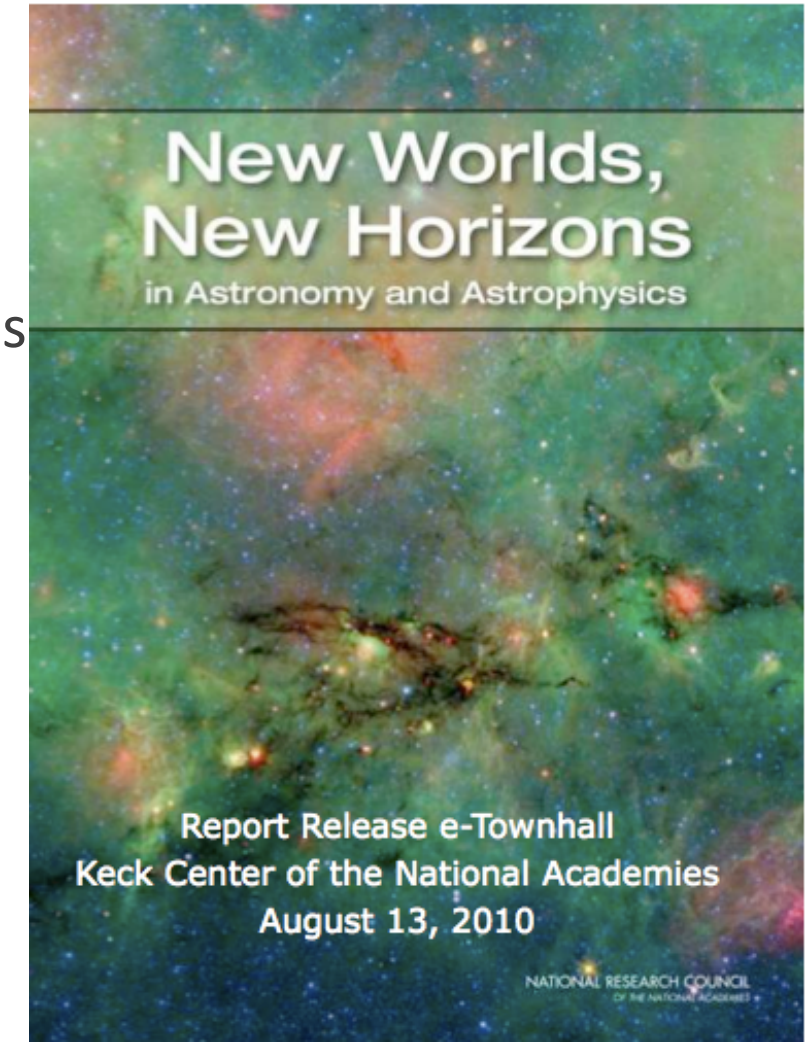
Plan B

What does X-ray Astronomy do now?

Martin Elvis

Harvard-Smithsonian
Center for Astrophysics



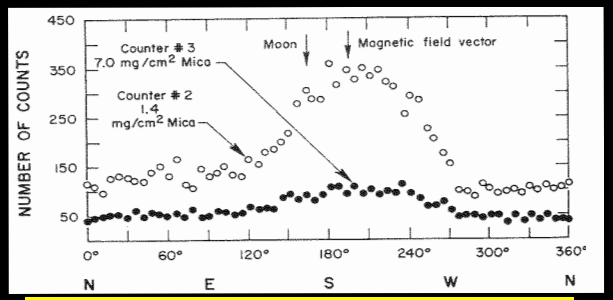
CfA, 24 August 2010
(Day 11 Post-Decadal)

50 Years of X-ray Astronomy:

1 billion times more sensitive

"Naked eye" to "Hubble Deep Field"

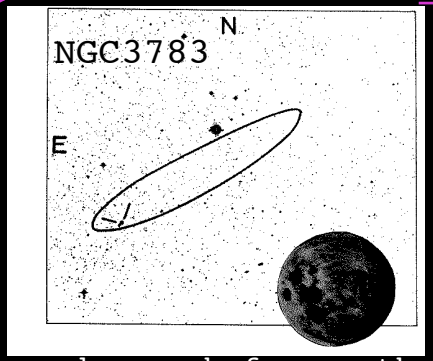
Sco X-1



Good for 1 (one) Nobel Prize

1/10,000

UHURU/Ariel V



good enough for my thesis

1/100,000

Chandra

Simply Great

Detector Area,
Exposure time

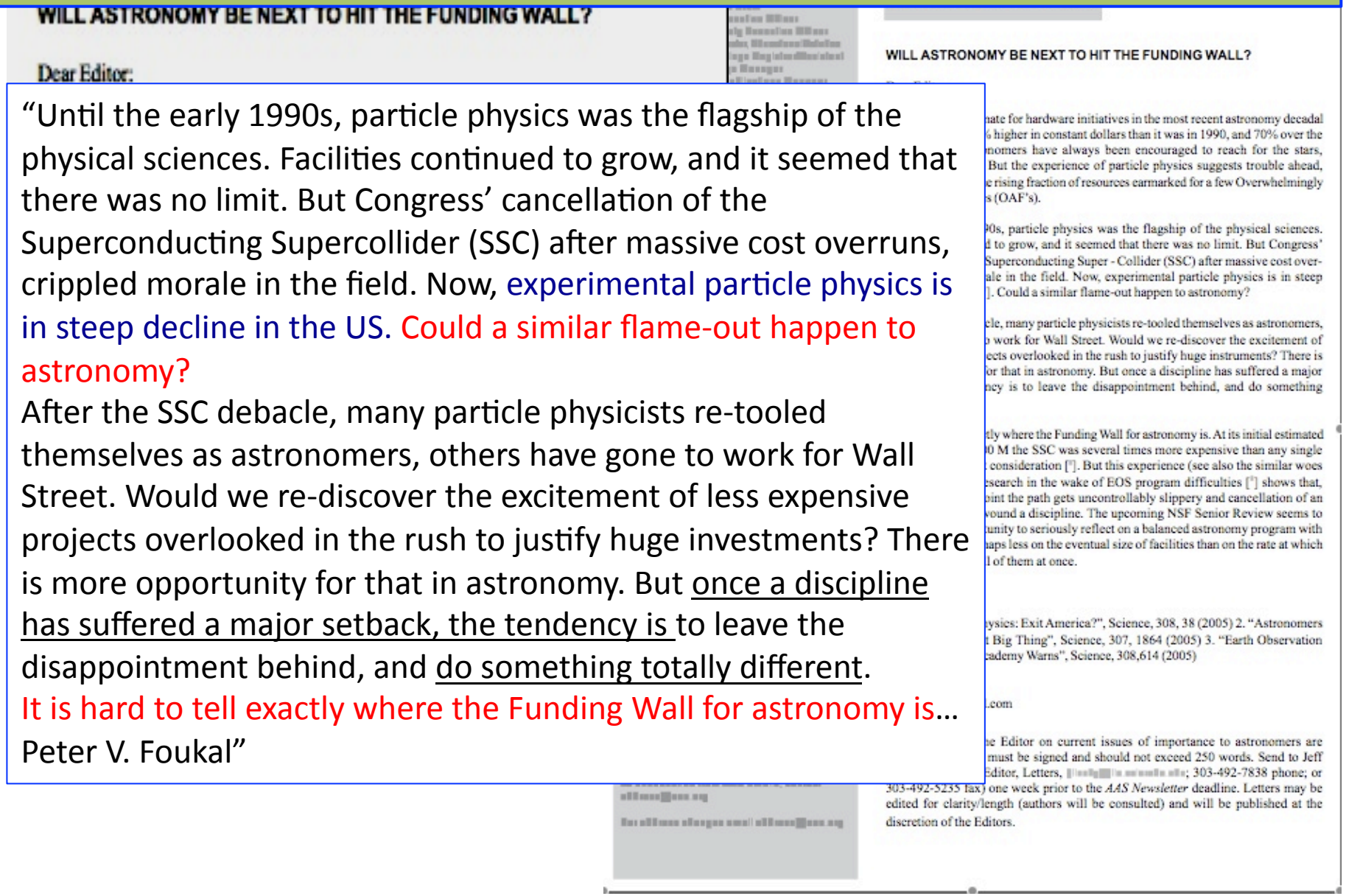
angular resolution

1962 1978 2010

We dreamed of IXO continuing this rapid progress

The Funding Wall

With Astro2010 Astrophysics has hit the Funding Wall



"Until the early 1990s, particle physics was the flagship of the physical sciences. Facilities continued to grow, and it seemed that there was no limit. But Congress' cancellation of the Superconducting Supercollider (SSC) after massive cost overruns, crippled morale in the field. Now, experimental particle physics is in steep decline in the US. Could a similar flame-out happen to astronomy?

After the SSC debacle, many particle physicists re-tooled themselves as astronomers, others have gone to work for Wall Street. Would we re-discover the excitement of less expensive projects overlooked in the rush to justify huge investments? There is more opportunity for that in astronomy. But once a discipline has suffered a major setback, the tendency is to leave the disappointment behind, and do something totally different.

It is hard to tell exactly where the Funding Wall for astronomy is…

Peter V. Foukal"

Pyramids, Cathedrals & Accelerators

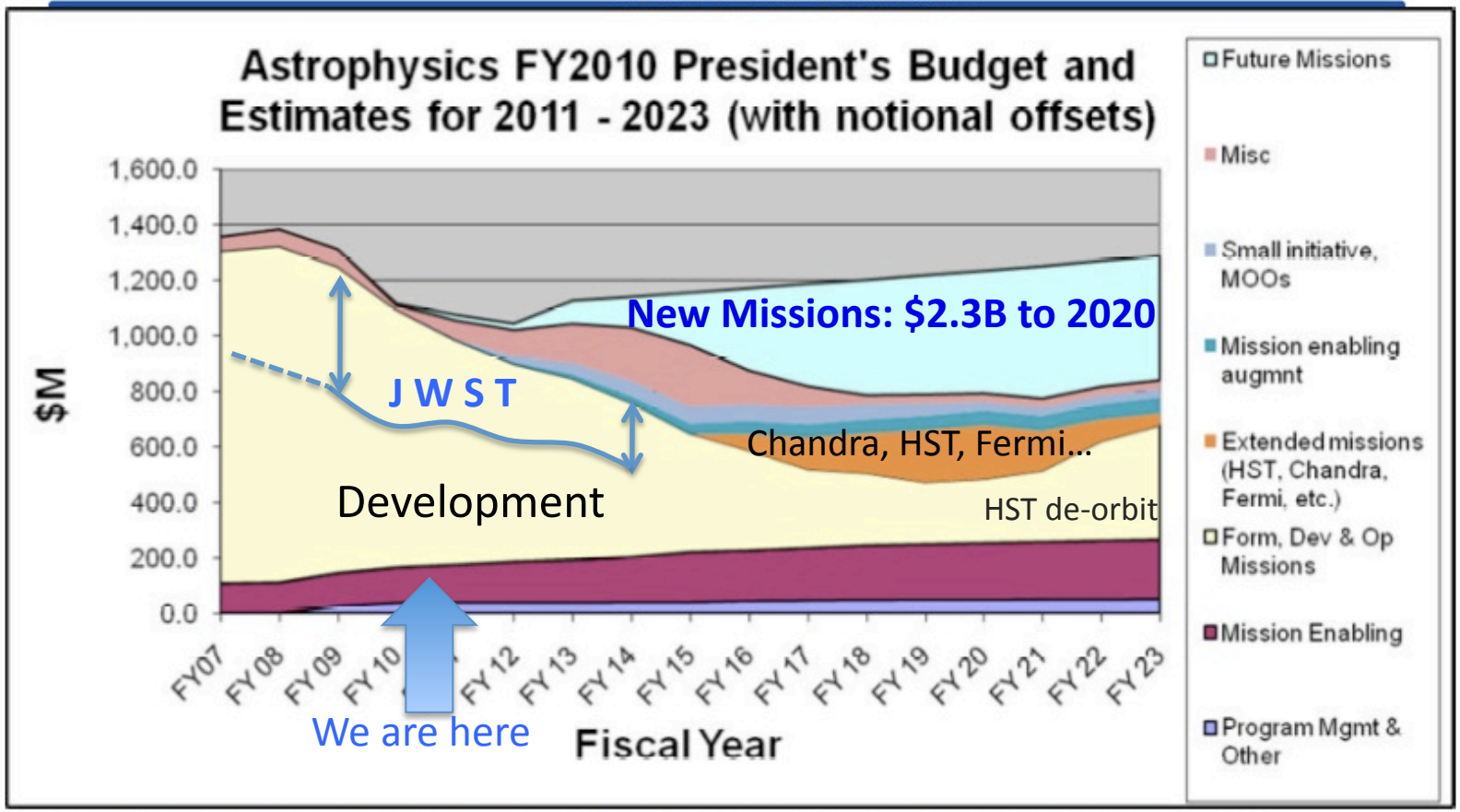
- Over time, ventures grow to the limit of what their societies can afford
  (c/o Shri Kulkarni)
- Pyramids,
- Cathedrals,
- Accelerators.
  - SSC abandoned after $2B
  - Cost rose from $5B to $12B.

NASA Astrophysics Funding Wall

Room for 1 Big Mission

Astrophysics Division

Budget Guidance for Decadal Survey – Notional scenario

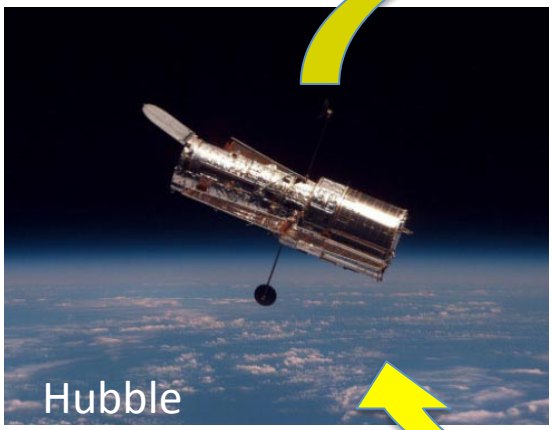


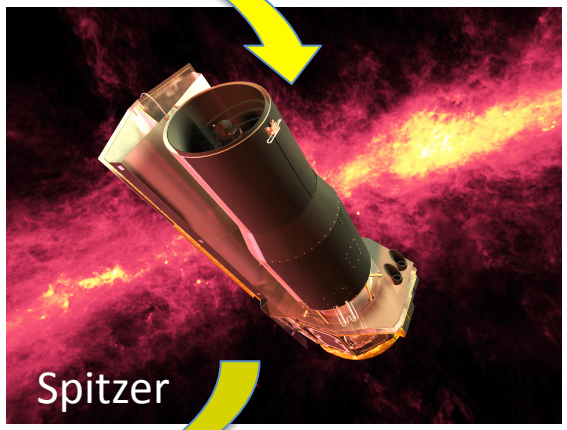
- Assumed operating missions beyond 2016 include JWST, SOFIA; plus HST, Chandra, Fermi, etc. (e.g., Astro-H)
- HST De-orbit mission development ramps up ~2020
- "Future Missions" wedge is for strategic missions recommended by the Astro2010 decadal survey
- The amount of "Future Missions" funding available between 2013 – 2020 in such a scenario would be ~$2.3B

Source: NASA October 2009 http://www.spacepolicyonline.com/pages/images/stories/Astro2010_NASA_Oct2009_v1.pdf

The Great Observatories

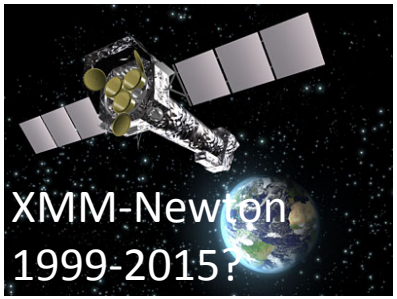
From X-ray discovery to IR follow-up now 1 year



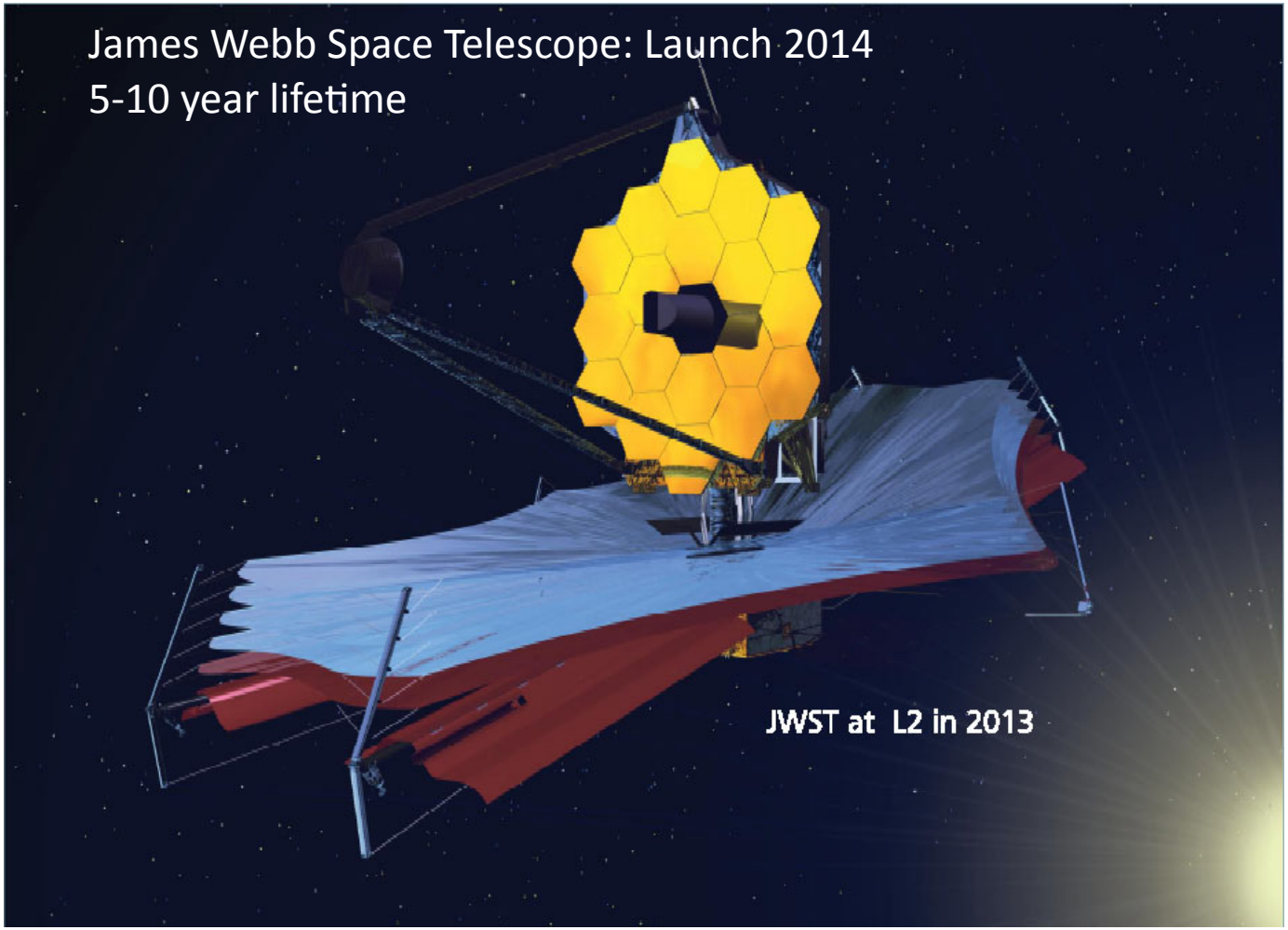


1990-2015? 1999-2015? 2003-2013

The Era of the Great Observatories is about to end



JWST Follow-up will take a decade

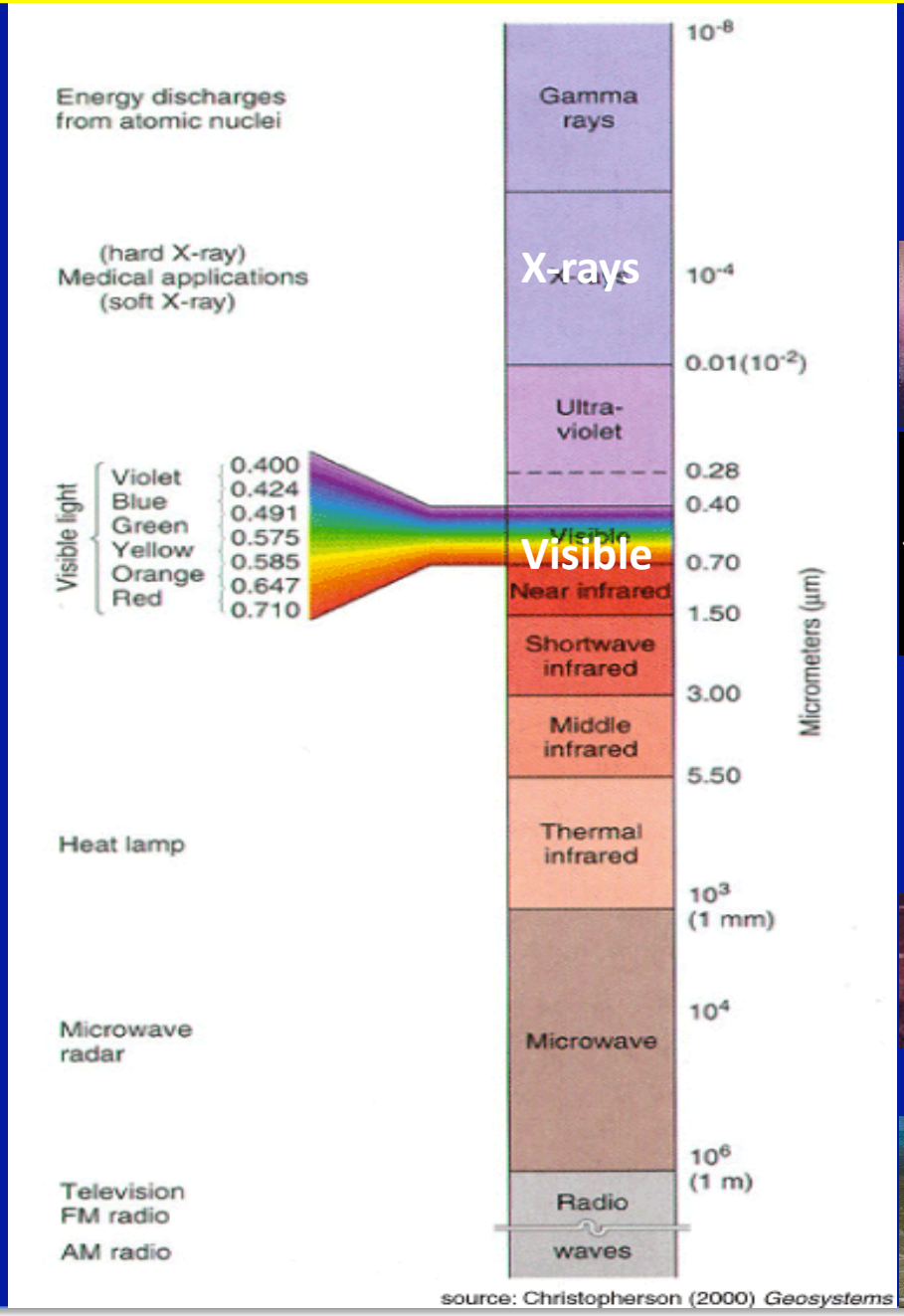


IXO Launch
NET 2025*?
>= 10 years
* Unless LISA trips

Or more: No UV/near-opt capability after HST

Has happened before: 10 years from HST to Chandra. But JWST not serviceable

Astronomical Objects don't know about our technologies



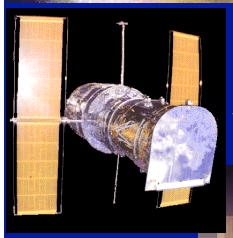
HESS/

Veritas

Fermi

CHANDRA/

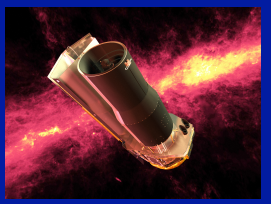
XMM



Hubble

VLT

Spitzer



Sub-millimeter array

EVLA

Astro2010 Space Recommendations

- Wide Field IR Survey Telescope
- Enhanced Explorer Program
- LISA
- IXO
- The new Flagship scale:

"…*allowing any major mission to exceed $2 billion in total cost to NASA would unacceptably imbalance NASA's astrophysics program.*" [p.7-22]

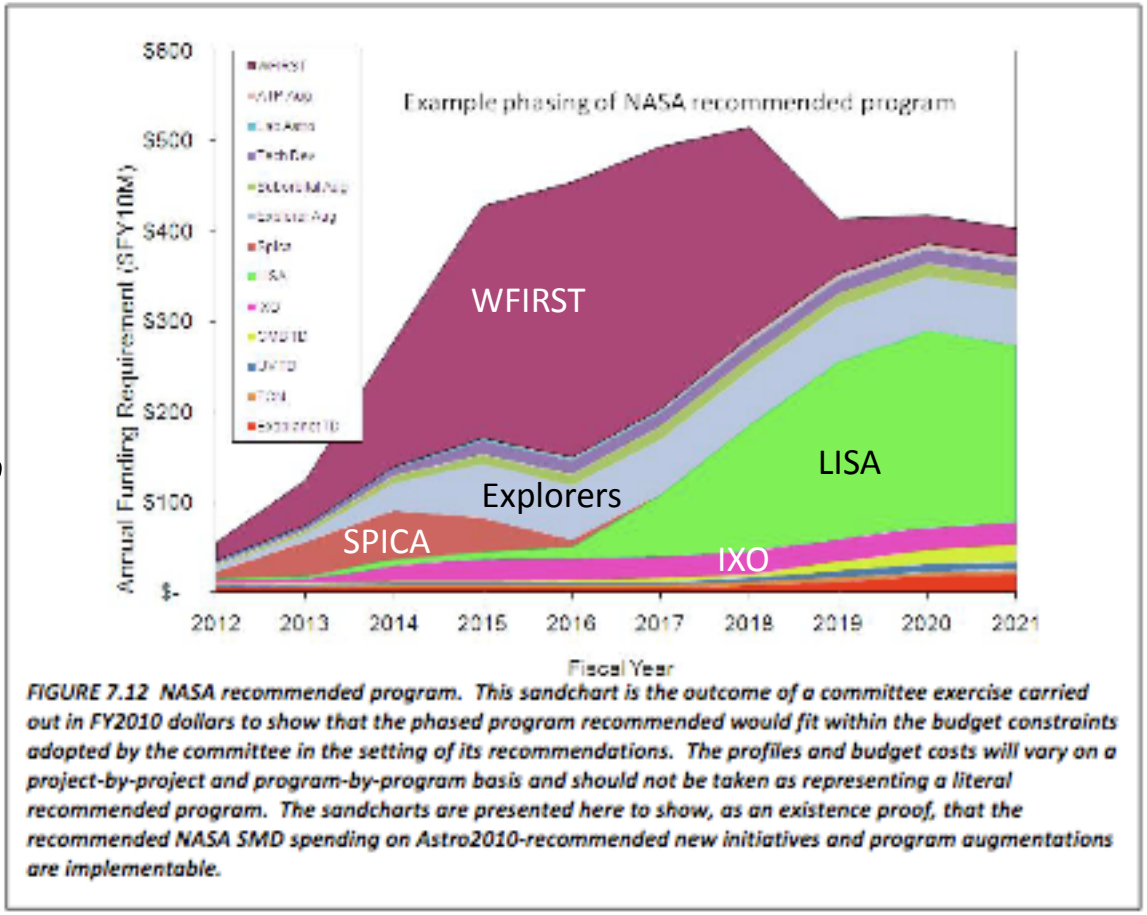
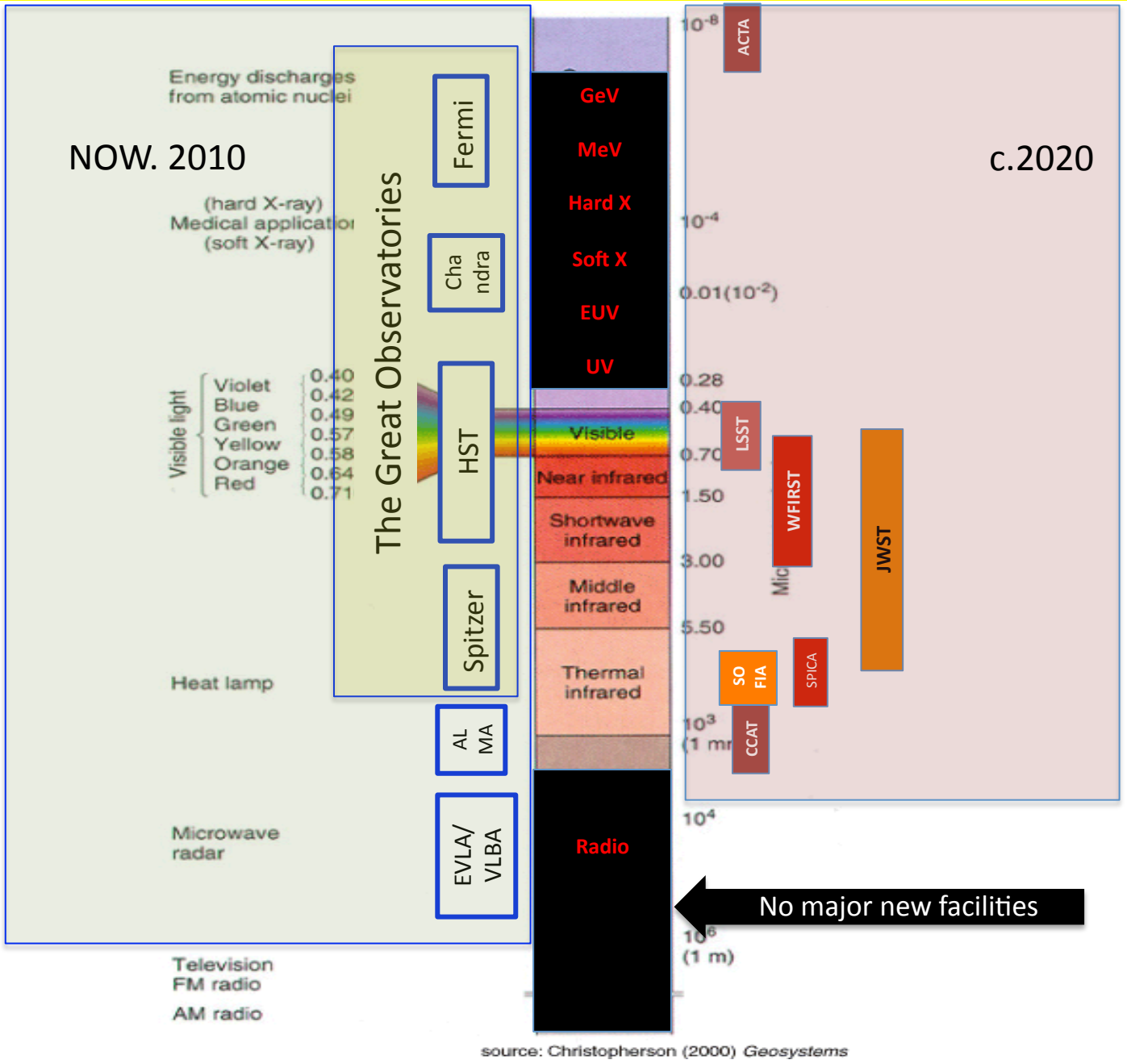


FIGURE 7.12 NASA recommended program. This sandchart is the outcome of a committee exercise carried out in FY2010 dollars to show that the phased program recommended would fit within the budget constraints adopted by the committee in the setting of its recommendations. The profiles and budget costs will vary on a project-by-project and program-by-program basis and should not be taken as representing a literal recommended program. The sandcharts are presented here to show, as an existence proof, that the recommended NASA SMD spending on Astro2010-recommended new initiatives and program augmentations are implementable.

Pre- and Post-Decadal Landscape



source: Christopherson (2000) *Geosystems*

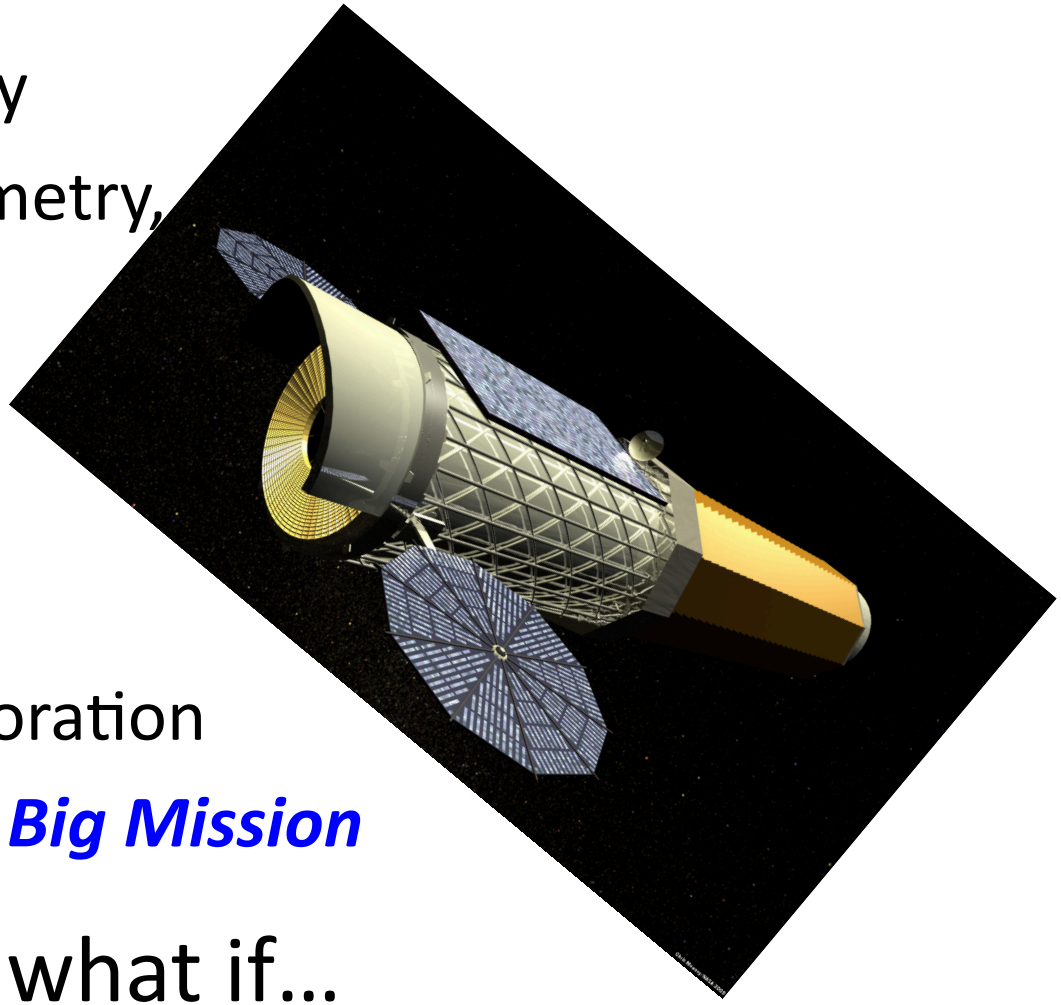
In development for 2020-2030 launch:

+ LISA
+ #4 IXO
+ New Worlds
+ B-mode CMB (+4m UV)

Pre-Decadal Situation

IXO: the International X-ray Observatory

- *Wonderful*
  - A powerful Observatory
  - Spectra, timing, polarimetry, imaging
  - 5” HPD
  - Launch NET 2021
  - $2B or so to launch
  - NASA/ESA/JAXA collaboration
  - ***IXO should be the One Big Mission***



But what if…

What if IXO isn't #1?

- Must get

  #1 rank in US Decadal Survey

  AND

  #1 rank in ESA "Cosmic Vision 2015-2025"

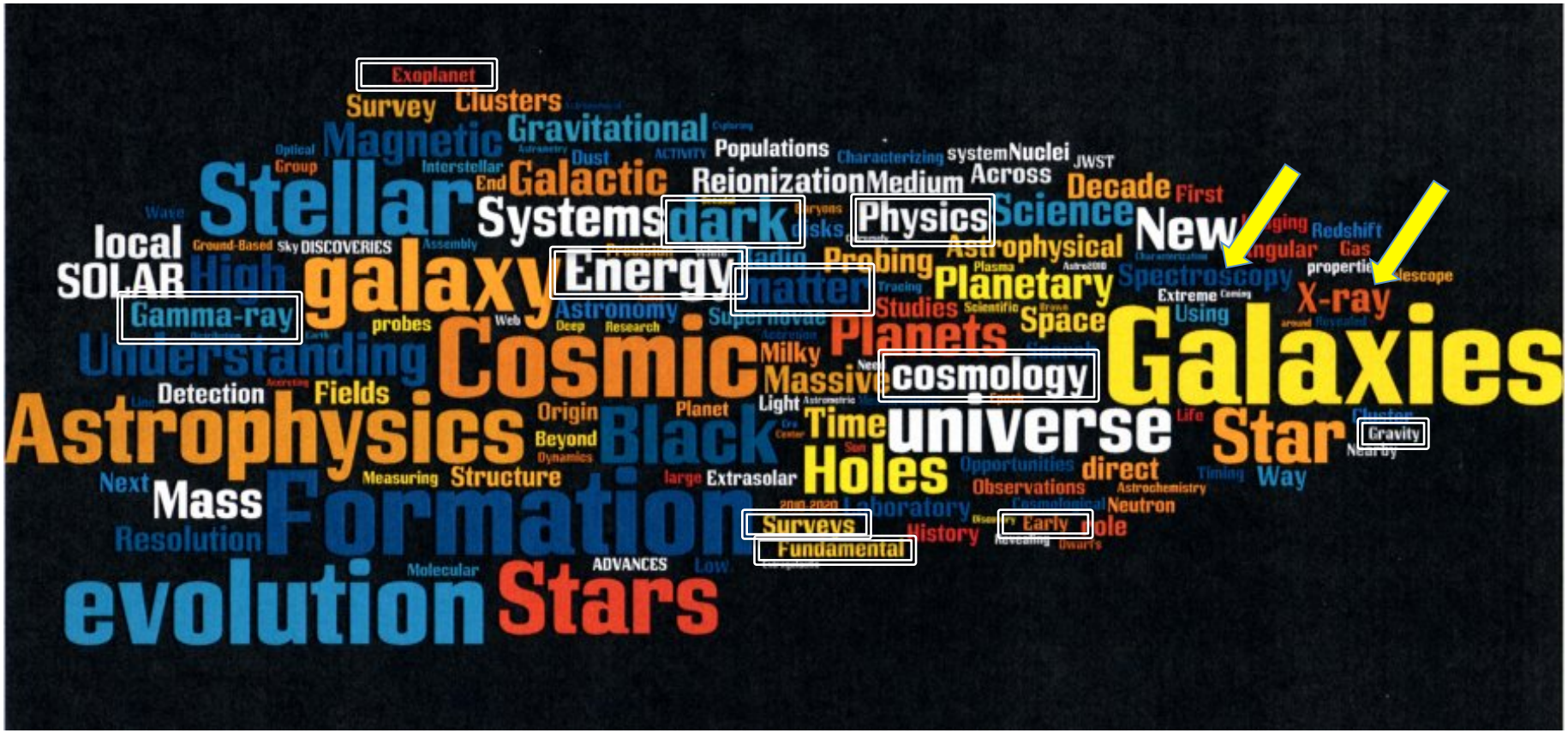
  1st of 3 'L class': IXO, LISA, Laplace (Jupiter) for L1 launch ~2020.

- Not quite as tough as betting on "22" twice in *Casablanca**
- Worst case: 2nd place.
  Waiting and waiting and waiting…

•The young Bulgarian refugee, Jan Brandel, has to bet on 22, twice, and win, to save his wife from Inspector Renault. Rick Blaine helps. Are we so lucky?

We need a "Plan B", just in case

White Paper Wordle & Decadal Choices



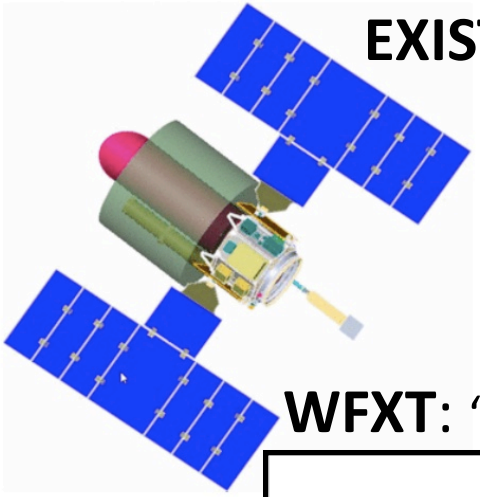
Factoid: DoE Particle Physics = $800M/year [6-1]; ~$80M/year Astro-particle

Option: Step back a factor 2-4 in Cost

- Expected a High Energy 'Consolation Prize'
- Unaffordable at ~$1B
- Much to be said about cost estimates, other choices…

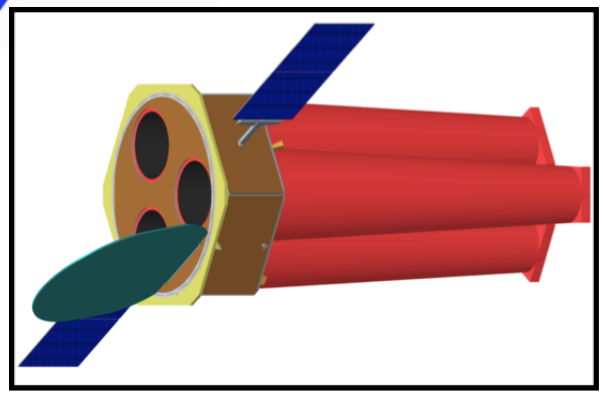
  irrelevant now
- Hard to scale down to Explorers

  ~1/5 scale
  - ESA M3?

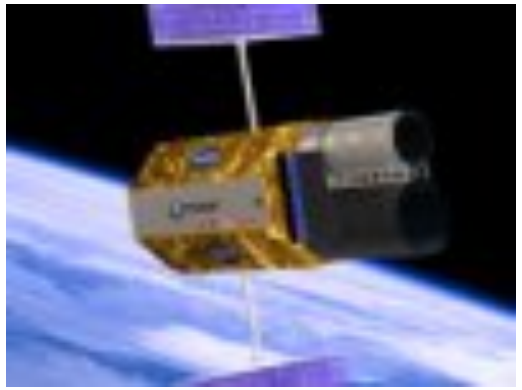


EXIST: 10-300 keV Survey/ASM, IR GRBs

WFXT: "Super-ROSAT"



XENIA : calorimeter



Astro2010 Recommendations

- What can we do with what is recommended?
  - Augmented Explorers
  - $200M in IXO development
- Other Opportunities
- No Magic Bullet

TABLE ES.5 Space: Recommended Activities—Large-Scale (Priority Order)

Recommendation	Launch Date[b]	Science	Technical Risk[c]	Appraisal of Costs[a] Total (U.S. share)	Appraisal of Costs[a] U.S. share 2012-2021
1. WFIRST - NASA/DOE collaboration	2020	Dark energy, exoplanets, and infrared survey-science	Medium low	$1.6B	$1.6B
2. Augmentation to Explorer Program	Ongoing	Enable rapid response to science opportunities; augments current plan by 2 MIDEXs, 2 SMEXs, and 4 MoOs	Low	$463M	$463M
3. LISA - Requires ESA partnership[d]	2025	Open low-frequency gravitational-wave window for detection of black-hole mergers and compact binaries and precision tests of general relativity	Medium[e]	$2.4B ($1.5B)	$852M
4. IXO - Partnership with ESA and JAXA[d]	2020s	Black-hole accretion and neutron-star physics, matter/energy life cycles, and stellar astrophysics	Medium high	$5.0B ($3.1B)	$200M

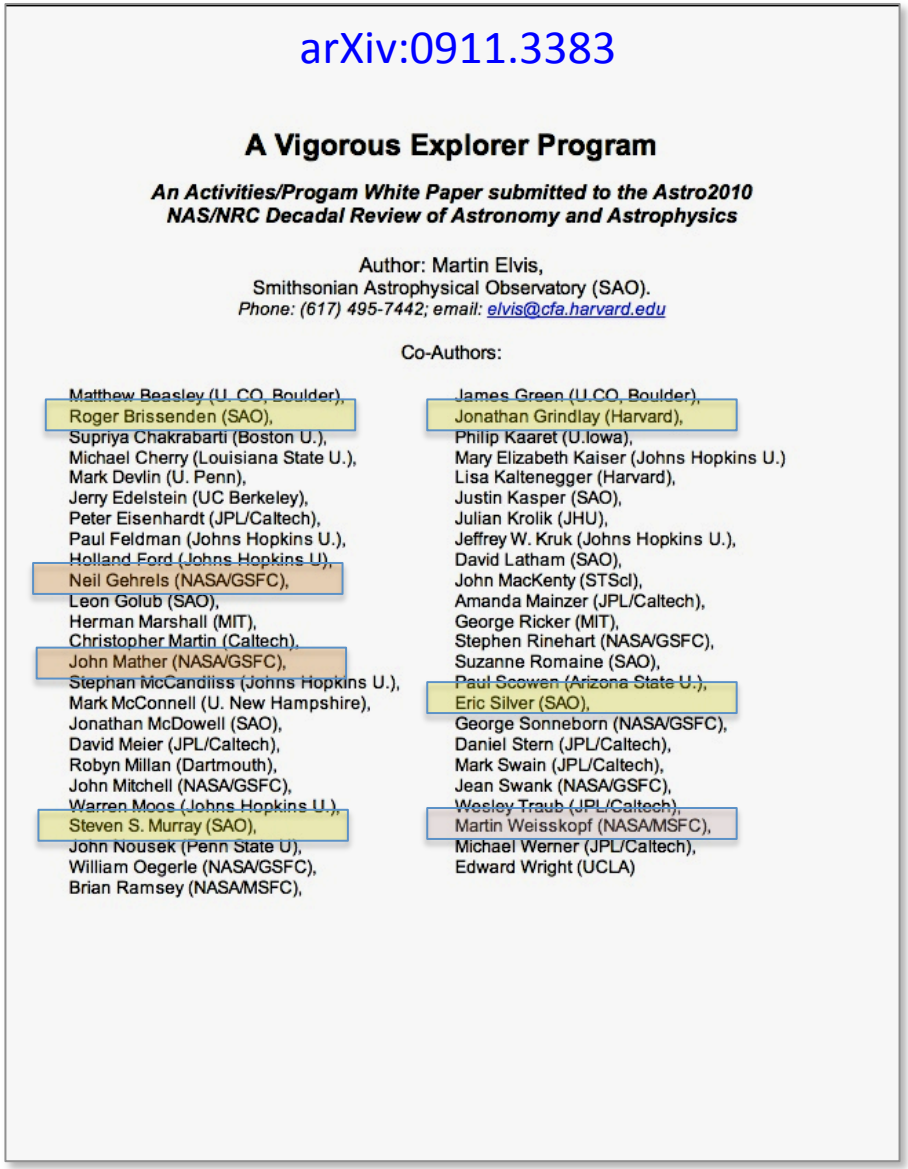
TABLE ES.4 Space: Recommended Activities—Medium-Scale (Priority Order)

Recommendation	Science	Appraisal of Costs[a]
1. New Worlds Technology Development Program	Preparation for a planet-imaging mission beyond 2020, including precursor science activities	$100-200M
2. Inflation Probe Technology Development Program	CMB/inflation technology development and preparation for a possible mission beyond 2020	$60-200M

(Definition of) a future UV-optical space capability	NASA	Technology development benefiting a future ultraviolet telescope to study hot gas between galaxies, the interstellar medium, and exoplanets	$40M

Enhanced Astrophysics Explorer Program

- #2 Priority in Decadal [p.7-19] (space, large)
  - Now 1 astrophysics launch/3 yr,
    - ~$40 M/yr
  - Increase in 2010-2020 to
    - $100M/yr for *astrophysics*
      - 2 MIDEX
      - 2 SMEX
      - 4 Missions of Opportunity
- Parallel Small Program enhancements
  - R&A +$2M → +$15M [p. 7-26]
    - TRL3 -> TRL5
  - Sub-orbital +25% launches [p.7-27]
  - Lowered costs, requirements?
  - Enhanced ADA/LTSA for Explorer exploitation?
- CXC offer Data Center services
  - heritage, cost →science



arXiv:0911.3383

A Vigorous Explorer Program

An Activities/Progam White Paper submitted to the Astro2010 NAS/NRC Decadal Review of Astronomy and Astrophysics

Author: Martin Elvis,
Smithsonian Astrophysical Observatory (SAO).
Phone: (617) 495-7442; email: elvis@cfa.harvard.edu

Co-Authors:

Matthew Beasley (U. CO, Boulder),
Roger Brissenden (SAO),
Supriya Chakrabarti (Boston U.),
Michael Cherry (Louisiana State U.),
Mark Devlin (U. Penn),
Jerry Edelstein (UC Berkeley),
Peter Eisenhardt (JPL/Caltech),
Paul Feldman (Johns Hopkins U.),
Holland Ford (Johns Hopkins U.),
Neil Gehrels (NASA/GSFC),
Leon Golub (SAO),
Herman Marshall (MIT),
Christopher Martin (Caltech),
John Mather (NASA/GSFC),
Stephan McCandliss (Johns Hopkins U.),
Mark McConnell (U. New Hampshire),
Jonathan McDowell (SAO),
David Meier (JPL/Caltech),
Robyn Millan (Dartmouth),
John Mitchell (NASA/GSFC),
Warren Moos (Johns Hopkins U.),
Steven S. Murray (SAO),
John Nousek (Penn State U),
William Oegerle (NASA/GSFC),
Brian Ramsey (NASA/MSFC),
James Green (U.CO, Boulder),
Jonathan Grindlay (Harvard),
Philip Kaaret (U.Iowa),
Mary Elizabeth Kaiser (Johns Hopkins U.)
Lisa Kaltenegger (Harvard),
Justin Kasper (SAO),
Julian Krolik (JHU),
Jeffrey W. Kruk (Johns Hopkins U.),
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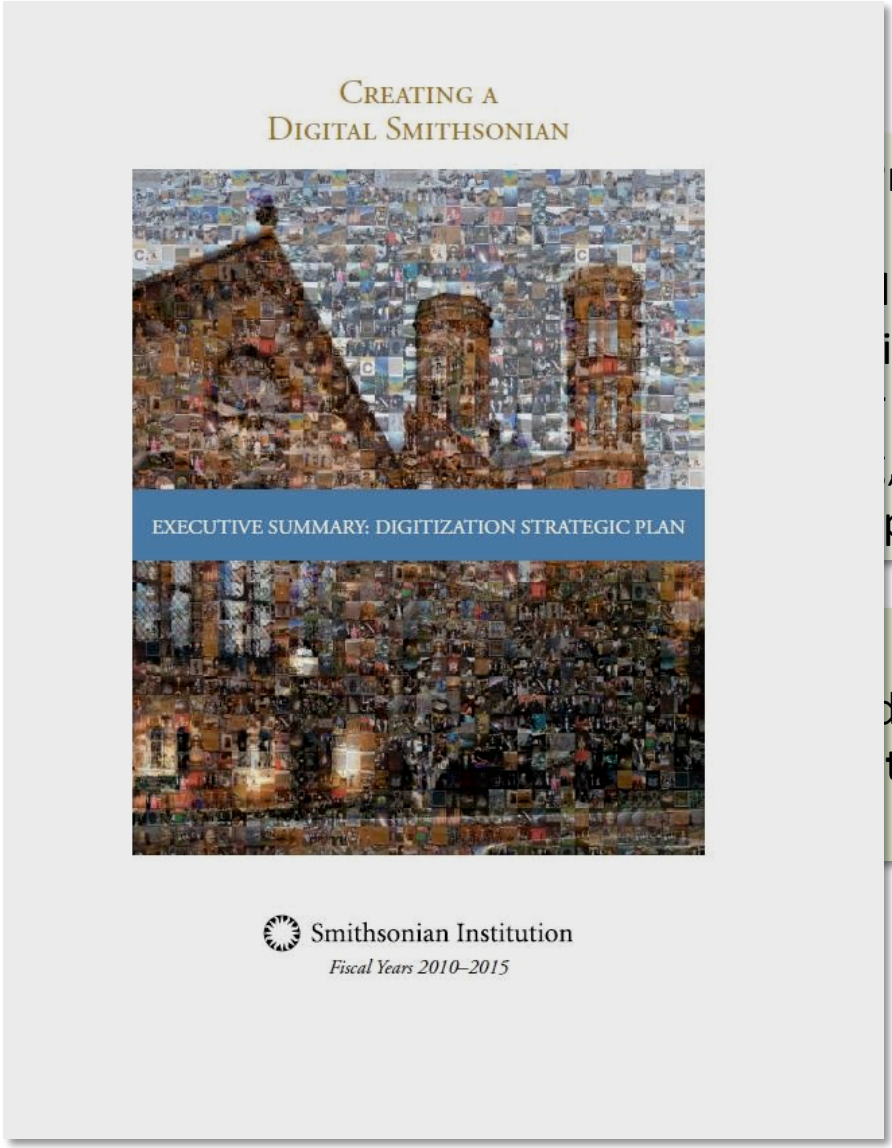
John MacKenty (STScI),
Amanda Mainzer (JPL/Caltech),
George Ricker (MIT),
Stephen Rinehart (NASA/GSFC),
Suzanne Romaine (SAO),
Paul Scowen (Arizona State U.),
Eric Silver (SAO),
George Sonneborn (NASA/GSFC),
Daniel Stern (JPL/Caltech),
Mark Swain (JPL/Caltech),
Jean Swank (NASA/GSFC),
Wesley Traub (JPL/Caltech),
Martin Weisskopf (NASA/MSFC),
Michael Werner (JPL/Caltech),
Edward Wright (UCLA)

Interoperable Archives becoming a requirement: CXC/VO experience is an asset



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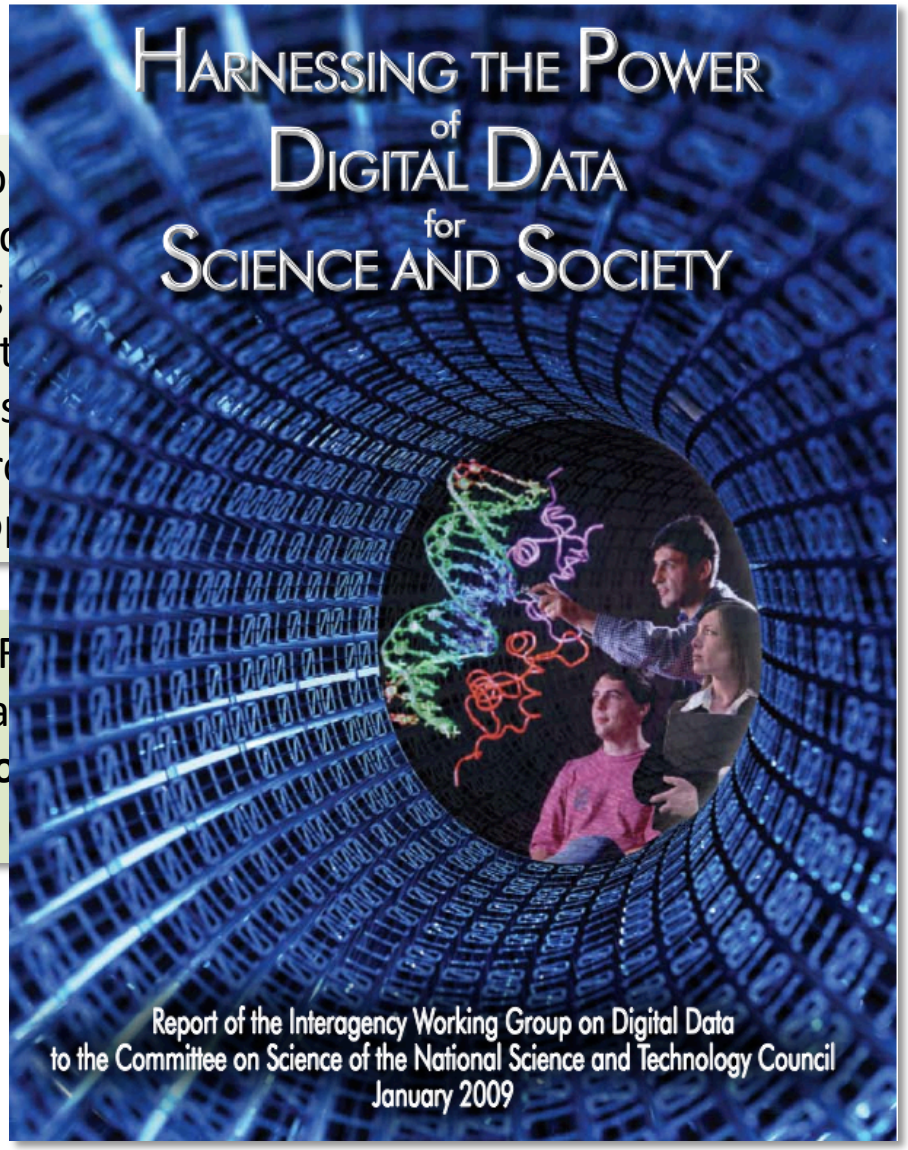
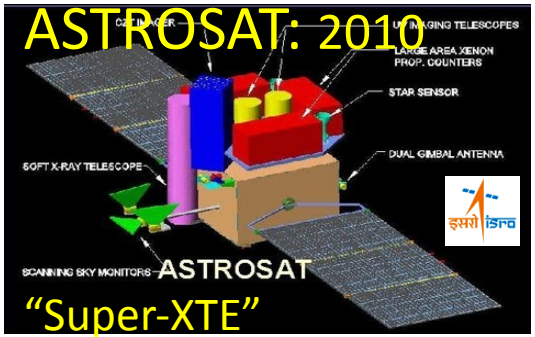
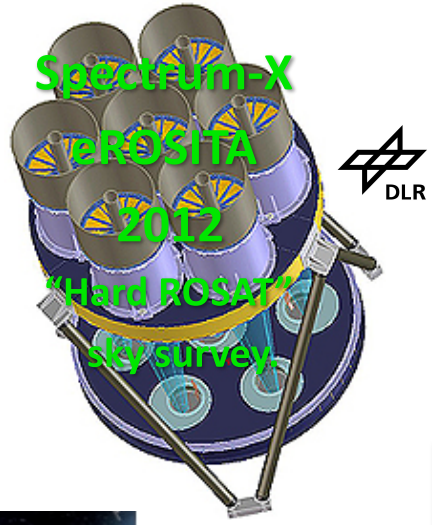
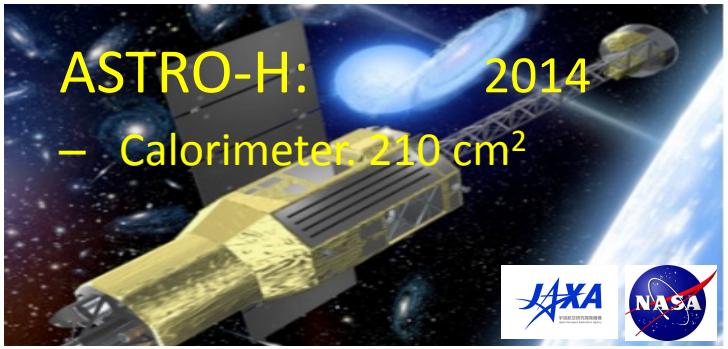


Step back factor ~10: Explorer-Class Missions to 2015

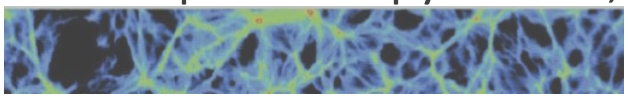






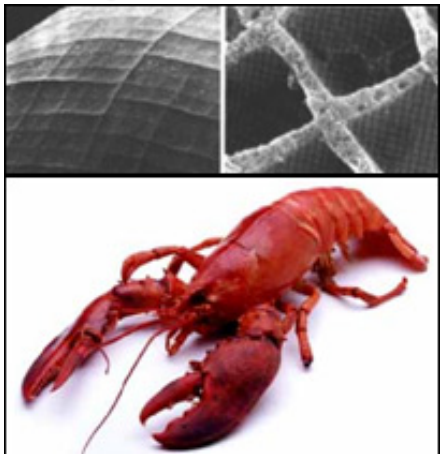
Looking good through ~2015

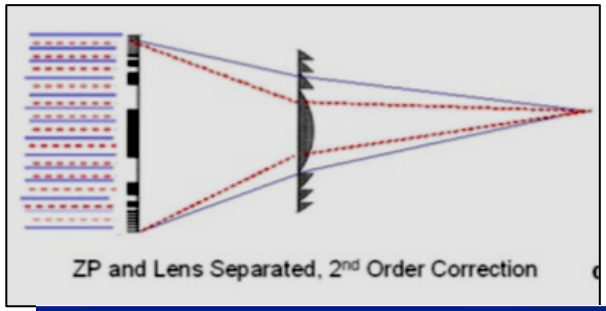
Post-2015 X-ray Explorer-Class Concepts

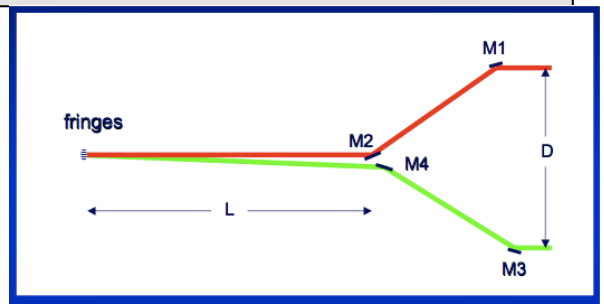
- LOBSTER: George Fraser 0.5-2keV ASM, survey
  Microchannel plate optics (Leicester/Photonis)
- Fresnel Zone Plates. sub-milli arcsec. 1/2m dia., 1000 km focal length Paul Gorenstein
- Telephoto X-ray Interferometer. 1mas, 20m physical length (40km f.l.) Dick Willingale
- Extreme Physics Explorer. 0.5-15keV Calorimeter spectra/fast timing. "Sq.meters" microchannel plate optics
- Pharos. 0.1-2keV R~3000 spectroscopy: WHIM, Physics, Hot Jupiters. 

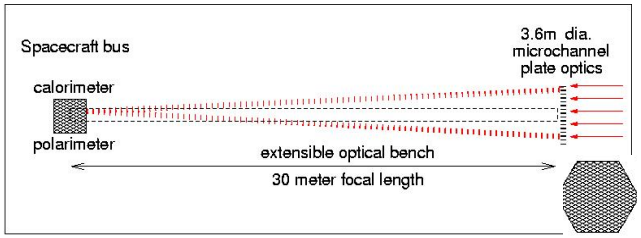
By optimizing for specialized missions
Explorers can rival IXO in sub-areas:

Do One Thing Right







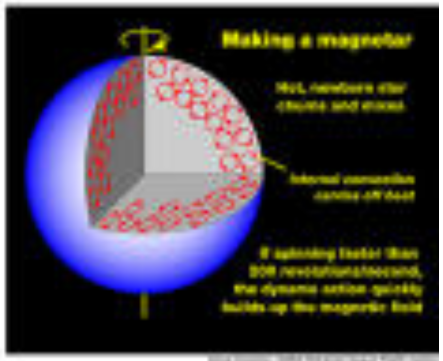


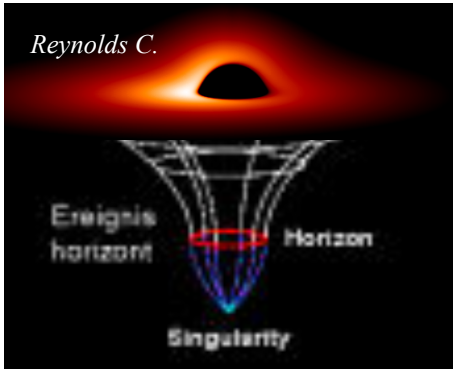
Extreme Physics Explorer

Science

- QCD effects: Magnetar polarization, Hydrogen Lyman series @ ~1 keV
- Strong Force: neutron star equation of state: M/R, R from bursts
- General Relativity: map metric around black holes: Fe-K, polarization

"You don't have to be a genius to see there's a potential Nobel Prize in here."

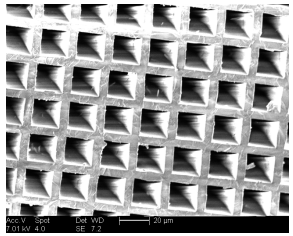


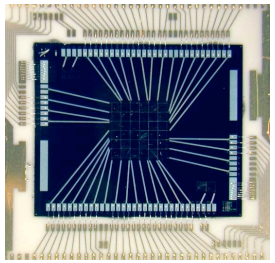


- Photon Hungry apps.
  - 10^3cts in 10^3 spec. bins/time bin
- Most IXO point source calorimeter science covered

Technology

- Big Bad Mirror:
  - Microchannel Plate Optics
  - ~1 arcmin, ~1cm spot
  - ~5 sq. meters @ 1keV
  - Light: 3.7 kg/m^2





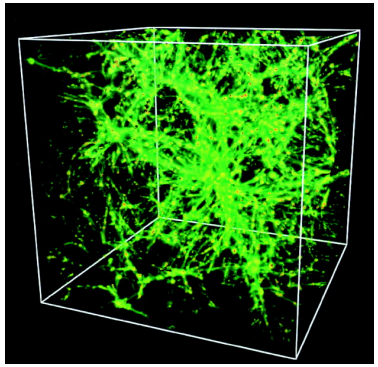
- Calorimeter array
  - Rapid timing 100 μs
  - High count rate 1000Hz/pixel, 32x32 ~10^6ct/s
  - High Res. Spectra 2eV. R~500 @ 1keV
- Polarimeter
- ASM? for state/transient alert

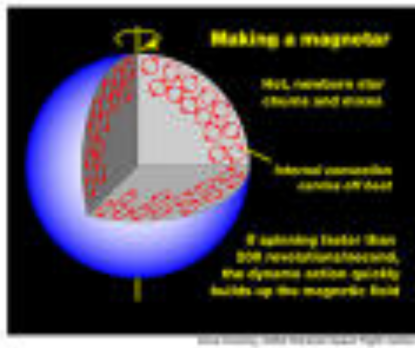
Not ready for 2010 Explorer: Do spadework for later round

Pharos

Science

- #1: Missing Baryons: the Warm-Hot Intergalactic Medium.
- #2 Physics: QED - Lyman series @ ~1 keV in magnetars; NS EOS
- *New:* Exoplanet-Star interactions





- Soft X-rays (<2keV)
- High Resolving power (~3000)

Technology

- Short Focal Length mirror
  - High area/mass ratio
  - XMM-class Ni Replica shells
  - 10” HPD -> ~2” in dispersion
- CAT blazed gratings (IXO)
  - ~50% dispersed power
- CCD readout; 0-order
- ~40% of IXO grating area
- 100% of observing time
- ½ SM for GRBs, blazars
- fast slew

Fits 2010 Explorer cost, weight envelope. High TRL. *We will propose it.*

Pharos & 2010 Explorer AO

- AO 'early Fall', +90 days due Jan/ Feb; Launch <2018
- $200M cap
  - Incl. 25% reserves
  - NASA adds launch
- LEO ~1000 kg (Taurus)
- 2 years (2-3 year extension)
- Pharos fits easily into Explorer envelope
- Team now forming rapidly:
  - Contact me right away if interested.
  - *Lots of work!*
  - *Prospect of great science reward*

Optimizing for "One Big Thing" gives a design that does virtually all the IXO grating science.

Other Opportunities, 1: Micro-satellites

(c/o Shri Kulkarni)

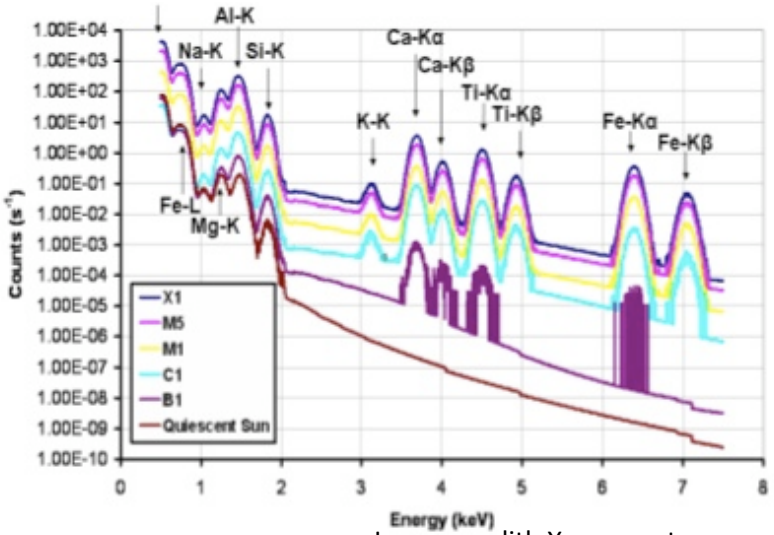
- Microsatellites: $10M, <100kg
- Canadian MOST
  - "Microvariability and Oscillations of Stars"
  - 15cm optical telescope + CCD
  - 60kg
  - 65x65x30cm "suitcase sized"
- Cheap enough for small countries, rich institutions (Allen, Keck, Harvard…)
- Culturally hard for big agencies?
- Lobby to include in MoO?
- X-ray astronomy apps?

Fig. 2.— Above: The phase diagram of the MOST photometry of HD 189733, and the transit model, folded at the orbital period of the planet. The data have been averaged in 2-min bins. Below: Residuals from the model.

Other Opportunities, 2: Human Program

- Core expertise: X-ray/Space Technology
- Asteroids: Humans to visit ~2025
- Need to characterize destinations
- X-rays give regolith composition
- Current asteroid X-ray tech. is collimated gas counters
- Serious funding possibilities: FY2011 request:

FY2011 $125M; FY2012 $506M; FY2013 $699M; FY2014 $797M; FY2015 $923M for *Robotic Precursor missions*. reduced by Congress



Lunar regolith X-ray spectrum
(simulation for Bepi Colombo MIXS-T Experiemnt) G.Fraser, U.Leicester UK
Pt M-shell is at 2.5-3.5keV

Regolith X-ray Imaging Spectrometer: proposed Student experiment for OSIRIS-REX

Table 1: *REXIS* parameters

Parameter	System	Value
Mass	Support structures	0.6kg
	Detector & electronics	0.4kg
	Mask & shields	0.4kg
Power	Detectors & data sys.	14W
Data	Readout rate	4s
	Total data req. (storage)	95Mb
	Hskeeping/instr. health	10bps
Commands	Pwr.; thresholds; data	8

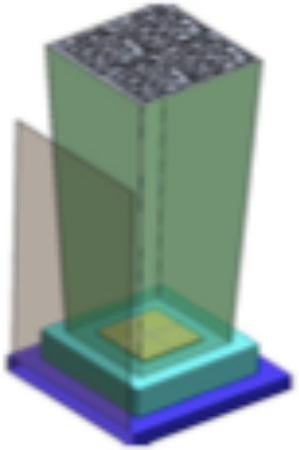


Fig. 2: 3-D view of *REXIS*.

IXO development funding

- $200M over 10 years (recommended)
  ~$5M/year for first few years
  Then ~$30M/year for ~5 years
  to accommodate SPICA funding?
- Implies mainly mirror development to high TRL
- Options:
  a. Continue as before. Tripwires on LISA may trigger
     - 2011 downselect by ESA: may eliminate LISA, or IXO
     - 2012 LISA Pathfinder launch, ~2014 results

     → IXO takes LISA's place for ~2020-2021 launch. All is well.
  c. Move to develop radically better optics.

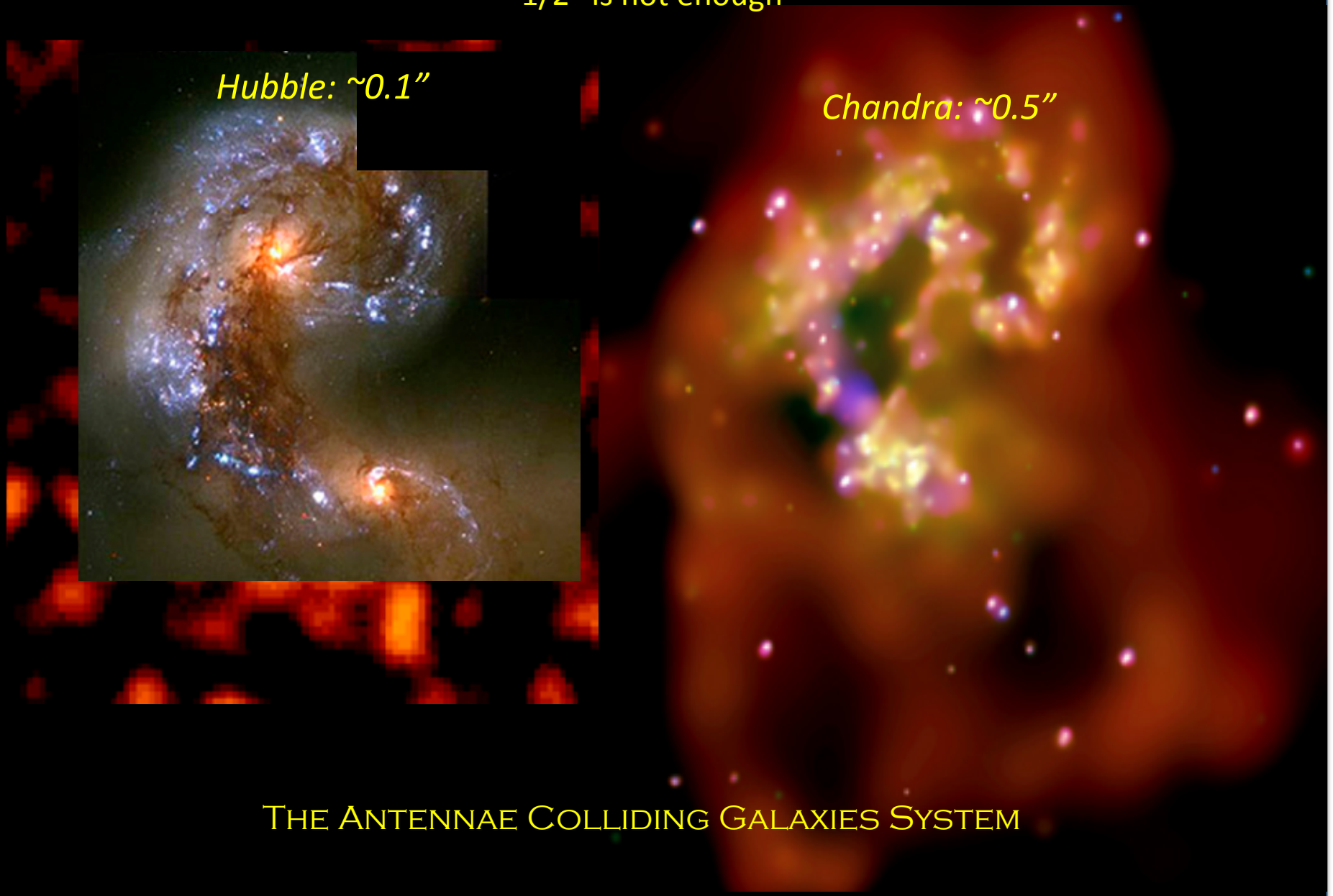
     "*Given the multidecade timescales required for development of major facilities from concept to construction to operation, it should not be surprising that many of these projects have evolved in technical and/or scientific scope since AANM* [2000 Decadal]…" [7-2]

IXO Development: A Problem

- Is re-proposing IXO in 2020 going to get #1 ranking?
- That sinking feeling: *E.g.* Stein Sigurdson, "Dynamics of Cats" blog post, 11 Aug 2010:
- *"That is ONE of the large scale projects, only, for the next decade. Maybe one or two medium/small projects to keep a community alive. I'm biased: I think JDEM screwed up, first by bumping in line demanding a new priority review, and then not being ready to go; I have had some involvement in LISA for over a decade, though only platonic for now, due to total absence of funding - I really like LISA as a concept, and there is the pesky matter of the agreement with ESA to do LISA;*
  IXO is solid, has a huge constituency of good hard working x-ray observers, but is incremental. *Unfortunately I don't see the TPFs as ready to go phase-A, though something like a New World Observer concept could fly early with some success and have strong secondary science."*
- IXO first proposed "BC": before Chandra launch (c. 1997)
  - Will be a >20 year old concept for next Decadal
  - Competition will be:
    - Earth-like planets imager,
    - Inflation: B-modes in CMB
    - UV 4-meter class telescope
    - other new concepts
- Newer approaches?
  - No alternative paths in 1997. Landscape now changed.
  - *Higher angular resolution: unmentioned in Astro2010*
  - Fresnel Zone plates? X-ray Interferometry?
  - *Super-Chandra*

Need a Replacement for Chandra

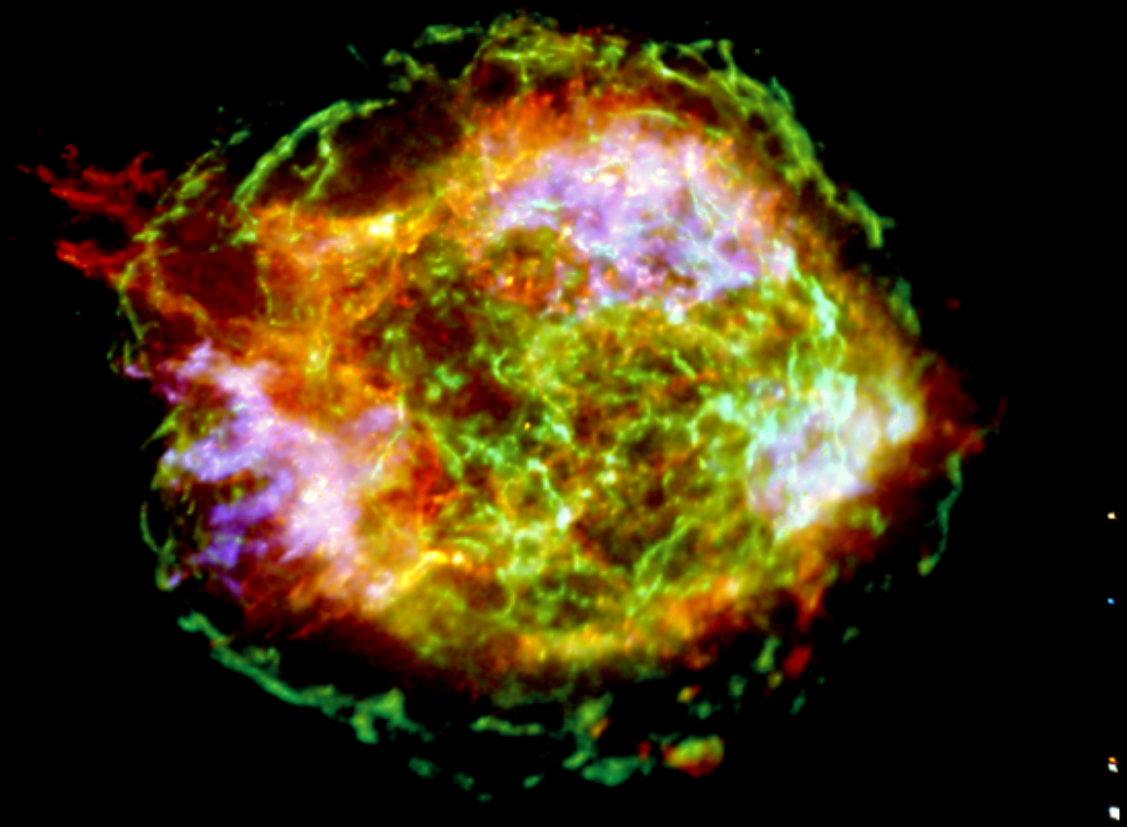
1/2” is not enough



The Antennae Colliding Galaxies System

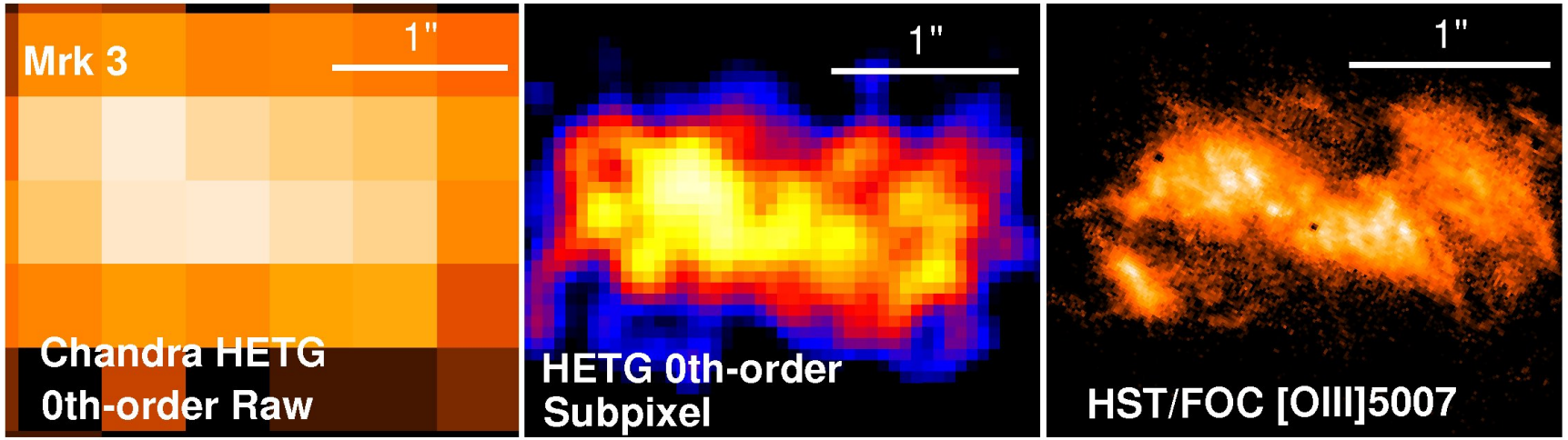
Need a Replacement for Chandra

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



The Supernova Remnant Cassiopeia A

Chandra is a ¼" Telescope



- 0.5" ACIS pixels
- ¼" HPD
- Can be retrieved
  - Sub-pixel positioning (PSU)
  - 'multi-drizzle' from dither (Leon van Speybroeck)
  - Will be part of pipeline, calibration in ~1 year
  - Thanks to $1.5M from Senior Review
  - shows level of excitement

IXO is Dead. Long Live IXO!

- Pharos, Extreme Physics Explorer reduce pressure to do everything on IXO: 3-4 instruments done
- Concentrate on One Thing – High Spatial Resolution
- New Optics
  - Cheaper, lighter, High resolution
  - Active, Piezo-controlled figure
  - 0.1” HPD goal. Promising in lab (Reid)
  - Presently targeted at “Generation-X”
    - 50 sq.meters: 1000 x Chandra
  - ***Decades away***
  - Re-orient to high resolution successor to Chandra?

ATHENA

Advanced Telescope for High ENergy Astrophysics

Greek Goddess of War and Wisdom

- A *'Super-Chandra'*
  - 10 x area, 5 x resolution
  - Active Piezo-optics
  - Small pixel "CCDs", Calorimeter array
- *Explorer Proposal to AO c.2015?* *(Reid, Schwartz)*
  - One imager
  - E< 3keV (cf Einstein): >5x area of 20m f.l.
- Need revolutionary science
  - Equivalent to AXAF/Chandra driver:

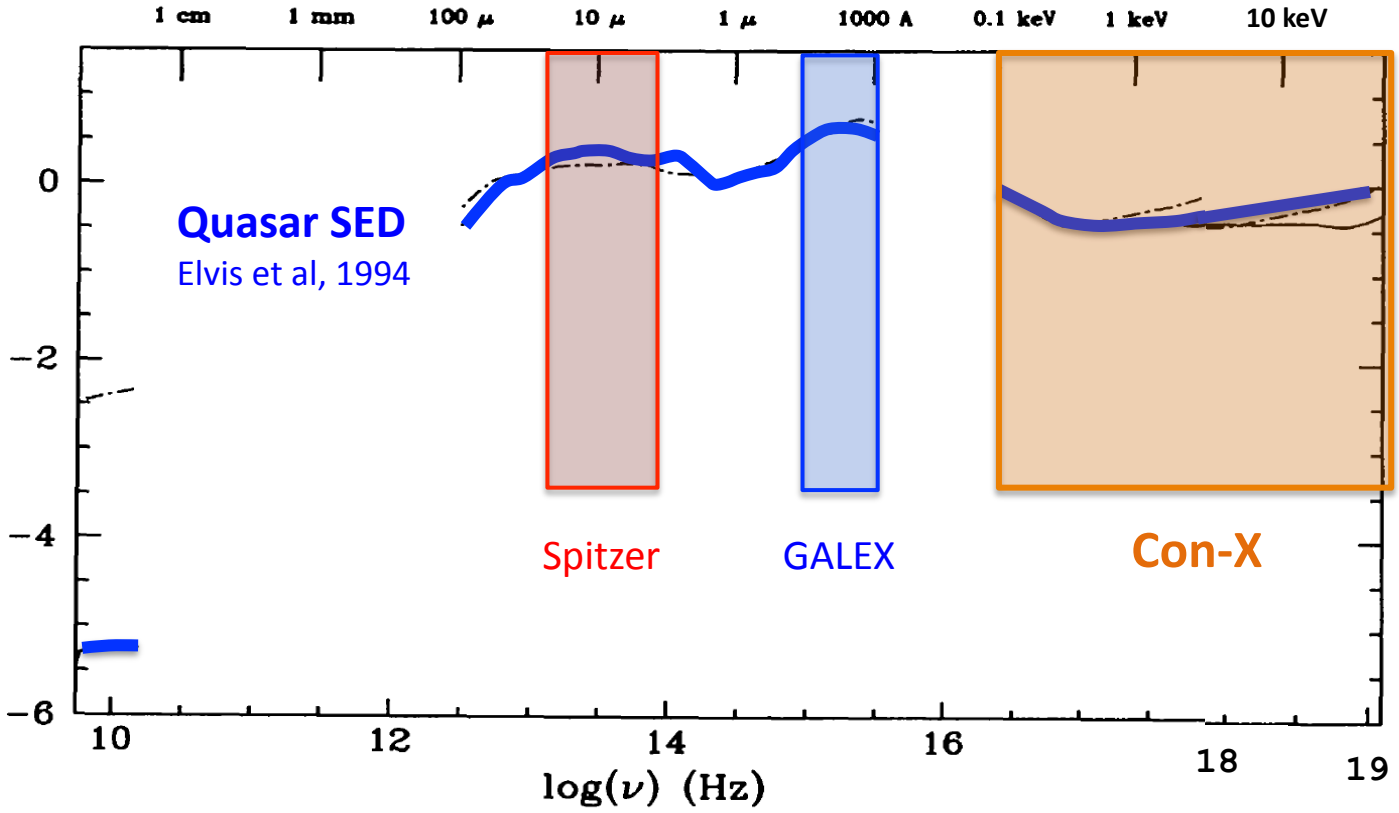
    "resolve the X-ray background"
  - What would YOU do with ATHENA?

A Post-Decadal Plan for X-ray Astronomy

1. No single All-or-Nothing venture
2. Specialized Explorers: *Pharos 1st*
3. *Super-Chandra* – ATHENA
4. Privately funded micro-satellites
5. Human space program [NEOs]
6. Data Center Services, VO

Another IXO Approach: 4 'Explorers"

- In 2004 Con-X had 4 identical spacecraft
  - Co-pointing Gratings, Calorimeter, Hard-X-rays: *inefficient*
  - Would rarely co-point GALEX –blue/hot- and Spitzer – red/cold
  - Same ΔlogE as Con-X: 1 or 2 instruments mostly idle

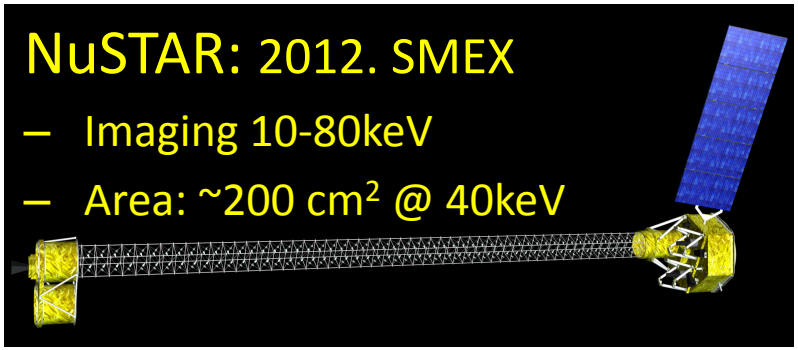


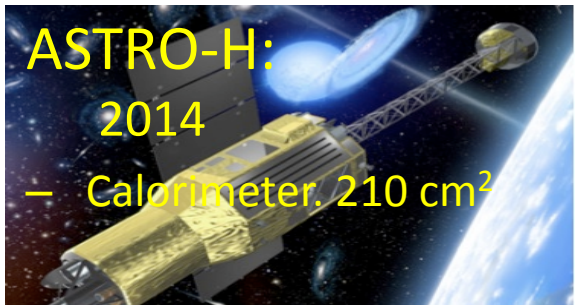
- Separate spacecraft gives 70% gain in instrument utilization
- Each mission MIDEX class: Σ is smaller

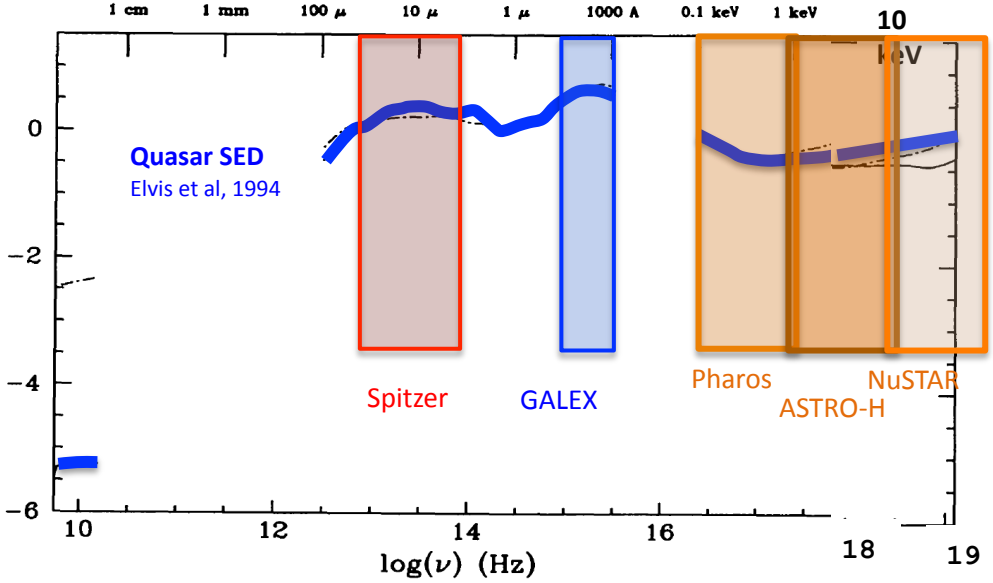
3 Explorer IXO Approximation

NuSTAR: 2012. SMEX

- Imaging 10-80keV
- Area: ~200 cm² @ 40keV







Pharos: Explorer 2017?

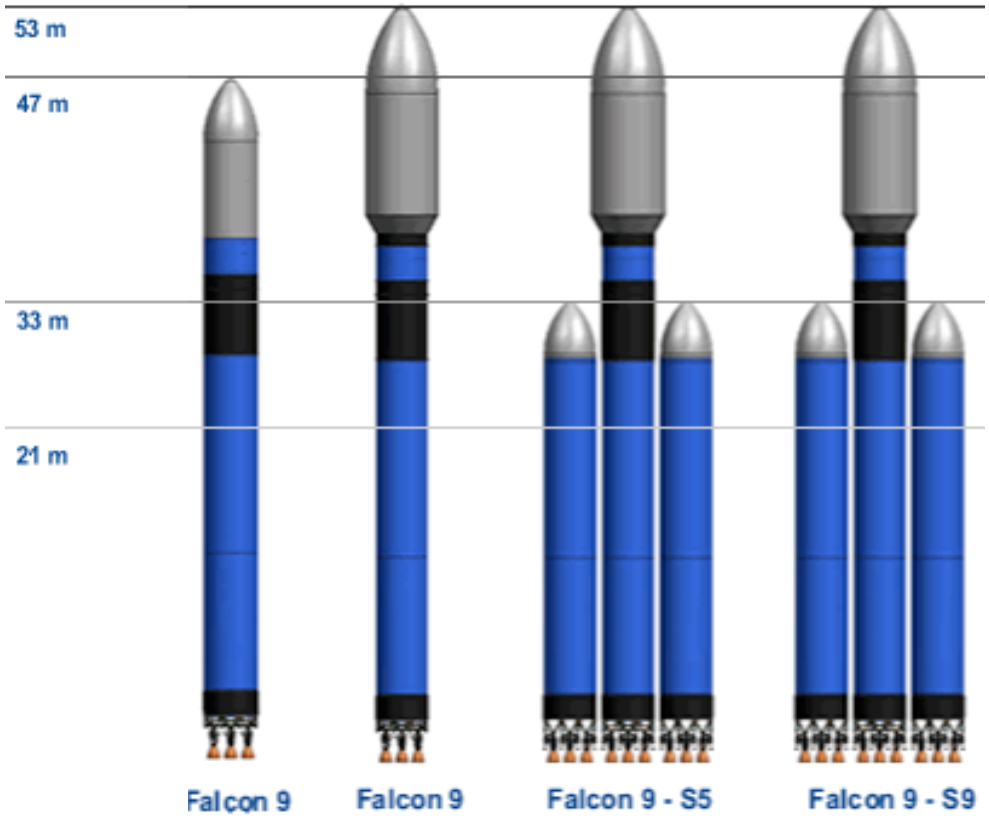
- R~3000 gratings @ E<1.2keV
- Area ~400 cm² (1.5m focal length)

10-40% Con-X

(Chandra News March 2004, launch: 2015)

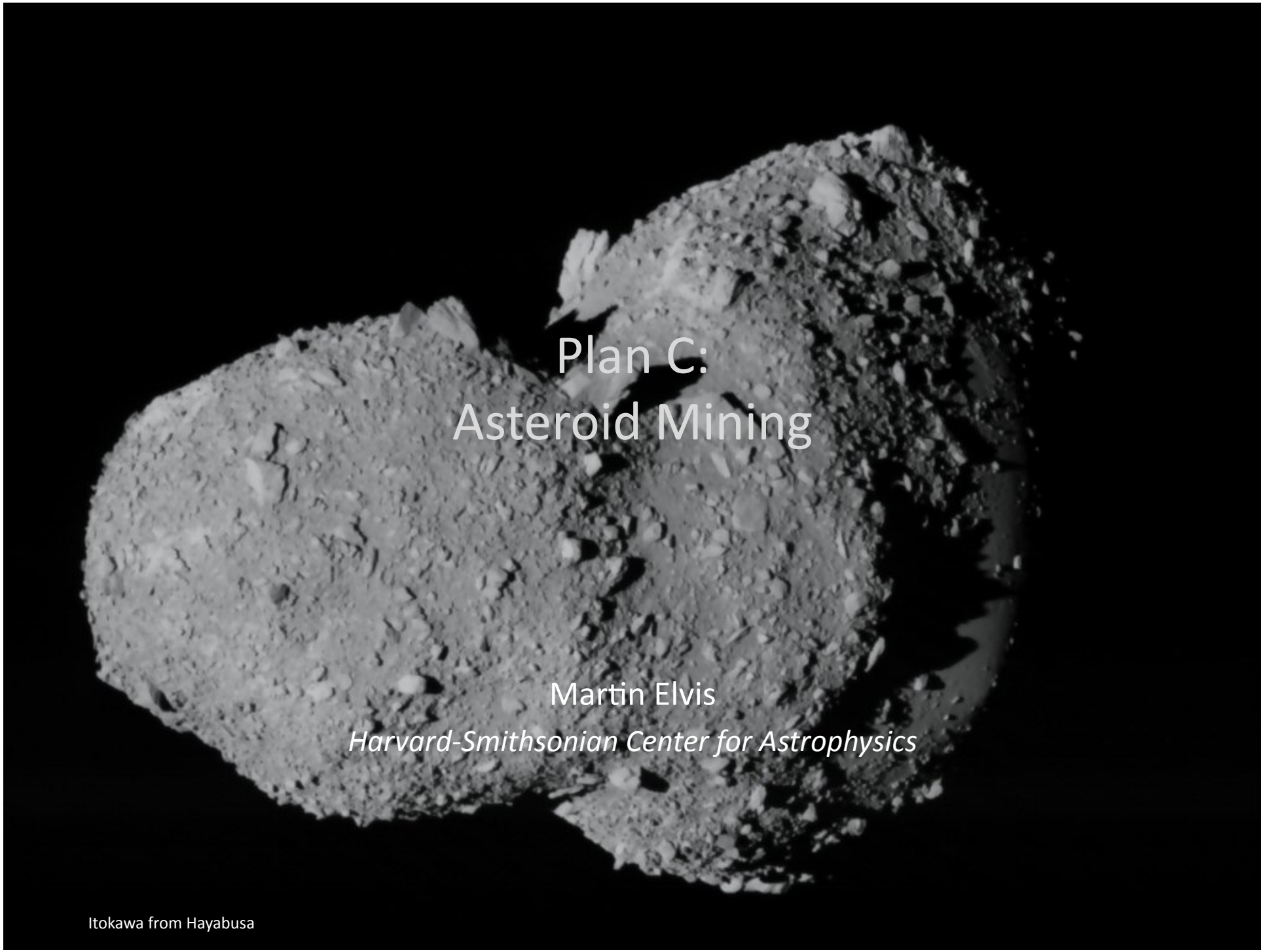
Tear Down that Funding Wall

- Can we ever beat the Funding Wall?
- Cheaper launches
  - No launchers designed with cost as a driver
  - SpaceX may be the first: factor 2-3 cheaper/kg, as of now
- Cheaper Space operations:
  - Needs a commercial driver



	Falcon 9	Falcon 9	Falcon 9 - S5	Falcon 9 - S9
LEO	,300 kg	8,700 kg	16,500 kg	24,750 kg
GTO	,400 kg	3,100 kg	6,400 kg	9,650 kg
Fairing diameter		5.2 m	5.2 m	5.2 m
Price in millions *	$27	$35	$51	$78

third party insurance and standard payload integration costs.



Plan C:
Asteroid Mining

Martin Elvis
Harvard-Smithsonian Center for Astrophysics

Itokawa from Hayabusa