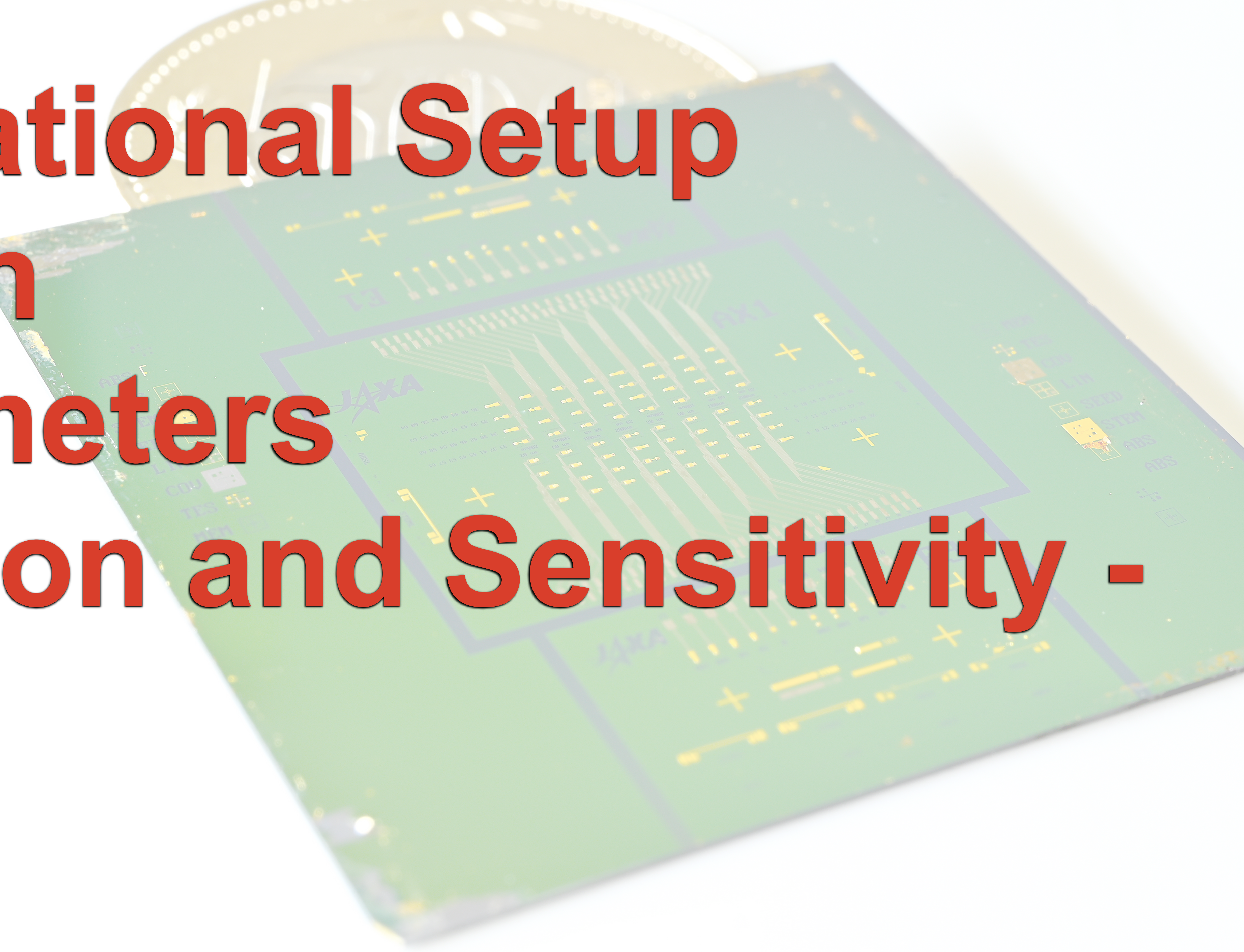
B04-report

Design of the Observational Setup for Solar Axion Search with TES Microcalorimeters - Practical Configuration and Sensitivity -



Yuta Yagi (Ph.D. candidate)

The University of Tokyo [2],

Institute of Space and Astronautical Science / JAXA [1]

Collaborators

Tasuku Hayashi [3,4], Keita Tanaka [1,2], Rikuta Miyagawa [1,2], Ryo Ota [1,2], Noriko Y. Yamasaki [1,2,3], Kazuhisa Mitsuda [1,3,4], Nao Yoshida [5], Mikiko Saito [5], Takayuki Homma [5]

1. JAXA Japan Aerospace Exploration Agency

2. 東京大学 THE UNIVERSITY OF TOKYO

3. QUP International Center for Quantum-field Measurement System for Studies of the Universe and Particles

4. 国立天文台 NAOJ National Astronomical Observatory of Japan

5. WASEDA University 早稲田大学

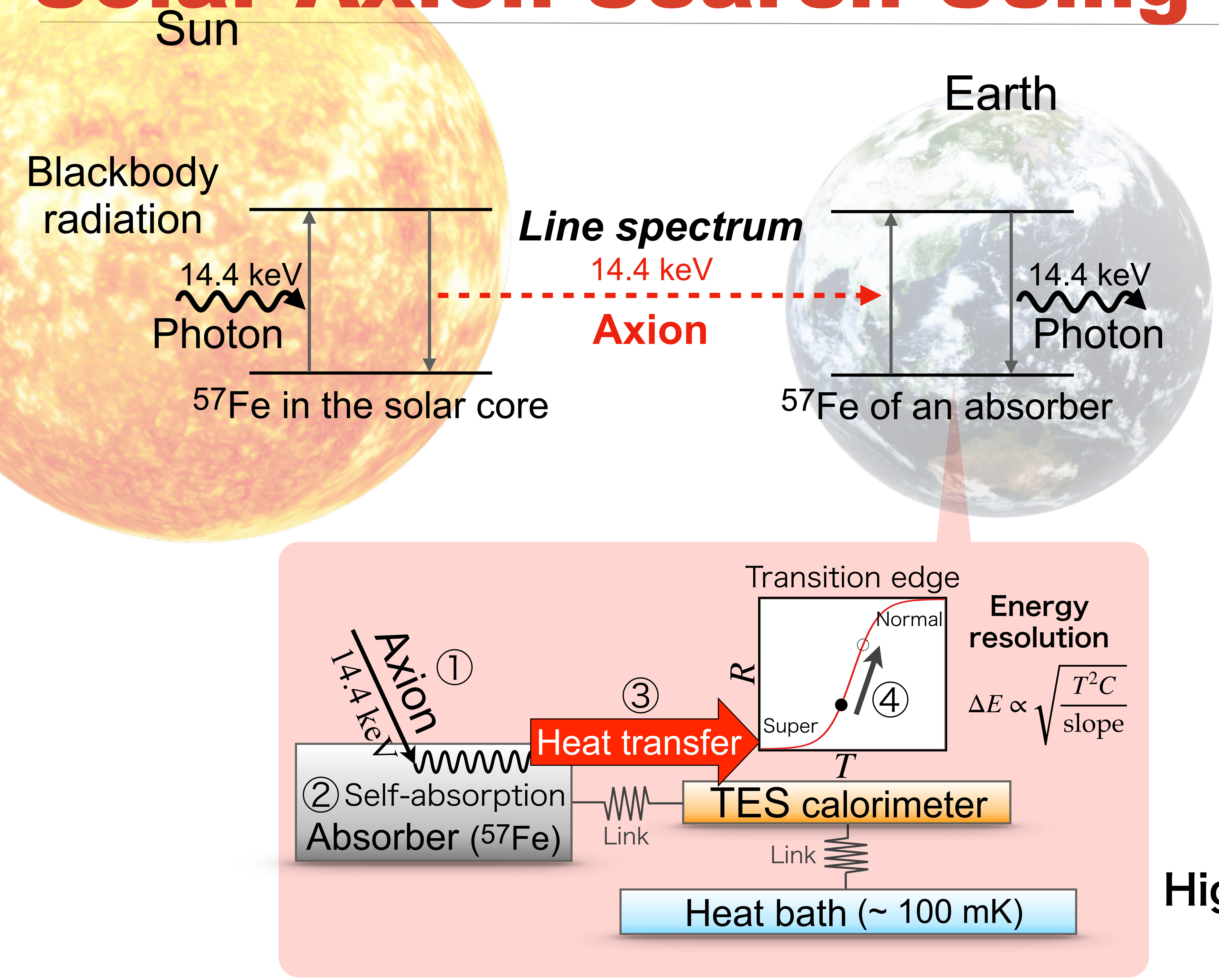
ダークマターの正体は何か？

広大なディスカバリースペースの網羅的研究

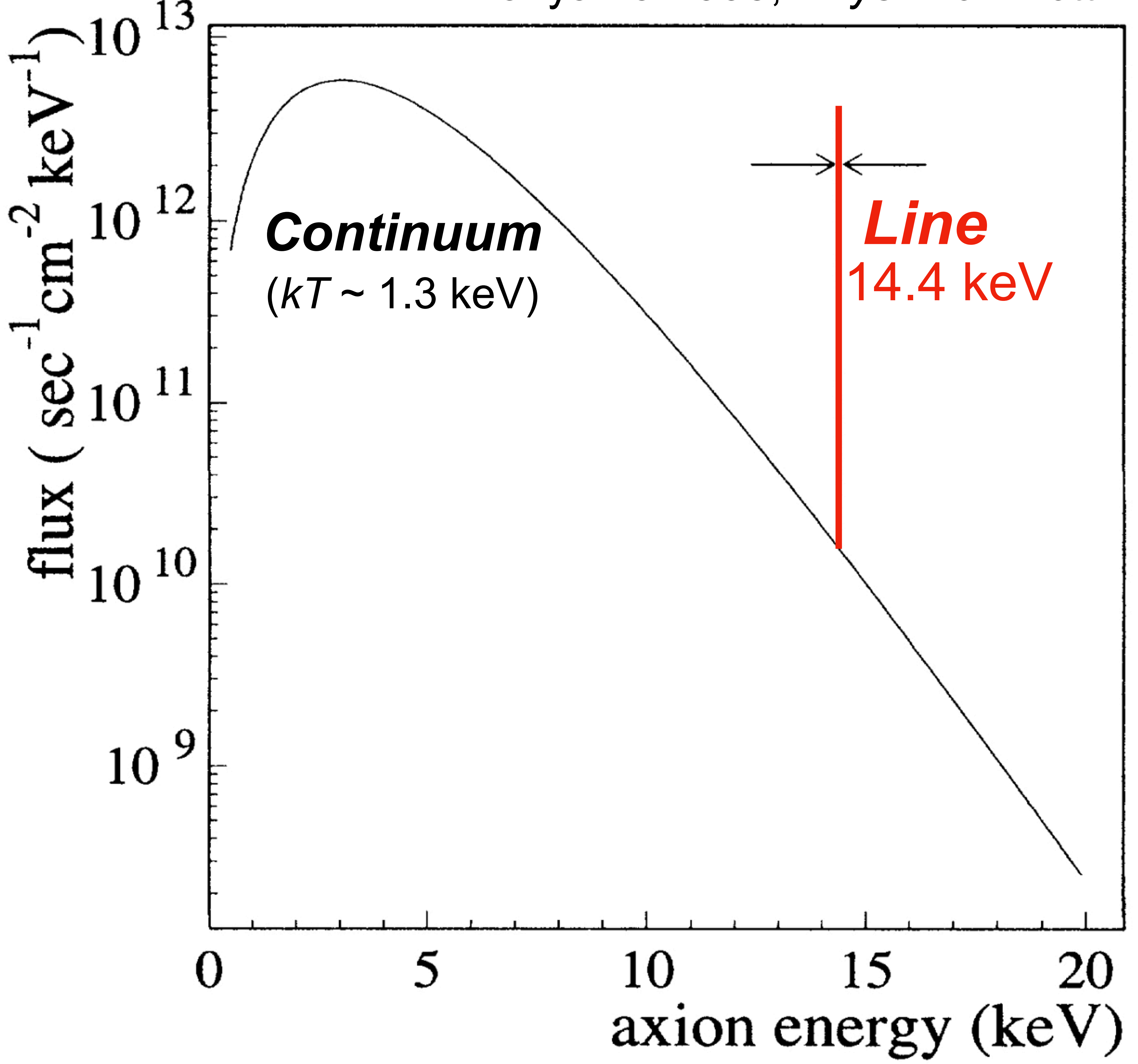
What is dark matter? - Comprehensive study of the huge discovery space in dark matter

文部科学省 科学研究費助成事業 学術変革領域研究 (2020–2024)

Solar Axion Search Using TES with 57Fe



Moriyama 1995, *Phys. Rev. Lett.*



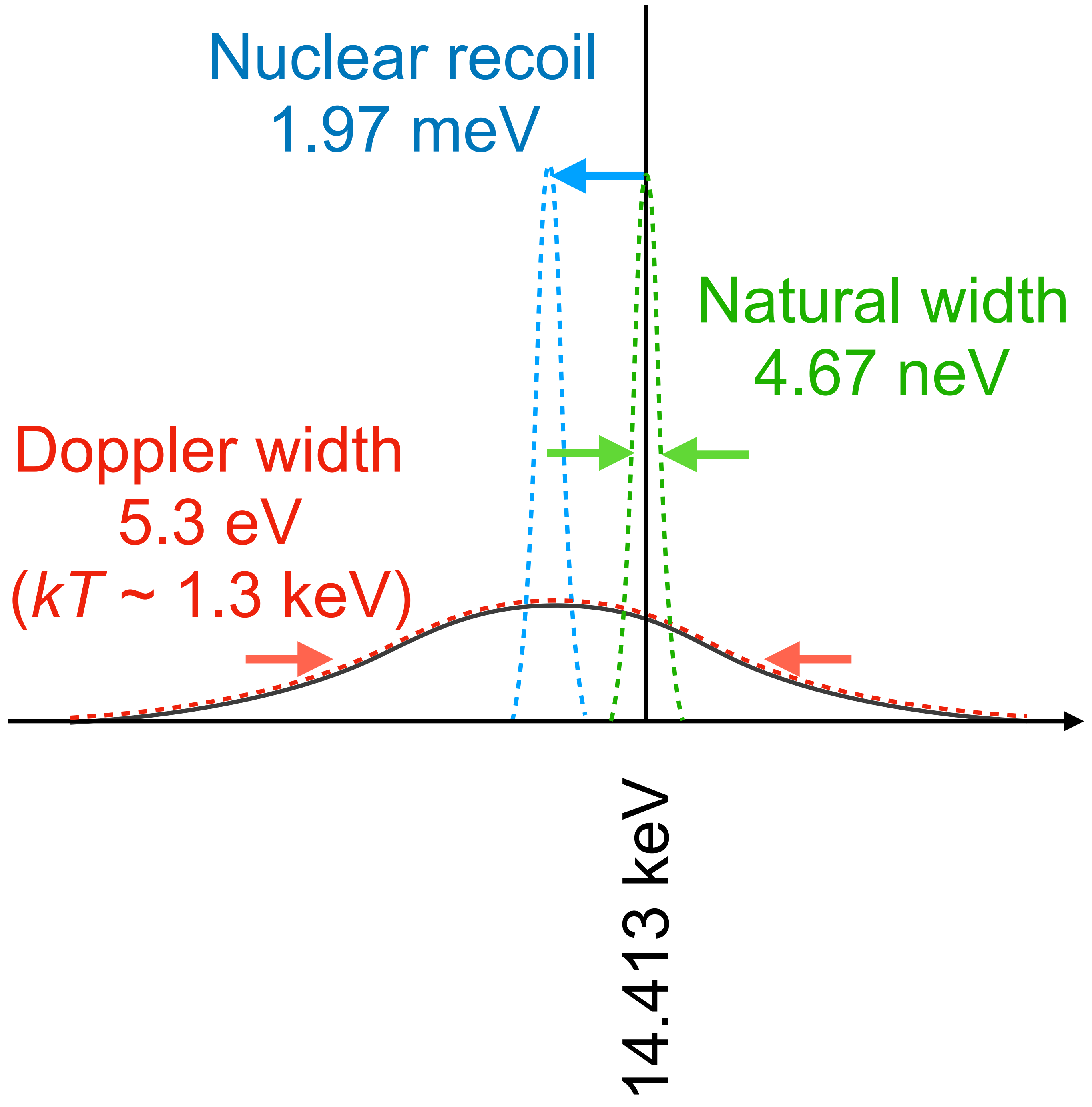
Transition Edge Sensor

High energy resolution E/ΔE ~ 3000

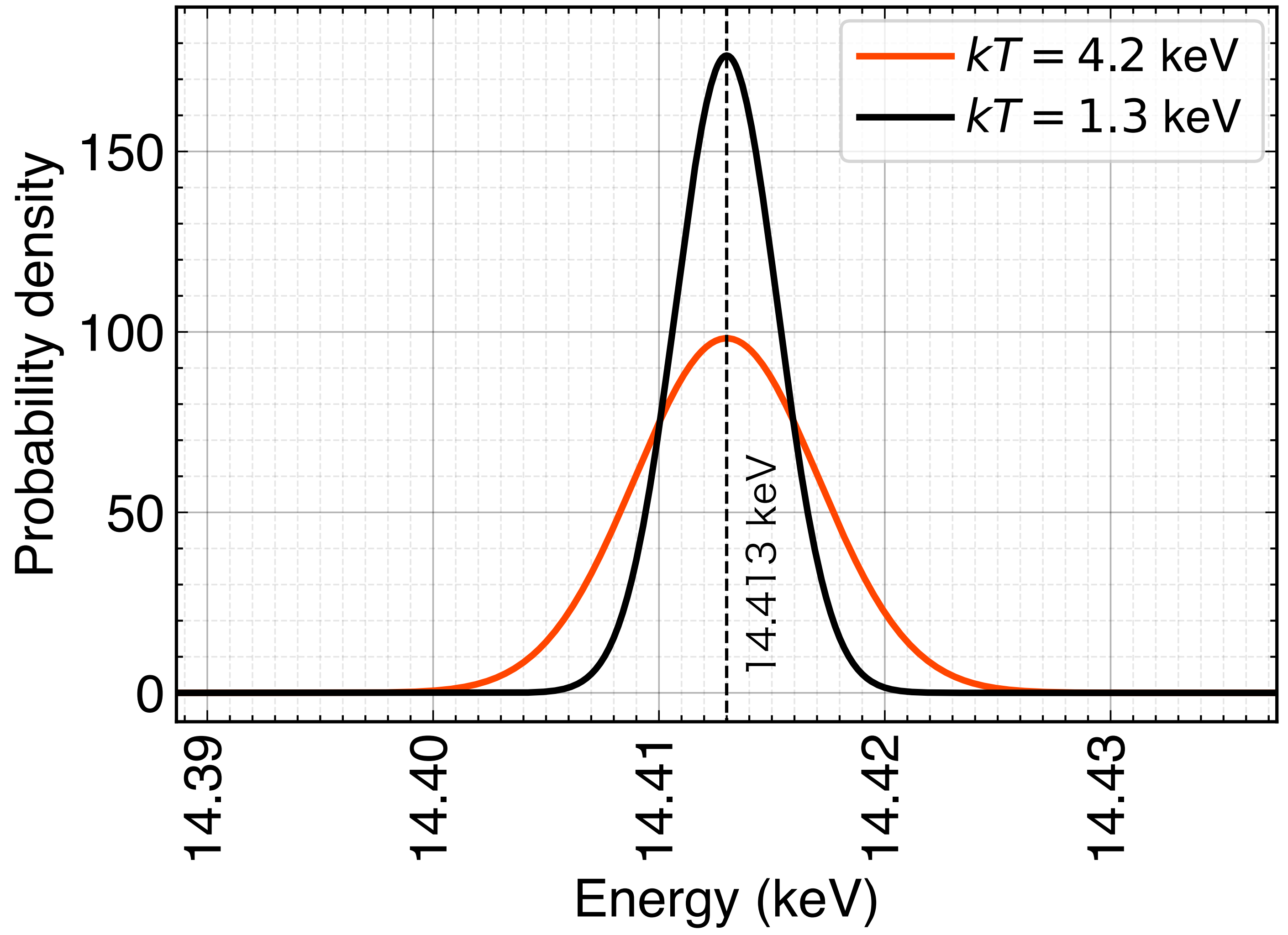
(cf. Si-detector E/ΔE ~ 60)

Effects of 57Fe Thermal Motion, Nuclear Recoil, and Natural Width

- ✦ Calculated fraction of axions emitted toward earth due to deexcitation of 57Fe nucleus in solar interior that react with 57Fe on earth and are resonantly absorbed.
- ✦ For resonance absorption on ground, emission should fall within natural width at center of the emission line, and integral over relevant energy range was obtained as a percentage of total.
- ✦ Calculating percentage of resonance absorption again on ground at solar temperature of 1.3 keV (4.2 keV) is only 1.8% (0.98%).



Spectrum of axion on the ground when all effects are taken into account



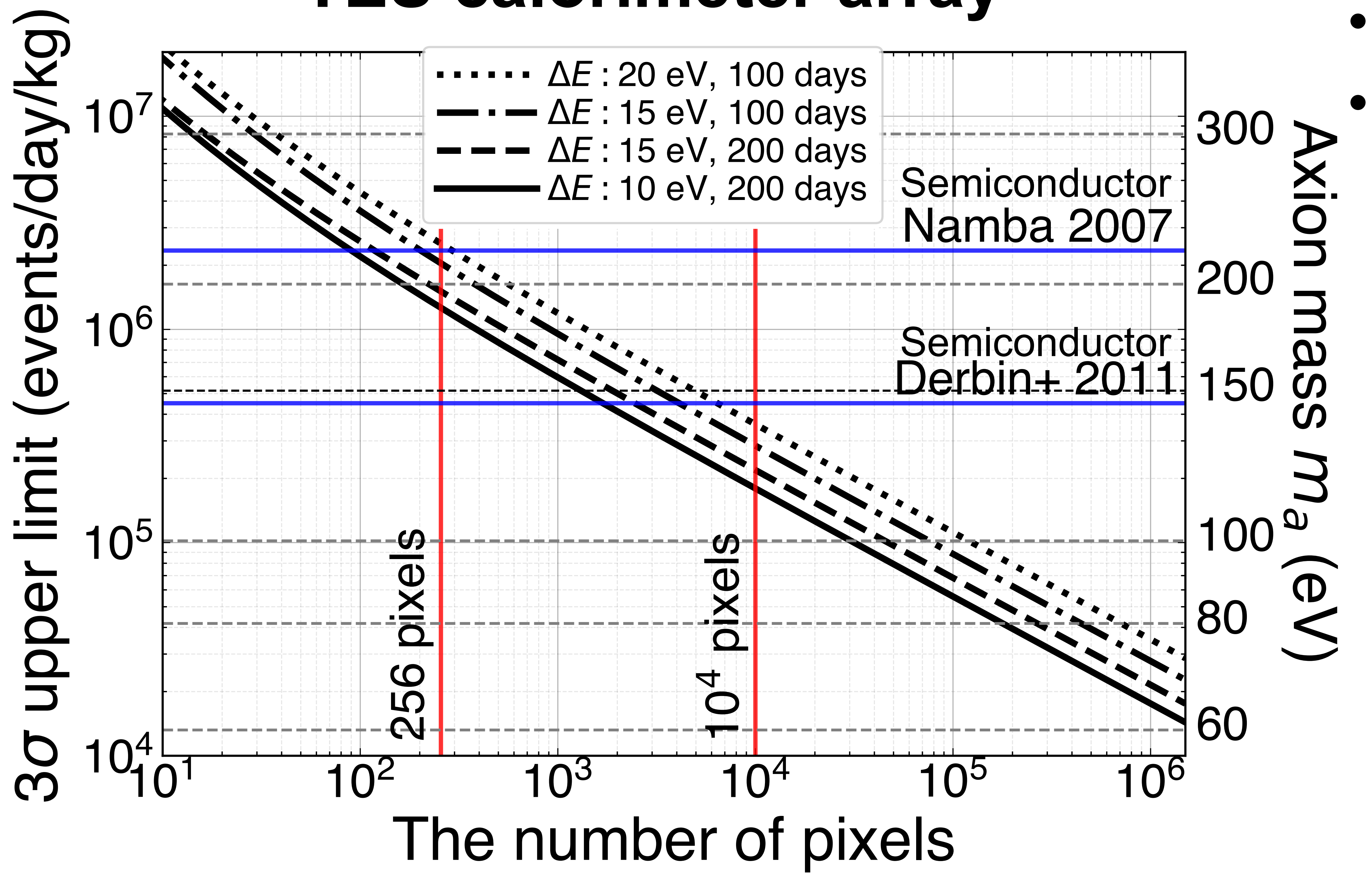
Effects of 57Fe thermal motion, nuclear recoil, and natural width

Solar temperature	Average temperature 4.2 keV	Blackbody temperature 1.3 keV
Natural width	4.67 neV	
Doppler width of 57Fe thermal motion	σ = 4.1 eV FWHM = 9.6 eV	σ = 2.3 eV FWHM = 5.3 eV
Nuclear recoil energy shift	1.97 meV	
Percentage of resonance absorption again on the ground	0.98%	1.8%

Detection Sensitivity

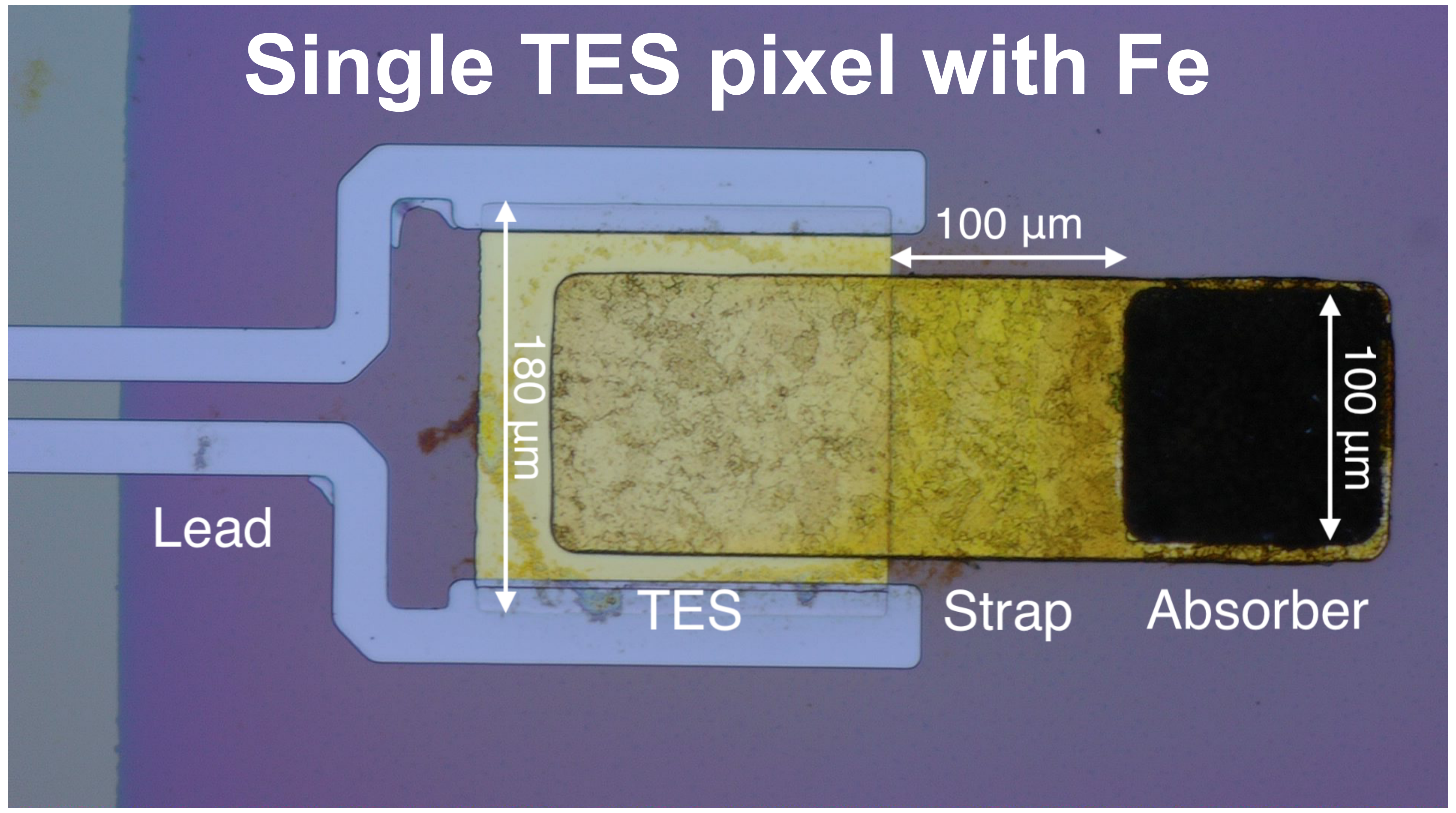
- ✦ TES calorimeters can detect self-absorbed thermal energy from axions
- ✦ Therefore, more than 70% of efficiency is expected
- ✦ Increase the converter mass by using an array device
- ✦ Low-noise microwave SQUID multiplexed readout

The detection sensitivity of TES calorimeter array

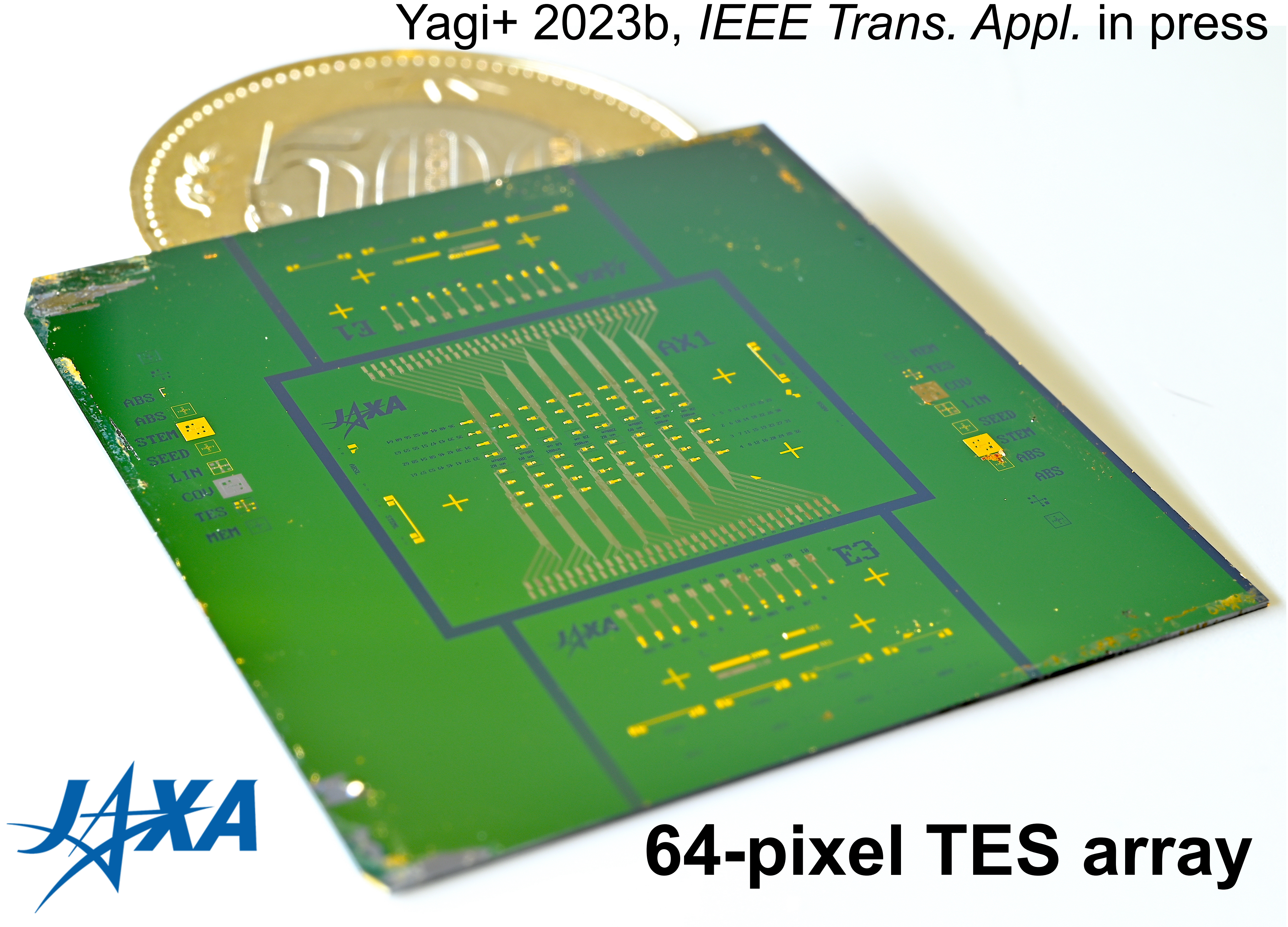


Yagi+ 2023a, *J. Low Temp. Phys.*

- Hadronic axion model
- f_a = 1e+6 GeV
- 57Fe; t10um×w100um×l100um
- With anti-coincidence detector; Conservative BGD rate = 1.0×10^{-2} counts/s/cm2/keV



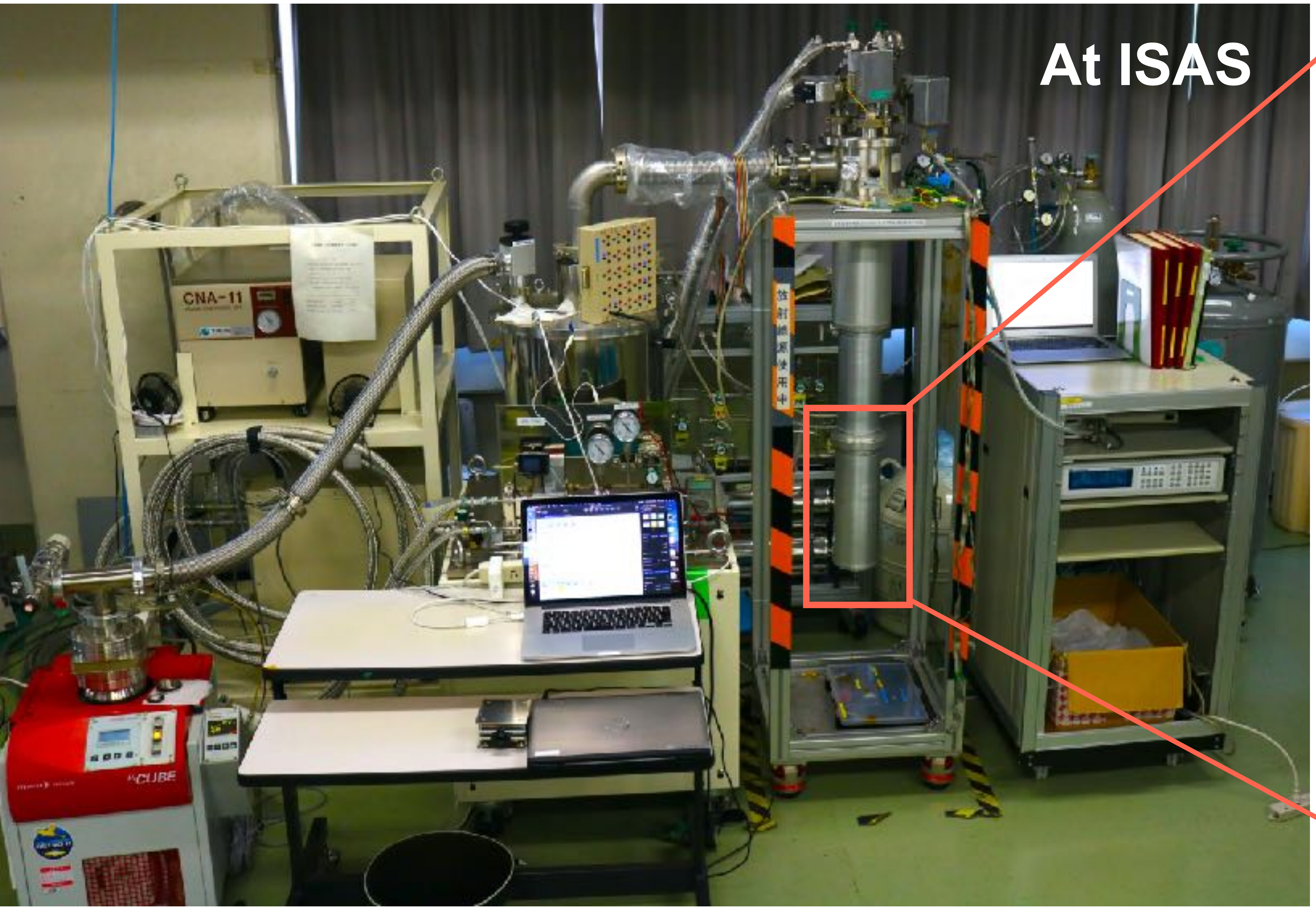
Yagi+ 2023b, *IEEE Trans. Appl.* in press

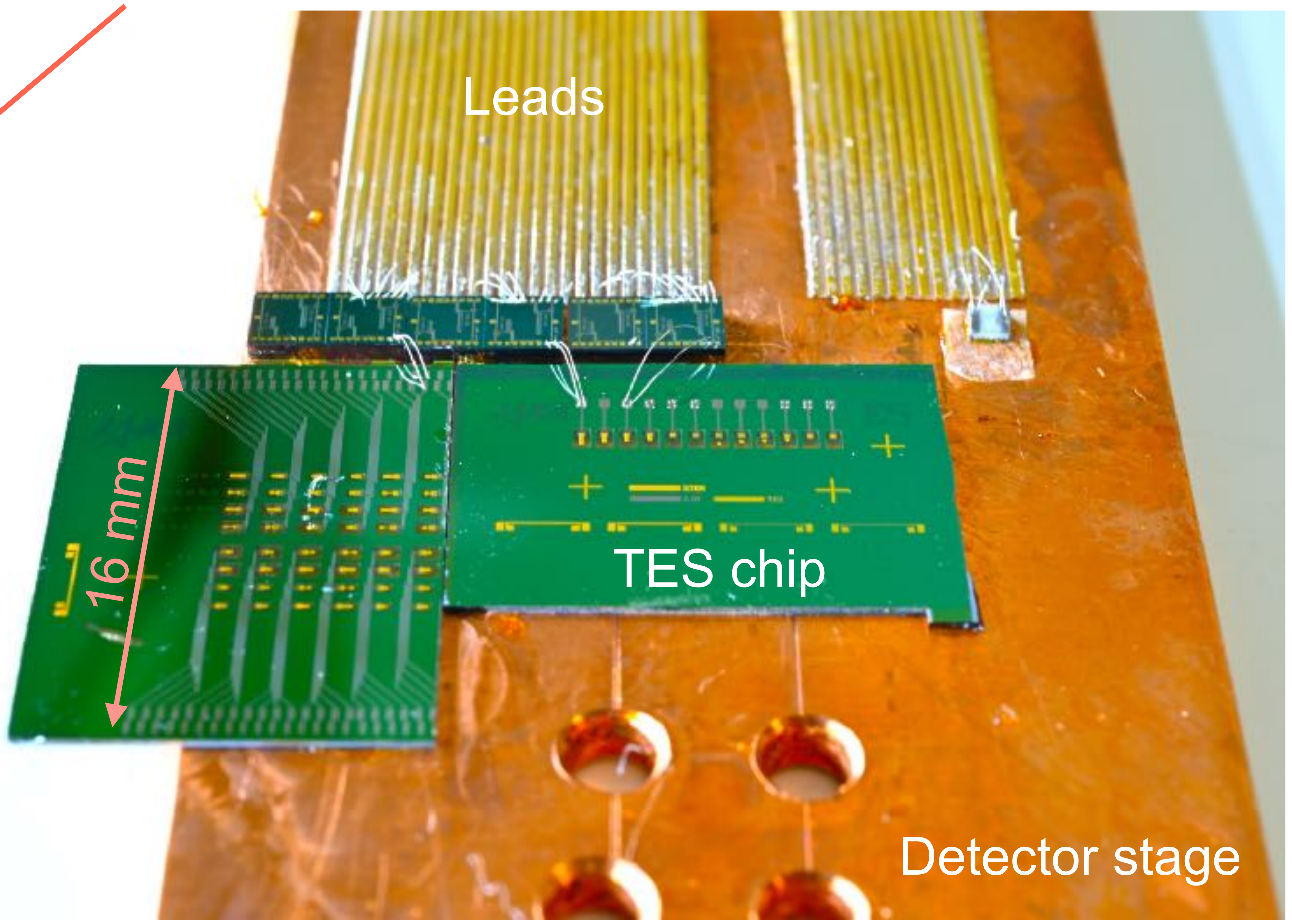


64-pixel TES array

Setup of a Conventional X-Ray Irradiation Experiment

Dilution refrigerator without signal multiplexing



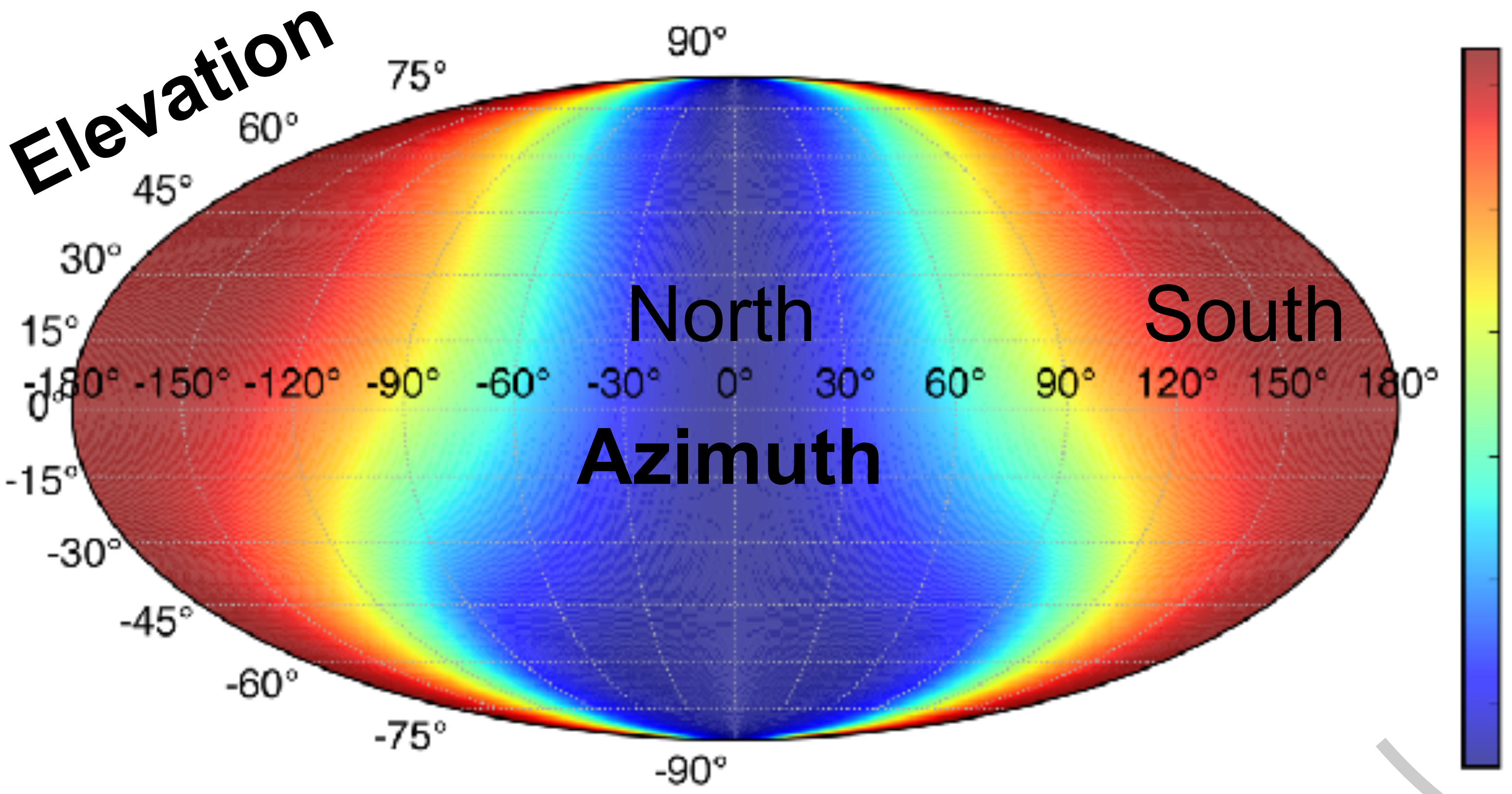


- ✦ TES is fixed to detector stage at a certain angle
- ✦ The angle cannot be changed freely
- ✦ To observe solar axion efficiently, consider the setup of the observation environment
  - Consider the appropriate observation direction
  - Optimize TES setup in the measurement environment

Direction of Detector Plane for Efficient Observation

Determine the staging angle that will provide the greatest detection efficiency throughout the year.

① Day Earth, Irradiation of front surface stage



Max efficiency ~ 24%

- ✦ Same procedure as solar panel installation

Efficiency × 1.5

② Day Earth, Double-sided irradiation of stage

Max efficiency ~ 35%

- ✦ Detection efficiency is 1.5 times higher
- ✦ Events can be simplified and detection efficiency can be improved.

Efficiency × 1.7

③ Day and night Earth, Double-sided irradiation of stage

Max efficiency ~ 61%

- ✦ Effects of magnetic field inside earth and its interaction with 57Fe nucleus could appear.

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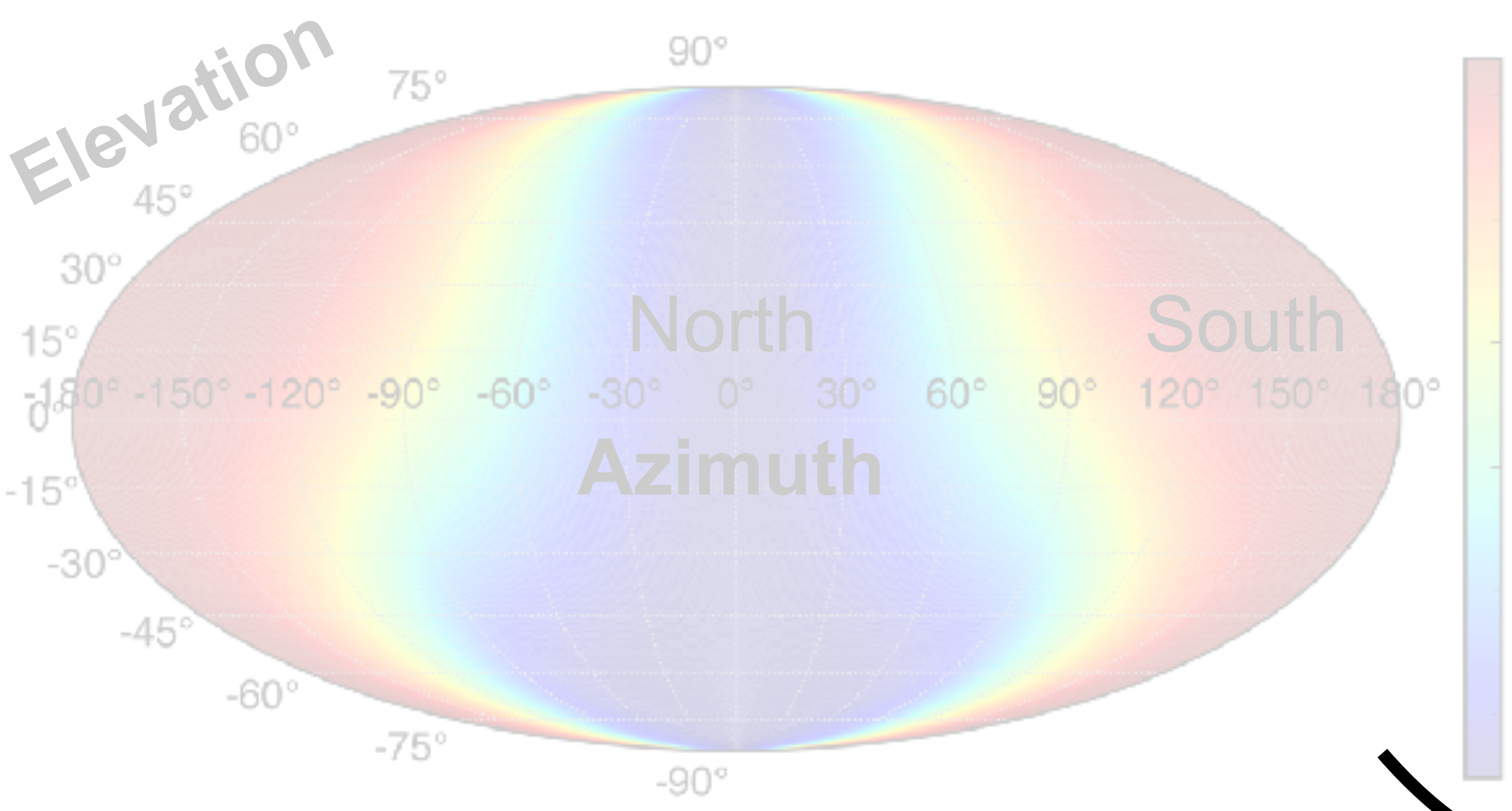

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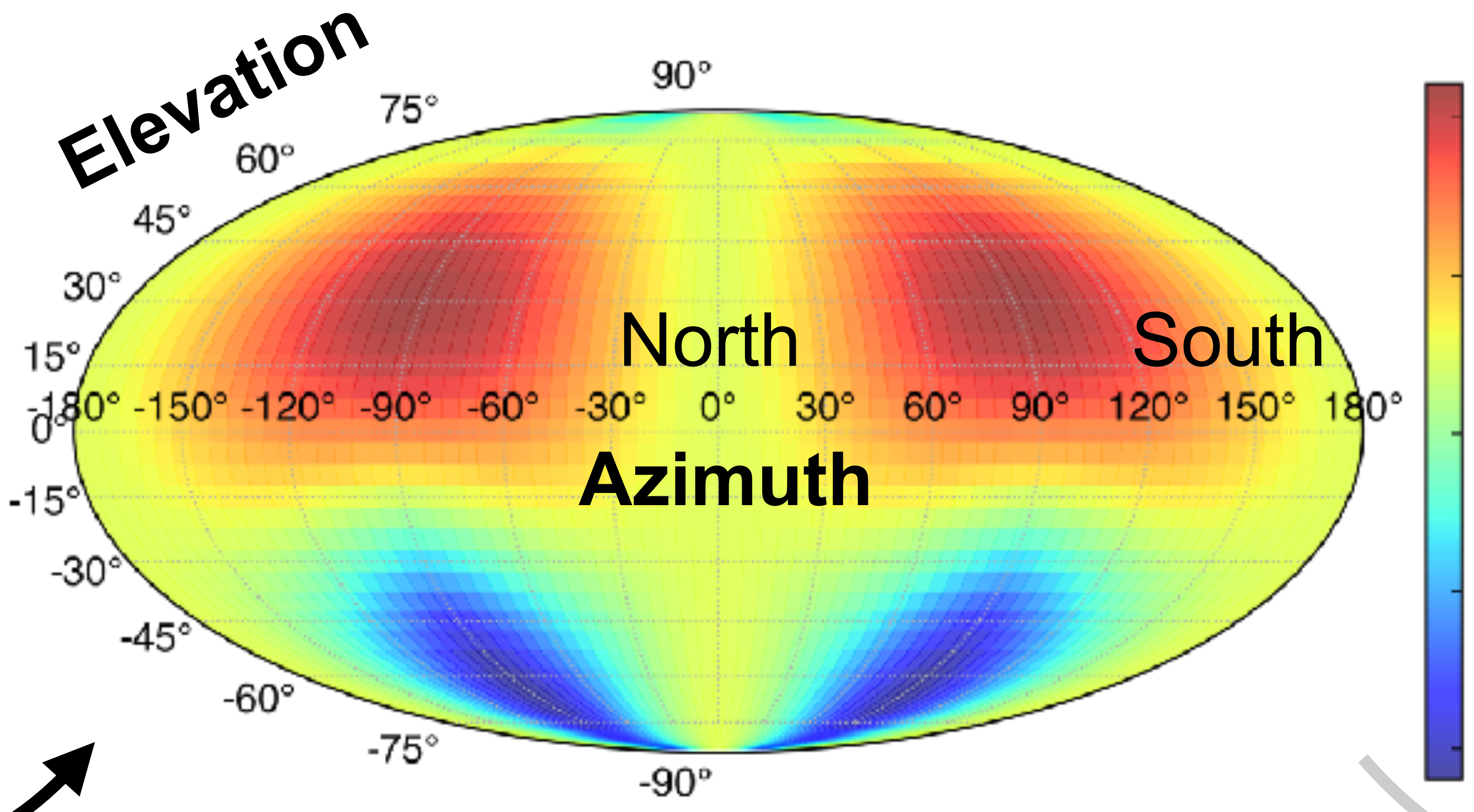

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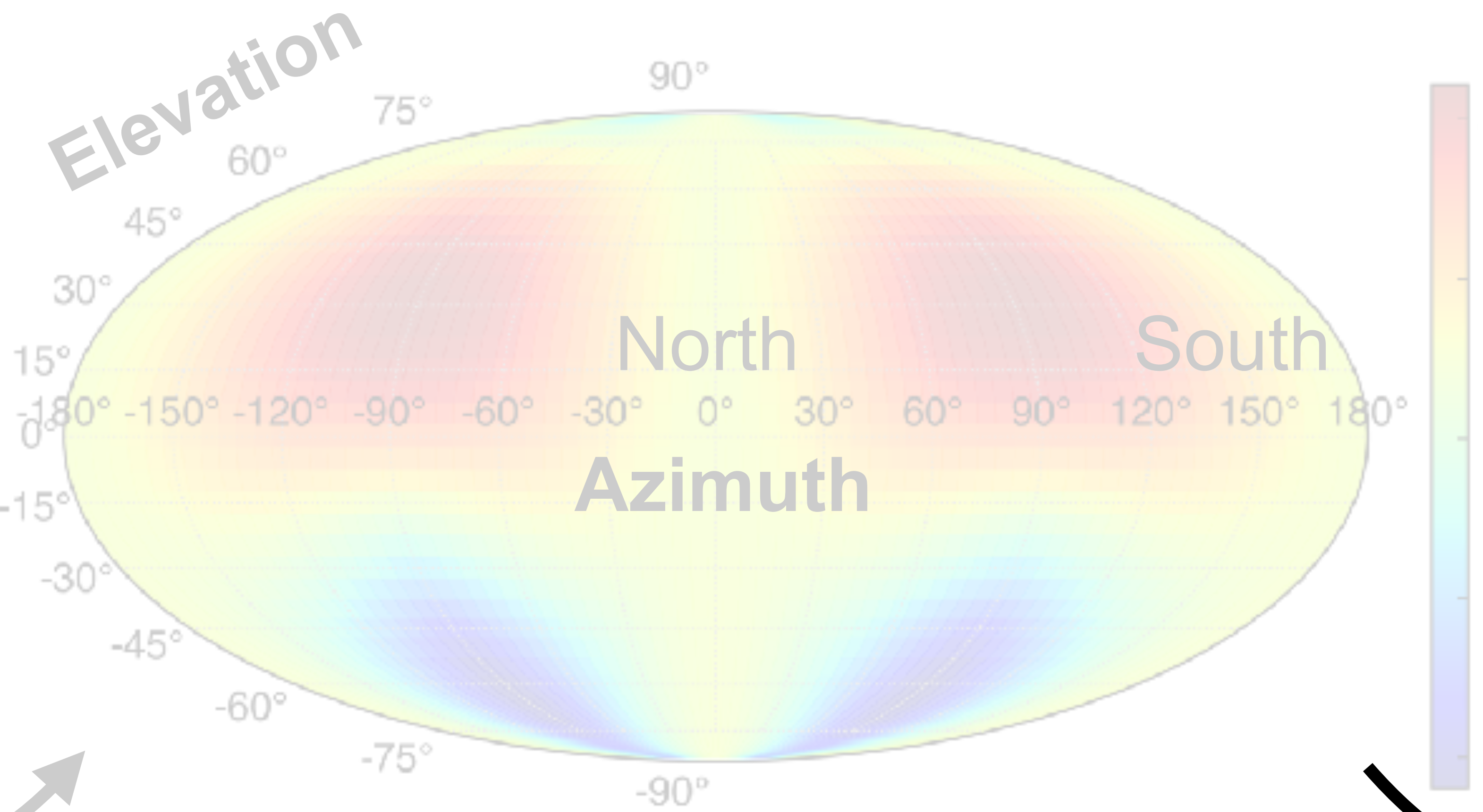

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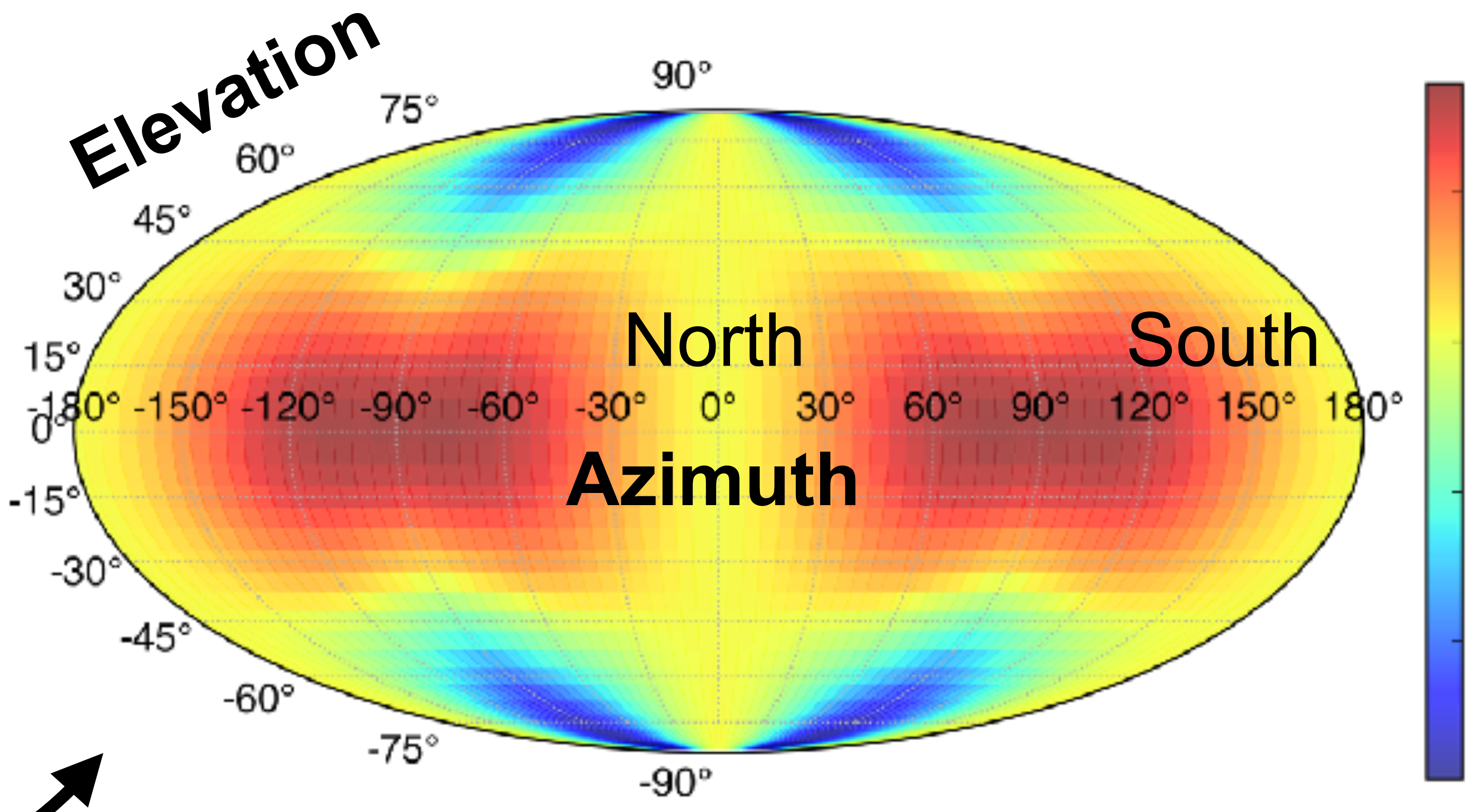

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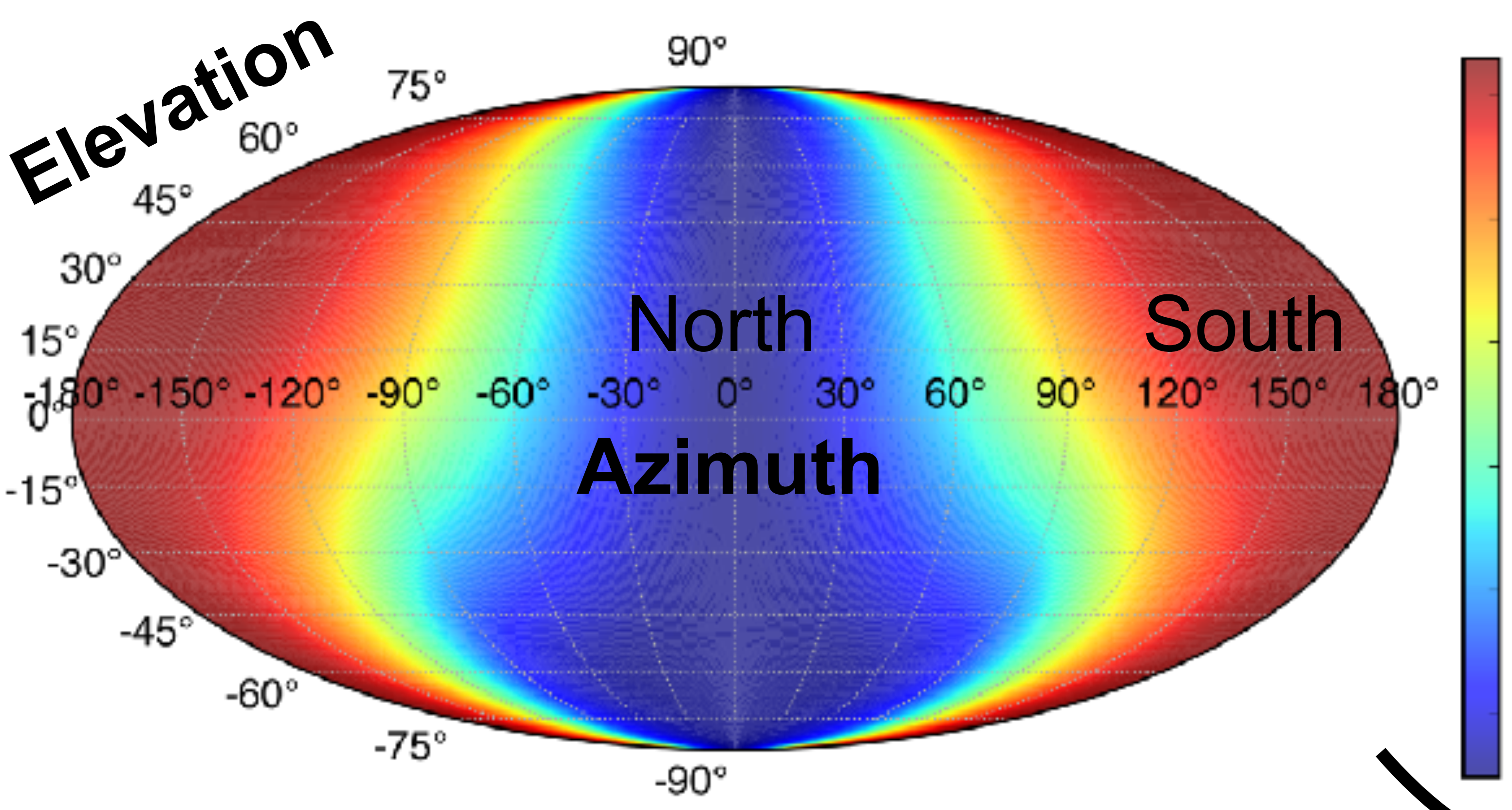

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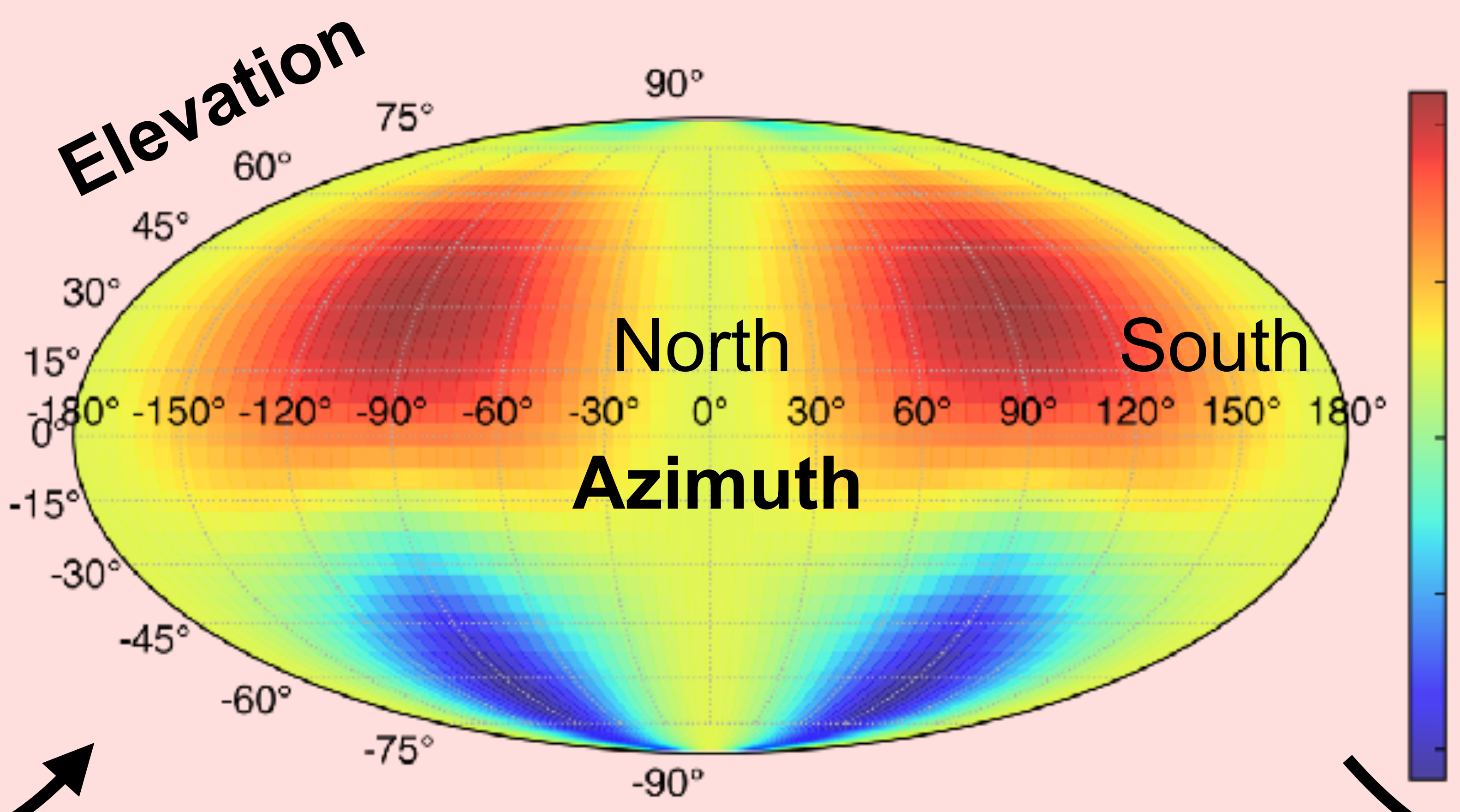

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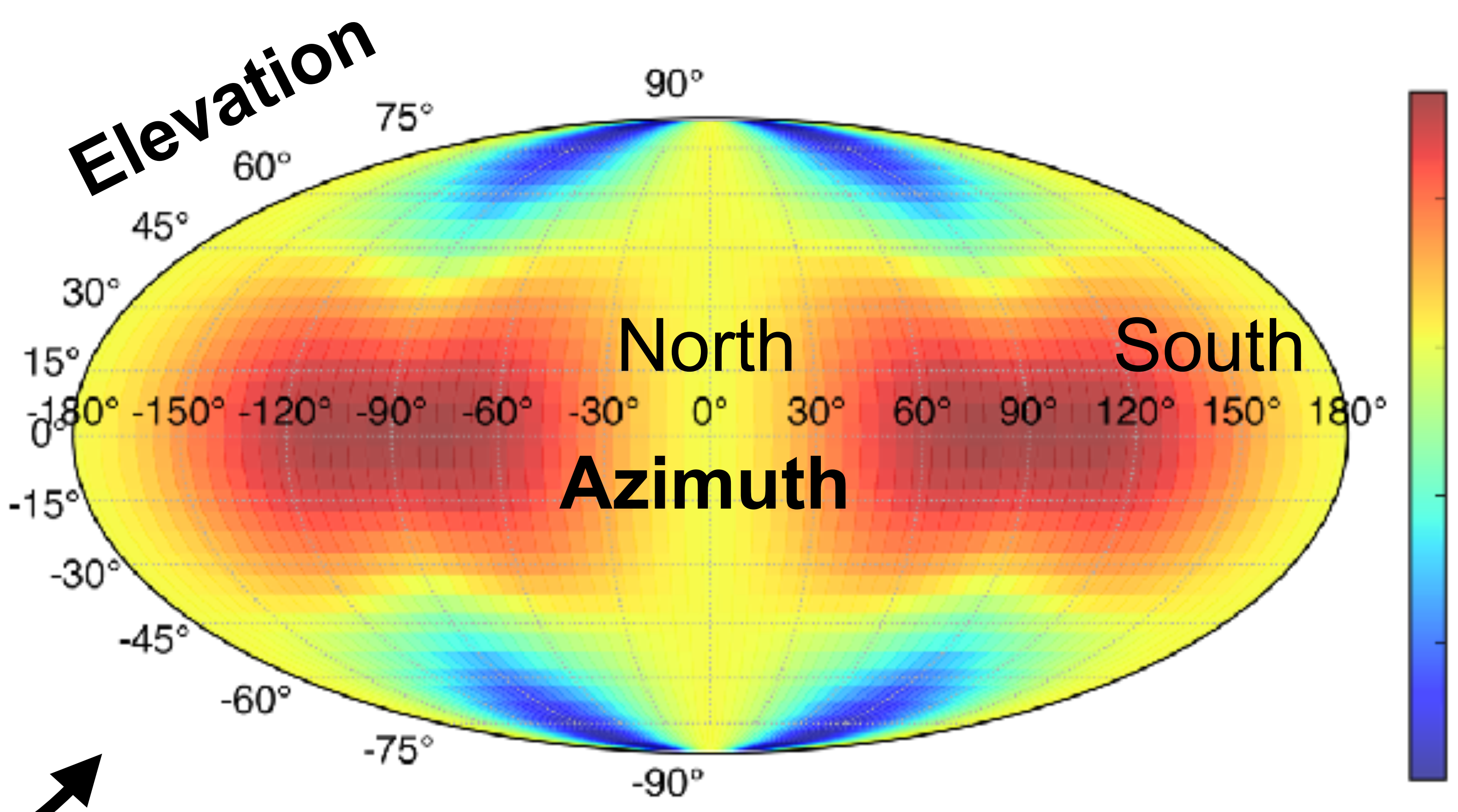

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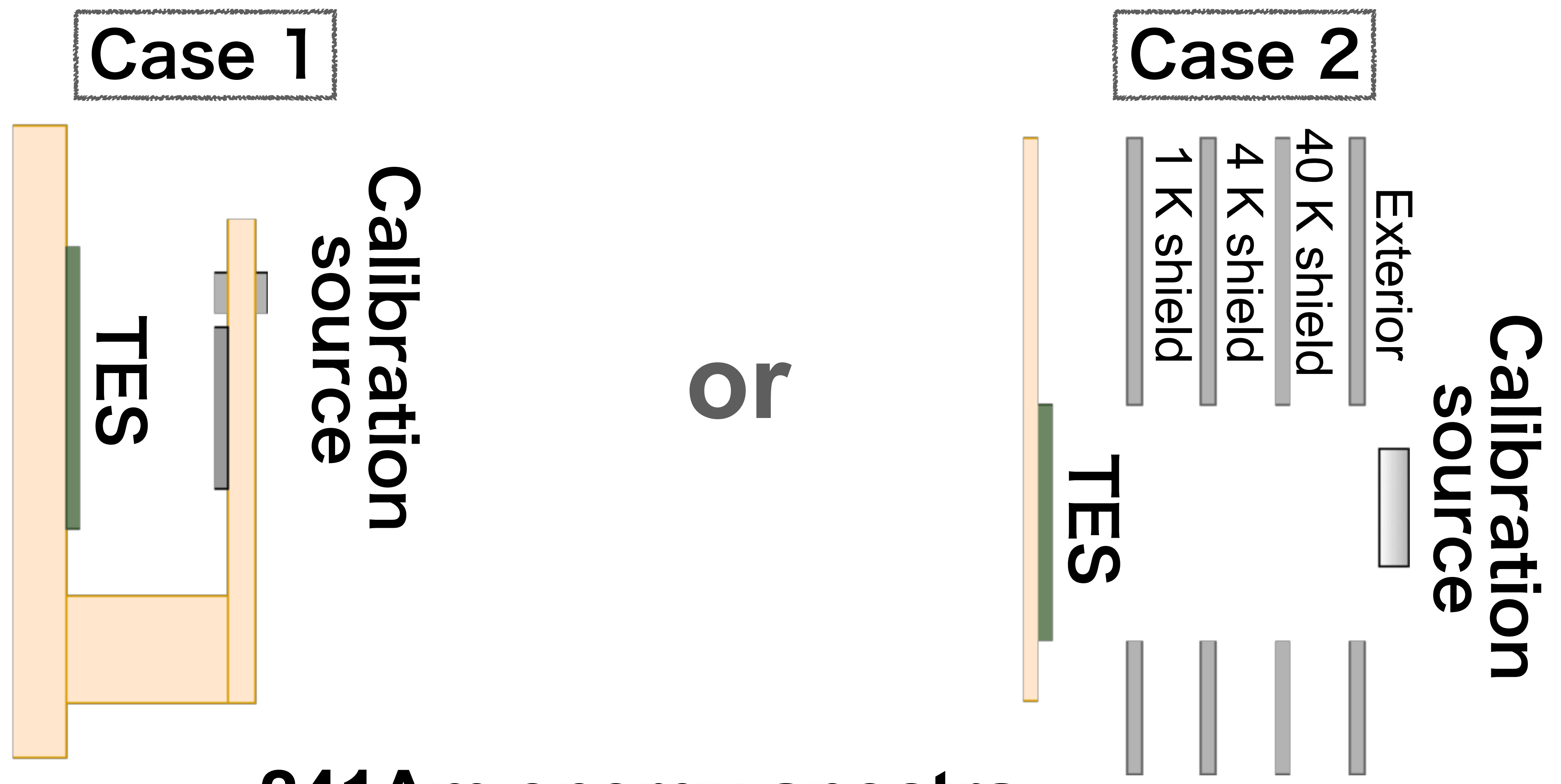
- ✦ Effects of magnetic field inside earth and its interaction with 57Fe nucleus could appear.

Radiation Sources for Energy Calibration

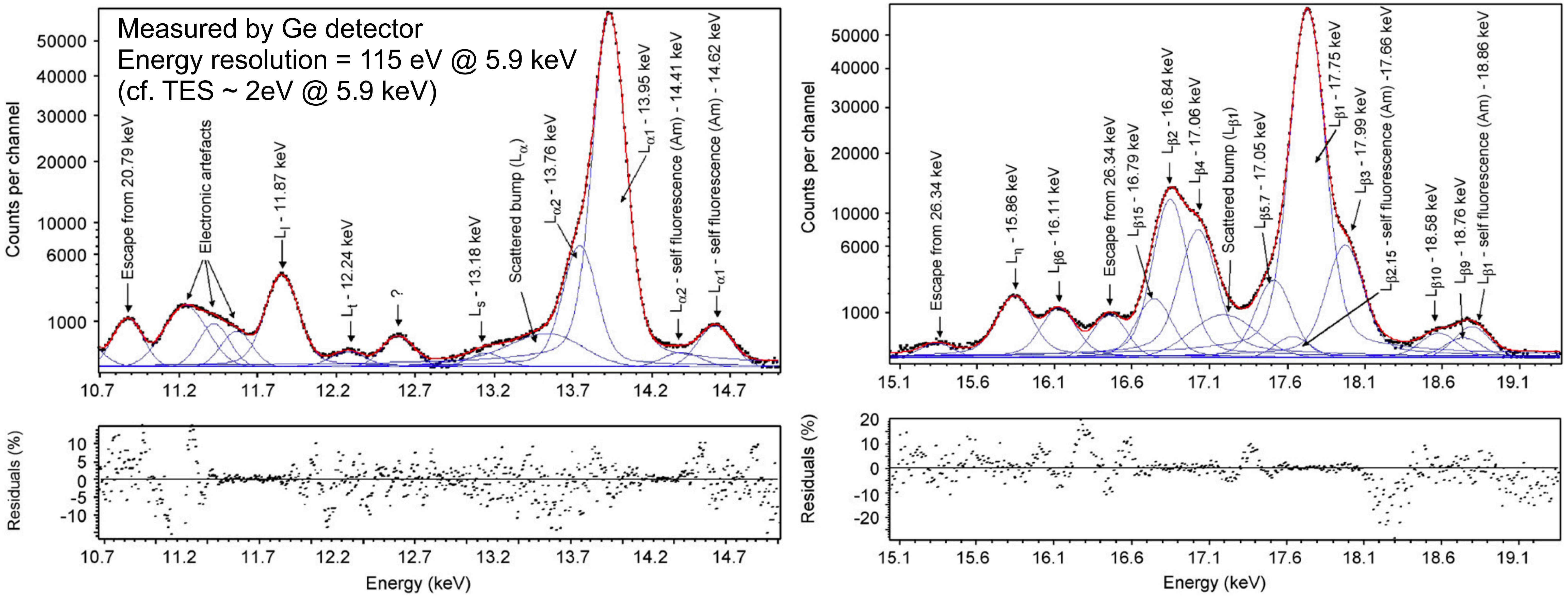
✦ Use two calibration sources for energy calibration

	57Co	241Am
Lines around 14.4 keV	14.4 keV	13.9, 16.8, 17.8 keV
Half-time	272 days	432 years
Merit	• Can calibrate the target line	• Lots of lines around the target line for easy calibration.
Demerit	• Emits 122 and 136 keV γ rays	• Emits γ rays above 59 keV • 5.4 MeV α ray • Emits weak 14.4-keV line

Irradiation method for calibration sources



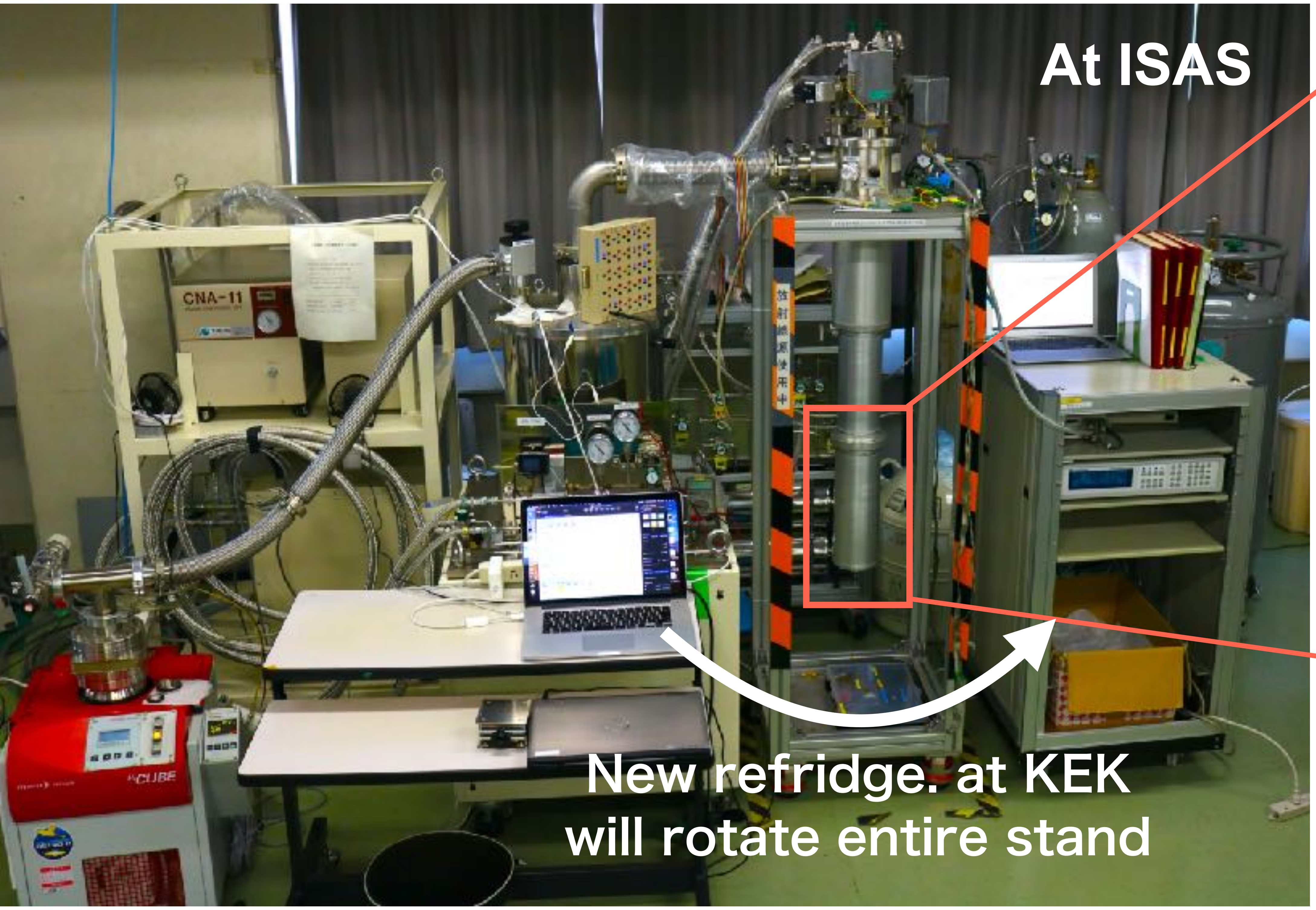
241Am energy spectra



Lépy+ 2008, *Appl. Radiat. Isot.*

Setup of Test Observation at ISAS

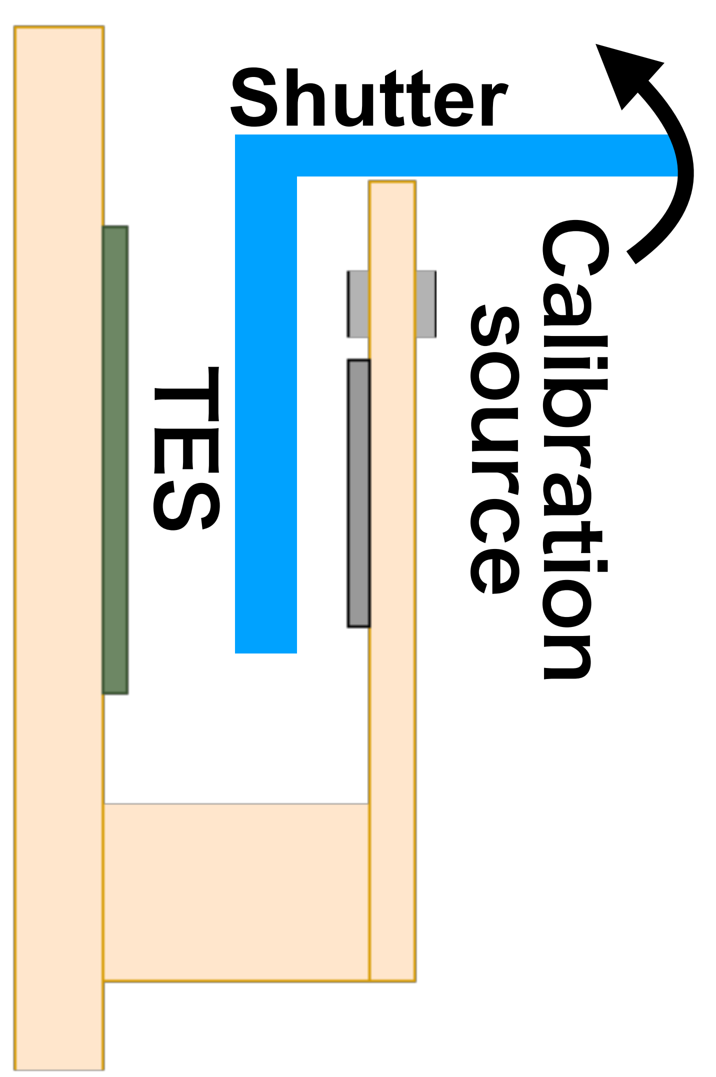
Dilution refrigerator without signal multiplexing



- 6th floor laboratory at ISAS
- Tilt stage 3° ~ 5° elevation angle

Production observation will be performed at KEK using MWMUX refrigerator

Case 1



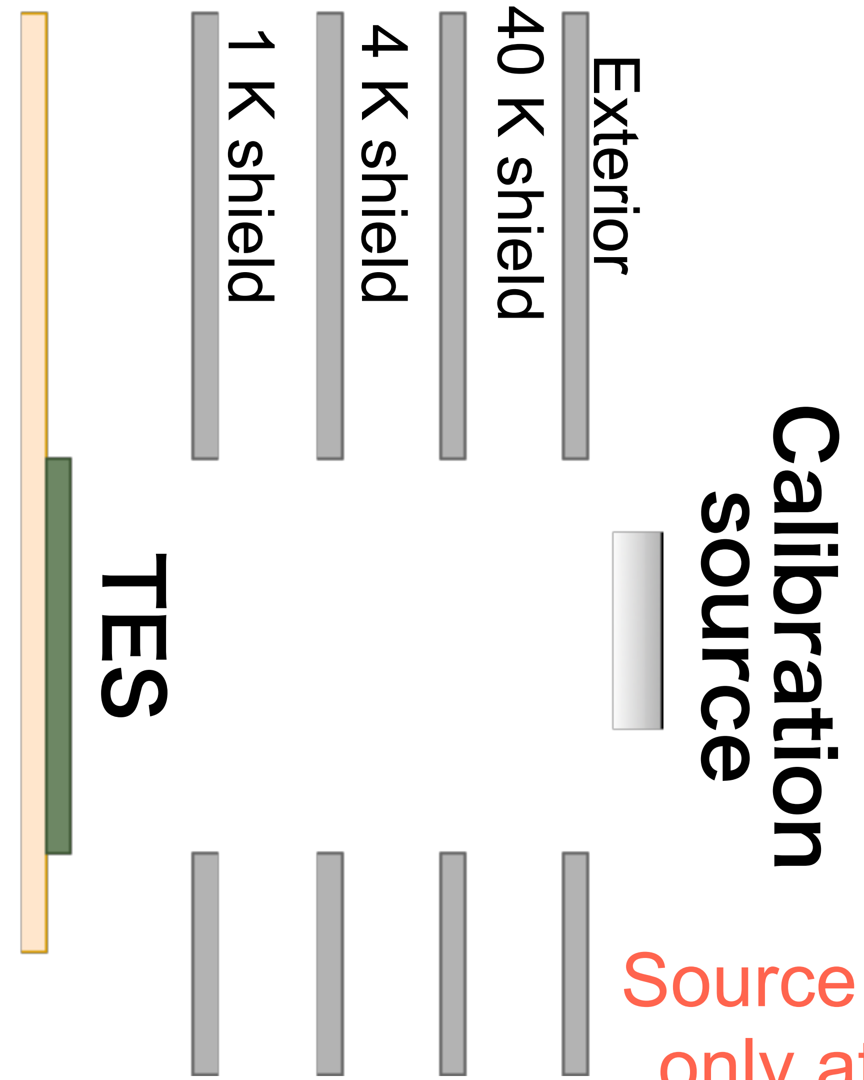
✦ No need to apply and remove the radiation source frequently

✦ Secondary X-rays from the shutter are generated

✦ Need to remove and apply the radiation source at sunrise and sunset.

or

Case 2



✦ Allows daily baseline calibration for more accurate energy calibration

✦ X-ray count will be less due to distance

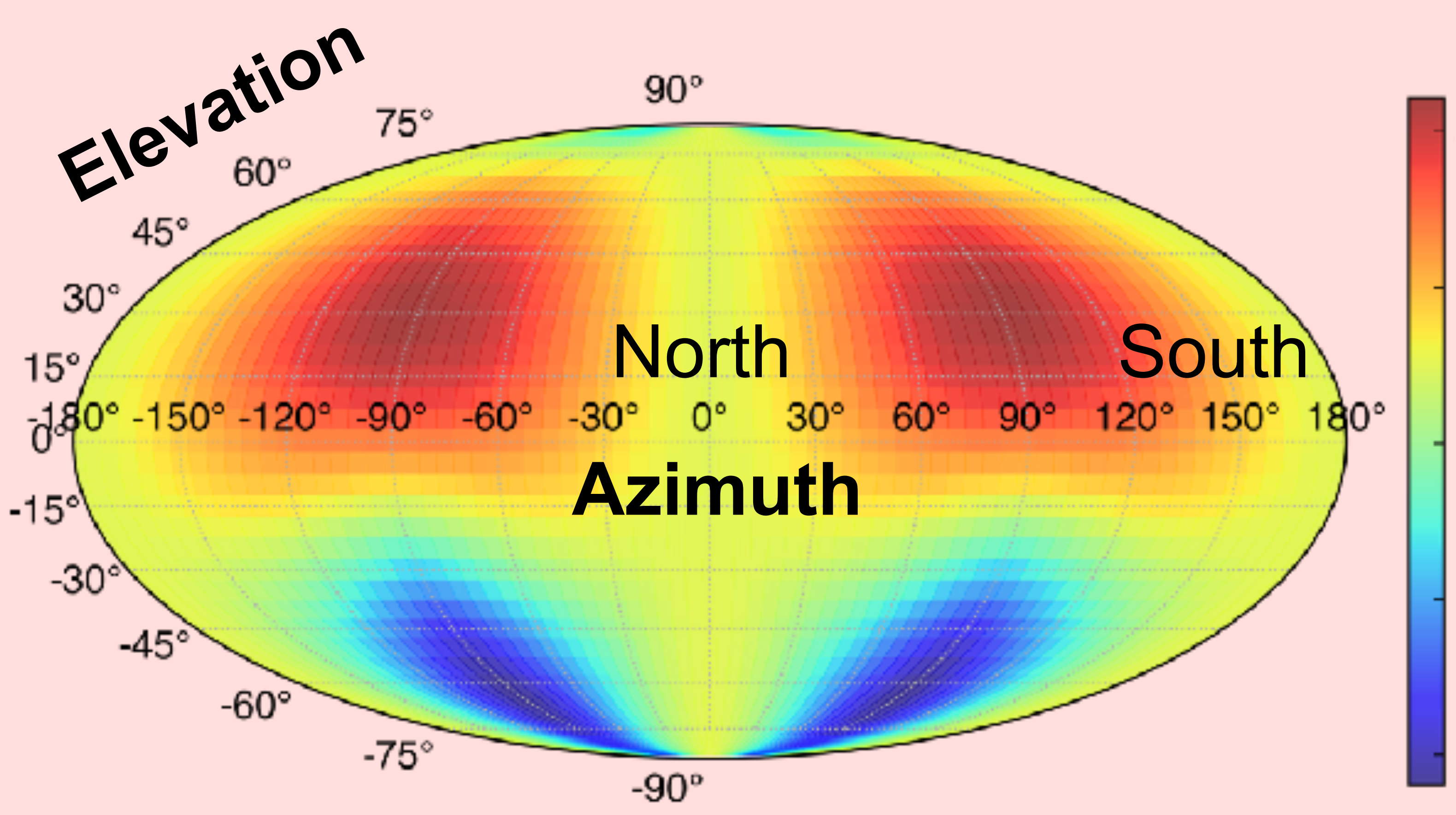
✦ Need to remove and apply the radiation source at sunrise and sunset.
→ Rotate and introduce automatically into the irradiation port

Practical Configuration and Sensitivity

Day Earth,
Double-sided irradiation of stage

Max. efficiency ~ 35%

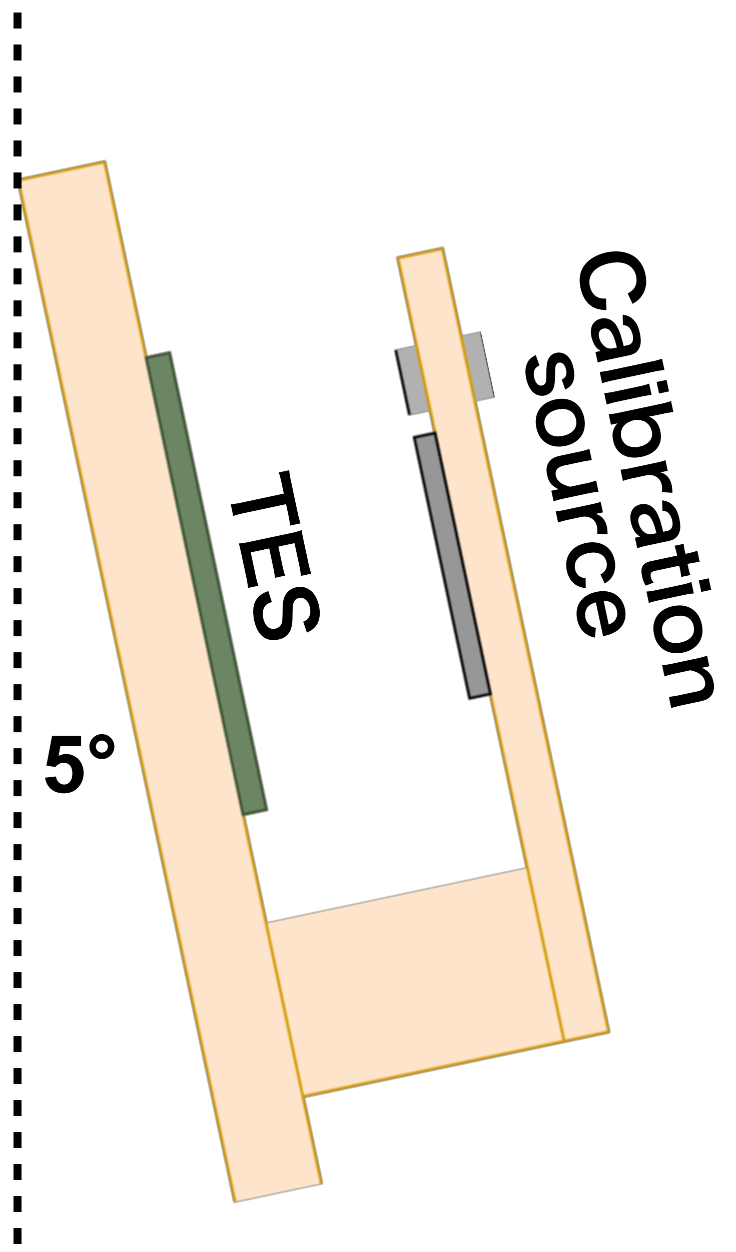
- ✦ Azimuth → West or East direction
- ✦ Elevation angle → 30°



Can't tilt dilution refridge.

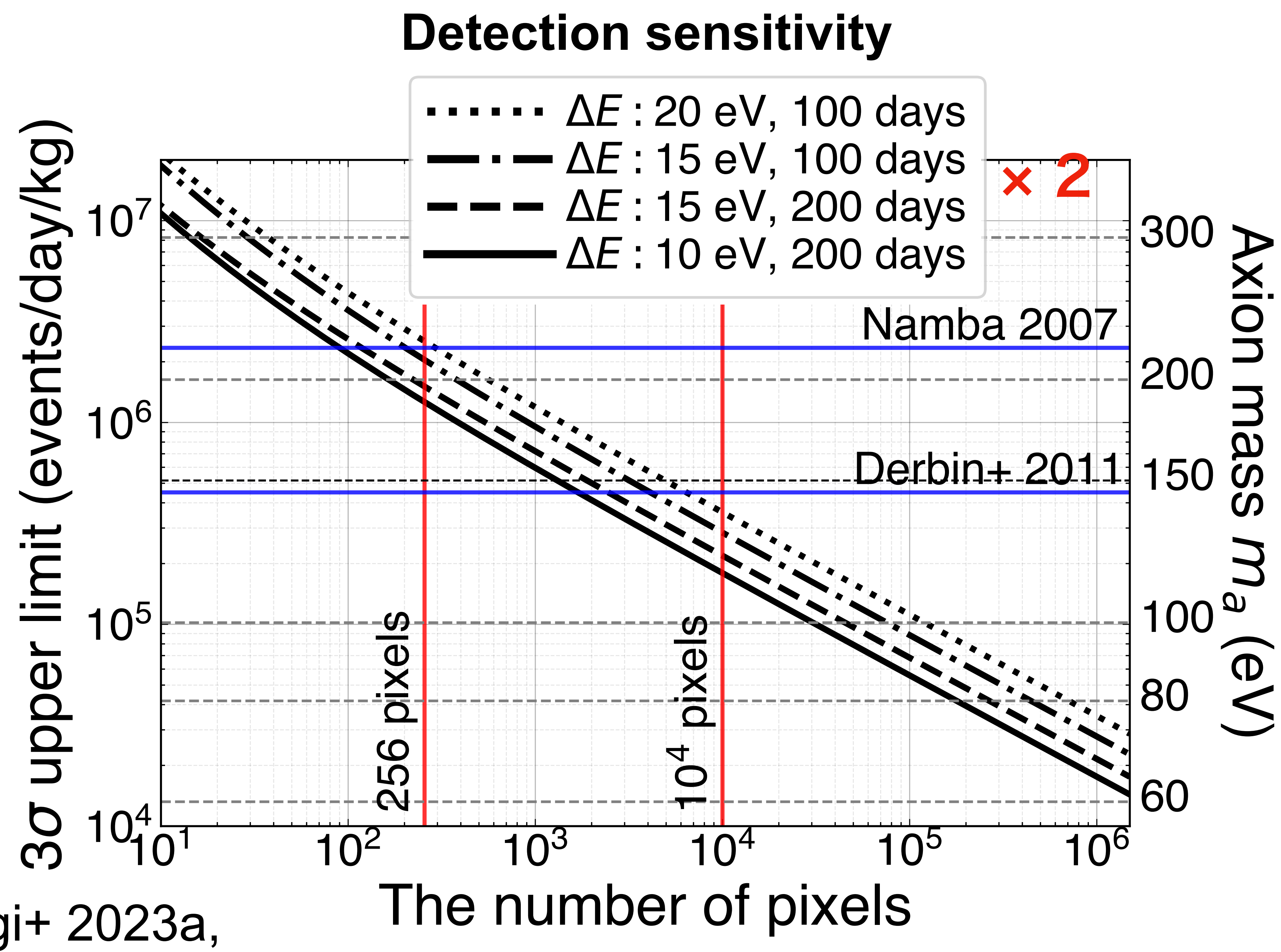
Efficiency ~ 32%

- ✦ Azimuth → West or East direction
- ✦ Elevation angle → maximum 5°



Tracks the sun on azimuth only

Efficiency ~ 46%



Yagi+ 2023a, *J. Low Temp. Phys.*

If include night Earth, efficiency ~ 89%

Still considering the method of observation and would appreciate any advice.

Summary and Next Steps

Summary

★ TES is promising for the most stringent bound for observations with 57Fe

- Successfully produced 64-pixel TES array with 56Fe absorber
- Can produce large TES arrays and readout systems by expanding our technologies

★ Practical configuration and sensitivity for the observation was considered

Next steps

★ Design of dilution refrigerator equipped with a system that can track the sun in the azimuthal direction with microwave multiplexing readout

★ Fabrication of TES array with sufficient performance for test observation