Past Solar Wind Fluxes At The Locations Of Gas-rich Meteorite Parent Bodies Based On Noble Gas Studies: Implications To The Past Heliocentric Distances

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Outline

- A calculation model for the past SW fluxes on the gas-rich meteorite parent bodies is established.
- Calculated past SW fluxes on the parent bodies of 6 out of 7 meteorites are roughly consistent with expected fluxes at current asteroid locations.
- Inner migration or ~4 times higher past SW flux than the current flux can account for the high SW flux on the PRE 95410 parent body.

Introduction

To understand the evolutions of asteroid orbits, past heliocentric distances of asteroids are critical information. Several studies attempted to obtain the past heliocentric distances of meteorite parent bodies by comparing SW noble gas concentrations in gas-rich meteorites with those in the lunar samples [e.g. 1-4], as the SW flux is inversely related to the square of the heliocentric distance, but with a problem that the different properties between the lunar and asteroid regolith such as maturities, gardening processes and effect of the Earth's magnetosphere, are not considered. Here we describe a new method to calculate past SW fluxes at the locations of meteorite parent bodies and estimate and re-estimate the past heliocentric distances of the parent bodies of seven meteorites.

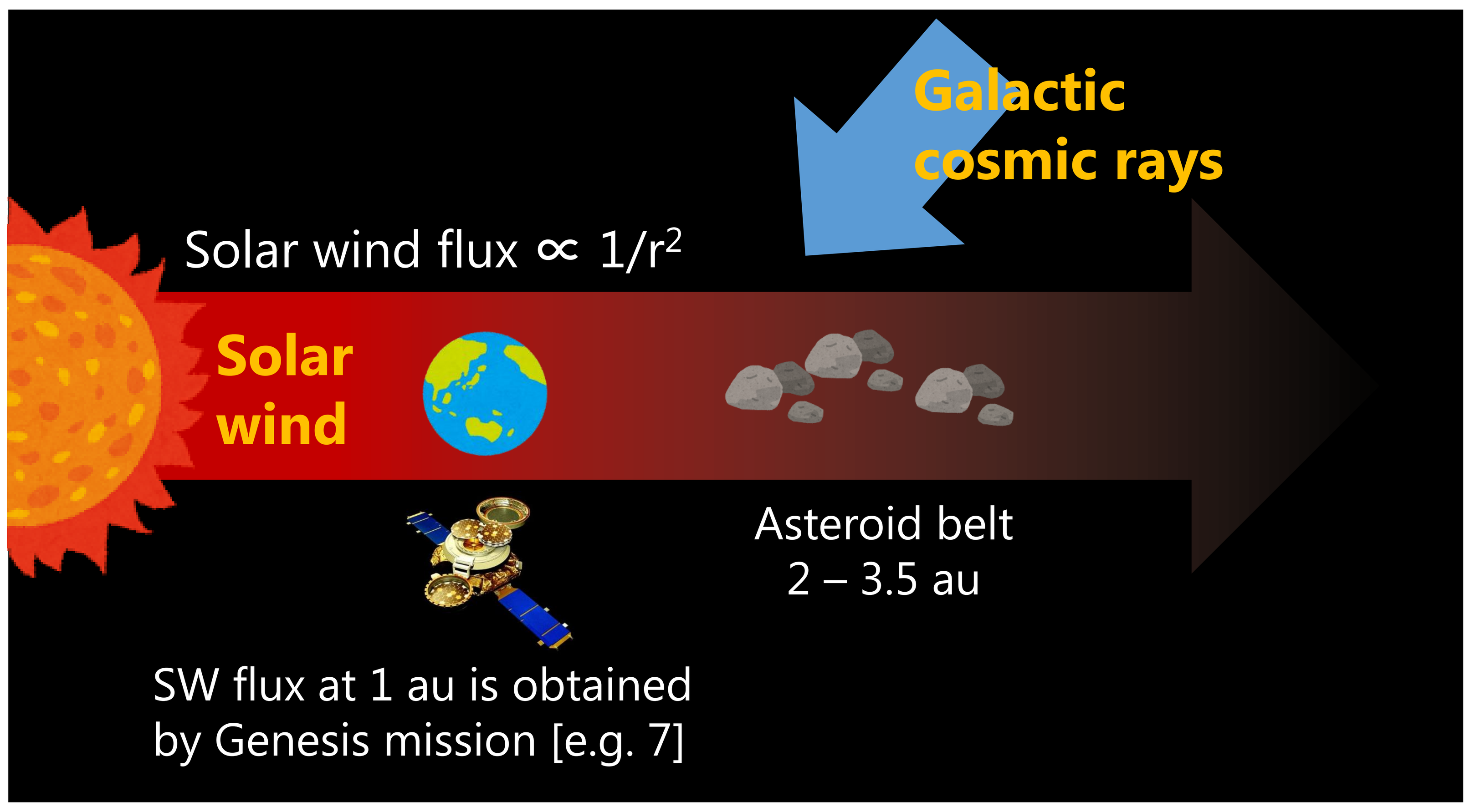
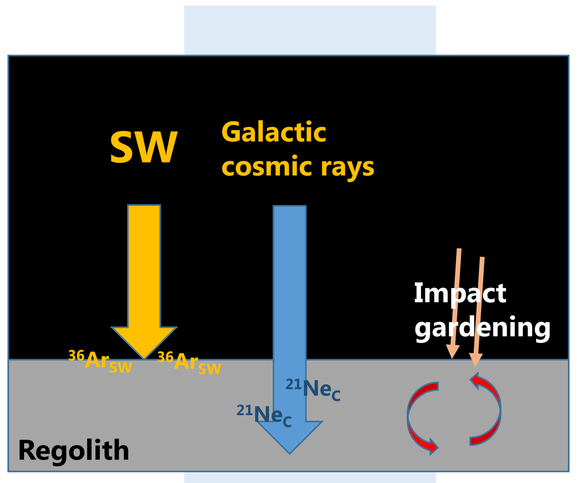


Fig. 1 Irradiation in the solar system; solar wind (SW) and galactic cosmic rays (GCRs).

◎Calculation of past $^{36}Ar_{SW}$ flux (F_{36}) on the parent body of a gas-rich meteorite

History of gas-rich meteorites (model)



◄ Fig. 2a Acquisition of noble gases on the regolith of meteorite parent body.
- $^{36}Ar_{SW}$ atoms are implanted (~50 nm [8]).
- $^{21}Ne_C$ atoms are produced via spallation (~m).
- Surface regolith is continuously mixed by small impacts (gardening process).

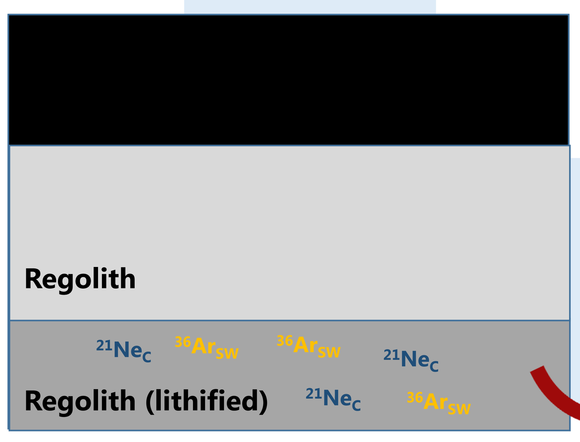


Fig. 2b Lithification of the regolith.

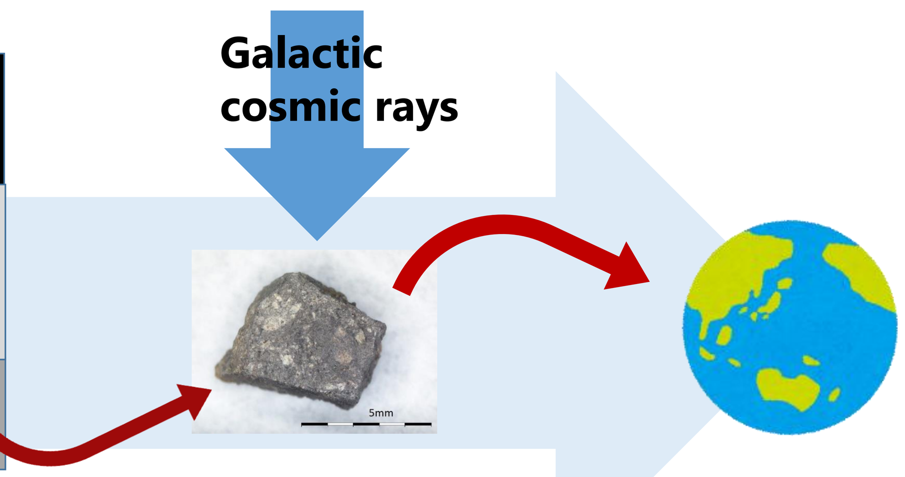
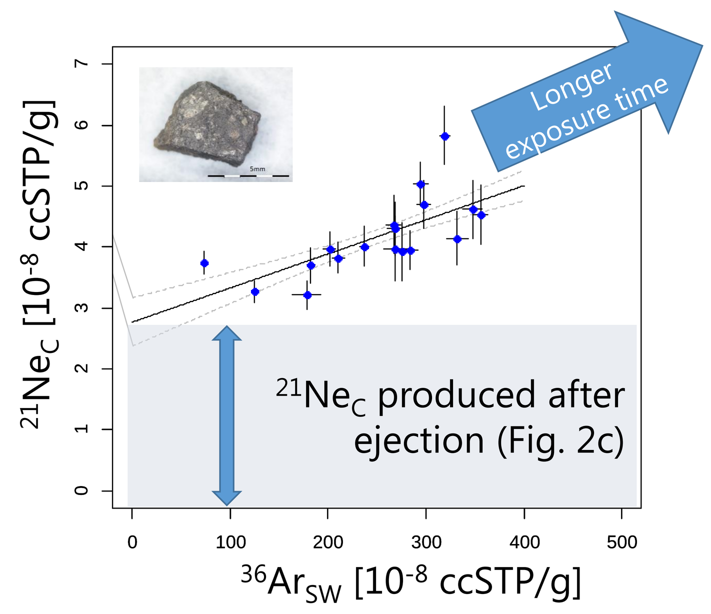
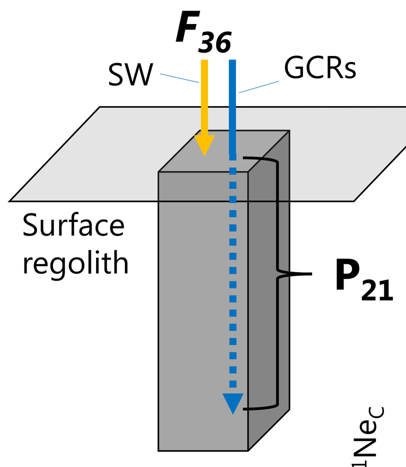


Fig. 2c Excavated by a large impact and fly to the Earth.

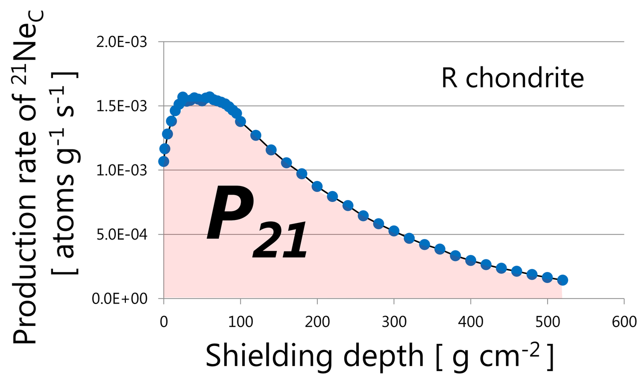
Calculation



▲Fig. 3a Concentrations of $^{21}Ne_C$ and $^{36}Ar_{SW}$ in matrix samples of the PRE95410 and a regression line (1σ).



◄ Fig. 3b The slope (a) of the regression line in Fig. 3a corresponds to the ratio of F_{36} ($^{36}Ar_{SW}$ flux) to P_{21} (production rate of $^{21}Ne_C$ per unit area) if the regolith is assumed to be well-mixed.

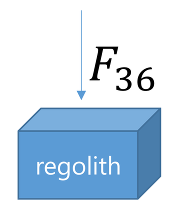


▲Fig. 3c The P_{21} [atoms cm^{-2} s^{-1}] is calculated from a physical model [9]

$$(1)\quad F_{36} = a^{-1}P_{21}$$

[atoms cm^{-2} s^{-1}]

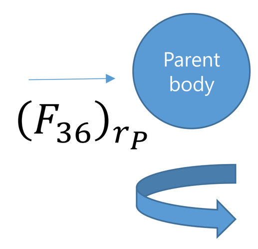
(1) $^{36}Ar_{SW}$ flux on the regolith.
a is a slope of the correlation line in Fig.3a and Fig.4 (see also Fig.3b). P_{21} is a production rate of $^{21}Ne_C$ per unit area [atoms cm^{-2} s^{-1}] (see Fig.3c).



$$(2)\quad (F_{36})_{r_P} \geq \pi F_{36}$$

[atoms cm^{-2} s^{-1}]

(2) $^{36}Ar_{SW}$ flux at the heliocentric distance (r_P).
π is because meteorite parent body is rotating. $(F_{36})_{r_P}$ is lower limit because SW flux is lower at higher latitudes due to the shallower angle of incident.



◎Past heliocentric distances (r_P) of the meteorite parent bodies

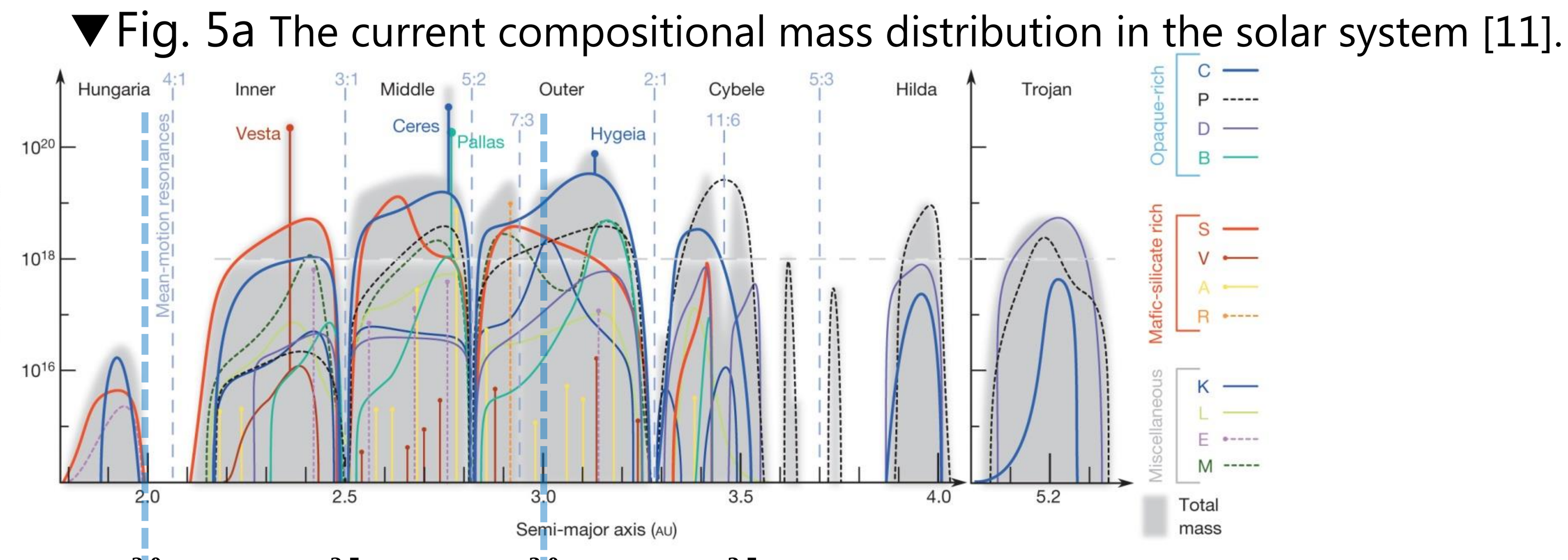
$$\underset{(au)}{r_P} = \sqrt{(F_{36})_{1au}/(F_{36})_{r_P}}$$

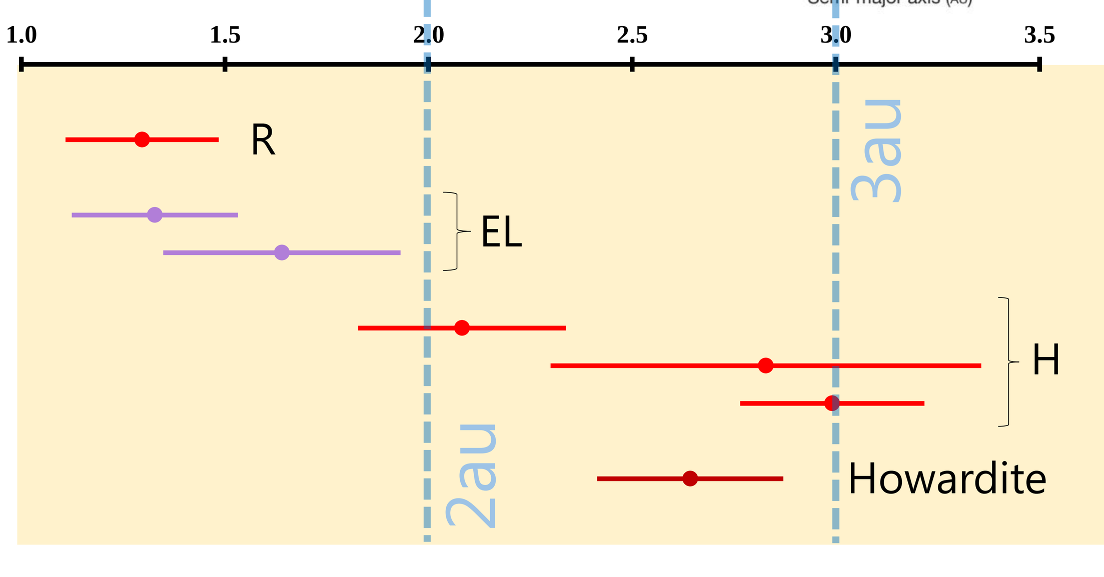
◄ Calculation of past heliocentric distance (r_P).
$(F_{36})_{1au}$ is the **past** $^{36}Ar_{SW}$ flux at 1 au. In this study, we used the **current** $^{36}Ar_{SW}$ flux at 1 au obtained by the Genesis mission [7] for the calculations of r_Ps.

	PRE 95410 (n = 18)	ALH 85119 (n = 19)	MAC 88136 (n = 18)	Fayette-ville (n = 19)	Tsukuba (n = 21)	Acfer 111 (n = 31)	Kapoeta (n = 28)	Genesis data [7]
$(F_{36})_{r_P}$	**221±64**	**<210**	**<138**	**86±21**	**46±17**	**41±6**	**53±9**	371±5
r_P [au]	**1.3±0.2**	**>1.3**	**>1.6**	**2.1±0.3**	**2.8±0.5**	**3.0±0.2**	**2.6±0.2**	-
r_P in previous estimation [au]	-	>1.1	>1.3	~2-3	$4.2^{+0.4}_{-1.2}$	-	-	-
Predicted formation location [au] [10]	2.6	1.9-2.1	1.9-2.1	2.43	2.43	2.43	2.36	-
Classification	R3	EL3	EL3	H4	H5-6	H3-6	Howardite	-
Noble gas data	[1]	[2]	[2]	[3]	[4]	[5]	[6]	-

Table 1. The past solar wind ^{36}Ar flux $(F_{36})_{r_P}$[atoms cm^{-2} s^{-1}] at the heliocentric distances of meteorite parent bodies with the current solar wind ^{36}Ar flux at 1 AU obtained by the Genesis mission [7] and the calculated and re-calculated past heliocentric distances r_P [au] of the meteorite parent bodies. The $(F_{36})_{r_P}$ is lower limit as described in equation (2), and the calculated r_P is upper limit.

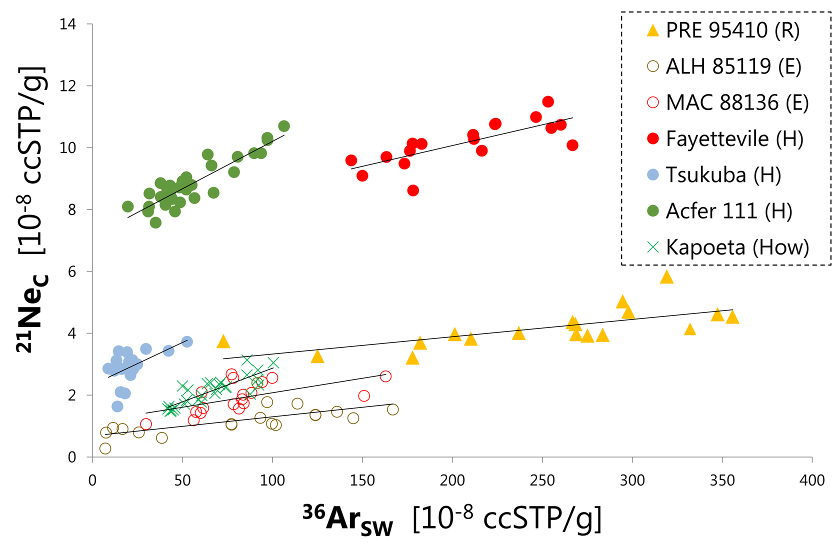
▼Fig. 5a The current compositional mass distribution in the solar system [11].





◄Fig. 5b The upper limits of past heliocentric distances (r_P) of the gas-rich meteorite parent bodies (1σ).

The calculated r_Ps are roughly in agreement with the current asteroid distribution (Fig. 5a) and the predicted formation locations (Table. 1) except for PRE 95410 (R3). The high SW flux on the PRE 95410 parent body may suggest inner migration of the parent body, or ~4 times higher past SW flux than the current SW flux. Dating the antiquities of the exposures are highly desirable for further constraints.



▲Fig.4 Concentrations of $^{21}Ne_C$ and $^{36}Ar_{SW}$ in the seven gas-rich meteorites.

How old is the "past"?

The antiquity of the exposure is **largely unconstrained**, as there have been no direct estimation technique except for a possible secular change of Kr/Xe ratio in the SW [11]. Compaction ages of meteorites provide lower limits of the antiquity of exposure though the number of reported data are limited.

Meteorite	Antiquity	Method
Fayettevile (H)	<~100 Ma [12]	$(Kr/Xe)_{SW}$ ratio
Kapoeta (How)	<~2* Ga [6]	K-Ar ages of clasts and matrix
CM chondrites	4.2-4.4* Ga [13]	Fission track density

*Compaction age

Is the past solar wind flux high?

The past $(F_{36})_{r_P}$ at the Kapoeta (howardite) parent body is larger than 53±9 [atoms cm^{-2} s^{-1}]. Assuming that the parent body is the asteroid 4 Vesta (at 2.4 au) and its heliocentric distance has never changed, the past $(F_{36})_{1au}$ is calculated as larger than 310±50. This is similar to the current $(F_{36})_{1au}$ (371±5 [7]), which suggests that **the past $^{36}Ar_{SW}$ flux (<~2 Ga; compaction age of the Kapoeta) is not high**. This is inconsistent with the model prediction (e.g. ~10 times larger than the current flux at 2.6 Ga [14]). Similarly, the amount of $^{84}Kr_{SW}$ atoms in the Apollo 15 and 16 deep drill core (2.4m) samples permits the average SW flux for ~4 Ga only ~2-3 times higher than the present-day value [12].

Summary

- The calculated past SW flux and past heliocentric distances of the meteorite parent bodies provide two implications: (1) the heliocentric distances of most meteorite parent bodies have never changed largely; (2) the intense past SW flux proposed by a model prediction [14] is less likely.
- The past SW flux on the PRE 95410 (R3) parent body is higher than expected. This can be explained by inner migration of the parent body or ~4 times higher past SW flux than the current flux.

References [1] Obase T. et al. (2015) *JPGU meeting 2015*, Abstract PPS22-08. [2] Nakashima D. et al. (2006) *M&PS* 41:851-862. [3] Wieler R. et al. (1989) *GCA* 53:1441-1448. [4] Nakashima D. et al. (2002) *AMR* 15:97-113. [5] Schultz L. and Franke L. (2004) *M&PS* 39:1889-1890. [6] Pedroni A. (1989) Ph.D. dissertation, ETH Zurich. [7] Meshik A. et al. (2014) *GCA* 127:326-347. [8] Eugster O. et al. (2006) *Meteorites Early Sol. Syst. II* 829–851. [9] Leya I. et al. (2001) *M&PS* 36:1547-1561. [10] Desch S. J. et al. (2018) *ApJ* 238:11. [11] Demeo F. E. & Carry B. (2014) *Nature* 505:629–634. [12] Wieler R. (2016) *CdE - Geochemistry* 76:463–480. [13] Macdougall J. D. & Kothari B. K. (1976) *EPSL.* 33:36–44. [14] Airapetian V. S. & Usmanov A. V. (2016) *AspJ.* 817, L24.