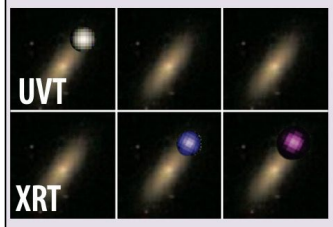
Survey and Time-domain Astrophysical Research eXplorer

# STAR-X – X-ray and UV Surveys Design

W.N. Brandt (Penn State) for the STAR-X Team

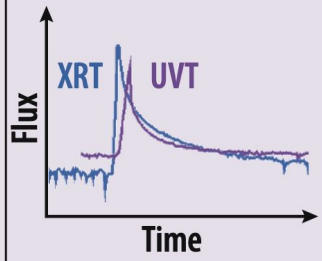
## Time-Domain Science Examples

### 1-1 Supernovae



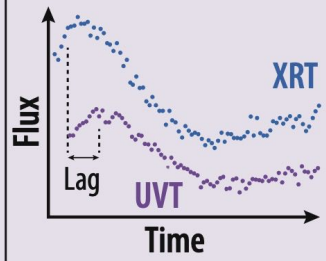

XRT discovers a shock breakout and triggers a ToO to catch cooling in the UV

### 2-1 Tidal Disruption




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

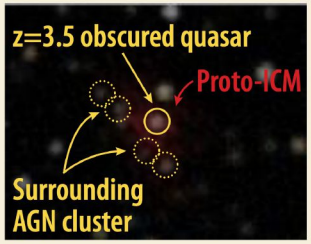
### 2-2 AGN Accretion Flows




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

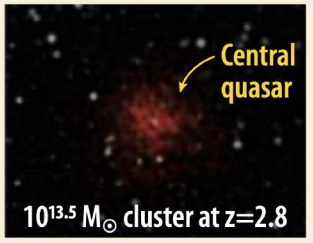
## Co-Added Static Science Examples

### 3-1 Protoclusters



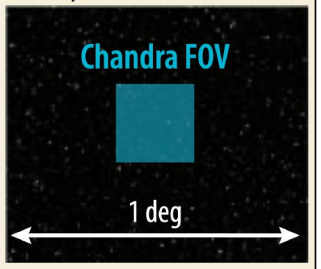

STAR-X will witness the birth of galaxy clusters at z>3 via AGN clustering and early intracluster medium

### 3-2 High-z Clusters




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

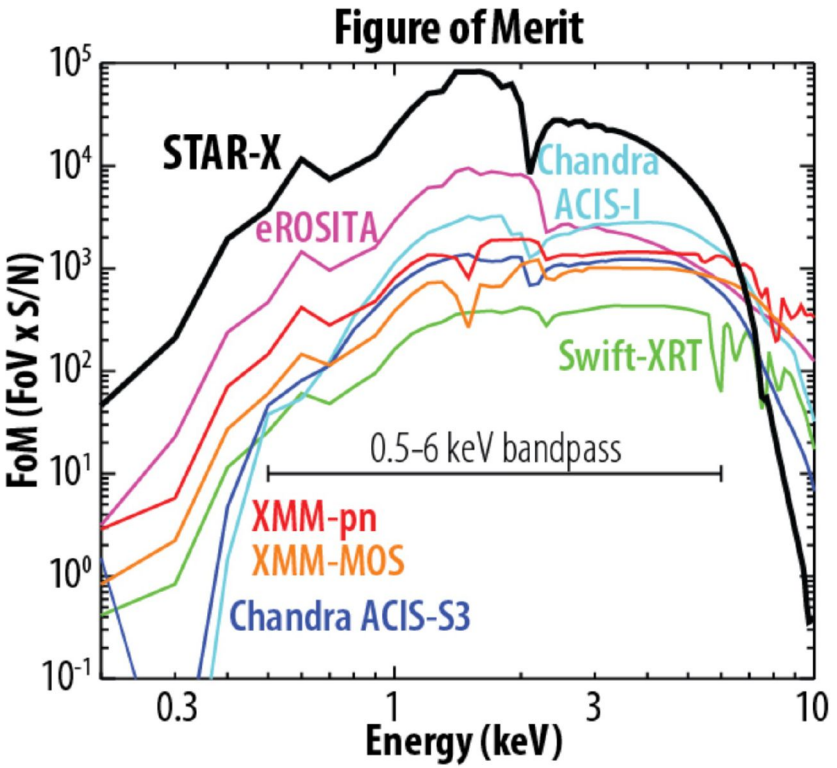
### Survey Science: z>6 AGNs




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

STAR-X surveys are kind of an “X-ray/UV version of the LSST”

# X-ray Telescope Figure of Merit




Wik et al.

The STAR-X XRT is uniquely powerful for surveys in its combined

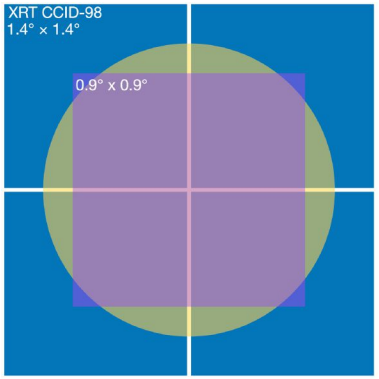
- Field of view (1 deg$^2$)
- Effective area (> 1700 cm$^2$ at 1 keV)
- Good PSF across field of view
- Low background (low-inclination orbit)

This gives it a superb "point-source discovery speed".

Figure of merit is point-source S/N integrated over the field of view.

Generalization of "grasp" to the faint-source limit.

# UV Telescope Grasp



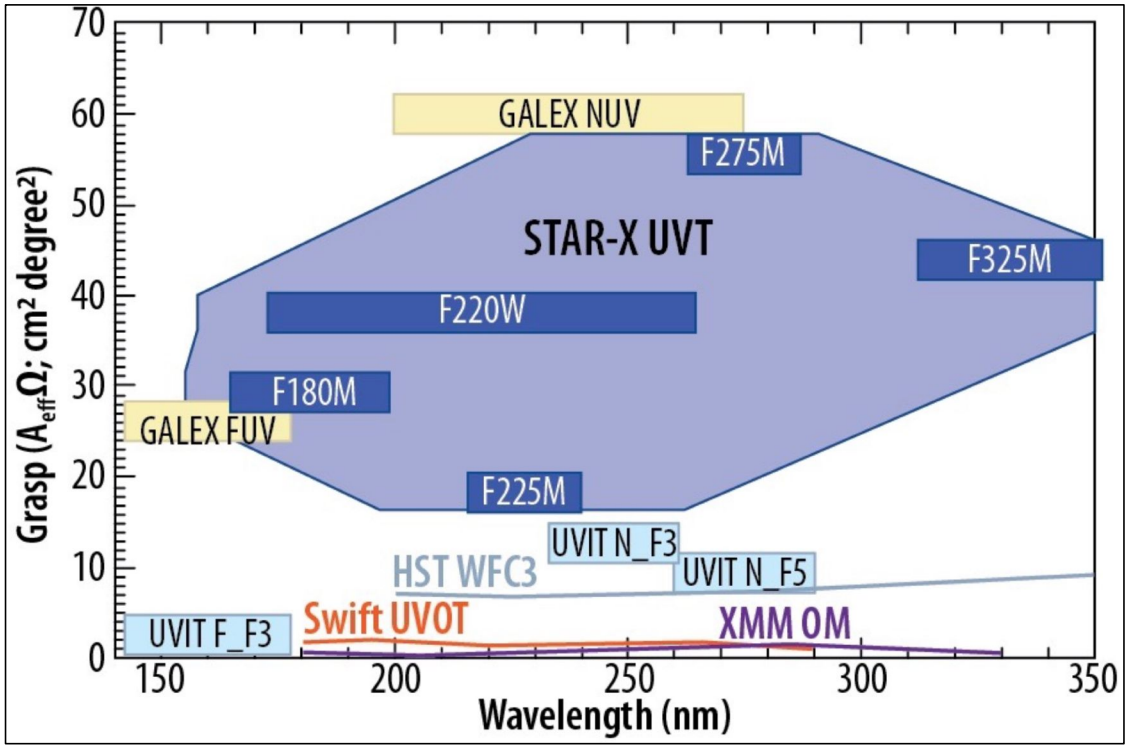

0.9º x 0.9º field of view, well matched to X-rays

PSF HPD is 5” averaged over field of view

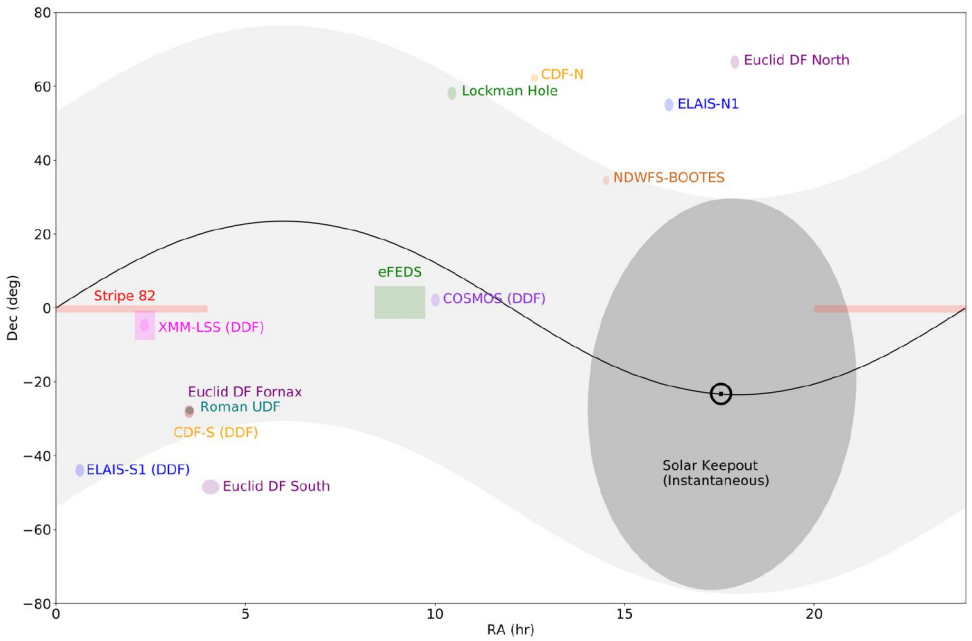
Good UV grasp for surveys

Comparable to GALEX and superior to XMM OM, Swift UVOT, AstroSat UVIT, and HST WFC3

Higher bandpass resolution than GALEX



# Good Field of Regard and Excellent Agility




2029 STAR-X Visibility (Sun Block Only)

| Name | RA | Dec. | January | February | March | April | May | June | July | August | Se |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CDF-N | 12:36:53 | 62:15:00 | | | | | | | | | |
| CDF-S | 03:32:30 | -28:06:00 | | | | | | | | | |
| XMM-LSS | 02:22:50 | -04:45:00 | | | | | | | | | |
| COSMOS | 10:00:24 | +02:10:55 | | | | | | | | | |
| ELAIS-N1 | 16:11:00 | +55:00:00 | | | | | | | | | |
| ELAIS-S1 | 00:37:48 | -44:00:00 | | | | | | | | | |
| Roman UDF | 03:32:39 | -27:47:29 | | | | | | | | | |
| Lockman Hole | 10:47:00 | +58:05:00 | | | | | | | | | |
| xBootes | 14:32:00 | +34:30:00 | | | | | | | | | |
| Euclid Deep Field North | 17:55:00 | 66:33:38 | | | | | | | | | |
| Euclid Deep Field South | 04:04:57 | -48:25:22 | | | | | | | | | |
| eFEDS [8.5 h] | 08:30:00 | 01:30:00 | | | | | | | | | |
| eFEDS [9.0 h] | 09:00:00 | 01:30:00 | | | | | | | | | |
| eFEDS [9.5 h] | 09:30:00 | 01:30:00 | | | | | | | | | |
| Stripe 82 [20 h] | 20:00:00 | 00:00:00 | | | | | | | | | |
| Stripe 82 [21 h] | 21:00:00 | 00:00:00 | | | | | | | | | |
| Stripe 82 [22 h] | 22:00:00 | 00:00:00 | | | | | | | | | |
| Stripe 82 [23 h] | 23:00:00 | 00:00:00 | | | | | | | | | |
| Stripe 82 [0 h] | 0:00:00 | 00:00:00 | | | | | | | | | |
| Stripe 82 [1 h] | 01:00:00 | 00:00:00 | | | | | | | | | |
| Stripe 82 [2 h] | 02:00:00 | 00:00:00 | | | | | | | | | |
| Stripe 82 [3 h] | 03:00:00 | 00:00:00 | | | | | | | | | |
| Stripe 82 [4 h] | 04:00:00 | 00:00:00 | | | | | | | | | |

At any given time, STAR-X can intensively target a variety of leading survey fields.

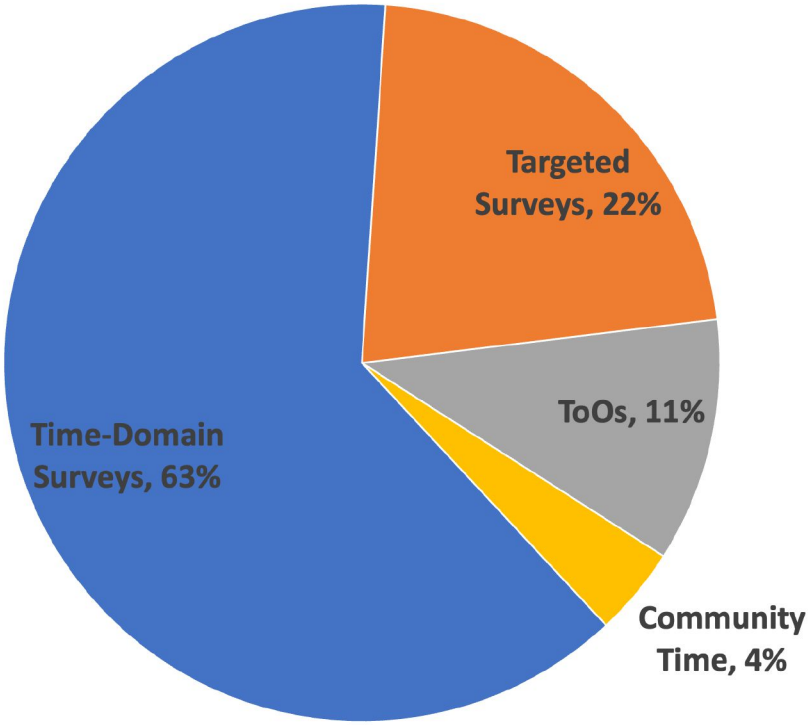
Excellent spacecraft agility allows deep fields to be built up efficiently via many short time-domain exposures (like LSST). And allows multi-mission coordination.

# Surveys Design

# Current Survey Design and Community Input

We have developed a surveys design capable of achieving the mission goals.

Serves as an “existence proof” that goals can be accomplished in 2 yr.



# Current Survey Design and Community Input

However, the overall surveys landscape will surely change substantially between now and the STAR-X launch, as new facilities conduct surveys.

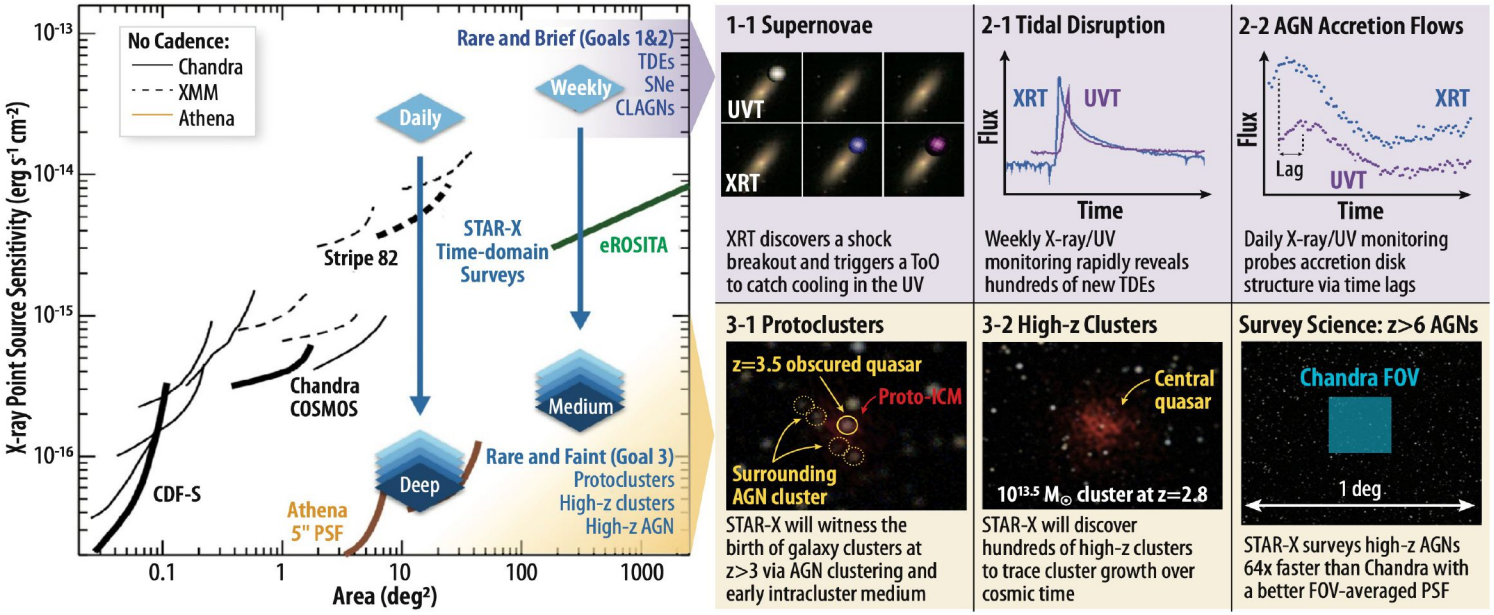


Roman


Flexibility is needed to accommodate these new developments.

If selected, we plan to solicit community input regularly (e.g., via workshops) until launch (in ~ 2028) to optimize the STAR-X surveys design.

# The STAR-X Surveys




UV depths (mag @ 180 nm)

Daily: 22.5
Weekly: 22.3

Deep: 25.7 (confusion)
Medium: 25.4

(Also 225, 275, 325 nm)

Deep Survey – 13 deg$^2$ reaching $F_{0.5\text{-}2}$ = 9 x $10^{-17}$ erg cm$^{-2}$ s$^{-1}$
- 1500 s observations with daily cadence – about 1 Ms in two years
- About 100 Chandra Deep Fields (1 Ms) - accesses Athena discovery space

Medium Survey – 350 deg$^2$ reaching $F_{0.5\text{-}2}$ = 5 x $10^{-16}$ erg cm$^{-2}$ s$^{-1}$
- 500 s observations with weekly cadence – about 45 ks in two years
- About 175 Chandra COSMOS fields

Can adjust uniform cadence to optimize science return – e.g., "accordion" cadences.

# Survey Source Yields: General and High-Redshift

| class | DEEP | MEDIUM | TOTAL |
|---|---|---|---|
| **ALL AGN** | 59670 | 598500 | 658170 |
| **logL210>42** | 48490 | 553000 | 601490 |
| **logL210>43** | 29380 | 420000 | 449380 |
| **logL210>44** | 6110 | 115500 | 121610 |
| **logL210>45** | 156 | 4200 | 4356 |
| **logNH>22** | 28600 | 189000 | 217600 |
| **logNH>23** | 11050 | 32550 | 43600 |
| **logNH>24** | 3770 | 10150 | 13920 |
| **z>3** | 3380 | 24150 | 27530 |
| **z>4** | 728 | 4550 | 5278 |
| **z>5** | 208 | 1050 | 1258 |
| **z>6** | 65 | 175 | 240 |
| **z>7** | 15 | 25 | 40 |
| **galaxies** | 8476 | 20650 | 29126 |

Gilli et al.

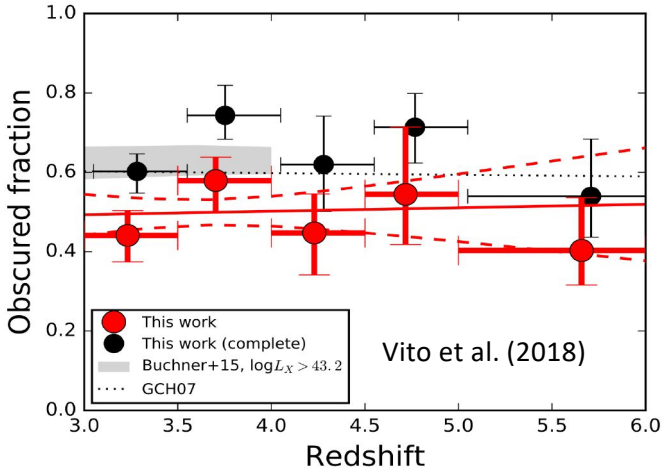
Note good yields for high-*z* AGNs

STAR-X will provide a ~ complete high-*z* survey, including *highly obscured AGNs*

Reliable space densities crucial at $z > 5$ where current data poorly constraining

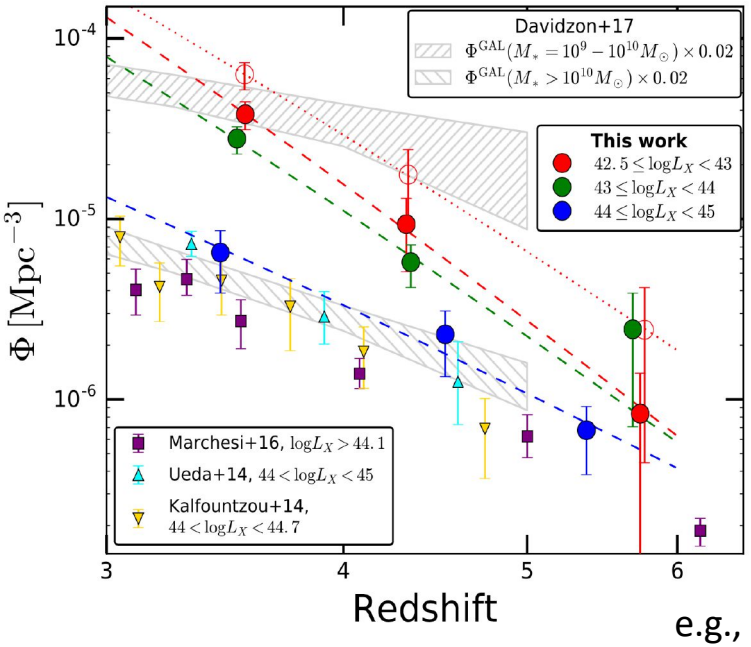
Also act as tracers of protoclusters

High Obscured Fraction ($N_H > 10^{23}$ cm$^{-2}$) for Chandra Deep Fields AGNs

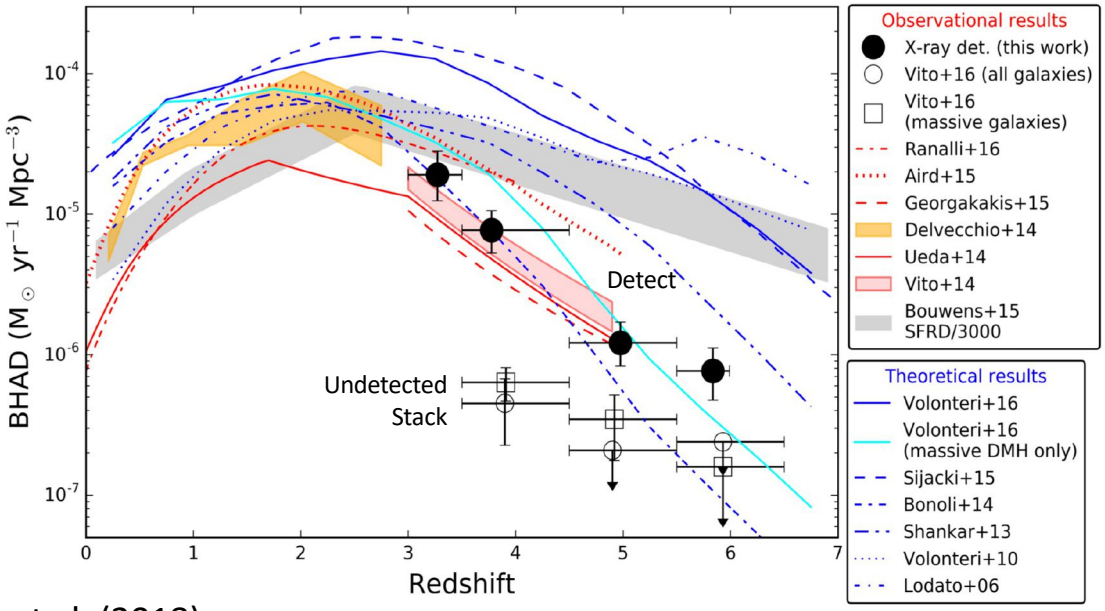


# High Obscured Fraction in Chandra Deep Fields

## High-Redshift Decline at Low, Moderate, and High Luminosities



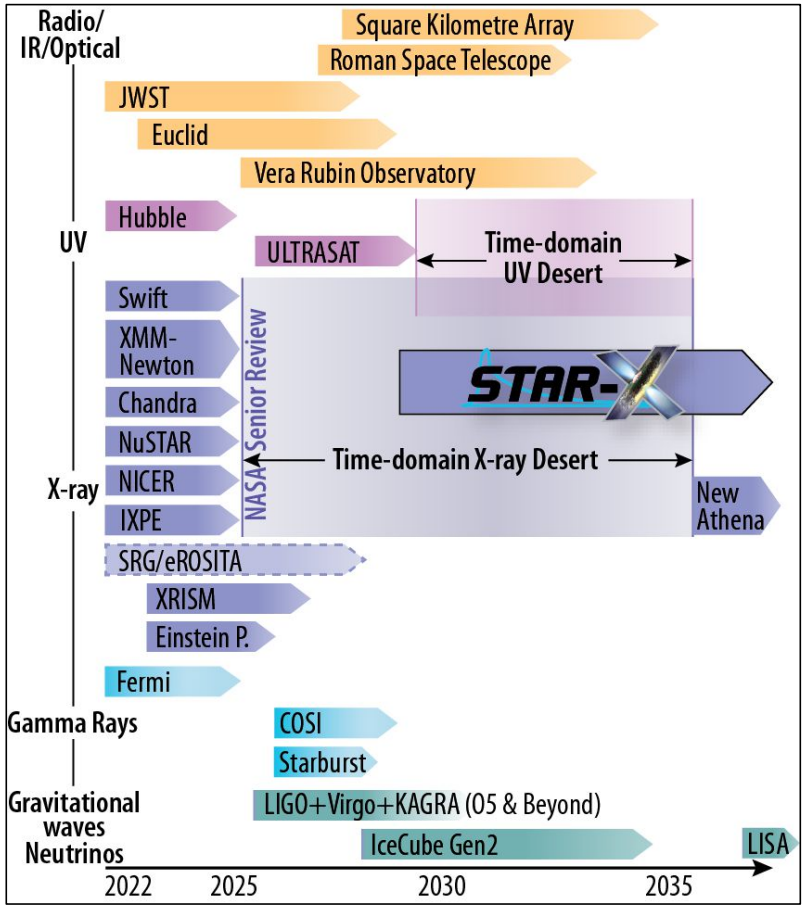

## Chandra Deep Field Constraints Upon High-Redshift SMBH Growth




e.g., Vito et al. (2018)

Deep optical/infrared data will be critical in selecting high-*z* X-ray AGNs from STAR-X for spectroscopic follow-up.

# Synergy with Other Survey Facilities

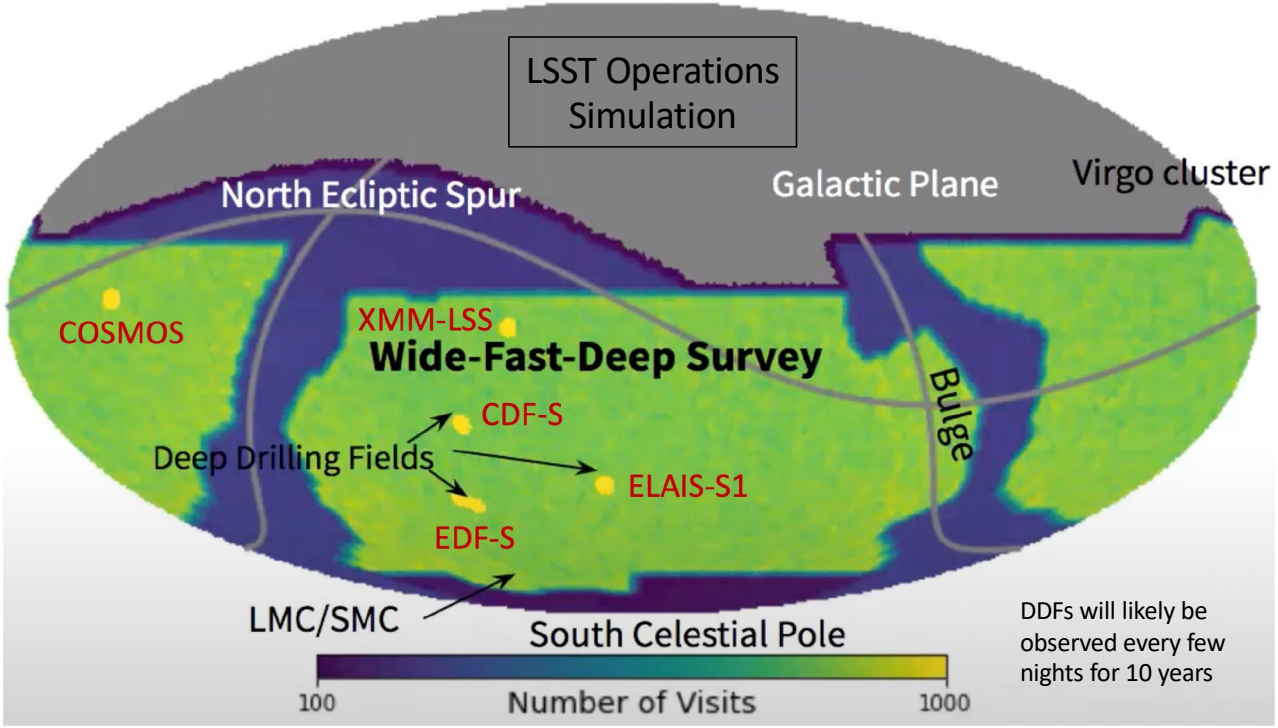



With suitable survey siting, STAR-X can work with Rubin, Euclid, Roman, SKA, etc. to have

- Contemporaneous coverage for optimal time-domain science
- Deepest possible supporting multiwavelength data

# STAR-X 13 deg$^2$ Deep-Survey Siting

The 13 deg$^2$ Deep Survey could be straightforwardly sited in the prime 22% of the 60 deg$^2$ LSST Deep-Drilling Fields




Key advantages:

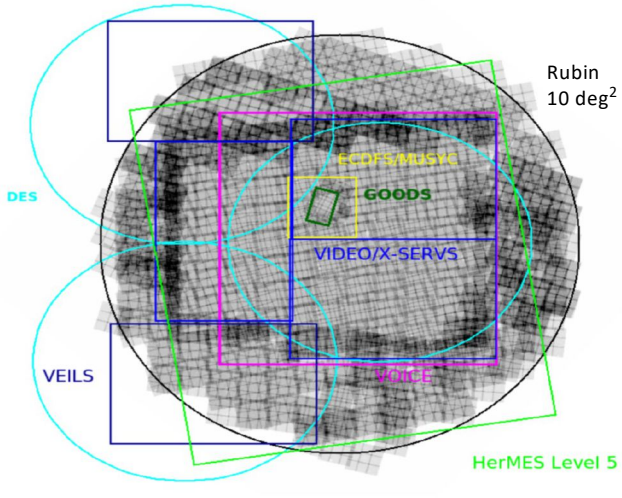
- Unmatched multiwavelength imaging and spectra
- Contemporaneous LSST coverage in *ugrizy*
- Good complementarity with Euclid and Roman

# STAR-X 13 deg$^2$ Deep-Survey Siting

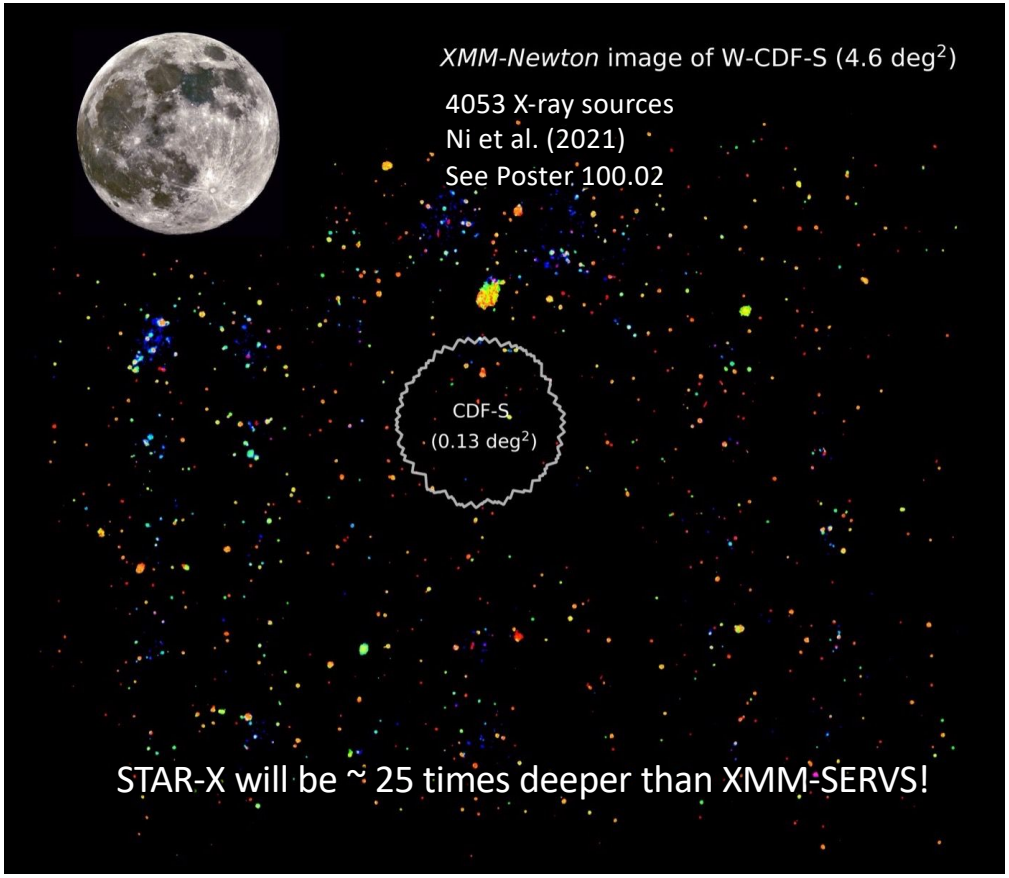
| | ELAIS-S1 | XMM-LSS | Wide Chandra Deep Field-South | Euclid Deep Field-South | COSMOS |
|---|---|---|---|---|---|
| RA 2000 | 00 37 48 | 02 22 18 | 03 31 55 | 04 04 58 | 10 00 26 |
| DEC 2000 | -44 01 30 | -04 49 00 | -28 07 00 | -48 25 12 | +02 14 01 |
| Galactic l | 311.28 | 171.10 | 224.07 | 256.06 | 236.78 |
| Galactic b | -72.88 | -58.91 | -54.60 | -47.17 | 42.13 |
| LSST Solid Angle (deg$^2$) | 10 | 10 | 10 | 20 | 10 |
| Prime Multiwavelength Solid Angle (deg$^2$) | 3.2 (XMM-SERVS) | 5.3 (XMM-SERVS) | 4.6 (XMM-SERVS) | TBD | 2 (COSMOS) |
| Relevant Reference | Ni et al. (2021) | Chen et al. (2018) | Ni et al. (2021) | Laureijs et al. (2019) | Civano et al. (2016) |

The prime multiwavelength areas total 15.1+ deg$^2$ and thus are sufficient to accommodate STAR-X.

# Example: Wide Chandra Deep Field-South

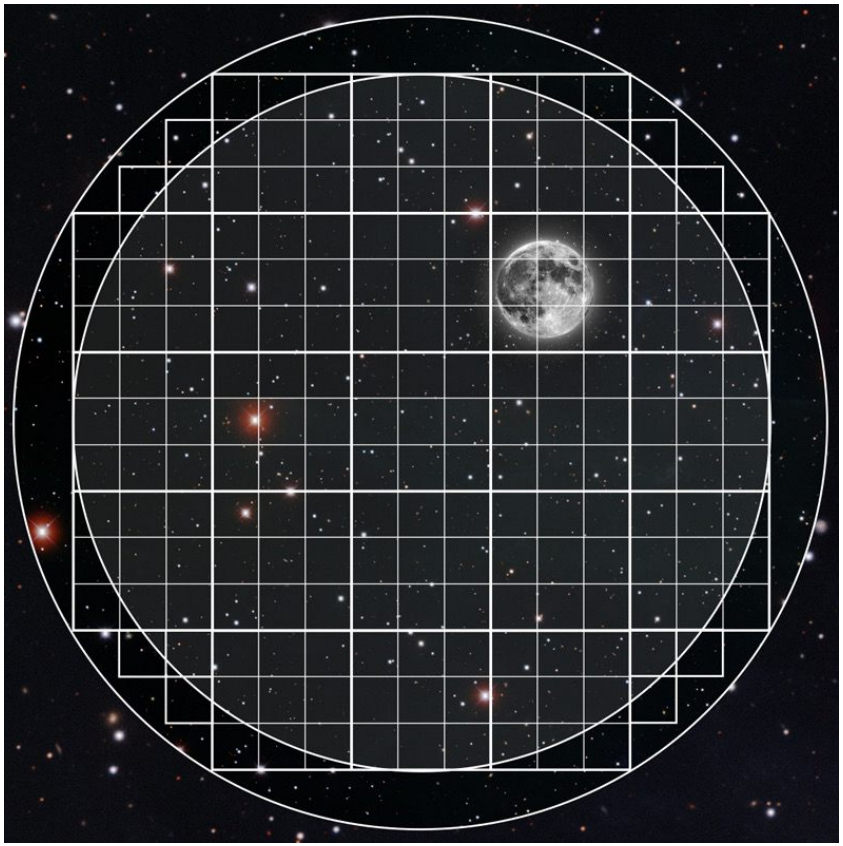



| | W-CDF-S |
|---|---|
| Center (J2000) | RA = $03^h32^m09^s$, Dec = $-28°08'32''$ |
| Area | 4.9 deg$^2$ |
| Source number | 799607 |
| Star* | 42628 |
| AGN* | 19612 |
| BQ galaxy* | 3624 |
| Normal galaxy* | 733743 |
| Reliable SED AGNs[♯] | 2652 |
| X-ray survey | XMM-SERVS[a]: X-ray |
| UV survey | GALEX[c]: FUV and NUV |
| Optical surveys | VOICE[d]: *ugri*<br>HSC[e]: *griz* |
| IR surveys | VIDEO[j]: $ZYJHK_s$<br>DeepDrill[k]: 3.6 and 4.5 $\mu$m<br>SWIRE[l]: 5.8, 8, 24, 70, and 160 $\mu$m<br>HerMES[m]: 100, 160, 250, 350, and 500 $\mu$m |

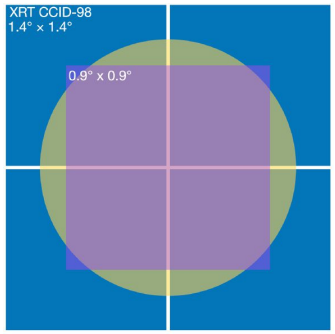


# Relative Field Sizes

Rubin LSST – 9.6 deg$^2$

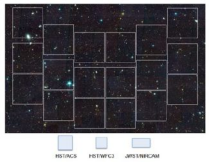


STAR-X - 1 deg$^2$




Roman – 0.28 deg$^2$

0.8 deg x 0.4 deg

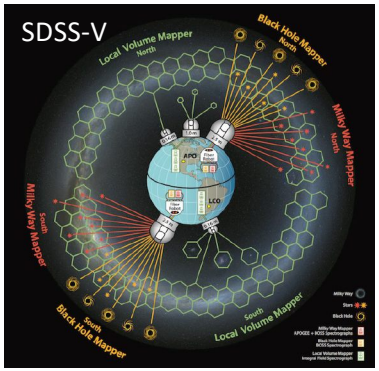


STAR-X field comfortably fits inside a Rubin DDF, and 2-4 STAR-X pointings can cover the prime multiwavelength area in each DDF.

Every time Roman observes an LSST Deep Drilling Field, STAR-X could co-observe – fields sizes fairly well matched.

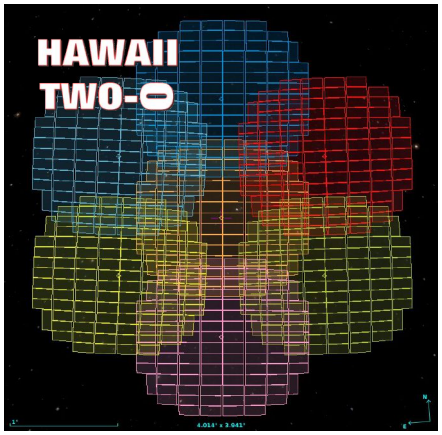
# Additional Incoming Data for the LSST DDFs

Much additional ground-based spectroscopic and imaging data are incoming for the LSST DDFs.

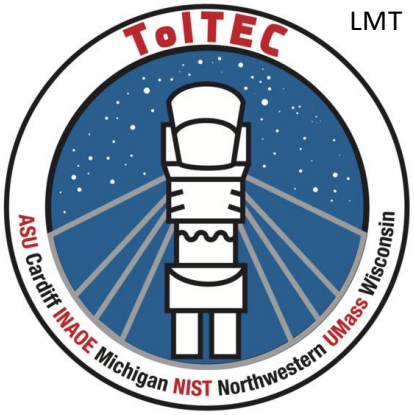


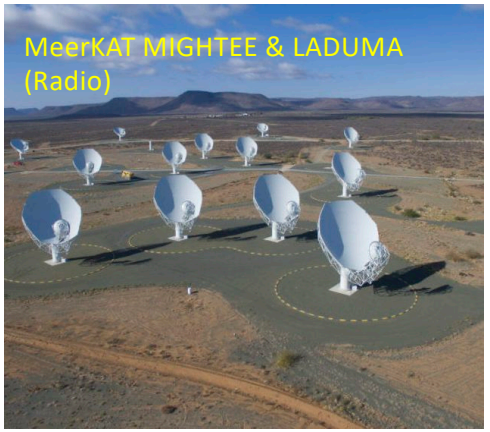





LMT

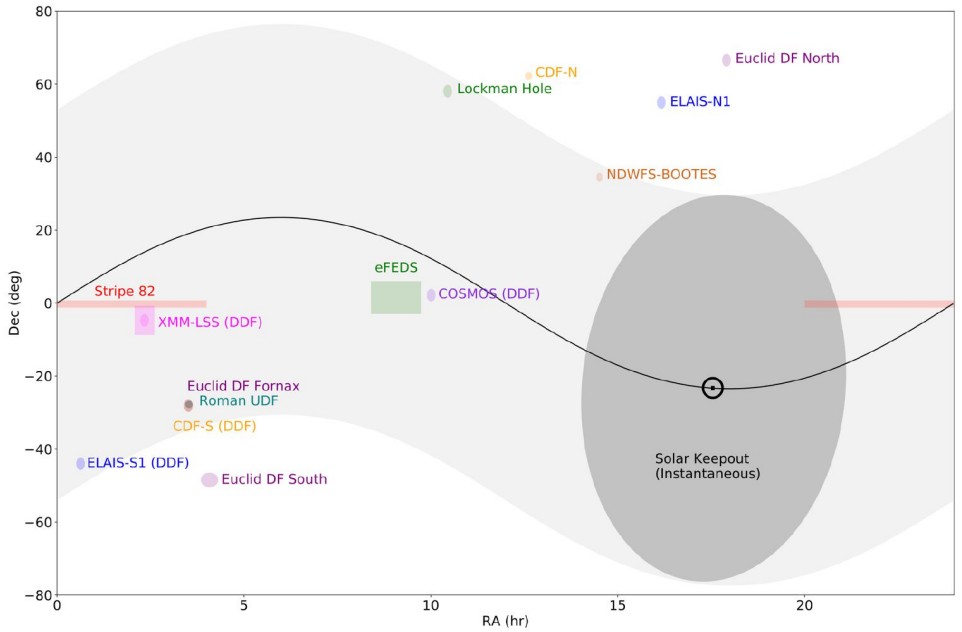


# STAR-X 350 deg$^2$ Medium-Survey Siting

There are excellent field candidates for the 350 deg$^2$ Medium Survey as well:

- Remaining 47 deg$^2$ of LSST DDFs
- Euclid Deep Field-North (20 deg$^2$)
- Stripe 82 SpIES (115 deg$^2$)
- eFEDS (140 deg$^2$)
- NDWFS-Boötes (9.3 deg$^2$)
- HSC Subaru Strategic Program
- Roman Supernova Fields




STAR-X operations simulations show that the Deep + Medium Surveys can be executed in 2 yr, along with the other proposed observations.

# Data Products and Extended Mission Prospects

We aim to deliver X-ray and UV enhanced data products, including survey source catalogs, promptly to the community.

We reasonably expect that STAR-X will operate for much longer than its 2-year requirement.

This will allow many additional X-ray and UV survey projects, driven by community ideas.

Please help us make the STAR-X surveys a great success!

# The End

Please see the STAR-X poster session (#112) for further information about the STAR-X surveys.

http://star-x.xraydeep.org