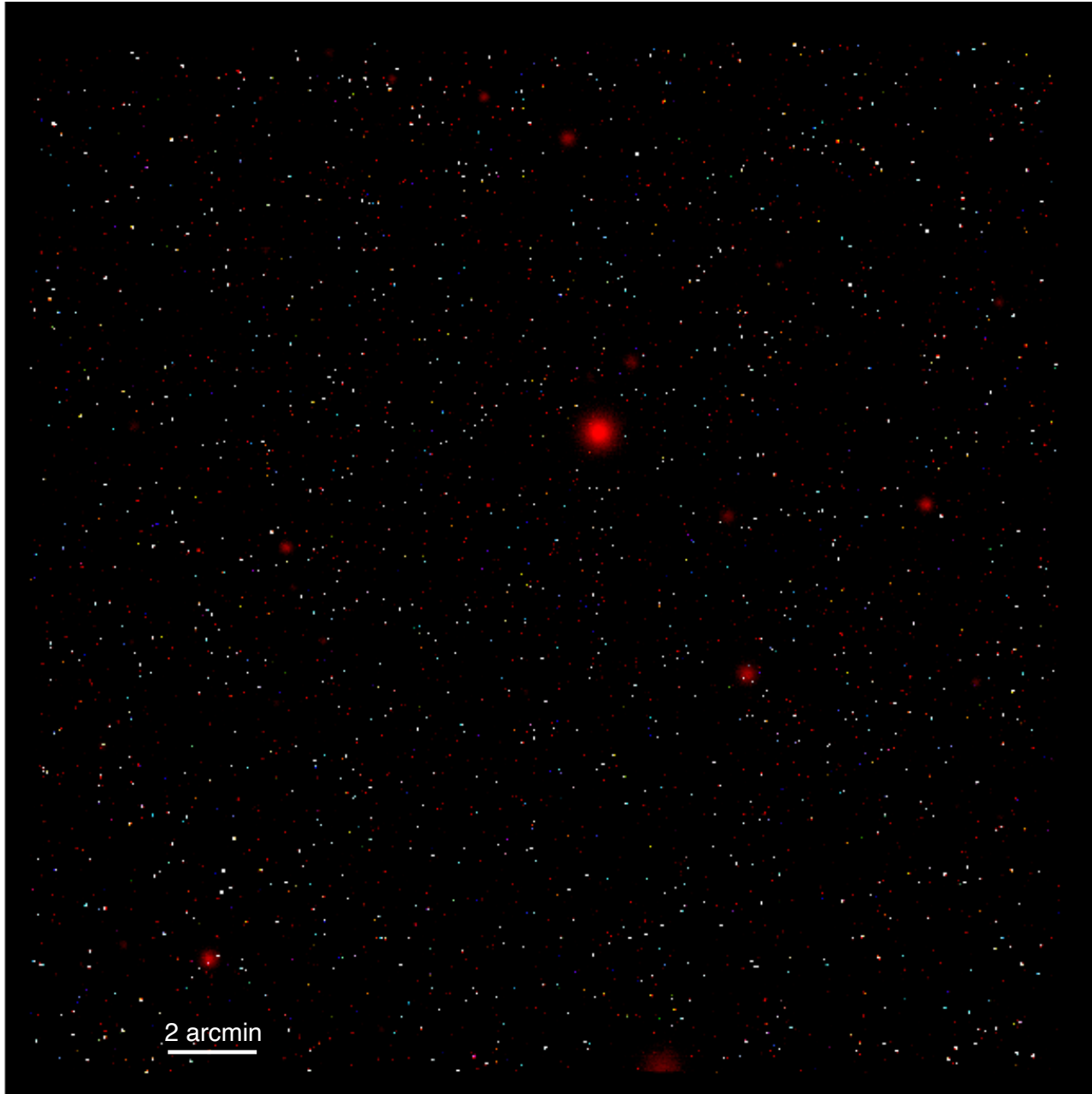


Understanding the AGN population: X-ray surveys



X-rays as a strategic tool in AGN analysis

X-ray emission contributes only to $<10\%$ to AGN bolometric luminosity. However, X-ray emission offers an unique point of view in the AGN analysis. In fact, X-ray offer the...

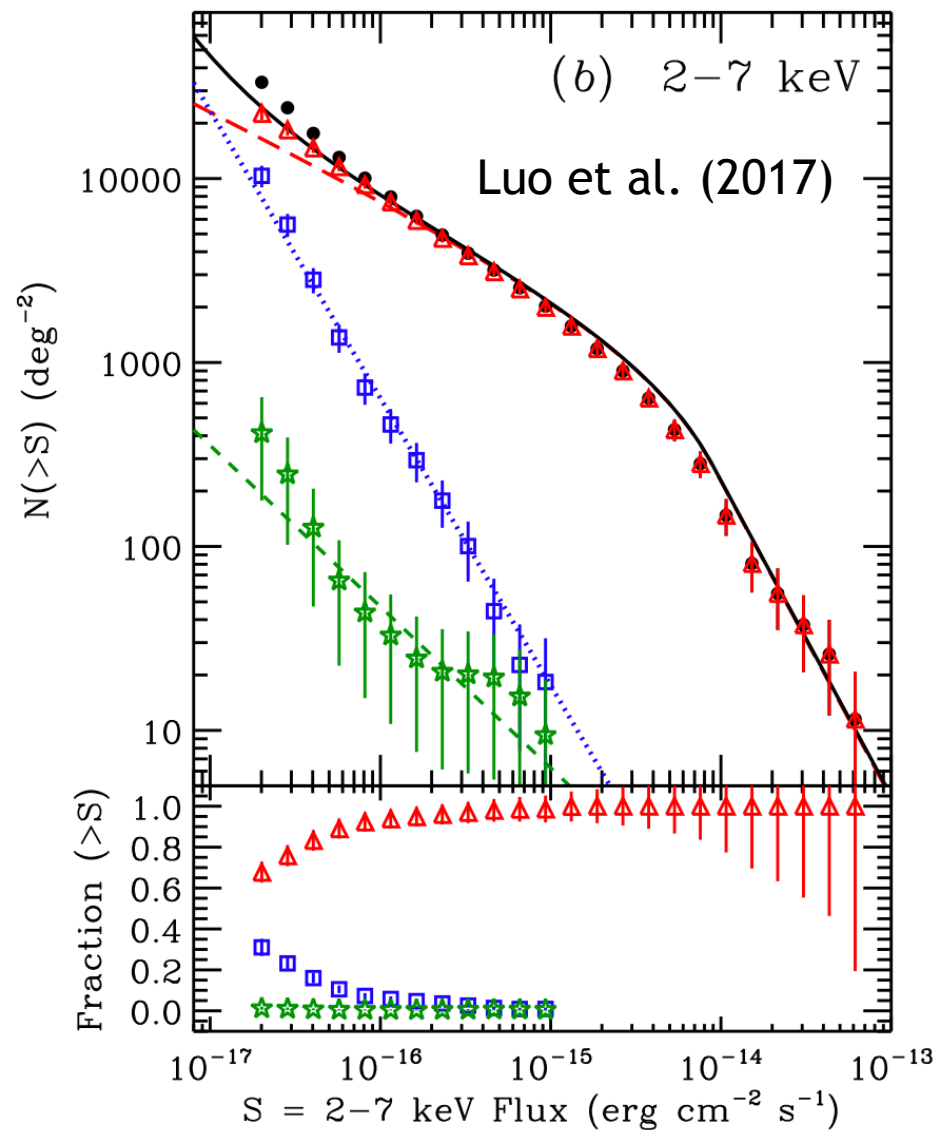
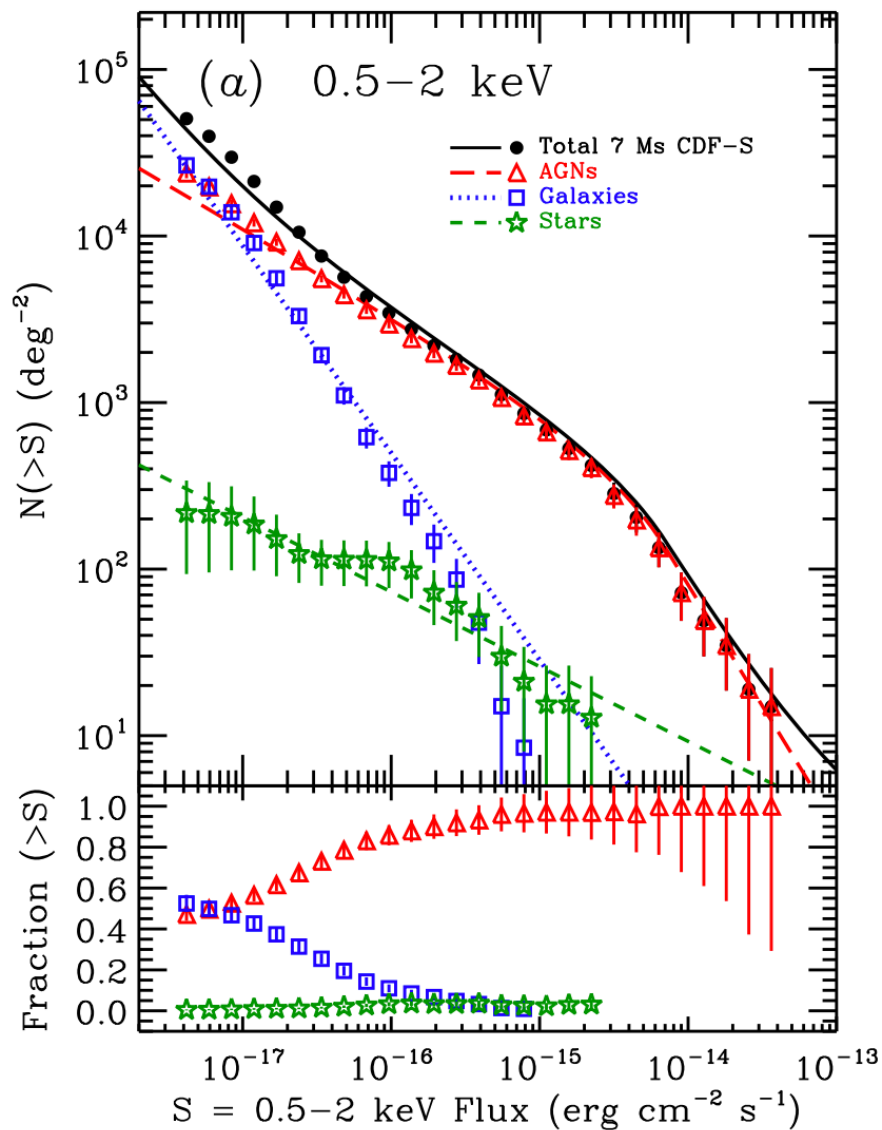
Donley et al. (2008, 2012); Ballantyne et al. (2011) Comastri et al. (2011); Georgantopoulos et al. (2013); Lanzuisi et al. (2015); Buchner et al. (2015)

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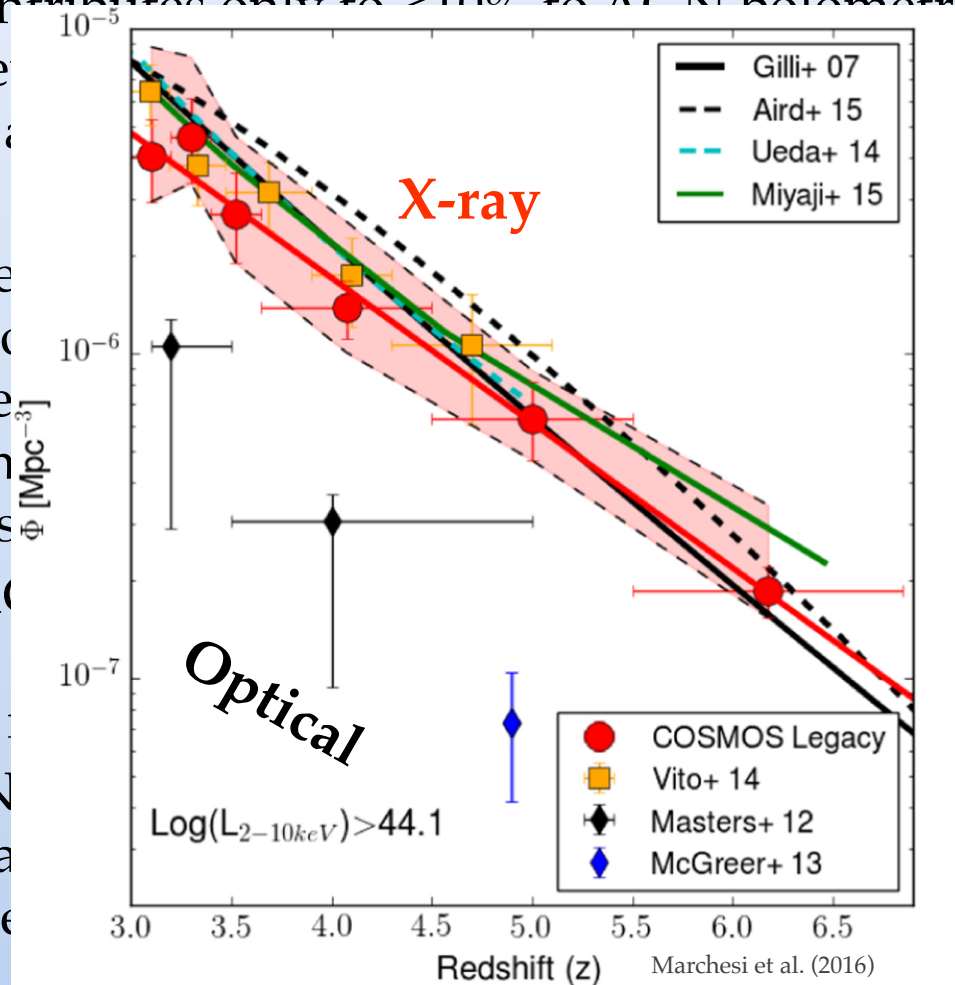
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X-rays as a strategic tool in AGN analysis

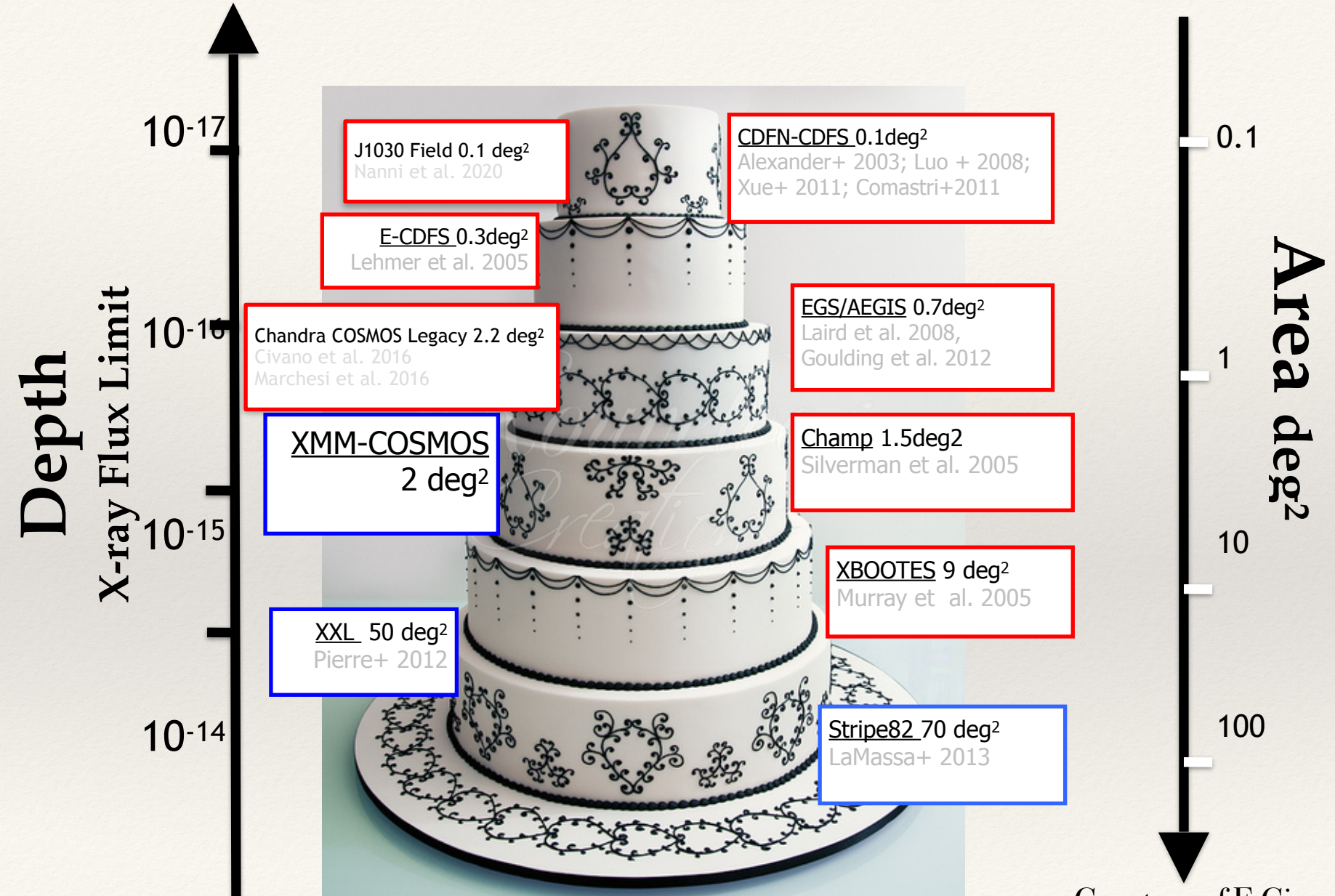
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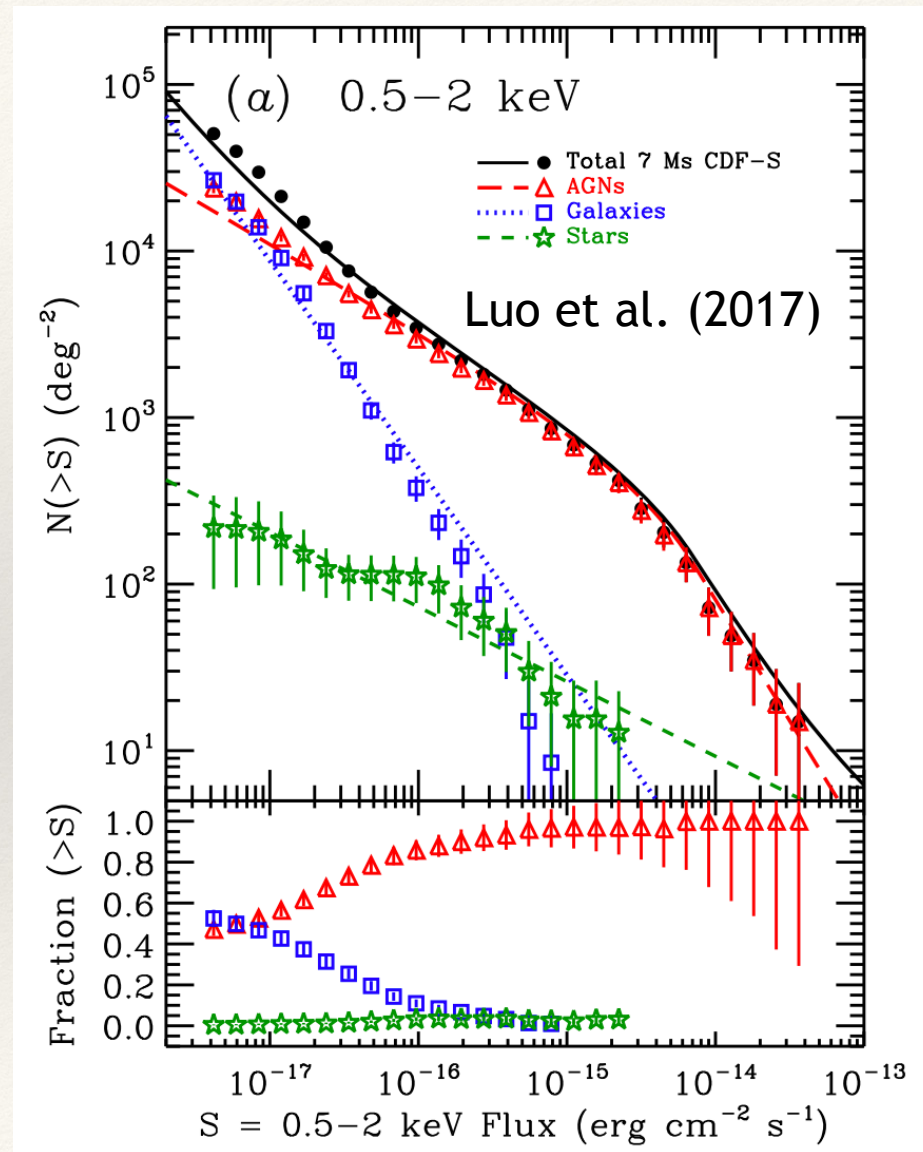
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The X-ray surveys wedding-cake strategy

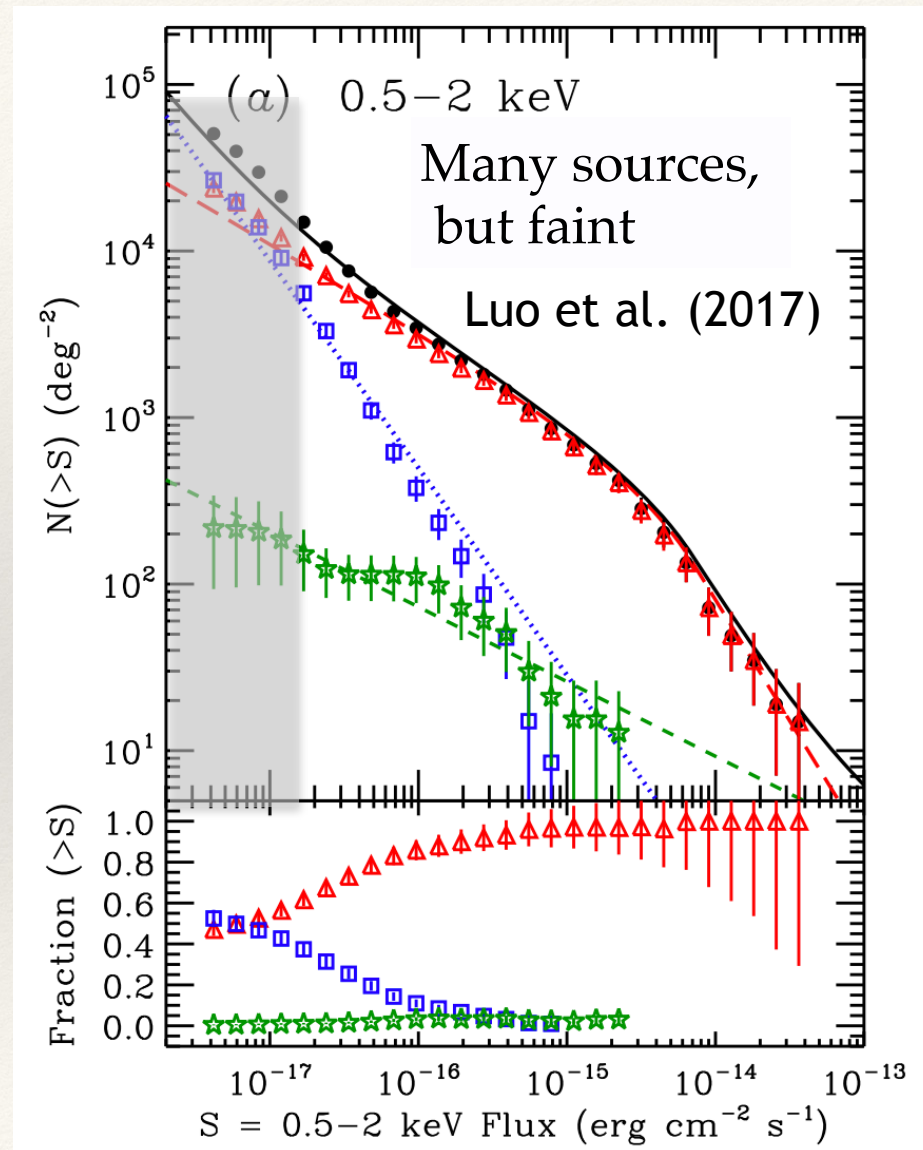


Courtesy of F.Civano

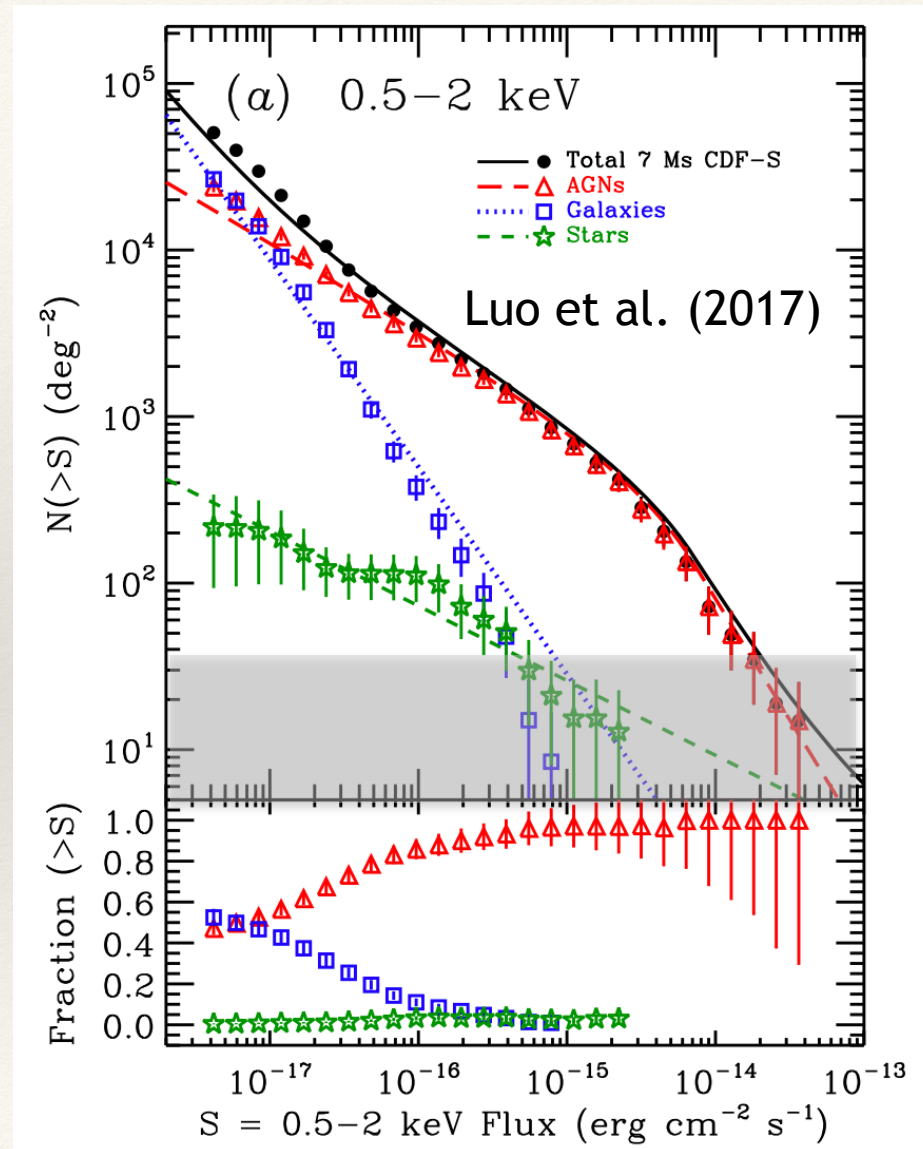
Different surveys for different science



Different surveys for different science

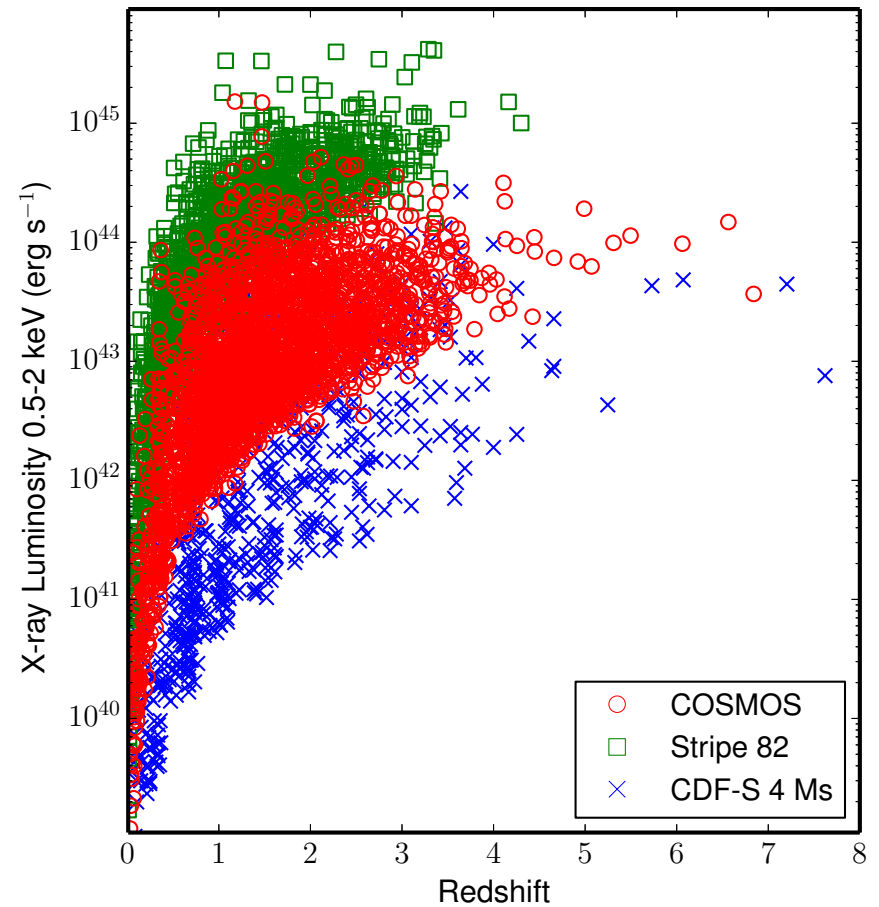
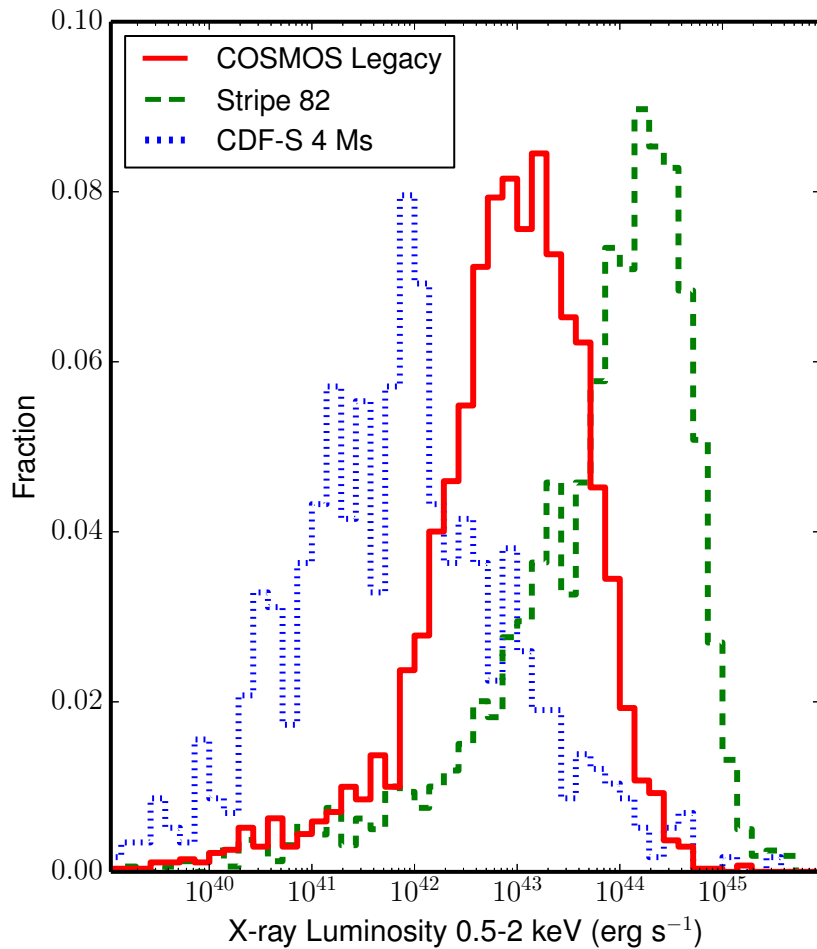


Different surveys for different science



Extremely
bright, but
rare

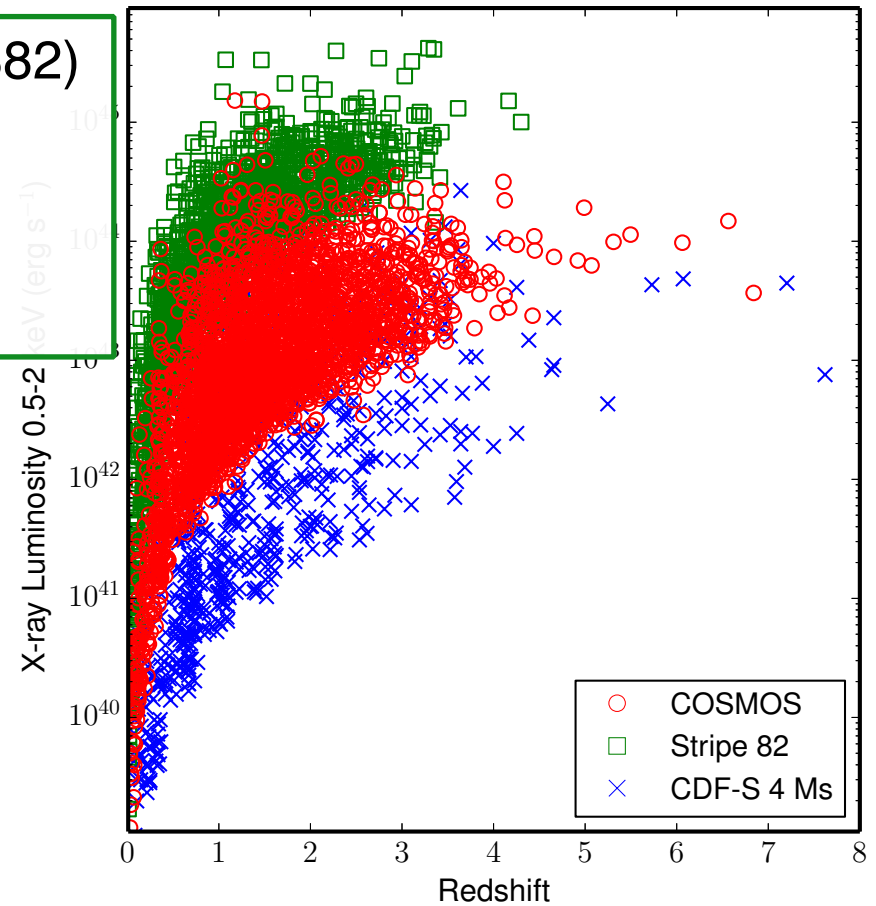
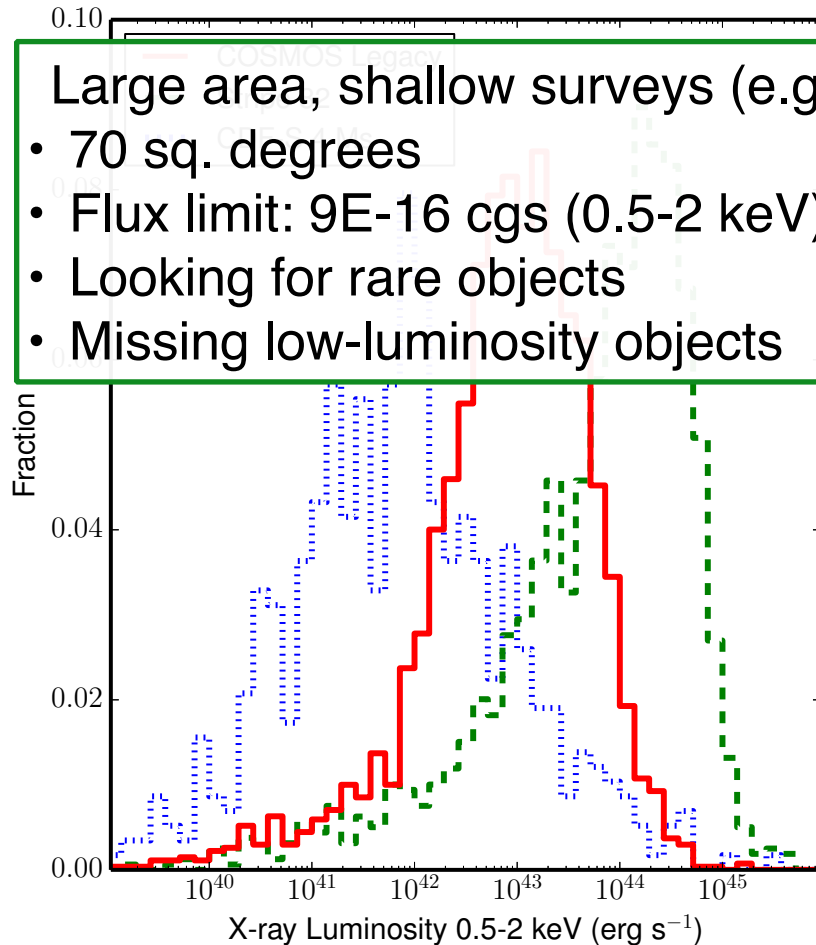
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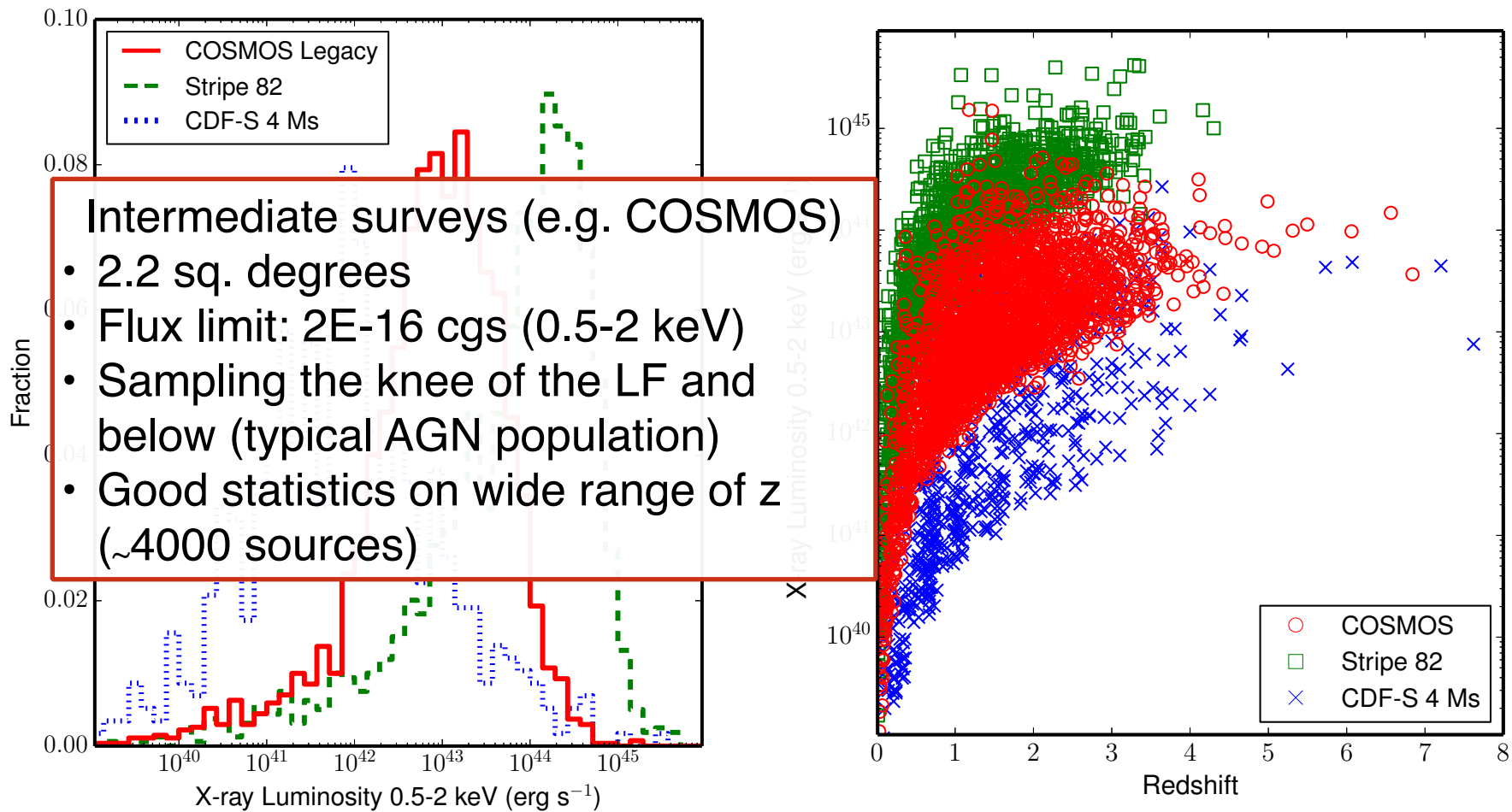
Different surveys for different science

Large area, shallow surveys (e.g., S82)

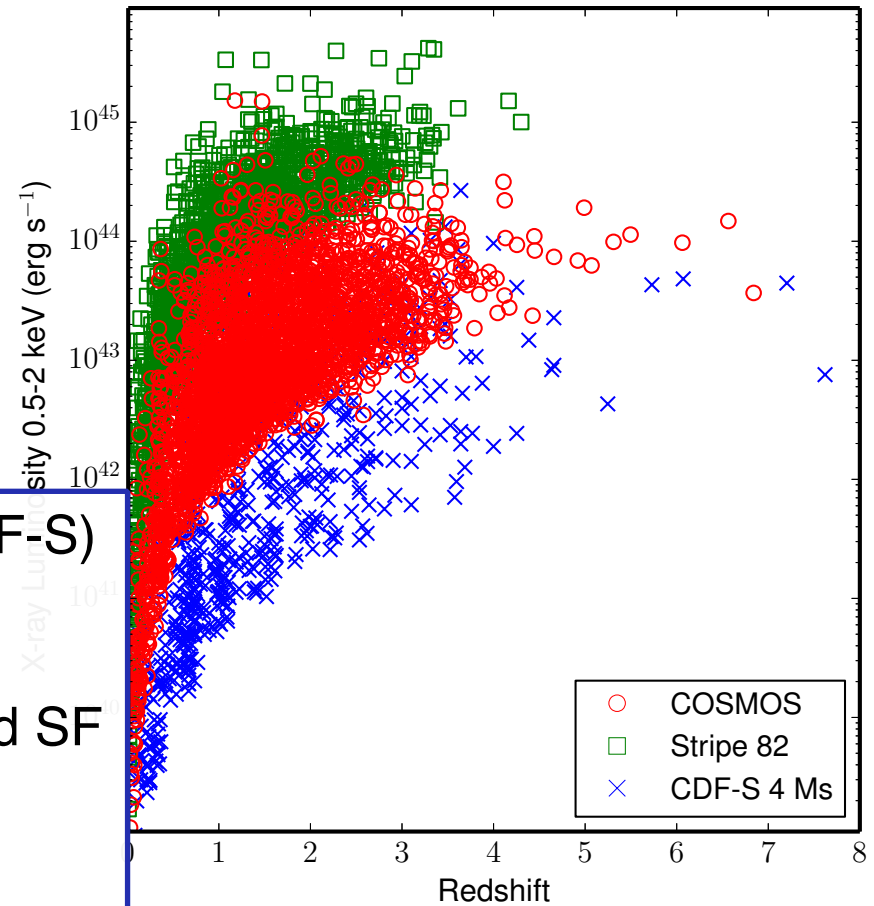
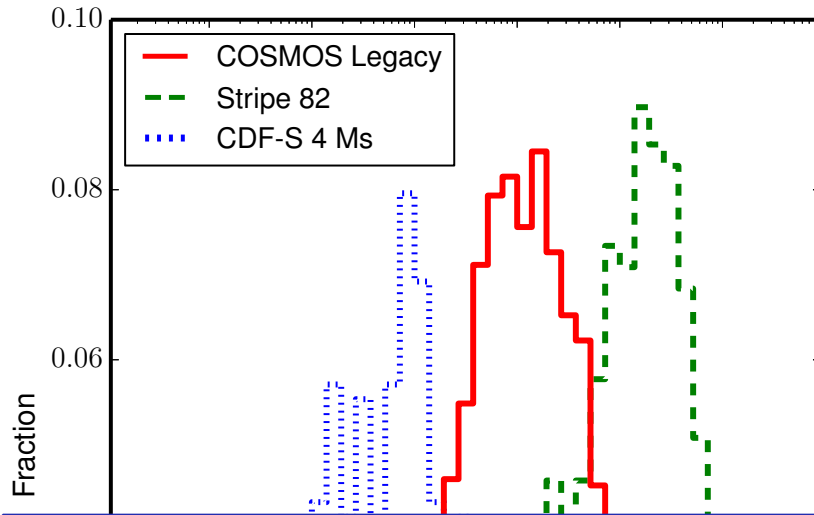
- 70 sq. degrees
- Flux limit: $9E-16$ cgs (0.5-2 keV)
- Looking for rare objects
- Missing low-luminosity objects



Different surveys for different science



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)

***Chandra* Deep Field-South (CDF-S)**

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

≈3Ms *XMM-Newton* exposure

Deep multi-wavelength coverage

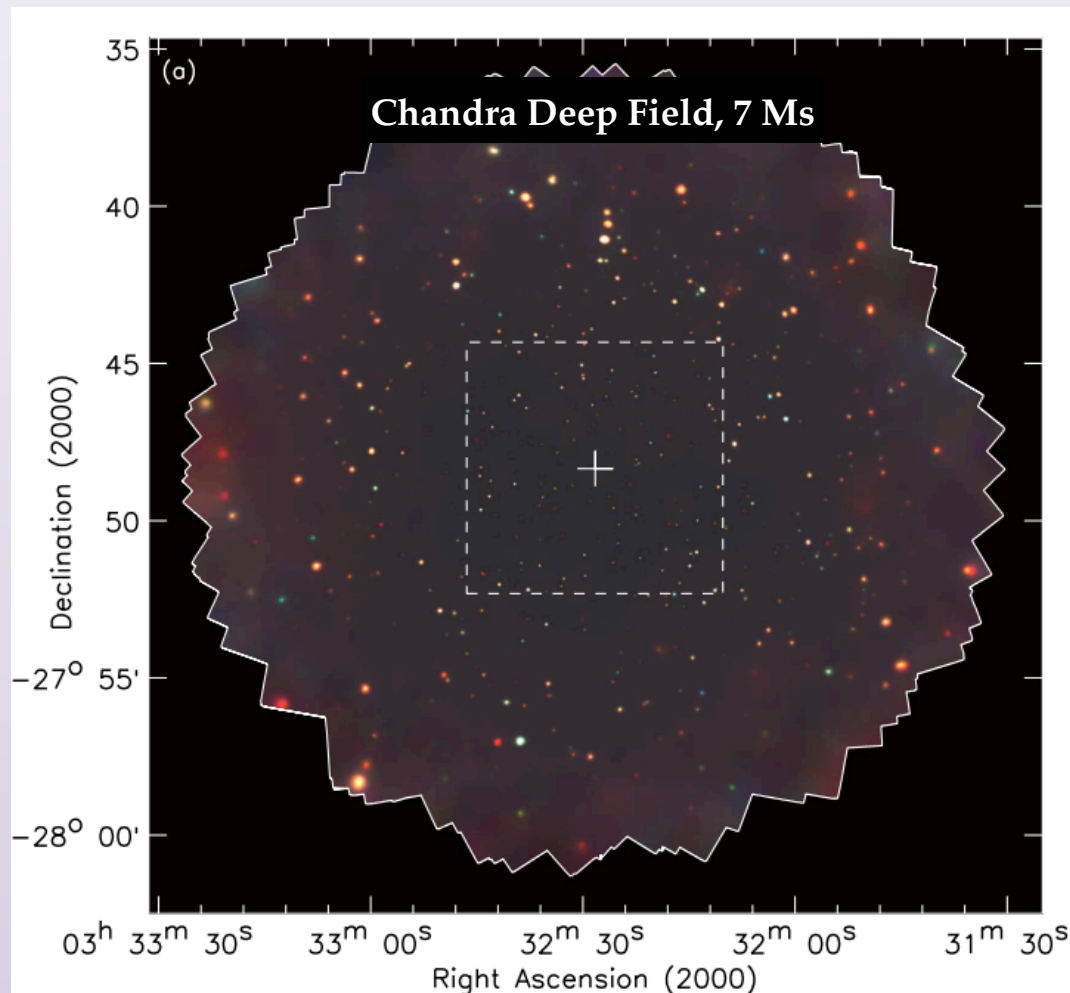
One of the legacy fields (no deeper field for the next 20 yrs)

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 need for new X-ray facilities

- Optical/NIR surveys are biased against obscured AGN at high-z.
- A complete census of accreting supermassive black holes (including obscured and/or intrinsically faint) requires X-ray facilities, and deep surveys.



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- However, the two most powerful X-ray telescopes currently available (*Chandra* and *XMM-Newton*) are both 21 years old.
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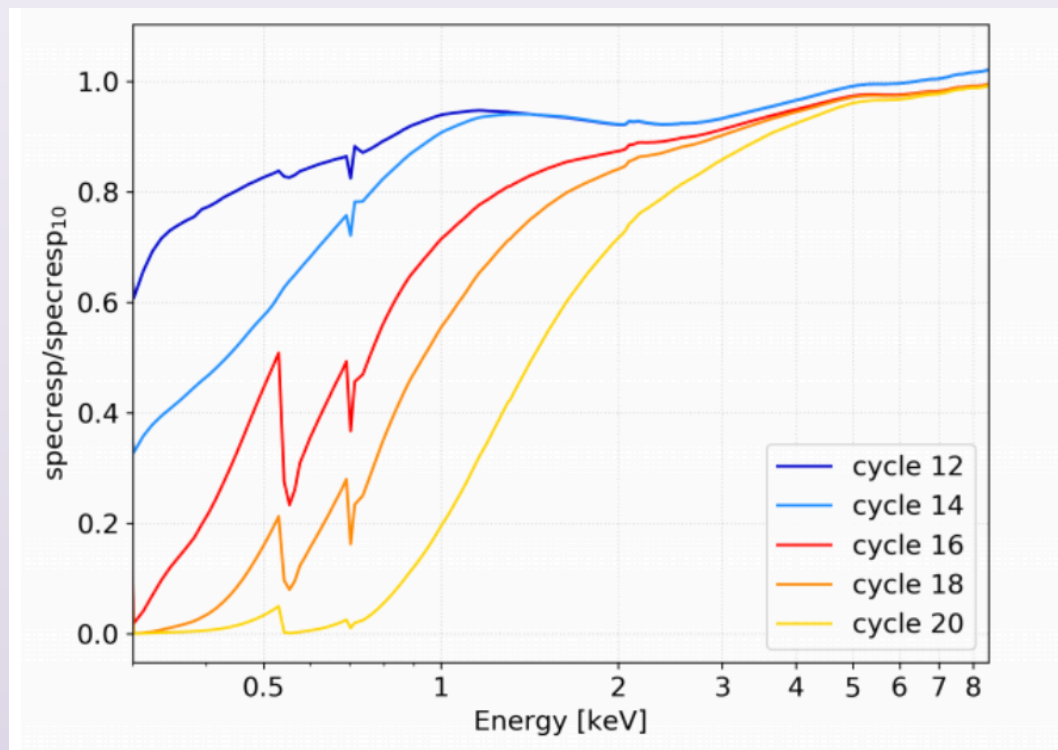
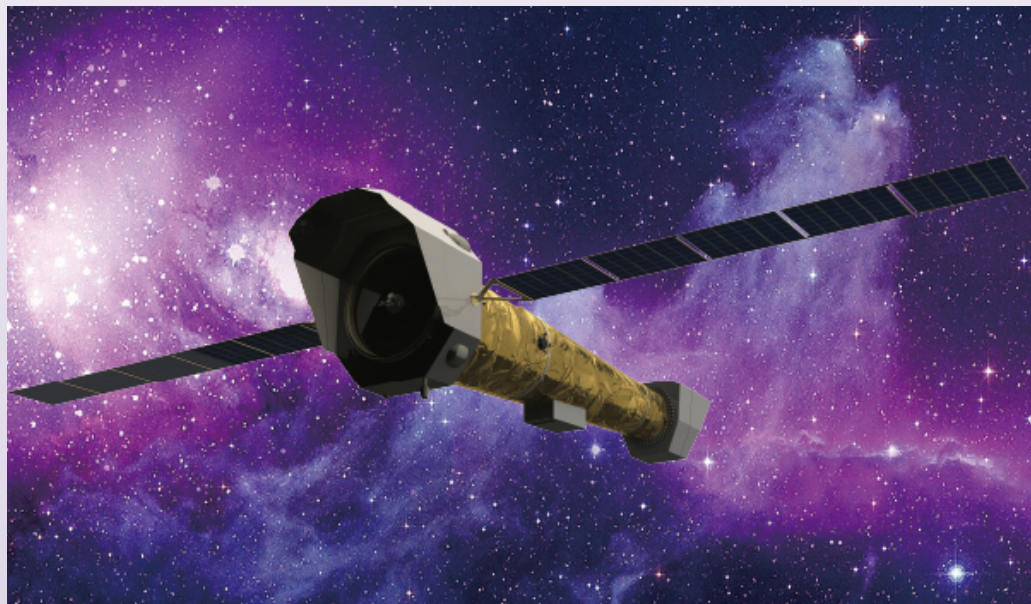


Figure 15. ACIS-I effective area degradation through years. We show the ARF ratios between cycles 12 (blue), 14 (light blue), 16 (red), 18 (orange), 20 (yellow) and the cycle 10.

The need for new X-ray facilities

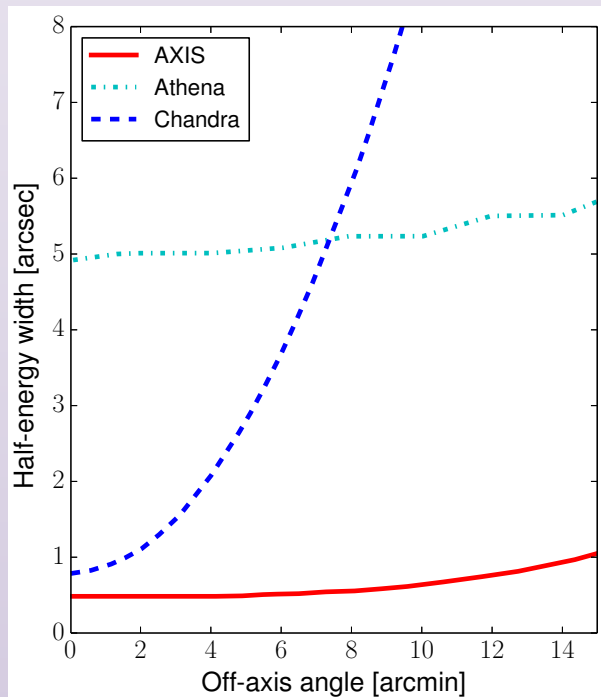
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- In particular *Chandra* (only sub-arcsecond X-ray instrument) has seen a significant worsening in effective area below 1 keV, which strongly limits its efficiency as a survey instrument.
- An “*XMM-Newton* 2.0” is being developed (*Athena*), but no X-ray instrument with *Chandra*-like spatial resolution has been cleared for development.



AXIS and *Athena*: a possible bright X-ray future

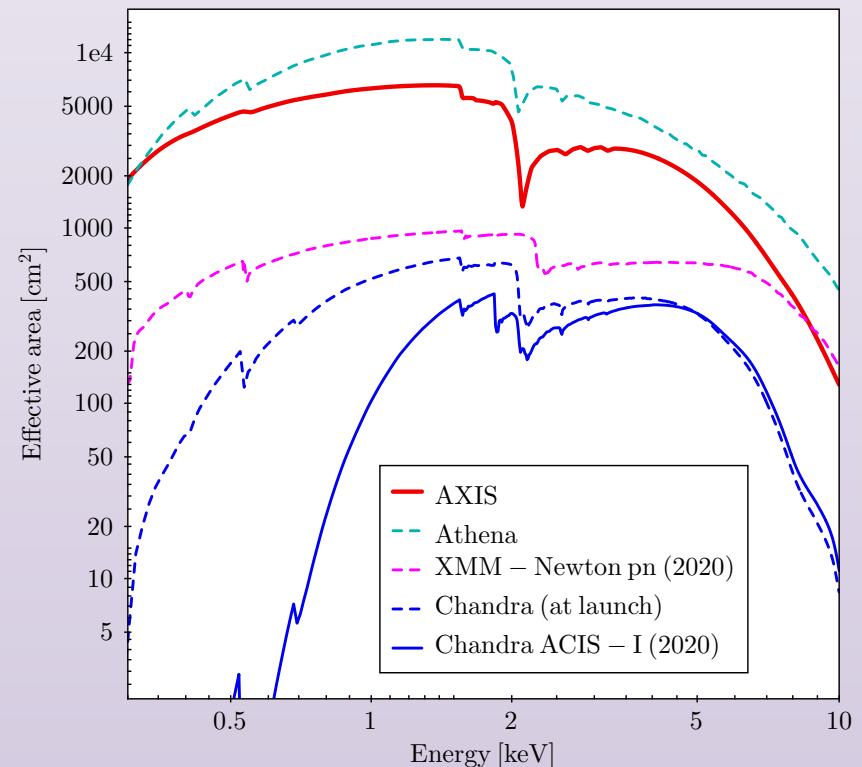
AXIS

- Probe mission (cost <1 B\$)
- Feasibility study funded by NASA.
- White paper (<https://ui.adsabs.harvard.edu/abs/2019BAAS...51g.107M/abstract>) submitted to NASA 2020 Decadal Survey.
- Subarcsecond resolution over wide (24'x24') field of view.
- Large effective area.



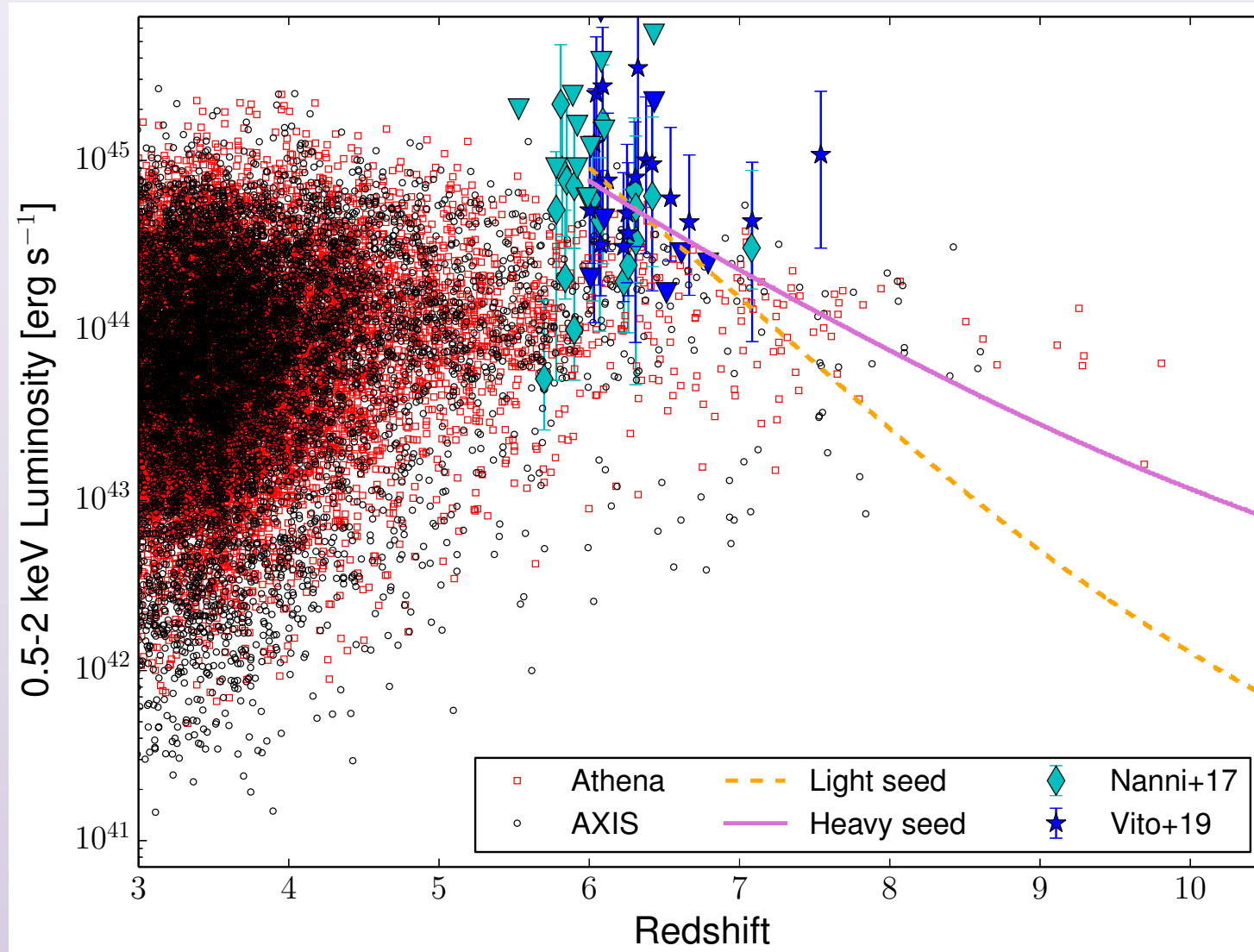
Athena

- *Athena*: next ESA X-ray observatory.
- Expected launch: early 2030s.
- Survey instrument: Wide Field Imager
- Excellent effective area and field of view (40' radius): ideal for surveys.
- Good PSF (5-10"), stable even at large off-axis angles.



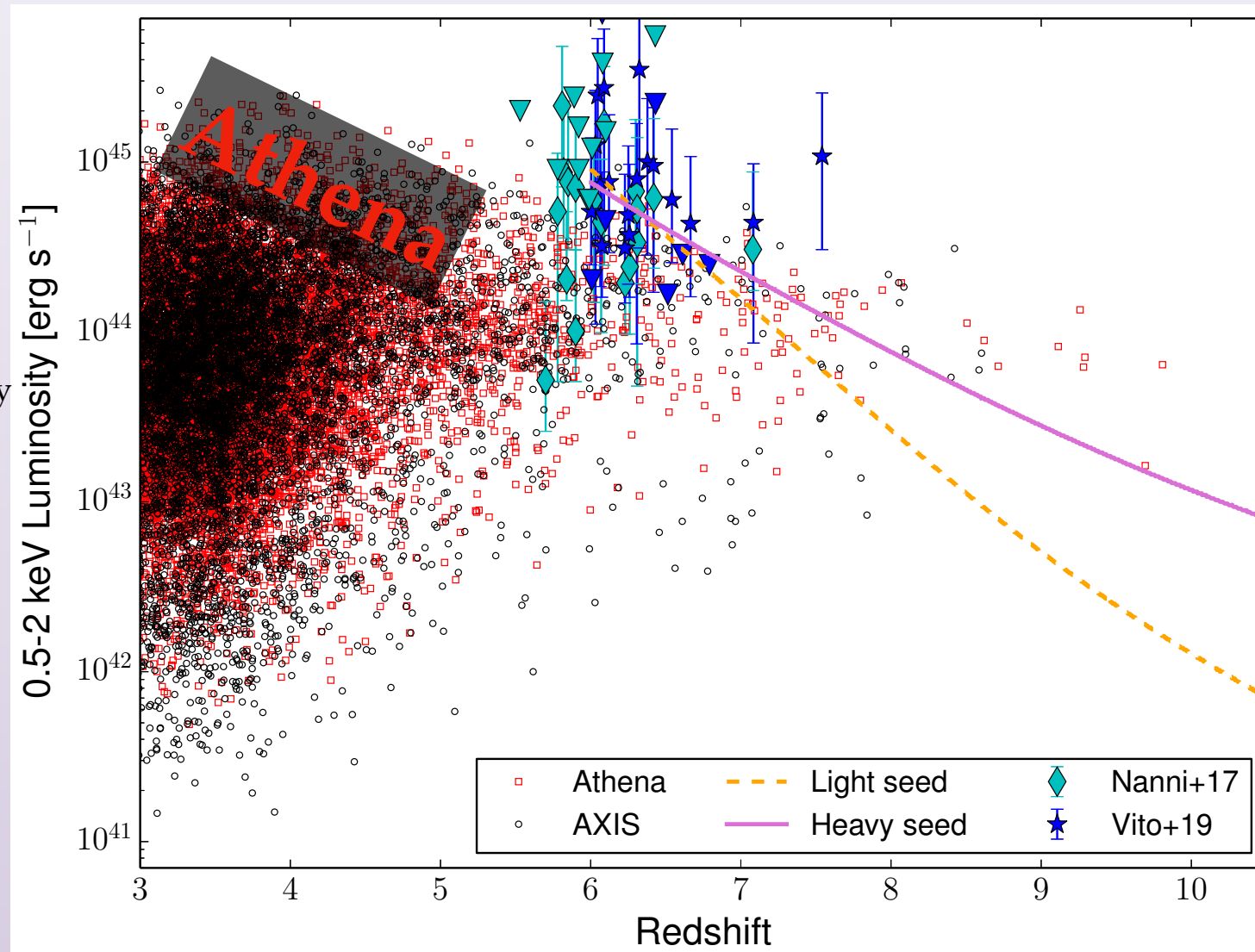
Science with *AXIS* and *Athena*: the high- z Universe

- Up to 20,000 $z > 3$ AGN (<500 in current X-ray surveys combined!)



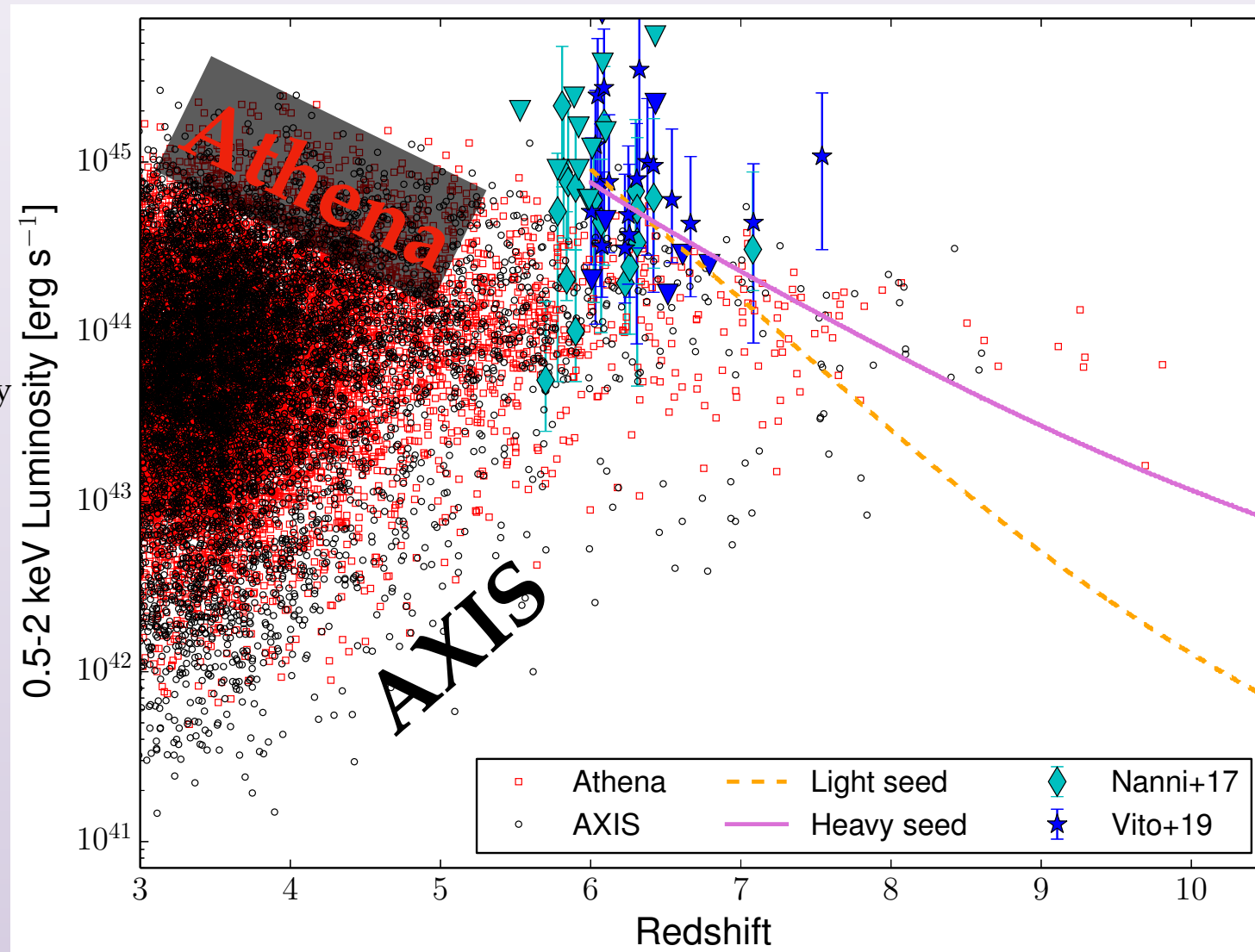
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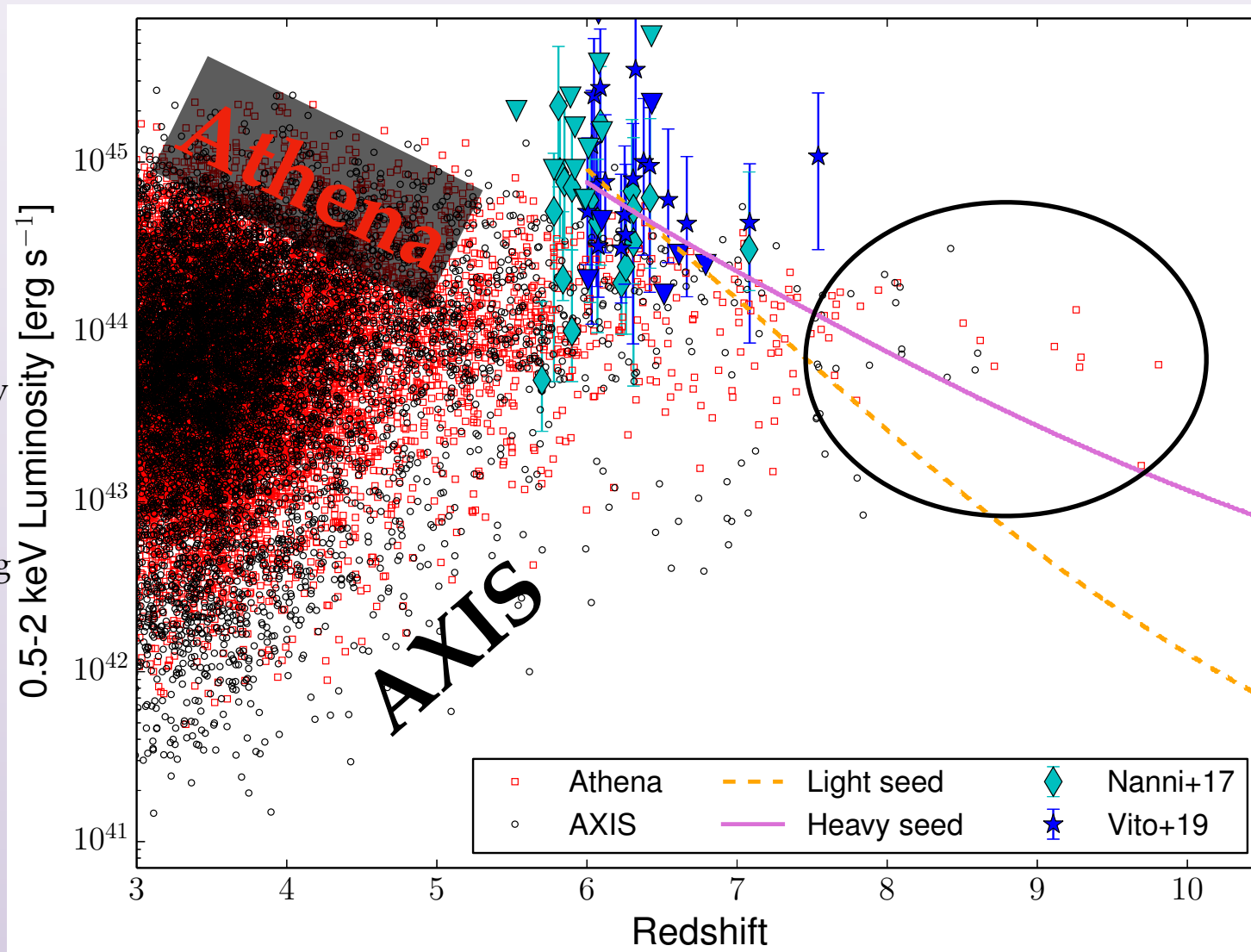
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Science with *AXIS* and *Athena*: the high- z Universe

- Up to 20,000 $z > 3$ AGN (<500 in current X-ray surveys combined!)
- Excellent complementarity: more sources (and generally more counts) detected by *Athena*
- Less luminous objects detected by *AXIS*.
- Tracking of first accreting BH seeds up to $z \sim 8-9$: a whole new science.



Survey and Time-domain Astrophysical Research eXplorer



EXPLORING THE FAST, FURIOUS, AND FORMING UNIVERSE

William W. Zhang, Principal Investigator
Ann Hornschemeier, Deputy Principal Investigator

In response to NASA's Astrophysics Explorers Program 2021 Medium Explorer (MIDEX)
Announcement of Opportunity – NNH21ZDA0180 · December 9, 2021



Courtesy A.
Hornschemeier

Survey and Time-domain Astrophysical Research eXplorer



August 18, 2022:

Out of 11 MIDEX proposals submitted in December 2021, STAR-X was selected as one of 2 finalists for a competitive Phase A MIDEX mission study. Process to be completed in late 2023, potential launch before 2030

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Courtesy A.
Hornschemeier

Exploring the Fast, Furious, and Forming Universe

The STAR-X Science Story

The FAST: Locally rare, brief events have an outsized impact on the Universe.



*Supernova
Explosion*

The heavy elements needed for life are synthesized in and dispersed by supernovae and neutron star mergers. Similarly, a single stellar superflare can evaporate an ocean or catalyze prebiotic pathways. The STAR-X wide field UV/X-ray design and fast and flexible operations captures these events.

The FURIOUS: Black holes grow extremely rapidly at early times in the Universe and are critical to galaxy evolution.



*Tidal Disruption
Event (TDE)*

STAR-X will uniquely probe the physics of rapid accretion that allowed massive black holes to grow so quickly in the early Universe. STAR-X will catch transient, extreme black hole feeding events, such as TDEs, where entire stars are disrupted.

The FORMING: Distant galaxy clusters provide maximal leverage in evolutionary studies of structure formation and chemical enrichment.



*Clusters of
Galaxies*

STAR-X will conduct deep surveys and discover the elusive diffuse emission from the largest bound objects in the Universe (clusters of galaxies), shortly after their birth. STAR-X's combination of excellent imaging and low particle background (due to orbit choice) makes this possible in a way that no other mission can.

Ann Hornschemeier NASA Goddard Space
Flight Center

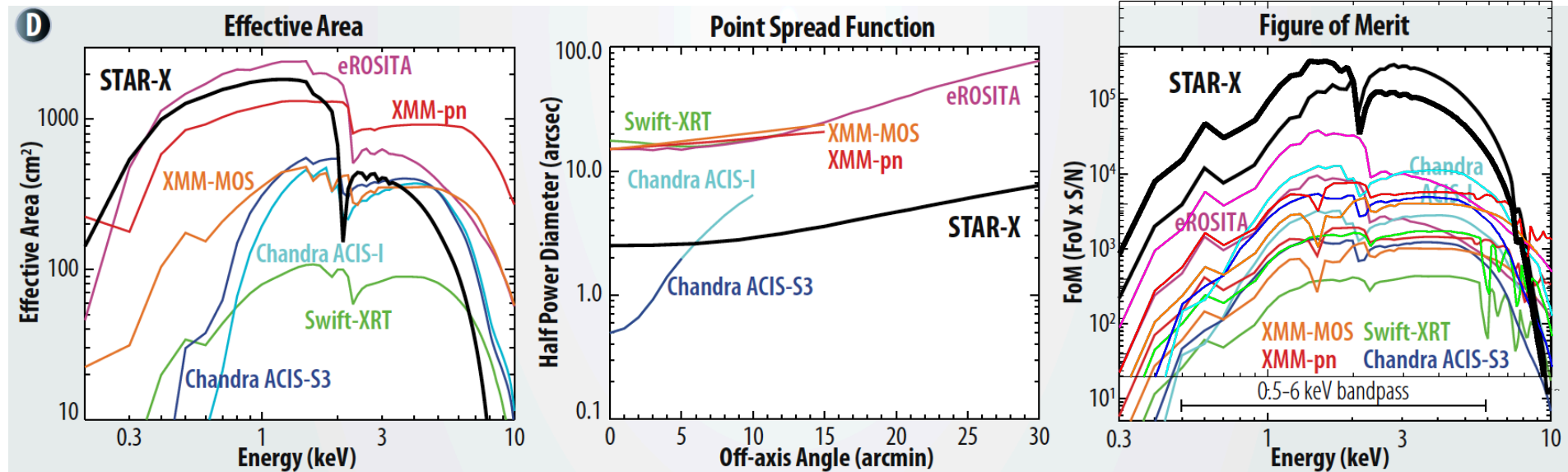
11

Courtesy A. Hornschemeier



Key Features of the X-ray Telescope

- Excellent PSF: 2.5" on-axis, 8" 0.5-deg off-axis.
- Large FOV: 1 deg².
- Large effective area: >1,800 cm² at 1 keV.
- Low particle background.



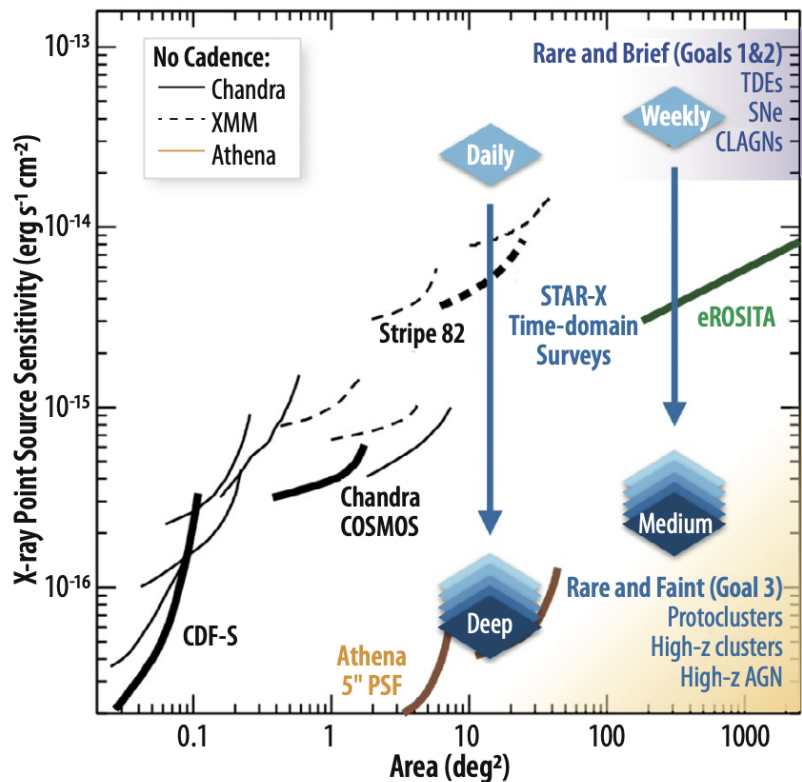
Ann Hornschemeier NASA Goddard Space Flight Center

Courtesy A. Hornschemeier

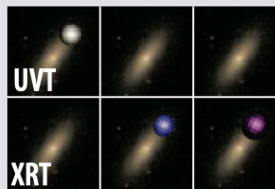
Survey Strategy



Survey and Time-domain Astrophysical Research eXplorer

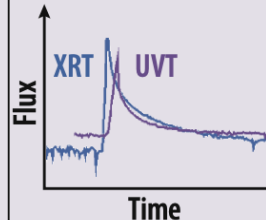


1-1 Supernovae



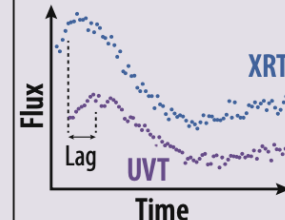
XRT discovers a shock breakout and triggers a ToO to catch cooling in the UV

2-1 Tidal Disruption



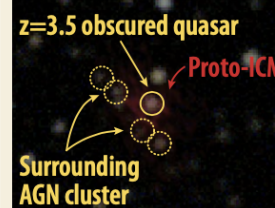
Weekly X-ray/UV monitoring rapidly reveals hundreds of new TDEs

2-2 AGN Accretion Flows



Daily X-ray/UV monitoring probes accretion disk structure via time lags

3-1 Protoclusters



STAR-X will witness the birth of galaxy clusters at $z > 3$ via AGN clustering and early intracluster medium

3-2 High-z Clusters



STAR-X will discover hundreds of high-z clusters to trace cluster growth over cosmic time

Survey Science: $z > 6$ AGNs



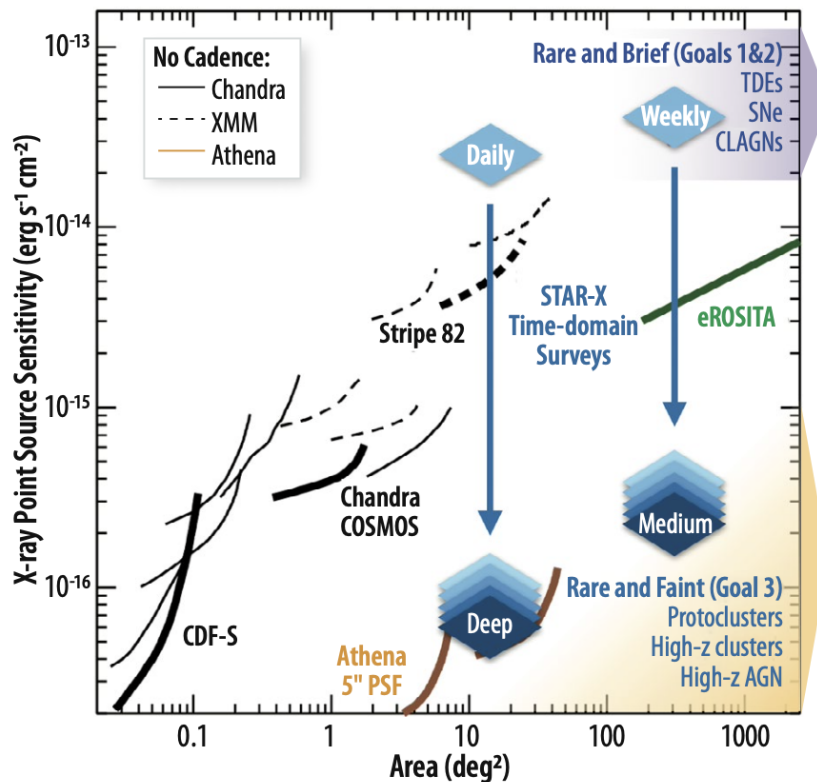
STAR-X surveys high-z AGNs 64x faster than Chandra with a better FOV-averaged PSF

STAR-X finds rare and brief events and rare and faint high-z objects

Survey Strategy



Survey and Time-domain Astrophysical Research eXplorer



1-1 Supernovae

XRT discovers a shock breakout and triggers a ToO to catch cooling in the UV

2-1 Tidal Disruption

Weekly X-ray/UV monitoring rapidly reveals hundreds of new TDEs

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Survey Science: $z > 6$ AGNs

STAR-X surveys high-z AGNs 64x faster than Chandra with a better FOV-averaged PSF

STAR-X finds **rare and brief events** and **rare and faint high-z objects**

Final depths: MEDIUM: 3×10^{-16} cgs over 300 deg² (~100 Chandra COSMOS fields)
 DEEP: 7×10^{-17} cgs over 12 deg²

This Lab Outline

- 1. Understand the parameters affecting the source catalog:** We will provide to you a series of catalogs performed using different detection parameter setups. Visualise 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) Explore different source catalogs

Lab Outline

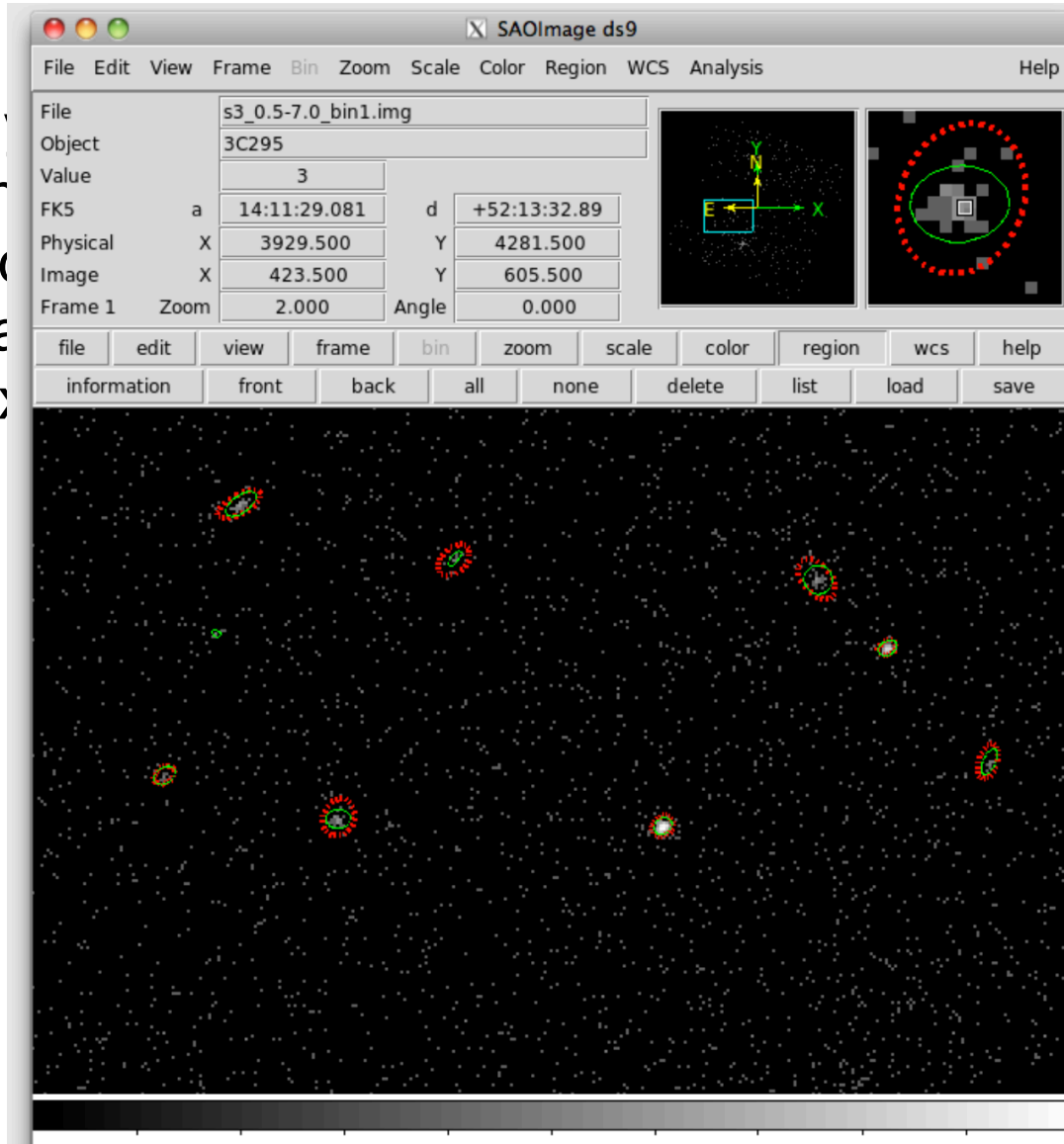
1) Explore different source catalogs

- a. We ran for you the wavdetect tool to search sources in a set of observations, using different significance thresholds (i.e., your detections can be more or less reliable; test $1E-6$; $1E-5$; $1E-4$) and different maximum wavelet scales (stop at 5.6 and at 11; important if there are extended sources and for objects in the external part of the field).

Lab Outline

1) Explore different source catalogs

a. We ran for
observation
detections (at
different mag
there are ex
the field).

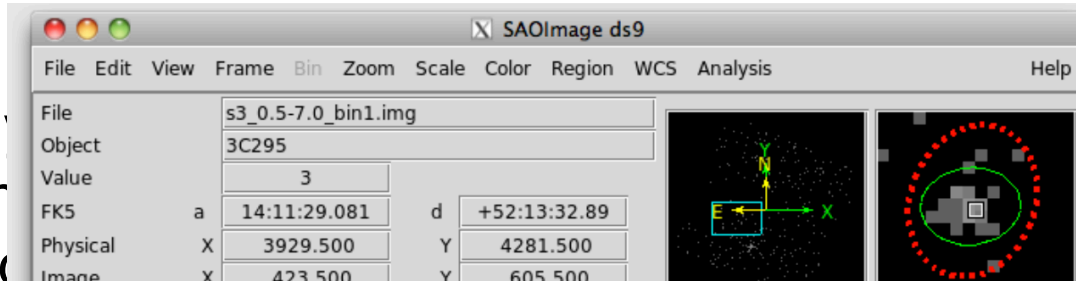


in a set of
i.e., your
-5; 1E-4) and
11; important if
ernal part of

Lab Outline

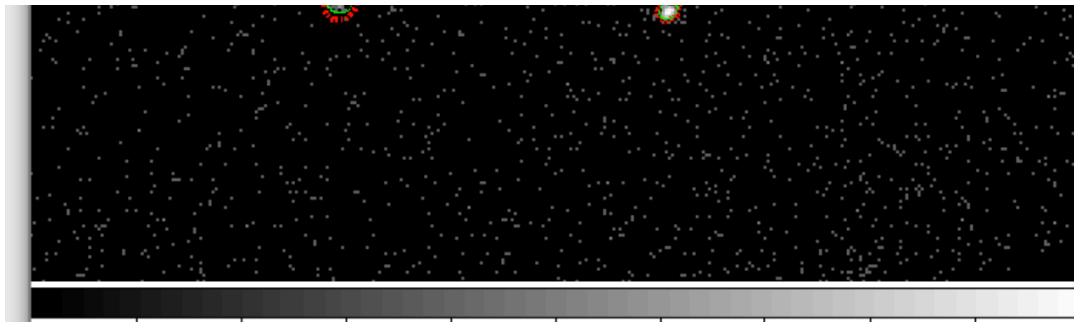
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a. We ran for
observation
detections



in a set of
i.e., your
-5: 1E-4) and

```
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 defnbgfile=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
```



if

Lab Outline

1) Build the source catalog

- a. 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)
- b. Cross-correlate the source lists with the official 7 Ms Chandra source catalog in the CDF-S (Luo et al. 2017), using various cross-matching radii.
 - Compute the fraction of 7Ms sources found in the 4-observation mosaic using the different catalogs and different 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 study their properties (e.g., number of counts, source significance, position in the field of view...) and their visual appearance: what are the possible explanations for their detection in the your shorter-exposure mosaic?

Lab Outline

1) Build the source catalog

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 various cross-matching radii (e.g., 1,2,3 arcsec)

Lab Outline

1) Build the source catalog

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 various cross-matching radii (e.g., 1,2,3 arcsec)

The screenshot displays the TOPCAT software interface. The title bar reads "TOPCAT". The toolbar contains various icons for file operations, data manipulation, and visualization. The main window is divided into two panes:

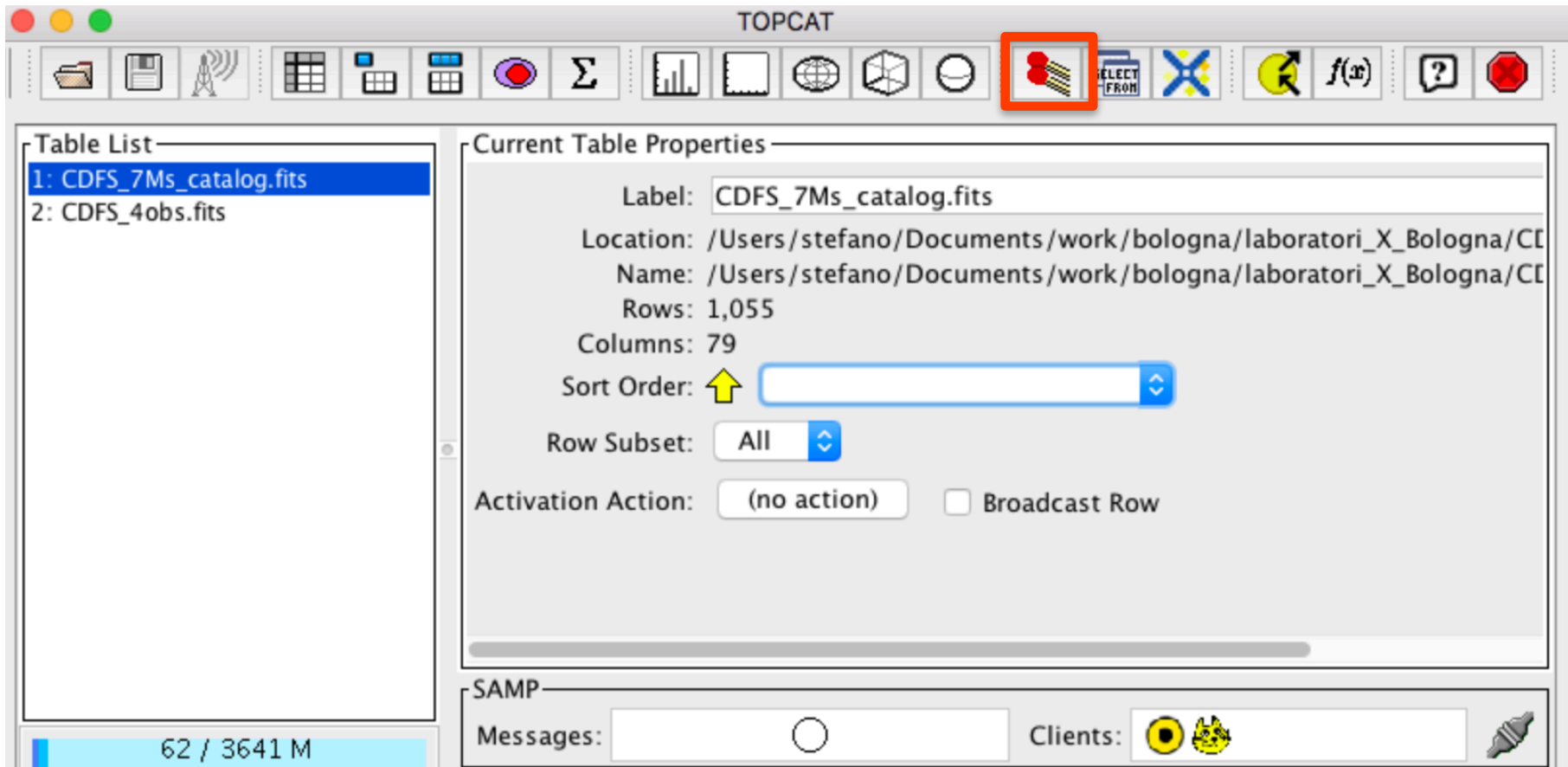
- Table List:** Shows a list of tables. The first table, "1: CDFS_7Ms_catalog.fits", is selected and highlighted in blue. The second table is "2: CDFS_4obs.fits".
- Current Table Properties:** Displays the following information for the selected table:
 - Label: CDFS_7Ms_catalog.fits
 - Location: /Users/stefano/Documents/work/bologna/laboratori_X_Bologna/CF
 - Name: /Users/stefano/Documents/work/bologna/laboratori_X_Bologna/CF
 - Rows: 1,055
 - Columns: 79
 - Sort Order: A dropdown menu with an upward-pointing arrow icon.
 - Row Subset: A dropdown menu set to "All".
 - Activation Action: A button labeled "(no action)" and a checkbox for "Broadcast Row" which is currently unchecked.

At the bottom of the window, there is a status bar showing "62 / 3641 M" and a "SAMP" section with "Messages:" and "Clients:" fields.


Lab Outline

1) Build the source catalog

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 various cross-matching radii (e.g., 1,2,3 arcsec)



The screenshot shows the TOPCAT software interface. The title bar reads "TOPCAT". The toolbar contains various icons, with a red box highlighting the "Cross-match" icon (two overlapping circles). The main window is divided into two panes:

- Table List:** Contains two entries:
 - 1: CDFS_7Ms_catalog.fits
 - 2: CDFS_4obs.fits
- Current Table Properties:** Displays details for the selected table:
 - Label: CDFS_7Ms_catalog.fits
 - Location: /Users/stefano/Documents/work/bologna/laboratori_X_Bologna/CF
 - Name: /Users/stefano/Documents/work/bologna/laboratori_X_Bologna/CF
 - Rows: 1,055
 - Columns: 79
 - Sort Order:  [Dropdown menu]
 - Row Subset: All [Dropdown menu]
 - Activation Action: (no action) Broadcast Row

At the bottom, the status bar shows "62 / 3641 M" and a "SAMP" section with "Messages:" and "Clients:" fields.

1) B

Cross-correlate the
with the official 7
al. 2017), using v

alog

previous steps
e CDF-S (Luo et
1,2,3 arcsec)

Match Tables

Match Criteria

Algorithm: Sky

Max Error: 2.0 arcsec

Table 1

Table: 1: CDFS_7Ms_catalog.fits

RA column: RA degrees

Dec column: DEC degrees

Table 2

Table: 2: CDFS_4obs.fits

RA column: RA degrees

Dec column: DEC degrees

Output Rows

Match Selection: Best match, symmetric

Join Type: 1 and 2

Go Stop

Messages: Clients:

Table List

1: CDFS_7Ms_catalog.fits

2: CDFS_4obs.fits

62 / 3641 M

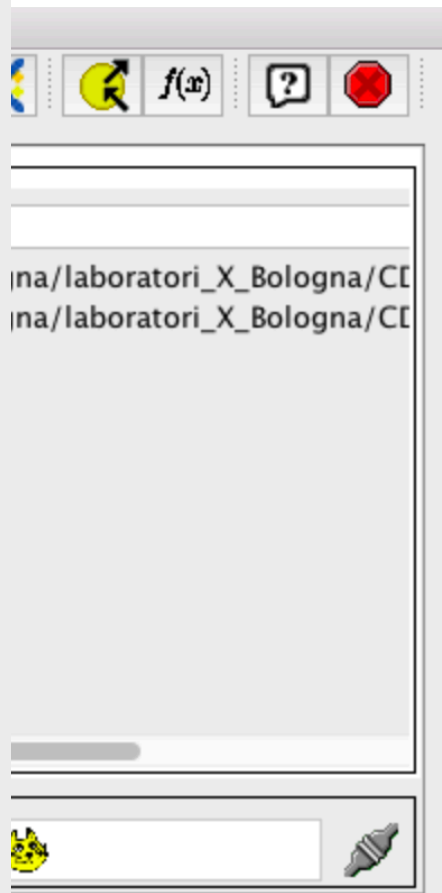
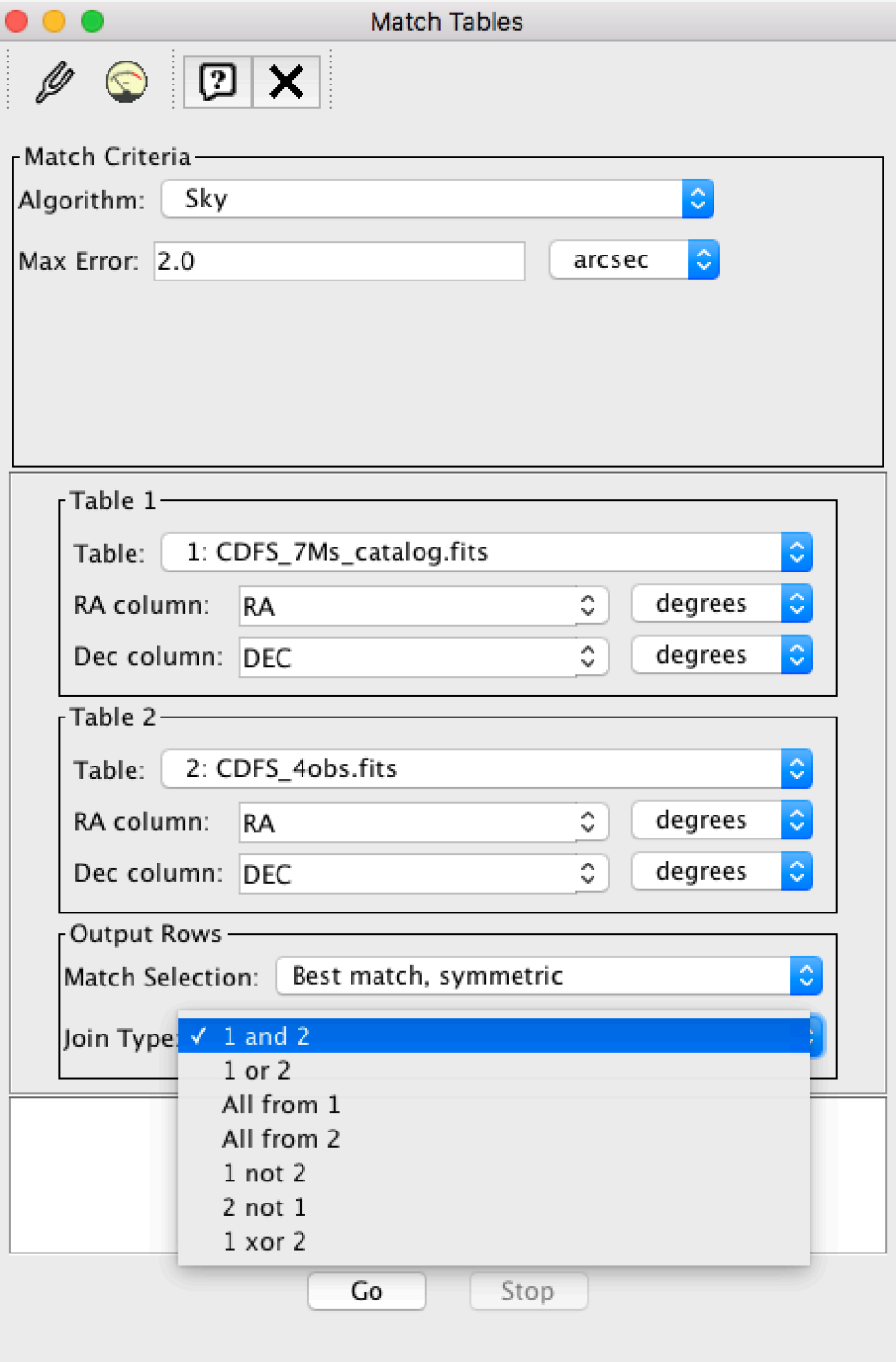
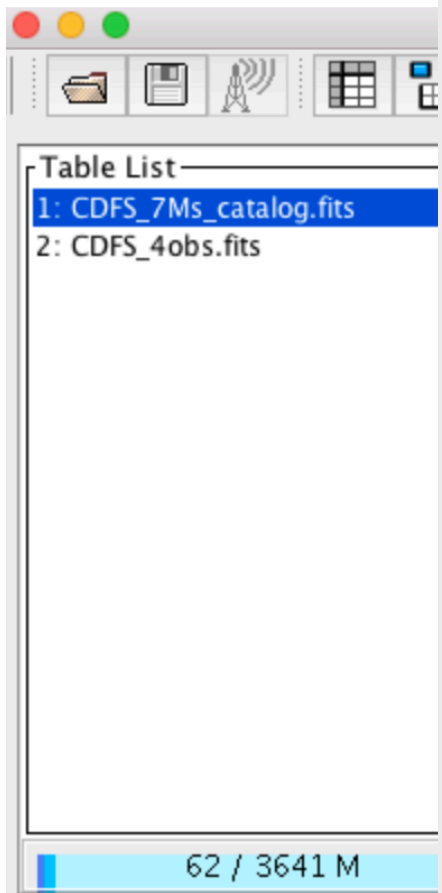
logna/laboratori_X_Bologna/CF
logna/laboratori_X_Bologna/CF

1) E

Cross-correlate with the official al. 2017), using

log

vious steps CDF-S (Luo et ,2,3 arcsec)



Lab Outline

2) Explore the source catalog

Lab Outline

2) Explore the source catalog

- 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.)

Lab Outline

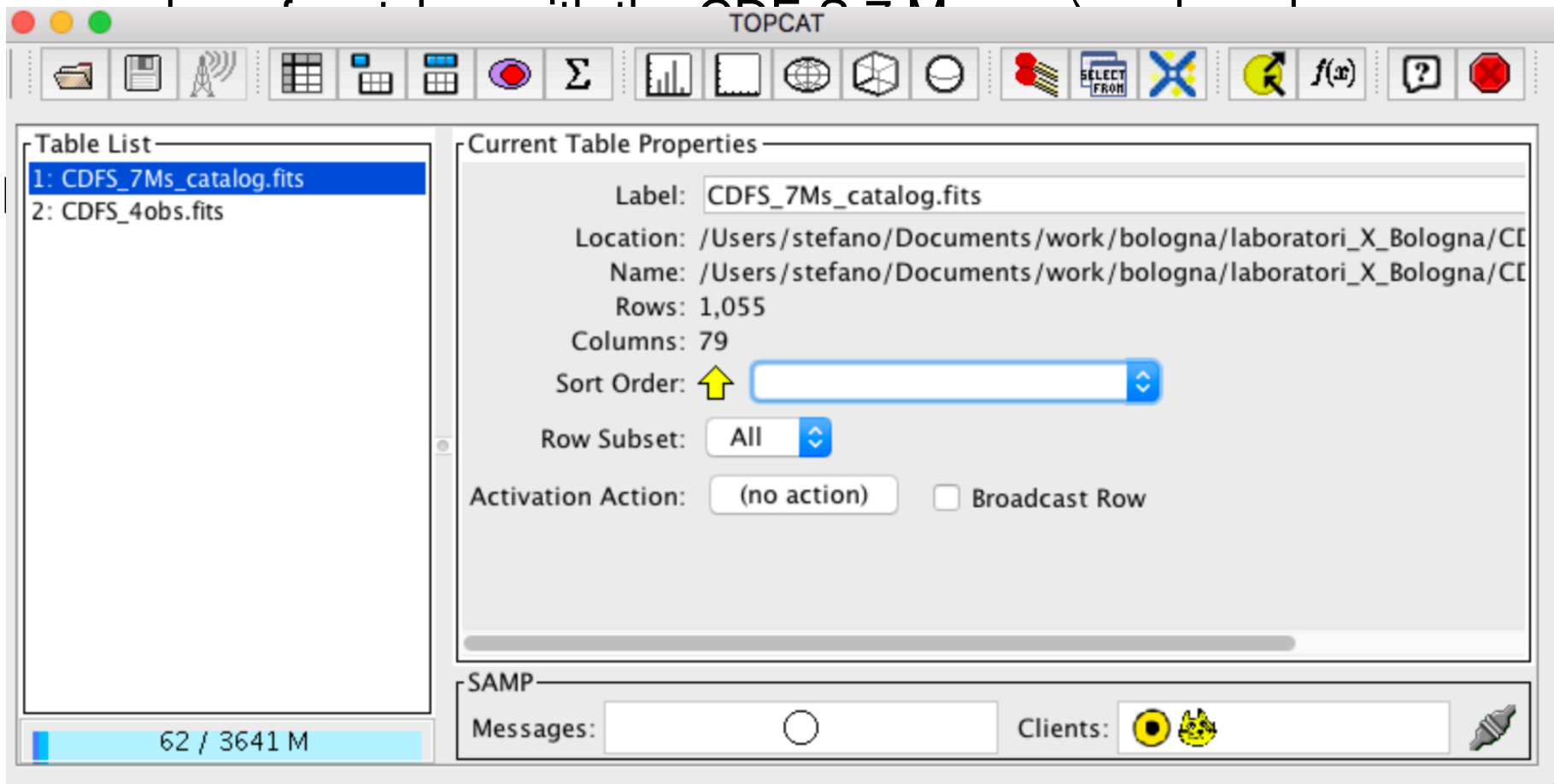
2) Explore the source catalog

- 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.)
- b. For the sources associated with the 7Ms source catalog, produce the redshift distribution histogram, L_x vs. z plot, etc.

Lab Outline

2) Explore the source catalog

a. Choose one of the catalogs you built (e.g., the one with largest



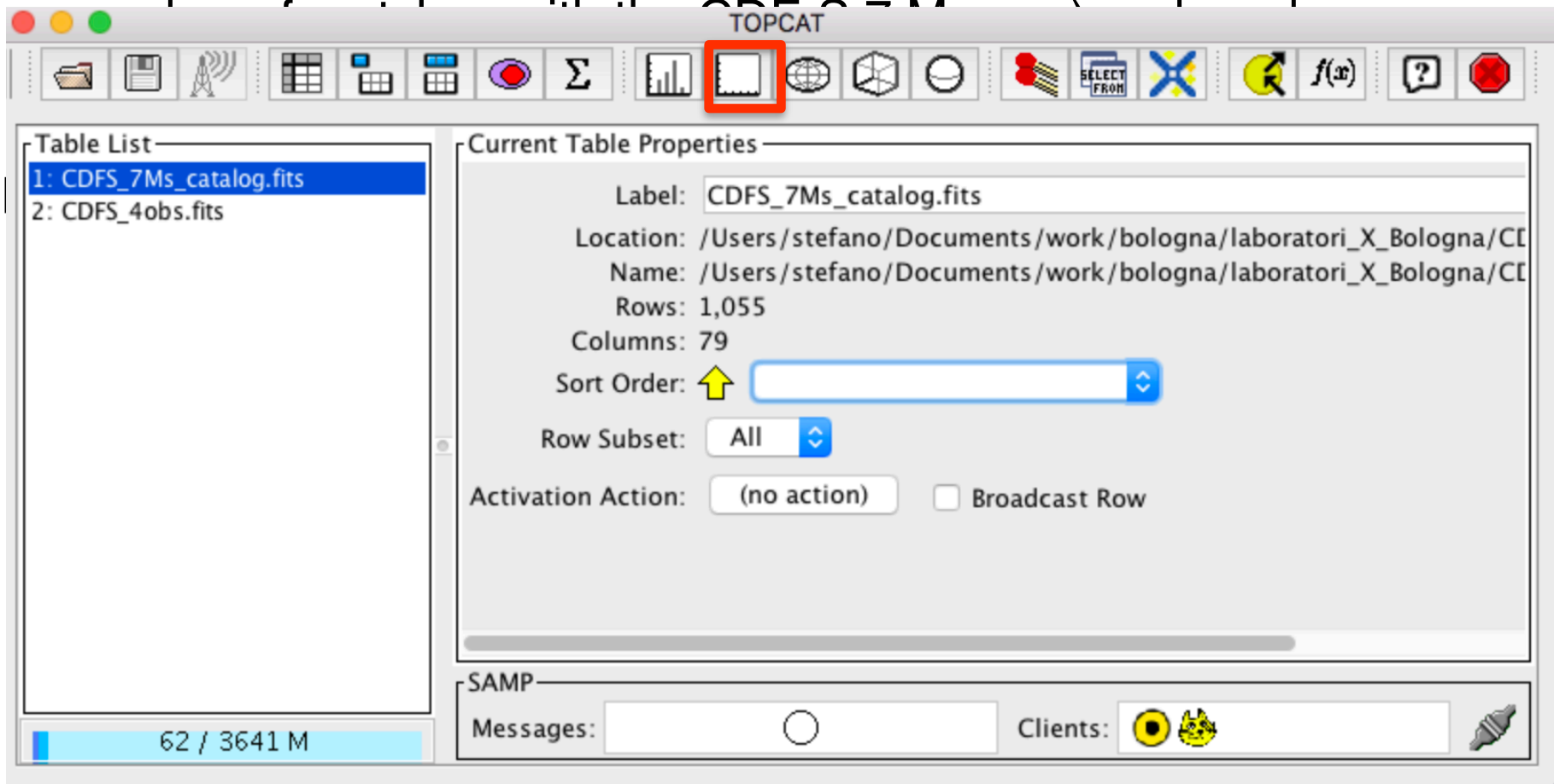
The screenshot shows the TOPCAT software interface. The window title is "TOPCAT". The interface is divided into several sections:

- Table List:** A list of tables with "1: CDFS_7Ms_catalog.fits" selected.
- Current Table Properties:** A panel showing details for the selected table:
 - Label: CDFS_7Ms_catalog.fits
 - Location: /Users/stefano/Documents/work/bologna/laboratori_X_Bologna/CF
 - Name: /Users/stefano/Documents/work/bologna/laboratori_X_Bologna/CF
 - Rows: 1,055
 - Columns: 79
 - Sort Order: A dropdown menu with an upward arrow icon.
 - Row Subset: A dropdown menu set to "All".
 - Activation Action: A button labeled "(no action)" and a checkbox for "Broadcast Row".
- SAMP:** A section at the bottom showing "Messages:" and "Clients:" with icons for a yellow circle and a yellow cat.
- Status Bar:** At the bottom left, it displays "62 / 3641 M".



Lab Outline



2) Explore the source catalog

a. Choose one of the catalogs you built (e.g., the one with largest



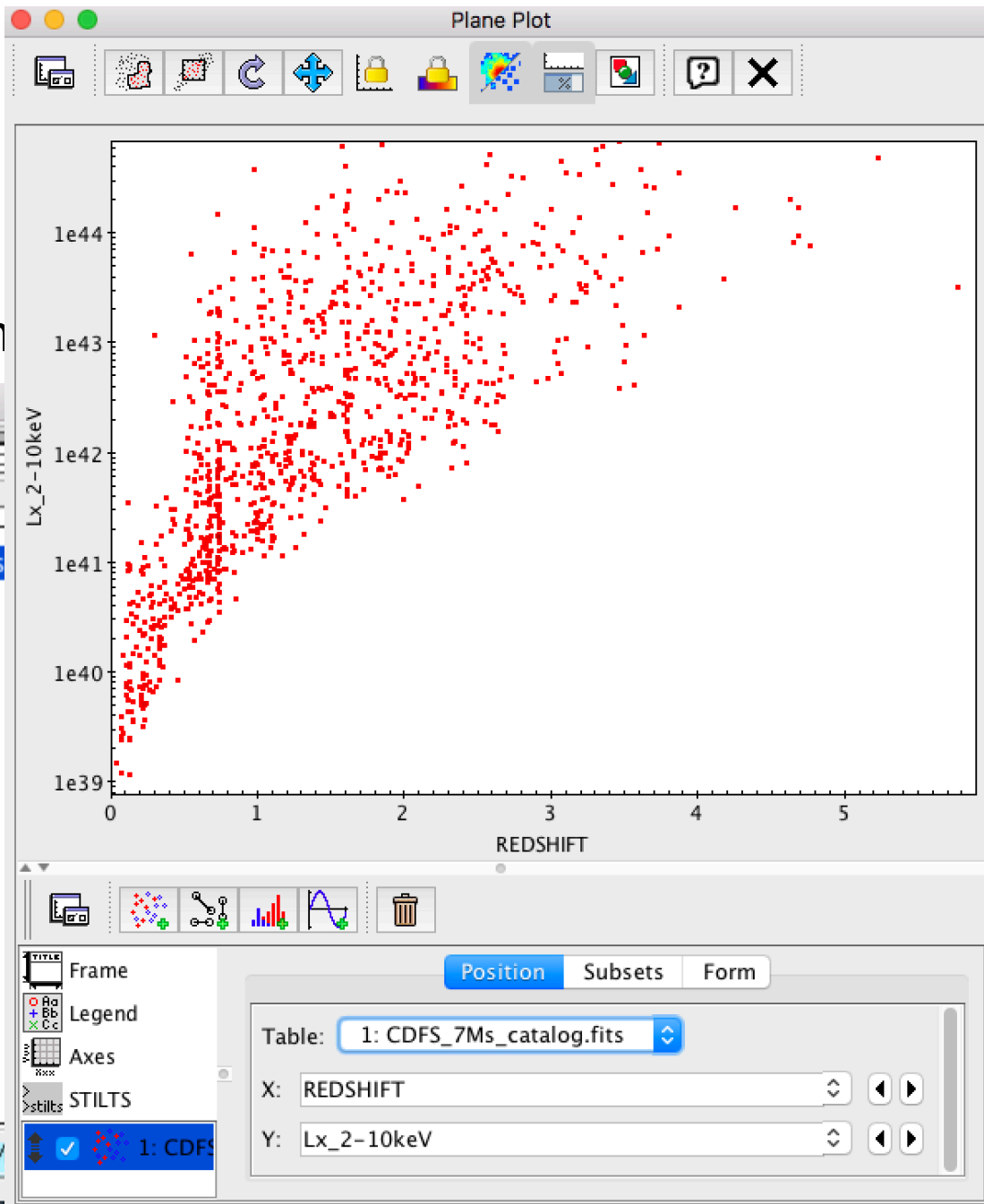
The screenshot shows the TOPCAT software interface. The title bar reads "TOPCAT". The toolbar contains various icons, with a red box highlighting the "Table List" icon. The "Table List" panel on the left shows two tables: "1: CDFS_7Ms_catalog.fits" (selected) and "2: CDFS_4obs.fits". The "Current Table Properties" panel on the right displays the following information:

- Label: CDFS_7Ms_catalog.fits
- Location: /Users/stefano/Documents/work/bologna/laboratori_X_Bologna/CF
- Name: /Users/stefano/Documents/work/bologna/laboratori_X_Bologna/CF
- Rows: 1,055
- Columns: 79
- Sort Order: 
- Row Subset: All 
- Activation Action: (no action) Broadcast Row

The status bar at the bottom shows "62 / 3641 M" and "Messages:  Clients: 

2)

a. Choose on



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th largest

Table List

- 1: CDFS_7Ms_catalog.fits
- 2: CDFS_4obs.fits

62 / 3641 M

$f(x)$

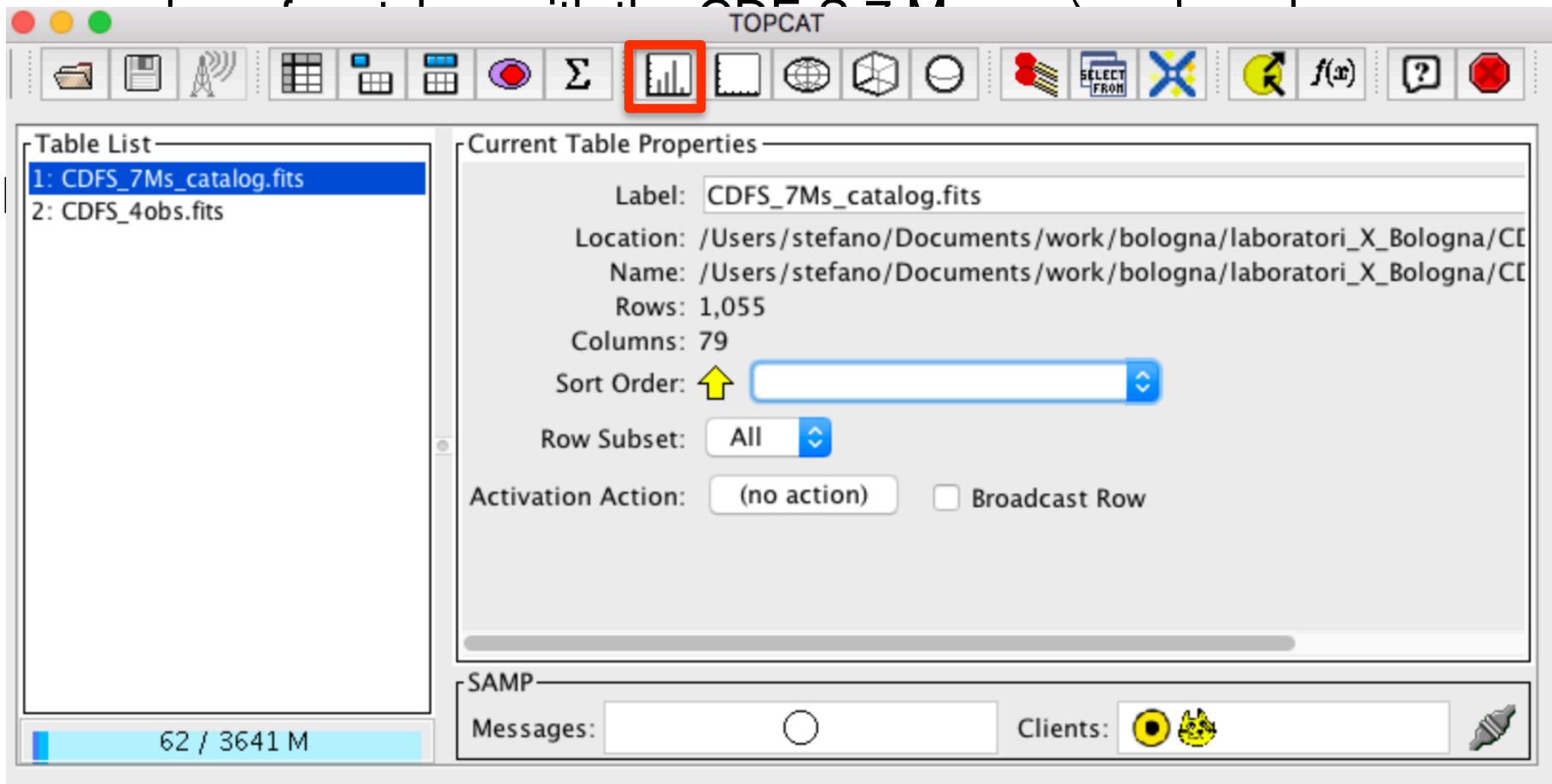
boratori_X_Bologna/CC

boratori_X_Bologna/CC

Lab Outline

2) Explore the source catalog

a. Choose one of the catalogs you built (e.g., the one with largest



The screenshot shows the TOPCAT software interface. The title bar reads "TOPCAT". The toolbar contains various icons, with a bar chart icon highlighted by a red box. The main window is divided into two panes:

- Table List:** A list of tables with "1: CDFS_7Ms_catalog.fits" selected and "2: CDFS_4obs.fits" below it.
- Current Table Properties:** A panel showing details for the selected table:
 - Label: CDFS_7Ms_catalog.fits
 - Location: /Users/stefano/Documents/work/bologna/laboratori_X_Bologna/CF
 - Name: /Users/stefano/Documents/work/bologna/laboratori_X_Bologna/CF
 - Rows: 1,055
 - Columns: 79
 - Sort Order: A dropdown menu with an upward-pointing yellow arrow.
 - Row Subset: A dropdown menu set to "All".
 - Activation Action: A button labeled "(no action)" and a checkbox for "Broadcast Row" which is unchecked.

At the bottom of the window, there is a "SAMP" section with "Messages:" and "Clients:" labels, and a status bar at the very bottom showing "62 / 3641 M".

2

a. Choose c

og

largest

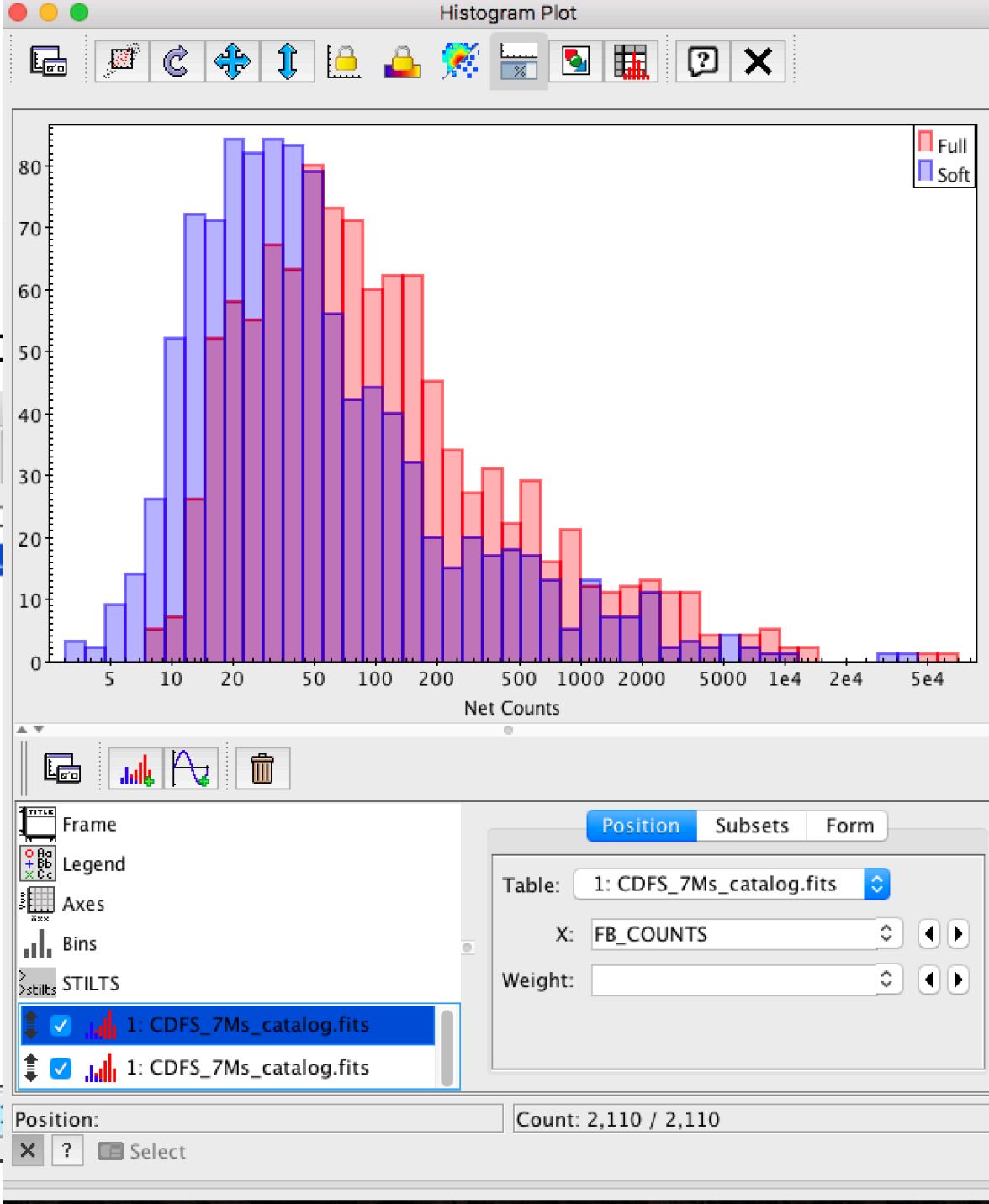


Table List

- 1: CDFS_7Ms_catalog.fits
- 2: CDFS_4obs.fits

62 / 364

$f(x)$? [Red X]

atori_X_Bologna/CC
atori_X_Bologna/CC

Position Subsets Form

Table: 1: CDFS_7Ms_catalog.fits

X: FB_COUNTS

Weight:

Position: Count: 2,110 / 2,110

Select

Lab Outline

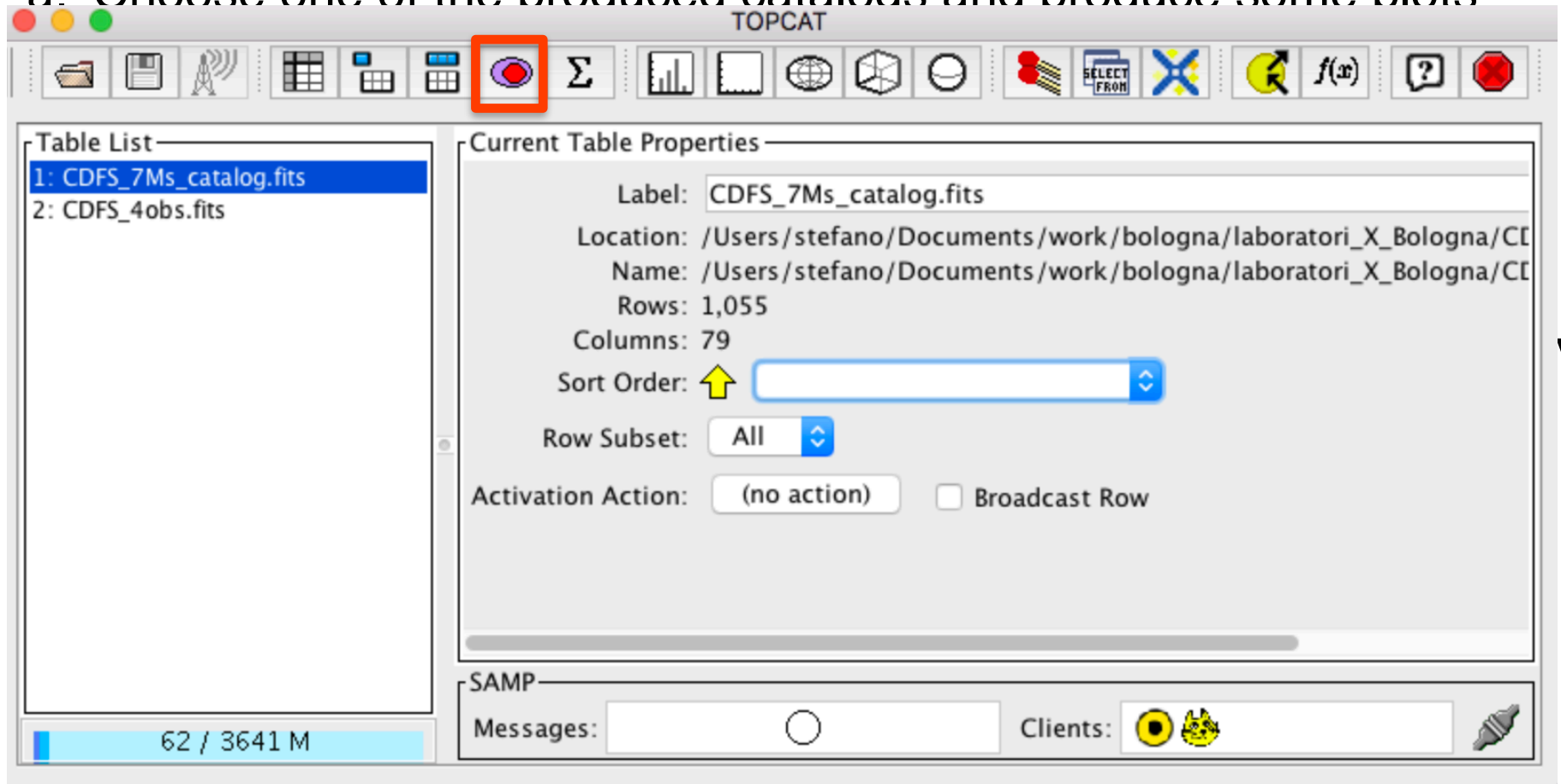
2) Explore the source catalog

- 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, L_x 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?

Lab Outline

2) Explore the source catalog

a. Choose one of the produced catalogs and produce some plots



The screenshot shows the TOPCAT software interface. The title bar reads 'TOPCAT'. The toolbar contains various icons, with the 'View Table' icon (a purple circle with a red dot) highlighted by a red square. The 'Table List' on the left shows two tables: '1: CDFS_7Ms_catalog.fits' (selected) and '2: CDFS_4obs.fits'. The 'Current Table Properties' panel on the right displays the following information:

- Label: CDFS_7Ms_catalog.fits
- Location: /Users/stefano/Documents/work/bologna/laboratori_X_Bologna/CF
- Name: /Users/stefano/Documents/work/bologna/laboratori_X_Bologna/CF
- Rows: 1,055
- Columns: 79
- Sort Order: ↑ [dropdown menu]
- Row Subset: All [dropdown menu]
- Activation Action: (no action) Broadcast Row

At the bottom, the 'SAMP' section shows 'Messages: [input field]' and 'Clients: [radio buttons]'. The status bar at the bottom left indicates '62 / 3641 M'.

VS

Lab Outline

2) Explore the source catalog

a. Choose one of the produced catalogs and produce some plots

TOPCAT

TOPCAT(5): Row Subsets

Table List

- 1: CDFS_7Ms
- 2: CDFS_4obs

Row Subsets for 5: CDFS_7Ms_catalog.fits

ID	Name	Size	Fraction
_1	All	1055	100%

SAMP

Messages: [] Clients: []

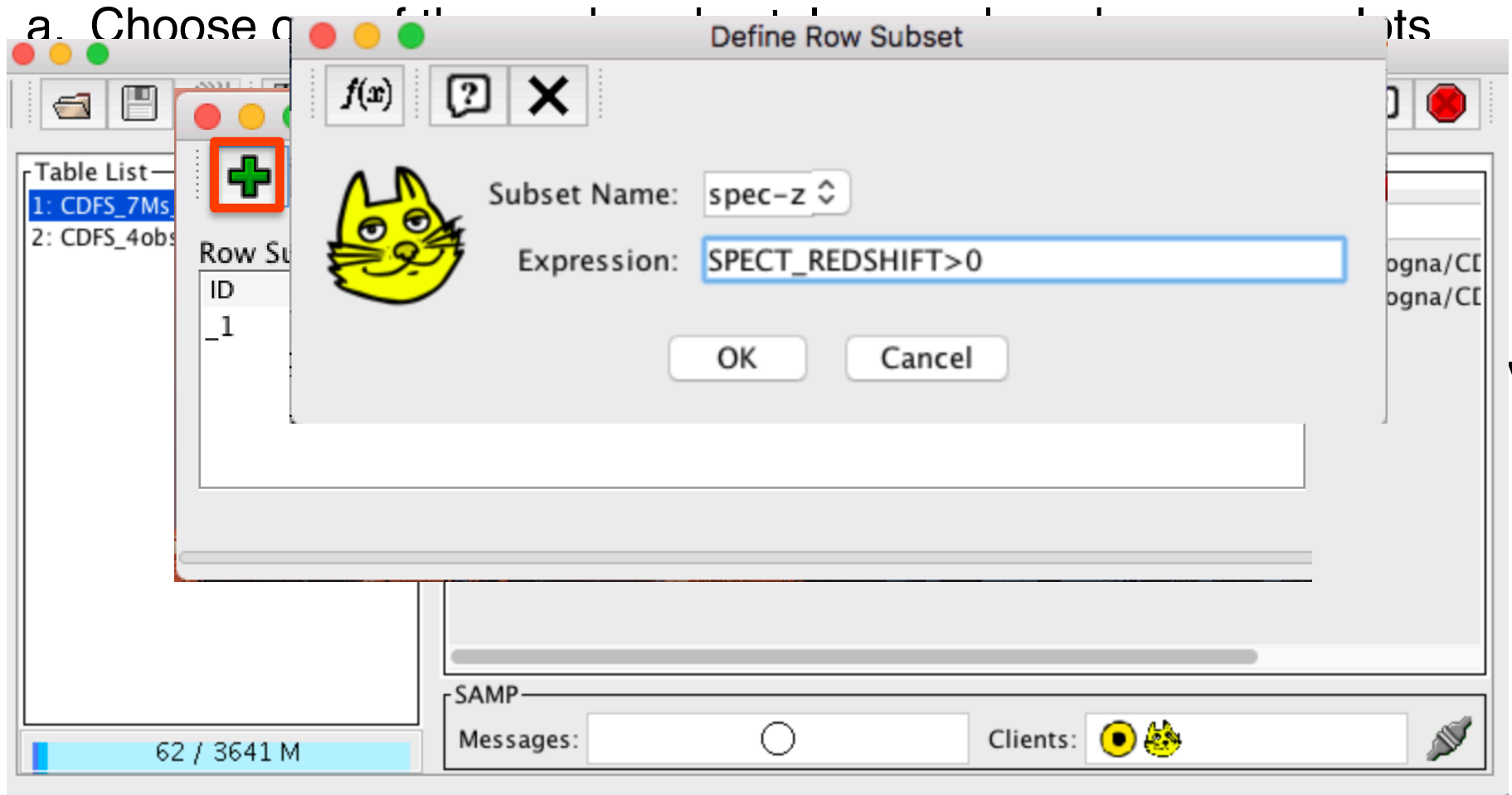
62 / 3641 M

VS

Lab Outline

2) Explore the source catalog

a. Choose a filter



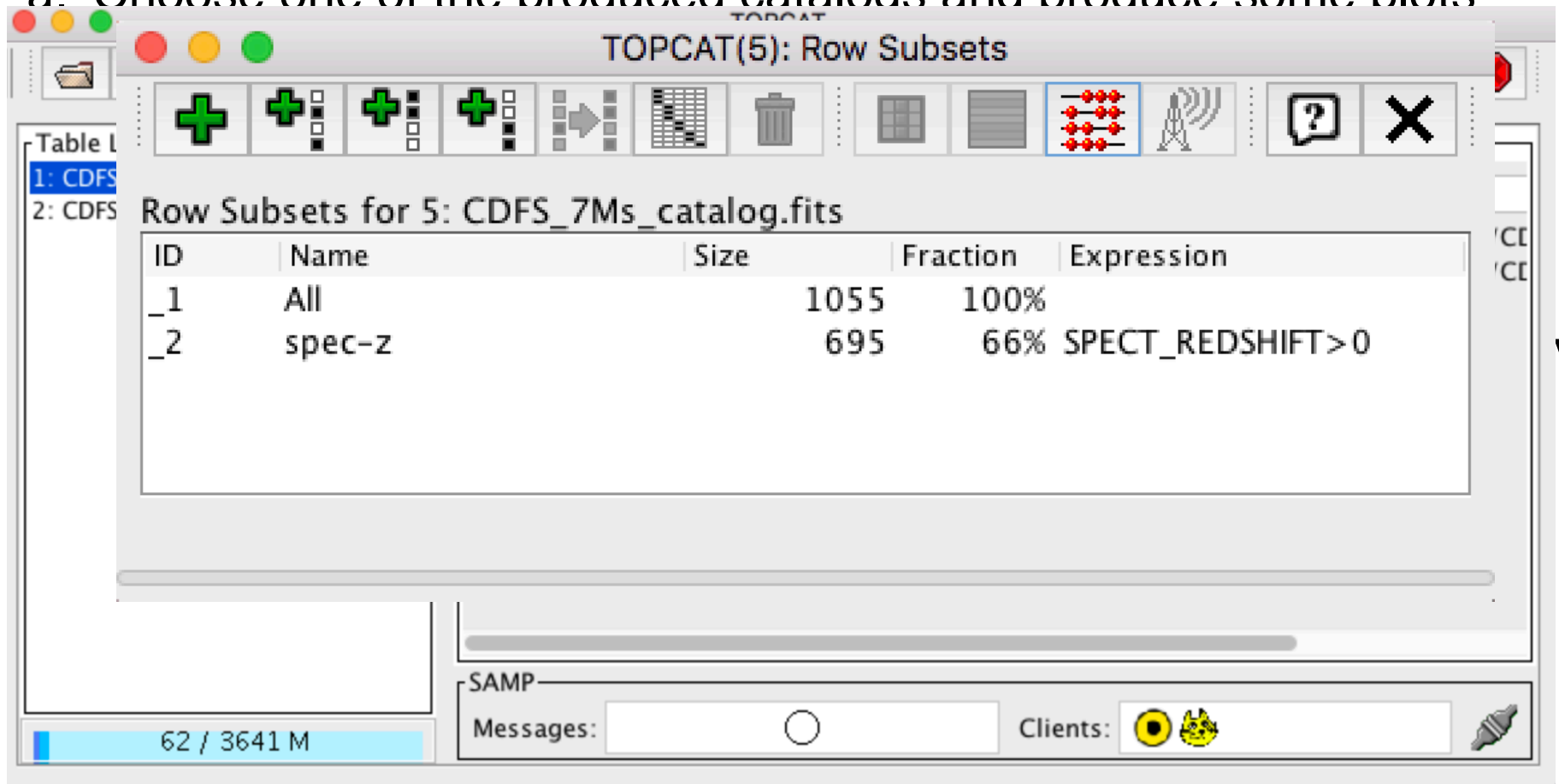
The screenshot shows a 'Define Row Subset' dialog box in the foreground. The dialog features a yellow cat icon on the left. The 'Subset Name' field contains 'spec-z' and the 'Expression' field contains 'SPECT_REDSHIFT>0'. Below these fields are 'OK' and 'Cancel' buttons. In the background, a window titled 'Table List' is visible, with a red box highlighting a green plus icon in its toolbar. The bottom status bar shows '62 / 3641 M' and 'Clients: [yellow circle] [yellow cat icon]'. The text 'VS' is written to the right of the dialog box.

VS

Lab Outline

2) Explore the source catalog

a. Choose one of the produced catalogs and produce some plots



The screenshot shows the TOPCAT(5) Row Subsets window. The title bar reads "TOPCAT(5): Row Subsets". The main area displays "Row Subsets for 5: CDFS_7Ms_catalog.fits" with a table of subsets. The table has columns for ID, Name, Size, Fraction, and Expression. Two subsets are listed: "_1" (All, Size 1055, Fraction 100%) and "_2" (spec-z, Size 695, Fraction 66%, Expression SPECT_REDSHIFT>0). The interface includes a toolbar with various icons for adding, deleting, and viewing subsets, and a status bar at the bottom showing "62 / 3641 M" and "Messages: Clients: 2".

ID	Name	Size	Fraction	Expression
_1	All	1055	100%	
_2	spec-z	695	66%	SPECT_REDSHIFT>0

VS

Lab Outline

2) Explore the source catalog

a. Choose

The screenshot displays a software interface with a 'Define Row Subset' dialog box in the foreground. The dialog box features a yellow cat icon on the left, a 'Subset Name' field containing 'phot-z', and an 'Expression' field containing 'REDSHIFT>0 & !_2'. Below the expression field are 'OK' and 'Cancel' buttons. In the background, a 'Table List' is visible with two entries: '1: CDFS_7Ms' and '2: CDFS_4obs'. A red box highlights a green plus icon in the background interface. The status bar at the bottom of the window shows '62 / 3641 M', 'Messages', and 'Clients' with two cat icons.

VS

Lab Outline

2) Explore the source catalog

a. Choose

Define Row Subset

TOPCAT(5): Row Subsets

Row Subsets for 5: CDFFS_7Ms_catalog.fits

ID	Name	Size	Fraction	Expression
_1	All	1055	100%	
_2	spec-z	695	66%	SPECT_REDSHIFT>0
_3	phot-z	325	31%	REDSHIFT>0 & !_2

SAMP

Messages: Clients:

62 / 3641 M

VS

Lab Outline

2) Explore the source catalog

- 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.

Lab Outline

2) Explore the source catalog

a. Repeat the operation done in b. after creating subsamples of

b.

TOPCAT

Table List

- 1: CDFS_7Ms_catalog.fits
- 2: CDFS_4obs.fits

Current Table Properties

Label: CDFS_7Ms_catalog.fits

Location: /Users/stefano/Documents/work/bologna/laboratori_X_Bologna/CF

Name: /Users/stefano/Documents/work/bologna/laboratori_X_Bologna/CF

Rows: 1,055

Columns: 79

Sort Order:

Row Subset: All

Activation Action: (no action) Broadcast Row

SAMP

Messages:

Clients:

62 / 3641 M

Lab Outline

2) Explore the source catalog

a

b

TOPCAT(5): Row Statistics

Row Statistics for 5: CDFS_7Ms_catalog.fits

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.	

Subset for calculations: spec-z
phot-z

Lab Outline

2) Explore the source catalog

- 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, L_x vs. z plot, etc.
- c. **OPTIONAL:** Select a few sources, then 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. Does it match the one used in the catalog?

Lab Outline

2) Explore the source catalog

PIMMS v4.11a: with ACIS Pile up and Background Count Estimation

Input	
<input checked="" type="radio"/> Count Rate	<input type="radio"/> Flux <input type="radio"/> Flux Density
Mission: CHANDRA-Cycle 11 ▼	Detector/Grating/Filter: ACIS-I/None/None ▼
Input Energy: 0.5	to 2 keV

Output	
<input type="radio"/> Count Rate	<input checked="" type="radio"/> Flux <input type="radio"/> Flux Density
Flux: Absorbed ▼	
Output Energy: 0.5	to 2

Model: Power Law ▼	Galactic NH: 7E19 cm** ⁻²	Redshift(z): 0	Redshifted NH: 0 cm** ⁻²	Photon Index: 1.7 N=AE** ^{-a}	Count Rate: 1E-2 cts/s
------------------------------	---------------------------------------------------	--------------------------	--------------------------------------------------	-----------------------------------------------------	-------------------------------------

CALCULATE CLEAR HELP

PIMMS Prediction:

6.383E-14
erg/cm**2/s absorbed flux

Lab Outline

2) Explore the source catalog

PIMMS v4.11a: with ACIS Pile up and Background Count Estimation

Input		Output	
<input checked="" type="radio"/> Count Rate	<input type="radio"/> Flux	<input type="radio"/> Count Rate	<input checked="" type="radio"/> Flux
<input type="radio"/> Flux	<input type="radio"/> Flux Density	<input type="radio"/> Flux Density	
Mission: CHANDRA-Cycle 11 ▾	Detector/Crating/Filter:	Flux:	
Input Energy: 0.5 to 2 keV		Output Energy: 0.5 to 2	

What happens changing the mission Cycle?

Model: Power Law ▾	Galactic NH: 7E19 cm** ⁻²	Redshift(z): 0	Redshifted NH: 0 cm** ⁻²	Photon Index: 1.7 N=AE** ^{-a}	Count Rate: 1E-2 cts/s
------------------------------	---------------------------------------------------	--------------------------	--------------------------------------------------	-----------------------------------------------------	-------------------------------------

CALCULATE CLEAR HELP

PIMMS Prediction:

6.383E-14

erg/cm**²/s absorbed flux

Lab Outline

2) Explore the source catalog

- 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, L_x vs. z plot, etc.
- c. **OPTIONAL:** Select a few sources, then 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. Does it match the one used in the catalog?

Lab Outline

2) Explore the source catalog

- 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.

c.

Table List

- 1: CDFS_7Ms_catalog.fits
- 2: CDFS_4obs.fits

Current Table Properties

Label: CDFS_7Ms_catalog.fits

Location: /Users/stefano/Documents/work/bologna/laboratori_X_Bologna/CF

Name: /Users/stefano/Documents/work/bologna/laboratori_X_Bologna/CF

Rows: 1,055

Columns: 79

Sort Order:

Row Subset: All

Activation Action: (no action) Broadcast Row

SAMP

Messages:

Clients:

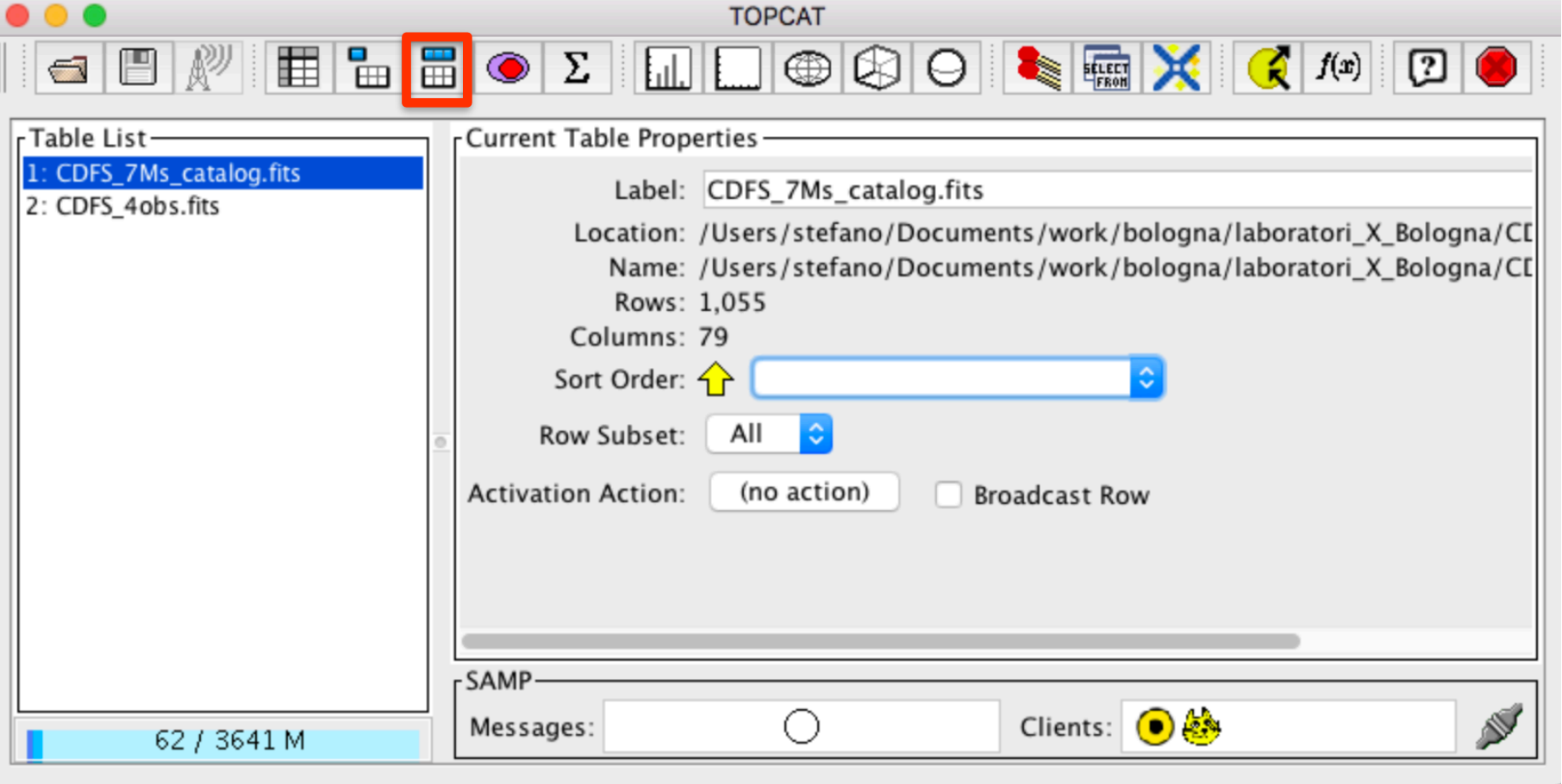
62 / 3641 M

Lab Outline

2) Explore the source catalog

- 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.






c.

Lab Outline

2) Explore the source catalog

a. Choose one source sign

b.   
c. Table List
1: CDFS_7Ms_cata
2: CDFS_4obs.fits


TOPCAT(3): Table Columns

Table Columns for 3: CDFS_7Ms_catalog.fits

Δ	Index	Visible	Name	\$ID	Class	Units	Description	Dataty
0		<input type="checkbox"/>	Index	\$0	Long		Table row index	
1	1	<input checked="" type="checkbox"/>	SOURCE_SAMPLE	\$1	String			char
2	2	<input checked="" type="checkbox"/>	XID_SOURCE_NUMBER	\$2	Long			long
3	3	<input checked="" type="checkbox"/>	NAME	\$3	String			char
4	4	<input checked="" type="checkbox"/>	ALT_NAME	\$4	String			char
5	5	<input checked="" type="checkbox"/>	RA	\$5	Float	DEGREE		float
6	6	<input checked="" type="checkbox"/>	DEC	\$6	Float	DEGREE		float
7	7	<input checked="" type="checkbox"/>	LII_1	\$7	Float	DEGREE		float
8	8	<input checked="" type="checkbox"/>	BII_1	\$8	Float	DEGREE		float
9	9	<input checked="" type="checkbox"/>	LOG_MIN_NS_PROB	\$9	Float			float
10	10	<input checked="" type="checkbox"/>	LOG_MIN_FP_PROB	\$10	Long			long
11	11	<input checked="" type="checkbox"/>	ERROR_RADIUS	\$11	Float	ARCSEC		float
12	12	<input checked="" type="checkbox"/>	OFF_AXIS	\$12	Float	ARCMIN		float
13	13	<input checked="" type="checkbox"/>	FB_COUNTS	\$13	Float	CT		float
14	14	<input checked="" type="checkbox"/>	FB_COUNTS_NEG_ERR	\$14	Float	CT		float
15	15	<input checked="" type="checkbox"/>	FB_COUNTS_POS_ERR	\$15	Float	CT		float
16	16	<input checked="" type="checkbox"/>	SB_COUNTS	\$16	Float	CT		float
17	17	<input checked="" type="checkbox"/>	SB_EXPOSURE	\$61	Float	S		float
18	18	<input checked="" type="checkbox"/>	SB_COUNTS_NEG_ERR	\$17	Float	CT		float
19	19	<input checked="" type="checkbox"/>	SB_COUNTS_POS_ERR	\$18	Float	CT		float
20	20	<input checked="" type="checkbox"/>	HB_COUNTS	\$19	Float	CT		float
21	21	<input checked="" type="checkbox"/>	HB_COUNTS_NEG_ERR	\$20	Float	CT		float
22	22	<input checked="" type="checkbox"/>	HB_COUNTS_POS_ERR	\$21	Float	CT		float
23	23	<input checked="" type="checkbox"/>	SOURCE_FLAG	\$22	String			char

SAMP

Messages:

Clients: 

62 / 3641 M

nts vs.



_Bologna/CC
_Bologna/CC

Lab Outline

2) Explore the source catalog

a. Choose one source sign

b.

c. Table List
1: CDFS_7Ms_cata
2: CDFS_4obs.fits

TOPCAT(3): Table Columns

Table Columns for 3: CDFS_7Ms_catalog.fits

Δ	Index	Visible	Name	\$ID	Class	Units	Description	Dataty
0		<input type="checkbox"/>	Index	\$0	Long		Table row index	
1	1	<input checked="" type="checkbox"/>	SOURCE_SAMPLE	\$1	String			char
2	2	<input checked="" type="checkbox"/>	XID_SOURCE_NUMBER	\$2	Long			long
3	3	<input checked="" type="checkbox"/>	NAME	\$3	String			char
4	4	<input checked="" type="checkbox"/>	ALT_NAME	\$4	String			char
5	5	<input checked="" type="checkbox"/>	RA	\$5	Float	DEGREE		float
6	6	<input checked="" type="checkbox"/>	DEC	\$6	Float	DEGREE		float
7	7	<input checked="" type="checkbox"/>	LII_1	\$7	Float	DEGREE		float
8	8	<input checked="" type="checkbox"/>	BII_1	\$8	Float	DEGREE		float
9	9	<input checked="" type="checkbox"/>	LOG_MIN_NS_PROB	\$9	Float			float
10	10	<input checked="" type="checkbox"/>	LOG_MIN_FP_PROB	\$10	Long			long
11	11	<input checked="" type="checkbox"/>	ERROR_RADIUS	\$11	Float	ARCSEC		float
12	12	<input checked="" type="checkbox"/>	OFF_AXIS	\$12	Float	ARCMIN		float
13	13	<input checked="" type="checkbox"/>	FB_COUNTS	\$13	Float	CT		float
14	14	<input checked="" type="checkbox"/>	FB_COUNTS_NEG_ERR	\$14	Float	CT		float
15	15	<input checked="" type="checkbox"/>	FB_COUNTS_POS_ERR	\$15	Float	CT		float
16	16	<input checked="" type="checkbox"/>	SB_COUNTS	\$16	Float	CT		float
17	17	<input checked="" type="checkbox"/>	SB_EXPOSURE	\$61	Float	S		float
18	18	<input checked="" type="checkbox"/>	SB_COUNTS_NEG_ERR	\$17	Float	CT		float
19	19	<input checked="" type="checkbox"/>	SB_COUNTS_POS_ERR	\$18	Float	CT		float
20	20	<input checked="" type="checkbox"/>	HB_COUNTS	\$19	Float	CT		float
21	21	<input checked="" type="checkbox"/>	HB_COUNTS_NEG_ERR	\$20	Float	CT		float
22	22	<input checked="" type="checkbox"/>	HB_COUNTS_POS_ERR	\$21	Float	CT		float
23	23	<input checked="" type="checkbox"/>	SOURCE_FLAG	\$22	String			char

62 / 3641 M

SAMP

Messages:

Clients:

nts vs.

_Bologna/CC
_Bologna/CC

Lab Outline

2) Explore the source catalog

a. Choose one source sign

b. Table List
1: CDFS_7Ms_cata
2: CDFS_4obs.fits

c.

TOPCAT(3): Table Columns

Table Columns for 3: CDFS_7Ms_catalog.fits

Δ	Index	Visible	Name	\$ID	Class	Units	Description	Dataty
0		<input type="checkbox"/>	Index	\$0	Long		Table row index	
1	1	<input checked="" type="checkbox"/>	SOURCE_SAMPLE	\$1	String			char
2	2	<input checked="" type="checkbox"/>	XID_SOURCE_NUMBER	\$2	Long			long
3	3	<input checked="" type="checkbox"/>	NAME	\$3	String			char
4	4	<input checked="" type="checkbox"/>	ALT_NAME	\$4	String			char
5	5	<input checked="" type="checkbox"/>	RA	\$5	Float	DEGREE		float
6	6	<input checked="" type="checkbox"/>	DEC	\$6	Float	DEGREE		float
7	7	<input checked="" type="checkbox"/>	LII_1	\$7	Float	DEGREE		float
8	8	<input checked="" type="checkbox"/>	BII_1	\$8	Float	DEGREE		float
9	9	<input checked="" type="checkbox"/>	LOG_MIN_NS_PROB	\$9	Float			float
10	10	<input checked="" type="checkbox"/>	LOG_MIN_FP_PROB	\$10	Long			long
11	11	<input checked="" type="checkbox"/>	ERROR_RADIUS	\$11	Float	ARCSEC		float
12	12	<input checked="" type="checkbox"/>	OFF_AXIS	\$12	Float	ARCMIN		float
13	13	<input checked="" type="checkbox"/>	FB_COUNTS	\$13	Float	CT		float
14	14	<input checked="" type="checkbox"/>	FB_COUNTS_NEG_ERR	\$14	Float	CT		float
15	15	<input checked="" type="checkbox"/>	FB_COUNTS_POS_ERR	\$15	Float	CT		float
16	16	<input checked="" type="checkbox"/>	SB_COUNTS	\$16	Float	CT		float
17	17	<input checked="" type="checkbox"/>	SB_EXPOSURE	\$61	Float	S		float
18	18	<input checked="" type="checkbox"/>	SB_COUNTS_NEG_ERR	\$17	Float	CT		float
19	19	<input checked="" type="checkbox"/>	SB_COUNTS_POS_ERR	\$18	Float	CT		float
20	20	<input checked="" type="checkbox"/>	HB_COUNTS	\$19	Float	CT		float
21	21	<input checked="" type="checkbox"/>	HB_COUNTS_NEG_ERR	\$20	Float	CT		float
22	22	<input checked="" type="checkbox"/>	HB_COUNTS_POS_ERR	\$21	Float	CT		float
23	23	<input checked="" type="checkbox"/>	SOURCE_FLAG	\$22	String			char

62 / 3641 M

Messages:

Clients:

nts vs.

Lab Outline

2) Explore the source catalog

a. Choose one source sign

b.

c. Table List
1: CDFS_7Ms_cata
2: CDFS_4obs.fits

Define Synthetic Column

$f(x)$? X

Name: SB_COUNTRATE

Expression: toFloat(\$16/\$61)

Units:

Description:

UCD: no UCD

Index: 19

OK Cancel

21	21	✓	HB_COUNTS_NEG_ERR	\$20	Float	CT	float
22	22	✓	HB_COUNTS_POS_ERR	\$21	Float	CT	float
23	23	✓	SOURCE_FLAG	\$22	String		char

62 / 3641 M

Messages: ○ Clients: 🐱

3. Analyse the data products: spectral fitting

Fit *Chandra* spectra for at least one source 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

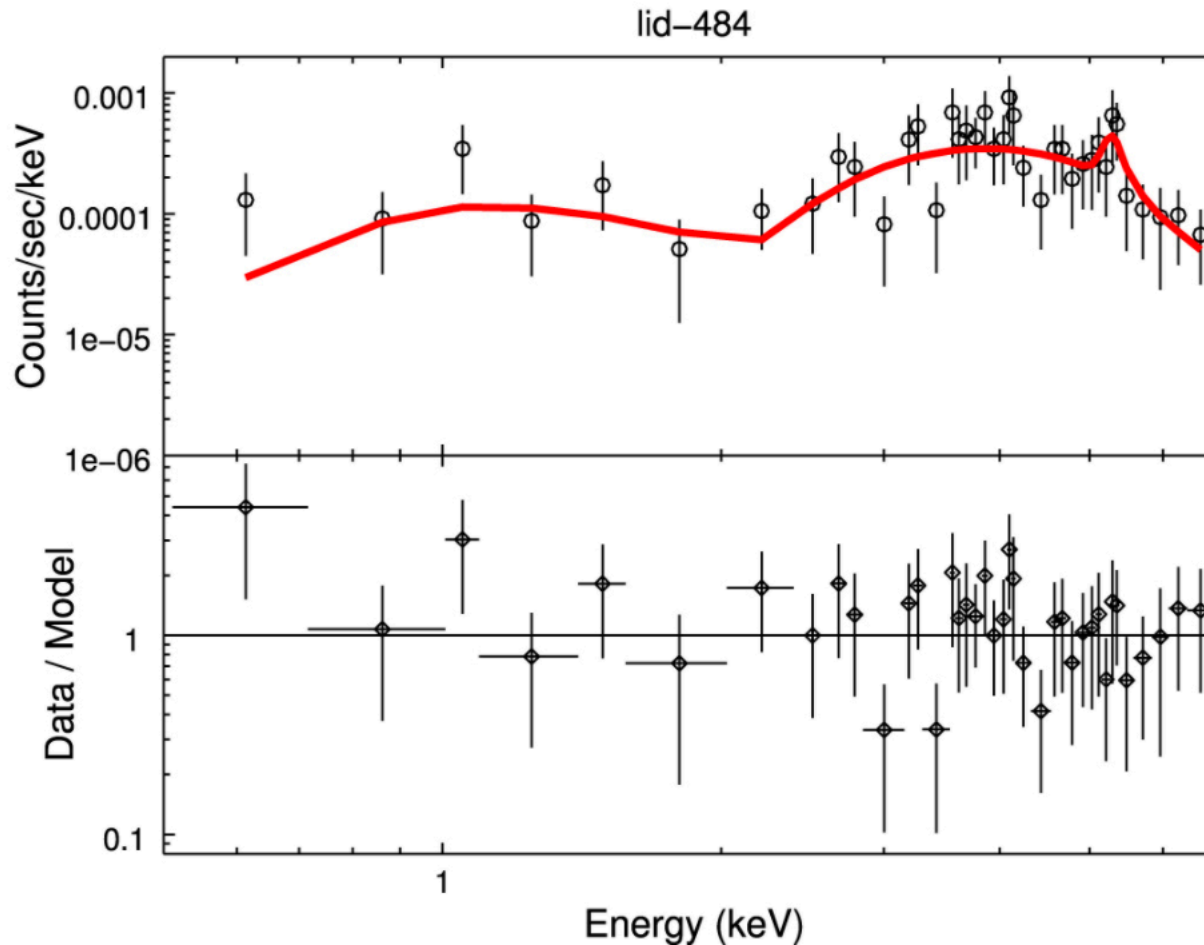
Spectral analysis pipeline

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. Step by step approach: starting with an absorbed power law, then adding additional components (e.g., secondary power law to account for scattered emission, Gaussian to model Iron line at 6.4 keV...)
5. Once a physically justified model is obtained, save the X-ray spectral parameters (including errors) and produce confidence contours

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.**