In-orbit Neutron and Radioactivation Background of the Hard X-ray Imager onboard Hitomi

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Introduction: Hard X-ray background

In order to achieve higher sensitivities in hard X-ray band (> 10 keV),

・ Improving S/N ratio by focusing X-rays.

◎ Reducing non-X-ray background (NXB).

→ Need to understand the properties of NXB.

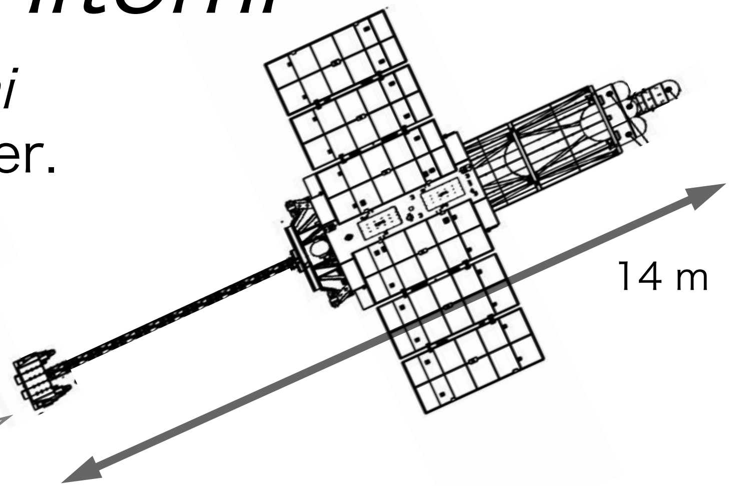
Principal components of NXB in future observations:

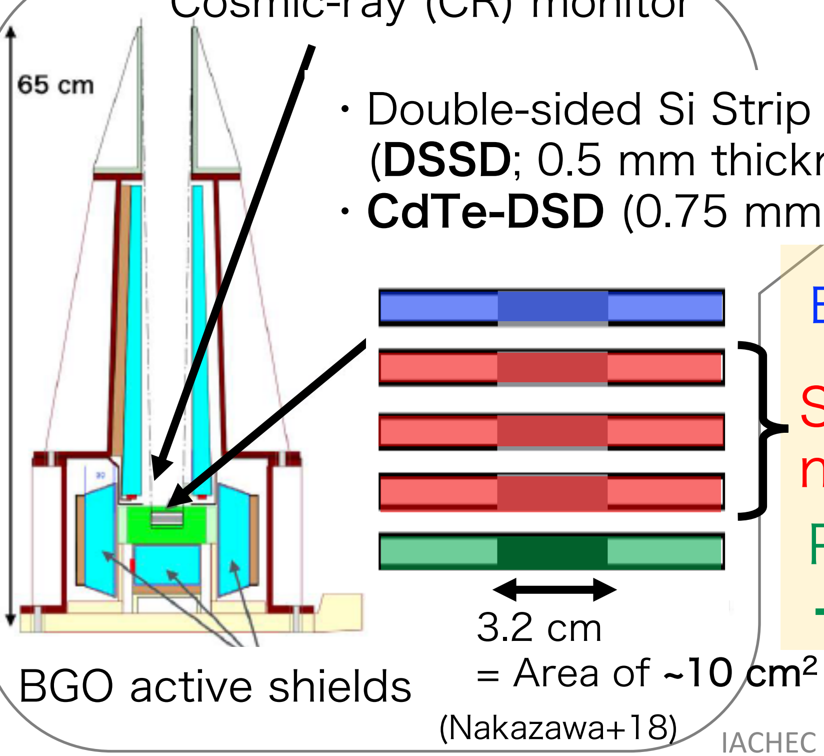
- **Atmospheric neutrons**
- **Radioactivation**

→ Aim of this work:
Understanding the contribution of each component quantitatively.

NXB measured by the Hard X-ray Imager (HXI) onboard *Hitomi*

- Hard X-ray Imager (HXI) onboard *Hitomi* achieved the best NXB performance ever.
  → Most suitable for **understanding NXB in greater detail.**





NXB components of each layer of the HXI

Electrons (Hagino+18)

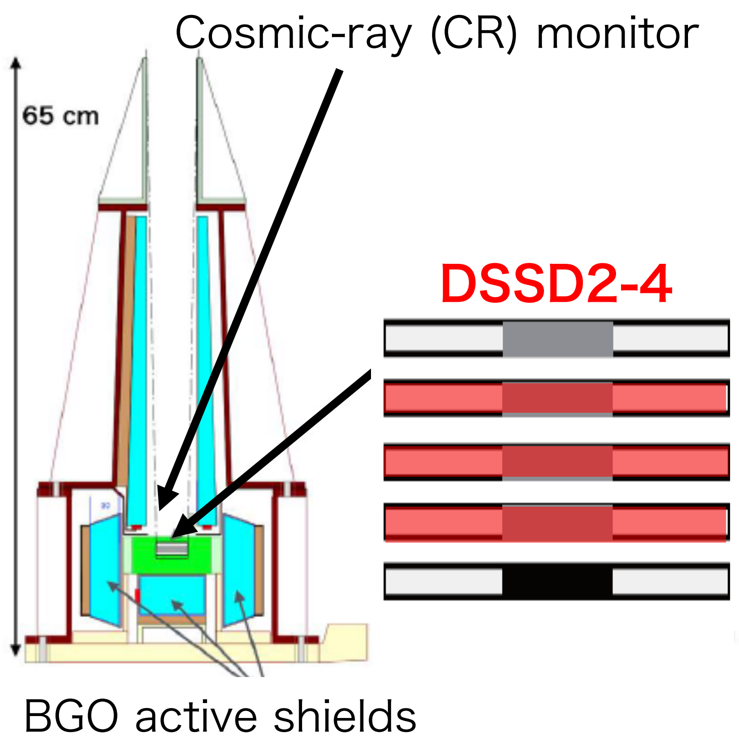
Seem to be dominated by atmospheric neutrons → **Formar half of this talk.**

Proton-induced radioactivation
→ **Latter half (briefly) (Odaka+18)**

1. Atmospheric Neutron Background

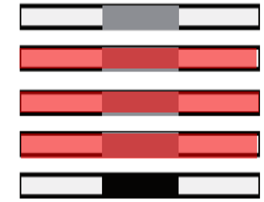
In order to extract **neutron NXB**, we did

- Checking spatial correlation of data and CR-rate in orbit (because **atmospheric-particle** rate ∝ CR rate)
- Comparison of measured spectrum to simulations to extract contribution of **neutrons**



Data reduction

DSSD2-4



- Data of the blank-sky observations obtained with DSSD 2-4 were used.
  -> Eff. exposure ~500 ks

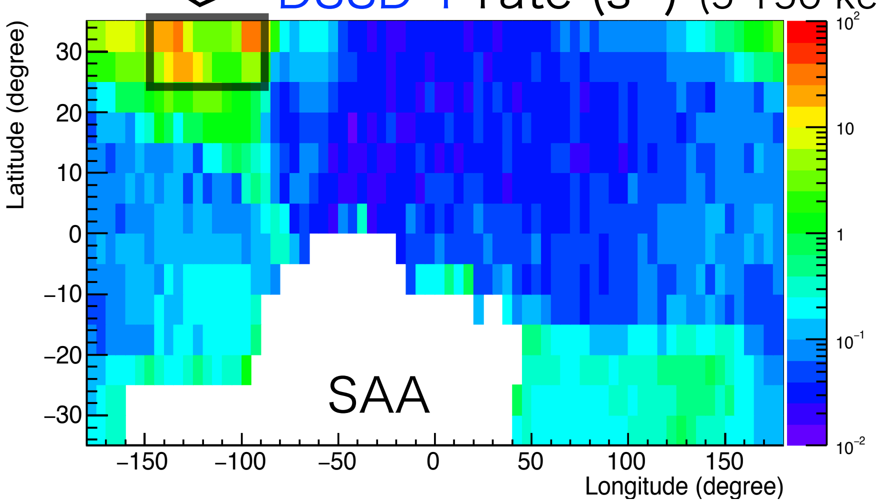
Observation period	OBSID	Target name
3/14 16:20–3/14 18:00	000007010	None2
3/14 18:00–3/15 17:56	000007020	None2
3/15 17:56–3/16 19:40	000008010–000008060	IRU Check out
3/16 19:40–3/19 19:00	100043010–100043040	RX J1856.5–3754
3/23 13:30–3/25 11:28	100043050–100043060	RX J1856.5–3754

- Excluded periods from the data:

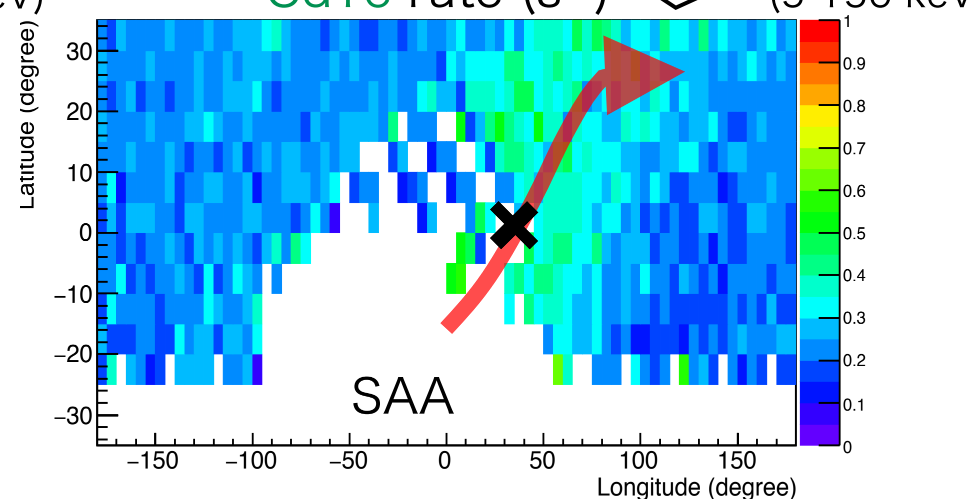
Periods with high electron rates

Periods with strong radioactivation

DSSD 1 rate (s^{-1}) (5-150 keV)

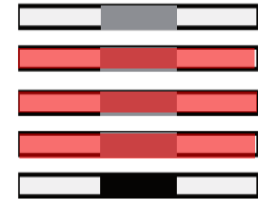


CdTe rate (s^{-1}) (5-150 keV)



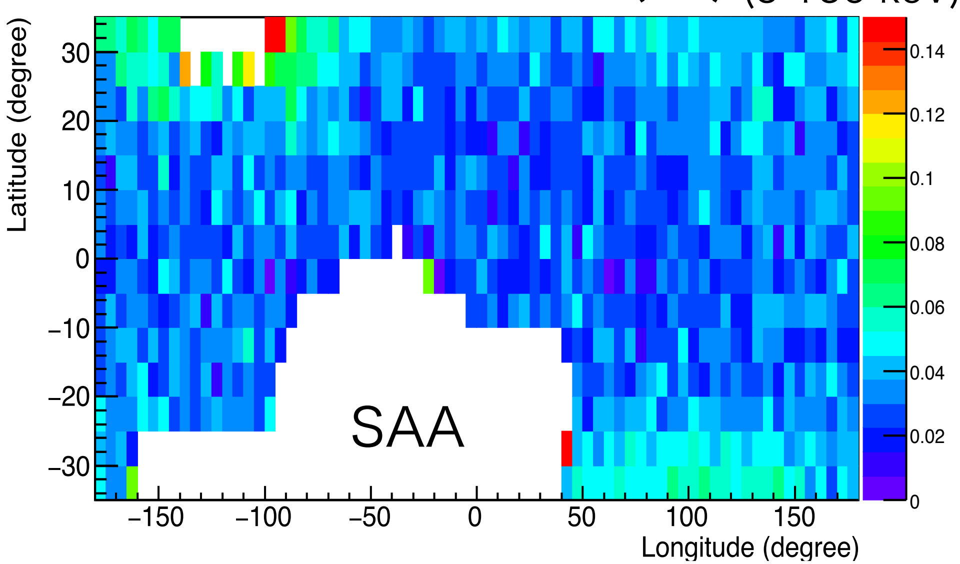
Spatial distribution of DSSD 2-4 rate

DSSD2-4

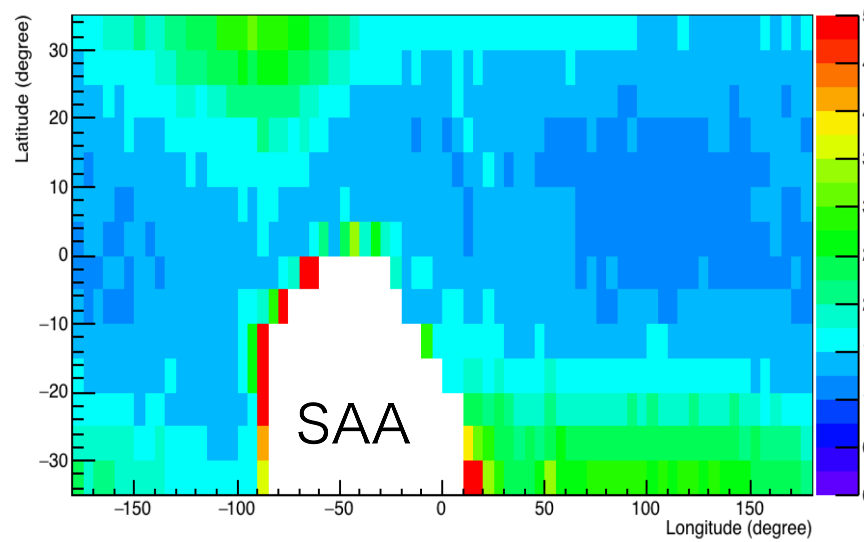


- Screened DSSD 2-4 rate showed a spatial correlation with CR rate obtained with the CR monitor.
  → NXB of DSSD 2-4 seemed to be dominated by **atmospheric particles (neutrons and gamma-rays).**

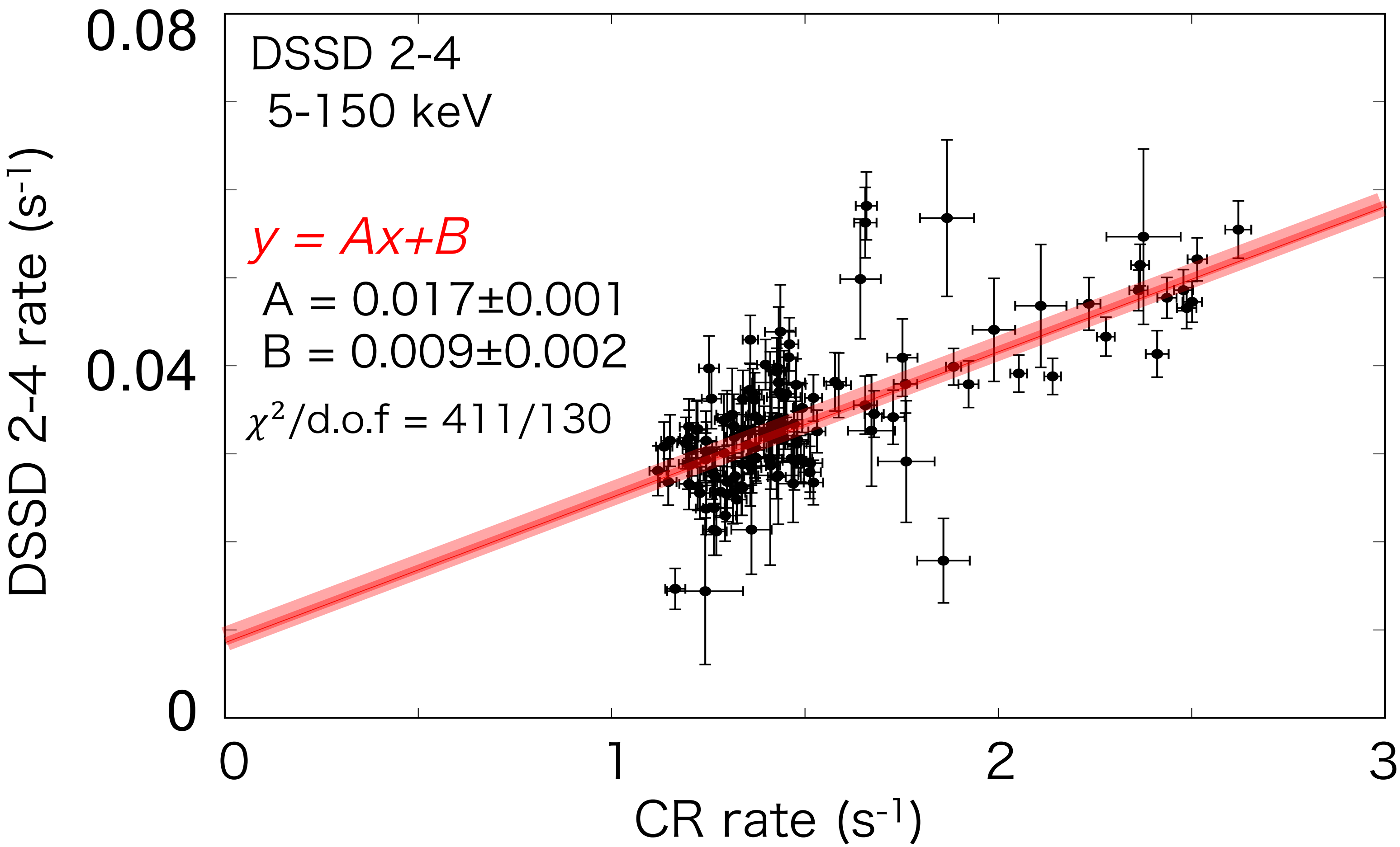
DSSD2-4 rate (s^{-1}) (5-150 keV)



CR-monitor rate (s^{-1})

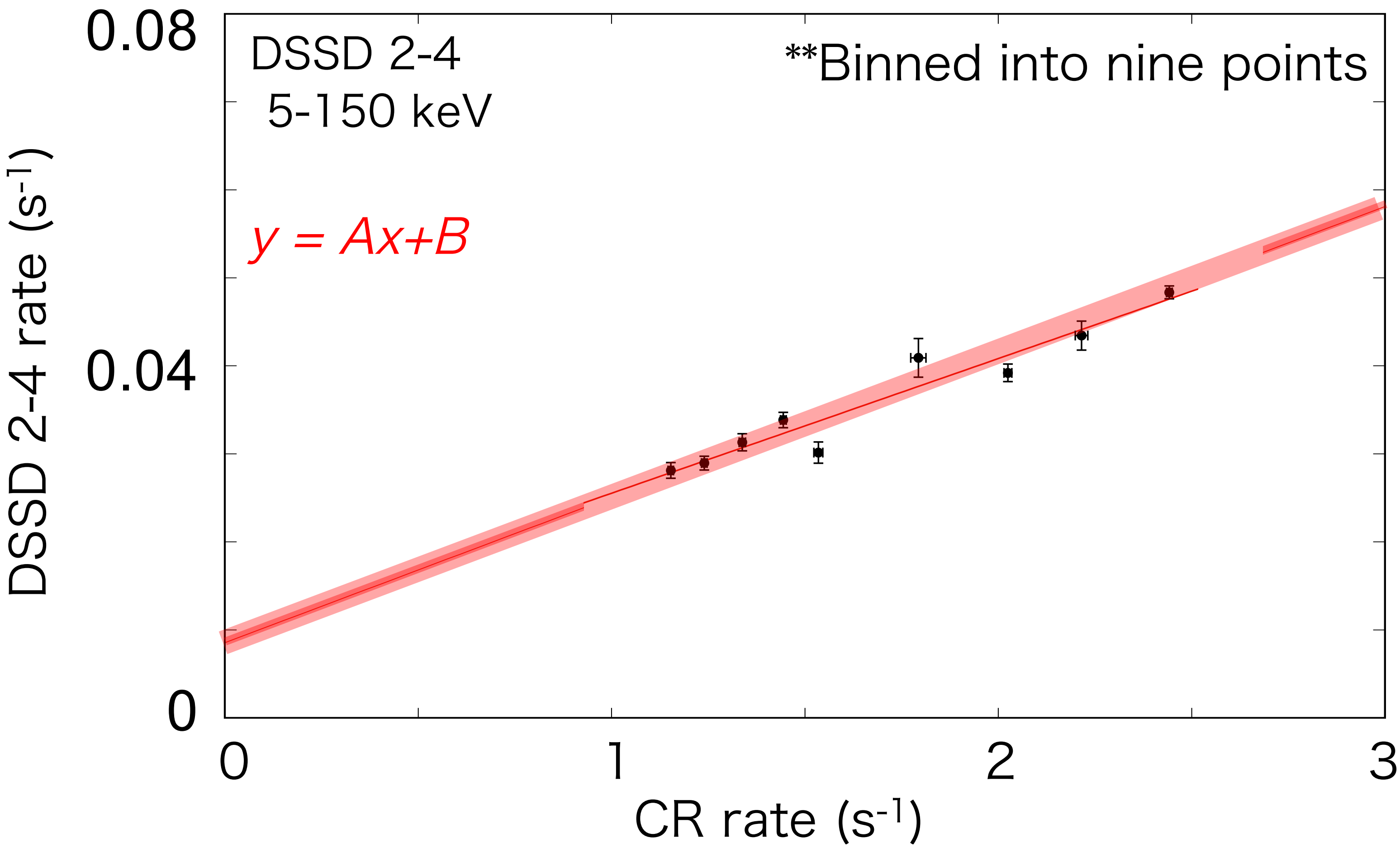


Spatial correlation between DSSD 2-4 and CR rates



- **Linear-function correlation** was found.
  → Atmospheric particles should compose the proportional component (Ax).

Spatial correlation between DSSD 2-4 and CR rates



- **Linear-function correlation** was found.
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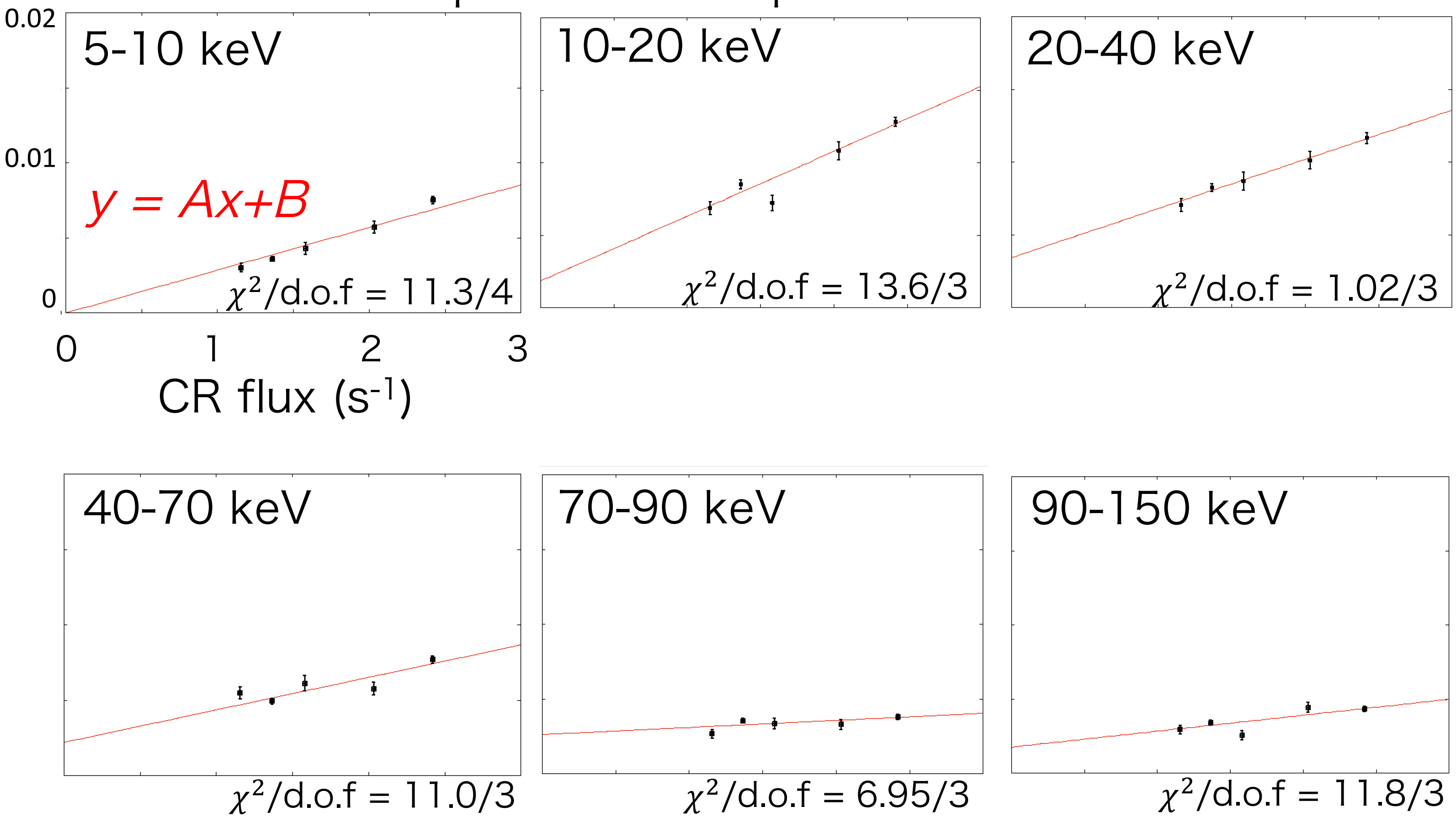
Spatial correlation between DSSD 2-4 and CR rates

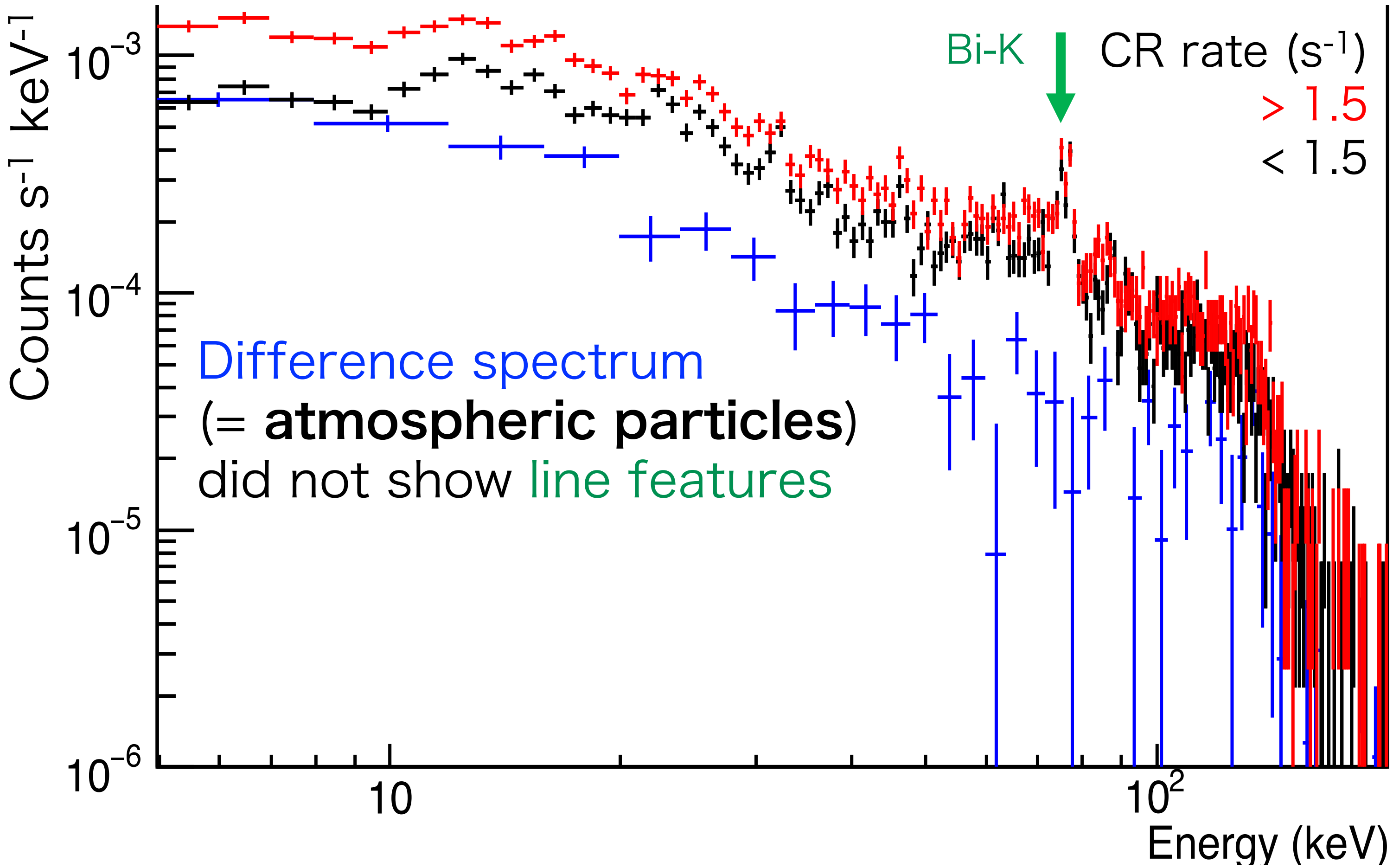
**Binned into five points in each panel



- **Linear-function correlation** was found.
  → Atmospheric particles should compose the proportional component (Ax).

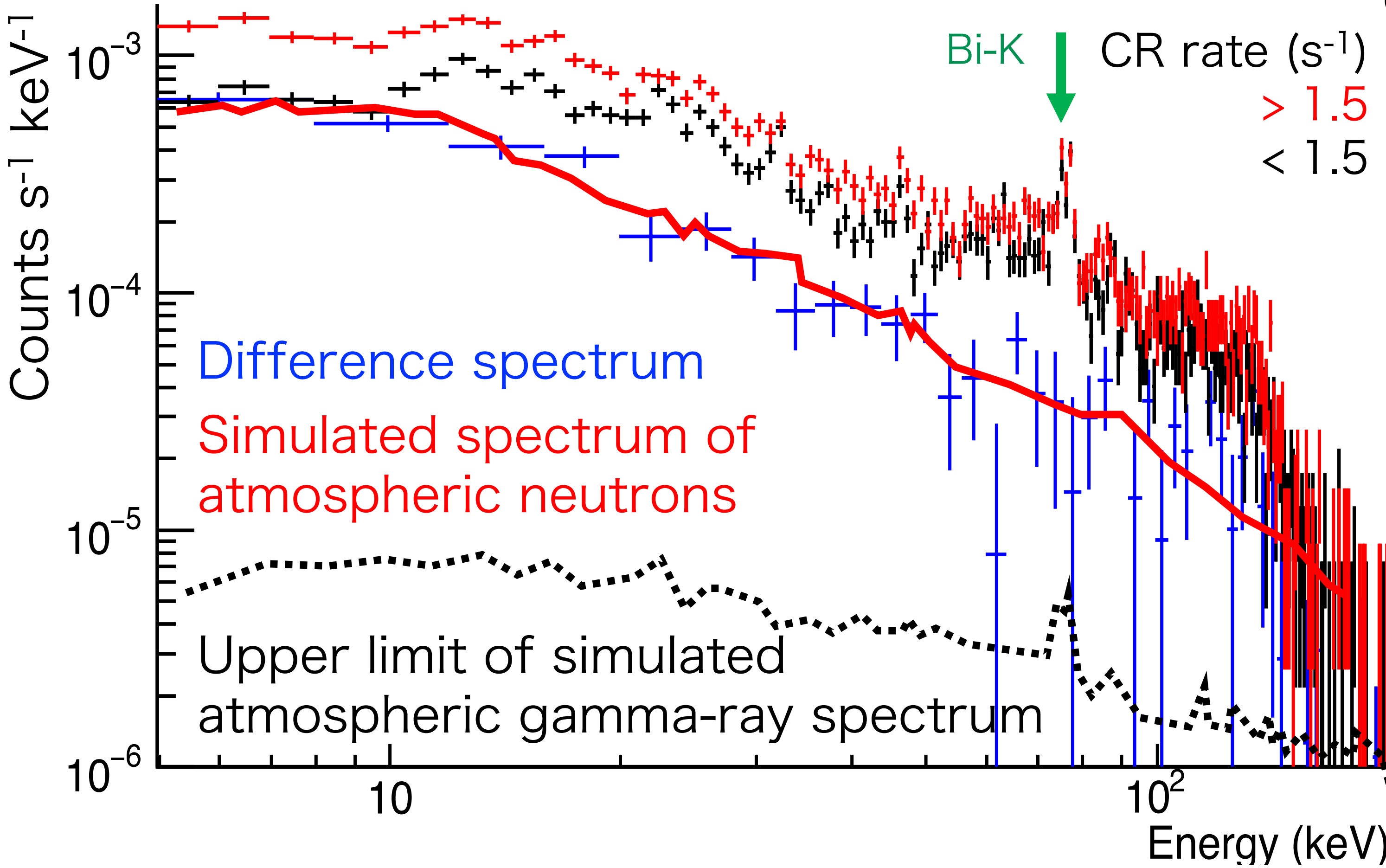
Extraction of the atmospheric particle components

- We subtracted the spectrum in low-CR periods from that in high-CR periods, to obtain "Difference spectrum".



Extraction of the atmospheric neutron component

- We conducted a Monte-Carlo simulation using Geant4 toolkit to estimate the spectra of atmospheric particles. (Armstrong+73; Odaka+18)

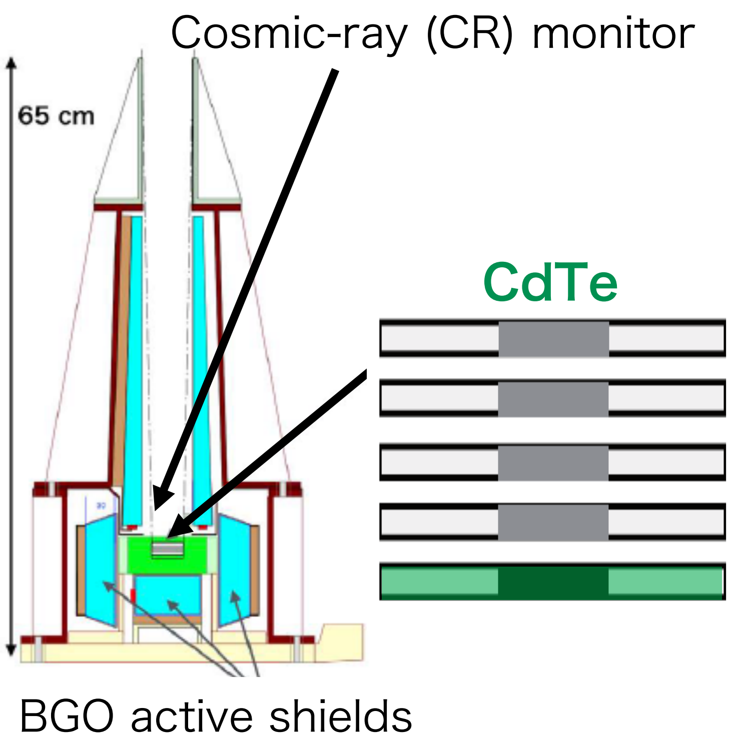


- Difference spectrum required only atmospheric neutrons.

2. Radioactivation Background

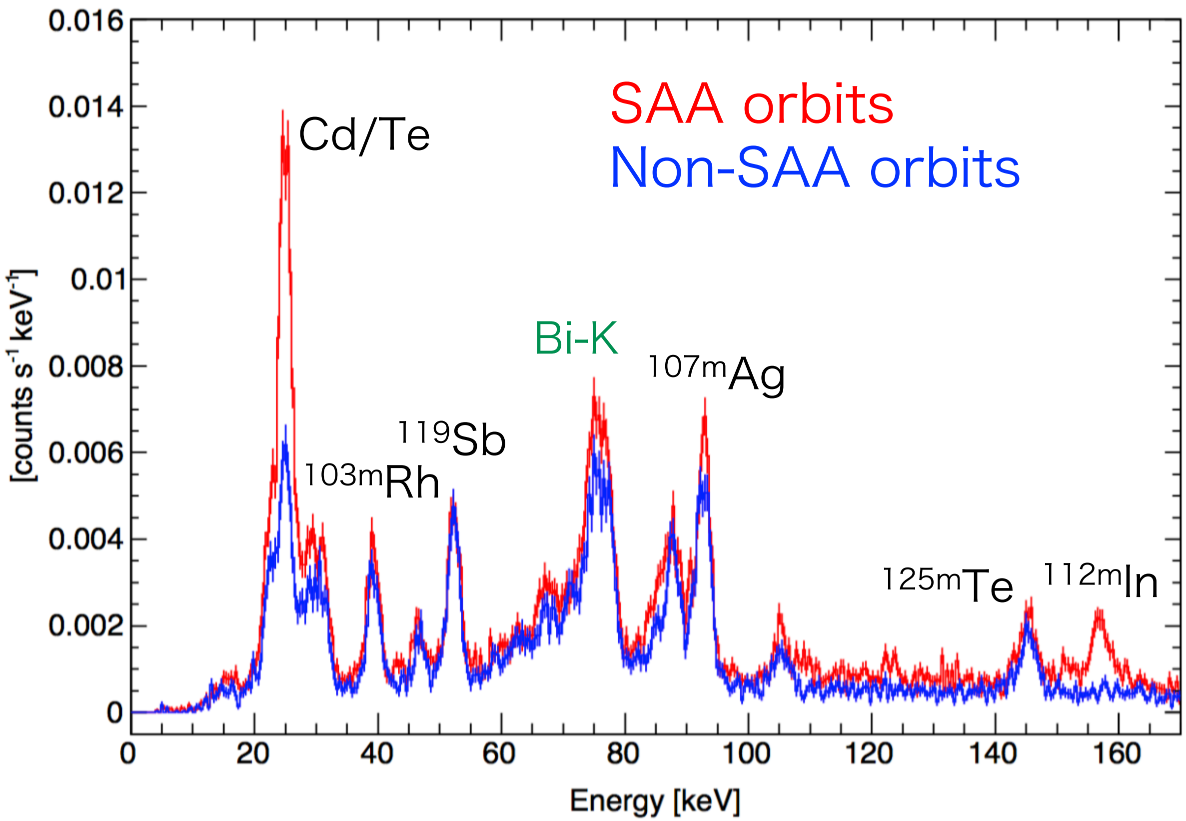
In order to extract radioactivation component, we

- Focused on CdTe-layer data
  = dominanated by radioactivation background
  (because of high-sensitivity in hard X-ray band)



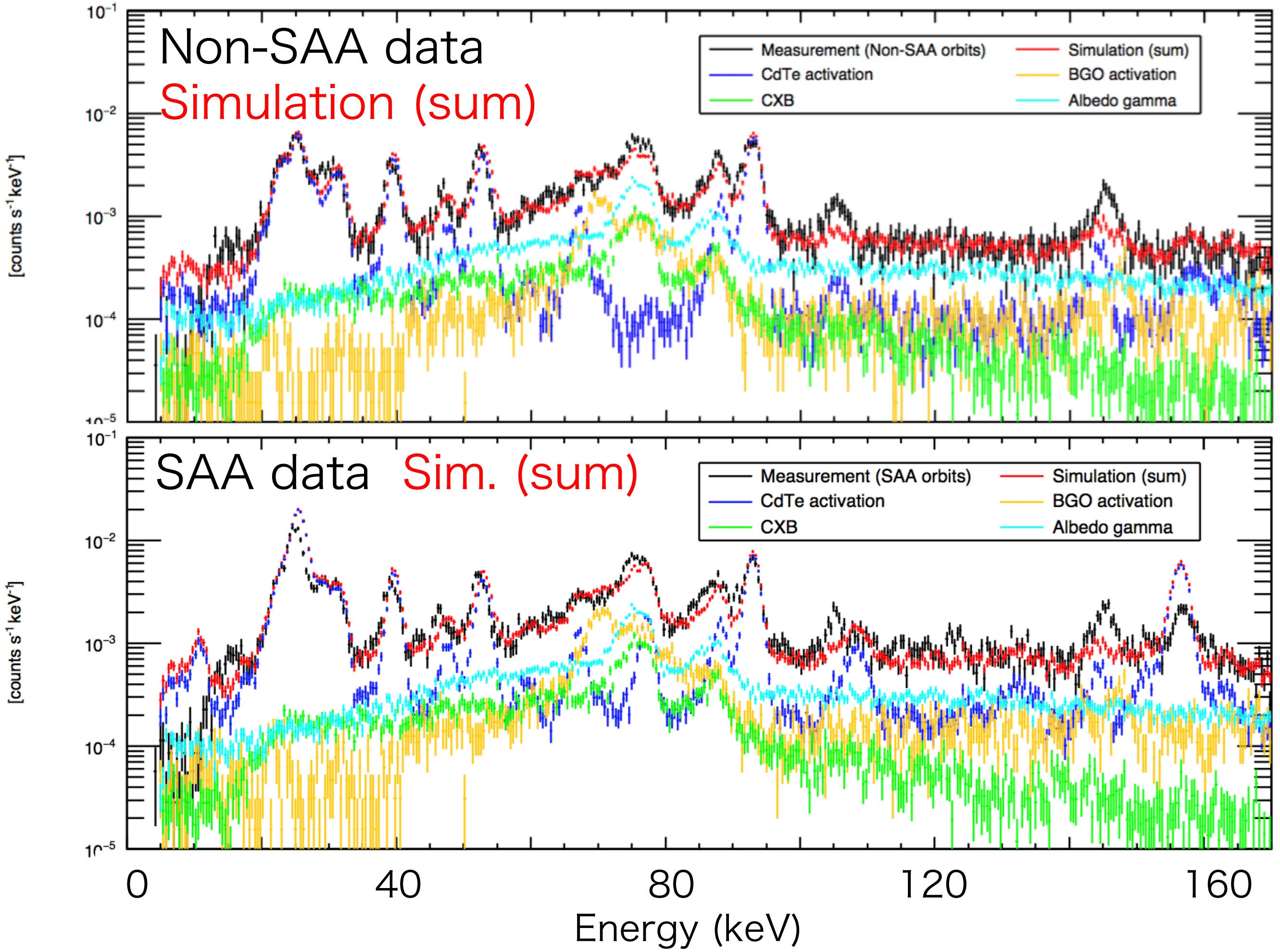
Measured spectra

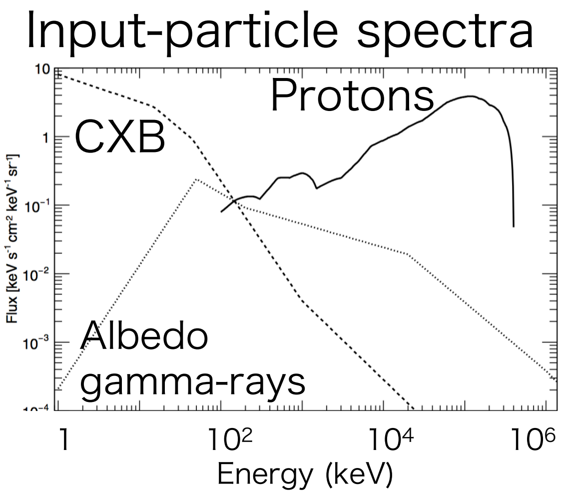
- Data selection
  - Earth occultation data of CdTe-layer of the HXI
  - Data were clasified into **non-SAA orbits** (time after SAA > 6 ks) and **SAA orbits** (time after SAA < 5 ks)
- Extracted spectra from each dataset



Comparison with our Monte-Carlo simulation

- We compared the measurement to our Monte-Carlo simulations, and confirmed that the data could be explained well.





See Odaka et al. (2018) NIM-A, 891, 92

Nuclear Inst. and Methods in Physics Research, A 891 (2018) 92–105

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Modeling of proton-induced radioactivation background in hard X-ray telescopes: Geant4-based simulation and its demonstration by *Hitomi*'s measurement in a low Earth orbit

Check for updates

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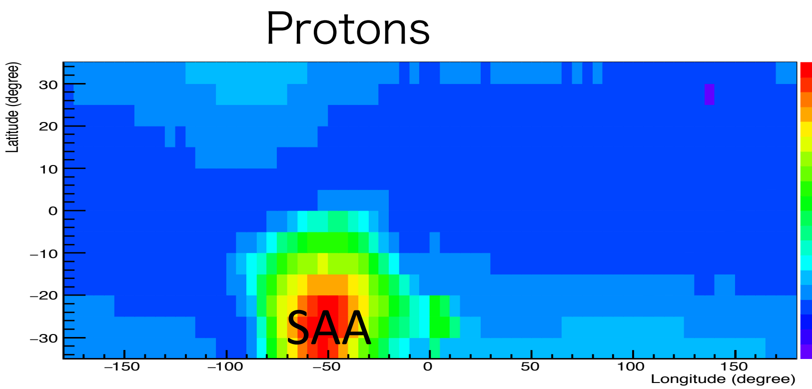
Summary

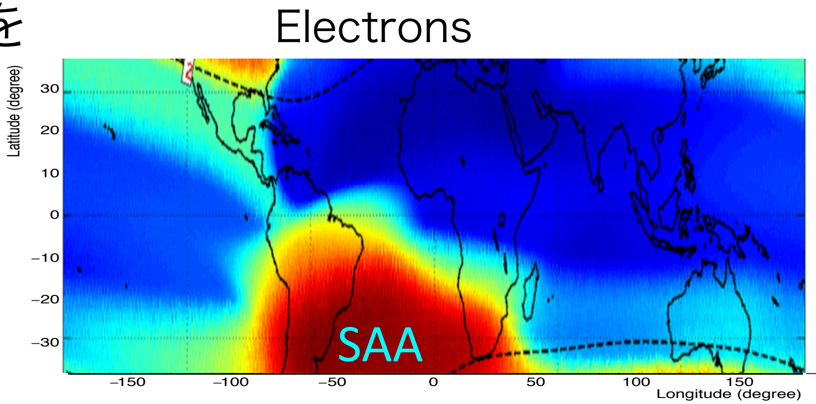
- We investigated NXB produced by atmospheric neutrons and radioactivation, both of which have significant contributions to the entire NXB, using HXI onboard *Hitomi*.
- **1. Atromspheric neutron background:**
  - We found that the screened data rate of the Si-layers of HXI onboard *Hitomi* had a positive correlation with CR rate.
  - We extracted the spectrum and spatial variations of the atmospheric-particle background.
  - Comparing to estimates by our Monte-Carlo simulations, the extracted data could be explained well only with atmospheric neutrons.
- **2. Radioactivation background:**
  - The screened data of the CdTe-layer of HXI, which were dominated by radioactivation, were explained well with our Monte-Carlo simulations.

Back-up

- ➢ 宇宙X線背景放射（CXB）
  変動しない

- ➢ 荷電粒子起源バックグラウンド（NXB）
  - 陽子起源成分（放射化）
    磁南極付近（南大西洋異常帯; SAA）を通過後 < 10 ksの時間帯のみ激しい
  - 電子成分
    磁南極・北極付近
    （SAAやアメリカ上空）で強い
  - 中性子成分
    地磁気の大きさにより
    宇宙線強度が座標ごとに違う
    → 中性子の強度も座標分布
  - Albedo光子成分
    中性子と同じ座標分布

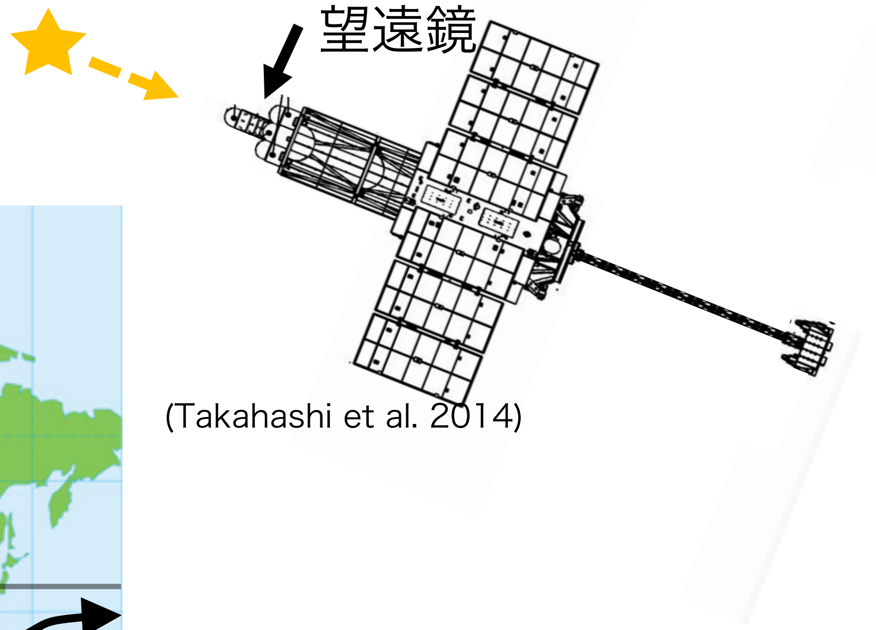




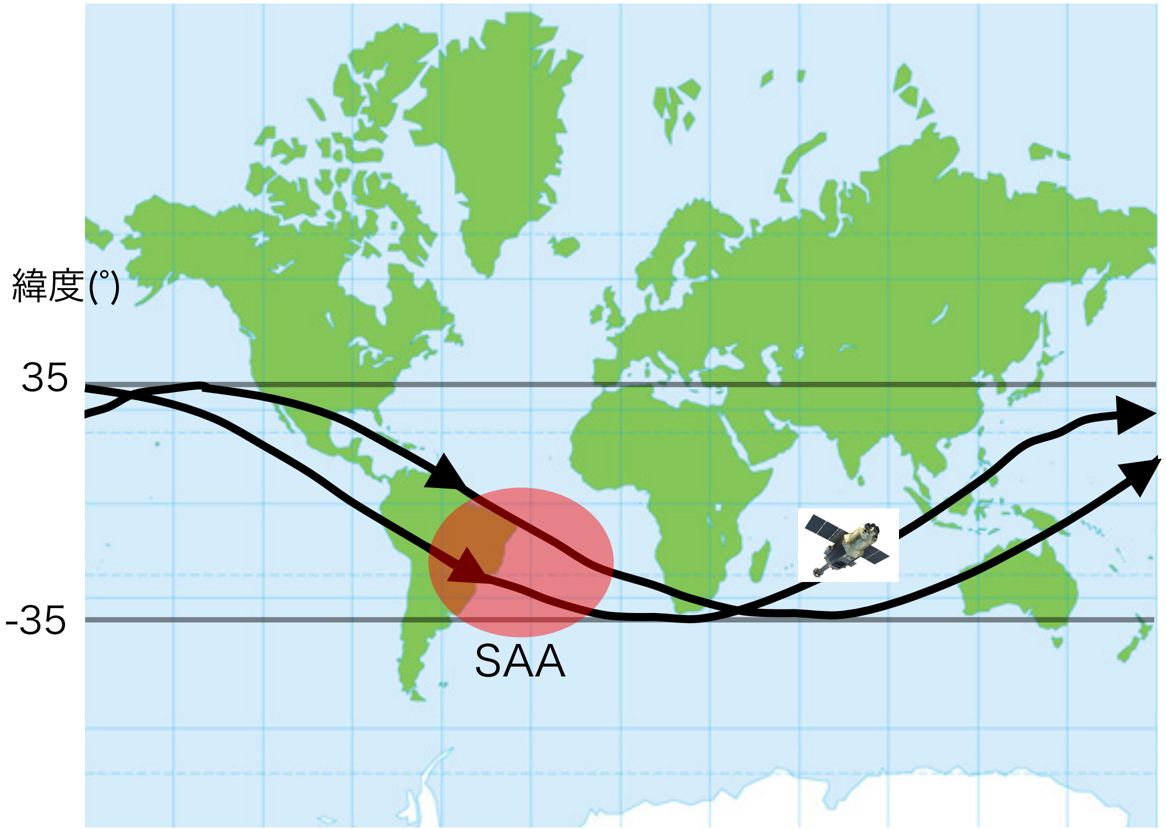
- ➢ 放射化, 電子の成分は
  よく理解され、シールドで削減可能
- ➢ **中性子(, Albedo光子)は予測の精度が ±50%と悪く、削減のめどがない**
  → 本研究で着目！

Hitomi

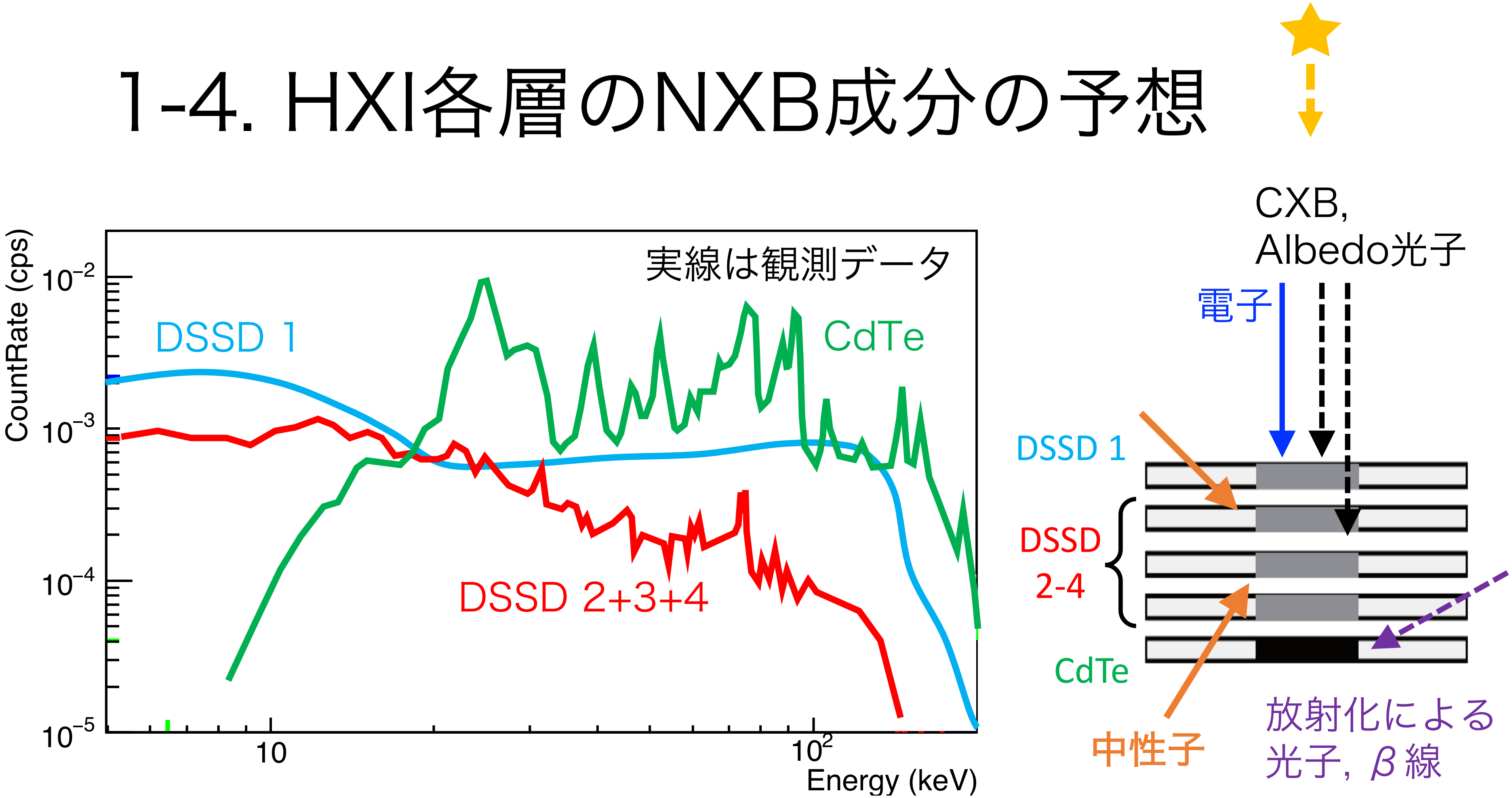
- 2016年2月 打ち上げ（4月 運用停止）
- 地球を約90分で1周する



(Takahashi et al. 2014)



1-4. HXI各層のNXB成分の予想



DSSD 1は主に電子とCXBで説明できる (Hagino et al. 2018 submitted)
CdTeは自身とシールドの放射化による輝線などで説明できる (Odaka et al. 2018 submitted)
} 予想通り

DSSD 2-4は中性子の寄与が大きいと予想できるが、分かっていない

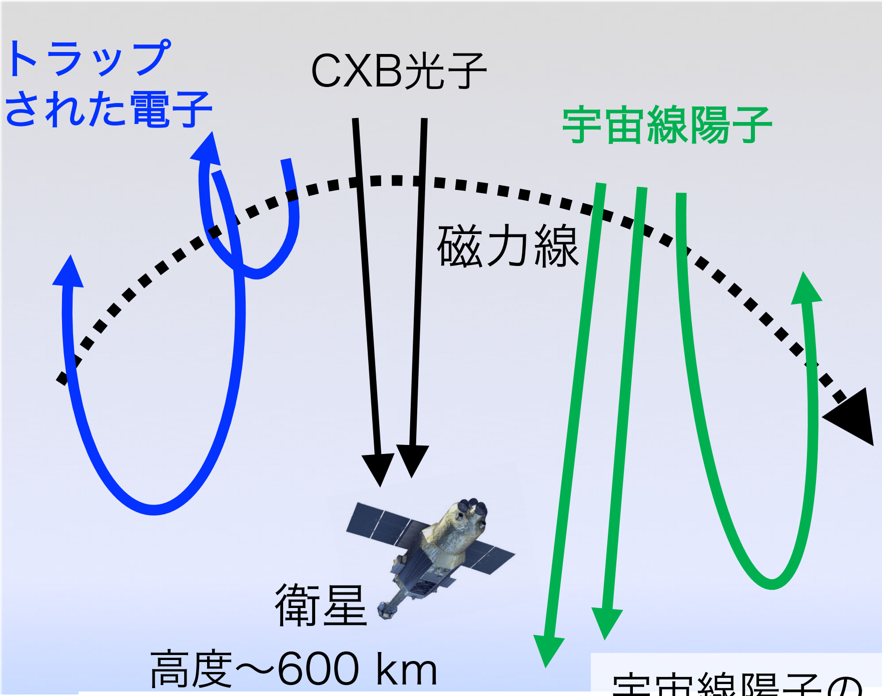
本研究：DSSD 2-4のNXBから中性子成分を抽出し定量評価

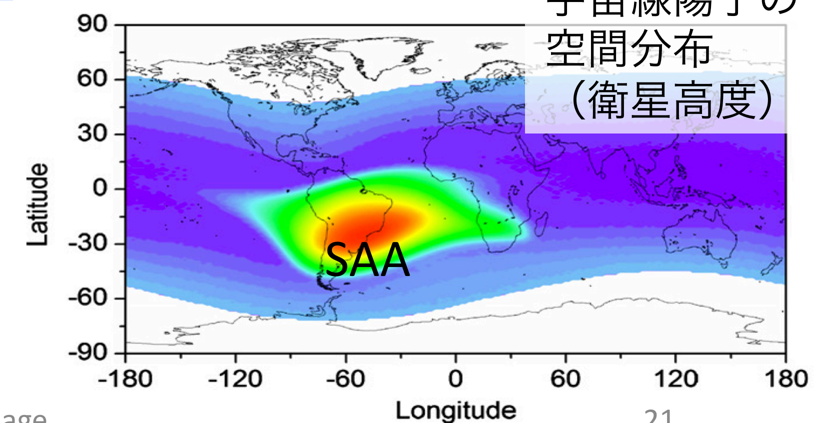
1-2. 軌道上バックグラウンド (§3)

- 宇宙X線背景放射（CXB）
  - ・遠方の暗い点源放射の重ね合わせ
    → 等方的・定常
- 主な荷電粒子起源BGD（NXB）
  - 陽子成分
    - ・直撃→ 反同時計数で除去
    - ・検出器まわりの物質の放射化
      - ・南大西洋異常帯（SAA）を通過した後に強い
    - ・地磁気に応じて場所依存
  - 電子成分
    - ・視野に侵入して検出器まで到達
    - ・SAAやアメリカ上空に強い領域あり

放射化, 電子の成分はよく理解され、シールドで大幅に削減できる

（Hagino et al. 2018 submitted,
Odaka et al. 2018 submitted ）

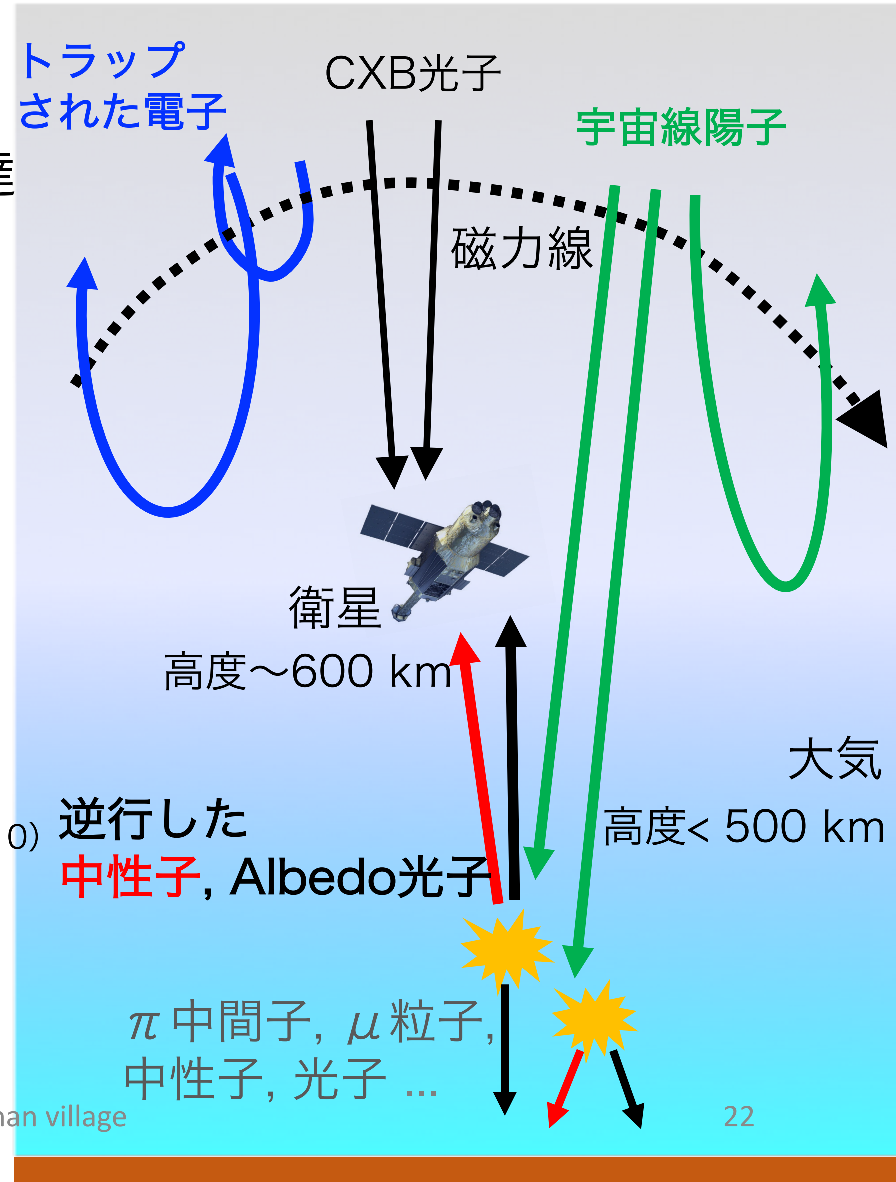




宇宙線陽子の空間分布（衛星高度）

1-2. 軌道上バックグラウンド (§3)

- 主な荷電粒子起源BGD（NXB）
  - 中性子成分
    - ・シールドを透過し検出器まで到達
    - ・強度が陽子と似た場所依存性
  - Albedo光子成分
    - ・CXBより1桁程度弱いが、寄与する可能性はある
    - ・中性子と同じ場所依存性

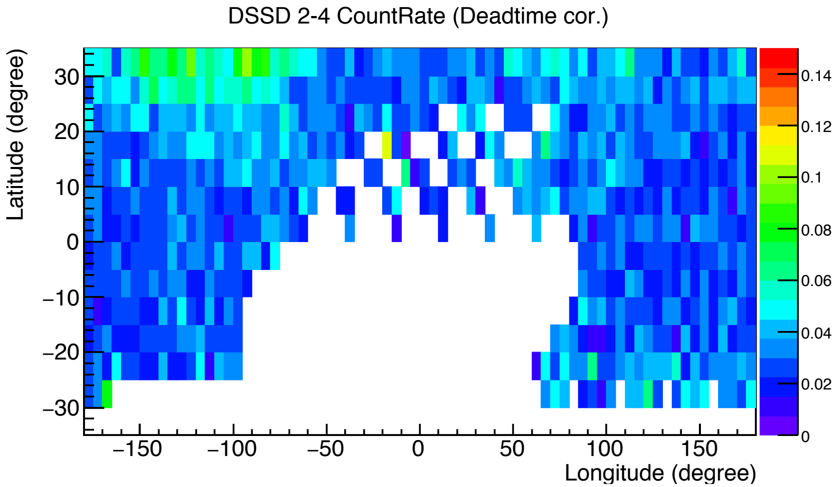


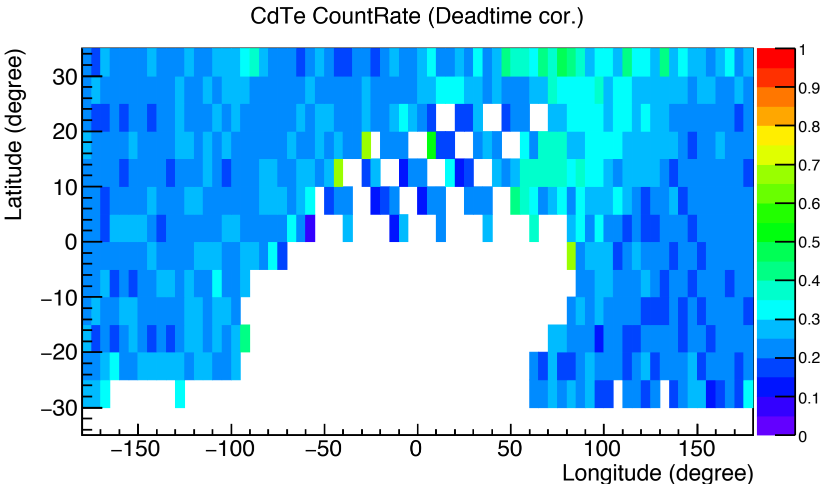
シールド性能が良い検出器では
中性子が卓越すると予想されているが、

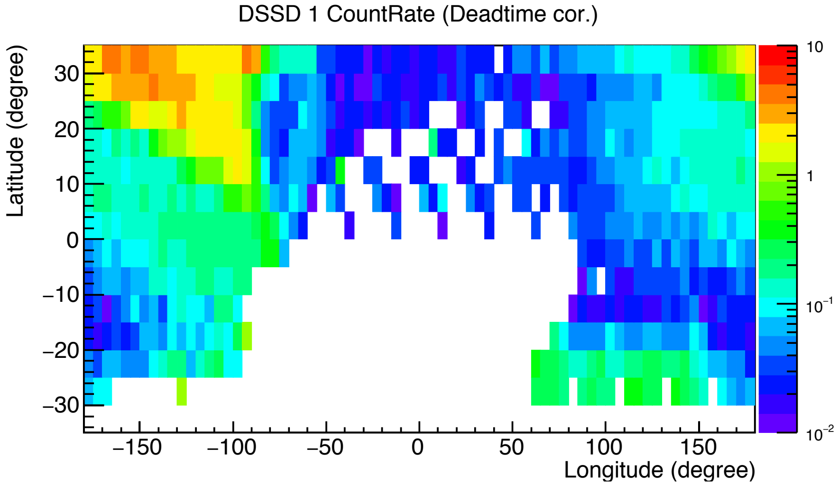
BGDレベルの予測精度が悪い(Mizuno et al. 2010)

→ 本当に中性子が主か、本研究で
軌道上のデータから確認

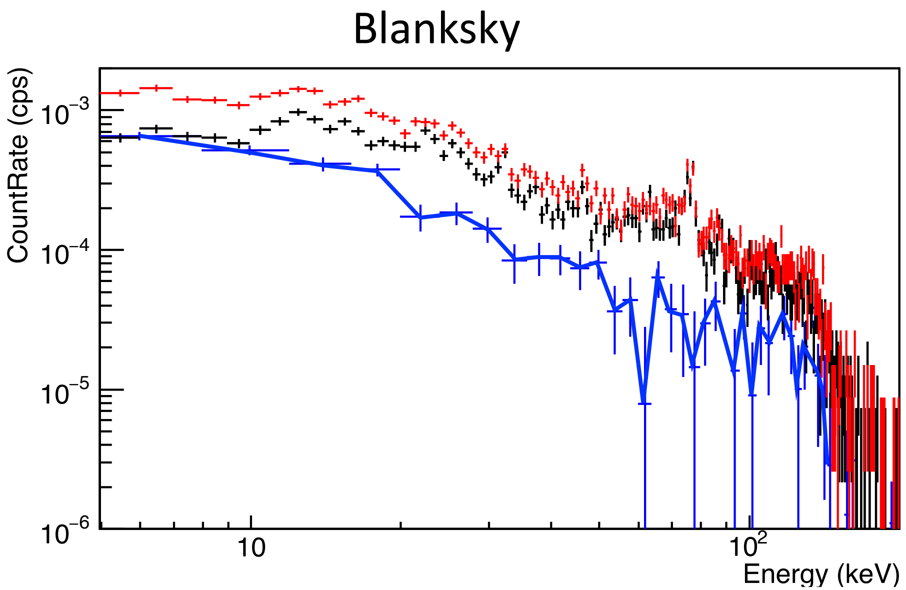
Occlutation ~340 ks

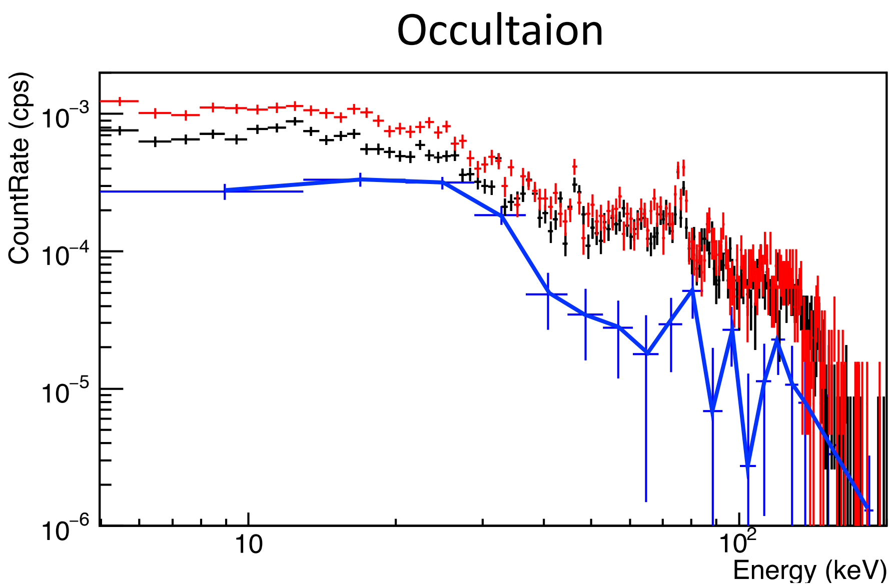






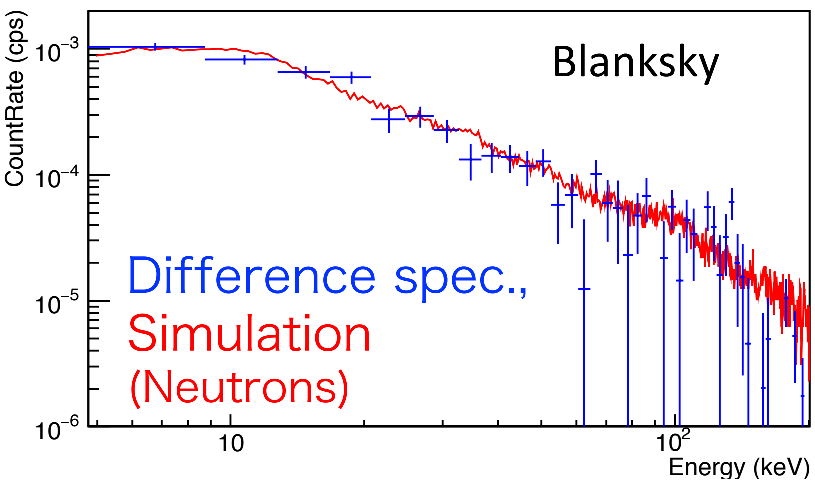
High-CR rate – Law-CR rate
= Difference spectrum

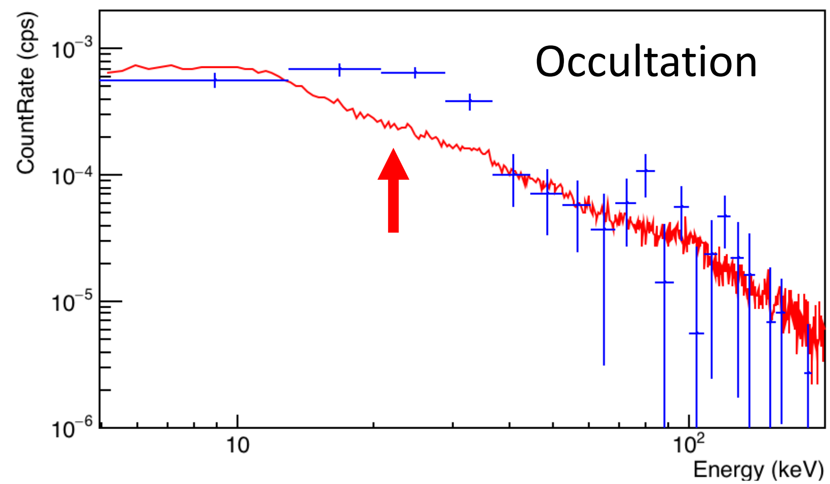




3-5. シミュレーションとの比較 (§6.11)

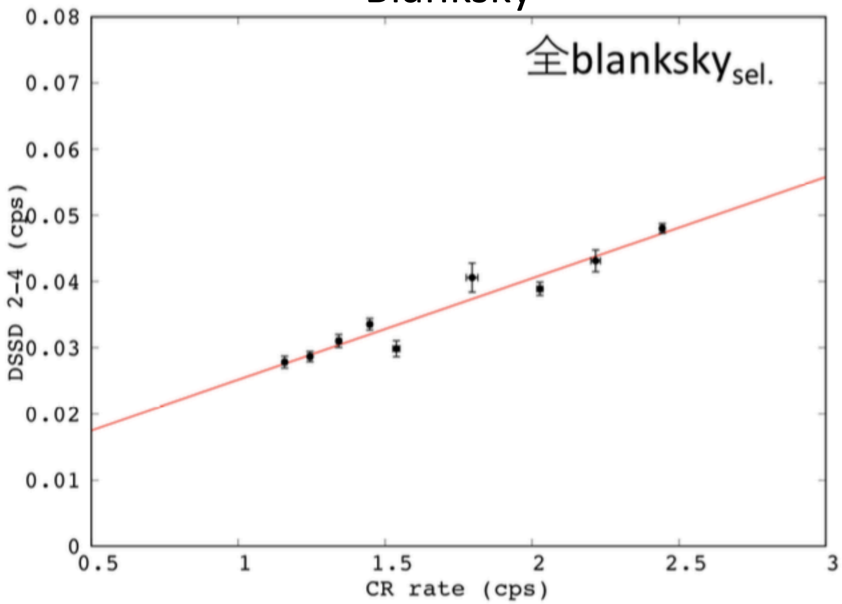
- HXIチームがすでに行ったシミュレーション結果 (Odaka et al. 2018 submitted) が本研究で得た相関成分データを説明できるか調べた
  - 中性子のみのシミュレーションを相関成分データのカウントレートと合うようにスケール



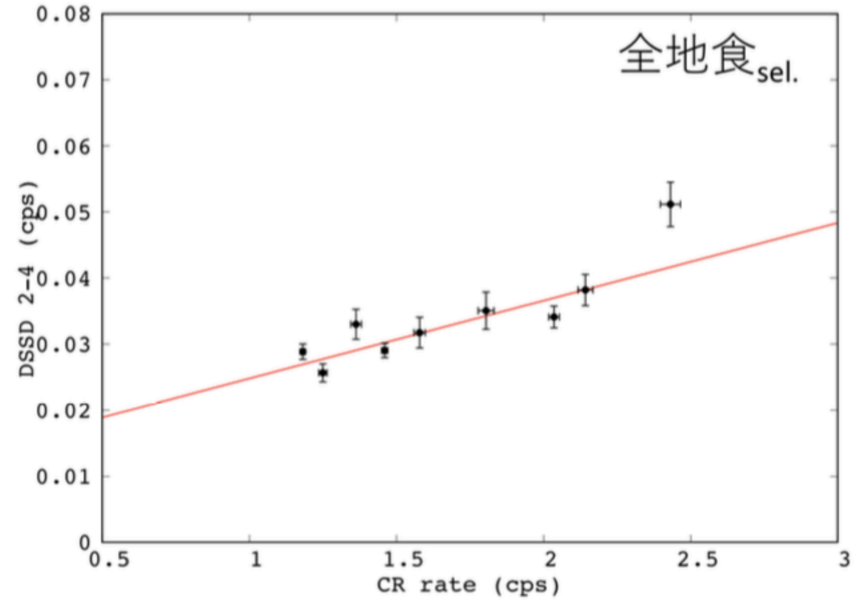


全地食では20-30 keVが盛り上がる

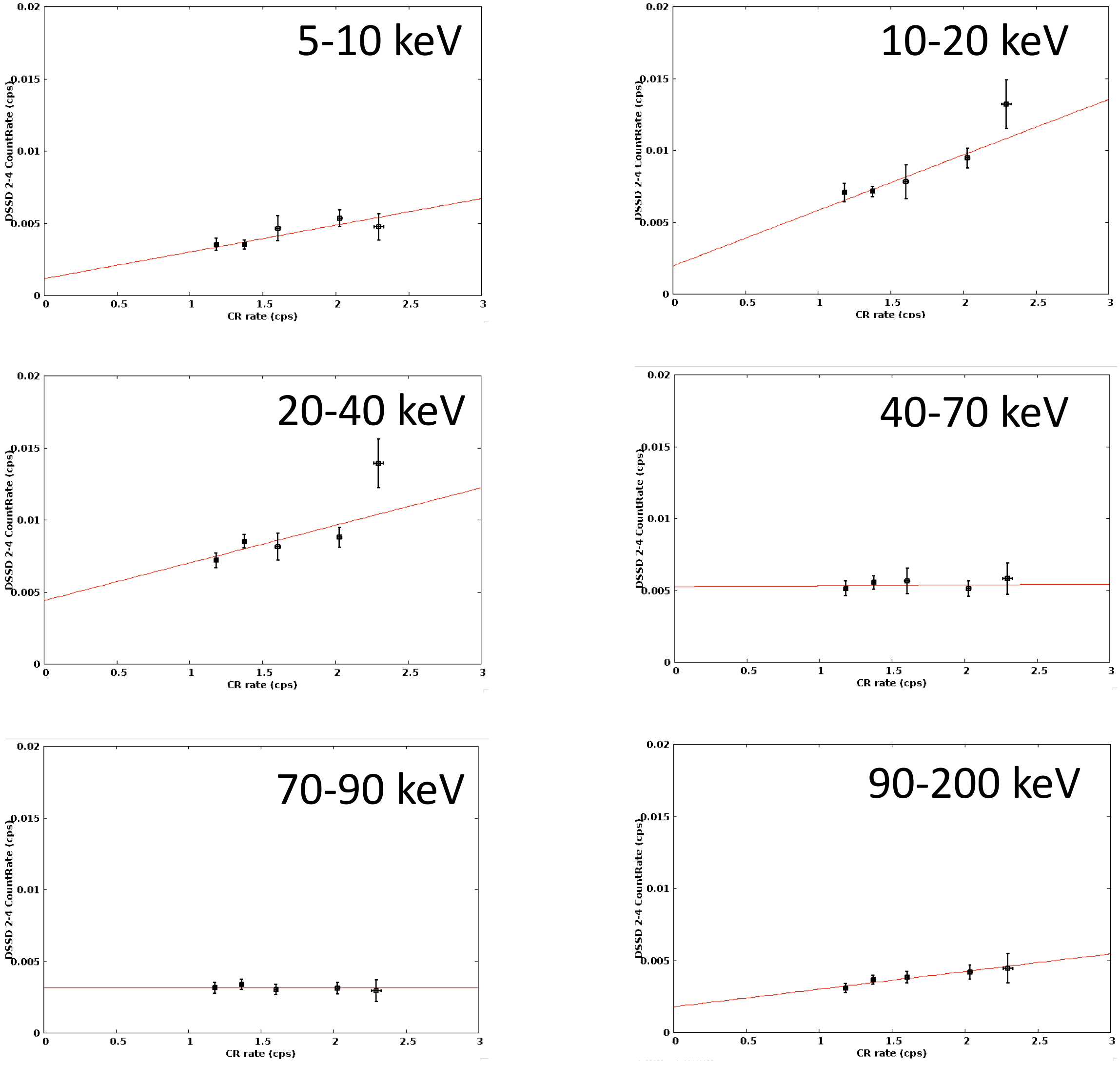
Blanksky



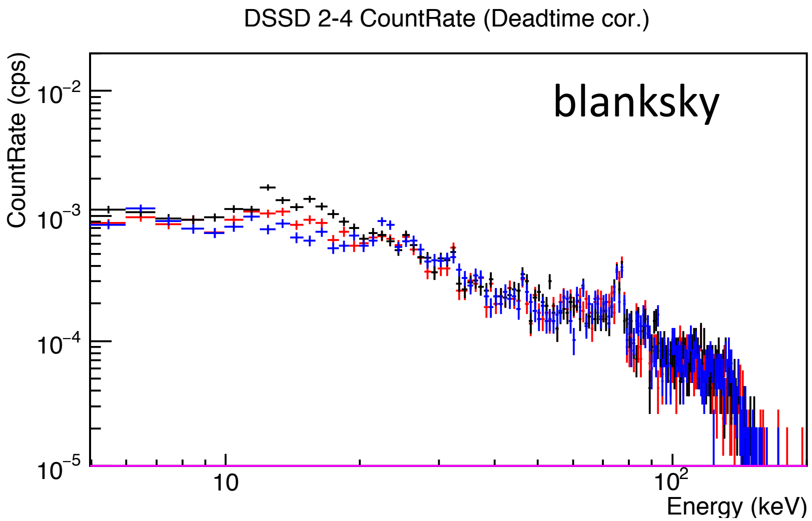
Occlutation

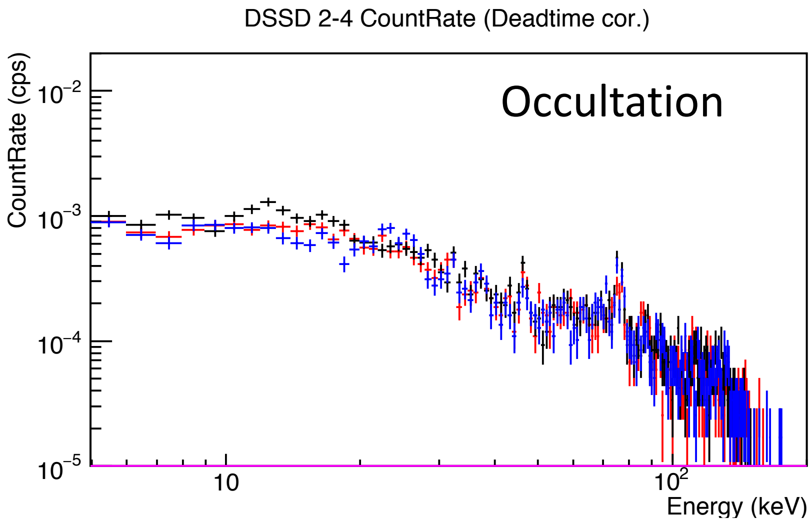


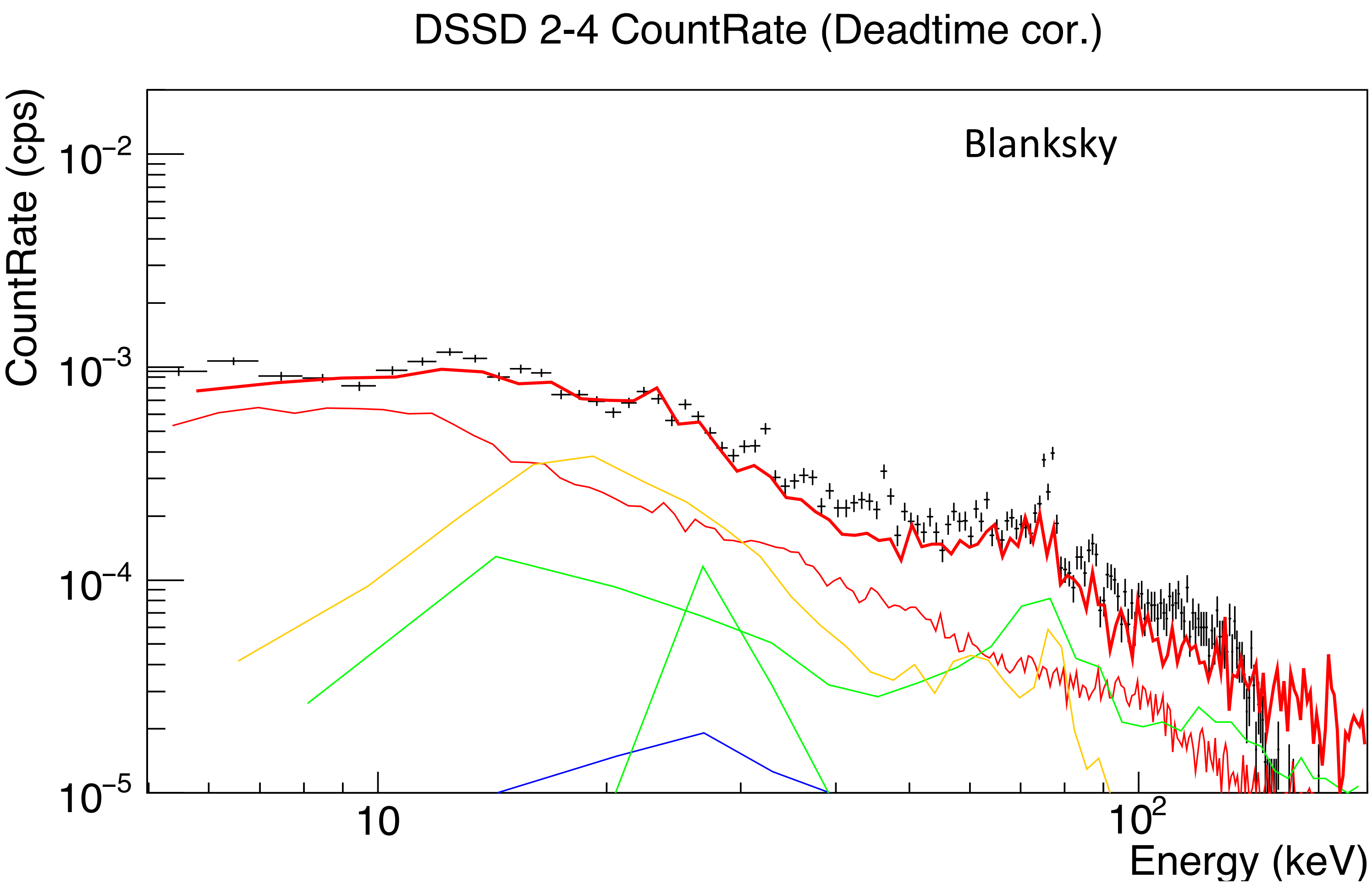
Occultation



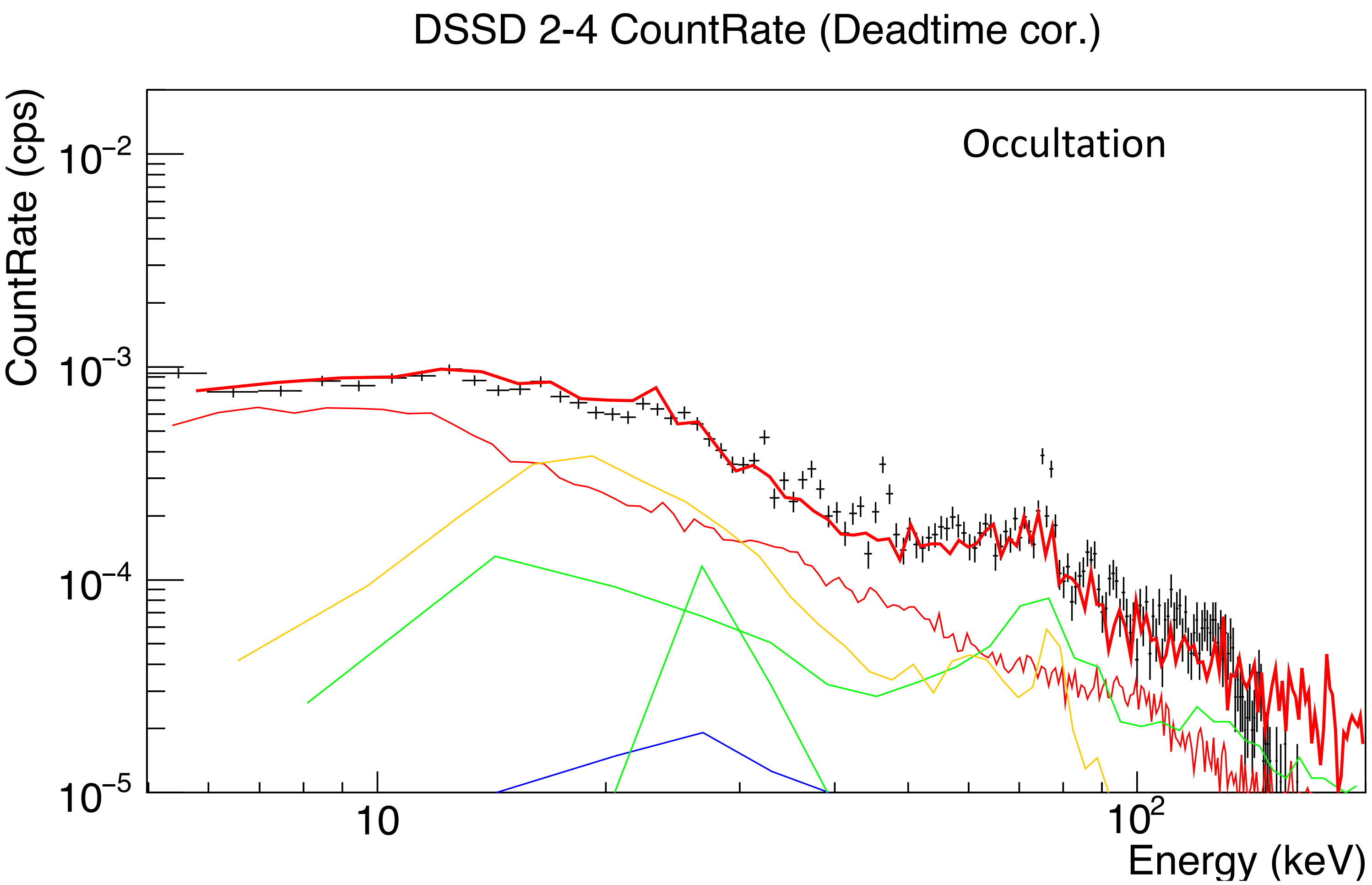
DSSD 2, 3, 4


DSSD 2-4 CountRate (Deadtime cor.)
blanksky
CountRate (cps)
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10
10^{2}
Energy (keV)


DSSD 2-4 CountRate (Deadtime cor.)
Occultation
CountRate (cps)
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10
10^{2}
Energy (keV)

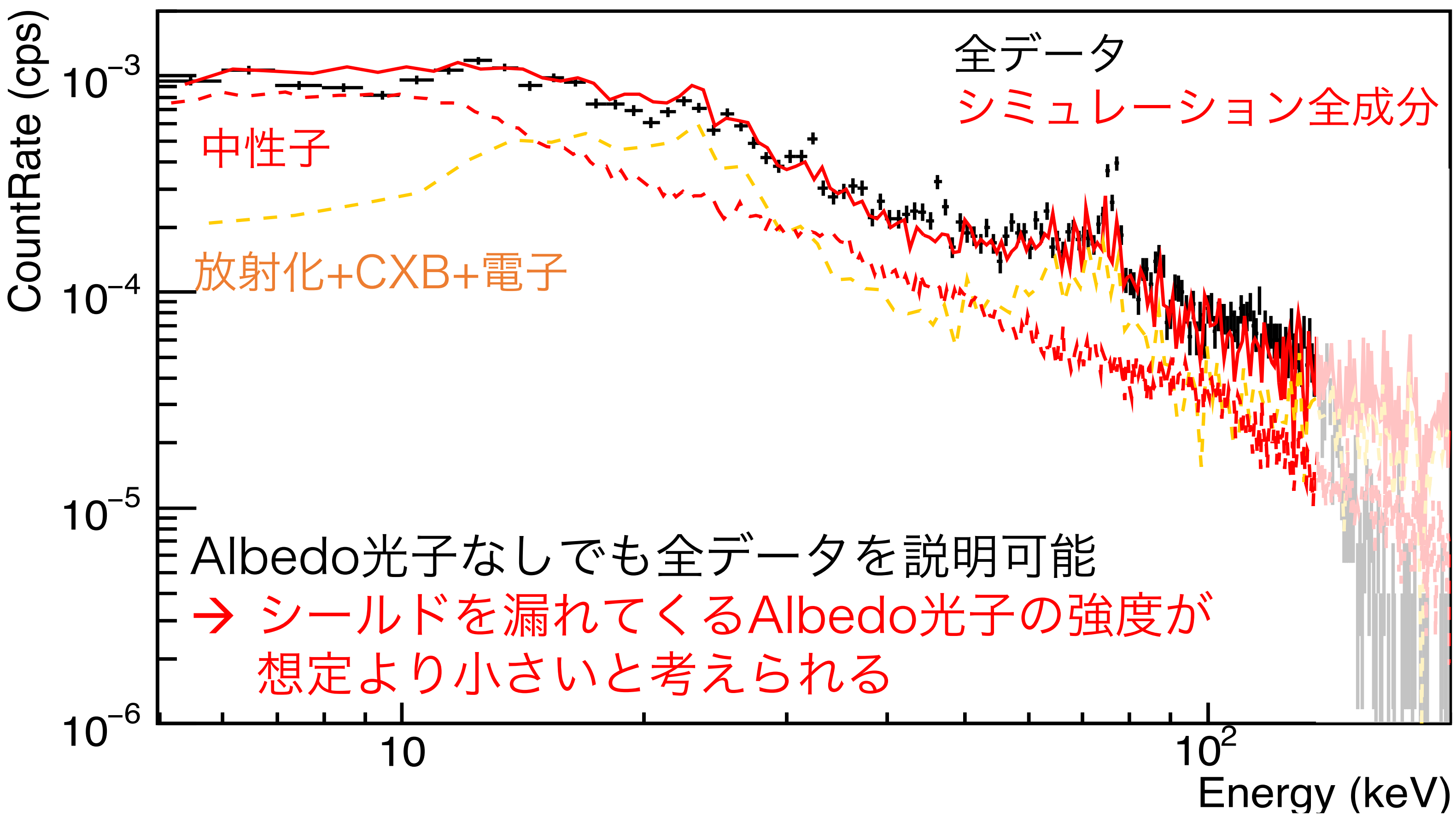


DSSD 2-4 CountRate (Deadtime cor.)
Blanksky
CountRate (cps)
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10
10^{2}
Energy (keV)


DSSD 2-4 CountRate (Deadtime cor.)
CountRate (cps)
Occultation
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10
10^{2}
Energy (keV)

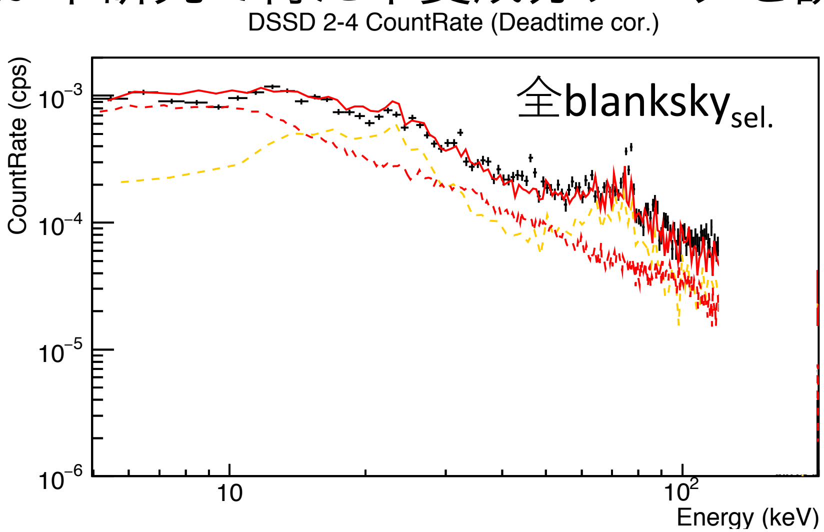
3-4. NXBシミュレーションとの比較

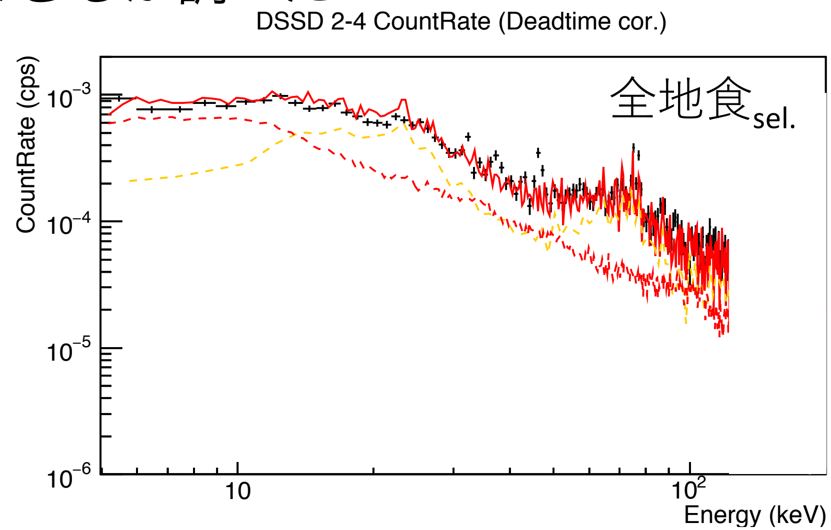
- HXIチームがすでに行ったシミュレーション結果 (Odaka et al. 2018 submitted) が本研究で得た相関成分データを説明できるか調べた
  - 中性子のシミュレーションスペクトルのみスケールし全成分のカウントレートをデータと合わせた



シミュレーションとの比較

- HXIチームがすでに行ったシミュレーション結果が本研究で得た不変成分データを説明できるか調べた





全データ
シミュレーション, Albedo光子を除く全成分（実線）
赤点線：シミュレーション中性子のみ（点線）
オレンジ：シミュレーション不変成分
シミュレーションの相関成分をスケールし、データと
シミュレーション全成分の5-120 keVカウントレートが合うようにした

シミュレーションAlbedo光子を除いてもよく合う
→ シールドを漏れてくるAlbedo光子の強度が小さい？