Levitating Dark Matter

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Based on work with A. Padilla, 0904.2394 [astro-ph]
& A. Padilla & P. Saffin (in preparation)

Outline

- Old ideas and new twists
- Cosmological oil-drop experiment & gravity bounds
- Out of darkness: Faradayan Cosmology
- Signatures & effects
- Exact solutions: McVittie's legacy
- Where next?

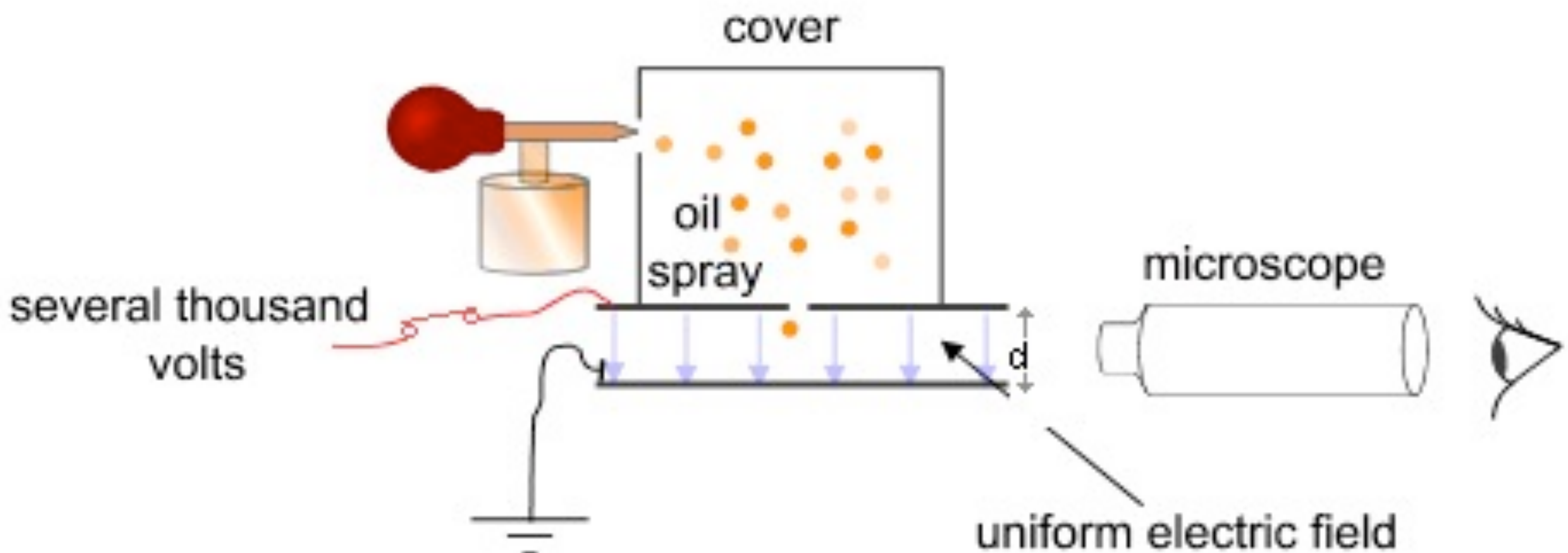
Old ideas

Suppose you have a $U(1)$ vector field. How do you discover it?

- You observe FORCES, and from measuring them determine CHARGES.
- You need an experiment of the right size to measure the forces, determined by the strength of the force
- An example: Millikan's experiment determining electric charge

For the standard Faraday-Maxwell U(1) you can do it on the tabletop:

- This is because the Faraday-Maxwell U(1) is STRONG!

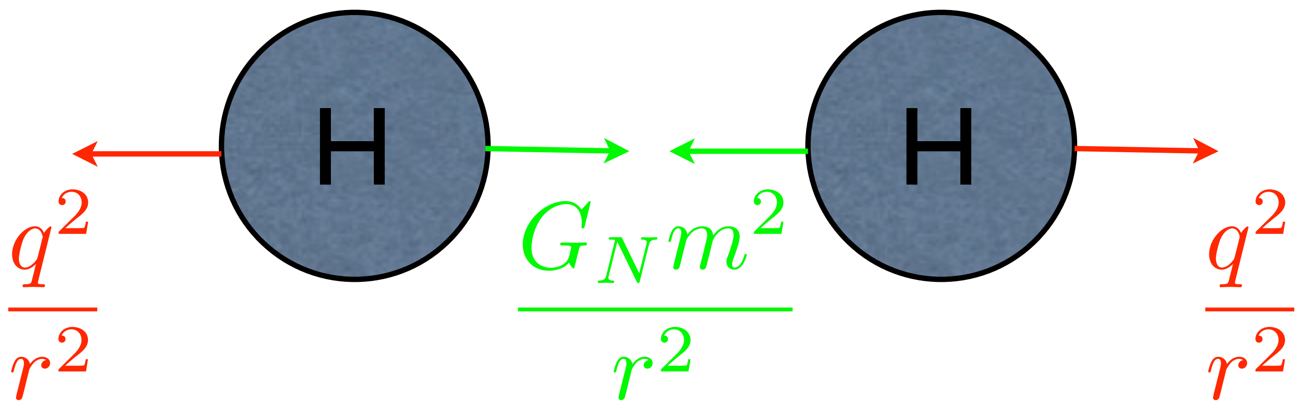


R.A. Millikan, 1913

But what if the force is MUCH weaker?

- Force is proportional to (charge)^2
- We measure WORK: $W = F \Delta x \sim (\Delta q)^2 \Delta x$
- If we DECREASE the charge by an amount α we need to INCREASE the experiment by an amount α^2
- For example: if we weaken U(1) down to gravitational strength, by 16 orders of magnitude, we need to ENLARGE the experiment by 32 orders of magnitude!
- This means that the scale of the analogous Millikan's experiment, originally ~ mm, must change UP to about ~ 10^{32} mm - the HUBBLE SCALE!

Bondi & Lyttleton Cosmology



Bondi & Lyttleton (1959)

- Imagine that hydrogen carries a small net monopole charge, q, because e and p charges are slightly different
- For this to impact on cosmology they needed electrostatic repulsion to be the order of gravitational attraction, ie

$$q \sim \frac{m_H}{m_{Pl}} \sim 10^{-18} \quad \text{for} \quad m_H \sim GeV$$

- This scaling is a manifestation of the gauge hierarchy problem!
- This motivated J. King to place strong bounds on $\Delta e/e < 10^{-22}$ (1960)

Into, and out of, darkness...

- Dark sector sector may have LOTS of hidden $U(1)'$ theories.
- Many are gravitationally coupled: eg in string theory, there are lots of gravitationally coupled vector fields, in higher-D SUGRAs or coming from dimensional reduction.
- Let charged DM not couple directly to the standard model. It may couple indirectly e.g. through gravity.
- Suppose that the dark $U(1)'$ is unbroken.
- We will imagine that our Hubble patch contains a net overall charge (clearly the biggest assumption; may be dynamical...).

Some asides: how `bad' is this?

- If there is charged DM with TeV mass and short range weak scale interactions among themselves, a "WIMPless miracle" can occur and it can have the right relic abundance to make up a significant fraction of dark matter in our Universe even if it does not couple to the Standard Model (Feng & Kumar, 2008)
- The bound on DM fine structure constant is

$$\alpha' < 10^{-3}$$ Ackerman et al, 2008

- This is MUCH weaker than the King bound:

$$\alpha_{eff\ QED} \sim (\Delta q)^2 < 10^{-44}$$

• Holographic arguments suggest that no force could be weaker than gravity (Arkani-Hamed et al), this in turn implies that the field theory cutoff, and mass scales, should be

$$\Lambda < g m_{Pl}$$

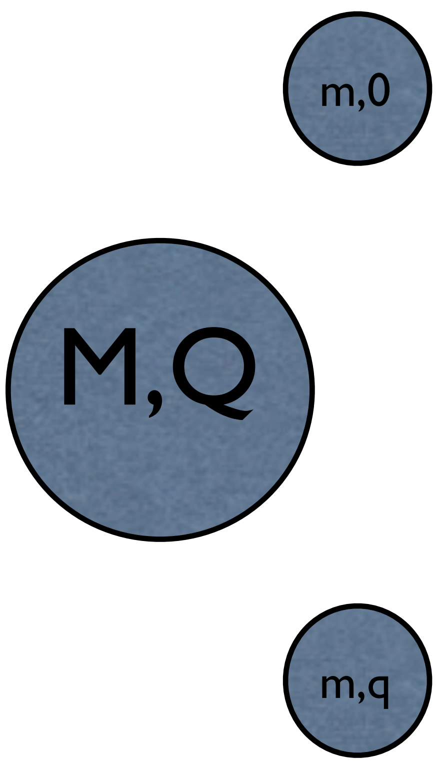
• This is an interesting connection between DM masses and charges!

• Indeed: if the lightest charged DM particle is BPS and saturates this bound, the dark U(1) has gravitational strength if the DM mass is TeV:

$$g \sim \frac{TeV}{m_{Pl}} \sim 10^{-15} \quad \rightarrow \quad \alpha' \sim g^2 \sim 10^{-30}$$

Measurement scores

Consider two probes orbiting a charged star. How might an observer try to determine the mass of the star using these probes?



Neutral probe feels a radial force $\frac{F}{m} = -G_N \frac{M}{r}$ per unit mass, and records a mass $M_{star} = M$

Charged probe feels a radial force $\frac{F}{m} = -G_N \frac{M}{r} + \frac{q}{m}\frac{Q}{r}$ per unit mass, and, being ignorant of its charge, records a mass $M_{star} = \left(1 - \frac{1}{G_N}\frac{q}{m}\frac{Q}{M}\right) M$

Normalizing `less mass' to the fixed cosmic ladder scale requires more dark energy which seems to grow in time - faking $w < w_{real}$

Faradayan cosmology

charge-to-mass ratio for probe

charge-to-mass ratio for charged background

$$H^2 = \frac{8\pi G_N}{3}\,\rho_{\rm total} - \frac{8\pi}{3}\left(\frac{q}{m}\right)_{\rm probe}\left(\frac{q}{m}\right)_{\rm background}\;\rho_{\rm charged}$$

total cosmological mass density: $\rho_{\rm total} = \lambda + \rho_{\rm neutral} + \rho_{\rm charged}$

What does one see?

$$1 = \sum_i \Omega_i - \frac{\left(\frac{q}{m}\right)_{\text{probe}} \left(\frac{q}{m}\right)_{\text{background}}}{G_N} \Omega_{\text{charged}}$$

Deceleration parameter: $q = \frac{1}{2} + \frac{3}{2} w_{DE} \Omega_{DE}$

CMB probe: $\left(\frac{q}{m}\right)_{\text{CMB}} = 0 \quad \rightarrow \quad 1 - \Omega_{DM} = \Omega_{DE}$

SN probe: $\left(\frac{q}{m}\right)_{\text{SN}} \neq 0 \quad \rightarrow \quad 1 - \Omega_{DM} = \Omega_{DE} - \frac{\left(\frac{q}{m}\right)_{\text{SN}} \left(\frac{q}{m}\right)_{\text{background}}}{G_N} \Omega_{\text{charged}} = \tilde{\Omega}_{DE}$

If we write the deceleration parameter in terms of the "effective" dark energy, we find

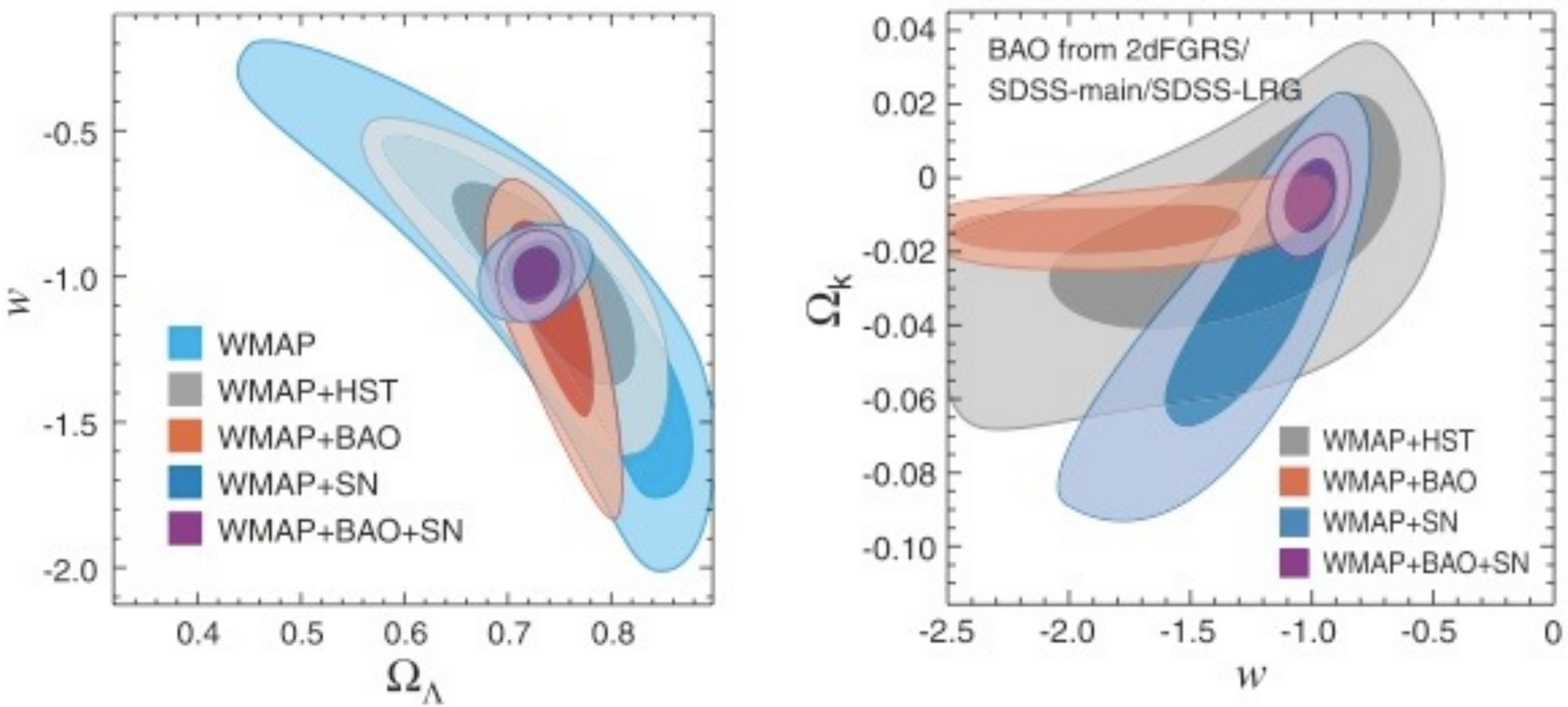
$$q = \frac{1}{2} + \frac{3}{2} \tilde{w}_{DE} \tilde{\Omega}_{DE}$$

where

$$\tilde{w}_{DE} = w_{DE} \left(1 + \frac{\left(\frac{q}{m}\right)_{\text{SN}} \left(\frac{q}{m}\right)_{\text{background}}}{G_N} \frac{\Omega_{\text{charged}}}{1 - \Omega_{DM}} \right)$$

By ignoring the gauge repulsion in the SN probe, we erroneously deduce a more negative equation of state!

The extra repulsion alters data interpretation!



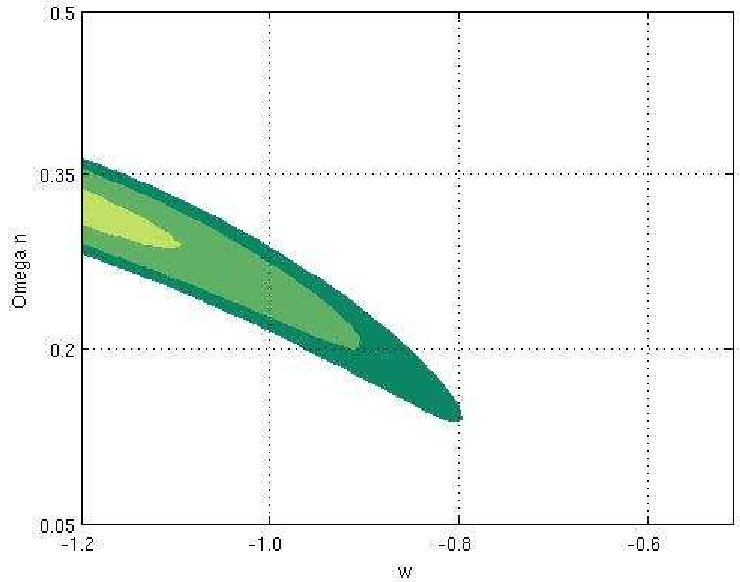
The standard results, WMAP collaboration, 2008

Enter the charges...

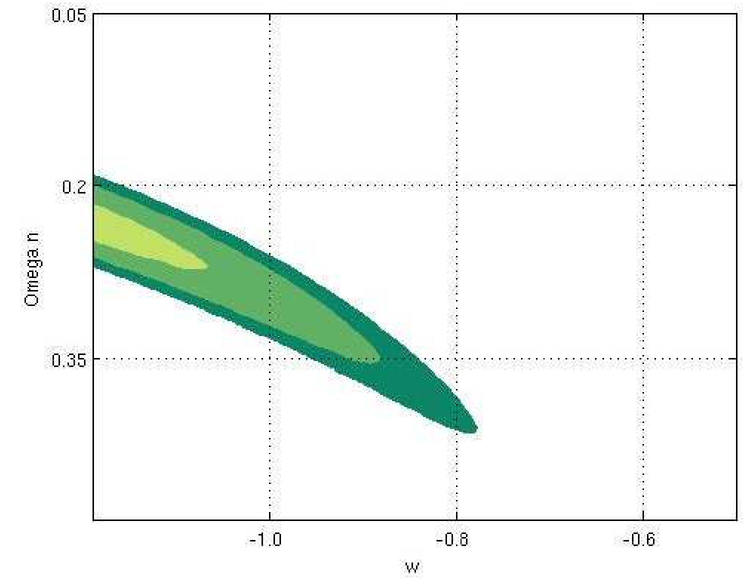
Luminosity distance is based on the `effective' Hubble scale:

$$H^2(z) = \frac{8\pi G_N}{3}\,\lambda + \frac{8\pi G_N}{3}\left\{\rho_{\rm neutral}(0) + \left[1 - \frac{\left(\frac{q}{m}\right)_{\rm probe}(z)\left(\frac{q}{m}\right)_{\rm background}(z)}{G_N}\right]\rho_{\rm charged}(0)\right\}(1+z)^3$$

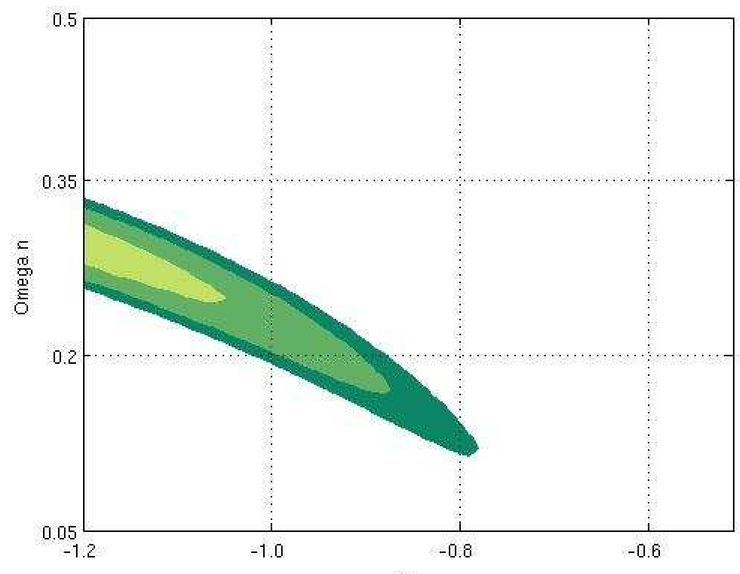
$$\frac{q}{m} = 0$$



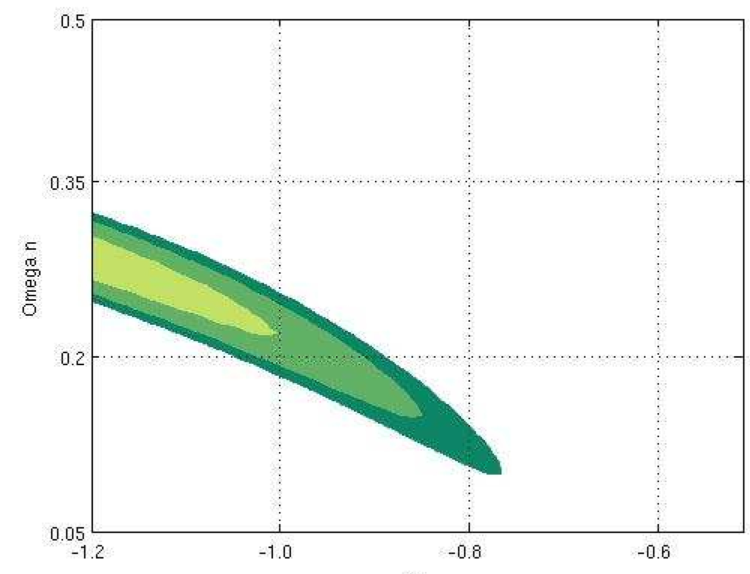
$$\frac{q}{m} = 0.1$$



$$\frac{q}{m} = 0.2$$



$$\frac{q}{m} = 0.3$$



McVittie's legacy: full covariant theory

The plots were obtained using the Faradayan description of the dynamics of charged DM agglomerates; thankfully, EXACT solutions describing such systems EXIST! They are based on the charged version of the McVittie solution (1933), which was constructed by Shah & Vaidya (1967) and generalized by Kastor & Traschen (1992).

$$ds^2 = -V(x,t)^{-2}dt^2 + a^2(t)V(x,t)^2 d\vec{x}^2 \qquad A = V^{-1}dt$$

$$V(x,t) = 1 + \sum_I \frac{\mu_i}{a(t)|\vec{x} - \vec{x}_i|} \qquad H^2 = \frac{\dot{a}^2}{a} = \frac{8\pi G_N}{3}\rho_{\rm neutral}$$

We can extract the Hubble parameter by writing this solution as a sub-horizon perturbation about the observers local Lorentz frame, in Newtonian gauge

In this way, we precisely reproduce the results of the Faradayan intuition. This means that the qualitative description is completely correct in the leading order. It remains to check what other effects there are.

In light of this, we need to reexamine...

- Luminosity distance, and BAO
- CMB and the acoustic peak structure
- Galaxy formation

Key questions:

- What fraction of DM may be charged under a dark U(1)′?
  - Not so well known, as a matter of fact! (More to follow in a jiffy!)
- Where does the net charge of the universe come from?
  - Interesting ideas by Dolgov & Silk: gauge symmetry breaking in the early universe/inflation, and subsequent restoration
- How do we best detect it/constrain it/rule it out?
  - This answer is obvious: cosmological data analysis! Careful rechecking...

Bounds on dark gravity?

To leading order: the extra repulsion looks Coulomb-ic - with an inverse square force. The reason is that the magnetic U(1)′ effects are small for virialized DM, if $v/c \sim (\delta\rho/\rho)^{1/2}$

Thus: DM appears to feel a bit SMALLER G_N . How much is allowed?

- Frieman & Gradwohl (1992): $\Delta G_N/G_N$ could be O(1) using cosmological data then to constrain a scalar tensor gravity with different DM couplings.
- Kamionkowski-Kesden (2006): $\Delta G_N/G_N < O(0.1)$ from stellar (non)stripping in Milky Way spiral arms by halo satellites
- However: Peebles et al (2009) objected, arguing that KK bound depends on the assumed contents of the satellites & galaxies

- Even if we take KK at face value, since $F \sim (q)^2$ it implies that as much as 30% of DM may in fact be charged!

Summary

• A net charge for a long range U(1)′ has interesting cosmological consequences.

• Searching for the presence of such weak forces is virtually impossible in the lab. Yet, an astronomer may do it, playing much the same role as Millikan.

• Different probes of cosmic expansion measure different cosmic contents, & yield different dark sector relative abundances. We showed such charges can affect the total fraction of DE, and its equation of state - a DE contaminant.

• This could also yield things like anomalous Hubble flows near galactic overdensitties. Claims of such flows were made eg by Kashlinsky et al (2008). A real physics or a fluke? Carefully analyze the cosmological data to place the bound on the fraction of charged DM. And perhaps, pray...

• Morale: any unusual cosmic phenomena may be caused by stuff other than just modified gravities, which may be under better physical control.


Domo arigato!