

XMM-LHAASO: X-ray observations of PeVatrons

Expected X-ray emission from PeVatrons

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Faint & Diffuse

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Good news:

**In theory detectable with current X-ray
instrumentation**

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Challenges:

**Bright background eventually brighter
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Bright background eventually brighter
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Important:

Understand the X-ray background!

Structure of the presentation

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1) What we have been doing (GC)

Our tools

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2) What we are doing

Our skills

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1) What we have been doing (GC)

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3) What we would like to do

Our aims

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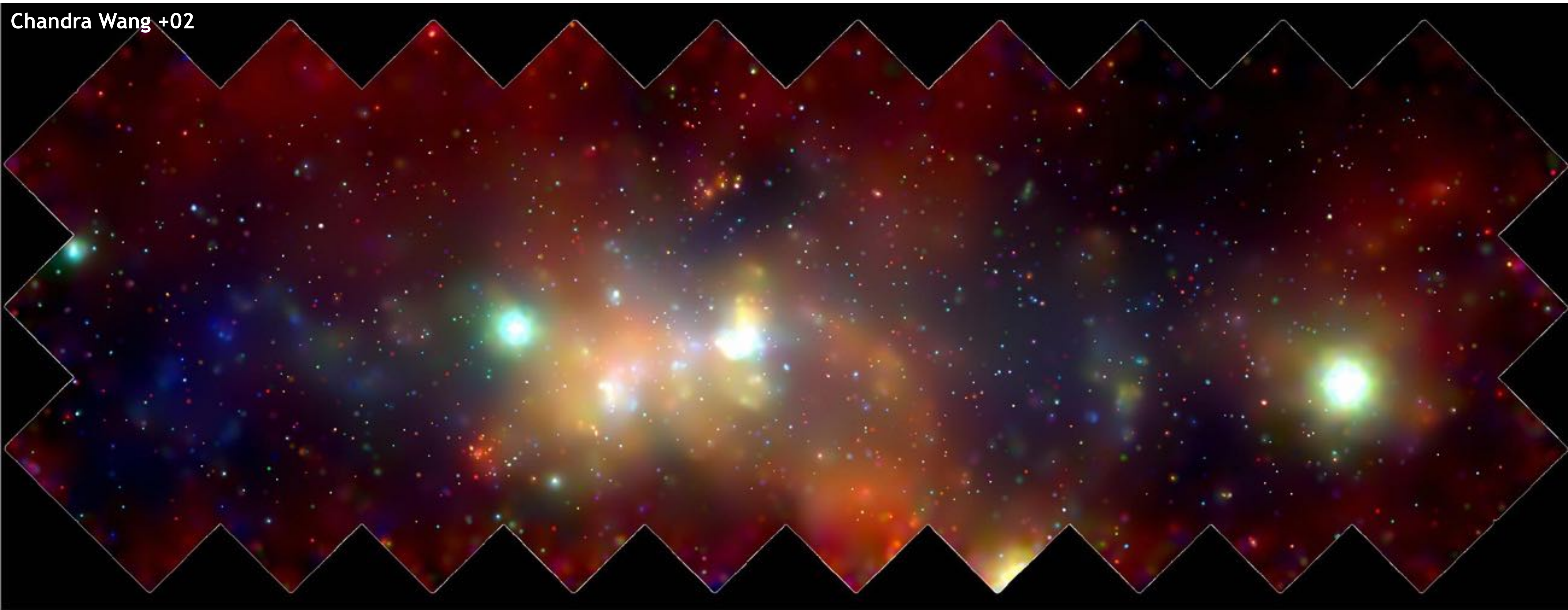
Our skills

4) What we will actually do

1) What we have been doing

Our tools

The Galactic center in X-rays: Chandra



Muno+03;+04;+09

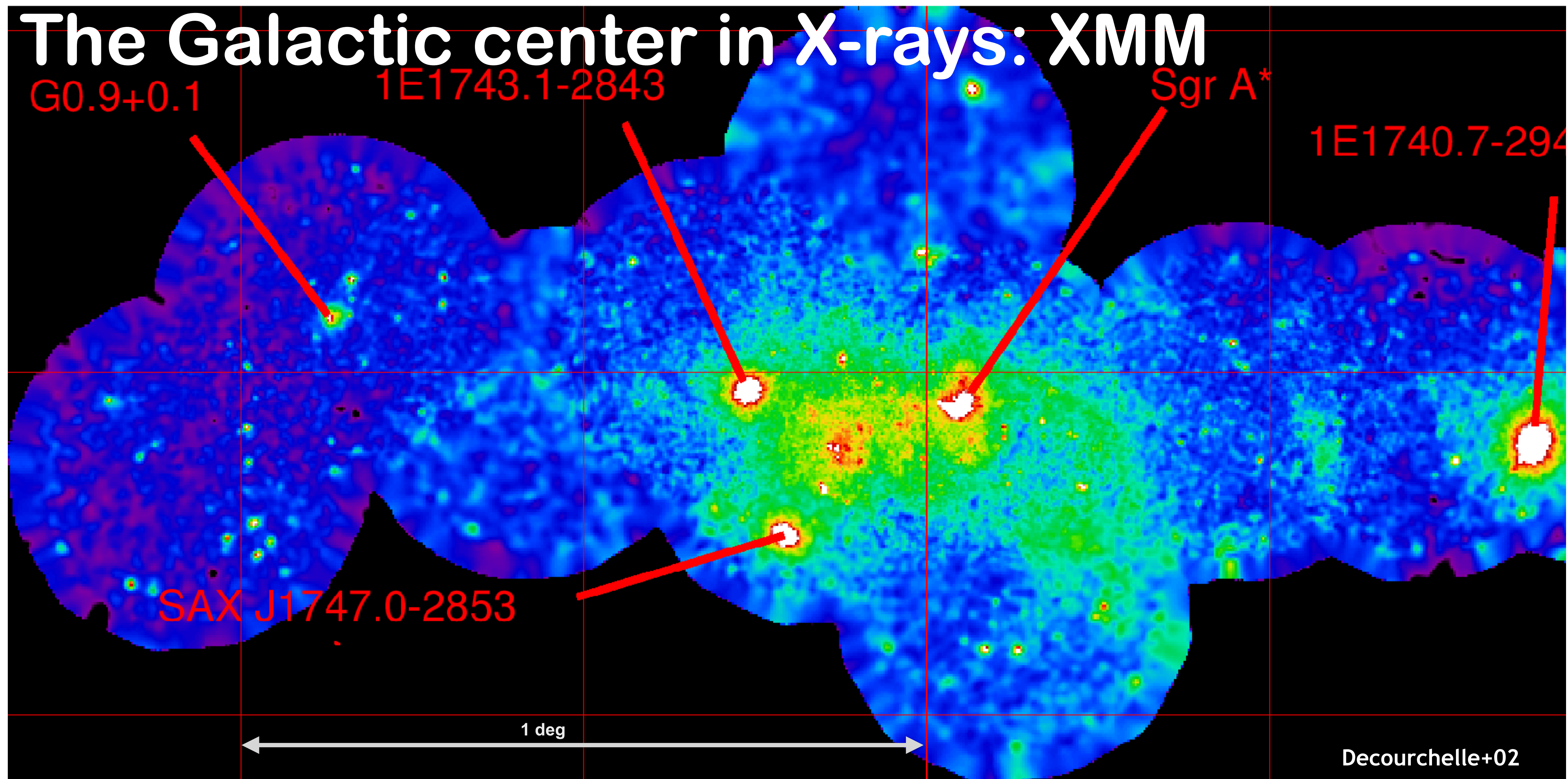
The Galactic center in X-rays: Chandra



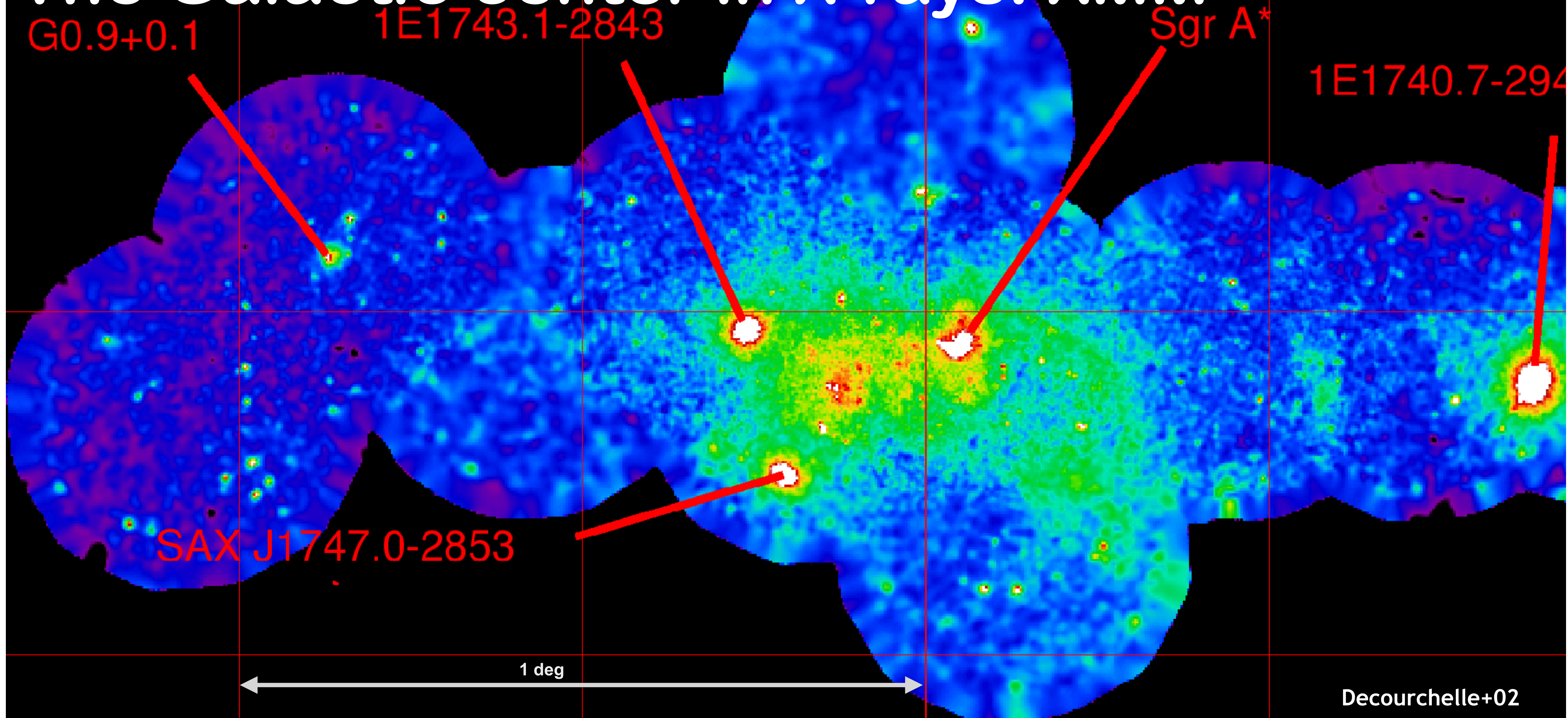
More than 9×10^3 point sources

Muno+03;+04;+09

The Galactic center in X-rays: XMM

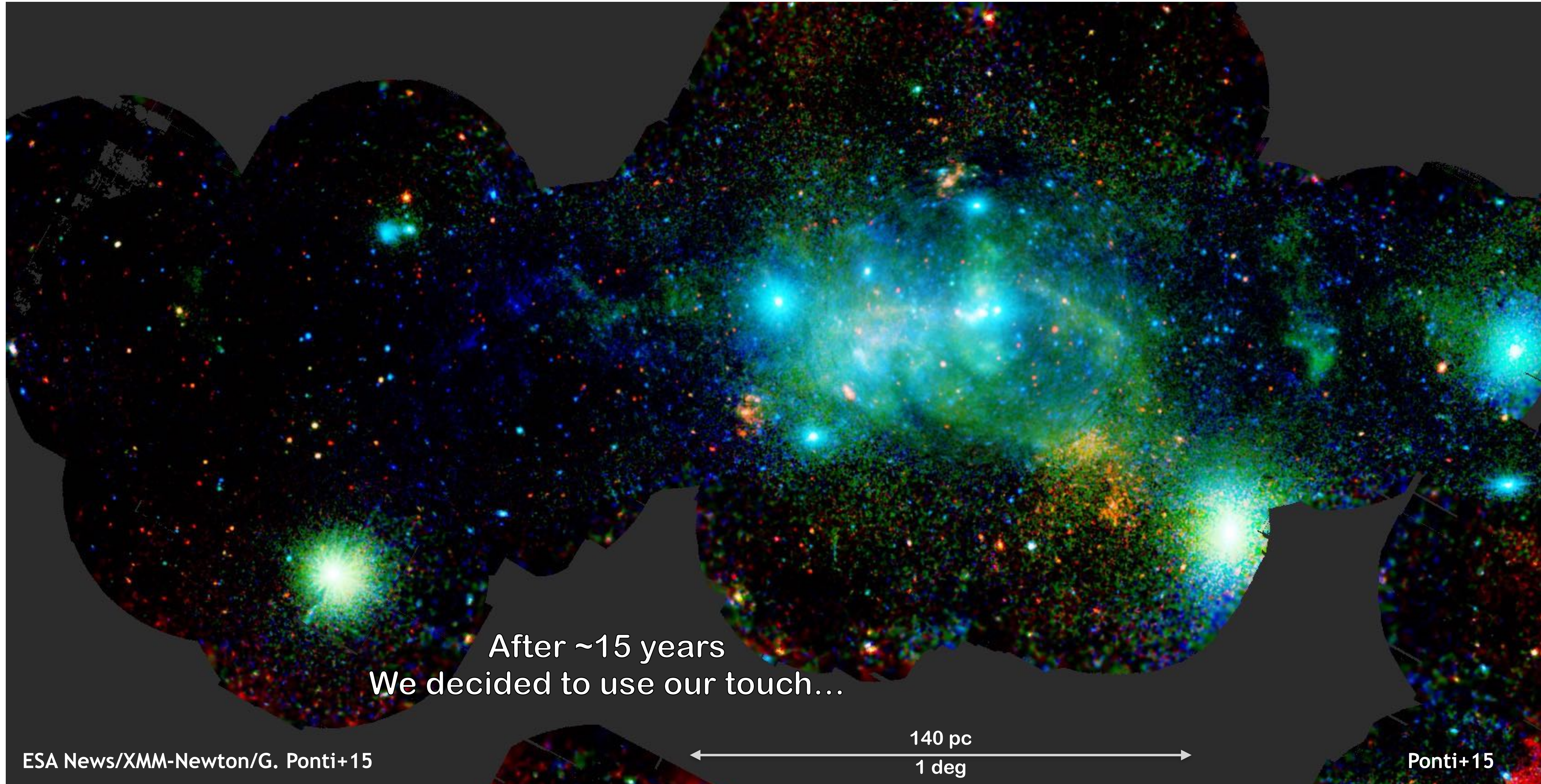


The Galactic center in X-rays: XMM



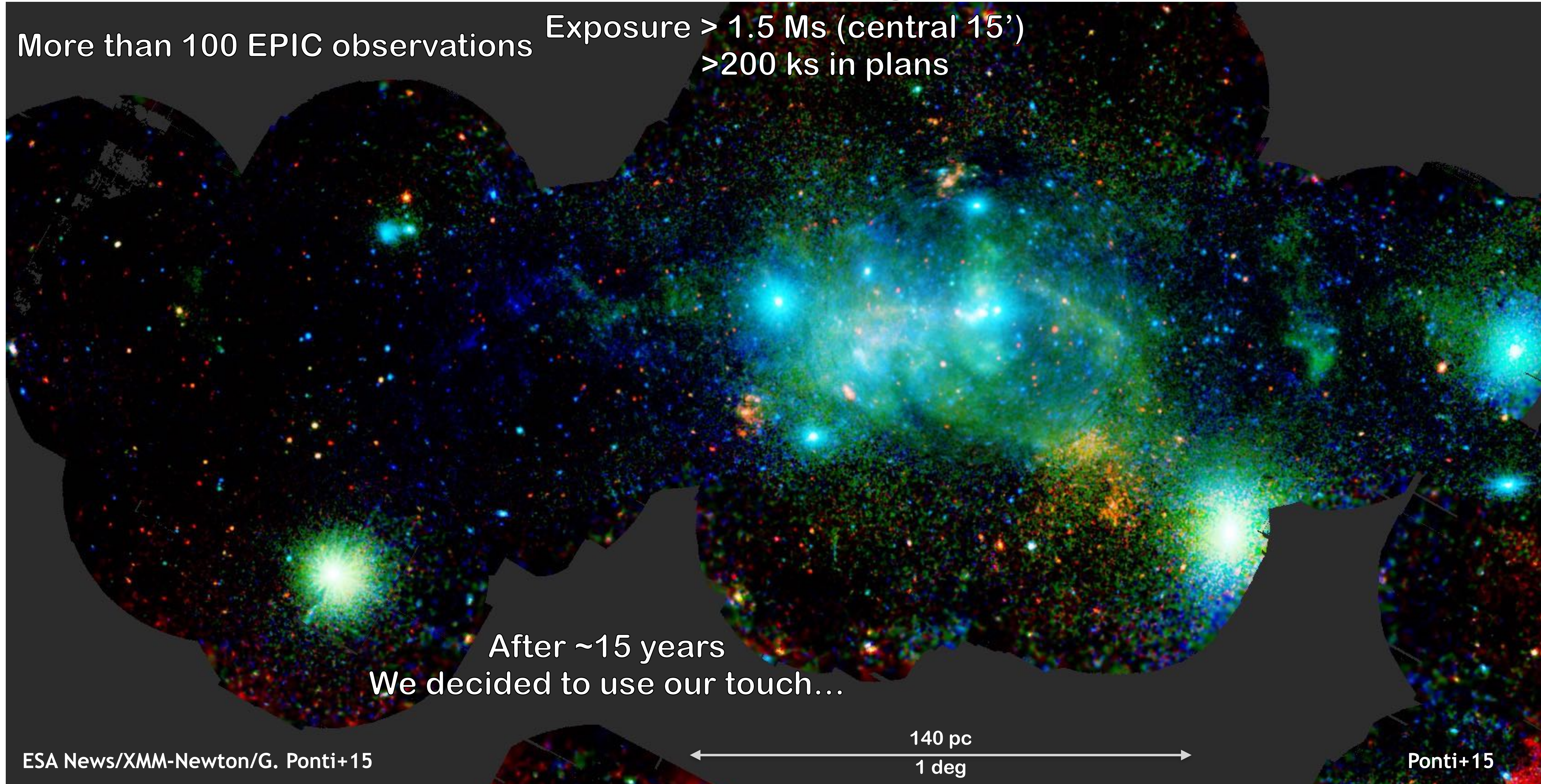
Among the first key projects of XMM (2000-2002)

The Galactic center in X-rays: XMM



The Galactic center in X-rays: XMM

More than 100 EPIC observations Exposure > 1.5 Ms (central 15')
>200 ks in plans



After ~15 years
We decided to use our touch...

140 pc
1 deg

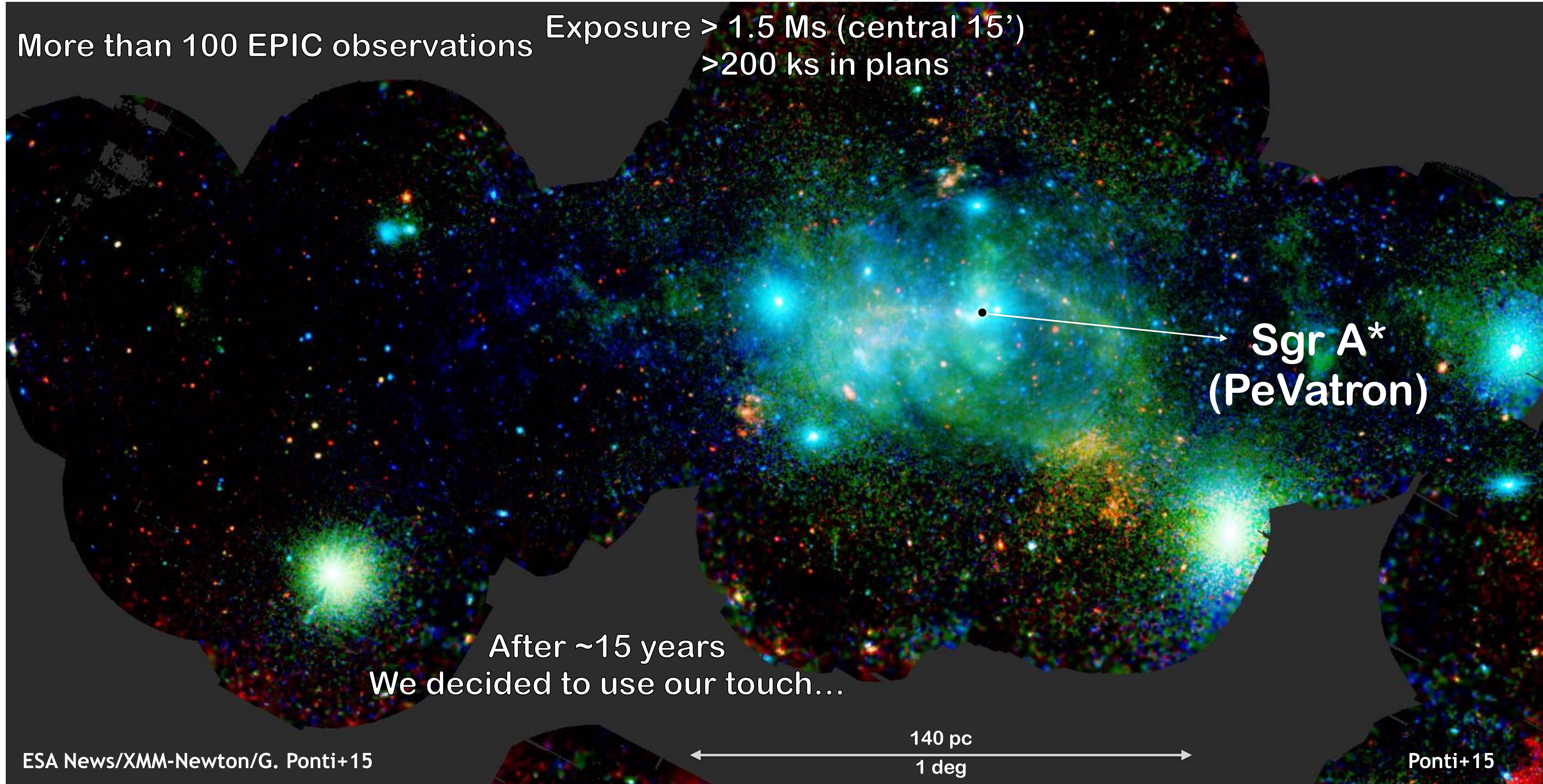
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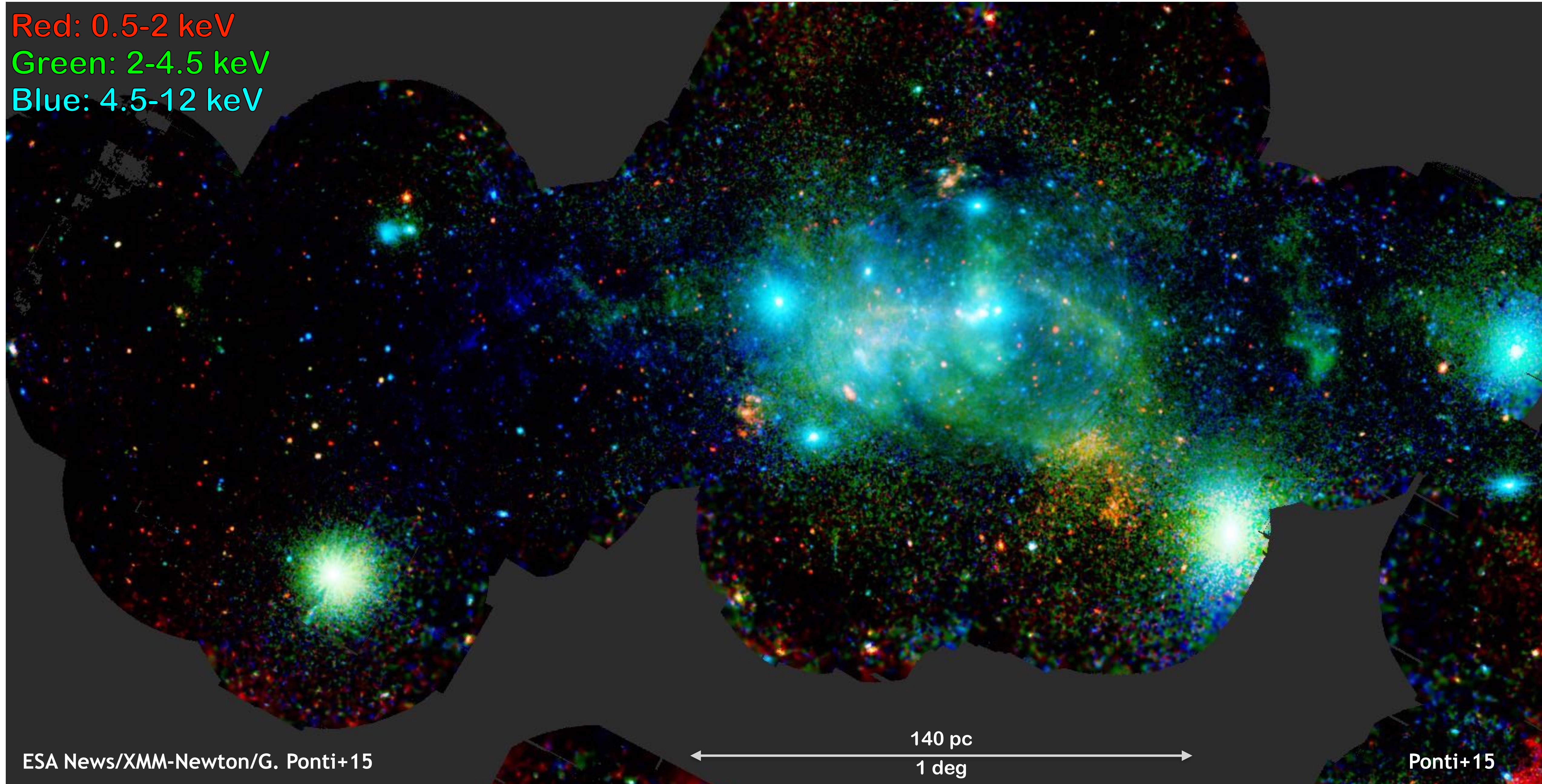
Sgr A*
(PeVatron)

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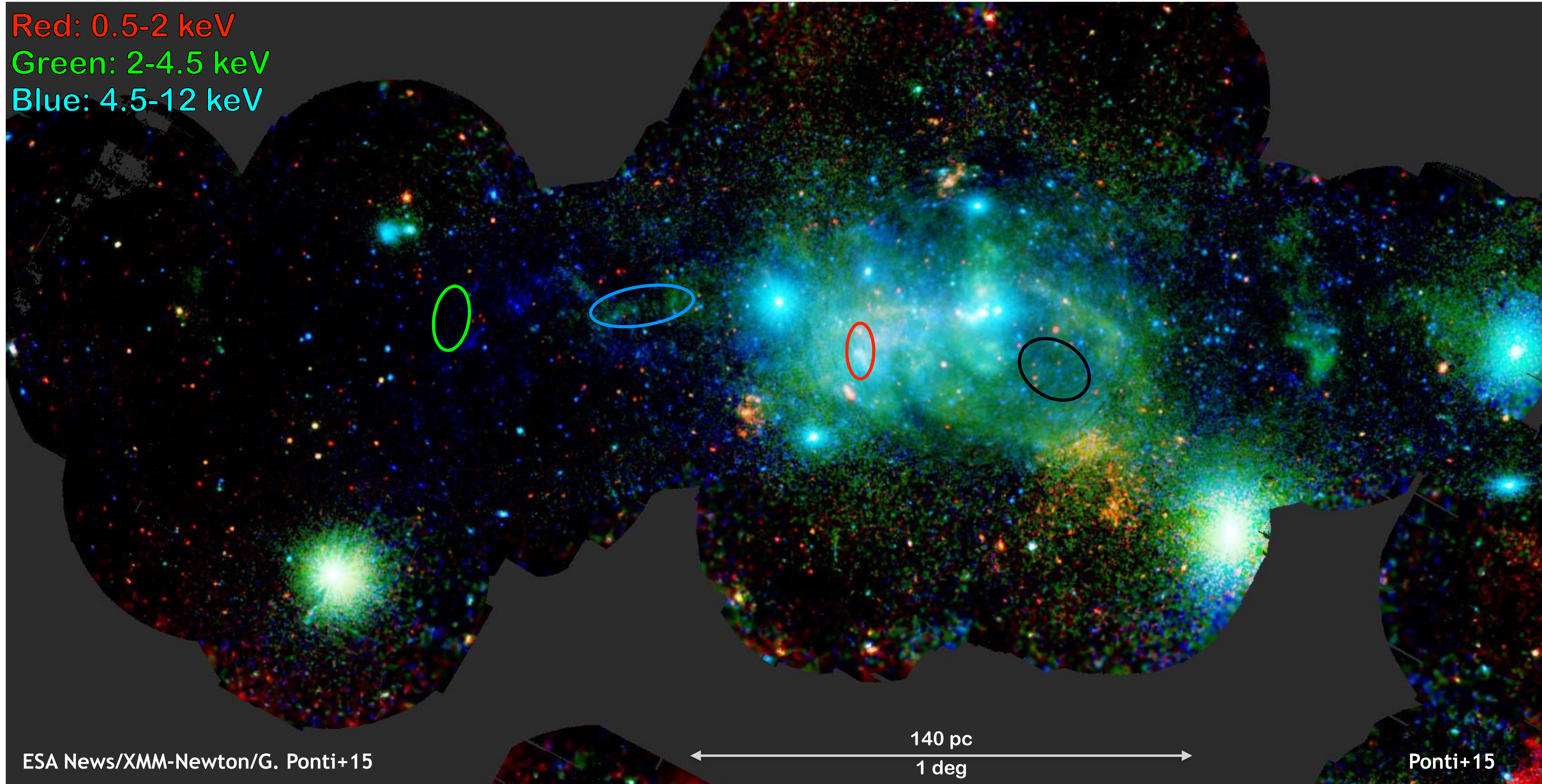
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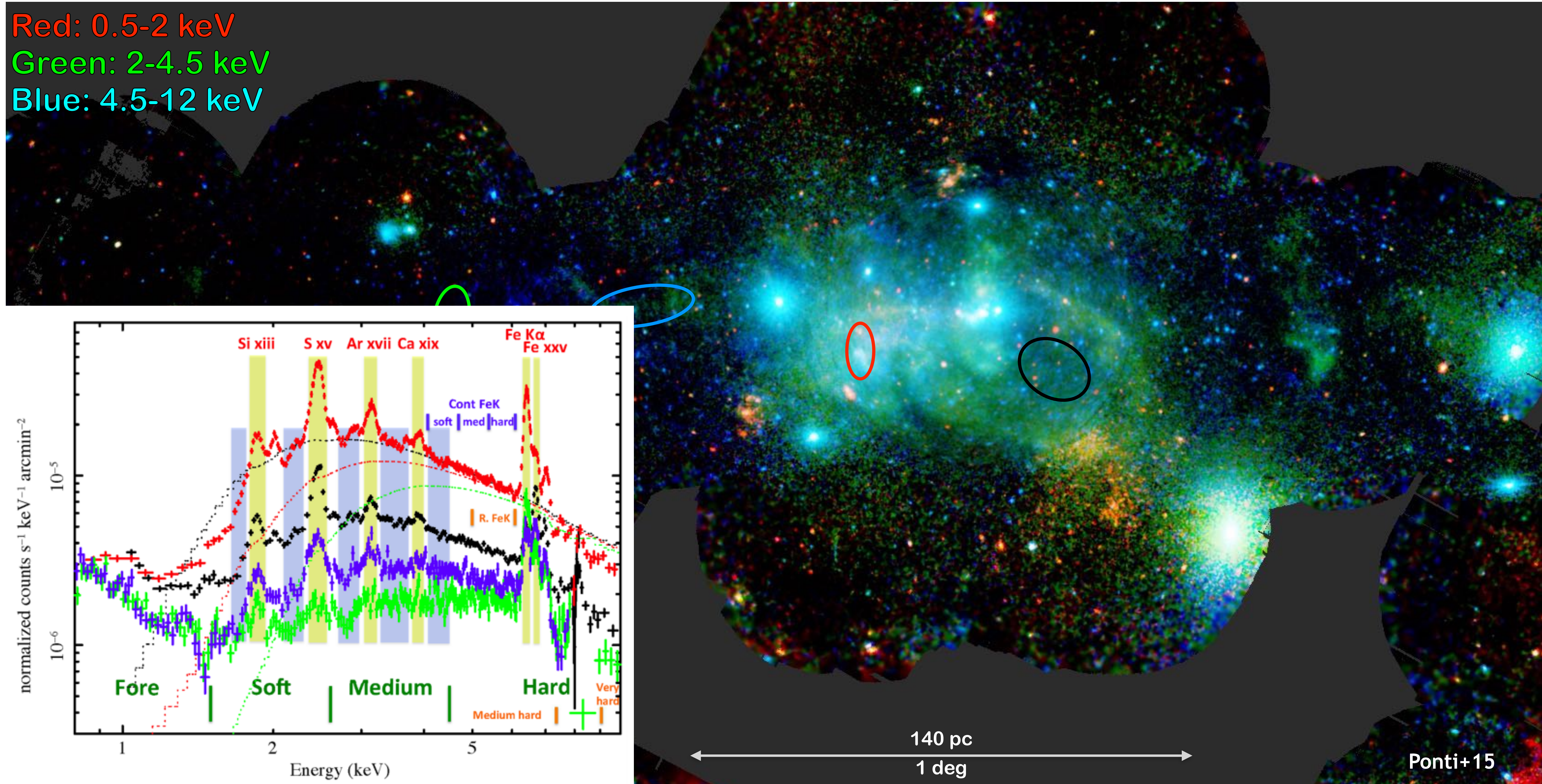
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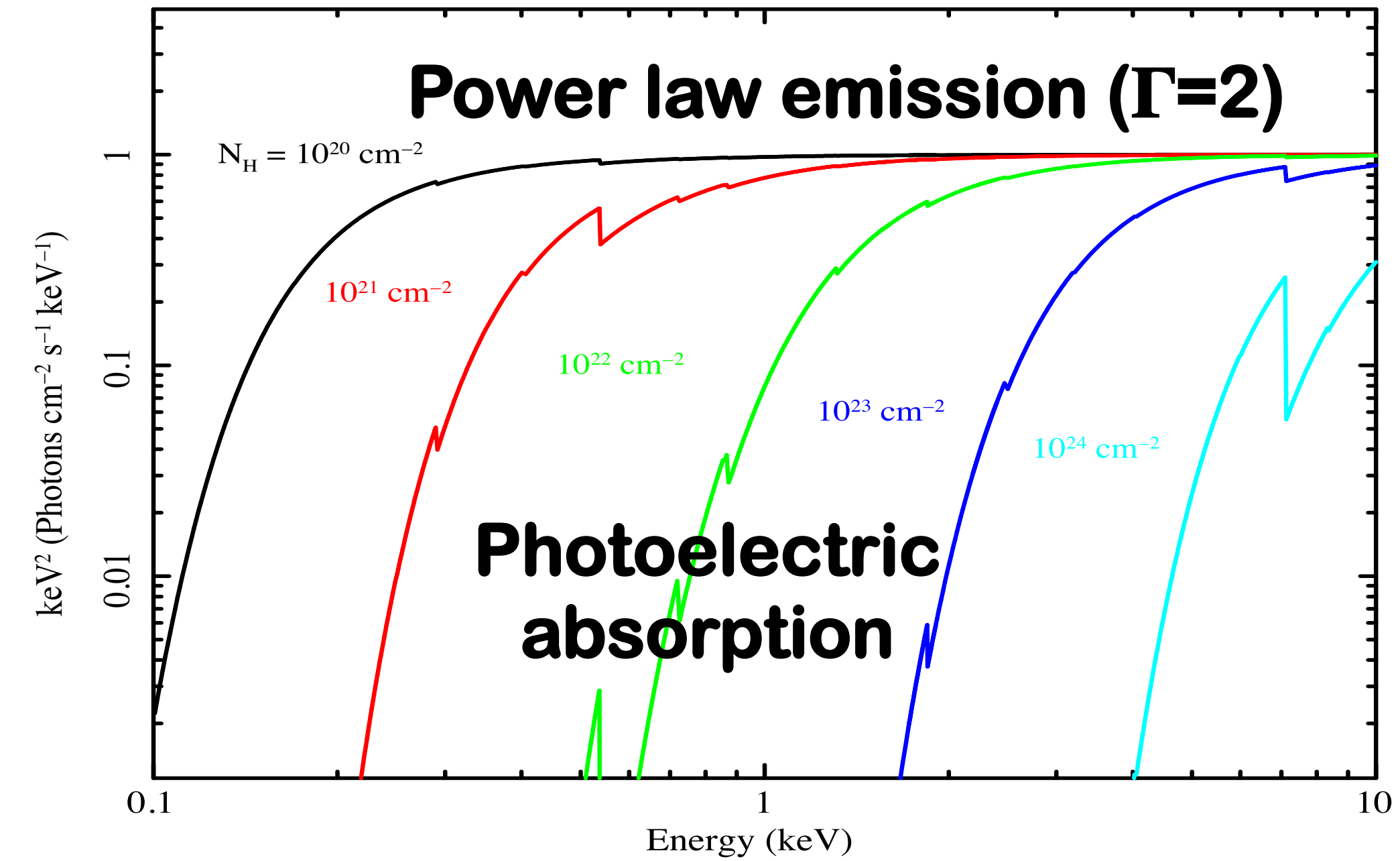
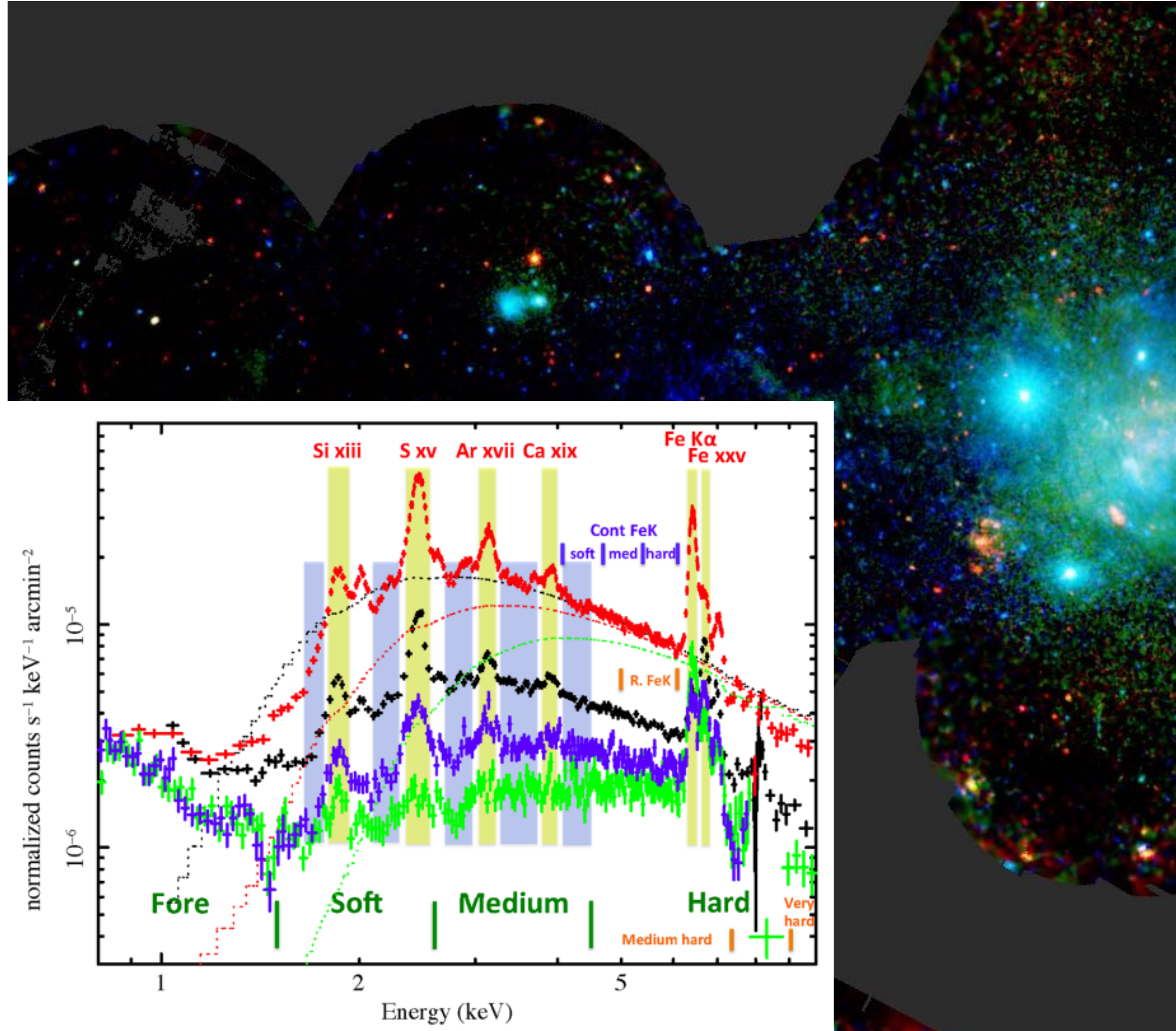
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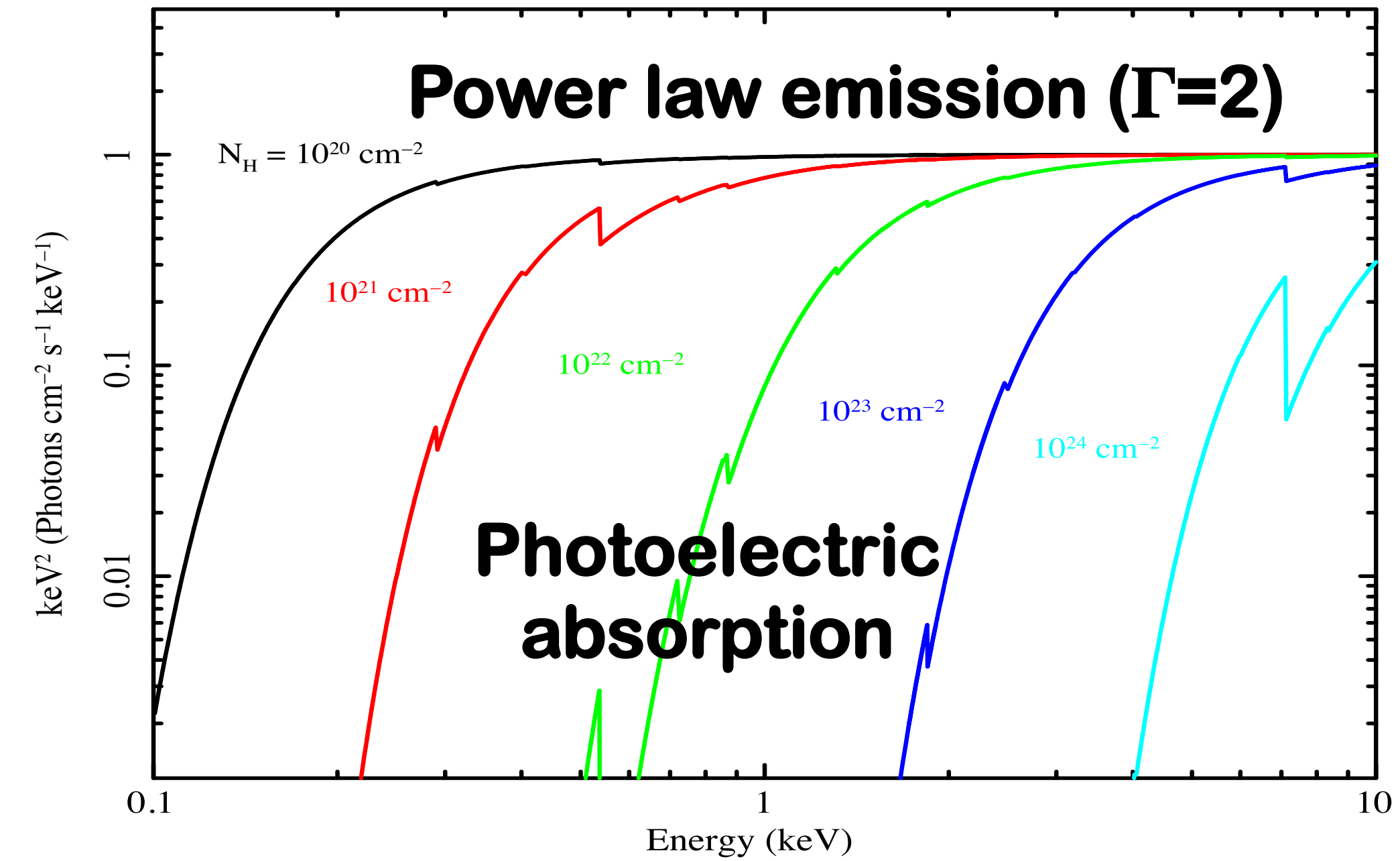
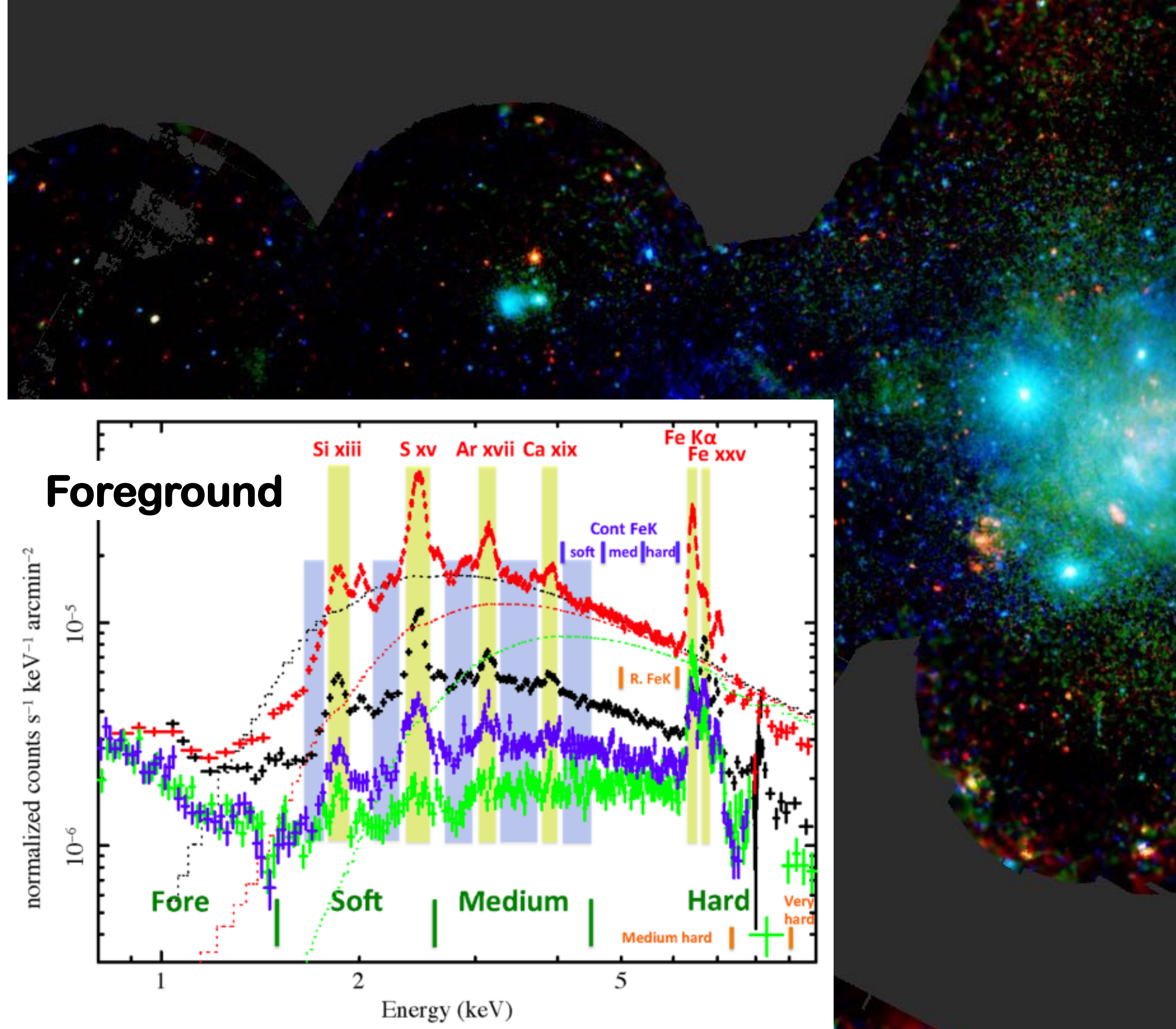
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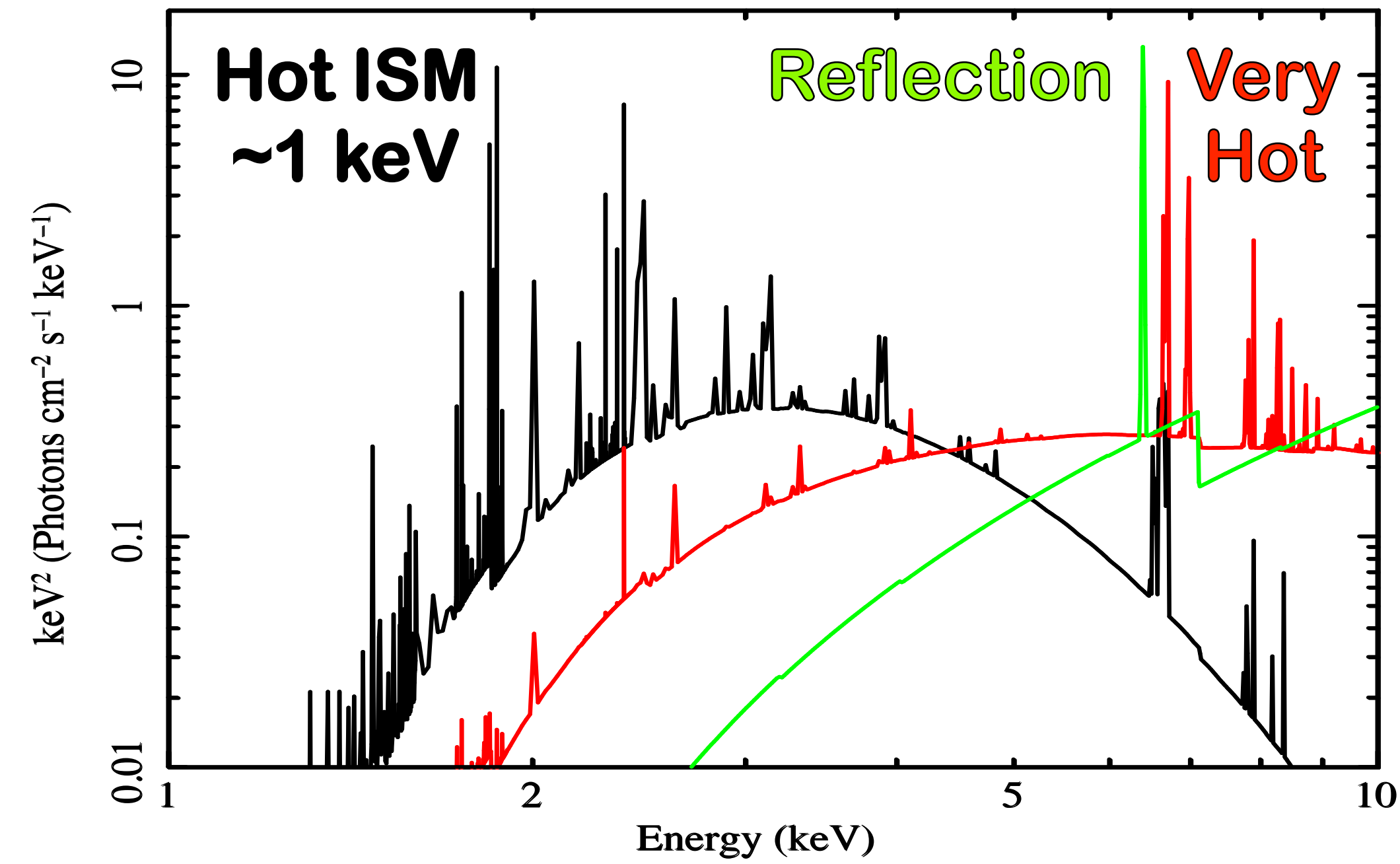
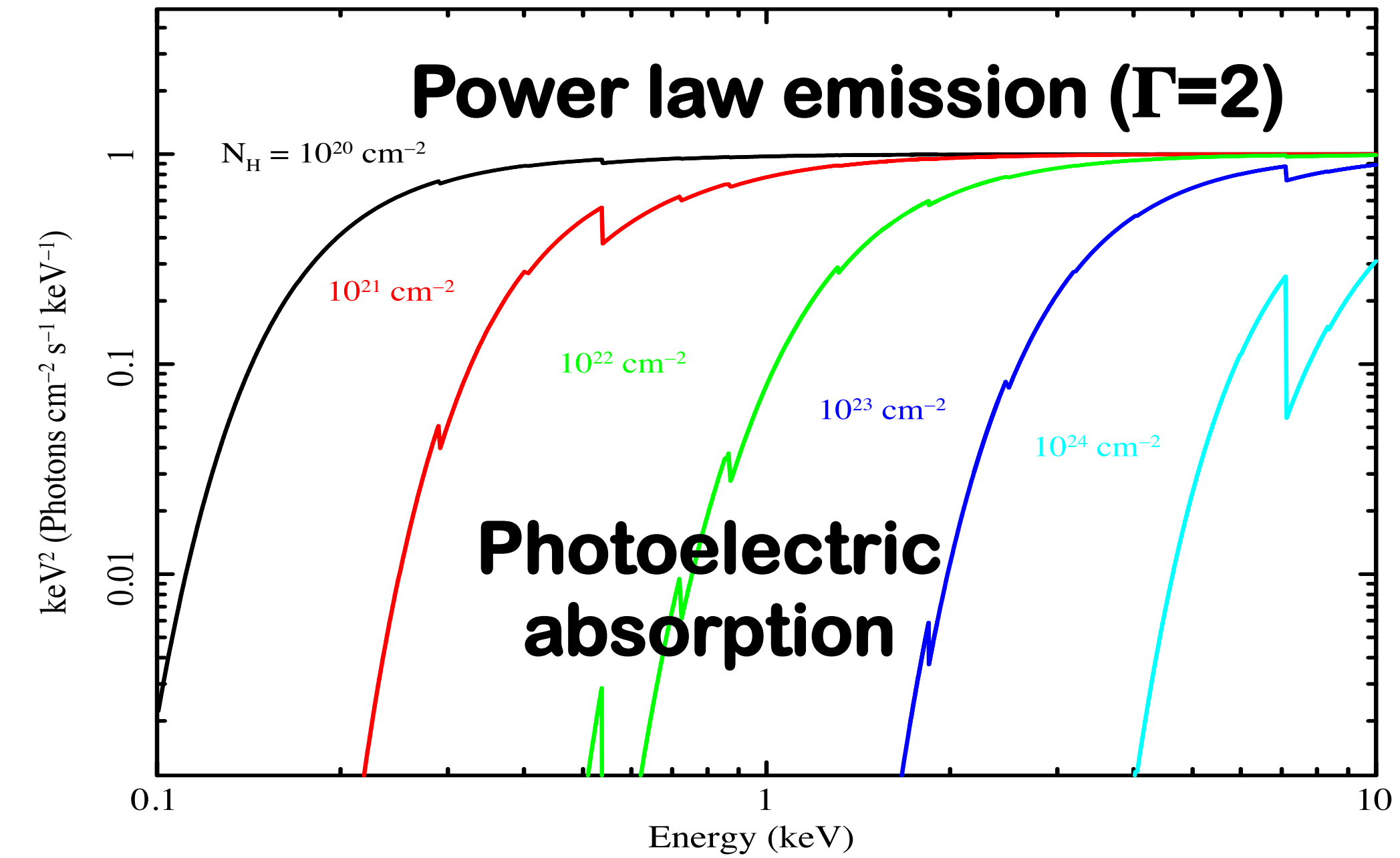
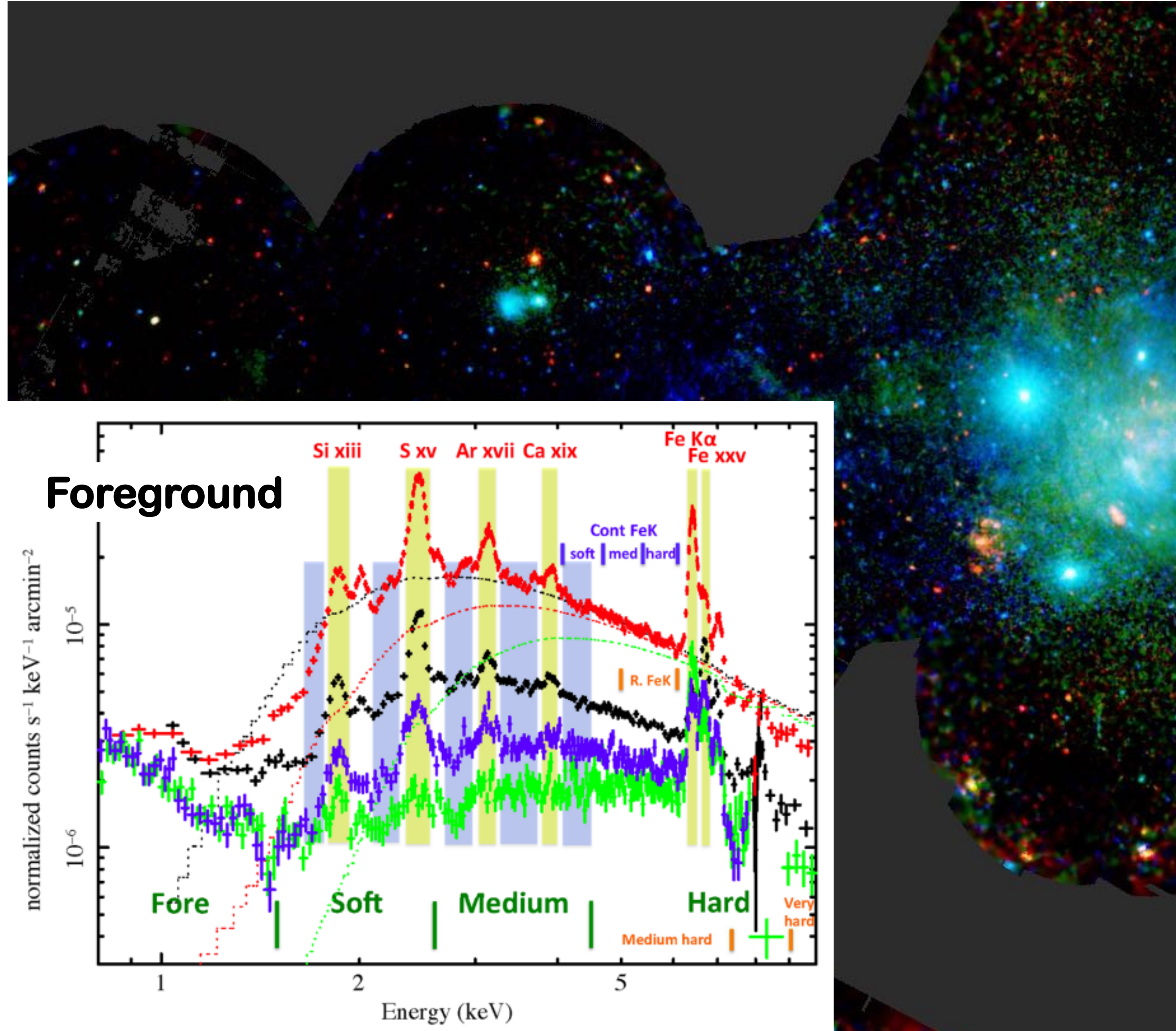
Components of the diffuse X-ray emission



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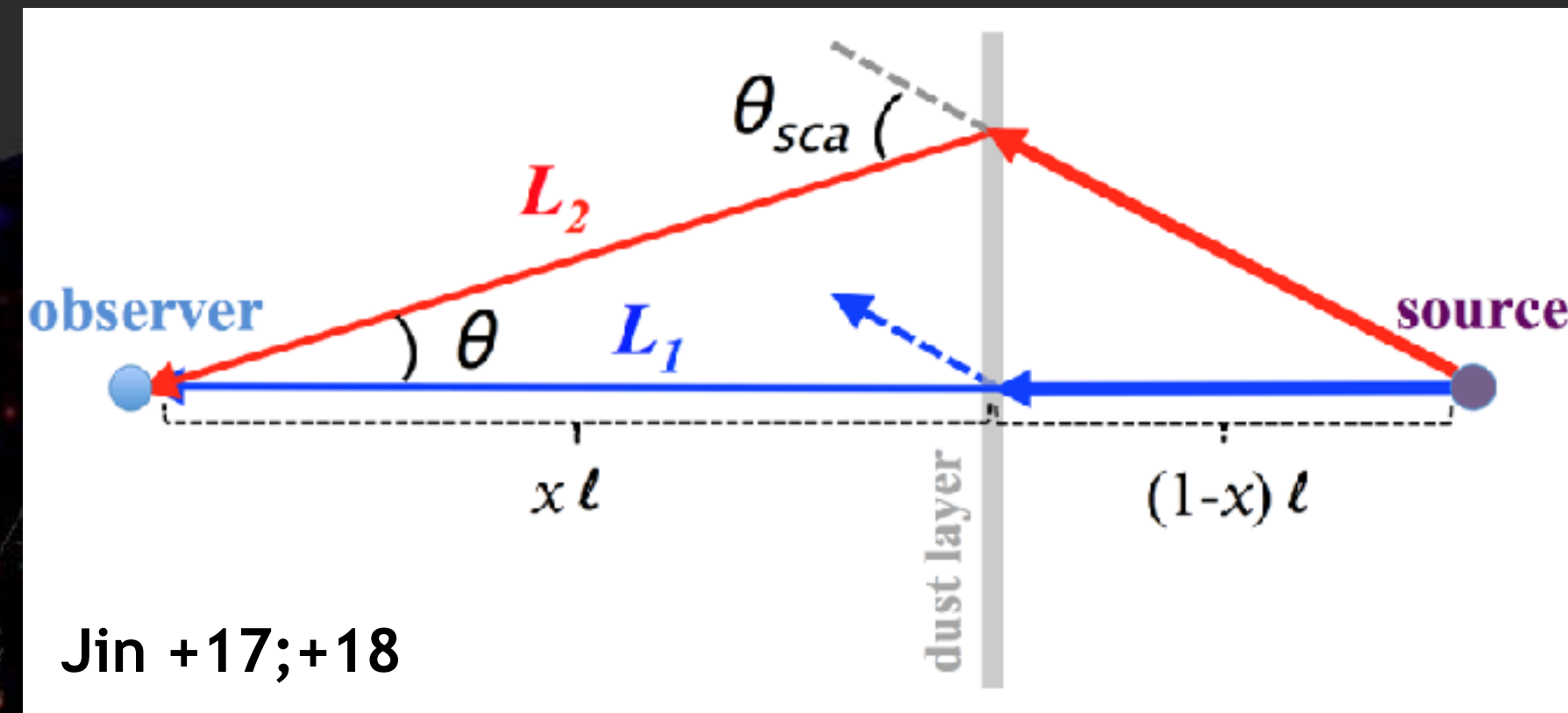


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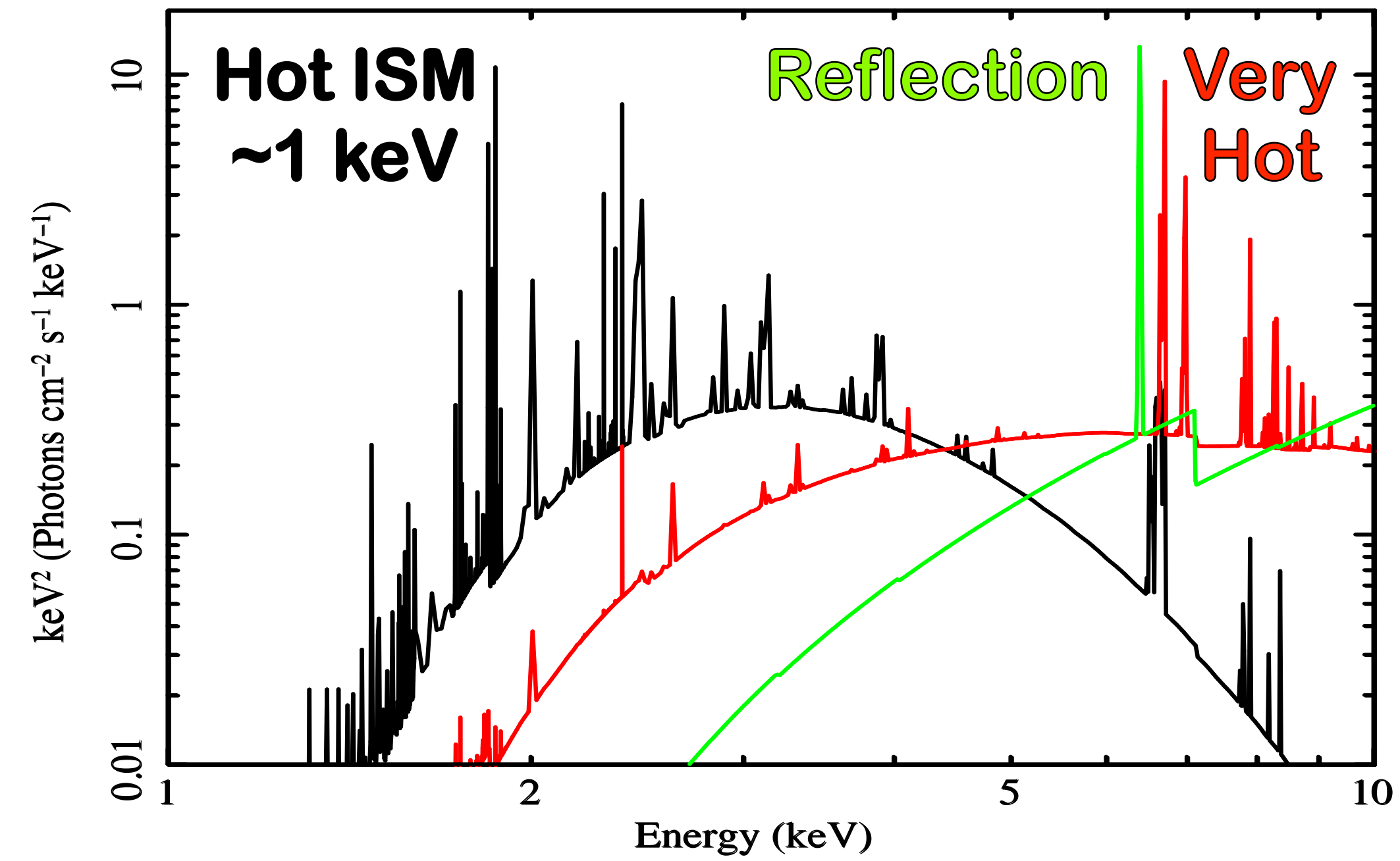
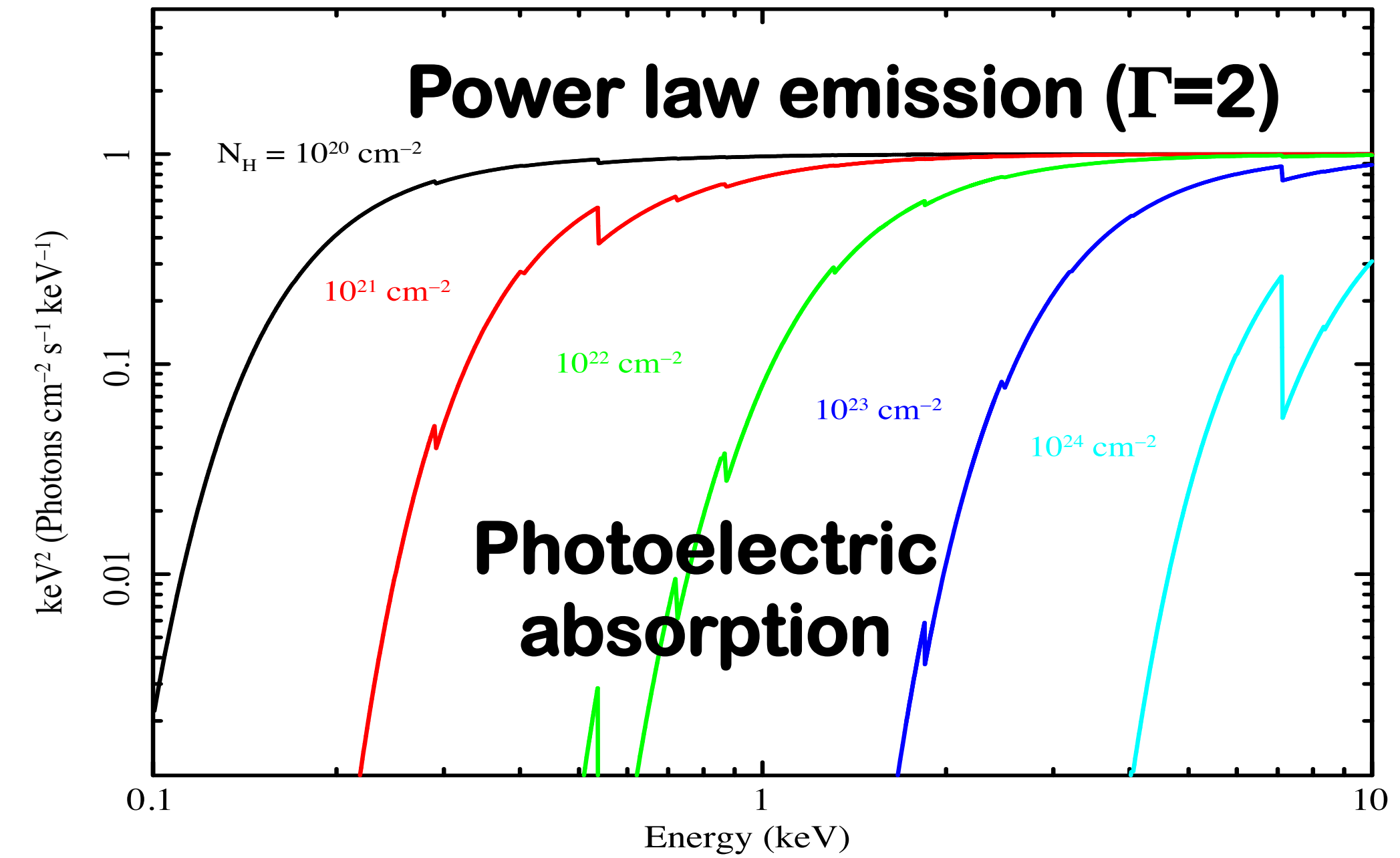
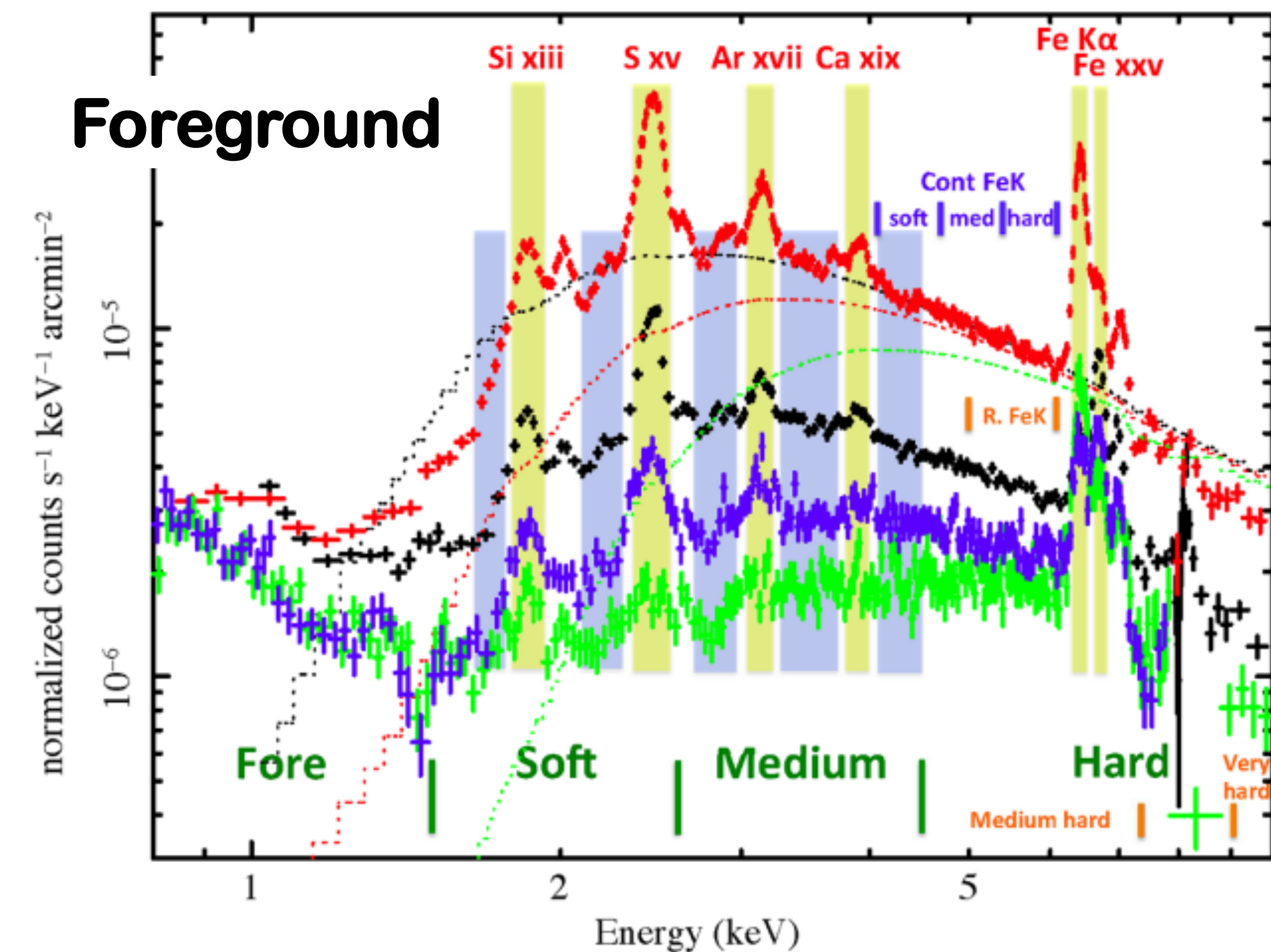


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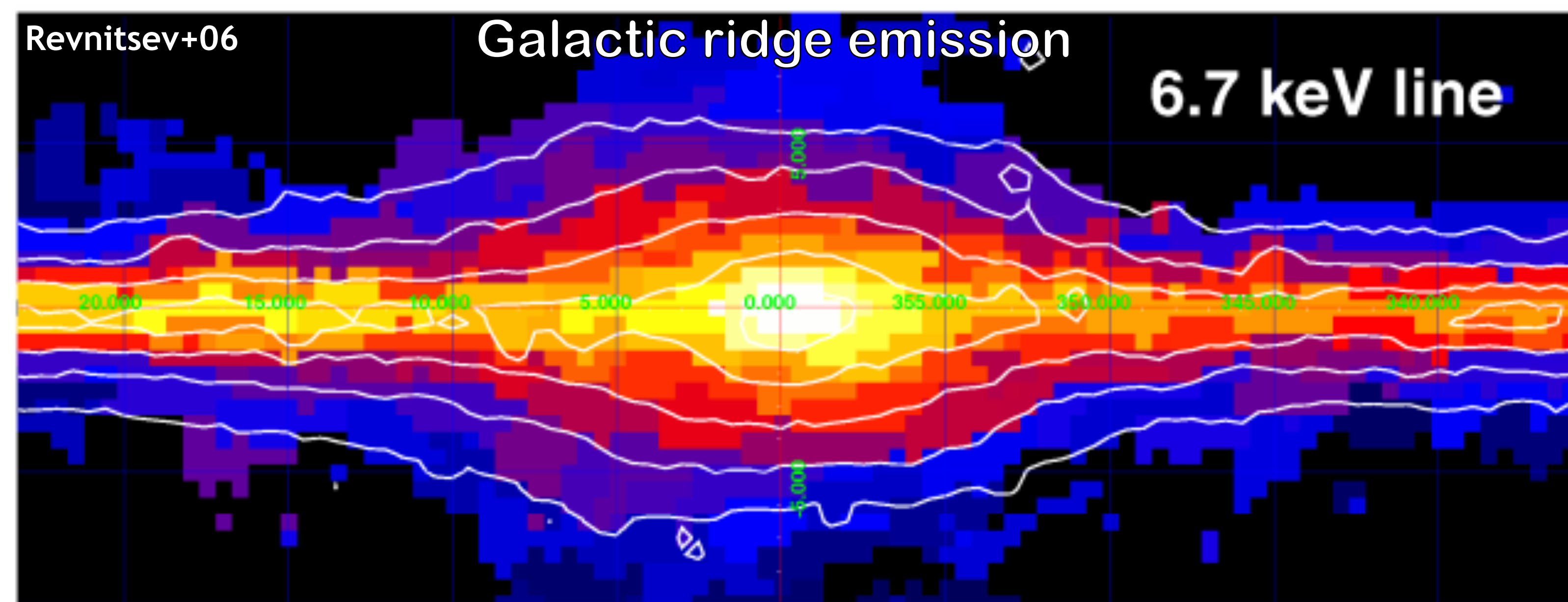
Dust scattering haloes



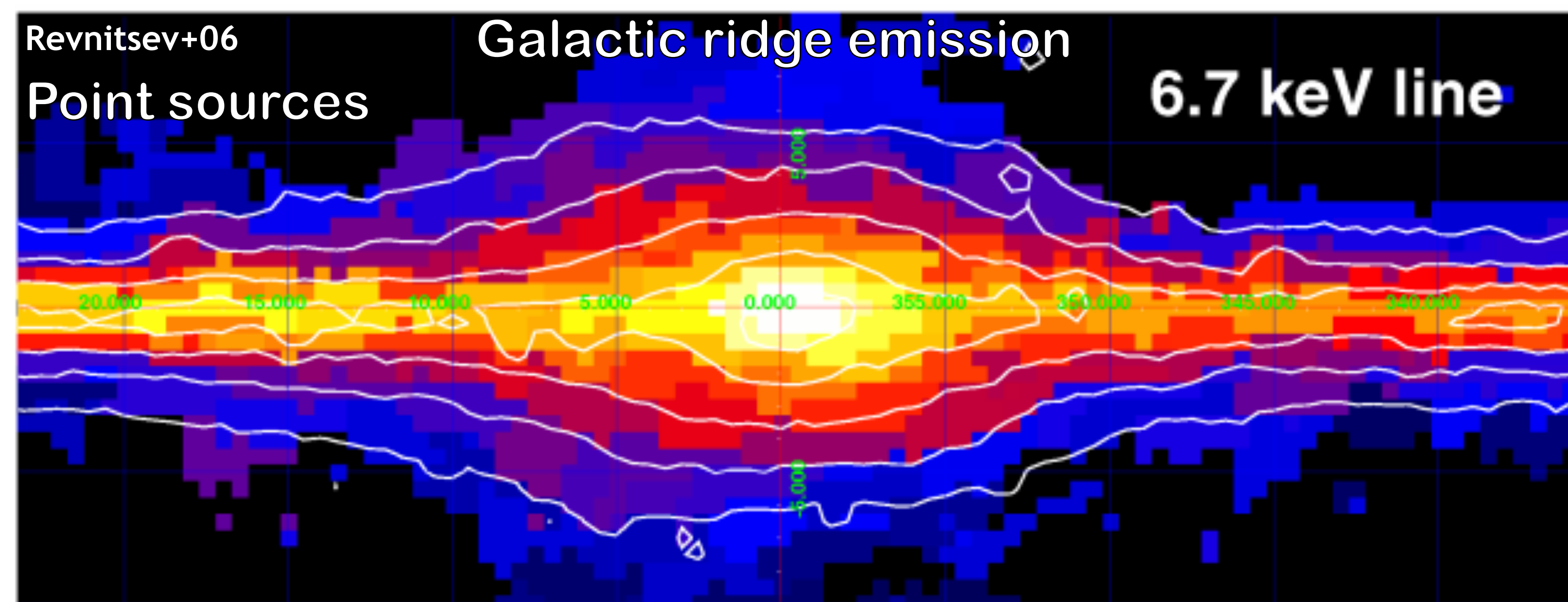
Foreground



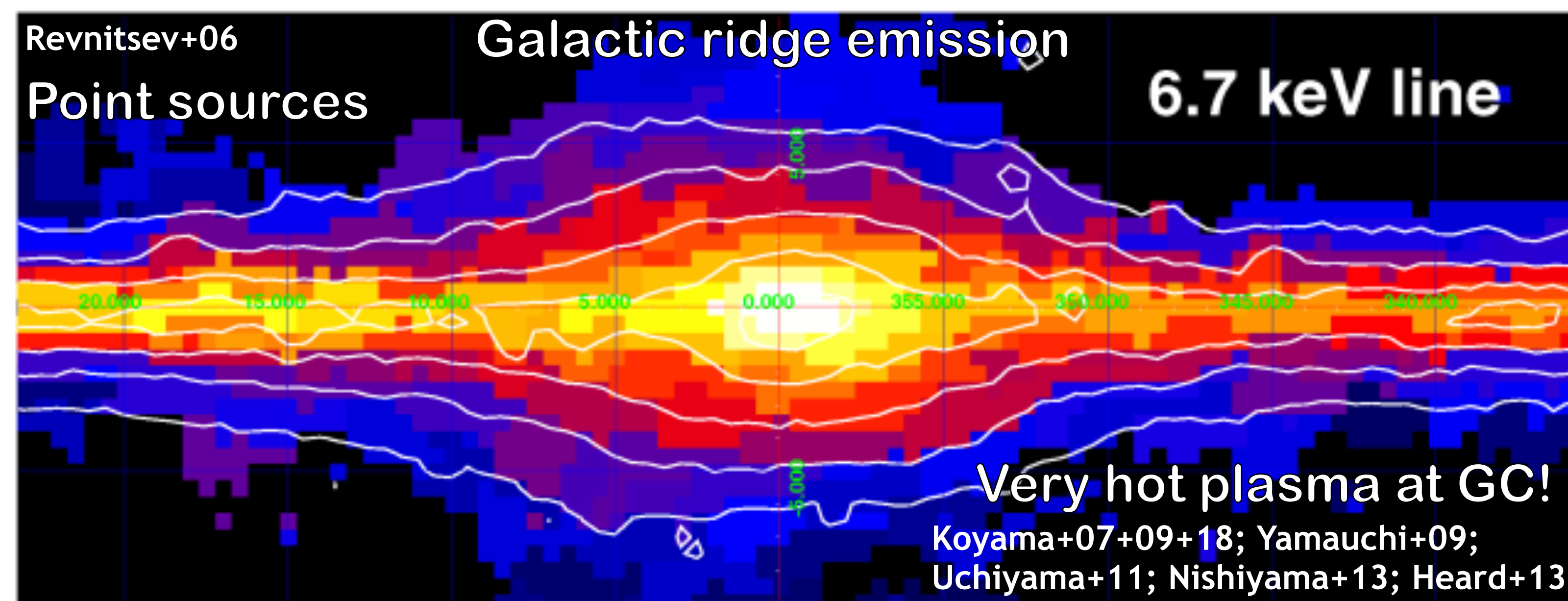
Very hot plasma or unresolved sources?



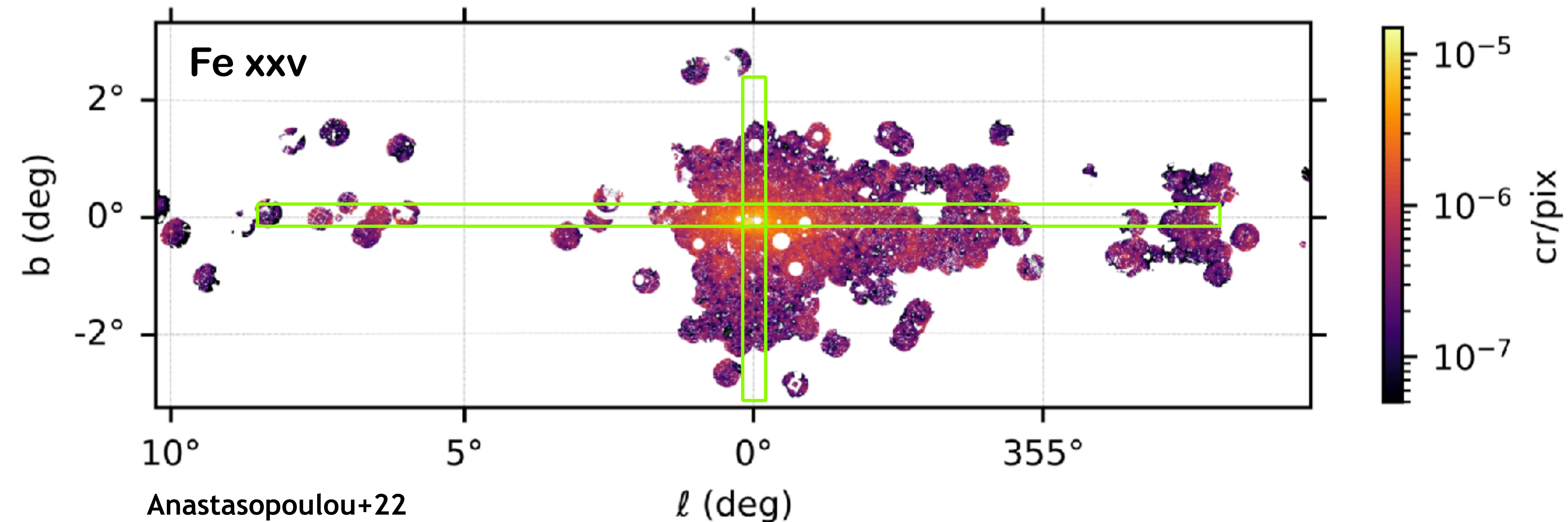
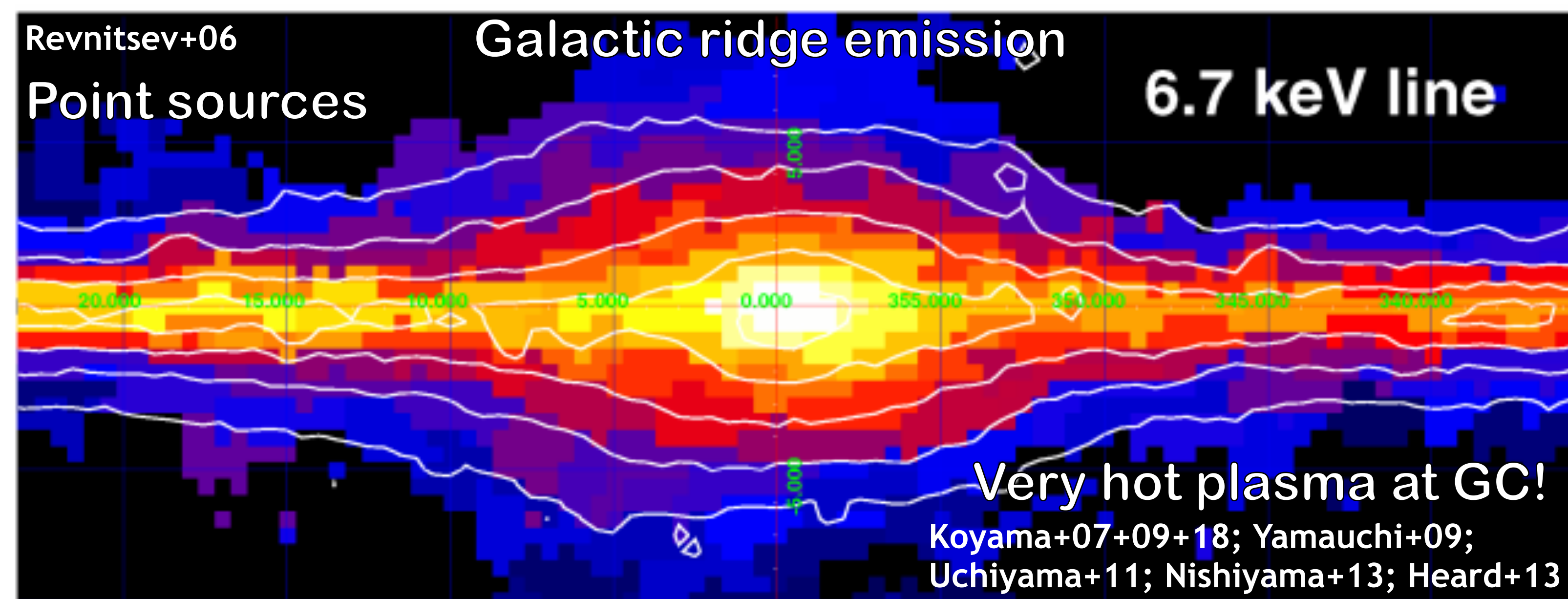
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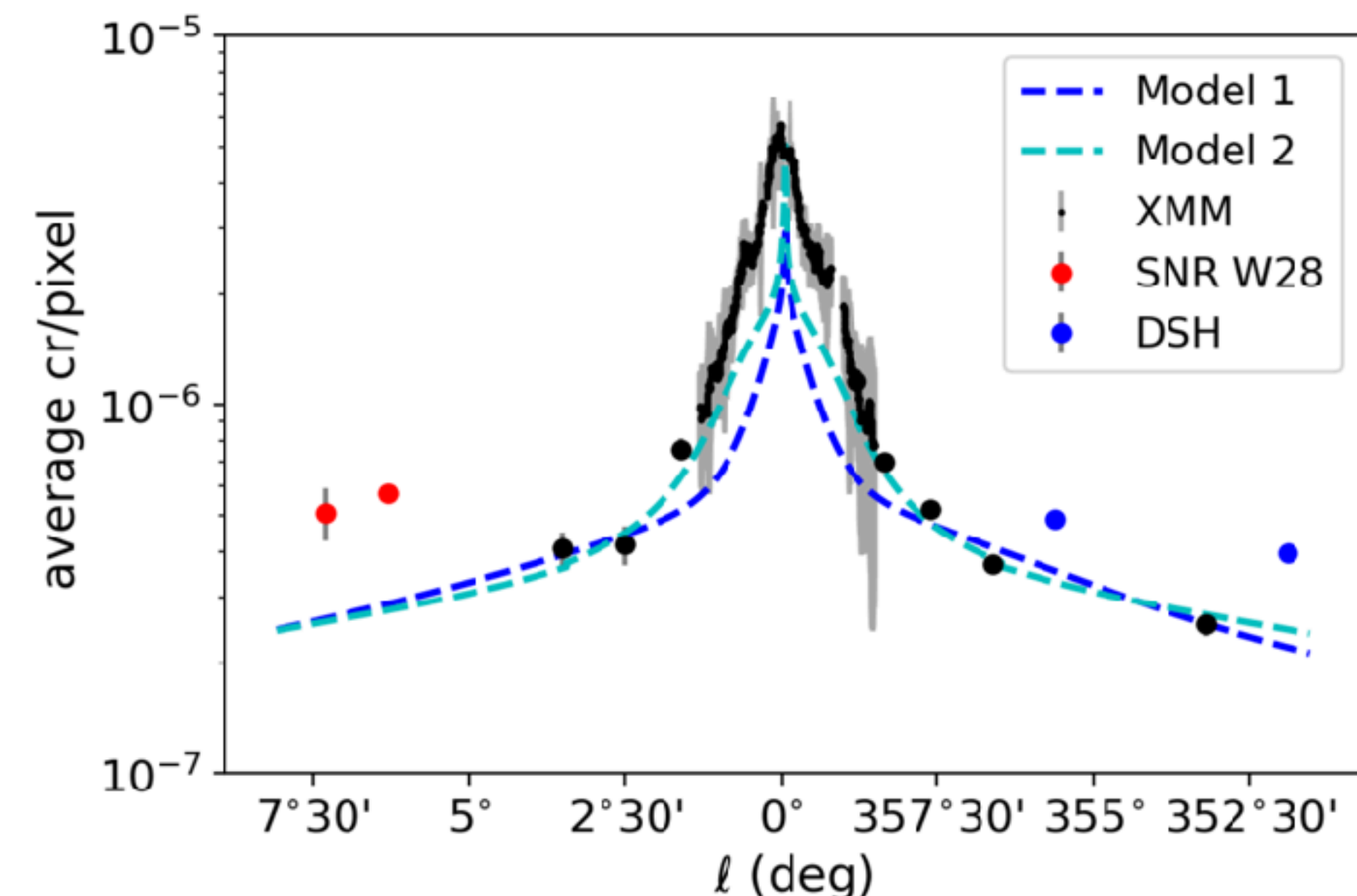
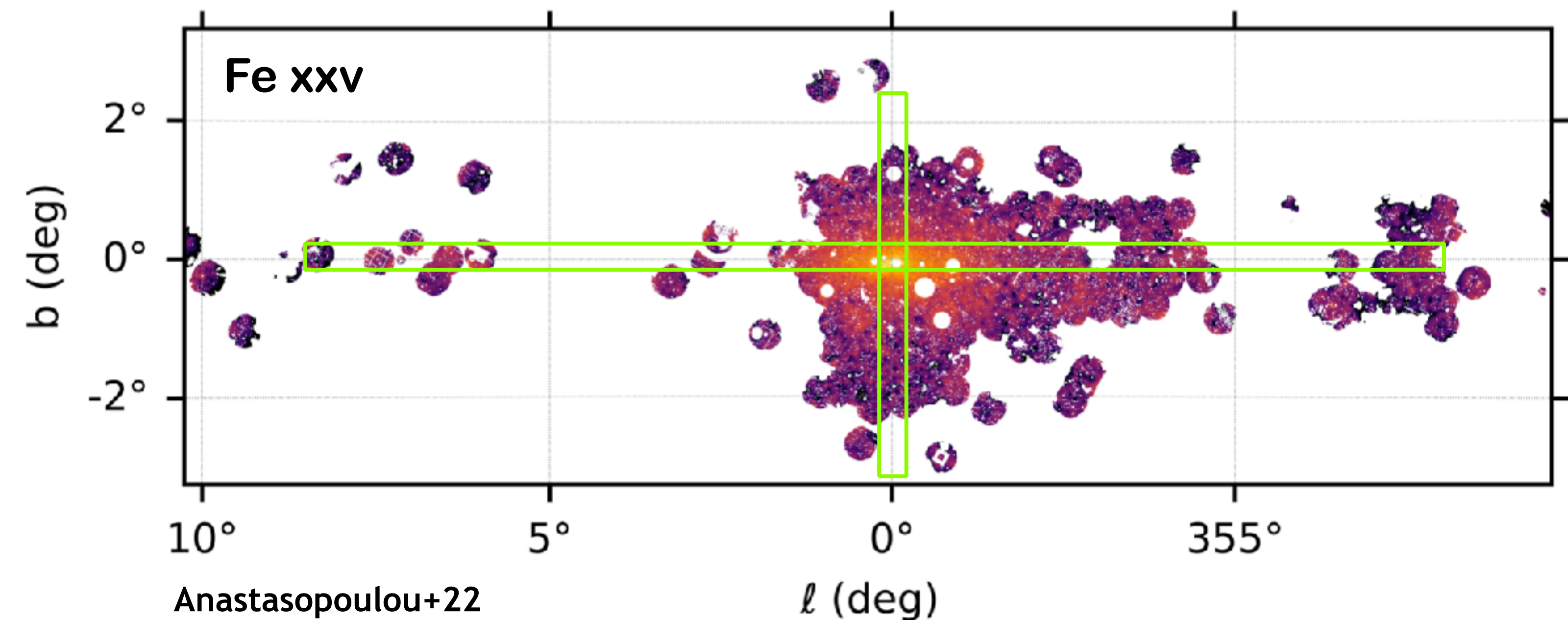
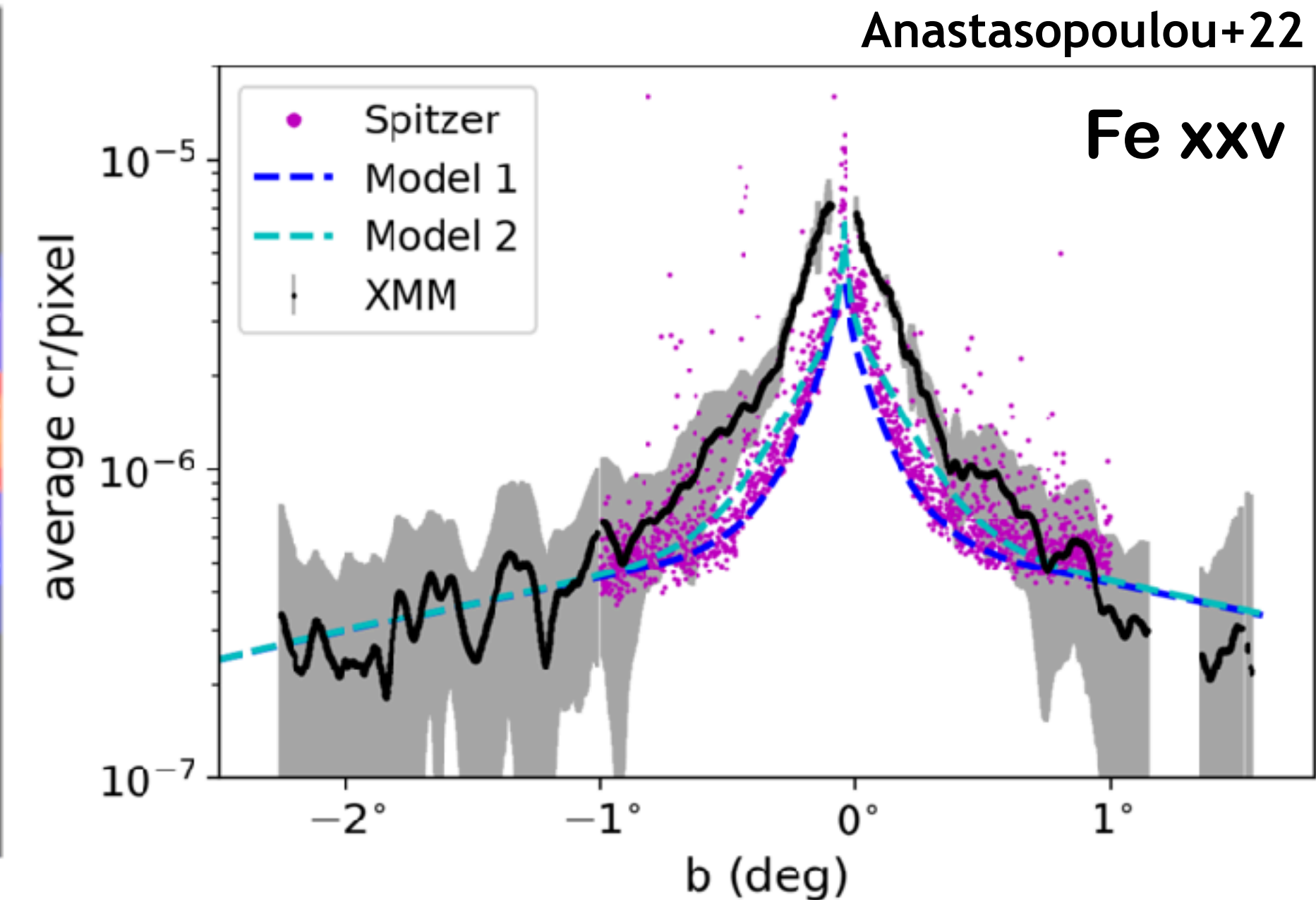
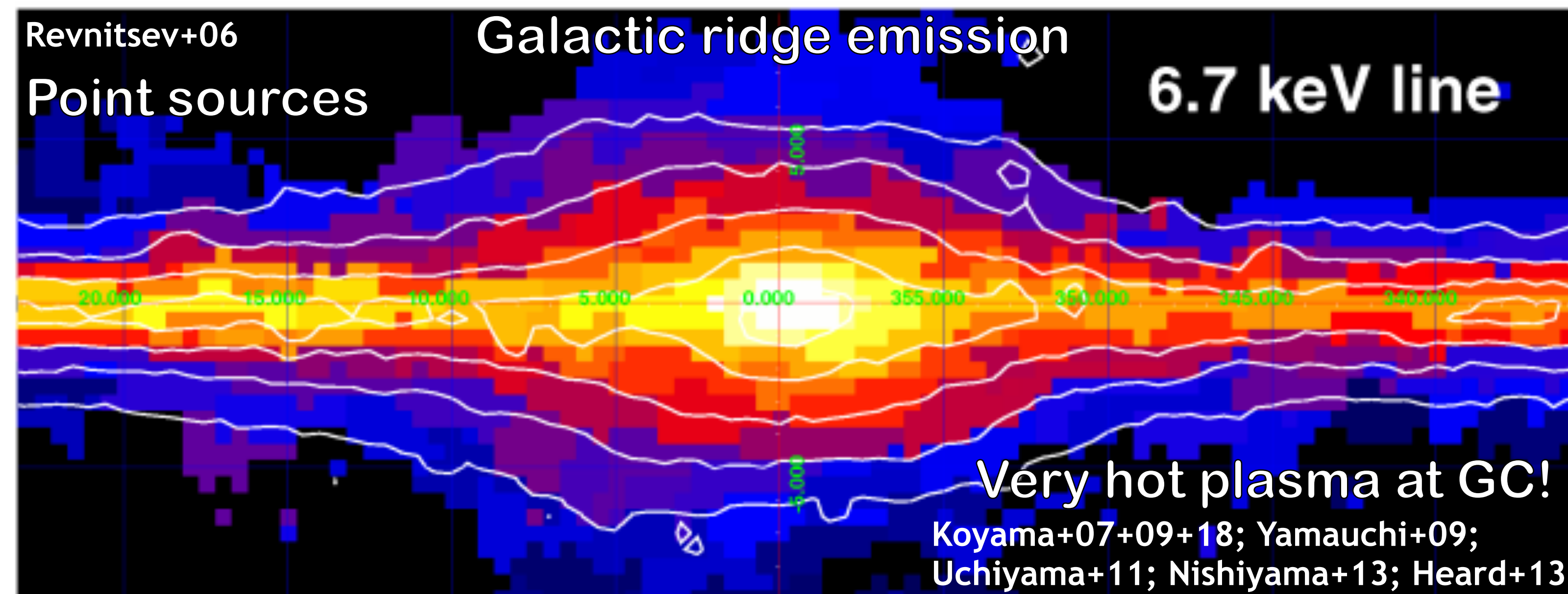
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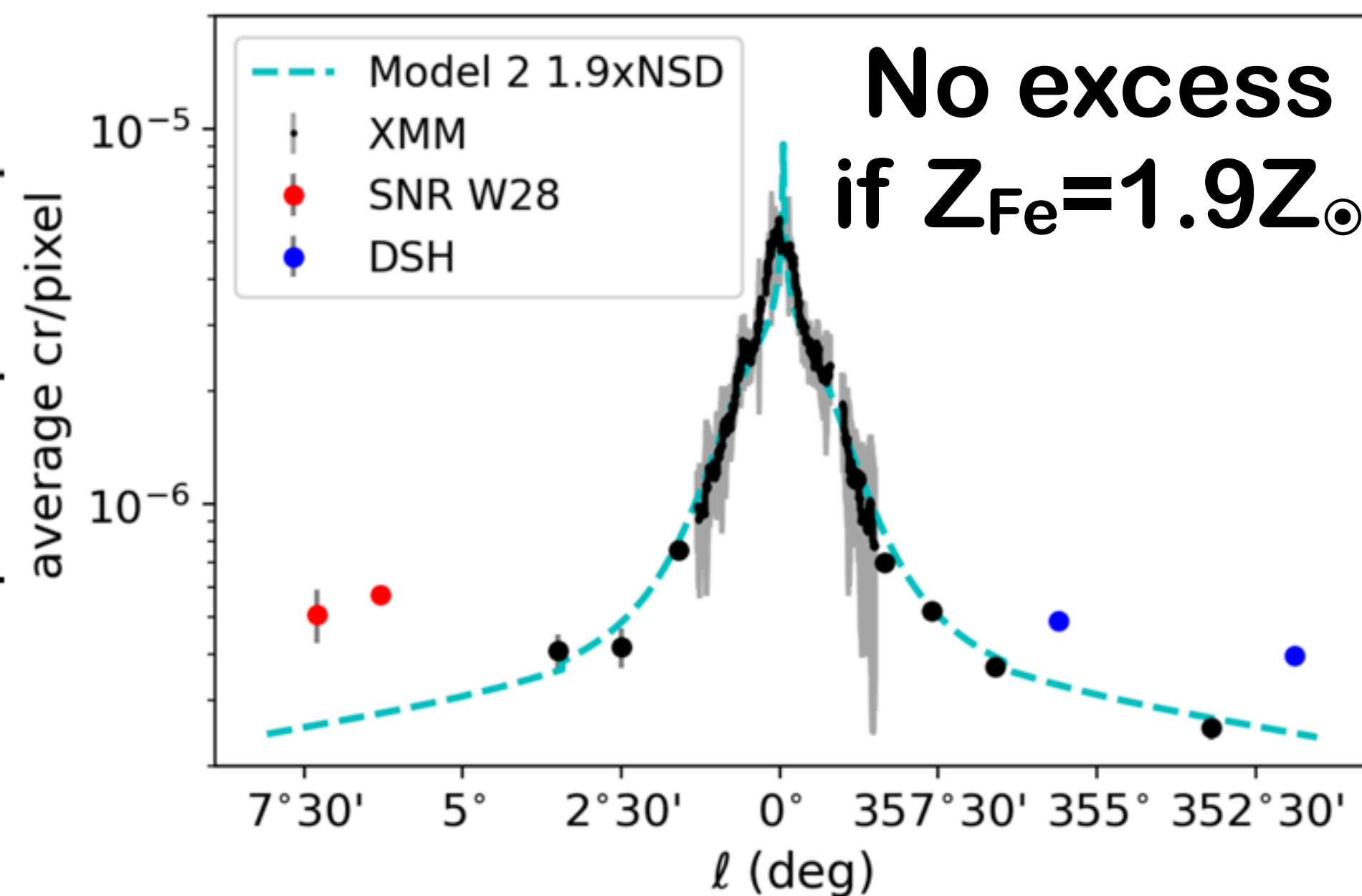
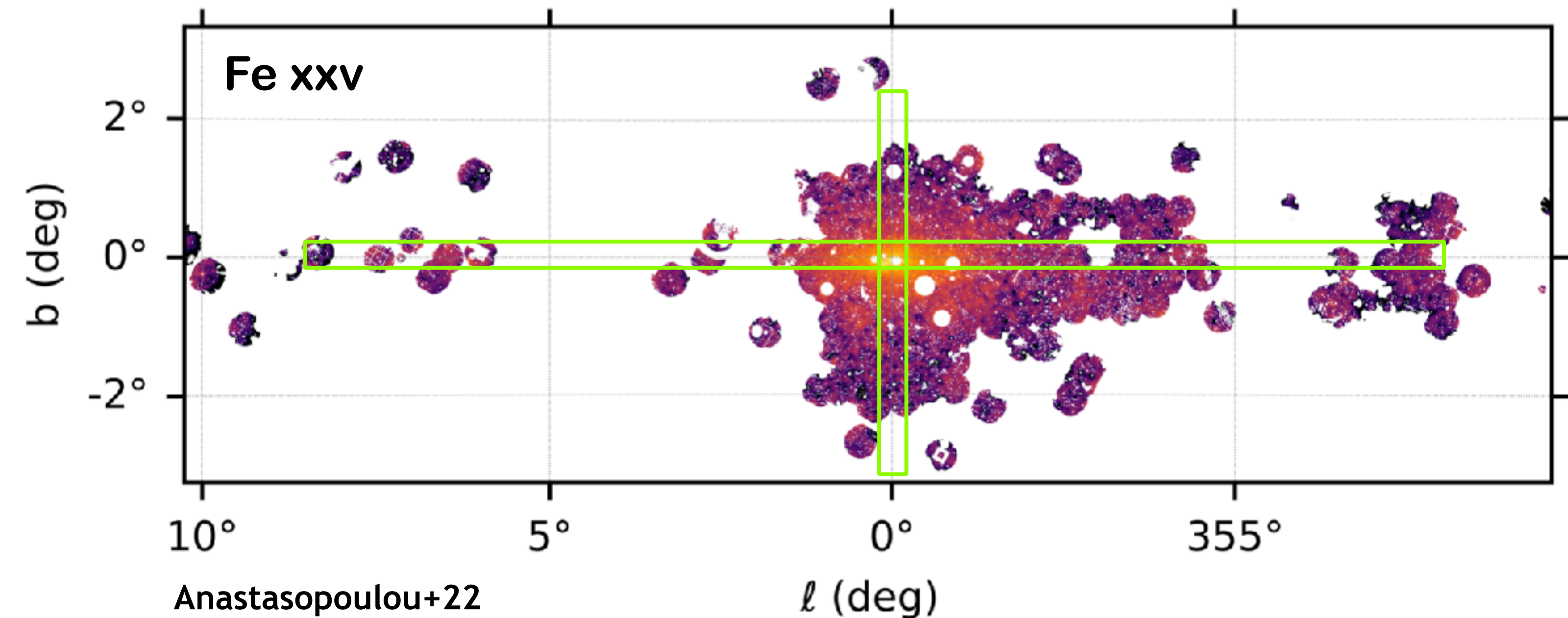
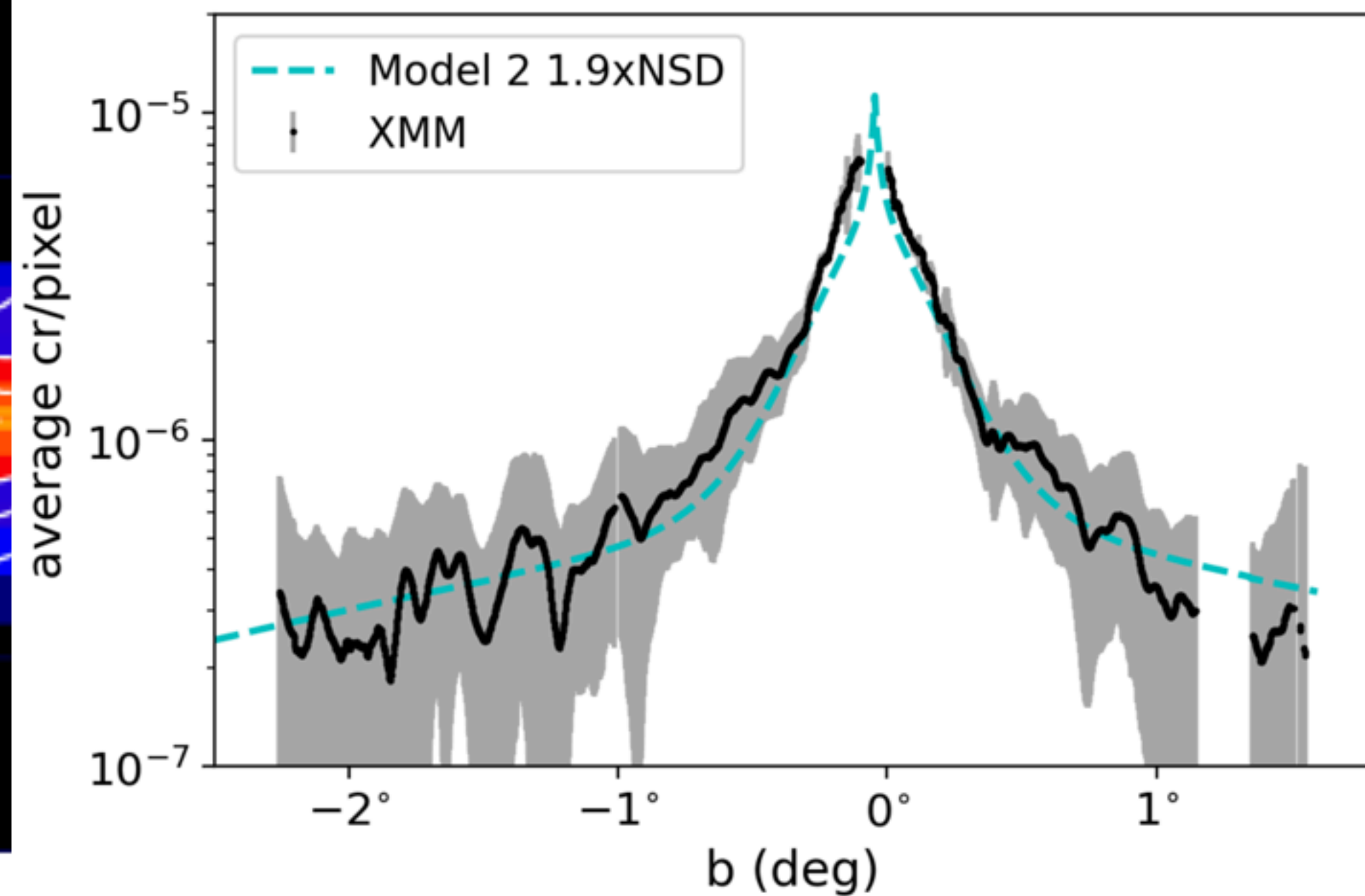
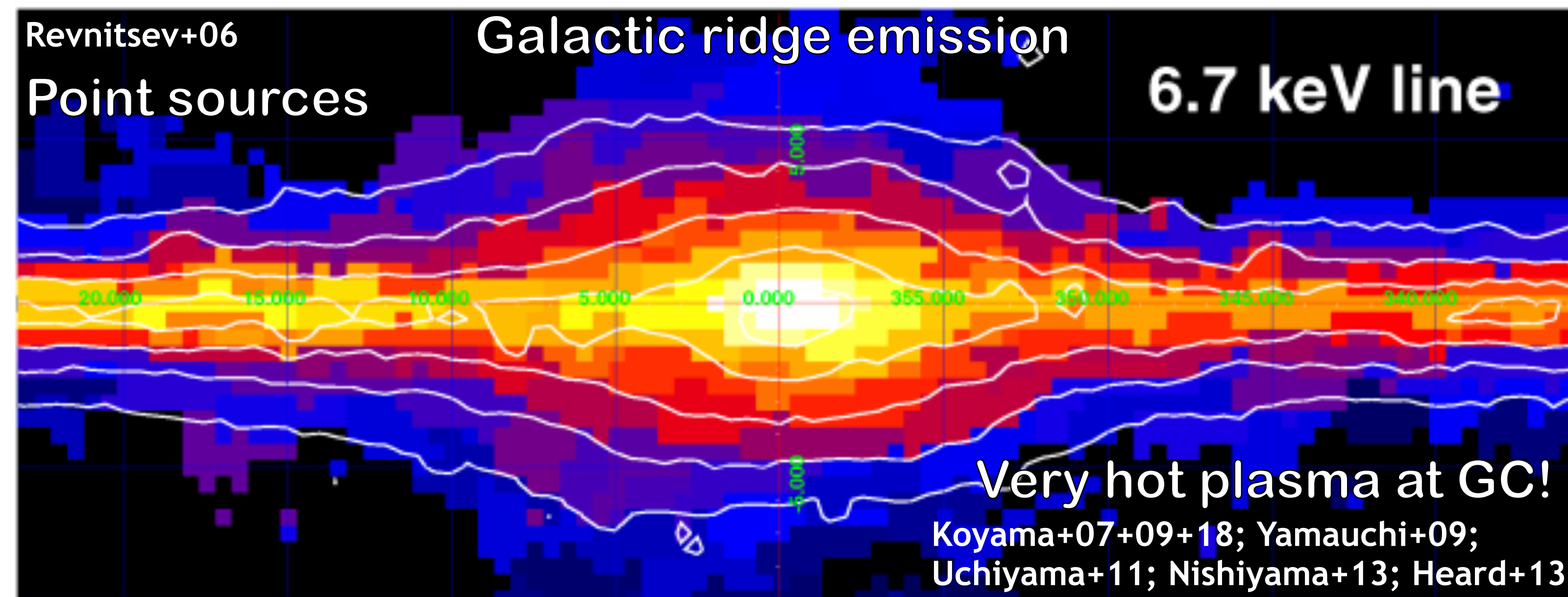
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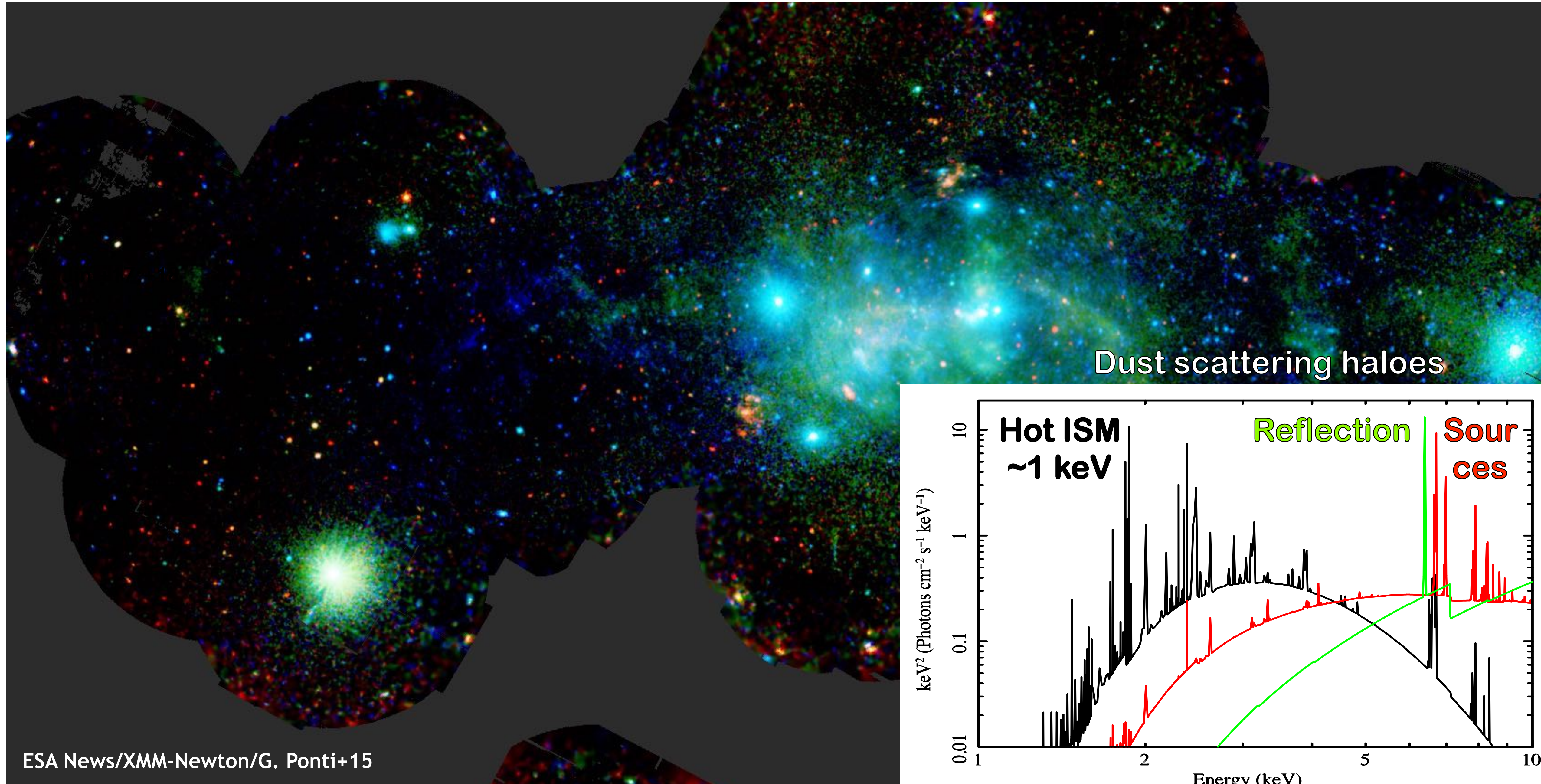
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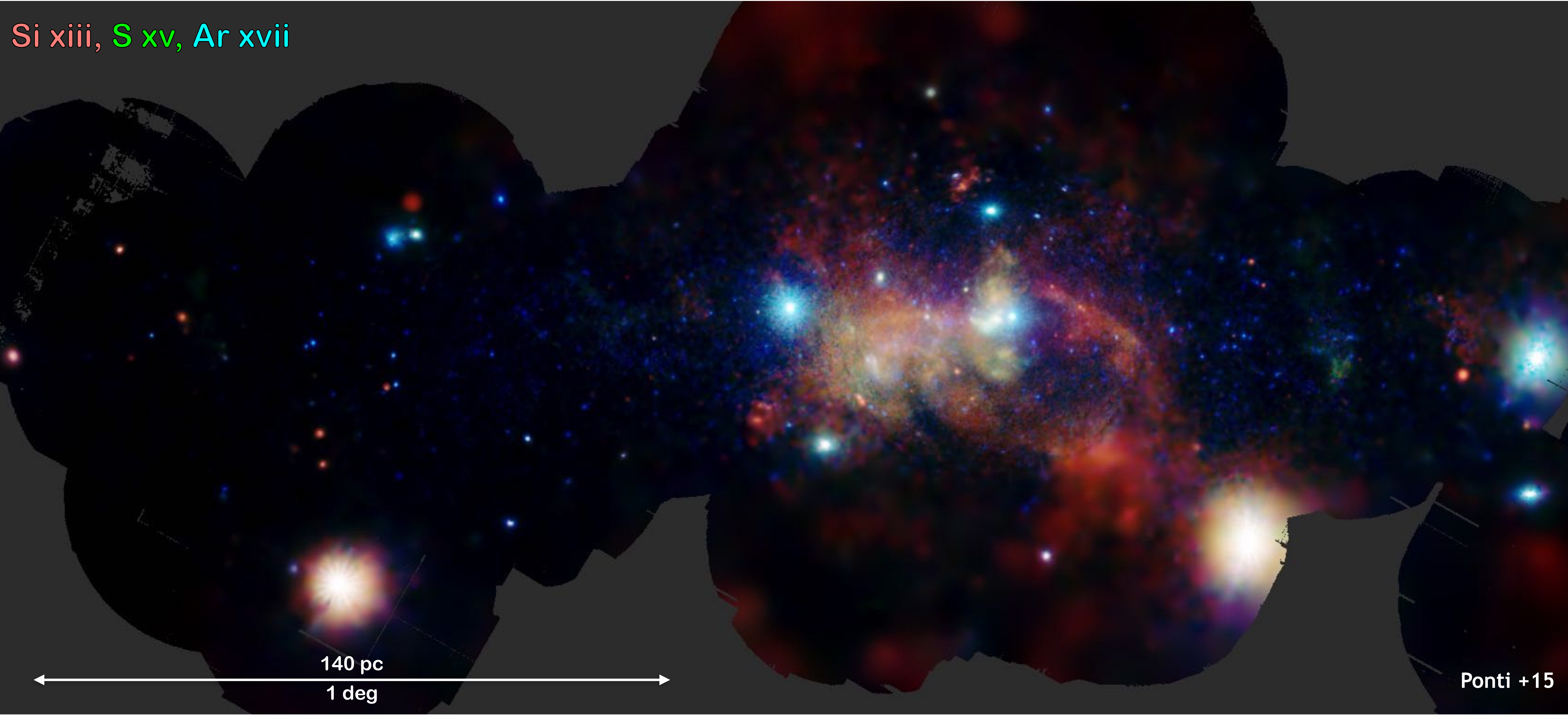


Components of the diffuse X-ray emission



Hot interstellar medium at GC

Si xiii, S xv, Ar xvii

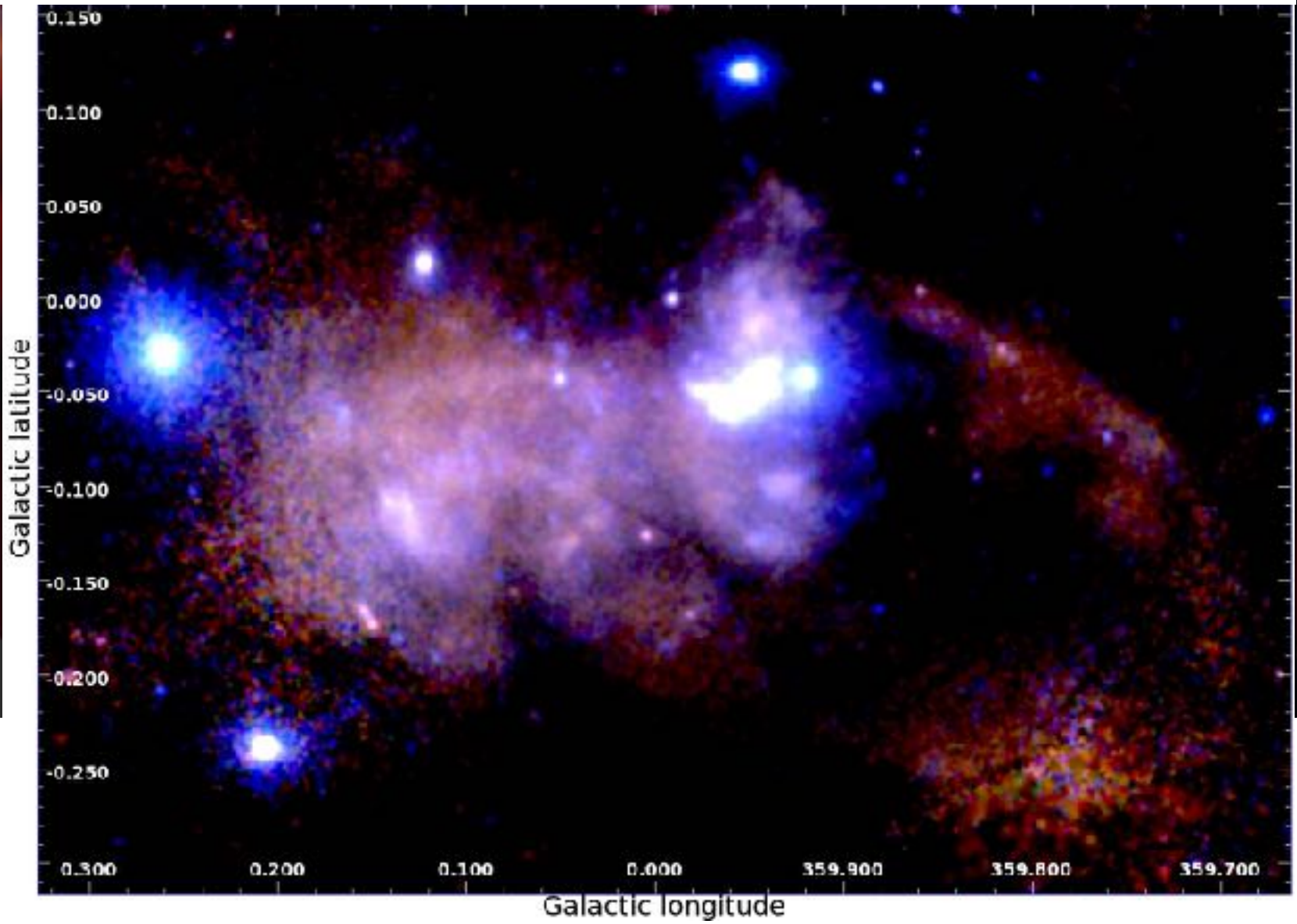
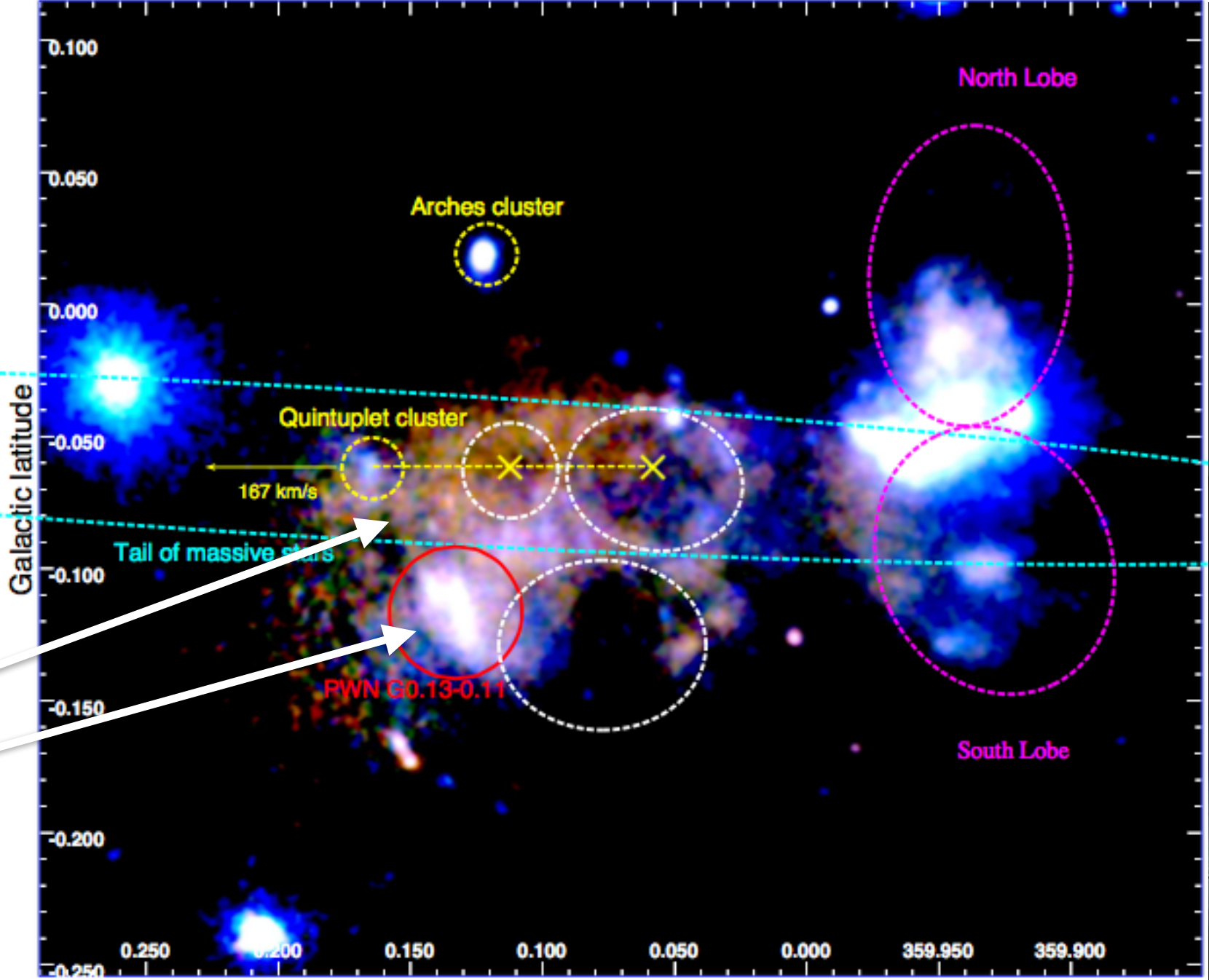
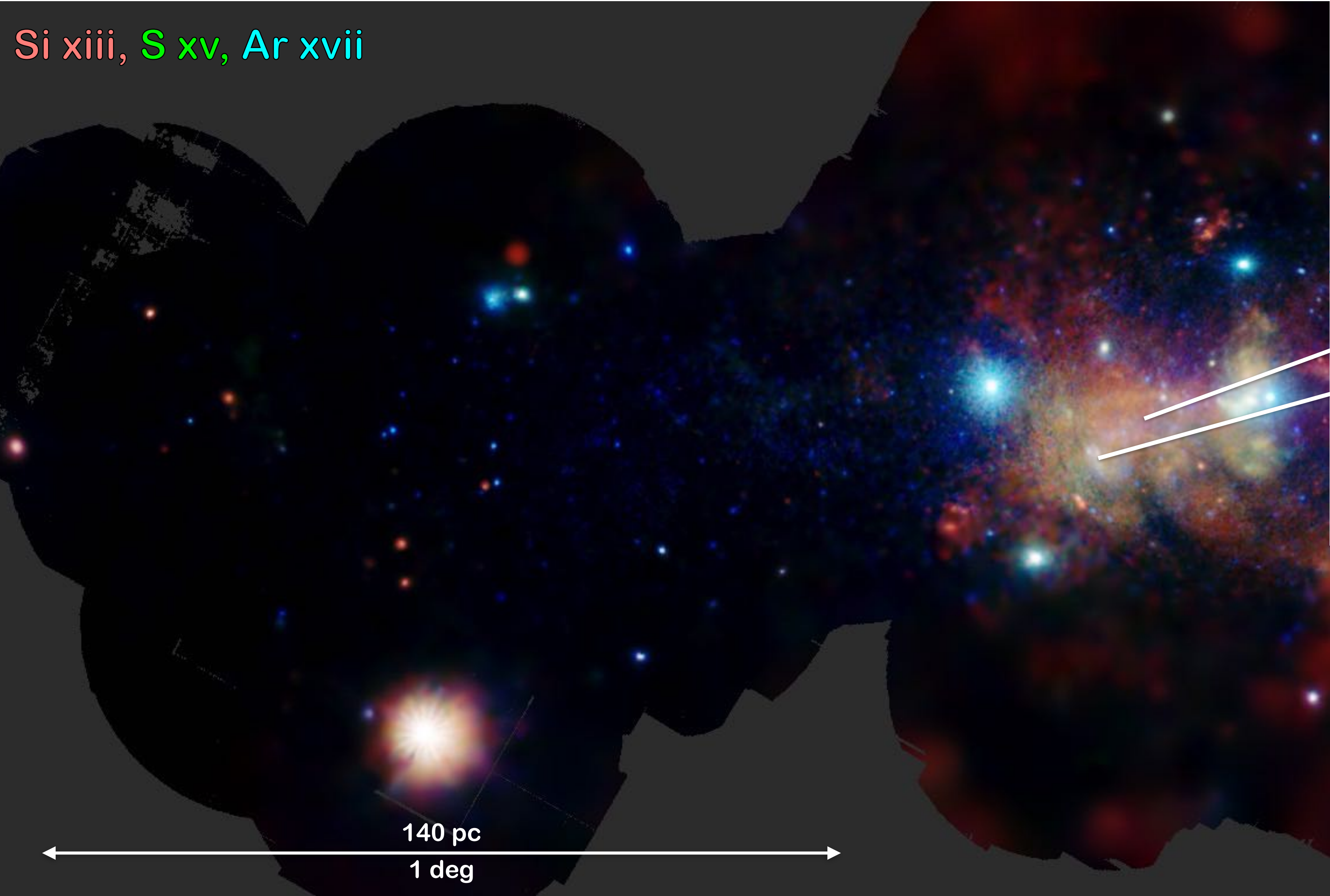


140 pc
1 deg

Ponti +15

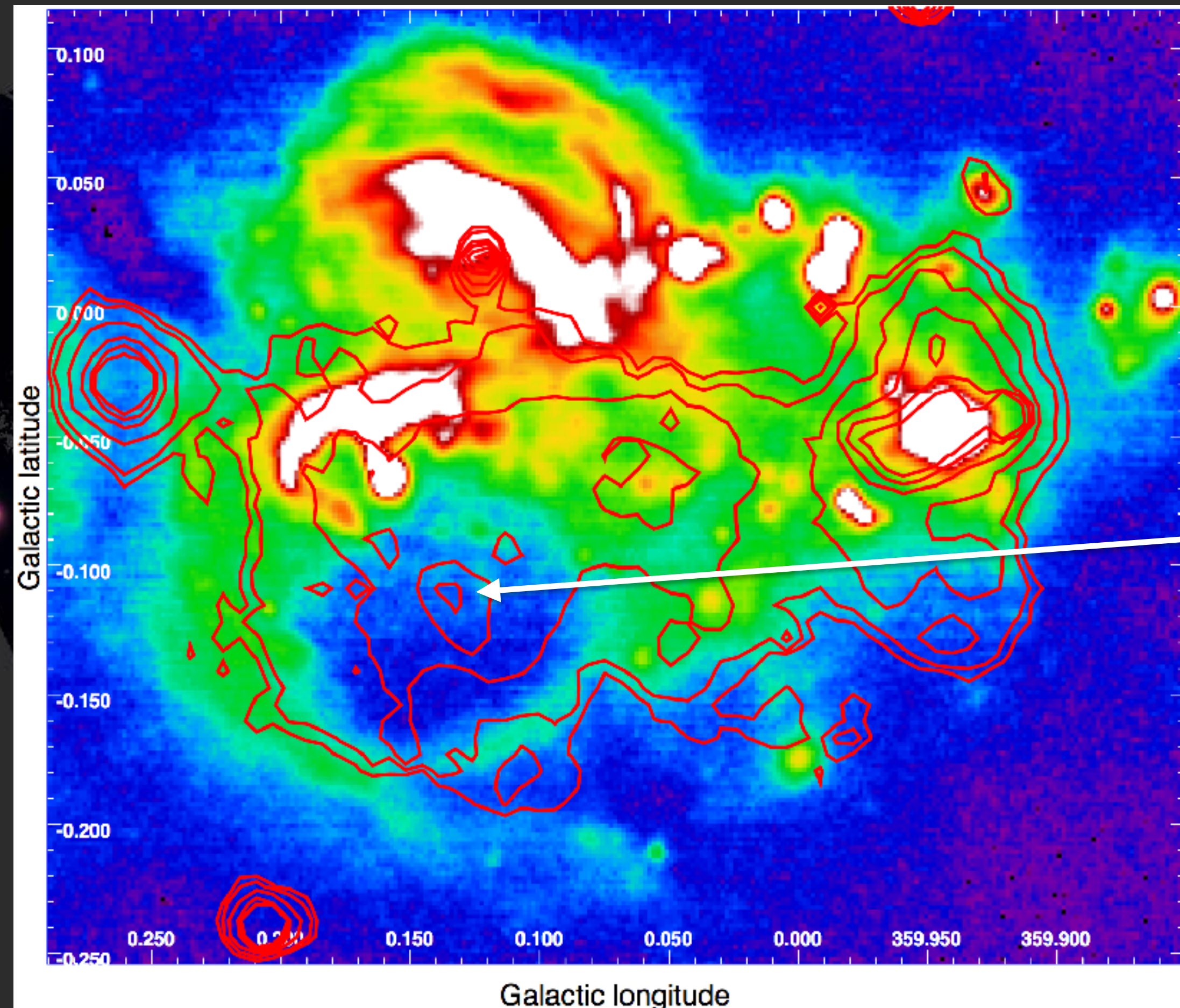
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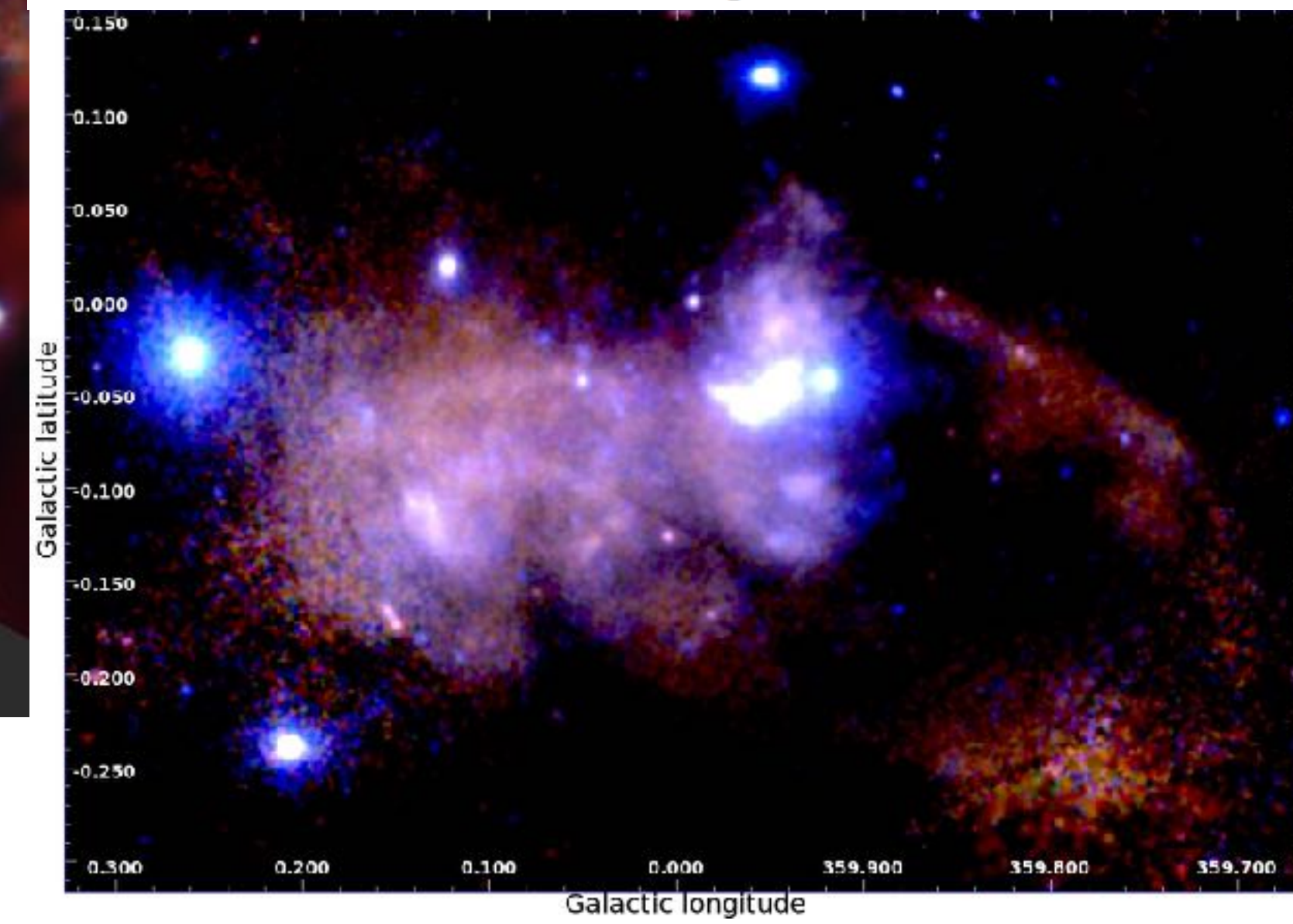
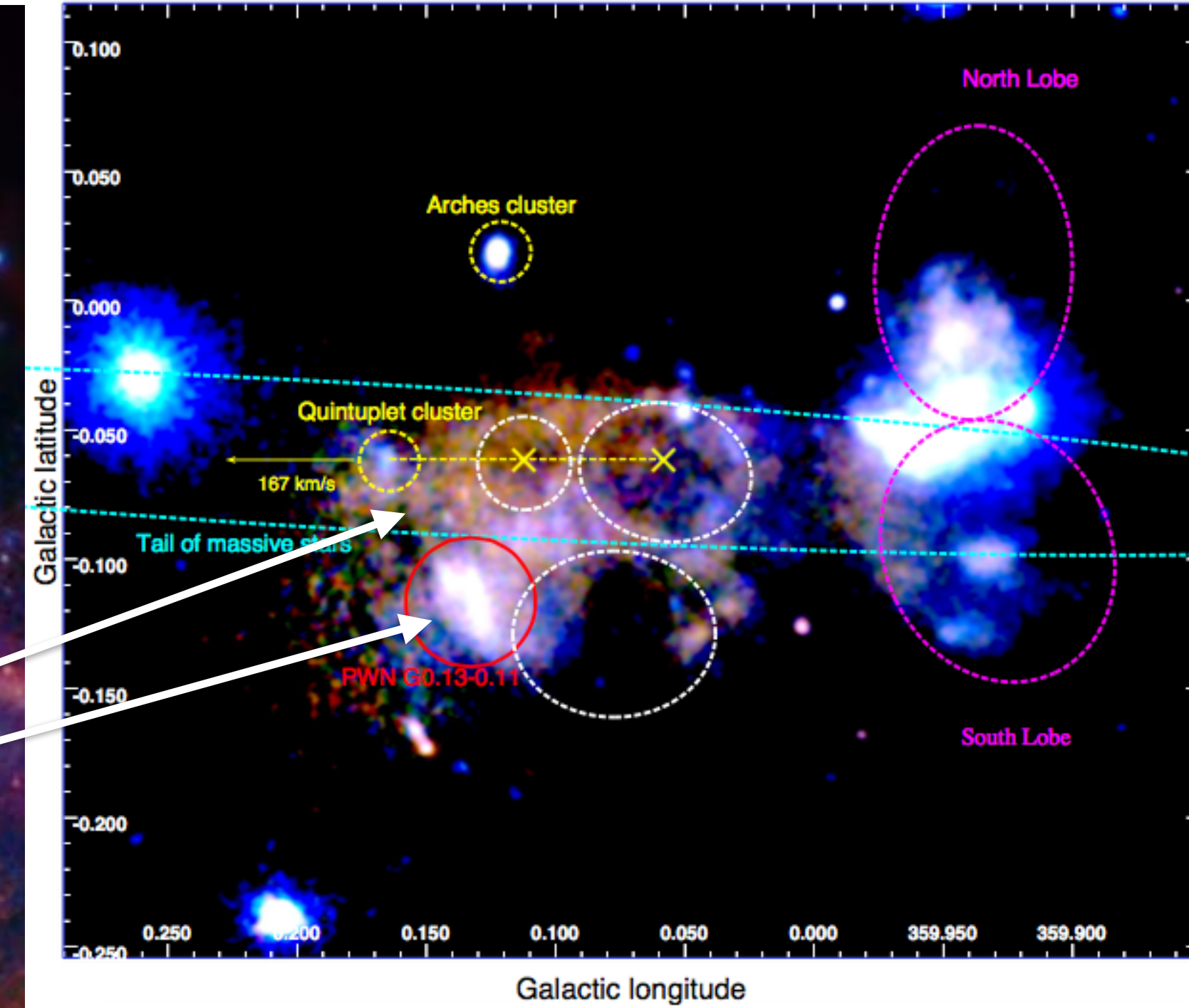
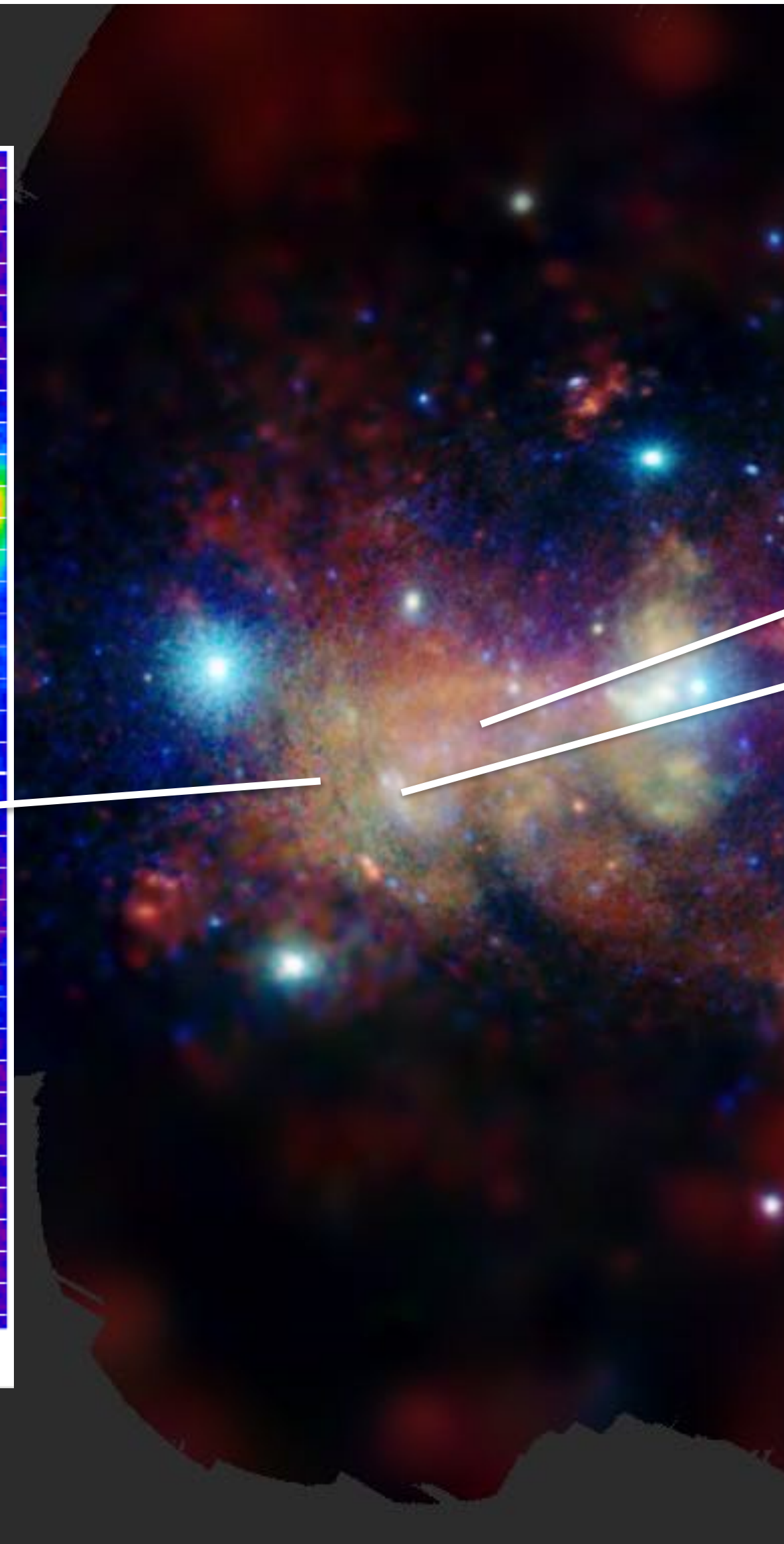
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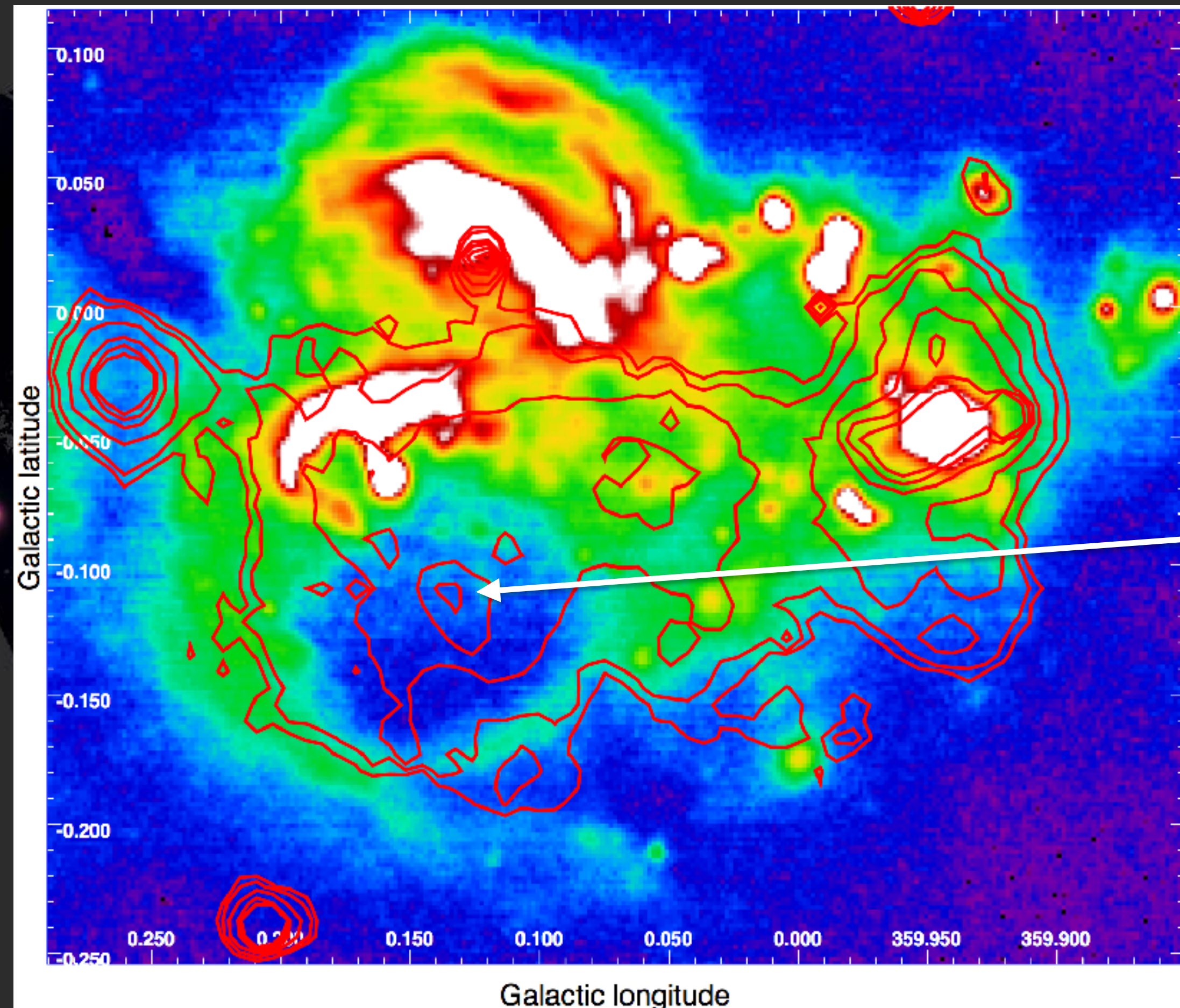
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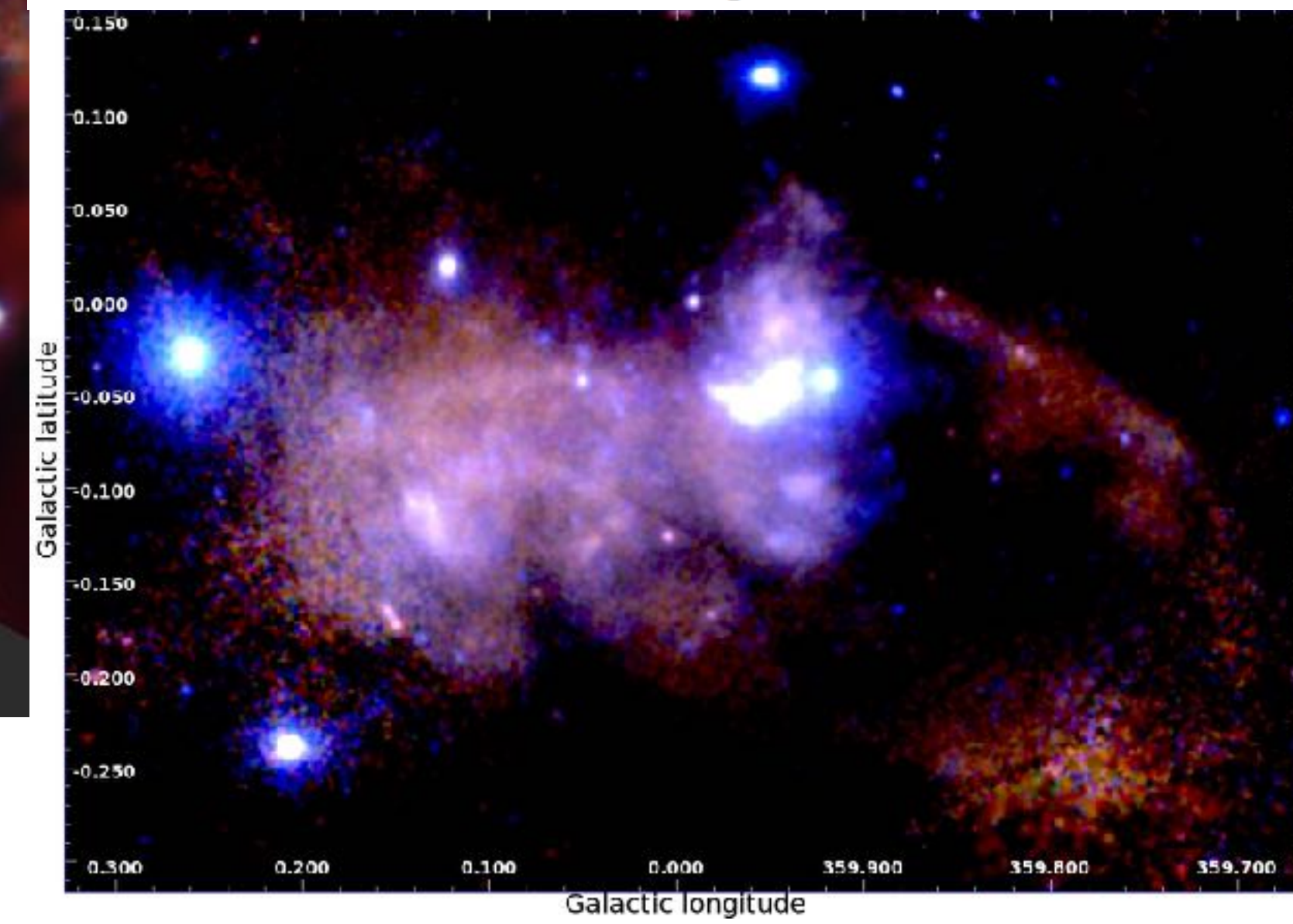
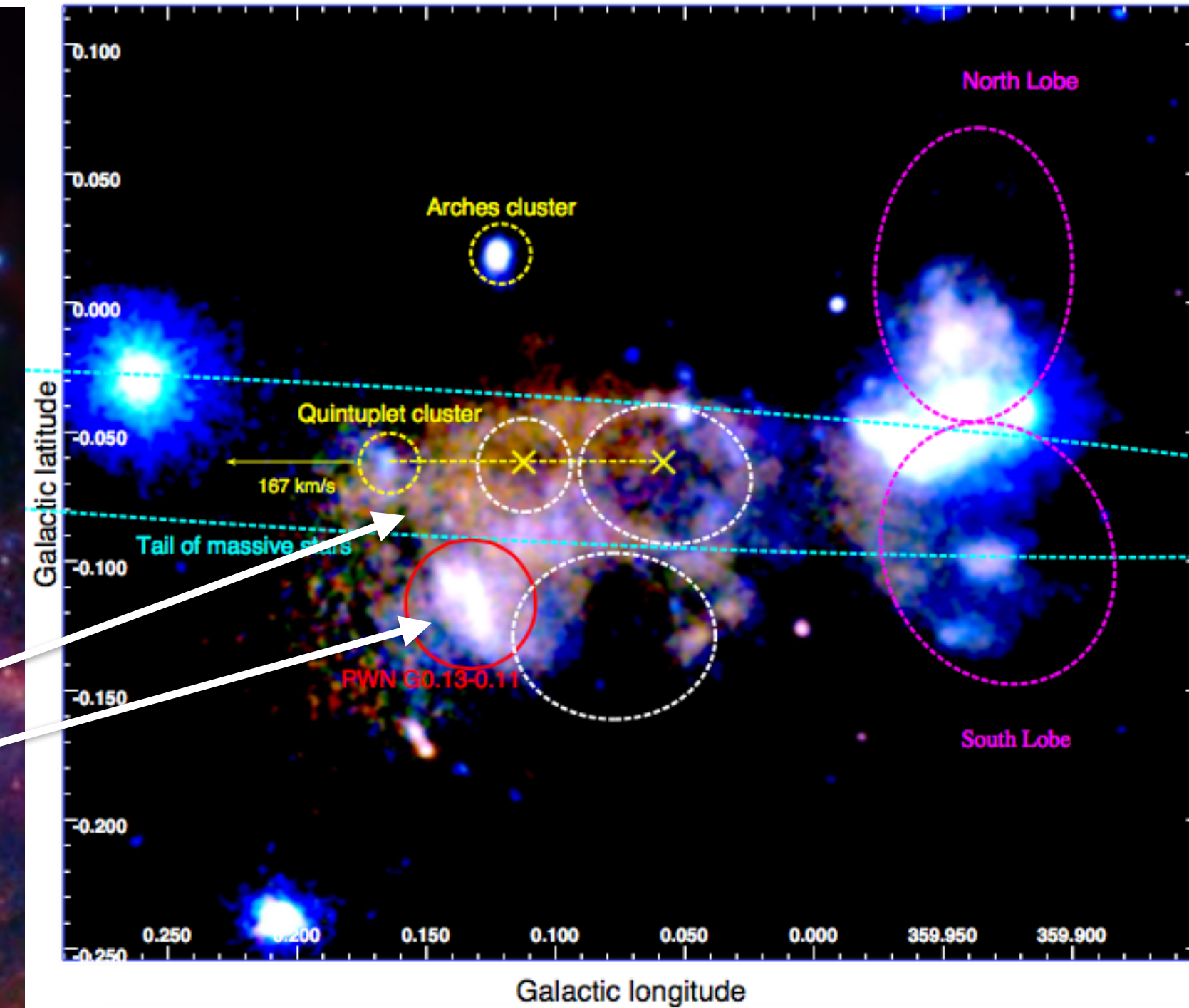
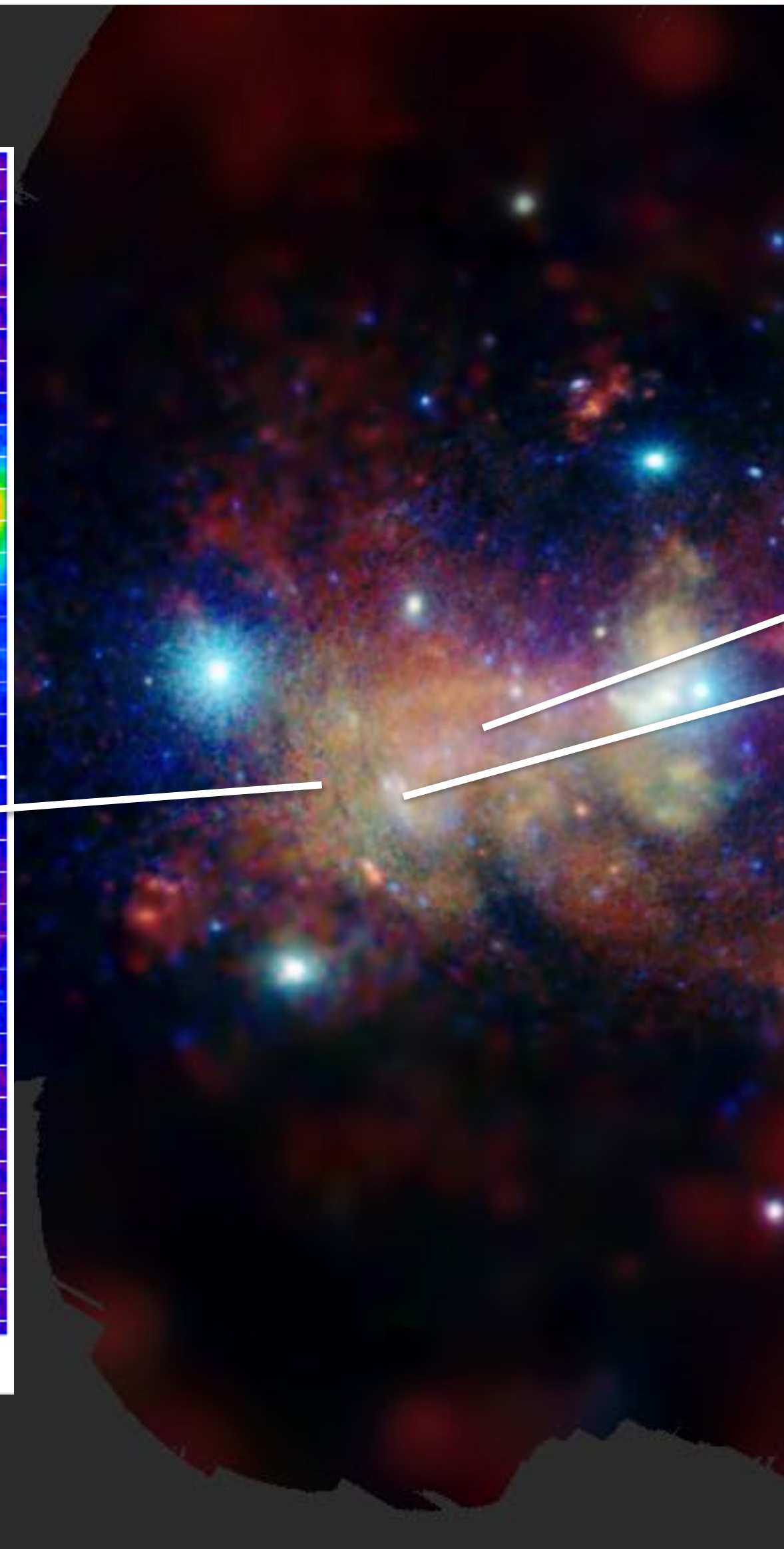
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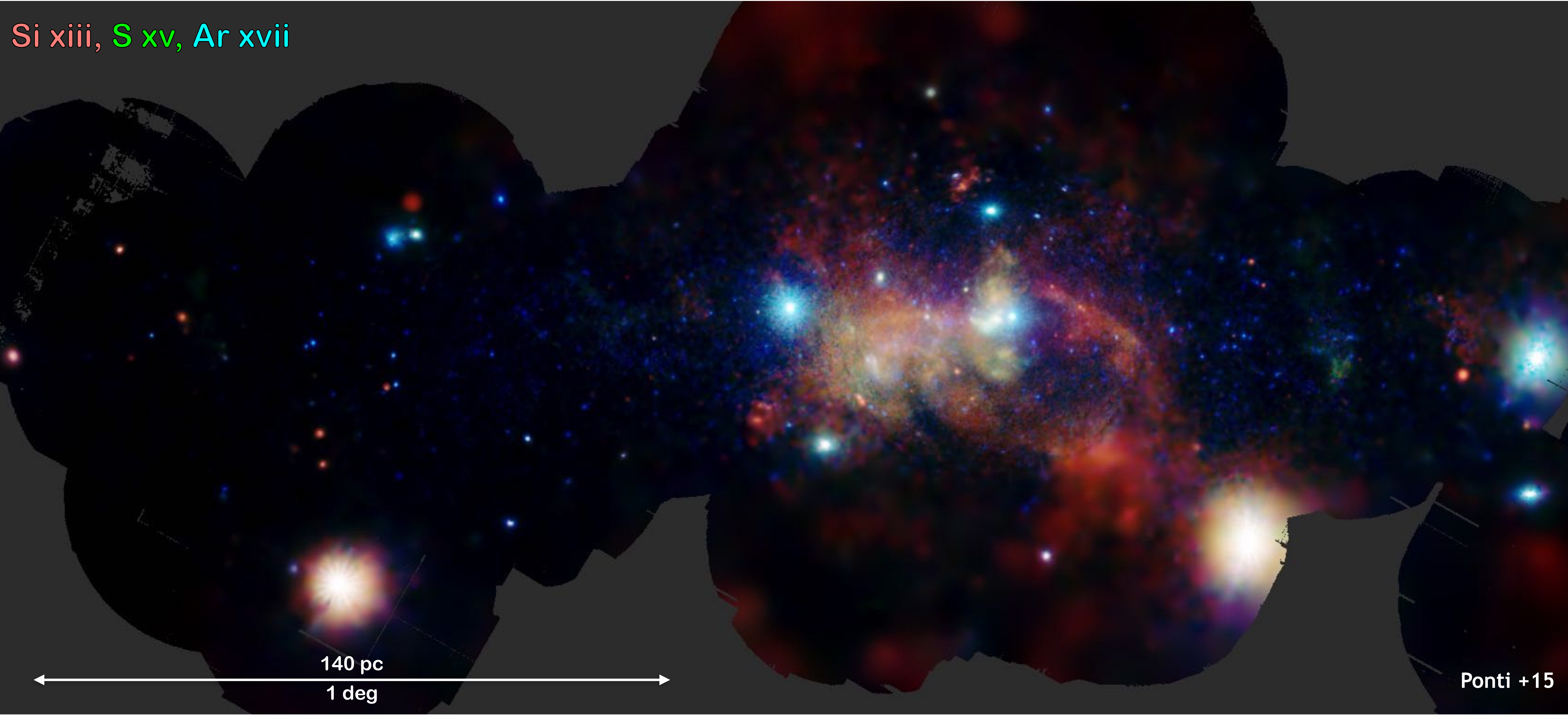


Ponti +15

Thermal X-rays fills the MIR arc bubble
Energetics: Superbubble powered by Quintuplet cluster

Hot ISM to trace the Galactic outflow

Si xiii, S xv, Ar xvii



140 pc
1 deg

Ponti +15

Ponti +15

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Hot ISM to trace the Galactic outflow

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Atlas of all (~15) SNR in the region

140 pc

1 deg

Ponti +15

Ponti +15

ATLAS OF DIFFUSE X-RAY EMITTING FEATURES				
Name	Other name	Coordinates (l, b)	Size arcsec	References
STAR CLUSTERS:				
Central star cluster		359.9442, -0.046	0.33	45,116,117,118
Quintuplet		0.1604, -0.0591	0.5	1,63,11
Arches	G0.12+0.02	0.1217, 0.0188	0.7	1,2,3,4,5,6,7,8,9,39,40,11
Sh2-10	DB00-6	0.3072,-0.2000	1.92	10,11,12,63,11
Sh2-17	DB00-58	0.0013, 0.1588	1.65	13,63,11
DB00-05	G0.33-0.18	0.31 -0.19	0.4	22,63,11
SNR - BUBBLES - SUPER-BUBBLES:				
G359.0-0.9	G358.5-0.9 - G359.1-0.9	359.03,-0.96	26 × 20	X-R 48,51,75,76,81,119,120
G359.07-0.02	G359.0-0.0	359.07,-0.02	22 × 10	R 14,48,51,66
	G359.12-0.05	359.12,-0.05	24 × 16	X 66
G359.10-0.5		359.10,-0.51	22 × 22	X-R 37,48,51,56,74,75,81,120,121
G359.41-0.12		359.41,-0.12	3.5 × 5.0	X 14
Chimney		359.46,+0.04	6.8 × 2.3	X 14
G359.73-0.35‡		359.73,-0.35	4	X 58
G359.77-0.09	Superbubble	359.84,-0.14	20 × 16	X 15,16,17,58
	G359.79-0.26‡	359.79,-0.26	8 × 5.2	X 15,16,17,58
	G0.0-0.16‡‡	0.00,-0.16		X This work
G359.87+0.44	Cane	359.87,+0.44	11 × 5	R 48
	G359.85+0.39			
20pc Sgr A* 's lobes		359.94, -0.04	5.88	R 32,33,34,17
G359.92-0.09‡	Parachute - G359.93-0.07	359.93,-0.09	1	R 35,38,43,47,58,60,61
Sgr A East	G0.0+0.0	359.963, -0.053	3.2 × 2.5	X-R 5,18,19,20,48,75,81
G0.1-0.1	Arc Bubble	0.109,-0.108	13.6 × 1.1	X This work
	G0.13,-0.12‡	0.13,-0.12	3 × 3	X 17
G0.224-0.032		0.224,-0.032	2.3 × 4.6	X This work
G0.30+0.04	G0.3+0.0	0.34,+0.045	14 × 8.8	R 21,48,51,81,82
	G0.34+0.05			
	G0.33+0.04			
G0.40-0.02	Suzaku J1746.4-2835.4	0.40,-0.02	4.7 × 7.4	X 22
	G0.42-0.04			
G0.52-0.046		0.519,-0.046◊	2.4 × 5.1	This work
G0.57-0.001		0.57,-0.001	1.5 × 2.9	This work
G0.57-0.018‡	CXO J174702.6-282733	0.570,-0.018	0.2	X 23,24,58,59,68,80
G0.61+0.01‡	Suzaku J1747.0-2824.5	0.61,+0.01	2.2 × 4.8	X 22,65,79
G0.9+01♡	SNR 0.9+0.1	0.867,+0.073	7.6 × 7.2	R 25,26,27,28,29,48,75,81,82
DS1	G1.2-0.0	1.17,+0.00	3.4 × 6.9	X 31
Sgr D SNR	G1.02-0.18	1.02,-0.17	10 × 8.0	R 30,31,48,51,75,77,81,82
	G1.05-0.15			
	G1.05-0.1			
	G1.0-0.1			
G1.4-0.1		1.4,-0.10	10 × 10	R 73,81,82

Hot ISM to trace the Galactic outflow

Si xiii, S xv, Ar xvii

Atlas of all (~15) SNR in the region
 $3.5 \times 10^{-4} \text{ yr}^{-1} < \text{SN rate} < 15 \times 10^{-4} \text{ yr}^{-1}$

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 $3.5 \times 10^{-4} \text{ yr}^{-1} < \text{SN rate} < 15 \times 10^{-4} \text{ yr}^{-1}$
Massive kinetic energy input $\sim 1.1 \times 10^{40} \text{ erg s}^{-1}$

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SNR - BUBBLES - SUPER-BUBBLES:				
G359.0-0.9	G358.5-0.9 - G359.1-0.9	359.03,-0.96	26 × 20	X-R 48,51,75,76,81,119,120
G359.07-0.02	G359.0-0.0	359.07,-0.02	22 × 10	R 14,48,51,66
	G359.12-0.05	359.12,-0.05	24 × 16	X 66
G359.10-0.5		359.10,-0.51	22 × 22	X-R 37,48,51,56,74,75,81,120,121
G359.41-0.12		359.41,-0.12	3.5 × 5.0	X 14
Chimney		359.46,+0.04	6.8 × 2.3	X 14
G359.73-0.35‡		359.73,-0.35	4	X 58
G359.77-0.09	Superbubble	359.84,-0.14	20 × 16	X 15,16,17,58
	G359.79-0.26‡	359.79,-0.26	8 × 5.2	X 15,16,17,58
	G0.0-0.16‡‡	0.00,-0.16		X This work
G359.87+0.44	Cane	359.87,+0.44	11 × 5	R 48
	G359.85+0.39			
20pc Sgr A* 's lobes		359.94, -0.04	5.88	R 32,33,34,17
G359.92-0.09‡	Parachute - G359.93-0.07	359.93,-0.09	1	R 35,38,43,47,58,60,61
Sgr A East	G0.0+0.0	359.963, -0.053	3.2 × 2.5	X-R 5,18,19,20,48,75,81
G0.1-0.1	Arc Bubble	0.109,-0.108	13.6 × 1.1	X This work
	G0.13,-0.12‡	0.13,-0.12	3 × 3	X 17
G0.224-0.032		0.224,-0.032	2.3 × 4.6	X This work
G0.30+0.04	G0.3+0.0	0.34,+0.045	14 × 8.8	R 21,48,51,81,82
	G0.34+0.05			
	G0.33+0.04			
G0.40-0.02	Suzaku J1746.4-2835.4	0.40,-0.02	4.7 × 7.4	X 22
	G0.42-0.04			
G0.52-0.046		0.519,-0.046◊	2.4 × 5.1	This work
G0.57-0.001		0.57,-0.001	1.5 × 2.9	This work
G0.57-0.018‡	CXO J174702.6-282733	0.570,-0.018	0.2	X 23,24,58,59,68,80
G0.61+0.01‡	Suzaku J1747.0-2824.5	0.61,+0.01	2.2 × 4.8	X 22,65,79
G0.9+01♡	SNR 0.9+0.1	0.867,+0.073	7.6 × 7.2	R 25,26,27,28,29,48,75,81,82
DS1	G1.2-0.0	1.17,+0.00	3.4 × 6.9	X 31
Sgr D SNR	G1.02-0.18	1.02,-0.17	10 × 8.0	R 30,31,48,51,75,77,81,82
	G1.05-0.15			
	G1.05-0.1			
	G1.0-0.1			
G1.4-0.1		1.4,-0.10	10 × 10	R 73,81,82

Hot ISM to trace the Galactic outflow

Si xiii, S xv, Ar xvii

Atlas of all (~15) SNR in the region
 $3.5 \times 10^{-4} \text{ yr}^{-1} < \text{SN rate} < 15 \times 10^{-4} \text{ yr}^{-1}$
Massive kinetic energy input $\sim 1.1 \times 10^{40} \text{ erg s}^{-1}$

→ Powering outflows to
Galactic center lobe?

Law +11; Crocker +11; 12;
Yoast-Hull +14; Jouvin +15

140 pc

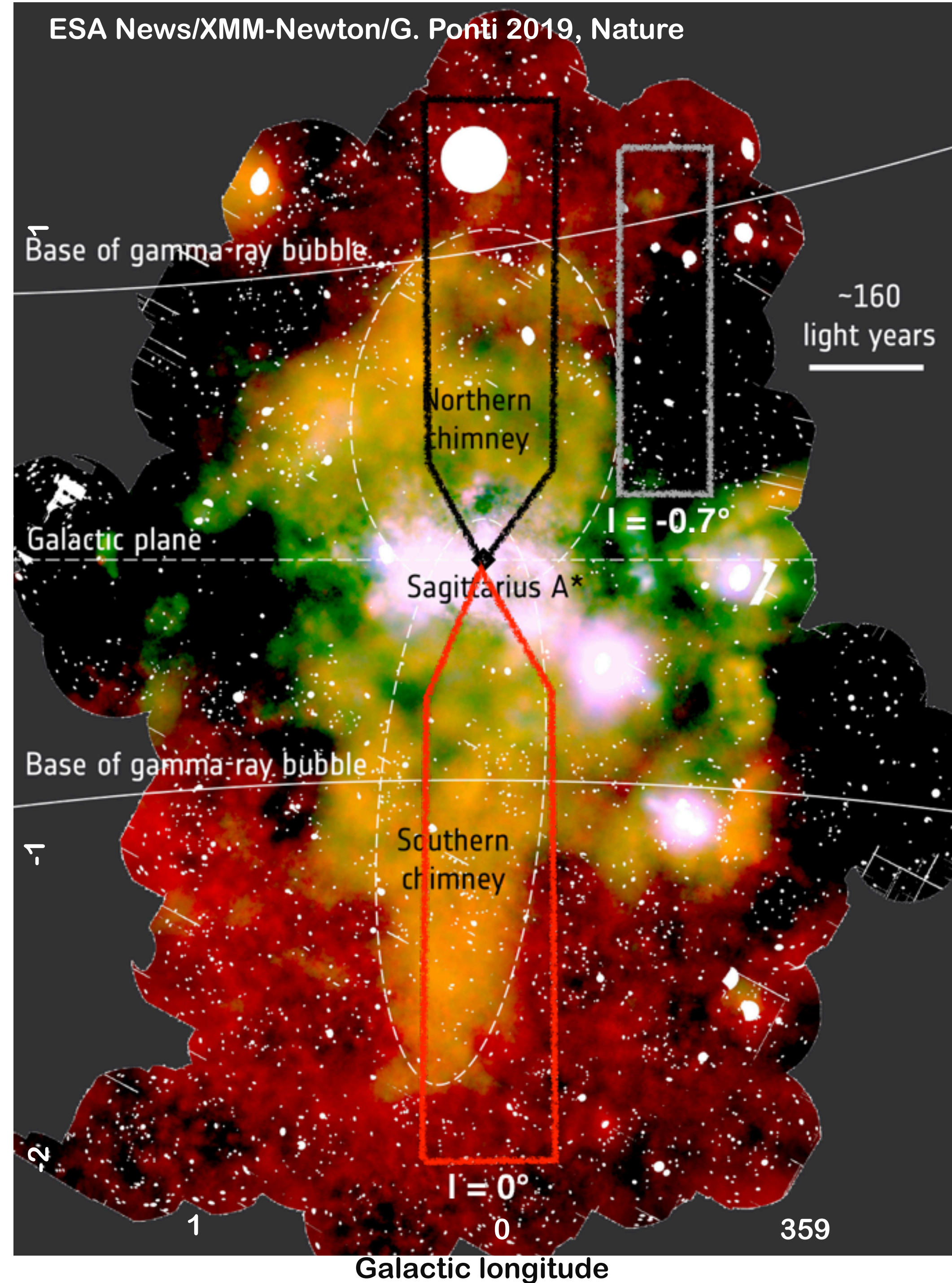
1 deg

Ponti +15

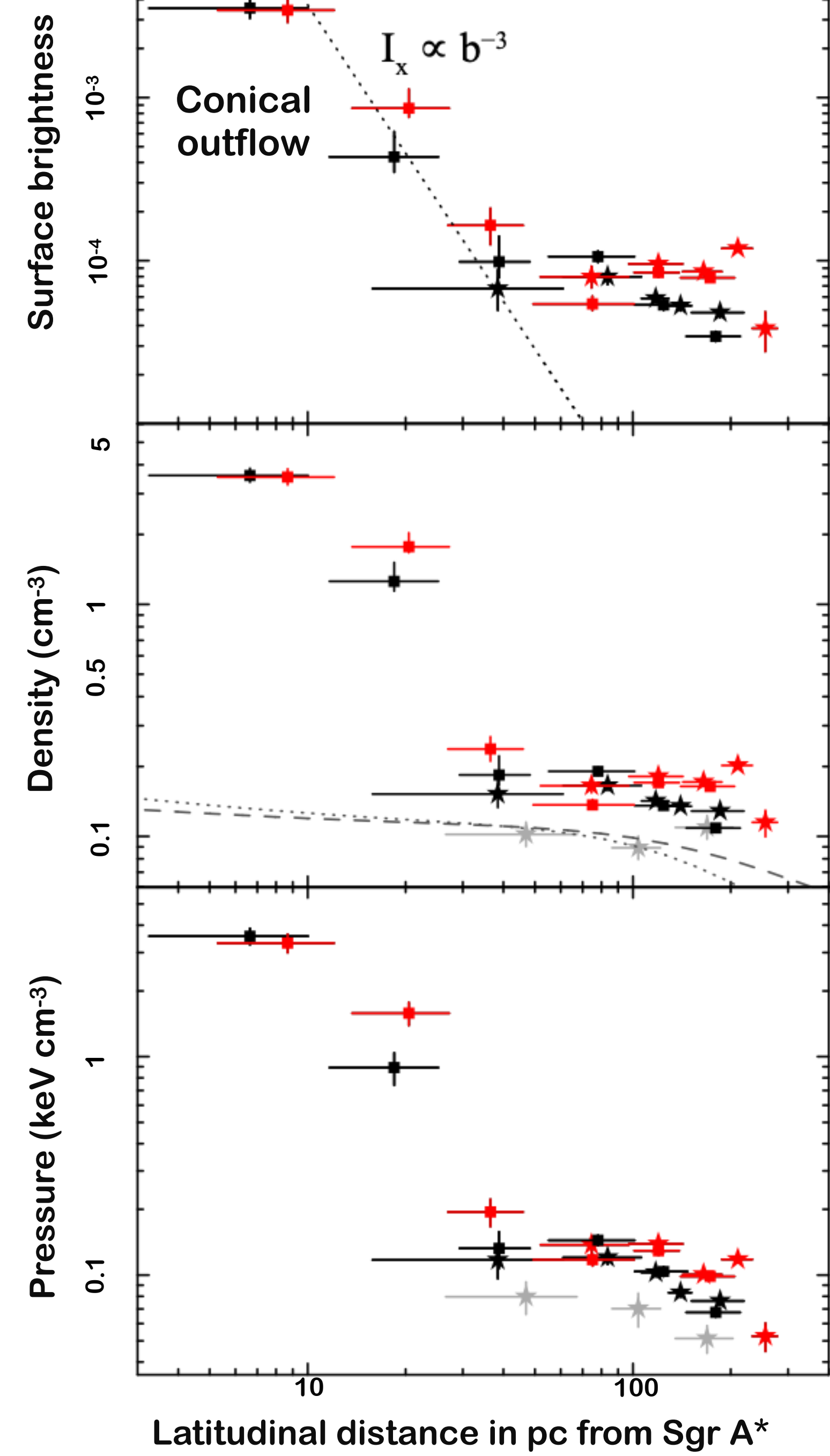
Ponti +15

ATLAS OF DIFFUSE X-RAY EMITTING FEATURES				
Name	Other name	Coordinates (l, b)	Size arcsec	References
STAR CLUSTERS:				
Central star cluster		359.9442, -0.046	0.33	45,116,117,118
Quintuplet		0.1604, -0.0591	0.5	1,63,11
Arches	G0.12+0.02	0.1217, 0.0188	0.7	1,2,3,4,5,6,7,8,9,39,40,11
Sh2-10	DB00-6	0.3072, -0.2000	1.92	10,11,12,63,11
Sh2-17	DB00-58	0.0013, 0.1588	1.65	13,63,11
DB00-05	G0.33-0.18	0.31 -0.19	0.4	22,63,11
SNR - BUBBLES - SUPER-BUBBLES:				
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G1.4-0.1		1.4,-0.10	10 × 10	R 73,81,82

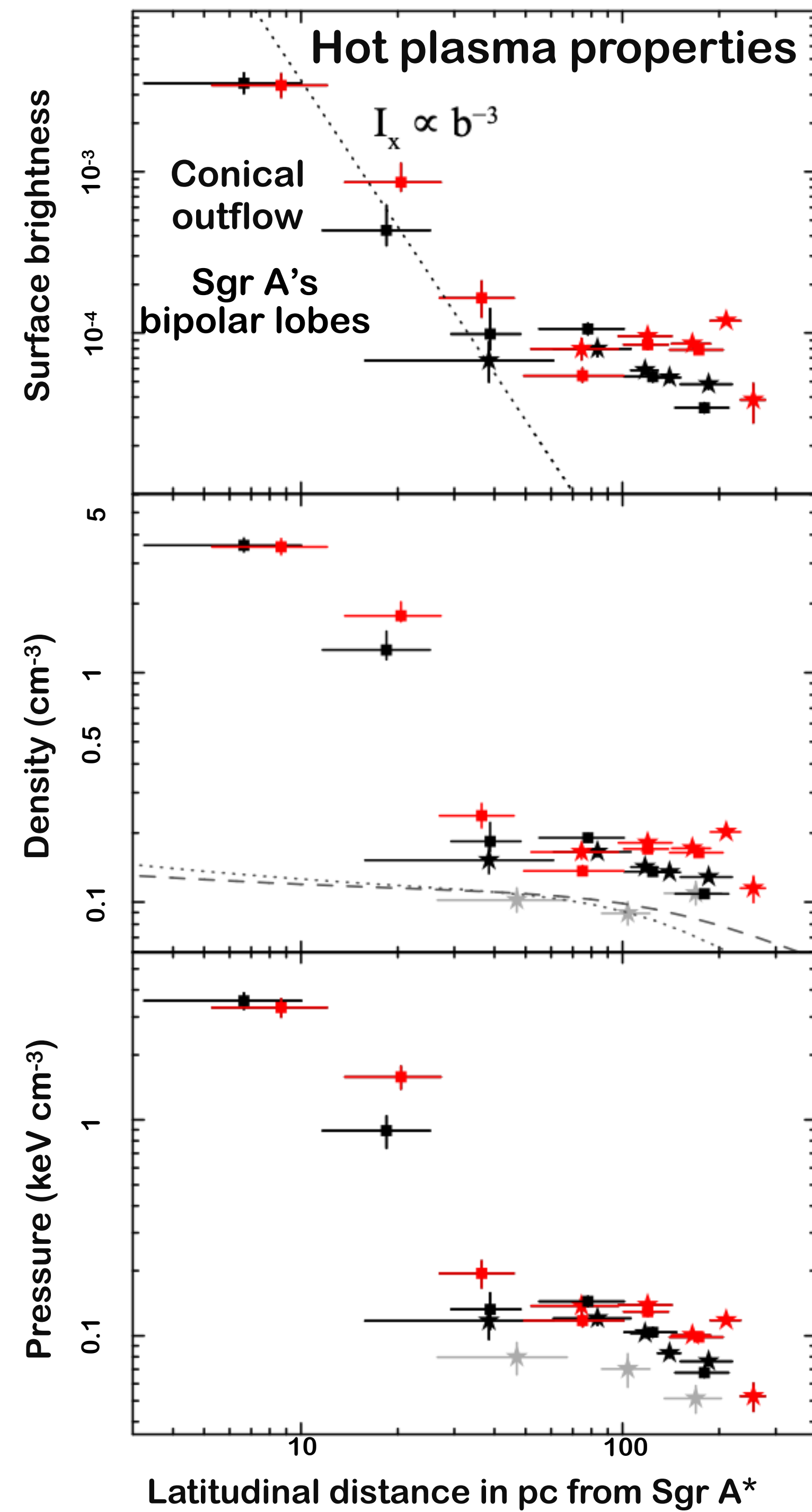
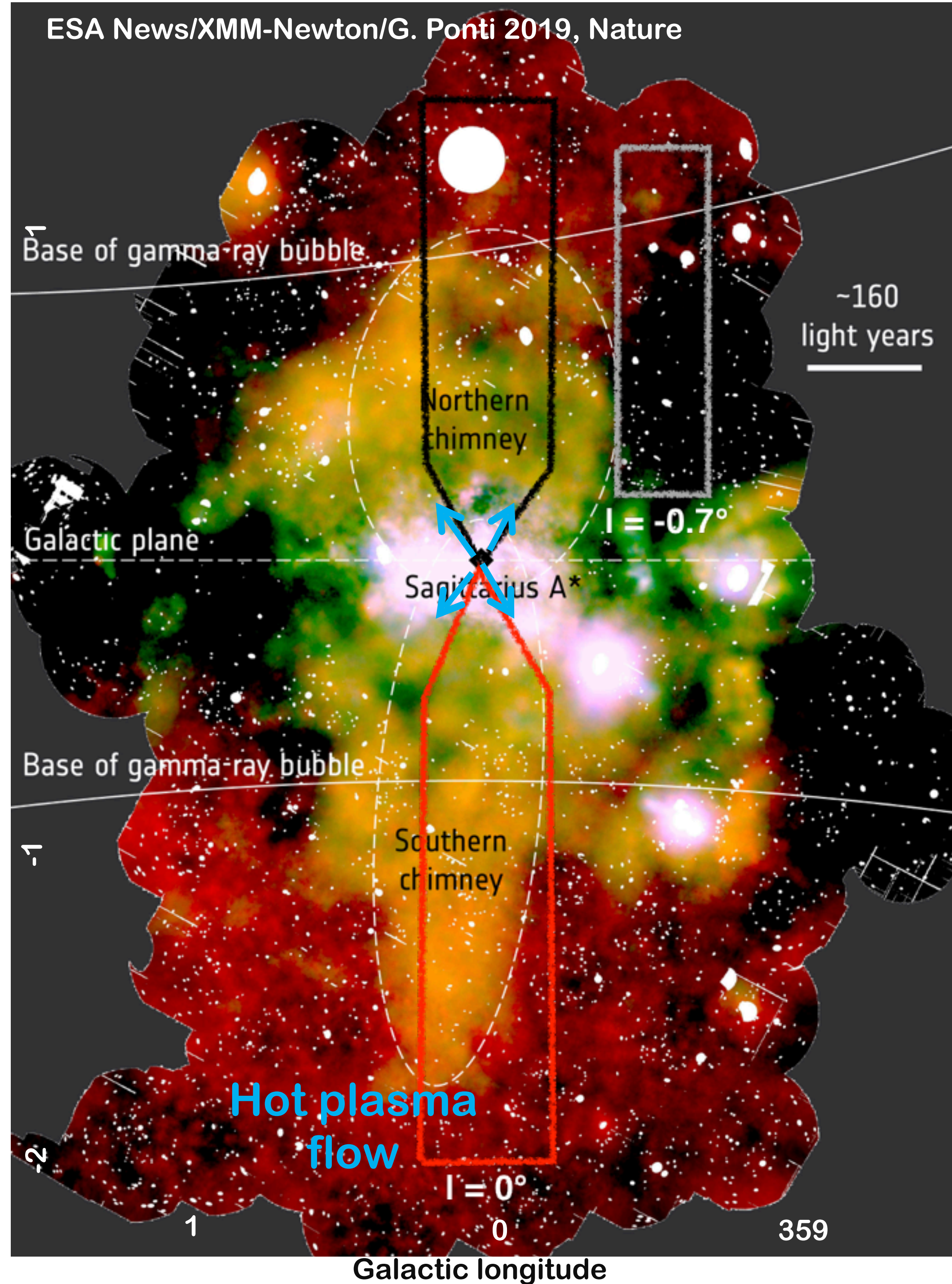
Galactic latitude



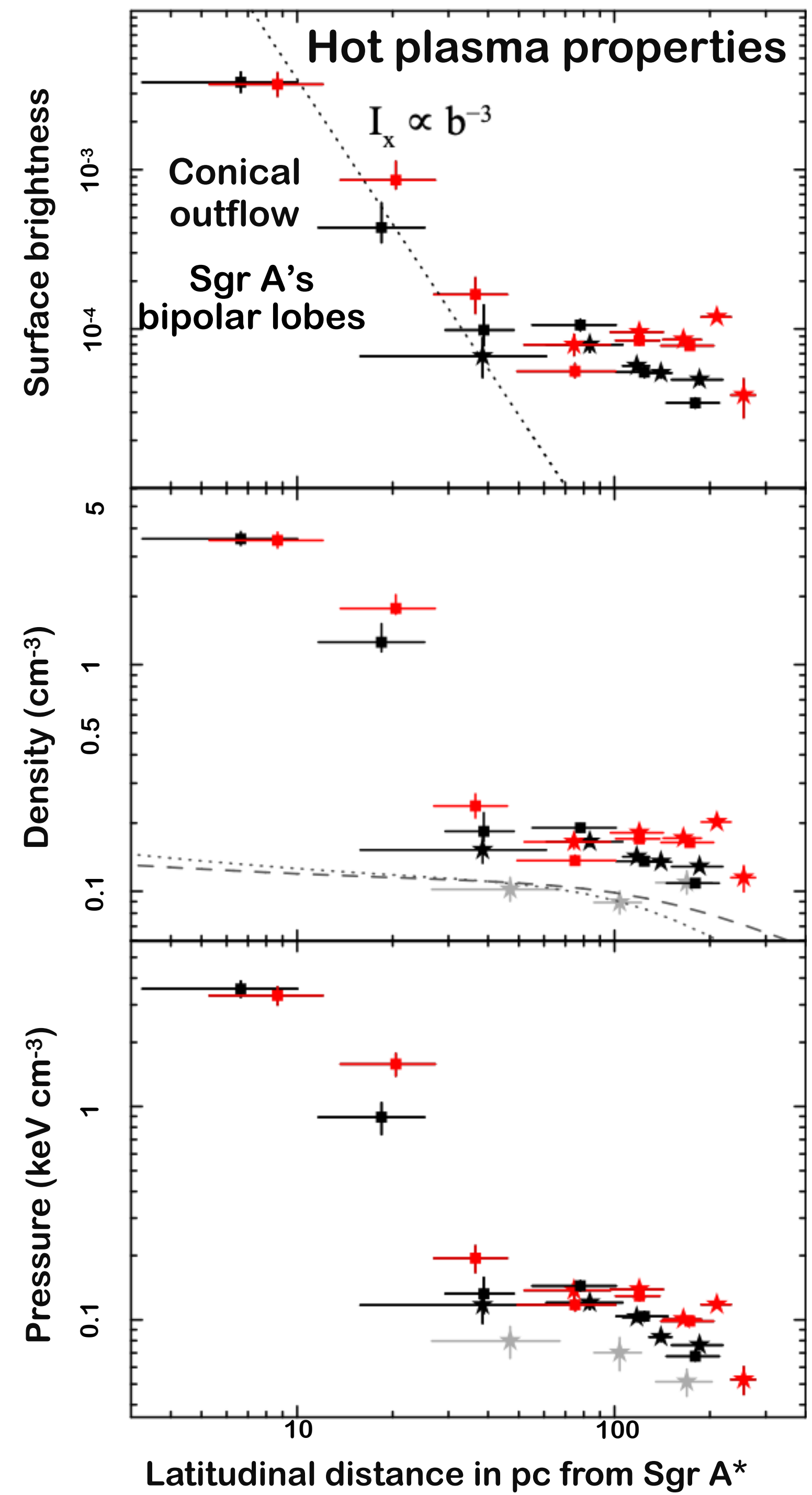
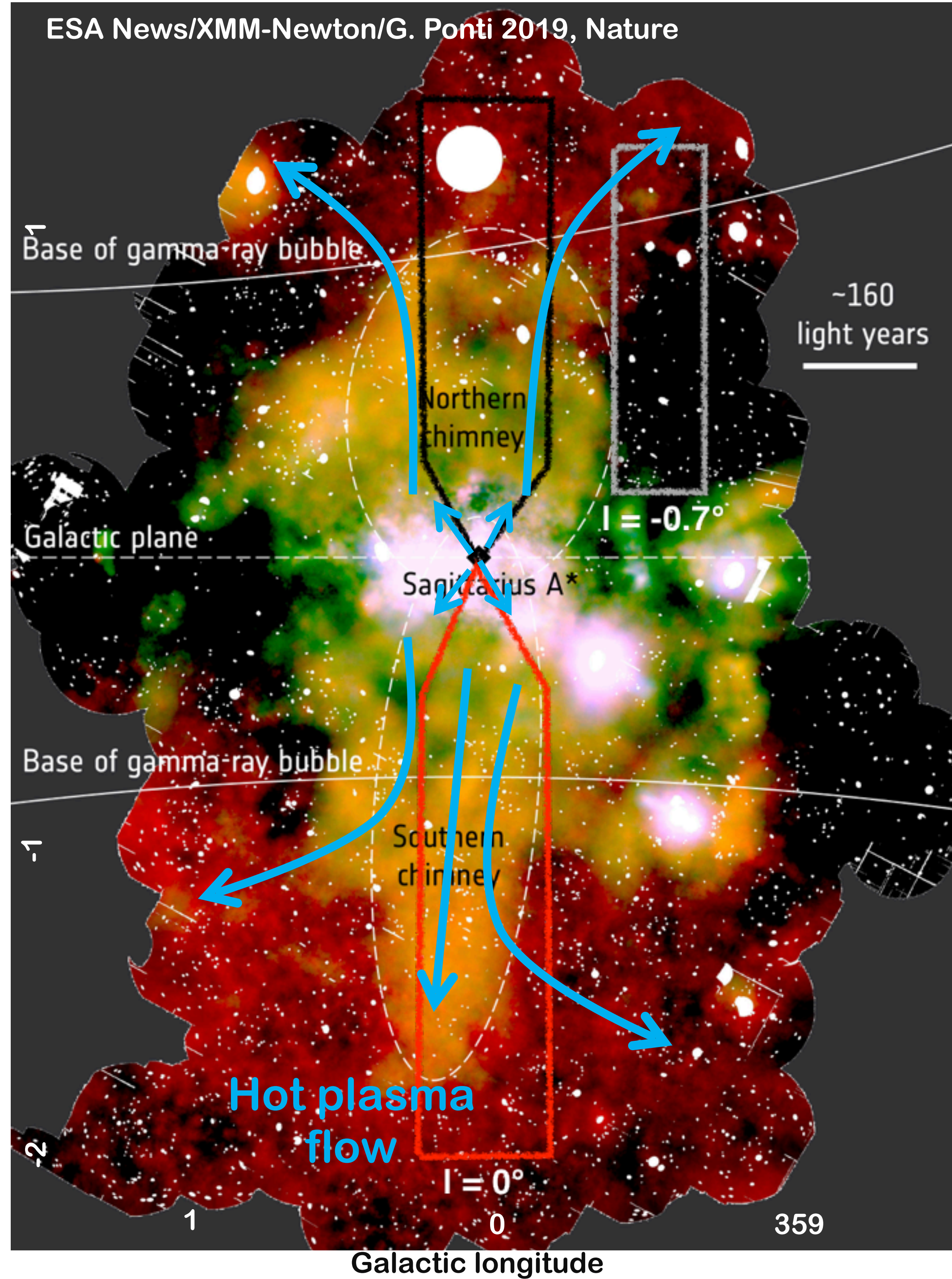
Hot plasma properties

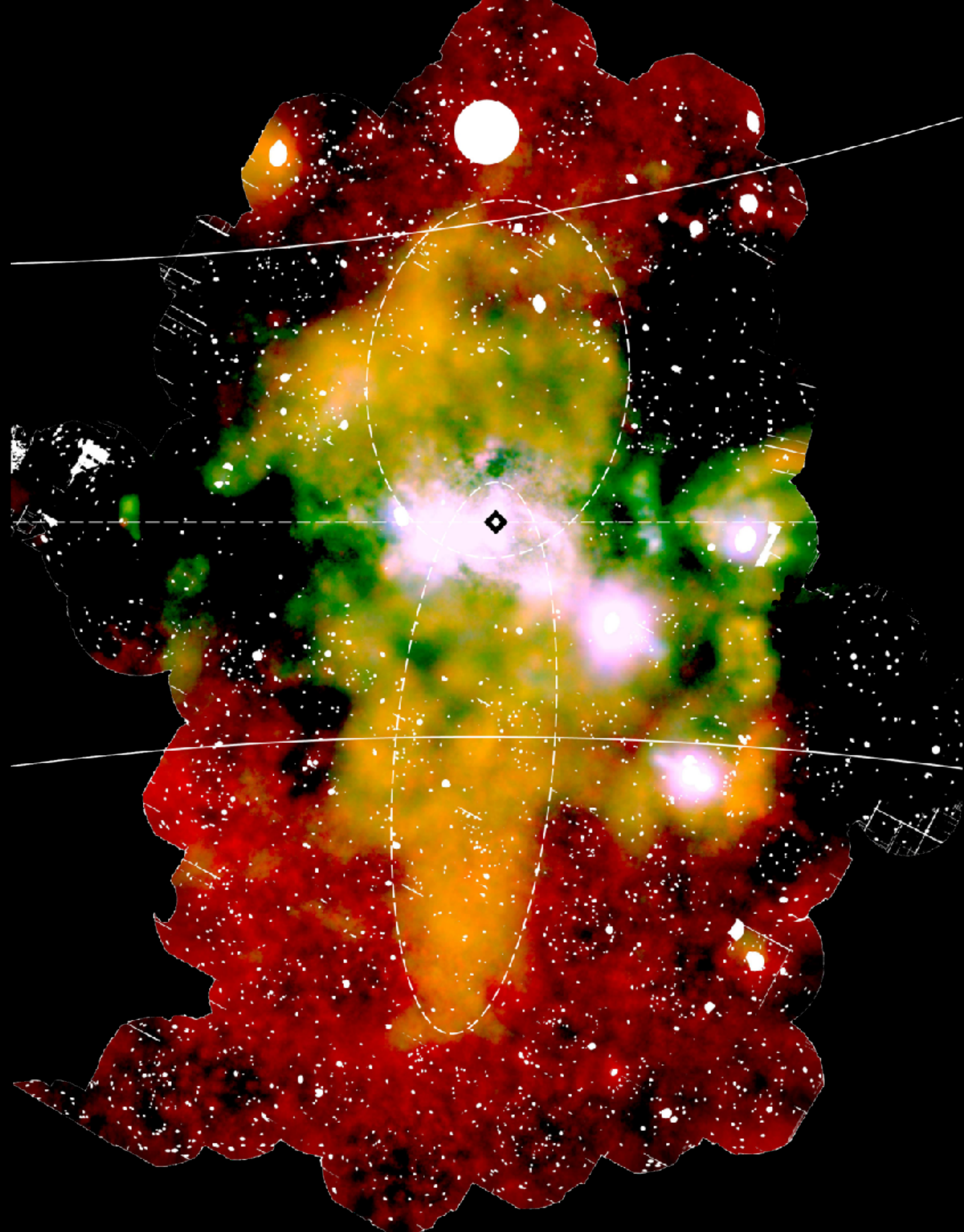


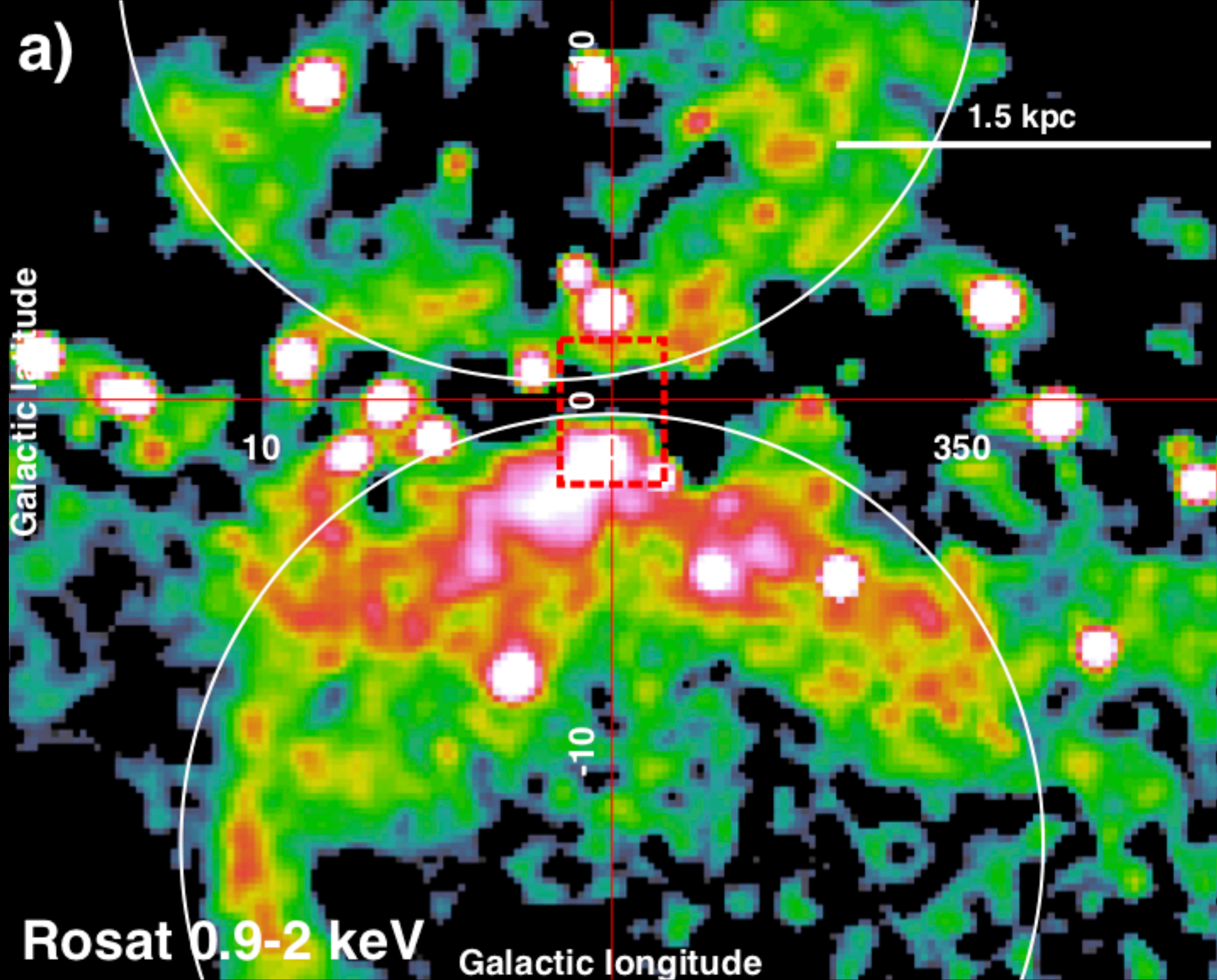
Galactic latitude

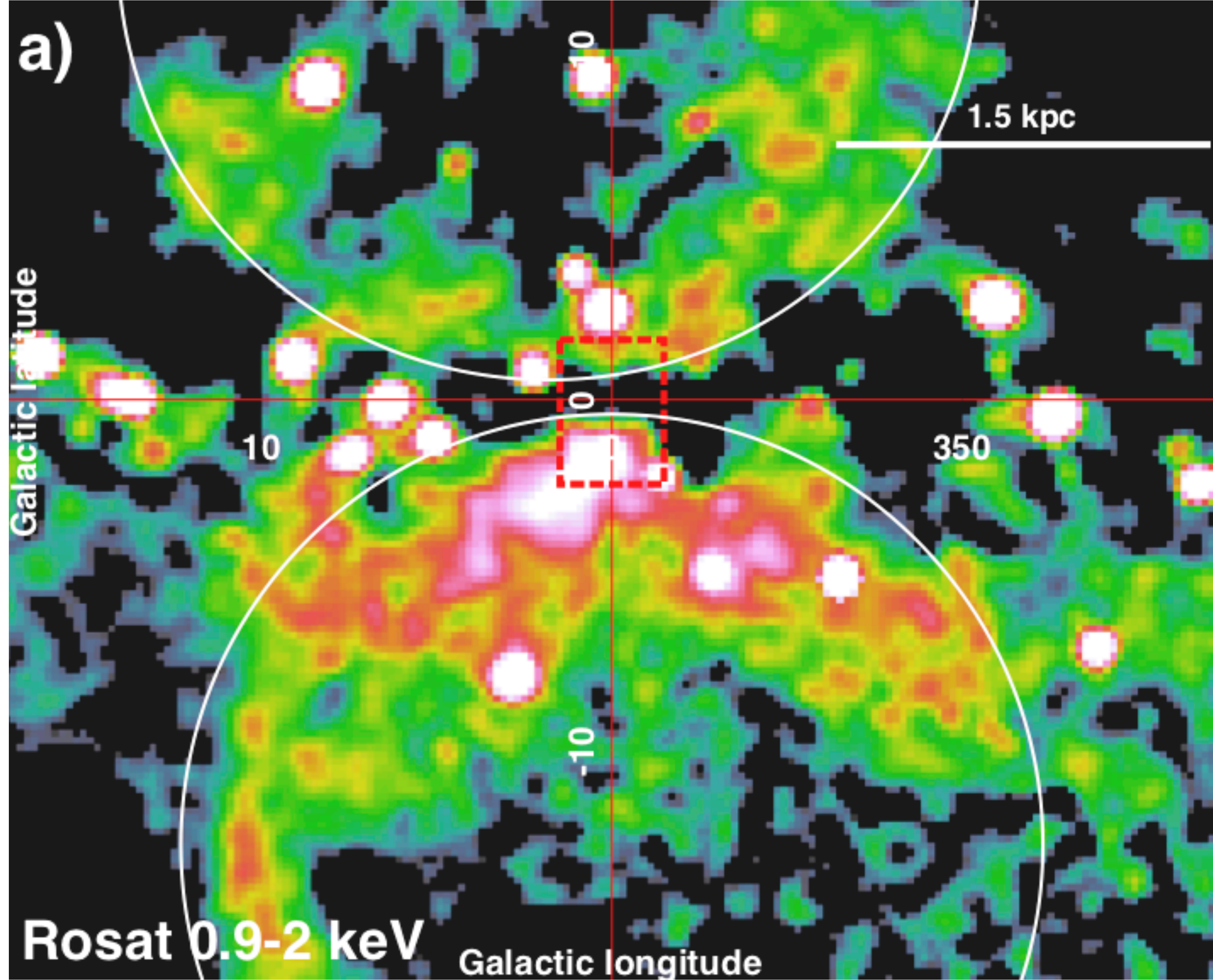


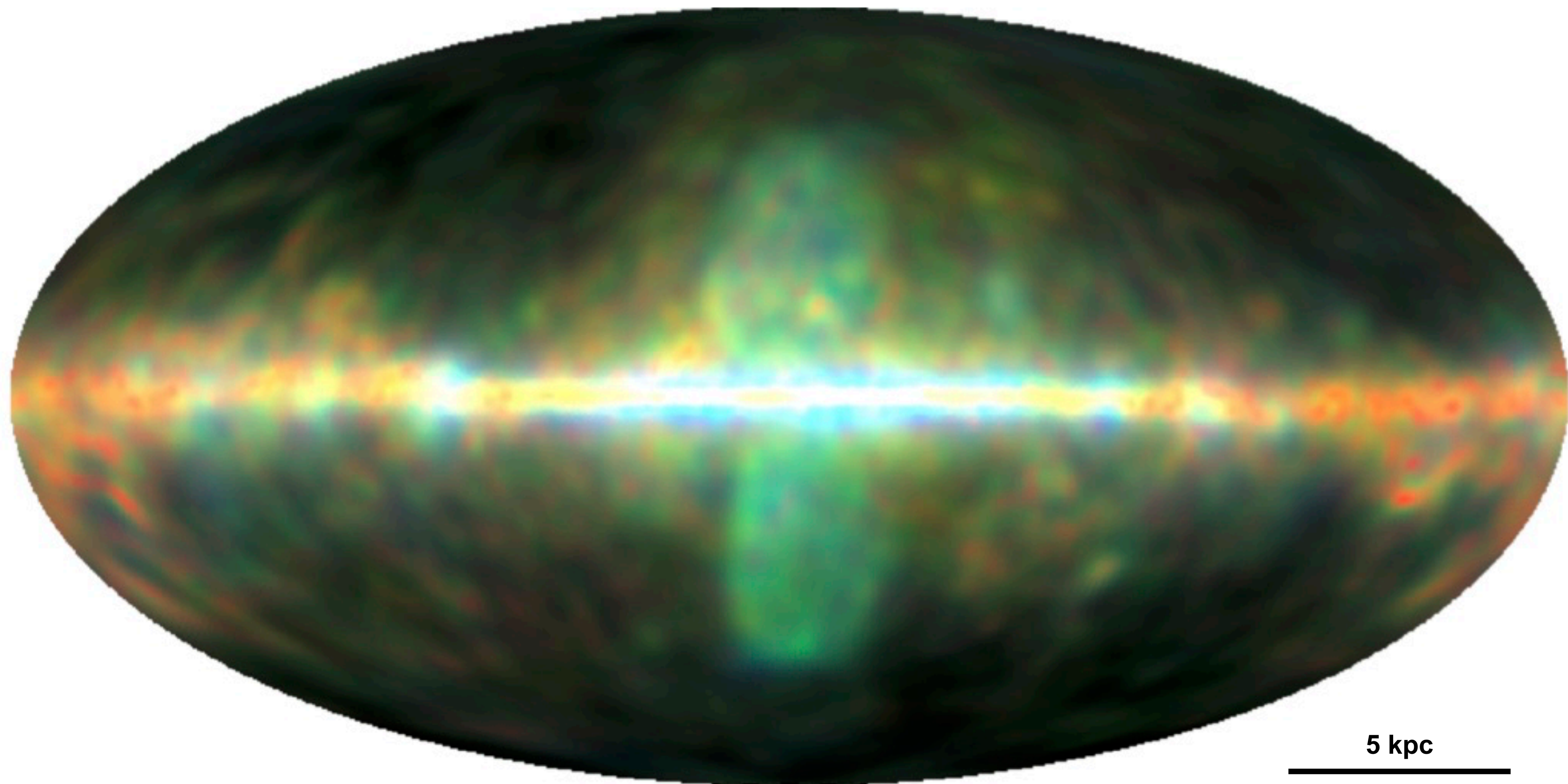
Galactic latitude











Fermi RGB image

Selig +15

eROSITA (Spektr-RG)'s launch

Baikonur, July 13th, 2019

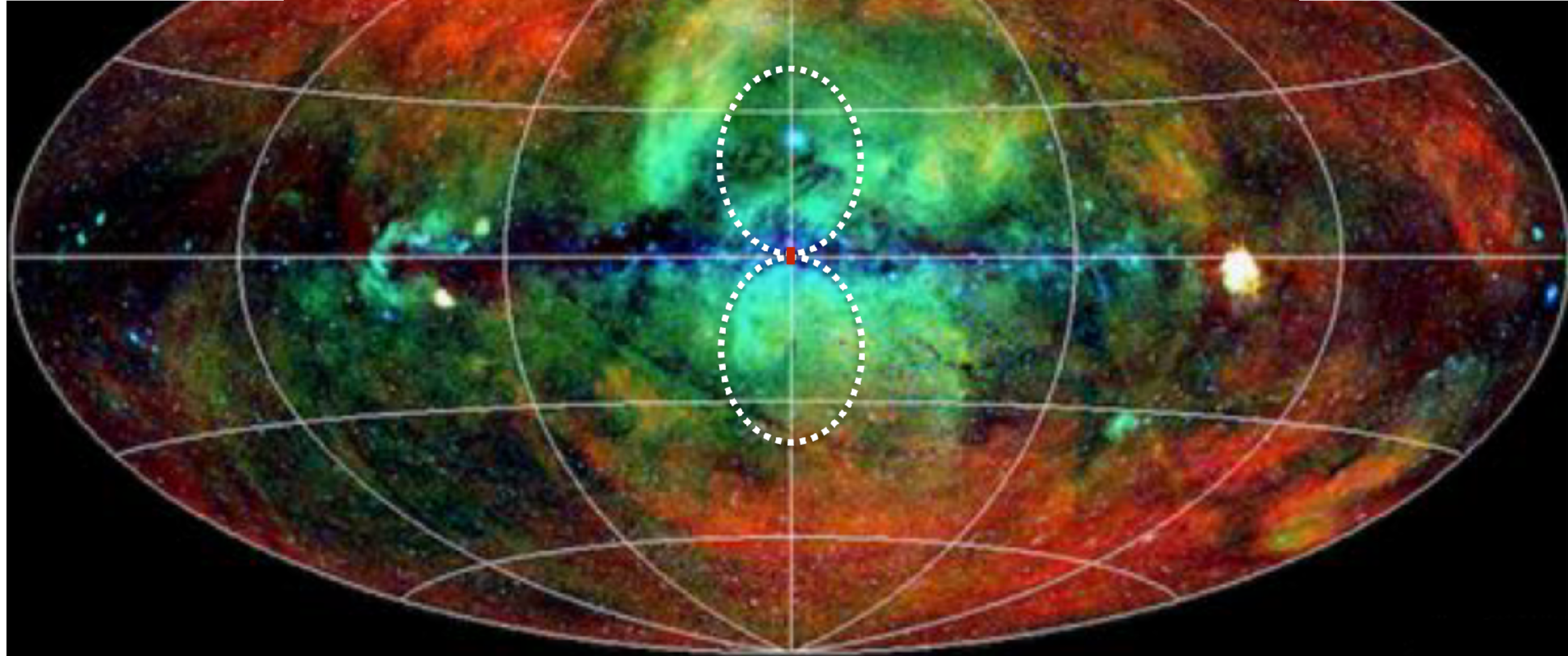


Source: Roscosmos

Map the flows of hot Galactic Baryons



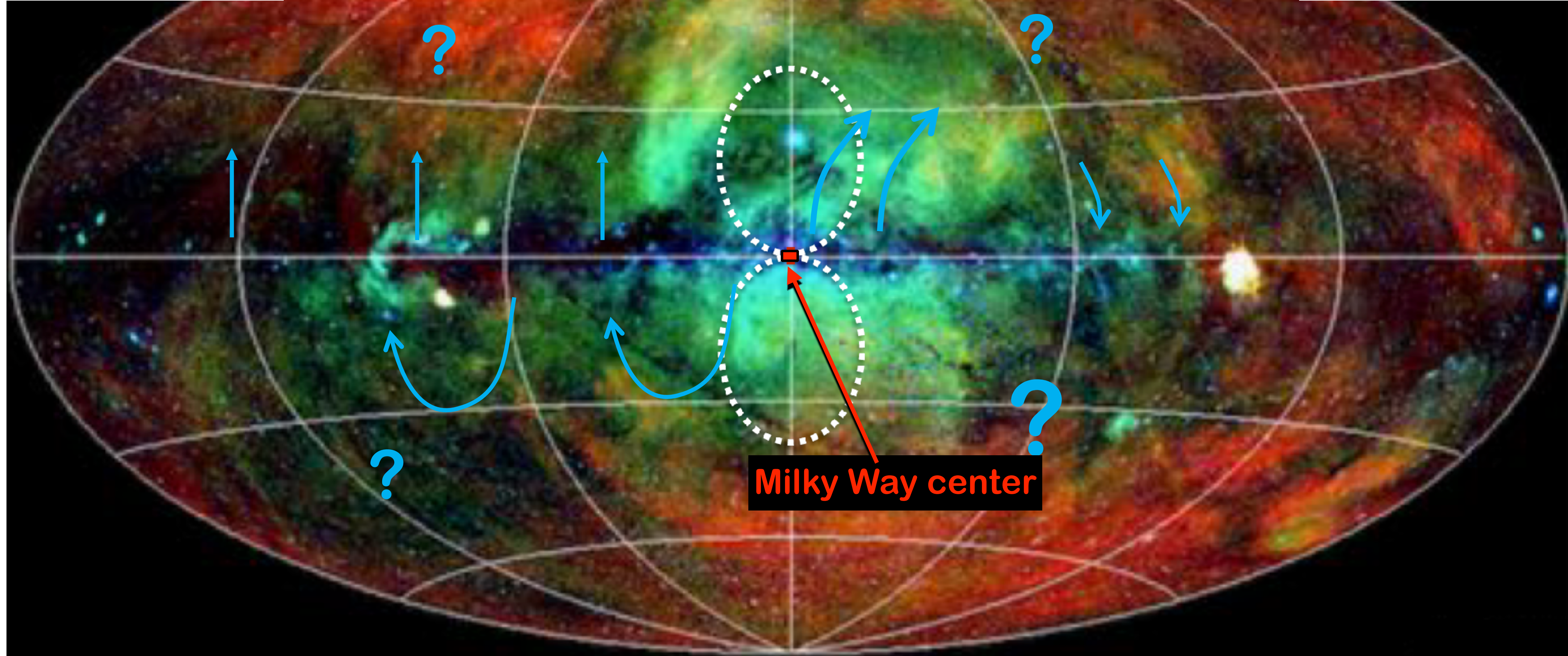
Rosat all-sky soft X-ray survey



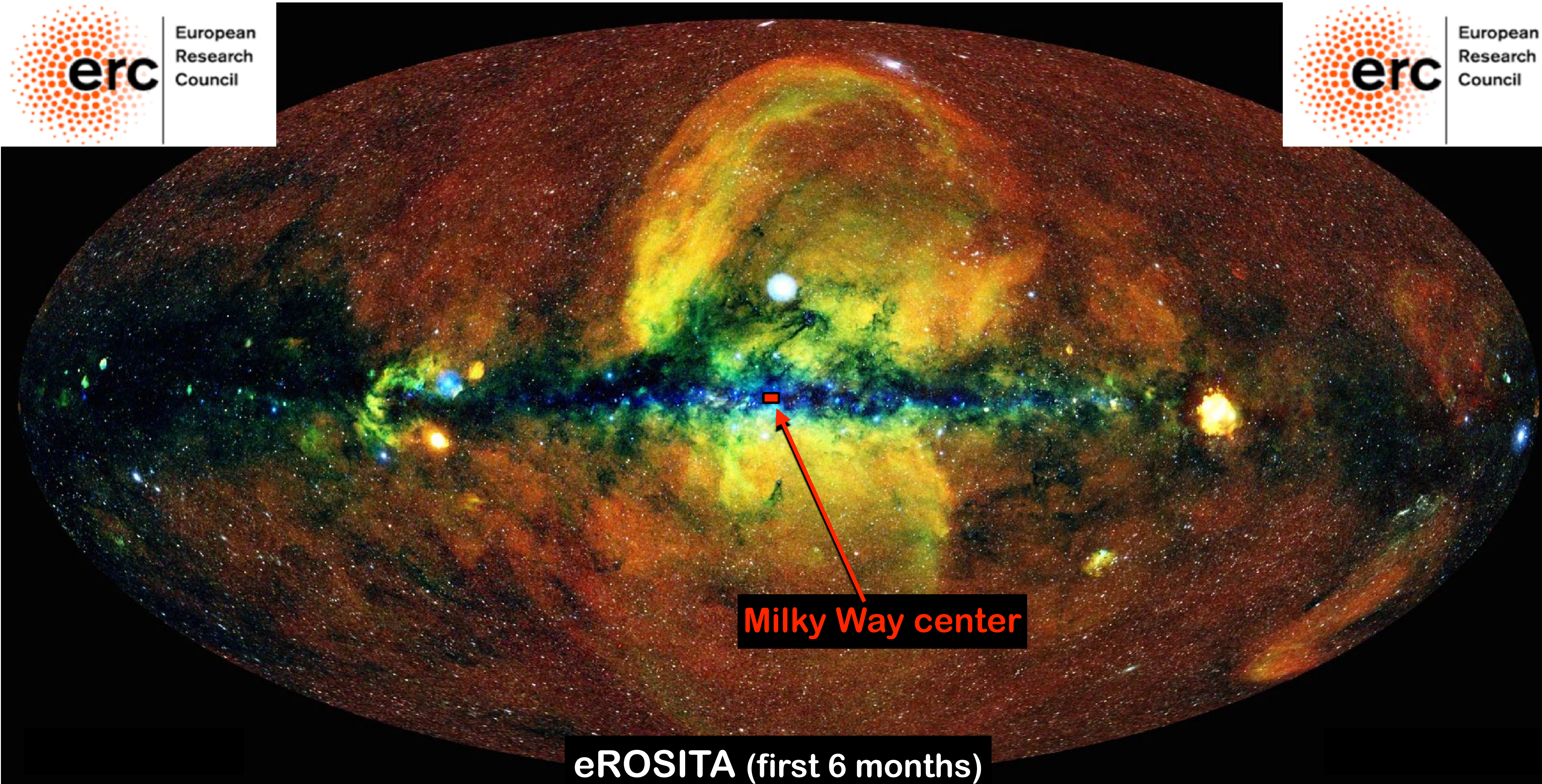
Map the flows of hot Galactic Baryons



Rosat all-sky soft X-ray survey



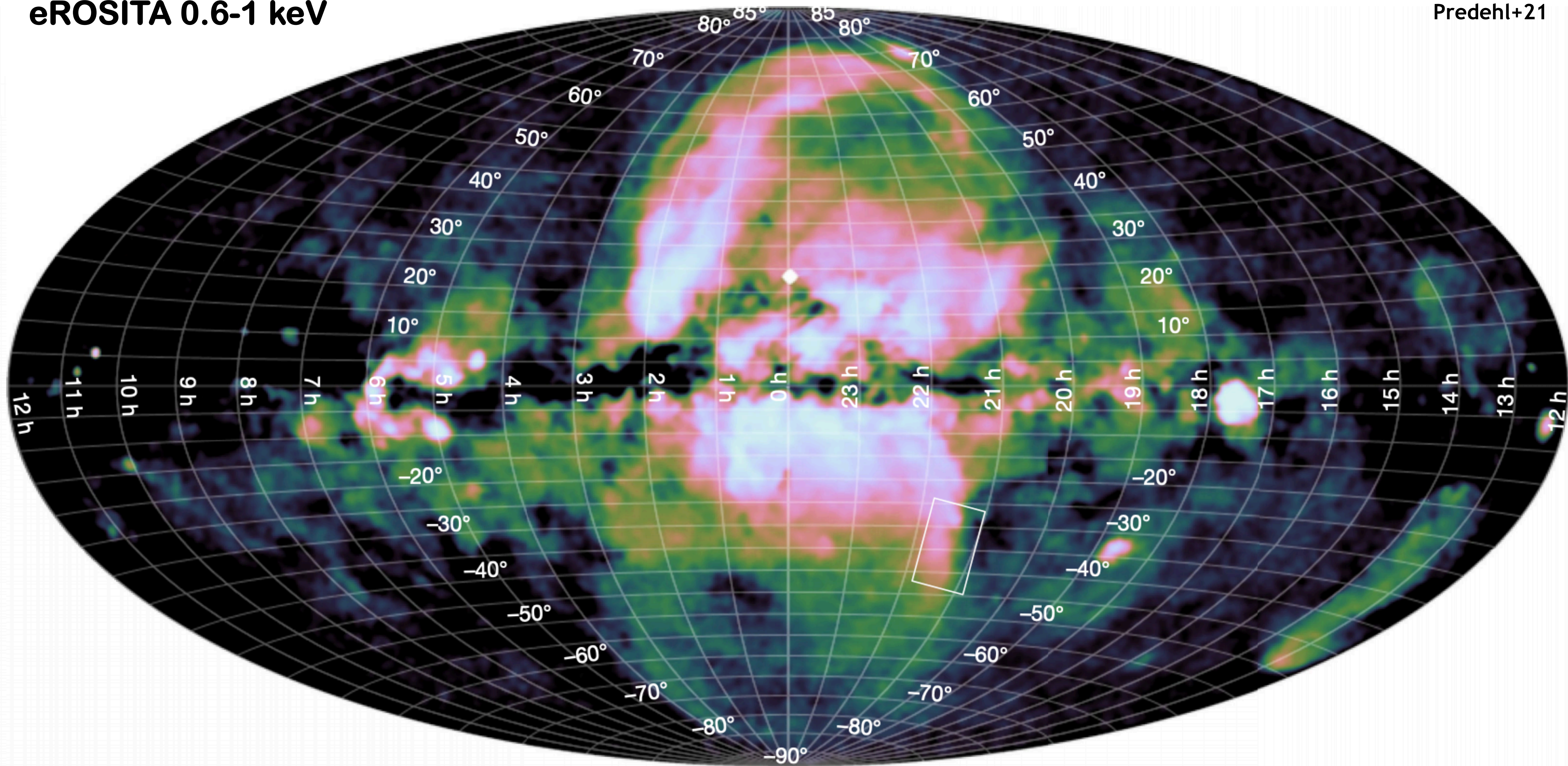
Map the flows of hot Galactic Baryons



Discovery of the eROSITA bubbles!

eROSITA 0.6-1 keV

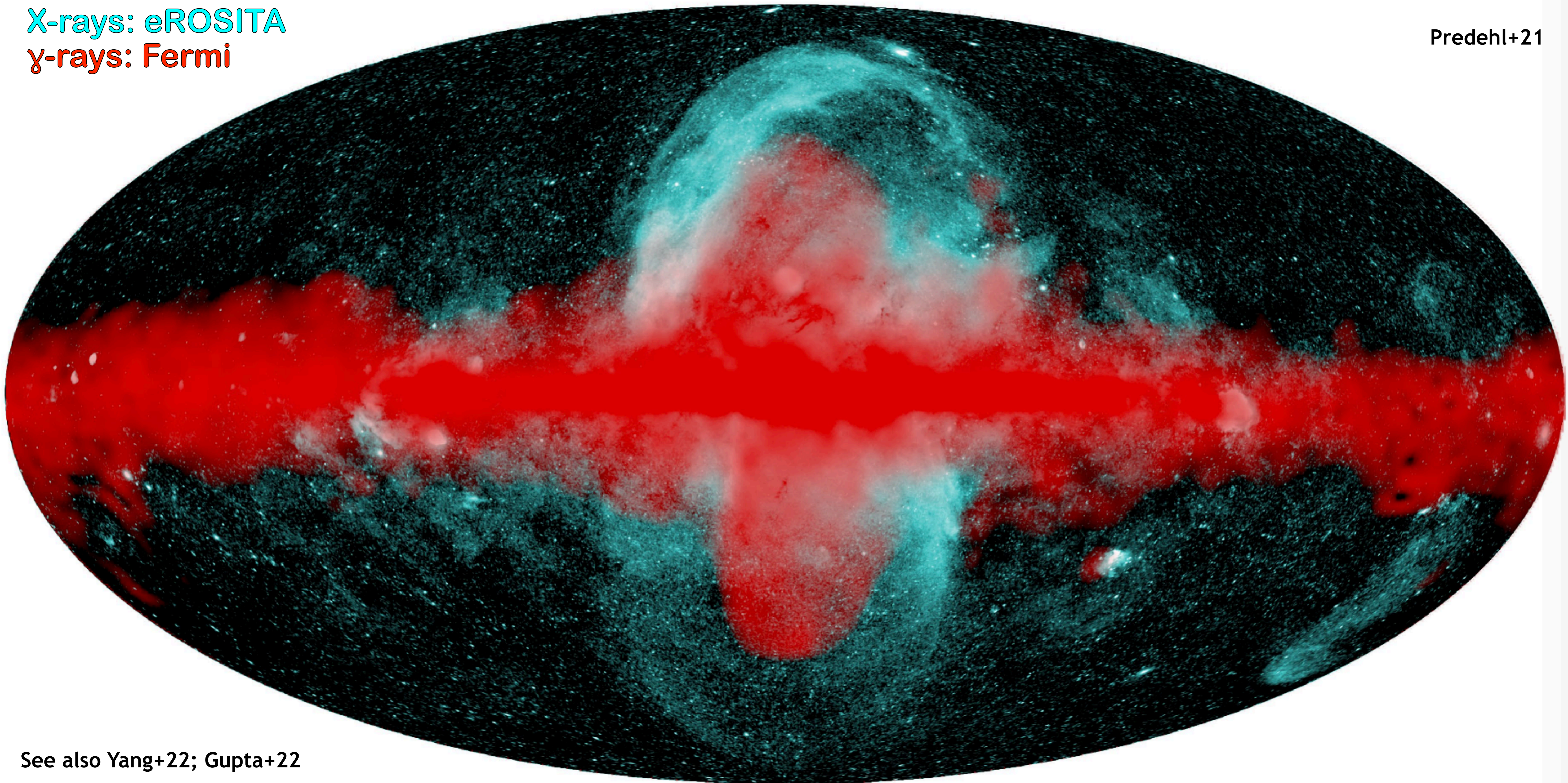
Predehl+21



Connection between Fermi & eROSITA bubble

X-rays: eROSITA
 γ -rays: Fermi

Predehl+21



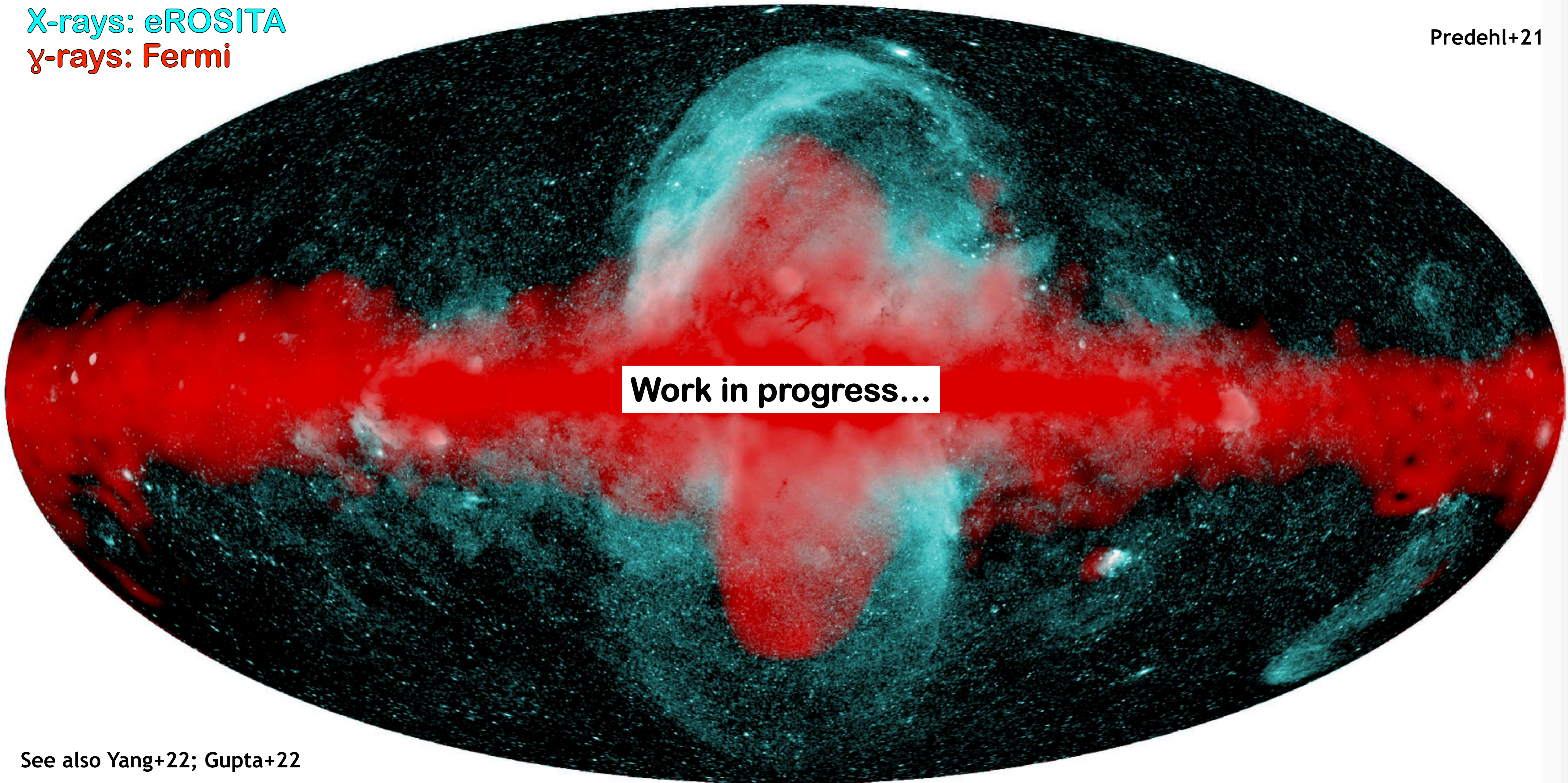
See also Yang+22; Gupta+22

Connection between Fermi & eROSITA bubble

X-rays: eROSITA

γ -rays: Fermi

Predehl+21

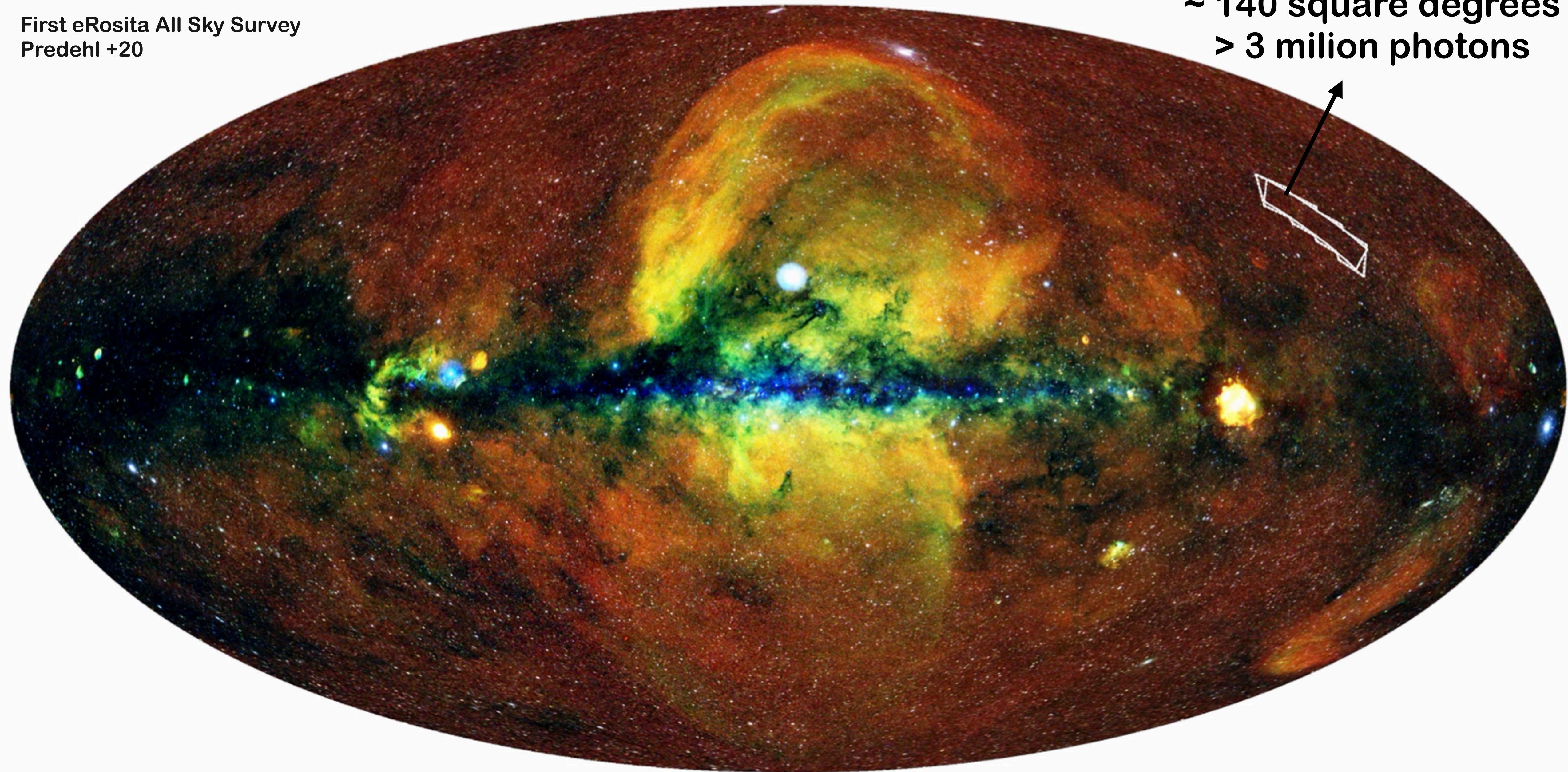


See also Yang+22; Gupta+22

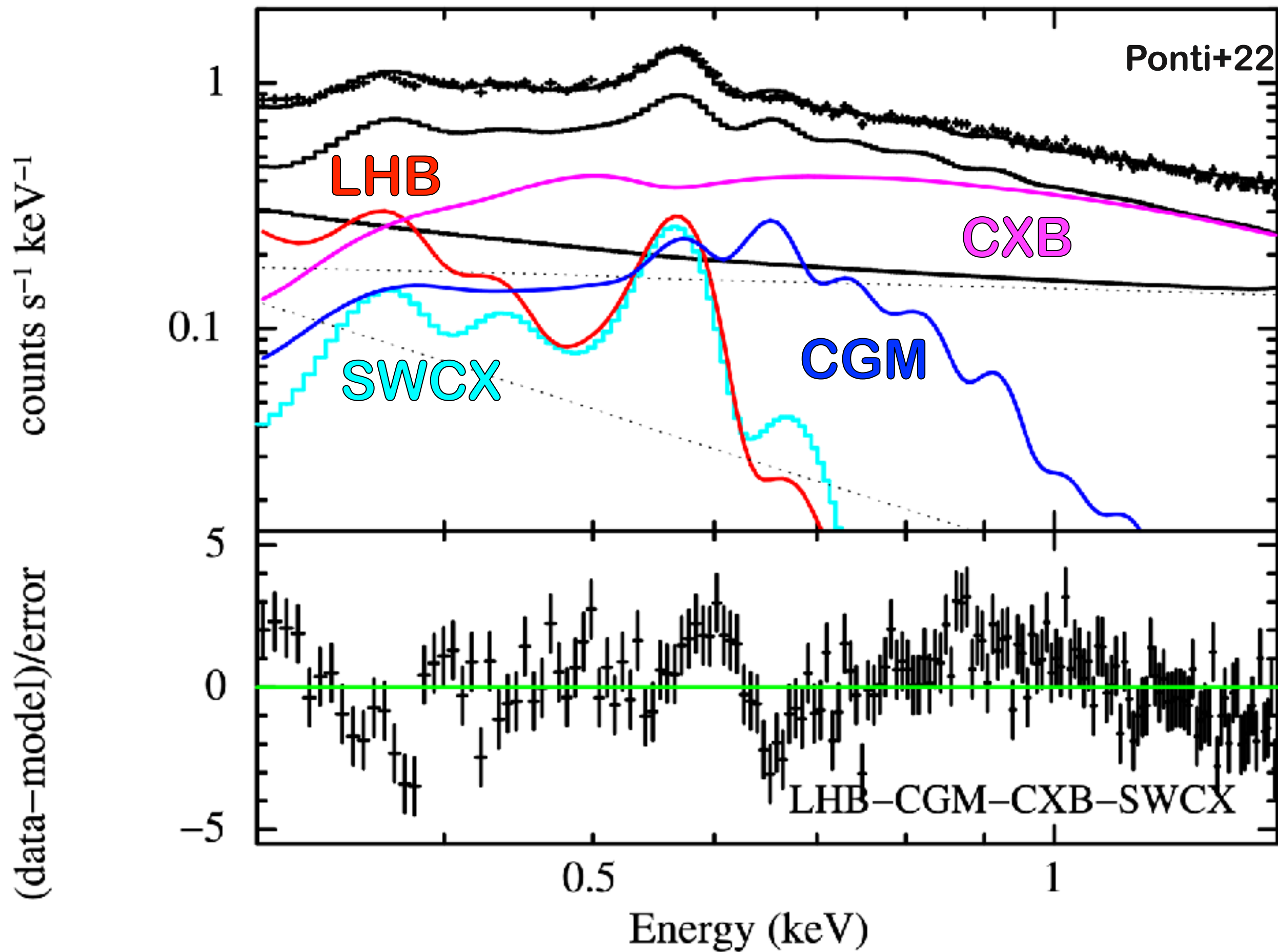
The hot CGM of the Milky Way

First eRosita All Sky Survey
Predehl +20

eFEDS:
~ 140 square degrees
> 3 milion photons



The hot CGM in the eFEDS field



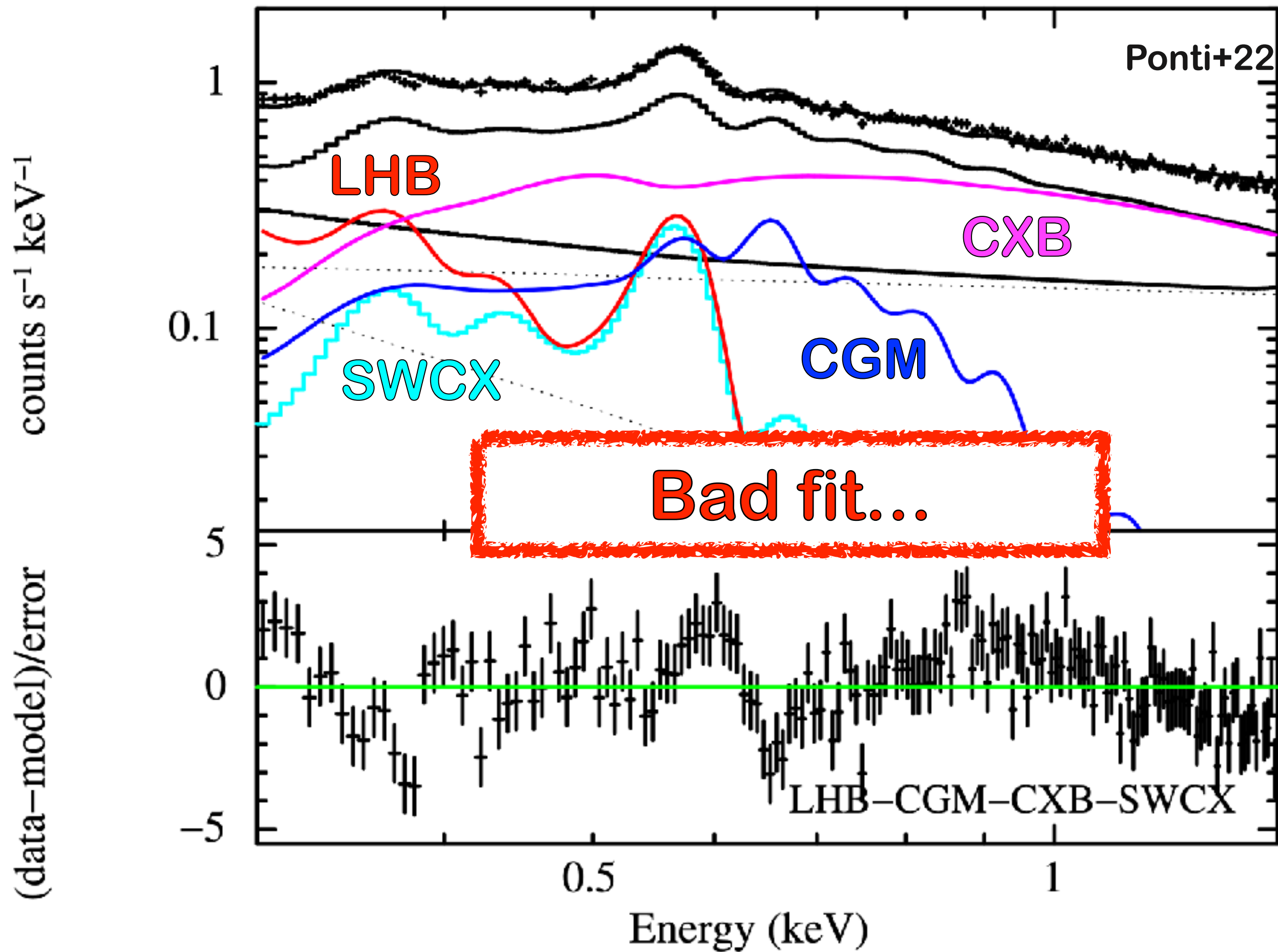
LHB: Local hot bubble

CGM: Circum-Galactic medium

CXB: Cosmic X-ray background

SWCX: Solar wind charge exchange

The hot CGM in the eFEDS field



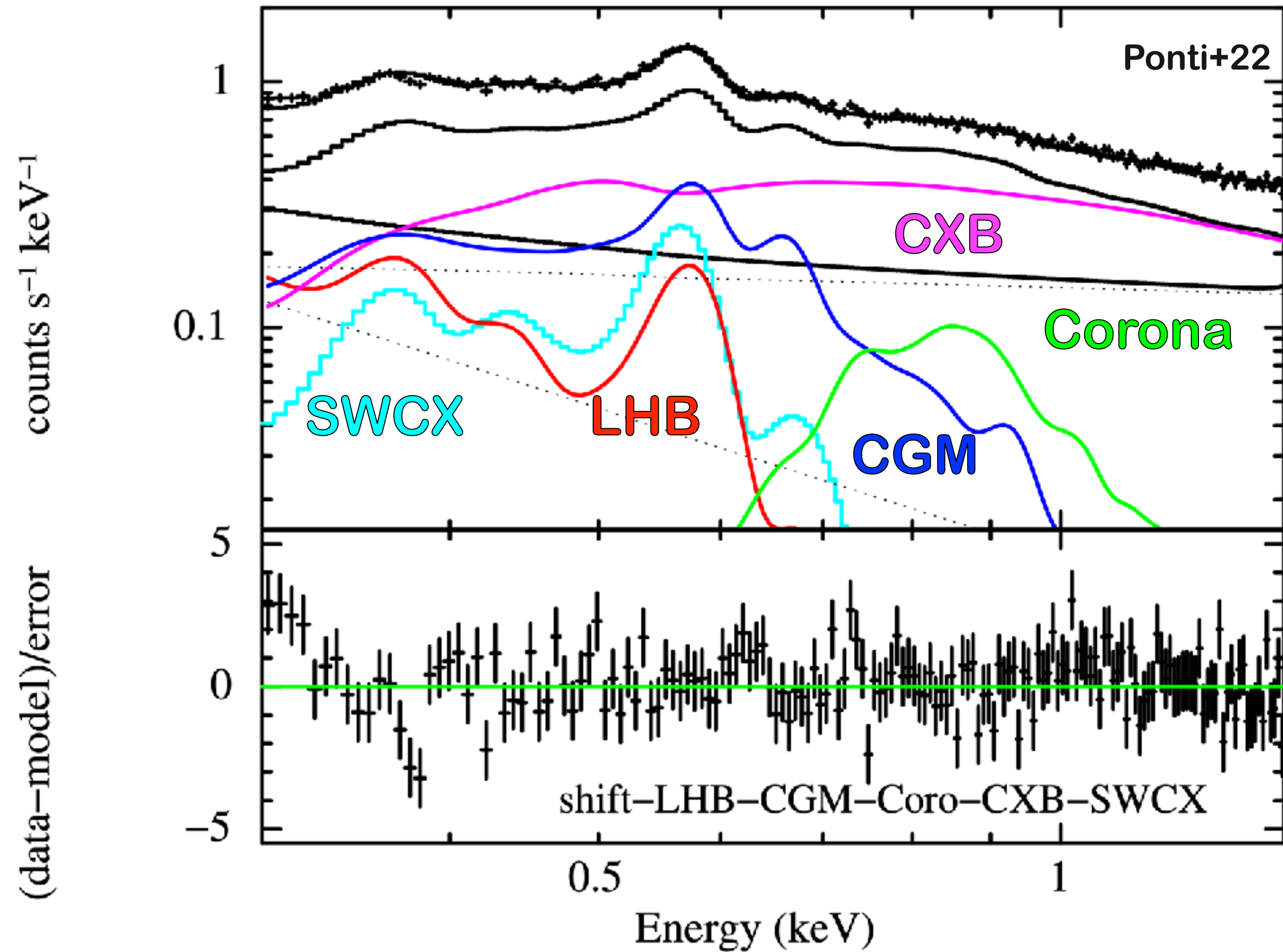
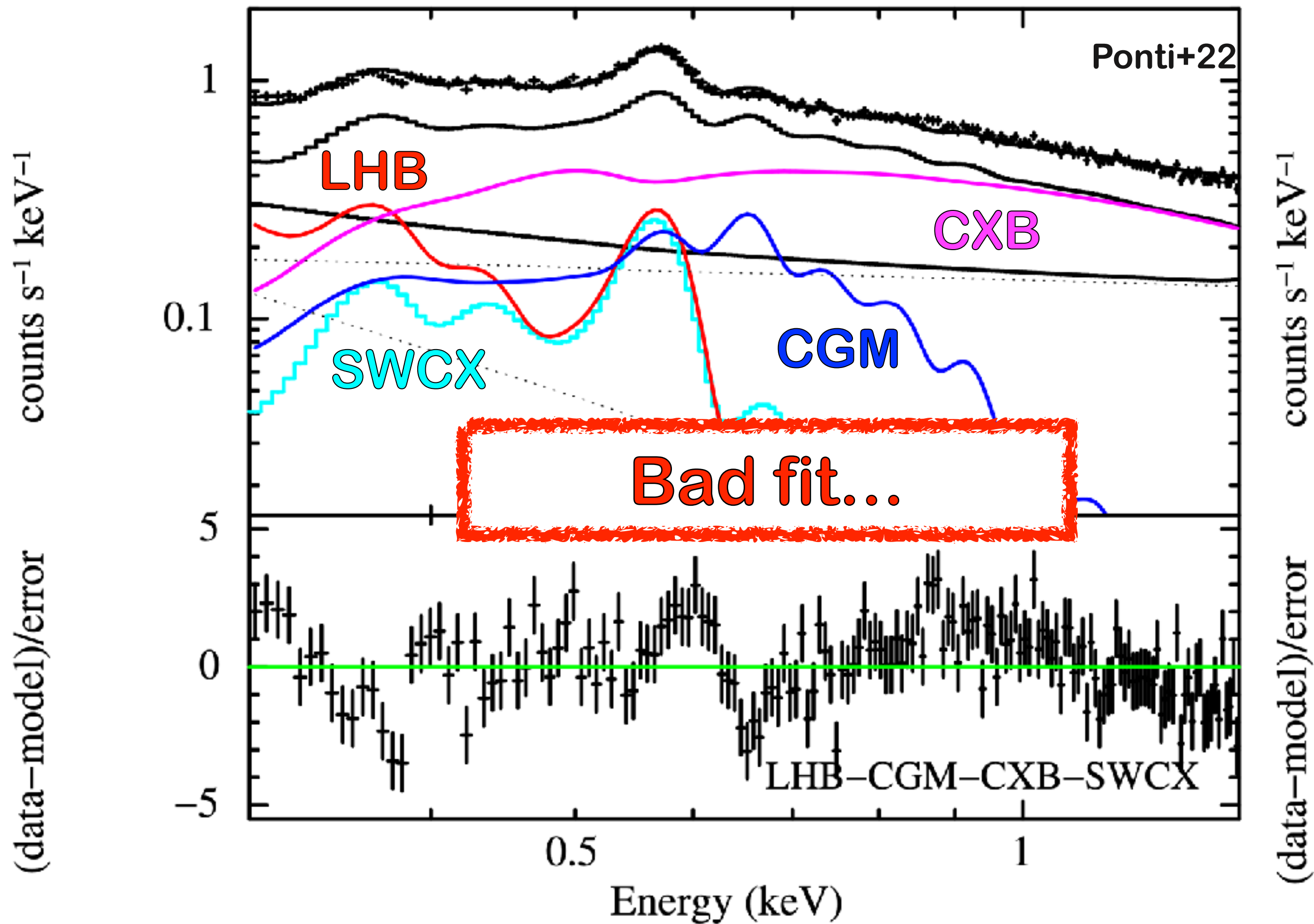
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The hot CGM in the eFEDS field



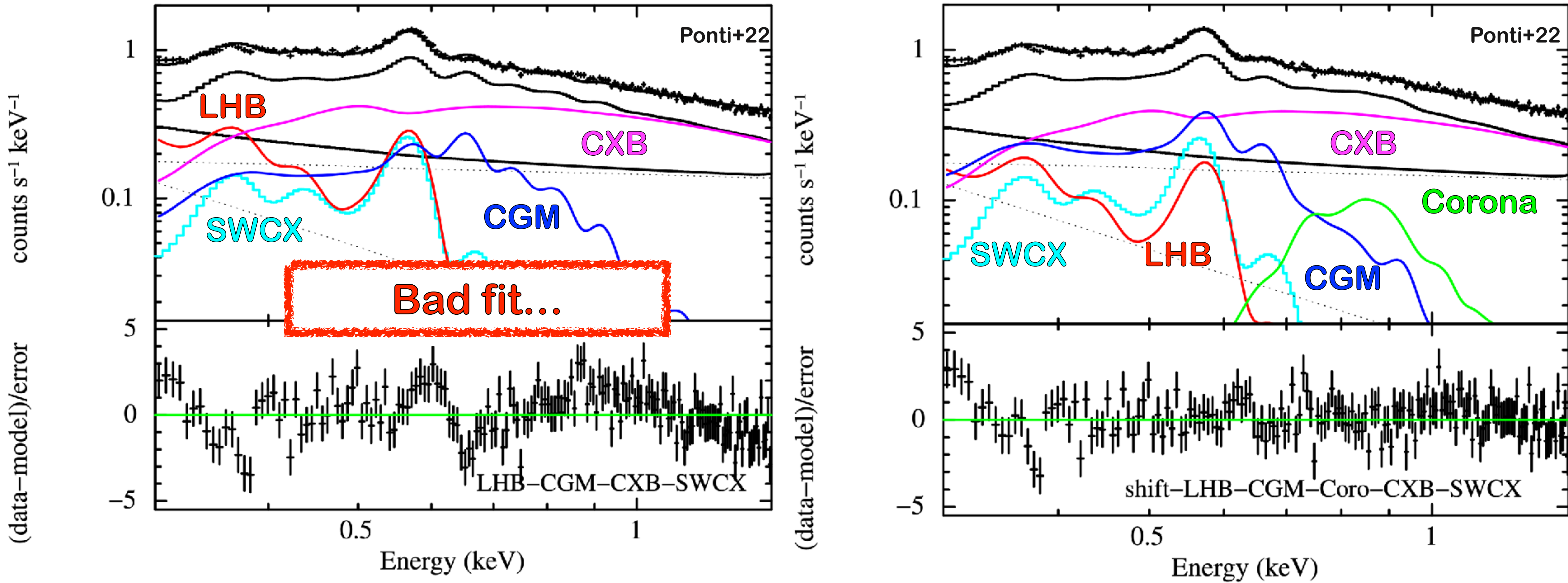
LHB: Local hot bubble

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The hot CGM in the eFEDS field



LHB: Local hot bubble

CGM: Circum-Galactic medium

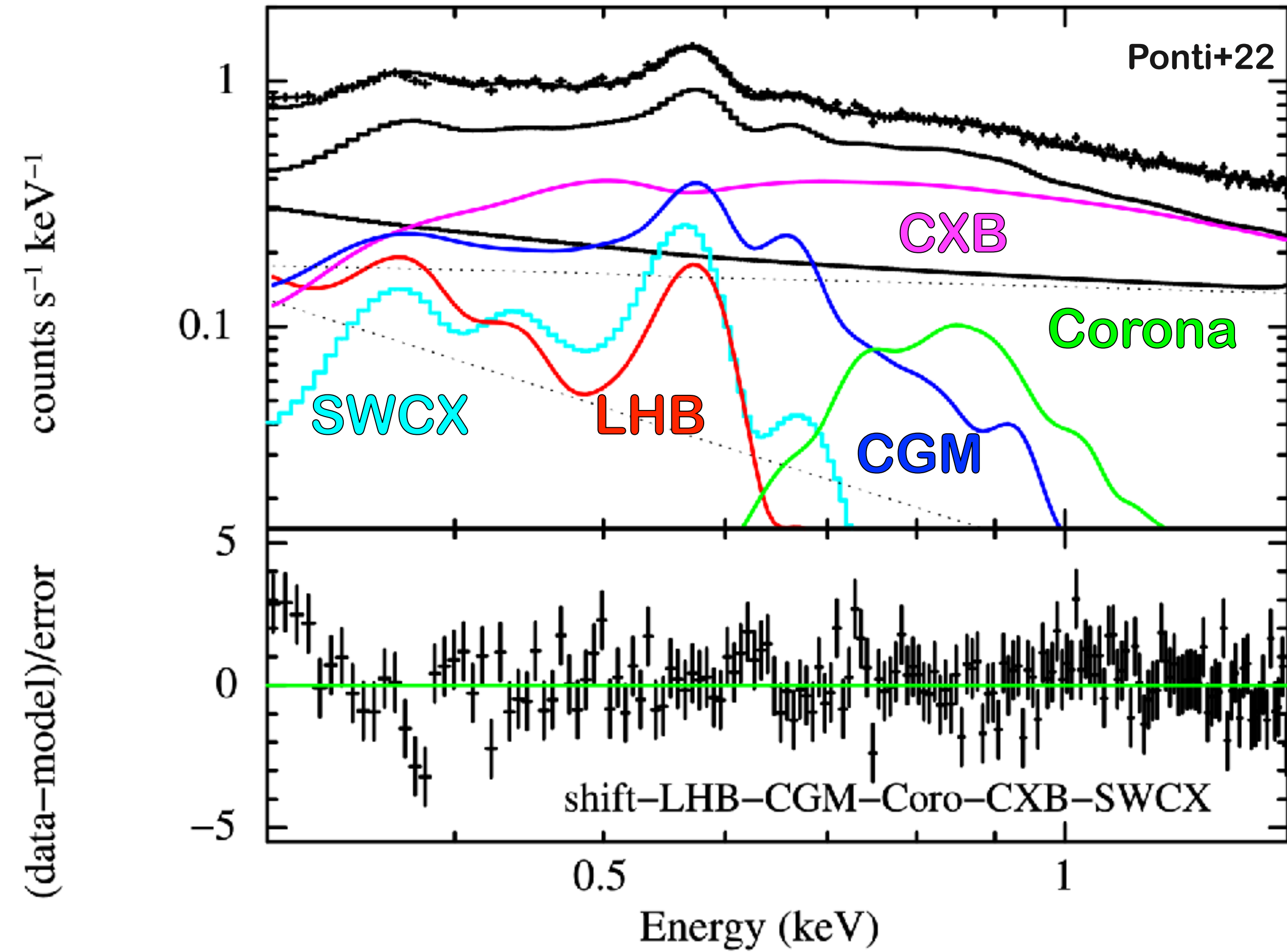
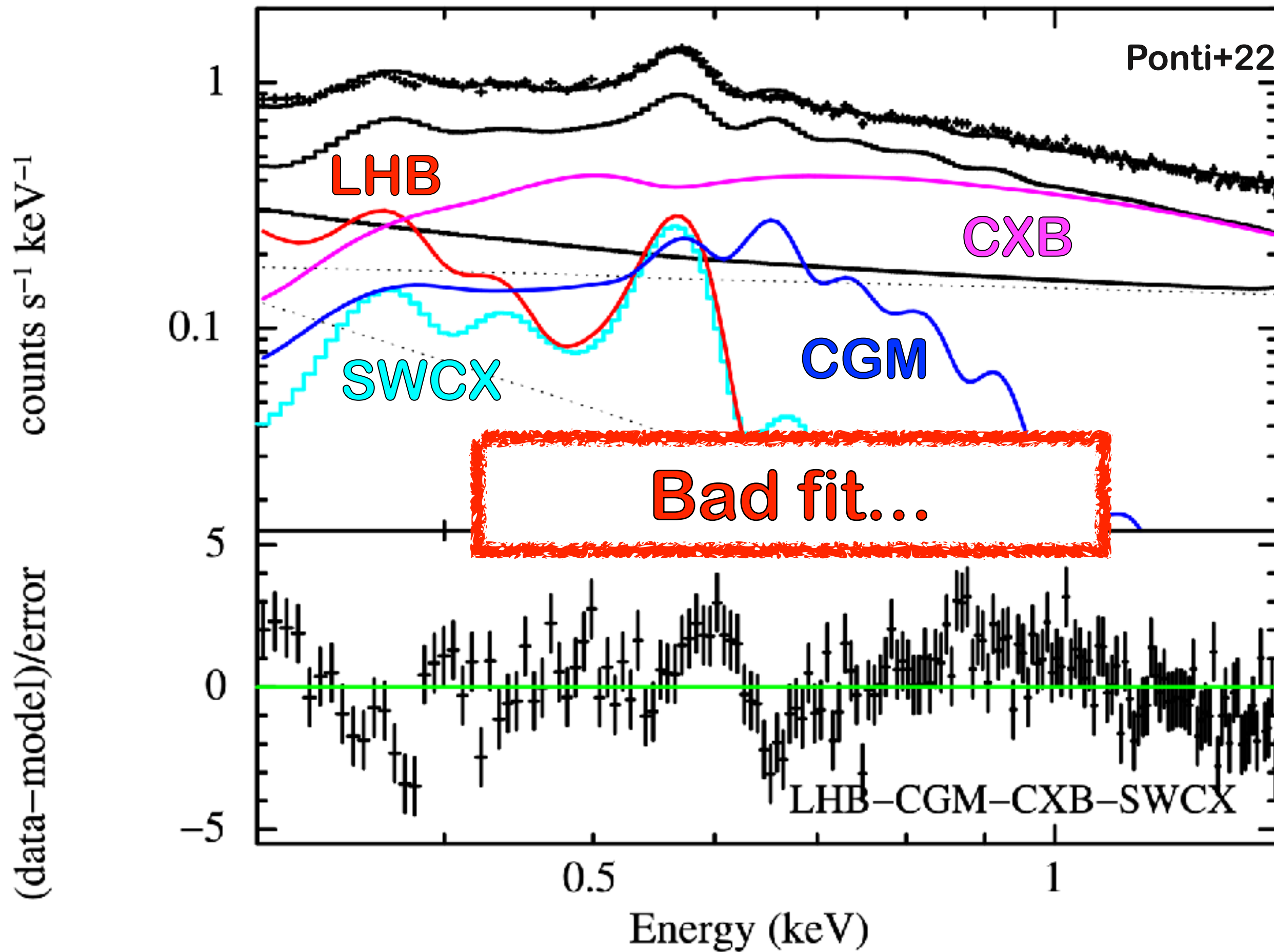
CXB: Cosmic X-ray background

SWCX: Solar wind charge exchange

Corona → Required!

$kT_{\text{Coro}} = 0.4 - 0.7 \text{ keV}$

The hot CGM in the eFEDS field



LHB: Local hot bubble

CGM: Circum-Galactic medium

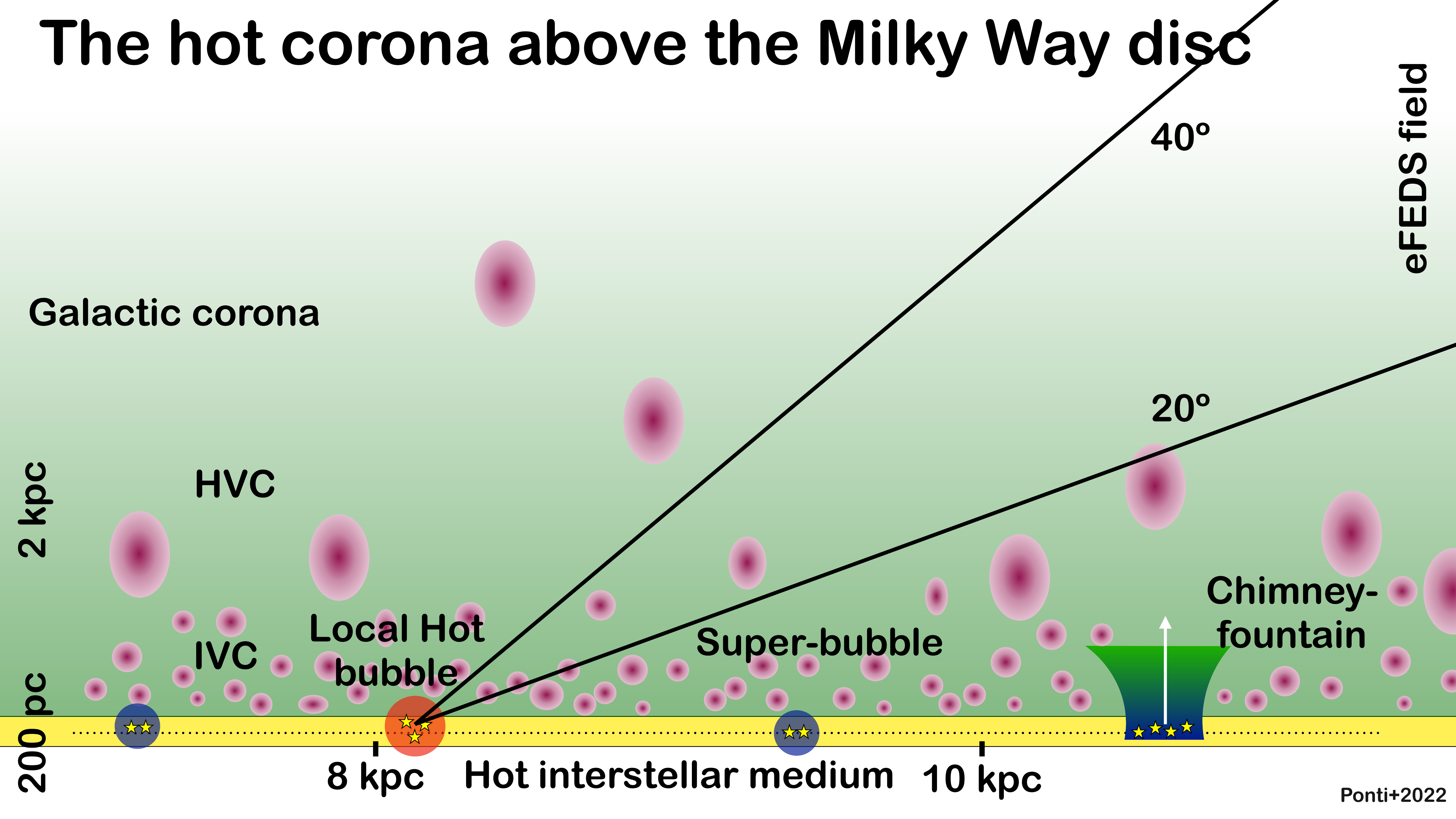
CXB: Cosmic X-ray background

SWCX: Solar wind charge exchange

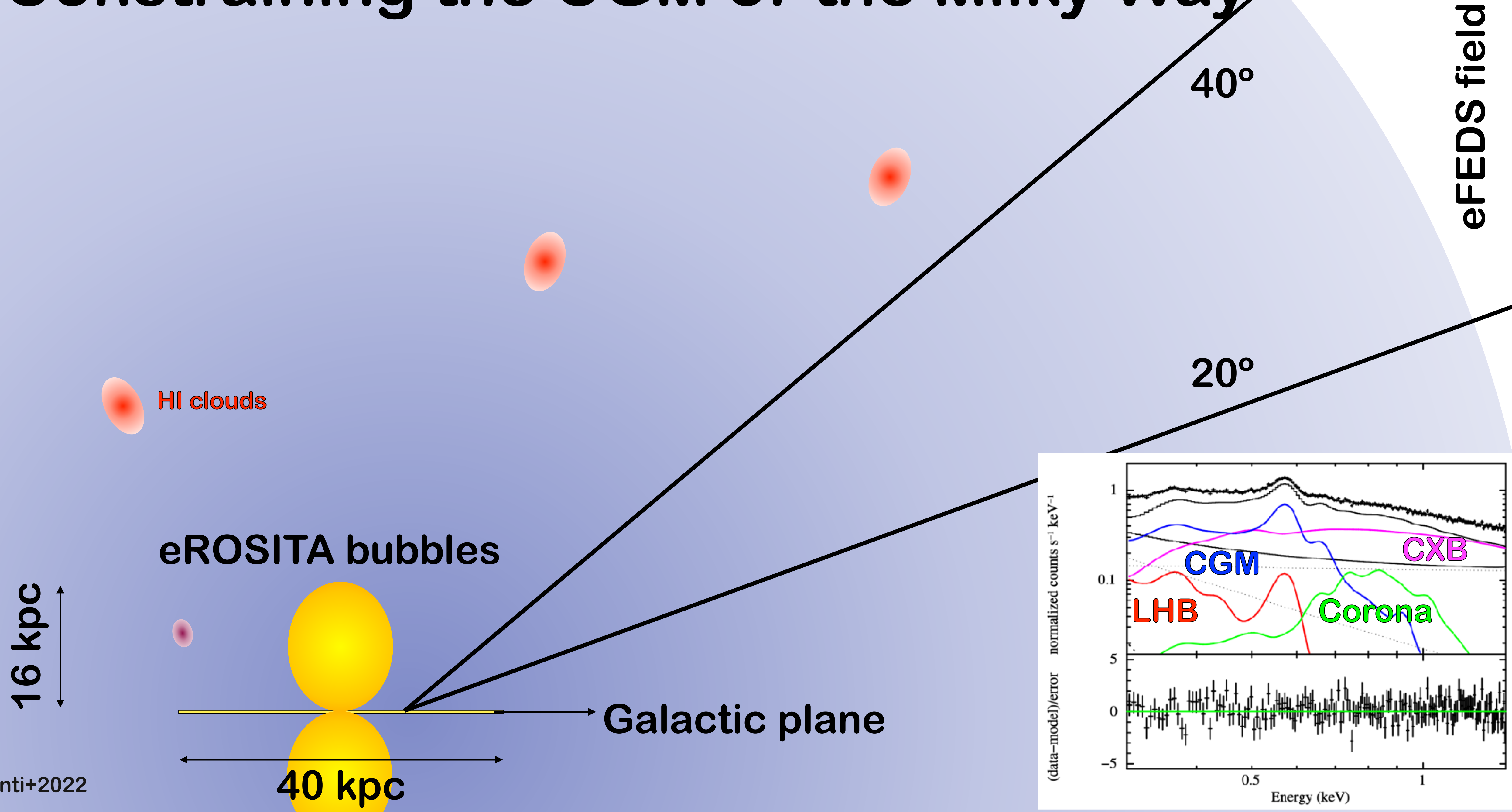
Corona → Required! $kT_{\text{Coro}} = 0.4 - 0.7 \text{ keV}$

→ What does this mean?

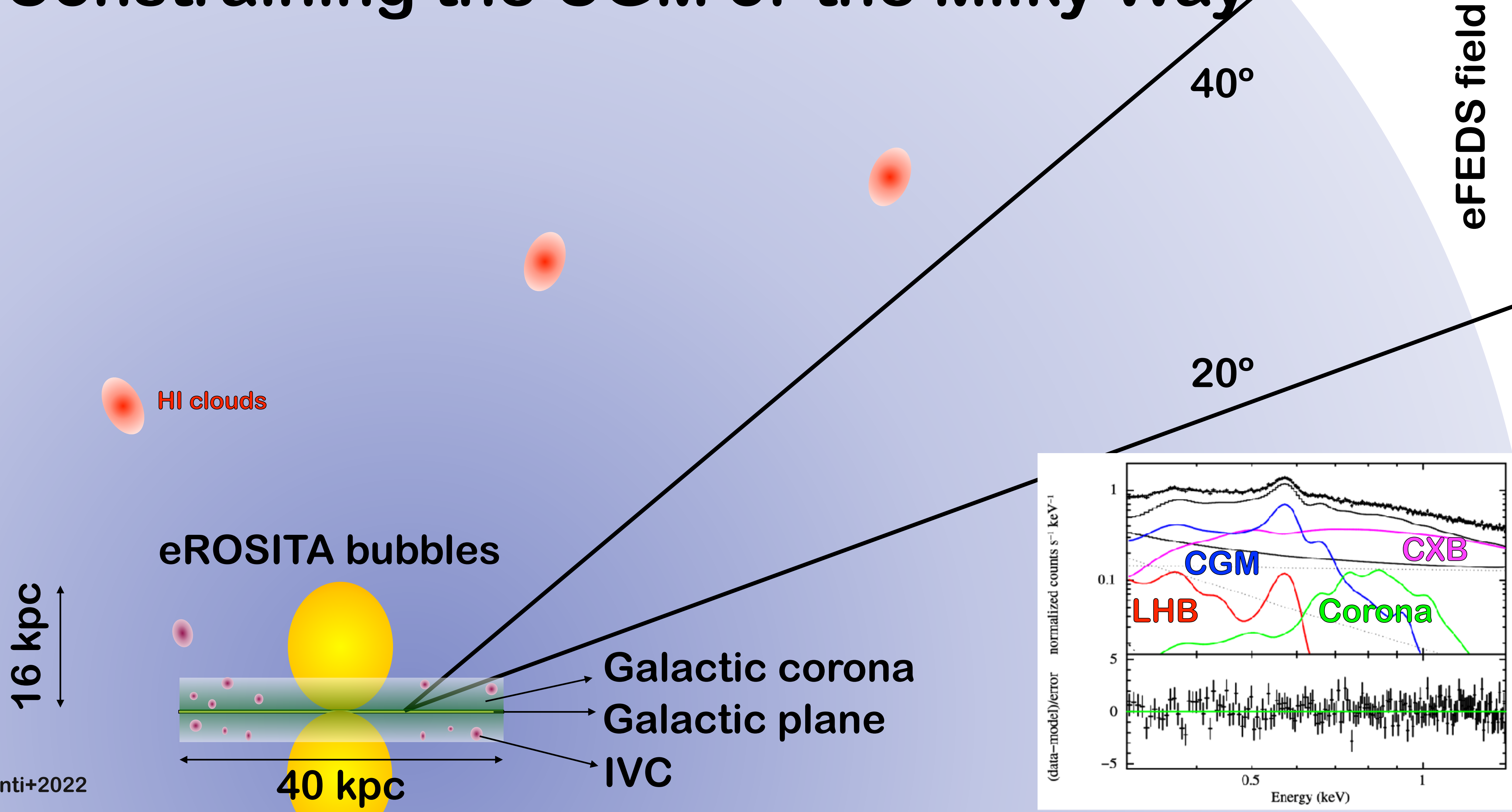
The hot corona above the Milky Way disc



Constraining the CGM of the Milky Way



Constraining the CGM of the Milky Way



Components of diffuse X-ray emission

Solar wind charge exchange

Local hot bubble

Circum-Galactic medium

Galactic corona

Galactic outflow

Cosmic X-ray background

Hot ISM

Unresolved sources (very hot ISM)

Reflection

Dust scattering haloes

Components of diffuse X-ray emission

High Galactic latitudes

Solar wind charge exchange

Local hot bubble

Circum-Galactic medium

Galactic corona

Galactic outflow

Cosmic X-ray background

Low Galactic latitudes

Hot ISM

Unresolved sources (very hot ISM)

Reflection

Dust scattering haloes

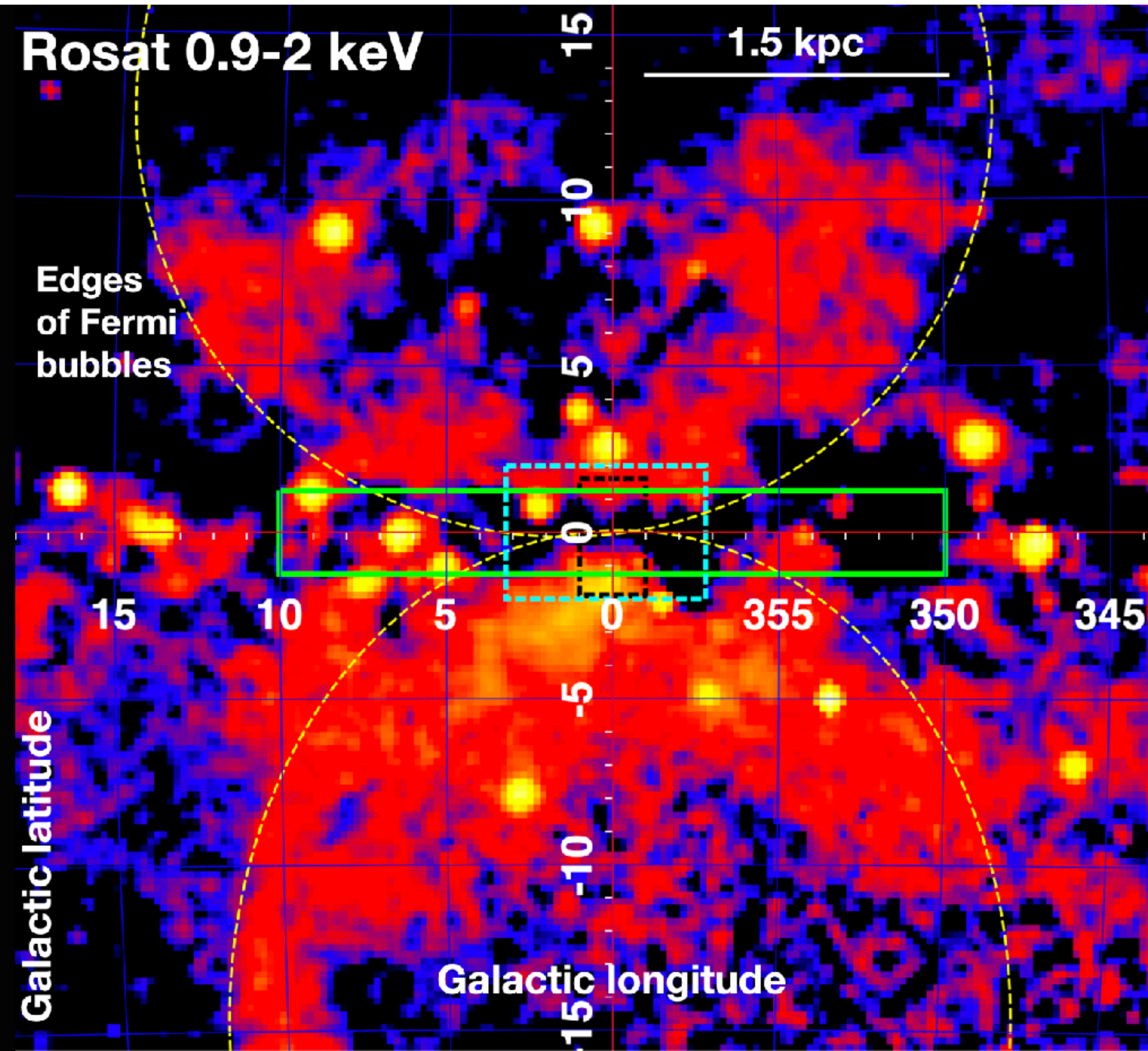
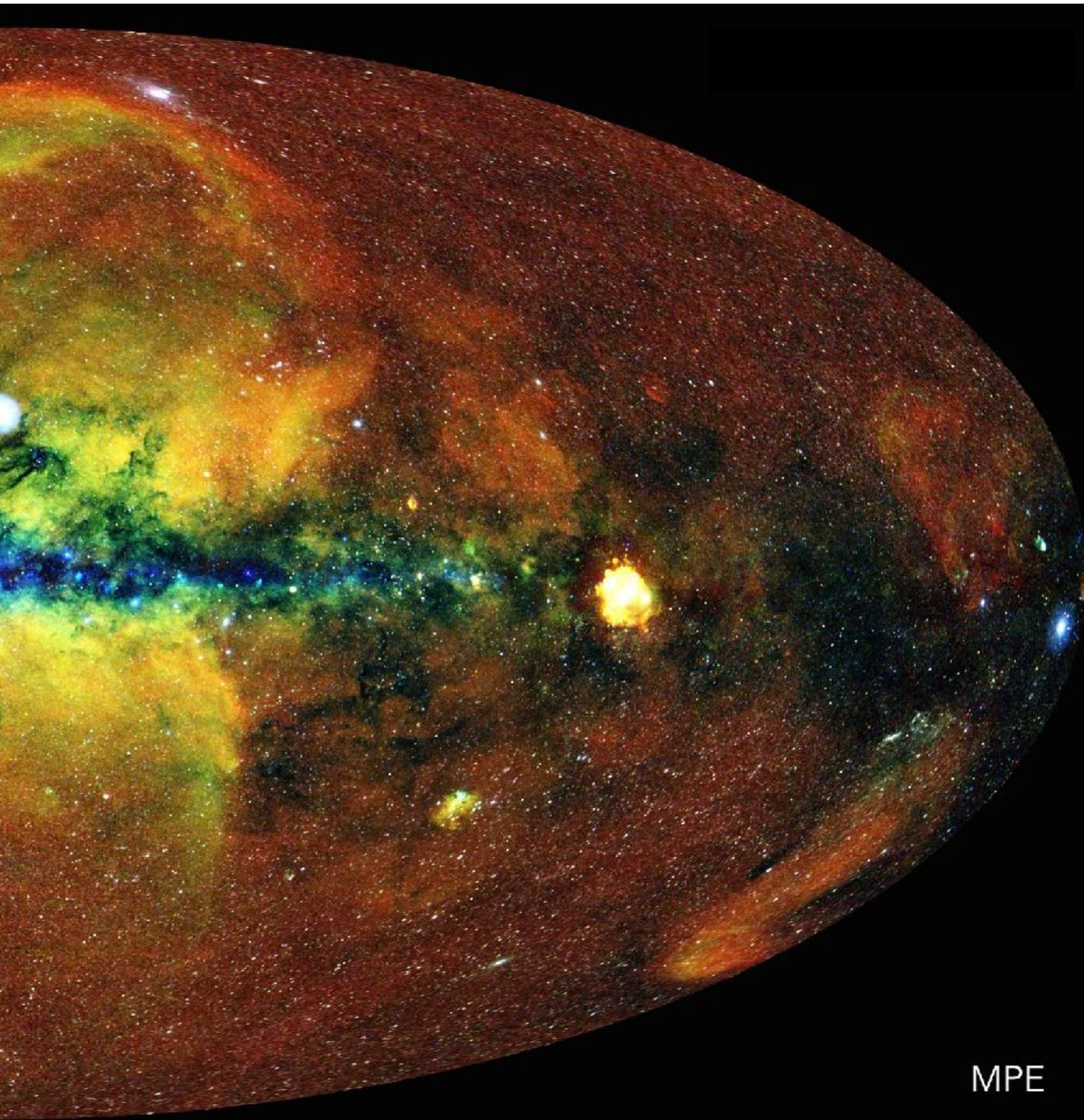
1) What we have been doing

Our tools

2) What we are doing

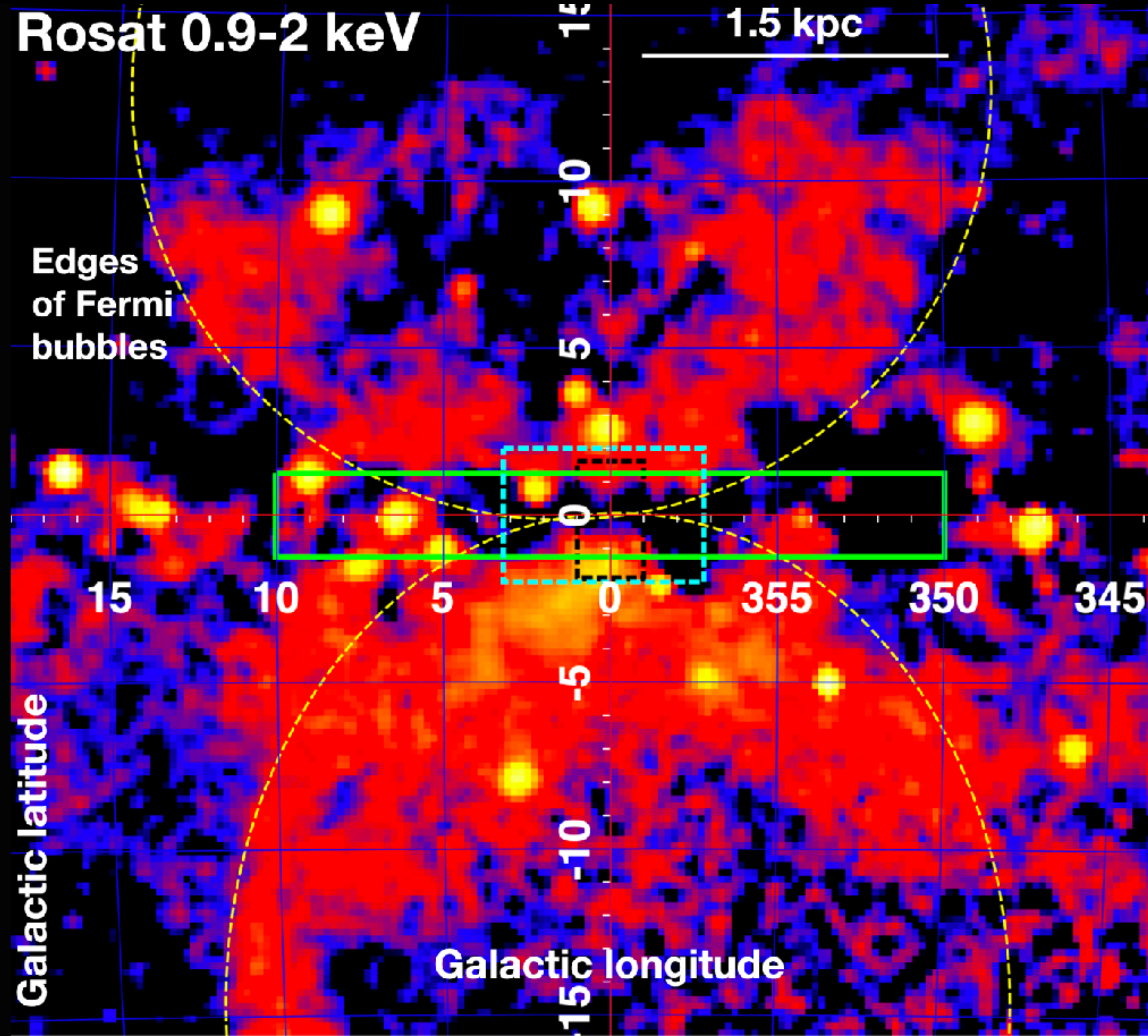
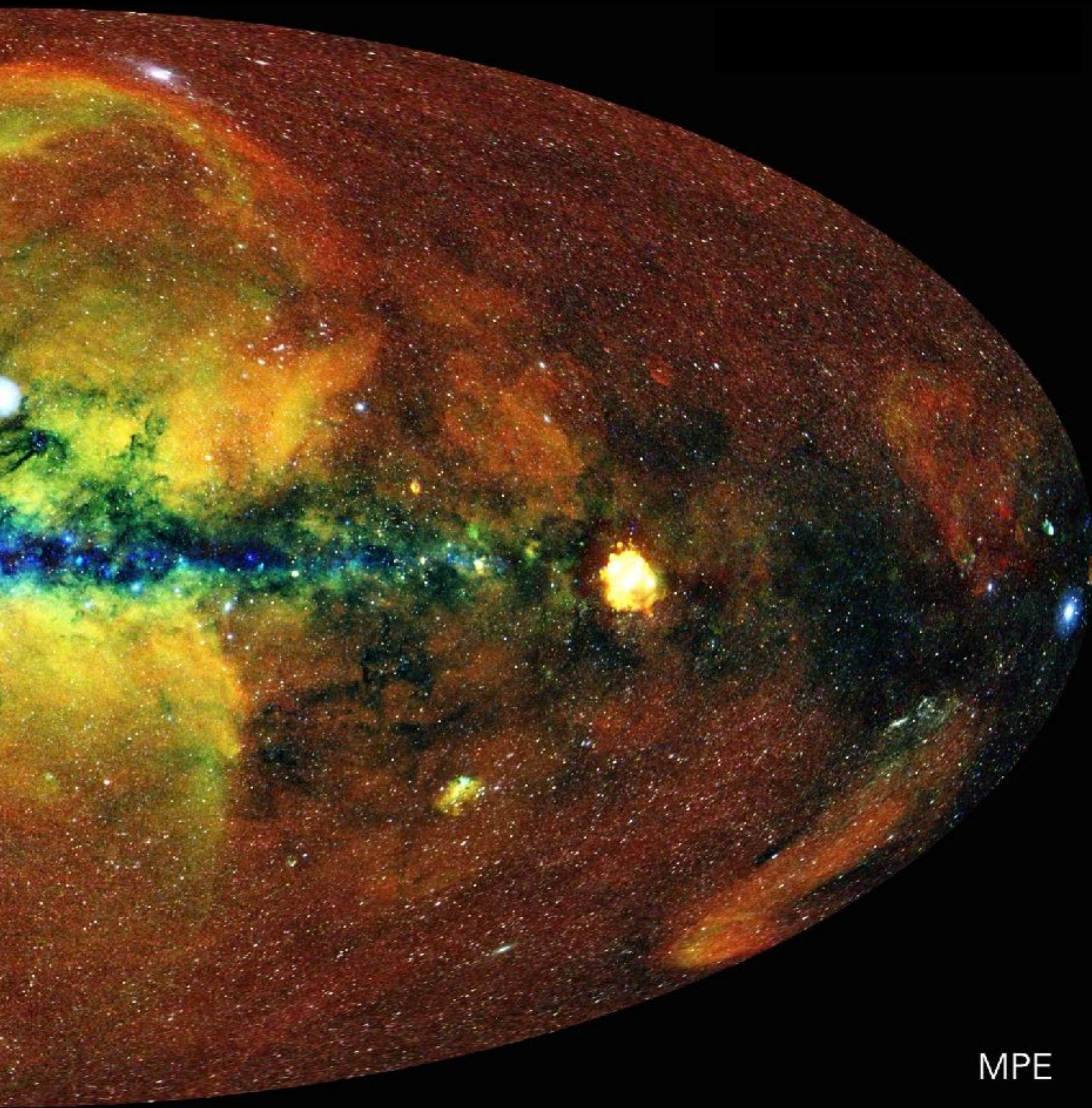
Our skills

What we are doing...



What we are doing...

Hot phase of the Milky Way (eROSITA) Surveys of Galactic disc (XMM+Chandra)



1) What we have been doing

Our tools

3) What we would like to do

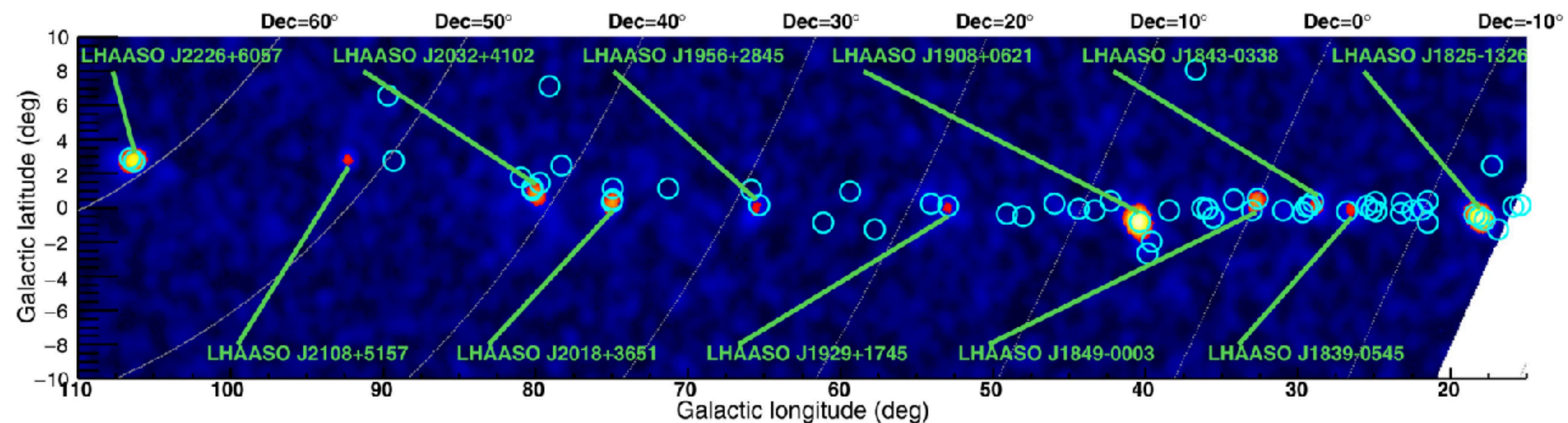
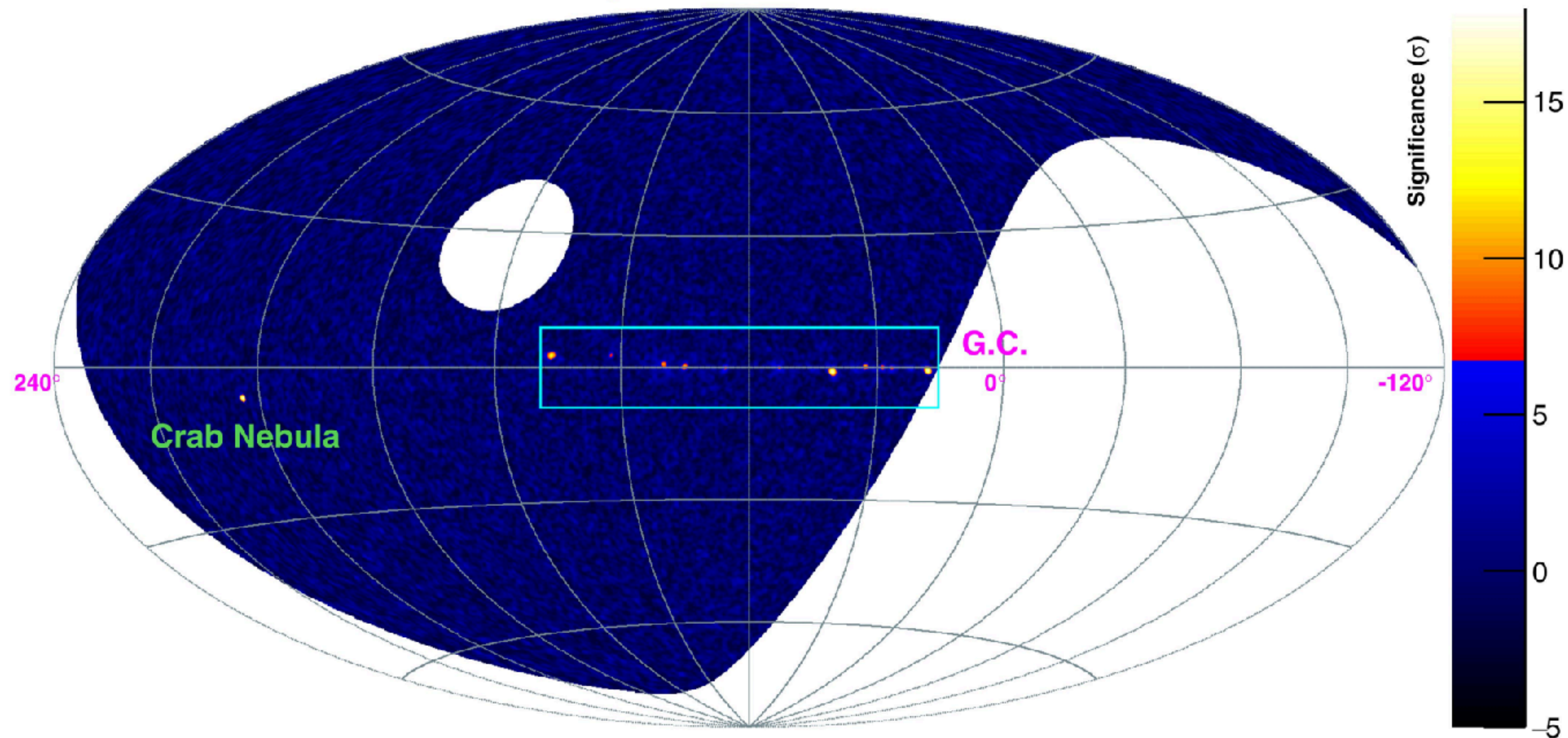
Our aims

2) What we are doing

Our skills

X-ray coverage of very high energy sources

LHAASO Sky @ >100 TeV



1) What we have been doing

Our tools

3) What we would like to do

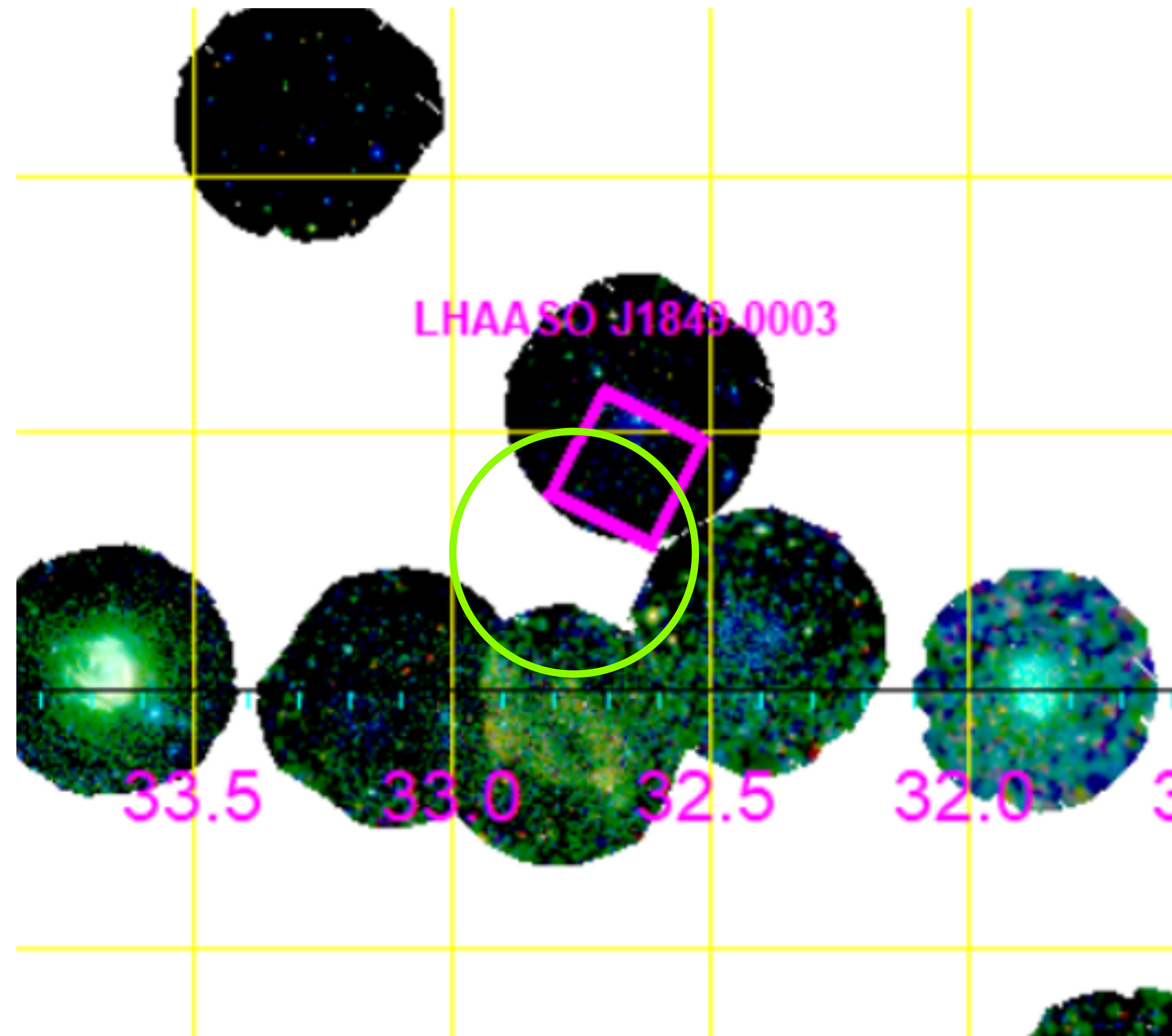
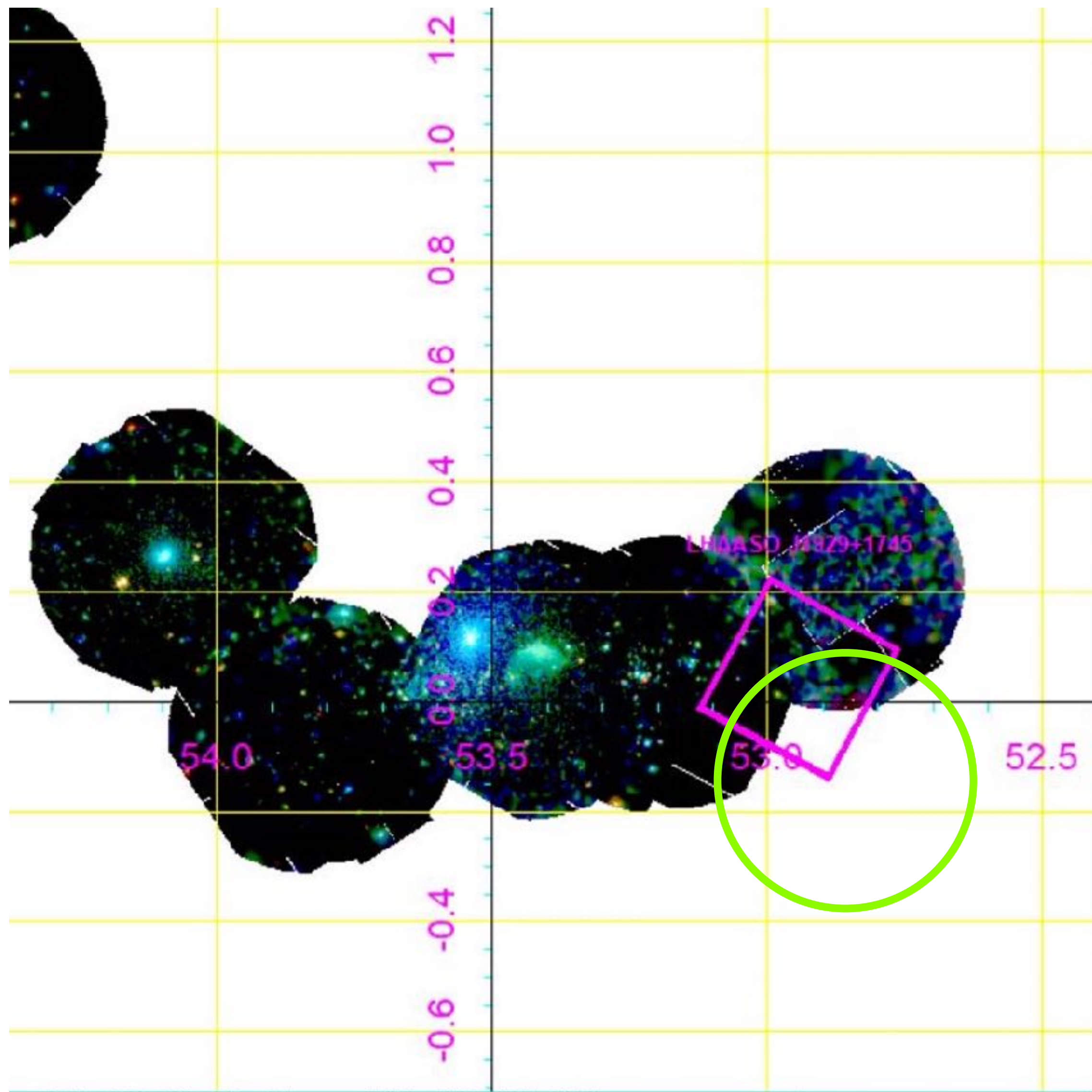
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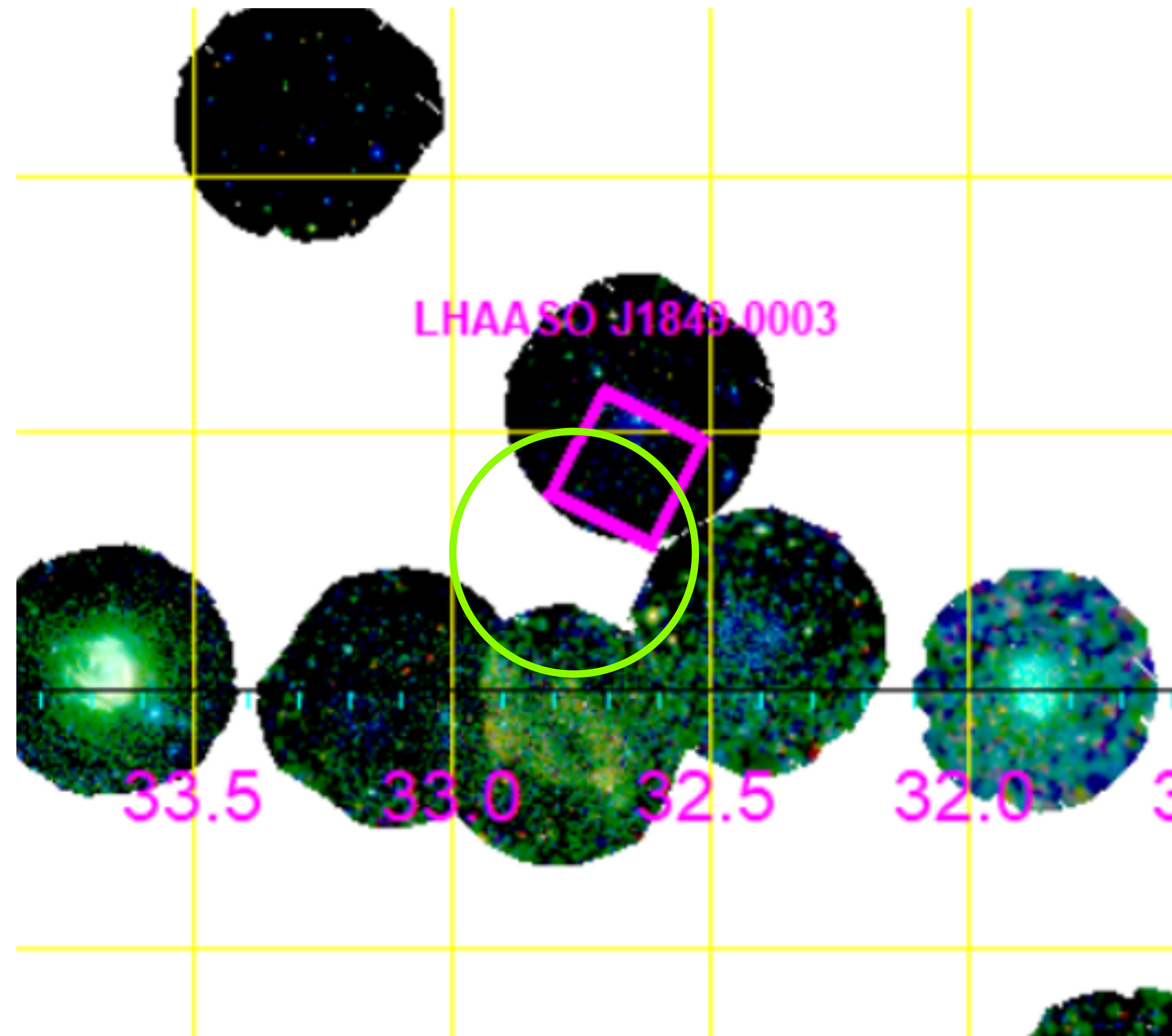
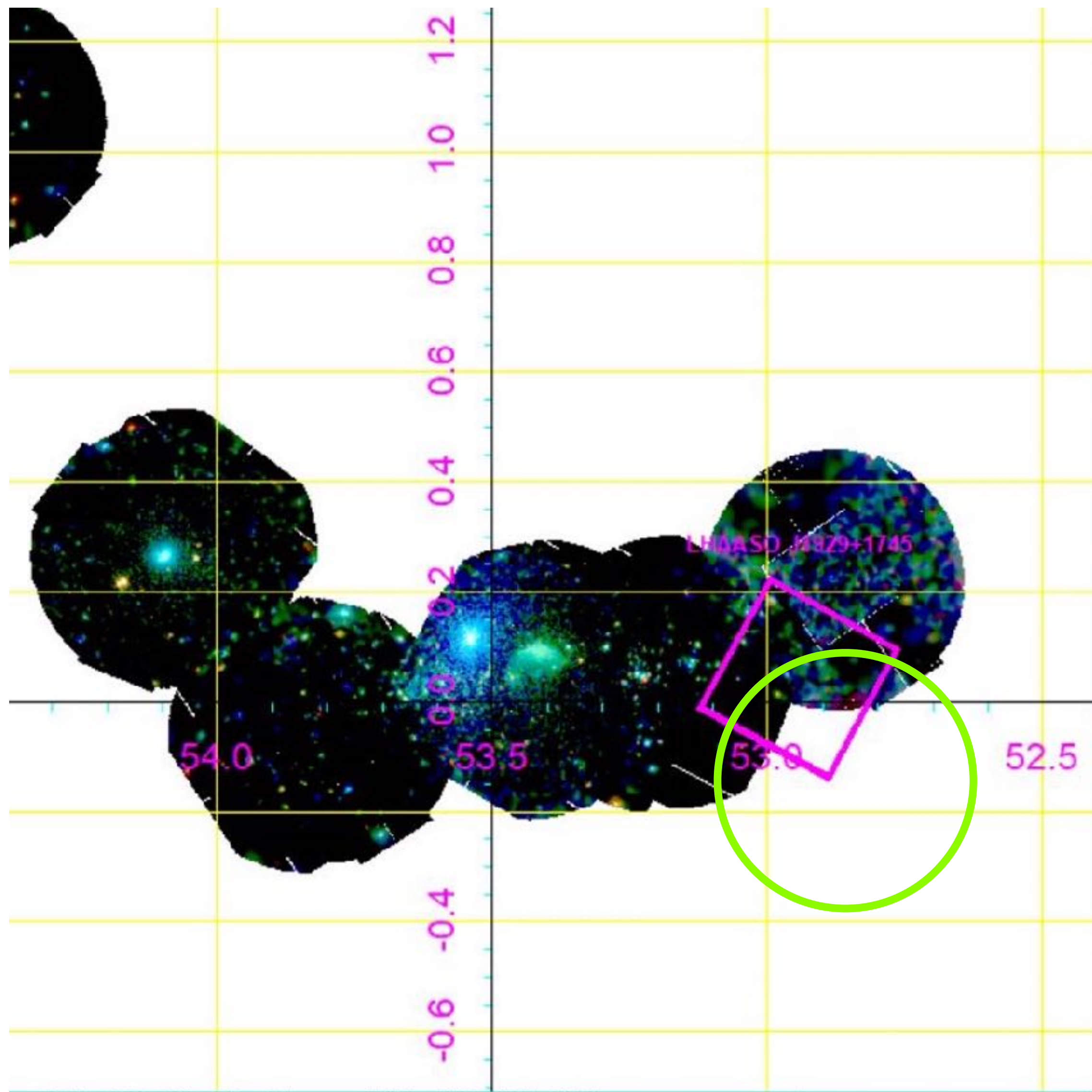
Our skills

4) What we will actually do

Approved XMM observations of 2 PeVatrons



Approved XMM observations of 2 PeVatrons



Stay tuned!