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 $T \sim 2.7$ K.
  – Assume locations of dark matter exhibit $T$ near $2.7$ K.
• The freezing temperature of $\text{H}_2$ is $14$ K.
  – The vapor pressure of solid $\text{H}_2$ at $2.7$ is tiny $\sim 10^{-14}$ atm.
• So frozen hydrogen could eliminate most $\text{H}_2$ 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 $\sim 0.16$ atm..
• Is there some way that frozen $\text{H}_2$ can trap He atoms?
Trapping of He Inside Solid $\text{H}_2$

• Frozen $\text{H}_2$ 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 $\text{H}_2$, 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 $\text{H}_2/\text{He}$ Snowball Model

• A $\text{H}_2/\text{He}$ 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 $\text{H}_2$ “Comets” Been Observed?

• Recently, interstellar object observed moving rapidly through solar system, named “Oumuamua”
  – Irregular shape, but less than $\sim 1$ 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 $R \sim 10^5$ light years $\sim 10^{18}$ km
  - Total Mass of stars $\sim 10^{12}$ solar mass $\sim 2 \times 10^{42}$ kg
- Dark matter halo with $M \sim 10^{43}$ kg in sphere $R \sim 10^{19}$ km
- Assume solid H$_2$ spheres with 1 km diameter
  - Density $86$ kg/m$^3$, $m \sim 4 \times 10^{10}$ kg
- Assuming uniform density for simplicity, this would require $\sim 2 \times 10^{32}$ snowballs $\sim 10^8$ 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\textsubscript{2} snowballs at 2.7 K also trap He atoms.

• A cryogenic laboratory experiment is proposed, to demonstrate trapping of He in frozen H\textsubscript{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


General References

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