Discussion on Future Missions

helped by

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Let’s assume: Time-Frame: ~2020-2050 (!)

And divide US, Japan, China and Canada-led (RS)

to ESA-led future missions (MC)

US-led (X-ray) Future Missions

- **IXPE (2-6 keV) X-ray polarimetry [proportional counters]**
  - XRB, AGN, SNR
- Arcus (12-50Å) X-ray grating spectroscopy [CCDs]
  - WHIM, AGN, Stars

- AXIS (0.1-16 keV) X-ray imaging [CCD]
  - Galaxies, Dual AGN, Feedback
- HEX-P (2-200 keV) X-ray imaging [CZT]
  - Resolving high E background, AGN
- Strobe-X (0.2-50 keV) X-ray timing [SDD, CCD]
  - Accretion, XRB, AGN
- TAP (0.2-10 keV + γ-ray) [CCD]
  - Transient followup
- XGS-P (10-60Å) X-ray grating spectroscopy [CCD]
  - WHIM, AGN, Stars
- XPP (0.2-60 keV, imaging 2-8 keV) X-ray polarimetry [PC]
  - Accretion, NS, B fields

- Lynx (0.2-10 keV) X-ray imaging & spectroscopy [uCal, CCD, gratings]
  - Broad range of topics

- **XRISM (0.3-13 keV) X-ray spectroscopy [uCal, CCD] [Japan]**
  - Structure, Formation of elements
- FORCE (1-80 keV) X-ray imaging [CZT] [Japan]
  - Resolving X-ray background, AGN
- HUBS (0.1-2 keV) X-ray spectroscopy [uCal] [China]
  - WHIM in emission, galaxy haloes
- Colibri (0.5-10 keV) X-ray timing spectroscopy [uCal] [Canada]
  - NS, AGN (non-imaging collector optics)

ESA-led (X-ray) Future Missions

- *Cosmic Visions (up to ~2035)*
  - ✓ L-missions: **Athena (Hot and Energetic Univ.)**
  - ✓ M-Missions: Theseus? (high-z GRBs)
  - ✓ MoOs:
    - ✓ XRISM (Hot and Energetic near Univ.)
    - ✓ eXTP?
    - ✓ Einstein Probe?
- *Voyage2050 (~2035-2050)*
  - ✓ 3 recent calls:
    - ✓ General public (>10000 answers)
    - ✓ TP members (>250 answers, ~50 selected)
    - ✓ White Papers (deadline August 5th!)

N.B: Key is to get 20% budget increase for ESA science at next Ministerial

Voyage2050's possible (X-ray) WPs that I know/heard about…

1. **«X-ray interferometry»– roadmap to reach μarcsec to probe EH to planetary transists**

- lead: P. Uttley, R. den Hartog

1. **"Physics of the cosmic web" – 1 deg^2 X-IFU to probe LSS -** contact: A. Simionescu/S. Ettori

2. **«Physics with high-res gratings» – R>5000 to probe plasmas physics in ISM/IGM -** lead: F. Nicastro

3. **"Democratising science" - nanosatellites – GRBs, or others? -** contact: N. Werner

4. **«Nextgen polarimeter» – post IXPE/eXTP -** contact: G. Matt

5. **«Hard X-ray telescope» – post FORCE -** contact: P. Laurent

6. **«Nucleosynthesis / MeV spectroscopy» -** contact: E. Costantini

7. **«Time domain astronomy» / "The variable sky" – post Theseus/Einstein probe/eXTP – GBHCs and GRBs physics**

Courtesy Aurora Simionescu @ SRON (after meeting end of May)

Voyage2050: One example of challenging mission

"Ultra-sharp imaging: towards a physical look into the most powerful engines in the Universe"

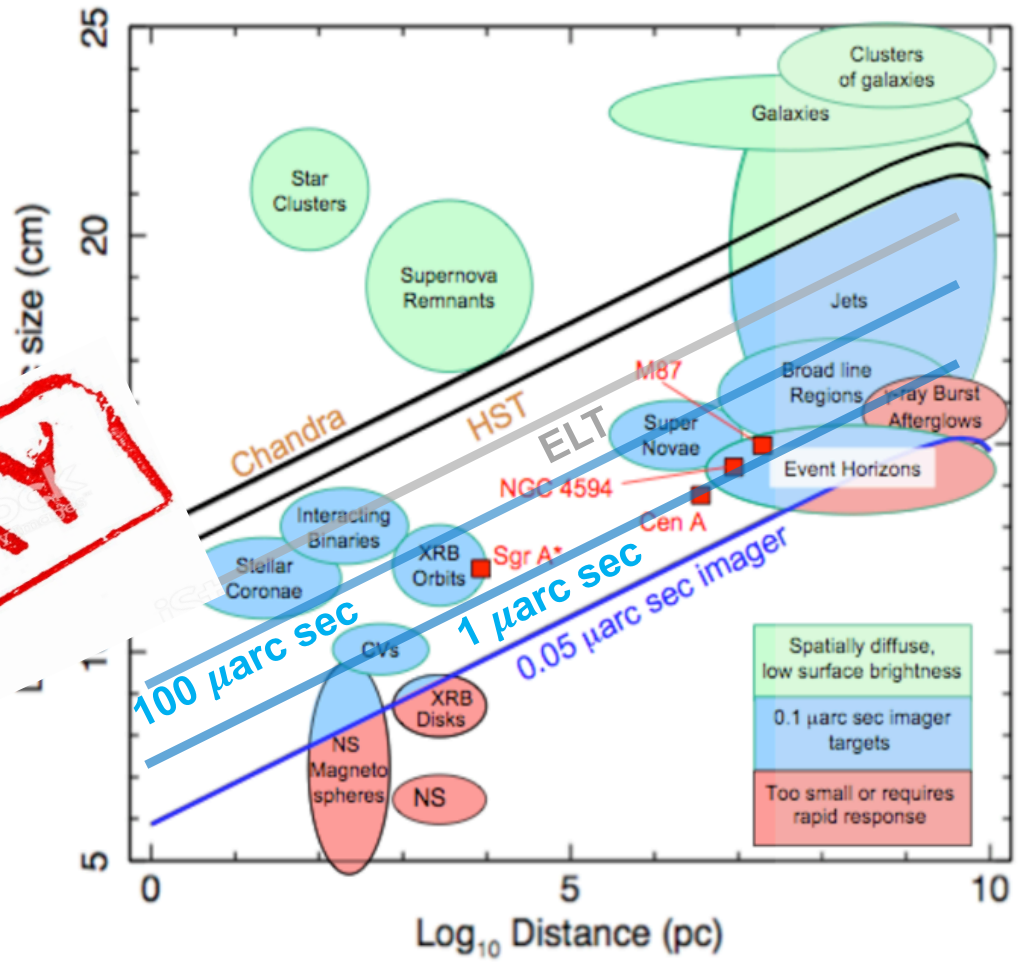
The advantages / trade-offs of intensity interferometry have yet to be studied. We may have to rely on EHT to tell us where to point (FoV will be small, ~mas)

Plan is to propose a "roadmap": science for various resolutions (100uas, 10uas, 1uas, <1uas), with i… science return for increasing complexity … and "holy grail" being spectral imag… horizons

First action item is to i… feasible science cases/…

PRELIMINARY

Adapted from Gendreau et al., 2009 US Decadal WP



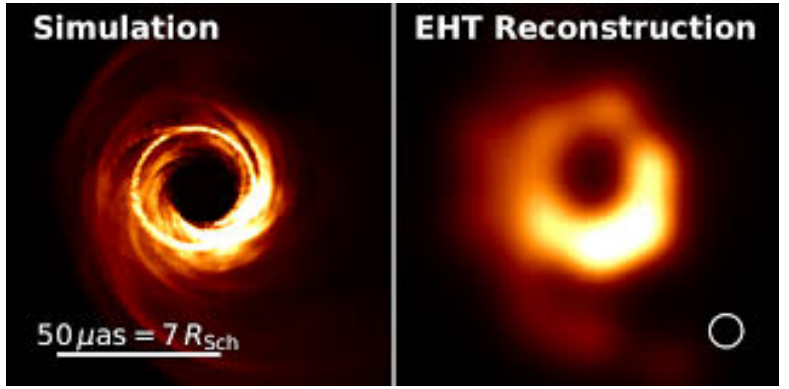
Courtesy: Aurora Simionescu @ SRON (Voyage2050@SRON meeting end of May)

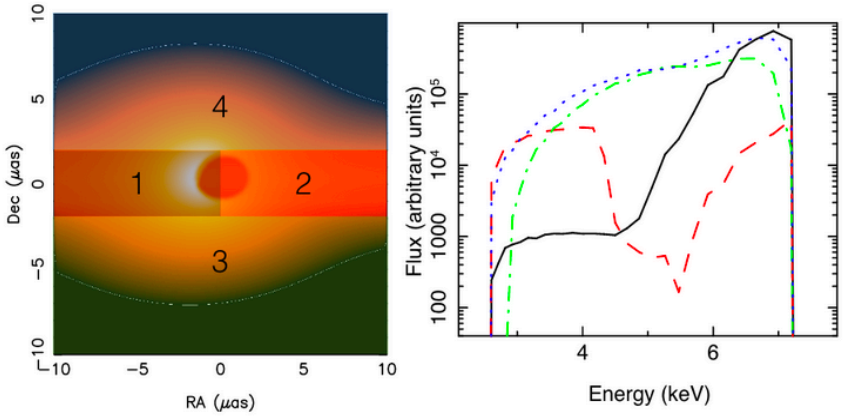
Voyage2050: Roadmap to Ultrasharp imaging

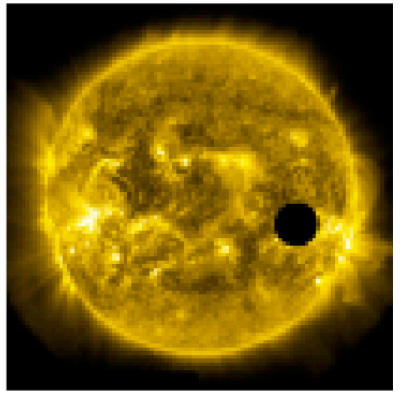
100 uas
- SMBH: Bondi radius, imaging spectroscopy of BLR, and disk winds in nearby AGN, jet base (resolve ~1 pc at 1 Gpc).
- Sgr A*/M87 inner accretion flow in X-rays
- Exoplanet science: X-ray (transit) imaging spectroscopy of super-Earths, giant planets
- Stellar-coronae, interacting binaries, Eta Carinae
- Pre MS stars, coronal activity

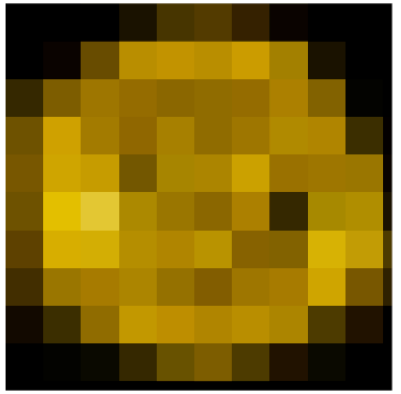
10 uas
- Possibly resolve ISCO in a handful of most nearby AGN
- CVs (provided they are predictable)

<1 uas
- Physics near the event horizon with Fe-K - Blandford-Znajek process
- Micro quasars (SS443,...), ULX?









Courtesy: P. Uttley, J. Svoboda

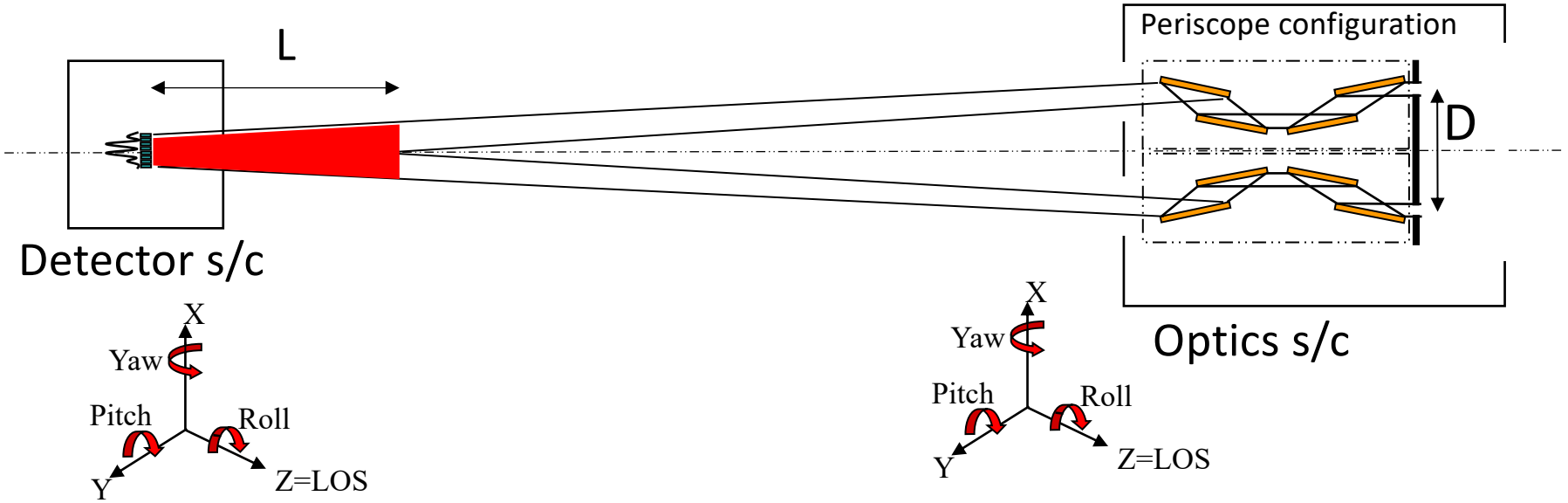
Overview / summary:

Mission concept	Science return
XRI: 1 s/c $\Delta\vartheta \geq 0.1$ mas A = 4 x 20 cm^2 λ = 0.6 - 2 nm	Possibly resolve ISCO in a handful of most nearby AGN. Imaging spectroscopy of larger-scale disk, disk winds, jet base in nearby AGN. Imaging stellar coronae.
XII: 1 s/c **XII+:** 2,3 s/c $\Delta\vartheta \geq 10$ μas $\Delta\vartheta \geq 1$ μas (?) A = 1000 cm^2 @ 6 keV λ = 0.2 nm	Dynamical time-resolved imaging spectroscopy of variable emitting regions on horizon scales in a few nearby AGN. Depending on variability mechanism could test metric in a few cases.
XRI+: 2 free-flying s/c $\Delta\vartheta \geq 10$ μas A = 100 cm^2 (?) λ = 0.2 nm	Resolve event horizon of a few nearby AGN. Test metric in a few case studies. Survey of larger-scale disk dynamics for 10s of AGN.
MAXIM: 26 free-flying s/c $\Delta\vartheta \geq 0.2$ μas A = 1000 cm^2 λ = 1 nm	Resolve event horizon of 10s of nearby AGN. Allows population study. Detailed disk imaging spectroscopy to study dynamics and test the metric.

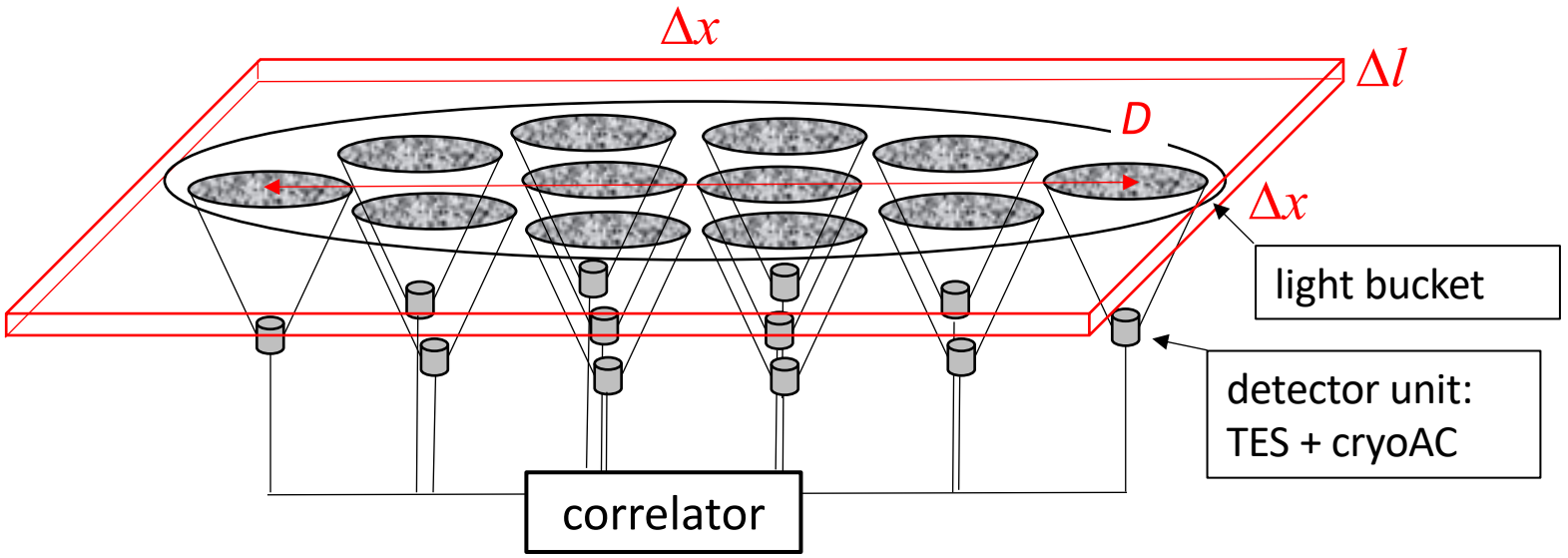
Courtesy: R. den Hartog, R. Willingale

Concept: XRI+

- Splitting the optics over two s/c introduces the necessary additional degree of design freedom to get to the 10 μas level.
- Periscope optics to relax s/c requirements out of the μas regime
- Combination of a detector and an optics s/c should still fit on an Ariane 6
- After a (succesful) eLISA, precision formation flying of a limited number of s/c should not scare ESA anymore
- After a (succesful) Athena, cryogenic detectors and high precision optics should not scare ESA anymore
- So we return to the XEUS base / MAXIM Pathfinder (Cash et al., SPIE 4506, 2001) configuration:



Concept: X-ray Intensity Interferometry



- Plato-like concept: N_{ap} = 30 'light buckets' of 30 cm^2 6 keV eff. collecting area connected with basic optics to a TES array.
- D up to ~4 m $\Rightarrow \Delta\vartheta \geq$ 10 μas at 6 keV
- # pixels driven by countrate, not imaging requirements (~1 r/o chain per unit)
- 1 μs timing resolution, 2.5 eV energy resolution feasible with current TES arrays

- Apertures need to stay inside coherence volume: $\Delta l \Delta x^2$
  with longitudinal coherence length $\Delta l = 0.6$ μm
  and transverse coherence length $\Delta x = \lambda/2\pi\Delta\theta \cong \sqrt{\lambda d_{obj}} \gg D$

$\Rightarrow$ pointing stability requirement: APE < $\Delta l/D \cong$ 30 mas over 10^4 s (Euclid: 35 mas)

$\Rightarrow$ Additonal modular s/c to simply enhance D, and thus $\Delta\vartheta$, requires sub μm positioning accuracy and μs clock distribution

Addresses *Science Frontier Questions* from the Astrophysics Decadal Survey

Show how baryons cycle in and out of galaxies

Measure the spatial and temperature distribution of hot gas at and beyond the edge of galaxies (including our own) – *revealing how galaxies formed & evolved*

Reveal how black holes impact their surroundings

Determine the mass & energy of winds – 'feedback' – from black holes of all sizes

Learn how stellar systems form & evolve

Observe the processes of stellar formation by watching hot gas accrete onto young stars & survey stellar coronae from stars of all types

Arcus bears on a broad range of key astrophysics challenges