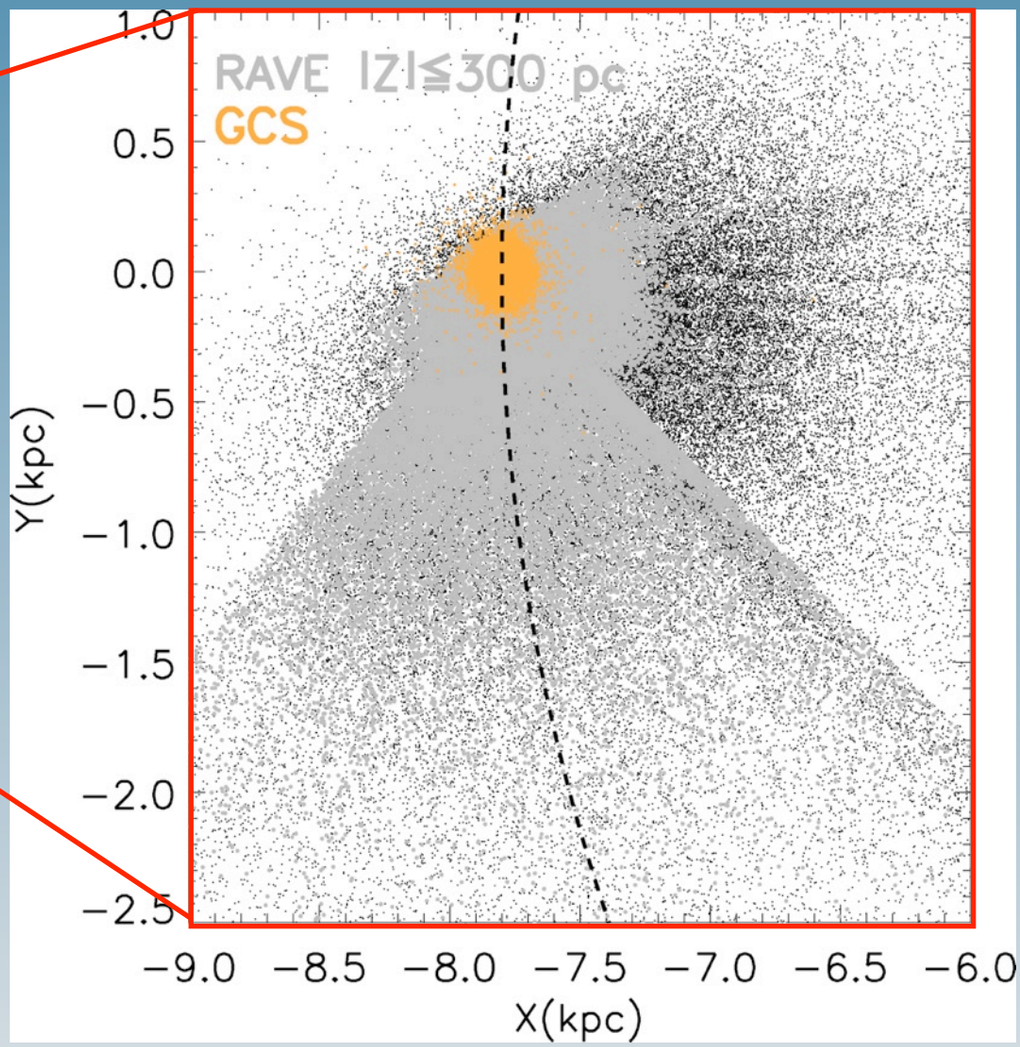

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Finding substructure: Wavelet Transform

MR Software (CEA, Saclay)

Starck & Murtagh 2002

Slezak et al. 1993

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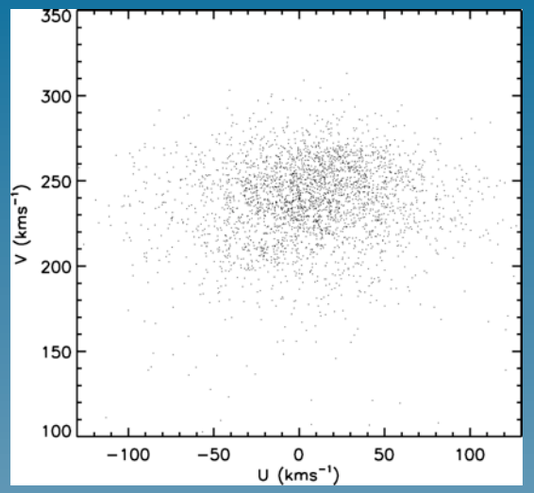

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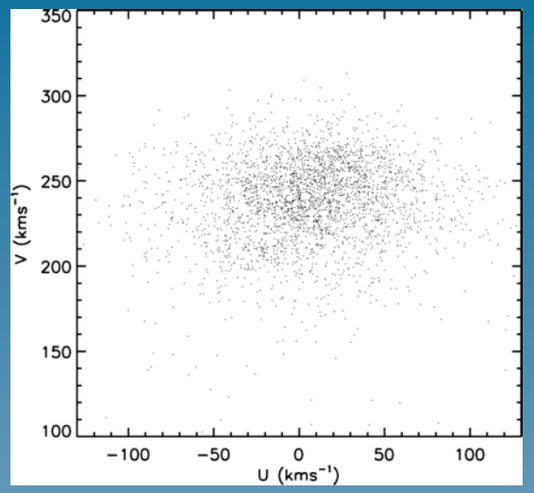

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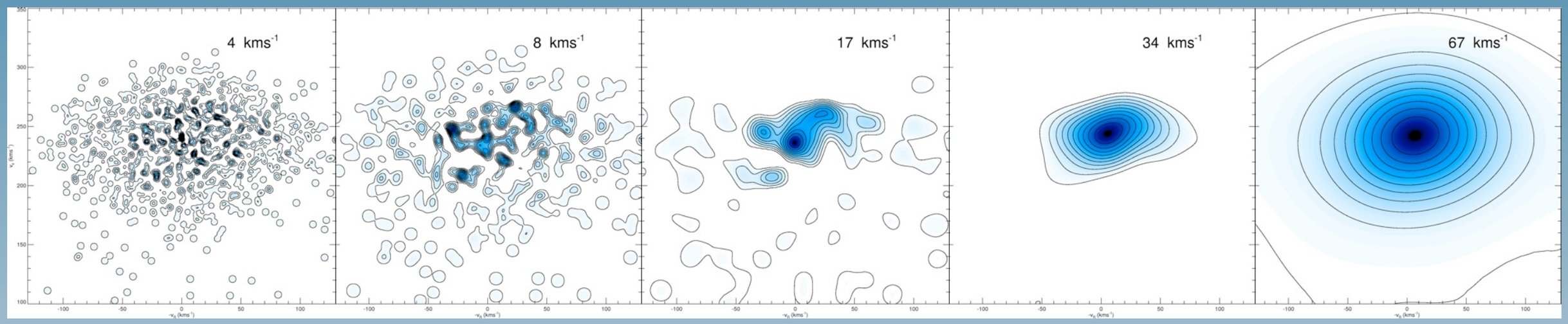

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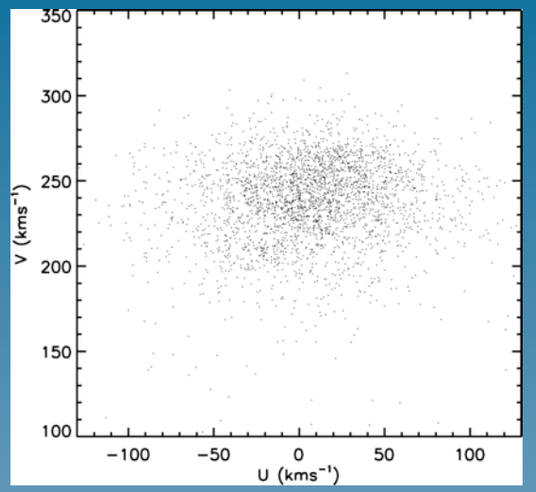

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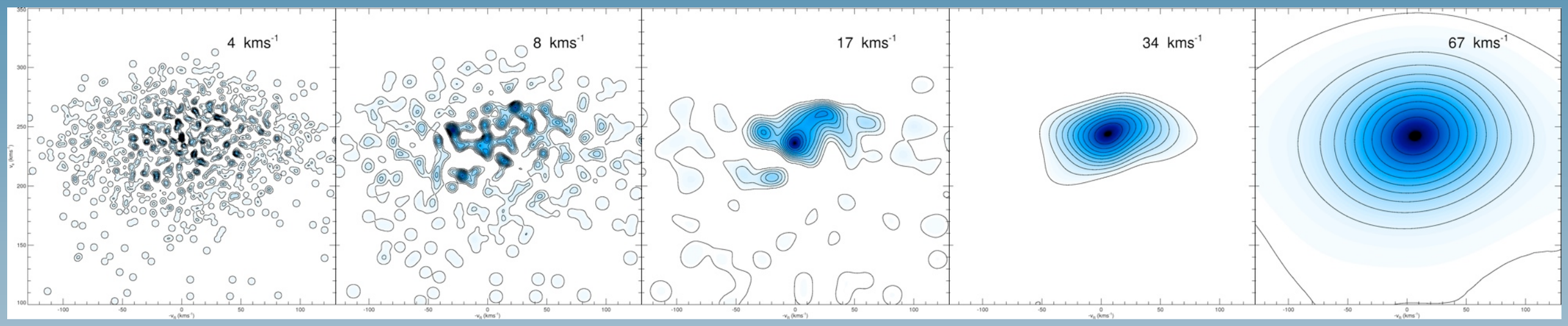
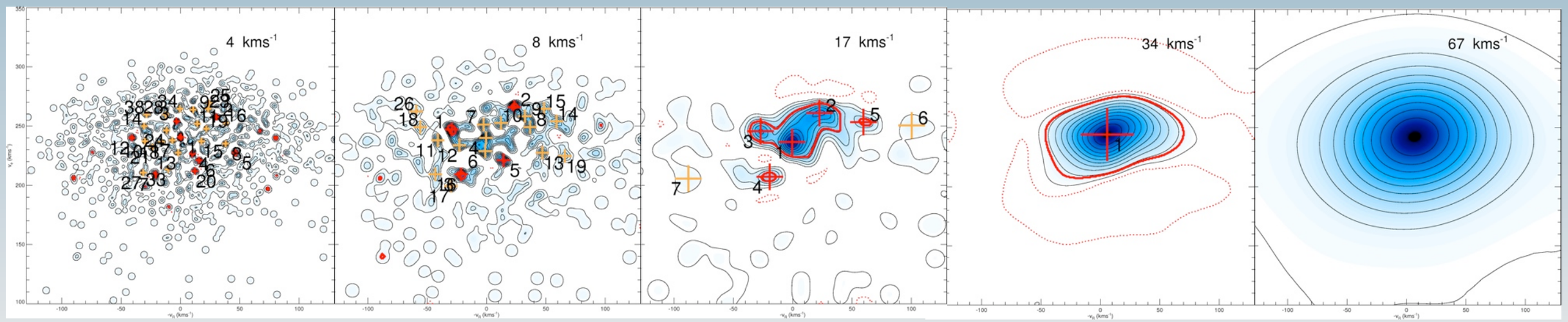


3) Significant peaks 2σ and 3σ

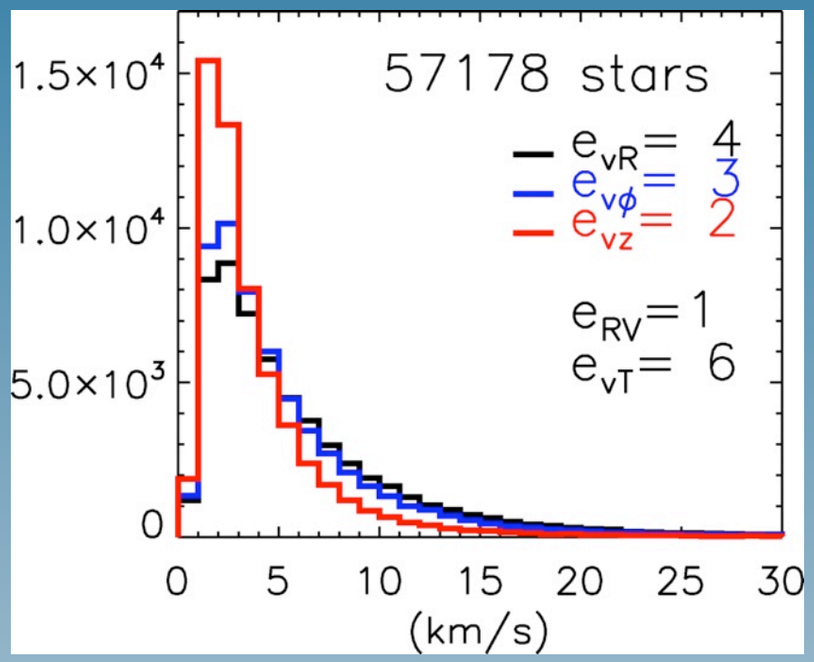


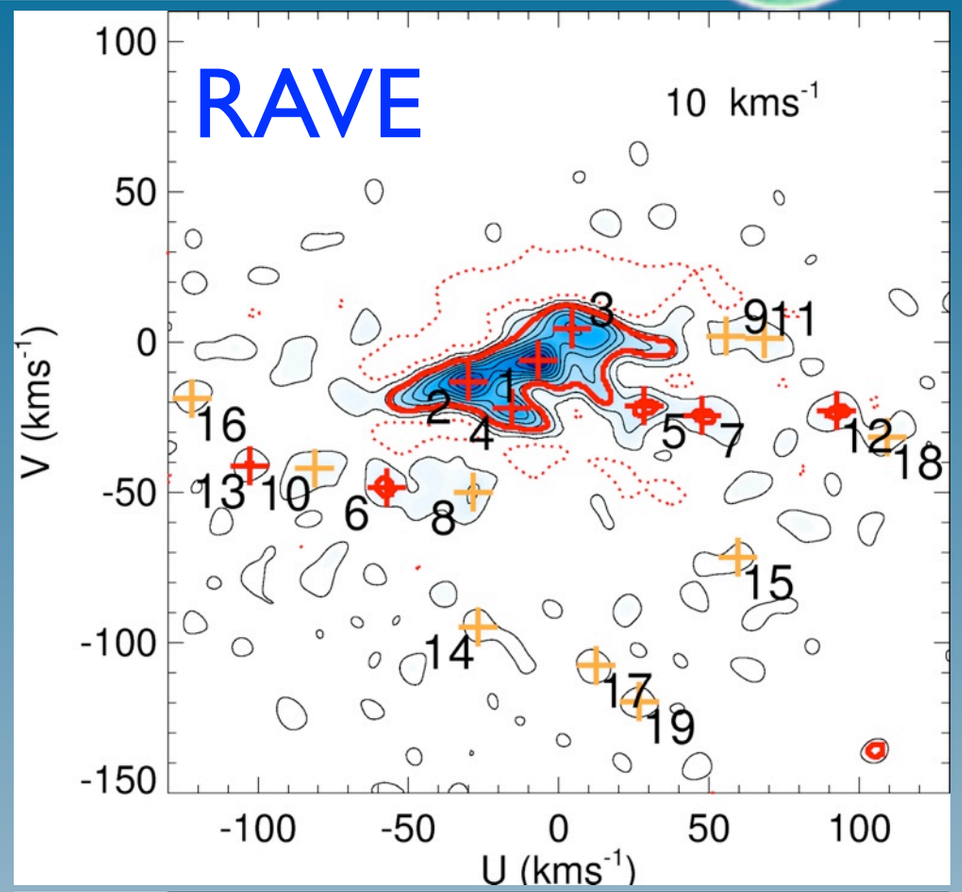
Revisiting the solar neighbourhood

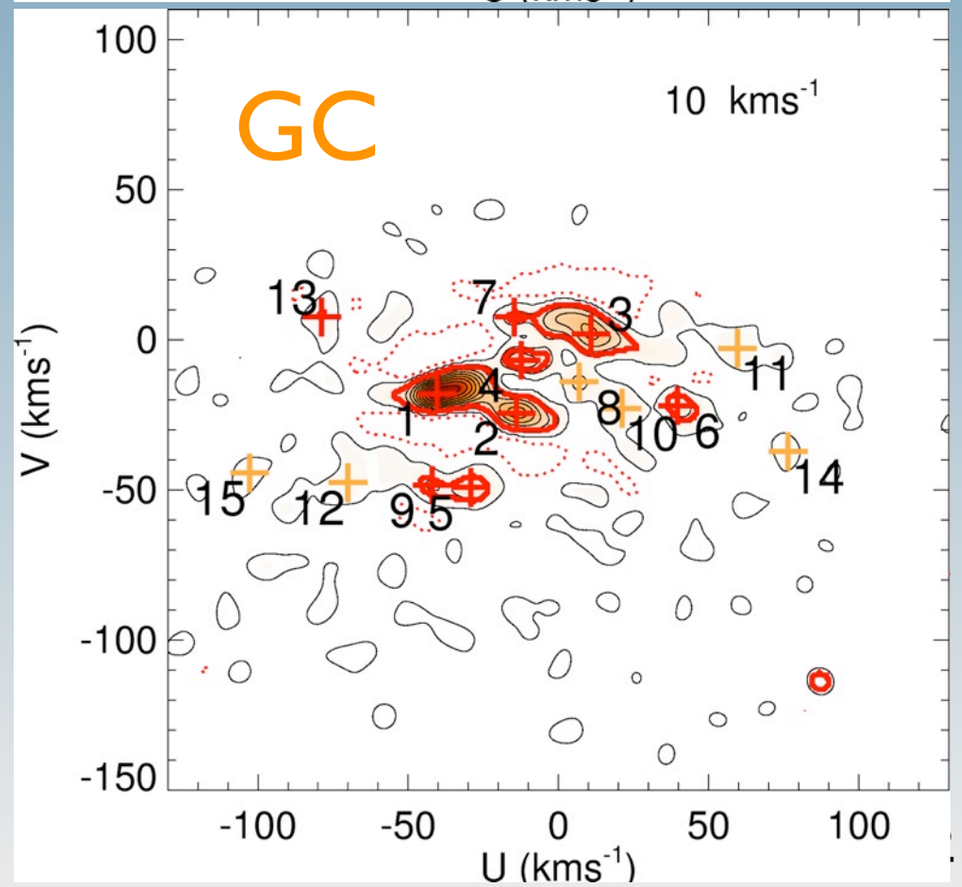
RAVE Local sample

$$d \cos b \leq 200\, pc$$

$$|Z| \leq 300\, pc$$







- Similar significant groups in GC and RAVE local sample
- Main groups: Coma Berenices, Hyades, Sirius, Pleiades, Hercules
- New group at (U,V)~ (90, -20) km/s
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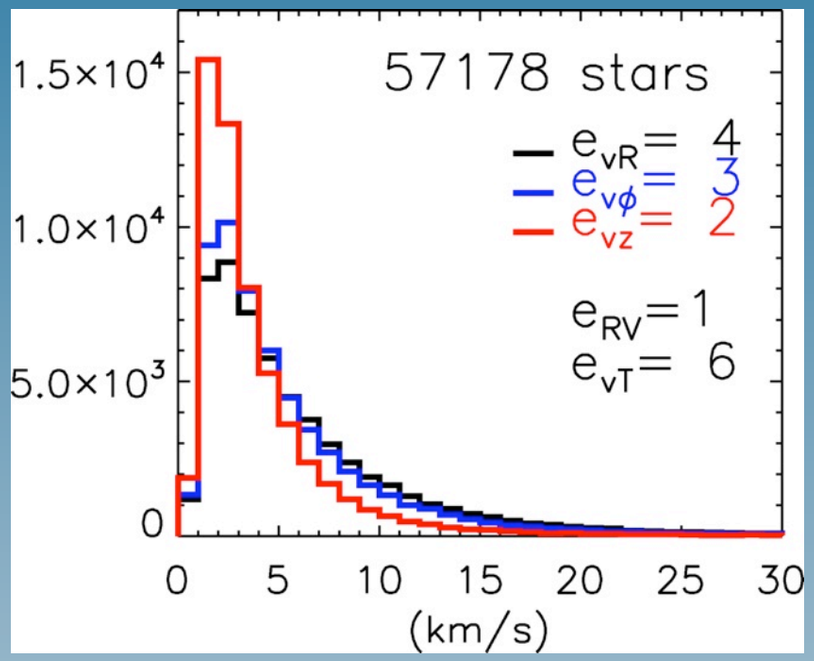

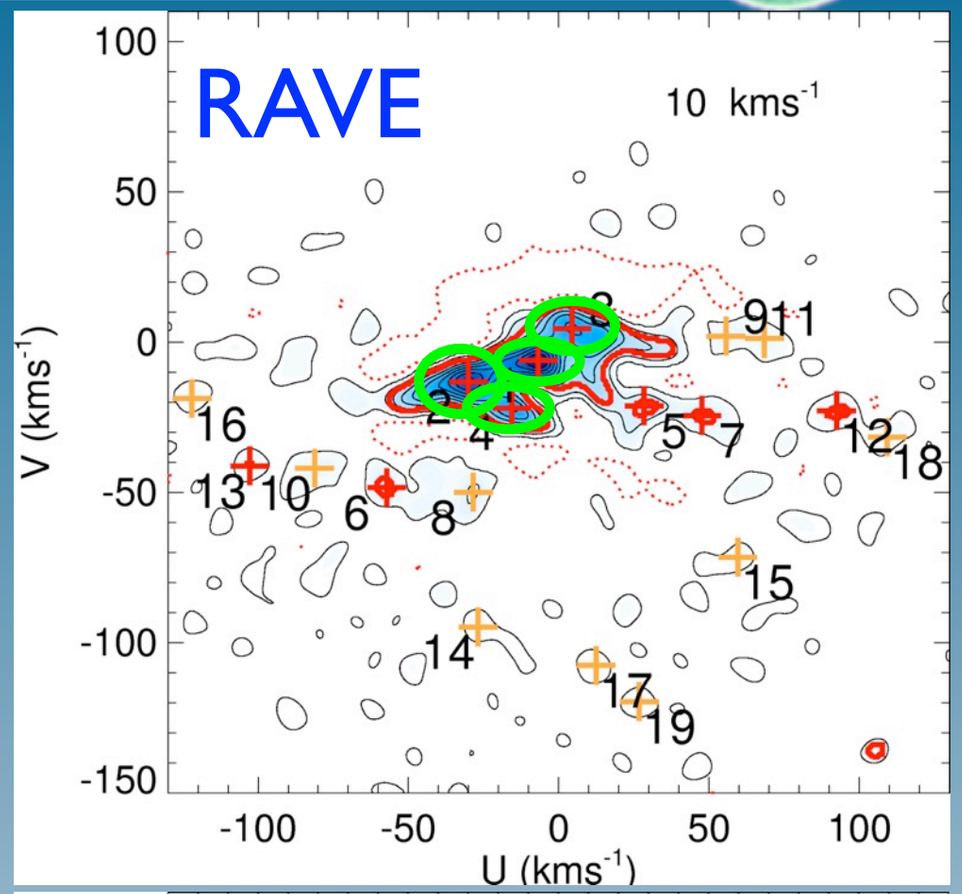

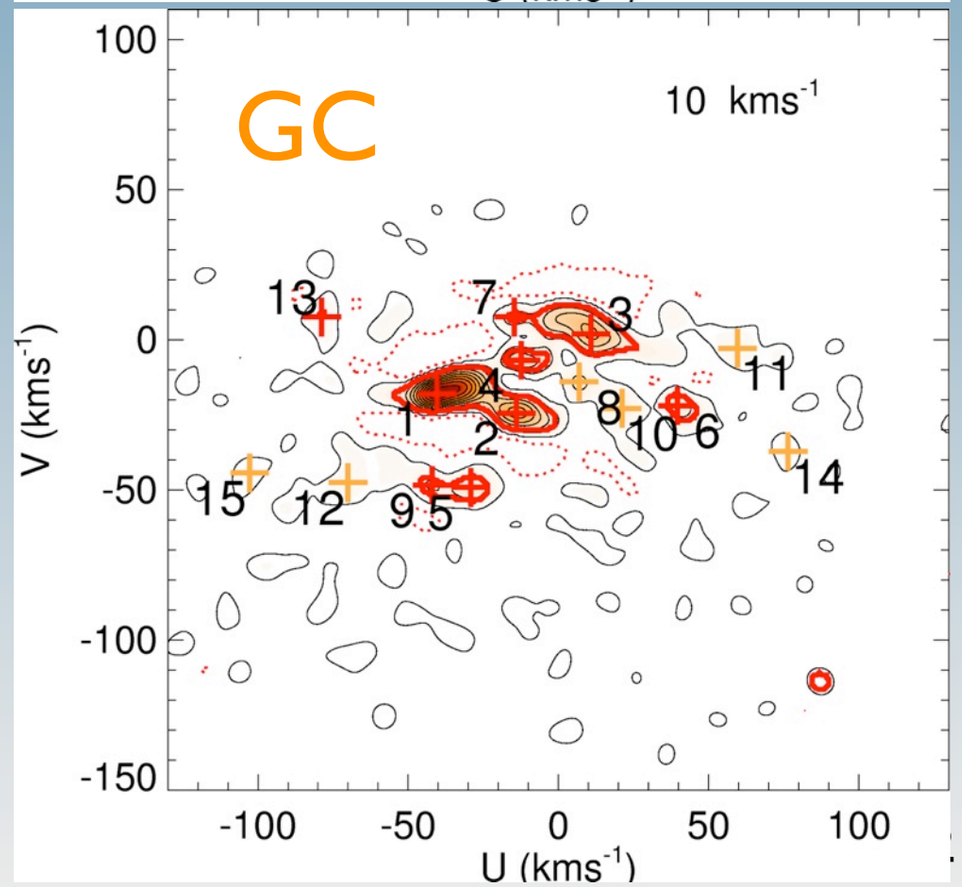

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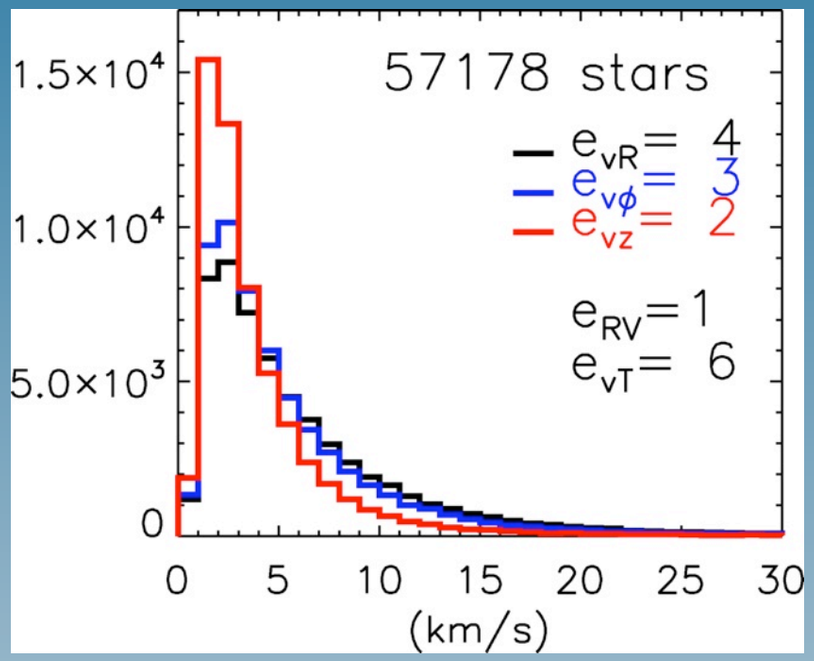

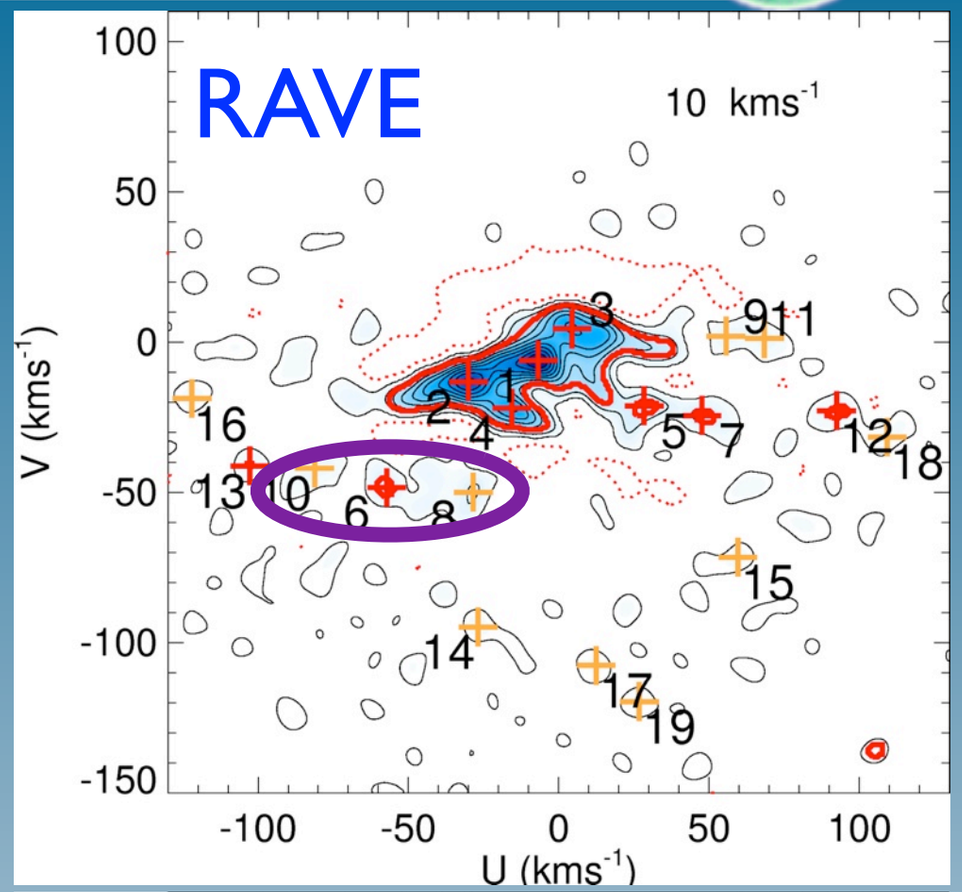

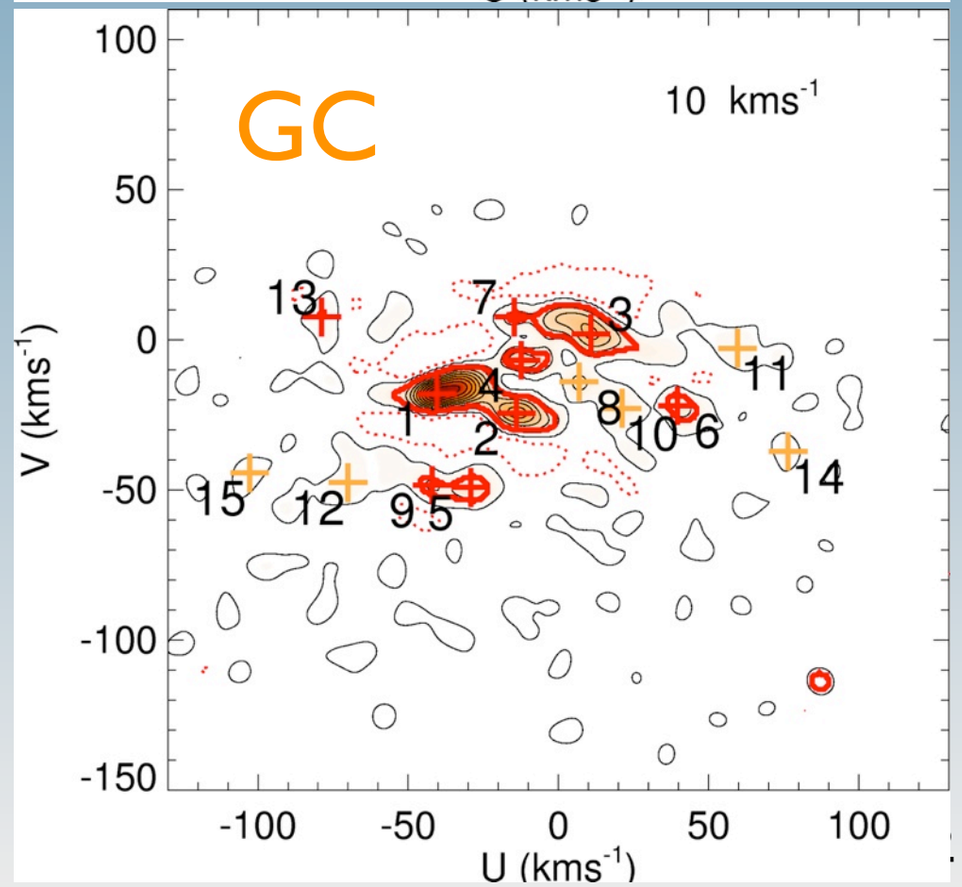

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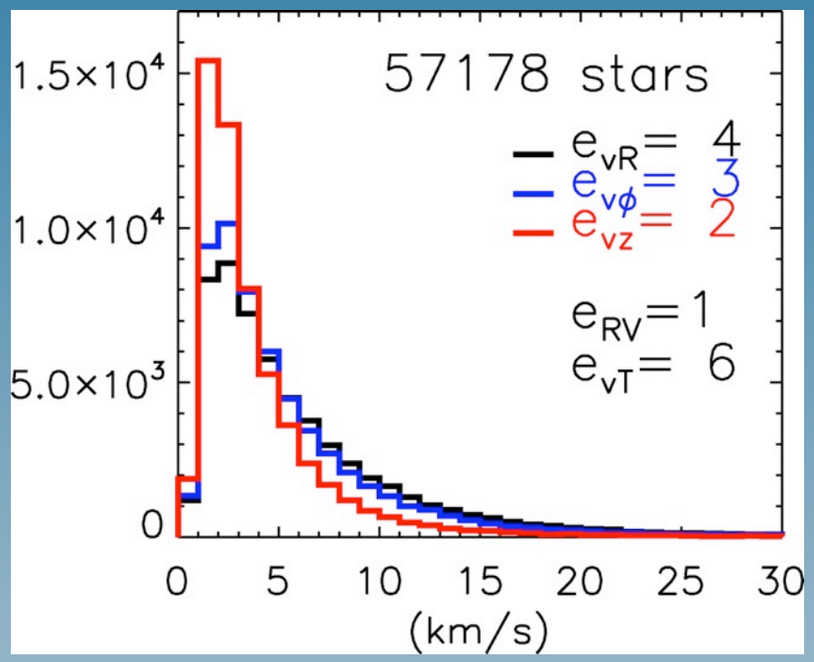

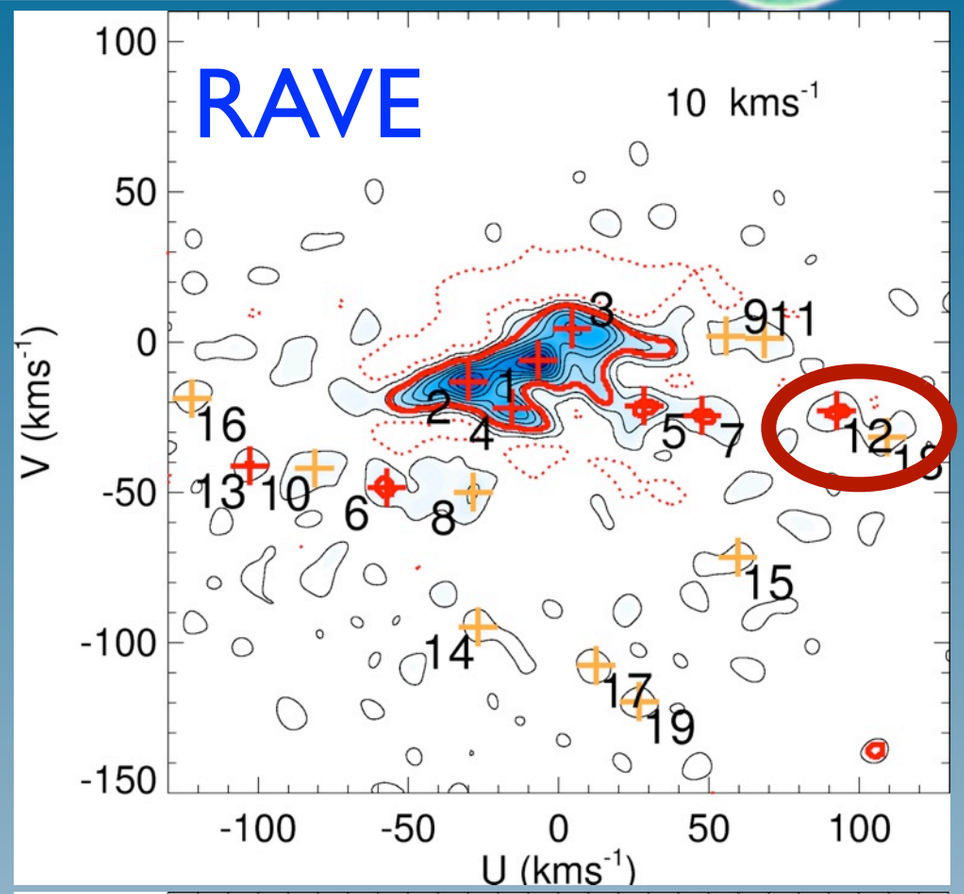

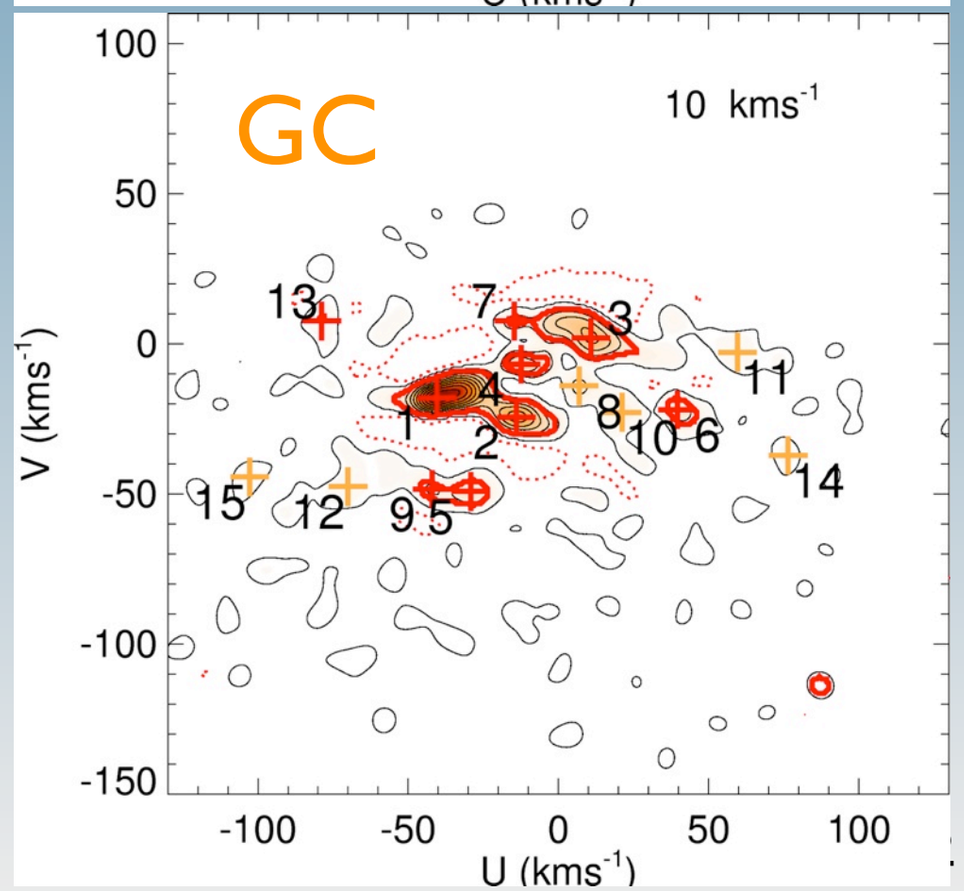

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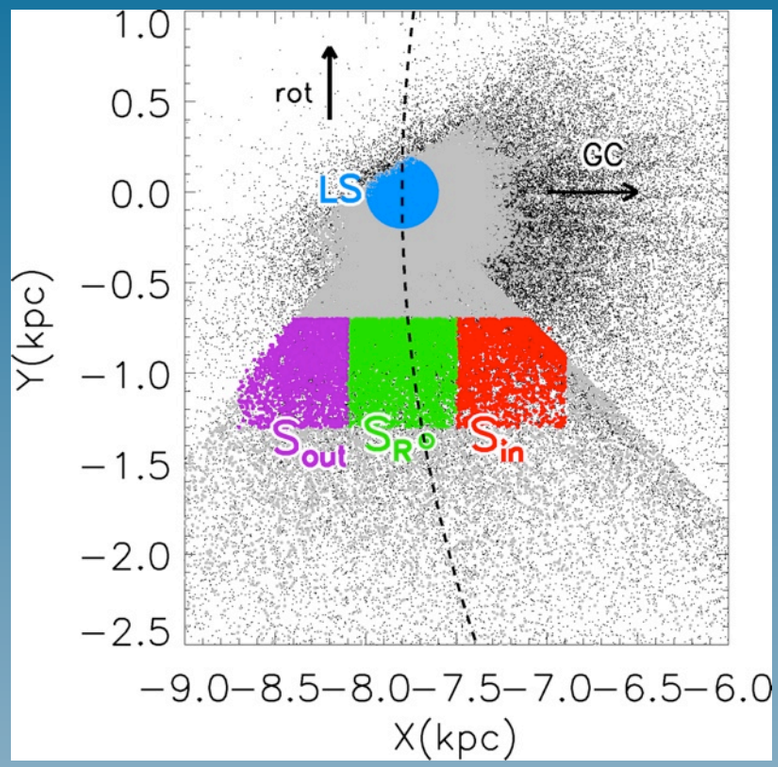
Beyond the solar neighbourhood

Antoja et al. 2012 (in prep.)



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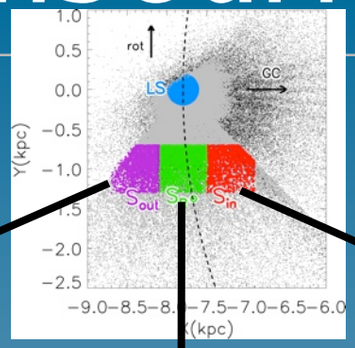
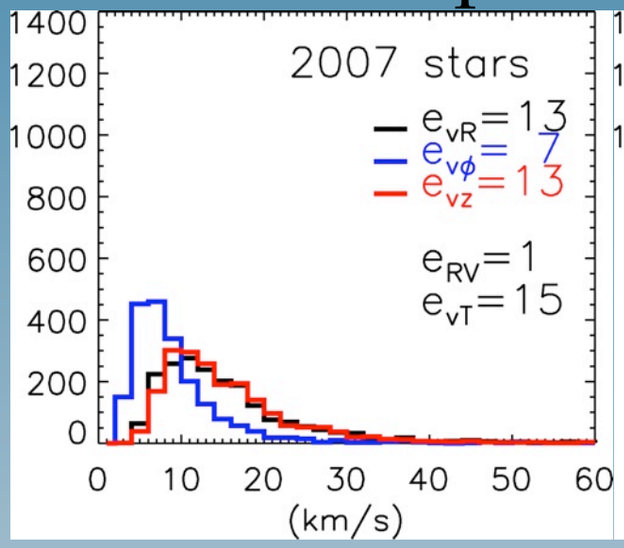
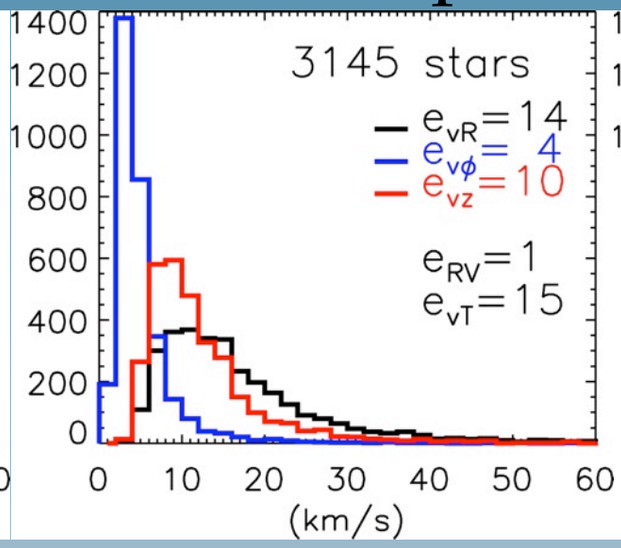


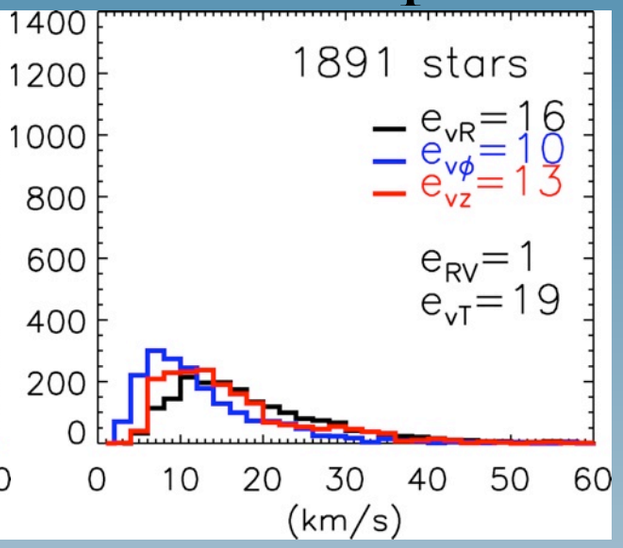
R~8.4 kpc



R~7.8 kpc



R~7.2 kpc



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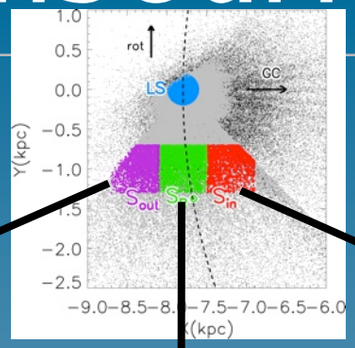
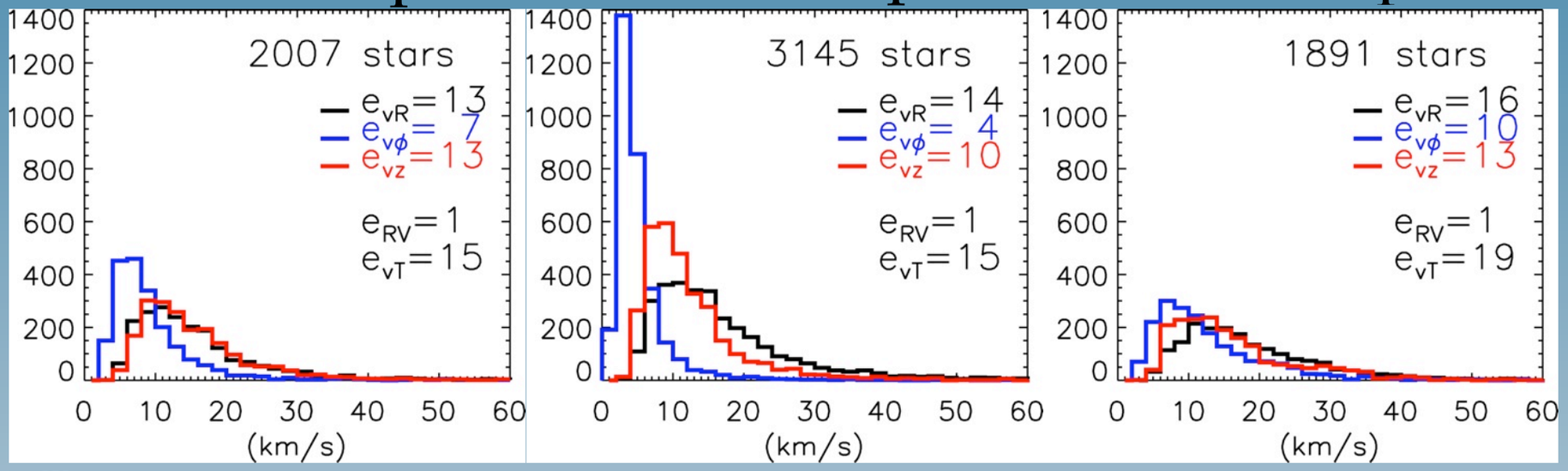
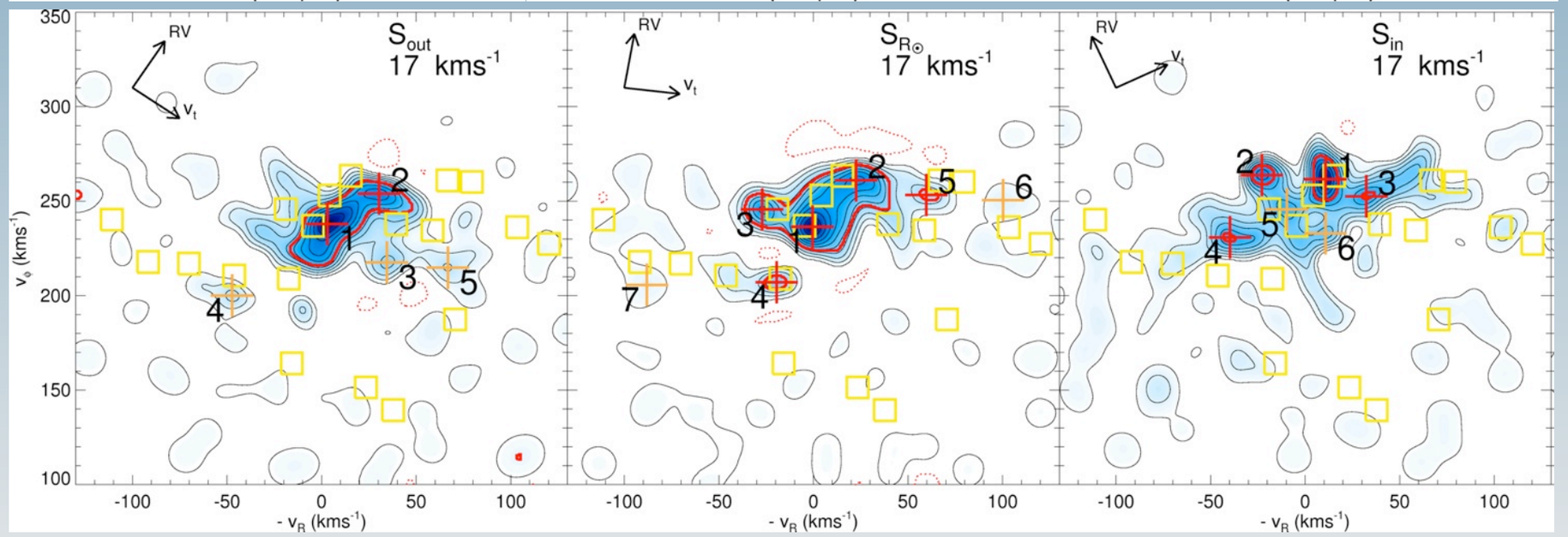


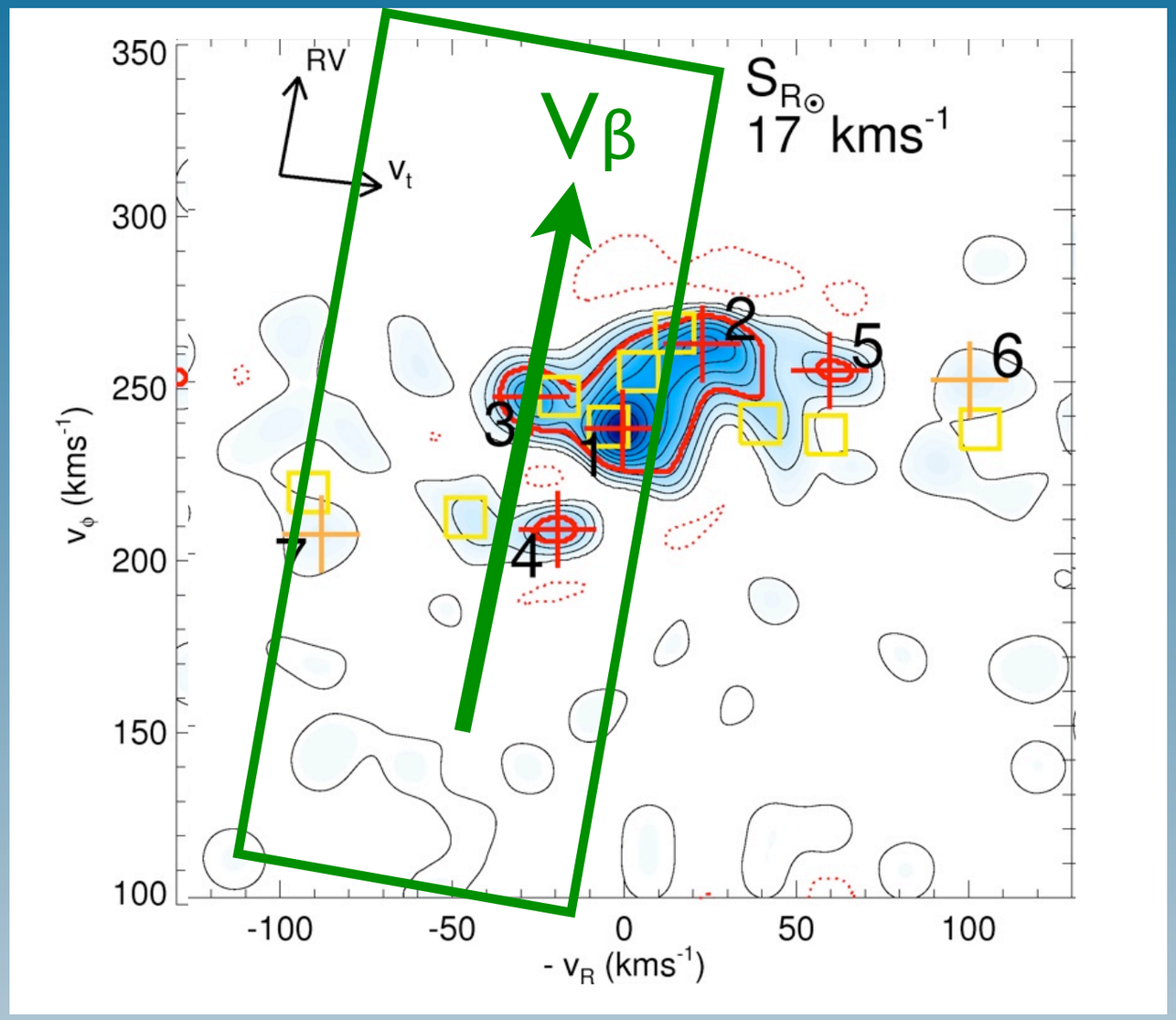
R~8.4 kpc | R~7.8 kpc | R~7.2 kpc



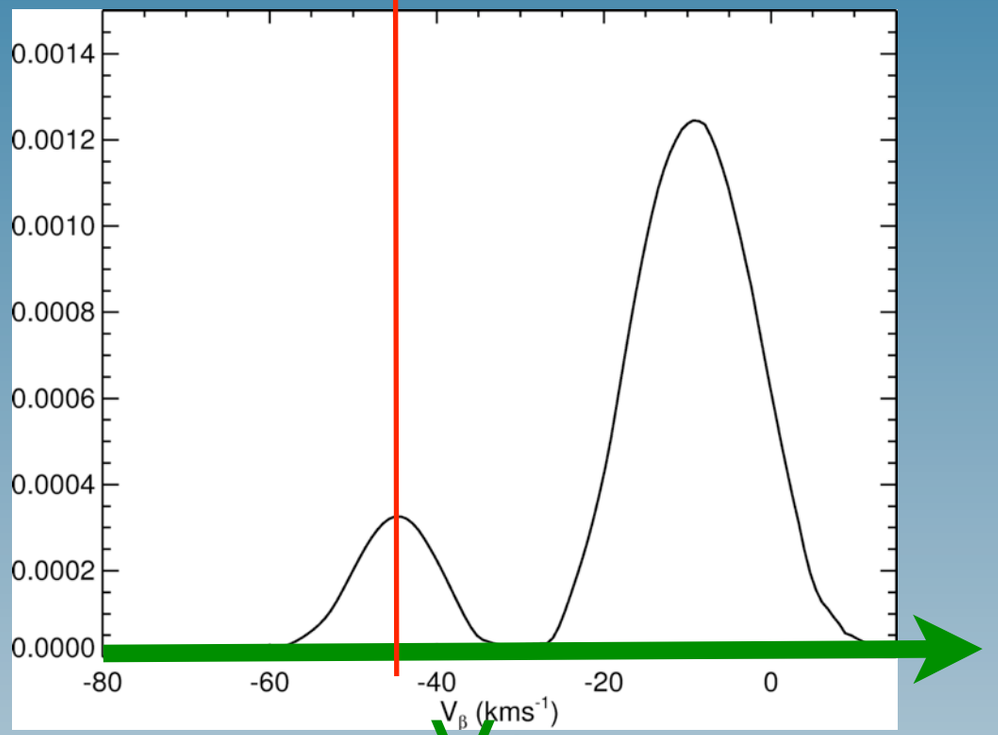


- First detection of non-local disc kinematic substructure
- Local known groups are still observed at 1 kpc in the solar circle
- Known groups are shifted in velocity inside and outside solar circle
- More changes in radius than in azimuth

Hercules shift with R



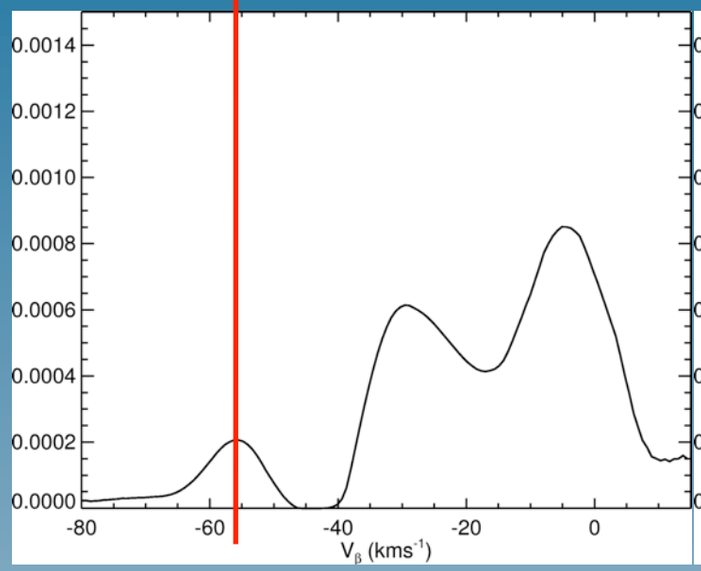
Hercules



V_β

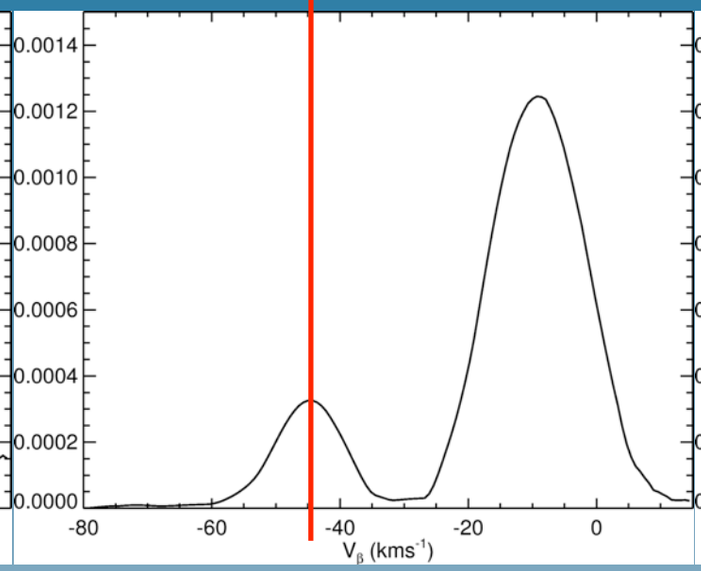
Hercules shift with R

R~8.4 kpc



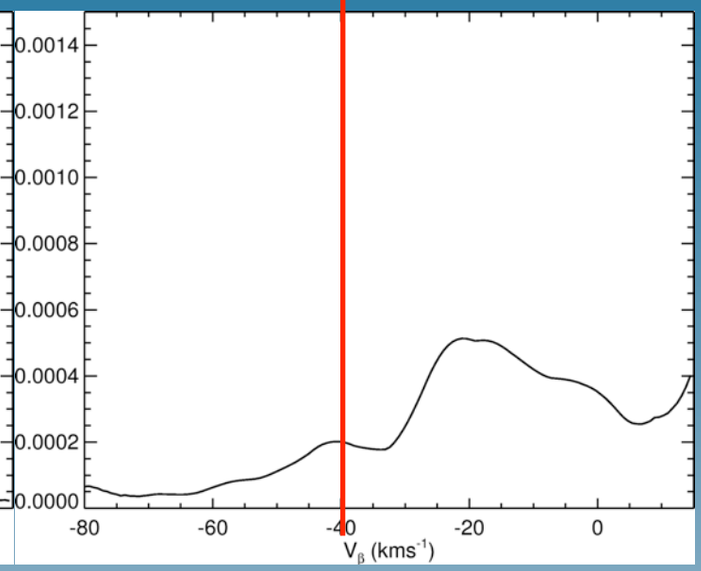
-55 km/s

R~7.8 kpc



-45 km/s

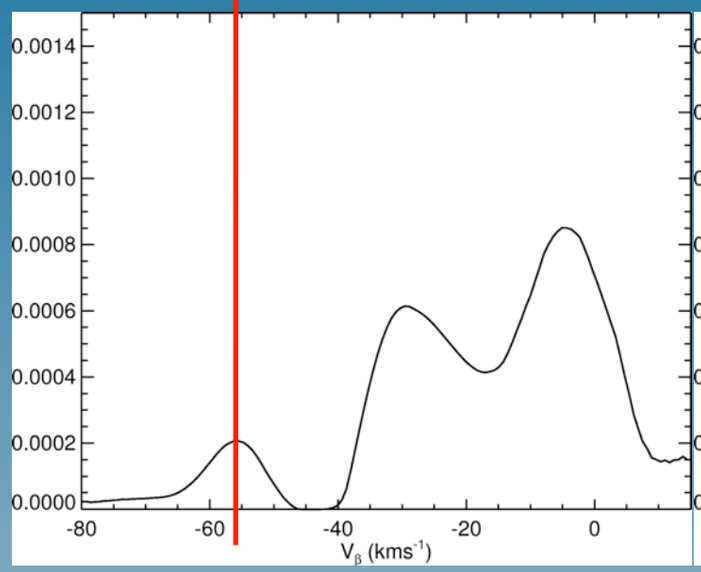
R~7.2 kpc



-40 km/s

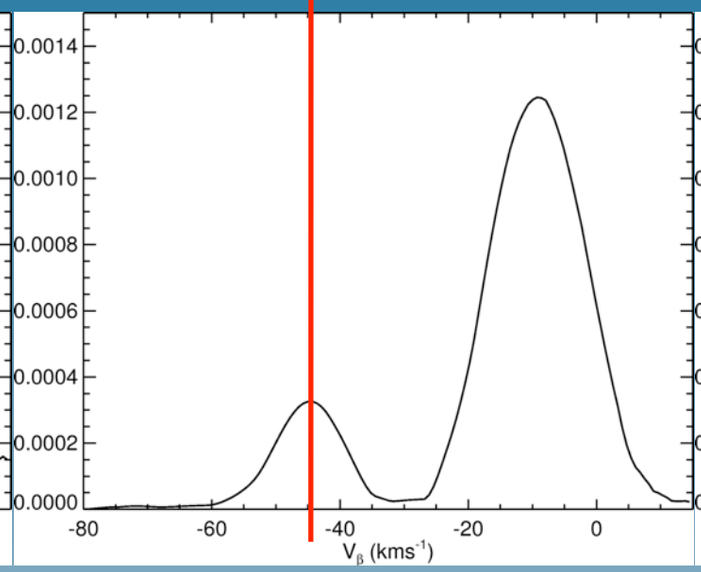
Hercules shift with R

R~8.4 kpc



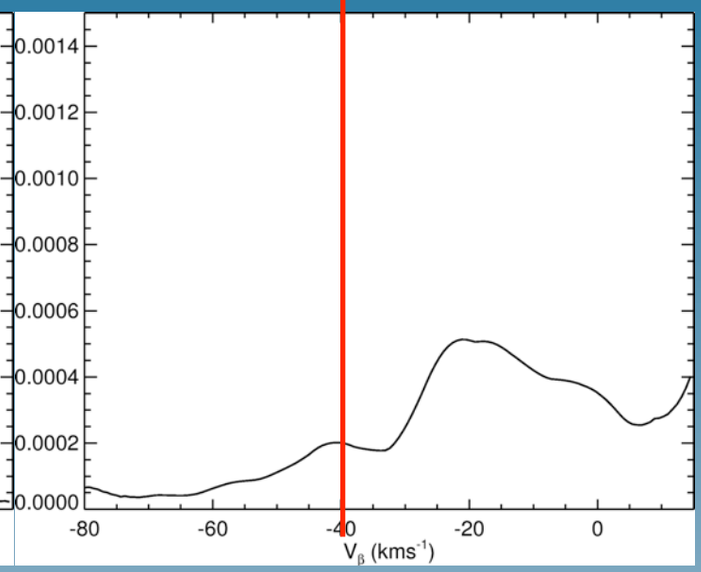
-55 km/s

R~7.8 kpc

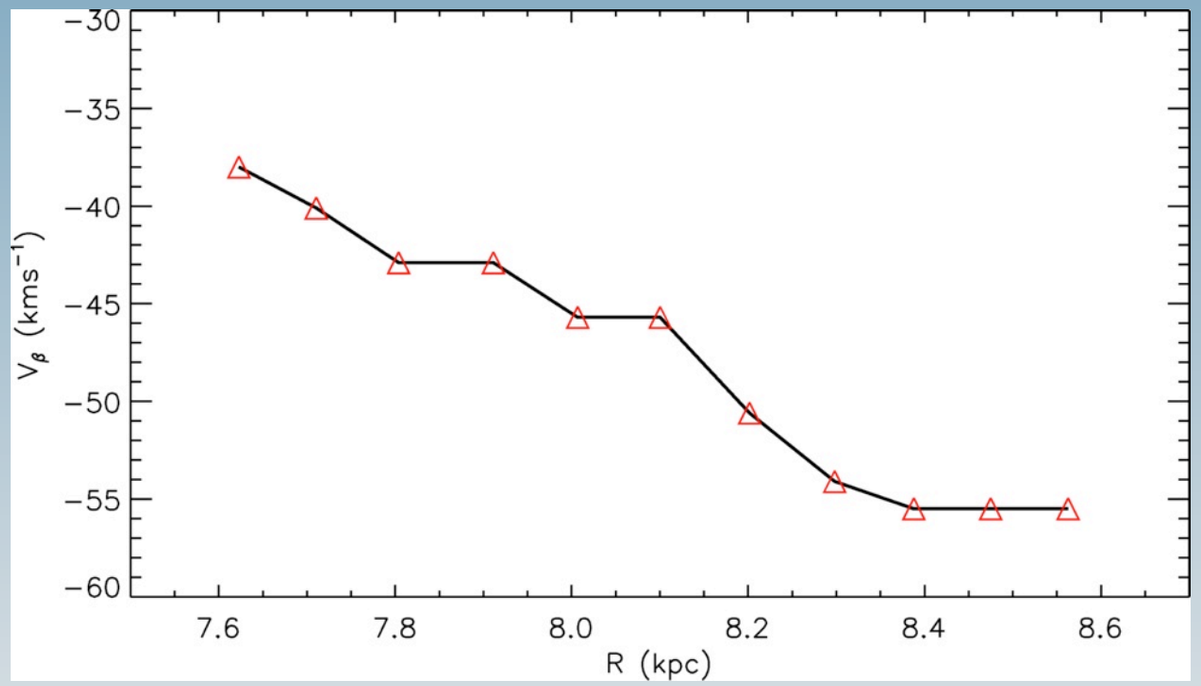


-45 km/s

R~7.2 kpc

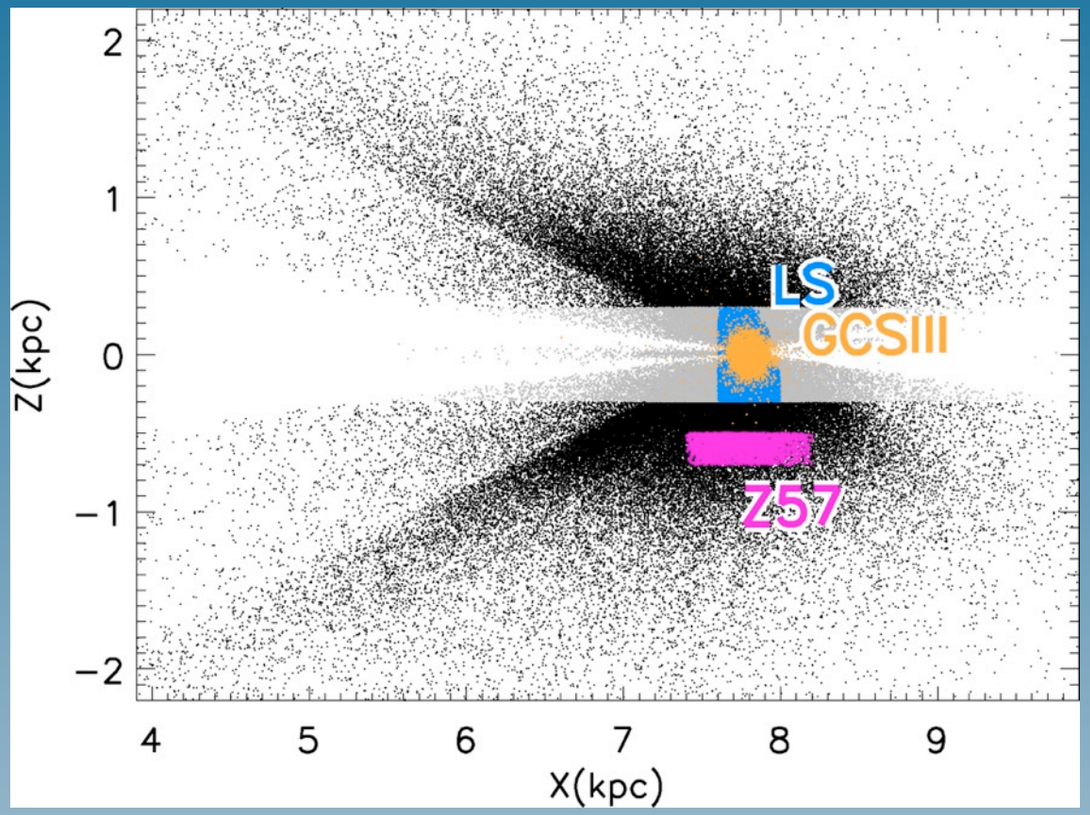


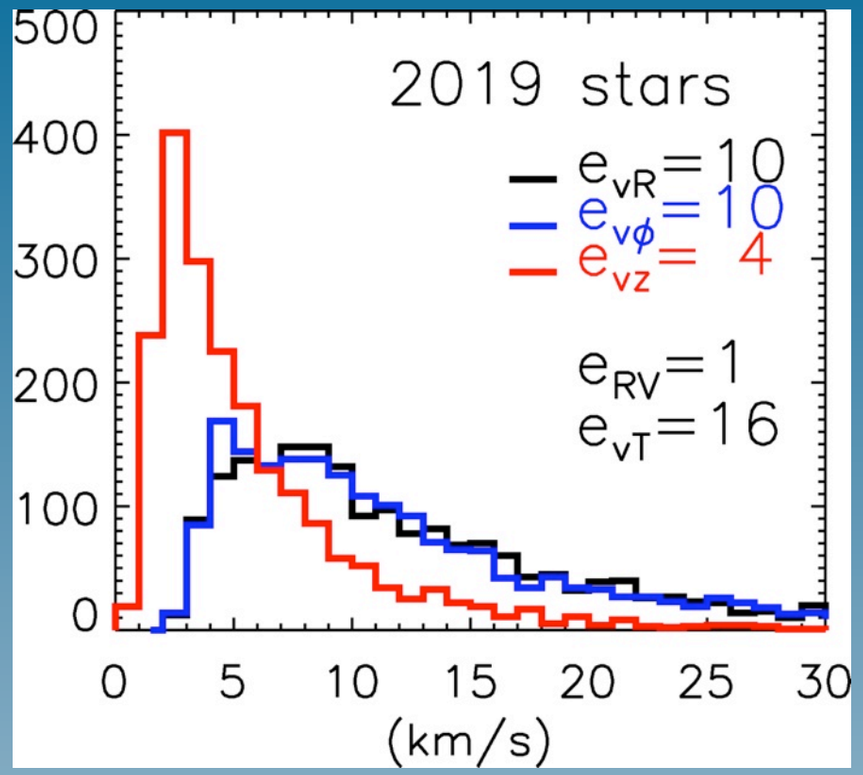
-40 km/s



- Hercules moves to low azimuthal velocities outside solar circle and to higher azimuthal velocities inside solar circle
- Consistent with the effects of the bar's OLR

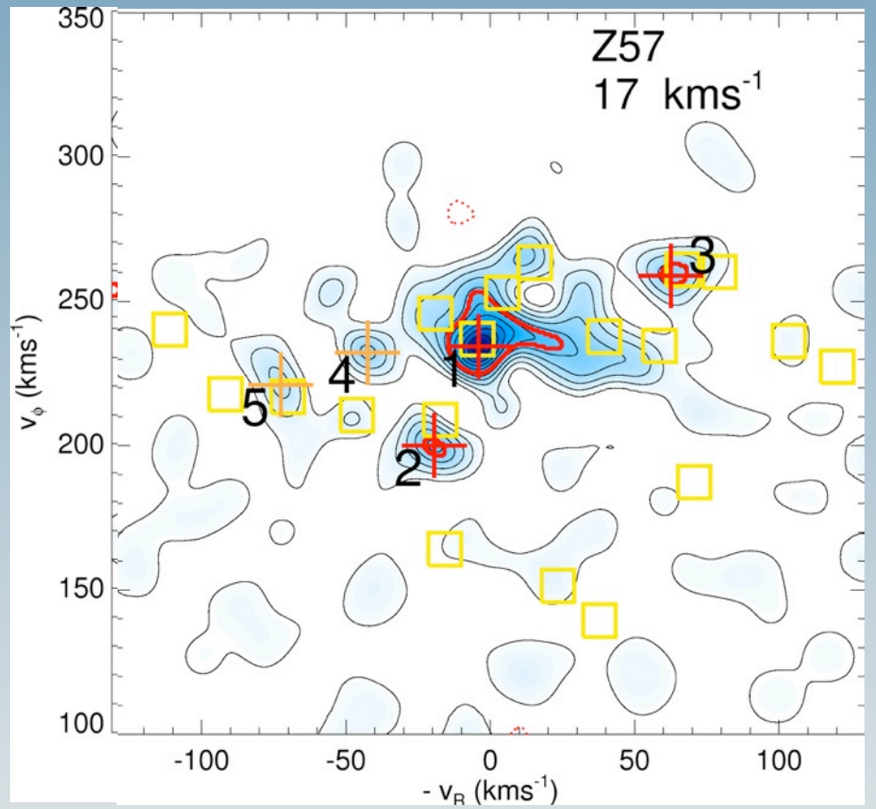
Below the plane





$$-700 \leq |Z| \leq -500\,\mathrm{pc}$$
$$d\cos b \leq 400\,\mathrm{pc}$$

- Some groups persist at low |Z| below the plane: Hercules, γLeo
- Models far from the plane?



Conclusions & Future work

MODELS

- ✦The models predict kinematic substructure beyond the local volume
- ✦They predict some trends in how the substructure change in distant regions

RAVE OBSERVATIONS

- ✦Most of the main local kinematic groups can still be detected at ~1 kpc distance
- ✦Large-scale features + age dispersion ⟶ favour dynamical origin
- ✦The groups shift in the velocity plane for distant samples

OBSERVATIONS vs DYNAMICAL MODELS

- ✦Scales of variation of the groups are roughly consistent with models
- ✦Hercules trend of azimuthal velocity with radius is consistent with effects of the 2:1 OLR
- ✦Use magnitude and direction of the shifts to constrain properties of the bar and spiral arms