Jessica A. Gaskin (Study Scientist, MSFC)
On Behalf of the X-Ray Surveyor Community

THE X-RAY SURVEYOR MISSION
X-ray Surveyor Goals

- **Scientifically compelling:** frontier science from Solar system to first accretion light in Universe; revolution in understanding physics of astronomical systems

- **Leaps in Capability:** large area with high angular resolution for 1–2 orders of magnitude gains in sensitivity, large field of view with subarcsec imaging, high resolution spectroscopy for point-like and extended sources

- **Feasible:** *Chandra*-like mission with regards to cost and complexity with the new technology for optics and instruments already at TRL3 and proceeding to TRL6 before Phase B

Consistent with:

*NASA Astrophysics Roadmap: Enduring Quests, Daring Visions*

*2010 Astrophysics Decadal Survey: New Worlds, New Horizons*
Scientifically Compelling

X-Ray Surveyor will allow us to explore all sources of high energy in the Universe and in doing so will address NASA Strategic Questions:

How does the Universe work?

and

How did we get there?

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.
Black Holes: From Birth to Today’s Monsters

SDSS

$z = 6, M_{BH} = 10^9 M_{\odot}$ quasar

Chandra

“nursing home” at $z=0$: 1010 $M_{\odot}$ black hole in the central cluster galaxy

M87, Chandra, 1” pixels

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

T~100,000 K

T<10,000 K

T>1,000,000

How do 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
The Thirty Meter Telescope will have 144 times the collecting area of Hubble and more than a factor of 10 better spatial resolution at near-infrared and longer wavelengths.

European Extremely Large Telescope (Visible, images 16x sharper than Hubble)
STDT Members

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

Alexey Vikhlinin, SAO (Chair)  Feryal Özel, Arizona (Chair)
Mike Pivovaroff, LLNL
Dave Pooley, Trinity
Chris Reynolds, UMD
Eliot Quataert, Berkeley
Andy Ptak, GSFC
Daniel Stern, JPL
Ex-Officio Non-Voting Members Of The STDT

Daniel Evans, NASA HQ (Program Scientist)
Ann Hornschemeier, PCOS Program Office Chief Scientist
Jessica Gaskin, MSFC (Study Scientist, voting member of STDT)

Rob Petre, GSFC X-ray Lab Branch Chief
Randall Smith, Athena liaison
Paul Nandra, DLR-Appointed Observer
Brian McNamara, CSA-Appointed Observer
Gabriel Pratt, CNES-Appointed Observer
STDT And Management Structure

- Science Working Groups
- Focal Plane Working Group
- Optics Working Group
- OBSERVERS [HQ, PCOS, International Partners]
- APD DD Decadal Studies Mgmt Team
- Integrated Review Team

STDT [Community]

- Design Trade and Analysis
- Study Products
- Design Products

STUDY TEAM [MSFC, SAO]

Analysis
MSFC AND SAO STUDY TEAM LEADERSHIP

Jessica Gaskin, MSFC, Study Scientist
Alexey Vikhlinin, SAO, STDT Chair
Gregg Gelmis, MSFC Study Manager
Martin Weisskopf, MSFC Senior Scientist
Harvey Tananbaum, SAO Senior Scientist
Doug Swartz, USRA/MSFC Deputy Study Scientist
STDT DELIVERABLES

Study output will provide the Decadal Survey Committee with:

1. A **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**
X-ray Surveyor Mission Concept

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

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

Leap in sensitivity:
High throughput with sub-arcsec resolution
- × 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)

- × 16 larger solid angle for sub-arcsec imaging — out to 10 arcmin radius

- × 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)

<table>
<thead>
<tr>
<th></th>
<th>Chandra</th>
<th>X-Ray Surveyor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative effective area (0.5 – 2 keV)</td>
<td>1 (HRMA + ACIS)</td>
<td>50</td>
</tr>
<tr>
<td>Angular resolution (50% power diam.)</td>
<td>0.5”</td>
<td>0.5”</td>
</tr>
<tr>
<td>4 Ms point source sensitivity (erg/s/cm²)</td>
<td>5x10⁻¹⁸</td>
<td>3x10⁻¹⁹</td>
</tr>
<tr>
<td>Field of View with &lt; 1” HPD (arcmin²)</td>
<td>20</td>
<td>315</td>
</tr>
<tr>
<td>Spectral resolving power, R, for point sources</td>
<td>1000 (1 keV) 160 (6 keV)</td>
<td>5000 (0.2-1.2 keV) 1200 (6 keV)</td>
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<tr>
<td>Spatial scale for R&gt;1000 of extended sources</td>
<td>N/A</td>
<td>1”</td>
</tr>
<tr>
<td>Wide FOV Imaging</td>
<td>16’ x 16’ (ACIS) 30’ x 30’ (HRC)</td>
<td>22’ x 22’</td>
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</tbody>
</table>

NOT THE FINAL CONFIGURATION!!!
X-Ray Surveyor Success

**Scientifically compelling**
- Gather broad (domestic and international) Science Community Support beyond the X-Ray Astronomy Community
- Maintain steadfast science requirements throughout the lifetime of the Program

**Leaps in Capability**
- Allow for multiple technology paths to achieve the requirements for the optics and Science Instruments.
- Formulate a strong plan for achieving these requirements
- Invest in technology development and proof-of-concept testing
  - Concept studies are great, but having working hardware is better

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

**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*)

X-ray Surveyor

**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
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)

Dimensions:
- Ø4.5 m
- 2.85 m × 12 m
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 And Management Structure

- **STDT [Community]**
- **STUDY TEAM [MSFC, SAO]**
- **OBSERVERS [HQ, PCOS, International Partners]**

**APD DD**
- Decadal Studies Management Team
- Integrated Review Team

**Design Products**
- Design Trade and Analysis

**Analysis**
- Study Products
Example Working Groups - TBD by STDT

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