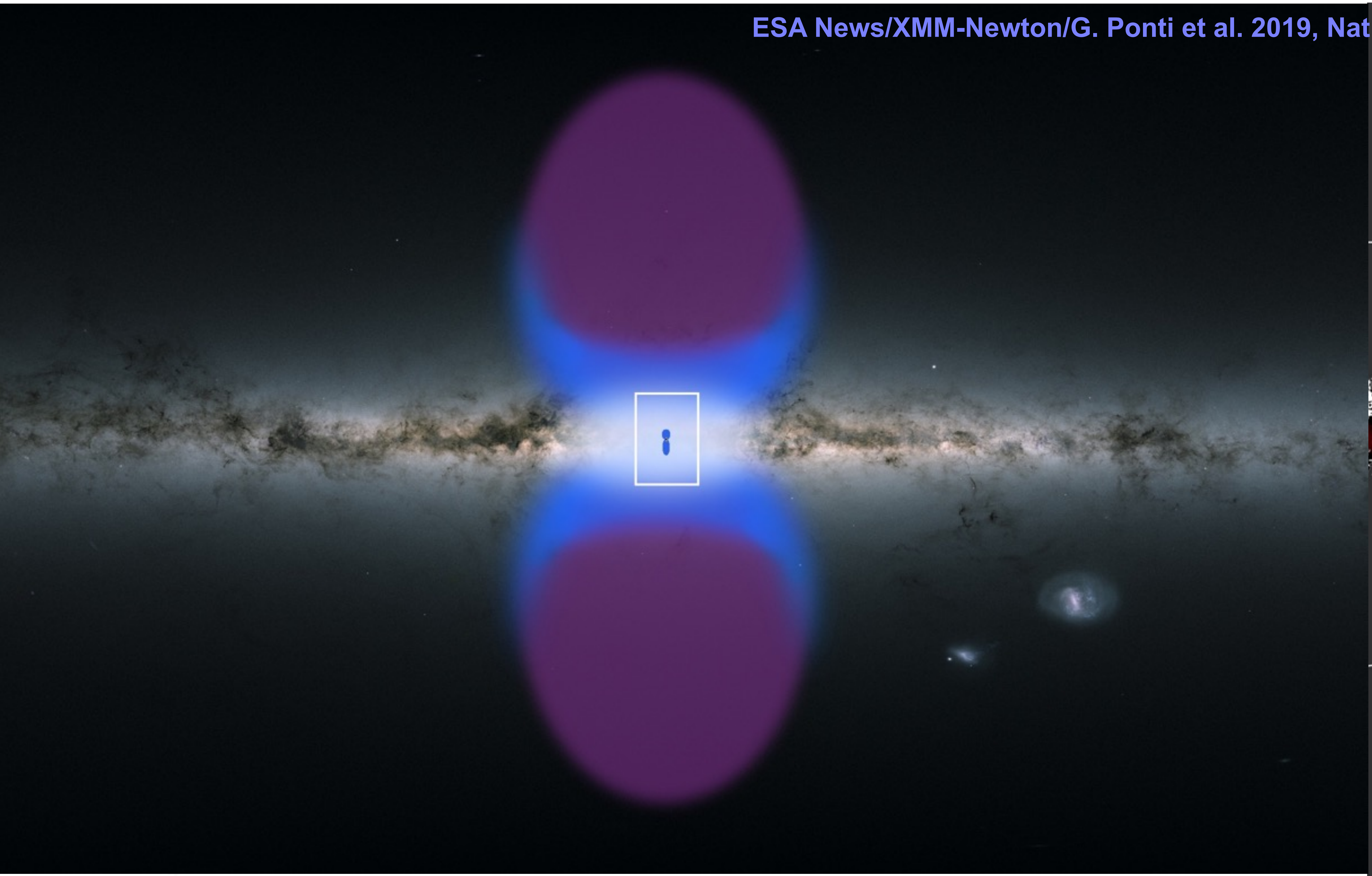
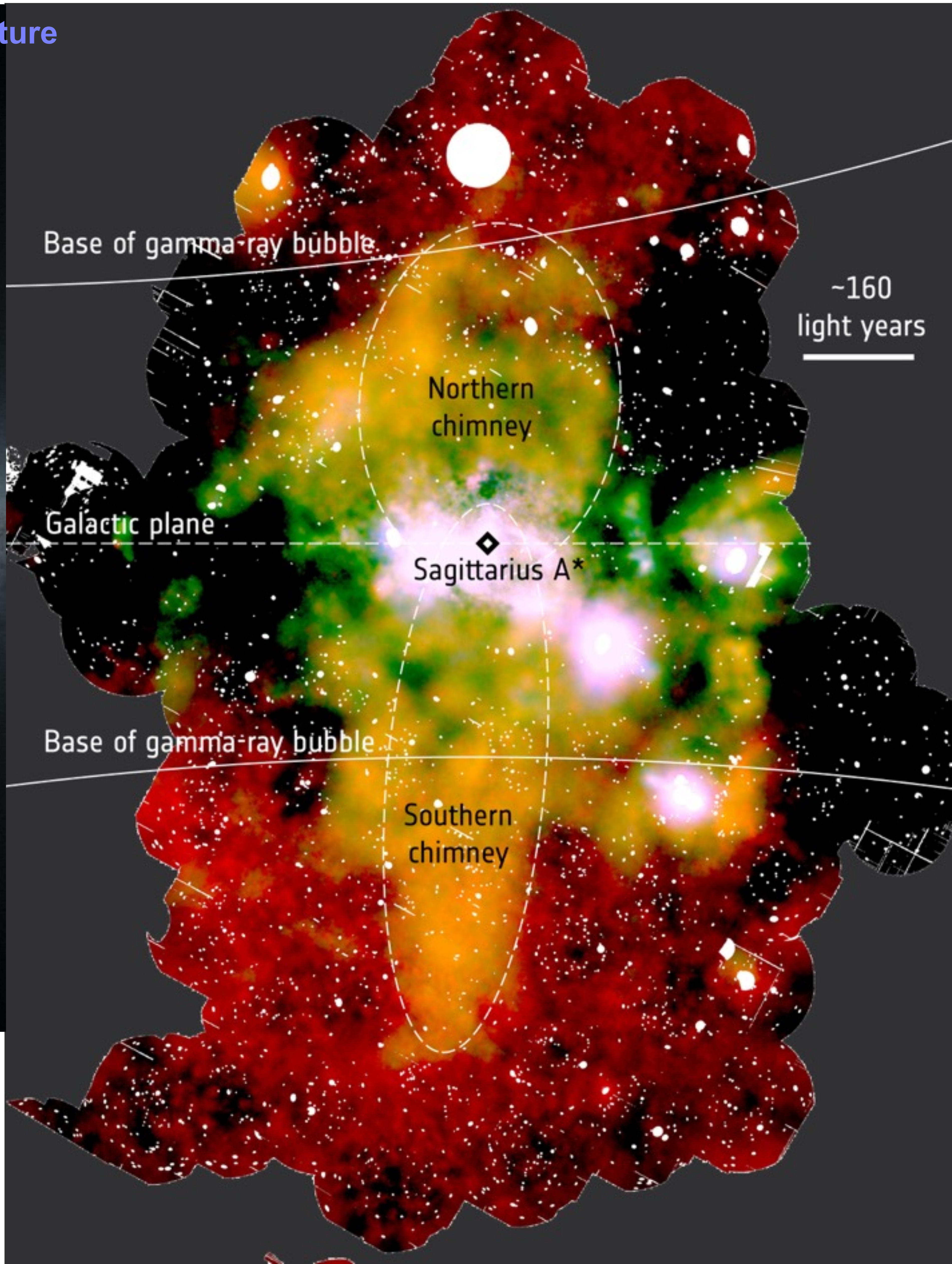
The outflow from the Galactic center



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

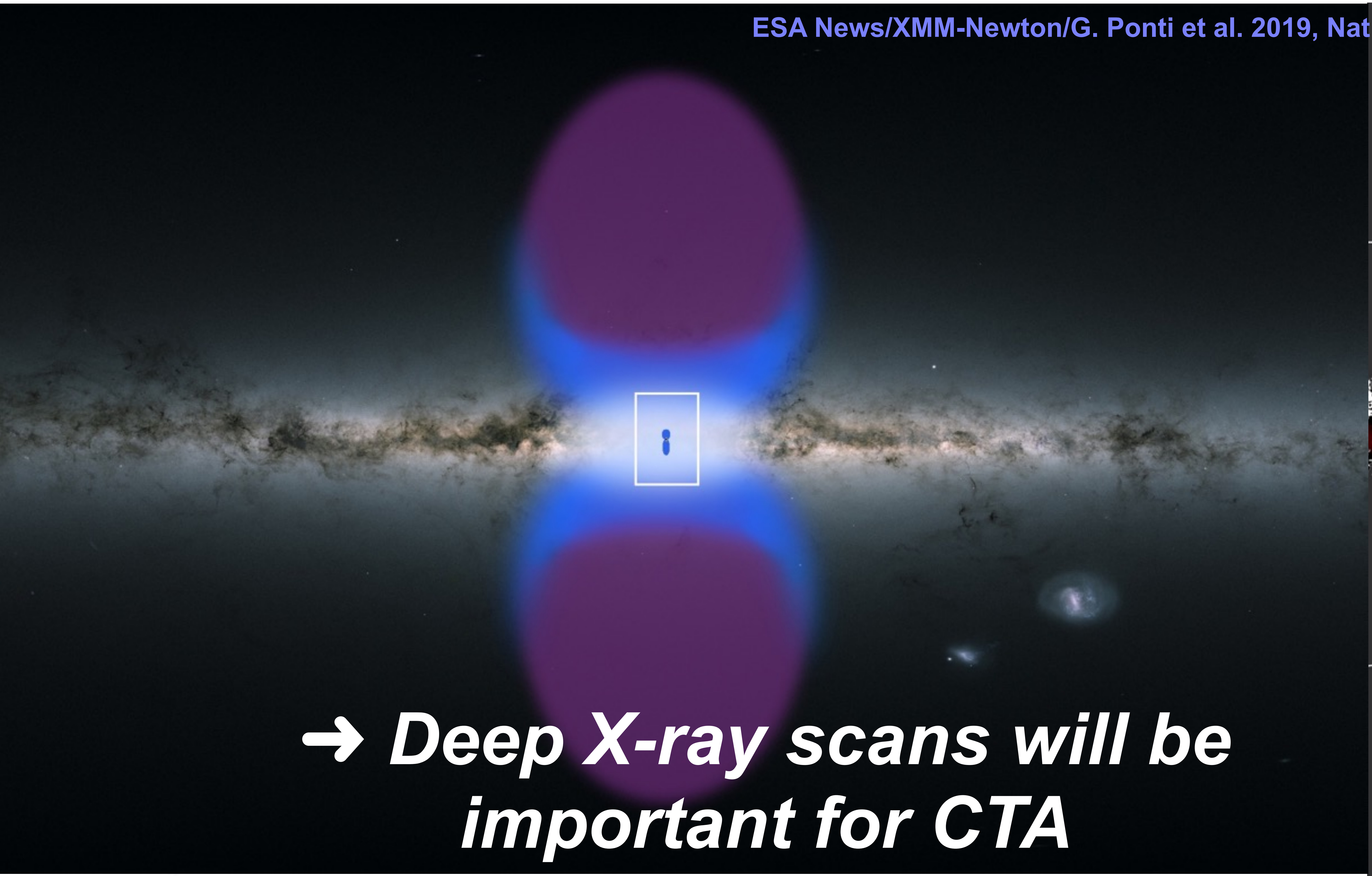


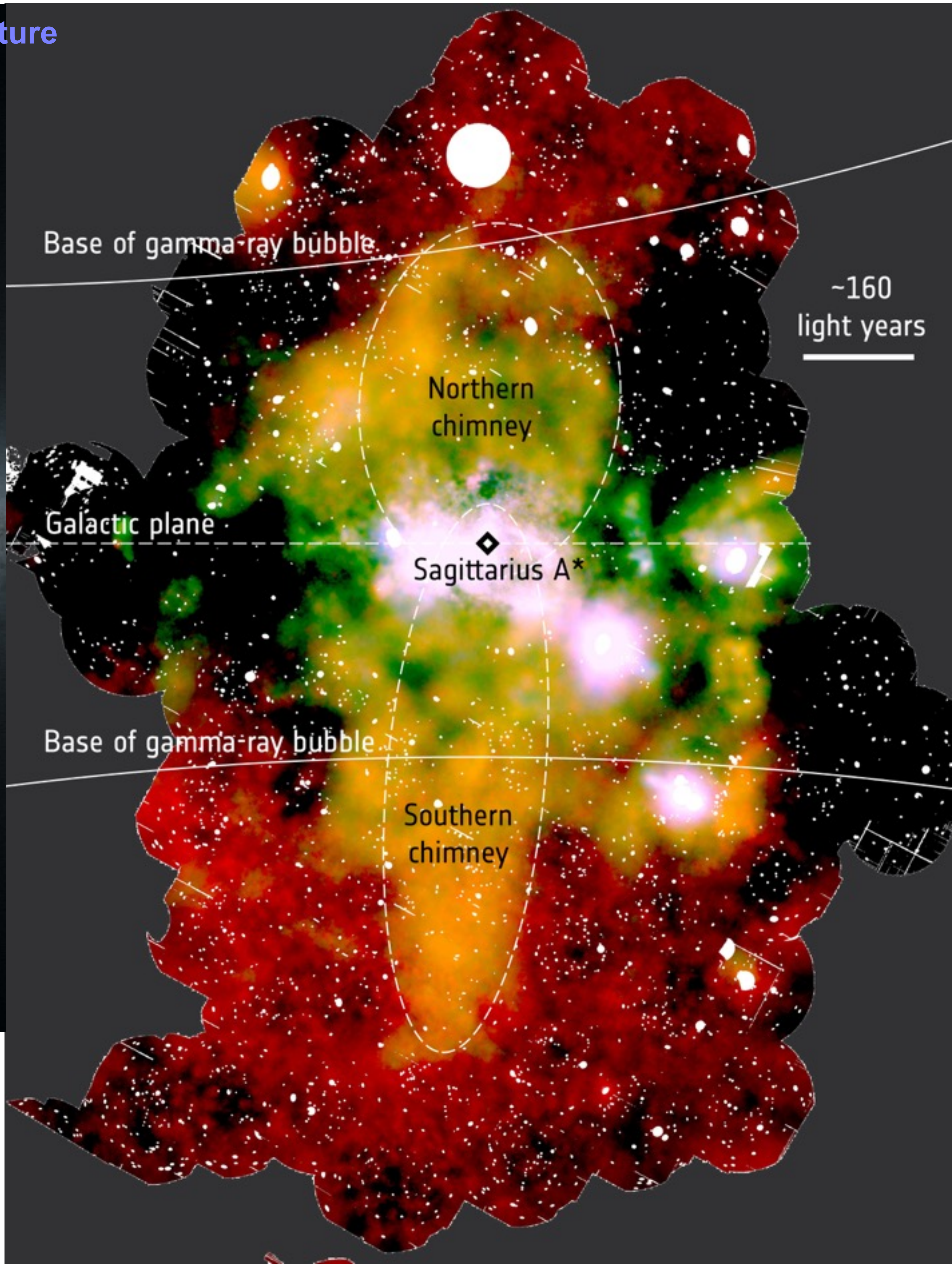
Gabriele Ponti

INAF Brera-Merate

OSSERVATORIO ASTRONOMICO DI BRERA

The outflow from the Galactic center

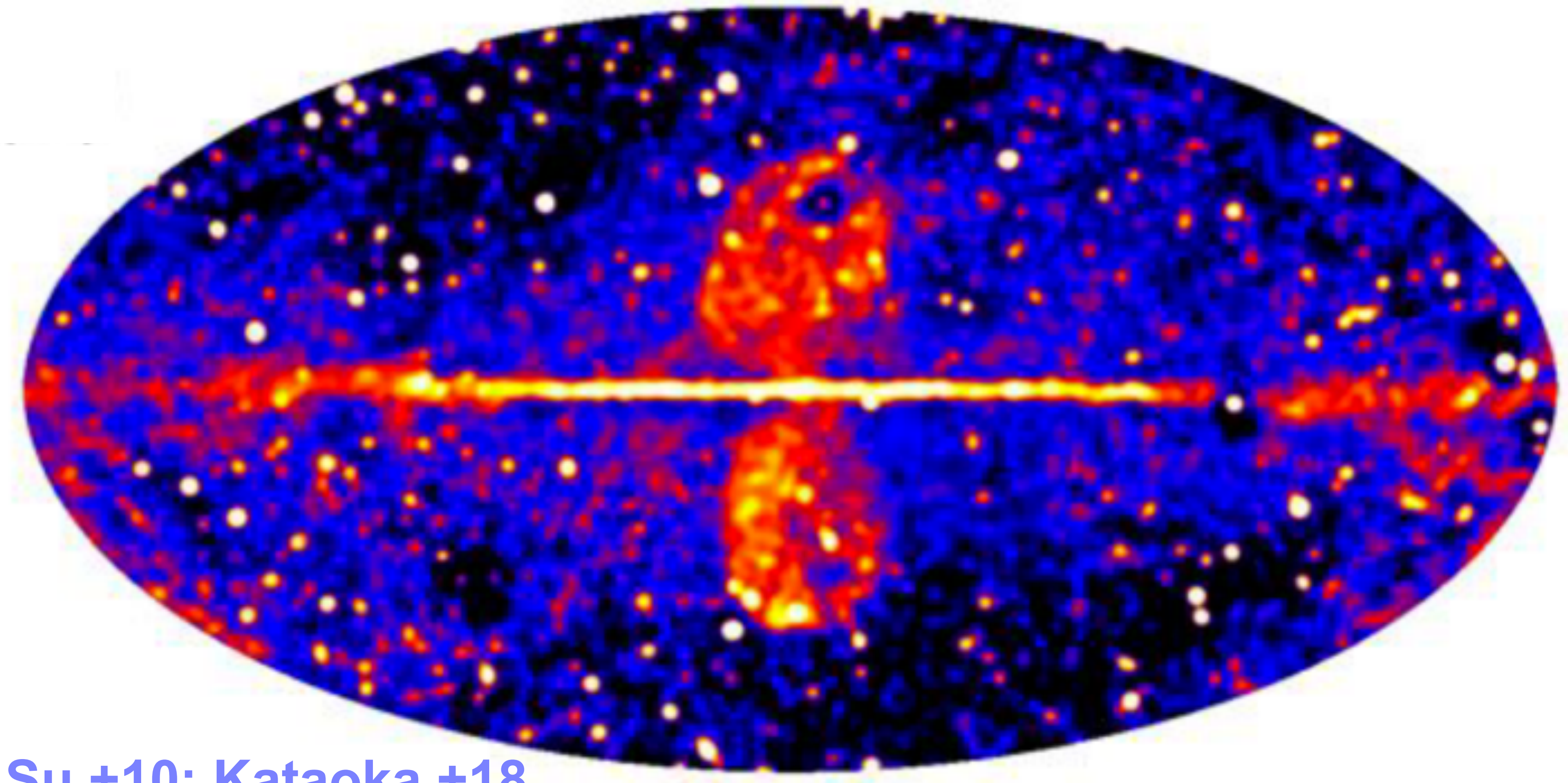




Gabriele Ponti
INAF Brera-Merate

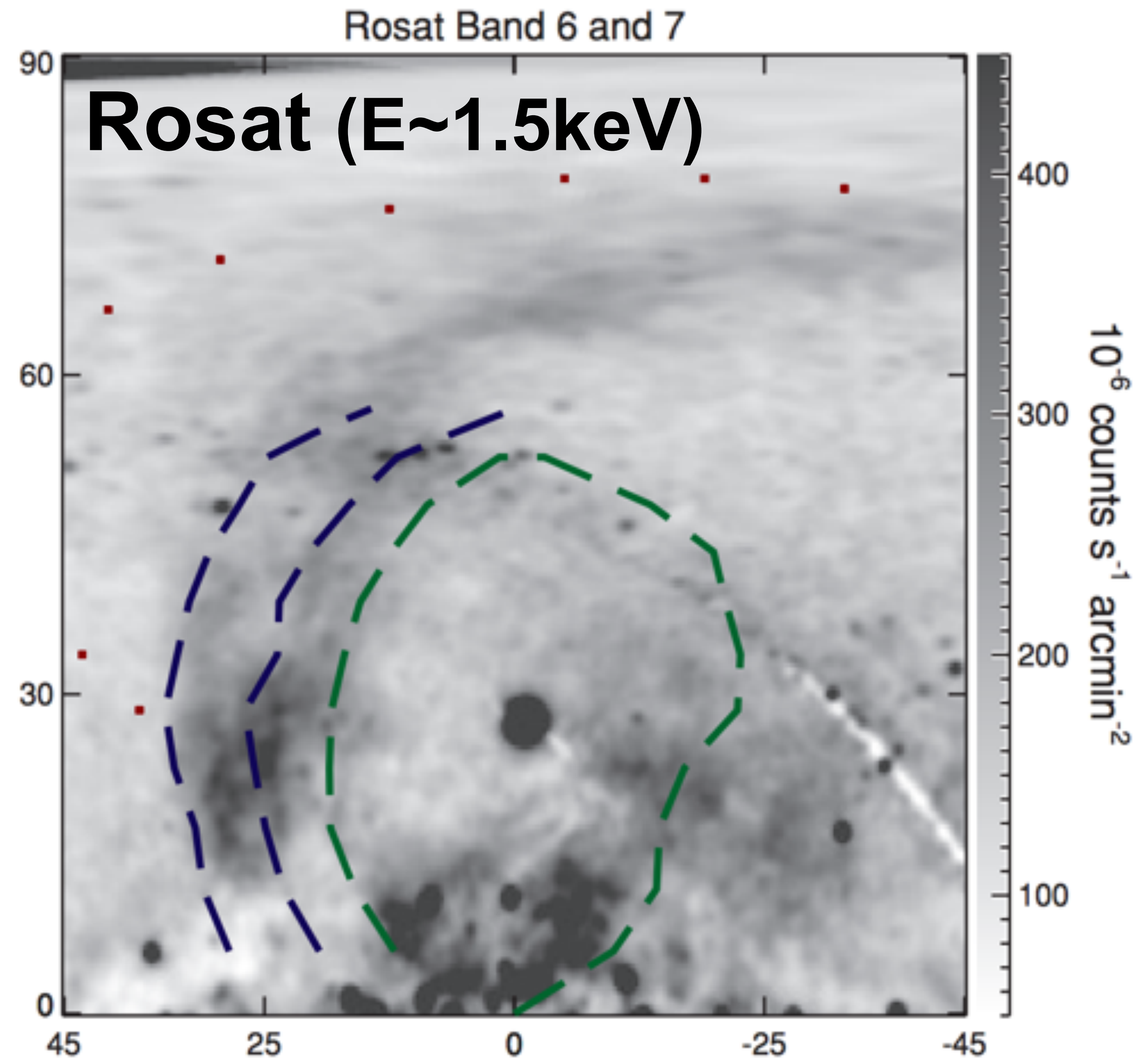
Outflows from the Milky Way center

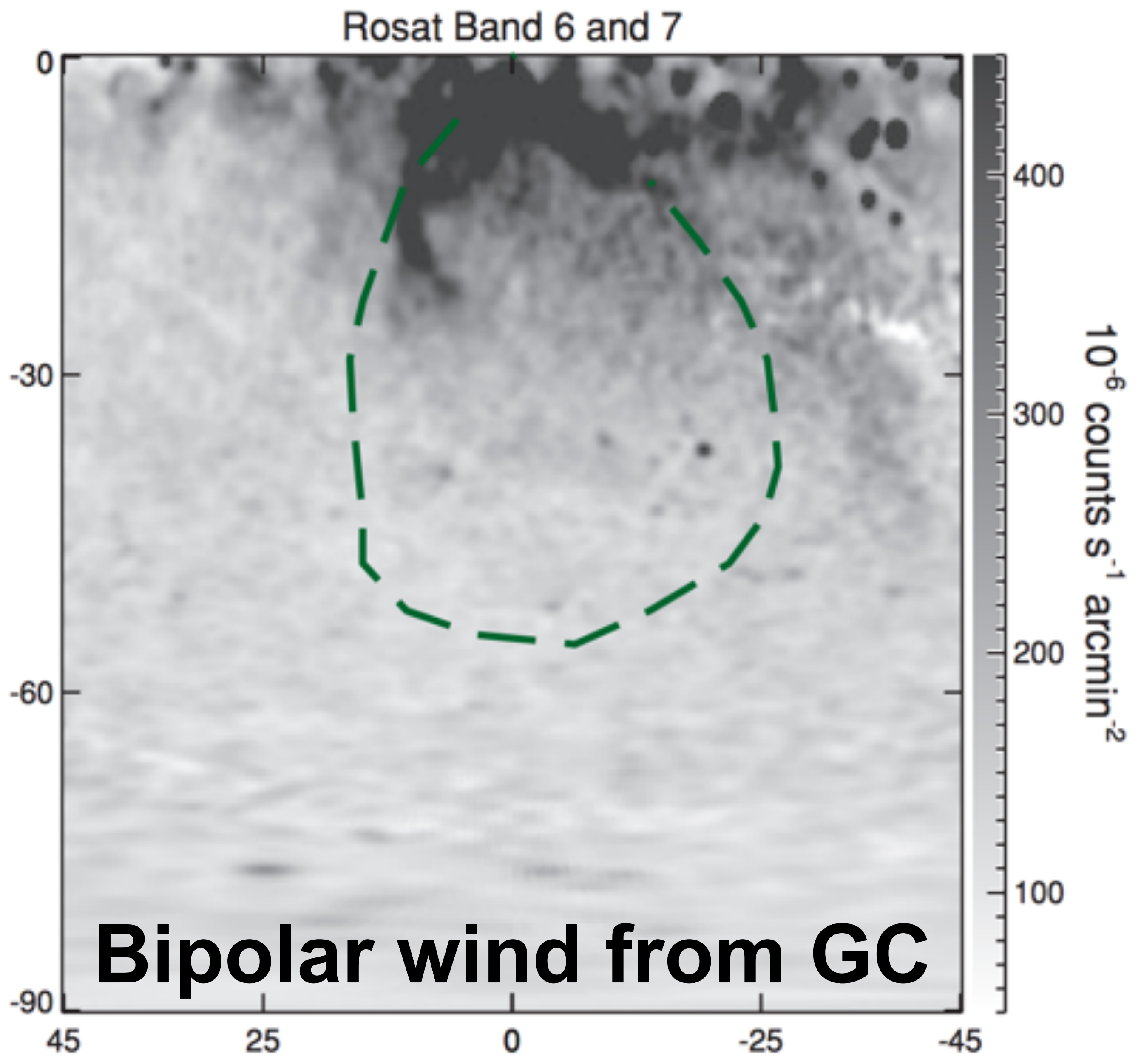
Fermi Bubbles (E>2GeV/E<2GeV)



Su +10; Kataoka +18

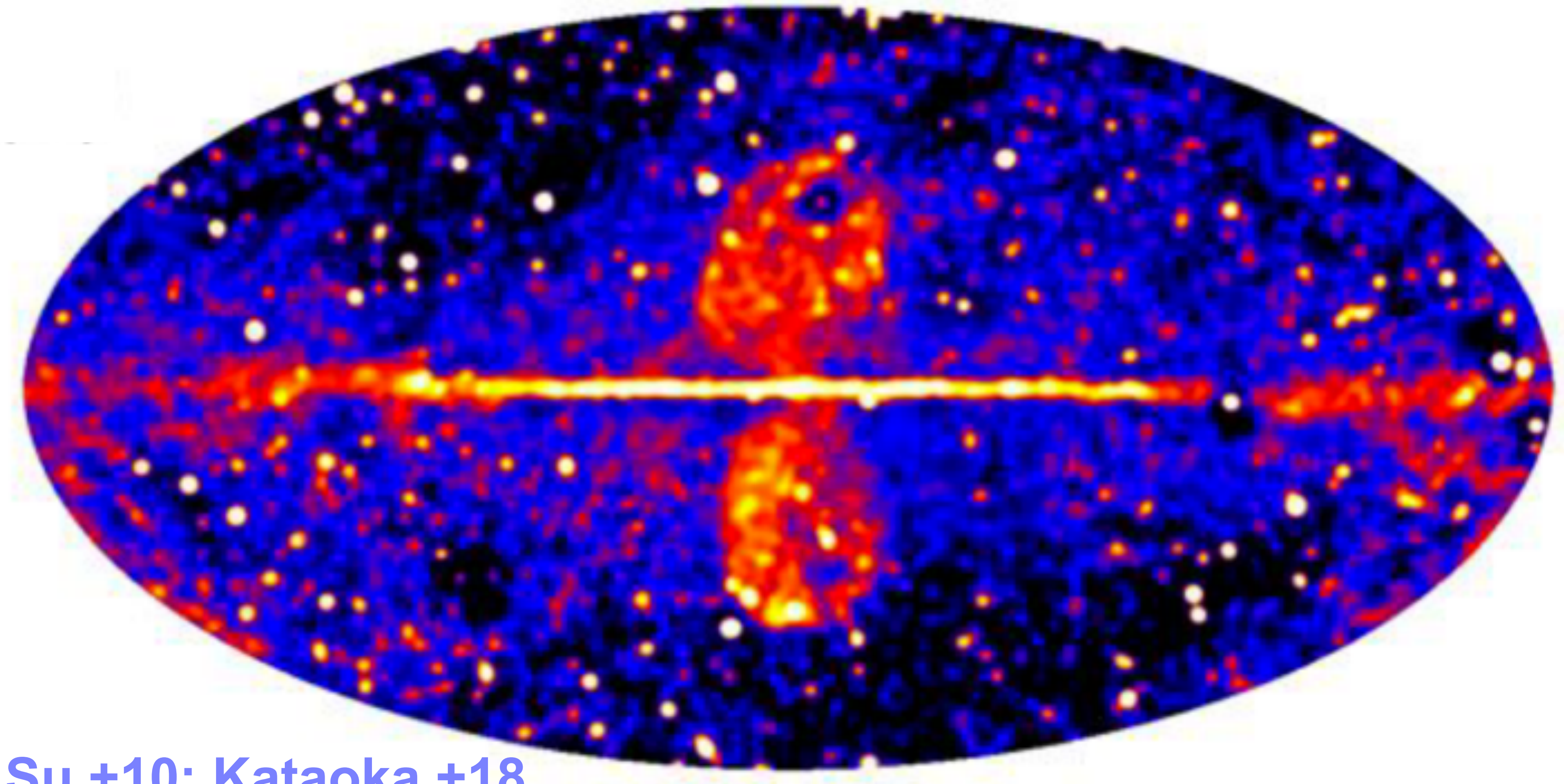
Outflows from the Milky Way center





Bland-Hawthorn +03; Su +10

Fermi Bubbles (E>2GeV/E<2GeV)



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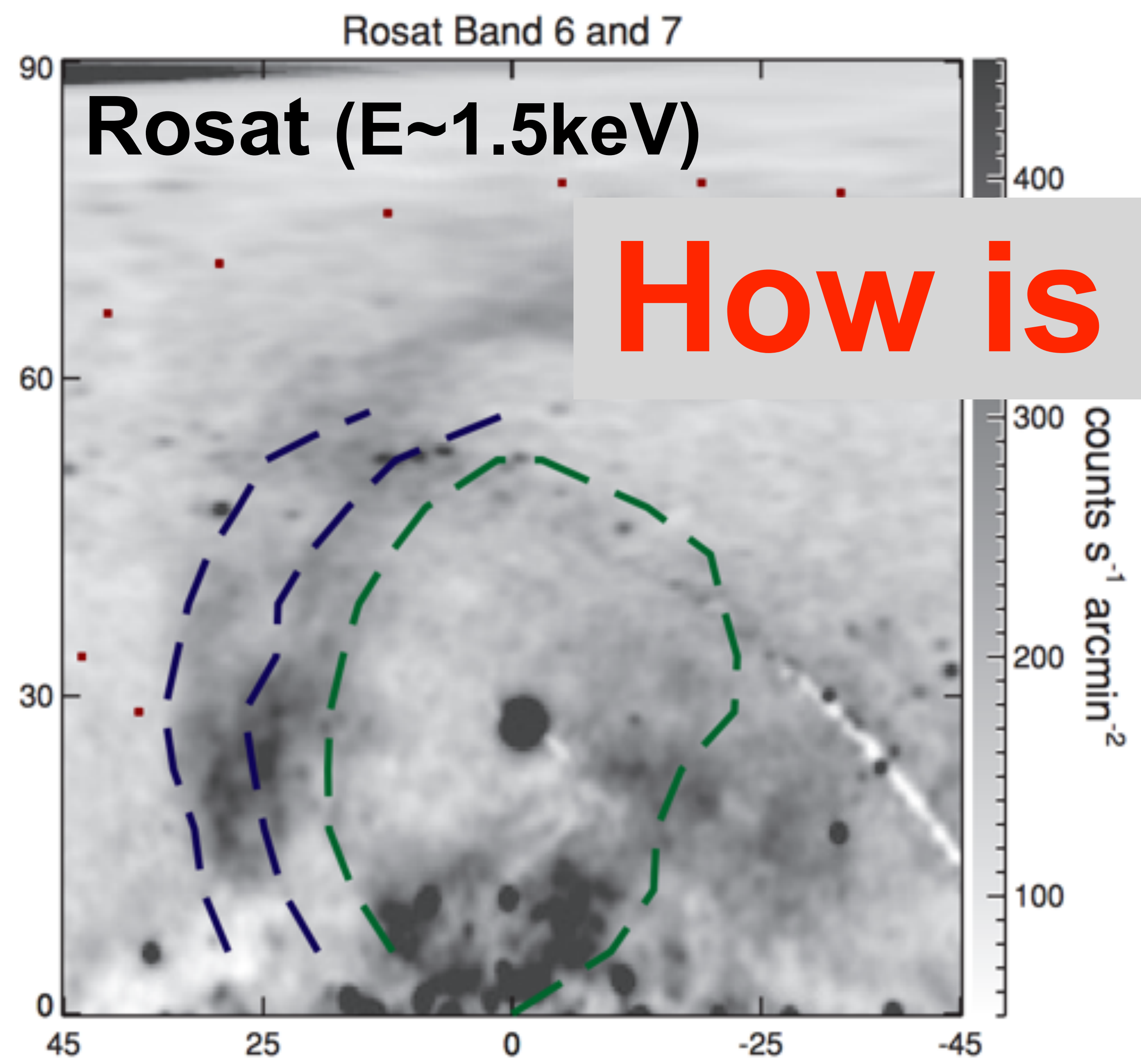
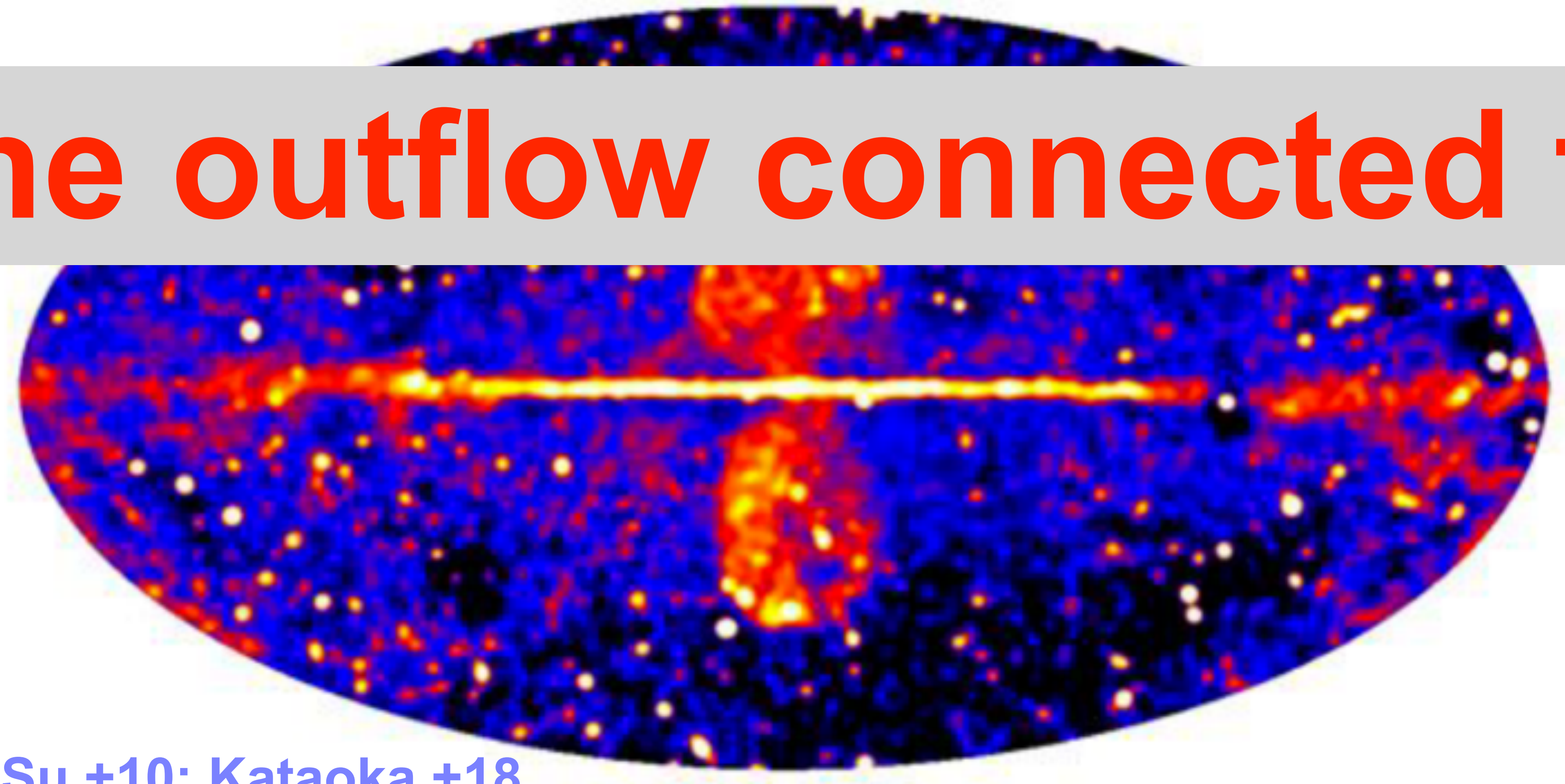
Outflows from the Milky Way center



Fermi Bubbles (E>2GeV/E<2GeV)

How is the outflow connected to the disc?



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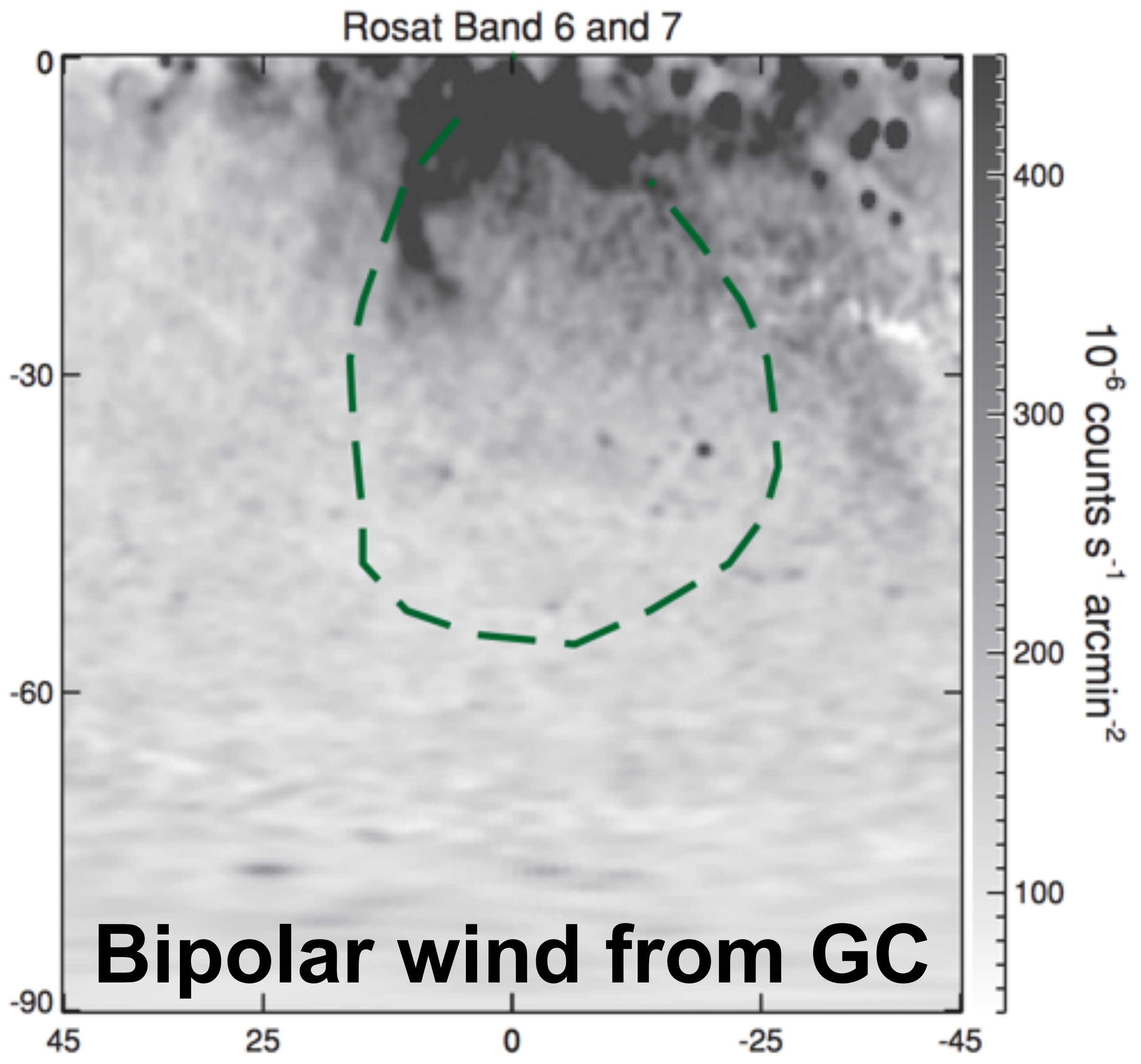

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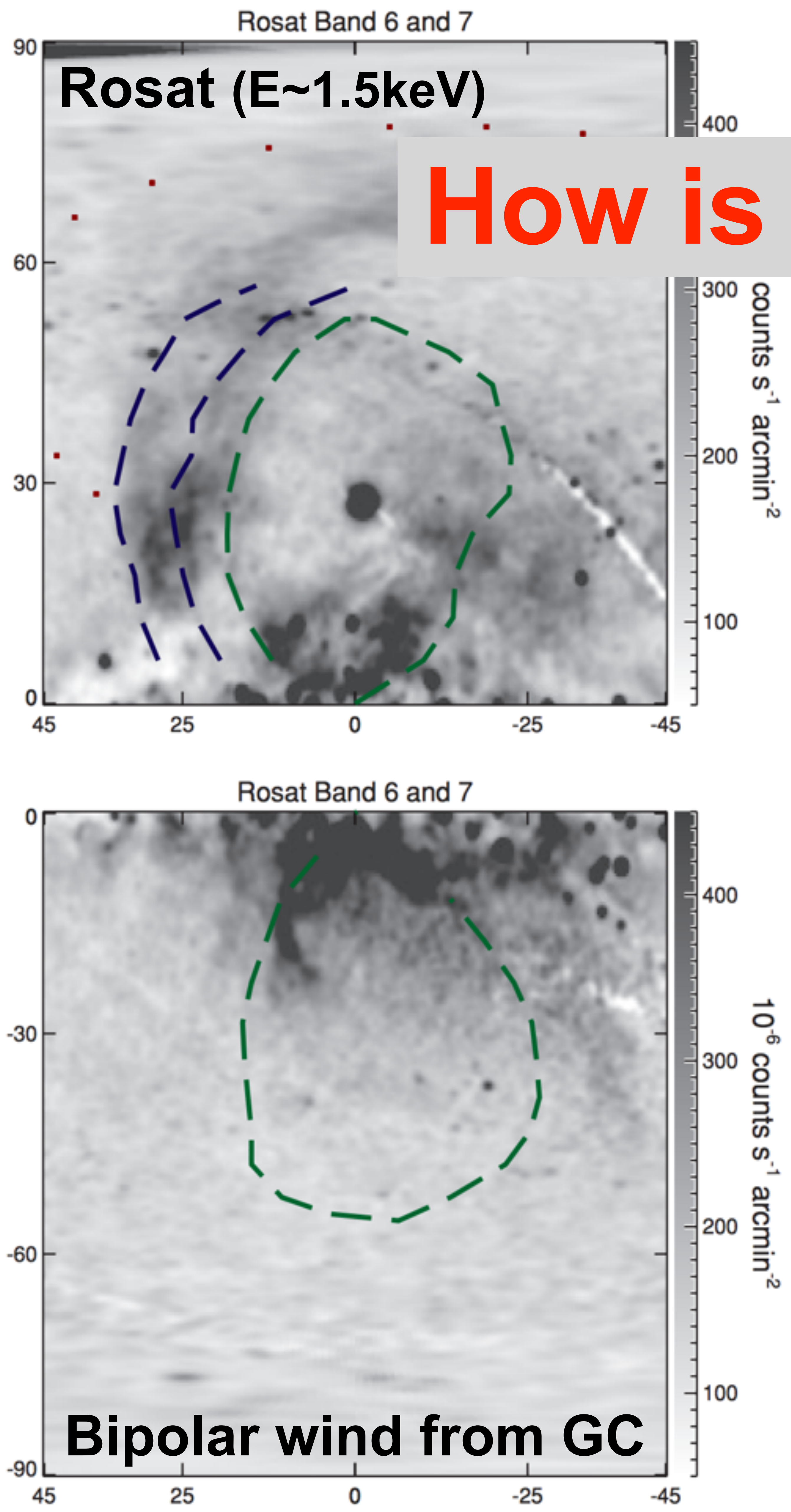

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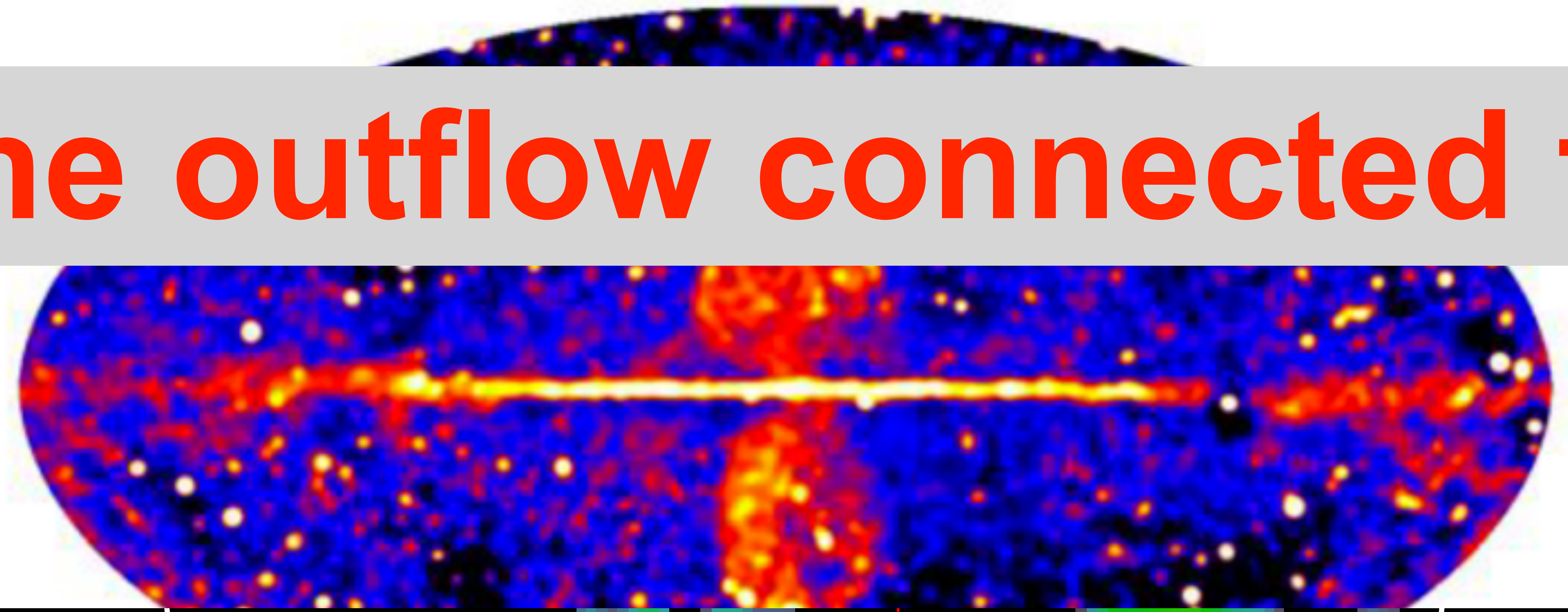

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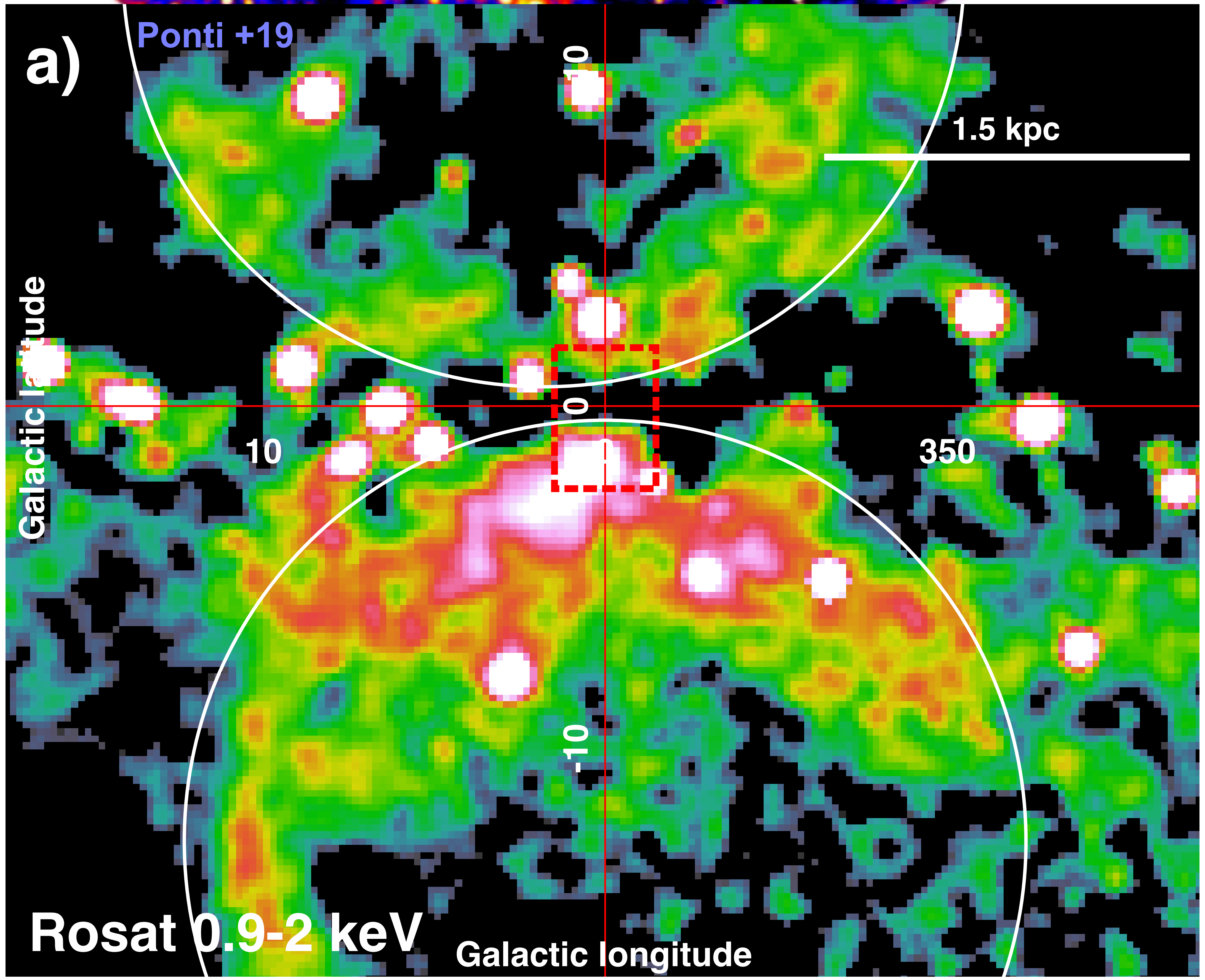
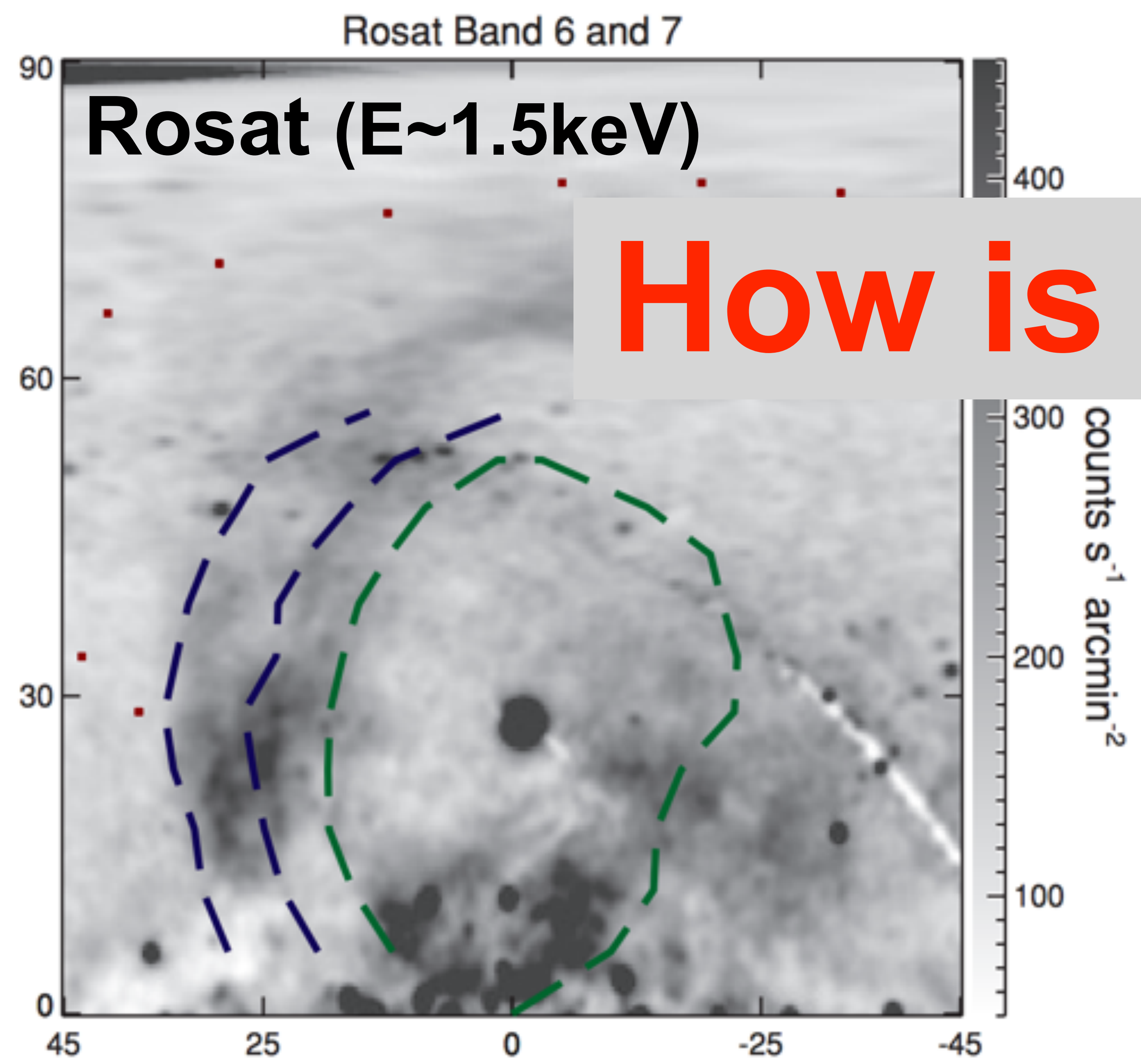
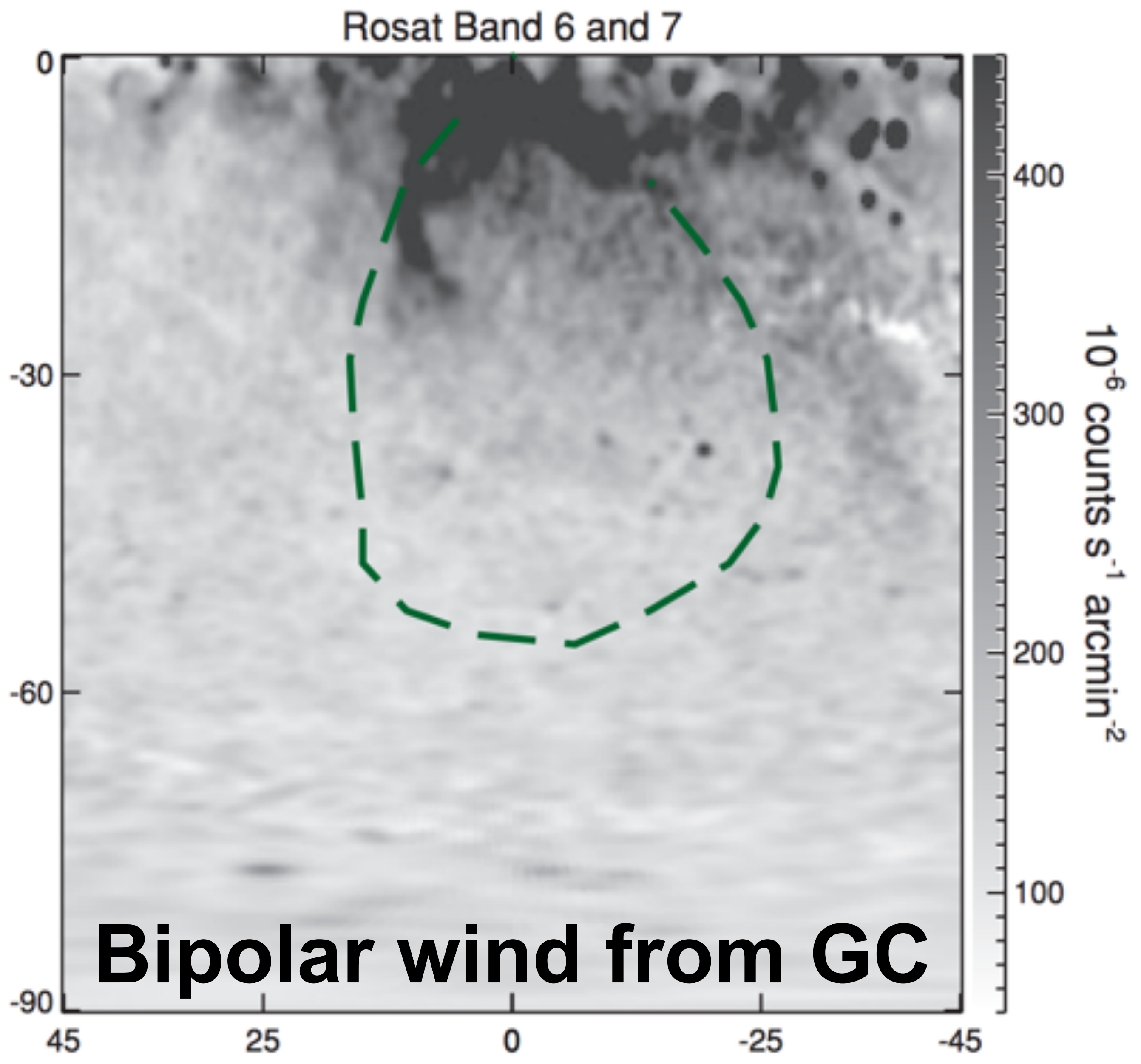


Outflows from the Milky Way center

How is the outflow connected





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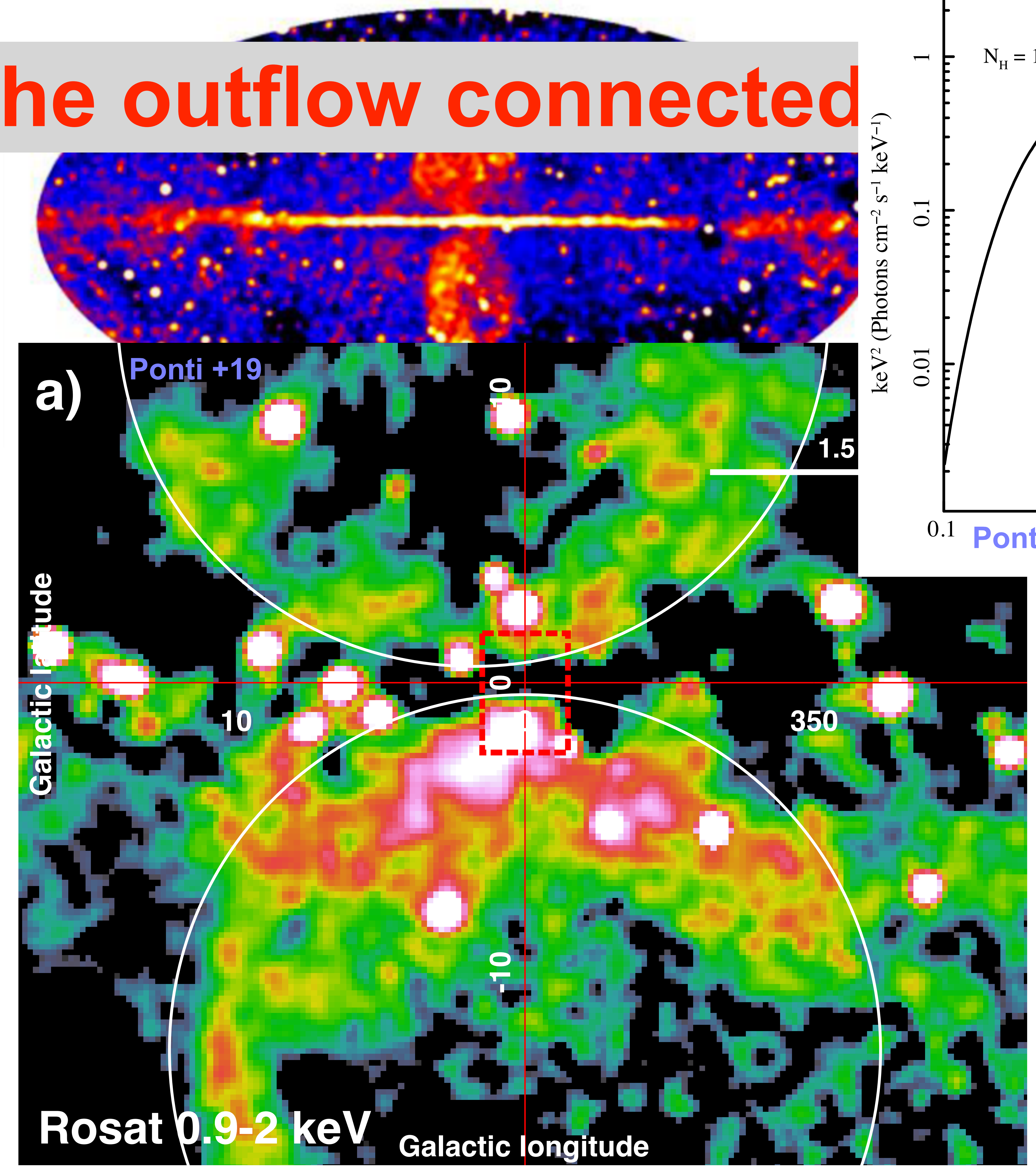
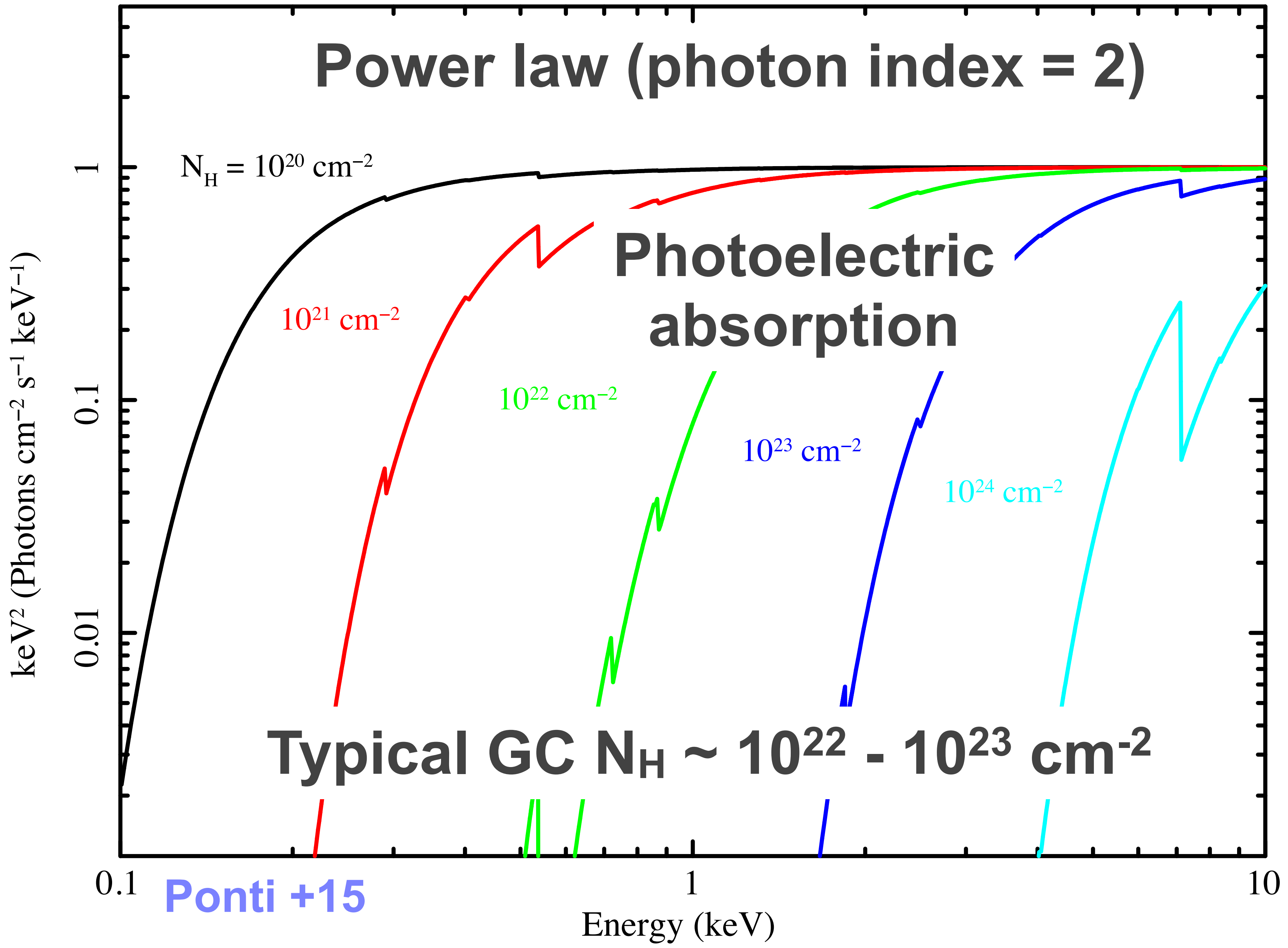


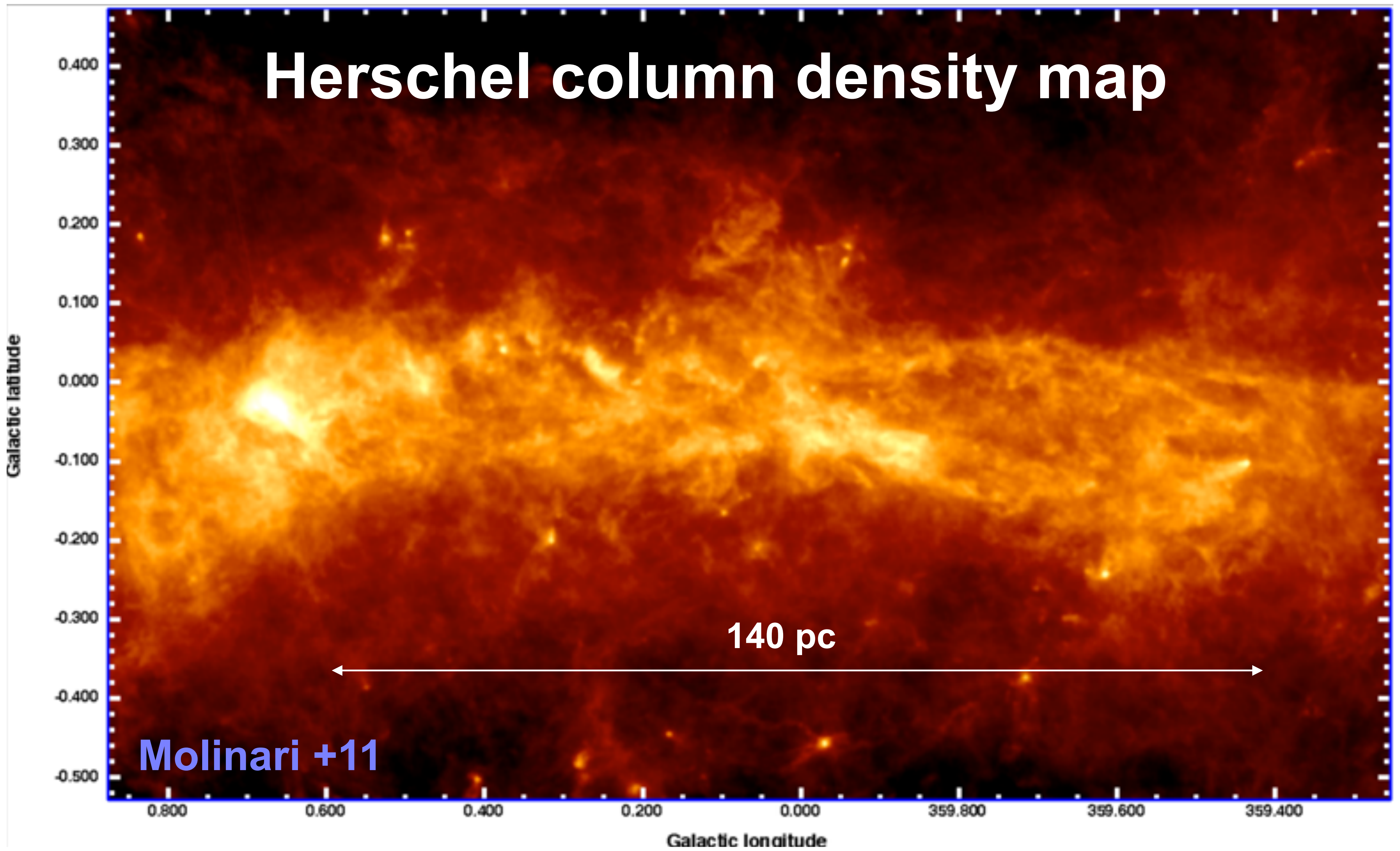


Ponti +15

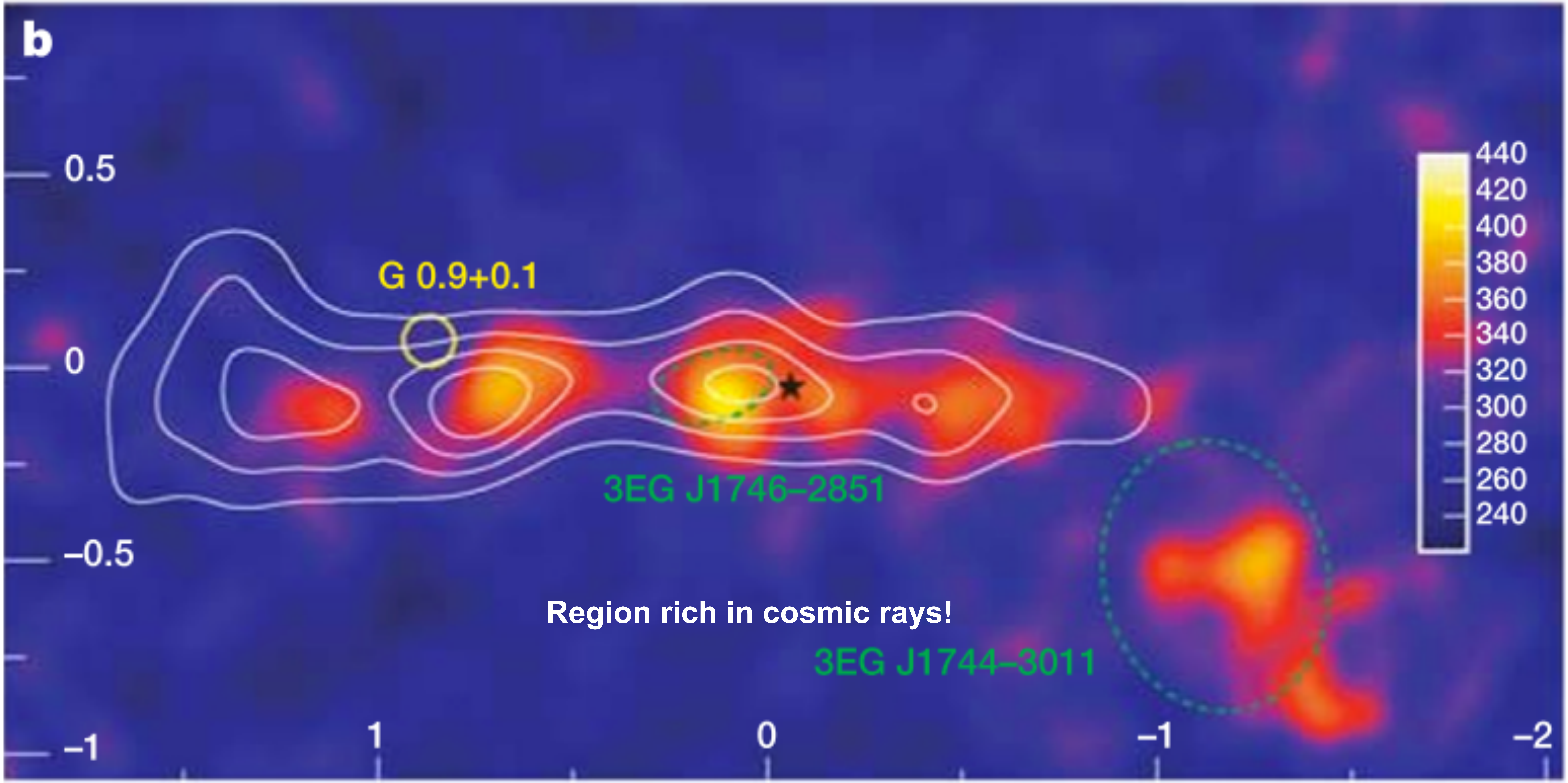
Absorption in soft X-ray

The central degrees of the Milky Way

Abundant gas reservoir ~3×10^7 M_{Sun} ➜ Mini starburst

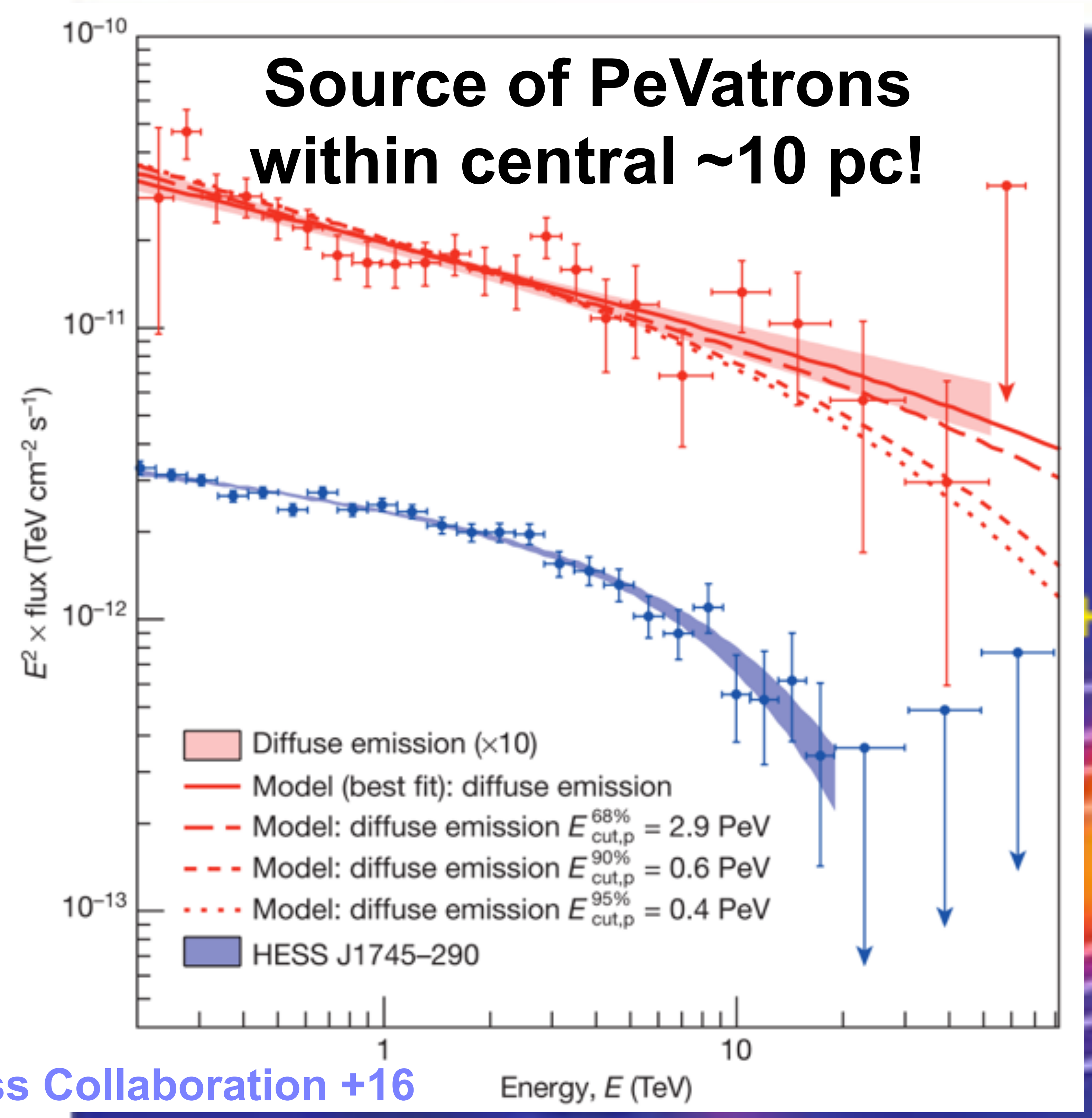


The central degrees of the Milky Way

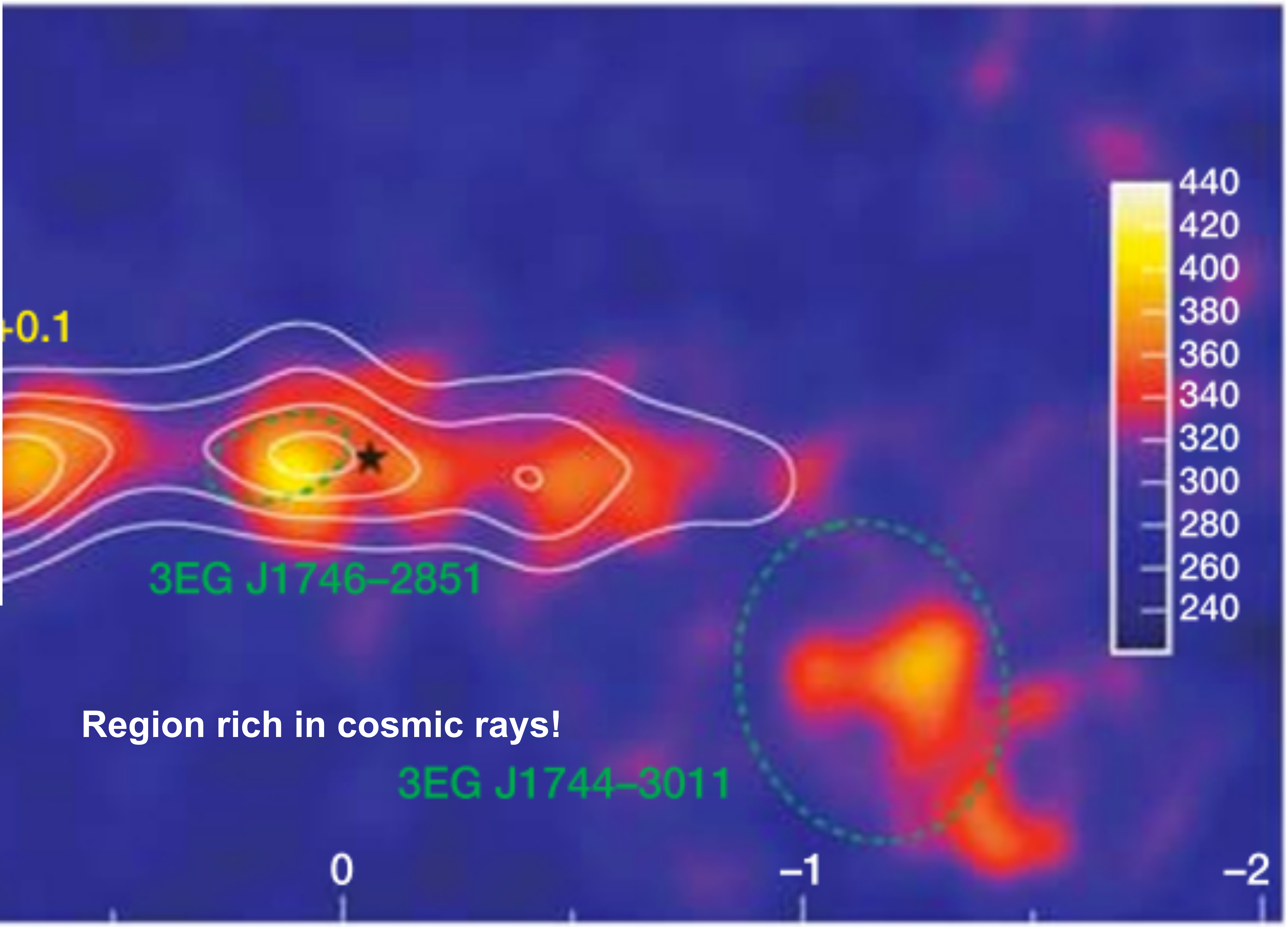


Hess Collaboration +06

The central degrees of the Milky Way

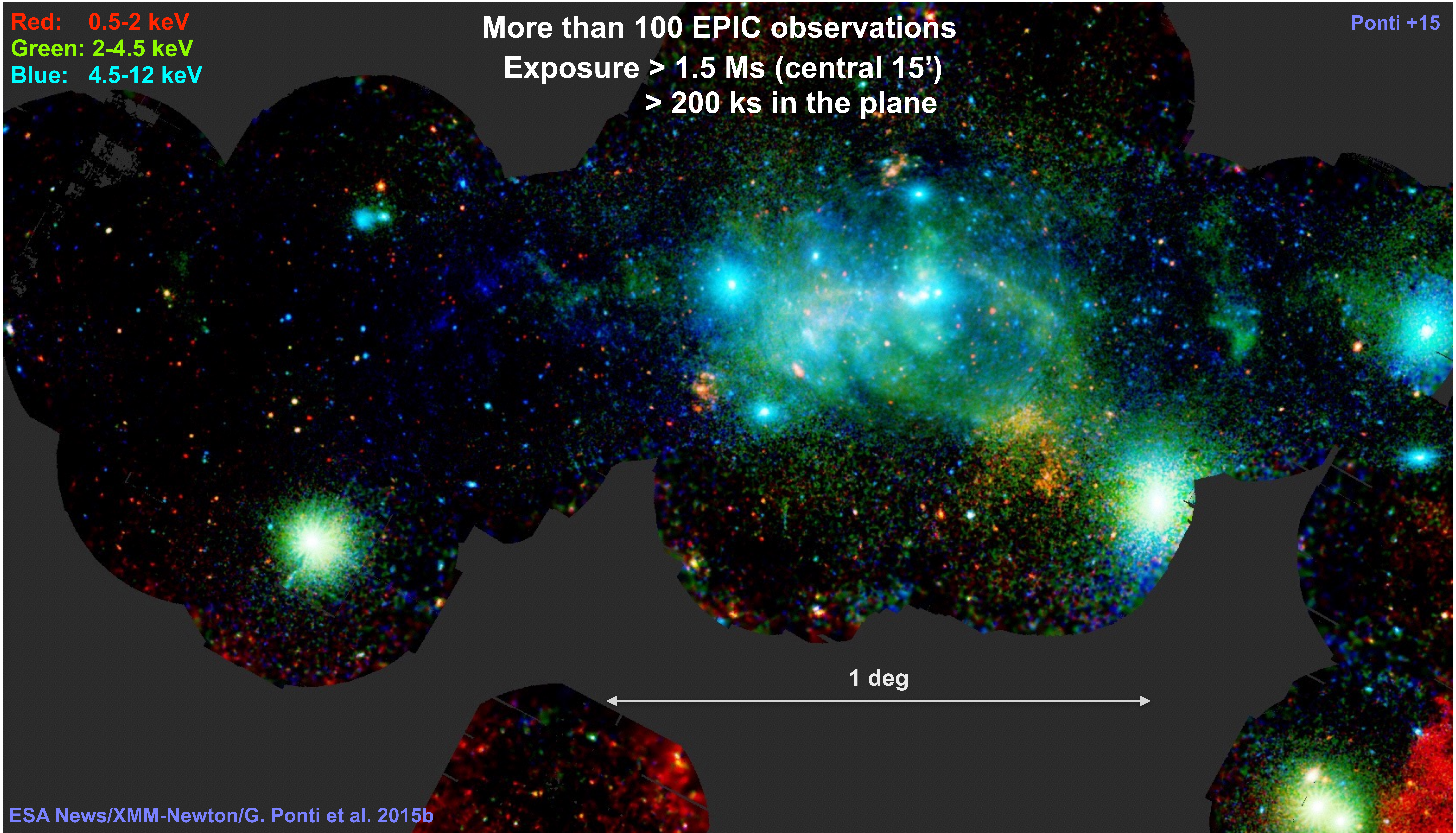


Hess Collaboration +16

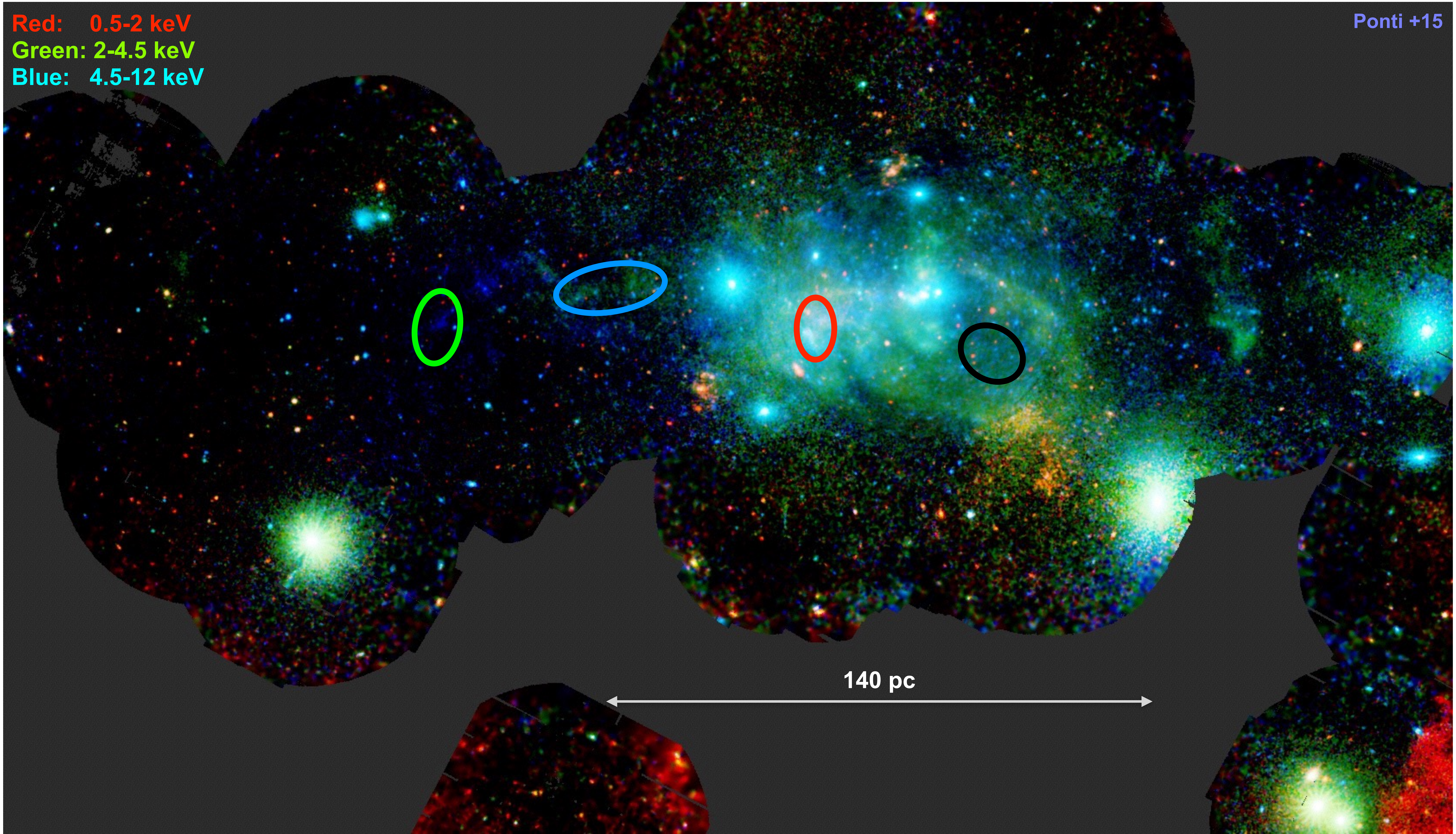


Hess Collaboration +06

The new XMM-Newton view of the Galactic center



What is the origin of the diffuse emission?



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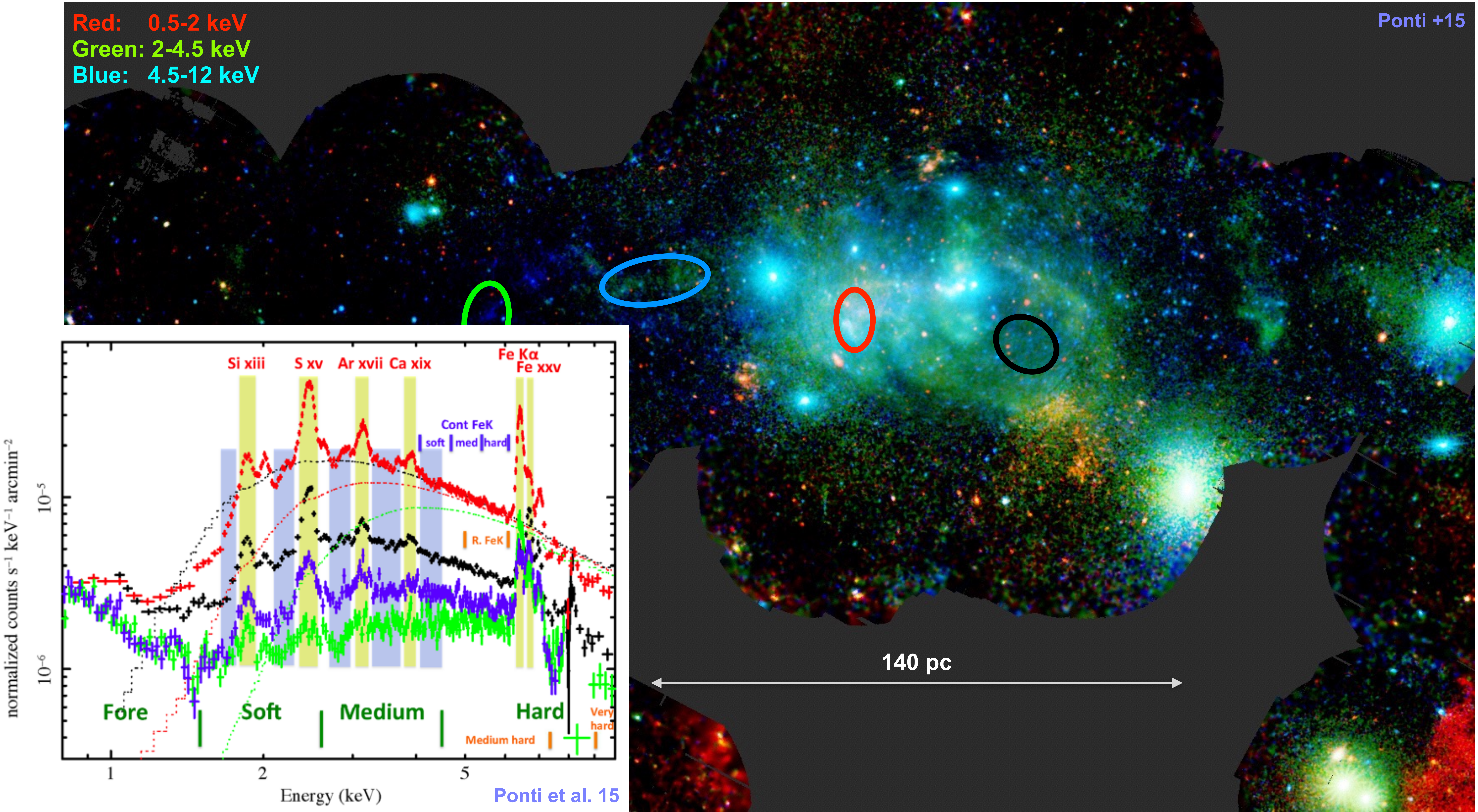

Distribution of hot plasma

Distribution of hot plasma

Distribution of hot plasma

Distribution of hot plasma

Patchy distribution: $L_X \sim 3.4\times10^{36}$ erg s^{-1} Ponti +15

Thermal X-rays fill the MIR arc bubble: $E_{th} \sim 1.5\times10^{51}$ erg ➔ Super bubble Ponti +15

Distribution of hot plasma

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Thermal X-rays fill the MIR arc bubble: $E_{th} \sim 1.5\times10^{51}$ erg ➜ Super bubble Ponti +15

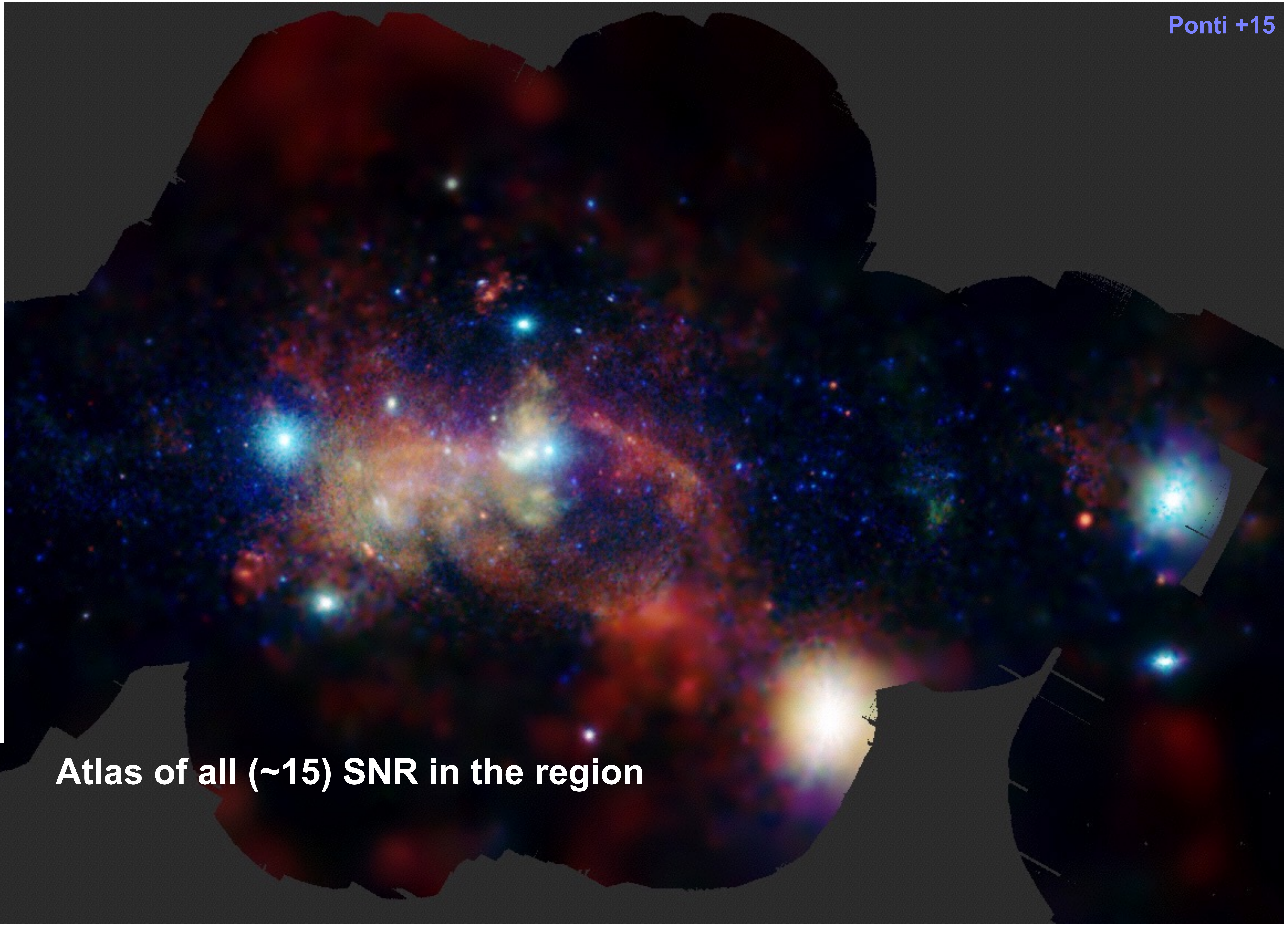
G359.77-0.09: Super bubble candidate Heard +13; Ponti +15

Sgr A's bipolar lobes ➜ outflow from central parsec Morris +13; Zhao +15; Ponti +19

A catalogue of X-ray features

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
	G359.79-026♮	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 × 11	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



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	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
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G359.77-0.09	Superbubble	359.84,-0.14	20 × 16	X 15,16,17,58
	G359.79-026♮	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
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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

Atlas of all (~15) SNR in the region

3.5×10^{-4} yr^{-1} < SN rate < 15×10^{-4} yr^{-1}

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3.5×10^{-4} yr^{-1} < SN rate < 15×10^{-4} yr^{-1}

Large kinetic energy input > 1.1×10^{40} erg s^{-1}

Assuming Kroupa IMF: SFR ~ 0.035-0.15 M_{Sun} yr^{-1}

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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
	G359.79-026♮	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 × 11	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

Atlas of all (~15) SNR in the region

3.5×10^{-4} yr^{-1} < SN rate < 15×10^{-4} yr^{-1}

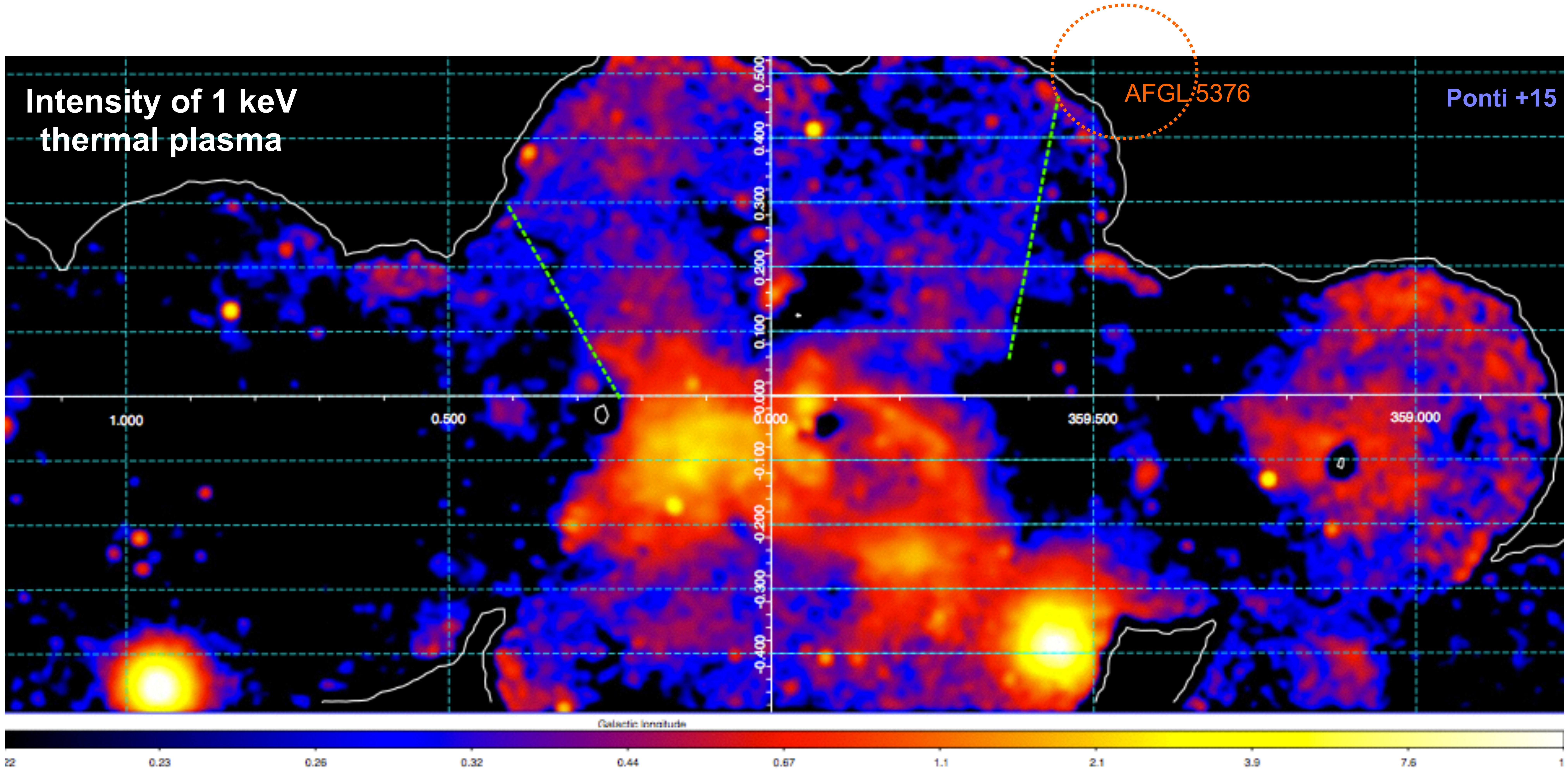
Large kinetic energy input > 1.1×10^{40} erg s^{-1}

Assuming Kroupa IMF: SFR ~ 0.035-0.15 M_{Sun} yr^{-1}

➜ Powering Galactic outflows?

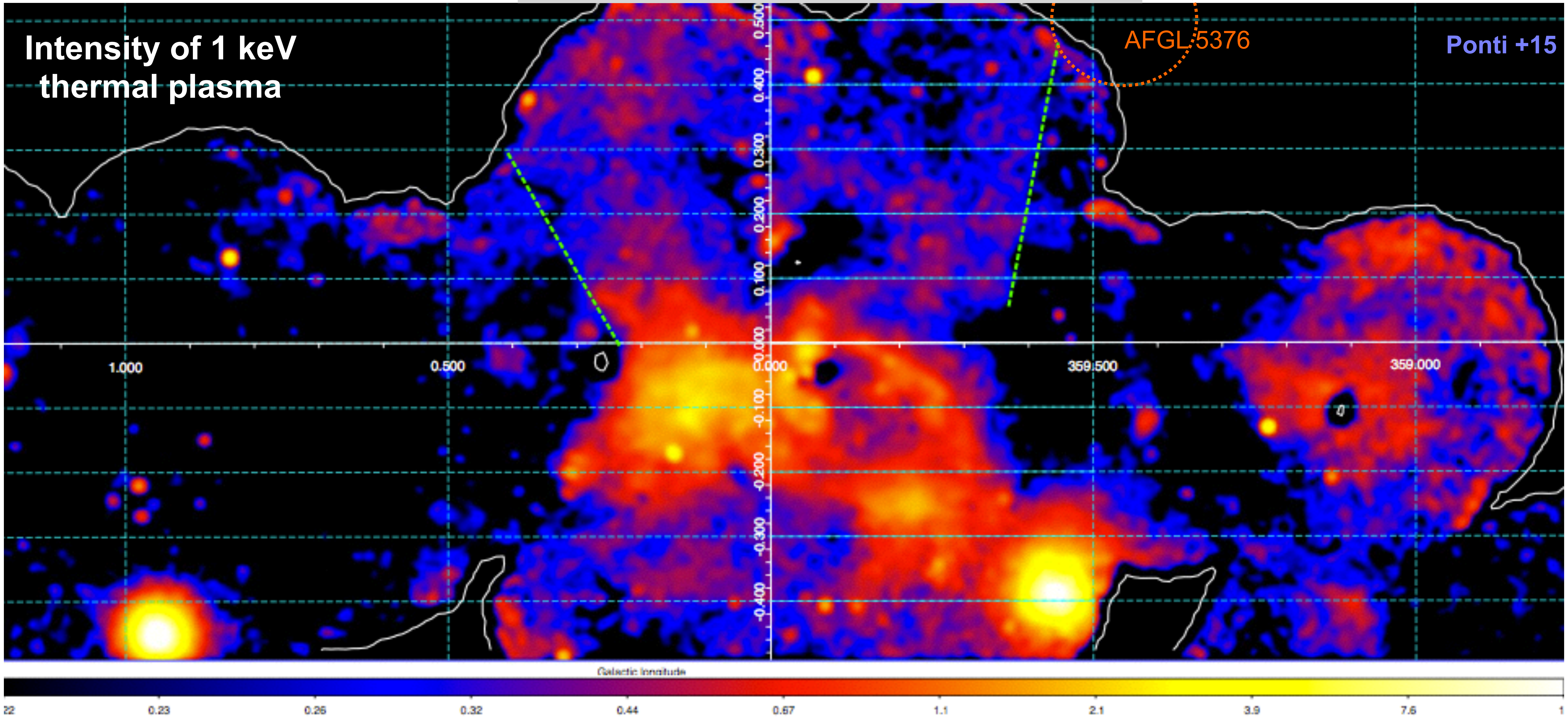
Law +11; Crocker +11; 12; Yoast-Hull +14; Jouvin +15

High latitude soft plasma



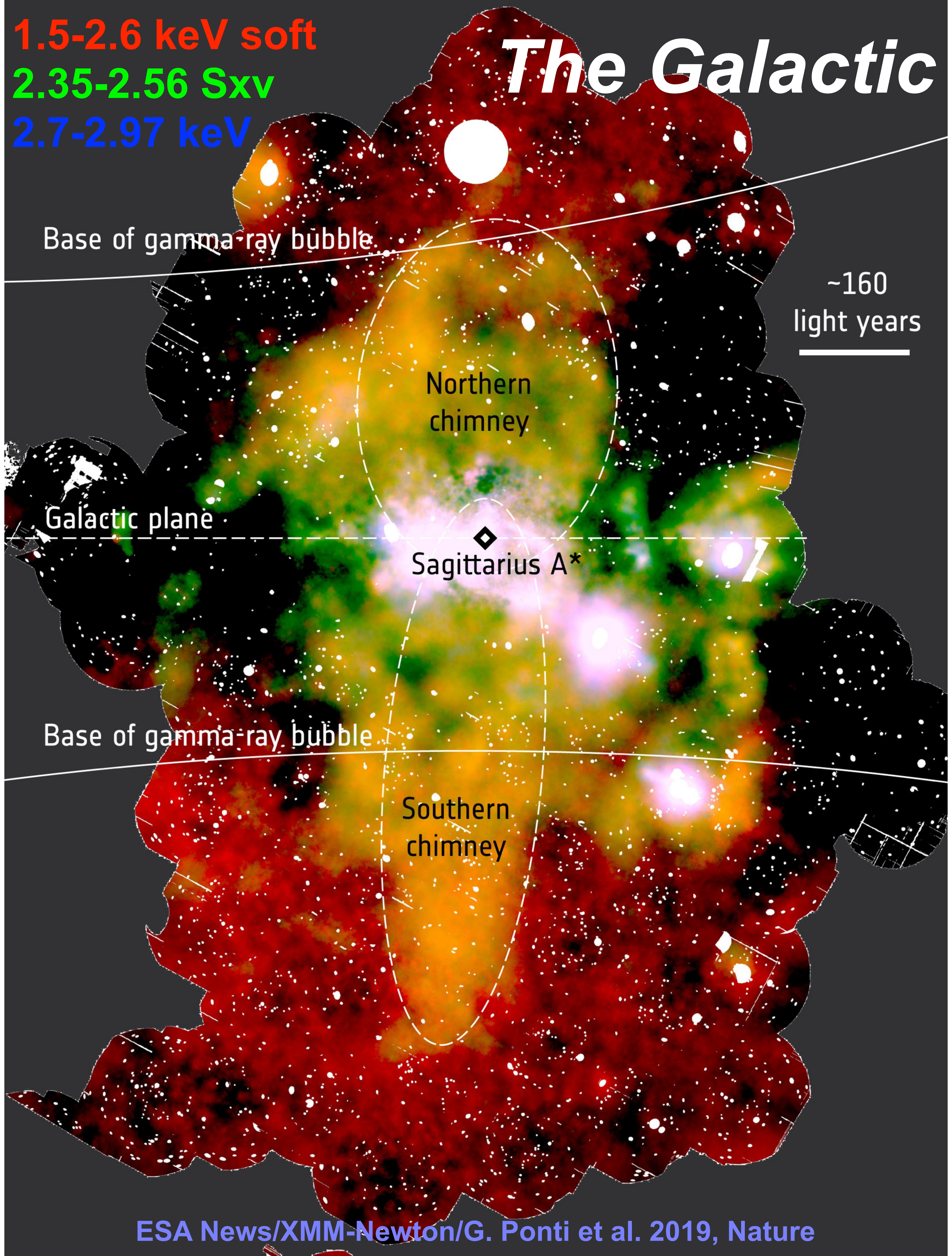
High latitude soft plasma

What is its origin?




ase of gamma-ray bubble
~160
light years
Northern
chimney
alactic plane
Sagittarius A*

The Galactic center Chimneys



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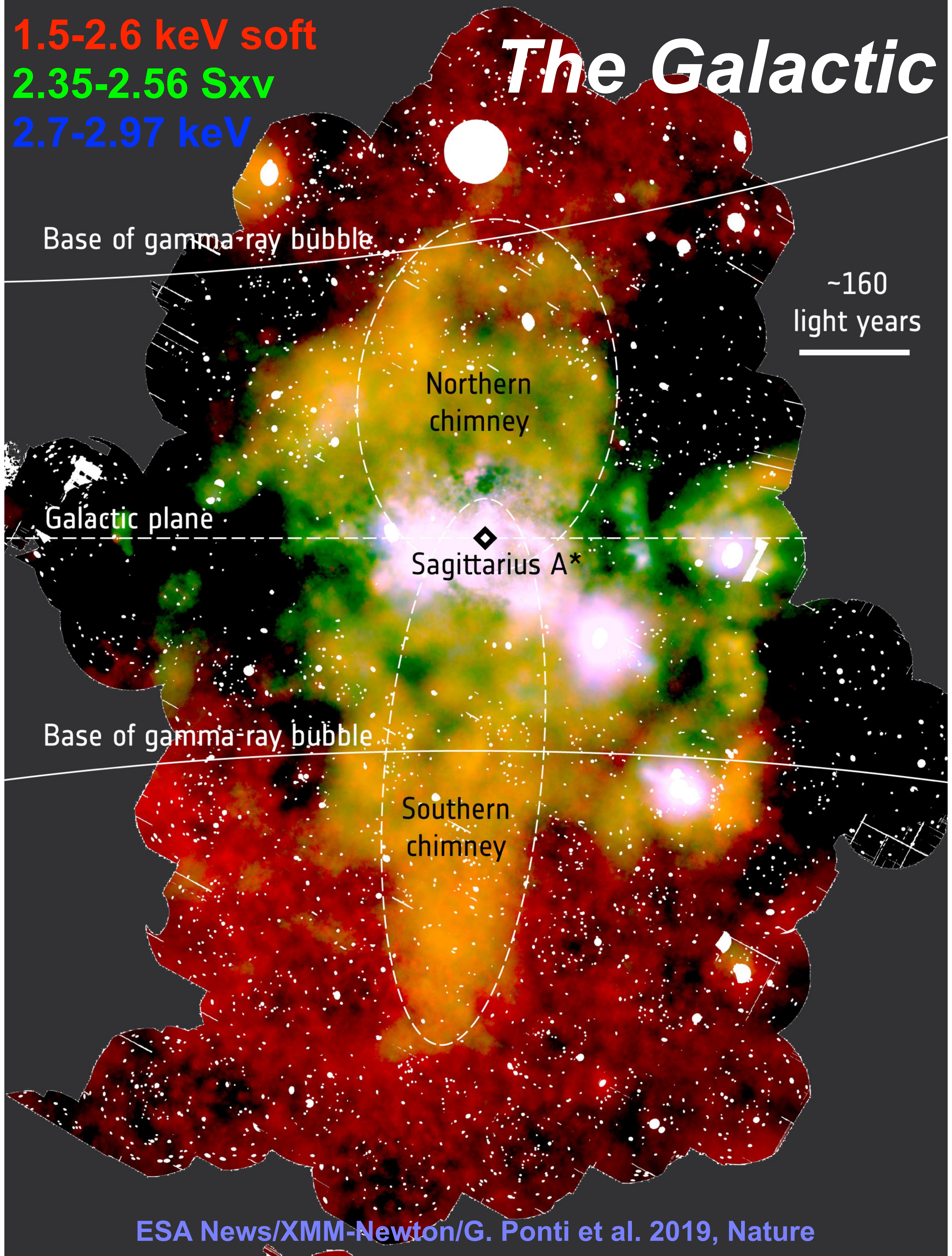
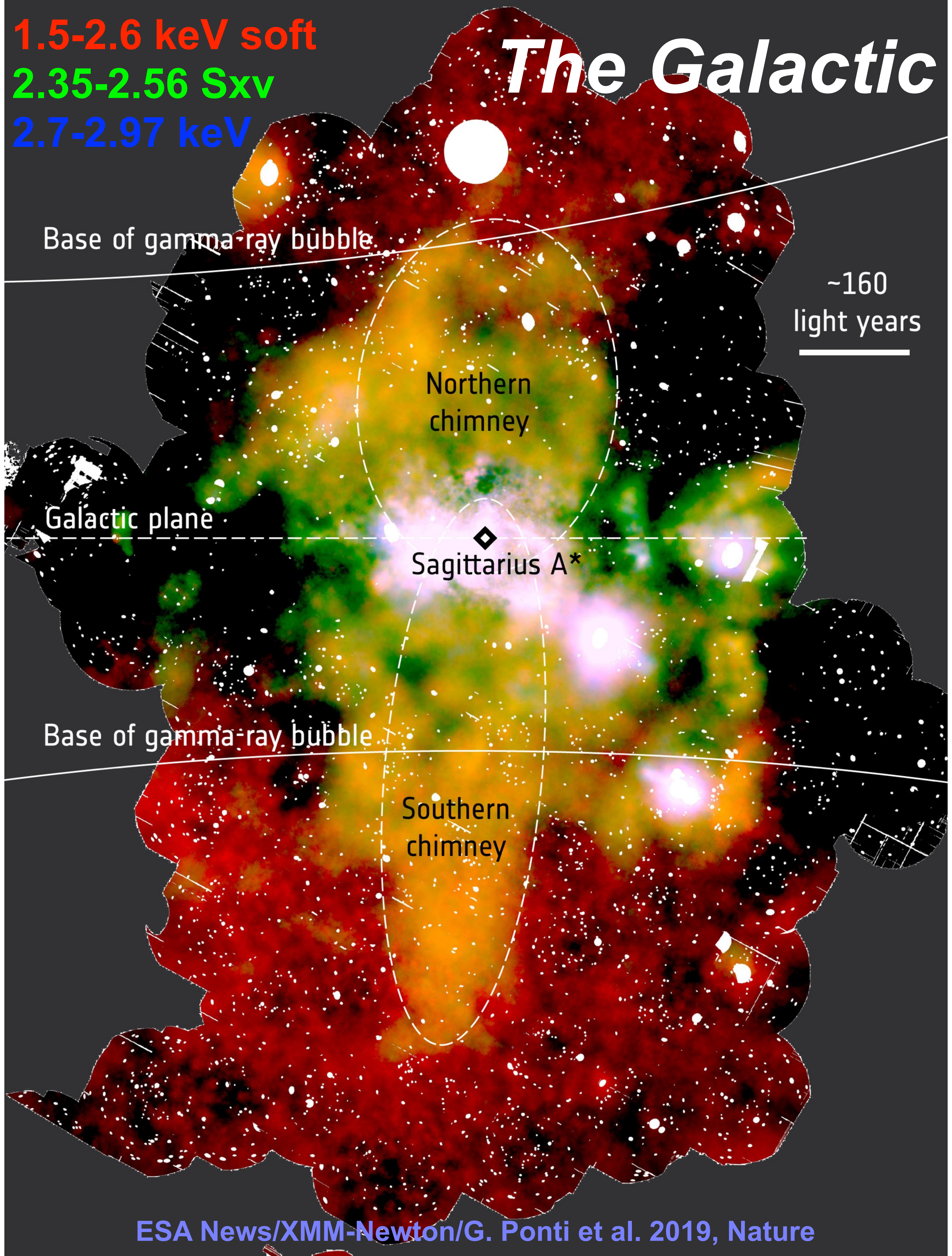


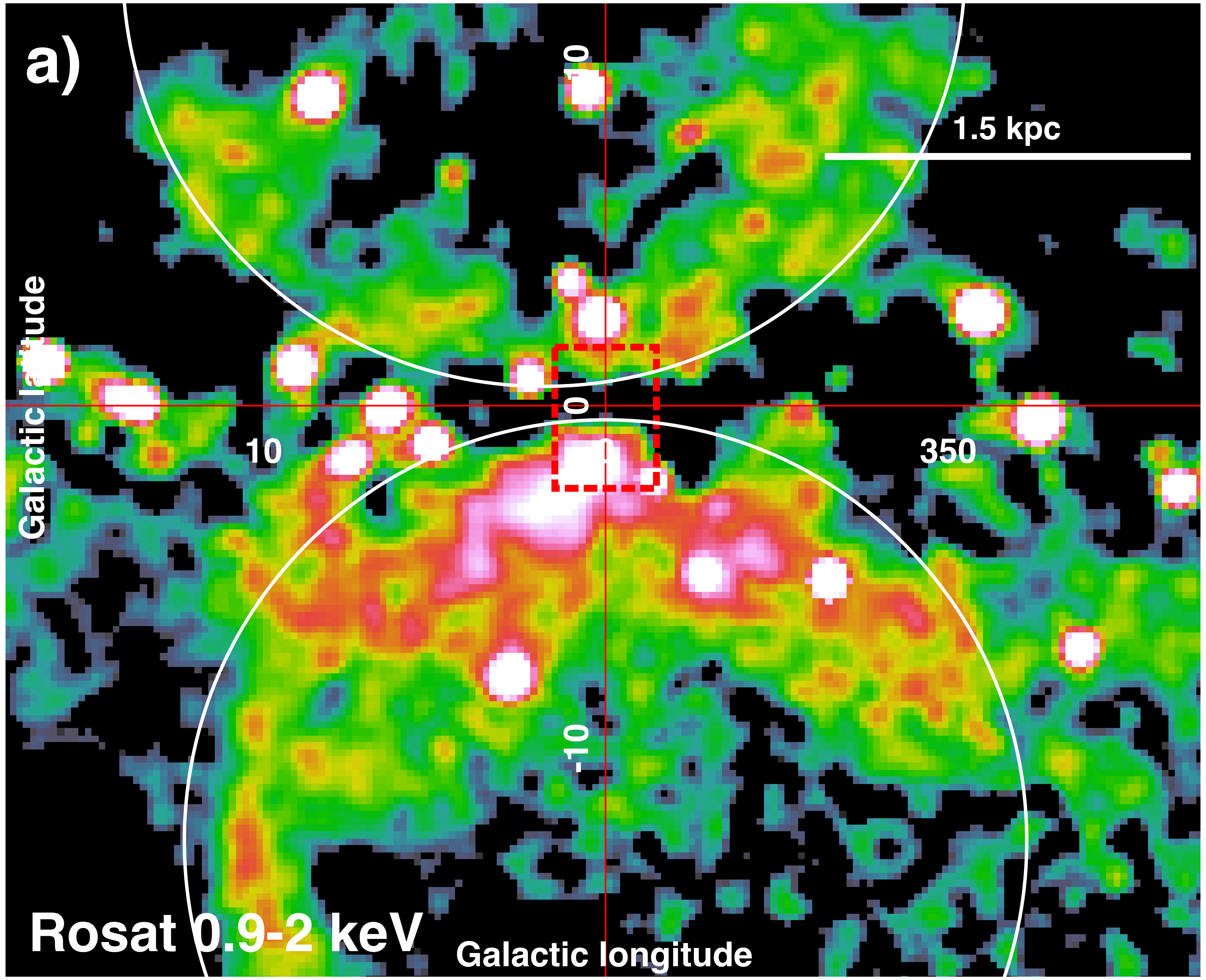
➜ **Discovery of prominent hot (X-ray emitting) features extending hundreds of parsecs above and below the Galactic plane**

The Galactic center Chimneys

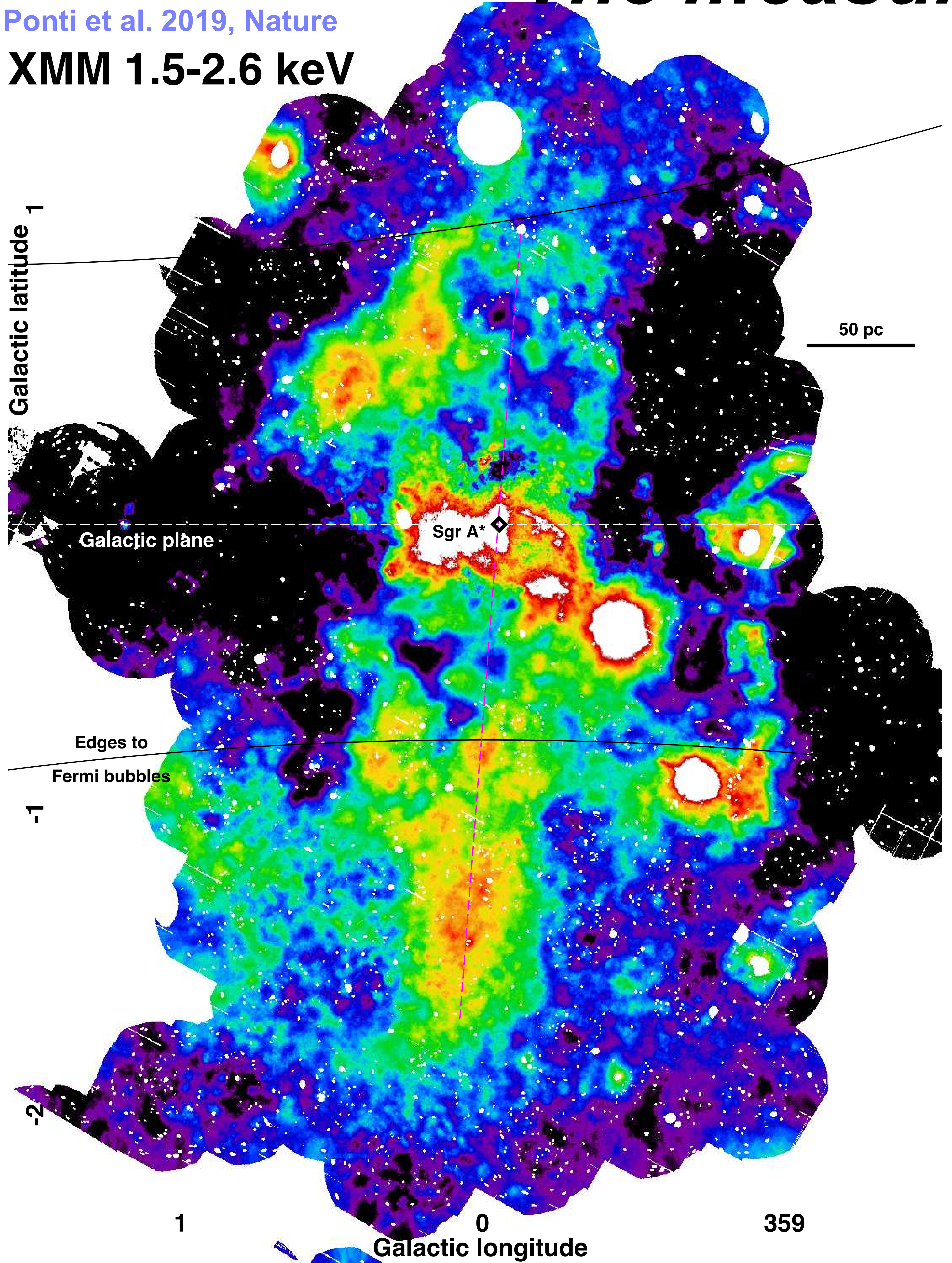


➜ Discovery of prominent hot (X-ray emitting) features extending hundreds of parsecs above and below the Galactic plane

➜ The Chimneys connect the central parsecs with the base of the Fermi bubbles



The measured physical parameters



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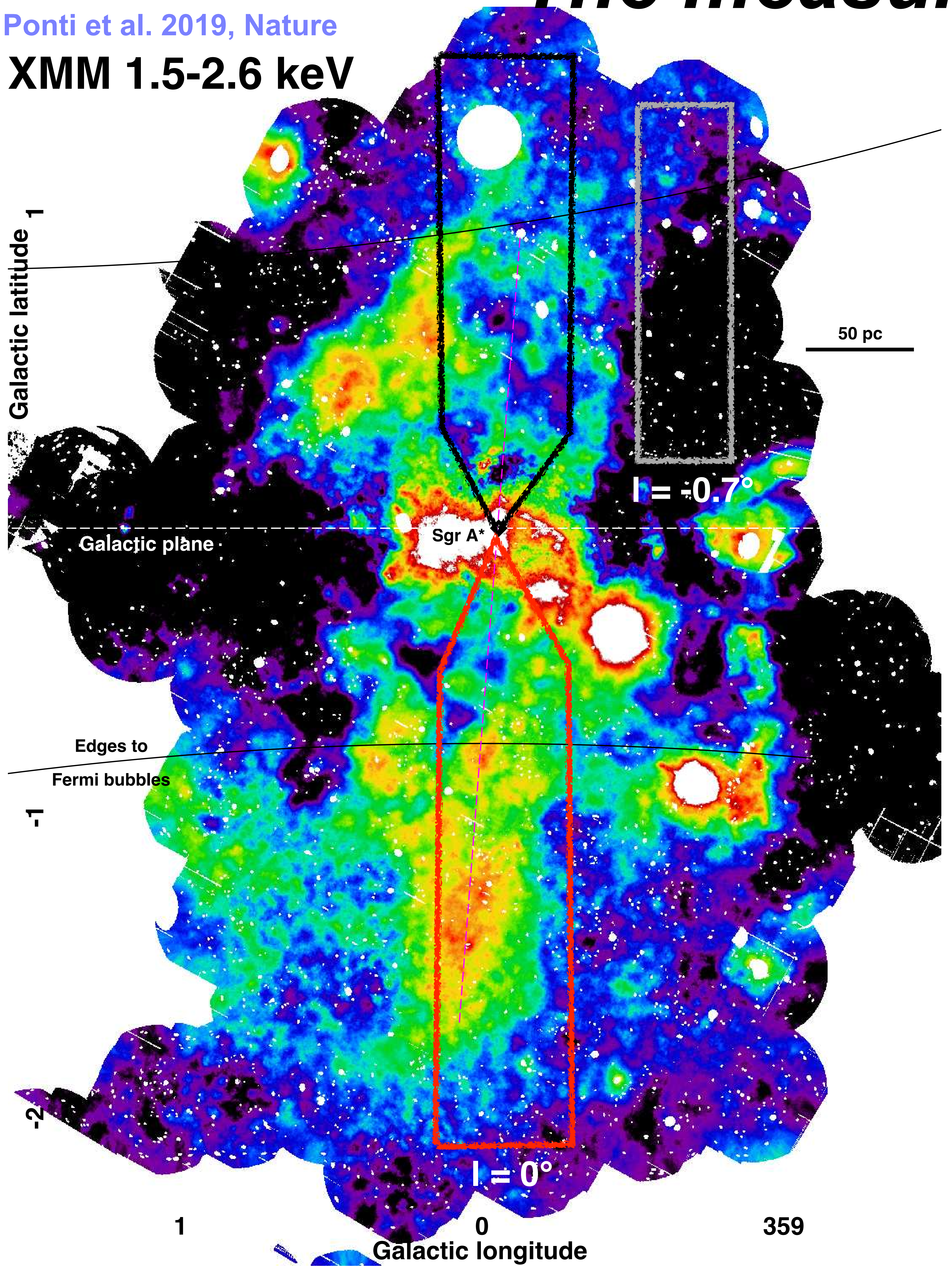
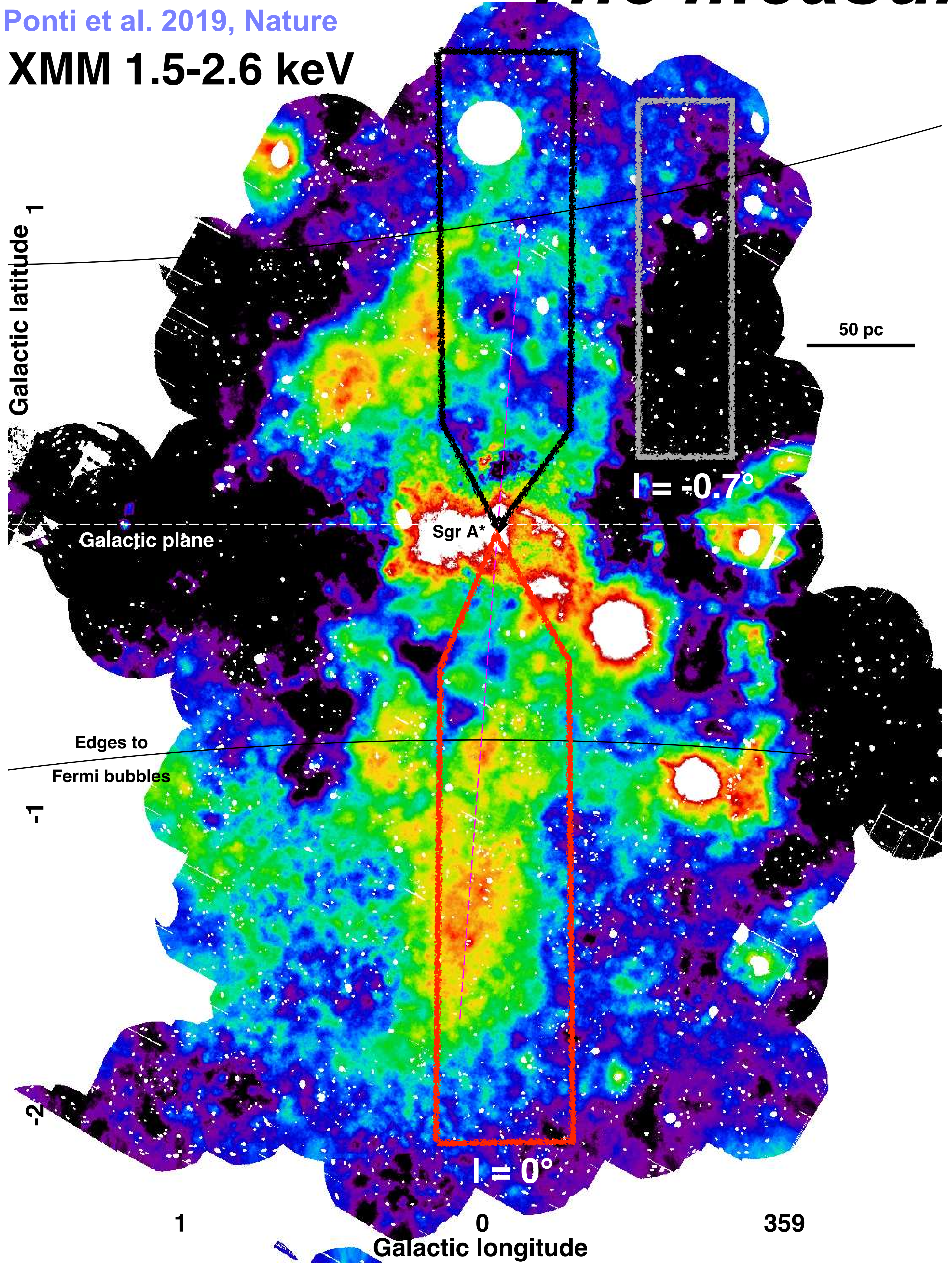
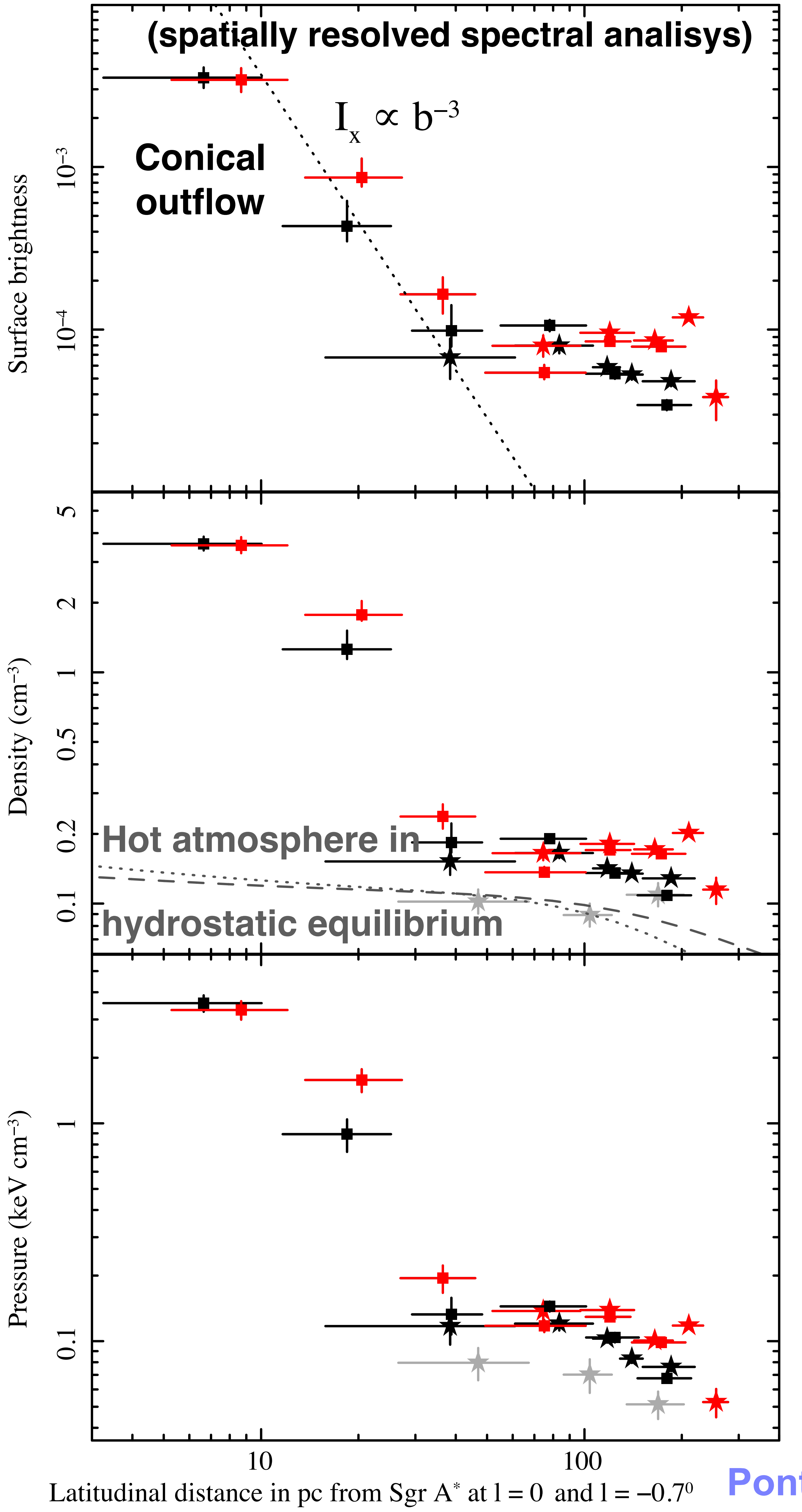


The measured physical parameters

Ponti et al. 2019, Nature



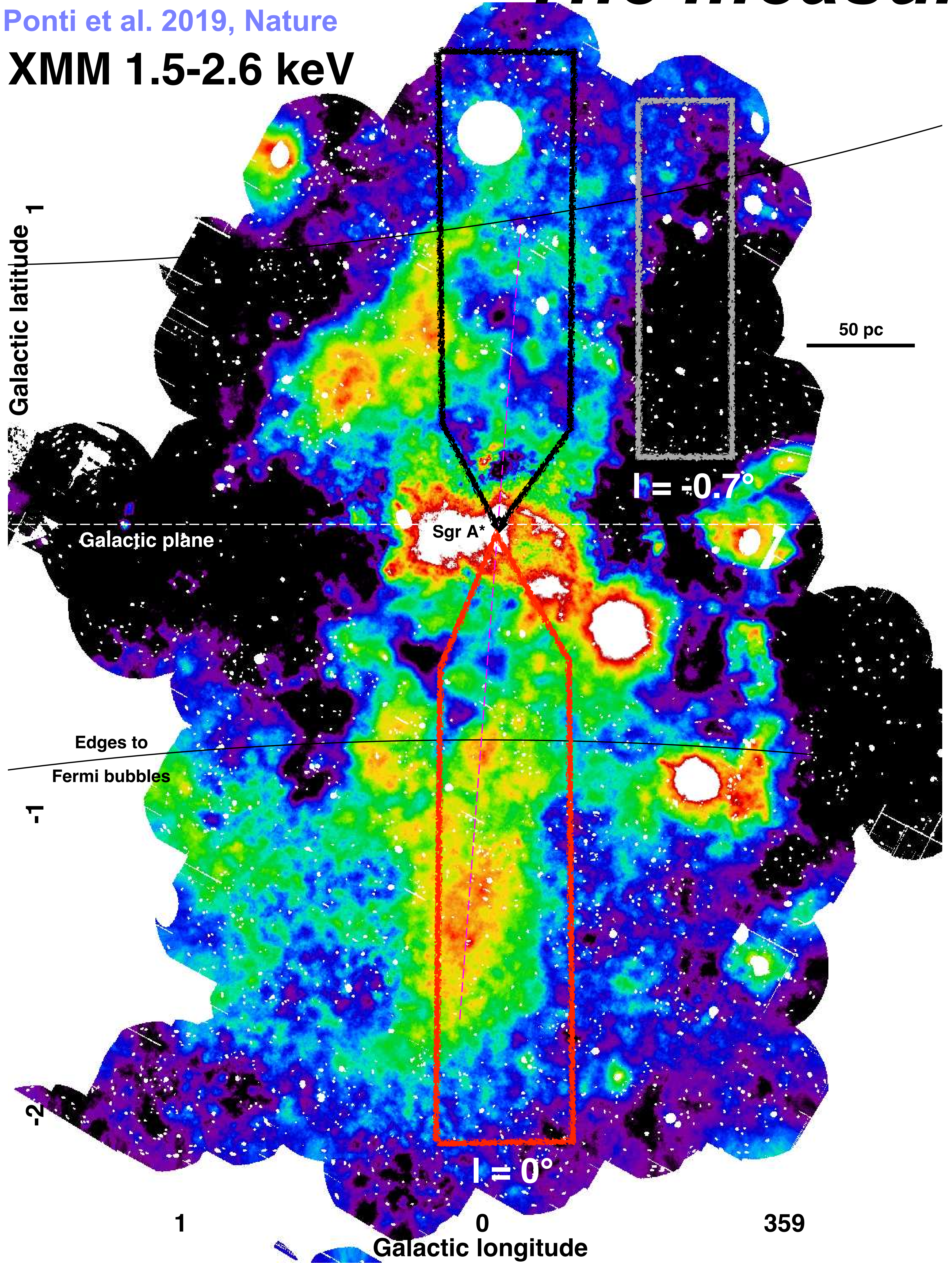
Latitudinal profiles of hot plasma properties



Ponti et al. 2019, Nature

The measured physical parameters

Ponti et al. 2019, Nature



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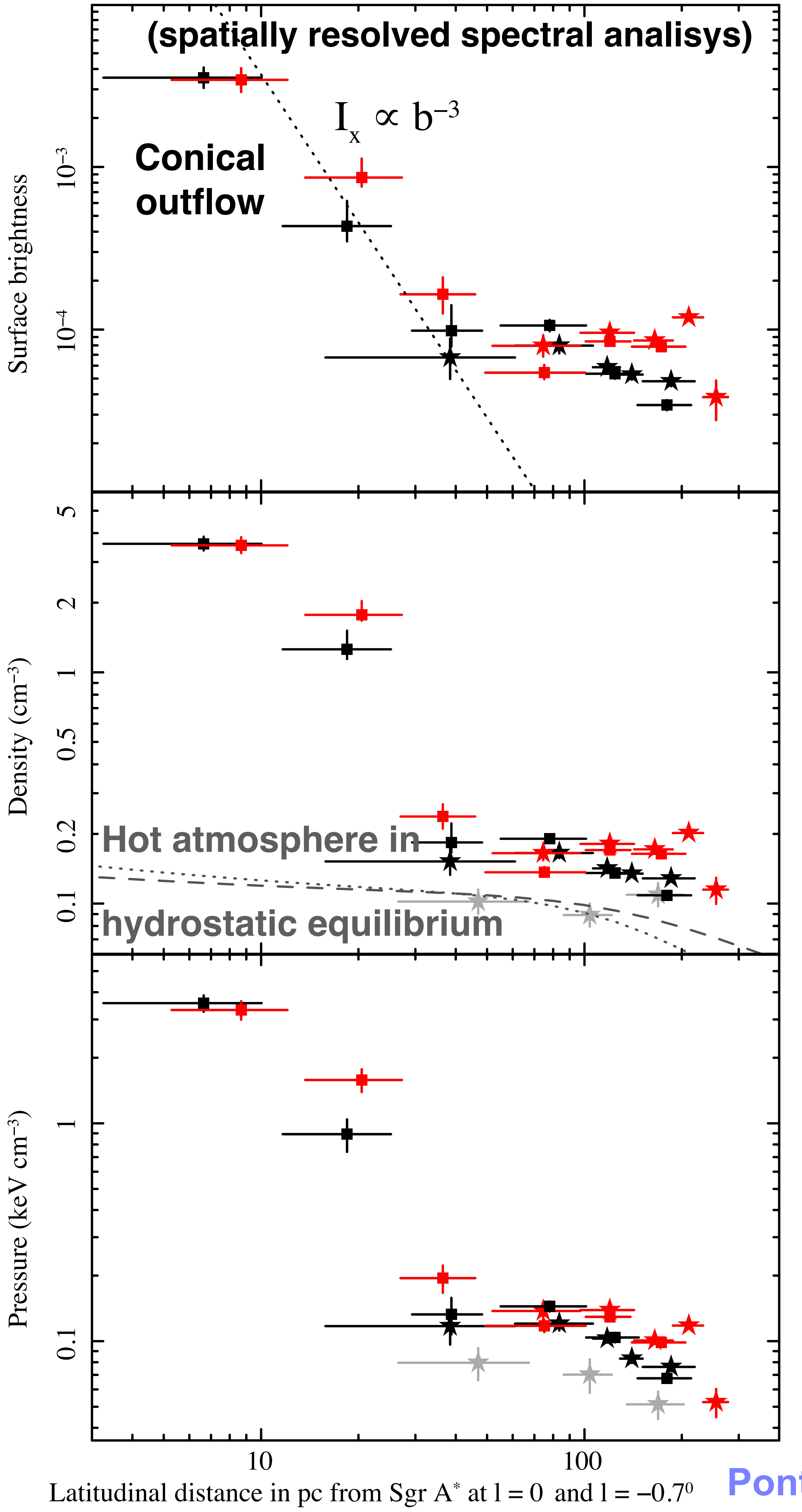


Ponti et al. 2019, Nature

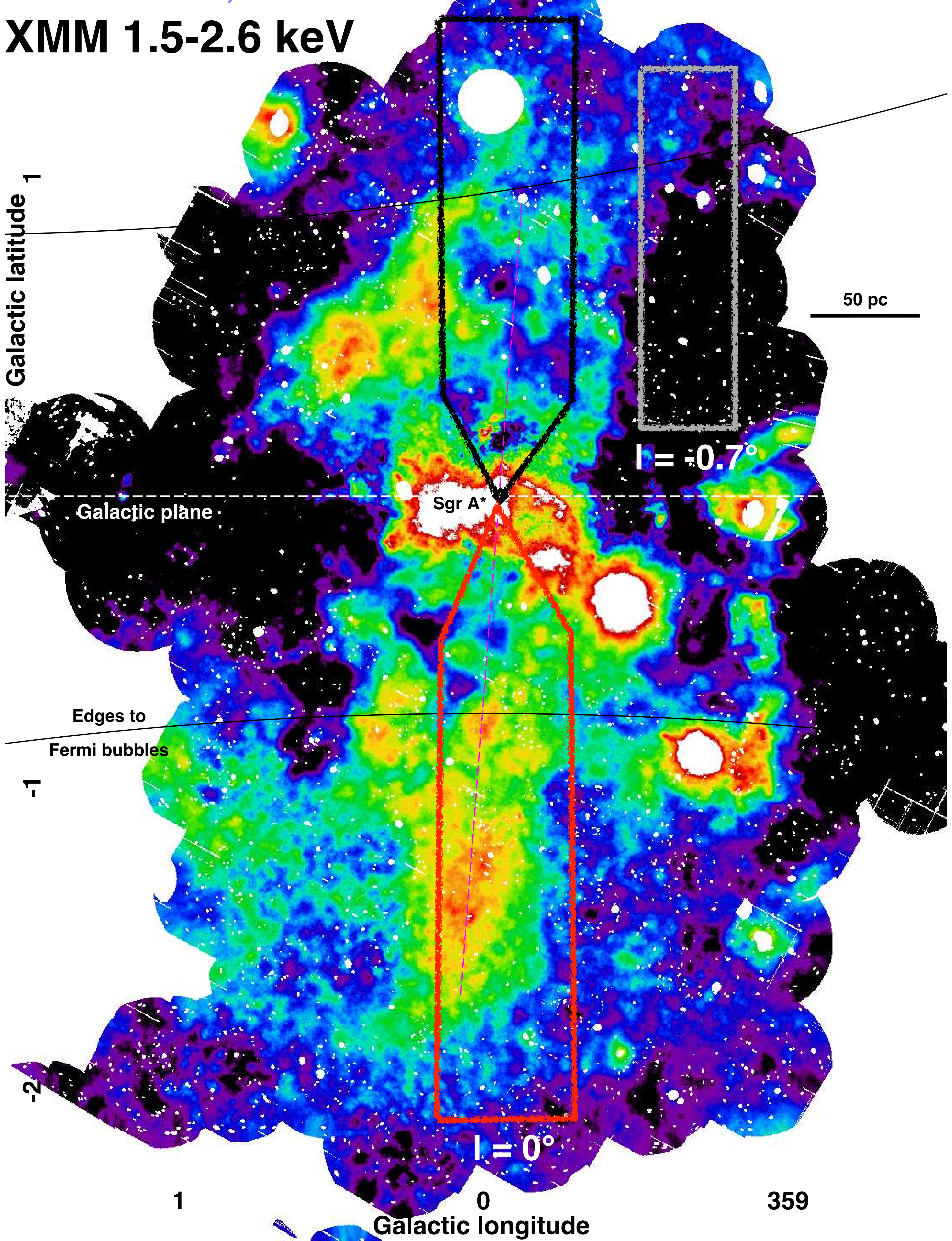
$E_{Th\ 15pc} \sim 5\times10^{50}$ erg

$t_{s\ 15pc} \sim 3\times10^{4}$ yr

➜ $L_{15pc} \sim 8\times10^{38}$ erg s^{-1}

The measured physical parameters

Ponti et al. 2019, Nature



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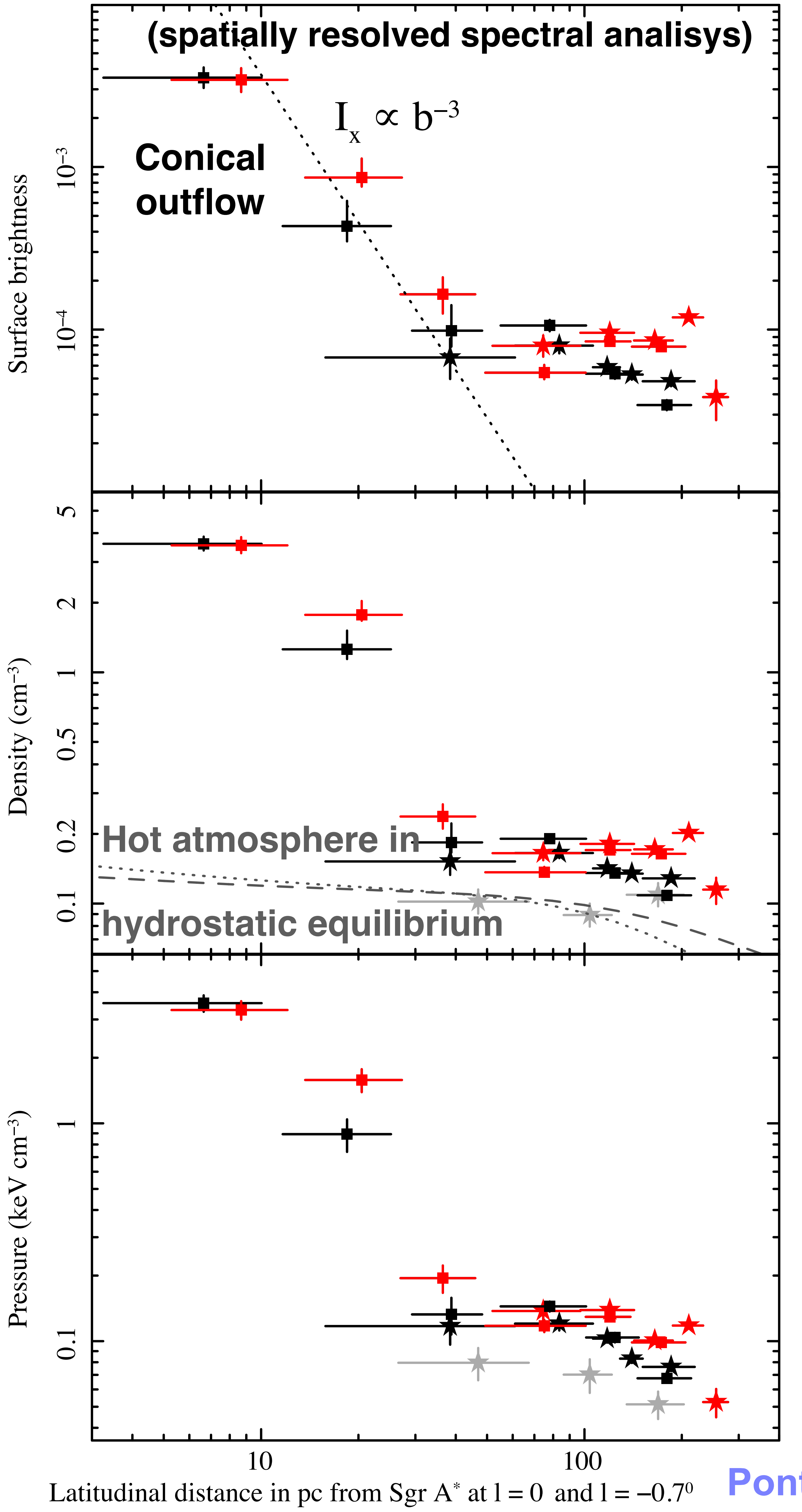

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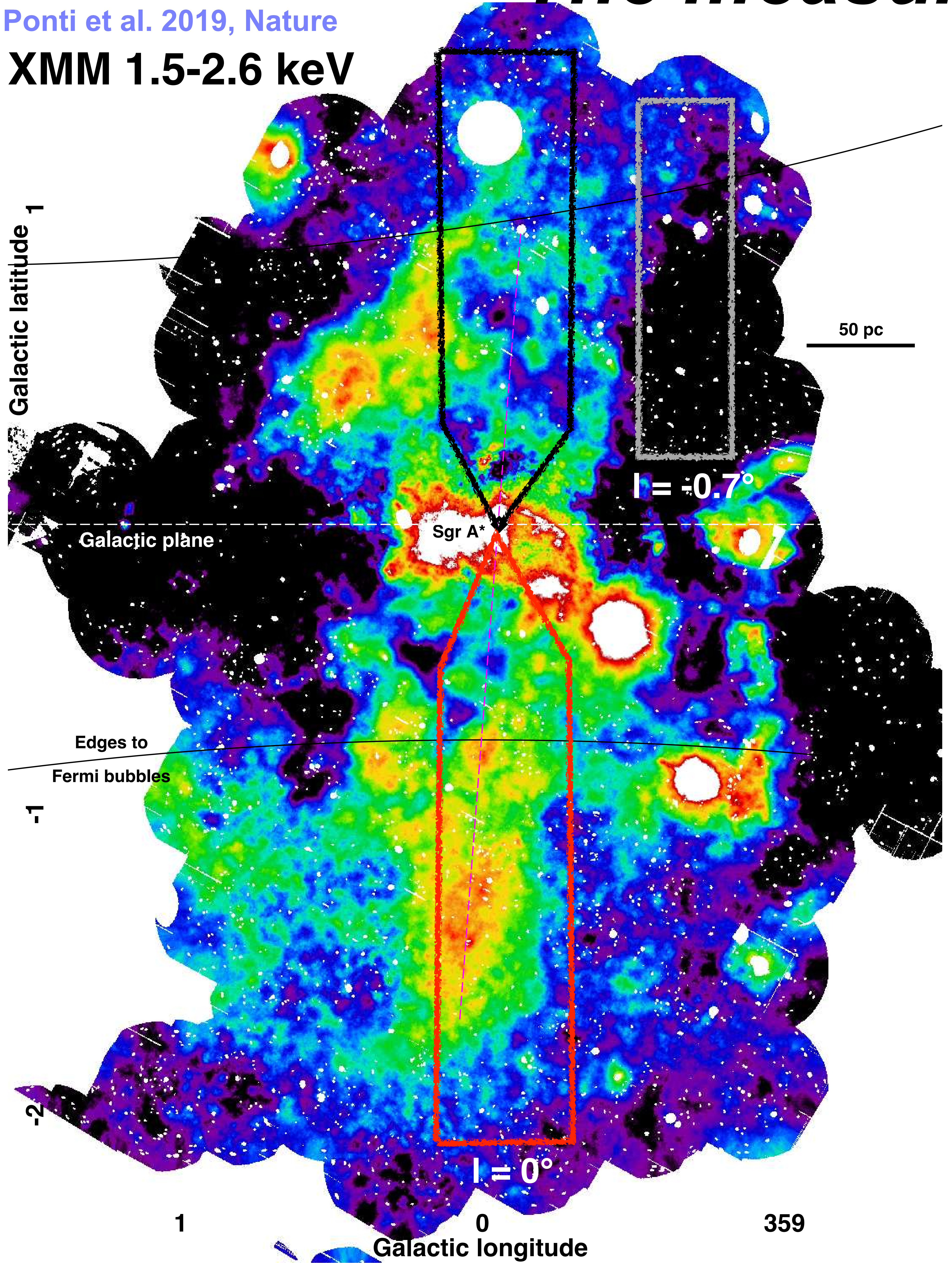
(10^{51-52} erg every 10^4 yr)

or SN of central star cluster

The measured physical parameters

Ponti et al. 2019, Nature



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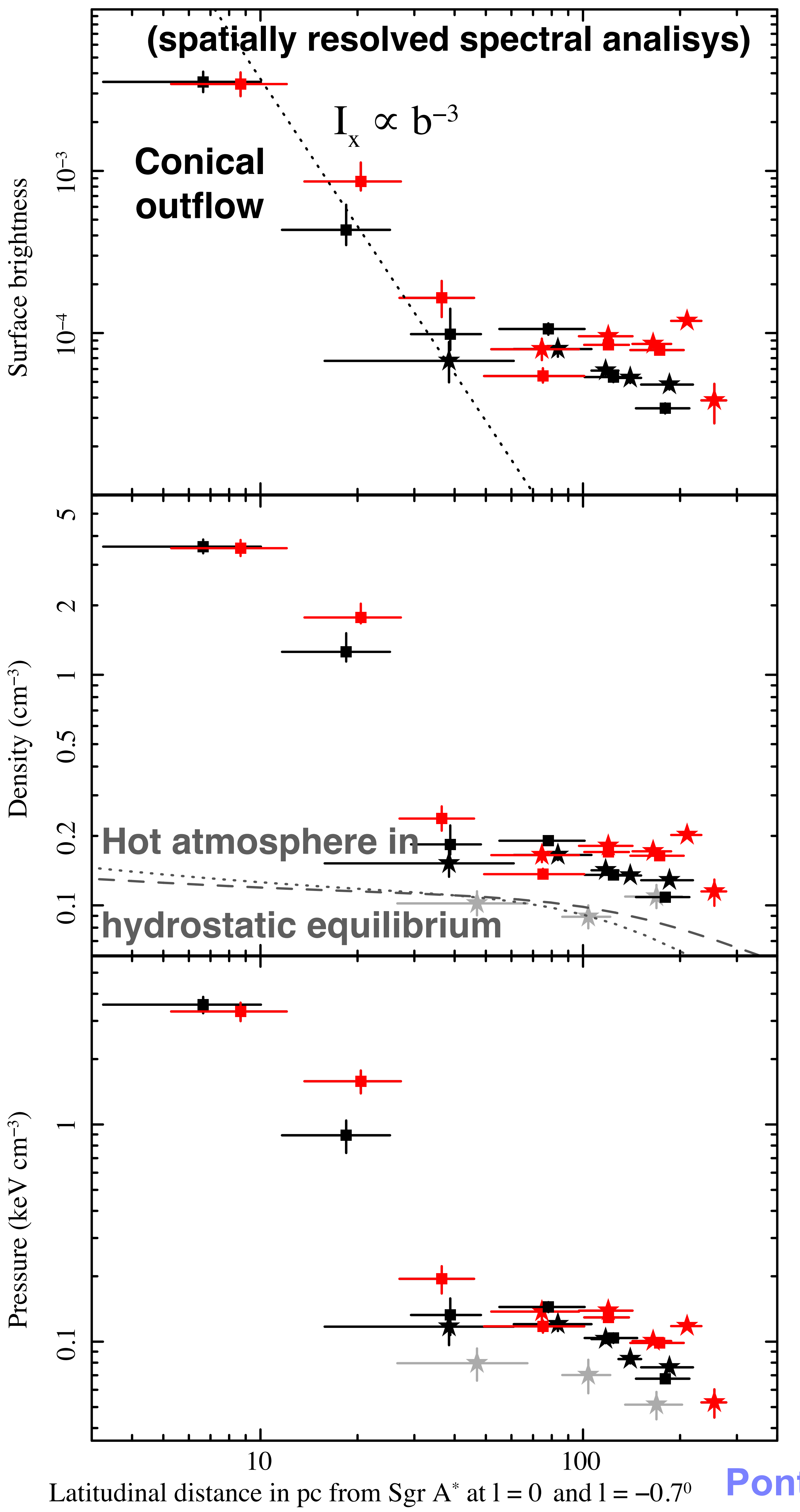

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$E_{Th\ Chim} \sim 4\times10^{52}$ erg
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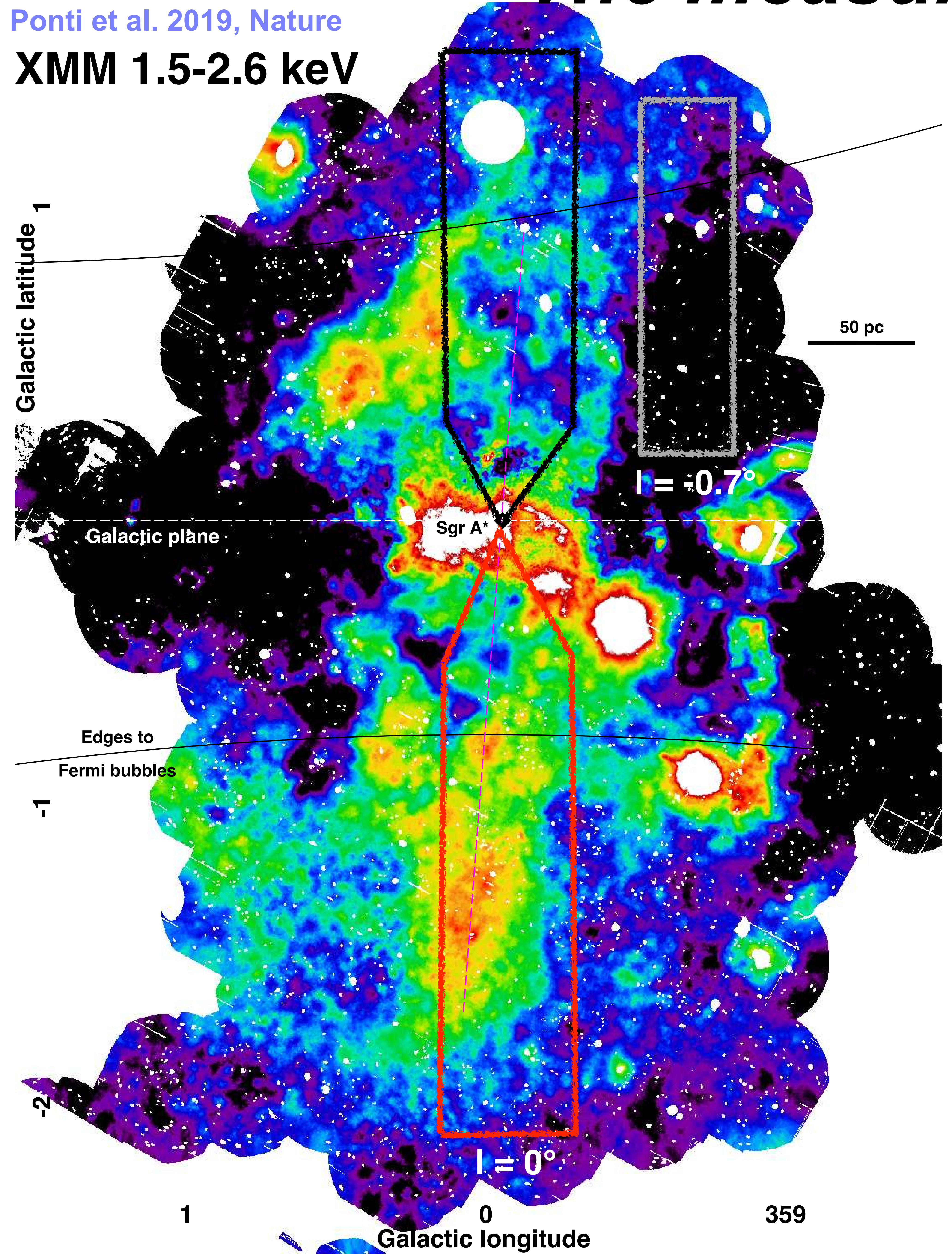
➜ $L_{Chim} \sim 4\times10^{39}$ erg s^{-1}

The measured physical parameters

Ponti et al. 2019, Nature



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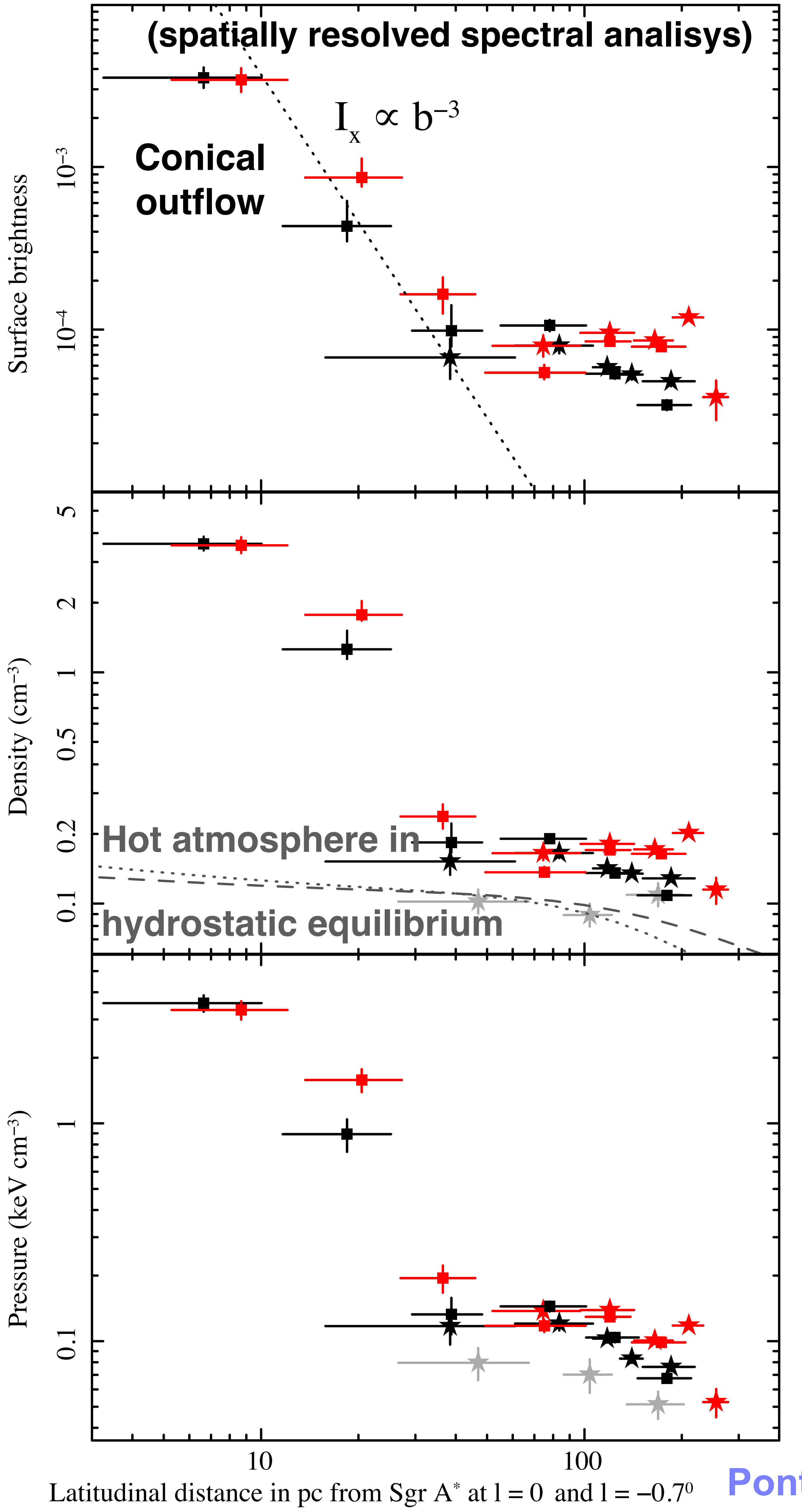

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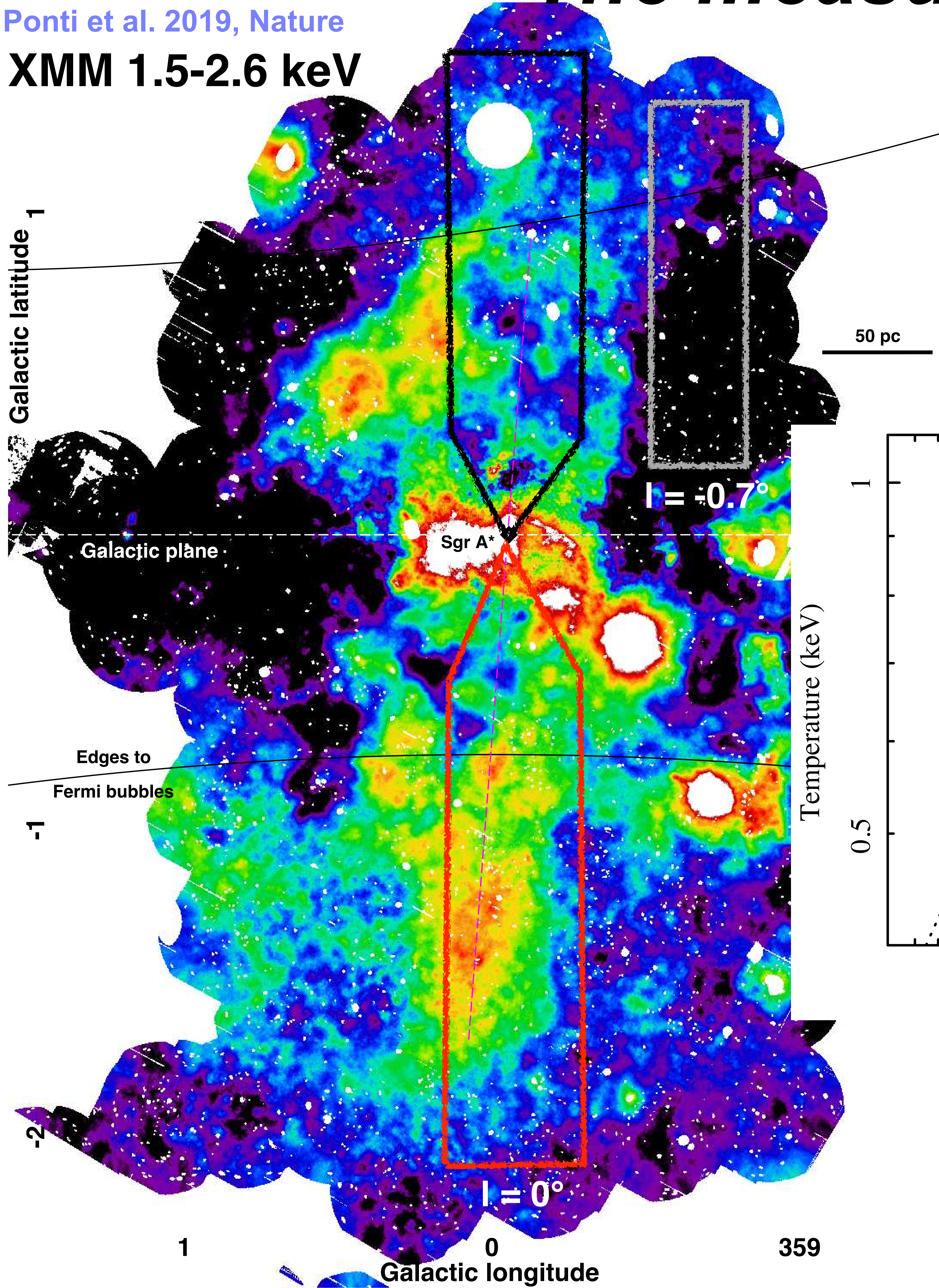
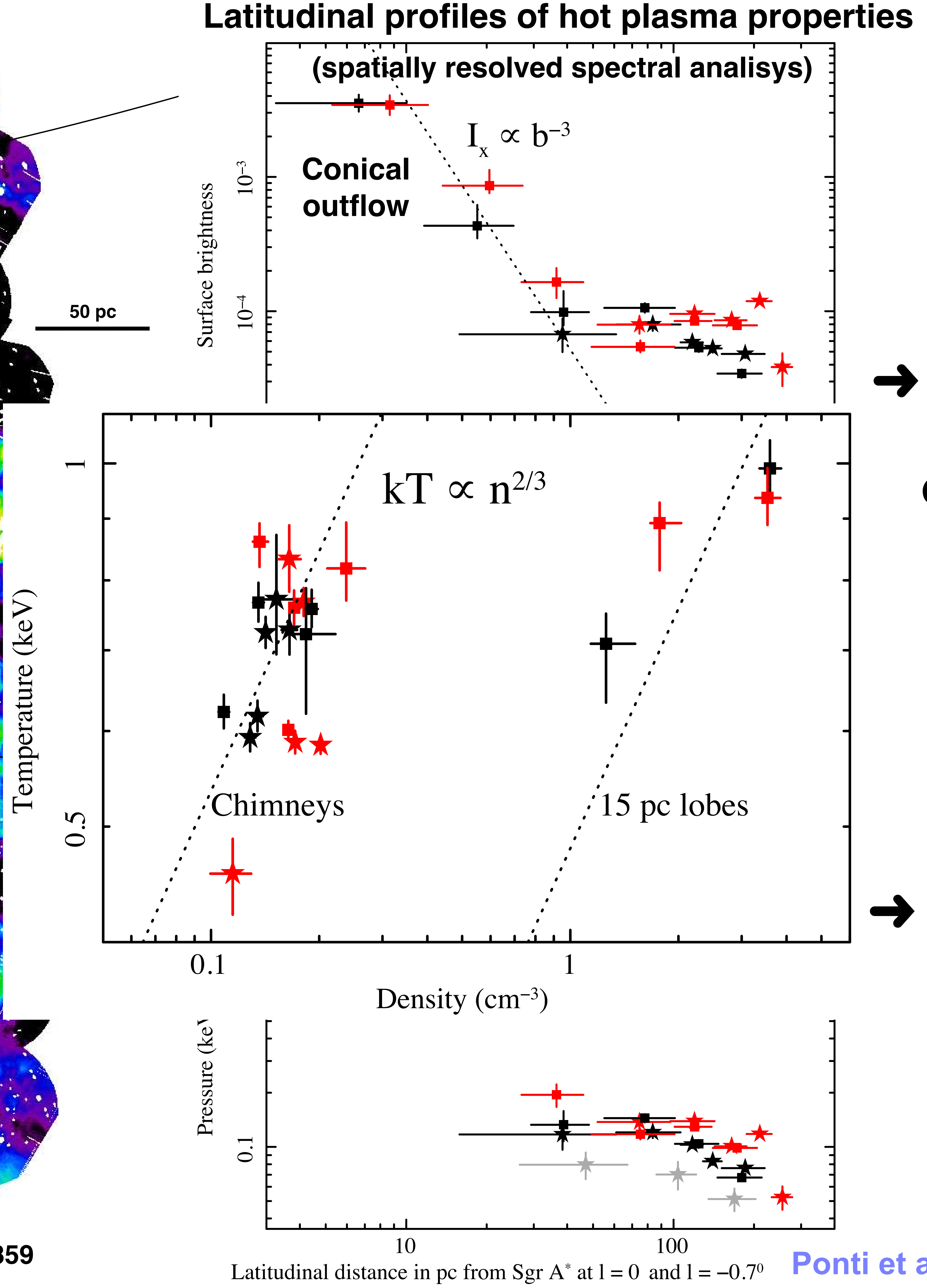
➜ Are these the same outflow?

The measured physical parameters





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➜ **Tidal disruptions onto Sgr A***

($10^{51\text{-}52}$ erg every 10^{4} yr)

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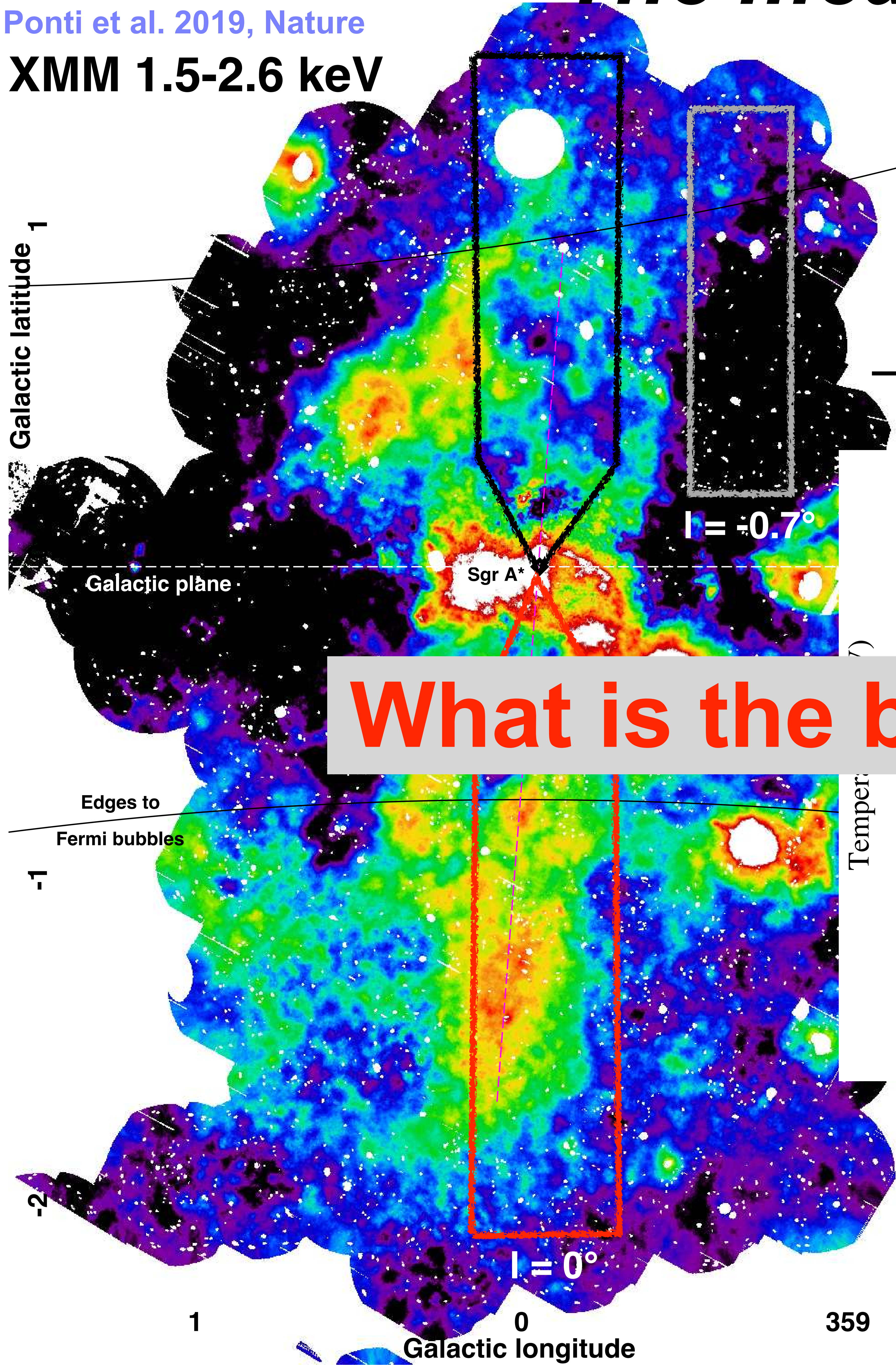
➜ **Are these the same outflow?**

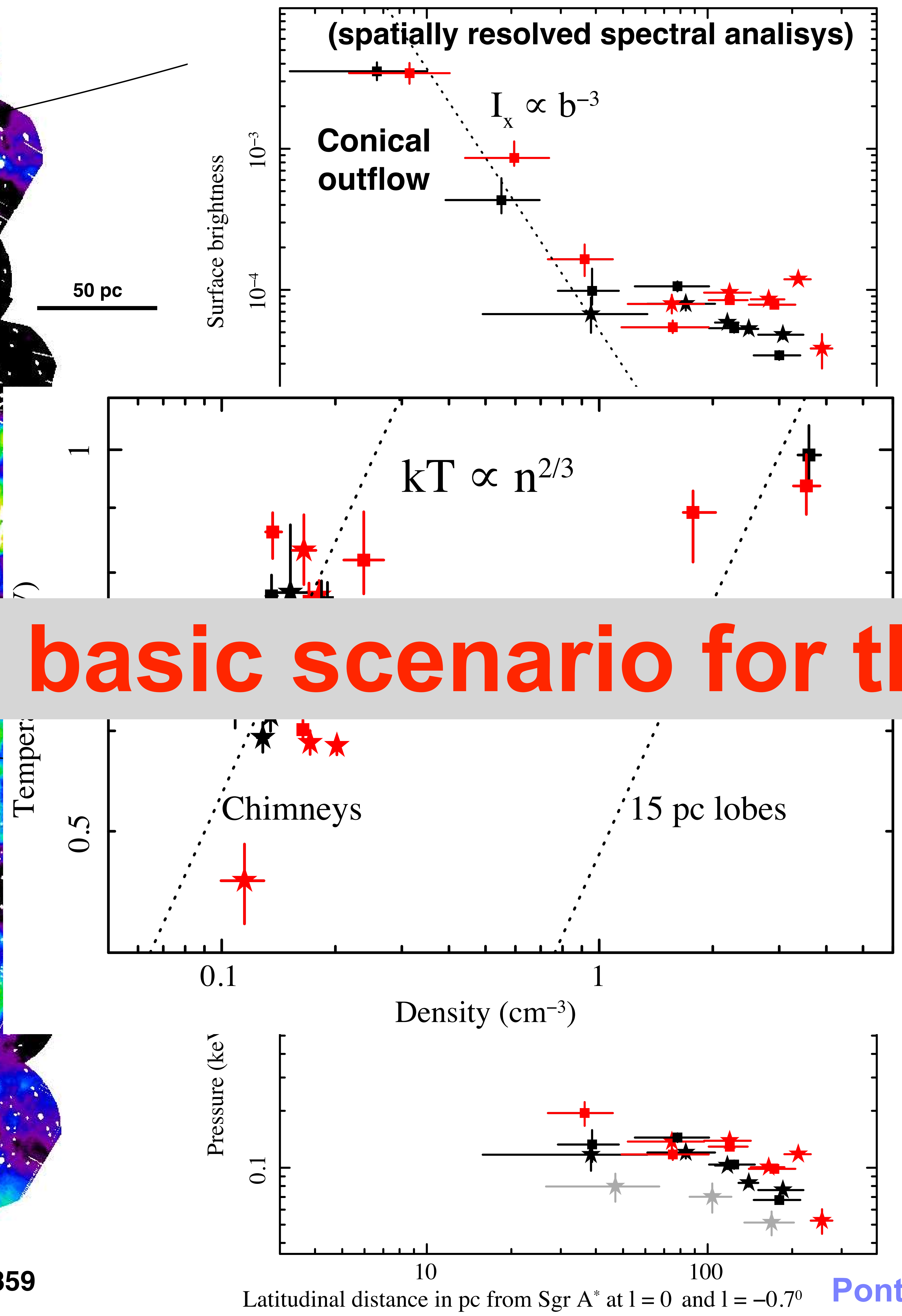
➜ **Similar adiabatic laws**

but different normalisation

(Chimney more powerful)

The measured physical parameters





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^{52} erg
^{5} yr

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but different normalisation
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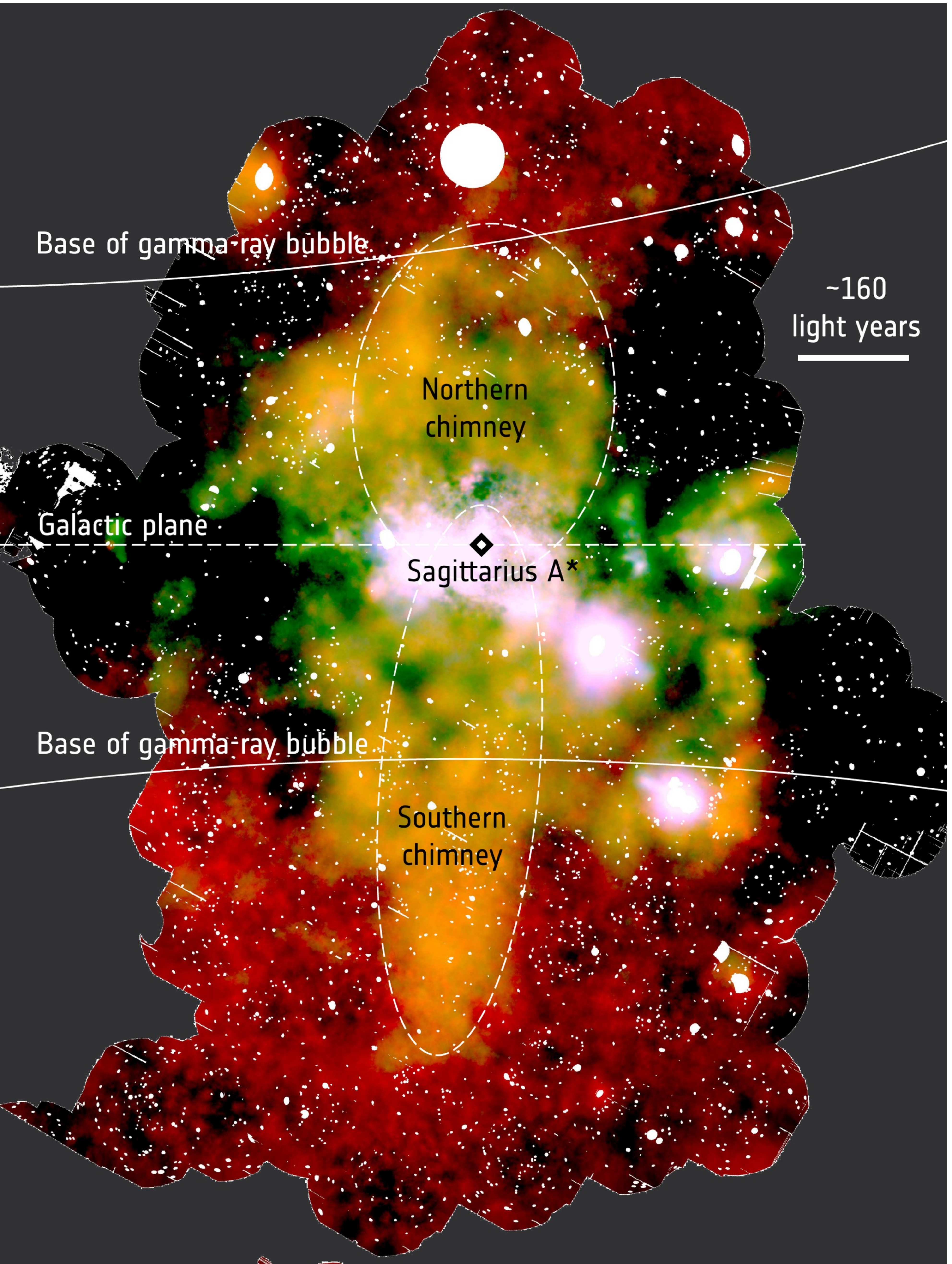
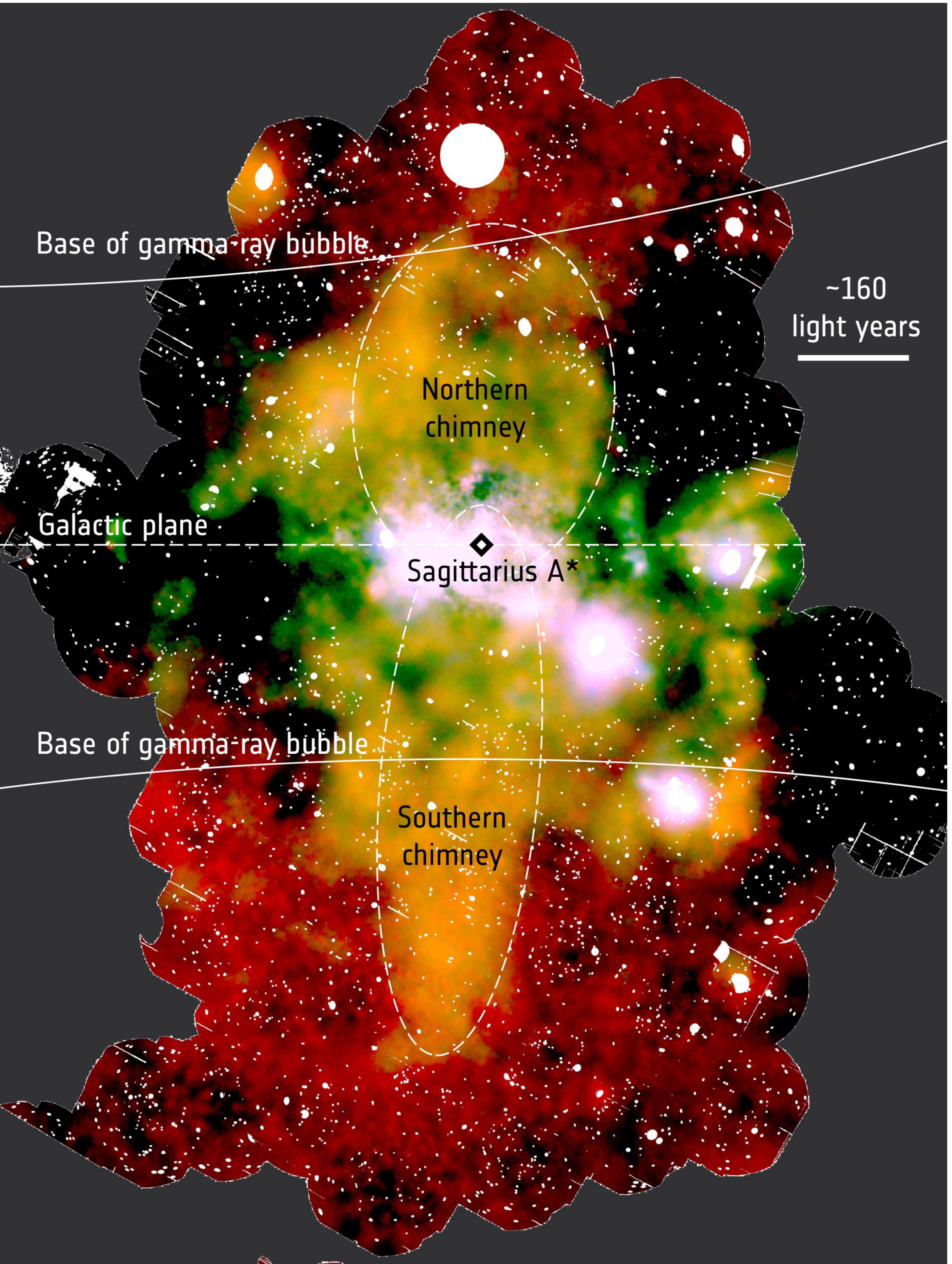
What is the basic scenario for the outflow?

Possible physical pictures of the outflow

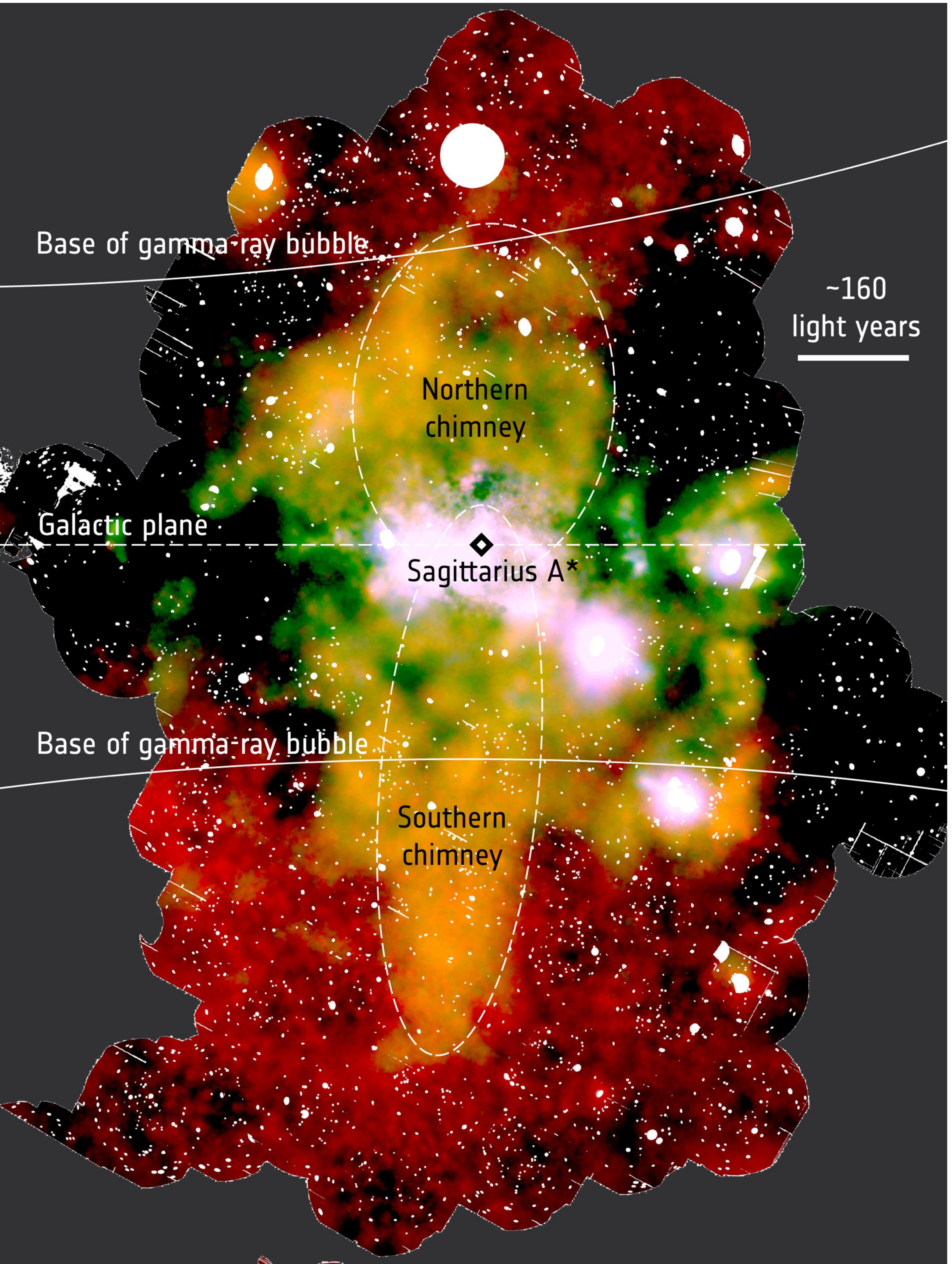


Possible physical pictures of the outflow



Quasi-continuous train of episodic energy injections (TDE-SN) **power a volume filling** (f ~ 1) **hot plasma** (as computed before)

Possible physical pictures of the outflow



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But filling factor might be f << 1… ➜ hot plasma tracer of a more powerful dark flow (as in starbursts)

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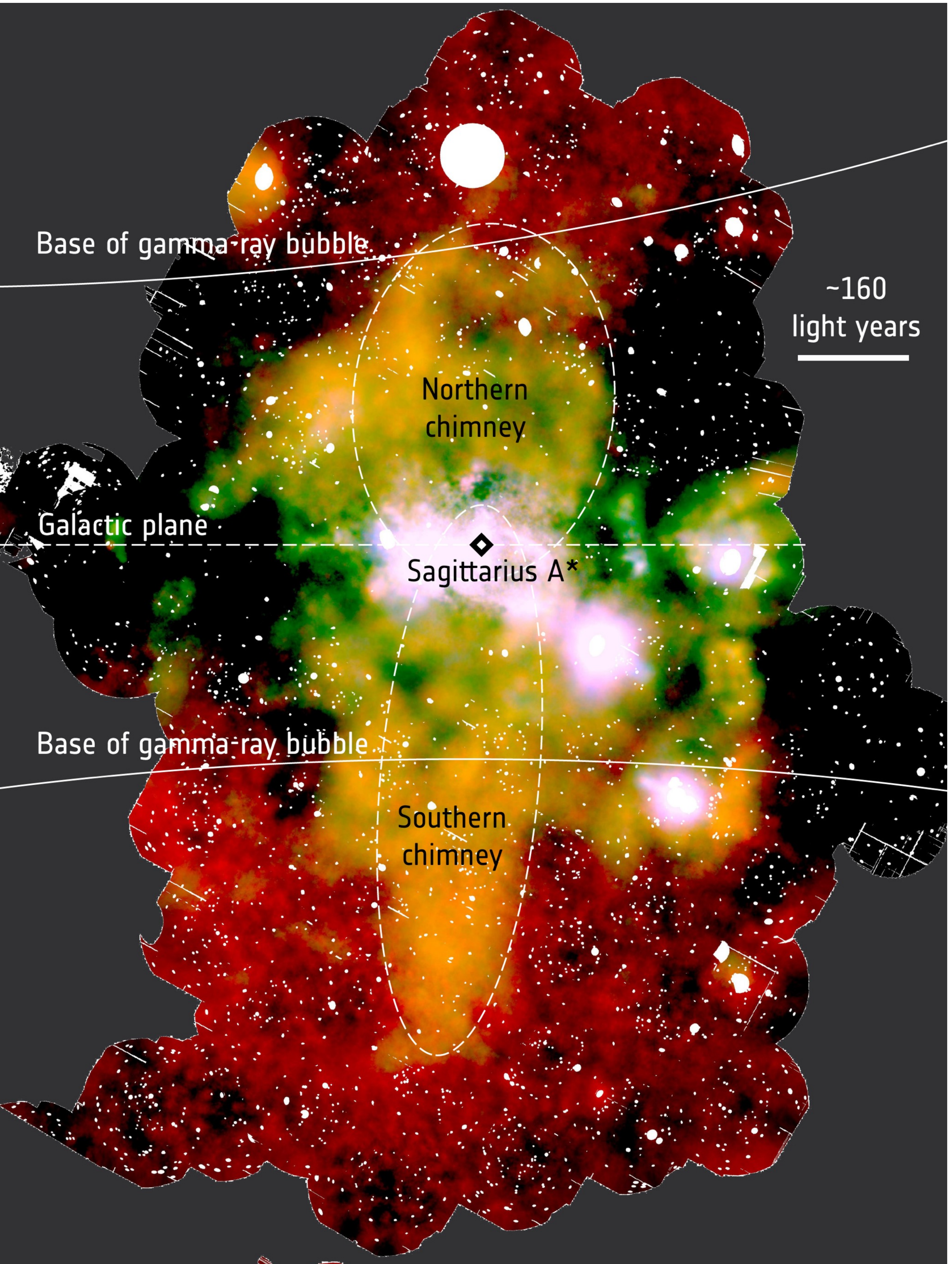

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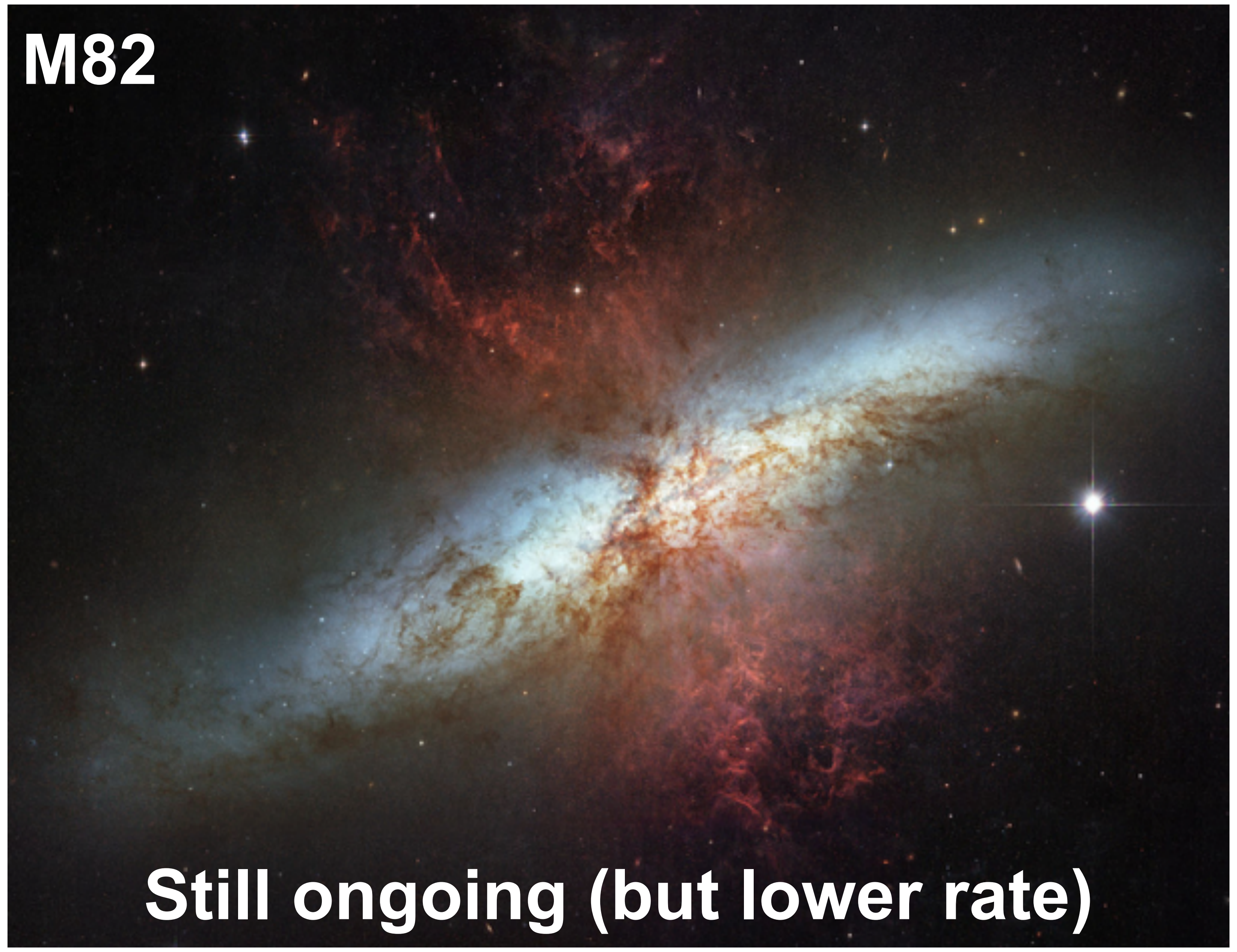
➜ Chimney's longitudinal extent ~ distribution of massive stars



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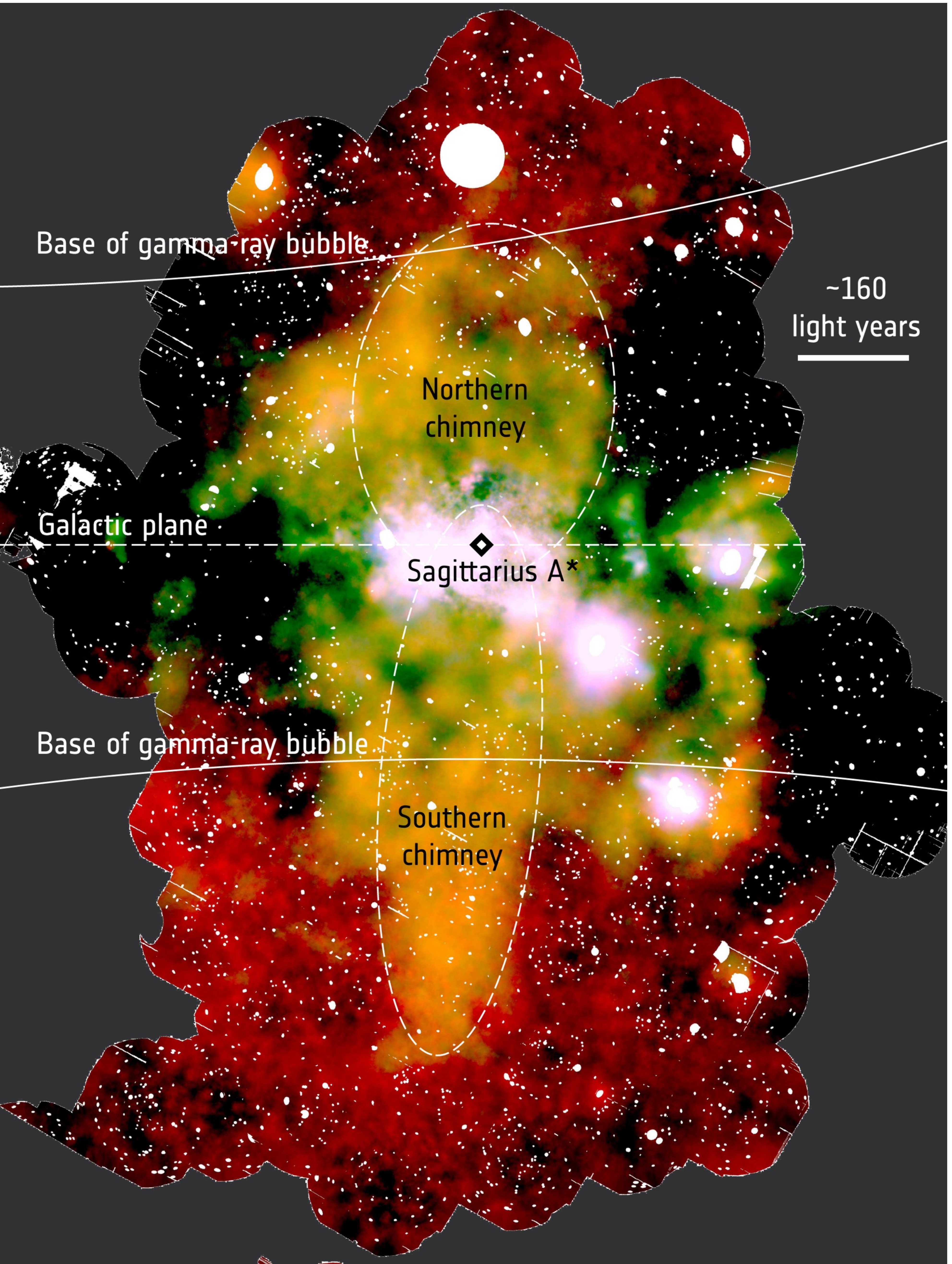

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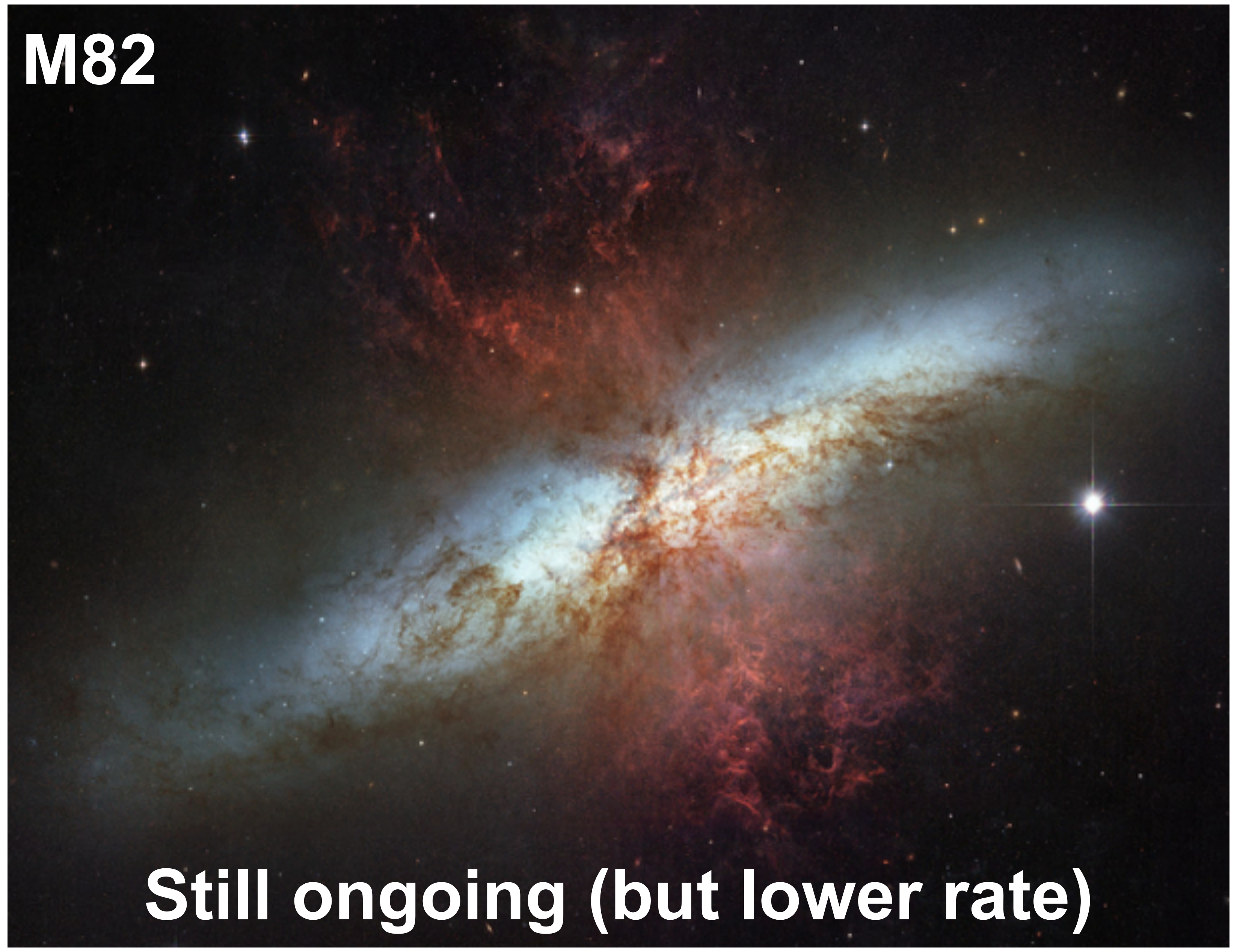
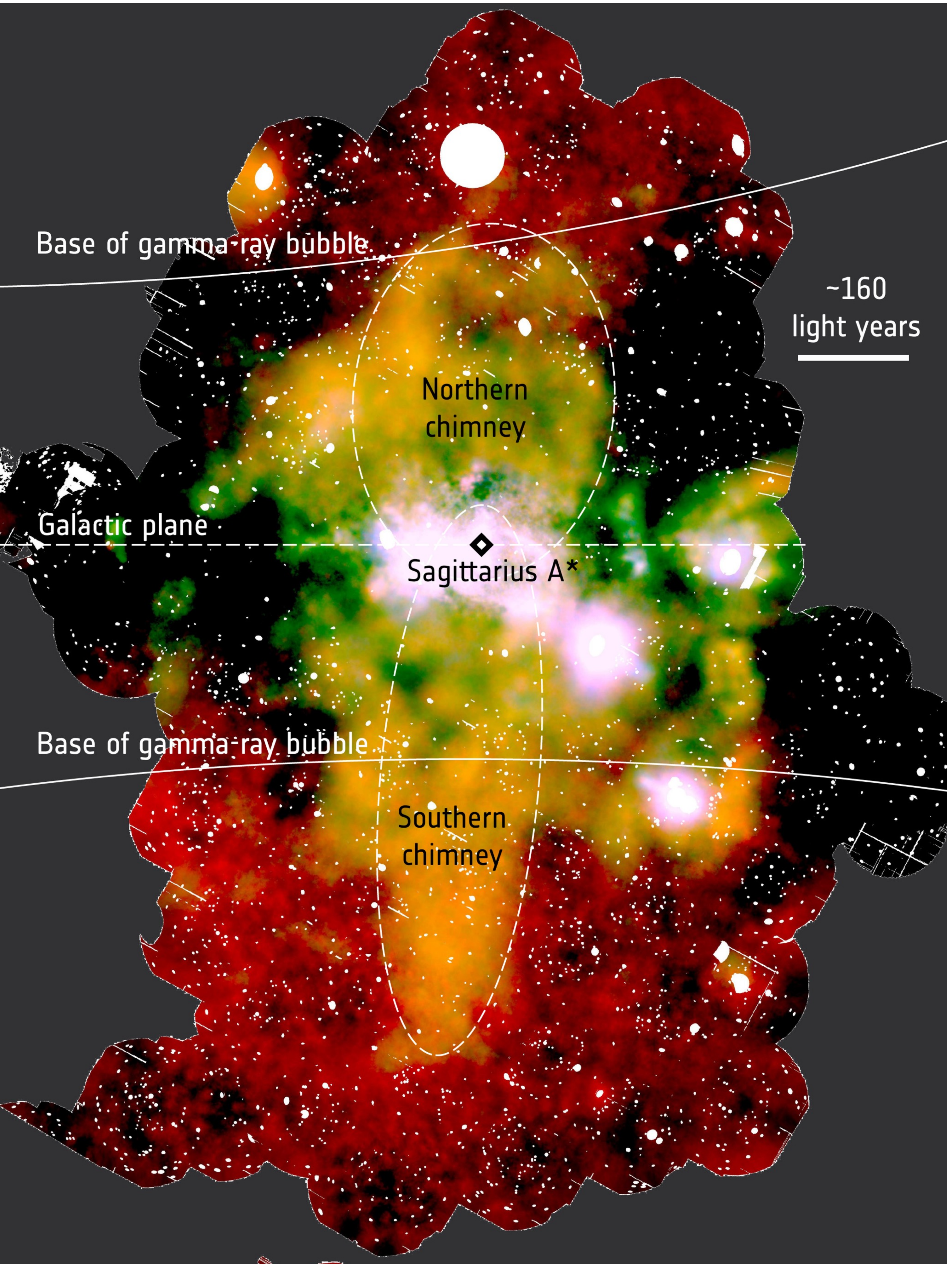


Alternatively: 1) Chimney's close to hydrostatic equilibrium

2) cooling time $t_c \sim 2{\times}10^7$ yr

Possible physical pictures of the outflow



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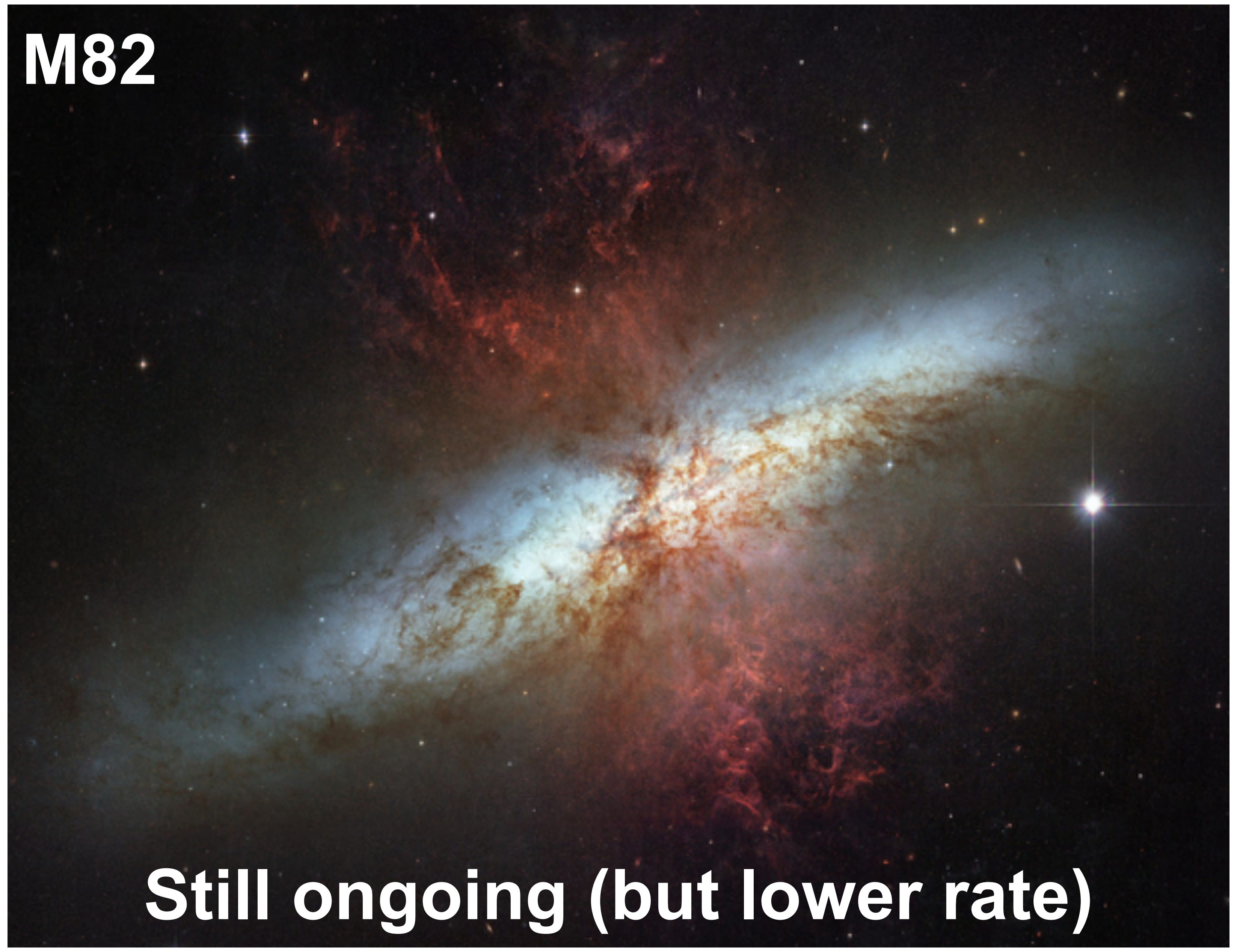

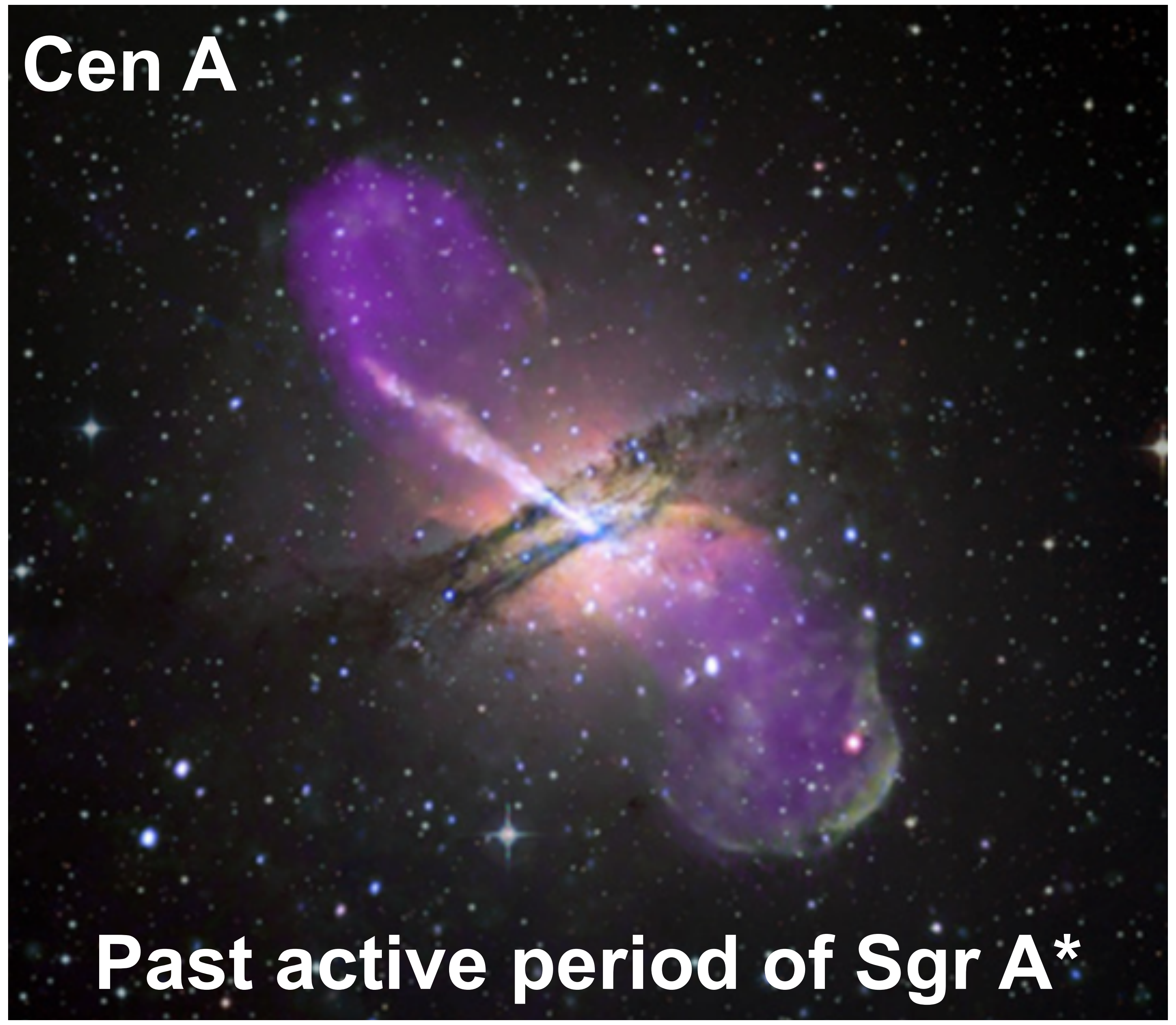

Alternatively: 1) Chimney's close to hydrostatic equilibrium

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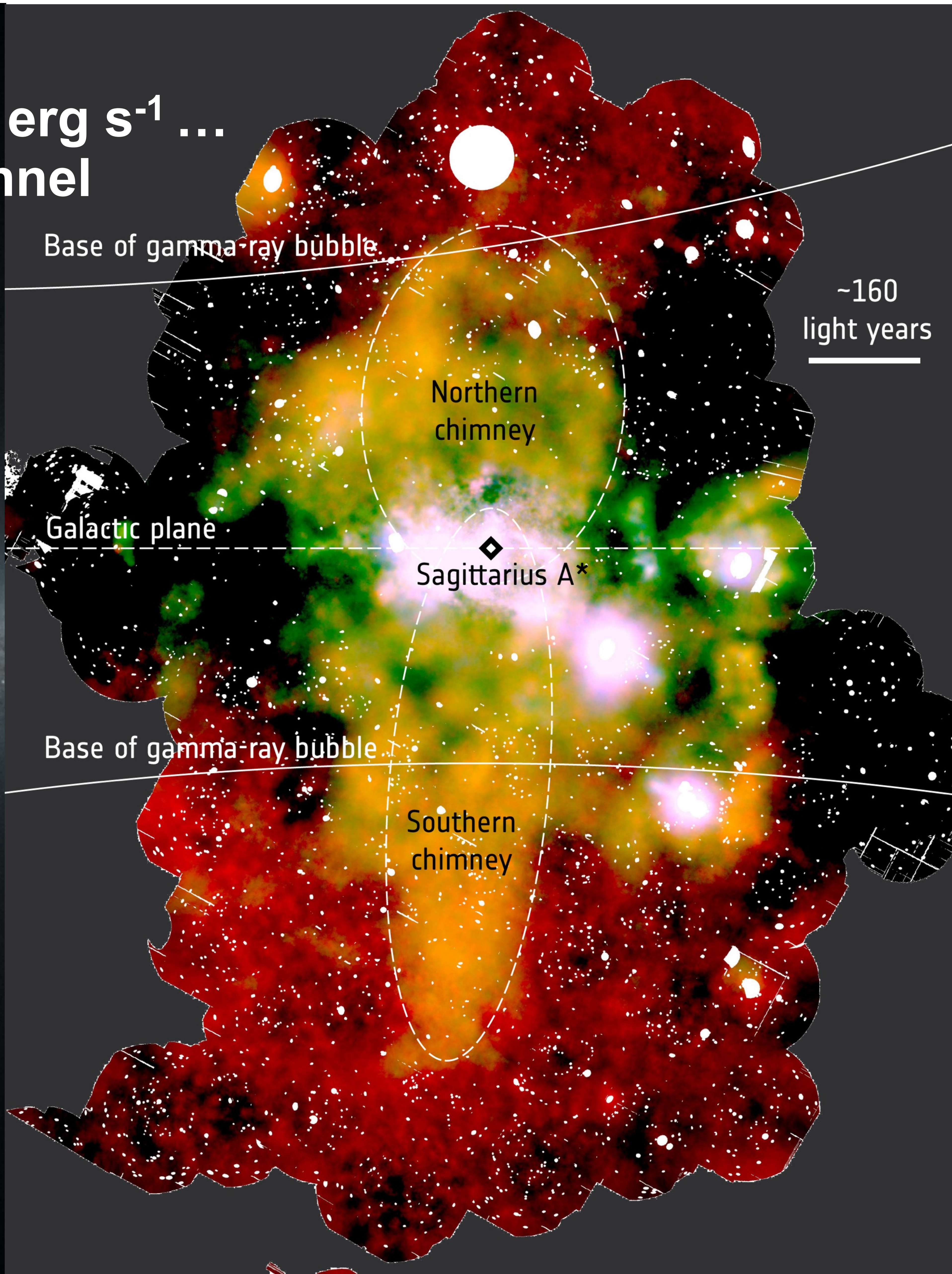
➜ Chimney's might be remnants of a past (much more powerful) **outflow** (e.g., AGN-like accretion onto Sgr A*)

The channel feeding the Fermi bubbles

To inflate Fermi bubbles L ~ 10^{40-44} erg s^{-1} …
➜ Chimneys can be this channel



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

Future: eROSITA!

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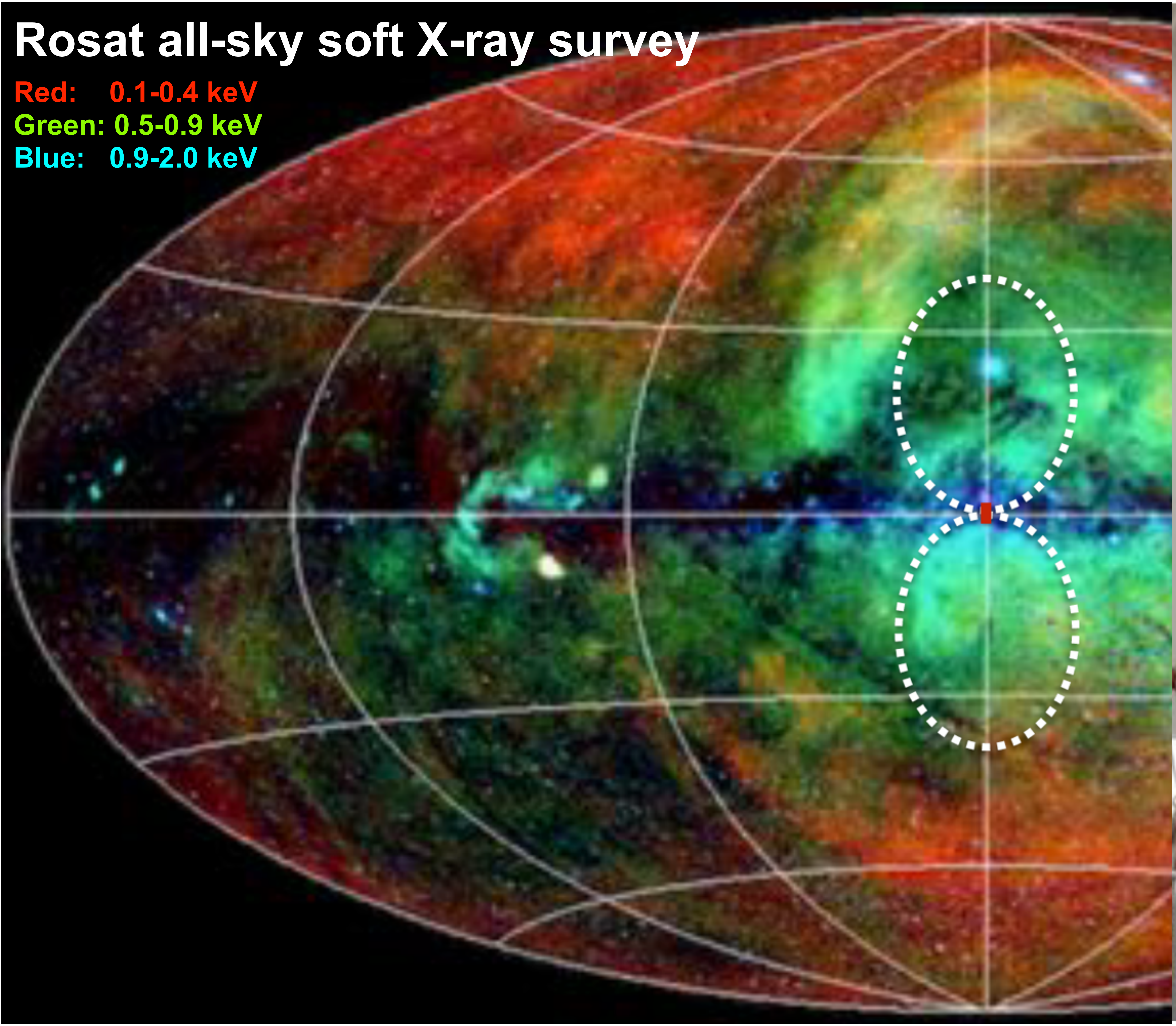
Merloni et al. 2012



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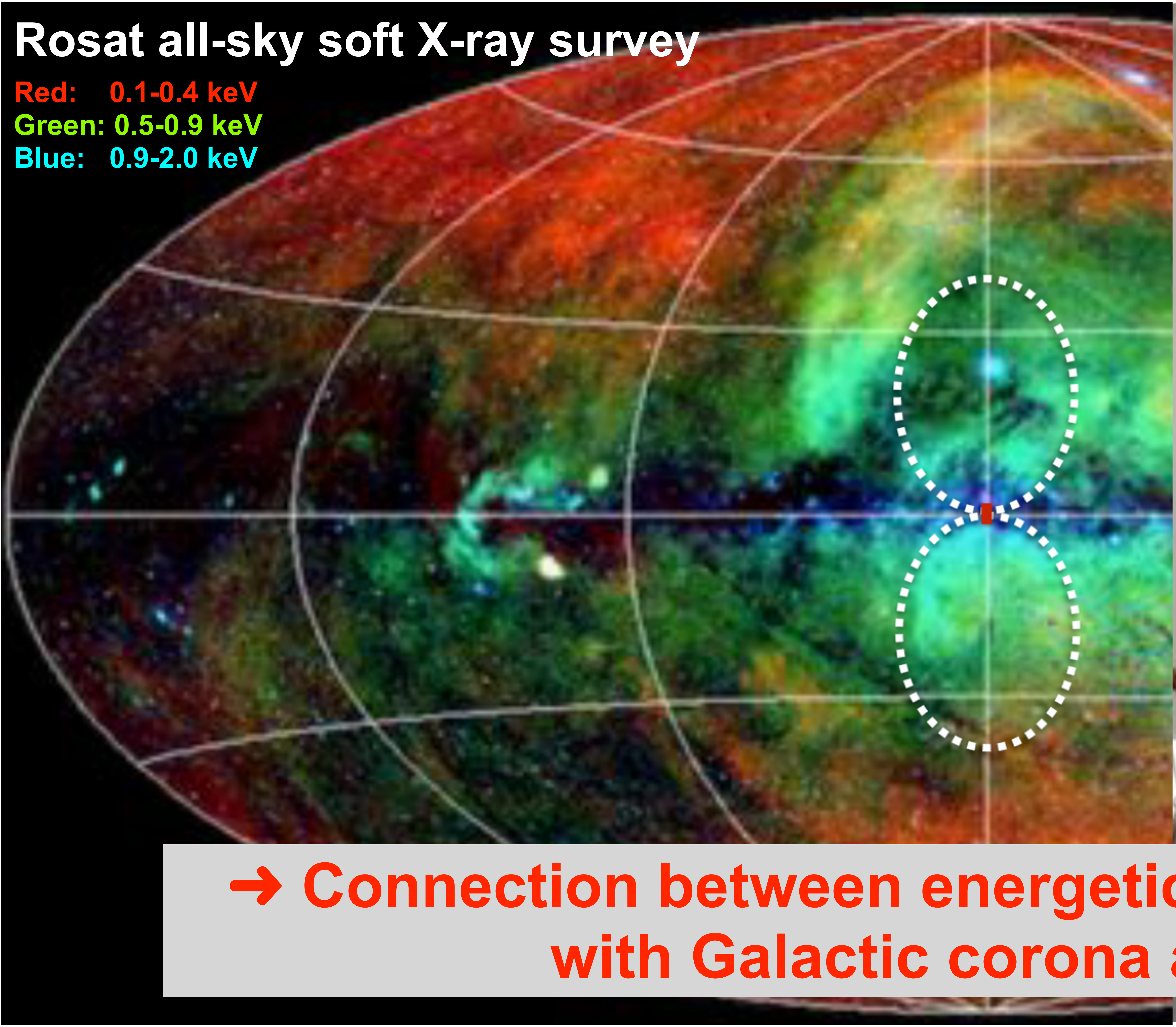
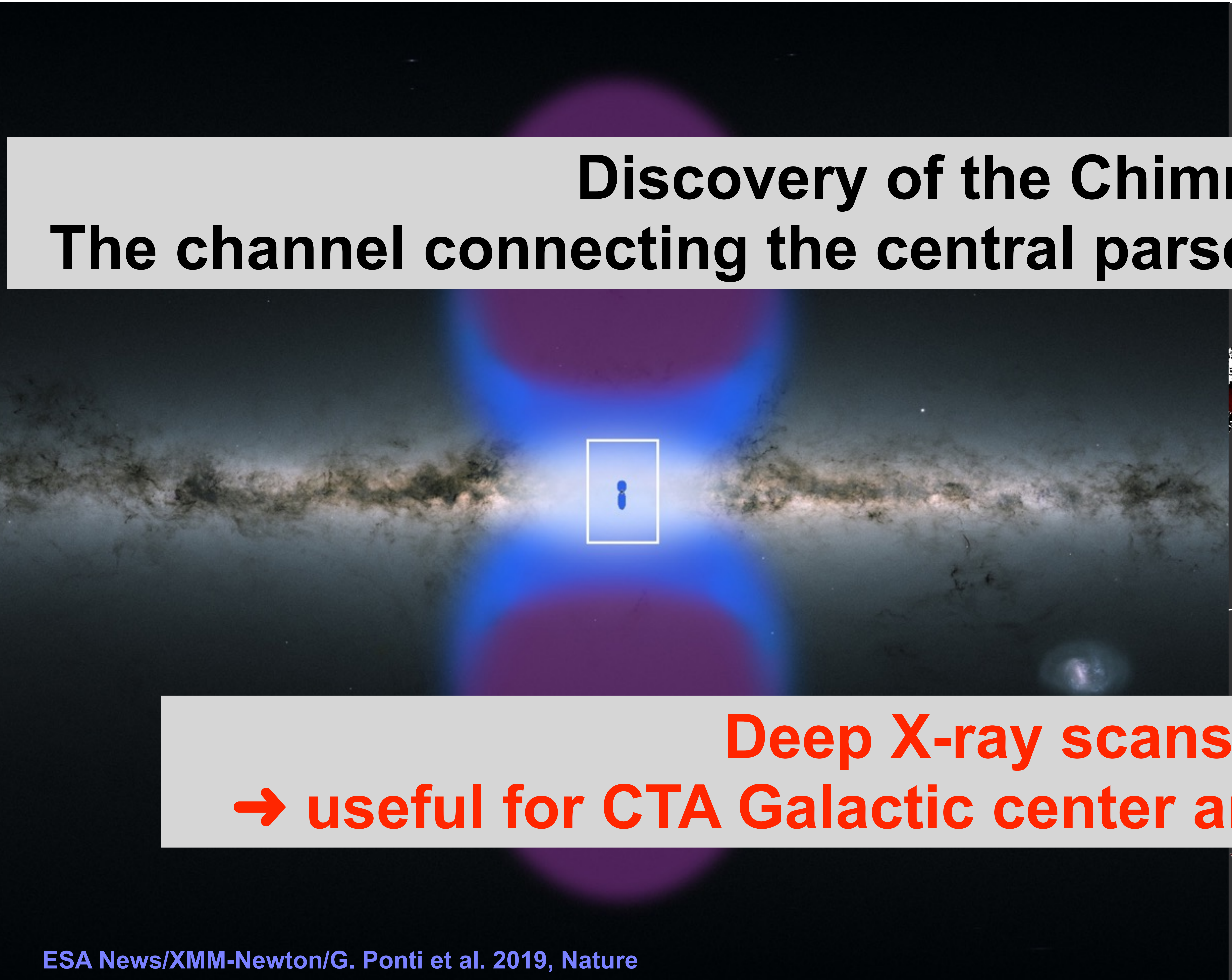
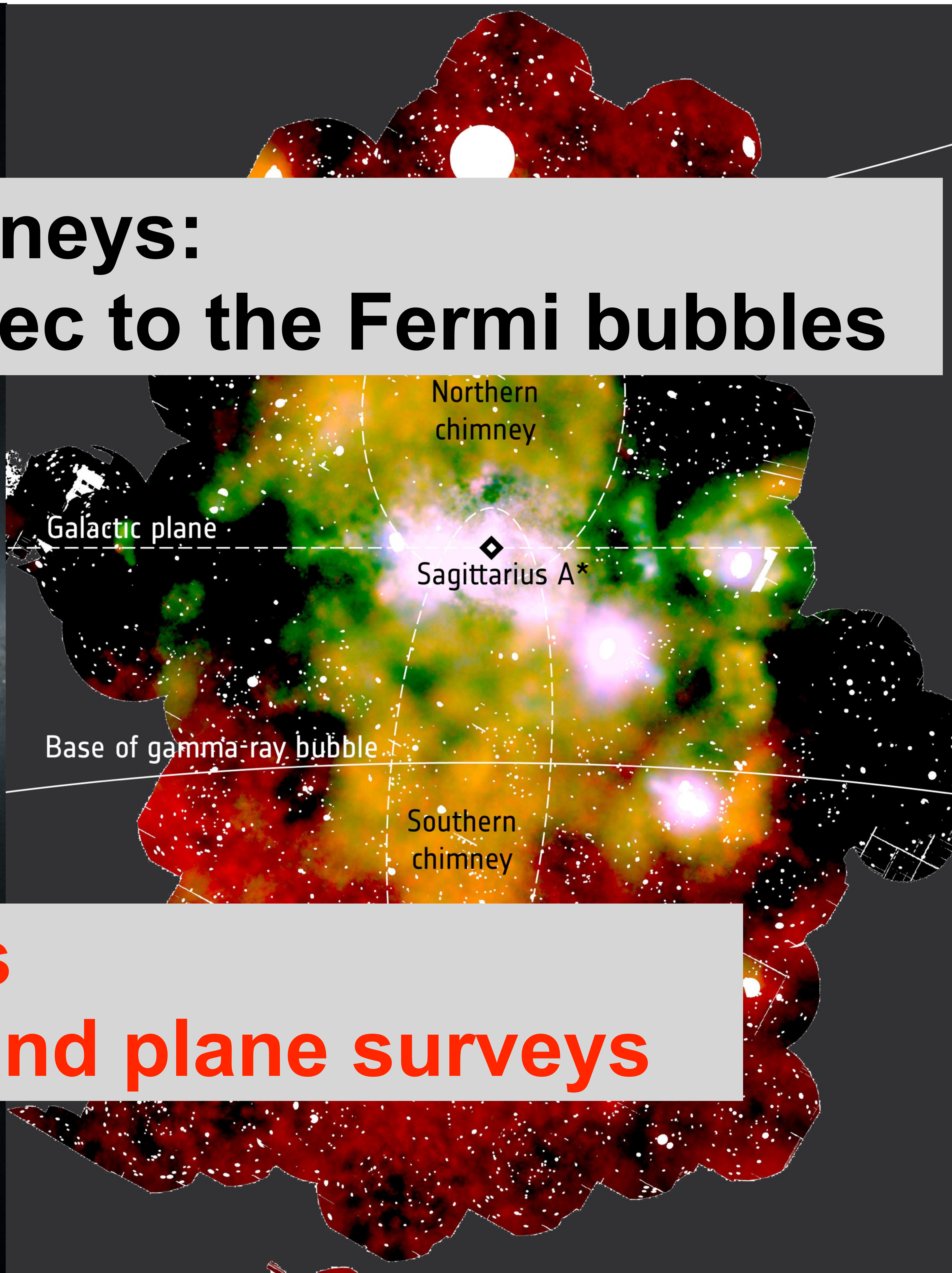


➜ Connection between energetic activity in the disc with Galactic corona and halo

Conclusions

Discovery of the Chimneys:
The channel connecting the central parsec to the Fermi bubbles



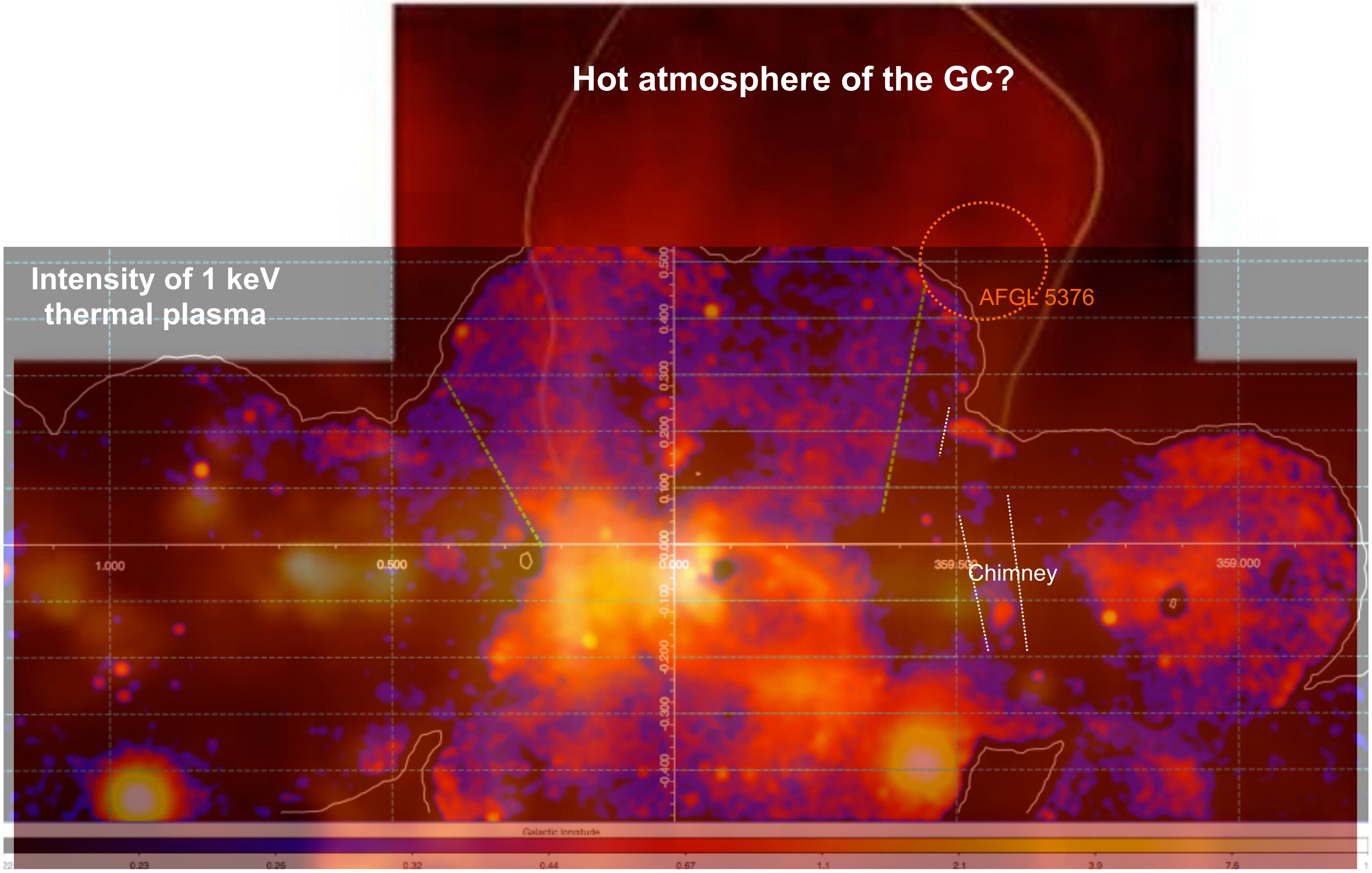


Deep X-ray scans
➜ useful for CTA Galactic center and plane surveys

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

High latitude soft plasma

GC mini-starburst environment ➜ Outflows



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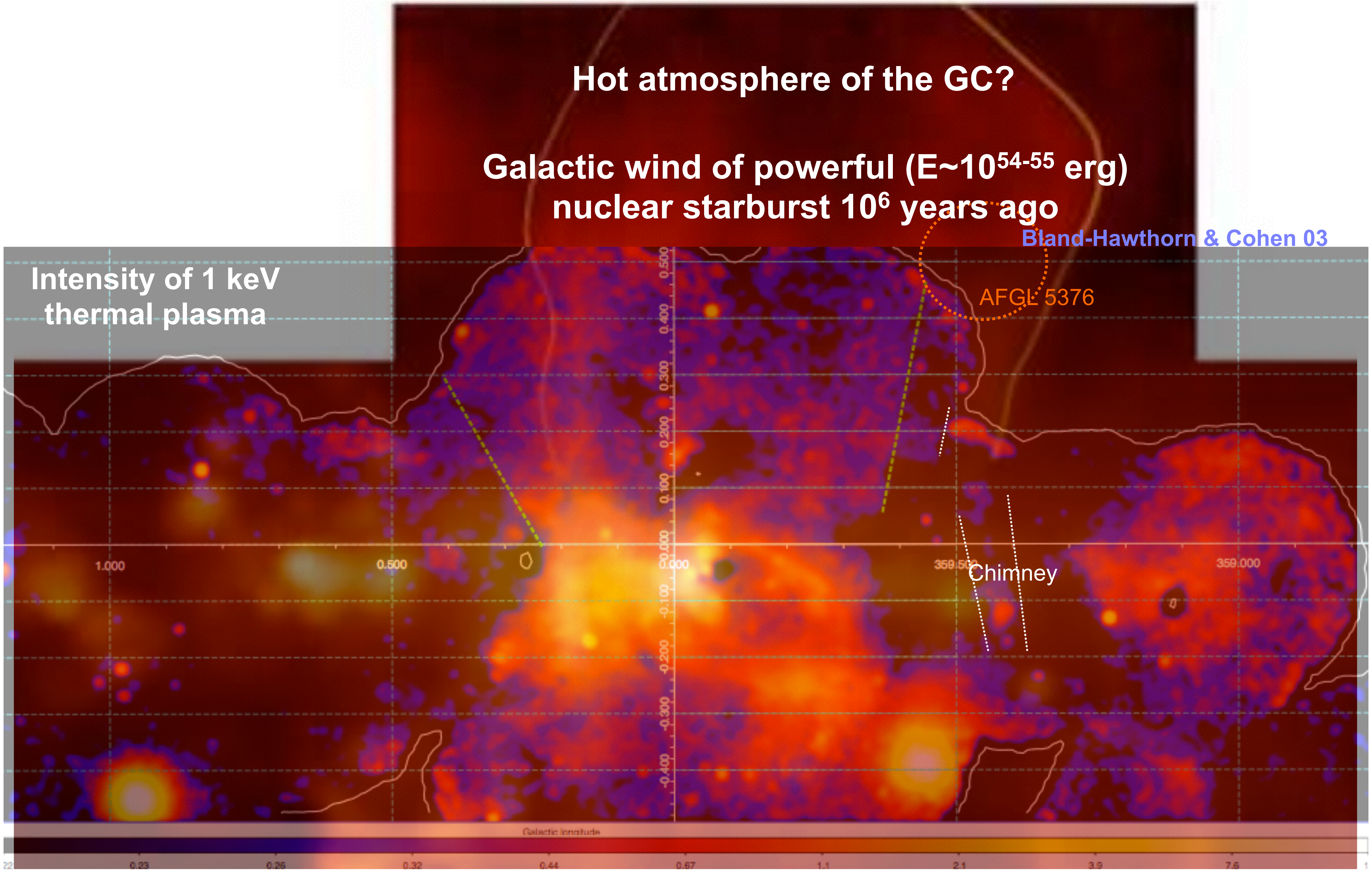

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GC mini-starburst environment ➜ Outflows Crocker +12