A Fresh Look At Axions: Using NuSTAR Solar Observations in Search for Dark Matter

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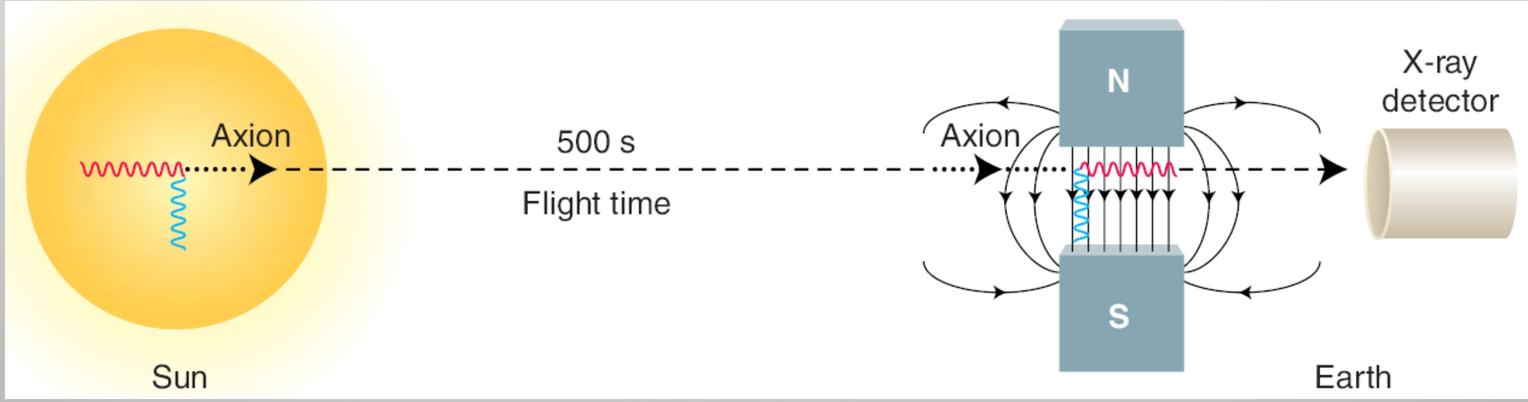
Outlook

- The Sun as an axion source
- Axion flux on Earth
  - Primakoff
  - Compton
  - Bremsstrahlung
- Expected photons from axion conversion
  - Sun structure
  - Coherence condition
  - Additive sensitivity
- Prospects from NuSTAR

The Sun as an axion source

Axion production mechanisms

- Blackbody photons (keV) in solar core can be converted into axions in the presence of strong electromagnetic fields in the plasma
- Reconversions of axions into x-ray photons possible in strong laboratory magnetic field, *but also possible in the photosphere of the Sun*



Sikivie *PRL* 51:1415 (1983)

Van Bibber et al. *Phys.Rev. D* 39:2089 (1989)

The Sun as an axion source

Axion production mechanisms

- Primakoff interaction (virtual photon interaction)
- Electron interactions (Compton and Bremsstrahlung)
- Others, such as axion decay constant

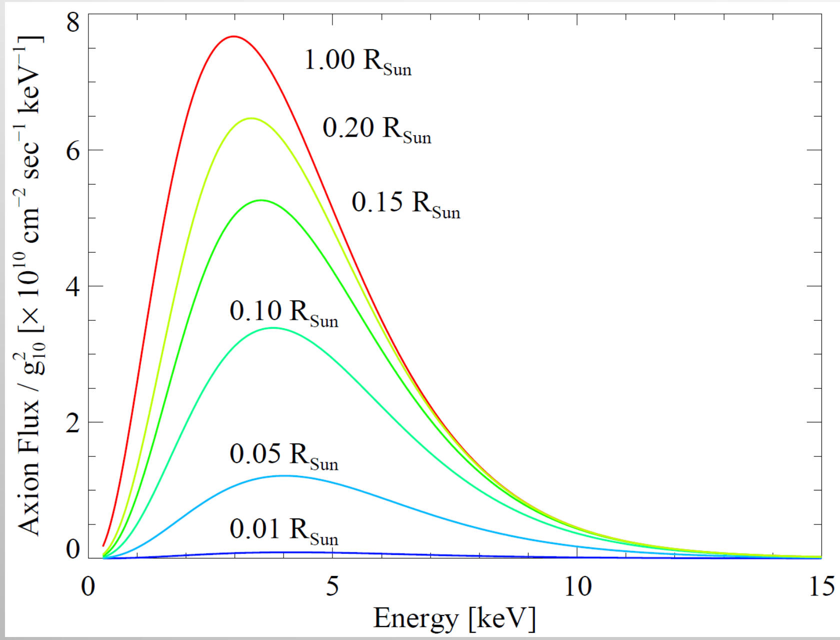
$$\left(\frac{d\phi_a}{dE_a}\right)_T = \left(\frac{d\phi_a}{dE_a}\right)_C + \left(\frac{d\phi_a}{dE_a}\right)_B + \left(\frac{d\phi_a}{dE_a}\right)_P = g_{ae}^2 \cdot C + g_{ae}^2 \cdot B + g_{a\gamma}^2 \cdot P$$

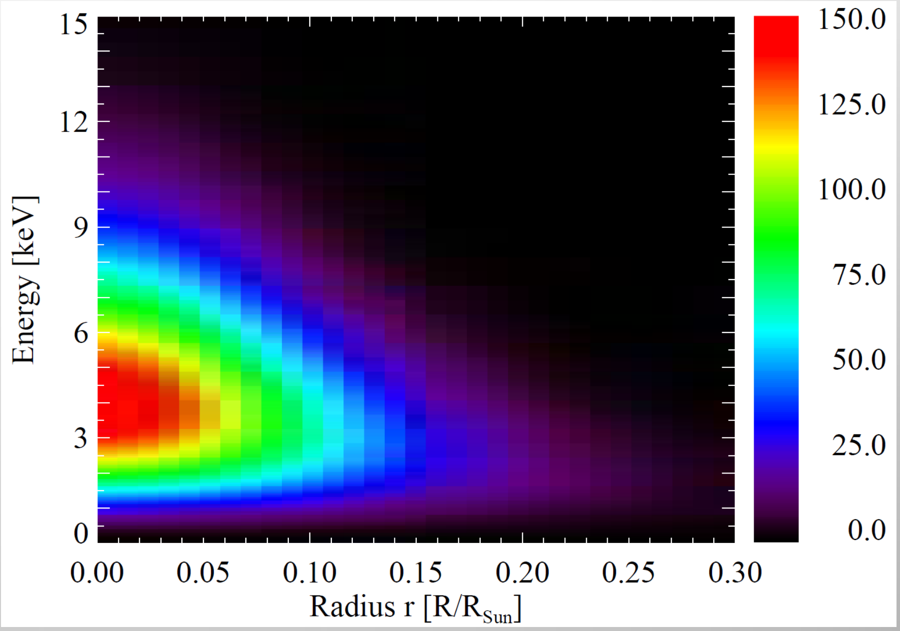
$g_{ae}^2 \cdot C \rightarrow 0$, $g_{ae}^2 \cdot B \rightarrow 0$

Let's assume we only have Primakoff conversion, which it is present in all axion models

Detection. Let's focus on hadronic

Primakoff axion flux and axion expectation for a given detector





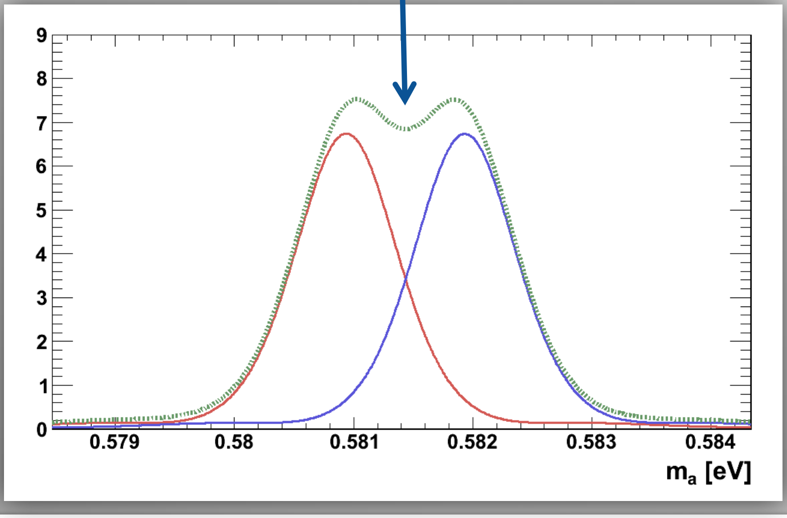
$$N_\gamma = \int_{E_a} \frac{d\phi_a}{dE_a} \cdot \wp_{a\to\gamma}(E_a) \cdot \varepsilon(E_a) \cdot t \cdot A \cdot dE_a$$

How can NuSTAR look for axions?

Primakoff conversion in many 'little' magnets

The axion mass band for which a Primakoff based experiment is sensitive can be extracted from the coherence condition

The converted photons may acquire an effective mass in the presence of gas extending the axion mass sensitivity range of an experiment that has a fixed magnet length



Conversion Probability

$$P_{a\gamma} = g_{10}^2 \times \left(\frac{B_\perp}{2}\right)^2 \frac{1}{q^2 + \Gamma^2/4}\left[1 + e^{-\Gamma L} - 2e^{-\Gamma L/2}\cos qL\right]$$

Coherence Condition

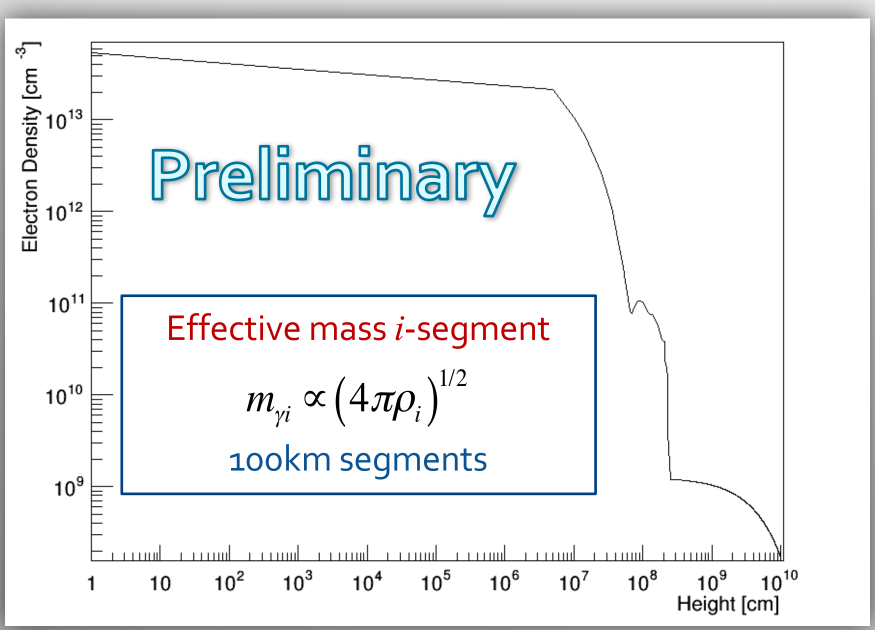
$$\left(m_a^2 / keV^2\right) << \left(m_\gamma^2 / keV^2\right) + 2\left(\frac{E_a / keV}{L \cdot keV}\right)$$

Axion-to-photon conversion in the presence of a nearly homogeneous magnetic field **B** is only effective when the polarization plane is parallel to the incident particle

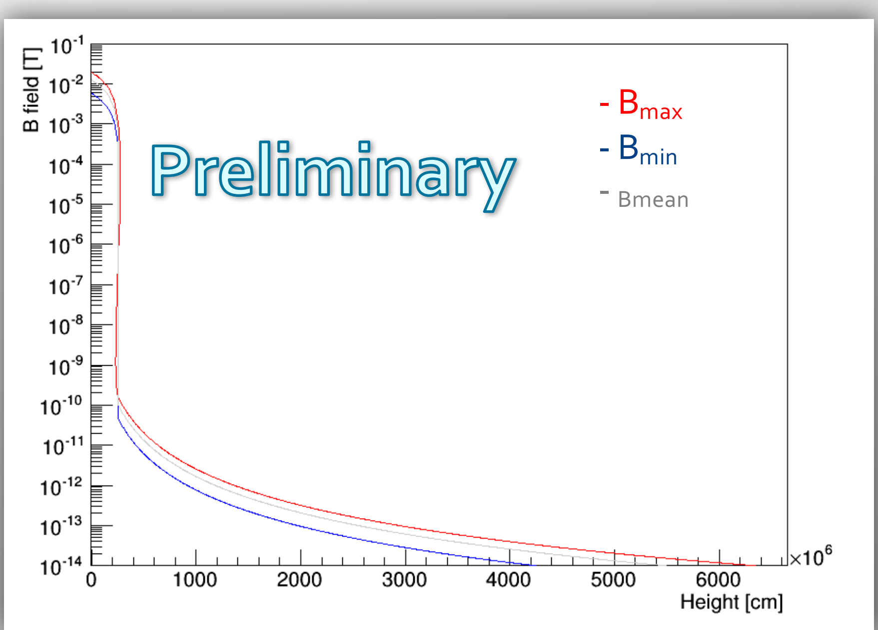
And how many magnets are we talking?

The Sun photosphere. A collection of magnets of low intensity but large distances.

Electron density



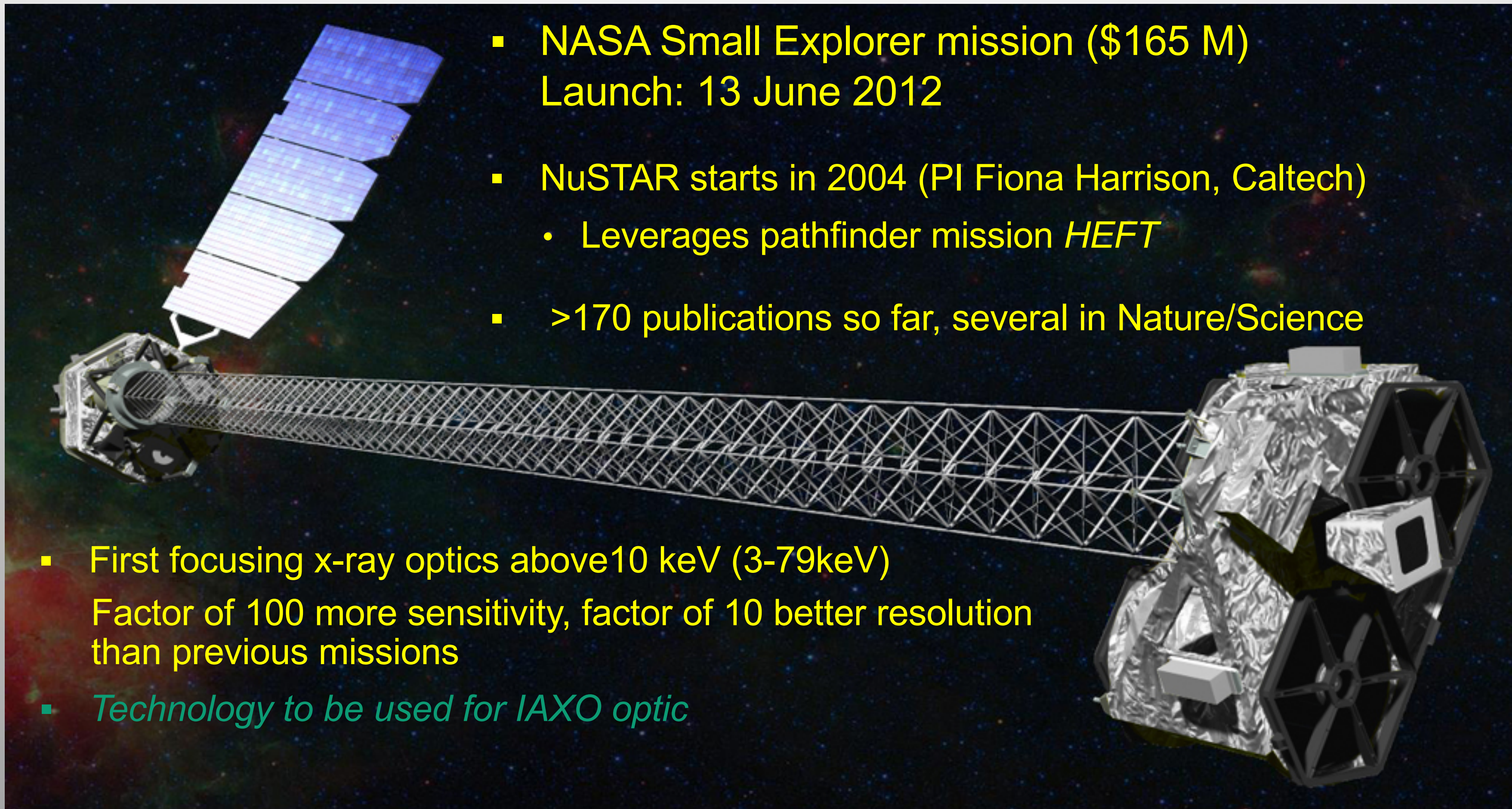
Magnetic field strength



Hudson et al. arxiv:1201.4607

NuSTAR

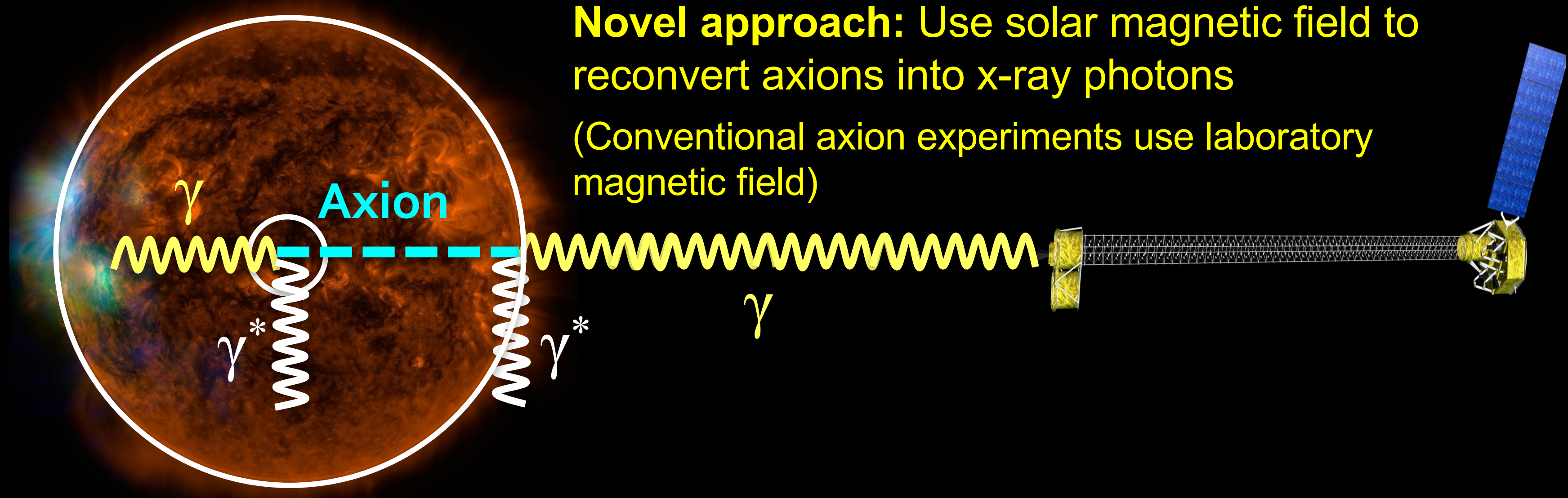
Nuclear Spectroscopic Telescope Array



- NASA Small Explorer mission ($165 M)
  Launch: 13 June 2012
- NuSTAR starts in 2004 (PI Fiona Harrison, Caltech)
  - Leverages pathfinder mission *HEFT*
- >170 publications so far, several in Nature/Science
- First focusing x-ray optics above10 keV (3-79keV)
  Factor of 100 more sensitivity, factor of 10 better resolution than previous missions
- *Technology to be used for IAXO optic*

NuSTAR Solar Axion Observations

Search for axions from the solar photosphere using NuSTAR



Novel approach: Use solar magnetic field to reconvert axions into x-ray photons

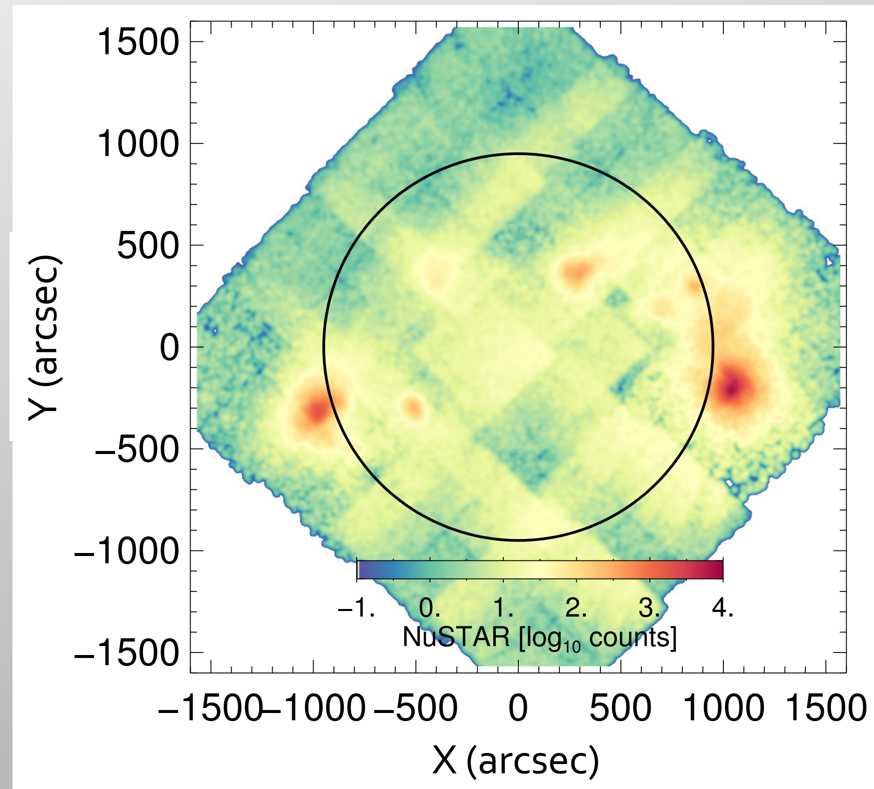
(Conventional axion experiments use laboratory magnetic field)

- **Why should we do this?**
  - Might find dark matter, but even in absence of signal: new stringent axion limits!
  - NuSTAR can explore significant regions of viable parameter space NOW, while conventional searches will get there in the coming decades
  - NuSTAR is complementary to traditional searches and providing first look

First NuSTAR Solar data

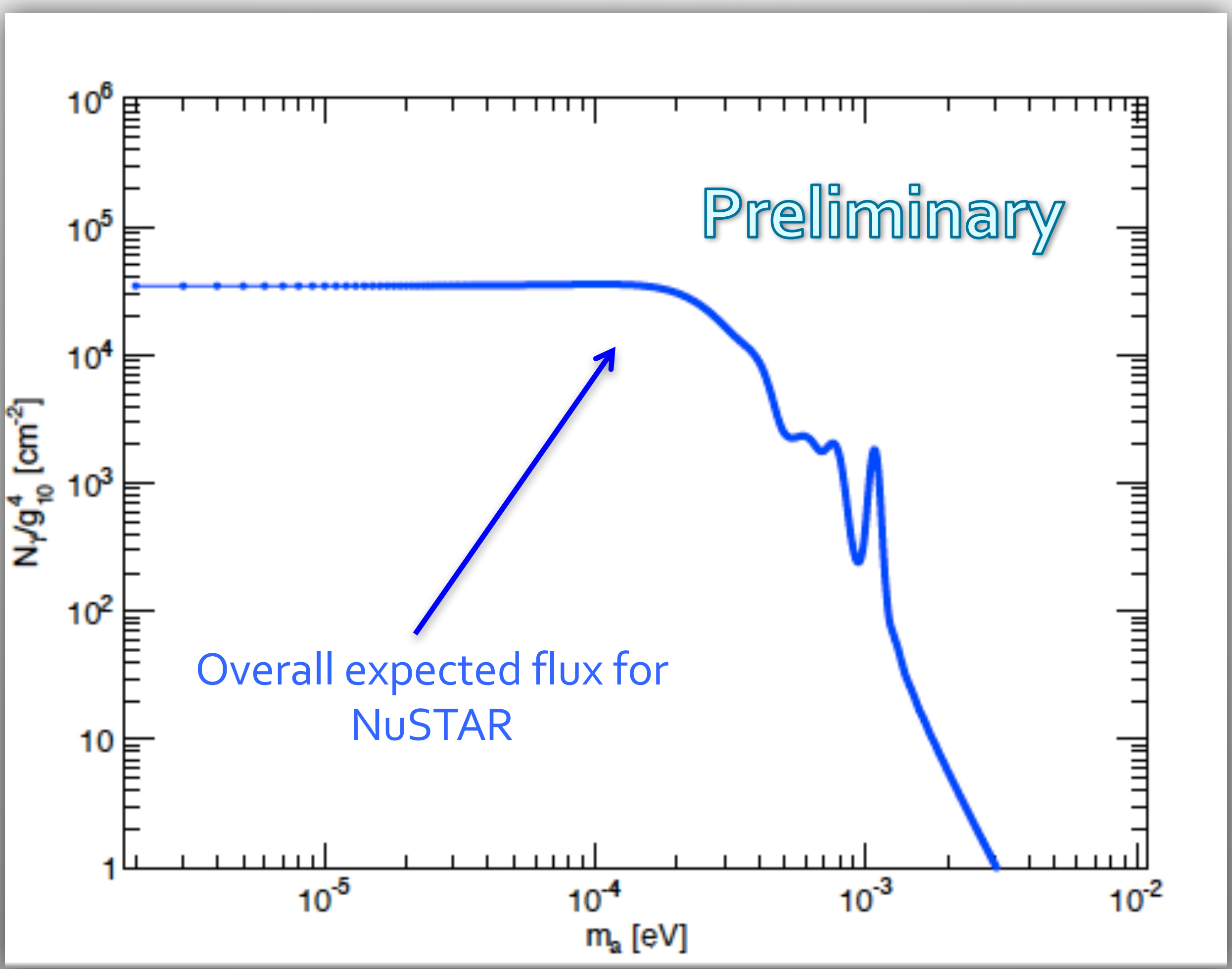
How does it look like?

- First *NuSTAR* solar observations (Sept/Nov/Dec 2014, Apr/Sept 2015, more in 2016) confirm the capability of the instrument to observe the Sun.
- Some of currently available NuSTAR solar data include solar disk center
- Solar conditions were not optimal (high magnetic activity → elevated dead times + single-reflection "ghost ray" interference)
- Now working on using existing data to obtain preliminary estimates and to optimize a future, dedicated observing session
- Plan is to establish initial limits based on the test data, but any detection of an axion signal is unlikely at this early stage.



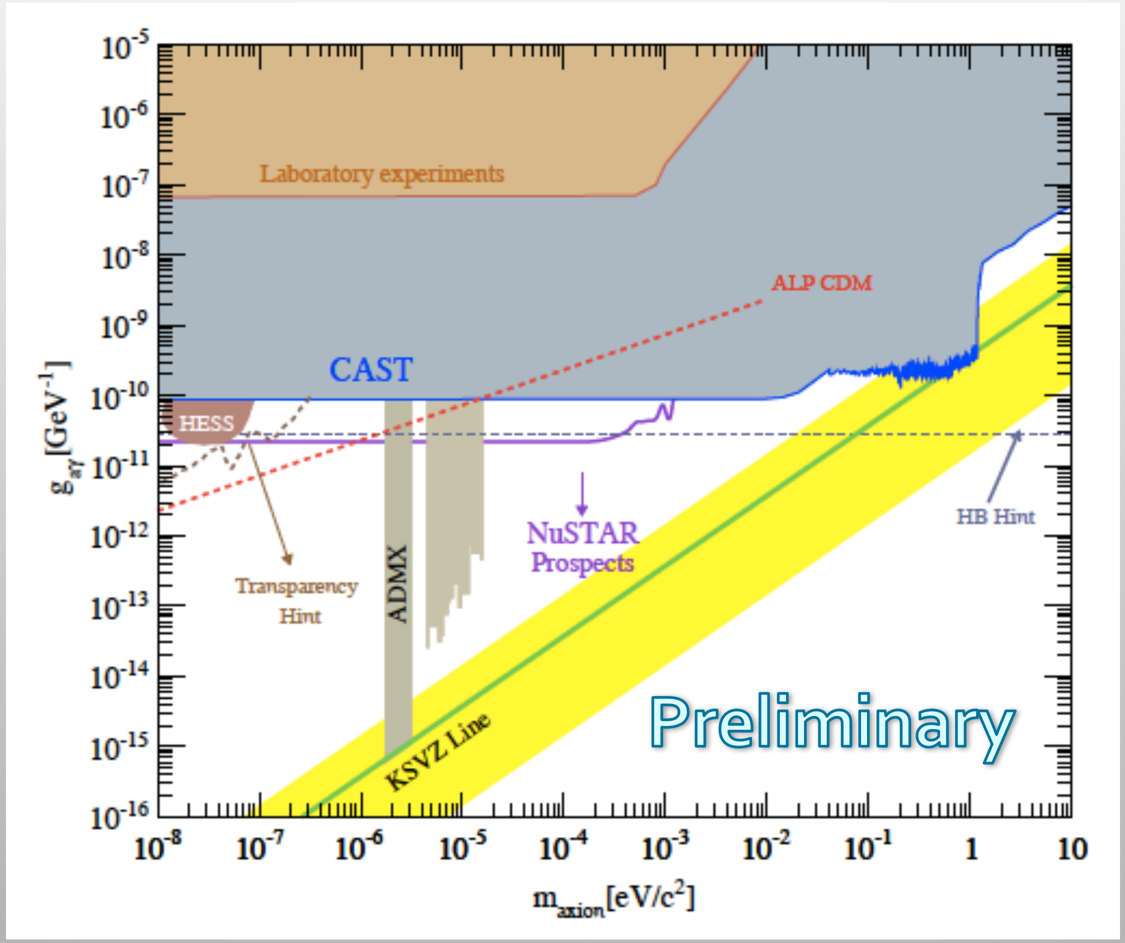
Detection of axions @ NuSTAR

Using satellite performance parameters



NuSTAR axion sensitivity.

95% CL Prospects in absence of signal



Summary

- Satellite mission offer alternative approach to solar axion searches (and axions from other objects)
- Expect good sensitivity to non-QCD axions at the low mass range
- First NuSTAR data available but needs additional work
  → Biggest challenge due to single-bounce photons ("ghost-rays")
- Stay tuned for first results from existing data and upcoming observations

Thank you!

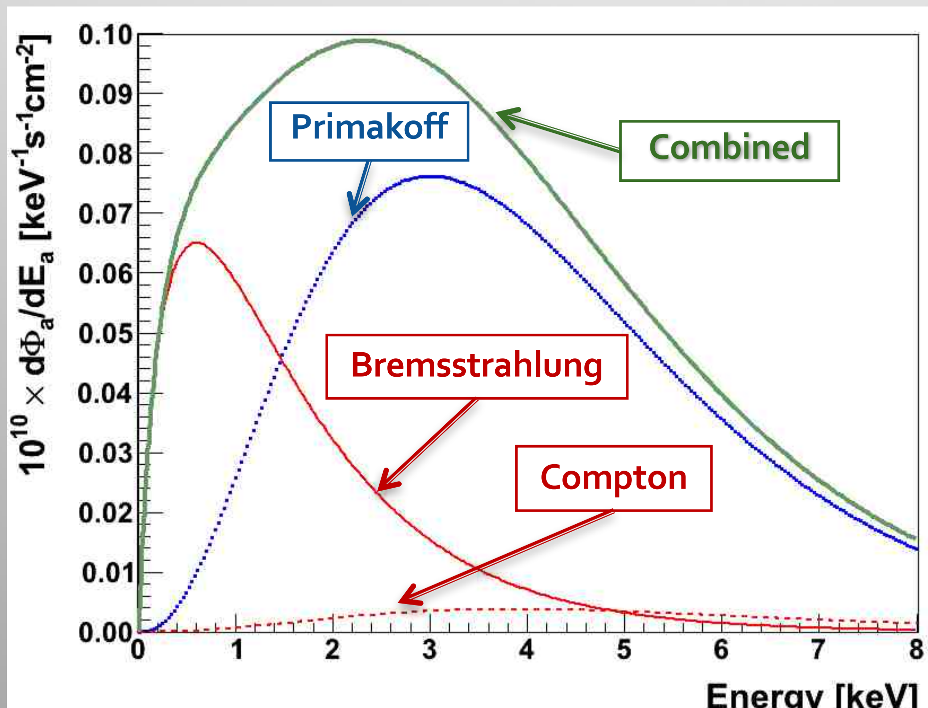
Back up slides

The Sun as an axion source

Axion production mechanisms

- Primakoff interaction:
- Electron interactions
- Axion decay constant

$$\left(\frac{d\phi_a}{dE_a}\right)_T = \left(\frac{d\phi_a}{dE_a}\right)_P + \left(\frac{d\phi_a}{dE_a}\right)_B + \left(\frac{d\phi_a}{dE_a}\right)_C$$



GENERIC VALUES

CAST

$g_{a\gamma}$ = 1e-11 GeV^{-1}

Red Giants

gae = 1e-13