About modified gravity theories, Bertone & Tait state

“the only way these theories can be reconciled with observations is by effectively, and very precisely, mimicking the behavior of cold dark matter on cosmological scales.”

Leaving aside just which observations need to be mimicked so precisely (I expect they mean power spectrum; perhaps they consider this to be so obvious that it need not be stated), this kind of reasoning is both common and powerful – and frequently correct. There are lots of positive things to be said for the standard cosmology.

This upshot of this reasoning is, in effect, that “cosmology works so well that non-baryonic dark matter must exist.”

I have sympathy for this attitude, but I also remember many examples in the history of cosmology where it has gone badly wrong. There was a time, not so long ago, that the matter density had to be the critical value, and the Hubble constant had to be 50 km/s/Mpc.

By and large, it is the same community that insisted on those falsehoods with great intensity that continues to insist on conventionally conceived cold dark matter with similarly fundamentalist insistence.

I think it is an overstatement to say that the successes of cosmology (as we presently perceive them) prove the existence of dark matter.

A more conservative statement is that the ΛCDM cosmology is correct if, and only if, dark matter exists.

But does it?

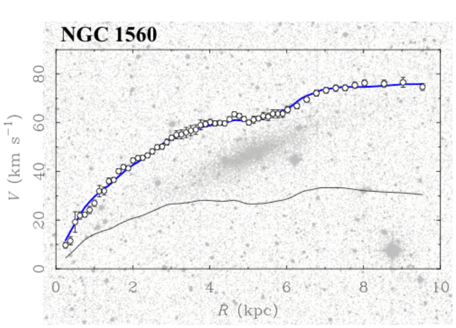
That’s a separate question, which is why laboratory searches are so important – including null results. It was, after all, the null result of Michelson & Morley that ultimately put an end to the previous version of an invisible aetherial medium, and sparked a revolution in physics.

Here I point out that the same reasoning asserted by Bertone & Tait as a slam dunk in favor of dark matter can just as accurately be asserted in favor of MOND.

“the only way ΛCDM can be reconciled with observations is by effectively, and very precisely, mimicking the behavior of MOND on galactic scales.”

This is a terrible problem for dark matter. Even if it were true, as is often asserted, that MOND only fits rotation curves, this would still be tantamount to a falsification of dark matter by the same reasoning applied by Bertone & Tait.

Lets look at just one example, NGC 1560:



The rotation curve of NGC 1560 (points) together with the Newtonian expectation (black line) and the MOND fit (blue line). Data from Begeman et al. (1991) and Gentile et al.

MOND fits the details of this rotation curve in excruciating detail. It provides just the right amount of boost over the Newtonian expectation, which varies from galaxy to galaxy. Features in the baryon distribution are reflected in the rotation curve.

That is required in MOND, but makes no sense in dark matter, where the excess velocity over the Newtonian expectation is attributed to a dynamically hot, dominant, quasi-spherical dark matter halo.

Such entities cannot support the features commonly seen in thin, dynamically cold disks. Even if they could, there is no reason that features in the dominant dark matter halo should align with those in the disk: a sphere isn't a disk.

In short, it is impossible to explain this with dark matter – to the extent that anything is ever impossible for the invisible.

NGC 1560 is a famous case because it has such an obvious feature.

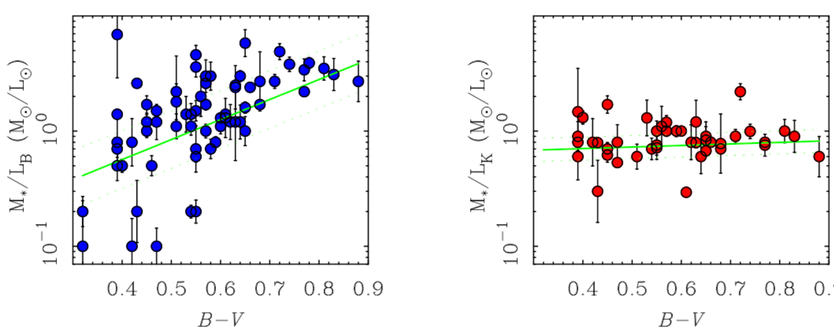
It is common to dismiss this as some non-equilibrium fluke that should simply be ignored. That is always a dodgy path to tread, but might be OK if it were only this galaxy.

But similar effects are seen over and over again, to the point that they earned an empirical moniker: Renzo's Rule.

Renzo's rule is known to every serious student of rotation curves, but has not informed the development of most dark matter theory. Ignoring this information is like leaving money on the table.

MOND fits not just NGC 1560, but very nearly every galaxy we measure. It does so with excruciatingly little freedom. The only physical fit parameter is the stellar mass-to-light ratio. The gas fraction of NGC 1560 is 75%, so M/L plays little role. We understand enough about stellar populations to have an idea what to expect; MOND fits return mass-to-light ratios that compare well with the normalization, color dependence, and band-pass dependent scatter expected from stellar population synthesis models.

One



can also fit

The mass-to-light ratio from MOND fits (points) in the blue (left panel) and near-infrared (right panel) pass-bands plotted against galaxy color (blue to the left, red to the right). From the perspective of stellar populations, one expects more scatter and a steeper color dependence in the blue band, as observed. The lines are stellar population models from Bell et al. (2003). These are completely independent, and have not been fit to the data in any way. One could hardly hope for better astrophysical agreement.

rotation curve data with dark matter halos. These require a minimum of three parameters to the one of MOND. In addition to M/L, one also needs at least two parameters to describe the dark matter halo of each galaxy – typically some characteristic mass and radius.

In practice, one finds that such fits are horribly degenerate: one can not cleanly constrain all three parameters, much less recover a sensible distribution of M/L.

One cannot construct the plot above simply by asking the data what it wants as one can with MOND.

The “disk-halo degeneracy” in dark matter halo fits to rotation curves has been much discussed in the literature. Obsessed over, dismissed, revived, and ultimately ignored without satisfactory understanding.

Well, duh.

This approach uses three parameters per galaxy when it takes only one to describe the data.

Degeneracy between the excess fit parameters is inevitable.

From a probabilistic perspective, there is a huge volume of viable parameter space that could (and should) be occupied by galaxies composed of dark matter halos plus luminous galaxies.

Two identical dark matter halos might host very different luminous galaxies, so would have rotation curves that differed with the baryonic component.

Two similar looking galaxies might reside in rather different dark matter halos, again having rotation curves that differ.

The probabilistic volume in MOND is much smaller. Absolutely tiny by comparison.

There is exactly one and only one thing each rotation curve can do: what the particular distribution of baryons in each galaxy says it should do.

This is what we observe in Nature.

The only way ΛCDM can be reconciled with observations is by effectively, and very precisely, mimicking the behavior of MOND on galactic scales.

There is a vast volume of parameter space that the rotation curves of galaxies could, in principle, inhabit. The naive expectation was exponential disks in NFW halos.

Real galaxies don’t look like that. They look like MOND.

Magically, out of the vast parameter space available to galaxies in the dark matter picture, they only ever pick the tiny sub-volume that very precisely mimics MOND.

The ratio of probabilities is huge. So many dark matter models are possible (and have been mooted over the years) that it is indefinably huge. The odds of observing MOND-like phenomenology in a ΛCDM universe is practically zero. This amounts to a practical falsification of dark matter.

I’ve never said dark matter is falsified, because I don’t think it is a falsifiable concept. It is like epicycles – you can always fudge it in some way.

But at a practical level, it was falsified a long time ago.

That is not to say MOND has to be right.

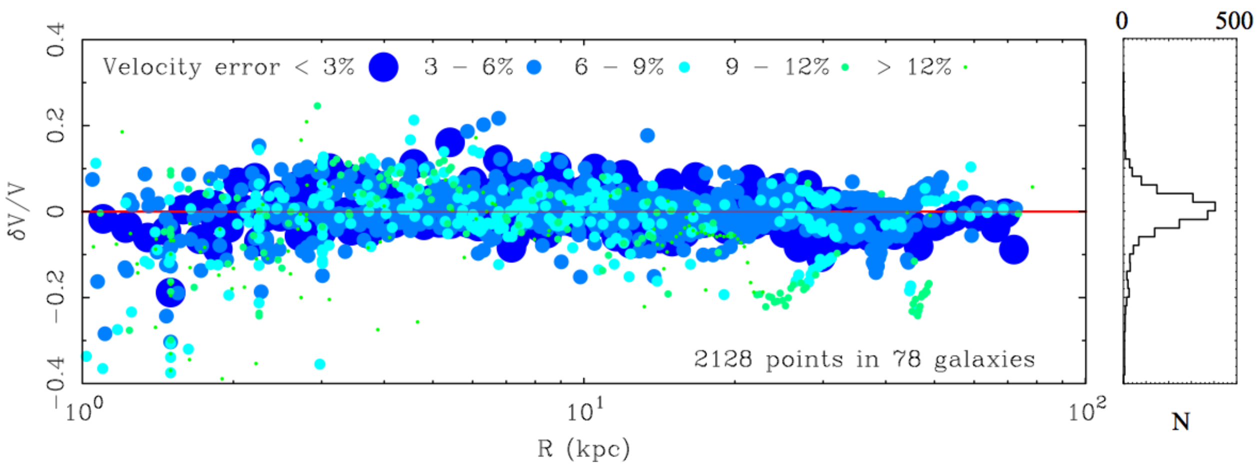
That would be falling into the same logical trap that says ΛCDM has to be right. Obviously, both have virtues that must be incorporated into whatever the final answer may be. There are some efforts in this direction, but by and large this is not how science is being conducted at present.

The standard script is to privilege those data that conform most closely to our confirmation bias, and pour scorn on any contradictory narrative.

In my assessment, the probability of ultimate success through ignoring inconvenient data is practically zero. Unfortunately, that is the course upon which much of the field is currently set.

There are of course exceptions: no data are perfect, so even the right theory will get it wrong once in a while. The goof rate for MOND fits is about what I expect: rare, but more frequent for lower quality data. Misfits are sufficiently rare that to obsess over them is to refuse to see the forest for a few outlying trees.

Here's a residual plot of MOND fits. See the peak at right? That's the forest. See the tiny tail to one side? That's an outlying tree.



Residuals of MOND rotation curve fits from Famaey & McGaugh (2012).