

# STIX imaging tutorial: brief methods overview

Anna Volpara, Andrea Francesco Battaglia, Paolo Massa, Hualin Xiao, Ewan C. M. Dickson, Frédéric Schuller, Alexander Warmuth, Gordon Hurford, Anna Maria Massone, Michele Piana, Säm Krucker & STIX Team

July 14, 2022



Imaging methods  
○

Back-projection  
○○○

CLEAN  
○

MEM\_GE  
○○

VIS\_FWDFIT\_PSO  
○

EM  
○

① Imaging methods

② BACK-PROJECTION

③ CLEAN

④ MEM\_GE

⑤ VIS\_FWDFIT\_PSO

⑥ EM

# Image formation problem

Image reconstruction problem for STIX:

$$\mathcal{F}\phi = V \quad (1)$$

# Image formation problem

Image reconstruction problem for STIX:


$$\mathcal{F}\phi = V \quad (1)$$

the intensity of the X-ray photon flux  
emitted from  $(x, y)$  on the Sun

# Image formation problem

Image reconstruction problem for STIX:

$$\mathcal{F}\phi = \mathbf{V} \quad (1)$$



the array containing the  $N_v$  complex values of the visibilities measured by STIX

# Image formation problem

Image reconstruction problem for STIX:

$$\mathcal{F}\phi = V \quad (1)$$

the Fourier transform defined by

$$(\mathcal{F}\phi)_k = \iint \phi(x, y) \exp(2\pi i(xu_k + yv_k)) \, dx \, dy \quad k = 1, \dots, N_v$$

## VISIBILITY-BASED METHOD

- BACK-PROJECTION
- CLEAN
- MEM\_GE
- VIS\_FWDFIT\_PSO

## COUNT-BASED METHOD

- EM

# BACK-PROJECTION (Mertz et al., 1986)

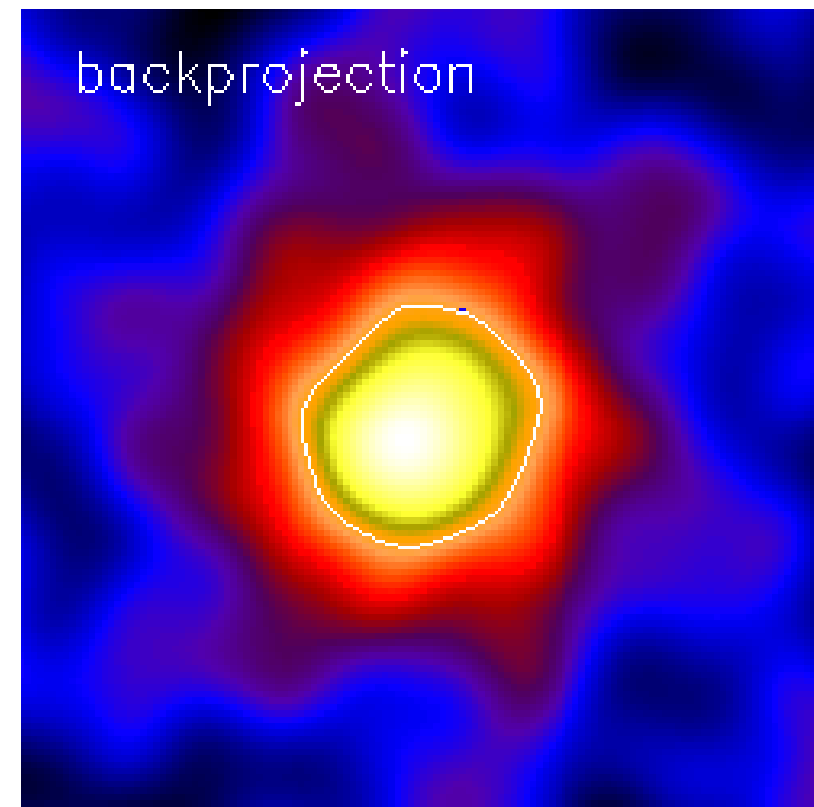
- Direct Fourier inversion of the visibilities
- The Back Projection of a single visibility is a sinusoidal wave

$$\phi(x, y) = A \sin(2\pi(xu + yv) - \theta) \quad (2)$$

Visibility  
amplitude

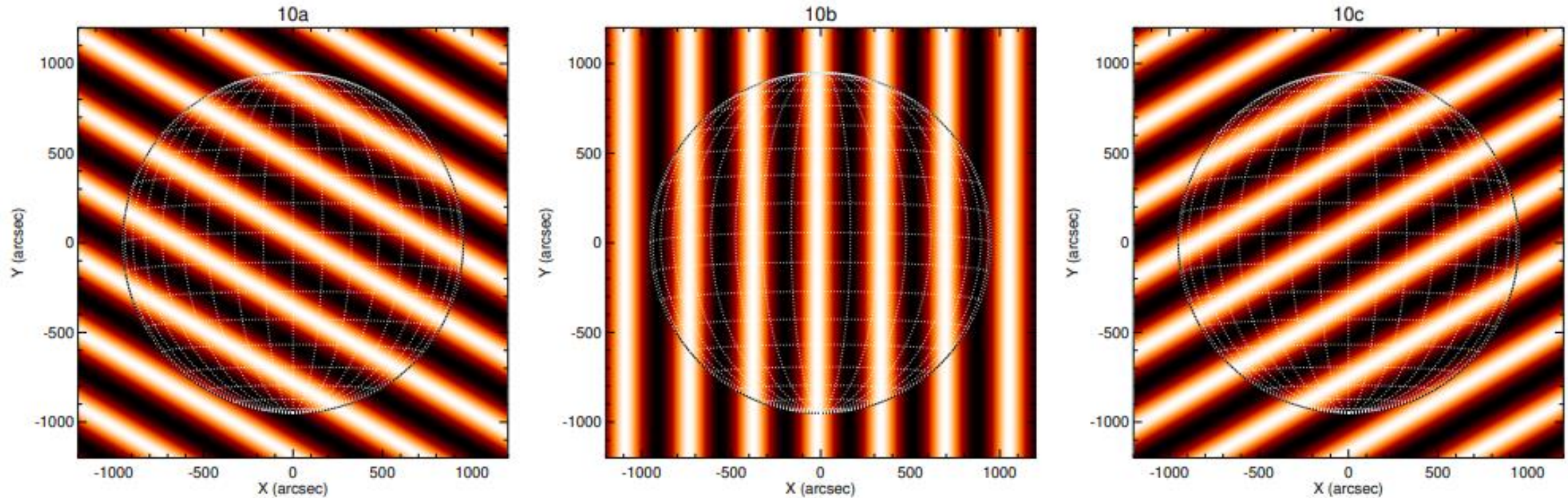
Visibility  
phase

frequency sampled by  
the sub-collimator



# BACK-PROJECTION (Mertz et al., 1986)

Courtesy P. Massa

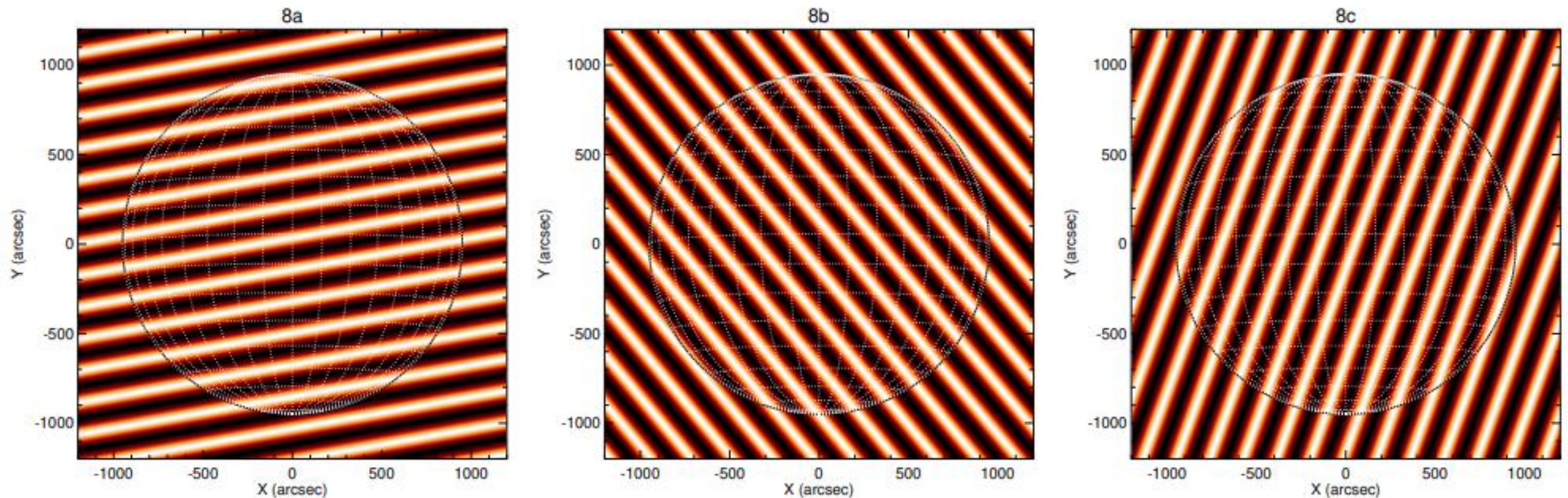


**Figure:** Detectors with the same resolution produce waves with same period but different orientation



# BACK-PROJECTION (Mertz et al., 1986)

Courtesy P. Massa



**Figure:** Detectors with the same resolution produce waves with same period but different orientation



Imaging methods



Back-projection



CLEAN



MEM\_GE



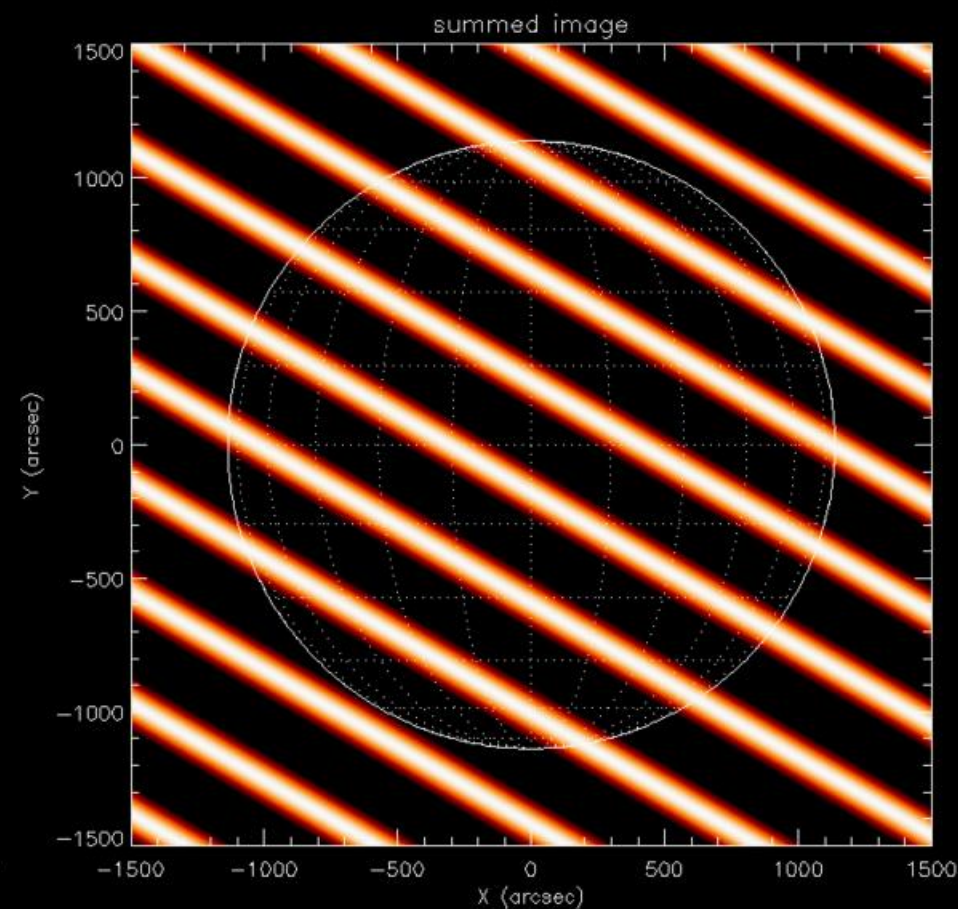
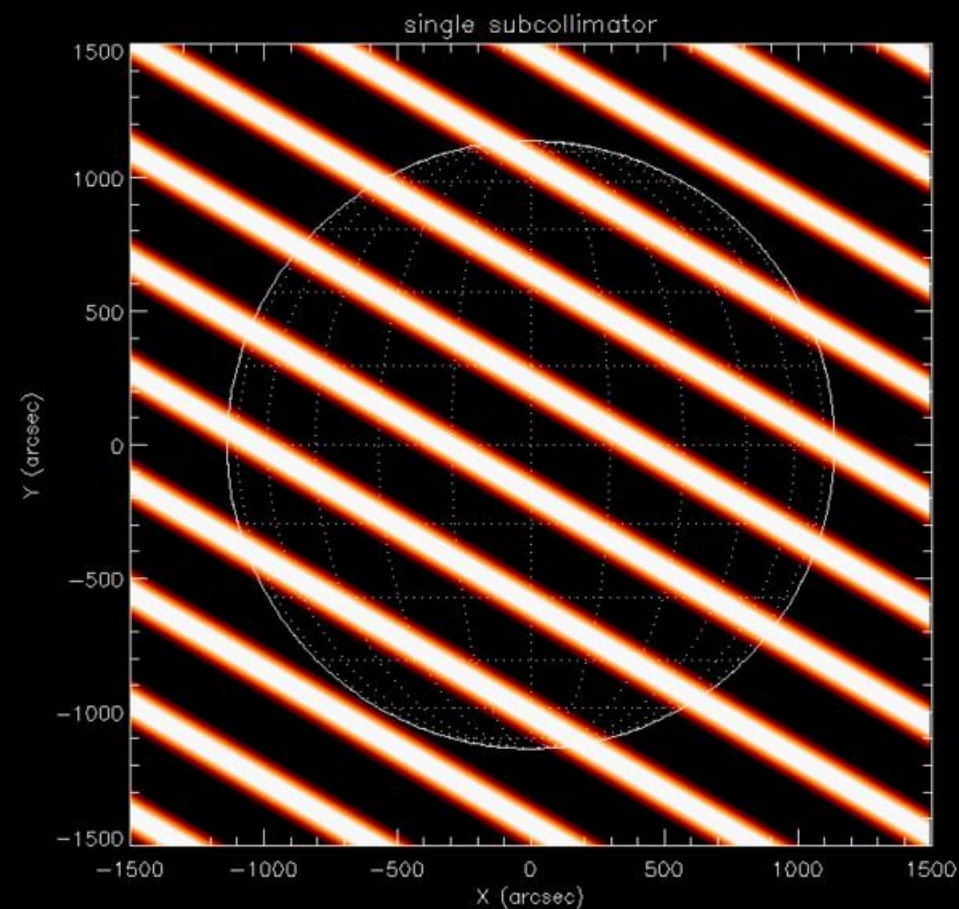
VIS\_FWDFIT\_PSO



EM



Courtesy S. Krucker

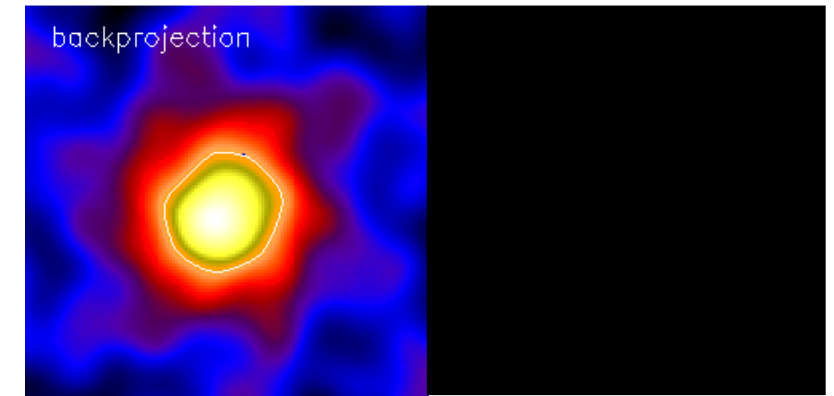


Flare of April 17, 2021

# CLEAN (Högbom, 1974)

Deconvolution algorithm:

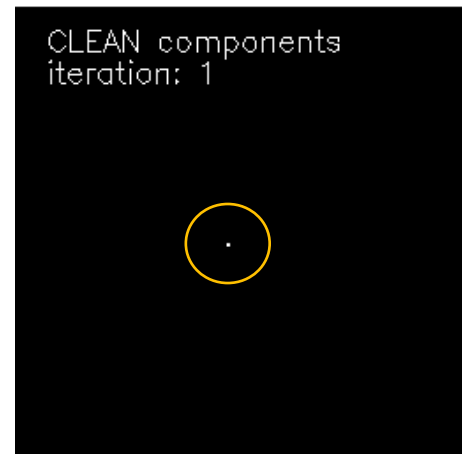
- Creates two maps:
  - DIRTY MAP (back-projection)
  - CLEAN COMPONENT (zero map)



# CLEAN (Högbom, 1974)

Deconvolution algorithm:

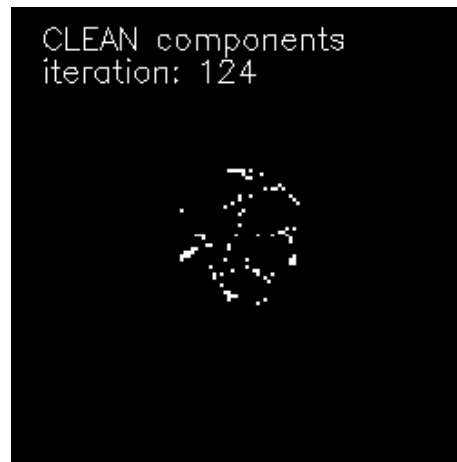
- Creates two maps:
  - DIRTY MAP (back-projection)
  - CLEAN COMPONENT (zero map)
- Finds maximum of the dirty map and add clean component in the clean component map
- Subtracts a fraction of the PSF from the dirty map



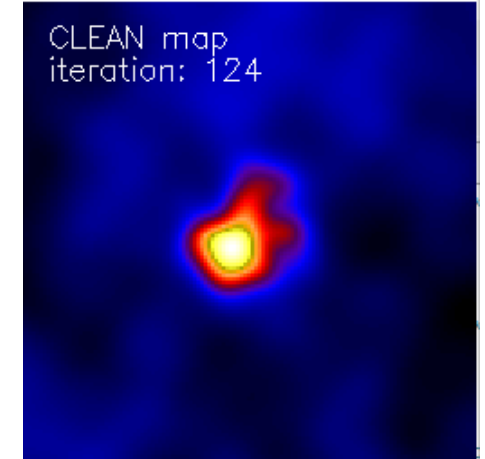
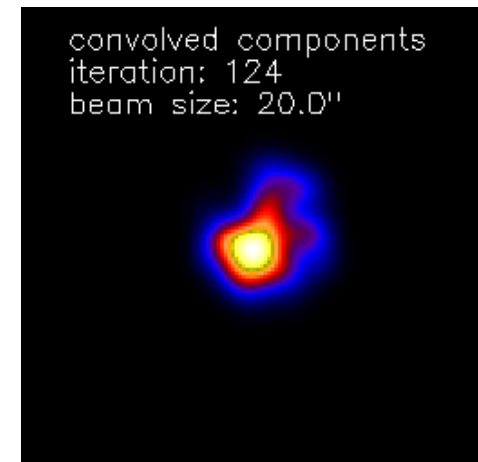
# CLEAN (Högbom, 1974)

Deconvolution algorithm:

- Creates two maps:
  - DIRTY MAP (back-projection)
  - CLEAN COMPONENT (zero map)
- Finds maximum of the dirty map and add clean component in the clean component map
- Subtracts a fraction of the PSF from the dirty map
- Iterates



Convolution with  
clean beam



Adds  
residuals

# MEM\_GE (Massa et al., 2020)

Solves:

$$\operatorname{argmin}_{\phi} \chi^2(\phi) - \lambda H(\phi)$$

# MEM\_GE (Massa et al., 2020)

Solves:

$$\operatorname{argmin}_{\phi} \chi^2(\phi) - \lambda H(\phi)$$

$$\chi^2(\phi) = \sum_i \frac{|(\mathcal{F}\phi)_i - V_i|^2}{\sigma_i^2}$$

$$H(\phi) = - \sum_j \phi_j \log \left( \frac{\phi_j}{me} \right)$$

# MEM\_GE (Massa et al., 2020)

Solves:

$$\begin{array}{ll} \underset{\phi}{\operatorname{argmin}} & \chi^2(\phi) - \lambda H(\phi) \\ \text{with} & \phi \succeq 0 \\ & F=0 \end{array}$$

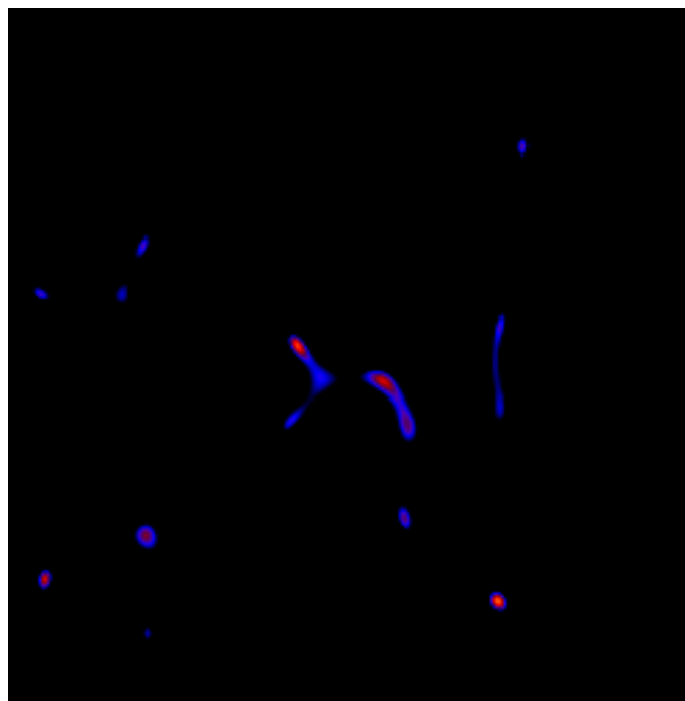
$$\chi^2(\phi) = \sum_i \frac{|(\mathcal{F}\phi)_i - V_i|^2}{\sigma_i^2}$$

$$H(\phi) = - \sum_j \phi_j \log \left( \frac{\phi_j}{me} \right)$$

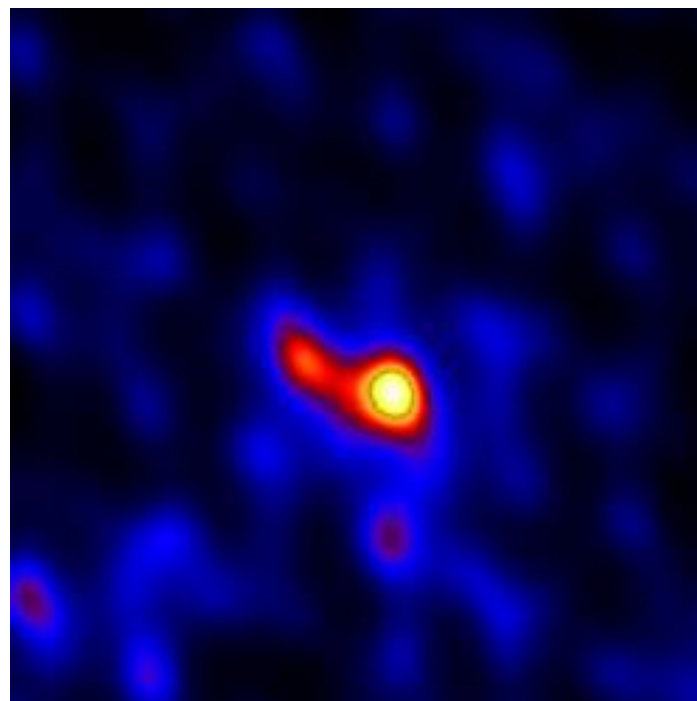
$$F = \sum_j \phi_j - F'$$



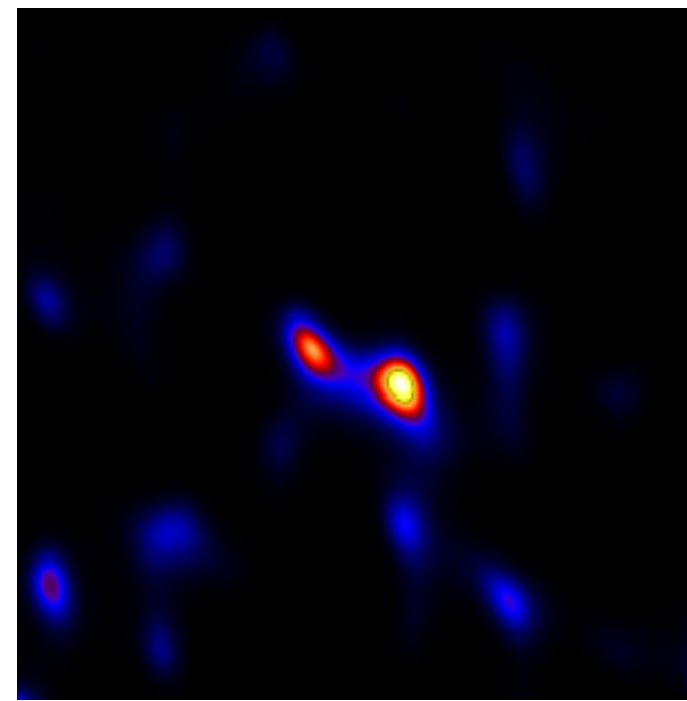
# MEM\_GE (Massa et al., 2020)



low



high



tradeoff

regularization parameter

Figure: MEM\_GE reconstruction with different regularization parameter

# VIS\_FWDFIT\_PSO (Volpara A. et al 2022)

Choose a parametric shape among:

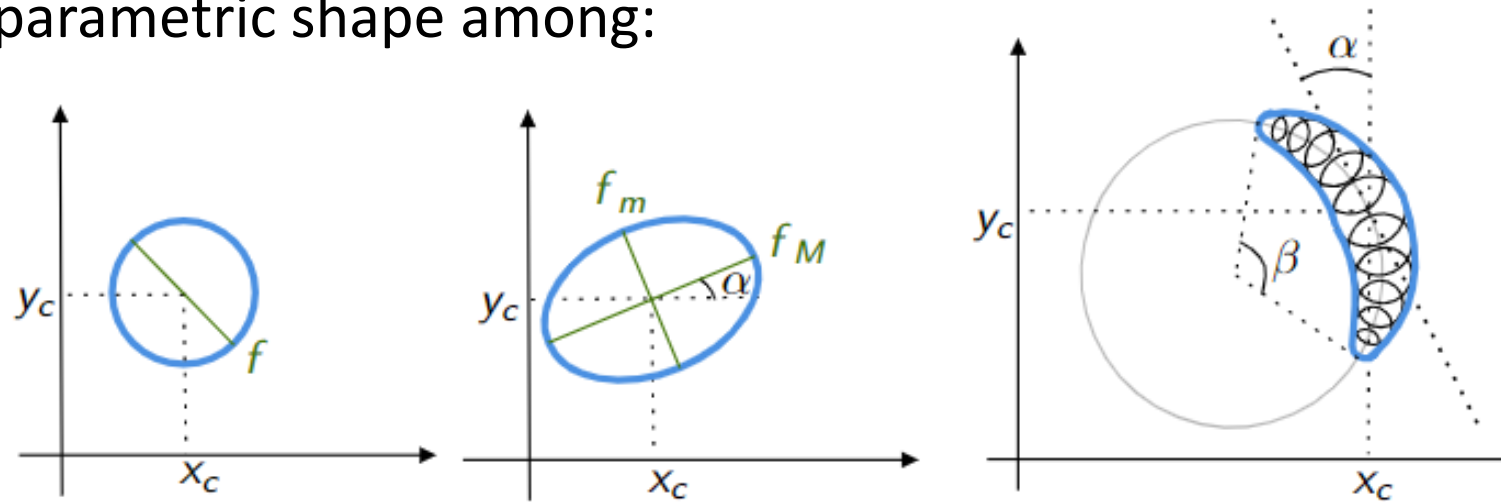


Figure: Gaussian shapes considered in the parametric imaging process.

and solve:

$$\operatorname{argmin}_{\theta \in \Theta} \frac{1}{N_v - N_\theta} \sum_{k=1}^{N_v} \frac{|V_k - (\mathcal{F}\phi_\theta)_k|^2}{\sigma_k^2} \quad (3)$$

More details tomorrow at "Parametric imaging for STIX: global search methods" talk

# EXPECTATION MAXIMIZATION (Massa, P., et al., 2019)

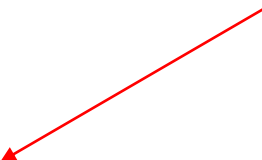
- Count-based method
- Solves:

$$M\phi = C \quad (4)$$

# EXPECTATION MAXIMIZATION (Massa, P., et al., 2019)

- Count-based method
- Solves:

$$M\phi = C \quad (4)$$



Matrix modelling the  
grid transmission

# EXPECTATION MAXIMIZATION (Massa, P., et al., 2019)

- Count-based method
- Solves:

$$M\phi = C \quad (4)$$



Array containing the  
measured counts

# EXPECTATION MAXIMIZATION (Massa, P., et al., 2019)

- Count-based method
- Solves:

$$M\phi = C \quad (4)$$

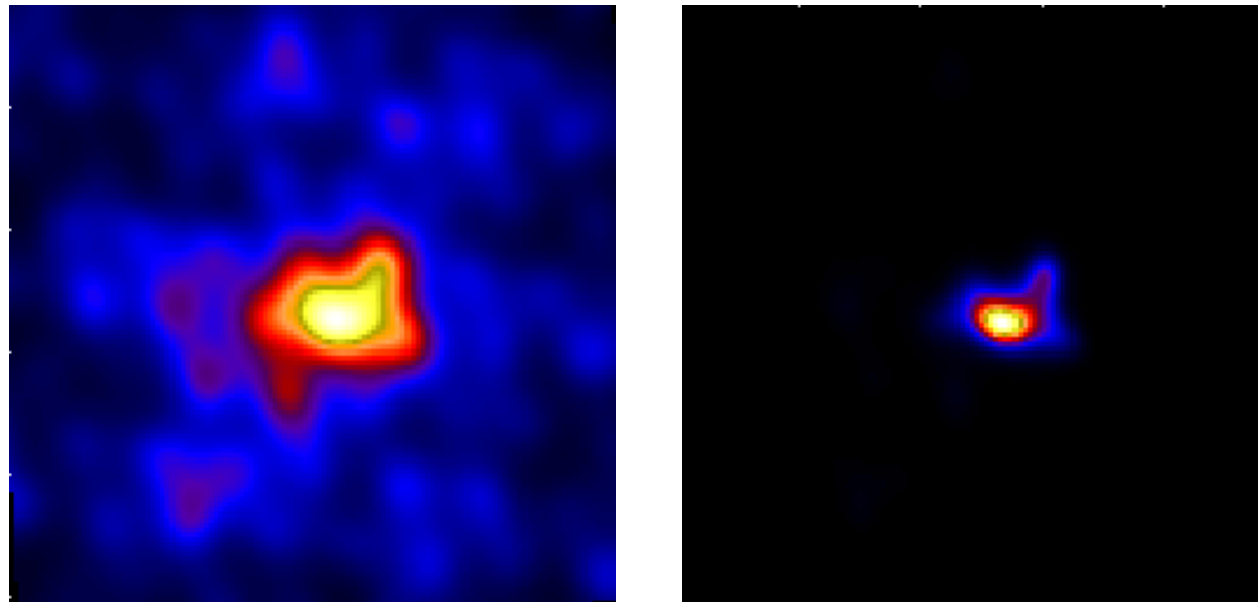


Figure: EM reconstruction with different iteration number.

# THANK YOU FOR THE ATTENTION!

Let's now reconstruct STIX images!  
Demo available at the link:

<https://www.dropbox.com/sh/rhsunyvj1mvxdm7/AAC-keBllTfQJ52EFF3H47aea?dl=0>