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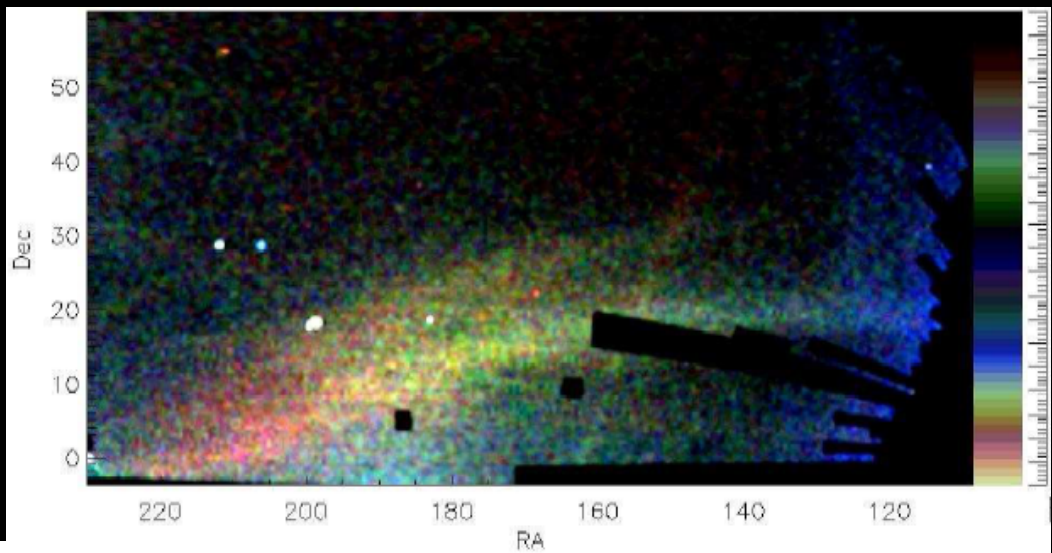
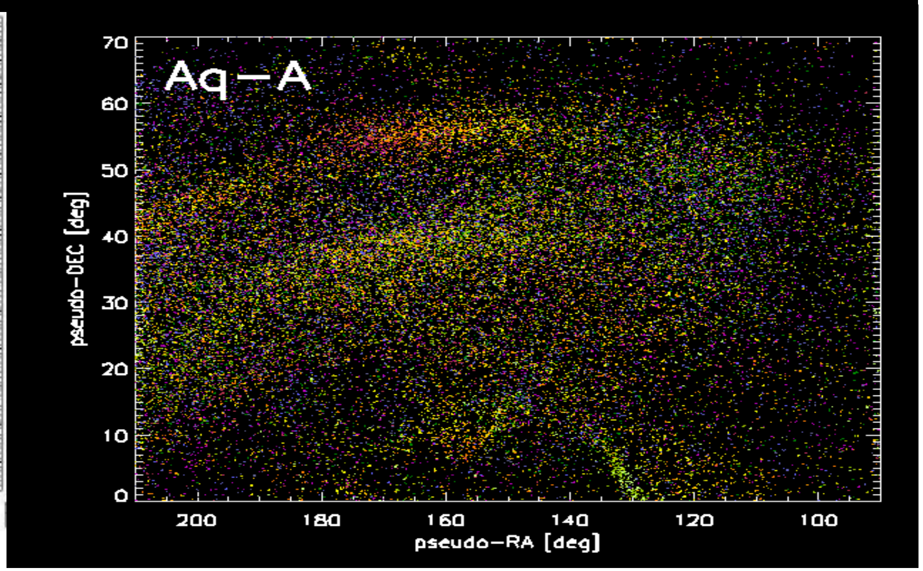
New perspectives in understanding the Galactic halo

Amina Helmi

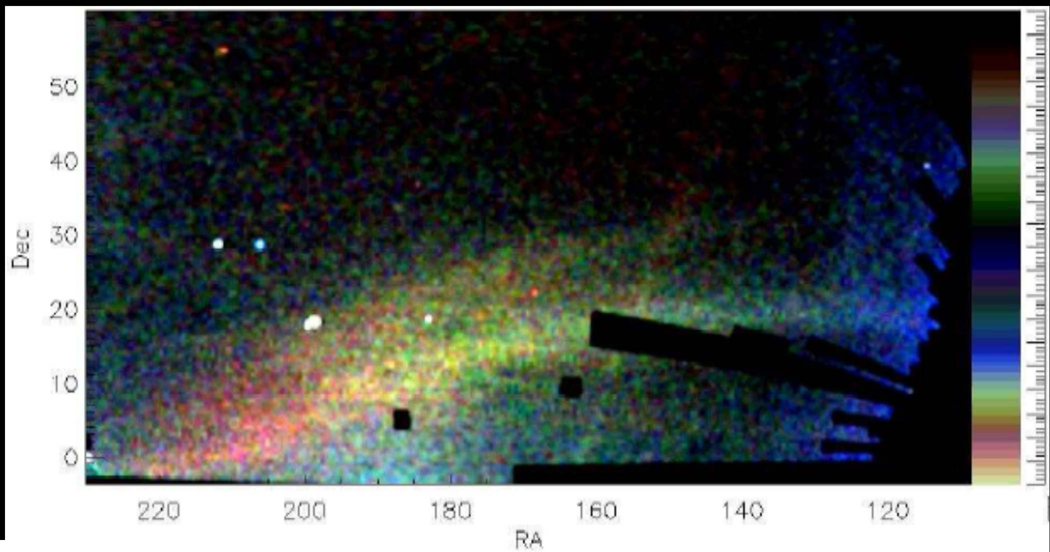


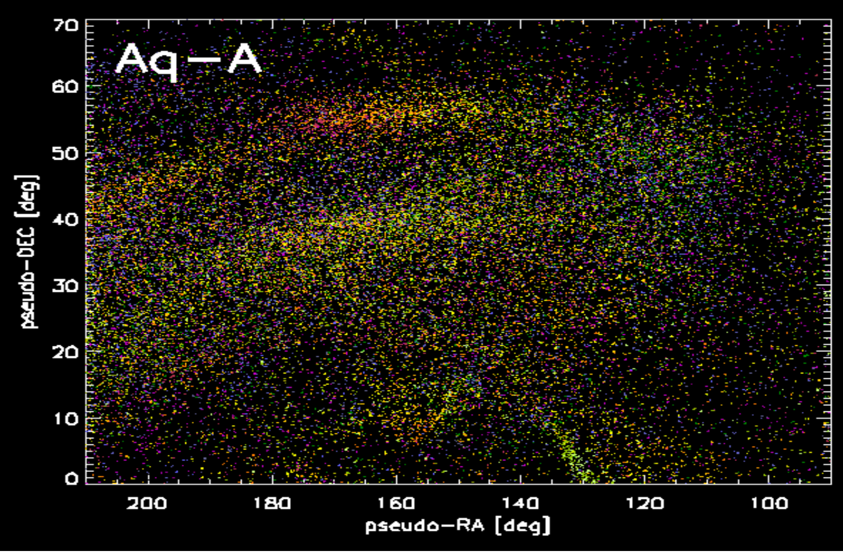


New perspectives in understanding the Galactic halo

In collaboration with

Facundo Gomez, Andrew Cooper, Simon White,
Anthony Brown, Yang-Shyang Li





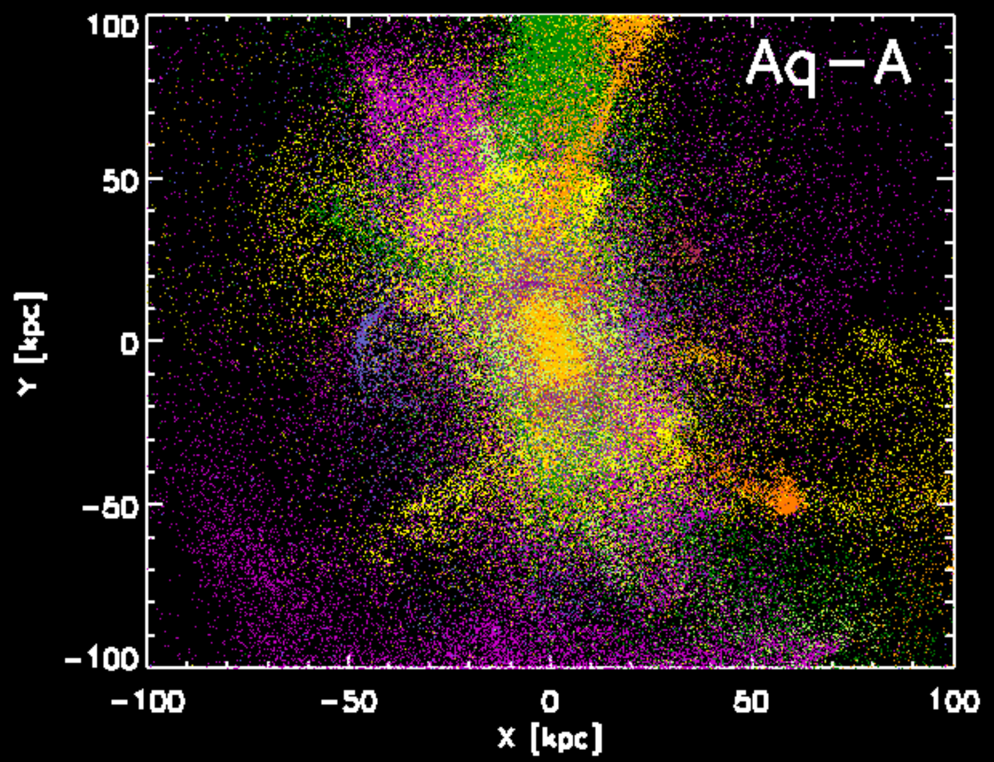
Why care about stellar halos?

- Most metal-poor and ancient stars in the MW
  - window into the early Universe

- Orbiting outskirts of galaxies: good mass probes

- Can form from the superposition of disrupted satellites

  •stars retain memory of their origin
  -> merger history



Helmi, Cooper et al. (2010)

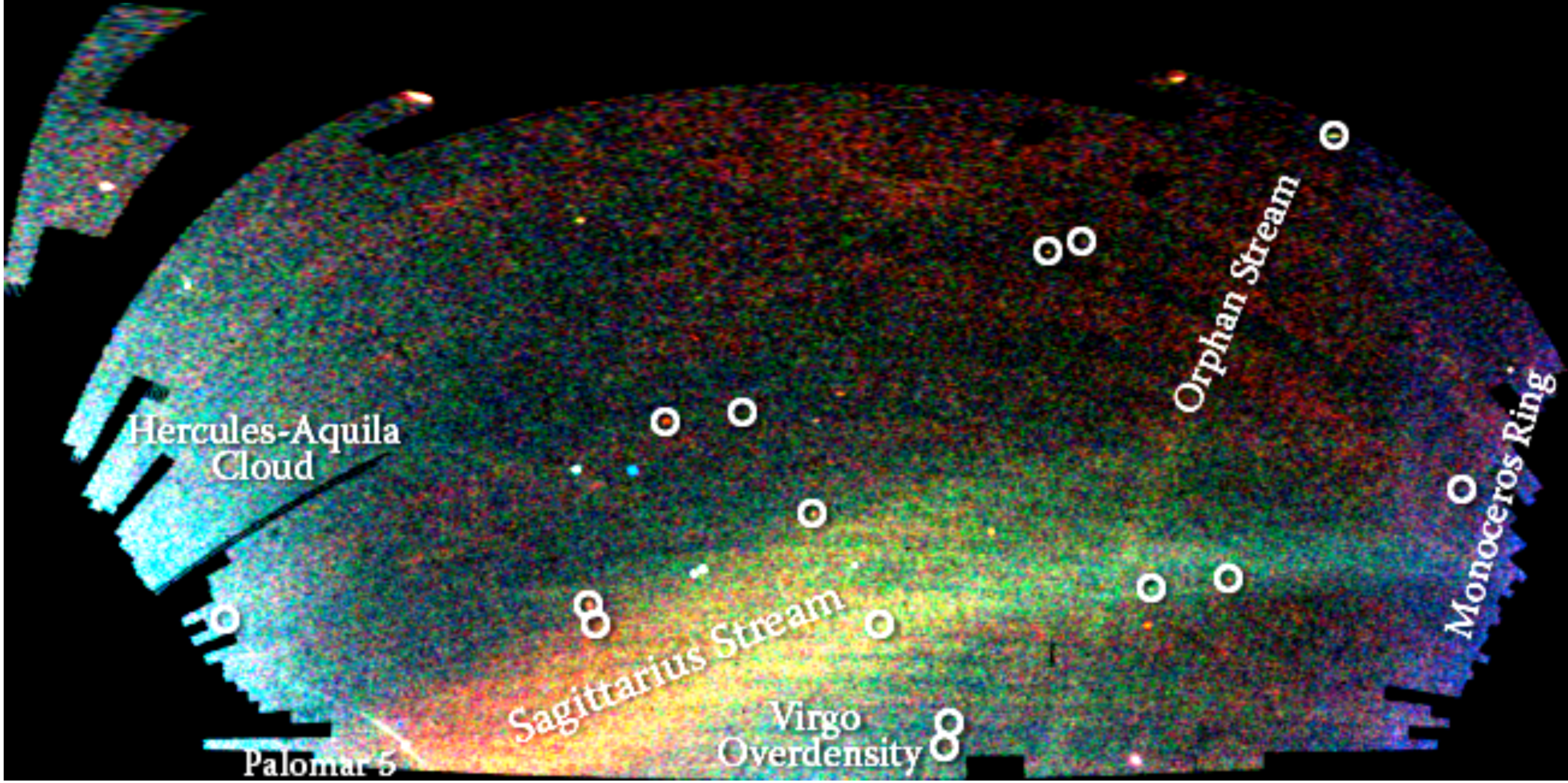
Outer Stellar halo

- Substructure common in the halo (SDSS, 2MASS…)

  -> mergers

  -> Broad, diffuse streams (large progenitors? …but beware of biases)

  overdensities -> nature not always clear



Belokurov et al 2007

Some questions

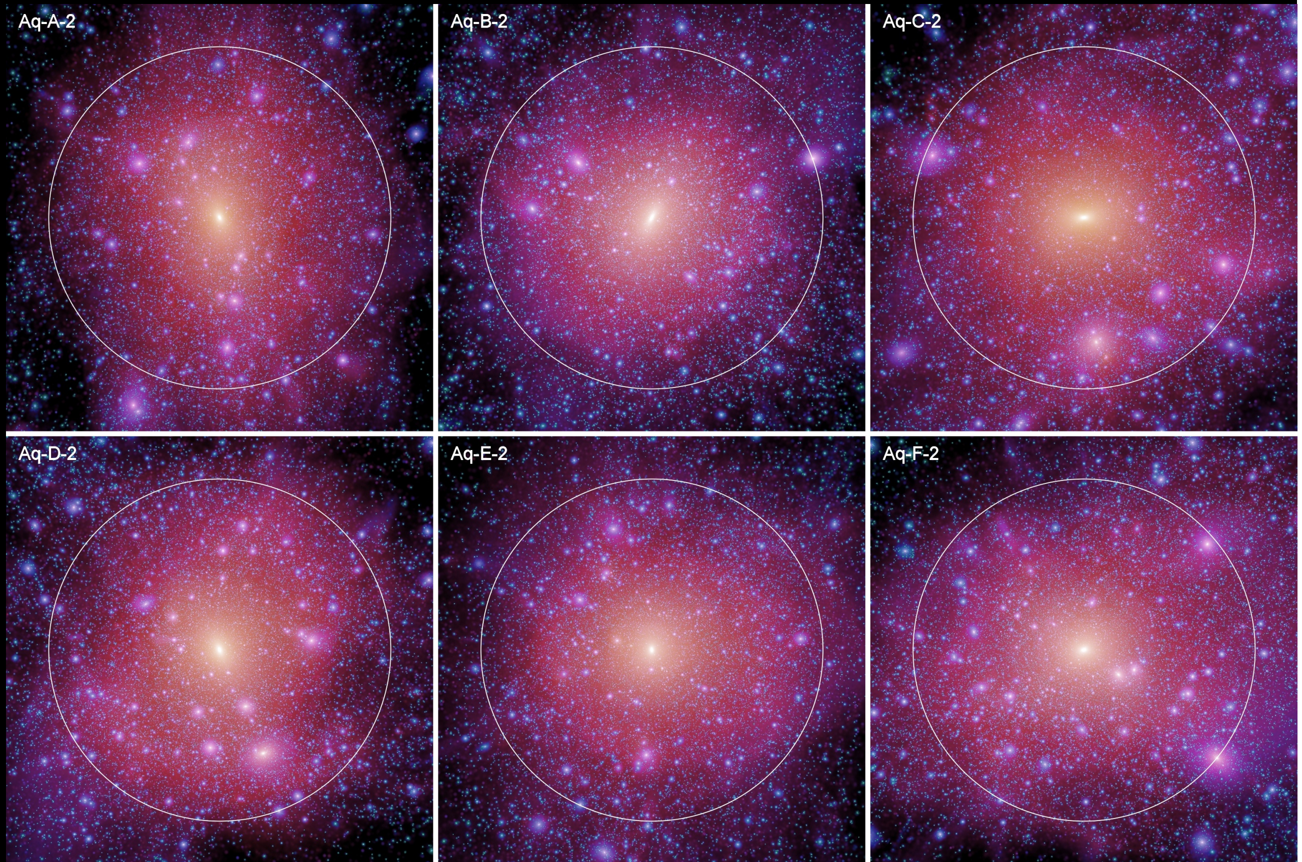
- What are the properties of stellar halos and satellites in ΛCDM? How do they compare to the Milky Way or M31?
- What are models predictions for future surveys?
- What do we learn about the history of a galaxy from its stellar halo?

Stellar halo and Substructure in ΛCDM

– Aquarius project: very high-resolution simulations of formation of 6 different dark matter halos ressembling the Milky Way (by mass)

- Cooper et al. (2009) combined with phenomenological galaxy formation model

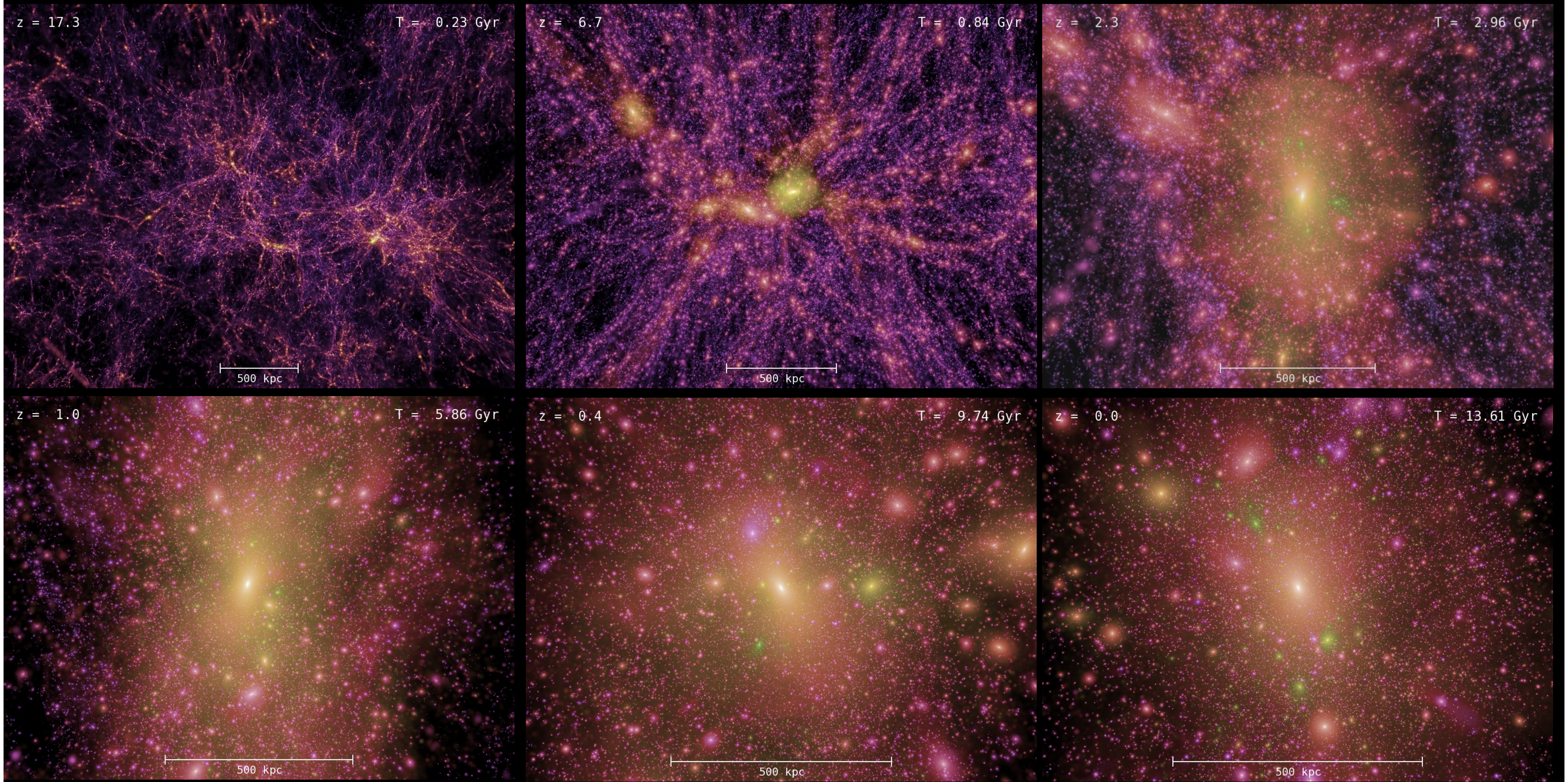
  -> predict properties of (accreted) stellar halos in CDM



See also Bullock & Johnston 2005; De Lucia & Helmi 2008

Springel et al. 2008

Aquarius stellar halos



- 1% most bound particles represent stars/stellar pops in these objects
- Follow the history, their present-day location and dynamics

Stellar halo formation in the Aquarius simulations

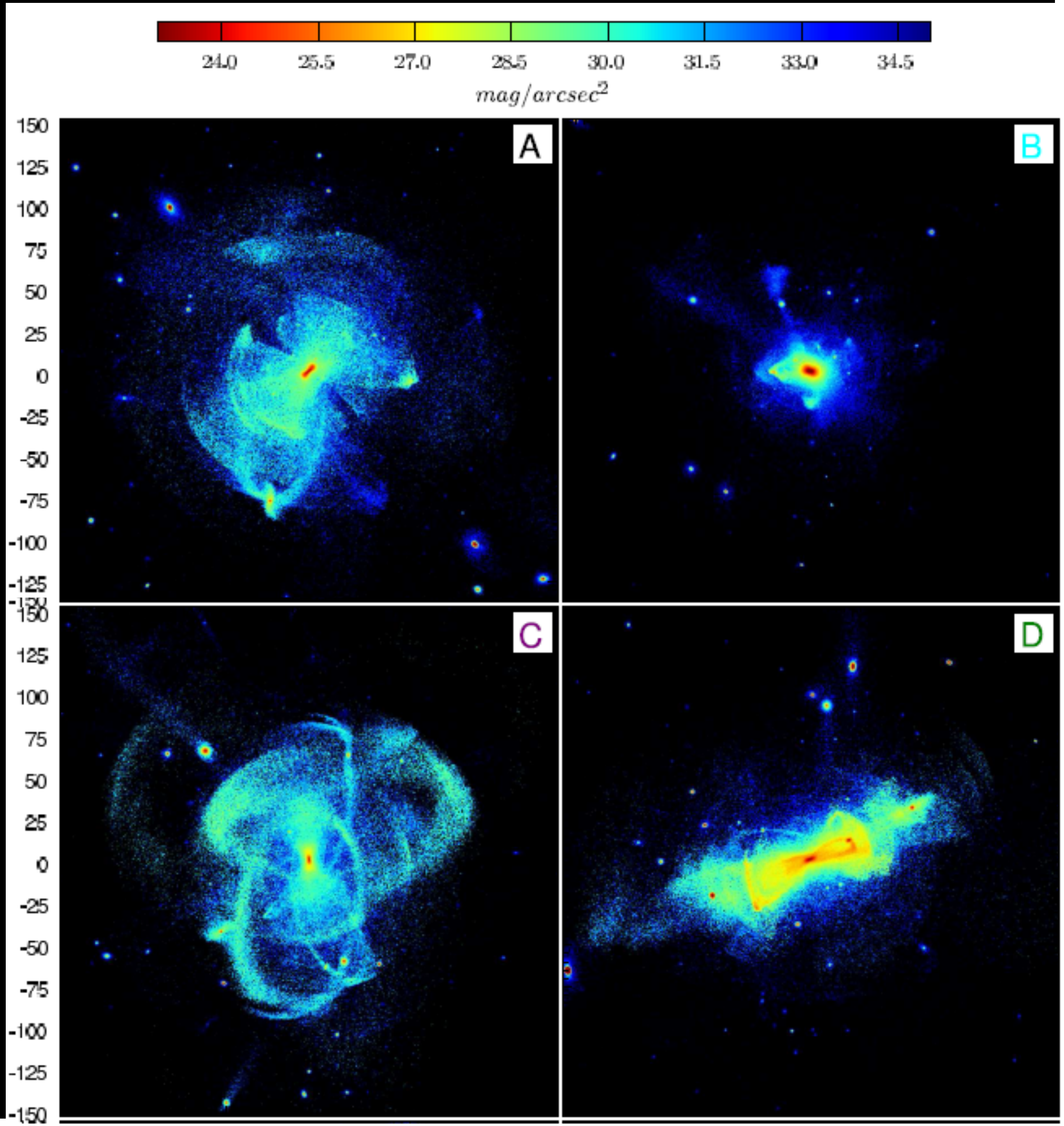
Cooper et al. 2010

Helmi, Cooper et al. 2010

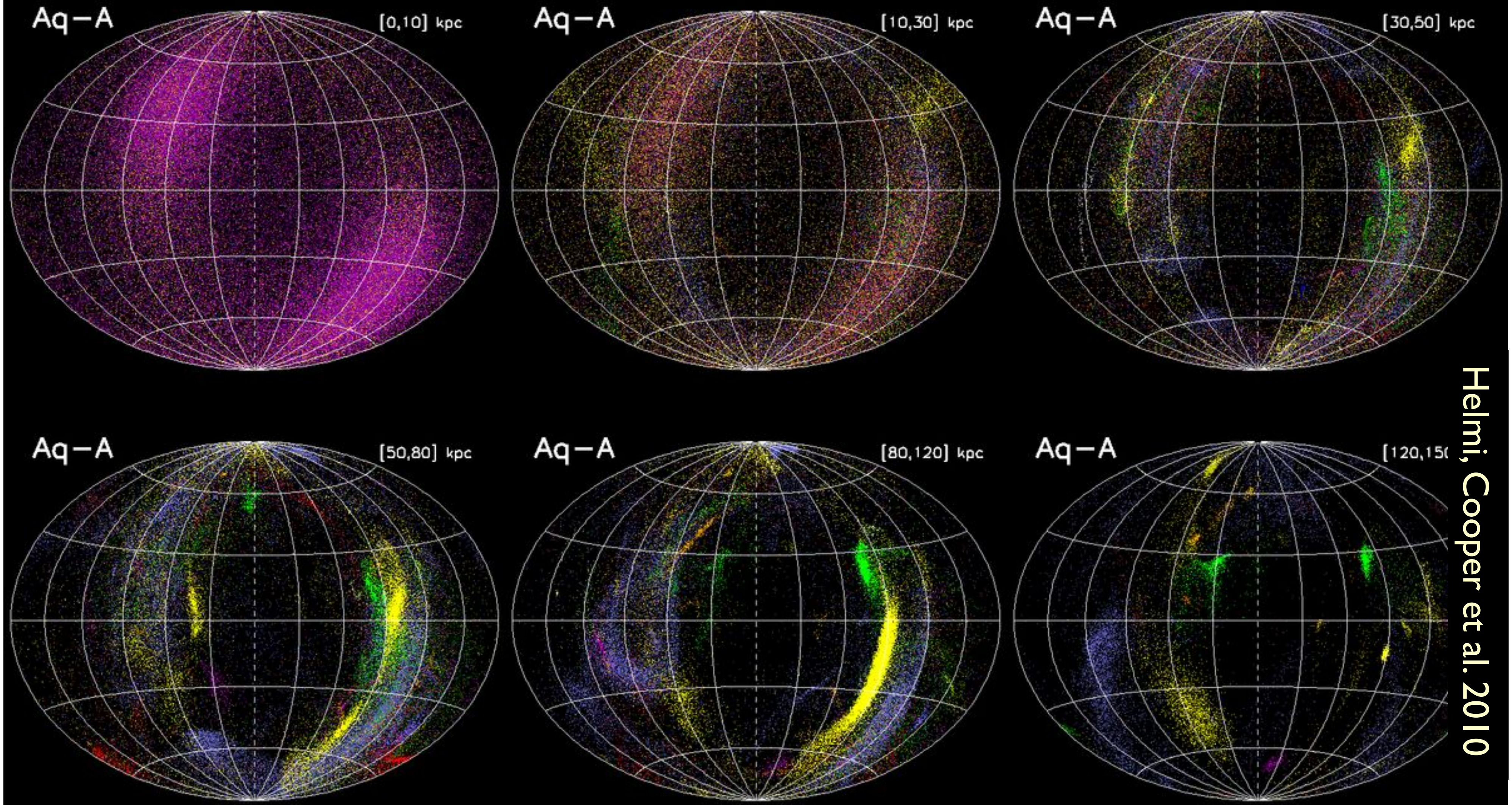
Aquarius “accreted” stellar halos

Large variation from halo to halo -> reflects different histories

Large amount of substructure -> history may be recovered



Aquarius on the sky



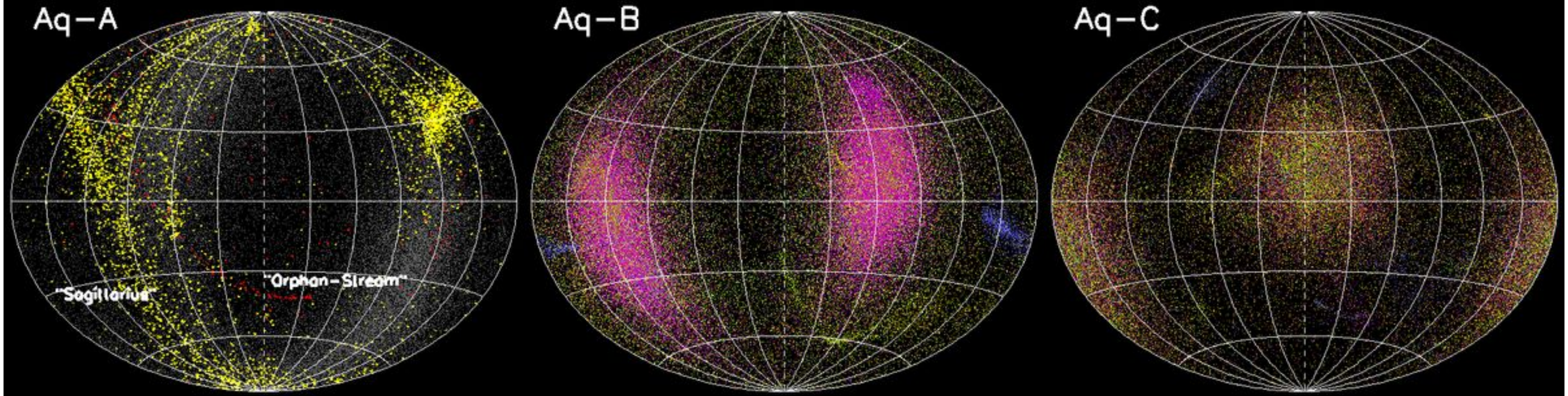
Helmi, Cooper et al. 2010

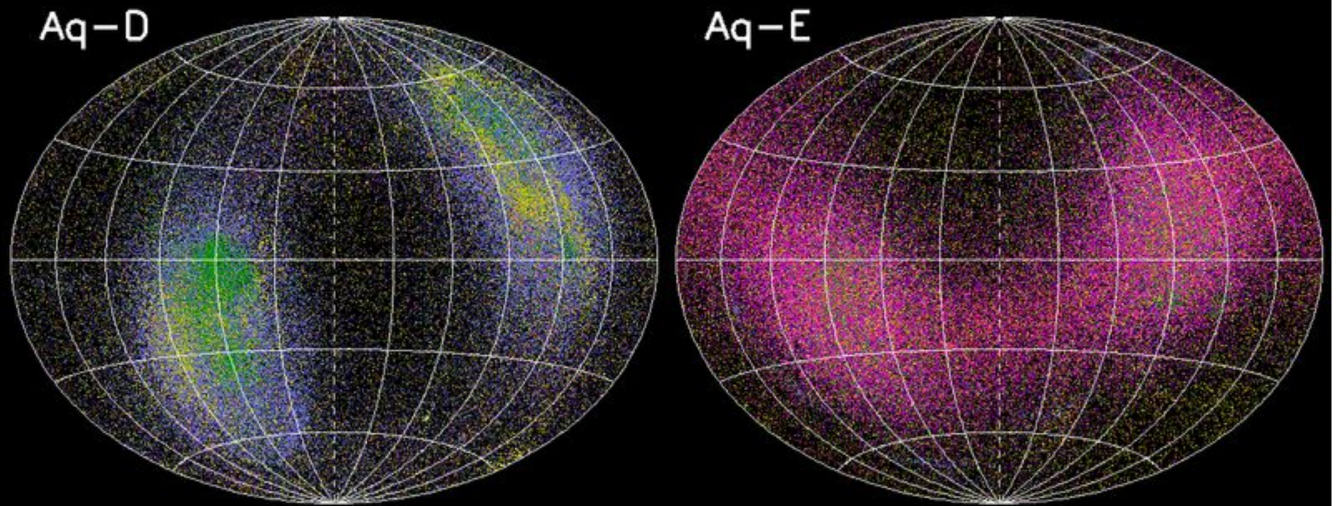
Inner halo (d < 10 kpc): very smooth (triaxial in shape)

Substructure apparent at d > 10 kpc and dominant at d > 30-50 kpc

Anisotropically distributed (coherent in dist): infall pattern!

Stellar halos at d ~ 10-30 kpc





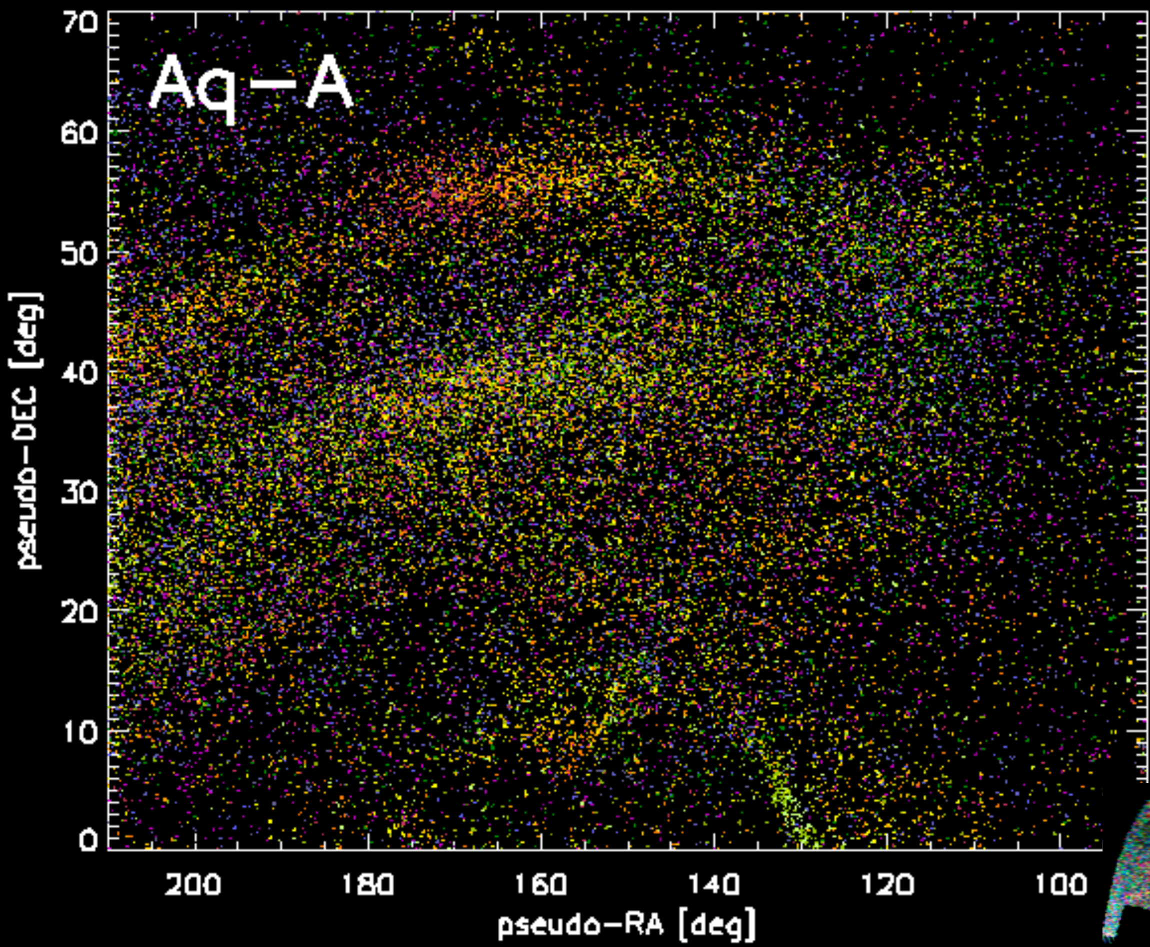
Broad/diffuse features dominant

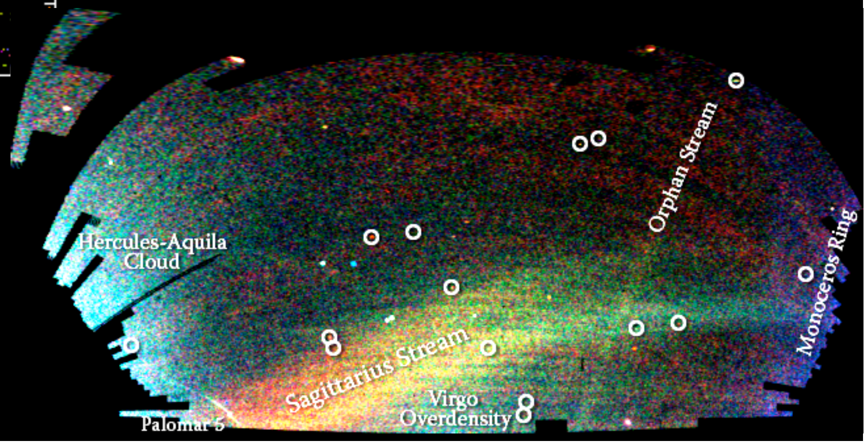
Narrow streams also present

Sgr and O-stream visible in the Aq-A sky!

Helmi, Cooper et al. 2010

The Aquarius "field of streams"





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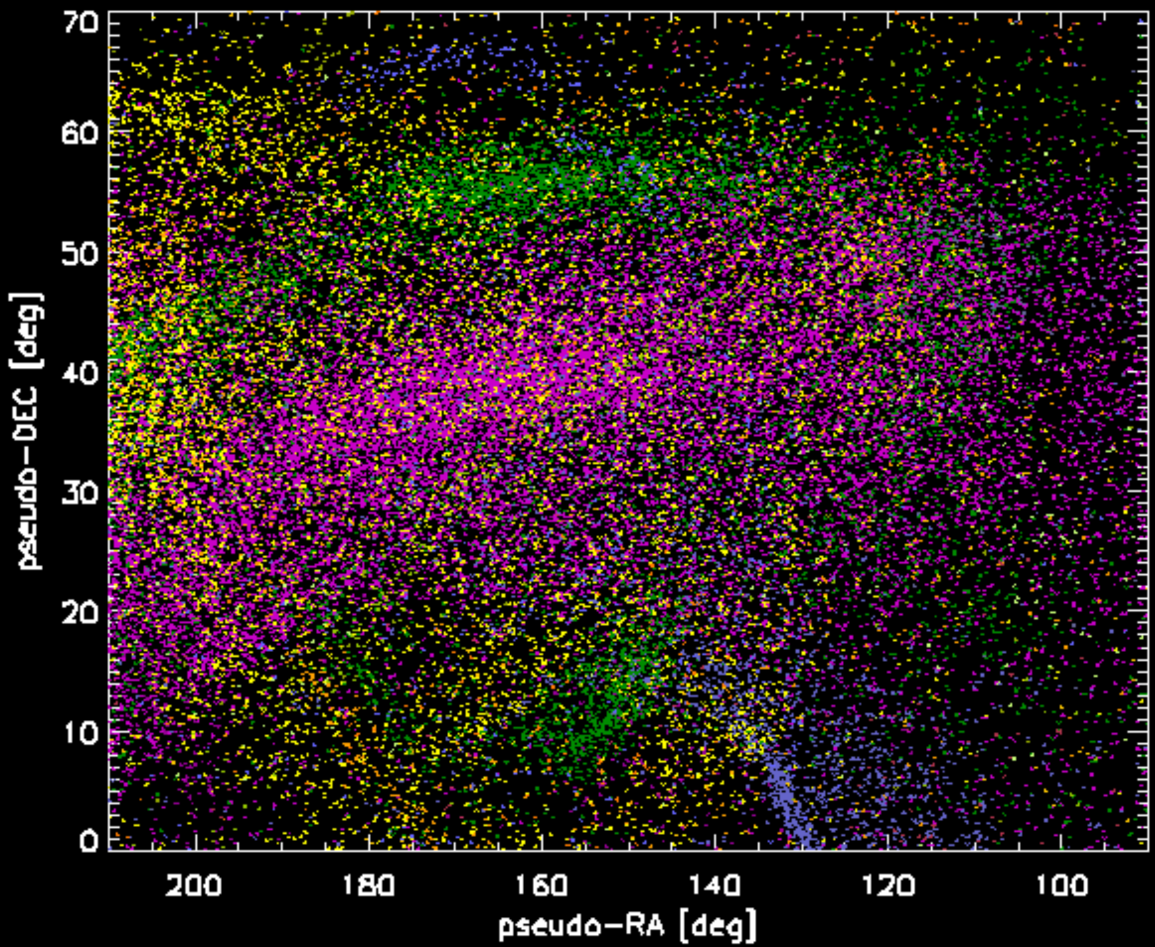
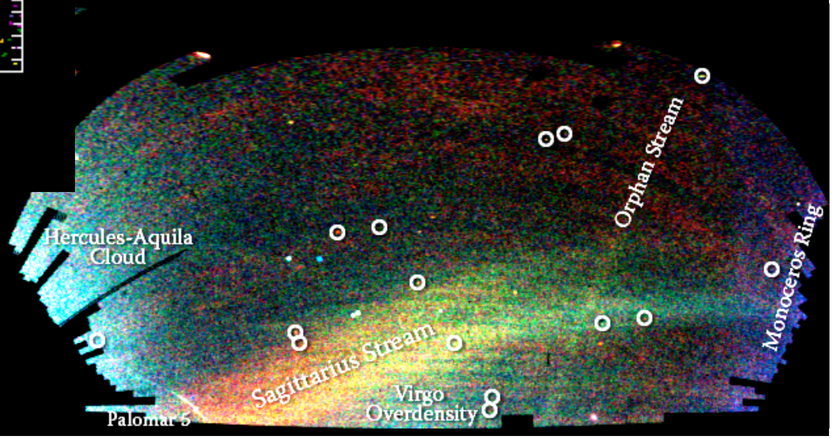


Streams from different progenitors may follow similar paths on sky

24 different objects contribute to this field

$M_* \sim 10^3\ M_{sun}$ (orange) upto $9 \times 10^7\ M_{sun}$ (purple)

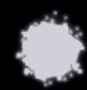


Stellar halo

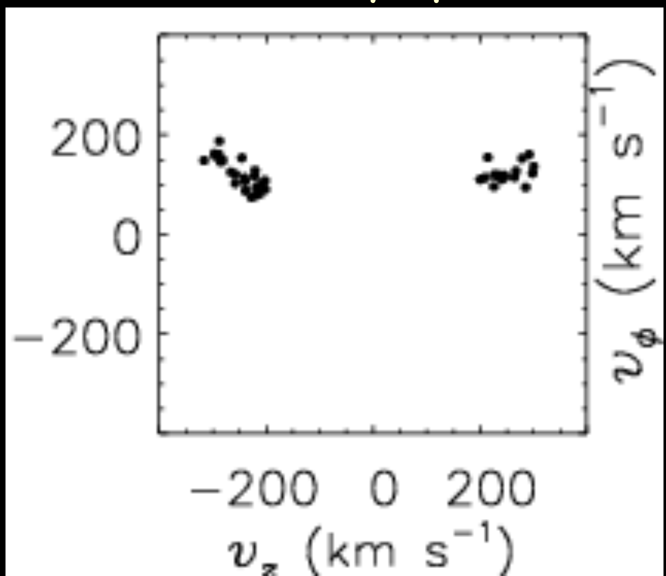
- Distribution on the sky: anisotropic at large radii
- New surveys likely to find (most) substructures in same regions as SDSS
- Reflects infall pattern of material; relation to large scale environment around galaxy
- Inner stellar halos are older: by age and dynamically
  - contain unique clues about early galactic history

Inner Galaxy

- More interesting:
  - location of large majority of stars
- Mixing timescales are short
  - Debris no longer spatially coherent
  - Memory is retained in kinematics

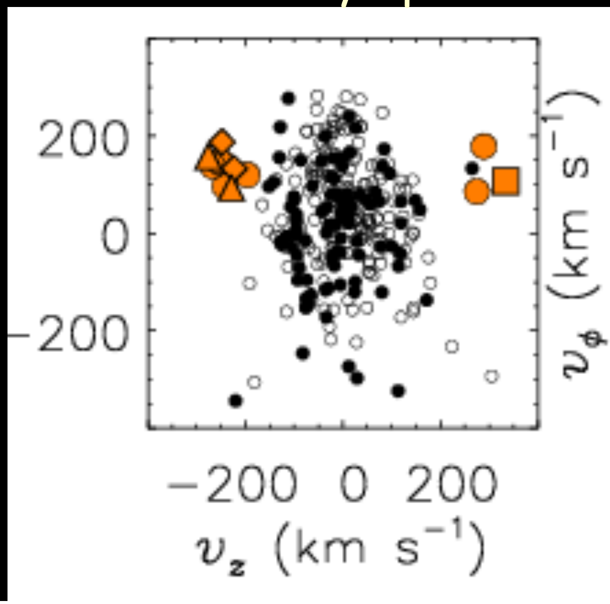


Velocity space



Helmi et al. 1999

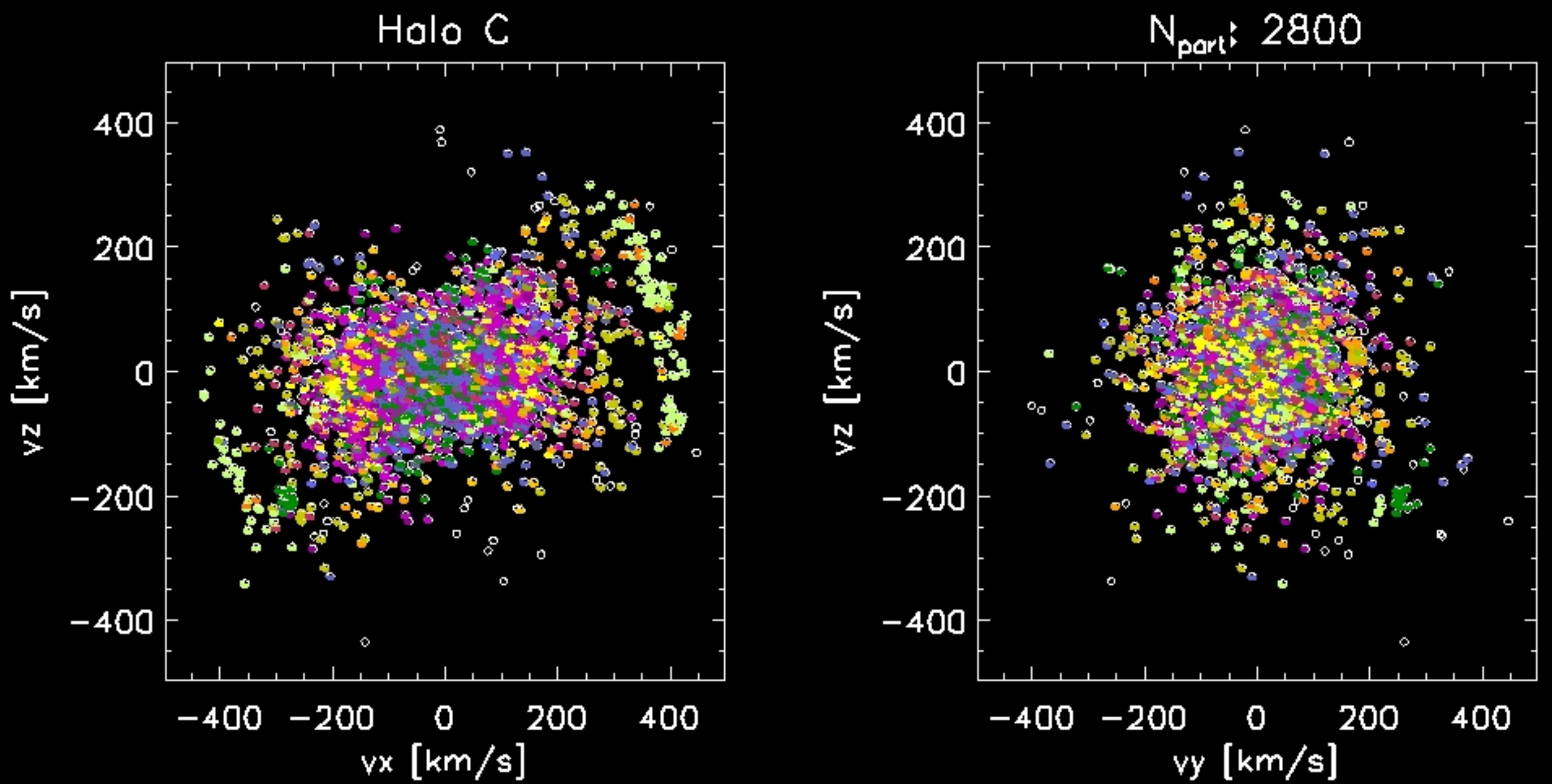
Velocity space



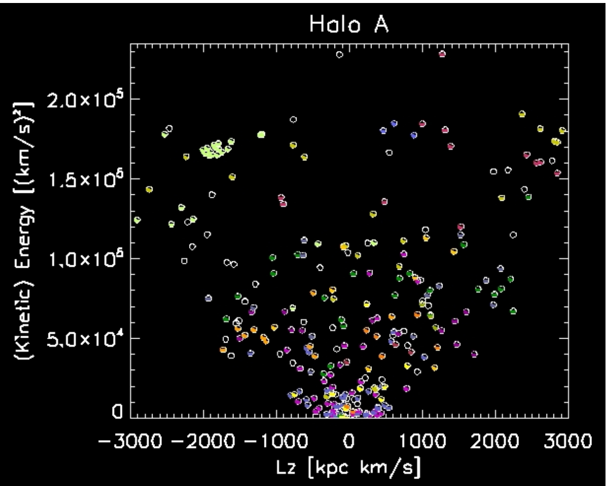
A galaxy disrupted
very early on
in our own
backyard

Inner/nearby stellar halo

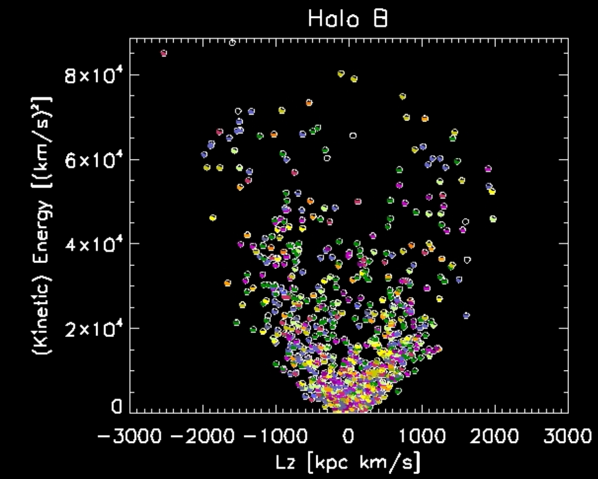
- Few objects contribute here: 75% of stars near Sun from 3-5 parents
- Memory in kinematics -> many streams crossing Solar neighbourhood
- Should be visible with Gaia!

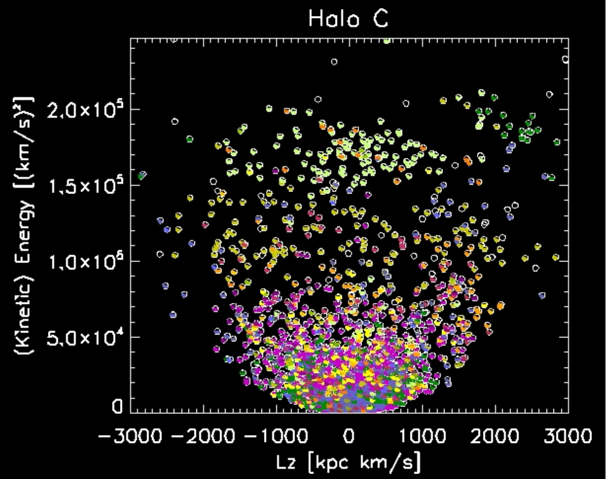


“Conserved” quantities/integrals

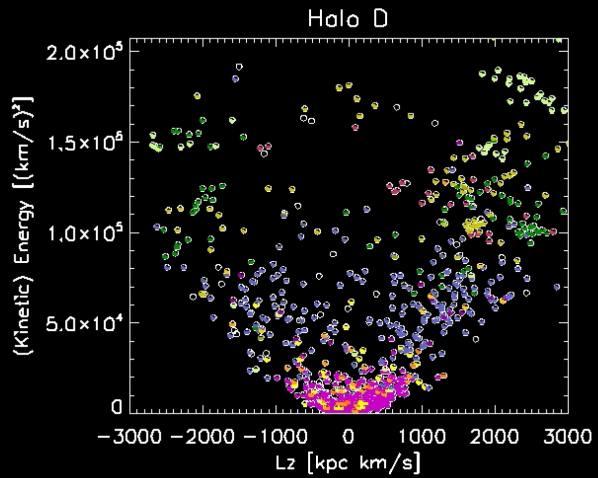


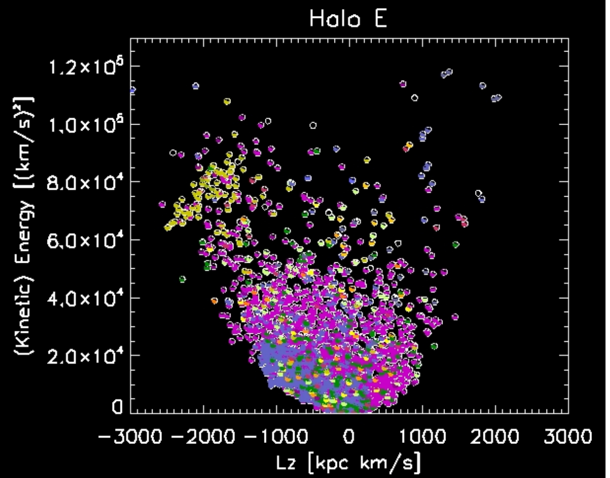
- Better spaces to look for clustering -> conserved quantities: “E” vs Lz





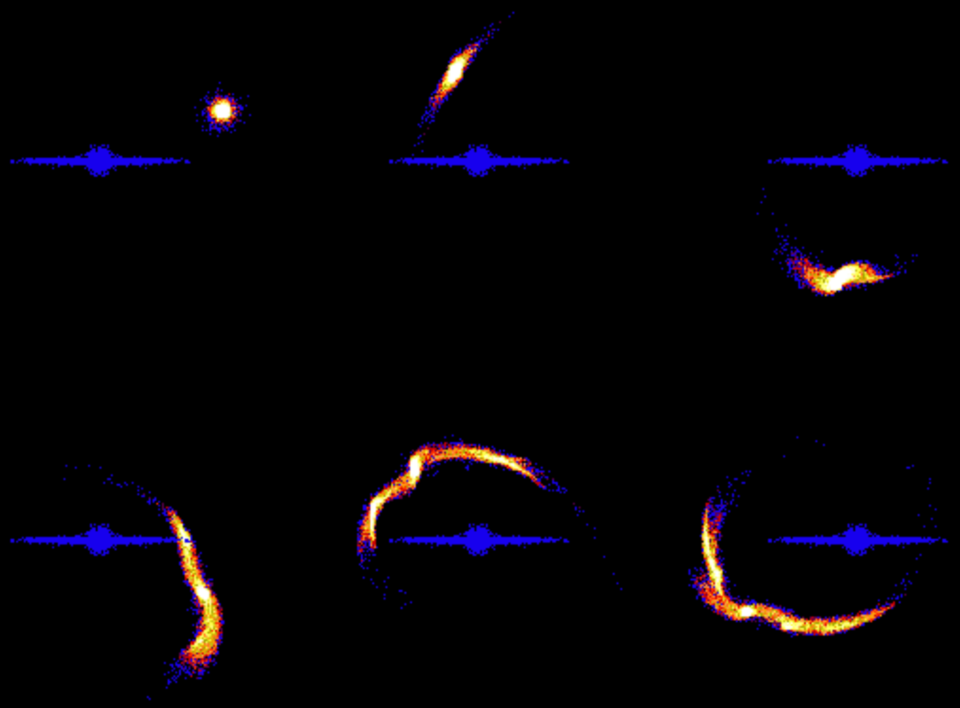
- Despite “chaotic build-up” : conservation of phase-space density ensures presence of many ever-colder streams for each accreted galaxy

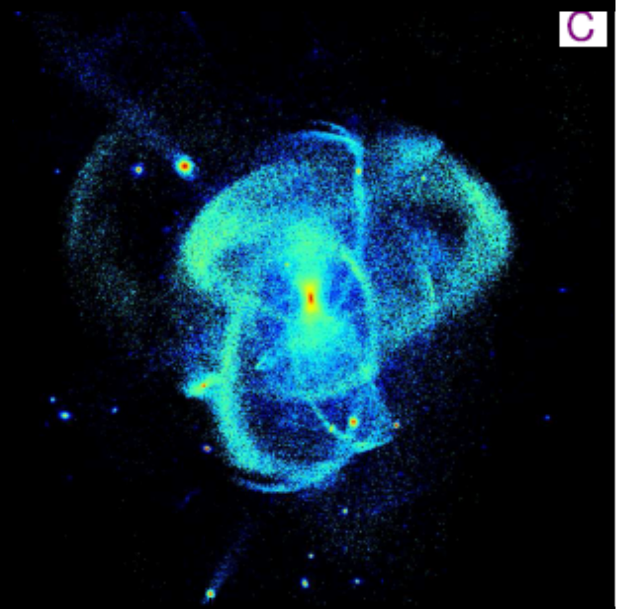




Frequency space

Johnston 1998

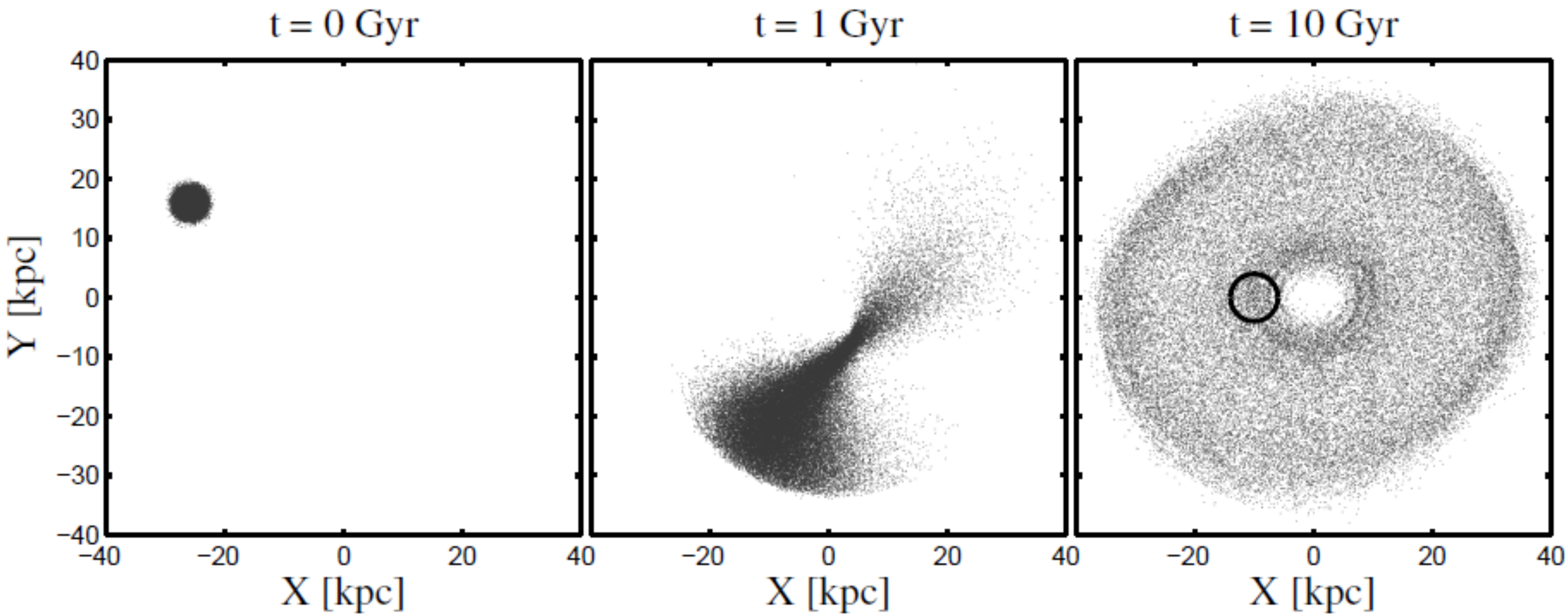




- Stars in a portion of a stream have very similar orbital frequencies (periods)

- As streams cross in space, they may still be recognized by their velocities or their frequencies

Frequency space: time since accretion



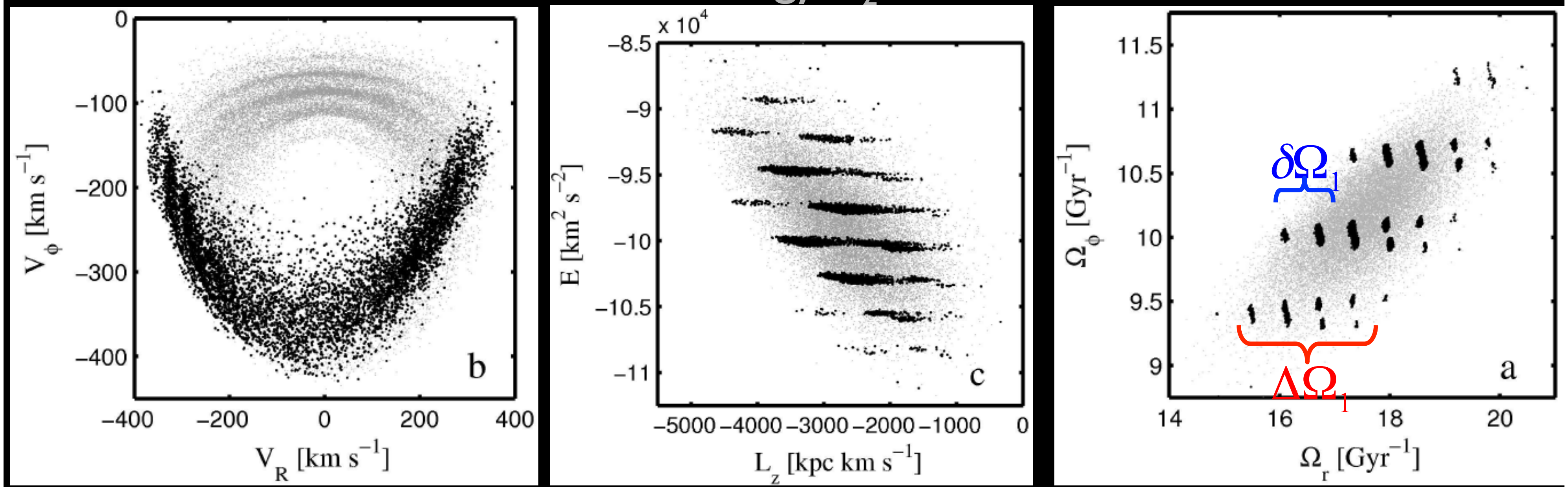
- Streams sharply defined on a regular grid
- Characteristic separation $\delta\Omega$ depends on time since accretion:

$$N_{str} = [\Delta\Theta(t)/ 2\pi] = [\Delta\Omega\ t /2\pi] \text{ and } \delta\Omega = \Delta\ \Omega/N_{str} \longrightarrow t_{acc} = \delta\Omega/2\pi$$

- Timescale easily estimated with Fourier analysis techniques
  - works well (within 15 – 25%) even in time-dependent, or live potentials

Frequency space: time since accretion

Velocities | Energy-L_z | Frequencies



Gomez & AH 2010

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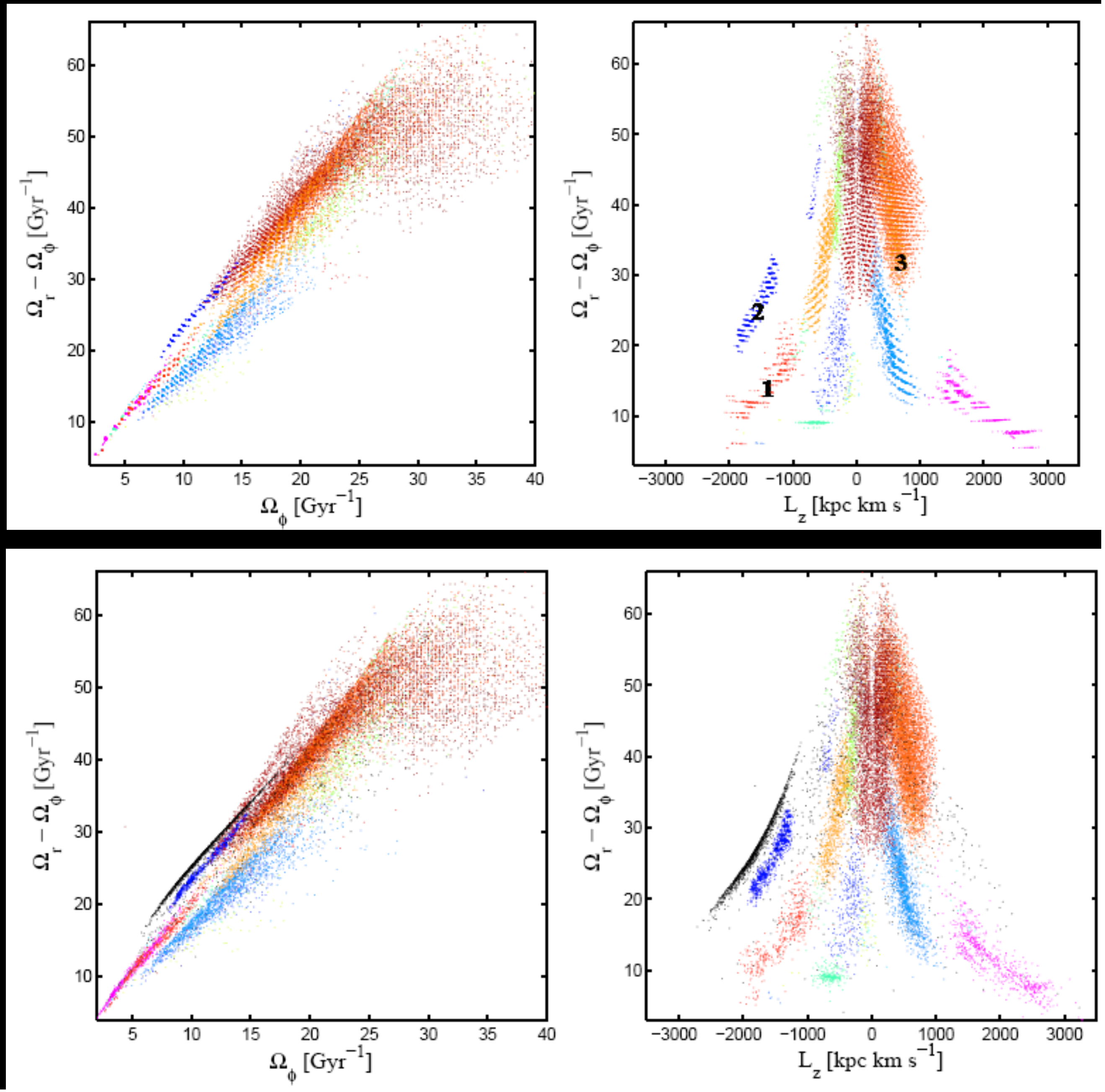
Gaia's errors and limitations

Gomez et al. 2010

- Semi-cosmological simulation of stellar halo (time-dependent analytic potential)
- Streams in SN clearly visible, particularly for large period orbits
- When errors are taken into account, streams are less "sharp"



Gaia's errors and limitations

Gomez et al. 2010

- Without errors: time of accretion is easily measurable

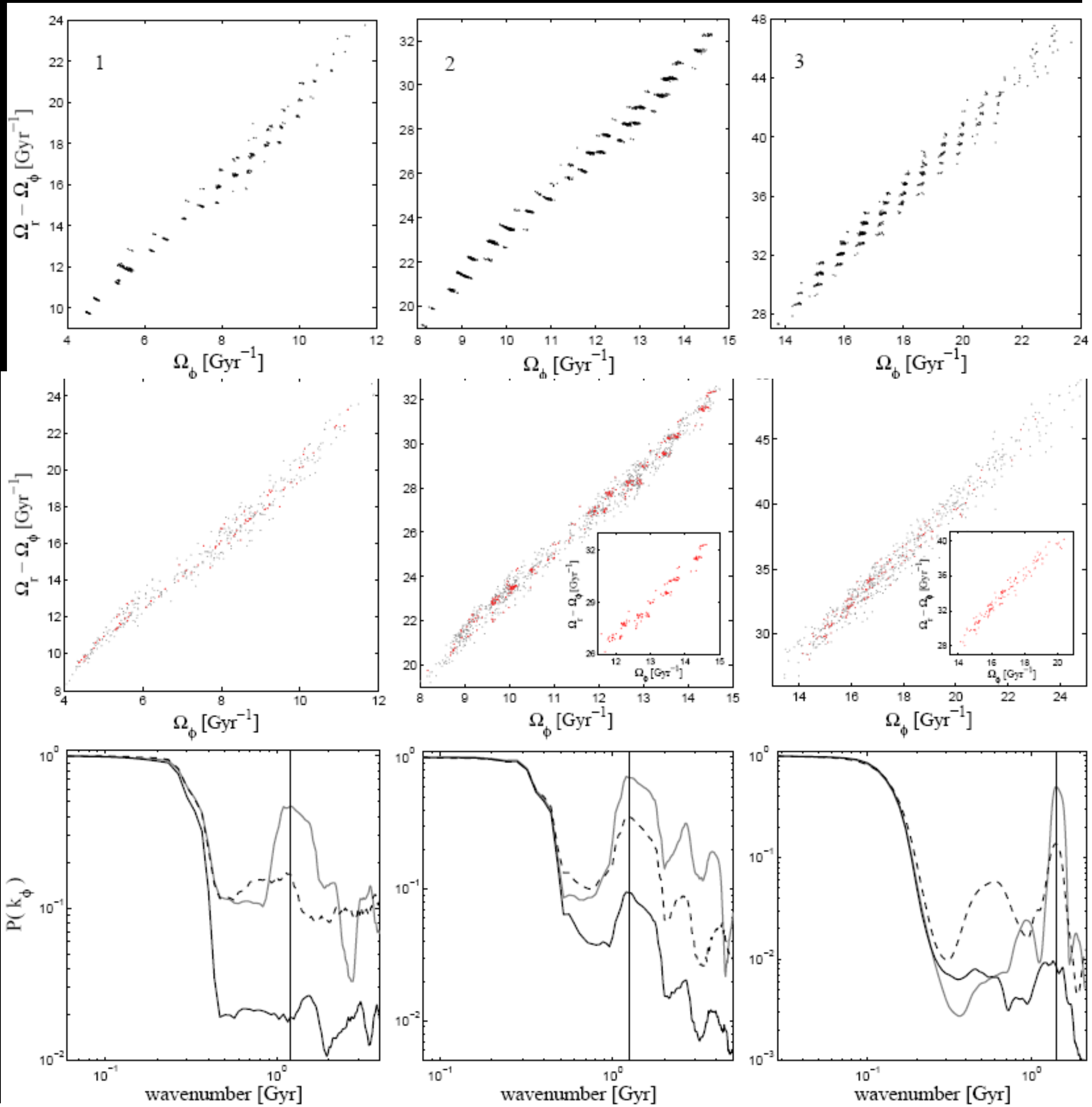
- With errors, streams are diffuse

- With error cut:

σ_V < 6 km/s or $\sigma_\pi/\pi \sim 0.02$

streams become sharp (though less populated)

- Time of accretion retrieved
  - If 100 stars from accreted satellite have very good velocities



Summary

- Accretion likely important in build-up of stellar halo
  - Objects?
    - how many? properties? masses, star formation and chemical histories?

- Cosmological models of formation
  - predict substructure at all radii
    - kinematic at r < 10-20 kpc; hundreds of streams near the Sun
    - Spatially coherent at large distances and anisotropic on sky ->infall pattern
  - Qualitatively in agreement w/observations

- Present and Future: many ongoing surveys and Gaia
  - Substructure from ancient events expected
  - More difficult to detect (IoM, frequencies)… but early epochs!
  - Gaia capable of unraveling accretion history of the Galaxy