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LETTERS

The mass of a dark matter WIMP derived from the Hubble constant conflict

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Abstract There continues to be good reason to believe that dark matter particles, which only "feel" the gravitational force, influence the local and distant Universe, despite drawing a complete blank in the search for such a particle. The expansion rate of the Universe is defined by the Hubble constant h. Measurements of the Hubble constant at different wavelengths produce different results, differing well beyond their errors. Here it is shown that the two precise but different values for the Hubble constant can be used to derive the mass of a weakly interacting massive particle (WIMP). An approximate mass of 10^{22} eV is determined with indications of why, so far, it has not been found and what is required to get positive confirmation of its presence. This result also indicates that the Hubble constant is the sum of more than one contribution with suggestions for experimental tests to determine, more precisely, the level of these contributions.

Key words: cosmology: theory — cosmology: dark matter — cosmology: cosmic background radiation

1 INTRODUCTION

The different values for the Hubble constant (h) measuring the rate of expansion of the Universe present a problem. Results from the Planck experiment (Ade et al. 2014) produce a value for h of 67.3($\pm$ 1.2) km s^{-1} Mpc^{-1} as measured against the Cosmic Microwave Background (CMB) radiation with the European Space Agency (ESA) Planck satellite. The value of h measured in the comparatively local Universe based on type Ia supernovae (SNIa) explosions as standard candles produces a value for h of 73.52 ($\pm$ 1.62) km s^{-1} Mpc^{-1} (Riess et al. 2018). This measurement also replies on the Hubble and Gaia telescopes to determine the distance-scale ladder. The value from the SNIa search is about 9% larger than the CMB measurement and "raises the current tension between the late and early Universe route to the Hubble constant to 3.8σ (99.99%)" (Riess et al. 2018).

The dynamics of galactic rotation (Rubin et al. 1980; Bosma 1981) indicate that possibly 24% of galactic matter is in a form that we currently can only partially describe. Our descriptions are limited to describing the matter as due to particles that only feel the gravitational force and are probably weakly interacting massive particles or WIMPs. The search for dark matter has over many years not produced a positive result both from operating the CERN Large Hadron Collider (Drees et al. 2001), or looking for the signature of WIMP interactions (Archambault et al. 2012), with a comprehensive review by Vasiliki A Mitsou (Mitsou 2015) and numerous searches hunting for interactions of dark matter particles locally, typically applying a range of detectors, like the Japanese XMASS detector (XMASS Collaboration et al. 2018), the Italian XENON programme (Aprile et al. 2019), the United States LUX experiment in the Homestake Mine in South Dakota (Akerib et al. 2016), or the UK programme from the University of Sheffield centred on the Boulby mine in Yorkshire (Battat et al. 2015).

In summary we have a significant difference of about 9% in two measurements of the Hubble constant and, in the search for an estimated 24% of the mass of the Universe, we have found nothing.

2 PROPOSAL

These two perplexing results are considered together, and it is proposed that the dark matter in the Universe has at least one component comprising a massive fermion that only feels the gravitational force. Its fermion characteristics include mass, spin and the other normal quantum characteristics. Here they are called Hoyle or H particles recalling the name of my local Bradford (UK) cosmologist Professor Sir Fred Hoyle.

It is proposed that such H particles will “see” each other and will form H “atoms” held together by the gravitational force. There are many ways in which such particles can gravitationally interact. There is also the possibility of spin interactions as with hydrogen atoms. With the H particles being gravitationally attracted, there will be a probability of H particles combining to form such gravitational pairs in a time t. The background radiation from starlight, the CMB radiation and cosmic rays will disrupt these pairs in a time T. Here it is assumed that the intensity of the background radiation is such that t is much smaller than T and there is a significant density of pairs of these H particles existing as a stable form. Two such H particles could orbit each other in the form of a Bohr “atom”, obeying the Pauli exclusion principle with two forms displaying spins both parallel and antiparallel. Like molecular hydrogen, they would display a large range of vibrational and rotational excited states. Other forms of hydrogen atoms, an alternative kind of hydrogen atom (AKHA), have been suggested by Oks (2001) governed by the quantum mechanics of the electromagnetic force. Here we are considering particles governed only by the gravitational force where the masses of the particles are many orders of magnitude greater than the proton so an analogue is more likely to be star formation where triples and other multiples exist but are rare. Such investigations would form the basis for further work on H particle interactions.

Since photons also have a virtual mass, they will see and interact with these particles and more importantly with these H “atoms”. One way would be through a process of “ionisation” breaking the particles free from each other and destroying the H “atom”. It is possible that there will be other forms of gravitationally attracted coupling just as with stars but here I will only consider pairs of H “atoms”. It is expected that this form of matter will also have a temperature and display a spectrum of energy states, producing an energy density approximating the Planck formula describing gases which satisfy the thermal radiation laws.

It is suggested that photons passing through space with its dark matter will lose energy “ionising” these “atoms” but also by exciting these “atoms” in a way similar to the way in which low energy electrons lose energy in solids (Frass 2009), approximating to 2 MeV $\text{gm}^{-1}\,\text{cm}^{-2}$, about 16.7 gm $\text{Mpc}^{-1}\,\text{cm}^{-2}$. It is now proposed that there are at least two processes producing the measured values of the Hubble constant. One of these is due to the interaction of photons with dark matter.

A priori, it may be thought that such WIMP matter would influence the passage of gravitational waves with an effective “refractive index” but in recent initial studies (Flauger & Weinberg 2018; Weinberg 2004; and Baym et al. 2017) this is considered to be too small to be relevant.

3 OBSERVATIONS

Such speculation adds nothing until we encounter what could be described as quantum steps in the energy loss of photons in space. There are two possibilities here. One is the apparent acceleration of the Universe at z=0.4 as measured by Riess et al. (1998). This has become less secure recently, with contributions by Nielsen et al. (2016) indicating that, with a much bigger sample of supernovae, the evidence is consistent with a constant rate of expansion and work at X-ray frequencies by Migkas et al. (2020) that suggests that the Universe is not isotropic at a level of 30%.

The other “quantum step” which is considered here is the apparent difference in the Hubble constant of 9% when measured using supernovae as standard candles, where the measurements are made in the visible wavelengths (Riess et al. 2018) and the value of the Hubble constant when measured against the CMB radiation at millimetre wavelengths with experiments like Planck (Ade et al. 2014) and its precursors COBE (Bennett et al. 1993) and WMAP (Hinshaw et al. 2013).

Here it is proposed that this difference in the Hubble constant measured at different wavelengths is due to the longer wavelength photons of the CMB at millimetre wavelengths not being energetic enough to “ionise” the Hoyle particle H “atom”. The optical wavelengths, with their greater energy, are able to “ionise” the H “atoms”. A value for this ionisation energy in the Hoyle particle “atom” enables the mass of the H particles to be calculated.

4 RESULTS

The visible waveband measurements of the Hubble constant are all at wavelengths less than one micron and the Planck measurements are all at frequencies less than 353 Ghz, i.e wavelengths greater than 0.85 mm. It is assumed here that the energy for the “ionisation” transition is 0.75 mm, but it could be anywhere between 1 µm and 0.85 mm. Since the mass value for the H particle is the result of taking a 5th root of the photon frequency, a 1000 fold difference in the wavelength of excitation only changes the value of the mass by a factor of 4, which in this initial consideration is not important.

Following the approach of Neils Bohr (Bohr 1913), it is assumed that the total angular momentum of each of the

H particles in the ground state can be described as equal to Planck's constant h, divided by 2π. The Hoyle "atom" can further be described by the centripetal force of the two Hoyle particles rotating around a common centre of mass being balanced by their gravitational attraction.

The key to solving these equations to produce the mass of the Hoyle particle is that the energy of this "ionisation" is given by the necessary photon energy hυ where h is Planck's constant and υ is the frequency of the photon necessary to produce this "ionisation" of the Hoyle "atom". As we suggest above, the frequency of this photon will lie between 353 GHz and 300 THz. Solving the equations for a 400 Ghz photon produces a mass for the Hoyle particle of about 2×10^{-14} kg or 1×10^{22} eV and for a 300 THz photon about 7×10^{-14} kg or 4×10^{22} eV.

5 DISCUSSION

The resulting mass is comparable to the papers discussing dark matter as Wimpzillas (Kolb & Long 2017) and as gravitational particles (Ema et al. 2018).

It is worth considering whether the various WIMP detector systems around the world, including LUX in South Dakota, USA (Akerib et al. 2016), Xenon100, Darkside50 and XENON-1T at Gran Sasso in Italy (Aprile et al 2019), Boulby Potash Mine in Yorkshire run by Sheffield University in the UK (Battat et al. 2015) and XMASS in Kamioka, Japan (XMASS Collaboration et al. 2018), will have seen anything. The detectors use liquid xenon and liquid argon. The area they present for the H particles to interact with varies from between about 0.025 m^2 to 1 m^2, and the path length in the liquid from around 15 cm in the smallest detector to 1 m in XENON-1T. The largest effective cross section is XMASS with a 0.4 m^2 cross section but an operation time of 9 years. The calculation of the cross-section for H particles and H "atoms" to produce a detectable interaction (nuclear recoil) with a liquid xenon or argon nucleus is the subject of ongoing work as is the fraction of dark matter that progresses in the form of H "atoms" deep under the surface of the Earth. Here I merely derive an approximate value for the number of H particles traversing the detector, which is unlikely to have produced a signal using the dark matter WIMP cross section discussed in a recent review paper (Marrodán Undagoitia & Rauch 2016).

Taking the density of dark matter in the solar neighbourhood from Nesti & Salucci (2012) as 0.43 GeV cm^{-3} which is about 0.7×10^{-21} kg m^{-3} and the mass of the Hoyle particle as 2×10^{-14} kg, we will get about 1000 per day passing through a 1 m^2 detector due to the velocity of the Sun in the Galaxy of 370 km s^{-1} and Earth around the Sun of 30 km s^{-1}, or from the work of Karachentsev & Telikova (2018) suggesting a dark matter density on a larger scale of around 4×10^{-27} kg m^{-3}. This would result in two particles every year passing through a 1 m square detector. Thus the largest detector XENON-1T would have about 1000 dark matter particles per day traversing the detector. The more pessimistic scenario of Karachentsev and Telikova would only have produced about 20 particles traversing the XMASS detector in the 9 years of operation. It would be expected that only single particles would traverse the detector since the interaction with the atoms of the atmosphere and 1 km of rock would probably break up any H two-particle "atoms".

In reality, the density of dark matter along the path of the Sun around the Galaxy is not well defined. The cross section of the H particle or H " atom" interaction with matter has yet to be calculated and the operating detectors have relatively small areas and not lengthy periods of operation. With cross sections of 10^{-45} cm^2 attributed to dark matter WIMPS (Marrodán Undagoitia & Rauch 2016), a lack of detections is understandable.

A bigger question is around the contributions of dark matter and other sources to the measured Hubble redshift of gravitational waves. Weinberg (2004) considered the passage of gravitational waves in the era of inflation and Flauger & Weinberg (2018) extended this work to consider the passage of gravitational waves through a medium containing massive particles. They determined that the effects would not be measurable but conceded that the inclusion of the massive particles made the calculation more complex with many assumptions. The work was further developed for massive particles by Baym et al. (2017) without producing definitive effects for the passage of gravitational waves through massive particle dark matter as detected recently by the LIGO and Virgo detectors. Goswami et al. (2017) developed the work considering space as a viscous fluid with the properties determined by the density of massive particles and their properties, but they only provided a "proof of principle demonstration that would fit future observations of gravitational waves by better constraining the properties of dark matter."

The international team of LIGO et al. (2019), working with gravitational wave detectors LIGO and Virgo, determined the Hubble constant to be 68 km s^{-1} Mpc^{-1}. This would imply that most of the Hubble constant is due to the expansion of the Universe, and a mere 9% may be due to a second process. But as with all new measurements of the Hubble constant, the errors are rather large and could easily accept a value of h, the Hubble constant, anywhere between 60 km s^{-1} Mpc^{-1} and 82 km s^{-1} Mpc^{-1} as one sigma deviation in the included errors. Inclusion of all the errors is the most difficult part of new experimental measurements.

For this discussion, the value of 68 km s^{-1} Mpc^{-1} (LIGO et al. 2019) of the gravitational wave detector teams will be assumed to be correct, giving a value for the Hubble constant h due to the expansion of the Universe. Flauger & Weinberg (2018) commented that in deriving the value of the Hubble constant from the LIGO and Virgo gravitational wave detectors, the team did not consider the impact of dark matter on the value of h, the Hubble constant, following the view of Flauger and Weinberg who consider the effect will not yet be measurable.

Thus 9% of the loss of intensity measured at optical wavelengths can be attributed to interactions with a massive WIMP or Hoyle particle of mass around 10^{-14} kg or 10^{22} eV. There are a number of tests that should be pursued to check this.

6 FURTHER WORK

The planned development of the liquid xenon detectors, LUX-ZEPLIN in South Dakota with a 2.25 m^2 cross section and XMASS-II in Japan with a cross section of about 4 m^2, would greatly increase the probability of the detection of H particles. It would be desirable to develop theoretical considerations of the spin and spin independent interaction cross-section for massive WIMP interactions with nuclei.

Radio measurements of the hydrogen line at 21 cm are another possibility and if they can be associated with a standard candle, they should consistently give a value of 68 km s^{-1} Mpc^{-1}. Recent measurements by Bowman et al. (2018) show the 21 cm hydrogen line at 78 MHz around z equal to 16. Any standard candle measurement at this z would be very useful considering SNIa, the Sunyaev-Zeldovich (S-Z) effect or gravitationally lensed quasars. The paper of Bowman et al. is also relevant because their 21 cm signal induced by early stars is a factor of 2 bigger than can be explained and suggests that there was a massive particle interacting with the hydrogen to cool it down. They attribute the particle to a dark matter WIMP. There have been numerous other explanations of the apparent cooling seen by Bowman including the explanation of Oks (2020) who suggested that the proposed AKHA could account for the puzzling observation by Bowman et al. (2018) both qualitatively and quantitatively. Clearly, further observational evidence is needed. The problem with 21 cm radio measurements is the resolution necessary to pick out the galaxy containing the supernovae. It is suggested that a radio telescope on the Moon, possibly in the Neper crater at 83 degrees East and 7 degrees North, could make such a detection. Such a telescope would be permanently shielded from radio pollution from the Earth but could still maintain direct contact with the Earth from the crater rim. The crater also contains a number of secondary craters which would assist in creating the parabolic shape for a reflecting radio telescope. Working with a radio telescope on the Earth, for example the Square Kilometre Array in South Africa and Australia, observing from the Neper crater near zenith, at a wavelength around 20 cm, the Lunar/Earth radio telescope would have a resolution of about one milliarcsecond. With this resolution, it would be able to match the best optical telescopes and observe galaxies at redshifts large enough to avoid confusion with local velocities and rotational velocities when measuring the redshift of the 21 cm hydrogen line.

There is also the possibility of H “atoms” producing a spin flip transition radio signal, but from a priori energy considerations this is only likely to be detected with radio telescopes in space or, completely away from the Earth-based radio pollution, on the far side of the Moon.

X-ray measurements of the brightness of distant clusters of galaxies can also be employed as a standard candle through the S-Z effect and these should give a much higher value for the Hubble constant. At the present time, the errors in S-Z measurements are too large to show this predicted difference.

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