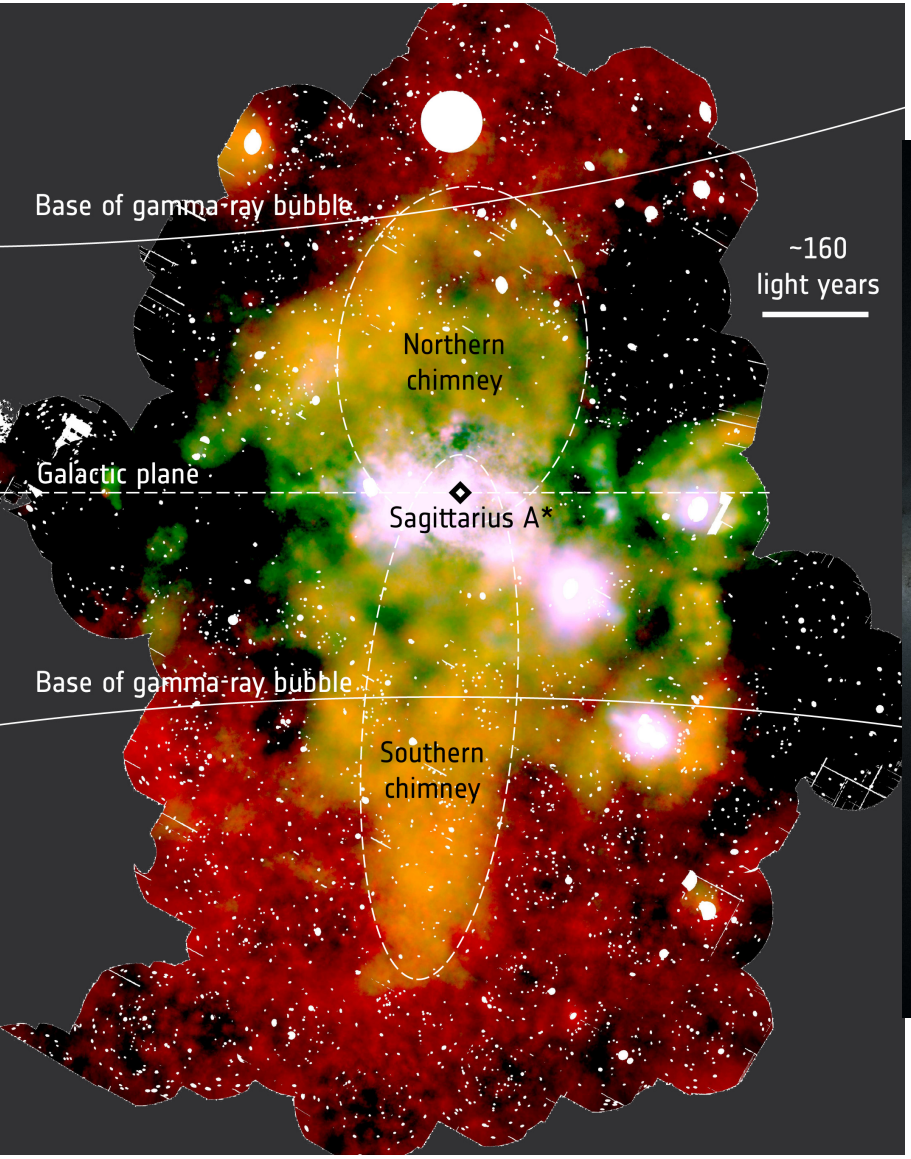
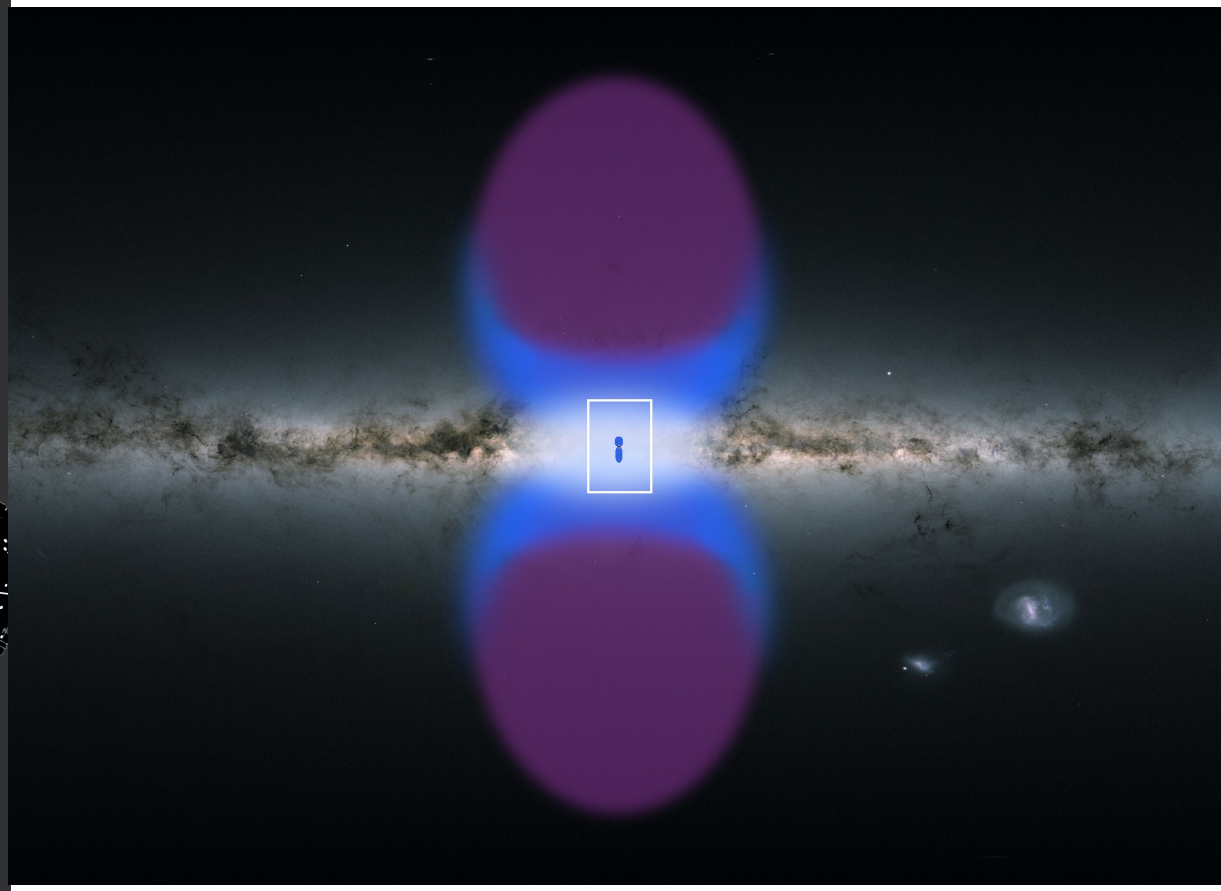
X-raying the Galactic centre





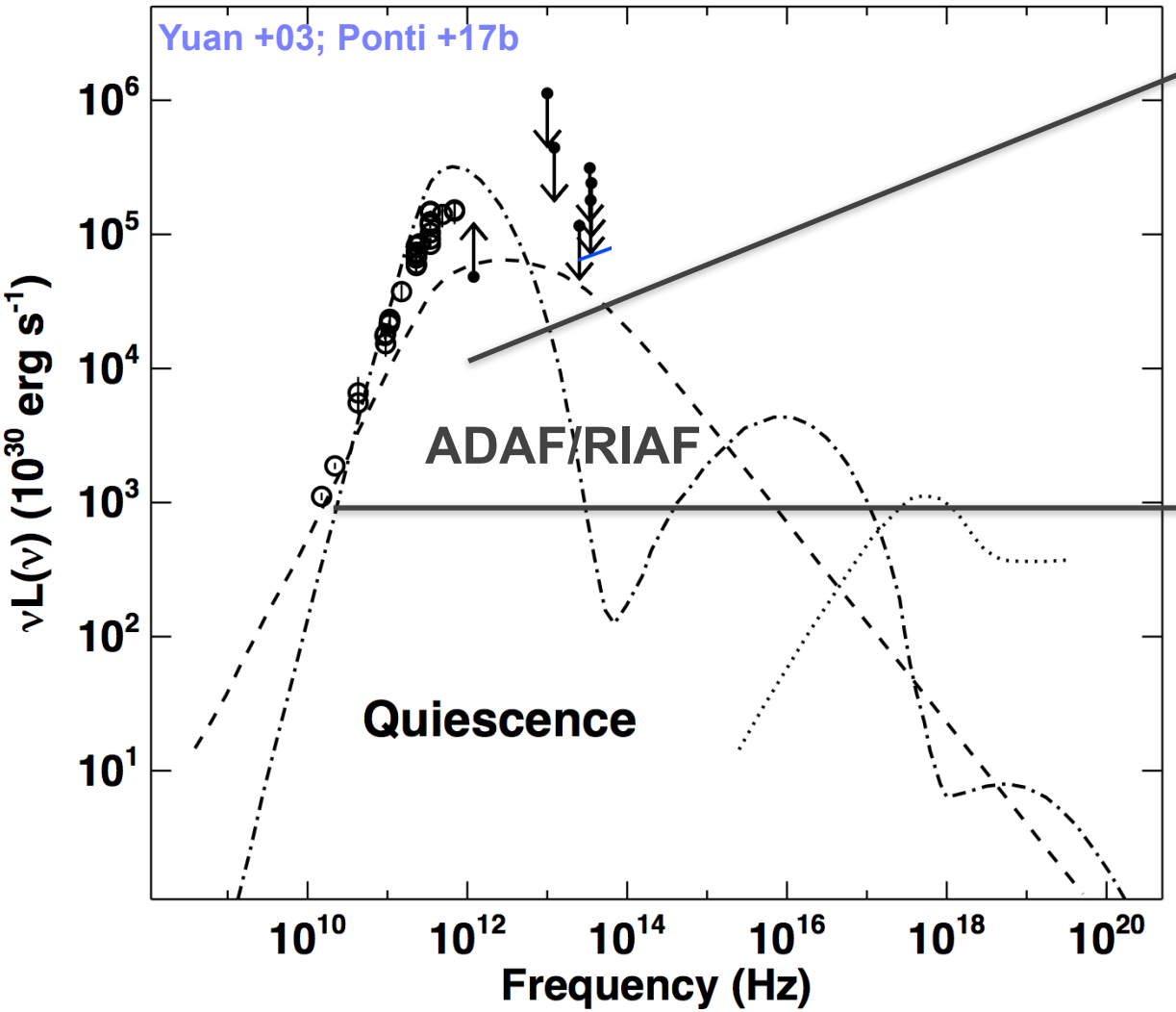
ESA News/XMM-Newton/G. Ponti et al. 2019, Nature

Gabriele Ponti (INAF OA-Brera)
Hofmann, Churazov, Morris, Haberl, Nandra, Terrier, Clavel, Goldwurm

Sgr A's quiescent emission*

$L_{Sgr\ A^*} \sim 10^{-9}\ L_{Edd}$

Best target to study low luminosity accretion



Optically thin synchrotron

r ~ 10 R_S

Linearly polarised — Marrone +06

Thermal e^- (γ_e~10)

$n_e \sim 10^6$ cm^{-3} — Loeb +07; Genzel +10

B ~ 20-50 G

➜ **Event horizon telescope!**

Radio flattening

Either:

Non thermal e^- — Oezel +00

Or:

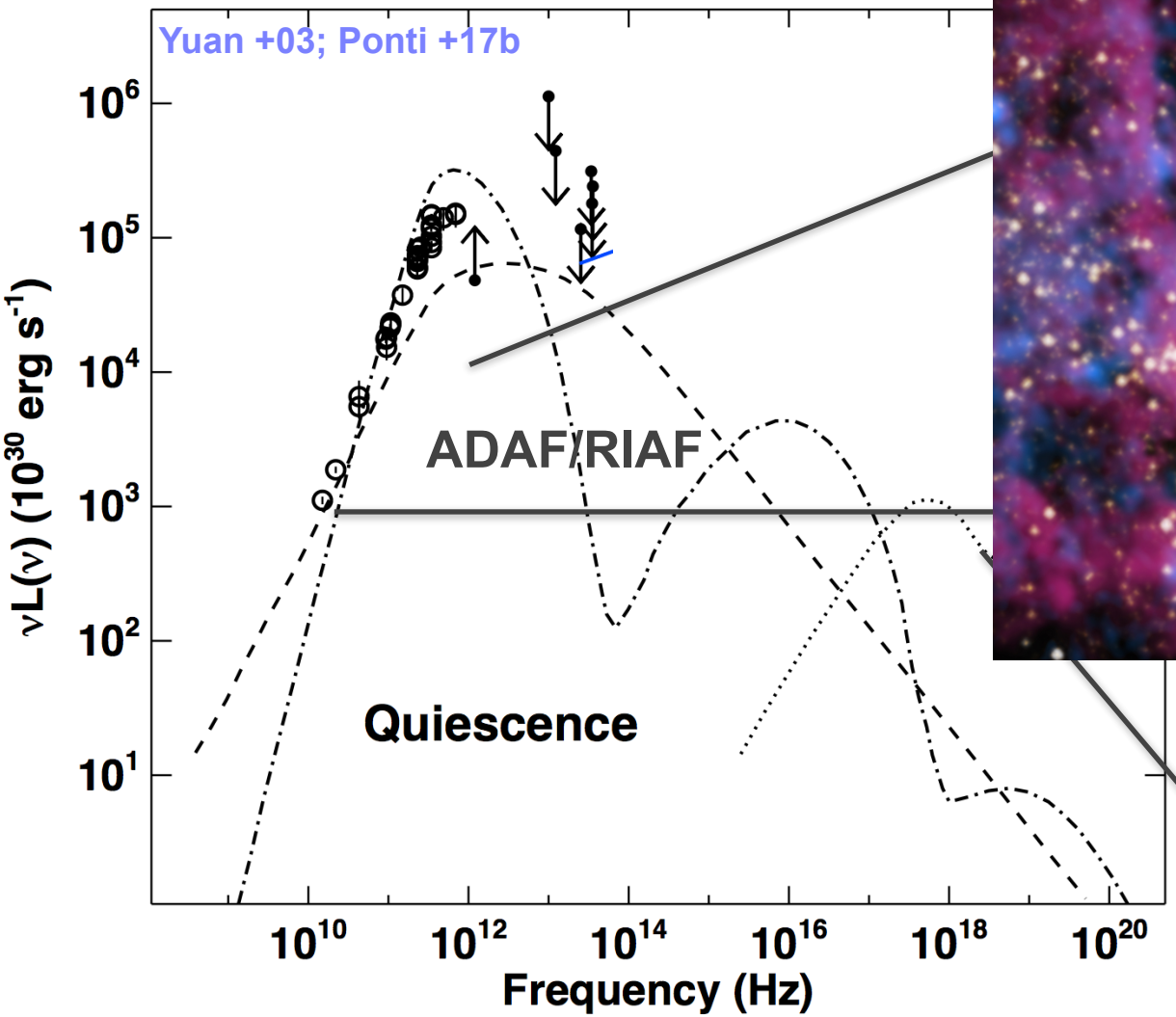
Compact jet — Falcke +98; Moscibrodzska +10

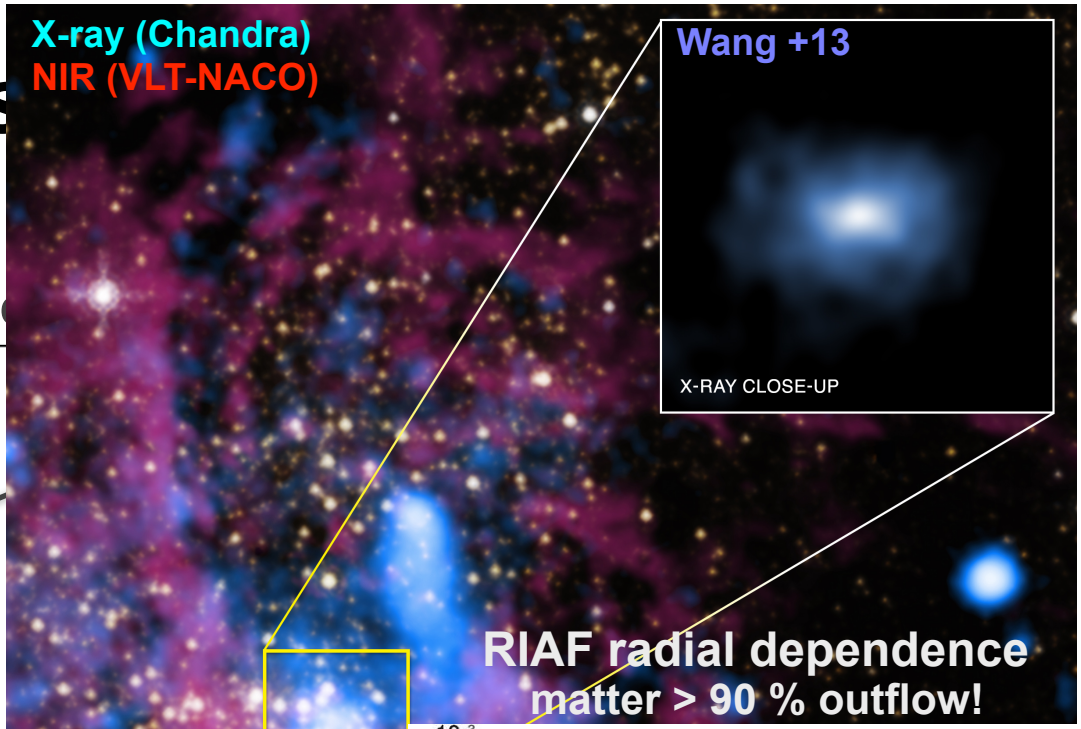
Falcke +98; Markoff +01; Yuan +03; Zhao +03; +04; Baganoff +03; Herrnstein +04; An +05; Xu +06; Marrone +06; +07; Schoedel +07; +11; Dodds-Eden +09; Trap +11; Wang +13; Bower +15; +18; +19; Brinkerink +15; Liu +16; Stone +16; Witzel +18; Lu +18; von Fellenberg 18; Fazio +18;

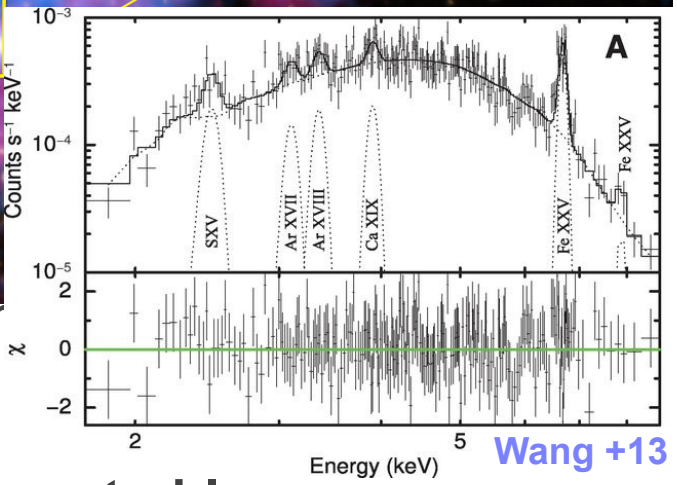
Sgr A*'s quies

$L_{Sgr\ A^*} \sim 10^{-9}\ L_{Edd}$

Best target to study low luminosity a







Wang +13

Bremsstrahlung

$r \sim 10^5\ R_S$

extended (~1") accretion from stars wind

$kT_e \sim 7 \times 10^7$ K

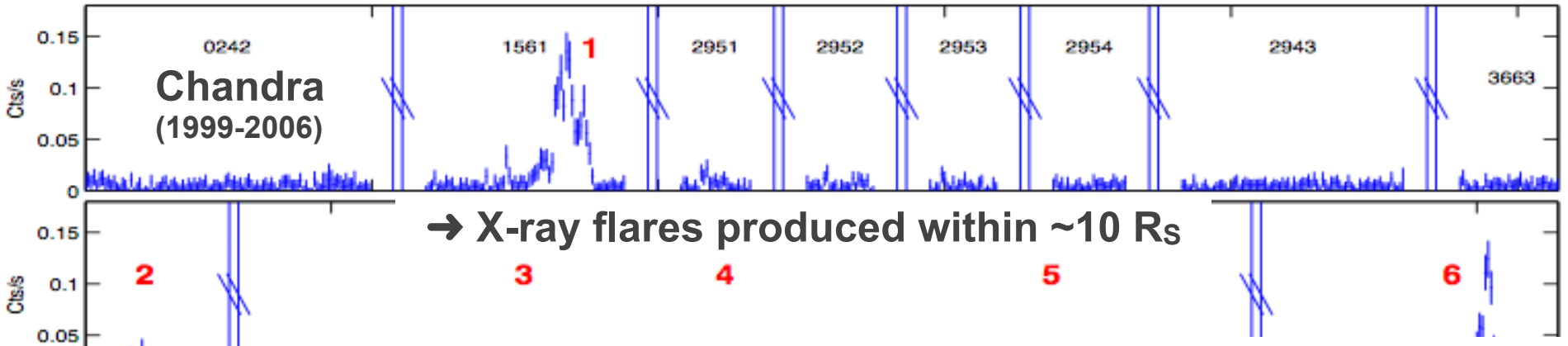
$n_e \sim 100$ cm^{-3}

Melia +92; Quataert 02; Baganoff +03; Cuadra +05; Xu +06; Wang +13

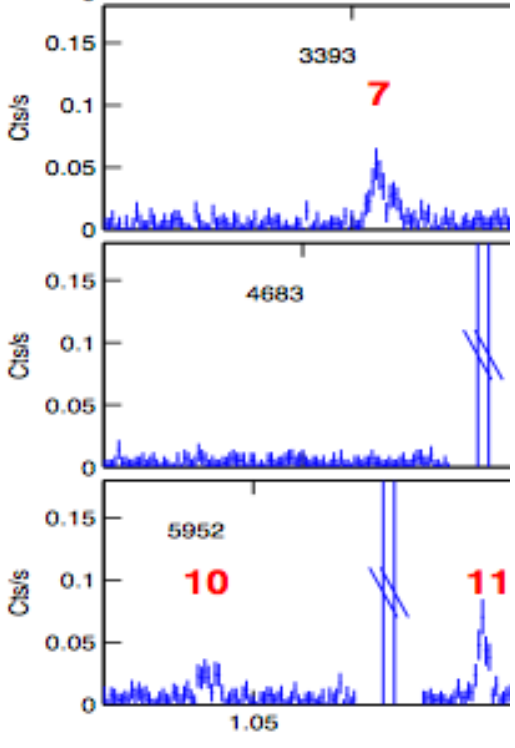
Falcke +98; Markoff +01; Yuan +03; Zhao +03; +04; Baganoff +03; Herrnstein +04; An +05; Xu +06; Marrone +06; +07; Schoedel +07; +11; Dodds-Eden +09; Trap +11; Wang +13; Bower +15; +18; +19; Brinkerink +15; Liu +16; Stone +16; Witzel +18; Lu +18; von Fellenberg 18; Fazio +18;

X-ray flares of Sgr A*

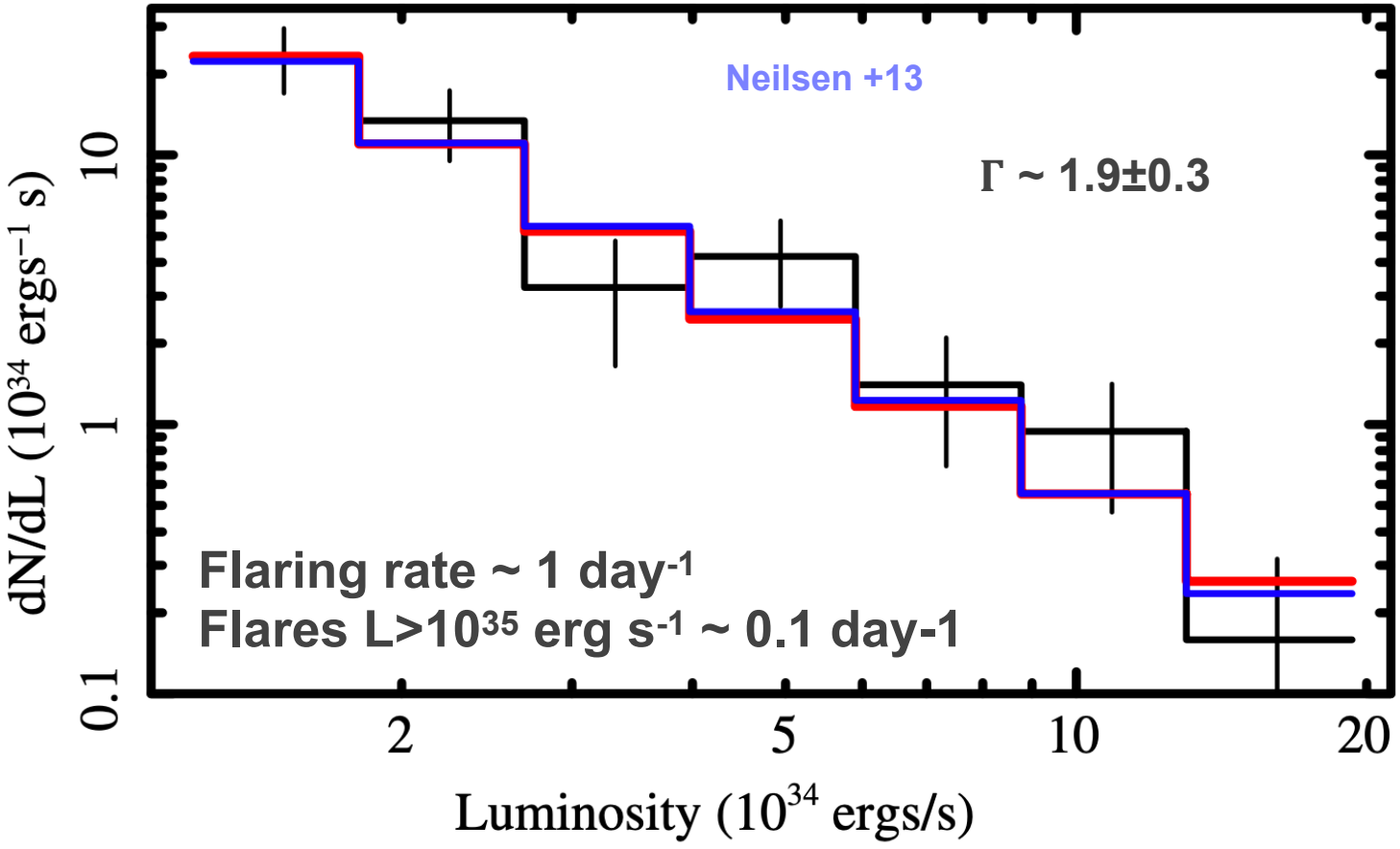
Ponti +15b



➜ X-ray flares produced within ~10 R_S

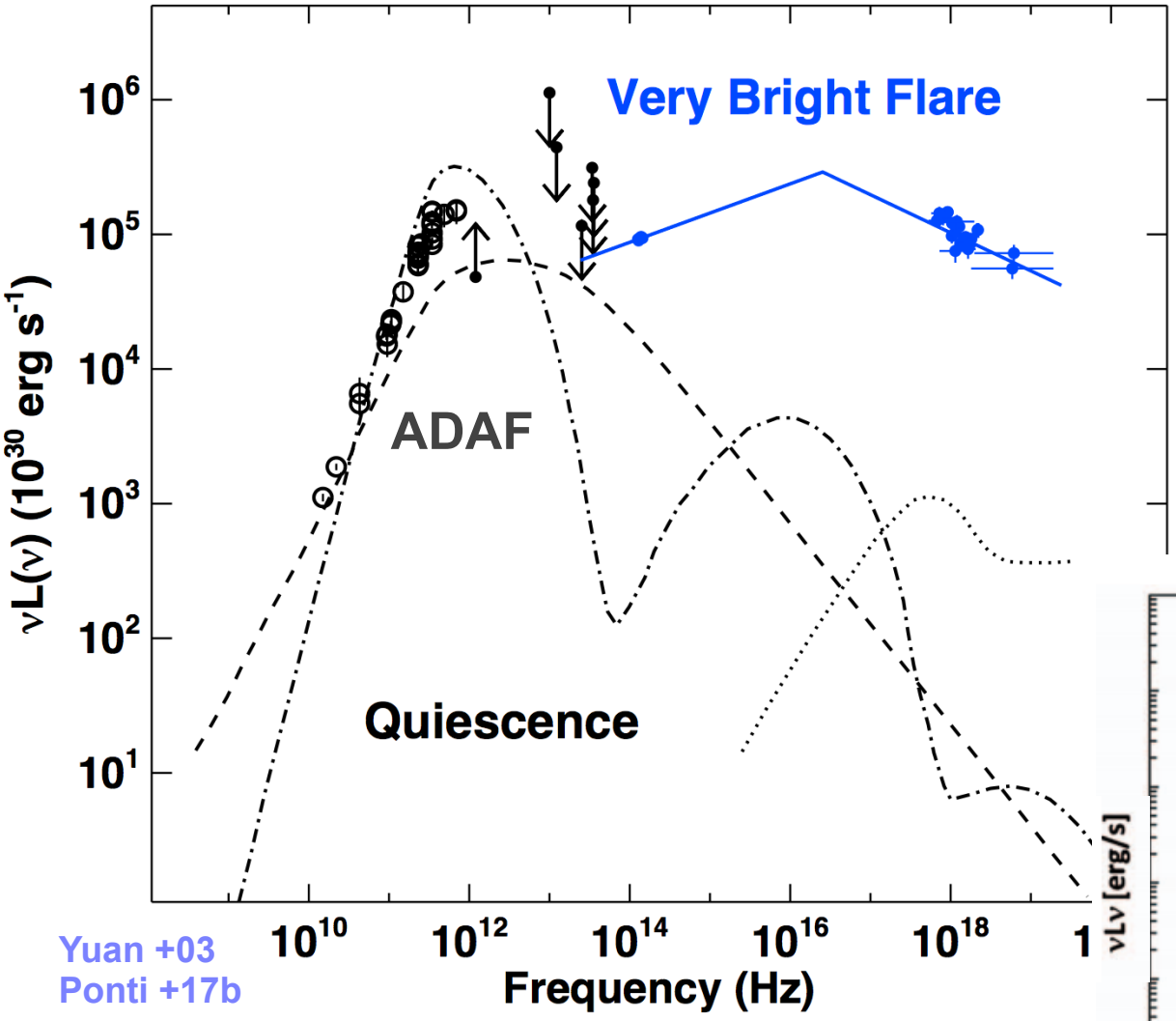


Baganoff +01; Goldwurm +
Barriere +14; Ponti +1



Sgr A's emission during X-ray flares?*

Best target to study low luminosity accretion

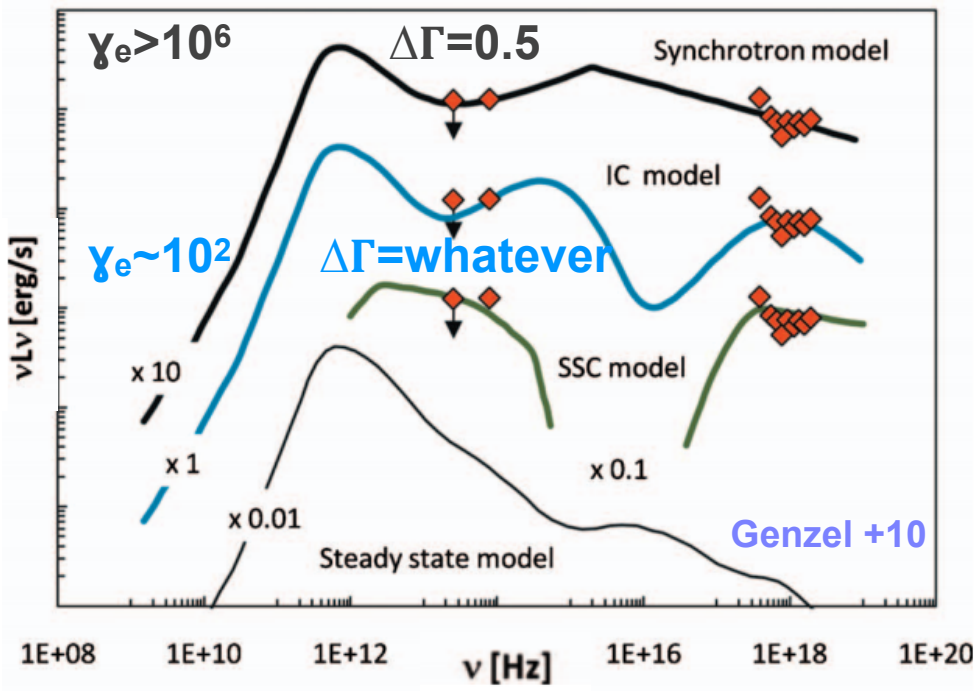


Yuan +03
Ponti +17b

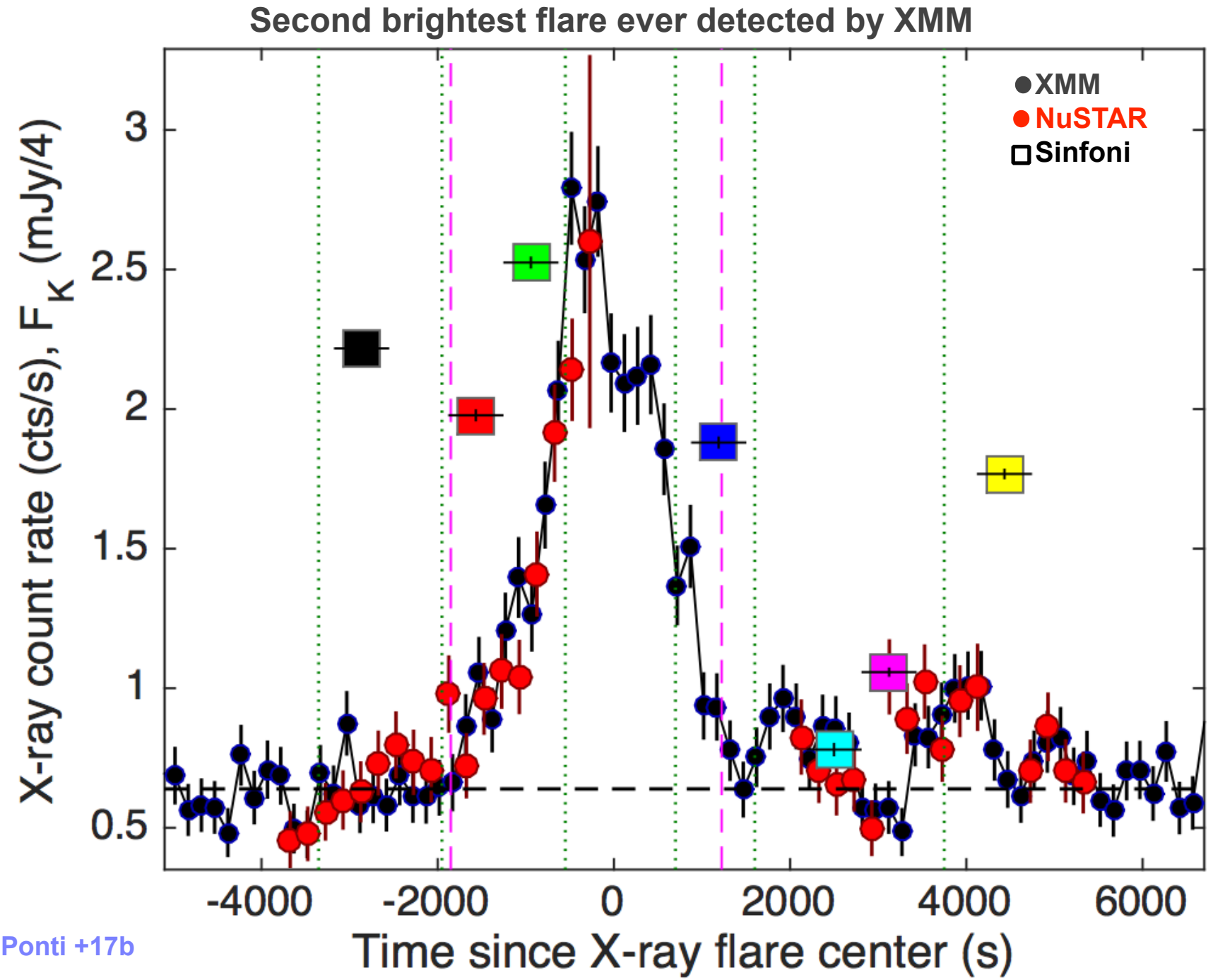
During flares
$\Gamma_{IR} \sim 1.6$
IR polarised
➜ Synchrotron

For 15 years we wondered…

What is the radiative process in X-ray?

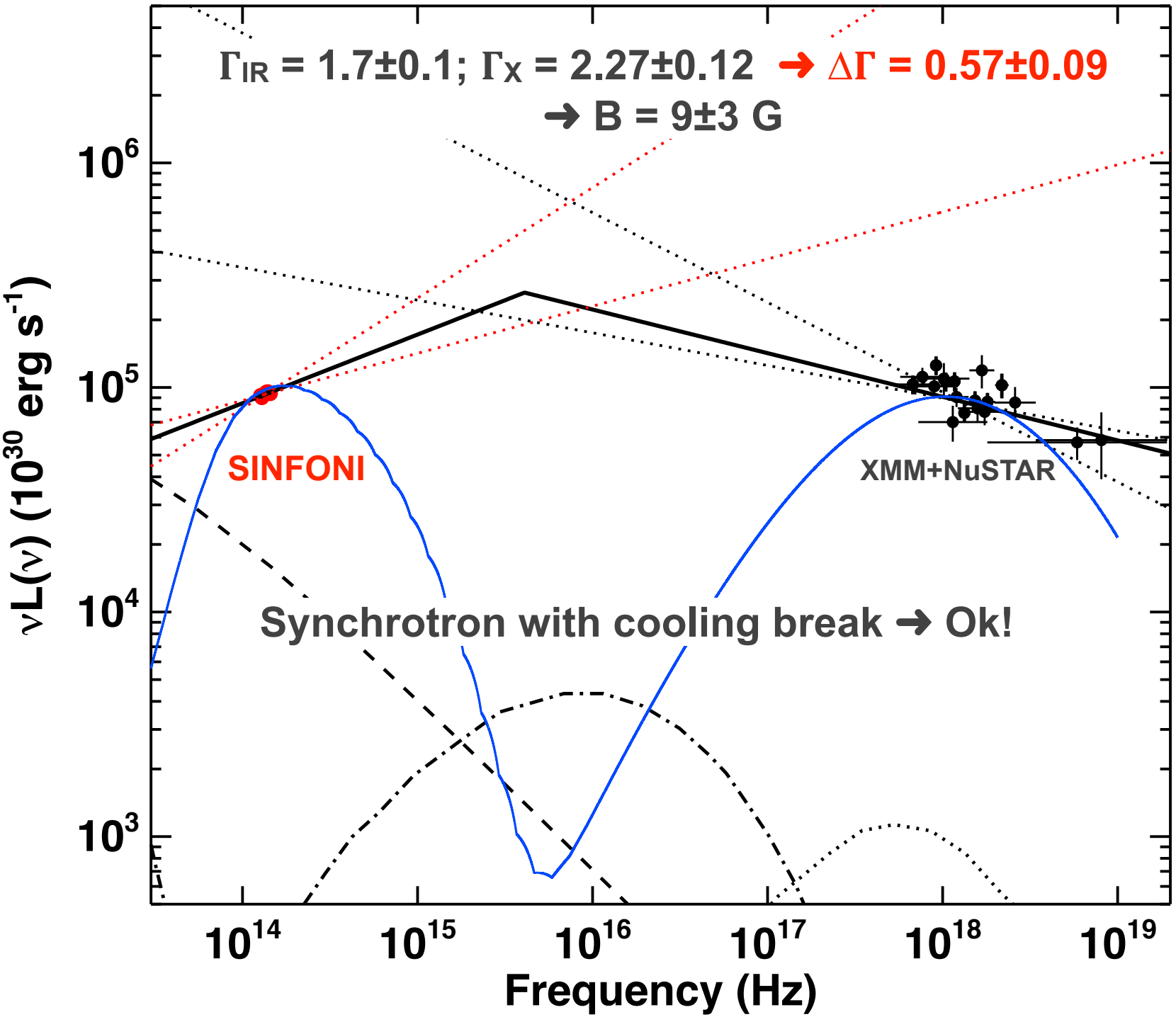


First NIR and X-ray spectrum of a flare!

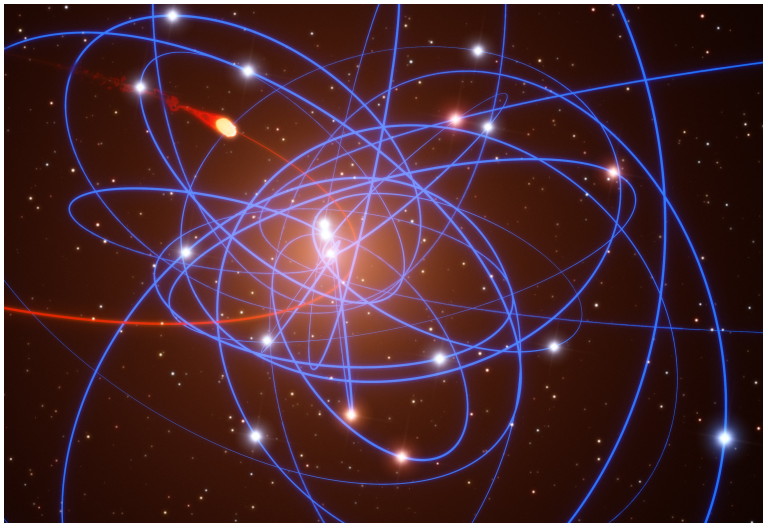


Ponti +17b

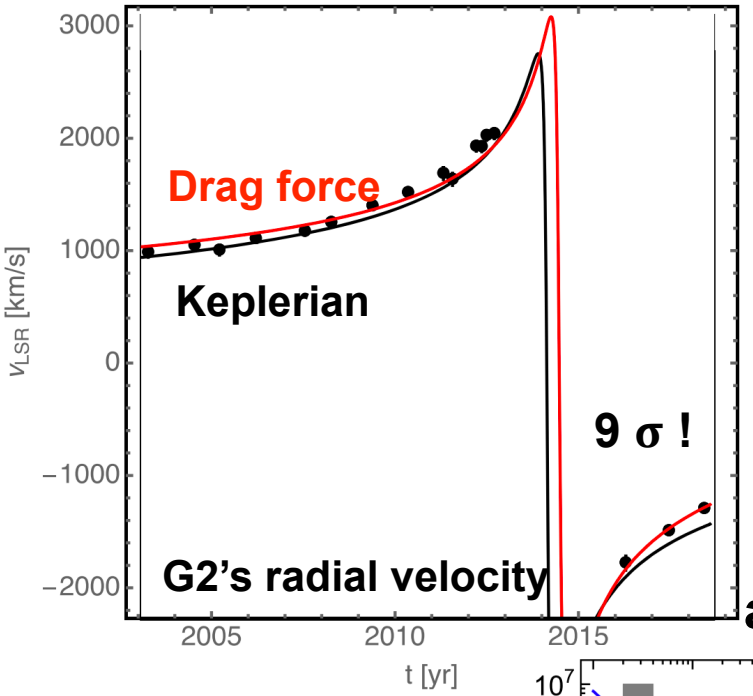
First NIR and X-ray spectrum of a flare!



The GC in IR: the Gravity interferometer

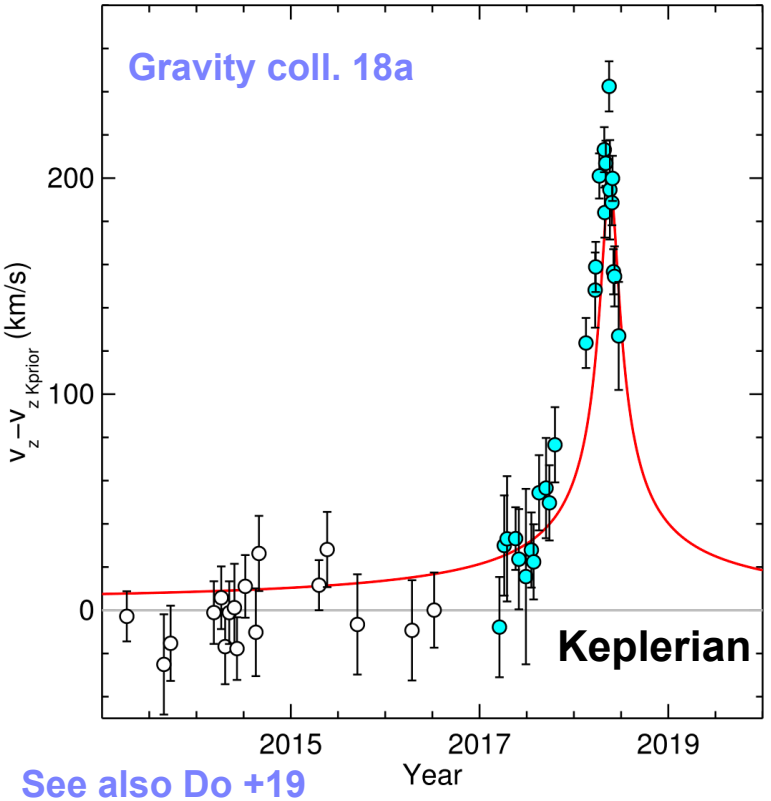


Detection of drag force in G2's orbit



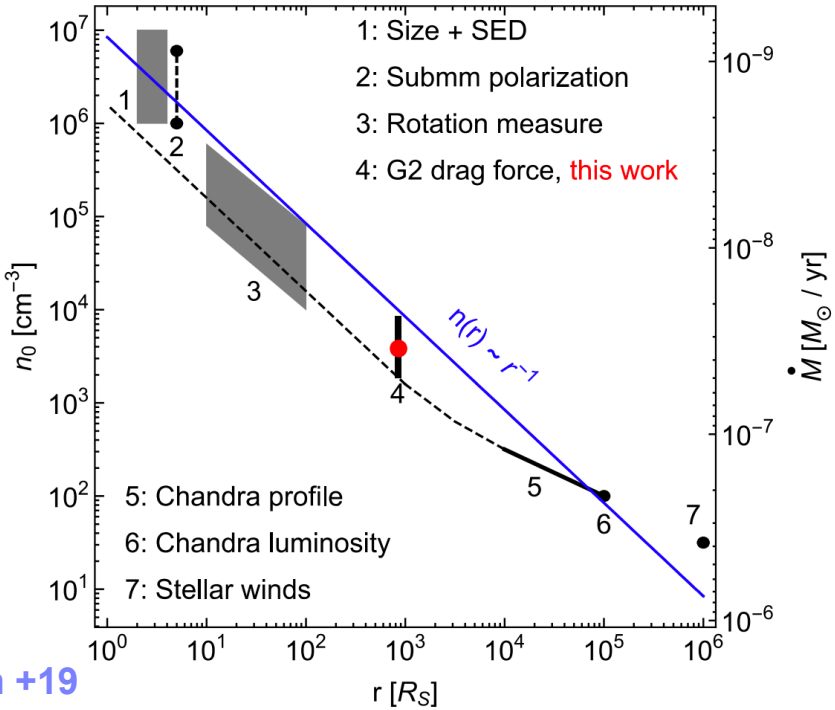
Gillessen +19

Detection of gravitational redshift in the orbit of S2



See also Do +19

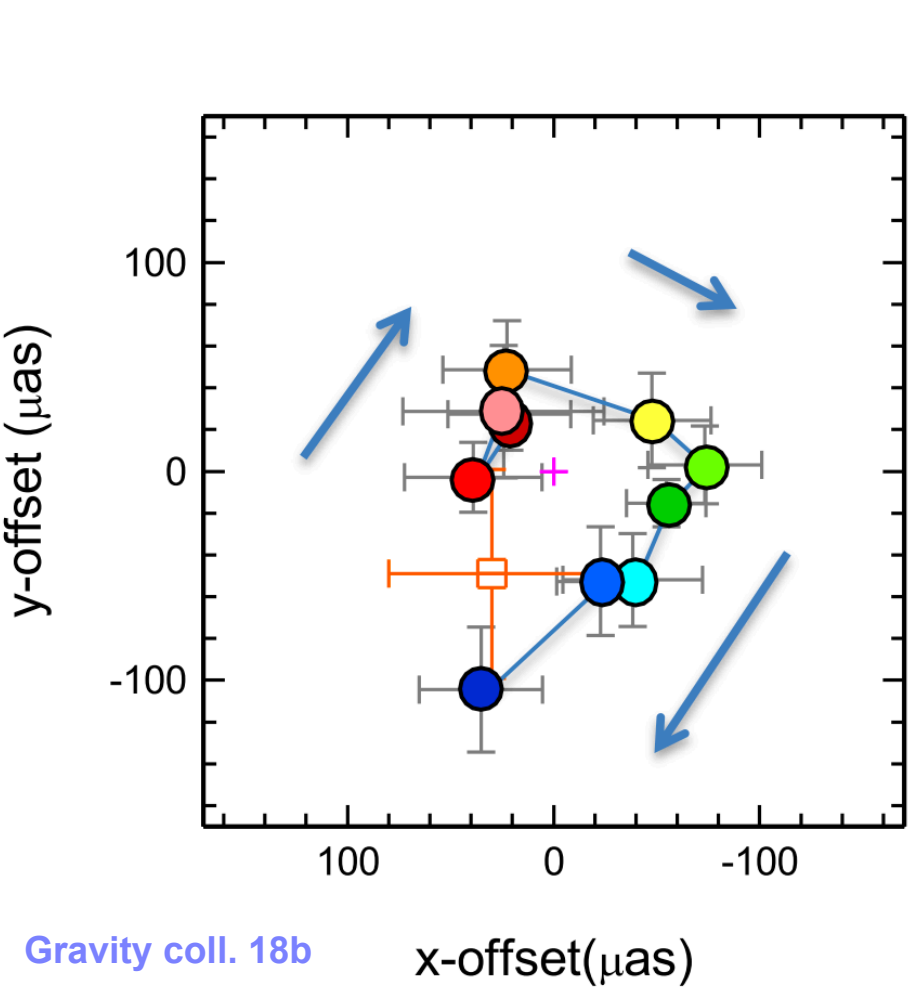
Constraints on the density of Sgr A*'s accretion flow at 10^3 r_g



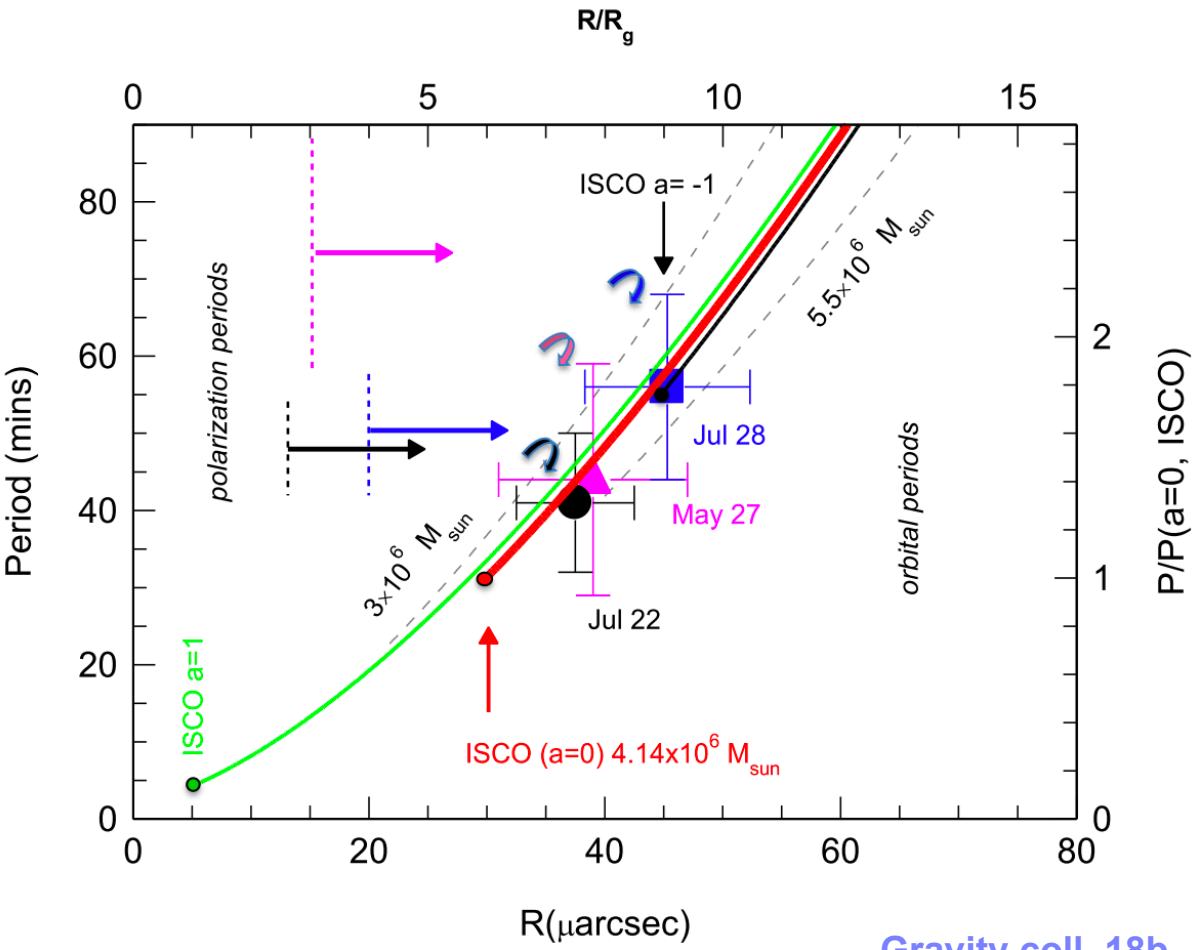
Gillessen +19

The GC in IR: the Gravity interferometer

Detection of orbital motions near the last stable circular orbit of Sgr A*



Gravity coll. 18b



Gravity coll. 18b

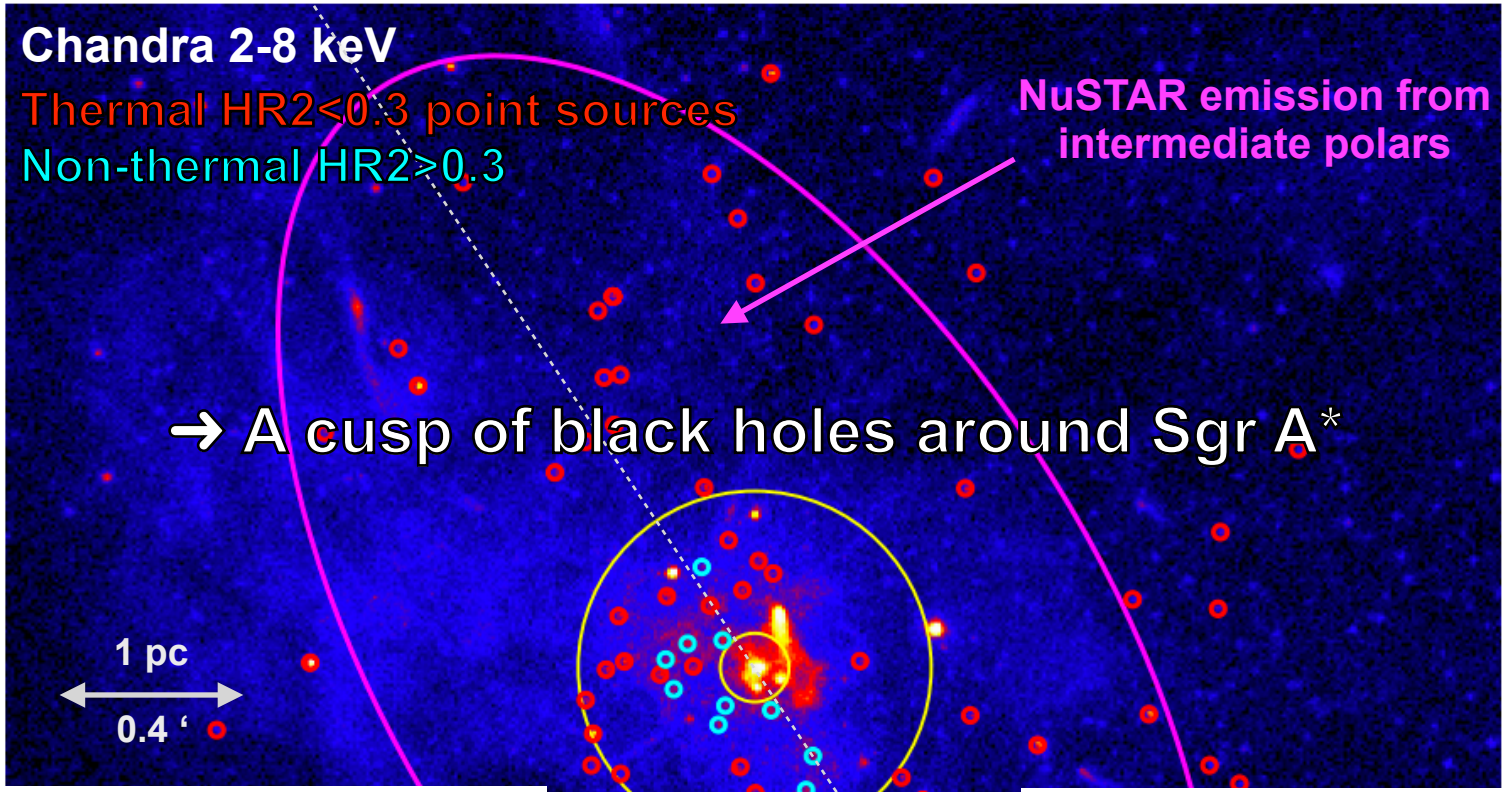
Scales beyond the reach of current X-ray instruments

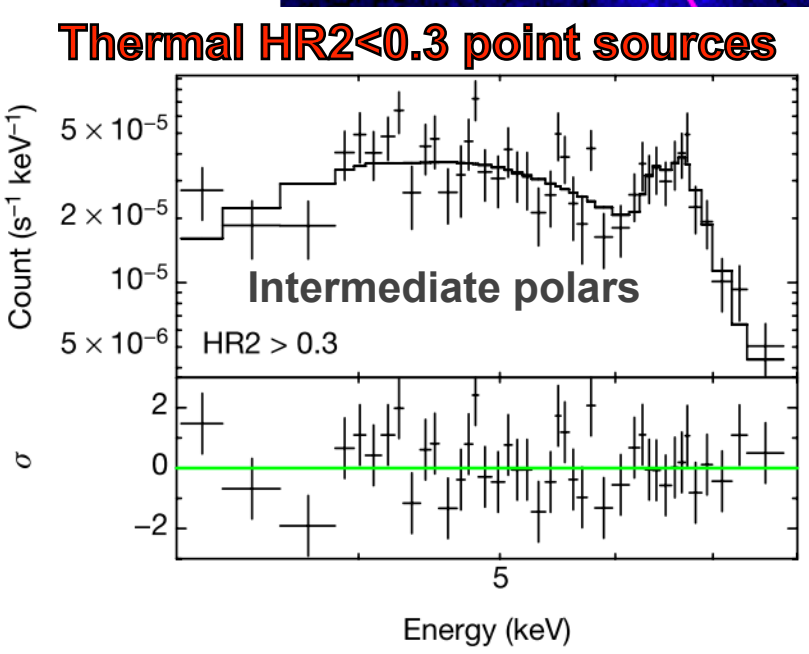
➜ Multi-wavelength campaigns

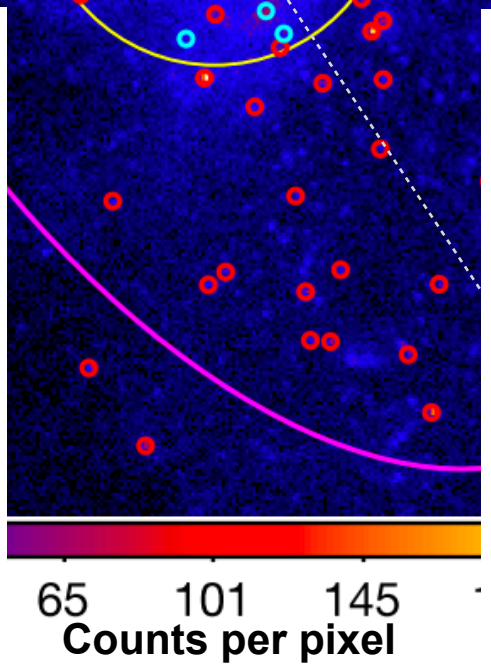
➜ **Larger scales**

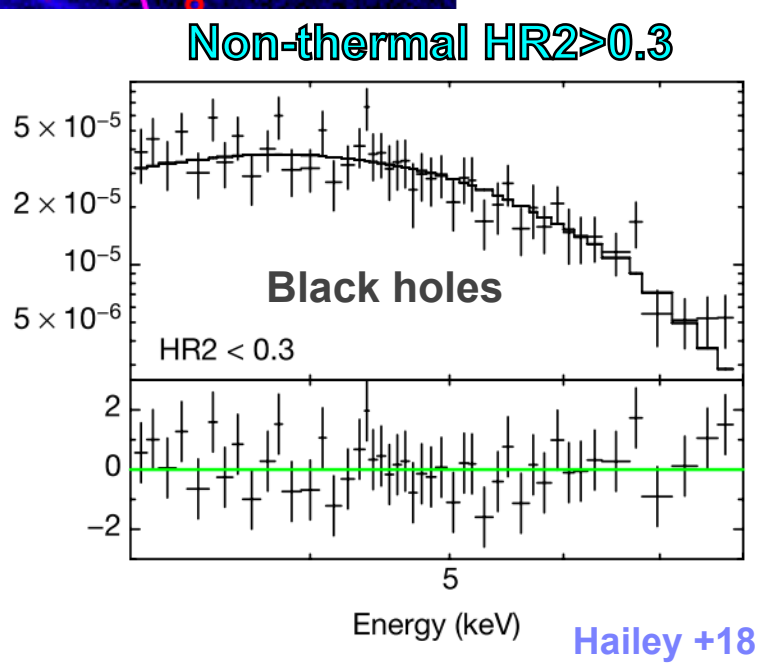
A cusp of black holes around Sgr A*

Hailey +18





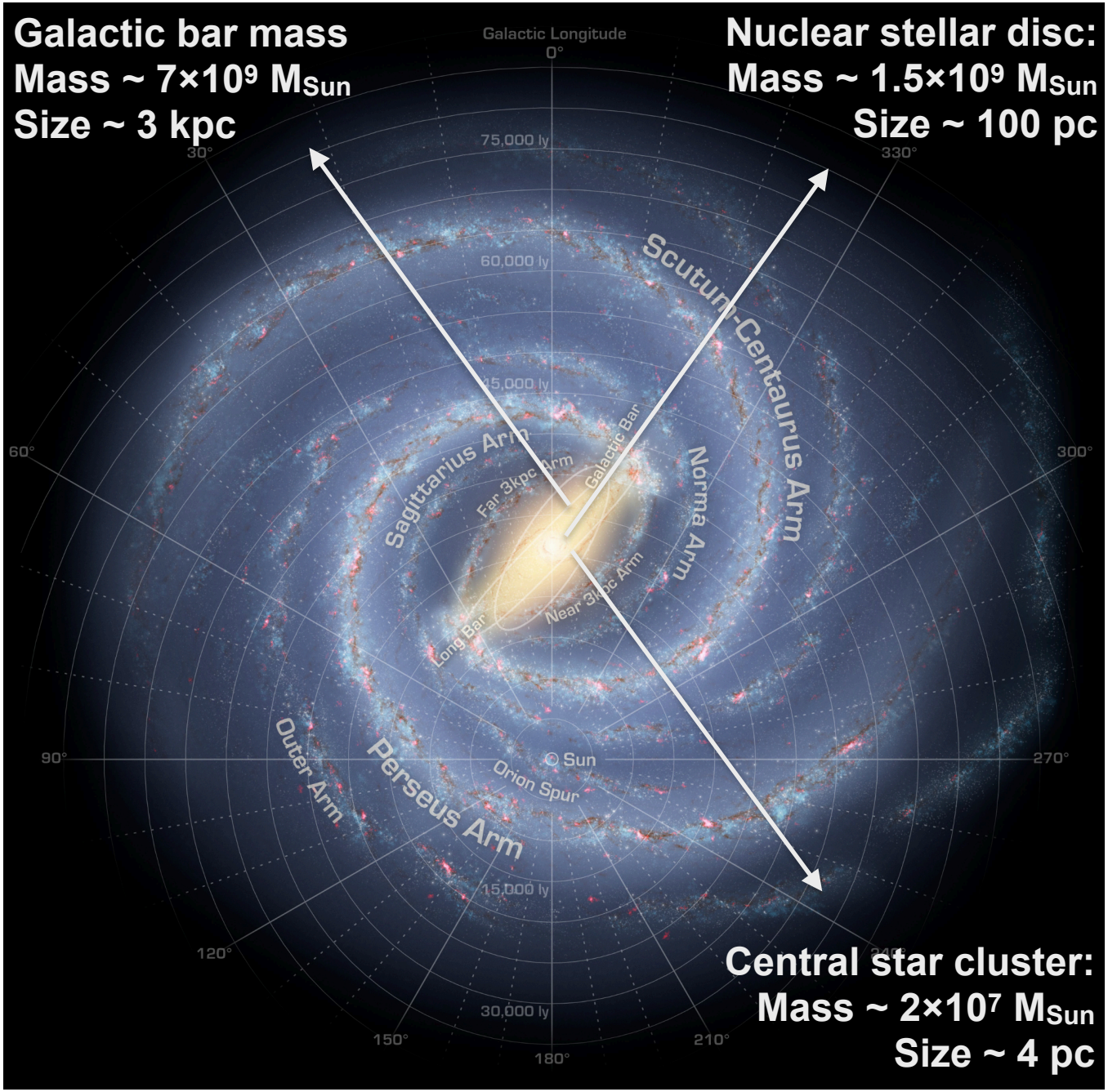




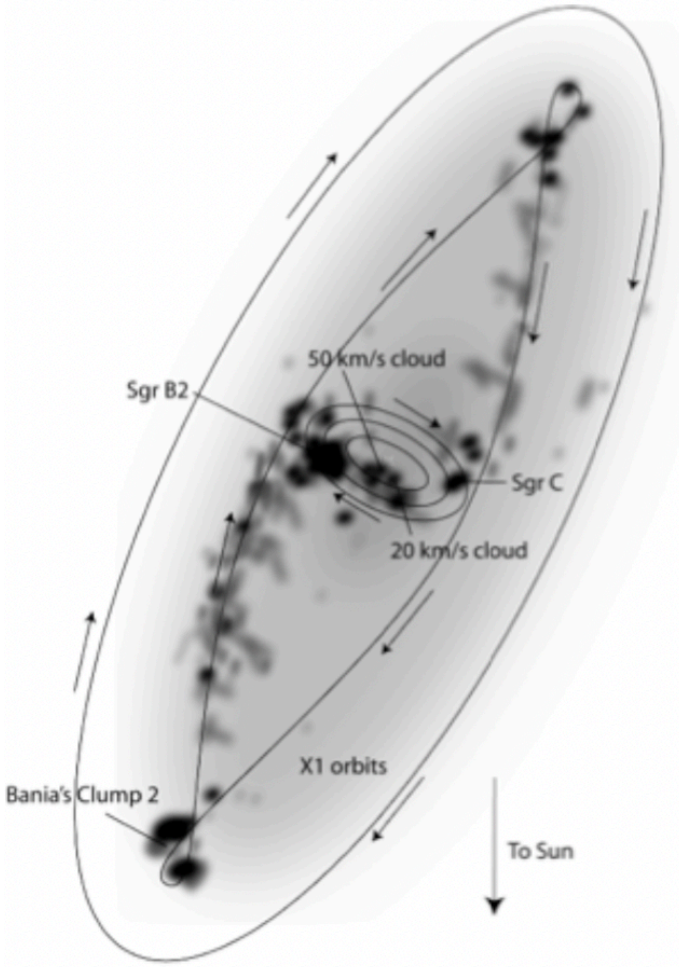
Hailey +18

➜ **Even larger…**

The structure of the Milky Way



From Spitzer/GLIMPSE data Churchwell +09

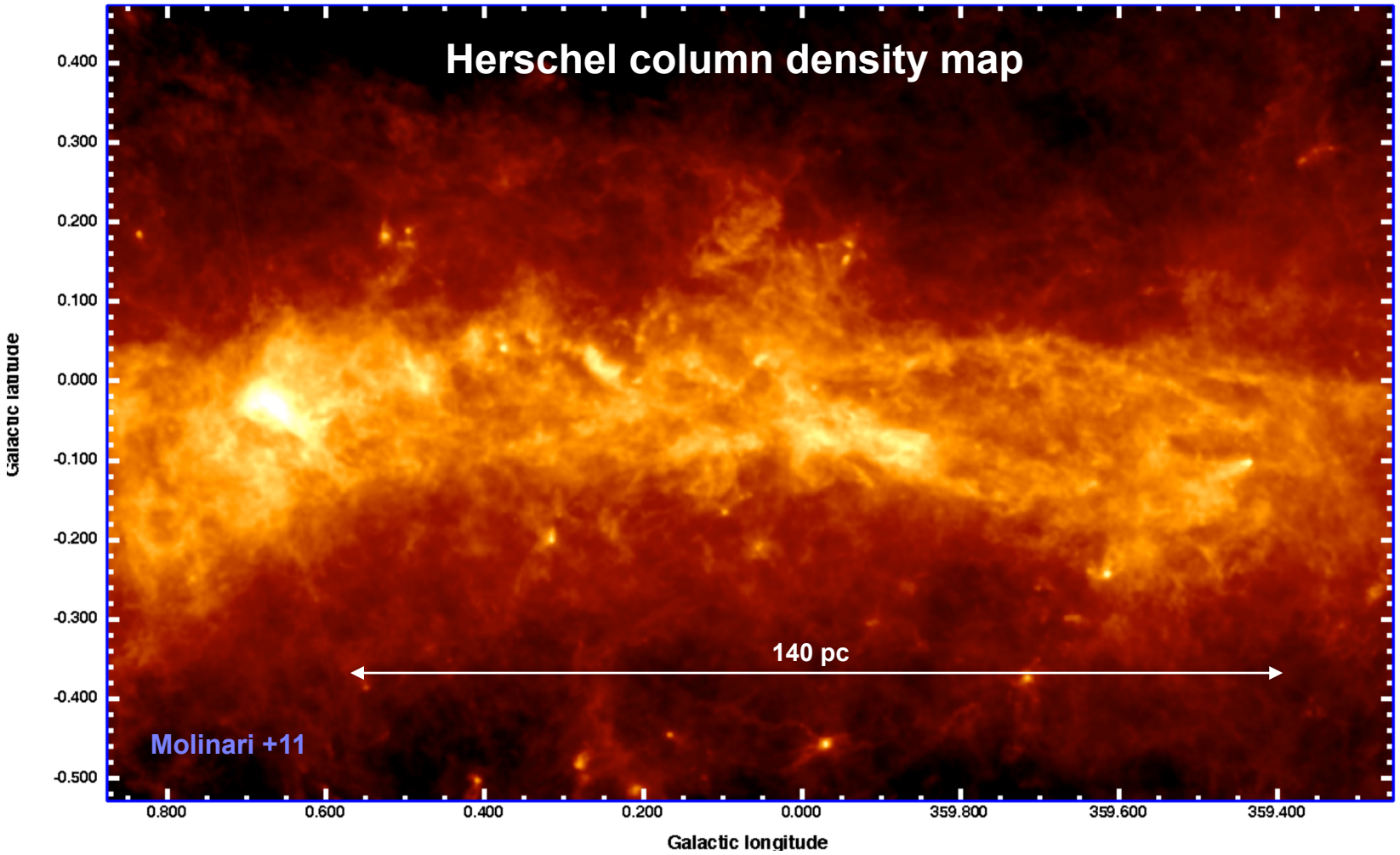


Binney +91; Bally +10; Ridley +17

The central degrees of the Milky Way

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

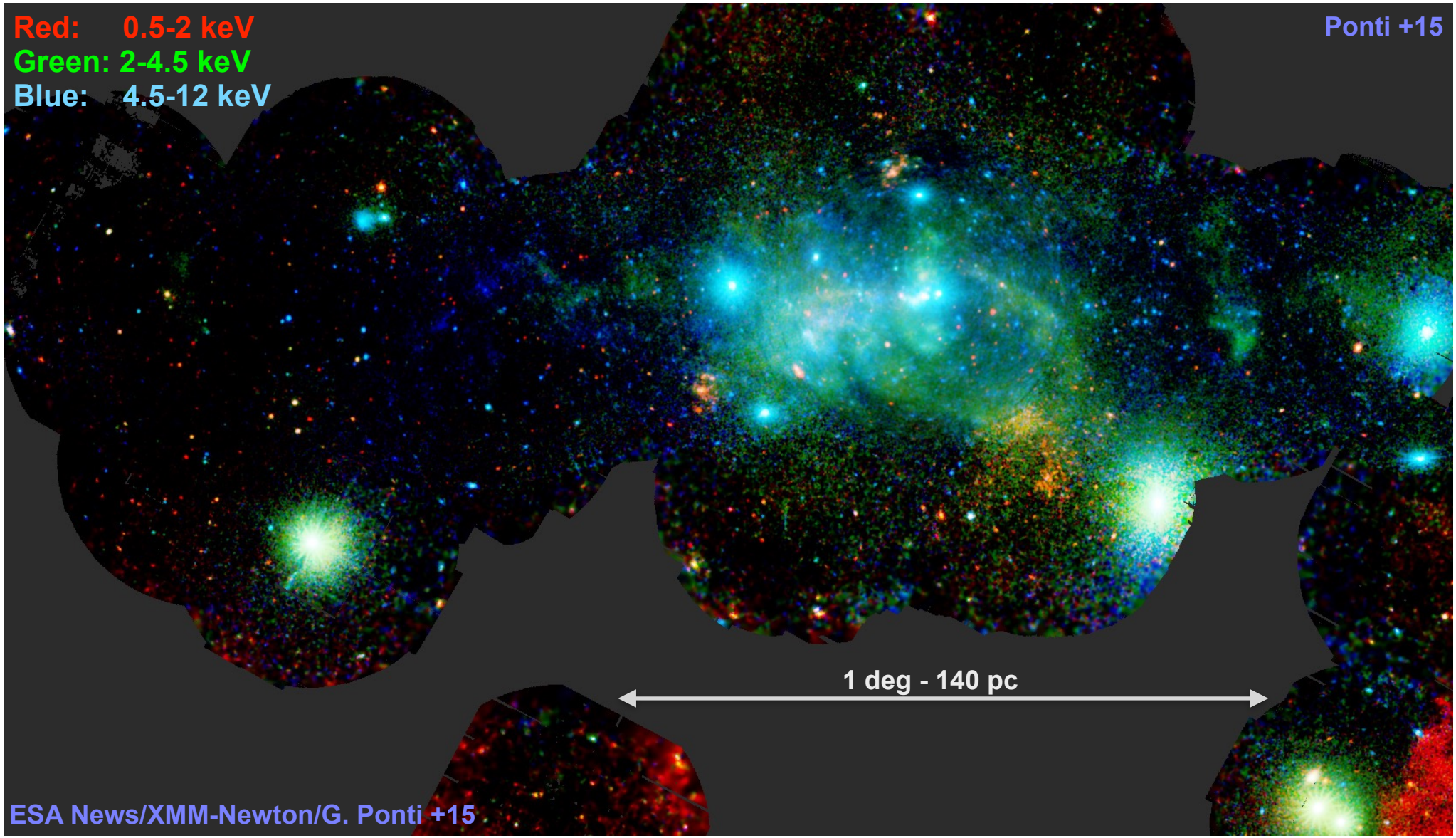
Molinari +11



The new XMM-Newton view of the GC

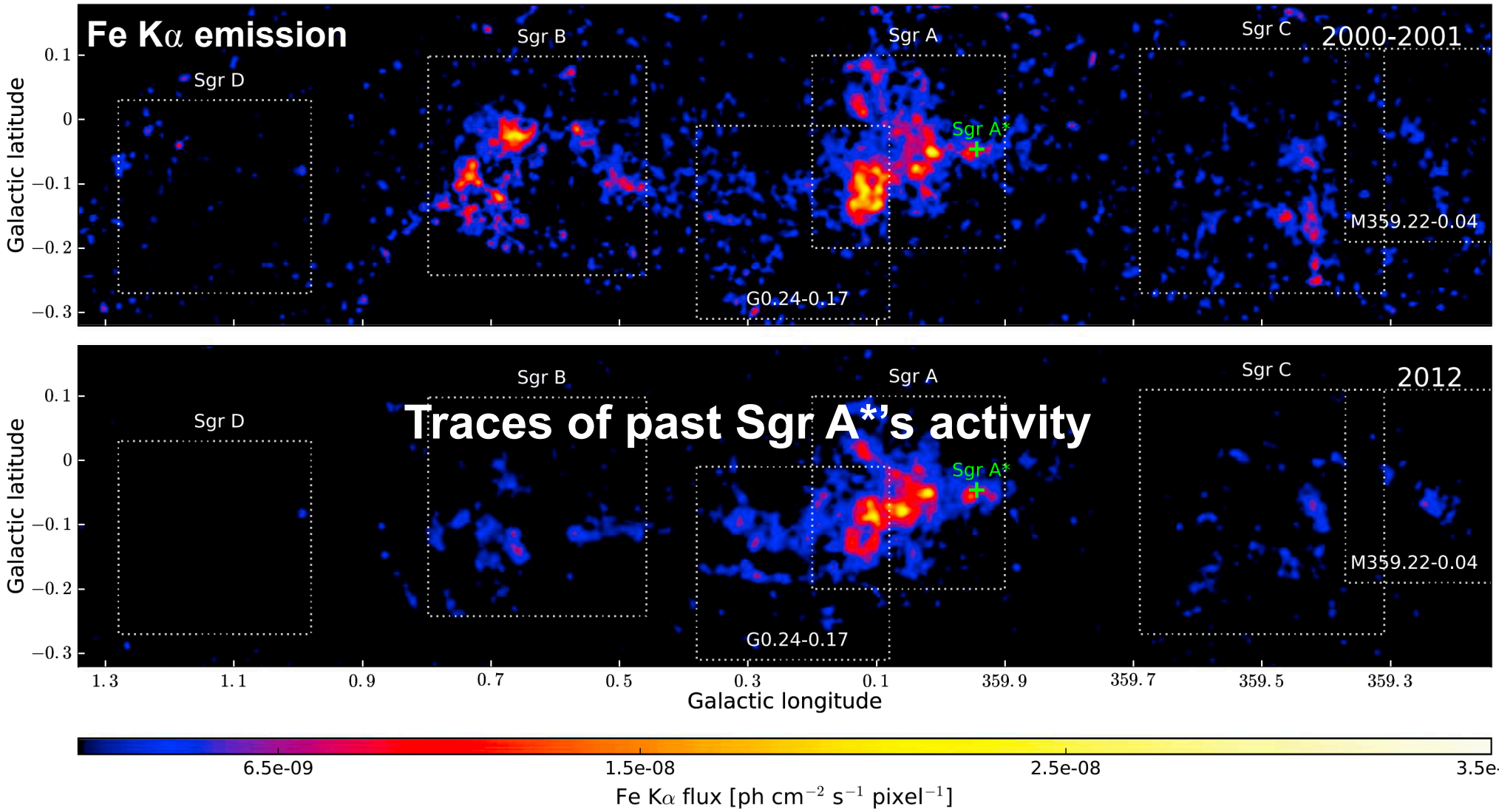
More than 100 EPIC observations

Exposure > 1.5 Ms (central 15')
> 200 ks in the plane



X-ray reflection clouds: Sgr A*'s past activity

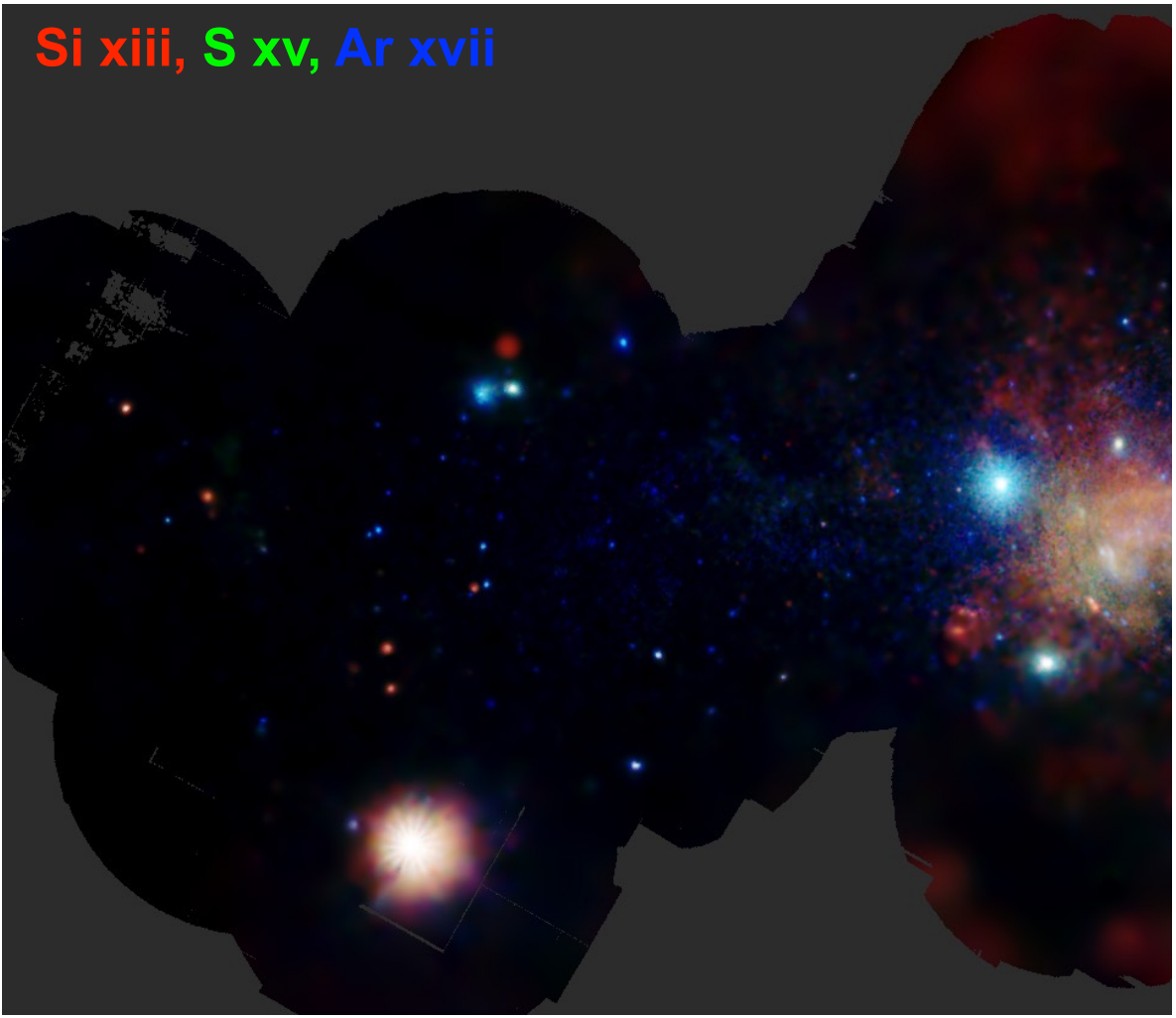
Terrier +18



See also Clavel +13; +14; Marin +14; Zhang +15; Mori +15; Nobukawa +15; +16; Walls + 16; Krivonos +14; +17; Churazov +17a,b,c; Chuard +18; Chernyshov +18; Kuznetsova +19

See Goldwurm's talk!

Soft X-ray lines: SNR, bubbles and outflows!



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

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}

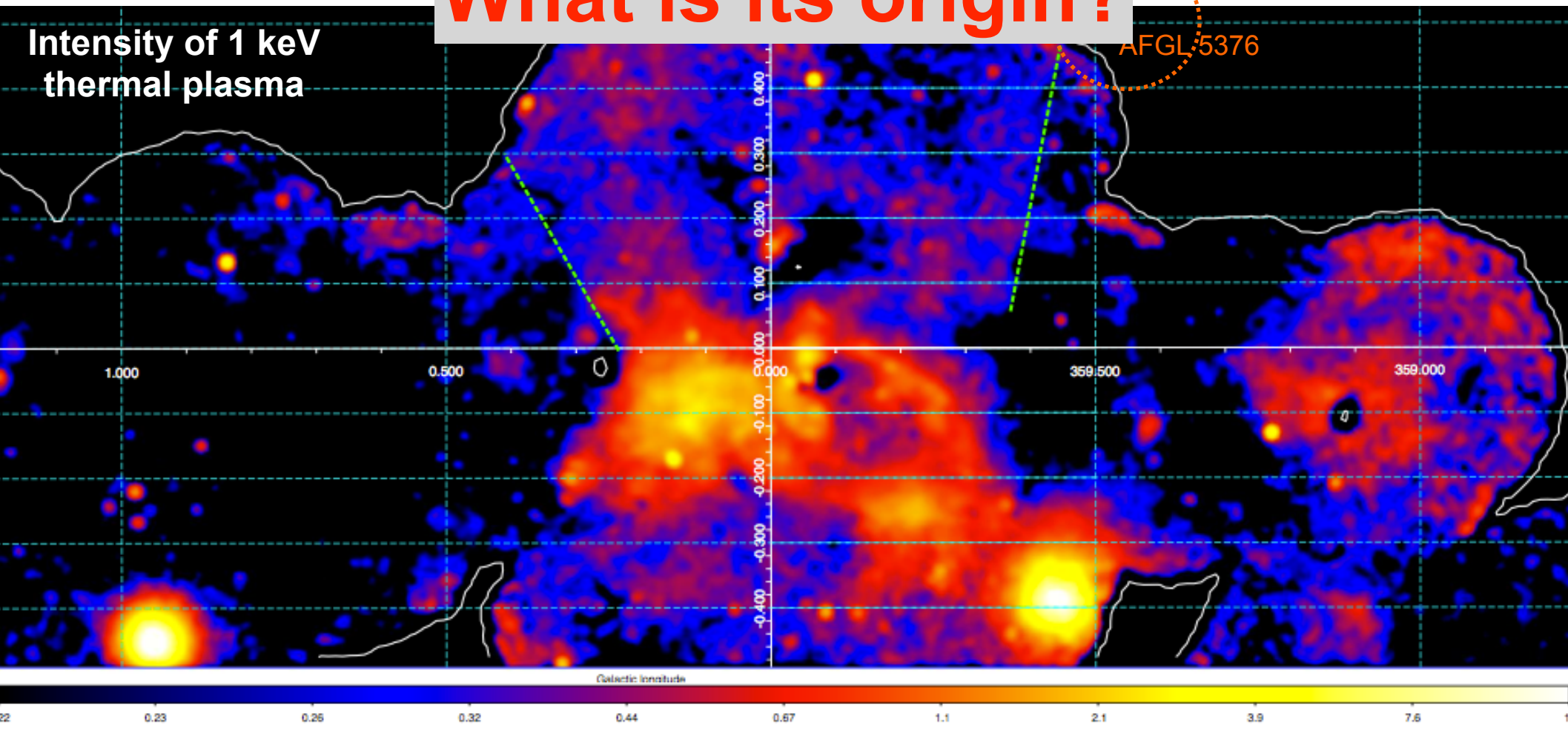
➜ Powering outflows to GC lobe?

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

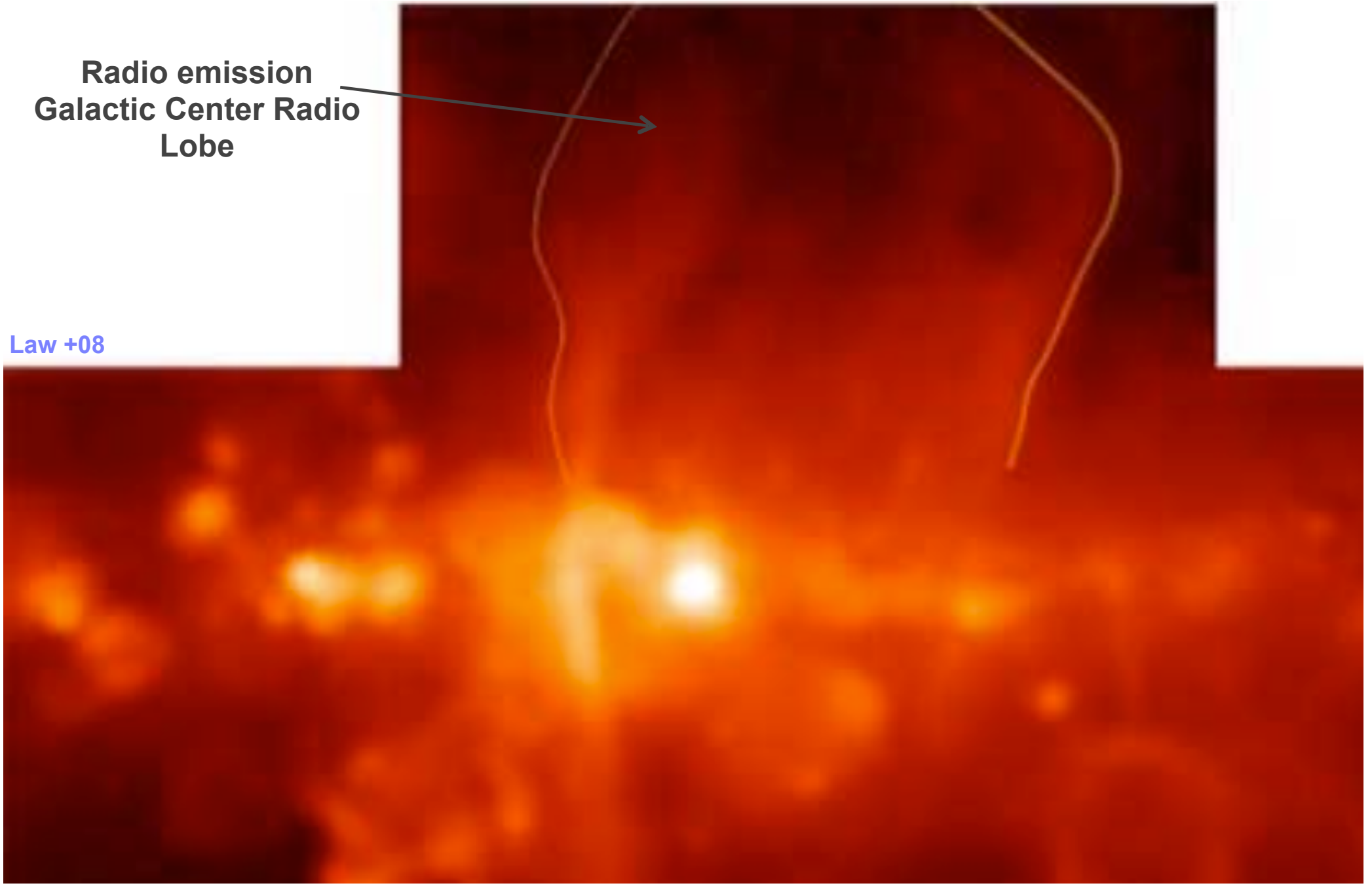
Discovery of high latitude 1 keV plasma

Ponti +15

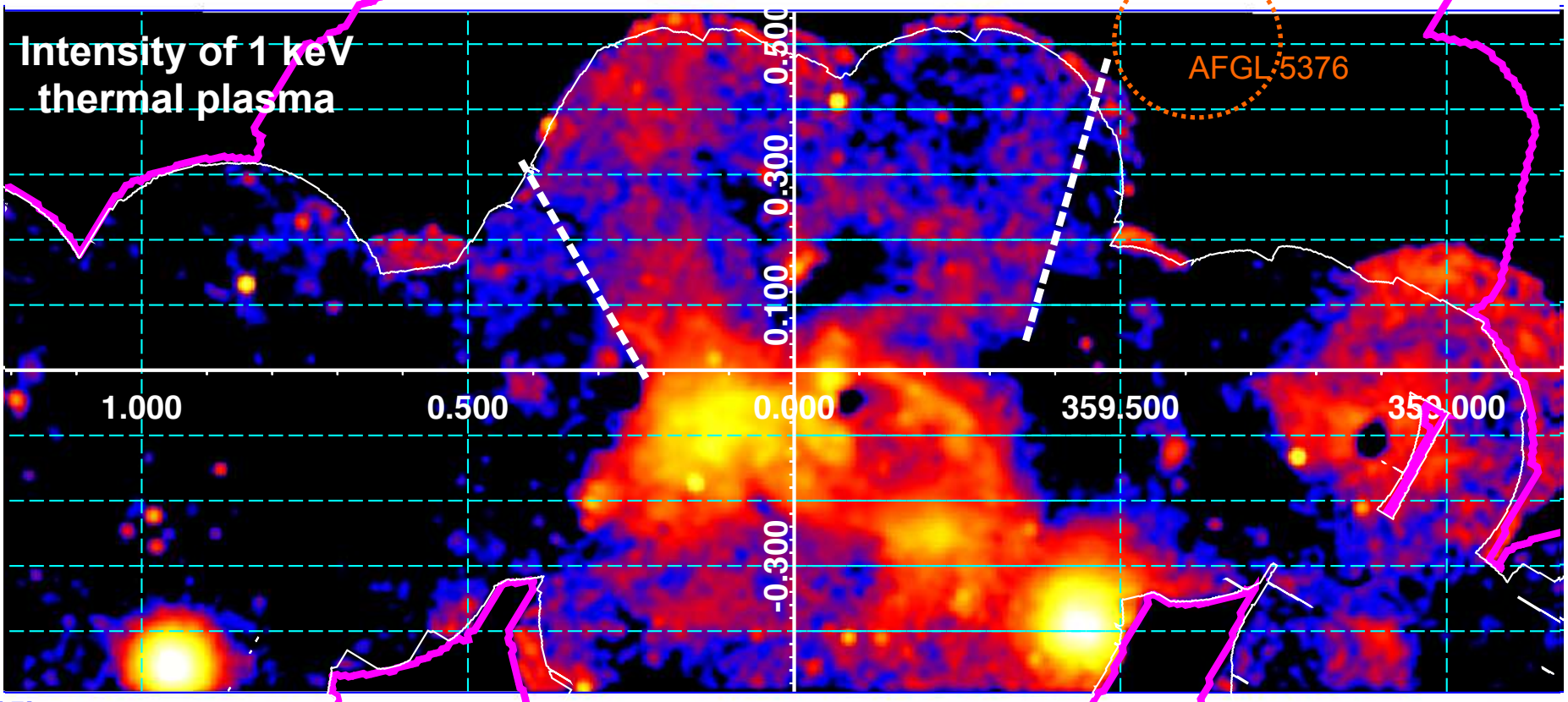
What is its origin?



High latitude 1 keV plasma



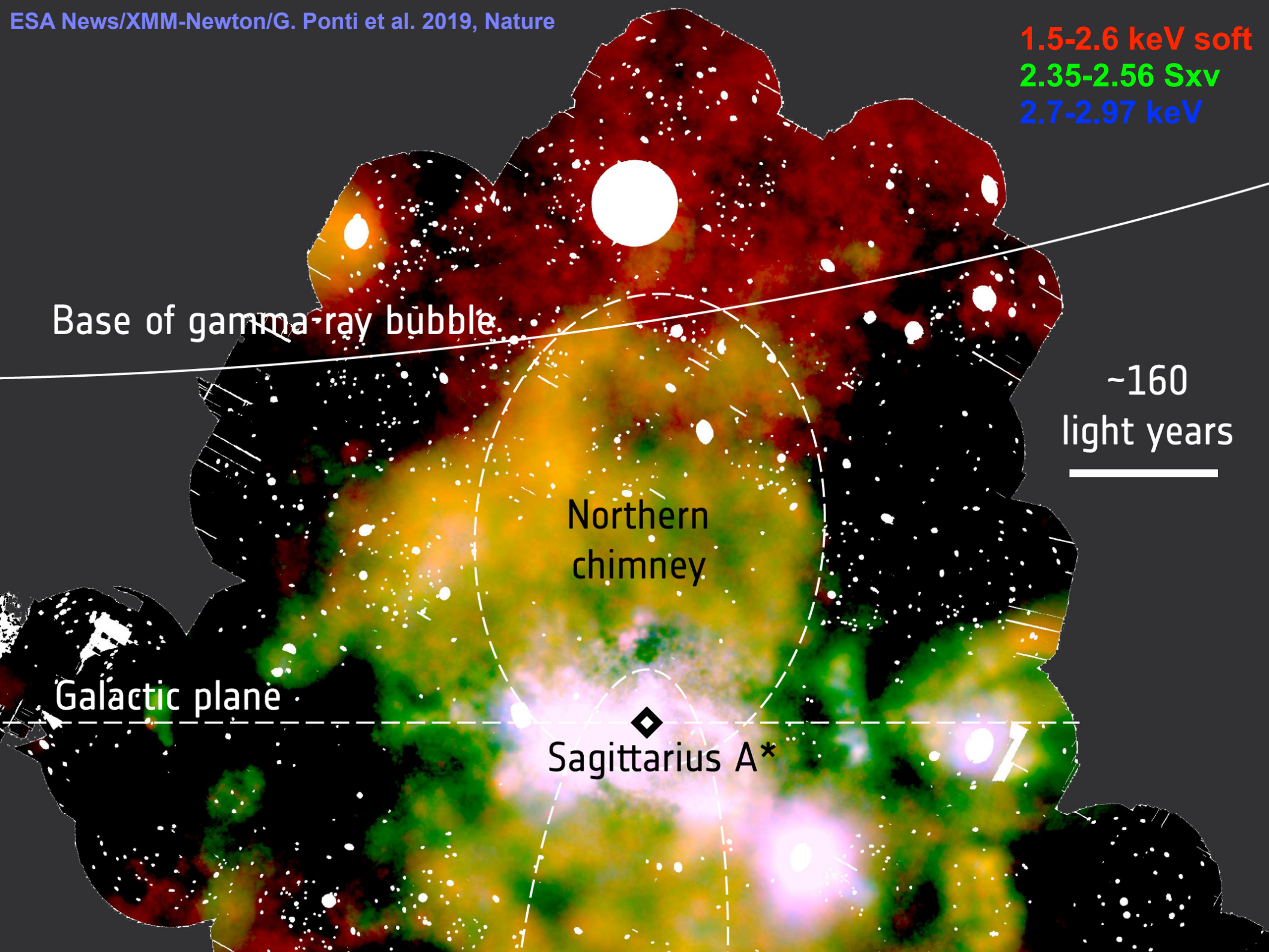
High latitude 1 keV plasma

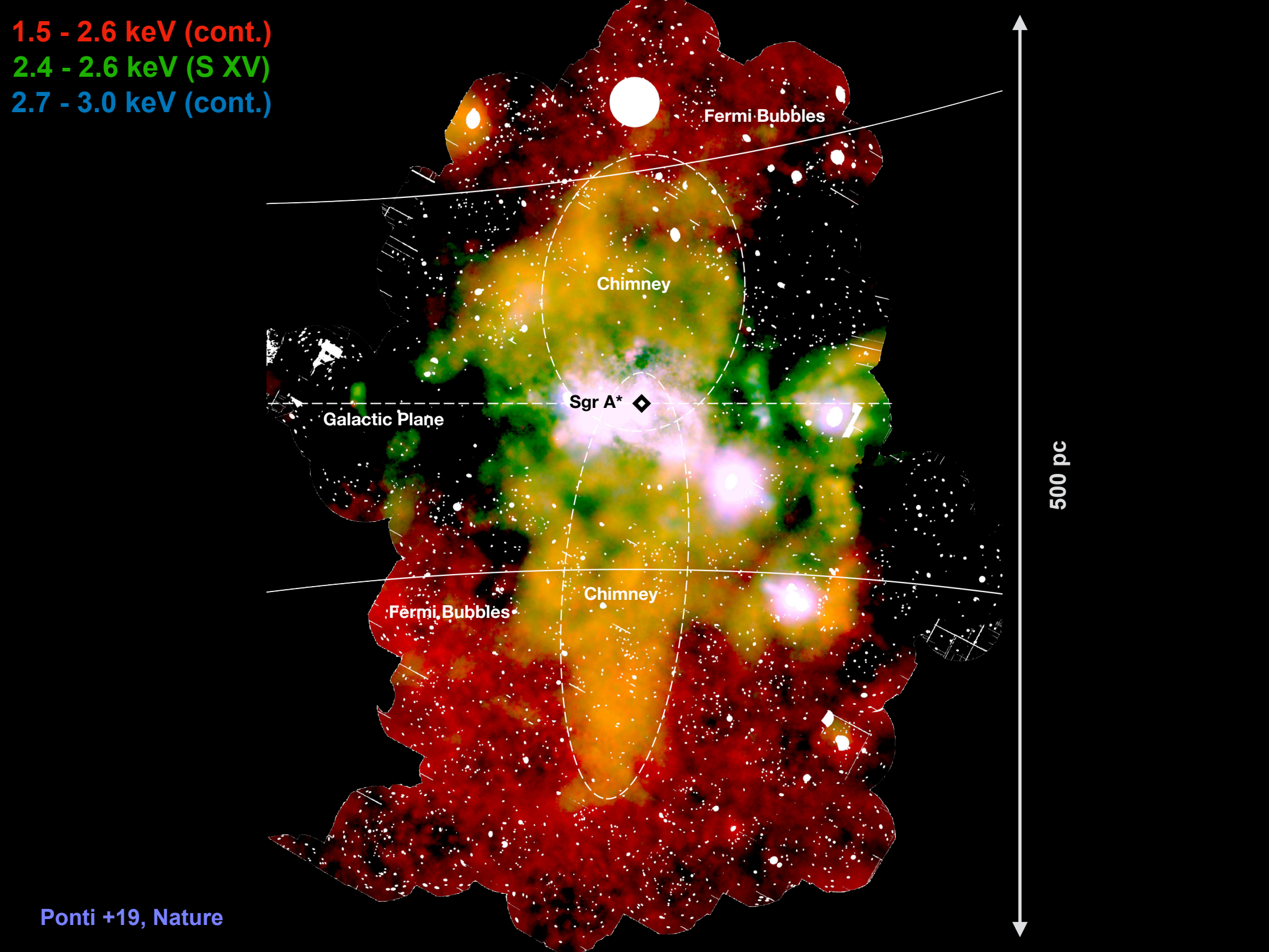


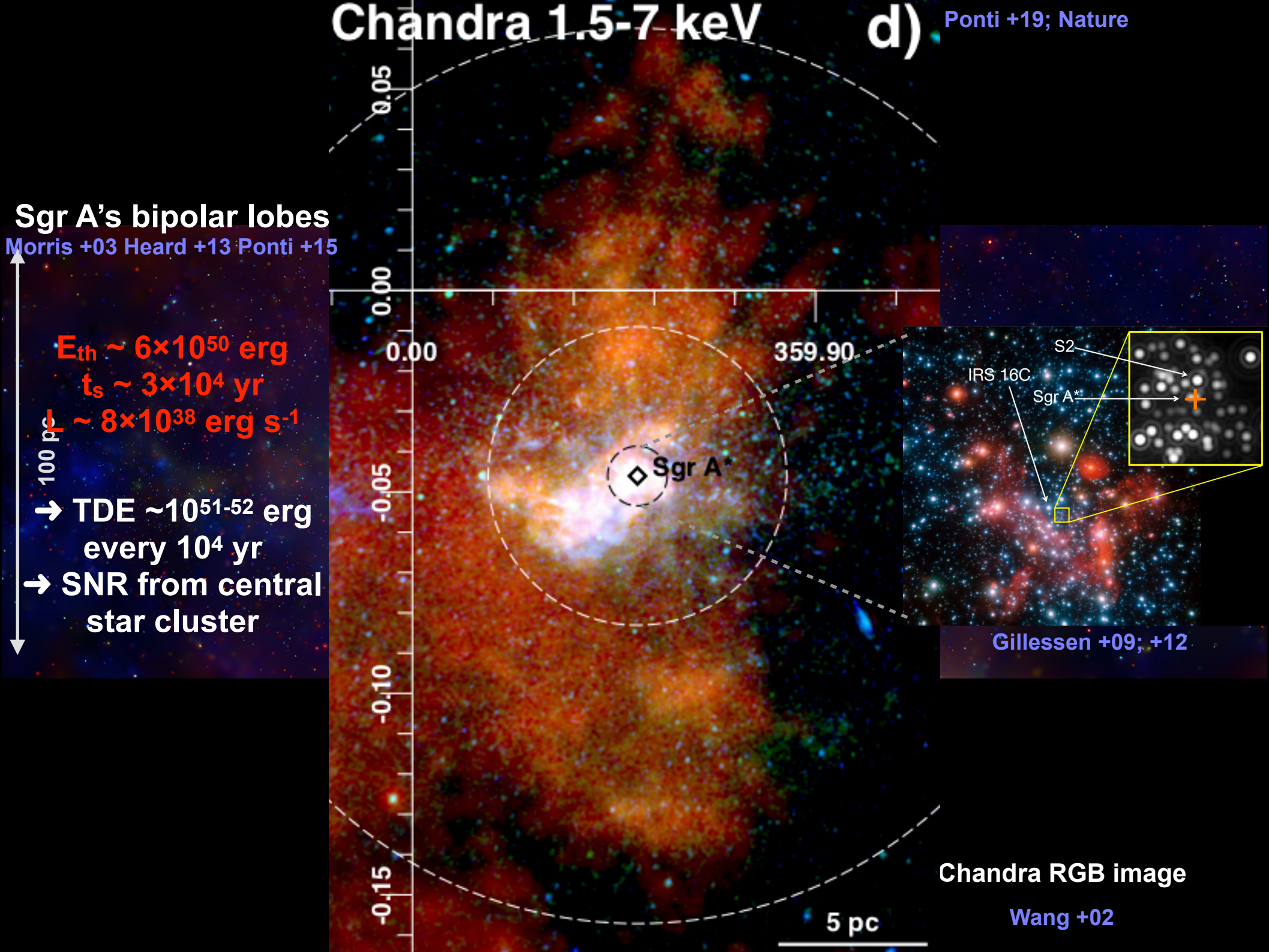
Ponti +15b

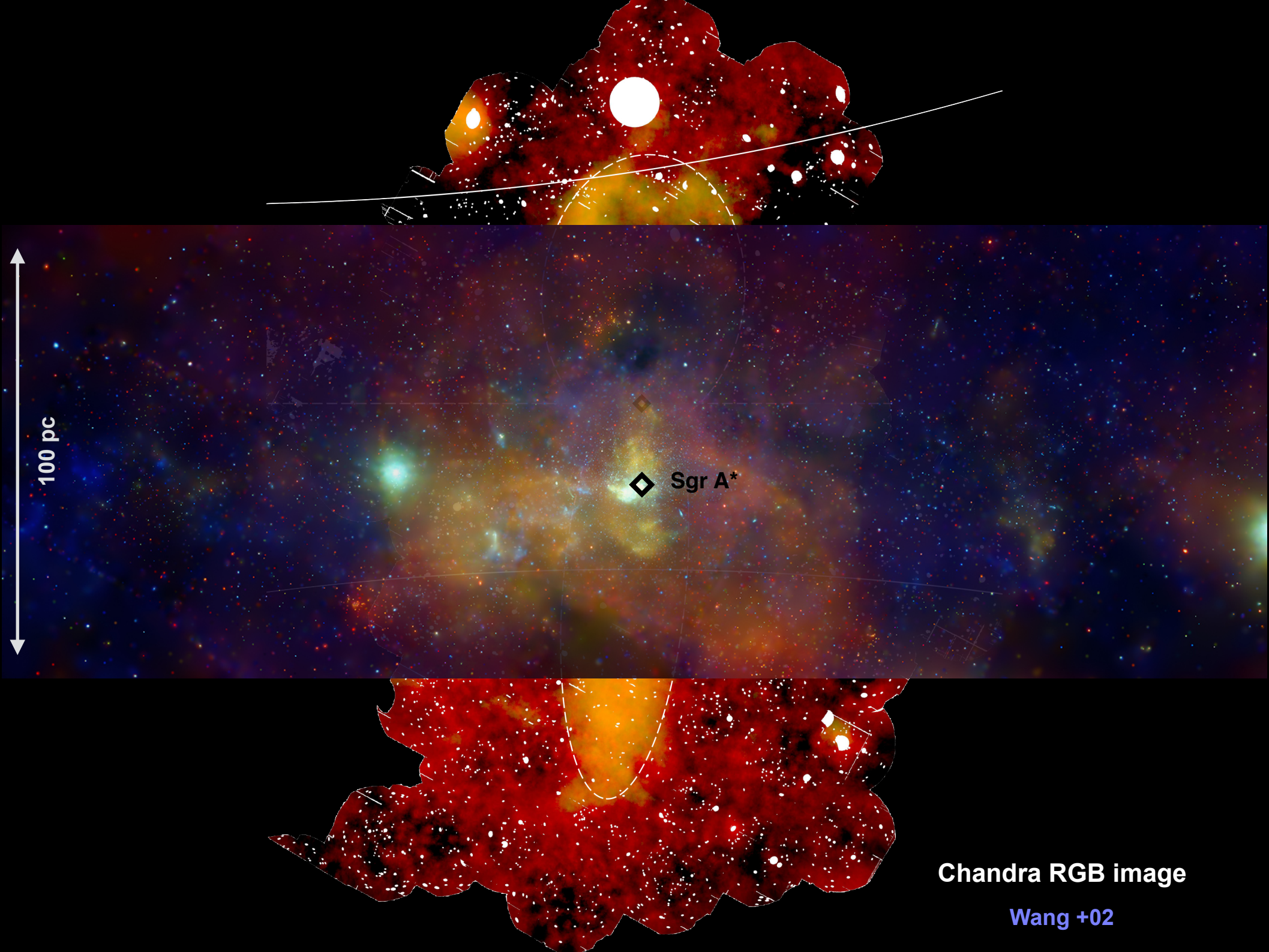
XMM LARGE PROJECT

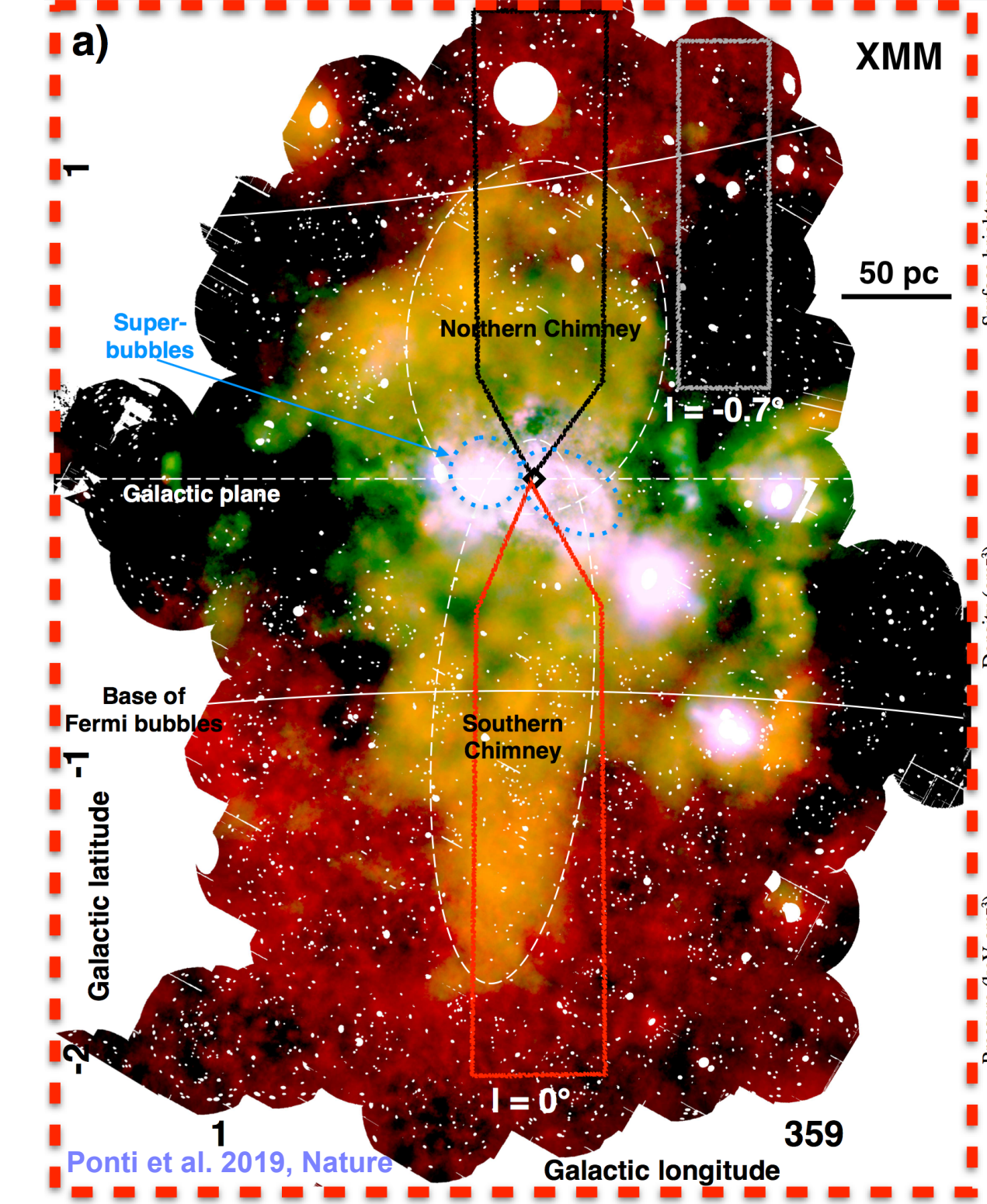
Suspense….

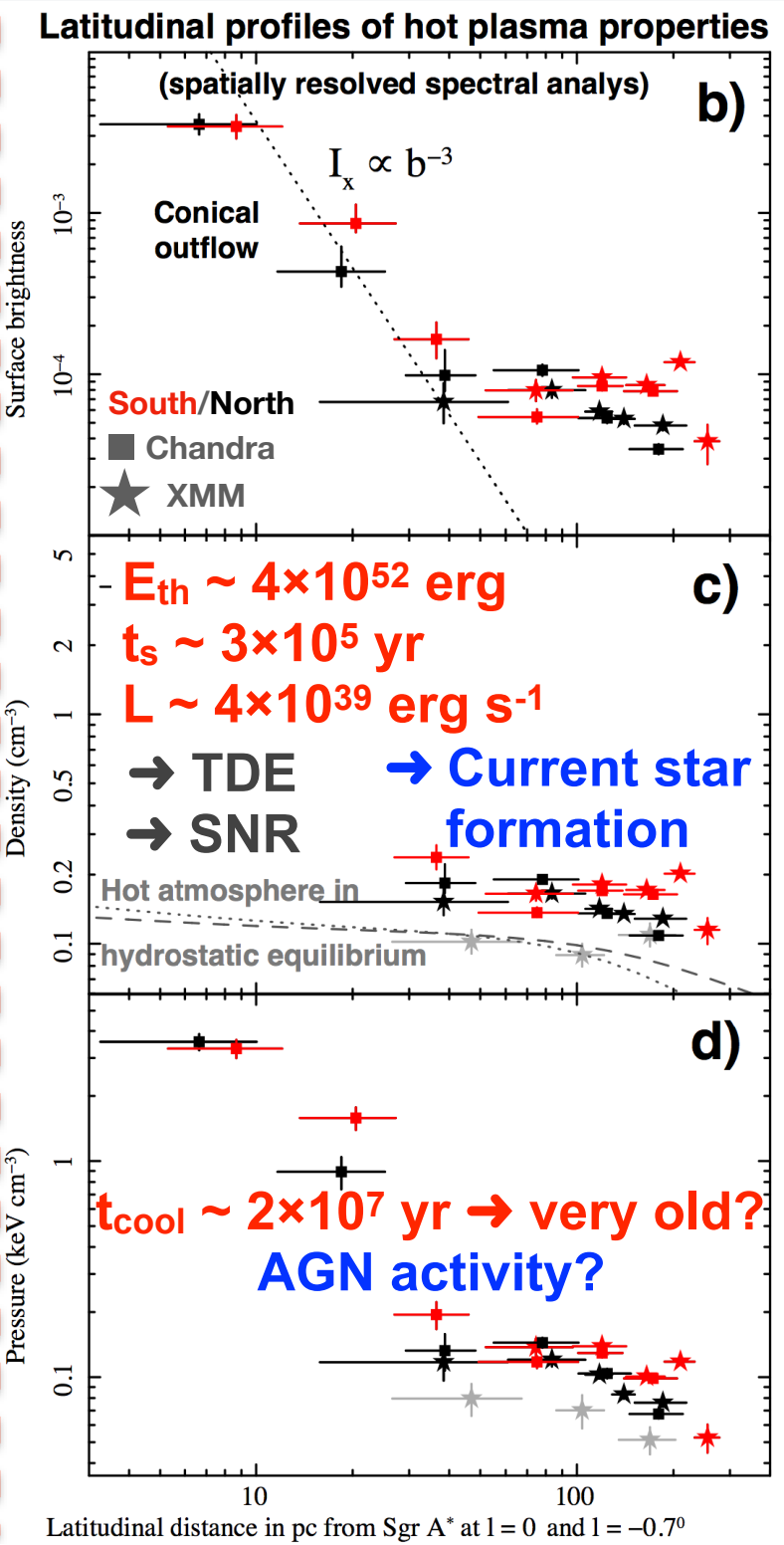

ESA News/XMM-Newton/G. Ponti et al. 2019, Nature
1.5-2.6 keV soft
2.35-2.56 Sxv
2.7-2.97 keV
Base of gamma-ray bubble
~160
light years
Northern
chimney
Galactic plane
Sagittarius A*

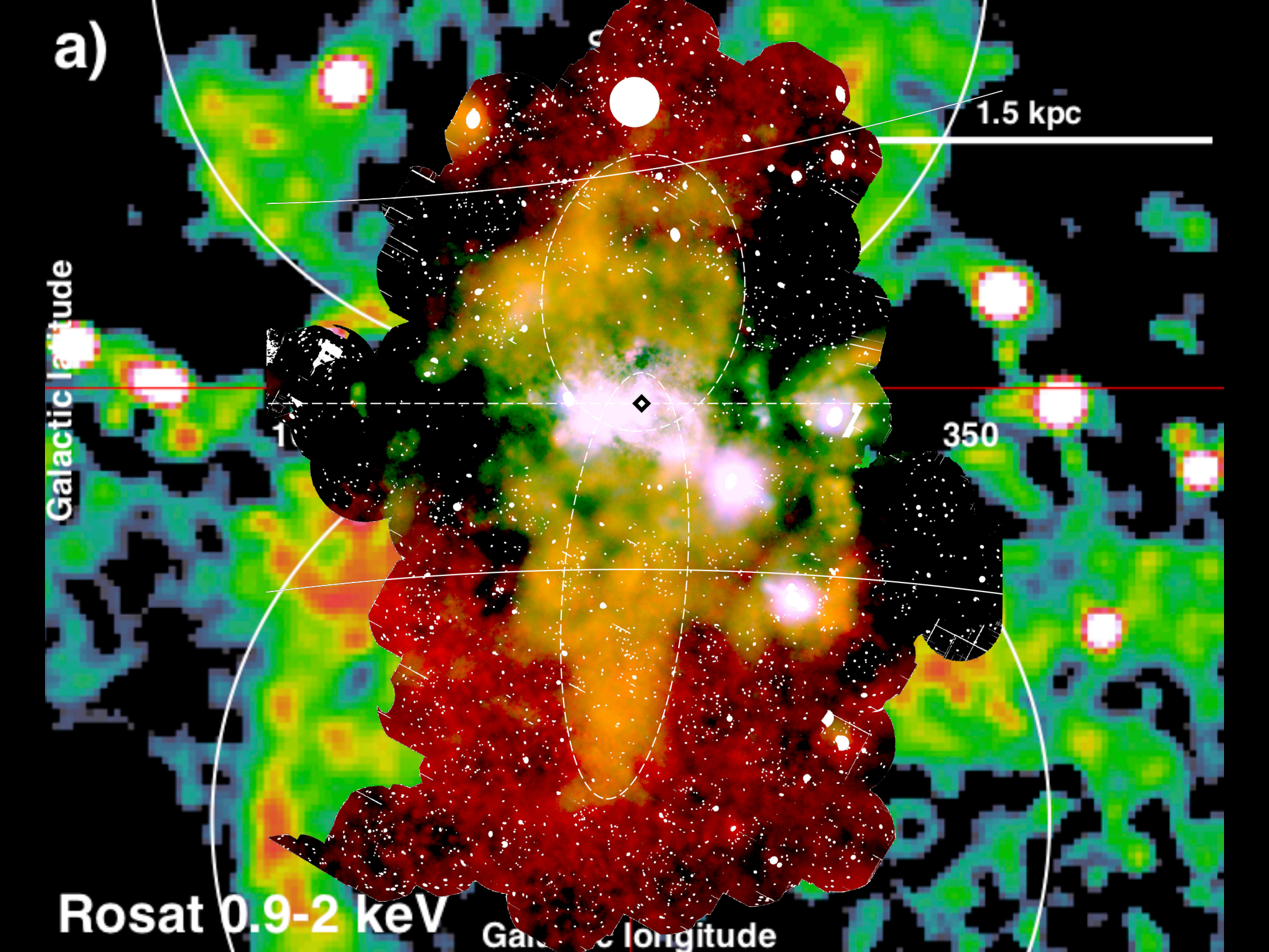

1.5 - 2.6 keV (cont.)
2.4 - 2.6 keV (S XV)
2.7 - 3.0 keV (cont.)
Fermi Bubbles
Chimney
Sgr A*
Galactic Plane
Chimney
Fermi Bubbles
500 pc
Ponti +19, Nature

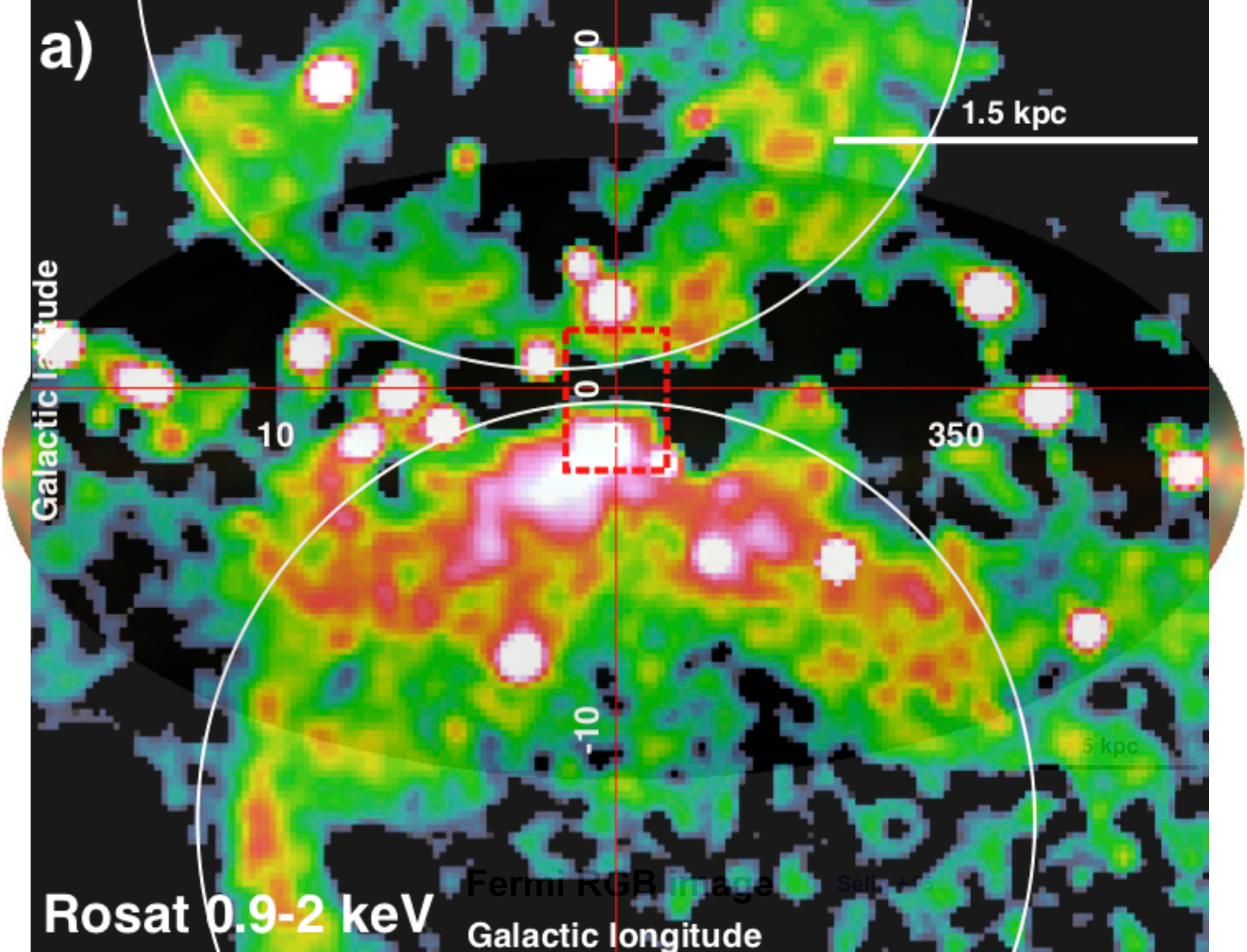

Chandra 1.5-7 keV
d)
Ponti +19; Nature
Sgr A's bipolar lobes
Morris +03 Heard +13 Ponti +15
100 pc
E_{th} ~ 6×10^{50} erg
t_s ~ 3×10^4 yr
L ~ 8×10^{38} erg s^{-1}
➜ TDE ~10$^{51-52}$ erg every 10^4 yr
➜ SNR from central star cluster
0.05
0.00
-0.05
-0.10
-0.15
0.00
359.90
Sgr A*
S2
IRS 16C
Sgr A*
Gillessen +09; +12
5 pc
Chandra RGB image
Wang +02


100 pc
Sgr A*
Chandra RGB image
Wang +02

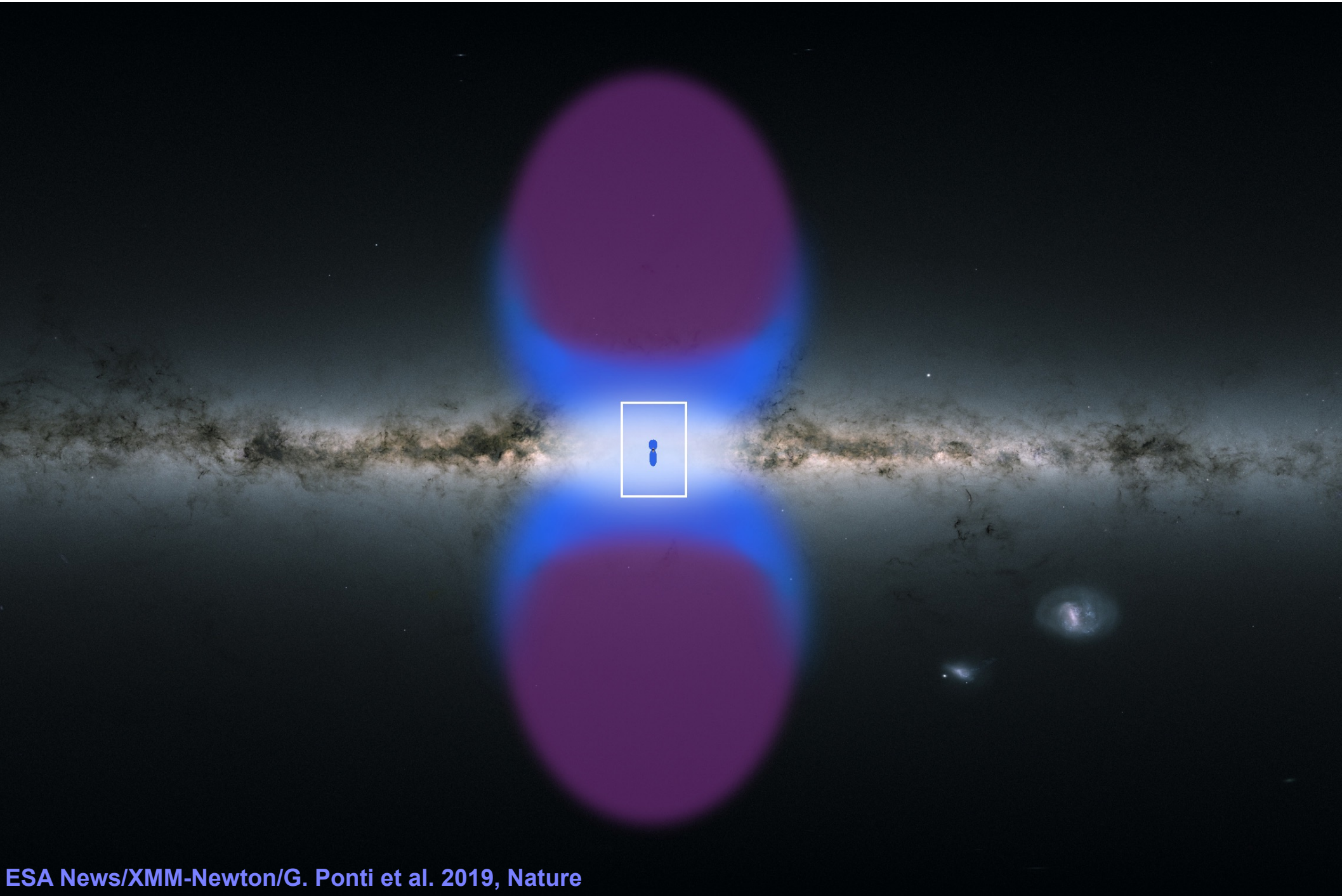

a)
XMM
50 pc
Super-
bubbles
Northern Chimney
l = -0.7°
Galactic plane
Base of
Fermi bubbles
Southern
Chimney
l = 0°
Galactic latitude
Galactic longitude
1
-1
-2
359
Ponti et al. 2019, Nature


Latitudinal profiles of hot plasma properties
(spatially resolved spectral analys)
b)
$I_x \propto b^{-3}$
Conical
outflow
South/North
Chandra
XMM
Surface brightness
10^{-3}
10^{-4}
c)
$E_{th} \sim 4\times10^{52}$ erg
$t_s \sim 3\times10^5$ yr
$L \sim 4\times10^{39}$ erg s^{-1}
➜ TDE
➜ SNR
➜ Current star formation
Hot atmosphere in
hydrostatic equilibrium
Density (cm^{-3})
5
2
1
0.5
0.2
0.1
d)
$t_{cool} \sim 2\times10^7$ yr ➜ very old?
AGN activity?
Pressure (keV cm^{-3})
1
0.1
10
100
Latitudinal distance in pc from Sgr A* at l = 0 and l = –0.7°

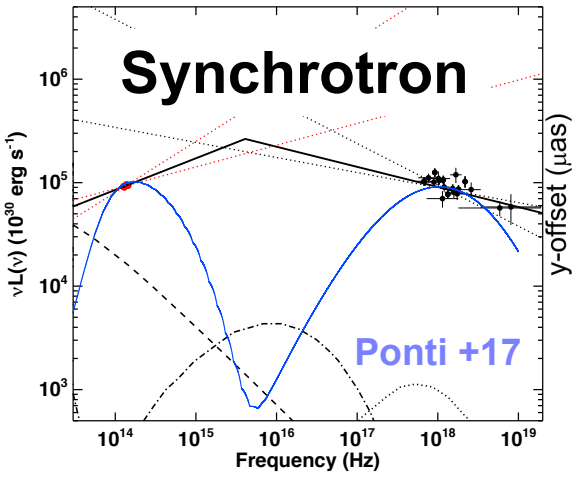

a)
1.5 kpc
350
Rosat 0.9-2 keV

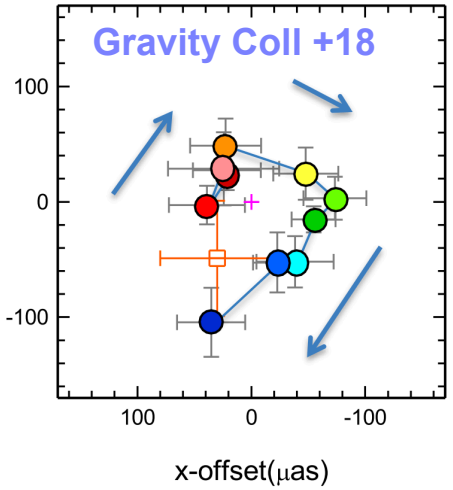

a)
1.5 kpc
10
0
-10
10
350
Galactic latitude
5 kpc
Rosat 0.9-2 keV
Fermi RGB image
Galactic longitude

The channel feeding the Fermi bubbles



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

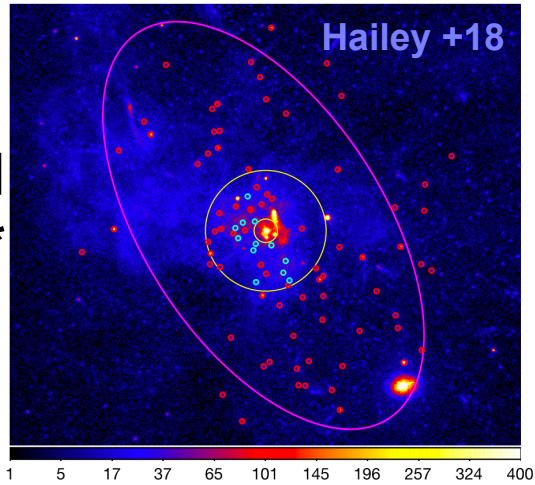


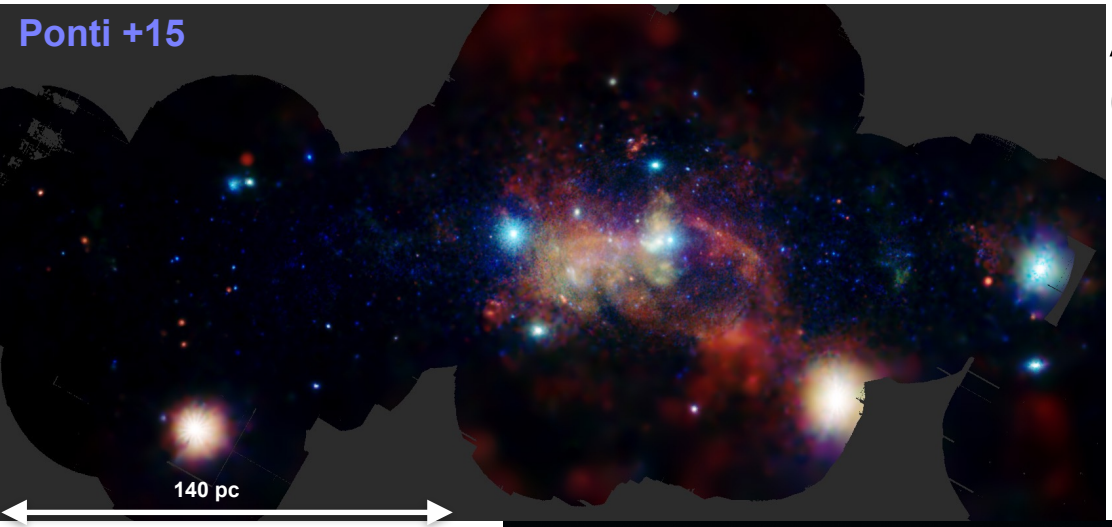


Summary

Density cusp of BH around Sgr A*

Orbital motion around Sgr A*

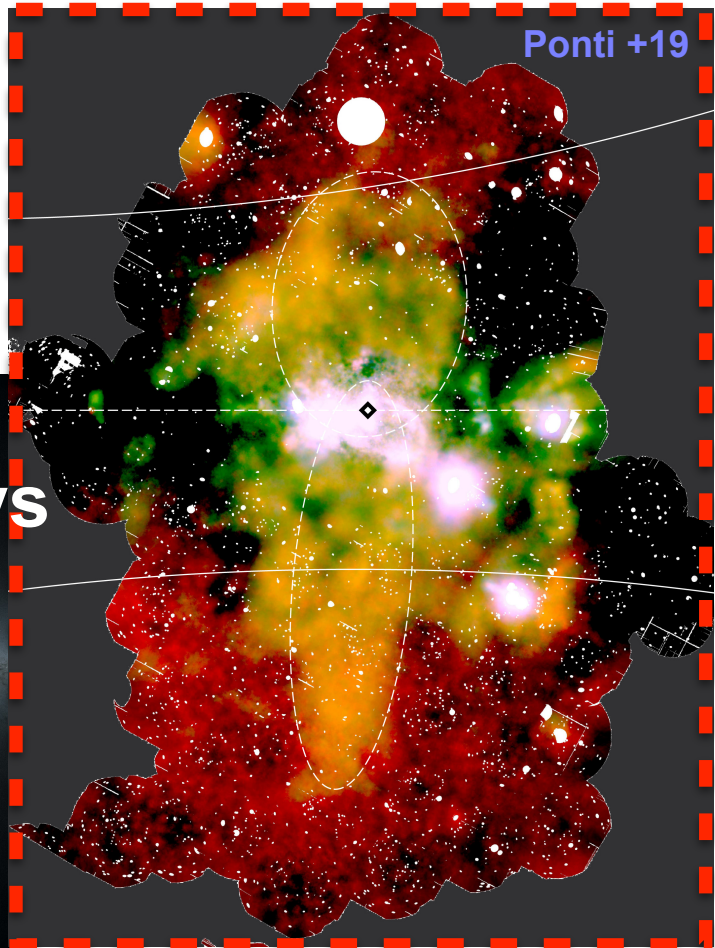




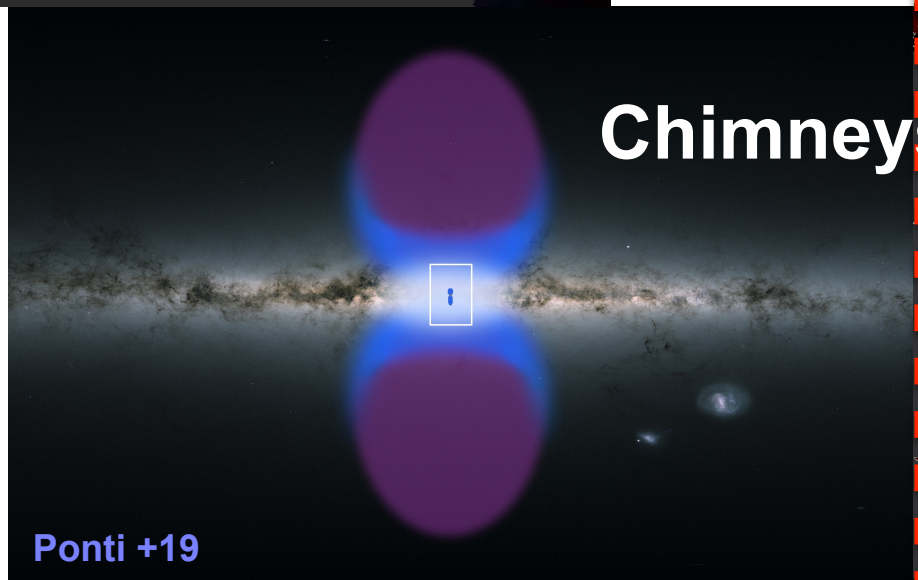
Atlas of diffuse X-ray features
(super-bubbles, SNR, filaments, etc) Ponti +15

$L_k > 10^{40}$ erg s^{-1}

High latitude plasma

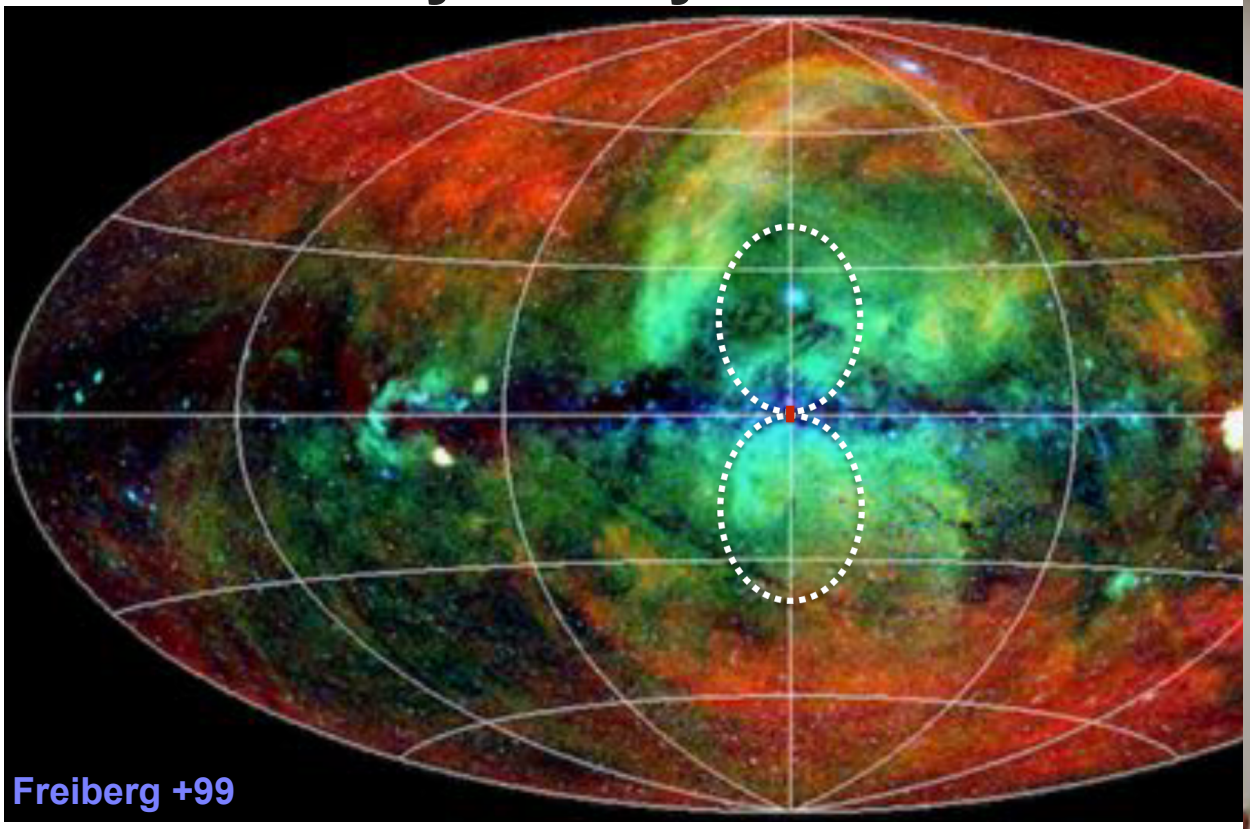


The channel connecting the GC activity with the Fermi bubbles



Future

Rosat all-sky survey

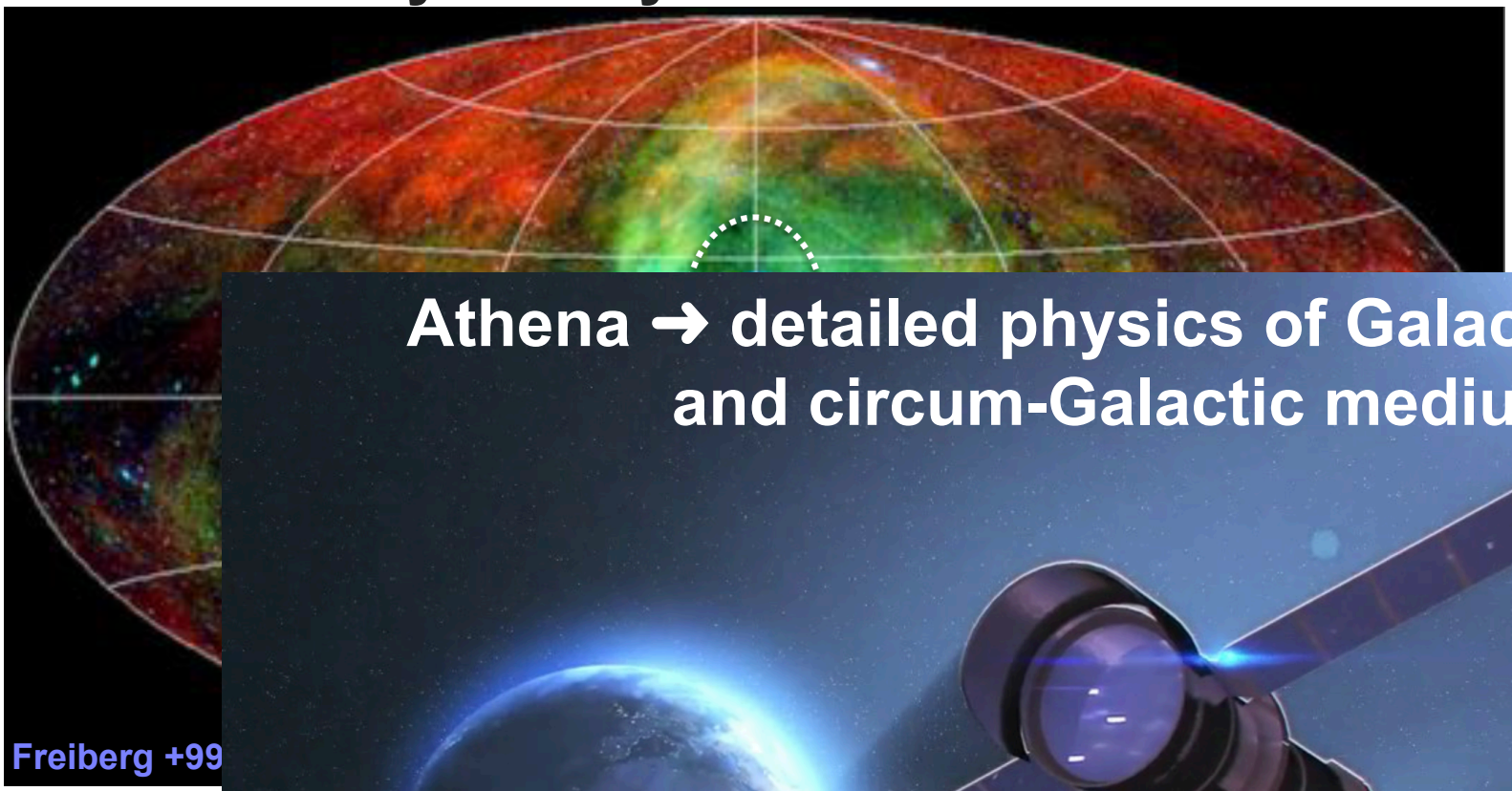


Merloni +12

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

Future

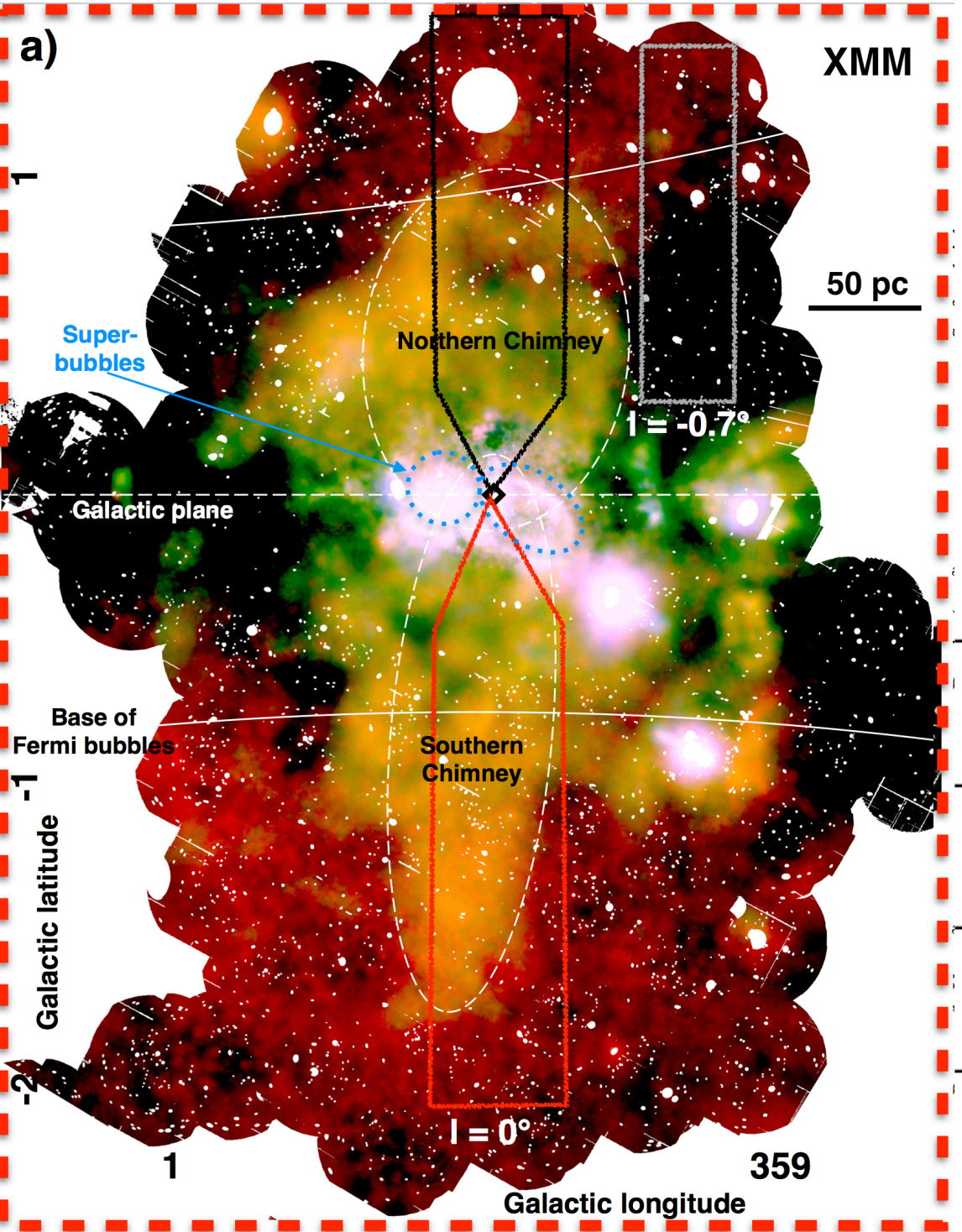
Rosat all-sky survey



Freiberg +99

Athena ➜ detailed physics of Galactic corona and circum-Galactic medium

Nakashima's result!



Discovery of recombining plasma!