3D evolution of a solar flare thermal X-ray loop-top source

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STIX Meeting, Wrocław, 7 November 2023

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The Sexy Part

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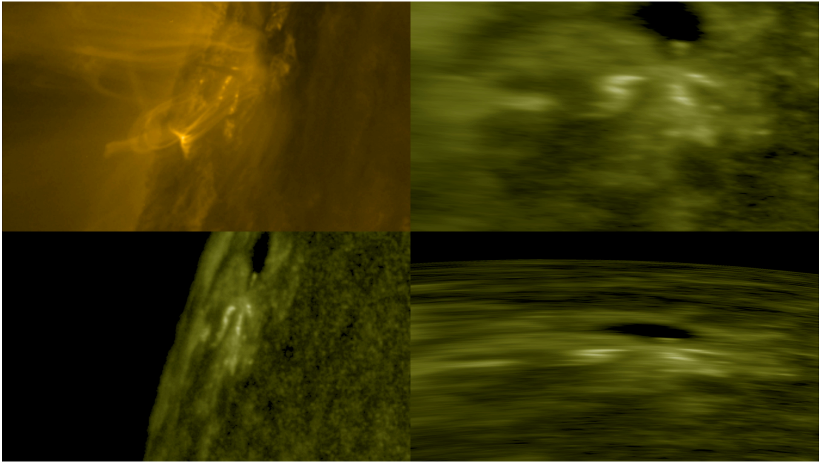

Magician's Mistake: Secrets Revealed

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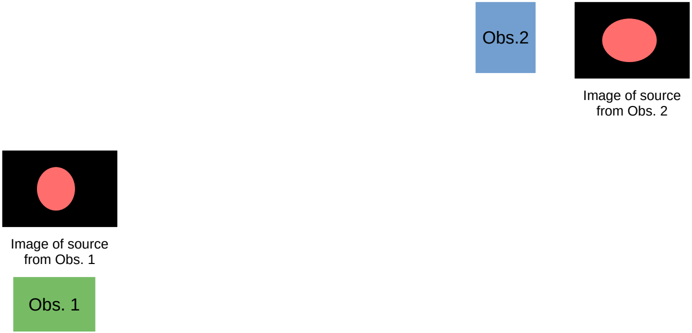

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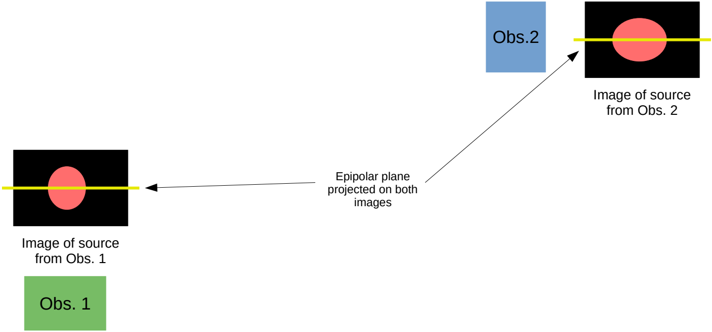

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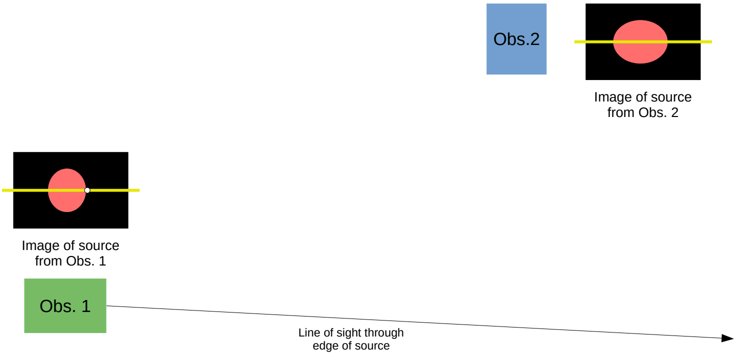

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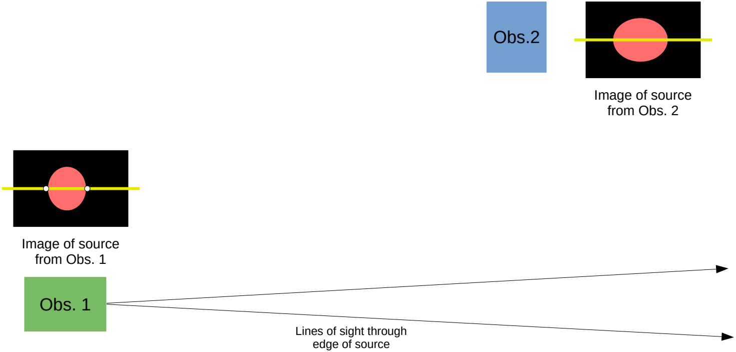

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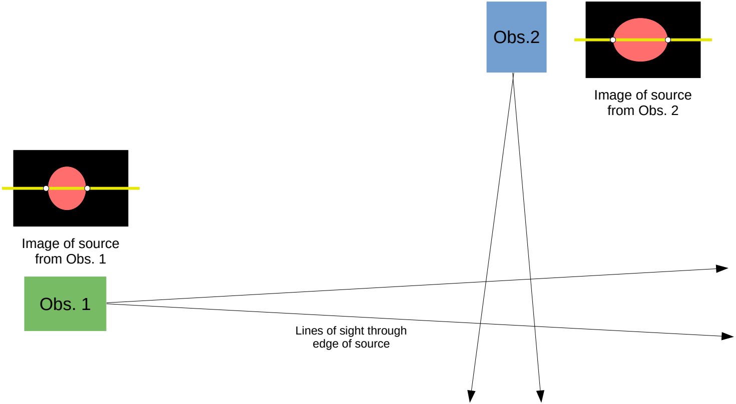

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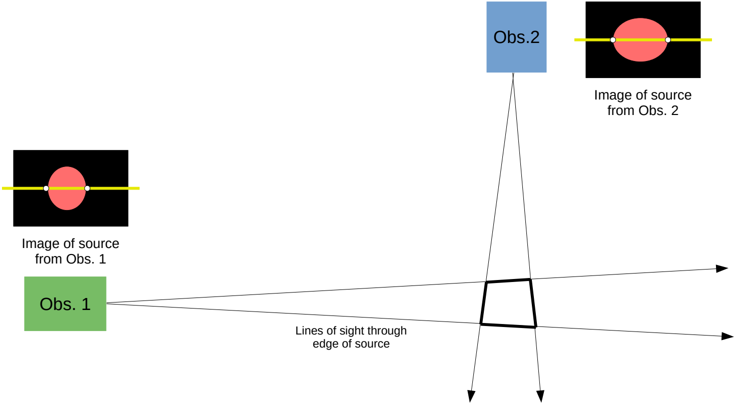

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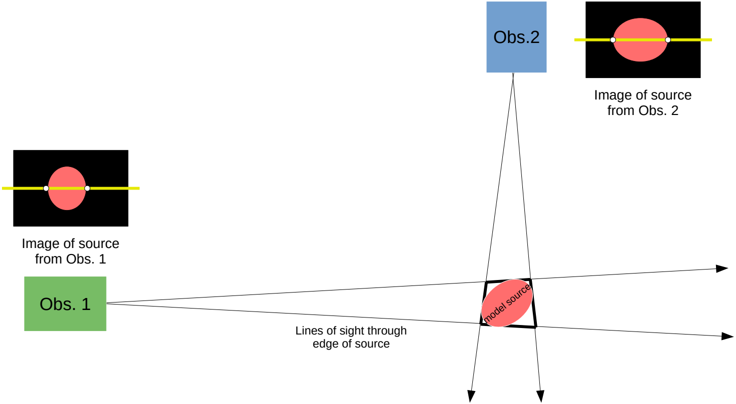

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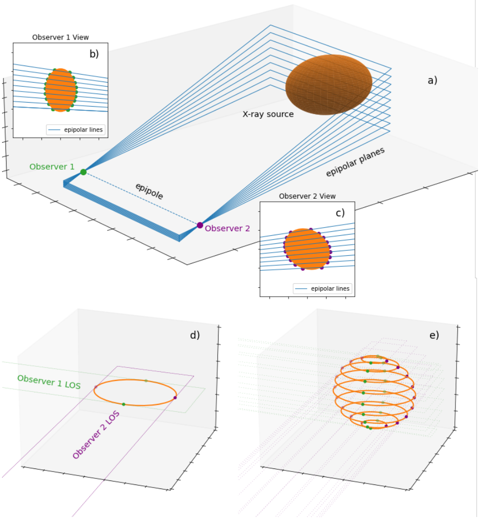

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Why Is This New?

What Do We Need?

Two X-ray telescopes with:

- Substantially different viewing angles;
- Same/similar passbands.

This has not previously been available...

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Two X-ray telescopes with:

- Substantially different viewing angles;
- Same/similar passbands.

This has not previously been available...

...until recently!

- Solar Orbiter/STIX 6 – 10 keV ($\gtrsim$8 MK)
- Hinode/XRT Be-thick filter ($\gtrsim$5 MK)

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Comparing STIX & XRT for X-ray 3-D Reconstruction

Solar Orbiter/STIX

Hinode/XRT

	Solar Orbiter/STIX	Hinode/XRT
Viewing Angle	Variable	Earth
Passbands	Spectral Imager (>4 keV)	Imaging filters
Temp. Sensitivity	$\gtrsim$8 MK	$\gtrsim$5 MK (Be-thick filter)
Angular Resolution	7"	2"
Spatial Resolution	1400 km (0.3 AU)	1420 km (1 AU)
Max. Cadence	0.5 s (intensity-dependent)	2 s

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Key Questions

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1. What is the 3-D evolution of a flare's thermal X-ray loop-top source?

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1. What is the 3-D evolution of a flare's thermal X-ray loop-top source?
2. How does the source's height and volume impact and its thermodynamic evolution?
3. How well do traditional area-to-volume scaling laws ($V \sim A^{3/2}$) approximate the 3-D volume?

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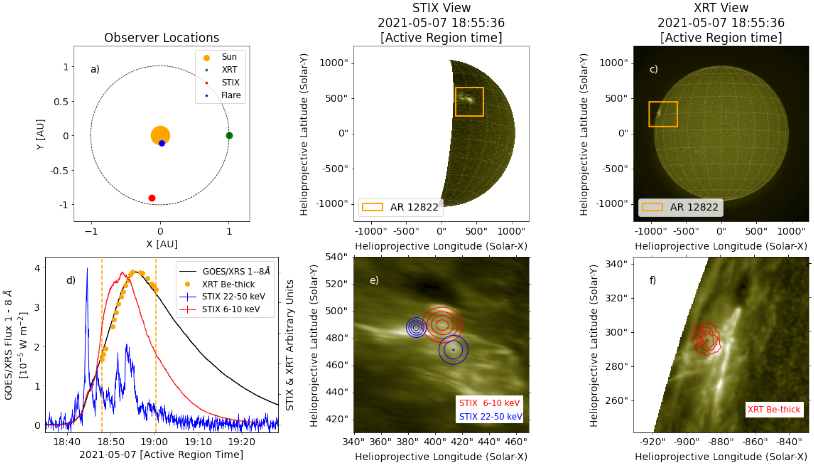
Result 1: 3-D Evolution of a Thermal Loop-top Source



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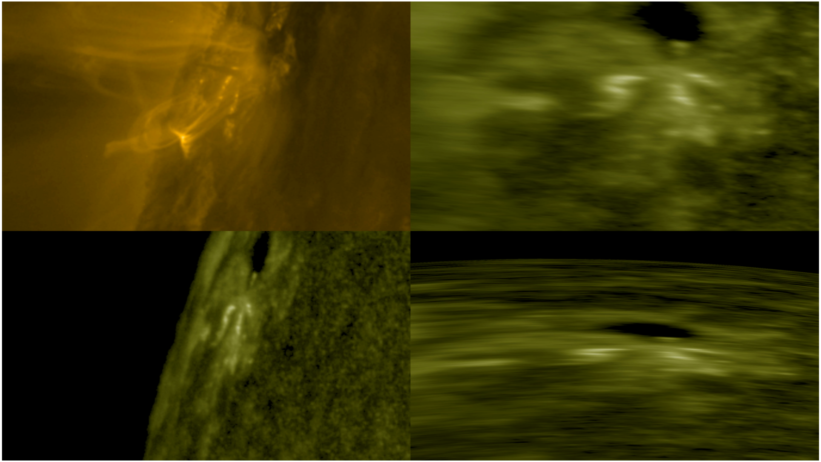

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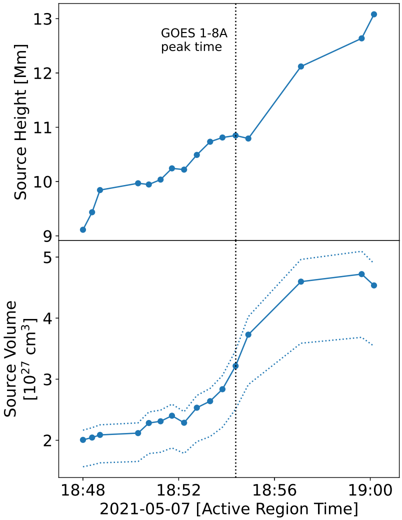

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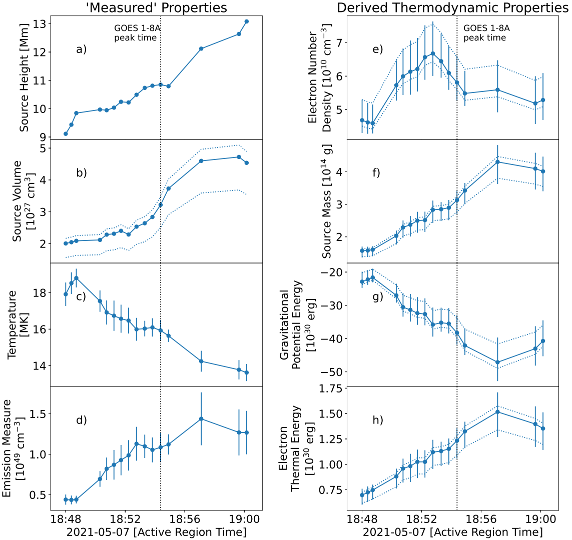
Result 2: X-ray Source Thermodynamic Evolution



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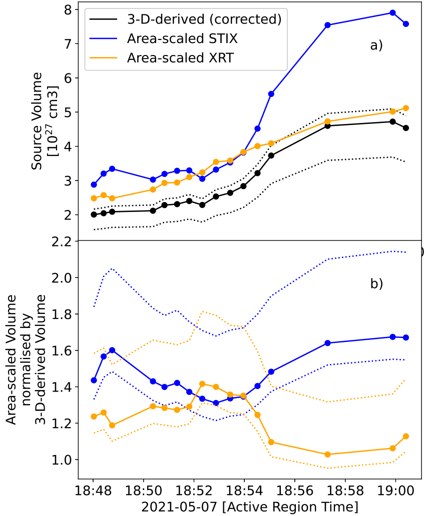
Result 3: How Do Area-to-volume Scaling Laws Perform?

Area-to-Volume Scaling Law

$$V = A^{3/2}$$

V: 3-D source volume

A: projected source area in image



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Conclusions

For more, see Ryan et al. (2023, submitted)

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1. **STIX & XRT** enable 3-D reconstruction of flare thermal X-ray sources for the first time.

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Conclusions

1. **STIX & XRT** enable 3-D reconstruction of flare thermal X-ray sources for the first time.
2. Area-to-volume scaling can overestimate the volume by up to a factor of 2, and **3-D analysis is required to capture asymmetric geometry evolution**.
3. **3-D analysis provides a way to quantify volume uncertainties**.
4. 3-D analysis helps us **better understand the geometry, thermodynamics, energy transport, etc.** in solar flares, especially in multi-wavelength/model comparison studies.

For more, see Ryan et al. (2023, submitted)

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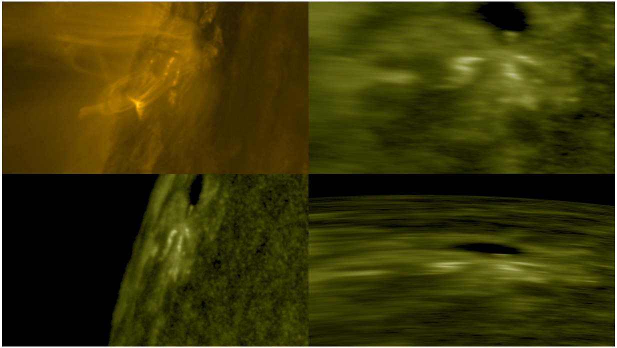
Conclusions

Thank you for your attention!



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BACKUP SLIDES

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IMPROVING VOLUME ESTIMATES AND DERIVING VOLUME UNCERTAINTIES

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Simply integrating the between the reconstructed cross-sections overestimates the true volume due to inherent assumptions.

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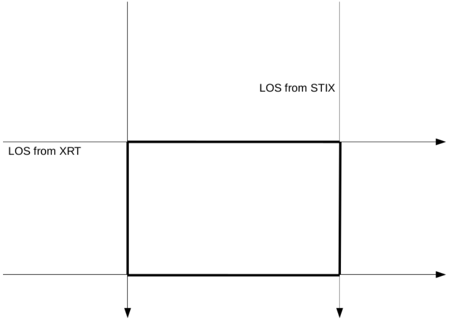

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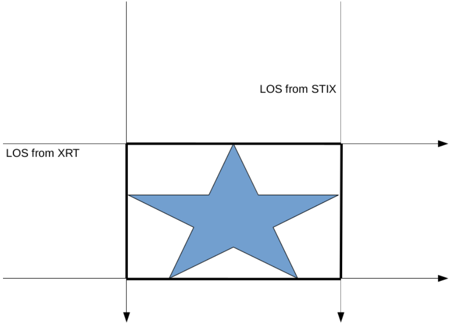

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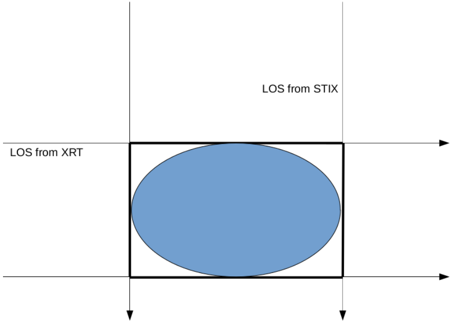

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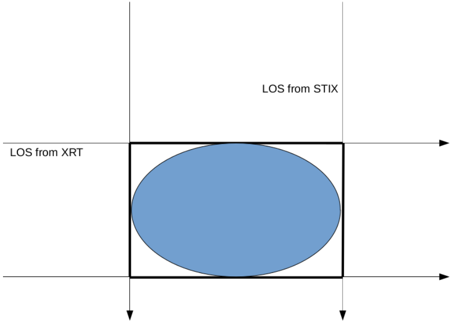
Assumptions

1. The source cross-section is an ellipse.
2. The ellipse occupies the maximum possible area within the bounding box.



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Resulting Caveats

- Derived geometry is an approximation.
- Cross-sectional area are upper limits.

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However, we can improve the volume estimates.

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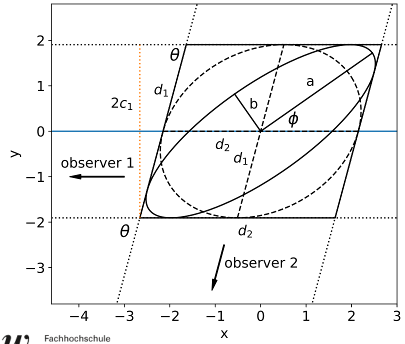
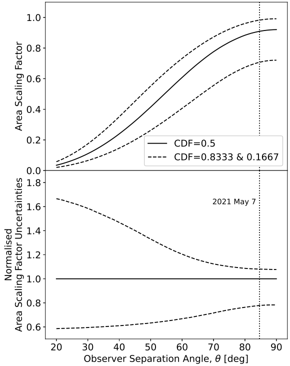
How Can We Improve Our 3-D Volume Estimates?

$$A_0 = \kappa A'; \qquad \kappa = \frac{\sin^2\theta}{\sqrt{(\sin^2\phi + \rho^2\cos^2\phi)\left[\frac{1}{\rho^2}\left(\frac{\sin\phi}{\tan\theta} - \cos\phi\right)^2 + \left(\frac{\cos\phi}{\tan\theta} + \sin\phi\right)^2\right]}}$$

A_0: True cross-sectional area; A': Derived cross-sectional area; $\rho = b/a$





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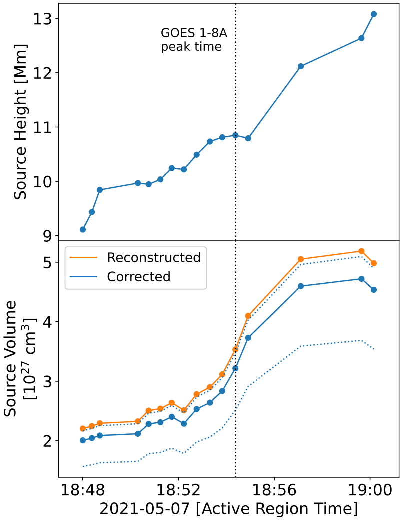
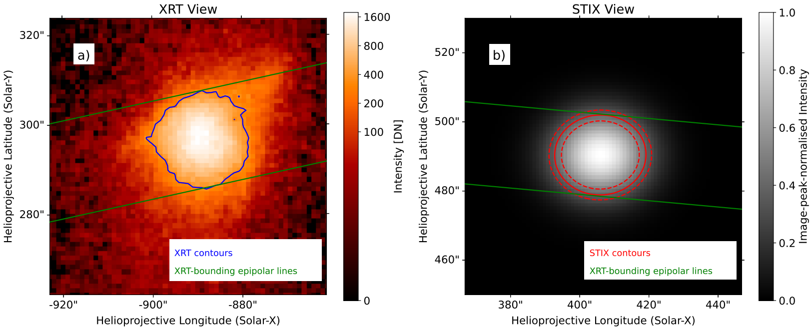


DEFINING SOURCE BOUNDARIES

How To Define Consistent Source Boundaries in STIX & XRT Images



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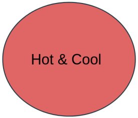
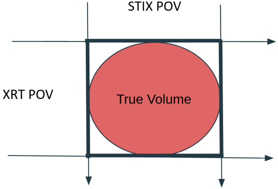
DO STIX & XRT SEE THE SAME VOLUME?

Do STIX & XRT See the Same Volume?

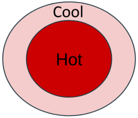
Spatially homogeneous temperature distribution



Volume derived with instruments with different temperature sensitivities



Spatially structured temperature distribution



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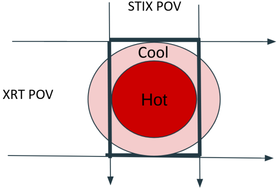

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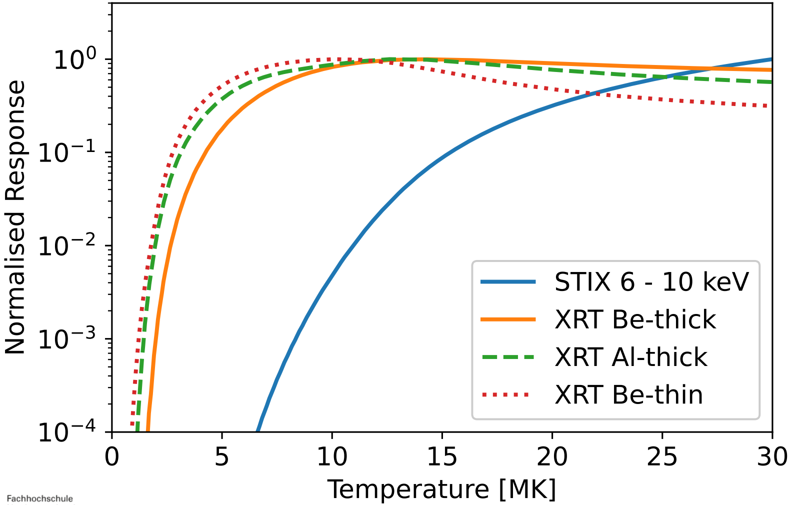

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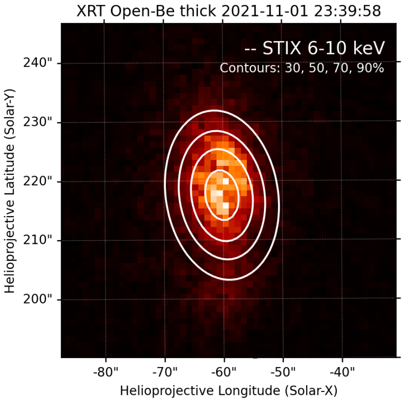
STIX & XRT Sources Areas From Same Viewing Angle?



In at least some cases, XRT & STIX see the same flare volume.

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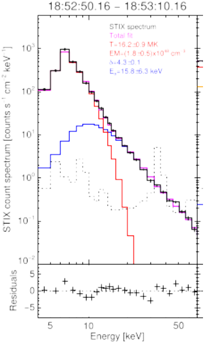
Can STIX T & EM Predict the XRT Intensity?

$$I_{flare} = R(T)\frac{EM_v}{A_{pix}}$$

I_{flare} = Flare-summed XRT intensity
R = XRT temperature response
A_{pix} = area of XRT pixel at source
T = flare temperature
EM_v = flare volume emission measure



I_{xrt}^{pred} = **4500 DN/s** I_{xrt}^{obs} = **3700 DN/s**

Agreement within ∼20%

The plasma seen by STIX is consistent with the XRT observations.

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