Jessica A. Gaskin (Study Scientist, MSFC)

On Behalf of the X-Ray Surveyor Community

X-RAY SURVEYOR – THE BEGINNING

SPIE 2016 – Edinburgh, UK

X-ray Surveyor Goals

Scientifically Compelling

Frontier science from Solar system to first accretion light in Universe; revolution in understanding physics of astronomical systems

-Gather broad Science Community Support – Domestic & International
-Maintain steadfast science requirements over Program lifetime

Leaps in Capability

Large area with high angular resolution with orders of magnitude gains in sensitivity, large field of view with subarcsec imaging, high resolution spectroscopy for point-like and extended sources, other?

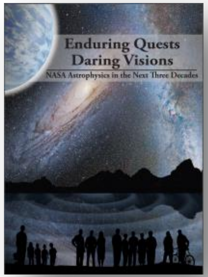
-Allow for multiple technology paths
-Formulate a strong plan for achieving requirements
-Invest in technology development and proof-of-concept testing

Feasible

Chandra-like mission for cost and complexity

-Embrace Chandra Heritage and lessons learned
-Utilize previous studies when possible (IXO, Con-X, AXSIO, etc…)

Consistent with:
NASA Astrophysics Roadmap:
Enduring Quests, Daring Visions



http://science.nasa.gov/media/medialibrary/2013/12/20/secure-Astrophysics_Roadmap_2013.pdf

Scientifically Compelling - Roadmap

How Did We Get Here?

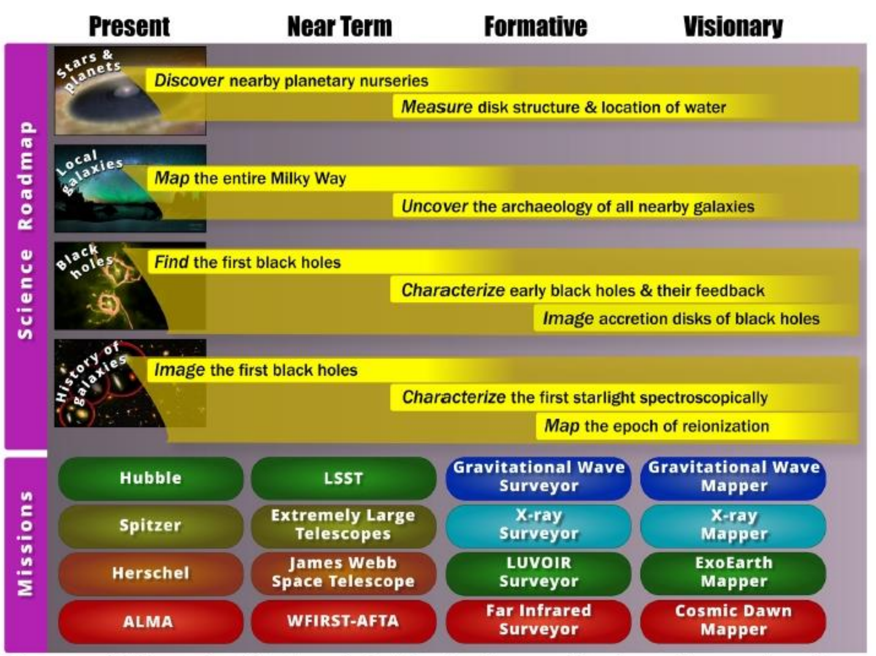


Figure 3.16 Schematic of the Cosmic Origins Roadmap, with science themes along the top and a possible mission sequence across the bottom. Credit: F. Reddy (NASA/GSFC)

How Does The Universe Work?

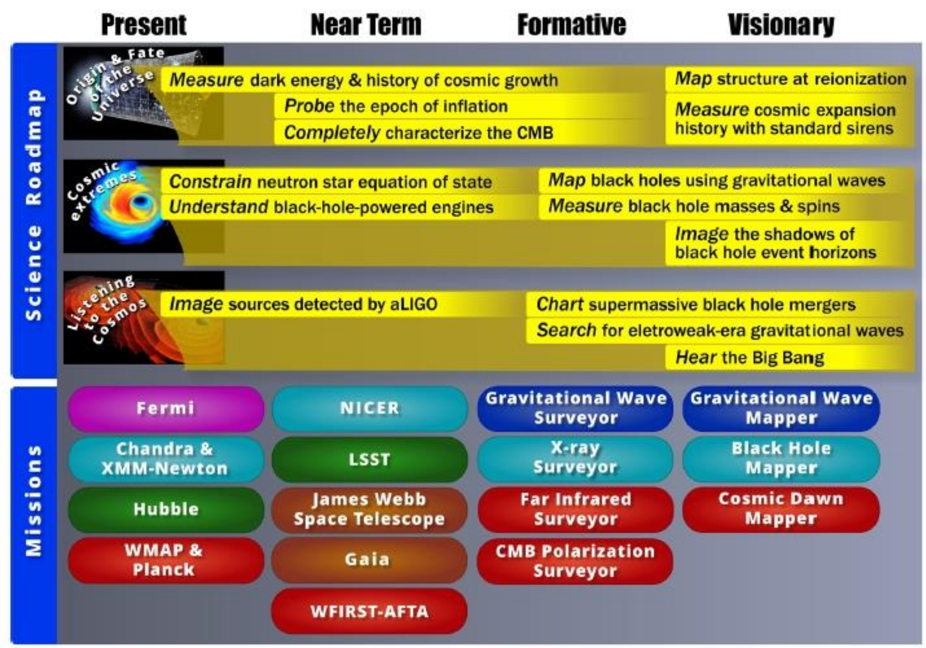


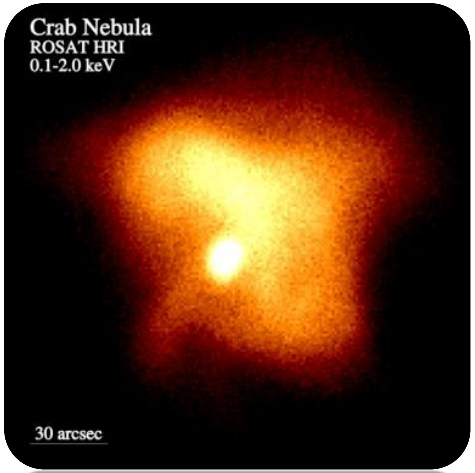
Figure 4.8 Schematic of the Physics of the Cosmos Roadmap, with science themes along the top and a possible mission sequence across the bottom. Credit: F. Reddy (NASA/GSFC)

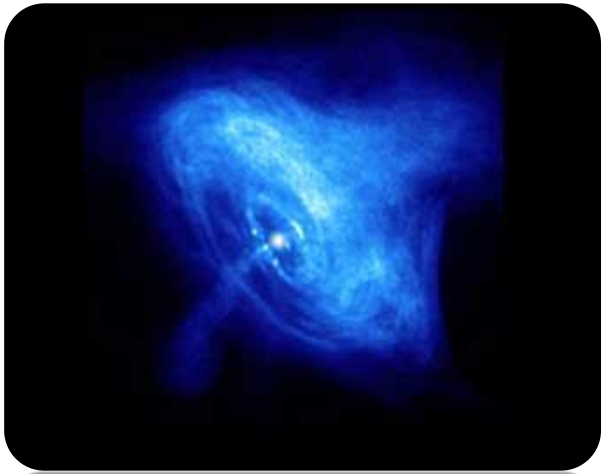
Key topics that will be addressed include:

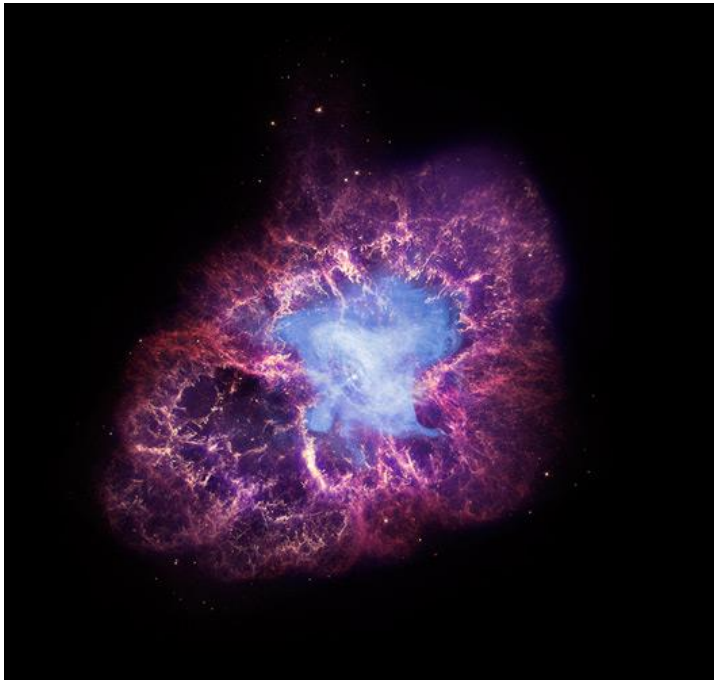
1) ***The Origin and Growth of the First Supermassive Black Holes***
2) ***The Physics of Feedback and Accretion in Galaxies and Clusters***
3) ***Galaxy Evolution and the Growth of Cosmic Structure***
4) ***The Physics of Matter in Extreme Environments***
5) ***The Origin and Evolution of the Stars that make up our Universe***

Scientifically Compelling – High Angular Resolution

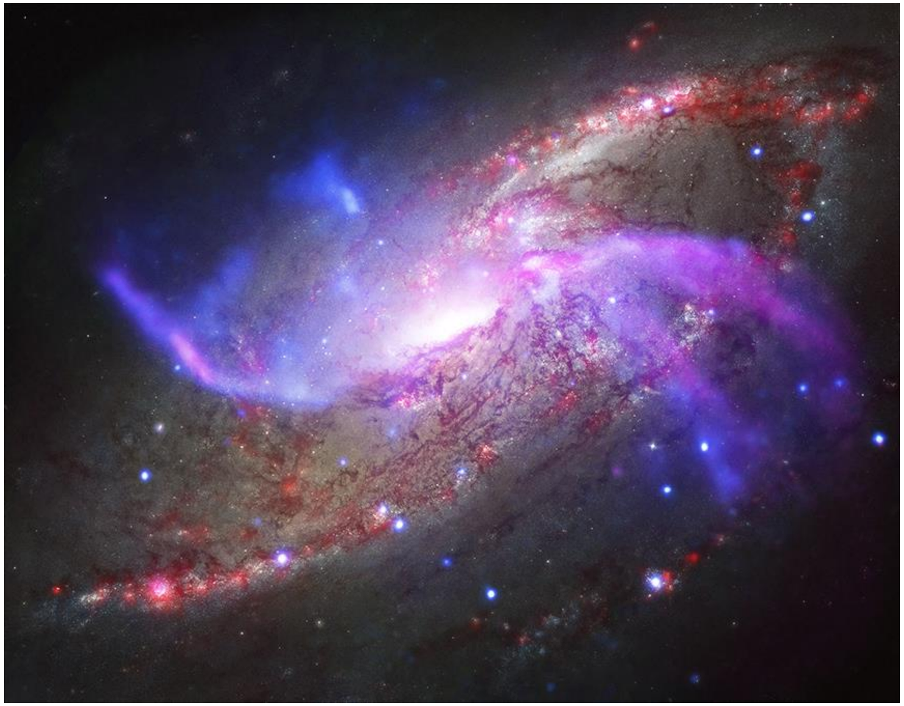
Imagine a Universe without *Chandra-Vision!*







Scientifically Compelling – NGC 4258 (M106)

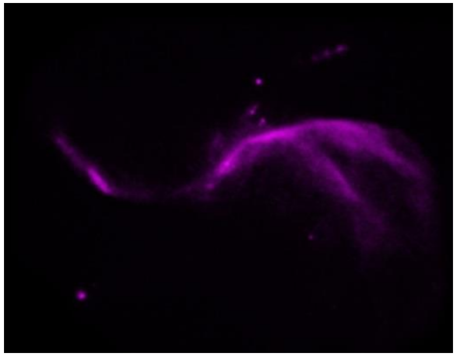


Credit: X-ray: NASA/CXC/Caltech/P.Ogle et al; Optical: NASA/STScI & R.Gendler; IR: NASA/JPL-Caltech; Radio: NSF/NRAO/VLA

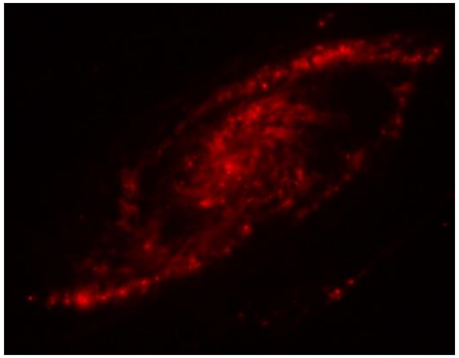
X-Ray
Bubbles of hot gas ejected out by jets

Optical
Stellar and gas distribution

Radio
SMBH producing jets that strike the disk



Infrared
Shock waves heat the gas



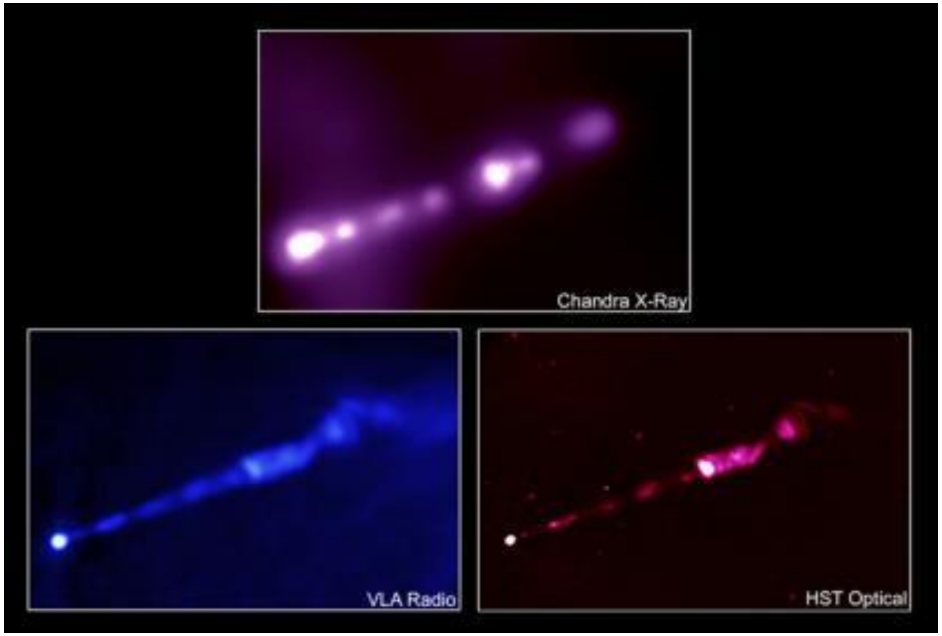
New Discovery Space

We are now in the process of defining the successor to Chandra.

30 Doradus – The Tarantula Nebula

Credit: X-ray: NASA/CXC/PSU/L.Townsley et al.; Optical: NASA/STScI; Infrared: NASA/JPL/PSU/L.Townsley et al.

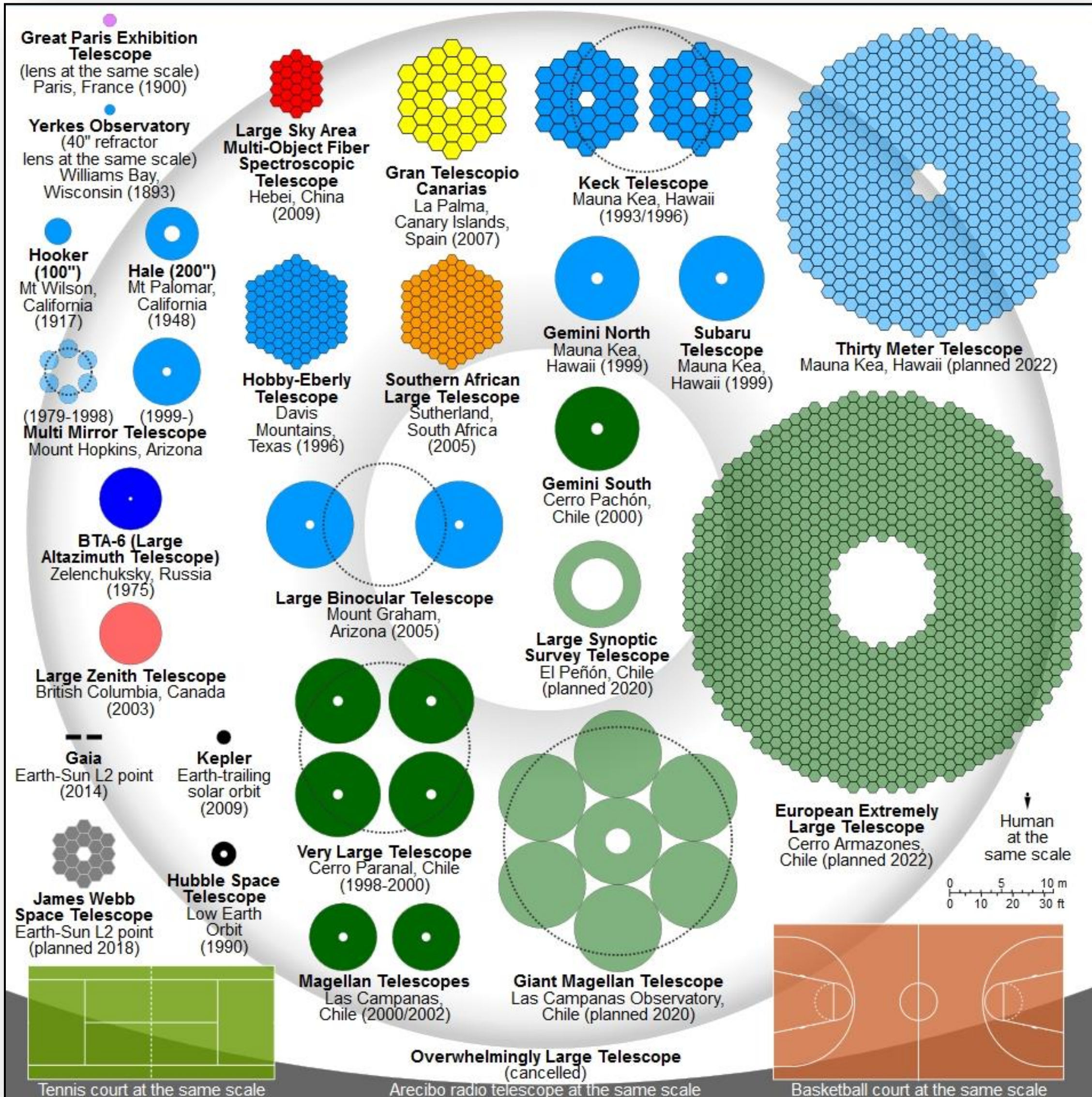
M87 Jet



Credit: X-ray: NASA/CXC/MIT/H.Marshall et al. Radio: F. Zhou, F.Owen (NRAO), J.Biretta (STScI) Optical: NASA/STScI/UMBC/E.Perlman et al.

We need your input!

Compelling & Complimentary



ATHENA

WFIRST

JWST

What's Next ???

https://xkcd.com/1294/

STDT Members

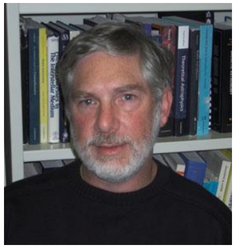
Alexey Vikhlinin, SAO (Co-Chair)

Feryal Özel, Arizona (Co-Chair)

Steve Allen, Stanford

Mark Bautz, MIT

Niel Brandt, Penn State



Joel Bregman, Michigan

Megan Donahue, MSU

Ryan Hickox, Dartmouth

Tesla Jeltema, UCSC

Juna Kollmeier, OCIW

Laura Lopez, Ohio State

Piero Madau, UCSC

Rachel Osten, STScI

Frits Paerels, Columbia

Mike Pivovaroff, LLNL

Dave Pooley, Trinity

Andy Ptak, GSFC

Eliot Quataert, Berkeley

Chris Reynolds, UMD

Daniel Stern, JPL

Ex-Officio Non-Voting Members Of The STDT

Daniel Evans, NASA HQ (Program Scientist)

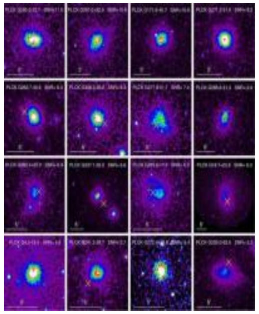
Ann Hornschemeier, PCOS Program Office Chief Scientist

Rob Petre, GSFC X-ray Lab Branch Chief

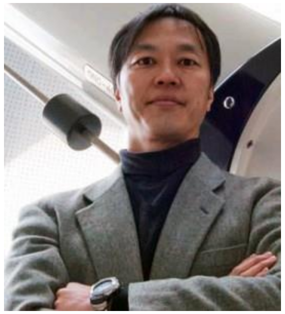
Randall Smith, Athena liaison

Kirpal Nandra DLR-Appointed Observer

Brian McNamara CSA-Appointed Observer



Gabriel Pratt CNES-Appointed Observer



Makoto Tashiro JAXA-Appointed Observer

MSFC AND SAO STUDY TEAM LEADERSHIP

Smithsonian Astrophysical Observatory

NASA

SRO Science Research Office

Alexey Vikhlinin,
SAO, STDT Co-Chair

Jessica Gaskin,
MSFC, Study Scientist

Mark King
MSFC Study Manager

Harvey Tananbaum
SAO Senior Scientist

Martin Weisskopf
MSFC Senior Scientist

Doug Swartz, USRA/MSFC
Deputy Study Scientist

STDT Deliverables

Study output will provide the Decadal Survey Committee with:

1. The ***science case*** for the mission
2. A ***notional mission*** and observatory, including a report on any tradeoff analyses
3. A ***design reference mission***, including strawman payload trade studies.
4. A ***technology assessment*** including: current status, roadmap for maturation & resources
5. A ***cost assessment*** and listing of the top technical risks to delivering the science capabilities
6. A ***top level schedule*** including a notional launch date and top schedule risks.

Concept Maturity Level 4 should be achieved by the end of the study

STDT Near-Term Plan & Task Summary

- **STDT Kickoff Meeting was held March 30, 2016**

- **First Face-to-Face Meeting, July 25-26th at CfA, Cambridge, MA**

- **Possible second Face-to-Face meeting in September, 2016**

Near-Term STDT tasks include:

1. Deciding on the structure and mechanics for the Working Groups
    - Optics Working Group
    - Instrument Working Group
    - Multiple Science Working Groups

2. Sketching out high-level science prioritizations and a path forward

3. Determining potential technology gaps for further development

4. Planning workshop and conferences for 2017

Community Participation

Informal X-Ray Optics Working Group

- Workshop March 28-29, 2016, University of Maryland
- Participants included a mix of government, university, industry:
    - MSFC
    - GSFC
    - Harvard-SAO
    - Ames
    - MIT
    - LLNL
    - Reflective X-Ray Optics
    - University of Maryland
    - Izentis, LLC
    - Northwestern University
    - Other

X-Ray Vision Science Workshop

•Workshop October 6-8, 2015, Washington DC
•Participants included ~100 participants from multiple universities and institutions
•http://cxc.harvard.edu/cdo/xray_surveyor/

Presentations and Brainstorming session white paper "X-ray Surveyor Discussion Session Results from the X-ray Vision Workshop" (*Editors*: G. Fabbiano, M. Elvis) are available on the website.

Technology Focus Areas

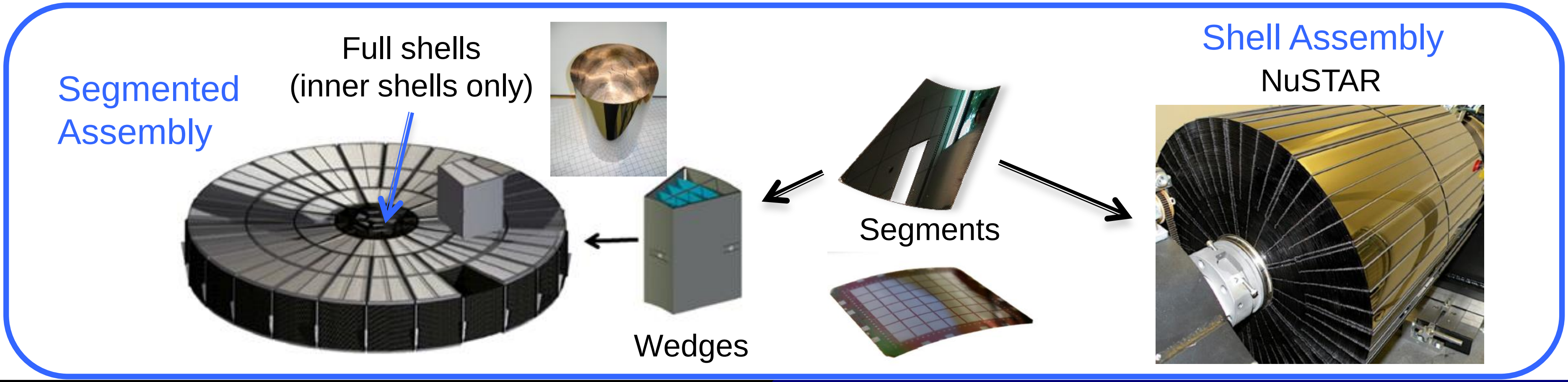
X-Ray Optics

- Segmented/Full-Shell
- Active/Passive
- High-resolution
- Light-weight
- Low-Stress Coatings/Surface Treatments
- Mounting/Assembly
- Metrology/Calibration
- Thermal Control
- Large-scale Fabrication

Focal Plane Instruments & Gratings

- High-definition Imager (CMOS/CCD)
- Microcalorimeter
- Gratings (CAT/OPGs)
- Grating readout (CCD/CMOS)

- Other???



Community Participation

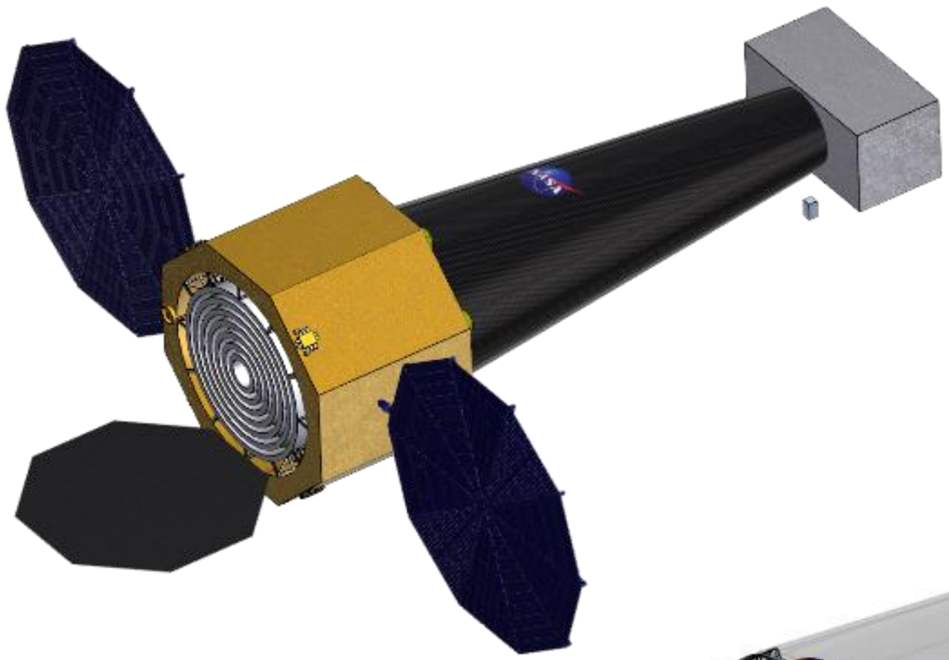
Your participation is fundamental to the X-Ray Surveyor mission top prioritization in the 2020 Decadal Survey.

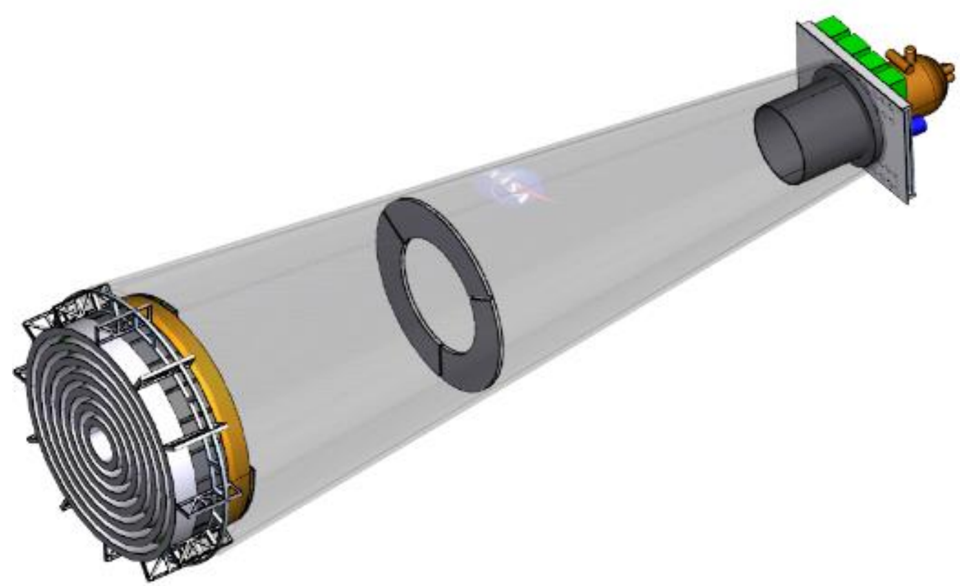
- Domestic & International Participation is Welcome
- Science Working Groups (formal and informal)
- Optics & Instrument Working Groups (formal and informal)
- Workshops and Conferences
    - We are open to suggestions (Scientifically Compelling and Complimentary)
- Public Website (join the X-Ray Surveyor News Group!)
- Requests for Information (RFIs) regarding relevant technologies
- Outreach (web-based Q&A, AAS "Future in Space" series of Hangouts-May 20)

http://wwwastro.msfc.nasa.gov/xrs/

BACKUP SLIDES

Configuration

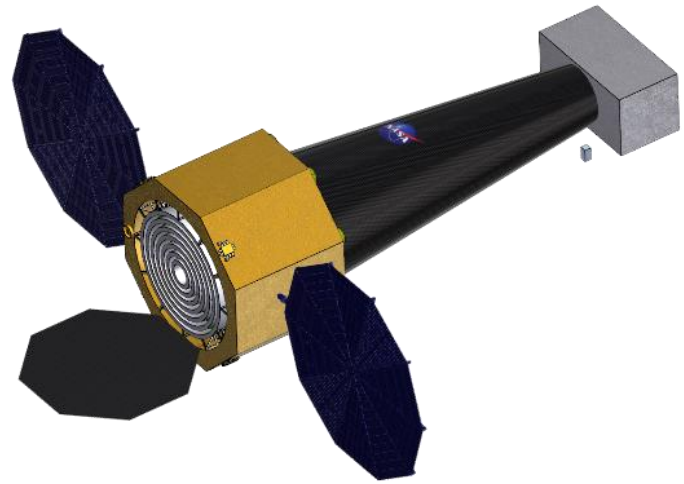




X-ray Surveyor Mission Concept

Study Goal: Obtain a feasible cost estimate and provide the STDT with one possible configuration as a starting point. <u>The STDT may choose to use all, some or none of the work resulting from this effort.</u>

Notional Mission Concept: Spacecraft, instruments, optics, orbit, radiation environment, launch vehicle and costing



Leap in sensitivity:
High throughput with sub-arcsec resolution

- $\times 50$ more effective area than *Chandra*. 4 Msec *Chandra* Deep Field done in 80 ksec.

Threshold for blind detections in a 4Msec survey is ~ 3×10–19 erg/s/cm2 (0.5–2 keV band)

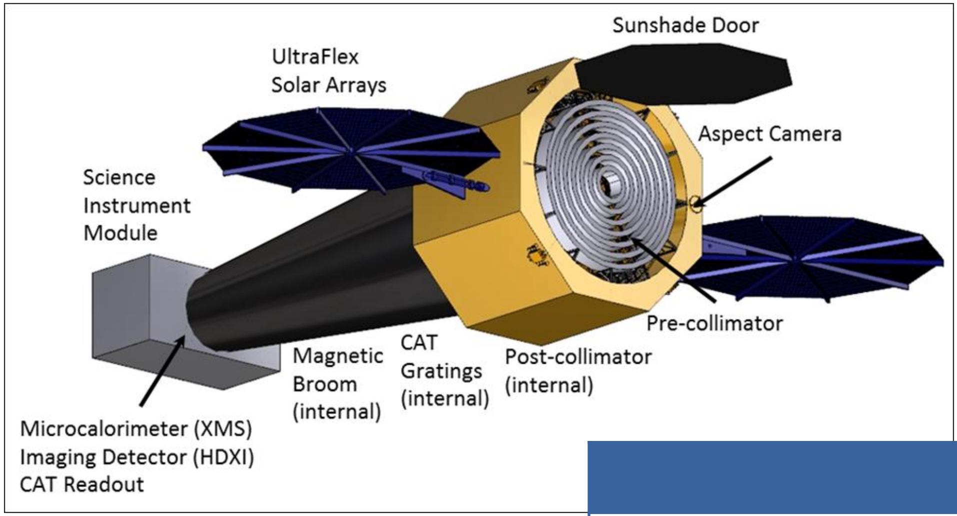
- $\times 16$ larger solid angle for sub-arcsec imaging — out to 10 arcmin radius

- **$\times 800$ higher survey speed at the *Chandra* Deep Field limit**

Informal Concept Definition Team:

J. A. Gaskin (MSFC), A. Vikhlinin (SAO), M. C. Weisskopf (MSFC), H. Tananbaum (SAO), S. Bandler (GSFC), M. Bautz (MIT), D. Burrows (PSU), A. Falcone (PSU), F. Harrison (Cal Tech), R. Heilmann (MIT), S. Heinz (Wisconsin), C.A. Kilbourne (GSFC), C. Kouveliotou (GWU), R. Kraft (SAO), A. Kravtsov (Chicago), R. McEntaffer (Iowa), P. Natarajan (Yale), S.L. O'Dell (MSFC), A. Ptak (GSFC), R. Petre (GSFC), B.D. Ramsey (MSFC), P. Reid (SAO), D. Schwartz (SAO), L. Townsley (PSU)

Notional Optics & Instruments



- High-resolution X-ray telescope
- Critical Angle Transmission XGS
- X-ray Microcalorimeter Imaging Spectrometer
- High Definition X-ray Imager

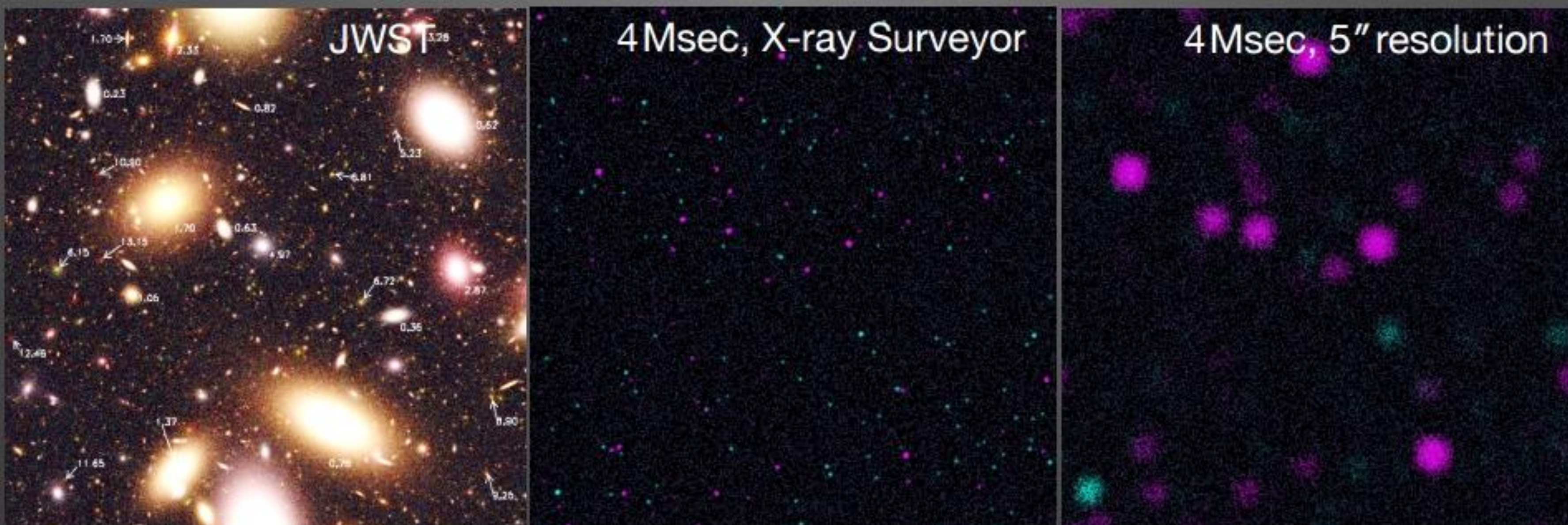
Concept Payload for:
- Feasibility (TRL 6)
- Mass
- Power
- Mechanical
- Costing (~**$3B**)

NOT THE FINAL CONFIGURATION!!!

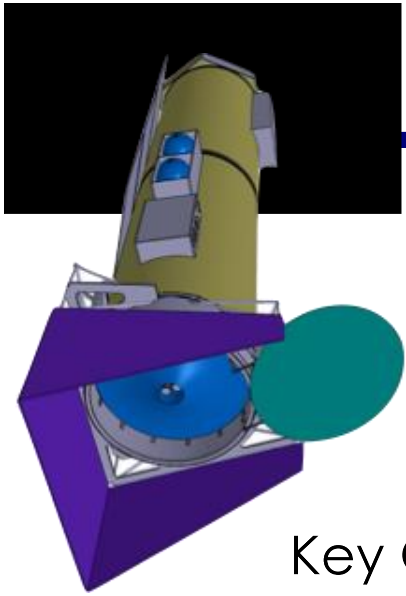
	Chandra	X-Ray Surveyor
Relative effective area (0.5 – 2 keV)	1 (HRMA + ACIS)	50
Angular resolution (50% power diam.)	0.5”	0.5”
4 Ms point source sensitivity (erg/s/cm^2)	5×10^{-18}	3×10^{-19}
Field of View with < 1” HPD (arcmin^2)	20	315
Spectral resolving power, R, for point sources	1000 (1 keV) 160 (6 keV)	5000 (0.2-1.2 keV) 1200 (6 keV)
Spatial scale for R>1000 of extended sources	N/A	1”
Wide FOV Imaging	16’ x 16’ (ACIS) 30’ x 30’ (HRC)	22’ x 22’

Nature of black hole seeds — First accretion light in the Universe

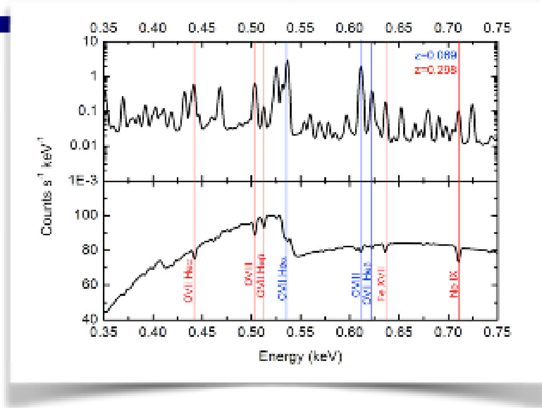
Simulated 2x2 arcmin deep fields observed with JWST, X-ray Surveyor, and ATHENA



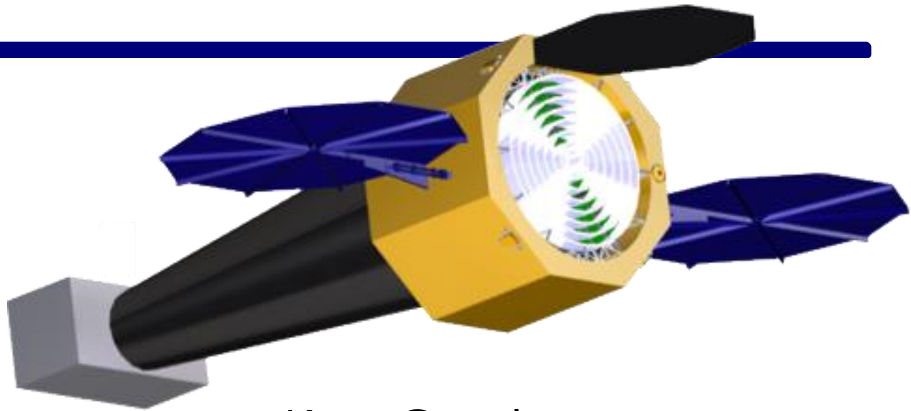
- JWST will detect ~2×10^{6} gal/deg^{2} at its sensitivity limit (Windhorst et al.). This corresponds to 0.03 galaxies per 0.5″ X-ray Surveyor beam (not confused), and 3 galaxies per ATHENA 5″ beam (confused).
- Each X-ray Surveyor source will be associated with a unique JWST-detected galaxy. Limiting sensitivity, ~1×10^{-19} erg/s/cm^{2}, corresponds to L_X ~ 1×10^{41} erg/s or $M_{\rm BH}$ ~ 10,000 M_{Sun} at $z=10$ — well within the plausible seed mass range.
- X-ray confusion limit for ATHENA is 2.5×10^{-17} erg/s/cm^{2} (5× worse than the current depth of *Chandra* Deep Field). This corresponds to $M_{\rm BH}$ ~ 3×10^{6} M_{Sun} at z=10 — above seed mass range. Confusion in O&IR id's further increases the limit ($M_{\rm BH}$~10^{7} M_{Sun} at z=8 is quoted by ATHENA team).



Athena



X-ray Surveyor



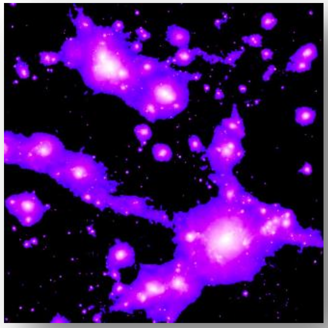
Key Goals:

- Microcalorimeter spectroscopy ($R \approx 1000$)
- Wide, medium-sensitivity surveys

Area is built up at the expense of angular resolution (10× worse) & sensitivity (5× worse than *Chandra*)

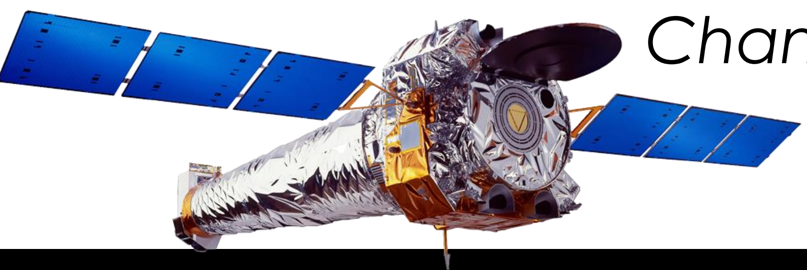
Key Goals:

- Sensitivity (50× better than *Chandra*)
- $R \approx 1000$ spectroscopy on 1″ scales, adding 3rd dimension to data
- $R \approx 5000$ spectroscopy for point sources



✓ Area is built up while preserving *Chandra* angular resolution (0.5″)

✓ 16× field of view with sub-arcsec imaging

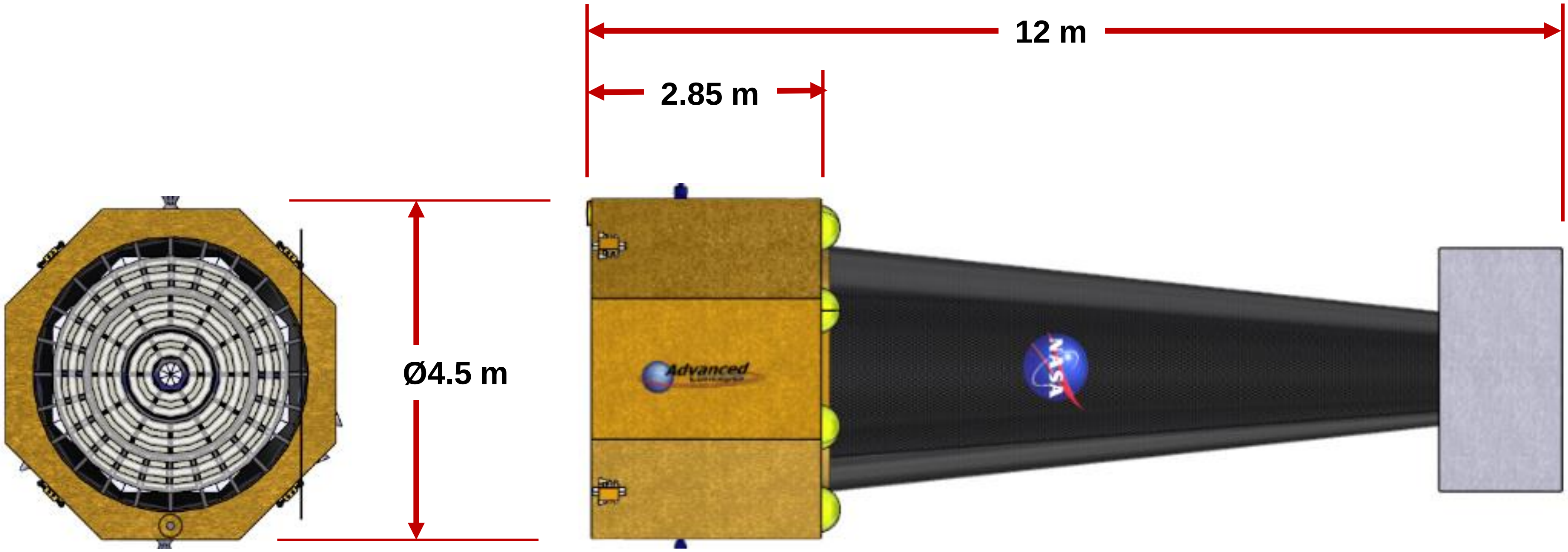


Chandra

A Successor to *Chandra*

- Angular resolution at least as good as *Chandra*
- Much higher photon throughput than *Chandra* (observations are photon-limited)

✓Incorporated relevant prior (Con-X, IXO, AXSIO) development and *Chandra* heritage → ✓ Limits most spacecraft requirements to *Chandra-like* → ✓ Achieves *Chandra-like* cost ($2.95B for Phase B through launch)



MSFC AND SAO SUPPORT

Support the STDT In Carrying Out Concept Development through the Advanced Concept Office at MSFC and Engineering/Science Design Studies for risk reduction

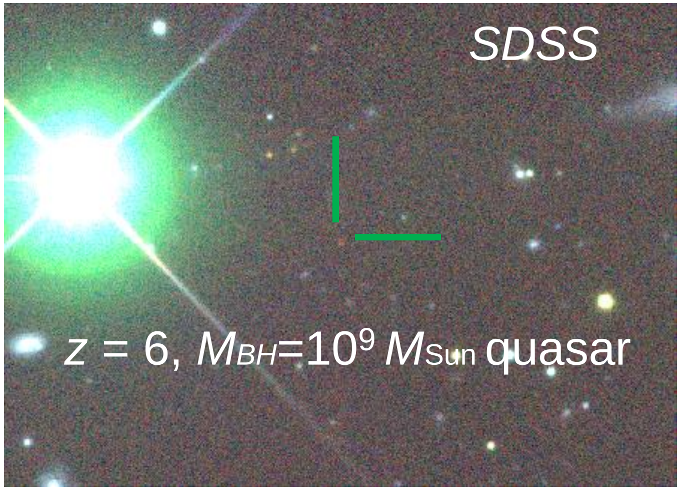
Example Engineering/Science Design Studies that can be carried out as requested by the STDT include:

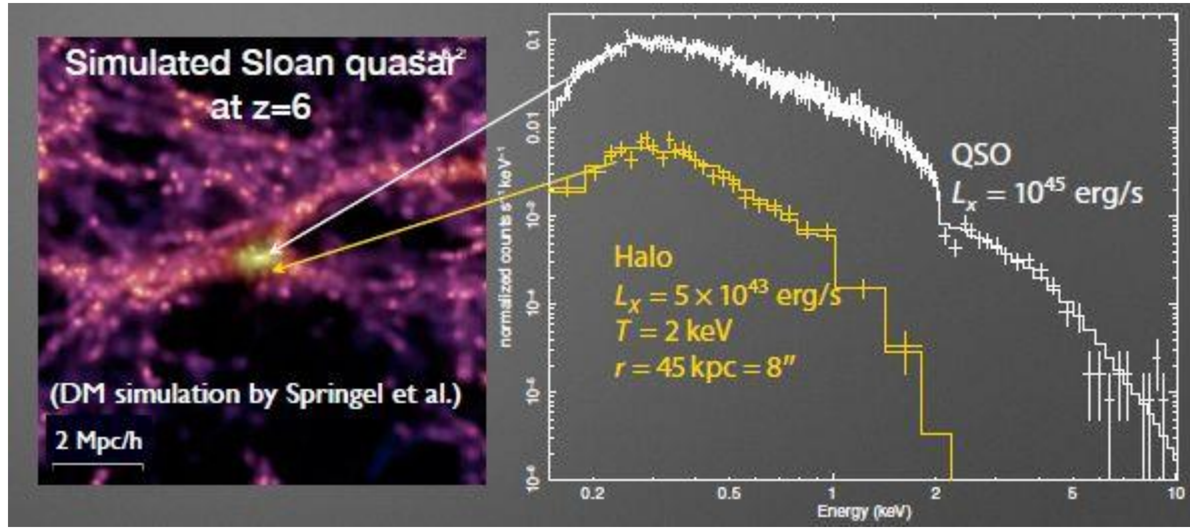
- develop a detailed optical prescription
- consider trades between angular resolution, effective area, and vignetting in different energy bands
- conceptualize an approach to a module mount design
- conceptualize an approach to full module design
- develop a model incorporating mechanical design and the notional assembly and alignment process
- perform structural, thermal, and optical analyses and check consistency with expected launch load
- develop independent error budget to assess allocations for reflector figure quality, mounting, aligning
- evaluate the type of metrology required, its accuracy and its volume
- develop a set of calibration requirements and use these to formulate a calibration plan
- develop a preliminary workflow for the assembly and alignment

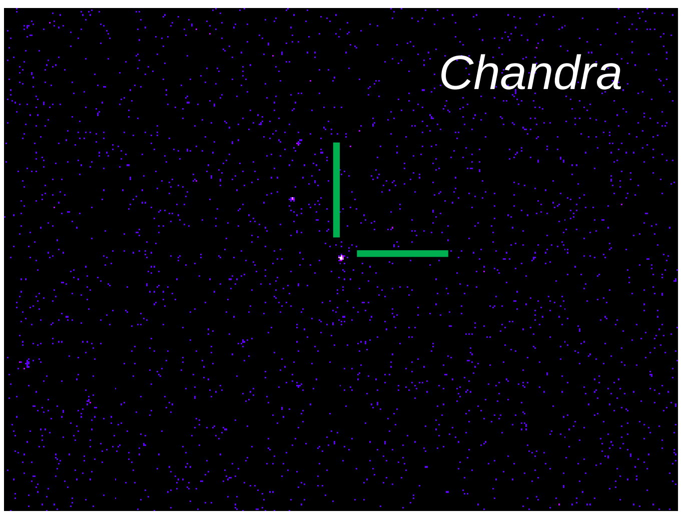
STDT Science & Technology Specializations

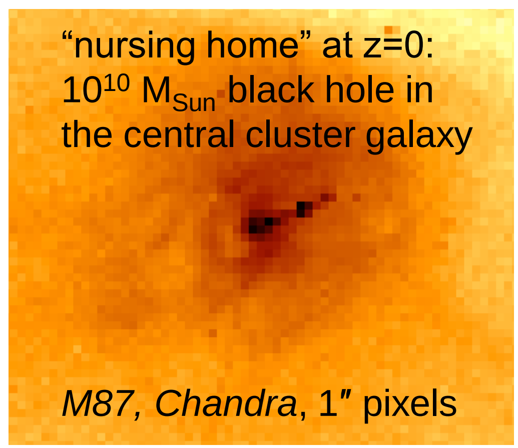
Last	First	Expertise	Mission Experience
Allen	Steve	Clusters, clusters as cosmological probes	Astro-H SWG, IXO, LSST DES collaboration, SPT
Bautz	Mark	Mission development, detectors, clusters, SZ	IXO, X-ray CST, ASTRO-H SWG, MSFC/SAO XRS concept team
Brandt	Niel	Deep surveys, high-z quasars, LSST	Athena SWG Chair, numerous previous X-ray mission teams, LSST Advisory Committee
Bregman	Joel	Missing baryons around galaxies, highly cognizant of instrumentation	Athena, Con-X, IXO US Science Chair
Donahue	Megan	Circumgalactic medium, diffuse gas, feedback	GMT Advisory Committee
Hickox	Ryan	AGN, surveys, large scale structure, X-ray background	WFXT mission concept, NuSTAR Sci Team
Jeltema	Tesla	Clusters, groups, supernovae, multi-wavelength, XRBs, DES, LSST	
Kollmeier	Juna	Hydrodynamical simulations, large scale structure, galaxy evolution, SMBH growth, IGM	
Lopez	Laura	Sne, SNR, PWN, high resolution spectroscopy	
Madau	Piero	High-z Universe, first generations of supermassive black holes, and epoch of reionization	E-ELT SWG
Osten	Rachel	Stellar atmospheres, stellar flares, high resolution spectroscopy	Con-X FST, IXO, XAP STDT, ALMA Advisory Commit
Ozel	Feryal	Neutron stars and black holes	NICER Co-I, LOFT Co-I
Paerels	Frits	High resolution spectroscopy	XMM RGS, STDTs for HTXS, Con-X, IXO, XEUS, ASTRO-H SWG
Pivovaroff	Mike	Design and manufacturing of X-ray optics	NuSTAR Science Team, Int Axion Observatory
Pooley	Dave	Lensed quasars, globular clusters, AGN mergers	
Ptak	Andy	Mission development, galaxies, LLAGN	WFXT, IXO, Athena, MSFC/SAO XRS Study
Quataert		Compact objects, plasma astrophysics, stellar physics, galaxy formation	
Reynolds	Chris	Accreting black holes	NuSTAR, ASTRO-H, Praxys, Con-X, IXO
Stern	Daniel	Heavily obscured AGN, mission operations and development	NuSTAR, WFIRST SDT, PolSTAR
Vikhlinin	Alexey	Clusters, mission development	Lead of MSFC/SAO XRS Study. Very familiar with X-ray optics and instrumentation

Black Holes: From Birth to Today's Monsters







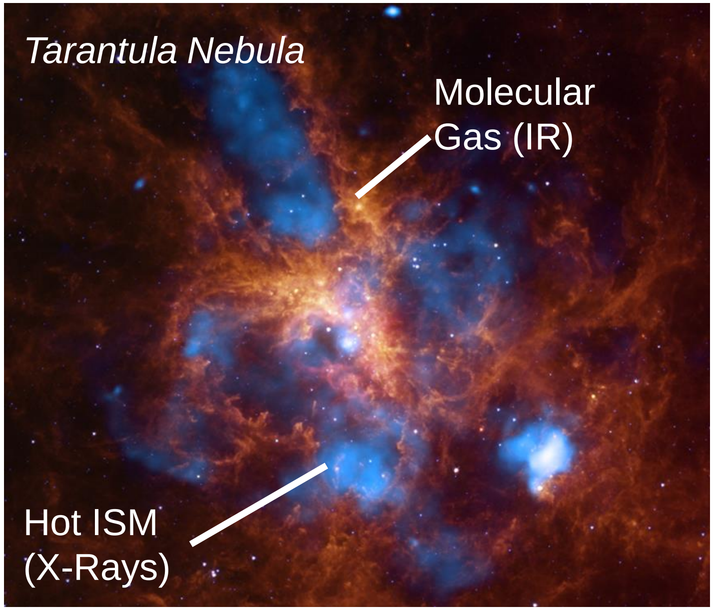


Also:
- Electromagnetic signatures of black hole mergers
- Using X-ray binary population as tracers of star formation, their role in cosmic reionization
- Jets

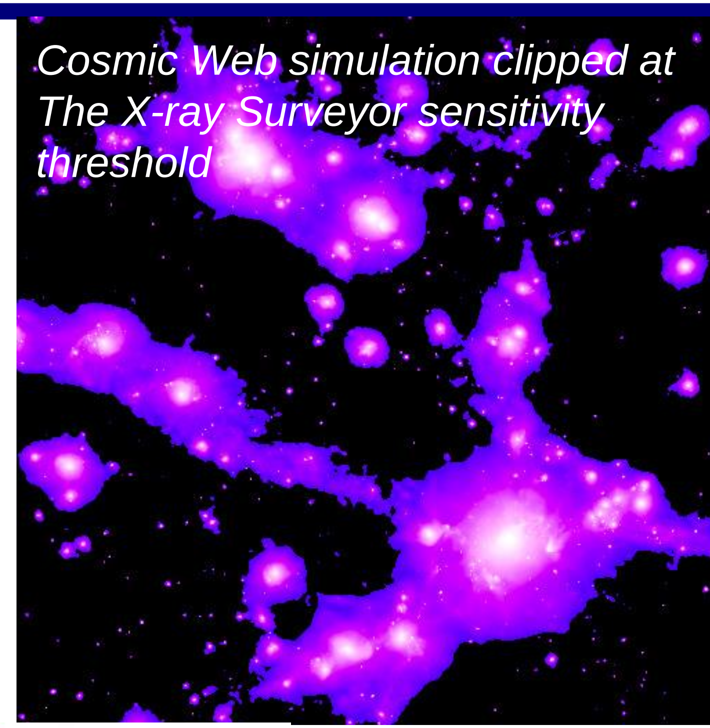
What is their origin?

How do they co-evolve with galaxies and affect environment?

Cycles of Baryons In and Out of Galaxies



Generation of hot ISM in young star-forming regions. How does hot ISM push molecular gas away and quench star formation?

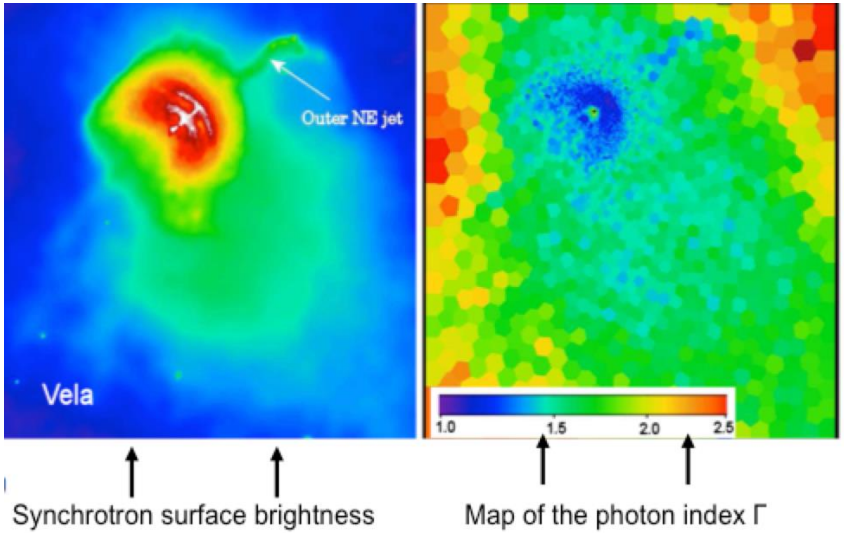


Structure of the Cosmic Web through observations of hot IGM *in emission*

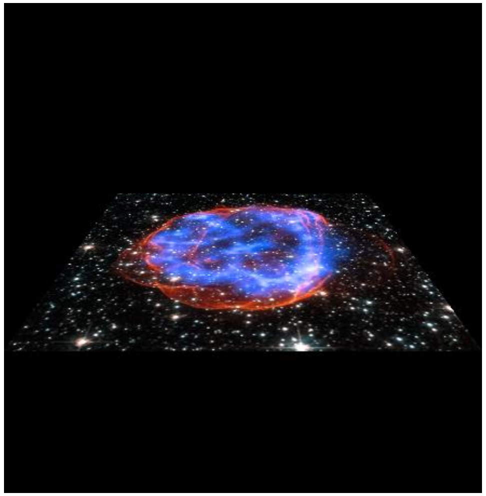
How did the "universe of galaxies" emerge from initial conditions?

What physics is behind the structure of astronomical objects?

Plasma physics, gas dynamics, relativistic flows in astronomical objects:

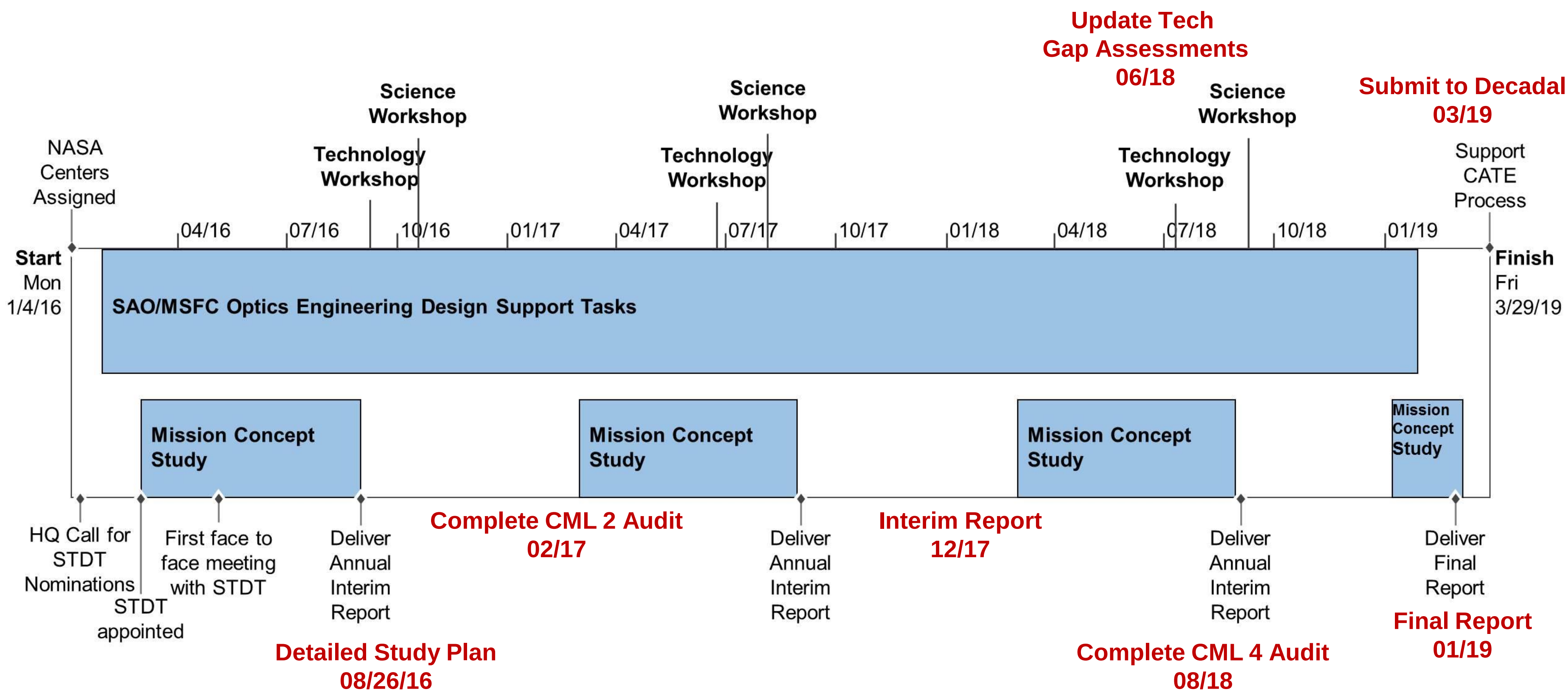


- Supernova remnants
- Particle acceleration in pulsar wind nebulae
- Jet-IGM interactions
- Hot-cold gas interfaces in galaxy clusters and Galactic ISM
- Plasma flows in the Solar system, stellar winds & ISM via charge exchange emission
- Off-setting radiative cooling in clusters, groups & galaxies
- …



Required capability: high-resolution spectroscopy ***and*** resolving relevant physical scales

Schedule (TBC by STDT)



- **Mission Concept Studies can be adjusted in time and duration as needed**
- **Workshops can be adjusted as needed to fit deliverables and schedules**

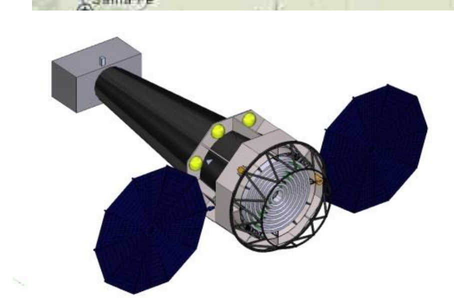
CML = Concept Maturity Level

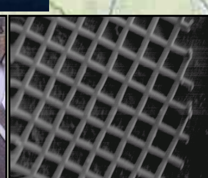
All Things Big and Small

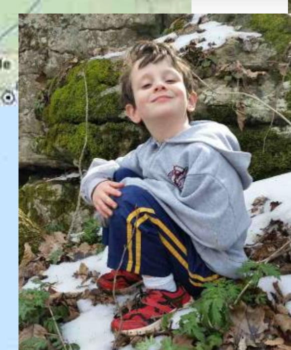
MARSHALL SPACE FLIGHT CENTER

Dr. Jessica Gaskin

Research Astrophysicist
X-Ray Astronomy Group
NASA MSFC








THE MISSING PIECE
ASTROPHYSICS
Decadal Survey Missions
UV/Visible
X-Ray
IR
IR
IR
1972 Decadal Survey Hubble
1982 Decadal Survey Chandra
1991 Decadal Survey Spitzer, SOFIA
2001 Decadal Survey JWST
2010 Decadal Survey WFIRST
-TMT will have 144 times the collecting area of Hubble and more than 10x better spatial resolution at near-infrared and longer
-EELT(Visible, images 16x sharper than Hubble)

STDT And Management Structure