Probing the mass of the Andromeda galaxy with DESI spectroscopy

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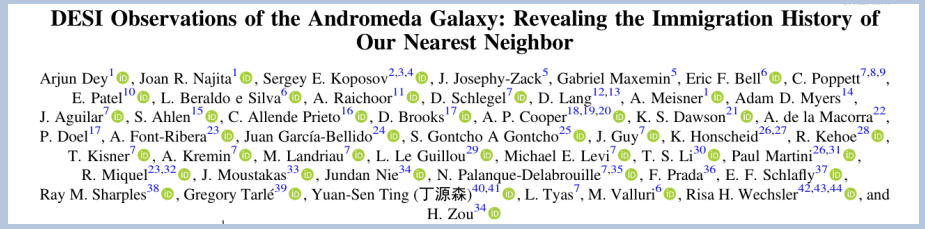
With **Arjun Dey**, **Joan Najita** & DESI MWS/ DESI collaboration

Based on: 2208.11683



DESI Observations of the Andromeda Galaxy: Revealing the Immigration History of Our Nearest Neighbor

Arjun Dey[1], Joan R. Najita[1], Sergey E. Koposov[2,3,4], J. Josephy-Zack[5], Gabriel Maxemin[5], Eric F. Bell[6], C. Poppett[7,8,9], E. Patel[10], L. Beraldo e Silva[6], A. Raichoor[11], D. Schlegel[7], D. Lang[12,13], A. Meisner[1], Adam D. Myers[14], J. Aguilar[7], S. Ahlen[15], C. Allende Prieto[16], D. Brooks[17], A. P. Cooper[18,19,20], K. S. Dawson[21], A. de la Macorra[22], P. Doel[17], A. Font-Ribera[23], Juan García-Bellido[24], S. Gontcho A Gontcho[25], J. Guy[7], K. Honscheid[26,27], R. Kehoe[28], T. Kisner[7], A. Kremin[7], M. Landriau[7], L. Le Guillou[29], Michael E. Levi[7], T. S. Li[30], Paul Martini[26,31], R. Miquel[23,32], J. Moustakas[33], Jundan Nie[34], N. Palanque-Delabrouille[7,35], F. Prada[36], E. F. Schlafly[37], Ray M. Sharples[38], Gregory Tarlé[39], Yuan-Sen Ting (丁源森)[40,41], L. Tyas[7], M. Valluri[6], Risa H. Wechsler[42,43,44], and H. Zou[34]

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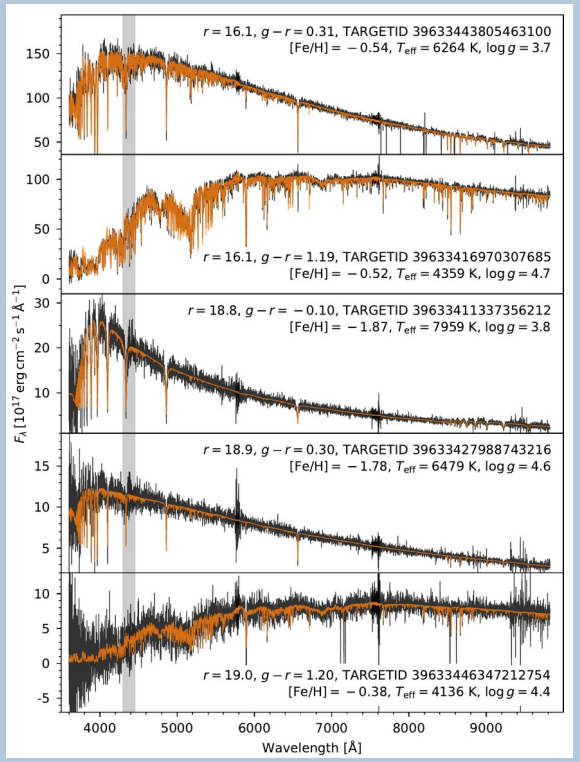
DESI

- (See Ting Li's talk for more details)
- Kitt Peak (4m)
- 3-arm (blue 3600-5500A, green 5500-7000A, red 7000A-10000A) spectrograph)
- **5000 fiber positioners**
- **3.2 degree diameter FOV**
- Flux calibration accurate to 1%
- Resolution R -- from 2000 at blue edge to 5000 at 10000A
- Highly efficient, **throughput 20-50%**



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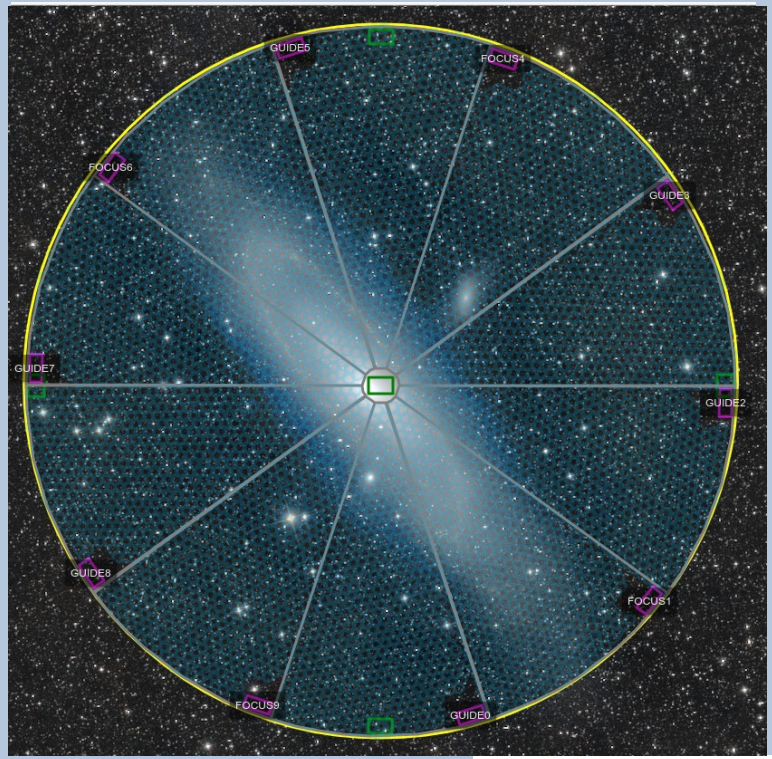
DESI Science Verification

- One of the science targets – M31
- DESI FOV ~ 40 kpc at distance of M31
- Each fiber has access to ~ 1’.5 patrol radius (300 pc)



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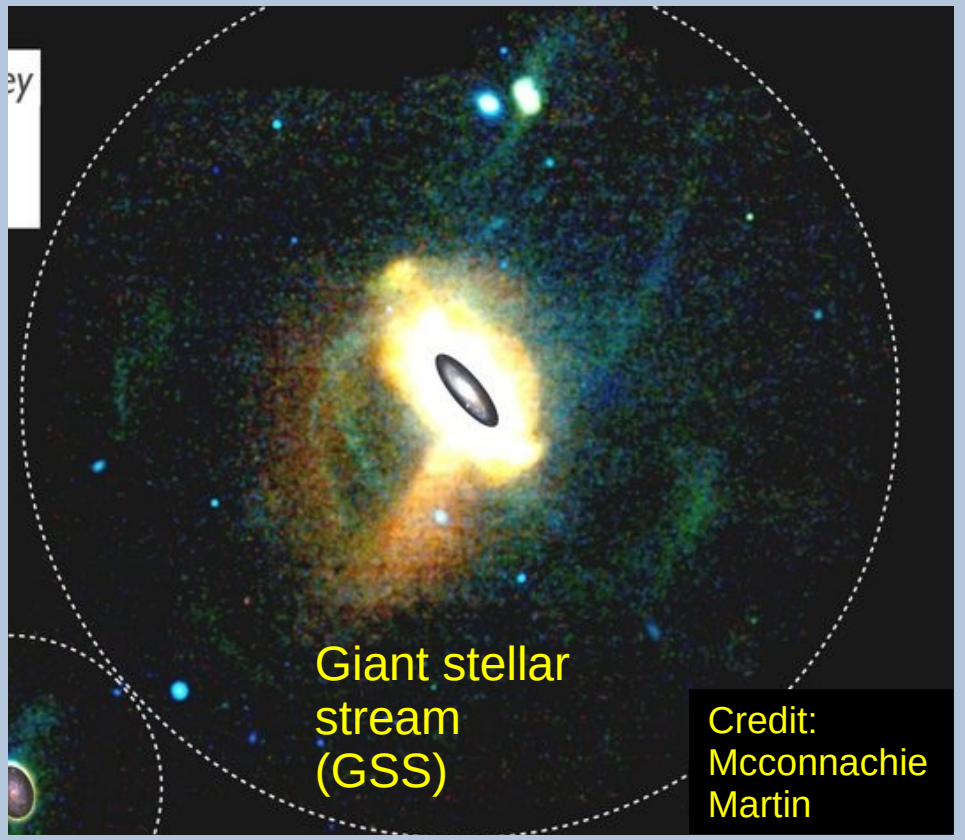
M31 past work

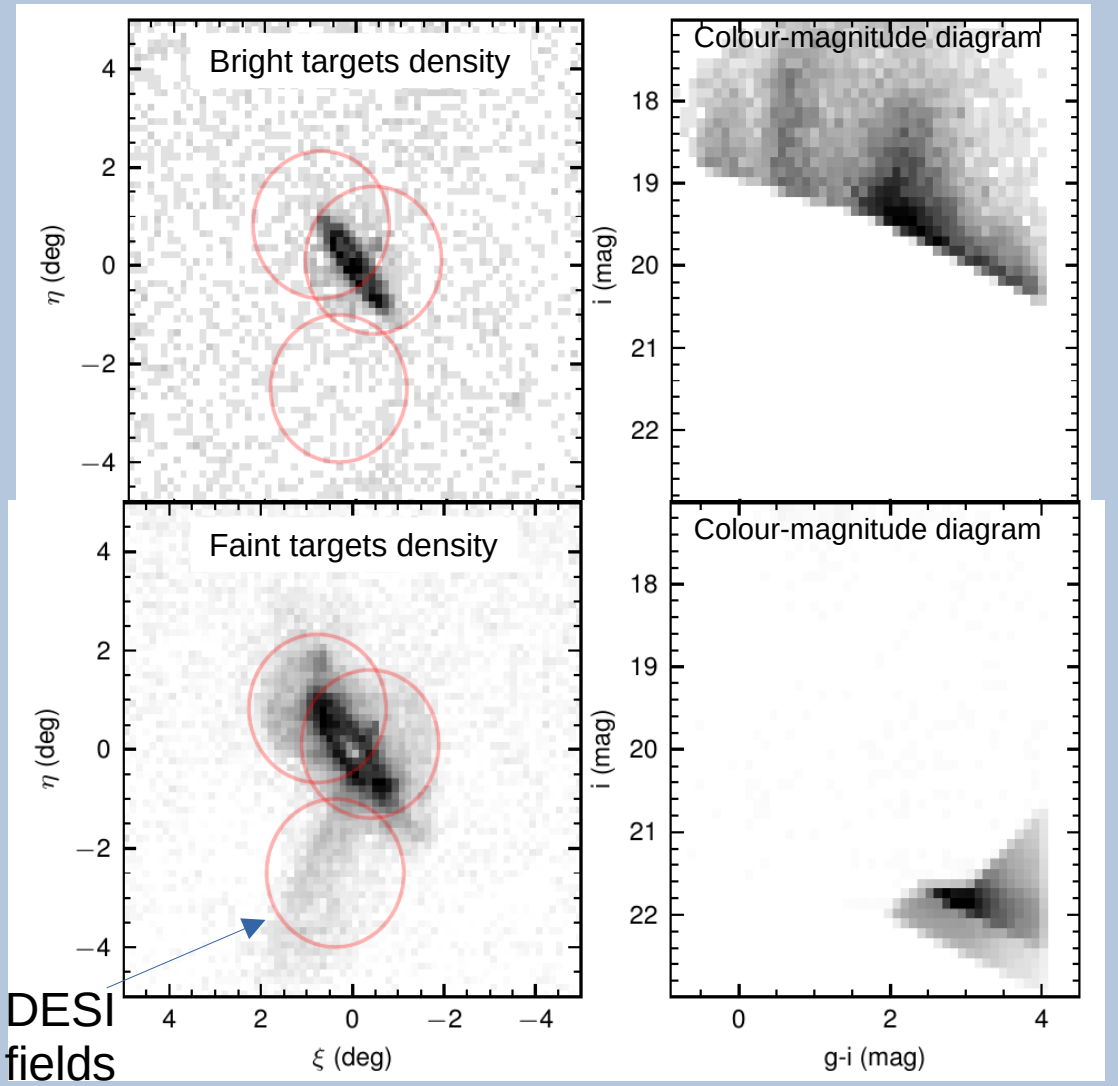
- A lot of results from last 20 years, revealing/analysing halo substructure
- **Photometry**: PANDAS survey (Mcconnachie+2018)
- **Spectroscopy**: SPLASH survey Gilbert+2012, Caldwell+2016, Escala+2019
- **Modelling**: Fardal+2013, Kirihara+2017, Hammer+2018 d'Souza+2020

(very incomplete list)



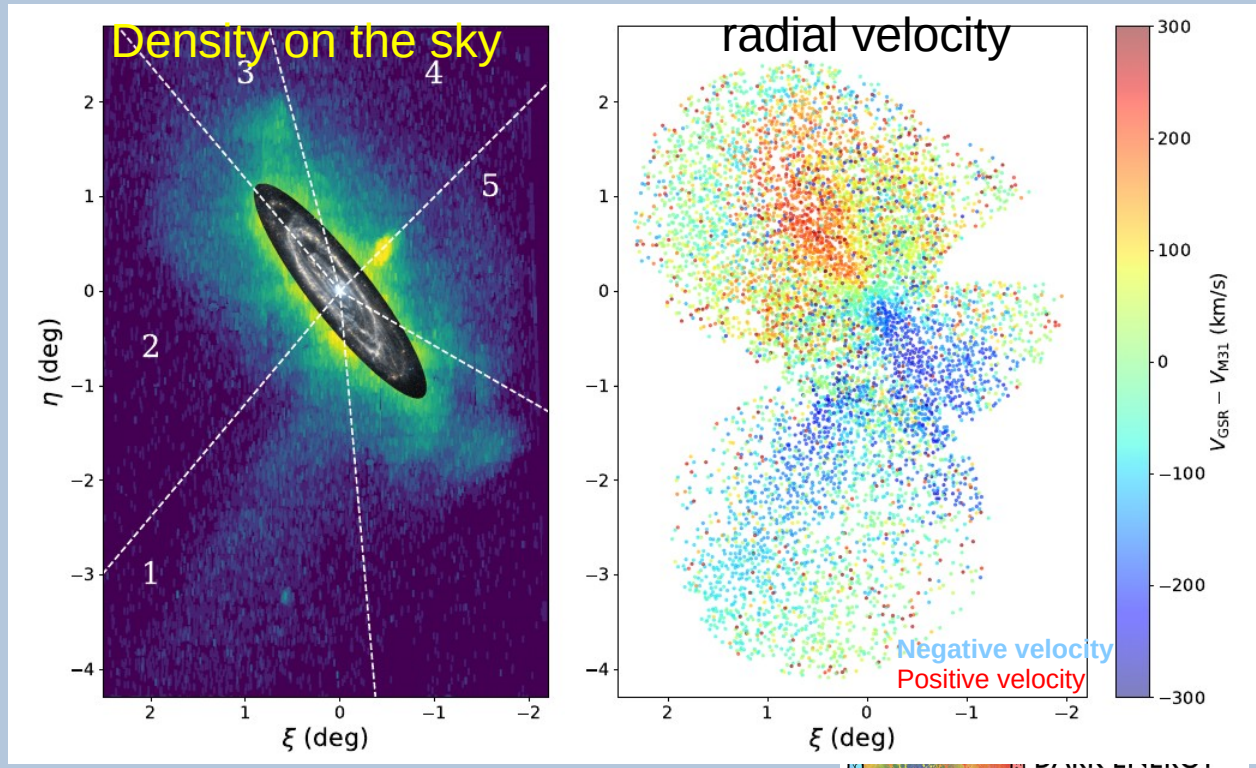
M31 DESI targeting

- Center of M31, bright tile i<19, targets HII regions, super-giants, GCs (Gaia selected)
- Outer tiles, selecting TRGB/AGB stars i~22-22.5
- We targeted g-i>2 red stars (hence metal-rich bias)
- Max exposure 1.5hr
- RV error 5-10 km/s at z~22



DESI M31 spectroscopy

- Total number of M31 member stars -- 7500
- 136 clusters
- ~ 50 HII regions/ PNs
- The majority of outer M31 stars are metal-rich [Fe/H]>-0.5



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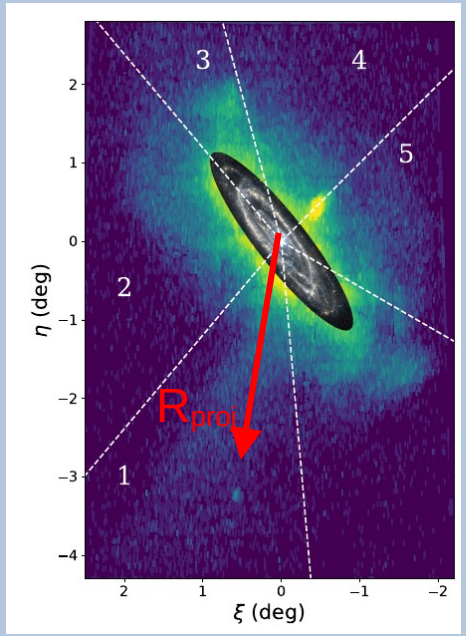
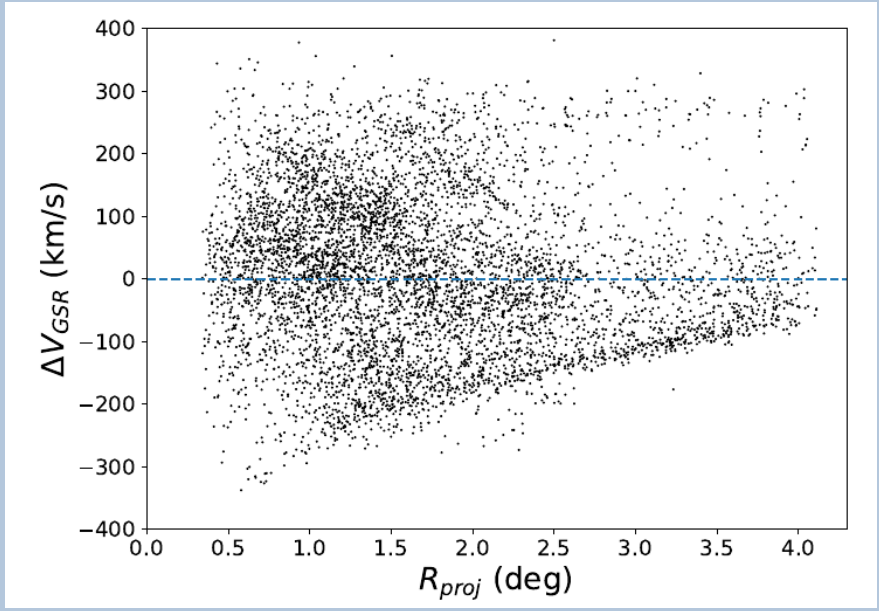
M31 position velocity diagram

- Clearly dominated by substructure

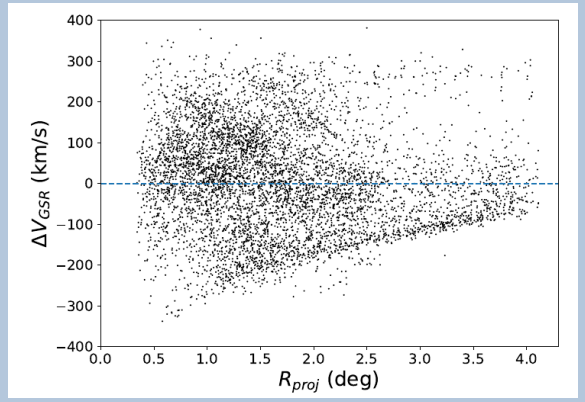


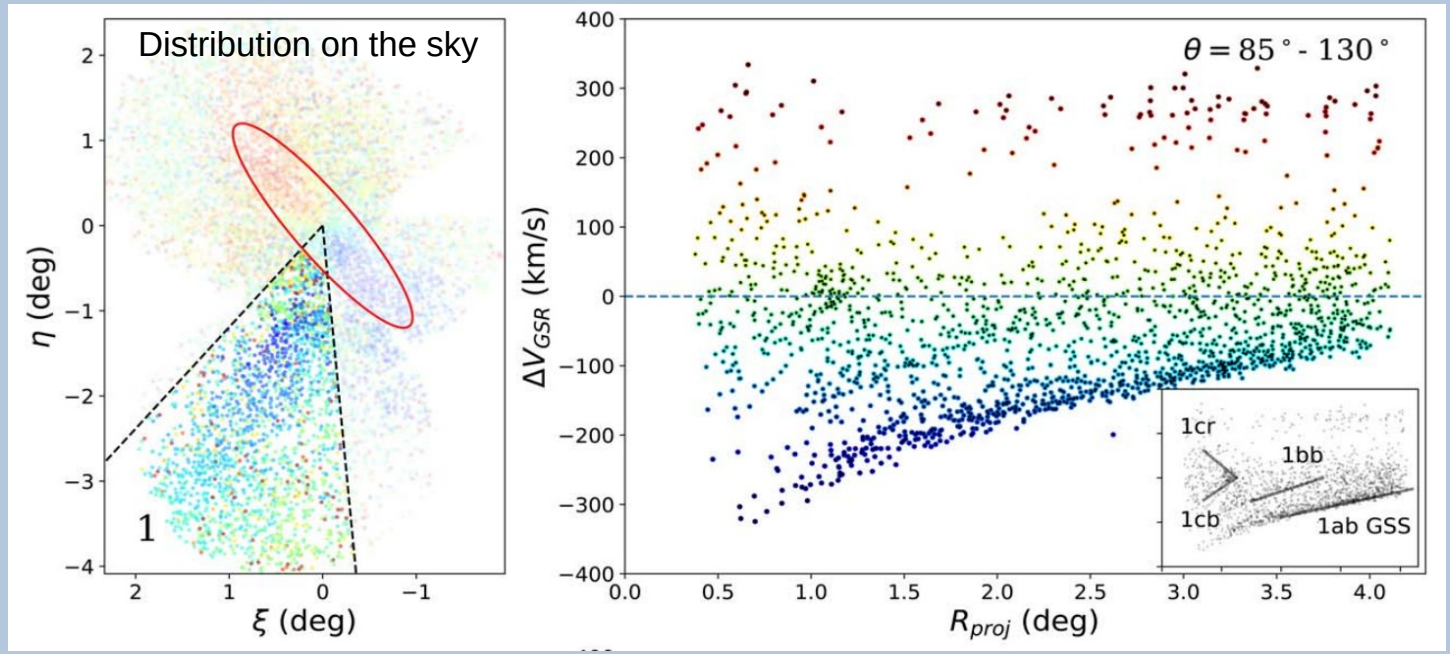


For the plot we excluded M31 disk stars

M31 shell system

- We see “chevrons” in position velocity diagrams of different sections of M31





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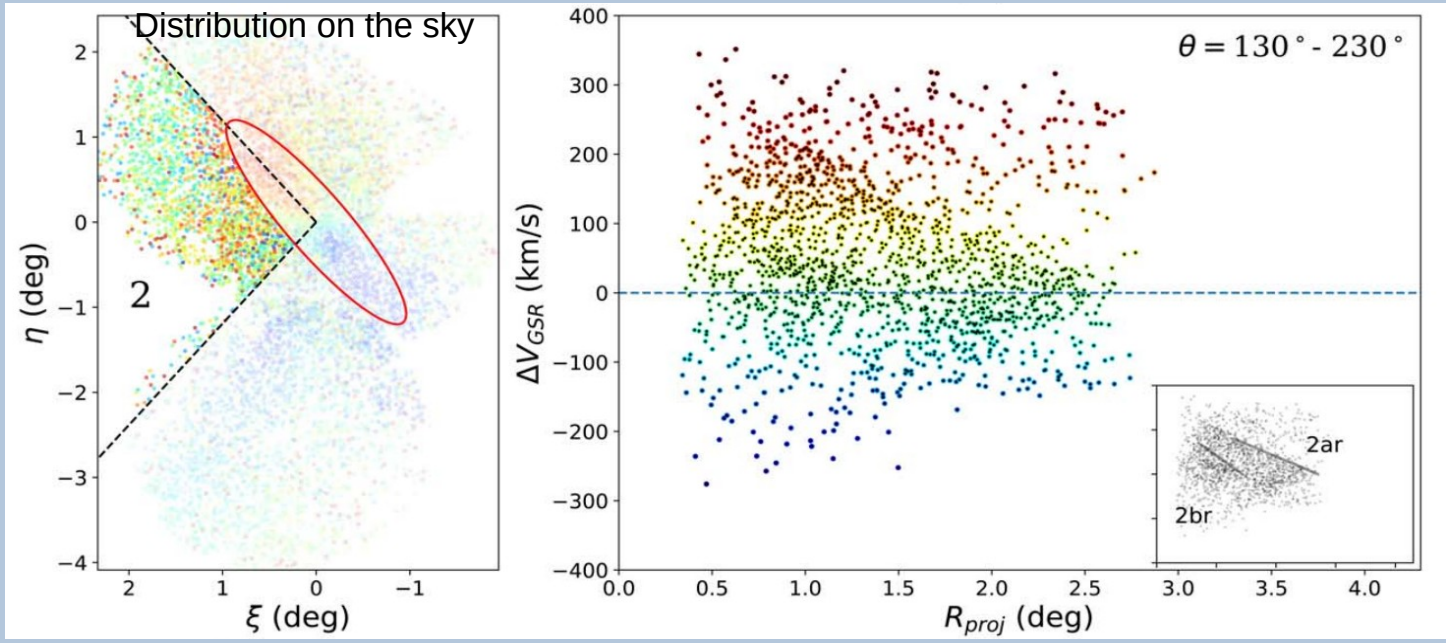

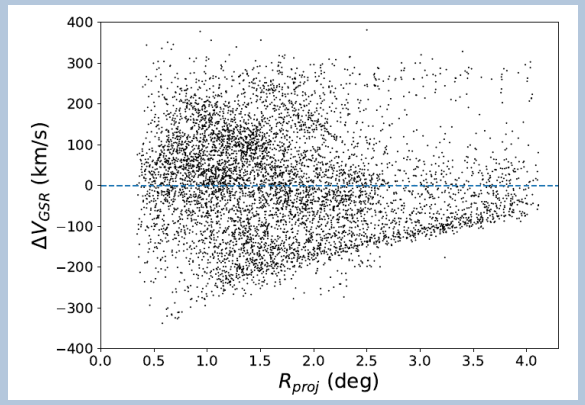

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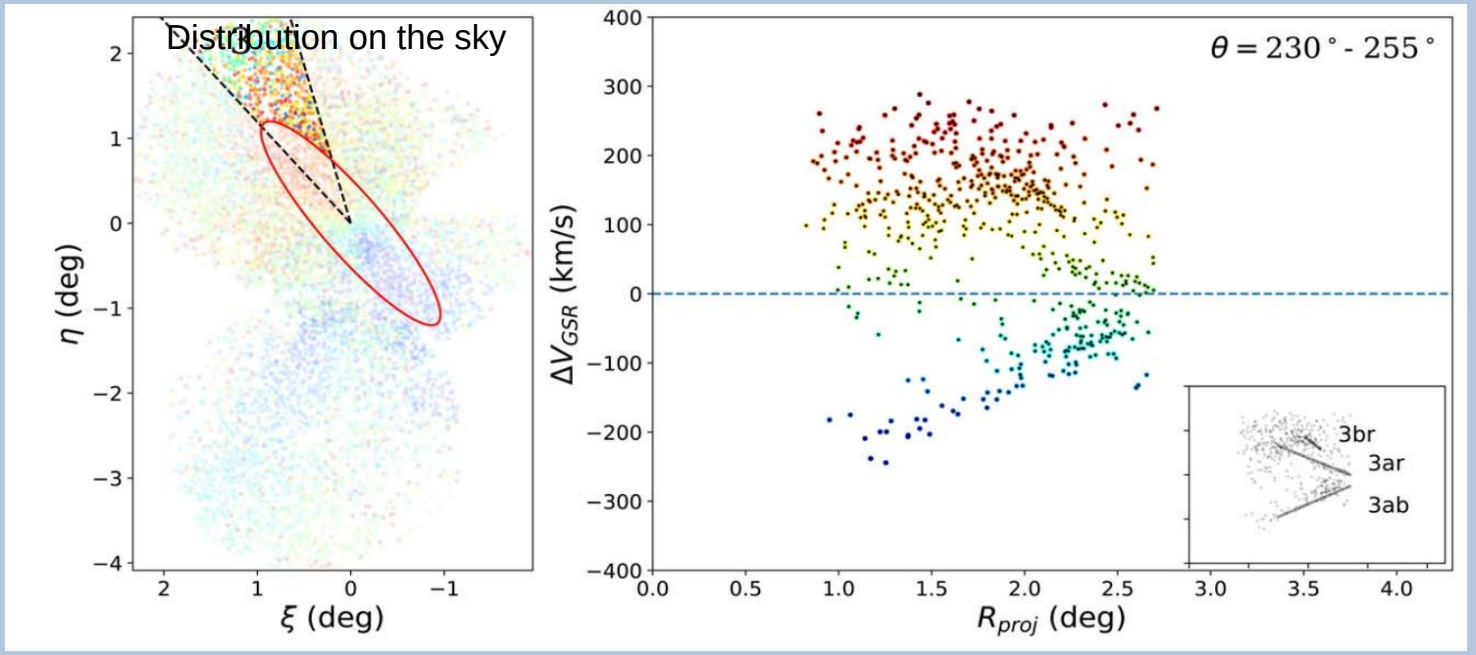

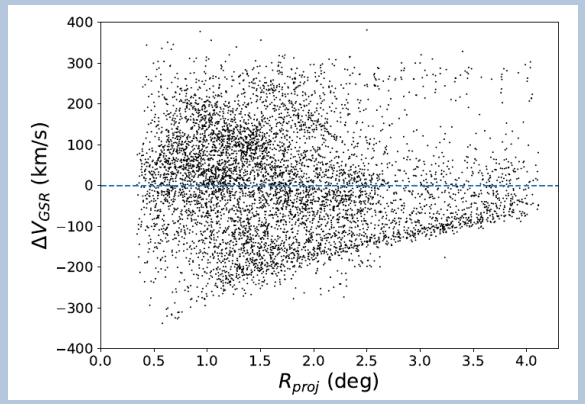

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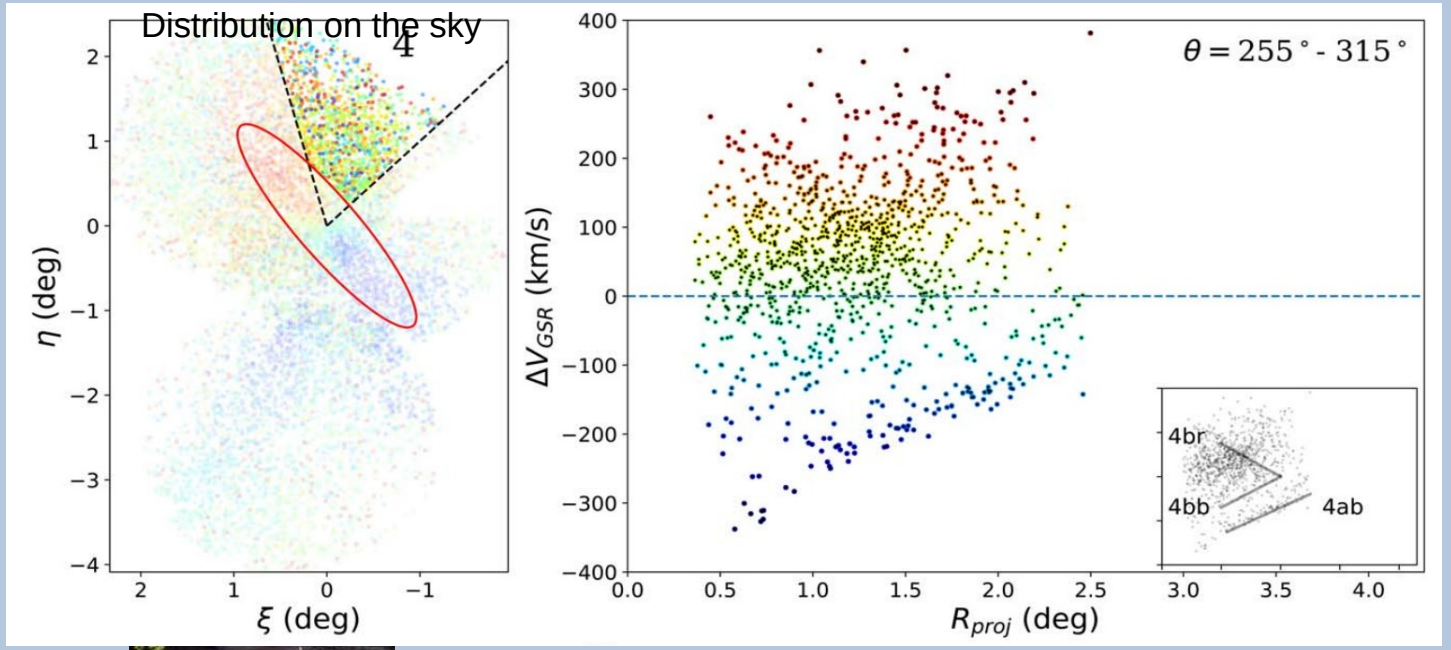

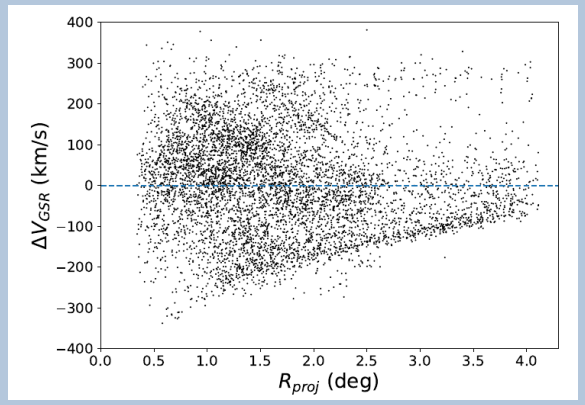

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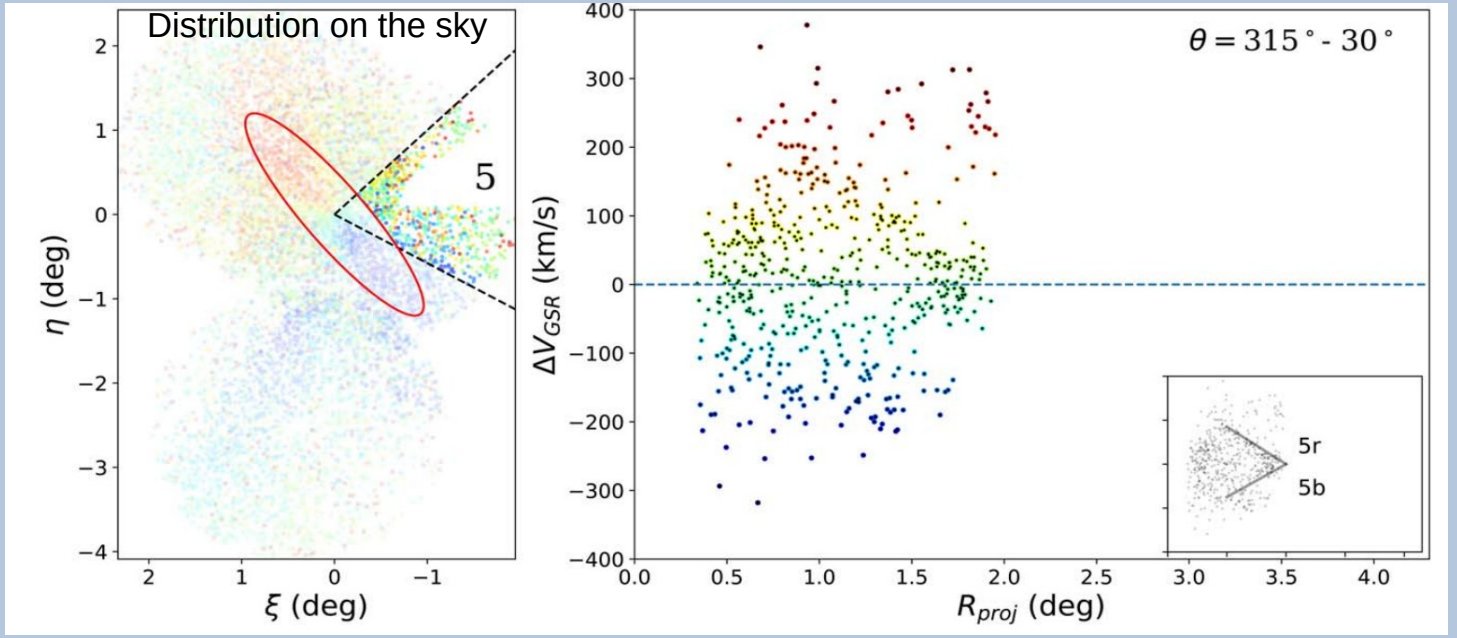
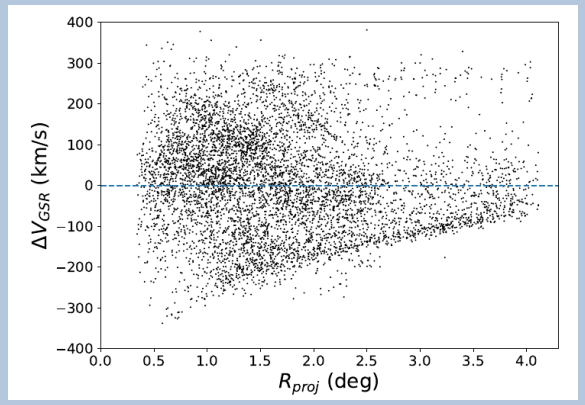
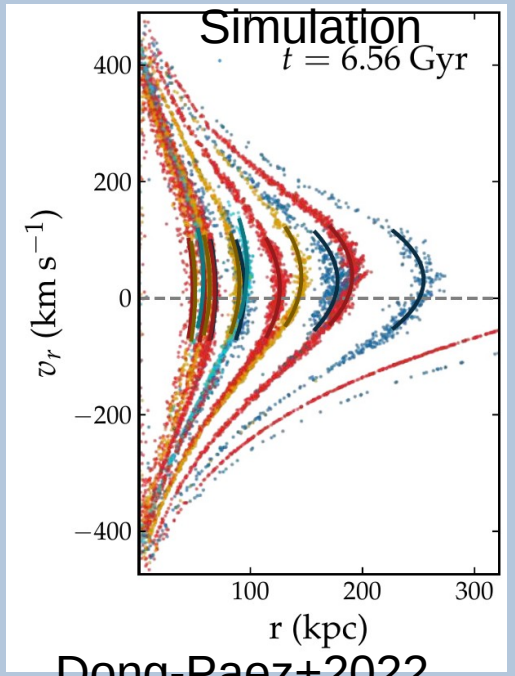


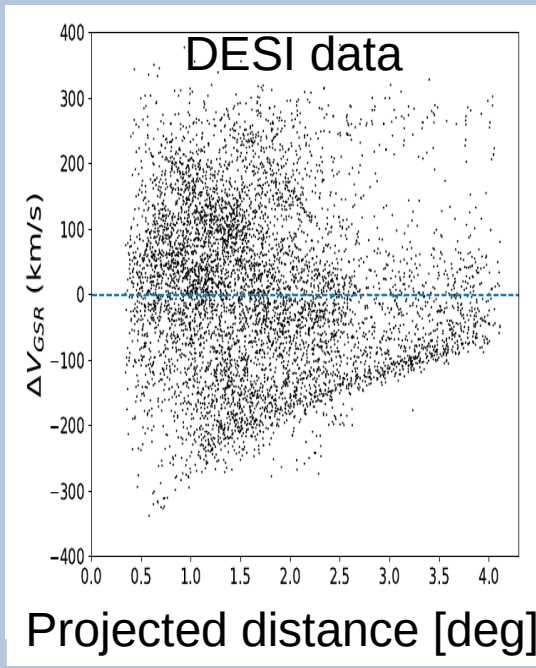


M31 shells

- Positions velocity “chevrons” are explained by wrapping of tidal debris with different energies (Dong-Paez+2022)
- Similar shells are seen in MW (Belokurov+2022) with GSE debris
- Chevrons can be from one or multiple pericentric passages
- Energy sorting along chevrons (high energy particles have longer periods)

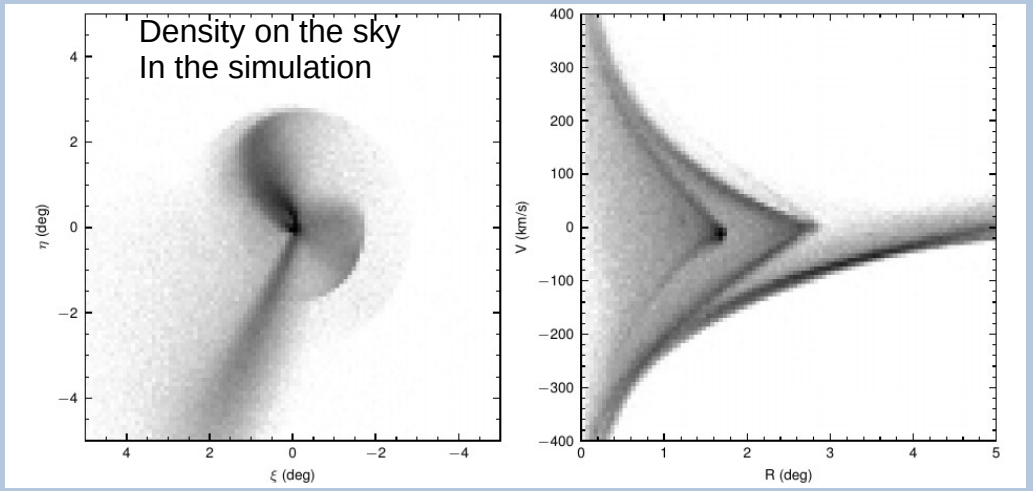


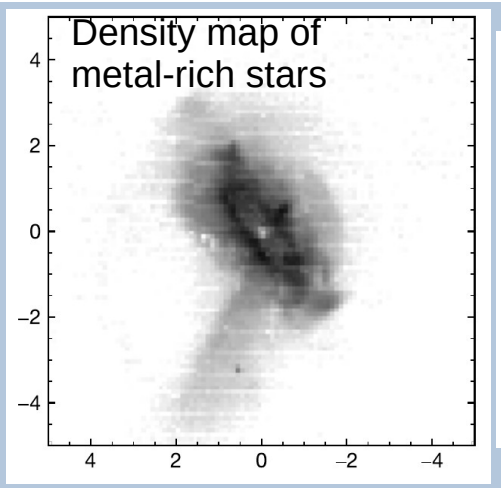
Dong-Paez+2022

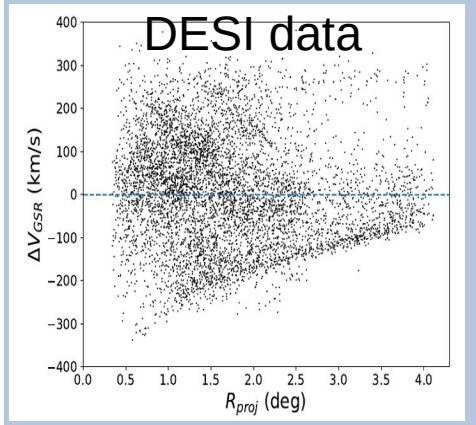


M31 model

- N-Body model based on initial conditions from Fardal+2013 Kirihara+2017
- Plummer sphere accreted ~ 1-2 Gyr ago
- The model approximately matches the GSS + chevrons in the western/eastern shells



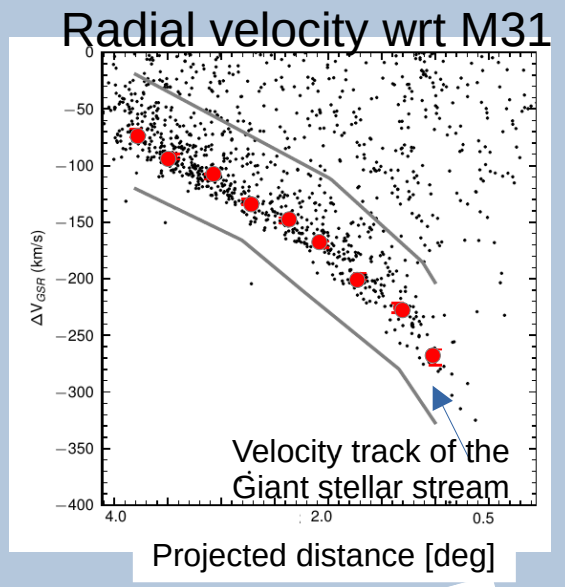


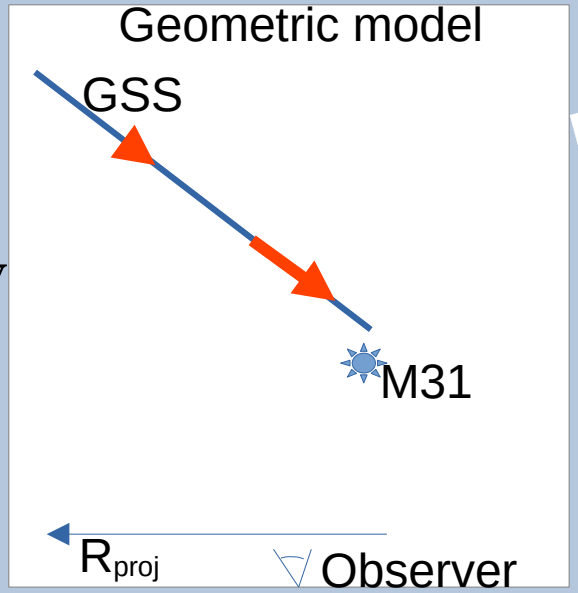


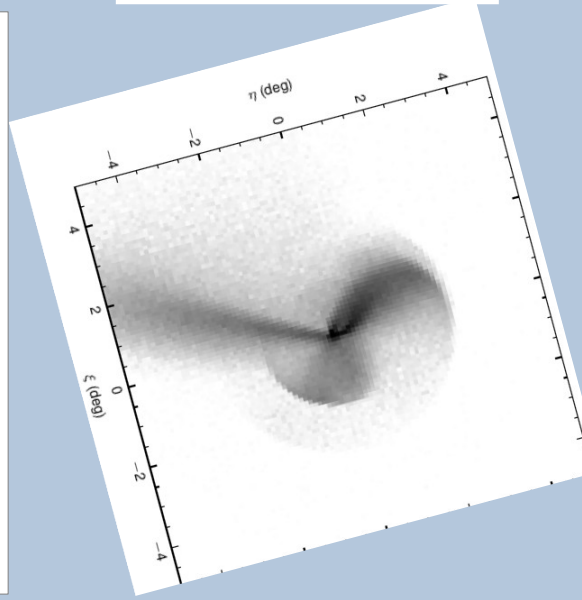
M31 mass modelling with Giant Stellar Stream

- We focus on the Giant Stellar stream (GSS) only
- Extract RV(R_{proj}) of the GSS.
- Constraints on the distance gradient along GSS (Cohn+2016)
- Assume almost radial track
- Energy conservation
- We can not assume constant energy (due to energy sorting in the shell)

$$\frac{V^2(R)}{2} + \Phi(\boldsymbol{X}) = E_0 + (R - R_0)\frac{dE}{dR},$$

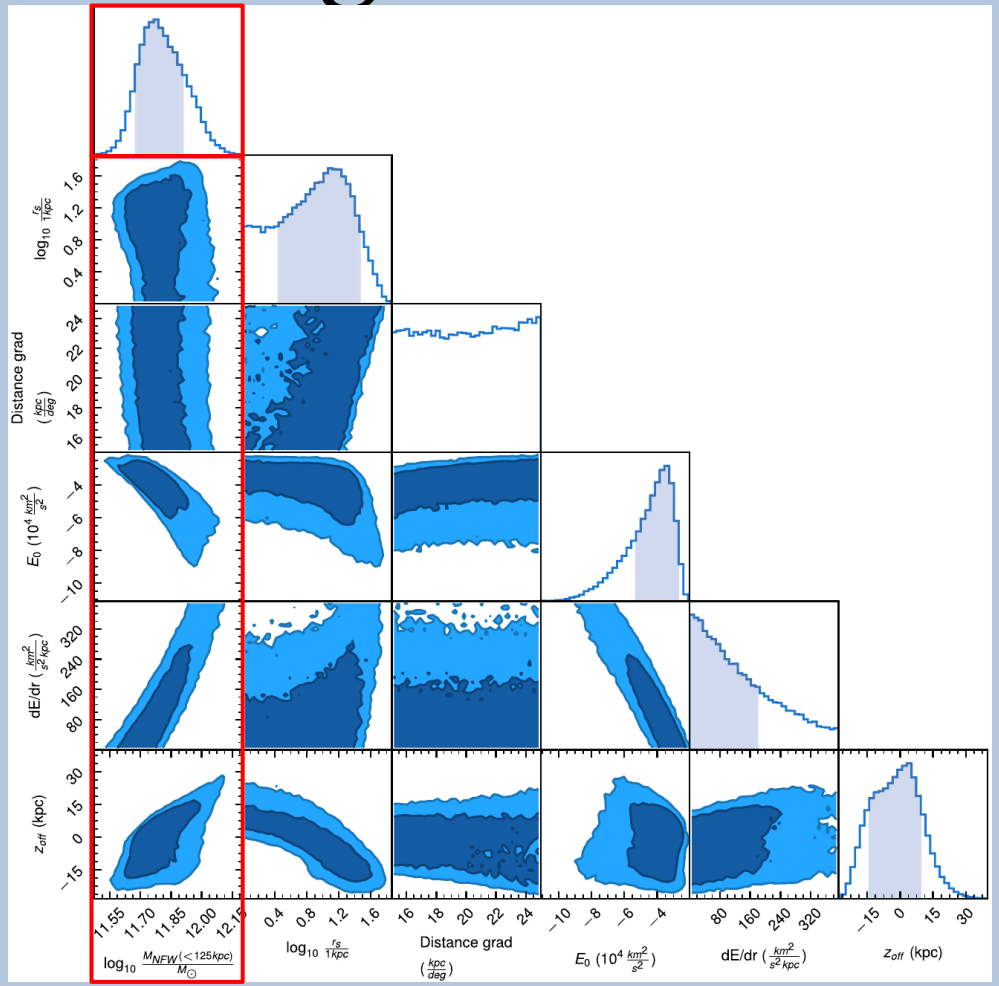






Mass modelling

- Free parameters: energy and energy gradient, halo mass and scale radius
- Prior on orientation from photometry
- NFW halo
- We can constrain the DM halo mass within 125 kpc $6 \pm 1 \times 10^{11}\, M_{sun}$



Conclusions

- More than 7500 stars in M31.
- The catalogue released on zenodo (link on Arxiv:**2208.11683**)
- We reveal a rich shell system in M31 in previously unseen detail. Most likely a single merger event.
- We constrain the M31 halo mass with the fit to just GSS. The modelling of the whole shell system is needed.
- We have more M31 data! (unpublished yet)
- DESI is an excellent tool for M31 mapping

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I will post slides on Slack

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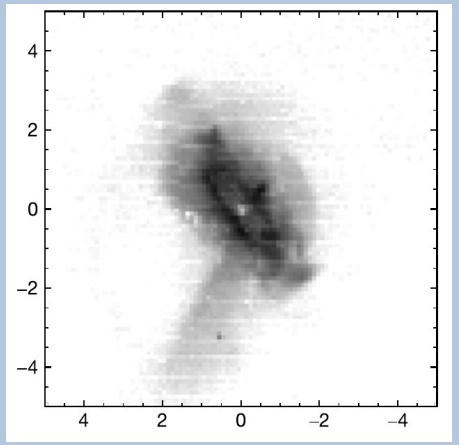
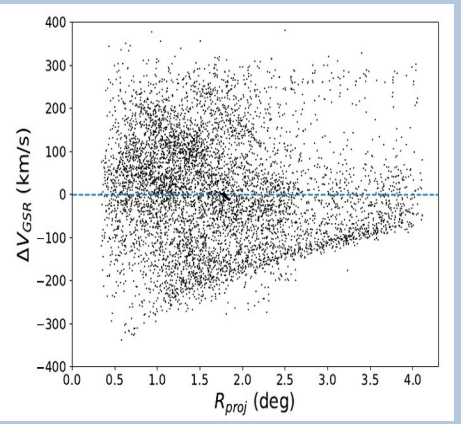
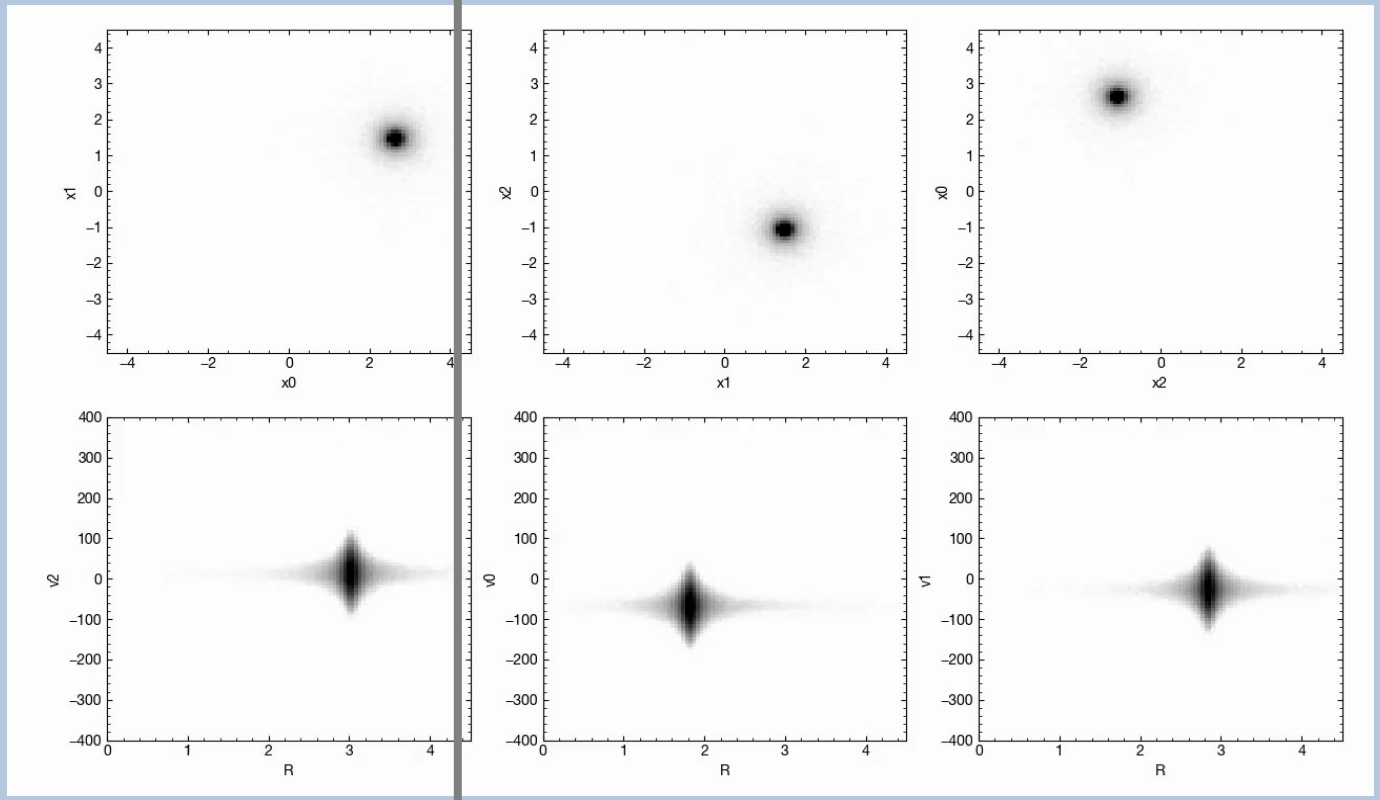
Data

Simulations







Distribution on the sky

Position-Velocity diagram

View from the MW direction

Other projections

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