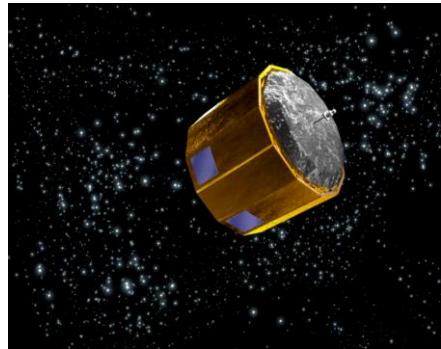


Galactic outer disc & LAMOST II

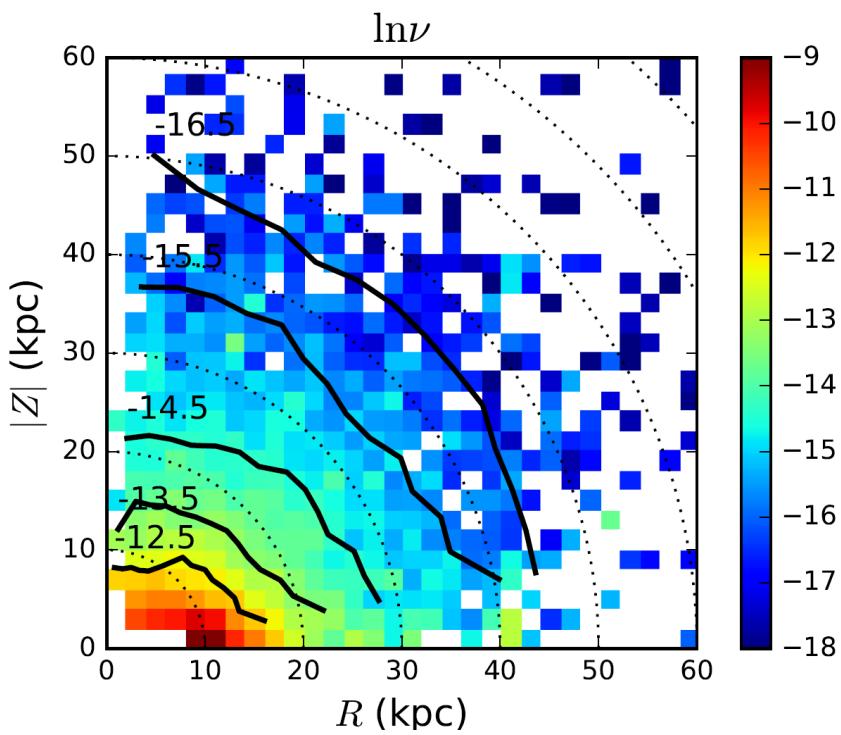
Chao Liu (NAOC)

Collaborated with: Yan Xu, Xinlun Cheng, Shude Mao,
Chervin Laporte

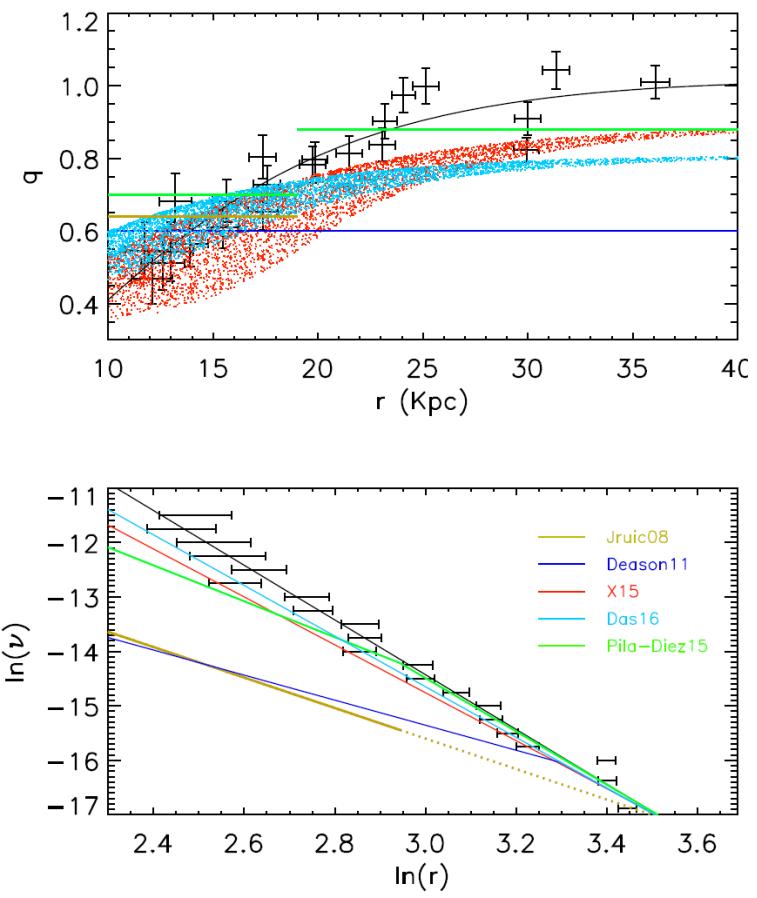


Highlight of LAMOST results

The stellar halo is oblate inside and spherical outside



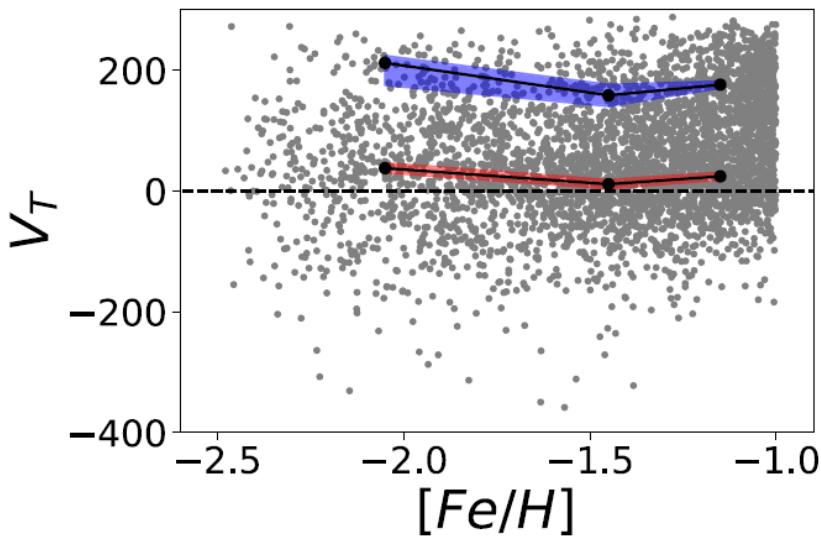
CL et al. 2017



Xu, CL et al. 2018

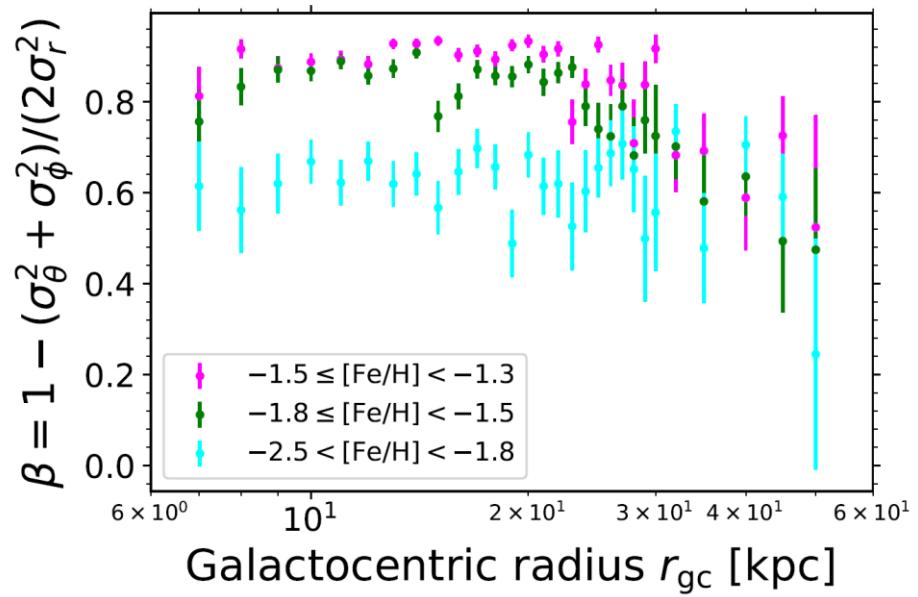
Highlight of LAMOST results

The local halo is moderately rotating with ~20 km/s



Tian, CL et al. 2019

Extremely radially elongated velocity ellipsoid with beta~0.8@<30kpc

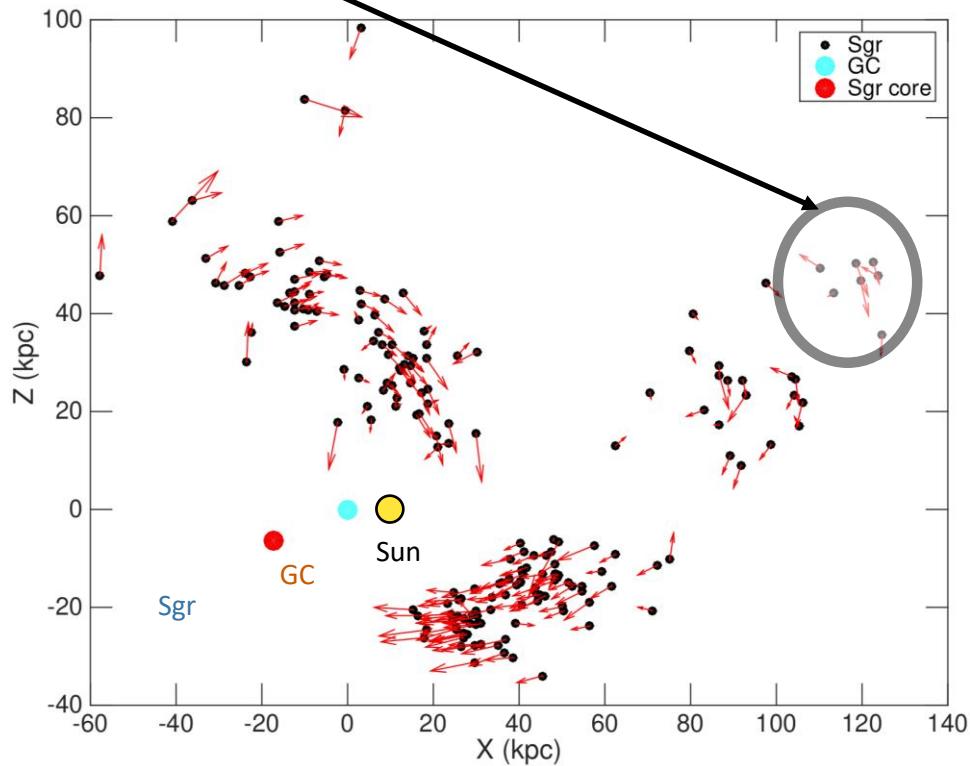


Bird, Xue, CL et al. 2019

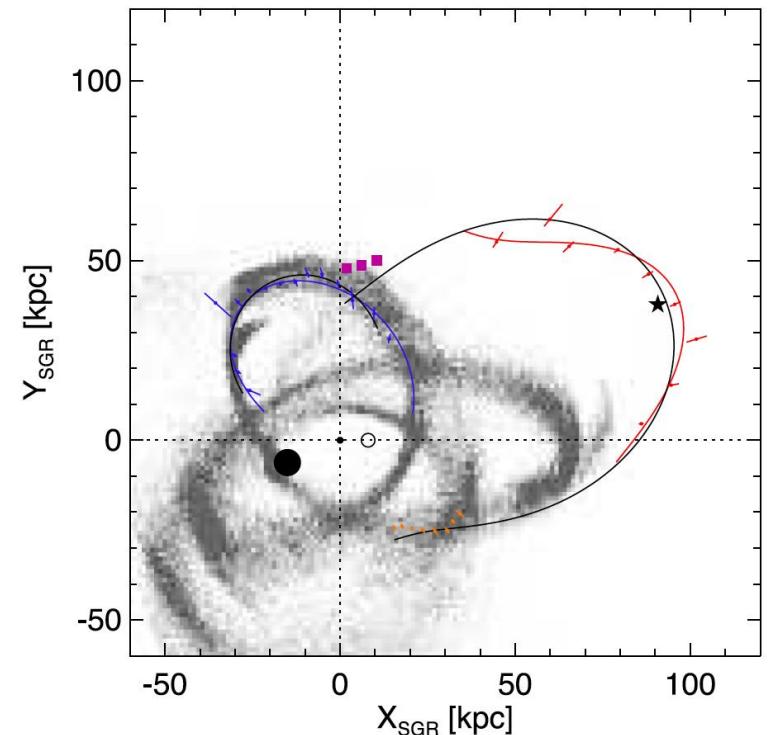
Highlight of LAMOST results

LAMOST M-giants + Gaia proper motions

More than 100 kpc

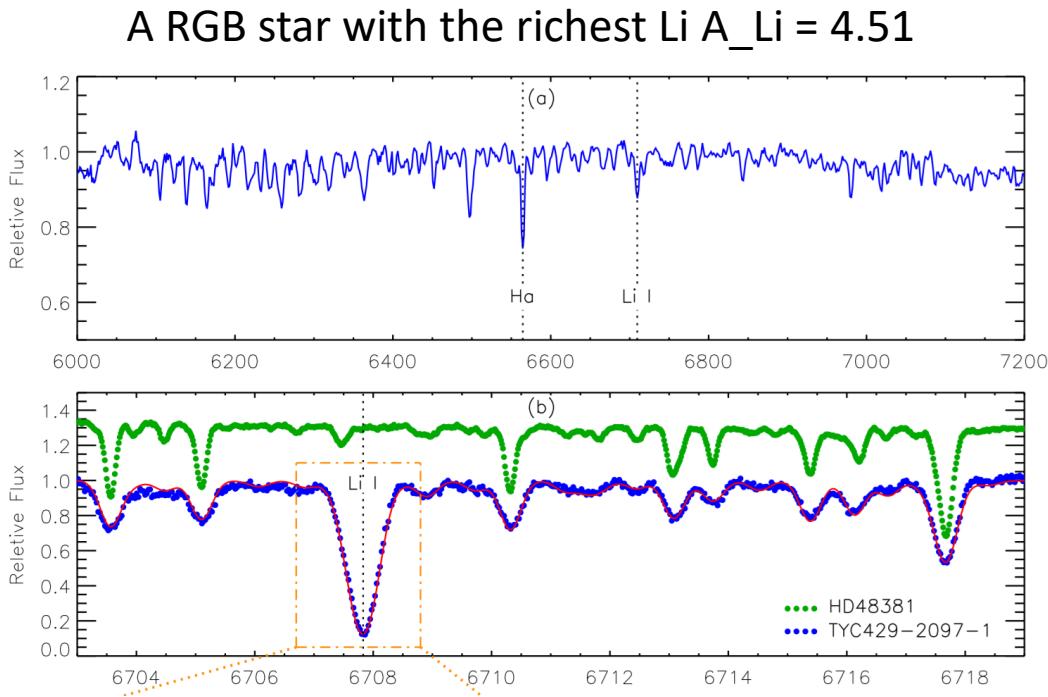


Li, LC et al. 2019



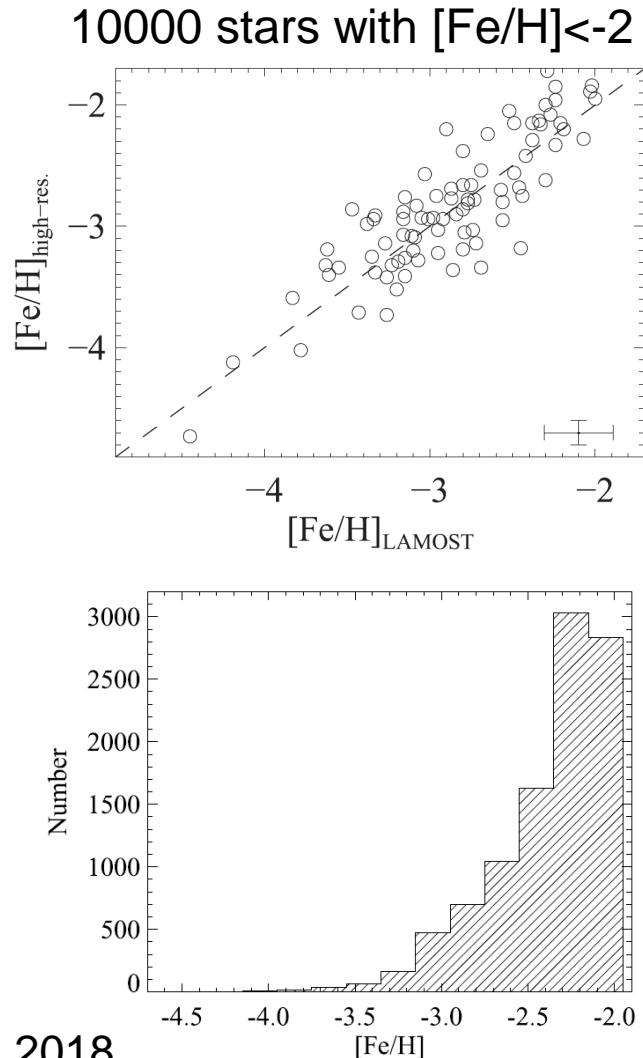
Belokurov+2014

Highlight of LAMOST results



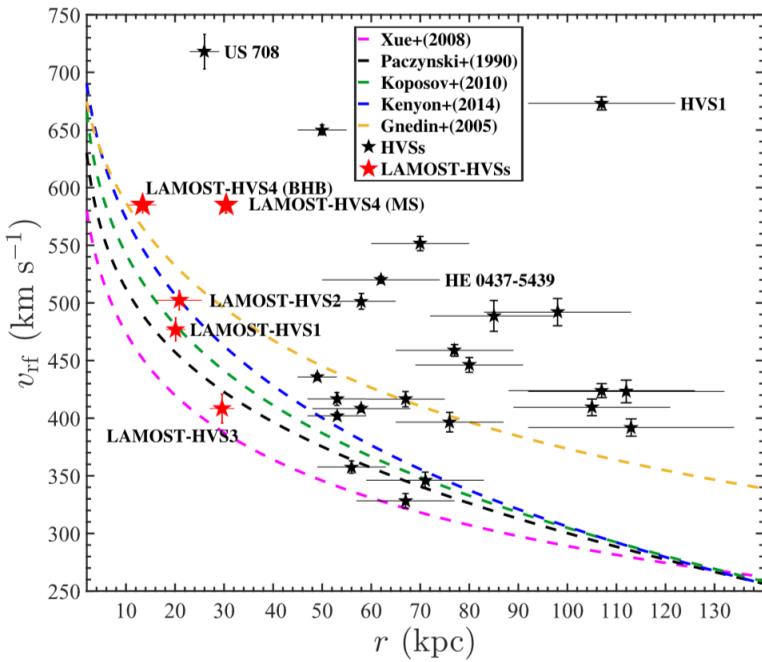
Yan et al. 2018

Li et al. 2018



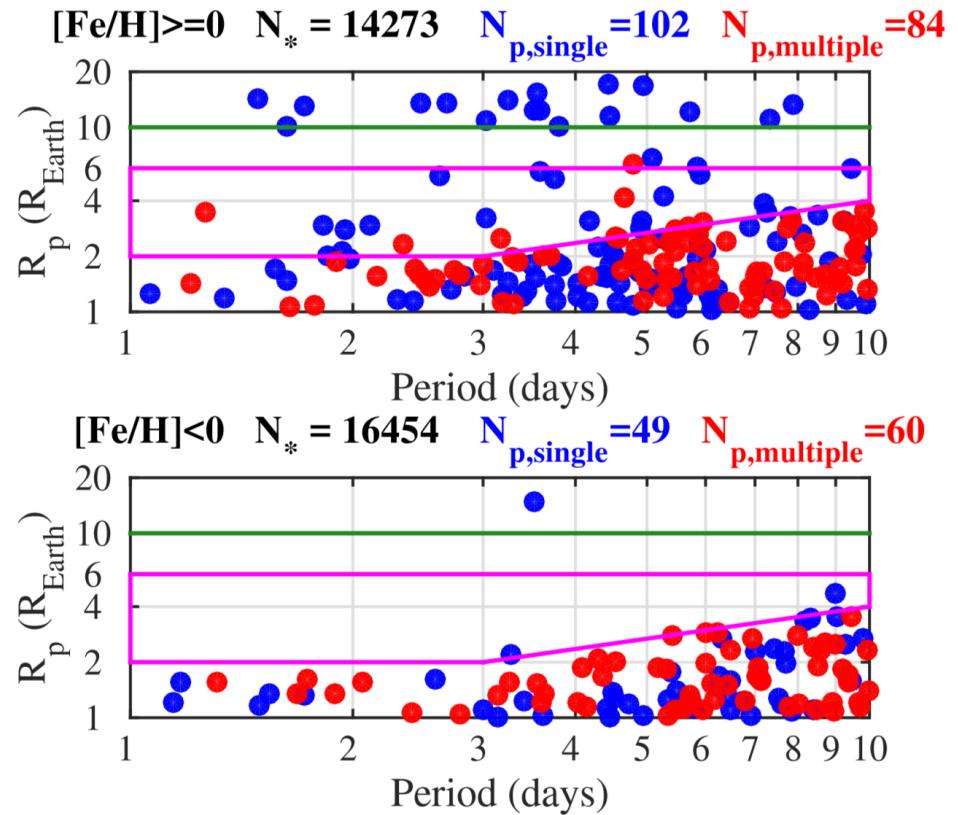
Highlight of LAMOST results

5 Hypervelocity stars in LAMOST



Li et al. 2018

Discovery of Neptune cousins of hot Jupiter

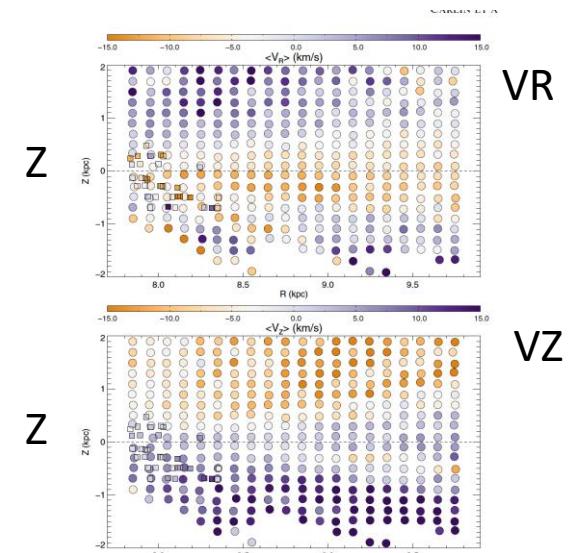
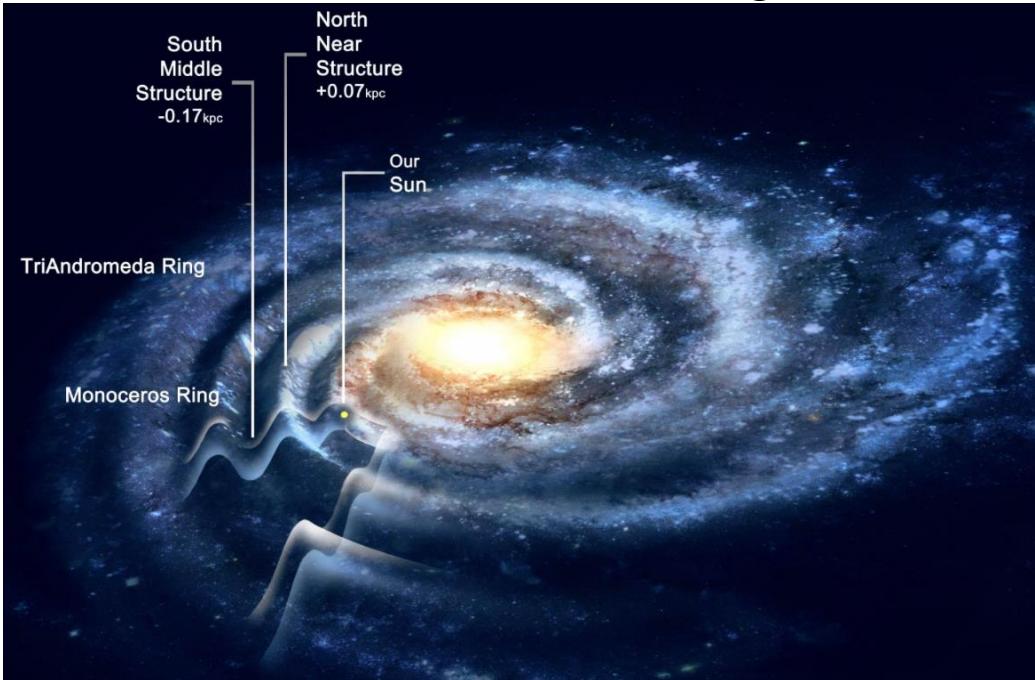


Dong et al. 2018

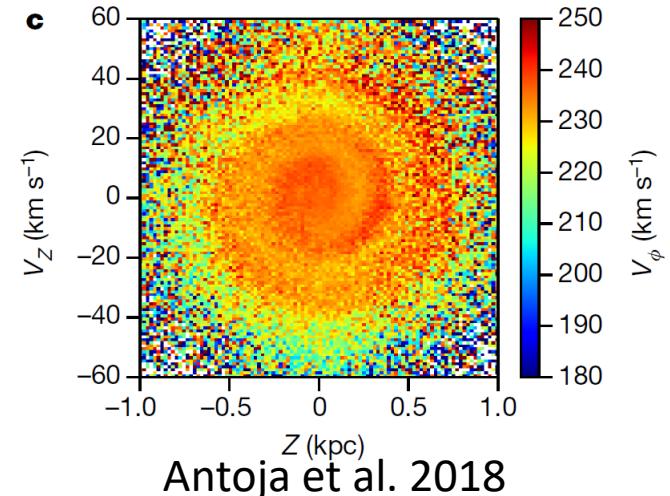
The MW has a larger disk in disequilibrium

- Corrugation in outer disk
- Disk is larger than 20 kpc

Xu, Newberg et al. 2015



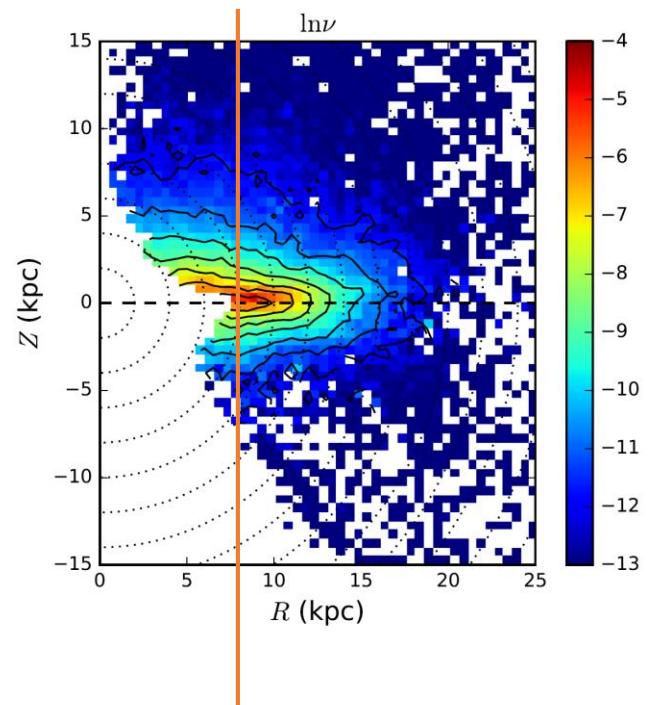
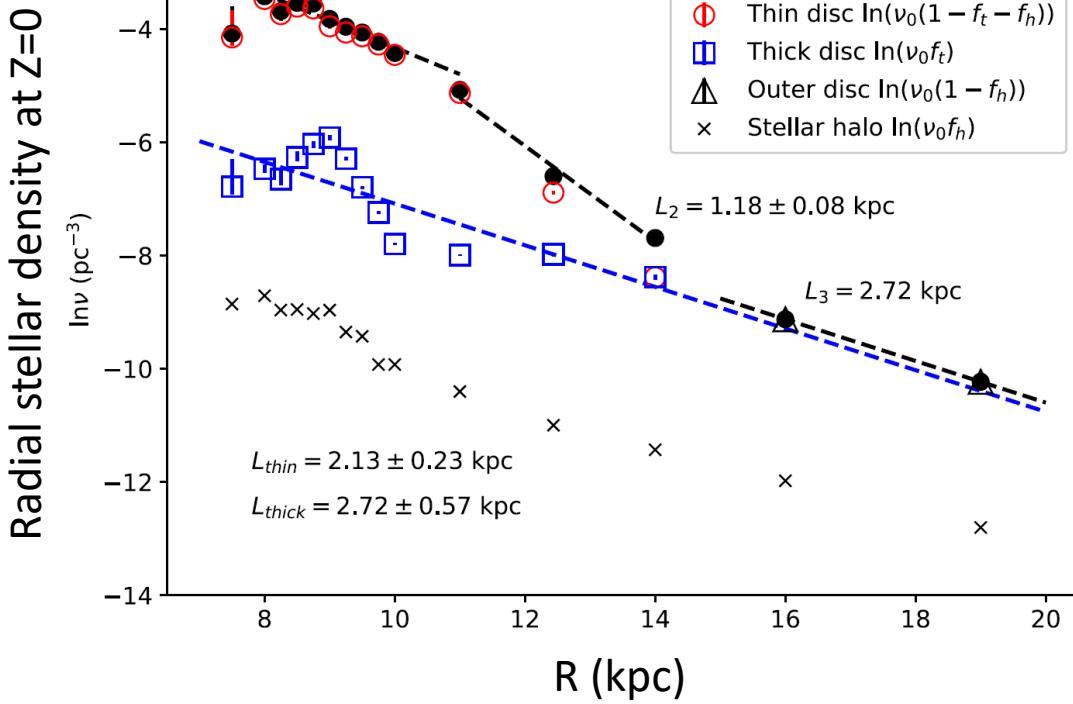
Carlin et al. 2013 R



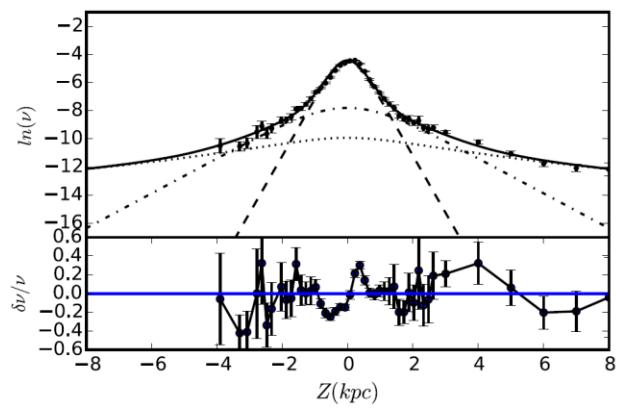
Antoja et al. 2018

Systematically mapping the outer disk

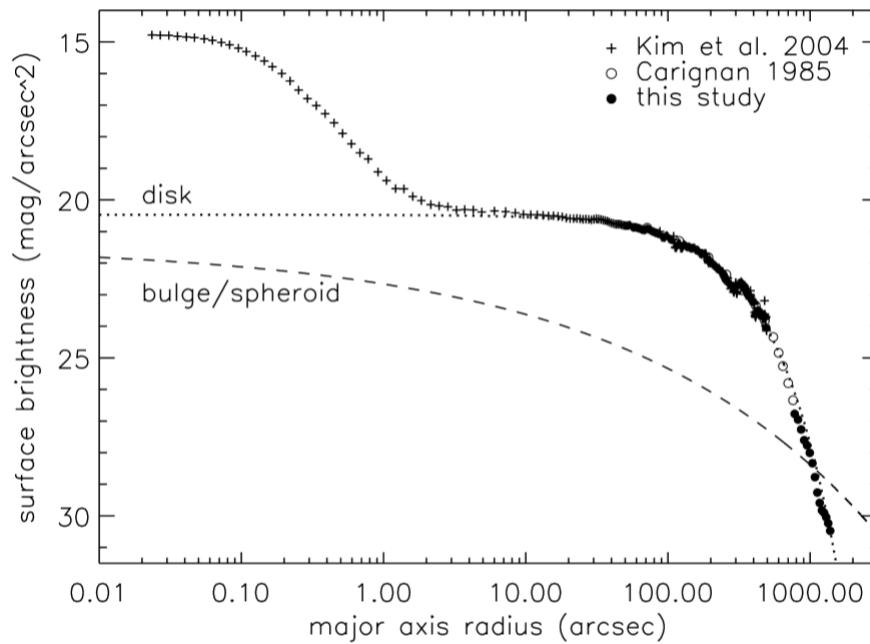
Wang, CL et al. 2018



CL et al. 2017

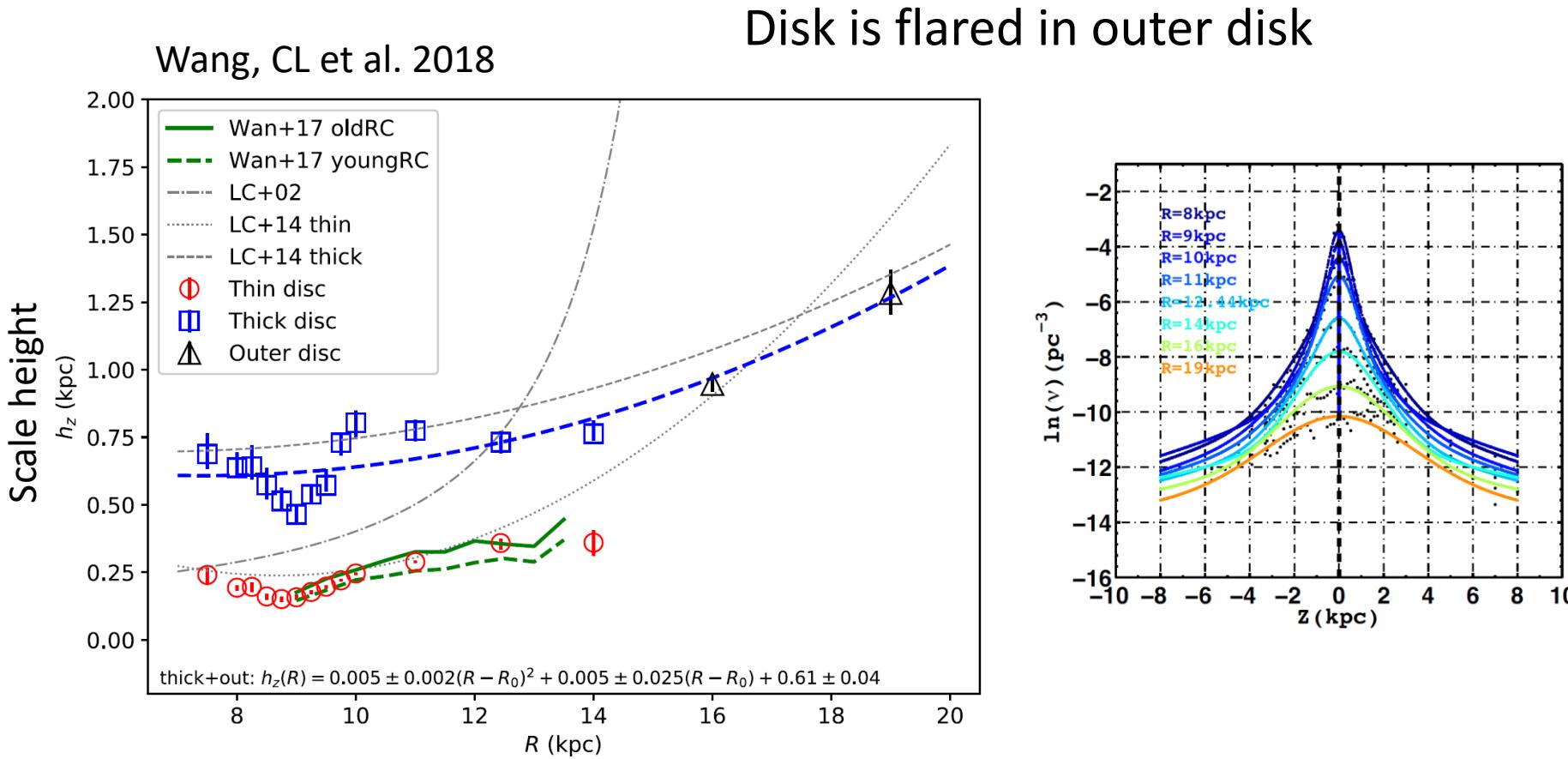


NGC 300



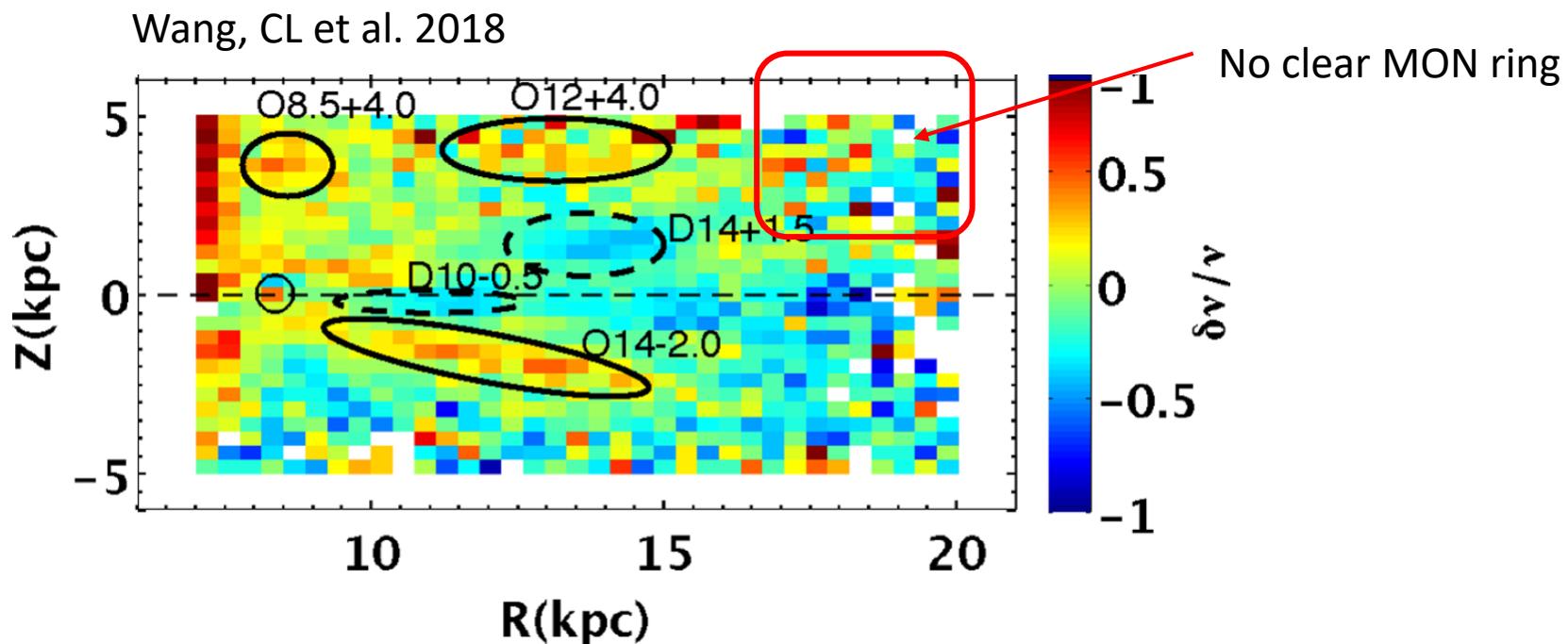
Bland-Hawthorn et al. 2005

Systematically mapping the outer disk



Systematically mapping the outer disk

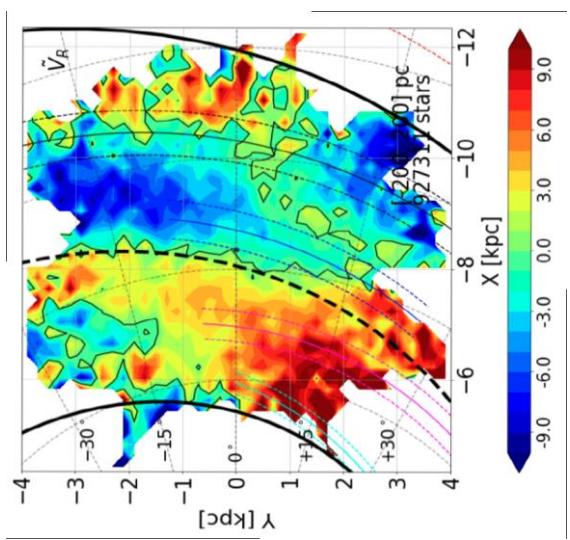
Residual density map after subtracting
an axisymmetric star count model



Rich substructures, N-S asymmetry implies the
disk is corrugated

VR ripples in X-Y plane

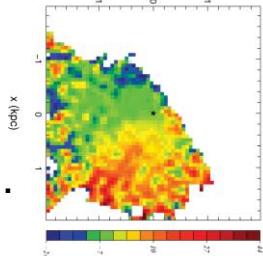
Gaia DR2



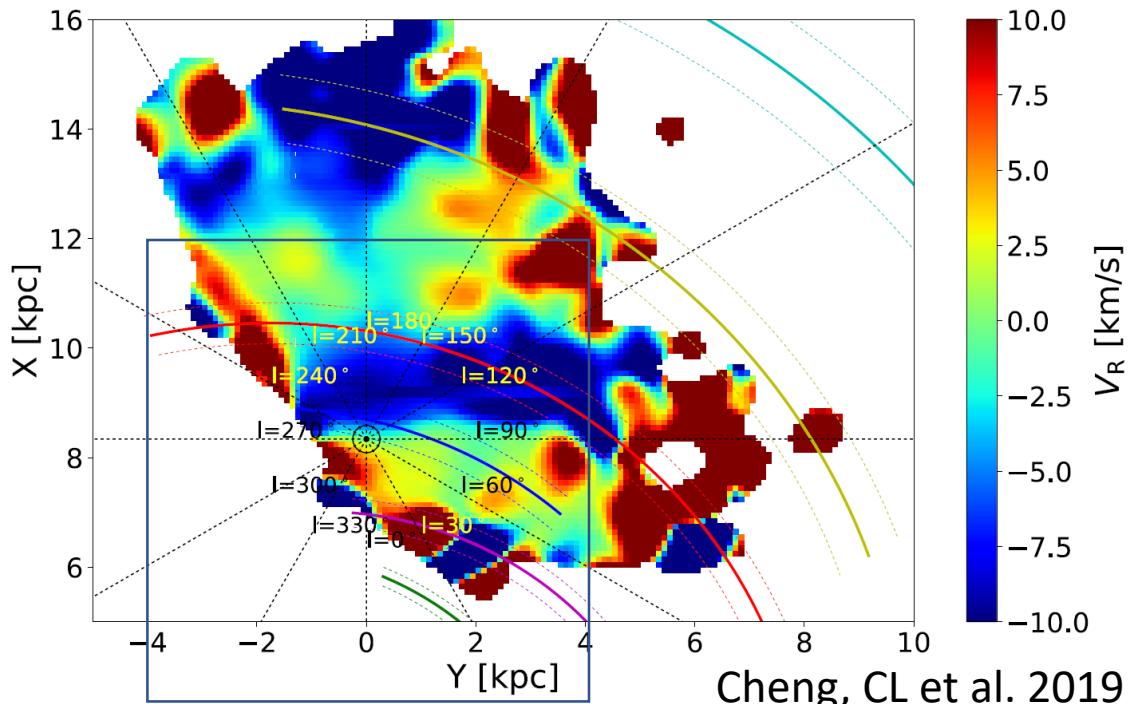
Katz et al. 2018

With RAVE data

Siebert et al.
2011, 2012

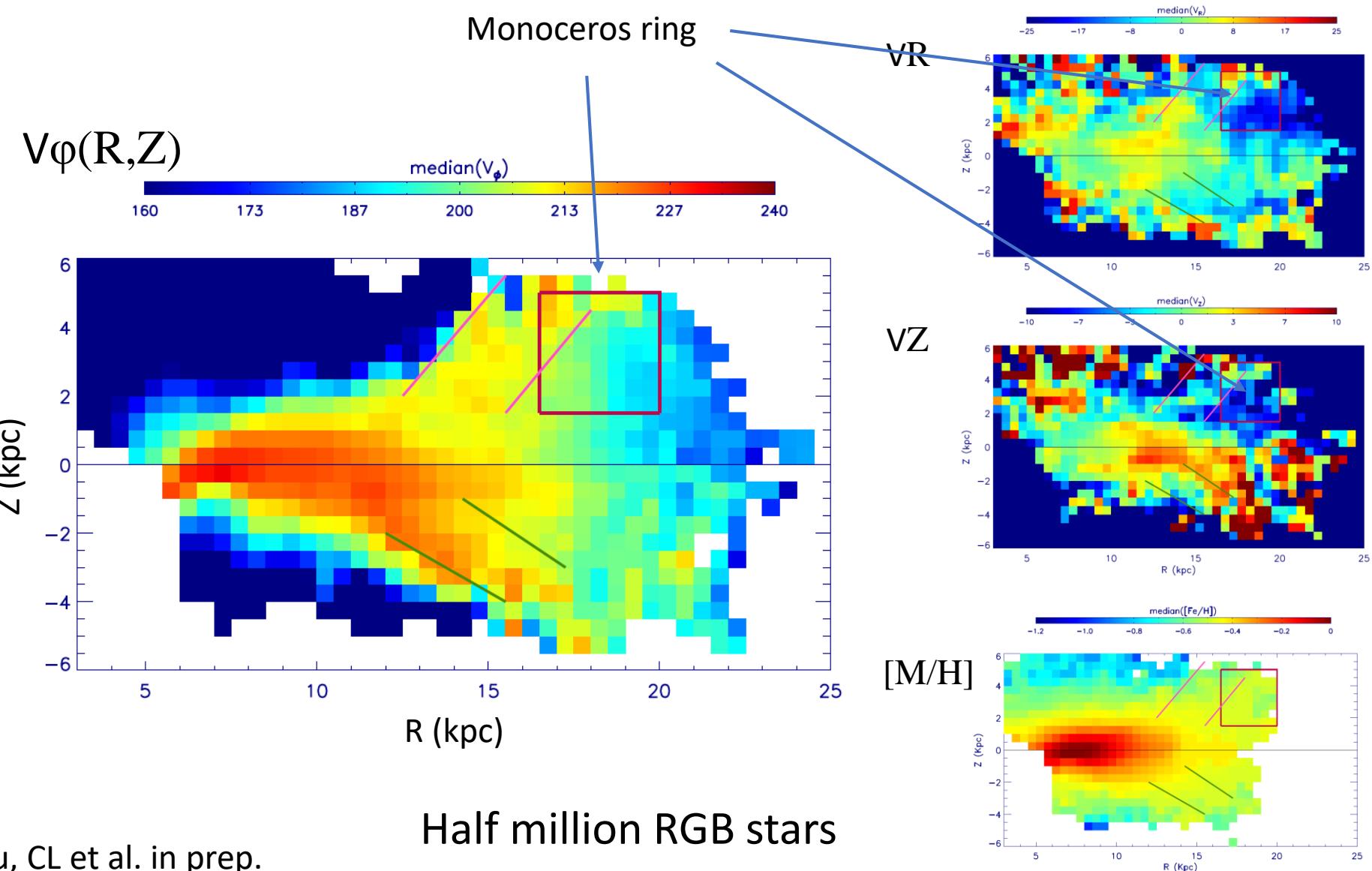


LAMOST 12000 OB stars



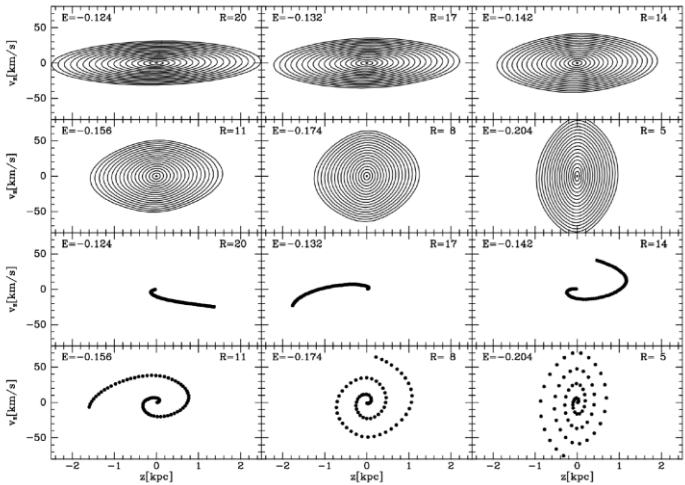
Cheng, CL et al. 2019

Velocity ripples in R-Z plane

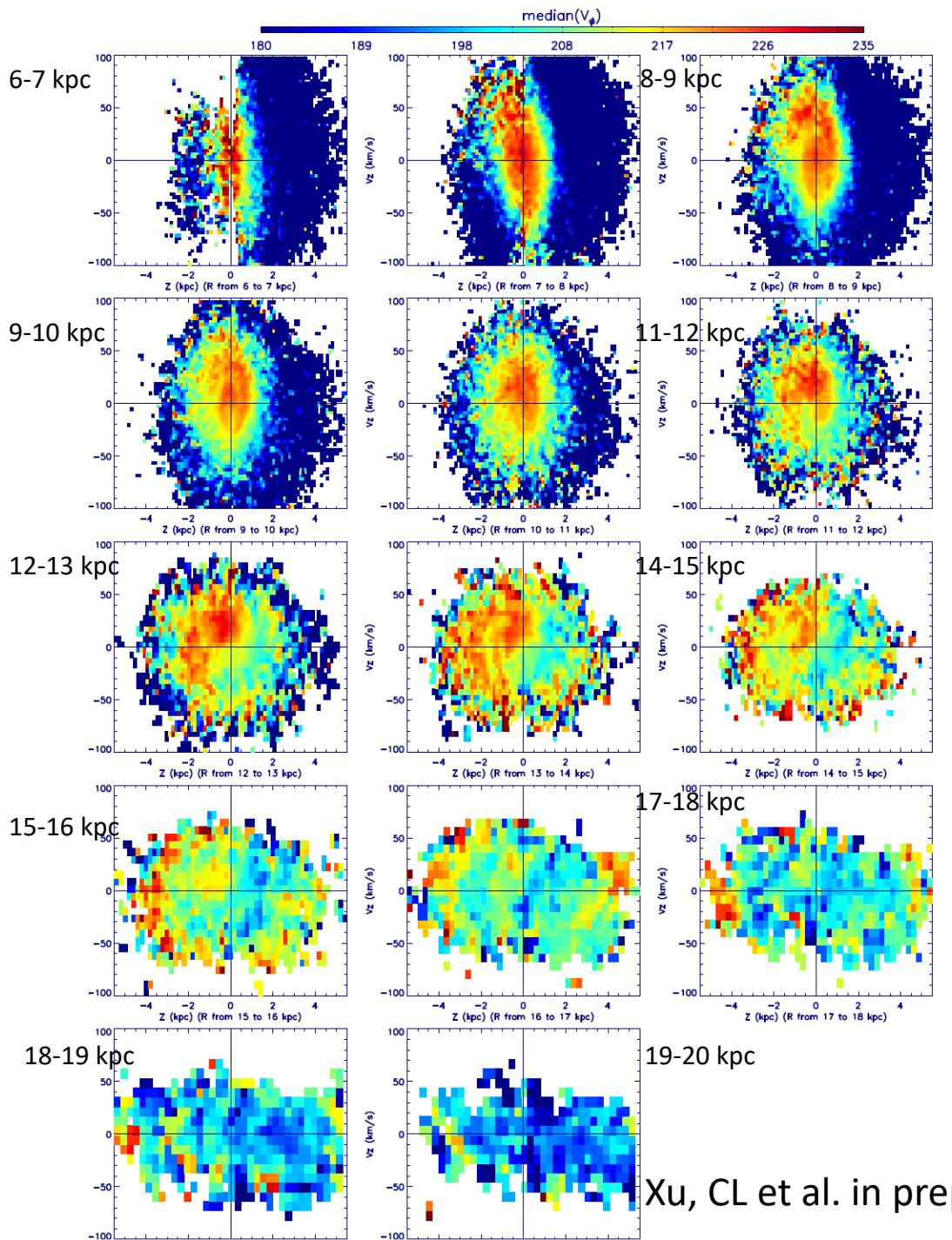


Phase spirals

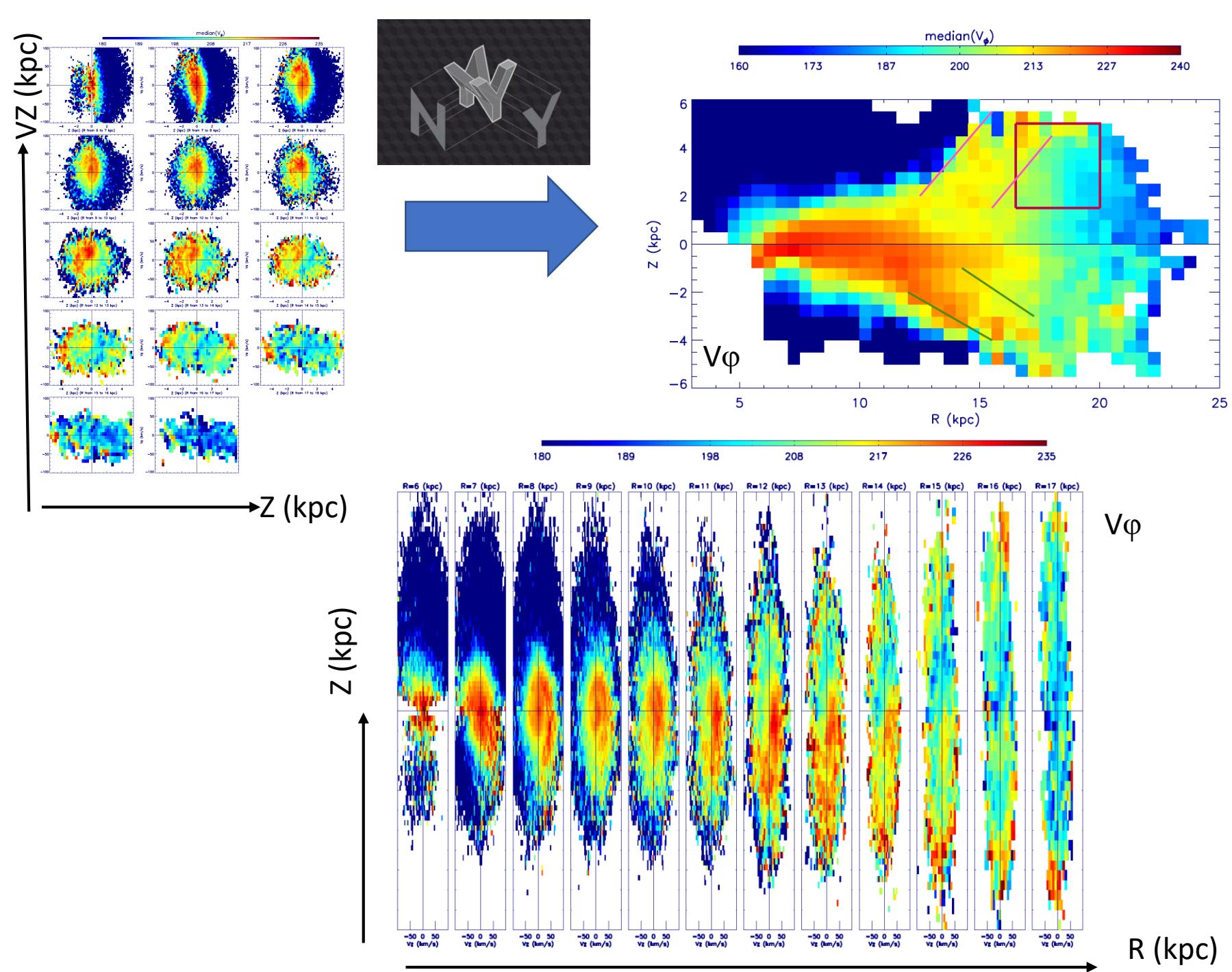
- R from 6 to 20 kpc



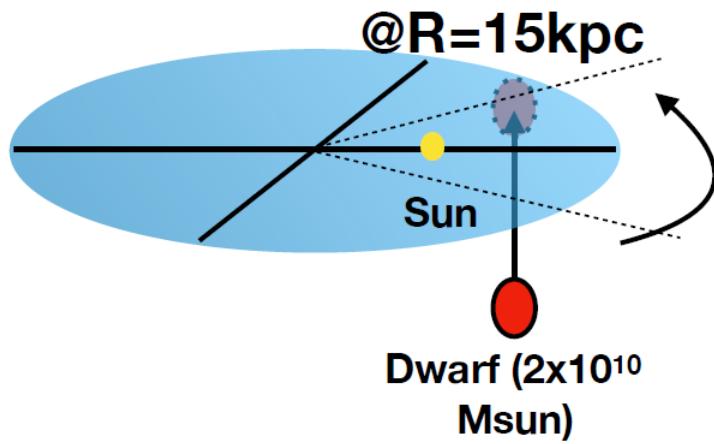
Bland-Hawthorn et al. 2018



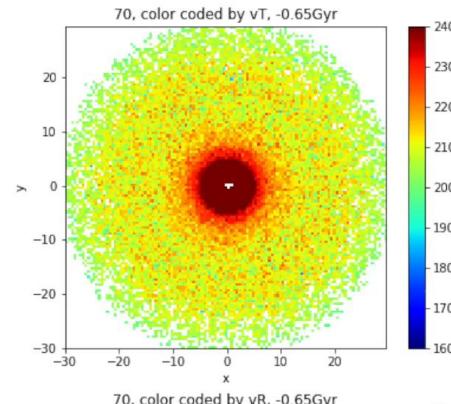
Xu, CL et al. in prep.



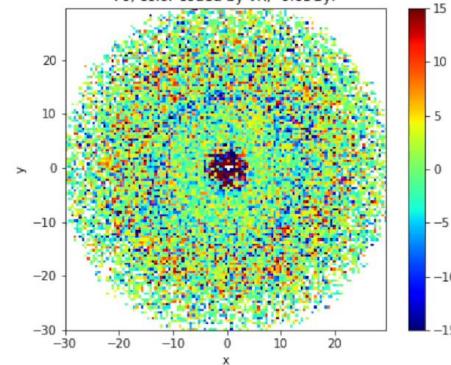
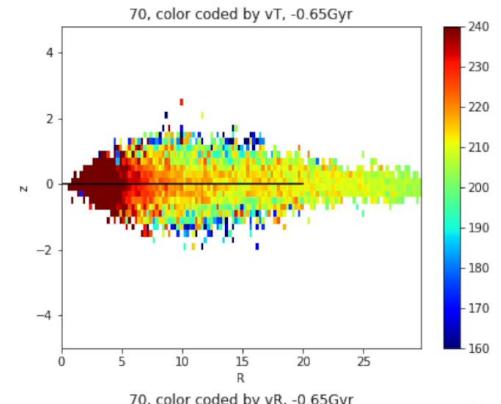
Test particle simulations



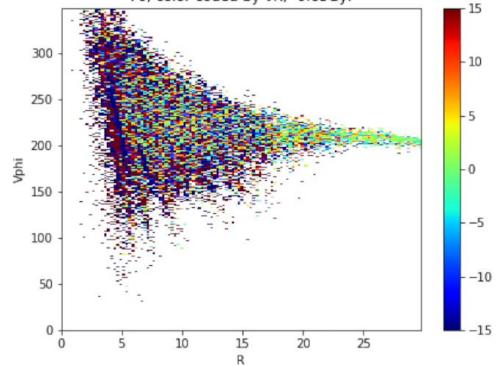
VT in X-Y plane



VT in R-Z plane



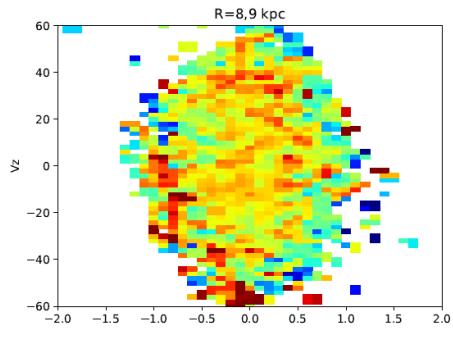
VR in X-Y plane



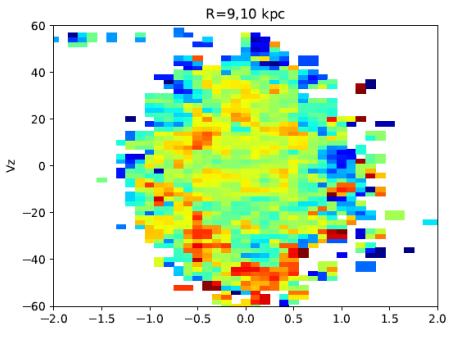
VR in R-VT plane

210 Myr after the impact

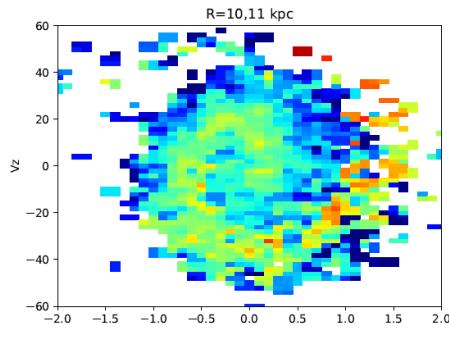
$R \sim 8.5$ kpc



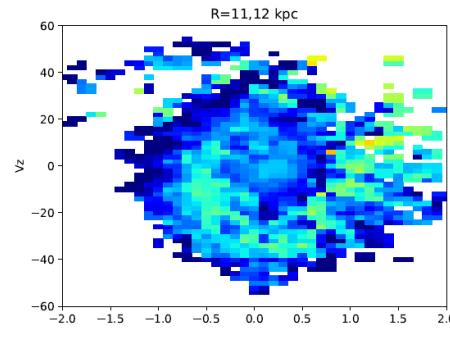
$R \sim 9.5$ kpc



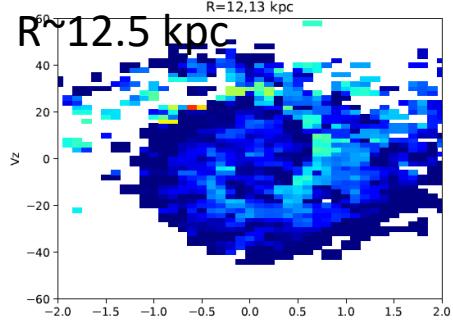
$R \sim 10.5$ kpc



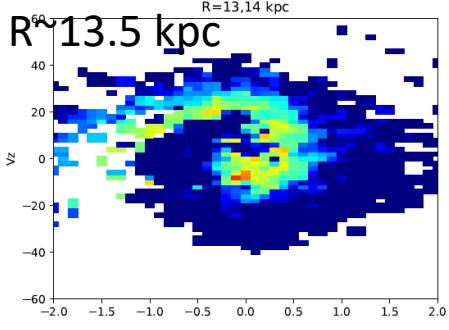
$R \sim 11.5$ kpc



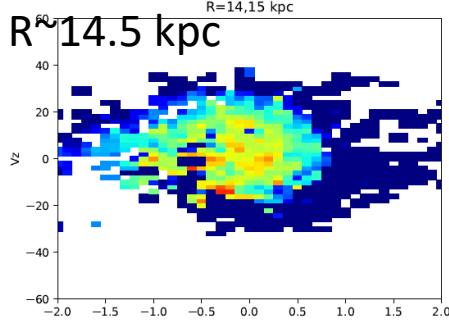
$R \sim 12.5$ kpc



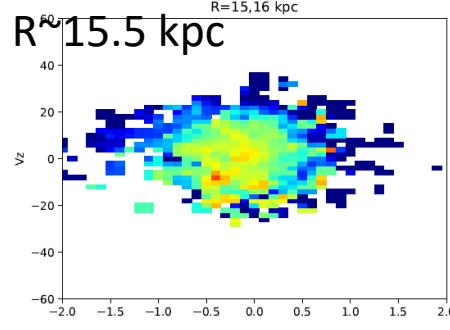
$R \sim 13.5$ kpc



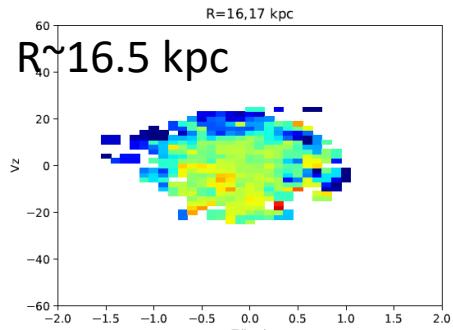
$R \sim 14.5$ kpc



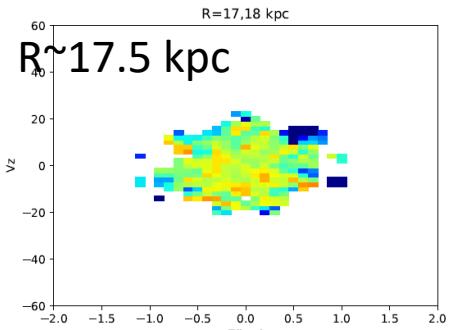
$R \sim 15.5$ kpc



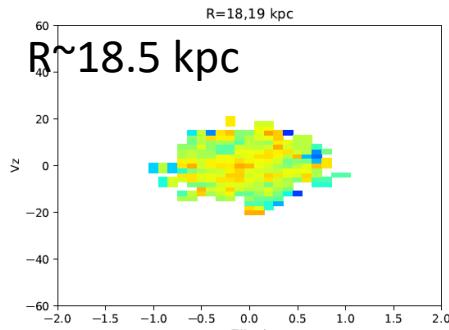
$R \sim 16.5$ kpc



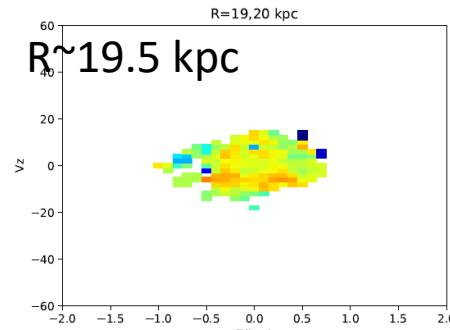
$R \sim 17.5$ kpc



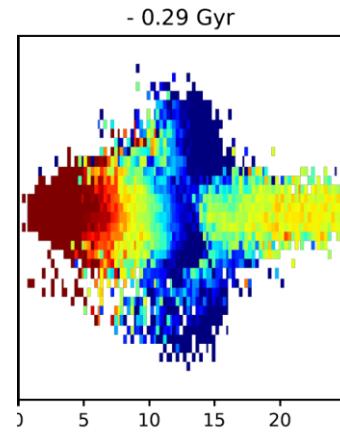
$R \sim 18.5$ kpc



$R \sim 19.5$ kpc

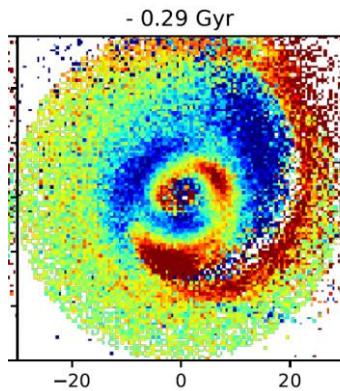
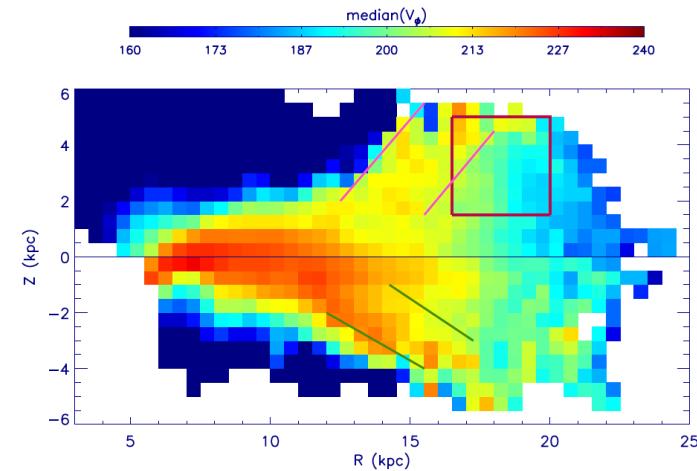


Test particle simulation

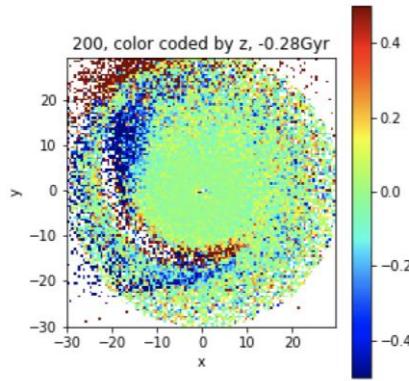
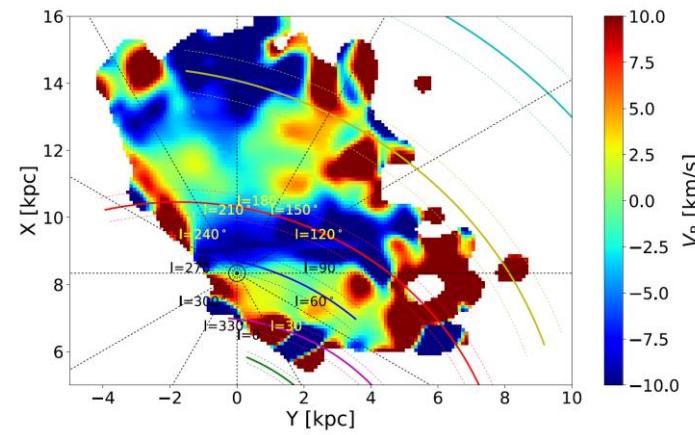


$V\phi(R, Z)$

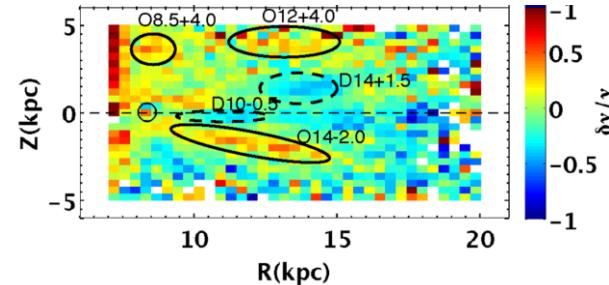
Observation



$V_R(X, Y)$

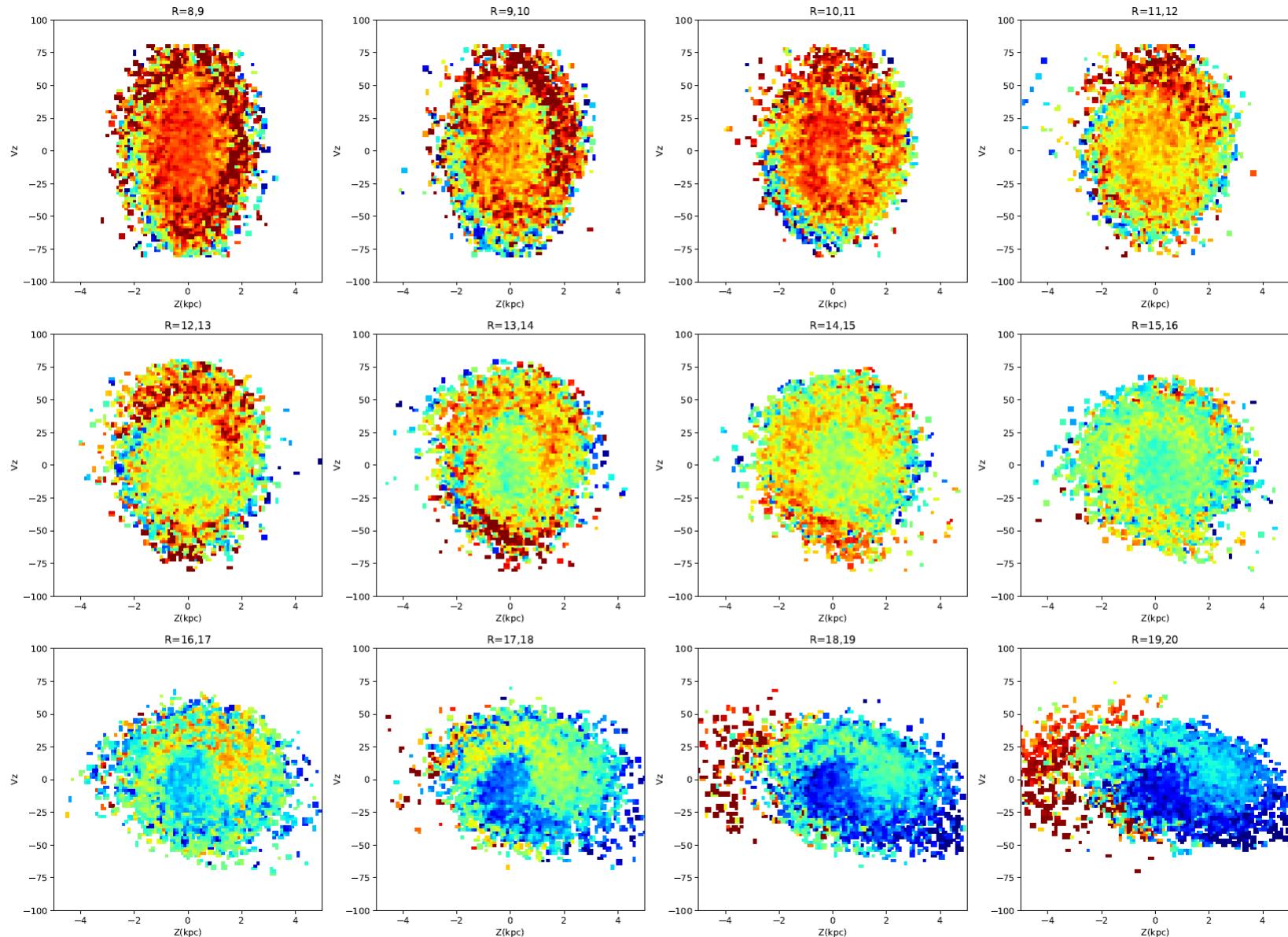


$Z_0(X, Y)$

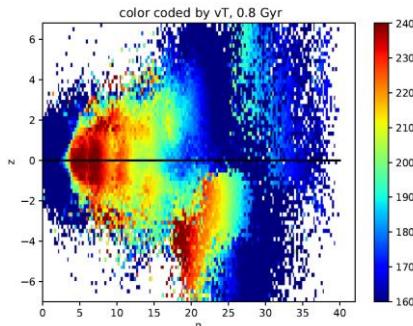


Corrugation

Laporte's N-body simulation



N-body Simulation

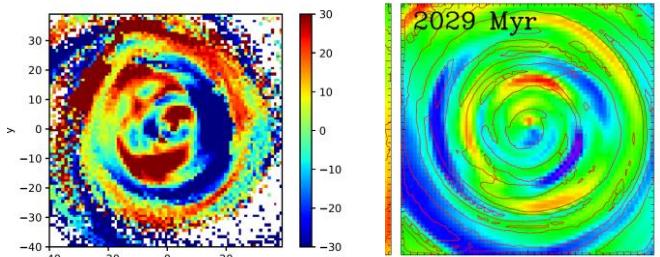
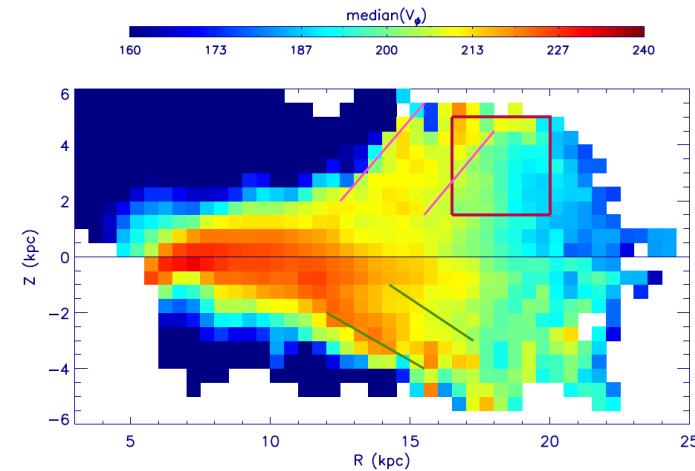


$\nabla\phi(R, Z)$



Flaring

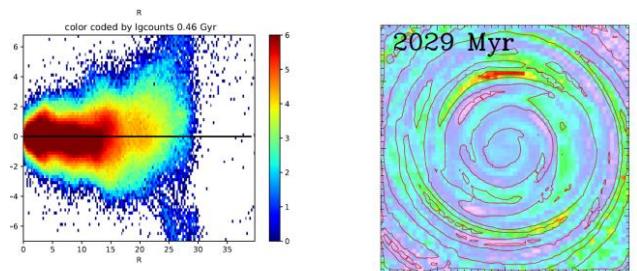
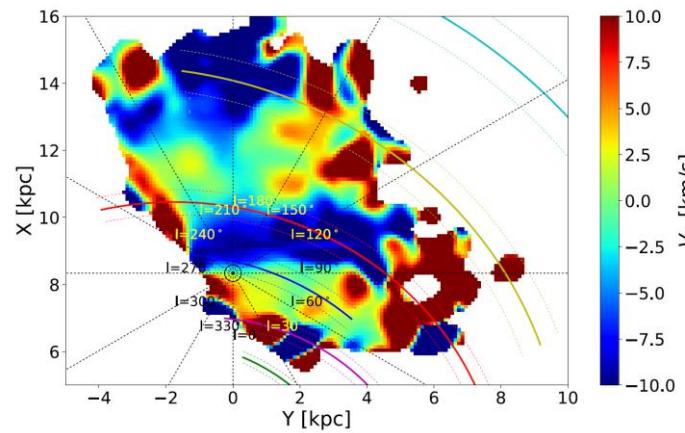
Observation



$\nabla R(X, Y)$



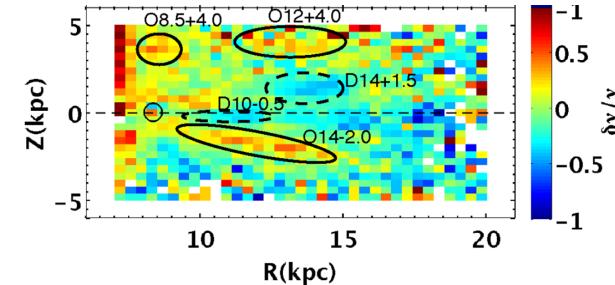
D'Onghia+16



$Z_0(X, Y)$



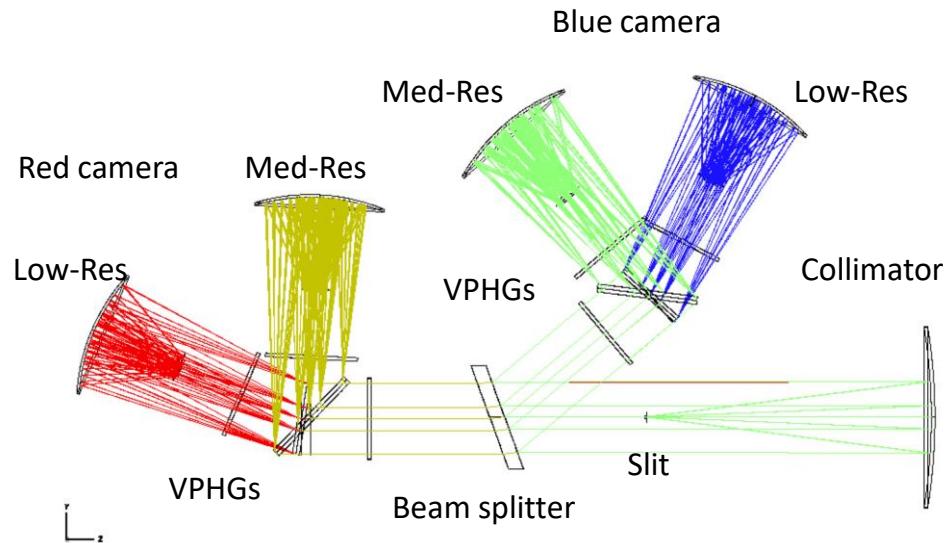
Corrugation



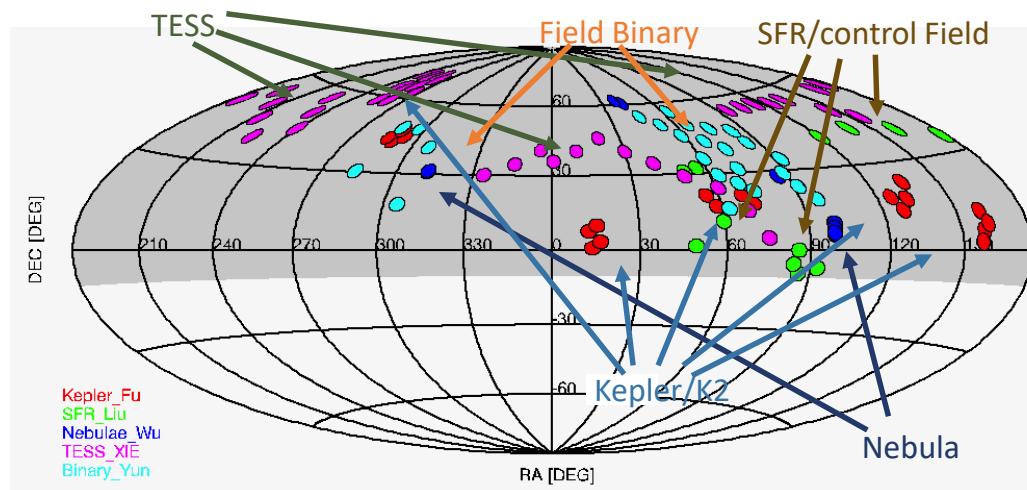
SUMMARY	Observed evidence	Spiral arms	Bar	Dwarf bombardment
Ripples, corrugations, waves	Vertical and radial waves in star count	Debattista14	?	Gomez+13, D'Onghia+16, Laporte+19, this work
	VR, VPhi ripples in large area of X-Y plane	Siebert+12; Faure+14; Monari+16; Katz+18	Liu17	D'Onghia+16, Laporte+19, this work
	Bird foot-like feature of VPhi in R-Z plane	?	?	Another aspect of the phase spiral (this work)
Spiral patterns in Z-VZ plane	Phase spirals wind tightly at small R but loosely at larger R	?	Khopersky+19	Binney+18, Bland-Hawthorn+18, Laporte+19, this work
Flared disk	Substantially flaring disk	?	?	Bland-Hawthorn+18; this work
MON ring	No over-density but has velocity streaming	?	?	A snapshot of stars in disequilibrium (this work)

LAMOST II

- Gratings have been upgraded to $R \sim 7500$
 - Blue arm: 496-533 nm (Mg Triplet, metal lines)
 - Red arm: 630-680 nm (Halpha, Li, [NII], [SII])



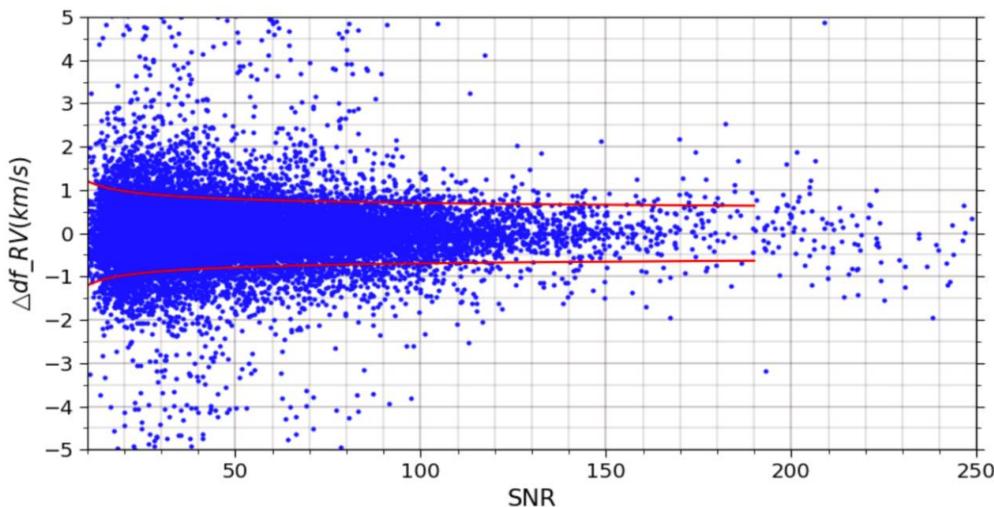
Time-domain vs. non-time-domain



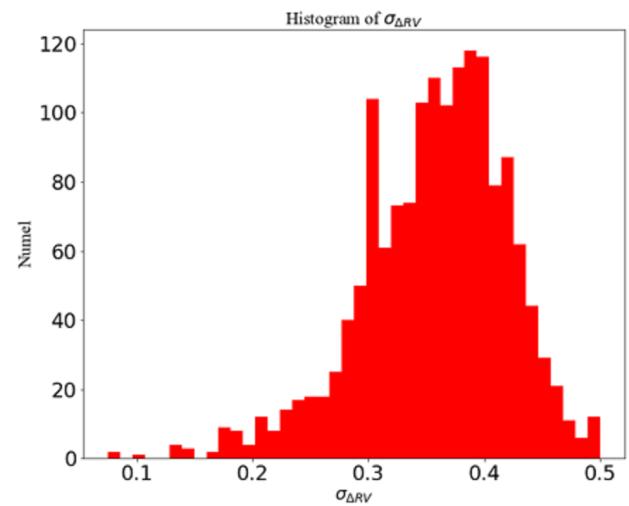
CL et al. in prep.

Radial velocity

Precision is around 1 km/s



Absolute RV : $\sigma_{RV} < 1$ km/s



Relative RV for time-domain observations: $\sigma_{RV} \sim 0.3$ km/s

LAMOST II (2018-2023)

- LAMOST II = Low-res (dark nights) + Med-res (bright nights)
- LAMOST II ==> Med-res Time-domain survey ($n_{\text{epoch}} \sim 60$)
- Future products:
 - 200K stars with time-domain med-res spectra ($G < 14$)
 - 2 million non time-domain med-res spectra ($G < 15$)
 - ~ 13 million low-res spectra (inc. LAMOST I) ($r < \sim 18$)
- Science:
 - Galactic archeology : Chemical tagging, Li-rich, extremely metal-poor stars
 - Nearby star forming region: Young populations
 - Kepler/K2 & TESS: Variables, binaries, exoplanet hosts
 - Fields: binaries
 - Open clusters
 - Galactic nebula: HII region, SNR, PNe