Probing the Anomalous Flux of Very-high-energy Gamma rays from the Sun with HAWC

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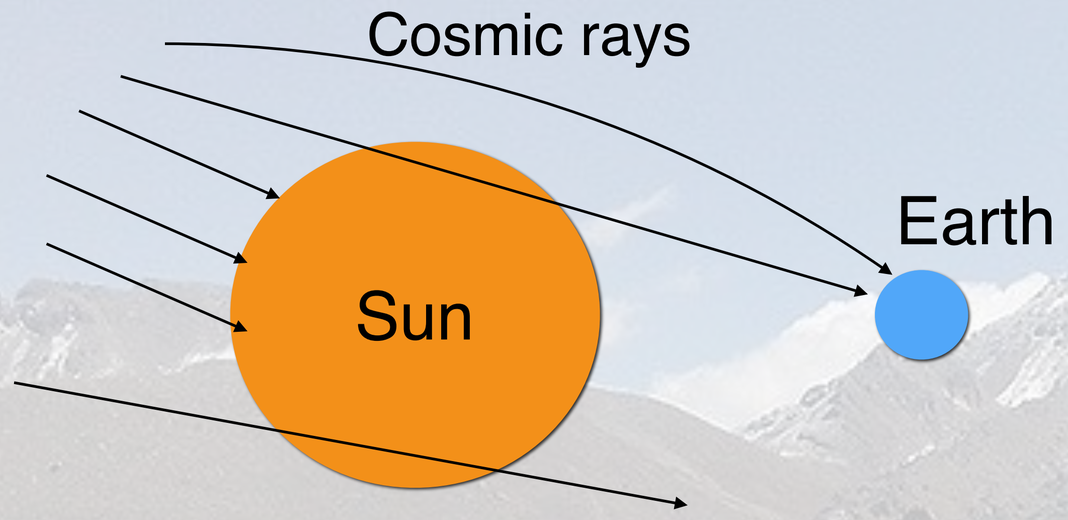
Michigan State University
ICRC 2019 — Madison, WI

MICHIGAN STATE UNIVERSITY

HAWC
High Altitude Water Cherenkov
Gamma-Ray Observatory

Cosmic-ray interactions with the Sun's atmosphere produce γ rays



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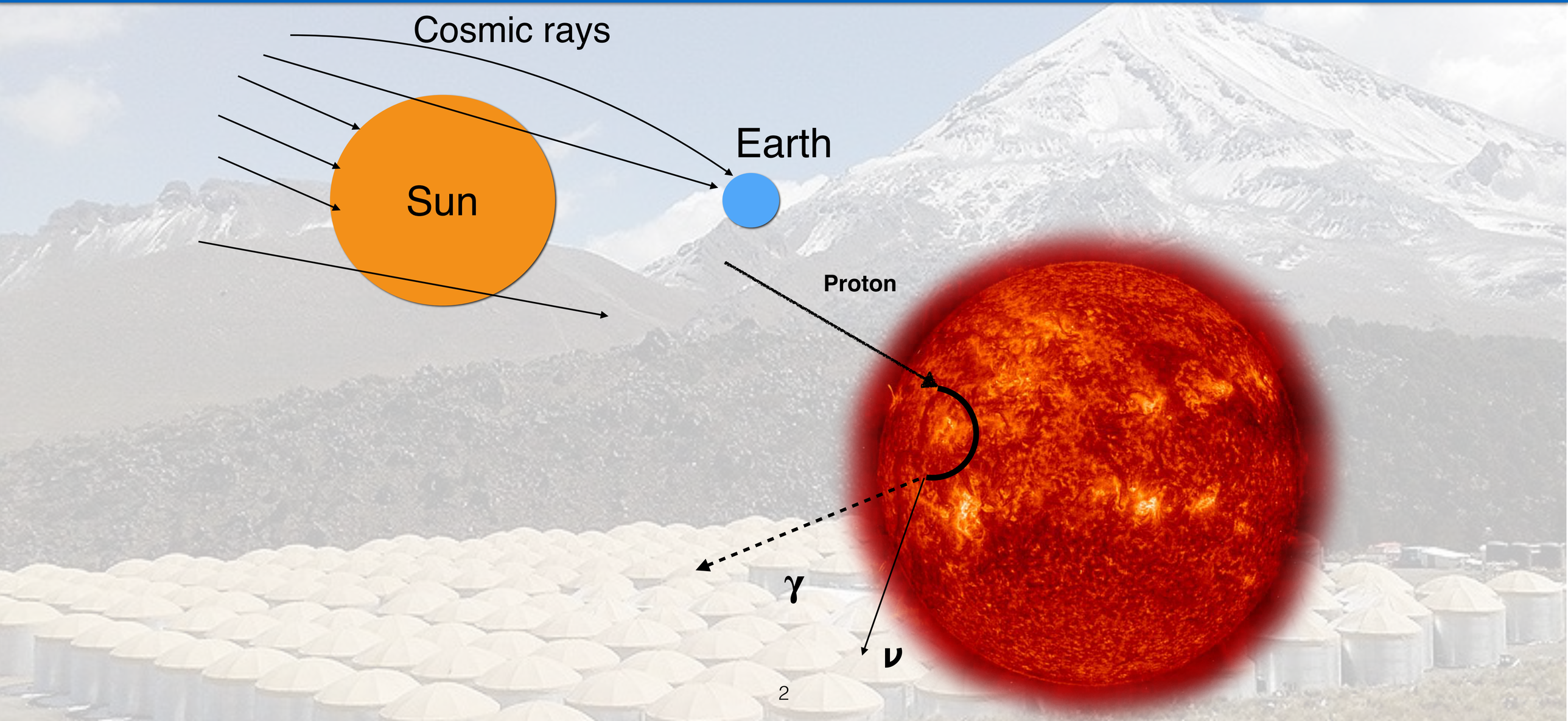

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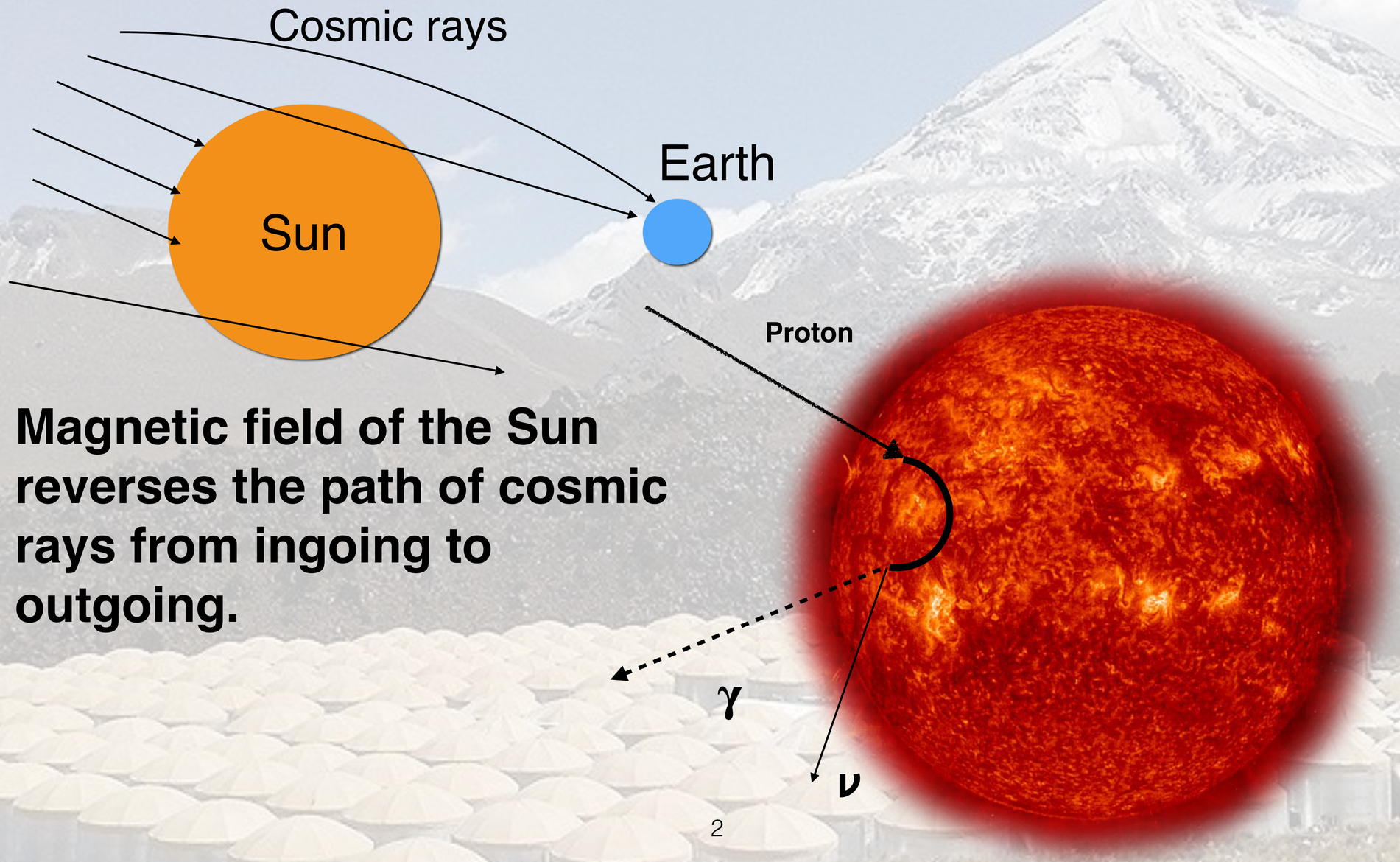

Magnetic field of the Sun reverses the path of cosmic rays from ingoing to outgoing.

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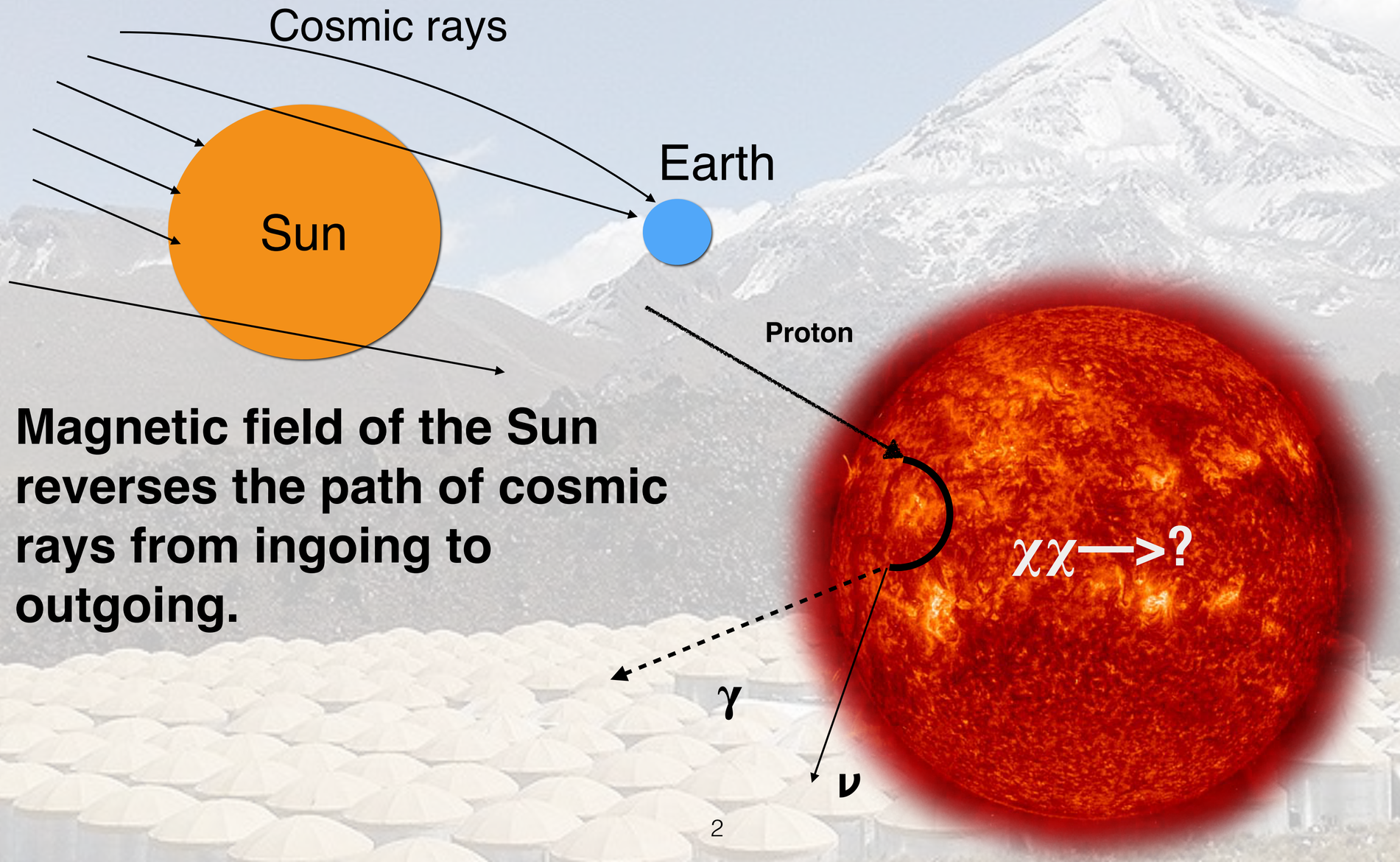

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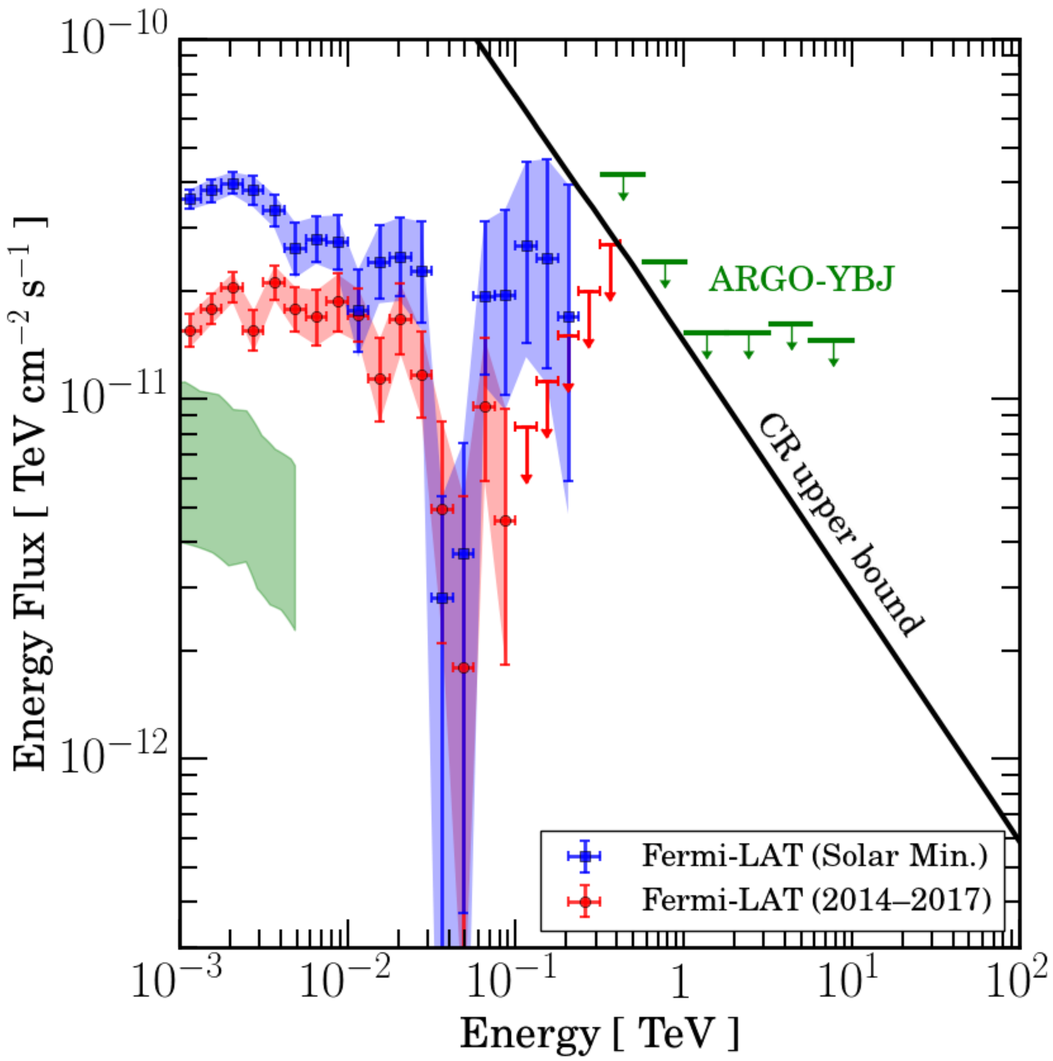
The Sun at GeV: Brighter than expected!



Astronomy and Astrophysics, 480:847–857, March 2008
The Astrophysical Journal 734 (2011) 116
Phys. Rev., D94(2):023004, 2016
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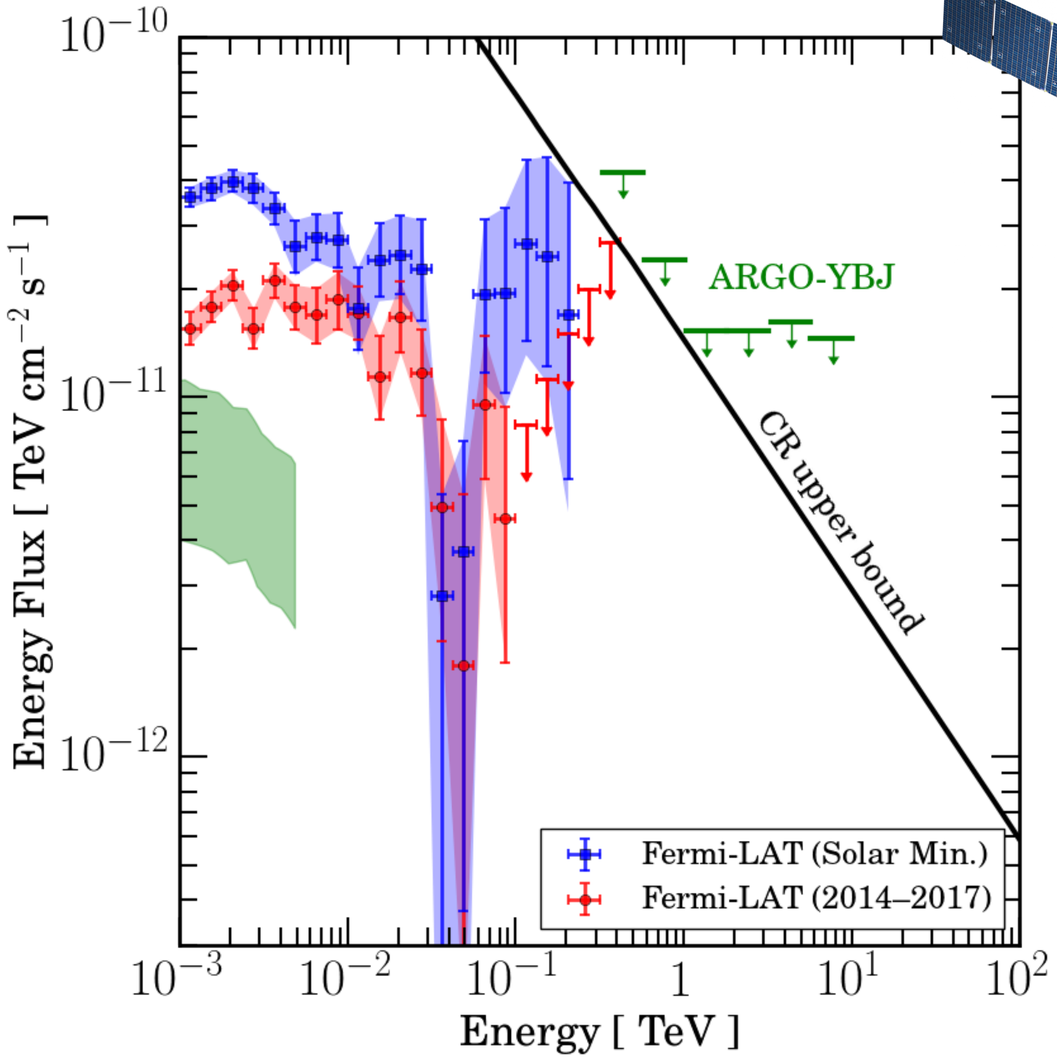

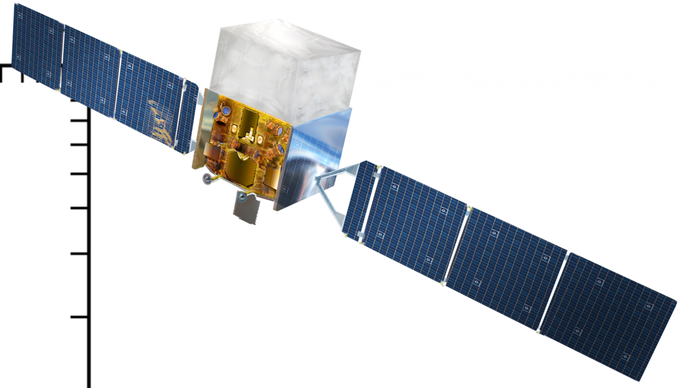

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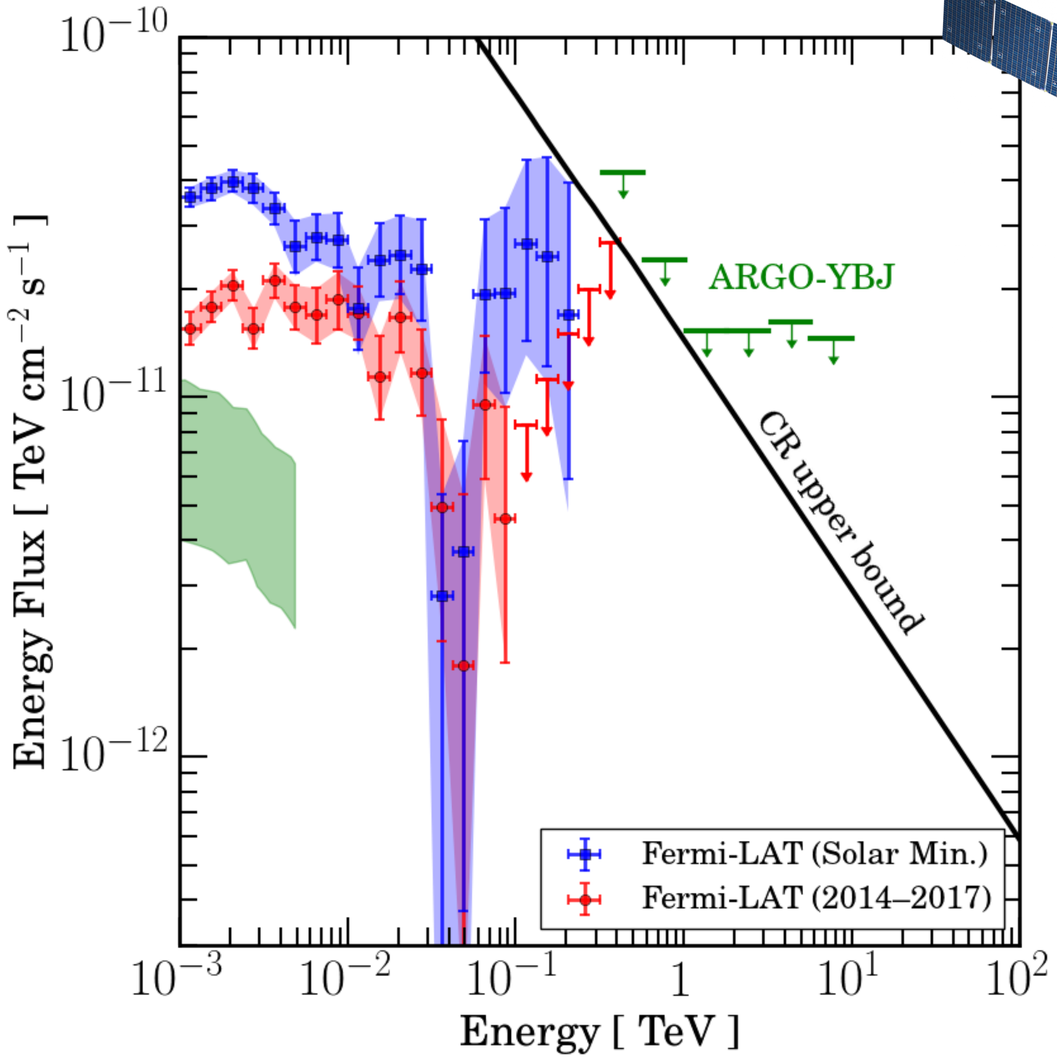

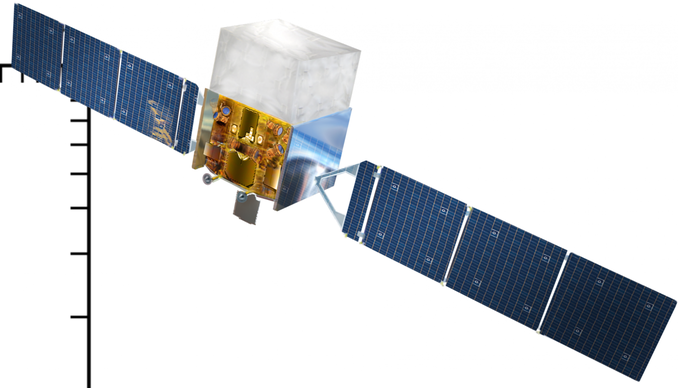

GAD4c: The Surprising Gamma Ray emission from the Sun (Kenny C. Y. Ng), SH5Ee (Zhe Li), DM1e (Davide Serine)

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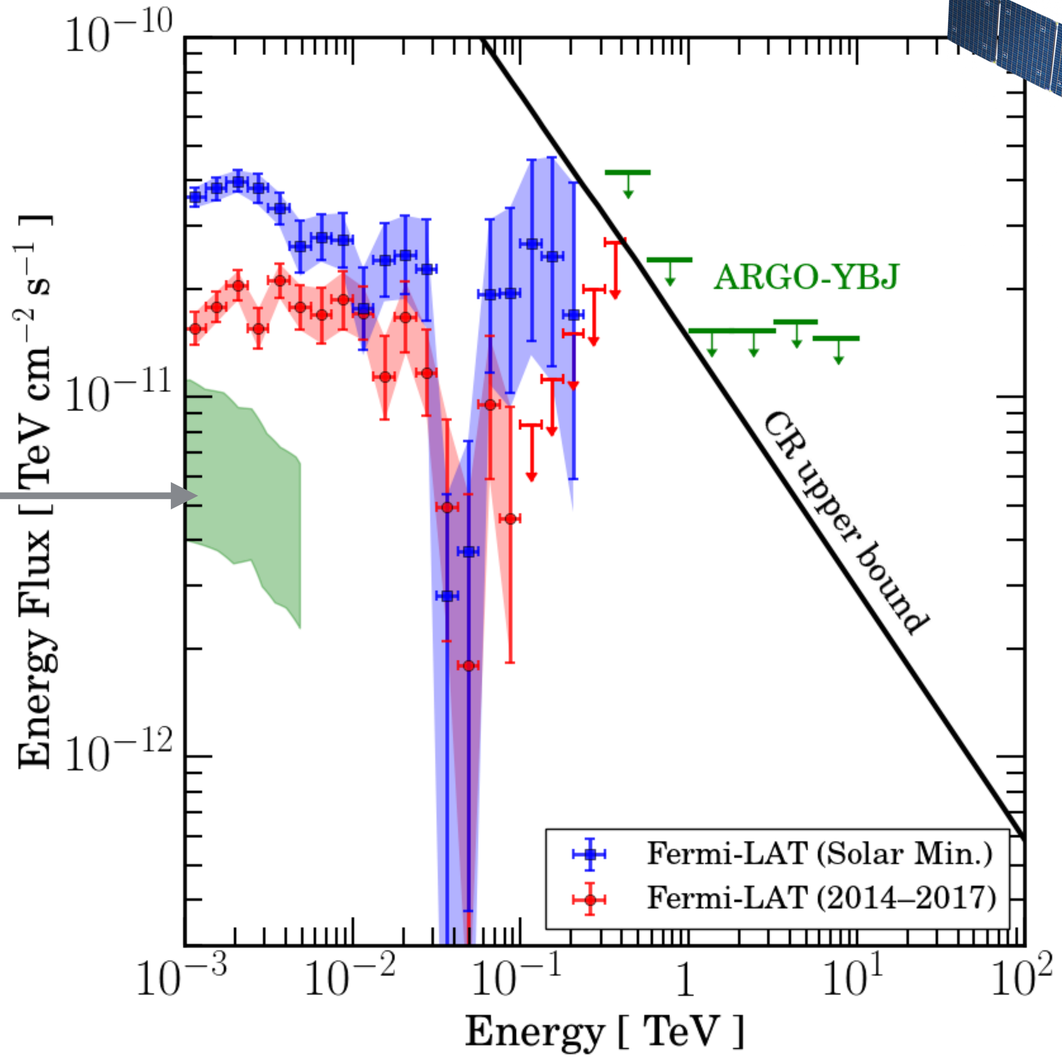

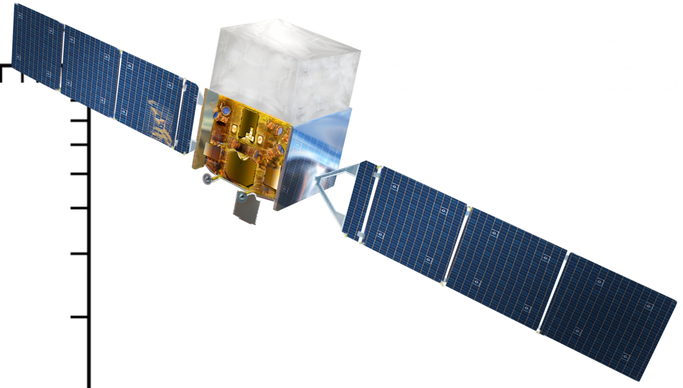

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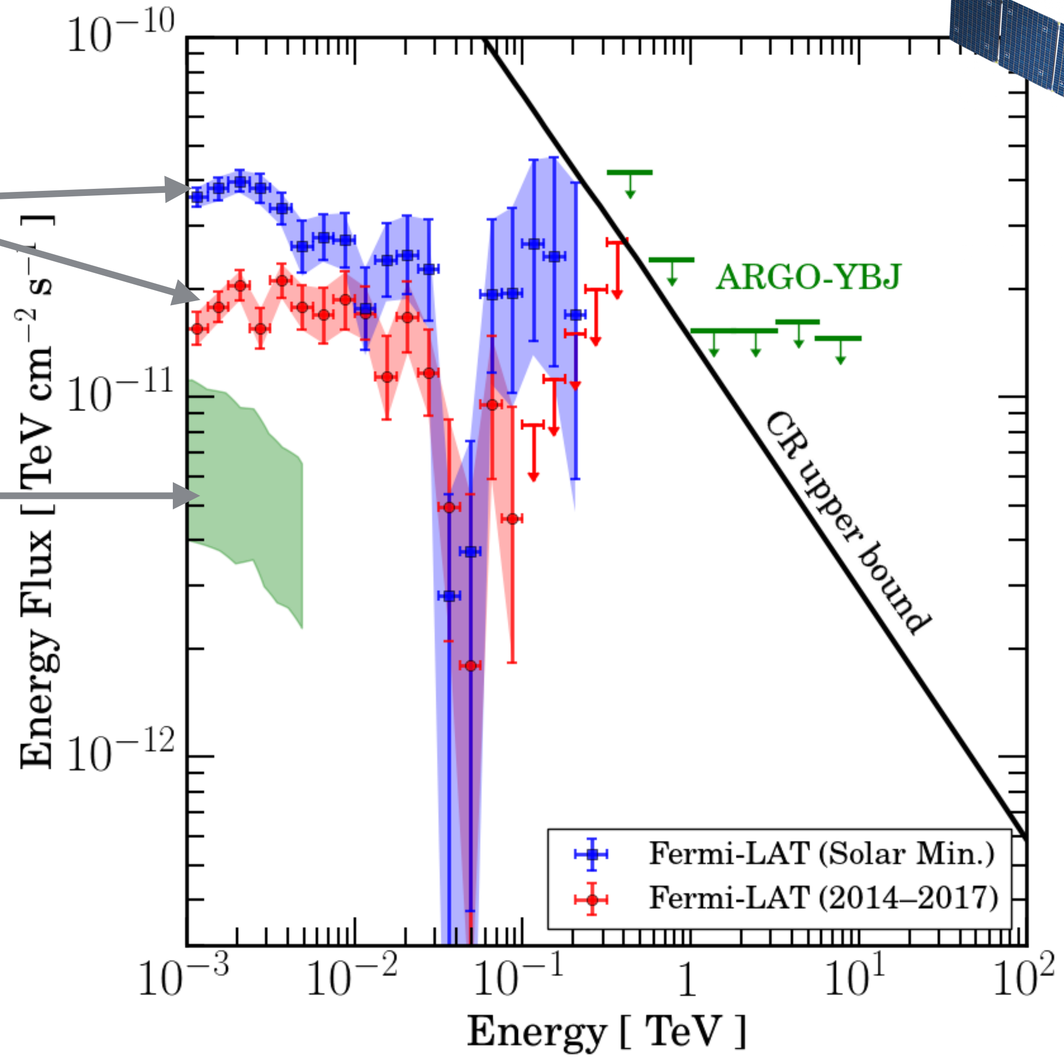

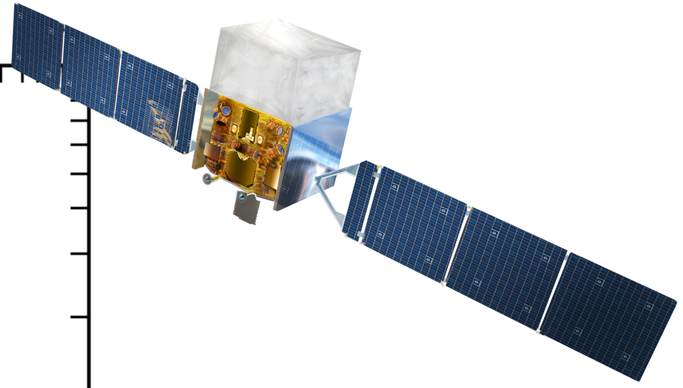

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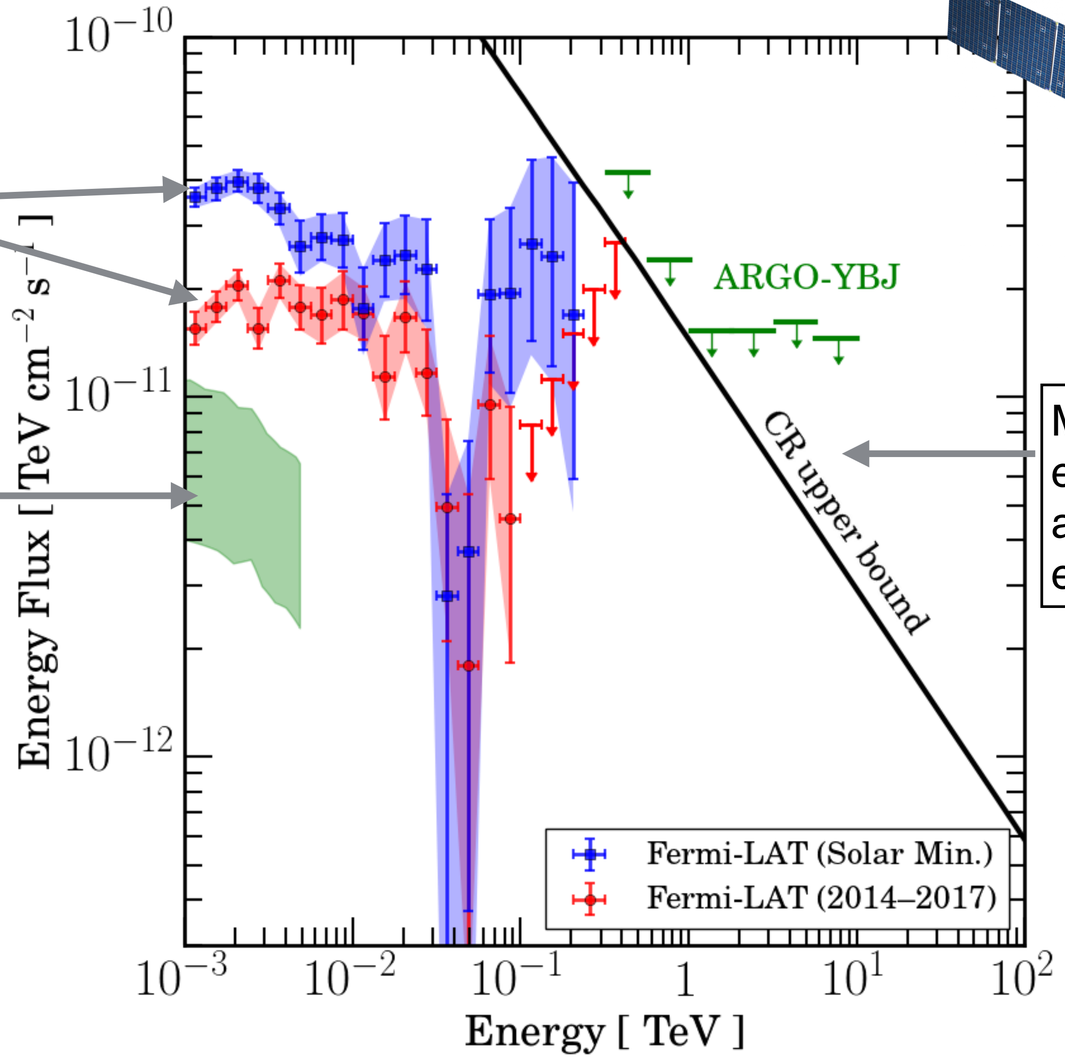

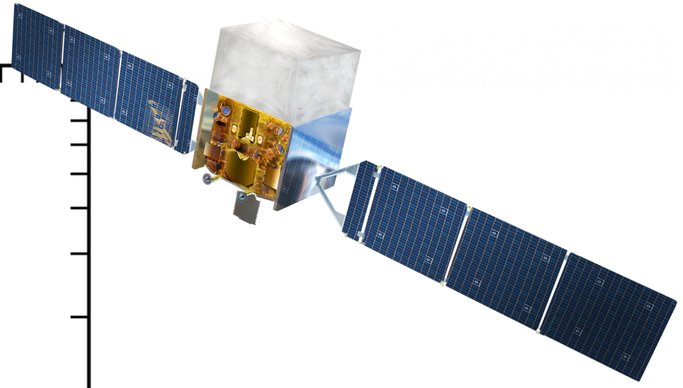

Max. theoretical emission assuming 100% efficiency

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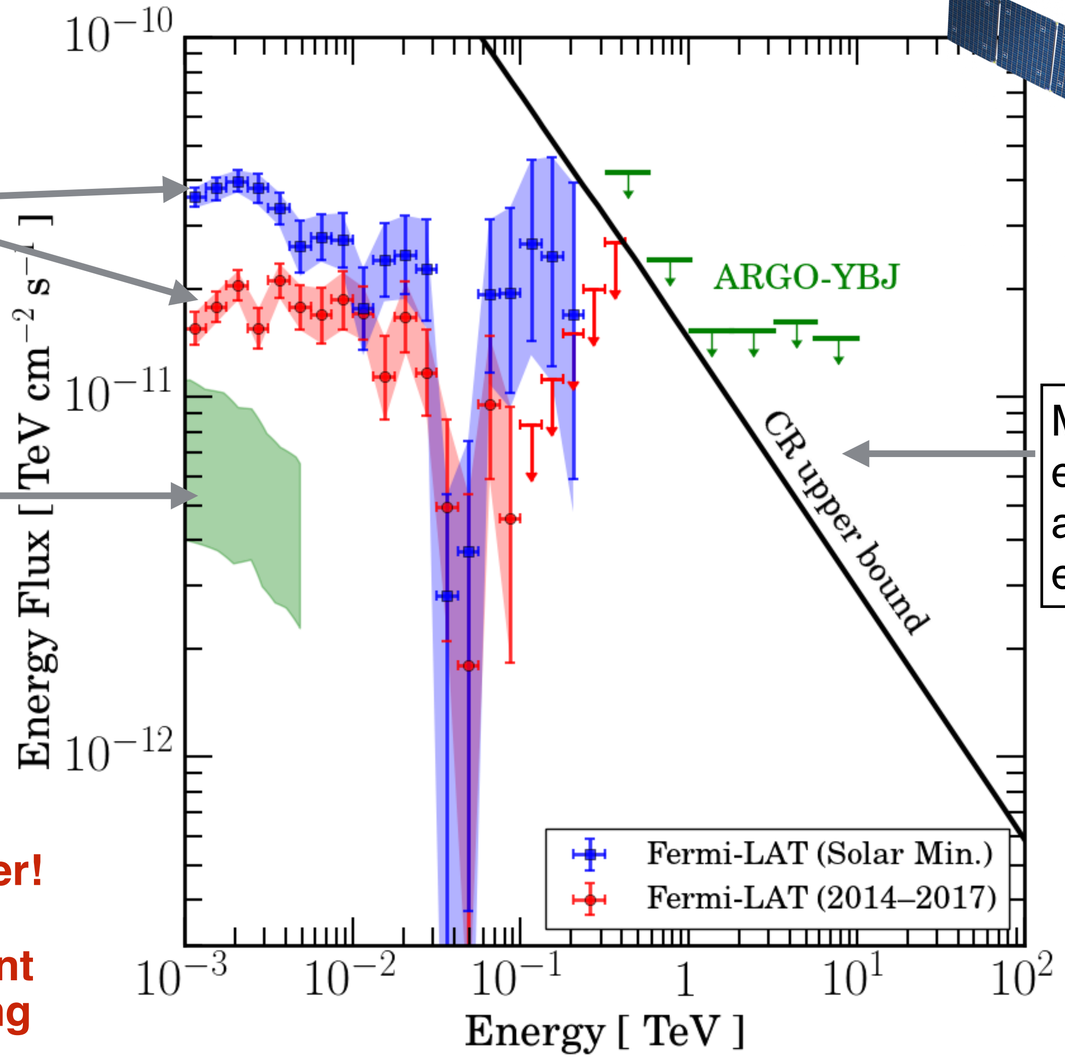

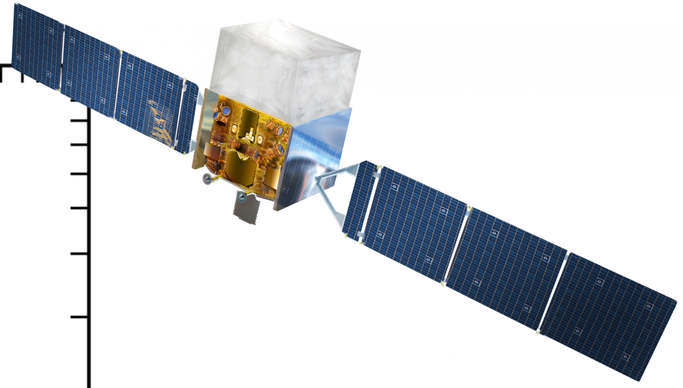

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- **Solar Minimum flux is much harder and brighter!**
- **Unforeseen measurement in a physically interesting range. Mechanism?**
- **TeV prospects?**

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High Altitude Water Cherenkov Observatory

One of the few TeV gamma-ray instruments taking gamma-ray data from the Sun

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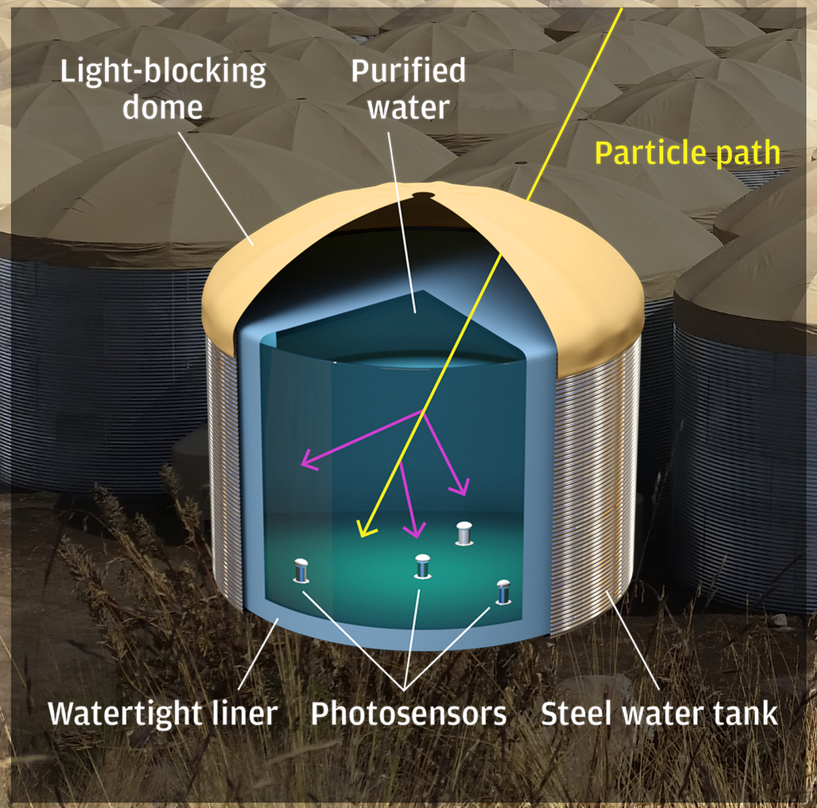
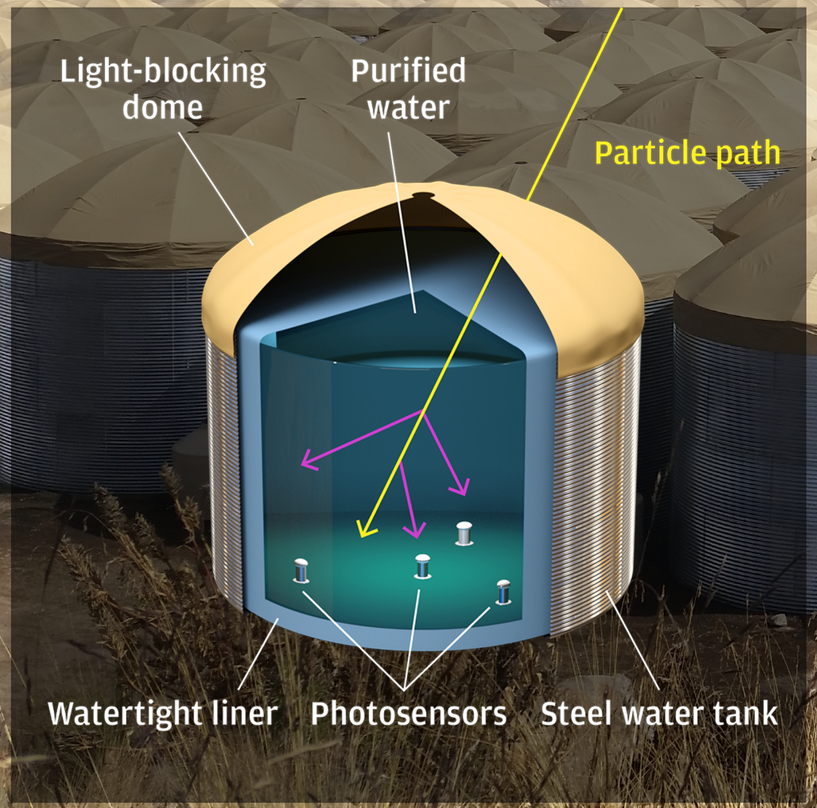


One of the few TeV gamma-ray instruments taking gamma-ray data from the Sun

High Altitude Water Cherenkov Observatory

- 300 water tanks with 4 PMTs each (plus 350 Outriggers)

- Area 22,000 m^2 (100,000m^2)
- Trigger rate of 25 kHz
- 300 GeV to > 100 TeV
- 2/3 sky daily coverage



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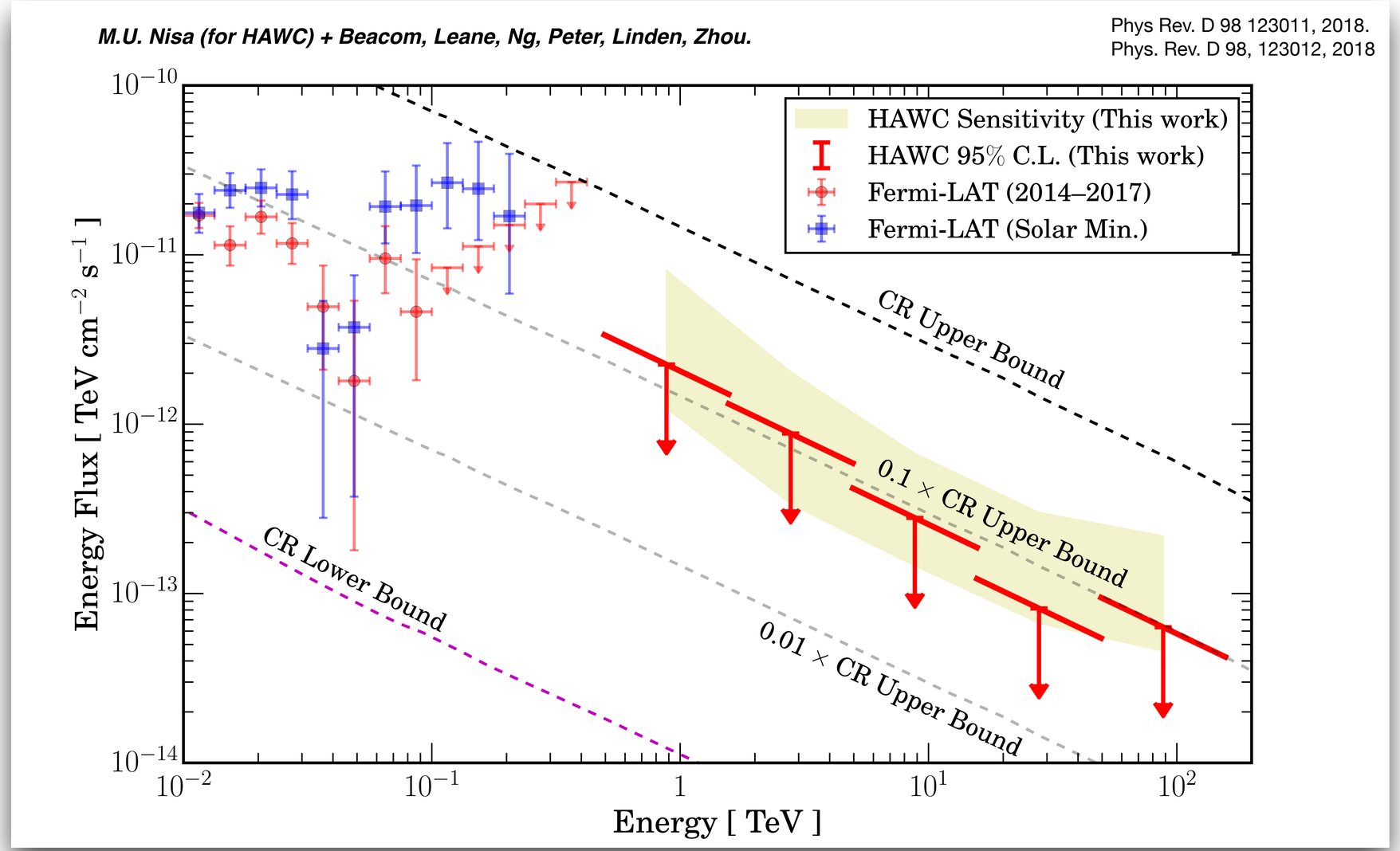
First HAWC Observations

- HAWC presented its first constraints using data from 2015—2017 just after the solar maximum.



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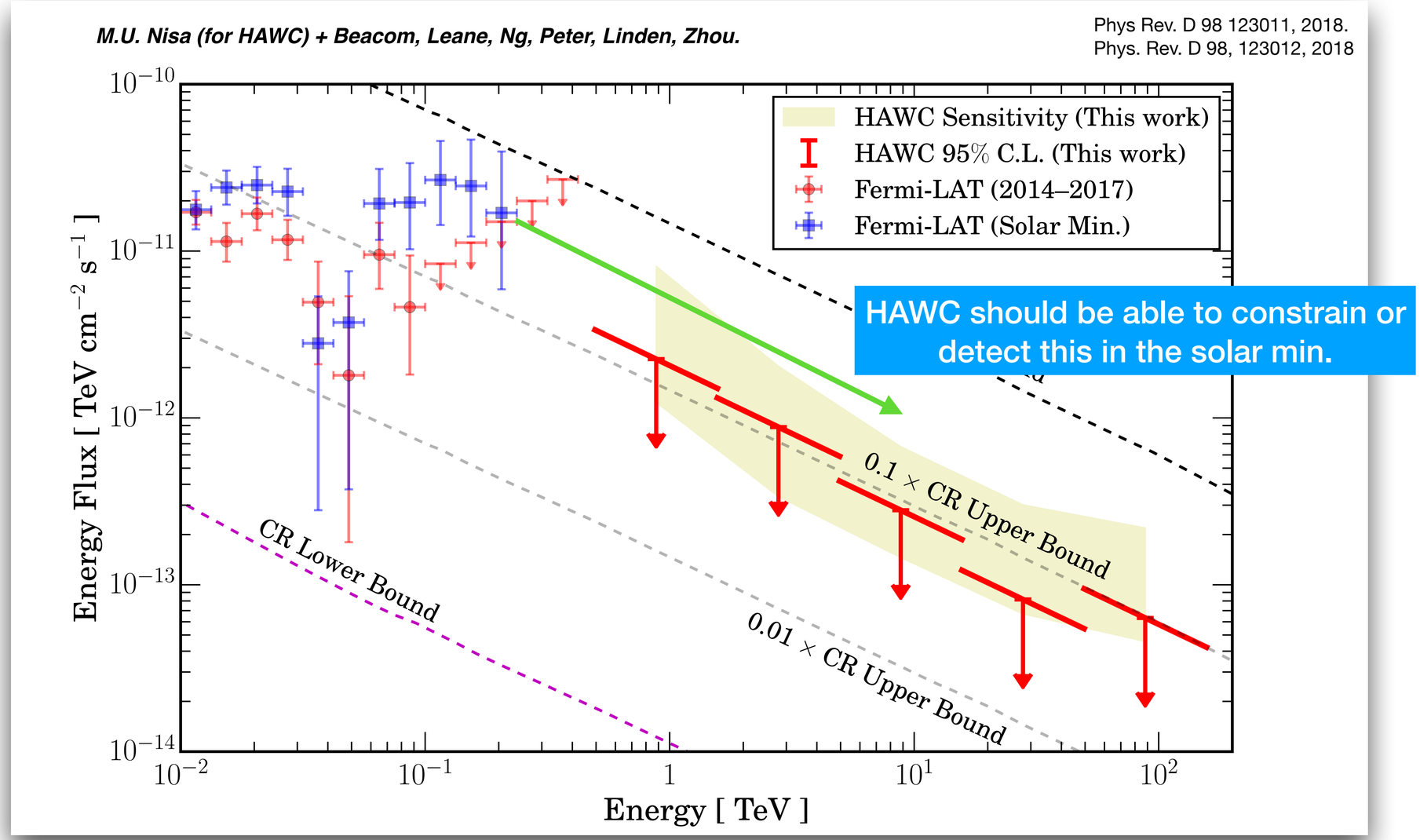
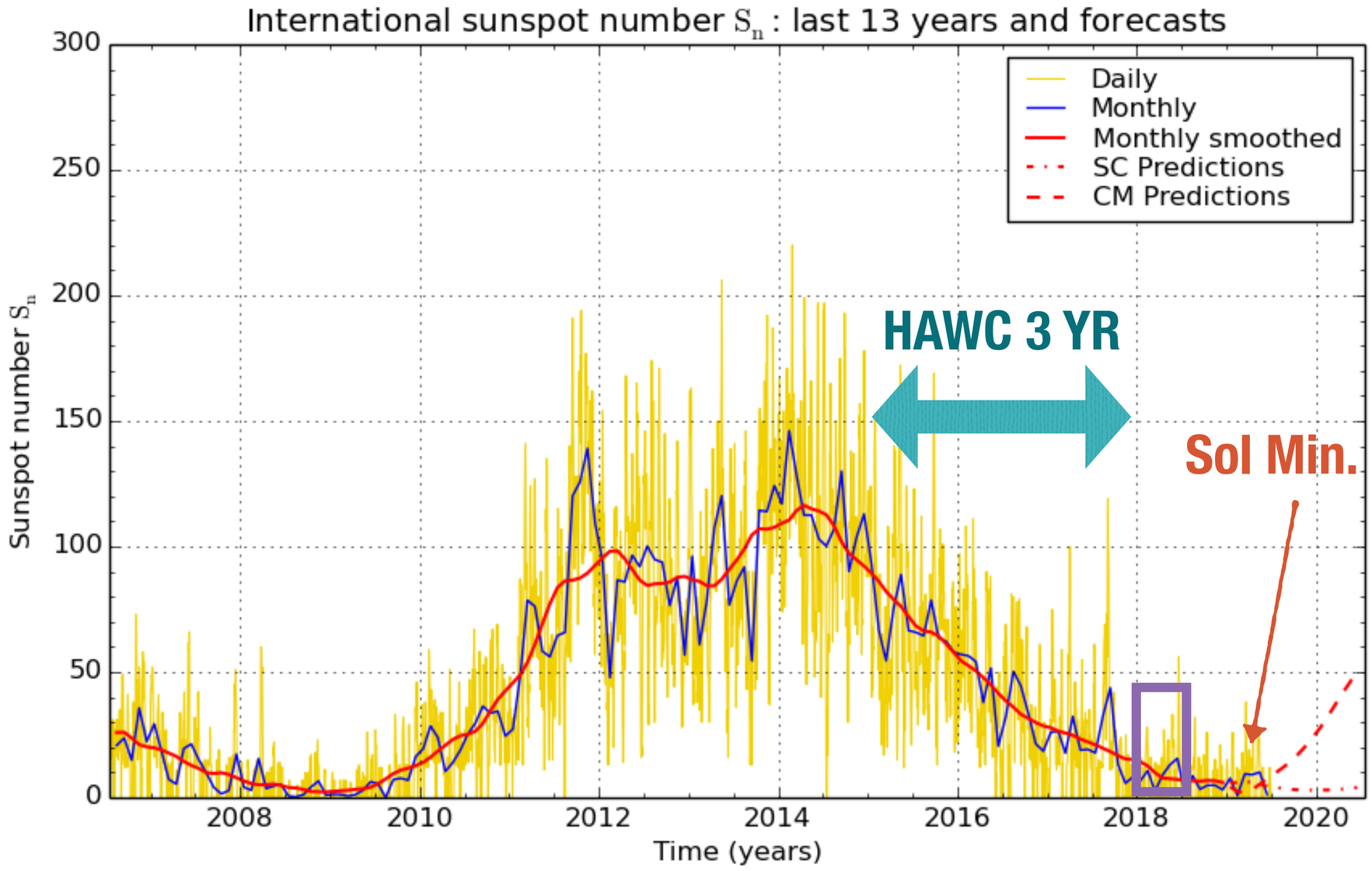


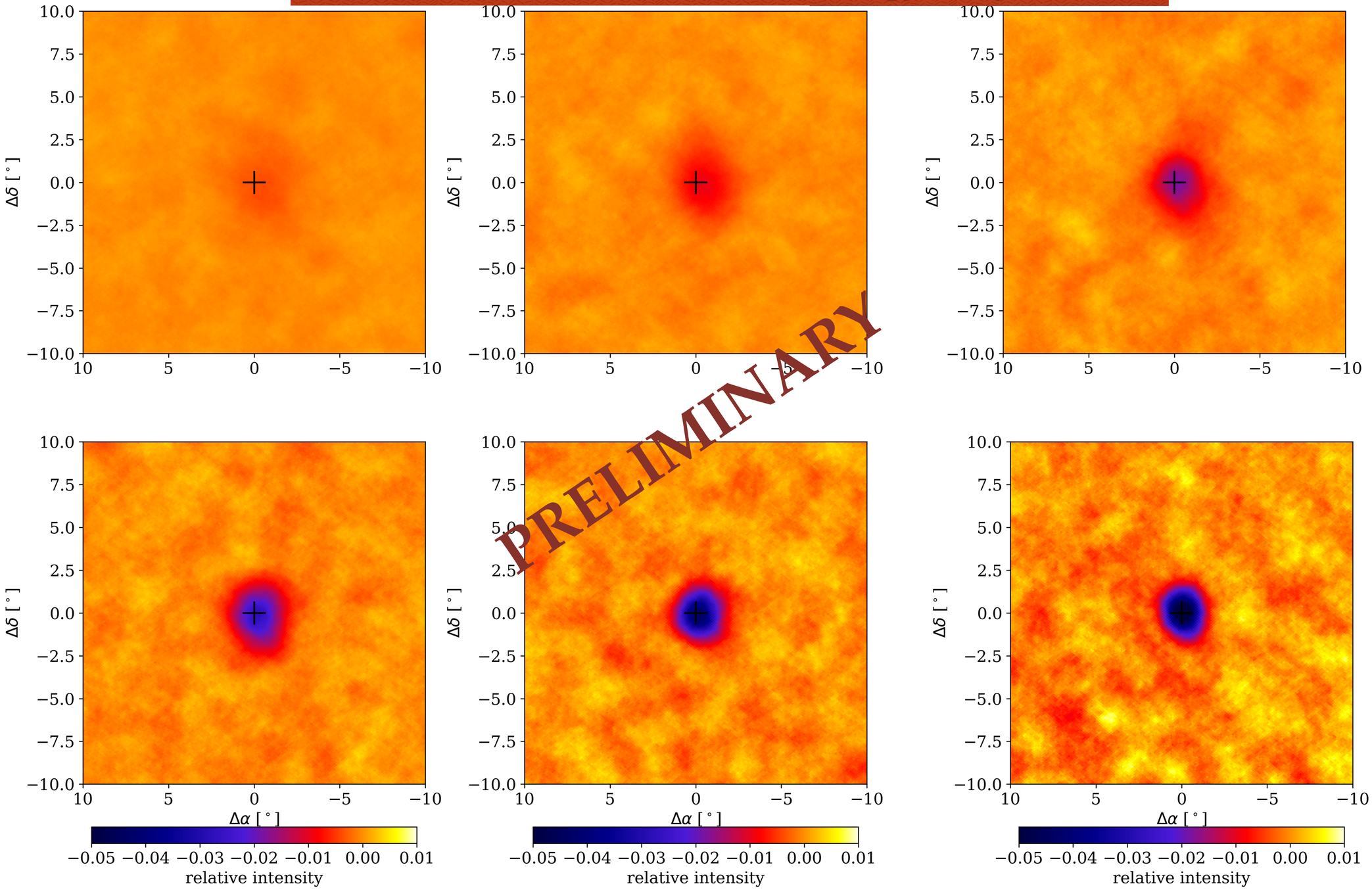
Transitioning into the Solar Minimum



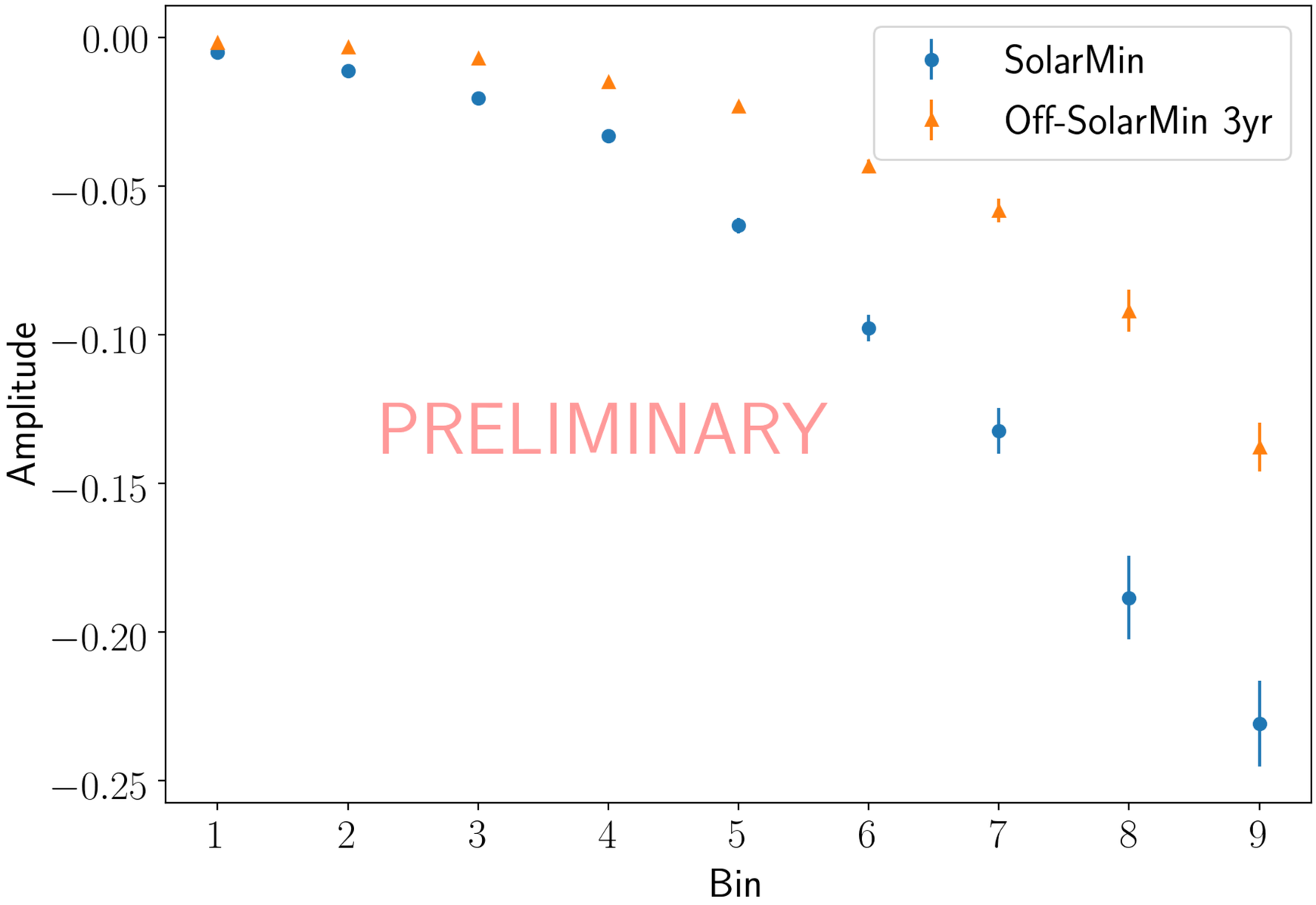
SILSO graphics (http://sidc.be/silso) Royal Observatory of Belgium 2019 July 4

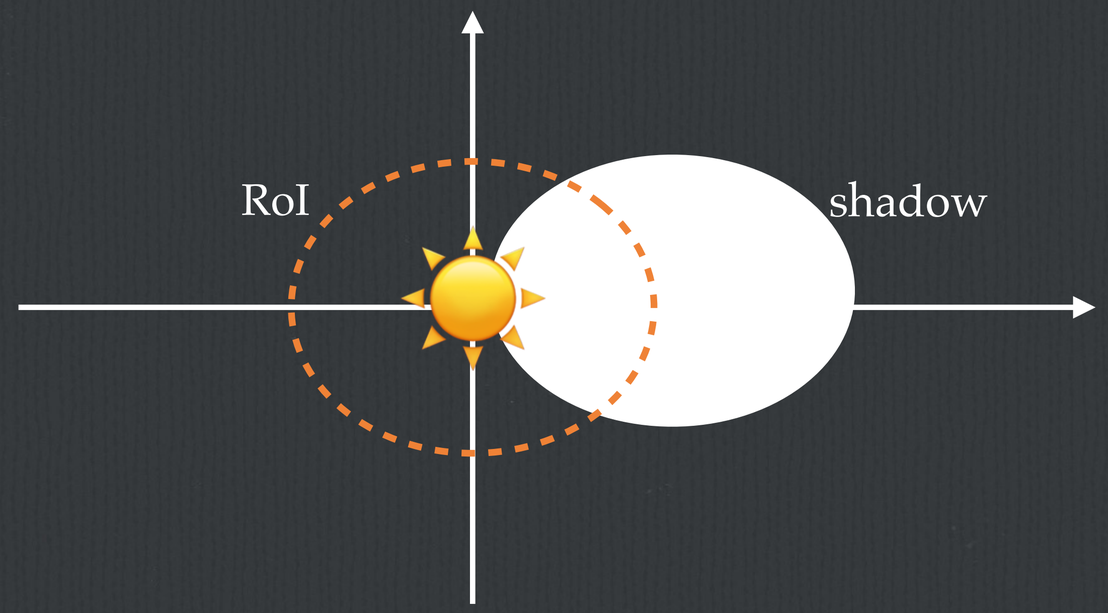
- ☐ How is the data changing from one solar cycle to the next?
- ☐ Change in the intensity of Sun Shadow?
- ☐ Towards a gamma-ray excess from the Sun?

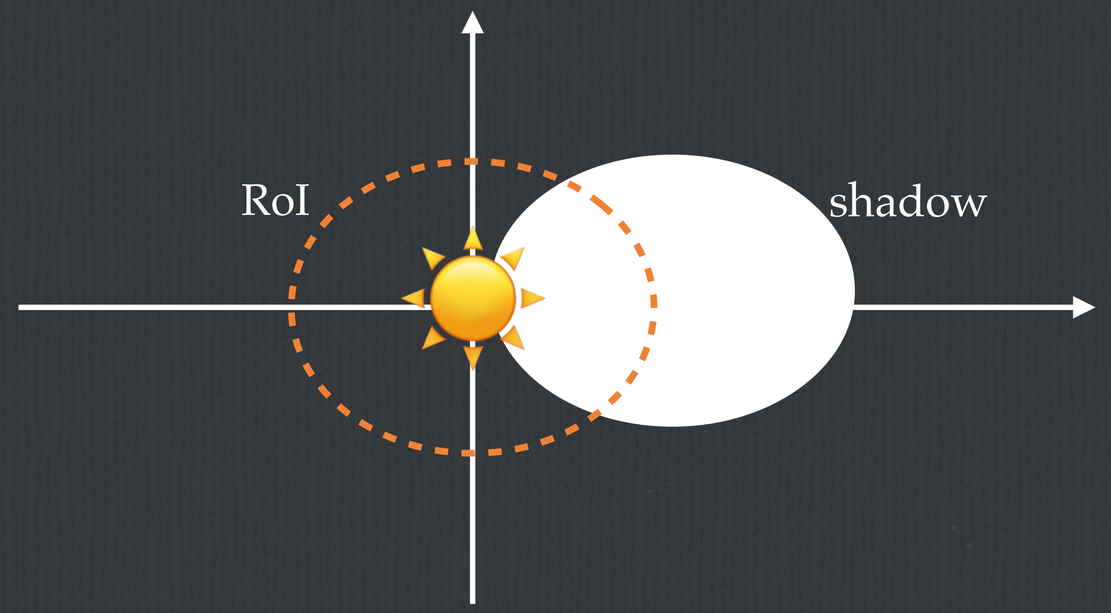
Sun Shadow Jan 2018 — Dec 2018: Energy Proxy Bins 1—6



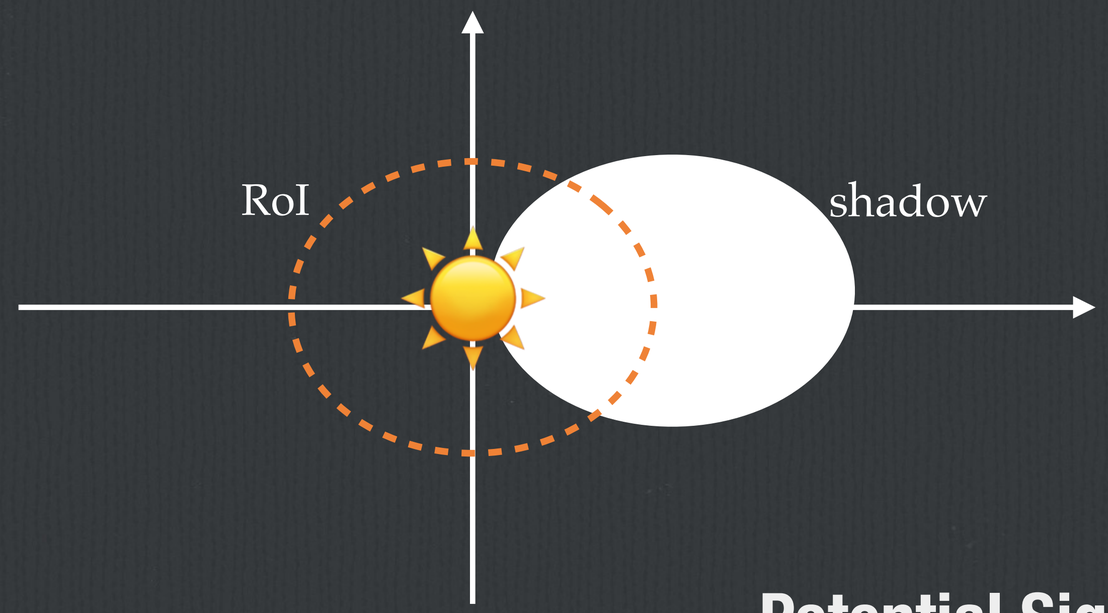
The Sun Shadow is deeper during the solar minimum




RoI
shadow



Background


RoI
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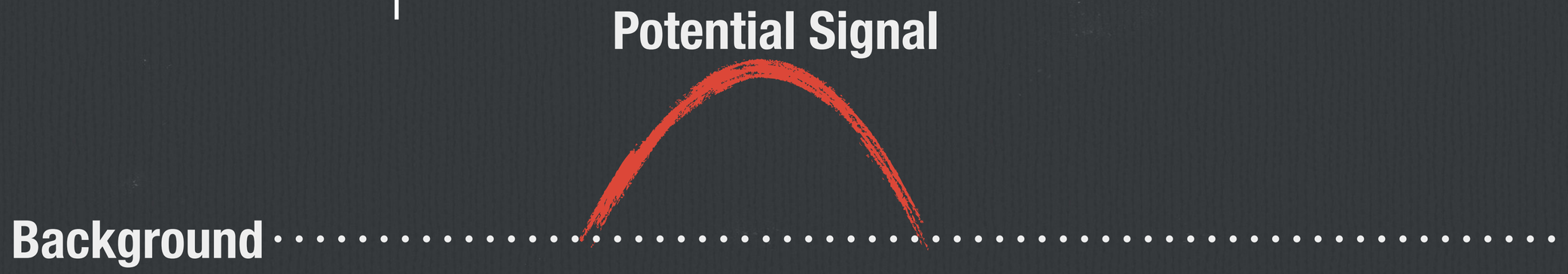
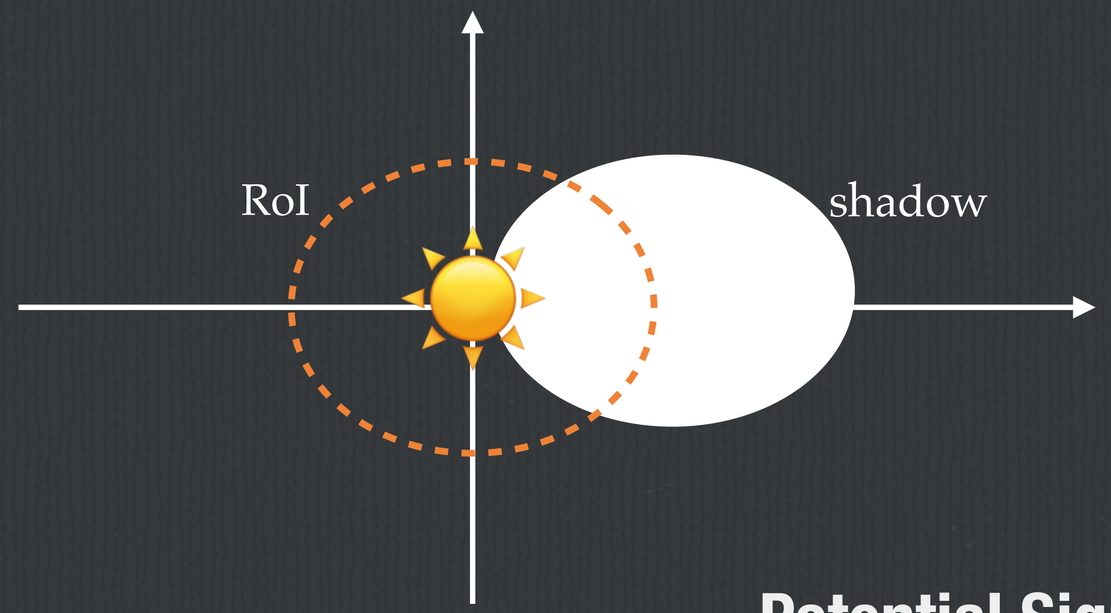

Potential Signal
Background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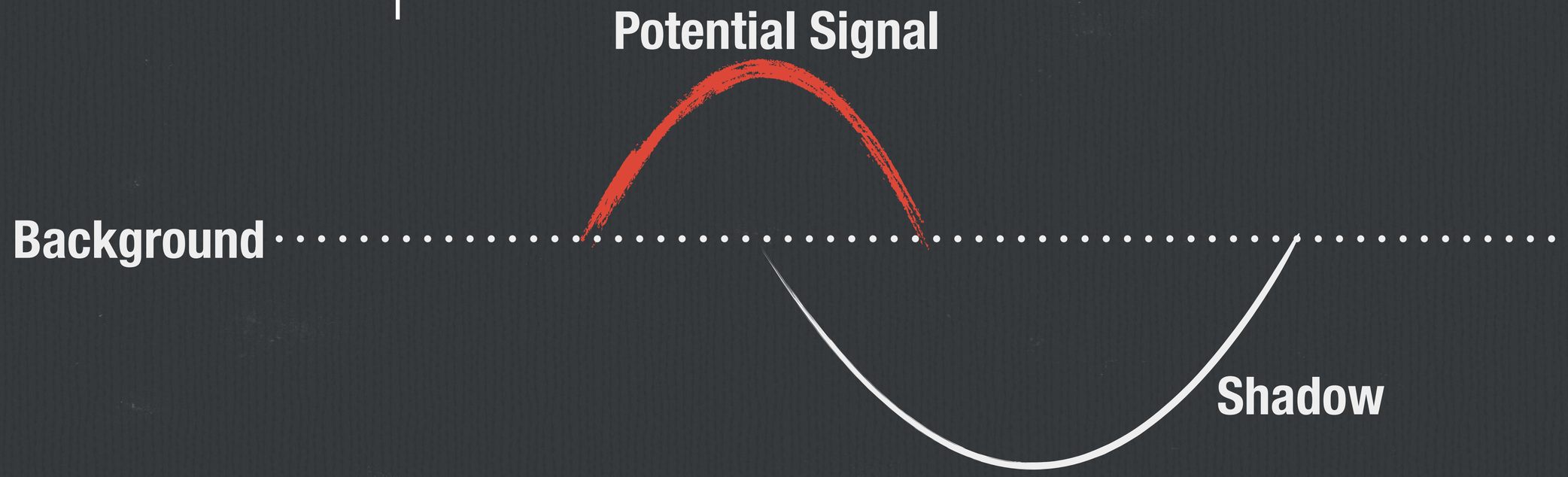
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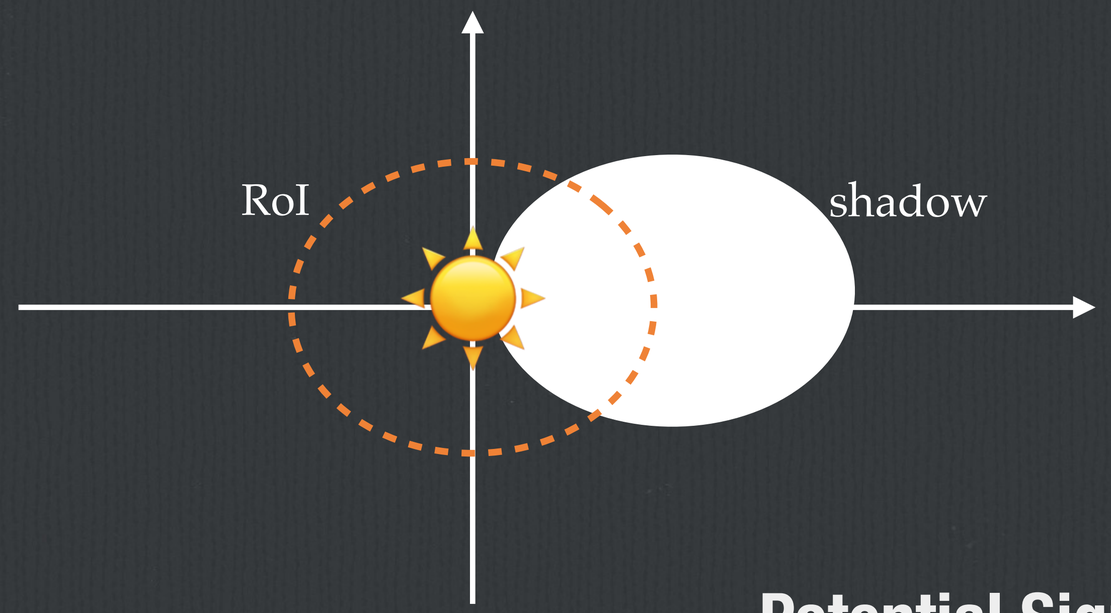
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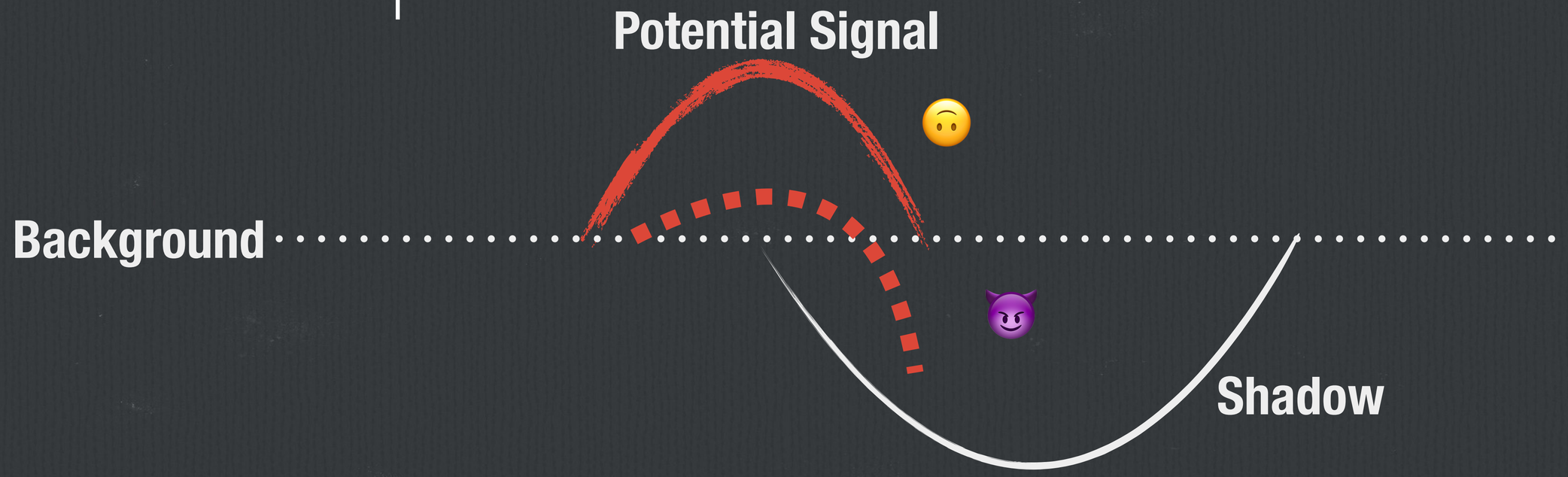
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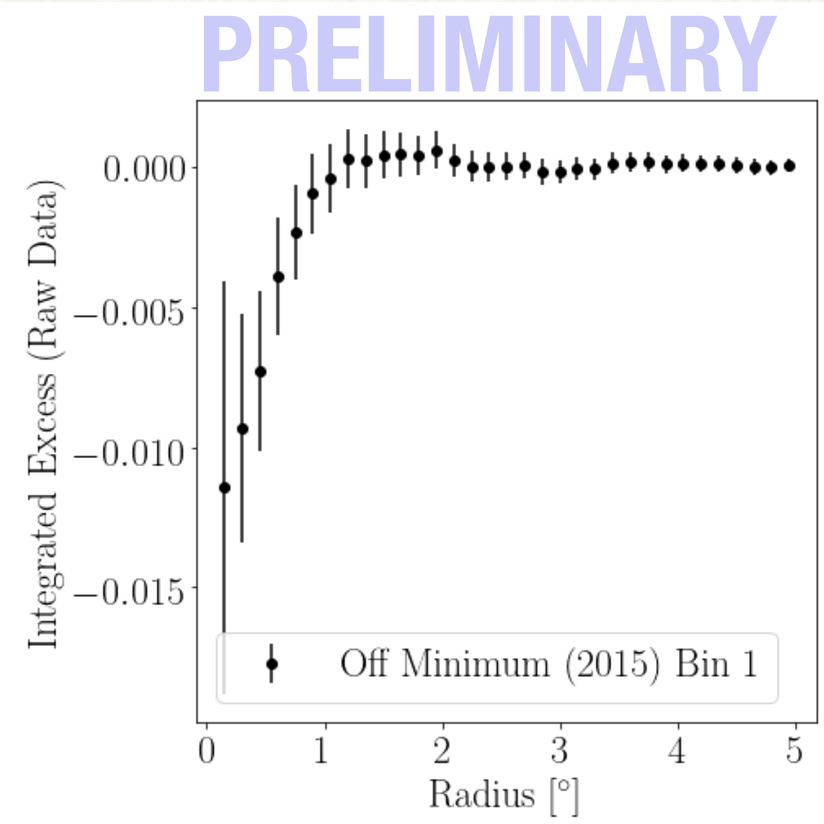
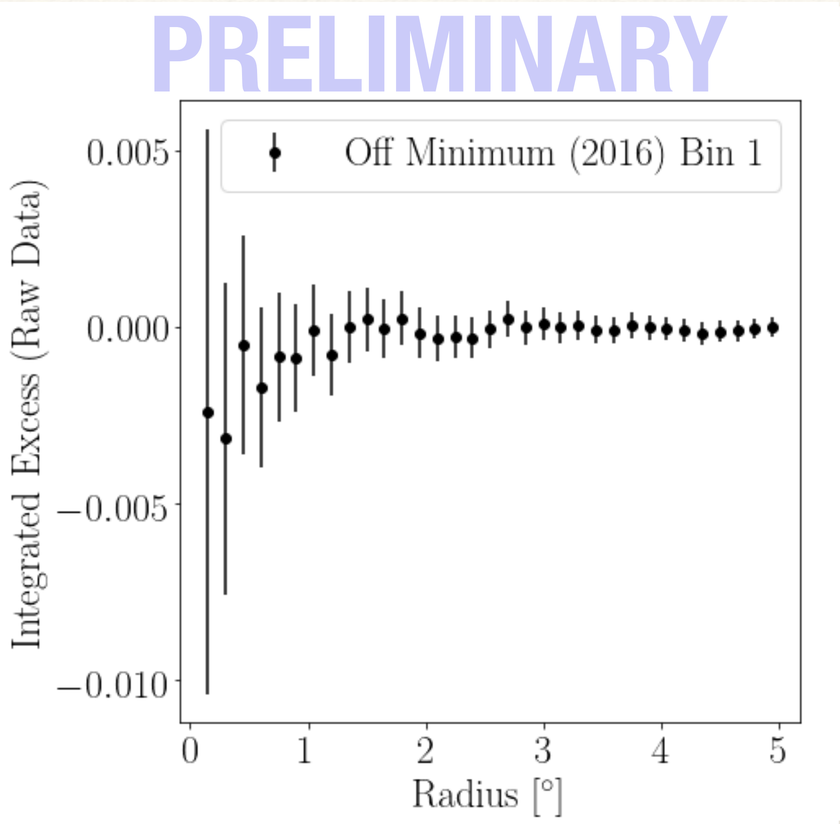
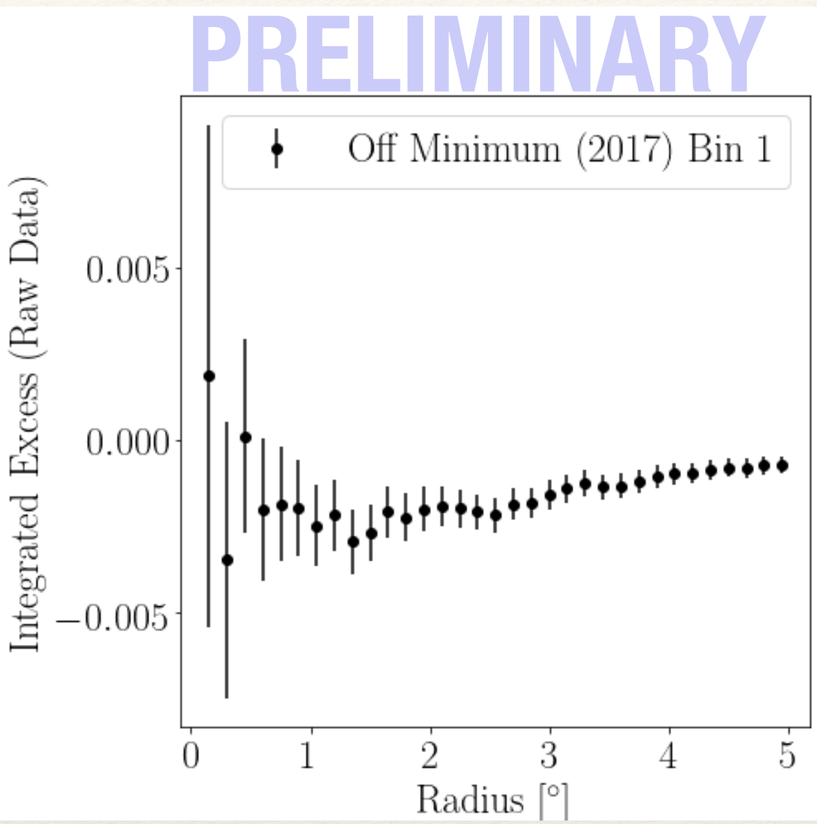
Data Away from the Solar Minimum



2015

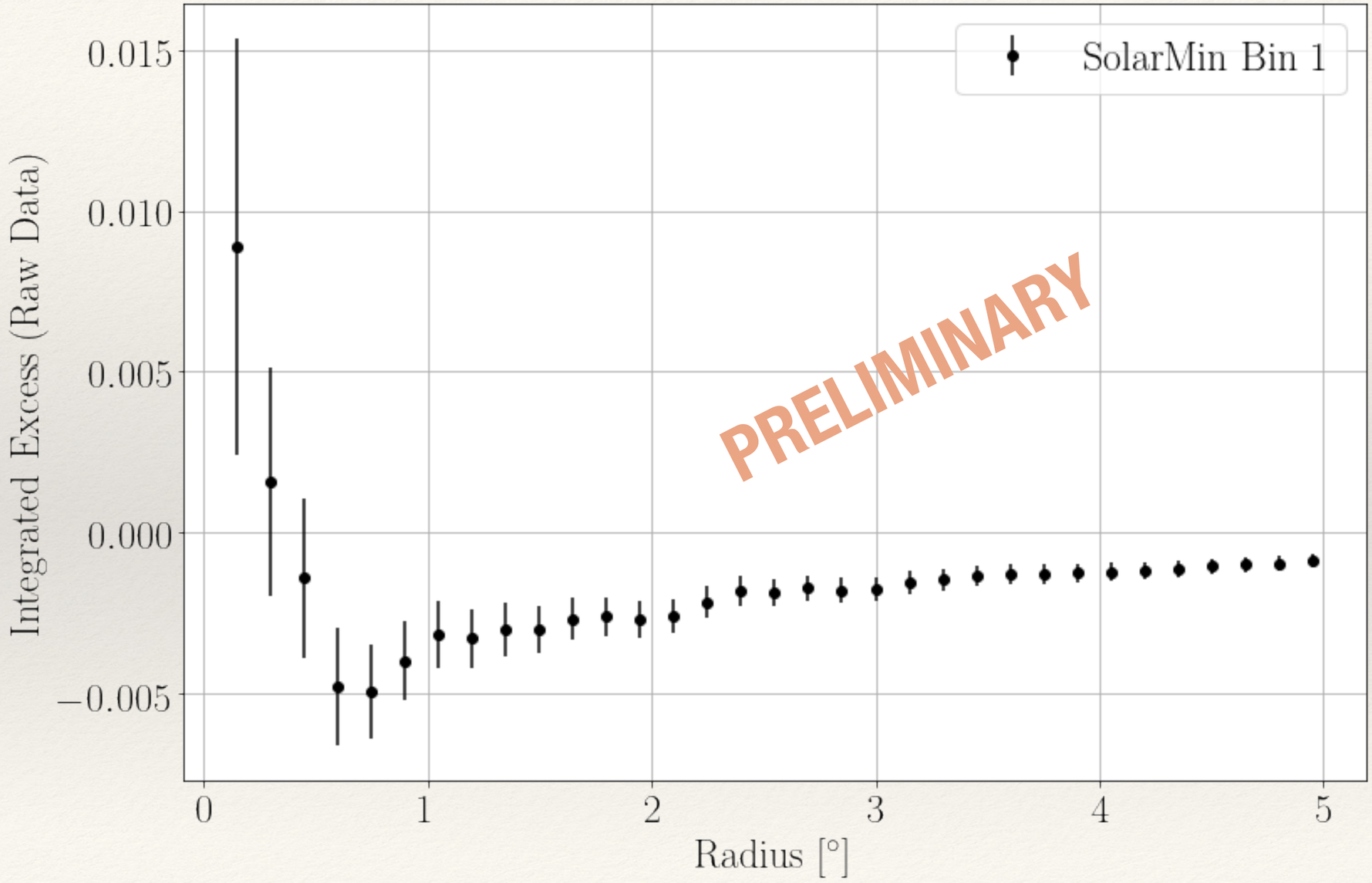


2016



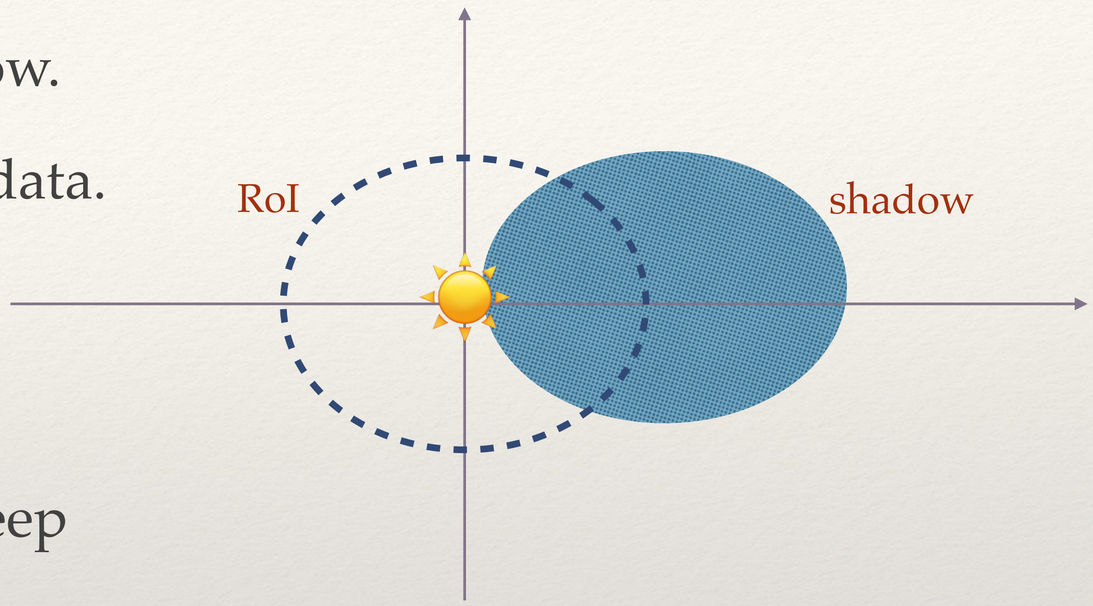
2017

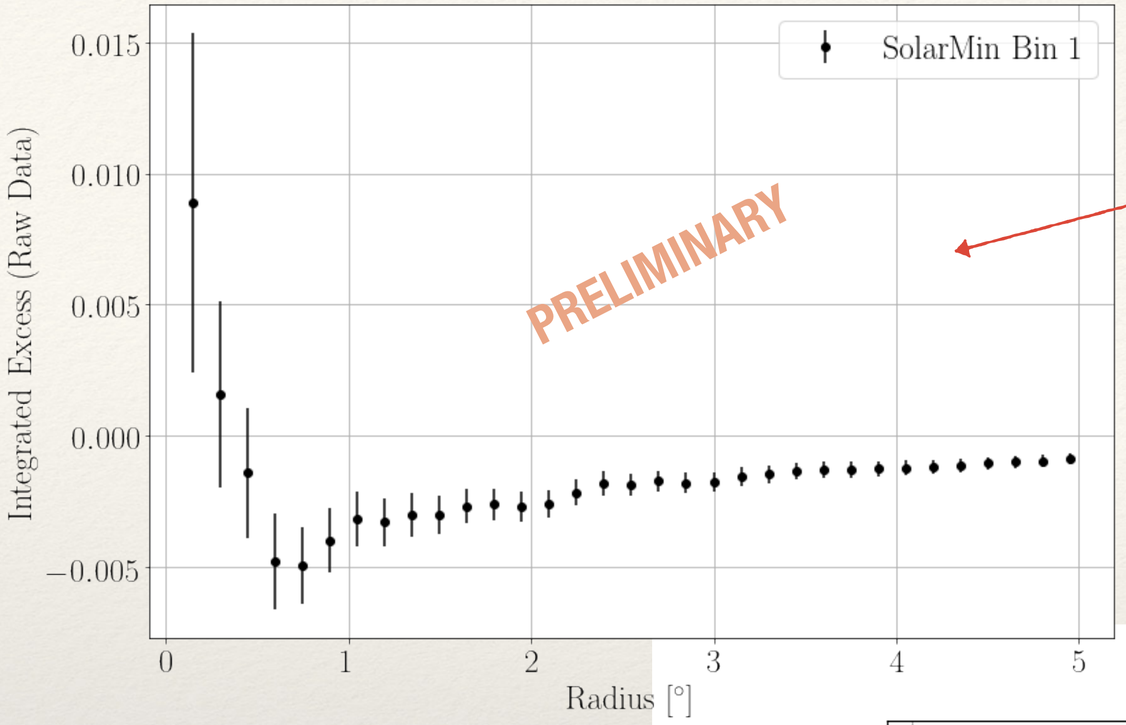
2018 Data: Enter Solar Minimum



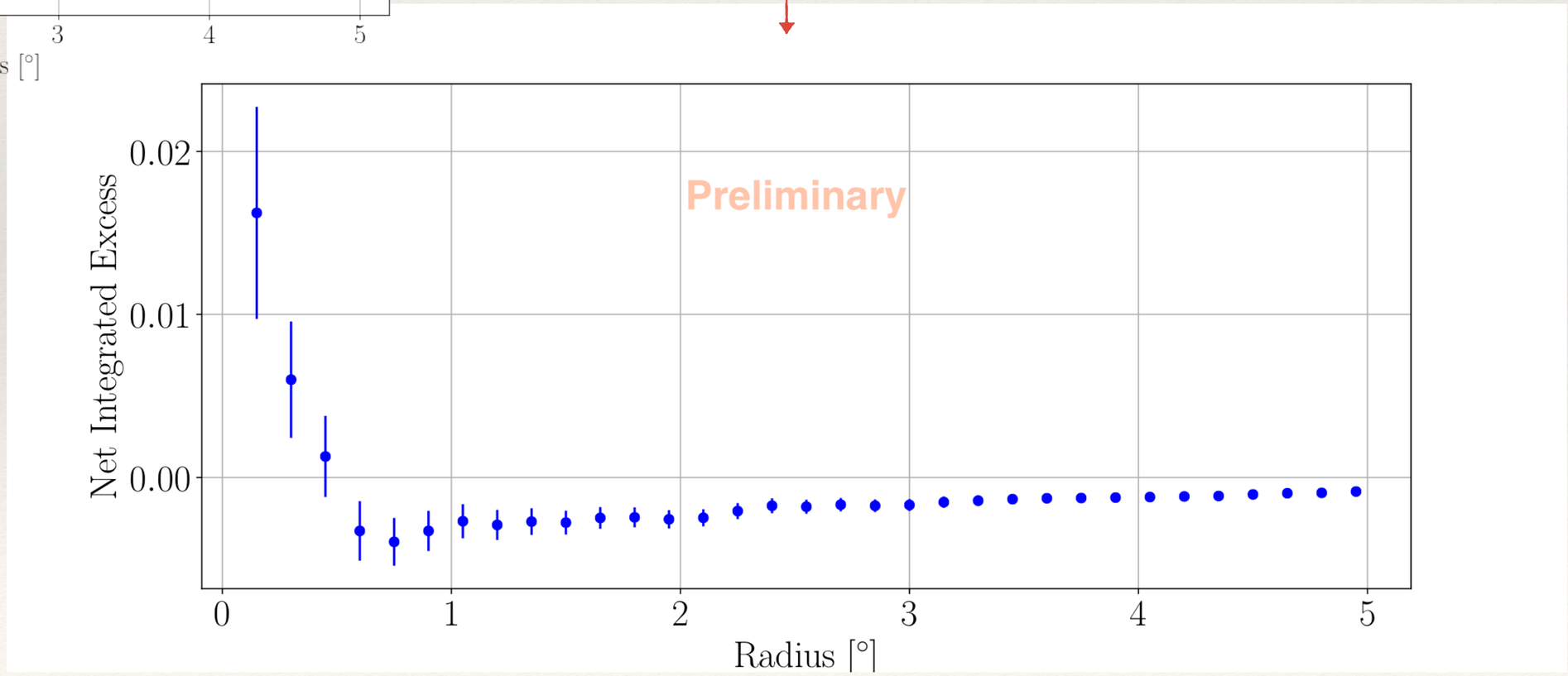
Shadow Subtraction

- The gamma-ray signal is contaminated by the sun shadow.
- We should subtract an estimate of the shadow from the data.
- Use solar max shadow as a first guess.
- Note: this would still be an underestimate of the contamination because the solarmax shadow is not as deep as solar min.
- We know we are not over-subtracting.
- We use the gaussian fit to 2015–2017 data as our model of the shadow.

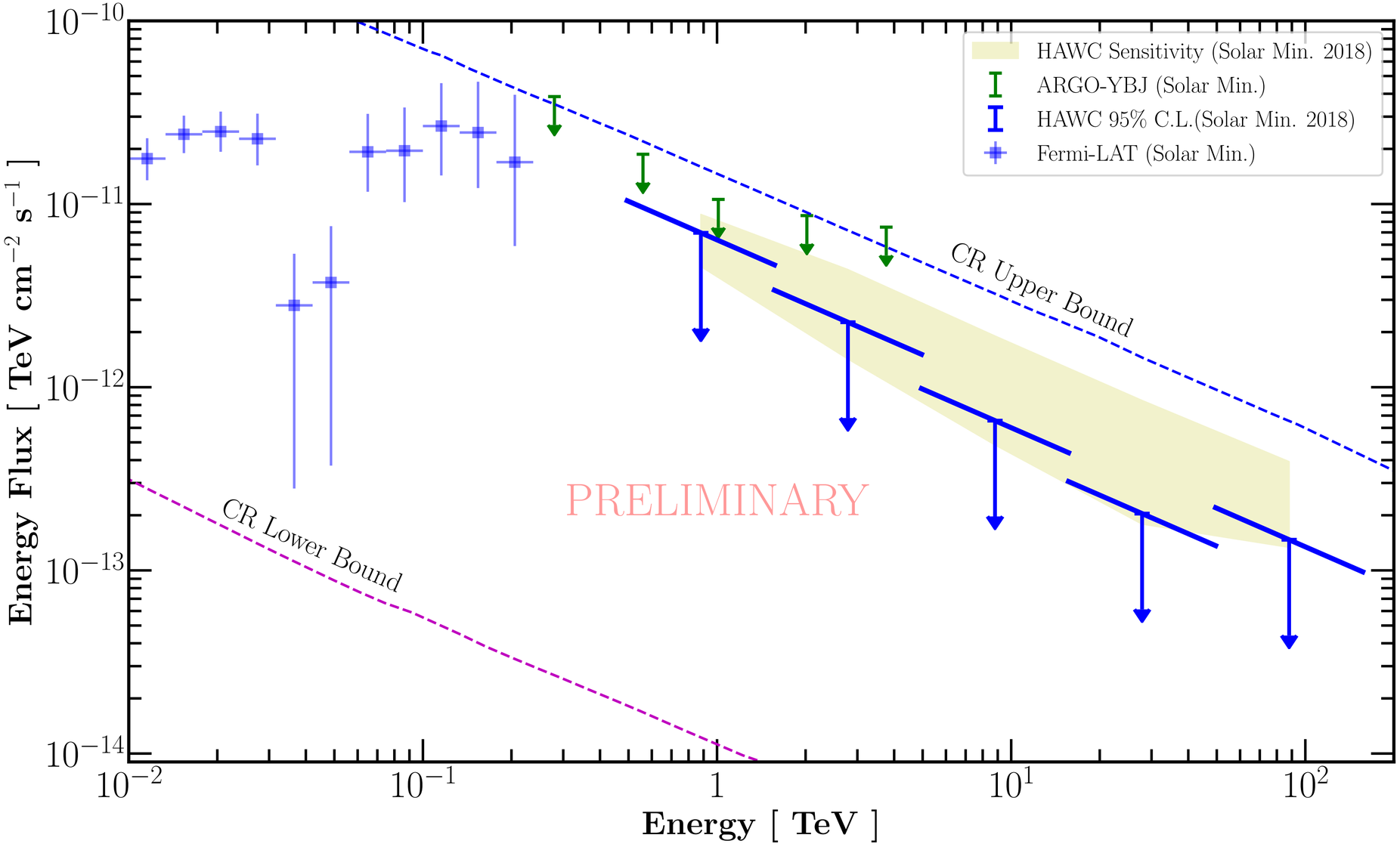




Before and after shadow subtraction



Upper Limits



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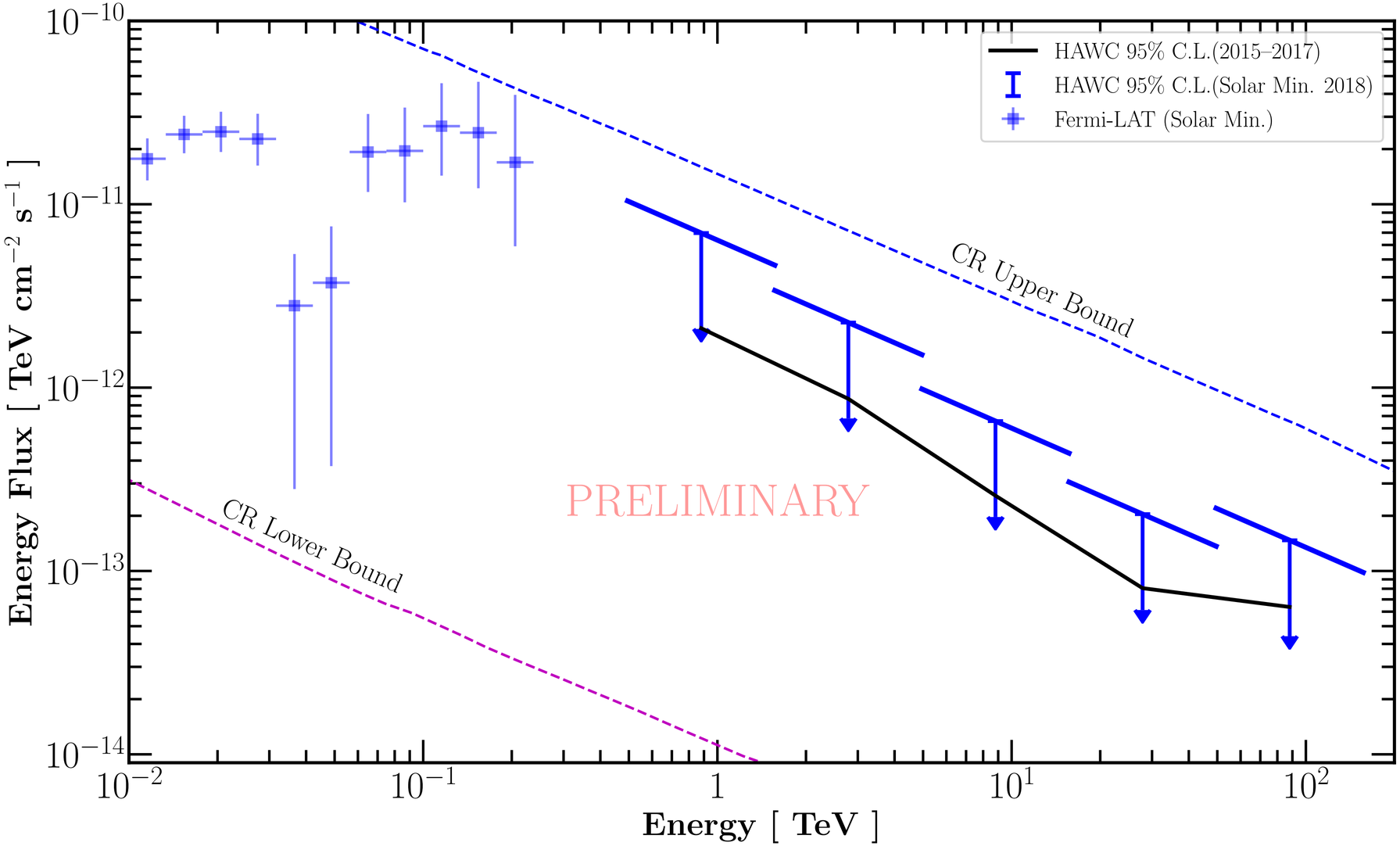


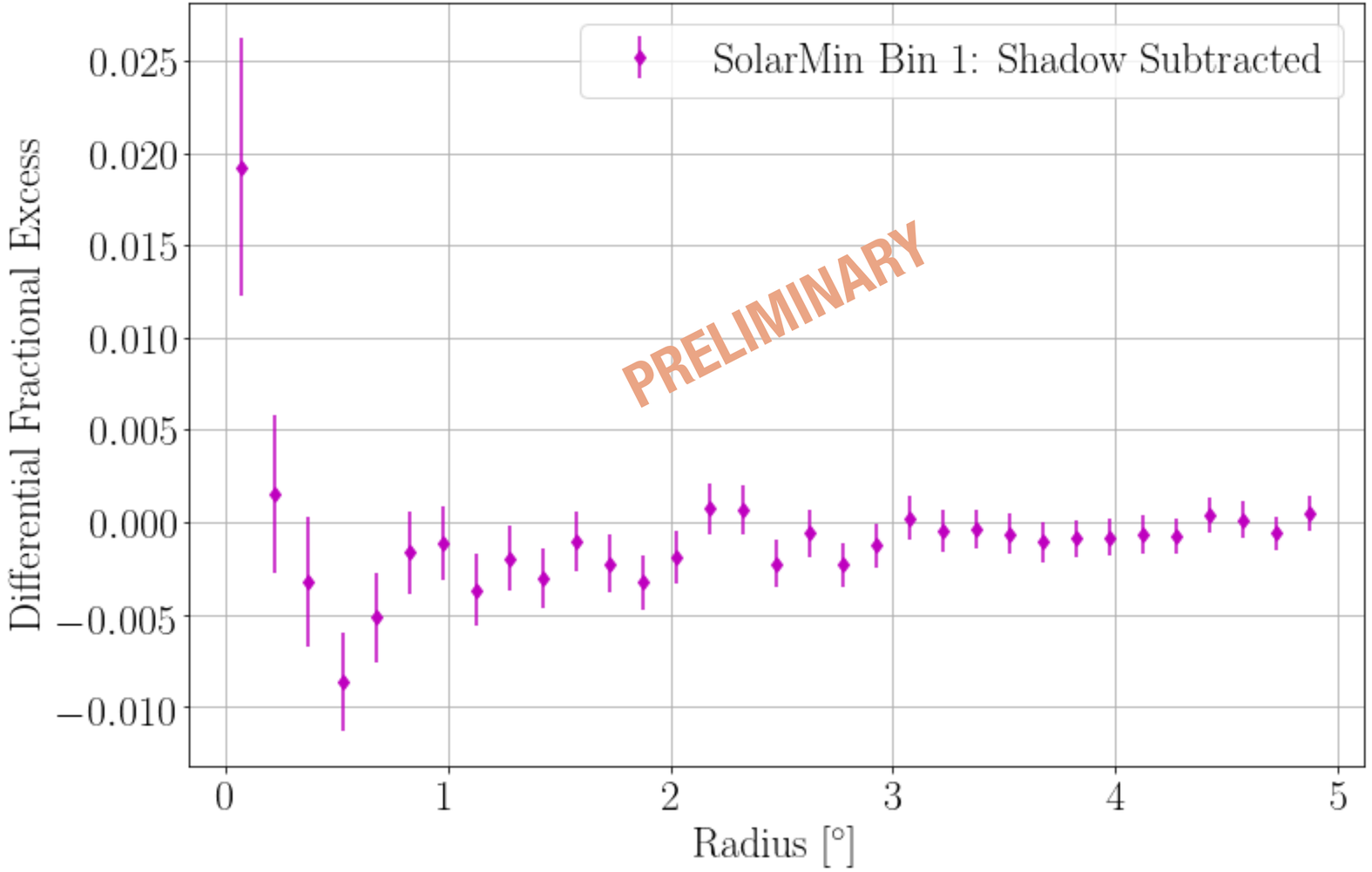
Summary and Outlook

- HAWC is performing follow-up observations of the Sun during the solar minimum
- Interesting trends in the data with change in solar activity 😎
- Does the hard GeV gamma-ray spectrum continue into the TeV? Solar Minimum data in the upcoming months will yield decisive results. Stay tuned!
- Complements studies in neutrinos and models of solar dark matter.
- Will impact our understanding of CR transport in the inner solar system.

Backup

SolMin data -SolMaxShadowModel

Excess in rings of increasing radius



Net gamma-ray excess using shadow-wide RoI

Following the analysis method in our solarmax paper (*Phys. Rev. D 98, 123011 (2018)*)