Hands-on sessions I and II

Simulations vs. Observations and mock catalogues

Santi Roca-Fàbrega and Despina Hatzidimitriou

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OBJECTIVES

- Learn how to download real data from the Gaia Archive
- Get expertise on using common analysis tools (multiplatform, and supporting multiple numerical n- body codes format)
- Make first comparisons of crude data from simulations and data from observations
- Use simulations to get insights on what is happening in the data, e.g. through variables that difficult to observe (age), with full spatial coverage in simulations (while for data we have only small part of the Galaxy), etc
- Generate mock observed data from simulated data

STEPS

1. Obtain real Gaia RVS catalogue (DR2 or DR3)

2. Obtain simulations (ART & NIHAO, alternatively RAMSES)

3. Compare mock and real catalogue

4. Explore simulation and resolve a particular challenge

5. Future: generate mock Gaia RVS catalogue from diferent simulations (ART & NIHAO)

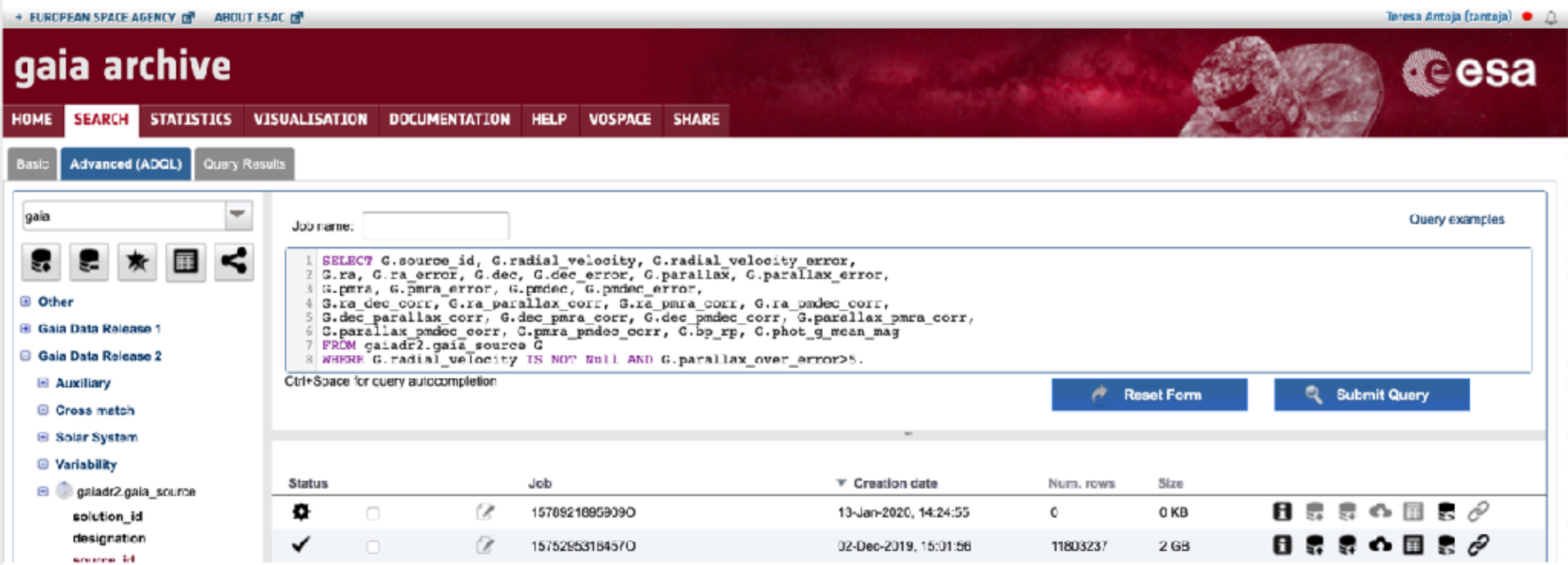
DATA

Gaia DR2 RVS sample

Download data from Gaia Archive -only stars with

$$\varpi/\sigma_{\varpi} > 5.$$

https://gea.esac.esa.int/archive/



Inversion of the parallax

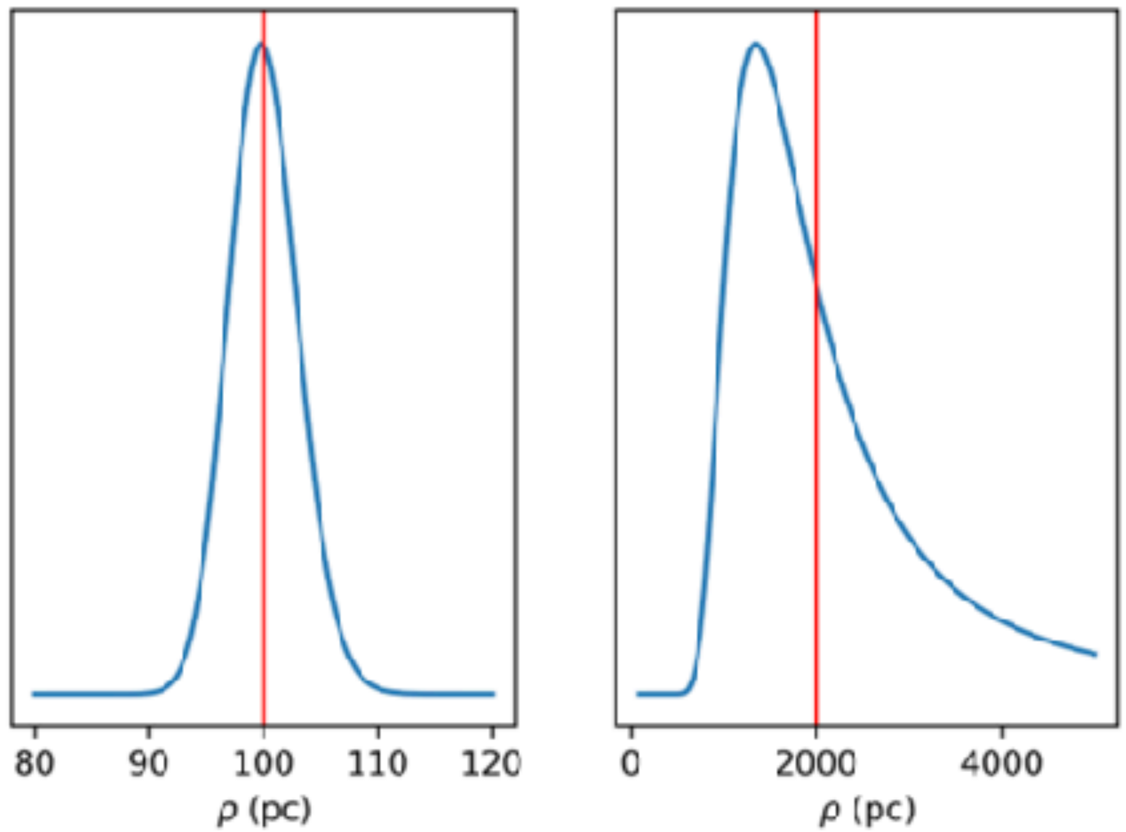


Fig. 3. PDF of $\rho = 1/\varpi$ in two extreme cases. The red vertical line indicates the true distance r. *Left*: object at $r = 100$ pc with an uncertainty on the observed parallax of $\sigma_\varpi = 0.3$ mas. *Right*: object at $r = 2000$ pc with an uncertainty on the observed parallax of $\sigma_\varpi = 0.3$ mas.

- Gaia DR2 with RV & $\sigma_\varpi/\varpi > 5$
- 6 376 803 stars
- median uncertainties $\sigma_{V_R} = 1.4\,\mathrm{km/s}$ $\sigma_{V_\phi} = 1.5\,\mathrm{km/s}$ $\sigma_{V_Z} = 1.\,\mathrm{km/s}$

Luri et al. 2018

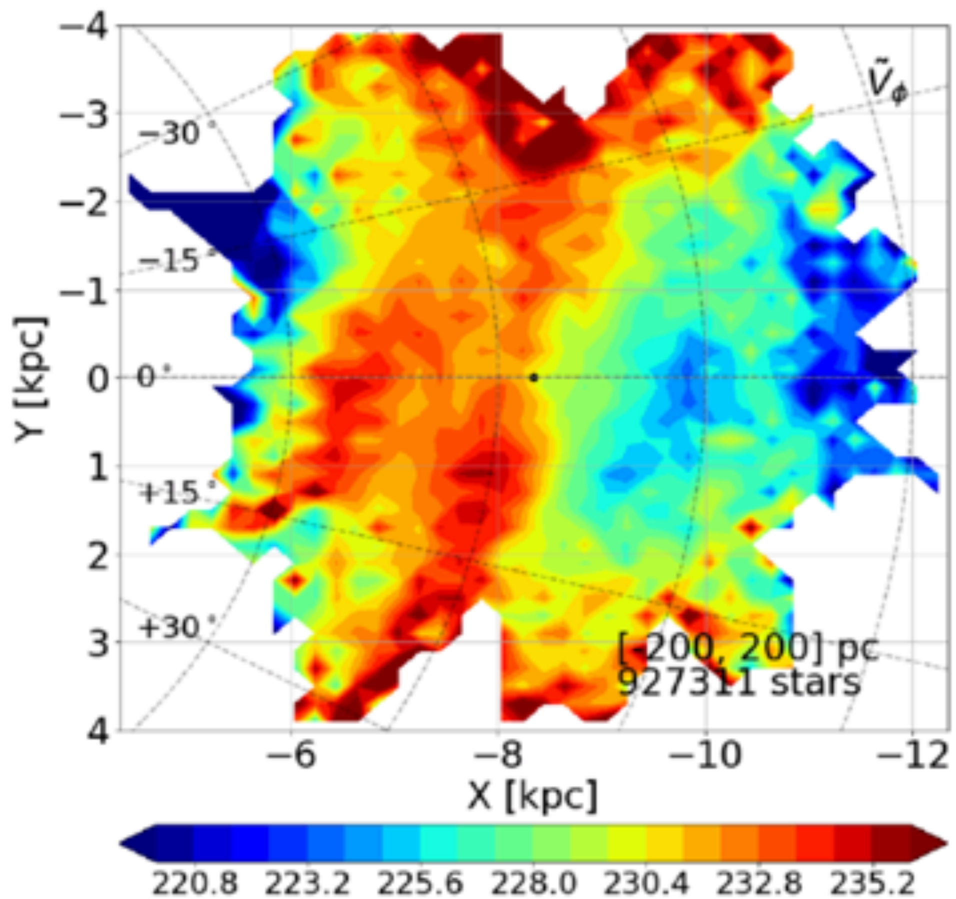
ADQL query (astrometry, radial velocities, photometry -DR2)

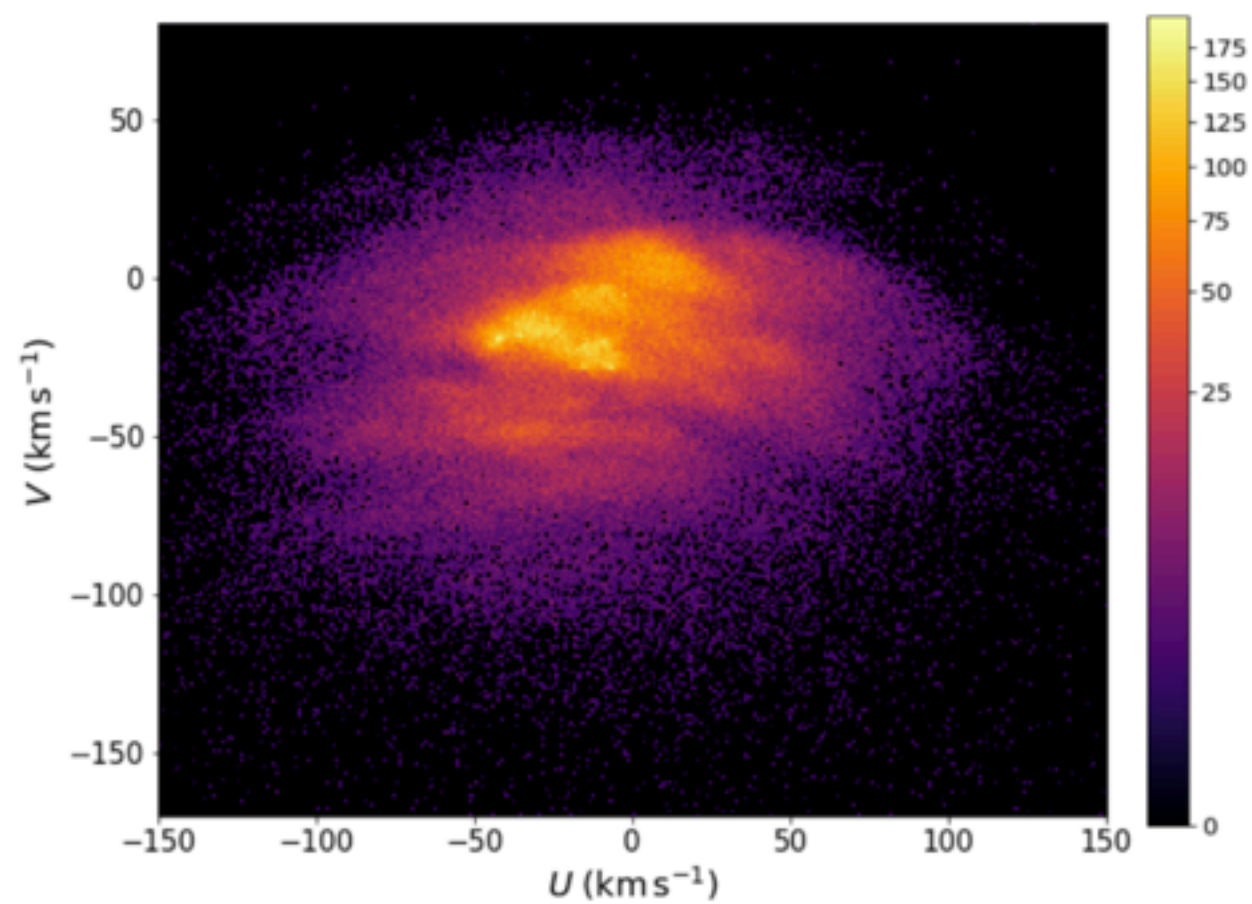
```
SELECT G.source_id, G.radial_velocity, G.radial_velocity_error,
G.ra, G.ra_error, G.dec, G.dec_error, G.parallax, G.parallax_error,
G.pmra, G.pmra_error, G.pmdec, G.pmdec_error,
G.ra_dec_corr, G.ra_parallax_corr, G.ra_pmra_corr, G.ra_pmdec_corr,
G.dec_parallax_corr, G.dec_pmra_corr, G.dec_pmdec_corr,
G.parallax_pmra_corr,
G.parallax_pmdec_corr, G.pmra_pmdec_corr, G.bp_rp, G.phot_g_mean_mag
FROM gaiadr2.gaia_source G
WHERE G.radial_velocity IS NOT Null AND G.parallax_over_error>5.
```

Gaia DR2 RVS sample

Compute cylindrical positions and velocities and their errors (including correlations) Make your own code or use available codes in pygaia, galpy

Reference: Gaia Collab., Katz, Antoja, et al. (2018, arXiv:1804.09380)





Gaia DR2 RVS sample

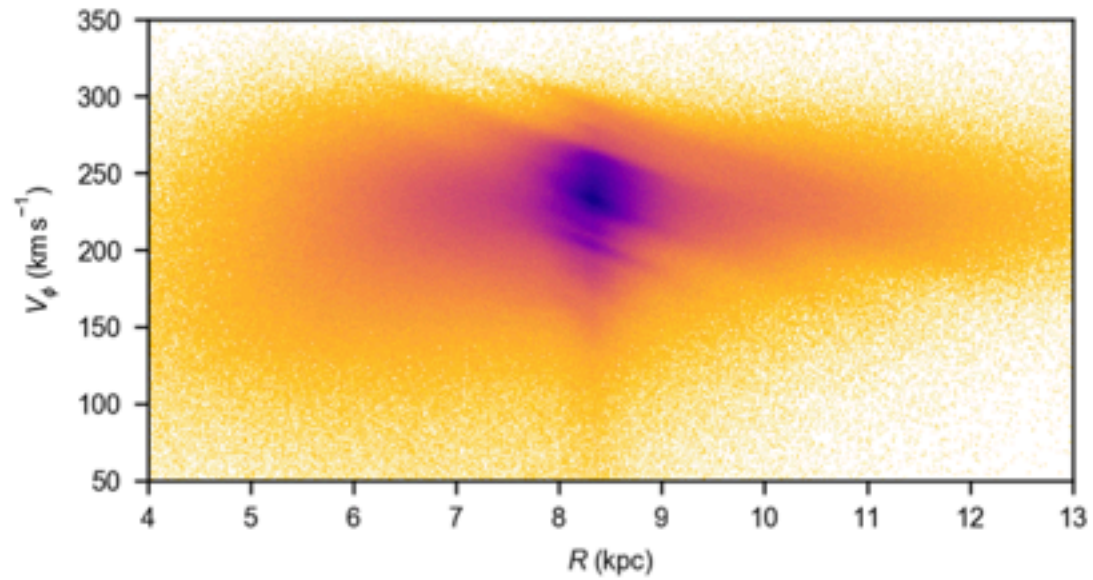
Here we look at the RVS sample – already converted to the Galactocentric cylindrical reference frame https://drive.google.com/drive/folders/1fxBK3qycT1fFmouz9JmIMw1mkAznfv1v?usp=sharing.

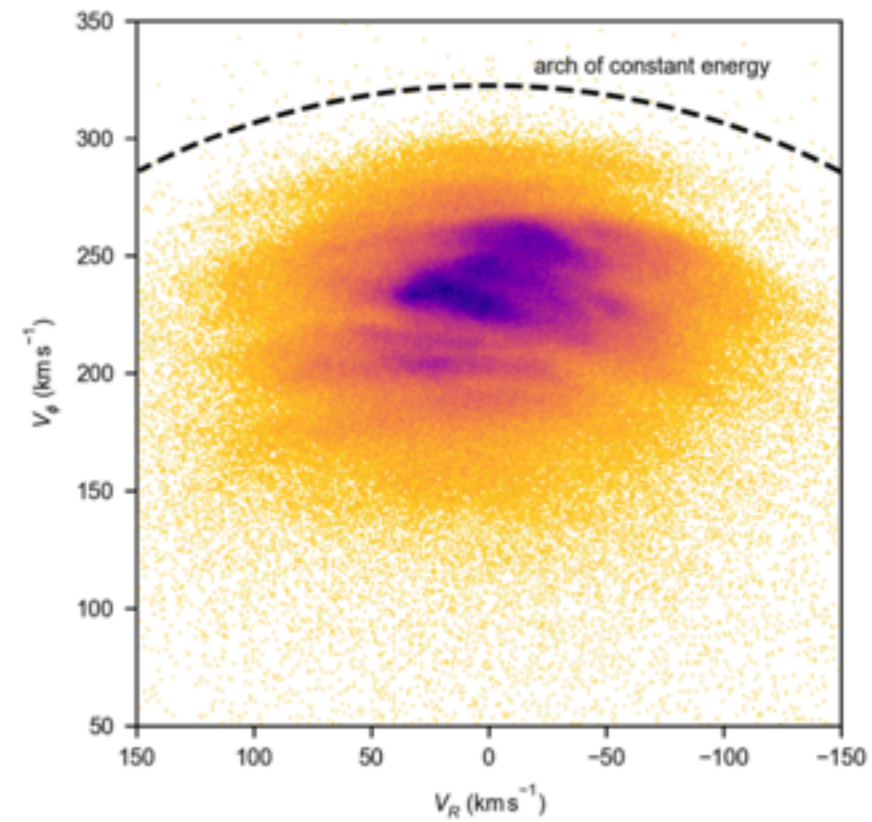
Available formats:

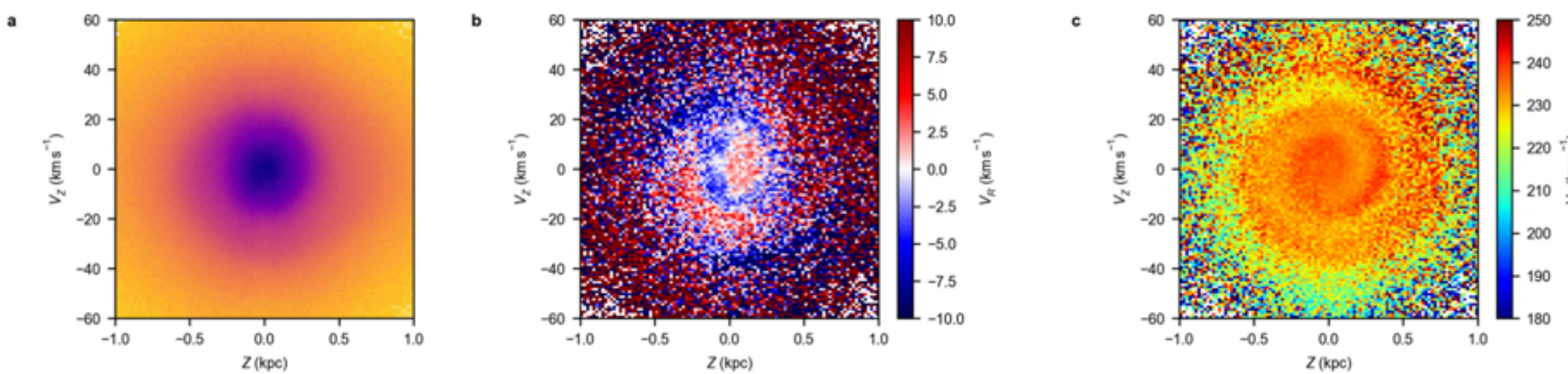
- HDF5 file (easily readable with python): **GaiaDR2_6d_cyl.h5**

- fits file (readable with TOPCAT): **GaiaDR2_6d_cyl.csv**
  Notebook that reproduces key phase space projections:
  GaiaDR2RVSphasespaceplots.ipynb

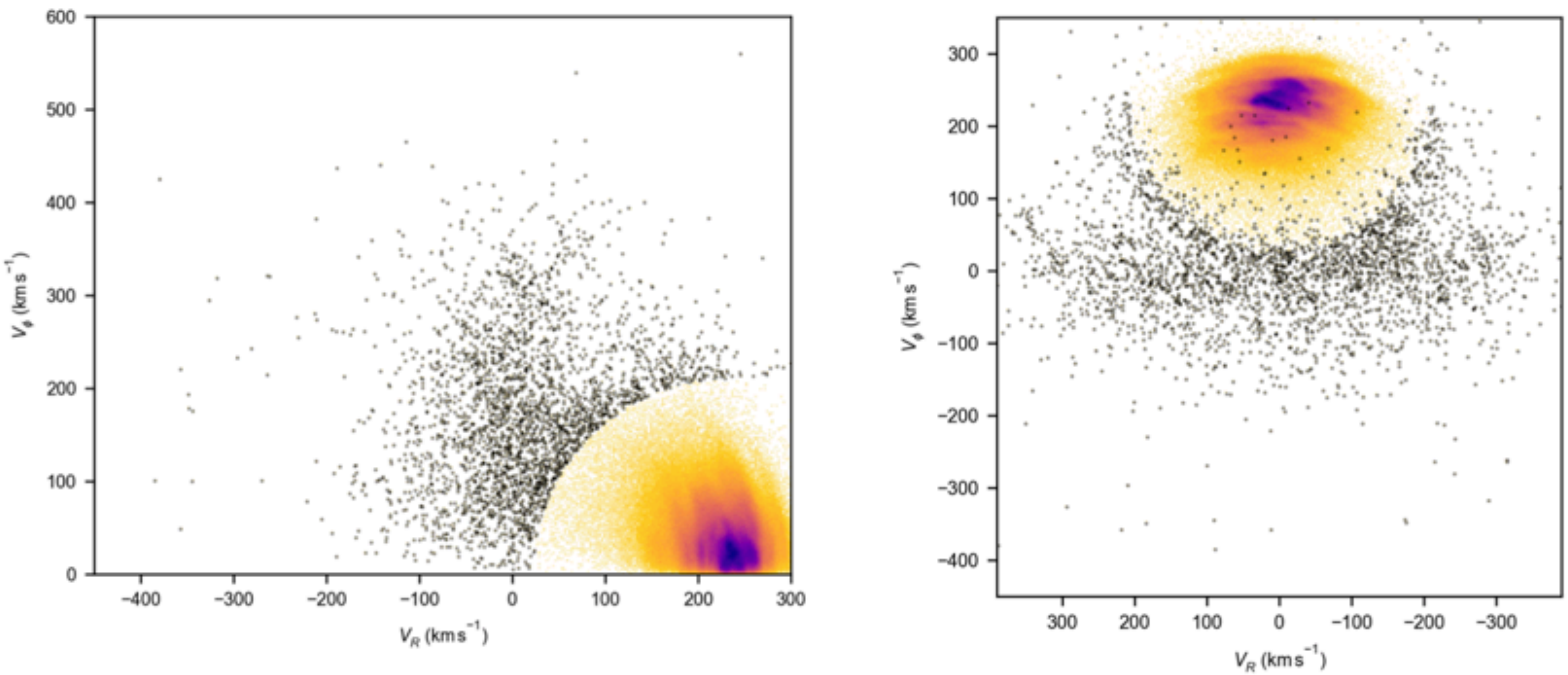
Phase space projections of Gaia DR2 RVS data







Phase space projections of Gaia DR2 RVS data



SIMULATIONS

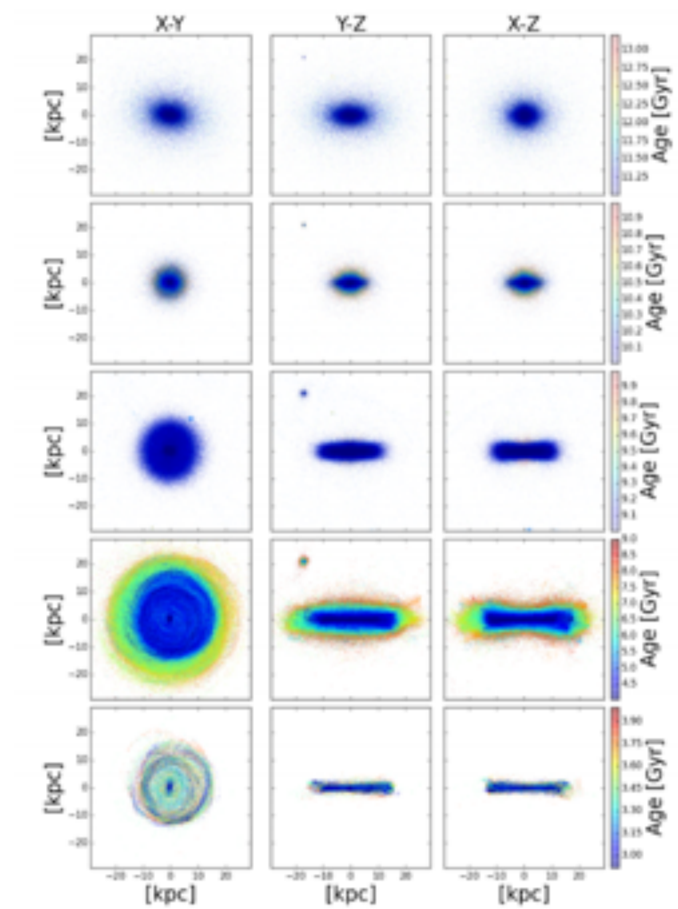
Simulations: GARROTXA-ART

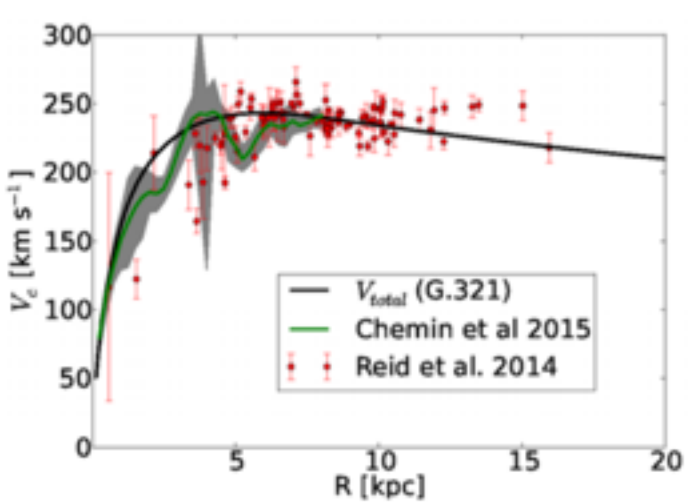
Cosmological hydrodynamical simulation of Milky Way mass galaxy
Reference: Roca-Fàbrega et al. (MNRAS, 2016)

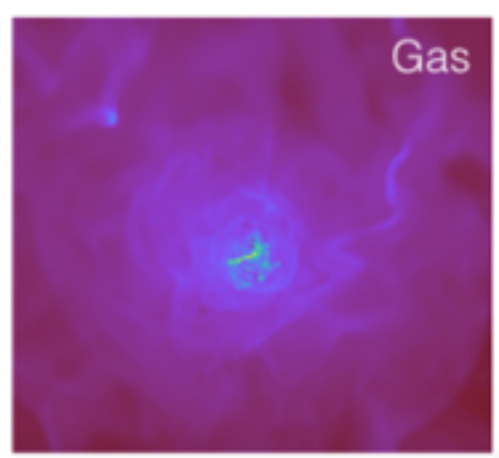
Here we only look at the snapshot at z=0). Available files:

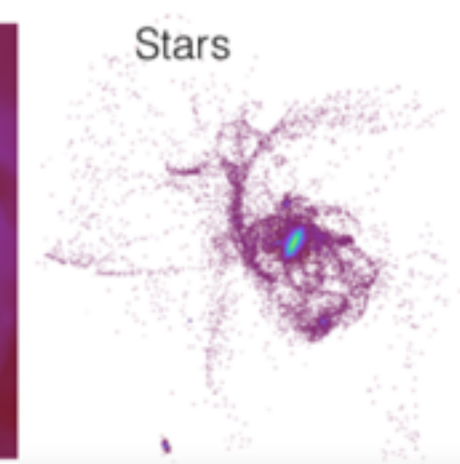
- Binary files (readable with yt – see jupyter notebook GARROTXA_ART) : https://drive.google.com/drive/folders/1kfF5L2T625_GPabMmo7dhPiKStSjeAYV?usp=sharing

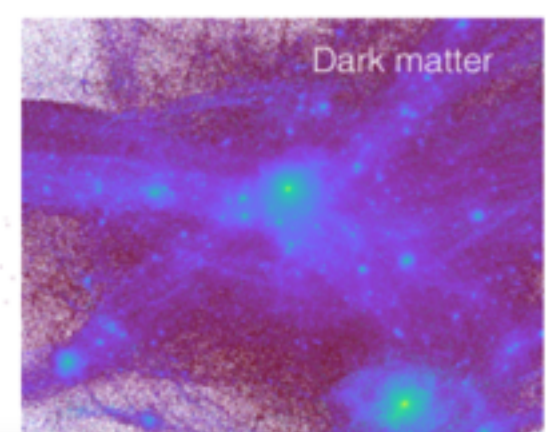
- Ascii files containing star particles in a 25 kpc sphere around the main halo (readable with TOPCAT) in cylindrical coordinates: https://drive.google.com/drive/folders/1MWOMlDgYtiGJLo7DK0GggKuoqXAiHTXl?usp=sharing**Main_Galaxy_z0_cyl.asc**

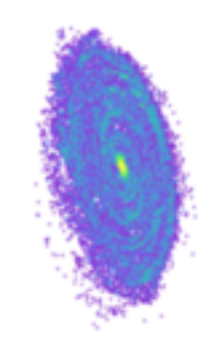






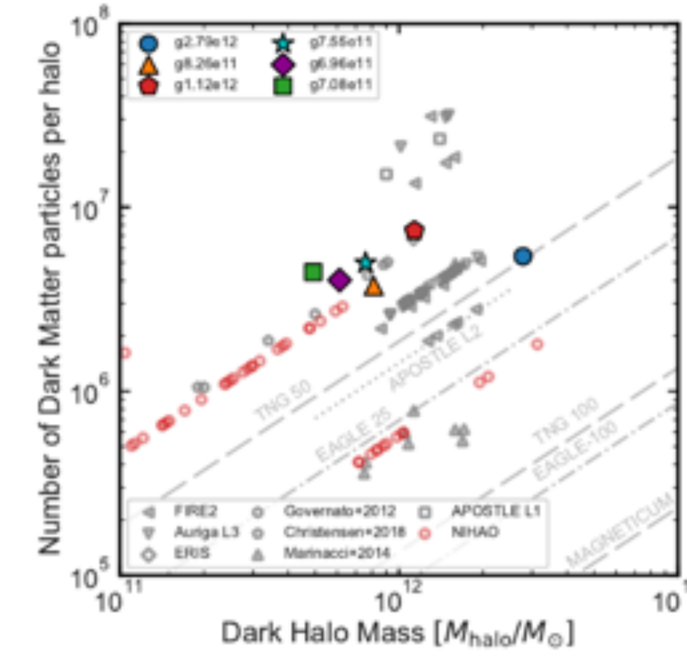






Simulations: NIHAO-UHD

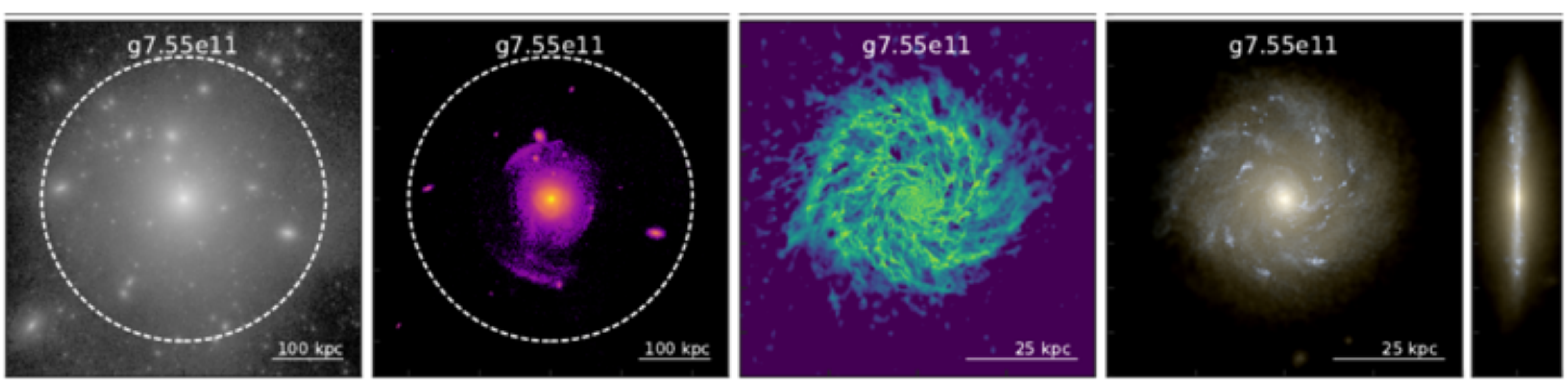
Suite of 6 cosmological hydrodynamical simulations of Milky Way mass galaxies
Reference: Buck, Obreja, Macciò et al. (MNRAS, 2020, arXiv:1909.05864)
Data: http://www2.mpia-hd.mpg.de/~buck/#sim_data



Here we only look at the galaxy g7.55e11 (snapshot z=0). Available files:

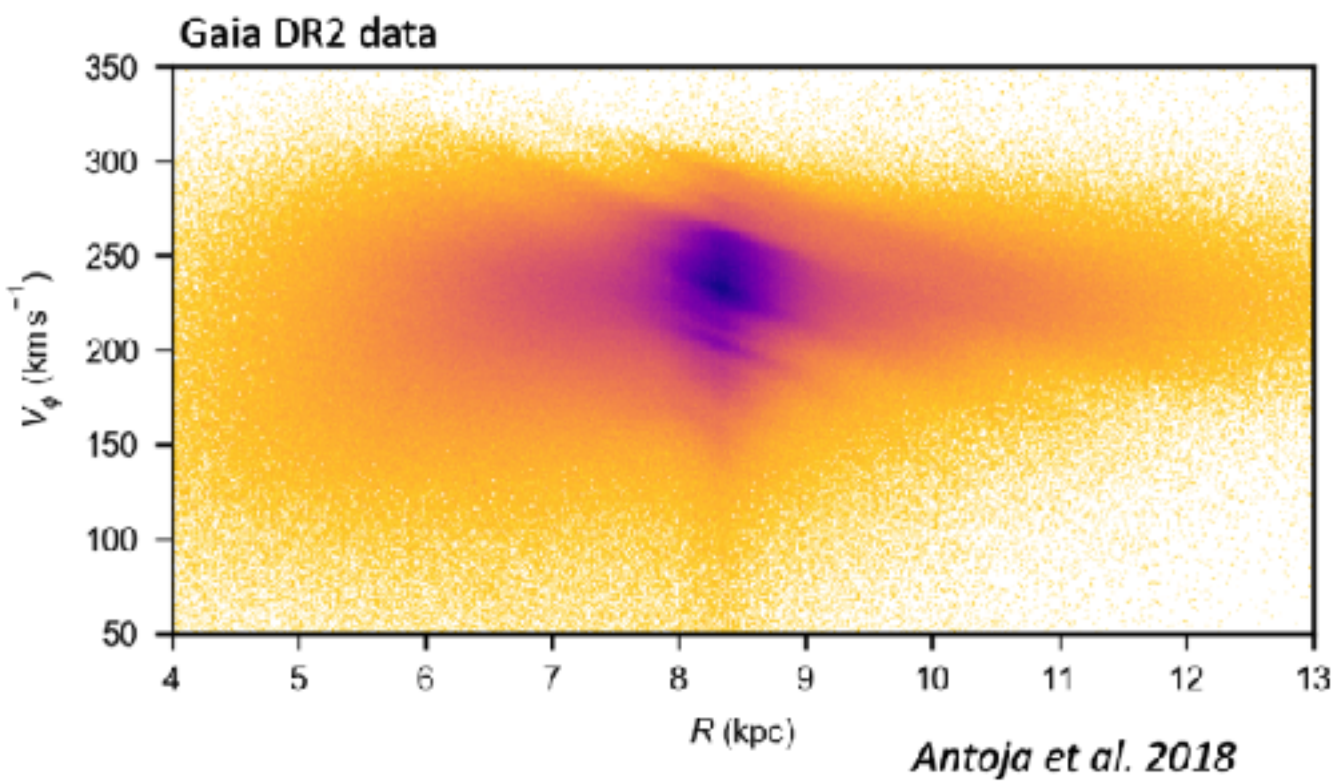
- gasoline snapshot (readable with pynbody – see jupyter notebook)

- fits file only containing star particles in a 25 kpc sphere around the main halo (readable with TOPCAT) in cylindrical coordinates: https://drive.google.com/drive/folders/1wfsr7_7A77ZuRE91m6dKHjtultoBN8Ef?usp=sharing
nihao_stars_25kpc_sphere.fits



Explore simulations freely and resolve some challenges

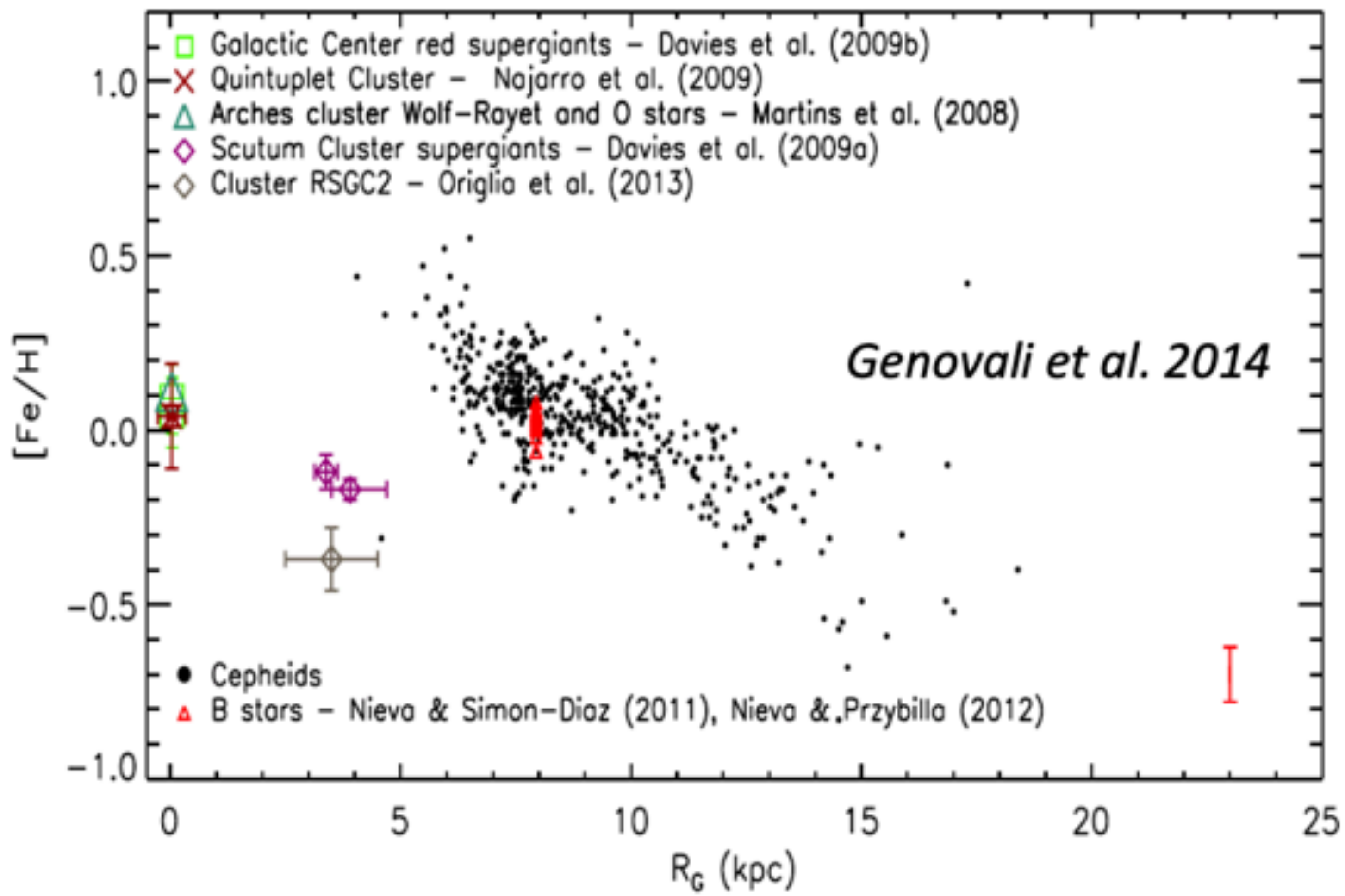
Challenge 1: What are the diagonal ridges?



- Are they caused by resonances of the spiral arms and bar, by external satellites or by transient spiral structure?
- In which populations (young/old? disk/halo?) do we find them?
- How are they related to density structures? How are they related to the vertical perturbations?
  How do they change azimuthally?

Challenge 2: Measure the radial metallicity gradient

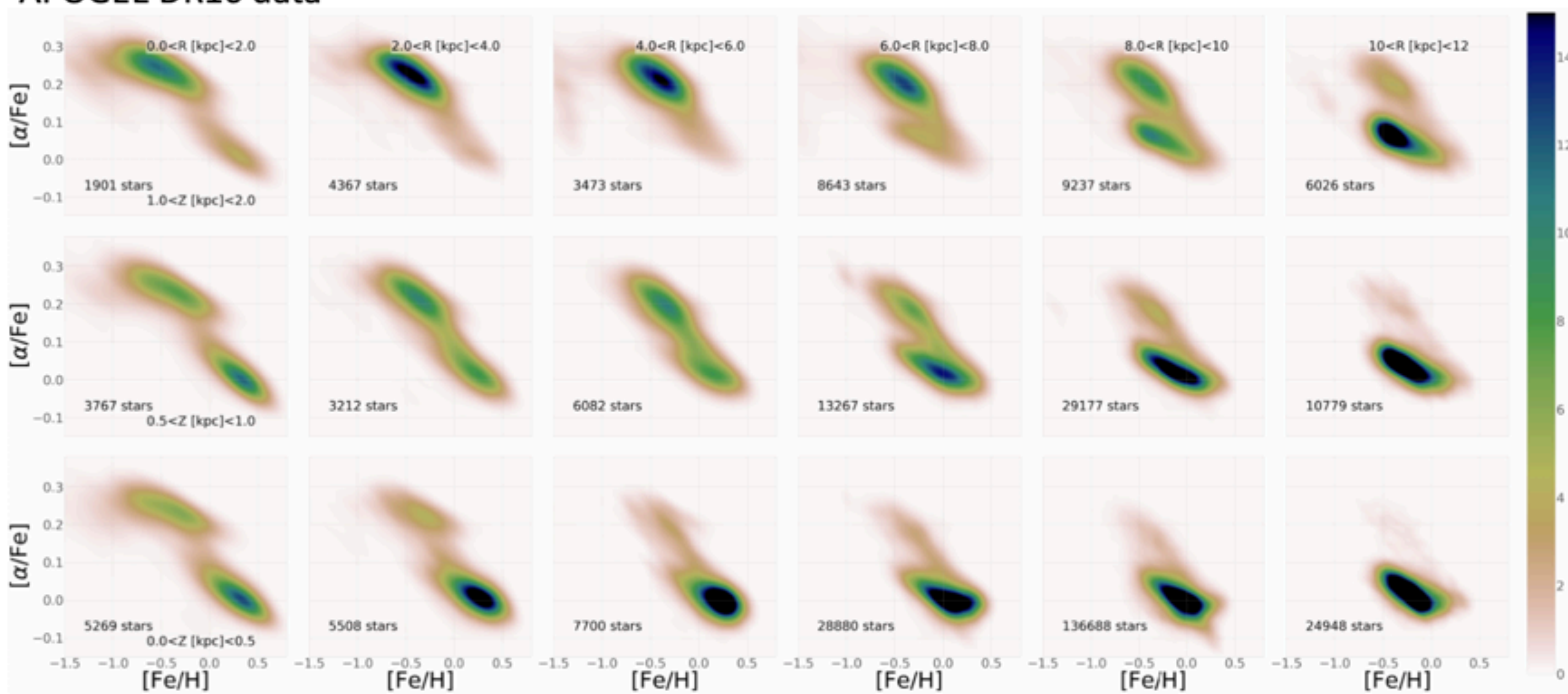
Galactic cepheids



- Try to measure the radial metallicity gradient in the simulated galaxies
- How does it depend on the stellar population (age)?
- How does it compare to Milky Way data?
- Does it make sense to fit a straight line?

Challenge 3: Visualise the [alpha/Fe] vs [Fe/H] diagram over the disc

APOGEE DR16 data

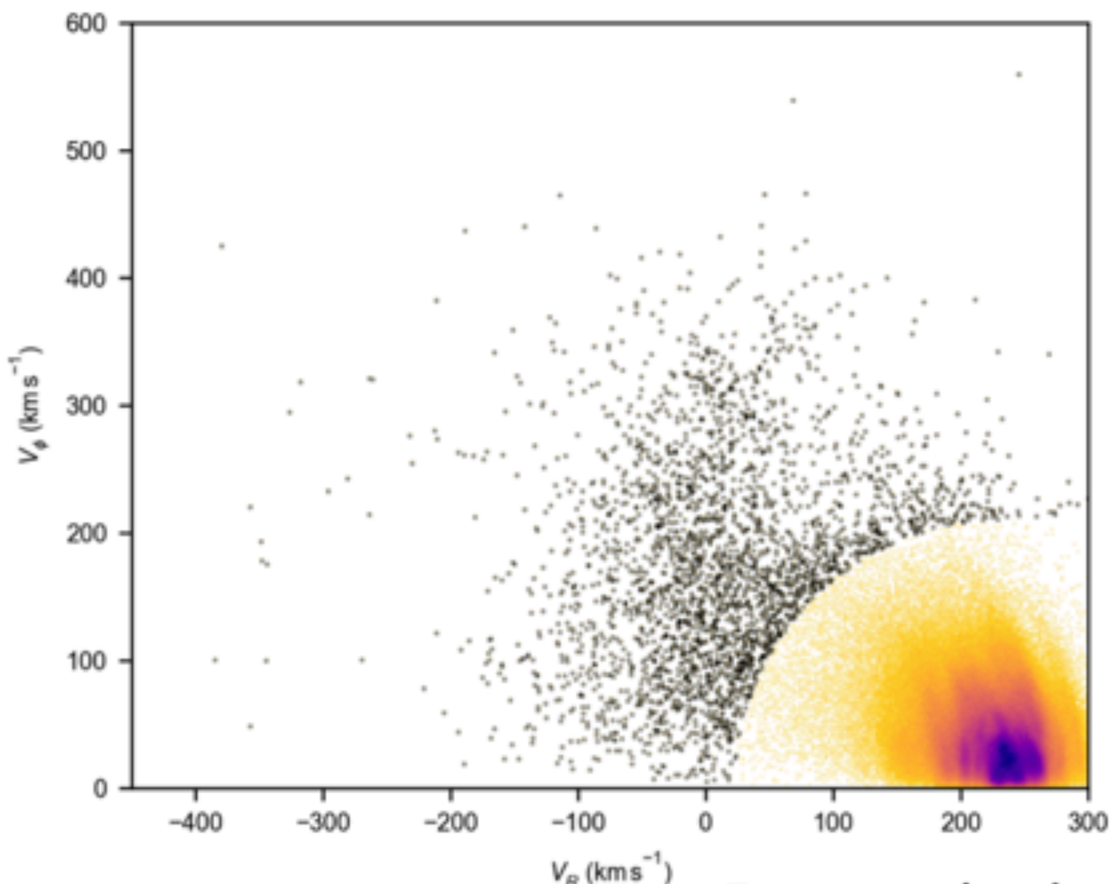


Queiroz et al. (arXiv:1912.09778)

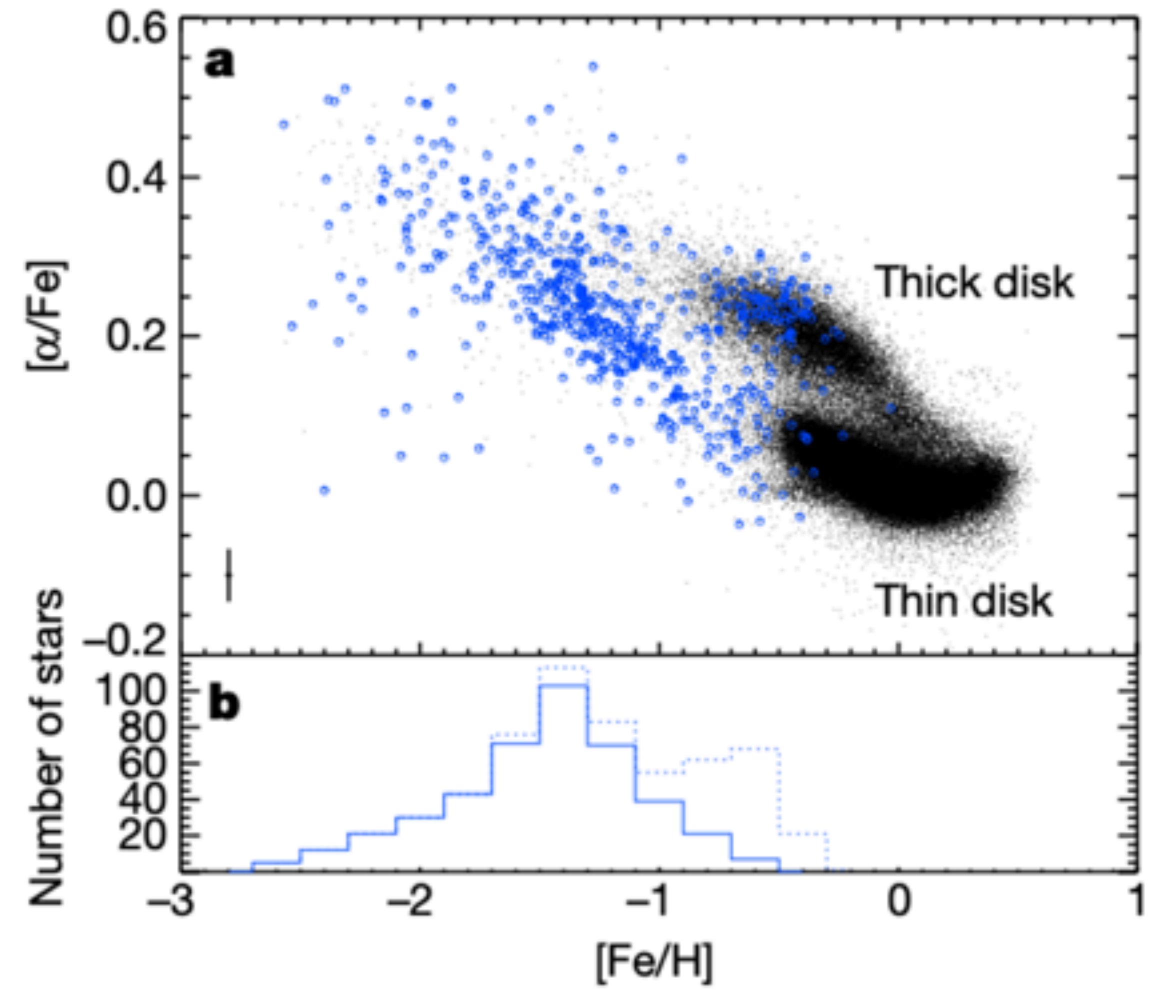
- Do you find the dichotomy in the [alpha/Fe]-[Fe/H] diagram in one of the simulations? (for NIHAO-UHD: use [O/Fe] instead of [alpha/Fe])
- Can you reproduce this figure? What does it mean? Do you see other structures? (Check also Buck 2020, arXiv:1909.09162)

- Are there different kinematic signatures for the 2 populations?

Challenge 4: Gaia-Enceladus



From notebook



Helmi et al. 2018

- How was Gaia-Enceladus accreted? What is its stellar distribution outside the local volume? What were the effects of the accretion on the primordial Milky Way?
- Do you find a similar structure in in phase space in the simulations? And in chemical space?
- How is it distributed throughout the Galaxy?
- How do we know it is an accreted structure or in-situ one?

How to explore the simulations

- **Topcat**, using ART_ascii or NIHAO_fits files - see google drive:

https://drive.google.com/drive/folders/1maY3LUaBSTZN3H3rnb4o5kXO2lU2OzUv?usp=sharing) : **GARROTXA_ART_ascii** and **NIHAO_fits**

- **Notebooks** (downloaded from GitHub in HandsOnI and HandsOnII folders):
  - Athens2022_simulation-tutorial-ART.ipynb
  - Athens2022_simulation-tutorial-NIHAO.ipynb
  - GaiaDR2RVSphasespaceplots.ipynb

• (additionally you can take a look to GARROTXA_RAMSES using Athens2022_simulation-tutorial-RAMSES.ipynb)