

# **Increasing the source detection sensitivity in Chandra Deep Field South with likelihood-based methods**

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# 7 Msec Chandra Deep Field South

100 pointings (2000 – 2016)

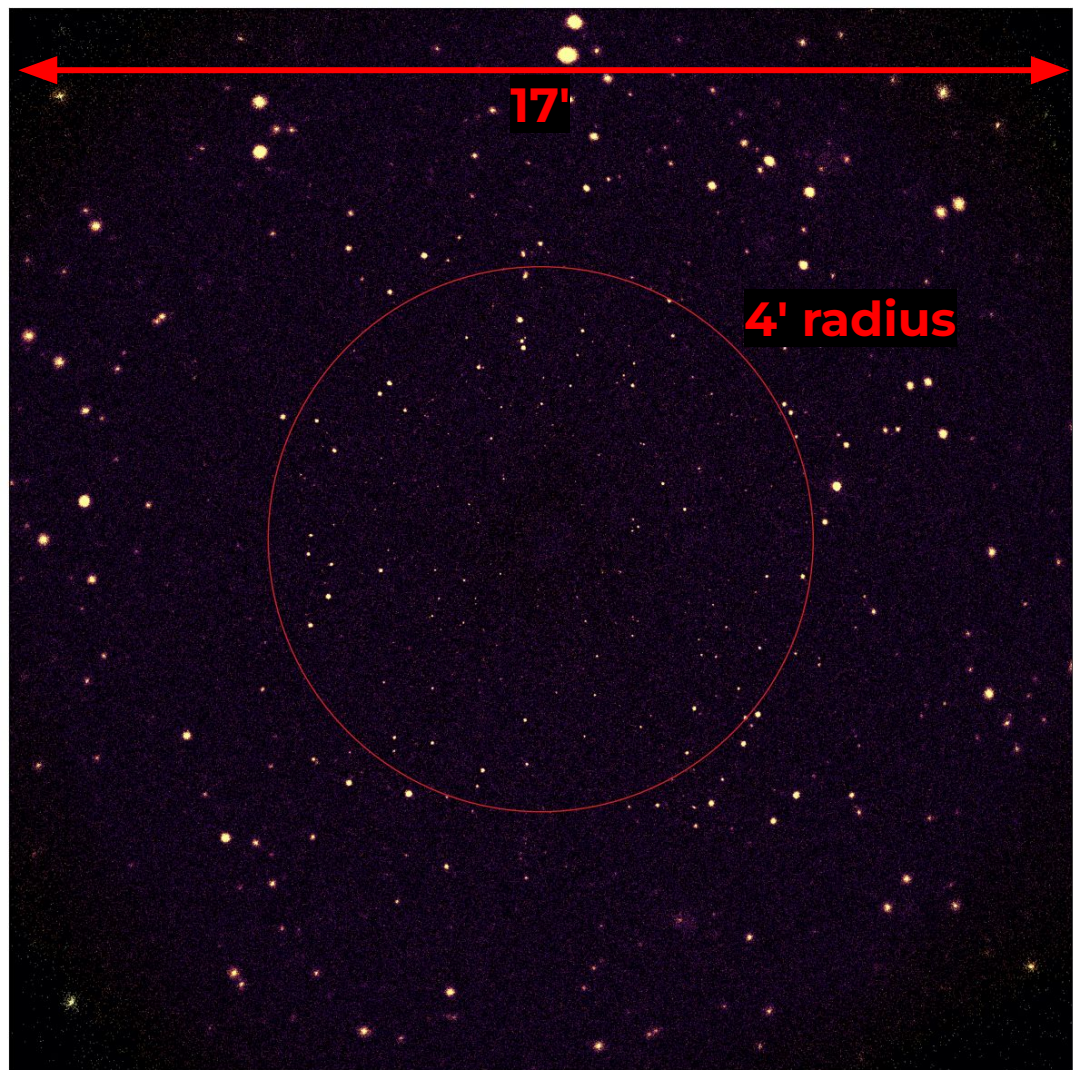
7 Ms exposure

1008 X-ray sources,  
6.3 source per arcmin<sup>2</sup> in the center  
(Luo et al 2017)

Excellent multiwavelength coverage,  
including HST, Spitzer, VLA, JWST

>40 papers published

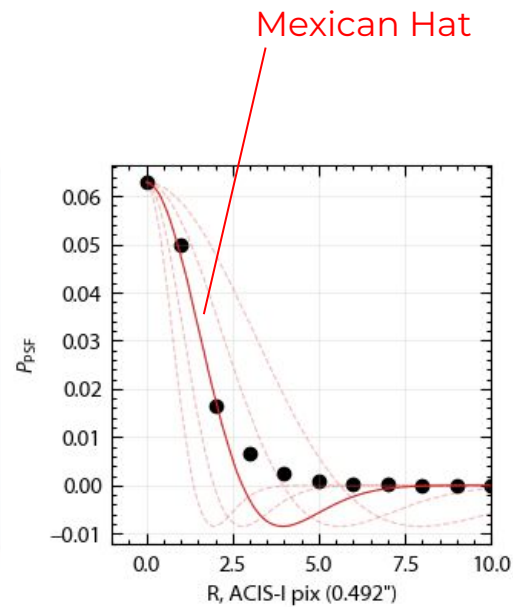
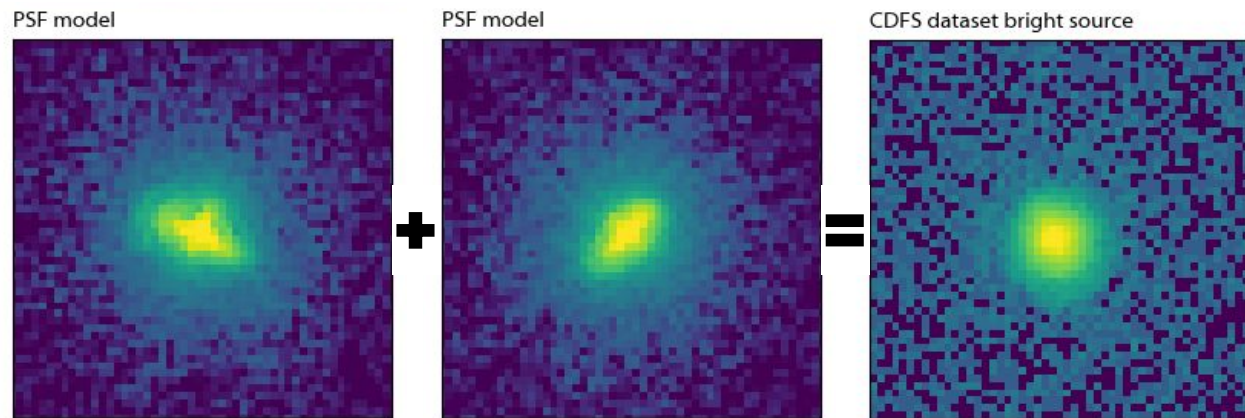
**Can we improve?**



- **Sources of additional X-ray information:**
  - **Spatial:** full use of the PSF structure
  - **Spectral:** differences between background and expected source spectra
  - **Time-dependence:** evolution of the detector response and background over 17 years of CDFS observations
  - **Instrumental:** differences in the ACIS event grade probabilities for sources vs. particle background (**NEW**)
- **Statistical Framework:** likelihood-based detection
- **Results:** Sensitivity gains and improved accuracy of source positions
- **Results:** Initial look at cross-IDs with JWST/JADES

# Spatial information

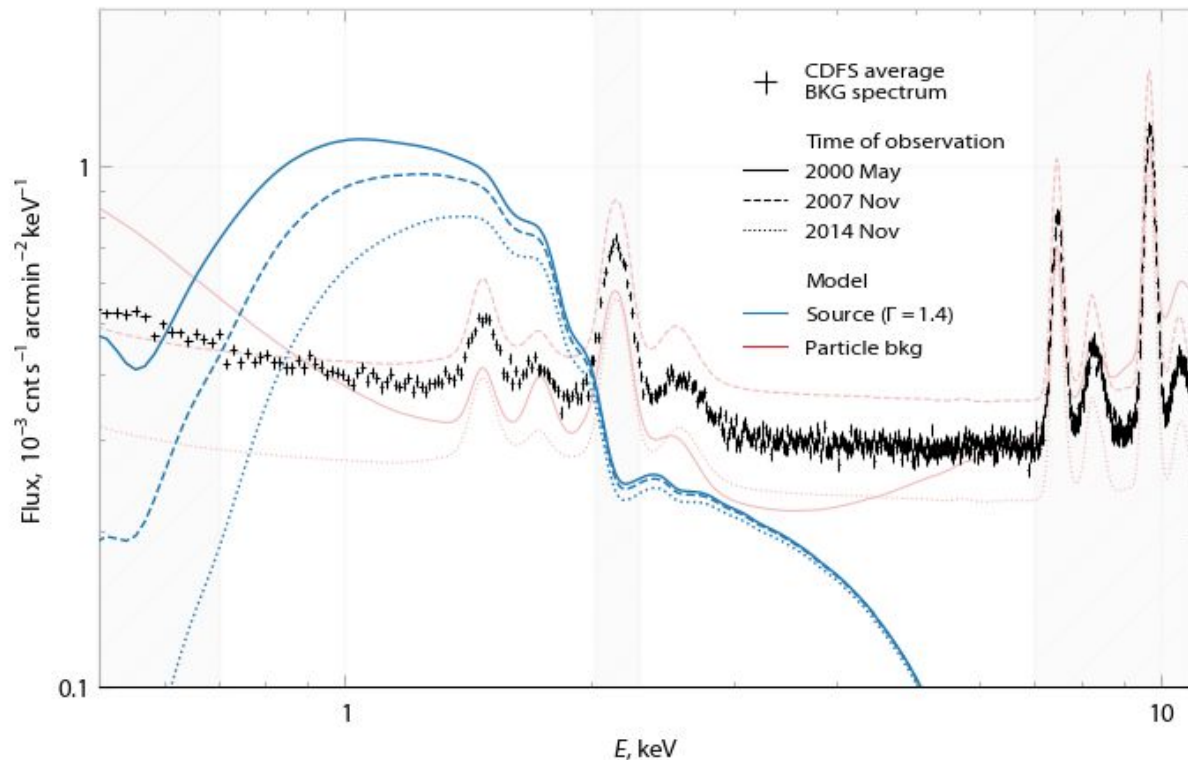
Full use of the PSF structure:



# Spectral information + Time dependence

**Spectral:** background and expected source spectra are very different

**Time:** contamination of the ACIS Optical Blocking Filter



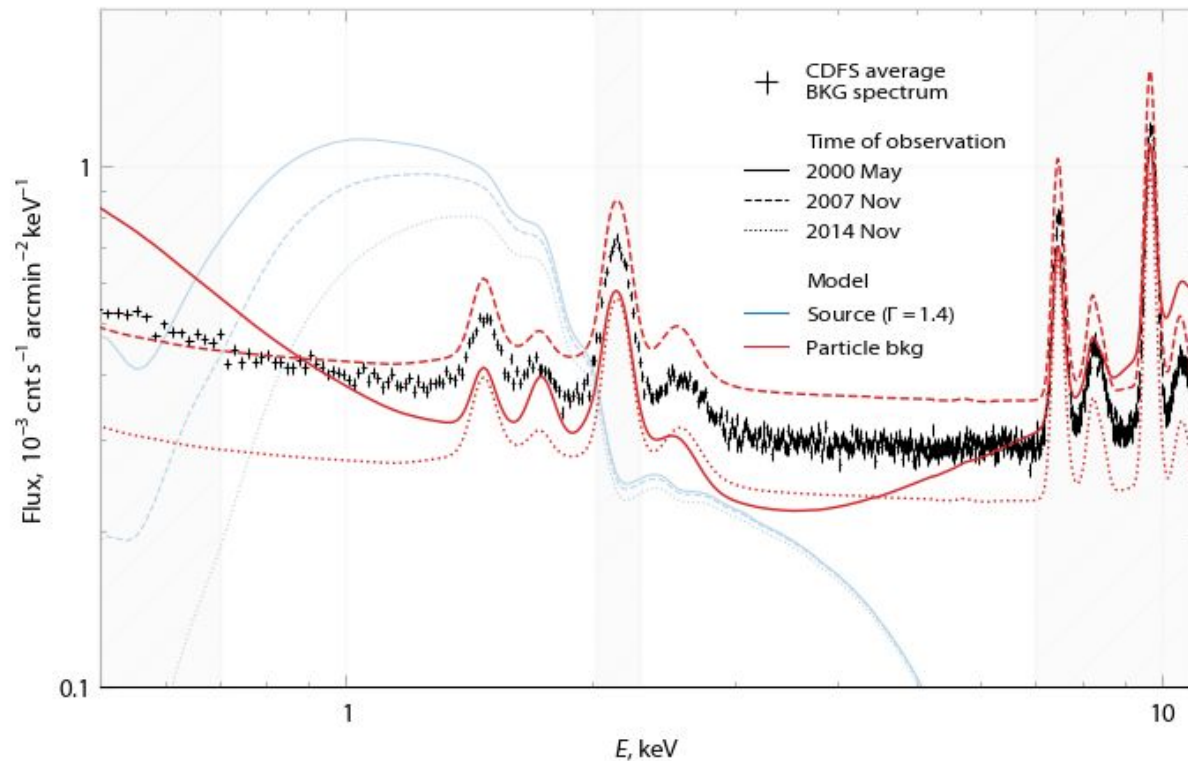
# Spectral information + Time dependence

**Spectral:** background and expected source spectra are very different

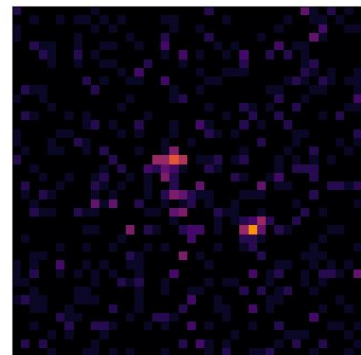
**Time:** contamination of the ACIS Optical Blocking Filter

**Time:** changes in the background:

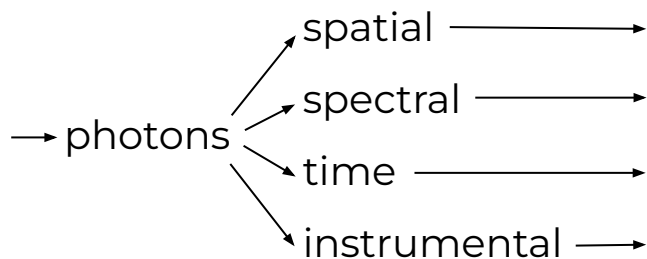
- Solar cycle
- Telemetry mode change (F vs VF)



# Statistical Framework: Likelihood-based source detection



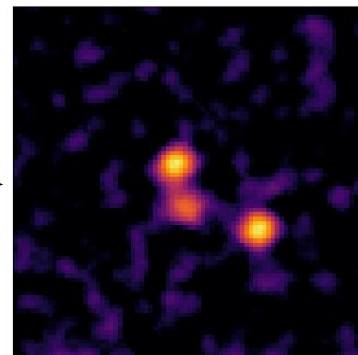
0.5–7 keV image



**Likelihood**

$$\Delta \ln L = \ln \frac{\max_F L(F)}{L(F=0)}$$

Semena et al 2024



$\Delta$  likelihood  
map

# Sensitivity gains

## Likelihood analysis: (green)

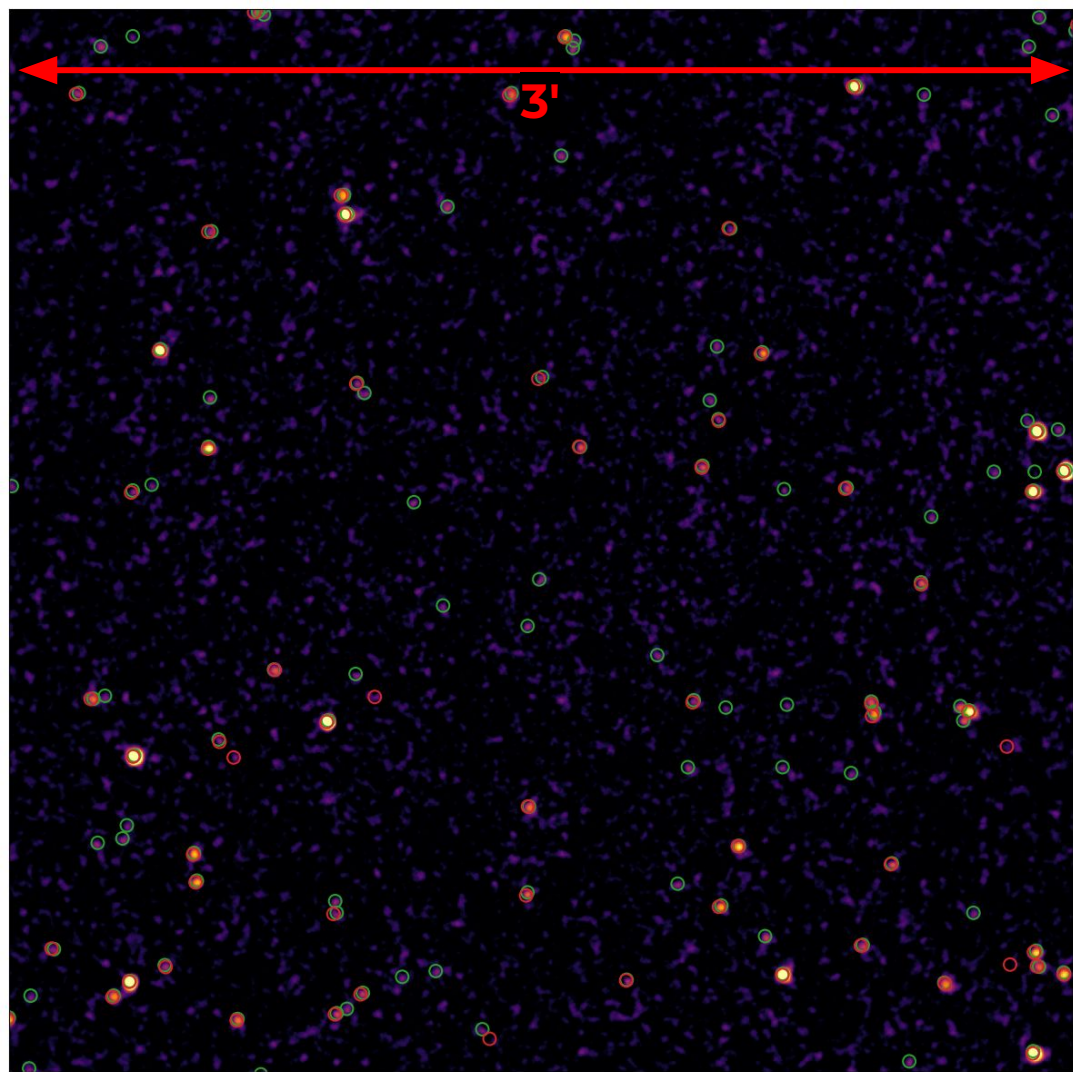
636 sources within the central 4' radius

## wvdetect-based analysis: (red)

341 sources in the same area  
(Luo et al. 2017)

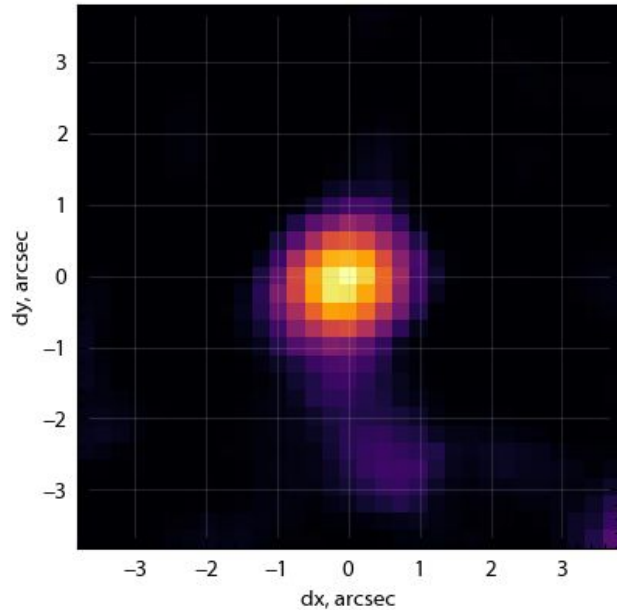
— at similar false-positive probability thresholds and sample purity

Sensitivity gains equivalent to  
 $\sim 2 \times$  exposure



# Source position uncertainty

$\Delta \ln L$  map



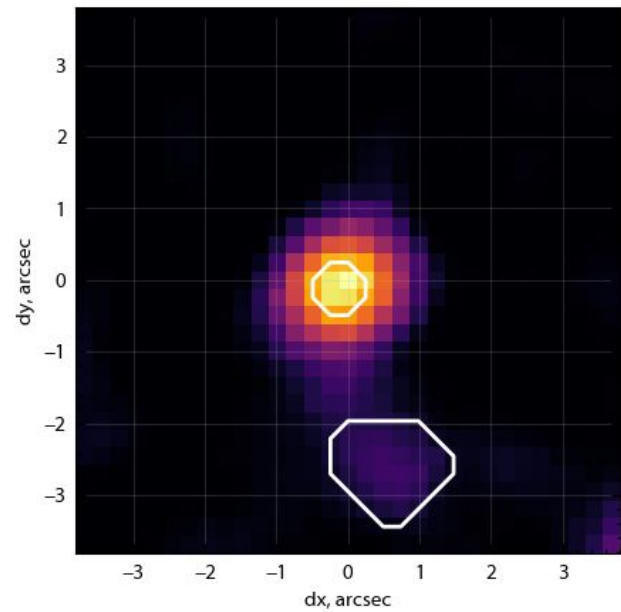
$\Delta \ln L = 1.15$  from the peak  $\Rightarrow$  68% uncertainty region

$\Delta \ln L = 2.3 \Rightarrow$  90% uncertainty,

and so on. ( $2\Delta \ln L$  follows  $\chi^2_2$  distribution)

# Source position uncertainty

$\Delta \ln L$  map

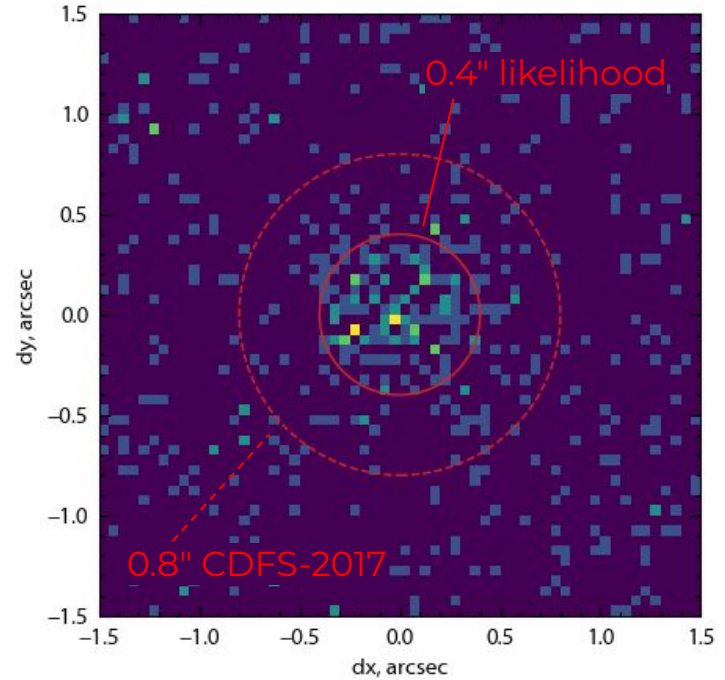
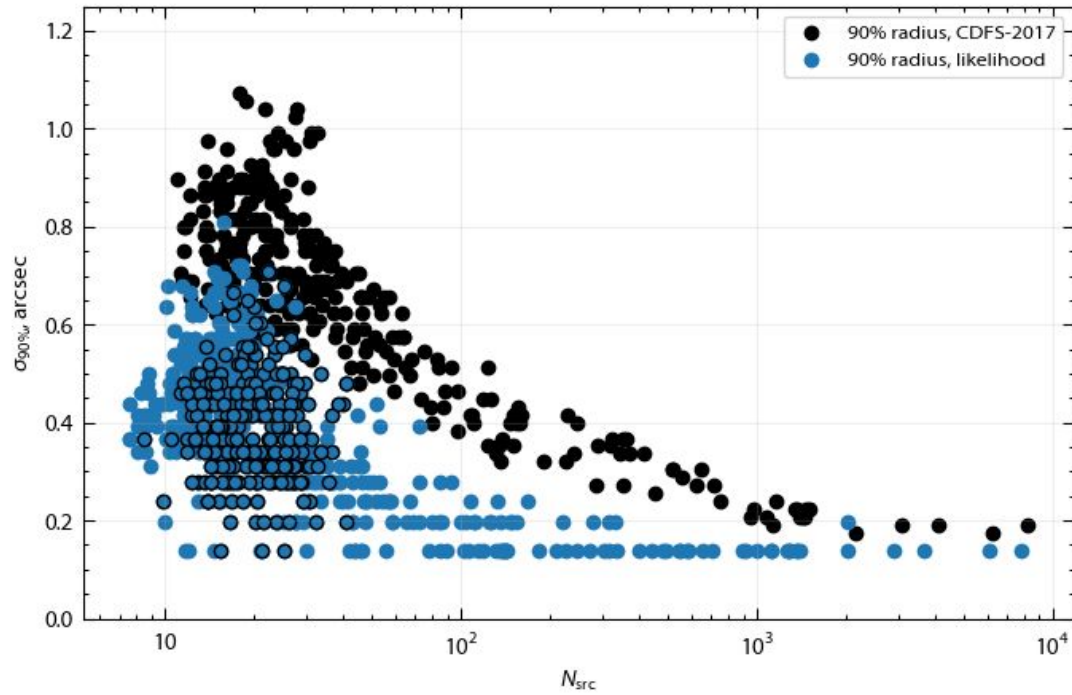


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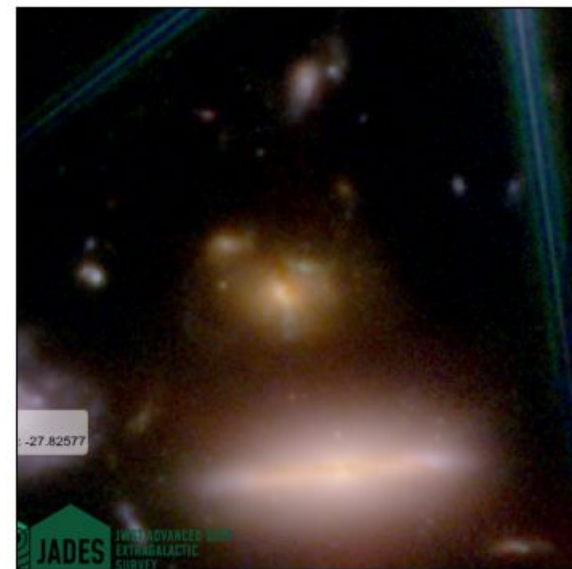
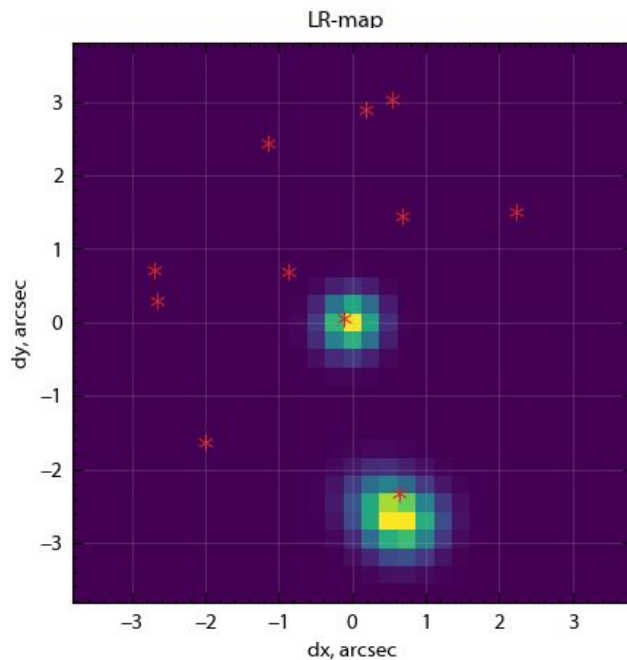
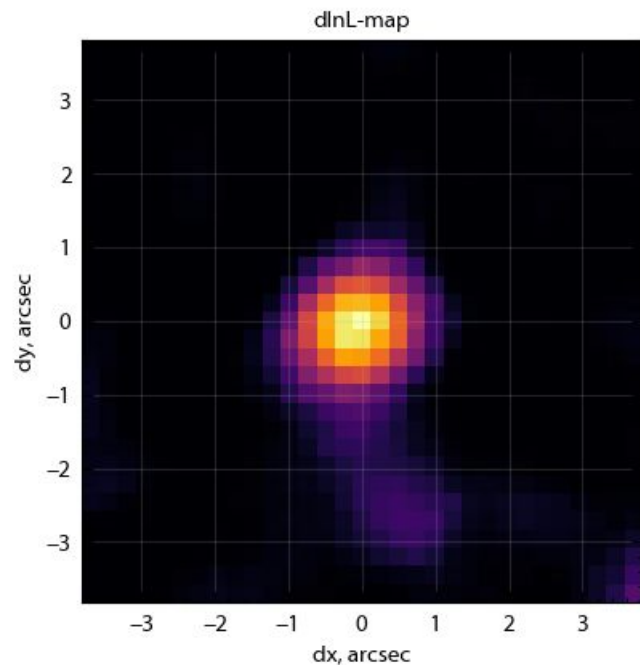
# Improvements in X-ray source positions accuracy



*Chandra* sources  $\otimes$  JWST/ JADES photometric catalog

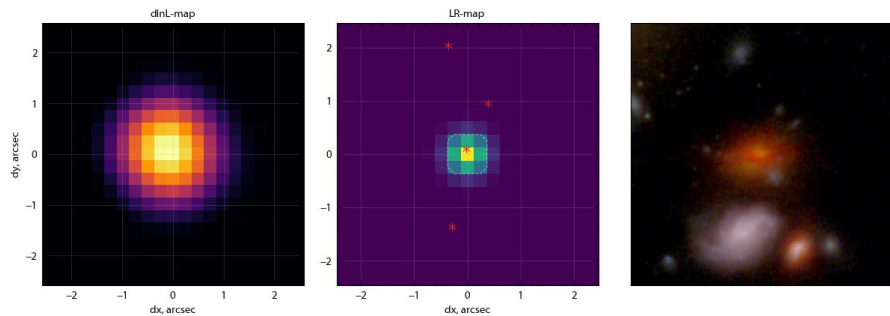
# Cross-ID with optical catalogs

$$\text{Likelihood Ratio} = \frac{L(\text{real source})}{L(\text{spurious source})} = \frac{L/L_{\text{peak}}}{2\pi n_{\text{opt}}}, \quad \text{use } LR_{\text{crit}} \implies 75\% \text{ reliability}$$

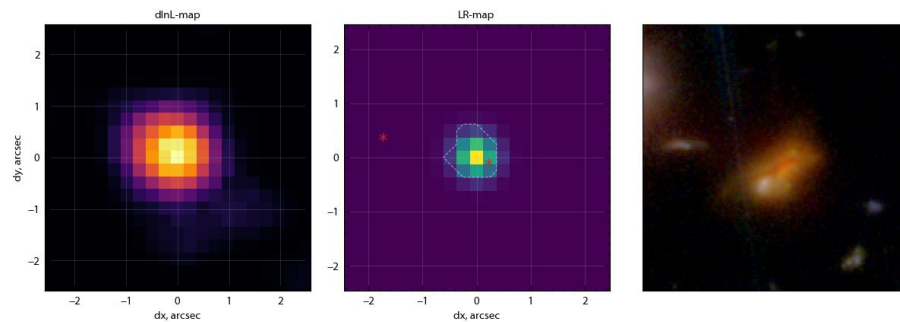


# CROSS-ID WITH JADES: CHANDRA SOURCES WITH ZPHOT > 5.5

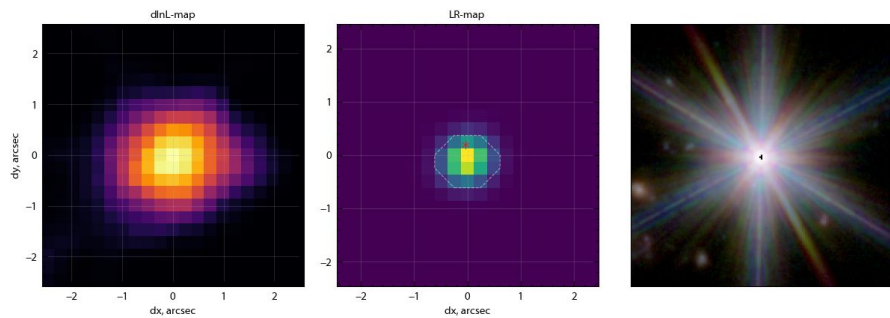
$\Delta \ln L = 593.5$      $z_{\text{phot}}=12.6$     ✓ absorbed



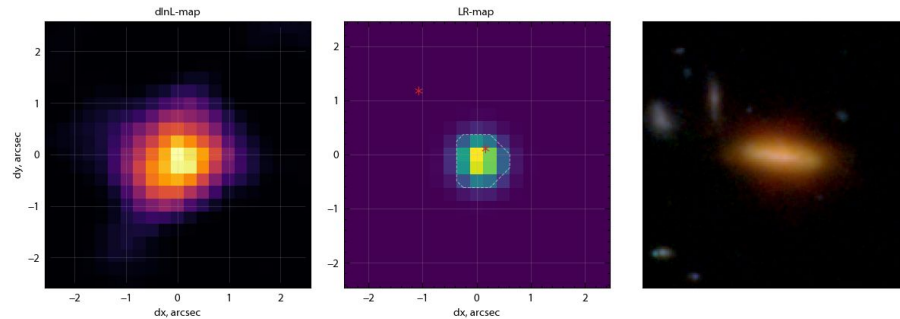
$\Delta \ln L = 44.1$      $z_{\text{phot}}=8.37$     ✓ absorbed



$\Delta \ln L = 26.05$      $z_{\text{phot}}=5.63$     ✗ not absorbed

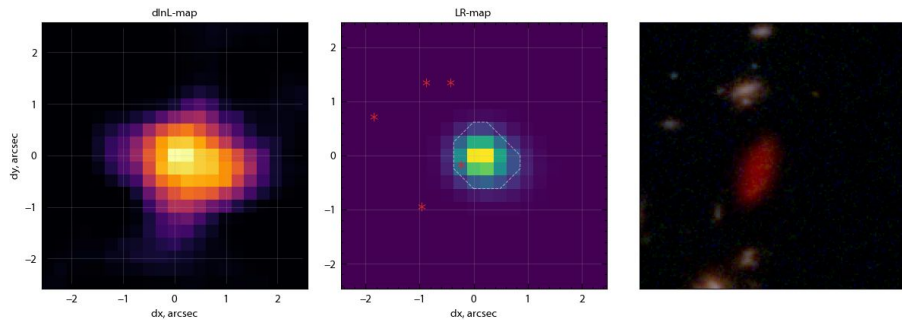


$\Delta \ln L = 18.94$      $z_{\text{phot}}=6.47$     ~ mildly absorbed

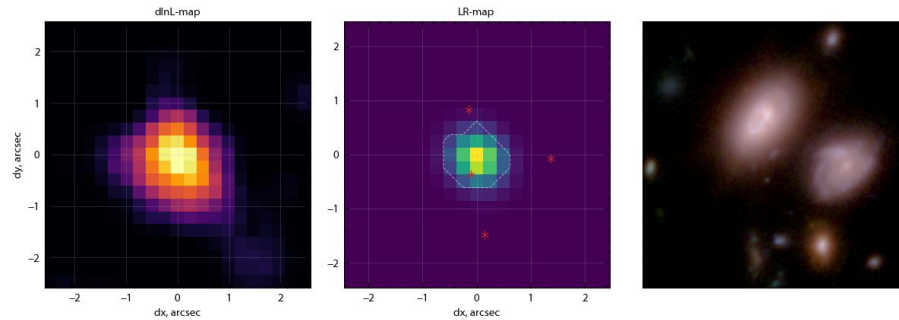


# CROSS-ID WITH JADES: CHANDRA SOURCES WITH ZPHOT > 5.5

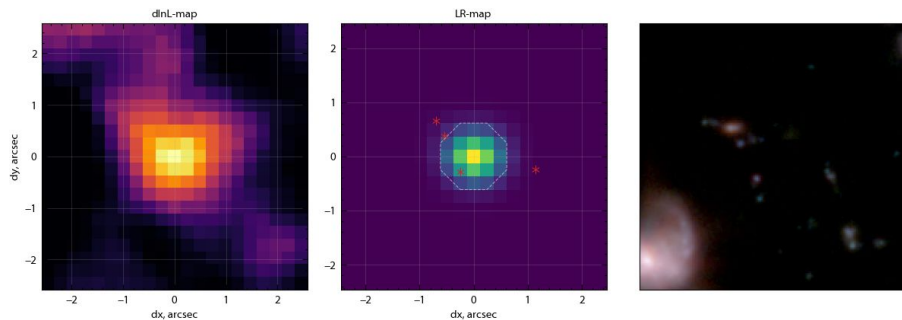
$\Delta \ln L = 15.63$      $z_{\text{phot}}=16.95$     ✓ absorbed



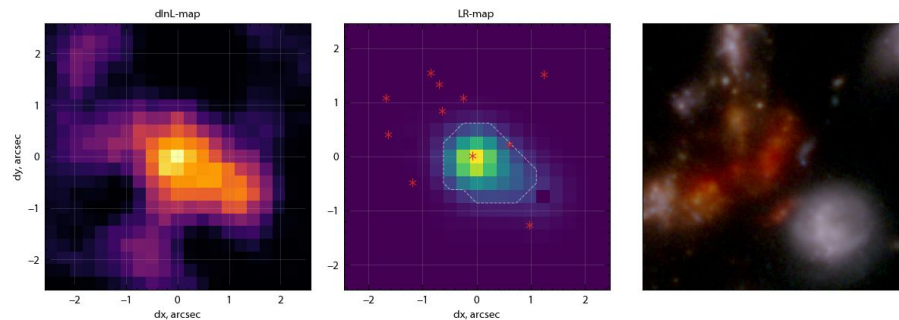
$\Delta \ln L = 13.25$      $z_{\text{phot}}=6.68$     ~ mildly absorbed



$\Delta \ln L = 12.94$      $z_{\text{phot}}=5.94$     ✗ not absorbed    ✓ NEW



$\Delta \ln L = 8.79$      $z_{\text{phot}}=12.6$     ✗ not absorbed    ✓ NEW



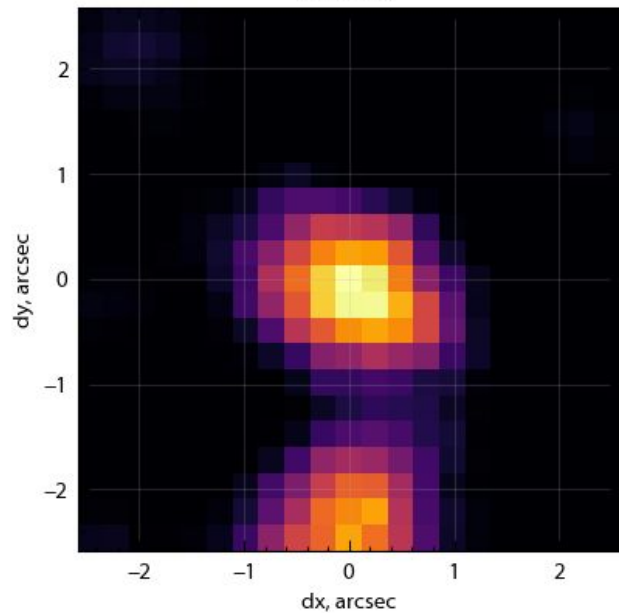
# Z > 5 source

$\Delta \ln L = 9.62$   $z_{\text{spec}} = 5.2585$

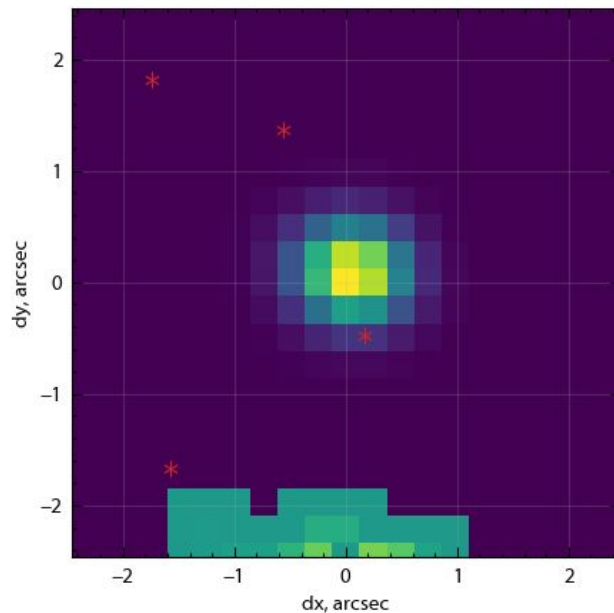
✓ absorbed

✓ NEW

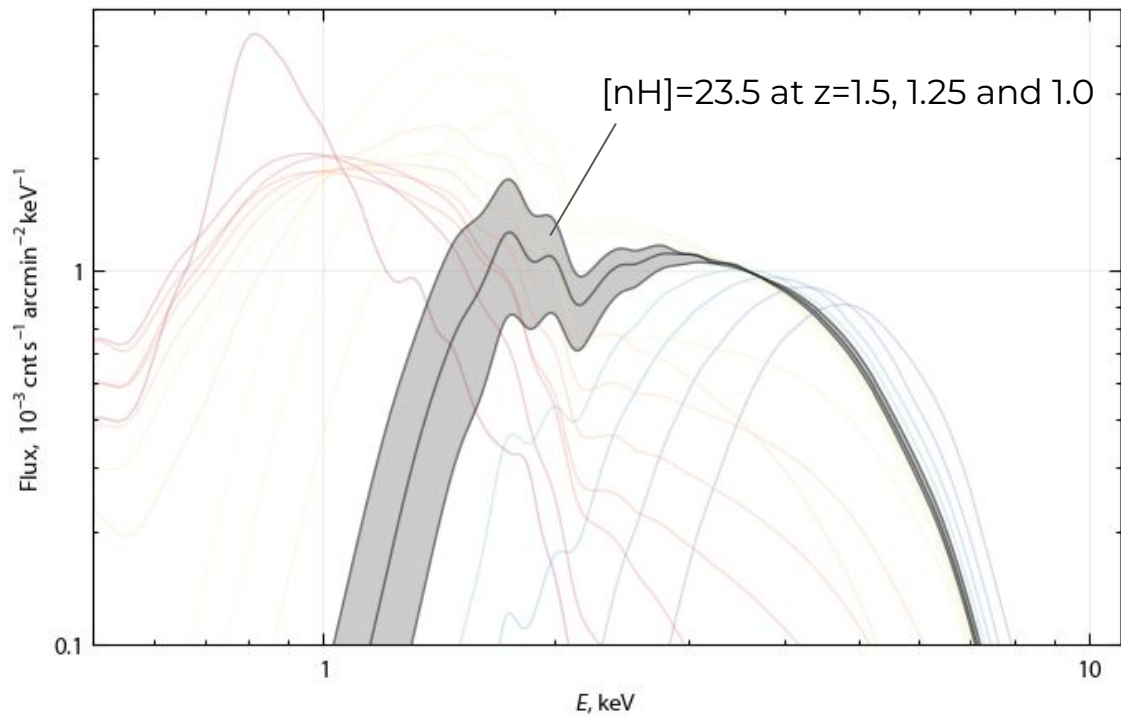
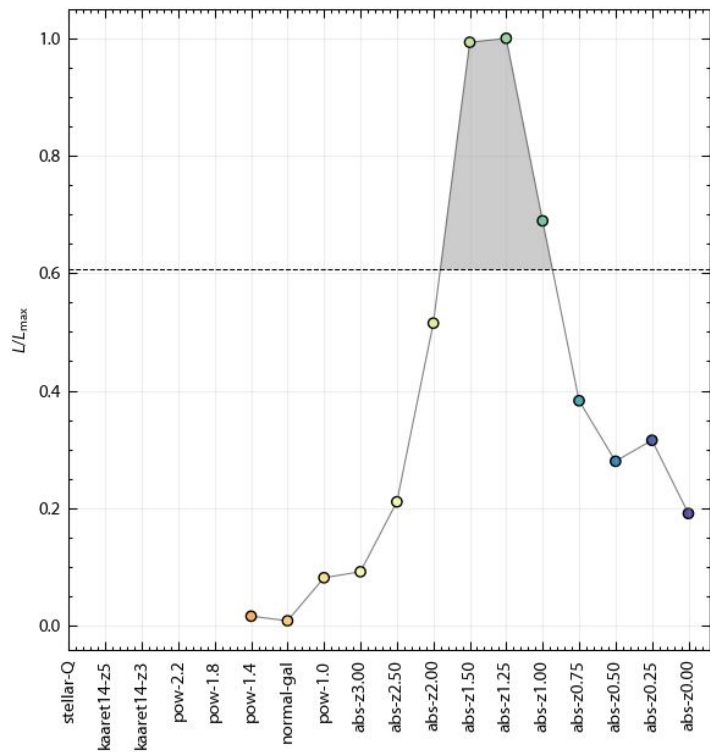
dnL-map



LR-map



# Spectral classification



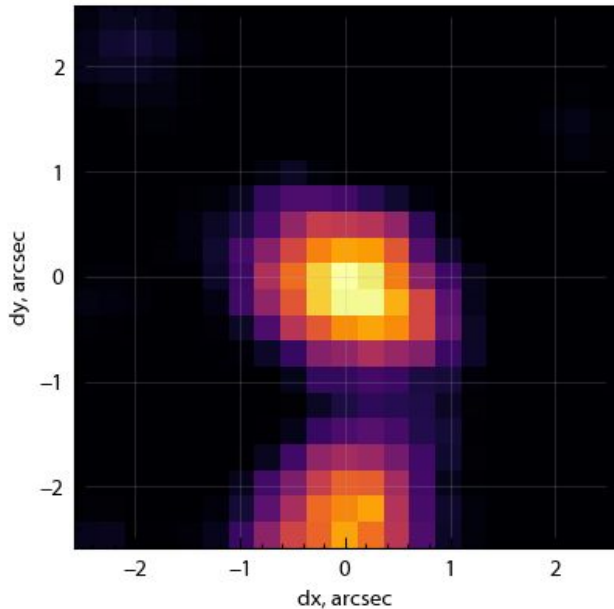
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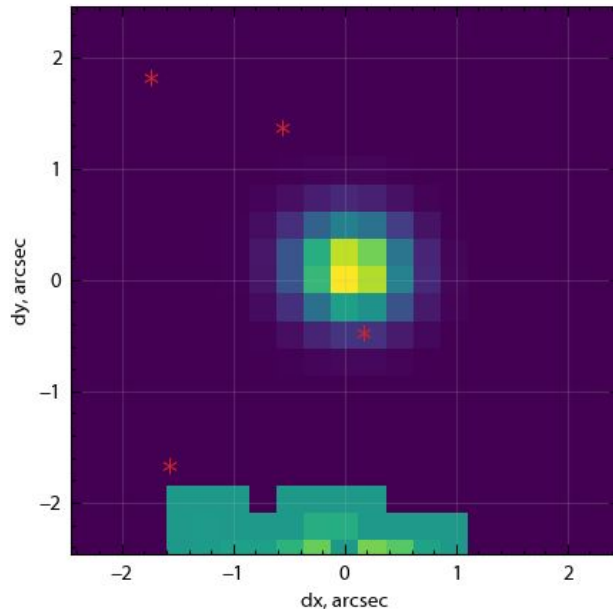
✓ ABSORBED

✓ NEW

dlnL-map



LR-map

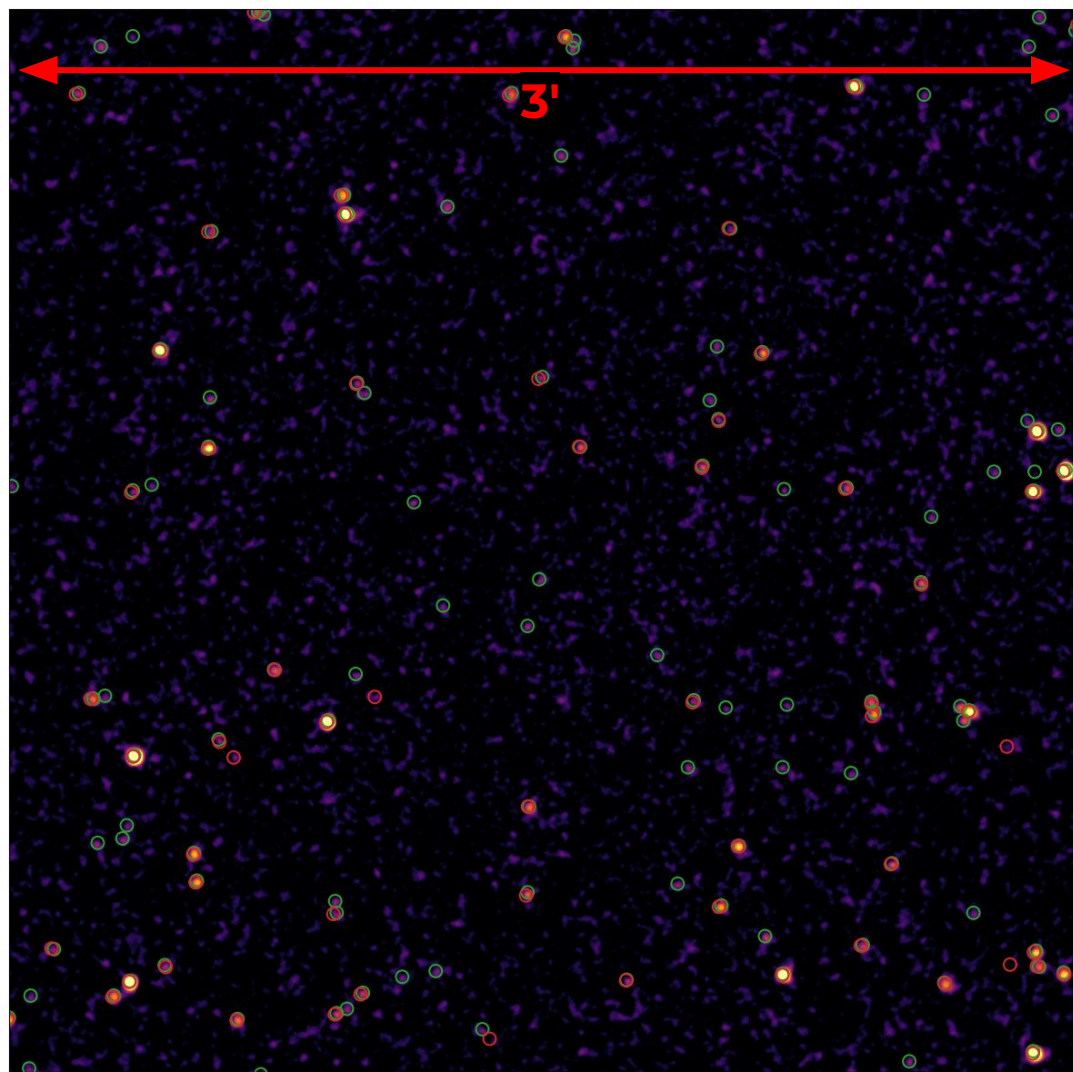


- Spectral classification implies  $n_H \sim 4 \times 10^{24} \text{ cm}^{-2}$  at  $z = 5.26$ .
- $L_X \sim 8 \times 10^{43} \text{ erg s}^{-1}$  (absorbed). Unabsorbed  $L_X \sim 3 \times 10^{44} \text{ erg s}^{-1}$  (0.5–30 keV rest-frame)
- Compton-thick AGN at  $z > 5$ ?

# Gains from using additional information & likelihood analysis:

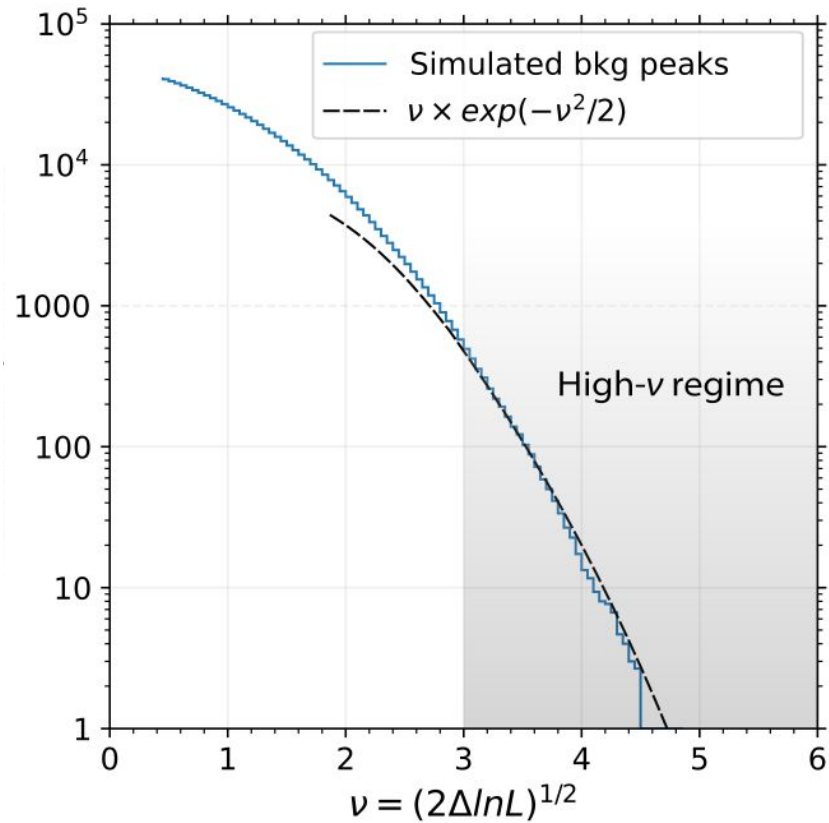
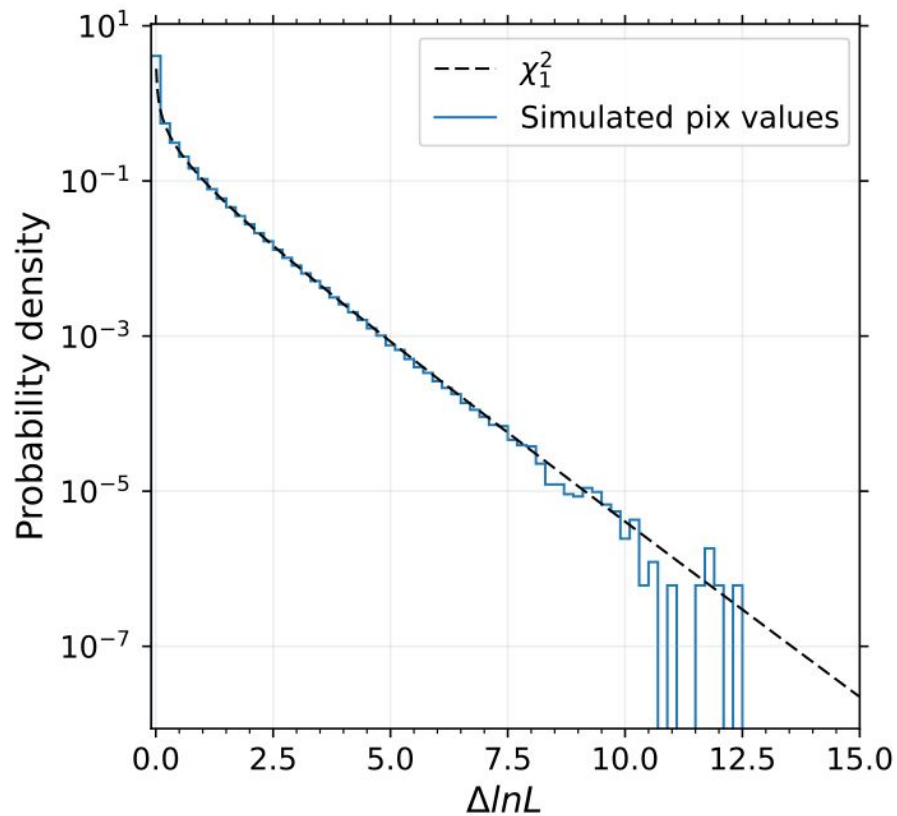
- 65% more X-ray detections compared to wvdetect-based analysis
- Sensitivity increase equivalent to ~ doubling the exposure
- ×2 better localizations make it possible to cross-ID with JWST/JADES
- Meaningful X-ray spectral classification

Work is supported by BASIS #25-1-5-113-1

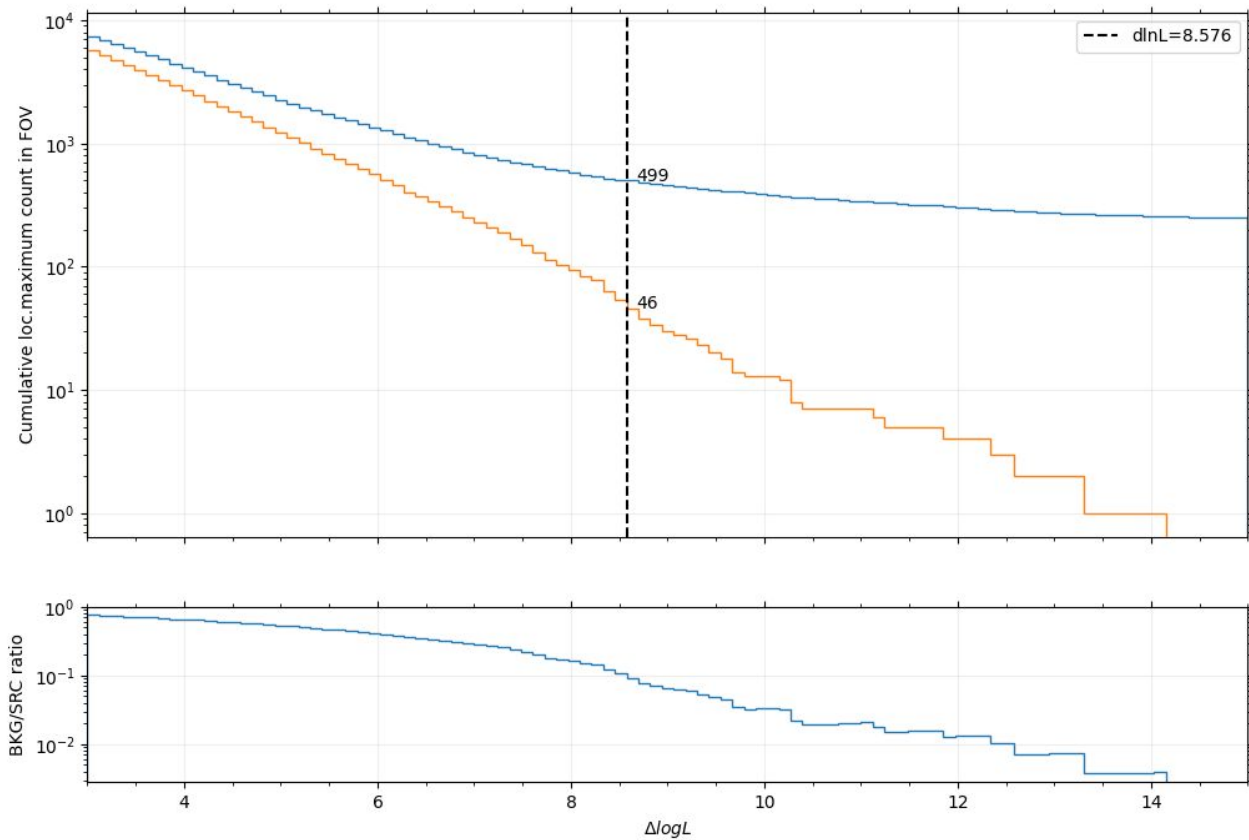


**Backup slides**

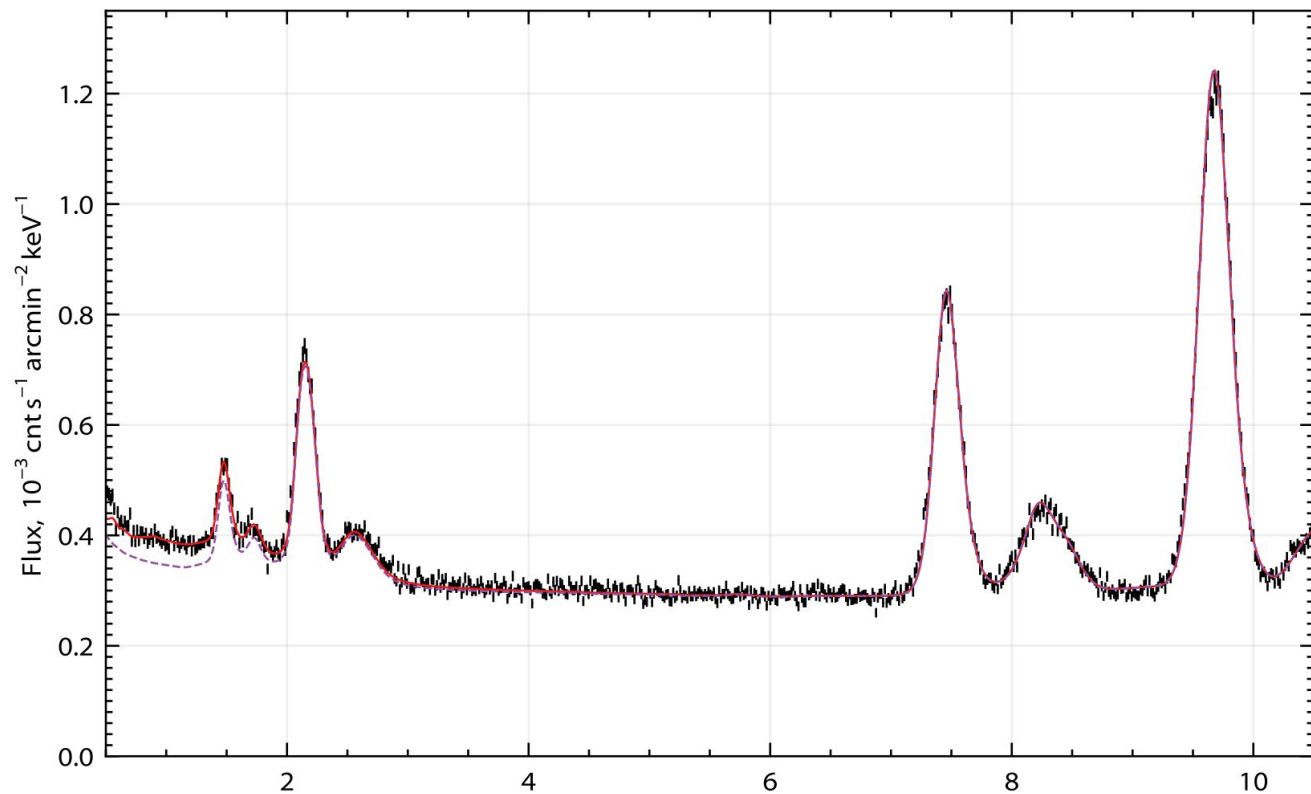
# False detection analytical approach



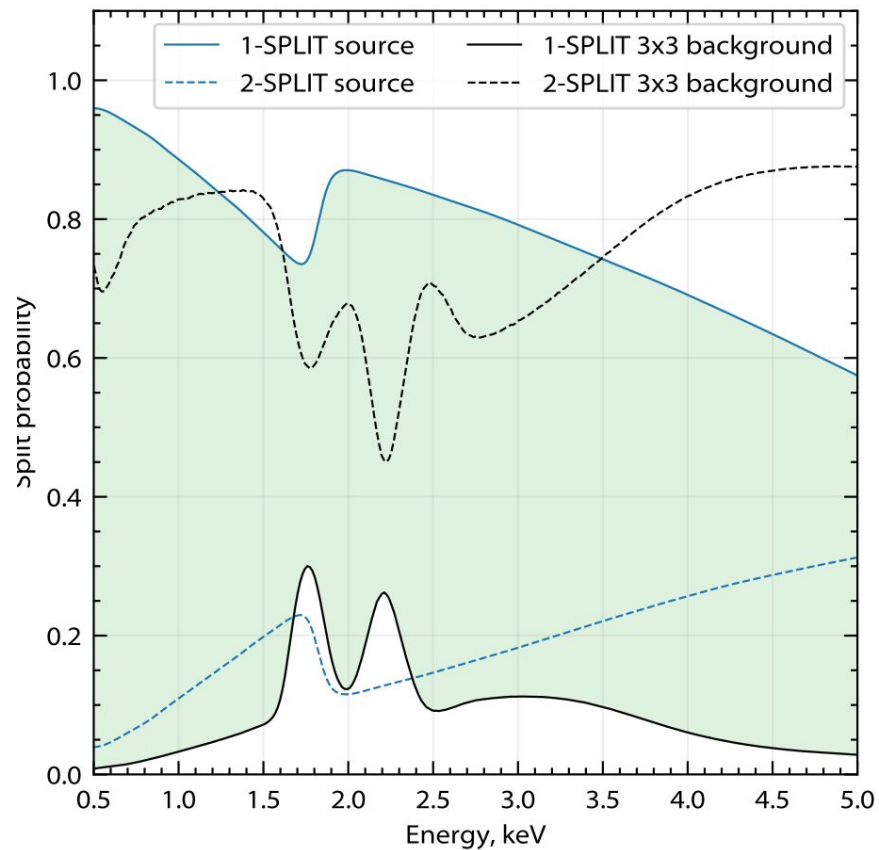
# N false estimation



# End-to-end background spectrum test



# Split information



# Detected sources

