Complex organic matter delivery by carbonate-rich meteorites: kinetic models

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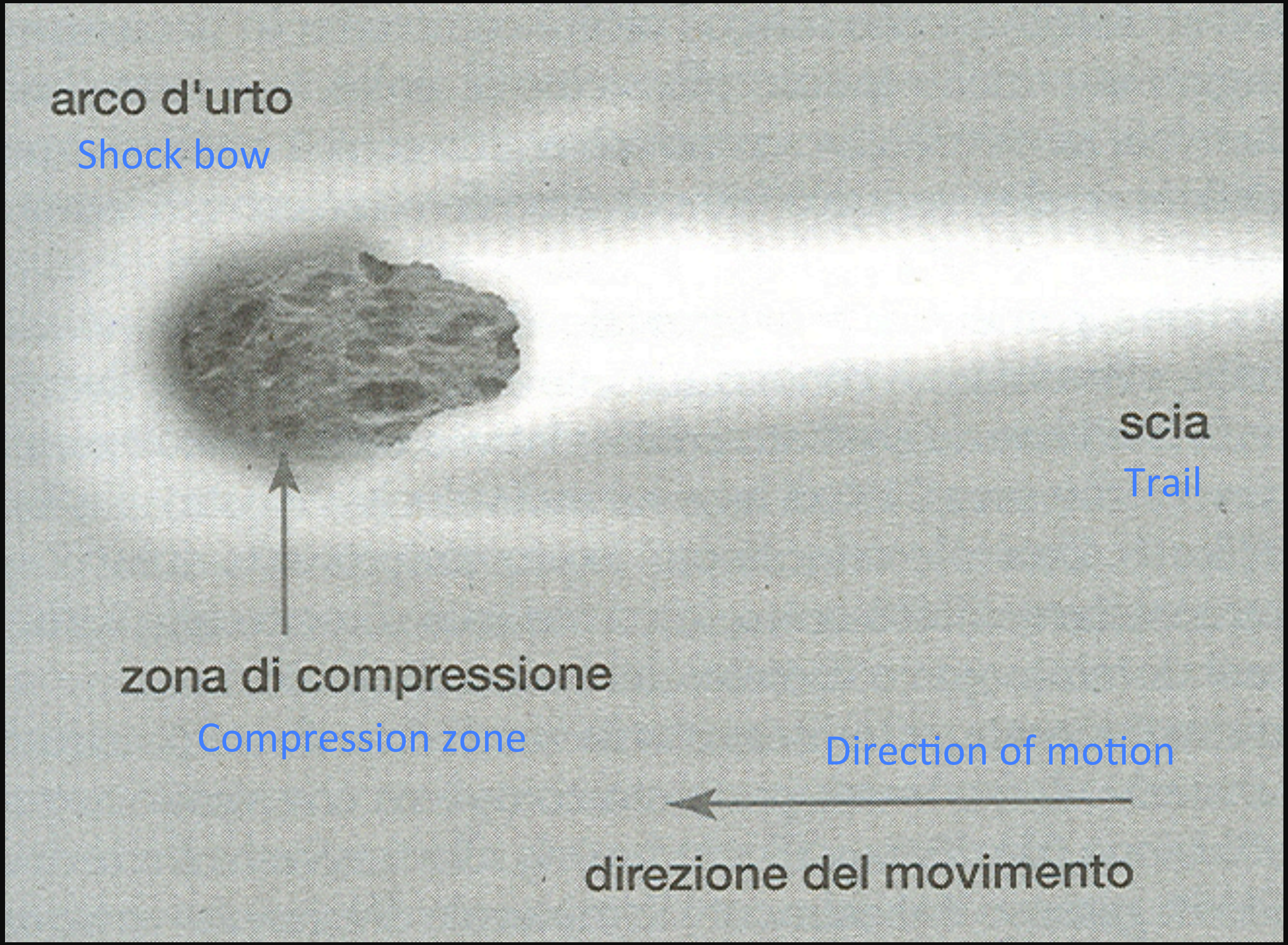
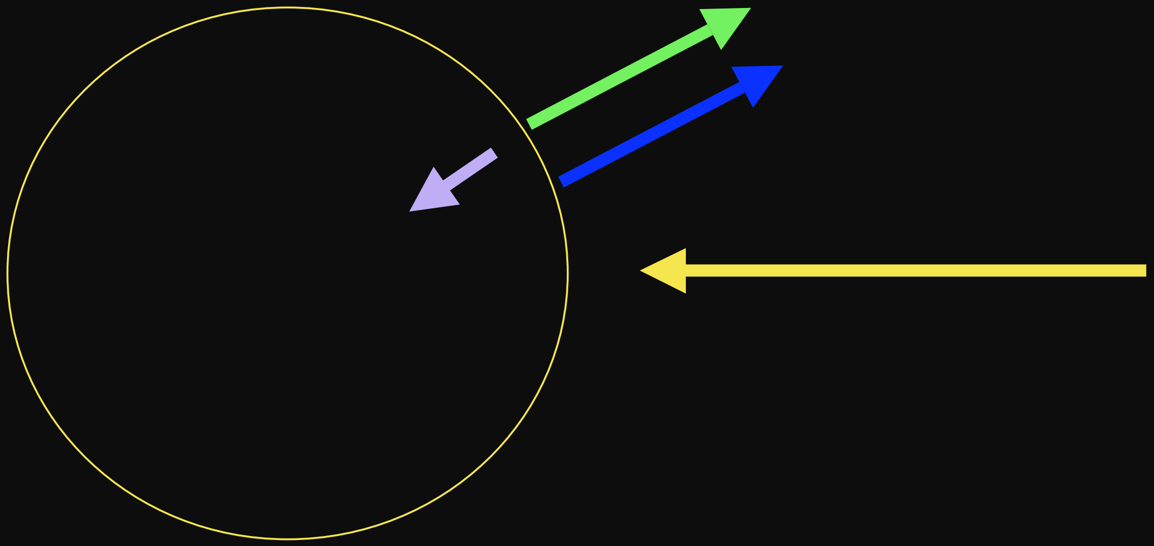


Villa M., Montanari E., *Meteore e meteoriti*, Astromedia 2001

Thermal balance of a meteor



→ Atmospheric molecule impact, +

→ Black body radiation, -

→ Evaporation-ablation, -

→ Diffusion, 0

Trajectory and thermal model
simplest version – small grain, plane parallel atmosphere

- v(t), h(t), T(t) and m(t)

$$\frac{dv}{dt} = -\rho_a \frac{v^2}{m} A \left(\frac{m}{\rho_m}\right)^{\frac{2}{3}} \qquad \frac{dh}{dt} = -v\cos\theta$$

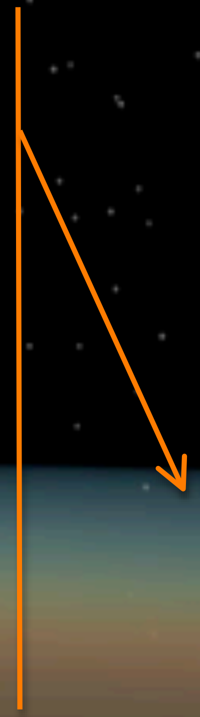
$$v(0) = v_0$$

$$\frac{dm}{dt} = -\rho_a v^3 \frac{A\Lambda_a}{2L} \left(\frac{m}{\rho_m}\right)^{\frac{2}{3}} \qquad m(0) = m_0$$

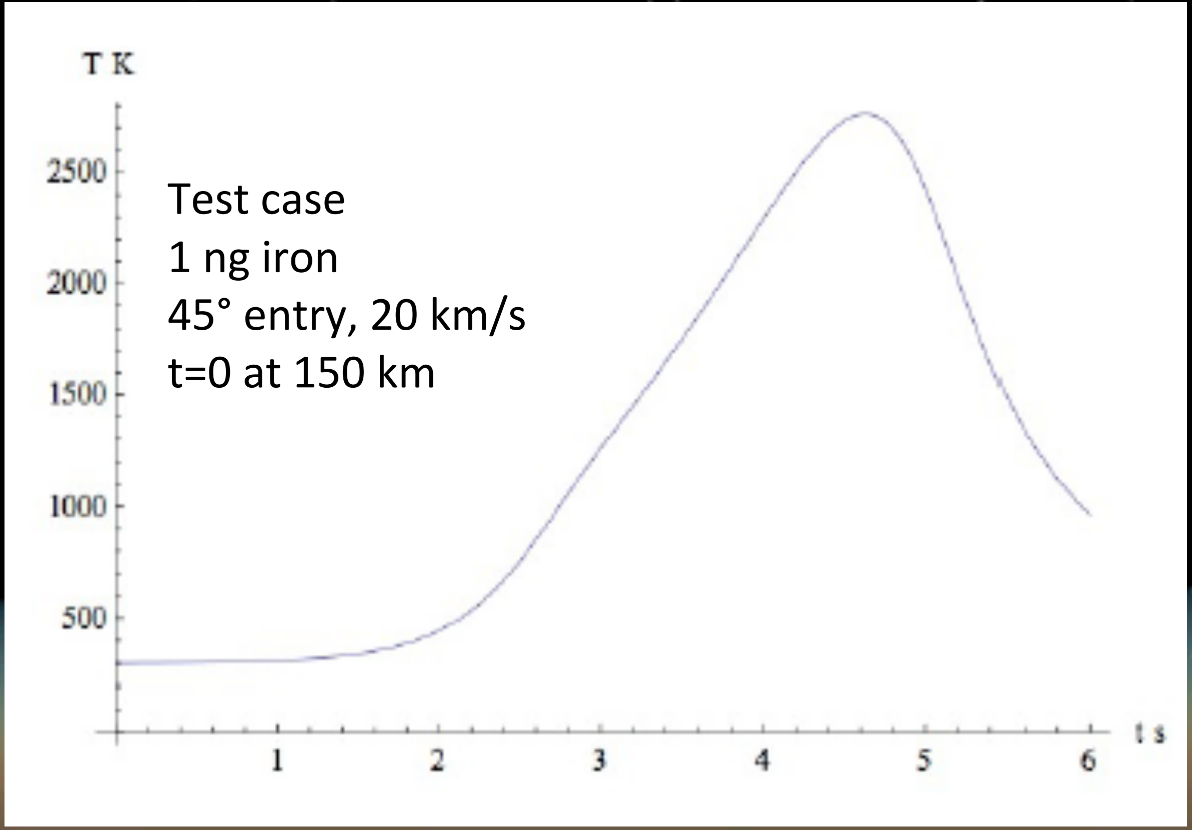
$$h(0) = h_0$$

$$\frac{dT_m}{dt} = \frac{1}{cm}\left[\rho_a \frac{v^3}{2} \Lambda A \left(\frac{m}{\rho_m}\right)^{\frac{2}{3}} - 4\sigma\varepsilon A \left(\frac{m}{\rho_m}\right)^{\frac{2}{3}} (T_m^4 - T_a^4) - L\frac{dm}{dt}\right]$$

$$\rho_a(t) = e^{-0.600577-0.000110\mathrm{h(t)}-2.741221\times10^{-10}\,\mathrm{h(t)}^2}$$



Trajectory and thermal model simplest version – plane parallel atmosphere



Test case
1 ng iron
45° entry, 20 km/s
t=0 at 150 km

Grain temperature vs. time

Test case elaboration: M.Colapinto, M.Sc. Thesis

Too hot for complex organic matter

Unless it rests deep inside …
but then delivery is difficult

Idea: *chemical* thermal protection can be achieved for a *carbonate grain* after exposure (high-altitude mechanical fragmentation of a larger body)

Rationale: much energy is absorbed by MCO_3 decomposition

$MCO_3 \rightarrow MO + CO_2$ at relatively low T

$Mg_xCa_yFe_{1-x-y}CO_3$ in meteorites

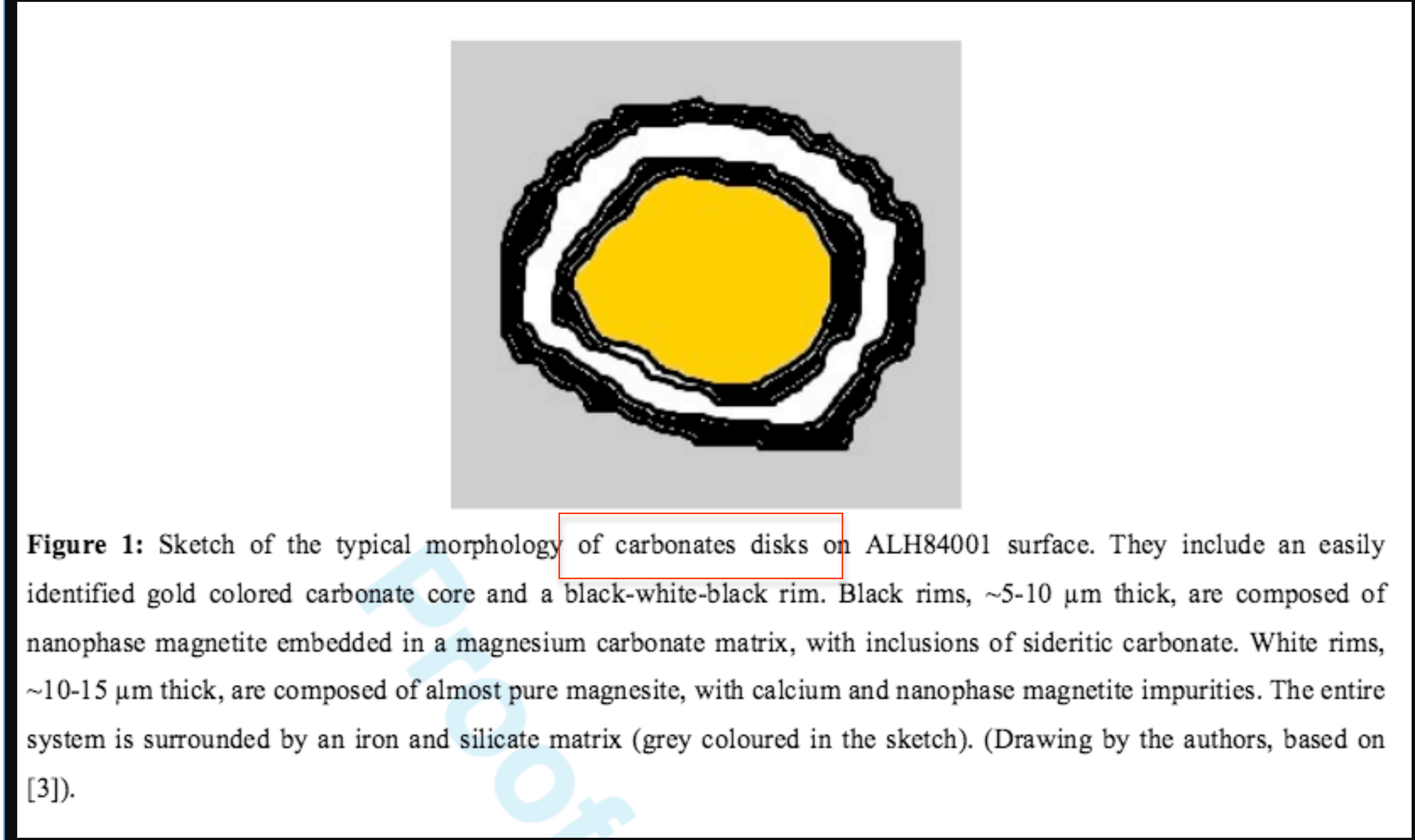
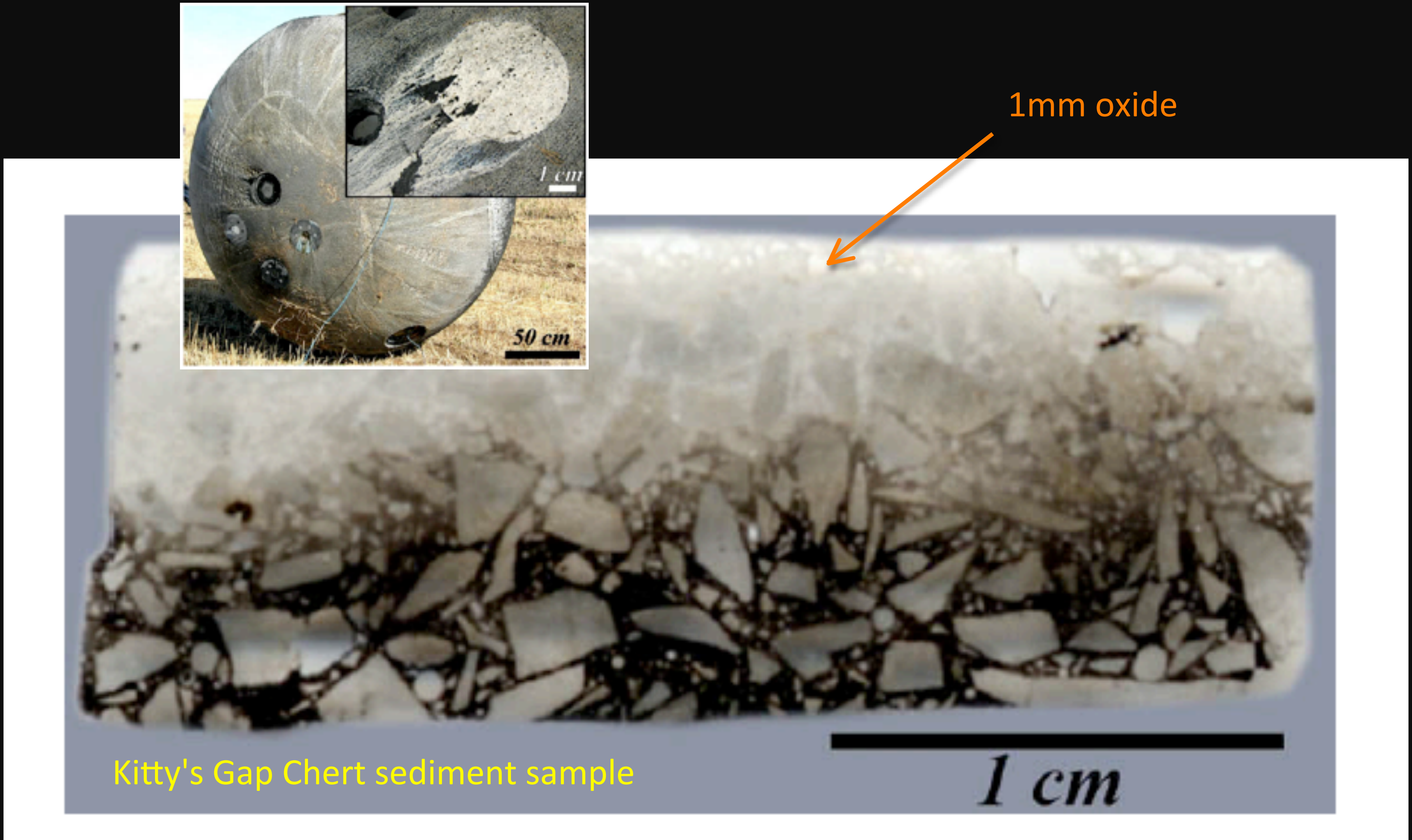


Figure 1: Sketch of the typical morphology of carbonates disks on ALH84001 surface. They include an easily identified gold colored carbonate core and a black-white-black rim. Black rims, ~5-10 µm thick, are composed of nanophase magnetite embedded in a magnesium carbonate matrix, with inclusions of sideritic carbonate. White rims, ~10-15 µm thick, are composed of almost pure magnesite, with calcium and nanophase magnetite impurities. The entire system is surrounded by an iron and silicate matrix (grey coloured in the sketch). (Drawing by the authors, based on [3]).

STONE atmospheric entry tests*



1mm oxide

Kitty's Gap Chert sediment sample

Foucher, F et al. Testing the survival of microfossils in artificial martian sedimentary meteorites during entry into Earth's atmosphere: the STONE 6 experiment, *Icarus*, 207 (2009) 616

Thermal protection (TP)

The 2 kinds of TP in aerospace studies:

1) Radiative (silicates, like the shuttle)
2) Ablative (carbon-phenolic, like Apollo)

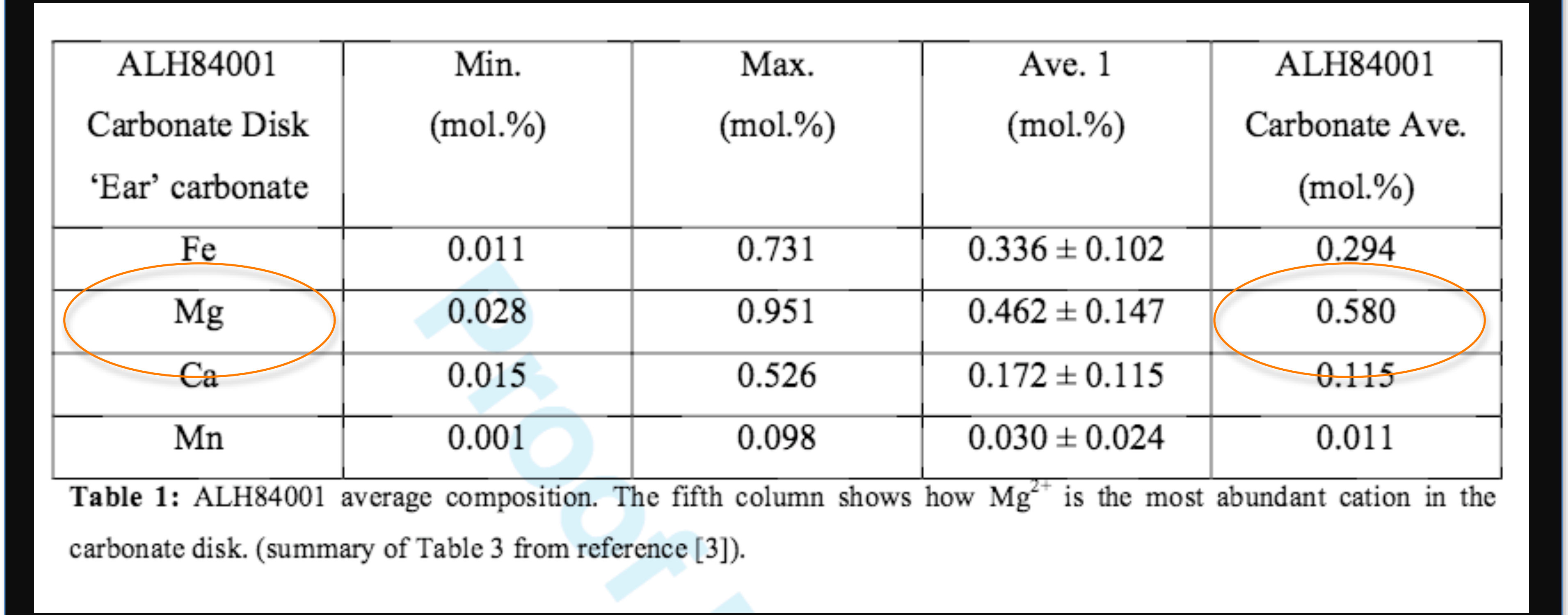
Ablative cooling of silicates is negligible for T < 2000°

The 3 kinds of TPS in astrochemistry according to our proposal:

1) Radiative
2) Ablative
3) Chemical ← (effective in vacuum at T as low as a few 100°s)

How much TP is provided by carbonates? --> theory

$Mg_xCa_yFe_{1-x-y}CO_3$ in meteorites again



ALH84001 Carbonate Disk 'Ear' carbonate	Min. (mol.%)	Max. (mol.%)	Ave. 1 (mol.%)	ALH84001 Carbonate Ave. (mol.%)
Fe	0.011	0.731	0.336 ± 0.102	0.294
Mg	0.028	0.951	0.462 ± 0.147	0.580
Ca	0.015	0.526	0.172 ± 0.115	0.115
Mn	0.001	0.098	0.030 ± 0.024	0.011

Table 1: ALH84001 average composition. The fifth column shows how Mg^{2+} is the most abundant cation in the carbonate disk. (summary of Table 3 from reference [3]).

→ We checked $MgCO_3$ as a test mineral for first calculations

Calculating the molecular outgassing rate using kinetic theory

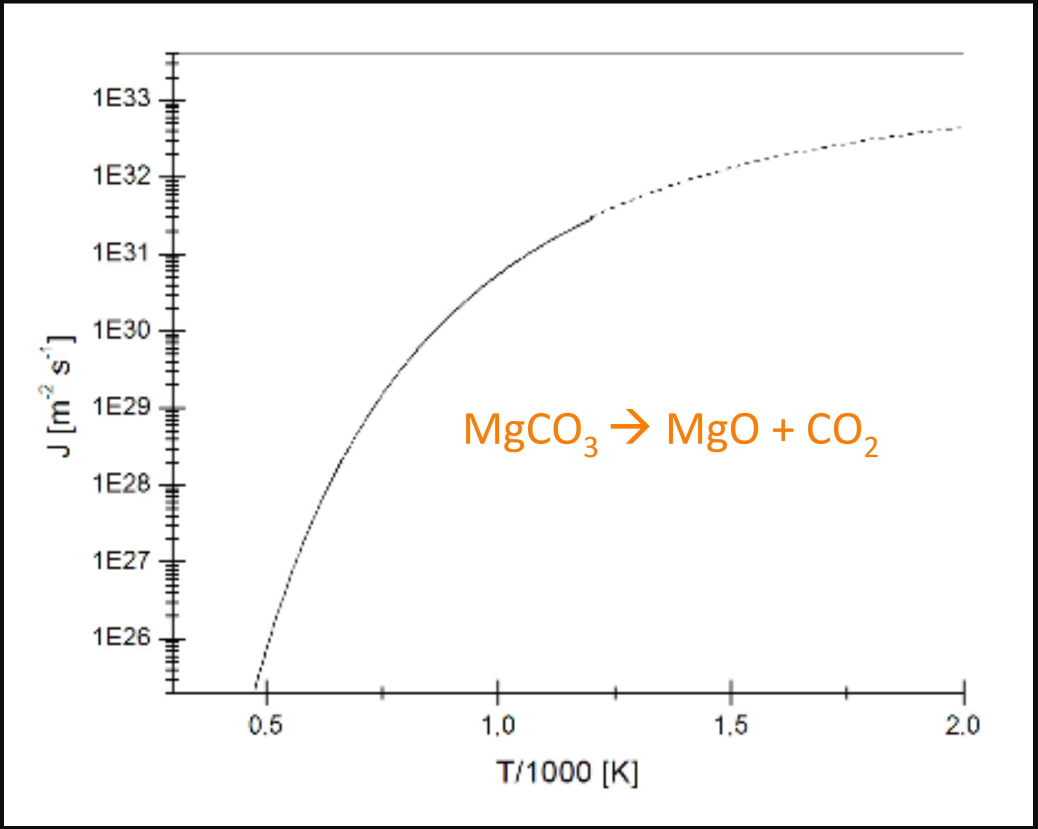
$$J = \frac{\#_{evaporating\ molecules}}{m^2\ s} = \frac{1}{4} v_{Th} \frac{1.01\times 10^5\ p_{CO_2}}{kT}$$

$$v_{Th} = \sqrt{\frac{8RT}{\pi M}}$$

Langmuir law

NIST thermochemical data for $MgCO_3$, MgO and CO_2

$$p_{CO_2} = e^{-\frac{\Delta G}{RT}}$$



$MgCO_3 \rightarrow MgO + CO_2$

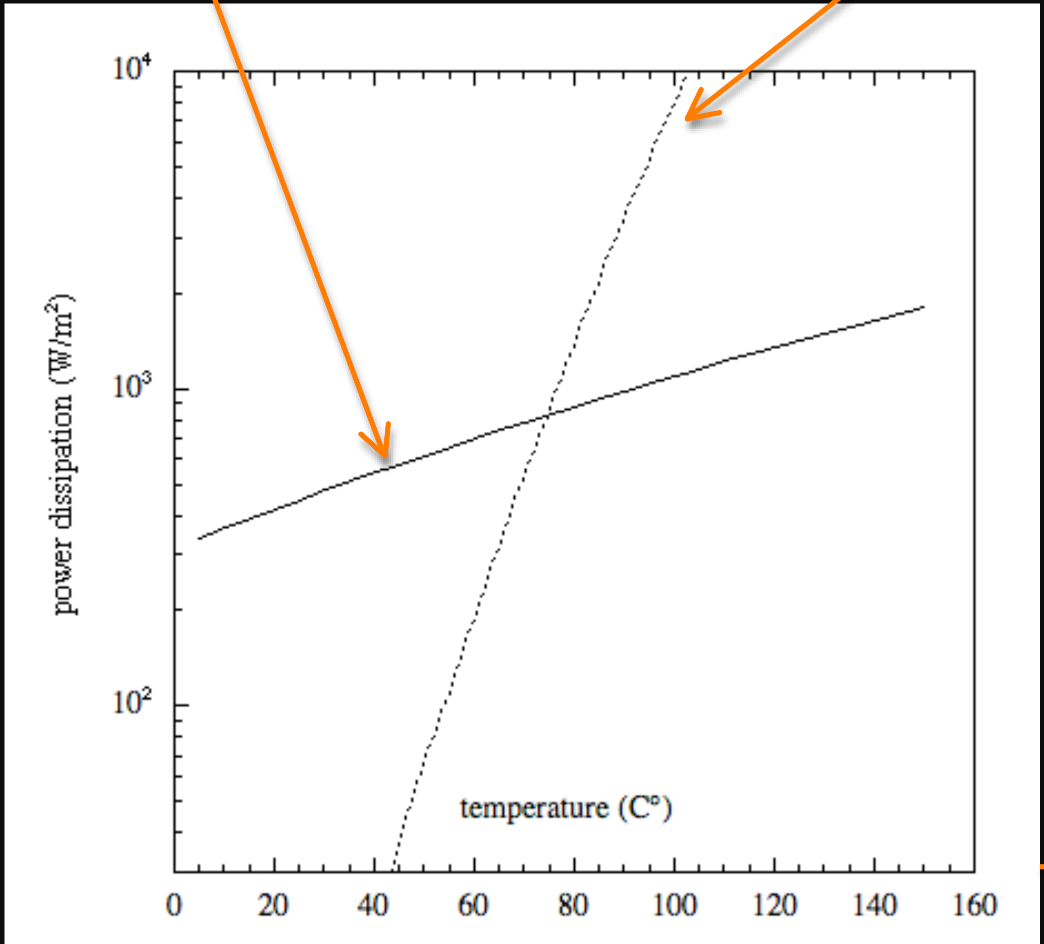
Bisceglia E, Micca Longo G, Longo S, *International Journal of Astrobiology* in press (2016)

Power dissipated per unit surface by thermal radiation

$$P_{rad}(T_{surf}) = \sigma_{SB}\varepsilon T_{surf}^4$$

Power dissipated per unit surface by thermal decomposition

$$P_{dec}(T_{surf}) = J\frac{\Delta H}{N_A} \sim v_{th}e^{-\Delta G/RT}\frac{\Delta H}{4RT}$$



DNA dry thermal decomposition
~ 190°

Karni, Moshe, et al. "Thermal degradation of DNA." DNA and cell biology 32.6 (2013): 298-301.

Conclusion: magnesium-rich carbonatic globules may offer much better thermal protection to complex organic species than typical meteor matter, thanks to facile decomposition reactions.

Evaporation rate model: Bisceglia E, Micca Longo G, Longo S, *International Journal of Astrobiology* *in press* (2016)

Test of the concept in context by an integrated entry model: *in preparation*

Other compositions (including Fe^{2+}) & solid state diffusion: *future work*

Collaborators

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