CUDOs and their impact (literal and figurative)

Johann Rafelski

Something STRANGE is sometimes hitting planetary bodies – Where is the meteorite? 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.

Major consequence for climate .

CUDOs maybe recognized by impact (exit) features, recent work suggests distinctly different crater morphology. In case of Earth impact we are interested in impactor exit =volcano(?!) accompanied by a major climatic excursion. Rocky objects in solar system accumulate CUDO 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.

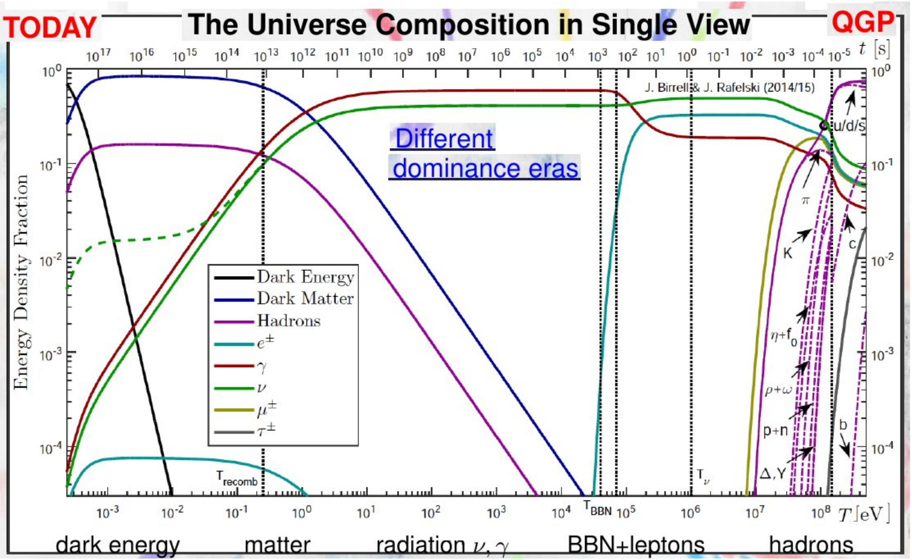
Most matter in the Universe unknown

Dominant content of the Universe and Origin of baryon asymmetry remain a mystery

The contents of the Universe today
(fractions change 'rapidly' in expanding Universe)

1. Visible (baryonic) matter: mainly hydrogen, helium
   (less 5% of present day total energy inventory)
   A mere 10^{-9} remnant of post QGP baryon annihilation period
2. Free-streaming matter
   i.e particles that do not interact – have 'frozen' out:
   - Photons: since $T = 0.235$eV *(insignificant in today's inventory)*
   - Neutrinos: since $T = 1.5$–3.5 MeV
   - Mystery dark matter *(25% in energy inventory)*
     1. Massive ColdDarkMatter free from way before QGP hadronization
     2. Warm dark matter: e.g. neutrinos of suitable mass
     3. Unknown massless dark matter: darkness: maybe 'needed', origin precedes neutrino decoupling

Domination eras of different forms of energy



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
$\Rightarrow$ evidence of independent dynamics
$\Rightarrow$ small self-interaction

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

THE ASTROPHYSICAL JOURNAL, 648:L109–L113, 2006 September 10

A DIRECT EMPIRICAL PROOF OF THE EXISTENCE OF DARK MATTER[1]

DOUGLAS CLOWE,[2] MARUŠA BRADAČ,[3] ANTHONY H. GONZALEZ,[4] MAXIM MARKEVITCH,[5,6]
SCOTT W. RANDALL,[5] CHRISTINE JONES,[5] AND DENNIS ZARITSKY[2]
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 maybe (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

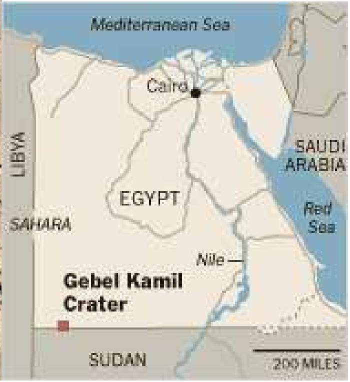
Ayuki Kamada, Manoj Kaplinghat, Andrew B. Pace, and Hai-Bo Yu

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.

Search for dark matter: cosmic impactor material



Normal matter iron-20%nickel impactor Gebel-Kamil crater: 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.

Where is the Meteorite that made 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 2.510^6 **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

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

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

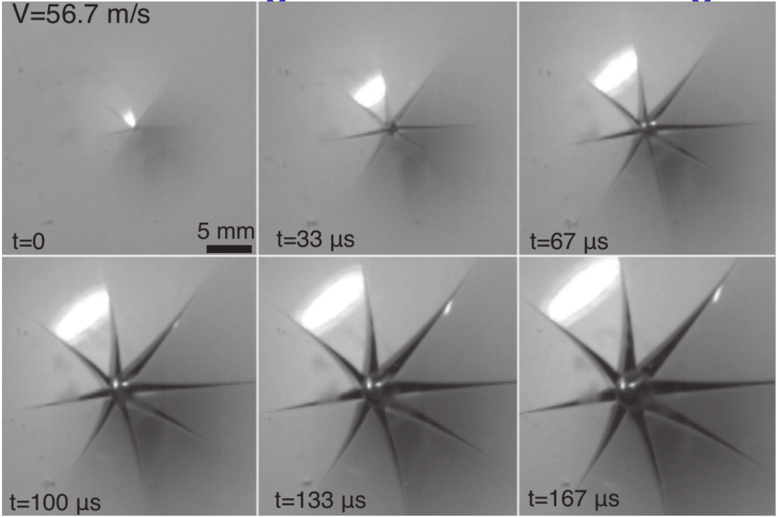
Are there impactors that cut into/across a planet?

Must be made of very dense matter which cannot be supported by surface tension. CUDOs (**compact ultradense objects**) loose energy along the path inside target - not on impact. Scenario example: collision with cold dark matter sitting still in the Universe through which we plough across with nearly 300 km/s – a shot across the Earth is the result. Such a CUDO would be a remnant of **Universe birth**. Certainly not a frequent event. But consequences for Earth very special:

- Impact-exit ionospheric deposit of material = **Climate** Winter
- Possible raining of matter (spherules)
- Mantle damage=Hot spots, continent breakup etc.

Also, some chance to capture shoot-through CUDOs inside Earth or more generally the Solar system: so we do not only look at craters, climate, but at what is flying now in Solar system, and even Earth's energy balance.

Exit shot through 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)

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.

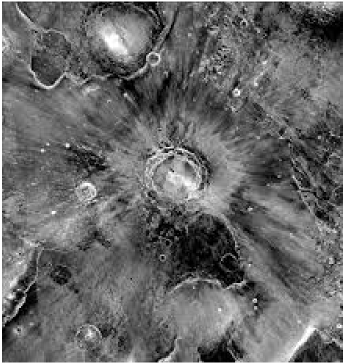
The Source Crater of Martian Shergottite Meteorites

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

Stephanie C. Werner[1,*], Anouck Ody[2], François Poulet[3]

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.

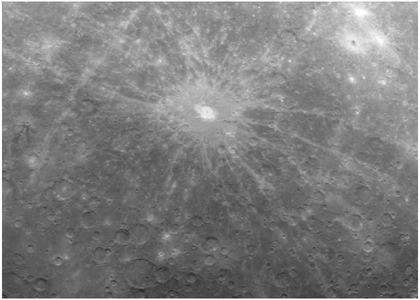


Mars, Mercury star-rayed craters

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:



Mars Pavonis Mons hole?

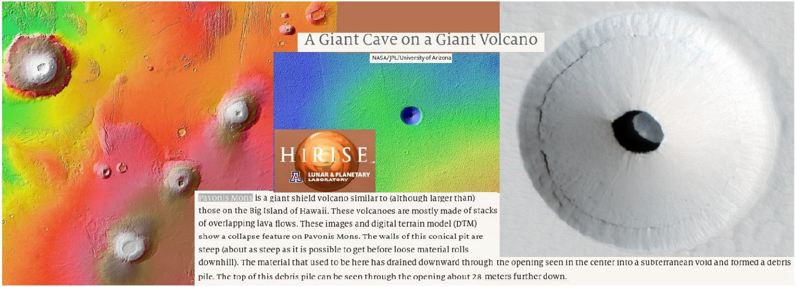
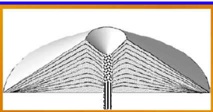
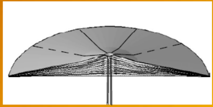


Fig. 9. The largest and aligned shield volcanoes in the Mars Tharsis Montes region are Ascraeus Mons, **Pavonis Mons**, Arsia Mons (on diagonal line), and Olympus Mons (off in NW corner). Arsia Mons has the largest caldera on Mars, having a diameter of 120 km. The main difference between the volcanoes on Mars and Earth is their size; volcanoes in the Tharsis region are up to 100 times larger than those anywhere on Earth. Detailed photography by University of Arizona LPL HiRISE of Pavonis Mons reveals a giant central conical and unexplained cave, see text for more detail. *Photo: Sources NASA, University of Arizona/LPL, Arizona State University*

cinder (scoria) cone		• single to multiple eruptions that extend over years to decades • moderately explosive eruptions of mafic (basaltic) composition, including lava flows, due to moderate gas content and low silica magma • builds a small volcano of ash, cinder, and scoria (fragmented magma) that is commonly 0.6 to 1.2 miles (1-2 km) in diameter
shield		• multiple eruptions of long lava flows from a central conduit over a moderately long time period • mostly non-explosive and fluid eruptions, due to low silica and low gas content magma • forms a low, broad volcano with some ash and cinder at the summit

CUDO structure candidates

1. Stable fragments of neutron stars = nuclear ‘strangelets ’
2. Dark matter starlets
   (self-interacting DM; maybe gravity bound DM)
3. Micro black holes

NOTE: Depending on primordial, or galactic origin, relative speed vastly different; the frequency of collision very different, mass of impactors very different. Morphology of impactor (exit) scars seen in Solar system suggest ALL of the above has happened.

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

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
arXiv:1612.03556 Acta Phys. Pol. B 49, 1917 (2018)
http://dx.doi.org/10.5506/APhysPolB.49.1917

Primordial DM Meteor Possible? – Qualitative Consideration

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

- **Becoming non-relativistic at an earlier time, heavy dark matter particles have a local high density allowing gravity to amplify local density fluctuations (dark matter helps visible matter assemble rapidly)**
- **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 tightly bind .**
- **High surface acceleration CUDOs stable against gravitational disruption (especially in collisions with normal matter objects)**

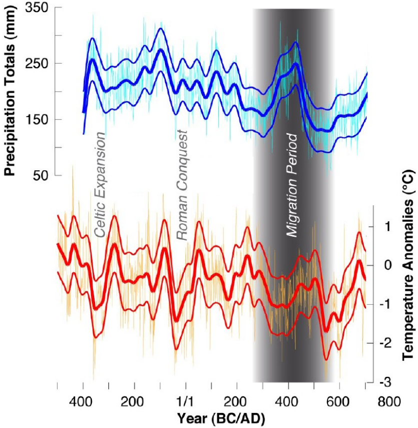
  $\Rightarrow$ **persist into present era nearly at rest in CBM frame of reference**

Dark impacts and 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*



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

BBC: 10 October 1465 E

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?

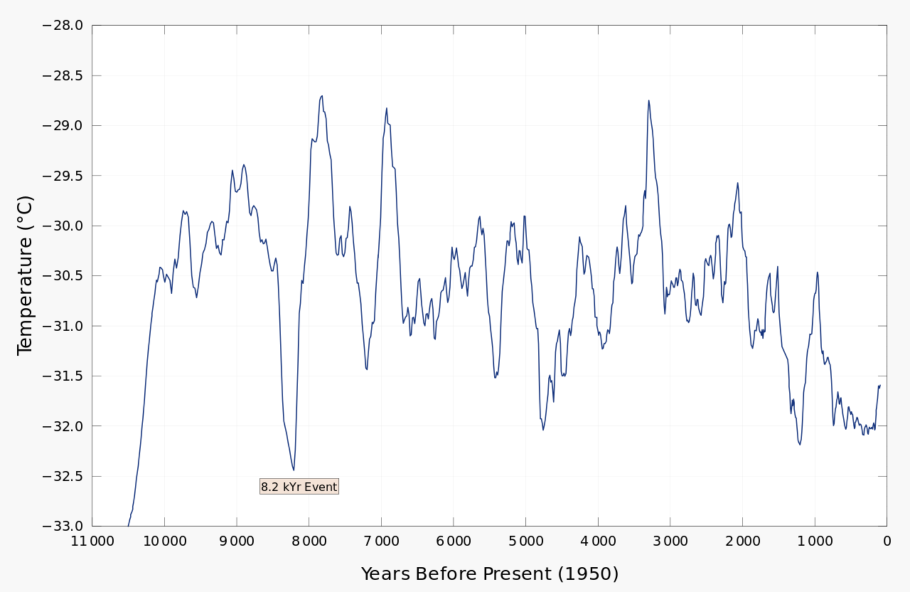
… produced an ash cloud which enveloped the Earth and led to the coolest decade for centuries.

> “*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.

ALSO reported by Janus Pannonius, a poet of King Matthias of Hungary. Source: http://mek.oszk.hu/06700/06722/06722.htm#975 (Thanks to Prof. László Szarka)

Groenland temperatures



Spherules

10.1073/pnas.1301760110

Proceedings of National Academy of Sciences (US) PNAS June 4, 2013 vol. 110 no. 23 E2088-E2097

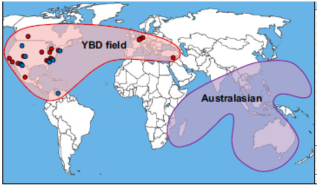
How did an impact distribute these spherules, that is the question here!

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.

Evidence for deposition of 10 million tonnes of impact spherules across four continents 12,800 y ago

James H. Wittke[a], James C. Weaver[b], Ted E. Bunch[a,1], James P. Kennett[c], Douglas J. Kennett[d], Andrew M. T. Moore[e], Gordon C. Hillman[f], Kenneth B. Tankersley[g], Albert C. Goodyear[h], Christopher R. Moore[i], I. Randolph Daniel, Jr.[j], Jack H. Ray[k], Neal H. Lopinot[k], David Ferraro[l], Isabel Israde-Alcántara[m], James L. Bischoff[n], Paul S. DeCarli[o], Robert E. Hermes[p,2], Johan B. Kloosterman[q,2], Zsolt Revay[r], George A. Howard[s], David R. Kimbel[t], Gunther Kletetschka[u], Ladislav Nabelek[u,v], Carl P. Lipo[w], Sachiko Sakai[w], Allen West[x], and Richard B. Firestone[y]

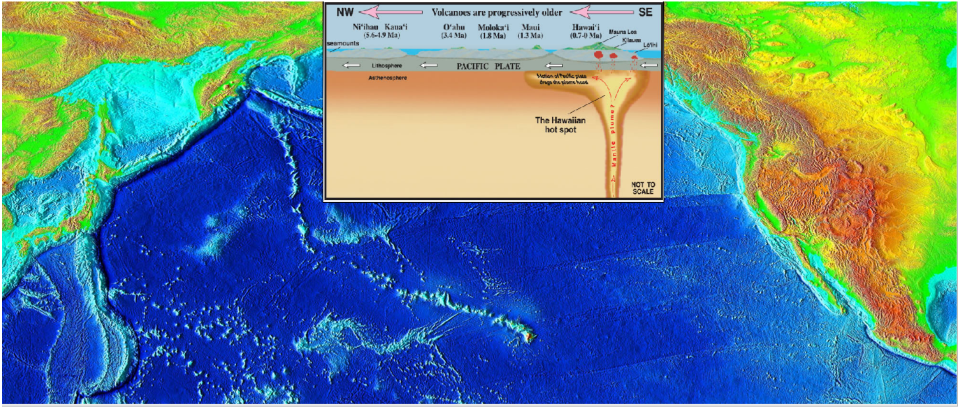


Site/Location	Details	Strat	Env	Setting
Arlington Cyn, CA	B,C,A,M	A	A	Coastal cyn
Barber Crk, NC	A	A,E	A	Relict dune
Big Eddy, MO	A	A	A	Flood-plain
Blackville, SC	--	A,E	I	Carolina bay
Blackwater, NM	B,C,A,M	A,L	A	Streambed
Chobot, ALB	B,C,A,M	A,L	A	Lakeshore
Cuitzeo, MEX	B,C,M	L	A	Lake bed
Gainey, MI	B,C,A,M	A,G	I	End-glacial
Kimbel Bay, NC	--	C,E	A	Carolina bay
Melrose, PA	--	C,G	I	End-glacial
Murray Spgs AZ	B,C,A,M	C,L	A	Streambed
Sheriden Cv, OH	B,C,A,M	C	A	Karst-cave
Talega, CA	B,A	A,C	I	Streambed
Topper, SC	A	A,C	I	River bank
Lingen, GER	B,C	E	A	Paleo-dunes
Lommel, BEL	B,CA	E	A	Paleo-dunes
Ommen, NED	B,C	E	A	Paleo-dunes
Abu Hureyra, SYR	B,C,A	A,E	I	Mound (tell)

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 ~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 location or in the vicinity). Also given are stratigraphic settings (Strat: A, alluvial; C, colluvial; E, eolian; G, glacial; and L, lacustrine) and relative physical stability of depositional paleoenvironments (Env: A, active, e.g., riverine, lacustrine, or eolian; I, inactive).

Some Earth puncture crates 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)



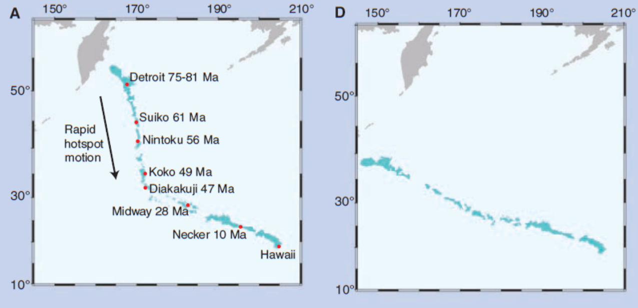
Plume may by (nearly) stable

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

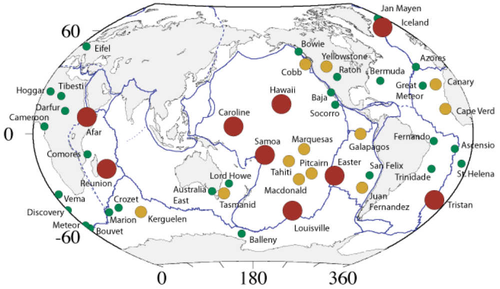
John Tarduno, Hans-Peter Bunge, Norm Sleep, Ulrich Hansen 3 APRIL 2009 VOL 324 **50**

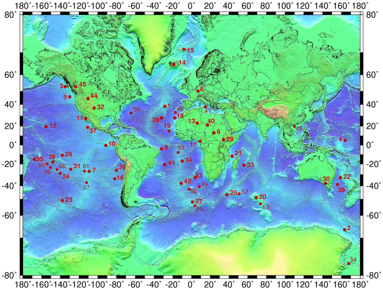
Bends in volcanic hotspot lineaments, best represented by the large elbow in the Hawaiian-Emperor chain, were thought to directly record changes in plate motion. Several lines of geophysical inquiry now suggest that a change in the locus of upwelling in the mantle induced by



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

Hotspot=Mantleplume? Shot-In or Out?





Global distribution of the 61 hot-spots listed in `https://en.wikipedia.org/wiki/Hotspot_(geology)`; Eurasian Plate:

Eifel hotspot (8) $50^0$12'N $6^0$42'E, w= 1 az= $082^0 \pm 8^0$ rate= 12 $\pm$2 mm/yr

Iceland hotspot (14) $64^0$24'N $17^0$18'W Azores hotspot (1) $37^0$54'N $26^0$00'W

Jan Mayen hotspot (15) 71^0N 9^0W Hainan hotspot (46) 20^0N 110^0E, az= $000^0 \pm 15^0$

`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

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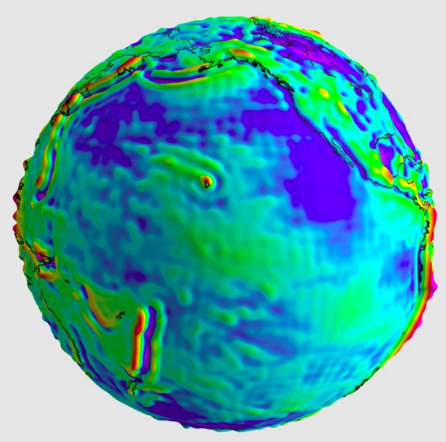
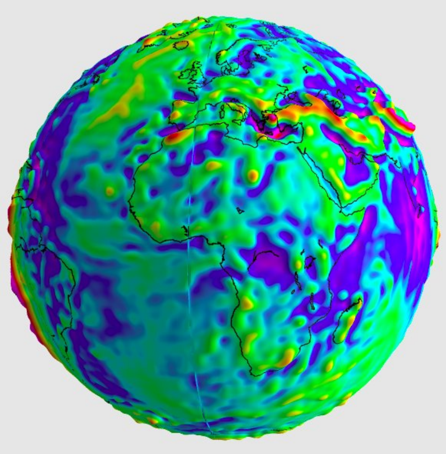
Jason Phipps Morgan
Department of Earth and Atmospheric Sciences, Snee Hall, Cornell University, Ithaca, New York 14853-1504, USA

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 °/m.y.). Errors in this pole location and rate are on the order of ±2°N, ±4°W, and ±3 mm/yr, respectively. The motions of other plates are related to this through the NUVEL-1A model.

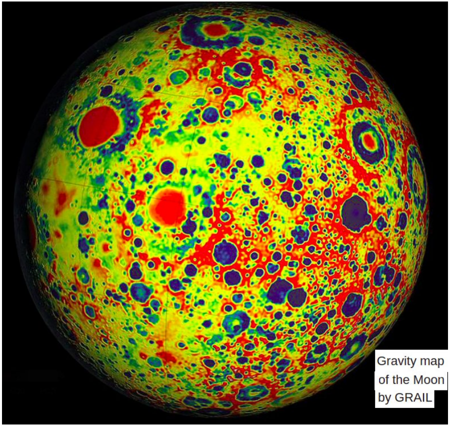
Some hot spots coincide with gravitational anomalies (mascons)

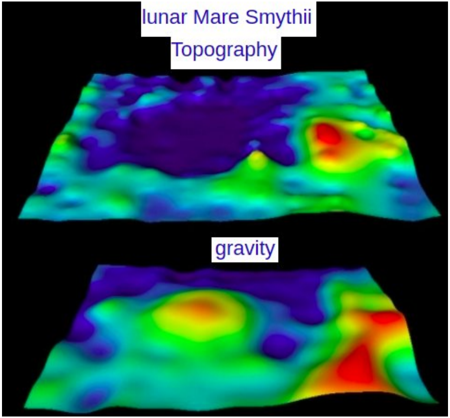




A mass concentration (or mascon) is a region of a planet or moon's crust that contains a large positive gravitational anomaly.

Moon gravity anomalies





Kimberley open pit diamond mine coincides with

negative mascon - ‘made(??) by asupersonic gas ejection’

Have CUDOs been captured: Earth energy balance

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

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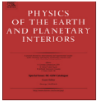

Heat flow evolution of the Earth from paleomantle temperatures: Evidence for increasing heat loss since ~2.5 Ga

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A R T I C L E I N F O

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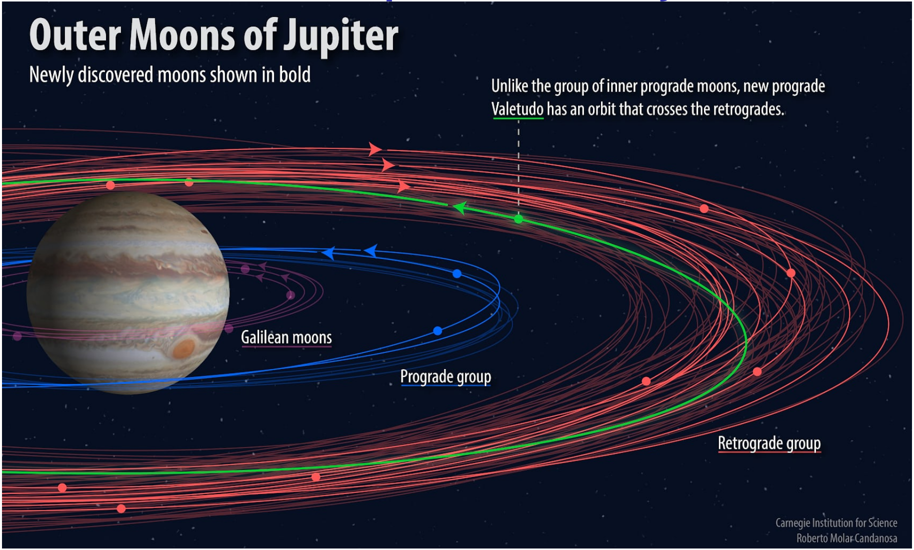
A B S T R A C T

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??

Have CUDOs been captured: Solar system?



Why is Valetudo not long destroyed by in collisions?? Mybe orbit characteristics are ‘recent’ and moon **stable** in collision?

On asteroids of high density

Planetary and Space Science 73 (2012) 98–118

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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

Table 1
Compilation of the average mass (M) and volume-equivalent diameter (ϕ) estimates (see Appendixes A–C), and resulting bulk density (ρ) and macroporosity ($\mathcal{P}$) 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 (✗) 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://genoide.imcce.fr/tools/public/densities.php.

Designation		Classification			Masses (kg)			Diameter (km)			Density		Porosity		Rank
#	Name	Dyn.	Tax.	Met.	M	δM	Fig.	ϕ	$\delta\phi$	Fig.	ρ	$\delta\rho$	$\mathcal{P}$	$\delta\mathcal{P}$	
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	✗
34	Circe	MBA	Ch	CM	3.66	$\pm 0.03 \times 10^{18}$	A.31	113.02	±4.90	B.32	4.83	±0.63	0	±13	✗

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

Asteroids of high density

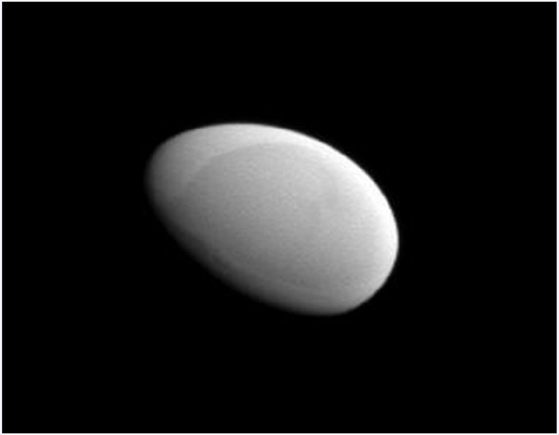
there are a few more suspects: List of anomalies/CUDO candidates:

		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

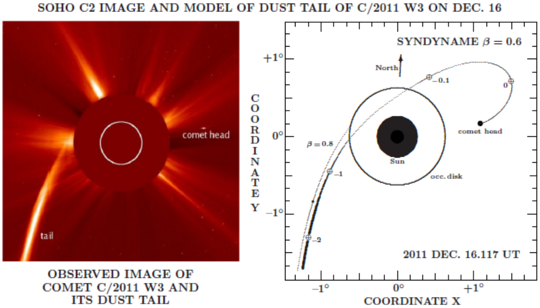


Figure 8. Appearance of comet C/2011 W3 and its dust tail in an image taken with the C2 coronagraph on board the *SOHO* spacecraft on December 16.117 UT, or 0.105 days after perihelion. The tail, to the south-southeast of the Sun, is seen to be completely disconnected from the comet's head, to the west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

The Astrophysical Journal, 757:127 (33pp), 2012 October 1 doi:10.1088/0004-637X/757/2/127

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 ~3 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

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

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Received 2014 January 2; accepted 2014 February 16; published 2014 March 12

ABSTRACT

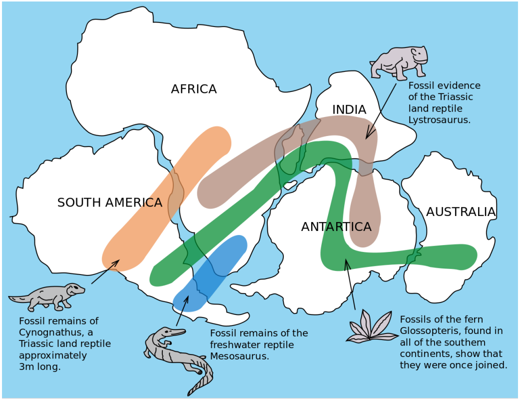
Much anticipation and speculation were building around comet ISON, or C/2012 S1, discovered on 2012 September 21 by the International Scientific Optical Network telescope in Russia, and bound for the Sun on 2013 November 28, with a closest heliocentric approach distance of 2.7 $R_\odot$. Here we present 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 2–6 $R_\odot$ 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’ meteorites**
- **Persistent hot-spots in middle of tectonic plates**
- **Dual impact/volcanic activity cooling climate events**
- **Young (post-cool-freezing) 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 and other flying anomalies**

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

What broke-up Pangea



Example of Strangelett Mass and Size Scales

$$10^{30} < A < 10^{56} \quad \Leftrightarrow \quad \begin{cases} 10^4\,\mathrm{kg} < M < 10^{29}\,\mathrm{kg} \\ 10^{-20} < M/M_{\mathrm{Earth}} < 10^5 \end{cases}$$

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

Normal matter asteroid	SQM "asteroid"
$M \sim 10^{-5} M_{\mathrm{Earth}}$	$M \sim 10^{-5} M_{\mathrm{Earth}}$
$R \sim 100\,\mathrm{km}$	$R \sim 1\,\mathrm{m}$

Compactness and high density mean...

- ► gravity relevant in interactions: $g_{\mathrm{surf}} = \dfrac{GM}{R^2} = \dfrac{4\pi G}{3}\rho R$
- ► Normal matter cannot support SQM: a strangelet "falls through"

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

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 $m_s > 0$

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

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 $T \simeq 50\,\mathrm{MeV}$ [Alcock & Farhi,PRD,32(1985)]

Strangeness enriched at surface $\to$ reduced emissivity of nucleons

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

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

- **Large objects $A \gtrsim 10^{23}\Omega_{\mathrm{nug}}^3 h^6 f_N^3$ 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

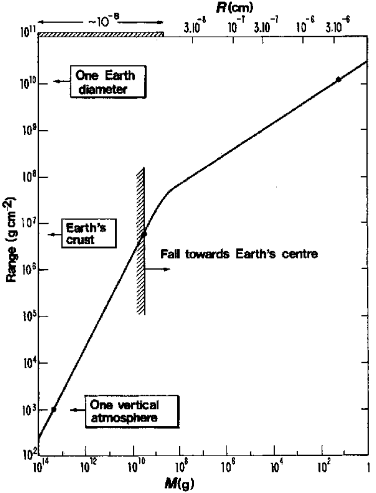
[Madsen,JPG,28(2002) & Bauswein,PRL,103(2009)]

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

$$10^{30} < A < 10^{56} \quad \Leftrightarrow \quad \begin{cases} 10^4\,\mathrm{kg} < M < 10^{29}\,\mathrm{kg} \\ 10^{-20} < M/M_{\mathrm{Earth}} < 10^5 \end{cases}$$

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$M \sim 10^{-5} M_{\mathrm{Earth}}$	$M \sim 10^{-5} M_{\mathrm{Earth}}$
$R \sim 100\,\mathrm{km}$	$R \sim 1\,\mathrm{m}$

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

- **gravity relevant in interactions:** $g_{\mathrm{surf}} = \dfrac{GM}{R^2} = \dfrac{4\pi G}{3}\rho R$
- **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:

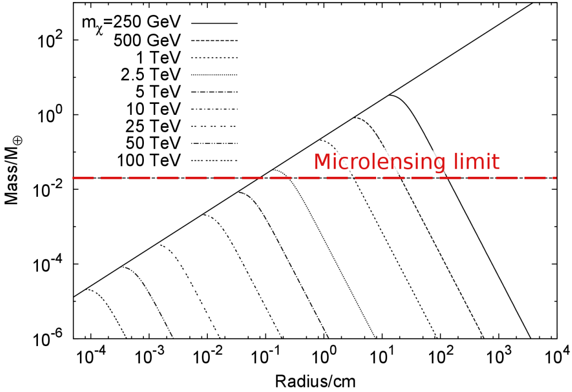
Fundamental fermion	**Composite**
mass $m_\chi \gtrsim 1\ \mathrm{TeV}$	**Bag model vacuum pressure** $B \gtrsim (1\ \mathrm{TeV})^4$
supported by pressure of degenerate fermi gas	**self-bound by interactions**
analogy to white dwarf, neutron star	**analogy to quark-star, strangelet**

Solve for equilibrium configuration in Oppenheimer-Volkoff equations **C. 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

$M_\oplus = 6\,10^{24}\ \mathrm{kg}$
$= $ **Earth mass**

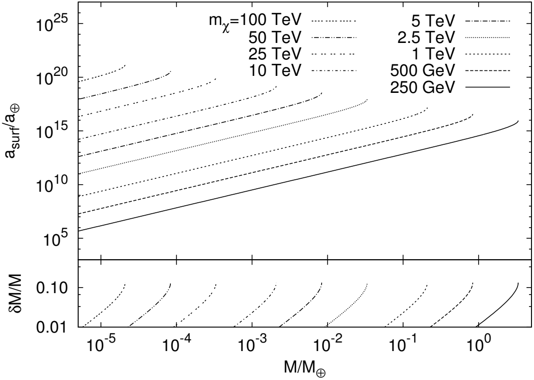
$M_{\max} \propto m_\chi^{-2}$



★ **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 ⇒ Tidal force important $a_{\rm tidal} = \frac{2GM}{r^2}\frac{L}{r} = a_{\rm surf}\frac{R^2_{\rm surf}}{r^2}\frac{2L}{r}$



$a_\oplus = 9.8{\rm m/s}^2$
$=$ **Earth surface**

- **Tidal acceleration pulls apart atoms in solids:** $a_{\rm surf} > 3.5\,10^{15} a_\oplus$

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 $m_\chi \gtrsim 1\ \mathrm{TeV}$	**vacuum pressure** $B \gtrsim (1\ \mathrm{TeV})^4$
$M_{\rm max} = 0.209 \left(\frac{1\ \mathrm{TeV}}{m_\chi}\right)^2 M_\oplus$	$M_{\rm max} = 0.014 \left(\frac{1\ \mathrm{TeV}}{B^{1/4}}\right)^2 M_\oplus$
$R = 0.809 \left(\frac{1\ \mathrm{TeV}}{m_\chi}\right)^2$ **cm**	$R = 0.023 \left(\frac{1\ \mathrm{TeV}}{B^{1/4}}\right)^2\ \mathrm{cm}$

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

★ **Due to high mass scale, common $M <$ Earth mass, $R < 1$ cm**

$\Rightarrow$ **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

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

Character of Gravit Bound Objects: Scaling Solution

If we have only $m, M_{\rm Pl}$ and need only 1 equation of state $p(\rho)$

Dimensionless...

1) pressure, density

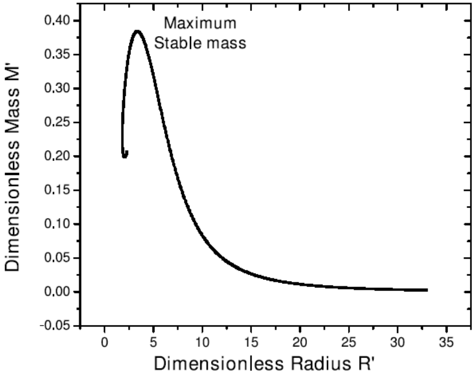
$$\widetilde{p}(\widetilde{\rho}) = m^{-4}\, p\left(\rho m^{-4}\right)$$

2) total mass of solution

$$\widetilde{M} = M \frac{m^2}{M_{\rm Pl}^3}$$

3) surface radius of solution

$$\widetilde{R} = R \frac{m^2}{M_{\rm Pl}}$$



[Narain, Schaffner-Bielich, Mishutsin, PRD **74** (2006)]

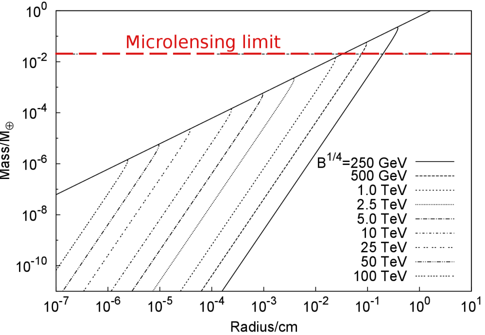
TOV equations now dimensionless – Solve once!

NOT the whole story: check stability against perturbation

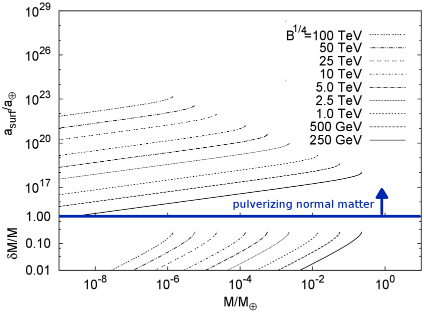
Oppenheimer/Serber 1936

Composite with TeV confinement energy

$M_\oplus = 6\,10^{24}\ \mathrm{kg}$ = Earth mass B = bag model vacuum pressure



Dietl et al, PLB **709** (2012)



$$M_{\rm max} \propto (B^{1/4})^{-2}$$

EROS Collaboration, Astron.Astrophys. **469** (2007)

Tidal force destructive for
$a_{\rm surf} > 3.5\,10^{15}\,a_\oplus$

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 $R_c := \frac{2GM}{v^2}$

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

Matter disrupted due to differential acceleration

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

To compromise structural integrity,

gravitational pressure $>$ compressional strength

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

$\Rightarrow$ **Material fails somewhere within Fracture length**

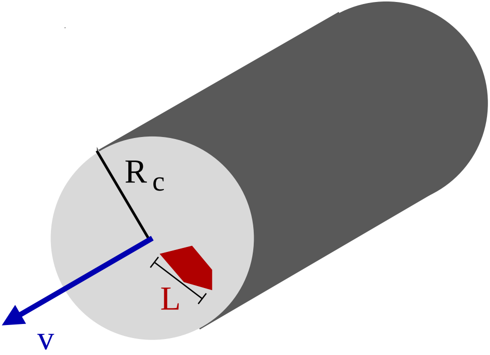
$$\frac{L}{R_c} = \sqrt{2}\frac{c_s}{v}\left(\frac{r}{R_c}\right)^{3/2}$$

$c_s =$ **Bulk sound speed**

Collisions: b) Fracture length and capture radius

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

$r < R_c$ **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**