Study for origin of Martian moons using neutron spectrometry

（中性子分光法による火星衛星の起源の研究）

Junya Ishii[1], Daisuke Aoki[1], Kouhei Yoshida[1], Masayuki Naito[1], Hiroshi Nagaoka[1], Nobuyuki Hasebe[1, 2]

[1]School of Advanced Science and Engineering, Waseda University, Tokyo, Japan,
[2]Research Institute for Science and Engineering, Waseda University, Tokyo, Japan
55S 303, 3-4-1 Okubo, Shinjuku, Tokyo, 169-8555, Japan

ABSTRACT

There are two moons around Mars, Phobos and Deimos. Because they have never been explored directly, their origin is uncertain. Currently, the exploration mission of the Martian moons is planned in Japan. Its most important purpose is the elucidation of Martian moons origin. It is possible to give a constraint of the origin if we reveal whether the compositions of Martian moons are closer to Martian or primordial by elemental analysis. There is the large deference of hydrogen concentration between compositions of Martian and primordial. The amount of hydrogen is one of the important indicators to reveal the origin of Martian moons. Neutron is sensitive to the amount of hydrogen, which is an effective moderator for neutron. Therefore, by comparing the neutron fluxes in each energy range, hydrogen concentration in Martian moons will be determined. In this study, we estimate the difference of the neutron fluxes emitted from surface of the Martian moons by simulation derived from the elemental composition and discuss the origin of Martian moons.

第49回 月・惑星シンポジウム

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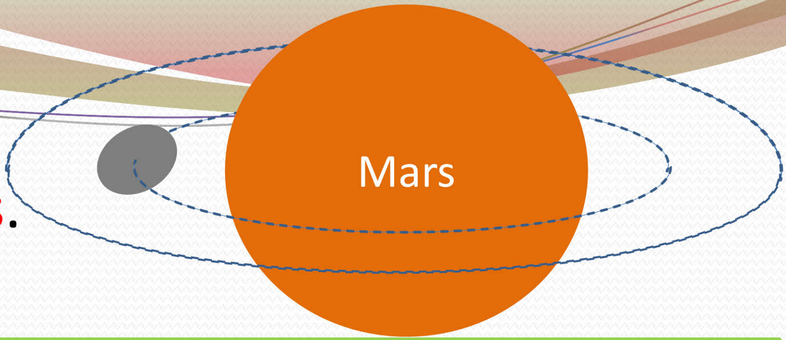
1. School of Advanced Science and Engineering, Waseda University, Tokyo, Japan,
2. Research Institute for Science and Engineering, Waseda University, Tokyo, Japan

Outline

- 研究背景・目的
- 中性子シミュレーションの概要
- シミュレーション結果
- 火星衛星観測のバックグラウンド
- 結論

Background

Mars has two moons, Phobos and Deimos.



Martian moons explorations in the past

Planned Mission in Russia

- Phobos1, 2 (1988) → Disruption of communication with the satellite
- Phobos-Grunt (2011) → Failure of leaving from the orbit around the earth

→ **Martian moons have never been explored directly.**
Their origin is uncertain.

Recently, the mission of Martian Moon eXploration (MMX) is planned in Japan.

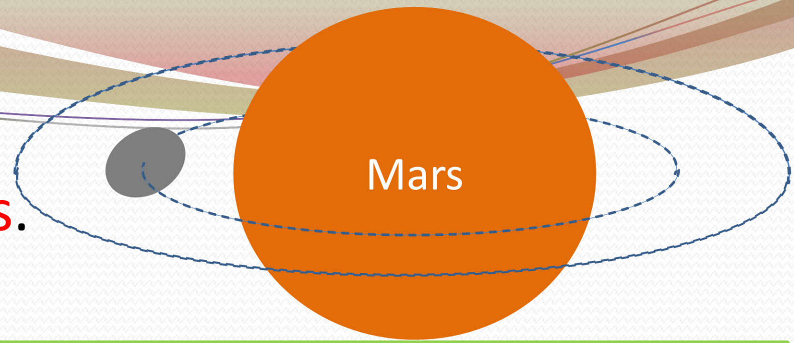
The most important purpose of the mission : origin elucidation of Martian moons

↑ Gamma-ray and Neutron Spectrometer (GNS) is proposed.

The purpose of my study : to give a constraint for elucidation of Martian moons origin by neutron measurement in the simulation

Background

Mars has two moons, Phobos and Deimos.



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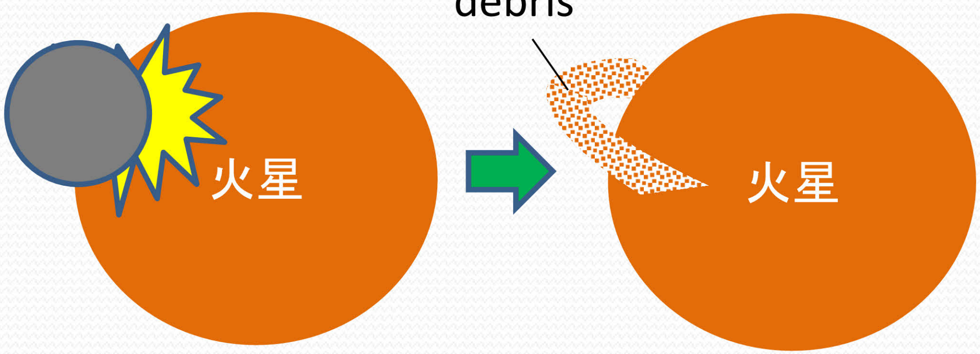
Their origin is uncertain.

Hypotheses of Martian moons origin

＜Giant impact＞



＜captured asteroid＞

Candidate composition of Martian moons

① Primitive composition → CI chondrite

② Martian composition → Martian meteorites (Shergotty, Chassigny, Nakhla)

Table1. Average concentrations of elements in meteorites (Martian meteorite Compendium, NASA, 2015; Anders and Grevesse, 2013)

	CI chondrite	Shergotty	Chassigny	Nakhla
H	2.02	0.00	0.00	0.00
C	3.45	0.00	0.00	0.00
O	46.4	41.4	39.6	41.0
Mg	9.53	9.24	19.1	5.86
Al	0.869	3.29	0.413	2.07
Si	10.7	21.7	17.6	22.9
S	5.26	0.17	0.080	0.070
Ca	0.928	5.34	0.474	9.31
Fe	18.5	15.0	21.0	15.2
Others	2.36	3.78	1.76	3.64

Most chondritic composition have high H-concentration.

Determination of H-concentration

Whether the composition is closer to Martian or Chondritic is distinguished.

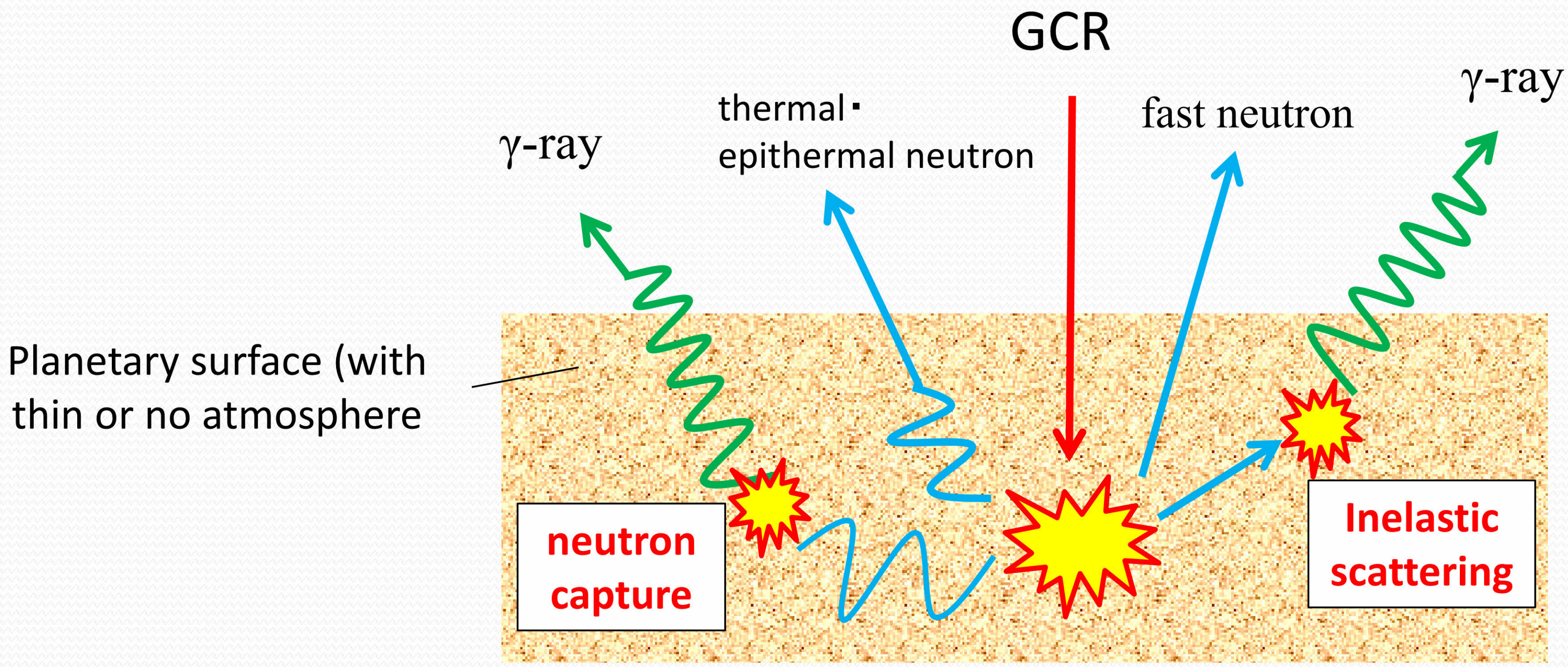
A constraint for elucidation of Martian moons origin will be given.

How to determine H-concentration of Martian moons

Neutron Spectrometry

(MESSENGER, Lunar Prospector, Dawn,…)

Neutron and gamma-ray production in planetary surface



<u>The fluxes of secondary neutrons are varied with H-concentration in planetary surface</u>

Hydrogen is an effective moderator for neutron

The H-concentration in planetary surface could be determined by comparing the neutron fluxes in each energy range.

シミュレーション概要

火星衛星(Phobos)表層で発生する中性子が中性子分光計でどのように観測されるかをみるシミュレーション

- **水素濃度の差**
- **元素組成の差**

Simulation code we used :
PHITS 2.76(Particle and Heavy Ion Transport code System) code

Models used in PHITS

- INCL4.6 (Intra-Nuclear Cascade of Liege) ; A. Boudard. et al. 2013
- JENDL-4.0; K. Shibata et al. 2011

Energy spectra of protons and helium nuclei

- Galactic Cosmic Ray (GCR)
  - Nuclei component (98%)
    - protons (87%)
    - helium nuclei (12%)
    - heavy particles(1%)
  - Electrons component (2%)

Empirical equation by Reedy et. al(1994),Lal et. al(1998)

$$\mathrm{J}(\mathrm{E},\varphi) = C \times \frac{E\left(E + 2m_p c^2\right)\left(E + \chi + e\varphi \times \frac{Z}{A}\right)^{-\gamma}}{\left(E + e\varphi \times \frac{Z}{A}\right)\left(E + 2m_p C^2 + e\varphi \times \frac{Z}{A}\right)} \ [\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ (\mathrm{MeV/n}){-1}]$$

$$\chi = a \exp(-bE)$$

C, a, b and γ are given by Lal (1998) and McKinney et al. (2006).

	C	a	b	γ
H	1.24×10^{6}	780	2.50×10^{-4}	2.65
He	2.26×10^{5}	660	1.40×10^{-4}	2.77

Energy spectra of protons and helium nuclei

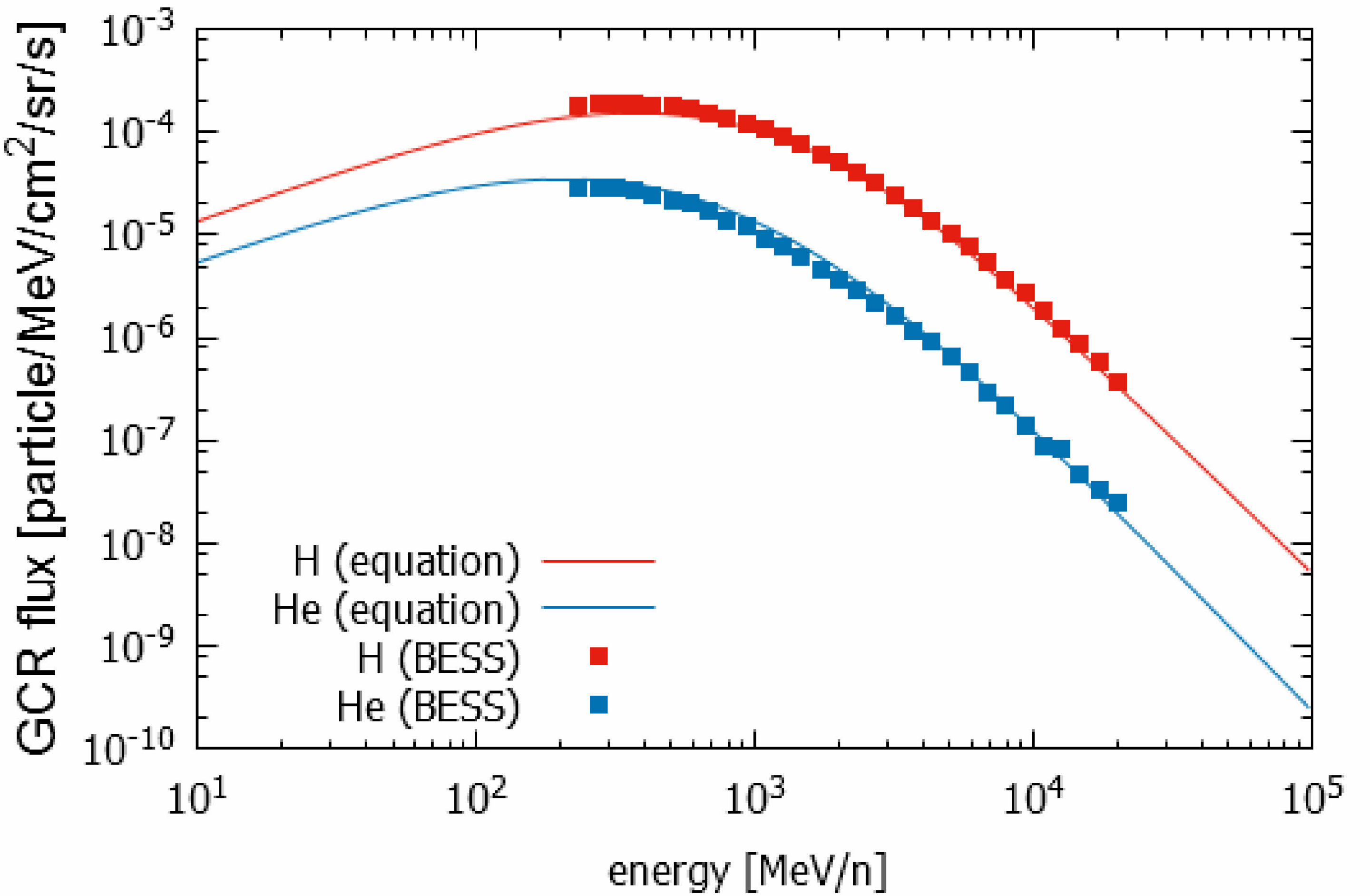
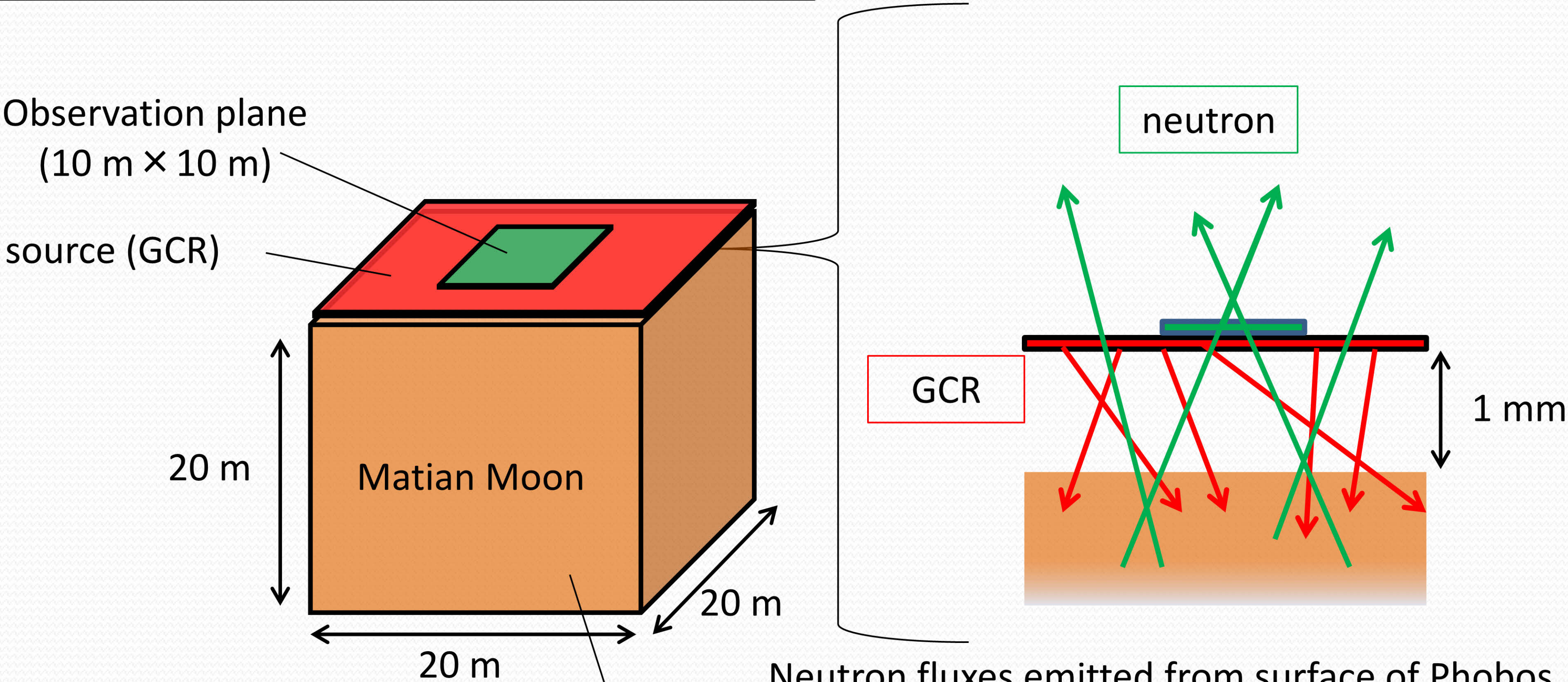


Figure. The comparison of GCR spectra between the data of BESS observation in 1997 (φ = 491 [MV]) and the energy spectra of proton and helium nuclei given by the empirical equation.

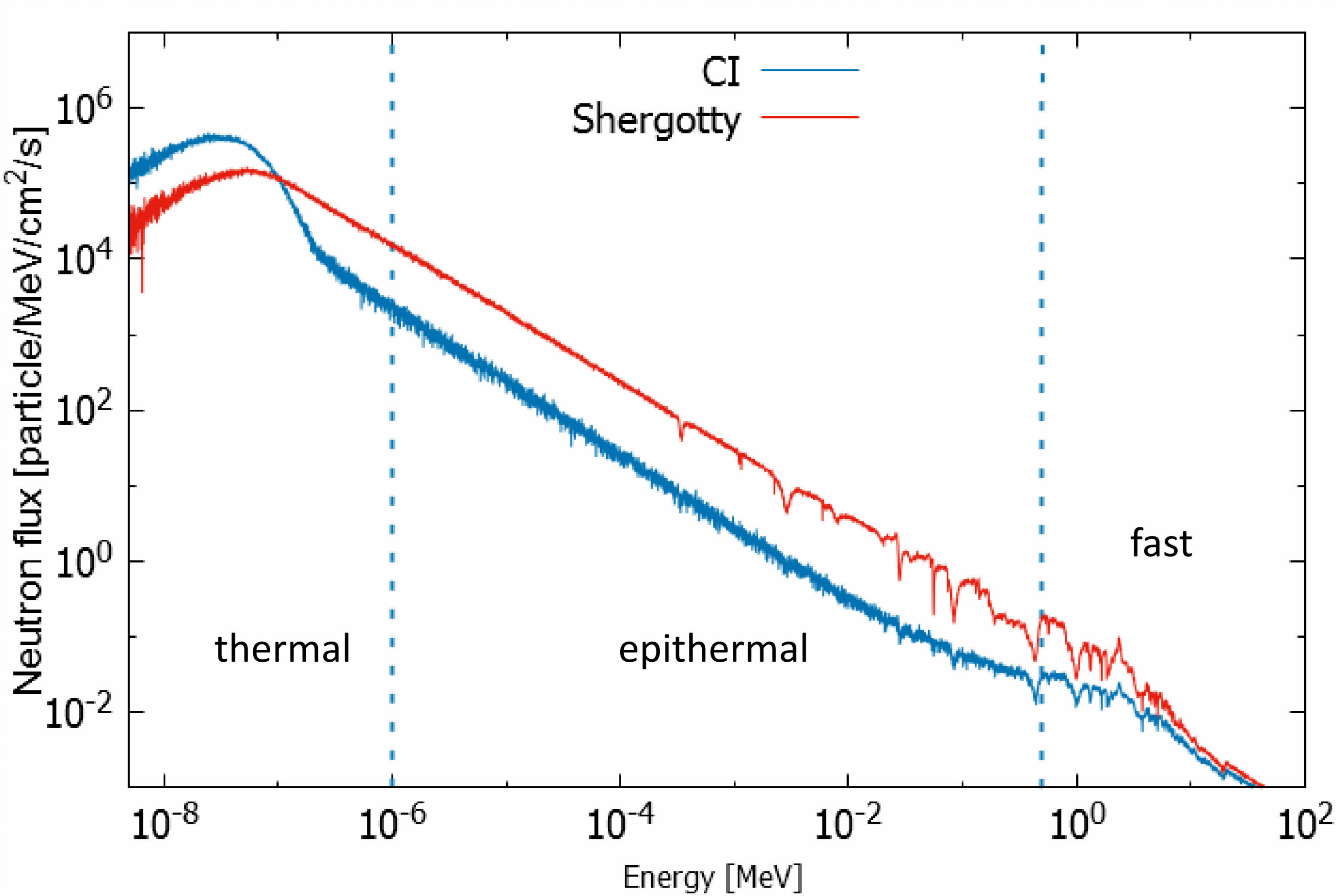
Simulation geometries (1)



Neutron fluxes emitted from surface of Phobos depending on H-concentration（0 to 20000 ppm）

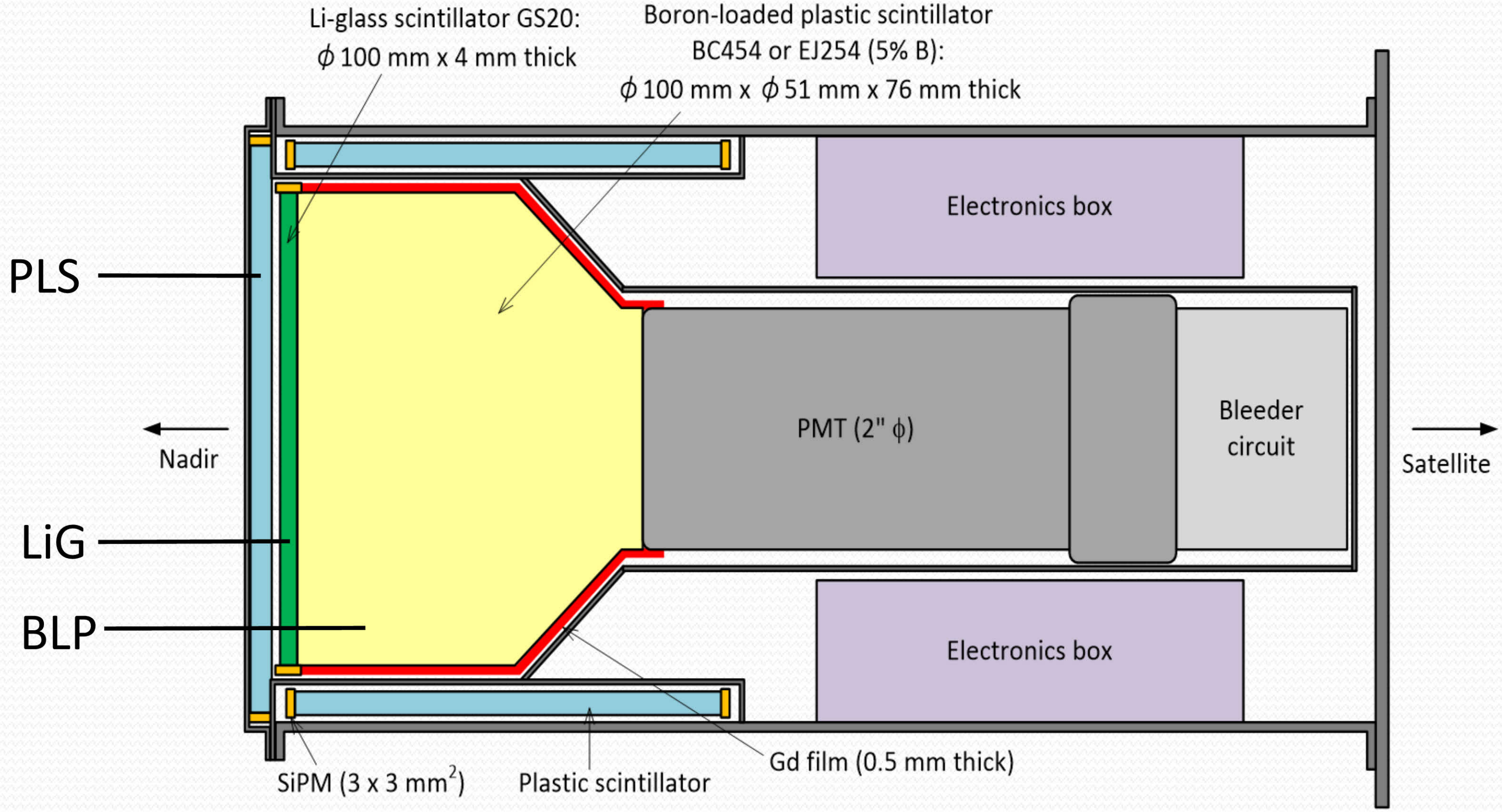
Compositions: CI chondrite or Martian meteorites (four types)
H-concentration: 0 to 20000 ppm

Results (1):各元素組成の中性子フラックスの比較



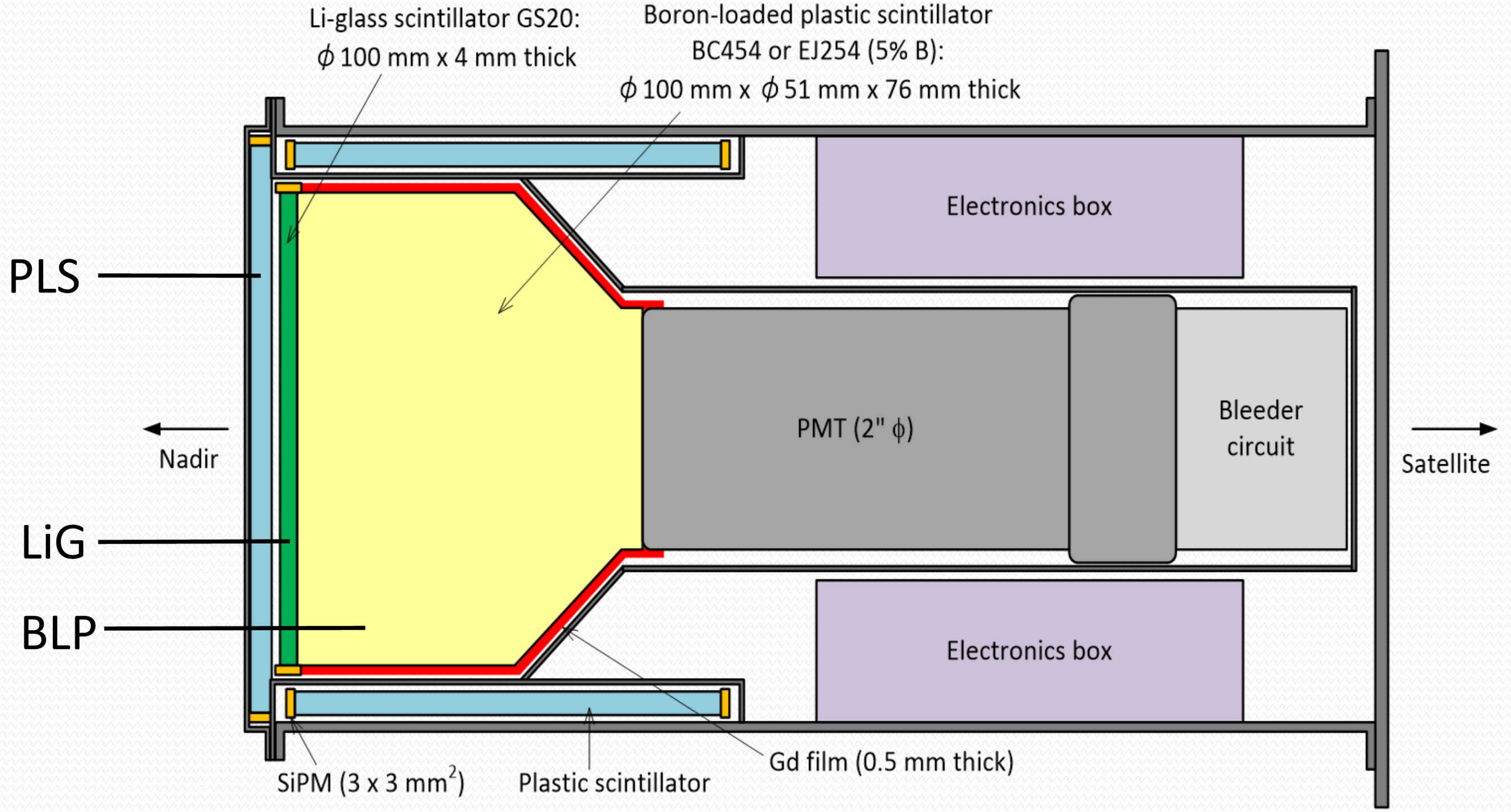
Figure：Neutron energy spectra of CI chondrite and Shergotty.

Neutron Spectrometer（NS)



- シンチレータの周りには、銀河宇宙線によるバックグラウンド除去のため、反同時計数用のプラスチックシンチレータ(PLS)を取り付ける。
- 後部には 2”ϕ のPMTを付ける。
- LiGおよびPLSの信号はMPPC (SiPM)により読み取る。

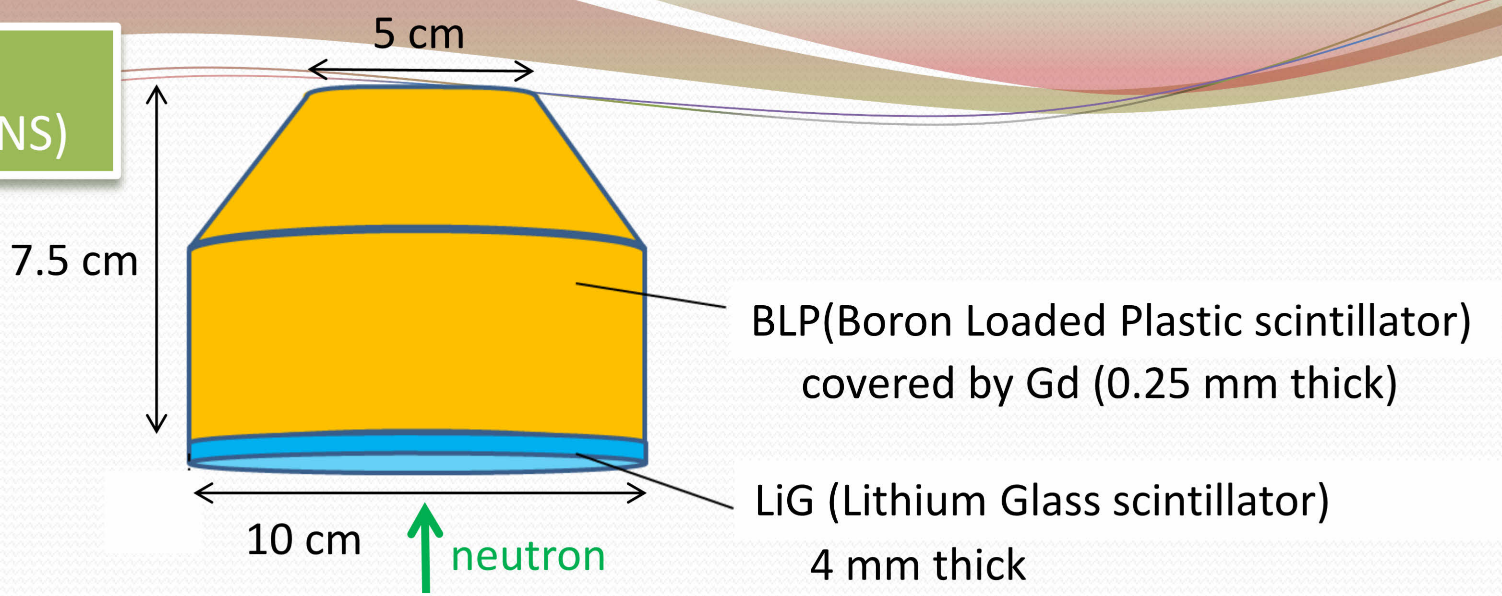
Neutron Spectrometer（NS）



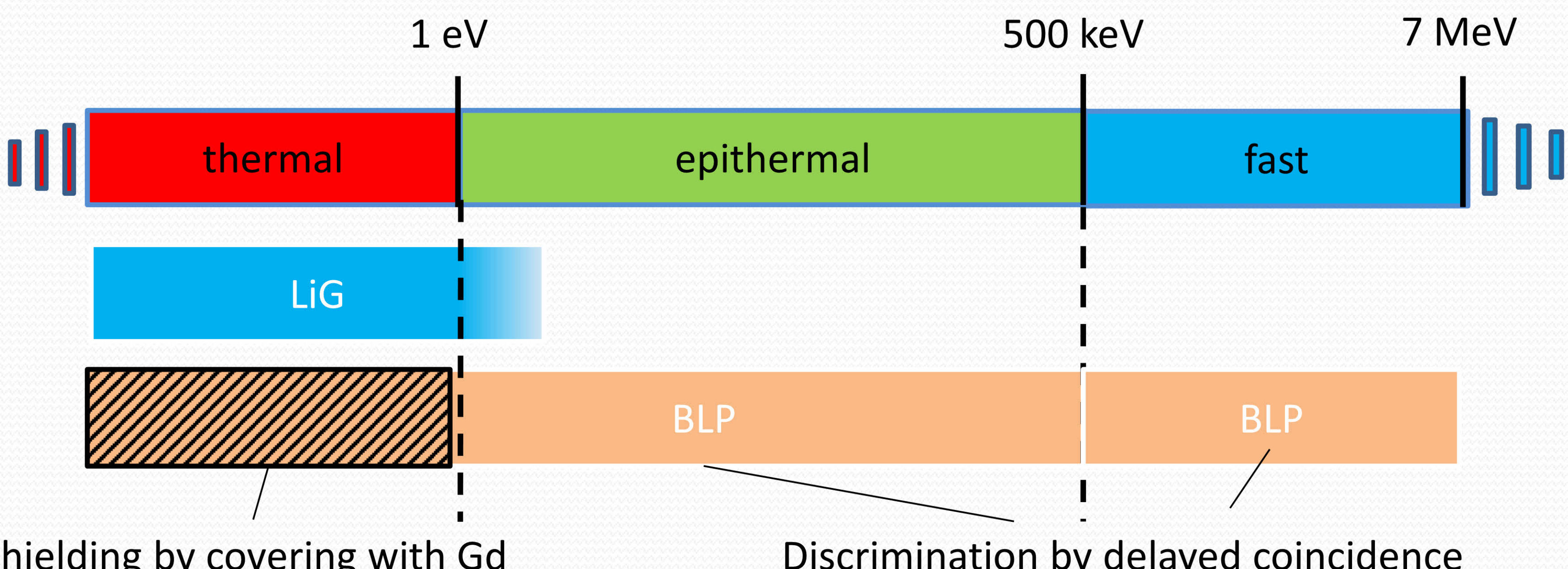
【LiG】 $^{6}_{3}Li + \mathrm{n} \rightarrow {}^{3}_{1}H + \alpha$ (Q値：4.78MeV)

【BLP】 $^{10}_{5}B + n \rightarrow \begin{cases} {}^{7}_{3}Li + \alpha \text{ (Q値：} 2.792 MeV) & \text{基底状態} \\ {}^{7}_{3}Li^{*} + \alpha \text{ (Q値：} 2.310 MeV) & \text{励起状態} \end{cases}$

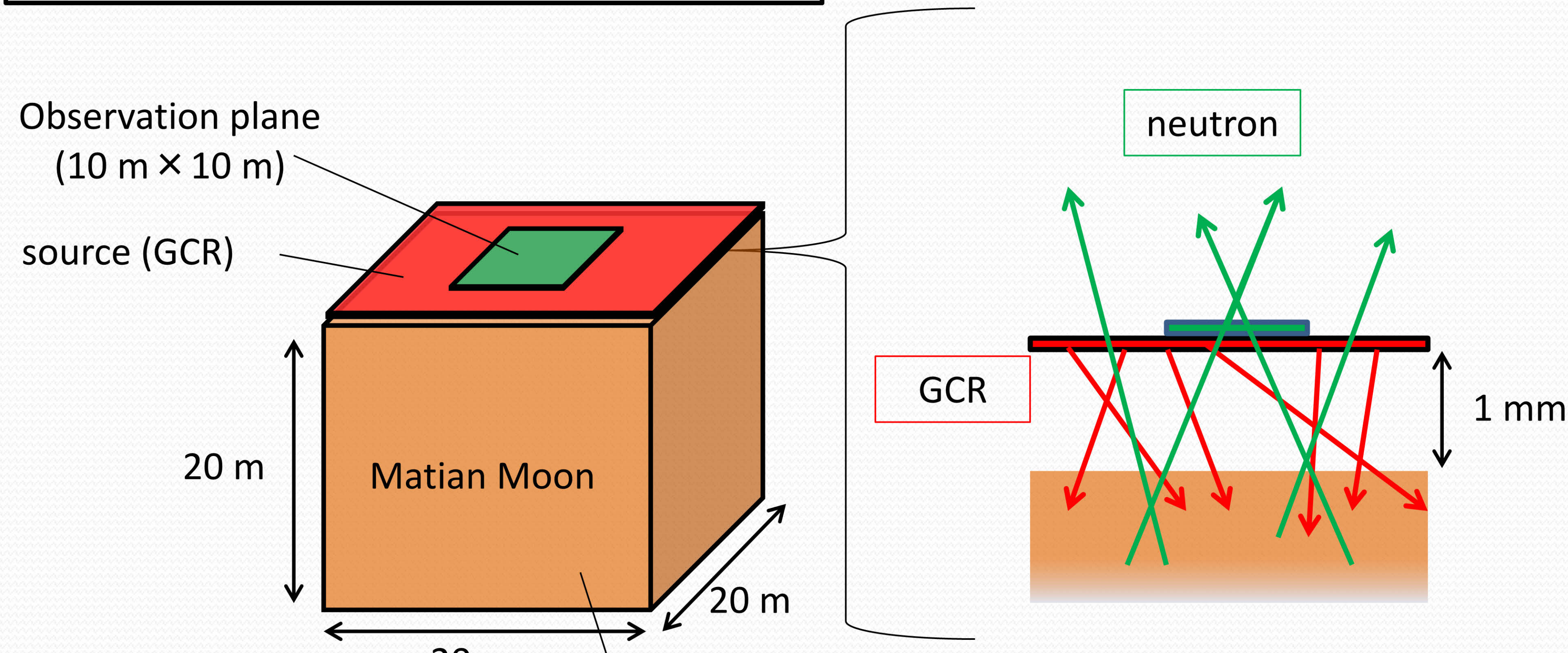
Neutron Spectrometer (NS)



Neutron energy ranges



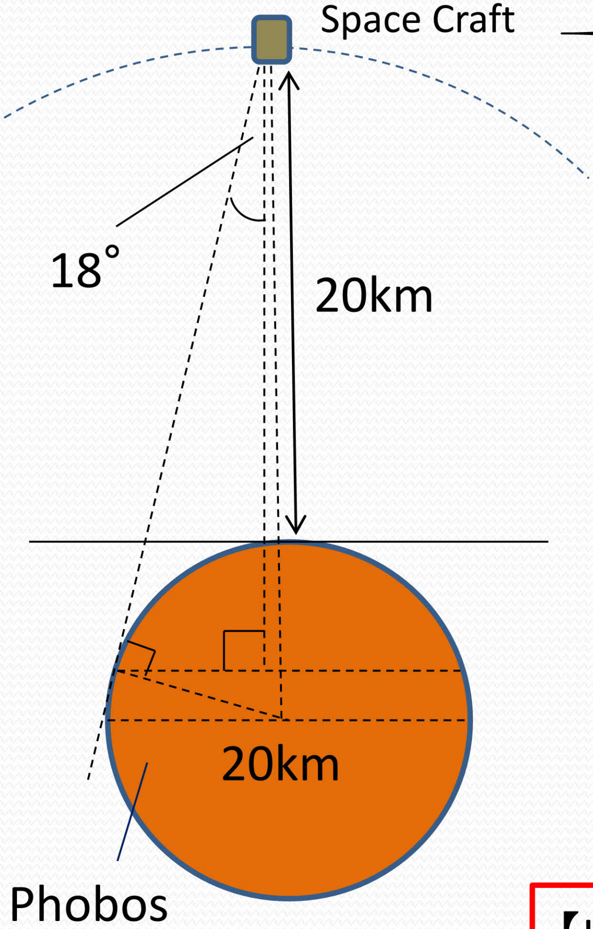
Simulation geometries (1)

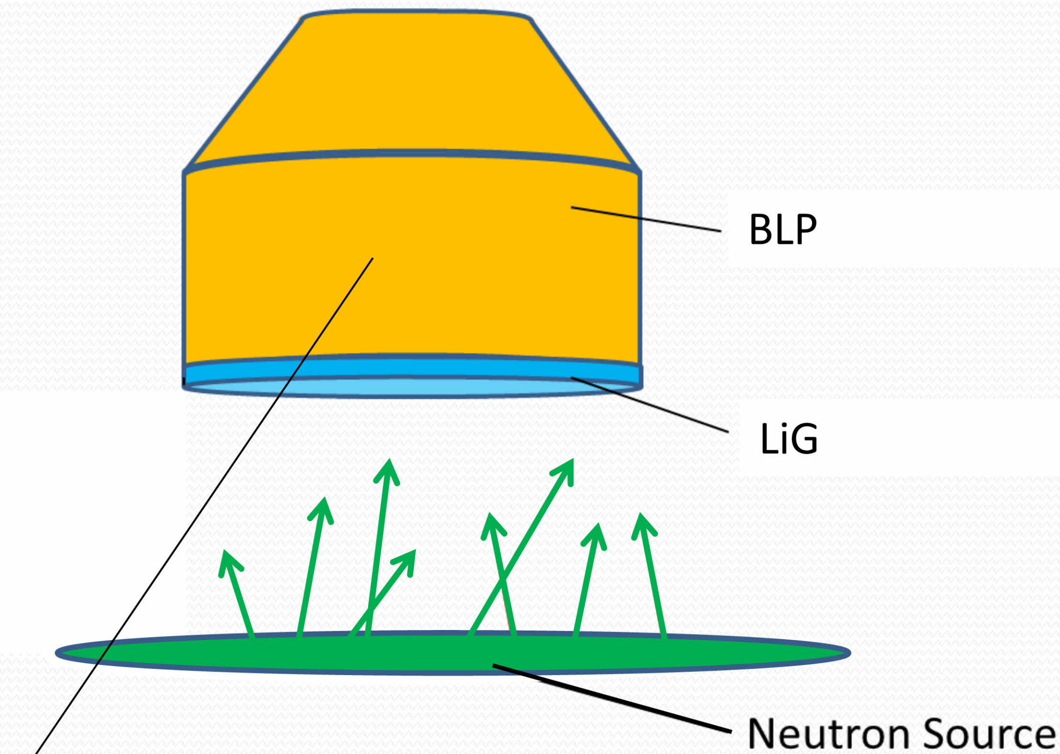


Neutron fluxes emitted from surface of Phobos depending on H-concentration（0 to 20000 ppm）

Compositions: CI chondrite or Martian meteorites (four types)
H-concentration: 0 to 20000 ppm

Simulation geometries (2)





Neutron fluxes emitted from surface of Phobos depending on H-concentration（0 to 20000 ppm）

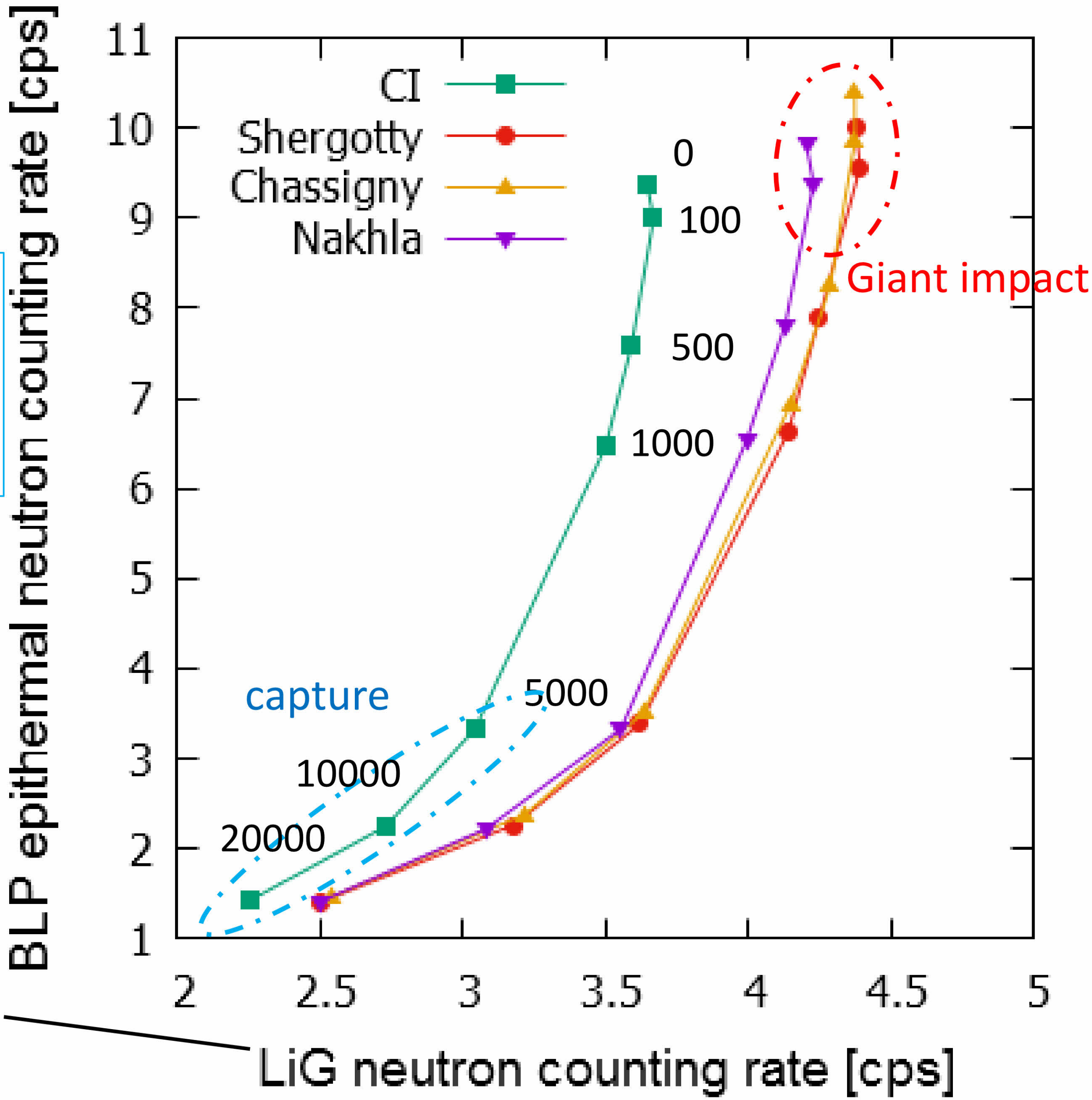
【LiG 】$^{6}_{3}Li + \mathrm{n} \rightarrow {}^{3}_{1}H + \alpha$ (Q-value：4.78MeV)

【BLP】$^{10}_{5}B + n \rightarrow \begin{cases} {}^{7}_{3}Li + \alpha \text{ (Q–value：} 2.792 MeV\text{)} & \text{grand state} \\ {}^{7}_{3}Li^{*} + \alpha \text{ (Q–value：} 2.310 MeV\text{)} & \text{ecited state} \end{cases}$

Results(2): Correlation of neutron counting between LiG and BLP

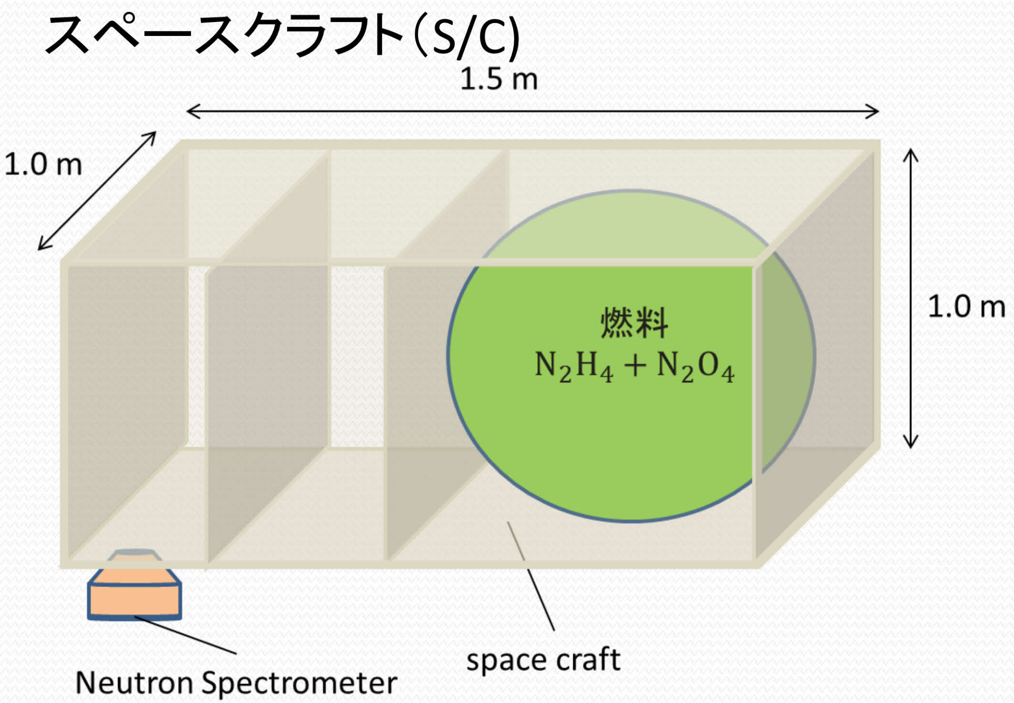
Epithermal neutron counting rates in BLP reflect difference of H-concentrations

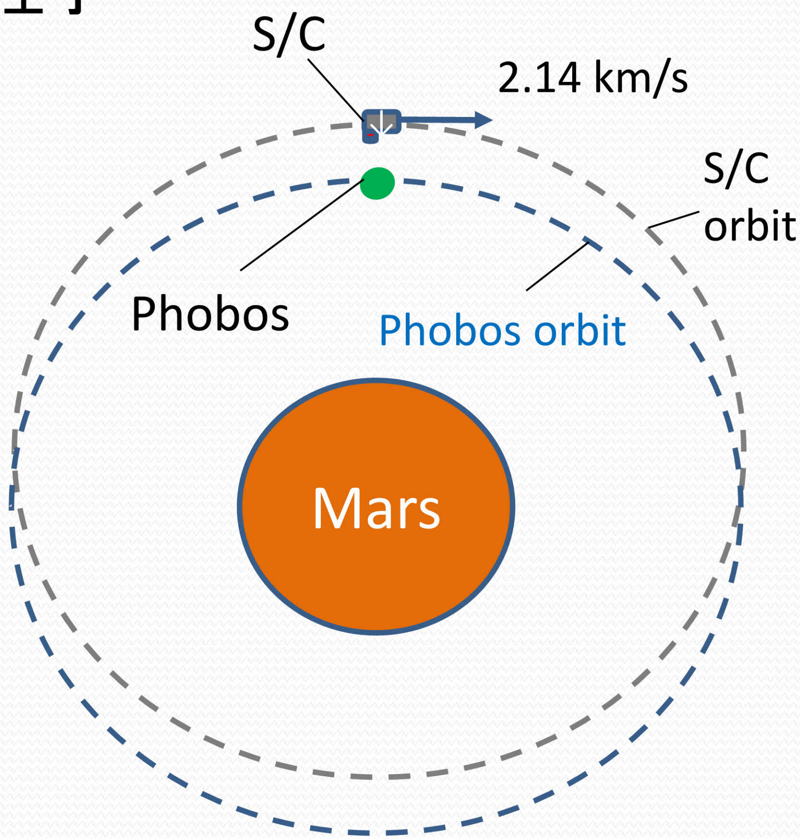
Neutron counting rates in LiG reflect difference of the elemental compositions



火星衛星観測におけるバックグラウンド

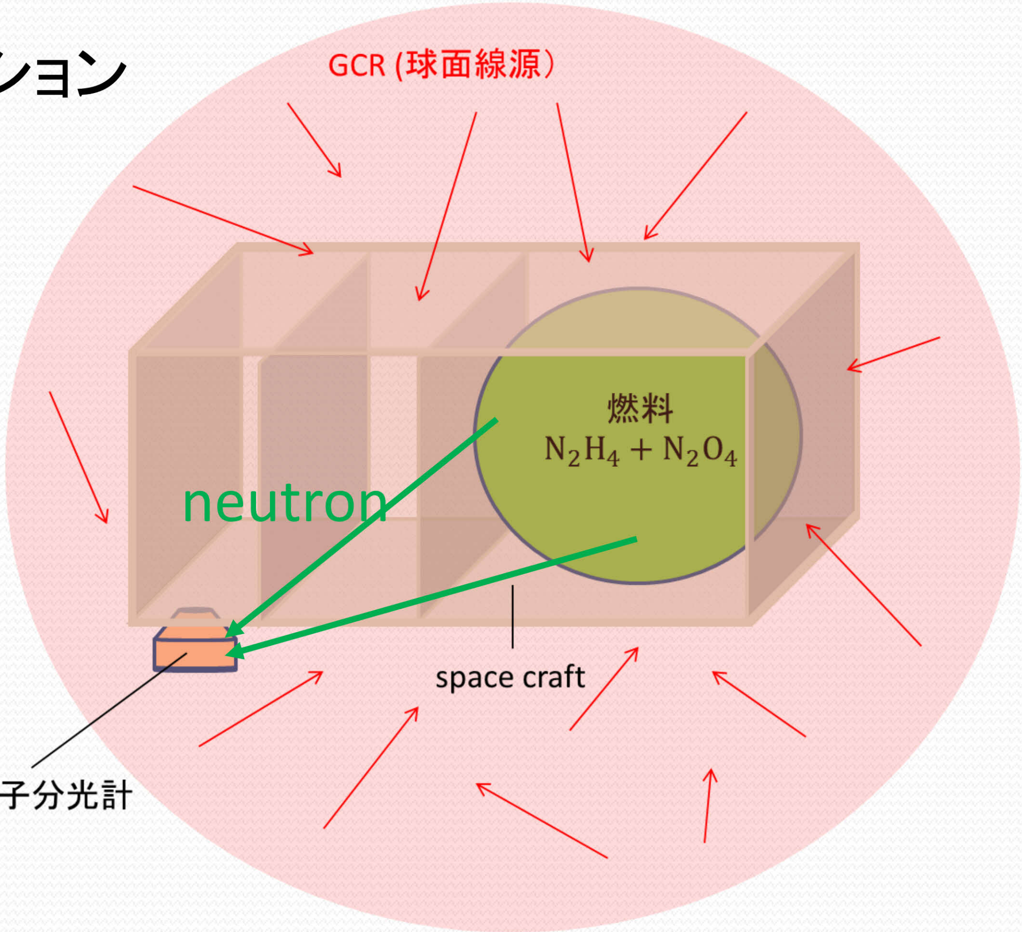
- スペースクラフト（S/C)からのバックグラウンド：
  S/CのAl機体および燃料がGCRsと相互作用し、発生する中性子
- 火星からのバックグラウンド:
  主星である火星から放出される中性子





S/Cからのバックグラウンド

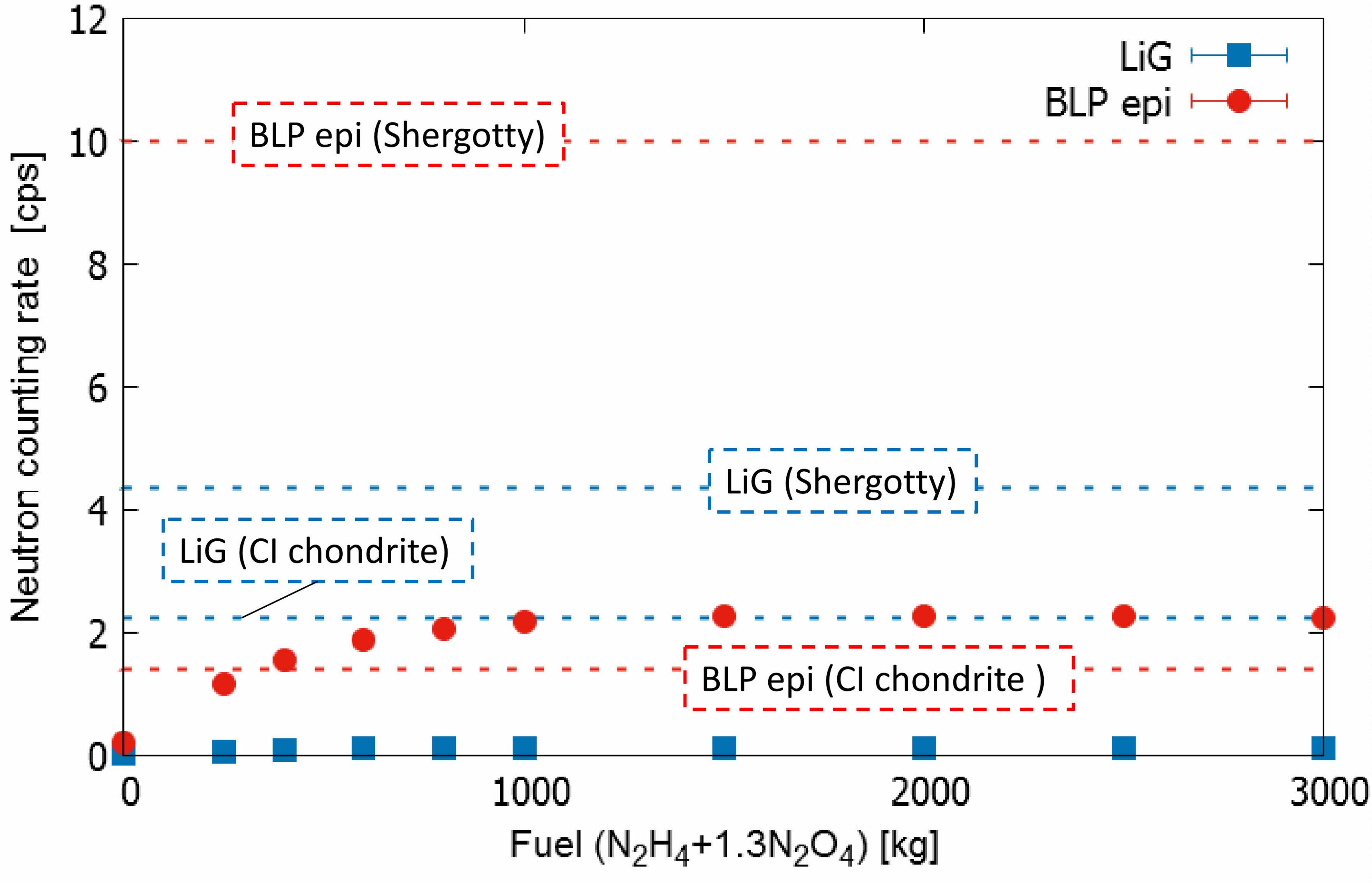
シミュレーション
ジオメトリ



- Al機体の重量は500 kgを仮定
- 燃料(N_2H_4 + 1.3N_2O_4)の重量を0～3000 kgで変化させる。

Background neutron counting rate from S/C as function of weight of the fuel

※dotted lines represent neutron counting rate from Phobos

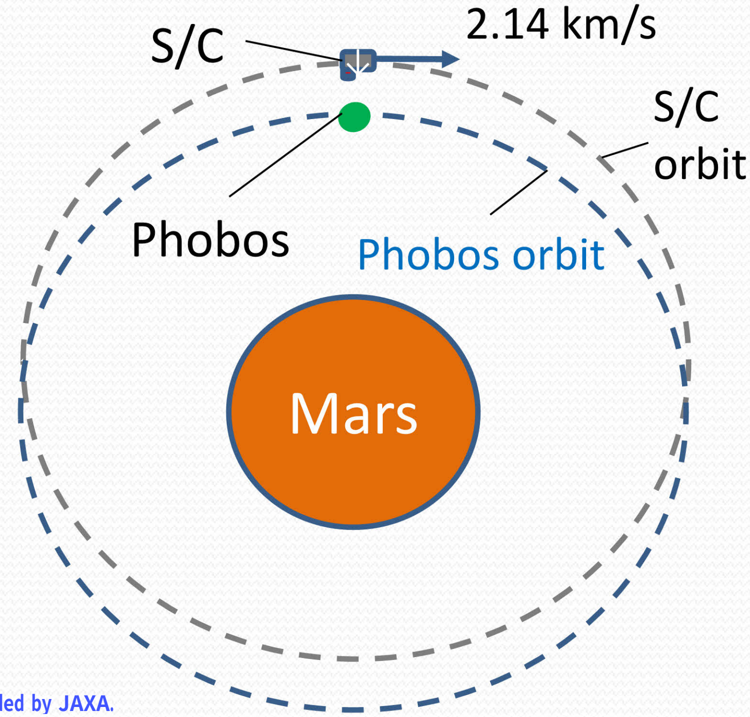


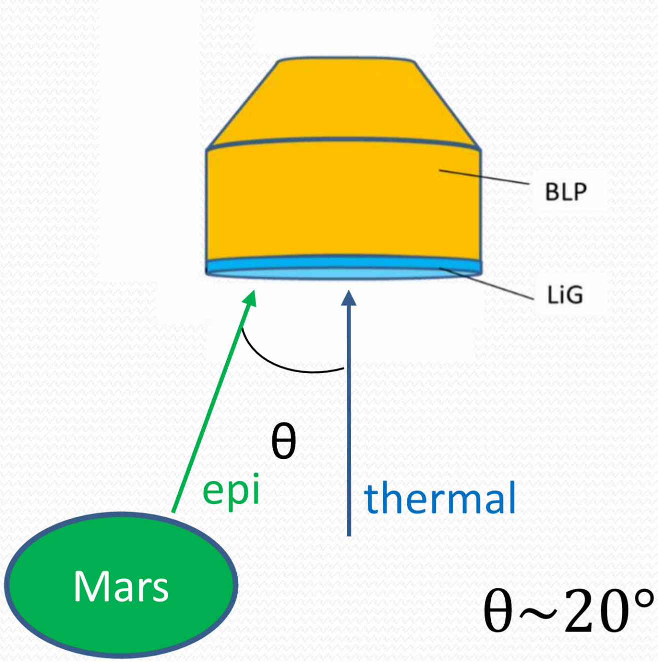
火星からのバックグラウンド(中性子)計算方法

- 火星からの第一脱出速度(3.55 km/s)として、火星から来る中性子のエネルギーの下限を0.15 eVとする。

  ➡熱中性子:　0.15 eV～1 eV

- 火星組成としては、火星隕石Shergottyの平均元素組成を使用する。



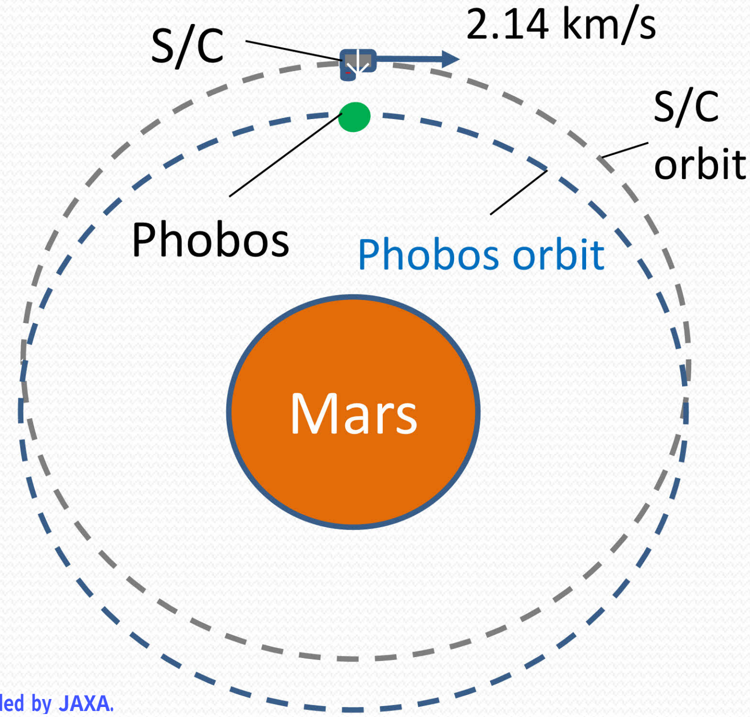


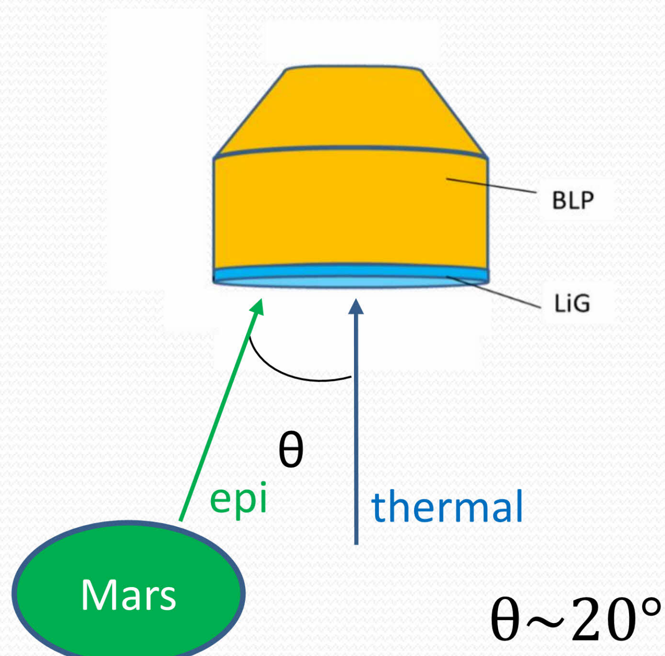
火星からのバックグラウンド(中性子)計算方法

- 火星から来る熱中性子が周回するS/Cに入射する角度の平均は$\theta \sim 20°$

$$(12.3° < \theta < 29.3°)$$

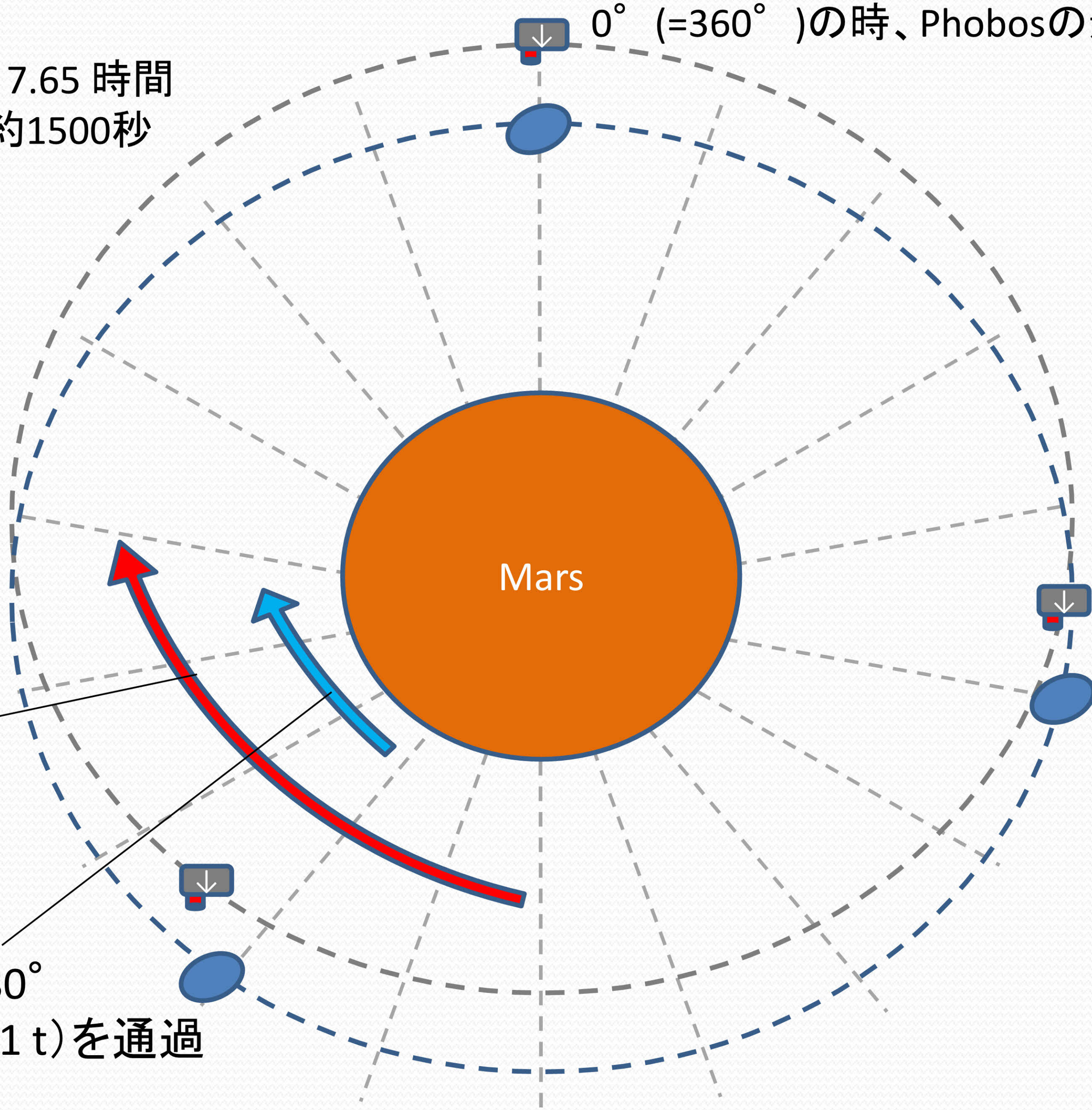
- 火星から来る熱外中性子の速度は衛星速度に比べずっと速いので真っ直ぐに飛んでくるとする。





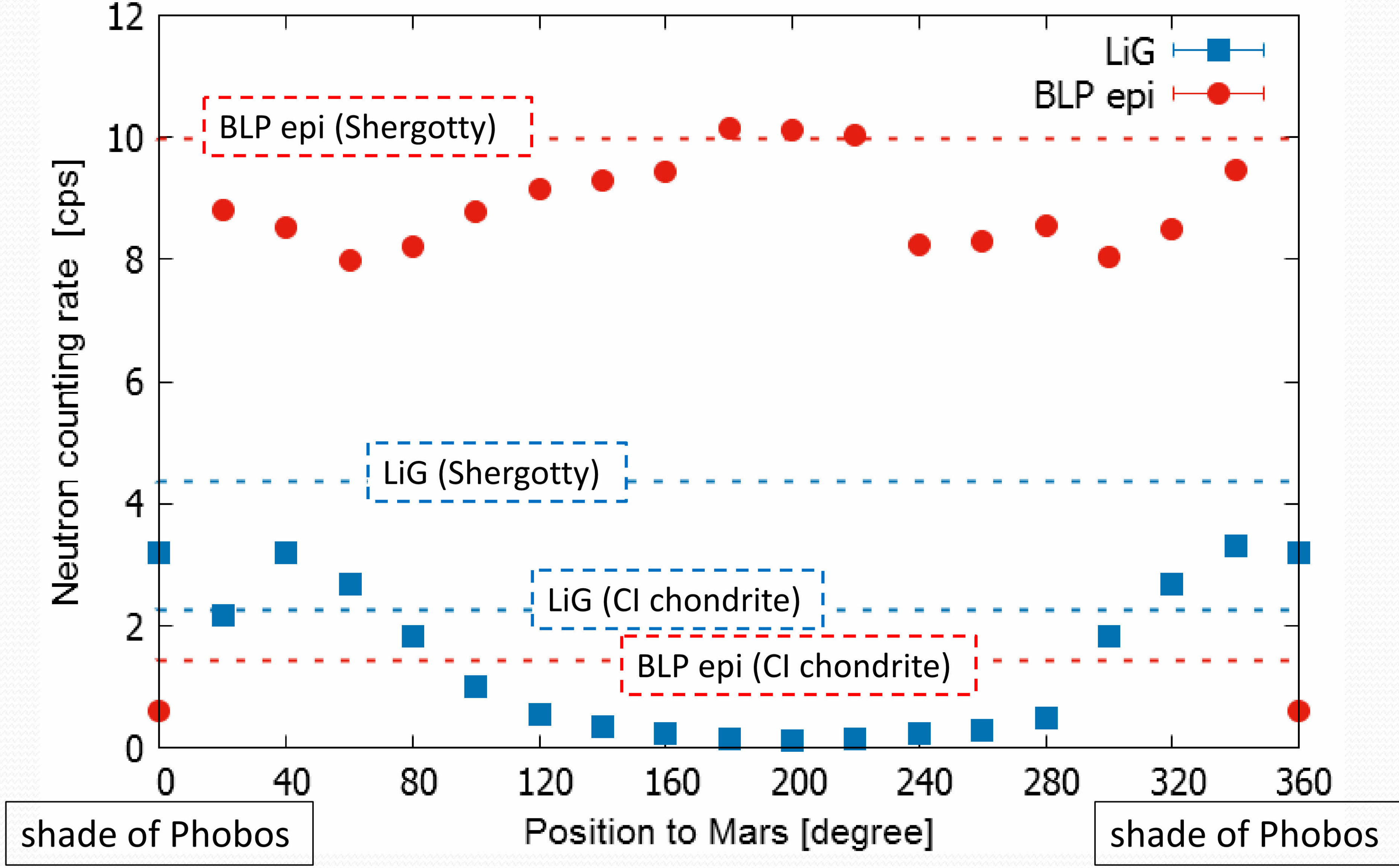
火星からのバックグラウンド

Phobos平均公転周期：7.65 時間
20°前後(10°) ➡ 約1500秒

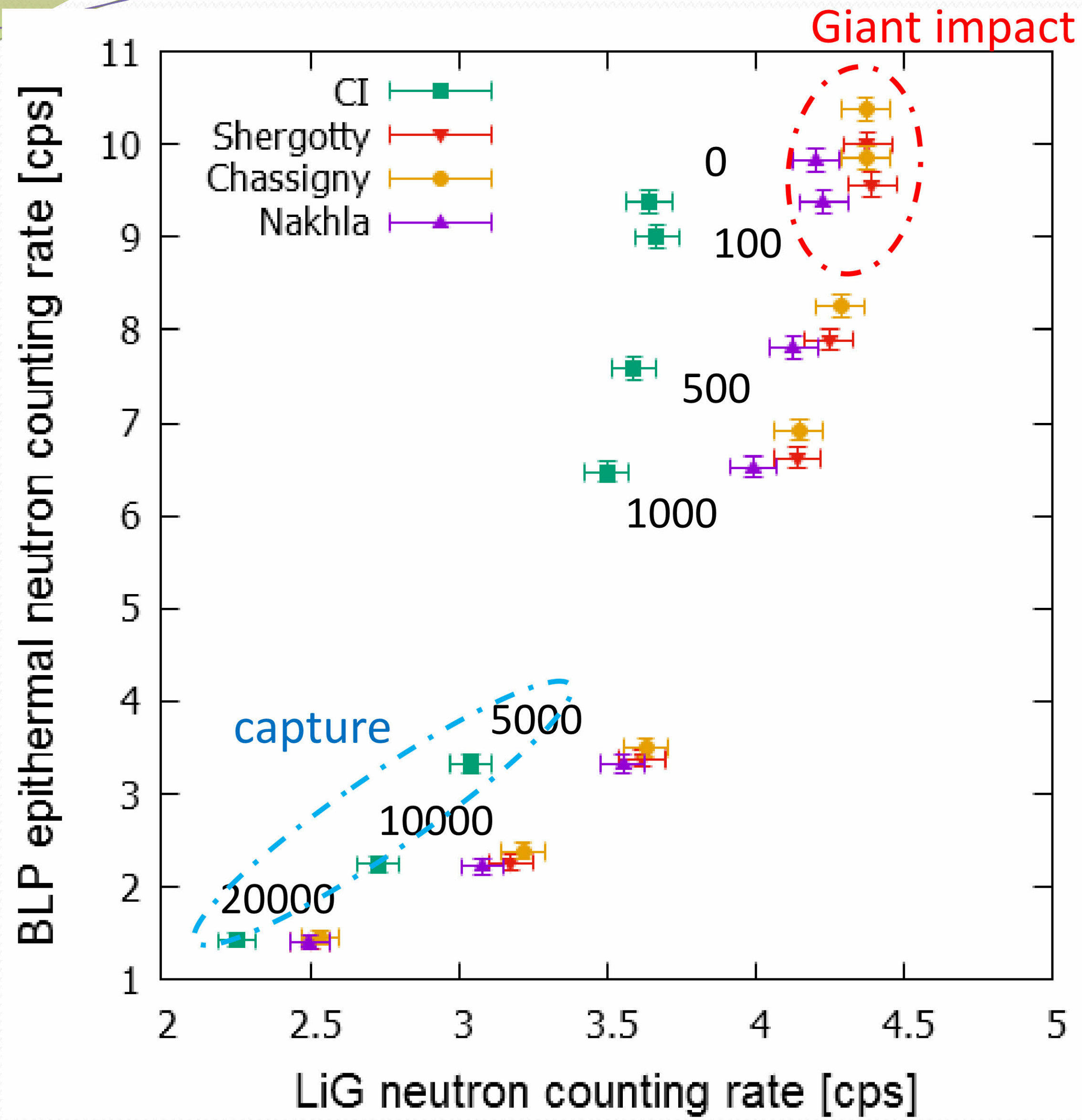


Comparison with the value of Phobos observation (simulation)

※dotted lines represent neutron counting rate from Phobos



Observation time and statistical error



・Phobos観測高度20 km観測時の計測時間1000秒での統計精度を表示

・S/Cの燃料2000 kg時および、LiGとBLPの各シンチレータでバックグラウンド中性子の計数率が最も高いときを仮定

・バックグラウンド観測時間は1週間とした。

今回仮定した中性子分光計は、数1000秒の観測時間で、始原天体組成と火星物質組成を分けることが可能。

結論

- 火星衛星の組成として、CIコンドライト組成と火星隕石組成を仮定し，LiGとBLPにおける中性子計数率の水素濃度依存性をシミュレーションにより示した。
- 火星衛星観測における中性子のバックグラウンド計数率が見積もられ、高度20 kmの観測では数1000秒の観測で始原天体組成と火星物質を分けることができ、火星衛星が捕獲起源か衝突起源を判別する重要な指標となる。
- 中性子分光は火星衛星探査において、火星衛星起源を解明する有力な手段となりうる。