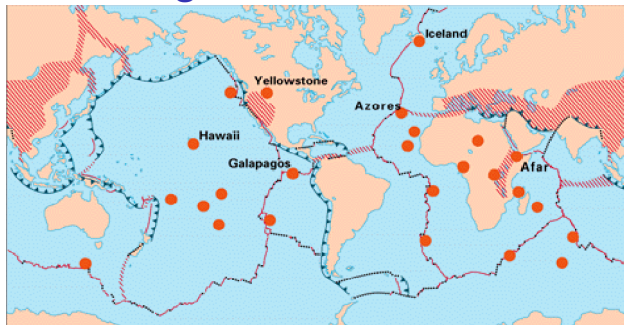







Something STRANGE hits the Earth



EXPLANATION

-  Divergent plate boundaries—Where new crust is generated as the plates pull away from each other.
-  Convergent plate boundaries—Where crust is consumed in the Earth's interior as one plate dives under another.
-  Transform plate boundaries—Where crust is neither produced nor destroyed as plates slide horizontally past each other.
-  Plate boundary zones—Broad belts in which deformation is diffuse and boundaries are not well defined.
-  Selected prominent hotspots

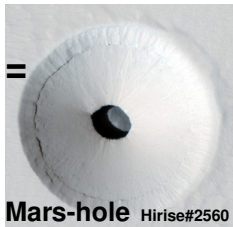
Where is the meteorite? Just maybe it went into the Earth: we consider compact ultra-dense objects (CUDO) meteors made predominantly of ultra dense matter such as STRANGElet = fragments of neutron stars filled with strange quarks, Dark Matter bound objects, MICRO BLACK HOLES. For such exotic impactors each planet or moon is a macroscopic detector accumulating CUDO impact signature over geological time scale. Only a fraction of the CUDO kinetic energy is damaging the entry/exit surface regions since CUDOs high density of gravitating matter assures surface-penetrating puncture – shot into, and even through, a moon or the planet. CUDOs could be the origin of hot-spots (random location shield volcanoes that are fed from depth of Earth across solid crust). Recent (geologically) CUDOs maybe recognized by impact (exit) features such as the cave in Pavonis Mons on Mars, and on Earth by coincident impactor with climatic excursions created by high atmosphere "volcanic" eruption (happening usually without a known volcano!). Rocky objects in solar system accumulate impact scars for billions of years. Asteroid belt could harbor captured CUDOS with 31 Polyhymnia a high density (75g/cc!) candidate and the "egg in space" offering another suspect case. Last not least, the Earth energy balance could depend on captured CUDOs.

Come in good company, lecture to be entertaining and (mostly) non-technical, equations inadvertently appearing on slides will be (mostly) skipped.

Reading document: <http://www.physics.arizona.edu/~rafelski/PS/1906CUDOinBalaton.pdf>

CUDO=Compact UltraDense Object:

A new type of space bodies and meteors made of very dense matter: STRANGElet fragments of neutron stars, dark matter bound objects, micro-black-holes are a few discussed in literature. This talk discusses how their presence is manifest



kudos (from Greek *kyddos*, singular)

honor; glory; acclaim; praise

kudo = back formation from kudos
construed as a plural

čudo (Slovak) = miracle

cudo (colloq. Polish) =
of surprising and exceptional
character (gender related)



Impactors:

The entertaining 40 min CUDO story

- **Impacts on Earth are usual and not so usual: some cause Impact Winter \Leftarrow : High atmosphere material lasts long**
- **Hot Spots**
- **CUDOs in solar system**
- **Why CUDOs make holes: gravity is strong**
- **Diverse pictures**

Questions, questions:

- 1 Are there (self-interacting) 'dark matter' meteor and asteroid-like bodies in the Universe? **Maybe – will describe fascinating possibilities.**
- 2 Why can we know CUDOs have collided with solar system bodies and the Earth? **All (rocky) objects in the solar system are 'detectors' for CUDO impacts**
- 3 What is CUDOs' distinct observable? **The surface penetrating puncture and sometimes shot through. On rocky planets impact signatures are long-lived.**
- 4 How is the 'target' damaged? **Only a fraction of the kinetic energy damaging the solid surface on both entry/exit (partial stopping).**
- 5 How can we distinguish CUDO from normal geological activity? **Impactors without impact material; high atmospheric 'eruptions' for shot across the body with rain down of material.**

Collisions: Stopping, Other Characteristics

Entrainment of Material

Captured matter acquires CUDO velocity \Rightarrow reduces CUDO speed, damage in target also reduces speed Expect \Rightarrow **Two surface punctures!** **Entry and Exit signatures**

Drag from Normal matter interactions

- ▶ Mixing of nearby entrained and nearly-entrained material

Pulling debris stream along behind CUDO

- ▶ Matter from previous collisions can “dress” CUDO,
giving appearance of normal (but overdense) meteor
- ▶ Fraction remains bound to impacted planet,
but re-distributed inside and above surface

Some of our arguments are published&arXiv-ed

Work by other groups will be cited in text

Compact ultradense matter impactors

JR, Lance Labun, and Jeremiah Birrell, Phys.Rev.Lett. 110 (2013) 111102
<http://prl.aps.org/abstract/PRL/v110/i11/e111102>

Compact Ultradense Objects in the Solar System

JR, Christopher Dietl, LL; Acta Phys.Polon. B43 (2012) 12, 2251-2260
<http://th-www.if.uj.edu.pl/acta/vol43/abs/v43p2251.htm>

Properties of Dark Compact Ultra Dense Objects

Christopher Dietl, LL, and JR, Phys.Lett. B709 (2012) 123-127
<http://dx.doi.org/10.1016/j.physletb.2012.02.015>

Planetary Impacts by Clustered Quark Matter Strangelets

LL and JR, Acta Phys.Polon.Supp. 5 (2012) 381-386
<http://dx.doi.org/10.5506/APhysPolBSupp.5.381>

Classification of exoplanets according to density

A. Odrzywolek and JR
<http://arxiv.org/abs/arXiv:1612.03556> [astro-ph.EP]

Two CUDO structure candidates

- 1 Stable fragments of neutron stars = nuclear 'strangelets'
- 2 Dark matter starlets
(self-interacting DM; maybe gravity bound DM)

NOTE: Most stuff of interest maybe hanging out in the Universe and we run into it plowing along with the Solar system and our galaxie, this means collisions involve speeds of a few hundred km/s rather than usual meteor few 10km/s.

Dark Matter is Matter

From standard cosmology, fractions of Non-Baryonic and Baryonic gravitating matter show 4/5 of gravitating matter not identified: 'dark'

Bullet Cluster, Abell 520, etc show

– Separation of luminous matter and gravity source

⇒ evidence of independent dynamics

⇒ small self-interaction



Many candidate particles could mean *many components of unseen* 'dark' matter,

THE ASTROPHYSICAL JOURNAL, 648:L109–L113, 2006 September 10
© 2006. The American Astronomical Society. All rights reserved. Printed in U.S.A.

A DIRECT EMPIRICAL PROOF OF THE EXISTENCE OF DARK MATTER¹

DOUGLAS CLOWE,² MARUŠA BRADAČ,³ ANTHONY H. GONZALEZ,⁴ MAXIM MARKEVITCH,^{5,6}

SCOTT W. RANDALL,⁵ CHRISTINE JONES,⁵ AND DENNIS ZARITSKY²

Received 2006 June 6; accepted 2006 August 3; published 2006 August 30

We present new weak lensing observations of 1E 0657–558 ($z = 0.296$), a unique cluster merger, that enable a direct detection of dark matter, independent of assumptions regarding the nature of the gravitational force law. Due to the collision of two clusters, the dissipationless stellar component and the fluid-like X-ray-emitting plasma are spatially

Dark Matter is (weakly) Self-Interacting

https://physics.aps.org/synopsis-for/10.1103/PhysRevLett.119.111102

Synopsis: Self-Interacting Dark Matter Scores Again

Dark matter that interacts with itself provides a better description of the speeds of stars in galaxies than dark matter that doesn't self-interact.



ESA/Hubble & NASA

Physics

September 13, 2017

Self-Interacting Dark Matter Can Explain Diverse Galactic Rotation Curves

Ayuki Kamada, Manoj Kaplinghat, Andrew B. Pace, and Hai-Bo Yu

Phys. Rev. Lett. 119, 111102 (2017)

Published September 13, 2017

Self-interacting dark matter—a hypothetical form of dark matter made of particles that interact with one another—is a problem fixer in cosmology. On galactic and smaller scales, it can fix discrepancies between observations and predictions of the standard cosmological model, which instead considers “cold” dark matter that doesn't interact with itself. And it does so while leaving intact the standard model's success on larger scales. Manoj Kaplinghat from the University of California at Irvine, Hai-Bo Yu from the University of California at Riverside, and colleagues now show that self-interacting dark matter can also explain the diversity of galaxy rotation curves—graphs of the speeds of stars in a galaxy versus their distance from the galaxy's center.

Primordial DM Meteor Possible?

– Qualitative Consideration

High mass/energy scale help with early-universe formation:

- Becoming non-relativistic at an earlier time, dark matter has a density proportionally higher at the time when gravity can begin to work on local density fluctuations
- CUDO comprises $10^{11} - 10^{19}$ fewer particles \Rightarrow requires smaller correlation volume contributing
- Dark particle-particle gravitational interaction $10^6 - 10^{10}$ times larger maybe capable to 'kick out' visible matter to bind .
- High surface acceleration CUDOs stable against gravitational disruption (especially in collisions with normal matter objects)
 \Rightarrow **persist into present era at rest in CBM frame of reference**

Stellar DM Meteor formation Possible?

– Qualitative Consideration

- **Dark matter accretion to stellar objects have been studied, concentration in stellar object cores**
- **Formation of gravitationally bound dark matter CUDOs unavoidable**
- **Stellar SN explosions practically always asymmetric, stellar core CUDO left behind**

Compact stars as dark matter probes

Citing Articles (70)

Gianfranco Bertone and Malcolm Fairbairn
Phys. Rev. D **77**, 043515 – Published 15 February 2008

PHYSICAL REVIEW D

We discuss the consequences of the accretion of dark matter (DM) particles on compact stars such as white dwarfs and neutron stars. We show that in large regions of the DM parameter space, these objects

Difference to primordial dark CUDOs which at rest in CBM frame:
Stellar catalysis CUDOs follow galactic dynamics, have strangelet-like velocity distribution

There can be lots of visible impactor material



Iron-nickel (20%) Gebel-Kamil: $22^{\circ}01'06''\text{N}$, $26^{\circ}05'16''\text{E}$ East Uweinat Desert, Egypt: 44.8m in diameter, 15.8m deep meteorite crater: 1600 kg of iron meteorite shrapnel, 3400 kg >10 g pieces remained today. Upon hypervelocity impact, the 1.3 meters wide 5 to 10 tons meteorite was disrupted into thousands of fragments located up to 200 m from the crater rim, largest known fragment 83 kg. Dated to about 4,500 years, explored first 2009/10. A possible source of Egypt-Pharaoh Iron.

Or: there is nothing: Where is the Meteorite that made our Arizona Meteor 'Barringer' Crater?



This is about 1 mile wide and 570 ft deep recent (50,000y old) crater where many tourists in Arizona visit. 110 years ago Daniel Barringer searched to profit from what he expected to be $2.5 \cdot 10^6$ tons of iron-nickel content of the meteorite. See what was found: a few (3!) meteorite fragments found in riverbeds many miles away. Short of a space ship crash site, of which remains were carefully removed, what is the causes for this gigantic hole in the ground? **There are many other "missing meteorite" impacts**



Missing meteorite case is not singular

Meteor crater



1.2km diameter/50ky old



Lonar crater: 1.8km, 15,000y? hole in basalt flow from 50 million years ago.....



3.44 km diameter $1.4 \pm 0.1 \times 10^6$ y old

Conservative colleagues hinder CUDO progress

As pointed out in this review, the book has several flaws in relation to its contents and concepts of what is a proven or possible impact structure, leaving considerable room for speculation. Furthermore, it conveys a very wrong message to those interested in impact craters, in the sense that it would be possible to discover new craters by just searching web-based satellite image services to find circular structures that indicate the occurrence of impact craters.

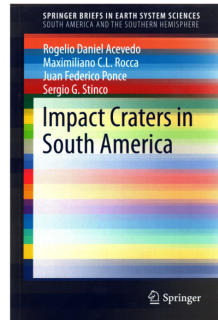
Proving the true nature of an impact crater *and eliminating anything we do not want to know about, JR* demands a lot more work, starting with appropriate geological ground truthing, and proper field analysis, in order to search and collect the necessary evidence, in the form of meteoritical components (fragments or geochemical traces) or shock-metamorphic features. Alvaro P. Crósta Brazil, Geosciences Institute, Campinas and Wolf Uwe Reimold Museum für Naturkunde, Leibniz Institute for Evolution and Biodiversity Science Invalidenstrasse 43, 10115 Berlin Germany

Impact Craters in South America, by Acevedo R. D., Rocca M. C. L., Ponce J. F., and Stinco S. G. Heidelberg: Springer, 2015. 104 p. SpringerBriefs in Earth Sciences: South America and the Southern Hemisphere. ISBN 978-3-319-13092-7.

SpringerBriefs in Earth System Sciences present concise summaries of cutting-edge research and practical applications. The series focuses on interdisciplinary research linking the lithosphere, atmosphere, biosphere, cryosphere, and hydrosphere building the system earth. It publishes peer-reviewed monographs under the editorial supervision of an international advisory board ... (From: <http://www.springer.com/series/10032>)

According to the authors of this publication, the book is aimed at presenting an extensive and exhaustive catalog of all geologic structures that have been mentioned or suggested as impact craters in South America. This is probably the main flaw of the book, namely mixing scientifically proven impact structures with a large number of generic and dubious circular structures, for which no evidence linking their origin to the impact process has been produced. To quote the authors (p. 2): "In our opinion, in the absence of meteorite remains or proof-of-shock metamorphism, geological evidence can prove the existence of an impact site and support these interpretations" (Acevedo et al. 2009). *And there we must disagree*—in our view it is mandatory to establish recognition criteria *first* in order to avoid misinterpretations *before* they enter the literature and can confuse newcomers to the research discipline and falsify databases.

After a short introductory chapter, the authors begin their account with Argentina (Chapter 2), a



John W. MORGAN et. al. ^{190}Pt - ^{186}Os and ^{187}Re - ^{187}Os systematics of the Sudbury Igneous Complex, Ontario; *Geochim. et Cosmochim. Acta* 66,(2),273-290 (2002)



4.2. Where is the Meteorite?

It is generally agreed now that the SIC was generated by a meteorite impact, and yet little evidence has been found of the signature of the impacting body. Highly siderophile elements (primarily PGE and particularly Ir) are a sensitive indicator of meteoritic influx (Peucker-Ehrenbrink and Ravizza, 2000) and impact (Evans et al., 1993). Siderophile element analysis has been outstandingly successful in identification of the worldwide chondritic signature of impact at the Cretaceous-Tertiary boundary (Ganapathy, 1980; Kastner et al., 1984; Evans et al., 1993), but this achievement has distracted attention from puzzling results at impact craters recognized by other criteria. Melt rocks from smaller craters often carry a signature of the impactor as, for example, at the 8.5 km Wanapitei Lake crater (Wolf et al., 1980; Grieve and Ber, 1994). In craters larger than ca. 30 km diam., however, melt rocks often show little or no PGE enrichment as at the 70 km Manicouagan, Quebec crater (Wolf et al., 1980). Nevertheless, the size distinction is not always clearcut since small craters such as the 1.8 km diameter Lonar, India, crater may be found with no meteoritic signature (Morgan, 1978), whereas the ≈ 70 km Morokweng, South Africa, crater has impact melts containing large amounts of siderophiles (Koeberl et al., 1997; Reimold and Koeberl, 1999).

Sudbury, Canada: (and Vredefort, South Africa;) major mining districts of the world, where “something” called an impact seems to have pulled from the depth the Earth siderophile metals.

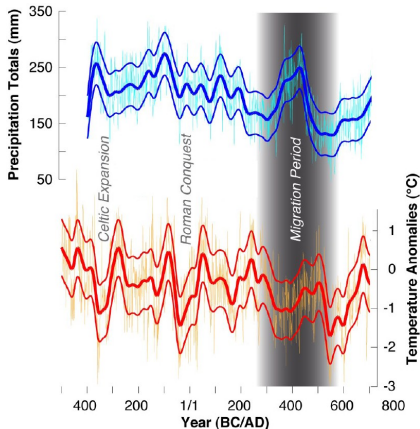
CLIMATE excursions: 1) AD 536 Event

E. Rigby, M. Symonds, D. Ward-Thompson, *A comet impact in AD 536?*
Astron. Geophys. 45, 1.23-1.26 (2004).

L.B. Larsen, et al. *New ice core evidence for a volcanic cause of the A.D. 536 dust veil*
Geophys. Res. Lett. 35, L04708 (2008).

...cause is contested: a comet or a giant volcano(not found) eruption. The 6-month (time measurement resolution) dual event coincidence has probability 10^{-3} . Can be more naturally explained by a dressed CUDO puncture and associated transport of material into upper atmosphere.

2) Other recent climate fluctuations are also not well understood: *BBC: It was 10 October 1465 -the day of the wedding of King Alfonso II of Naples ... middle of the day, the Sun had turned a deep azure, plunging the city into eerie darkness ... Four years later, Europe was hit by a mini ice age... It was the biggest eruption for 700 years but scientists still can't find the volcano*



U. Büntgen, et al *2500 Years of European Climate Variability and Human Susceptibility Science* 331 (6017) pp. 578-582 (2011)

BBC: 10 October 1465 Event

The massive volcano that scientists can't

BBC
By Zaria Gorvett
3 July 2017

It was the biggest eruption for 700 years but scientists still can't find the volcano responsible.

It was 10 October 1465 – the day of the hotly anticipated wedding of King Alfonso II of Naples. He was set to marry the sophisticated Ippolita Maria Sforza, a noblewoman from Milan, in a lavish ceremony.

Though it was the middle of the day, the Sun had **turned a deep azure**, plunging the city into eerie darkness.

This was just the beginning. In the months that followed, European weather went haywire. In Germany, it rained so heavily that corpses surfaced in cemeteries. In the town of Thorn, Poland, the inhabitants took to travelling the streets by boat. In the unrelenting rain, the castle cellars of Teutonic knights were flooded and whole villages were swept away.

Four years later, Europe was hit by a mini ice age.

The thing is, scientists can't find the volcano that did it. What's going on?

■ ■ ■ produced an ash cloud which enveloped the Earth and led to the coolest decade for centuries.

“

This is a true geological mystery, which has left geologists scratching their heads for decades

That the 'unknown eruption' happened is undisputed – like most mega-eruptions, it vapourised vast quantities of sulphur-rich rock, which was blasted into the atmosphere and eventually snowed down on the poles as sulphuric acid. There it was locked into the ice, forming part of a natural record of geological activity that spans millennia. There's no other event capable of doing this, short of an asteroid impact.

Glass rain from the sky: Spherules

Significance

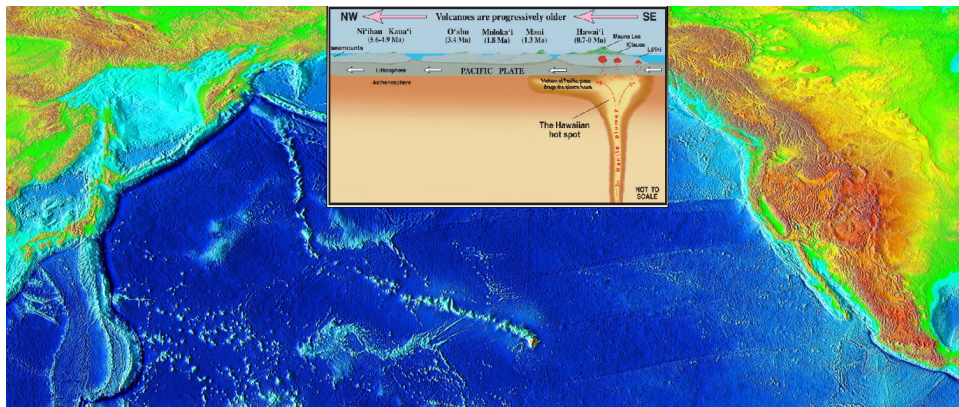
We present detailed geochemical and morphological analyses of nearly 700 spherules from 18 sites in support of a major cosmic impact at the onset of the Younger Dryas episode (12.8 ka). The impact distributed ~ 10 million tonnes of melted spherules over 50 million square kilometers on four continents. Origins of the spherules by volcanism, anthropogenesis, authigenesis, lightning, and meteoritic ablation are rejected on geochemical and morphological grounds. The spherules closely resemble known impact materials derived from surficial sediments melted at temperatures $>2,200$ °C. The spherules correlate with abundances of associated melt-glass, nanodiamonds, carbon spherules, aciniform carbon, charcoal, and iridium.

Fig. 1. YDB impact field, based on data from 27 locations. In the YDB strewnfield (red), there are 18 YDB sites in this study (red dots; see table on *Right*). Eight independent studies have found spherules and/or scoria-like objects at nine additional sites (blue dots) located in Arizona, Montana, New Mexico, Maryland, South Carolina, Pennsylvania, Mexico, and Venezuela. The largest accepted impact strewnfield, the Australasian (purple), is shown for comparison with each strewnfield covering ~ 50 million square kilometers or $\sim 10\%$ of the planet. Table shows location of sites and lists site details (A, archeological material; B, black mat; C, charcoal; M, megafaunal remains, present either at the sampling



Some Earth puncture leaves a lasting damage that cures slowly

Hawaii is a 'hot-spot': the central Pacific plate moving NW over the deep hot spot giving birth to chain of a dozen islands (edge: next slide)



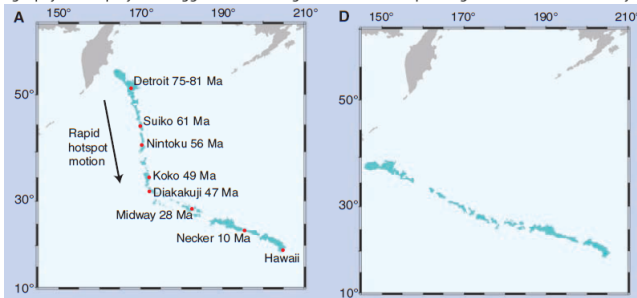
Plume may be by (nearly) stable

The edge in island ridge explained to be dominated by plume dynamics implies plume stable over 50 million years. WHY?

The Bent Hawaiian-Emperor Hotspot Track: Inheriting the Mantle Wind SCIENCE

John Tarduno, Hans-Peter Bunge, Norm Sleep, Ulrich Hansen 3 APRIL 2009 VOL 324 50

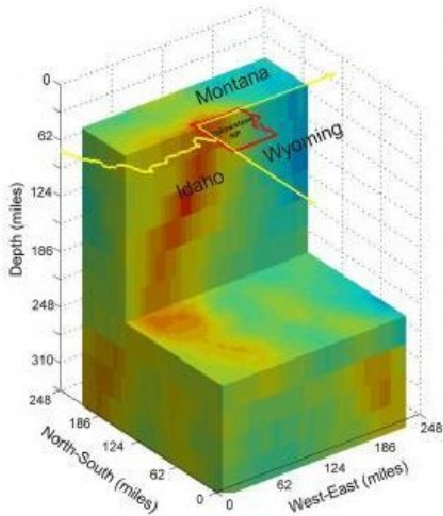
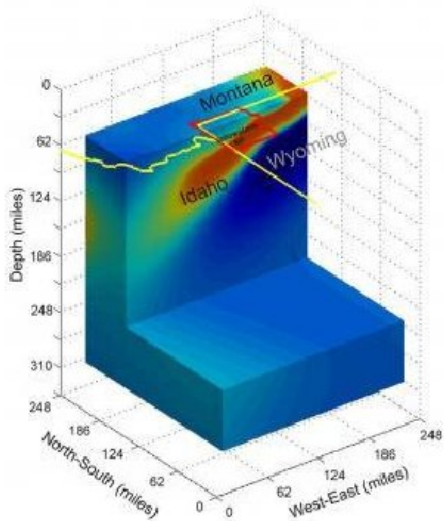
Bends in volcanic hotspot lineaments, best represented by the large elbow in the Hawaiian-Emperor chain, were thought to directly record changes in plate motion. Several lines of geophysical inquiry now suggest that a change in the locus of upwelling in the mantle induced by



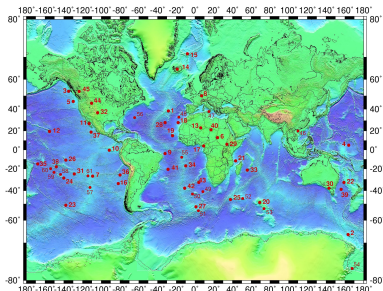
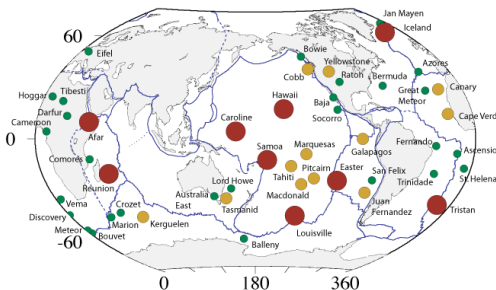
Alternative Hawaiian-Emperor traces. (A) Present-day track with ages and episode of rapid hotspot motion highlighted. (D) Trace that would have been produced had the Hawaiian hotspot been fixed in the deep mantle

Hot-spot plume may be not vertical

Example: Yellowstone plume



Hotspot=Mantle plume? Shot-In or Out?



Global distribution of the 61 hot-spots listed in

[https://en.wikipedia.org/wiki/Hotspot_\(geology\)](https://en.wikipedia.org/wiki/Hotspot_(geology)); Eurasian Plate:

Eifel hotspot (8) $50^{\circ}12'N$ $6^{\circ}42'E$, $w=1$ $az=082^{\circ} \pm 8^{\circ}$ rate= 12 ± 2 mm/yr

Iceland hotspot (14) $64^{\circ}24'N$ $17^{\circ}18'W$

Azores hotspot (1) $37^{\circ}54'N$ $26^{\circ}00'W$

Jan Mayen hotspot (15) $71^{\circ}N$ $9^{\circ}W$ Hainan hotspot (46) $20^{\circ}N$ $110^{\circ}E$, $az=000^{\circ} \pm 15^{\circ}$

<http://www.mantleplumes.org/Hawaii.html>: The Emperor and Hawaiian

Volcanic Chains: How well do they fit the plume hypothesis? by G. R. Foulger & Don L. Anderson

Hot Spots provide lasting (50mY) reference frame

The Geological Society of America
Special Paper 430 2007

Plate velocities in the hotspot reference frame

W. Jason Morgan*

*Department of Earth and Planetary Sciences, 20 Oxford Street,
Harvard University, Cambridge, Massachusetts 02138, USA*

Jason Phipps Morgan

*Department of Earth and Atmospheric Sciences, Snee Hall,
Cornell University, Ithaca, New York 14853-1504, USA*

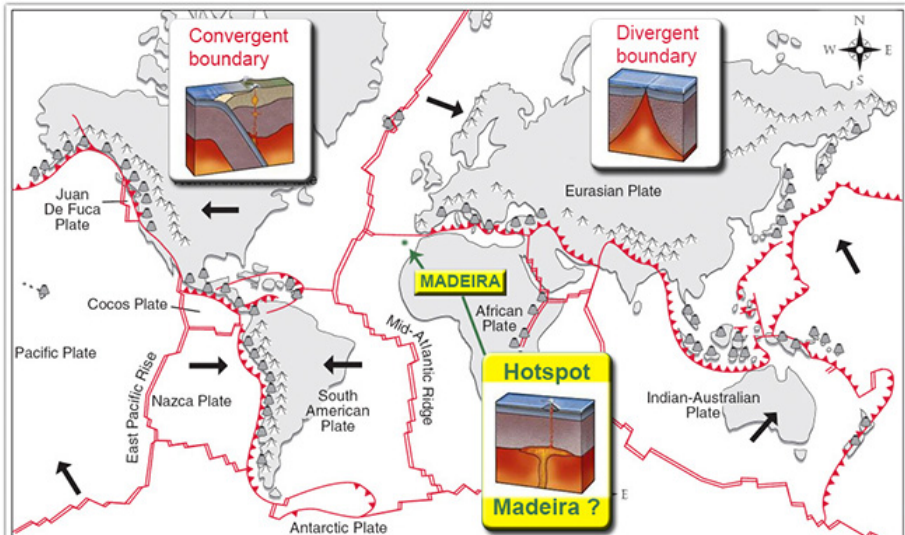
We present a table giving the “present-day” (average over most recent ~5 m.y.) azimuths of tracks for fifty-seven hotspots, distributed on all major plates. Estimates of the azimuth errors and the present-day rates for those tracks with age control are also given. An electronic supplement contains a discussion of each track and references to the data sources. Using this table, the best global solution for plates moving in a fixed hotspot reference frame has the Pacific plate rotating about a pole at 59.33°N , 85.10°W with a rate that gives a velocity at this pole’s equator of 89.20 mm/yr ($-0.8029^{\circ}/\text{m.y.}$). Errors in this pole location and rate are on the order of $\pm 2^{\circ}\text{N}$, $\pm 4^{\circ}\text{W}$, and ± 3 mm/yr, respectively. The motions of other plates are related to this through the NUVEL-1A model.

Field trip: this is worth a CUDO trip



Islands formed **ONLY 5-15 million years ago**

Madeira Island is top of a massive shield volcano that rises about 6 km from the floor of the Atlantic Ocean well away from the edge of African plate and Eurasian plate – it is a popular and geological hot-spot.



MORE FUN RIDDLES

What is the matter with Earth heat?

We begin to recognize that Earth heat radiance estimated at 44.2 TW is out of balance: we radiate about 2-3 times the amount produced radiogenically.

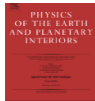


ELSEVIER

Physics of the Earth and Planetary Interiors 269 (2017) 165–171

Physics of the Earth and Planetary Interiors

journal homepage: www.elsevier.com/locate/pepi



Heat flow evolution of the Earth from paleomantle temperatures:
Evidence for increasing heat loss since ~ 2.5 Ga

Javier Ruiz *Departamento de Geodinámica, Facultad de Ciencias Geológicas, Universidad Complutense de Madrid, 28040 Madrid, Spain*

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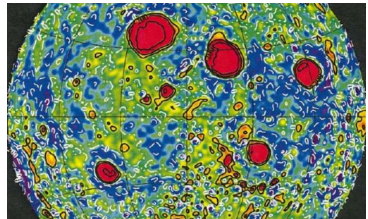
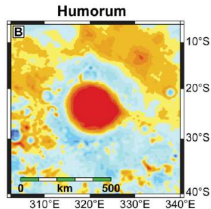
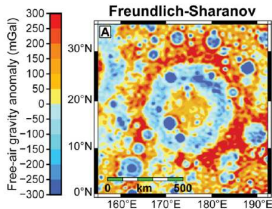
ABSTRACT

Earth currently loses two to five times as much heat through its surface as it is internally produced by radioactivity. This proportion cannot be extrapolated into the past, because it would imply high interior temperatures and catastrophic melting of the planet in ancient times. The heat loss evolution of the Earth cannot therefore be described by a constant heat flow decreasing. This is consistent with previous work

Extreme condition measurement of iron heat conductivity: Earth should have cooled in one billion years (lots of discussion about that in recent years). Easy way to reconcile these two observations is that Earth has a 20+ TW internal power generator. How??

Remote Sensing: MASCONS

MASCONS (mass concentration): Lunar mascons appear due to old impacts, but how such strong anomalies were created/preserved is debated. Is excess mass due to denser lava material filling the crater or due to upwelling of denser iron-rich mantle material to the crust? Mascons make the Moon the most gravitationally lumpy body known in the solar system, anomaly is 0.5%. Mascons also exist on Mars, none have been found on Venus or Earth – as of 2001; those two larger planets, however, have had an active tectonic (geological) past that has drawn their crusts down into their interiors several times in the past few billion years, homogenizing the distribution of mass. Forward to 2012/2013: High-resolution gravity GRAIL mission show that gravitational fields resembling a **bull's-eye pattern**: a center of strong, or positive, gravity surrounded by alternating rings of negative and positive gravity.
<http://web.mit.edu/newsoffice/2013/an-answer-to-why-lunar-gravity-is-so-uneven-0530.html>



PLANETARY CRATERING

BEYOND EARTH: I LIKE STAR-RAYED CRATERS

Mojave Crater on Mars: Source of 80% Mars impactors on Earth – 55km large ‘recent crater’

... **55-kilometer-wide Mojave crater on Mars formed 3-5 million years ago. Based on their cosmic ray exposure, the shergottites from Mars must have broken off between 1 and 5 million years ago. Prior confusion on dating due to melting; this supports CUDO hypothesis. Note rayed structure.**

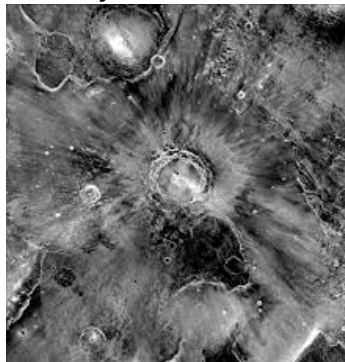
The Source Crater of Martian Shergottite Meteorites

Science 21 Mar 2014:
Vol. 343, Issue 6177, pp. 1343-1346
DOI: 10.1126/science.1247282

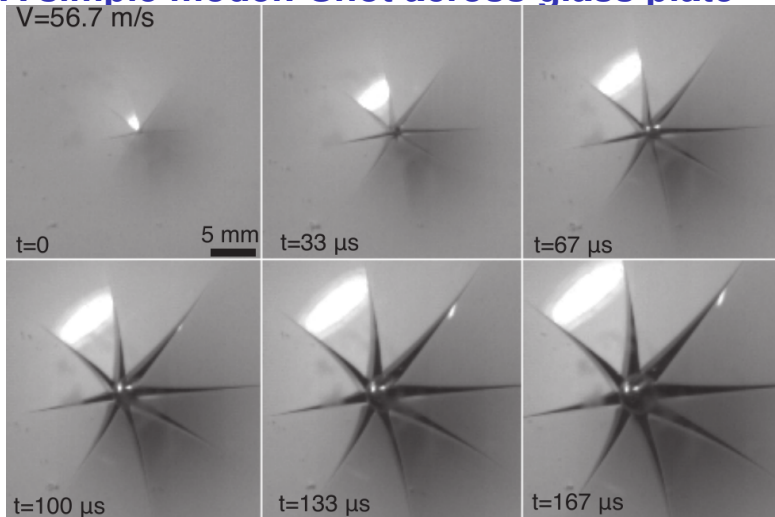
Stephanie C. Werner^{1,*}, Anouck Ody², François Poulet³

Sourcing Martian Meteorites

There are nearly 150 recognized martian meteorites, but where exactly they came from on Mars is not known. **Werner et al.** (p. **1343**, published online 6 March) present evidence that the <5 million-year-old Mojave impact crater on Mars is the single ejection site of one type of martian meteorites: the shergottites. The Mojave crater formed on an ancient terrain on Mars, and so the shergottites represent old martian crustal material.



A simple model: Shot across glass plate



Glass shot from: Fig 1 b from Nicolas Vandenberghe, Romain Vermorel, Emmanuel Villermaux. “Star shaped crack pattern of broken windows” *Physical Review Letters* **110** 174302 (2013)

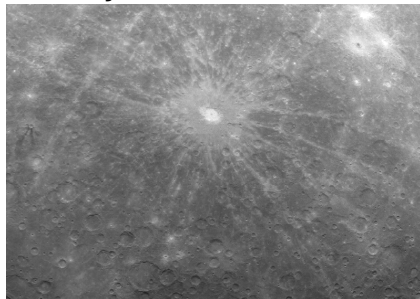
More Mars, Mercury star-rayed craters?

Mars:



A dramatic Mars impact crater created between July 2010 and May 2012 photographed by [HiRISE camera on board NASA's Mars Reconnaissance Orbiter on Nov. 19, 2013](#). The 30 meters in diameter crater is surrounded by a 15km large, rayed blast zone.

Mercury:



Are CUDOs Flying in the Solar system?



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Planetary and Space Science

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Density of asteroids

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ABSTRACT

The small bodies of our solar system are the remnants of the early stages of planetary formation. A considerable amount of information regarding the processes that occurred during the accretion of the early planetesimals is still present among this population. A review of our current knowledge of the density of small bodies is presented here. Density is indeed a fundamental property for the understanding of their composition and internal structure. Intrinsic physical properties of small bodies are sought by searching for relationships between the dynamical and taxonomic classes and density.

B. Carry / Planetary and Space Science 73 (2012) 98–118

Table 1

Compilation of the average mass (M) and volume-equivalent diameter (ϕ) estimates (see Appendices A–C), and resulting bulk density (ρ) and macroporosity (P) for 287 objects, with their associated uncertainties. For each object, the dynamical class is listed (Dyn.), together with the taxonomic class (Tax., for asteroids only) and associated meteorite (Met.). The density estimates are ranked A–E, owing to the level of confidence at which they are determined (see text). Unrealistic density estimates are marked with a cross (\times) and uncertainties on the macroporosity larger than 100% are listed as ∞ . **References:** (1) Clark et al. (2010), (2) Ockert-Bell et al. (2010), and (3) Fornasier et al. (2011). An electronic version of this table is available at <https://geoide.imcce.fr/tools/public/densities.php>.

Designation		Classification			Masses (kg)		Diameter (km)			Density		Porosity		Rank	
#	Name	Dyn.	Tax.	Met.	M	ΔM	ϕ	$\Delta\phi$	Fig.	ρ	$\Delta\rho$	ν	$\Delta\nu$		
1	Ceres	MBA	C	CM	9.44	$\pm 0.06 \times 10^{20}$	A.1	944.79	± 22.99	B.1	2.13	± 0.15	4	± 1	A
2	Pallas	MBA	B	CK ¹	2.04	$\pm 0.04 \times 10^{20}$	A.2	514.41	± 19.12	B.2	2.86	± 0.32	0	± 11	A
3	Juno	MBA	Sq	OC	2.73	$\pm 0.29 \times 10^{19}$	A.3	241.79	± 10.58	B.3	3.68	± 0.62	0	± 16	A
4	Vesta	MBA	V	HED	2.63	$\pm 0.05 \times 10^{20}$	A.4	519.33	± 6.84	B.4	3.58	± 0.15	0	± 4	A
5	Astraea	MBA	S	OC	2.64	$\pm 0.44 \times 10^{18}$	A.5	113.41	± 3.53	B.5	3.45	± 0.66	0	± 19	B
33	Polyhymnia	MBA	S	OC	6.20	$\pm 0.74 \times 10^{18}$		53.98	± 0.91		75.28	± 9.71	0	± 12	A
34	Circe	MBA	Ch	CM	3.66	$\pm 0.03 \times 10^{18}$	A.31	113.02	± 4.50	B.32	4.83	± 0.63	0	± 13	\times

33 Polyhymnia: $\rho = 75.28 \pm 9.71$ g/cc. Other with high probability above $\rho_{\text{Au-U}} = 20$ g/cc: 152 Atala 47.92 ± 13.10 g/cc; & 675 Ludmilla 73.99 ± 15.05

Asteroids of high density

there are a few more suspects: List of anomalies/CUDO candidates:

		M [10^{18} kg]	Diameter [km]	ρ [g/cm ³]
33	Polyhymnia	6.20 ± 0.74	53.98 ± 0.91	75.3 ± 9.7
152	Atala	5.43 ± 1.24	60.03 ± 3.01	47.9 ± 13.1
675	Ludmilla	12.0 ± 2.4	67.66 ± 0.95	74.0 ± 15.1
1686	DeSitter	6.76 ± 3.18	30.60 ± 1.41	450.5 ± 221
57	Mnemosyne	12.6 ± 2.4	113.01 ± 4.46	16.62 ± 3.73
72	Feronia	3.32 ± 8.49	83.95 ± 4.02	10.71 ± 27.44
112	Iphigenia	1.97 ± 6.78	71.07 ± 0.52	10.48 ± 36.06
126	Velleda	0.47 ± 5.79	44.79 ± 1.33	10.00 ± 123.00
132	Aethra	0.41 ± 2.71	35.83 ± 6.59	17.09 ± 112.83
148	Galia	4.89 ± 1.67	83.45 ± 5.07	16.06 ± 6.22
204	Kallisto	0.60 ± 1.81	50.36 ± 1.69	8.98 ± 27.07
210	Isabella	3.41 ± 1.09	73.70 ± 8.47	16.26 ± 7.65
234	Barbara	0.44 ± 1.45	45.62 ± 1.93	8.84 ± 29.17
485	Genua	1.36 ± 0.44	56.31 ± 4.15	14.53 ± 5.68
582	Olympia	0.43 ± 1.17	43.39 ± 1.49	10.00 ± 27.35
1013	Tombecka	0.17 ± 1.43	35.18 ± 2.24	7.50 ± 62.74
1036	Ganymed	0.167 ± 0.318	34.28 ± 1.38	7.91 ± 15.10

Egg moon of Saturn: Methone

[Discover the cosmos!](#) Each day a different image or photograph of our fascinating universe is featured, along with a brief explanation written by a professional astronomer.

2012 November 6



Methone: Smooth Egg Moon of Saturn

Image Credit: [Cassini Imaging Team](#), ISS, JPL, ESA, NASA

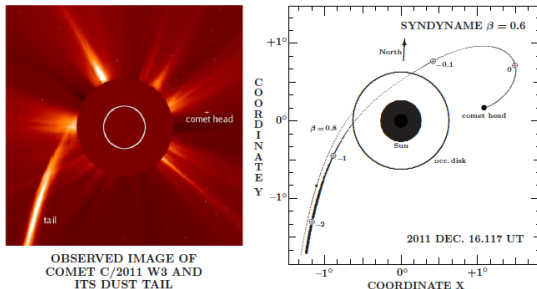
Explanation: Why is this moon shaped like a smooth egg? The robotic Cassini spacecraft completed the first flyby ever of Saturn's small moon [Methone](#) in May and discovered that the moon has no obvious craters. Craters, usually caused by impacts, have been seen on every [moon](#), [asteroid](#), and [comet nucleus](#) ever imaged in detail -- until now. Even the [Earth](#) and [Titan](#) have [craters](#). The smoothness and egg like shape of the [3 kilometer diameter moon](#) might be caused by [Methone's](#) surface being able to shift -- something that might occur were the moon coated by a deep [pile](#) of sub-visual [rubble](#). If so, the most similar objects in our Solar System would include Saturn's moons [Telesto](#), [Pandora](#), [Calypso](#), as well as asteroid [Itokawa](#), all of which show sections that are unusually smooth. [Methone](#) is not entirely featureless, though, as some surface sections [appear darker](#) than others. Although flybys of Methone are [difficult](#), interest in the nature and history of this unusual moon is sure to continue.

Low 'density' and yet surface reforms and object not blown into pieces

Comet Lovejoy survives encounter with Sun

THE ASTROPHYSICAL JOURNAL, 757:127 (33pp), 2012 October 1 SEKANINA & CHODAS

SOHO C2 IMAGE AND MODEL OF DUST TAIL OF C/2011 W3 ON DEC. 16



OBSERVED IMAGE OF
COMET C/2011 W3 AND
ITS DUST TAIL

Figure 8. Appearance of comet C/2011 W3 and its dust tail in an image taken with the C2 coronagraph on board the *SOHO* spacecraft on December 16.117 UT, or 0.105 days after perihelion. The tail, to the south-southeast of the Sun, is seen to be completely disconnected from the comet's head, to the west of the Sun.

THE ASTROPHYSICAL JOURNAL, 757:127 (33pp), 2012 October 1

doi:10.1088/0004-637X/757/2/127

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COMET C/2011 W3 (LOVEJOY): ORBIT DETERMINATION, OUTBURSTS, DISINTEGRATION OF NUCLEUS, DUST-TAIL MORPHOLOGY, AND RELATIONSHIP TO NEW CLUSTER OF BRIGHT SUNGRAZERS

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Received 2012 May 12; accepted 2012 July 30; published 2012 September 11

ABSTRACT

We describe the physical and orbital properties of C/2011 W3. After surviving perihelion passage, the comet was observed to undergo major physical changes. The permanent loss of the nuclear condensation and the formation of a narrow spine tail were observed first at Malargue, Argentina, on December 20 and then systematically at Siding Spring, Australia. The process of disintegration culminated with a terminal fragmentation event on December 17.6 UT. The postperihelion dust tail, observed for > 2 months, was the product of activity over > 2 days. The

Comet Ison survives encounter with Sun

THE ASTROPHYSICAL JOURNAL LETTERS, 784:L22 (4pp), 2014 April 1

doi:10.1088/2041-8205/784/2/L22

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IMAGING COMET ISON C/2012 S1 IN THE INNER CORONA AT PERIHELION

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ABSTRACT

Much anticipation and speculation were building around comet ISON, or C/2012 S1, discovered on 2012 September 21 by the International Scientific Optical Network telescope in Russia, and bound for the Sun on 2013 November 28, with a closest heliocentric approach distance of $2.7 R_{\odot}$. Here we present the first white light image of the comet's trail through the inner corona. The image was taken with a wide field Lyot-type coronagraph from the Mees Observatory on Haleakala at 19:12 UT, past its perihelion passage at 18:45 UT. The perfect match between the comet's trail captured in the inner corona and the trail that had persisted across the field of view of $2\text{--}6 R_{\odot}$ of the *Solar and Heliospheric Observatory* Large Angle and Spectrometric Coronagraph Experiment/C2 coronagraph at 19:12 UT demonstrates that the comet survived its perihelion passage.

To conclude: one new idea: CUDO allows to explain

- “Disappearing” giant (iron-nickel) meteorites
- Volcanic hot-spots in middle of thick continental crust
- Mantle plumes: deep origin of magma and long-term stability, **(some not vertical!)**
- Dual impact/volcanic activity ‘nuclear winter’ climate events
- Young (post-cooling) volcanic activity on Moon, Mars
(not described in detail today)
- Recent large rayed crater on Mars, transfer of material to Earth
- Comets fly through Sun
- Superdense extraterrestrial bodies

Earth (all rocky bodies) seem to be punctured many times – NOTE
(crust puncture not possible with normal matter impactor
[Ivanov, Geology, 31 (2004)])

NOW APPENDIX: MORE TECHNICAL

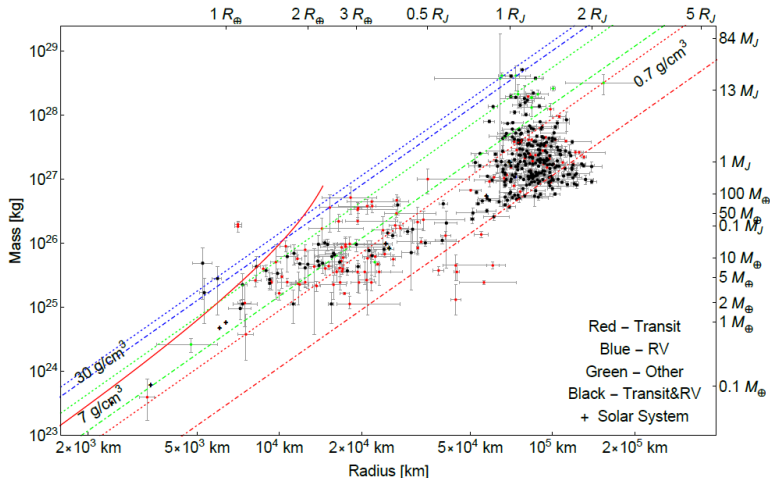
DETAILS

CUDOs beyond the Solar system?

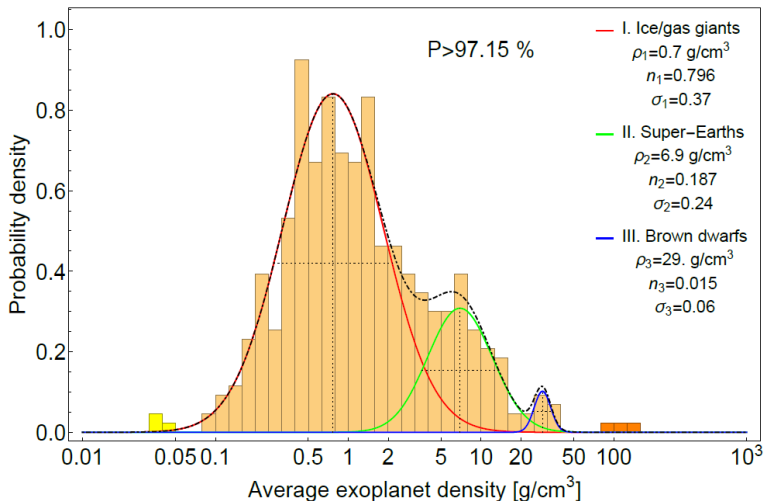
On exoplanets of high density

arXiv:1612.03556v1 [astro-ph.EP] 12 Dec 2016

Classification of exoplanets according to density



On exoplanets of high density



Microlensing constraints on clumps of matter

MACHOs = Massive Compact Halo Objects

sought by gravitational microlensing surveys (MACHO, EROS, OGLE)

Examples

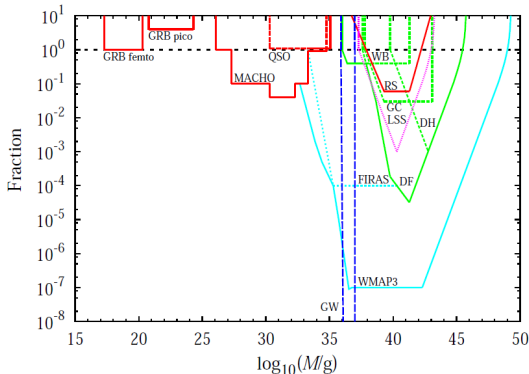
failed stars (brown dwarfs)

supermassive planets

neutrino stars

Bose stars

black holes



B.J. Carr et al PRD 81 04019 (2010);

$$M_{\text{Sun}} = 2 \times 10^{33} \text{g}, M_{\text{Earth}} = 6 \times 10^{27} \text{g},$$

Update of Carr's results

of Kepler Source Microlensing Data

Kim Griest, Agnieszka M. Cieplak, and Matthew J. Lehner
Phys. Rev. Lett. **111**, 181302 – Published 31 October 2013

ABSTRACT

We present new limits on the allowed masses of a dark matter (DM) halo consisting of primordial black holes (PBH) (or any other massive compact halo object). We analyze two years of data from the Kepler satellite, searching for short-duration bumps caused by gravitational microlensing. After removing background events consisting of variable stars, flare events, and comets or asteroids moving through the Kepler field, we find no microlensing candidates. We measure the efficiency of our selection criteria by adding millions of simulated microlensing events into the Kepler light curves. We find that PBH DM with masses in the range $2 \times 10^{-9} M_{\odot}$ to $10^{-7} M_{\odot}$ cannot make up the entirety of the DM in the Milky Way. At the low-mass end, this decreases the allowed mass range by more than an order of magnitude.

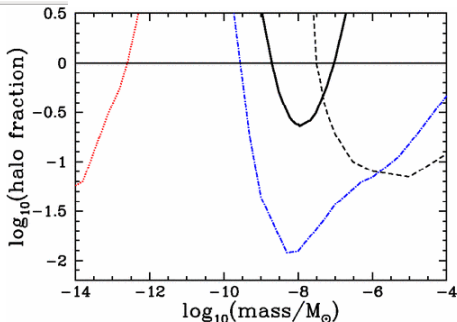


Figure 2

Upper limits (95% C.L.) on PBH DM from nonobservation of PBH microlensing in two years of Kepler data. The solid black line is our new limit, the dashed black line is the previous best limit (Ref. 11), the blue dot-dash line is the theoretical limit from Paper II, and the red dotted line is the femtolensing limit from Ref. 32. The black horizontal line indicates a halo density of 0.3 GeV cm^{-3} .

CUDO matter Example: Strangelets:

uds-symmetric matter: $p = uud, n = ddu, \Lambda = uds$

Strangelet = piece of $n_u \simeq n_d \simeq n_s$ matter, large baryon number A

Simple argument for (meta)stability

Chemical equilibrium:

$$\mu_d = \mu_u = \mu_s$$

Charge neutrality:

$$\frac{2}{3}n_u - \frac{1}{3}n_d - \frac{1}{3}n_s = 0$$

Compute thermodynamic potentials

$$\Omega_{u,d} = -\frac{\mu_{u,d}^4}{4\pi^2}$$

with massive strange quark $m_s > 0$

$$\Omega_s = -\frac{\mu_s^4}{4\pi^2} \left(\sqrt{1-x^2} \left(1 - \frac{5}{2}x^2\right) + \frac{3}{2}x^4 \ln(x^{-1} + \sqrt{x^{-2}-1}) \right) \quad x = m_s/\mu_s$$

Third fermi sea reduces Energy/baryon: $\frac{E/A(3 \text{ flavors})}{E/A(2 \text{ flavors})} < 1$

Proposed sources of Strangelets

1. Cosmological

First order phase transition to hadronic vacuum [Witten,PRD,30(1984)]

Objects $A < 10^{55}$ evaporate at $T \simeq 50$ MeV [Alcock & Farhi,PRD,32(1985)]

Strangeness enriched at surface \rightarrow reduced emissivity of nucleons

** Quasi-equilibrium $A \sim 10^{46} \Leftrightarrow M \simeq 10^{19}$ kg = $10^{-5} M_{\text{Earth}}$ **

[Madsen,PRD,34(1986) & 43(1991)]

► Large objects $A \gtrsim 10^{23} \Omega_{\text{nug}}^3 h^6 f_N^3$ consistent with BBN

► Quark matter in nuggets does not contribute to BBN limit on Ω_b

2. Strangeness in depth of compact stars

(30y track of work [Glendenning, Alcock, Alford, 1986-present])

Neutron star mergers or collisions eject fragments

[Madsen,JPG,28(2002) & Bauswein,PRL,103(2009)]

Strangelet meteorites='Nuclearites' considered for 30+ years:

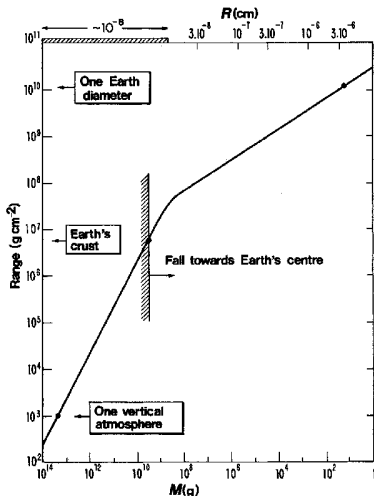
micro-micro-CUDO impacts on Earth:
de Rujula & Glashow, Nature (1984)

Proposed searching for

- 1 tracks preserved in mica
- 2 visible light emission
- 3 large scale scintillators
- 4 Seismic waves

continued: Herrin et al, PRD, 53 (1996) & 73 (2006), AMS (ongoing), Lunar Soil Search, PRL (2009)

▶ all but (1) above require *real time* observation of impact, and we do not think this is realistic: small strangelets unstable, large CUDO's rare.



Example of Strangelet Mass and Size Scales

Strangelet = piece of $n_u \simeq n_d \simeq n_s$ matter, large baryon number A

Madsen astro-ph/9809032, astro-ph/0612740

$$10^{30} < A < 10^{56} \quad \Leftrightarrow \quad \left\{ \begin{array}{l} 10^4 \text{ kg} < M < 10^{29} \text{ kg} \\ 10^{-20} < M/M_{\text{Earth}} < 10^5 \end{array} \right.$$

- **Constant density:** $M \sim R^3$
- **Density scale set by nuclear length** $R_{\text{nuc}} \sim 1 \text{ fm}$ (10^5 reduction relative to normal matter atomic length $R_{\text{atom}} \sim 1 \text{ \AA}$)

Normal matter asteroid

$$\begin{aligned} M &\sim 10^{-5} M_{\text{Earth}} \\ R &\sim 100 \text{ km} \end{aligned}$$

SQM “asteroid”

$$\begin{aligned} M &\sim 10^{-5} M_{\text{Earth}} \\ R &\sim 1 \text{ m} \end{aligned}$$

Compactness and high density $\rho_{\text{nuc}} \sim 10^{15} \rho_{\text{atomic}}$ **mean...**

► **gravity relevant in interactions:** $g_{\text{surf}} = \frac{GM}{R^2} = \frac{4\pi G}{3} \rho R$

► **Matter cannot support a strangelet: “punctures the Earth”**

[see e.g. DeRujula/Glashow, Nature,312(1984), Herrin et al,PRD,53(1996) & 73(2006)]

High Density ($\times 10^{15+}$) = Strongly Interacting Gravity

Moving fast across the following physics pages, those interested please consult these references:

Compact ultra dense matter impactors

JR, Lance Labun, and Jeremiah Birrell, Phys.Rev.Lett. 110 (2013) 111102
<http://prl.aps.org/abstract/PRL/v110/i11/e111102>

Properties of Gravitationally Bound Dark Compact Ultra Dense Objects

C. Dietl, L. Labun and JR, Phys. Lett. B 709, 123 (2012)
<http://www.sciencedirect.com/science/article/pii/S0370269312001463>

Compact Ultradense Objects in the Solar System

JR, Christopher Dietl, LL; Acta Phys.Polon. B43 (2012) 12, 2251-2260
<http://th-www.if.uj.edu.pl/acta/vol43/abs/v43p2251.htm>

Planetary Impacts by Clustered Quark Matter Strangelets

LL and JR, Acta Phys.Polon.Supp. 5 (2012) 381-386
<http://dx.doi.org/10.5506/APhysPolBSupp.5.381>

We considered two types of DM CUDOs

Analogous to compact objects composed of SM matter:

Fundamental fermion	Composite
mass $m_\chi \gtrsim 1 \text{ TeV}$	Bag model vacuum pressure $B \gtrsim (1 \text{ TeV})^4$
supported by pressure of degenerate fermi gas	self-bound by interactions
analogy to white dwarf, neutron star	analogy to quark-star, strangelet

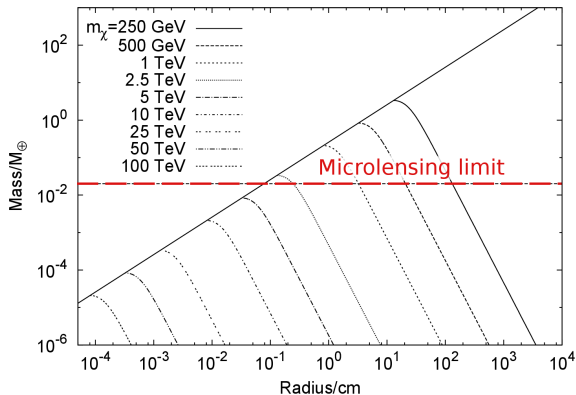
Solve for equilibrium configuration in Oppenheimer-Volkoff equations.

sc. Dietl, L. Labun and J. Rafelski, *Properties of Gravitationally Bound Dark Compact Ultra Dense Objects*, Phys. Lett. B 709, 123 (2012) [arXiv:1110.0551]

TeV-scale Fundamental Fermi particle

$$M_{\oplus} = 6 \cdot 10^{24} \text{ kg} \\ = \text{Earth mass}$$

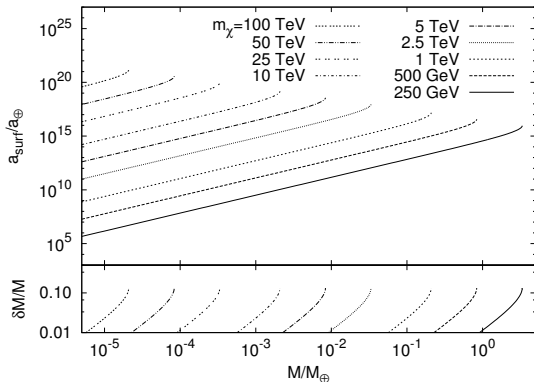
$$M_{\text{max}} \propto m_{\chi}^{-2}$$



★ upper end (near 'diagonal' of curve are objects stable and robust in collisions

Gravitational Stability and Tidal Force

Compact: Size of object comparable to gradient of gravitational field \Rightarrow **Tidal force important**

$$a_{\text{tidal}} = \frac{2GM}{r^2} \frac{L}{r} = a_{\text{surf}} \frac{R_{\text{surf}}^2}{r^2} \frac{2L}{r}$$


$$a_{\oplus} = 9.8 \text{ m/s}^2$$

= **Earth surface**

• **Tidal acceleration pulls apart atoms in solids: $a_{\text{surf}} > 3.5 \cdot 10^{15} a_{\oplus}$**

Dietl et al, PLB 709 (2012)

CUDOs not stopped by impact with normal visible matter

Summary: Fundamental Fermi and Composite/Bag

Fundamental fermion	Composite particle
mass $m_\chi \gtrsim 1 \text{ TeV}$	vacuum pressure $B \gtrsim (1 \text{ TeV})^4$
$M_{\text{max}} = 0.209 \left(\frac{1 \text{ TeV}}{m_\chi} \right)^2 M_\oplus$	$M_{\text{max}} = 0.014 \left(\frac{1 \text{ TeV}}{B^{1/4}} \right)^2 M_\oplus$
$R = 0.809 \left(\frac{1 \text{ TeV}}{m_\chi} \right)^2 \text{ cm}$	$R = 0.023 \left(\frac{1 \text{ TeV}}{B^{1/4}} \right)^2 \text{ cm}$

$$M_\oplus = 6 \cdot 10^{24} \text{ kg} = \text{Earth's mass}$$

★ Due to high mass scale, common $M < \text{Earth mass}$, $R < 1 \text{ cm}$

⇒ Highly compact and not too heavy

Summary: Mass and Size Limit Examples

Fermion mass	$M_{max}(M_{\odot})$	R_{min}	comment
100 GeV	10^{-4}	1 m	neutralino star (cold dark matter)
1 GeV	1	10 km	neutron star
1 GeV/0.5 MeV	1	10^3 km	white dwarf
10 keV	10^{10}	10^{11} km	sterile neutrino star
1 keV	10^{12}	10^{13} km	axino star (warm dark matter)
1 eV	10^{18}	10^{19} km	neutrino star
10^{-2} eV	10^{22}	10^{23} km	gravitino star

Maximum M_{max} and R_{min} for various cold compact stars made of a free Fermi gas

$$M_{max} = 0.627 M_{\odot} \cdot \left(\frac{1 \text{ GeV}}{m_f} \right)^2 \quad R_{min} = 8.115 \text{ km} \cdot \left(\frac{1 \text{ GeV}}{m_f} \right)^2$$

Collisions: a) Tidal Forces

in PRL

Consider CUDO passing through normal density matter: capture for distance R_c when energy gain of attached matter is greater than the kinetic energy this material must acquire $R_c := \frac{2GM}{v^2}$

$$\frac{R_c}{R_\oplus} = \frac{M_{\text{CUDO}}}{M_\oplus} \left(\frac{v_\oplus}{v} \right)^2$$

Matter disrupted due to differential acceleration

$$a(r - L/2) - a(r + L/2) = a_{\text{tidal}} = \frac{2GML}{r^3}$$

To compromise structural integrity,

gravitational pressure > compressional strength

$$\frac{F_{\text{tidal}}}{\text{area}} = \rho L a_{\text{tidal}} > \rho c_s^2 \text{ (bulk modulus)}$$

⇒ Material fails somewhere within Fracture length

$$\frac{L}{R_c} = \sqrt{2} \frac{c_s}{v} \left(\frac{r}{R_c} \right)^{3/2}$$

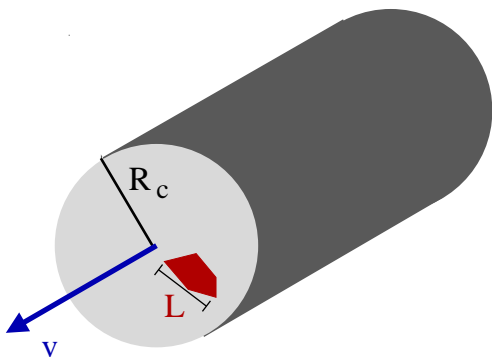
c_s = Bulk sound speed

Collisions: b) Fracture length and capture radius

Length scale: Gravitational capture radius $R_c = \frac{2GM}{v^2}$

$r < R_c$ material accreted to passing CUDO

$r > R_c$ material pulled in direction of motion, but left behind



In solid medium, material must be broken into pieces small enough to accrete

$$\frac{L}{R_c} = \sqrt{2} \frac{c_s}{v} \left(\frac{r}{R_c} \right)^{3/2} < 1$$

sound speed c_s representing bulk modulus (strength) of medium

STRANGElet impacts offer possible explanation of

- 1 Hot spots;
- 2 Impacts without impactors;
- 3 Comet Ison survives (2013) grazing collision; Comet Lovejoy (2011/2) C/2011 W3 grazes within Roche limit the solar corona and survives the passage only to explode later
- 4 10 million tons of spherules 12.8kyears ago altered climate and are not of 'conventional origin
- 5 Climatic excursion 536-545A.D. Ice Cores indicate 'explosive' volcanic origin, no impact wound and upper atmosphere material needed was initially interpreted as a 500m cometary impact.

and much more as we will see in quick slide show at the end of talk (in lieu of summary).