Dark Matter Halo History
and
Tidal Streams
Good Vibrations

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Fully Dynamical Globular Clusters in a Cosmological Simulation

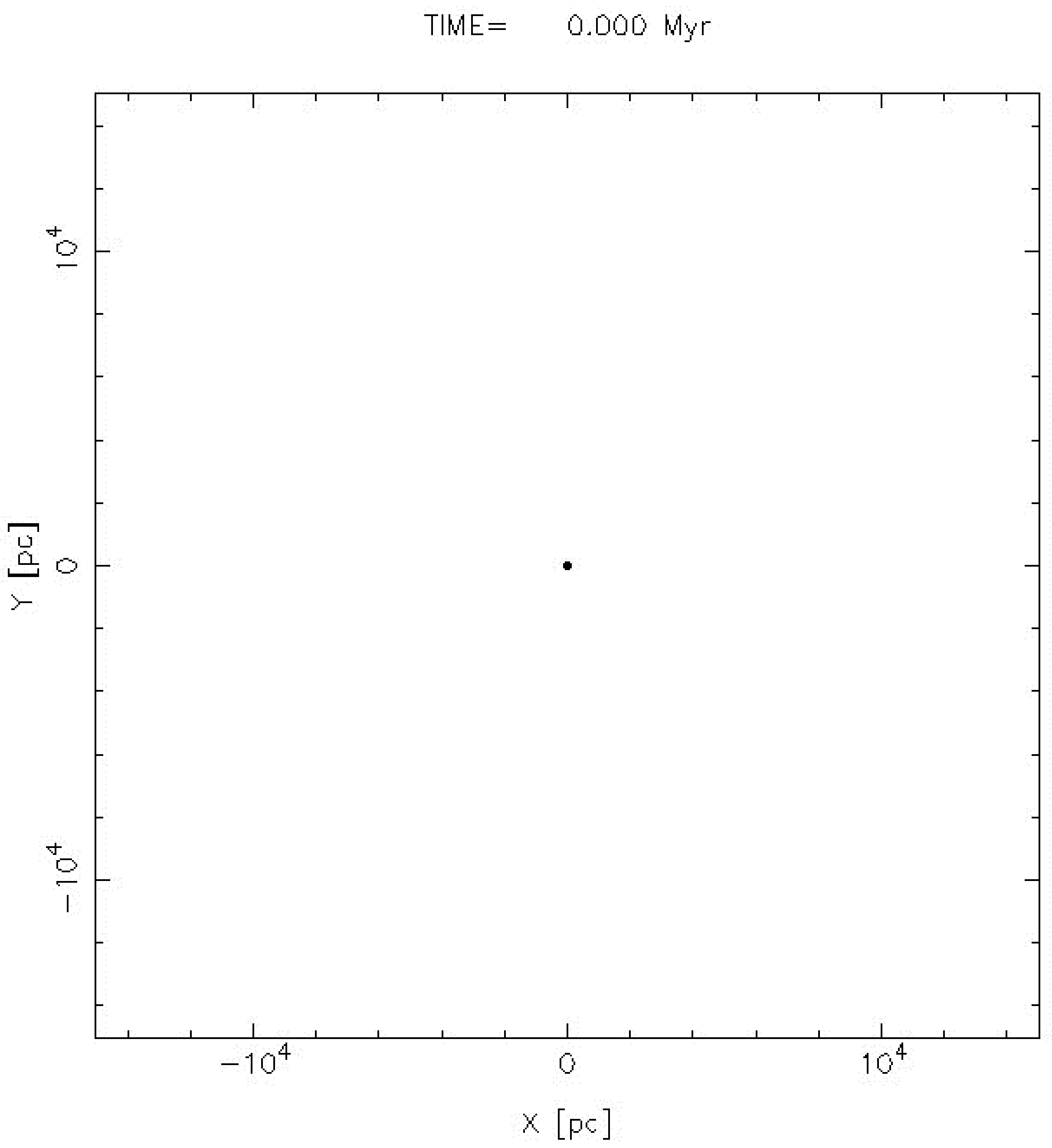
- Stellar dynamical models
  - Insert King model star clusters
  - Distributed in a rotating exponential disk
  - Within a Dark Matter Halo
  - Soften, but add collisional heating with an MC approach
- The Dark Matter is a fully cosmological Milky Way sub-region
  - The Via Lactae II simulation
  - (Sub-) halo catalog

Conclusions

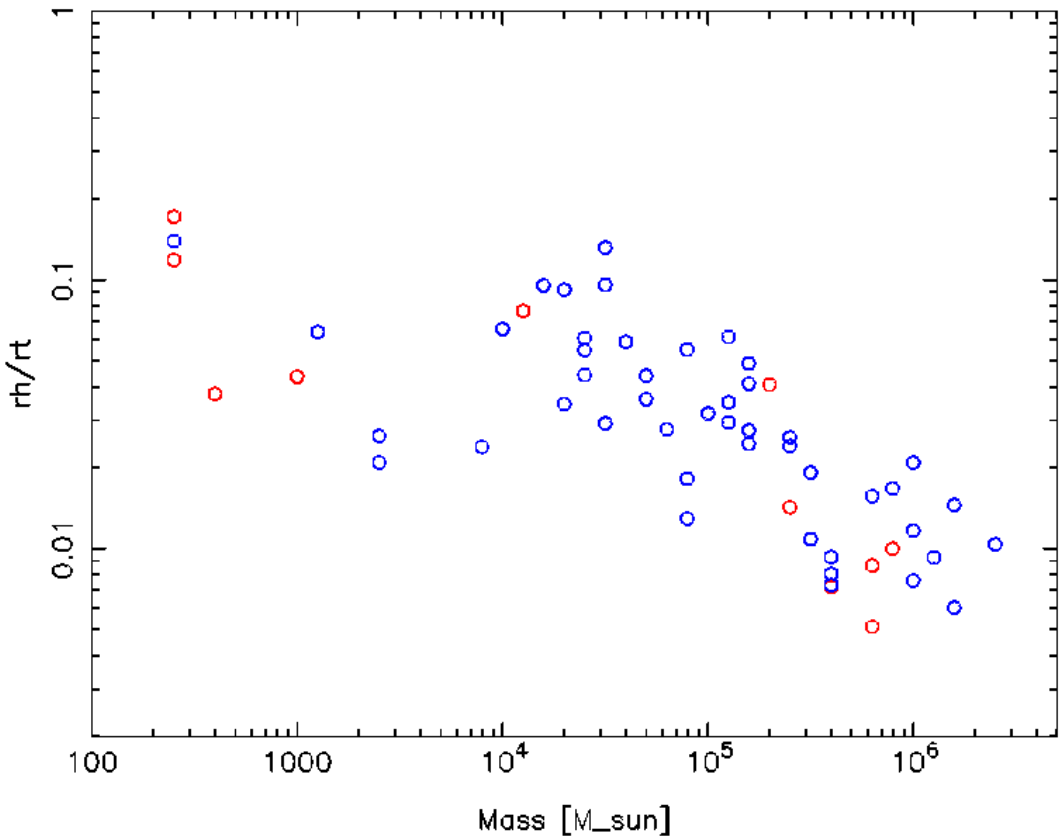
- GC tidal dissolution during the hierarchical assembly of a Milky-Way like halo can be followed in an Nbody code.
- A GC thin stream normally is imbedded in a wider “cocoon”, a consequence of hierarchical assembly
  - Broad stream width indicates size of orbit in initial halo(s).
- Stream stars should have velocities perpendicular to the stream of 10’s of km/sec, a consequence of **collisionless** halo vibrations.
  - SIDM DM reduces the velocities
  - Requires a large sample of streams.

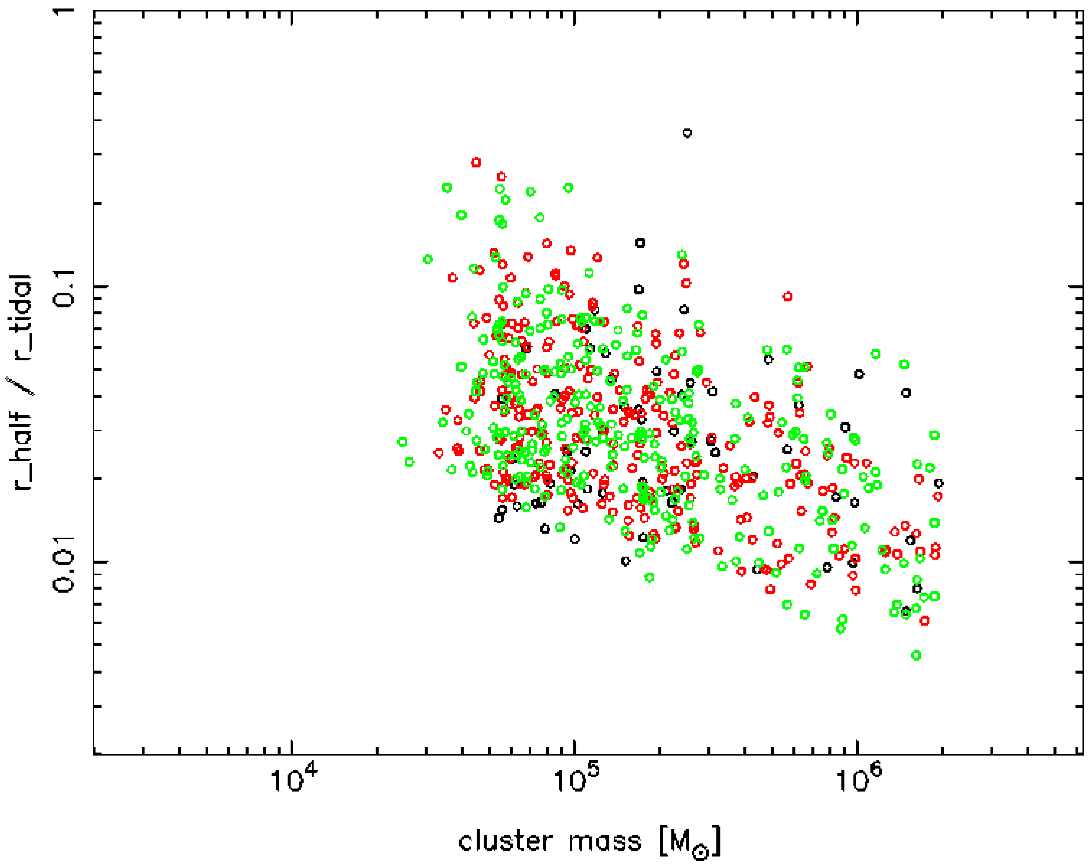
N=1M, m*~0.44 M_sun
SFB881 model
Jongsuk Hong
Jeremy Webb

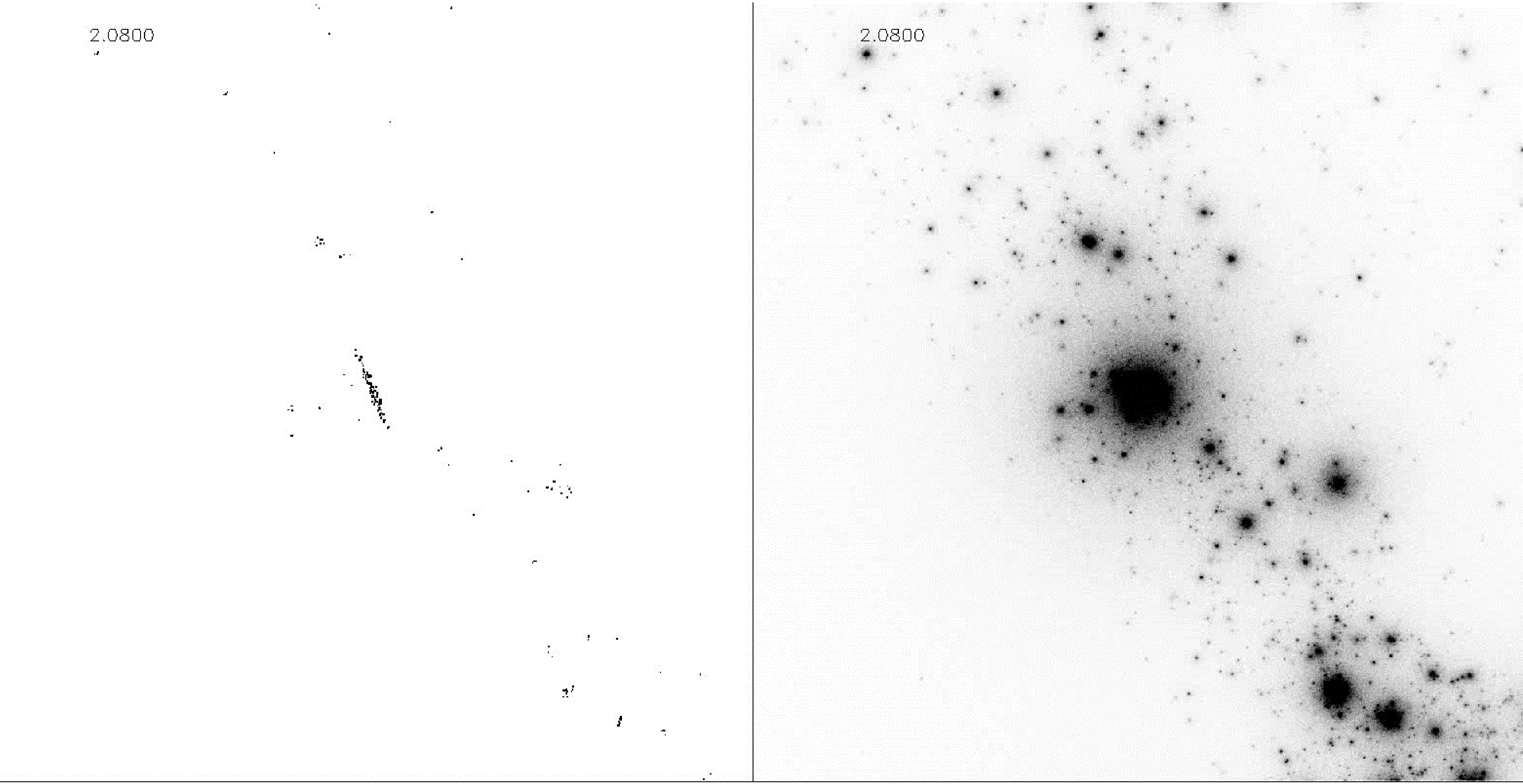
Top View***
We see edge on generally

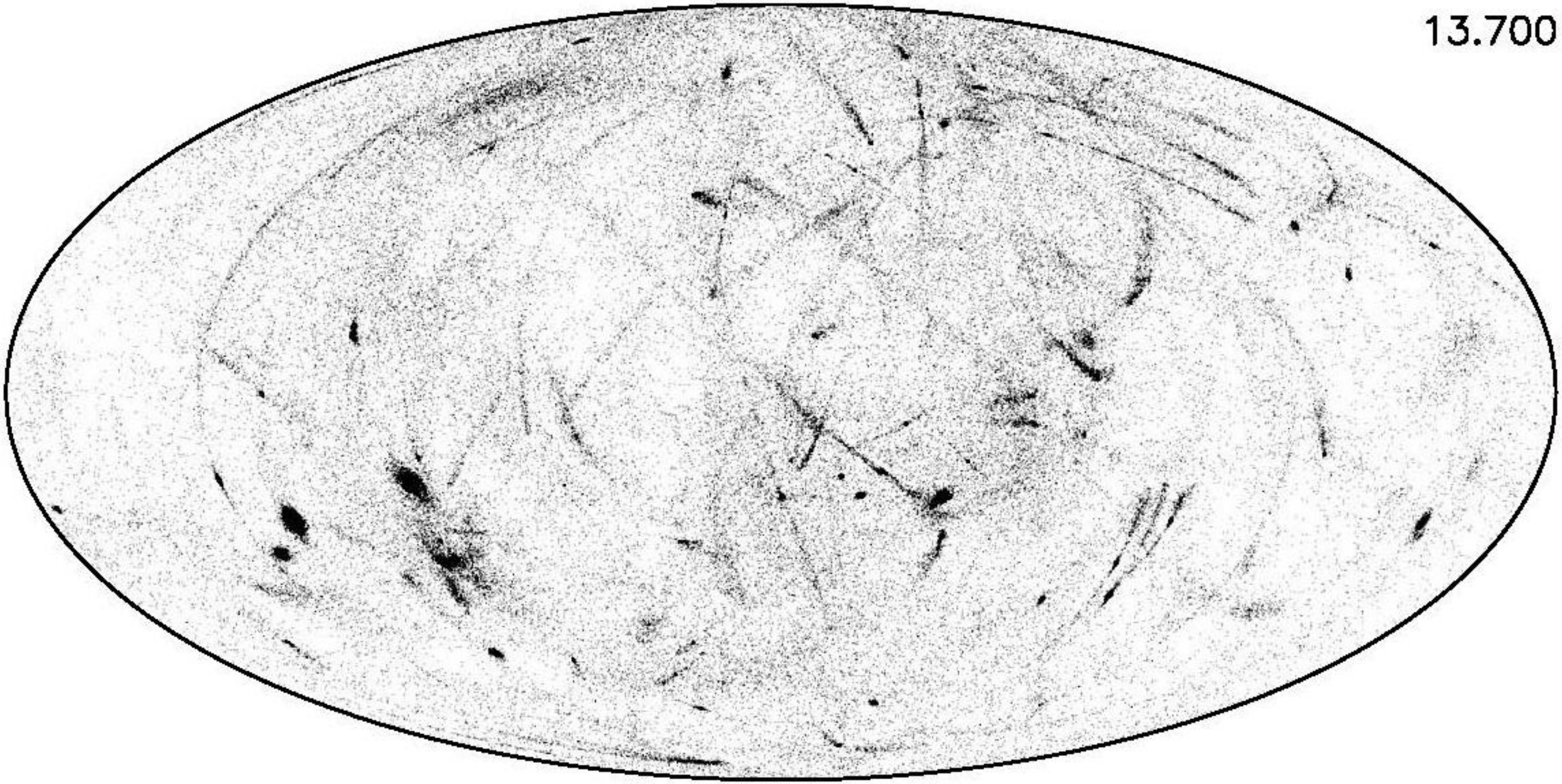


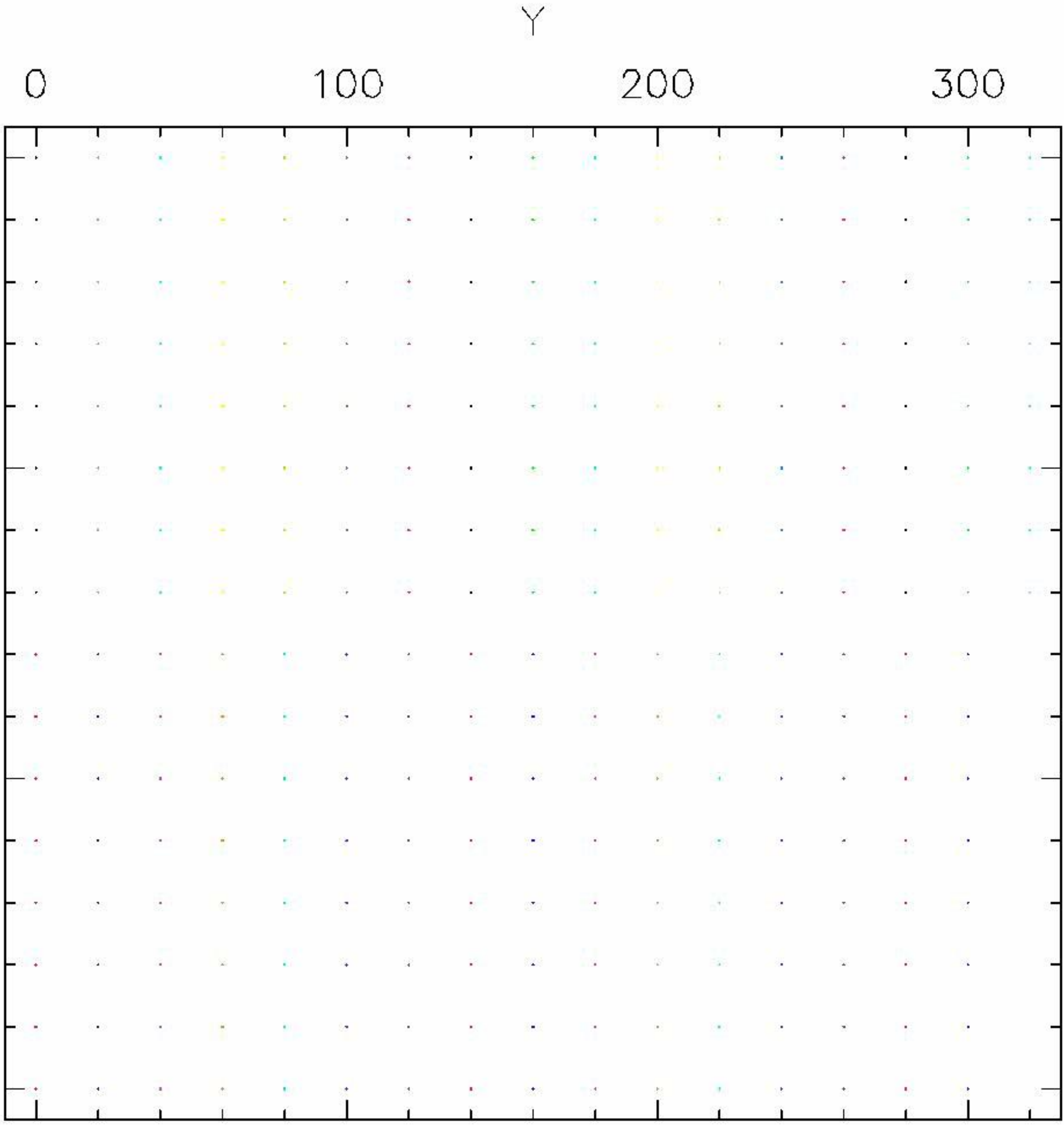
Rhalf/Rtide vs Mass
MW>8kpc left,
sims right
$M>10^5$ underfill tidal surface

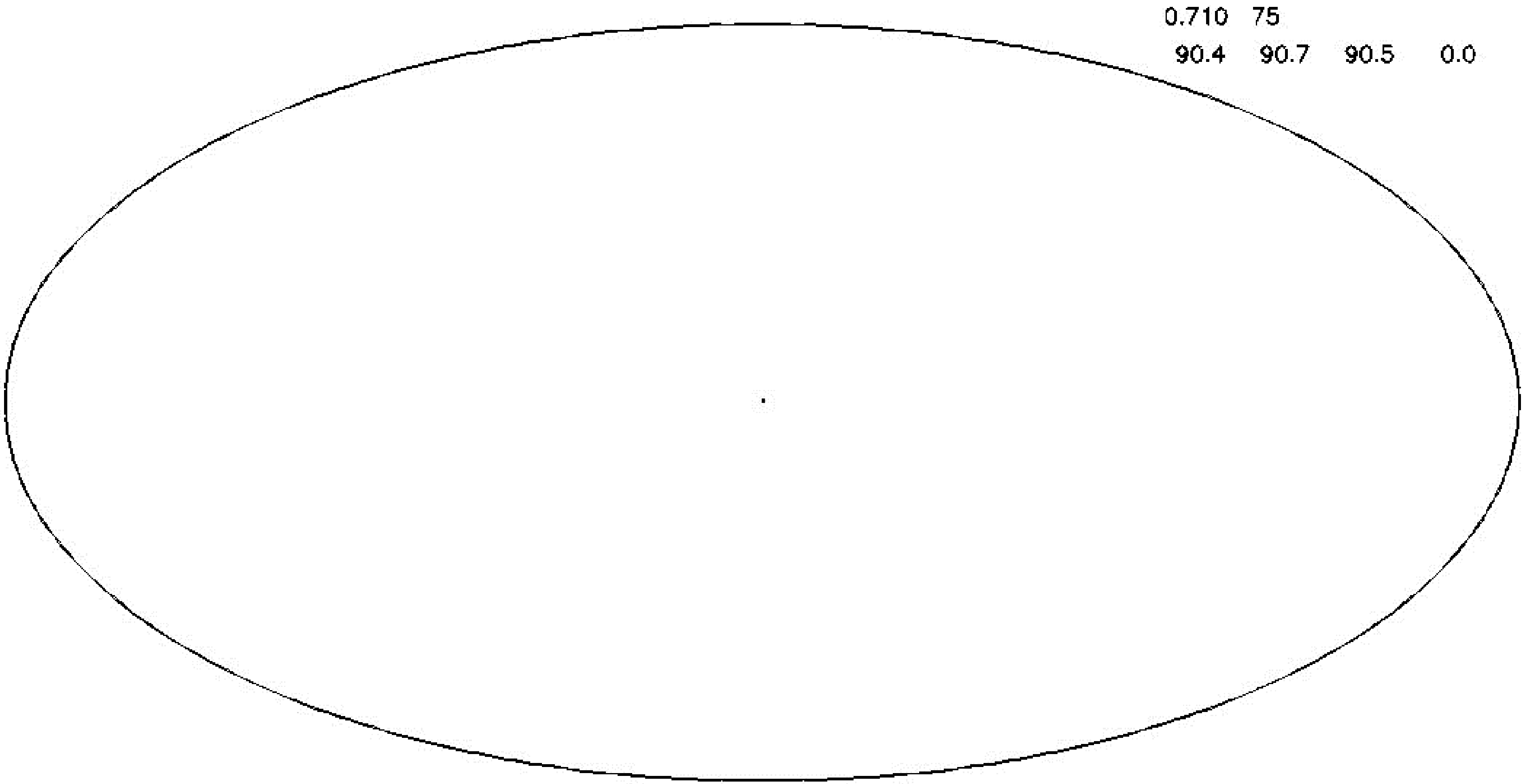


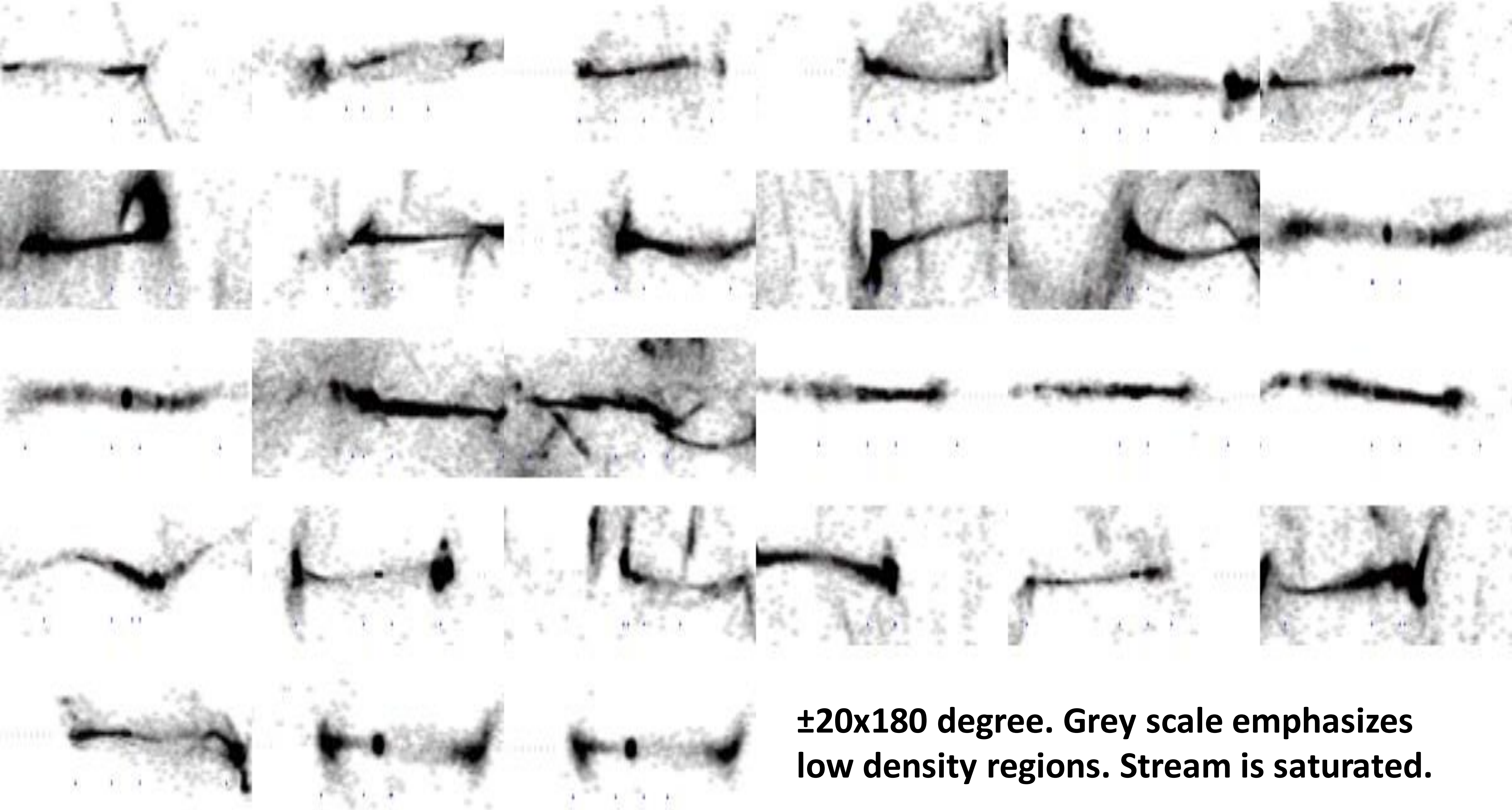



2.0800
2.0800


13.700


Y
0
100
200
300


0.710 75
90.4 90.7 90.5 0.0

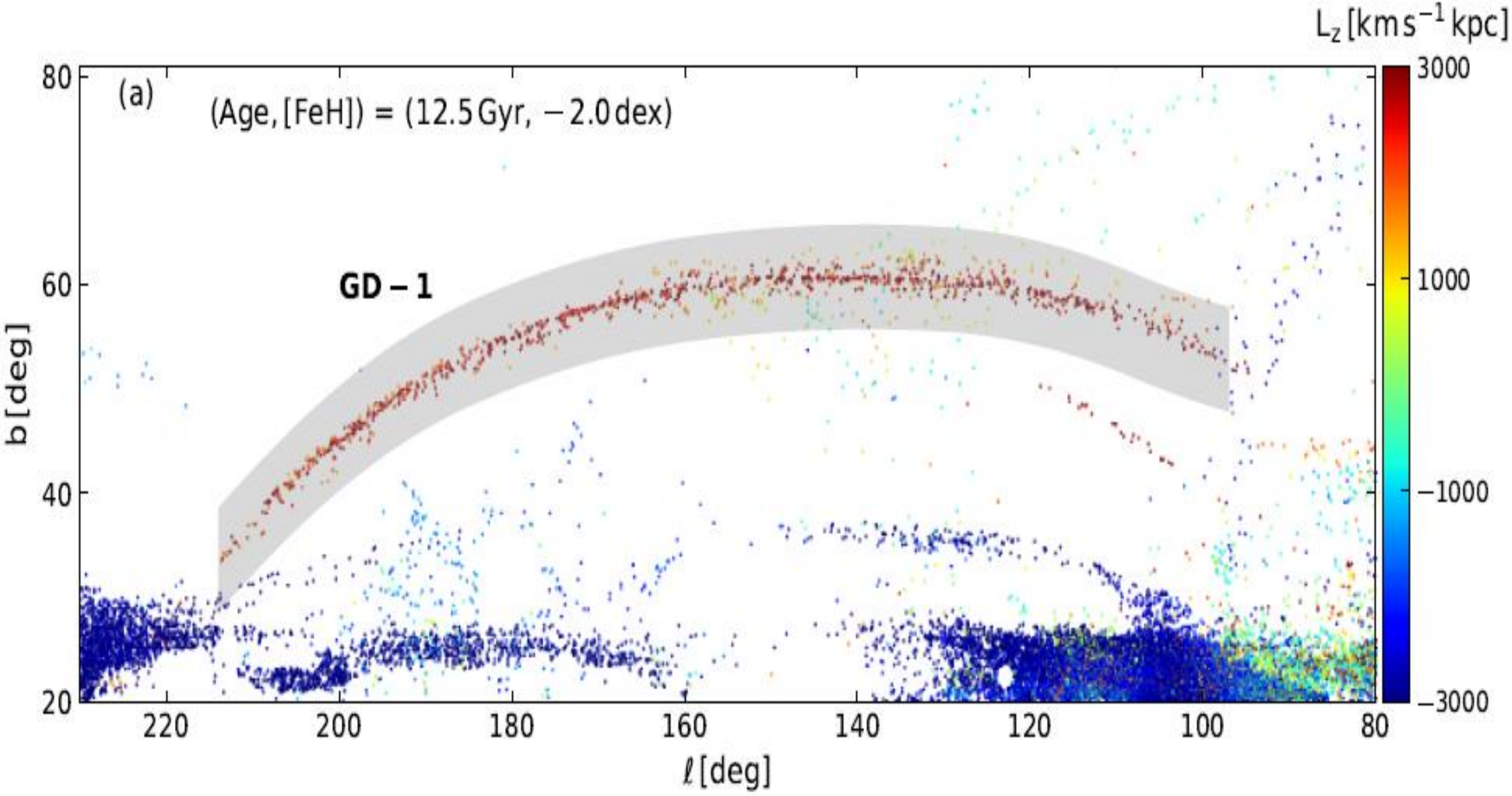


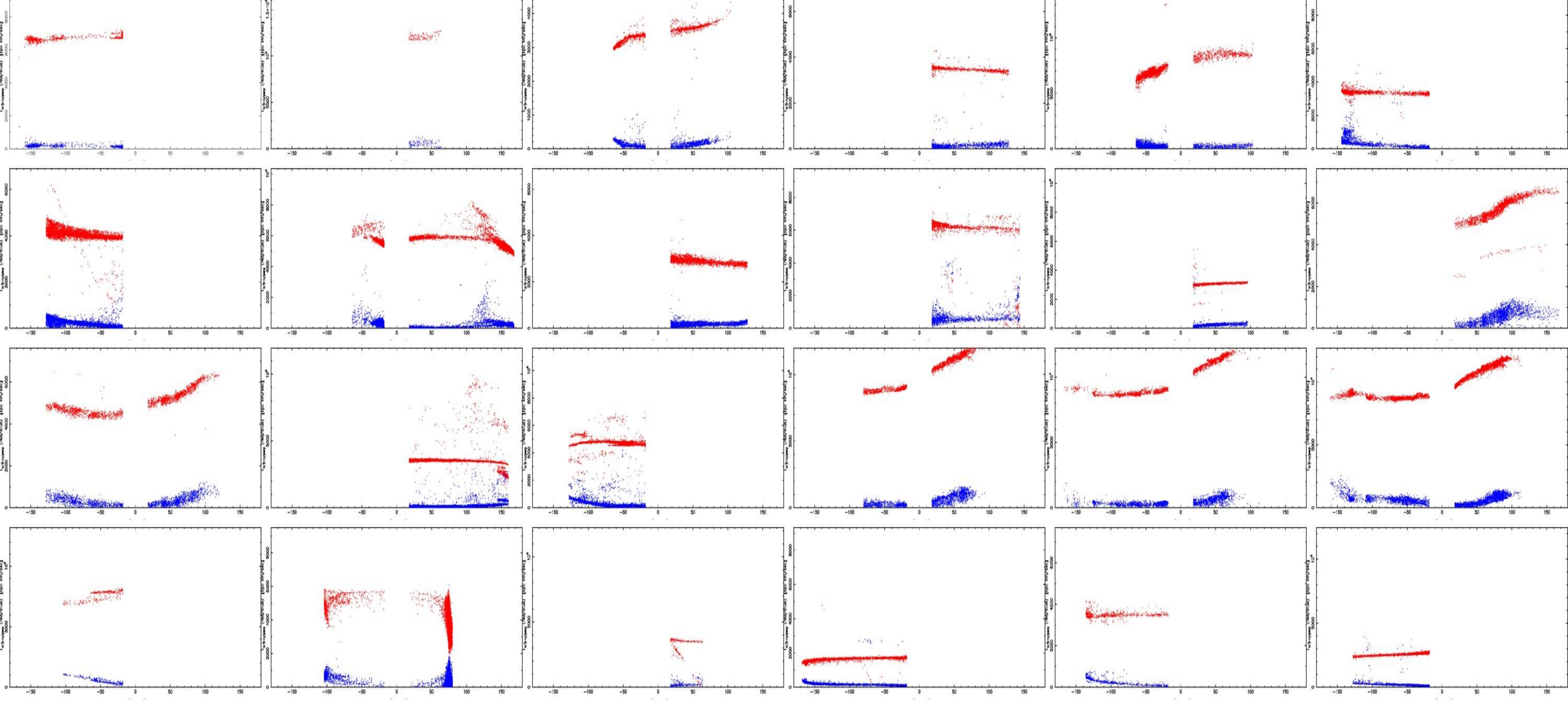
±20x180 degree. Grey scale emphasizes low density regions. Stream is saturated.

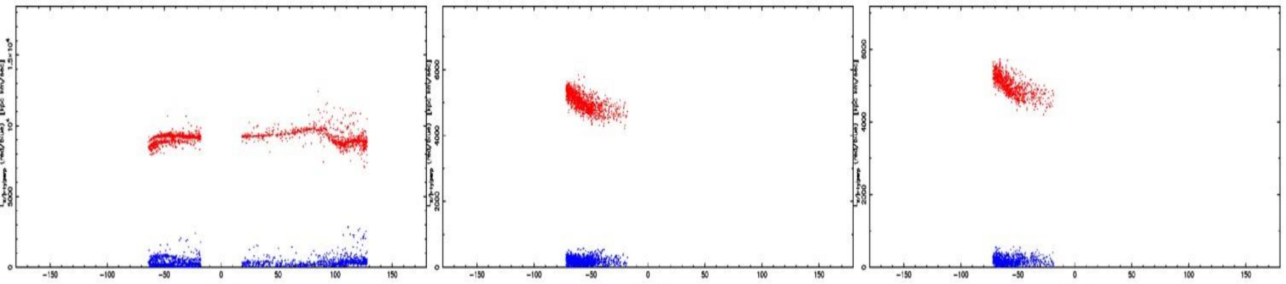
Two stage Tidal Stream structure:
Thin stream and cocoon

- Dwarf galaxy stage:
  - Stream wraps around in a 1-2 kpc size orbit
  - Accretes into main halo
- Main halo stage:
  - Early stage stream is now a stream 1-2 kpc wide
  - Newly released stars give the thin (100pc) stream
- Small angular width streams usually near pericenter.
- **Cocoons should be almost universal if progenitor clusters are created in pregalactic sub-halos (dwarfs).**

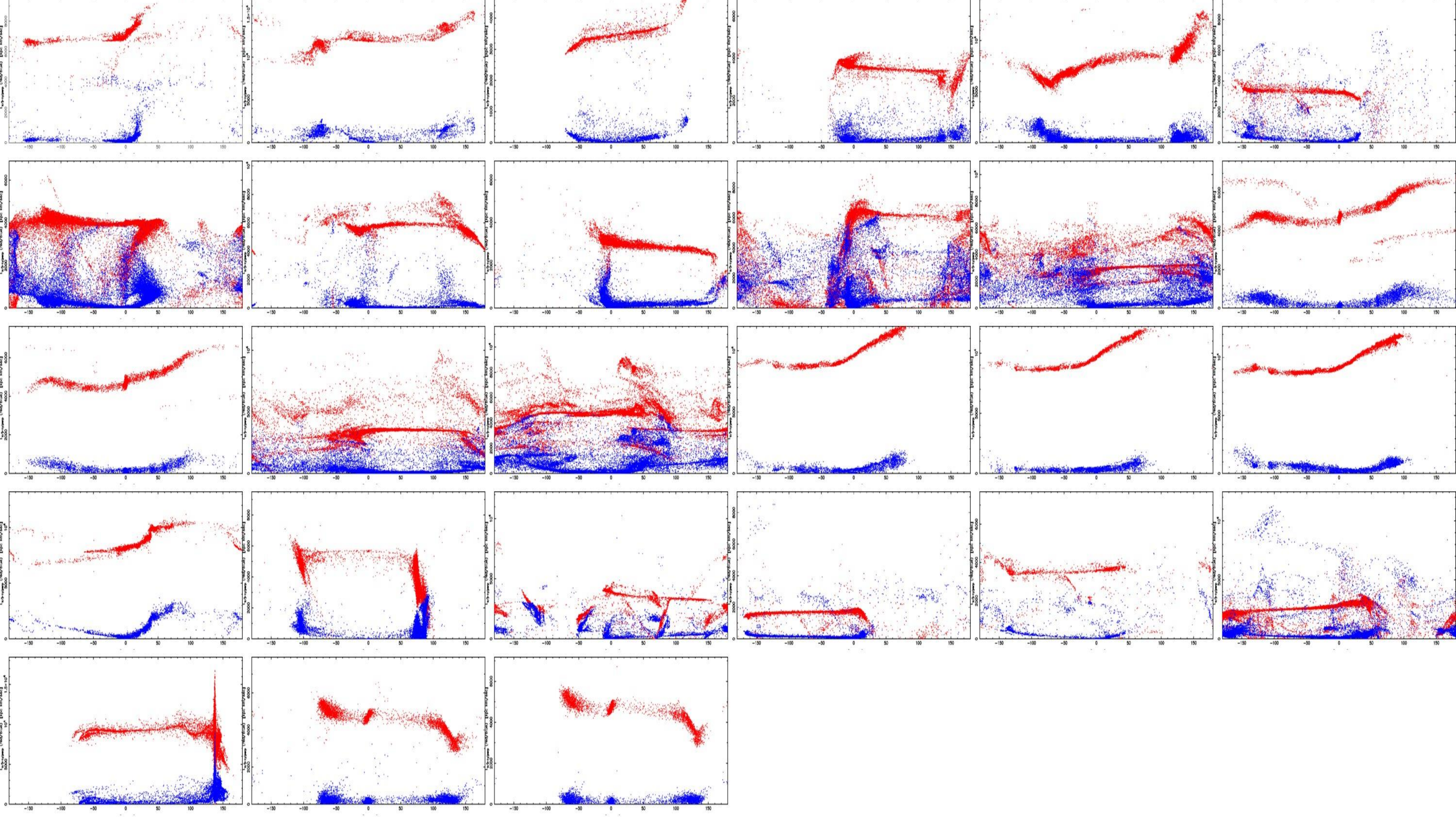
Malhan, Ibata, Carlberg, Valluri, Freese astroph 1903.08141: Streamfinder





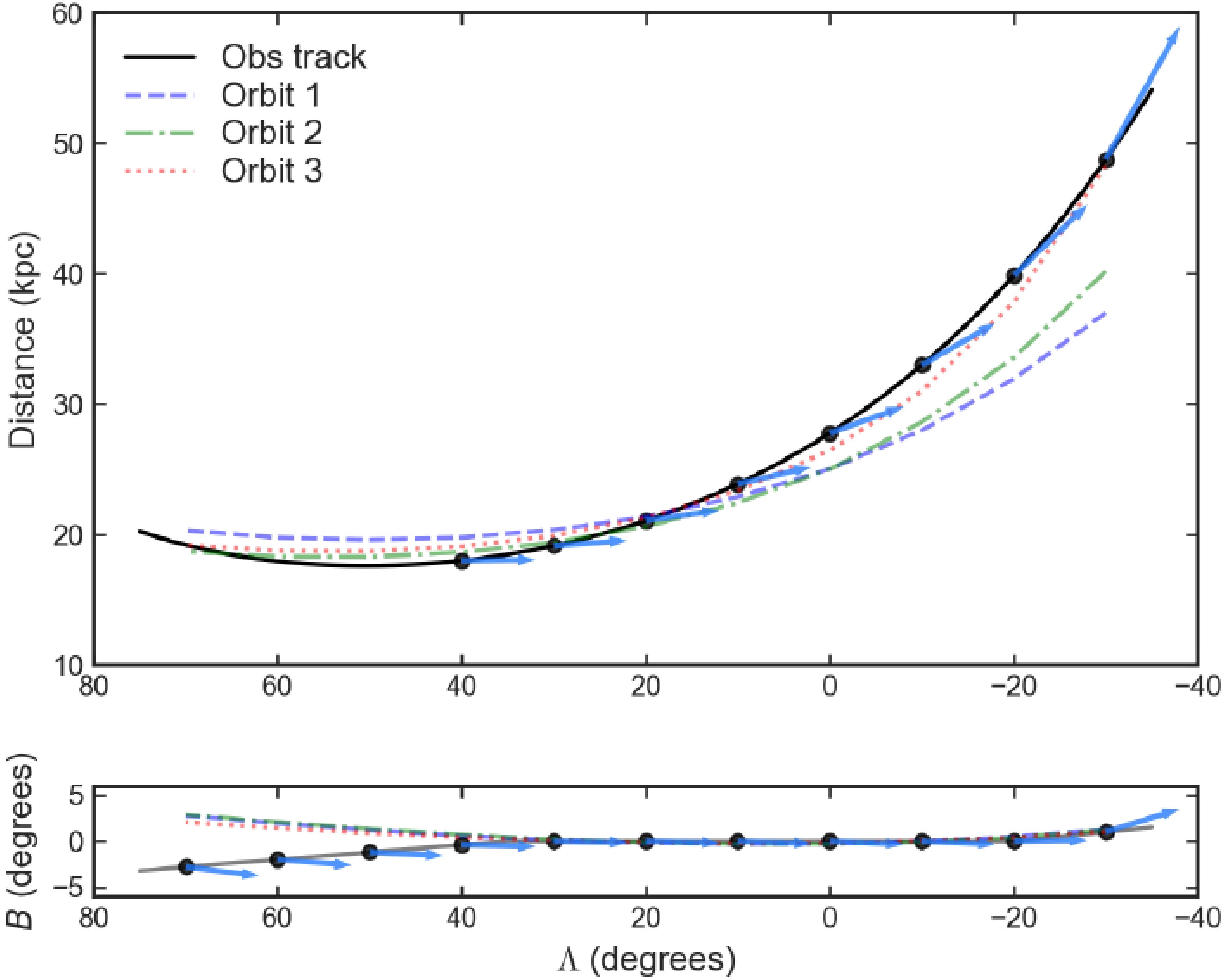


L_z and L_perp calculated for stream rotated into instantaneous orbital plane of progenitor. The L values will not in general be conserved quantities.



Incommensurate Stream Velocities

- In the simplest case, stream velocities are oriented along the stream.
- Perpendicular velocities should be small
- In a static potential.



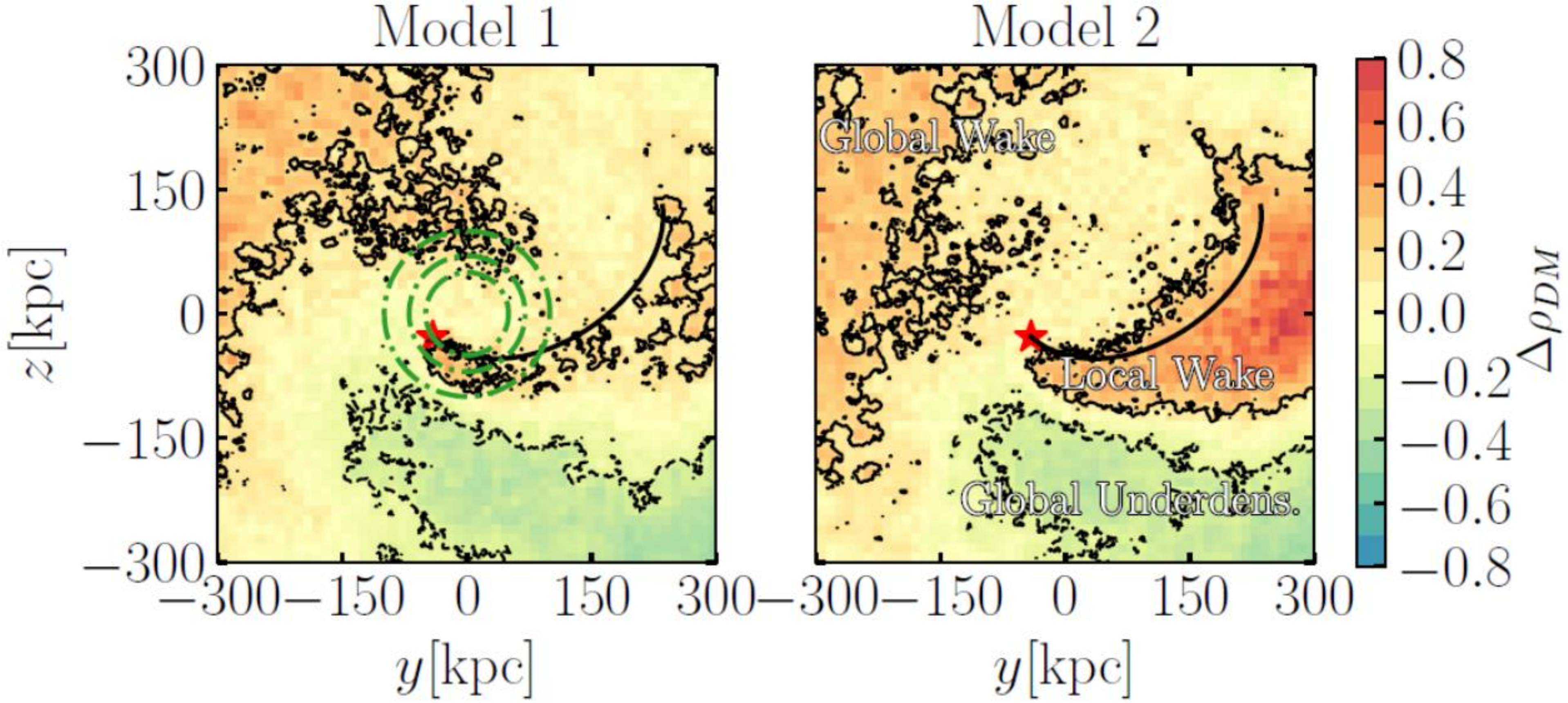
Orphan kinematics

Fardal, van der Marel, Sohn, Molina

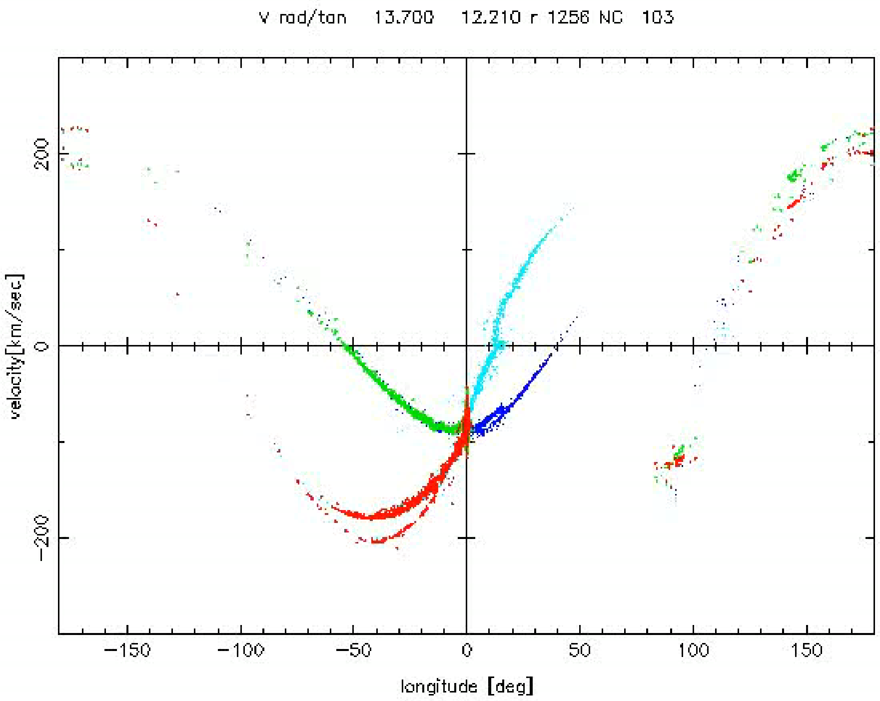
LMC wake:

Garavito-Carmargo, Laporte, Johnston, Gomez & Watkins

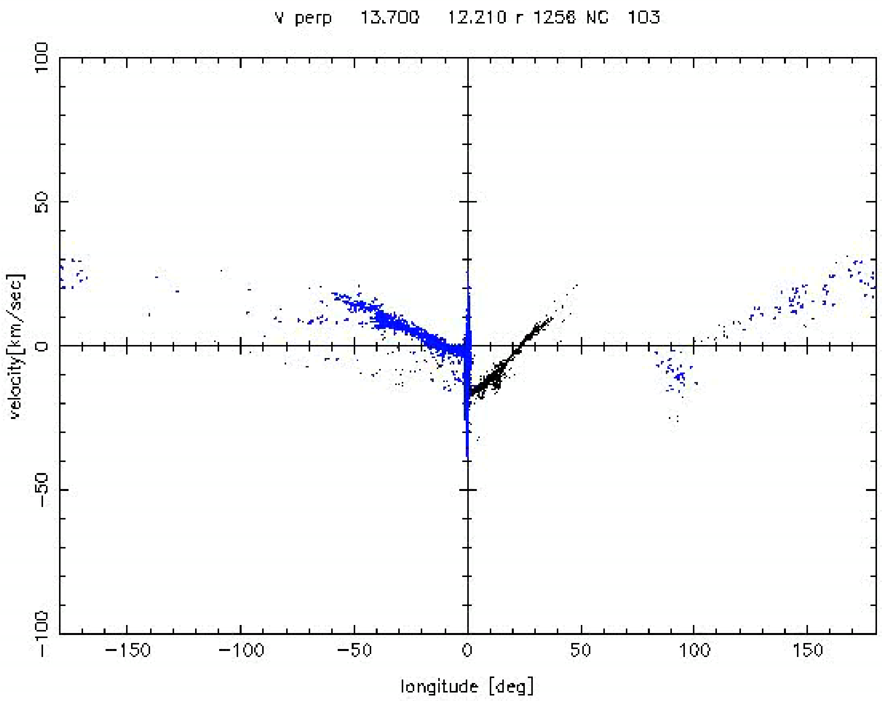
LMC wake



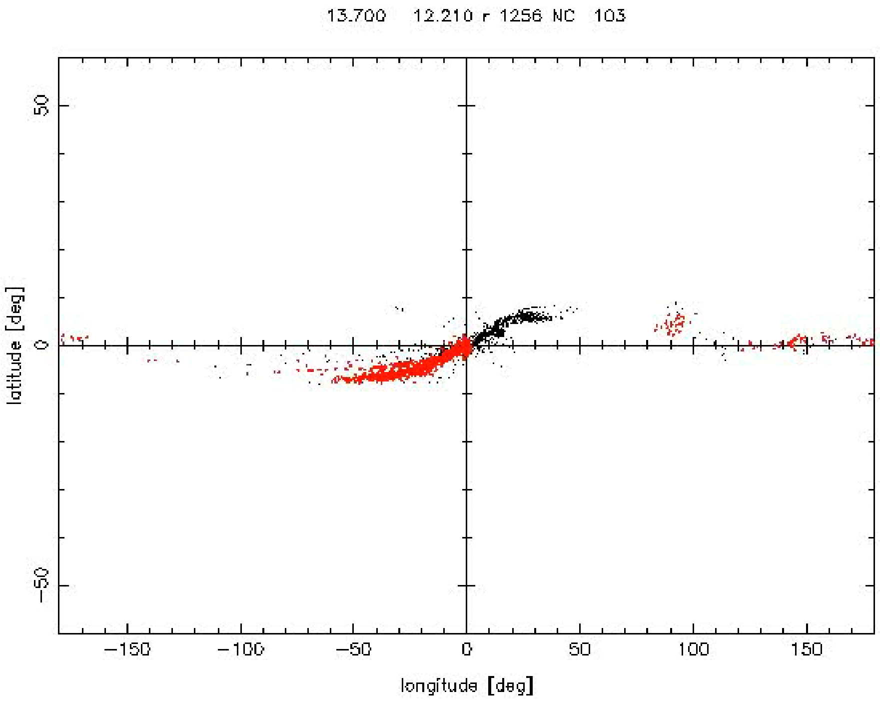
V_r, V_tan Vs latitude



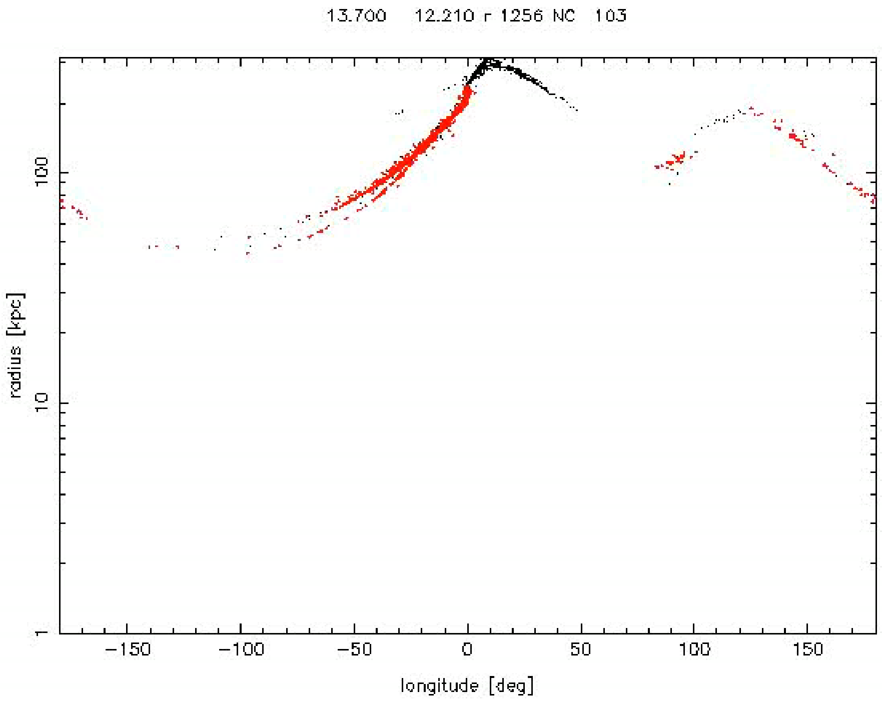
V_perp Vs latitude

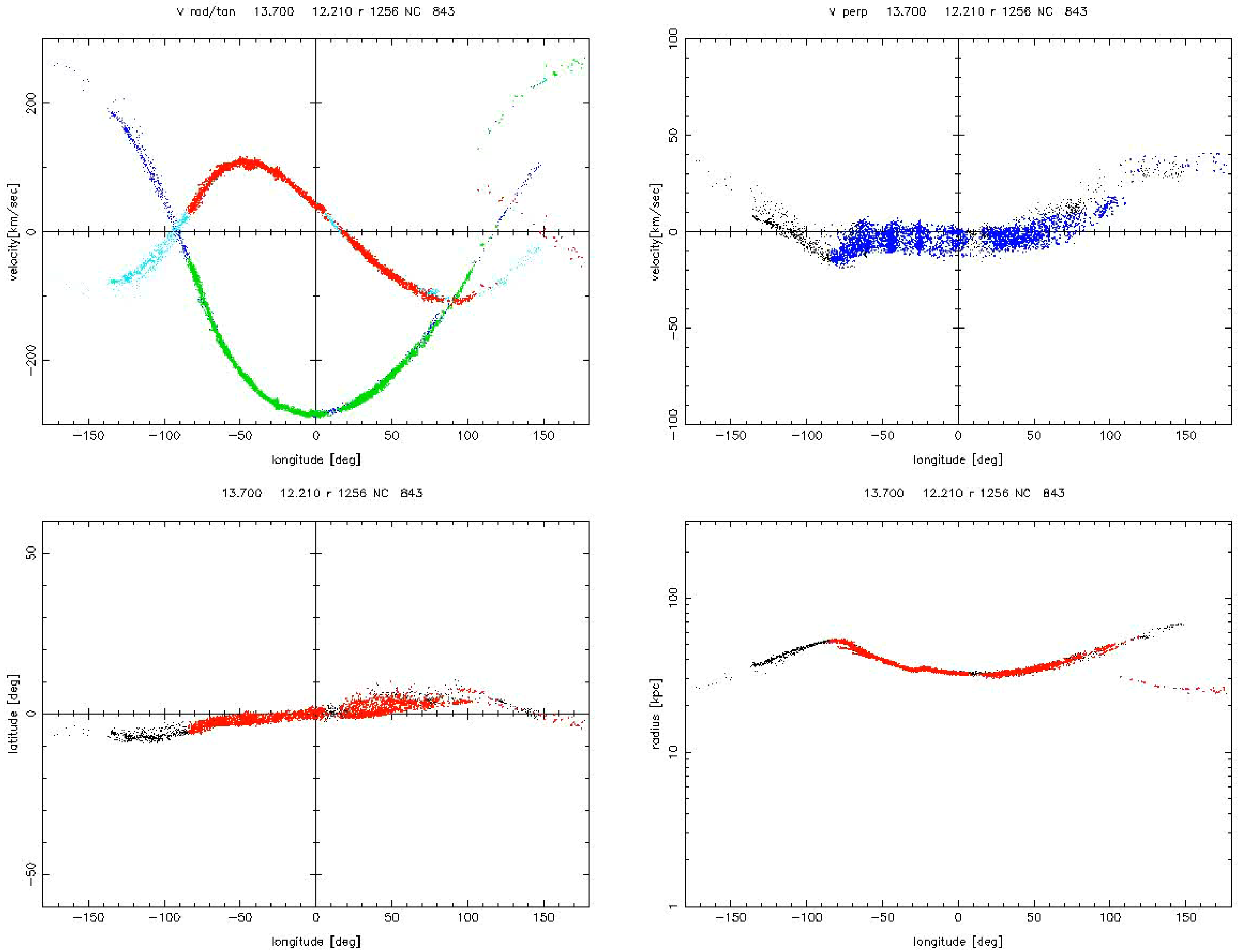


Sky Latitude vs longitude



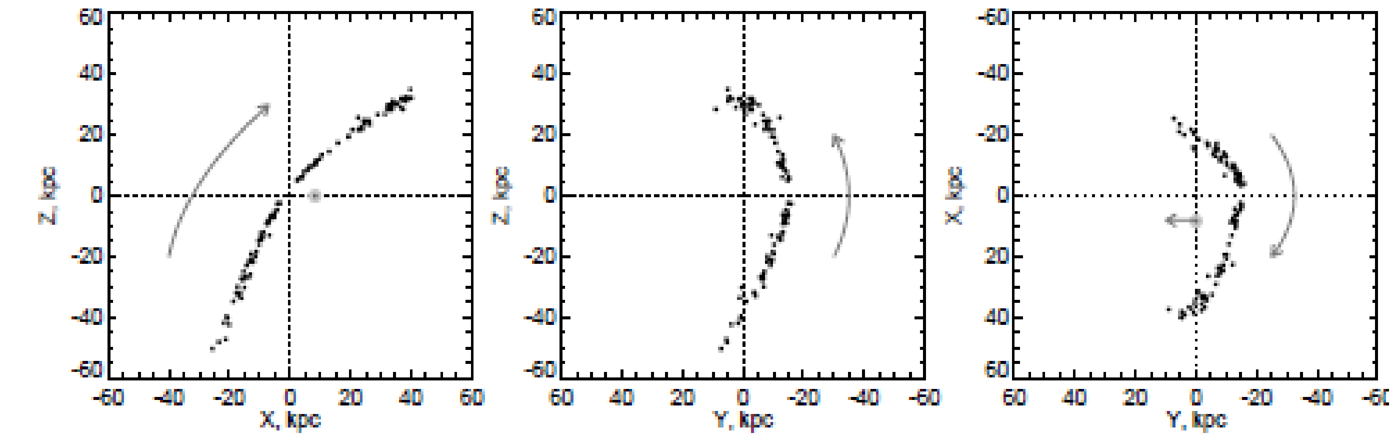
Radius Vs latitude



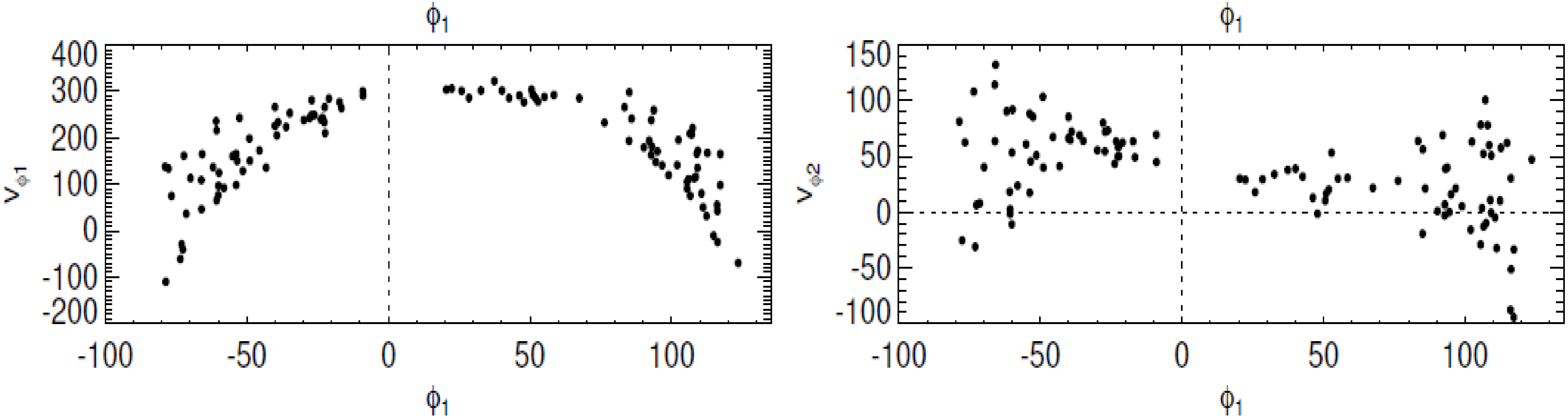


V rad/tan 13.700 12.210 r 1256 NC 843
velocity[km/sec]
200
0
−200
−150
−100
−50
0
50
100
150
longitude [deg]
V perp 13.700 12.210 r 1256 NC 843
100
50
0
−50
−100
13.700 12.210 r 1256 NC 843
latitude [deg]
13.700 12.210 r 1256 NC 843
radius [kpc]
10
1

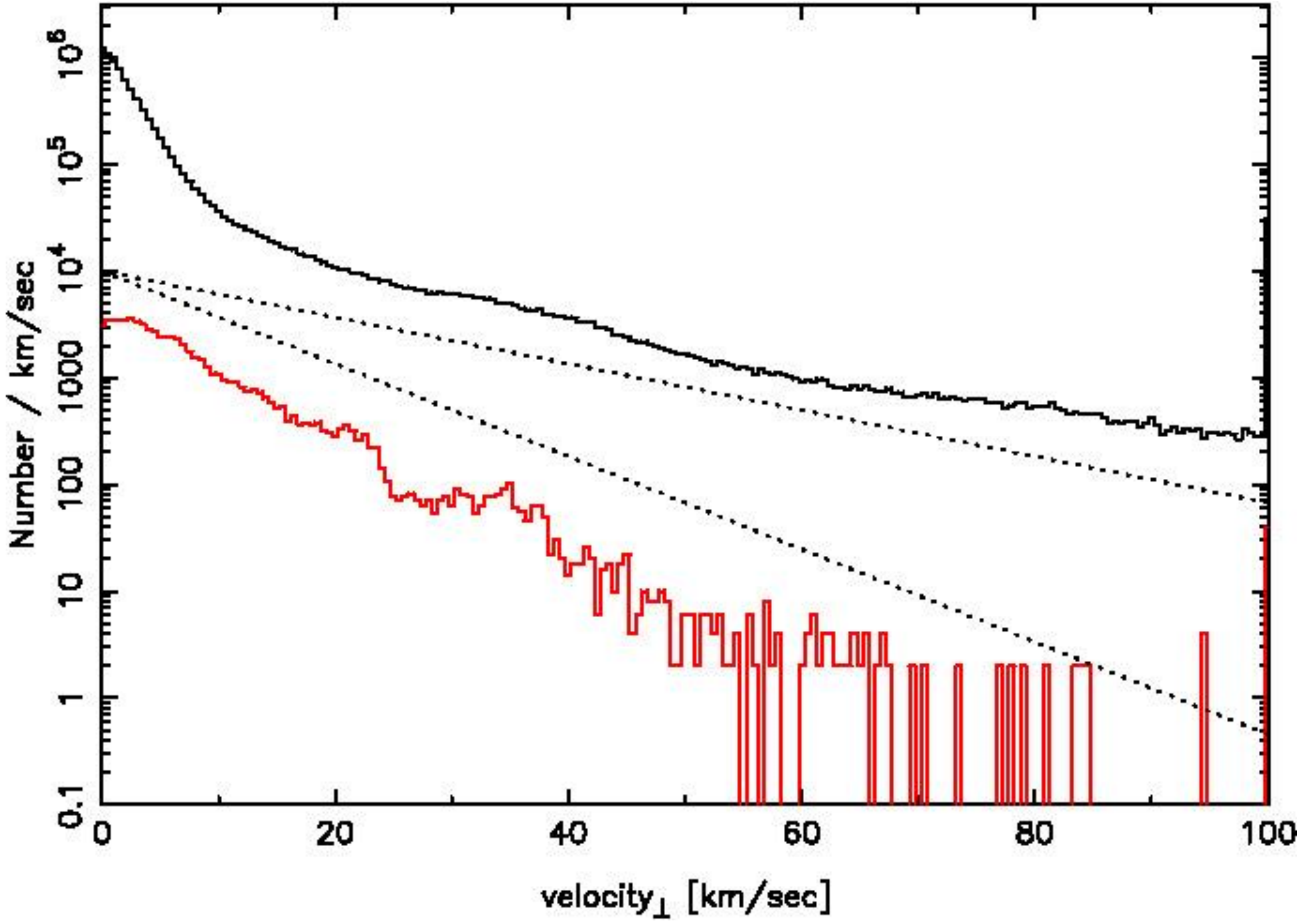
Orphan Stream Koposov, Belokurov, et al



Velocities perpendicular to the stream



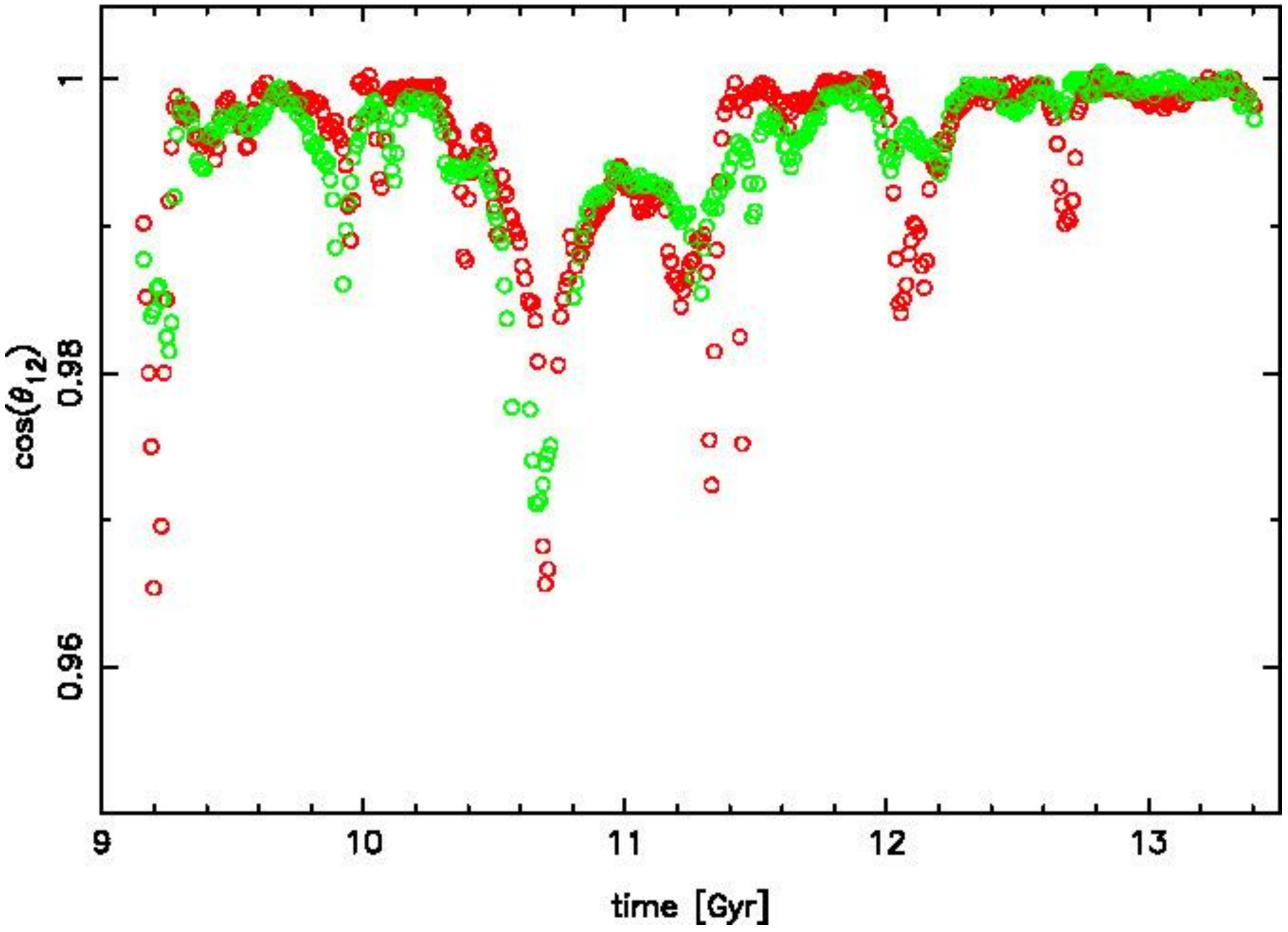
Distribution of stream perpendicular velocities in simulation



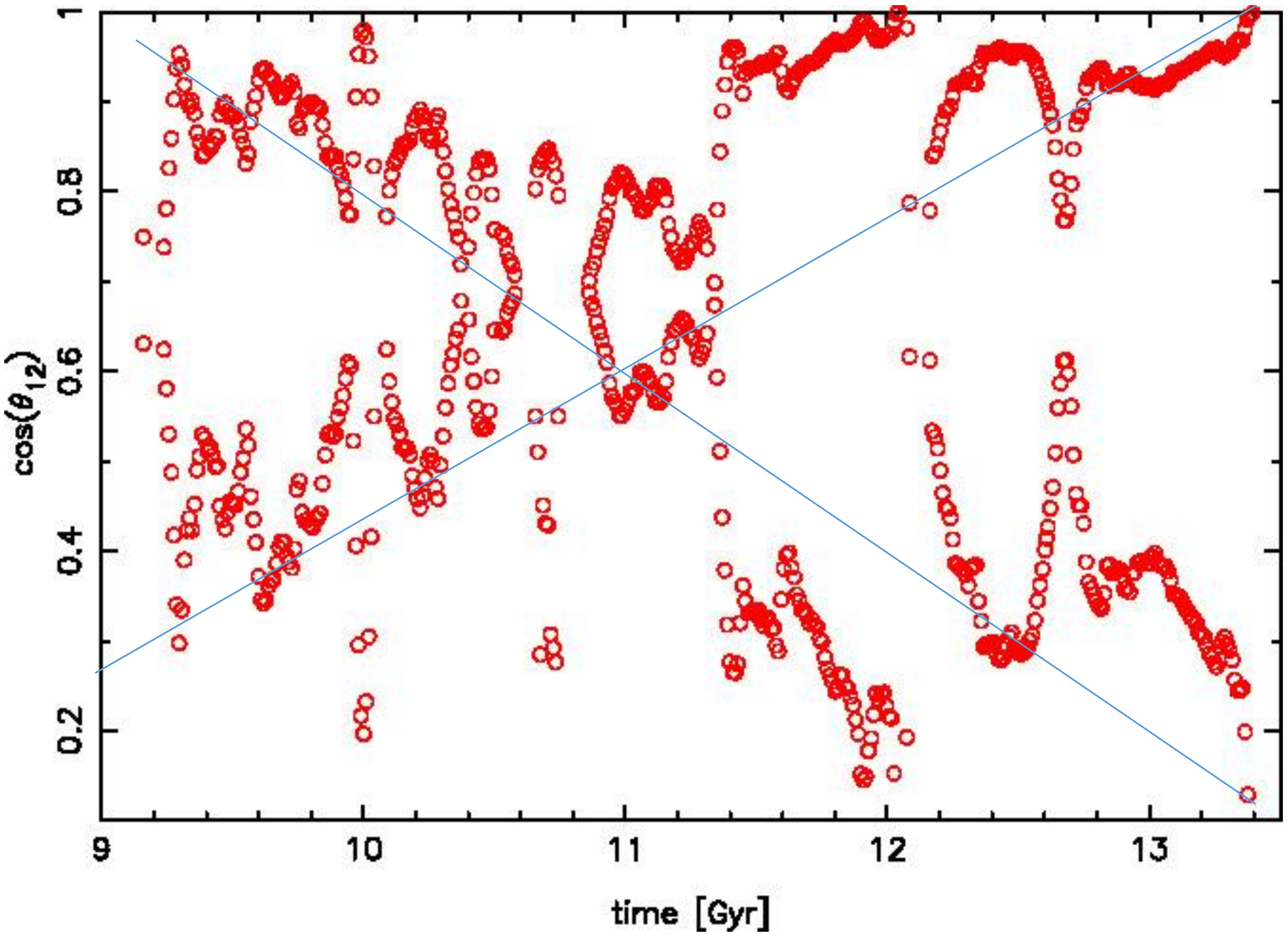
Dashed lines are Exp[-v/s] with s of 10 and 20 km/sec

Forces perpendicular to stream

Halo major axis at ~20-30 kpc constant



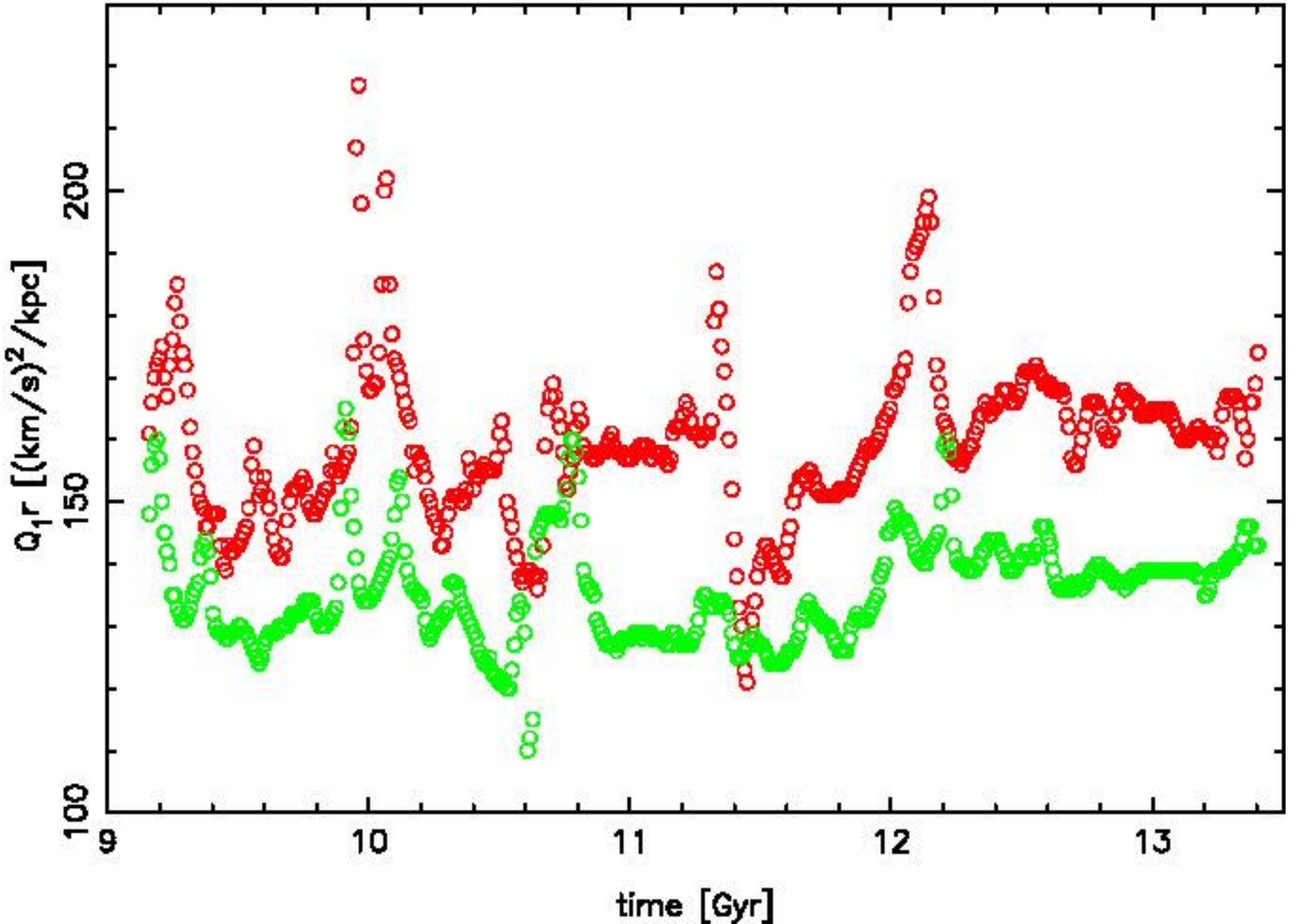
Halo 2nd and 3rd axes with time, vibrating, possible erratic rotation



Perpendicular quadrupole force fluctuations

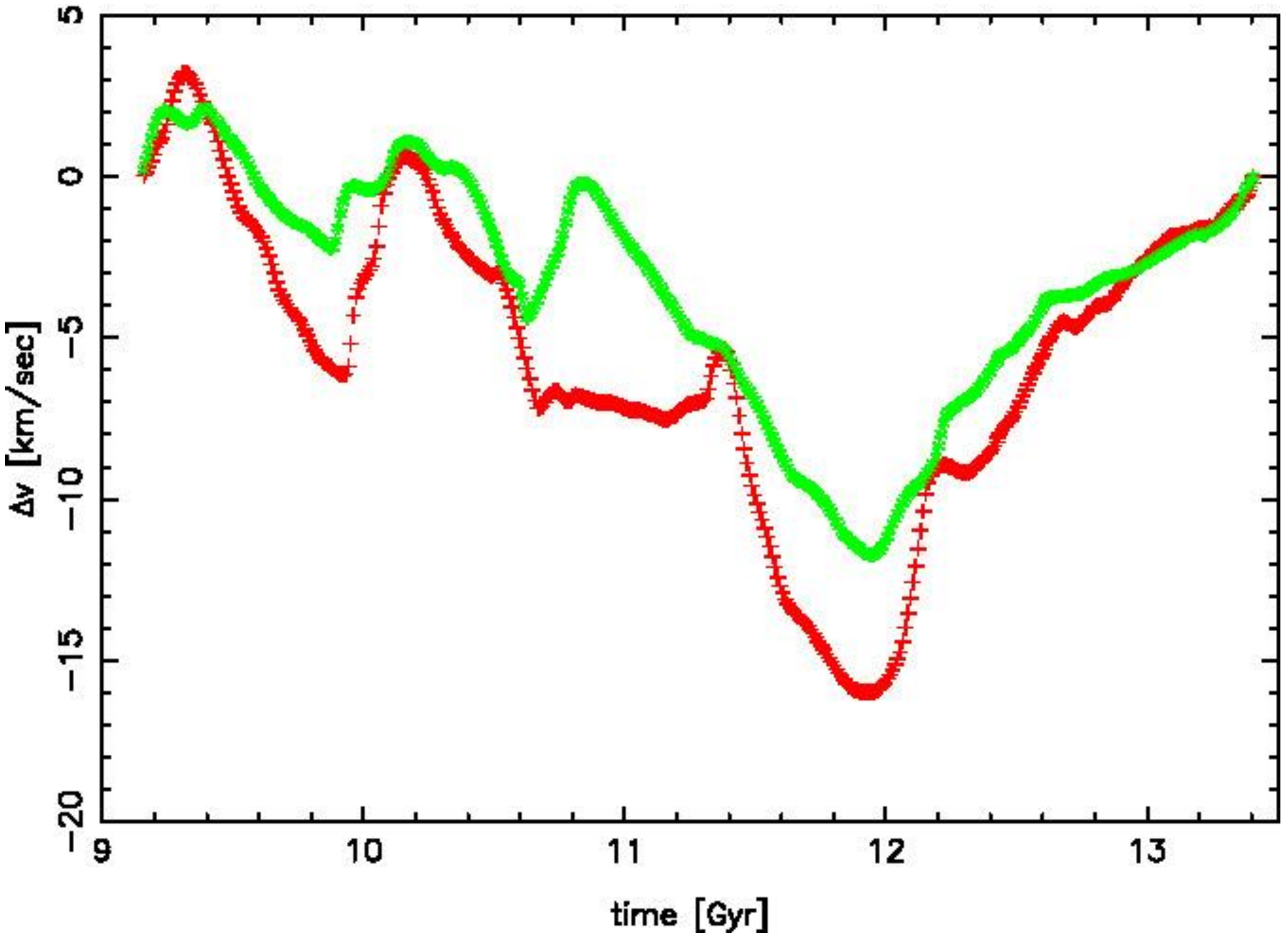
Q matrix largest eigenvalue at 20-30 kpc

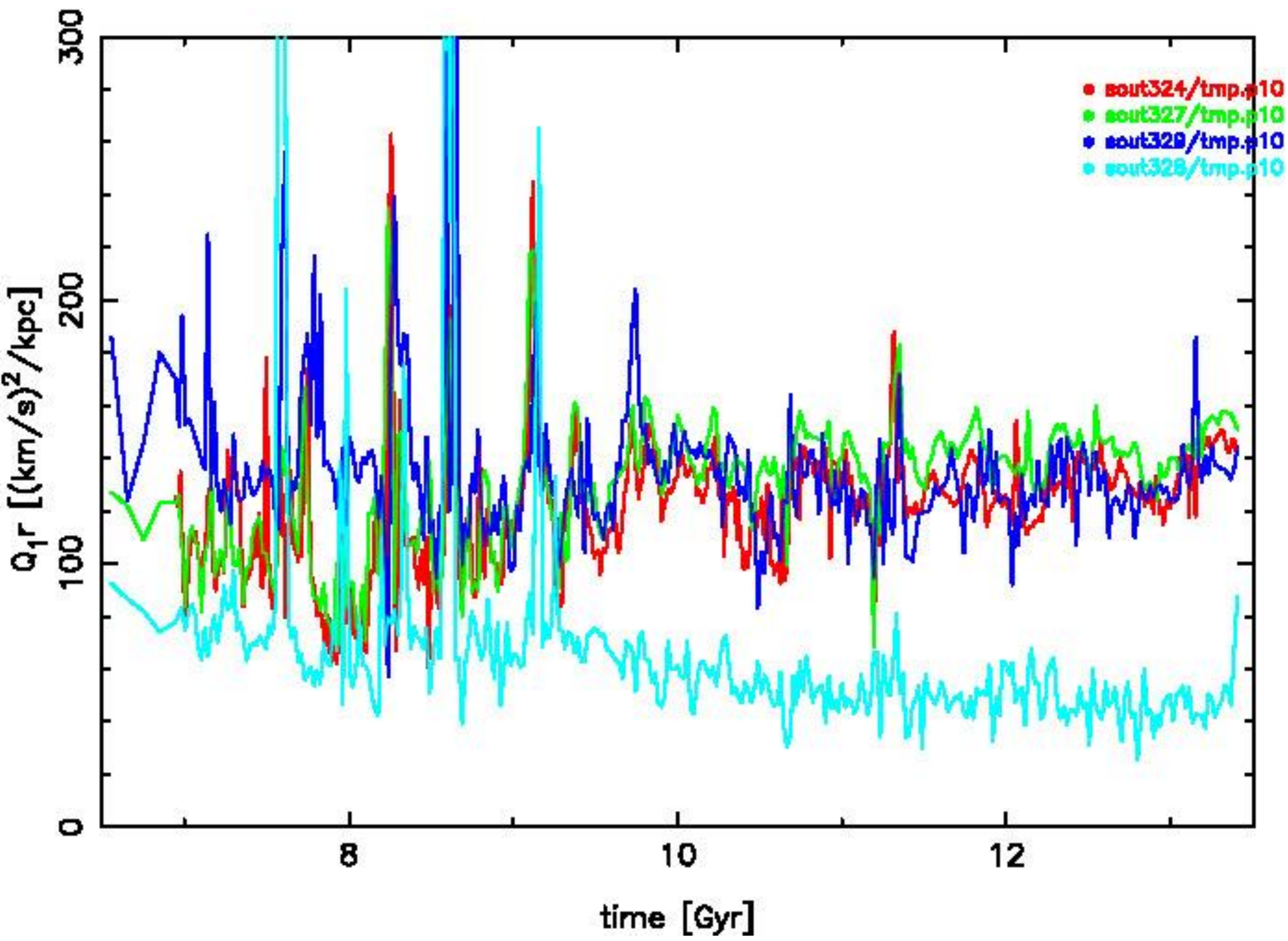
The fluctuations about mean are the interesting part.



$V_c^2/r \sim 10^4$
$\Delta Qr \sim 50$

Indicative tangential velocities (zero mean)
integral of $\frac{3}{2}Q^*r\,dt$ (no orbit)

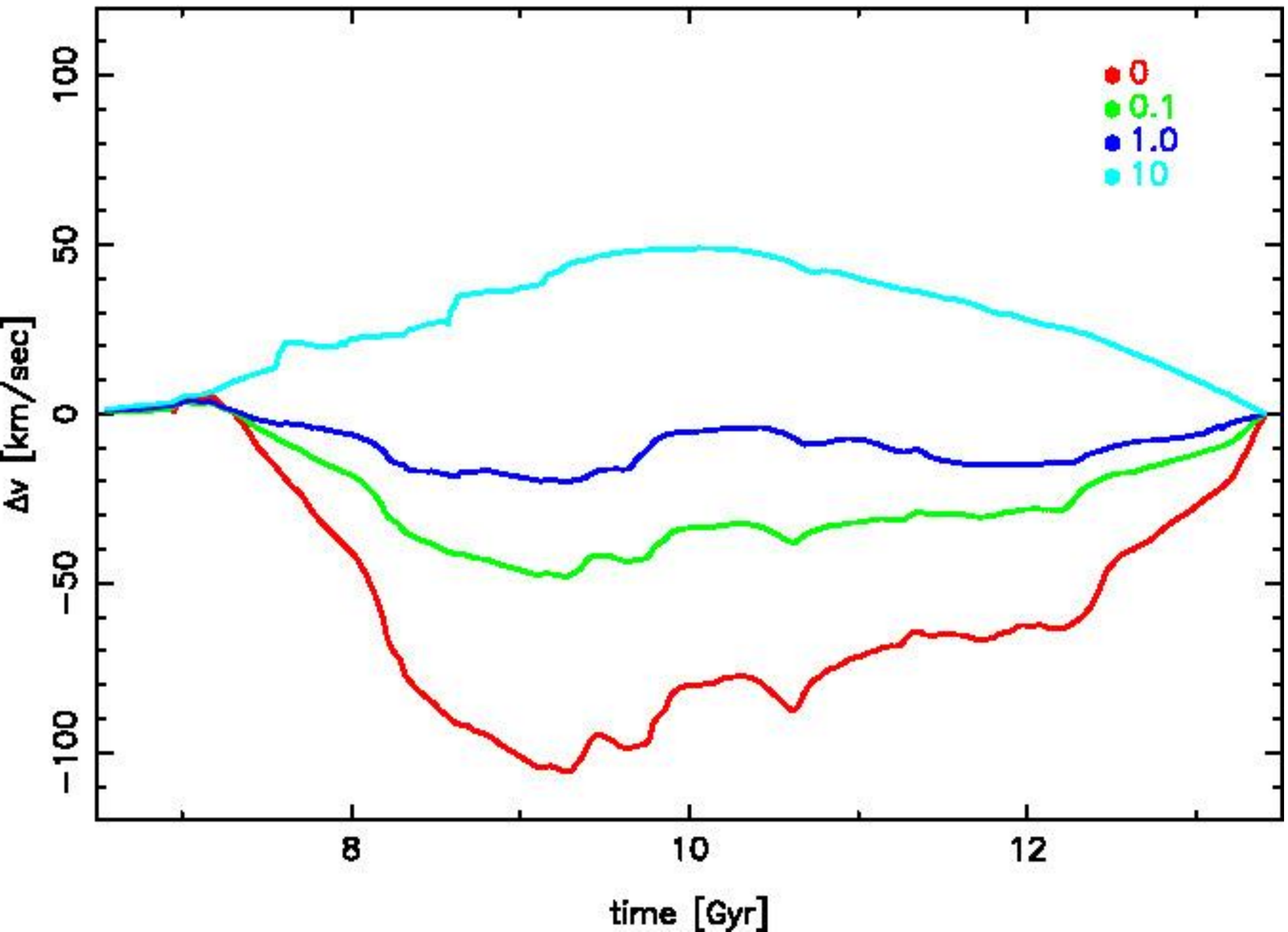



sout324/tmp.p10
sout327/tmp.p10
sout329/tmp.p10
sout328/tmp.p10
$Q_1 r$ [(km/s)^2/kpc]
time [Gyr]
0
100
200
300
8
10
12

With SIDM

Self-interacting Dark Matter damping

Cross-section in $cm^2\ gm^{-1}$



$\Delta v = 3/2\int Q\, r\ \ dt$
Indicative velocity. Not an orbit.

Red line is a collisionless halo
Increasing SIDM cross-section

Viscosity ~ mfp * velocity dispersion
Mean free path ~1/cross-section

SIDM 0.1-1 very effective at suppressing vibrations

Caveats and Concerns, Conclusions

- Streams are a powerful probe of DM and its history.
- Star cluster mass loss started in sub-galactic fragments (dwarf galx)
  - All thin star streams should have accompanying "cocoons"
  - Evidence for a cocoon for GD-1
- Galactic halos continue to gain mass and have potential fluctuations
  - Collisionless halos "ring" or "vibrate". Monopole nearly constant
  - Quadrupole force fluctuations a few percent,
  - at frequencies that couple to orbits
  - Streams should have ~20 km/sec perpendicular velocities
  - Orphan (LMC surely plays a role as well)