

# The STIX image reconstruction problem: early results

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Joint work with Battaglia A.F., Perracchione E., Volpara A., Collier H., Hurford G. J., Garbarino S., Massone A.M., Benvenuto F., Piana M., Krucker S. and the STIX team



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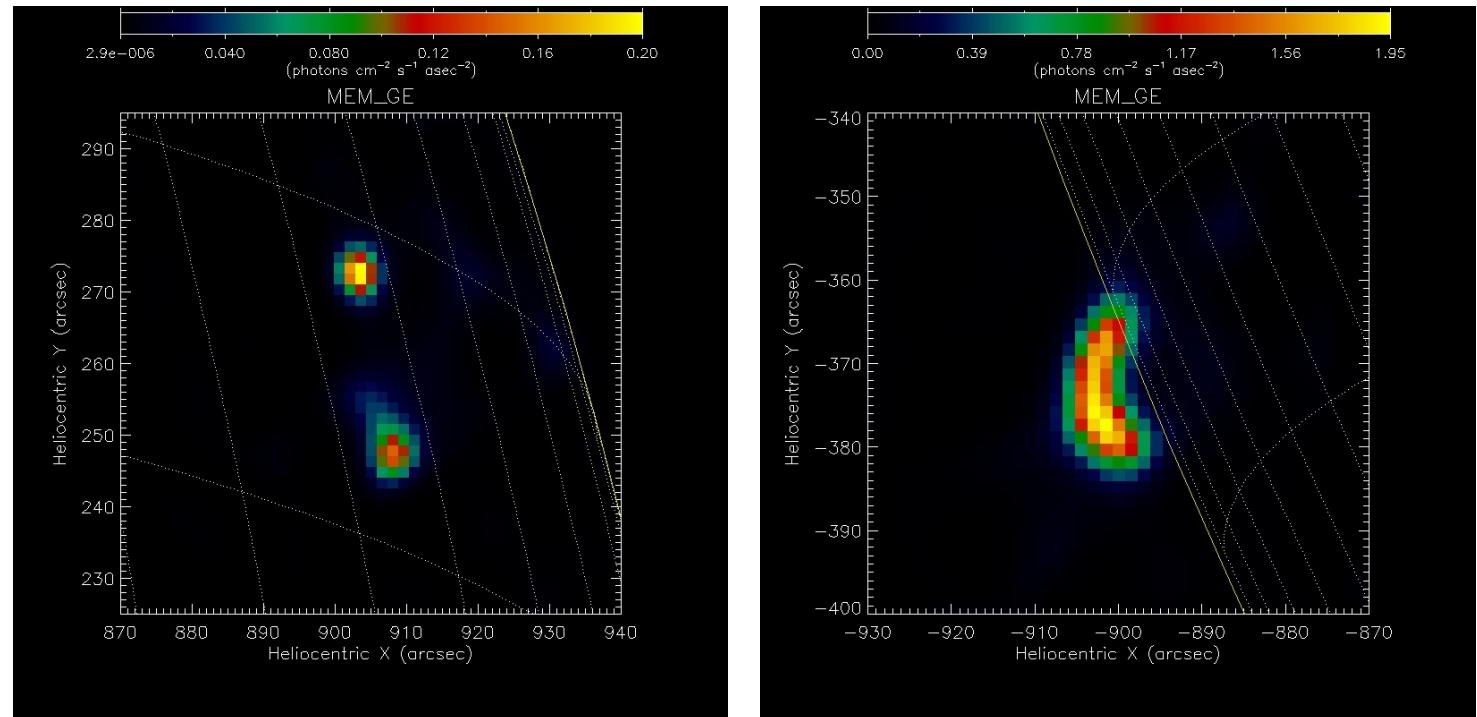
# The STIX instrument

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- **Scientific goal:** provide information on electrons accelerated during a solar flare and diagnostics of the hottest flare plasma
- **How:** by measuring X-ray photons emitted by bremsstrahlung

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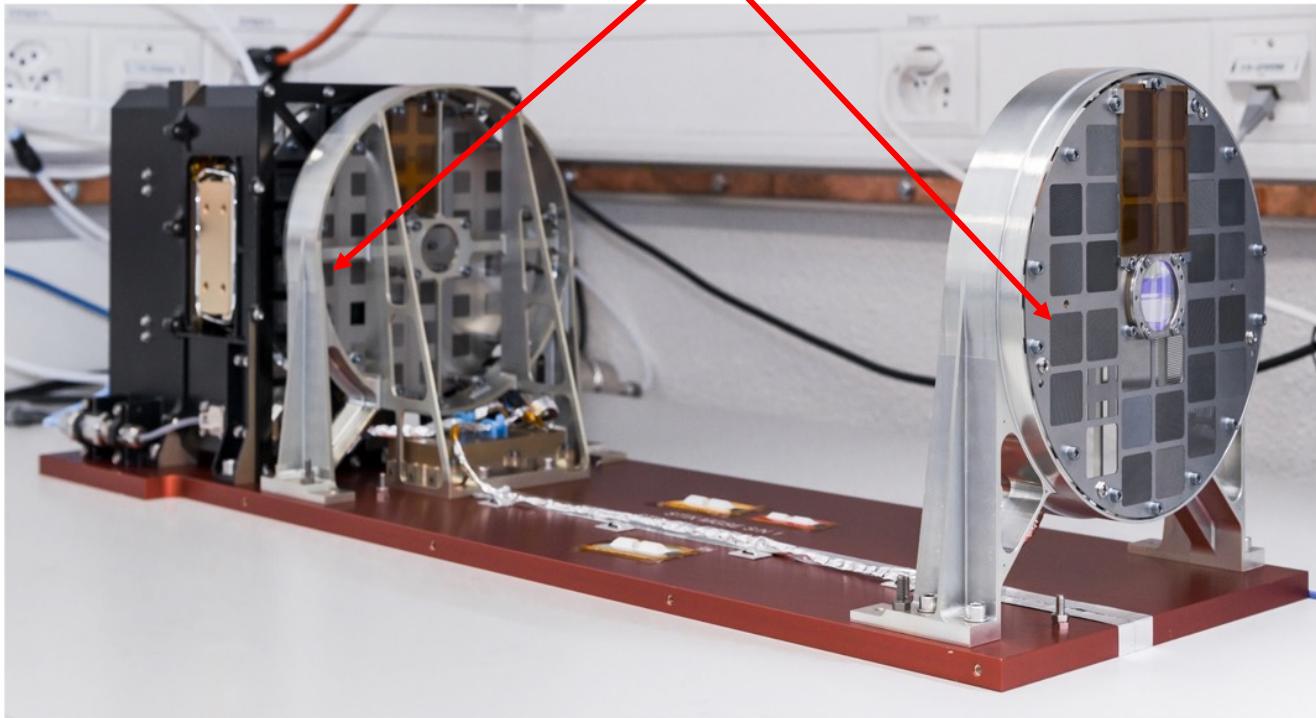
Images of solar flare X-ray emissions (from RHESSI data)



**STIX imaging objective:** reconstruct the image of the flaring X-ray emission form indirect measurements

# The STIX instrument

Sub-collimator = front grid + rear grid + detector



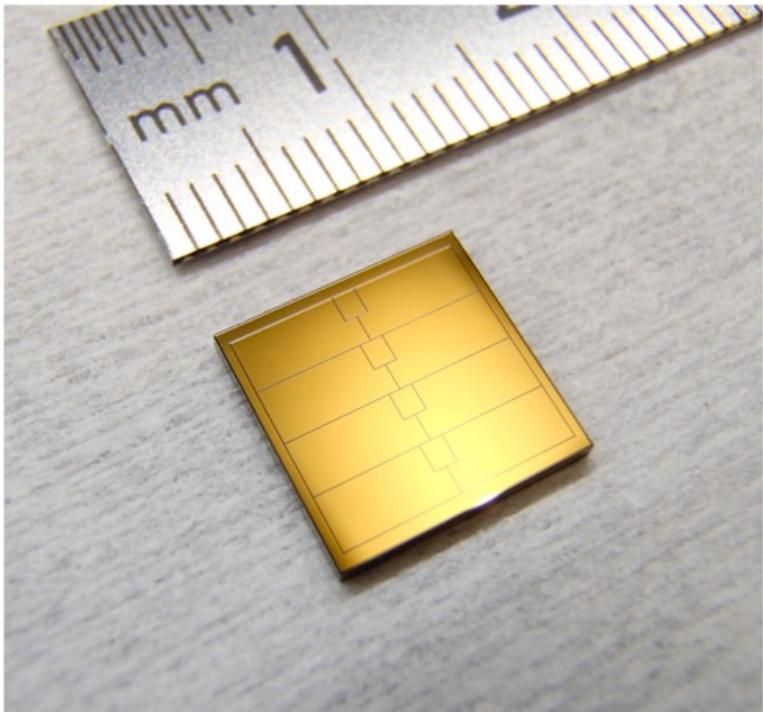
(Krucker et al., 2020)

- Bi-grid imaging system
- STIX consists of 32 subcollimators:
  - 30 are used for imaging
  - Coarse Flare Locator
  - Background monitor

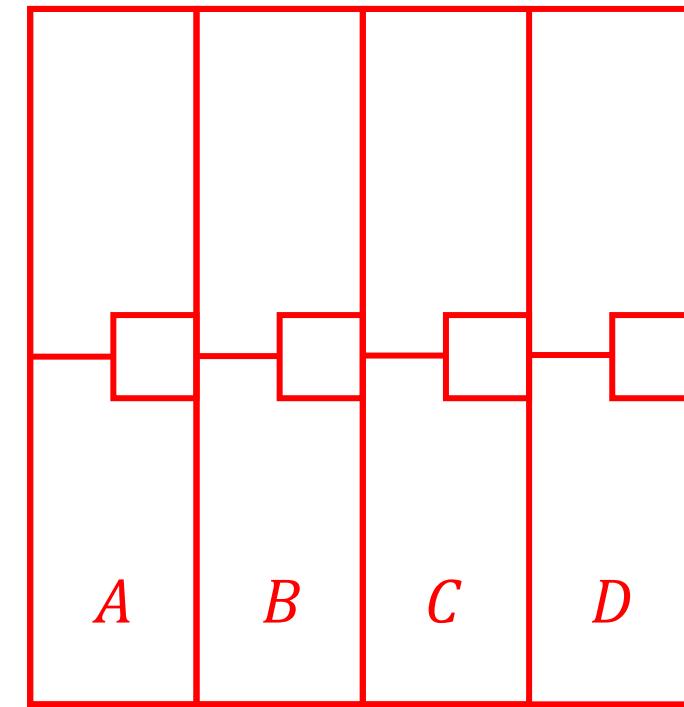
# The STIX instrument

## STIX Cadmium-Telluride detector

(Meuris et al. 2015)

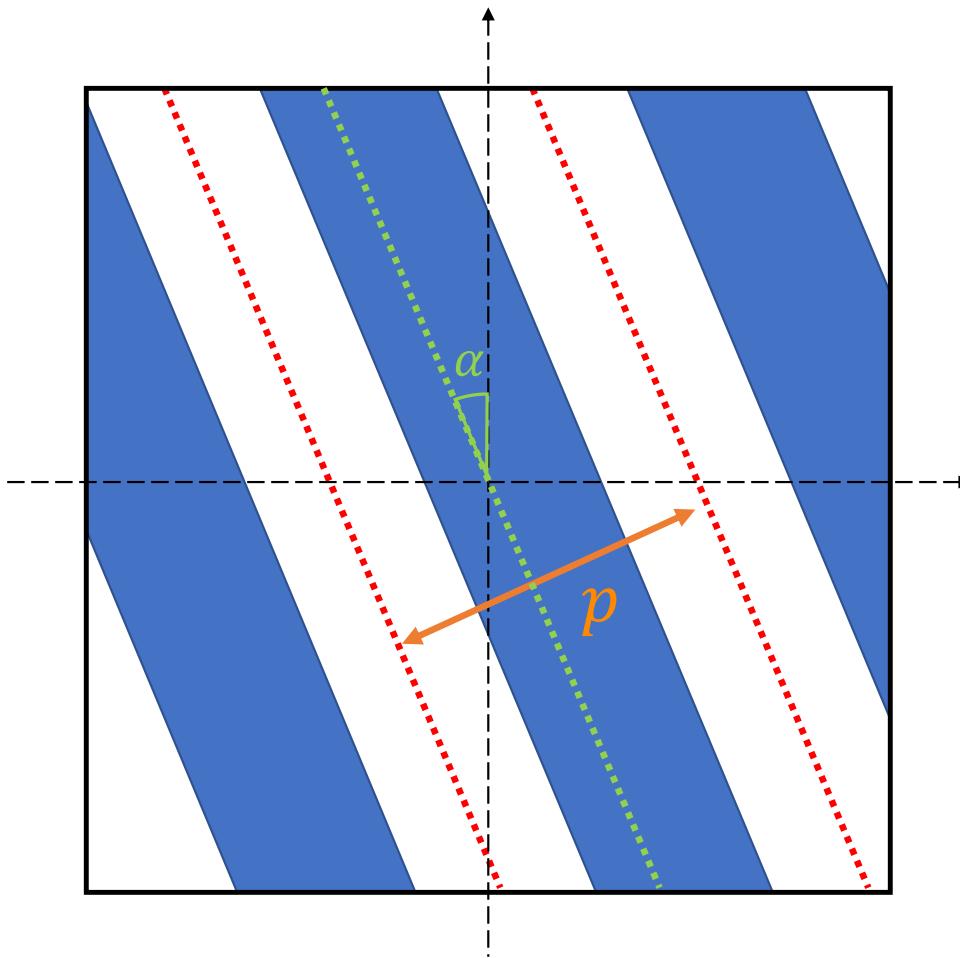


Krucker et al., 2020



A, B, C and D: number of counts  
recorded by the detector pixels

# The STIX instrument

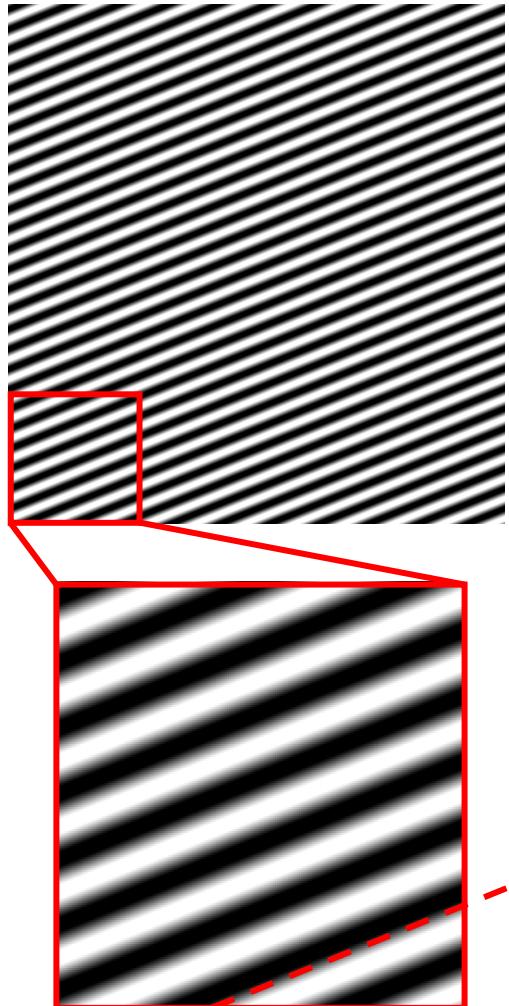


## Grid parameters:

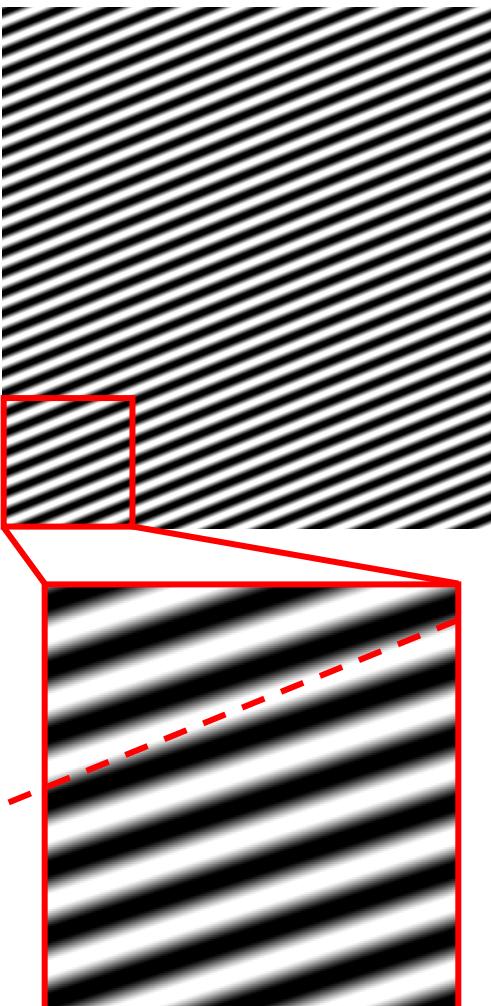
- $\alpha$ : orientation angle
- $p$ : pitch = distance  
between two consecutive  
slit centers

# The STIX imaging concept

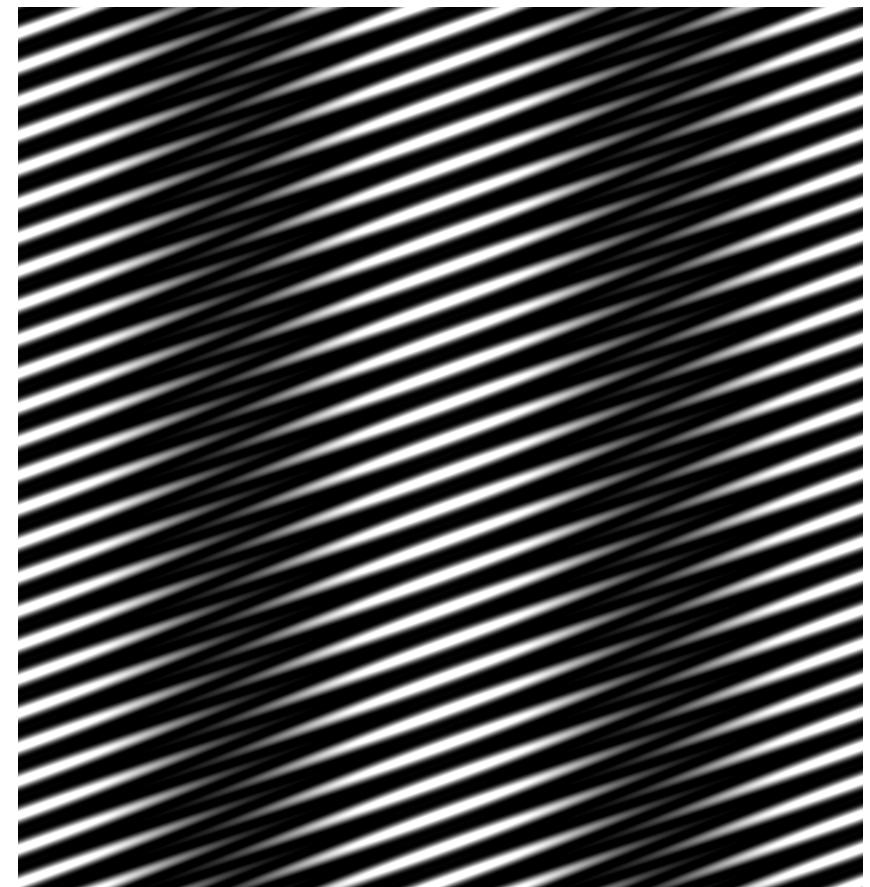
Front grid



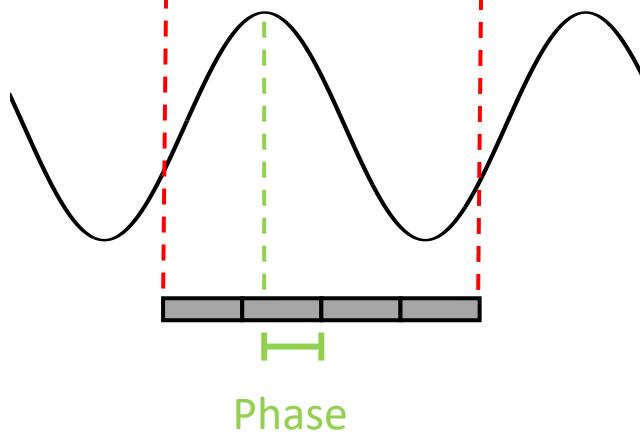
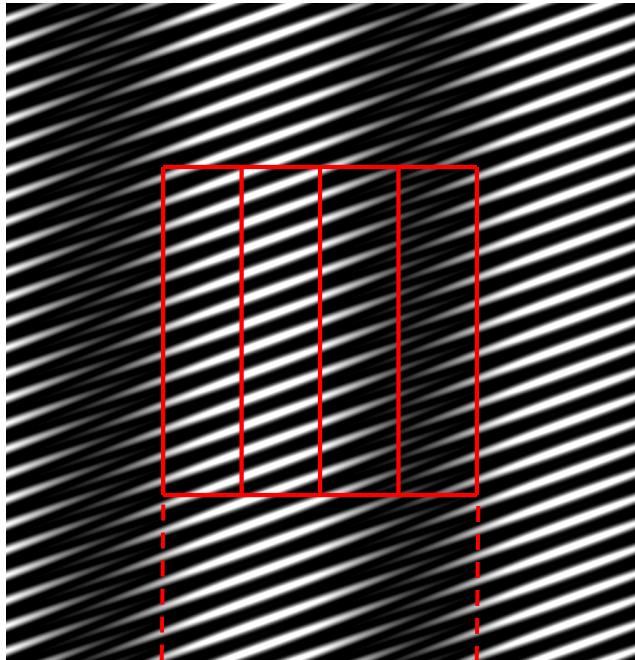
Rear grid



Moiré pattern



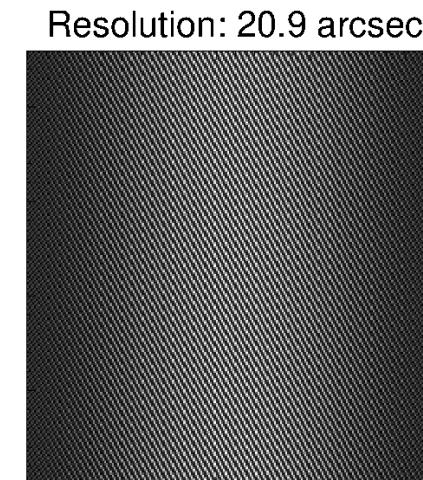
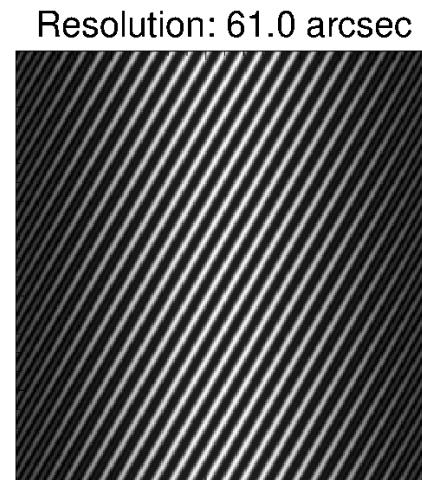
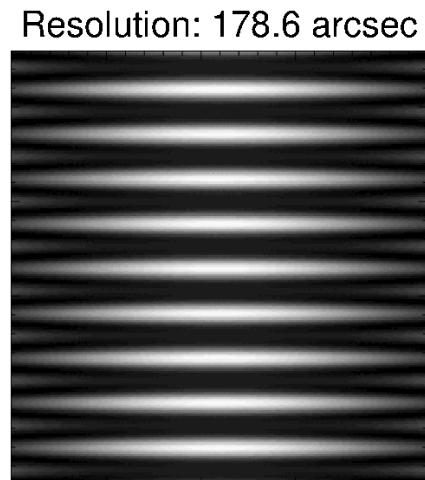
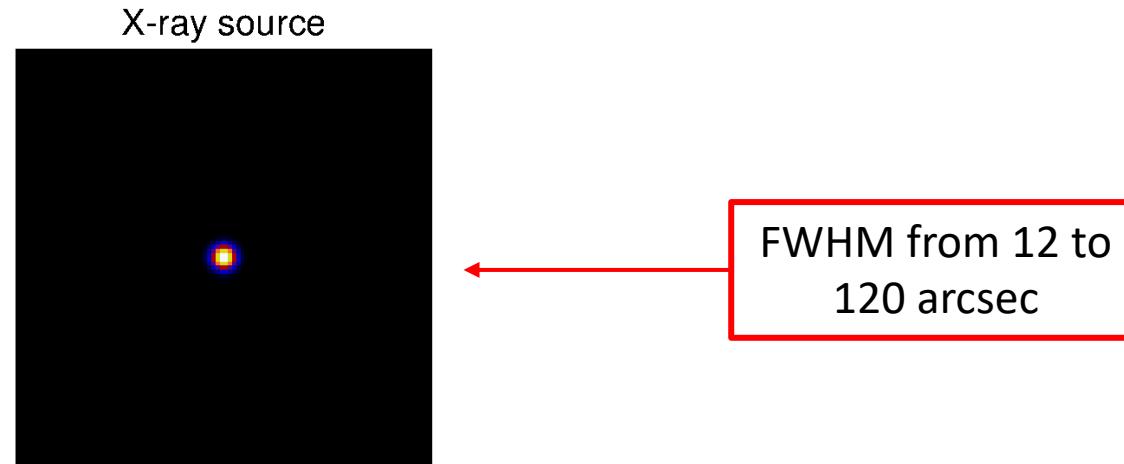
# The STIX imaging concept



- Moiré pattern: sinusoidal wave with period equal to the detector width
- Amplitude and phase of the pattern → amplitude and phase of a Fourier component of the photon flux (**visibility**)

# The STIX imaging concept

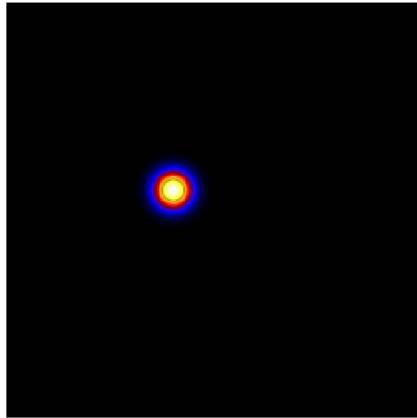
The amplitude of a Moiré pattern is sensitive to the source size and shape



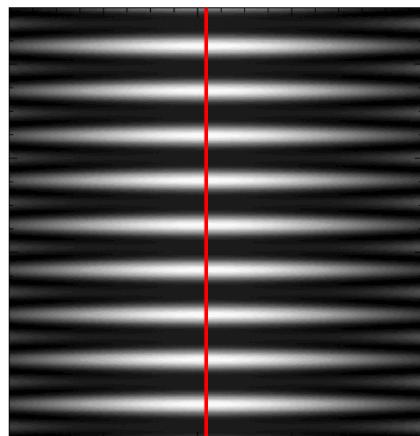
# The STIX imaging concept

The phase of a Moiré pattern is sensitive to the source location

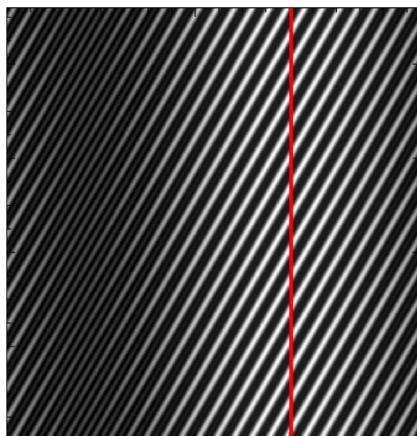
X-ray source



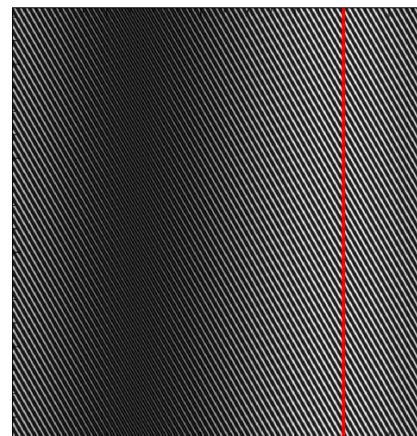
Resolution: 178.6 arcsec



Resolution: 61.0 arcsec

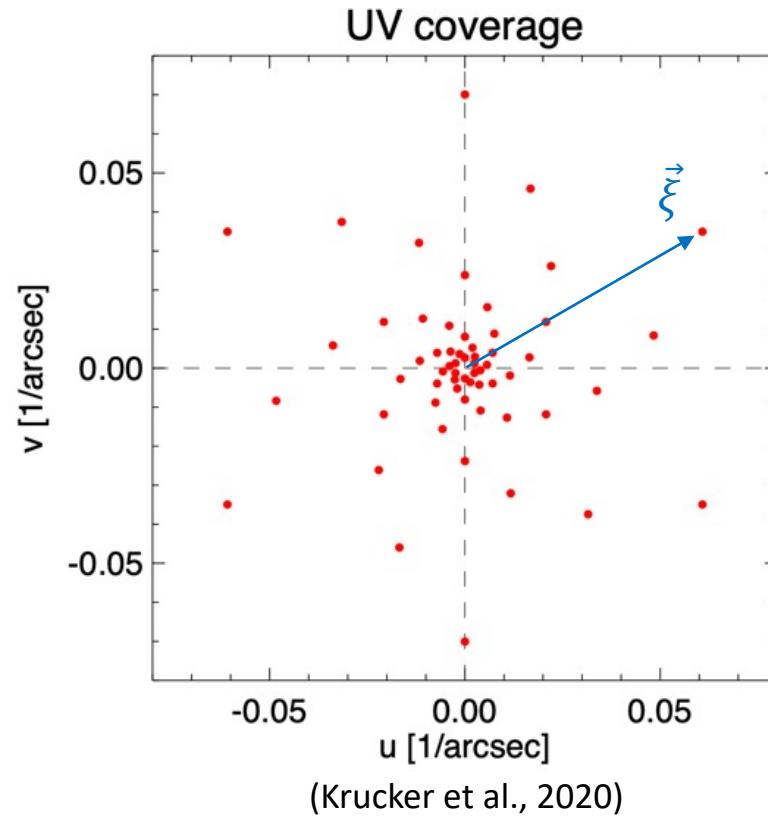


Resolution: 20.9 arcsec



# The STIX imaging concept

Each sub-collimator measures a visibility value



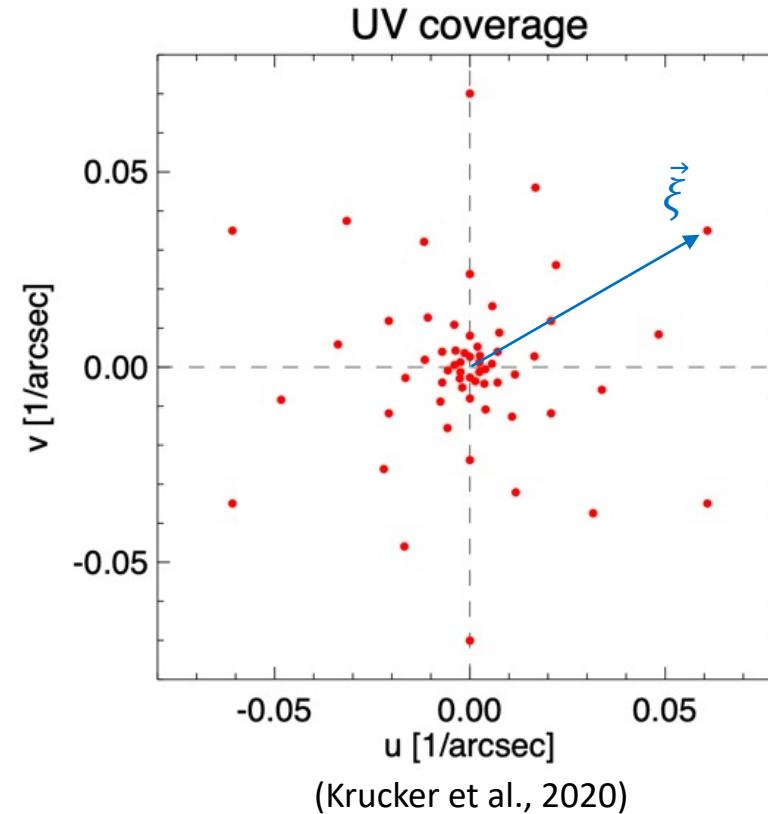
# The STIX imaging concept

Each sub-collimator measures a visibility value

The sampling frequency  $\xi \rightarrow$  is determined by the grid pitch and orientation

Amplitude and phase of the visibility are determined by the measured counts:

- $|V| \propto \sqrt{(C - A)^2 + (D - B)^2}$
- $\phi = \text{atan} \left( \frac{D-B}{C-A} \right) + 45^\circ + \phi_{calib}$



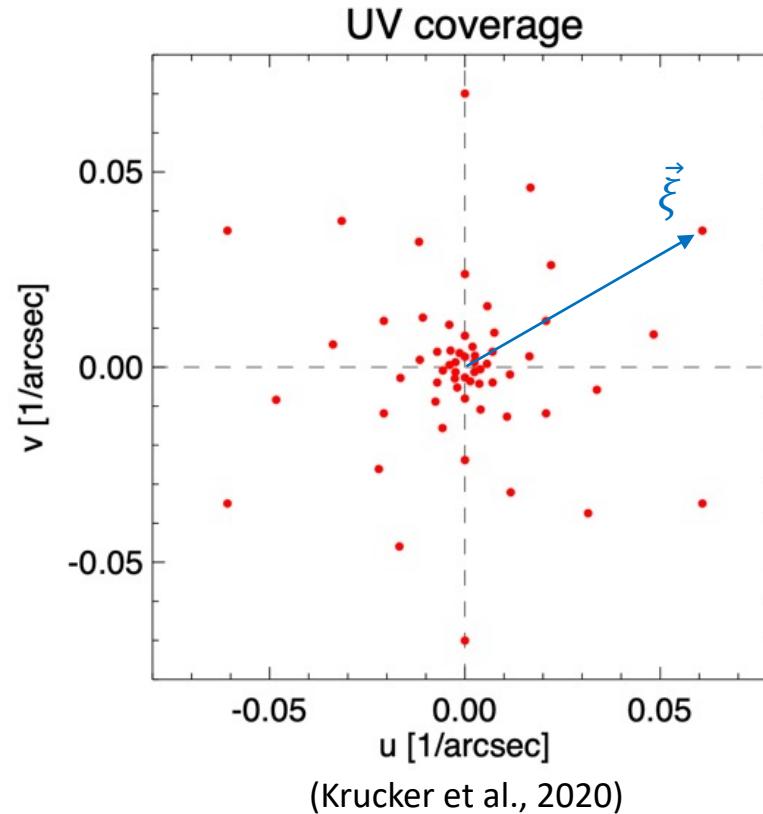
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**The data measured by STIX are 30 visibilities**

# Image reconstruction problem

Image reconstruction problem for STIX:

$$F\phi = V$$

Where:

- $\phi$  is the image to reconstruct
- $F$  is the Fourier transform
- $V$  is the complex array of visibilities

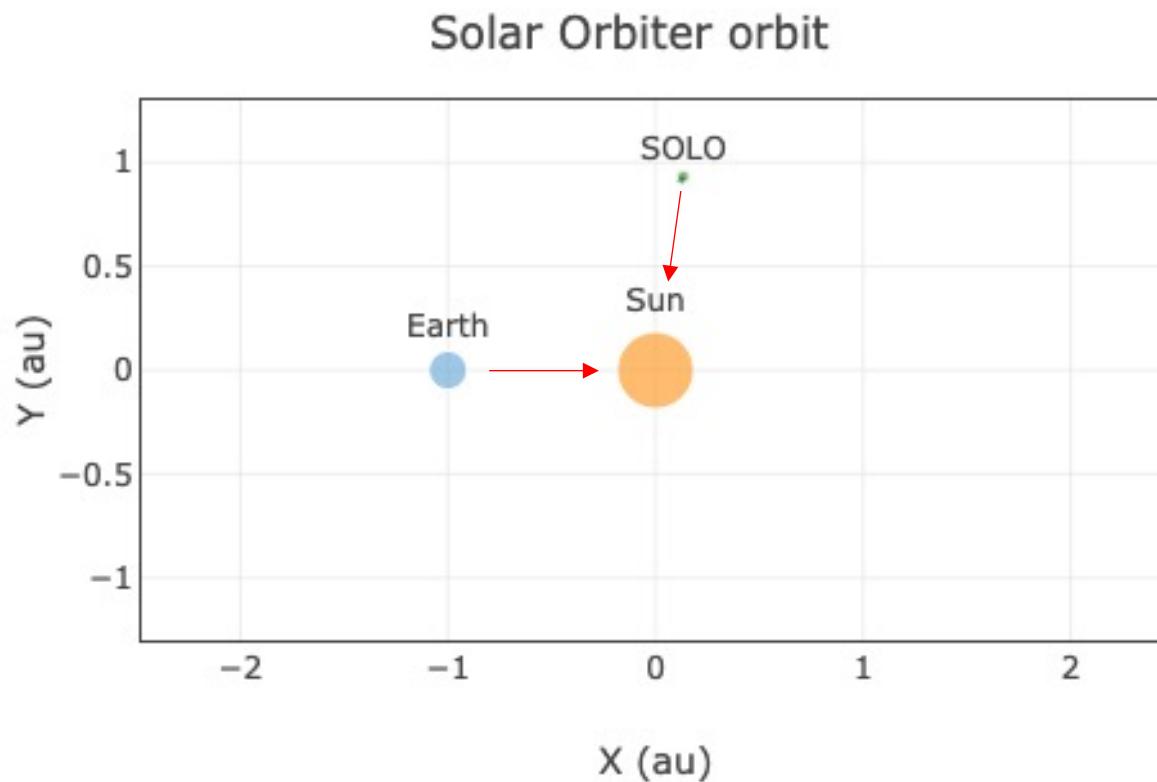
# Image reconstruction methods

Legacy of the Reuven Ramaty High Energy Solar Spectroscopic Imager (**RHESSI**, Lin et al., 2002):

- Back Projection (Mertz et al., 1986)
- Clean (Högbom, 1974)
- Maximum Entropy Method: MEM\_GE (Massa et al., 2020)
- Expectation Maximization (Massa et al., 2019)
- Forward fit (Hurford et al., 2002)

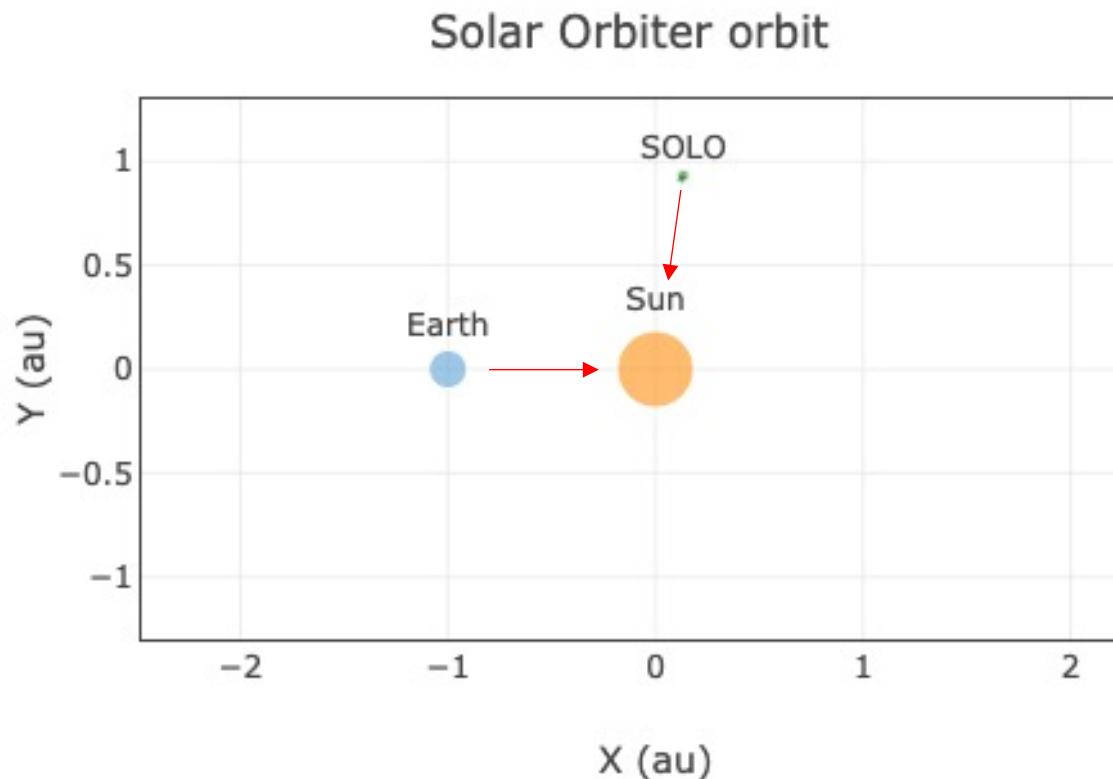
# May 2021 events (Massa et al., in preparation)

Angle relative to Earth-Sun (in May 2021):  $97.4^\circ - 98.2^\circ$



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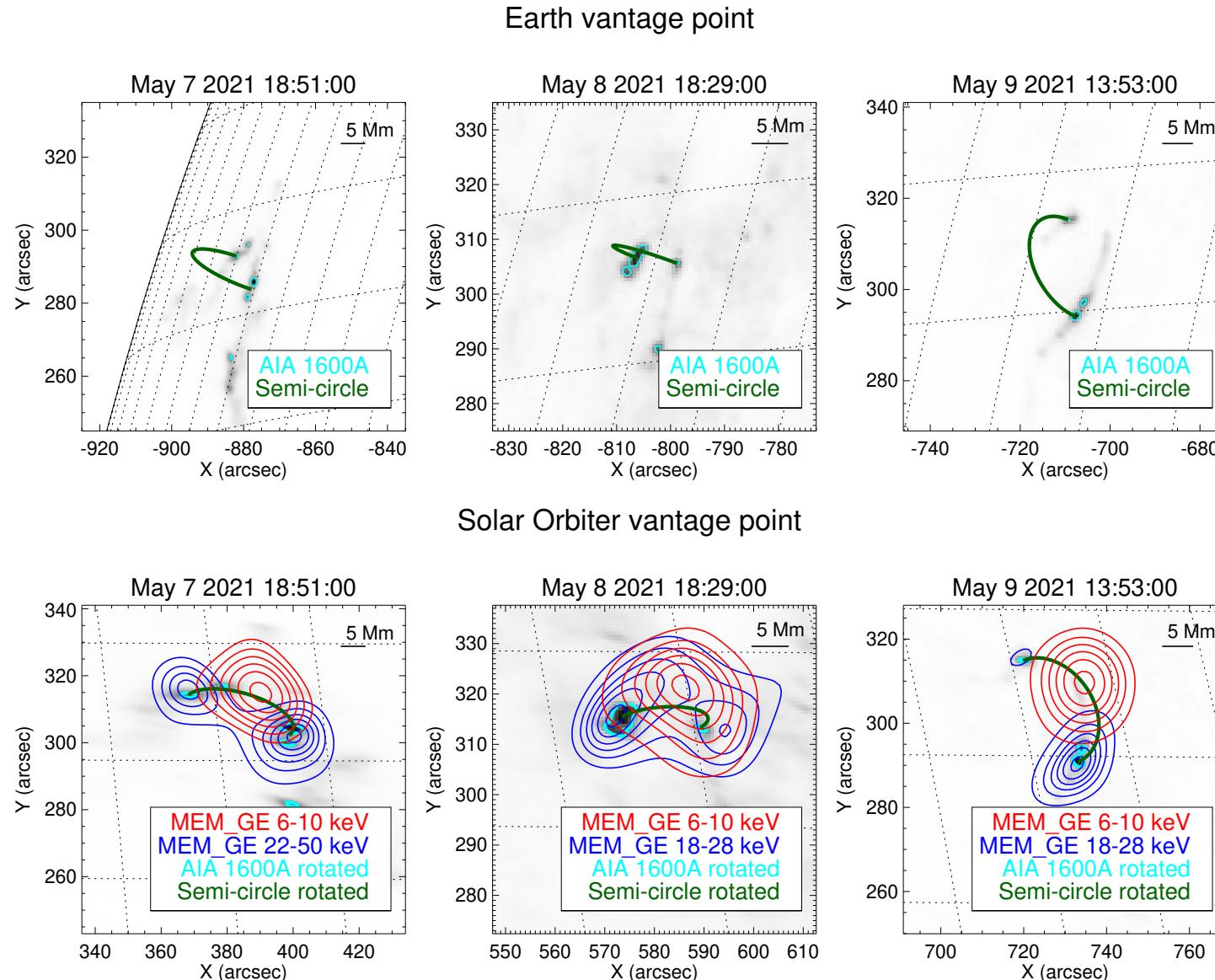
Angle relative to Earth-Sun (in May 2021):  $97.4^\circ - 98.2^\circ$



AIA images rotated by means of the  
*reproject* Python package  
(see Battaglia et al., 2021)

<https://reproject.readthedocs.io/en/stable/>

# May 2021 events (Massa et al., in preparation)



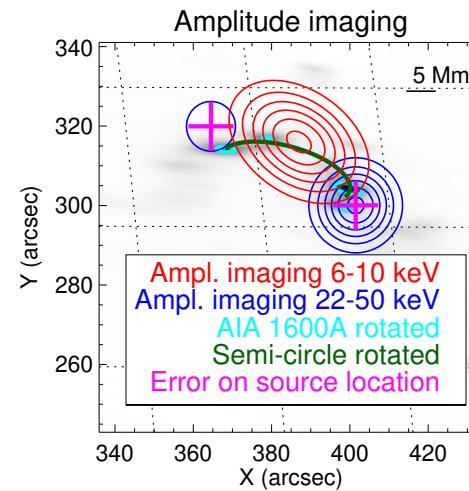
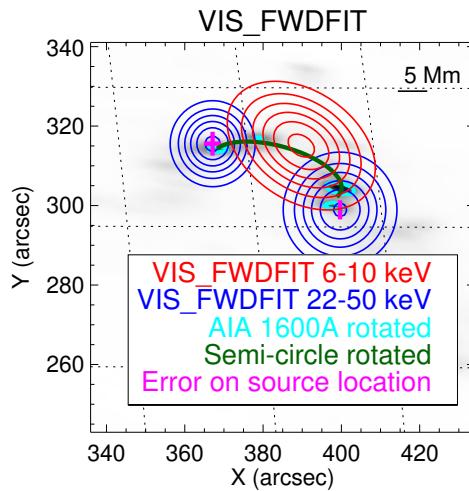
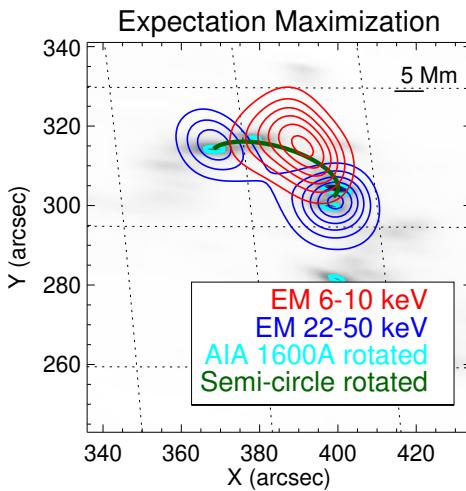
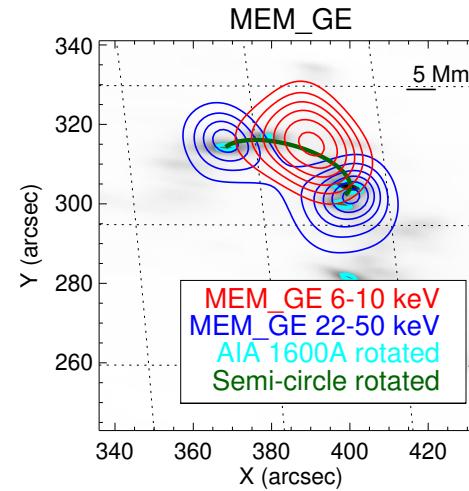
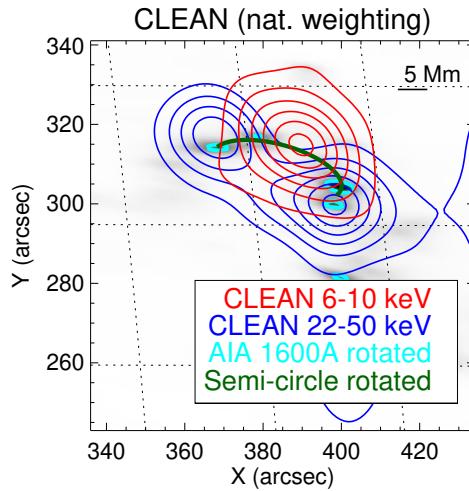
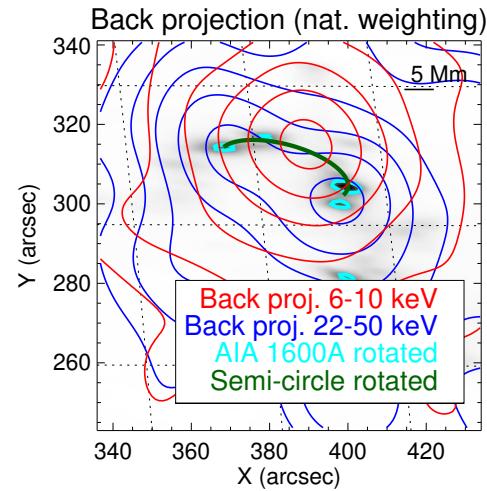
## Active region AR2822

- May 7: GOES M3.9
- May 8: GOES C8.6
- May 9: GOES C4.0

## Manual shift STIX reconstructions

Event	$\Delta x$ (arcsec)	$\Delta y$ (arcsec)
May 7	44	54
May 8	45	57
May 9	47.5	53

# May 2021 events (Massa et al., in preparation)



Thermal component

Method	$\chi^2$
Clean	3.95
MEM_GE	1.73
EM	5.08
VIS_FWDFIT	8.39

Non-thermal component

Method	$\chi^2$
Clean	2.33
MEM_GE	1.54
EM	2.08
VIS_FWDFIT	2.84

# Conclusions

- The calibration of the STIX visibilities is almost completed and the results are reliable
- A set of imaging method is already available

## Future work:

- Calibration of the 6 detectors with highest angular resolution
- Improvement of the state-of-the-art visibility calibration
- Automatic image placement
- Implementation of new methods

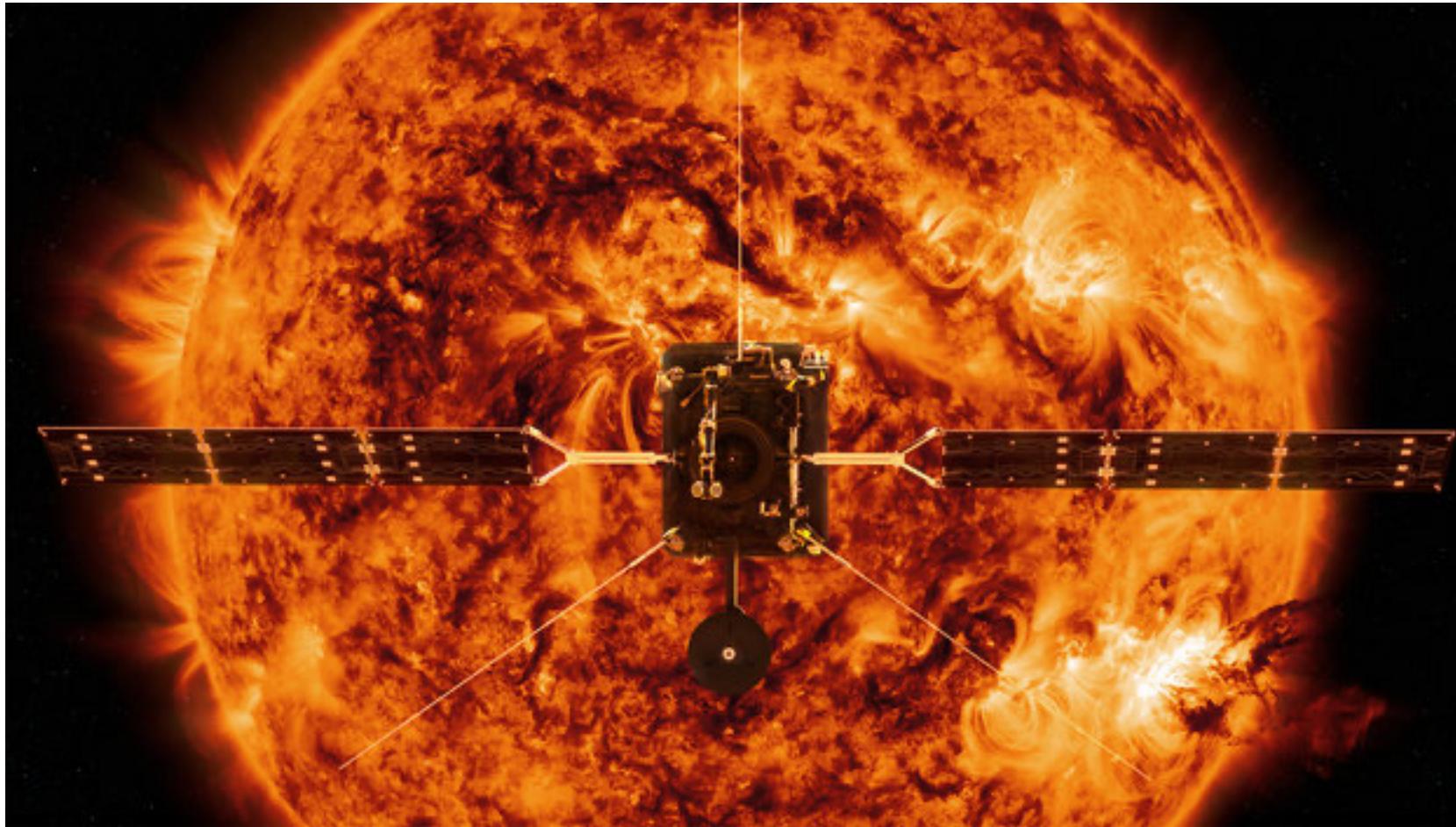
# Acknowledgements

- STIX team
- ASI and INAF for the financial contribution to STIX and to the AI-FLARES project

# References

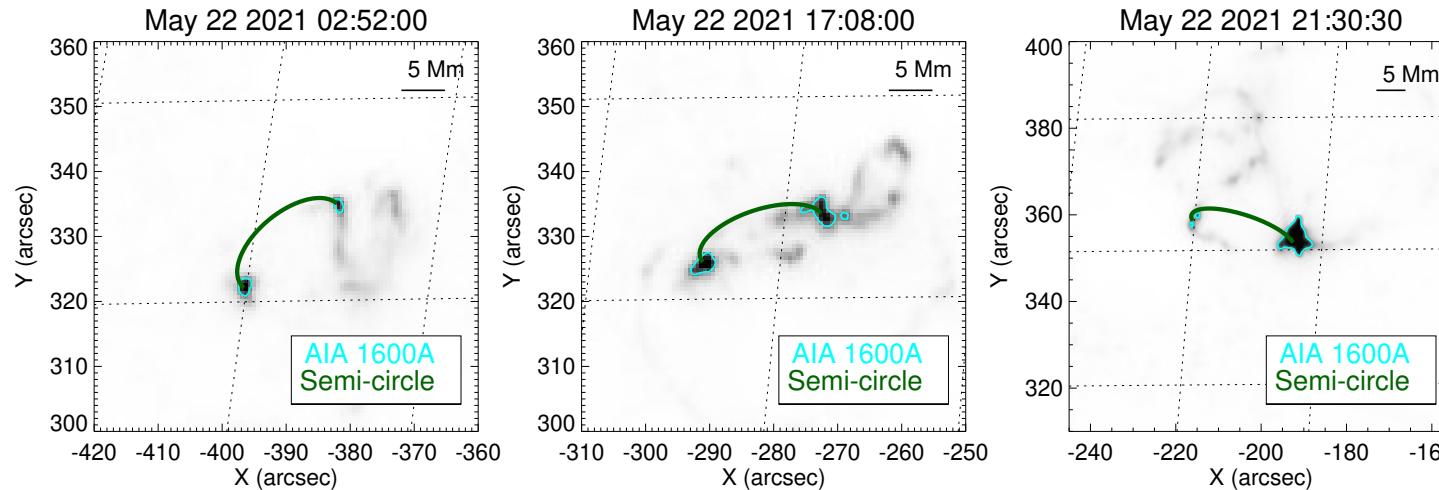
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Thank you for the attention!

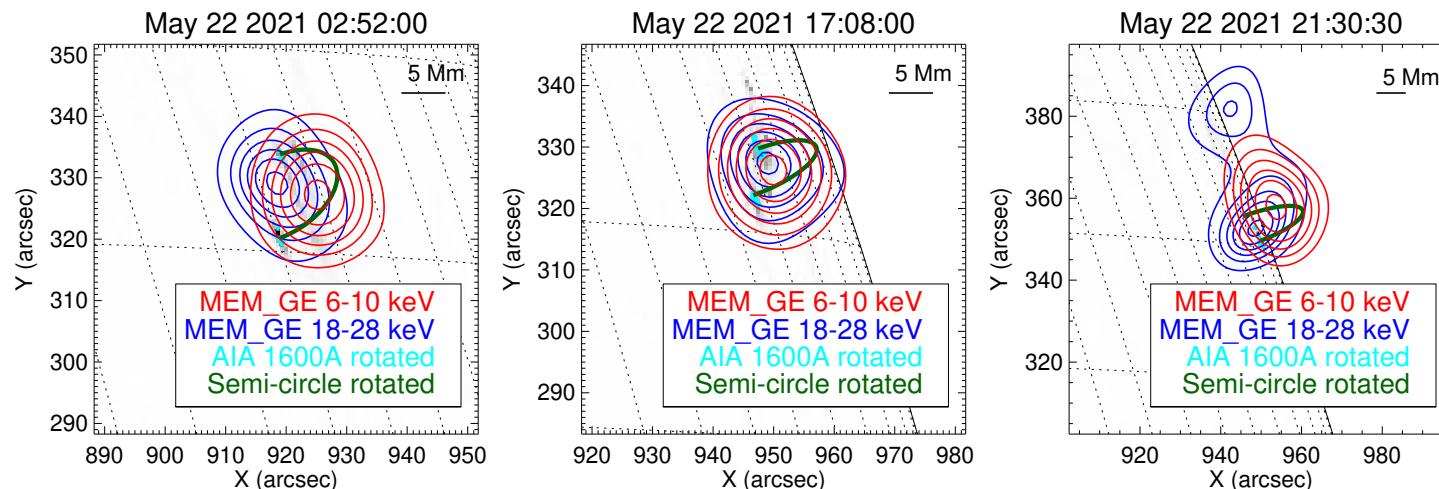


# May 2021 events (Massa et al., 2022, in preparation)

Earth vantage point



Solar Orbiter vantage point



## Active region AR2824

May 22:

- 02:52:00 UT: GOES C6.1
- 17:08:00 UT: GOES M1.1
- 21:30:30 UT: GOES M1.4

## Manual shift STIX reconstructions

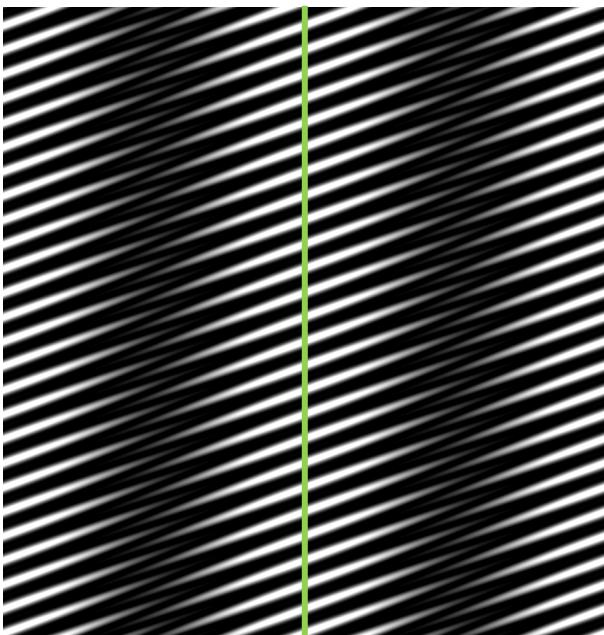
Event	$\Delta x$ (arcsec)	$\Delta y$ (arcsec)
02:52	47	55
17:08	47	50
21:30	50	50

# Visibility calibration

## Amplitude calibration:

- background subtraction
- grid transmission (including the flare location)
- ELUT
- livetime

**Phase calibration:** keeps into account the grid geometry

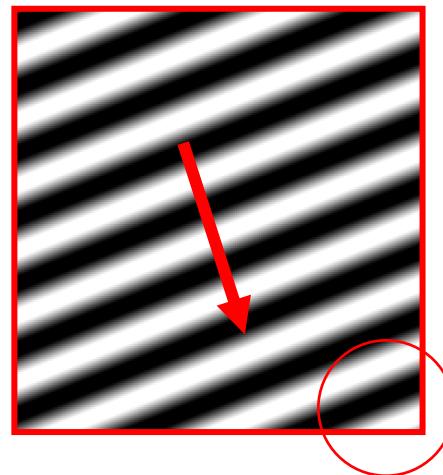
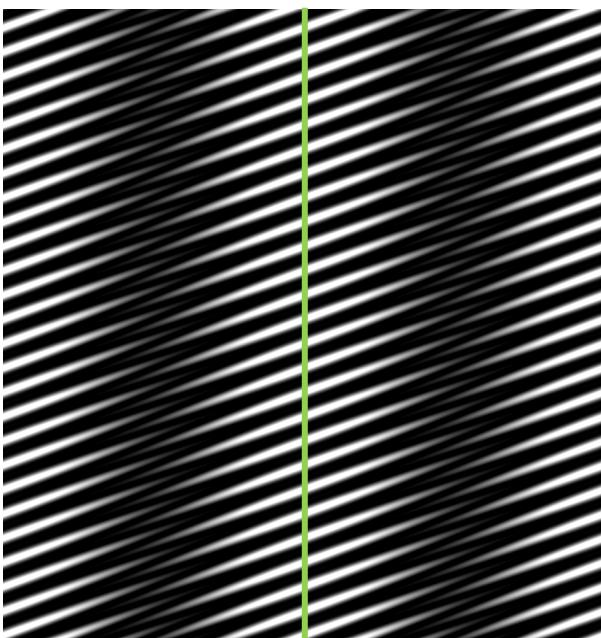


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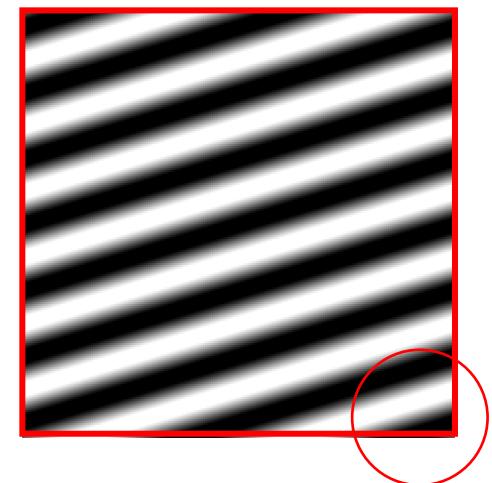
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Shift front grid

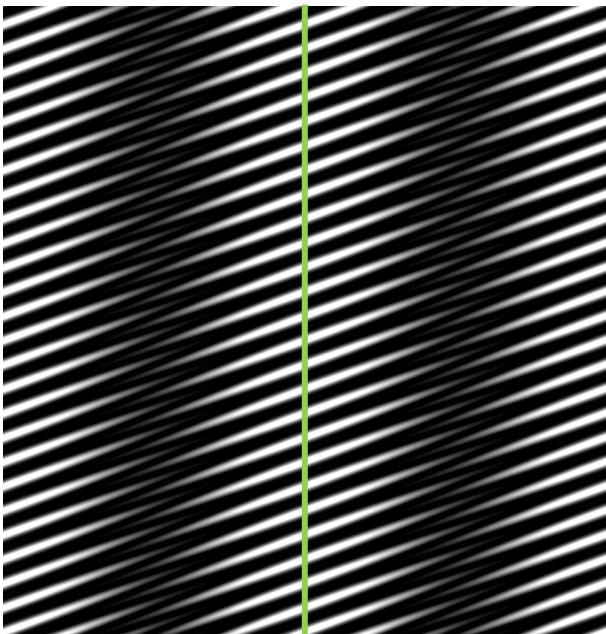


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