DUST TRAJECTORIES IN THE INNER HELIOSPHERE AND CIRCUMSTELLAR DEBRIS DISCS

Ingrid Mann[1], Johann Stamm[1], Andrzej Czechowski[2], Carsten Baumann[1], Margareta Myrvang[1], Aigen Li[3]

[1] UiT The Arctic University of Norway, **Tromsø, Norway**
[2]Space Research Center, Polish Academy of Sciences, **Warsaw, Poland**
[3]University of Missouri, **Columbia, Missouri**, USA

ingrid.b.mann@uit.no

Solar Wind 15 - Brussels 2018

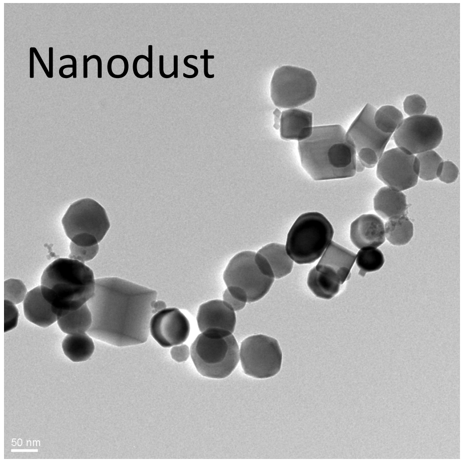
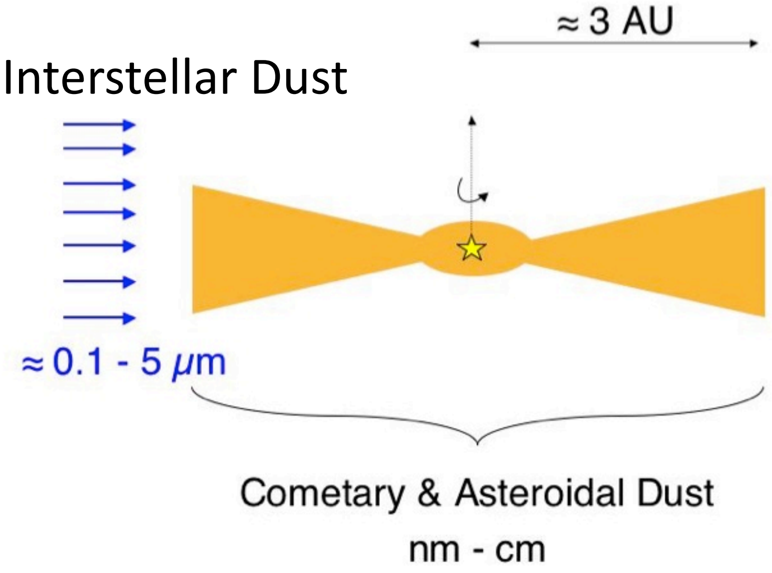


Fig. Y. Kimura
Hokkaido University

Interplanetary Medium Dust Cloud



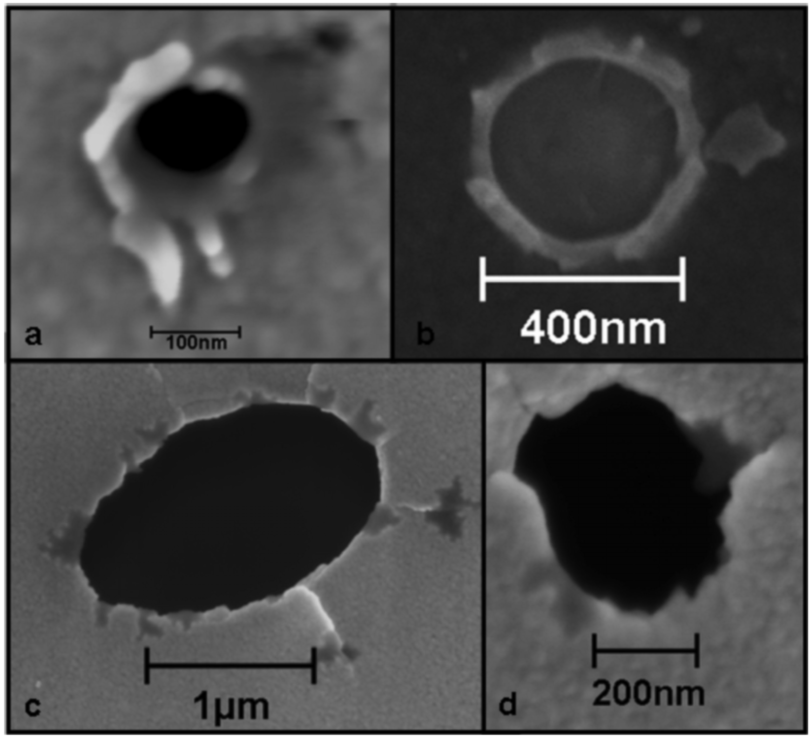
- originates from small bodies
- forms by collision cascade
- covers terrestrial planet zone
- smallest fragment unknown

Collisional evolution < 1 AU	Δ v ~ 10 – 200 km/s
Dust production:	10^3 - 10^5 kg s^{-1}
Vaporized dust mass:	10^2 - 10^5 kg s^{-1} ≈ inner pui
Radiation pressure ejection:	50 - 10^3 kg s^{-1}

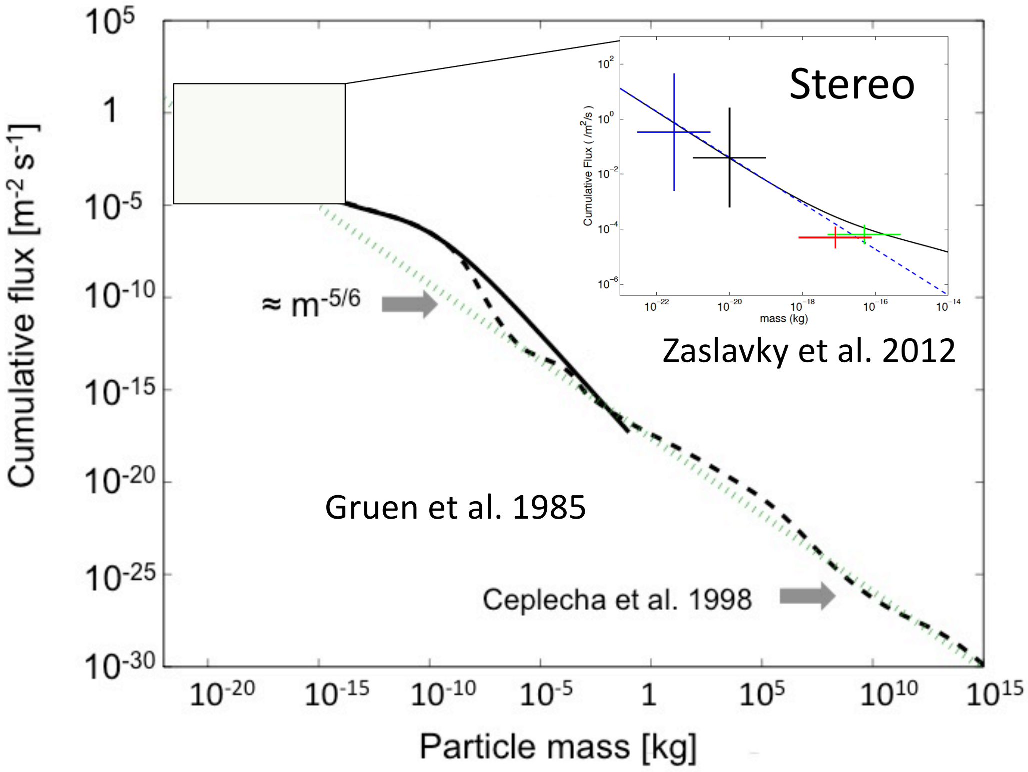
(Mann & Czechowski 2005)

Dust Flux Curve & Nanodust (open questions)

ISS (~ 340 km) 60 nm Al foils
→ ≈ 10 nm dust impacts?



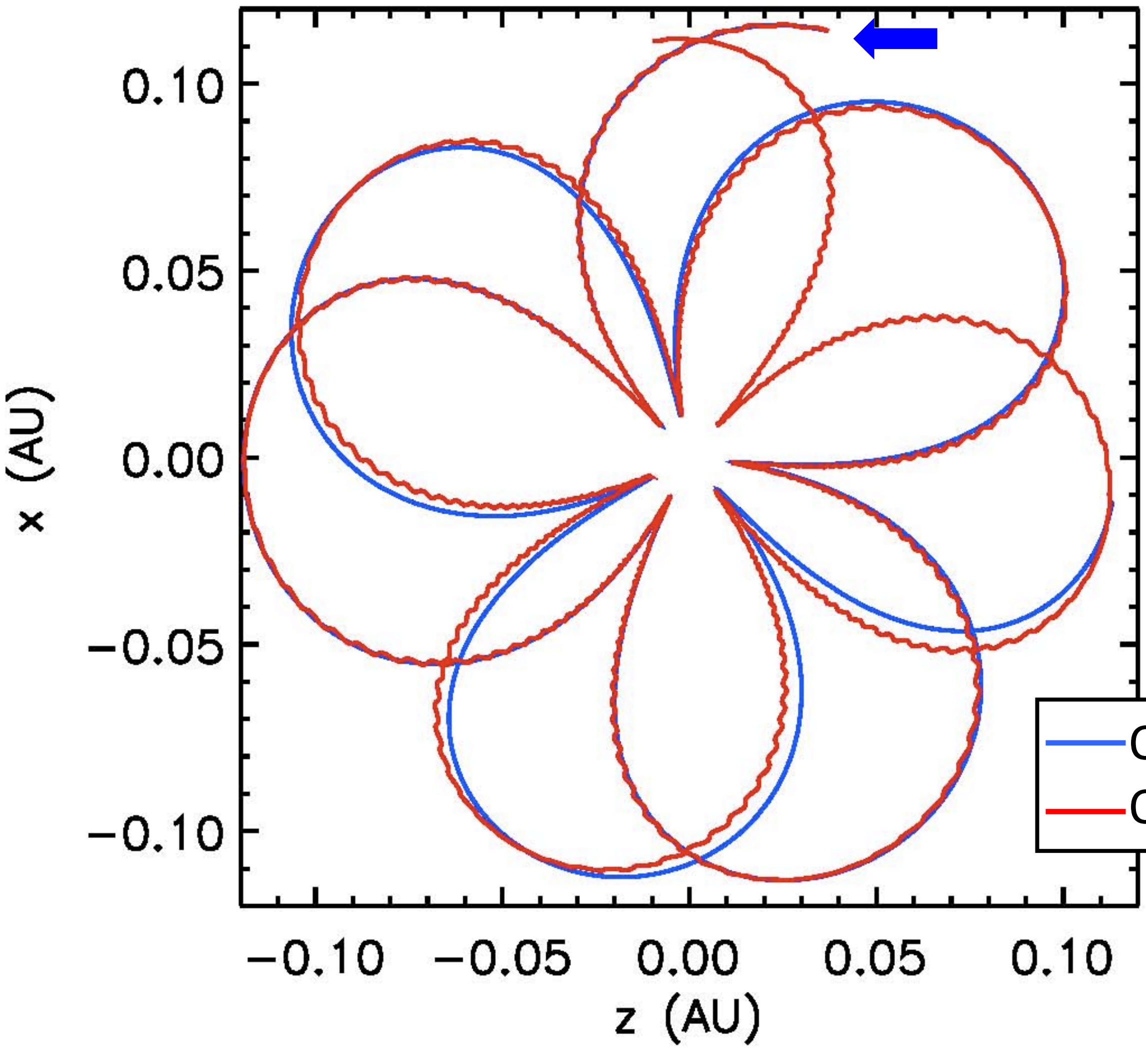
(Carpenter et al. 2007)



STEREO observations are discussed in a poster by Issautier et al. today

(Cassini also observed nanodust)

Trapped Nano Dust: Trajectories



$Q/m = 10^{-4}\ e/m_p$ ~ 3 nm

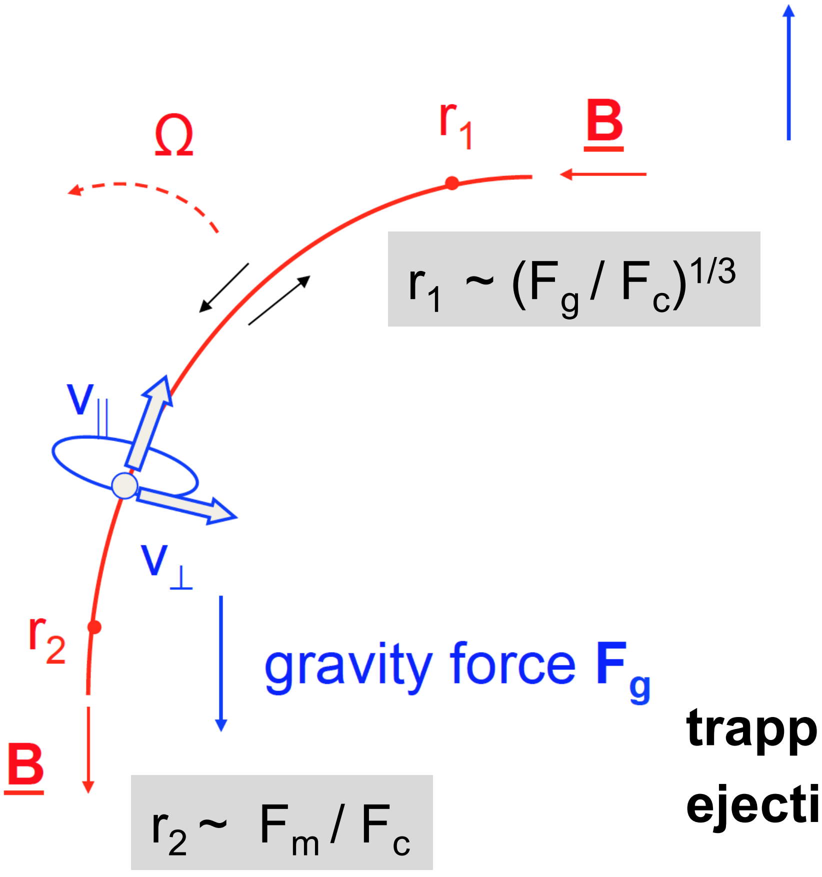
$Q/m = 10^{-5}\ e/m_p$ ~ 10 nm

release:
≈ 0.12 AU
perihelia:
≈ 0.01 AU
aphelia:
decreasing
start from circular orbits
(Czechowski & Mann 2010)

This motivated suggestion of dust trapping in debris disks (Su et al. 2013)

Note: perihelia outside of limit of applicability of B - field model

Dust trajectories for large Q/m (nanodust)



mirror force $\mathbf{F_m}$

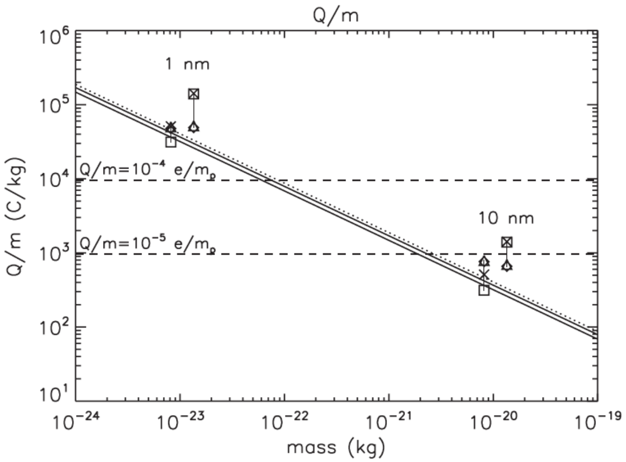
centrifugal force $\mathbf{F_c}$

$r_1 \sim (F_g / F_c)^{1/3}$

gravity force $\mathbf{F_g}$

$r_2 \sim F_m / F_c$

(Czechowski and Mann 2010)



trapping zone within **≈ 0.15 AU**

ejection from > 0.2 AU with ≈ v_{sw}

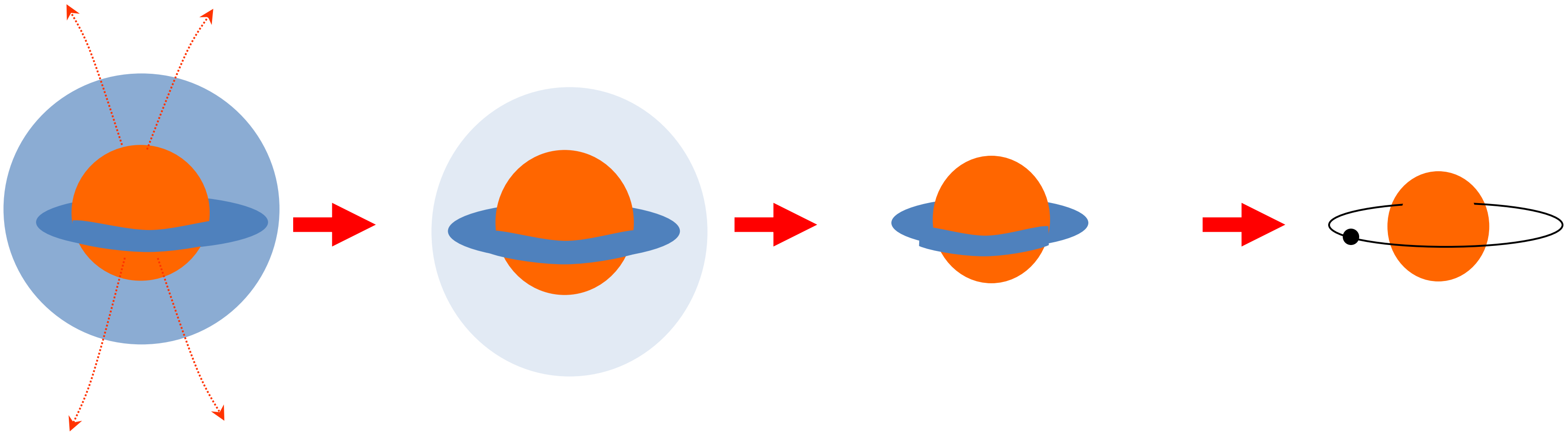
Andrzej Czechowski presents near – Sun trajectory calculations later this afternoon

Planetary System Formation

Proto star
T ~ 10^5 yr

Pre main sequence
T ~ 10^6 - 10^7 yr

Main sequence
T > 10^7 yr



Shell, polar jets & disk

Shell, gas- & dust disk
("protoplanetary system")

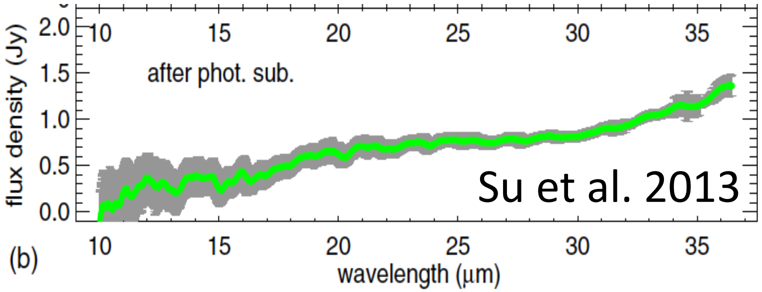
Exo planets & "dust debris"

..in star forming regions

..'field stars'

Hot Dust Emission in Debris Disks

Su et al. 2013 propose trapped nanodust explains observed thermal emission



Su et al. 2013

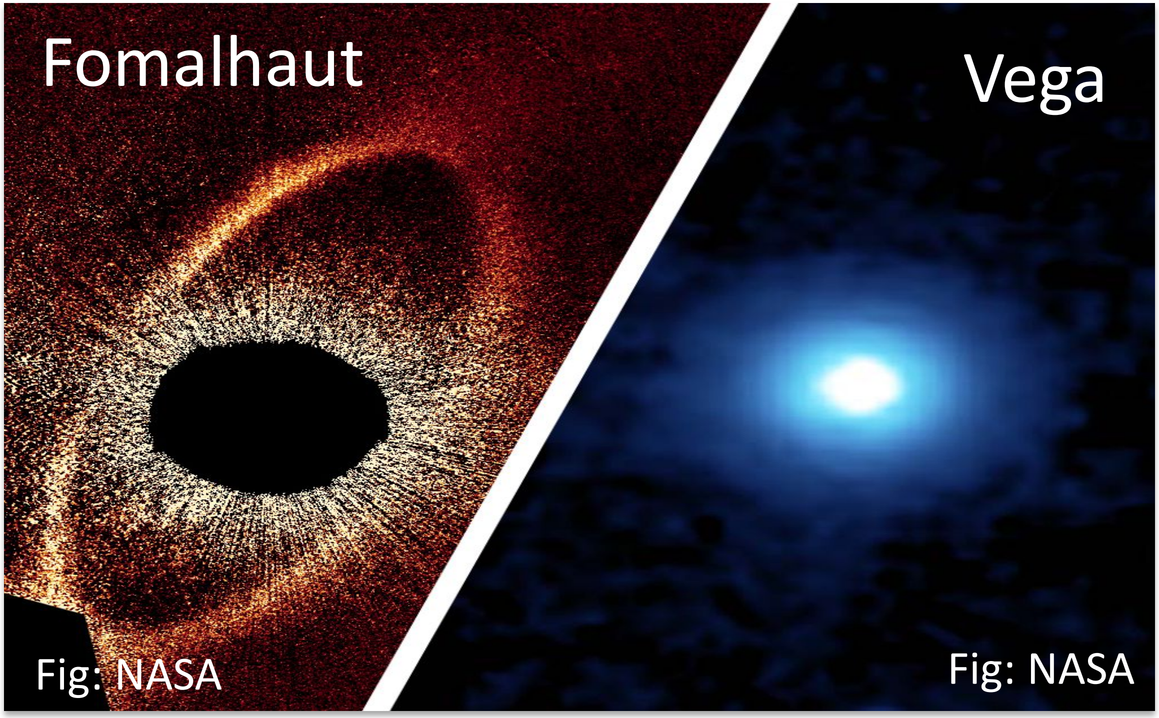
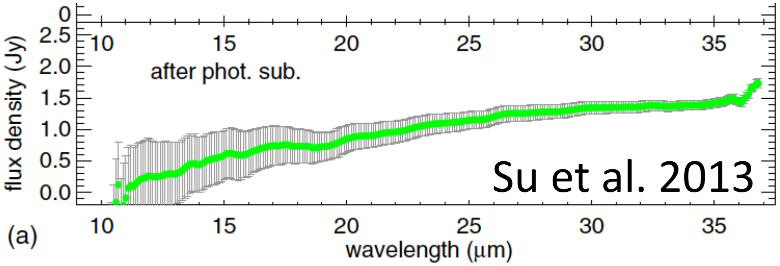


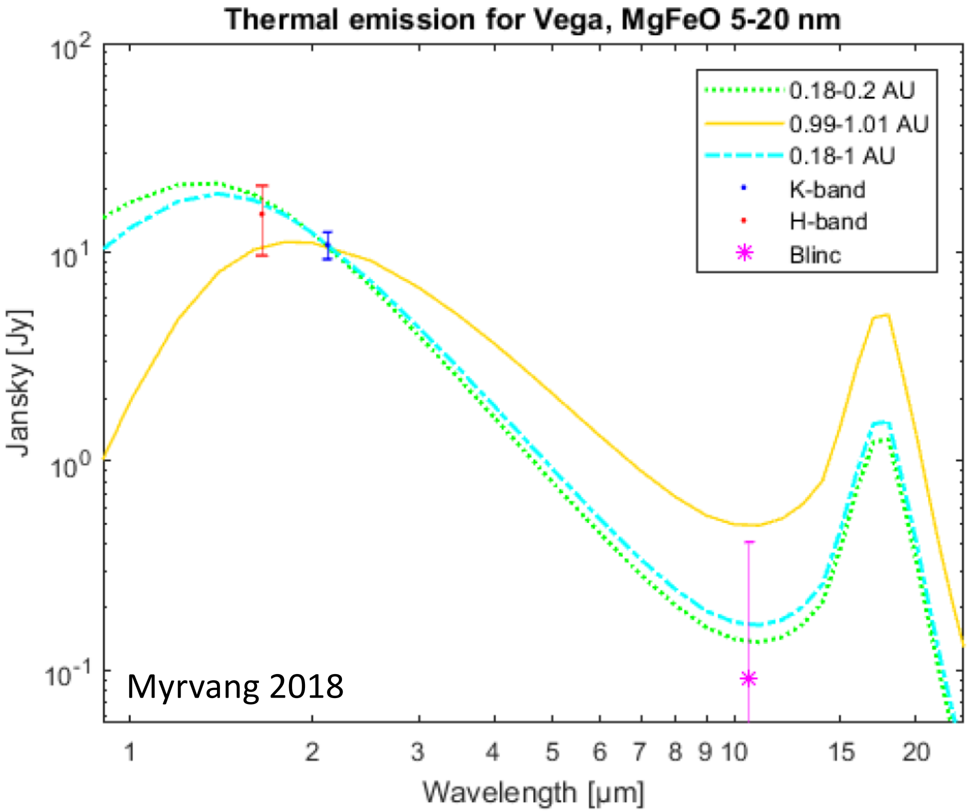
Fig: NASA

Fig: NASA



Su et al. 2013

Our calculations show that nanodust near the star is only one possible model to explain observations



Thermal emission for Vega, MgFeO 5-20 nm

Myrvang 2018

Figure 23: Comparison of MgO/FeO with a size of 5-20 nm in a ring at 0.18-0.2 AU and another ring at 0.99-1.01 AU and dust distributed continuously from 0.18-1 AU.

Observations:

Vega:

K-band (FLUOR): 2.12 μm (Absil et al. 2006).

H-band (IONIC): 1.65 μm (Defrère et al. 2011)

Blinc: 10.6 μm (Defrère et al. 2011)

Fomalhaut:

K-band: 2.18 μm (Absil et al. 2009).

N-band: 8.25-12.69 μm (Mennesson et al. 2013).

Spitzer/MIPS: 23.68 μm (Lebreton et al. 2013).

Herschel/PACS: 70 μm (Lebreton et al. 2013).

Trajectory Calculations

Equation of motion:

$$\frac{d^2\vec{r}}{dt^2} = -\frac{GM}{r^2}\hat{r} + \frac{GM}{r^2}\beta\left(\left(1-\frac{v_r}{c}\right)\hat{r}-\frac{\vec{v}}{c}\right) + \frac{q}{m}(\vec{v}-\vec{u}\ )\times\vec{B}$$

Gravitation Radiation pressure Lorentz acceleration

Parker magnetic field model

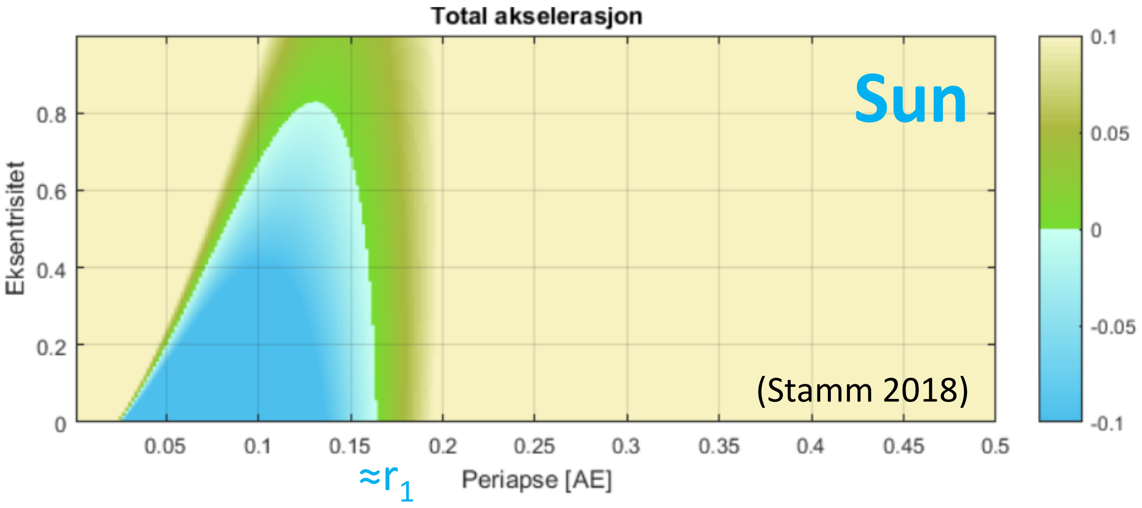
Vega T ≈ 9500 K

B ≈ 90 B_{sun} (derived from observation of stellar field)

Fomalhaut T ≈ 8750 K

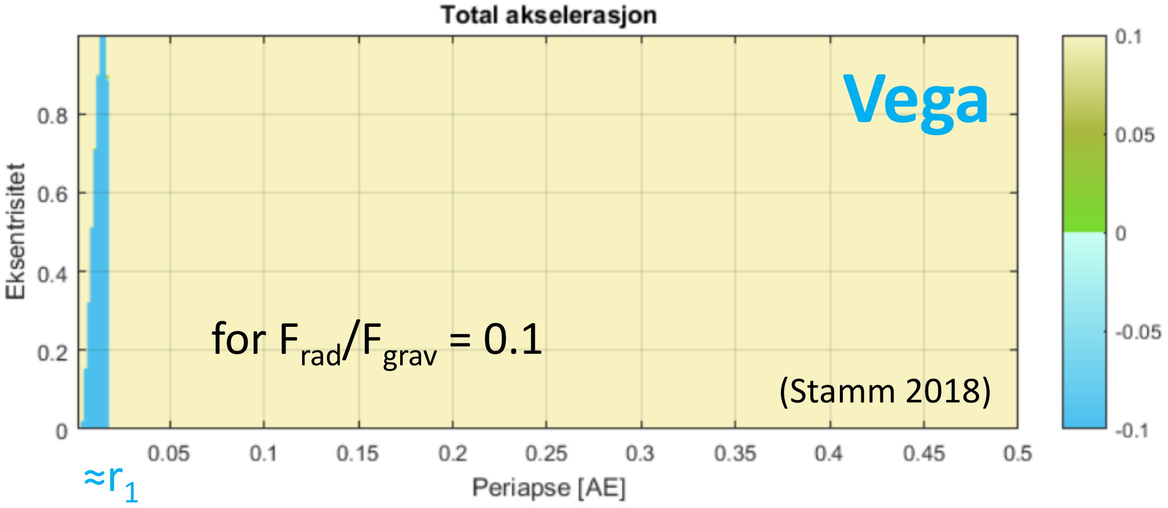
B≈ 30 – 100 B_{sun} (extrapolation)

Trapped Particle Condition



$\approx r_1$

(Stamm 2018)



for $F_{rad}/F_{grav} = 0.1$

$\approx r_1$

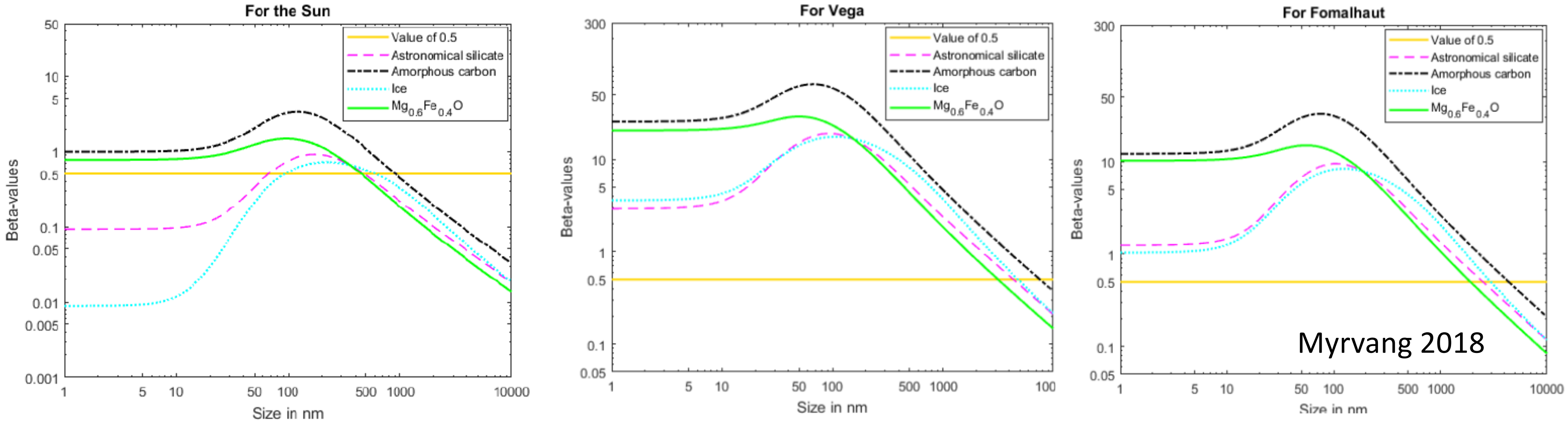
(Stamm 2018)

In blue region the radial acceleration is directed inward - a necessary, but not sufficient conditions for trapping

→

For Vega, radial inward acceleration occures only for $\lesssim$ 0.020 AE, so no trapping in outward stellar wind (similar for Fomalhaut)

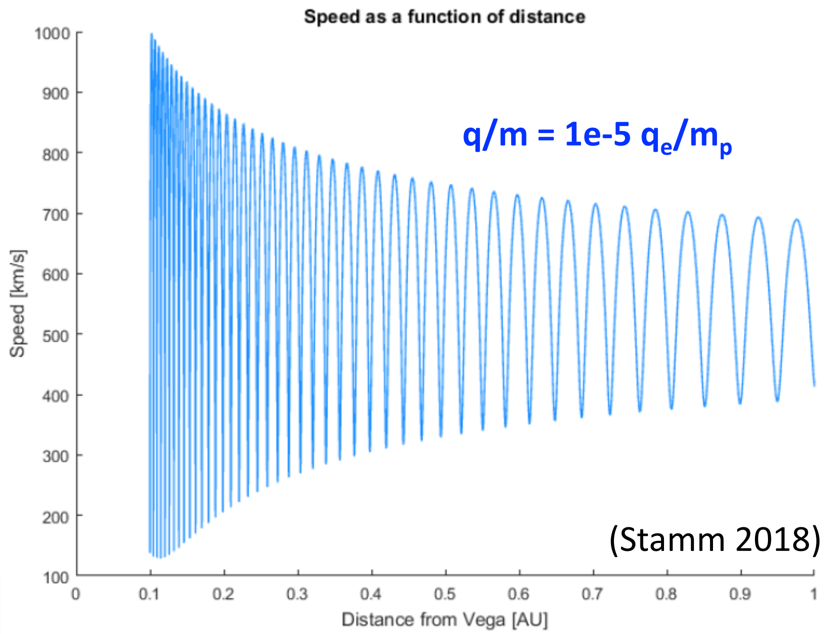
Compare radiation pressure to gravity ratio



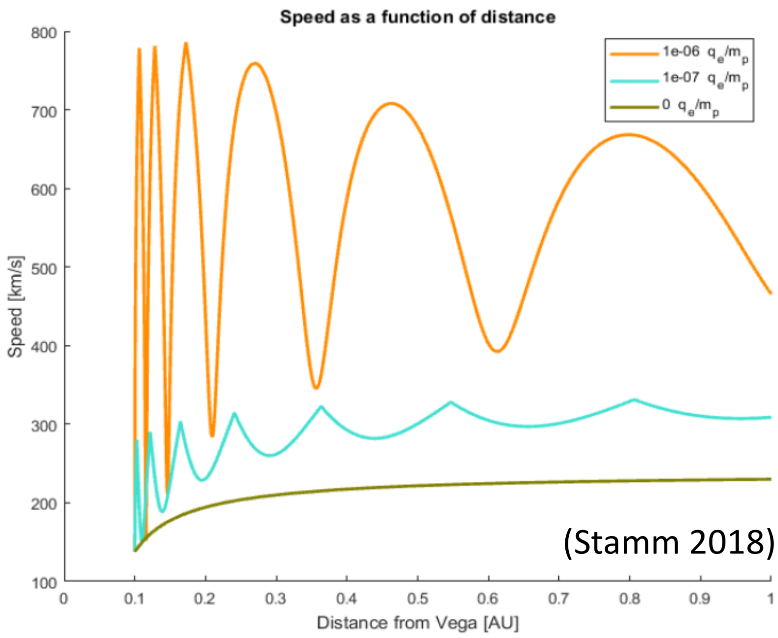
Myrvang 2018

$F_{rad}/F_{grav} \gg 1$ for Vega and Fomalhaut

Ejected Particle Speed



(Stamm 2018)

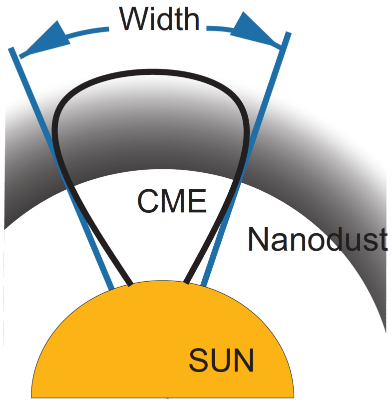


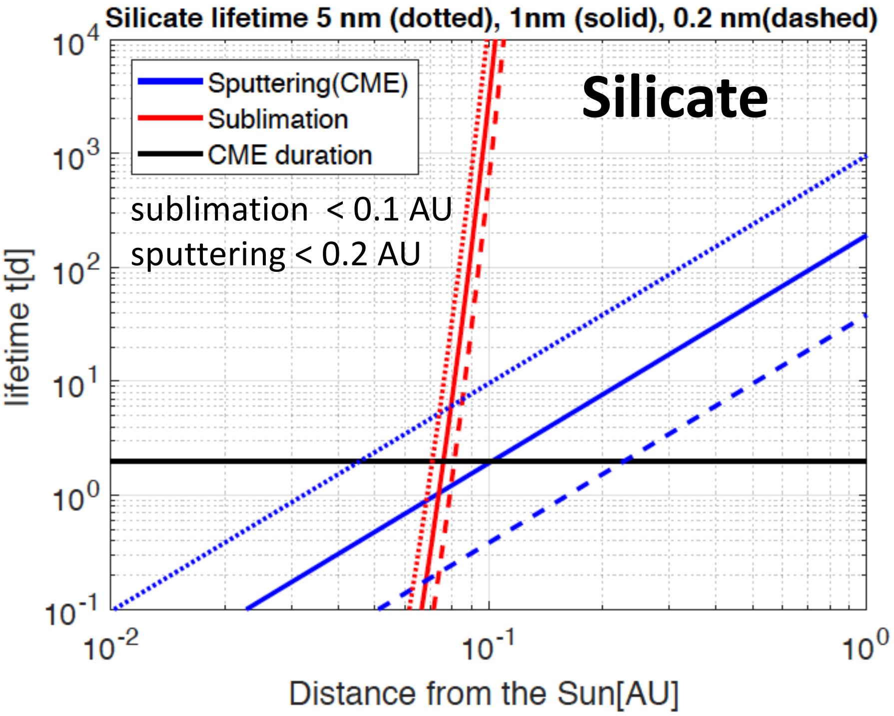
(Stamm 2018)

Particles ≲ 30 nm reach 1 AU from Vega/Fomalhaut within ≈ 3 days

Particles ≲ 10 nm reach 1 AU from Sun within ≈ 10 days

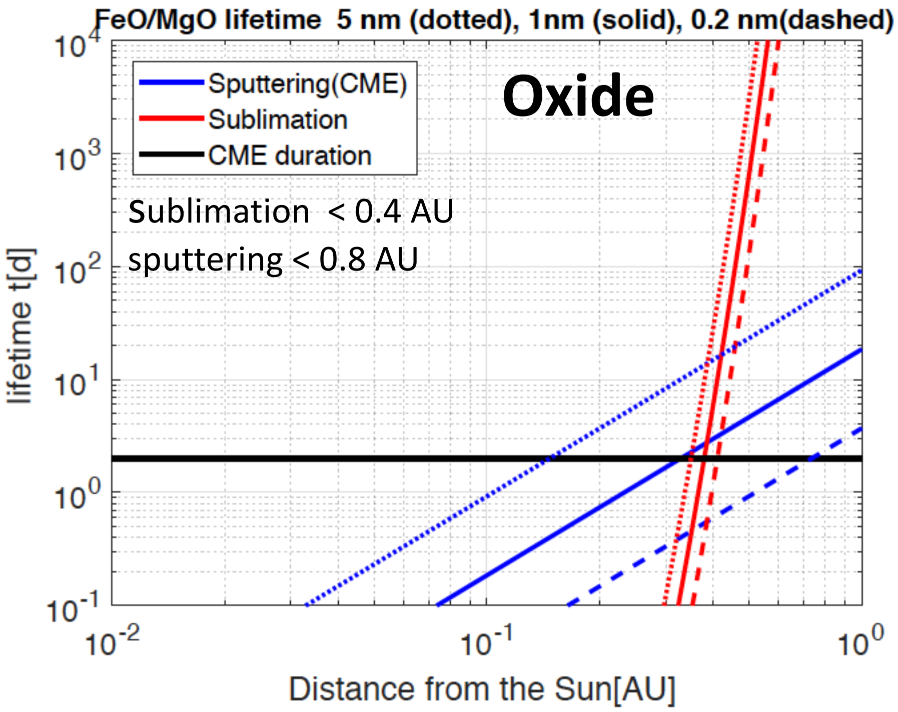
Dust Destruction by Sublimation & Sputtering enhanced during CME?





sublimation < 0.1 AU

sputtering < 0.2 AU



Sublimation < 0.4 AU

sputtering < 0.8 AU

(Baumann et al. work in progress)

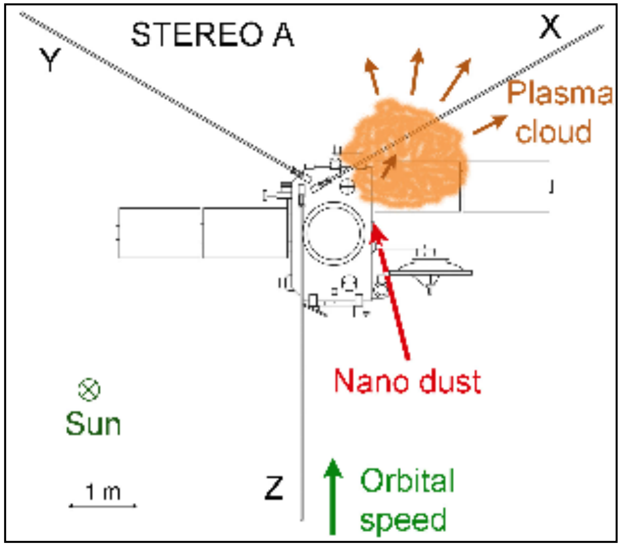
Summary

- For our B-field estimate, trapping is not relevant for Vega & Fomalhaut in presence of stellar wind (also unlikely because of $F_{rad}/F_{grav} >> 1$)
- We point out Rieke et al. 2016 find trapped orbits
- Dust ejection by stellar wind important for disk evolution (models?)
- Lifetime and mass loss estimates need to include dust erosion by sputtering (during CME)

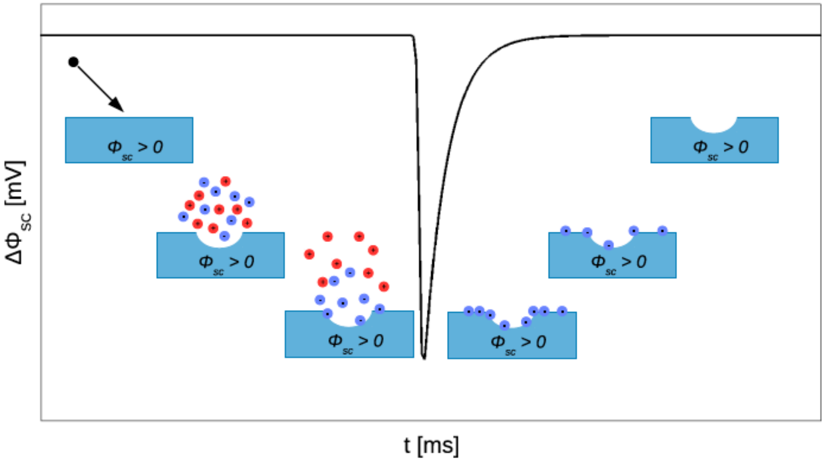
This research is funded by the Research Council of Norway (grant number 262941)

Physics of dust impacts: detection of cosmic dust by spacecraft and its influence on the plasma environment

ISSI International Team 2018 - 2019



Meyer – Vernet et al. 2009



Vaverka et al. 2016

Ingrid Mann (team leader)
Jiri Pavlu - Prague
Jakub Vaverka - Prague
Asta Pellinen-Wannberg
Shengyi Ye - Iowa
Arnaud Zaslavsky - Meudon
Ove Havnes - Tromsø
Frank Postberg - Heidelberg
Tarjei Antonsen - Tromsø
Joan Stude - Pfaffenhofen
Sigrid Close - Stanford
Åshild Fredriksen - Tromsø
Charles Lue - Kiruna
Zoltan Sternovsky - Boulder

http://www.issibern.ch/teams/physdustimpact/

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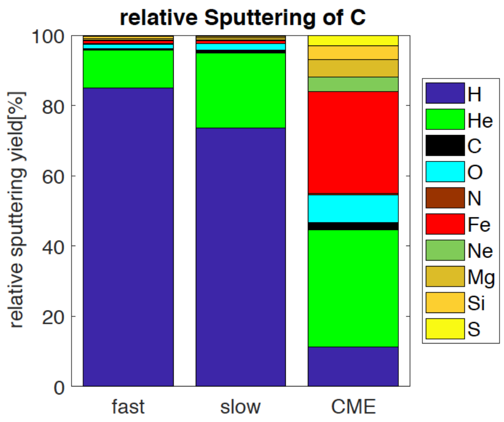
additional slides

Stare	**Sola**	**Vega**	**Fomalhaut**
Distance from Earth	1 AE	7,76 pc	7,70 pc
Radius	1 $R_\odot$ = 6,957 × 10^8 m (0,00465 AE)	2,818 $R_\odot$ ** (0,0131 AE **)	1,842 $R_\odot$ (0,00857 AE)
Mass · G	1 $GM_\odot$ = 1,3271 × 10^{20} $1/ms^2$	2,135 $GM_\odot$	1,92 $GM_\odot$
Temperature	5772 K	9500 K	8750 K
Spectral class	G2V	A0V	A3V
Rotation speed	2,86 × 10^{-6} rad/s*	1,20 × 10^{-4} rad/s **	7,76 × 10^{-5} rad/s
Surface speed	(6,1 × 10^5 m/s)**	(5,4 × 10^5 m/s)**	(6,3 × 10^5 m/s)**
Reference	(IAU 2015, Hakamada og Kojima 1994)	(Köhler og Mann 2002, Yoon mfl. 2010)	(Mamajek 2012, Díaz mfl. 2011)

Relative sputtering yield



- relative sputtering yield: $\frac{C_i \cdot Y_i}{\sum C_i \cdot Y_i}$
- Solar wind sputtering is proton and helium dominated
- CME sputtering influenced by heavier ions

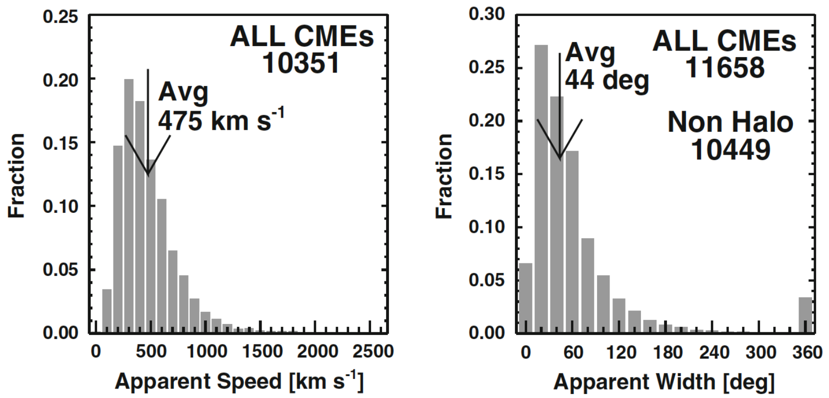
CME statistics

- slow SW $n_e = 8cm^{-3}$ v=300 km/s
- fast SW $n_e = 3cm^{-3}$ v=800 km/s
- CME $n_e = 70cm^{-3}$ v=500 km/s

- dust lifetime from r_0 to 0

$$t_{sput}(d) = \frac{4 r_0 \rho N_A}{f_{SW}(d) Y_{tot} M}$$

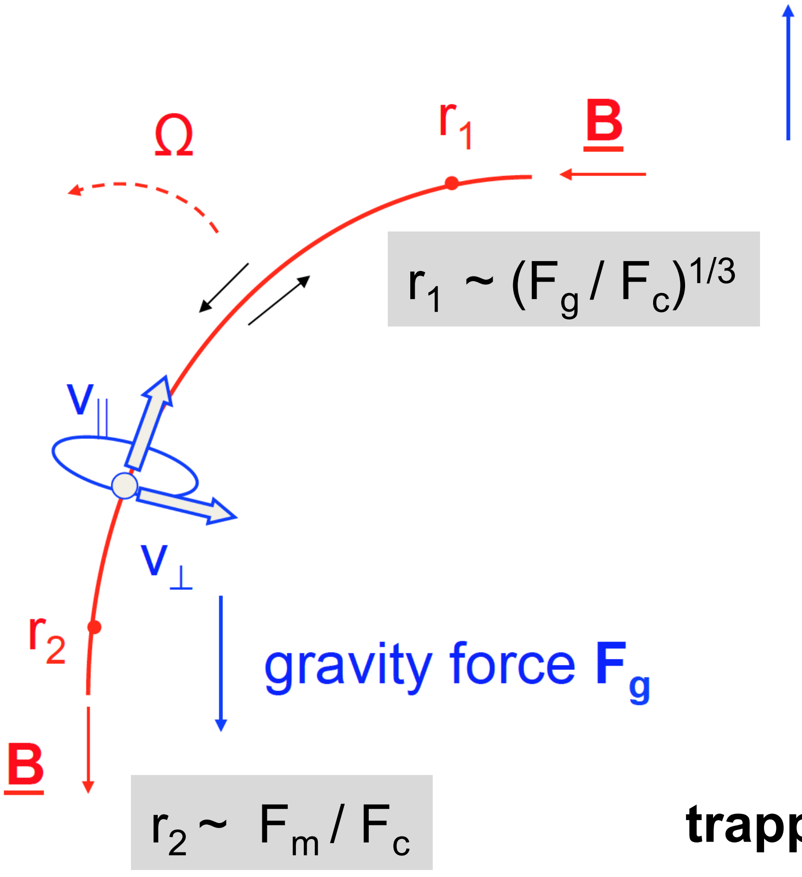
(Baumann et al., work in progress)



Gopalswamy et al. 2009

- occurence rate can be up to 2 CMEs per day
- mean width corresponds to 14% influenced space
- local depletion of dust population possible
- used 500 km/s mean speed in this study

Dust trajectories for large Q/m (nanodust)



mirror force $\mathbf{F_m}$

centrifugal force $\mathbf{F_c}$

$r_1 \sim (F_g / F_c)^{1/3}$

gravity force $\mathbf{F_g}$

$r_2 \sim F_m / F_c$

$$\frac{d\mathbf{v}}{dt} = \frac{Q}{mc}(\mathbf{v} - \mathbf{V}) \times \mathbf{B} - \frac{GM_\odot}{r^2}\widehat{\mathbf{e}}_r + \mathbf{F}_{PR}$$

$\mathbf{v}$	dust velocity	G	gravity constant
m	dust mass	$M_\odot$	solar mass
Q	dust surface charge	$\mathbf{F}_{PR}$	Poynting Robertson force
$\mathbf{V}$	plasma velocity		
$\mathbf{B}$	magnetic field		

$$\mathbf{F}_{PR} = \frac{GM_\odot}{r^2}\beta\left(\left(1 - \frac{v_r}{c}\right)\widehat{\mathbf{e}}_r - \frac{\mathbf{v}}{c}\right) \approx \frac{GM_\odot}{r^2}\beta$$

$$\frac{Q}{m}(t) = const \qquad \beta = \frac{F_{rad}}{F_{grav}} \approx 0.1$$

trapping zone: near ecliptic within **≈ 0.15 AU**

ejection > 0.2 AU: speed close to v_{sw}

(Czechowski and Mann 2010)

Andrzej Czechowski gives update on trajectory calculations later this afternoon