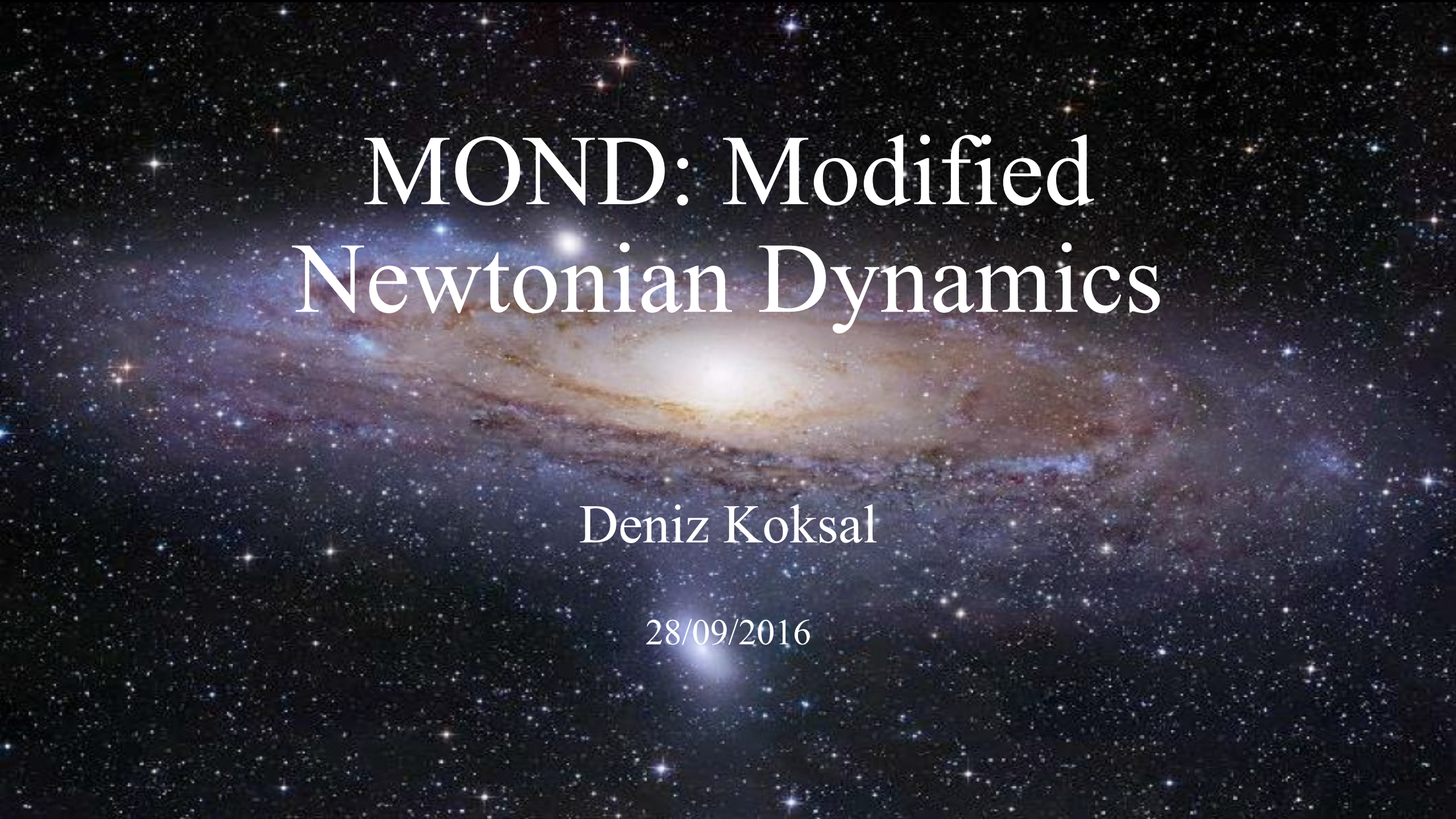
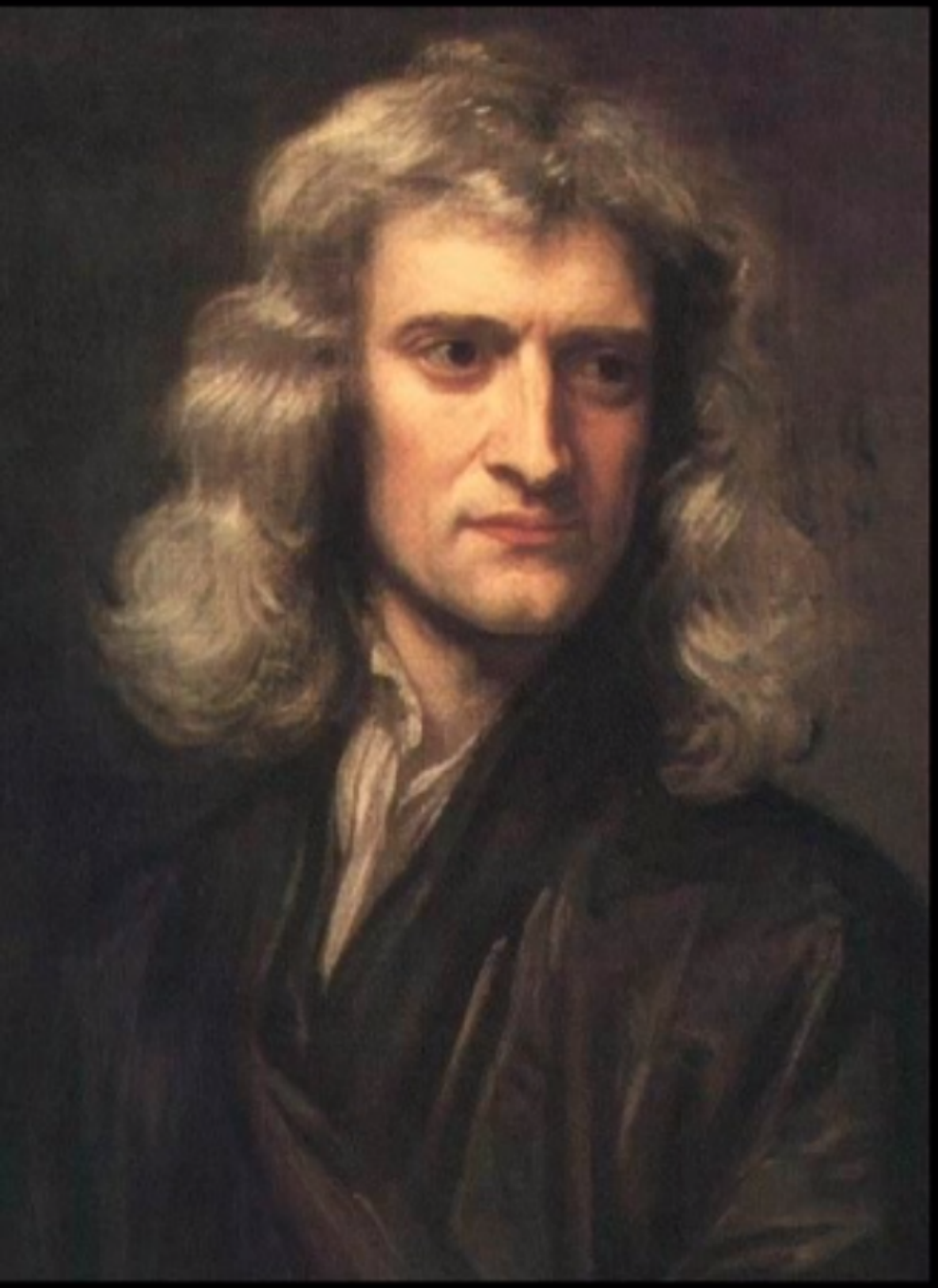


MOND: Modified Newtonian Dynamics

Deniz Koksal

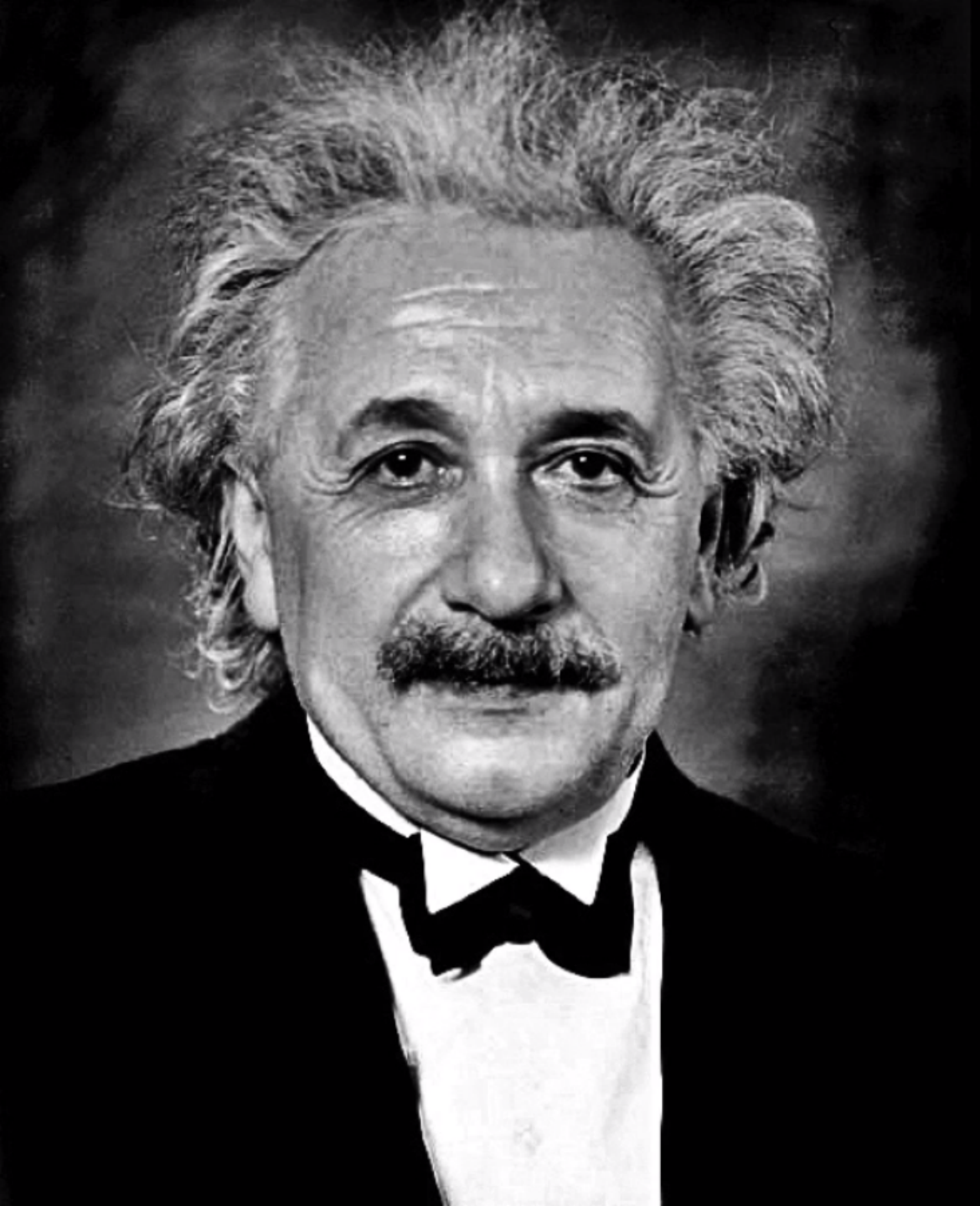
28/09/2016



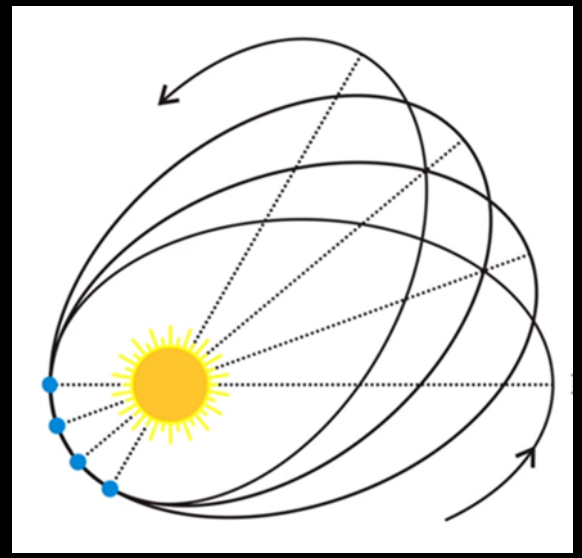
Sir Isaac Newton

Universal Law of Gravity

Everything happens ... ***as if***



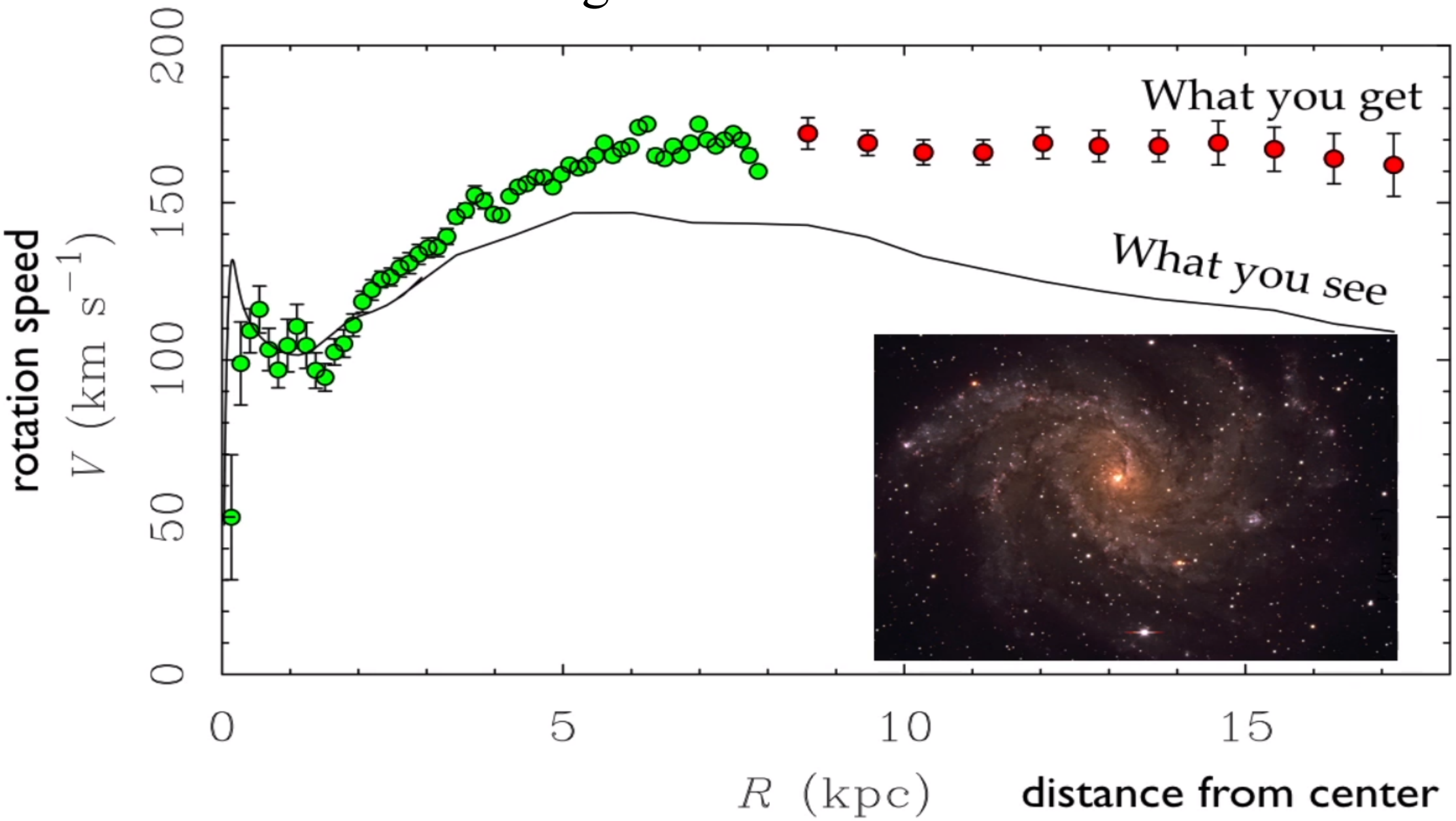
Albert Einstein



General Relativity

Naturally explains “extra” precession of the perihelion of Mercury’s orbit.

However at the galactic scale:

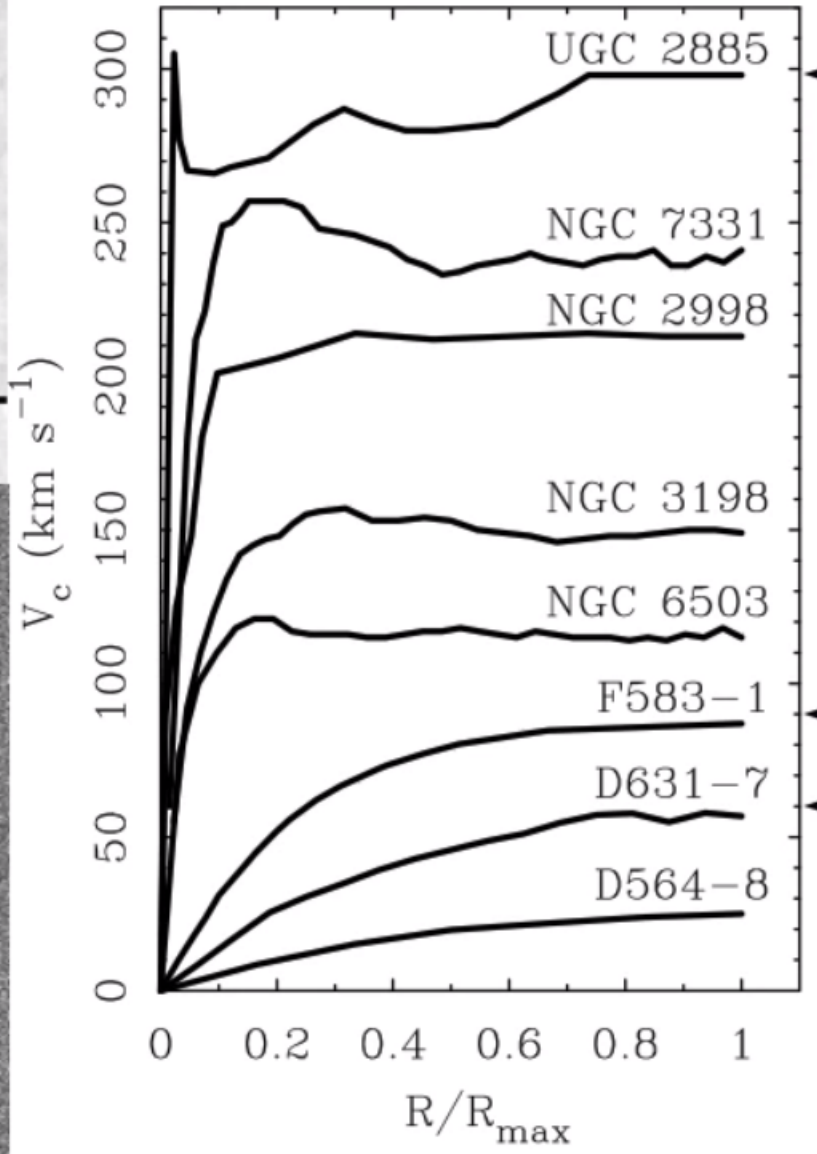


High Surface Brightness

Low Surface Brightness

rotation speed

Flat rotation curves



Spiral galaxy

Gas rich, low surface brightness galaxies

Moti Milgrom

(1983)

MOND

Modify gravity at an acceleration scale

$$a_0 \approx 10^{-10}\ \mathrm{m\,s^{-2}} \sim cH_0 \sim c\Lambda^{1/2}$$

$$a \gg a_0 \qquad a \to g_N$$

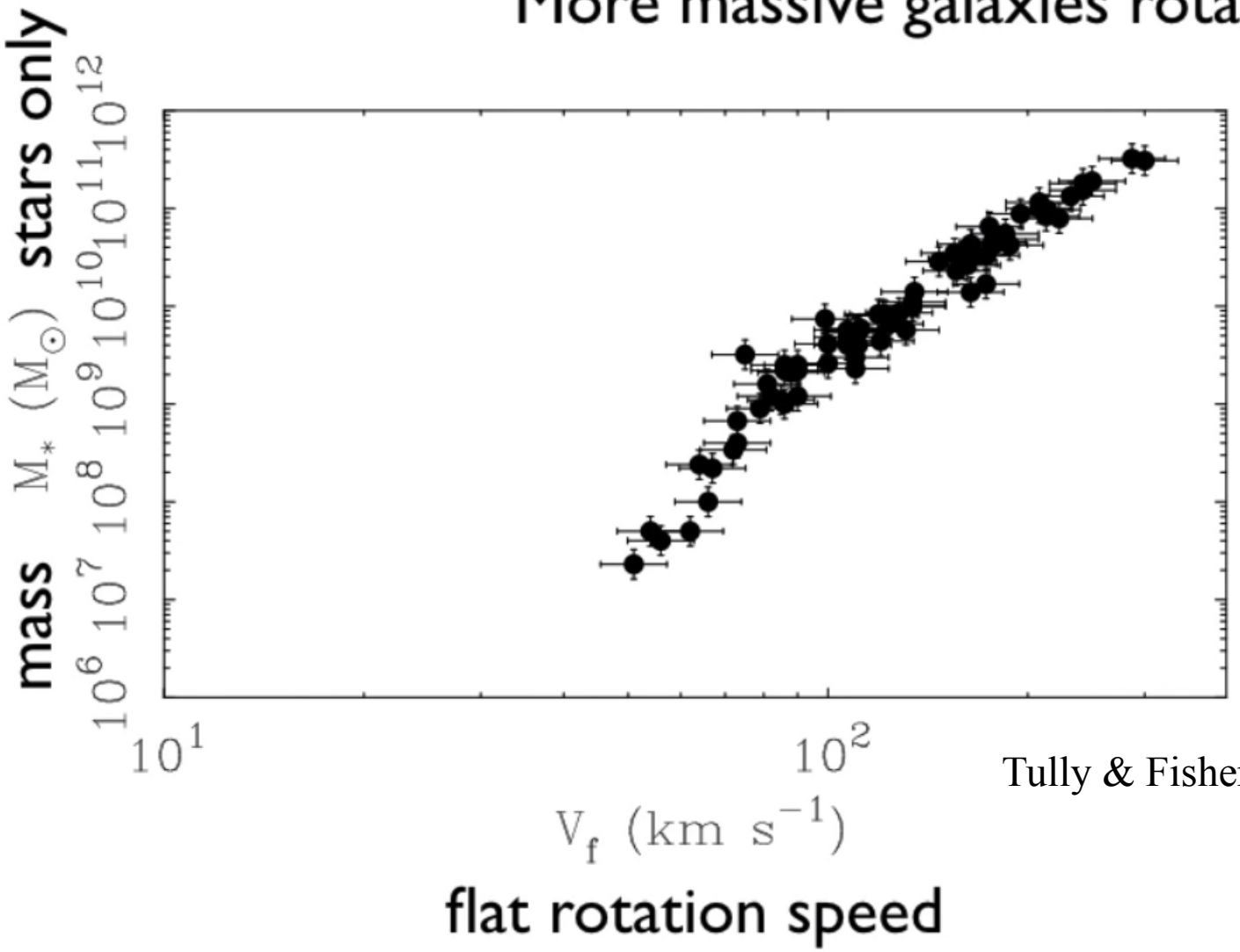
$$a \ll a_0 \qquad a \to \sqrt{g_N a_o}$$

Suggested modifying Newton's Law below a tiny acceleration scale

$a_0 = 1.2 \times 10^{-10}$ m/s/s

The Tully-Fisher Relation

More massive galaxies rotate faster



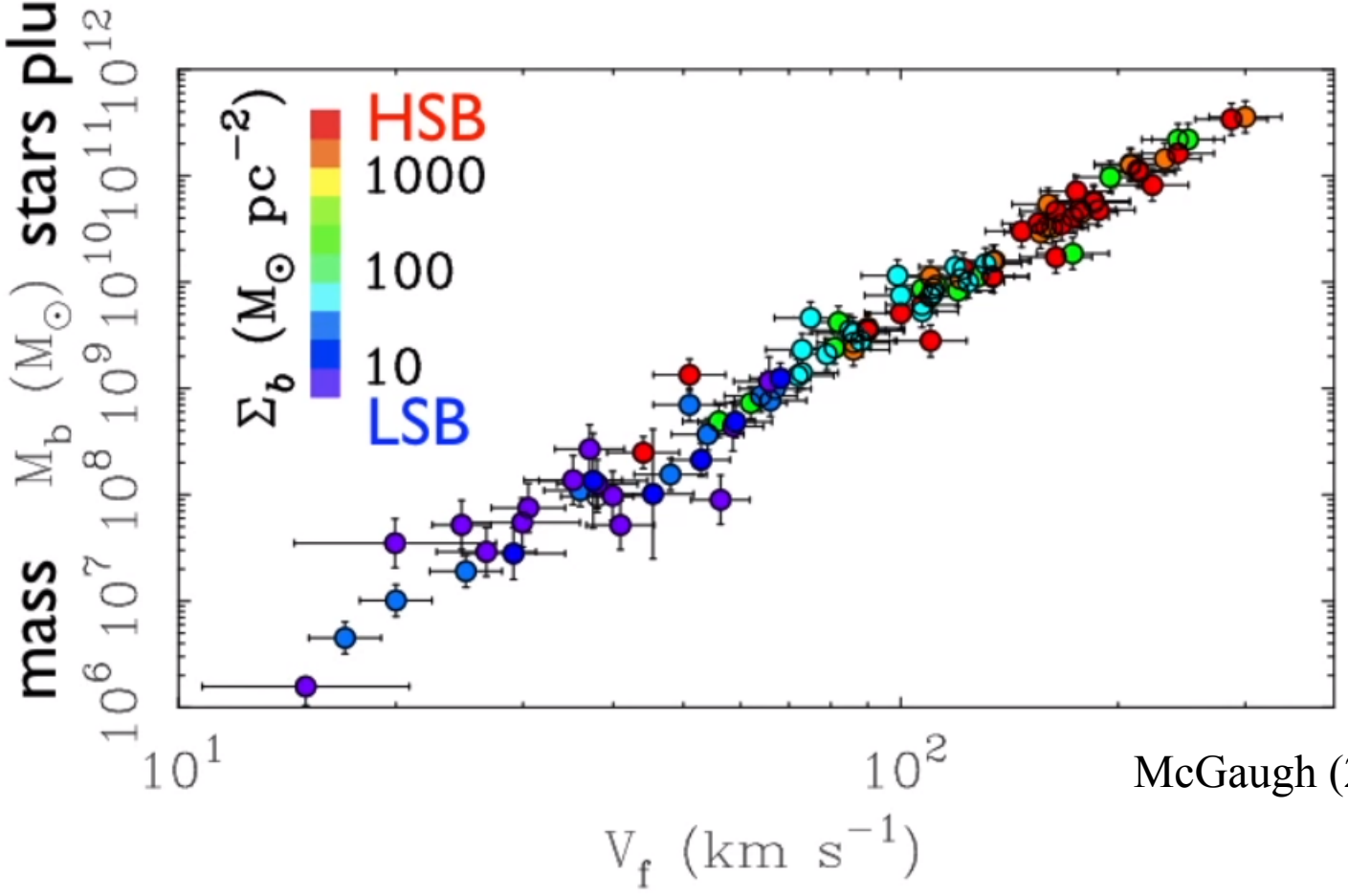
Tully & Fisher (1977)

Brent Tully

Rick Fisher

The Baryonic Tully-Fisher Relation

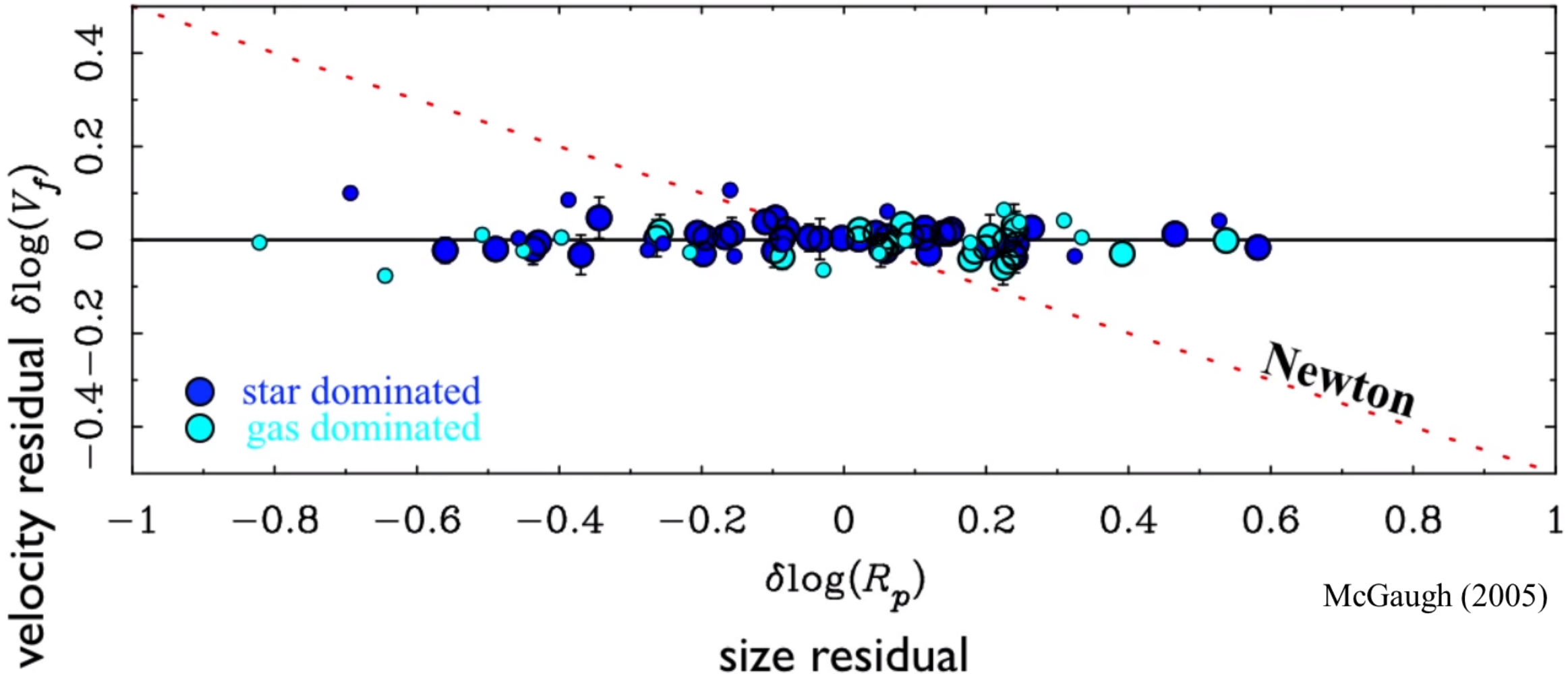
The mass of both stars and gas matters



flat rotation speed

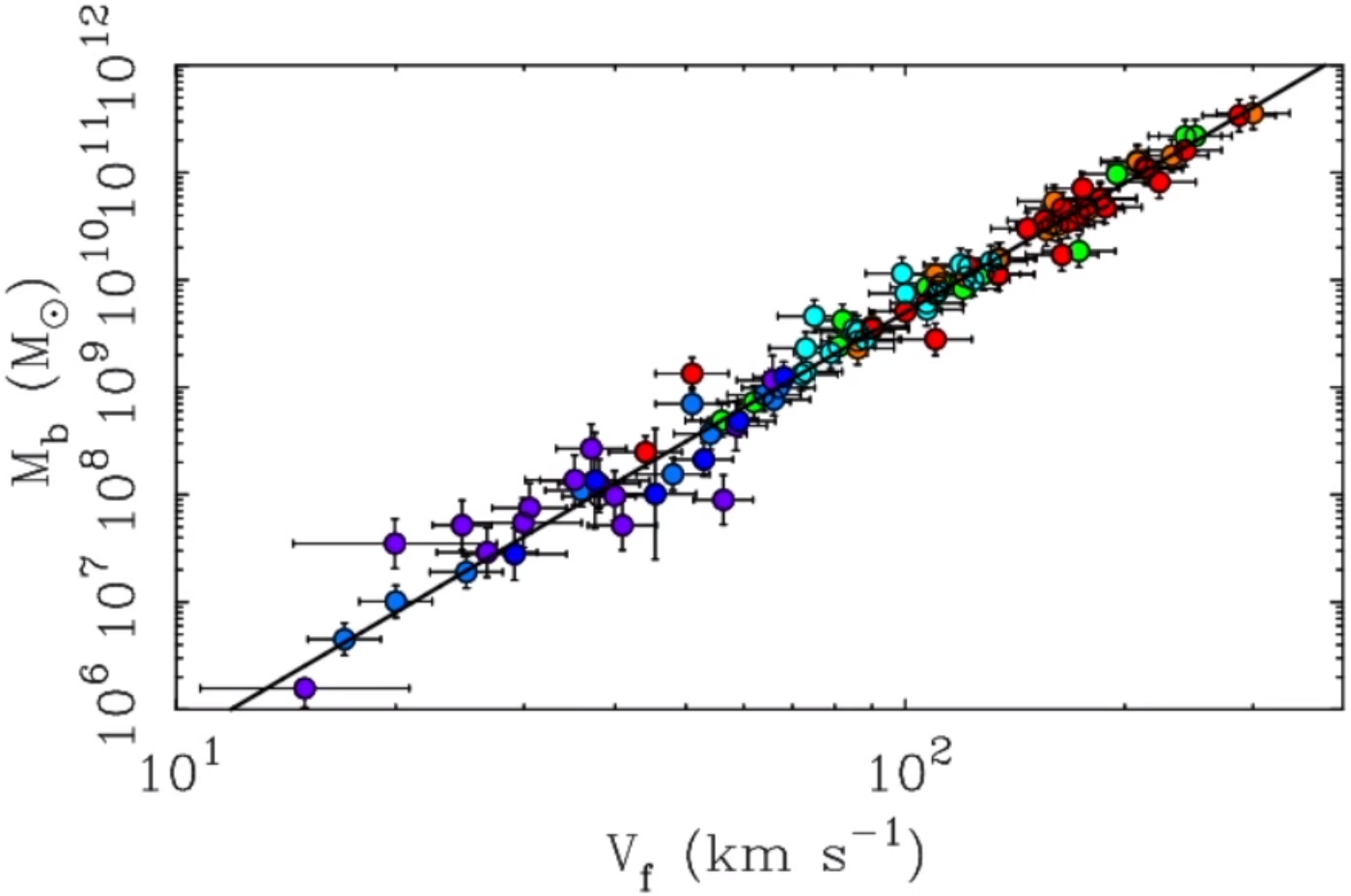
McGaugh (2005)

Newton predicts residuals that are not observed!



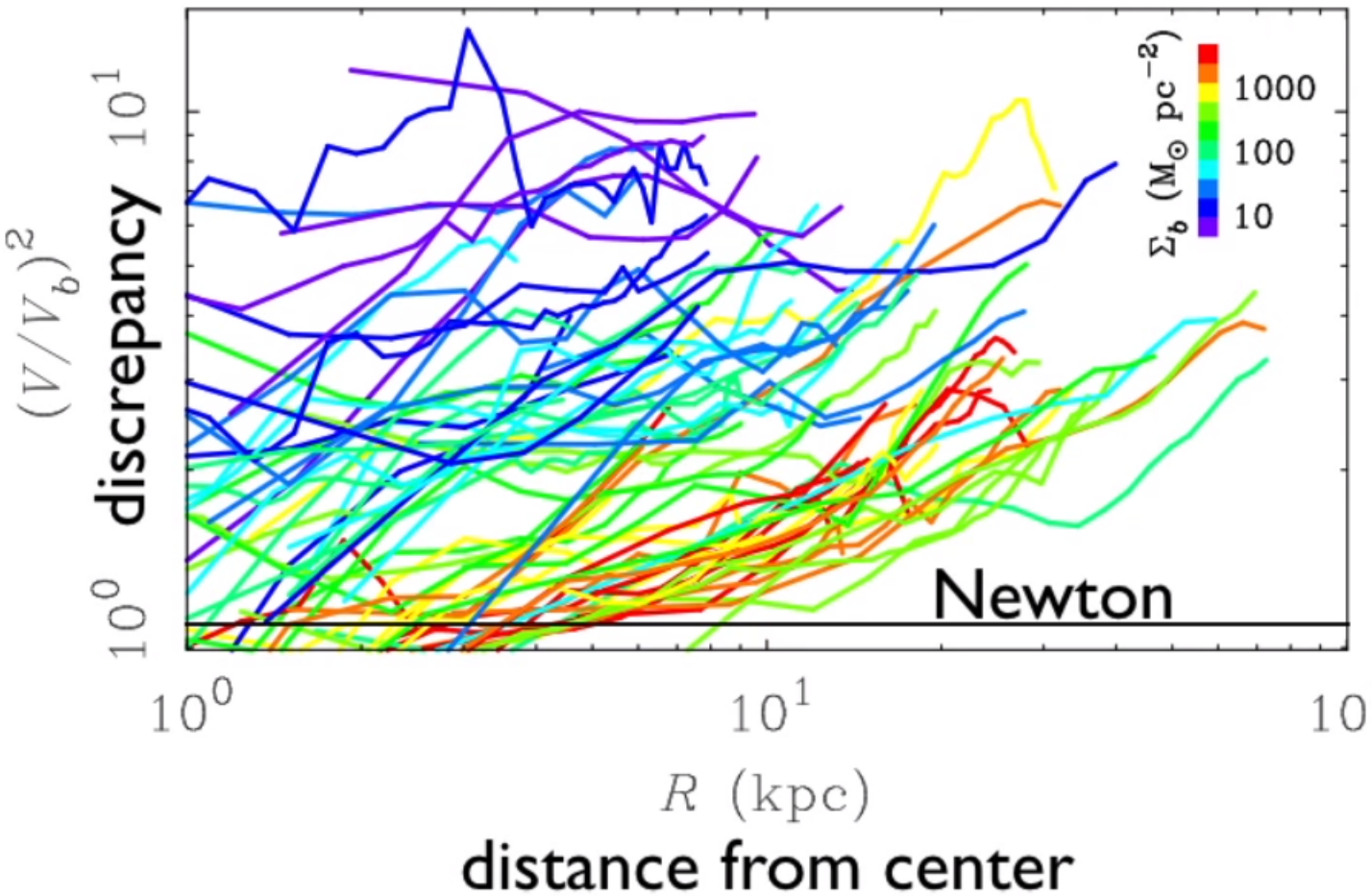
McGaugh (2005)

MOND predictions



- The Tully-Fisher Relation
  - ✓ Slope = 4
  - ✓ Normalization = $1/(a_0 G)$
  - ✓ Fundamentally a relation between Mass and V_{flat}
  - No Dependence on Surface Brightness !
- Dependence of discrepancy on radius and surface brightness
- Rotation Curve Shapes
- Acceleration ~ Surface Brightness
- Detailed Rotation Curve Fits
- Stellar Population Mass-to-Light Ratios

MOND predictions



distance from center

- The Tully-Fisher Relation
  - ✓ Slope = 4
  - ✓ Normalization = $1/(a_0 G)$
  - ✓ Fundamentally a relation between Mass and V_{flat}
  - ✓ No Dependence on Surface Brightness
- ✓ Dependence of discrepancy on radius and surface brightness
- Rotation Curve Shapes
- Acceleration ~ Surface Brightness
- Detailed Rotation Curve Fits
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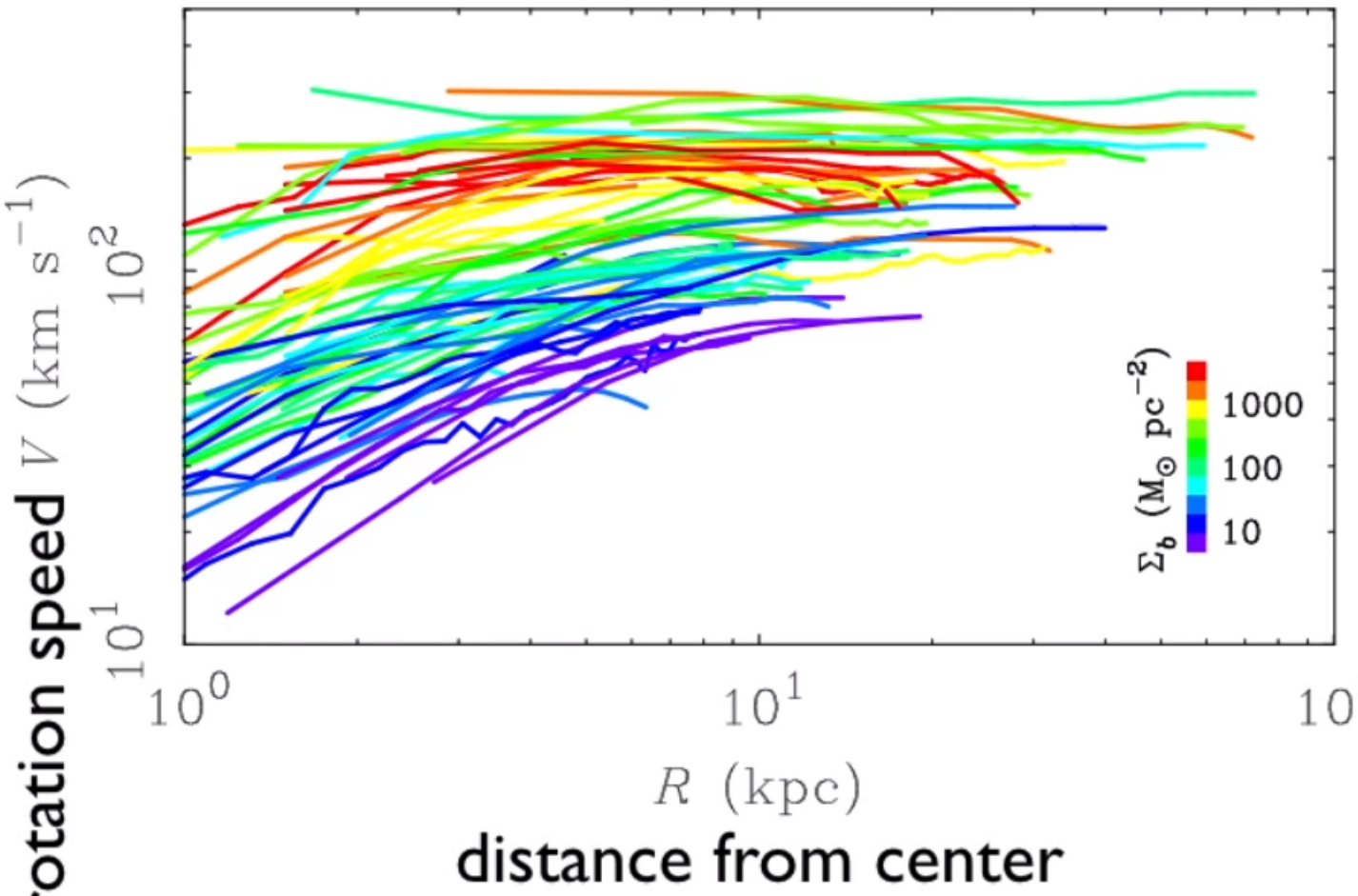
McGaugh (2005)

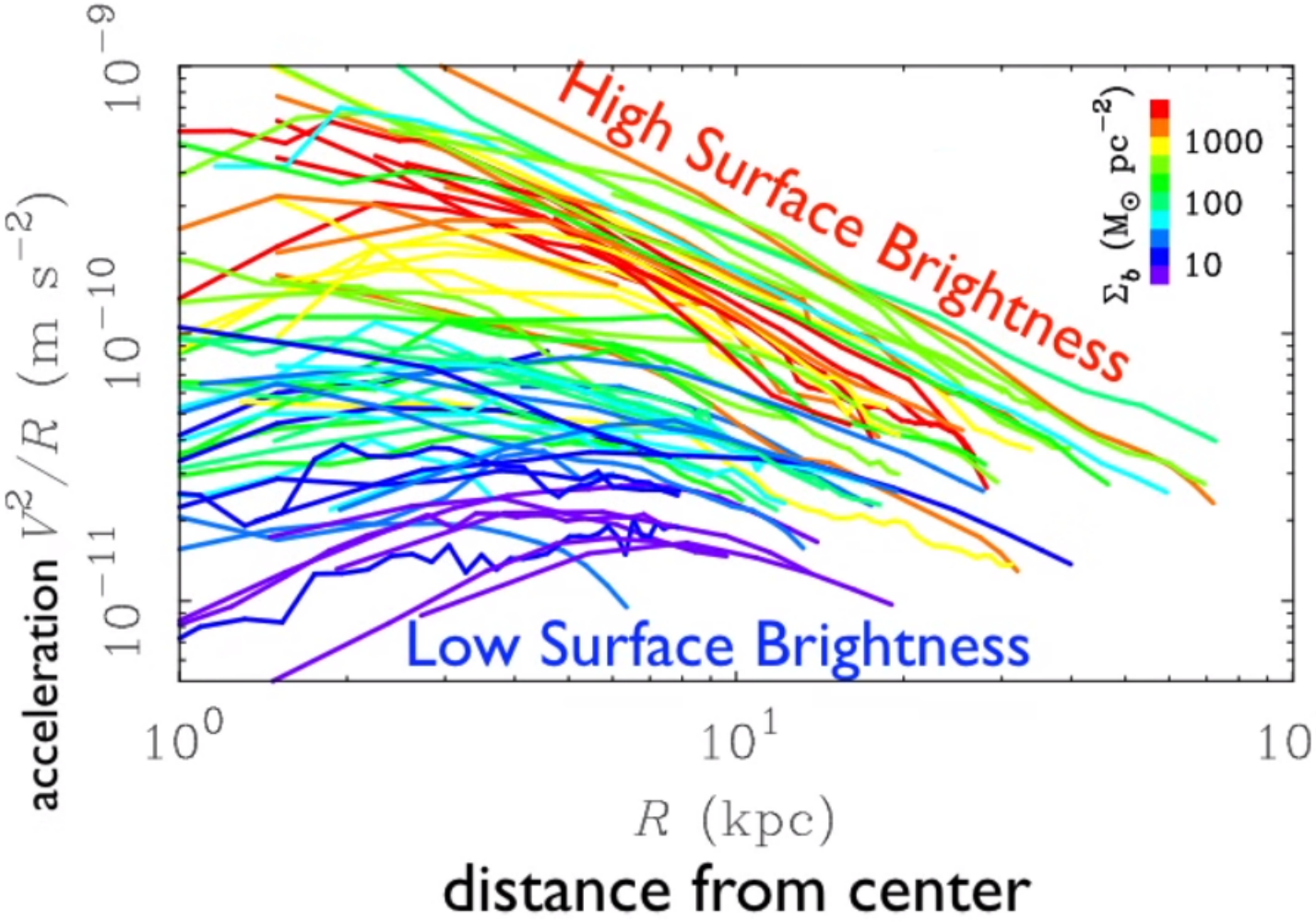
MOND predictions



distance from center

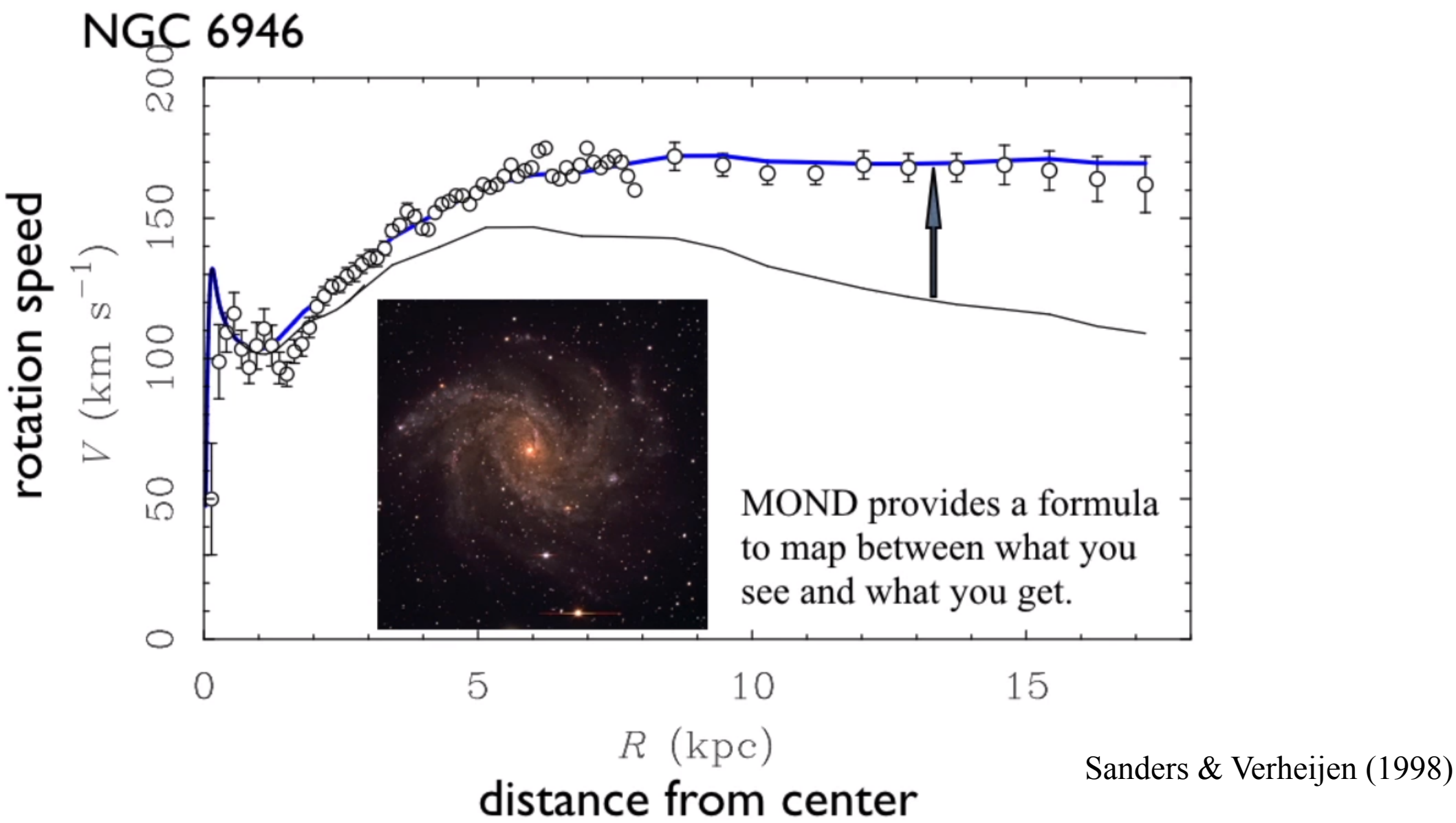
- The Tully-Fisher Relation ✔
  - Slope = 4 ✔
  - Normalization = $1/(a_0 G)$ ✔
  - Fundamentally a relation between Mass and V_{flat} ✔
  - No Dependence on Surface Brightness
- Dependence of discrepancy on radius and surface brightness ✔
- Rotation Curve Shapes ✔
- Acceleration ~ Surface Brightness
- Detailed Rotation Curve Fits
- Stellar Population Mass-to-Light Ratios

MOND predictions



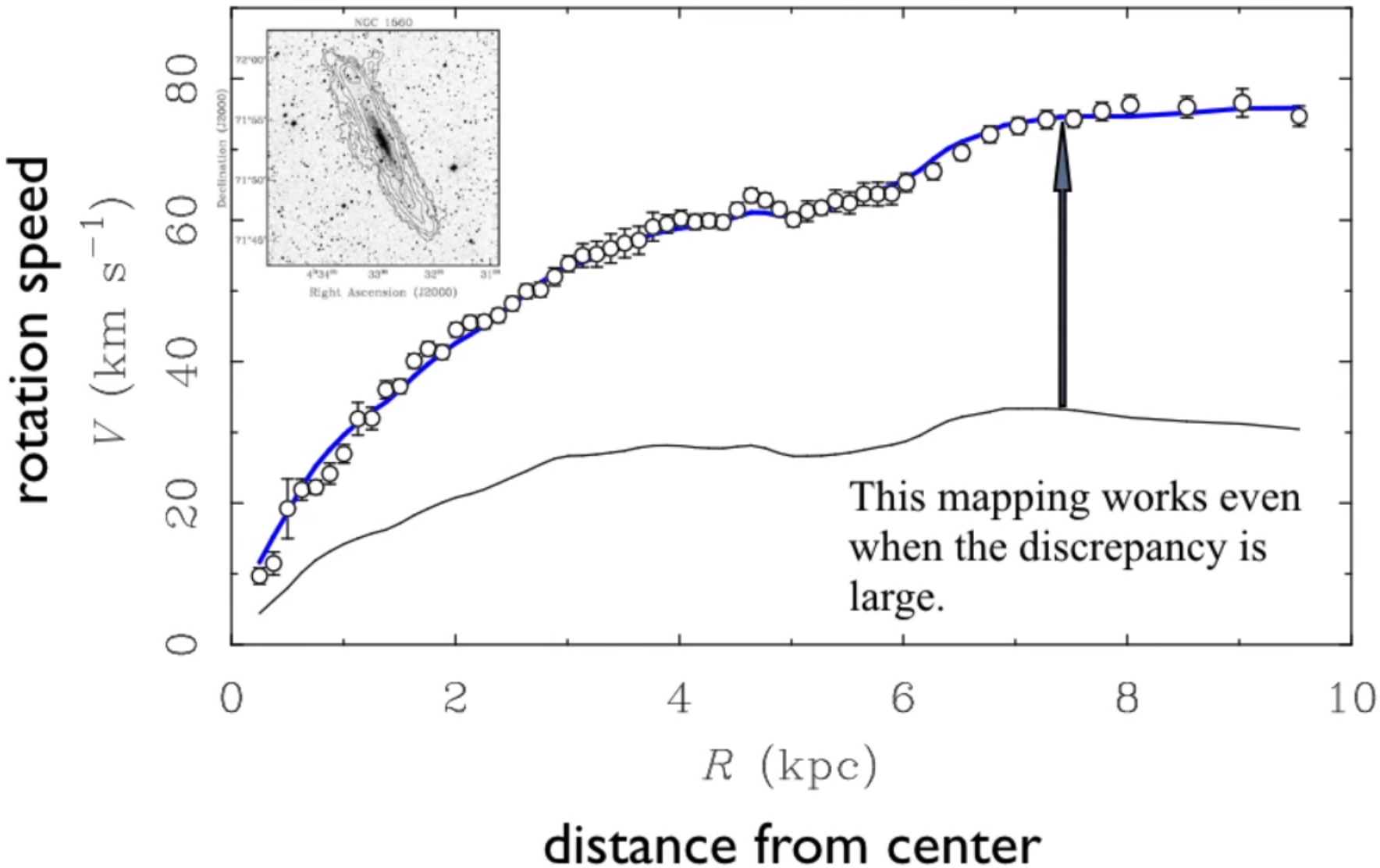
distance from center

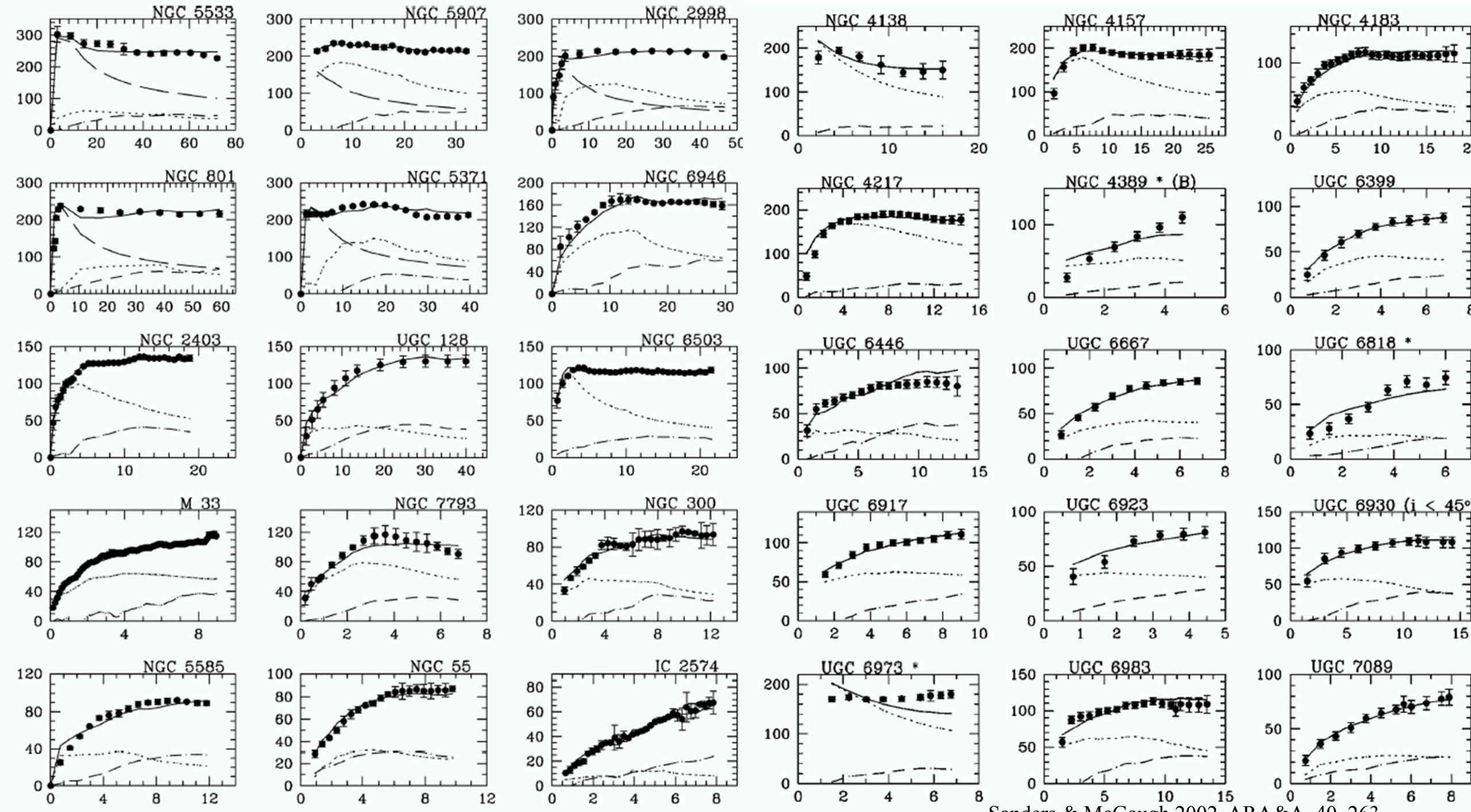
- ✔ The Tully-Fisher Relation
  - ✔ Slope = 4
  - ✔ Normalization = $1/(a_0 G)$
  - ✔ Fundamentally a relation between Disk Mass and V_{flat}
  - ✔ No Dependence on Surface Brightness
- ✔ Dependence of discrepancy on radius and surface brightness
- ✔ Rotation Curve Shapes
- ✔ Acceleration ~ Surface Brightness
- Detailed Rotation Curve Fits
- Stellar Population Mass-to-Light Ratios



Sanders & Verheijen (1998)

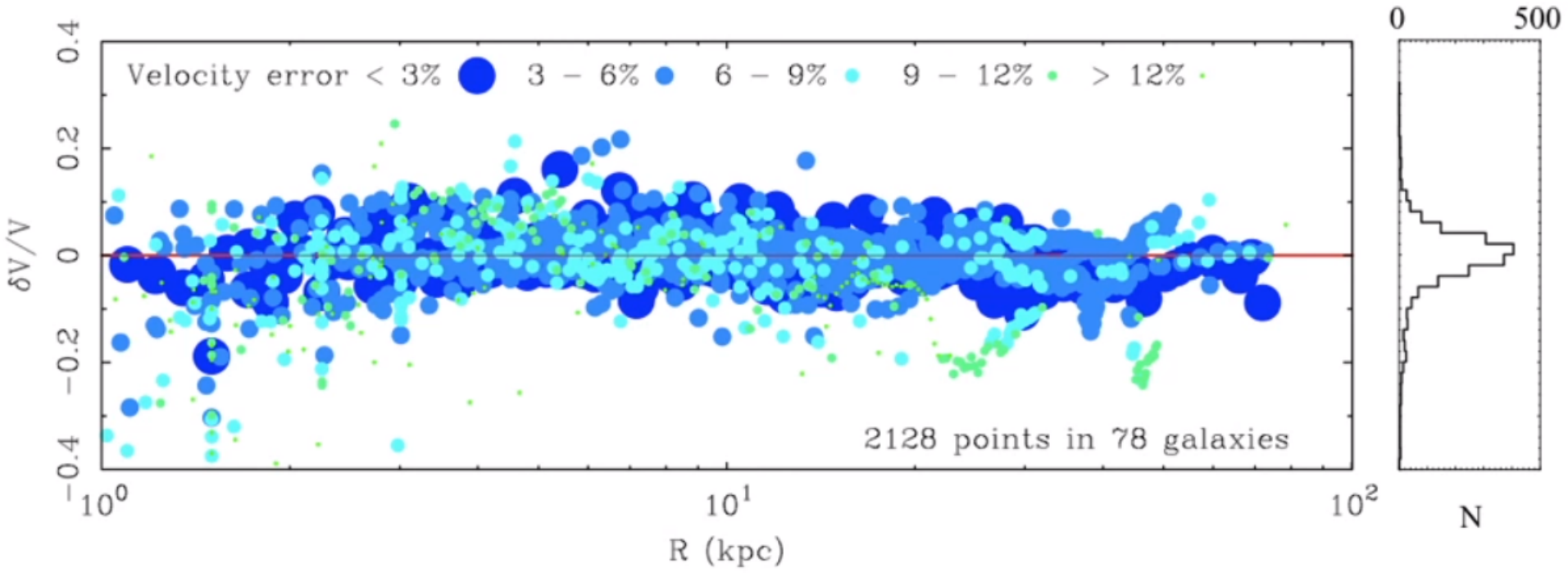
NGC 1560


rotation speed
V (km s^{-1})
0
20
40
60
80
0
2
4
6
8
10
R (kpc)
distance from center
NGC 1560
Declination (J2000)
Right Ascension (J2000)
This mapping works even when the discrepancy is large.



Sanders & McGaugh 2002, ARA&A, 40, 263

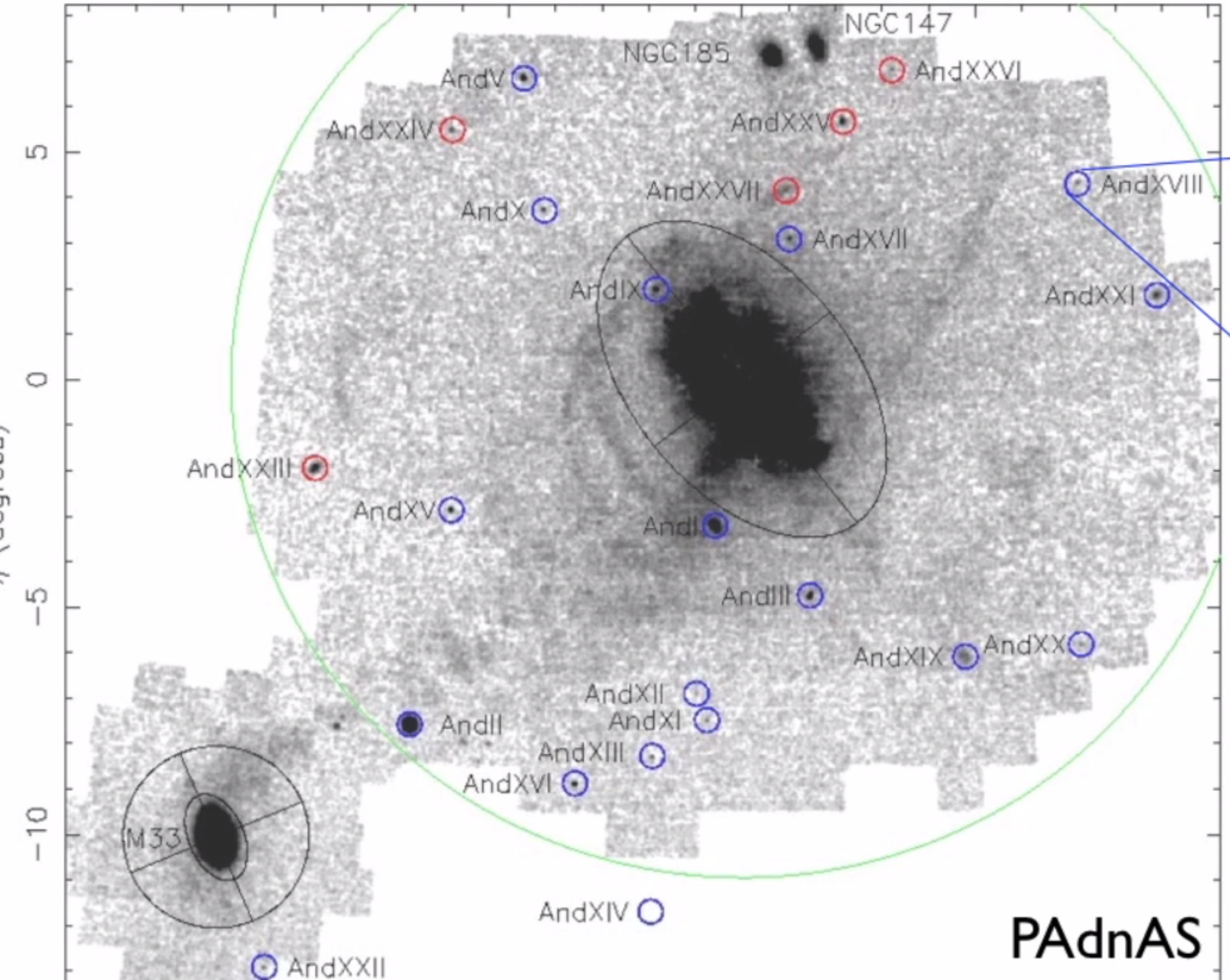
Residuals of MOND fits



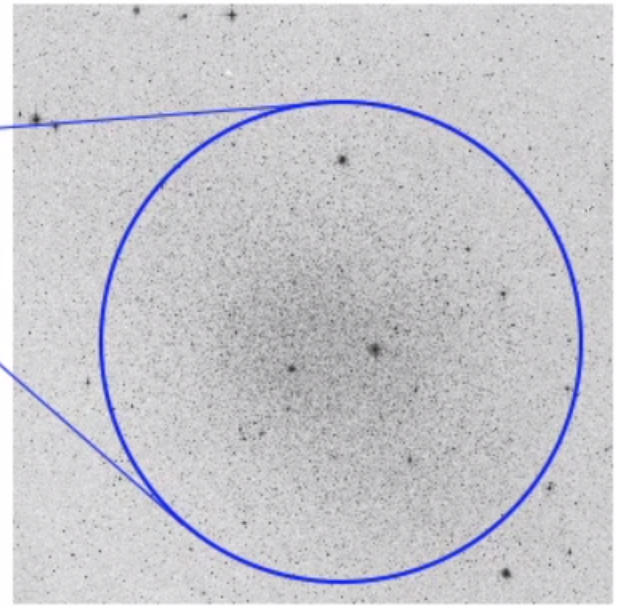
Sanders & McGaugh (2002)

A new test: the dwarf satellites of Andromeda

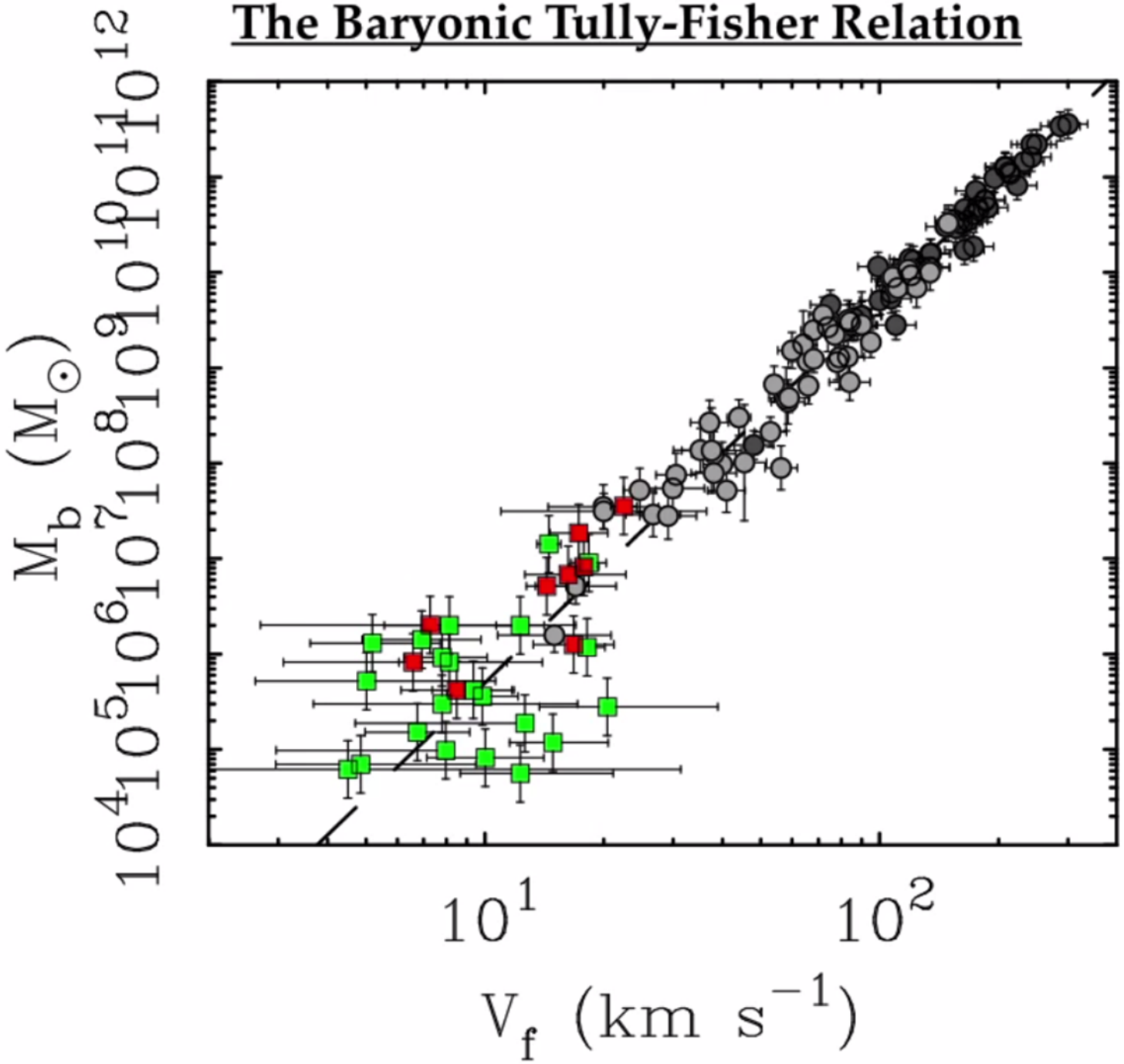
Andromeda & environs



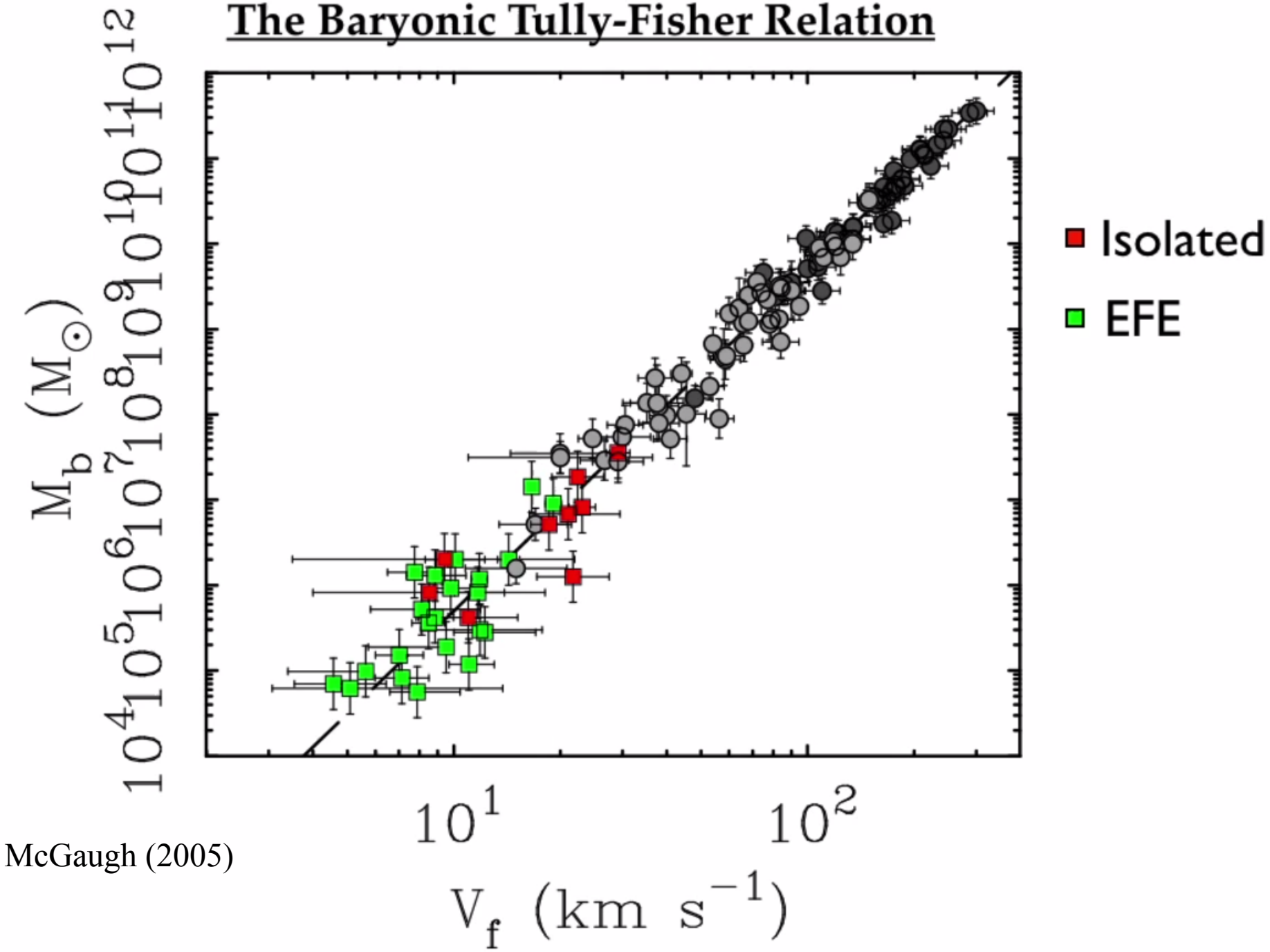
Typical dwarf satellite galaxy



No MOND correction



MOND
correction

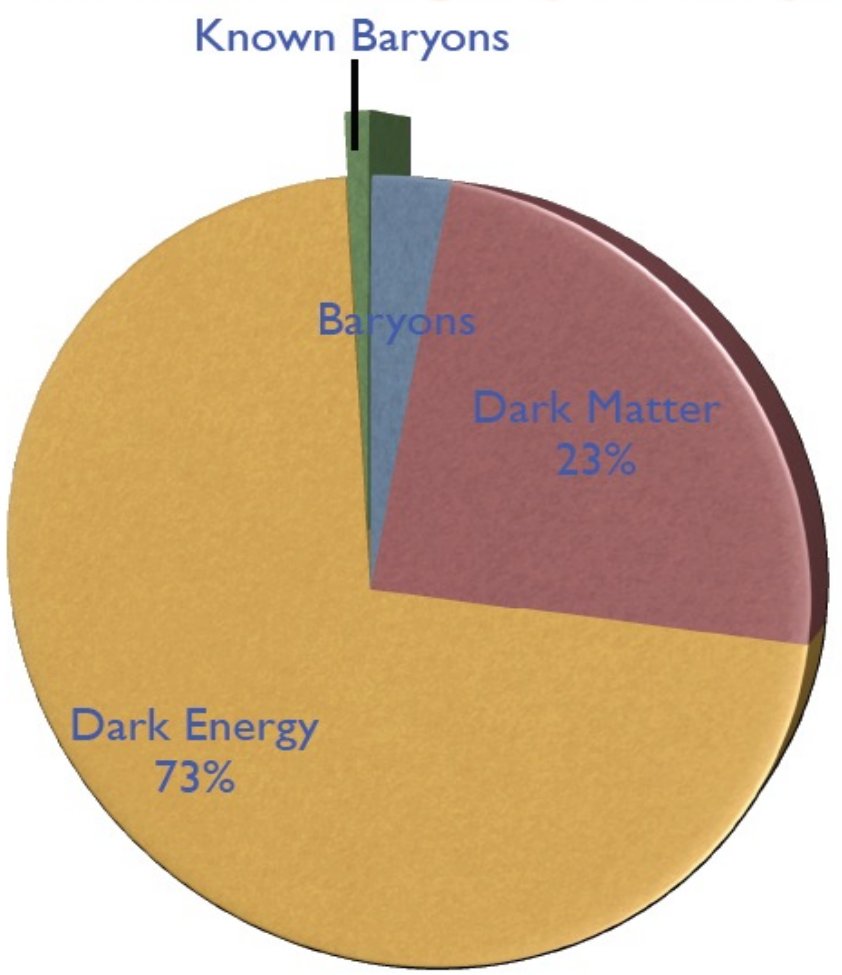


McGaugh (2005)

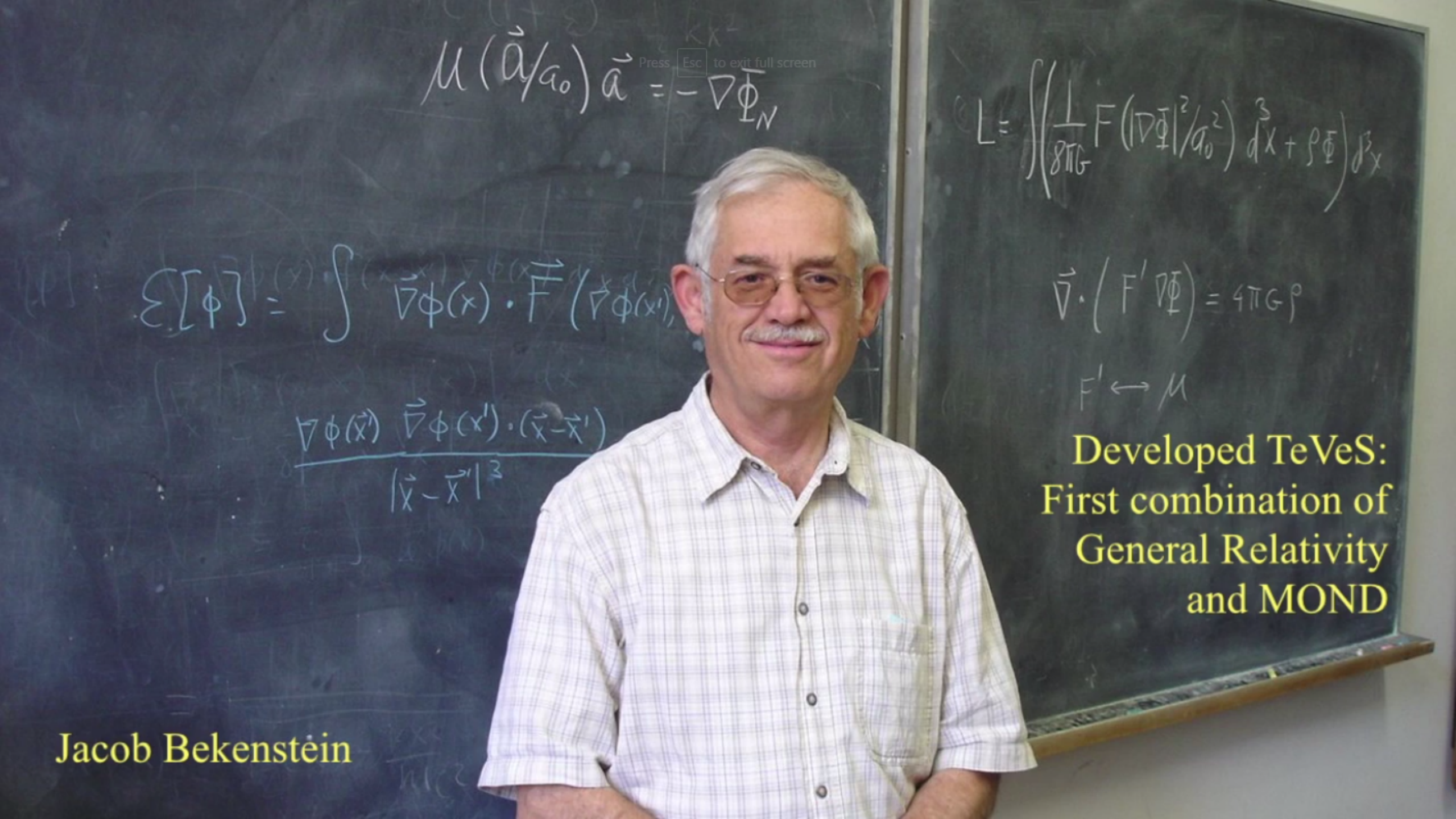
New physics at the c^2/R scale?

Do we need DM?

What is Dark Energy &
the Cosmological Constant?



"Cosmologists are often wrong, but never in doubt"
- Lev Landau


Press Esc to exit full screen
Developed TeVeS:
First combination of
General Relativity
and MOND
Jacob Bekenstein

References:

- *A Modification of the Newtonian dynamics: Implications for galaxies* - Milgrom, M. Astrophys. J. 270 (1983) 371-383
- *The Baryonic Tully-Fisher relation* - McGaugh, Stacy S. et al. Astrophys. J. 533 (2000) L99-L102 astro-ph/0003001
- *Testing the hypothesis of modified dynamics with low surface brightness galaxies and other evidence* - McGaugh, Stacy S. et al. Astrophys. J. 499 (1998) 66-81 astro-ph/9801102
- *Modified Newtonian dynamics as an alternative to dark matter* – Sanders, Robert H, McGaugh, Stacy S. , Apr 2002. 52 pp., Ann.Rev.Astron.Astrophys., 40 (2002) 263-317.
- *The Baryonic Tully-Fisher Relation of Galaxies with Extended Rotation Curves and the Stellar Mass of Rotating Galaxies,* McGaugh, Stacy S., Astrophys.J.vol. 632 no.2 (2005).
- *Rotation Curves of Ursa Major Galaxies in the Context of Modified Newtonian Dynamics,* Sanders, R. H.; Verheijen, M. A. W., The Astrophysical Journal, Volume 503, Issue 1, pp. 97-108.
- *A new method of determining distances to galaxies,* Tully, R. B.; Fisher, J. R., Astronomy and Astrophysics, vol. 54, no. 3, Feb. 1977, p. 661-673.