



-RAY ASTRONOMY 2019

*Current Challenges
and New Frontiers
in the Next Decade*

Concluding Remarks

Martin Elvis

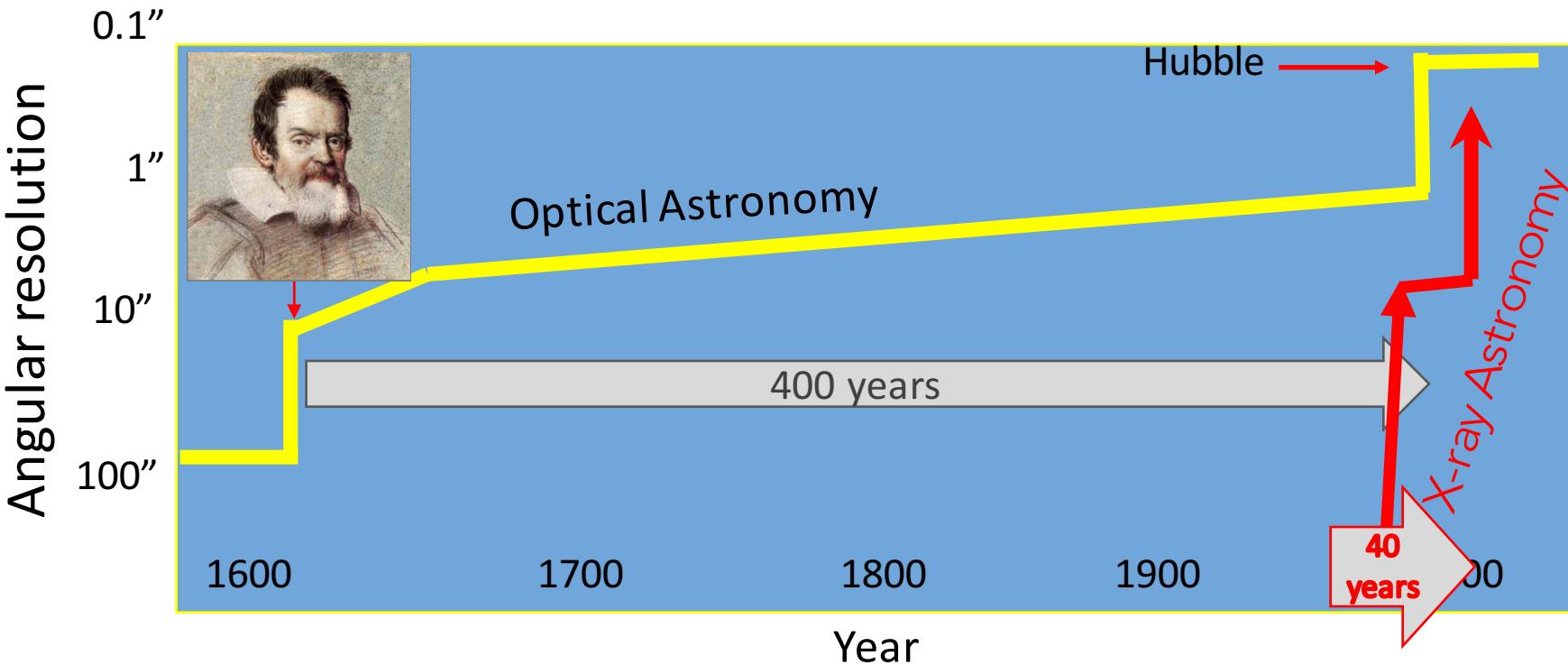
September 13, 2019

Well, that was fun!



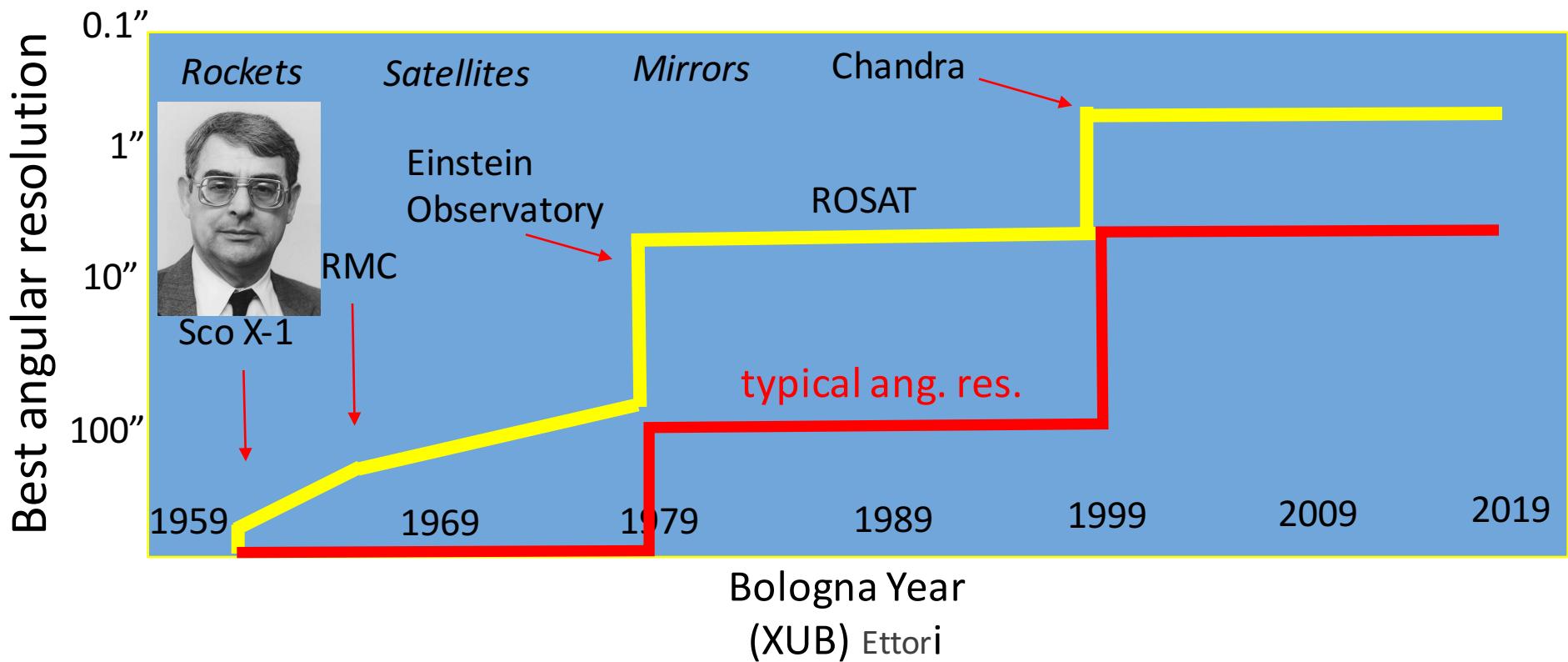
Perspective

Since 1989 X-ray Astronomy
has gone from a 'Galileo' era to a 'Hubble' era



X-ray astronomy took just 40 years
to match 400 years of optical astronomy

How did X-ray Astronomy do that?



X-ray Imaging Since 1969

Tycho's SN of 1572

Lu et al,

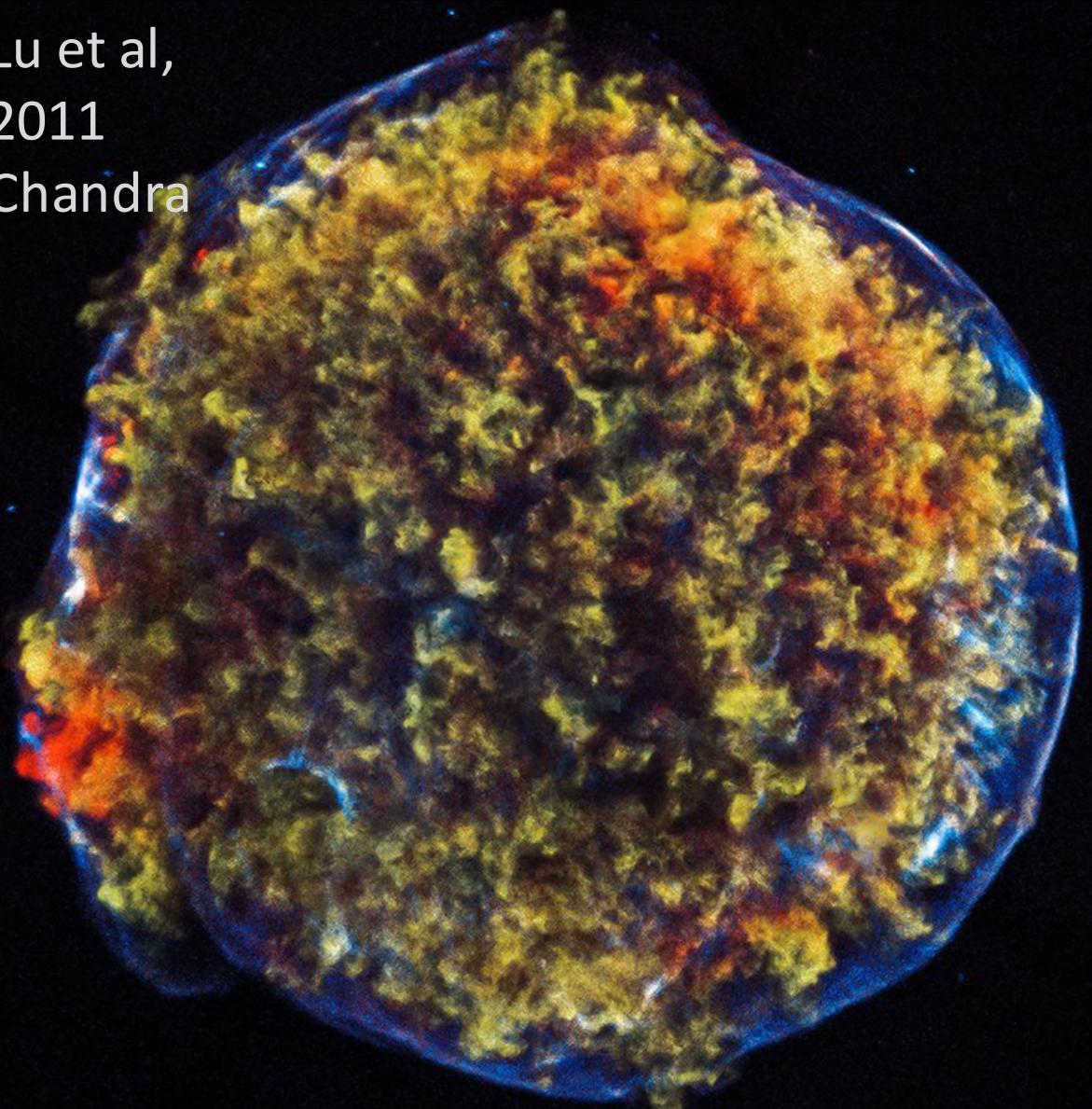
2011

Chandra

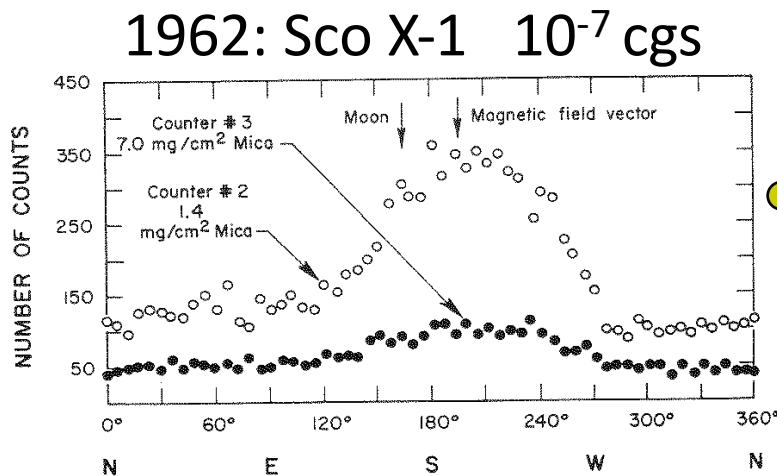
63°

63

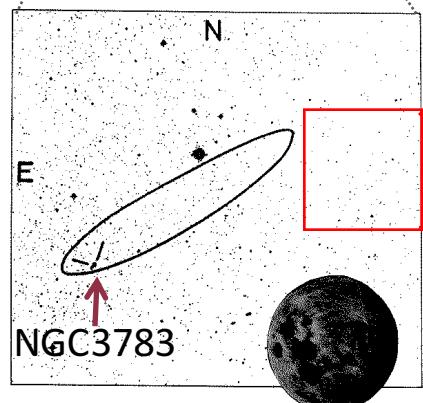
63°



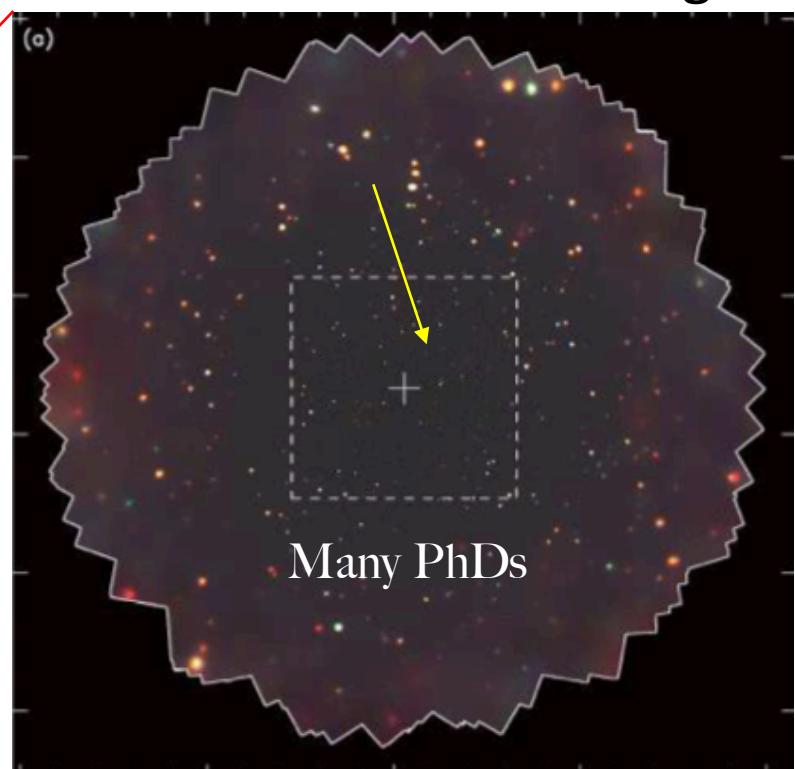
Ten billion times more sensitive



1978: AGN 10^{-11} cgs



2016: 7Ms CDF-S 10^{-17} cgs



1989 - 1999 – 2009 – 2019

It's not just about angular resolution

Einstein Observatory
1978 – 1981



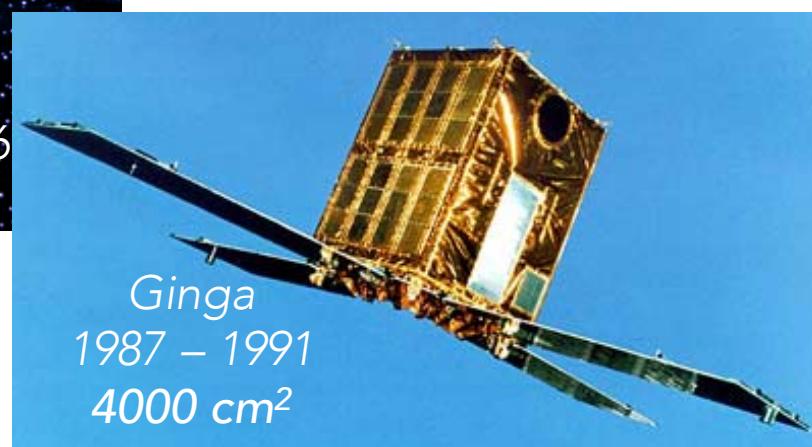
Area



TYCHO'S SUPERNOVA
EINSTEIN OBSERVATORY

120 ARC-SECS

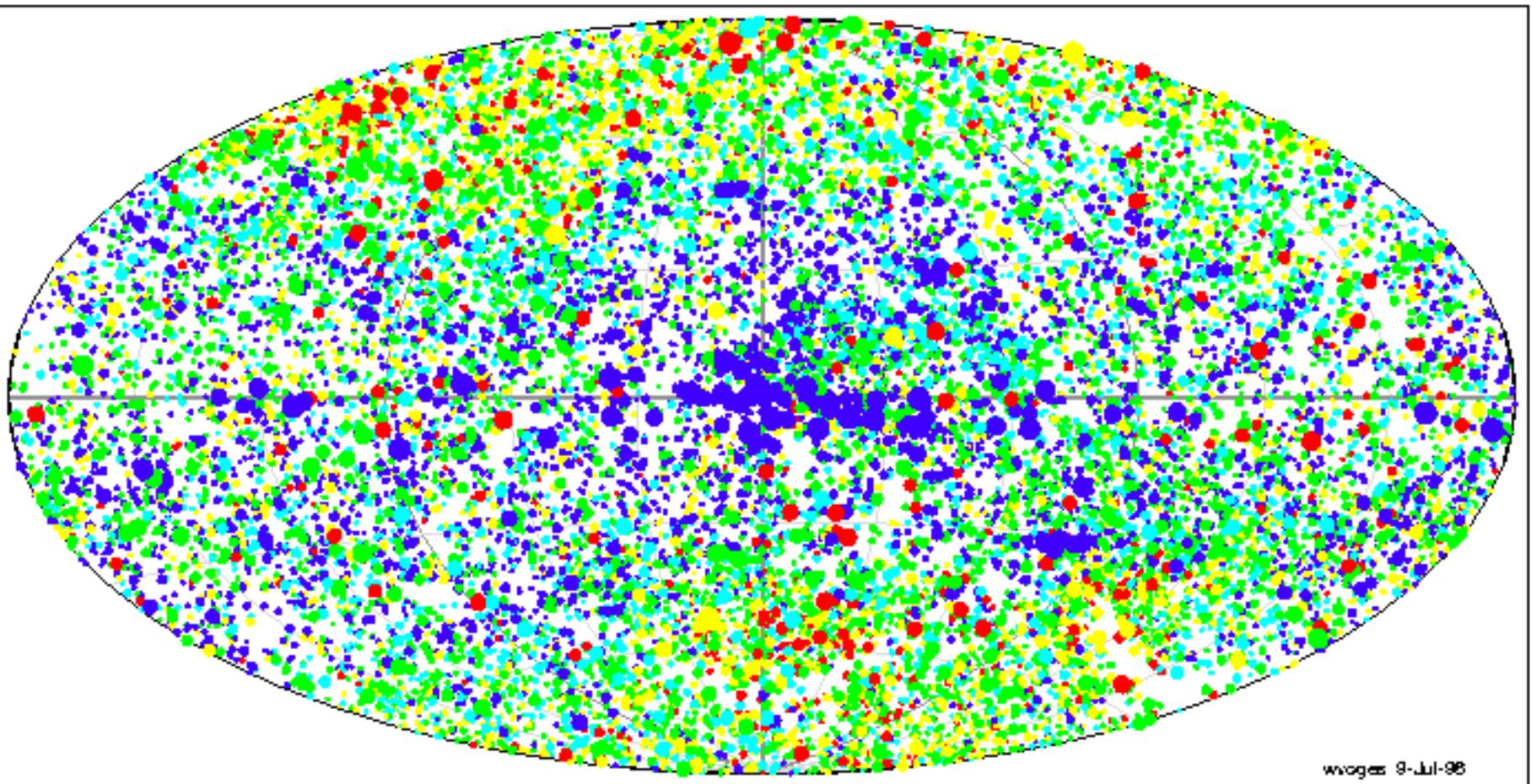
Ginga
1987 – 1991
4000 cm²



1989 1999 – 2009 – 2019

ROSAT ALL-SKY SURVEY Bright Sources

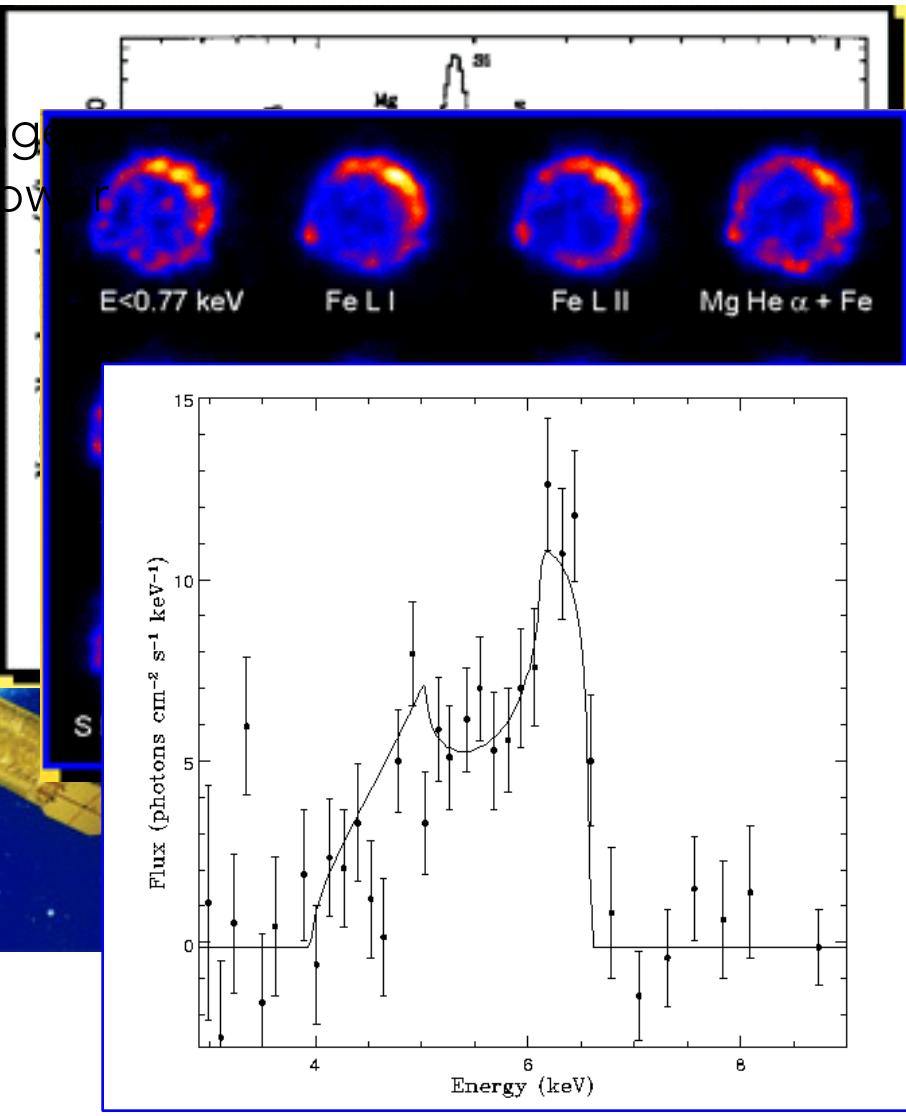
Aitoff Projection
Galactic II Coordinate System



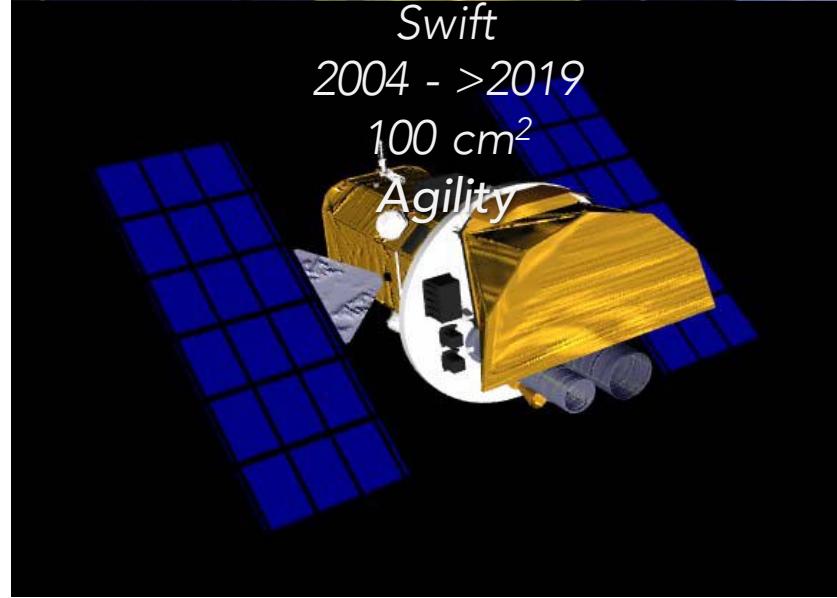
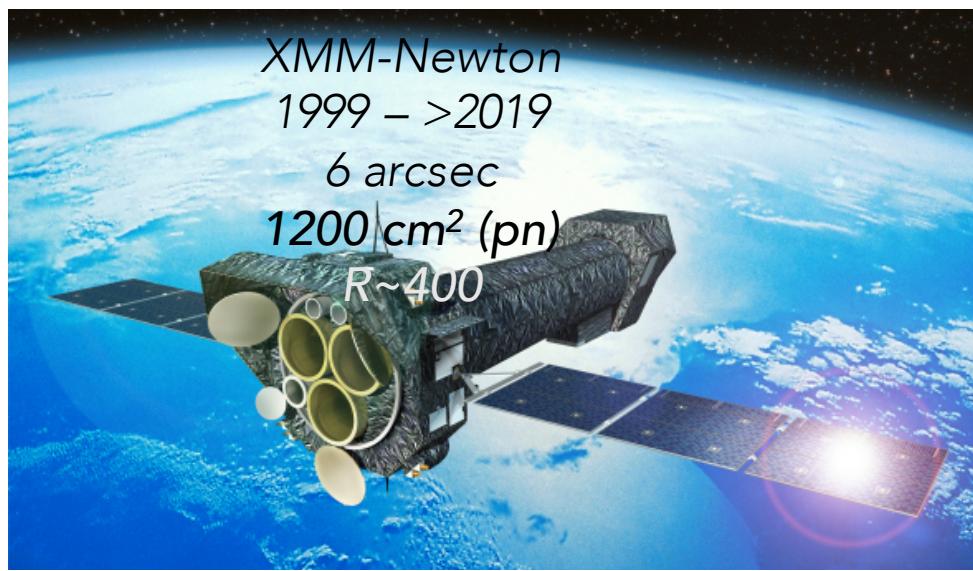
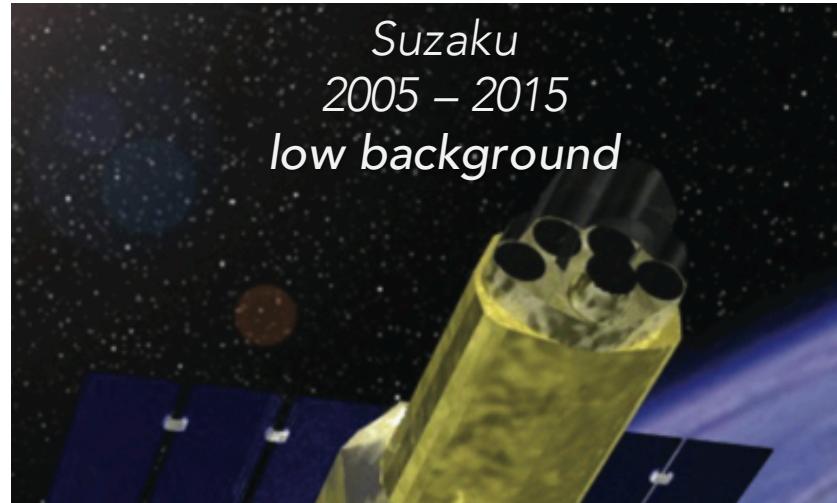
1989 – 1999 – 2009 – 2019 30 Years of Rapid Progress in X-ray Astronomy



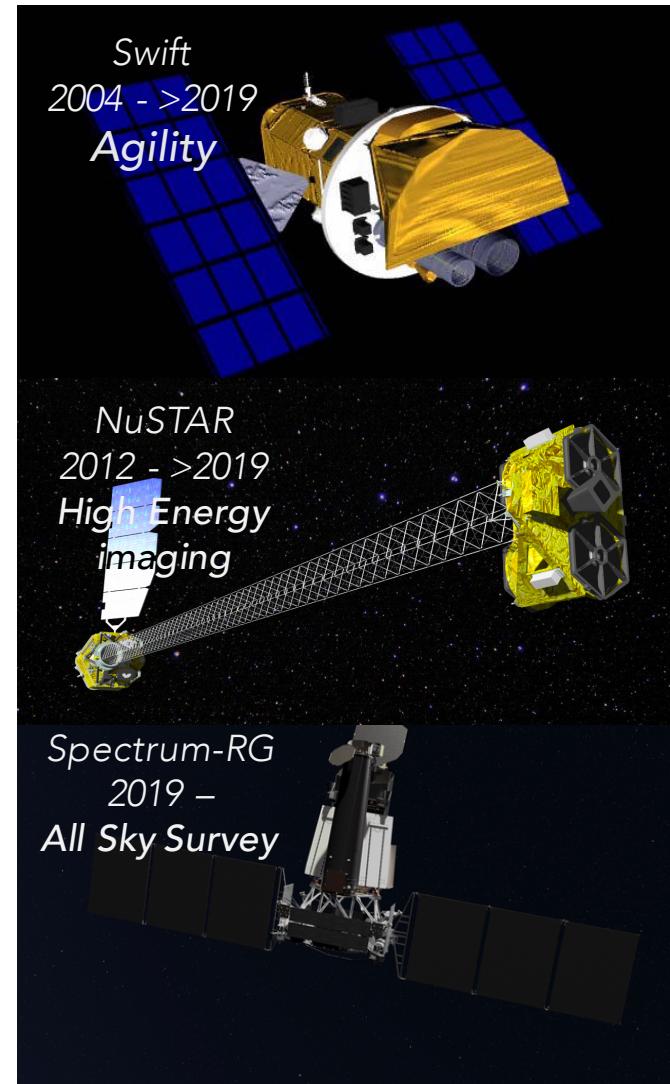
Sky coverage
Resolving power
Timing



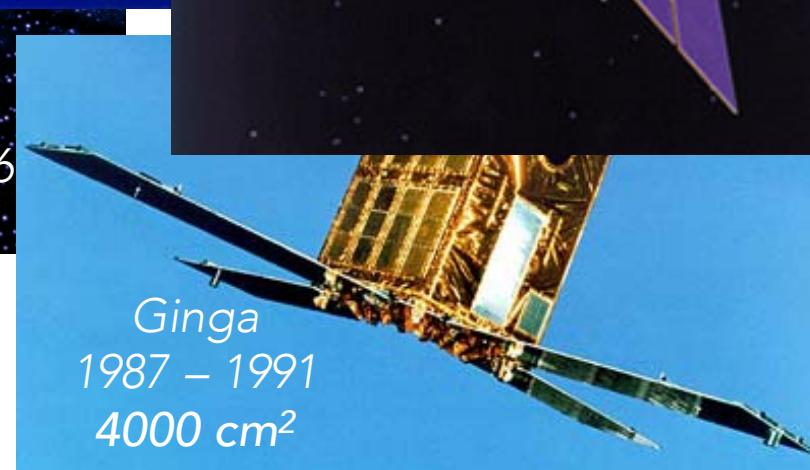
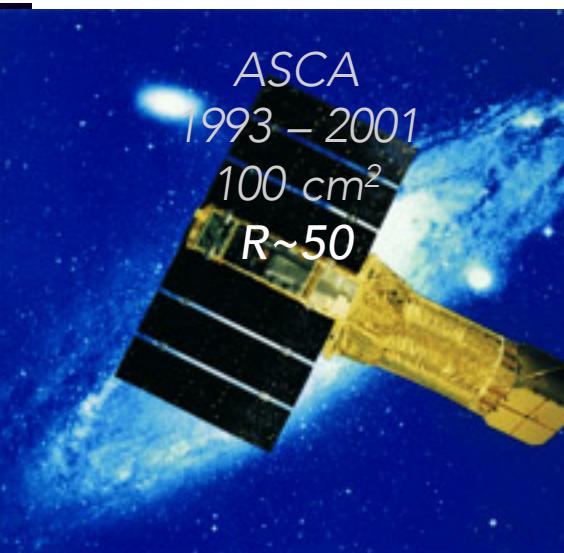
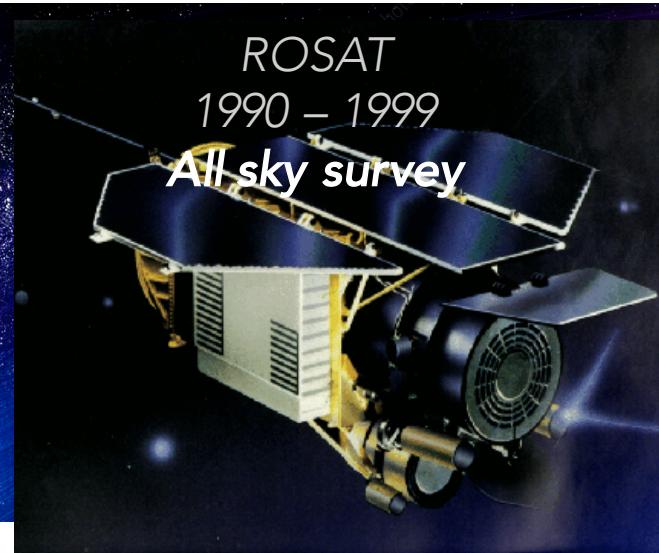
1989 - 1999 - 2009 - 2019
30 Years of Rapid Progress in X-ray Astronomy



1989 - 1999 – 2009 - **2019** 30 Years of Rapid Progress in X-ray Astronomy



1989 ~~1999~~ - 2009 – 2019
30 Years of Rapid Progress in X-ray Astronomy



1989 X 1999 X 2009 X 2019
30 Years of Rapid Progress in X-ray Astronomy



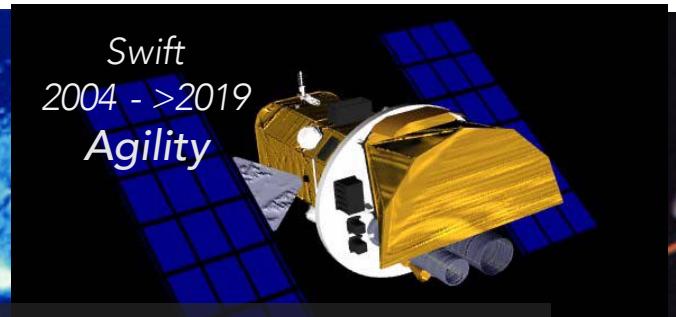
XMM-Newton
1999 – >2019



Martin Elvis, melvis@cfa.harvard.edu
X-ray Astronomy, Bologna, 13 Sept 2019.



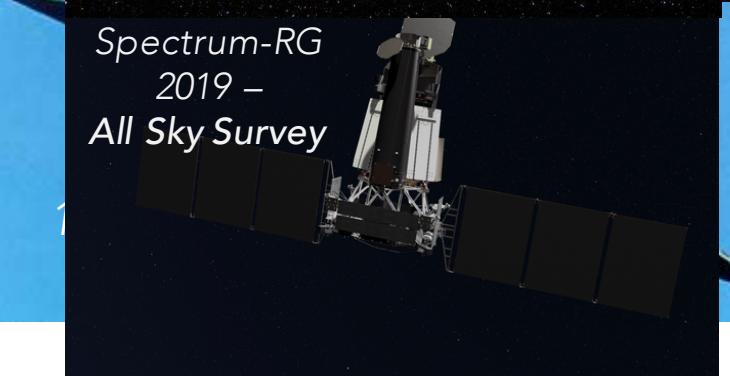
Swift
2004 - >2019
Agility



NuSTAR
2012 - >2019
High Energy
imaging



Spectrum-RG
2019 –
All Sky Survey



2019 Bologna The State of the Art in X-ray Astronomy

6 Science Sessions:

- | | |
|---|-----------------|
| 1. Multi-messenger and transient astrophysics | <i>7 talks</i> |
| 2. Sources in galaxies, point and diffuse | <i>17 talks</i> |
| 3. Hot and Diffuse Plasma | <i>15 talks</i> |
| 4. AGN physics | <i>14 talks</i> |
| 5. AGN demography and evolution | <i>15 talks</i> |
| 6. Cosmic frontiers = high z SMBH | <i>4 talks</i> |
- 33 AGN talks ! 46%*

Lacking: White dwarf systems? SN & SNR? Blazars? Stars? Star formation? Planets?

Imbalance in the field?
or just at this conference?

2019 Bologna

Is there an X-ray Astronomy anymore?

-
- | | |
|---------------------------------|-----------------|
| 1. Multi-messenger astrophysics | 1/7 pure X-ray |
| 2. Sources in galaxies | 8/17 pure X-ray |
| 3. Hot and Diffuse | 9/15 pure X-ray |
| 4. AGN physics | 7/14 pure X-ray |
| 5. AGN demography | 2/15 pure X-ray |
| 6. Cosmic fronts | 2/4 pure X-ray |
- Overall 29/61

2019 Bologna personal highlights

What's new?

What opens paths to the future?

i.e. What would I advise a student to work on?

2019 Bologna personal highlights

New acronyms!

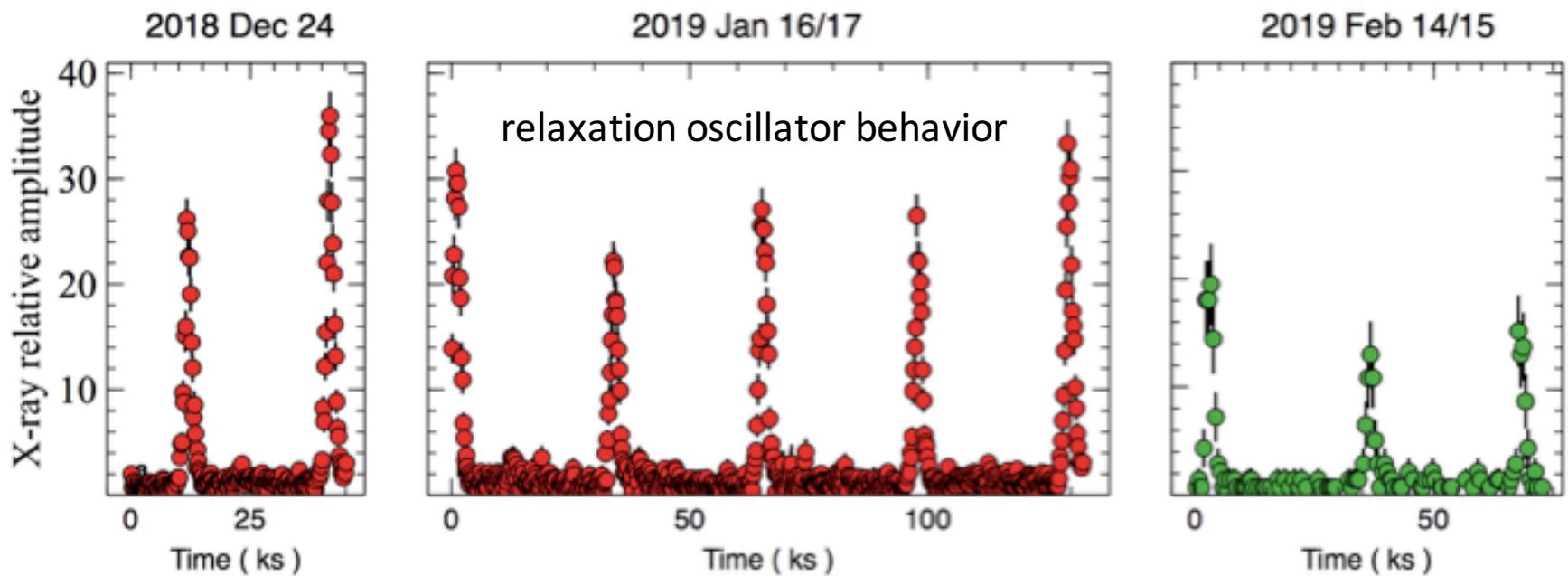
SFXTs (Lara Sidoli) “supergiant fast x-ray transients”

TOEs (Barbara De Marco) “transient obscuring events”

QPEs (Giovanni Miniutti) “quasi-periodic eruptions”

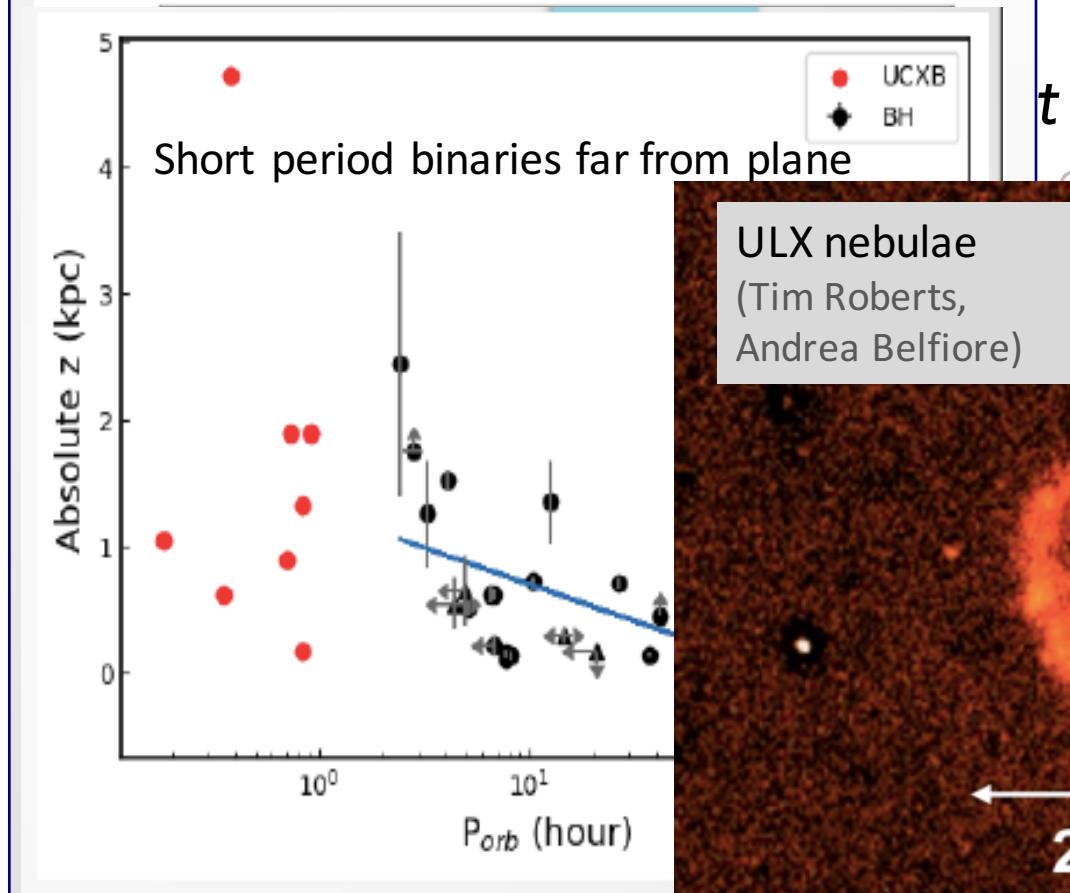
→ new phenomena; new astrophysics.

Physics! RT unstable



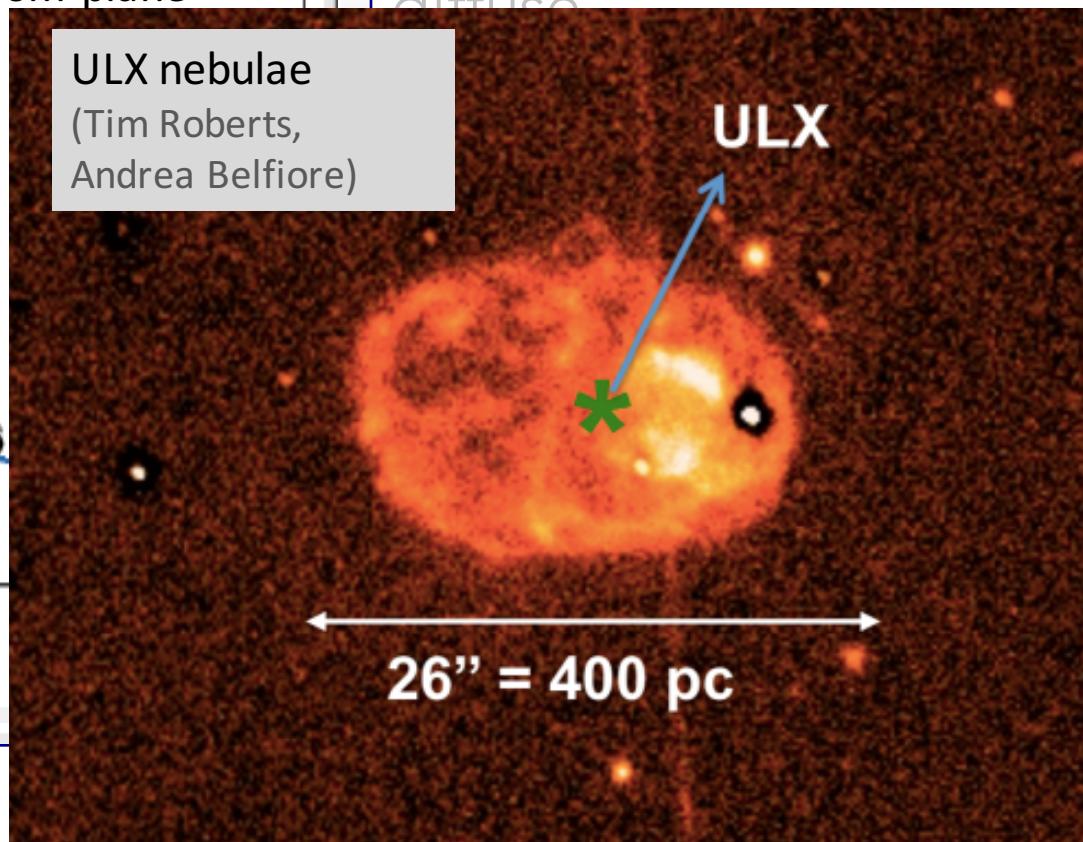
2019 Bologna personal highlights

Anjali Rao: Using Gaia to learn about XRB origins

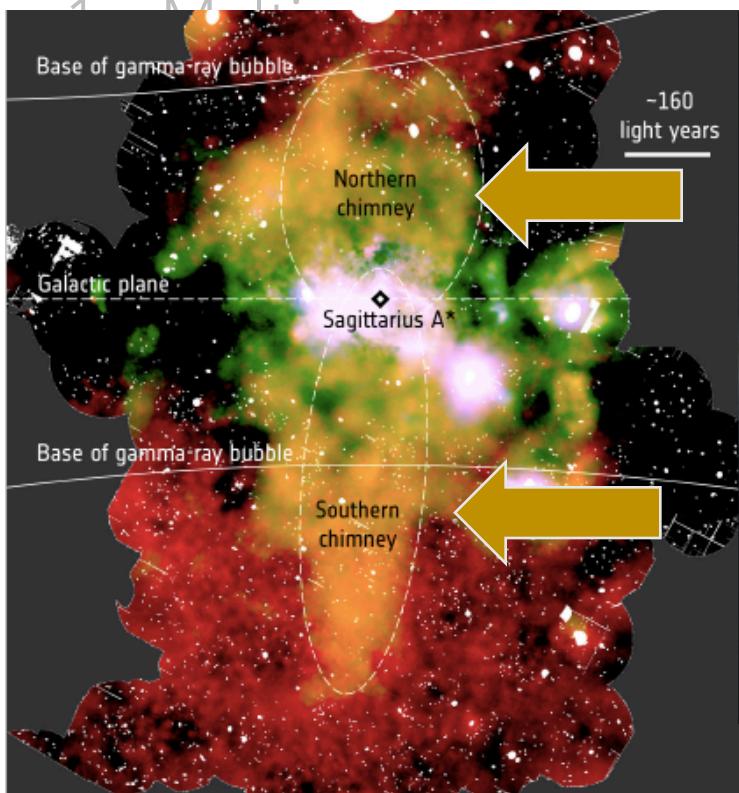


at astrophysics New! Agility!

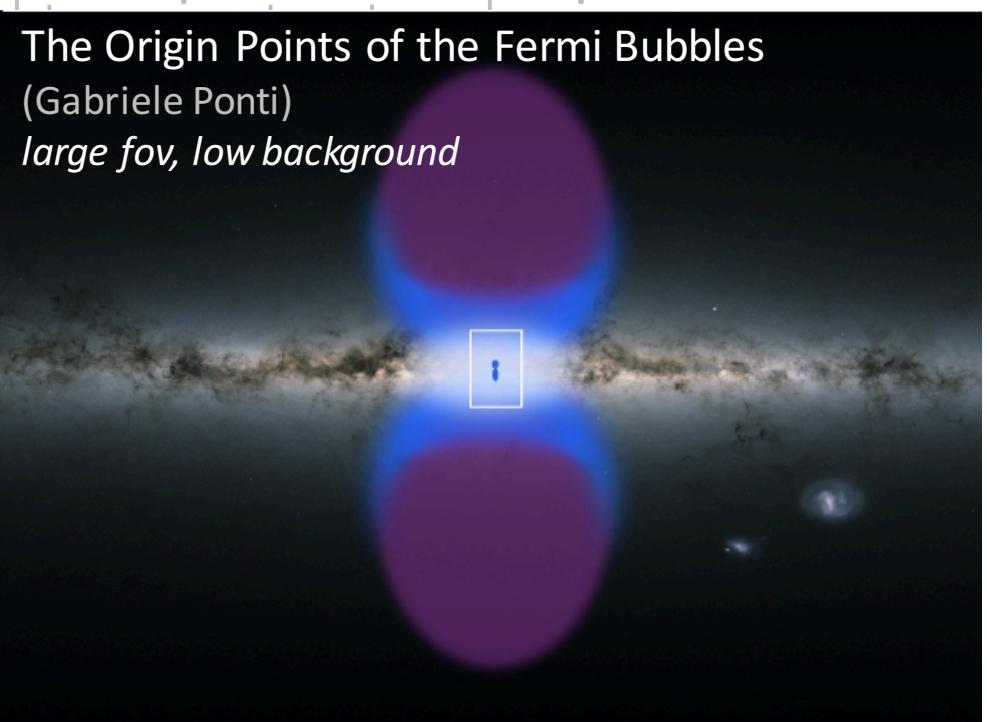
diffuse



2019 Bologna personal highlights



The Origin Points of the Fermi Bubbles
(Gabriele Ponti)
large fov, low background



ESA News/XMM-Newton/G. Ponti et al. 2019, Nature

2019 Bologna personal highlights

1. Multi-messenger and transient astrophysics
2. Sources in galaxies, point and diffuse
3. ***Hot and Diffuse Plasma***

Cluster cosmology via X-ray+S-Z

(Stefano Ettori, D. Barnes,
Vittorio Ghirardini)

Can reach 5%.

Was great.

Now good.

Soon not good enough ☹

Can we reach 1% - 2%? (Pop)

Cosmic Web:

Absorption (Fabrizio Nicastro)

Emission (Thomas Conner)

Web theory getting good (Miao Li)

Just possible but very expensive

→ Athena IFU (Point source removal?)

→ Lynx LXM (=IFU) + XGS (gratings)

Don't rule out Arcus!

2019 Bologna personal highlights

1. Multi-messenger and transient astrophysics
2. Sources in galaxies, point and diffuse
3. Hot and Diffuse Plasma
- 4. AGN physics**
5. AGN demography and evolution
6. Cosmic frontiers

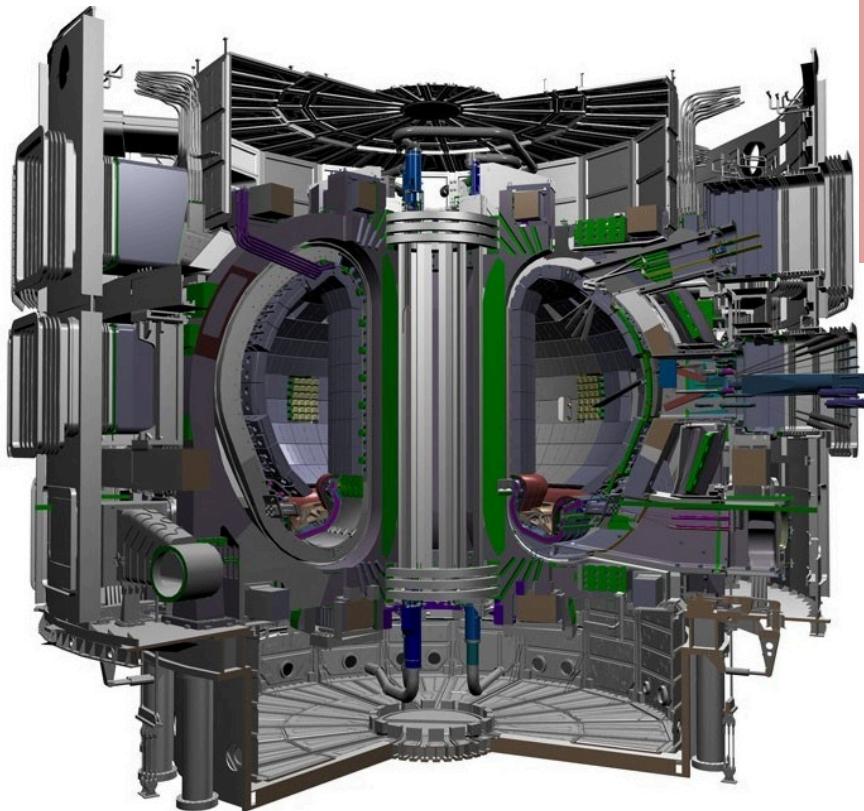
X-ray "Corona" is similar to a Tokamak

*Tokamaks are notoriously unstable
corona sound crossing time ~ 1 day
Yet tight L_{UV}/L_X correlation*

AGN Corona

$T \sim 10^8$ K

$N_e \sim 10^{12}$ cm $^{-3}$
 $B > 10^5$ gauss



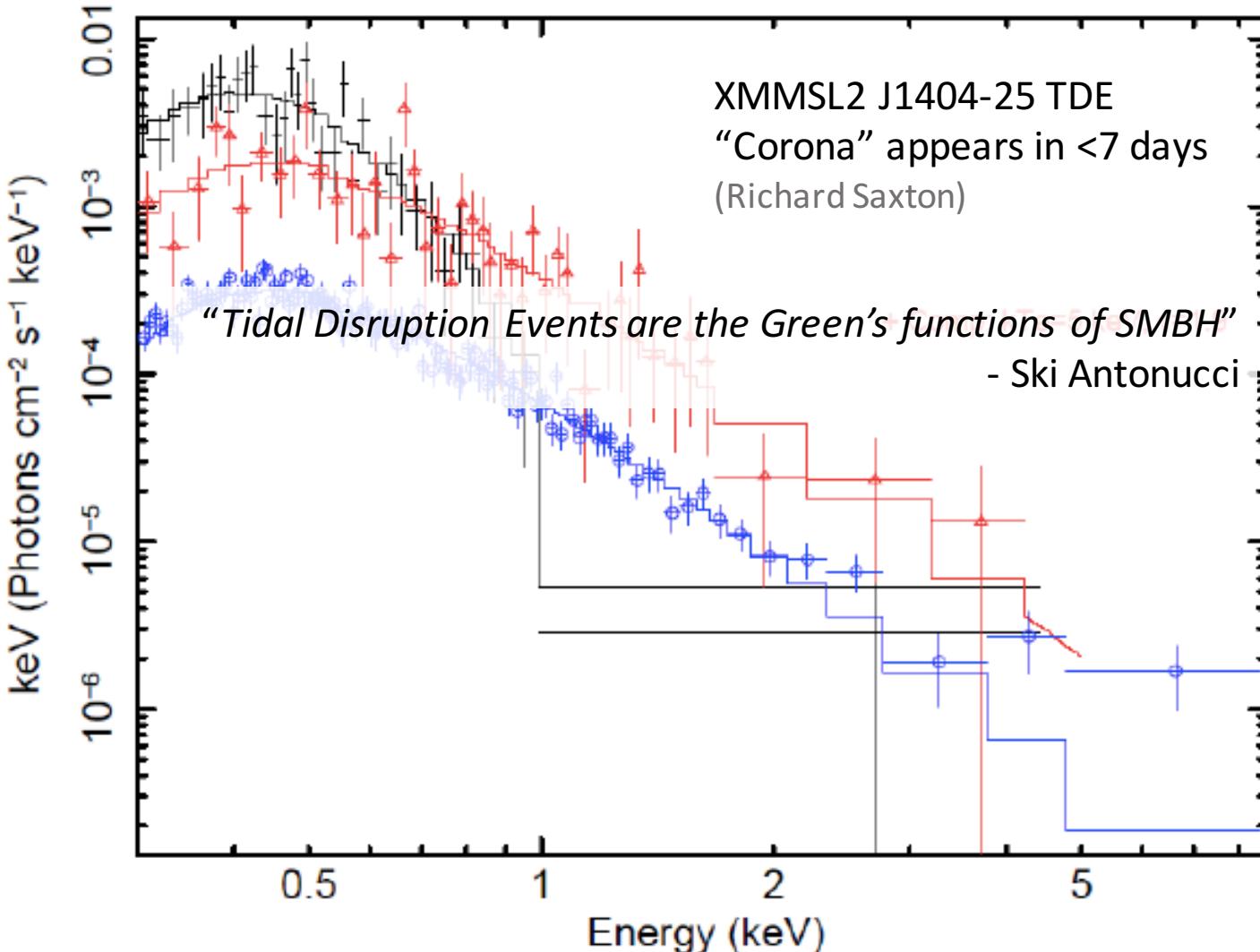
ITER

$T \sim 10^8$ K

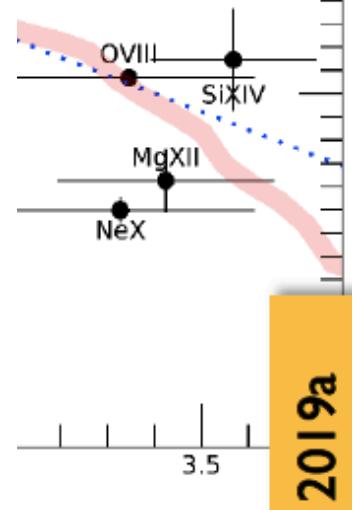
$N_e \sim 10^{15}$ cm $^{-3}$
 $B \sim 10^5$ gauss

2019 Bologna personal highlights

NGC4151: Differential Emission Measure Distribution



the NLR
compression'
(Laor)



2019a

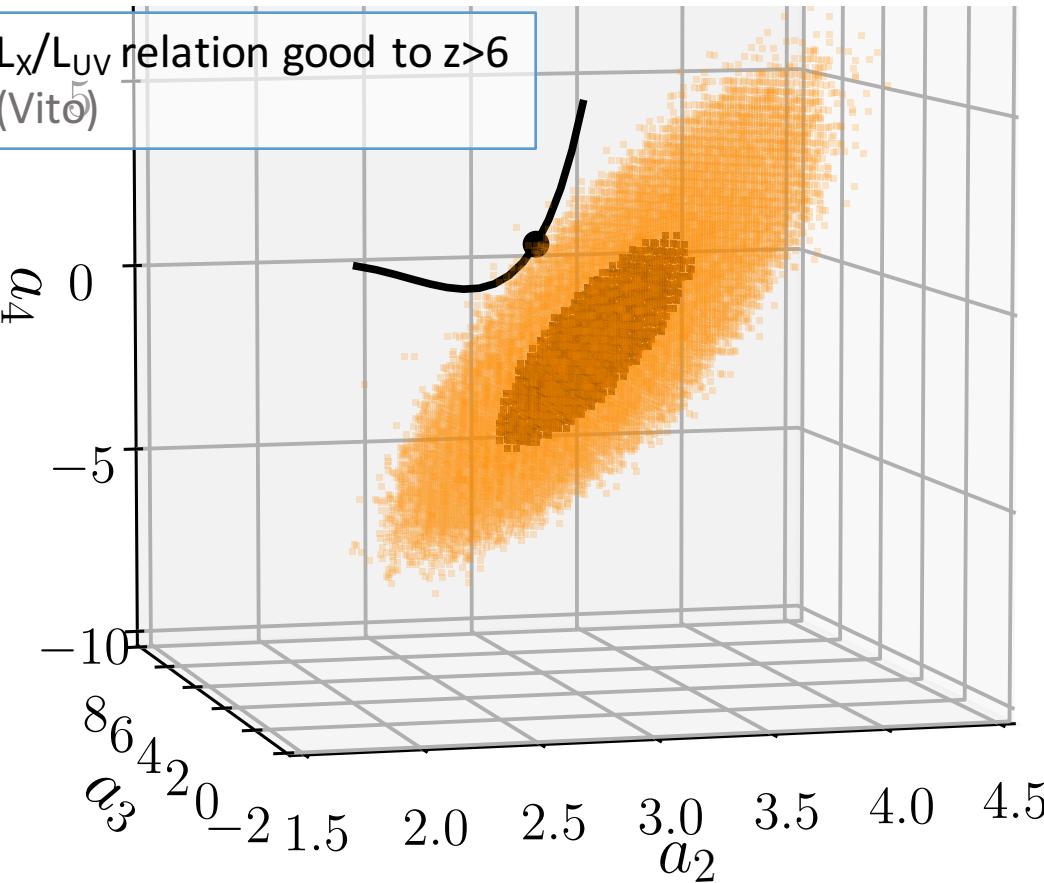
2019 Bologna personal highlights

1. Multi-wavelength AGN
2. Sour
3. Hot
4. AG
5. AG
6. Cos

Cosmography with Quasars

4σ tension Λ CDM (Beta Lusso)

L_x/L_{UV} relation good to $z>6$
(Vito)



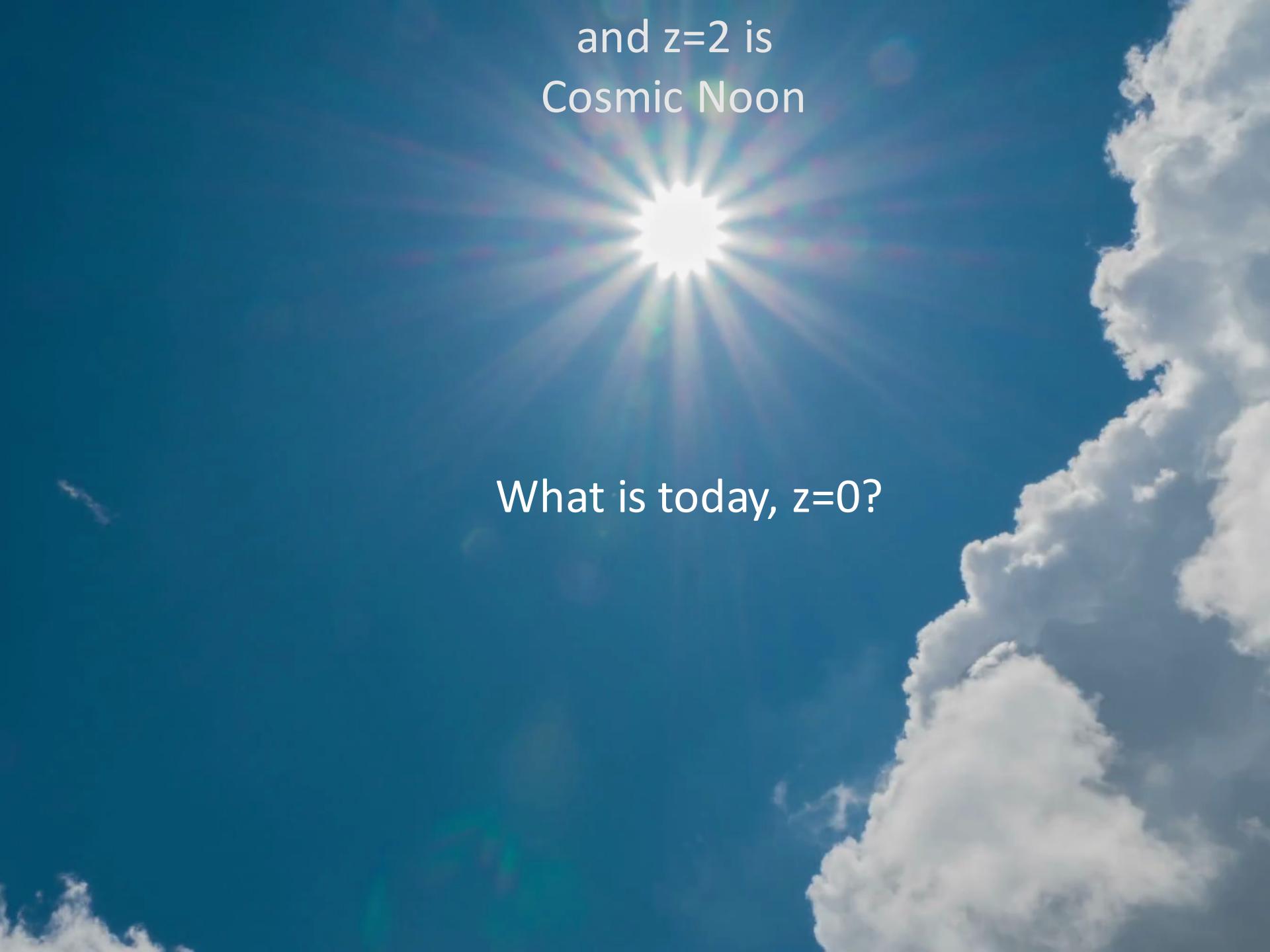
2019 Bologna personal highlights

1. Multi-messenger and transient astrophysics
2. Sources in galaxies, point and diffuse
3. Hot and Diffuse Plasma
4. AGN physics
5. AGN demography and evolution
- 6. Cosmic frontiers**

“Cosmic Dawn to Cosmic Noon”
(Overzier)

If $z \sim 10$ is
Cosmic Dawn



A photograph of a bright sun in a blue sky. The sun is positioned in the upper right quadrant, emitting a starburst of light rays. The sky is a clear, vibrant blue. In the lower right corner, there are large, white, cumulus clouds. The overall scene is bright and airy.

and $z=2$ is
Cosmic Noon

What is today, $z=0$?

$z=0$

COSMIC

HAPPY



HOUR

Thanks to Misty Bentz

2019 Bologna personal highlights

1. Multi-messenger and transient astrophysics
2. Sources in galaxies
3. Hot and Diffuse IGM
4. AGN physics
5. AGN demography, and evolution
6. Cosmic frontiers

SMBH at $z > 7$ are detectable with Chandra
Must be rare.
(Aird, Cappelluti, Vito, Nanni)
→ Athena and (especially) Lynx

Cluster progenitors @ $z > 4$ (Overzier)
Large faint structures → Athena WFI

2019 Bologna personal highlights

1. Multi-messenger and transient astrophysics
2. Sources in galaxies, point and diffuse
3. Hot and Diffuse Plasma
4. AGN physics
5. AGN demography and evolution
6. Cosmic frontiers
- 7. Future Missions**

more 2019 – 2029 – 2039 - 2049

30 Years of Rapid Progress in X-ray Astronomy?

2019 - 2029

10 Years of OK Progress in X-ray Astronomy

Two aging giants

How can we do new things with them?



2019 – 2029

New Science with Old Missions

XMM example: Large Programs

Quasar Cosmology: EPIC

WHIM/IGM: RGS

more Megasecond programs means fewer programs



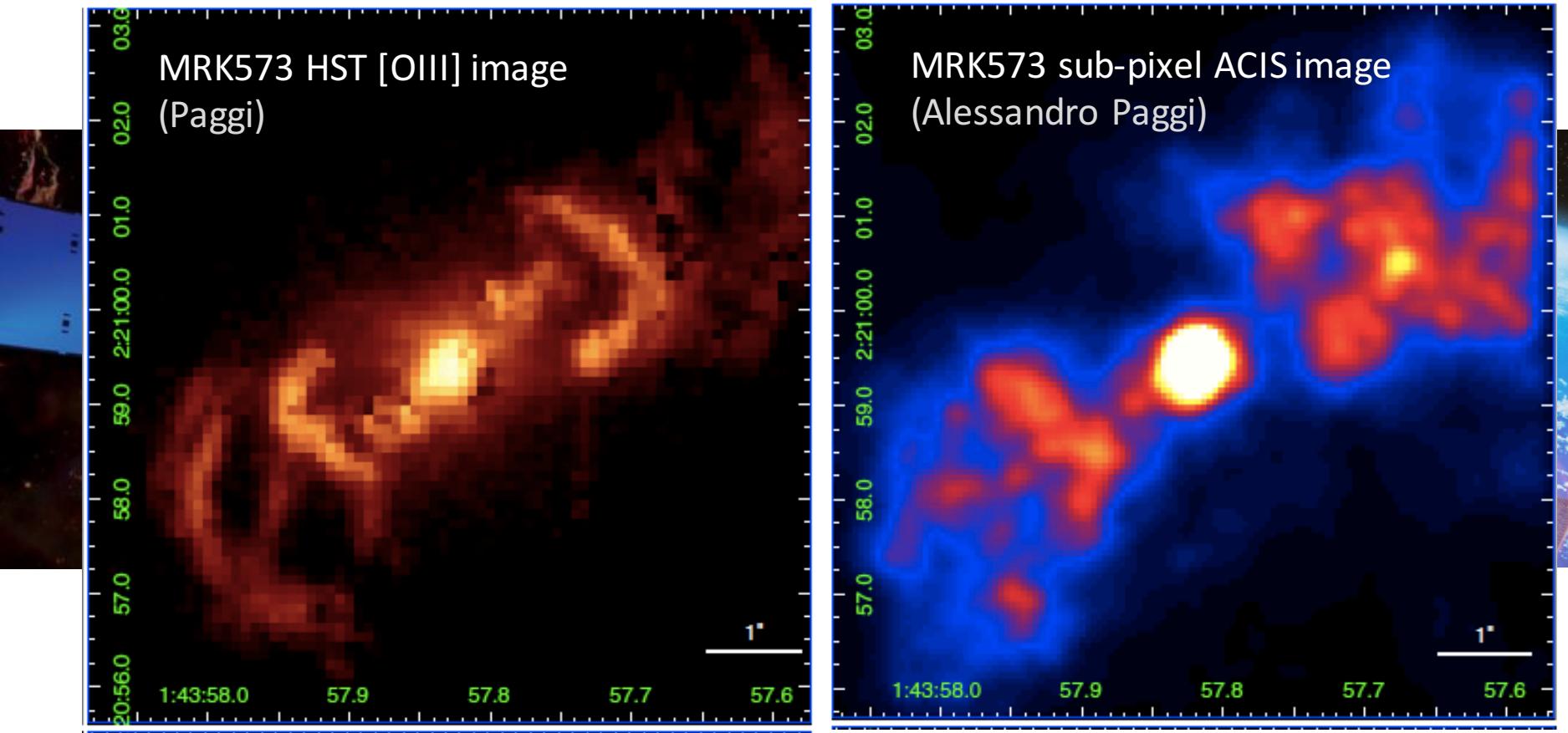
2019 – 2029

New Science with Old Missions

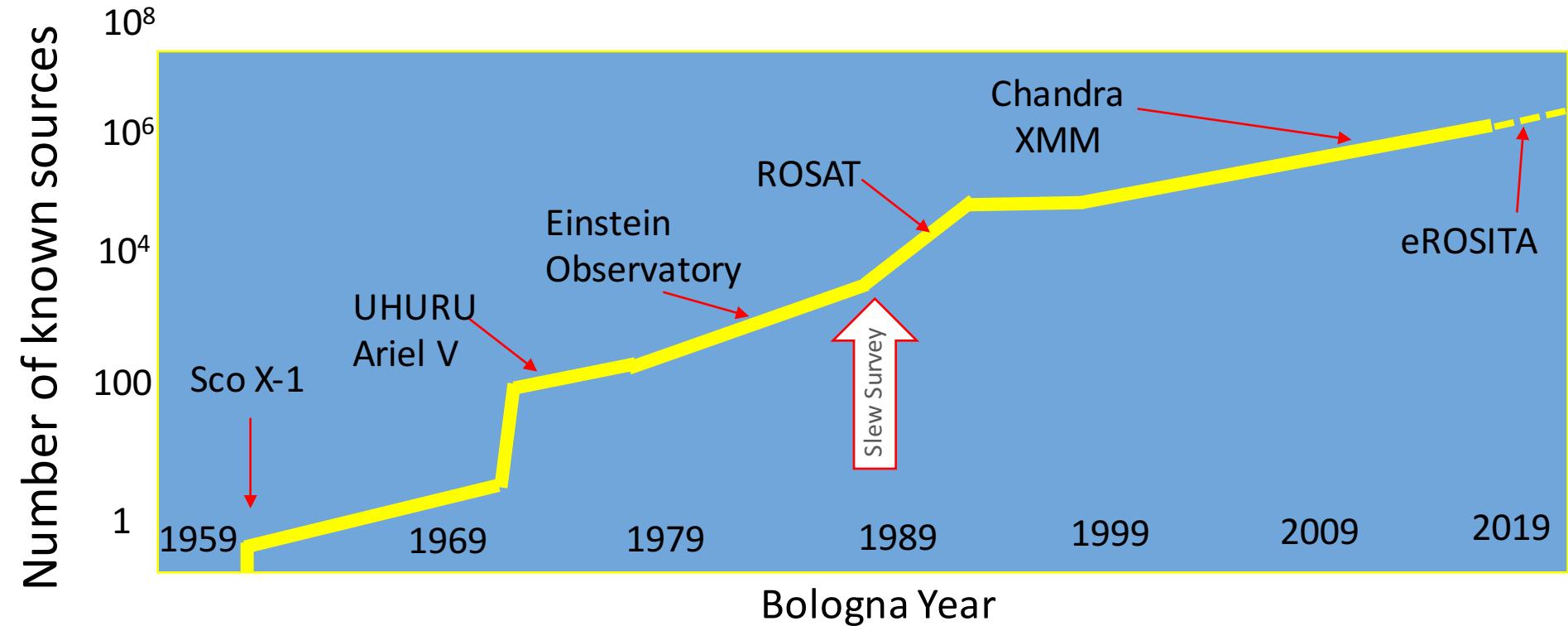
Chandra examples:

Stacking: Fornasini z-2 XRBs

Sub-pixel ~1/4" imaging: Fabbiano AGN feedback



Since 1989 X-ray Astronomy
has gone from 1000 to 1 million sources
 $10^{10} \leftarrow$ optical



3XMM-
DR8
513,000
sources

~1 million X-ray Sources

Opportunity!

X-ray astronomy enters the Big Data era
What new, rare, objects lie within?

CSC 2.0
315,000
sources

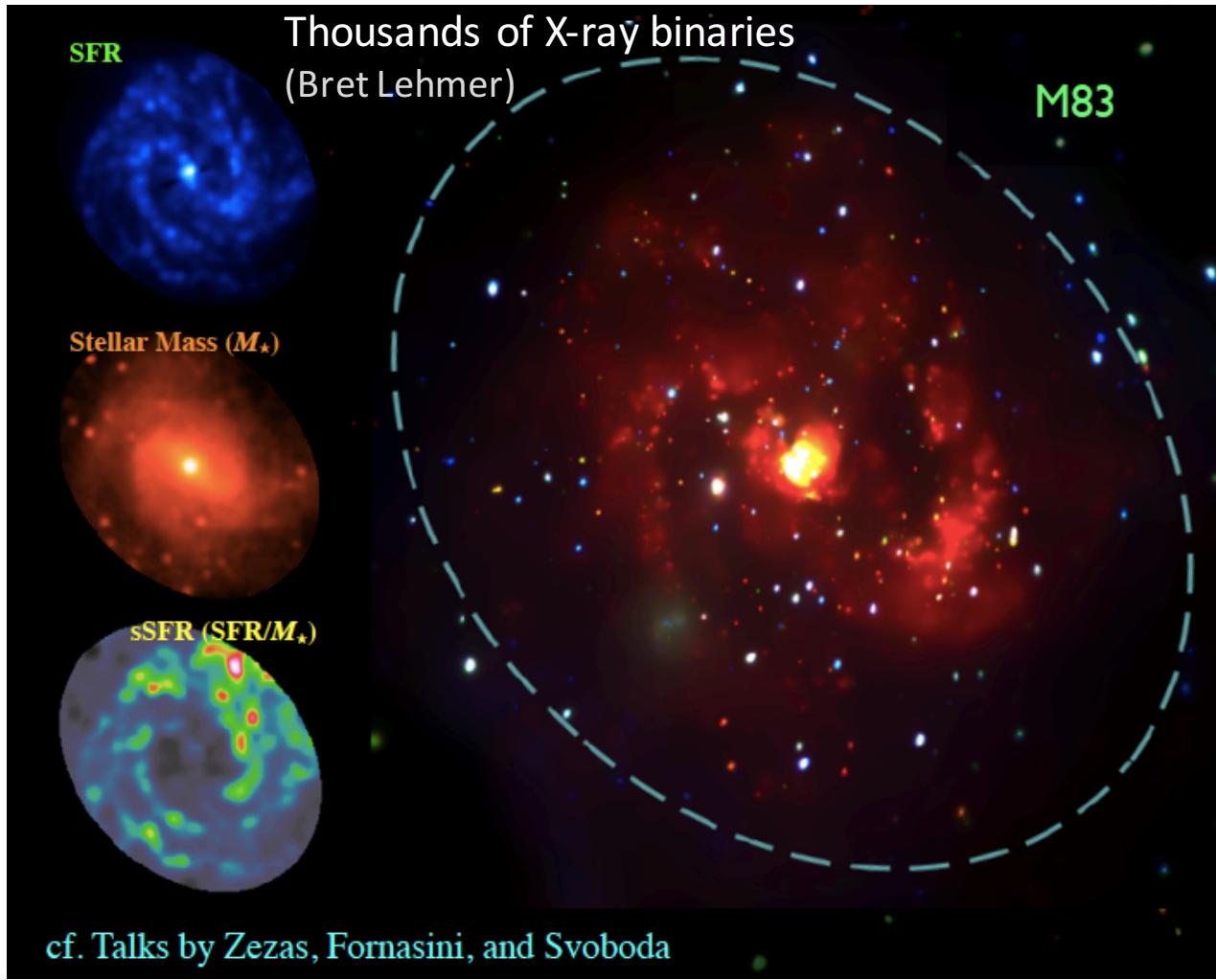
Need: New statistical tools,
Multi-wavelength matching

Swift 2SXPS
~200,000 sources

2019 – 2029

X-ray Astronomy with Large Samples

Well-built Archives Enable New Science



cf. Talks by Zezas, Fornasini, and Svoboda

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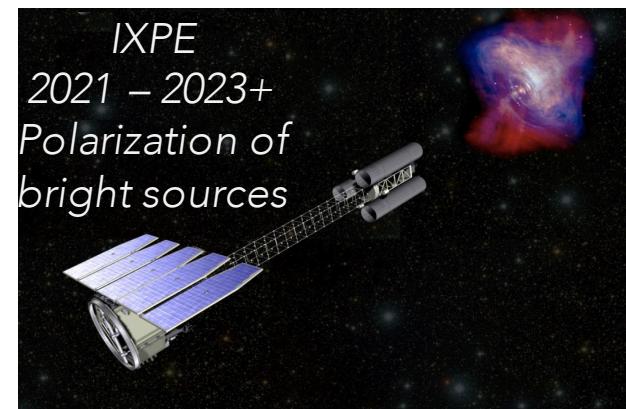
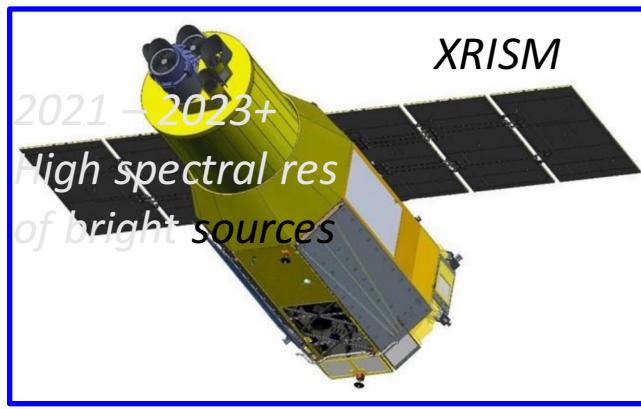
X-ray Astronomy, Bologna, 13 Sept 2019.

2019 – 2029 10 Years of OK Progress in X-ray Astronomy

Real new missions



Spectrum-RG
2019 – 2024+
All Sky Survey



Will these be enough to support today's large X-ray astronomy community?

Wished for new missions

HERMES - FORCE - THESEUS - eXTP - ARCUS – StarX ?

TAP - HEX-P - STROBE-X - AXIS ??

GW follow-up desiderata:
Agility,
Sensitivity,
Field of regard,
Mapping speed

more
30 Years of Rapid Progress in X-ray Astronomy?

by 2029
devoutly wished for

ESA		
HERMES	FORCE	Theseus
Swarm (Burderi)	high-E (Mori)	M5 (Amati)
China eXTP (Zhang)		

NASA (Petre):
Explorer-class ARCUS STAR-X

Probe-class
TAP
HEX-P
STROBE-X
AXIS

more

2019 - 2029 – 2039 - 2049

30 Years of Rapid Progress in X-ray Astronomy

*Our telescopes have been laughably small to an optical astronomer
For photon rates 1/1000 as high*

Now starting the dinner table era



more

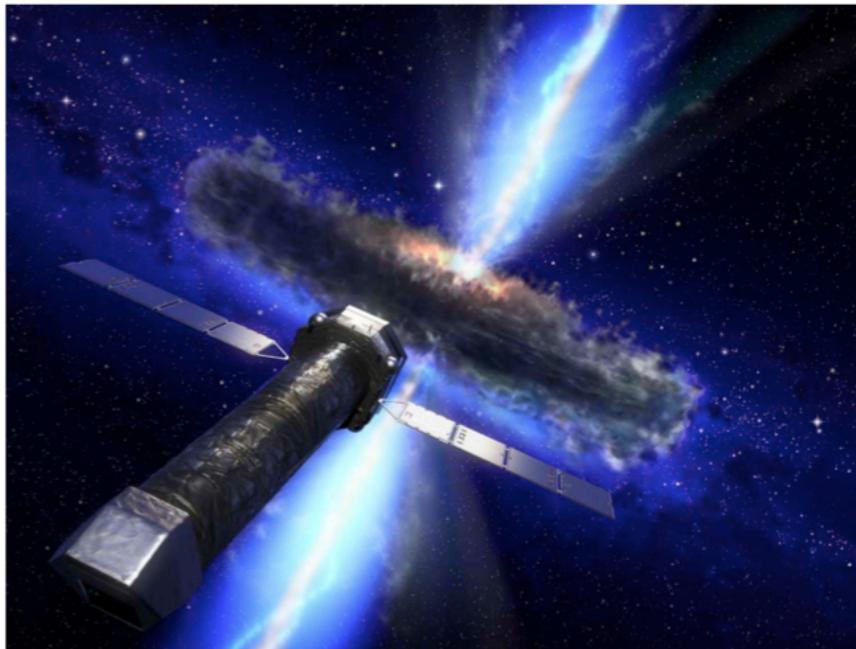
2019 - 2029 – 2039 – 2049

20 Years of Rapid Progress in X-ray Astronomy

from dinner plate to dinner table areas

ATHENA:

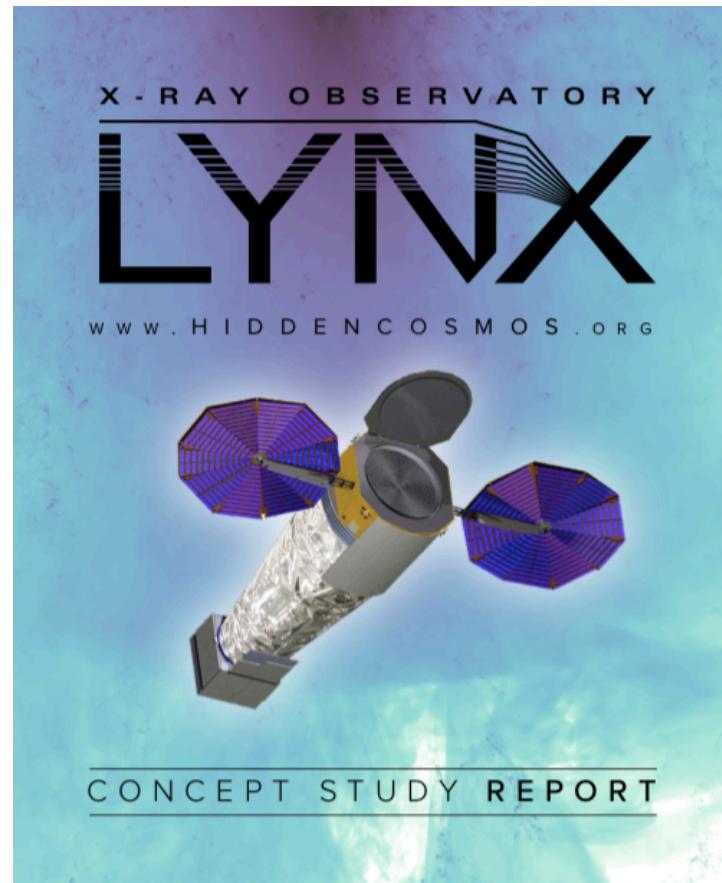
**The extremes of the Universe:
from black holes to large-scale structure**



Assessment Study Report

Martin Elvis, melvis@cfa.harvard.edu

X-ray Astronomy, Bologna, 13 Sept 2019.

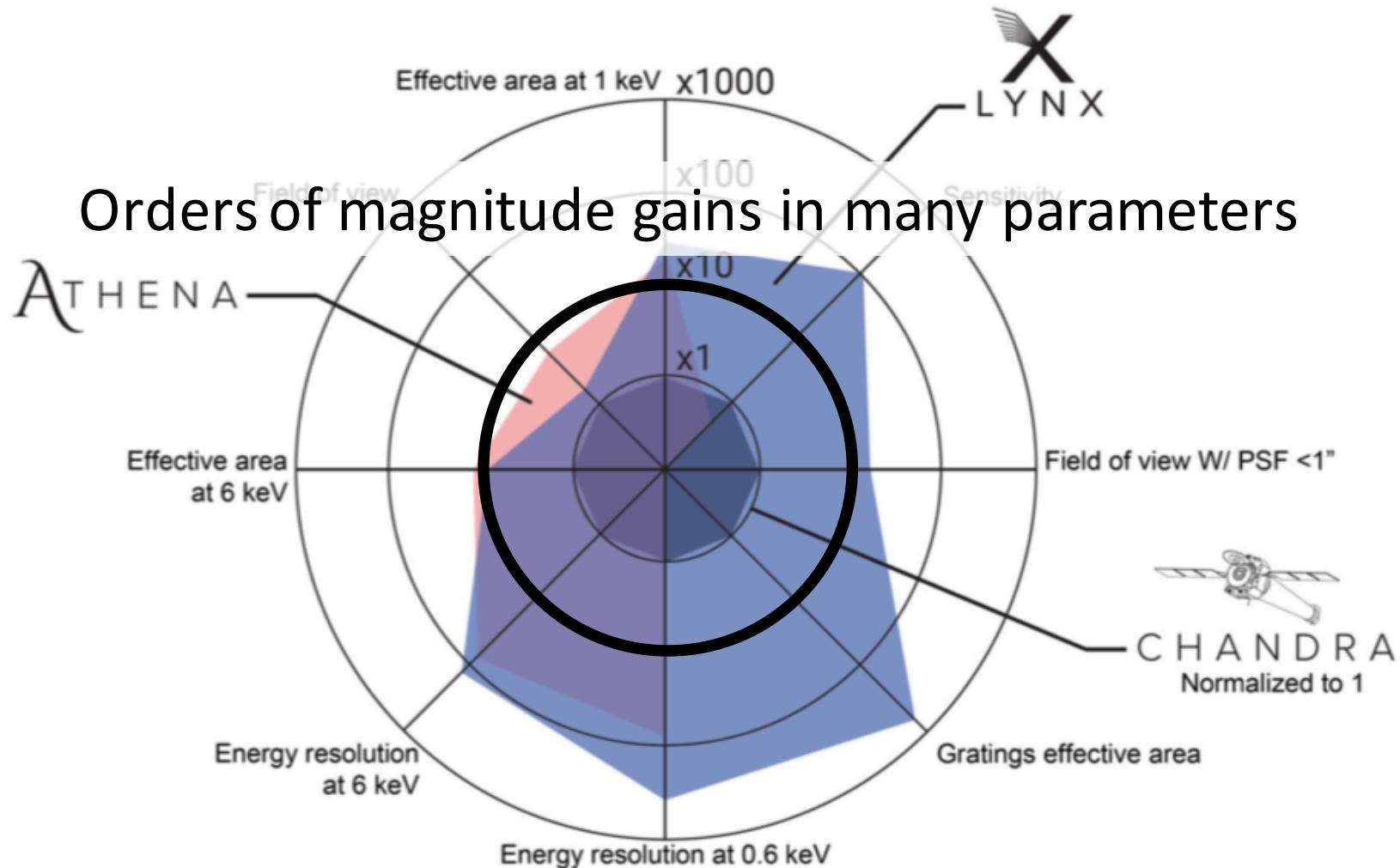


CENTER FOR ASTROPHYSICS

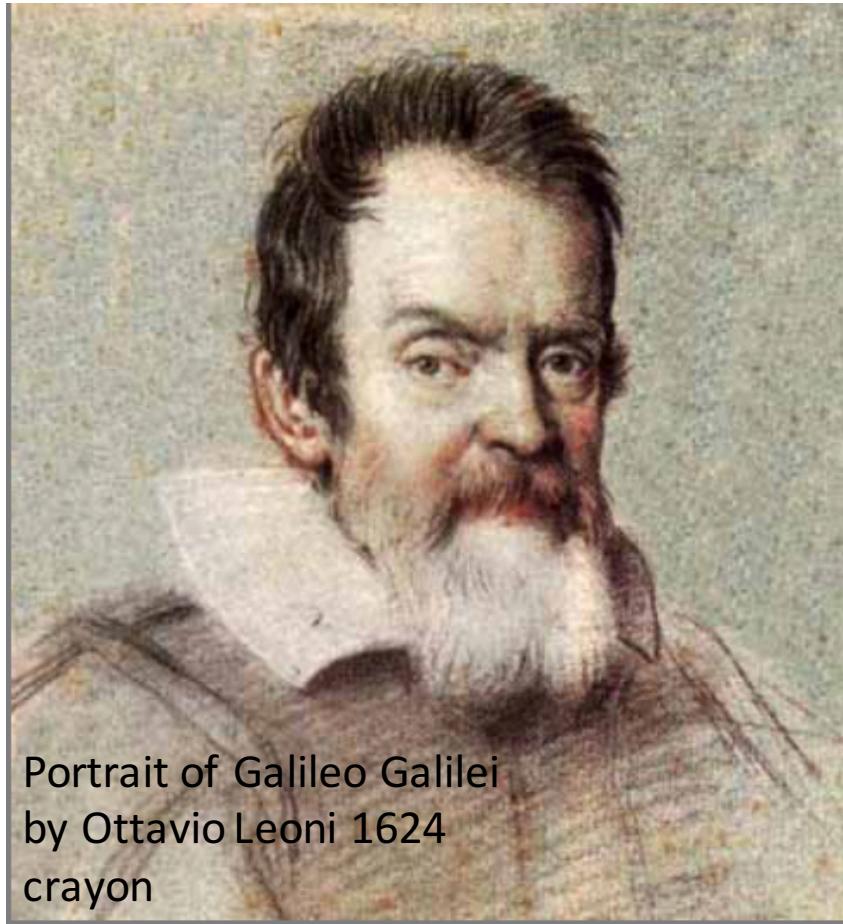
HARVARD & SMITHSONIAN

2019 – 2029 – 2039 – 2049

more
20 Years of Rapid Progress in X-ray Astronomy



2019 – 2029 – 2039 – 2049

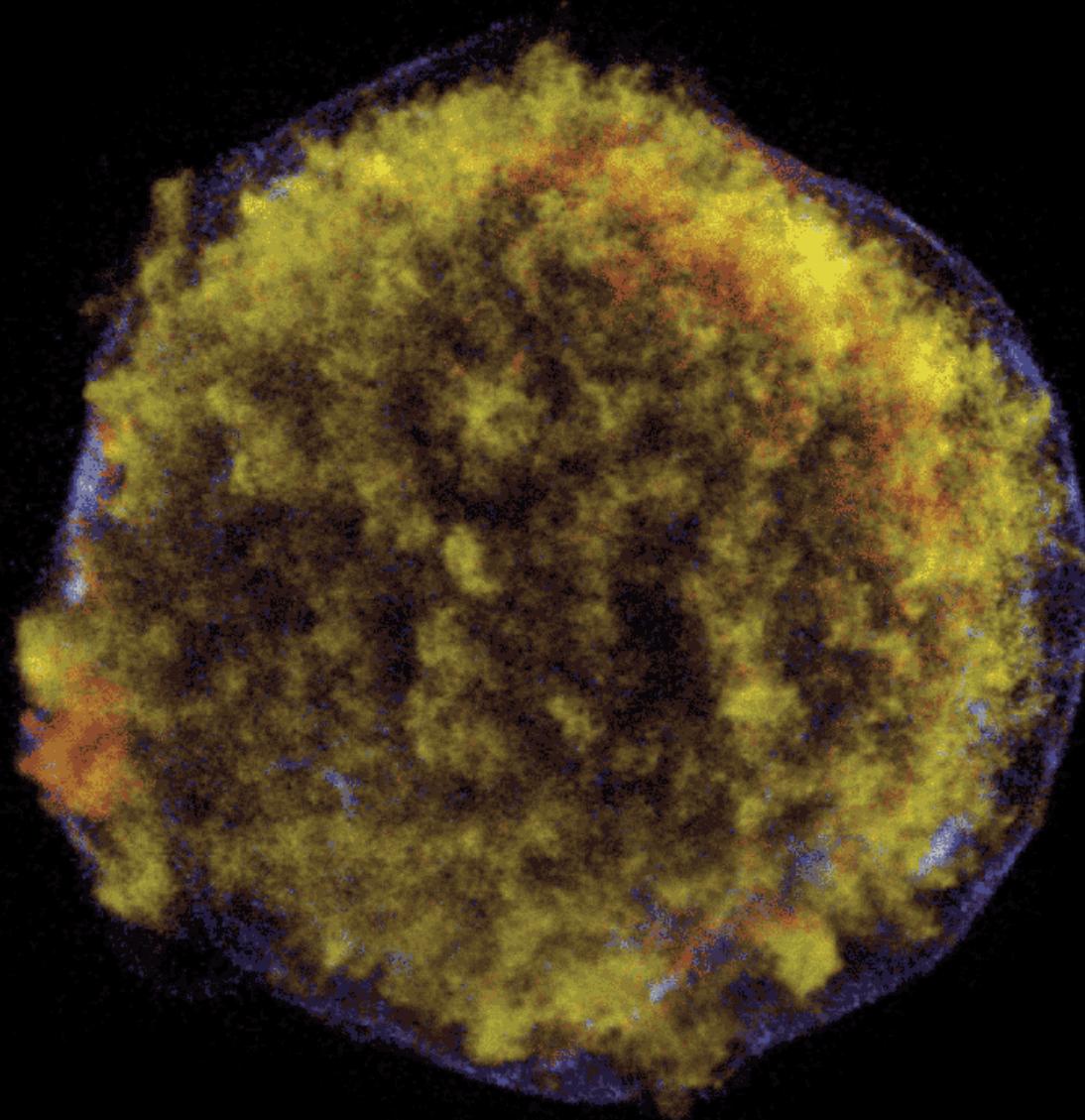


“Eppur **si** muove”

absolutely everything

Tycho

X-ray
(2000)



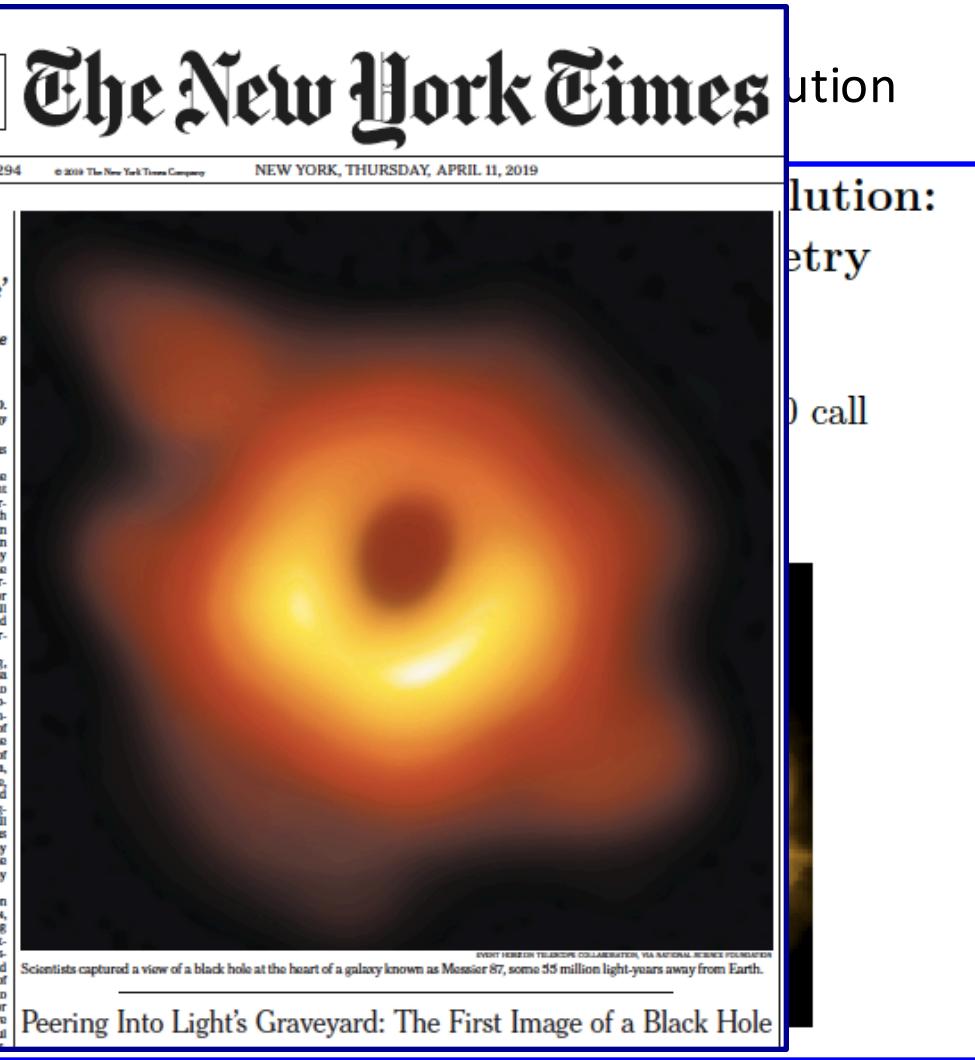
Also: Cas A, Crab, M87 jet

more
^

2019 – 2029 – 2039 - 2049

30 Years of Rapid Progress in X-ray Astronomy

Nothing is really a point source





Local Organizing Committee:

Marcella Brusa (co-chair) Mauro Dadina (co-chair), Angelo Basili, Elena Bertola, Stefano Bondani, Massimo Cappi, Deborah Costanzo, Quirino D'Amato, Myriam Gitti, Alessandro Ignesti, Giorgio Lanzuisi, Duccio Macconi, Angela Malizia, Stefano Marchesi, Giulia Migliori, Riccardo Nanni, Niccolò Parmiggiani, Francesco Salvestrini, Milena Schiavone, Alessandro Tacchini, Eleonora Torresi.

Scientific Organization Committee

R. Gilli - co-chair, C. Vignali - co-chair, F. Bauer, L. Brenneman, P. Campana, M. Colpi, A. Comastri, A. De Rosa, C. Done, D. Eckert, A. Finoguenov, E. Gallo, P. Gandhi, I. Georgantopoulos, S. Gilfan, G. Ghirlanda, P. Grandi, L. Ho, A. Ptak, J. Vink, V. Ueda, M. Volonteri

Local Organization Committee

M. Brusa - CO-CHAIR, M. Dadina - CO-CHAIR, M. Cappi, D. Costanzo, Q. D'Amato, M. Gitti, A. Ignesti, P. Lanzuisi, A. Malizia, G. Migliori, R. Nanni, N. Parmiggiani, F. Salvestrini, M. Spiga, A. Tacchini, E. Torresi

Invited Speakers

James Aird, Dave Alexander, Lorenzo Amati, Aya Bamba, Stefano Citteri, Andy Fabian, Erin Kara, Julian Malzac, Andrea Merloni, Koji Mukai, Kirpal Nandra, Fabrizio Nicastro, Roderik Overzier, Robert Petre, Gabriele Ponti, Claudio Ricci, Jeremy Sanders, Norbert Schartel, Alberto Sesana, Makoto Tashiro, Eleonora Troja, Sjoert van Velzen, Fabio Vito, Martin Weisskopf, Relinda Wilkes, Shuang Nan Zhang

Appreciation & Thanks

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For their patronage: CNR/Area della Ricerca ASI, University of Bologna, Comune di Bologna

For organisation: Fondazione Alma Mater, Alessandro Vriz in particular

Scientific Organizing Committee:

Roberto Gilli & Cristian Vignali (co-chairs), Franz Bauer, Laura Brenneman, Francisco, Monica Colpi, Andrea Comastri, Alessandra De Rosa, Chris Done, Dominique Eckert, Alexis Finoguenov, Elena Gallo, Poshak Gandhi, Ioannis Georgantopoulos, SuviGezari, Giancarlo Ghirlanda, Paola Grandi, Luis Ho, Andrew Ptak, Jacco Vink, Yoshihiro Ueda, Marta Volonteri.