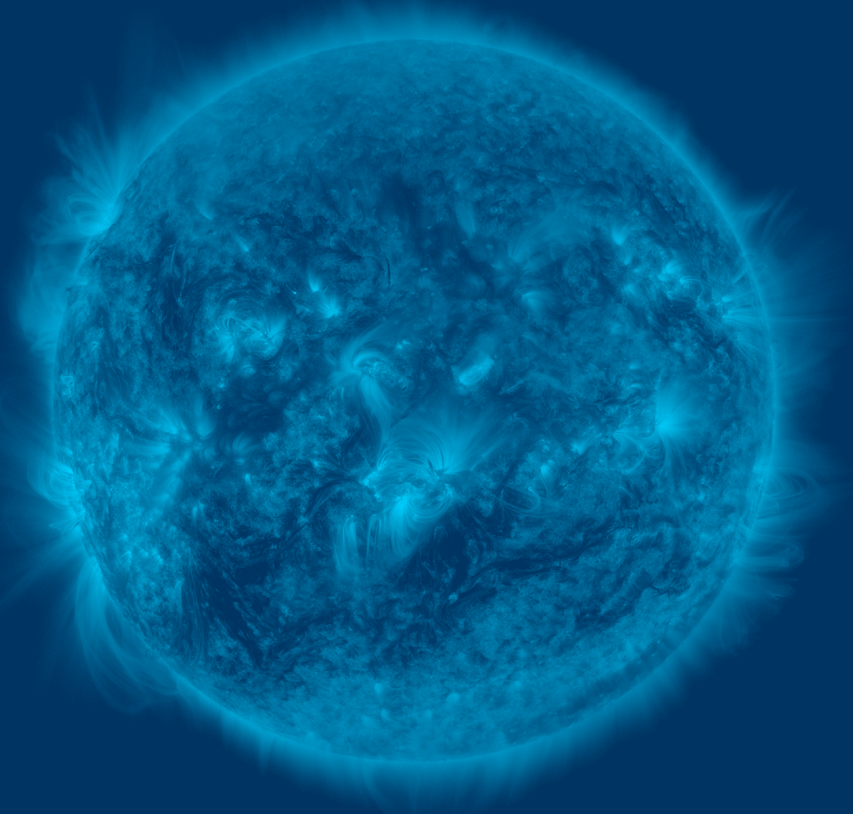


Assessing quiet Sun hard X-rays

using observations from the FOXSI Sounding Rockets

Milo Buitrago-Casas - on behalf of the FOXSI team

Why observe hard X-rays from the quiet Sun?

Faint hard X-ray emission from the **quiet Sun** might be a direct consequence of **nanoflares**

Nanoflares understood as **very small flares** releasing magnetic energy in quiet coronal regions.

Do nanoflares follow the same physics as their larger counterparts?

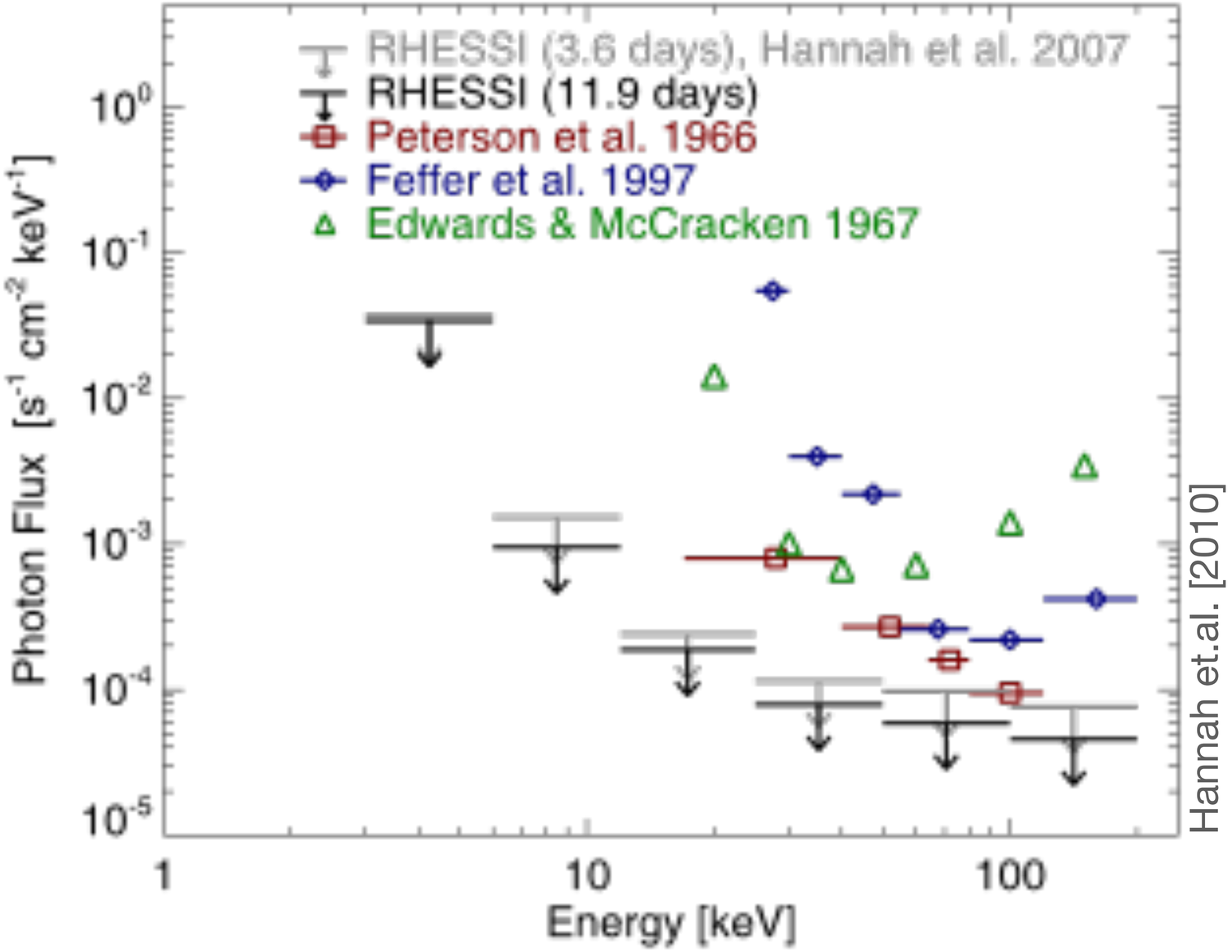
A **copious** presence of **nanoflares**

will result in a **sustained** and **persistent** emission in hard X-rays

might release large amounts of energy into the corona accounting for its high temperatures.

Has anyone directly observed sustained, persistent hard X-rays from the quiet Sun yet?

Not quite, but Hannah et.al. (2010) set upper limits using almost 12 days of RHESSI off-pointing observations



What do we need to be able to observe such faint hard X-rays?

We need an instrument with high sensitivity and superior dynamic range.

FOXSI

The **F**ocusing **O**ptics **X**-ray **S**olar **I**mager

FOXSI has successfully flown three times

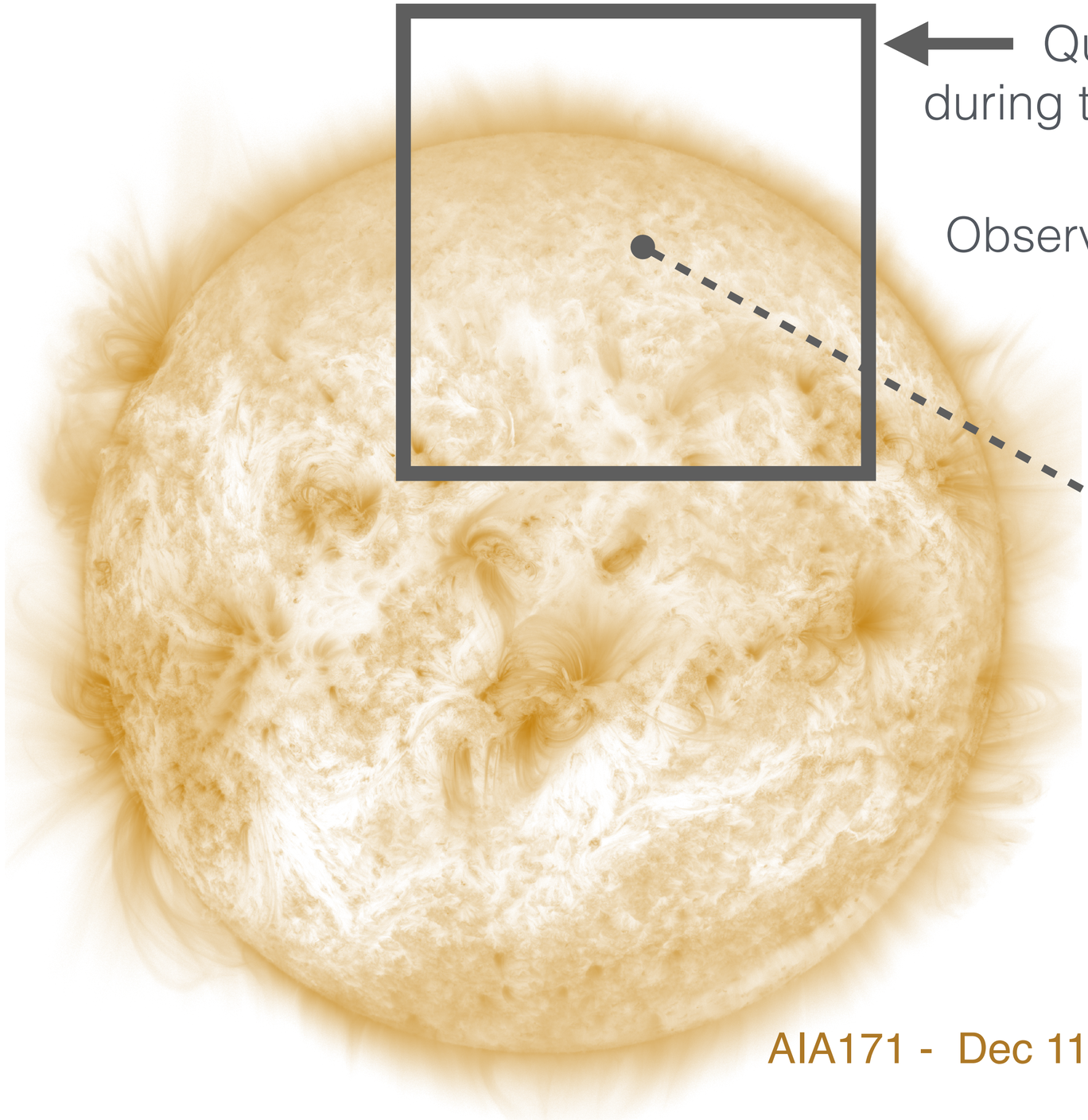
observing for ~6 minutes for each flight

Nov 2012

Dec 2014

Sep 2018

All the analysis we present here is based on observations obtained during the second flight

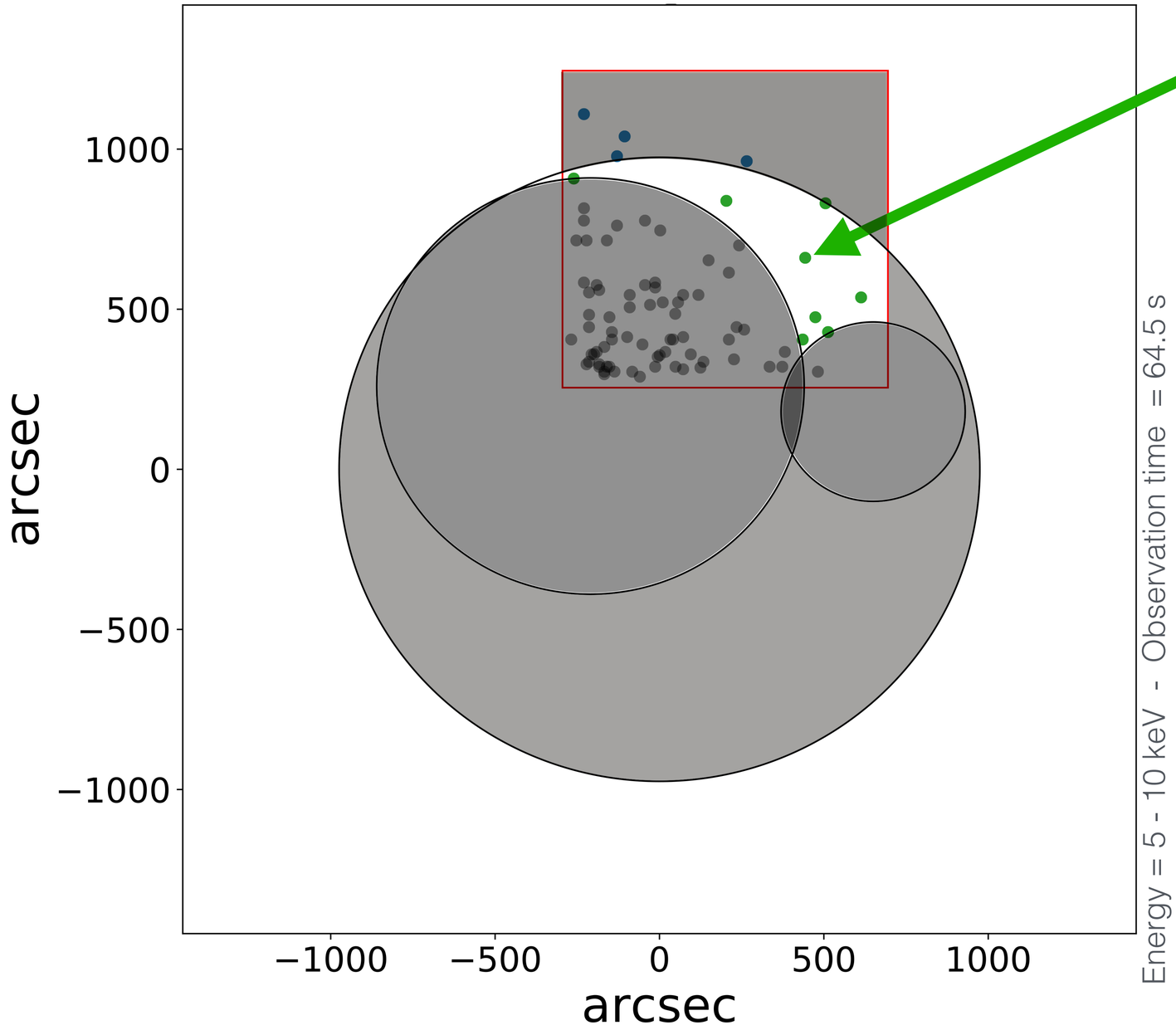


Quiet Sun pointing
during the FOXSI-2 flight

Observation time: **64.5** s

AIA171 - Dec 11, 2014 at 19:17 UT

Observation from ONE of the FOXSI pairs optics/detector



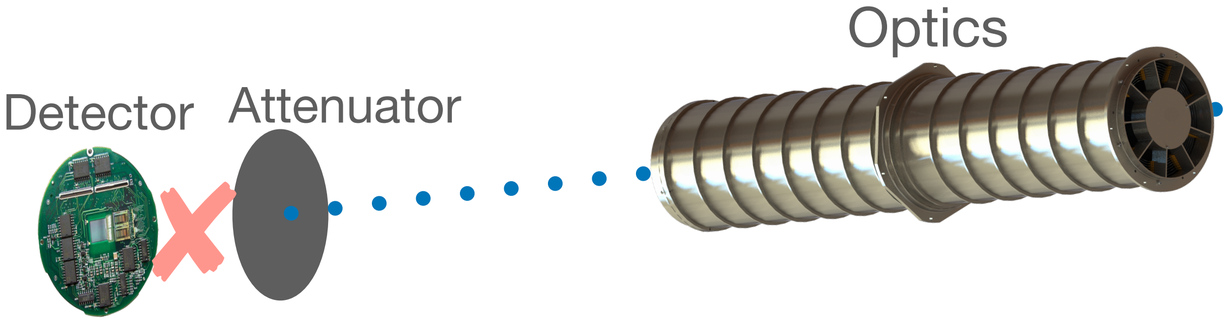
Events observed with FOXSI in a region within the solar disk free of ghost rays

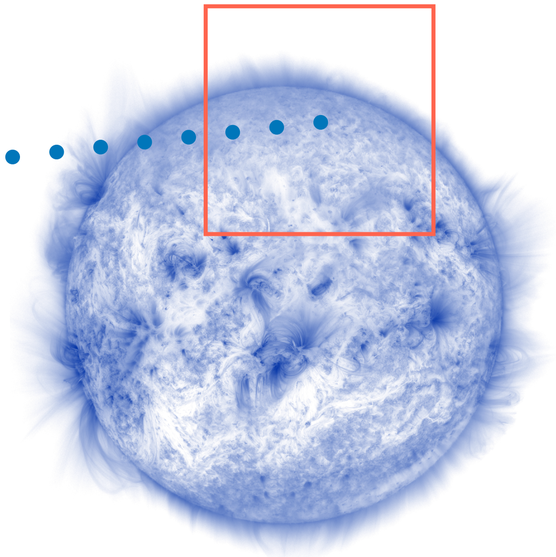
8 events

Background + Signal ?

To assess the existence of any **signal**, we need to have a good **measurement** of the **background**.

Background measurements

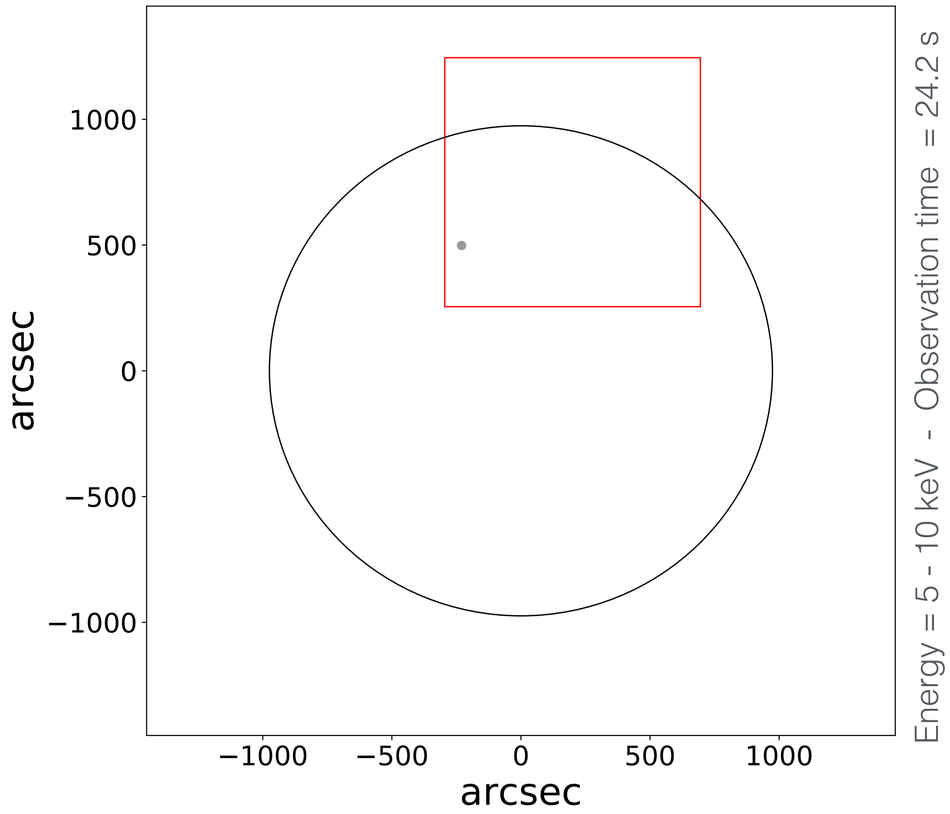




during **24.2** s attenuators were placed in front of the detectors for background measurements

Background measurement for ONE of the FOXSI pairs optics/detector

1 event



We have two different measurements:

Background
Observed a # of events
in a certain period of time

Vs

Background (“and a signal?”)
Observed other # of events
in other certain period of time

Very low statistics

Our approach:

On-Off Problem Method

Max Ludwig Ahnen (2015)

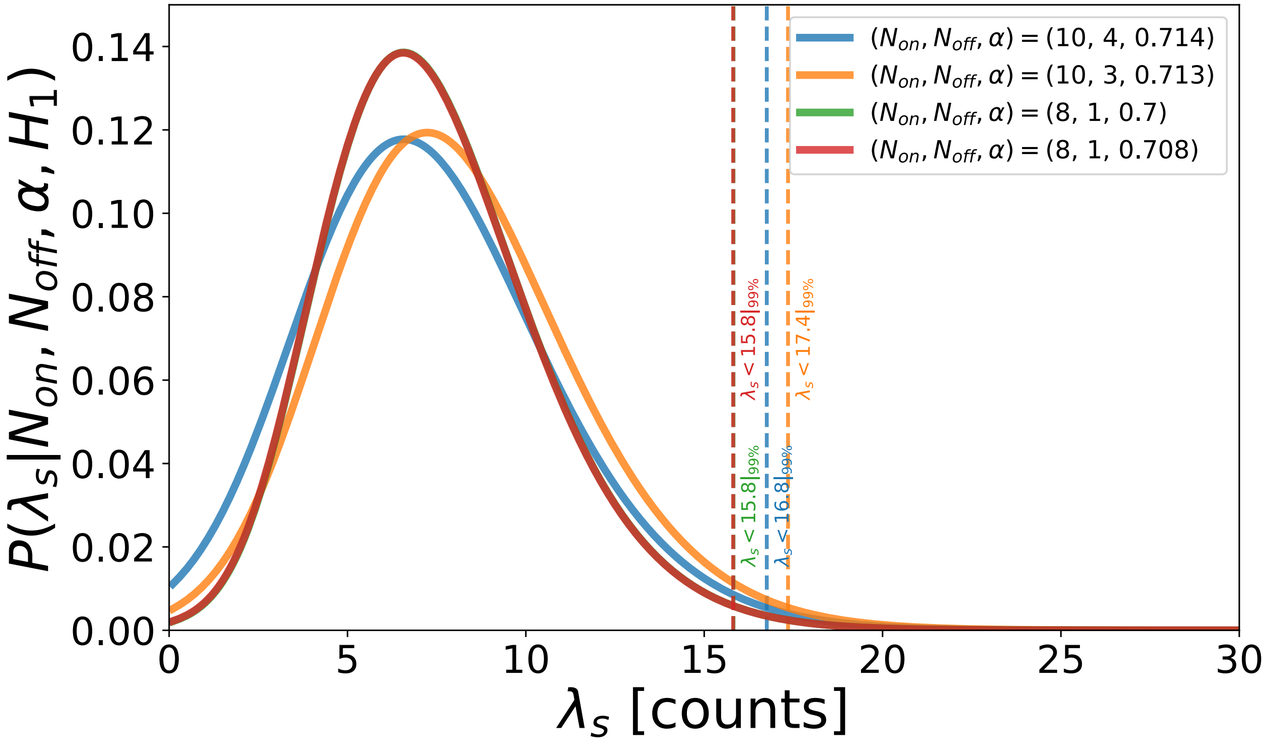
Intended to infer a signal rate in the presence of a known background rate

Input

- N_{on} : events in some “on” region with potential signal.
- N_{off} : events in some “off” region, known to be signal free
- α : ratio of exposures and region sizes together

Output

- Significance of a signal detection
- Upper limit, assuming the signal is there, but too weak to be measured.



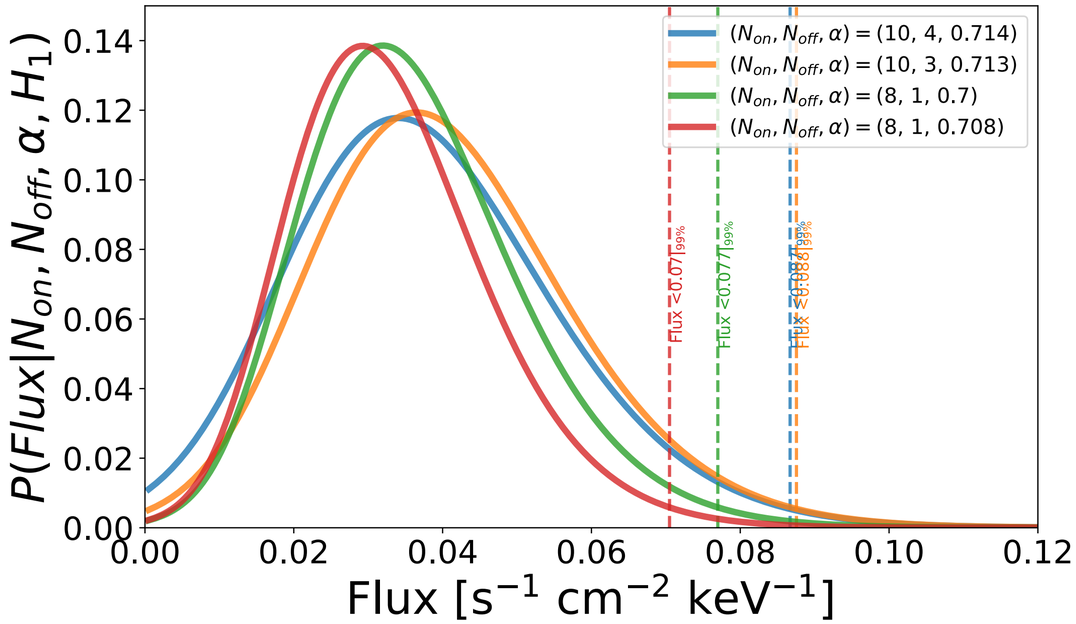
λ_s are the expected counts from the signal during the time we observed.

- We used the expected counts upper limits to estimate a solar flux upper limit:

$$\text{Flux}_{99\%} = \frac{\lambda_s|_{99\%}}{\Delta t \Delta E \Delta A} \frac{\Delta\Omega_{FullSun}}{\Delta\Omega_{ON}}$$

For the detector of our example,
$N_{on} = 8$, $N_{off} = 1$, and $\alpha = 0.708$

- The signal would have a distribution function like the one in **red**.
- The dashed line represents the upper limit at 99% certainty.

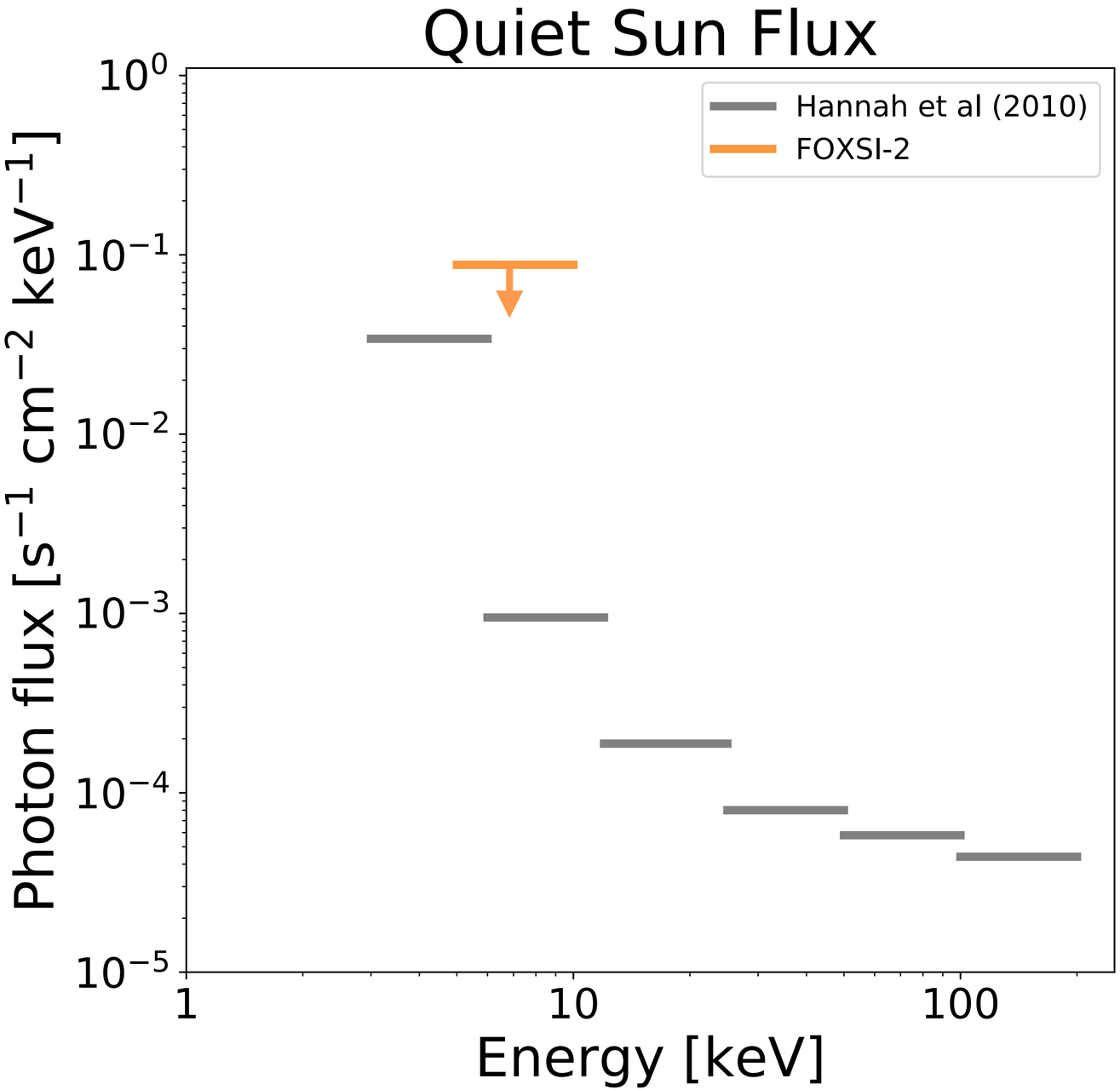


Result: Quiet Sun Hard X-ray upper limit

With a 99% of certainty, our observations (FOXSI-2) show that if there are HXRs from the quiet Sun, their flux must be less than

0.088 photons s^{-1} cm^{-2} keV^{-1}

Comparing our result with previous results:



Remarks:

- We have demonstrated a powerful method to assess very weak emissions mixed with backgrounds for solar hard X-rays.
- The improvement of this upper limit (and even possibly a detection) could be done with larger observation times for both: signal and background.
- We expect to complement the present analysis, using observations from FOXSI-3. Stay tuned.

Thanks!

Contact info: Milo Buitrago-Casas
milo@ssl.berkeley.edu
@astronomilo

The FOXSI Team:

L. Glesener, S. Christe, S. Krucker, J. Vievering, S.Athiray, S. Musset, D. Ryan, N. Narukage, S. Ishikawa, S. Bongiorno, K. Furukawa, B. Ramsey, L. Davis, S.Courtade, G. Dalton, P. Turin, Z. Turin, T. Takahashi, J. Duncan, W. Baumgartner, I. Mitsuishi, S. Nagasawa, S. Watanabe, Y. Zhang, A. Pantazides.

Support Slides

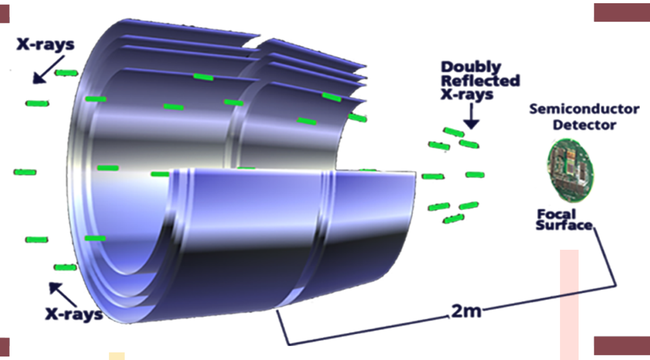
Overview

- Why observe hard X-rays from the quiet Sun?
- The FOXSI rocket payload - a few generalities
- FOXSI-2 quiet sun observations & ghost-ray treatment
- **Results**: Upper limits for the quiet Sun emission in hard X-rays
- Future perspectives

FOXSI The Focusing Optics X-ray Solar Imager

Main Goal: Demonstrate use of **focusing** optics for **solar** observations in **hard X-rays**

7x



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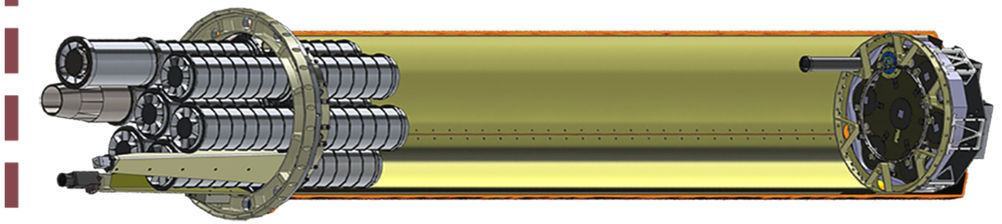
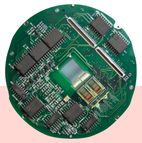


Rocket payload

Optics

- **Wolter-I** shaped
- Electroformed Ni at NASA/MSFC
- Nested sets or 7 or 10
- FWHM ~5 arcsecs
- HPD ~25 arcsecs

Detectors



- **Si** or **CdTe** detectors from ISAS
  - ✳ **Si**: 75μm pitch
  - ✳ **CdTe**: 60μm pitch
- Readout by **low-power**, **low-noise** ASICs

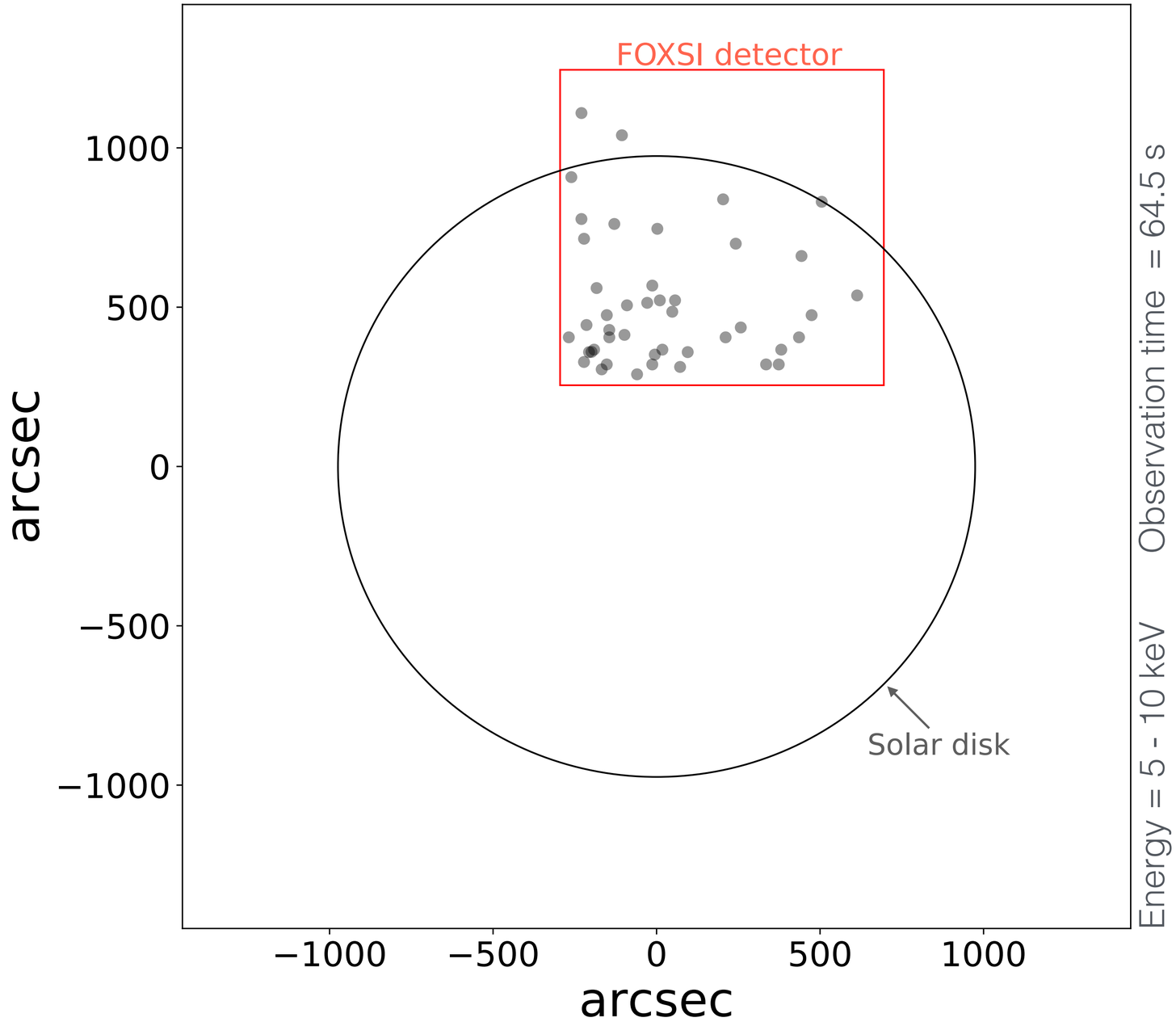
Field of view

~ A quarter of the solar disk

Energy range

~ 5 - 20 keV

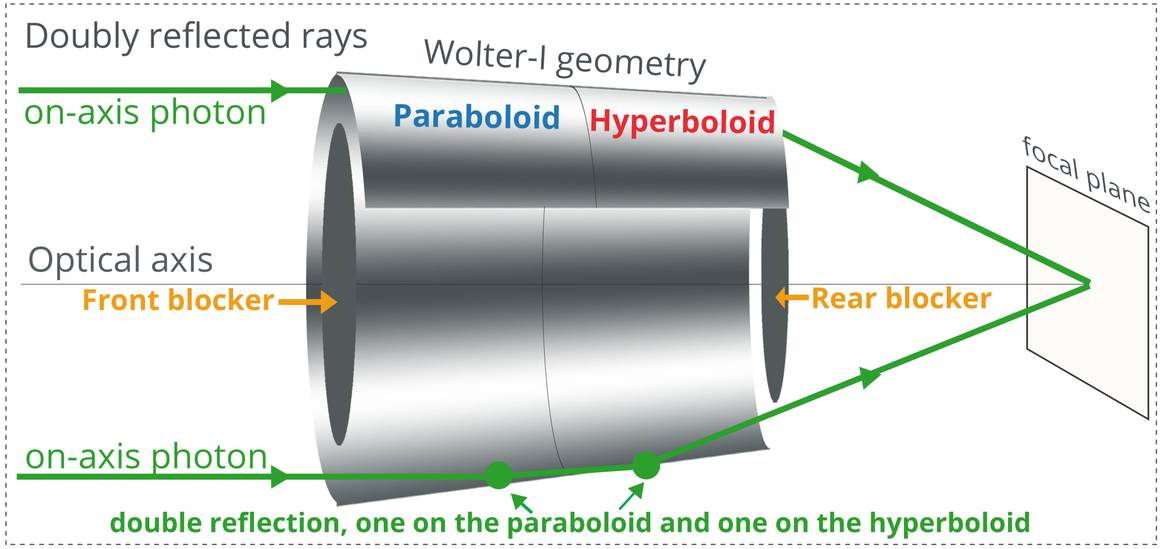
Observation from ONE of the FOXSI pairs optics/detector

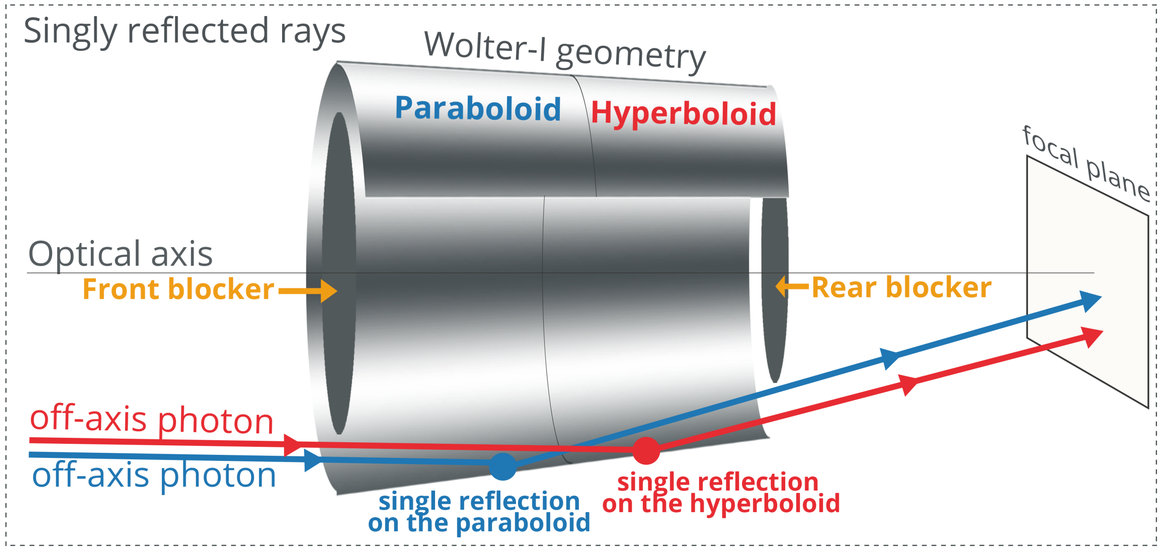


To assess this very faint emission, we need to **throughly understand all backgrounds**

Ghost ray background

generated by rays undergoing a single reflection on the optics and still reaching the detector

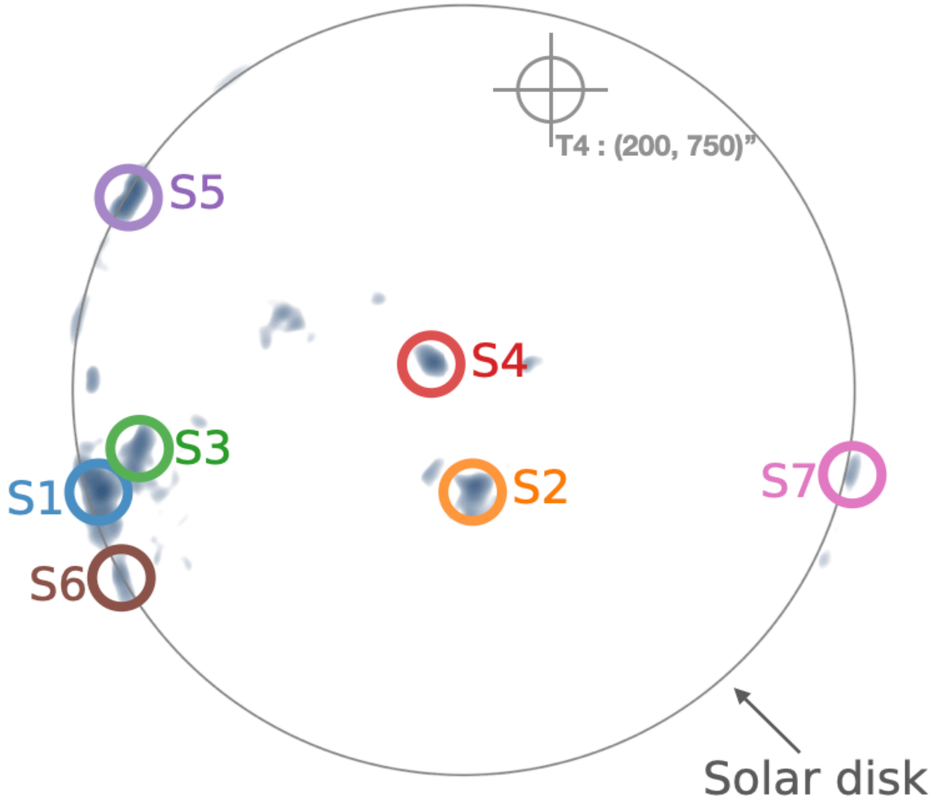




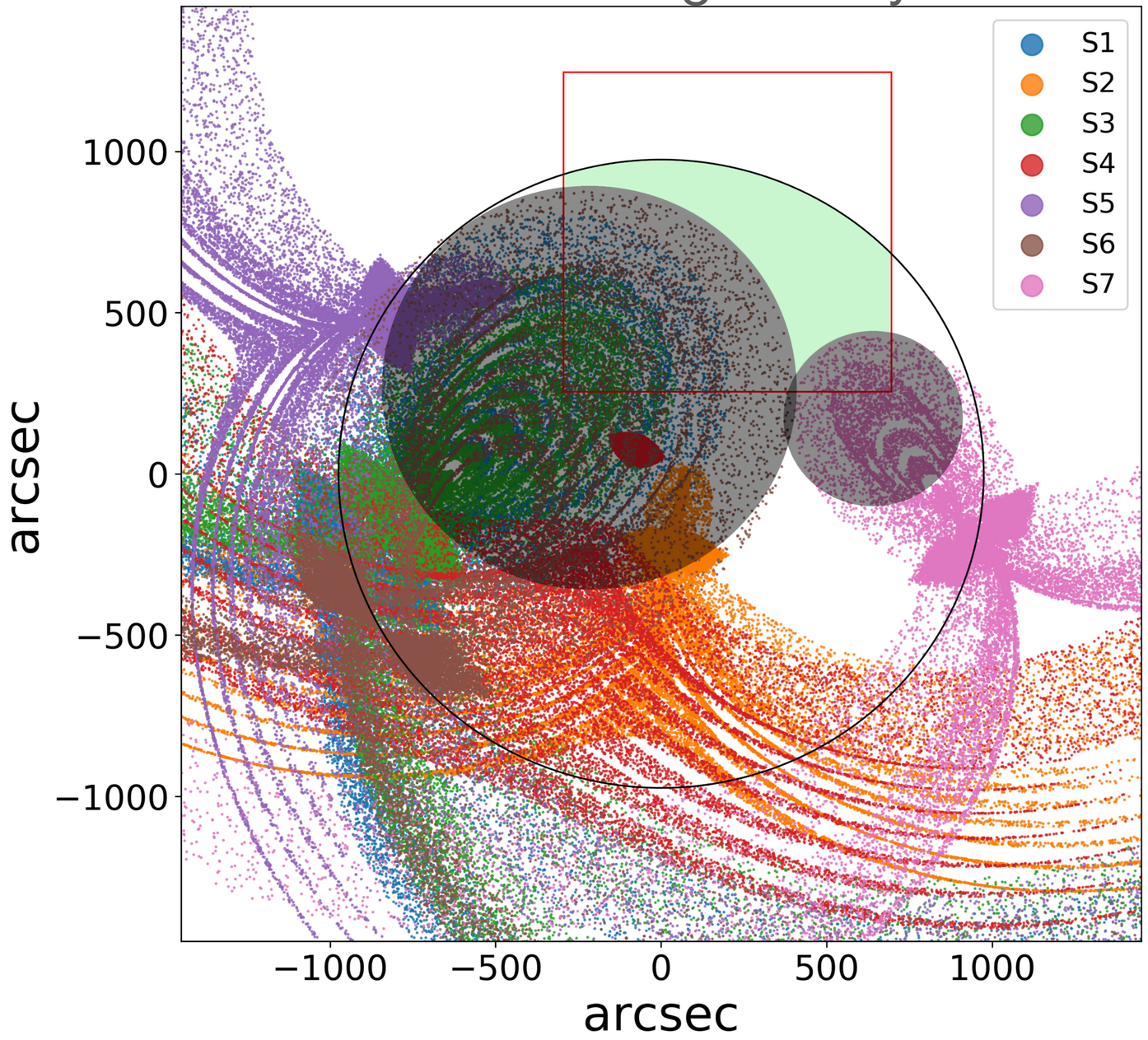
We used a ray-tracing simulation to characterize ghost rays during the observation of quiet Sun in FOXSI-2

Sources of ghost-rays

Fe XVIII map (AIA/SDO):



Simulated ghost rays



We identified a region within the solar disk free of ghost rays