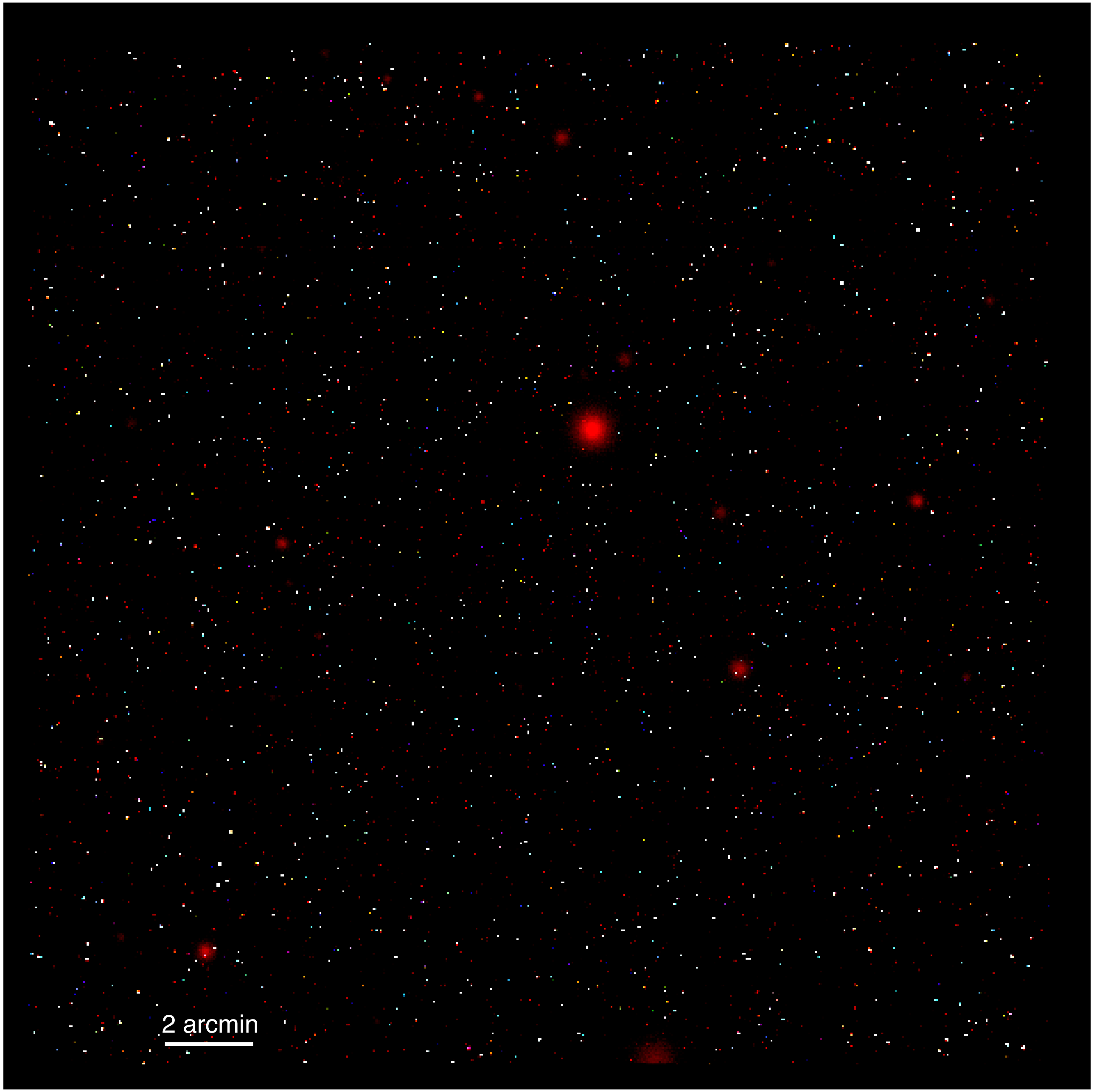
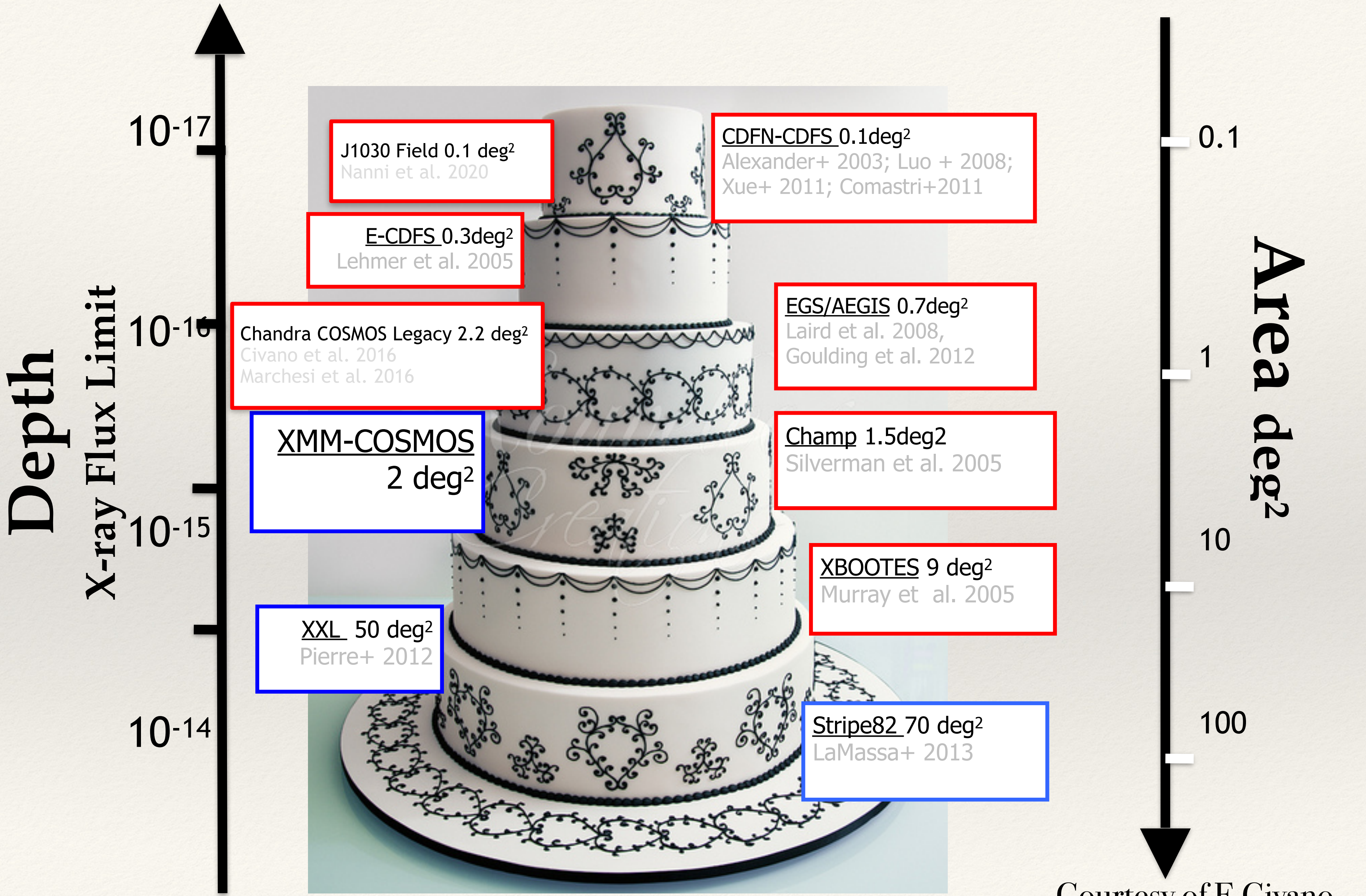
Understanding the AGN population: X-ray surveys

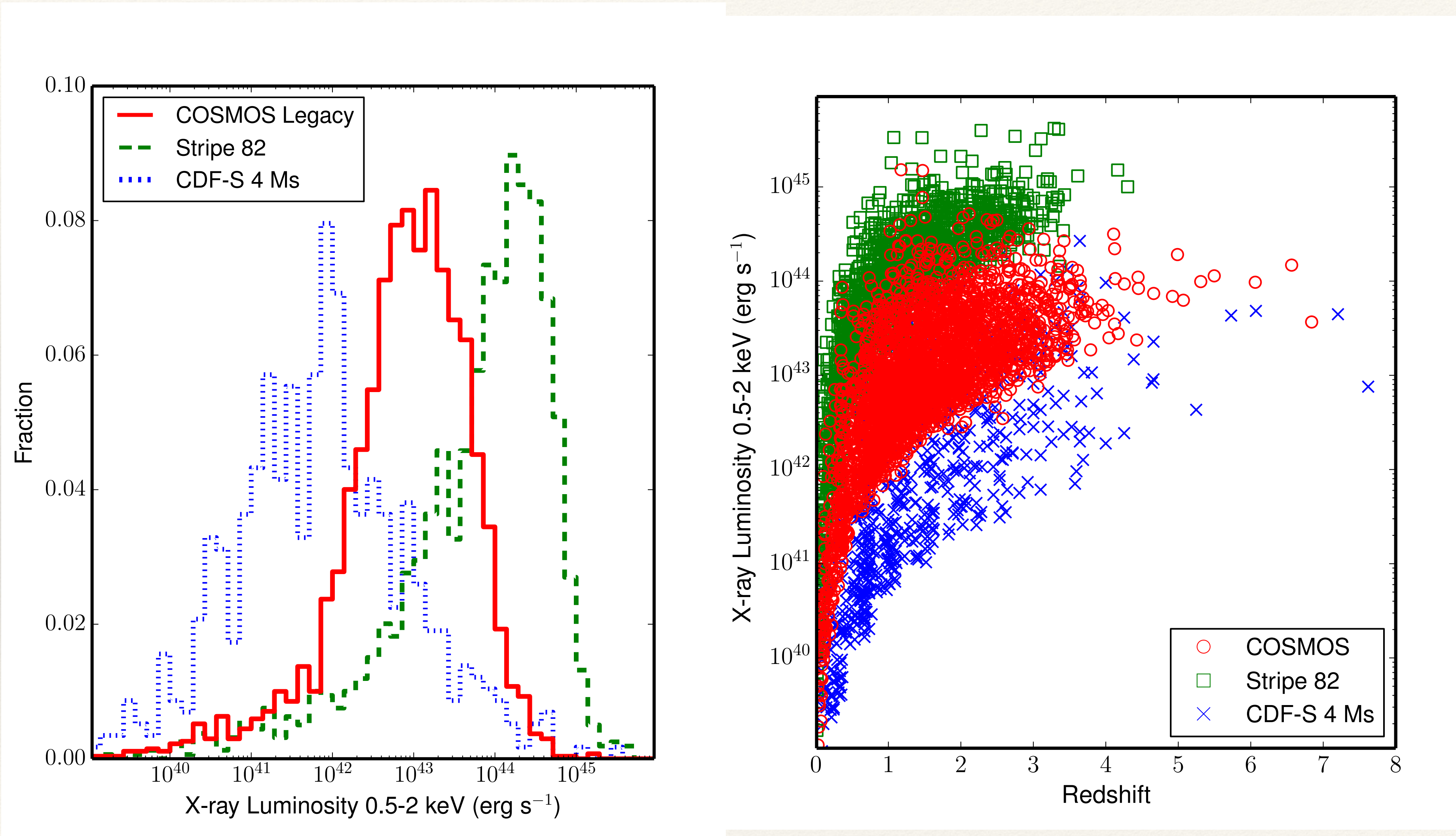


The X-ray surveys wedding-cake strategy



Courtesy of F.Civano

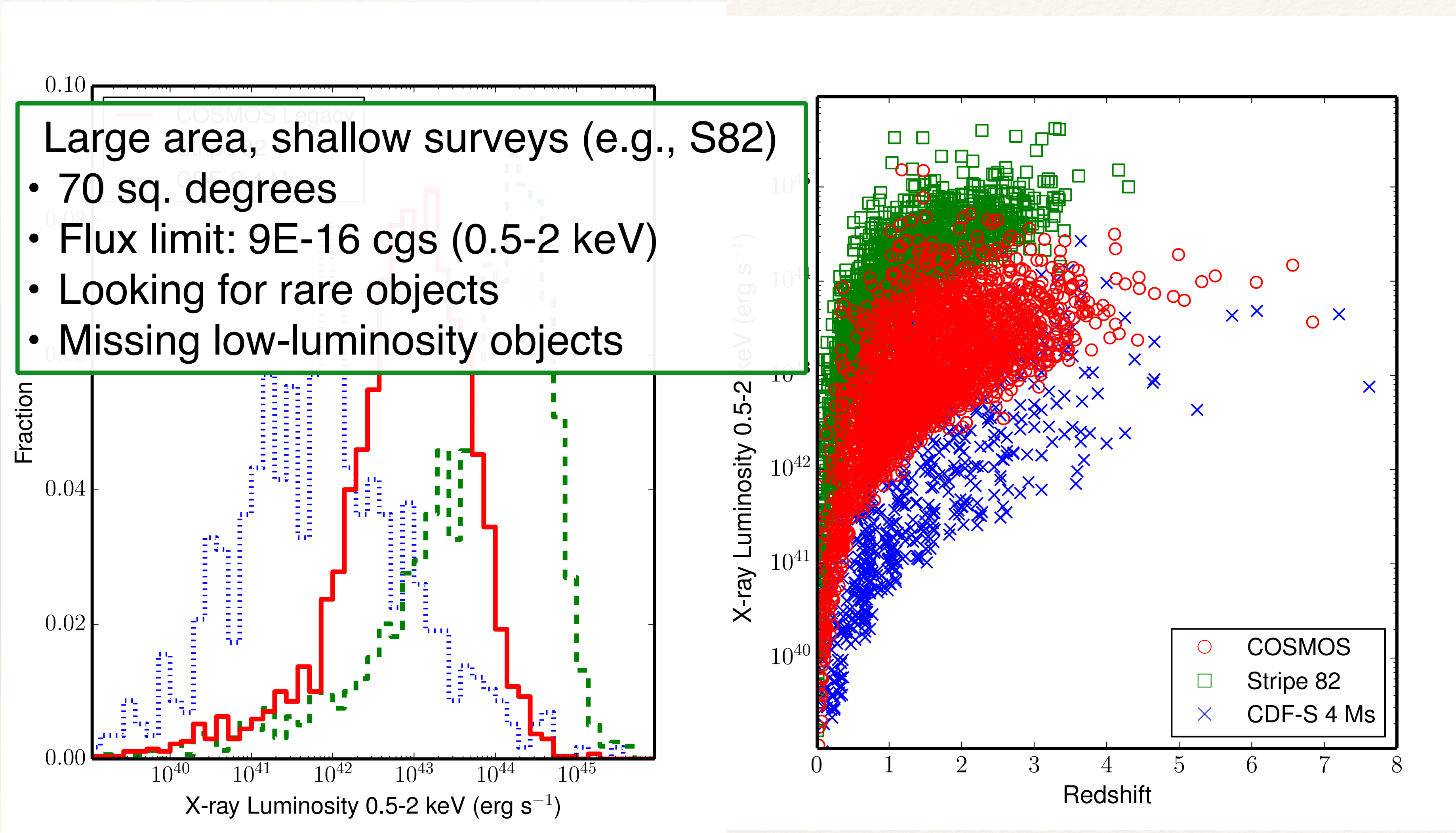
Different surveys for different science



Marchesi et al. 2016

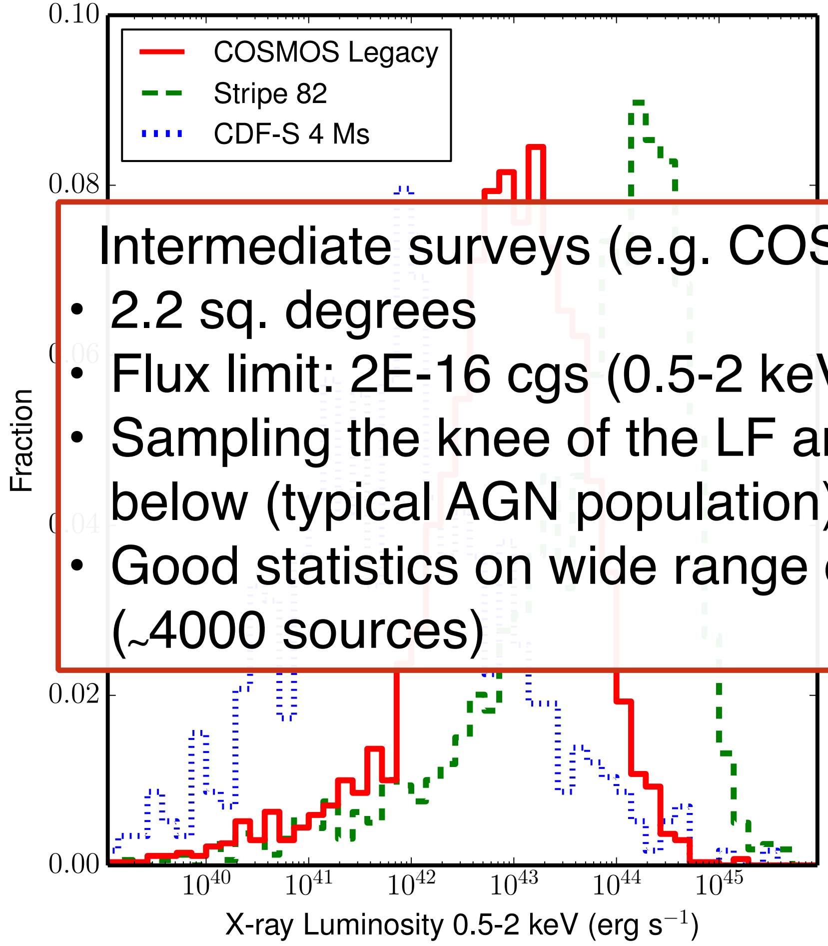
Different surveys for different science

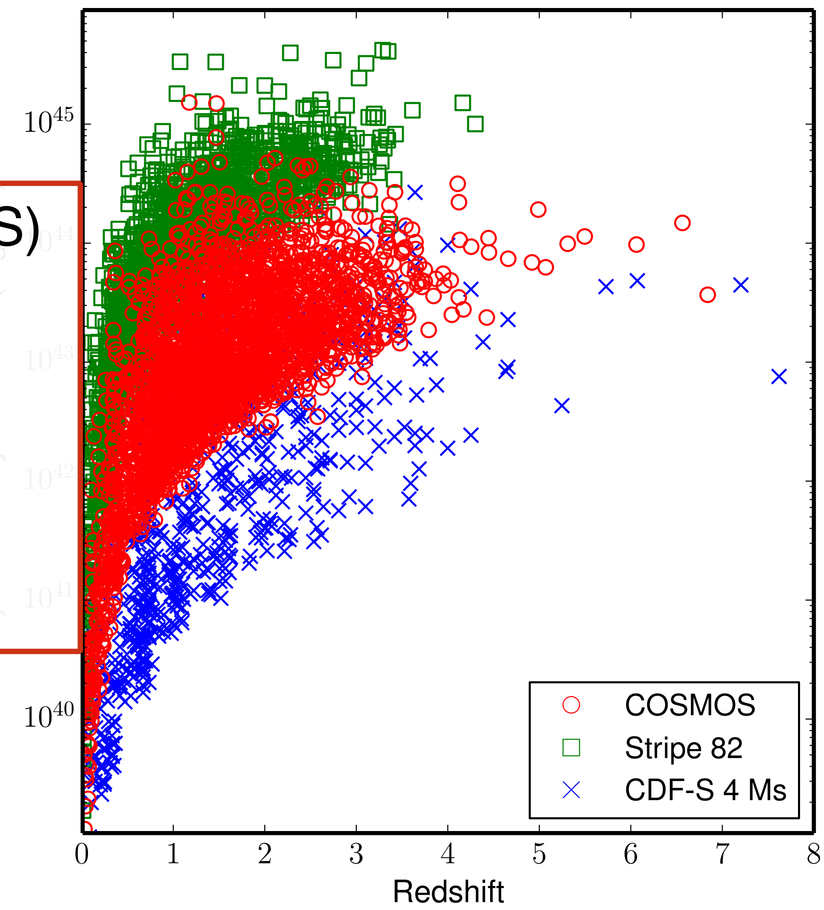
Large area, shallow surveys (e.g., S82)
- 70 sq. degrees
- Flux limit: 9E-16 cgs (0.5-2 keV)
- Looking for rare objects
- Missing low-luminosity objects



Marchesi et al. 2016

Different surveys for different science



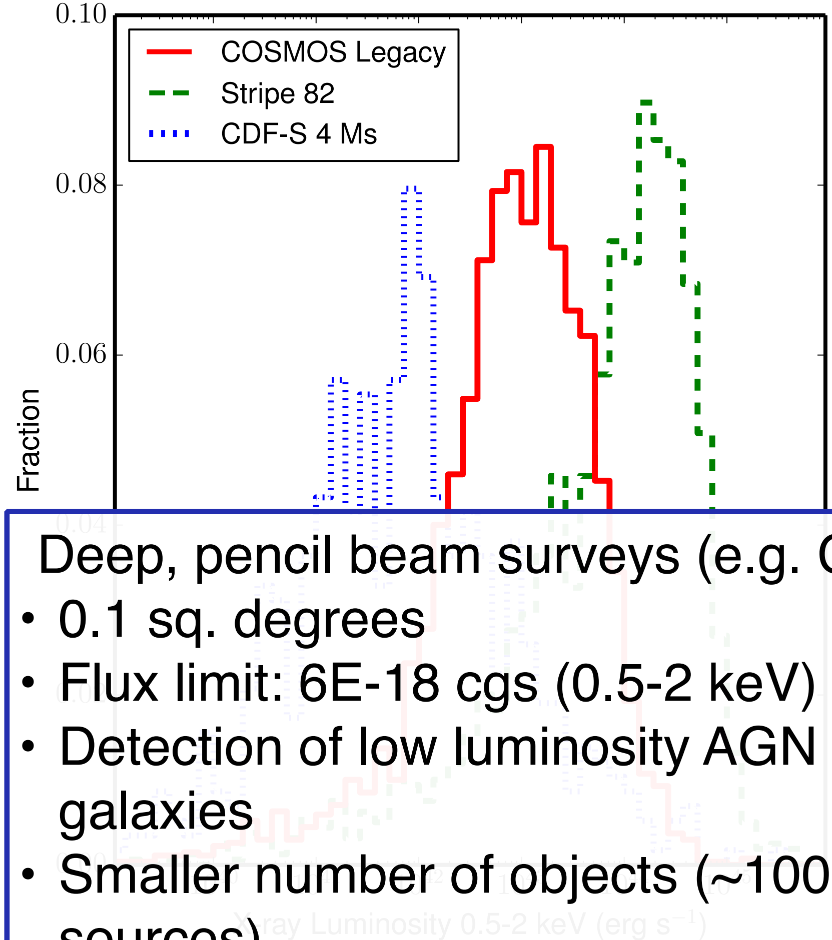


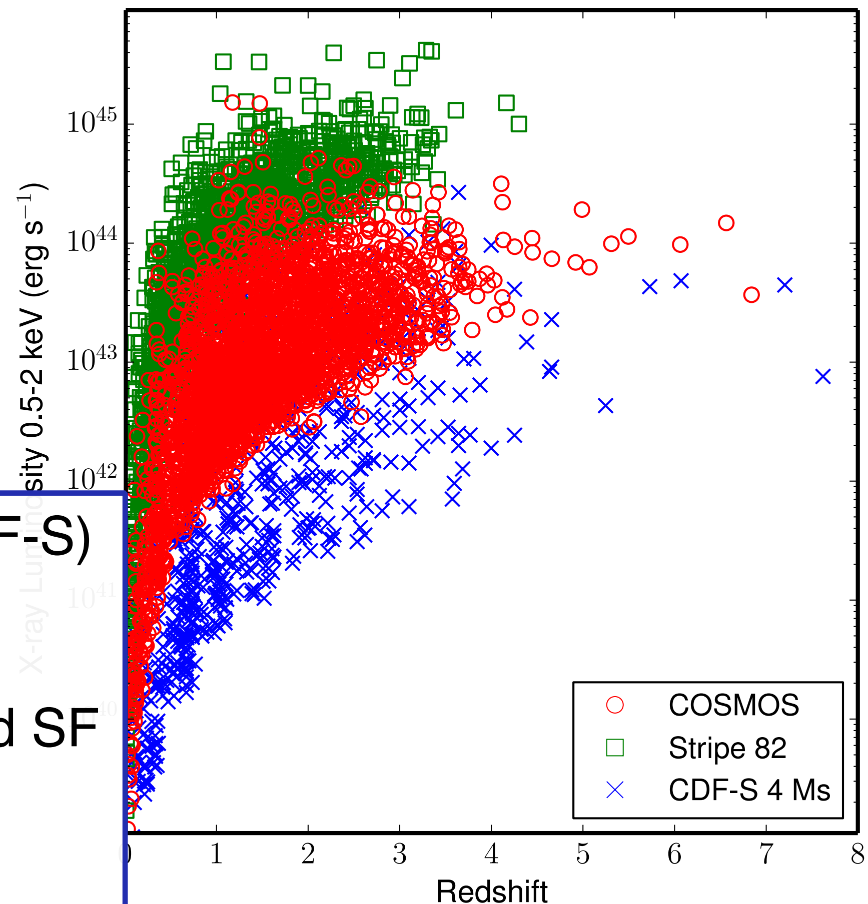
Intermediate surveys (e.g. COSMOS)

- 2.2 sq. degrees
- Flux limit: 2E-16 cgs (0.5-2 keV)
- Sampling the knee of the LF and below (typical AGN population)
- Good statistics on wide range of z (~4000 sources)

Marchesi et al. 2016

Different surveys for different science





Deep, pencil beam surveys (e.g. CDF-S)

- 0.1 sq. degrees
- Flux limit: 6E-18 cgs (0.5-2 keV)
- Detection of low luminosity AGN and SF galaxies
- Smaller number of objects (~1000 sources)

Marchesi et al. 2016

Chandra Deep Field-South (CDF-S)

≈7Ms *Chandra* exposure (last obs. at March 2016)

≈3Ms XMM-*Newton* exposure

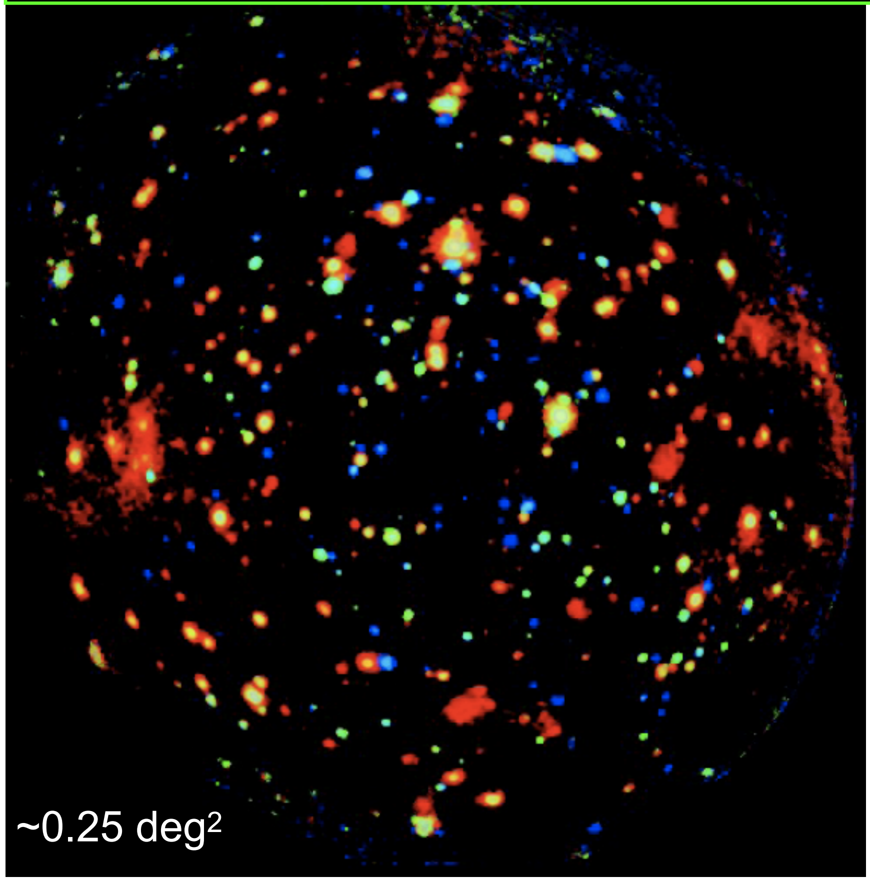
Deep multi-wavelength coverage

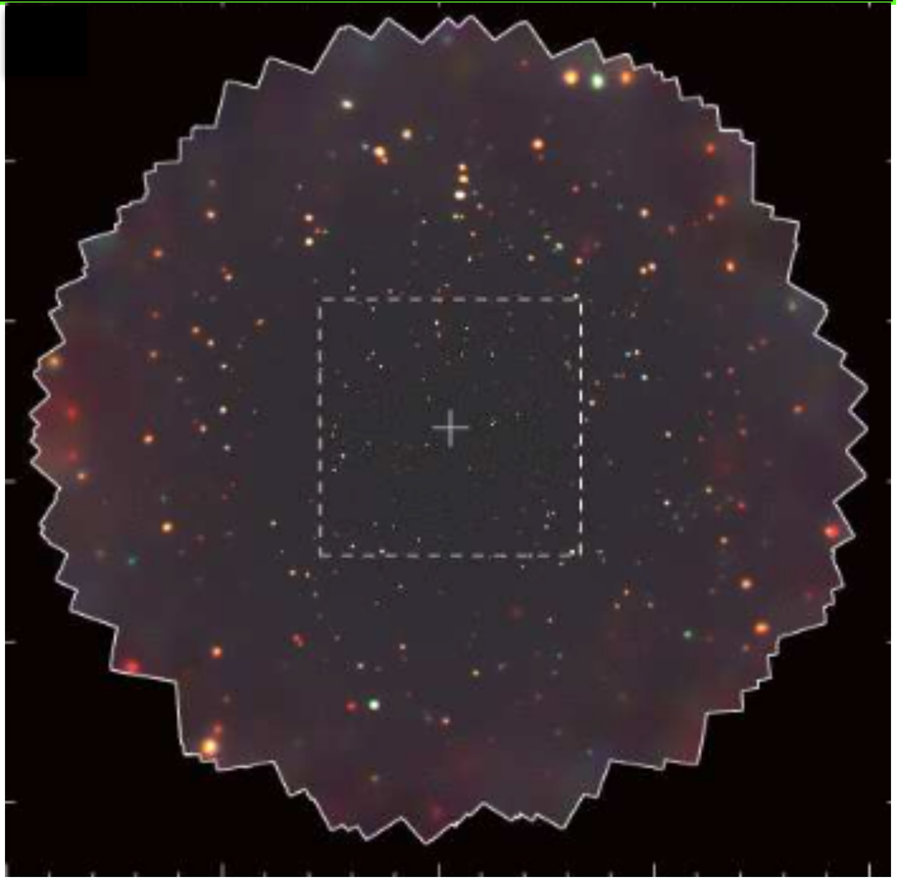
One of the legacy fields (no deeper field for the next 20 yrs)

Chandra: good on-axis PSF (i.e., excellent angular resolution) and low background
➔ Sensitive to faint and distant AGN

XMM-*Newton*: larger effective area (hence photon statistics), but much worse angular resolution and higher background
➔ Better for X-ray spectroscopy of relatively bright AGN

The deepest X-ray field: CDF-S





XMM-CDFS 3 Ms survey
(PI: A. Comastri; Ranalli+13)

Chandra-CDFS 7 Ms survey
(PI: R. Giacconi, W.N Brandt; Xue+11, Luo+17)

F(2-10keV)≈6.6×10^{-16} erg/cm^2/s

F(0.5-2keV)≈6.4^{-18} erg/cm^2/s

Capable of probing the high-z Universe with some photon statistics

This Lab Outline

1. **Build the source catalog**: Produce a mosaic using 4 long CDFS exposures and provide source detections with different setups. Visualize the outputs and cross-match sources with the official 7Ms source catalog.
2. **Explore the source catalog**: For one of the newly produced catalogs, produce some relevant plots, and compare quantities with those reported in the 7Ms source catalog
3. **Analyse the data products**: Fit the X-ray spectra of a few, particularly interesting sources.

Lab Outline
1) Build the source catalog

a. Reprocess with chandra_repro four different Chandra observations of the CDF-S. Generate all data products (event files, exposure maps…) that are needed to perform a source detection using the merge_obs tool.

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```
punlearn merge_obs
pset merge_obs infiles=@infile.lis
pset merge_obs outroot=CDFS_4obs
pset merge_obs asolfiles=@asol.lis
pset merge_obs badpixfiles=@bpix.lis
pset merge_obs maskfiles=@mask.lis
pset merge_obs parallel=yes
pset merge_obs nproc=4
pset merge_obs units=time
pset merge_obs bands=broad
pset merge_obs xygrid=0.5:8192.5:1,0.5:8192.5:1
pset merge_obs psfecf=0.9
pset merge_obs psfmerge=exptime
merge_obs
```

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a. Download and combine four different Chandra observations of the CDF-S. Generate all data products (event files, exposure maps…) that are needed to perform a source detection using the merge_obs tool.

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b. Run the wavdetect tool to search sources in your observations, using different significance thresholds (i.e., your detections can be more or less reliable) and different maximum wavelet scales (important if there are extended sources and for objects in the external part of the field).

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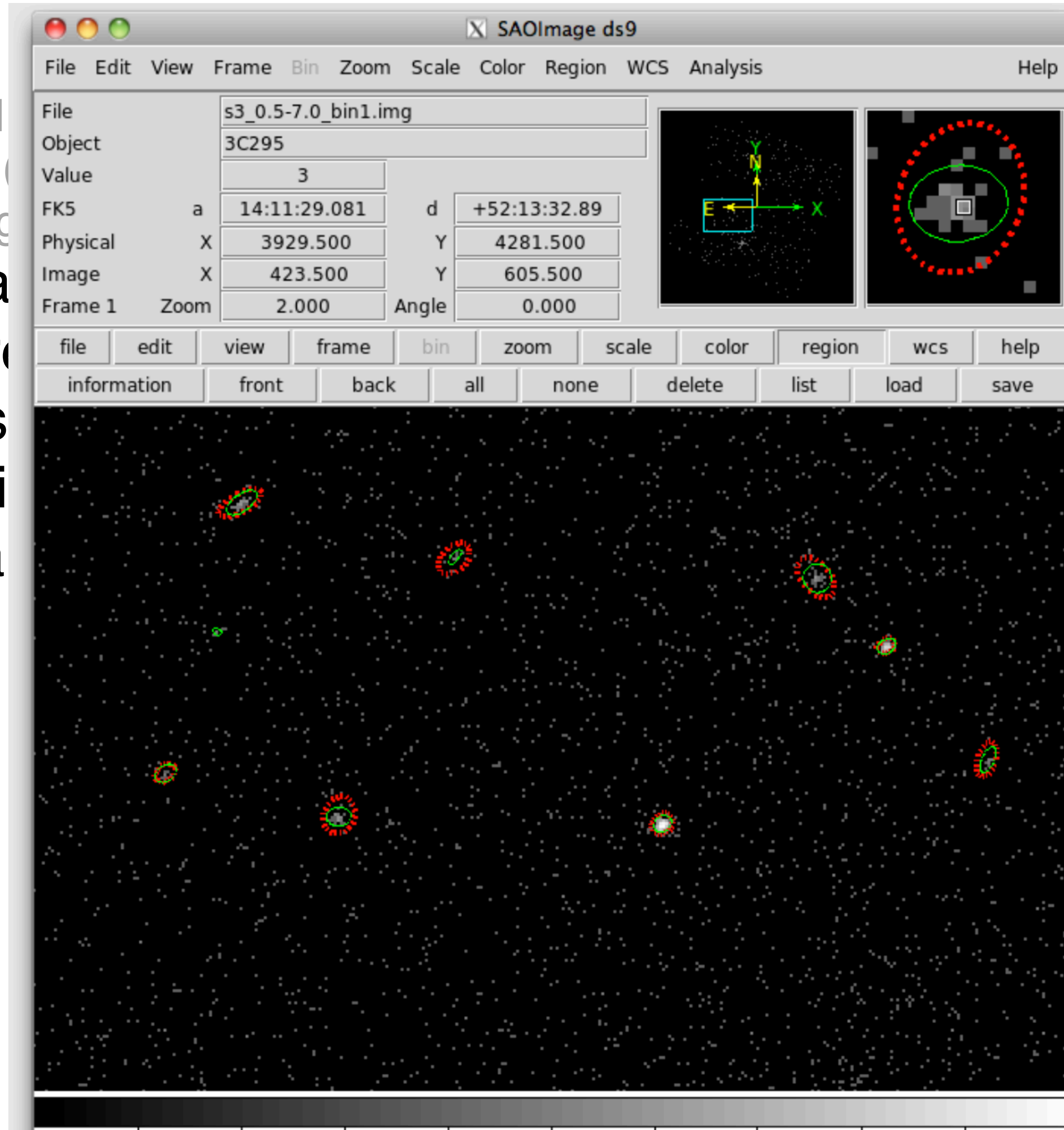

b. Run the wa… …ervations, using differ… …ctions can be more or les… … scales (important i… …cts in the external pa…

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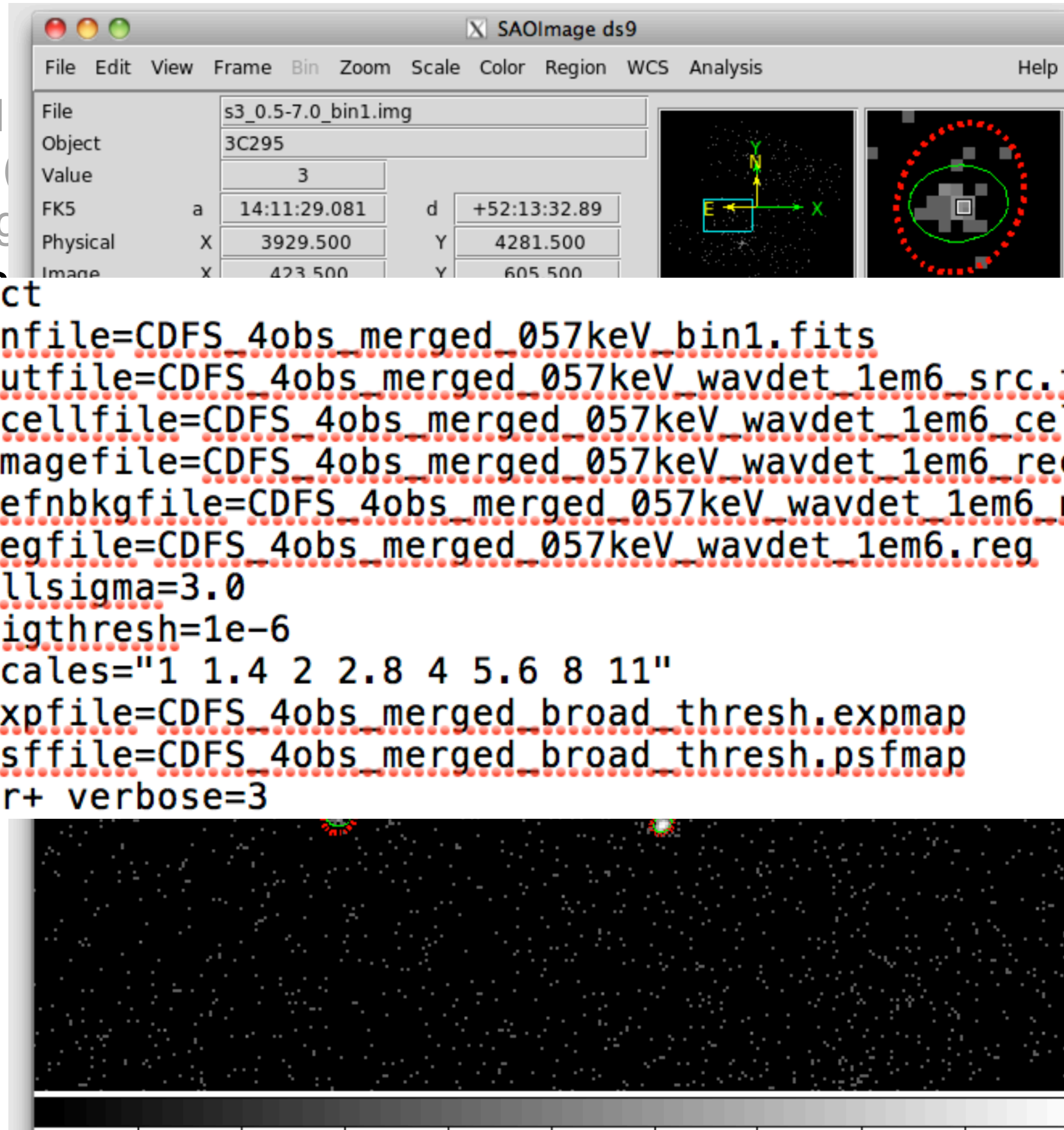


```
punlearn wavdetect
pset wavdetect infile=CDFS_4obs_merged_057keV_bin1.fits
pset wavdetect outfile=CDFS_4obs_merged_057keV_wavdet_1em6_src.fits
pset wavdetect scellfile=CDFS_4obs_merged_057keV_wavdet_1em6_cellimage.fits
pset wavdetect imagefile=CDFS_4obs_merged_057keV_wavdet_1em6_reconstructed.fits
pset wavdetect defnbkgfile=CDFS_4obs_merged_057keV_wavdet_1em6_normbakg.fits
pset wavdetect regfile=CDFS_4obs_merged_057keV_wavdet_1em6.reg
pset wavdetect ellsigma=3.0
pset wavdetect sigthresh=1e-6
pset wavdetect scales="1 1.4 2 2.8 4 5.6 8 11"
pset wavdetect expfile=CDFS_4obs_merged_broad_thresh.expmap
pset wavdetect psffile=CDFS_4obs_merged_broad_thresh.psfmap
wavdetect clobber+ verbose=3
```

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c. Cross-correlate the source lists generated in the previous steps with the official 7 Ms Chandra source catalog in the CDF-S (Luo et al. 2017), using varius cross-matching radii.
    - Compute the fraction of 7Ms sources found in the 4-observation mosaic using different thresholds (1E-6/1E-5/1E-4)/scales (5.6/8/11)/matching radii (1/2/3”).
    - For your source list which has the largest number matches within 2” with the 7 Ms CDF-S catalog, compute the number of sources detected in the 4-observation mosaic and not in the 7Ms catalog, and visualize them: what are the possible explanations for their detection in the your shorter-exposure mosaic?

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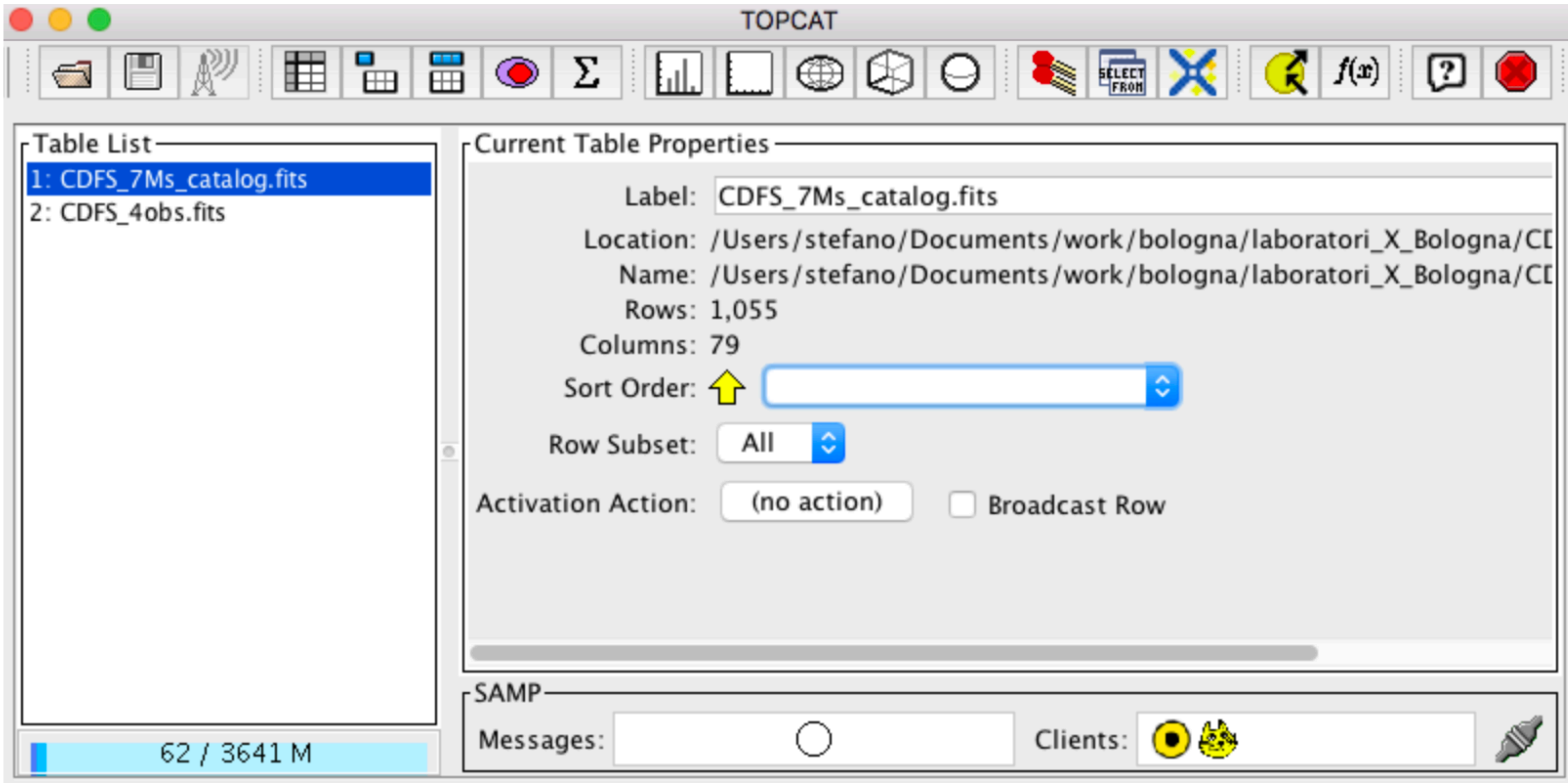

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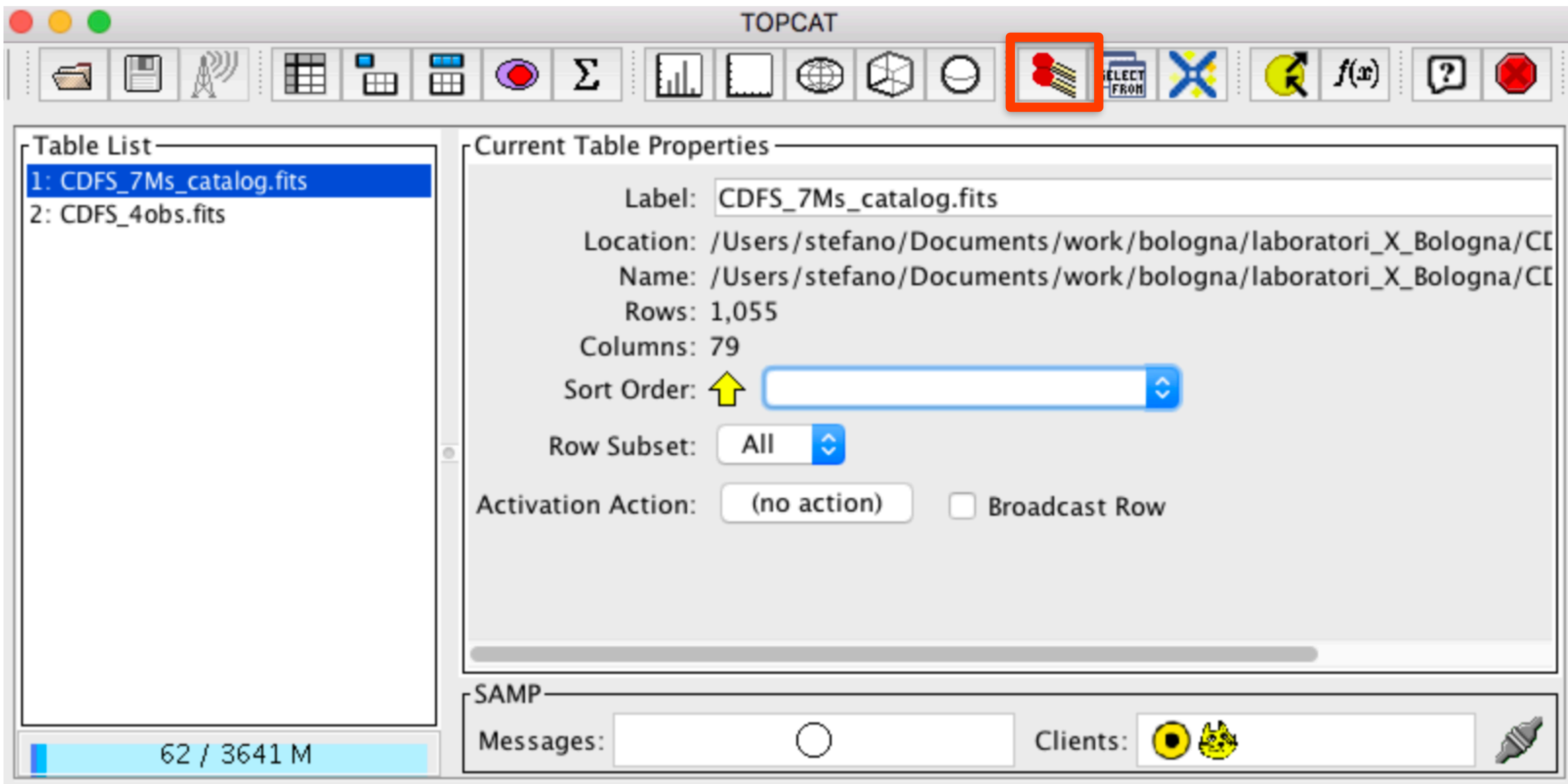

1) B … alog

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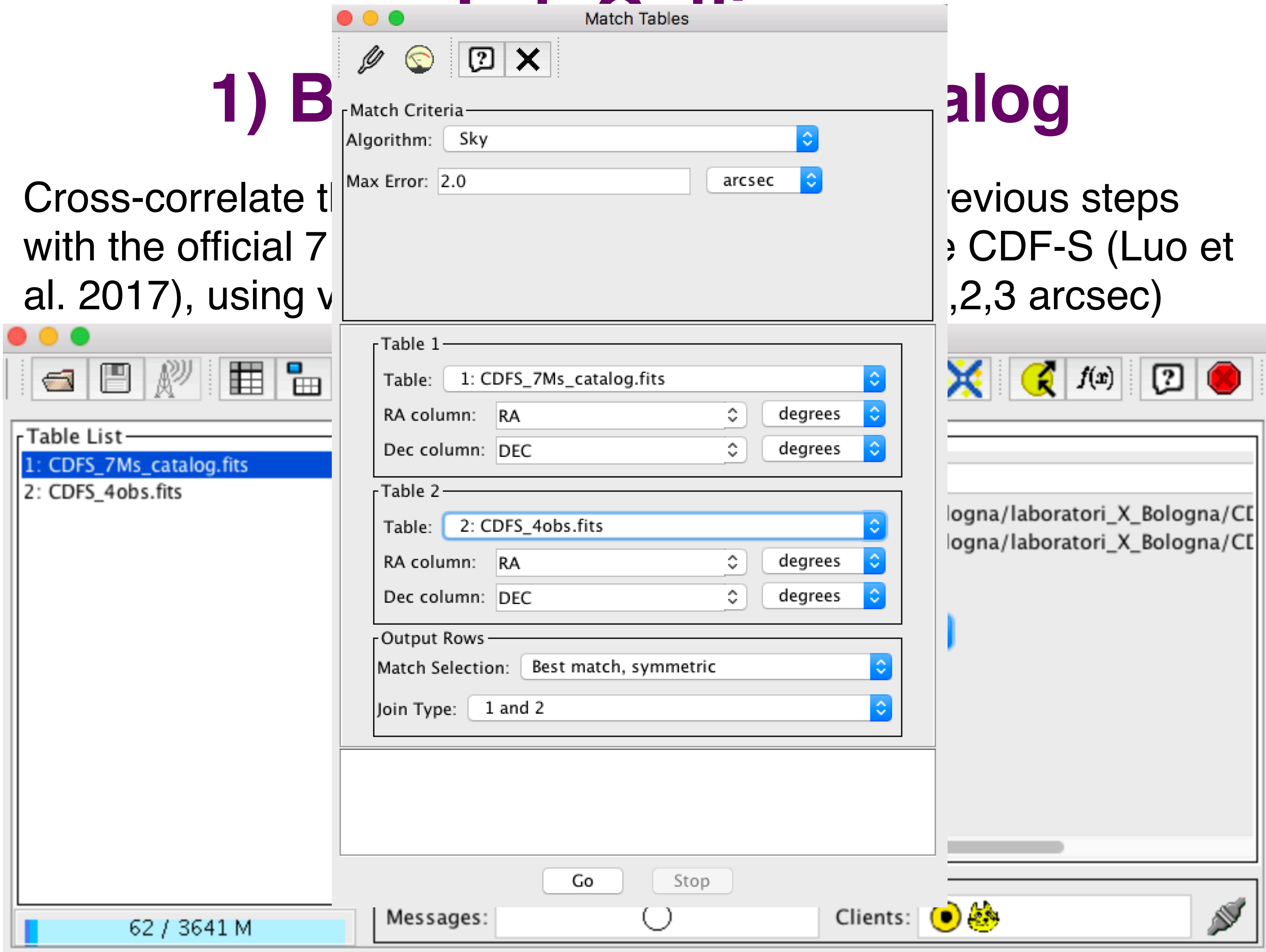

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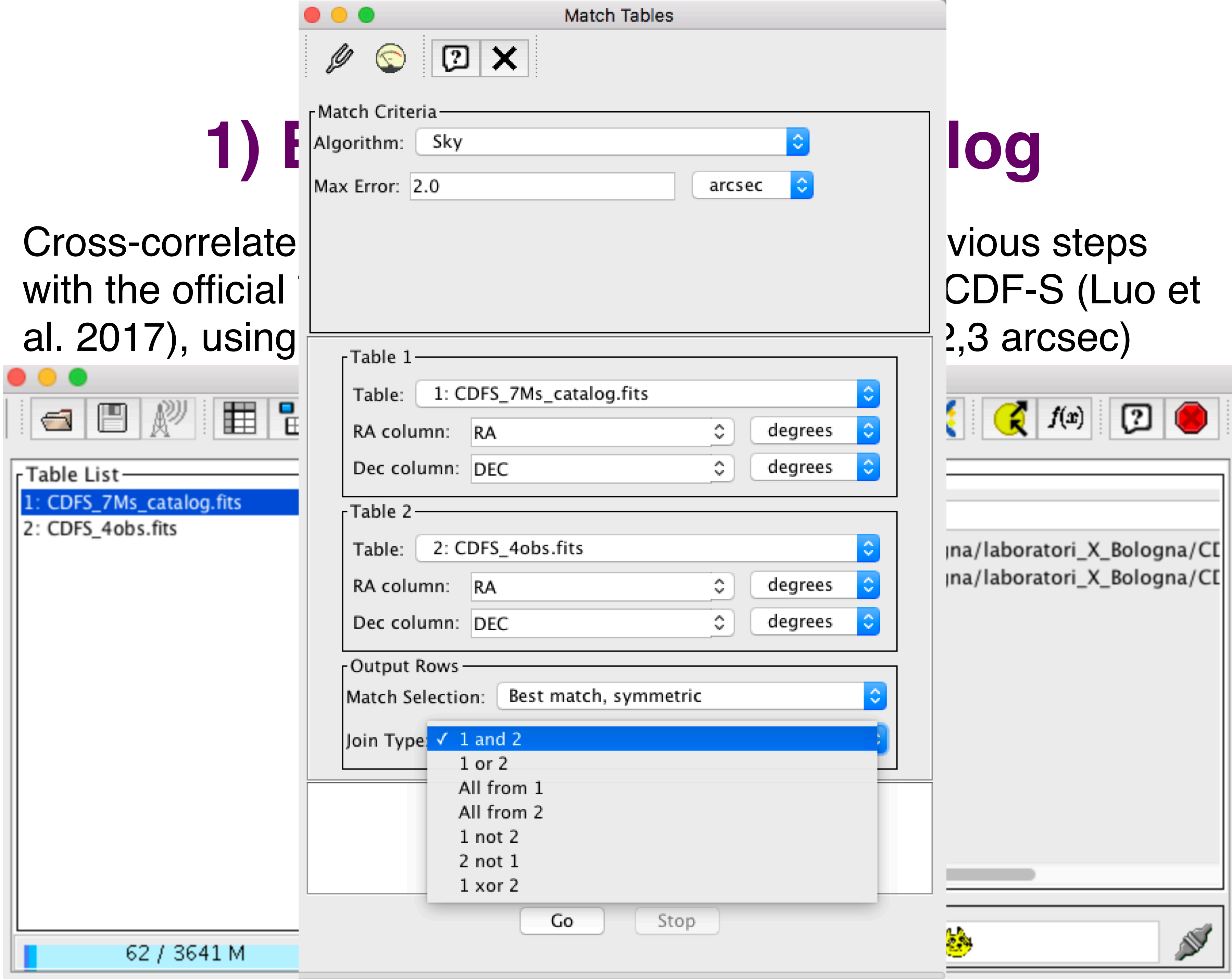

Lab Outline
2) Explore the source catalog

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a. Choose one of the catalogs you built (e.g., the one with largest number of matches with the CDF-S 7 Ms one) and produce some plots (number of counts vs. source significance, vs. exposure time, vs. positional uncertainty, etc.)

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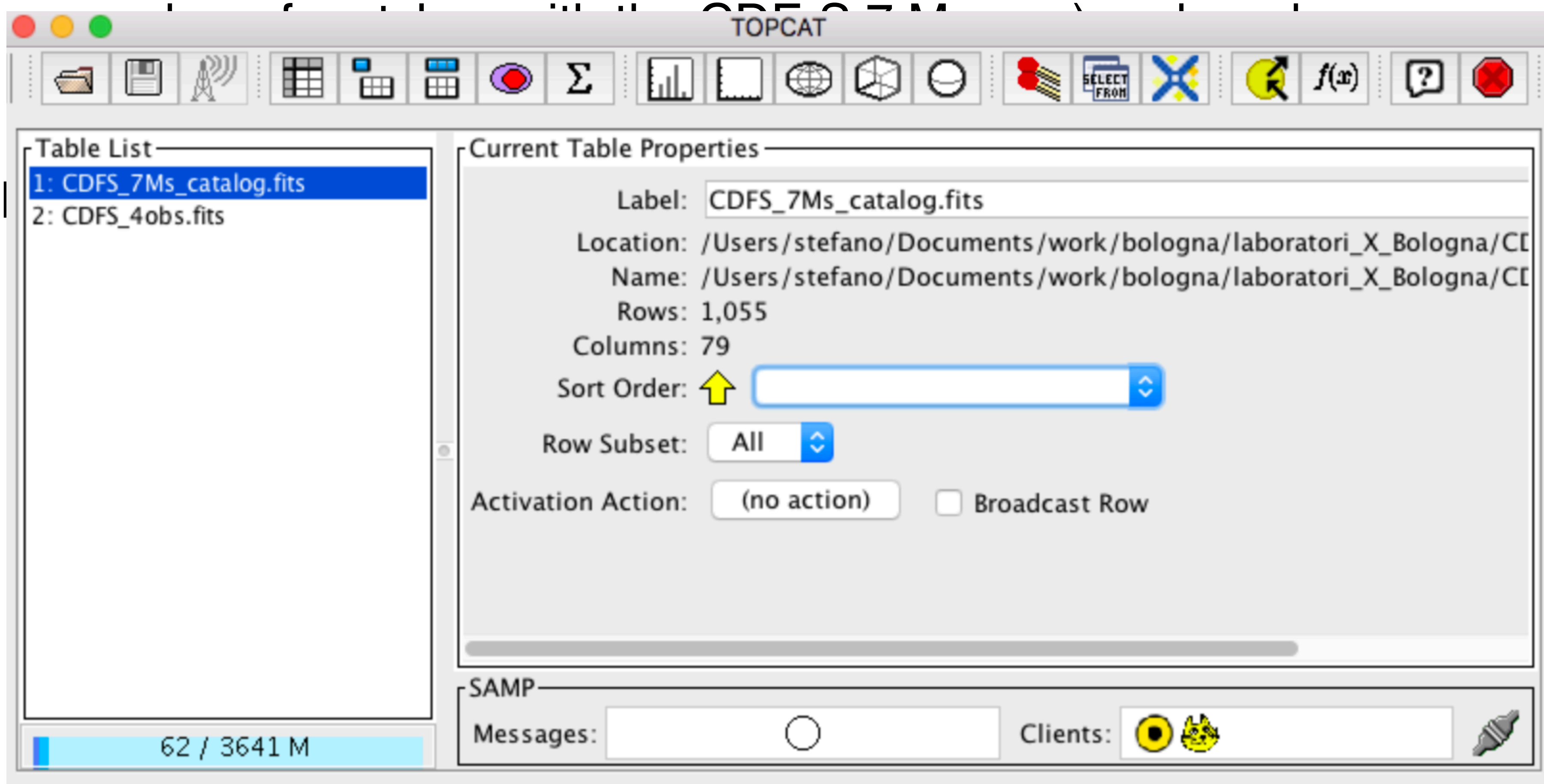

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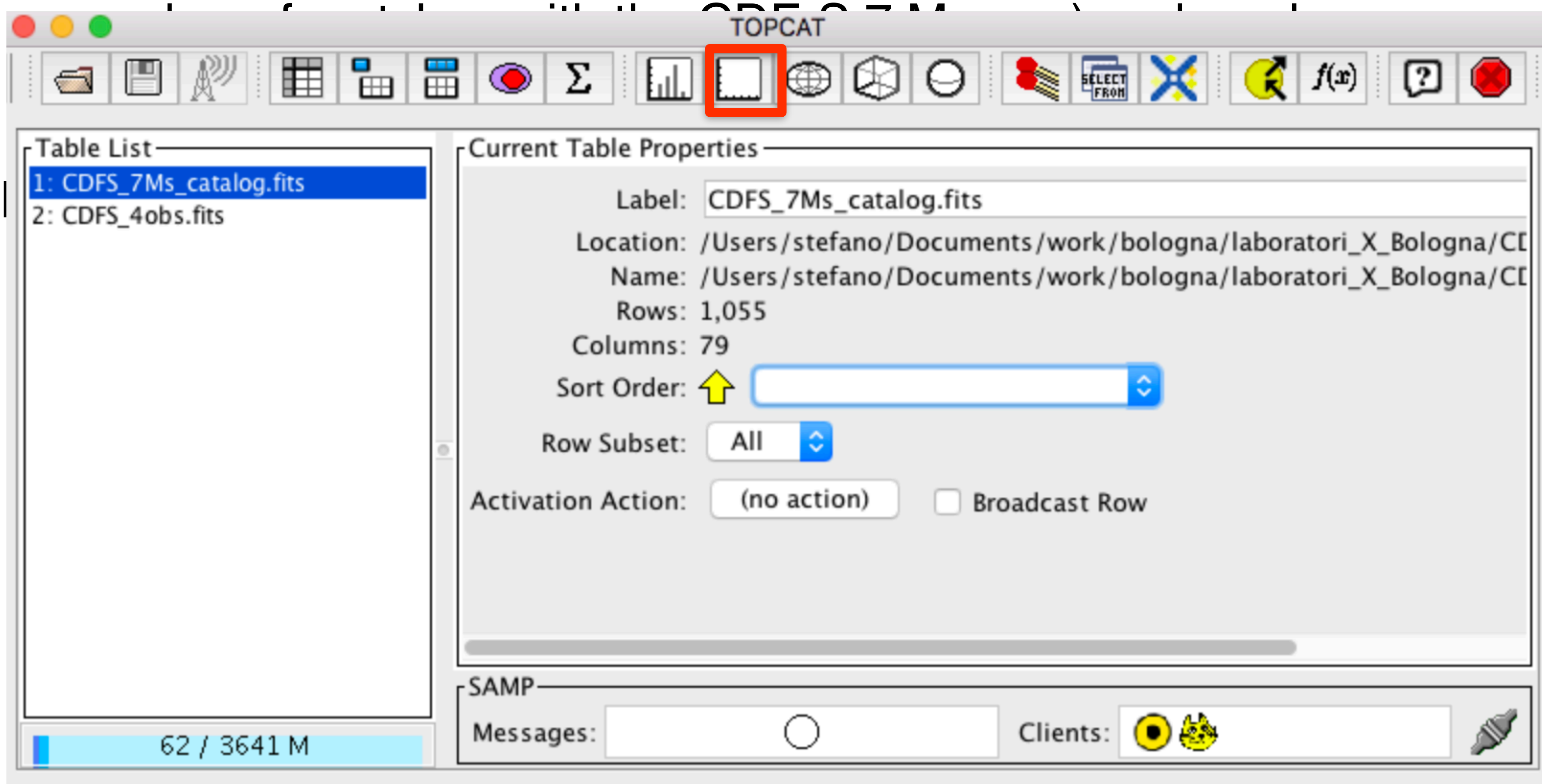

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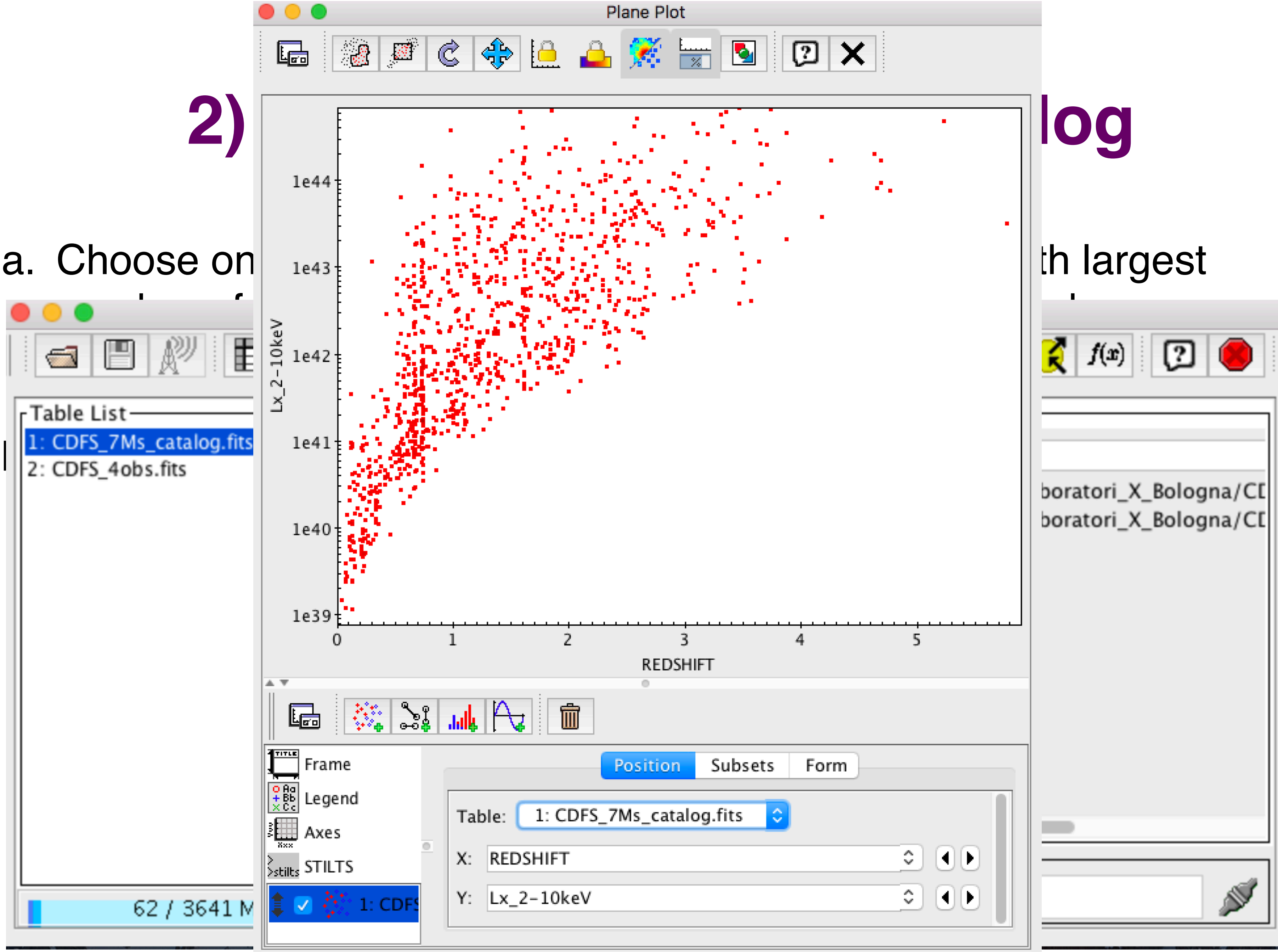

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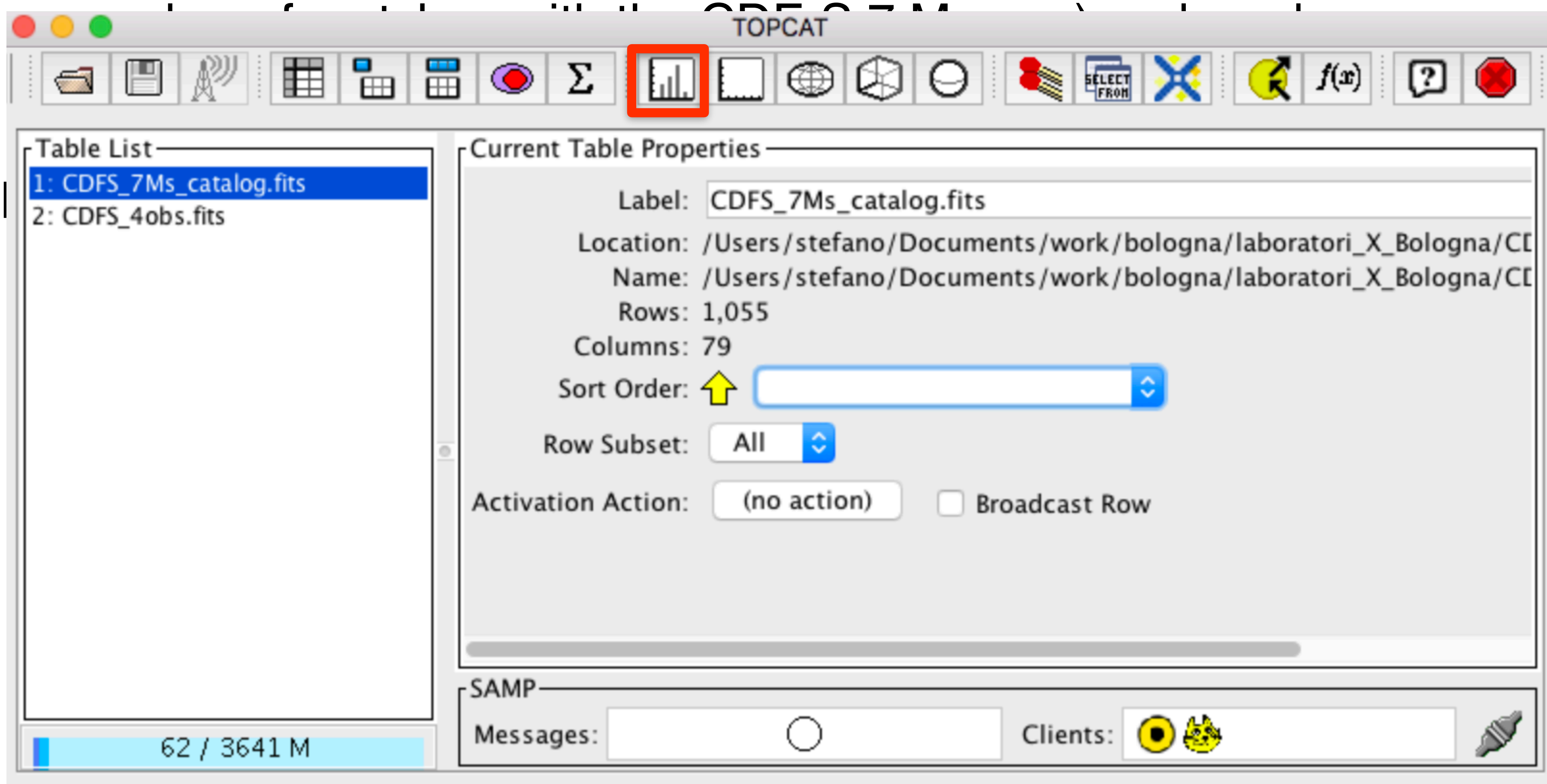

2 ... og

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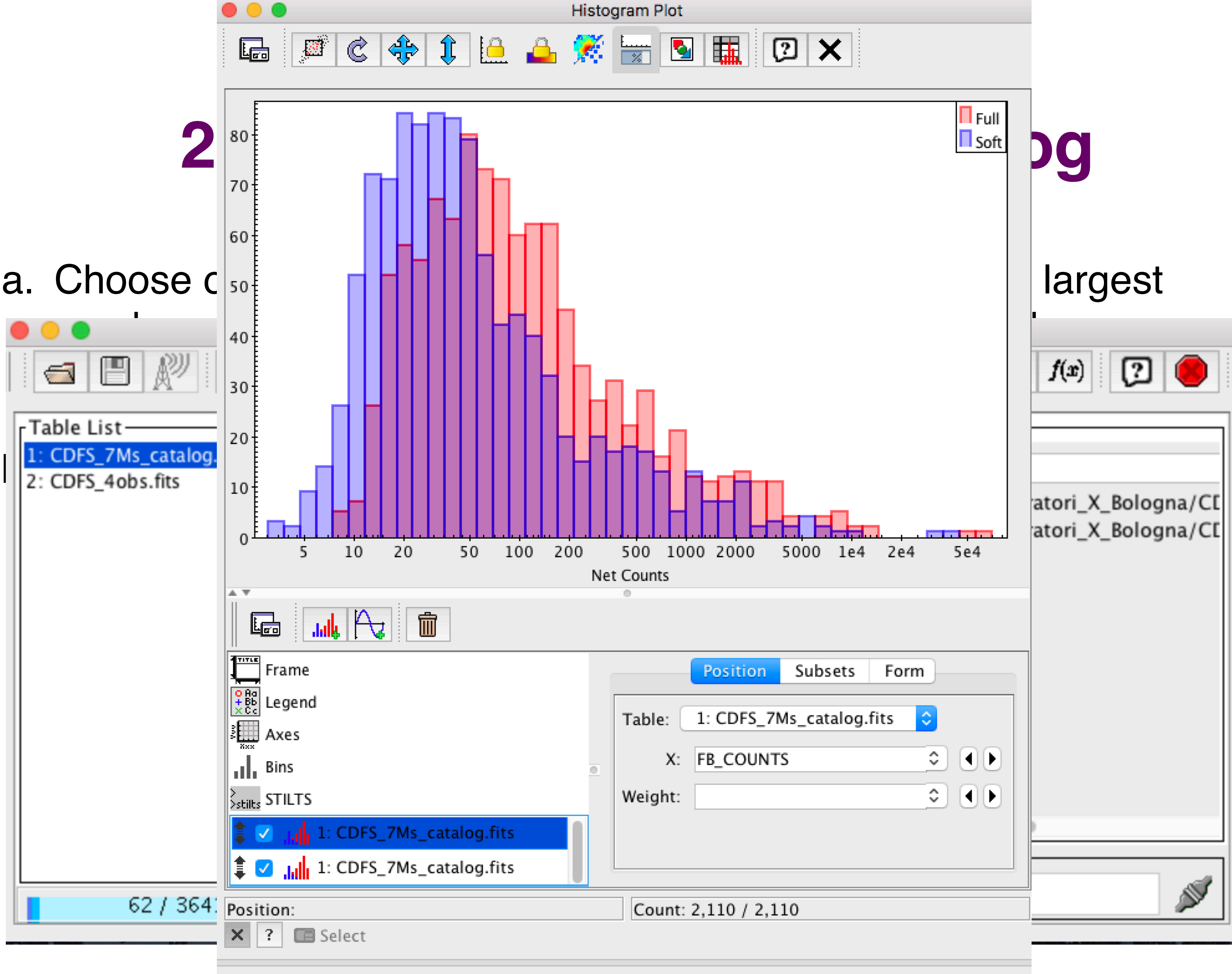

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a. Choose one of the produced catalogs and produce some plots (number of counts vs. source significance, vs. exposure time, vs. positional uncertainty, etc.)
b. For the sources associated with the 7 Ms source catalog, produce the redshift distribution histogram, Lx vs. z plot, etc.
c. Repeat the operation done in b. after creating subsamples of sources from the 7 Ms source catalog (e.g., spec-z vs phot-z; low vs high band-ratio…). Are there any noticeable trends?

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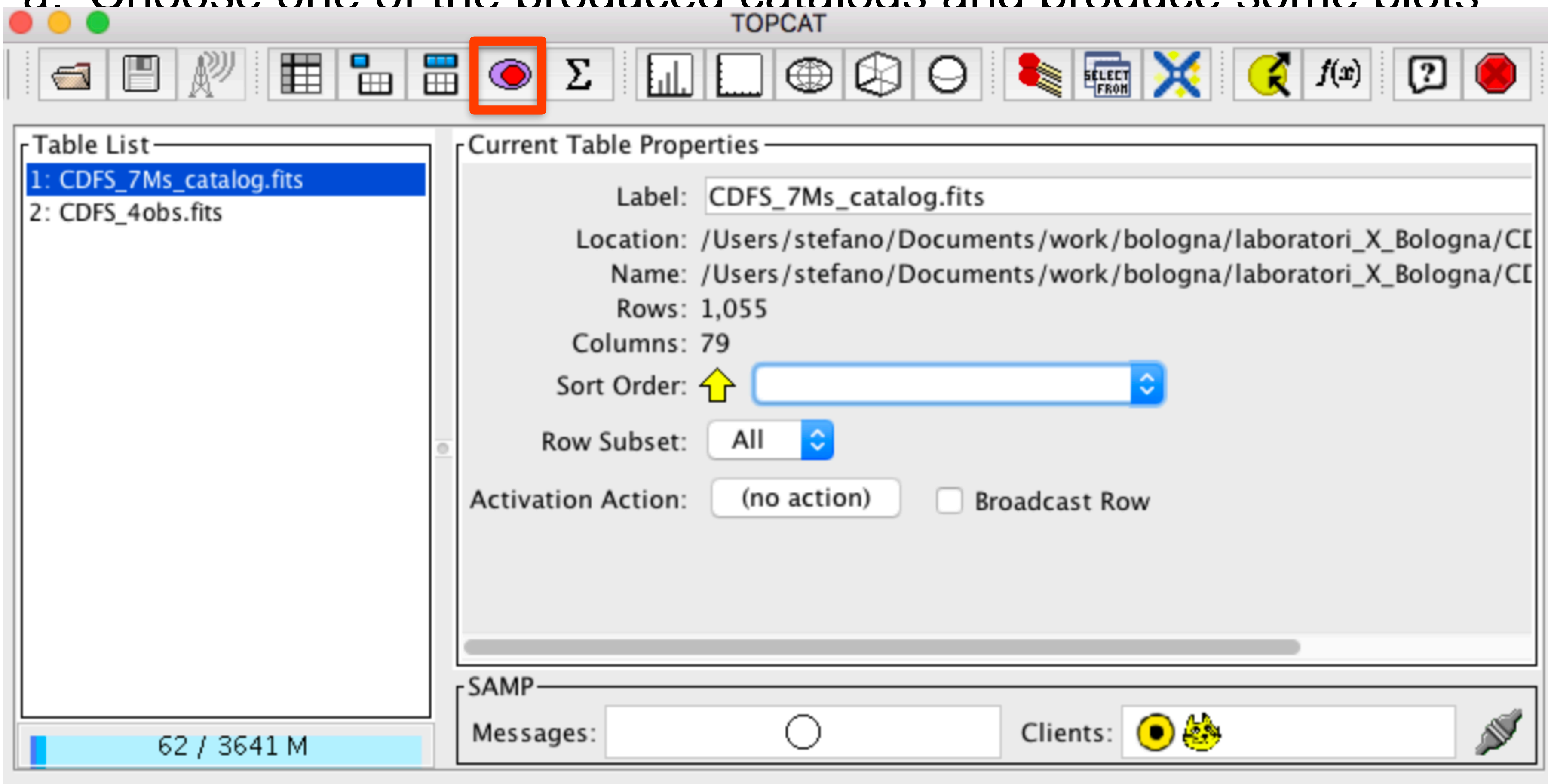

vs

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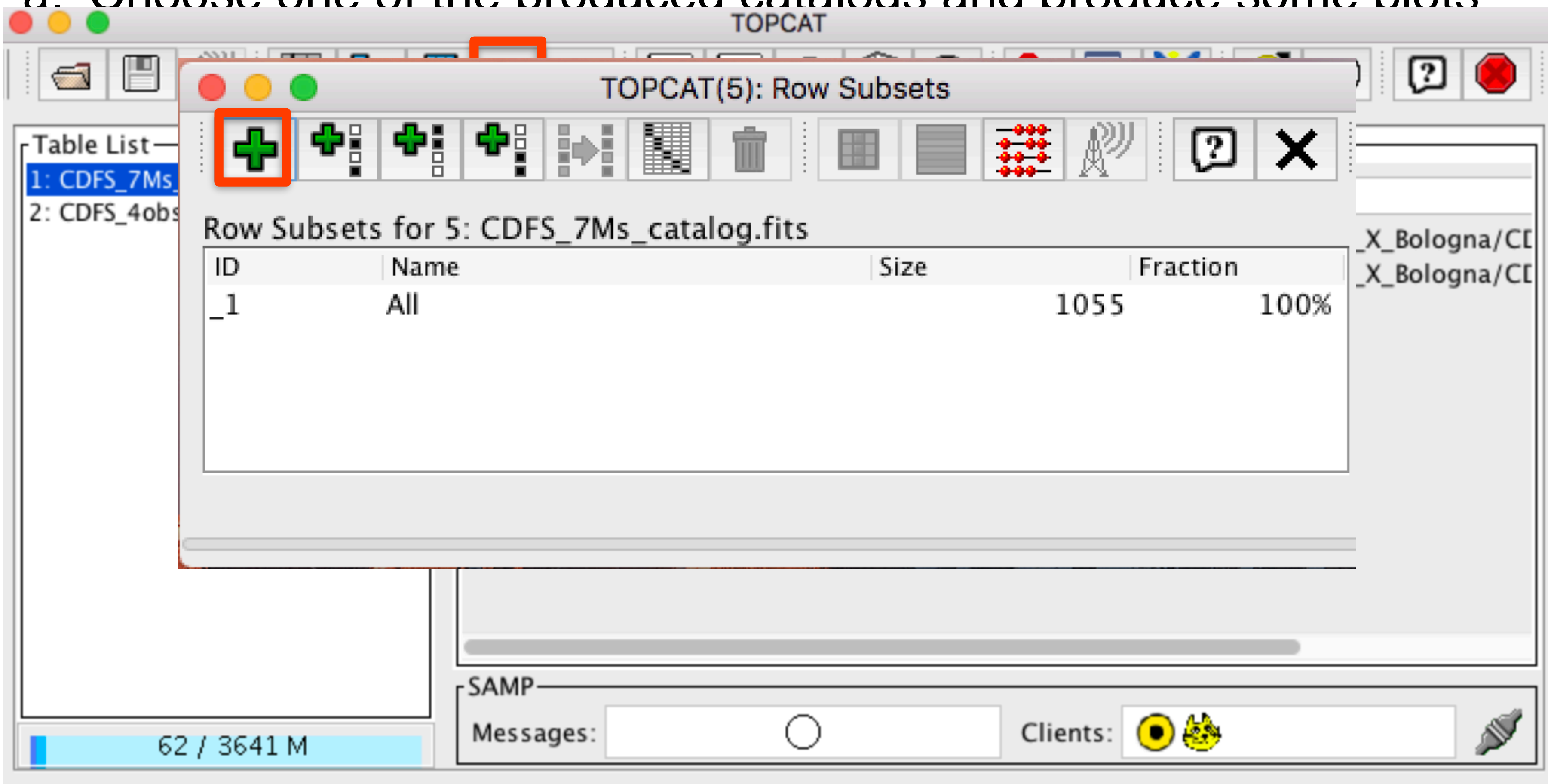

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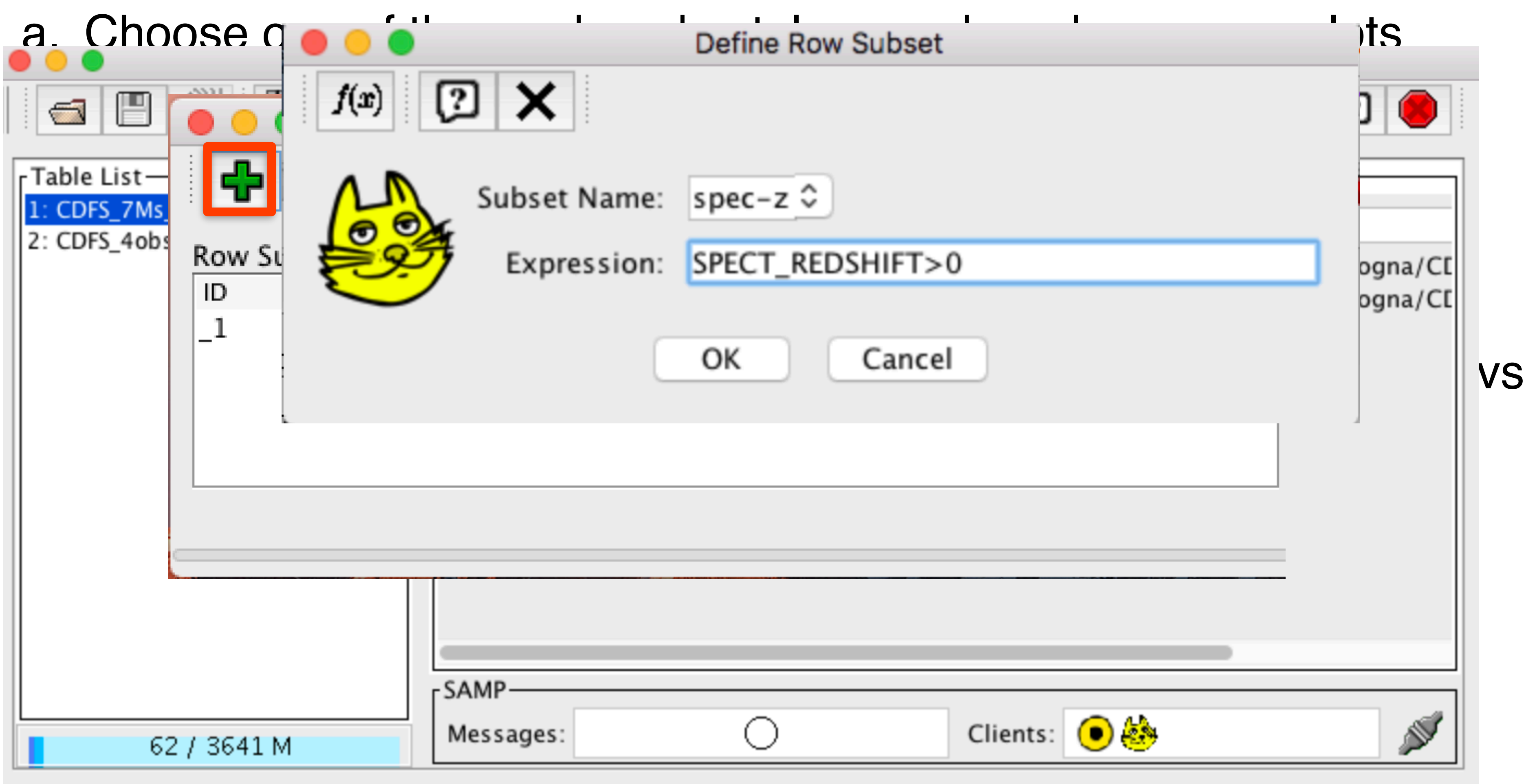

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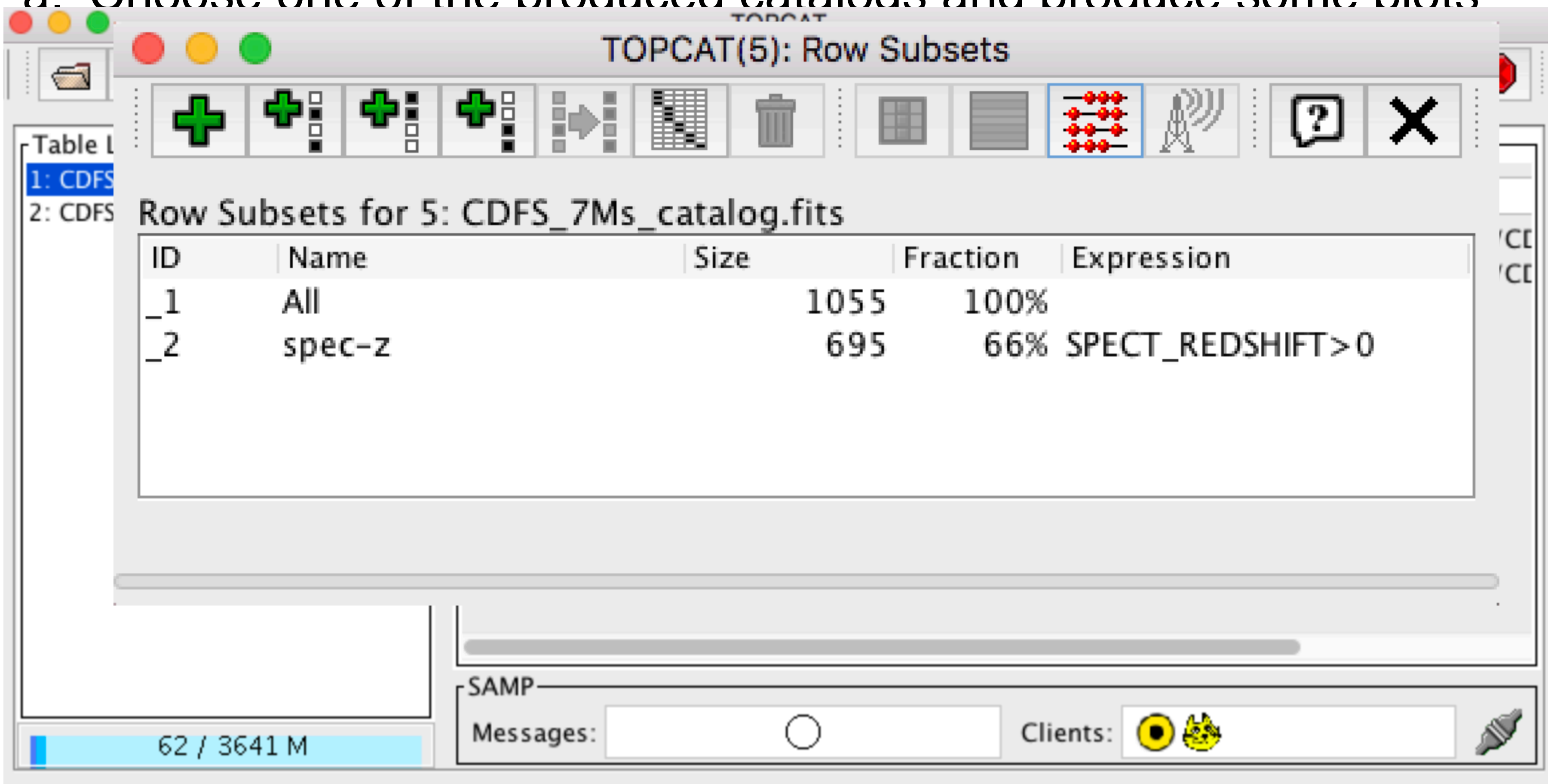

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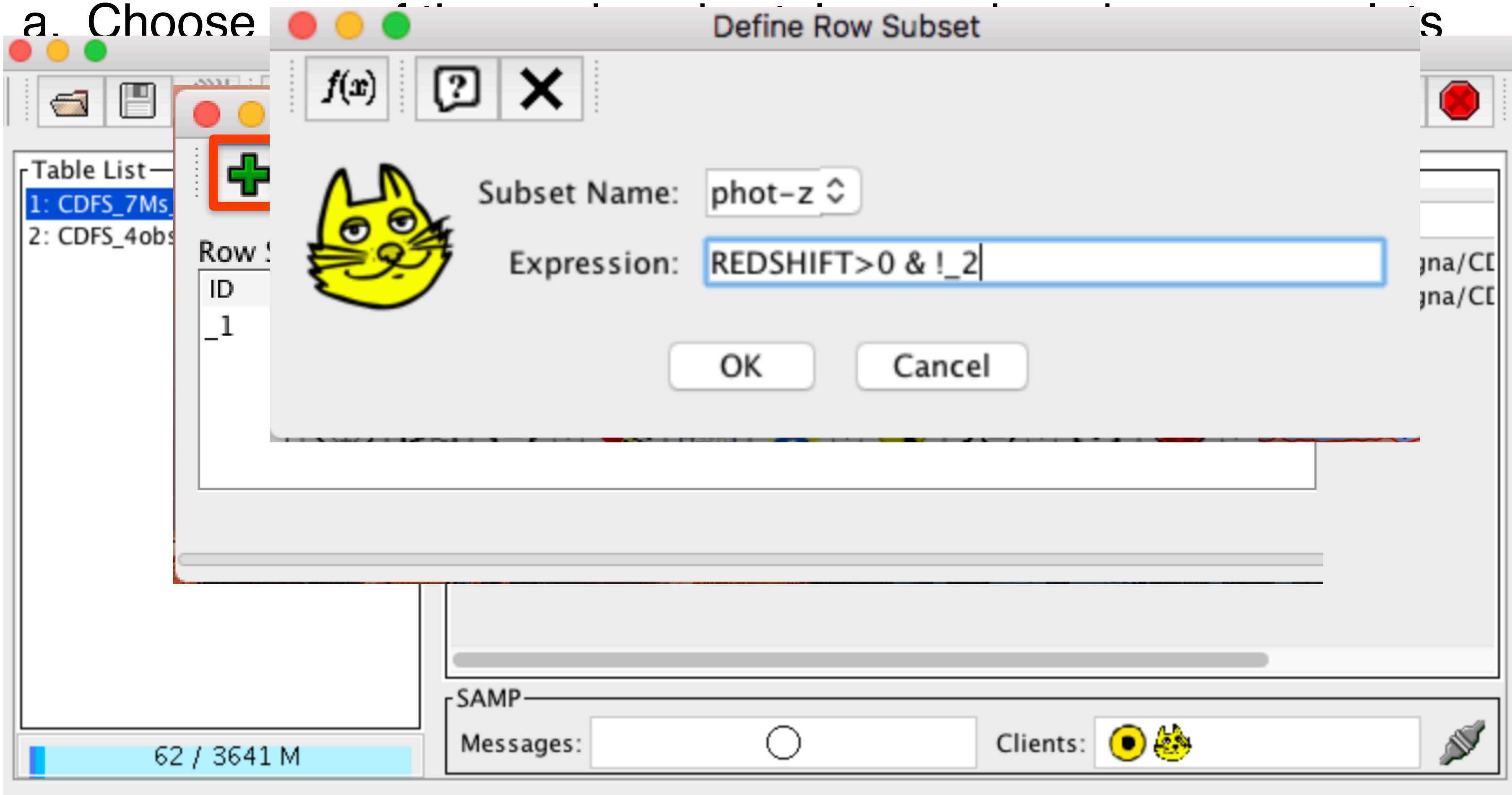

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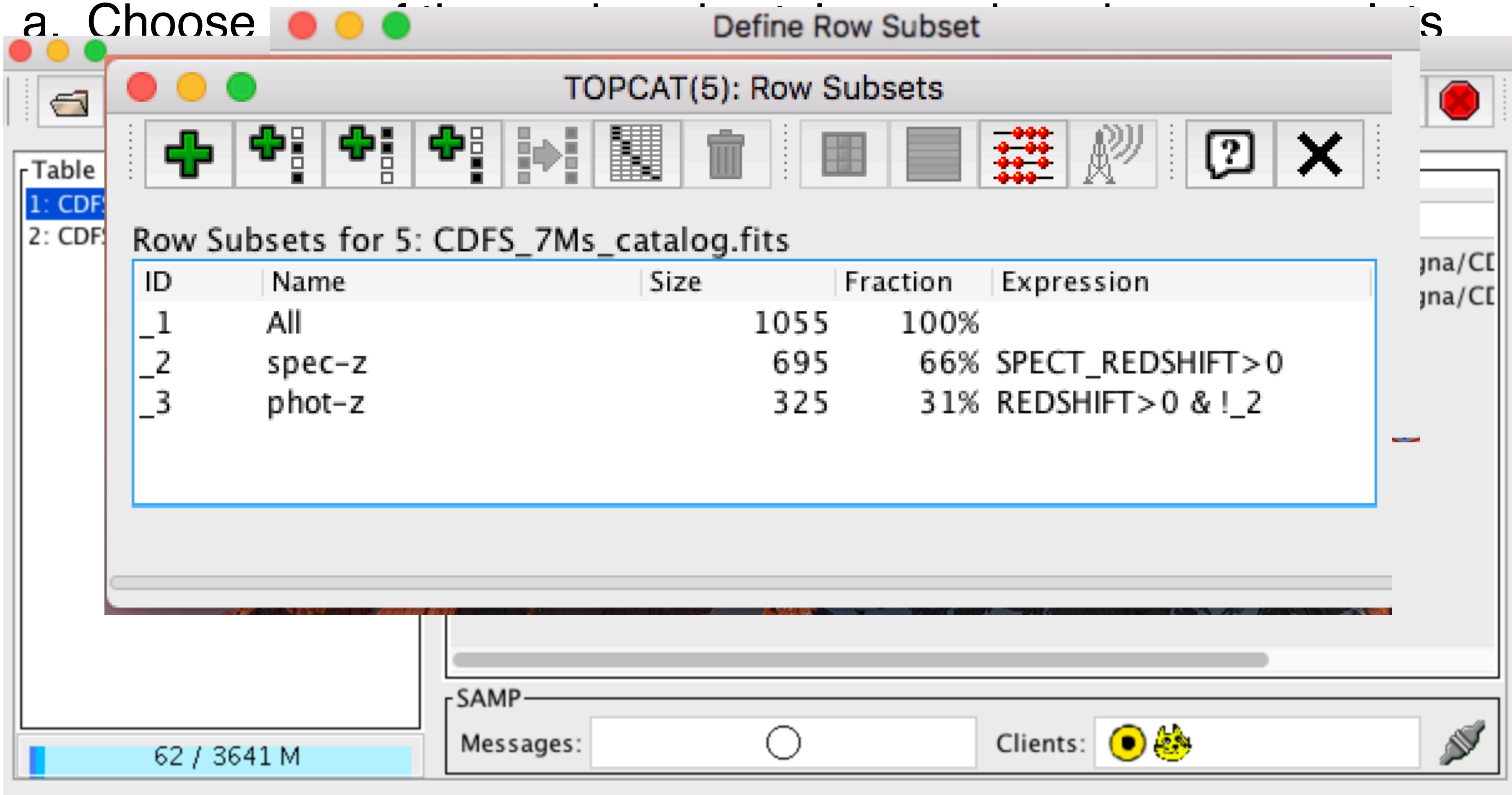

vs

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a. Repeat the operation done in b. after creating subsamples of sources from the 7 Ms source catalog (e.g., spec-z vs phot-z; low vs high band-ratio…). Are there any noticeable trends?
b. The trends can also be quantified using the Topcat statistics tool.

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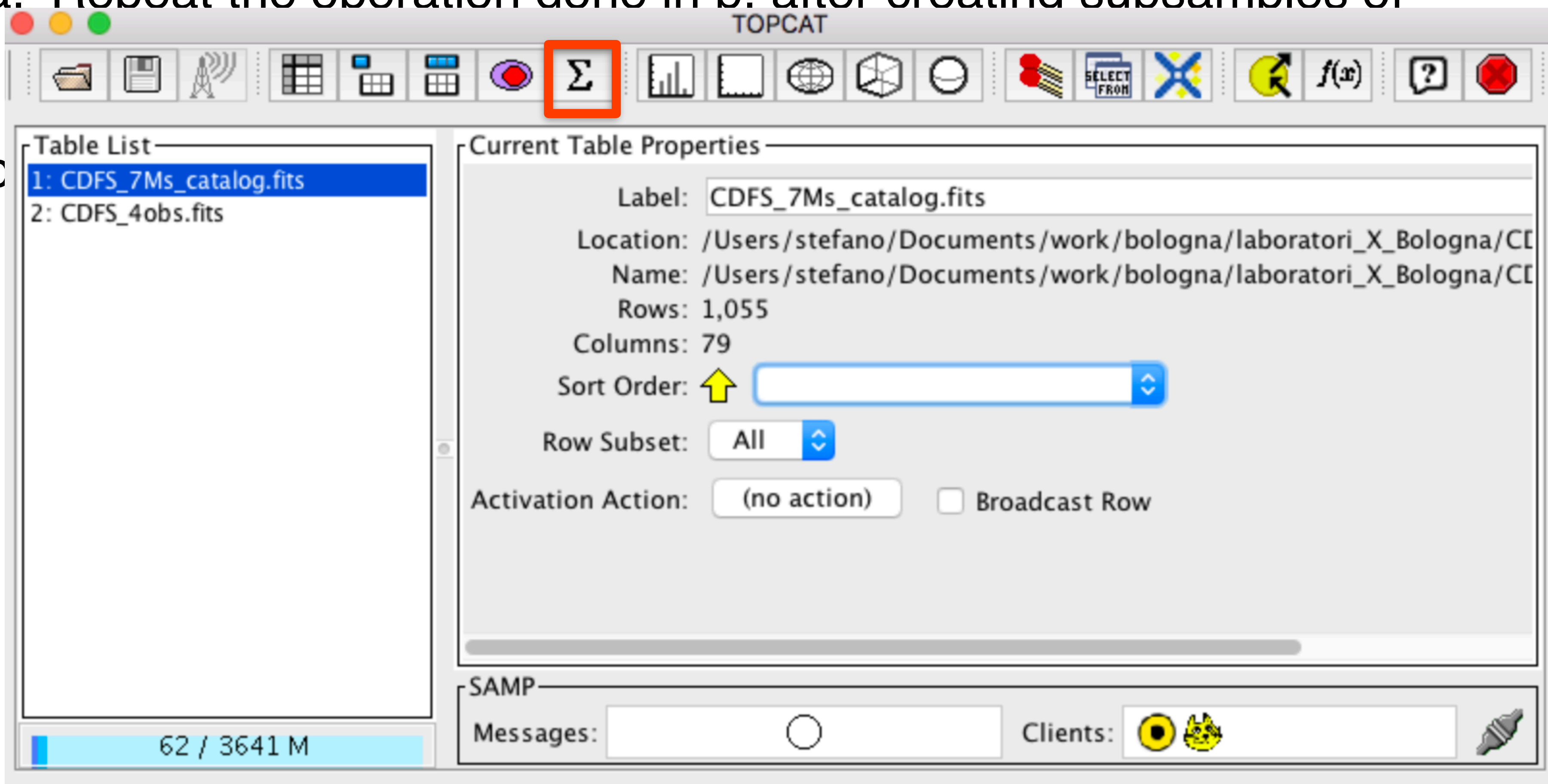
b



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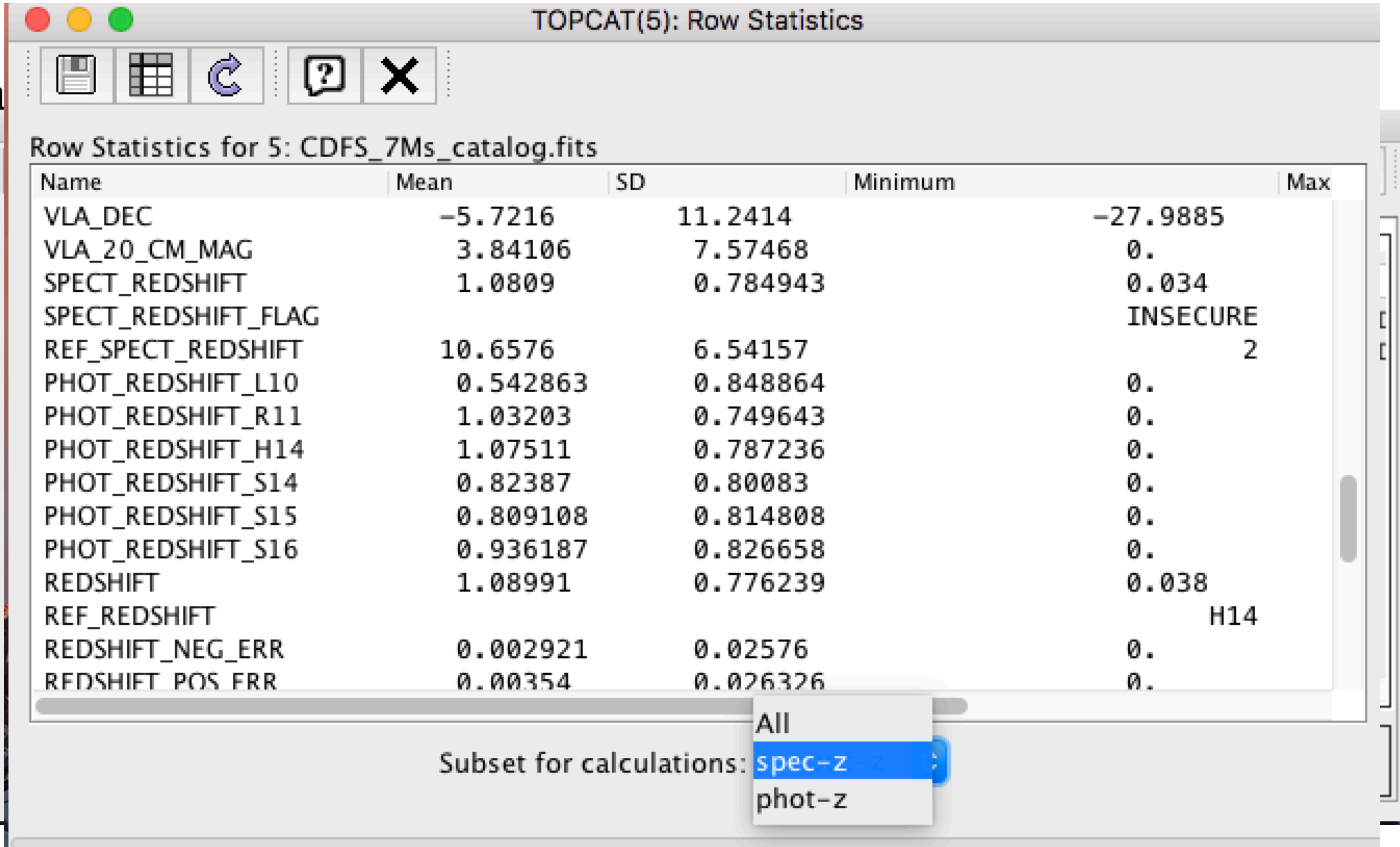

Name	Mean	SD	Minimum	Max
VLA_DEC	-5.7216	11.2414	-27.9885	
VLA_20_CM_MAG	3.84106	7.57468	0.	
SPECT_REDSHIFT	1.0809	0.784943	0.034	
SPECT_REDSHIFT_FLAG			INSECURE	
REF_SPECT_REDSHIFT	10.6576	6.54157	2	
PHOT_REDSHIFT_L10	0.542863	0.848864	0.	
PHOT_REDSHIFT_R11	1.03203	0.749643	0.	
PHOT_REDSHIFT_H14	1.07511	0.787236	0.	
PHOT_REDSHIFT_S14	0.82387	0.80083	0.	
PHOT_REDSHIFT_S15	0.809108	0.814808	0.	
PHOT_REDSHIFT_S16	0.936187	0.826658	0.	
REDSHIFT	1.08991	0.776239	0.038	
REF_REDSHIFT			H14	
REDSHIFT_NEG_ERR	0.002921	0.02576	0.	
REDSHIFT_POS_ERR	0.00354	0.026326	0.	

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a. Choose one of the produced catalogs and produce some plots (number of counts vs. source significance, vs. exposure time, vs. positional uncertainty, etc.)
b. For the sources associated with the 7Ms source catalog, produce the redshift distribution histogram, Lx vs. z plot, etc.
c. Use the PIMMS Online tool (https://cxc.harvard.edu/toolkit/pimms.jsp) to compute the count rate-to-flux correction factor, using the photon index available in the catalog.

Lab Outline

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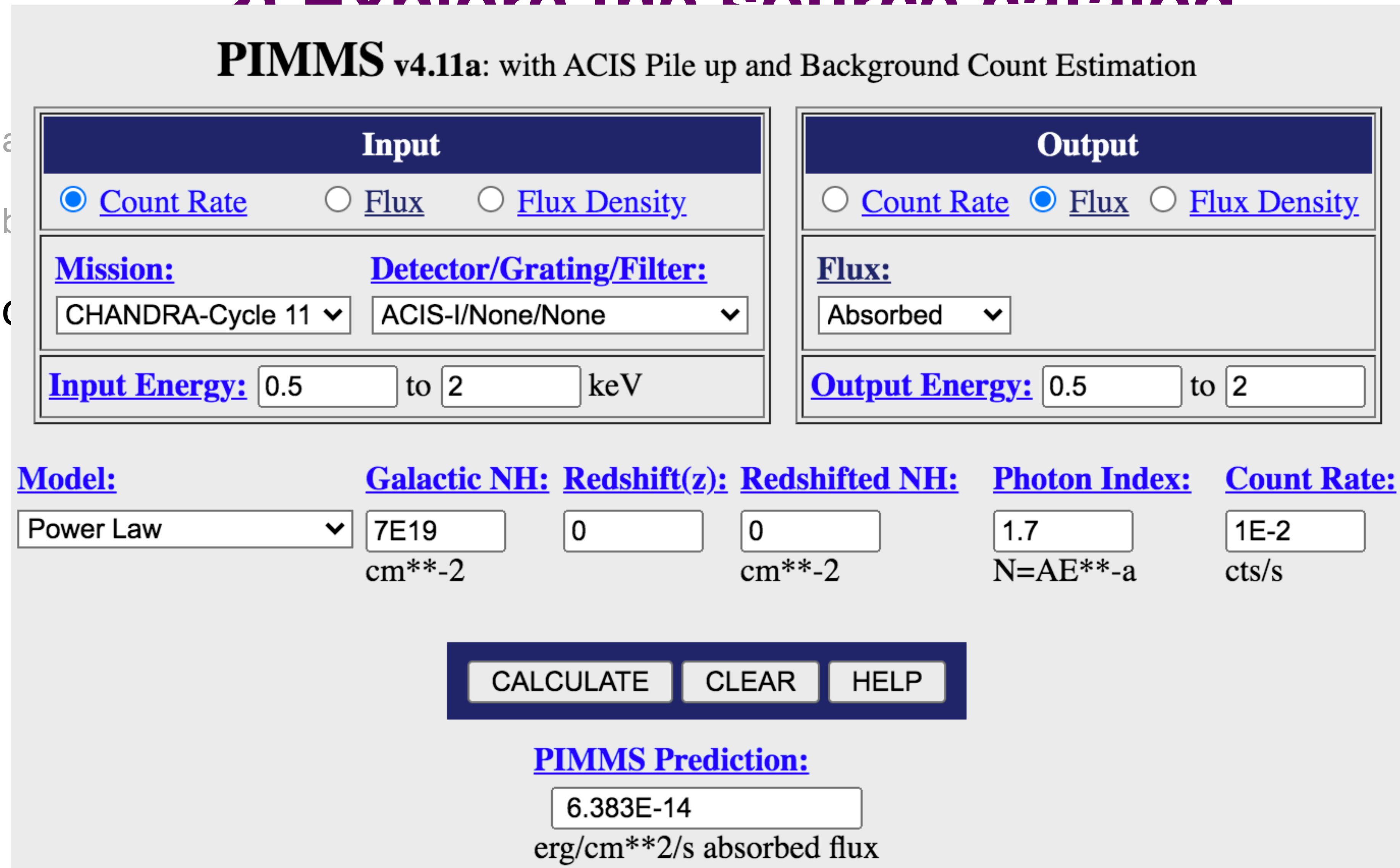

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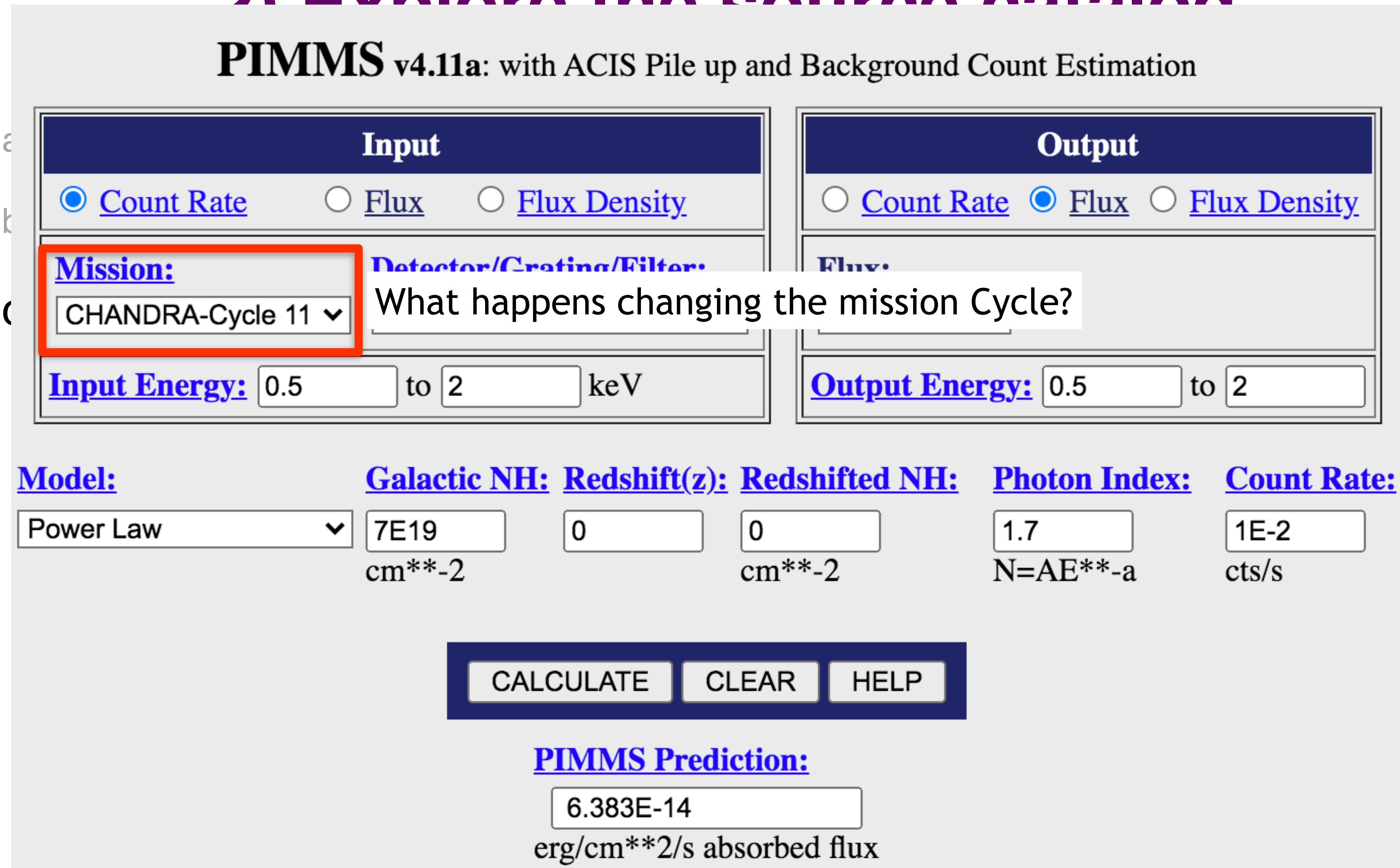


3. Analyse the data products: spectral fitting

Fit *Chandra* spectra for sources whose properties suggest potential interesting outcome (e.g, high-z, high obscuration based on hardness ratio…).

XID_Luo17	Source coordinates	z	Opt. Class + Info
551	03:32:29.85 -27:51:05.71	3.700	NL (Comastri+11)
746	03:32:39.66 -27:48:50.64	3.064	NL (Vito+13)
730	03:32:38.91 -27:57:00.48	0.298	NL
242	03:32:13.24 -27:42:40.96	0.605	NL

IDs reported in the spectral files we provide

All spectra and response matrices are provided

3. Analyse the data products: spectral fitting

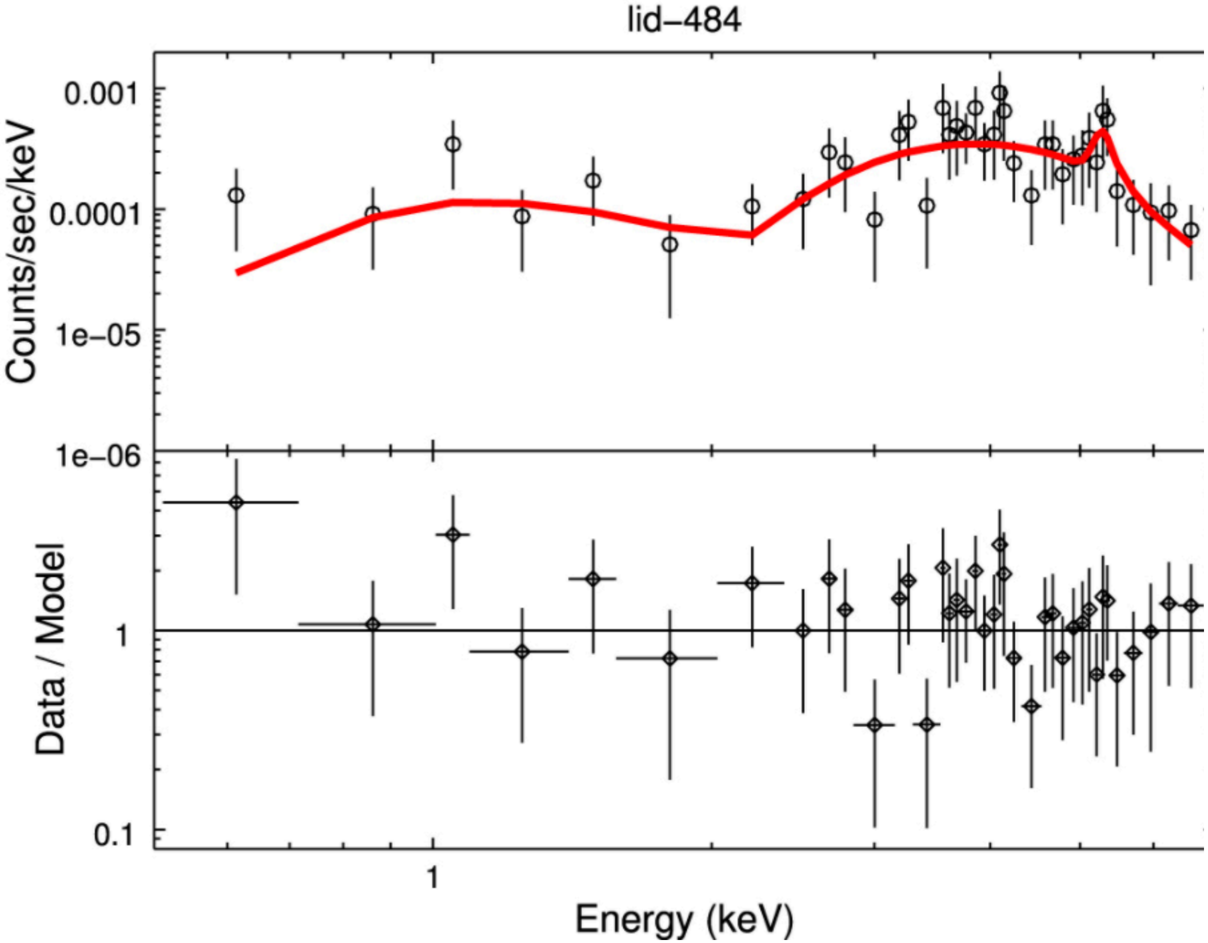
Spectral analysis pipeline

1. Choose one of the four sources
2. Group the spectra (*grppha*) accordingly to the quality of the data
3. Load spectra in XSPEC
4. Define a spectral model and fit it to the data
5. Once a physically justified model is obtained, save the X-ray spectral parameters (including errors) and produce confidence contours
6. Check for further components (to lower the data/model residuals) – Return to point 3

PLAN (III)

OPTIONAL

a. Re-run the procedure for a second source, better if at a different redshift range.



Main publications

- Xue Y.Q. et al. 2011, ApJS, 195, 10 **4 Ms Chandra source catalog.**
- Vito F. et al. 2013, MNRAS, 428, 354 **High-redshift AGN population in the CDF-S**.
- Luo B. et al. 2017, ApJ Suppl., 228, 2 **The Chandra Deep Field-South Survey: 7 Ms Source Catalogs.**

Command list: merge_obs

```
punlearn merge_obs
pset merge_obs infiles=@infile.lis
pset merge_obs outroot=CDFS_4obs
pset merge_obs asolfiles=@asol.lis
pset merge_obs badpixfiles=@bpix.lis
pset merge_obs maskfiles=@mask.lis
pset merge_obs parallel=yes
pset merge_obs nproc=4
pset merge_obs units=time
pset merge_obs bands=broad
pset merge_obs xygrid=0.5:8192.5:1,0.5:8192.5:1
pset merge_obs psfecf=0.9
pset merge_obs psfmerge=exptime
merge_obs
```

Command list: wavdetect

```
punlearn wavdetect
pset wavdetect infile=CDFS_4obs_merged_057keV_bin1.fits
pset wavdetect outfile=CDFS_4obs_merged_057keV_wavdet_1em6_src.fits
pset wavdetect scellfile=CDFS_4obs_merged_057keV_wavdet_1em6_cellimage.fits
pset wavdetect
imagefile=CDFS_4obs_merged_057keV_wavdet_1em6_reconstructed.fits
pset wavdetect defnbkgfile=CDFS_4obs_merged_057keV_wavdet_1em6_normbakg.fits
pset wavdetect regfile=CDFS_4obs_merged_057keV_wavdet_1em6.reg
pset wavdetect ellsigma=3.0
pset wavdetect sigthresh=1e-6
pset wavdetect scales="1 1.4 2 2.8 4 5.6 8 11"
pset wavdetect expfile=CDFS_4obs_merged_broad_thresh.expmap
pset wavdetect psffile=CDFS_4obs_merged_broad_thresh.psfmap
wavdetect clobber+ verbose=3
```