# REDUX
## A Flexible Path for X-ray Astronomy

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# “Flexible Path”

- From 2009 report of Augustine Commission
- Response to budget limitations
- Straight to ultimate goal is unachievable
- Define range of enabling steps
- Each good in itself
- Same situation as X-ray Astronomy now

# X-ray Astronomy Responses

- Tactical:
  - This decade launch
- Strategic:
  - Launch >2020, 2025
- Keep flexible on both
  - RFI responses are only existence proofs:

    "Point designs"

# Tactical in 300 Words

Archive Volume 472 Issue 7344 Correspondence Article

*NATURE* | CORRESPONDENCE

## 'Plan B' for X-ray astronomy

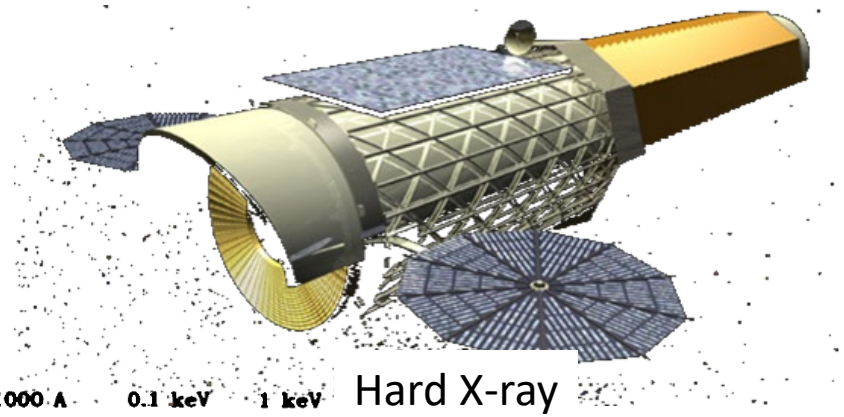
**Martin Elvis**

*Nature* **472**, 418 (28 April 2011) doi:10.1038/472418b
Published online 27 April 2011

**Subject terms:** Astronomy

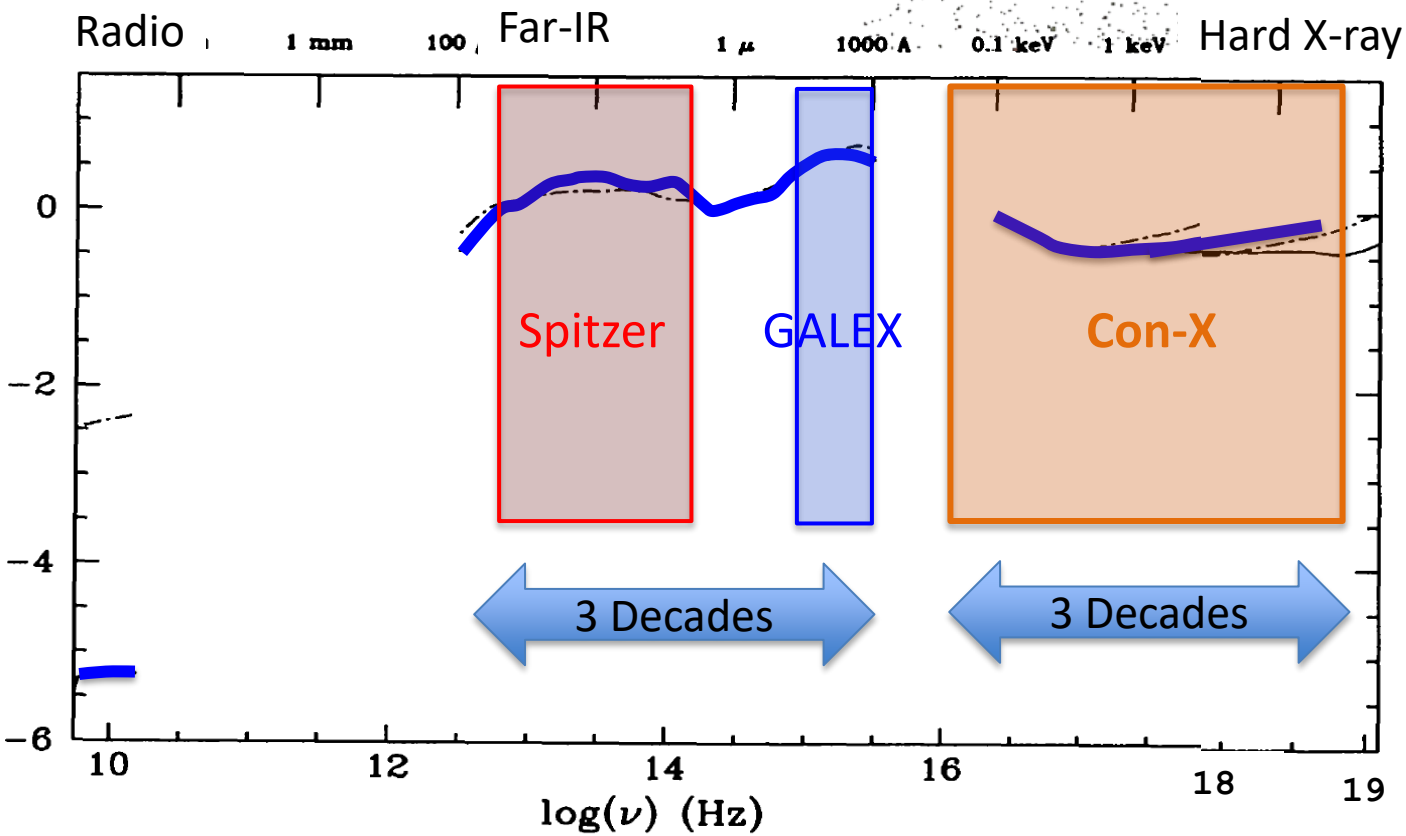
The European Space Agency (ESA) decision to go ahead without NASA support in selecting its next large astronomy mission (*Nature* **471**, 421; 2011) has dashed hopes for the International X-ray Observatory (IXO). X-ray astronomy needs a cheaper 'plan B'.

# IXO: Overly Broad Scope?



Quasar Spectral Energy Distribution

Elvis et al, 1994

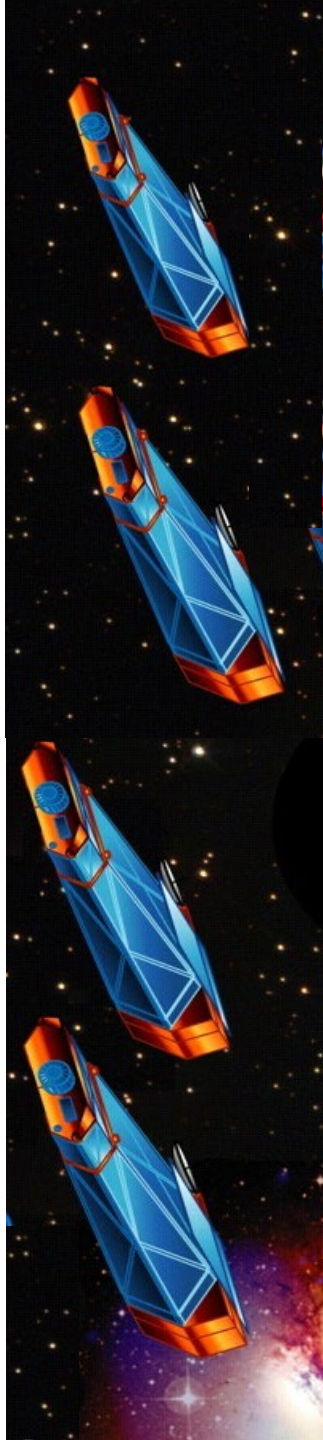



- Forced Co-pointing of Gratings, Calorimeter, Hard-X-rays, timing, polarimeter
- Would rarely have common targets. several instruments typically idle

# REDUX: One Mission, 3 Specialized Telescopes*

*Research Explorers for the Discovery of the Universe in X-rays*

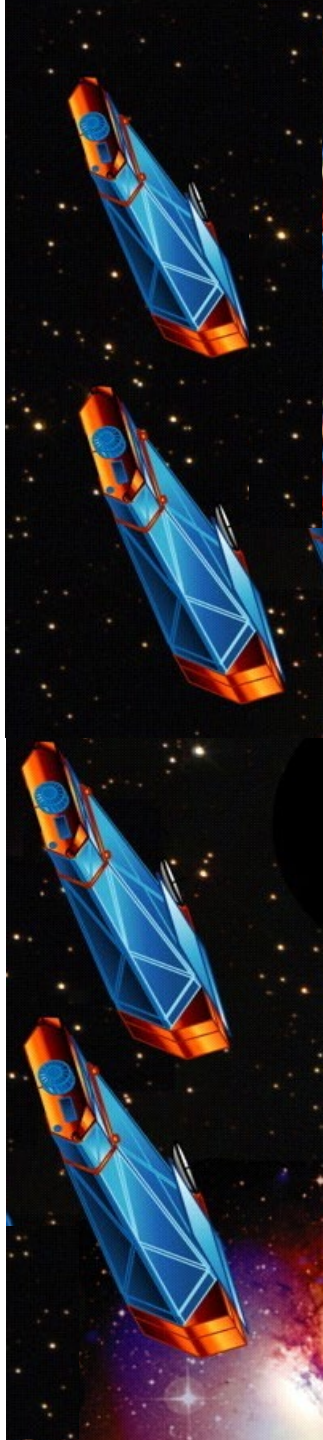
- Re-imagines Con-X concept
  - **Gratings:** <4m <1keV ~10”
  - **Calorimeter**: 10m >1keV ~60”
  - **Hard X-ray**: 30m >10keV ~20”
- Optimizes area/kg of mirror
- Much more time for each instrument
- *Weakness:* wide field imaging only in gratings 0-order.



*proposed by ME to Con-X SWG in 2004 to FST, shown here with minor modifications

# REDUX: One Mission, 3 Specialized Telescopes

- Each “Explorer”-sized
- Strengthens ‘Constellation-X’ concept
  - > 70% more science per year
    - Larger gain with 5 instrument IXO
    - Calibration in parallel, not serial gains ~5%-10%
  - Co-point when needed
  - Harder to cut: each spacecraft is unique



# REDUX vs. Con-X Design Ref. Mission 2004

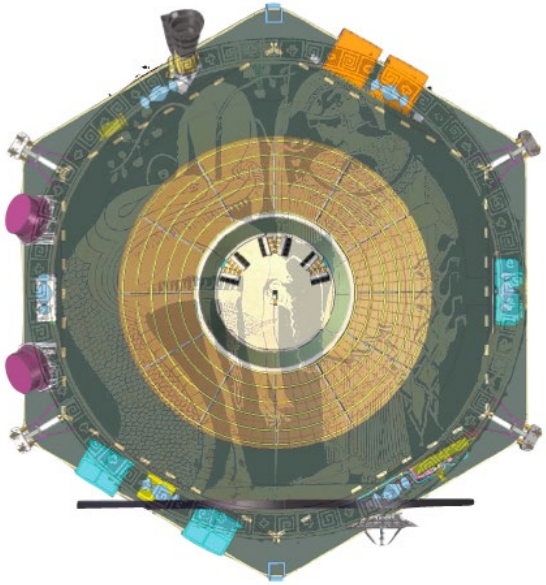
| Category | Time Msec | SXT-XMS | SXT-RGA | HXT | Instrument Utilization | Util x time |
|---|---|---|---|---|---|---|
| **Bright AGN** | 9.0 | Prime | Prime | Prime | **1** | 9.0 |
| **Other AGN** | 5.5 | Prime | 2nd | 2nd | **2/3** | 3.7 |
| **Clusters** | 10.8 | Prime | --- | ---- | **1/3** | 3.6 |
| **Ellipticals/Groups** | 4.0 | Prime | --- | --- | **1/3** | 1.3 |
| **QSOs & IGM** | 10.0 | 2nd | Prime | --- | **1/2** | 5.0 |
| **Faint X-ray background sources** | 15.0 | Prime | --- | 2nd | **1/2** | 7.5 |
| **Spirals/starbursts** | 2.4 | Prime | --- | 2nd | **1/2** | 1.2 |
| **SNR** | 9.0 | Prime | --- | 2nd | **1/2** | 4.5 |
| **X-ray Binaries** | 3.8 | Prime | Prime | Prime | **1** | 3.8 |
| **Black Hole Candidates** | 2.0 | Prime | Prime | Prime | **1** | 2.0 |
| **Neutron stars** | 6.0 | Prime | Prime | 2nd | **2/3** | 4.0 |
| **Stars** | 9.0 | 2nd | 2nd | --- | **1/2** | 4.5 |
| **Solar System** | 0.4 | 2nd | 2nd | --- | **1/2** | 0.2 |
| **TOTAL** (3 years) | **86.9** | | | | | **50.3** |
| | **[1.0]** | | | | | **[0.58]** |

5 instrument IXO → Larger gains

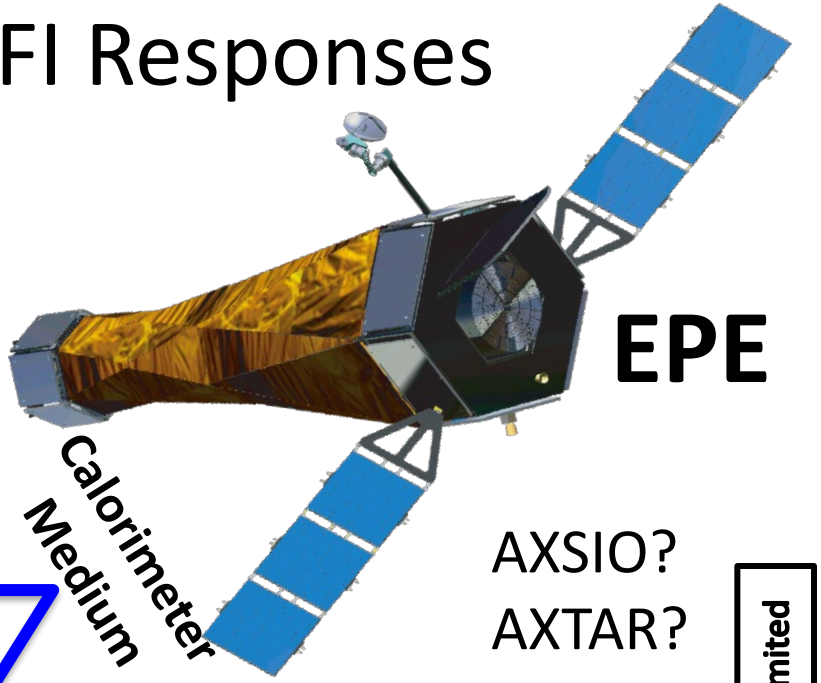
Gain over Con-X = 1/0.58 = 1.72

# Sample REDUX Compliant RFI Responses

ÆGIS

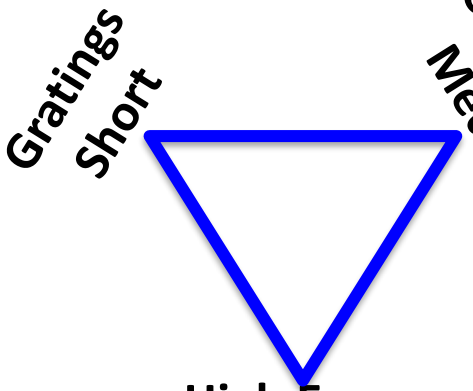


WHIM-Ex
SAHARA?
XENIA?

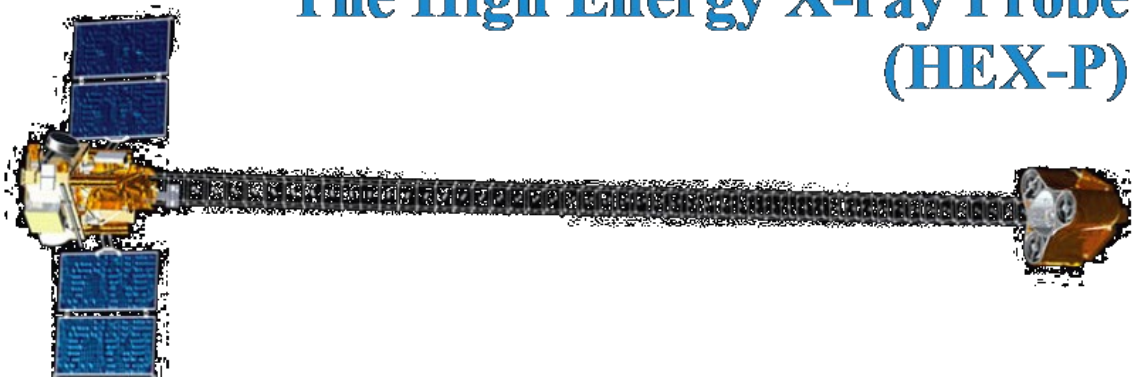


EPE

AXSIO?
AXTAR?



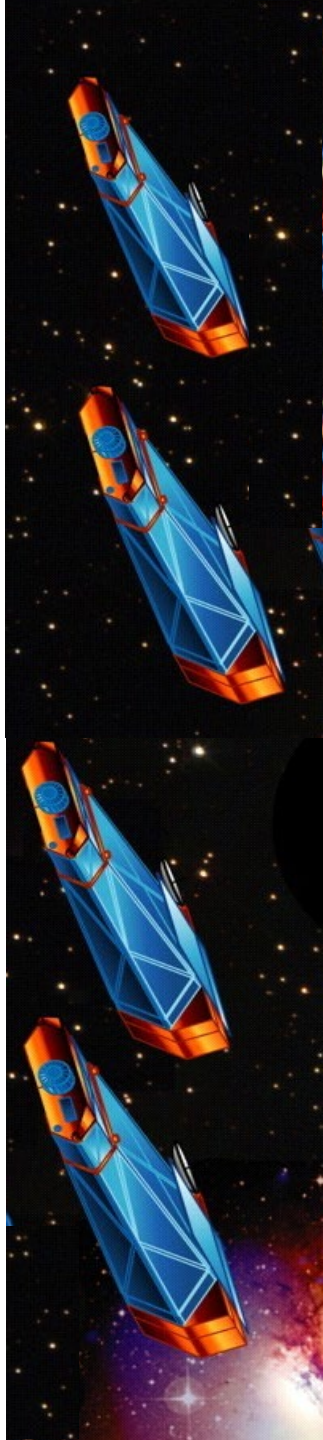

The High Energy X-ray Probe (HEX-P)



BEST
HXT

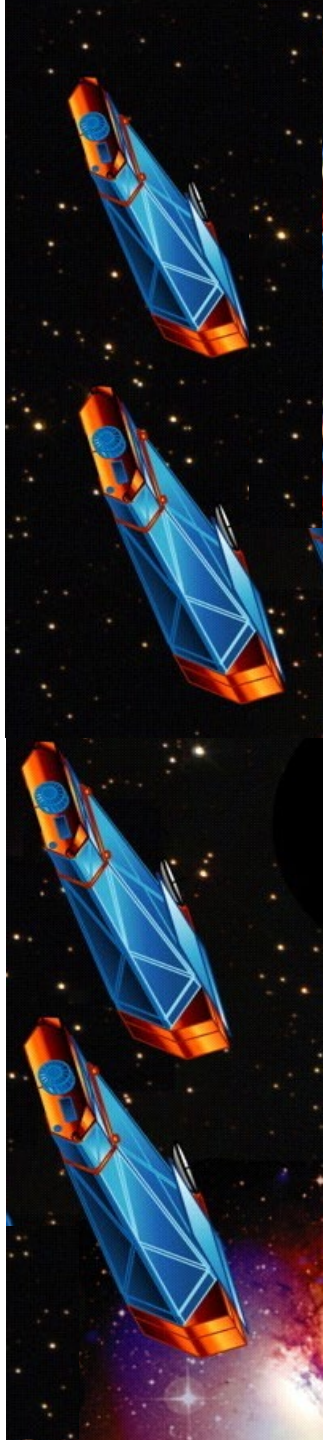
# REDUX: One Mission, 3 Specialized Telescopes

- Budgetary flexibility
  - "Explorer"is broad: allows scaling
  - RFI responses tend to match IXO – large
  - $\Sigma$ AEGIS + EPE + HEX-P = $2B.
  - Greater efficiency allows smaller missions. [except for timing studies]
  - Take RFI responses as point models
  - Explore options



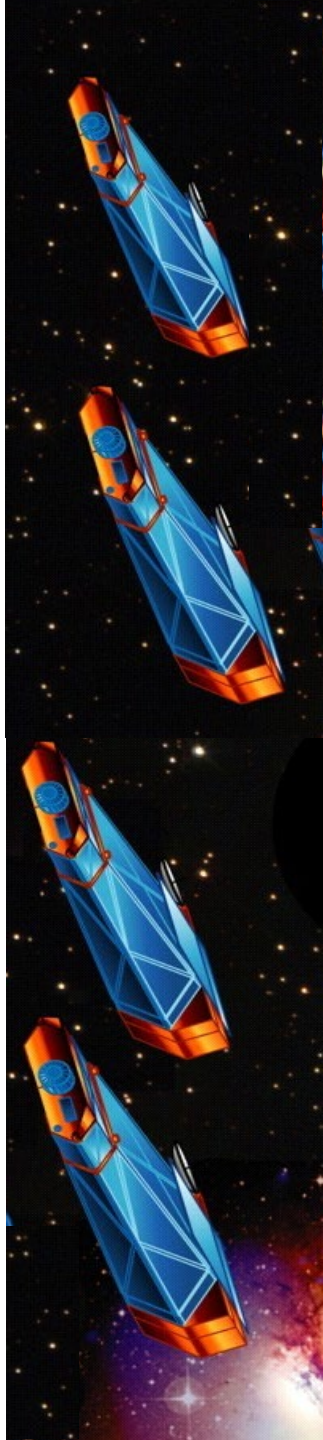
# REDUX: One Mission, 3 Specialized Telescopes

- Politically flexible:
  - Inter-Agency collaboration without technology or (strong) schedule dependence
    - Launches can be spaced over a few years
  - If ESA punts on ATHENA, US can do up to 3
  - If ESA chooses ATHENA, US can do gratings/high energy
  - If ESA chooses LOFT for M3, US can downplay timing
  - Encourage JAXA to lead/collaborate on 1 or more



# REDUX: One Mission, 3 Specialized Telescopes*

- Strengthens ‘Constellation-X’ concept
  - > 70% more science per year
  - Co-point when needed, independent otherwise
  - Harder to cut as each spacecraft is unique
- Co-pointing synergy: implications
  - Overlapping fields of regard
  - Some % of time applied for jointly



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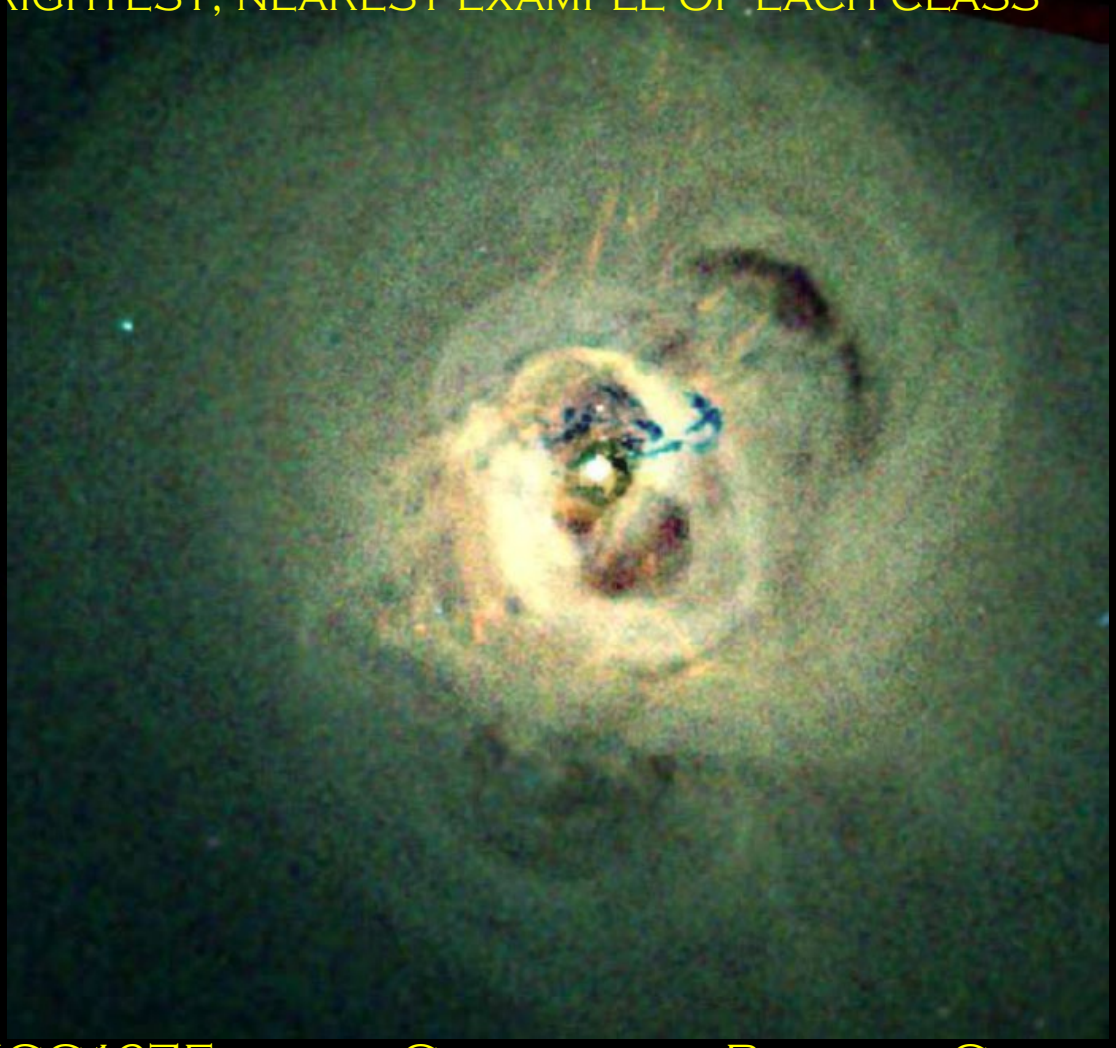
# Strategic: No IXO Flagship in 2020

- 2020 Decadal won't give it #1 ranking
- That sinking feeling: *E.g.* Stein Sigurdson, "Dynamics of Cats" blog post, 11 Aug 2010:
- *"IXO is solid, has a huge constituency of good hard working x-ray observers, but is incremental.."*
- Change is allowed: "*Given the multi-decade timescales required for development of major facilities from concept to construction to operation, it should not be surprising that many of these projects have evolved in technical and/or scientific scope since AANM"* [2000 Decadal, 7-2]
- Need high resolution, large area Chandra successor

# Strategic:
# Need a Replacement for Chandra

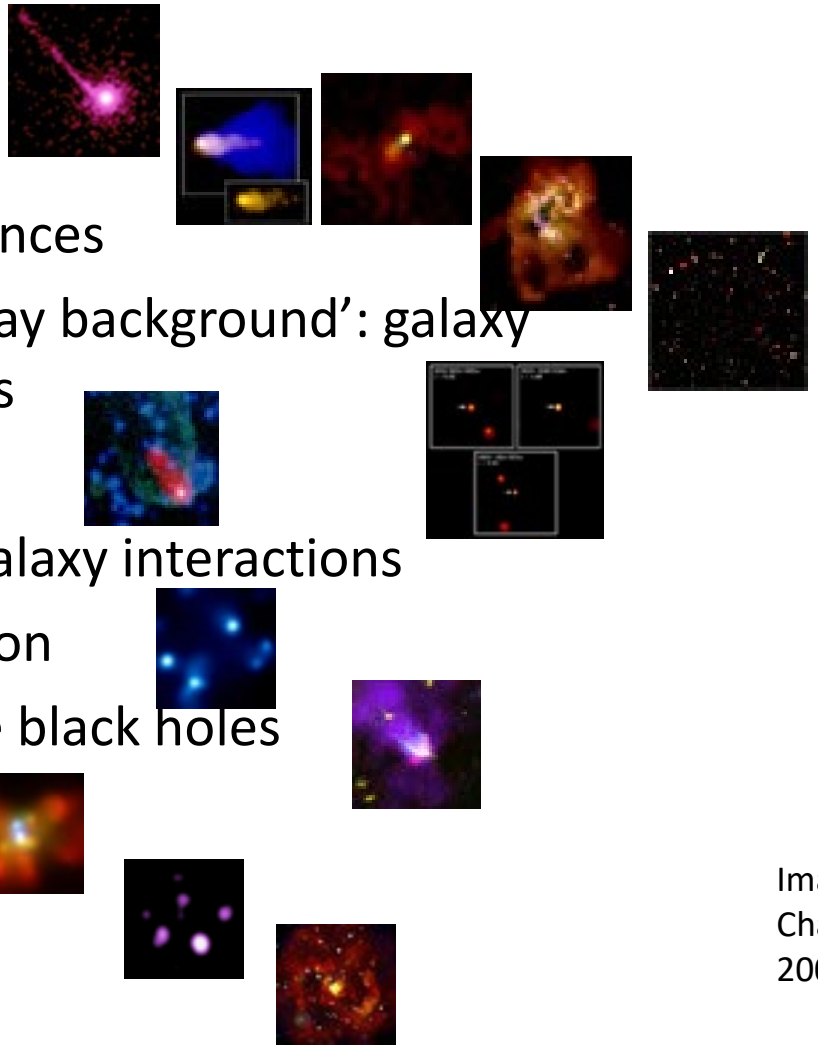
Megasecond class observations for the brightest, nearest example of each class



NGC 1275 in the Core of the Perseus Cluster

# Science gained from 10” to <1”

- Quasar jets at high z
- Pulsar wind nebulae
- Starburst galaxy abundances
- Sources ‘beyond the X-ray background’: galaxy evolution, high z quasars
- Star formation regions
- Cluster cooling fronts, galaxy interactions
- Cluster-Quasar interaction
- Quiescent supermassive black holes
- Binary black holes
- Gravitational lenses
- Galaxy XRB populations
- …



Images selected from Chandra press releases 2002-2004

All essentially inaccessible at 10arcsec HPD

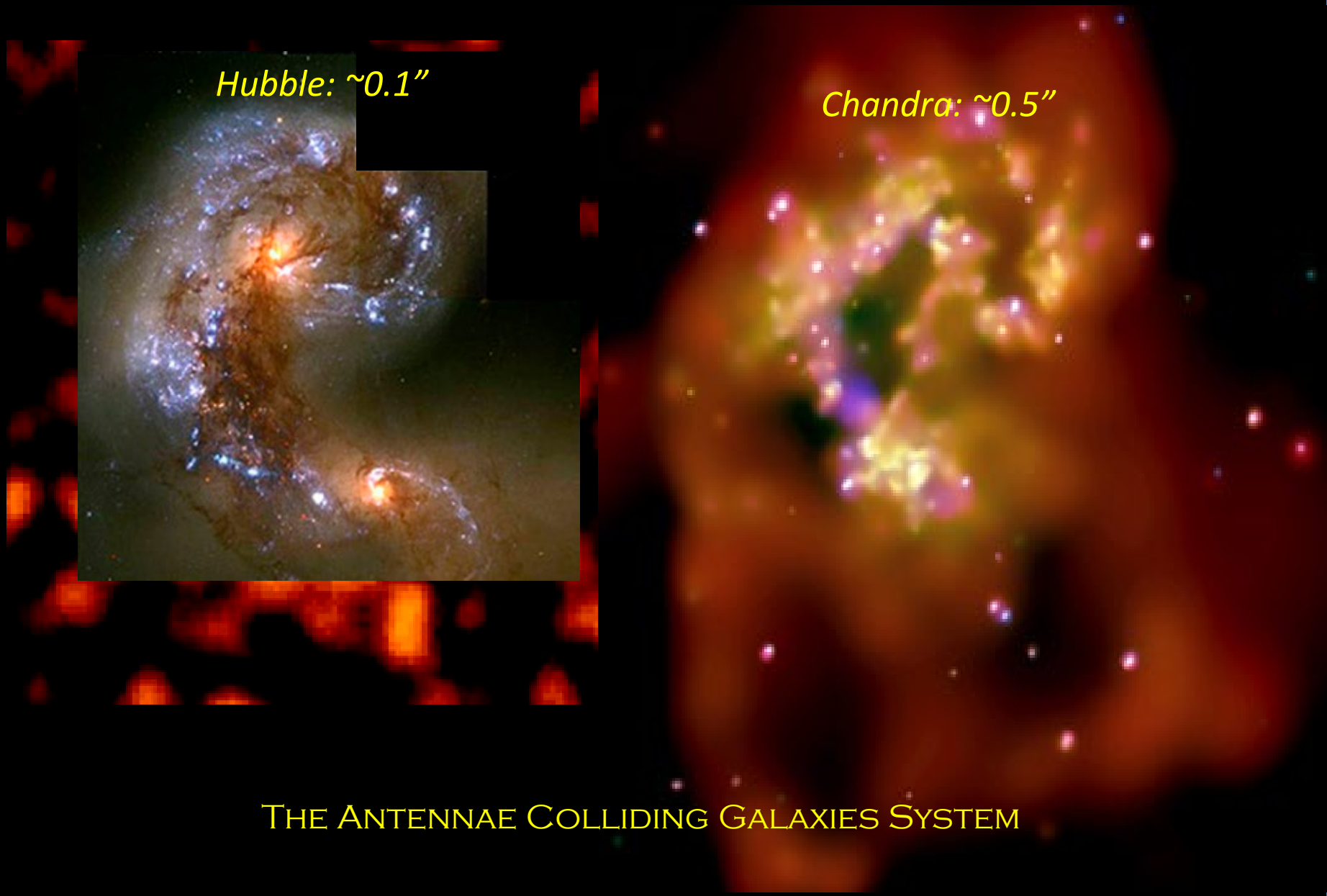
# SMART-X

- The Right Approach.
- Point design proposed
- Demonstrating Optics comes first
- *BUT*: *Is 20x Chandra area enough in 2020?*
- Competition for #1 slot will be tough:
  - Earth-like planets imager
  - Inflation: B-modes in CMB
  - UV 4-meter class telescope
  - Other, new, concepts
- Need revolutionary science
  - Equivalent to AXAF/Chandra driver:
    "Resolve the X-ray background"

# SMART-X

- Stay Flexible
  - for 5 years, while developing optics
  - Consider minor tweaks: factors of 2 can add up. e.g.
    - C-layer to mitigate 2keV edges
    - Minimize vignetting: H-length, packing density, outer radius
    - Is 6 keV sacrosanct? More area, fewer shells at 5 meters
      - Depends on driving science. E.g. Fe-K @ z>1, E(obs)<3.2 keV

# Is 1/2” enough?




The Antennae Colliding Galaxies System

# SMART-X

- Stay Flexible
  - for 5 years, while developing optics
  - Consider minor tweaks: factors of 2 can add up. e.g.
    - C-layer to mitigate 2keV edges
    - Minimize vignetting: H-length, packing density, outer radius
    - Is 6 keV sacrosanct? More area, fewer shells at 5 meters
- Explore matching Hubble, JWST angular resolution
  - Ray trace limit is near 0.1”
- Explore beyond Wolter optics
  - *E.g*. 4 reflection designs to widen high resolution field
    - at cost of factor 2 in area
- Explore beyond calorimeters, *e.g.*
  - R>5000 where the lines are, <2keV, needs $\Delta E < 0.4$eV, 0.08eV @ 0.4keV
  - Focal plane, long slit spectrographs?
  - Kumakhov lenses for Integral Field Unit spectrographs?
  - Area losses acceptable now area is large

# REDUX

Tactical:

- Specialized missions give better return/$
- Develop shorter term optimized technologies
- Explore options, respond to changes

Strategic:

- Keep exploring options
- Pursue game-changing long term technologies *simultaneously* with tactical
- *Stay Flexible*