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Why don't clumps of cirrus dust gravitationally collapse?

Rudolph E Schild[1], **Carl H Gibson**[2,4], **Theo M Nieuwenhuizen**[3]
and N Chandra Wickramasinghe[4]

[1] Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA
[2] Mechanical and Aerospace Engineering Department, Scripps Institution of Oceanography, UCSD, La Jolla, CA 92093-0411, USA
[3] Institute for Theoretical Physics, Science Park 904, PO Box 94485, Amsterdam, The Netherlands
[4] Buckingham Centre for Astrobiology, The University of Buckingham, Buckingham MK18 1EG, UK

E-mail: rschild@cfa.harvard.edu

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Abstract
We consider the Herschel–Planck infrared observations of presumed condensations of interstellar material at a measured temperature of approximately 14 K (Juvela *et al* 2012 *Astron. Astrophys.* **541** A12), the triple point temperature of hydrogen. The standard picture is challenged that the material is cirrus-like clouds of ceramic dust responsible for Halo extinction of cosmological sources (Finkbeiner, Davis and Schlegel 1999 *Astrophys. J.* **524** 867). Why would such dust clouds not collapse gravitationally to a point on a gravitational free-fall time scale of 10^8 years? Why do the particles not collide and stick together, as is fundamental to the theory of planet formation (Blum 2004 *PASP Conf. Ser.* **309** 369; Blum and Wurm 2008 *Annu. Rev. Astron. Astrophys.* **46** 21) in pre-solar accretion discs? Evidence from 3.3 μm and UIB emissions as well as extended red emission data point to the dominance of polycyclic aromatic hydrocarbon (PAH)-type macromolecules for cirrus dust, but such fractal dust will not spin in the manner of rigid grains (Draine and Lazarian 1998 *Astrophys. J.* **494** L19). IRAS dust clouds examined by Herschel–Planck are easily understood as dark matter proto-globular-star-cluster clumps of primordial gas planets, as predicted by (Gibson 1996 *Appl. Mech. Rev.* **49** 299–315) and observed by (Schild 1996 *Astrophys. J.* **464** 125).

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(Some figures may appear in colour only in the online journal)

1. Introduction

When the IRAS infrared satellite (Soifer *et al* 1987) discovered strong evidence of a new component of infrared emission, it was already understood that such cold emission was found in star forming regions, and so was attributed to dust. Hundreds of infrared galaxies were soon discovered by IRAS emitting $\geqslant 95\%$ of their radiation over 7 decades of luminosity from 10^6 to $10^{13} L_{\odot}$. What is the source of all this power? Despite the low resolution of imaging in the DIRBE experiment, the emission was found to be thinly extended across the entire Galaxy Halo in long filamentary structures reminiscent of cirrus clouds. An improved representation of this can be seen in figure 1 below, the IRAS map of $T \approx 15$K emission published as figure 1 of Juvela *et al* (2012). The review 'Cold Dark Clouds: The Initial Conditions for Star Formation' by Bergin and Tafalla (2007) calls for the Herschel and Planck satellites launched in May 2009 to settle the many mysteries about the temperatures of the clouds of cirrus dust and their infrared luminous cold cores.

We have previously proposed (Gibson 1996, Schild 1996, Nieuwenhuizen *et al* 2011) that the observed structures are in fact metastable clumps of Jeans mass, fragmented in planet masses (proto-globular-star-clusters (PGC), also called Jeans clusters) that formed primordially at the plasma to gas transition, and which comprise the missing baryonic dark matter of all galaxies. The clumping is initiated by hydro-gravitational-dynamics (HGD) fragmentation of

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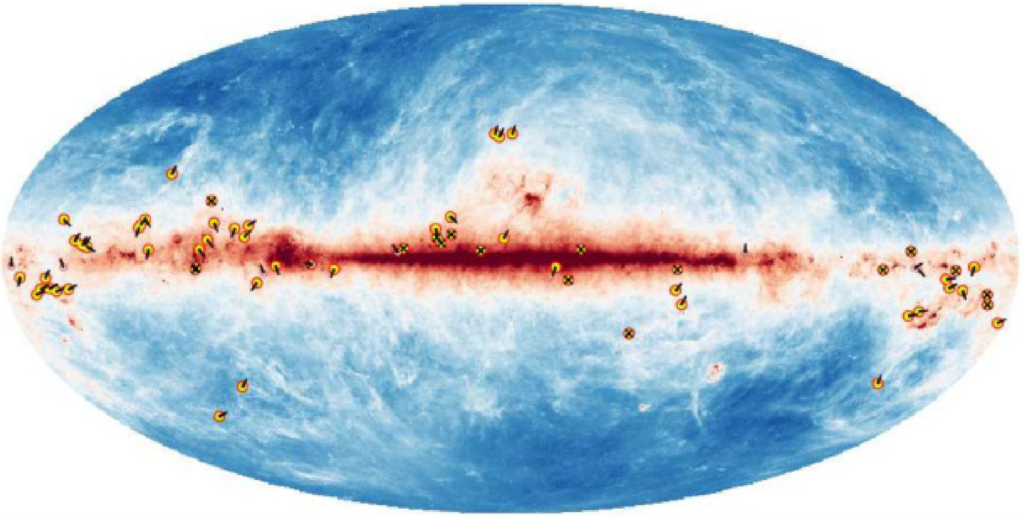

Figure 1. IRAS 100 μm surface brightness map of the sky. Credit: Juvela M *et al* 2012 *Astron. Astrophys.* **541** A12, reproduced with permission ©ESO.

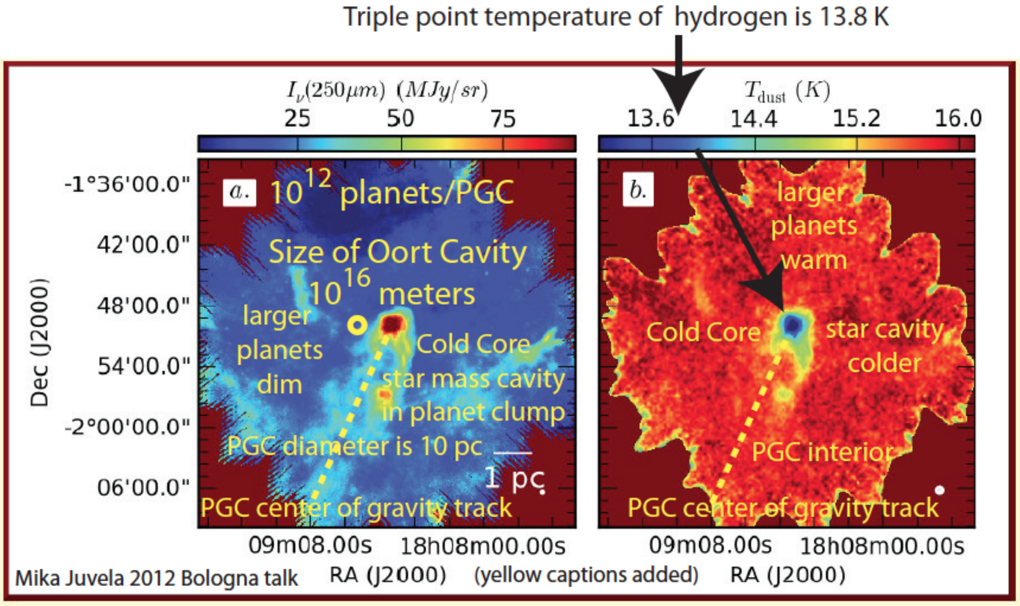

Figure 2. Herschel–Planck infrared images of radiation and temperature within cold clouds, reported by Juvela at the Planck 2012 Cold Cores Project meeting, Bologna and adapted with his kind permission. Added to the original figure are our interpretations in yellow. Image (a): An intensity map of what we understand as a PGC, to which we add the supposed track of a core. Image (b): The radiation temperature of the Cold Core is brighter at the triple point of hydrogen, 13.8 K, than the surroundings which are at higher temperature but lower surface brightness. The HGD cosmology interpretation is that mergers of cold gas planets, rather than ceramic or PAH dust, best explain the radiation and temperature patterns (Gibson 2010, 2011, Gibson *et al* 2011).

primordial plasma protogalaxies (Gibson 1996), and is fractal (non-Gaussian) in statistical properties, and concentrically structured, in clumps of clumps. An individual Jeans mass clump will consist of a trillion Earth mass hydrogen spheres originally detected (Schild 1996) in quasar microlensing. These will be in quasi-stable equilibrium and have survived as coherent Halo structures for 13.7 billion years. When disturbed they become the Giant Molecular Clouds that host star formation in an accretional cascade from planet mass to stellar mass.

With much higher resolution, particularly of the Herschel telescope, the ‘Cirrus Dust’ is revealed to be a network of small condensations carefully analyzed as regions within the disc and halo of our Galaxy by Juvela *et al* (2012). (See hereto figure 2 above.) The clumps were found and studied at a number of distances and environments and have shown surprising consistency in their properties. From SPIRE photometry at wavelengths 250, 350 and 500 μm (combined with AKARI photometry at 90, 140 and 160 μm), temperatures estimated for 71 regions averaged (Juvela *et al* (2012), table 2, column 6) about 14 K, though estimates, where a background temperature was subtracted, were 1.5 K lower. A slightly different temperature was determined from spectral energy distributions that introduce the longer-wavelength WMAP flux densities (Veneziani *et al* 2010, 2012).

The understanding of the Herschel–Planck data in figure 2 is confounding to astrophysics, because the situation revealed is opposite to the Planck radiation law that ordinarily shows hotter radiating objects emitting at a higher intensity. In contrast, figure 2 shows a pair of cold core sites of star formation radiating at a higher luminosity but at lower temperature, in contradiction to a straightforward application of the virial theorem. We shall come back to this paradox in section 2.

It is surprising that so little diversity was found in the estimated temperatures. Because the radiation environment would be expected to be very different for sources in the Galactic plane than for sources (far) above the plane, it would be easier to understand the temperature as being thermostatically controlled by the 13.8 K triple point phase transition of Hydrogen, as proposed by Nieuwenhuizen *et al* (2011). Indeed, before traversing the first order phase transition line from gas to solid which emerges from the triple point, the latent heat has to be radiated out.

At present it is accepted that the dust temperature is maintained primarily by radiation from spinning dust particles (Hoyle and Wickramasinghe 1970, Draine and Lazarian 1998) Schlegel *et al* 1998. An elongated rigid grain with average moment of inertia I acquires a spin ω by energy equipartition with a hot gas of temperature T governed by the condition $I\omega^2/2 = 3kT/2$. For sufficiently small grains (small I) we may have rigid grains spinning at far infrared, microwave and radio frequencies. The ability of these grains, carrying a net electric charge and a non-zero dipole moment, to emit electromagnetic waves has been recognized for a few decades and is not in dispute (Hoyle and Wickramasinghe 1970, Draine and Lazarian 1998). However, in order to reproduce the observed flux data from SPIRE and AKARI photometry, one has to require implausible and artificial constraints on any spinning grain model. Moreover, observations of 3.3 μm and other UIB emissions, as well as extended red emission in cirrus clouds imply that cirrus dust is mostly composed of polycyclic aromatic hydrocarbon (PAH) macromolecules of undefined provenance (Szomoru and Guhathakurta 1998, Wickramasinghe 2010), with only minor contributions from silicate dust. Large PAH molecules with an inherent fractal structure will not behave like small mineral grains, so a rigid spinning grain model will not apply in this case.

A more plausible explanation of the observed infrared luminosity from HGD cosmology is that the merging of gas planets in PGC clumps releases large quantities of latent heat as the merging gas planets evaporate at the triple point temperature of the primordial hydrogen gas (14 K).

The morphologies of structures encountered in the observations is even more surprising. Independently of where the clumps were located, whether at high or low galactic latitude, the clumps were found in small clusters, and also in filamentary structures, though isolated clumps are more common at high galactic latitudes (Juvela *et al* 2012).

Although some of the clumps are quiescent at the low 14 K temperature, most are apparently sites of star formation, as evidenced by the existence of emission at mid-infrared wavelengths. The warmer emission co-exists with the cold 14 K clumps.

About half of the fields studied show a filamentary structure which was not predicted for 'dust cirrus clouds' before the HERSCHEL detection. The individual filaments tend to be broken into individual knots of strong emission, also not predicted before their observational discovery. The typical filament width is 1/4 pc, measured as an infrared brightness full width half maximum (FWHM), and sub-structure within and along the extended filament structures is commonly found. This observed size closely matches the Oort cavity scale $L_{\mathrm{Oort}} \approx (M_\odot/\rho_0)^{1/3} = 4 \times 10^{15}$ m from the typical density of the PGC $\rho_0 \approx 4 \times 10^{-17}\,\mathrm{kg\,m^{-3}}$. This is the size of the cavity produced in a PGC cloud of dark matter gas planets of density ρ_0 when they merge to form a solar mass star, as shown in yellow font in figure 2(a); in the Solar system $L_{\mathrm{Oort}} \sim 0.5$ Lyr marks the transition from inner to outer Oort cloud.

In contrast with the view of the nature and distribution of interstellar dust implied by the HERSCHEL observations, the older view is very different. The prevailing view is that interstellar dust has condensed into cores of planets orbiting stars in their pre-stellar discs, and that this occurs in a process of grain growth, collision and sticking (Blum and Wurm 2008), on a time scale of approximately 1 million years, set by the observed ages of young star-forming regions. Based upon laboratory data, it follows that the porosity (or volume filling fraction) has a value of approximately 0.5, or twice the density of liquid water. Experiments with crushing the ensembles of growing dust particles of SiO_2 showed that filling factors in the range 0.2–0.3 are measured, with corresponding porosities of approximately 0.66 and densities of $1.5\,\mathrm{g\,cm^{-3}}$ (Blum 2004). These mechanical properties of interstellar cirrus dust are presumed to underlie the process of planet formation.

However it is obvious that the HERSCHEL-observed 14 K temperature cannot be maintained by cirrus dust whose temperature is maintained by spinning of the dust particles. The Herschel image shows that the dust exists in clumps of particles presumed to have been produced in collisional interaction, and the presumed spin would have not credibly been maintained during the phase of crushing by the self-gravity of the clumps. Thus we examine an alternative to the identification of the radiating structures as dust.

2. Alternative explanation: primordial gas planets contained in Jeans clusters (PGCs)

We offer an alternative to the cosmic dust condensation model for producing the compact, centrally condensed regions of thermal emission at 15 K discovered by Juvela *et al* (2012) and others. Our model involves the hypothesis of gas spheres of planetary mass clumped in PGC (Jeans clusters) related to the ordinary globular clusters observed in all galaxies. As originally proposed by Gibson (1996) from hydrodynamical considerations, these structures would have formed in weak turbulence at the plasma–gas transition at $z = 1100$ on scales of Jeans mass, $5 \times 10^5 M_\odot$ (or perhaps only the $15\,000\,M_\odot$ of Nieuwenhuizen *et al* (2012)) and additionally at planetary mass, $10^{-6}\,M_\odot$. Such structure was observed in quasar microlensing (Schild 1996) and described as 'rogue planets' and as 'micro-brown dwarfs' by Nieuwenhuizen *et al* (2011).

Since the original discovery, the existence of rogue gas planets has been confirmed in four additional quasar lens systems having sufficient data to indicate a time delay, but also with sufficient accuracy to reveal the rapid microlensing (see Paraficz *et al* 2006, for further references). Their wider detection and properties have been further elucidated by Nieuwenhuizen *et al* (2011), who introduce the term 'micro-brown dwarfs' for them.

The hydrodynamical theory that predicted their existence has further bearing upon the nature of structure that should be evident in the low-z universe. Following their formation as turbulent residual perturbations they would have collapsed on a timescale $1/\sqrt{G\rho_0}$ of approximately 6×10^5 years, and thereafter cooled throughout the 13.7 Gyr history of the universe, with their difficult cooling history lagging slightly behind the lowering Cosmic Background Temperature of the Universe. An important temperature in the physical chemistry of the universe is $T_{\rm tr} = 13.8$ K, related to the triple point for gas–liquid–solid phase transition in hydrogen gas, from which a first order gas-to-solid transition line emerges. Lacking enough metals that would offer spectral lines, the difficulty to radiate out the latent heat would set the thermostat for hydrogen spheres with warm cores trying to radiate away their original heat of gravitational collapse. The accumulated metals in their warm cores would also produce heat by radioactive decay (Wickramasinghe *et al* 2010). Because the objects are observed to be cooling and radiating at 14 K, a temperature gradient in their atmospheres to drive outward heat flow might leave a detectable signal of slightly higher temperature, easily confused with core-shine.

Let us now return to figure 2. Firstly, with the core temperature $T_{\rm core}$ lying at ~ 13.6 K, below $T_{\rm tr}$, we stress that this does not look like a run-away effect toward 2.7 K as may be anticipated naively. Since the first-order transition line that emerges from the triple point goes toward smaller temperature for smaller pressures, and the actual pressure likely lies below the triple point value $p_{\rm tr} = 7.04$ kPa, the $T_{\rm core}$ temperature probably lies just above the transition line, as asserted by HGD. Secondly, the virial theorem by itself does not allow the combination of cooling and radiating. Hence, to explain this property exposed in figure 2, energy has to be put into each primordial gas planet (rogue gas planet, micro-brown dwarf). This can be achieved, in particular when there is a central mass, by going into a more bound orbit, and using part of the gravitational energy gain for both radiation and cooling. For a central mass of about one solar mass, a cooling by 2 K relates to the gravitational energy at a distance of 0.2 pc, about the radial scale of the central core in figures 2(a) and (b). Thirdly, the higher intensity of the central zone in figure 2, despite its lower temperature, exhibits, within this picture, an enhanced concentration of these constituents. This enhancement of in-spiraling orbits clearly supports the proposition that star formation occurs by the merging of these primordial gas planets (Gibson 1996).

The picture can also be tested in our immediate neighborhood. The Local Leo Cold Cloud is a large (∼5°), cold (15–20 K), nearby (10–20 pc) H cloud (Peek *et al* 2011). Like the ill-understood Lyman-alpha clouds (Rauch 1998), it can be long-lived if it contains many unresolved rogue gas planets or micro-brown dwarfs, that bind the gas gravitationally, thus explaining why the gas can have the observed large pressure discussed in (Meyer *et al* 2012). The observed velocity differences inside the Local Leo Cold Cloud are explained by the local winds due to mostly random motion of these gas planets that sweep the gas with them.

3. Comparison of predicted structure to sub-mm observations

The Juvela *et al* (2012) analysis of the clumping of matter seen at the wavelength peak of 15 K emission gives an important perspective on the evolution of primordial structure and its evolution to presently observed (local universe) structure. They report structure dominated by knots of 0.32 pc diameter in clumps and filaments of characteristic diameter 6.1 pc. Structures like these must have evolved into the globular clusters seen today with a mean diameter of 6.6 pc. (All dimensions are expressed as FWHM and the knot and clump diameters are averages from Juvela *et al* tables 2 and 3. The quoted mean diameter for globular clusters is from the Harris (1996) compendium). Thus we conclude that the clumps of knots seen today as 15 K emission are precursors of today's globular clusters.

In an accompanying paper Nieuwenhuizen *et al* (2012) point out that several thousands of cold ∼15 K clouds can be discriminated in the Halo toward the Magellanic Clouds, the properties and distribution of which is consistent with them being PGCs (Jeans clusters) created by the Jeans instability and HGD fragmentation into Earth mass-scale gas clouds, that comprise all the missing dynamical mass of the Galaxy.

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References

Bergin E A and Tafalla M 2007 *Annu. Rev. Astron. Astrophys.* **45** 339
Blum J 2004 *PASP Conf. Ser.* **309** 369
Blum J and Wurm G 2008 *Annu. Rev. Astron. Astrophys.* **46** 21
Draine B T and Lazarian A 1998 *Astrophys. J.* **494** L19
Finkbeiner D P, Davis M and Schlegel D J 1999 *Astrophys. J.* **524** 867
Finkbeiner D P, Schlegel D J, Frank C and Heiles C 2002 *Astrophys. J.* **566** 898
Gibson C H 1996 *Appl. Mech. Rev.* **49** 299
Gibson C H 2010 *Phys. Scr.* **T142** 014030
Gibson C H 2011 *J. Cosmol.* **15** 6030
Gibson C H, Schild R E and Wickramasinghe N C 2011 *Int. J. Astrobiol.* **10** 83
Hoyle F and Wickramasinghe N C 1970 *Nature* **227** 473
Harris W E 1996 *Astron. J.* **112** 1487
Juvela M *et al* 2012 *Astron. Astrophys.* **541** A12
Meyer D M, Lauroesch J T, Peek J E G and Heiles C 2012 *Astrophys. J.* **752** 119
Nieuwenhuizen Th M, Schild R E and Gibson C H 2011 *J. Cosmol.* **15** 6017
Nieuwenhuizen Th M, van Leusden E F G and Liska M P 2012 *Phys. Scr.* **T152** 014085
Paraficz D *et al* 2006 *Astron. Astrophys.* **455** L1

Peek J E G *et al* 2011 *Astrophys. J.* **735** 129

Rauch M 1998 *Annu. Rev. Astron. Astrophys.* **36** 267

Schild R E 1996 *Astrophys. J.* **464** 125

Schlegel D J, Finkbeiner D P and Davis M 1998 *Astrophys. J.* **500** 525

Soifer B T, Houck J R and Neugebauer G 1987 *Annu. Rev. Astron. Astrophys.* **25** 187

Szomoru A and Guhathakurta P 1998 *Astrophys. J.* **494** L93–7

Veneziani M *et al* 2010 *Astrophys. J.* **713** 959

Veneziani M *et al* 2012 Estimating interstellar medium dust temperature and spectral index in the far-infrared and submillimeter *Presented at American Astronomical Society meeting 219 (Austin, TX, 8-12 Jan. 2012)* presentation 444.16

Wickramasinghe N C 2010 *J. Cosmol.* **11** 3476

Wickramasinghe N C, Wallis J H, Gibson C H and Schild R E 2010 *Proc. SPIE* **7819** 13