E6

イカロス探査機搭載ダスト検出器「ALADDIN」による 地球・金星間の大型宇宙塵分布の直接計測

Direct Measurement of Large Meteoroid Distribution between the Earth and Venus by the ALADDIN Dust Detector onboard the IKAROS Spacecraft

○矢野創, 平井隆之 (JAXA 宇宙科学研究所), 岡本千里 (神戸大学),
藤井雅之（ファムサイエンス）, 田中真（東海大学）, IKAROS-ALADDIN チーム
○Hajime YANO, Takayuki HIRAI (JAXA/ISAS, Japan), Chisato OKAMOTO (Kobe University, Japan),
Masayuki FUJII (FAM Science), Makoto TANAKA (Tokai University), IKAROS-ALADDIN Team

2010 年 5 月に JAXA が打ち上げたソーラー電力セイル小型実証機「IKAROS」に展開された 0.54 m^2 の有効面積を持つ PVDF 型ダストその場計測器「ALADDIN」は、2010 年 6 月から 2011 年 11 月まで、地球～金星近傍空間を約 1.5 公転しながら、ほぼ連続的に宇宙塵フラックスを計測した。宇宙での実測データは厳密な信号スクリーニングと地上での超高速衝突校正実験を経ることにより、従来は黄道光の散乱光計測でのみ議論が可能だった、内惑星領域における数十ミクロン以上の大型宇宙塵のその場検出に成功した。本講演では、日本初の国産宇宙塵計測器である ALADDIN の機器構成、宇宙空間でのパフォーマンス、軌道上運用実績、検出された宇宙塵分布により明らかになった太陽系内の大型宇宙塵の分布構造とその科学的意義、および本ミッションの教訓を受け継ぐ次世代計測器の構想について論じる。

The ALADDIN (Arrayed Large Area Dust Detector for INterplanetary Space) is the first Japanese-design/built/ calibrated in-situ dust detector successfully operated in space, as an onboard instrument of the IKAROS solar sail demonstrator spacecraft launched in May 2010. With its 0.54 m^2 detection area of the PVDF film, it detected hundreds of large (>10-micron) micrometeoroids in the interplanetary space between the Earth and Venus, which were only observable as light scattering of the zodiacal cloud in the past, for 1.5 years, after careful data screening and ground impact calibration experiments. In this presentation, we discuss ALADDIN's instrumentation, in-flight performance, operational events, dust structure in the inner planetary region revealed by the large micrometeoroid detection and its scientific implications, as well as future plans of next generation meteoroid and debris detectors with heritages and lessons from ALADDIN.

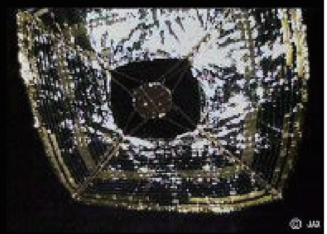
図　イカロス探査機に搭載された ALADDIN のシステム構成

The 6th JAXA Space Debris Workshop

Direct Measurement of Large Meteoroid Distribution between the Earth and Venus by the ALADDIN Dust Detector onboard the IKAROS Spacecraft

イカロス探査機搭載ダスト検出器「ALADDIN」による
地球・金星間の大型宇宙塵分布の直接計測

December 18th, 2014
ARD/JAXA, Chofu, Tokyo, Japan



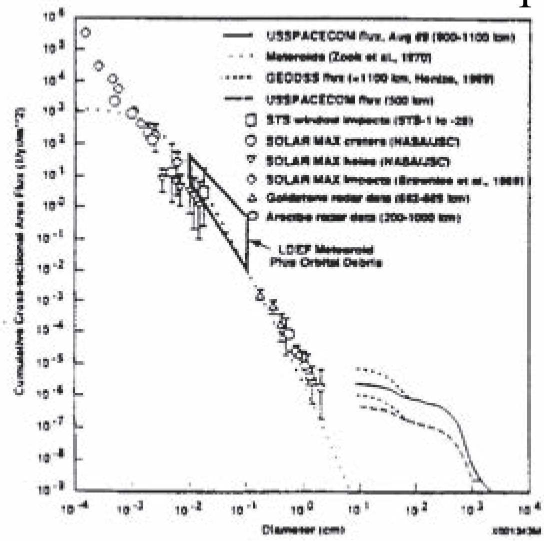
Hajime YANO[1,2],
Takayuki HIRAI[1], Chisato OKMAOTO[3], Masayuki FUJII[4], Makoto TANAKA[5], and IKAROS-ALADDIN Team
1JAXA/ISAS; 2 JAXA/JSPEC; 3 Kobe University, 4 FAM Science, 5 Tokai University

○矢野創，平井隆之（JAXA/ISAS），岡本千里（神戸大学），藤井雅之（ファムサイエンス），
田中真（東海大学），IKAROS-ALADDINチーム

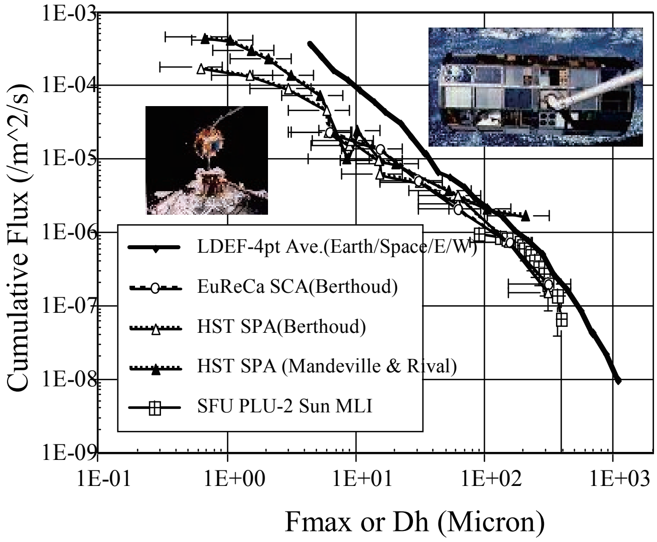
Agenda

- Dust Flux near the Earth and at 1 AU
- IKAROS, a Solar Sail Demonstrator
- ALADDIN System and Operation
- Initial Data Analysis
- Scientific Discovery (1) near Earth
- Scientific Discovery (2) near Venus
- Future Prospects
- Summary

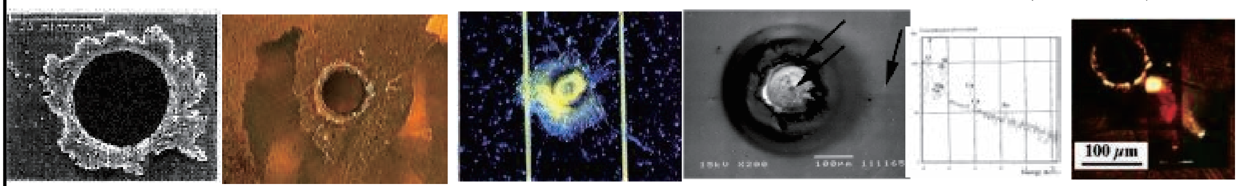
Direct Static Flux Measurements at 1 AU via Spacecraft Impact Studies



(Loftus & Potter, 1990)

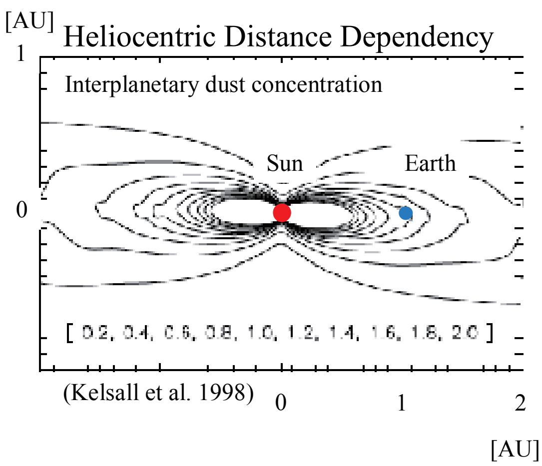


(Yano, 1995)



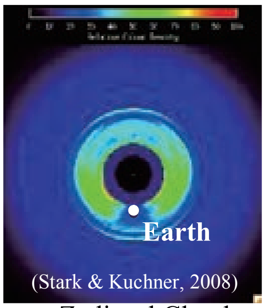
(All Impact Images courtesy: H. Yano)

Scientific Objectives: Dust Flux as a Function of the Heliocentric Distance and Local Structure nearby Planets in the Inner Planetary Regions

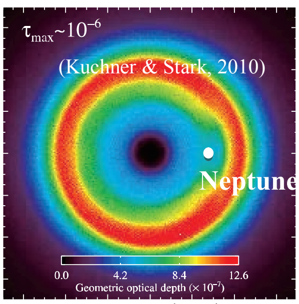


(Kelsall et al. 1998)

Local Dust Flux Enhancements Predicted by Numerical Models



Zodiacal Cloud
(Inner Region)



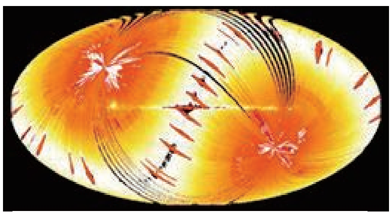
EKB Cloud
(Outer Region)

Validation by optical observation and in-situ measurement

e.g. IKAROS & Solar Power Sail

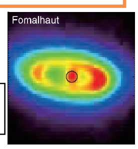
e.g. New Horizons

Zodiacal light observed by AKARI

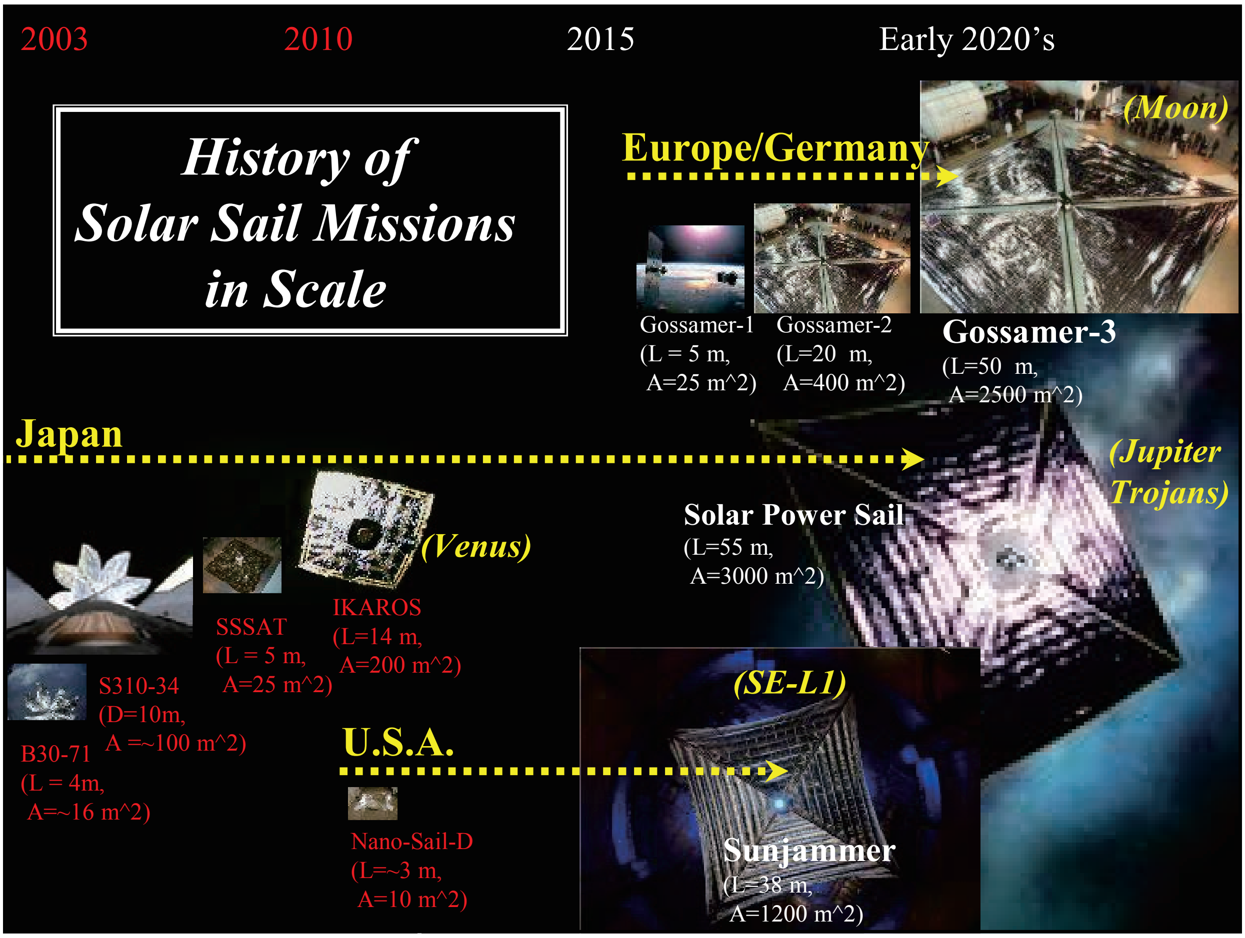


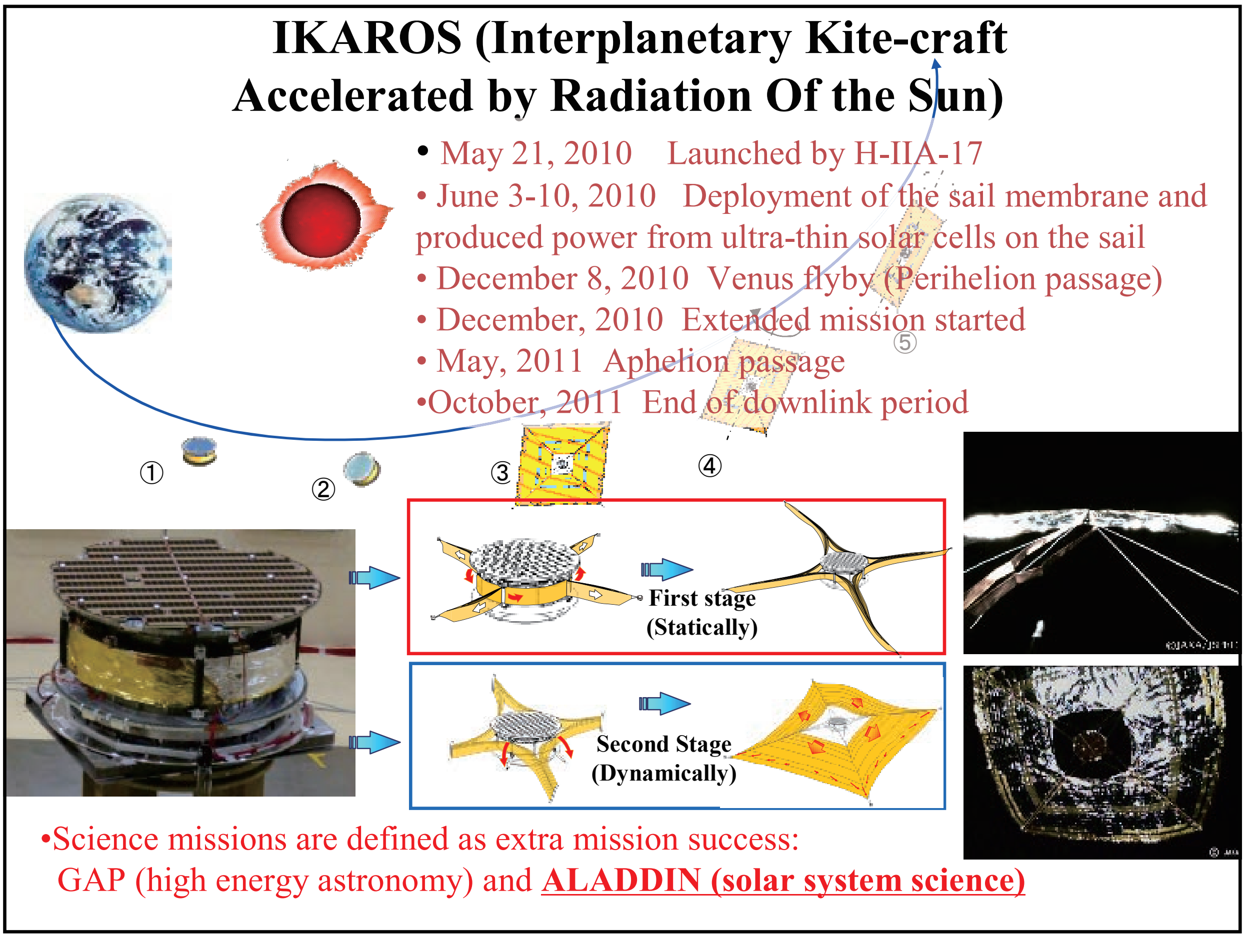
(© JAXA/ISAS Akari Team)

Exo-debris Disk Model

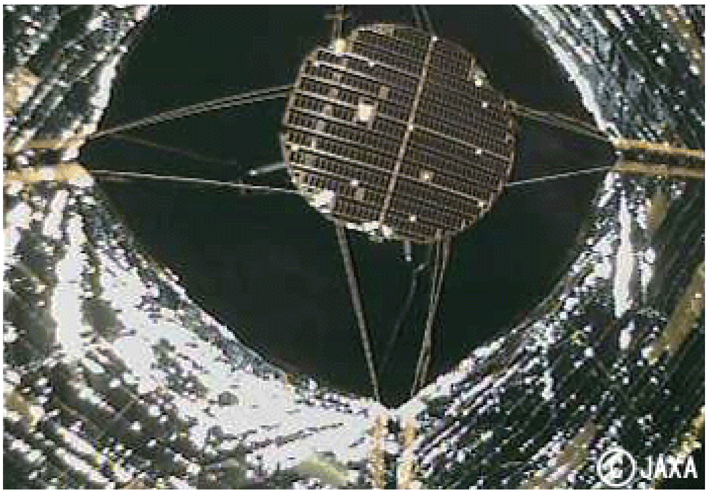


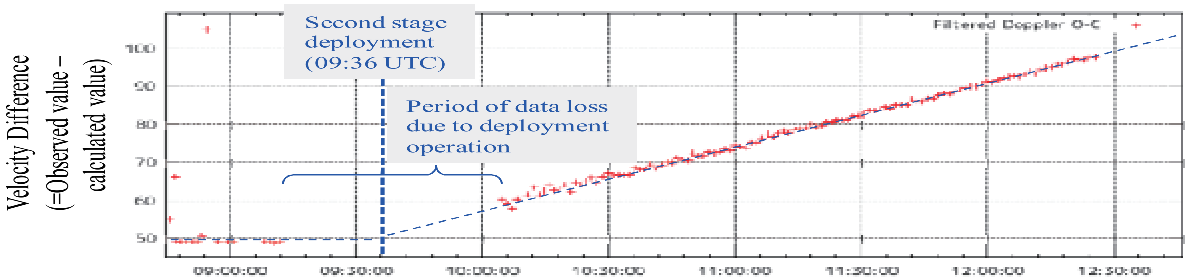
4


2003
2010
2015
Early 2020's
History of
Solar Sail Missions
in Scale
Europe/Germany
(Moon)
Gossamer-1
(L = 5 m,
A=25 m^2)
Gossamer-2
(L=20 m,
A=400 m^2)
Gossamer-3
(L=50 m,
A=2500 m^2)
Japan
(Jupiter
Trojans)
Solar Power Sail
(L=55 m,
A=3000 m^2)
(Venus)
IKAROS
(L=14 m,
A=200 m^2)
SSSAT
(L = 5 m,
A=25 m^2)
S310-34
(D=10m,
A =~100 m^2)
B30-71
(L = 4m,
A=~16 m^2)
(SE-L1)
U.S.A.
Nano-Sail-D
(L=~3 m,
A=10 m^2)
Sunjammer
(L=38 m,
A=1200 m^2)


IKAROS (Interplanetary Kite-craft
Accelerated by Radiation Of the Sun)
• May 21, 2010 Launched by H-IIA-17
• June 3-10, 2010 Deployment of the sail membrane and produced power from ultra-thin solar cells on the sail
• December 8, 2010 Venus flyby (Perihelion passage)
• December, 2010 Extended mission started
• May, 2011 Aphelion passage
•October, 2011 End of downlink period
①
②
③
④
⑤
First stage
(Statically)
Second Stage
(Dynamically)
•Science missions are defined as extra mission success:
GAP (high energy astronomy) and ALADDIN (solar system science)

The Successful Deployment and Solar Photon Acceleration of IKAROS in Interplanetary Space in June 2010





(Mori, Tsuda, et al., 2011)

IKAROS Trajectory in the Inner Planetary Region Compared with Those of the Spacecraft with Dust Counters : Helios, Galileo, IKAROS

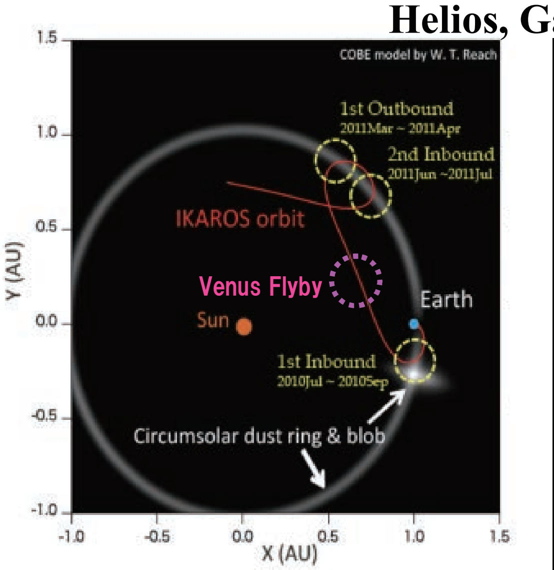
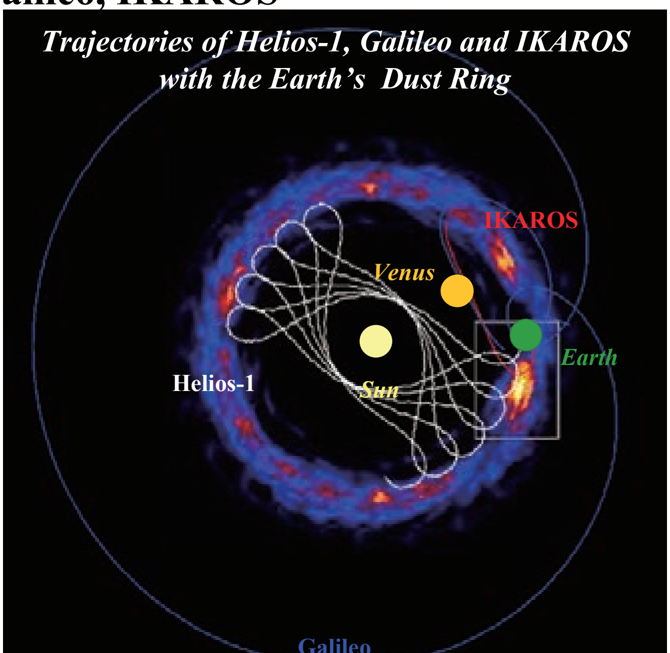


Fig.5 IKAROS trajectory and COBE cross section density model [2] in the Sun-Earth line fixed rotating frame. IKAROS entered into CDA region three times (the first one is the most dense region, blob and ring).

(Hirai, 2014)



(Courtesy: Dermott, et al.)

IKAROS passed the enhancement region of the Earth's circumsolar dust ring right after its launch

8

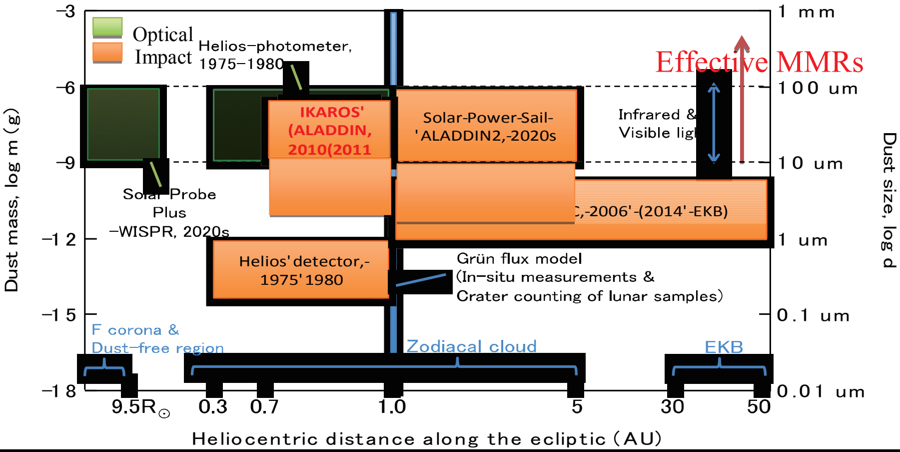
ALADDIN (Arrayed Large-Area Dust Detectors in Interplanetary space) onboard IKAROS

<Mission Objectives>

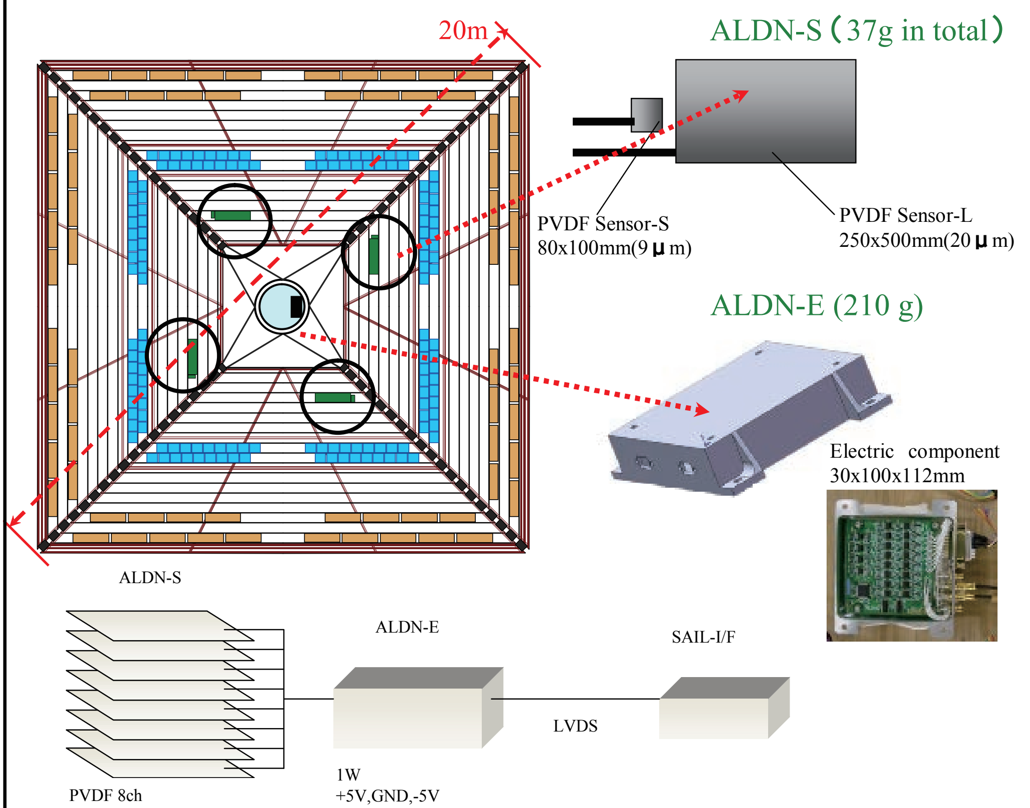
(1) Engineering demonstration of Japan's first and the world's largest dust detector to function in deep space, as a precursor of future outer planet exploration

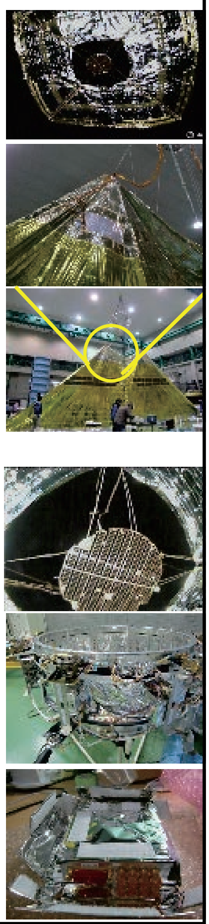
(2) Measure dust flux variation in heliocentric distance inside 1 AU with statistically reliable data

Comparison with Past Dust Measurements

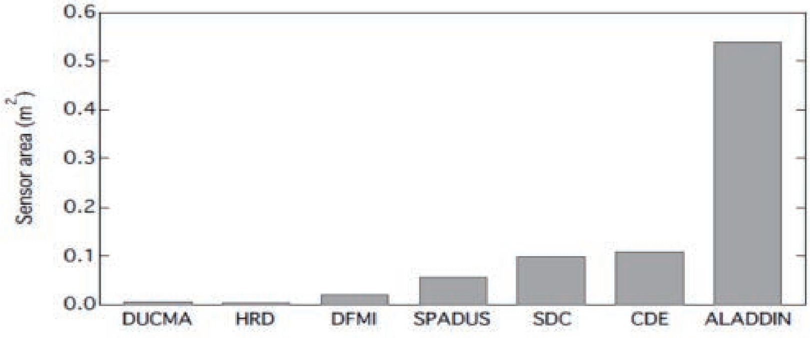


IKAROS-ALLADIN System

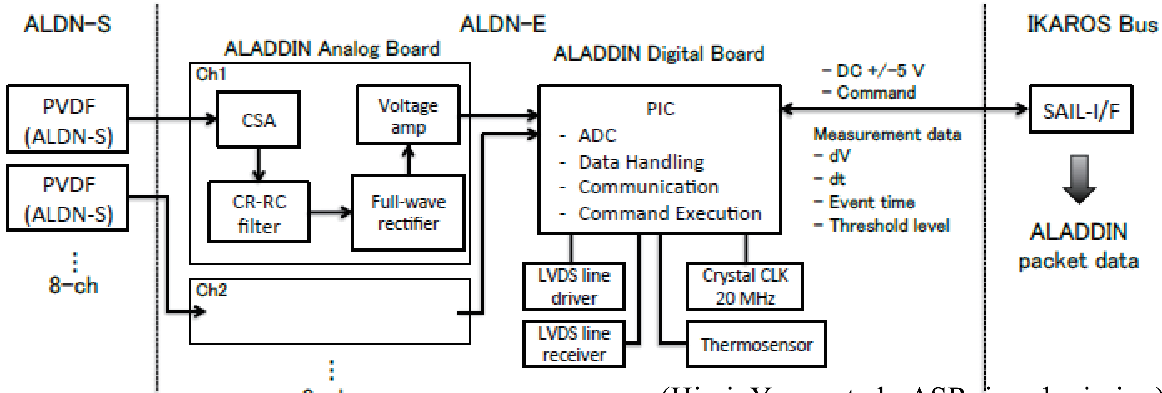




Sensor Area Comparison among Past Dust Detectors



ALDN-S/E System Block Diagram



(Hirai, Yano, et al., ASR, in submission)

Operation Record of IKARS-ALADDIN in 2010.06~2011.10.

<2010>

5/21 Launch

6/21 ALDN-E switched on、Started the initial operation

6/21-30 Health check and detection sensitivity validation of ALDN—E and -S

6/22 Detection of the first dust impact

6/30~ Nominal operation started; continuous measurement without RCD and SAP operations to avoid interference noise and out-of-communication periods

12/8 Flyby of Venus (Perihelion passage)

12-end Nominal operation ended and extended mission started

<2011>

4/27~5-end Aphelion passage

6/~ The second round of inbound cruising measurement started

10/ The last downlink of the ALADDIN data due to telecomm resource limit

<2012>

9/ The first resuming of telecom and health check after hibernation

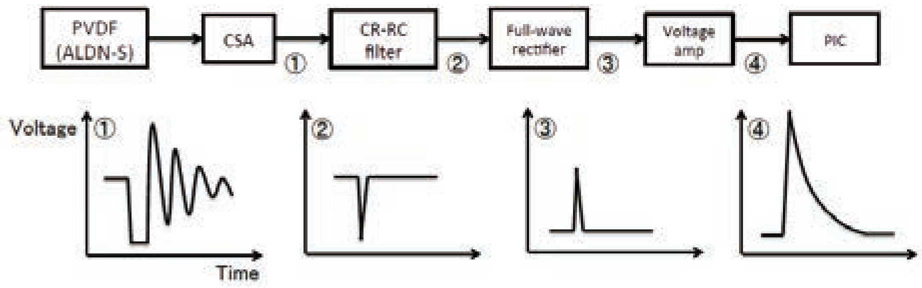
<2013>

3/31 Official closure of the IKAROS project

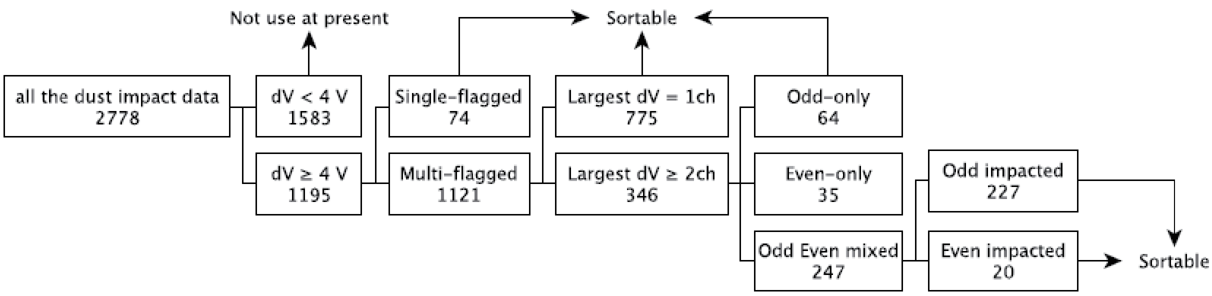
6/ The second resuming of telecom and health check after hibernation

12

PVDF Impact Data Processing

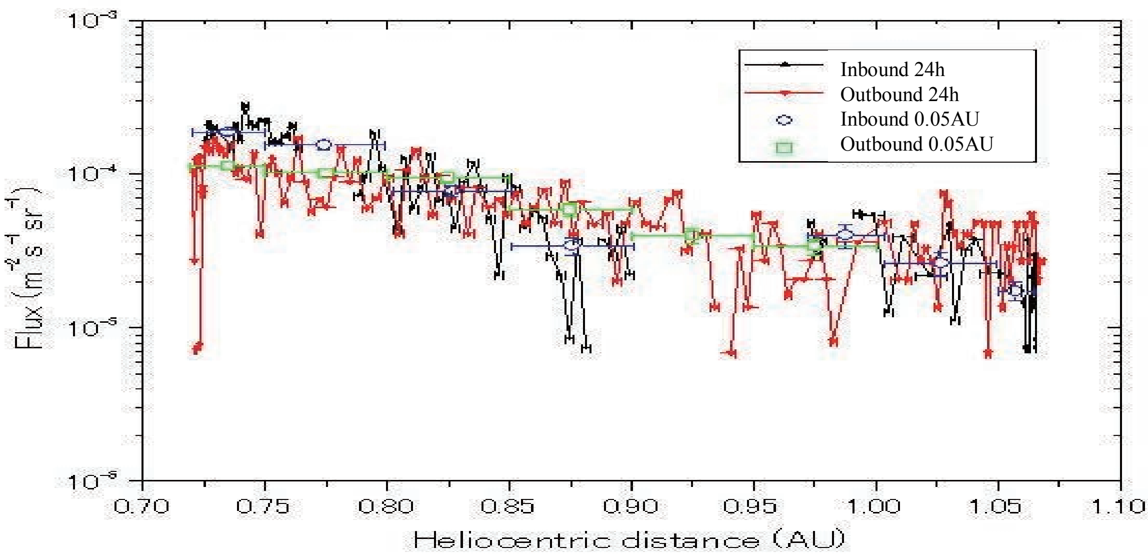


ALDN-S Acquired Data Screening & Deduction



(Hirai, Yano, et al., ASR, in submission)

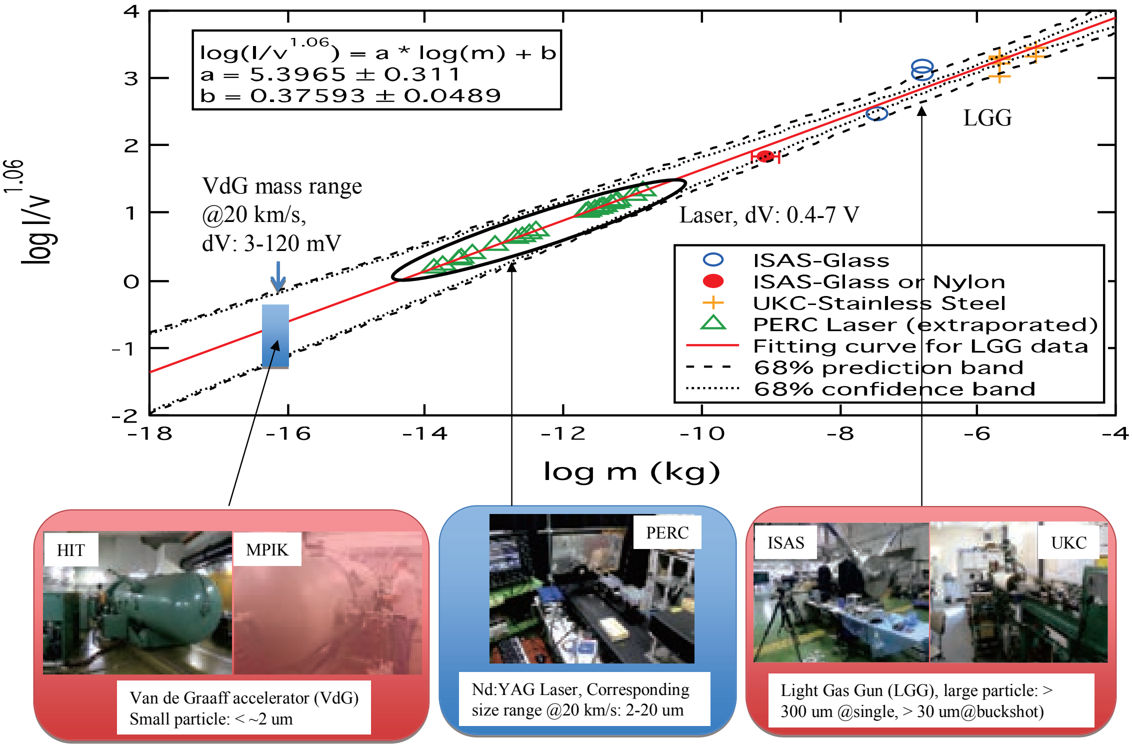
Fine Temporal Measurements of Round-Trip Flux of IKAROS Trajectories between the Perihelion and the Aphelion in 24-hours Bin



(Yano, et al., 2011)

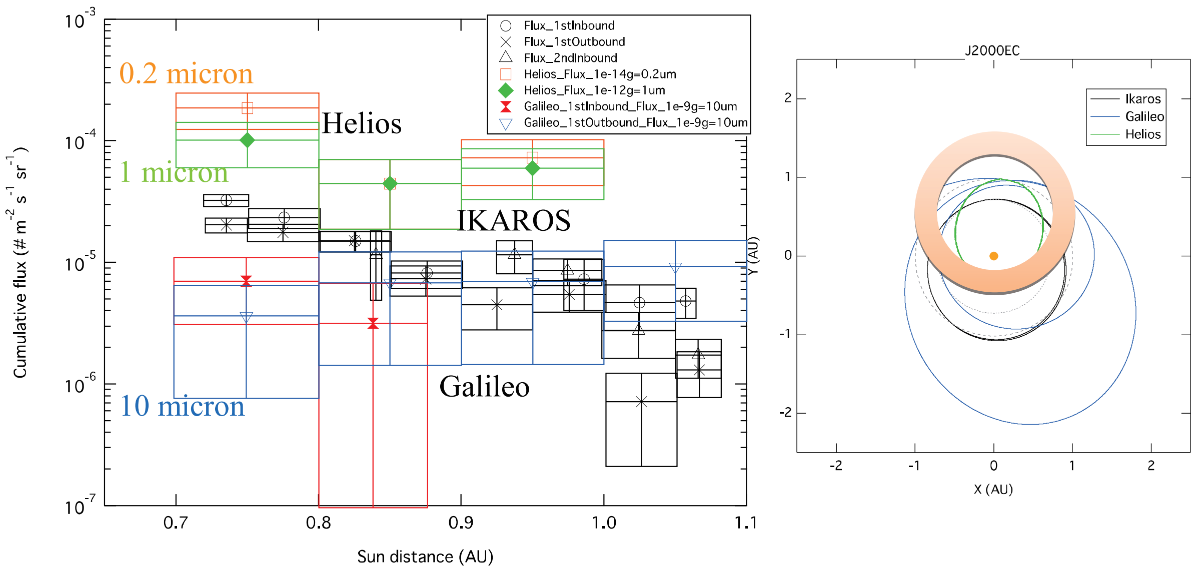
14

Wide-Range, Integrated Hypervelocity Impact Calibration Curve for ALADDIN PVDF Sensors



(Hirai, Yano, et al., PSS, 2014) 15

Flux Comparison of IKAROS-ALADDIN with Past Data in Different Size Range (HELIOS, Galileo) inside 1 AU



- ALDN Flux Data only selected for the dVmax > 4 V:
  ➔ Equivalent to 10 micron order impacts for inbound near Earth.

16

Dust Flux Enhancement at the Earth's Trailing Blob

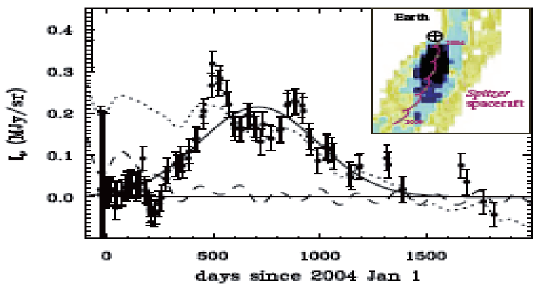
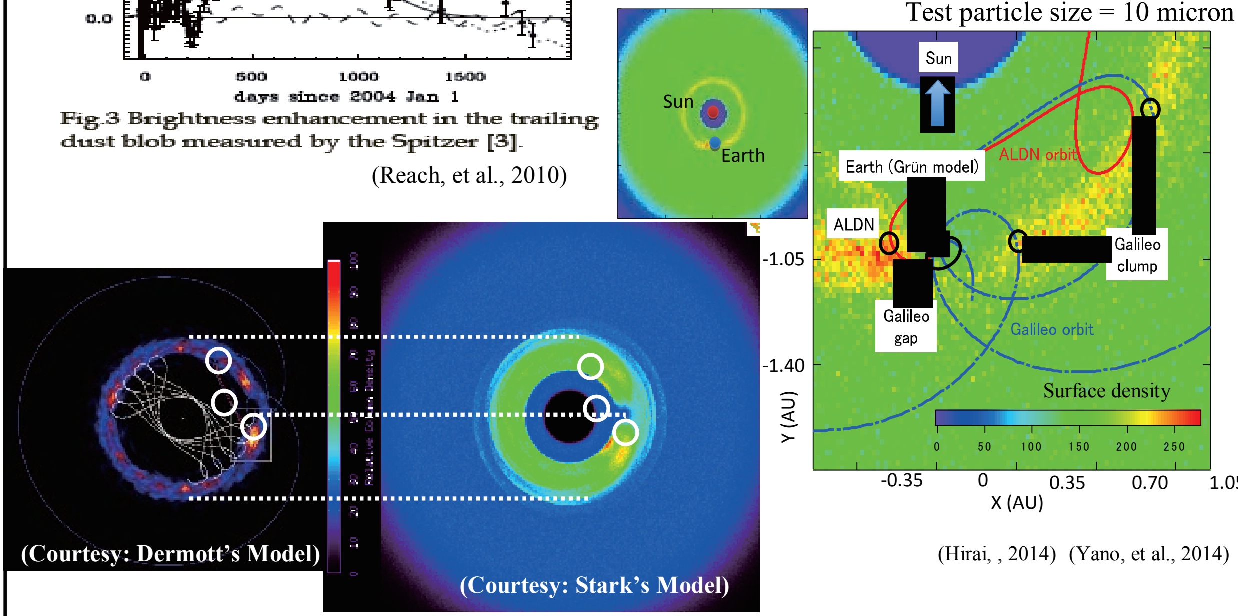


Fig.3 Brightness enhancement in the trailing dust blob measured by the Spitzer [3].

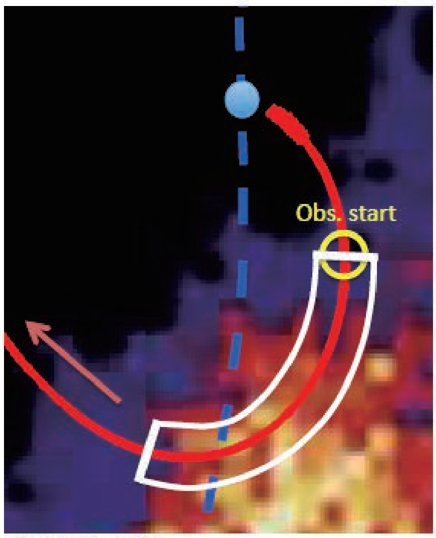
(Reach, et al., 2010)

Trajectory Comparison among the Earth's Mean Motion Resonance Dust Ring Models by Dermott et al. and Stark respectively

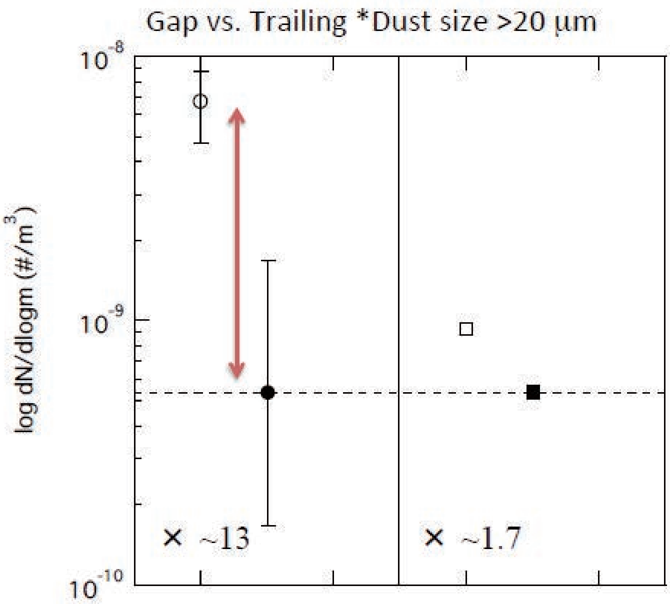


(Hirai, , 2014) (Yano, et al., 2014)

IKAROS Trajectory through the Earth's Circumsolar Dust Ring Blob Confirmed by ALADDIN

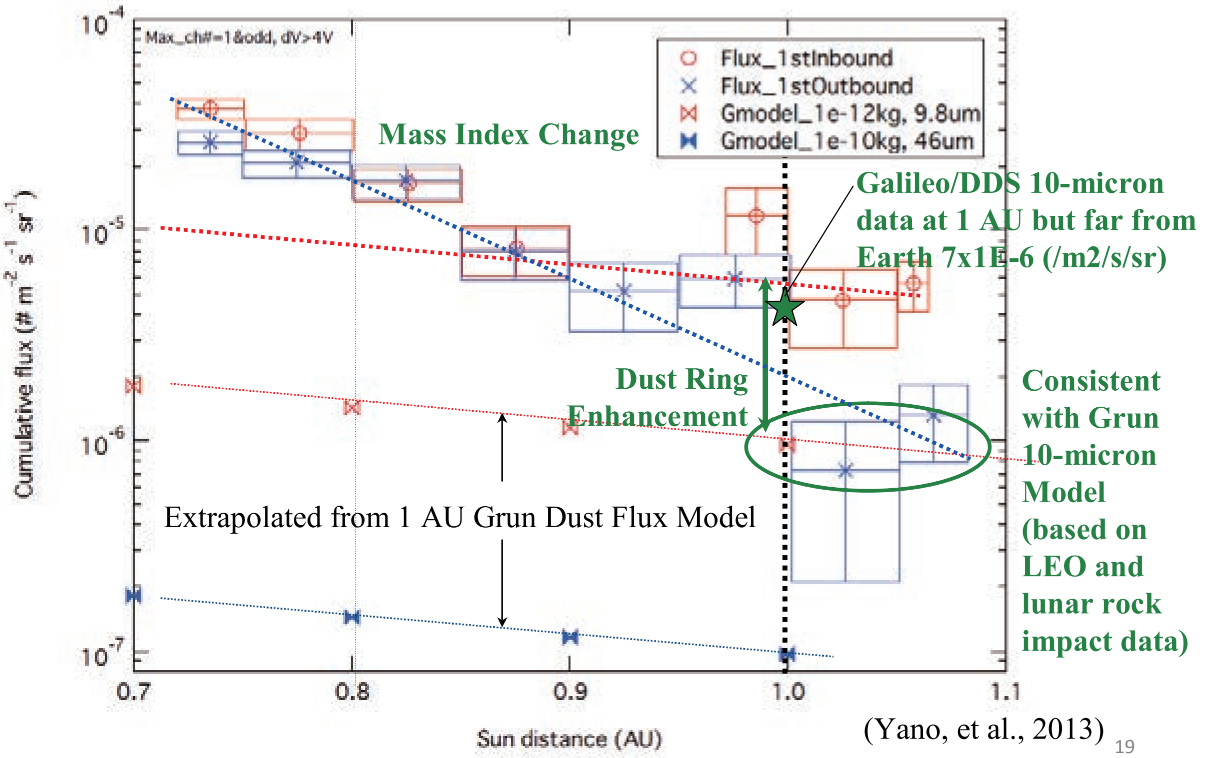


Dermott+1994



(Hirai and Yano, 2014)

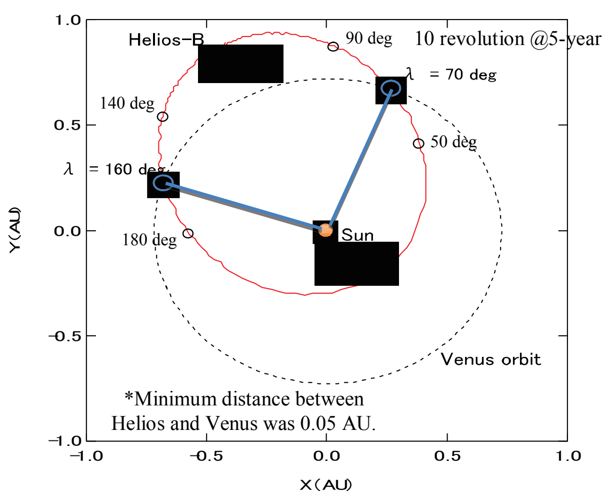
Direct Confirmation of Dust Ring Enhancement at the Earth’s Trailing Blob

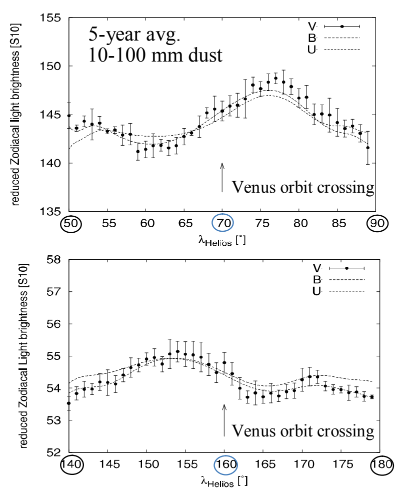


(Yano, et al., 2013) 19

Venus Circumsolar Dust Ring Detected by Optical Scattering by Helios-B and More Recently by STEREO

***Cf.* Optical observation by Helios-B photometer (Leinert&Moster, 2007)**

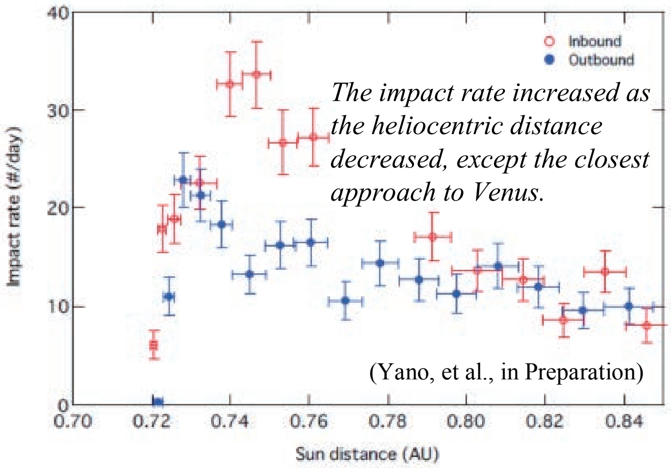




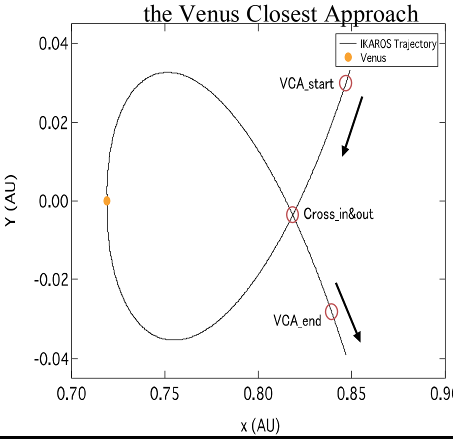
Ring width ≈ 0.06 AU (FWHM)

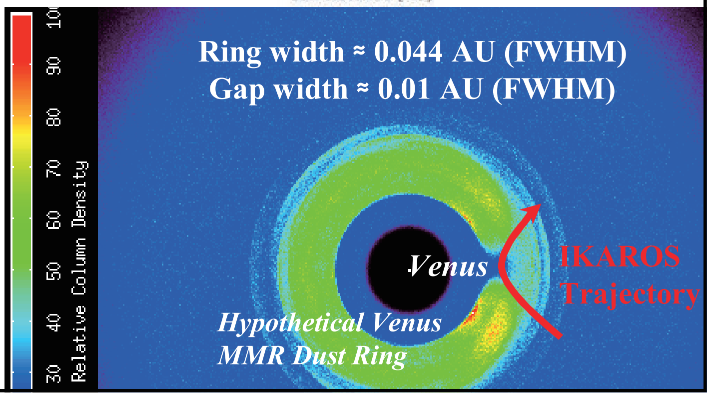
(Also by Jones et al., Nature, 2014)

Impact Rate of IKAROS-ALADDIN near Venus



IKAROS Trajectory near the Venus Closest Approach





The S&K Model Predicts that Mean Motion Resonance near 1 AU Triggers Impact Fragmentation

Venus Earth

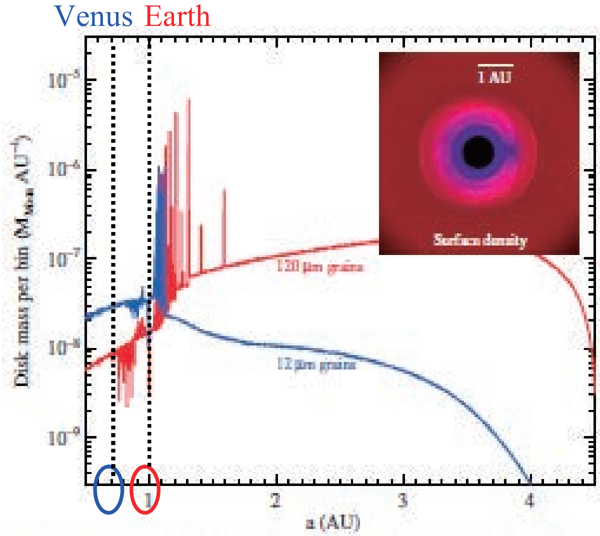
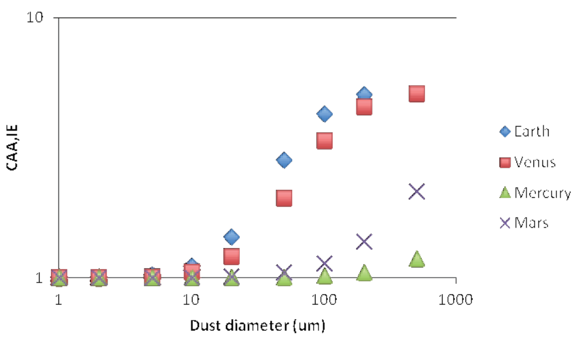


Figure 9. Disk mass (in Lunar masses) as a function of semimajor axis for a disk of fragmenting grains in the presence of an Earth-mass planet at 1 AU orbiting the Sun. The inset false-color image shows the face-on surface density of the disk. MMRs near 1 AU trigger fragmentation, a process which may explain the population of small warm dust interior to Fomalhaut's resolved ring structure (Stapelfeldt et al. 2004).

(Stark and Kuchner, 2009)

➔ Impact-induced, fragmented small meteoroids are expected to contribute flux enhancements inside the circumsolar dust ring near 1 AU

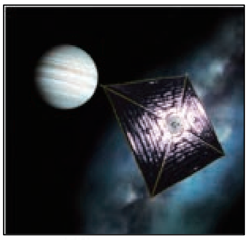
CAA,IE at 4 planets

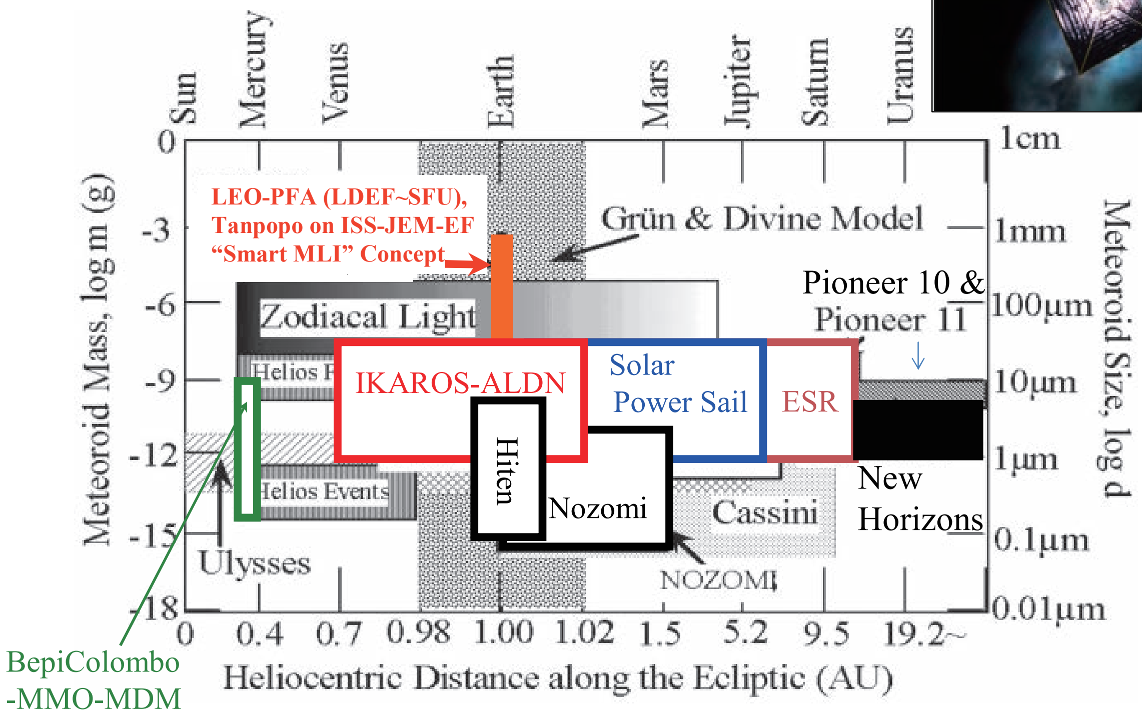


➔ Surface Density Contrast Efficiency by Planets and Dust Size

22

Meteoroid Measurement Opportunities by Japanese Space Exploration and Experiments





Summary

• ALADDIN is Japan's first interplanetary dust detector composed of 8 channel PVDF sensors deployed on the thin sail membrane at 0.54 m^2, the largest ever detection area in the history of cosmic dust detection.

•ALADDIN was successfully launched onboard the IKAROS solar sail spacecraft in May 2010 and recorded >2800 dust impact detections of >1-2 micron on the anti-Sun face in the Earth-Venus space (0.73-1.06 AU), between June 2010 and October 2011.

•ALADDIN results directly measured statistically significant increase of dust flux both by heliocentric distance decrease and the presence of circumsolar structure of 10-micron order dust for the Earth and Venus as well as the gap regions nearby the planets, which require a new dust model compliant with MMR dust ring and collisional evolutions.