

Constraining the DM density profile of the Milky Way's central kpc



~1 kpc

COBE/DIRBE/NASA GSFC

SSI 42 Project
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Motivation

Galaxy formation: big unsolved problem

Sims key, right now disagree with observation

3 possibilities:

1) DM model right, sims of it wrong

2) DM model wrong

3) DM model and sims of it right, baryon feedback modifies (SNe, adiabatic contraction)

**Finally, density profile needed for comparison with possible annihilation signals

Orientation and challenges

Disk

Bulge ~ 8 kpc

~ 1 kpc

disk radius ~ 15 kpc

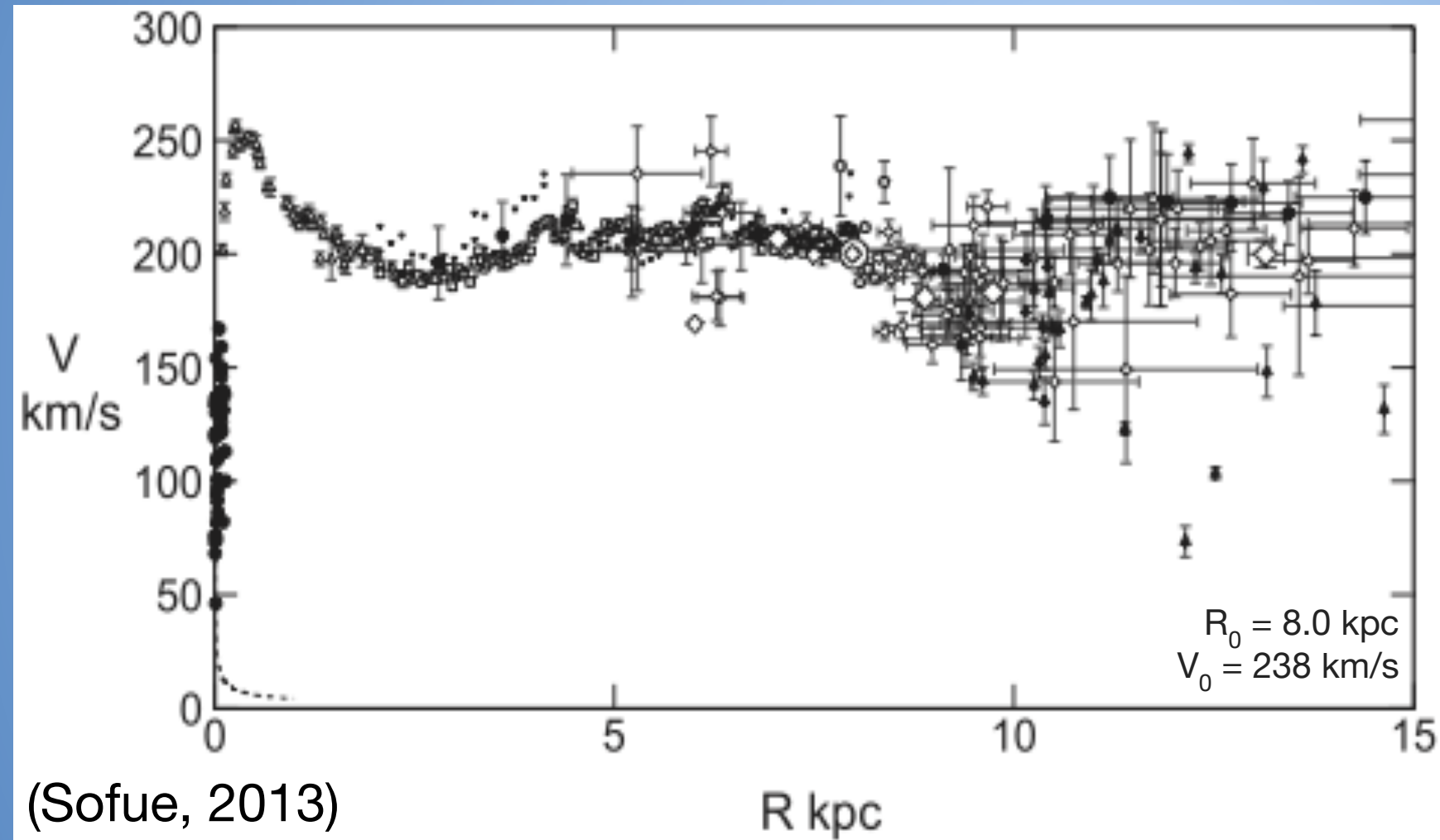
COBE/DIRBE/NASA GSFC

stellar disk dominates, then bulge and gas

DM negligible

Traditional measurement:

Rotation curve



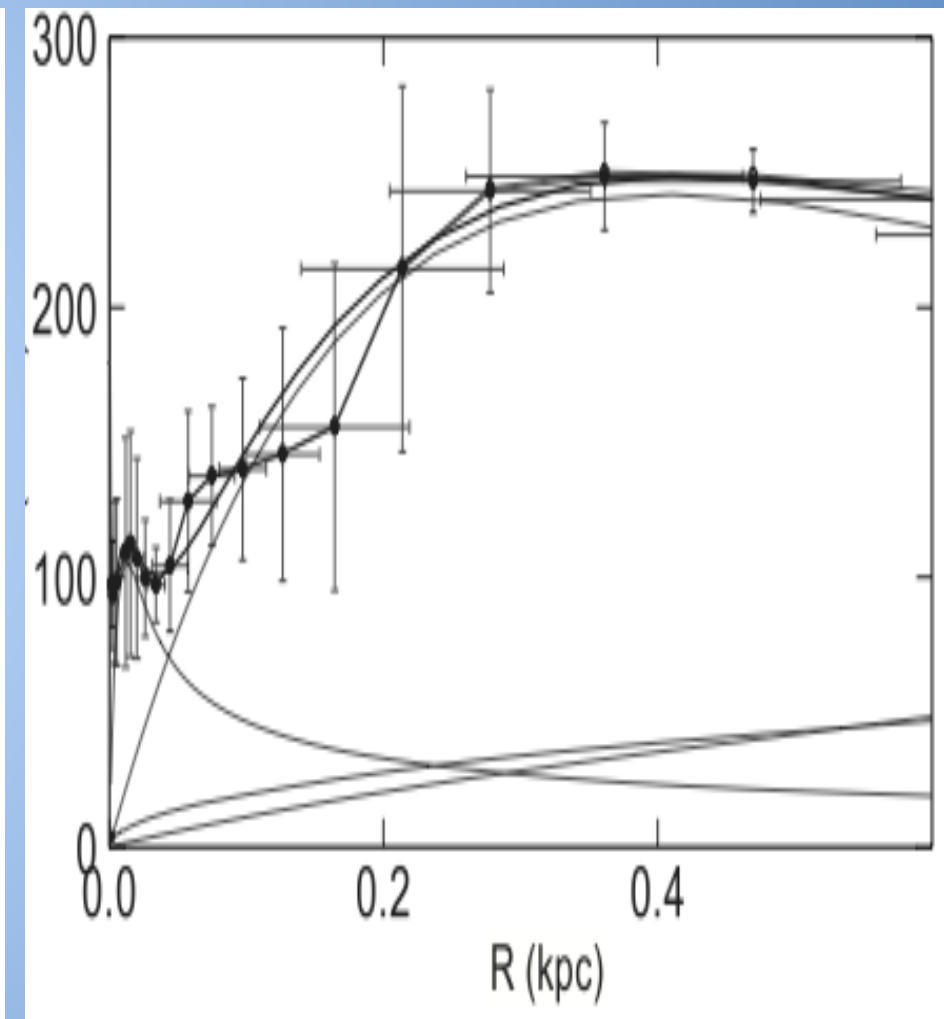
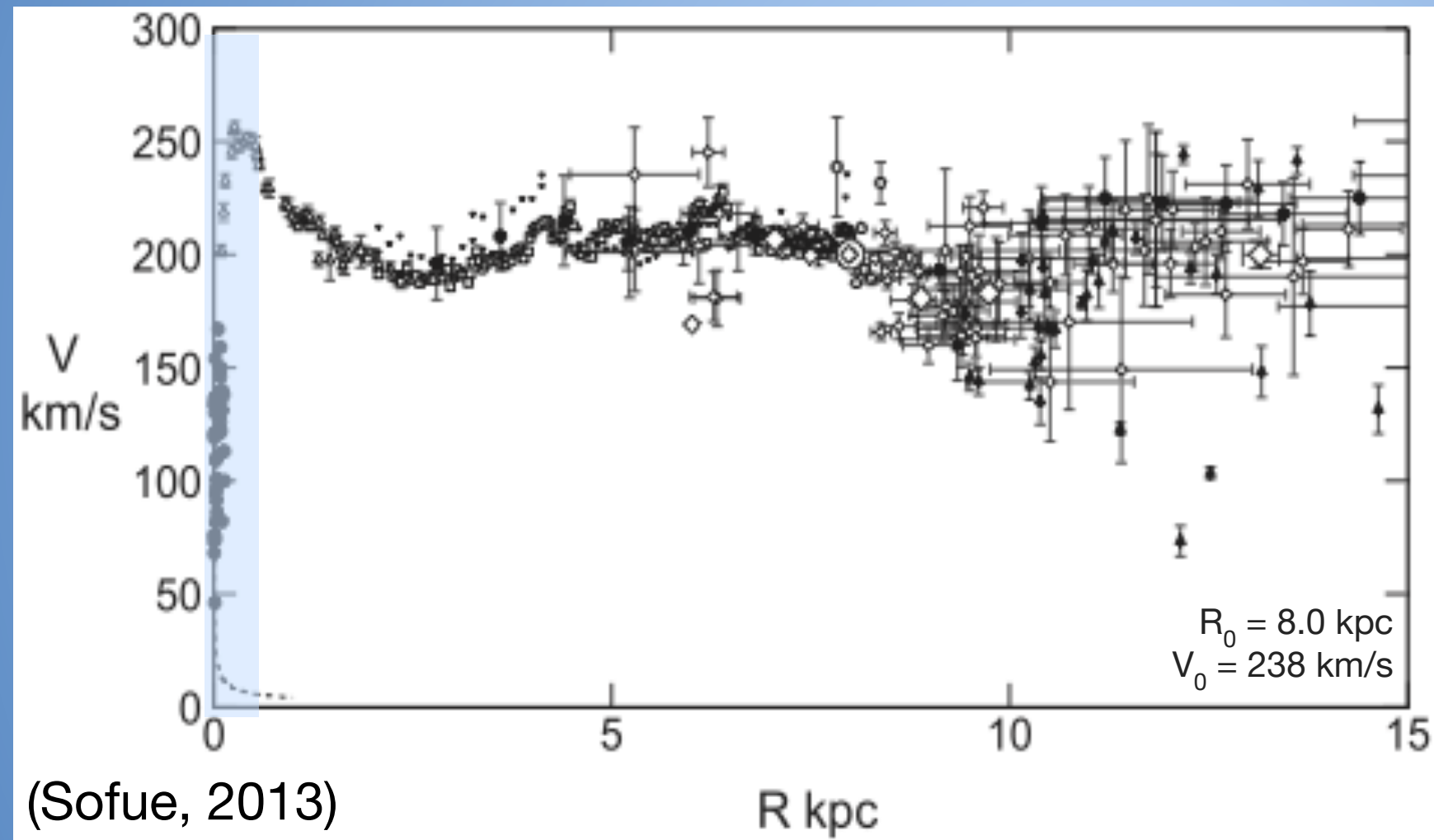
Circular Velocity

$$\nabla^2 \Phi = 4\pi G \rho$$

$$v_c = \sqrt{r \frac{d\Phi}{dr}}$$
$$= \sqrt{\frac{GM(< r)}{r}}$$

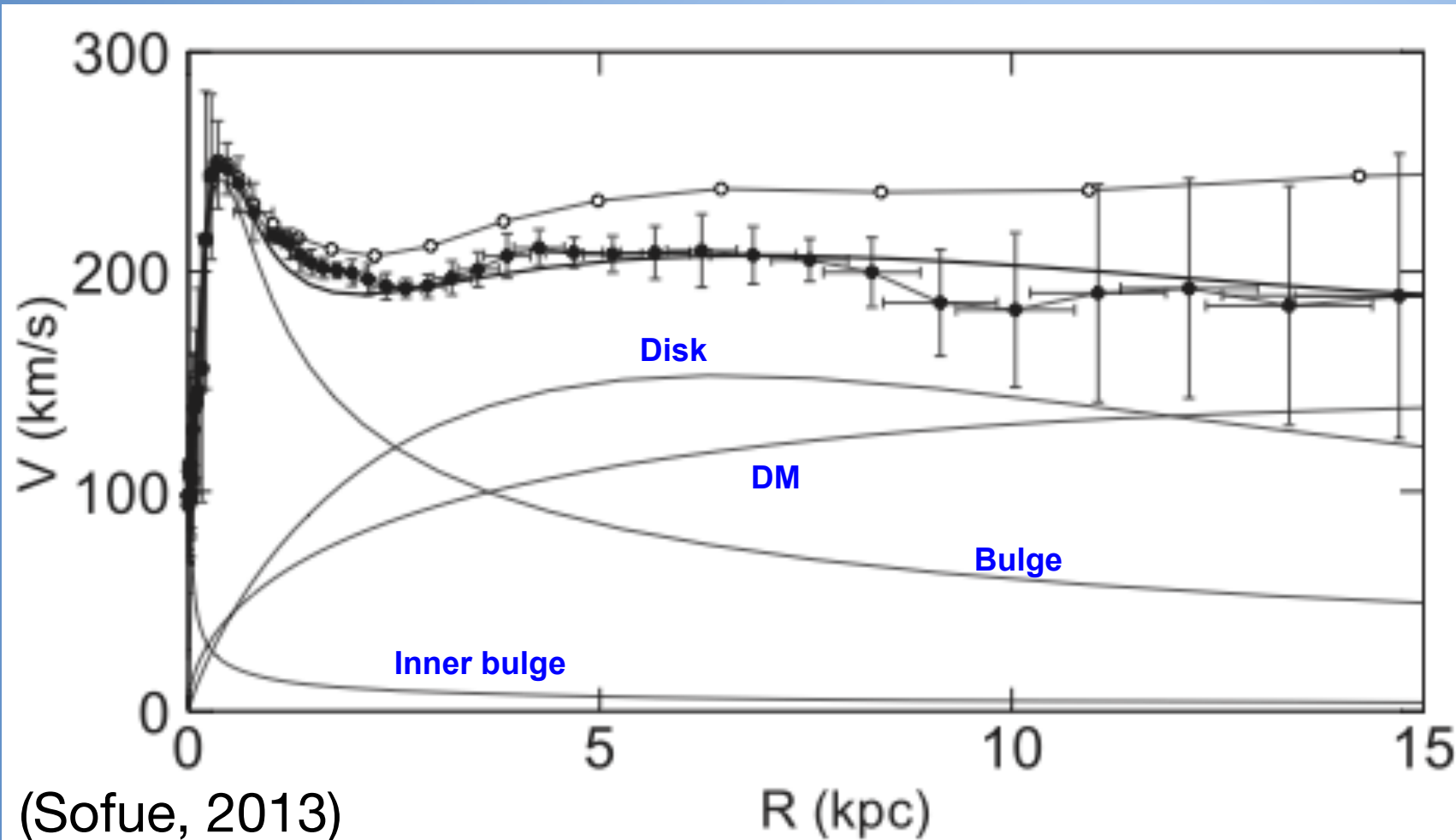
Traditional measurement:

Rotation curve



Traditional measurement:

Rotation curve



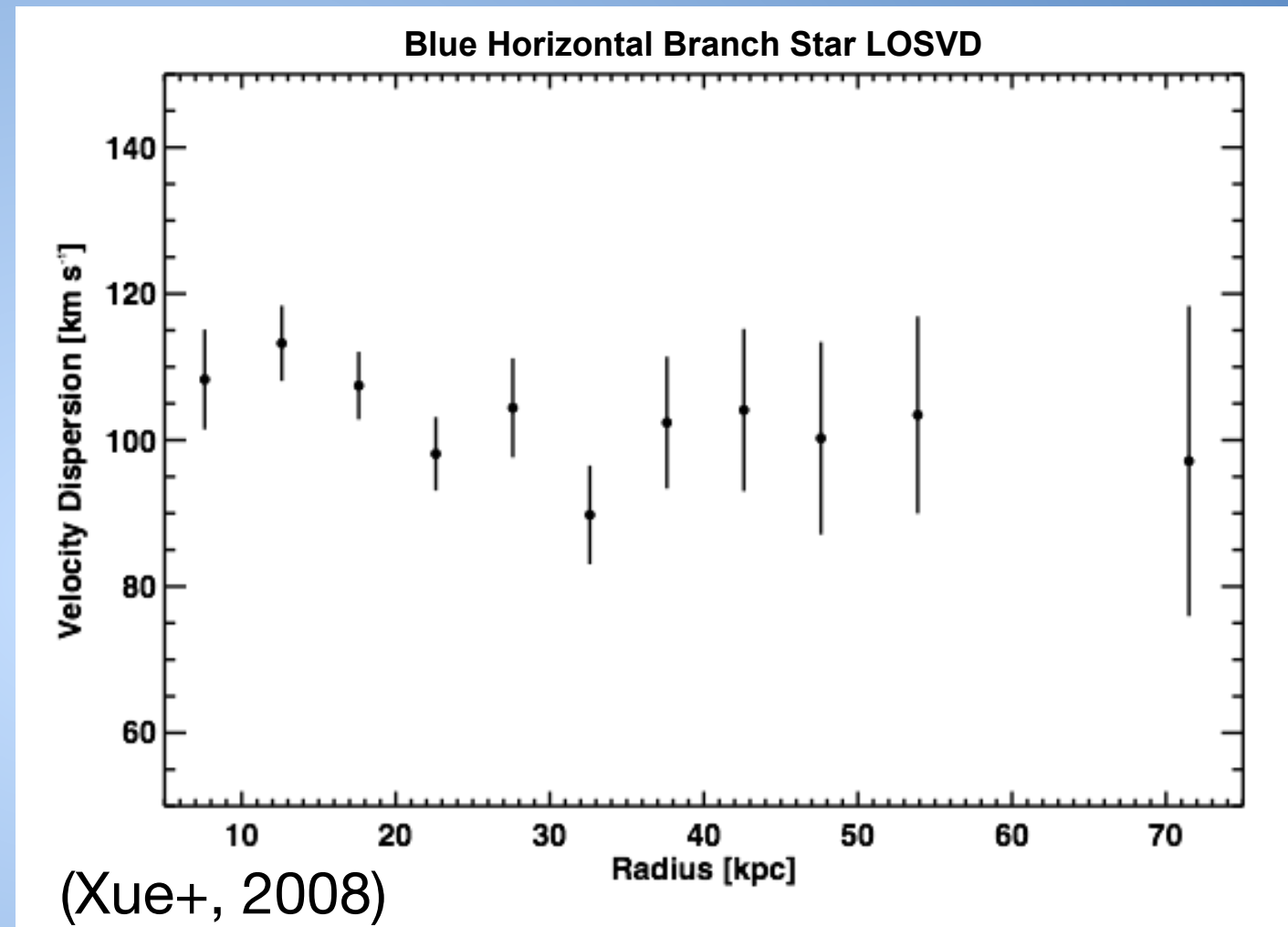
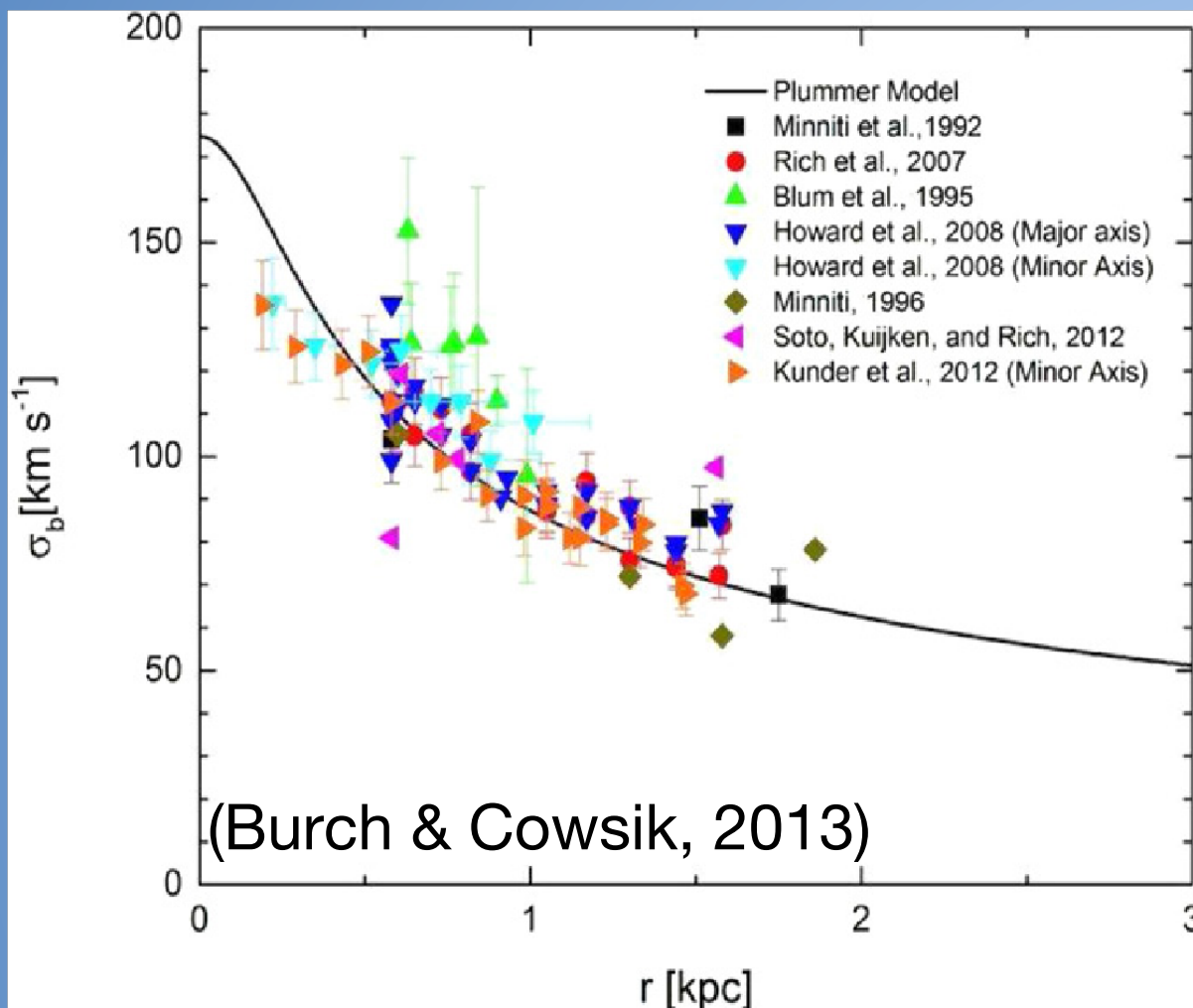
Circular Velocity

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Traditional measurement:

Velocity dispersion



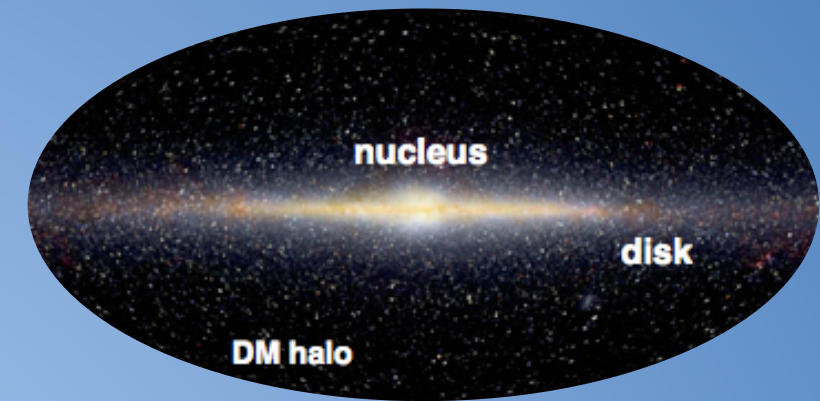
Radial Velocity Dispersion

If isotropic:

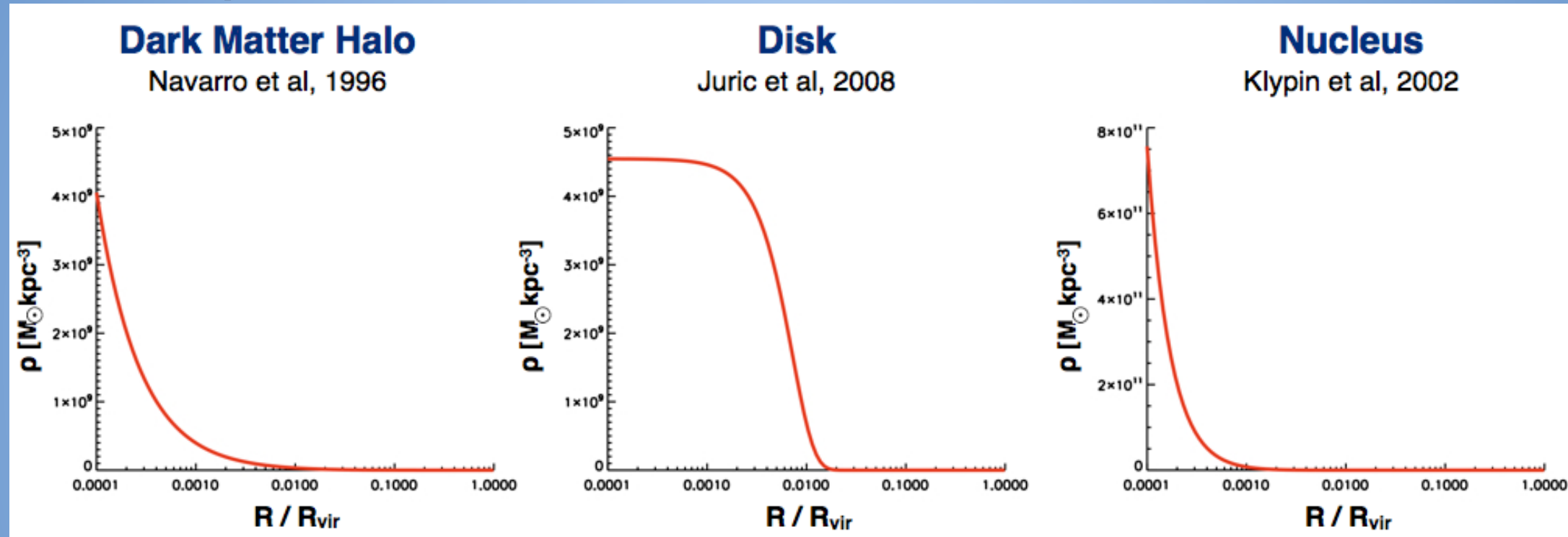
$$\sigma^2(r) = -\frac{1}{\rho_{tr}(r)} \int_{\infty}^r \rho_{tr}(r') \frac{d\Phi}{dr'} dr'$$


Mass models:

Connecting observations to density profiles



Model Components:

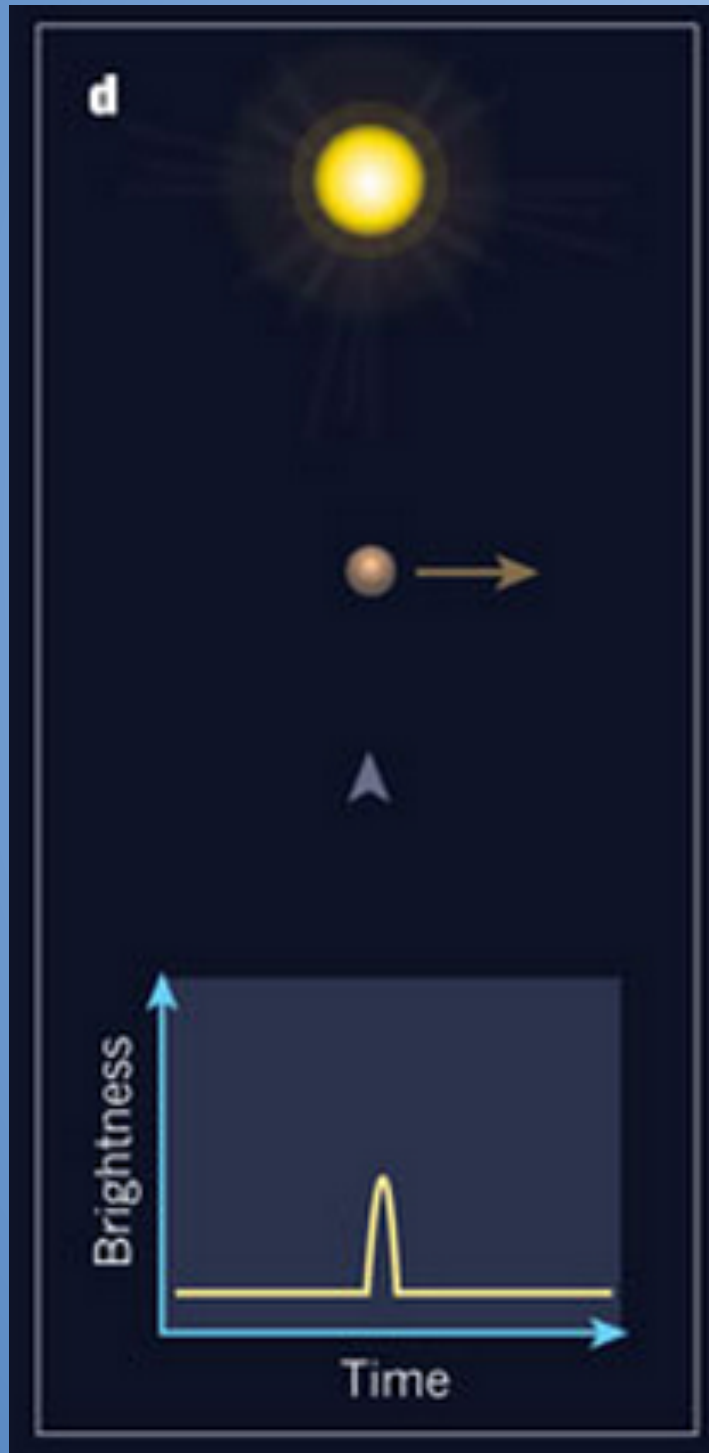


$$\rho_{\gamma}(r) \propto \frac{1}{\left(\frac{r}{r_s}\right)^{\gamma} \left[1 + \left(\frac{r}{r_s}\right)\right]^{3-\gamma}}$$


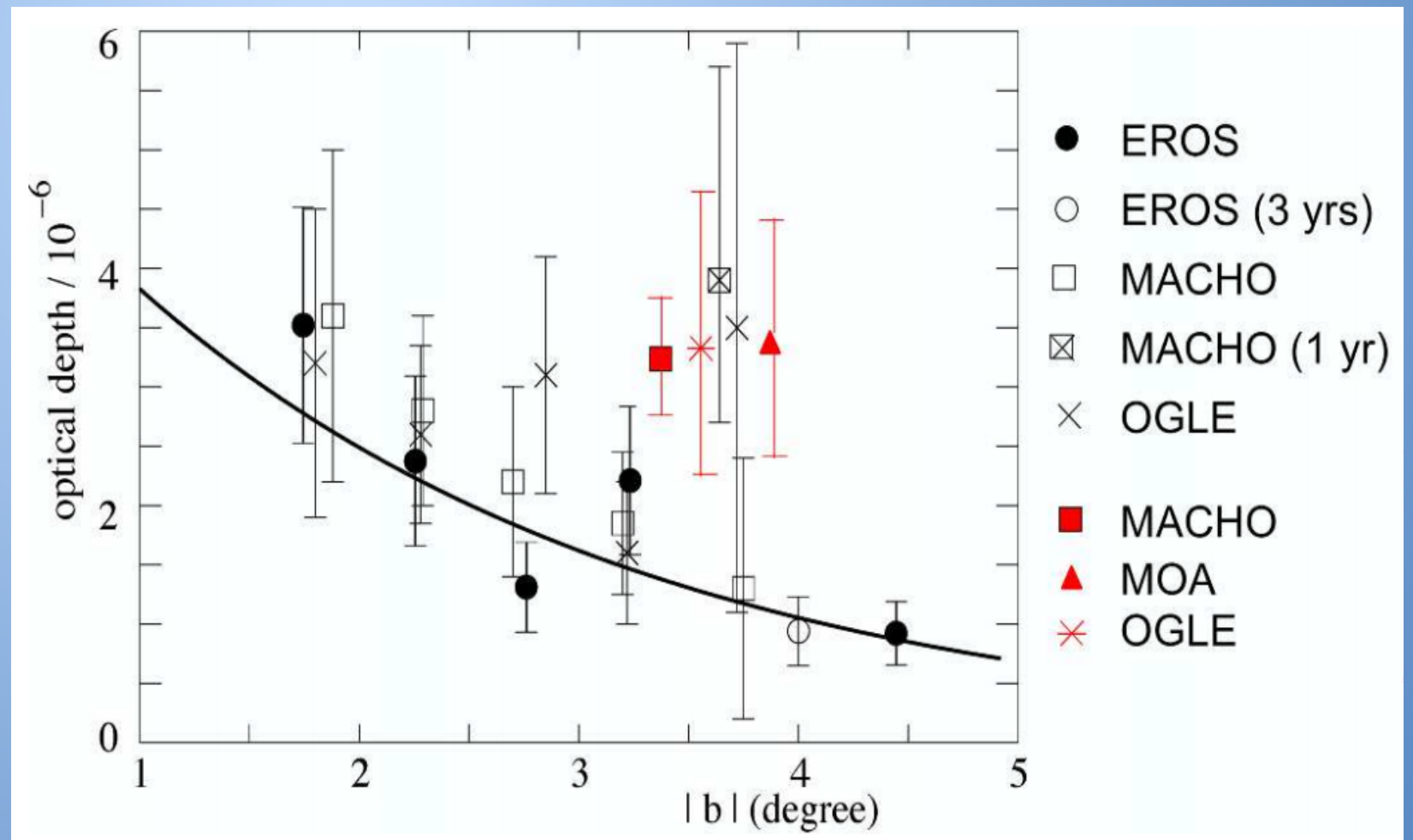
Determine density profile parameters by fitting the model to the data

Traditional measurement:

Microlensing



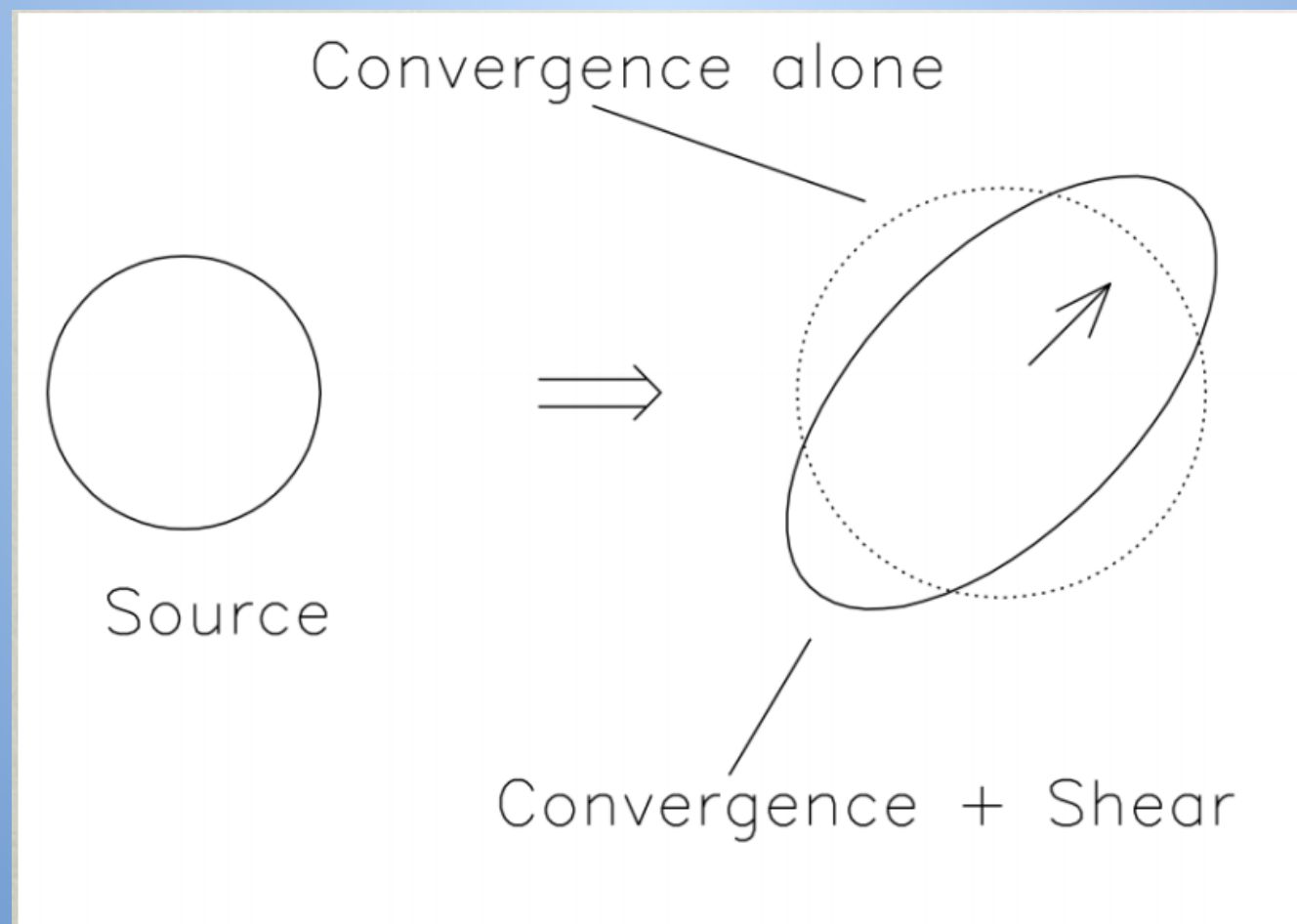
- Compact objects (stars) as lenses
- Constrain mass model
- Survey: OGLE, MACHO, EROS, MOA, DUO



Innovative measurement:

Weak lensing

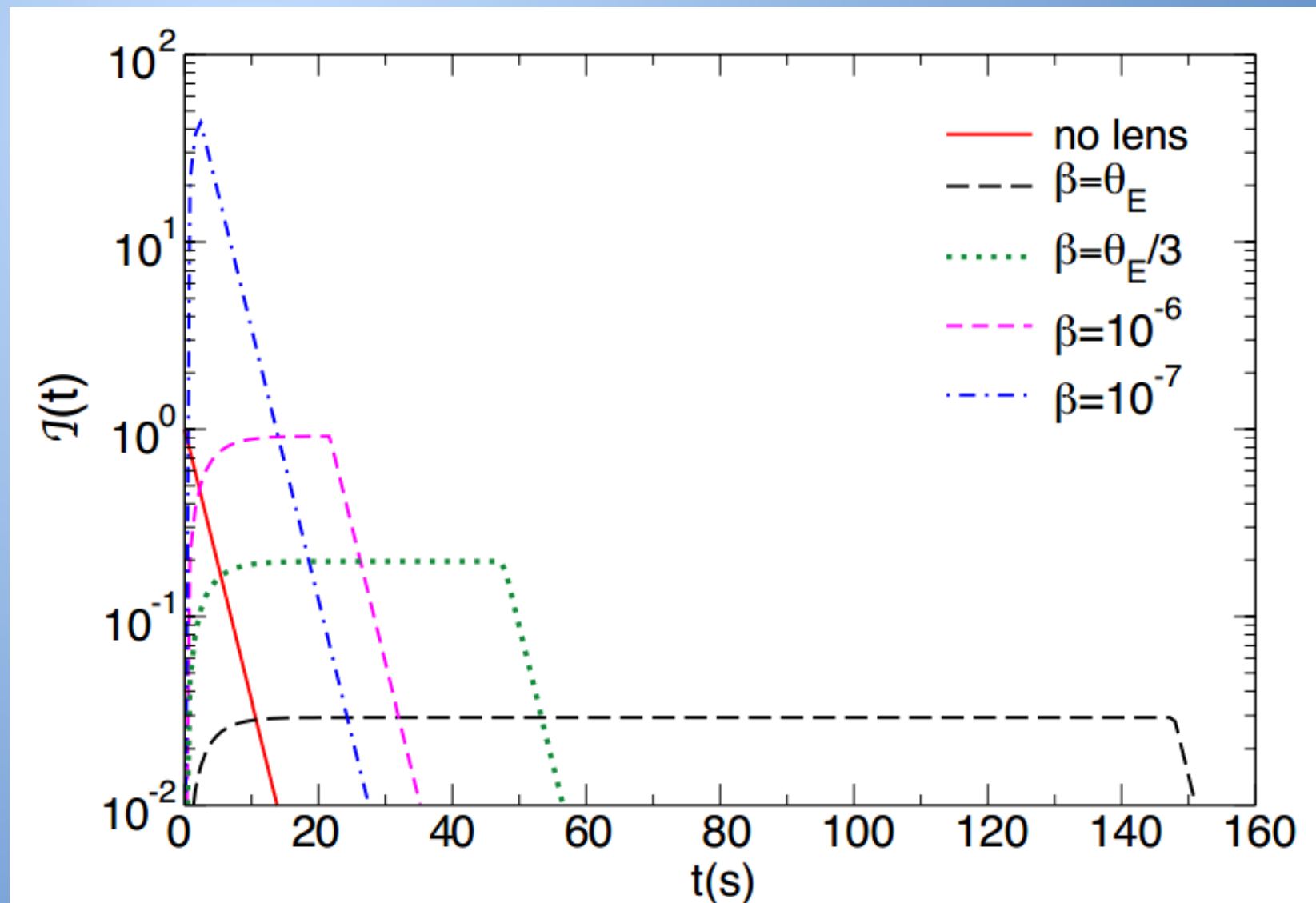
- A statistics game
- Signal \sim Distance involved
- Cosmological distance Signal/Noise \sim 0.01



Innovative measurement:

SNe Neutrino lensing

- Enough neutrinos from a supernova explosion
- Similar to microlensing
- Lens is the central black hole
- Magnification and delay
- 10s of million yrs



Innovative measurement:

DM annihilation signal

Ideal world:

- LHC produces DM

- direct detection sees seasonal modulation, directional dependence

- we know everything about DM particle's properties

- use annihilation signal for density profile

- Still offers new information: diagnose sims' accuracy, baryon effects

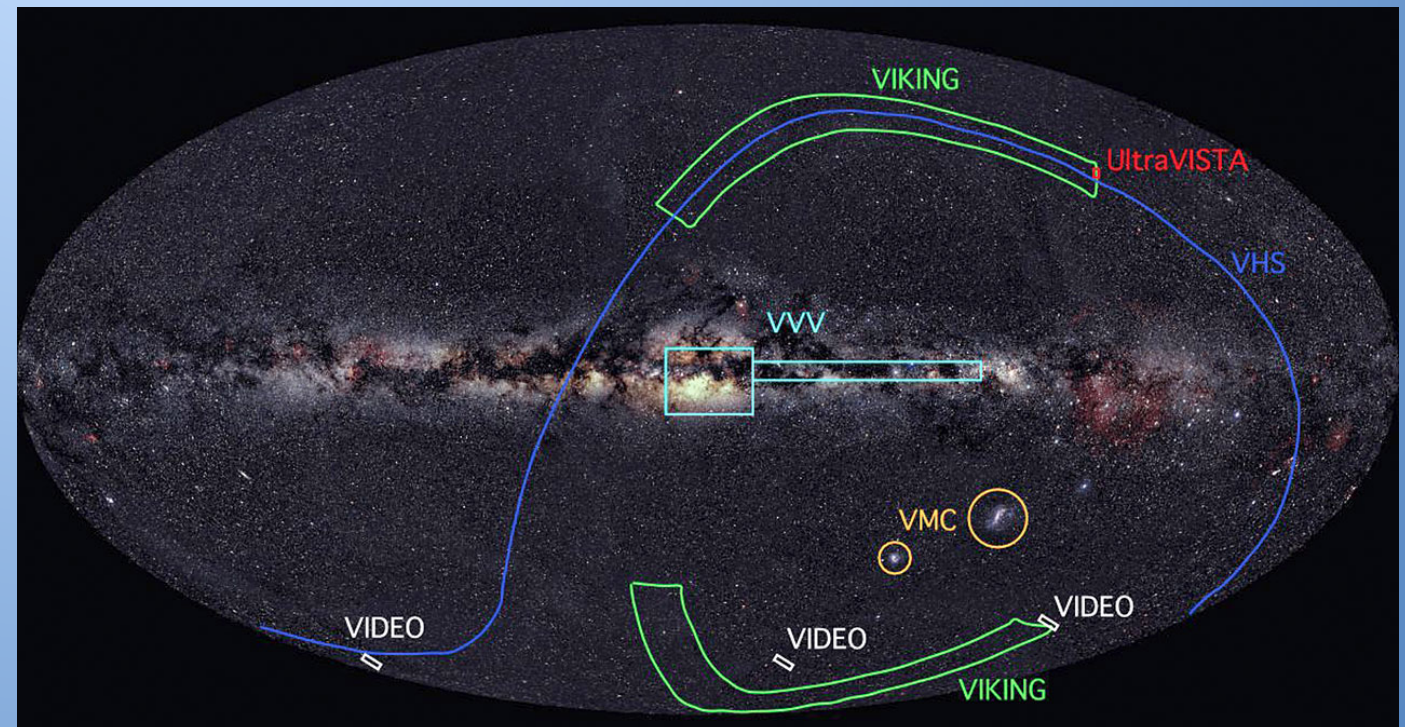
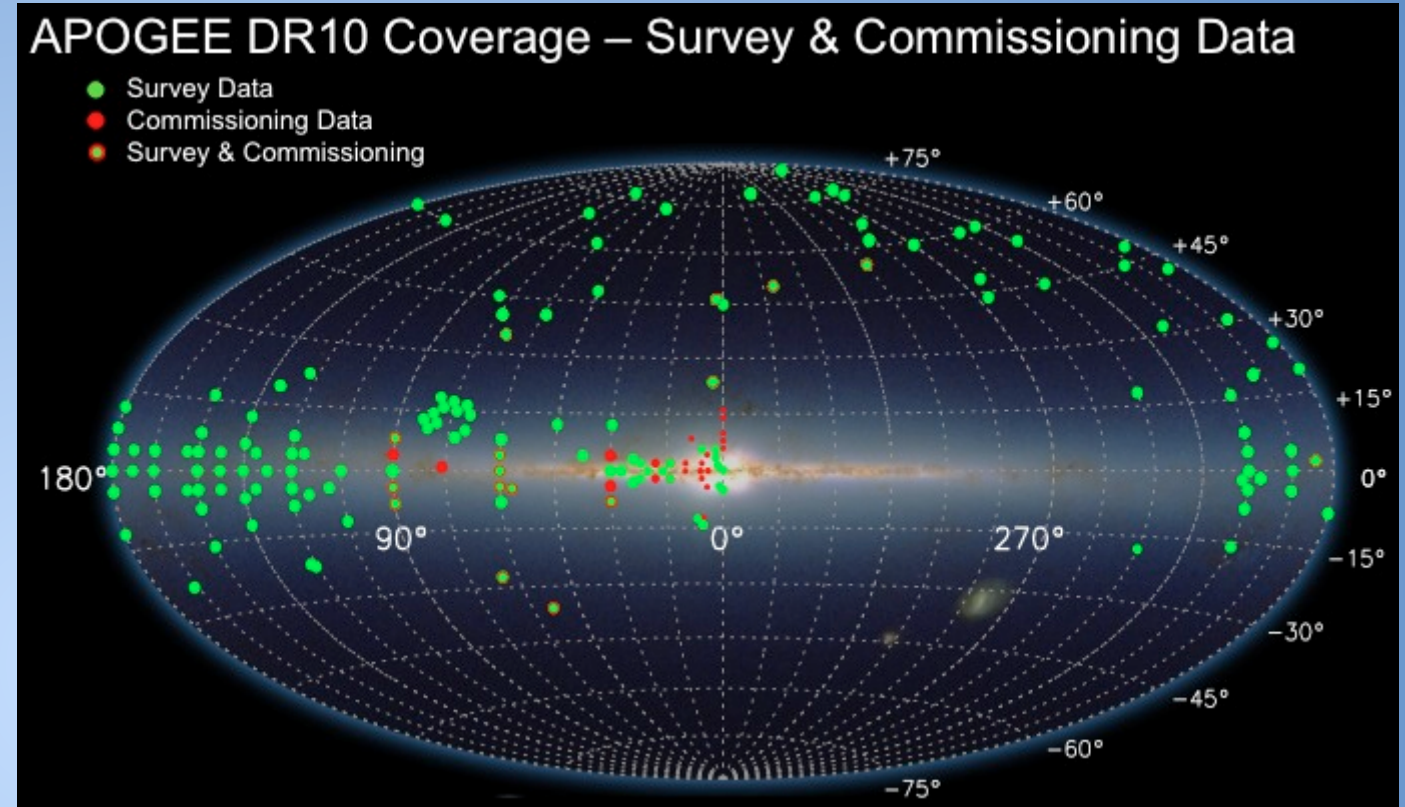
Current Surveys

-SDSS APOGEE

- Apache Point Observatory Galactic Evolution Experiment
- measures radial velocities
- final data release Dec 2014

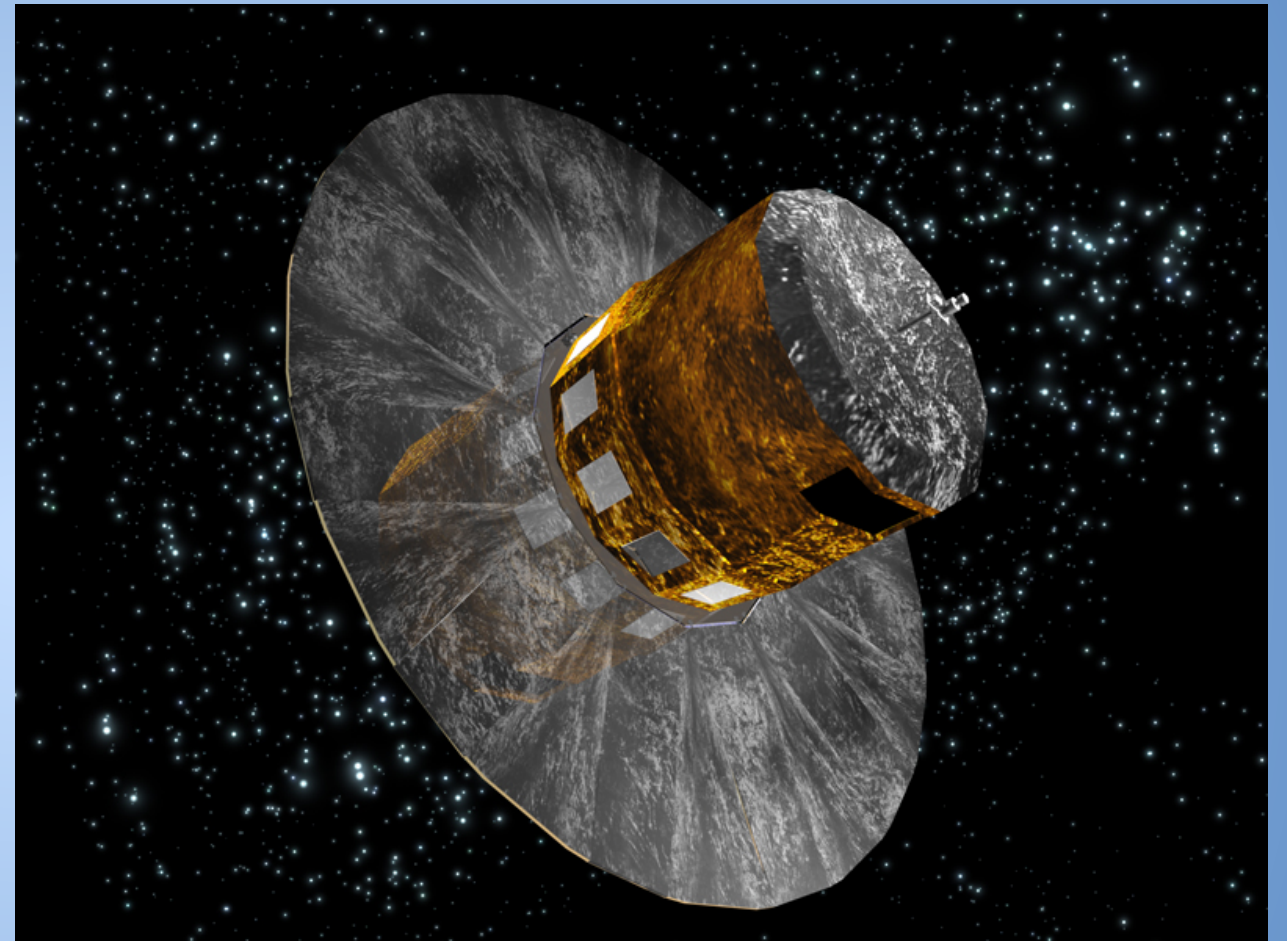
ESO VVV Survey

- VISTA Variables in the Via Lactea
- Infrared Microlensing survey of galactic bulge
- Ongoing

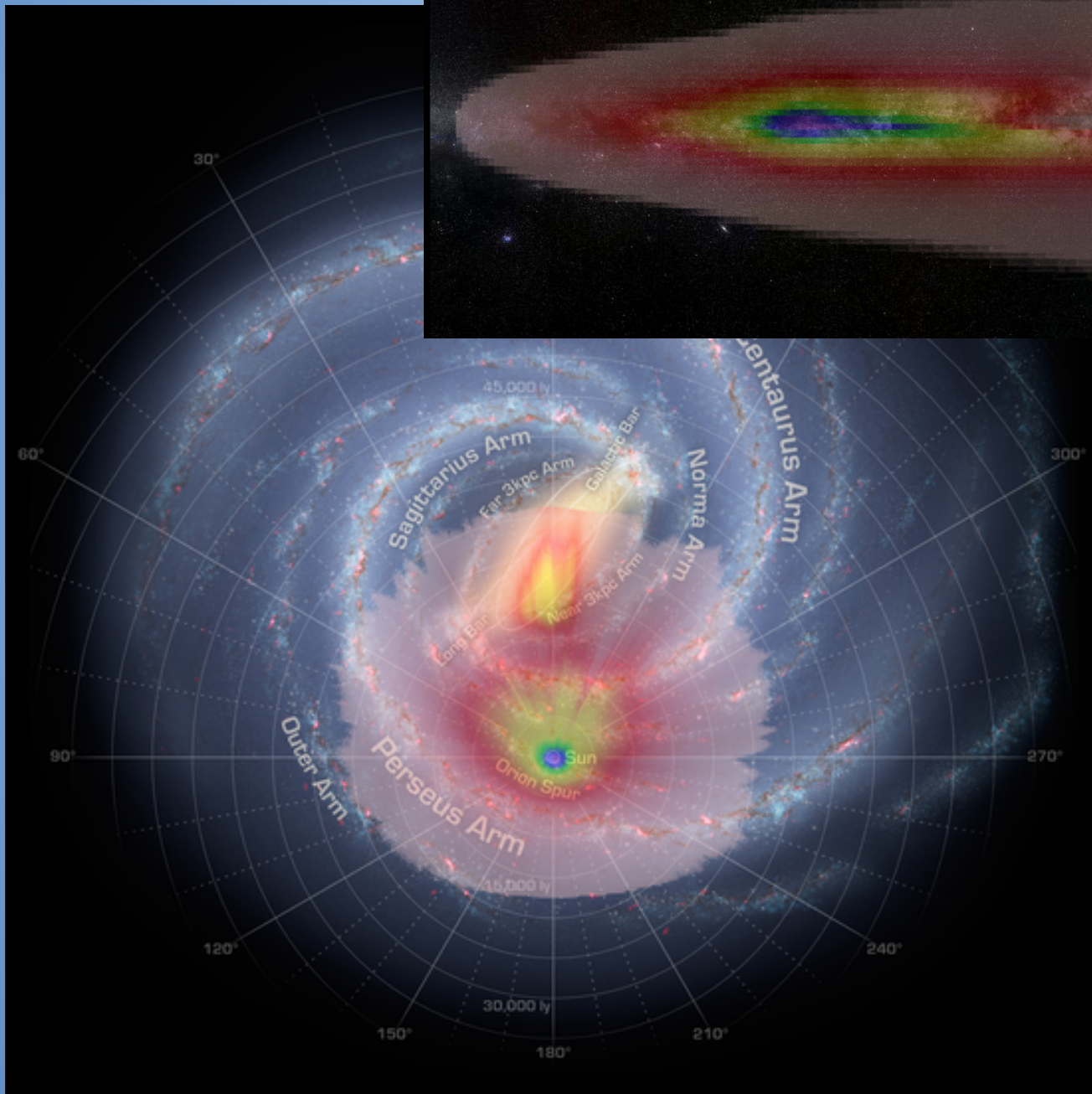
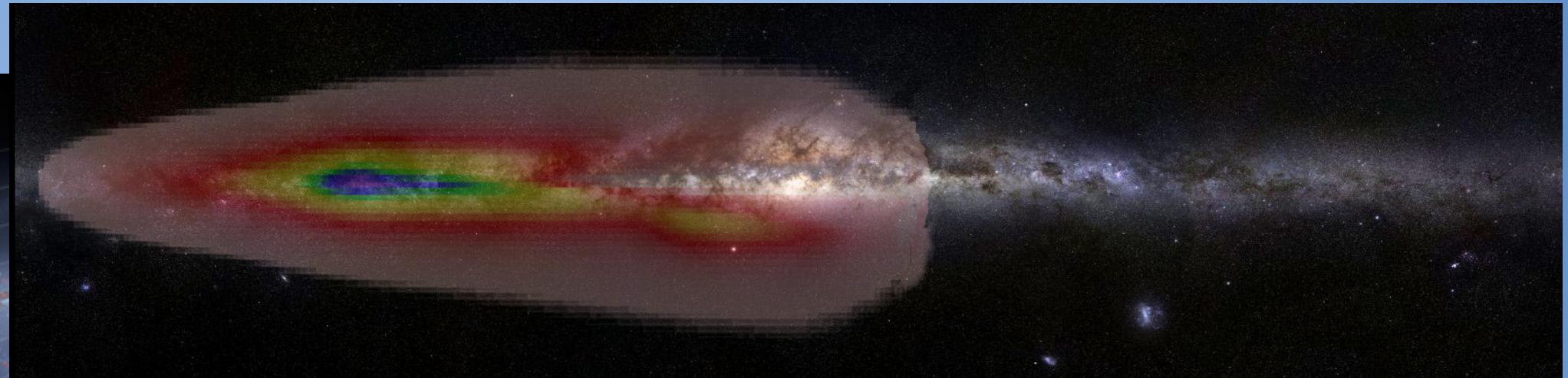


New Experiments: Gaia

- Launched December 2013
- First data release 2016, final data set 2022
- 3D positions and 3D velocities for a billion stars -> huge amount of stellar tracer data
- Spectral information for determining which population they belong to
- Similar concept to Hipparcos satellite operational from 1989-1993.



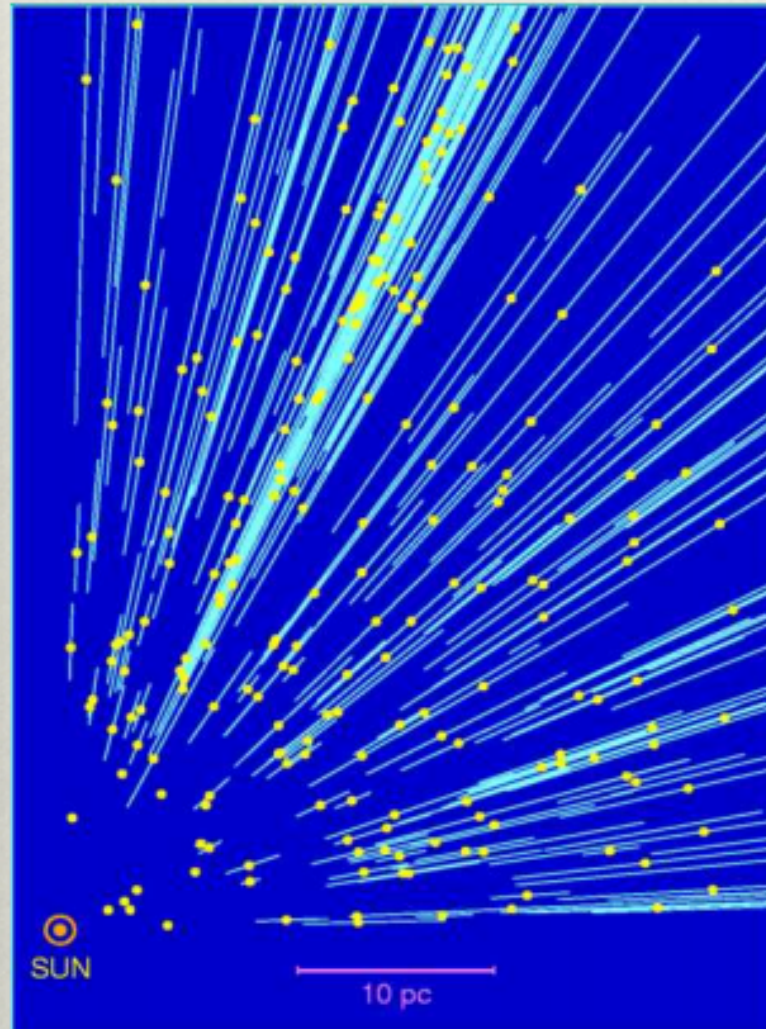
New Experiments: Gaia



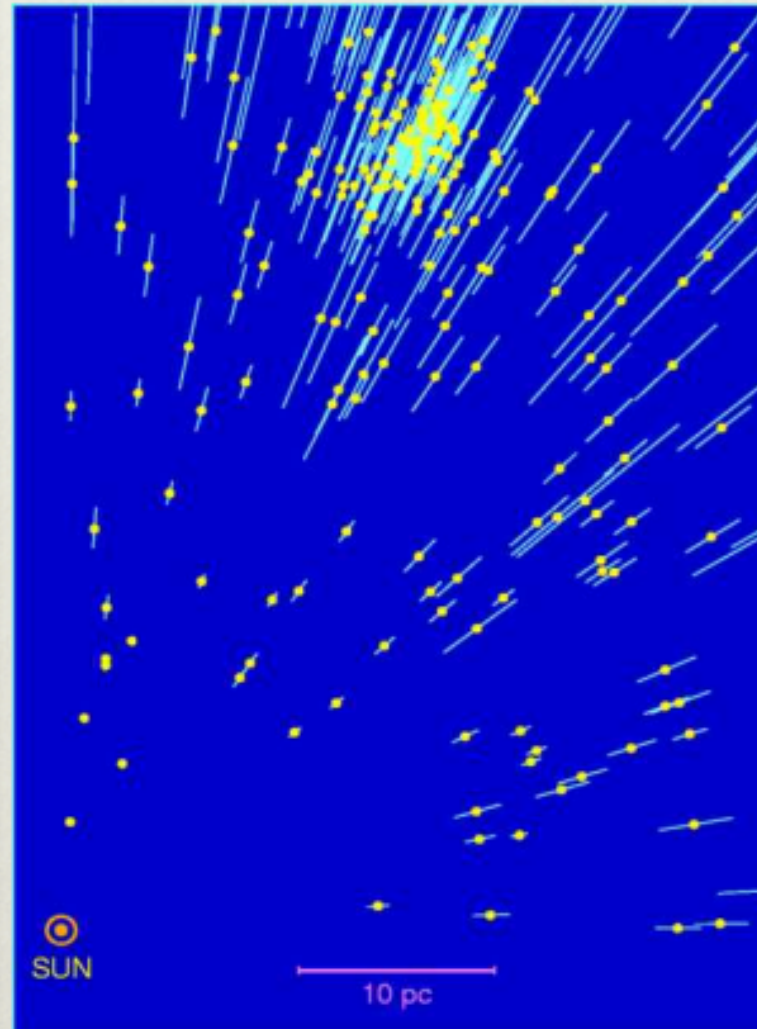
- Estimated distribution of Gaia catalogue.
- Will reach the galactic bulge
- O(100) improvement in position accuracy over Hipparcos
- Radial velocities with accuracy of 3 km/s

New Experiments: GAIA

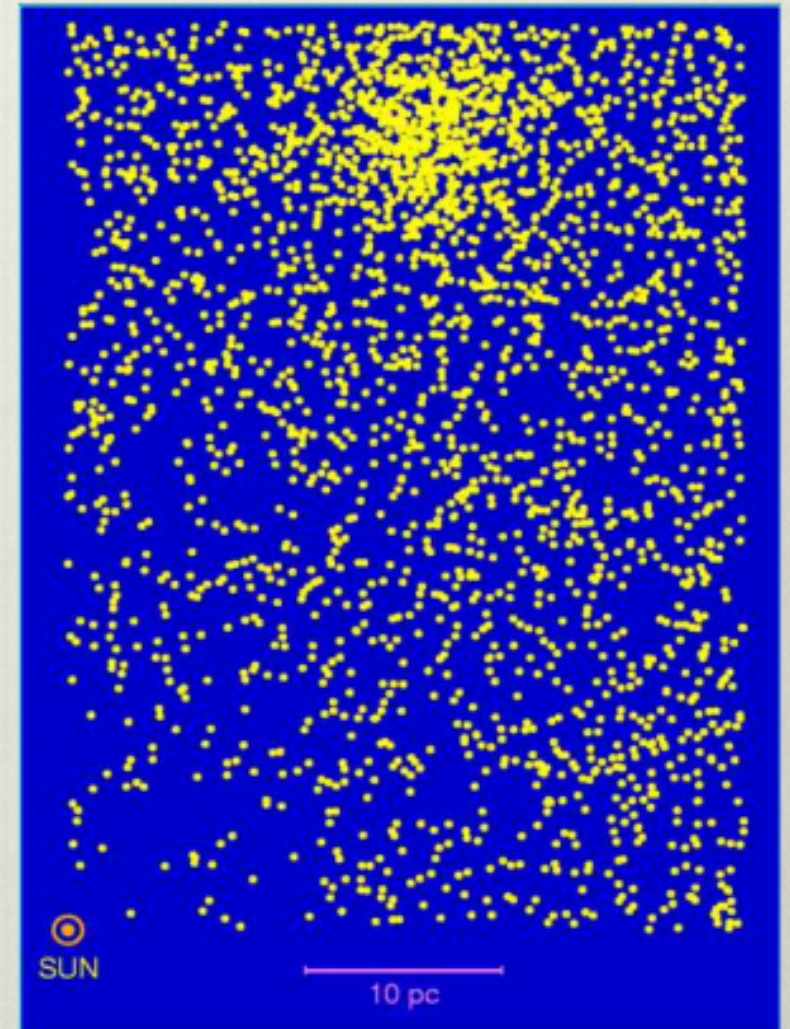
Courtesy Paola Marrese



Ground



Hipparcos



Gaia

Shamelessly lifted from a talk by Marco Castellani

Future Experiments - Astrometry

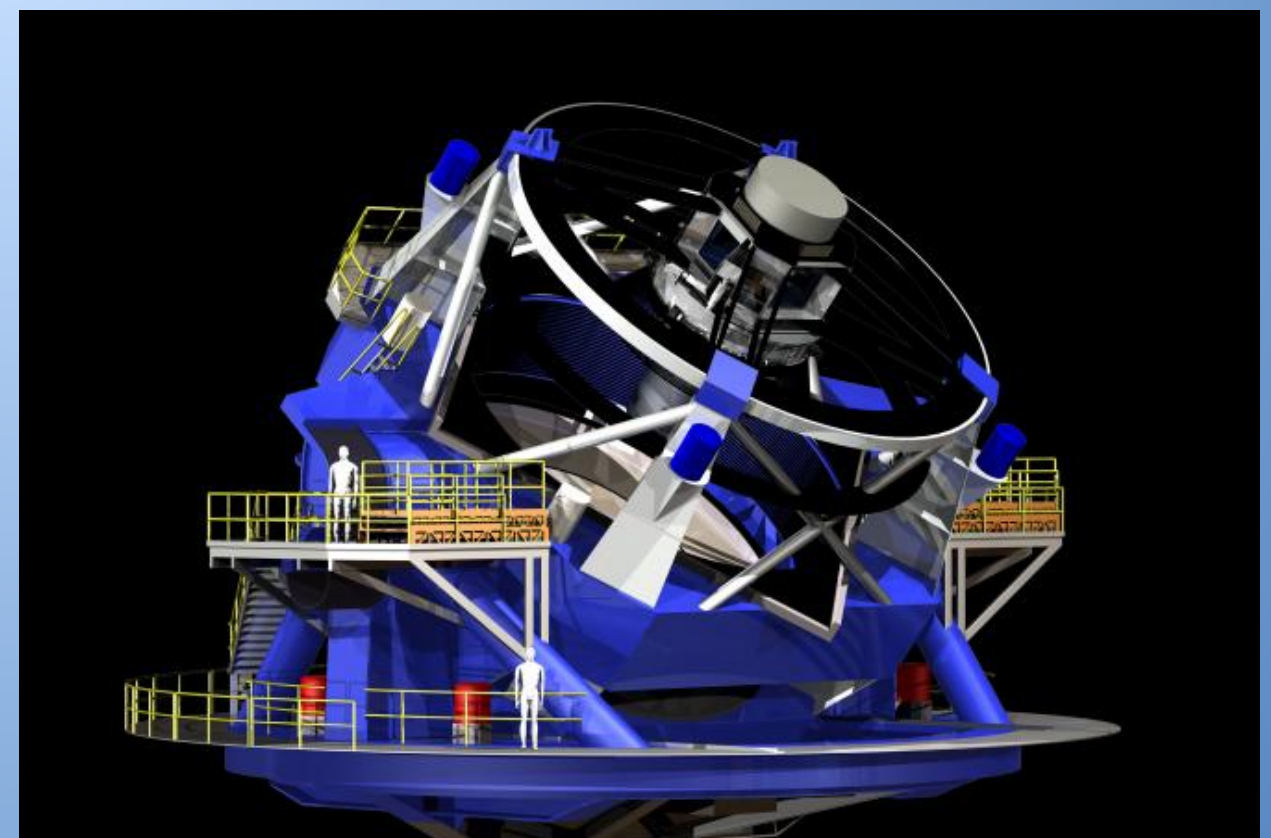
WFIRST - Wide Field Infra-Red Survey Telescope

- Launch post 2020
- Microlensing survey
- Stellar proper motions of 300 million stars in the bulge with 0.3% accuracy

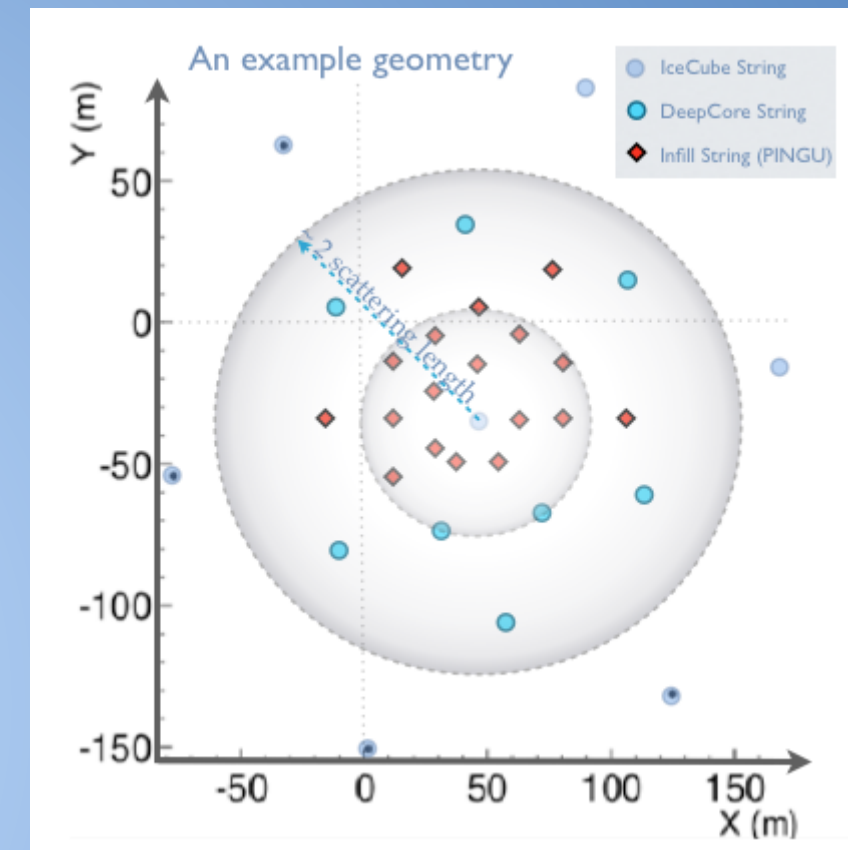
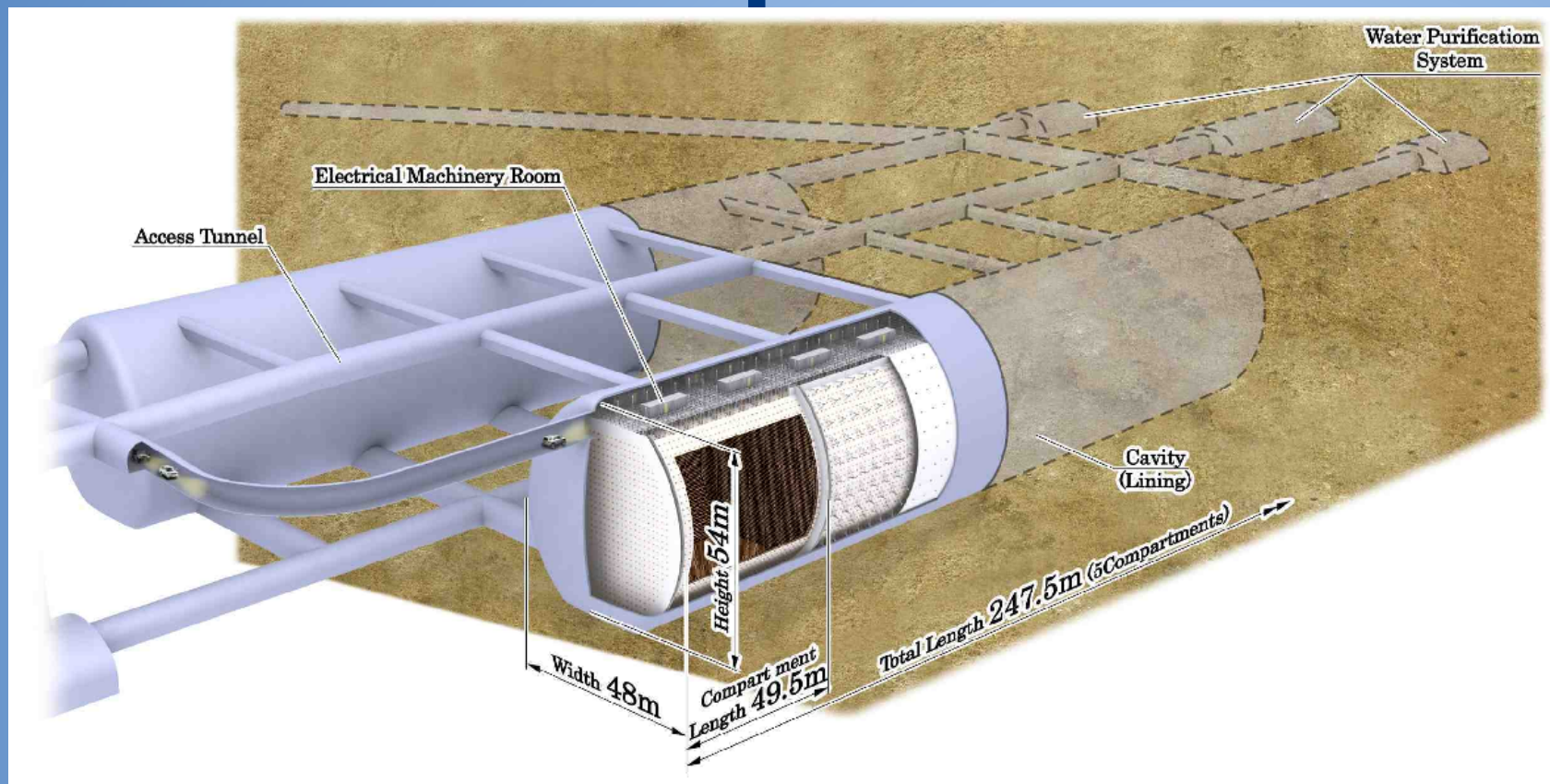


LSST - Large Synoptic Sky Telescope

- First light 2021
- large aperture, large field of view
- survey the whole sky twice a week
- extend GAIA survey by 4 magnitudes
- similar accuracy to faint stars with GAIA



Future Experiments - Neutrinos



Hyper-Kamiokande

- successor to Super-Kamiokande
- would see 110000 events from supernova

PINGU Experiment

- Addition to IceCube-DeepCore detector at South Pole
- denser strings at detector centre
- would see 1 million neutrinos from supernova

Astrometry:
Gaia, WFIRST,
LSST

Tracer Stars

Mass Model

DM

Stars

Gas

Dust

Compact Objects

What
we want

Multispectral Surveys

Microlensing

Other Observations

Summary

We can probe the DM density profile of the Milky Way's central kpc with:

Traditional observations

- Rotation curve
- Velocity dispersion

Innovative observations

- Weak lensing
- SNe neutrino lensing
- DM annihilation

With the DM density profile, we can

- Test our understanding of sims' faithfulness and DM particle's nature
- Understand baryon feedback on DM
- Help solve galaxy formation