Can We Reach Stars?

Interaction of Relativistic Spacecrafts with Interstellar Gas and Dust

Thiem Hoang (티엠 황)

Center for Theoretical Astronomy, KASI

KNAG, Oct 21, 2016

Apr 20, 2016: Stephen Hawking and Yuri Milner announced Breakthrough Starshot Initiative

Goal:

To send ~ 1 gram spacecrafts to the nearest star, Alpha Centauri

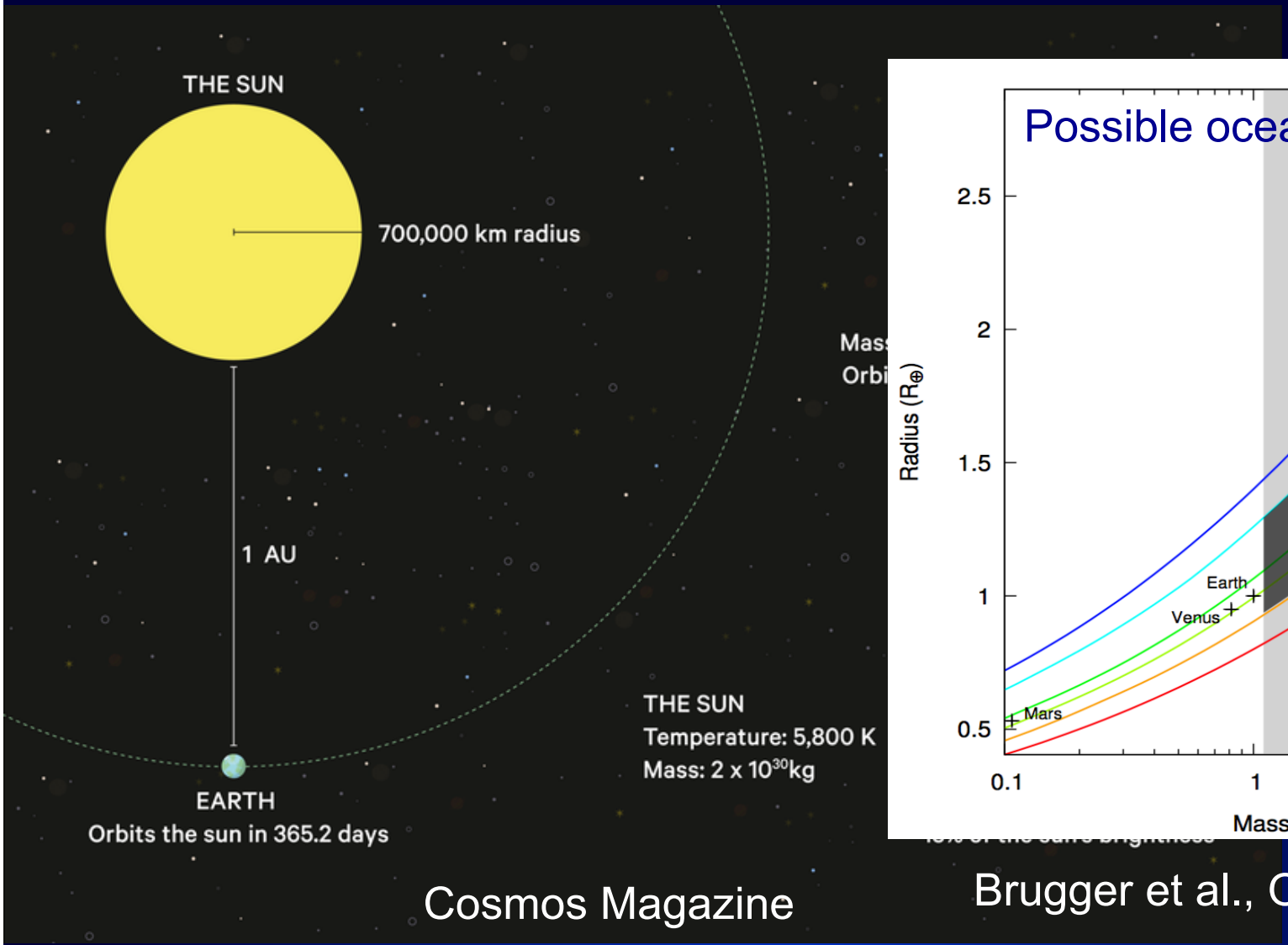
Apr 20, 2016: Breakthrough Starshot Initiative

Science Goals

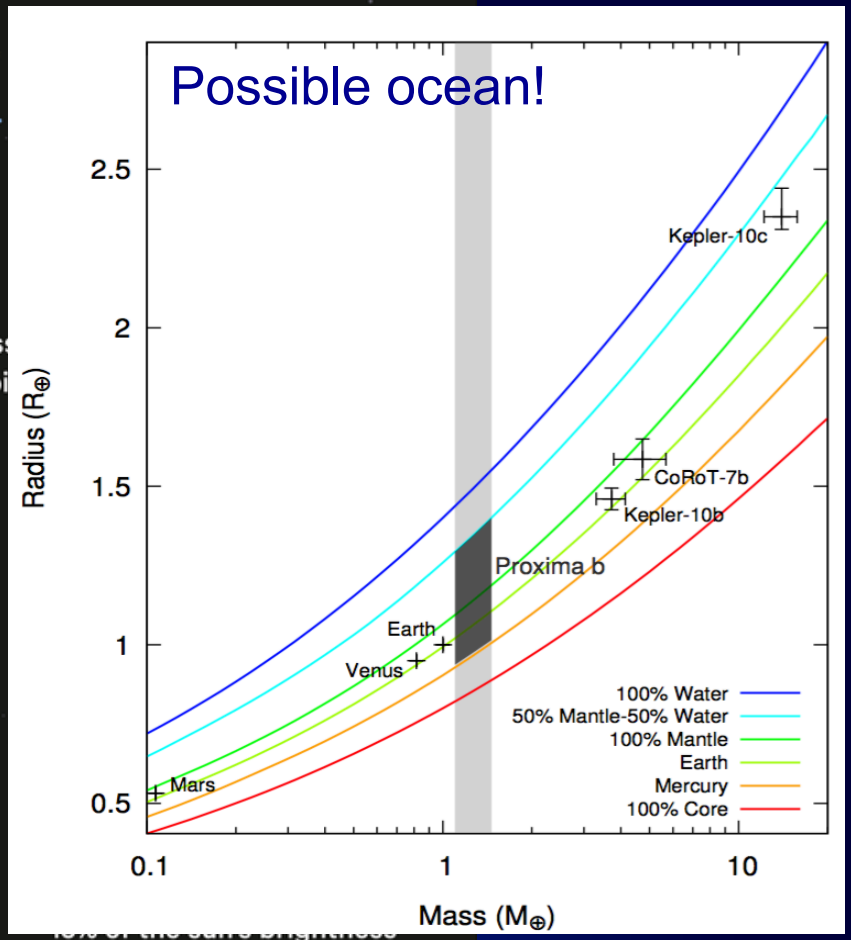
- Proof of concept research on relativistic space travel
- Perform flyby mission to reach Alpha Centauri in 20 years
- Take images of the Earth-like planet Proxima b
- Collecting science data of the local interstellar medium
- Discovery of other planets in Solar system

Aug 24, 2016: Earth-like planet, Proxima b, discovered at 4.2 ly

Anglada-Escudé et al. 2016

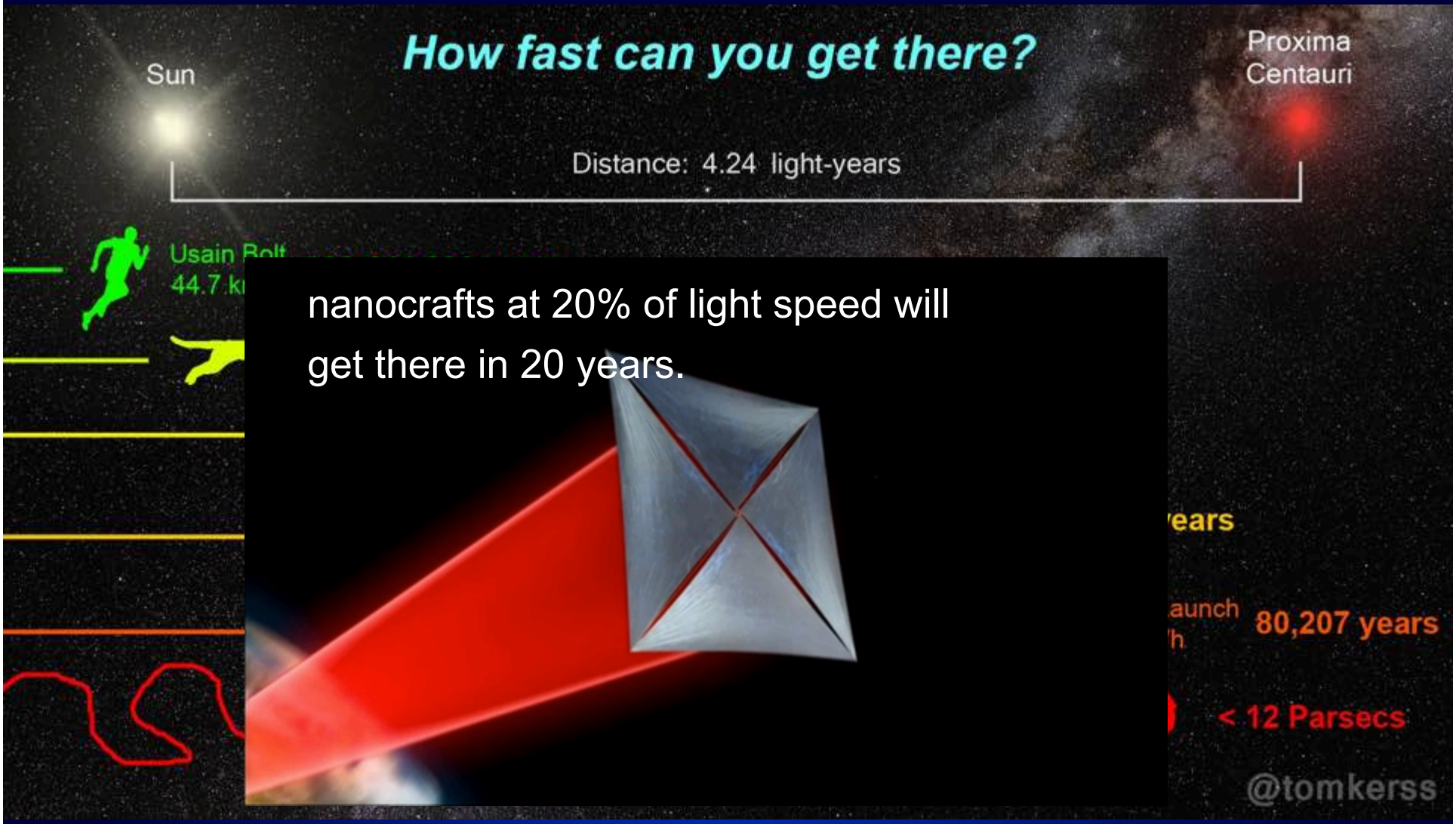


Cosmos Magazine



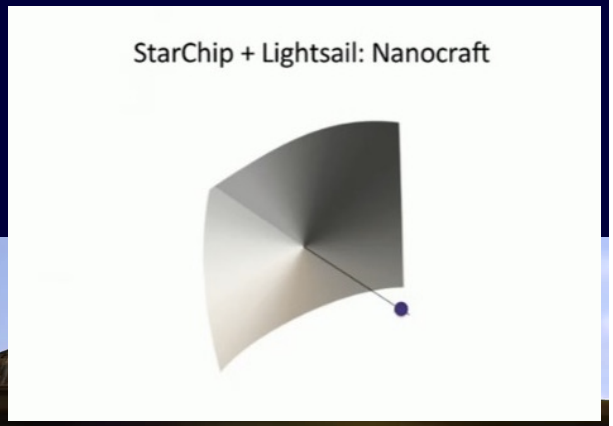
Brugger et al., Oct 2016

How Can We Get to Proxima b?



Proof of Concept

- Nanocrafts ~ 1 gram:
  - Starchip
  - Lightsail
- Light Beamer

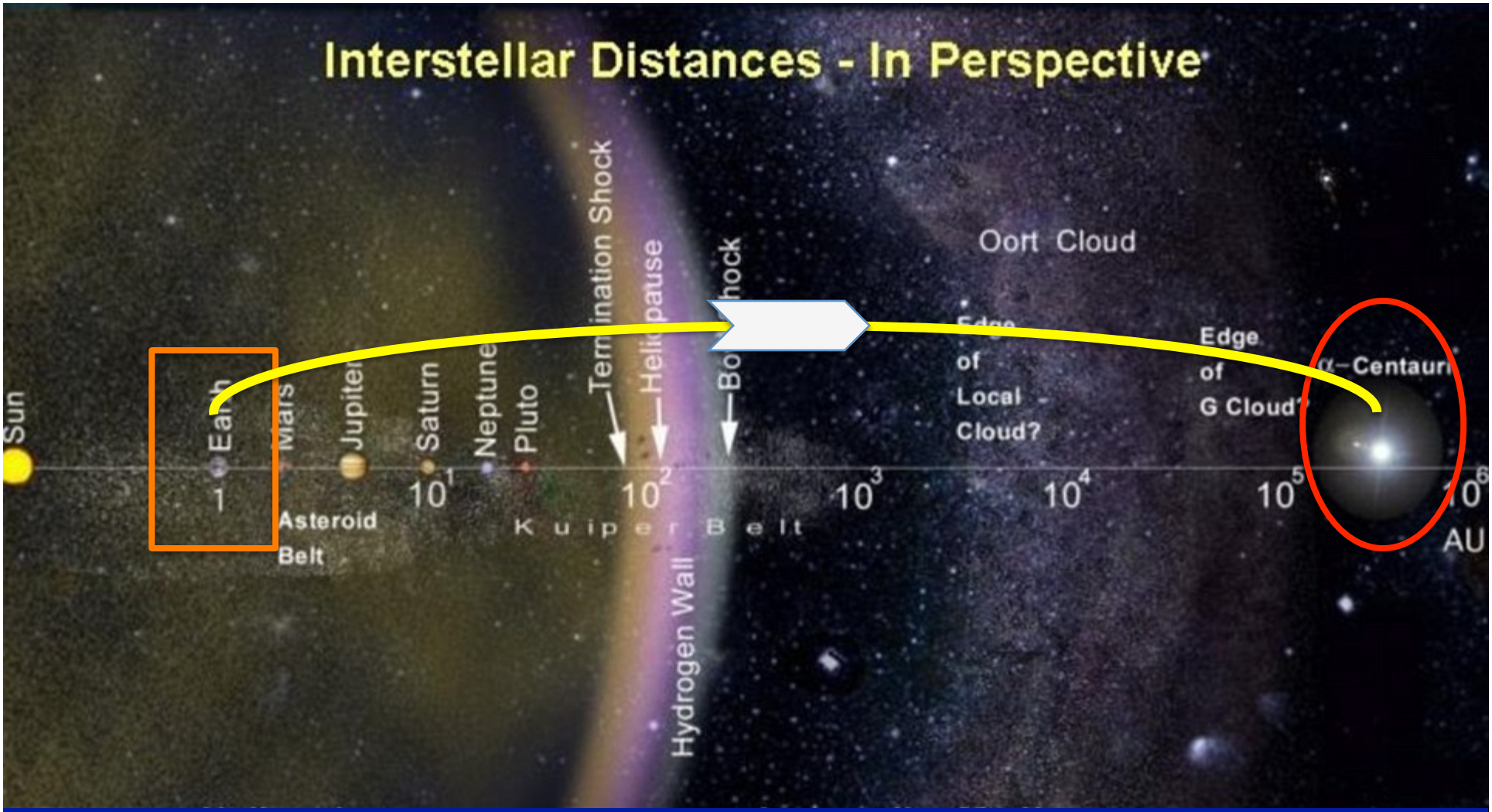


Technical Challenge and Global Effort

- **Electronic components:**
  - **camera, chip, navigation in this coin**

- **Launch: technology (light propulsion), cost, and sites (Moon, orbits, etc)**
- **Lightsail: shape and material**
- **Risk on the way to α Centauri/Proxima b**
- **Communication, Pointing**

See more https://breakthroughinitiatives.org/Challenges/3



Interstellar medium (ISM) contains gas atoms, dust grains, asteroids, etc

- Would ultrafast spacecrafts survive in the ISM?
- How to mitigate damage by gas and dust?

Collaborators:

Alex Lazarian

UW-Madison

Avi Loeb

ITC, Harvard

Blakesley Burkhart

ITC, Harvard

A brand new research submitted to ApJ (1st positive referee report)
https://arxiv.org/abs/1608.05284

- 32 votes from 23 different institutions

Harvard ITC

voxcharta

ITC Astro-ph Disc

(1

ArXiv discussions for 362 institutions including Boston University, I
Institute for Theoretical Physics, Dartmouth College, McGill, and FS
Astrophysics.

Home About Help Tools

Keyword, author, o

Hide Sidebar | Log in | Register

« Proposed low-energy absolute calibration of nuclear recoils in a dual-phase noble element TPC using D-D neutron scattering kinematics *[Cross-Listing]*
The OmegaWhite Survey for short period variable stars II: An overview of results from the first four years »

The interaction of relativistic spacecrafts with the interstellar medium

0 votes @Harvard ITC
(32 votes from 23 institutions)
Please log in or create an account to vote!

Thiem Hoang, A. Lazarian[1†], Blakesley Burkhart, Abraham Loeb[2†]
[1]UW-Madison, [2]Harvard University
[†]Listed affiliation is based on previous publications and was not specified in this preprint.

ArXiv #: 1608.05284 (PDF, PS, ADS, Papers, Other)
Comments: 15 pages, 16 figures, submitted
Originally posted by astro-ph from Unaffiliated on 08/18/2016

HE
GA

32 's: Xing Lu (Nanjing University), Flor Allaert (Ghent University), mdcleir (Ghent University), MonchoReyRaposo (University of Surrey), oliver.piattella (UFES Cosmology), JensErler (AIFA Clusters), starwyh (NTHU), CelesteA (IAFE, UBA - CONICET), Reiko (AIfA-Cosmo), blinov (University of Crete), gbe (University of Kentucky), Mike Cooper (UCI), wparmentrout (WVU), tapauly (Cornell), Monika M. (Radboud University Nijmegen), matteoluisi (WVU), tomo (NTHU), Justin Wu (NTHU), paul_the_baker (WVU), okargaltsev (George Washington University), mssgill (Stanford), andrews (University of Crete), nmpingel (WVU), rpconnol (Michigan State), kanamoro (NAOJ ALMA), zhengz (University of Utah), dccollins (FSU Astrophysics), hebecked (DESY Zeuthen), vlb9398 (RIT), Cameron Van Eck (Radboud University Nijmegen), su9000 (IAFE, UBA - CONICET), kadrlica (Fermilab)

The Breakthrough Starshot initiative aims to launch a gram-scale spacecraft to a speed of $v \sim 0.2c$, capable of

- Media coverage: CBC, Dailymail, newscientist, etc…

Damage by Interstellar Gas Atoms

Table 4
Element Depletion Parameters[a]

Elem. X (1)	Adopted $(X/H)_\odot$[b] (2)	A_X (3)	B_X[c] (4)	z_X (5)	$[X_{gas}/H]_0$[c] (6)	$[X_{gas}/H]_1$[c] (7)	χ^2 (8)	ν (9)	Prob. Worse Fit (10)
C	8.46 ± 0.04	-0.101 ± 0.229	-0.193 ± 0.060	0.803	-0.112 ± 0.194	-0.213 ± 0.075	3.7	8	0.881
N	7.90 ± 0.11	-0.000 ± 0.079	-0.109 ± 0.111	0.550	-0.109 ± 0.119	-0.109 ± 0.117	28.8	32	0.628
O	8.76 ± 0.05	-0.225 ± 0.053	-0.145 ± 0.051	0.598	-0.010 ± 0.060	-0.236 ± 0.055	75.0	64	0.164
Mg	7.62 ± 0.02	-0.997 ± 0.039	-0.800 ± 0.022	0.531	-0.270 ± 0.030	-1.267 ± 0.029	79.0	103	0.962
Si	7.61 ± 0.02	-1.136 ± 0.062	-0.570 ± 0.029	0.305	-0.223 ± 0.035	-1.359 ± 0.052	19.4	16	0.247
P	5.54 ± 0.04	-0.945 ± 0.051	-0.166 ± 0.042	0.488	0.296 ± 0.049	-0.649 ± 0.050	69.5	65	0.330
Cl	5.33 ± 0.06	-1.242 ± 0.129	-0.314 ± 0.065	0.609	0.442 ± 0.102	-0.800 ± 0.082	38.9	44	0.688
Ti	5.00 ± 0.03	-2.048 ± 0.062	-1.957 ± 0.033	0.430	-1.077 ± 0.043	-3.125 ± 0.049	50.7	43	0.195
Cr	5.72 ± 0.05	-1.447 ± 0.064	-1.508 ± 0.055	0.470	-0.827 ± 0.062	-2.274 ± 0.064	24.1	20	0.239
Mn	5.58 ± 0.03	-0.857 ± 0.041	-1.354 ± 0.032	0.520	-0.909 ± 0.038	-1.765 ± 0.038	106.3	83	0.043
Fe	7.54 ± 0.03	-1.285 ± 0.044	-1.513 ± 0.033	0.437	-0.951 ± 0.038	-2.236 ± 0.041	48.5	66	0.948
Ni	6.29 ± 0.03	-1.490 ± 0.062	-1.829 ± 0.035	0.599	-0.937 ± 0.051	-2.427 ± 0.043	30.7	34	0.630
Cu	4.34 ± 0.06	-0.710 ± 0.088	-1.102 ± 0.063	0.711	-0.597 ± 0.089	-1.307 ± 0.068	15.3	32	0.995
Zn	4.70 ± 0.04	-0.610 ± 0.066	-0.279 ± 0.045	0.555	0.059 ± 0.058	-0.551 ± 0.054	25.6	19	0.142
Ge	3.70 ± 0.05	-0.615 ± 0.083	-0.725 ± 0.054	0.690	-0.301 ± 0.078	-0.916 ± 0.059	12.4	24	0.975
Kr	3.36 ± 0.08	-0.166 ± 0.103	-0.332 ± 0.083	0.684	-0.218 ± 0.109	-0.384 ± 0.089	18.9	26	0.839

In the craft's frame, atoms become highly energetic, as cosmic rays, energy of 0.1 GeV/amu at v=0.2c

Swift heavy ions produce tracks in solid

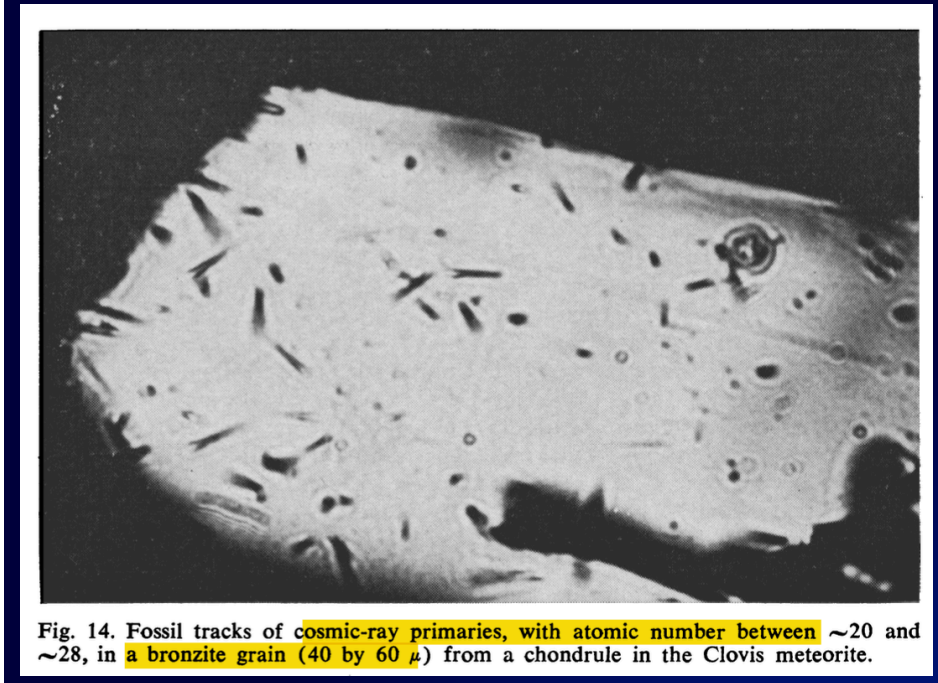


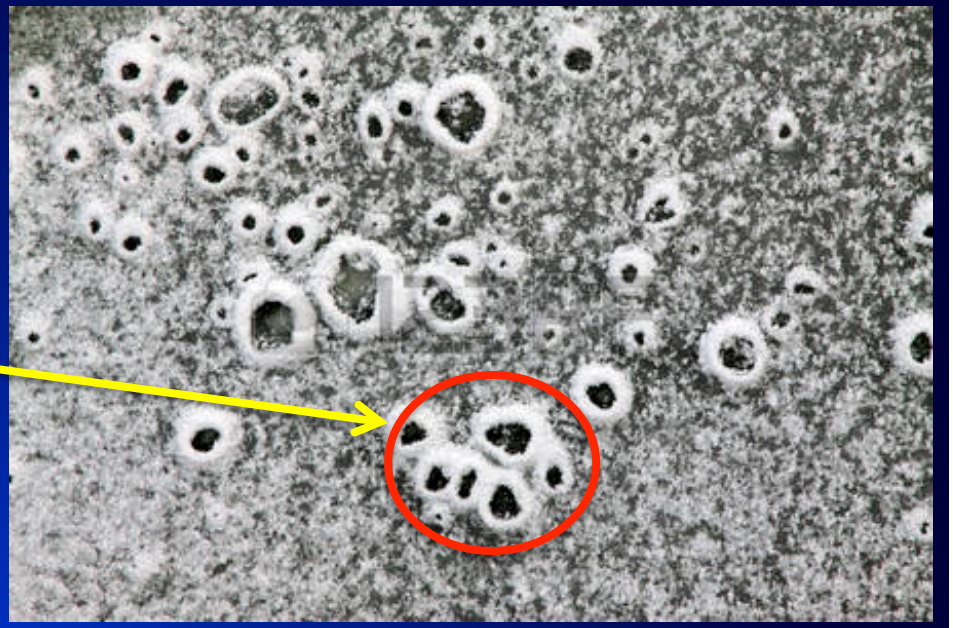
Fig. 14. Fossil tracks of cosmic-ray primaries, with atomic number between ~20 and ~28, in a bronzite grain (40 by 60 μ) from a chondrule in the Clovis meteorite.

See Fleischer et al. 1965

History:

Fossil tracks formed by cosmic rays were found in meteorite

- Heavy ions can produce damage tracks in the craft surface

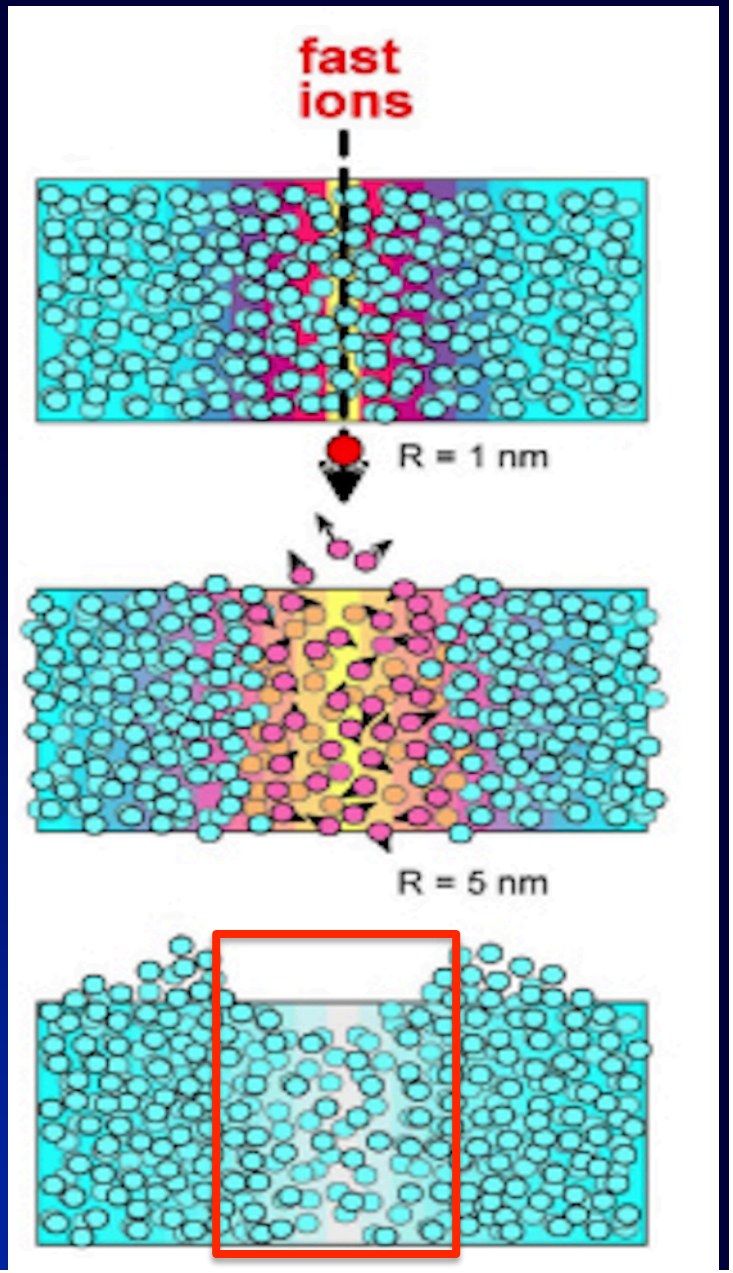


How is Damage Track Formed?

Thermal Spike Model

- Secondary electrons form a hot cylinder due to (lateral) heat transfer
- Material in hot cylinder melted & quenched

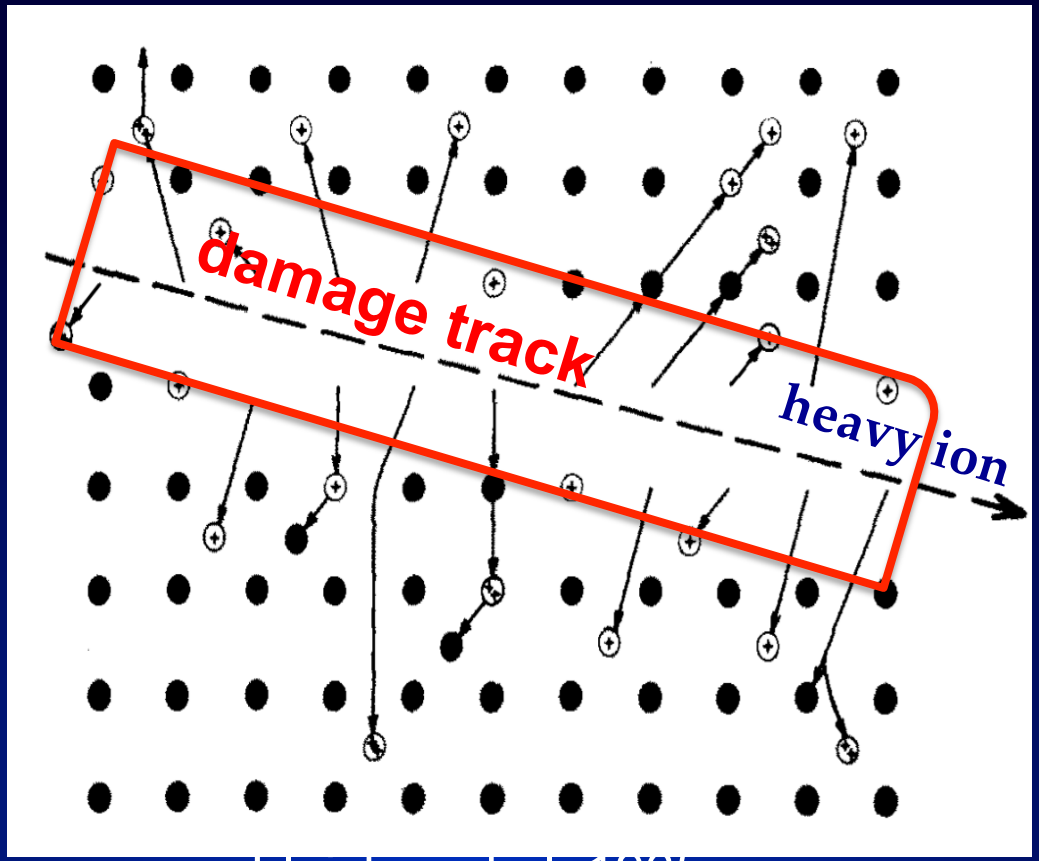
Animation: Reimar Spohr



How is Damage Track Formed?

Coulomb Displacement Model

- Swift heavy ion can create many secondary ions
- Coulomb force acts between nearby ions, resulting in dilute/ empty cylinder



Fleisher et al. 1965

Ion Track Radius and Length

- A needle-like craft model
- Use experimental data

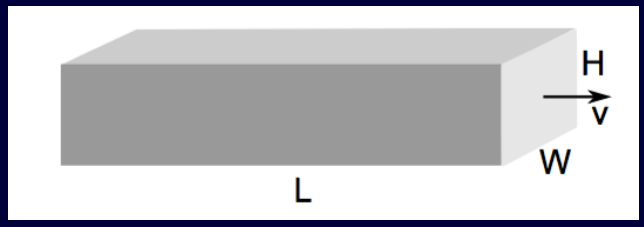
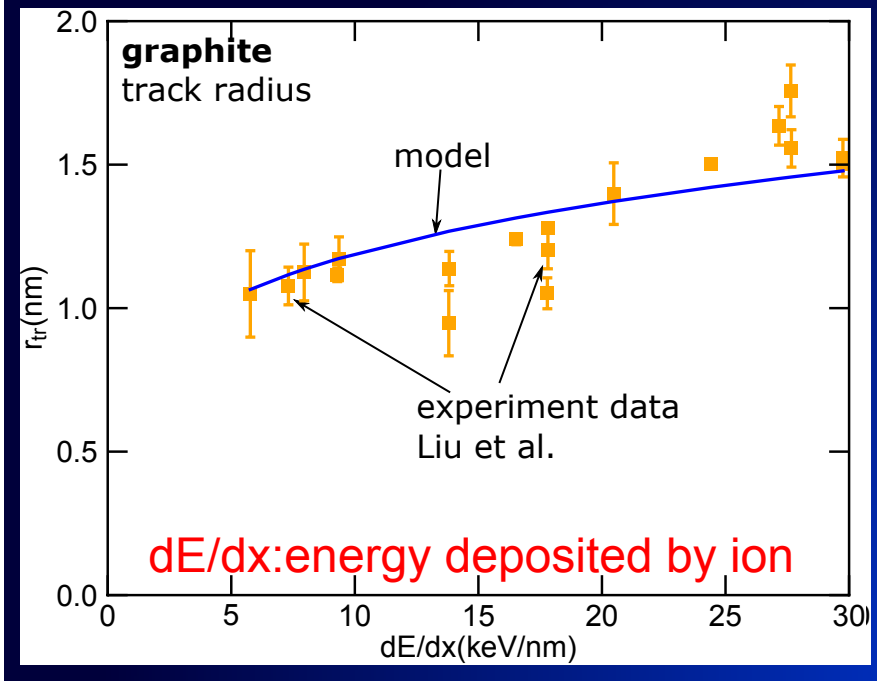
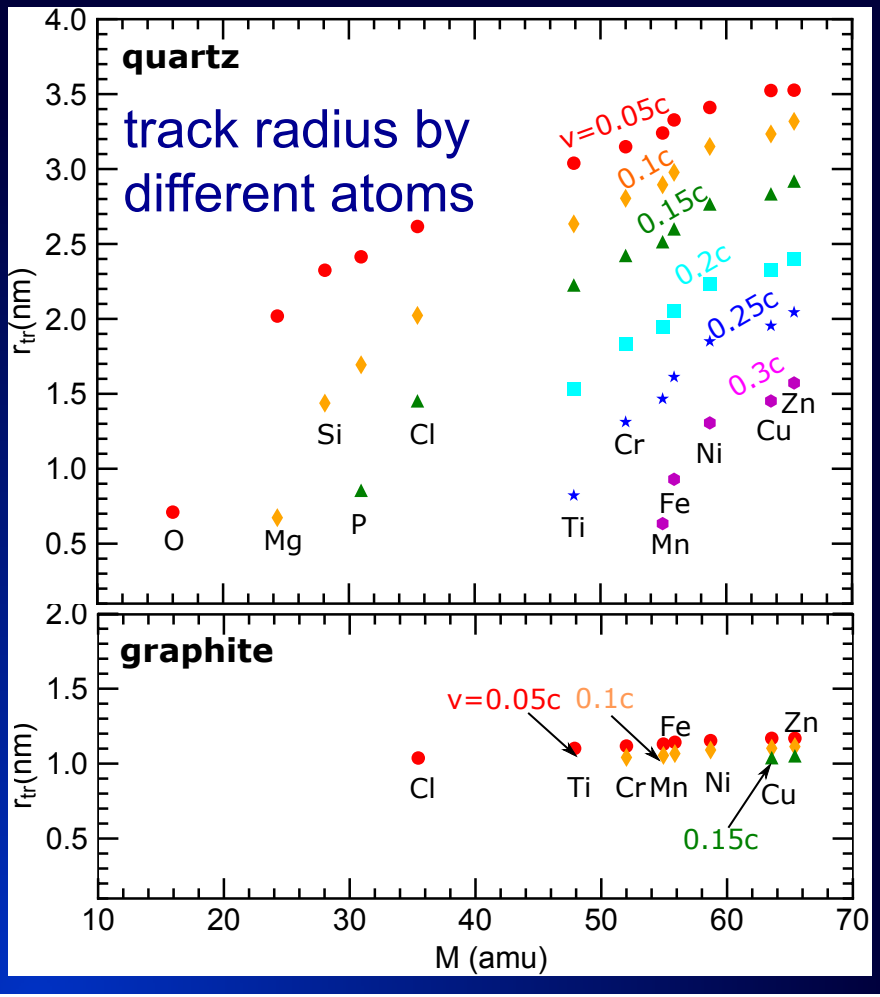


TABLE 1
PHYSICAL PROPERTIES OF SPACECRAFT MATERIALS CONSIDERED IN THIS PAPER.

Material	S_{th}(keV/nm)	ρ(g cm^{-3})	n(cm^{-3})	U_0(eV)	T_m(K)
SiO_2	1.5	2.32	6.98E+22	6.4	1800
Graphite	5.1	2.25	1.12E+23	4.0	4000

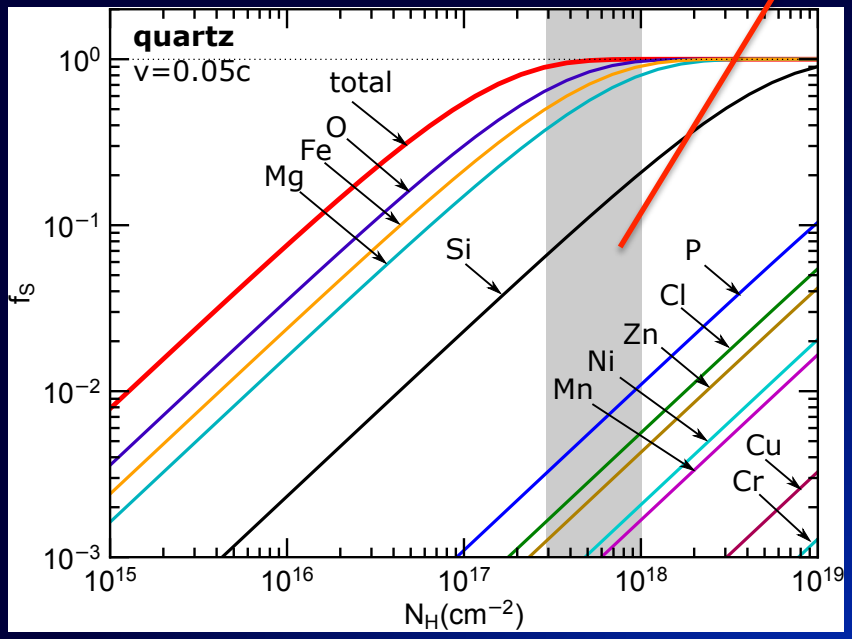


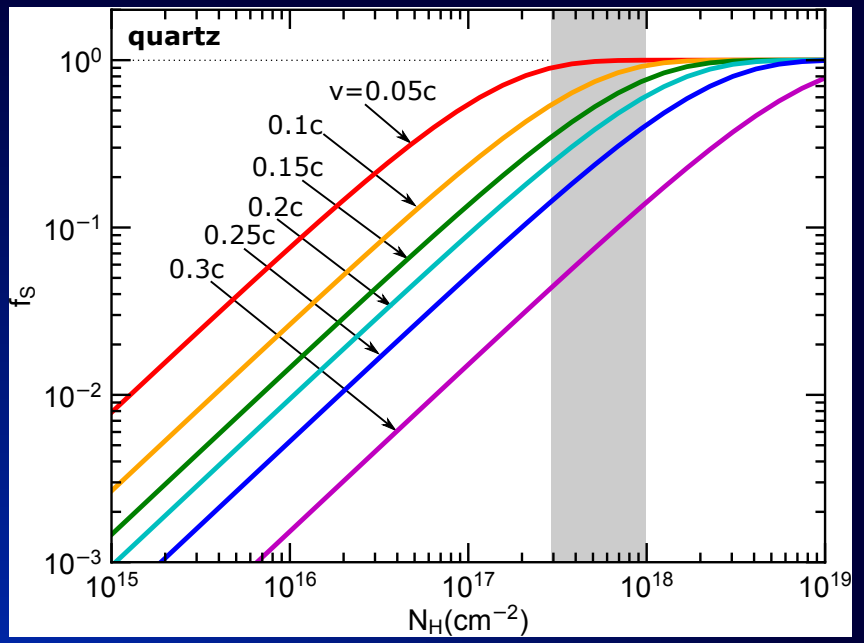


Surface Damage Fraction

$$f_S = \frac{\int_0^S dS}{A} = 1 - \exp\left(-\sum_i \pi r_{tr,i}^2 x_i N_{\rm H}\right)$$

gas column measured toward α Centauri



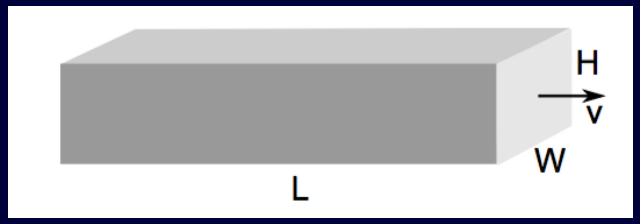


- Entire surface can be eroded before reaching α Centauri

Hoang, Lazarian, Loeb & Burkhart (2016)

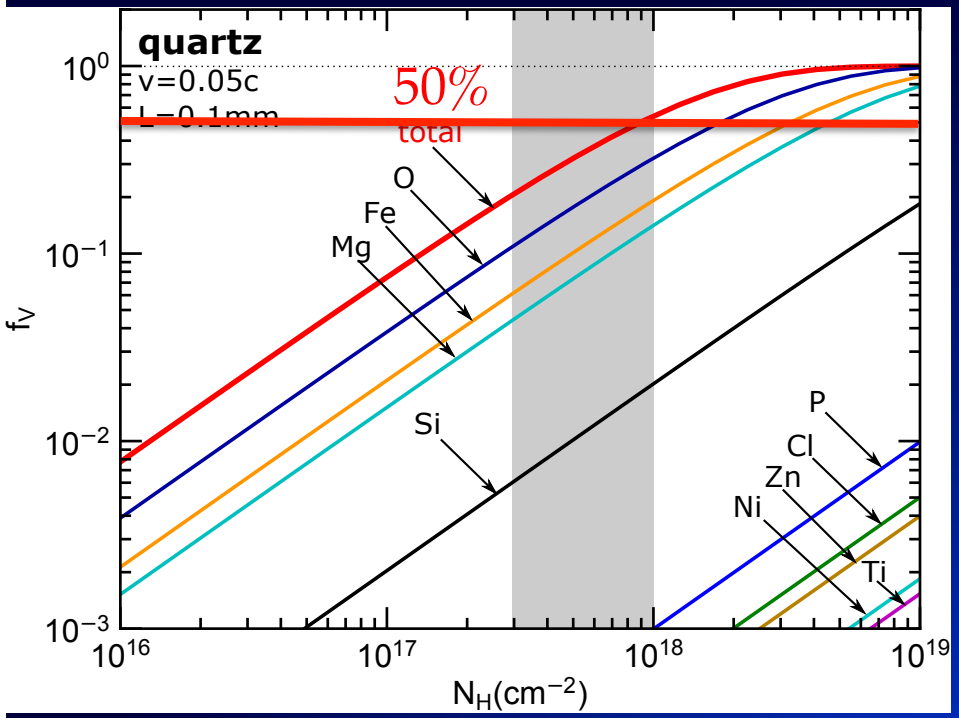
Volume Damage Fraction

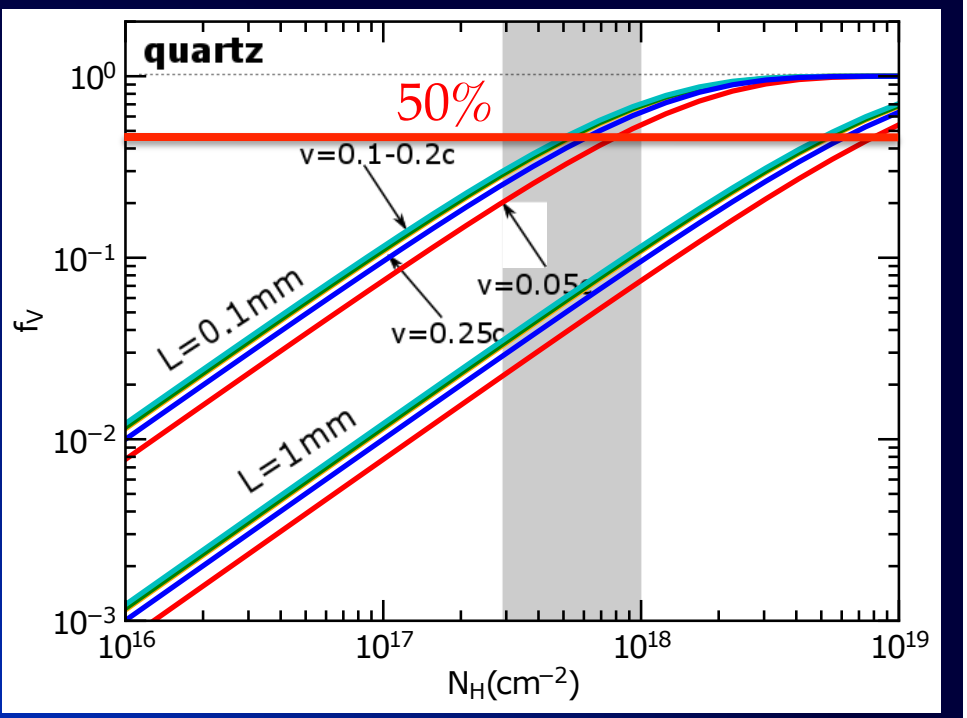
$$f_V = \frac{\int_0^V dV}{LA} = 1 - \exp\left(-\frac{\sum_i \pi r_{tr,i}^2 R_i x_i N_{\rm H}}{L}\right)$$



Volume damage is determined both by r_{tr} and penetration length (R)

Total damage by all atoms



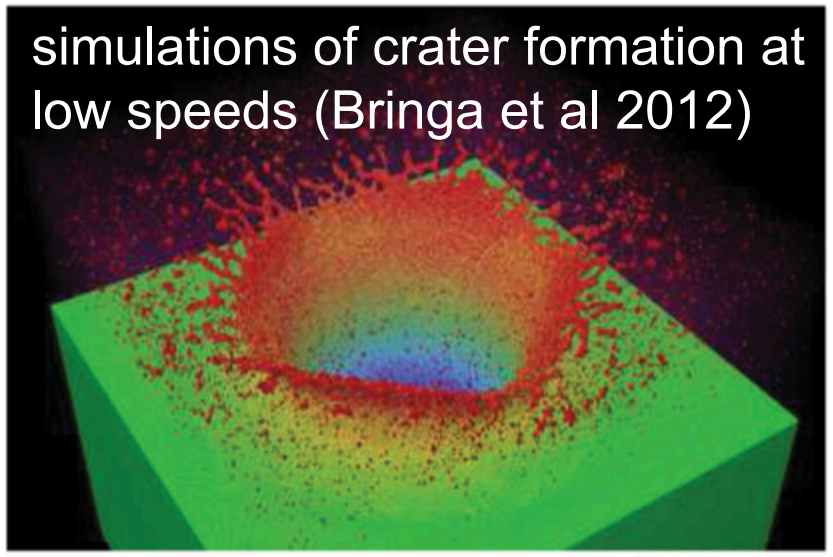


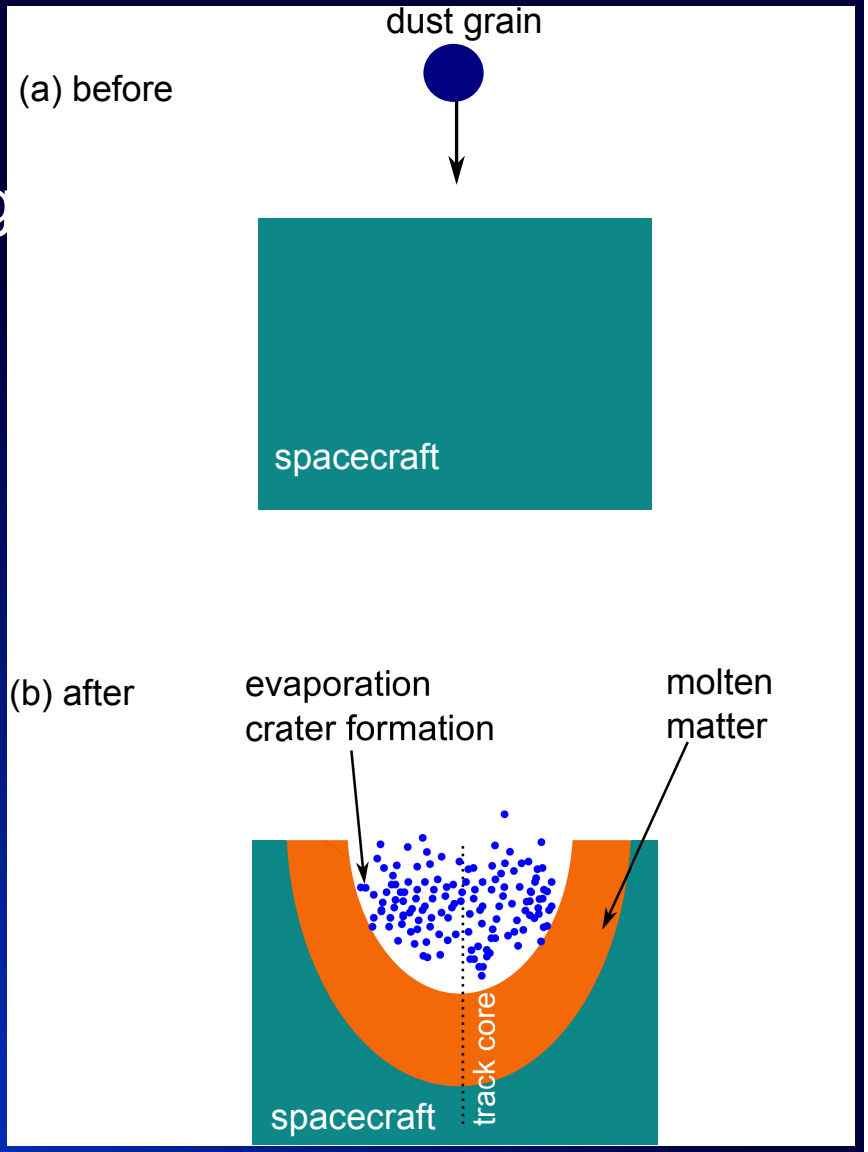
Hoang, Lazarian, Loeb & Burkhart (2016)

Damage by Dust Collision

- a 0.1μm grain has ~10^9 heavy ions
- a heavy ion carry ~ 1 GeV at 0.2c

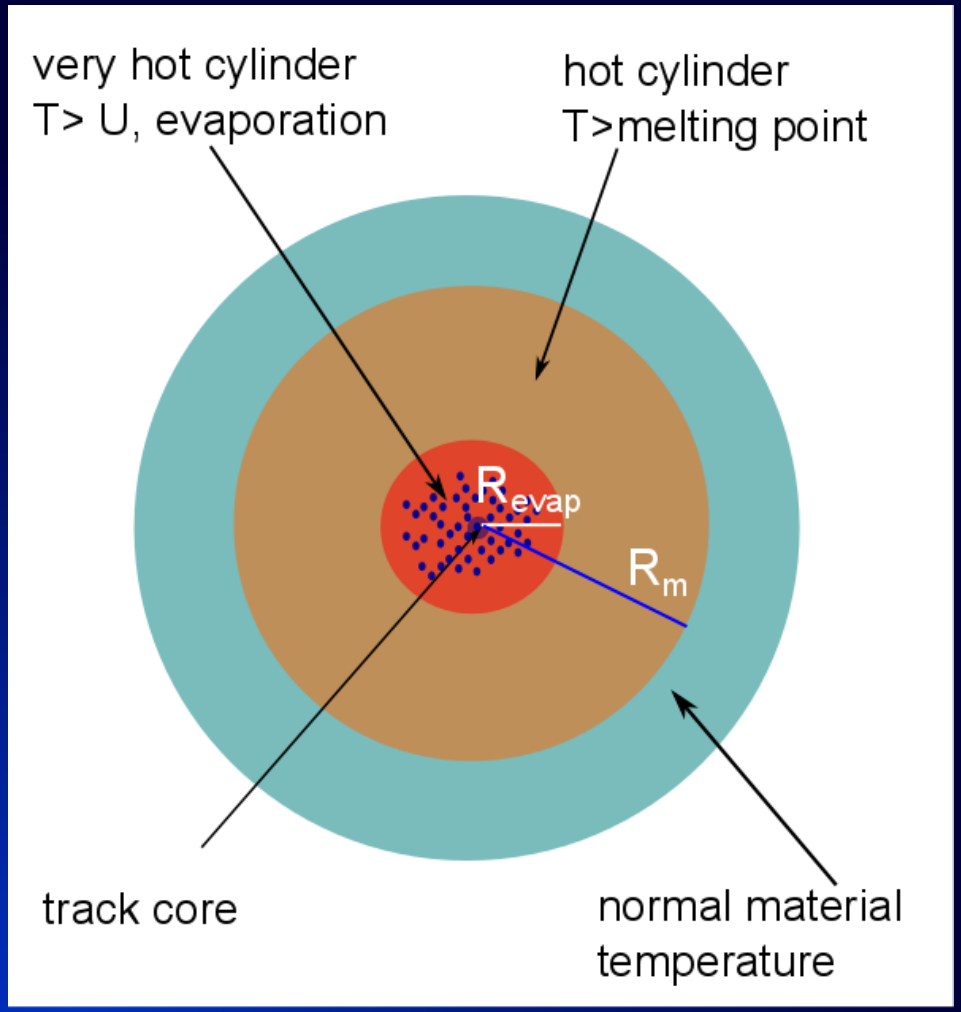
- Melting: atom energy above melting
- Evaporation: atom energy above the binding energy in solid





Thermal Spike Model for Dust Impact

- No experiment data for v=0.2c dust bombardment
- We use thermal spike model as heavy ion impacts

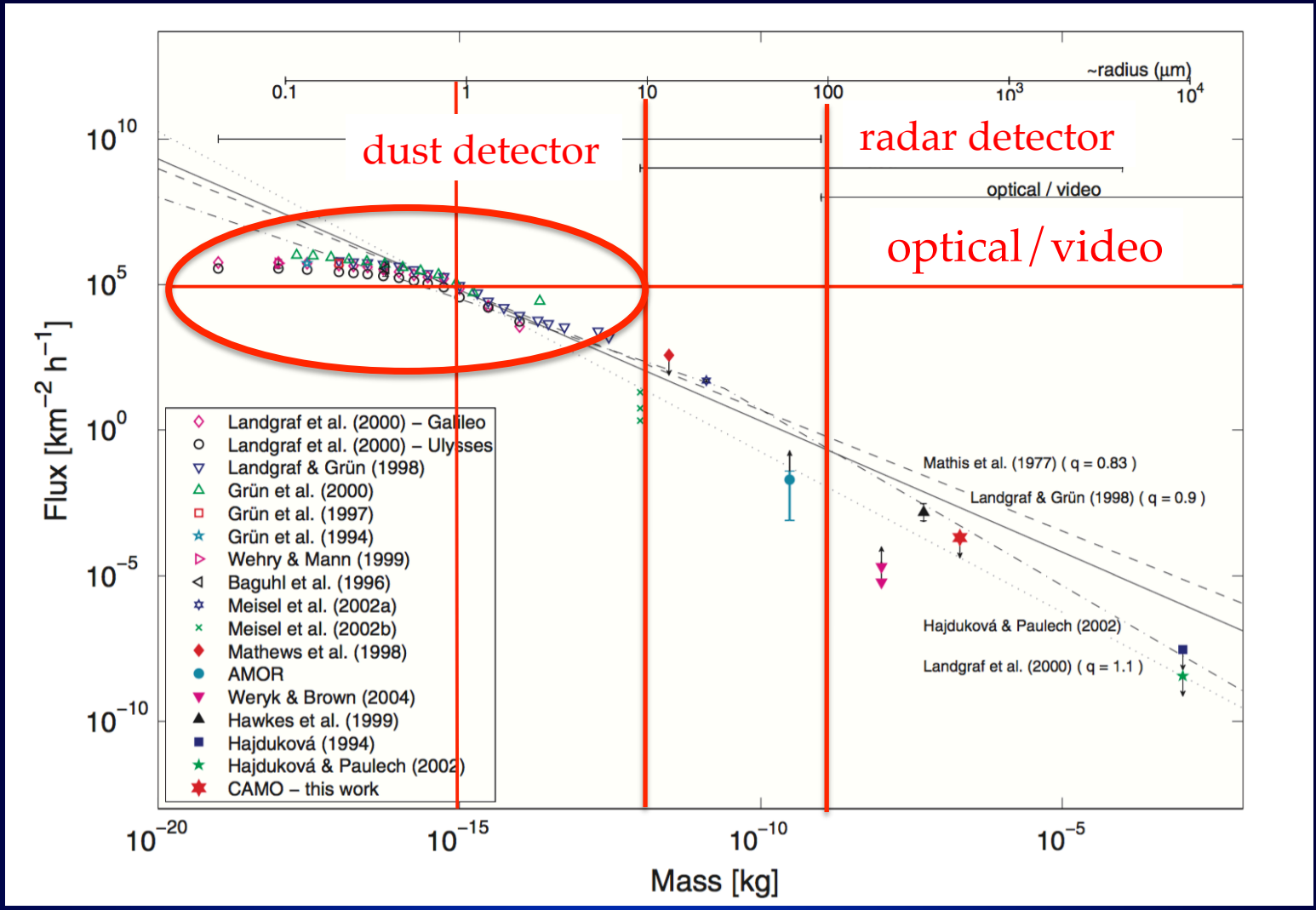


- Cross-section of molten cylinder:

$$\pi R^2_{\mathrm{cyl,m}} = \frac{\epsilon dE_d/dx}{3n_s kT_m} = \frac{4\pi a^3 \epsilon dE_1/dx}{9kT_m}$$

- dE_d/dx = energy deposited by a dust grain per cm

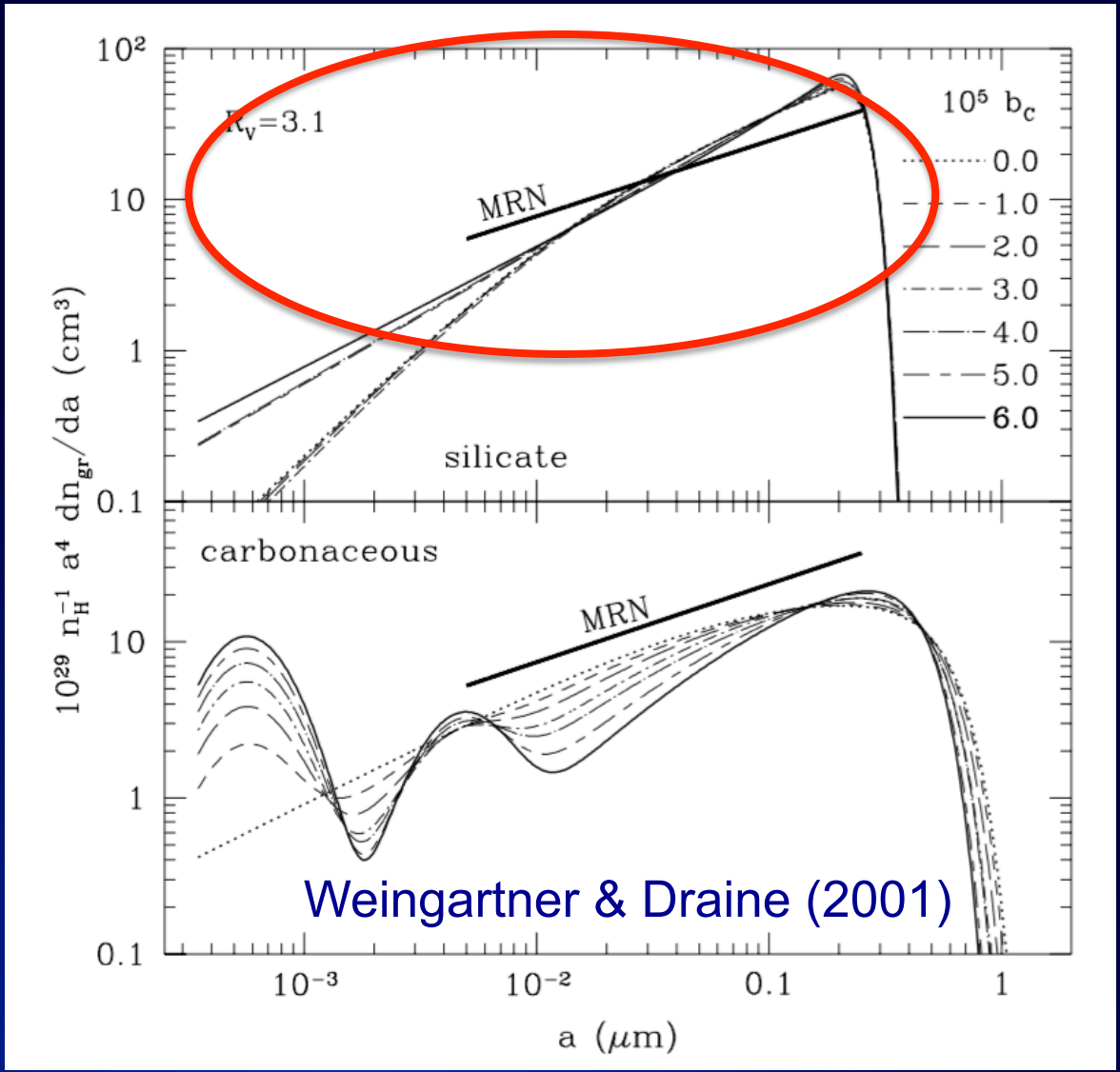
What we know about interplanetary dust?



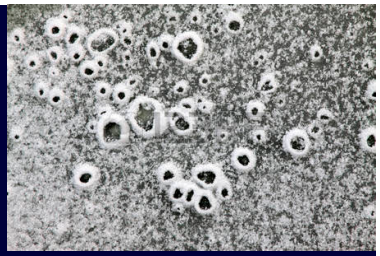
Baggeley et al. (2000)

What we know about interstellar dust?

- Most of dust have radius < 1μm
- Little dust above 10μm

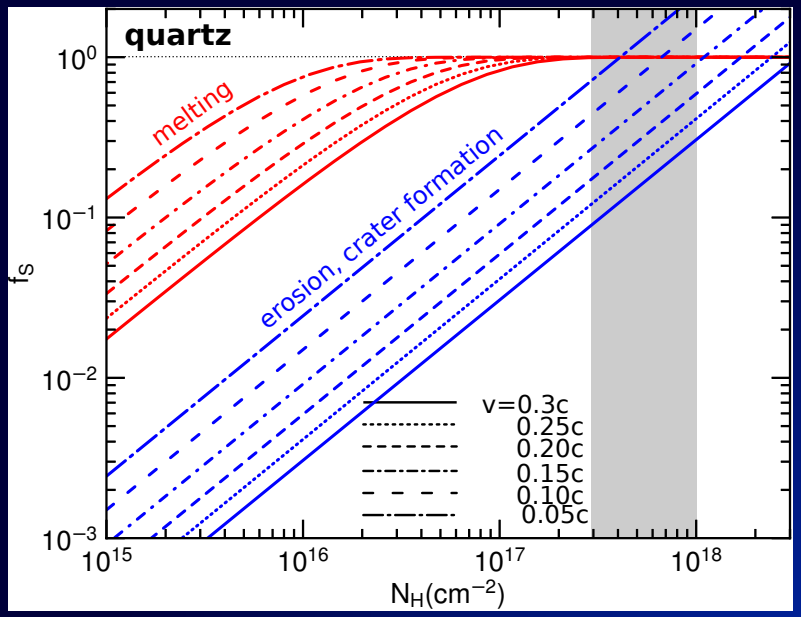


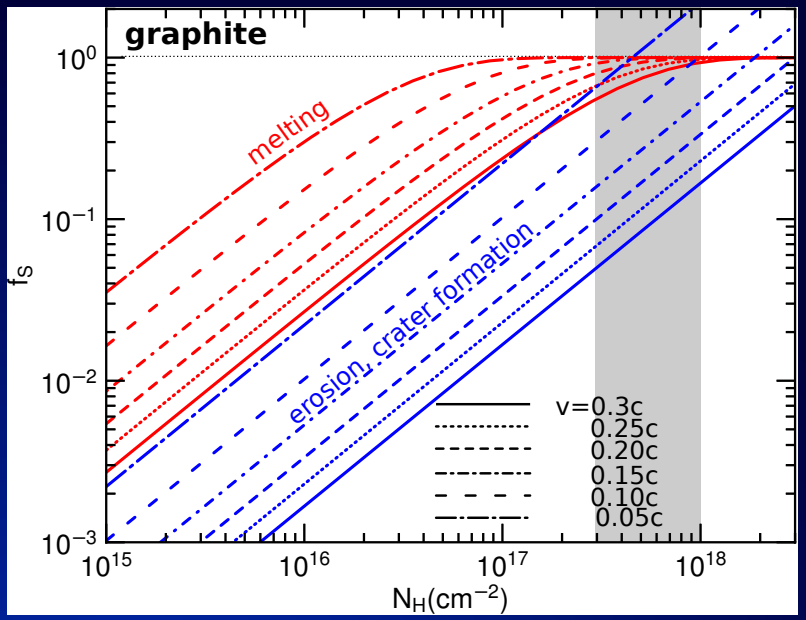
Surface Damage by ISM Dust



- Fraction of molten surface
- dn/da: dust size distribution

$$f_{S,m} = 1 - \exp\left(-N_{\rm H}\sum_j \int_{a_{\rm min}}^{a_{\rm max}} \frac{4\pi a^3}{9}\frac{\epsilon dE_1/dx}{kT_m}\frac{dn_j}{da}da\right)$$





- Entire surface can be eroded and melted before reaching Alpha Centauri
- Higher speeds cause less damage due to low energy loss

Hoang, Lazarian, Loeb & Burkhart (2016)

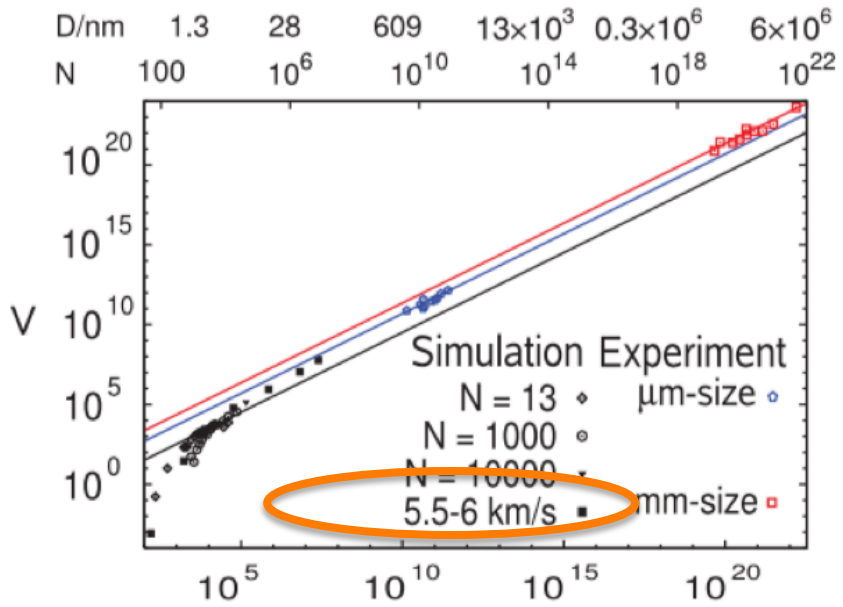
Volume Damage by ISM Dust

Crater volume by a dust grain:

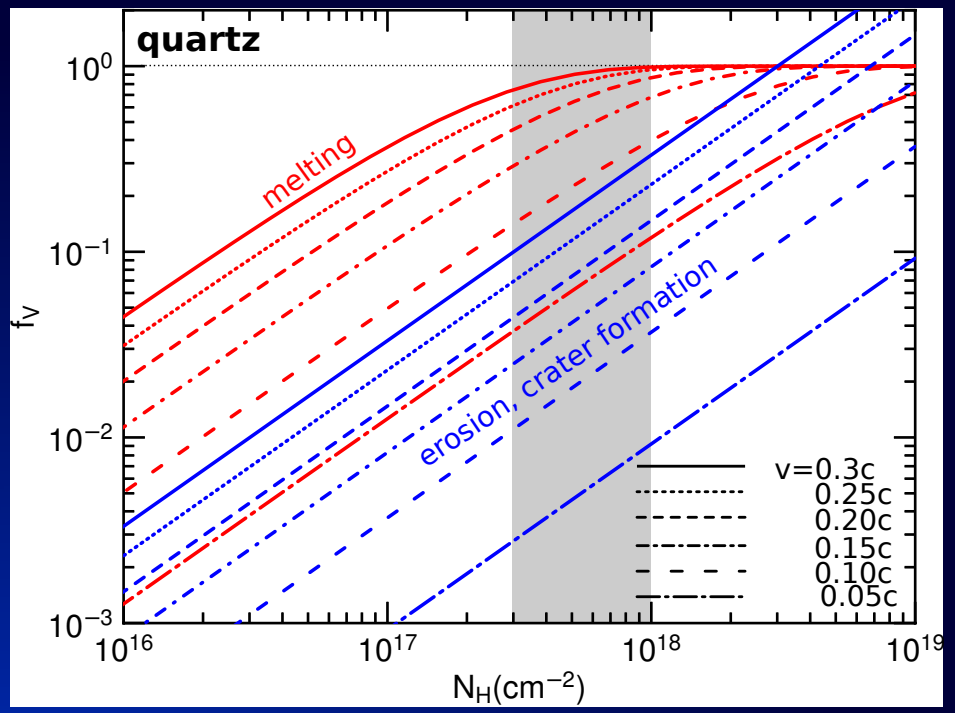
$$n_s \delta V(a) U_0 = \epsilon_V E_d = \frac{4\pi a^3 n_d}{3} \frac{\epsilon_V m v^2}{2},$$

Total fraction of volume

$$f_{V,m} = 1 - \exp\left(-N_{\rm H} \sum_j \int_{a_{\rm min}}^{a_{\rm max}} \frac{4\pi}{3L} \frac{\epsilon_V m v^2}{6kT_m} \frac{a^3 dn_j}{da} da \right)$$



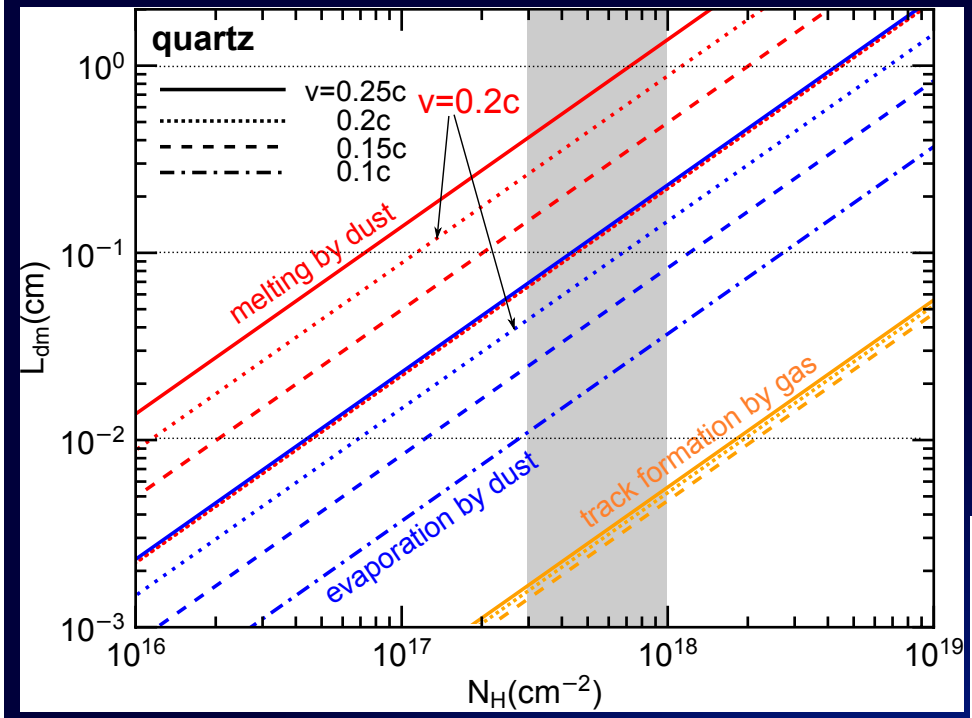
Bringa et al. (2012)

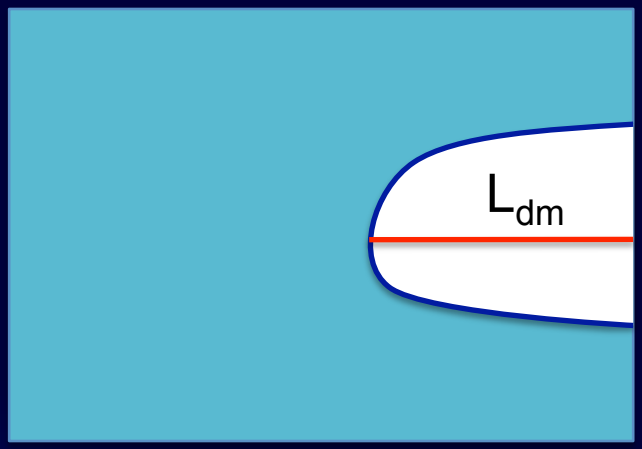


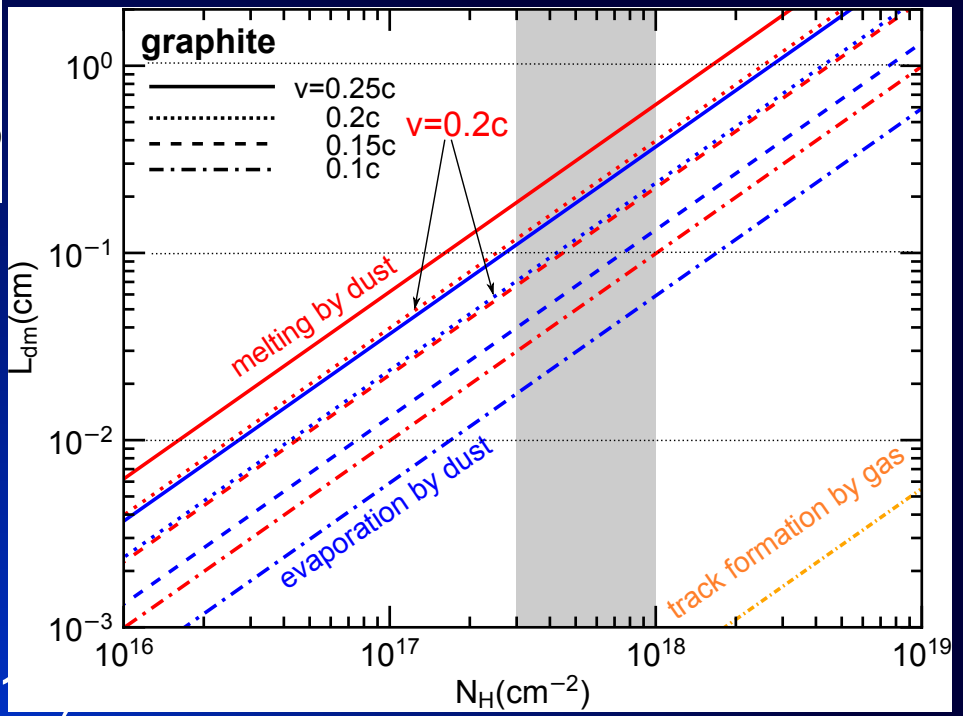
Computational simulations of dust impact at ~ 0.2c are required.

Hoang, Lazarian, Loeb & Burkhart (2016)

Erosion Depth by Gas and Dust





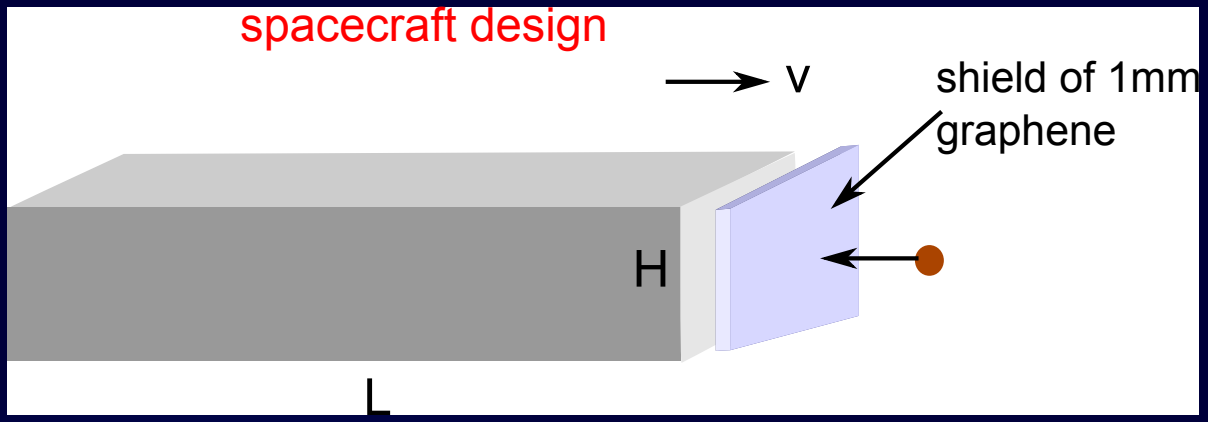


- Erosion by dust is most efficient
- Melting is less severe for graphite

Hoang, Lazarian, Loeb & Burkhart (201

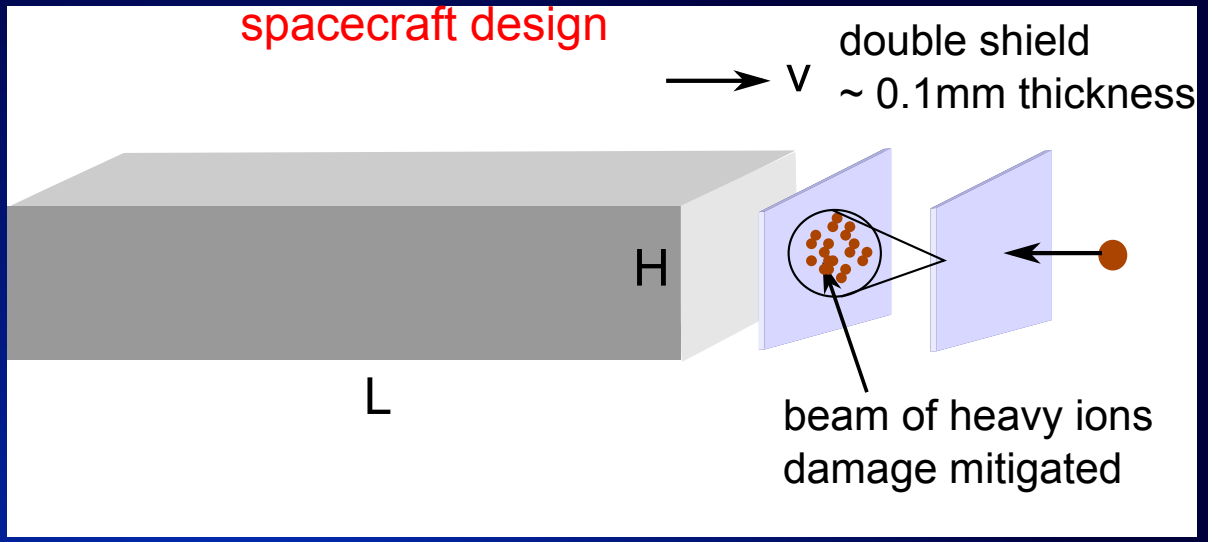
How to mitigate dust damage?

- Put a shield, a graphene foil of 1mm thickness



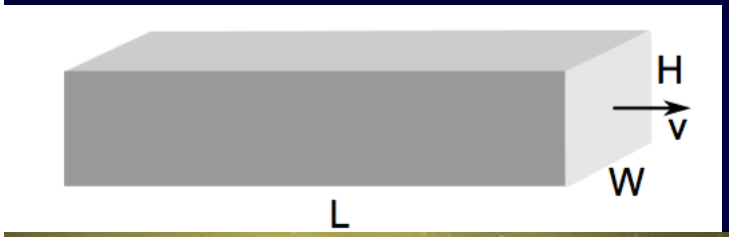
- Double shield, benefit from Coulomb explosion after first foil

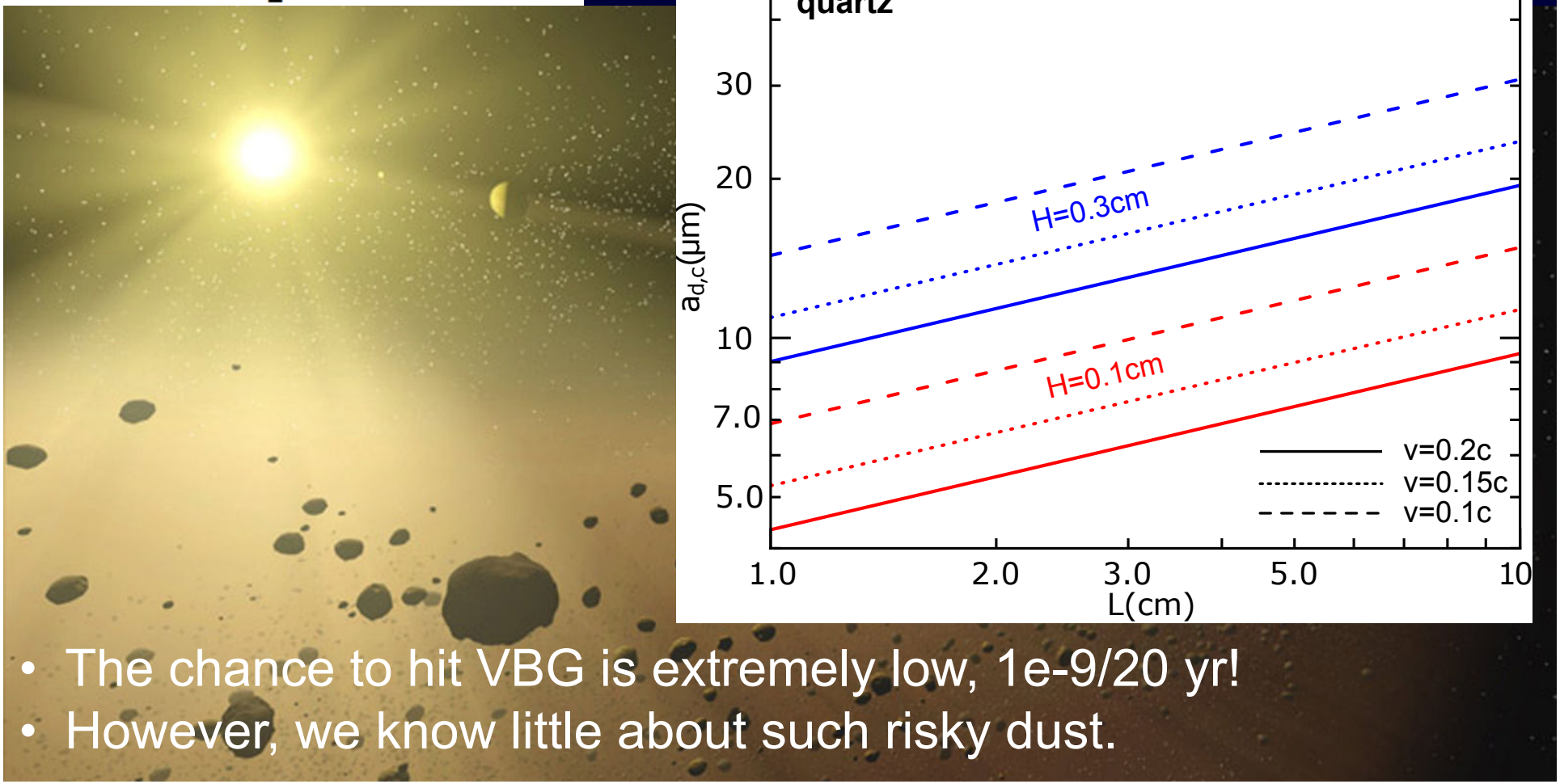
- Computer simulations urgently needed



Hoang, Lazarian, Loeb & Burkhart (2016)

Collisions with very big grains or asteroids?





- The chance to hit VBG is extremely low, 1e-9/20 yr!
- However, we know little about such risky dust.

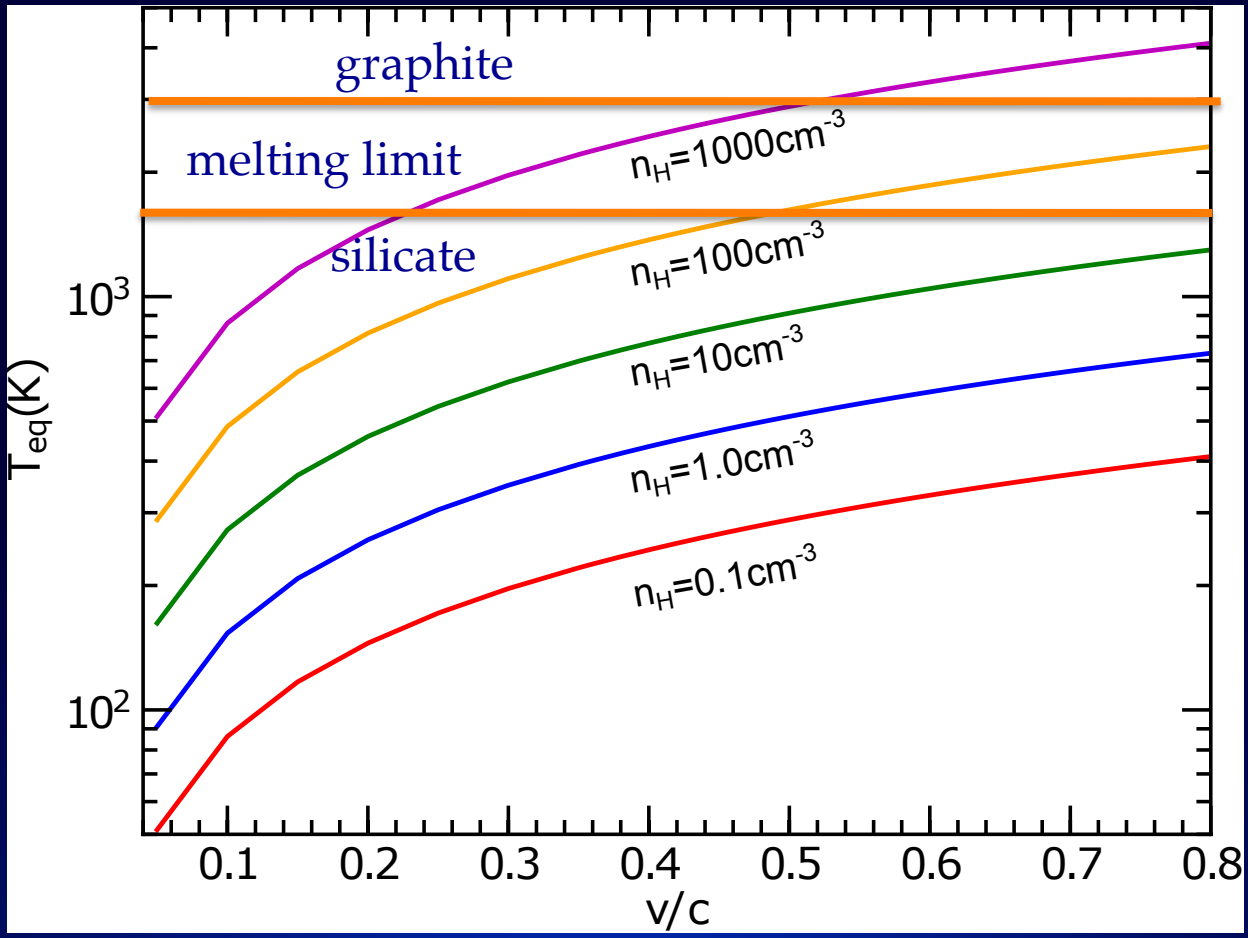
Summary and Discussion

- Breakthrough Starshot initiative aims to send v~0.2c nanoscrafts, reaching Alpha Centauri in 20 years.
- Discovery of an Earth-like exoplanet Proxima b, potential life. Then, “Are we alone?” would soon be answered
- Lots of grand challenges must be resolved. Global efforts are needed.
- We find damage by dust impacts is severe, but can mitigate.
- Computational simulations on dust impacts at relativistic speeds will be performed for different spacecraft prototypes.
- KASI may become one of first movers in realizing the Alpha Centauri dream

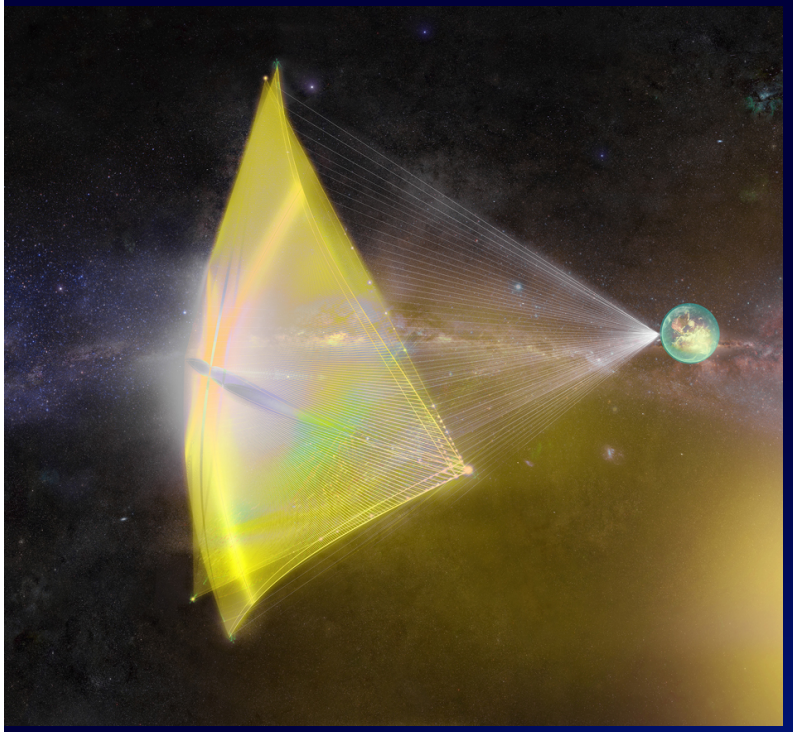
감사합니다!

Please join us to dinner at Gyejeol Bapsang, meet at 6:00 PM

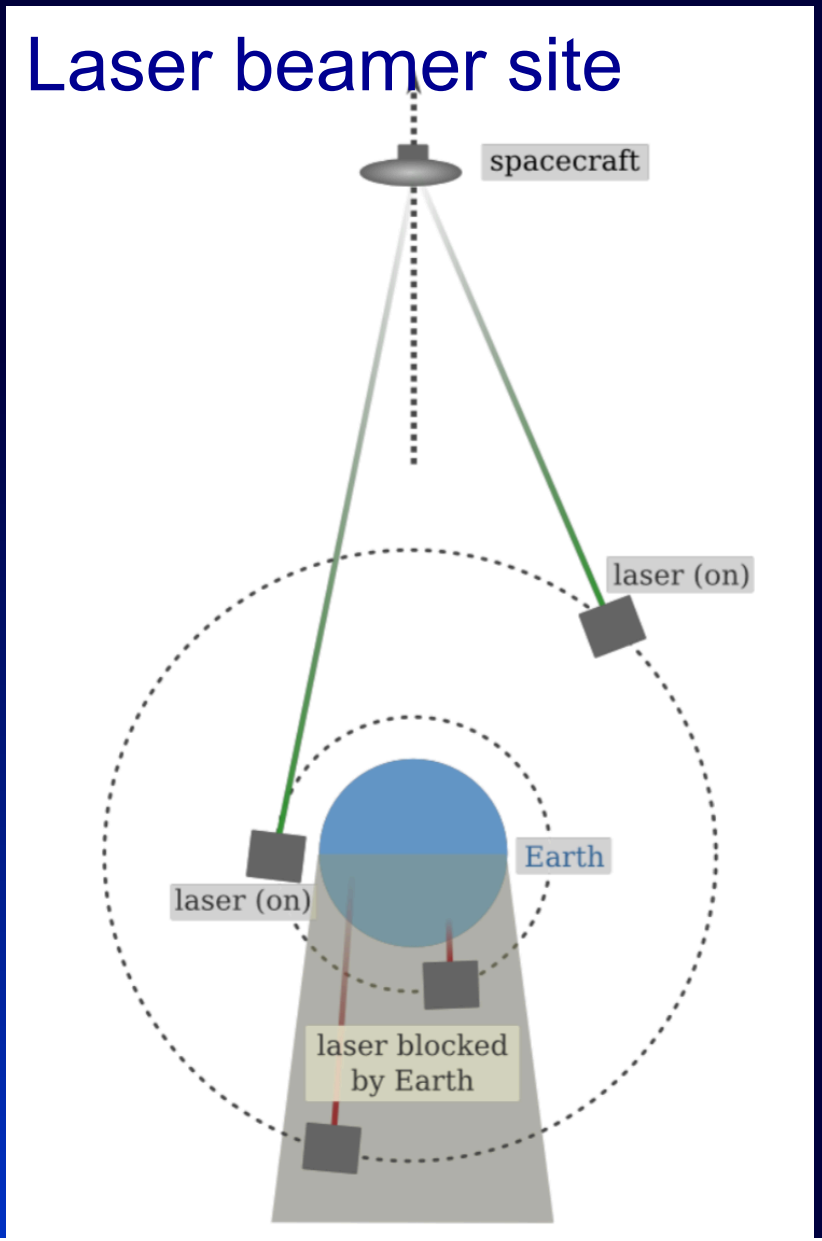
Heating by Dense Clumps



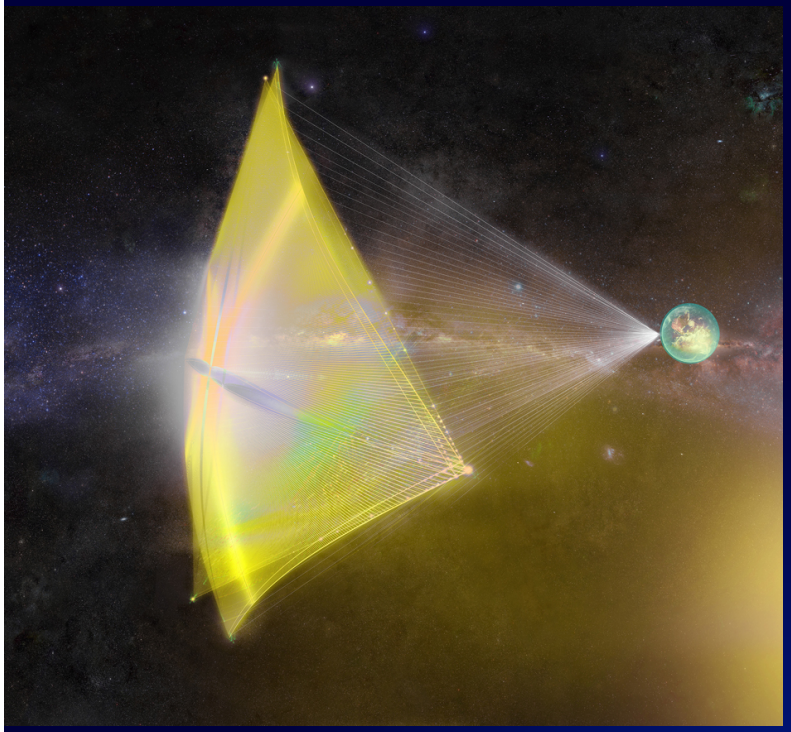
Supplements



Very thin sail transparent to gas
Pinch holes by dust grains



Optimal designs of lightsail



This lightsail is not stable

Spherical mirrored craft: Most stable (Loeb &)

Very thin sail transparent to gas

Pinch holes by dust grains

Are we alone?

3 Breakthrough Initiatives to answer:

Where is everybody?

- **Breakthrough Listen**
- **Breakthrough Message**

Can we reach the stars?

- **Breakthrough Starshot**

The Breakthrough Initiatives are a program of scientific and technological exploration, probing the big questions of life in the Universe: Are we alone? Are there habitable worlds in our galactic neighborhood? Can we make the great leap to the stars? And can we think and act together – as one world in the cosmos?