Do we really need dark matter?– From perspective of MOND

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Outlines

- Background
- Clues for dark matter
- MOND—the alternative to dark matter
- Discussion

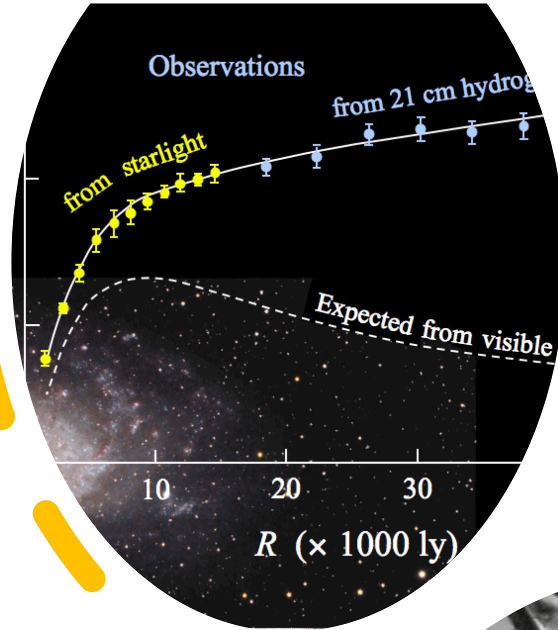
Background

Two interpretations:

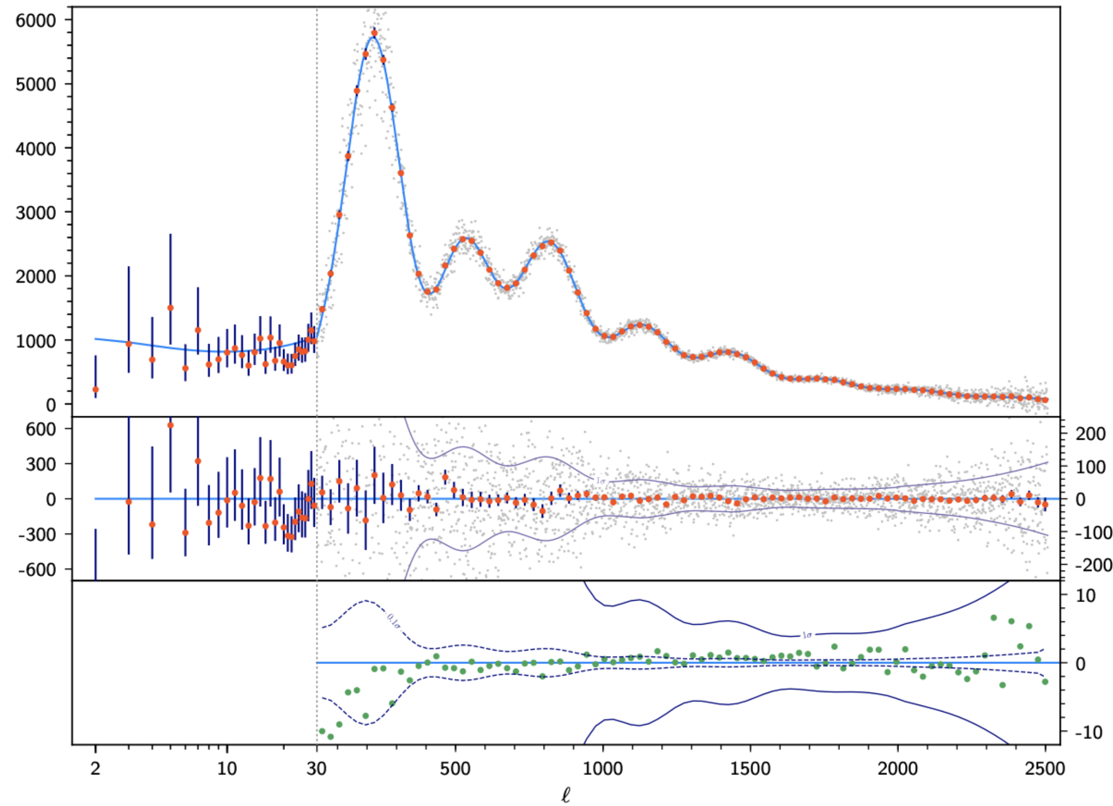
◆There are large quantities of unseen matter

◆Newton's Laws do not apply to galaxies

21 cm line



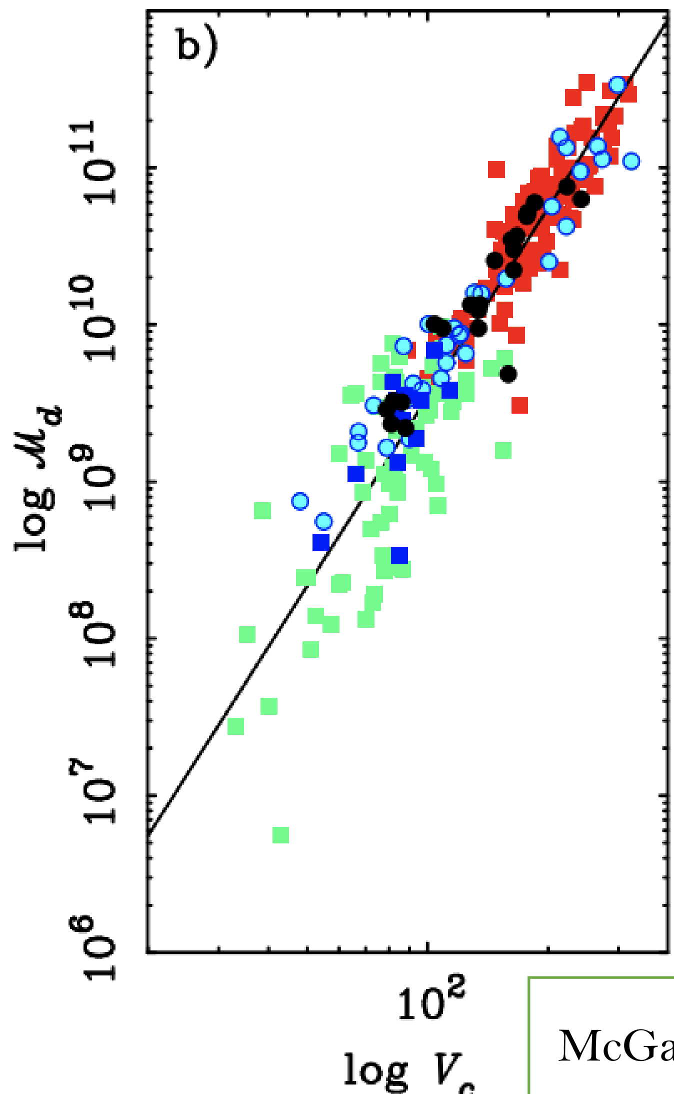
Vera Rubin



Clues for DM paradigm

- Velocity dispersions
- Galaxy clusters
- Gravitational lensing
- CMB
- Structure formation

MOND—alternative to DM



McGaugh (2000)

- In 1983, Milgrom developed an *ad hoc* empirical theory to explain the observations in galaxies
- $\mu(|\vec{a}|/a_0)\vec{a} = -\nabla\Phi_N$

  with $\begin{cases} \mu(x) \approx 1 & x \gg 1 \\ \mu(x) \approx x & x \ll 1 \end{cases}$
- Two direct result:
  - ◆ In $x \ll 1$ regime, it reproduce flat rotation curve

    $$v_c = (GMa_0)^{1/4}$$
  - ◆ Baryonic Tully-Fisher relation

    $$M = (Ga_0)^{-1}v_c^4$$

Corrections to original MOND

- This simple theory does not conserve momentum
- Using Lagrangian or action

$$\mathcal{L} = -\frac{a_0^2}{8\pi G} f\left(\frac{|\nabla\Phi|^2}{a_0^2}\right) - \rho\Phi$$

Gives the field equation

$$\nabla \cdot \left[\mu\left(\frac{|\nabla\Phi|}{a_0}\right)\nabla\Phi\right] = 4\pi G\rho$$

Relativistic MOND

- Phenomenological requirements
  a) Return to GR (hence Newtonian gravity) when $\nabla\Phi \gg a_0$
  b) Reproduce MOND law when $\nabla\Phi \ll a_0$
  c) Reproduce cosmological observations like CMB and MPS
  d) Reproduce the observed lensing effect
  e) Propagate tensor mode GWs at the speed of light (GW170817)

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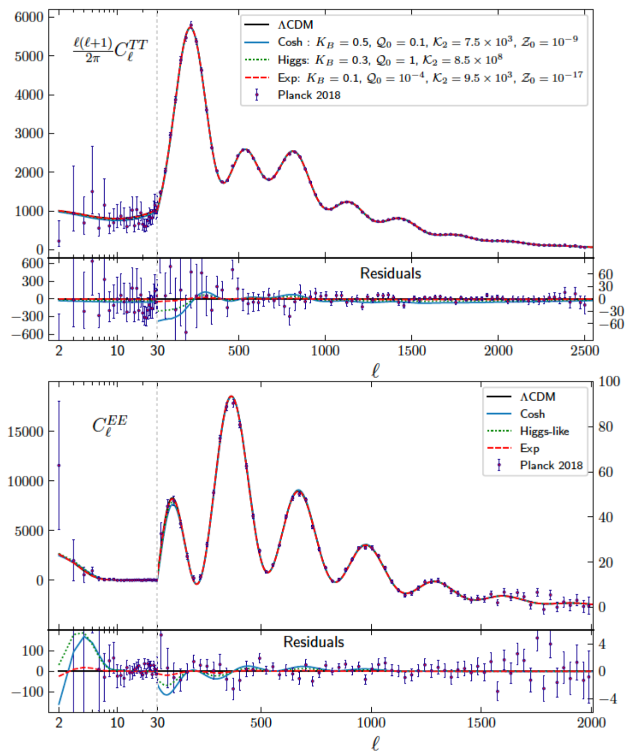
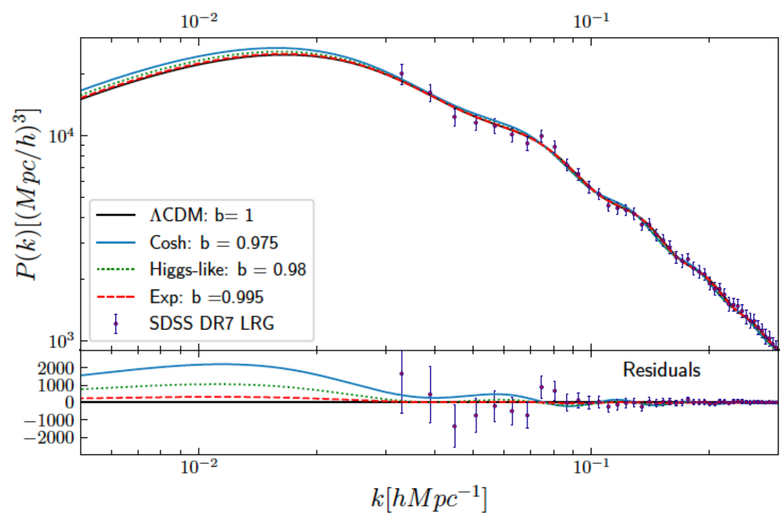
A new theory (2007.00082)

- An extra scalar field ϕ and vector field A^{μ} to compensate the gravity originally contributed by DM
- Different from DM paradigm

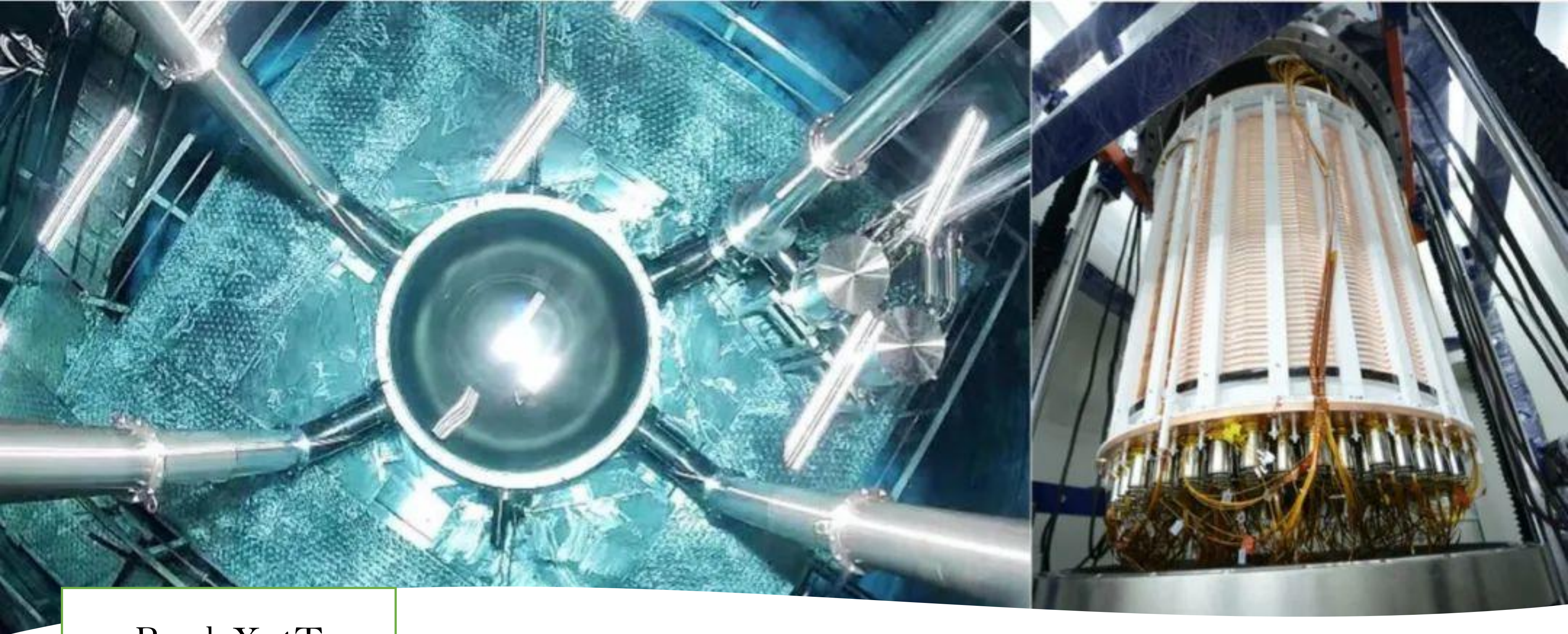




Discussion

Dark matter paradigm	Relativistic MOND
1 parameter	5 parameters
Simple	Complicated
Almost fit with Observation	To be verified but can explain BTFR

Do we really need DM?



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Yes and No!

- Yes: Simple enough to explain almost every observational facts
- No: We haven't detected any signal of DM particles

Take home message

- A cosmological model without DM can now successfully reproduce the key observables: CMB and MPS

- Until now DM paradigm is sufficient for us. But if we still can not detect the DM particles in the next several decades, we might seek for the other solution.

Questions

- Will this relativistic MOND help to solve Hubble tension?

- How can we confirm the existence of the extra fields?