

Dark Matter

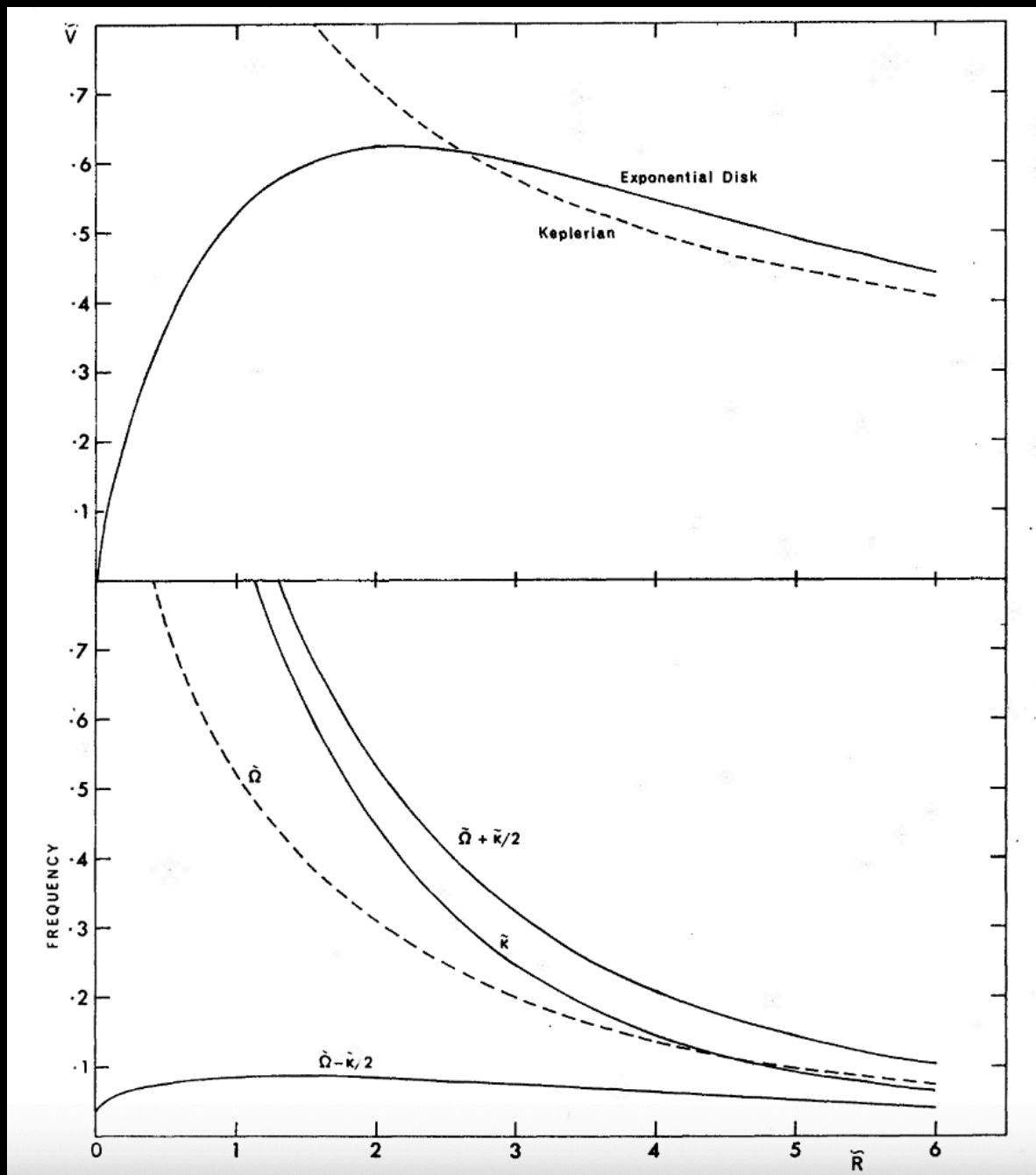
Ay 20, Fall 2019, Lecture 18

Vikram Ravi

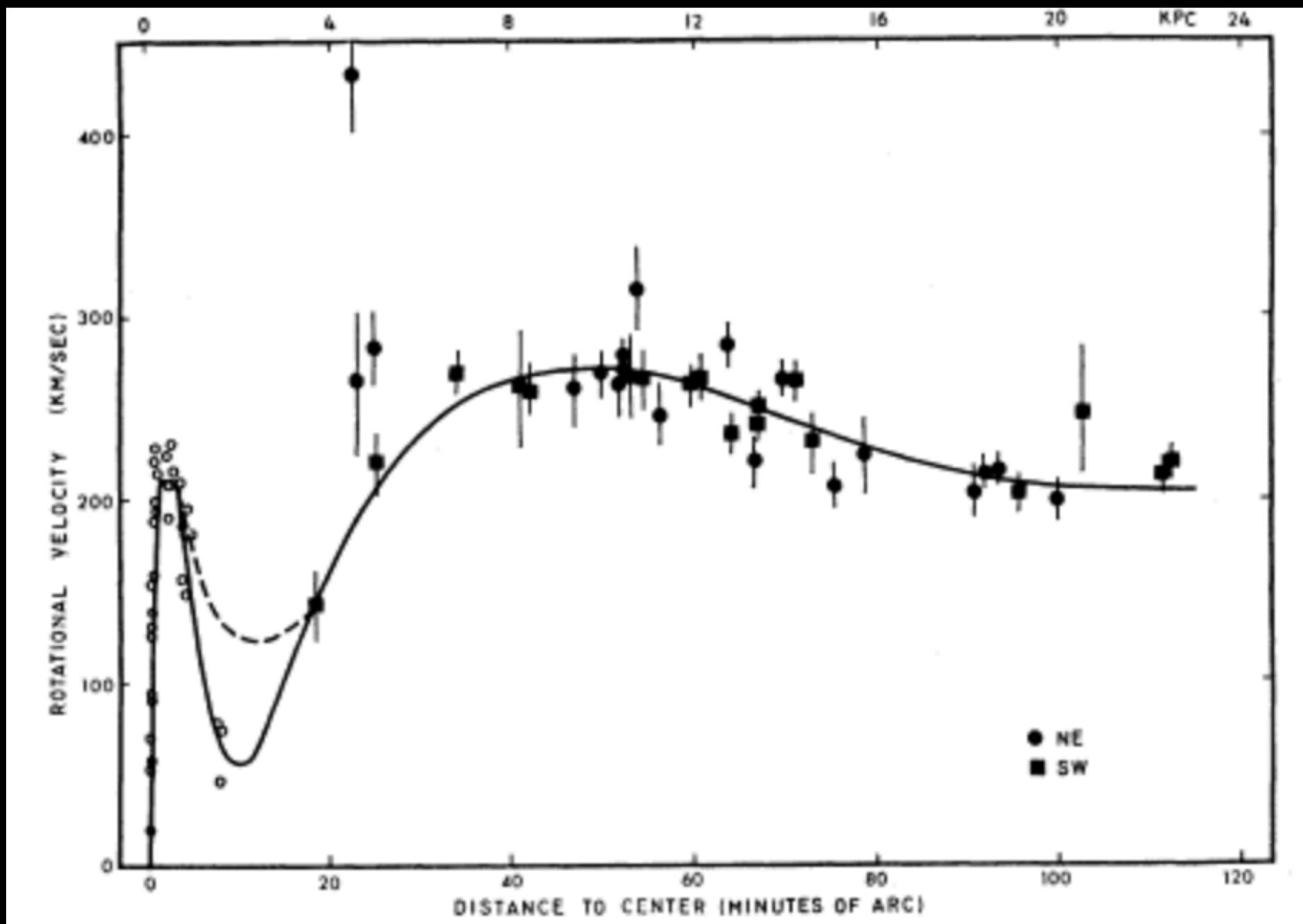
Freeman (1970) properties of self-gravitating disks.

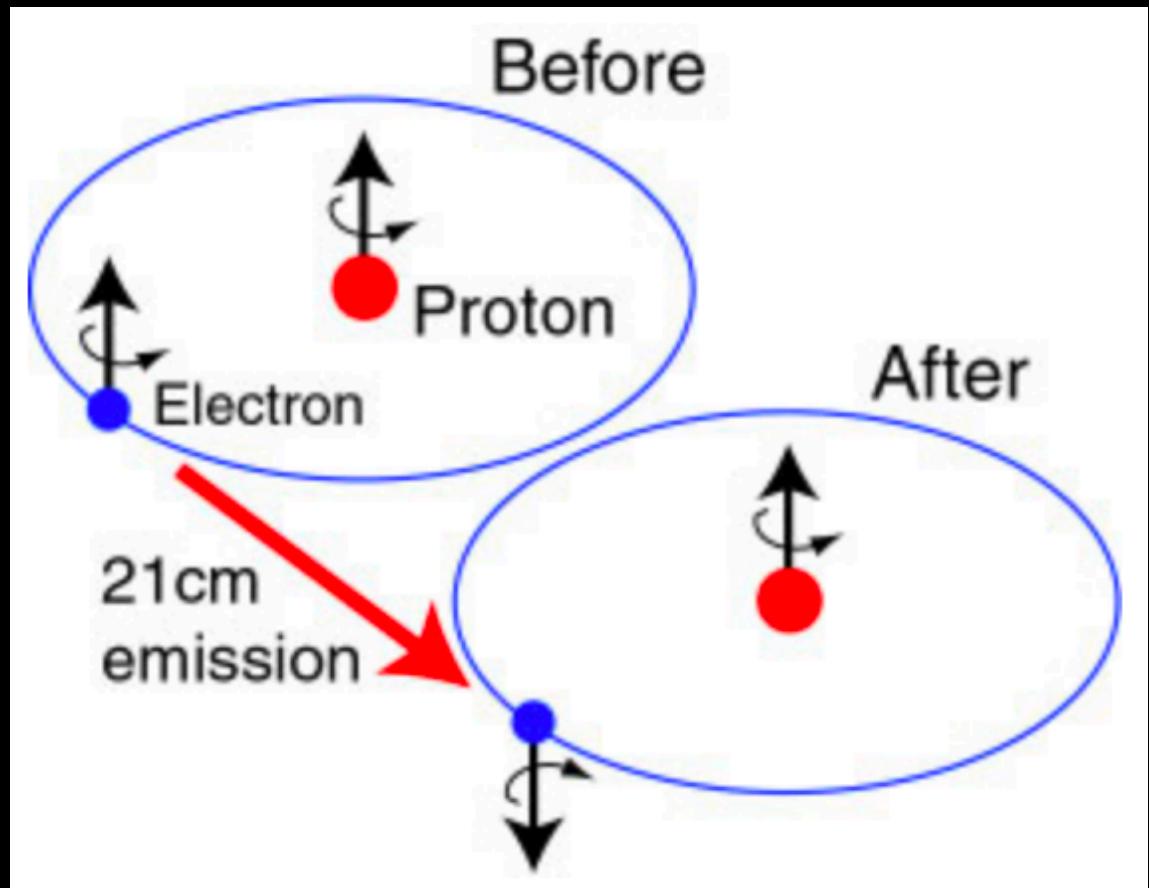
Circular velocity

Angular velocity,
etc.

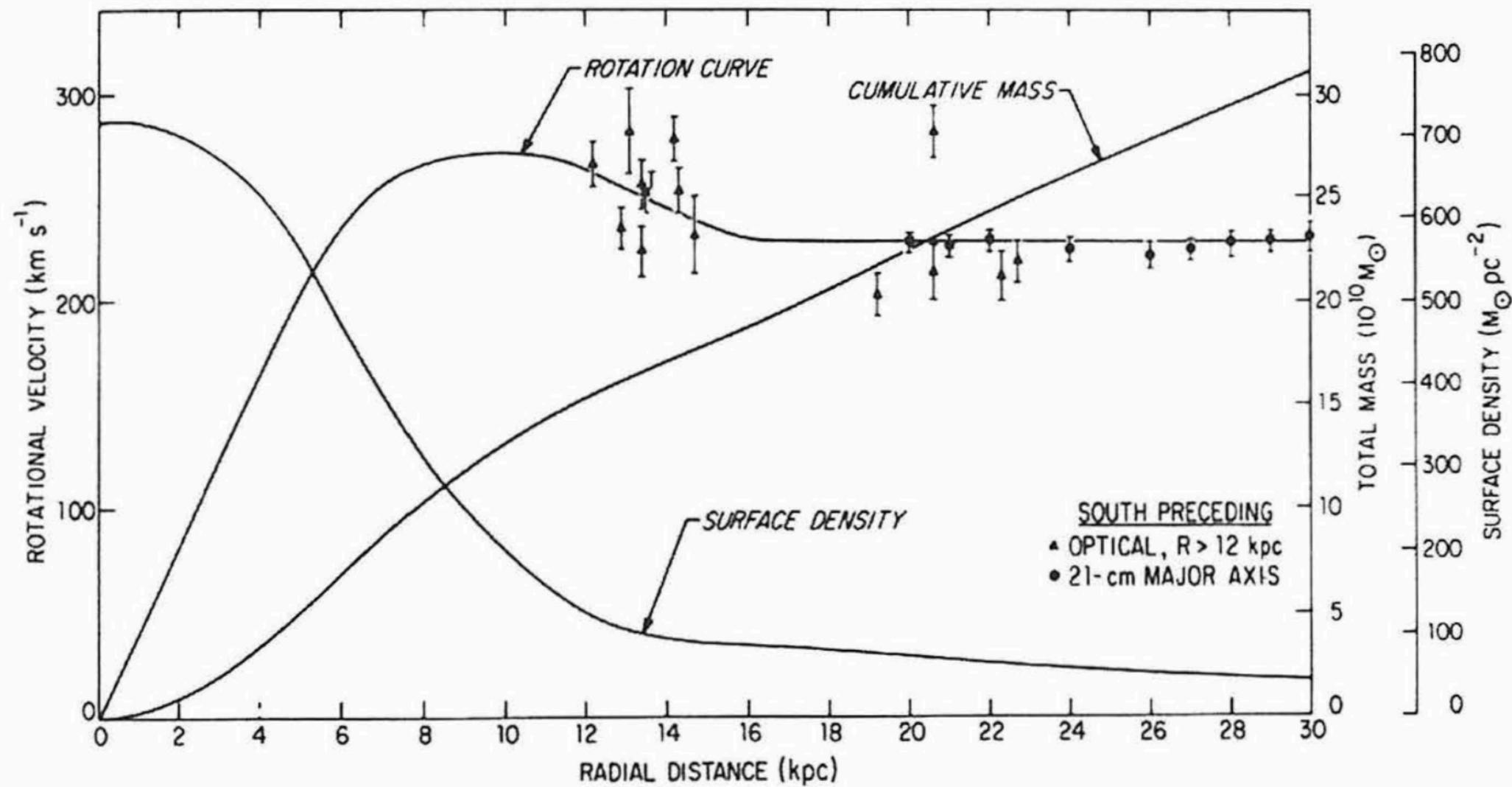


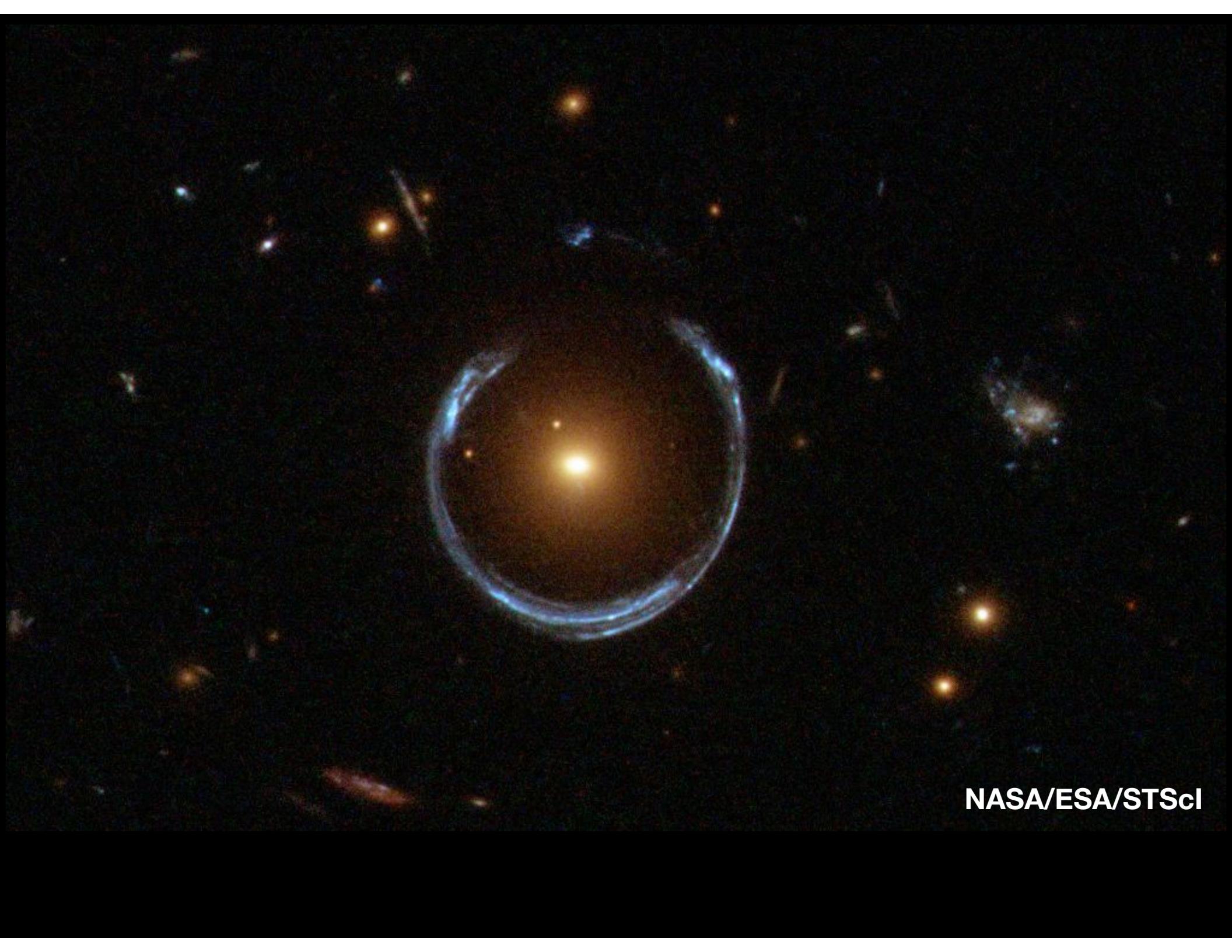
Rubin & Ford (1970) rotation curve of Andromeda from HII region spectra





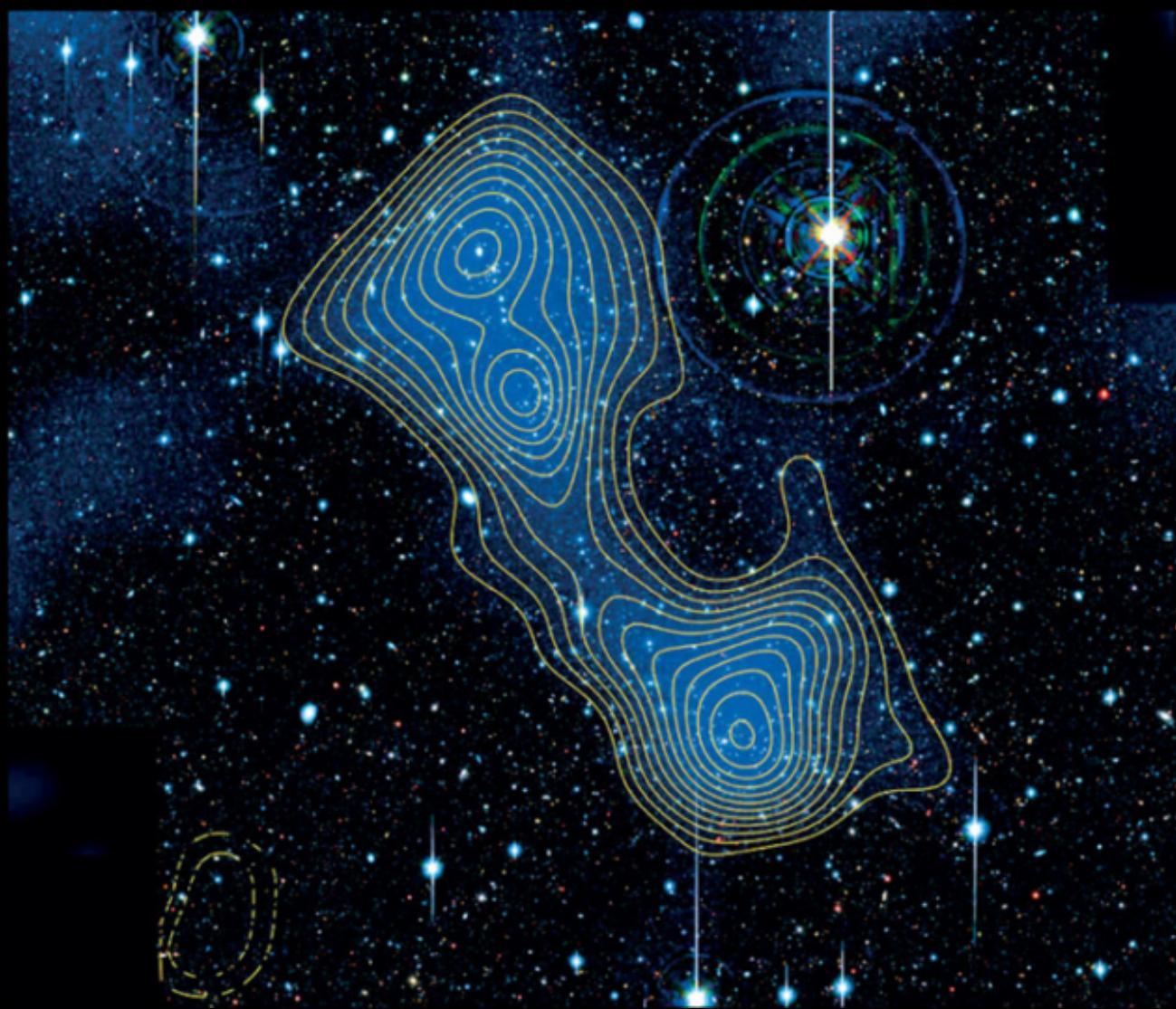
Radio data from the Owens Valley Radio Observatory (Roberts & Whitehurst 1975)



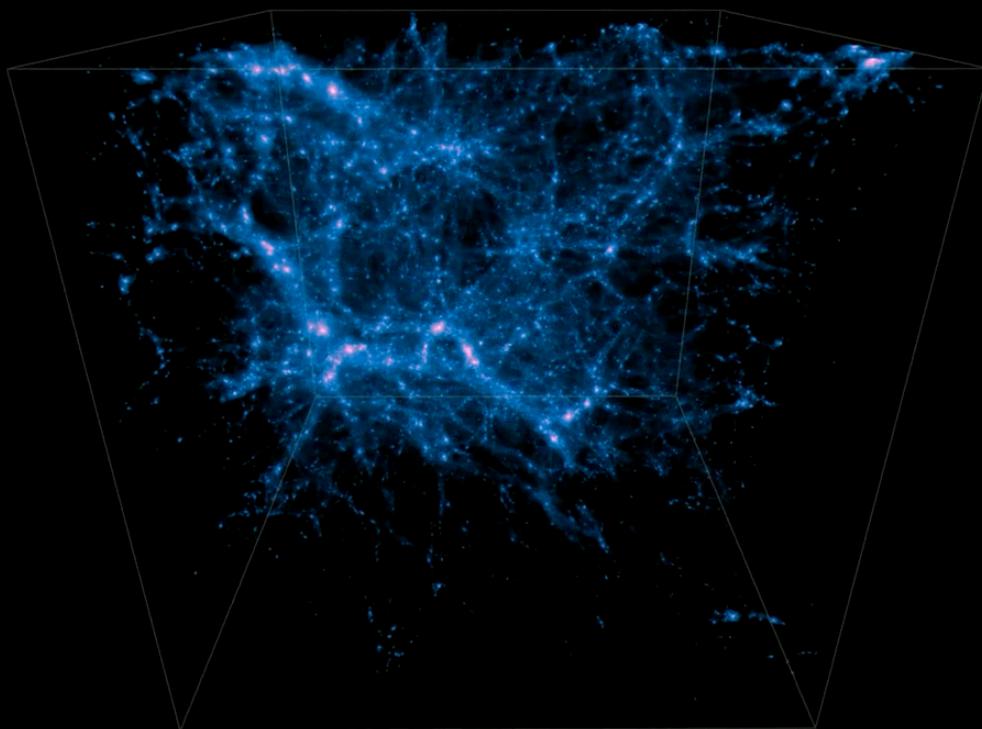


NASA/ESA/STScI

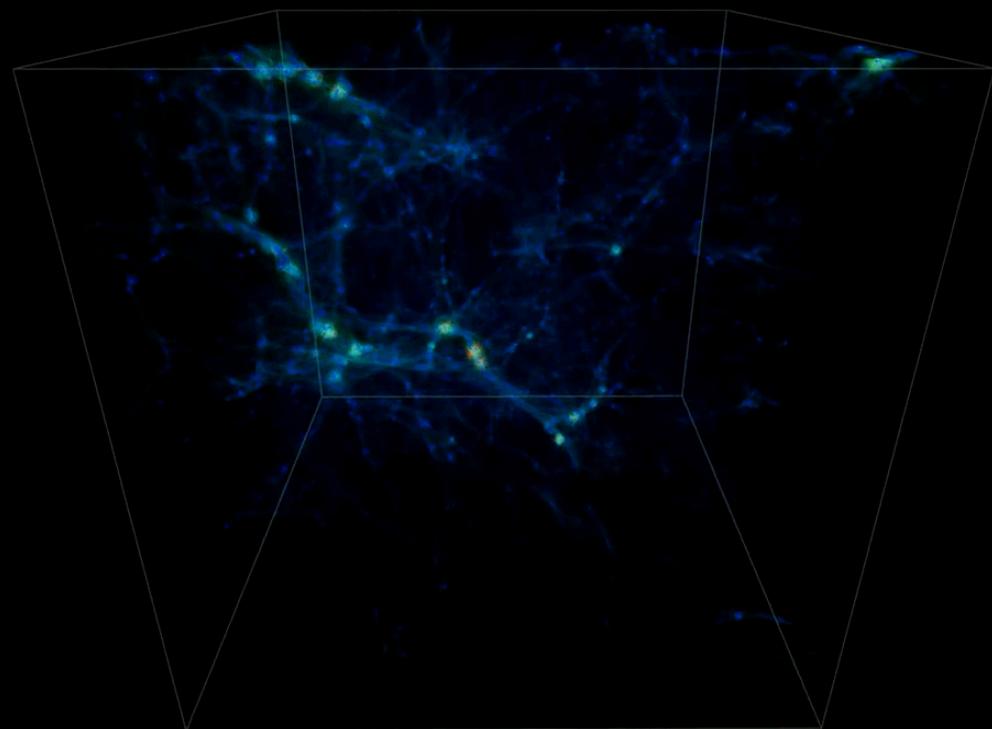
Dietrich et al. (2012) map of dark matter in clusters A222 and A223.



Dark matter density



Temperature of normal matter



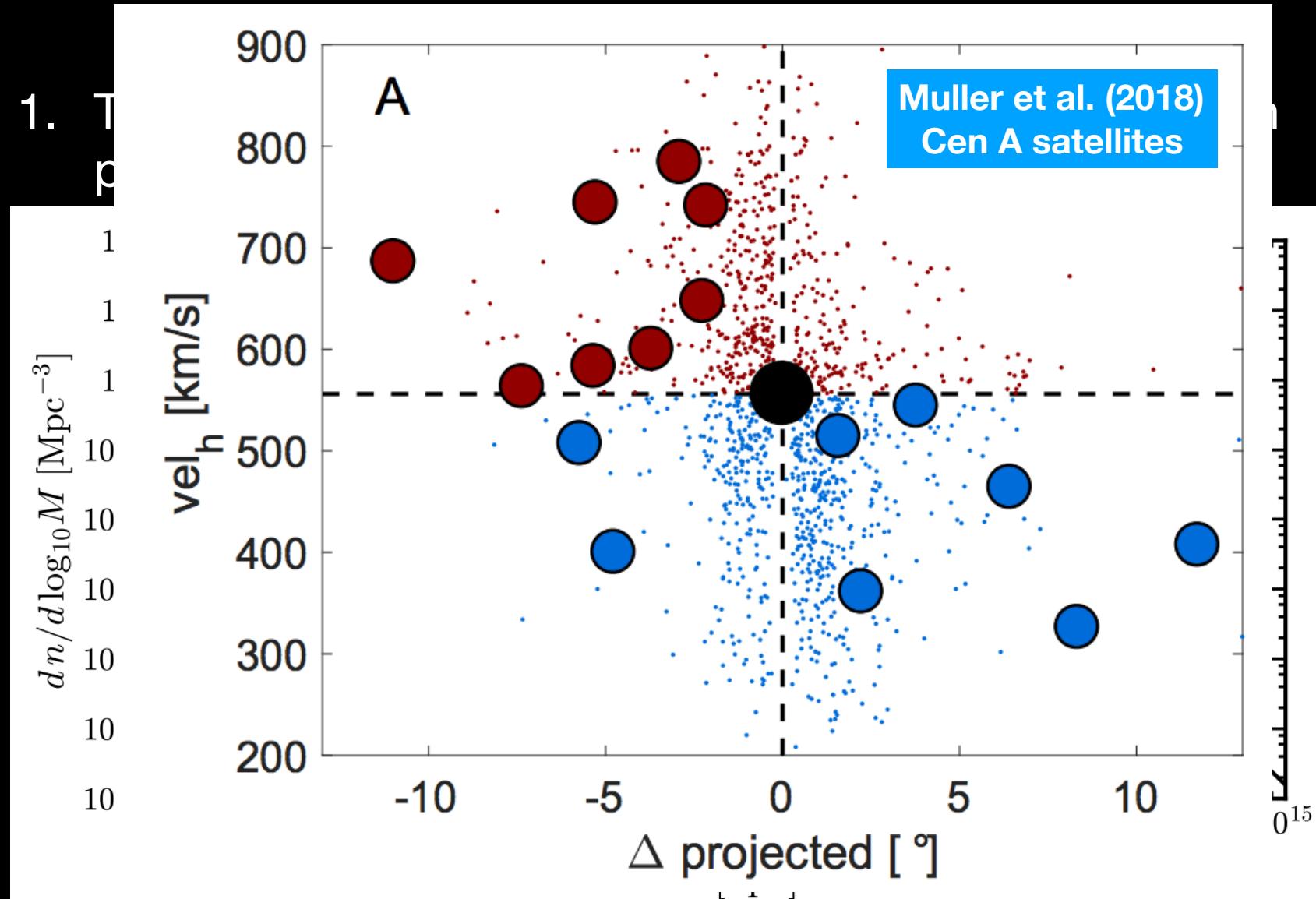
redshift : 3.95
Time since the Big Bang: 1.6 billion years

stellar mass : 2.1 billion solar masses

ILLUSTRIS

M. Vogelsberger, et al., *Nature*, **509**, 177 (2014)

Small-scale problems in (Lambda)-CDM cosmology

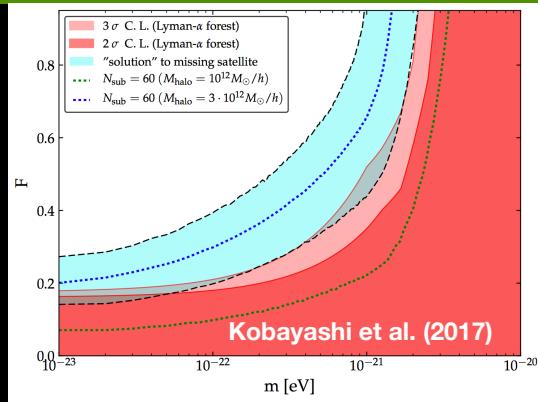


e.g., Bullock & Boylan-Kolchin (2017)

Ultralight scalar dark matter

Forms BECs on few-kpc scales (the de Broglie wavelength), solving the missing-galaxies and core-cusp problems.

Runs afoul of the Ly-alpha forest.



$10^{-6} \quad 10^{-3} \quad 10^4$

$10^9 \quad 10^{13}$

$10^{67}-10^{68}$

Mass (eV/c²)

$10^{-23} \quad 10^{-21}$

Light (scalar) bosons

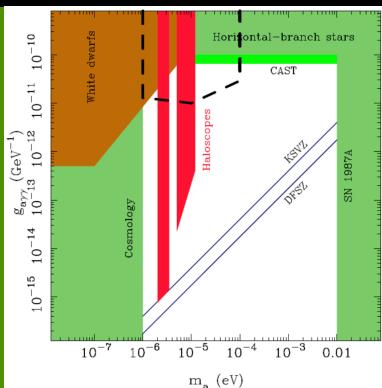
Solves Lee-Weinberg 2GeV bound by postulating scalar bosons. Motivated by INTEGRAL 511 keV GC excess.

QCD axions, axion-like particles

Solution to CP-symmetry in QCD. Firm prediction of interaction cross-section.

Can be warm.

Tightly bounded parameter space, by over-production, SN1987A, stellar cooling.



WIMPs

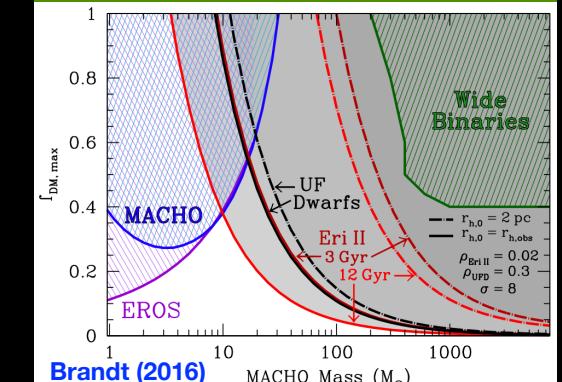
Weakly-interacting thermal relics - frozen out in early Universe with correct density, given weak-interaction cross section.

The leading CDM model, with associated problems.

Primordial black holes

Potentially produced in inflationary era. Solve small-scale problems through dynamics.

Constrained through microlensing surveys, dwarf-galaxy cores, and wide Galactic binaries.



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WIMPZillas

Massive WIMPs produced non-thermally (e.g., due to gravitational collapse at the end of inflation).

Origin of UHECRs?

Self-interacting dark matter

Specifies self-interaction cross section to solve small-scale problems.

Recent simulations alleviate potential problems with interacting clusters.

Little particle physics basis.