Tracking Changing-State AGN & Quasi-Periodic Eruptions with THESEUS SXI

(THESEUS' capabilities for detecting/monitoring "transient" AGN)

Alex Markowitz (CAMK-PAN & CASS, Univ. of California, San Diego)
Mirko Krumpe (Leibniz-Inst. Potsdam)
Tathagata Saha (CAMK-PAN)
Maria Caballero-Garcia (IAA-CSIC)
Julian Osborne (Univ. Of Leicester)

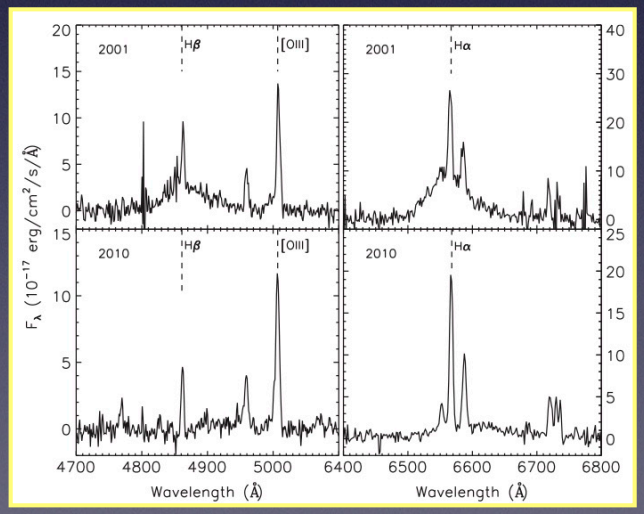
THESEUS CONFERENCE 2021, 23–26 Mar. 2021

Changing-State/Changing-Look AGN (ignition/shutdown events)

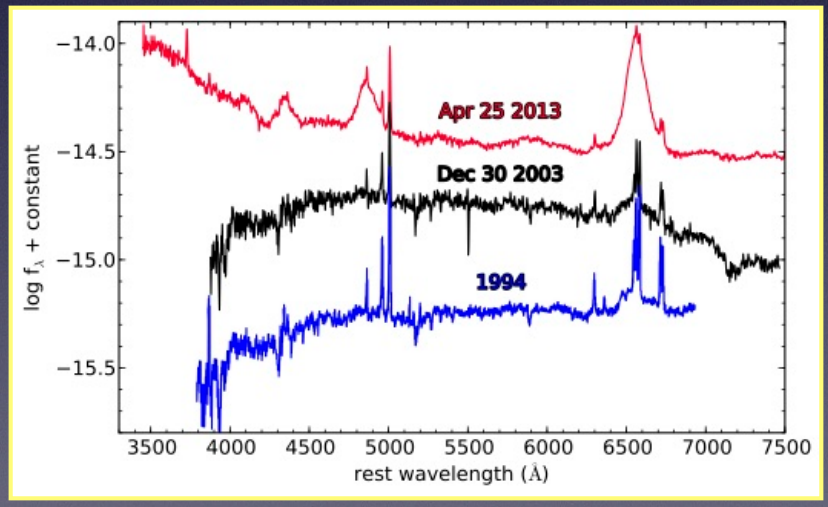
AGN whose optical/X-ray continuum change by 10–30, over timescales of years
Optical BLs appear/disappear (type 1—1.5 ⟷ type 1.8—2)
(Shappee+2014; La Massa+2015; MacLeod+2016,2019; Shapovalova+2019)

~60 CLAGN, ~100 CLQs identified, mainly via archival data, some serendipitously (Yang+2018, Graham+2021)

Likely caused by changes in global accretion supply:
opt/UV ionizing thermal continuum —> BLR response (Noda & Done 2018)



La Massa+2015



Shappee+2014

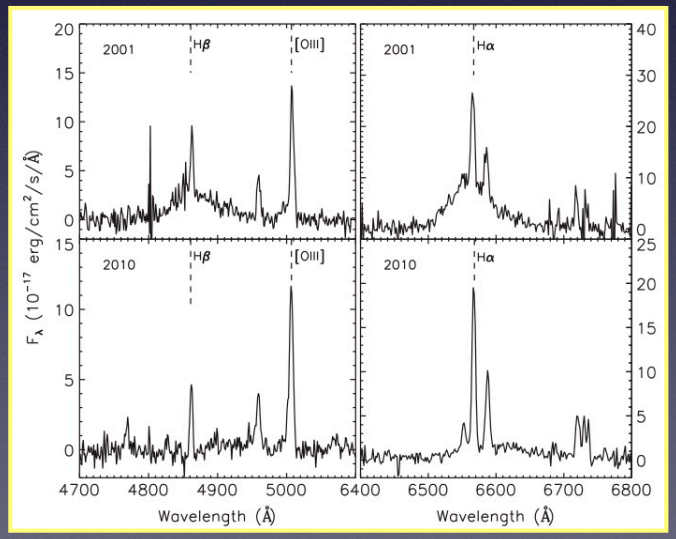
Changing-State/Changing-Look AGN (ignition/shutdown events)

First insight into how accretions flows respond to major changes in accretion rate

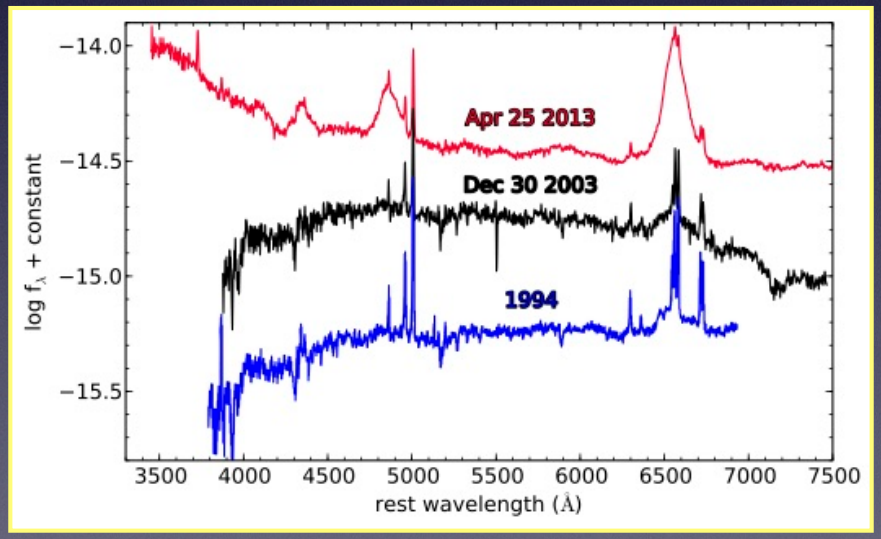
Mechanism: Disc evaporation/condensation? Propagating cooling/warming fronts due to H ionization instability? (Noda & Done 2018)

Need to study how X-ray corona, disk, and BLR each interact during transitions, but currently: relatively low numbers,

Solution: catch more “in the act”, apply multi-λ monitoring to directly study transition phase



La Massa+2015

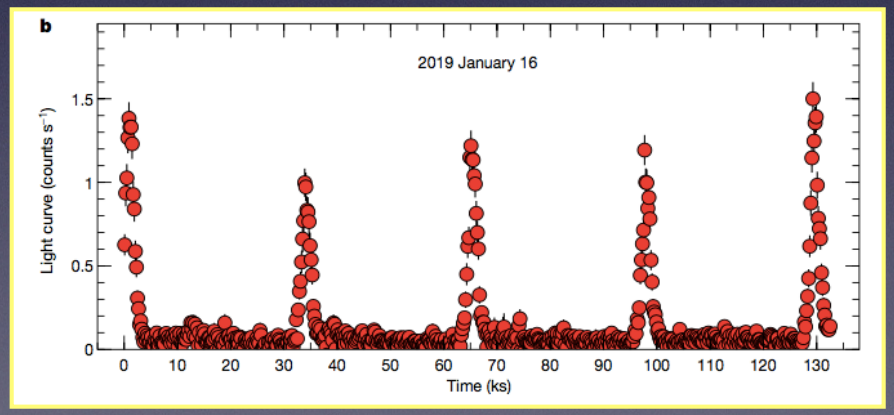


Shappee+2014

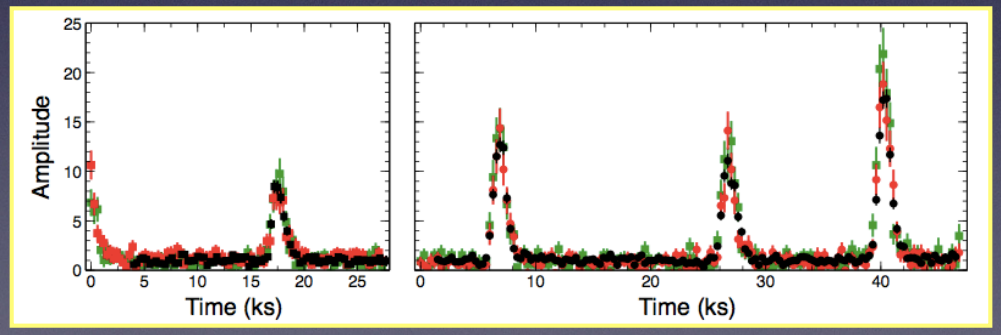
QPEs = Quasi-Periodic Eruptions

X-rays show discrete, quasi-regular time-localized bursts by factor of ~50−100:
Two known so far, detected with XMM:
GSN69 (Miniutti+2019) & RX J1301.9+2747 (Giustini+2020)
Bursts last ~1 hour. Recur every 9 hrs (GSN) & 4−6 hrs (RXJ)

Similar to “heartbeat” state of μ-qsr GRS1915+105 & BHC IGR17091−3624 (Belloni+1997; Altamirano+2011)



GSN69 (Miniutti+2019)



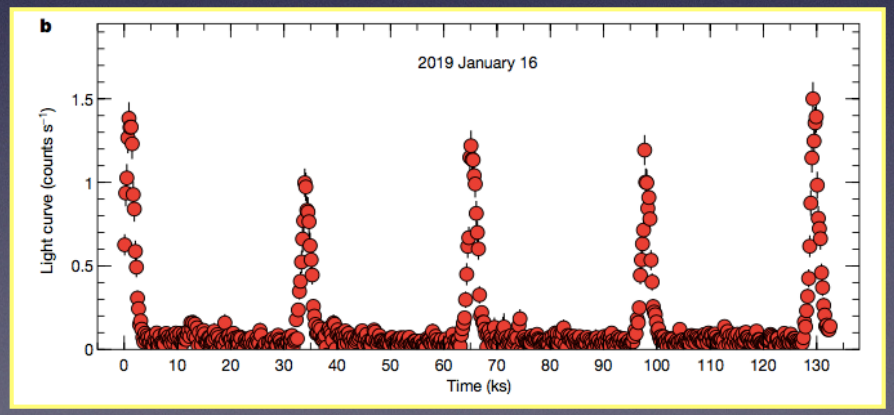
RX J1301.9+2747 (Giustini+2020)

QPEs = Quasi-Periodic Eruptions

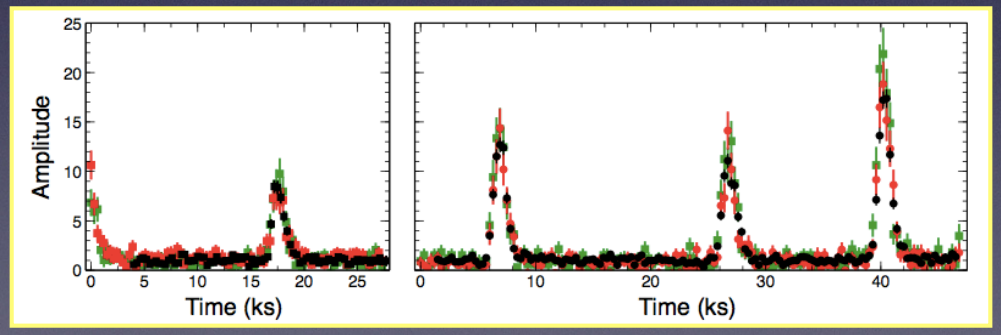
X-ray spectra: Thermal-dominated
kT = 30−50 eV (quiescient) ⟶ 100−200 eV (bursts)
RXJ1301: hard X-ray non-thermal component (corona?)

Cause? Radiation-pressure disk instability (Janiuk+2011)?
Magnetically-elevated accretion flow (Dexter+2019)?
SMBH Binaries? (Ingram+2021)

But only two QPEs have been confirmed so far



GSN69 (Miniutti+2019)



RX J1301.9+2747 (Giustini+2020)

Big-Picture Questions for (Transient) AGN

How long are typical AGN duty cycles?
Is accretion persistent? intermittent? (Schawinski+2015)

Parallels between BHXRB + AGN state transitions as a function of accretion rate?

What disk accretion modes are at play?
H-ionization/radiation-pressure instabilities (Noda & Done 2018; Janiuk+2011)?

How rapidly can disk, X-ray corona, BLR evolve in response to major changes in L_{Bol}/L_{Edd} or luminosity changes?

Such events can occur very rarely (on a per-object basis).
To amplify numbers: monitor large fractions of the sky and cover as large a starting sample as possible

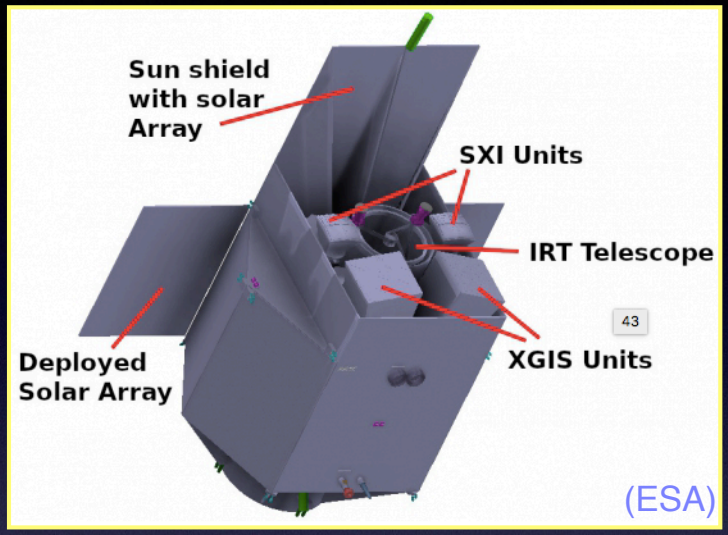
THESEUS' attributes

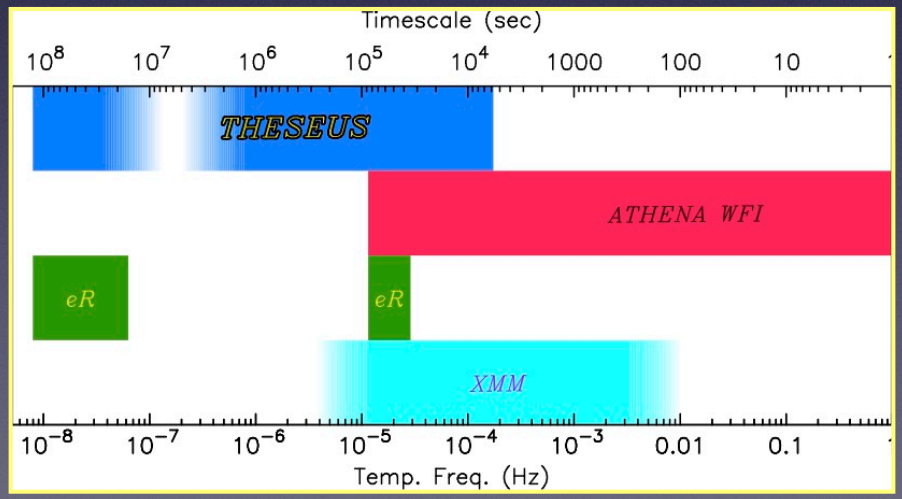
The currently-ongoing eROSITA mission is expected to boost initial insight into transient AGN and "open the door," but its field of view is small

Survey mode with SXI:
−wider range of variability timescales than XMM or eROSITA
−sensitive to variability mechanisms spanning a much wider range of M_{BH}.

eROSITA surveys end in ~mid 2020s

Besides THESEUS, there is no other mission in the 2030s for time-domain X-ray astrophysics via large-area X-ray monitoring!





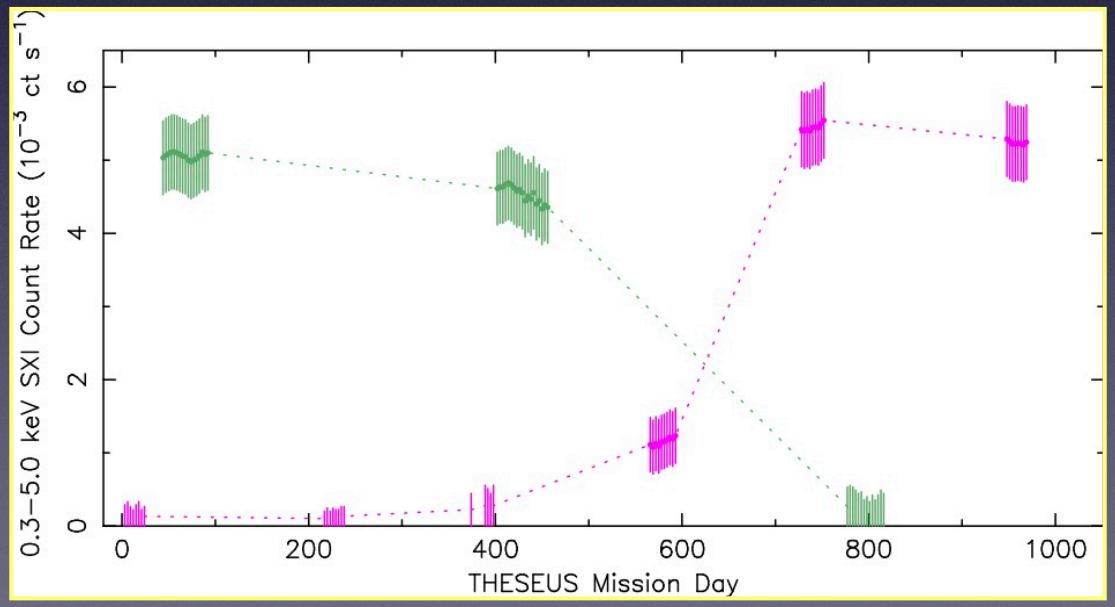
How THESEUS will advance (X-ray-selected) CSAGN studies

Detect new accretion ignition or shut-down events as they are occurring

THESEUS' flux monitoring over days−weeks ⟶ track the X-ray corona
and establish time constraints for replenishing or depleting it (e.g., Trakhtenbrot+2019)

Trigger follow-up X-ray (ATHENA), opt. photometric/spectroscopic observations or use ongoing monitoring (LSST/SKA) ⟶ track disk/corona/BLR/jet

Accumulate statistics for estimating AGN duty cycles



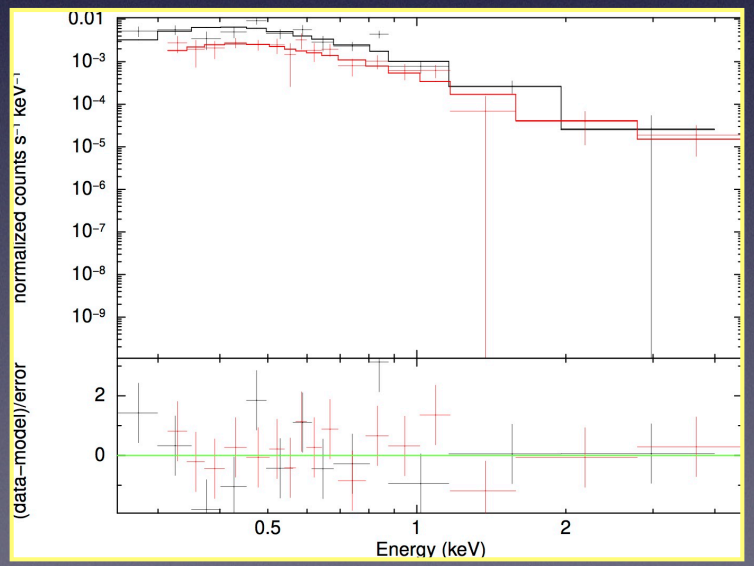
How THESEUS will advance (X-ray-selected) CSAGN studies

Distinguish between CSAGN & TDEs based on light curves

THESEUS can detect Δflux of 10−20 in 0.3−5 keV
from $\lesssim 4\times10^{-13}$ to $\gtrsim 7\times10^{-12}$ erg cm^{-2} s^{-1} at 5σ confidence (few days binning).

For ignition events: Monitor coronal activity if flux remains $>\sim 2-4\times10^{-12}$ erg cm^{-2} s^{-1}

Detection estimates: Assuming 10^6 currently quiescent or LLAGN in THESEUS' Field of Regard (26000 sq. deg.) capable of brightening to $\gtrsim 7\times10^{-12}$ erg cm^{-2} s^{-1}, and an average AGN duty cycle of 10^5 yrs, we expect **<u>~5 events/year</u>**



(to be refined pending results from eRASS…)

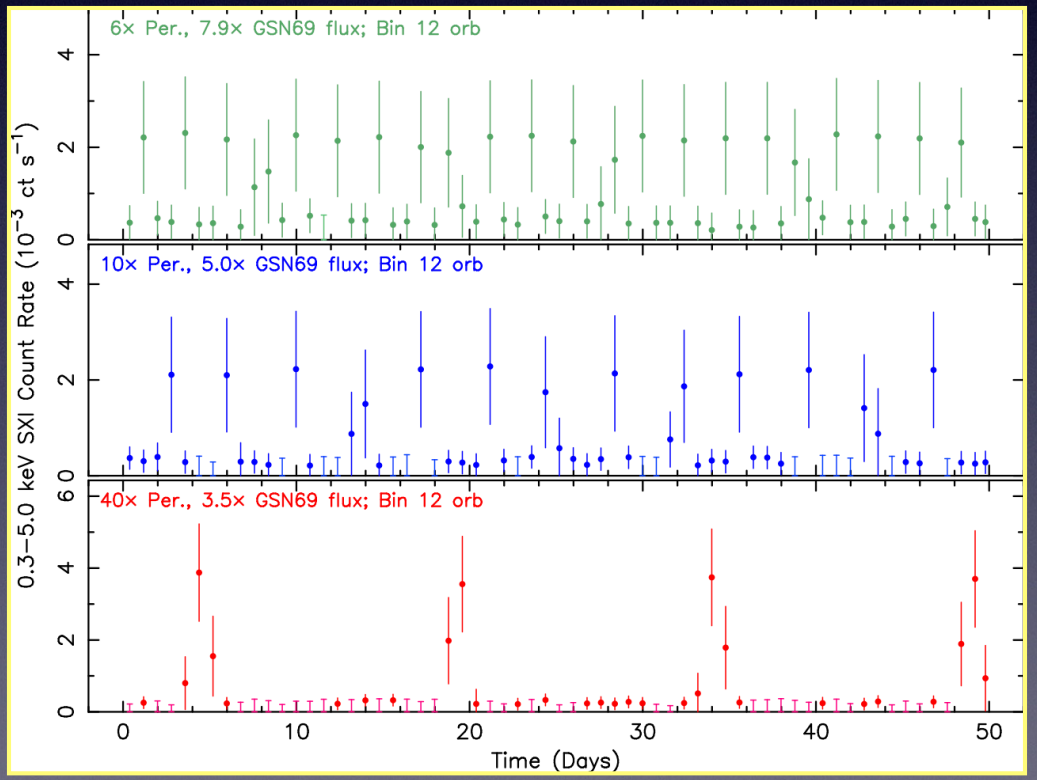
How THESEUS will advance QPE studies

XMM-Newton and eROSITA can monitor only short-period (hours) bursts; GSN69 & RXJ1301.9 have $M_{BH} \sim 1{-}6{\times}10^6\ M_\odot$.

THESEUS monitoring can detect longer-period bursts, likely higher-mass SMBHs

Build up database of periods, luminosities, waveform profiles, spectral behavior, flare shapes, and flare–recurrence time correlations

Contemporaneous optical monitoring (e.g. LSST) to track optical disk emission



How THESEUS will advance QPE studies

Detection estimates:
F(0.3−5 keV) at peak should be >~ 6×10^{-12} erg cm^{-2} s^{-1} (3x peak flux of GSN69), with binning every ~8-10 orbits

THESEUS is most sensitive to QPEs with peaks lasting ~10 − tens of hours, occurring a few days apart (>10 x slower than in GSN69/RXJ1301.9)

How many new QPEs might THESEUS detect during its mission?
−Distribution of pulse periods is completely unknown.
−Assuming a uniform pulse period distribution,
considering peaks 3x brighter than in GSN69,
assuming QPE distribution in low-z Universe tracks that of soft X-ray-emitting AGN XLFs

⟶ ~ **10 new QPEs** in THESEUS' Field of Regard.

Conclusions

THESEUS's survey mode X-ray monitoring over days–years will help probe new discovery space in Time-Domain X-ray astrophysics

Probe complementary timescales to eROSITA, other missions in 2020s-30s

Detect transient AGN with peak 0.3–5.0 keV fluxes above ~ 6×10^{-12} erg cm^{-2} s^{-1} (bin SXI to ~ a few days)

<u>Changing-State AGN:</u>
Detect ~ 1–2 dozen new events during the mission
Trigger multi-wavelength followups to track how corona/disk/BLR interact
Track replenishment/depletion of X-ray corona

<u>Quasi-Periodic Eruptions:</u>
Detect ~ a dozen new QPEs during the mission
THESEUS likely most sensitive to longer-period bursts (higher-mass SMBHs, $10^{7\text{-}8}$ $M_\odot$) than the two found so far with XMM.

For more details: see the RQ AGN chapter in the THESEUS Time-Domain W.G. (SWG3) White Paper!