

## 2) A “dwarf planet” is a celestial body that...

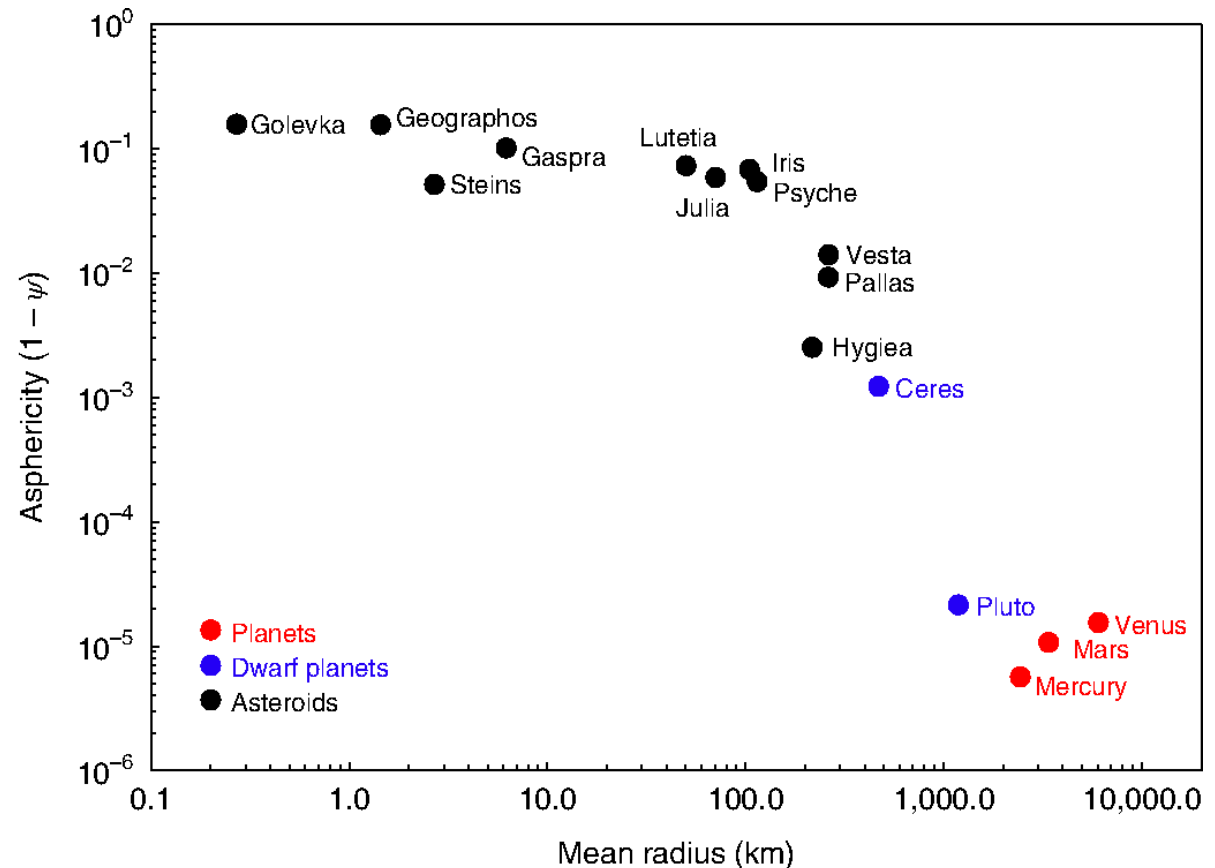
- a) is in orbit around the Sun,
- b) has sufficient mass for its self-gravity **to overcome rigid body forces** so that it assumes a hydrostatic equilibrium (nearly round) shape<sup>2</sup>,
- c) has not cleared the neighbourhood around its orbit, and
- d) is not a satellite.

Ref. IAU Res. GA 26 B5

Ceres, Pluto, Eris, Makemake, Haumea, ...

# Sphericity

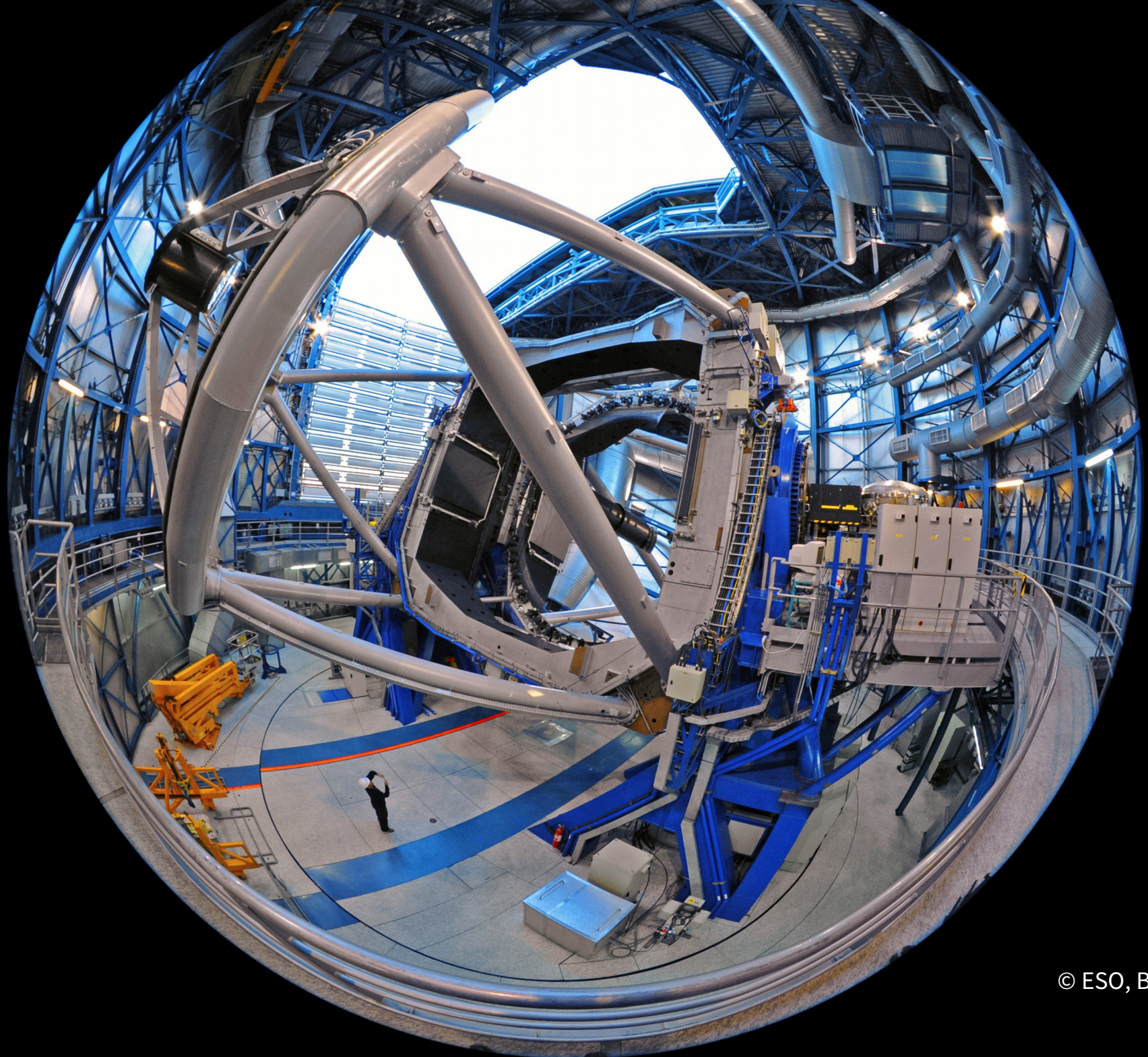
- $\psi = \pi^{1/3}(6V)^{2/3}/S \leq 1$ ,  
i.e. volume vs surface  
(Wadell 1935)
- asphericity  $1 - \psi$
- 3D shape model...
- multipole expansion  
(10<sup>th</sup> order)
- $\psi$  of Hygiea ~ Ceres
- both C-types



**Fig. 4 | Asphericity of Solar System objects as a function of their mean radius.** The parameter  $\psi$  corresponds to the sphericity index<sup>26</sup> applied to spherical harmonics developments of the 3D shape models of each object. Hygiea appears nearly as spherical as the dwarf planet Ceres.

# Reviews

- description SPH w. self-gravity? ← see Ševeček et al. (2019)
- use **friction!** ← but Hygiea is round
- 4-h timescale of fluidisation? ← another t. *not* applicable
- $c_s = 3 \text{ km s}^{-1}$ , crossing time  $t = D/c_s = 170 \text{ s}$ , i.e.  $\sim 10^2$  crossings
- **self-gravity** must overcome rigid-body forces (not r.)
- cratering (cf. Carruba et al. 2014)? ← SFD is reaccumulated  
c. → reaccumulative → catastrophic → super-catastrophic
- age 1.3 Gy (cf. Spoto et al. 2015)? ←  $v_{\text{esc}} = 226 \text{ m/s}$ ,  $v_{\text{ej}} \sim v_{\text{esc}}$



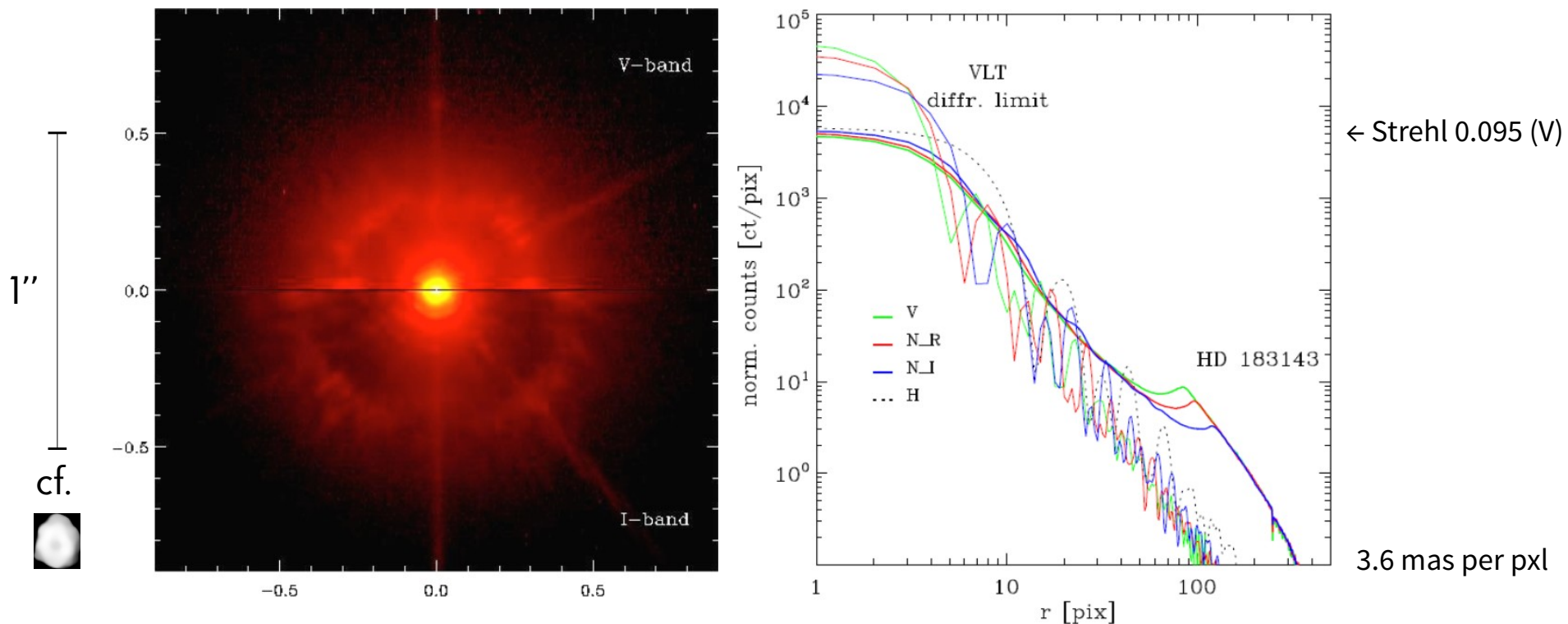
# AO imaging $\neq$ direct i. ← see Albireo ..

- stellar vs semi-analytic, axisymmetric (Moffat) **PSF**
- deconvolution algorithms w. priors, regularisation
- non-convex shape model (ADAM; Viikinkoski *etal.* 2015),
- or **inclinometry** (Jorda *etal.* *in prep.*)
- limited phase coverage vs “geological mapping”



# PSF & its variability

- N\_R filter ( $645 \pm 28$  nm), dependence on  $\lambda$ , seeing ( $<0.8''$ )
- asteroid as NGS, nearby \* as PSF, 5 of 10-s exposures @ epoch



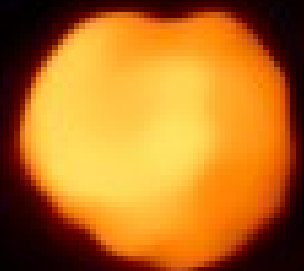
degraded image



stellar PSF



deconvolved image



=

\*

# Deconvolution (Bayes statistics)

- $I$  ... degraded image,  $H$  ... PSF,  $O$  ... ideal image,  $N$  ... Noise

$$I = H * O + N$$

- Bayes theorem for conditional probabilities, where  $p(I) = I \div 65535$  ADU

$$p(O \wedge I) = p(O|I)p(I) = p(I|O)p(O) \rightarrow p(O|I) = \frac{p(I|O)p(O)}{p(I)}$$

- maximalisation of  $p(O|I)$ , i.e. minimalisation of the functional wrt.  $O$ :

$$J = -\ln[p(I|O)p(O)] = -\ln p(I|O) - \ln p(O) \equiv J_N + J_O$$



# Myopic deconvolution ← MISTRAL algorithm

- problems of Richardson-Lucy: **divergence** (if not Poisson), artifacts, “ringing”
- Gaussian noise (photon, PSF, seeing, jitter, ...), regularisation (Conan et al. 2000):

$$p(x; \sigma) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{x^2}{2\sigma^2}} \quad \rightarrow \quad J_N = \sum_r \frac{1}{2\sigma^2} (I - H * O)^2$$

- additional priors (edge, seeing), 2<sup>nd</sup> regularisation:

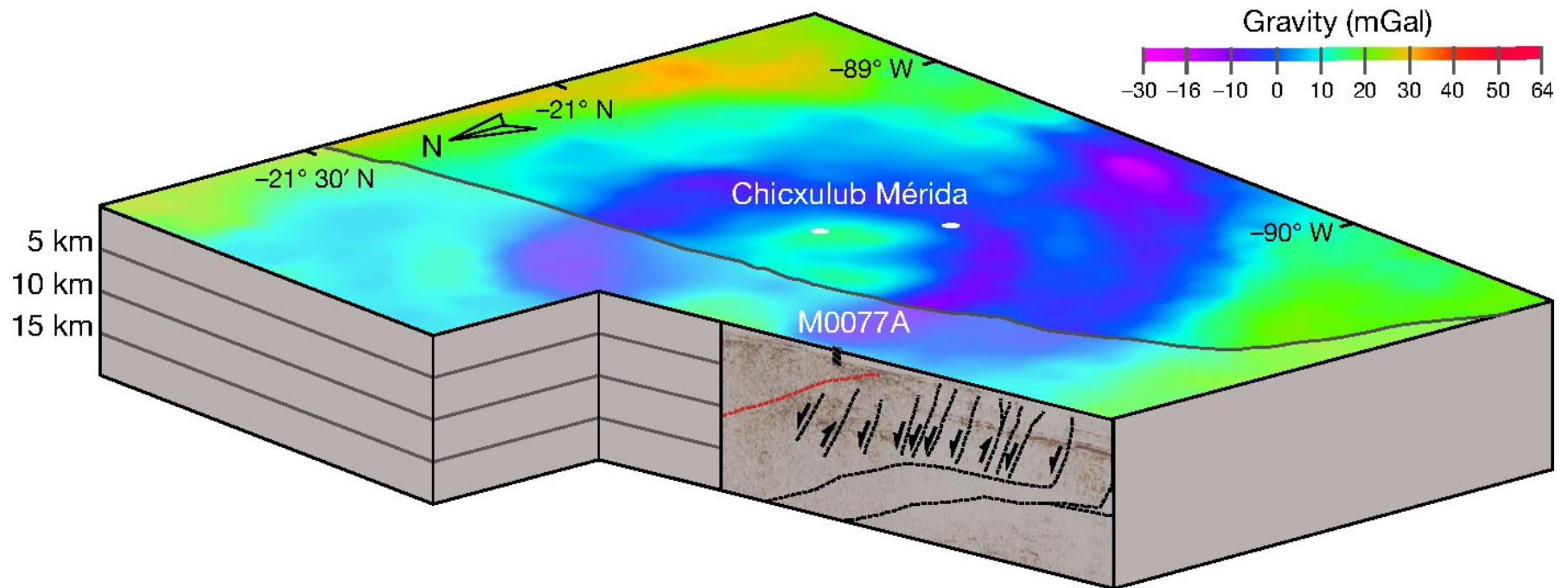
$$J_O = -\ln p(O) = \mu \sum_r \left[ \frac{|\nabla O|}{\delta} - \ln \left( 1 + \frac{|\nabla O|}{\delta} \right) \right]$$

$\delta, \mu$  ... free parameters,  
 $E()$  ... expectation (average over  $\lambda$ ),  
 $\tilde{H}$  ... Fourier transform, i.e. MTF

$$J_H = \frac{1}{2} \sum_q \frac{|\tilde{H} - E(\tilde{H})|^2}{E[|\tilde{H} - E(\tilde{H})|^2]}$$

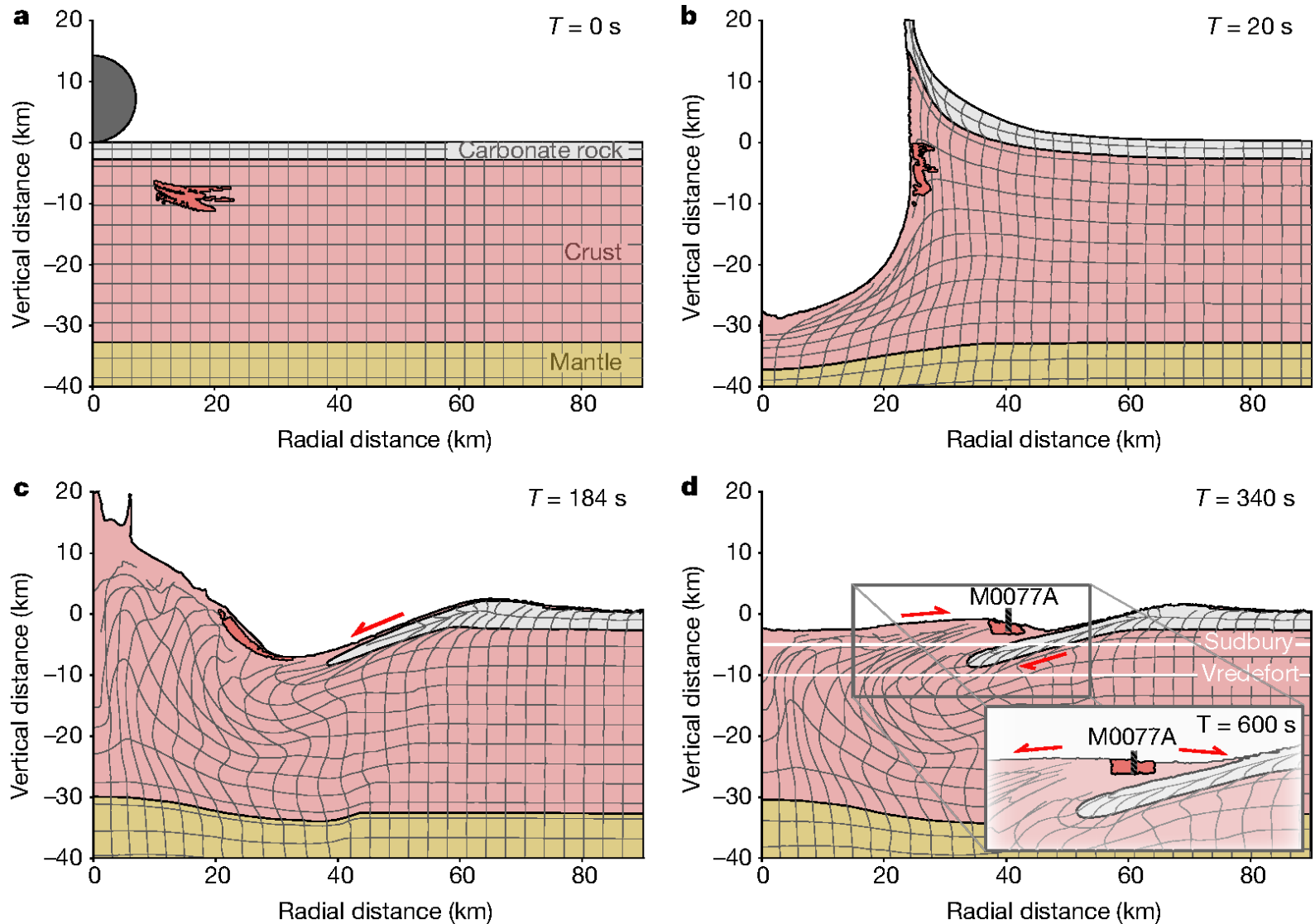
# Acoustic fluidisation ← experiment

- block model (Melosh 1989)
- used for Vesta (Jutzi et al. 2013), or **Chicxulub** (Riller et al. 2018)



also higher-order oscillations?

Riller et al. (2018);  $c_s = 3$  km/s,  $D = 30$  km,  $t \sim 10^1$  s, but ring & peak collapse  $\rightarrow$  more sound waves...



**Fig. 2 | Modelled formation of the Chicxulub impact structure.** The mechanism is based on numerical modelling of peak-ring crater formation<sup>4,23,24,34</sup>. A grid of tracer particles is shown to highlight the sub-crater deformation. Dark red area of crust in each panel tracks the material that eventually forms the peak ring.  $T$  denotes time in seconds after impact. Red half-arrows indicate the direction of major shear displacements relative to adjacent material. **a**, Undisturbed configuration of model lithosphere before impact. **b**, Cratering starts by shock-wave-

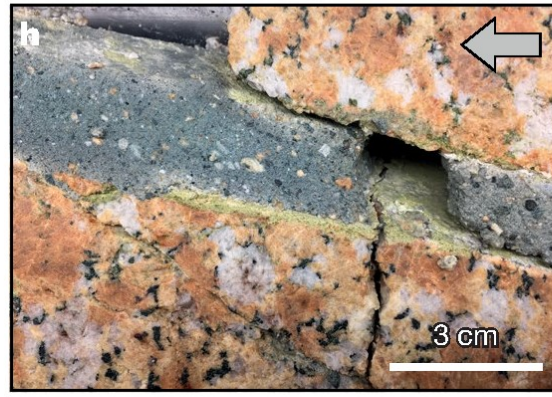
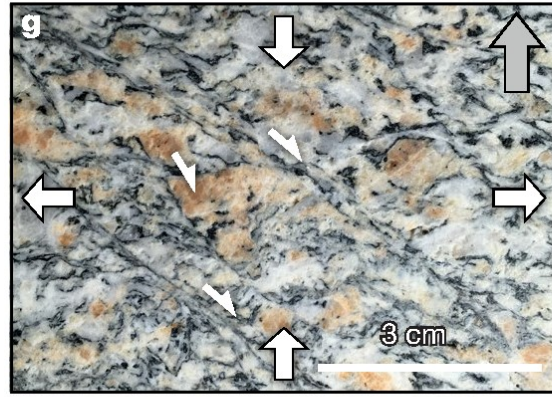
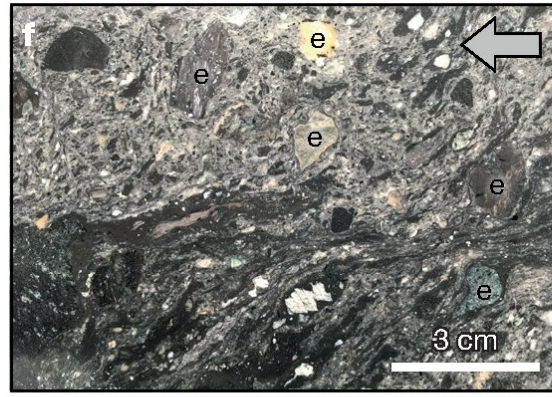
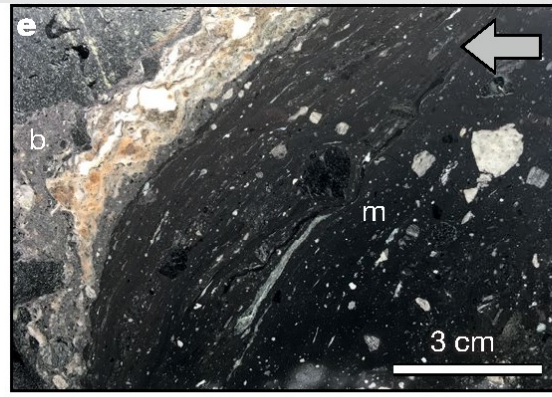
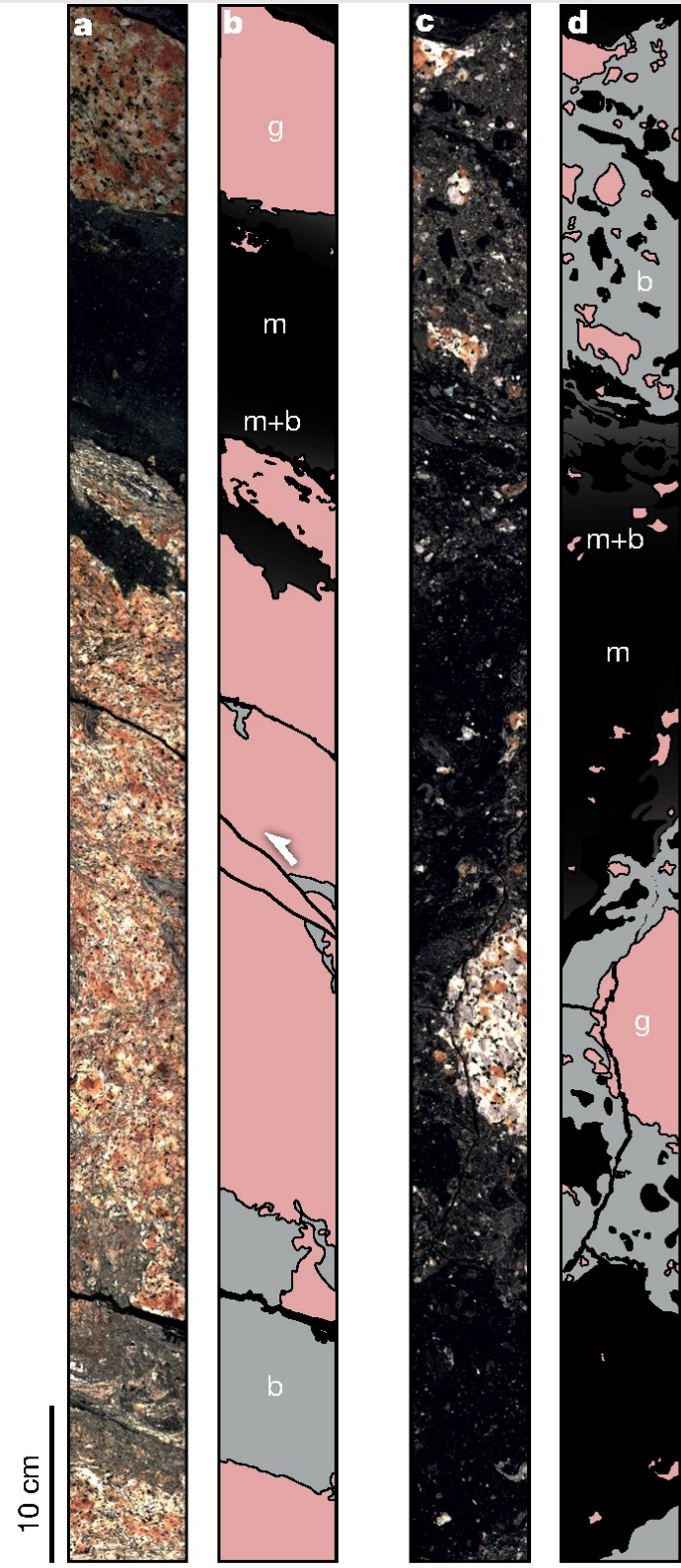
induced, crustal-scale excavation of a bowl-shaped transient cavity. **c**, Gravitational instability of the transient cavity causes uplift of the crater centre and concomitant inward slumping of the cavity wall. **d**, Collapse and radial outward displacement of uplifted material over inward-slumped cavity wall segments followed by gravitational settling of the peak ring (inset) characterize the terminal phase of modelled crater modification. White lines indicate the approximate current erosion levels of the Sudbury and Vredefort impact structures.

Riller et al. (2018)

g ... granitoid

m ... melt

b ... breccia



e ... „exotic“  
shear zone

horizontal extension  
vertical shortening

c ... cataclasite  
fracture

# Some newspapers...

- CNN
- Fox News
- NBC News
- Independent
- Space.com
- Science News
- SciTechDaily
- Geek.com
- Universe Today
- Inverse
- Daily Mail
- The Sun
- ...

It's an asteroid! No, it's the new smallest dwarf planet in our solar system

By Ashley Strickland and Amy Woollatt, CNN  
Updated 02:08 GMT (12:08 HKT) October 29, 2019

See dwarf planet in stunning detail 01:19

(CNN) — A large asteroid could be reclassified as a dwarf planet — which could make it the smallest in the solar system — after new research revealed its shape, astronomers said on Monday.

Nested in the asteroid belt between Mars and Jupiter is an object that may have been overlooked: They believe the asteroid Hygiea should actually be classified as a dwarf planet.

Asteroid Hygiea could become the tiniest dwarf planet

By Chris Clarke | Fox News

Planet 1 Published 6 days ago

Planet 2

Planet 3

Planet 4

As the debate rages on whether Pluto, currently a dwarf planet, should be given back its planet status, it may soon be joined by an asteroid that could wind up being the smallest dwarf planet in the solar system.

Asteroid Hygiea, the fourth largest space rock in the Asteroid Belt, was observed for the first time by astronomers in high-resolution. It's spherical in shape and may wind up taking the crown for the smallest dwarf from Ceres, also located in the Asteroid Belt.

THERE IS AN UNKNOWN DWARF PLANET IN OUR SOLAR SYSTEM, SCIENTISTS SAY

According to scientists a rock at the far reaches of our solar system might actually be a dwarf planet.

This result came as a real surprise, says scientist

Andrey Galka (@andrey\_galka) [Monday 28 October 2019 16:37]

A rock at the far reaches of our solar system might actually be a dwarf planet, scientists have said.

New research — using the Very Large Telescope in northern Chile — has shown that Hygiea may not actually be an asteroid, as previously thought, but a dwarf planet.

That would make it the smallest dwarf planet in our solar system, according to the findings published in the journal *Nature Astronomy*.

Asteroid Hygiea May Be the Smallest Dwarf Planet in the Solar System

By Doris Elin Umlauf 8 days ago Science & Astronomy

Step aside, Ceres. There's a new smallest dwarf planet in town.

Get breaking space news and the latest updates on rocket launches, skywatching events and more!

On This Day in Space! Nov. 3, 1957: Laska the Dog Launches with Sputnik 2

OffWorld's Smart Robots Could Swarm Solar System to Help Astronauts and Settlers

Why Mars Base Tech Should Be Tested on the Moon First

The solar system may have a new smallest dwarf planet: Hygiea

New images reveal the wee world is round, a final criterion for dwarf planet status.

By Maria Temming  
OCTOBER 28, 2019 AT 12:00 PM

The asteroid belt object known as Hygiea may be the new baby of the dwarf planet family.

'Asteroid' Hygiea Could Actually Be Smallest Dwarf Planet in the Solar System

SciTechDaily: Home of the best science and technology news since 1998. Keep up with the latest sci-tech news via email or social media.

How the Big Bang Ignited — Solving One Mystery to the Origin of the Universe

University of Central Florida researchers discover mechanism for the cause of the Big Bang. Knowing the criteria behind the Big Bang explosion will be key to understanding the universe.

Asteroid Hygiea Could Be the Smallest Dwarf Planet in the Solar System

BY GENIEVE SCARANO 10/29/2019 - 4:15PM EST

STRV ON TARGET

Move over, Ceres: Astronomers using an ESO telescope revealed that asteroid Hygiea may be classified as the tiniest dwarf planet in our solar system.

Asteroid Hygiea, which was observed using ESO's SPHERE instrument at the Very Large Telescope (VLT) in Chile, could be the solar system's smallest dwarf planet yet. (Photo Credit: ESO / P. Vermaas et al. / MISTRAL algorithm - ONERA / CNRS)

Asteroid Hygiea Could Be the Smallest Dwarf Planet in the Solar System

NOVEMBER 1, 2019 BY MATT WILLIAMS

Asteroid Hygiea is Round Enough That It Could Qualify as a Dwarf Planet, the Smallest in the Solar System

Within the Main Asteroid Belt, there are a number of larger bodies that have defied traditional classification. The largest among them is Ceres, which is followed by Vesta, Pallas, and Juno. It's still somewhat of a mystery whether these bodies are asteroids or dwarf planets.

HIDE AND SEEK New 'dwarf planet' like Pluto found hidden in our Solar System - and is only the second found this side of Neptune

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DWARF PLANET FOUND

A NEWLY identified dwarf planet named after a Greek goddess may be the smallest in our Solar System.

Dubbed Hygiea, the mysterious world sits in the asteroid belt between Jupiter and Mars and measures just 270 miles across.

It makes it nearly ten times smaller than the Moon, which stretches over 2,300 miles across.