UiT THE ARCTIC UNIVERSITY OF NORWAY

Solar Orbiter will cross interplanetary dust cloud

Dynamics of Dust Particles near Sun, Vega and Fomalhaut

Johann Stamm[1], Ingrid Mann[1], Andrzej Czechowski[2], Carsten Baumann[1] and Margaretha Myrvang[1]
[1] Department of Science and Technology, UiT The Arctic University of Norway
[2] Space Research Center, Polish Academy of Sciences

This presentation participates in OSPP

EGU Outstanding Student Poster & PICO Contest

Poster X4.312

/ INTRODUCTION

- Several stars have debris belts that cover all sizes from small bodies to dust.
- Some systems probably have a close (<0.2 AU) dust belt [5].
- The dust there is influenced by gravitation and radiation pressure.
- Nanodust is charged and influenced by the stellar magnetic field via the Lorentz force.
- Dust belts around the Sun can be reached by spacecraft
- The region close to the Sun will be explored by Solar Orbiter and Parker Solar Probe.

/ METHOD

- Equation of motion:
- $$\frac{d^2\vec{r}}{dt^2} = \underbrace{-\frac{GM}{r^2}\hat{r}}_{\text{Gravitation}} + \underbrace{\frac{GM}{r^2}\beta\left(\left(1-\frac{v_r}{c}\right)\hat{r}-\frac{\vec{v}}{c}\right)}_{\text{Radiation pressure}} + \underbrace{\frac{q}{m}(\vec{v}-\vec{u})\times\vec{B}}_{\text{Lorentz acceleration}}$$
- Particle trajectories calculated by numerical methods.
- The radiation pressure to gravity ratio, β, is calculated for astronomical silicate using Mie theory, see also poster X4.311.
- Charge-to-mass-ratios (q/m) are typical for sub-µm dust in solar wind conditions c.f. [2], q/m given here in units of elemental charge over proton mass (1 $q_e/m_p \approx 9.6 \cdot 10^7$ C/kg)
- Magnetic field was estimated as described below.

/ RESULTS

- When $\beta \geq 1$ virtually all particles escape from the stellar system. This corresponds to dust size ≤ ~4 µm at Vega,~1 µm at Fomalhaut and ~300 nm at the Sun.
- For $q/m > 10^{-6}$ q_e/m_p, particles follow the magnetic field lines. By extrapolating models as in [2] this corresponds to a size of 30 nm.
- The magnetic field parameters we estimated for Vega and Fomalhaut prevent the charged particles from being trapped .
- Some trapping occurs near the Sun (see fig. 1).
- The speed of escaping particles with $q/m > 10^{-6}$ q_e/m_p around Vega and Fomalhaut approaches the stellar wind speed.

/ MAGNETIC FIELD

- Approximated magnetic fields by Parker spirals (see fig. 7)
- Field line form is caused by stellar wind and rotation.
- Stellar wind speed, u, set equal to escape speed for V. & F.. Result similar to model by [3]
- Field direction (in/out) same as at the stellar surface.
- Magnetic field strength of V. estimated by extrapolating Parker field to surface and fitting to measurement. Field strength of F. by interpolation w.r.t mass.
- Field strength at 1 AU is 5 nT for S., 435 nT for V. and 355 nT for F.

/ TRAPPED PARTICLE ORBIT

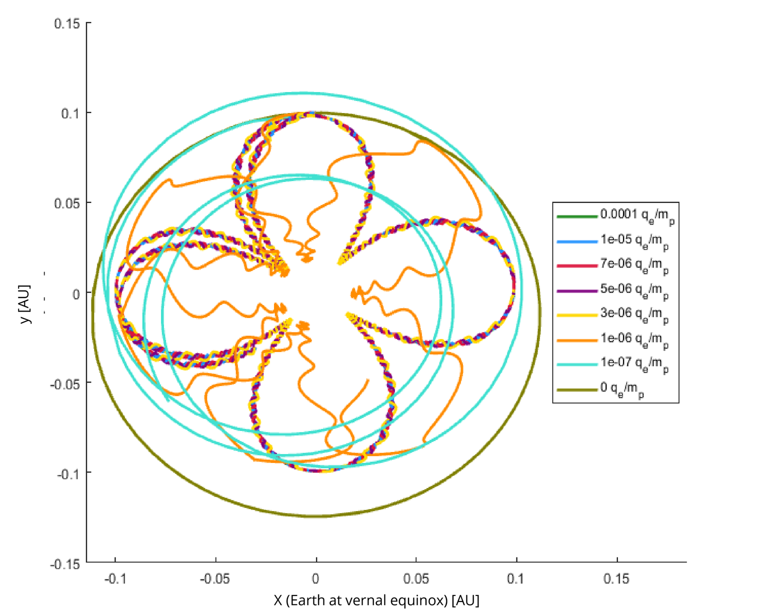

Figure 1. Orbits of trapped particles around the Sun. The uncharged particle (in olive) continue on a Kepler-like orbit. The highly charged particles (green to yellow) are strongly influenced by Lorentz force. The others have orbits in-between.

/ GYRORADIUS

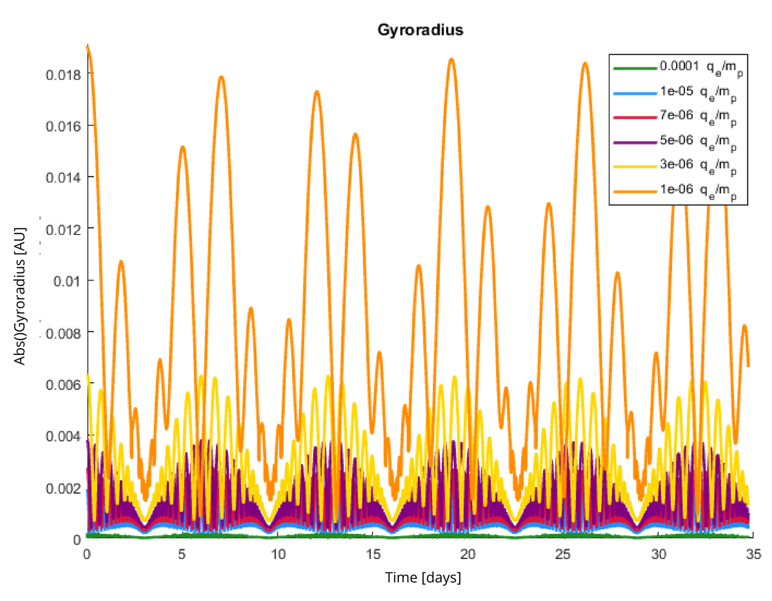

Figure 2. Gyroradius of trapped particles around the Sun. It increases when it gets further away from the Sun.

/ EJECTED PARTICLE SPEED 1

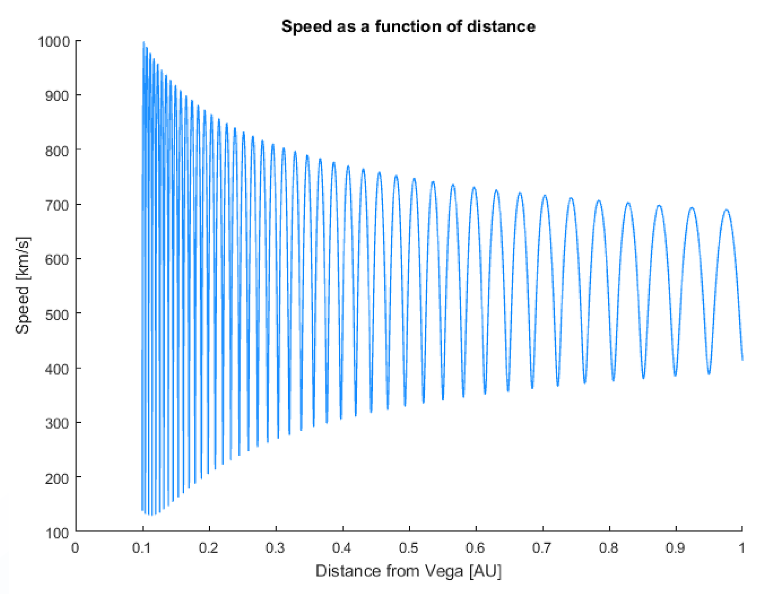

Figure 3. Speed of a particle with $q/m = 10^{-5}$ q_e/m_p escaping from Vega. The speed of escaping particles from Fomalhaut is similar.

/ EJECTED PARTICLE SPEED 2

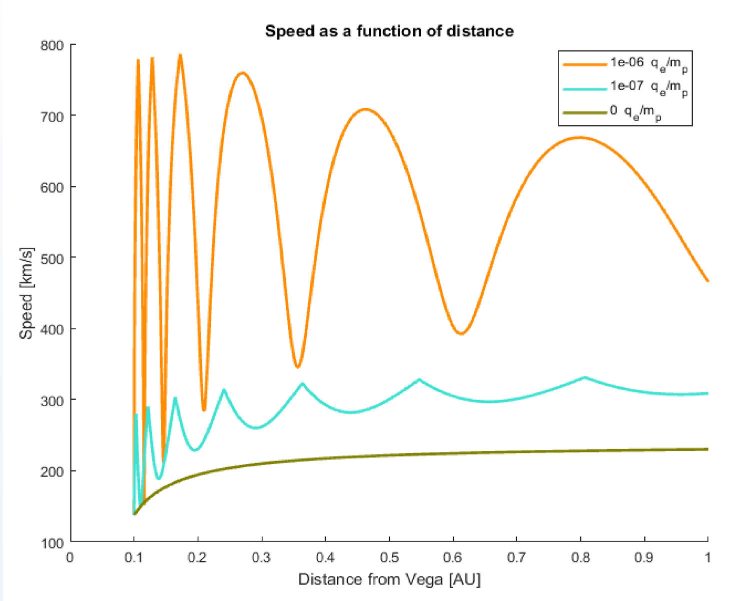

Figure 4. Speed of particles with other q/m escaping from Vega. The speed of escaping particles from Fomalhaut is similar.

/ MORE RESULTS

- Escaping particles reach Earth orbit after 10 or more days.
- Acceleration from V. & F. is more effective, see fig. 3-4. There the particles reach 1 AU after ~3 days for $q/m \geq 10^{-6}$ q_e/m_p.
- Particles with large q/m reach 1 AU faster than ones with low q/m.
- [4] use an other magnetic field. Charged particles were then trapped around stars like Vega and Fomalhaut. Their magnetic field strength at 1 AU is 1.2 nT for a reference star.

/ INITIAL CONDITIONS

- Tested different initial conditions.
- Shown results use circular orbits with radius 0.1 AU inclined 5° rel. to ecliptic/magnetic equator.

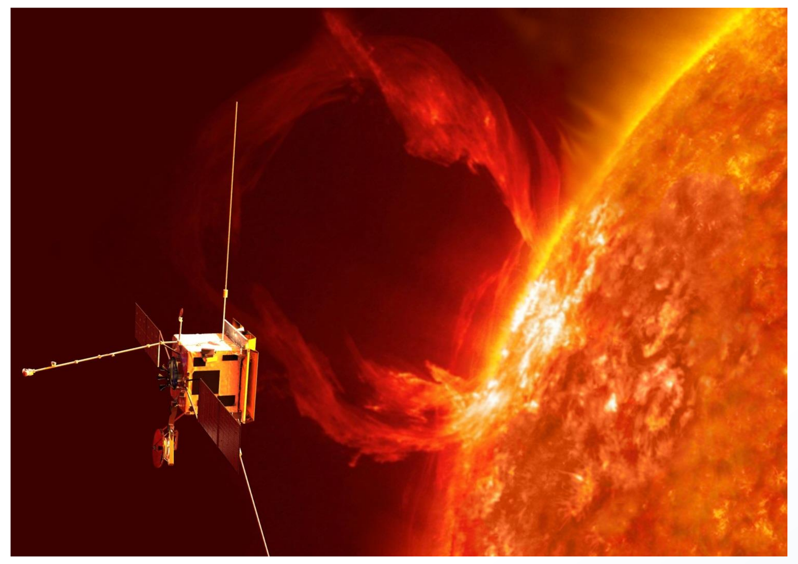

Figure 5. Artist's concept of Solar Orbiter exploring the Sun's vicinity. Once arriving the Sun it will have passed through "huge" amounts of escaping and trapped dust.
Source: ESA,
http://sci.esa.int/jump.cfm?oid=50294

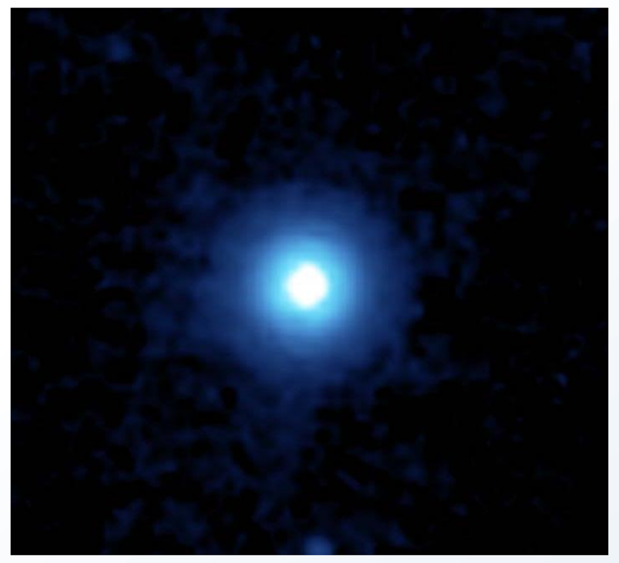

Figure 6. Vega at wavelength 24 µm. This image is roughly 45 astronomical units (6 arcseconds) wide. The resolution is not high, it is easier to look at the inner dust by looking at the spectrum.
Source: NASA/JPL-Caltech/University of Arizona,
https://photojournal.jpl.nasa.gov/catalog/PIA07218

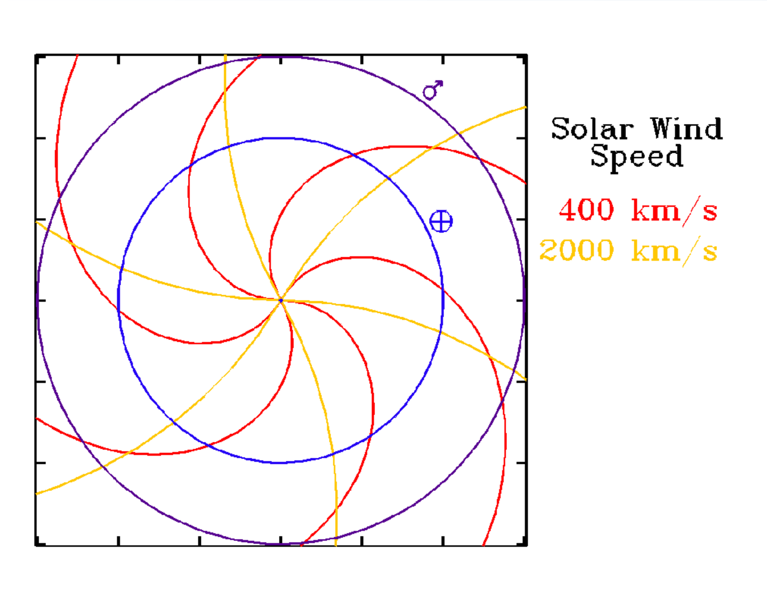

Figure 7. Parker spiral for slow and (very very) fast solar wind. Earth orbit in blue and Mars orbit in purple.
Source: NASA
https://sdo.gsfc.nasa.gov/mission/spaceweather.php

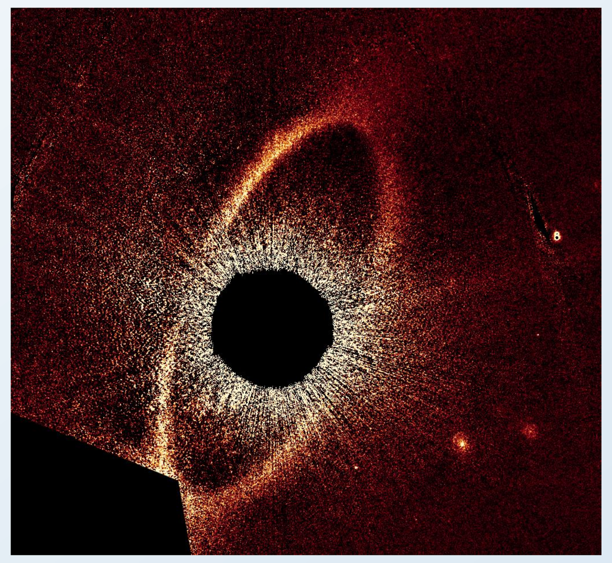

Figure 8. Image of Fomalhaut. The dots to the right are stars in the background. The outer ring is clearly visible. This image is roughly 462 astronomical units (60 arcseconds) wide.
Source: NASA,
http://hubblesite.org/image/3130/news_release/2013-01

/ REFERENCES

[1] Czechowski, Andrzej and Ingrid Mann (2010): «Formation and acceleration of nano dust in the inner heliosphere». *The Astrophysical Journal*, volume 2010, number 714: Pages 89-99. https://doi.org/10.1088/0004-637X/714/1/89

[2] Czechowski, Andrzej and Ingrid Mann (2012): «Nanodust dynamics in interplanetary space». In Mann, Ingrid, Nicole Meyer-Vernet, and Andrzej Czechowski [eds.]: Nanodust in the Solar System: Discoveries and Interpretations, pages 47-75. Astrophysics and Space Science Library 385. Springer, Heidelberg.

[3] Johnstone, Colin P., Manuel Güdel, Theresa Lüftinger, Gabor Toth, Ines Brott (2015): «Stellar winds on the Mail sequence: I. Wind model». Astronomy & Astrophysics, volume 577. https://doi.org/10.1051/0004-6361/201425300

[4] Rieke, George H., András Gáspár and Nicholas P. Ballering (2016): «Magnetic grain trapping and the hot excesses around early-type stars». The Astrophysical Journal, volume 816, number 2. https://doi.org/10.3847/0004-637X/816/2/50

[5] Su, Kate Y. L., George H. Rieke, Renu Malhotra, Karl R. Stapelfeldt, A. Meredith Hughes, Amy Bonsor, David J. Wilner, et.al. (2013): «Asteroid belts in debris disk twins: Vega and Fomalhaut». *The Astrophysical Journal* volume 763, number 2,. https://doi.org/10.1088/0004-637X/763/2/118

The stellar wind pressure was neglected here, but it is of importance, see also Andrzej Czechowski and Jens Kleimann (2017): «Nanodust dynamics during a coronal mass ejection». *Annales Geophysicae*, volume 35, pages 1033-1049. https://doi.org/10.5194/angeo-35-1033-2017

Acknowledgements
This research is funded by the Research Council of Norway (grant number 262941).
J.S. and M.M. acknowledge travel support from the Norwegian Space Center.

UNIVERSITY OF TROMSØ