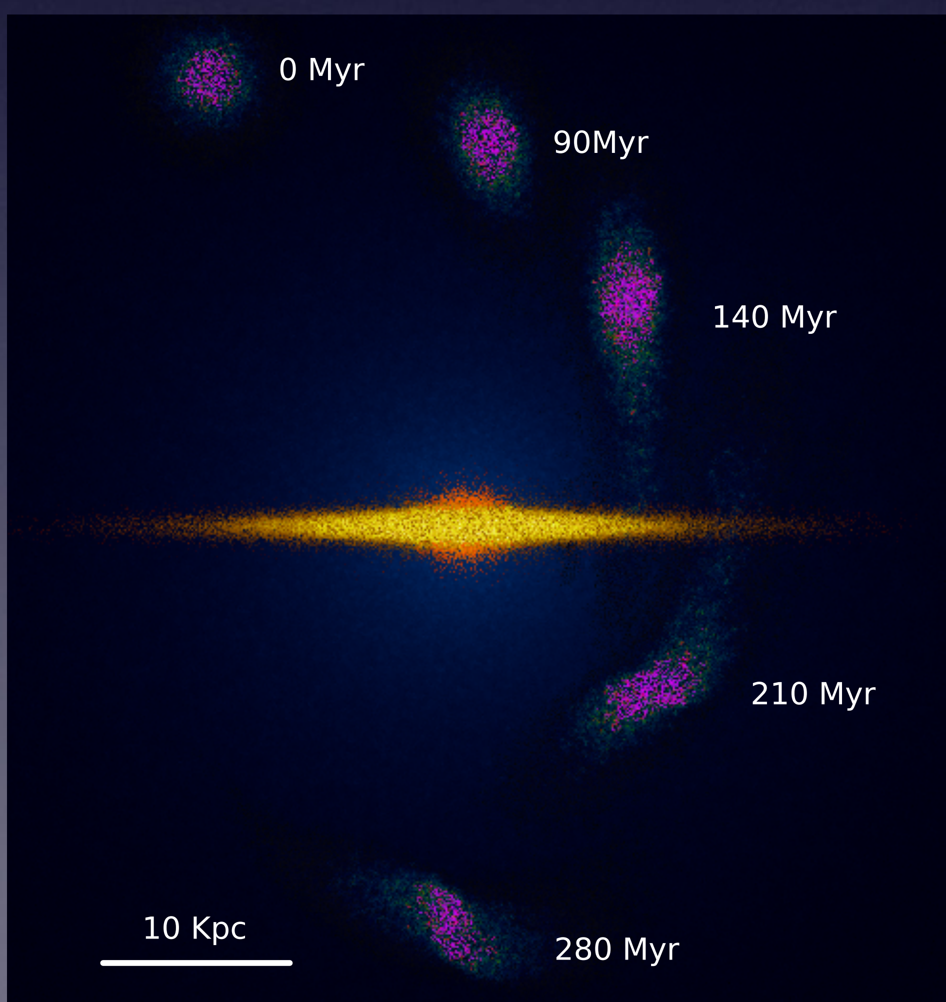
The Heart of Darkness: The Galactic center

Douglas Spolyar

Oskar Klein centre

Disk Perturbations



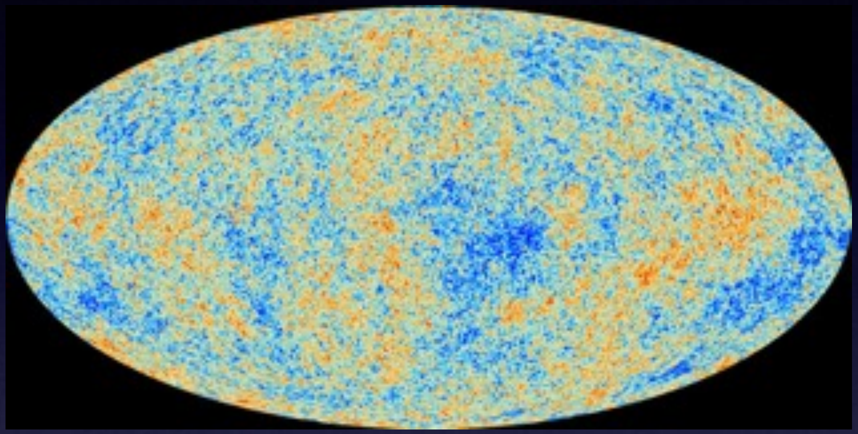
Galactic Center (DM profile)

Dark Matter

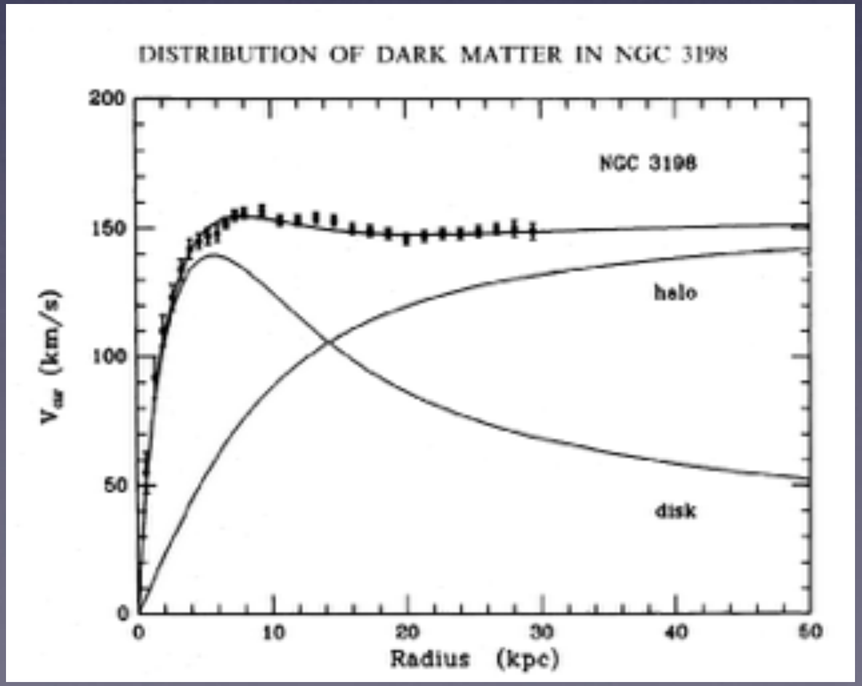
First Observational Evidence found by Knut Lundmark (1925) Lund Sweden from Rotation Curves.

Gravitational effects of Dark Matter are also well known from Lensing, the Bullet Cluster, the Cosmic Microwave Background (CMB), etc…

CMB



Rotation Curves

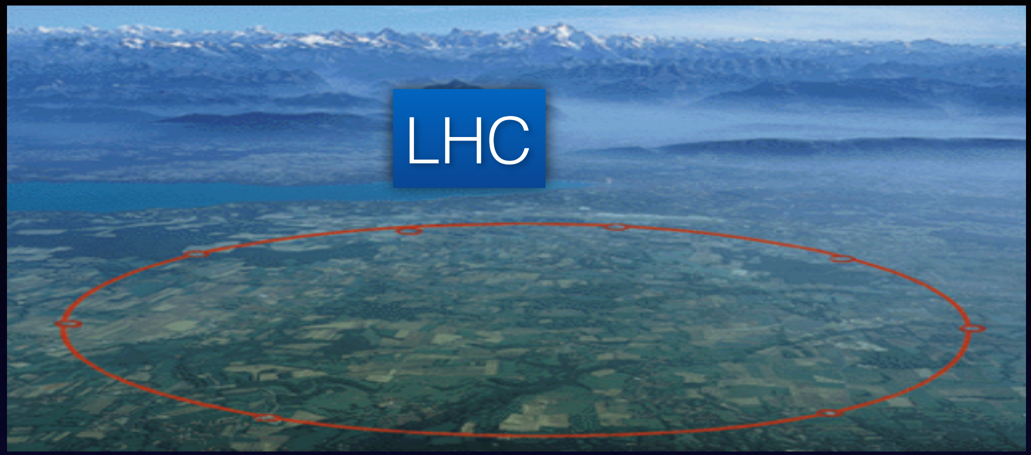


Lensing

Bullet Cluster

Cold Dark Matter (CDM) Paradigm

- From The Cosmic Microwave Background
  - 85 % of the mass of the Universe is Dark Matter (Plank ESA Mission 2015)
  - Dark Matter is fairly cold (heavy)
  - Fairly collisionless
  - Test with Gaia and Theia
- Possible candidates (Weakly Interacting Massive Particles) WIMPs, Axions, Sterile Neutrinos
  - ➡ Focus on WIMPs very well motivated by theory
  - ➡ Lots of experiments looking for WIMPS
    - ➡ Colliders (LHC)
    - ➡ Direct Detection (Xenon etc)
    - ➡ Indirect Detection (Fermi and IceCube)
    - ➡ Test with the First Stars



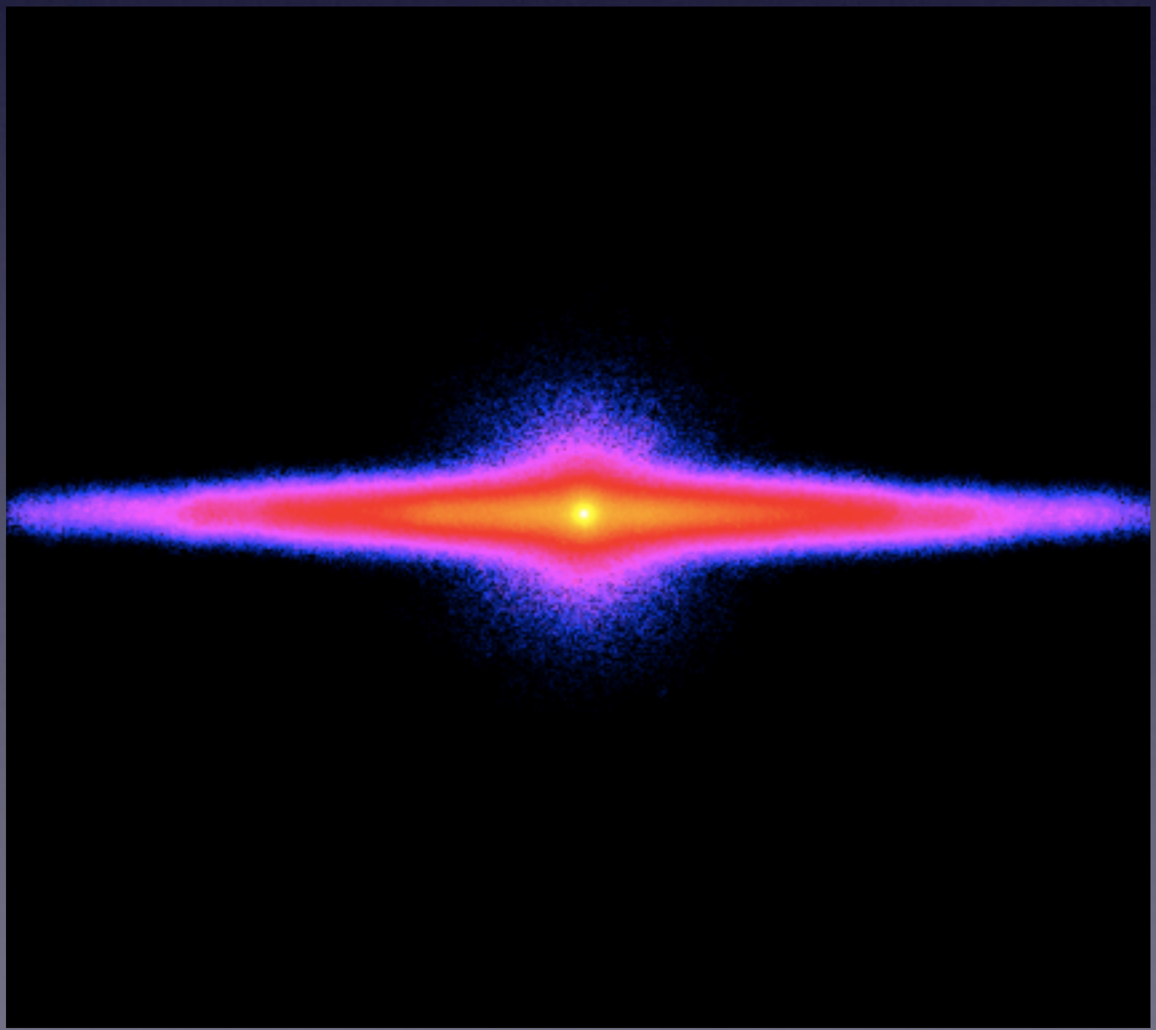
Astrometric Tests of Dark Matter

Nature of Dark Matter unknown, except that it is

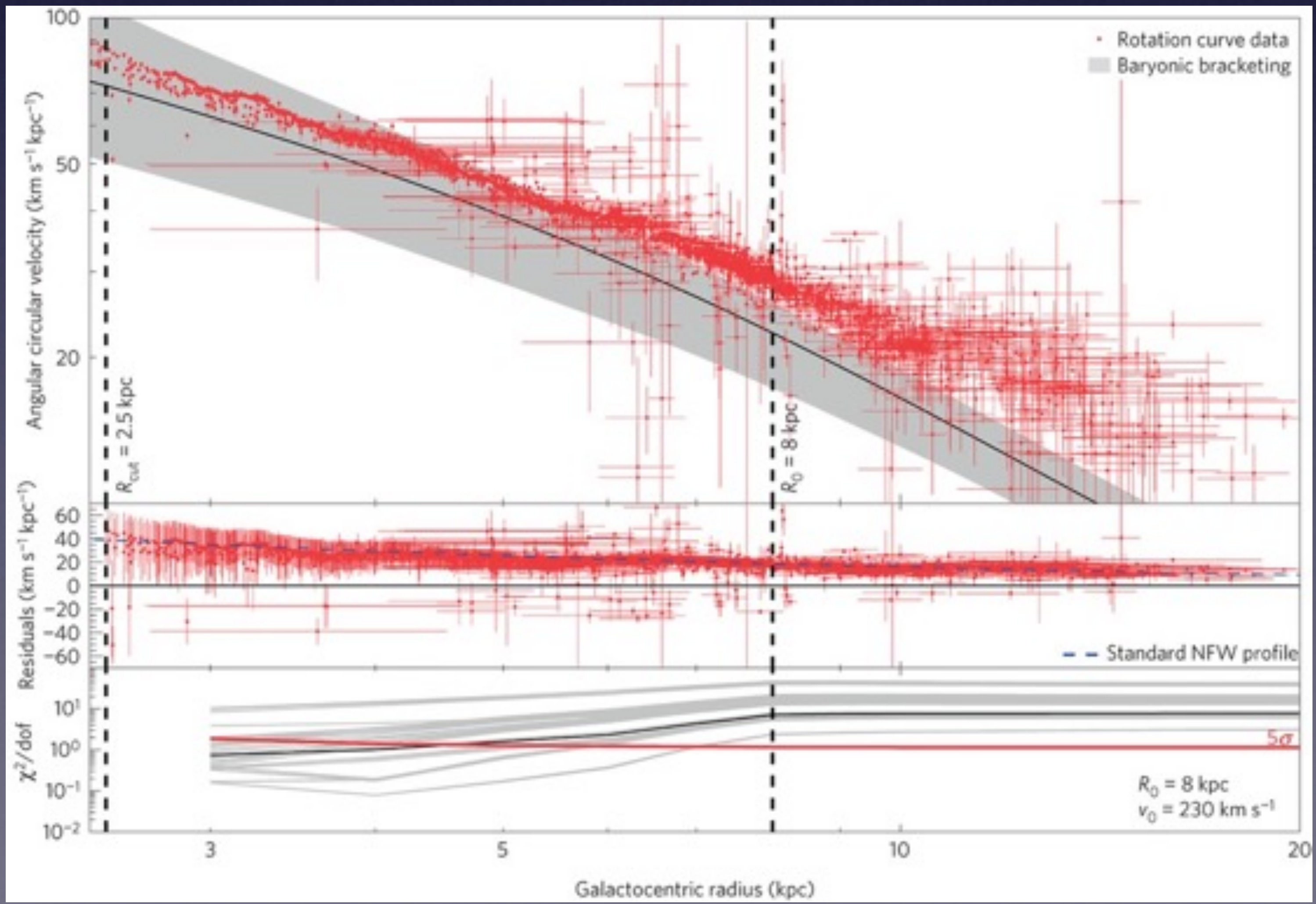
-Fairly cold (heavy)
- Fairly collision-less

How cold?
How collisionless?

Perturbations of the Disk



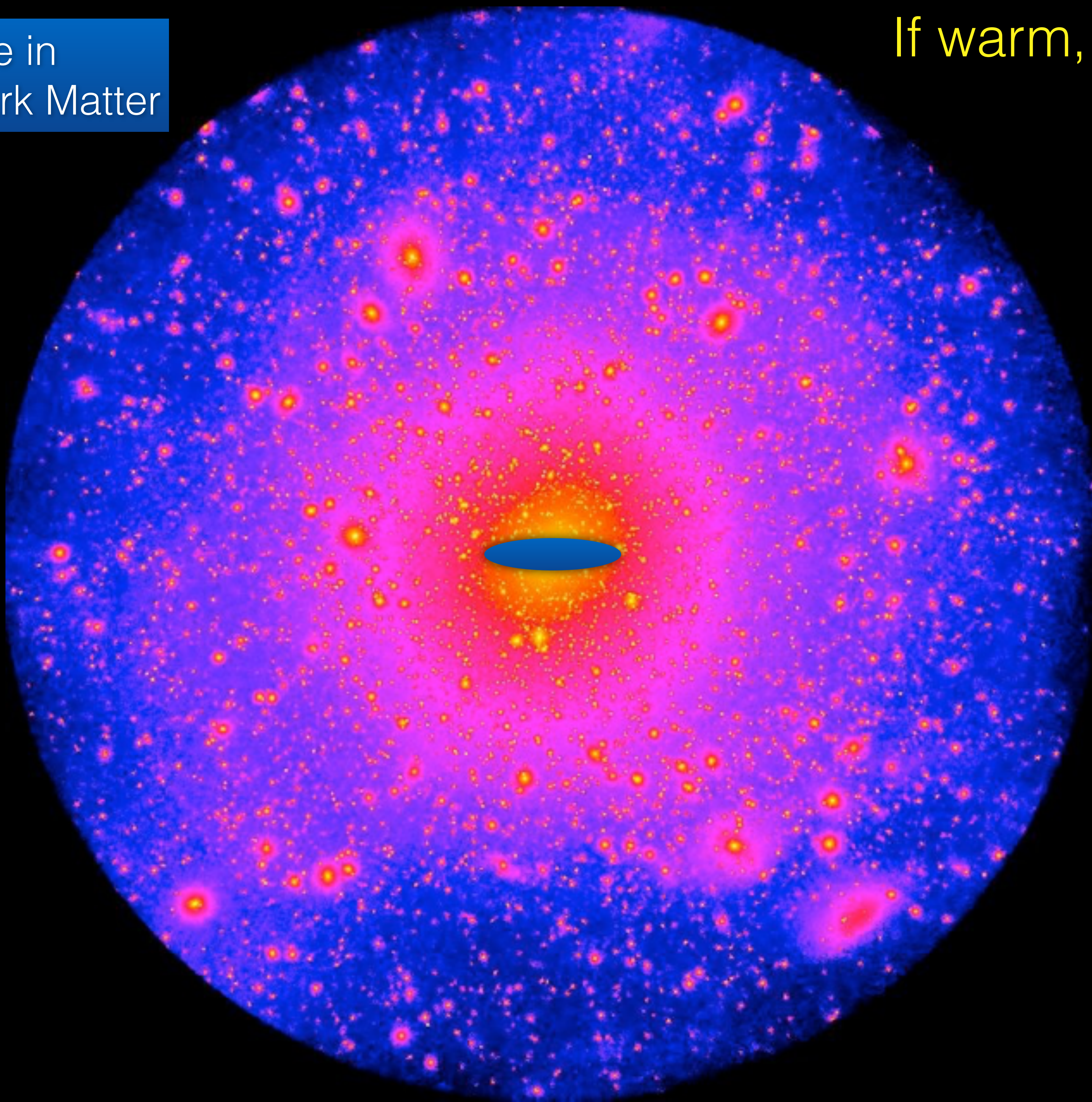
Dark Matter profile of the MW



Smoking Gun: If cold (very Massive), Lots of clumps of Dark Matter

We live in
a halo of Dark Matter

If warm, No Clumps



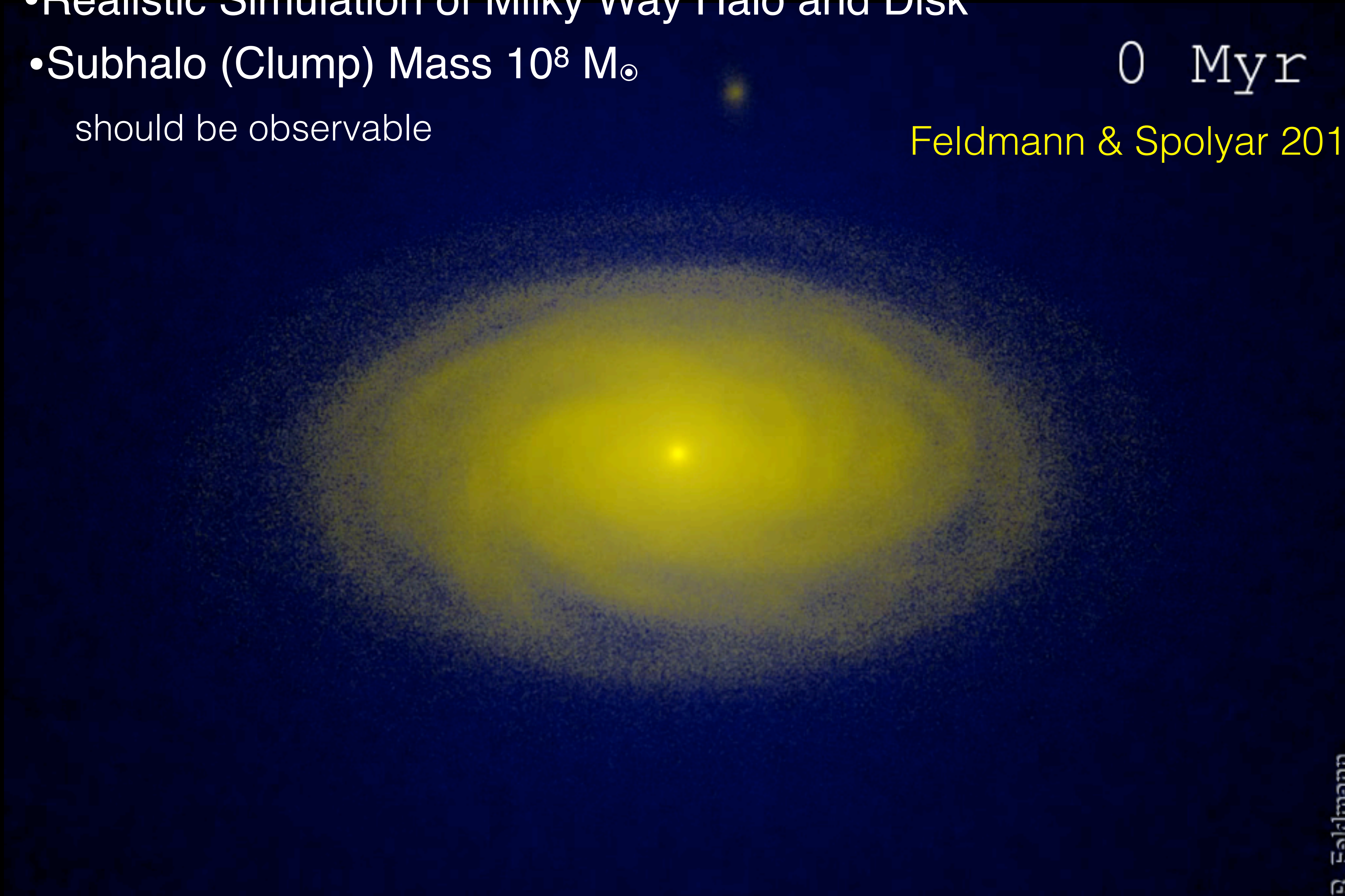
250 kpc

Aquarius Simulation of Milky Way

- Realistic Simulation of Milky Way Halo and Disk
- Subhalo (Clump) Mass $10^8\ M_\odot$

  should be observable

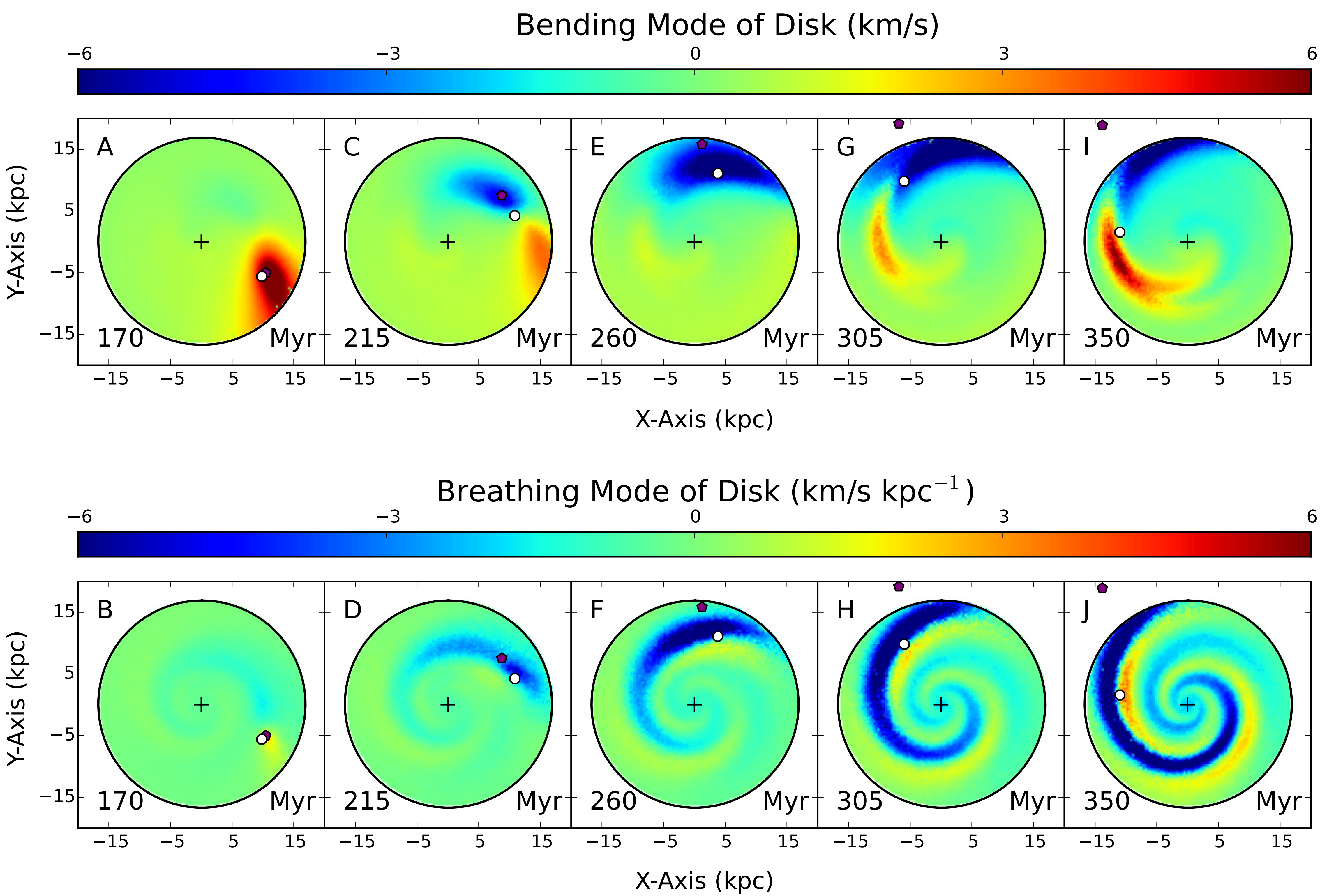
Feldmann & Spolyar 2013



Consider Many Cases

N-body solver PKDGRAV and L. Widrow Code.

Effect of Perturbation



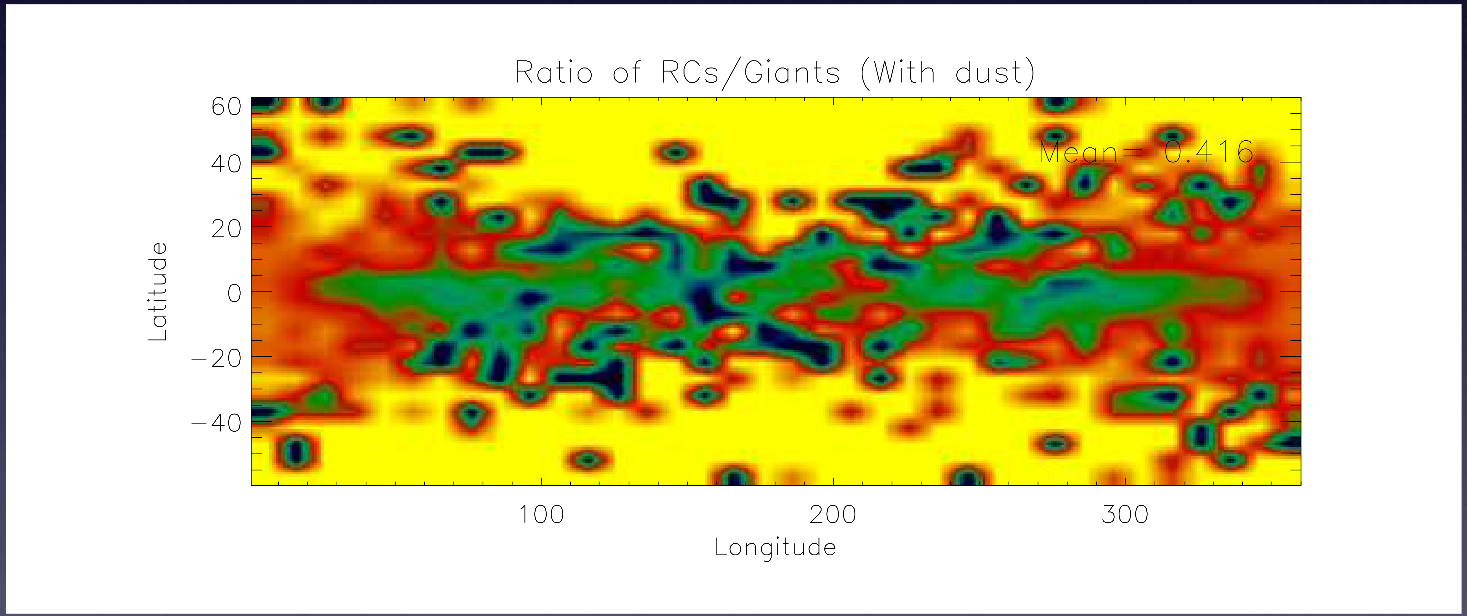
Galaxia

Generate mock catalogs of the MW

Besancon Model for the disk

Bullock & Johnson for halo

Realistic Dust Model

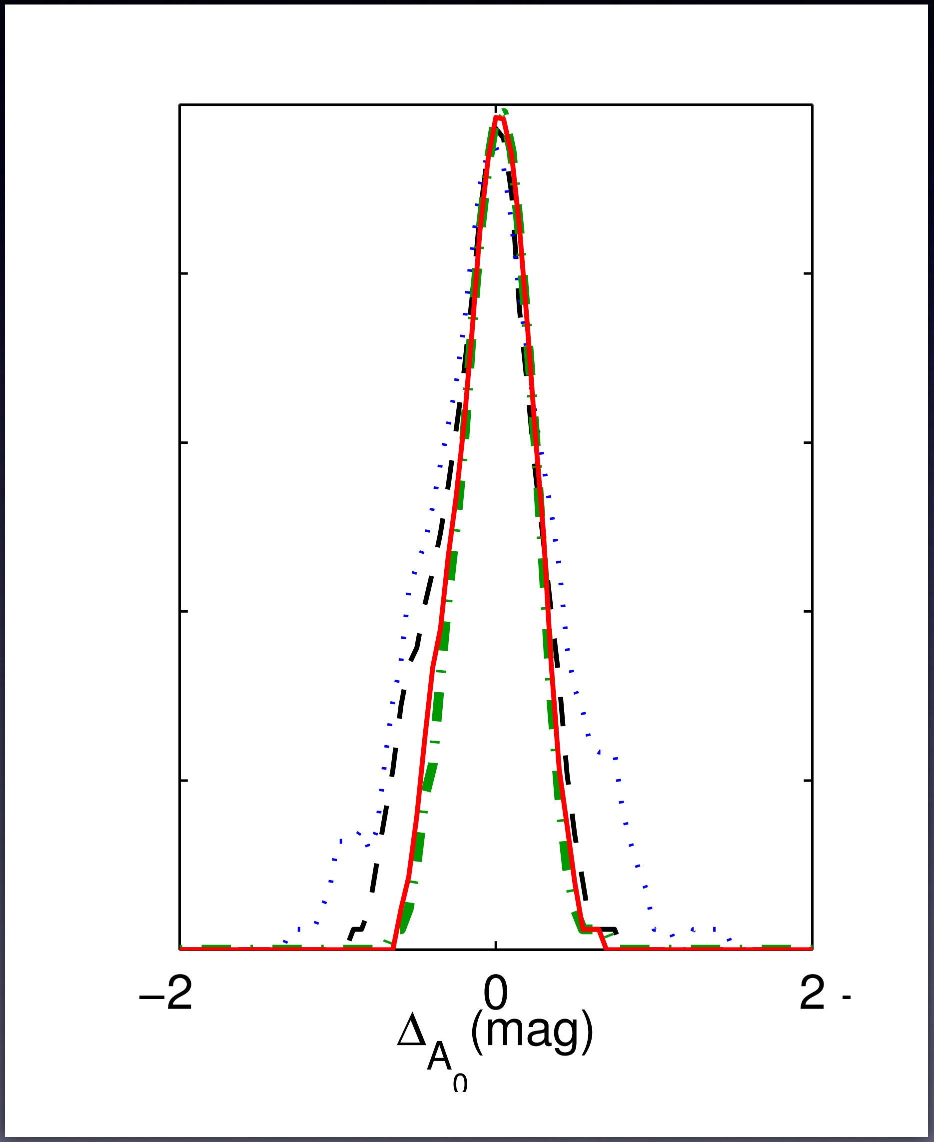


Generate mock and then paint perturbation from simulation onto mock catalog

Sharma et al 2011

Improve distance errors

- parallax (largest errors)
- Improve errors with spectra
  - From 10-20 percent errors to 5-10 percent (possibly better).
    - 0.05 mag Extinction
    - From Gaia determination
    - better than 5 with better spectra



C. Liu et al 2012

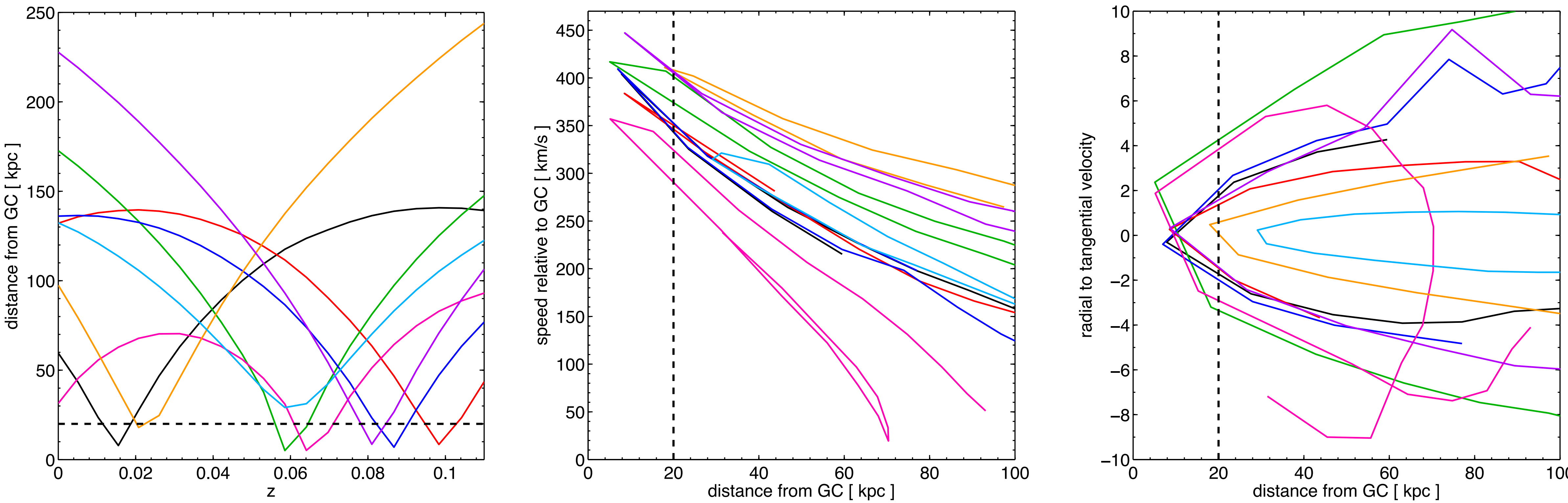
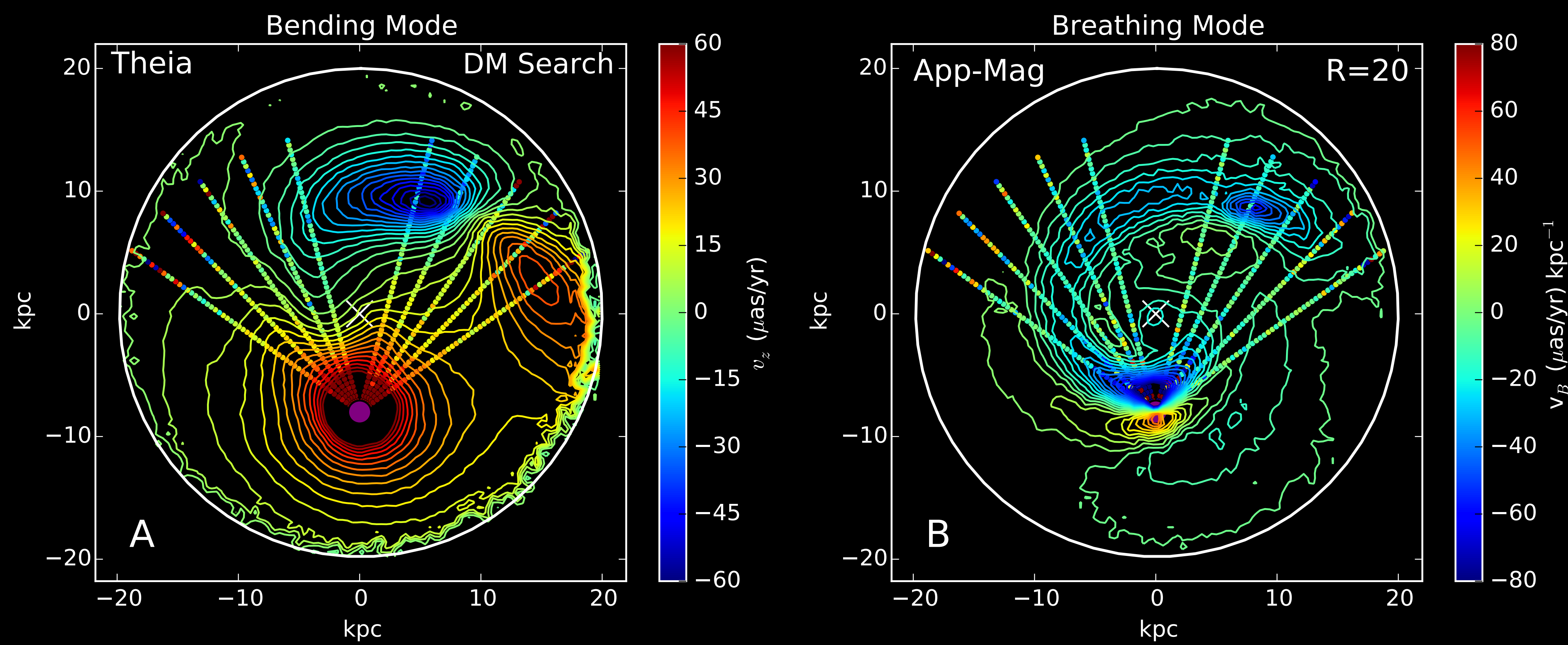


Figure 6. Orbits of selected substructures in the Via-Lactea I simulation. Substructures are selected based on their mass ($>10^8\ M_\odot$), their peak maximum rotation velocity ($>20\,\mathrm{km\,s^{-1}}$), and their distance from the Galactic Centre ($<30\,\mathrm{kpc}$). Seven substructures match these criteria and enter the innermost 20 kpc of the main halo (dashed lines). Left panel: distance from the Galactic Centre versus redshift. About one selected substructure crosses the disc of the MW per 100 Myr. Middle panel: speed of the selected substructures versus distance from the Galactic Centre. Substructures intersecting the MW disc have typical speeds of $\sim$300–450 $\mathrm{km\,s^{-1}}$. Right panel: ratio of radial to tangential velocity versus distance from Galactic Centre. The ratio is negative if the substructure moves inward and positive if it moves outward. Substructures intersecting the MW disc have typical radial to tangential velocity ratios in the range of -3 to $+3$.

Note Aquarius has 3 times as much substructure

Theia Fields



20 Fields with 10 above the disk (2 degree) and below

On the order of a million stars in each field

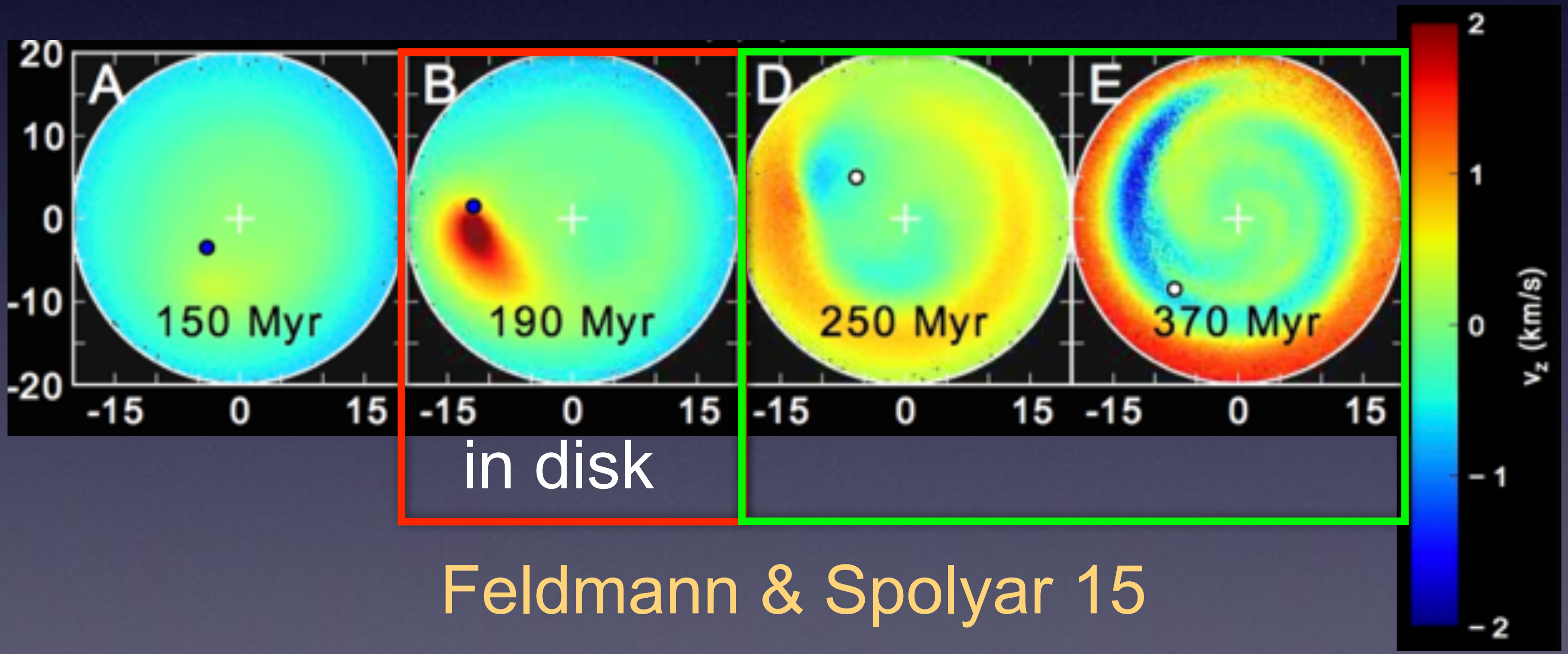
Effect scales with halo mass

Detecting subhalos in Milky Way

- By perturbations of stellar orbits

need subhalo to be massive and concentrated:
$r_{\rm half}$ = 2 kpc for log M =8 , 1000 pc for log M = 6

Largest effect when subhalo passes through disk | still visible after 1st passage

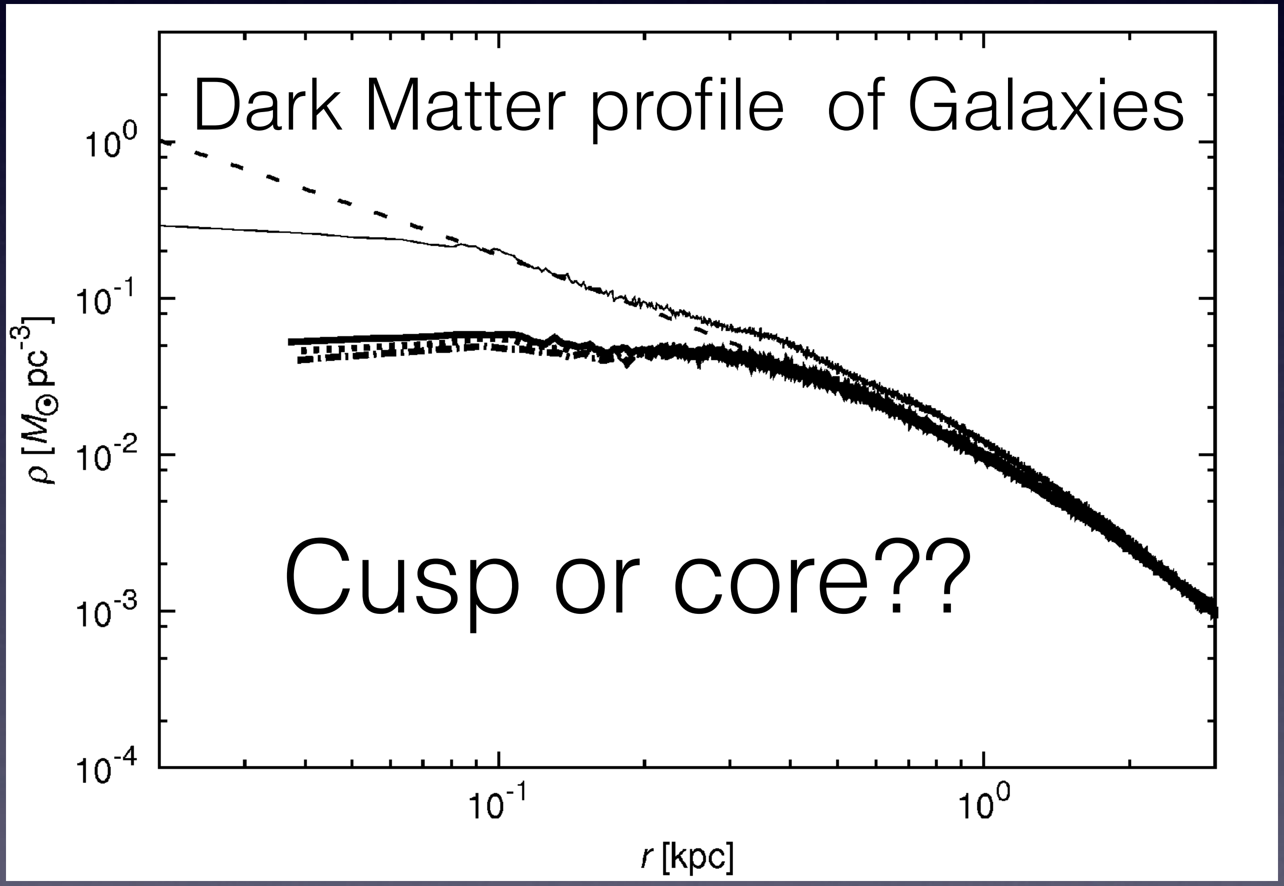


Feldmann & Spolyar 15

GAIA can detect log M/Msun = 8 subhalos (rare: closest at 3 kpc)
THEIA (20 LOS in 2 yr) can unambiguously detect log M/Msun = 6.7 subhalos
→ avoid confusion with other perturbers

Dark Matter Profile

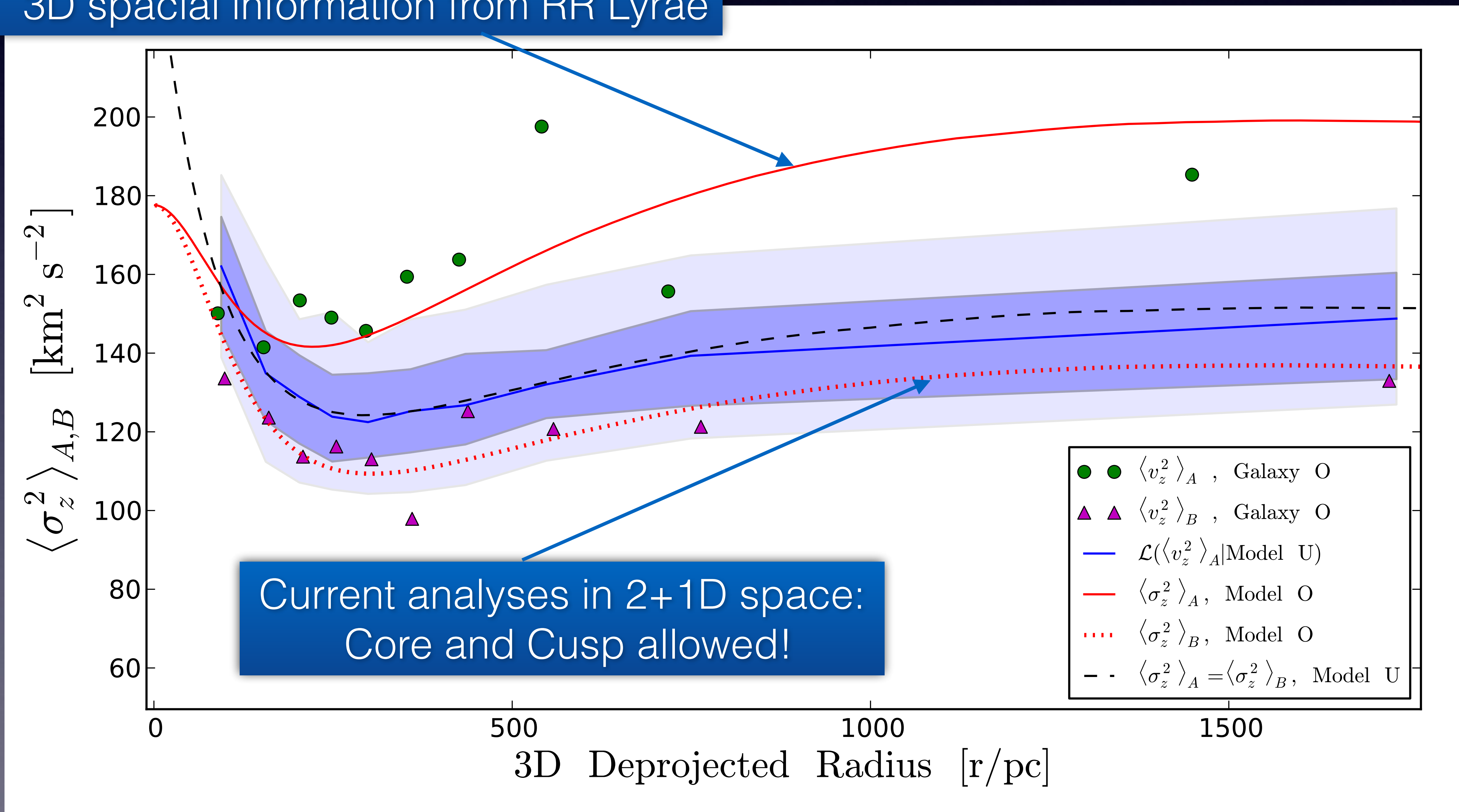
- Cold Dark Matter alone predicts cusps (NFW)
- But halos may have a core
  - New Physics (Fundamental test)
  - Critical for Indirect Detection Experiments (go where the DM is)
- Targets:
  - Dwarf Galaxies (Malcolm)
  - Galactic Center



Measuring Dark Matter inner slopes

Dark Matter- anisotropy degeneracy!
Orbital Structure of stars and Dark Matter profile are degenerate
Cusp and Core allowed

Break Degeneracy With
3D spacial information from RR Lyrae

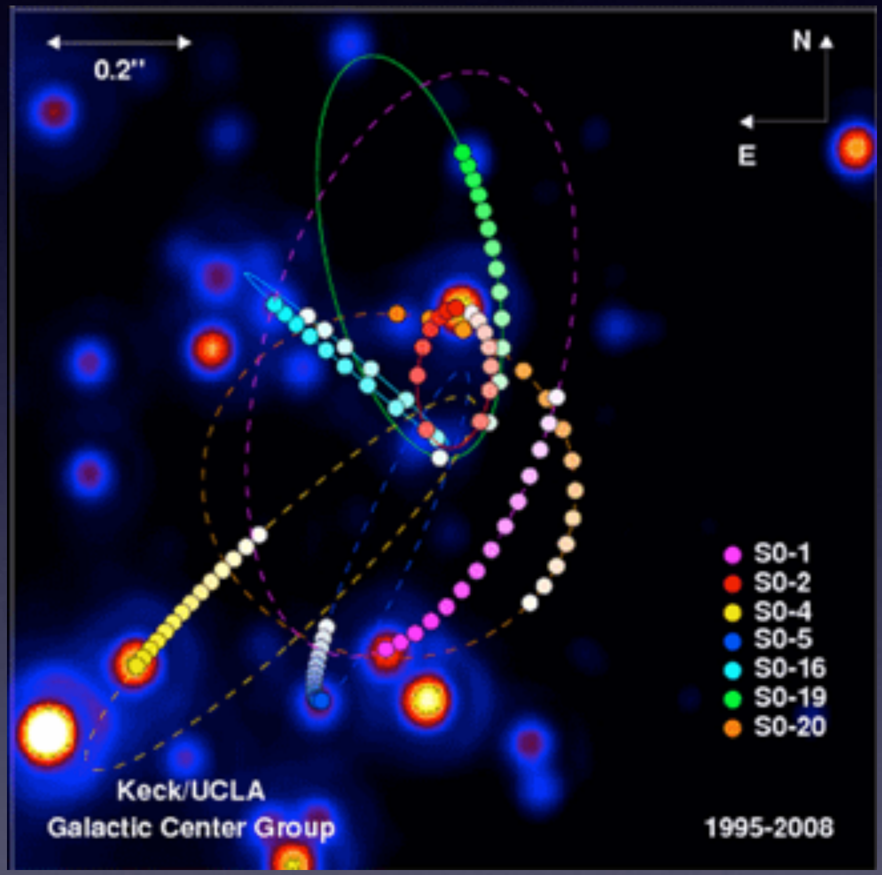


Current analyses in 2+1D space:
Core and Cusp allowed!

Richardson, Spolyar, and Lehnert 2014

Galactic Center

- Very active (SMBH)
- Presumably lots of Dark Matter
  - Best target to search for DM annihilation (lots and lots of DM)
  - Discover Signal then want know profile (critical test)
    - Repeated claims of discovery (Hooperon)



SMBH GC

Gaia DM

- Will get large scale structure
  - Gaia (kpc scale)
  - V band (more or less)
  - Too much dust!
  - Could look at Dust Free windows
    - Baade's window (2.7 mags) not too Bad
    - other windows comparable
    - Versus 20 in V band

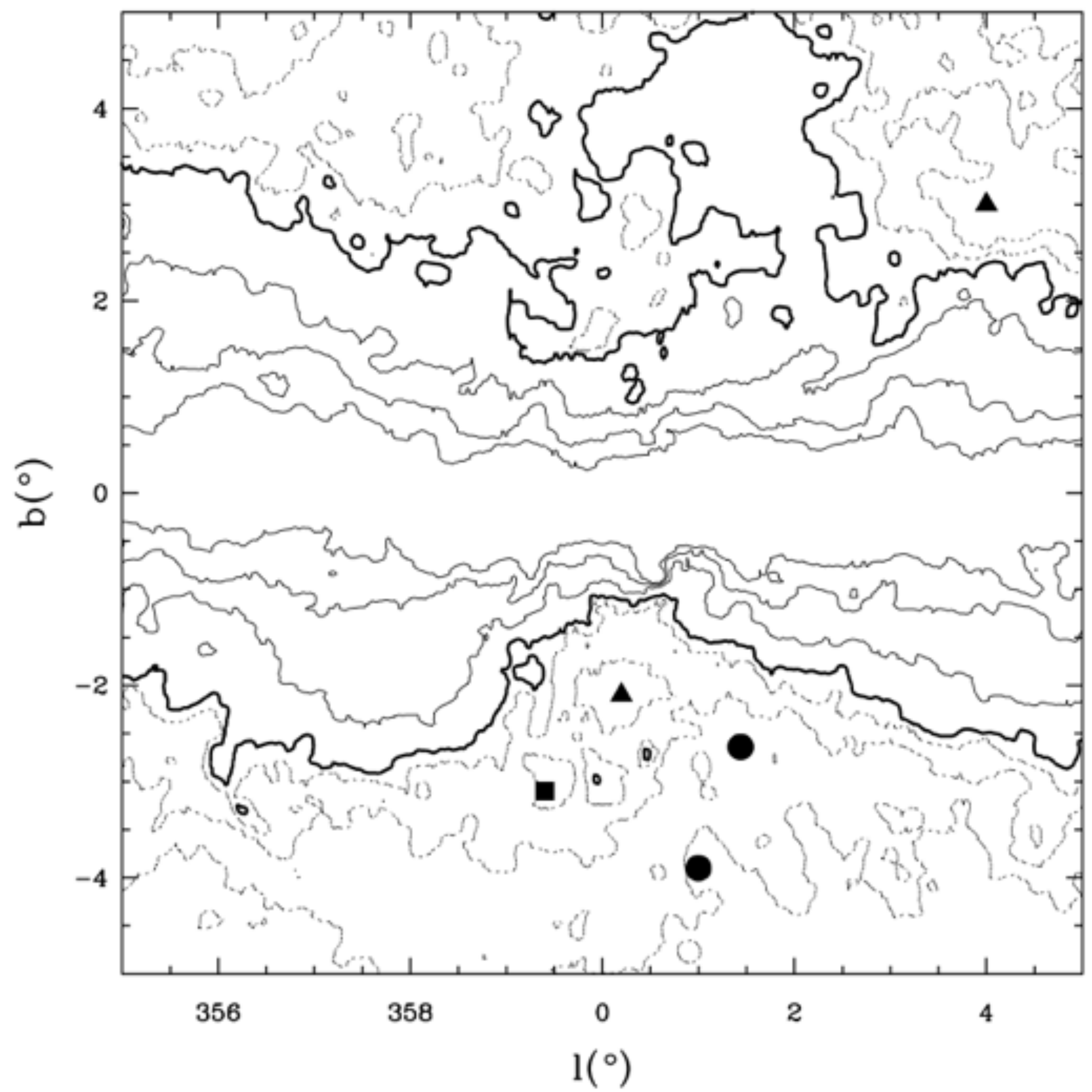
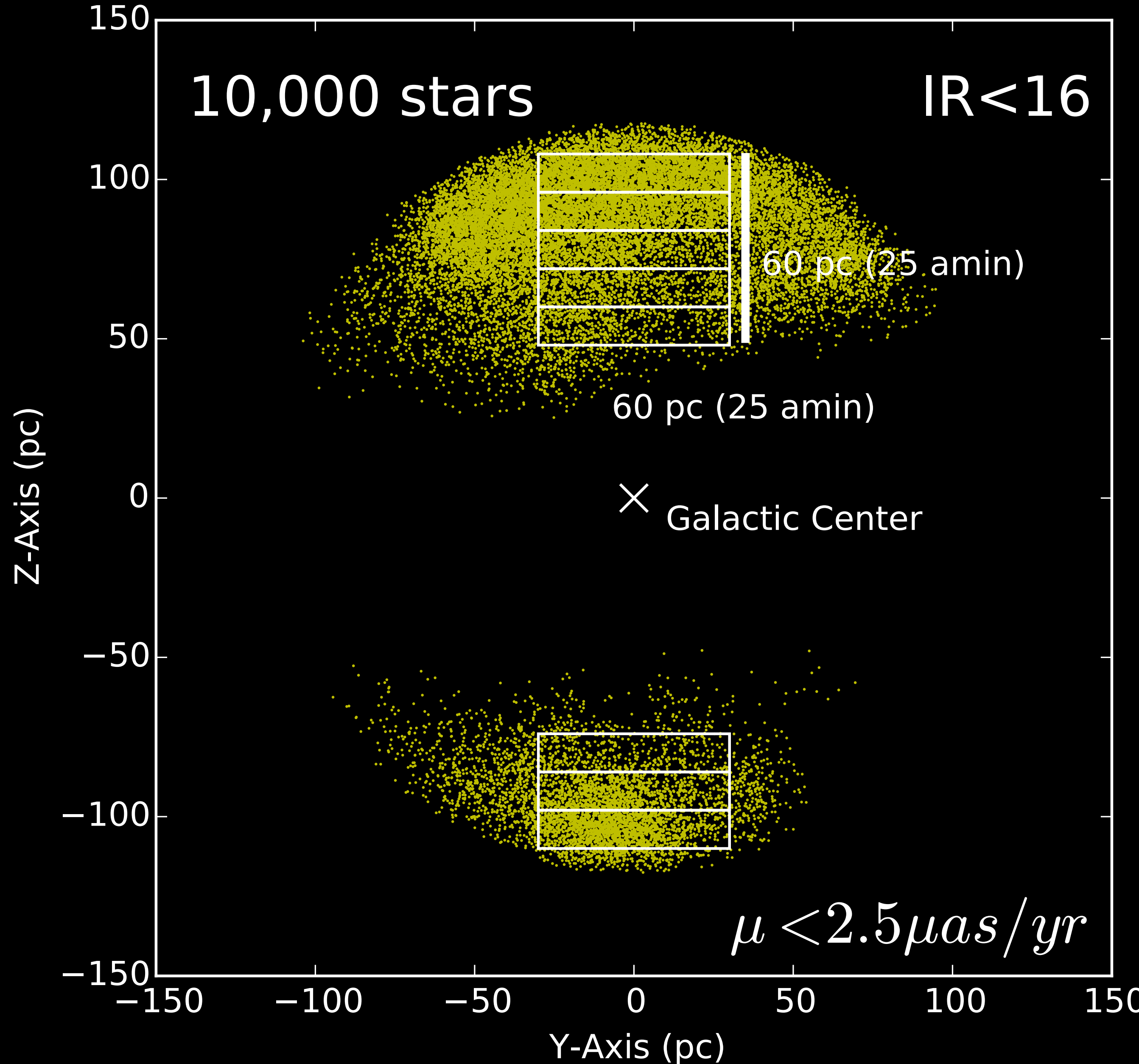


Fig. 1. $10^\circ \times 10^\circ$ FIR extinction map centred on the Galactic Nucleus. The line width is coded according to the $A_{K,\ FIR}$ value. Dotted lines correspond to lower than average levels: 0.7, 1.05 and 1.4. The thick solid line is close to the field average and corresponds to $A_{K,\ FIR} = 1.75$. The thin solid lines are above average: 3, 6, 10. Filled circles indicate positions of windows from Baade (1963), triangles from Stanek (1998), and the square from the present study.

IR add on

- Assume <1.7 microns
- Number of stars based on the confusion limit.
- Viral argument gives mass to a few percent is this good enough?

mock of GC



500 pc from galactic center

Opportunities

- Theia could do better at galactic center compared
    - Gaia (v band vs IR)
    - Wfirst (Better angular resolution)
- Gaia and WFirst does large scale DM Structure of the Galaxy (Scales>1kpc)
- Theia (Scales<1kpc)