



LYNX X-RAY OBSERVATORY

JESSICA A. GASKIN

MARSHALL
SPACE
FLIGHT
CENTER

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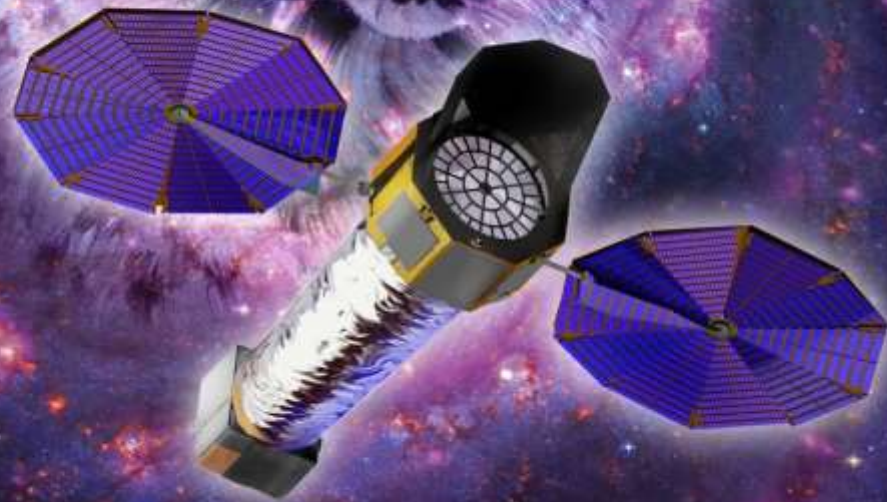
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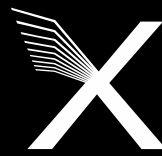
The Lynx Study Office is jointly operated by



Marshall Space
Flight Center

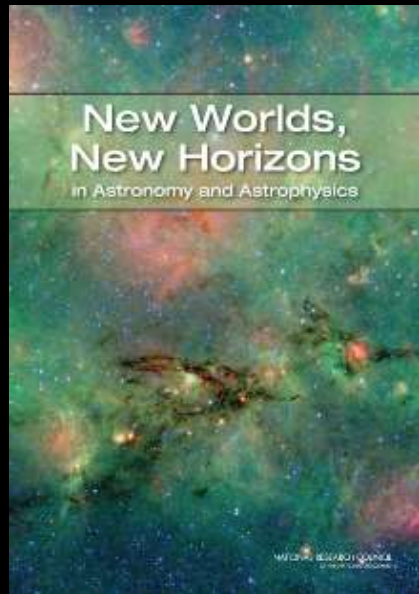
CENTER FOR **ASTROPHYSICS**
HARVARD & SMITHSONIAN

Original art by David O. Miller (David O. Miller Design/Illustration)
Wordmark by Tanya Borman-Voit (Design Five Seven)
Lynx Branding & Graphics Design Lead: Grant Tremblay (SAO)

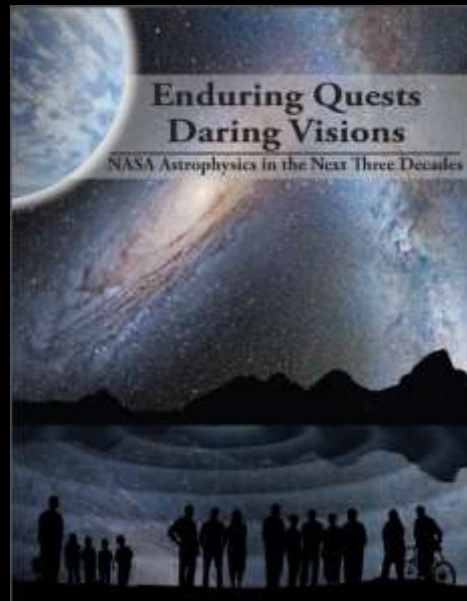


BRIEF HISTORY OF LYNX

2010

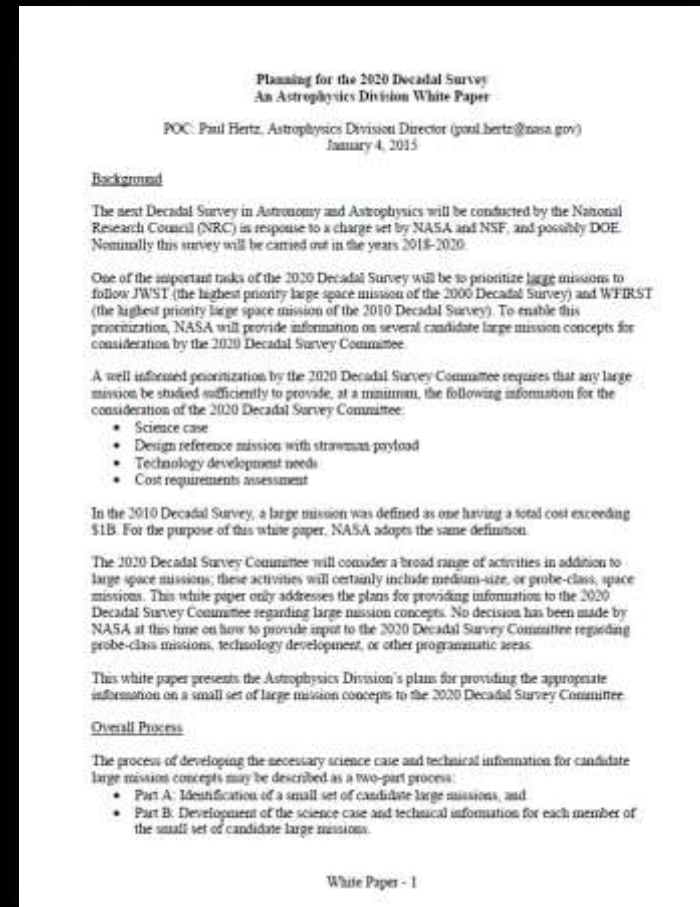


2013/2014



- Characterize early black holes and their feedback
- Uncover the archeology of all nearby galaxies
- Characterize the first starlight spectroscopically
- Measure dark energy and the history of cosmic growth

2015



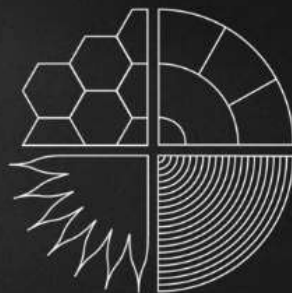
<http://cor.gsfc.nasa.gov/copag/rfi/>



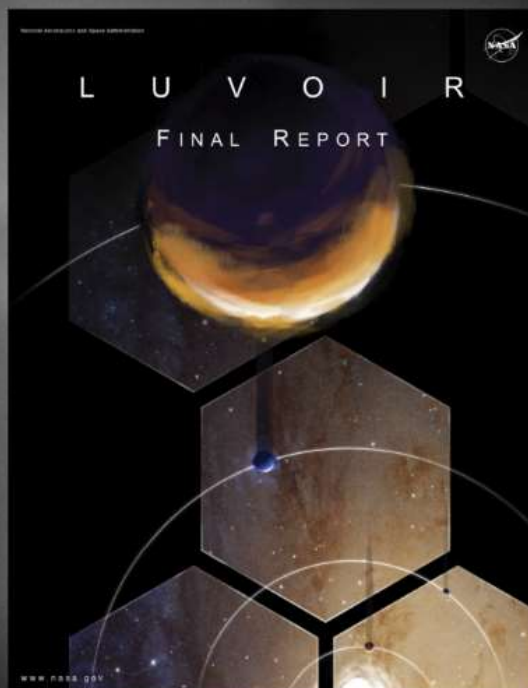
2016

Lynx Team Formulation

- STDT
- Ex-Officio
- Working Groups
- Study Office



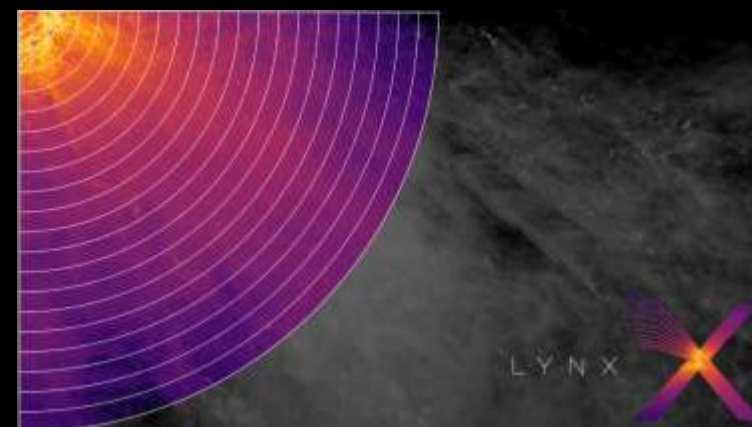
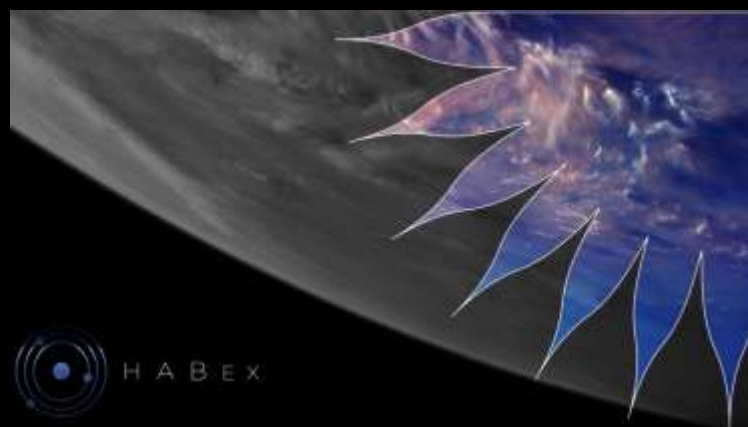
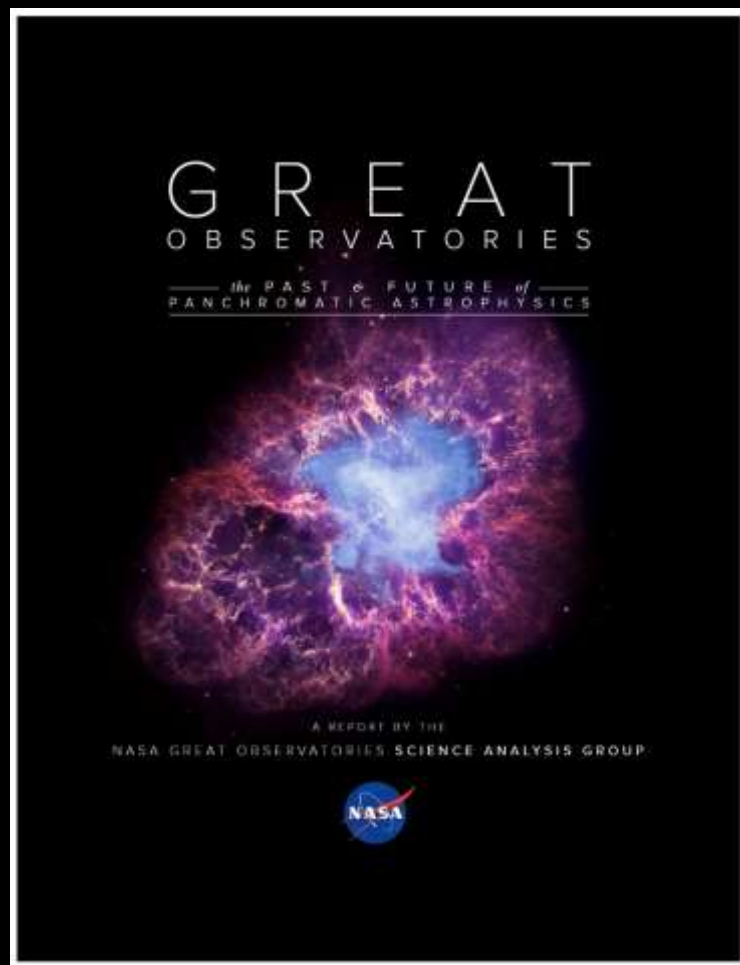
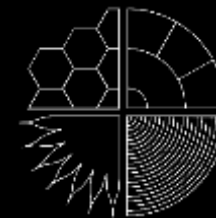
a NEW EPOCH *o f* DISCOVERY



WWW.GREATOBSERVATORIES.ORG

DECADES OF DREAMS
FOUR MISSIONS
ONE VISION

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LYNX X-RAY OBSERVATORY

the DAWN *of*
BLACK HOLES



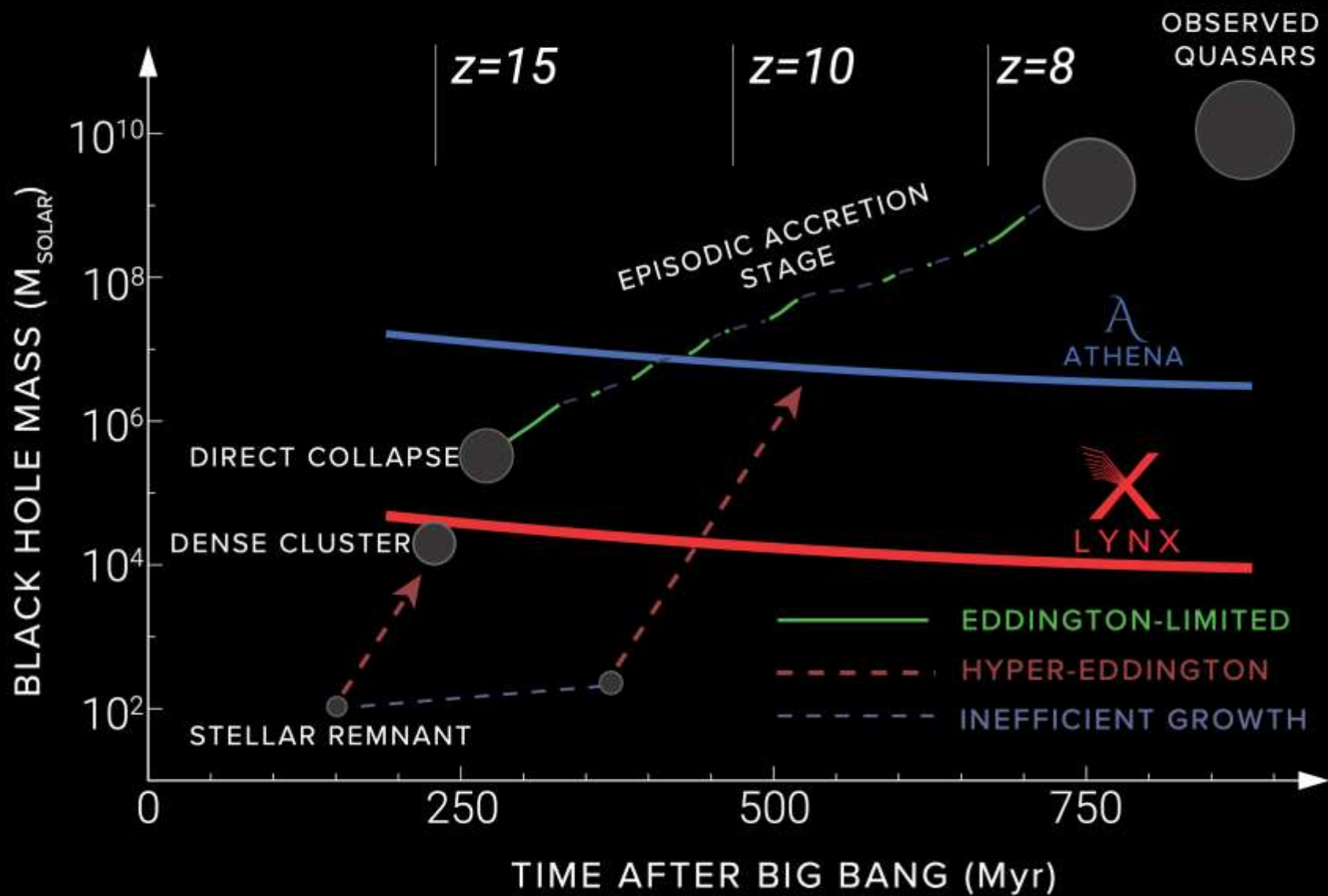
the DRIVERS *of*
GALAXY EVOLUTION

the ENERGETIC SIDE *of*
STELLAR EVOLUTION

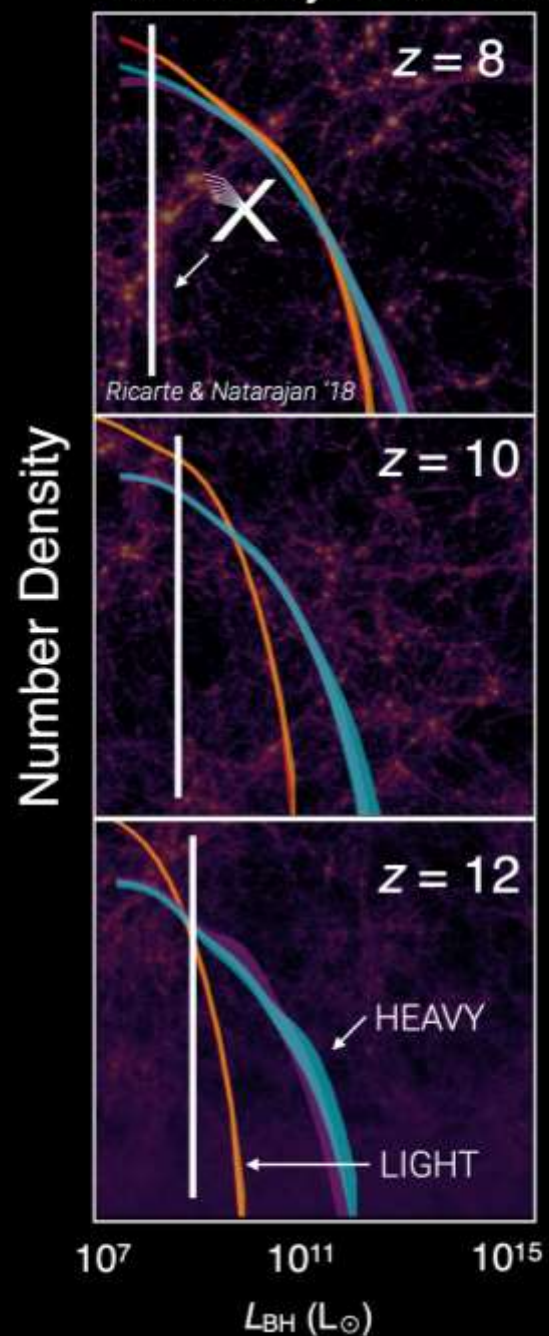
t h e D A W N *o f* B L A C K H O L E S

- Black holes define many aspects of cosmic evolution
- Were in place very early in the history of the Universe
- What is their origin? Light seeds or heavy seeds? Did any of the massive BH form directly into $10^5 M_{\text{Sun}}$ objects?

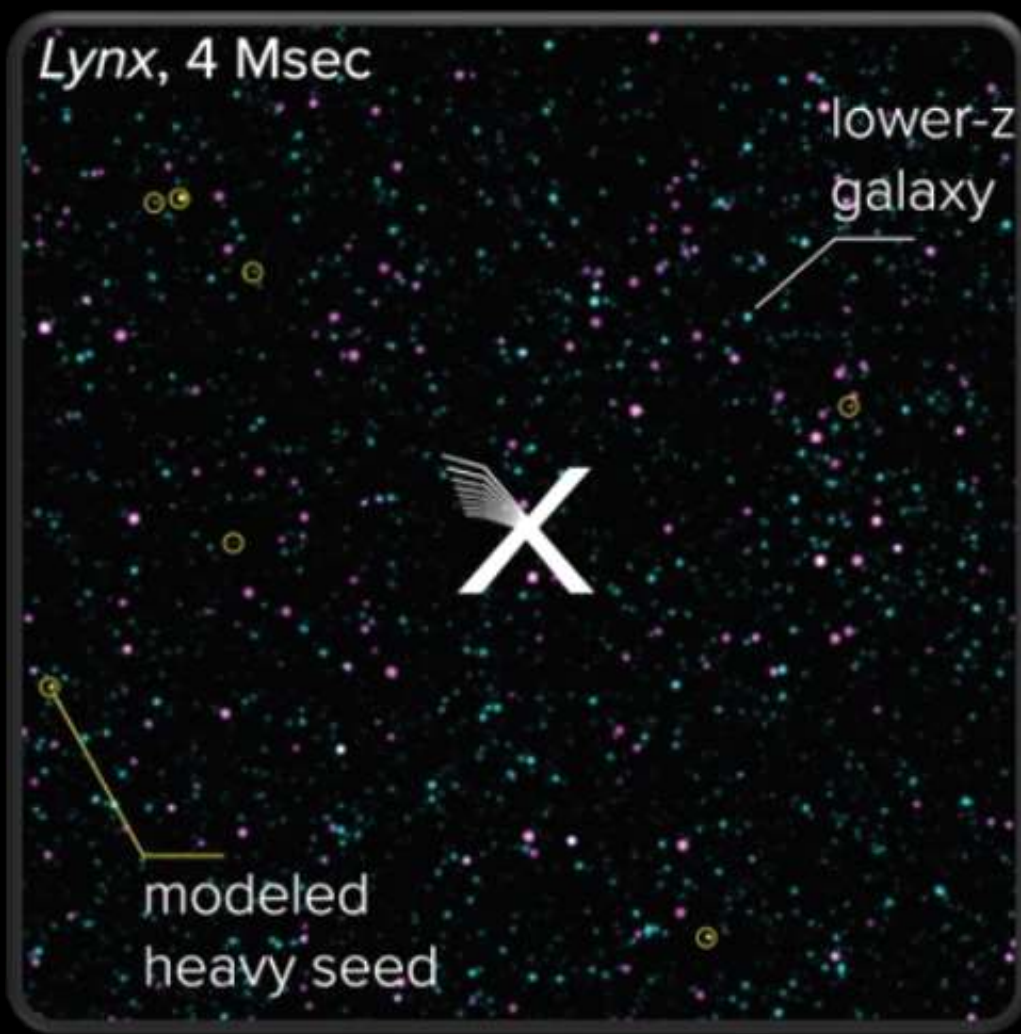
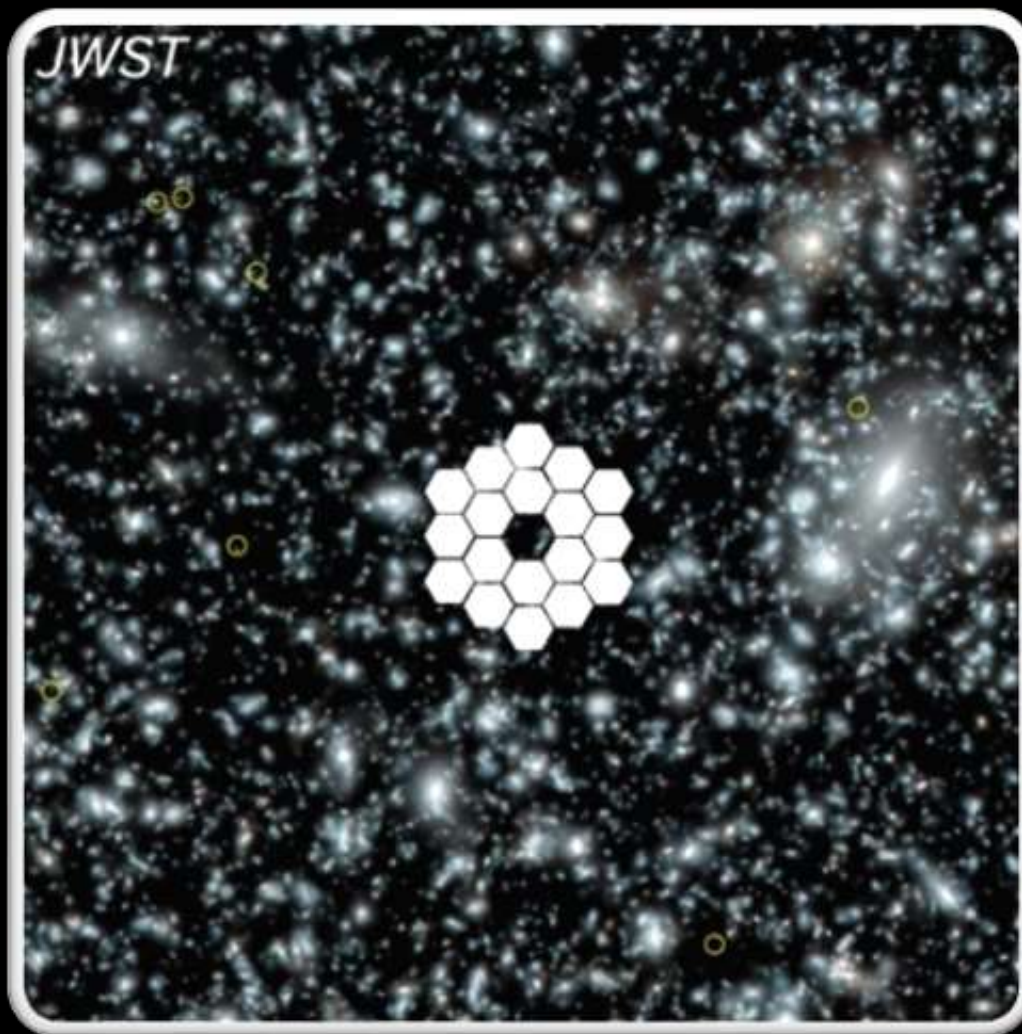
BLACK HOLE DAWN



Luminosity Functions



the DAWN of BLACK HOLES

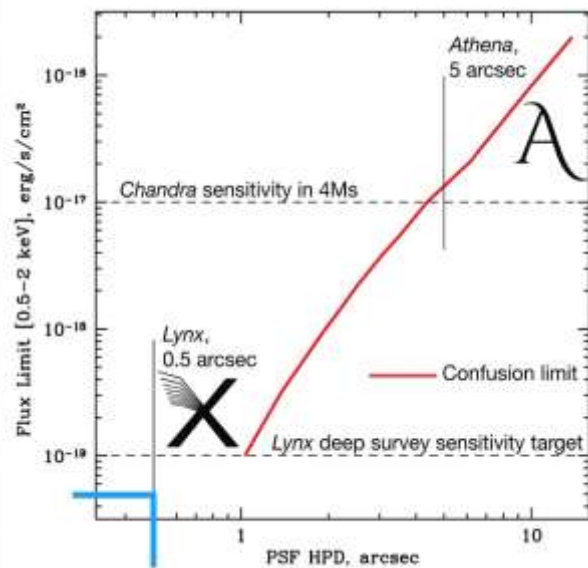


Key observations: surveys over $\sim 1 \text{ deg}^2$ down to $f_x \sim 10^{-19} \text{ erg s}^{-1} \text{ cm}^{-2}$ to detect black hole seeds with $M_{\text{BH}} = 10,000 M_{\text{SUN}}$ at $z=10$.

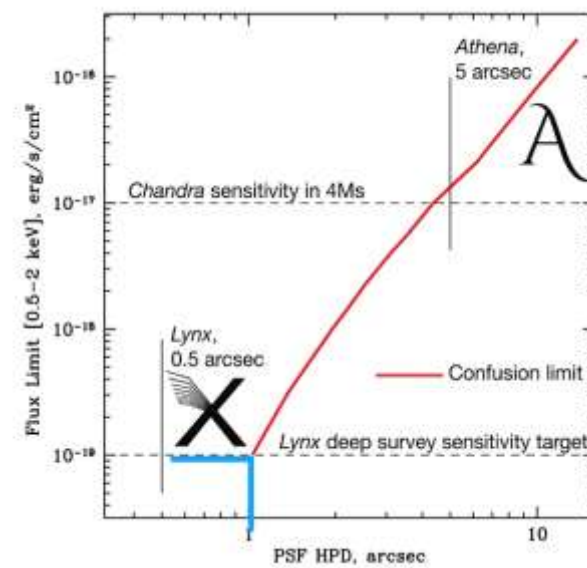
Key requirement:

- $< 1''$ PSF across the FOV; FOV $\times$ Aeff

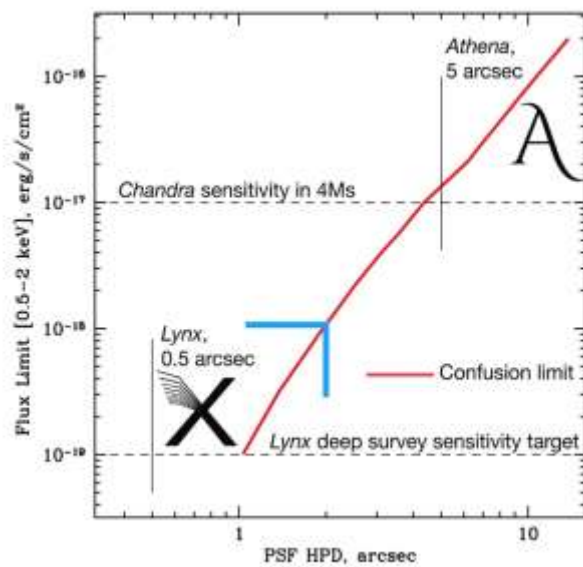
0.5''



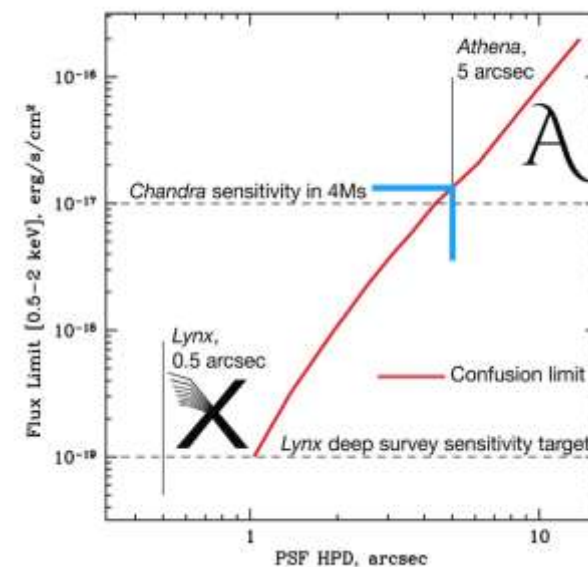
1.0''



2.0''



5.0''



FROM DAWN TO NOON TO NOW

BLACK HOLE MASS

$10 M_{\text{SUN}}$

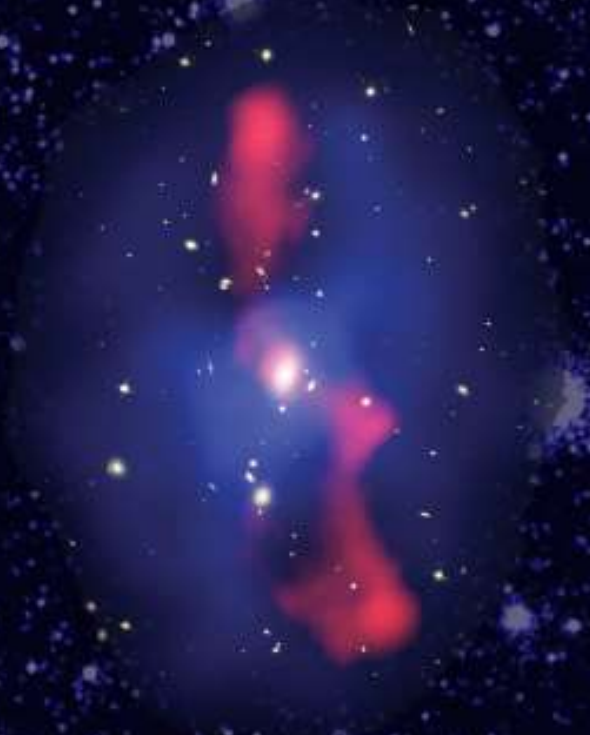
$10^{10} M_{\text{SUN}}$

STELLAR
MASS

INTERMEDIATE
MASS

MASSIVE

SUPERMASSIVE

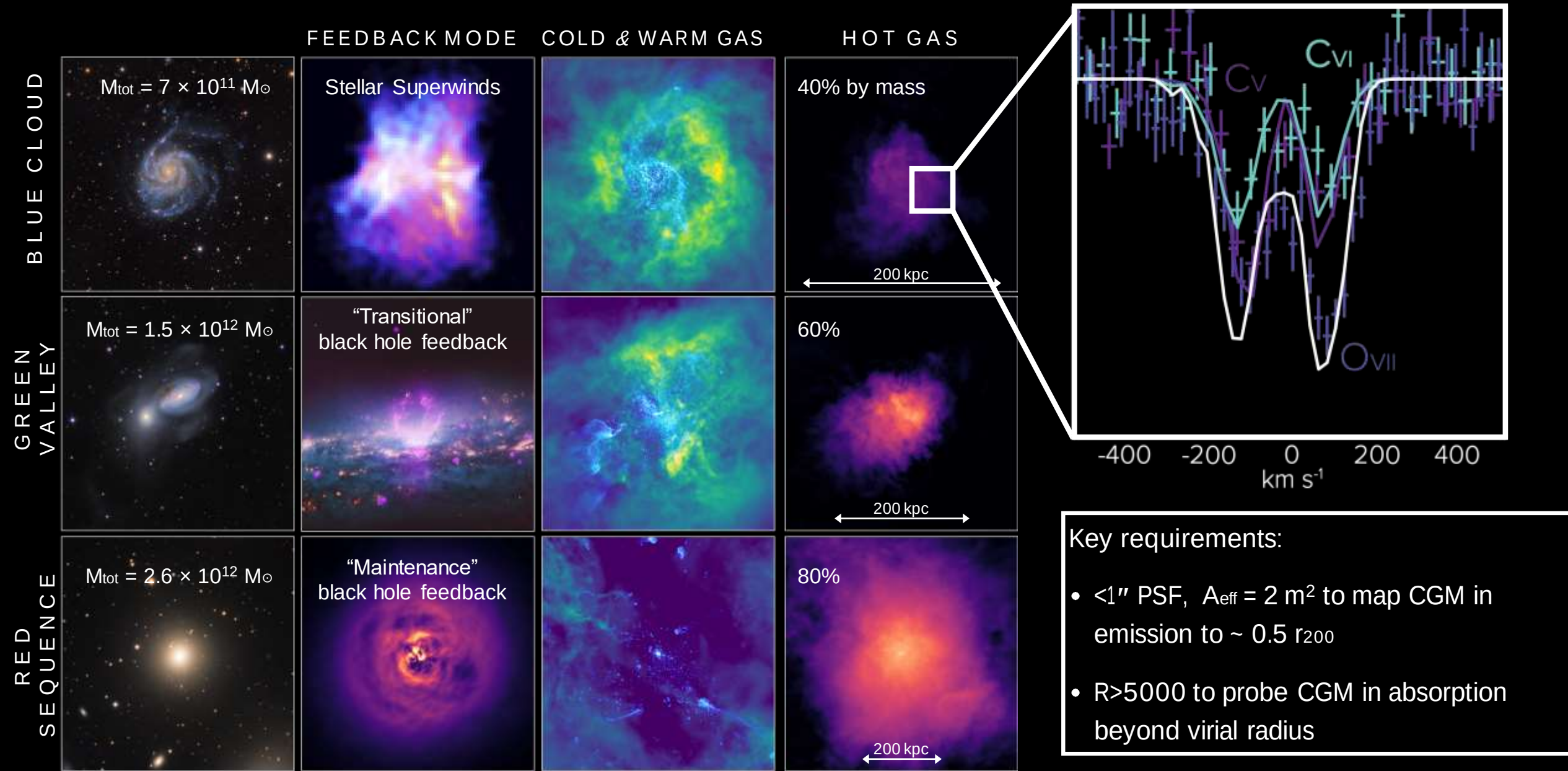


t h e D R I V E R S *o f*
G A L A X Y E V O L U T I O N

- Exquisite data available on stellar, dust, and cold gas contents of galaxies.
- Yet, there is a dearth of understanding of their exact formation mechanism
- Main drivers are imprinted in hot CGM and in signatures of on-going feedback

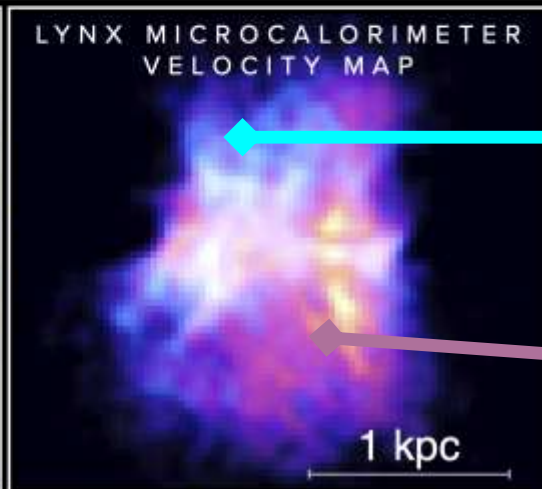
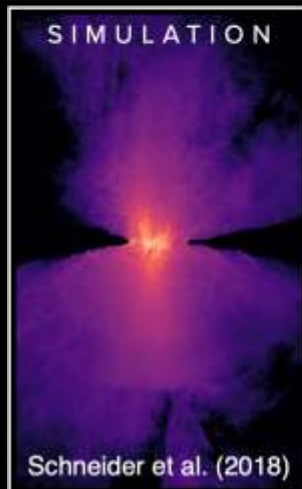
t h e DRIVERS *o f* GALAXY EVOLUTION

t h e HOT CIRCUMGALACTIC MEDIUM



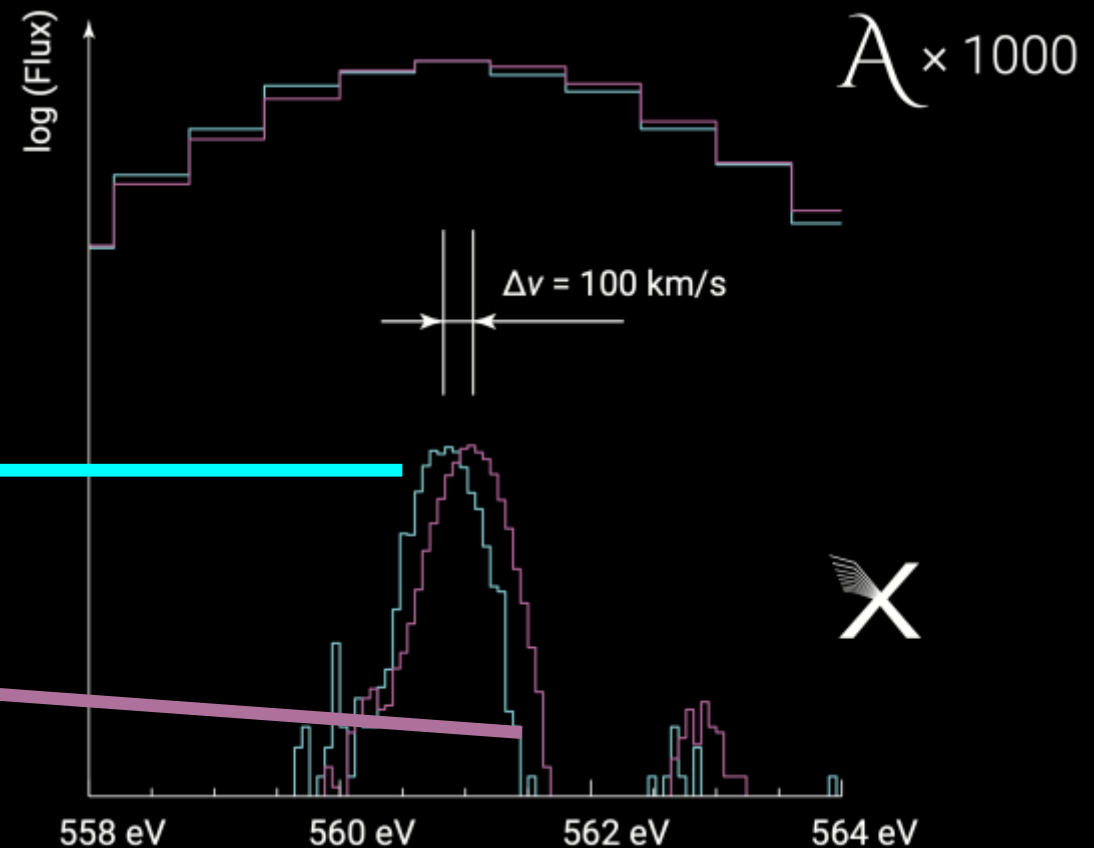
the DRIVERS of GALAXY EVOLUTION

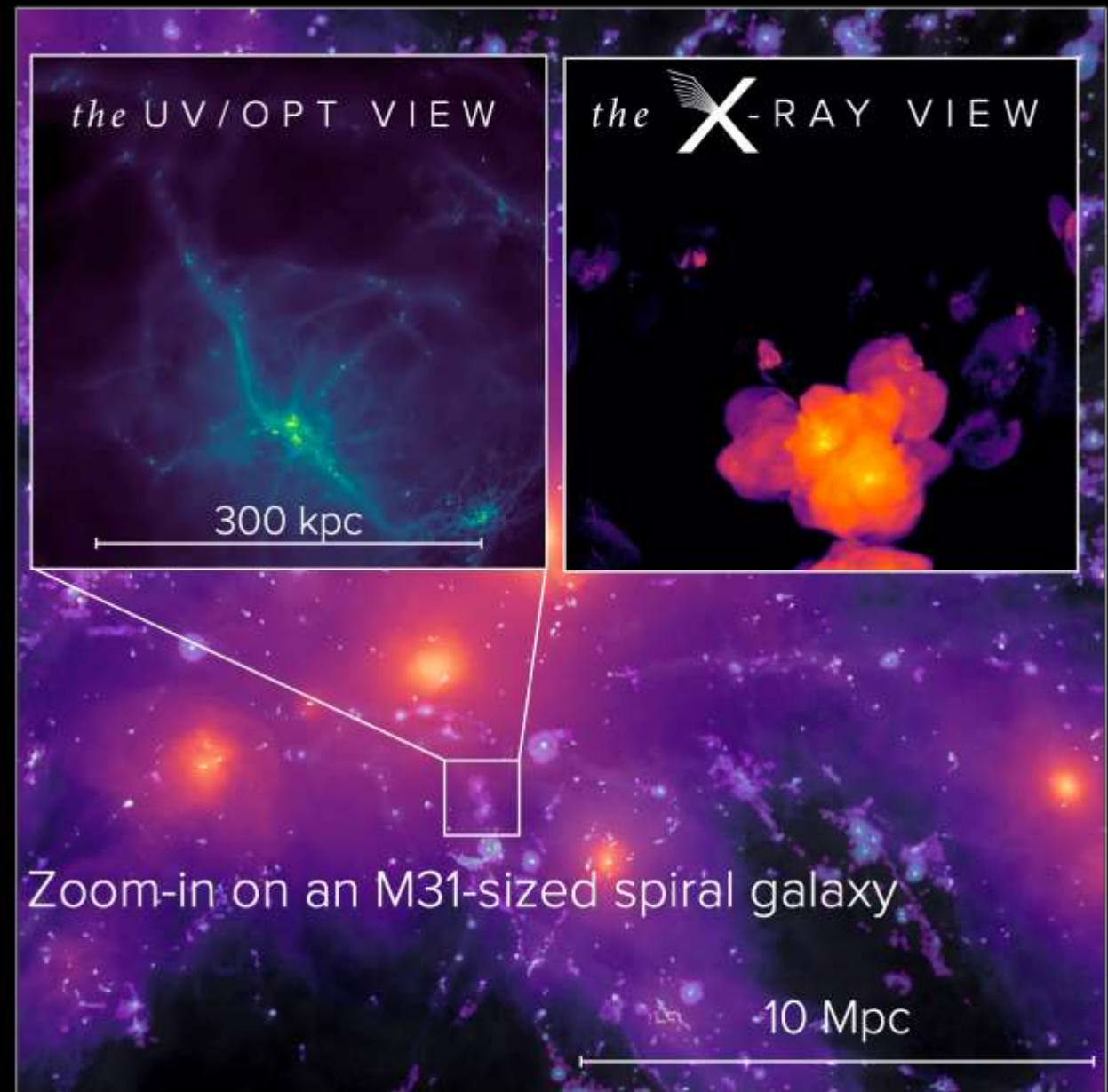
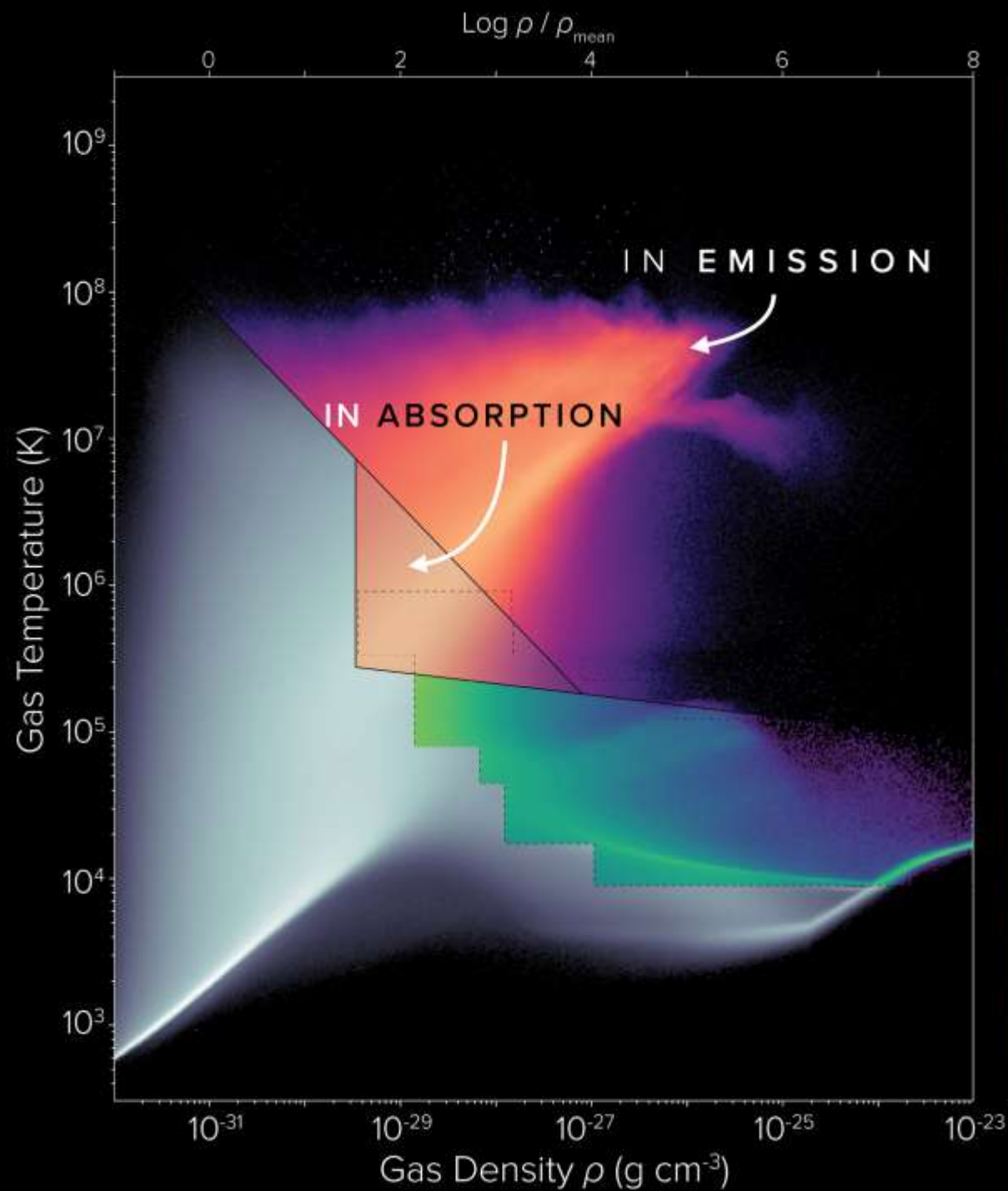
— FEEDBACK in ALL MODES, on ALL SCALES —



Key capabilities:

- Microcalorimeter with $R=2000$ at $E = 0.6$ keV to map velocities in ~ 100 km/s galactic outflows
- Microcalorimeter with $0.5''$ pixels to study AGN feedback in galaxies and clusters





t h e E N E R G E T I C S I D E *o f*
S T E L L A R E V O L U T I O N

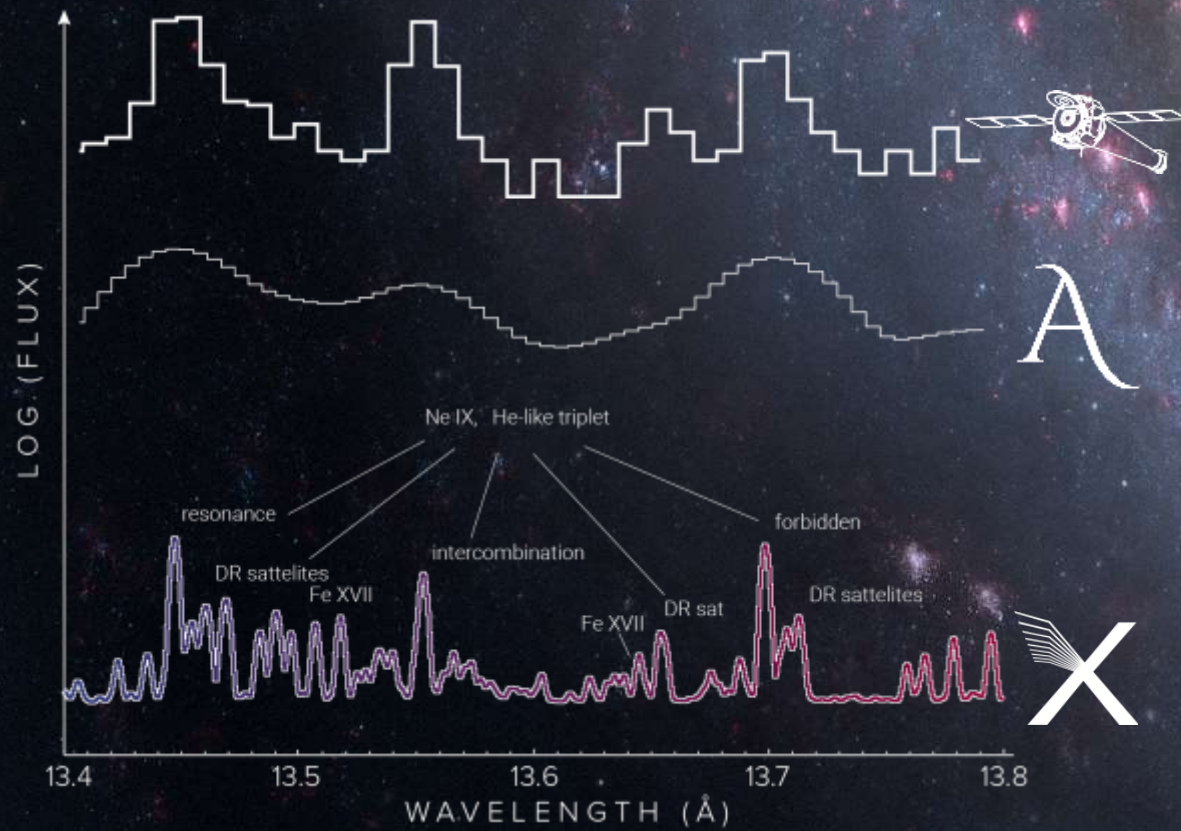
- We are in the era of multi-messenger astronomy. Planet studies evolve to holistic assessment of habitable conditions. Leaps in data on star formation are needed to understand the galaxies and cycles of elements.
- Science needs include observations of key high-energy processes associated with stellar birth, life, and death.

t h e M I L K Y W A Y

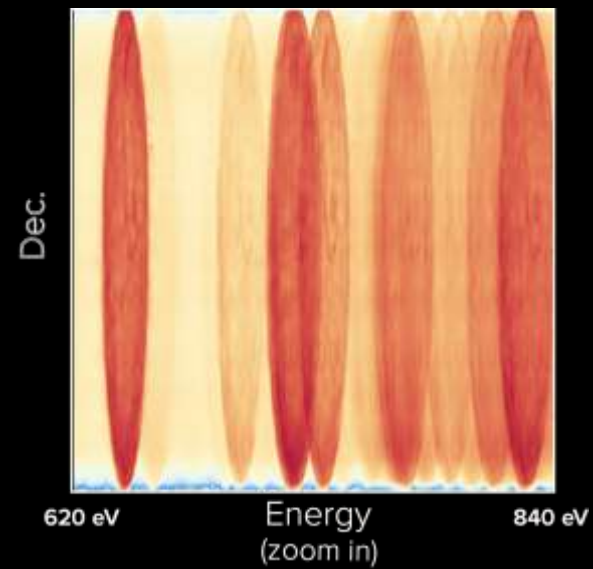
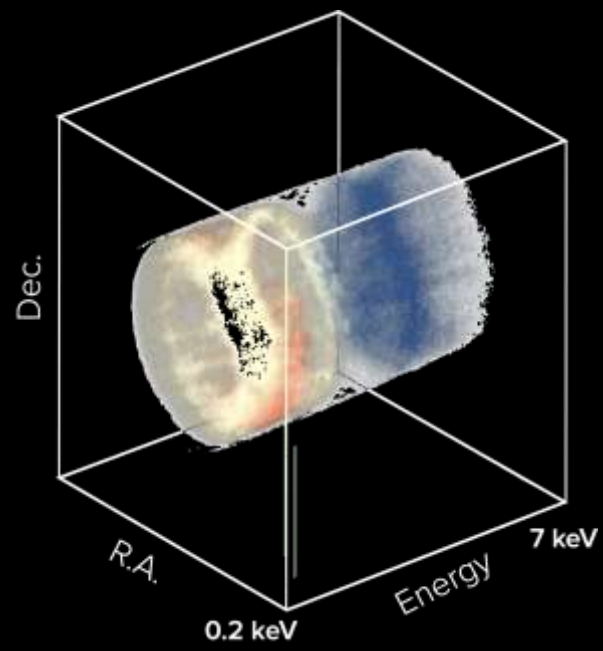
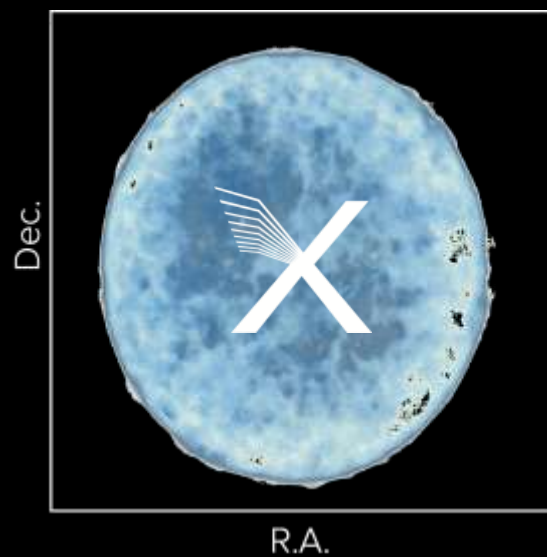
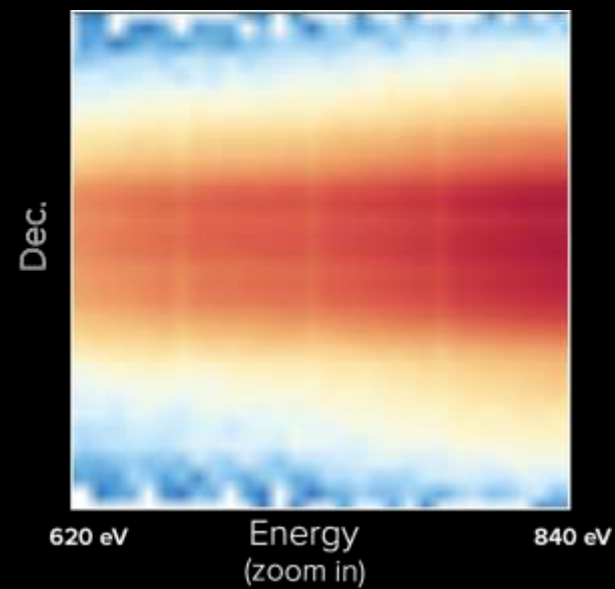
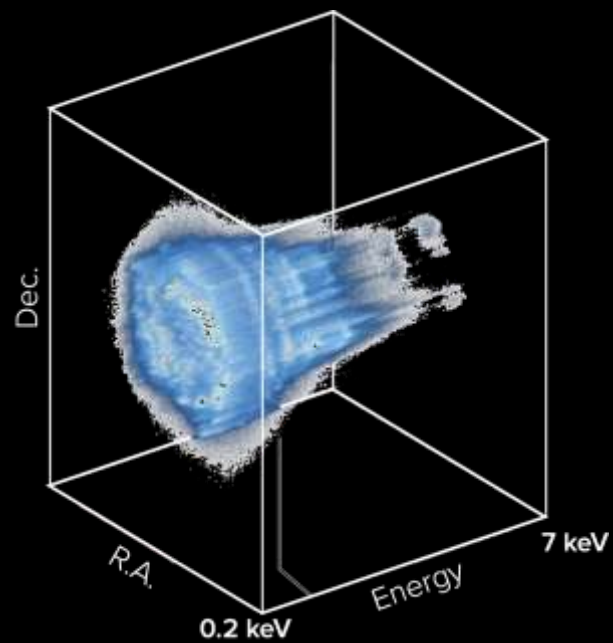
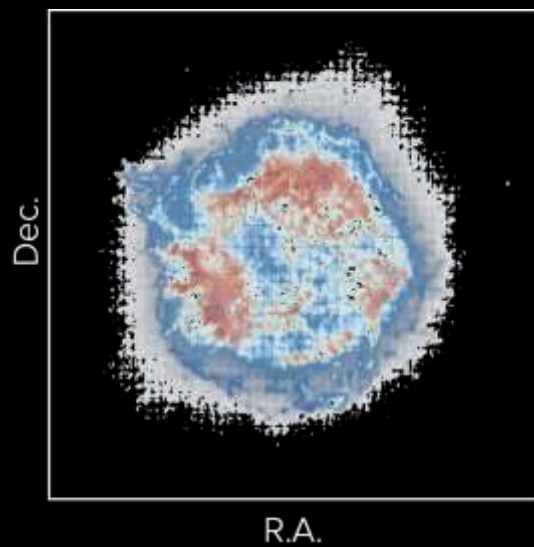



H O R I Z O N
5 kiloparsecs


C H A N D R A
H O R I Z O N
400 parsecs

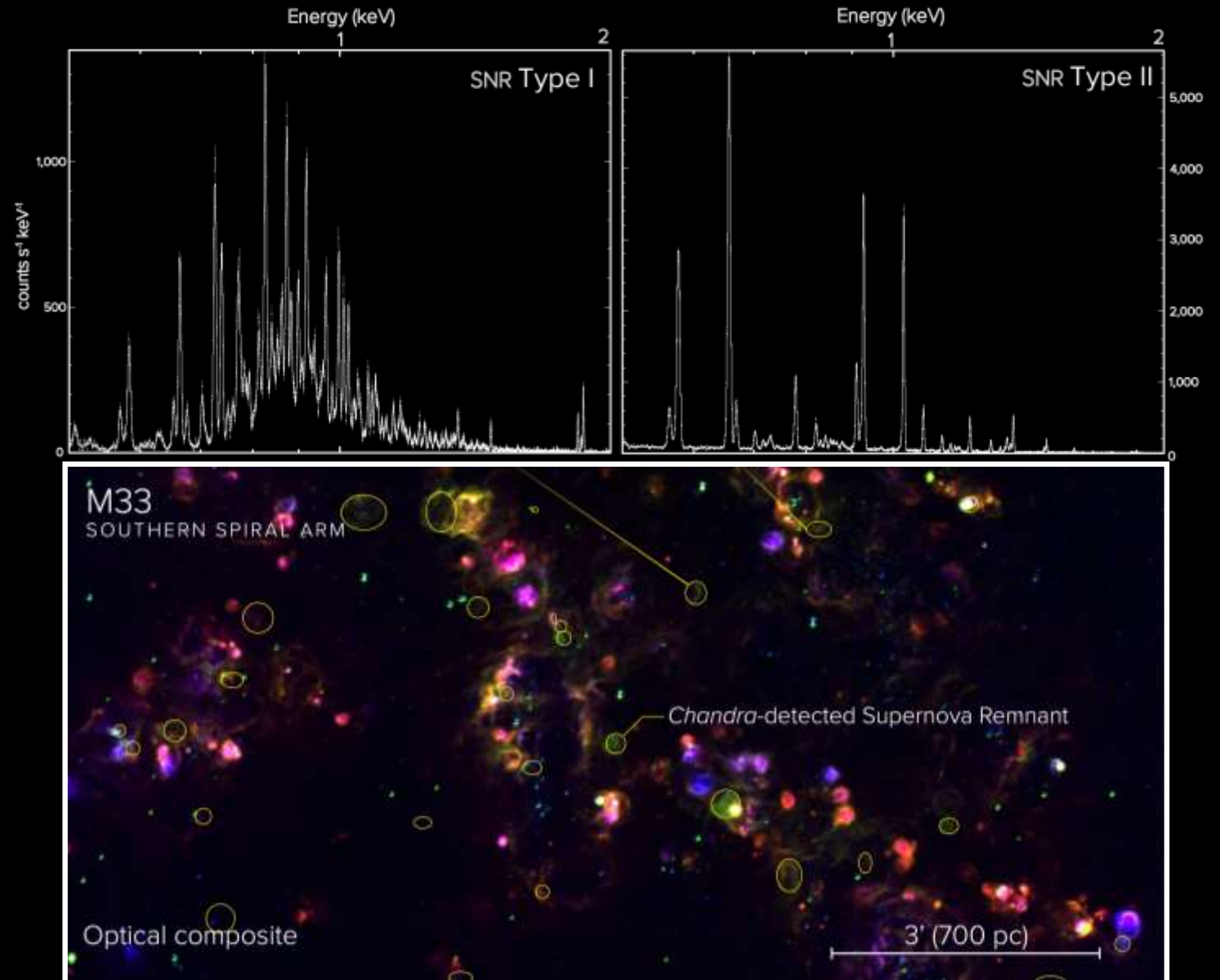


STELLAR DEATH *in* 3D



STELLAR DEATH, EXTRAGALACTIC

- Statistical samples of SNRs (age, type, etc.)
- SN activity & relation to on-going star formation
- Sensitive XRB studies beyond the Local Group



X SCIENCE TRACEABILITY MATRIX						
Science Goal	Science Objective	Key Observations	Measurement Requirements	Mirror and Instrument Requirements		
				Instrument	Property	Value
See the Dawn of Black Holes	Observe progenitors of supermassive black holes at their seed stage at $z=10$	Detection of black holes in $z=10$ galaxies down to a mass limit of $M_{\text{BH}}=10,000 M_{\text{Sun}}$ over a volume with $10^4\text{--}10^7$ potential host galaxies. §1.1.3, Appendix A.3	Surveys with flux limits (0.5–2 keV): • 1.6×10^{-19} erg/s/cm ² over 1 deg ² • 7×10^{-20} erg/s/cm ² over 400 arcminutes ²	Mirror+ HDXI	Angular Resolution (HPD)	<1 arcseconds across the field
					Grasp @ 1 keV	$\sim 2\text{ m}^2\times 300\text{ arcminutes}^2$
					Imager pixel size	0.33 arcseconds
Reveal Invisible Drivers of Galaxy and Structure Formation	Determine the state of diffuse baryons in galactic halos to guide the galaxy formation models	Direct imaging observations of 15 low- z galaxies with $M_{\text{tot}}\sim 3\times10^{12} M_{\text{Sun}}$. §2.1.4, Appendix A.5	Reach 10% accuracy for derived thermodynamic parameters of hot gas at $0.5 r_{200}$	Mirror+ HDXI	Effective Area @1 keV	2 m ²
					Field of View	10 arcminute radius
					Spectral Resolution @1 keV	60 eV (FWHM)
					Particle Background @0.5-2 keV	< 0.0005 cnt/s/arcmin ² /keV
	Establish the energetics, physics, and the impact of energy feedback on galactic scales	Characterization of hot halos beyond the virial radius in $z=0\text{--}3$ galaxies with $M_{\text{tot}}\sim 10^{11.5}\text{--}10^{12.5} M_{\text{Sun}}$ at $z=0\text{--}1$. §2.1.5, Appendix A.5	Observe 80 bright AGN sight lines to reach the sensitivity of 1 mJy for O VII and O VIII absorption lines	XDS	Central Resolving Power	5,000
		Spatially and spectrally resolve the structure of starburst-driven winds in low-redshift galaxies. §2.2	Measure the outflow velocity profile in 20 galaxies with 100 km/s accuracy, and derive the momentum and energy flux	LXM / Ultra High Resolution Array	Effective Area at 0.45-0.7 keV	4,000 cm ²
					Spectrometer Pixel Size	1 arcsecond
					Energy Resolution @0.2-0.75 keV	0.3 eV (FWHM)
		Determine the effects of AGN energy feedback on ISM, and determine the physical state of gas near the SMBH sphere of influence in nearby galaxies. §2	In 30 nearby galaxies, resolve extended emission line regions, AGN inflated bubbles, and characterize the thermodynamic state of gas with 10% precision at or close to the Bondi radius from the central black hole	Mirror + LXM / Enhanced Main Array	Spectrometer Subarray Size	1 arcminute $\times$ 1 arcminute
					On-axis Angular Resolution	0.5 arcseconds (HPD)
					Spectrometer Pixel Size	0.5 arcseconds
	Unveil the Energetic Side of Stellar Evolution and Stellar Ecosystems	Survey of young SNR in Local Group galaxies. §3.3	Measure spatial structure of SNRs in spectral lines of individual elements (e.g. Fe-K α), and in non-thermal emission	LXM / Main Array	Energy Resolution @0.6-7 keV	3 eV (FWHM)
					Spectrometer Field of View	5 arcminutes $\times$ 5 arcminutes
					Effective Area @6 keV	1,000 cm ²

the PILLARS

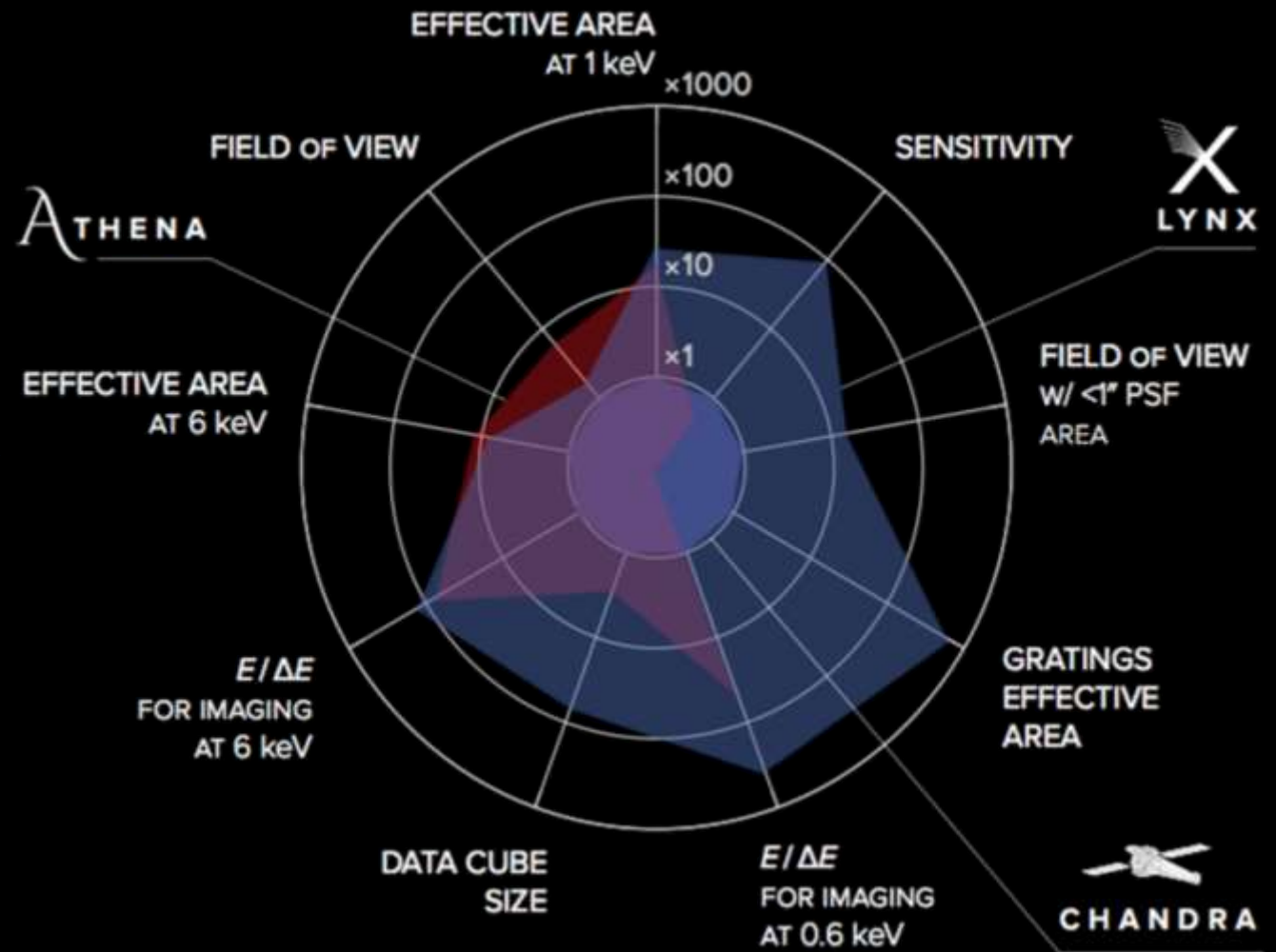
BLACK HOLE
D A W N

DRIVERS of
G A L A X Y
E V O L U T I O N

ENERGETIC SIDE of
S T E L L A R
E V O L U T I O N



TRANSFORMATIONAL SCIENCE *requires*
TRANSFORMATIONAL CAPABILITIES



the SCIENCE

KEY OBSERVATIONS

REQUIREMENTS



BLACK HOLE D A W N

Surveys over 1 deg^2 down to
 $10^{-19} \text{ erg/s/cm}^2$

PSF $< 1''$ across the FOV
FOV $\times$ Effective Area



G A L A C T I C H A L O S

Imaging out to $1/2$ of virial radius

FOV
Effective Area

Absorption Line Spectroscopy
out to virial radius

Spectral resolving power $R=5000$
Spectroscopic Effective Area



F E E D B A C K A L L M O D E S A L L S C A L E S

Velocity mapping of 100 km s^{-1}
outflows on $1''$ scales

$\Delta E = 0.3 \text{ eV}$ at 0.6 keV ,
 $1''$ pixels

Spatial structure near AGN
on $< 1''$ scales

$\Delta E = 3 \text{ eV}$ at $0.6\text{--}7 \text{ keV}$,
 $0.5''$ pixels



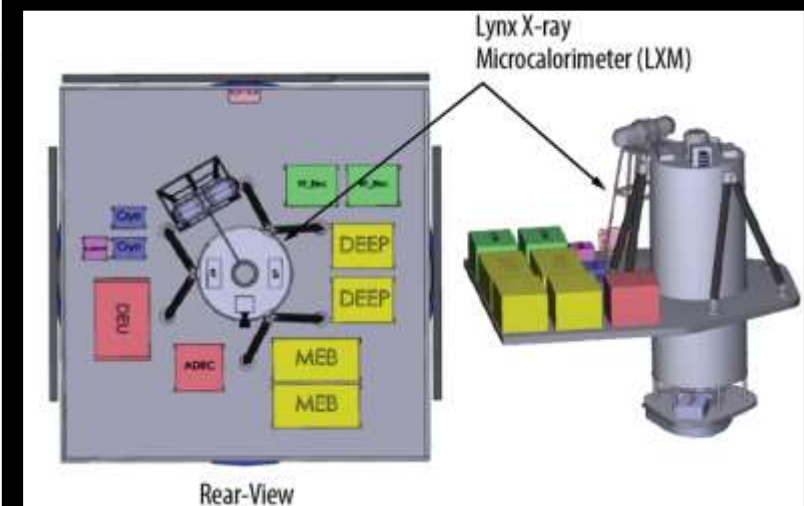
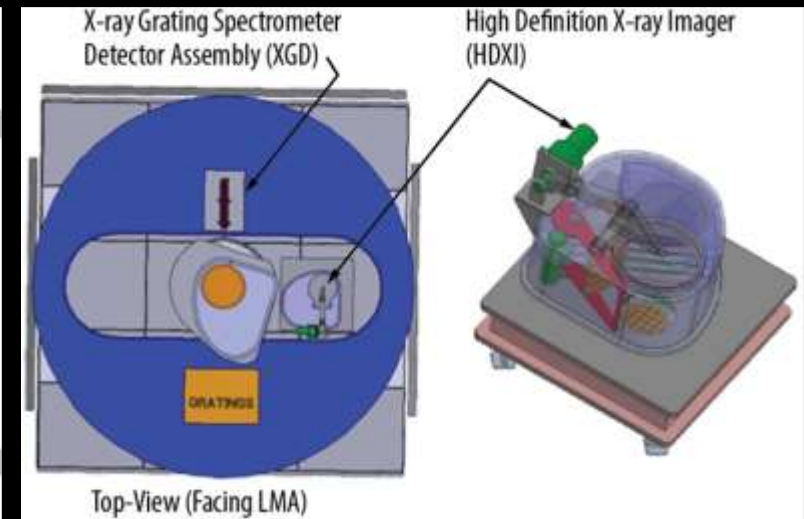
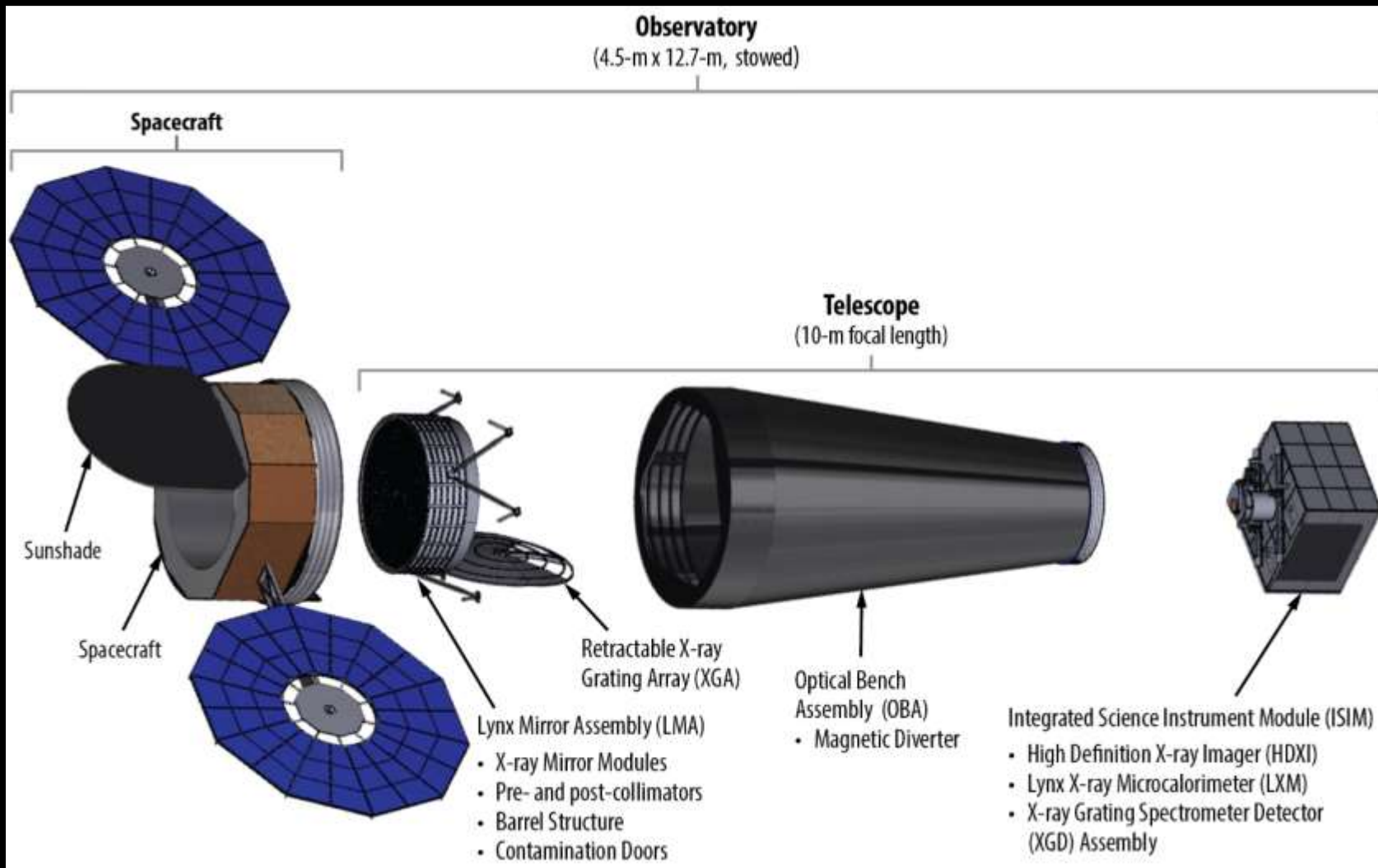
S T E L L A R D E A T H

Spectro-imaging on $1''$ scales
over remnant or host galaxy

$\Delta E = 3 \text{ eV}$ at $0.6\text{--}7 \text{ keV}$,
 $1''$ pixels, $5'$ FOV

REVOLUTIONARY INSTRUMENTATION

on a PROVEN SPACECRAFT DESIGN

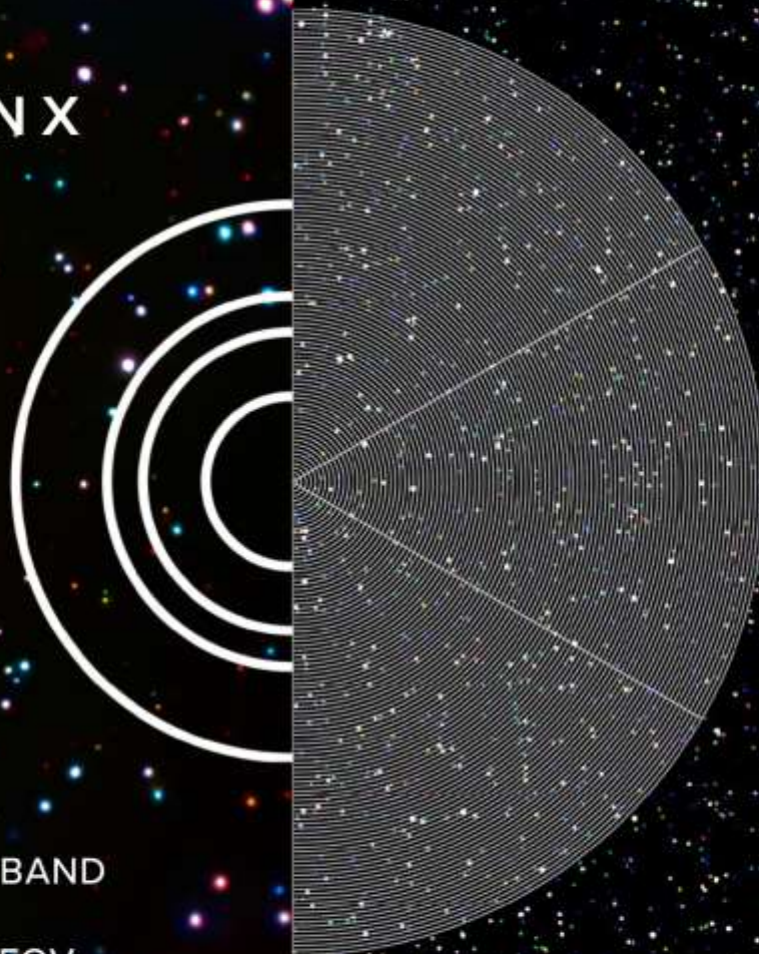


4 Msec, *Chandra*

4 Msec, *Lynx*



EYES, SHARP AS A LYNX



0.5 ARCSEC PSF on-axis

50× CHANDRA'S THROUGHPUT IN SOFT X-RAY BAND

STABLE, SUB-ARCSEC PSF across the 22'×22' FOV
(≈ 20× CHANDRA)

1000× CHANDRA'S SURVEY SPEED

M U L T I P L E F E A S I B L E M I R R O R T E C H N O L O G I E S

REQUIREMENTS

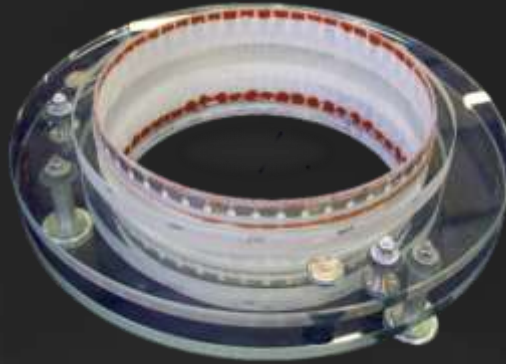
0.5'' on-axis

1'' to 10' off-axis

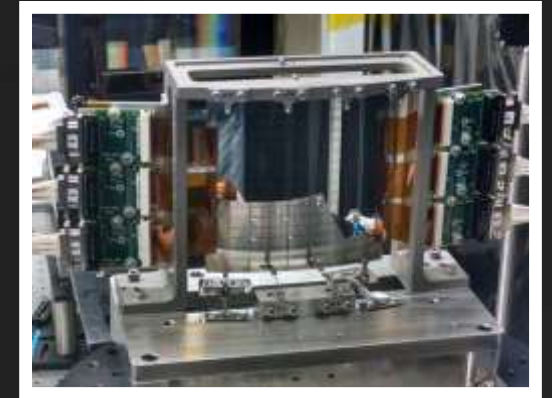
~2 m² of effective area



Silicon Meta-shell Optics
NASA GSFC



Full Shell/Monolithic Optics
NASA MSFC/INAF Brera



Adjustable Optics
SAO

Lynx Mirror Architecture Trade (LMAT): Community working group conducted an open, science, technical, and programmatic evaluation.

A broad consensus was reached on the recommendation

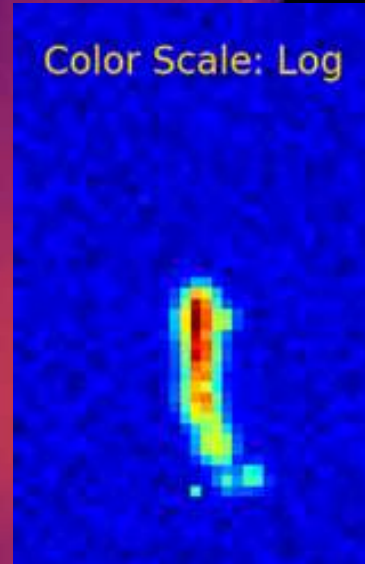
- Team from industry, universities, and NASA Centers
- ~5,000 person-hours over 6 months
- ~100 documents produced (~650 pages of material)

Recommendation: The LMAT recommends Silicon Meta-Shell Optics as the DRM concept Mirror Optical Assembly Architecture to focus the design for the Final Report. Full Shell and Adjustable Optics are determined to be feasible alternates.

t h e s t a t e o f M I R R O R T E C H N O L O G Y

————— S I L I C O N M E T A S H E L L O P T I C S —————

W. ZHANG & TEAM (GSFC)

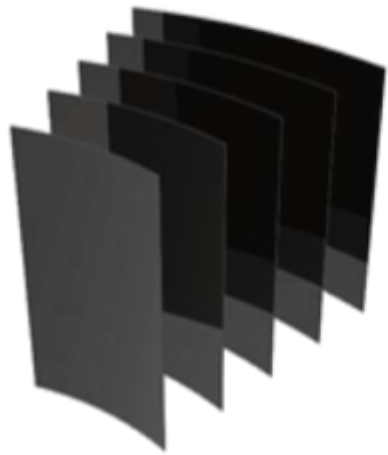


Presented at
APS2020(W. Zhang)

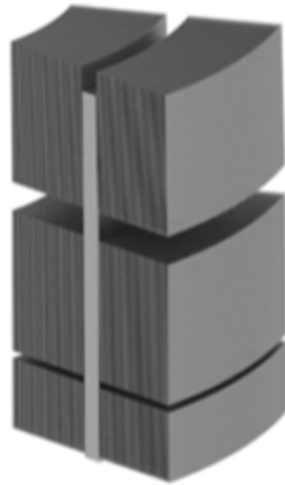
0.83" (HPD) at 4.5 keV,
influenced by gravity distortions

Full-illumination X-ray test of aligned mirror pair

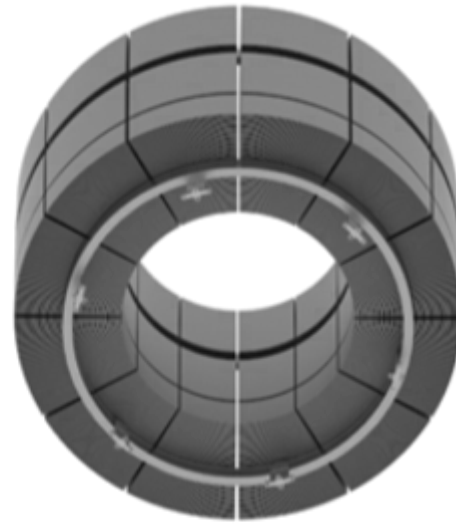
MASS-PRODUCIBLE, MODULAR,
PARALLELIZABLE



37,492 SEGMENTS



611 MODULES



12 META-SHELLS



1 ASSEMBLY



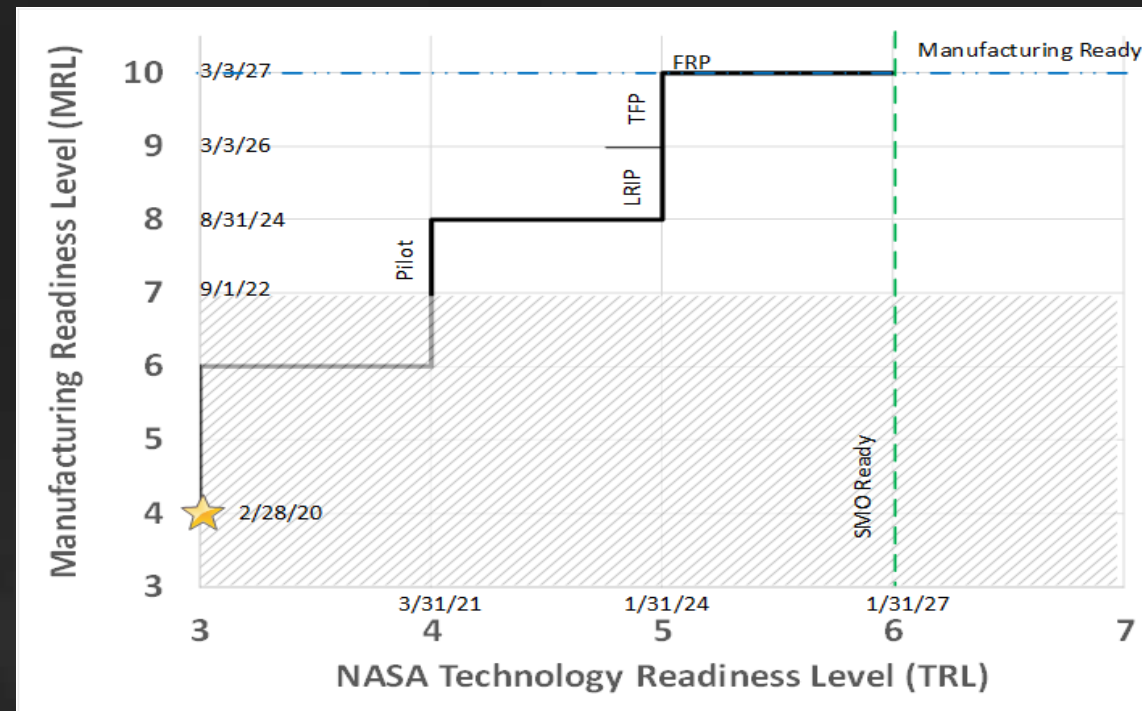


Detailed Manufacturing Plan

- CAN initiated with Northrop Grumman and L3Harris to apply principles of industrial engineering to optimize equipment and labor across multiple parallel lines with the capability to minimize bottlenecks and wait times, with definite savings potential already identified

Timely Completion of X-ray Mirror Assembly Requires Technology and Manufacturing Readiness

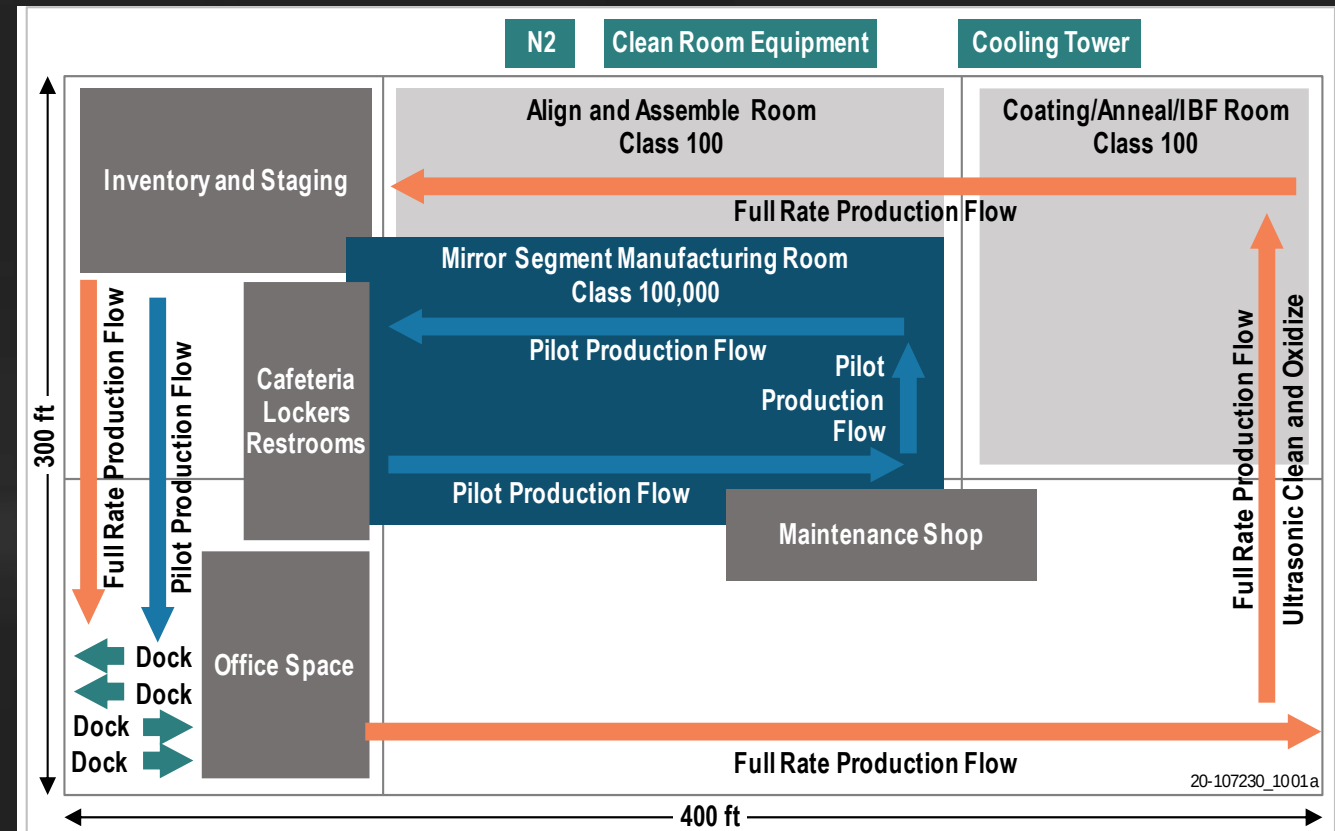
- Transition of mirror production from laboratory to factory
 - Industrialization of manufacturing process
 - Optimization of manufacturing flow
- Mirror assembly delivery in 2031 requires development in the near term of both technology and manufacturing



Further process optimization possible

X Factory and Staffing are Executable

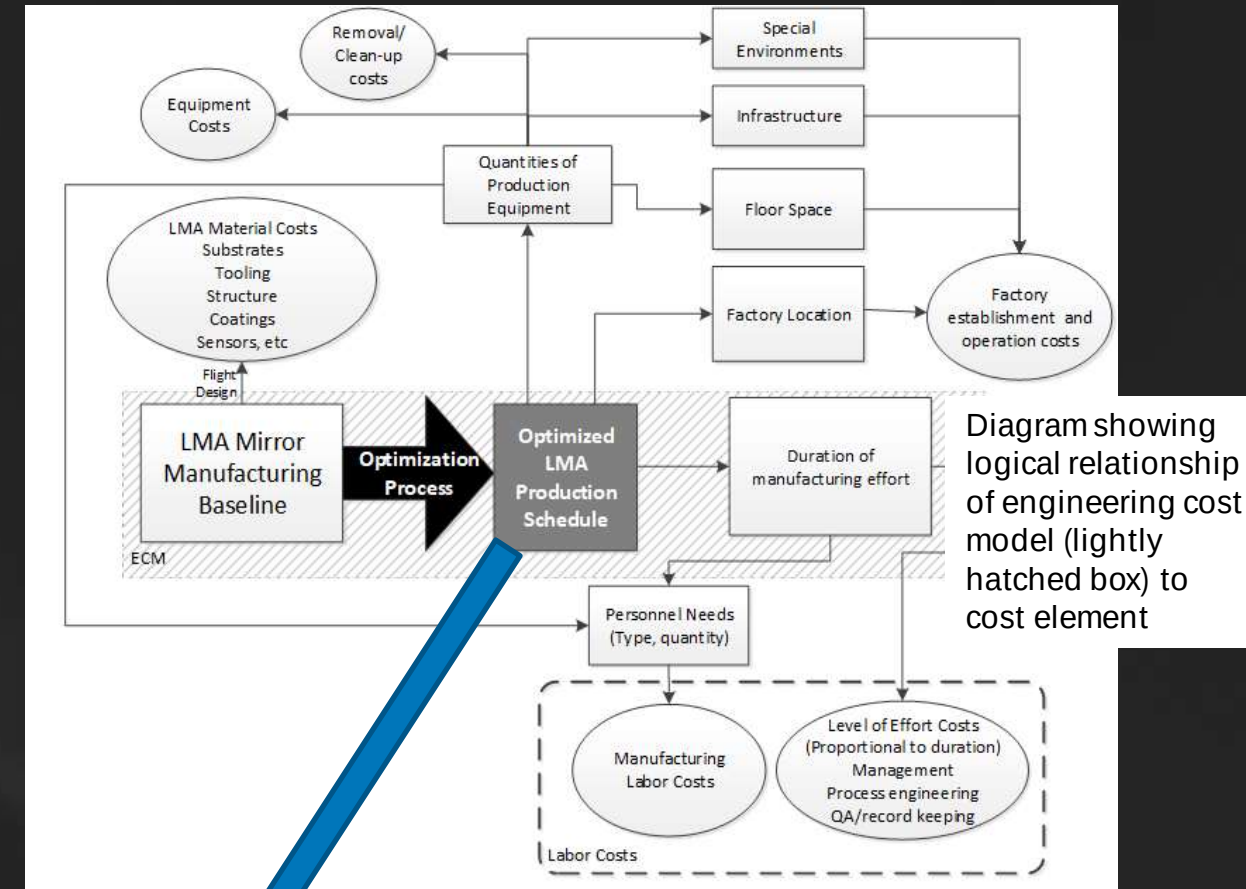
- A single facility will be used for pilot and full rate production
 - Facility needed is a typical large industrial facility
- Staffing and training plan and procurement of machinery also studied— found to be similar to many other production jobs
 - Time to acquire staff and equipment studied and built into time line





COSTING AND SCHEDULE OF XMA

- A mathematical model XMA production has been developed [1-4] and is central to the quantification of manufacturing process optimization
- Risk is treated as uncertainty in the model, both statistical and non-statistical

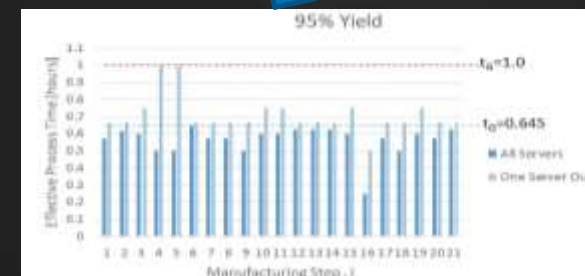


[1] Jonathan W. Arenberg, Lynn N. Allen, James Mooney, Bill Purcell, Steven Jordan, "Cost, schedule and risks modeling for the Lynx Mirror Array," Proc. SPIE 10699, Space Telescopes and Instrumentation 2018: Ultraviolet to Gamma Ray, 1069916 (10 July 2018)

[2] Jonathan W. Arenberg, "Formulation of the production time and cost of the Lynx x-ray mirror assembly based on queuing theory," J. Astron. Telesc. Instrum. Syst. 5(2), 021016 (2019), doi: 10.1117/1.JATIS.5.2.021016.

[3] Jonathan Arenberg and William Zhang, "Analysis of the cost, schedule, and risk for Lynx mirror assembly production", SPIE San Diego 2019.

[4] Jonathan W. Arenberg, "Uncertainty in the time to complete a complex manufacturing campaign", in preparation for SPIE Astronomical Telescopes and Instruments Conference, San Diego, 2020



Effective Process Times for 95% average manufacturing yield: All servers functioning (solid bars) and one server failed (hatched bars)

Optimized plan will consider statistical and non-statistical risks, to design the most efficient manufacturing process

TECHNOLOGY DEVELOPMENT PLAN

SILICON METASHELL OPTICS

Development Challenges

- Demonstrate a fabrication process to mass produce quality mirror segments
- Demonstrate processes for assembling mirror modules and meta-shells.
- Demonstrate final assembly, alignment, and testing processes

TRL4: Refine and perfect all technical elements (fabrication, coating, alignment, bonding) such that modules containing at least three co-aligned pairs of mirror segments can be repeatedly built and tested and shown to meet Lynx requirements.

AD² = 3-4 (TRL3 → TRL4)

TRL5: Develop this technology to meet spaceflight environment requirements: thermal vacuum, vibrations, acoustics, and shocks.

AD² = 2-3 (TRL4 → TRL5)

TRL6: An engineering model X-ray mirror assembly with multiple aligned and integrated meta-shells will be fabricated and tested. The finished assembly engineering model meets all science and environmental requirements. The entire production logistics, schedule, and cost risks are retired

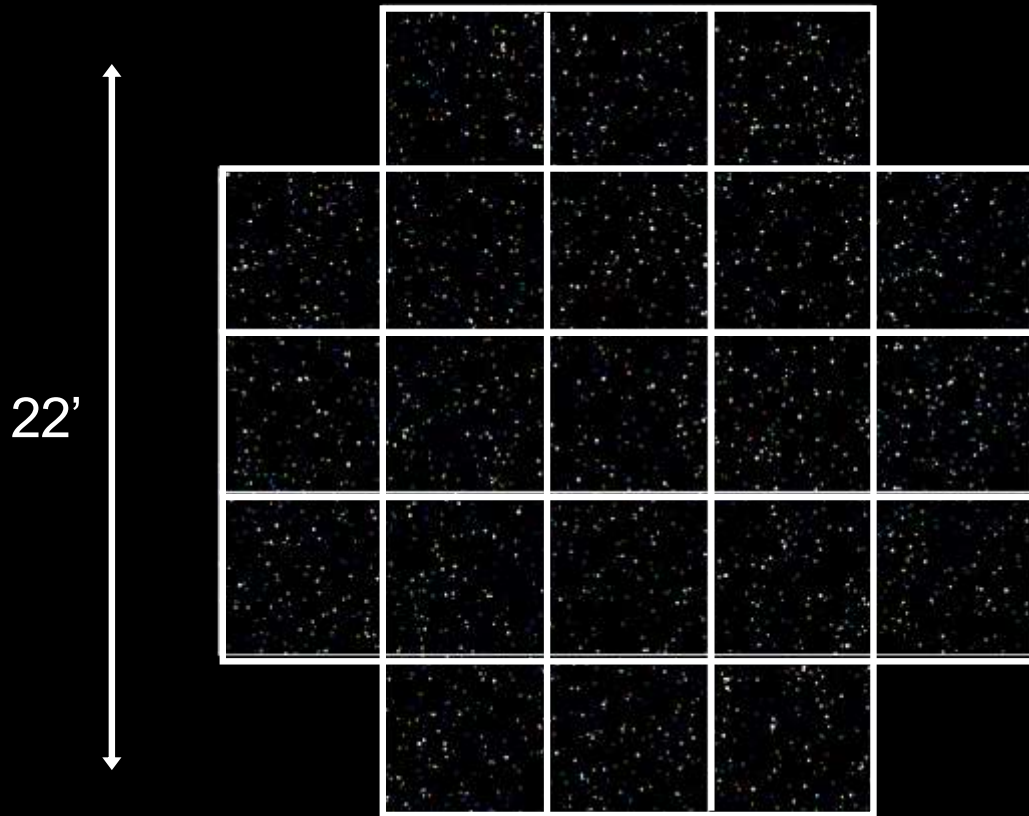
AD² = 2-3 (TRL5 → TRL6)



No fundamental barriers to developing multi-mirror module assembly demonstrator (TRL6).

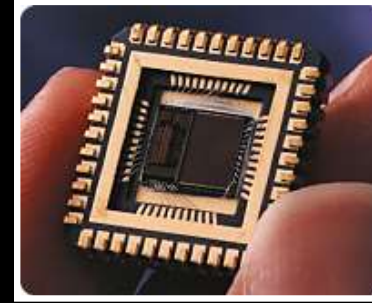
the HIGH DEFINITION X-RAY IMAGER

HDXI Instrument Working Group Leads
M. Bautz (MIT), R. Kraft (SAO), A. Falcone (PSU)



Pixel size well matched to telescope PSF of 0.5" HPD
Large, curved, focal plane (22' x 22')

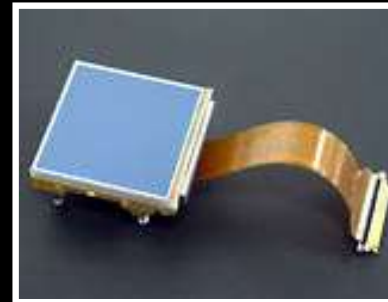
Monolithic CMOS (Sarnoff/SAO & MPE)



High gain ($135 \mu\text{V}/e^-$), low noise ($3 e^-$ rms) amplifiers

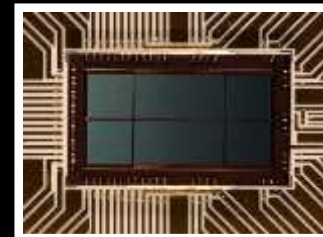
PMOS devices ready for X-ray testing with $< 1e^-$ rms read noise and no RTS noise

Hybrid CMOS (Teledyne & PSU)



Achieves ~ 80 eV (FWHM) energy resolution at 0.5 keV, in-pixel CDS, no crosstalk. Event-driven readout achieved. Latest scaled-up designs include on-chip digitization.

Digital CCD with CMOS Readout (MIT / Lincoln Lab)



Fast (2.5 MHz), low noise ($3.2 e^-$) outputs, low-power CMOS clocks. Large (2 Mpix) device in fabrication. ASIC video processor in design.

WE KNOW *how to* MAKE THIS

the HIGH DEFINITION X-RAY IMAGER

TECHNOLOGY DEVELOPMENT PLAN

Development Challenges

- Demonstrate low-energy X-ray response (high QE) and fine spatial resolution at high rates.
- Demonstrate low detector noise, high pixel-to-pixel response uniformity, and reliable readout processing.

TRL 4: A breadboard sensor with flight pixel size, frame-rate, X-ray QE and resolution demonstrated.

AD² = 5 (TRL 3 → TRL 4)

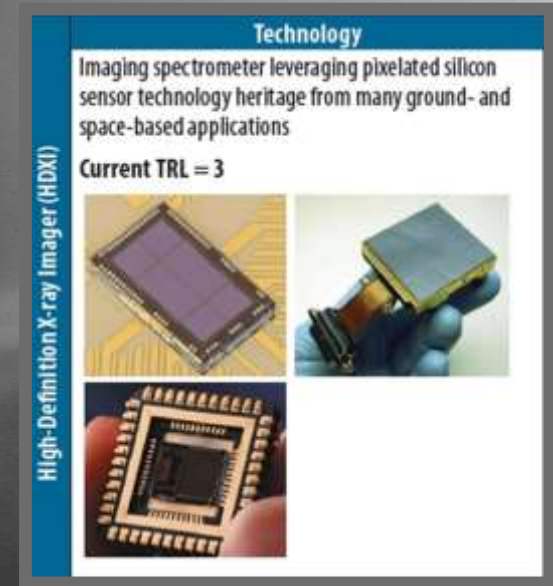
-Each technology requires an iterative cycle of design improvement, lithographic mask production, wafer fabrication and test, device packaging, and laboratory characterization. The duration of this cycle is typically ~9 months.

TRL 5: Sensor/ASIC system performance is consistent with the expected flight performance. Format and area at least 1/4 of required full-scale, representative number of parallel outputs, with a clear path to scaling to meet flight framerate requirement, operating with required readout rate with required noise with brassboard ASIC, back-illuminated with X-ray quantum efficiency and resolution meeting flight requirements.

AD² = 2-3 (TRL 4 → TRL 5).

TRL 6: An array of flight-sized sensors + ASICs providing at least 1/4 of total focal plane area mounted in a realistic geometry and flight-like sensor-to-ASIC electrical interconnects, and environmental and x-ray testing.

AD² = 2 (TRL 5 → TRL 6)



Development in these areas is extremely well understood.

There are no fundamental technical barriers.

the LYNX X-RAY MICROCALORIMETER

MAIN ARRAY

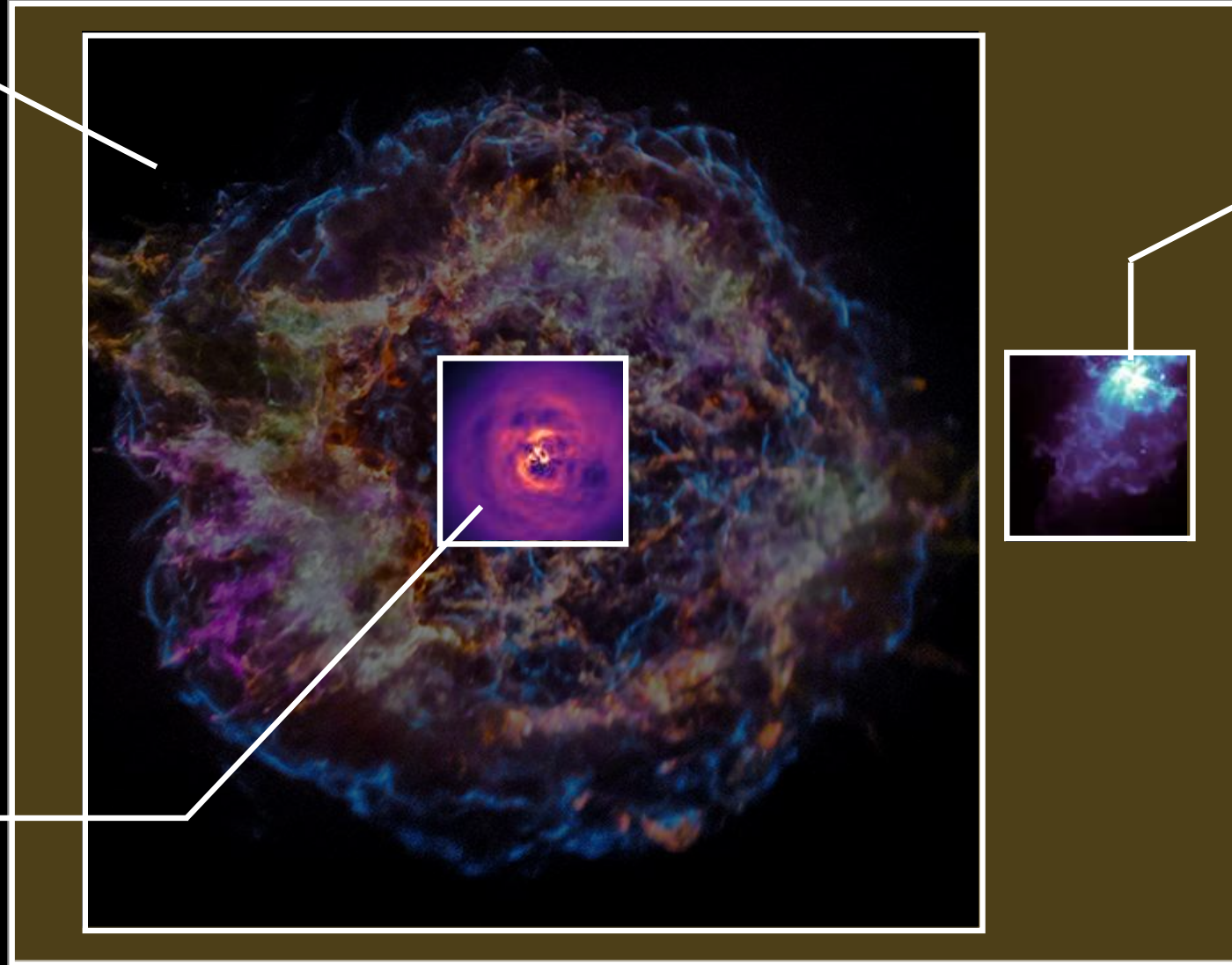
5' FOV
1" pixels (50 μm pitch)
 $\Delta E \sim 3 \text{ eV}$, $E < 7 \text{ keV}$
 $R=2000$ at 6 keV

25-pixel Hydras
86k pixels

ENHANCED MAIN ARRAY

1' FOV
0.5" pixels (25 μm pitch),
 $\Delta E \sim 2 \text{ eV}$, $E < 7 \text{ keV}$
 $R=3000$ at 6 keV

25-pixel Hydras
13k pixels

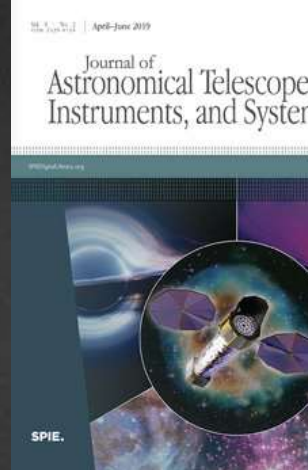


ULTRAHIGH RESOLUTION ARRAY

1' FOV
1" pixels (singles)
 $\Delta E \sim 0.3 \text{ eV}$, $E < 0.7 \text{ keV}$
 $R=2000$ at 0.6 keV

Single-pixel array
3.6k pixels

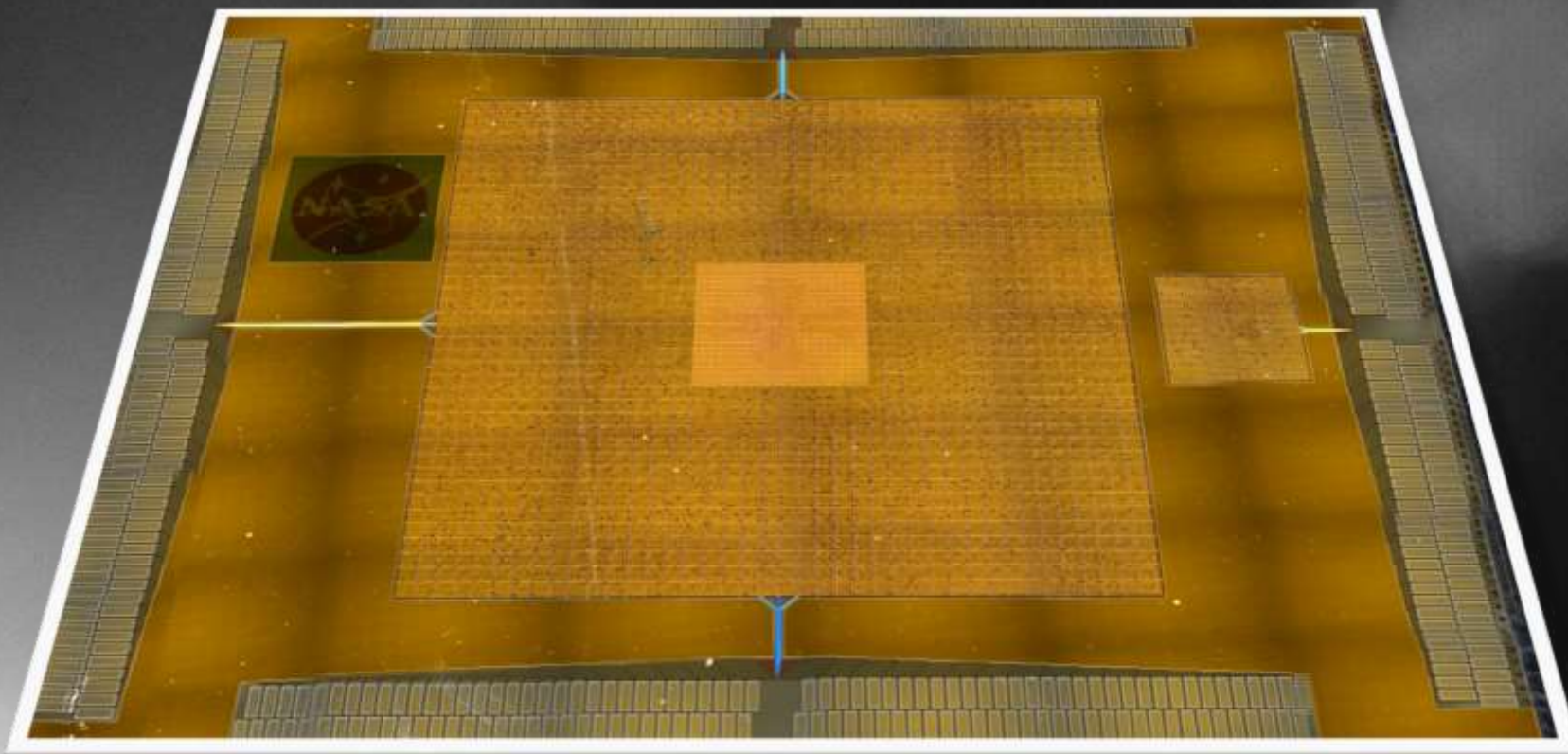
the LYNX X-RAY MICROCALORIMETER



JATIS
VOL. 5 · NO. 2
April 2019

LXM Working Group Leads: Simon Bandler (GSFC), Megan Eckart (LLNL)

LXM working group members: Kent Irwin (Stanford), Joel Ullom (NIST), Doug Bennett (NIST), Ben Mates (NIST), Dan Swetz (NIST), Stephen Smith (GSFC), Kazu Sakai (GSFC), Mike DiPirro (GSFC), Wonsik Yoon (GSFC), Dan McCammon (Wisconsin), Kevin Ryu (MIT-LL), Tali Figueroa-Feliciano (Northwestern), Jeff Olson (Lockheed Martin), Ben Zeiger (Luxel)

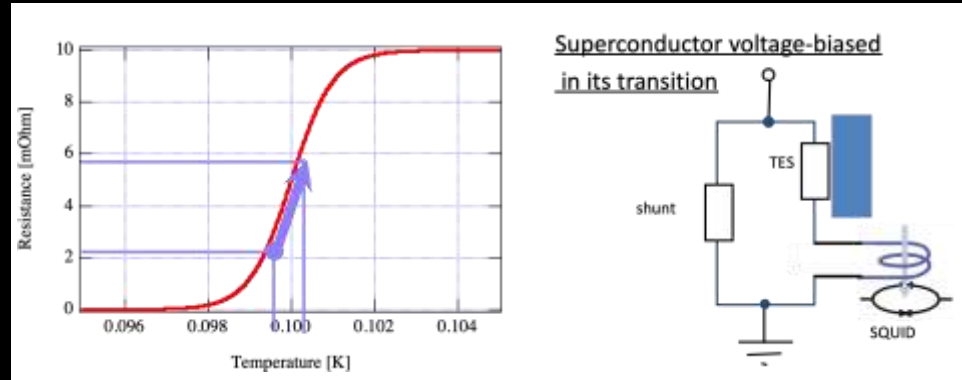
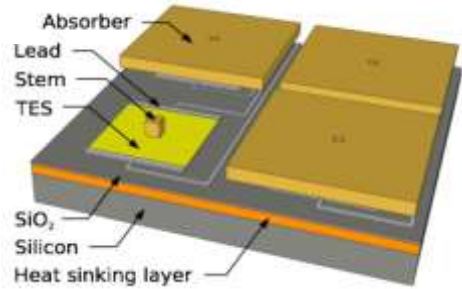


- Have already fabricated arrays with nearly 100k pixels (half final array size).
- Large array of microcalorimeter pixels on 100µm pitch now feasible: integrated pixels with 100µm pitch, multi-layer, micro-stripped, superconducting wiring buried beneath planarized substrate (MIT-LL).
- Allows fabrication of required array size with wiring yield ~100%.
- Although there are ~100k pixels, design requires only ~4k sensors (transition-edge sensors), in the 5' *Main Array* (similar to APOGEE X-IFU), and 3.6k sensors in the UHR array.

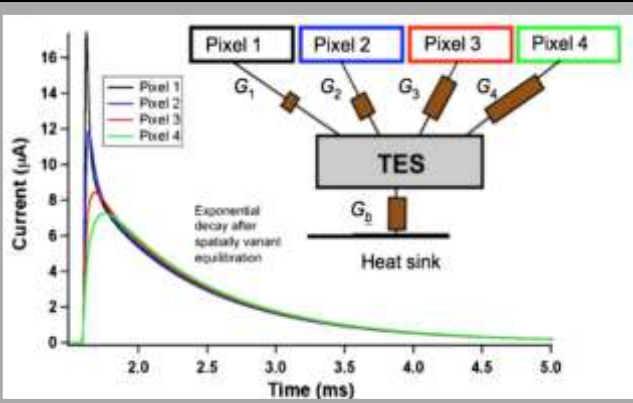
Transition-edge sensor (TES) microcalorimeters

Single Pixels (UHR Array)

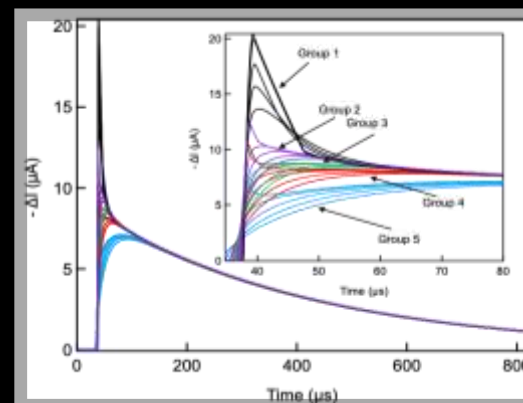
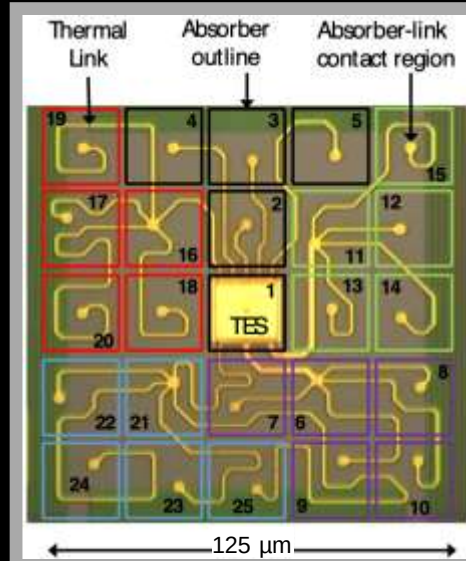
- Required performance ($\Delta E \sim 0.3$ eV) demonstrated at low energies
- Calibration using 3 eV photons from blue laser diode
- Work is supported by University of Wisconsin



Hydras (Main & Enhanced Main Arrays)

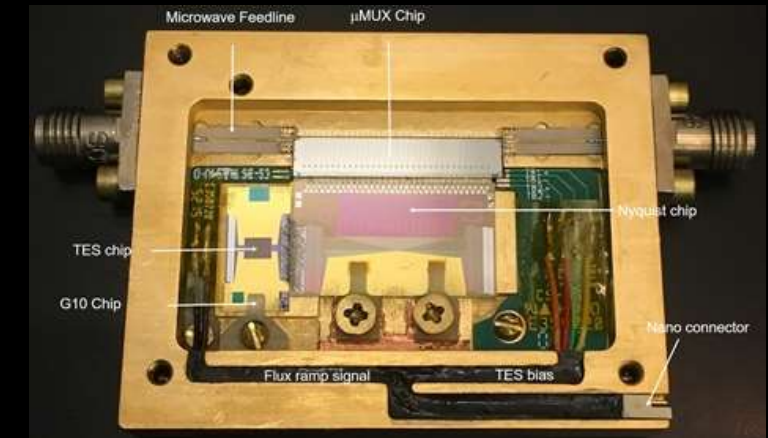


Hydra before absorber deposition



Microwave SQUID Readout

The microwave multiplexed SQUID readout allows for a large number of TESs to be coupled to individual resonator circuits at a range of frequencies. These are all coupled to a **single** HEMT amplifier for bringing out all the signals to the room temperature electronics.



μMUX readout of X-rays demonstrated at GSFC (collaboration between NIST-Boulder & GSFC))

- Discrimination between pixels demonstrated down to 300 eV.
- Achieved $\Delta E_{FWHM} = 3.34 \pm 0.02$ eV (50 μm pitch) & $\Delta E_{FWHM} = 1.66 \pm 0.02$ eV (25 μm pitch)
- Required performance for *Main Array* & *Enhanced Main Array* demonstrated at 1.5 keV & 6.4 keV.

[Stephen Smith et al. 2019]

the LYNX X-RAY MICROCALORIMETER

TECHNOLOGY DEVELOPMENT PLAN

Development Challenges

- Optimize slew rates for thermal multiplexed pixels to minimize μ MUX readout requirements
- Integrate heatsinking underneath pixels to reduce thermal crosstalk
- Advance cryocooler & ADR technologies within schedule and budget

TRL 4: Following completion of pixel circuit design, μ MUX readout is optimized. Demonstrate readout of >100 sensors on a single readout channel with representative energy resolution.

AD² = 2-3 (TRL 3 → TRL 4)

TRL 5: Demonstrate system performance is consistent with instrument requirements.

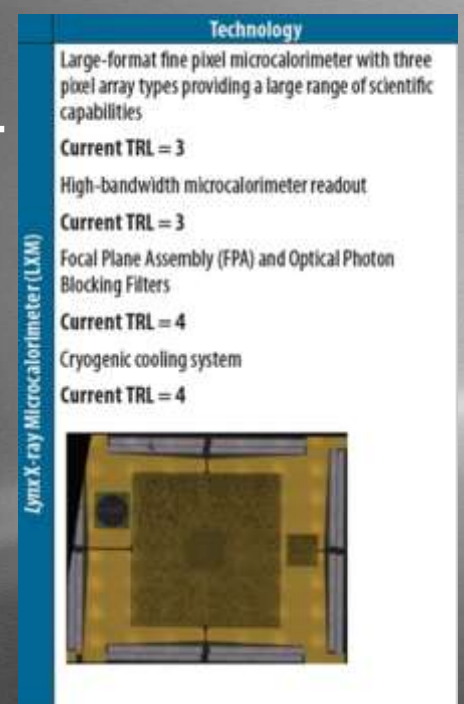
- Detector subarrays with required form-factor and performance.
- Microwave SQUID reading out all three different pixel types and agree with expected performance.
- Cooling system that meets typical TRL 5 level cooling requirements.

AD² = 2-4 (TRL 4 → TRL 5).

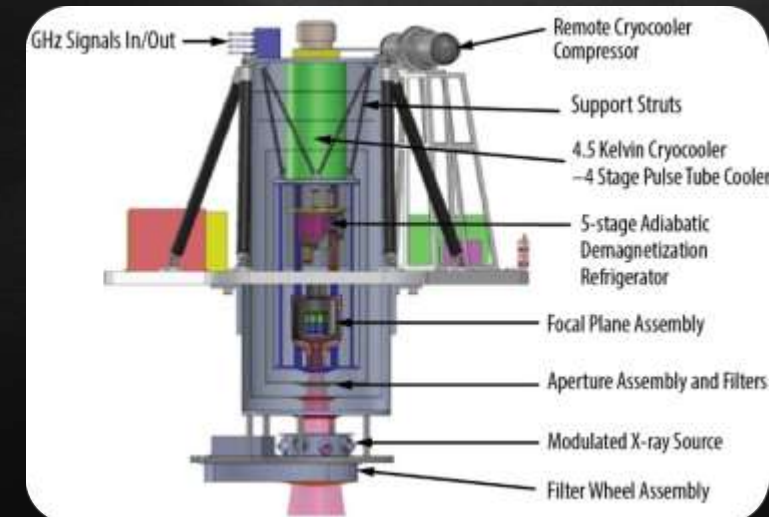
TRL 6: A prototype system demonstration with full-size flight-like array and read-out.

- High pixel yield, flight-like low-temperature readout components
- Flight-like electronics, and representative event processor.
- LXM-like thermal architecture

AD² = 2 (TRL 5 → TRL 6)



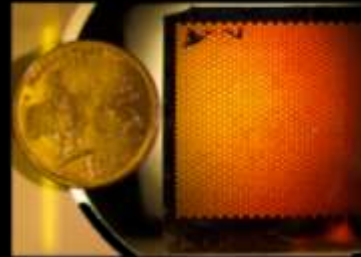
No technical limits or show stoppers. Leverages Heritage from XRISM Resolve and Athena X-IFU



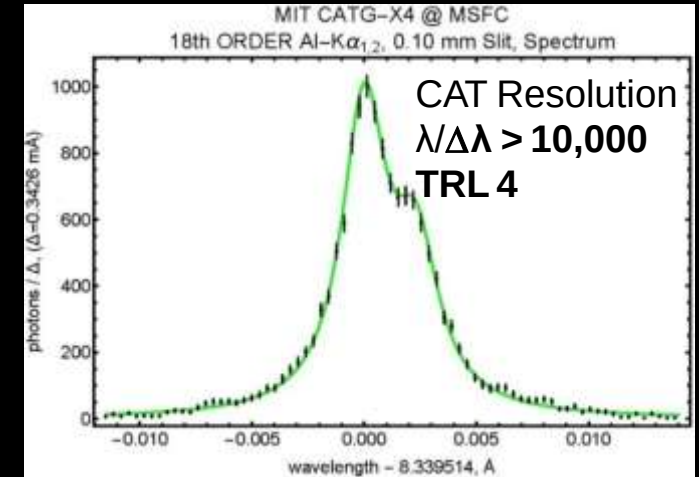
the X-RAY GRATING SPECTROMETER

XGS Instrument Working Group Leads
R. Heilmann (MIT), R. McEntaffer (PSU)

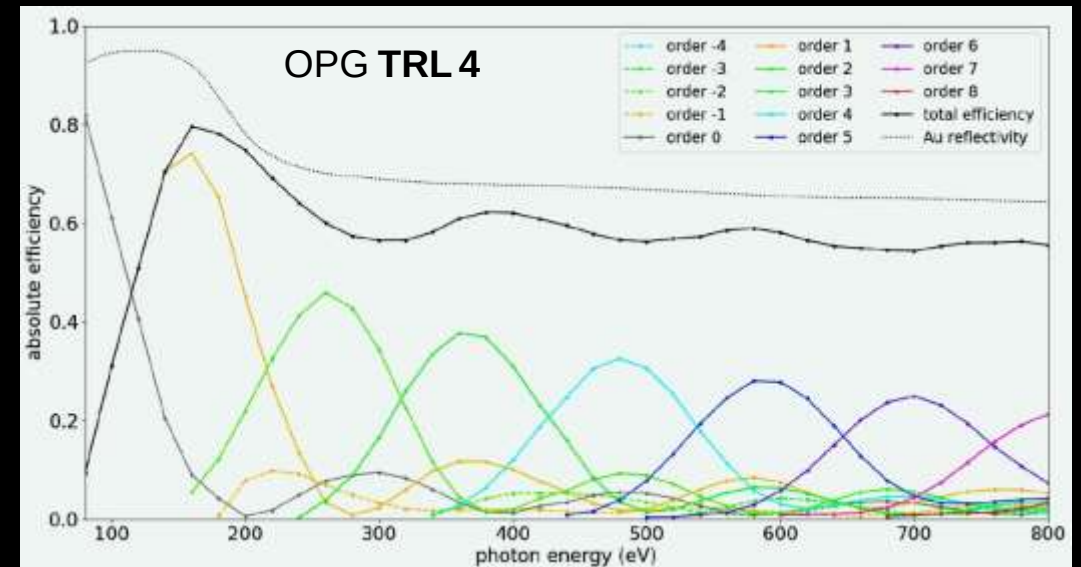
Critical Angle
Transmission
Gratings



Off-Plane
Gratings



(Heilmann et al. 2019)



Total absolute diffraction efficiency exceeds 40% in the SXR bandpass, indicating that gratings fabricated by TASTE meet *Lynx* requirements in terms of spectral sensitivity (McCoy et al. 2020).

Effective Area: 4,000 cm² @ OVII
Spectral Resolving Power: R=5,000 (R = 10,000 Goal)

the X-RAY GRATING SPECTROMETER

TECHNOLOGY DEVELOPMENT PLAN

Development Challenges

- Increase diffraction efficiency (See OPG Recent Results)
- Advance metrology for alignment and mounting to preserve spectral resolution
- Develop “chirped” gratings to maintain Line Spread Function of larger grating facets – can increase the effective area by ~35%! (H.M. Günther, 2020)

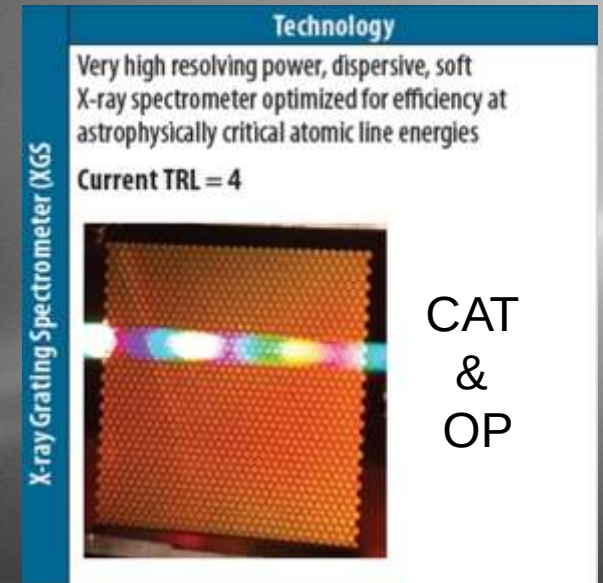
TRL 5: X-ray test an aligned array of representative CAT grating facets illuminated by an aligned array of high-quality mirrors. Gratings are placed in representative positions across the array, with mass simulators in place of missing gratings. The array and grating dimensions are ~1/4 the size of the grating array in the point design. OP gratings test of blazed gratings planned for Q3-Q4 2021 and aligned stack planned for Q1-Q2 2022.

AD² = 3-4 (TRL 4 → TRL 5)

TRL 6: X-ray test an aligned array of representative gratings illuminated by an aligned array of high-quality mirrors. The prototype units must be tested in an operational environment that includes vibration and thermal vacuum.

AD² = 2-3 (TRL 5 → TRL 6)

No showstoppers! Model and experimental testing show that $R > 5,000$ with the projected 0.5-arcsecond PSF Lynx mirrors do not present a significant challenge, and $R > 10,000$ has been demonstrated.



a new GREAT OBSERVATORY

Mission Risk Class A | General Observer-driven Observatory

HIGH OBSERVING EFFICIENCY

- >85% visible at any time
- Continuous data collection 1 - 100 ksec/target and 1-20 targets / day

LONG MISSION LIFE:

- 5 years baseline
- Provisioned for 20 years
- Provides for in-space servicing
- SE-L2 a relatively benign environment

RELAXED COMMUNICATION

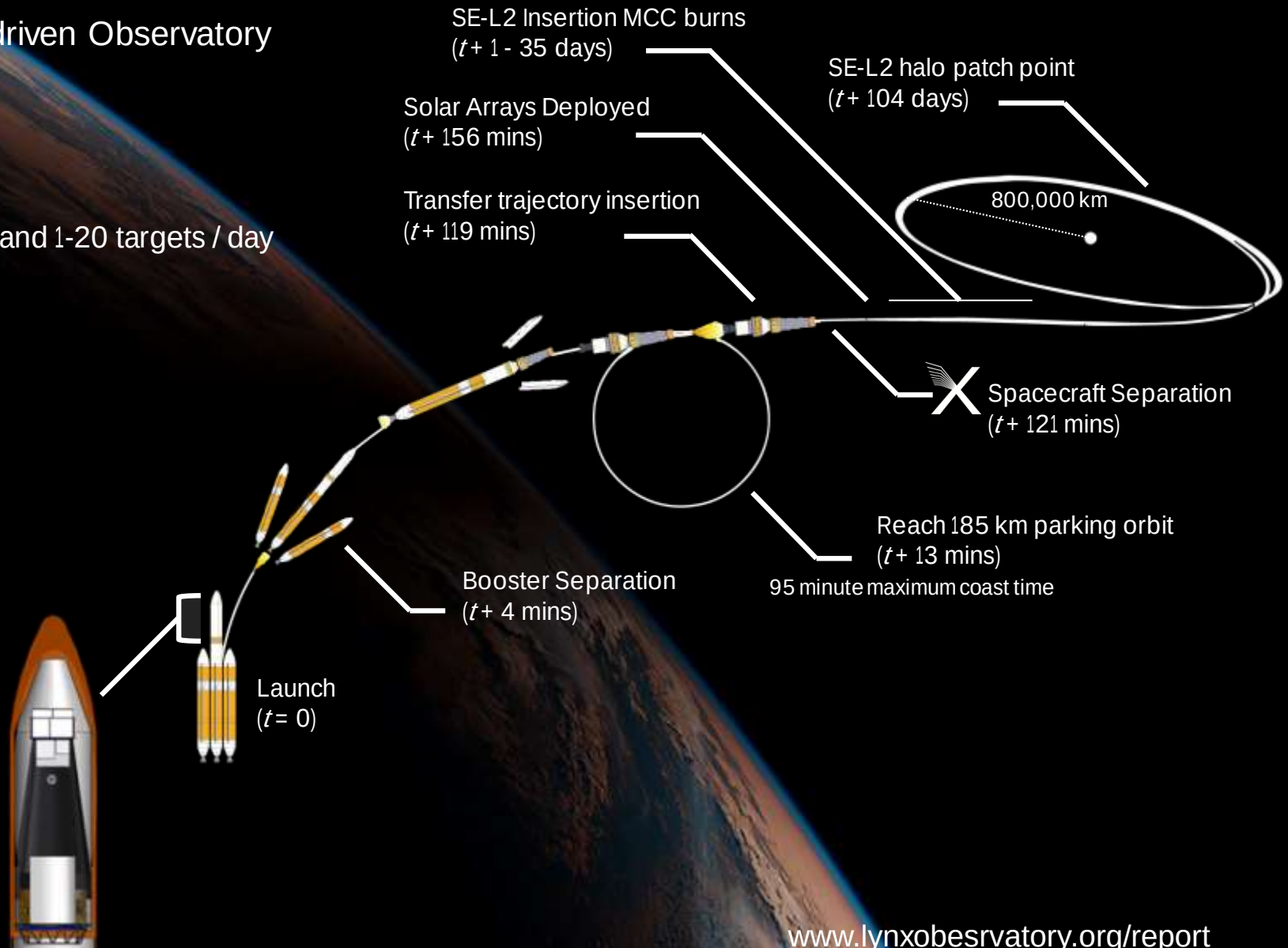
- Up to 3 passes per day via DSN
- Maximum of 240 Gbits / day
- Downlink rate of 22.2 Mb

PROVEN OPERATIONS

- Tested ground system data processing and delivery, archiving, software, etc.

FLEXIBLE LAUNCH VEHICLE

- Heavy class, 5m fairing
- SLS co-manifested payload possible



www.lynxobesrvatory.org/report

Ascent timeline provided by NASA LSP for Delta IV Heavy



C O N C L U D I N G R E M A R K S



TRANSFORMATIONAL SCIENCE

TESTED MISSION DESIGN
leveraging STRONG HERITAGE

STATE *of the* ART PAYLOAD
that WE KNOW HOW *to* BUILD

BROAD IMPACT *across the*
ASTROPHYSICAL LANDSCAPE

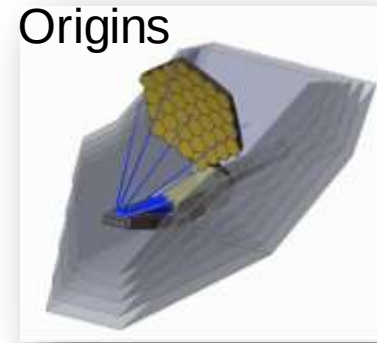
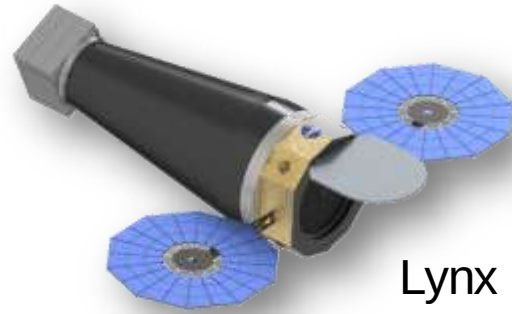
\$4.8B *to* \$6.2B

40 - 70% Confidence Intervals, \$FY20

Independent cost validations fall within $\pm 5\%$ of the Parametric Cost Estimate

Includes \$350M for launch
and ~\$400M for operations (after 2035)

Does not include potential foreign contributions



“One builds large missions not because they can do what a small mission can do better. The large missions can do what a small mission can't do at all.”

- Dr. Megan Donahue,
Professor Michigan State University
President American Astronomical Society
Lynx STDT Member

