DARK MATTER PLANS IN ZURICH

Marek Matas
UPC group meeting at Decin 14.-16.9.2020

DARK MATTER HISTORY

FRITZ ZWICKY

Zwicky in 1933 noticed that the galaxies in Comma cluster have a large velocity dispersion (just as Hubble did before him).

He went on to estimate this dispersion with virial theorem from thermodynamics and with the number off observed galaxies in the cluster.

He arrived to an average dispersion of 80 km/s.

The observed one was 1000km/s.

He then concluded:

If this would be confirmed, we would get the surprising result that dark matter is present in much greater amount than luminous matter.

Fritz Zwicky 1933

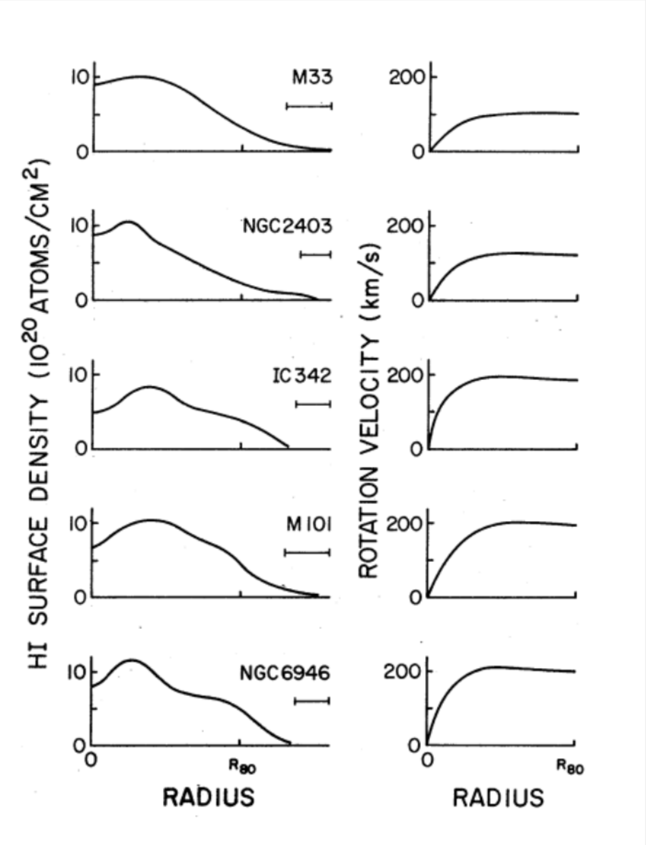
GALACTIC ROTATION CURVES

The rotation curves of galaxies – i.e. the circular velocity profile of the stars and gas in a galaxy, as a function of their distance from the galactic center – played a particularly important role in the discovery of dark matter.

It was the observation of “flat” rotation curves at very large galactocentric distances that showed that large amounts of dark matter is present in the outer regions of galaxies.

if [the data] are correct, then there must be in these galaxies additional matter which is undetected, either optically or at 21 cm. Its mass must be at least as large as the mass of the detected galaxy, and its distribution must be quite different from the exponential distribution which holds for the optical galaxy.

Ken Freemen1970



Rogstad and Shostak 1972

DARK MATTER CANDIDATES

NEUTRINOS

Neutrinos come at first as a natural candidate for the DM discrepancy. They are

- weakly-interacting
- stable
- already incorporated in the SM

$\sim$10 eV neutrinos might make up the "missing mass" in the Universe, and in galaxy clusters.

1976, A. S. Szalay and G. Marx

In the 1980s numerical simulations came into play. Very light and relativistic (hot) DM particles would firstly form large intergalactical structures and then form smaller scale bodies. The non-relativistic (cold) would form firstly small-scale structures and then bind them to larger ones. Those would then have a very different morphology.

We find [the coherence length] to be too large to be consistent with the observed clustering scale of galaxies...The conventional neutrino-dominated picture ap- pears to be ruled out.

1983 Simon White, Carlos Frenk and Marc Davis

SUPERSYMMETRY

In Supersymmetry, each particle has its supersymmetry partner with the same quantum numbers. This then gives rise to additional neutral and non-strongly interacting particles such as the partners of

neutrinos, photon, Z boson, Higgs boson, and graviton

In order for these superpartners to be stable a new rule of R-parity had to be imposed. This then stabilizes the proton (which would otherwise decay) and allows for the lightest superpartner to be stable.

The motivation off supersymmetry comes from particle physics and its implications for solving this cosmological problem is a huge motivation for physicist in both fields.

If in some other universe, astrophysicists had measured the cosmological density of matter to be consistent with the observed density of stars, gas, and other baryons, particle physicists in that universe may have been just as interested in supersymmetry as they are in ours.

2016 Gianfranco Bertone and Dan Hooper

AXIONS

The strong CP-problem of QCD is a troubling issue of this theory. Its lagrangian contains the term

$$\mathcal{L}_{\mathrm{QCD}} \supset \bar{\Theta}\,\frac{g^2}{32\pi^2}\,G^{a\mu\nu}\tilde{G}_{a\mu\nu}.$$

Here $G^{a\mu\nu}$ is the gluon field strength and $\bar{\Theta}$ is closely related to polarisation off QCD vacuum. If this variable was ~1, large CP-violating effects would emerge causing the magnetic moment of the neutron to be 10^{10} times larger then its value.

therefore $\bar{\Theta}$ has to be ~10^{-10}, which is viewed as a huge coincidence and an implication that there is some additional physics missing that suppresses this parameter.

A new global U(1) symmetry that is spontaneously broken would suppress this factor to zero and its value would be naturally explained.

1977 Roberto Peccei and Helen Quinn

This implies the existence of an additional Nambu-Goldstone boson dubbed Axion.

These could be generated in the early universe by drawing energy from suppressing the field associated with $\bar{\Theta}$ to densities comparable with DM.

BARYONIC DARK MATTER

One of the obvious explanations for DM is that it is composed of much less luminous matter, but still of ordinary baryonic matter such as

planets, brown dwarfs, red dwarfs, white dwarfs, neutron stars, and black holes

These objects have been termed as MACHOs---massive astrophysical compact halo objects.

Today, it is not believed that MACHOs could be identified as the missing DM. Two main lines of research have proved this statement.

1. Gravitational microlensing
2. The Universe's Baryon Budget

BARYONIC DARK MATTER

1. Gravitational microlensing

Einstein's theory of relativity predicts that massive object could serve a lenses for distant light sources.

In 1924, Orest Chwolson proposed, that the deflected light might make a ring or multiple images and due to the precise alignment of massive bodies necessary, Einstein stated that

There is no great chance of observing this phenomenon.

The effect has been observed and in 1986 Bohdan Paczynski proposed that it could be used to search for compact massive dark objects in our galaxy.

The strategy of search was to look to the Large Magellanic Cloud (orbiting galaxy close to Milky Way), monitor large number of stars and look for magnifications due to microlensing events.

BARYONIC DARK MATTER

1. Gravitational microlensing

If the halo consisted of MACHOs, 1 in 2 000 000 starts would brighten for duration of

$t \sim 130\,\mathrm{days} \times (M/M_{\odot})^{0.5}$, where $\sim 10^{-7} M_{\odot}$ to $\sim 10^{2} M_{\odot}$ would correspond to timescales of hours to a year.

In the year 1993, first microlensing event was measured by the MACHO collaboration of 0.03 to 0.5 solar masses. At first, the rate was consistent with the anticipated rate for DM.

After the discovery of MACHOs in 1993, some thought that the dark matter puzzle had been solved.

However, over 5.7 years, 40 million stars were monitored and only 14-17 microlensing events were detected. This (combined with EROS measurement) lead to an upper limit of 8% of the missing DM to be made of MACHOs.

BARYONIC DARK MATTER

2. The Universe's Baryon Budget

After the discovery of the cosmic microwave background in 1965, it was possible to use its temperature to calculate the initial ratios of primodial Helium to 26-28%, which was consistent with observations.

Light element abundances (such as Deuterium, that is not produced in stars) served to place an upper limit on the amount of cosmologic baryon density to be $\Omega_b \lesssim 0.1\,\Omega_{\rm crit}$. (where our universe is believed to be close to the critical mass of a flat universe)

The angular power spectrum of the CMB is also sensitive of this variable. The WMAP experiment and later the Planck collaboration agreed with the conclusion that less then 20% of matter is of baryonic origin.

PRIMORDIAL BLACK HOLES

There is a possibility that in the initial genesis of the universe, a large amount of black holes were created below the mass limit necessary for gravitational microlensing experiments.

There is a large spectrum of possible masses, that these black holes could have. Since there is a lack of the observed Hawking-radiation, and accounting for null-microlensing results, the accepted mass range is 10^{14} to 10^{23} kg.

However, the predicted formation rate for these object in the early universe is negligible if one assumes scale-invariant spectrum of density fluctuations observed in the CMB.

That is why the initial enthusiasm for such explanation of DM has been somewhat tempered.

MODIFIED GRAVITY

In the year 1982, Mordehai Milgrom postulated Modified Newtonian Dynamics (MOND). If instead of

$$F = ma$$

altered version of this formula

$$F = ma^2/a_0$$

was assumed for very low accelerations of

$$(a \ll a_0 \sim 1.2 \times 10^{-10} \text{ m/s}^2)$$

this would naturally explain the DM observations without the need for any missing mass in the Universe.

In order to describe also gravitational lensing experiment, this theory was improved in the Tensor-Vector-Scalar gravity in 2004.

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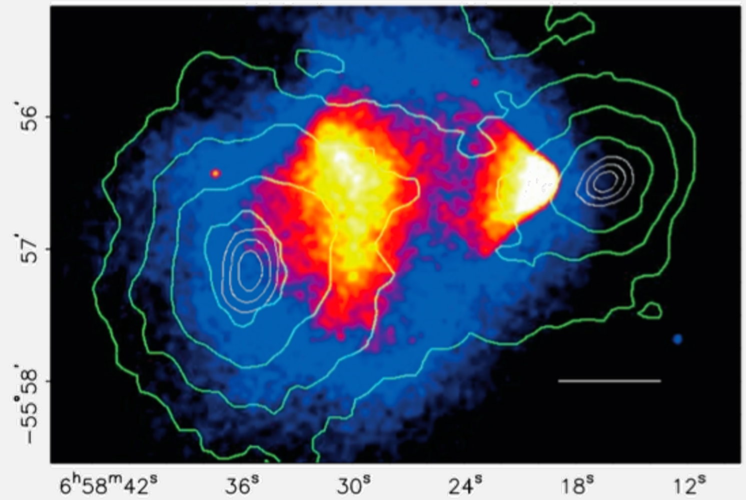

The bullet cluster observed in 2006 shows a collision of two clusters and how the baryonic matter (colored) gets displaced from the lensing mass (contour).

Clowe, D., M. Bradac, A. H. Gonzalez, M. Markevitch, S. W. Randall, C. Jones, and D. Zaritsky (2006)

MY FUTURE WORK WITH DM

DAMA EXPERIMENT

DAMA/LIBRA (and DAMA/NaI) experiment is located in Gran Sasso (IT) and uses annual modulation of direct detection signal produced by Earth orbiting around the sun.

It claims to have seen a model-independent annual modulation of signal in the keV range therefore effectively observing DM-matter interactions in thallium doped NaI scintillators.

These experiments work with DM-nucleus scattering, whereas DM-electron scattering in semiconductors should be more precise for this mass-range.

MY WORK

Numerous other experiments have tested this mass range with null results. There is still room to reconcile these null results with the DAMA signal.

My work *Light Dark Matter through its Interaction with Electrons in Solids*

will focus on using condensed matter approach to model materials of the detectors with particle physics calculations.

The semiconductor targets are especially sensitive for such DM candidates, but the complex electron structure of these crystals makes it difficult to understand what signal should be expected.

I will try to estimate how would a potential DM signal look in these detectors and which DM candidates are possible to be consistent with existing measurements.

CONCLUSIONS

- It will be fun

THANK YOU FOR YOUR ATTENTION

No matter what, don’t lose hope. We are all bombastic.

- Dan Nekonečný