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Can Frozen Hydrogen Snowballs Account for Galactic Dark Matter?

or

A Cryogenic Physicist Thinks about Astronomy

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Abstract

- DARK MATTER: Most mass in galaxies is invisible – what is it?
  - >80% of matter lies in halo around galaxies, but not in stars or other visible objects.
  - Cannot be dilute gas of H_2 and He – absorption lines would appear in spectra.
  - Popular theories suggest novel particles or novel dark objects such as black holes.
- Simpler alternative: frozen H_2 snowballs at 2.7 K.
  - Could also trap most He atoms internally.
  - This model could be tested using a cryogenic laboratory experiment.

Dark Matter Halos

- Dark Matter consists of inferred mass well outside visible stars and clusters in Milky Way and other galaxies
  - Orbital rotation rates of galaxies require distribution of mass in spherical region around galaxy.
  - This accounts for 80-90% of the mass in most galaxies.
  - This matter is not associated with stars or anything else visible.
  - This is a “dark matter halo”, although nothing is glowing.
  - The composition and origin of Dark Matter is one of the major mysteries of modern astrophysics.
- Dark Energy is another completely different mystery.
  - Related to gravitational repulsion in expansion of distant galaxies.
  - This analysis does not relate to Dark Energy in any way.

Current Explanations for Dark Matter

- Many varying alternative explanations, but none widely accepted.
  - Cold hydrogen seems to have been ruled out early for various reasons.
  - Revised theory of gravity to fit the rotation (Modified Newtonian Dynamics or MOND).
  - Massive Compact Halo Objects (MACHOs) such as primordial black holes or cold dark matter.
  - Novel particles such as WIMPs (weakly interacting massive particles) or sterile neutrinos.

Hydrogen and Helium Form the Universe

- Hydrogen is most common element in universe
  - 90% of nuclei are protons
- Helium is about 9% of atoms
  - Almost all He-4
- All other atoms total < 1%
  - We can neglect them here
- Could Dark Matter be mixture of hydrogen and helium?

Could Dark Matter be Warm Hydrogen?

- Uniform dilute gas of H_2 and He, with sufficient density to account for dark matter, would produce absorption lines in spectra of interstellar medium – not observed.
- Model of cosmic microwave background (at 2.7 K) suggests that most matter should not interact with light as nucleons do, encouraging alternative basis for dark matter.
- Dark matter based on hydrogen seems to have been abandoned.

Could Dark Matter be Cold Hydrogen?

- The temperature far from stars is limited by cosmic microwave background to T ~ 2.7 K.
  - Assume locations of dark matter exhibit T near 2.7 K.
- The freezing temperature of H_2 is 14 K.
  - The vapor pressure of solid H_2 at 2.7 is tiny ~ 10^{-14} atm.
- So frozen hydrogen could eliminate most H_2 gas, which could be compatible with dark matter in galaxies.
  - Noted years ago in the literature (White 1996), but mostly ignored.
- But He has a much higher vapor pressure.
  - Vapor pressure of liquid He at 2.7 K is large ~0.16 atm..
- Is there some way that frozen H_2 can trap He atoms?

Trapping of He Inside Solid H_2

- Frozen H_2 may be in the form of comet-like giant snowballs, held together by cohesion rather than by gravity.
  - The size may increase by condensation from gas as well as collision of smaller snowballs.
- A monolayer of He will adhere to surfaces of frozen H_2, and may also be trapped in internal surfaces of such a snowball.
  - For a large-enough snowball with multiple adsorption and collision events, a substantial portion of He atoms may be trapped internally.
  - If most He atoms are trapped, this could provide a strong candidate for dark matter.
- Similar cryogenic gas trapping with other condensed gases has been seen in the laboratory.

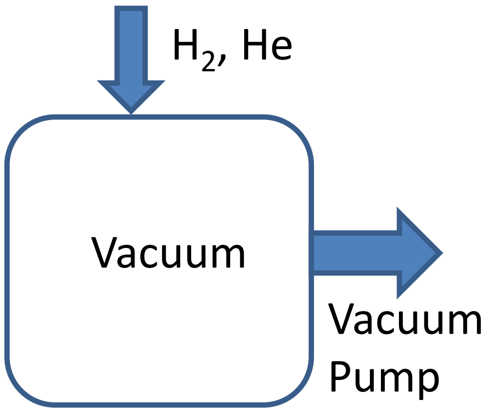
Ways to Enhance He Trapping

- Rather than dense solid H_2, consider a nano-porous composite down to an atomic scale.
  - This might form by condensation of H_2 from gaseous state.
  - This would increase possible surfaces for He adsorption.
- Vacuum evaporation of He from external surfaces could lead to cooling below the superfluid transition of 2.17 K for at least part of the life cycle of the snowball.
  - In the superfluid state, He would likely penetrate all internal nanoscale surfaces
  - This may trap more He atoms internally, even after the snowball warms back up to 2.7 K

Ways to Test H_2/He Snowball Model

- A H_2/He snowball could be simulated in a cryogenic laboratory experiment (next slide).
- If this model is correct, then it is likely that a small fraction of He gas would be present.
  - This He gas should provide a spectroscopic signature.
  - The combination of He spectra without H spectra would be a key indicator in support of this model.

Proposed Laboratory Experiment



- Vacuum chamber cooled to 2.7 K.
- Experiment #1:
  - Admit sufficient H_2 gas to coat surfaces.
  - Admit H_2/He gas mixture to chamber.
  - Repeat multiple times as desired.
  - Pump out excess gas, maintaining T = 2.7 K.
  - Warm up chamber and measure content of gases.
  - Determine fraction of He trapped in frozen H_2.
- Experiment #2:
  - Same initial steps, but permit pumping to cool down frozen H_2 below 2.17 K, so that superfluid He may penetrate all internal surfaces.
  - Compare trapped He fraction with and without cooldown.
- Develop quantitative model for larger H_2/He snowballs.

Have H_2 "Comets" Been Observed?

- Recently, interstellar object observed moving rapidly through solar system, named "Oumuamua"
  – Irregular shape, but less than ~ 1 km in size.
  – Origin and composition of this body remain subject of debate.
- One analysis (Seligman 2020; Oberhaus 2020) suggests that this may be solid hydrogen, coming from a very cold region of the galaxy.
  – This analysis suggests that non-gravitational acceleration caused by sublimation of hydrogen from the object in the warmer environment of the solar system.
- While this does not address the question of dark matter, it suggests that objects of this type and size may be possible.

Could H_2 Snowballs Provide Enough Mass for Dark Matter?

- Rough estimate based on size and mass of Milky Way
  - Radius R~ 10^5 light years ~ 10^{18} km
  - Total Mass of stars ~ 10^{12} solar mass ~ 2 x 10^{42} kg
- Dark matter halo with M ~10^{43} kg in sphere R ~ 10^{19} km
- Assume solid H_2 spheres with 1 km diameter
  - Density 86 kg/m^3, m ~ 4 x 10^{10} kg
- Assuming uniform density for simplicity, this would require ~ 2 x 10^{32} snowballs ~ 10^8 km apart.
- Such objects would have negligible gravitational attraction, collide very rarely, and would be difficult to detect.
- This all seems plausible.

Conclusions

- A new model for galactic dark matter is proposed, whereby frozen H_2 snowballs at 2.7 K also trap He atoms.
- A cryogenic laboratory experiment is proposed, to demonstrate trapping of He in frozen H_2.
- If this model is responsible for dark matter, some small fraction of He gas might be present, which could be observed spectroscopically.
- *The bias in the astrophysics community against "regular matter" as the solution to the dark matter mystery should be reconsidered.*

References

- R.S. White, “Can Baryonic Dark Matter be Solid Hydrogen?”, Astrophysics and Space Science, 240, 75 (1996). http://adsabs.harvard.edu/full/1996Ap%26SS.240...75W
- D. Seligman and G. Laughlin, “Evidence that 1I/2017 U1 (Oumuamua) was composed of molecular hydrogen ice”, Astrophys. J. Lett. 895, L8 (2020). https://arxiv.org/abs/2005.12932
- D. Oberhaus, “Oumuamua might be a giant interstellar hydrogen iceberg,” Wired Magazine (May 2020). https://www.wired.com/story/oumuamua-might-be-a-giant-interstellar-hydrogen-iceberg/

General References

- Dark Matter, Wikipedia article
  https://en.wikipedia.org/wiki/Dark_matter
- Dark Matter Halo, Wikipedia article
  https://en.wikipedia.org/wiki/Dark_matter_halo
- Superfluid Helium-4, Wikipedia article
  https://en.wikipedia.org/wiki/Superfluid_helium-4
- Milky Way, Wikipedia article
  https://en.wikipedia.org/wiki/Milky_Way