Concluding remarks

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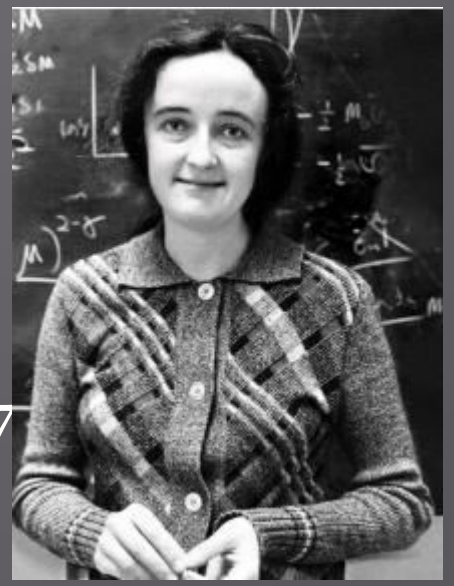
40 years of DM



- Rumours about DM date back to Zwicky ~1937
- But DM became canonical quite suddenly @ the 1977 meeting
- Organized by Beatrice Tinsley (1941-1981), pioneer of population synthesis, chemical evolution, detection of merger remnants,..

Is LCDM correct?
Does DM exist?

- After Monday I'm much less sure
- When CDM arrived in the 1980s, its big plus was that it was predictive
- In the 1990s conflict between its predictions and observations of CMB, clustering and SNIa led to its demise in favour of LCDM
- CDM made sense
  - we know there is DM in the form of 3 families of (massive) neutrinos
  - it would be natural for other stuff to exist that would first manifest itself gravitationally
- But DE is incomprehensible

Does DM exist?

- DE demonstrates that we don't understand gravity at low energy densities
- If we have to change / reinterpret gr to account for DE, we have to hope that the required change will simultaneously banish DM
- Maurice van Putten presented an intriguing idea for abolishing DM
  - Inertia is reduced when acceleration so small that Rindler horizon lies beyond cosmic horizon, so the mass that can act per Mach is diminished
- Stacey McGaugh struck a powerful blow at DM:
  - The actual acceleration everywhere in any galaxy can be *precisely* computed from the baryon distribution *alone*
- How can dark & visible matter be so precisely coupled?
- The case against DM is greatly strengthened by Stacey's successful prediction of the low dispersion in Crater 2, on which Matt Walker reported
  - True prediction is the gold standard of science!

DM in simulations

- In the noughties it emerged that LCDM ins predictive in principle only
  - In practice it's too hard to compute what the baryons will do
  - It's also clear that on small scales (where most of the data are) the baryons do affect DM
- Since the full range of relevant scales (1 – 10^{15} M., 1 – 10^{6} pc) cannot be simultaneously simulated, analytic approximations to large-scale impact of (known) small-scale physics are required
  - This is absolutely standard for physicists: hydrodynamics, thermodynamics, continuum mechanics, condensed-matter physics
  - normally analytic approximations derived from (experimental or theoretical) studies of resolved systems
  - Cosmological simulators ignore known small-scale physics & judge trial analytic approximations by their ability to reproduce large-scale phenomenology
  - I find this worrying epistemologically
- James Bullock reported that even with carte blanche for the sub-grid physics he's not confident of being able to reproduce the observational constraints
- So the simulators are considering WDM, SIDM, dark atoms..
- This report doesn't build my confidence that DM exists!

Is DM an illusion?

- An illusion cannot soak up E, p or J!
- So to prove the existence of DM one just has to demonstrate that baryons surrender energy, momentum and angular momentum to DM
- Carlo Nipoti showed us dramatic differences between galaxies in MOND and their Newtonian equivalent
- In MOND merging is less likely and takes much longer
- In MOND fluctuations are much larger so dynamical friction is stronger
- If a bit of the computing power expended on WDM, SIDM, .. were diverted to MOND simulations of well studied z=0 systems (Antenae, M51, M15, ..) DM surely DM would be either ruled out or put beyond reasonable doubt
- Ralph Schoenrich told us that with the cosmologically predicted dark halo, sensible simulations of disc formation make a disc very like that of the MW, but with more or less dark halo, you get a disc you don't recognise
- These experiments sustain my faith in DM in the face of Stacey's alarming plot
- They show the importance of cross talk between light & dark matter

Apropos the MW

- Dennis Erkal explained the potential of tidally shredded GCs to allow us to detect dark dark haloes down to 10^6 M.
  - With the first major data release from Gaia due in <1yr, the potential here is huge
  - Currently streams are detected using only photometry
  - With Gaia we'll be able to exploit that all stream stars have essentially the same proper motion
  - So many more will be detected, and their dynamics will be tightly constrained
- Ortwin Gerhard presented a detailed picture of the bulge/bar
  - Which is quite strongly coupled to the dark halo
  - And in which the stellar mass fn can be determined to Jupiter masses with microlensing
- David Cole presented a dynamical model of the dark halo, including its irrefutable core
  - Note that cored halos have a scale length in addition to rs: you shouldn't just reduce alpha
- Why were there only 4 contributions relating to the MW?
  - The data for the MW are orders-of-magnitude better than the data for even z=0 galaxies, never mind barely resolved blobs at z=2-4!

Apropos smudges at z>=2

- Filippo Fraternali made 2 crucial points
  - 1. One should model a full data cube, not velocity moments
  - 2. We should interpret low-quality data from high z in light of knowledge of the z=0 universe
  - 3. We should model objects at z=0 in light of knowledge of the MW
- Filippo convinced me that star-forming discs at z>=2 aren't so different from star-forming discs now
  - This has interesting implications for the formation of thick discs, but not now
- Magda Arnoboldi showed that z=0 stellar discs are, like that of the MW, essential maximal
  - The work illustrates the importance of engaging with the composite nature of galaxies and the interplay of age, chemistry and dynamics that the MW teaches
  - It could be taken to be an argument for MOND..

Groups & clusters

- Piero Rosati illustrated that galaxy clusters are now nearly as important for cosmology as globular clusters were in the 1950s for stellar structure
  - A mixture of strong & weak lensing yields accurate knowledge of mass profiles
  - Their centres have rather flat DM densities
  - Mass estimates from dynamics & X-rays now agree with lensing masses
- Using galaxy clusters as telescopes we can now observe the formation of probable GCs
  - extraordinary objects that suffer from "familiarity breeds contempt"
    - How can SF be so efficient?
    - What's the origin of the sharp steps in He abundance..
- Julian Merten told us lensing masses are now robust & yield the c-M predicted by LCDM
- Henk Hoekstra updated us on the use of cosmic shear to determine S8
  - there's still tension between Planck value from CMB
  - Probably Planck's wrong but
  - Evolving DE would resolve both this tension and that between H from Planck H and SNIa
- Simon Driver made the case for more attention being paid to groups
  - They dominate the DM budget
  - He argued convincingly that we have a complete inventory of stars and SF

What next?

- The field continue to be driven forward by engineering marvels
  - Gaia (2018 ff) will yield a detailed map of Galactic DM, prove the existence of mini-halos, and with a fair wind demonstrate bar/halo and disc/halo interactions
  - JWST 2018 will reach the edge of the dark ages
  - eROSITA (2019ff) will do an all-sky survey ~10 times deeper than ROSAT
  - EUCLID will survey 1/3 of the sky to g=24.5 with spectacular image quality
  - ELT 2024 will allow spectroscopy at extraordinary faintness
- Will we make progress with DM? Surely it will be either established to revealed to be an illusion
- Will we make progress with DE? I doubt it, but hope to be proved wrong

And finally

- This has been an exceptionally interesting and enjoyable meeting
- A very special vote of thanks is due to Nicola Napolitano for the huge effort of organising this meeting
- Nicola, my heartfelt thanks for your kindness, foresight, patience and care!