# Learning about first galaxies using large surveys

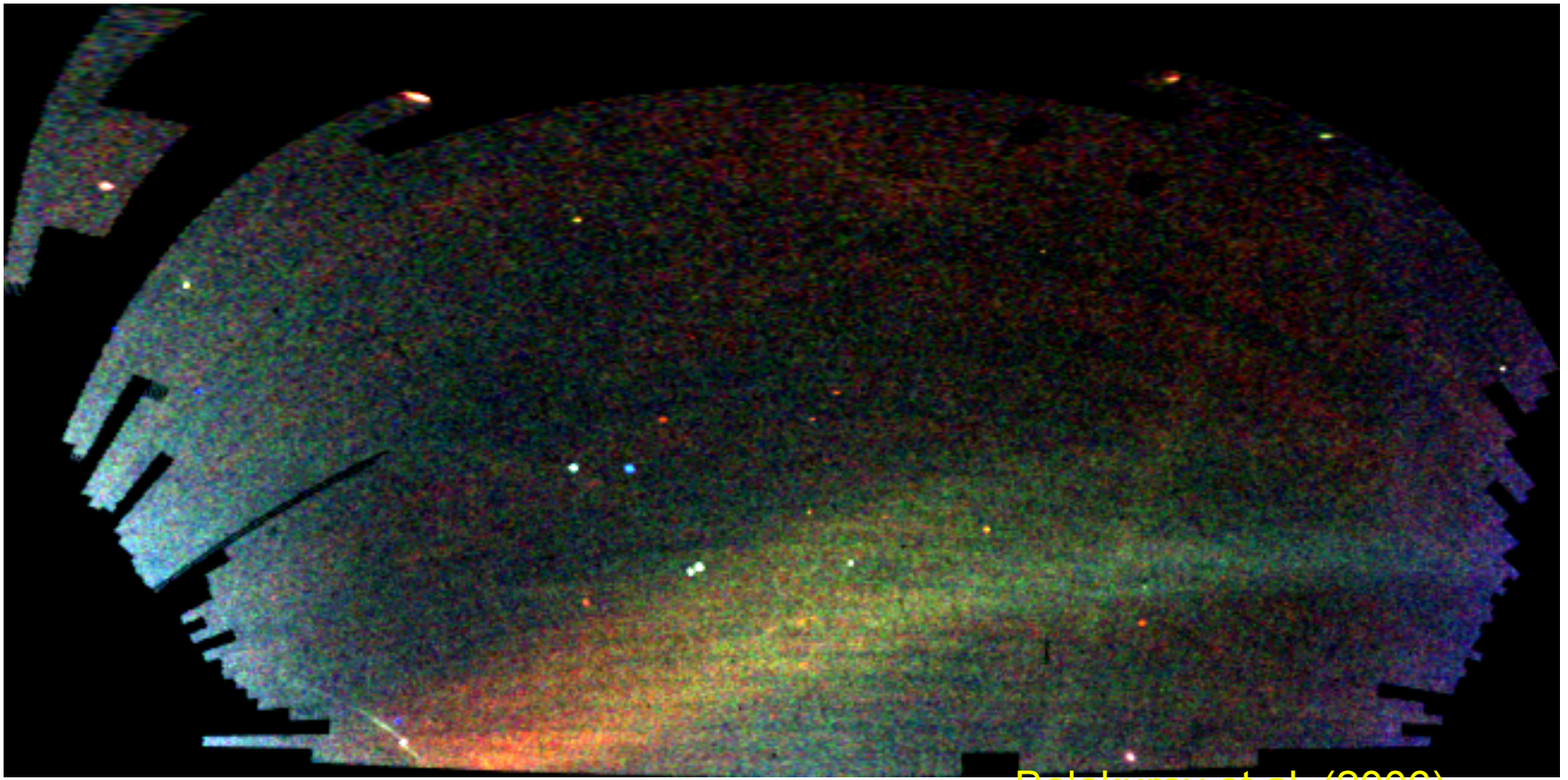
**Sergey Koposov**

**IoA, Cambridge**

# Learning about first galaxies/stars

- Dwarf galaxies
- Stellar streams
- Large spectroscopic surveys of the MW halo
- Gaia

# Searches for dwarf galaxies



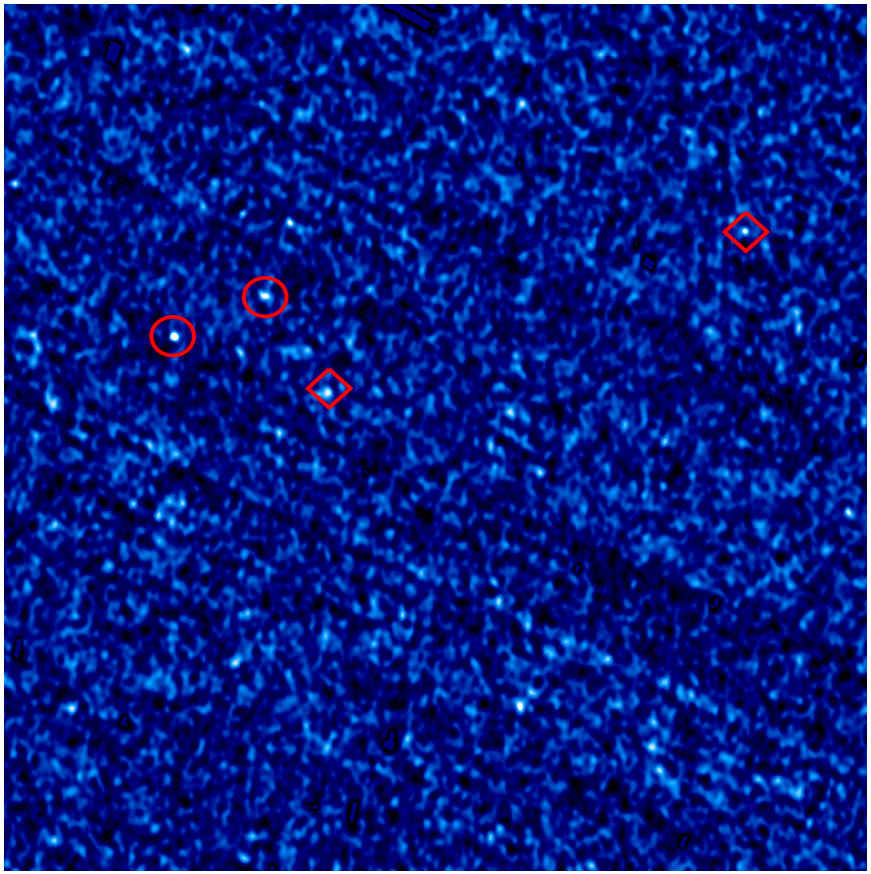
Belokurov et al. (2006)

Tens new galaxies discovered in MW only: Willman et al(2005), Belokurov et al(2006-2010), Walsh et al (2007), Irwin et al. (2007), Zucker et al. (2006)

# Searches for dwarf galaxies

The ideas were very simple:

- Select the stars of appropriate magntiudes and color
- Convolve with the filter.
- Look for overdensities.

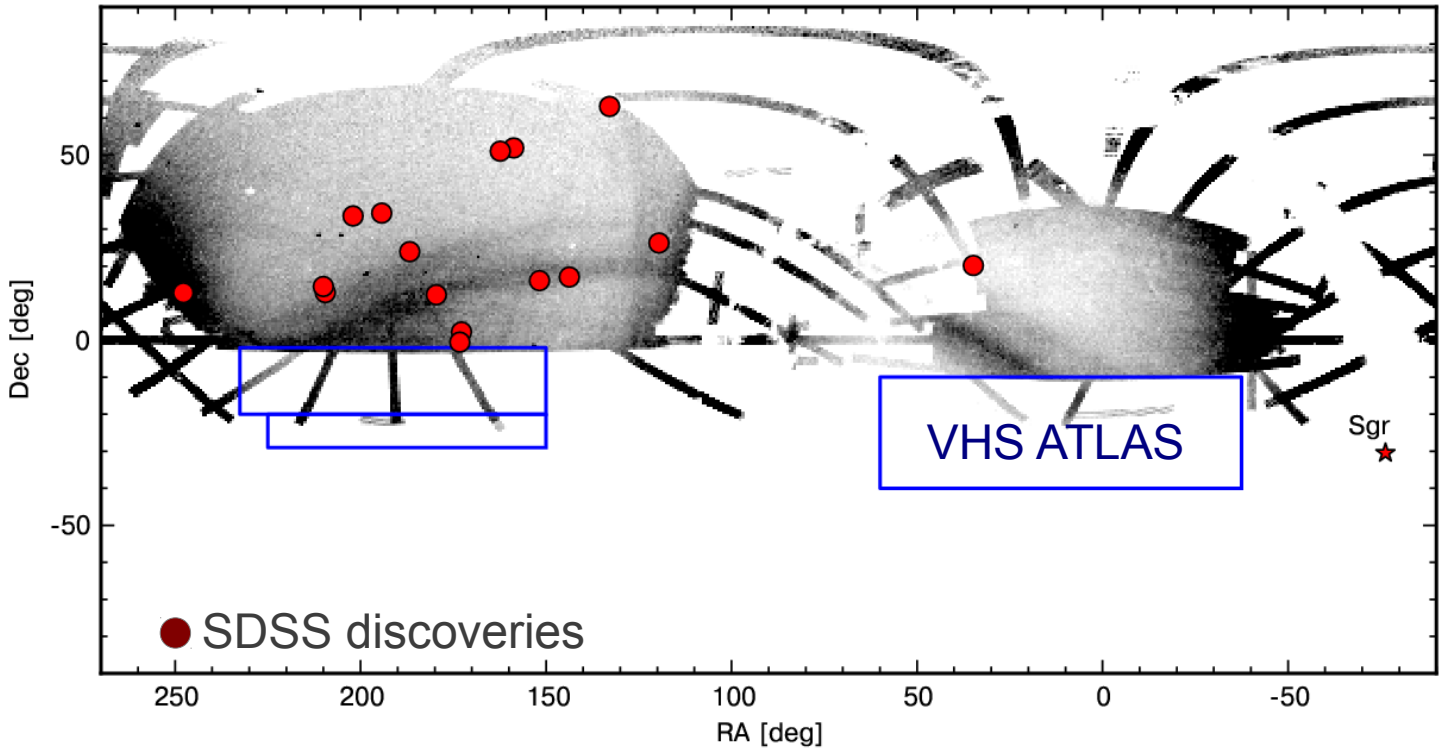


- The whole nothern sky has been surveyed. Southern sky – more extinction, existing surveys do not have full sky coverage.

# New deep surveys

Optical surveys are much better at separating dwarfs and giants

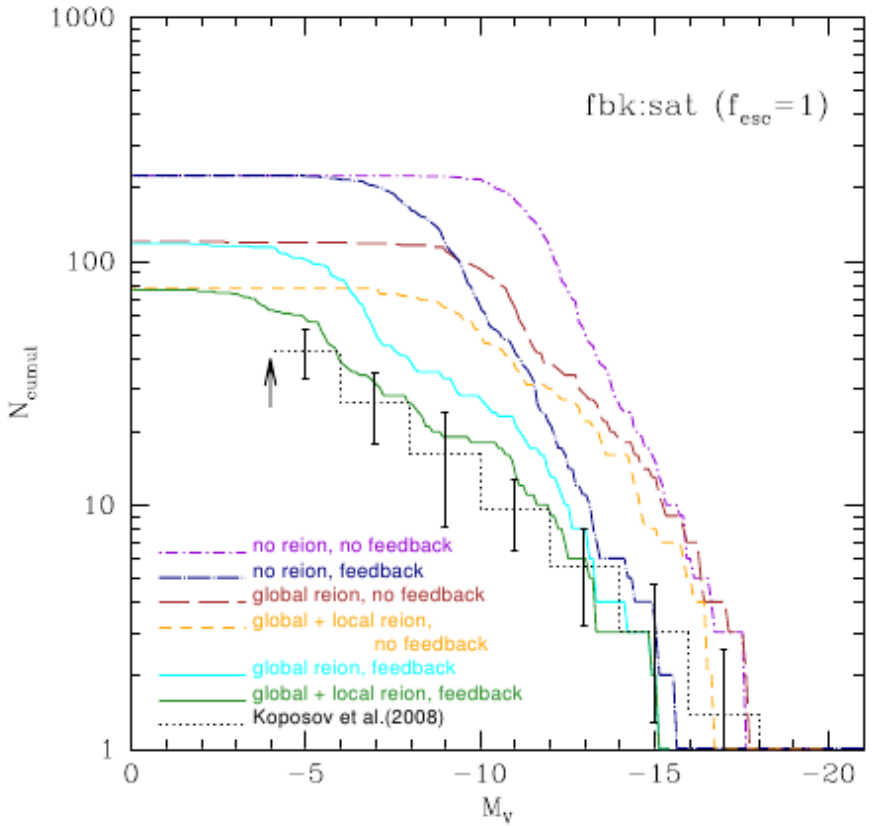
- PANSTARRS
- VHS
- VST
- DES



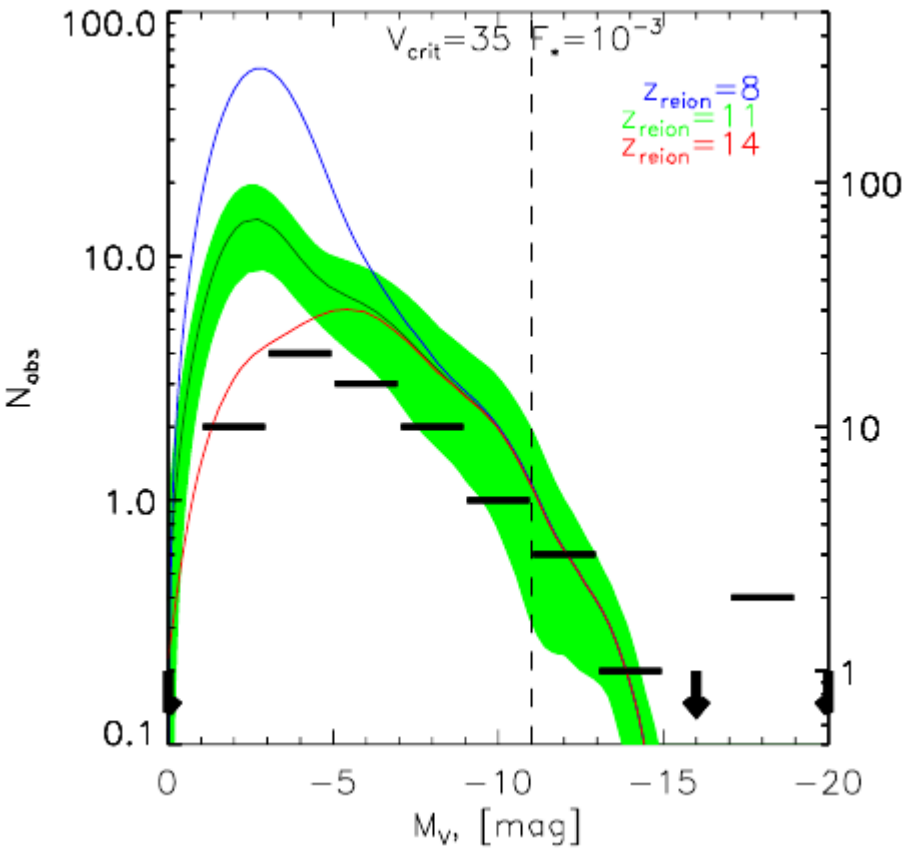

- Plane of satellites ?
- Satellite Accretion history
- Existing satellites show very anisotropic distribution

# Number of First galaxies vs physics

- The LF of dwarfs is very sensitive to galaxy formation physics: reionization, cooling, tidal disruption




Font et al. (2011)



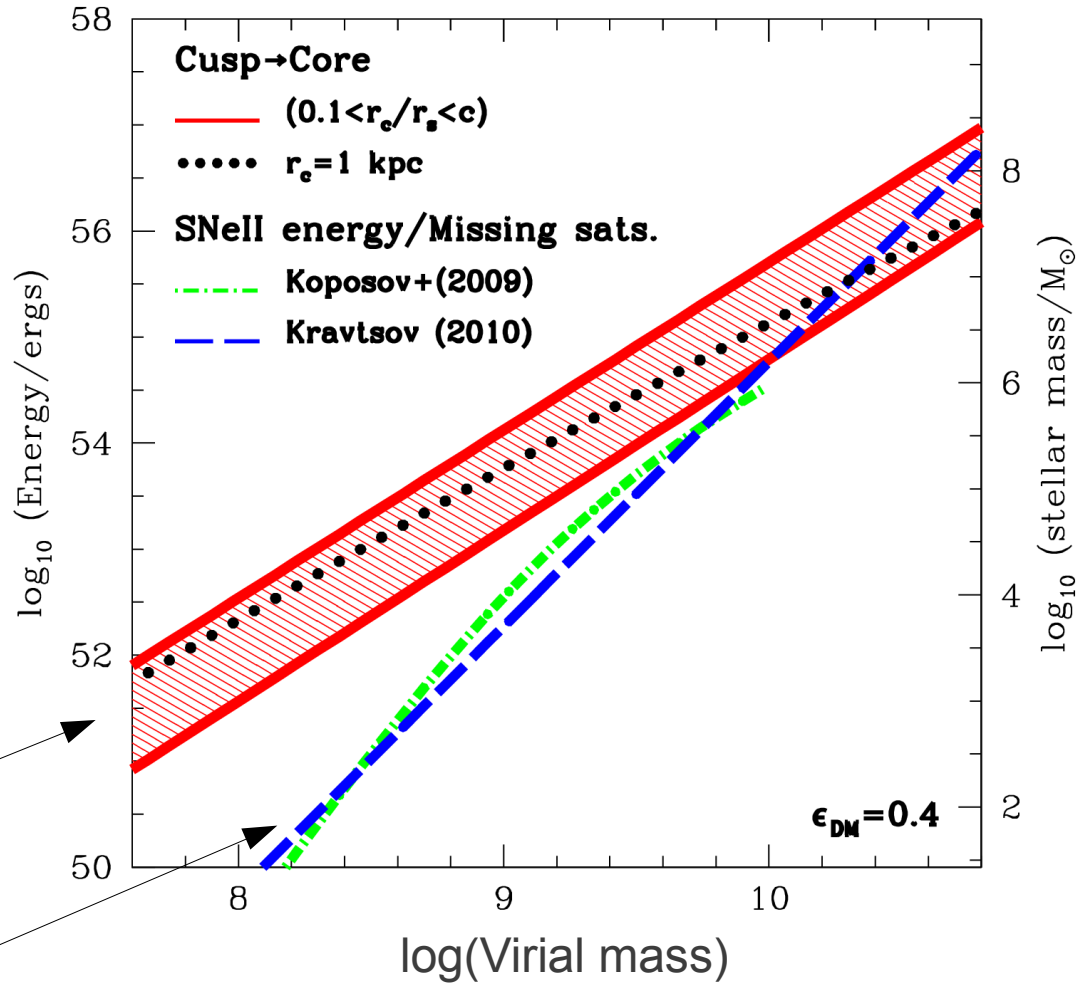

Koposov et al. (2009)

# Core&Cusp vs Missing Satellites

- There is a contradiction between the amount of SN needed to create the cusp

  vs the amount of SN required to reproduce the LF.

- Complicated interplay between Star and cusp formation may be needed



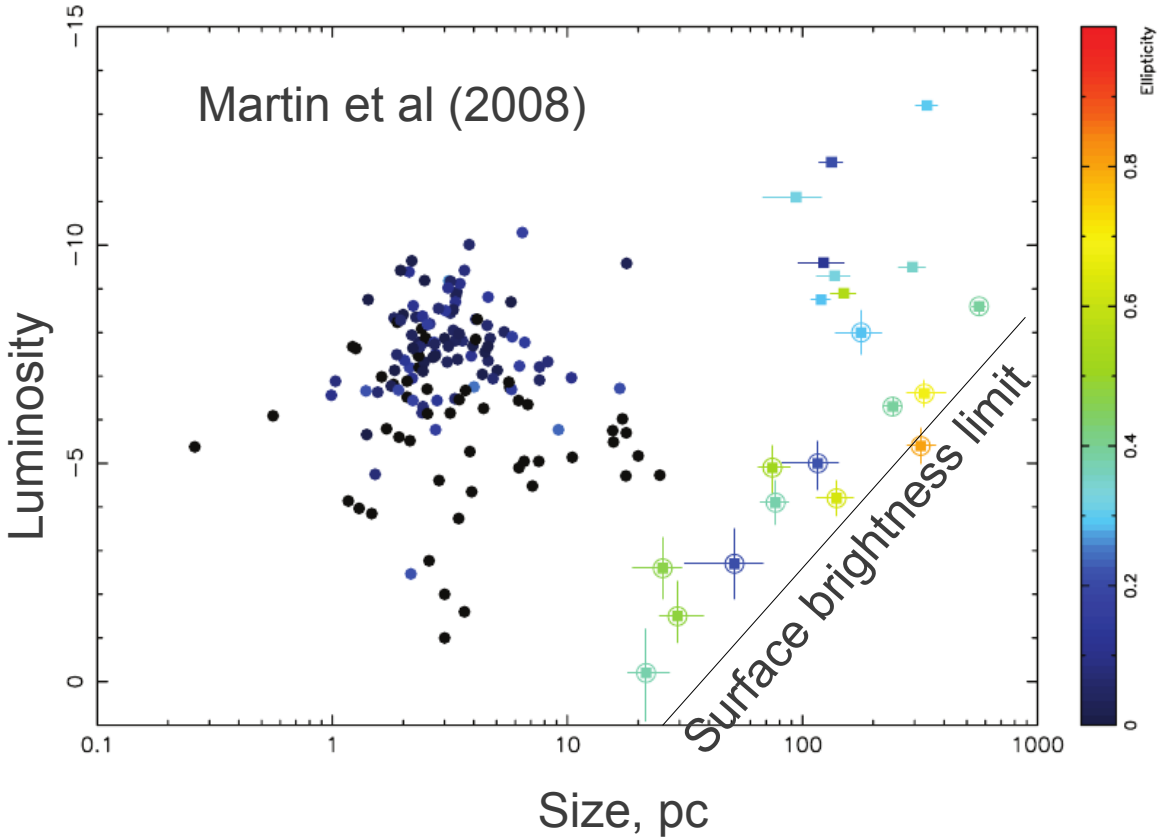

SF required to remove the cusp

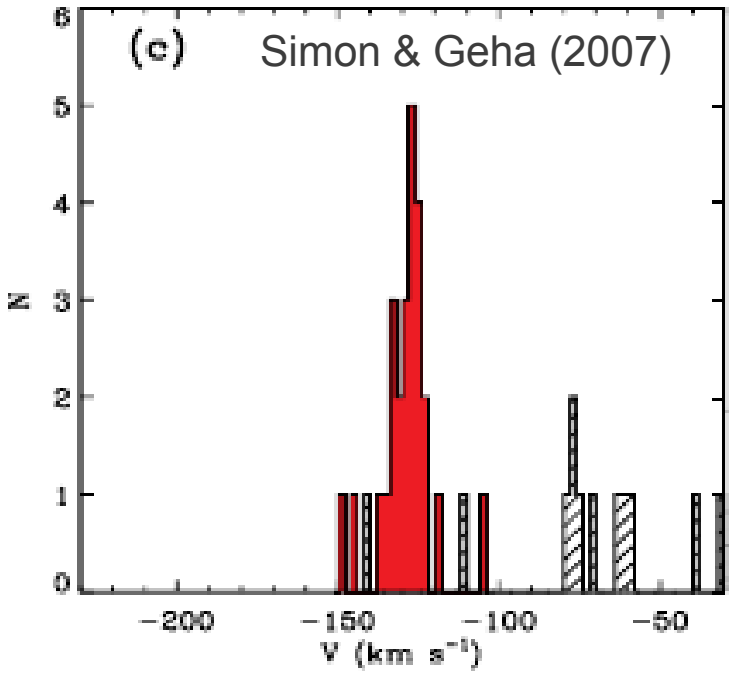
SF required to reproduce MW LF

Penarrubia, Walker, Pontzen, Koposov (2012)

# Properties of Ultra-faints

- Extremely large sizes
- Low Luminosities
- High ellipticities
- Low velocity dispersions

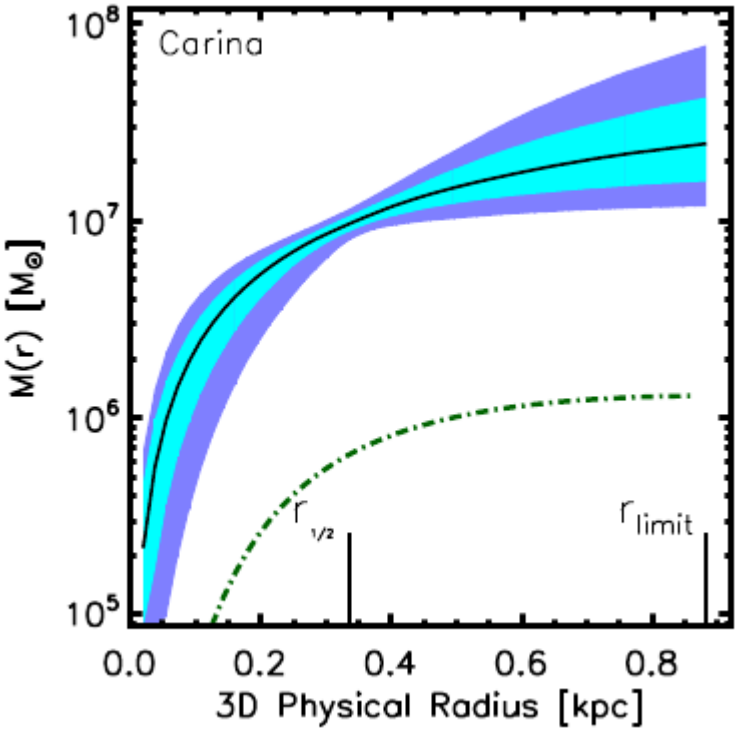


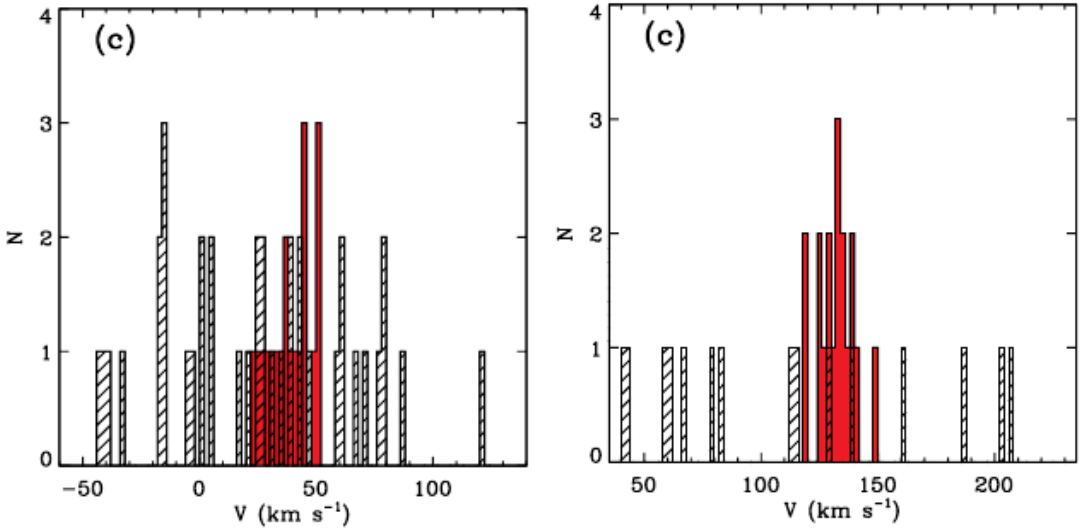



# Kinematics of dwarfs

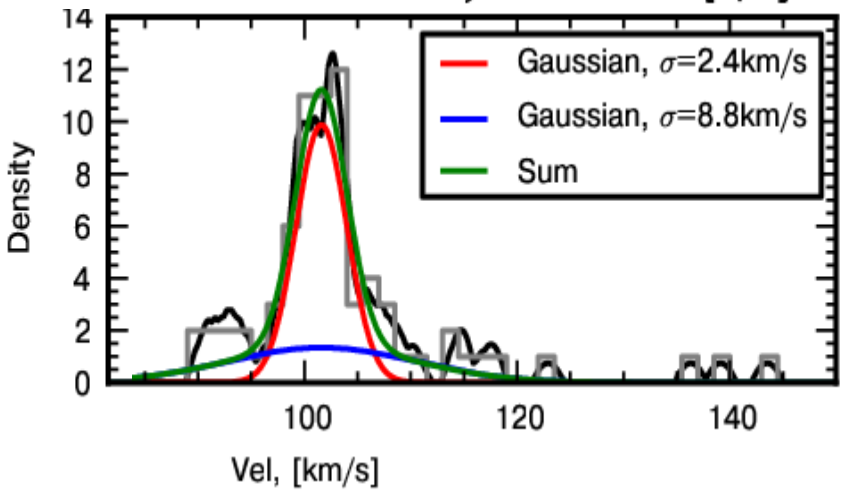
- Low velocity dispersions, high M/L
- Possible contamination by Binaries/foreground/stream
- Impossible to estimate the density profile (only half-light mass), because of mass-anisothropy degeneracy
- Possible complex velocity structure in Cvn I, Bootes I (Ibata et al 2006, Koposov et al 2010)

Wolf et al (2010)




Simon&Geha (2007)

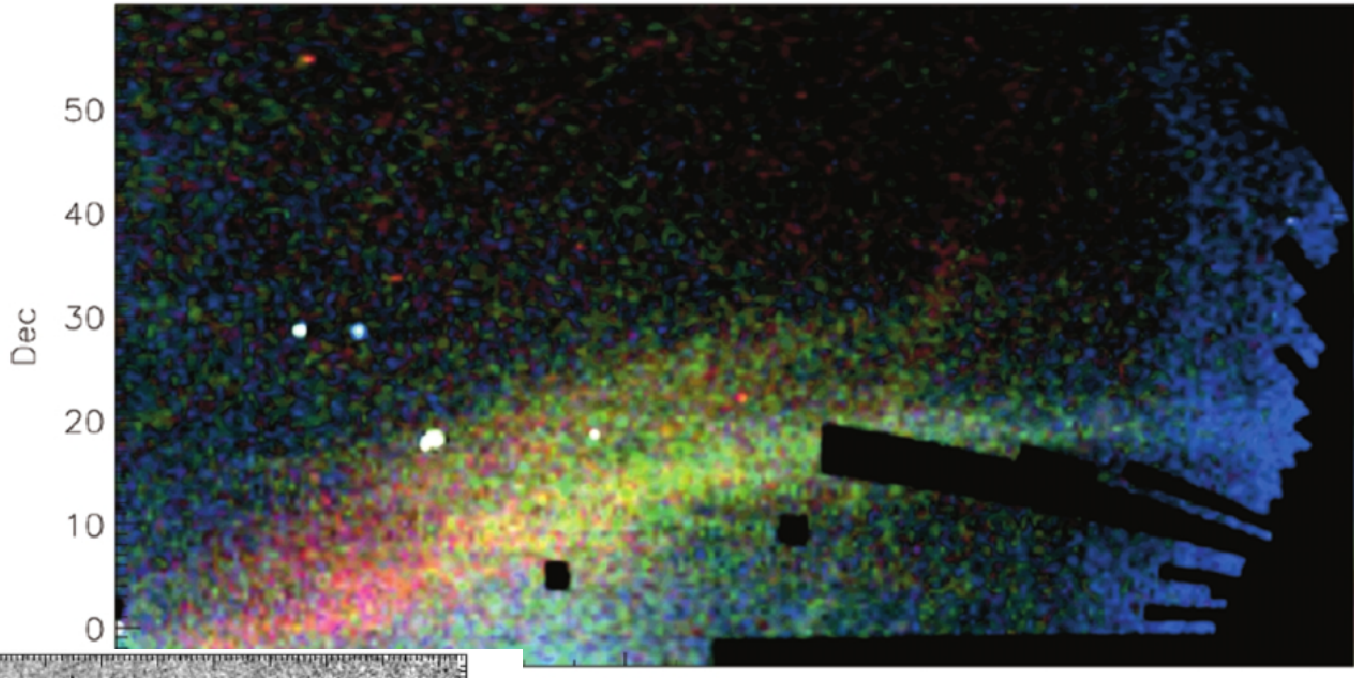


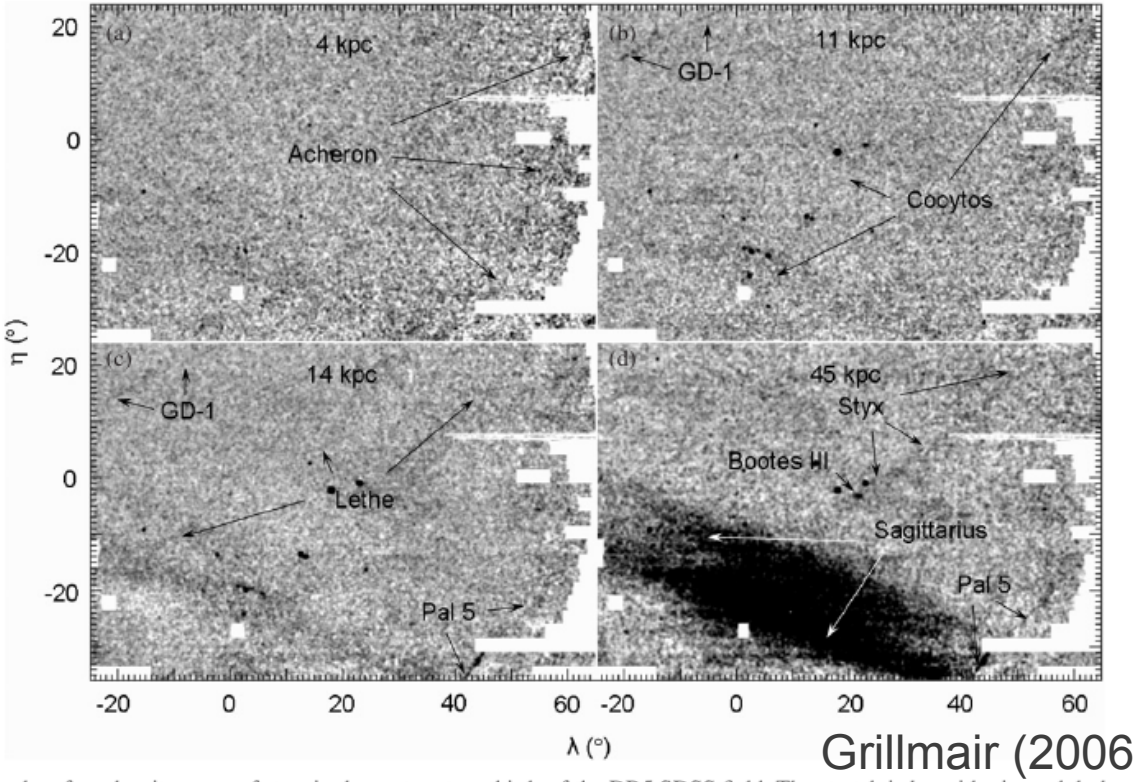

Koposov et al.(2011)

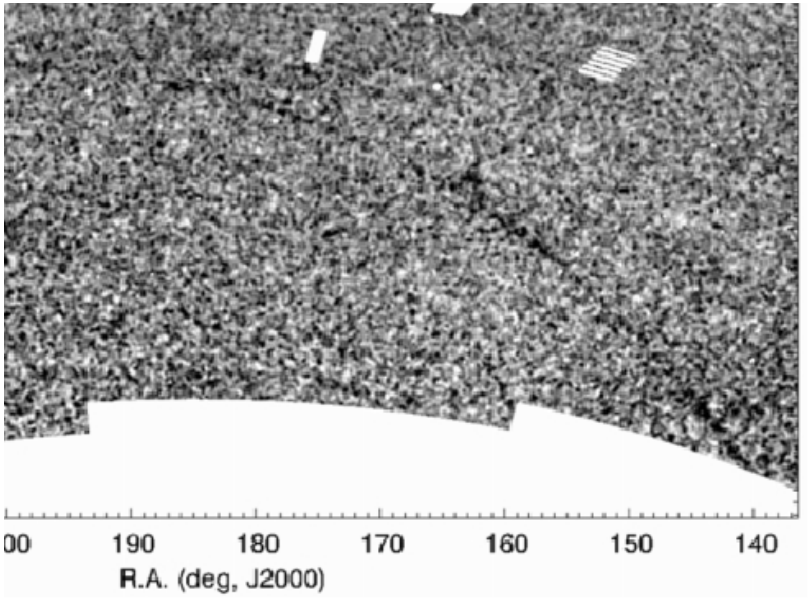
# Stellar streams

Tens new streams discovered

- Majewski et al. 2003
- Belokurov et al. 2006
- Grillmair et al. (2006,2009)

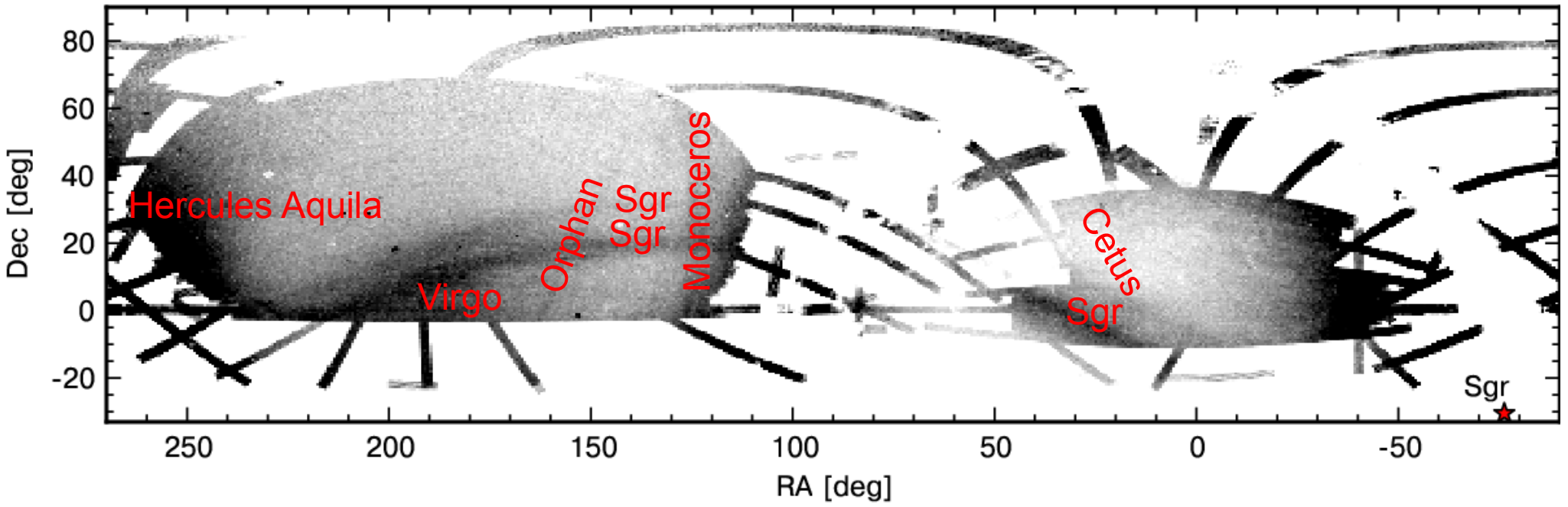



Grillmair (2006,2009)

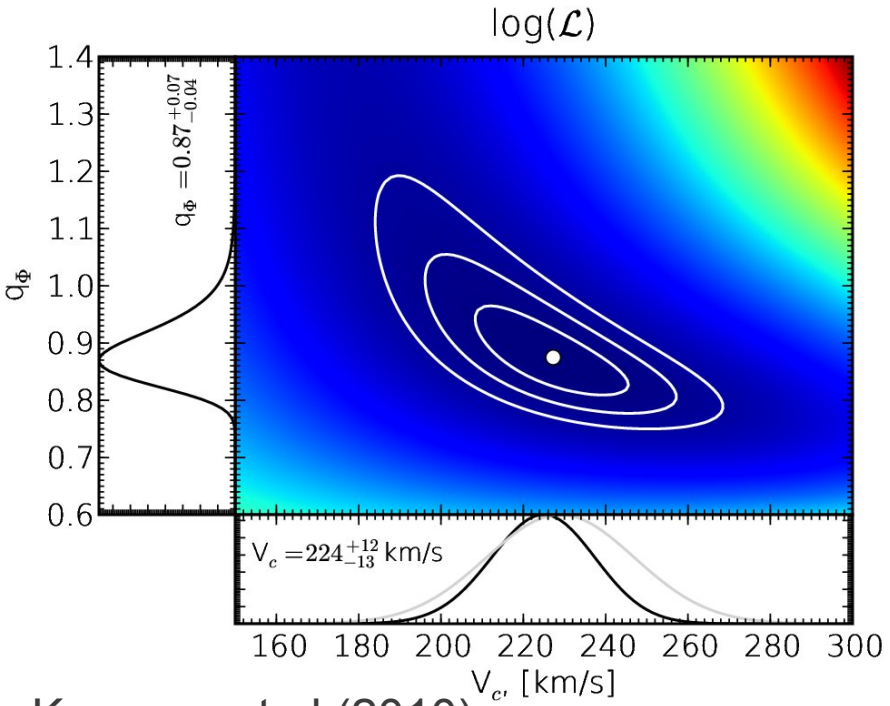
# Complicated picture



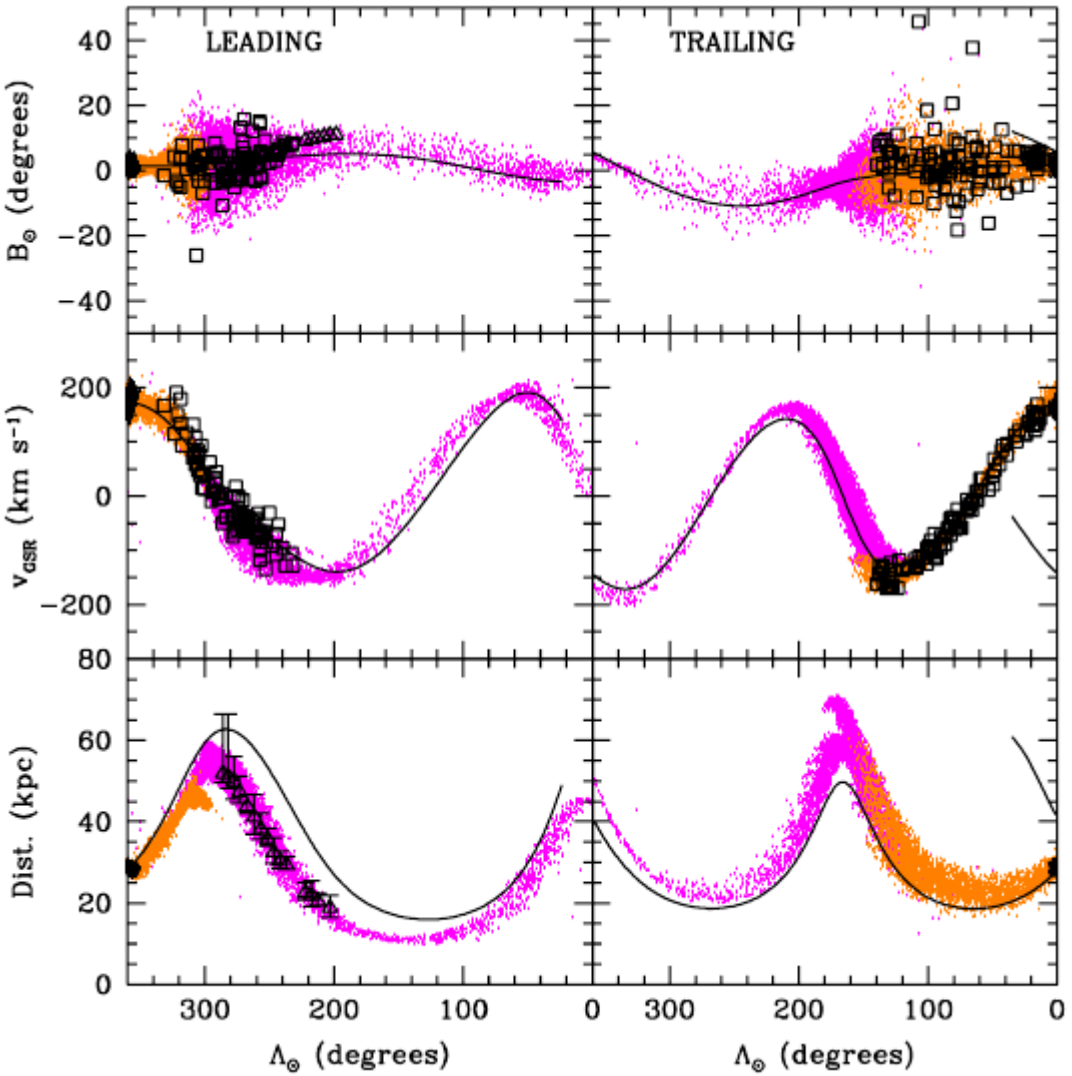

- Complicated intersections of different structures.
- Coinciding positions velocities: Orphan with Segue 1, Orphan/UmaII, Sgr/Cetus, several Sgr streams + multiple wraps
- Hard to disentangle without 6D phase space info

# Streams as a measure of the potential

- Several streams have been used individually to measure MW potential: Sgr, GD-1
- Multiple streams together hasn't been used yet



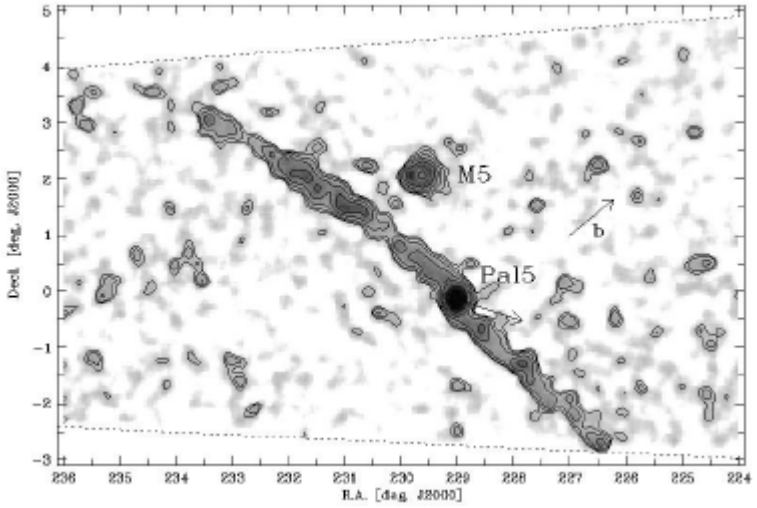

Koposov et al (2010)



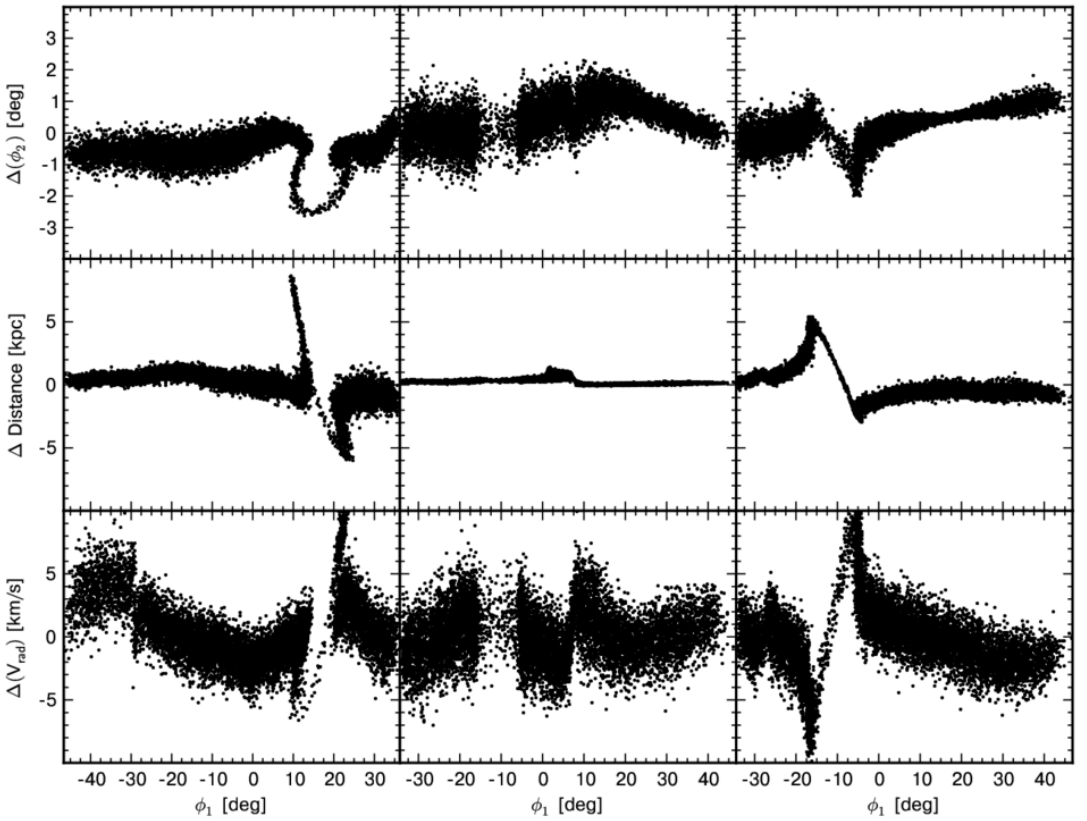

Law&Majewski(2010)

# Stream perturbations/gaps

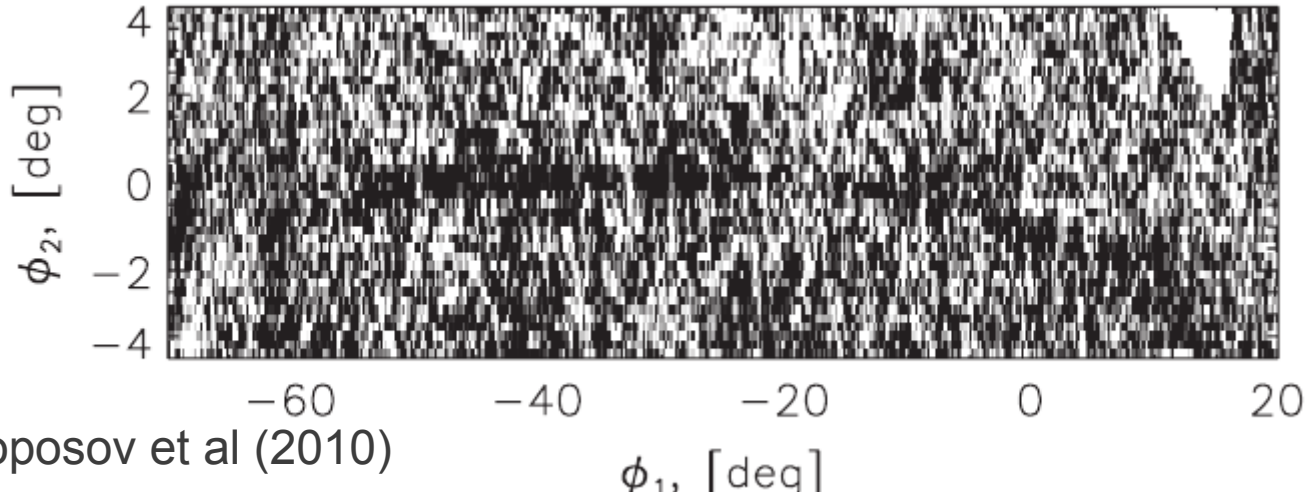
- The simulations predict large gaps/twists in the stellar streams.
- Gaps are observed in Pal5, GD1, N5466 streams. Their cause is not completely clear




Odenkirchen (2003)




Stream perturbations in the simulation after few Gyrs




Koposov et al (2010)

# Gaia

- 1 billion stars down V~ 20

Key parameters:

- High precision proper motions (distances up to tens kpc )
- Distances (~10 % precision at 10kpc)

- Radial velocities ~ 15km/s at V=17
-

  6D data: X,Y,Z,Vx,Vy,Vz will be available for millions of stars

# How Gaia can help ?

- Dwarf galaxies:

  Proper motions will help solving mass-anisothropy degeneracy

  Accurate distances will help with 3D structure of dwarf galaxies

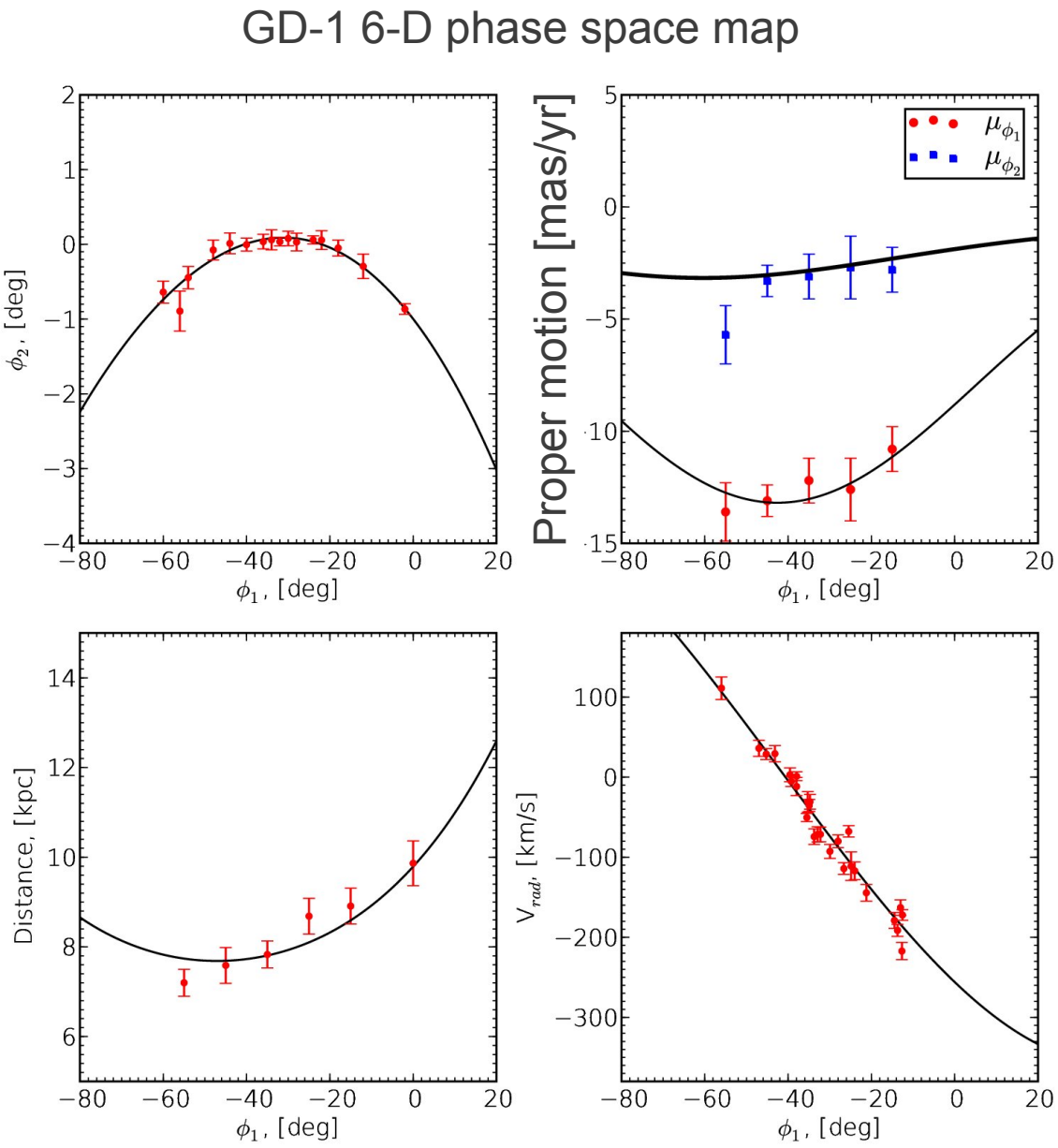
  Identify low density streams around dwarfs

# Streams with Gaia

6D phase space measurement of the streams:

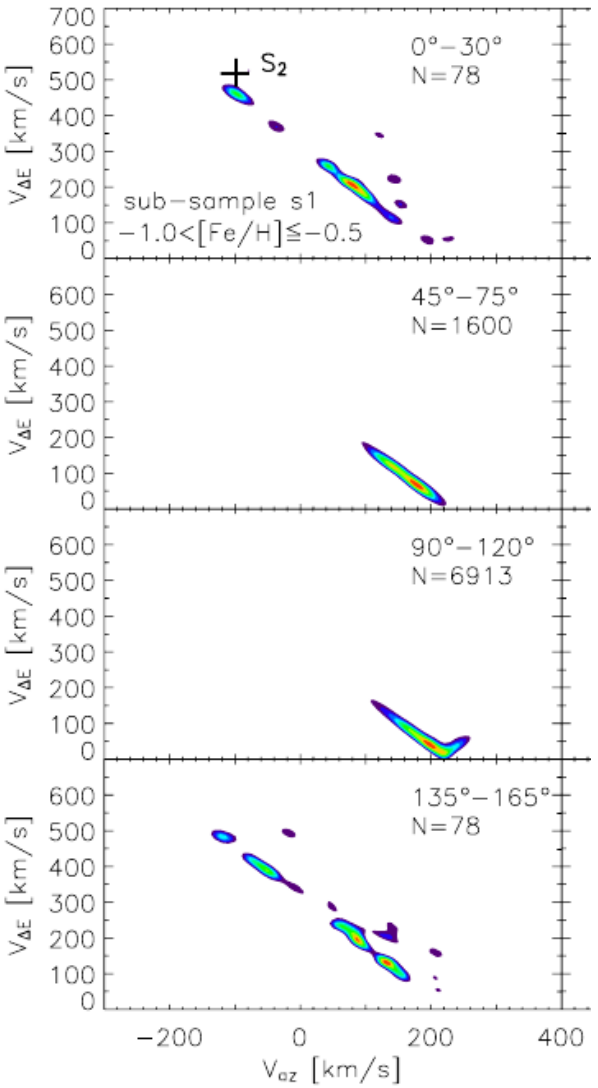
- Distance precision (x10 better)
- Proper motions (nx10 better)

The precision will allow measurement of perturbation of the streams

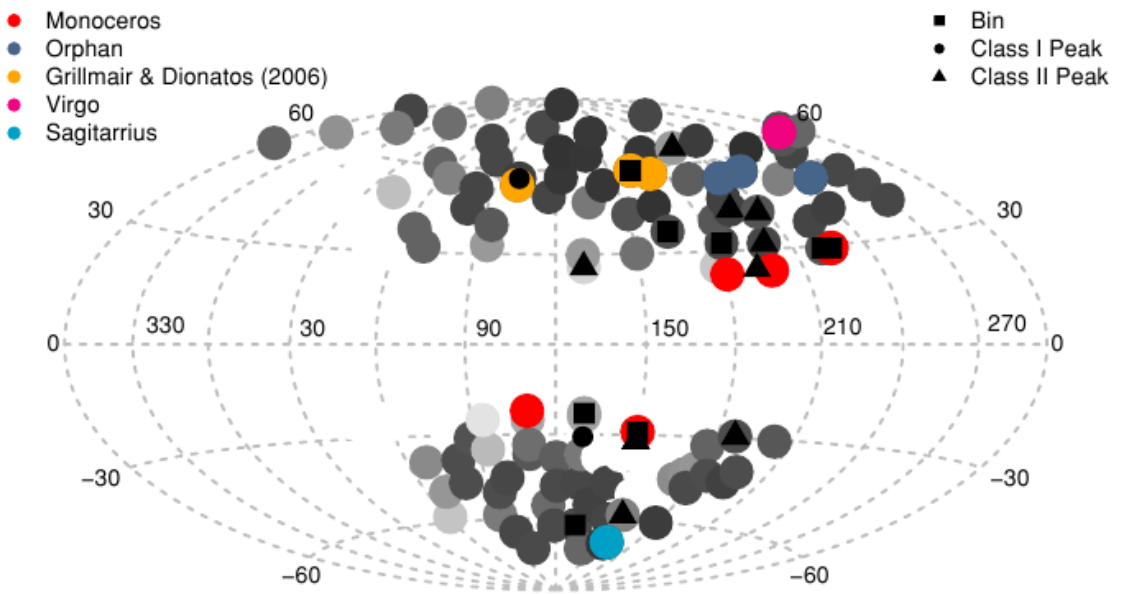



Koposov et al (2010)

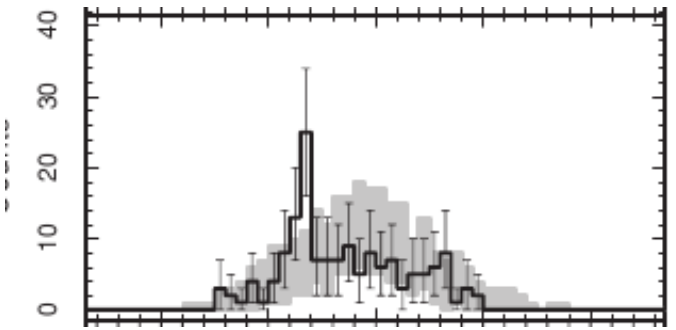
# Gaia: Search for fainter streams, phase-space and kinematic discoveries of streams




Klement et al. (2009)

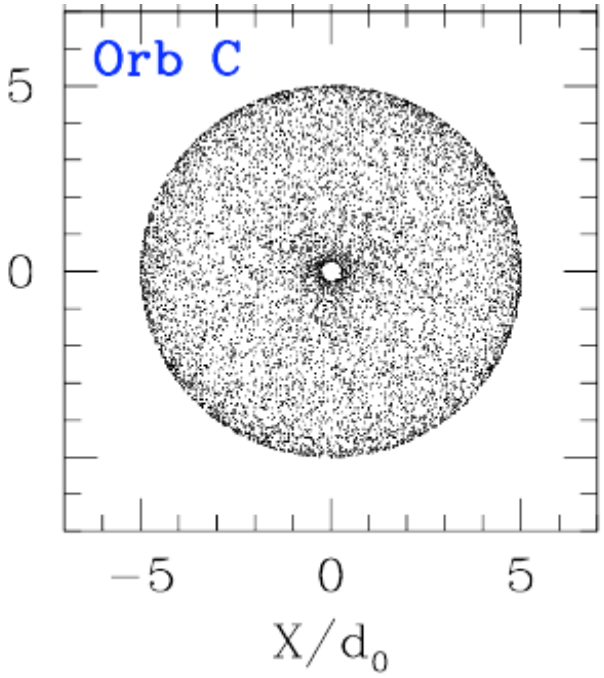


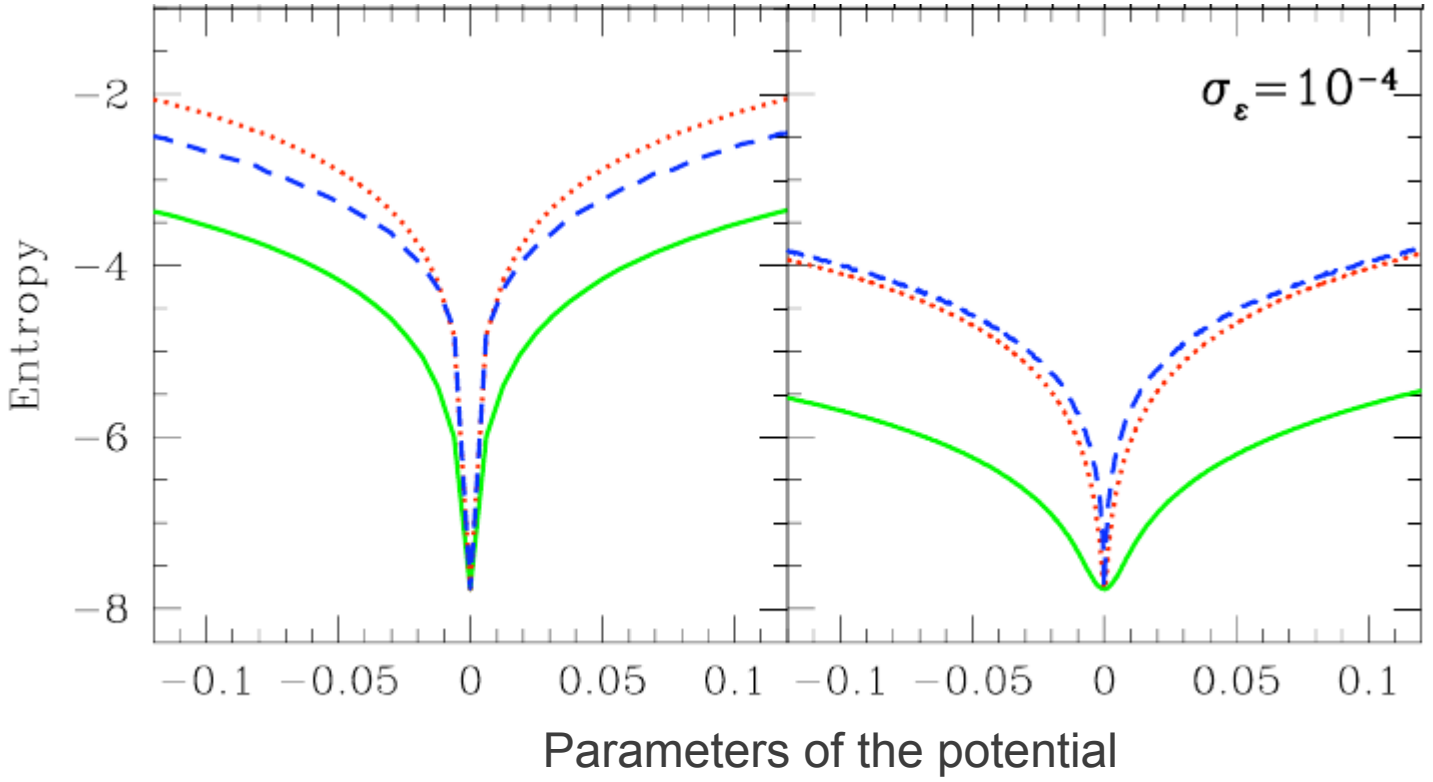

Schlaufmann et al. (2009)



# Non-parametric approach of fitting the Galactic potential using Gaia-like data

- By minimizing entropy of energy distribution of tidal debris, it is possible to determine the parameters of the potential



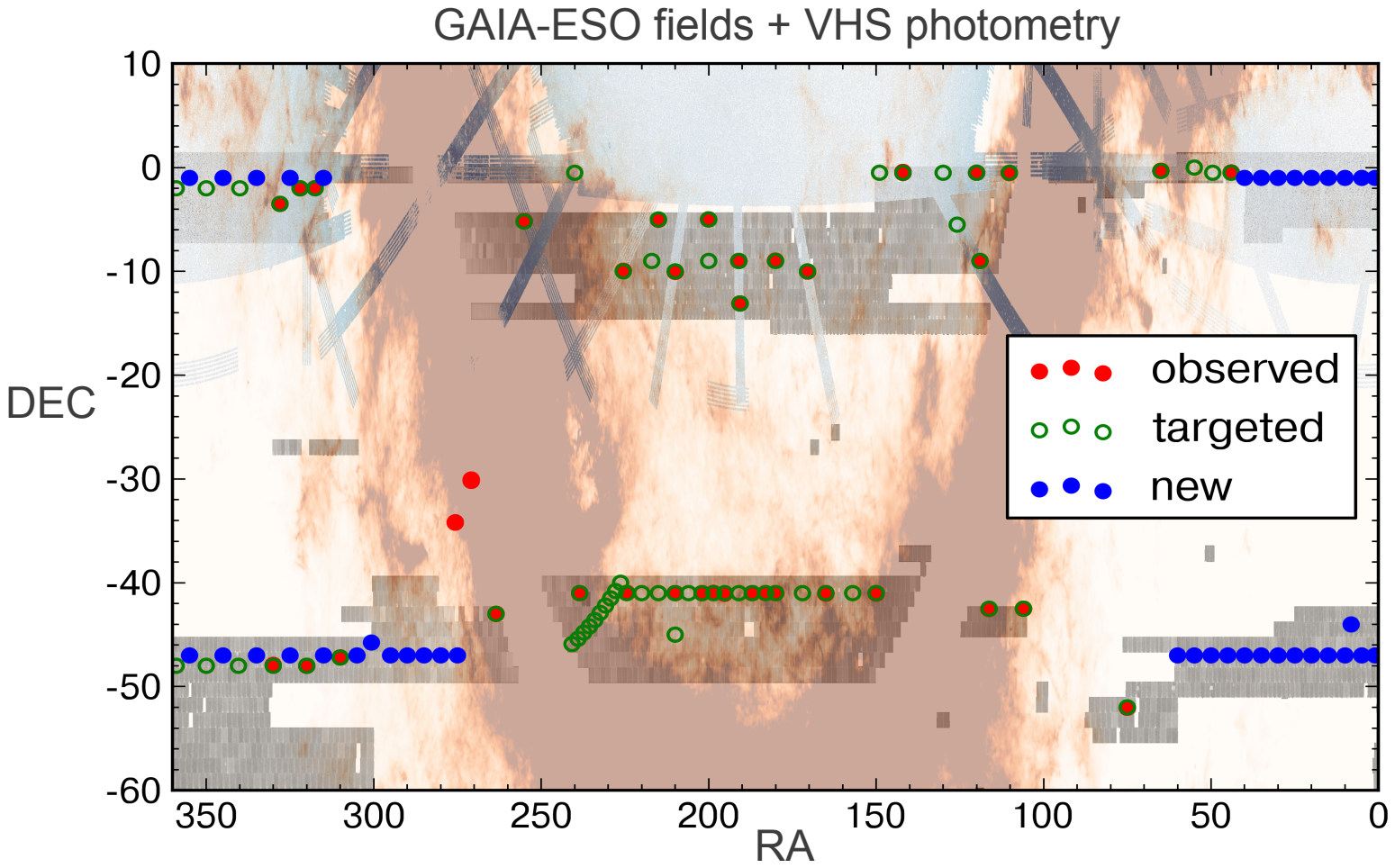




Penarrubia, Koposov & Walker (2012)

# Gaia & spectroscopic surveys

Future/ongoing spectroscopic surveys: Gaia-ESO, APOGEE, 4MOST

Combination of 6D phase space information with chemical tagging



# Conclusions

- Dwarf galaxy luminosity function is the key to the first galaxy SF
- Dwarf galaxy kinematics should help us understand star formation process, and dark matter distribution. Gaia data will help tremendously
- There is a delicate interplay between core/cusp and missing satellite problems
- Stellar streams are going to tell us the DM distribution in the galaxy
- The perturbation of the streams should tell us how many invisible DM halos there are.
- Spectroscopic surveys will combined with Gaia will allow detection of even fainter tidal debris via chemical tagging + phase space methods.