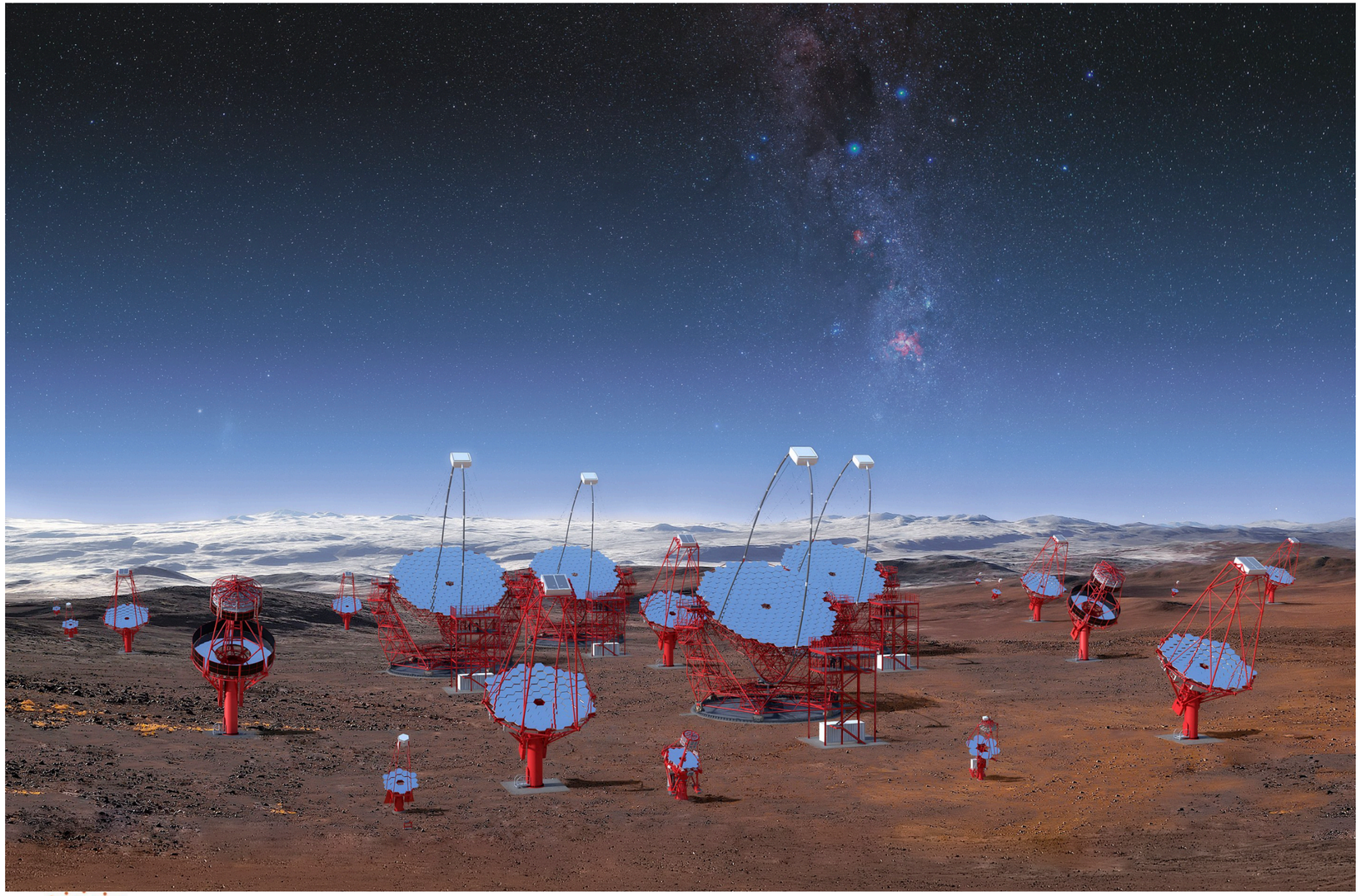
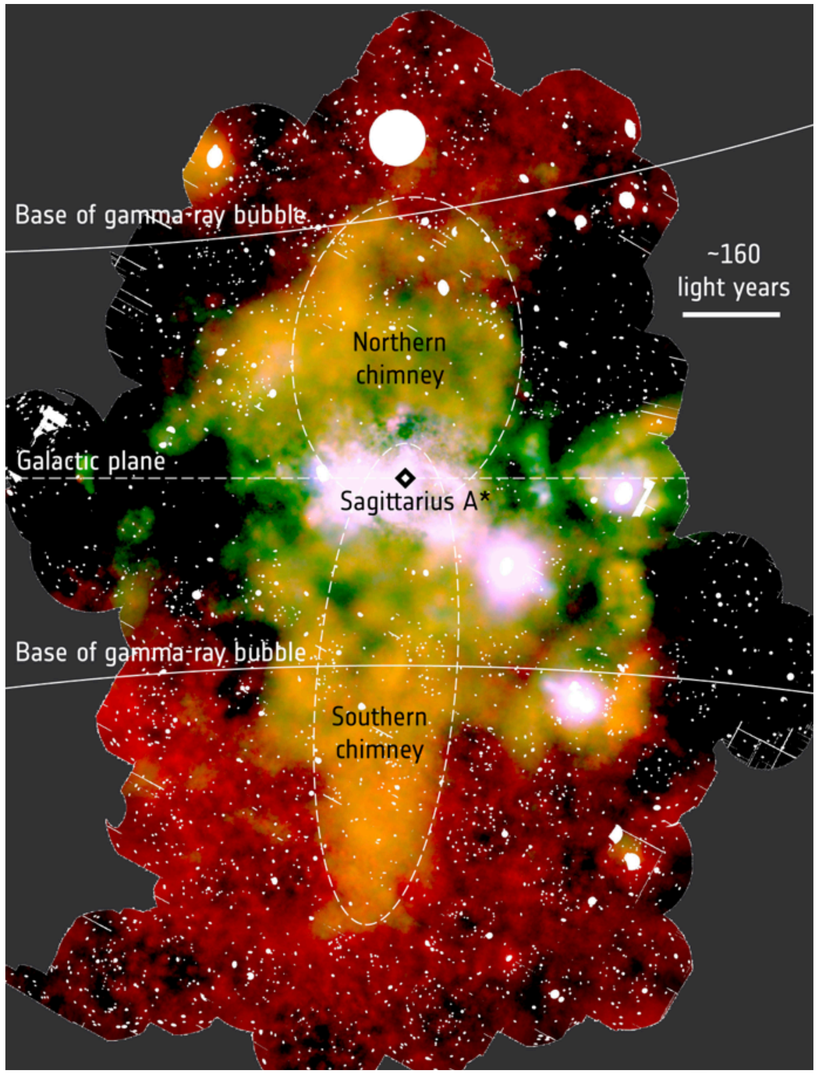
The Galactic center at very high energy





European Research Council

Gabriele Ponti
INAF OA Brera - MPE

OSSERVATORIO ASTRONOMICO DI BRERA

The Galactic center is a peculiar environment

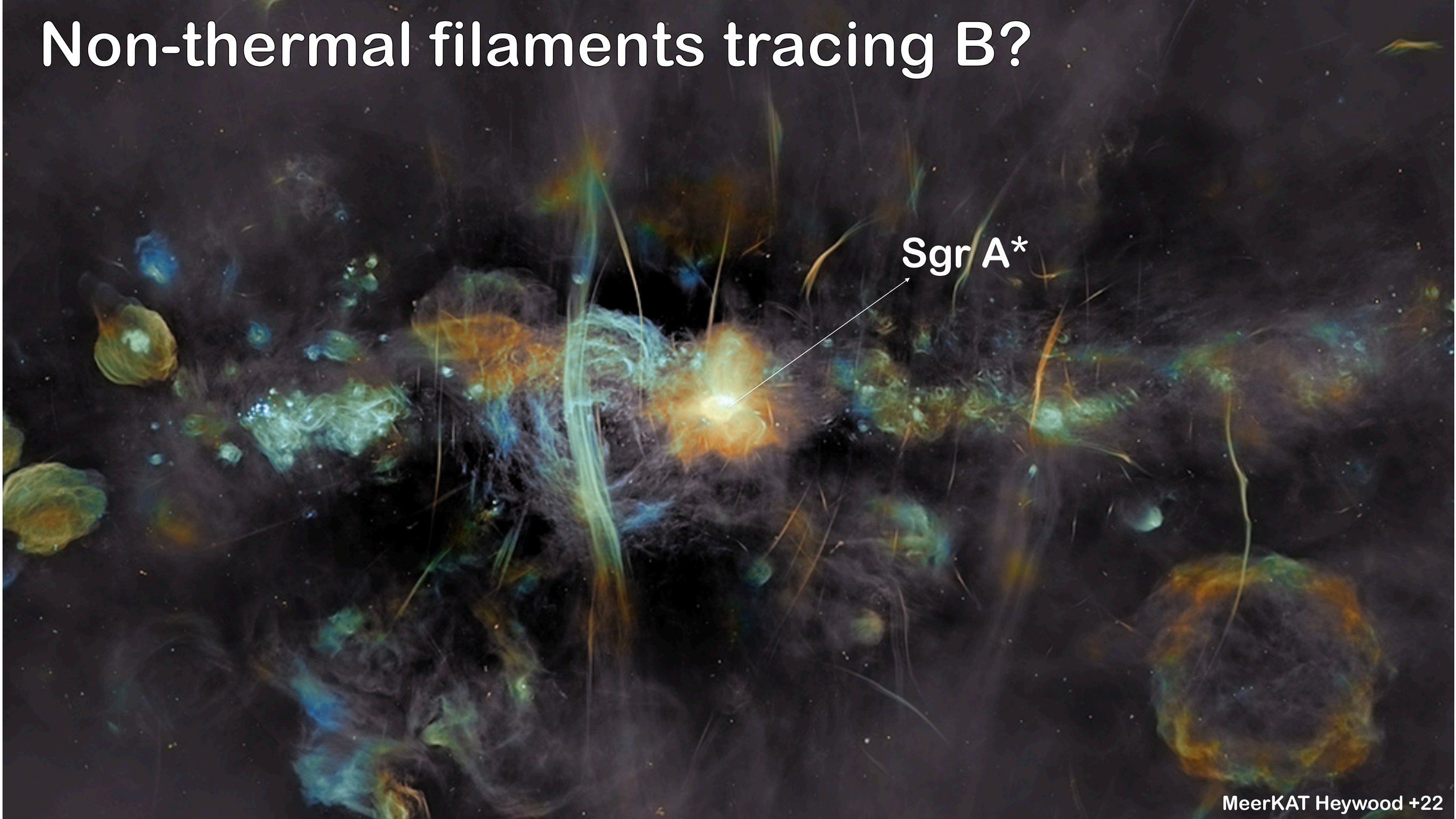
The Galactic center is a peculiar environment

➜ Interesting to study!

Non-thermal filaments tracing B?

MeerKAT Heywood +22

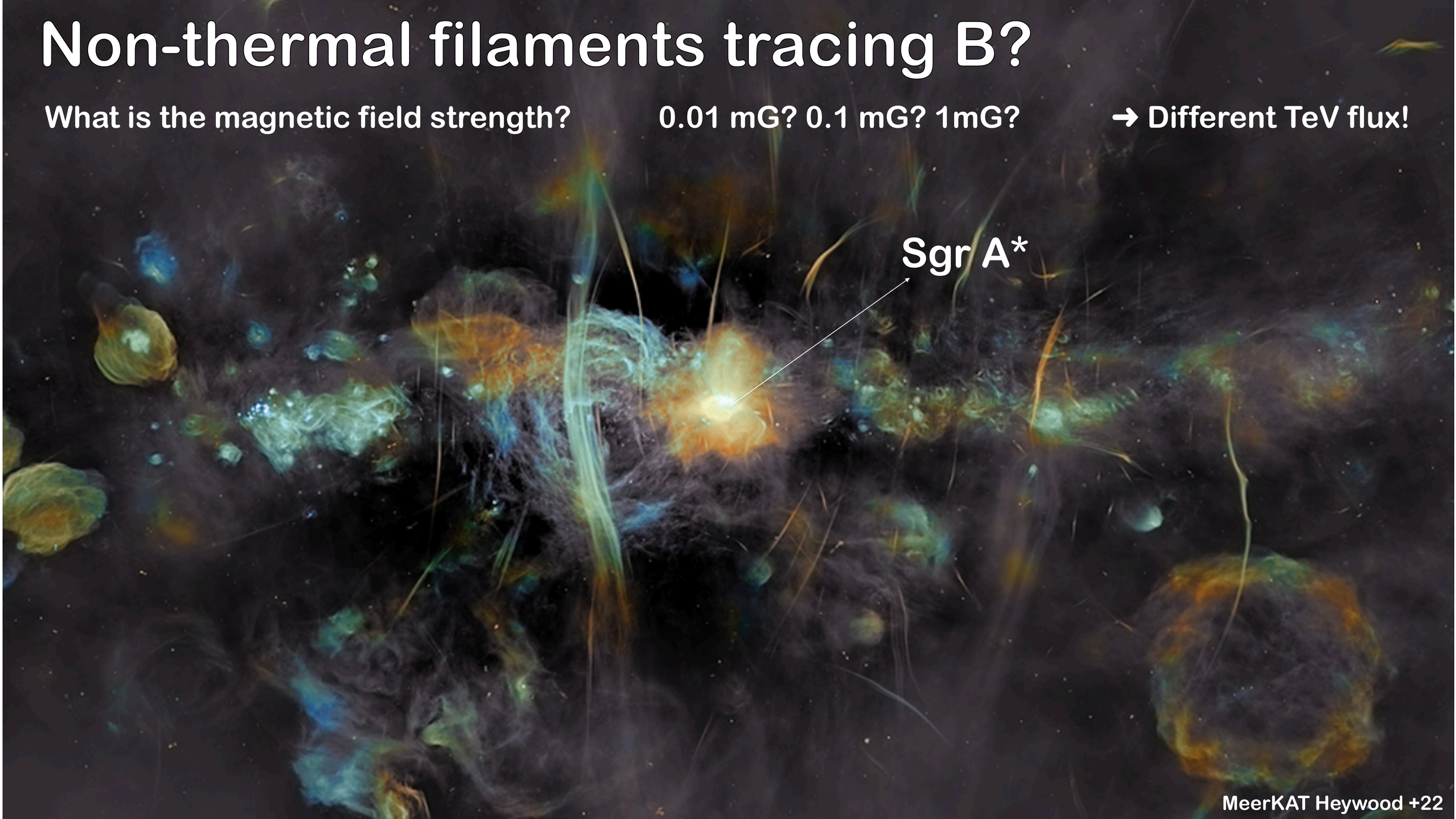
Non-thermal filaments tracing B?



MeerKAT Heywood +22

Non-thermal filaments tracing B?

What is the magnetic field strength? 0.01 mG? 0.1 mG? 1mG? ➜ Different TeV flux!



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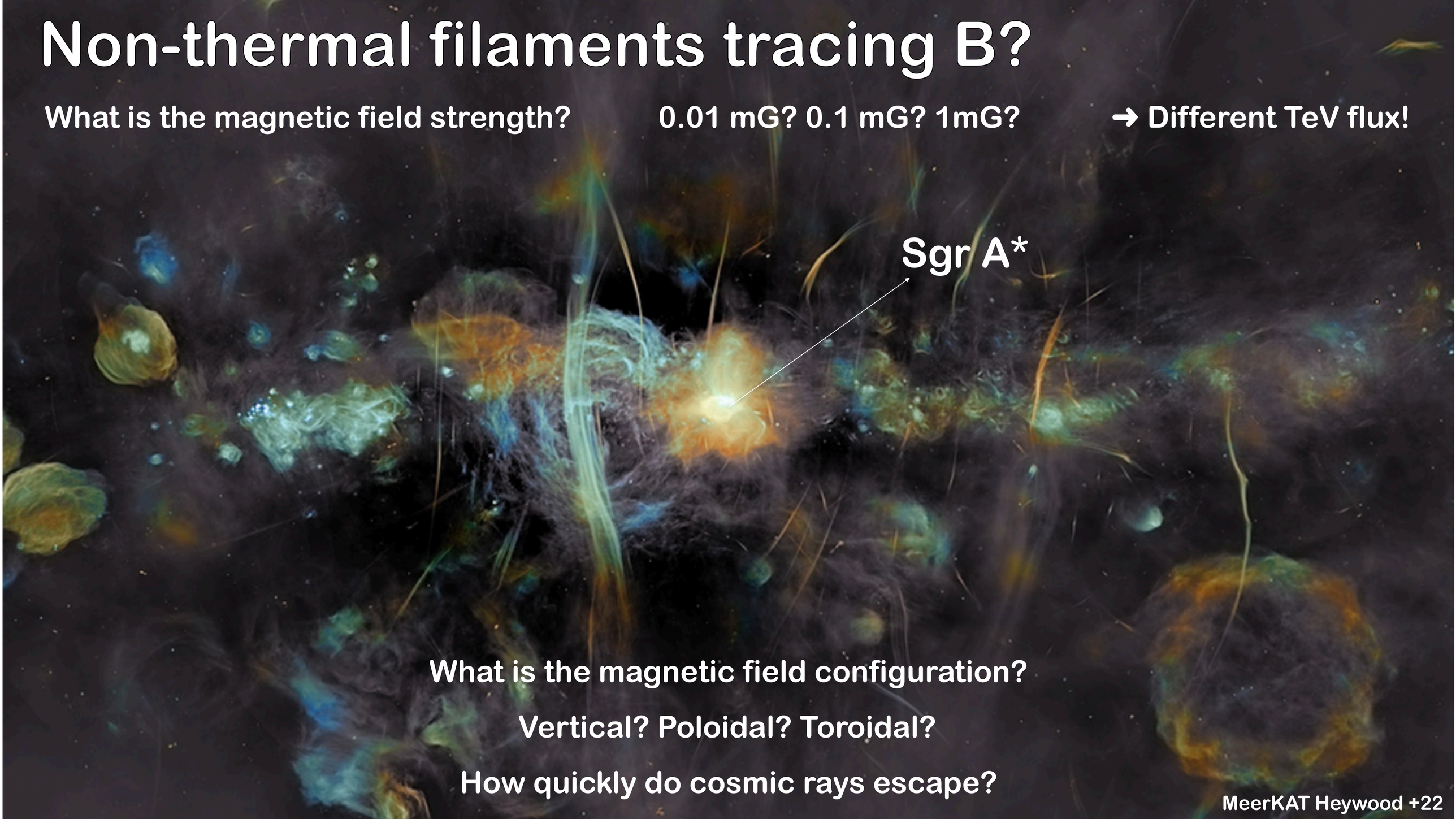

What is the magnetic field configuration?

Vertical? Poloidal? Toroidal?

How quickly do cosmic rays escape?

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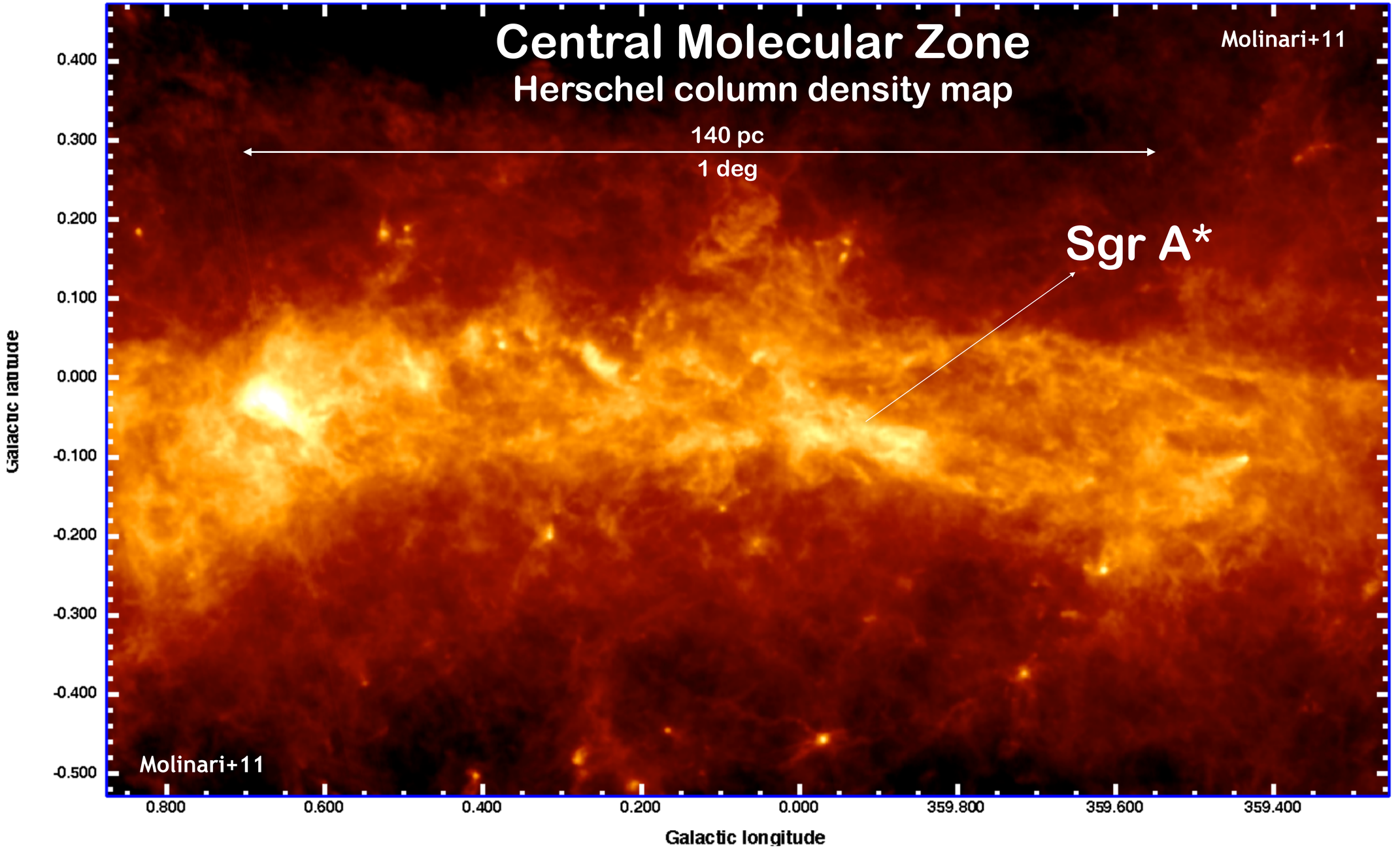
The central degrees of the Milky Way



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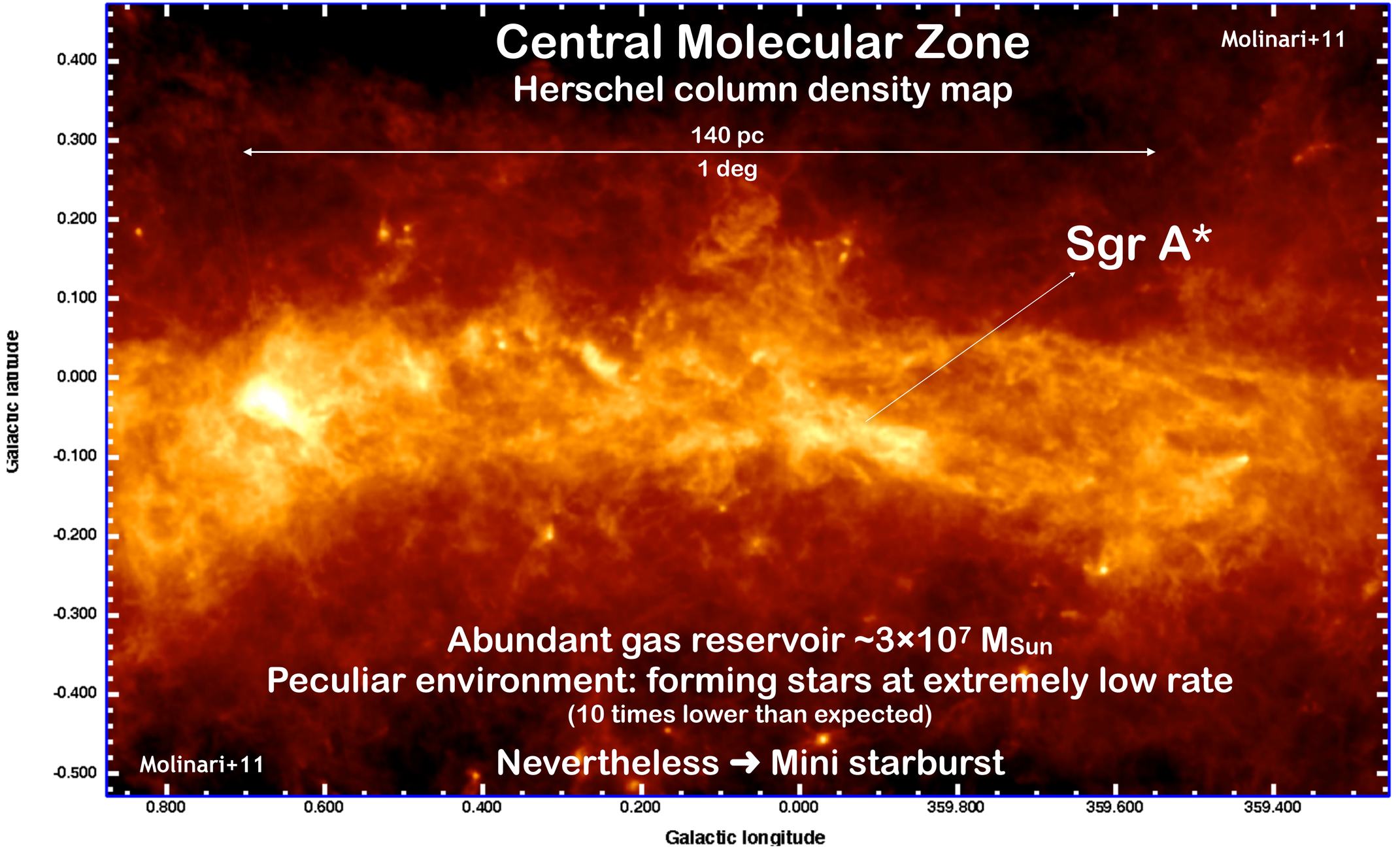
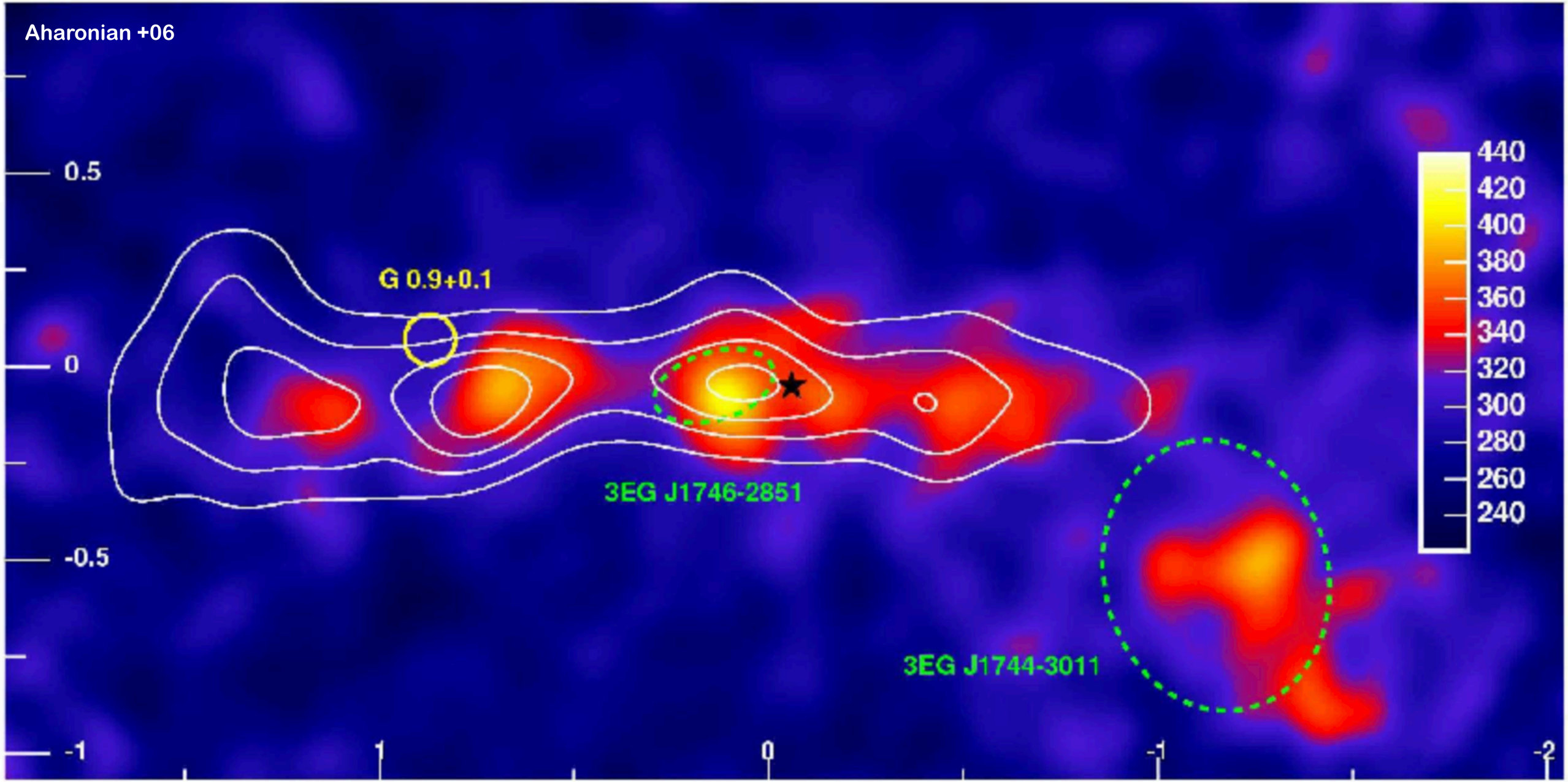


The H.E.S.S. view of Galactic center



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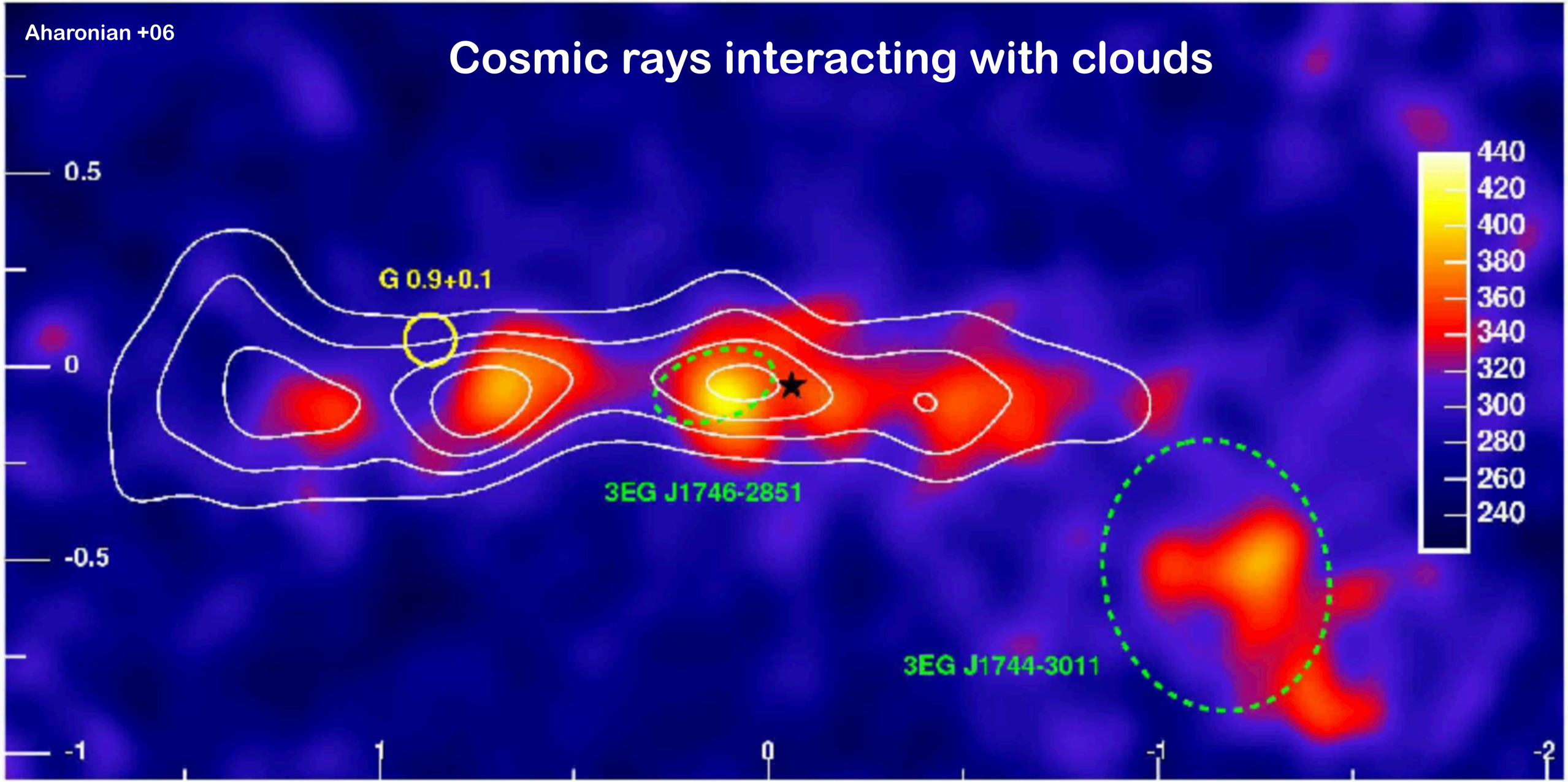

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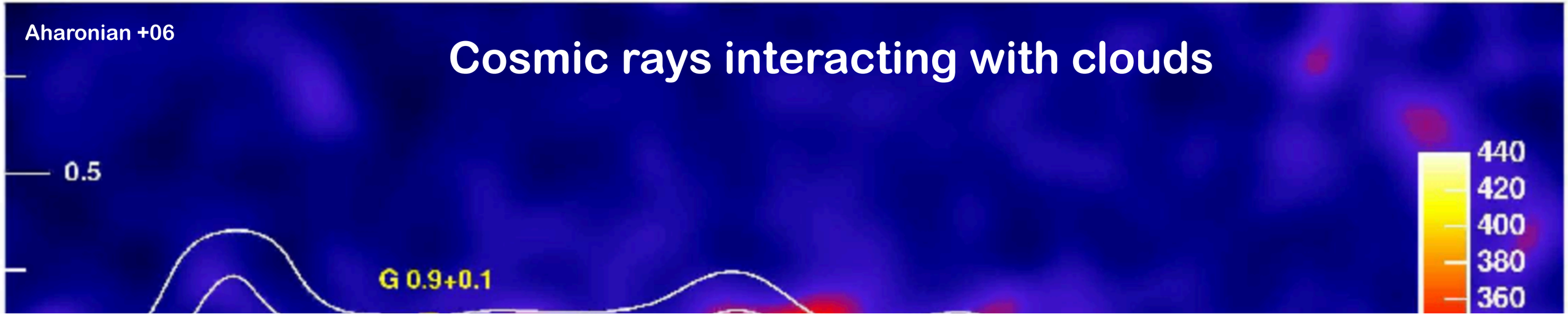
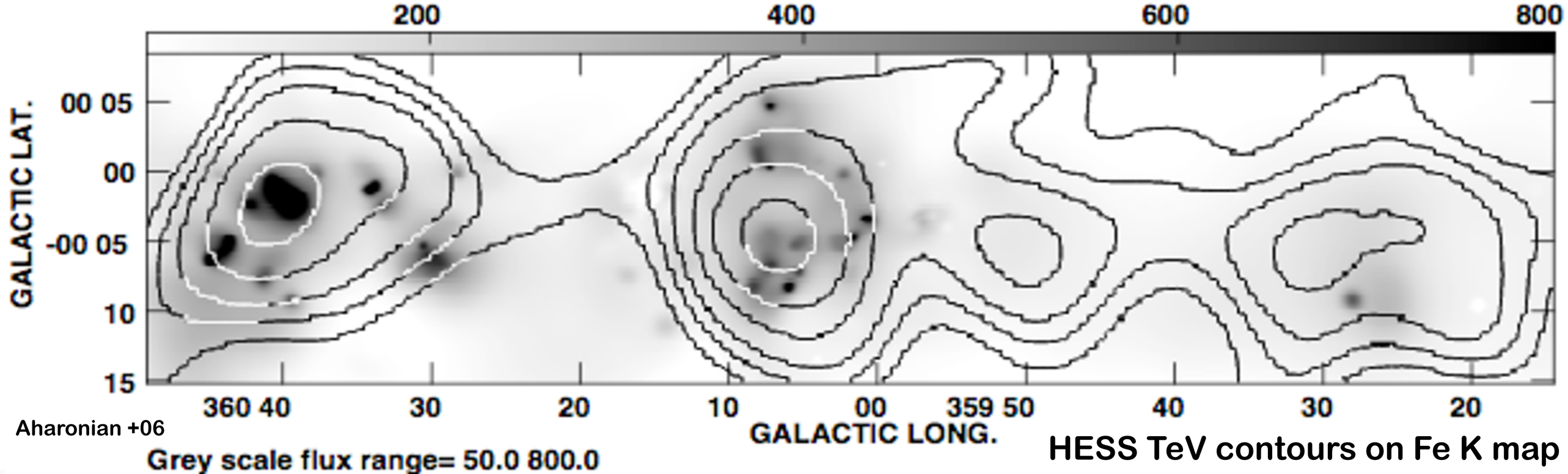


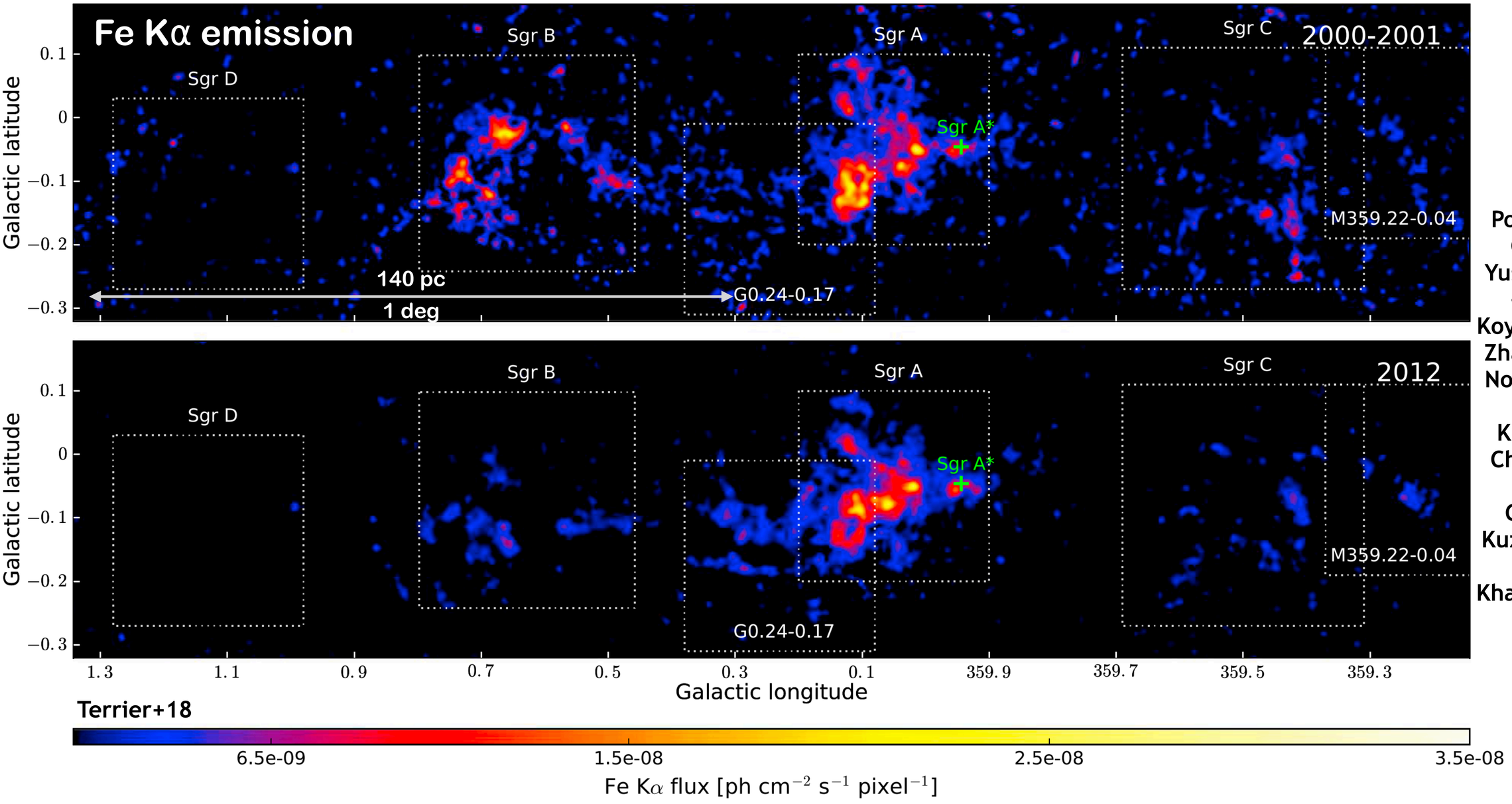


Aharonian +06

Grey scale flux range= 50.0 800.0

HESS TeV contours on Fe K map

Reflection of a past bright flash



Terrier+18

Fe Kα flux [ph cm^{-2} s^{-1} pixel^{-1}]

See also
Ponti+10;+13;+14;
Clavel+13;+14;
Yusef-Zadeh+13a,b;
+19; Marin+14;
Koyama+14;+18;+21;
Zhang+15; Mori+15;
Nobukawa+15; +16;
Walls+16;
Krivonos+14;+17;
Churazov+17a,b,c;
Chuard+18;
Chernyshov+18;
Kuznetsova+19;+22;
Di Gesu+20;
Khabibullin+20a,b,22
Tanaka+21;
Ferrazzoli+21

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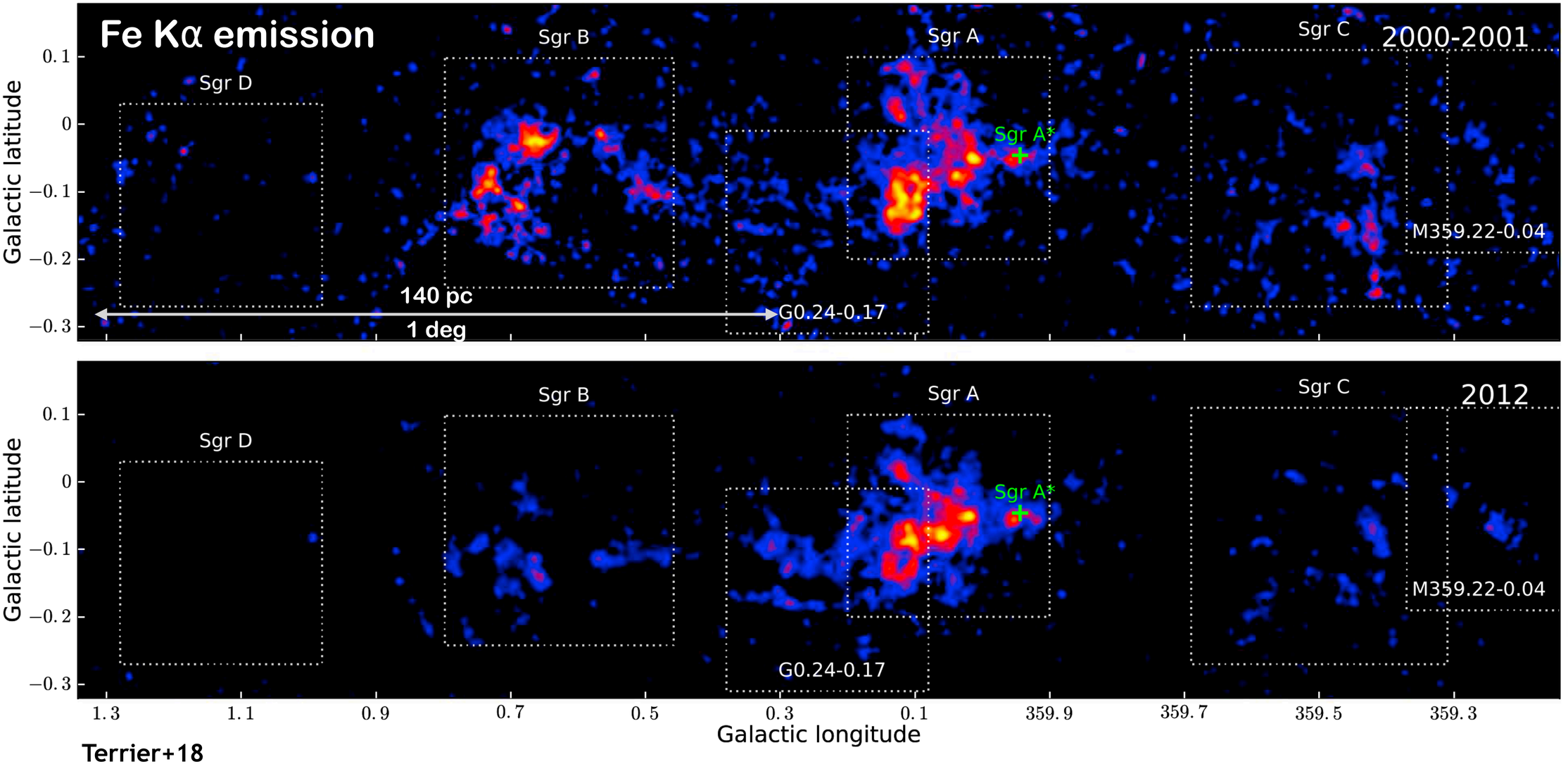

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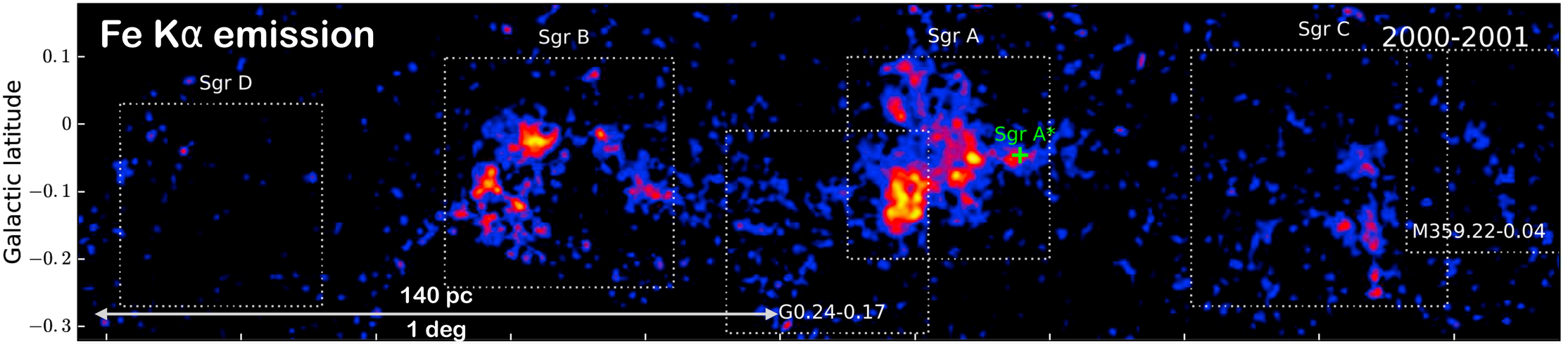
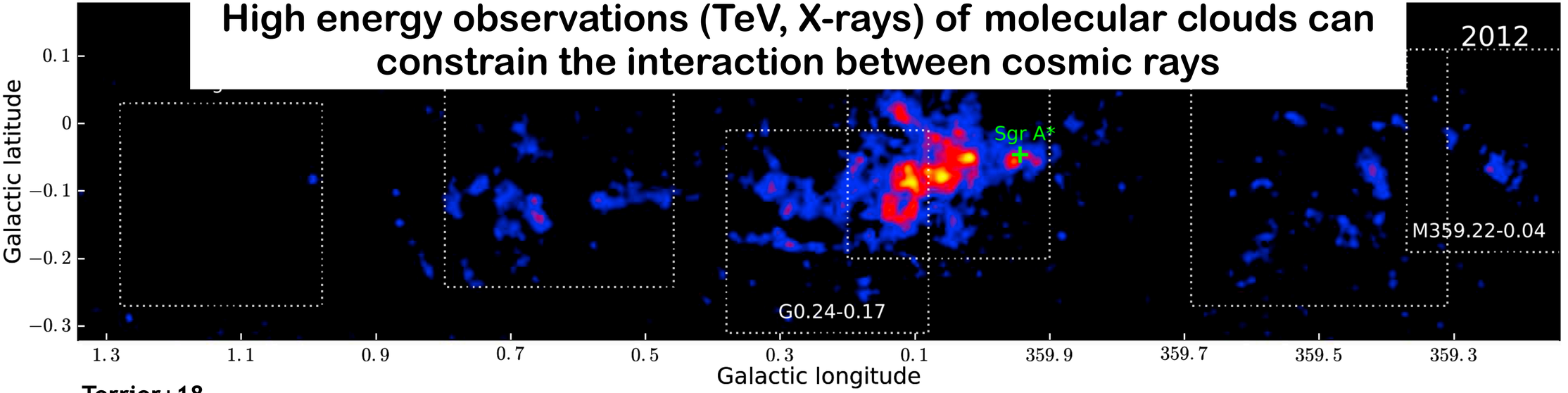
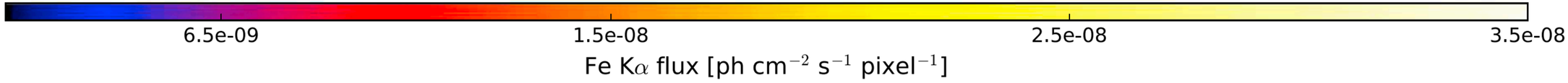
All Fe Kα bright regions are variable ➜ Reflection by bright flash in the center

Reflection of a past bright flash





Terrier+18



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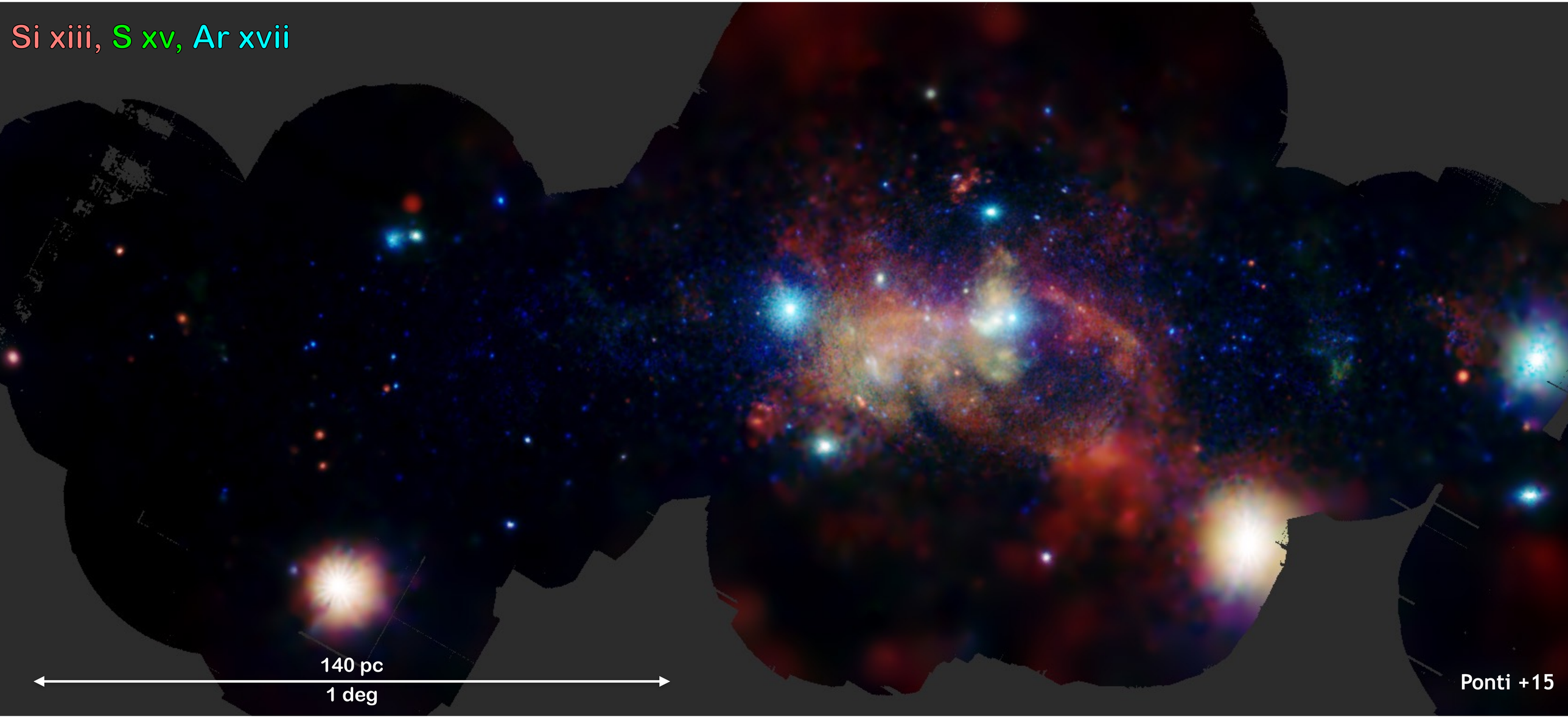
Hot plasma to trace past activity



Ponti +15

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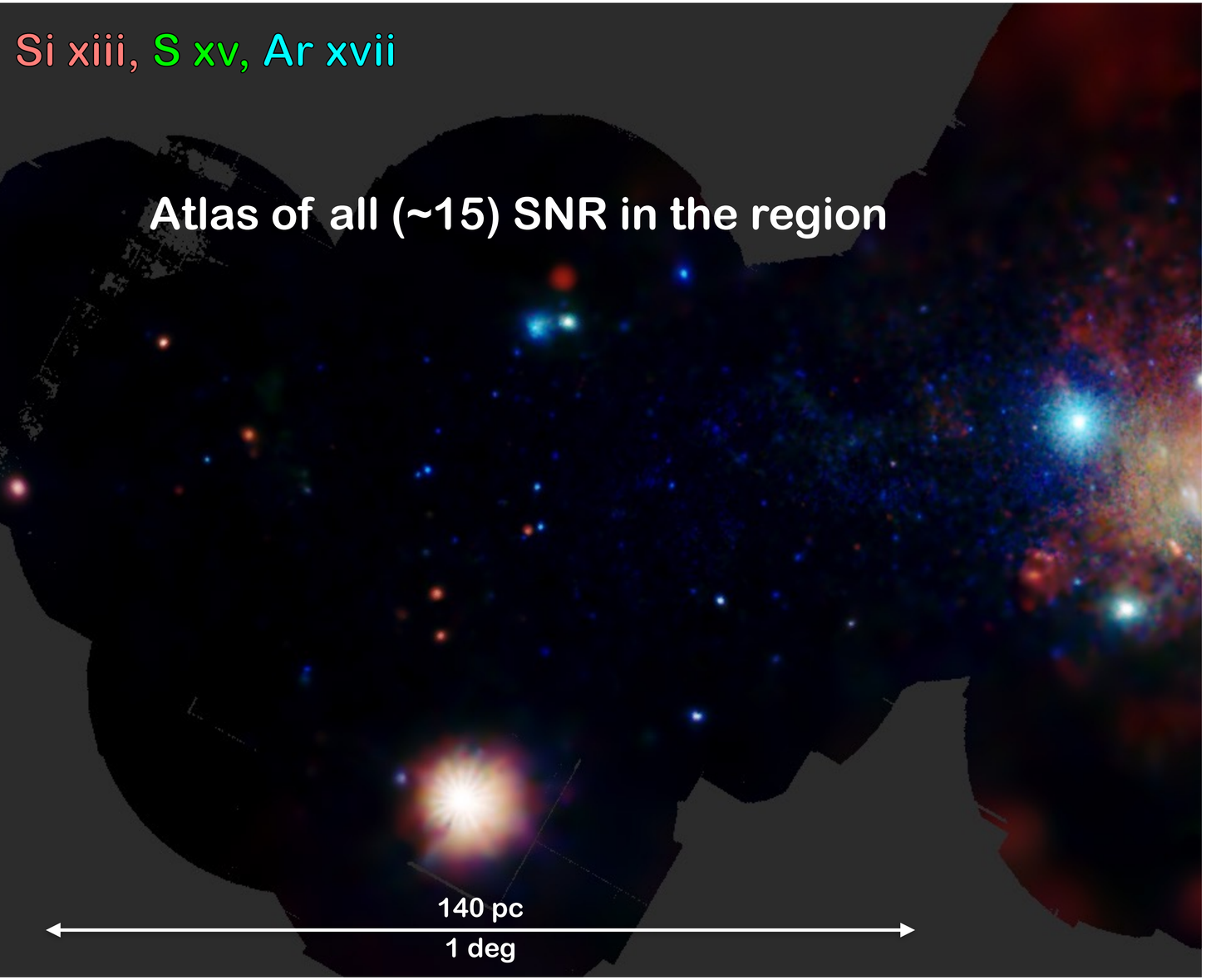

Ponti +15

ATLAS OF DIFFUSE X-RAY EMITTING FEATURES

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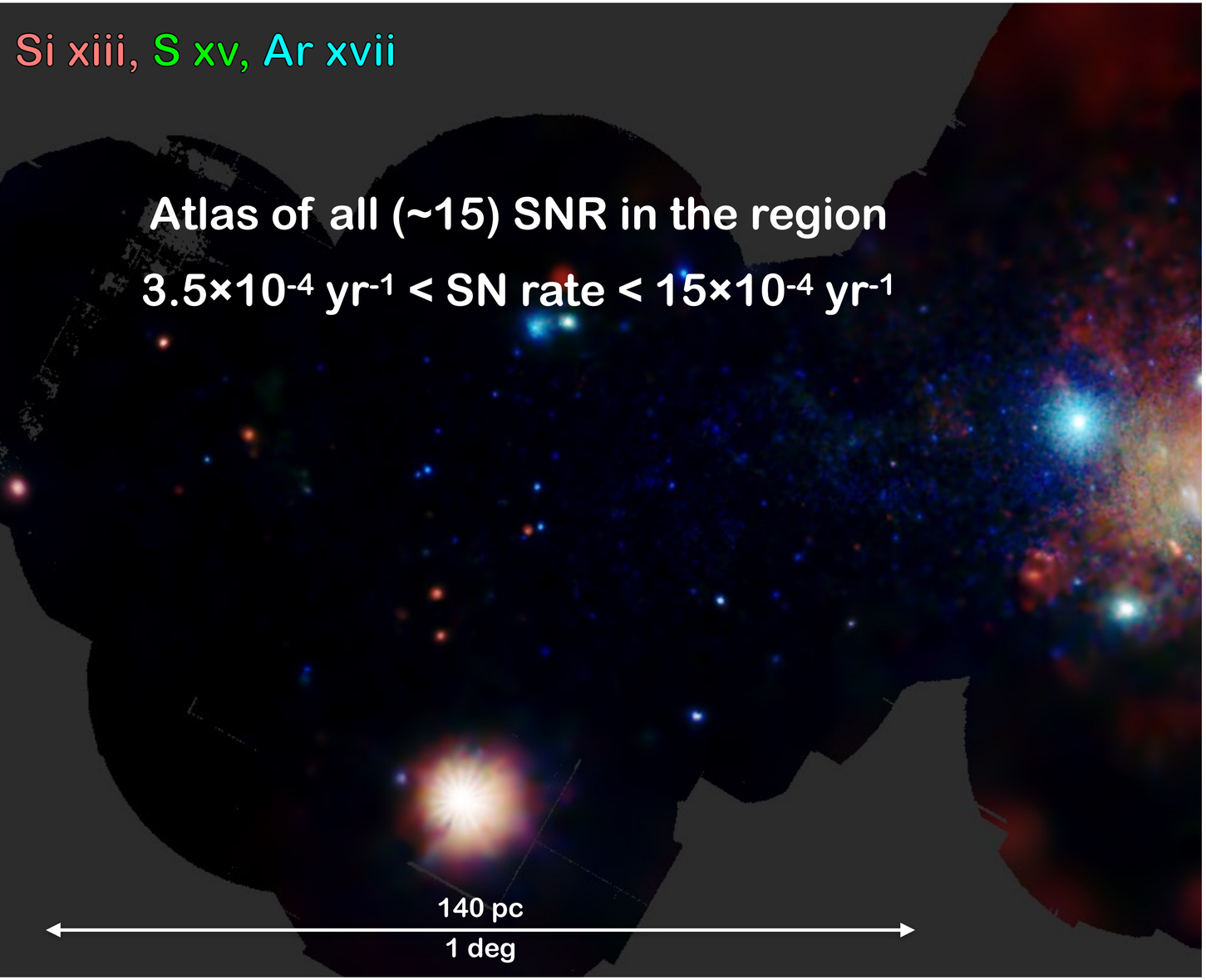
STAR CLUSTERS:				
Central star cluster		359.9442, -0.046	0.33	45,116,117,118
Quintuplet		0.1604, -0.0591	0.5	1,63,11
Arches	G0.12+0.02	0.1217, 0.0188	0.7	1,2,3,4,5,6,7,8,9,39,40,11
Sh2-10	DB00-6	0.3072,-0.2000	1.92	10,11,12,63,11
Sh2-17	DB00-58	0.0013, 0.1588	1.65	13,63,11
DB00-05	G0.33-0.18	0.31 -0.19	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

Ponti +15

Hot plasma to trace past activity



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	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
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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
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	G1.05-0.1			
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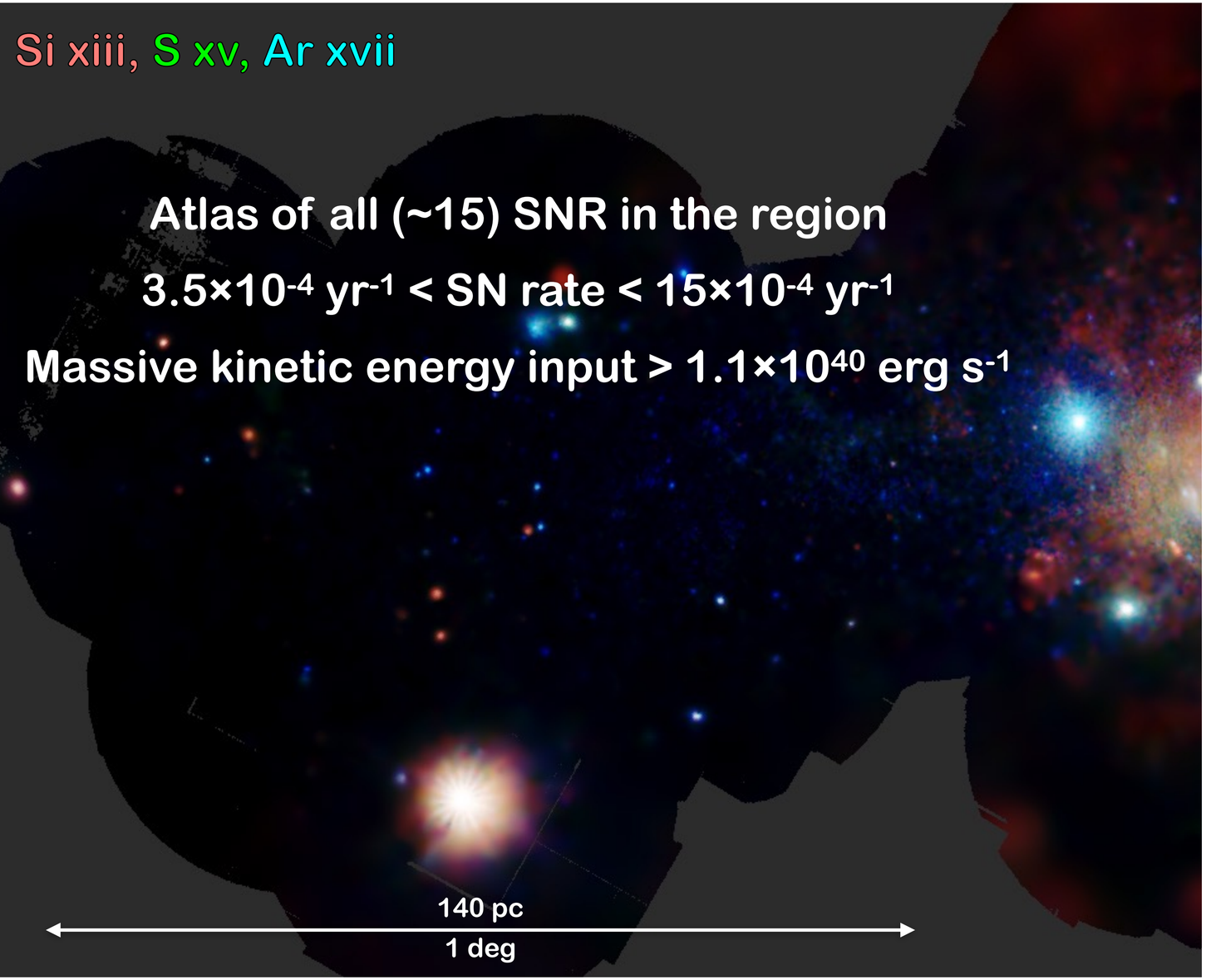

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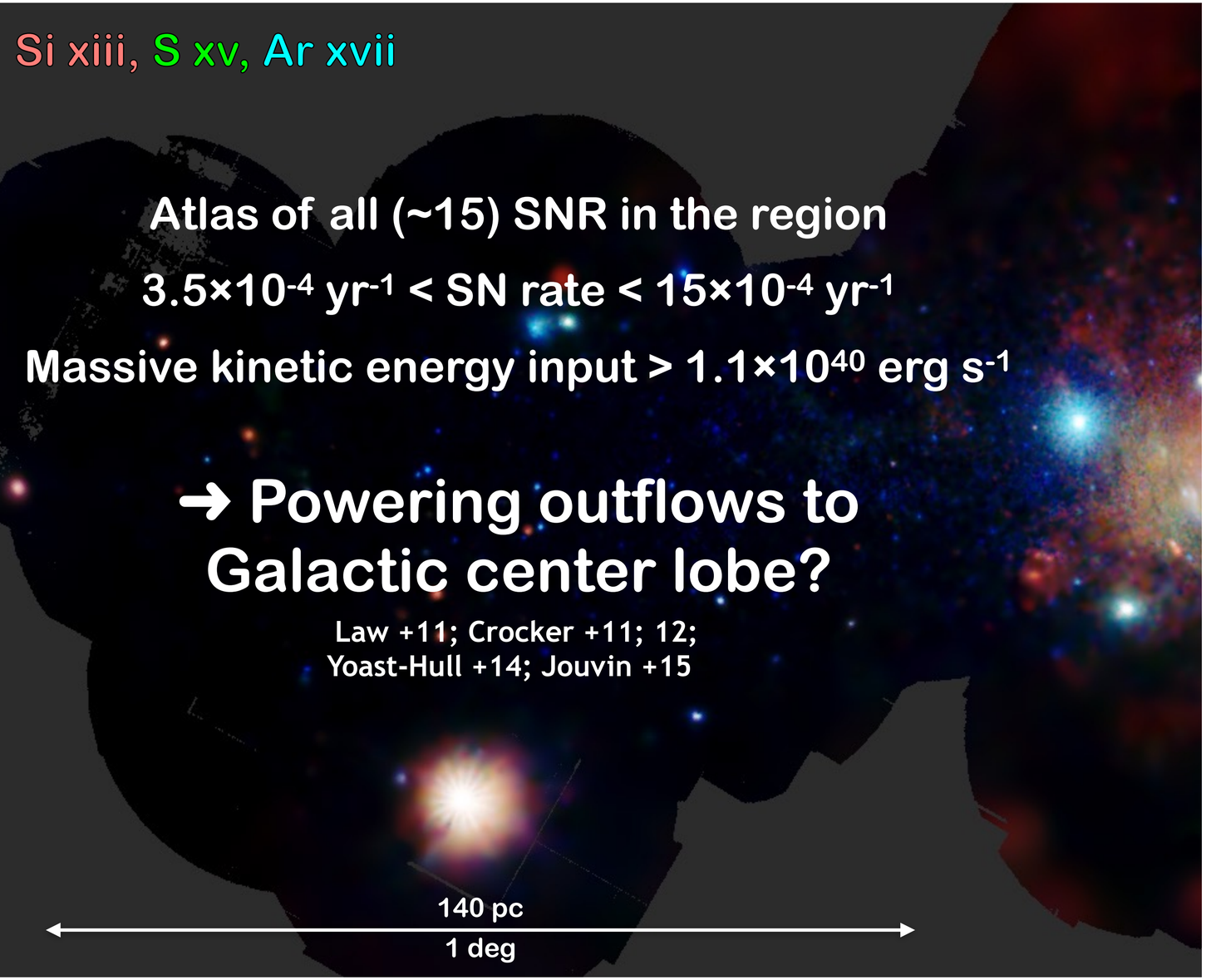

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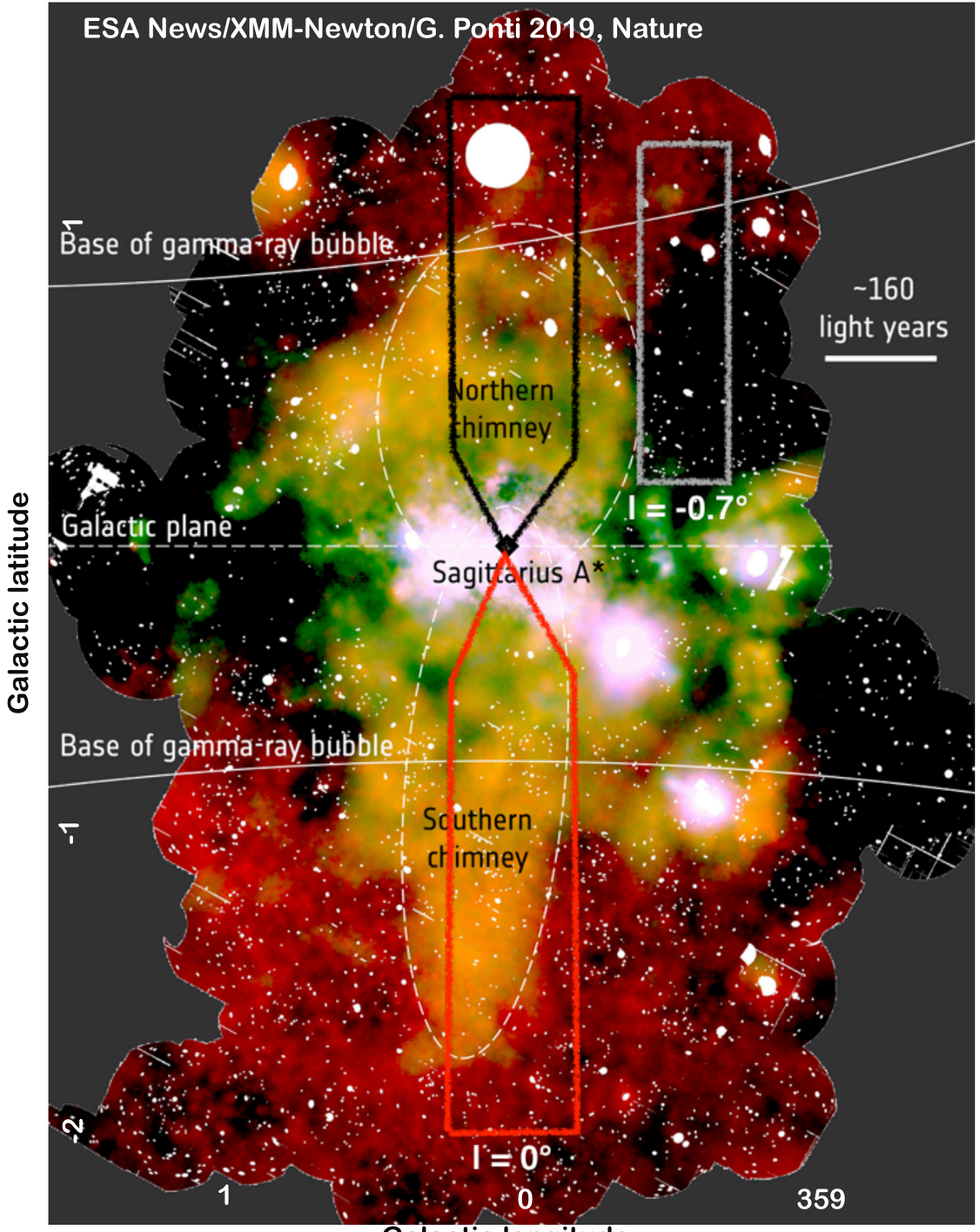
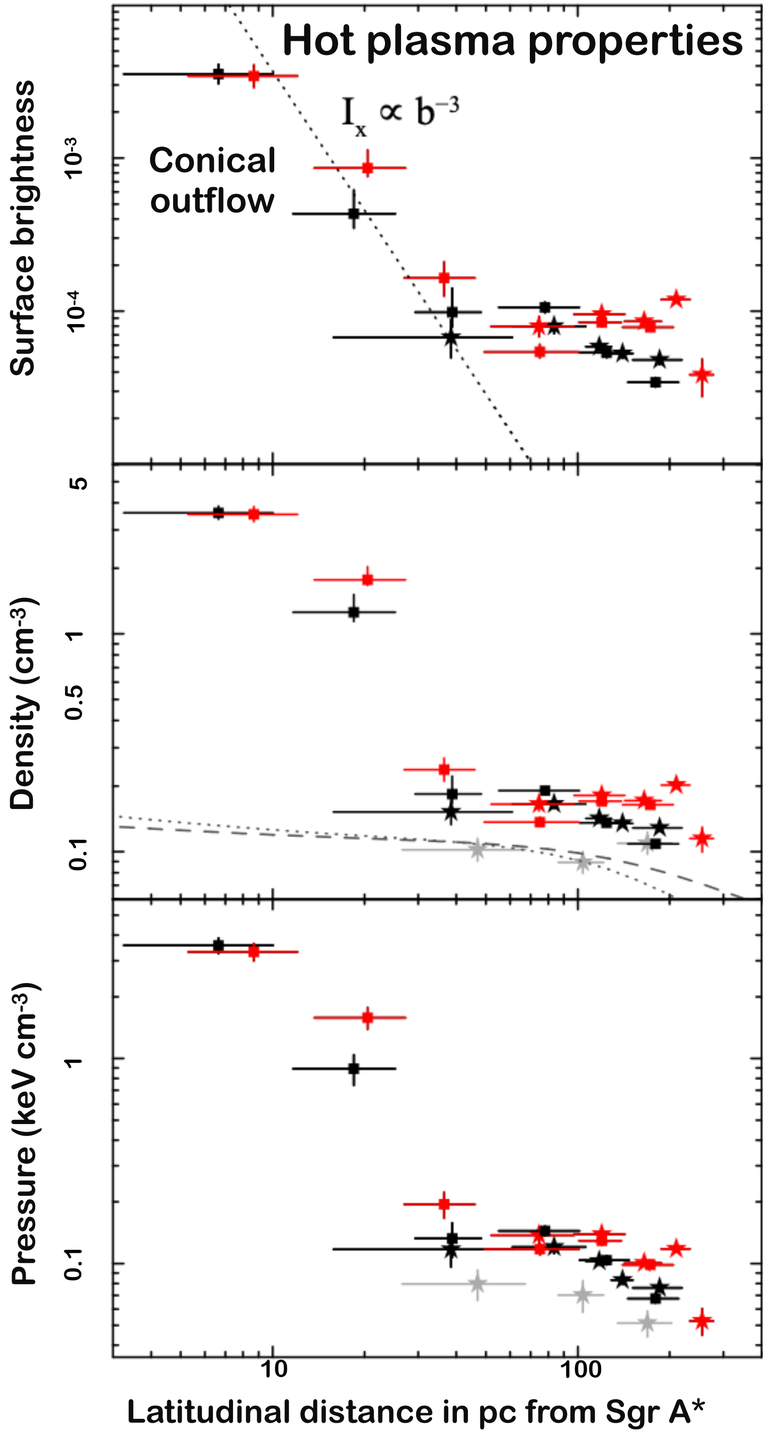
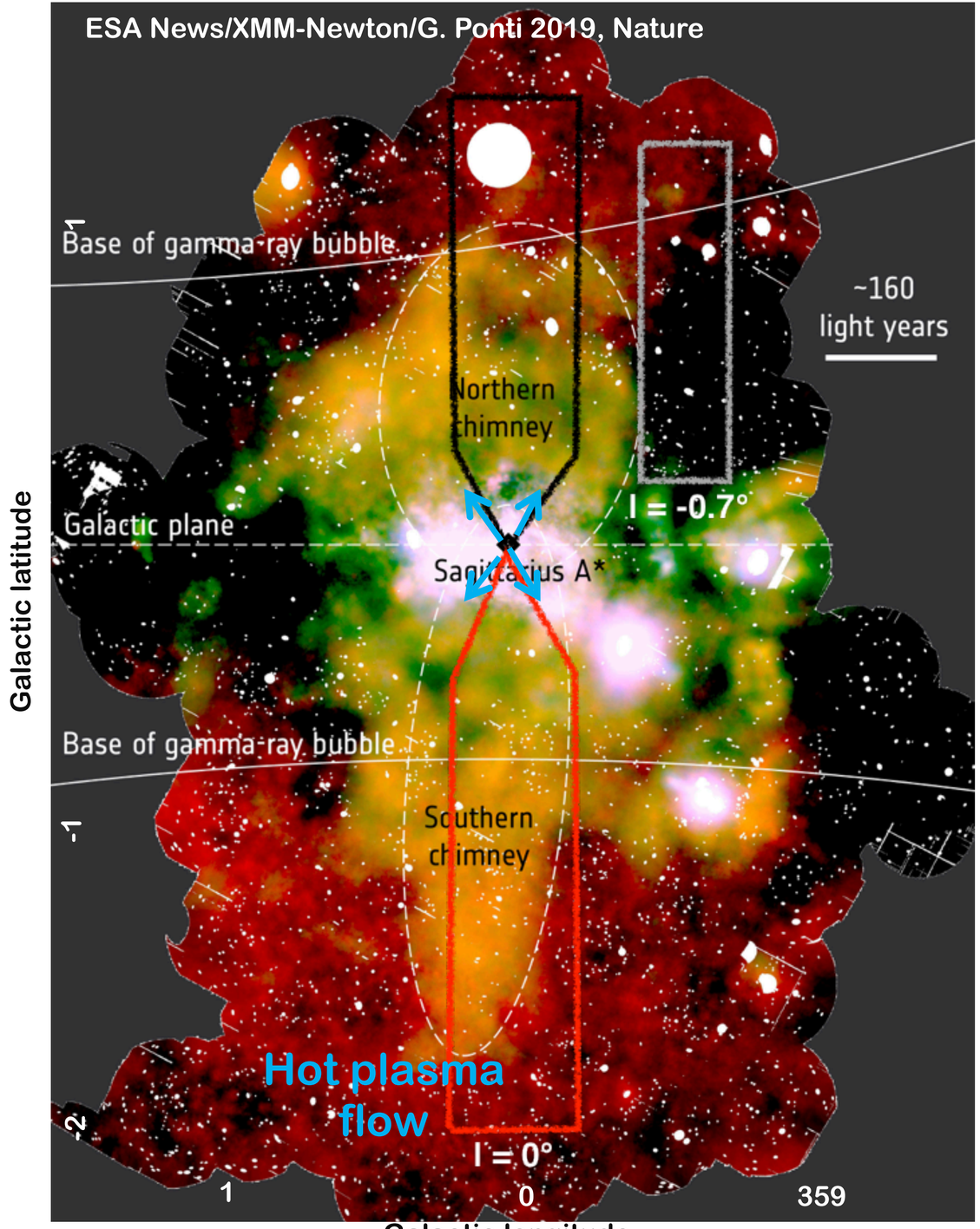
DB00-05	G0.33-0.18	0.31 -0.19	0.4	22,63,11
SNR - BUBBLES - SUPER-BUBBLES:				
G359.0-0.9	G358.5-0.9 - G359.1-0.9	359.03,-0.96	26 × 20	X-R 48,51,75,76,81,119,120
G359.07-0.02	G359.0-0.0	359.07,-0.02	22 × 10	R 14,48,51,66
	G359.12-0.05	359.12,-0.05	24 × 16	X 66
G359.10-0.5		359.10,-0.51	22 × 22	X-R 37,48,51,56,74,75,81,120,121
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

Ponti +15


ESA News/XMM-Newton/G. Ponti 2019, Nature
Base of gamma-ray bubble
~160
light years
Northern
chimney
l = -0.7°
Galactic plane
Sagittarius A*
Base of gamma-ray bubble
Southern
chimney
l = 0°
1
0
359
Galactic longitude
Galactic latitude
1
-1
-2


Hot plasma properties
$I_x \propto b^{-3}$
Conical
outflow
Surface brightness
10^{-3}
10^{-4}
Density (cm^{-3})
5
1
0.5
0.1
Pressure (keV cm^{-3})
1
0.1
10
100
Latitudinal distance in pc from Sgr A*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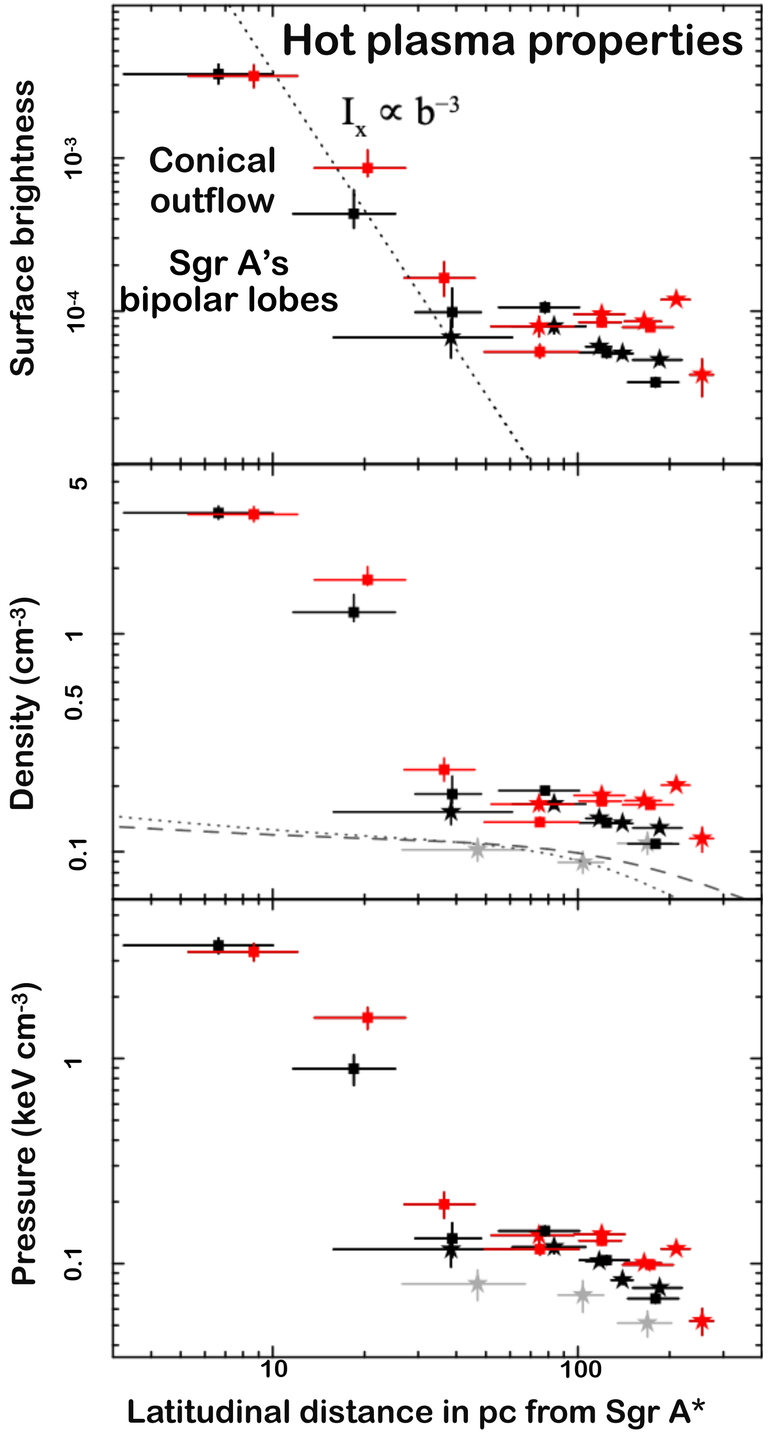
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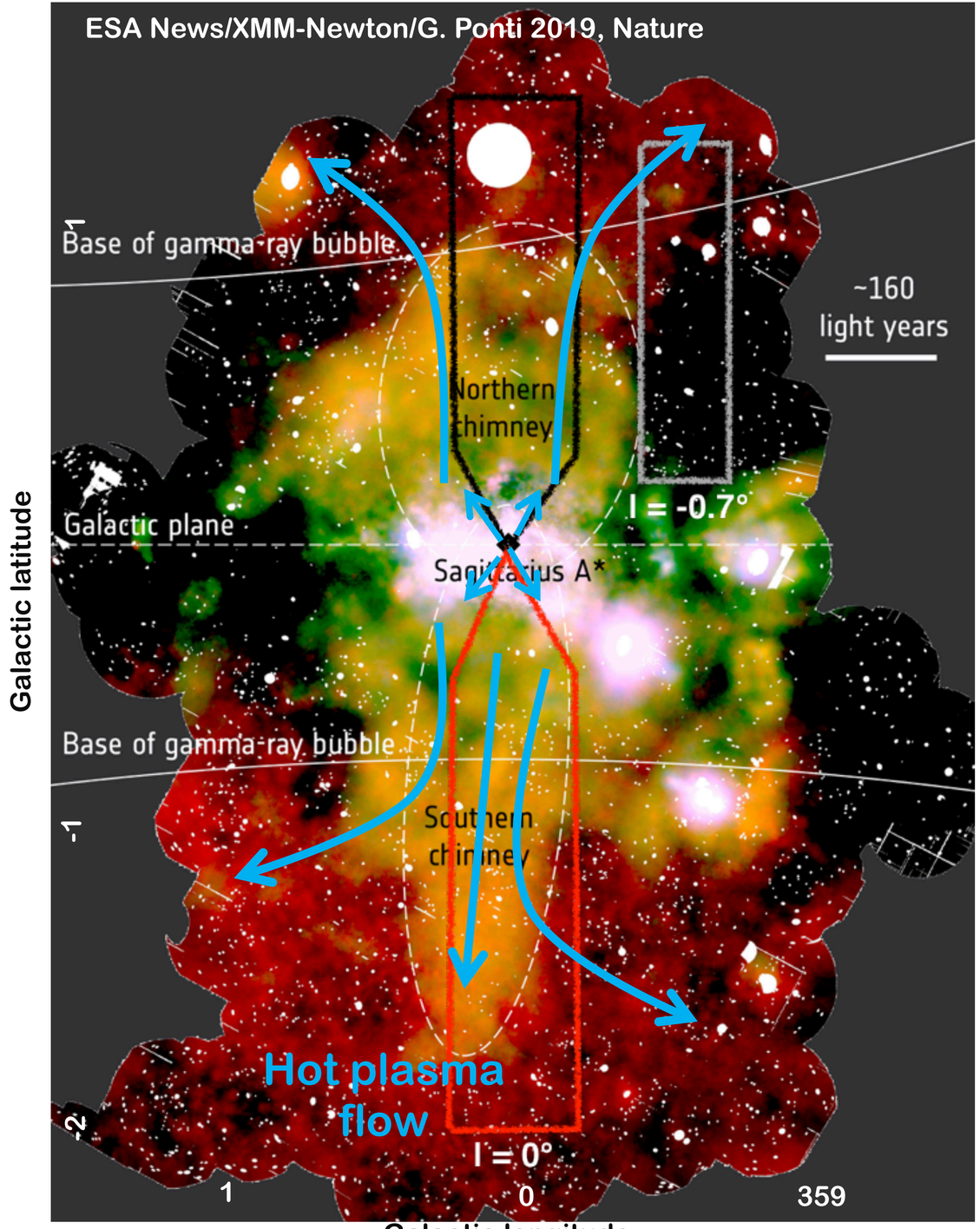
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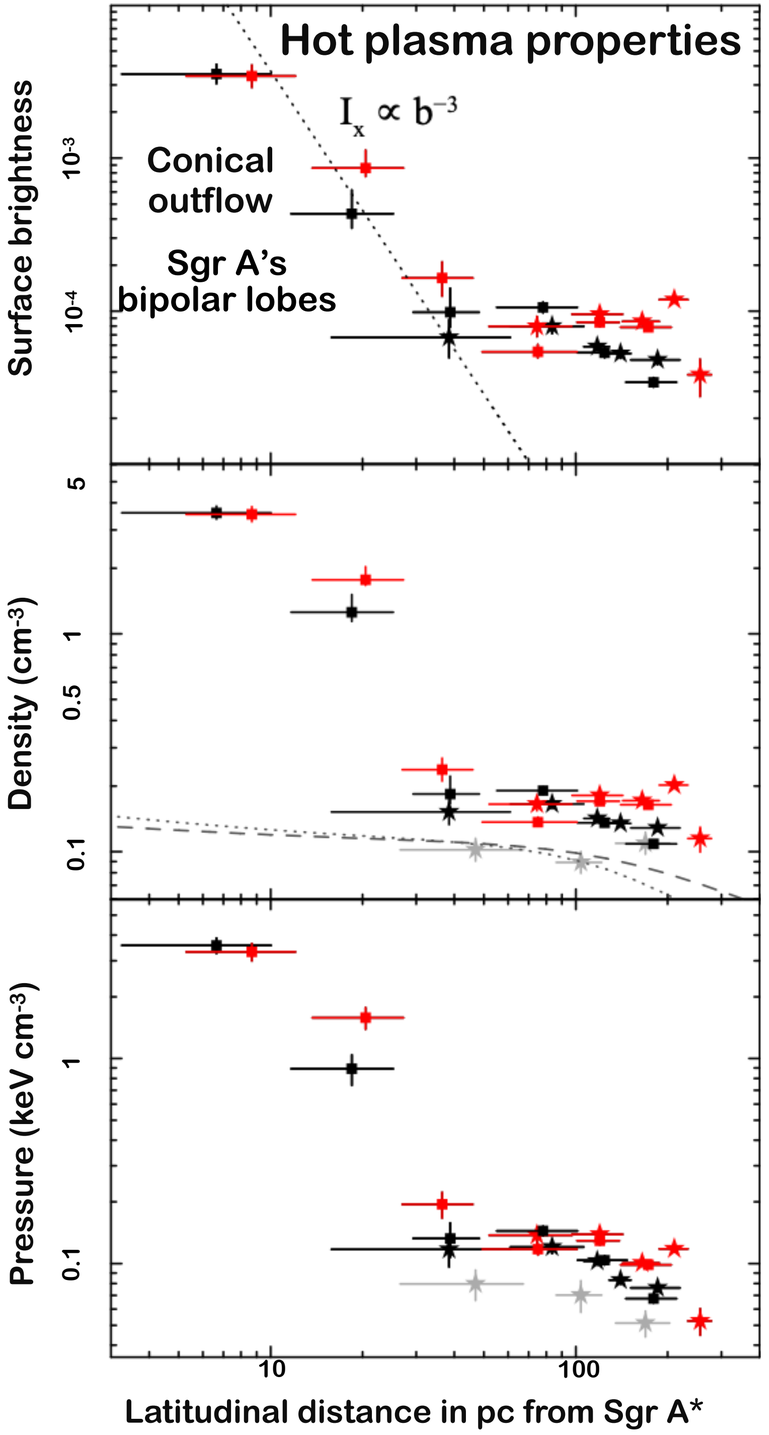
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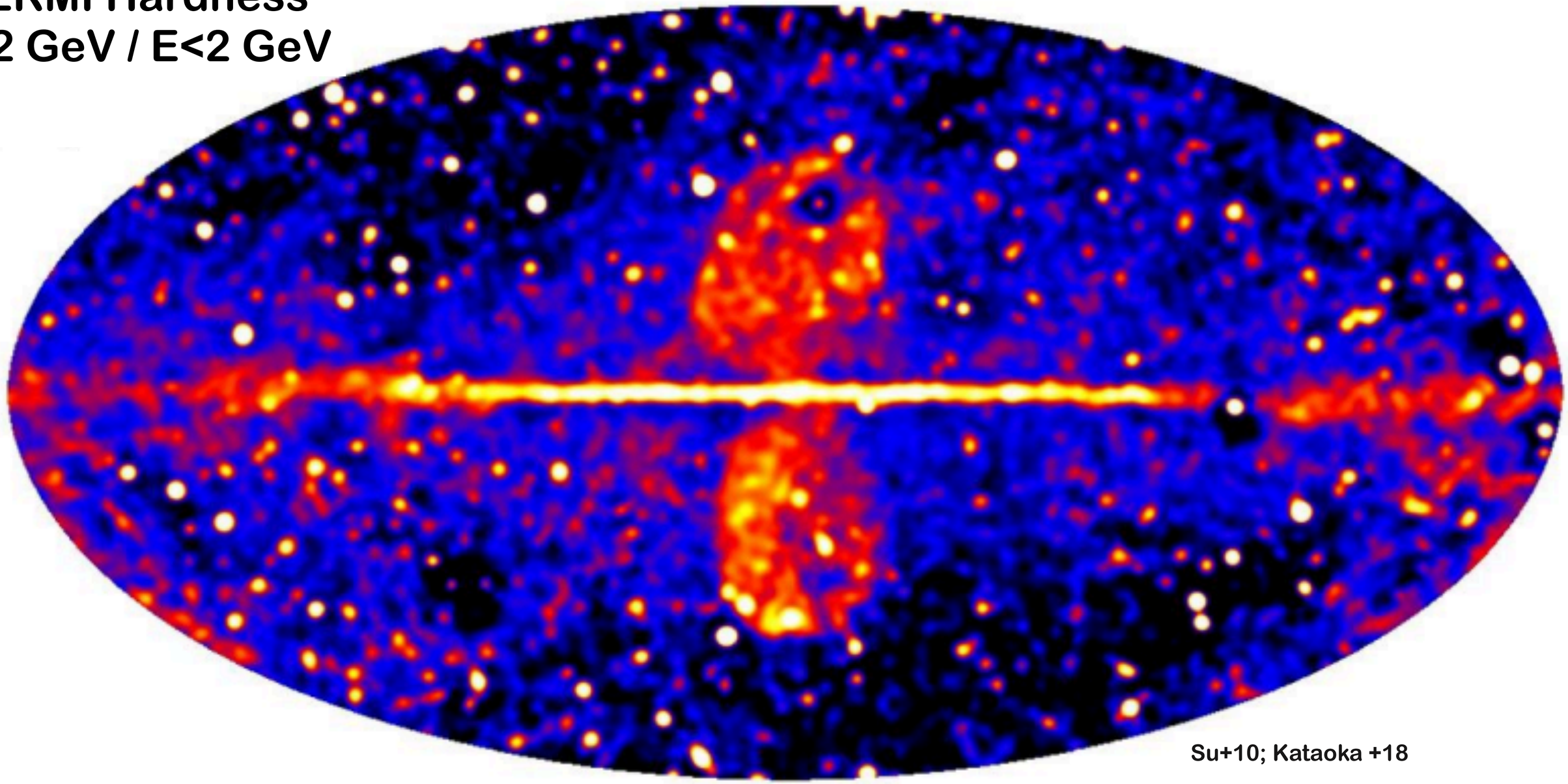
Latitudinal distance in pc from Sgr A*

Discovery of the FERMI bubbles

FERMI Hardness
E>2 GeV / E<2 GeV

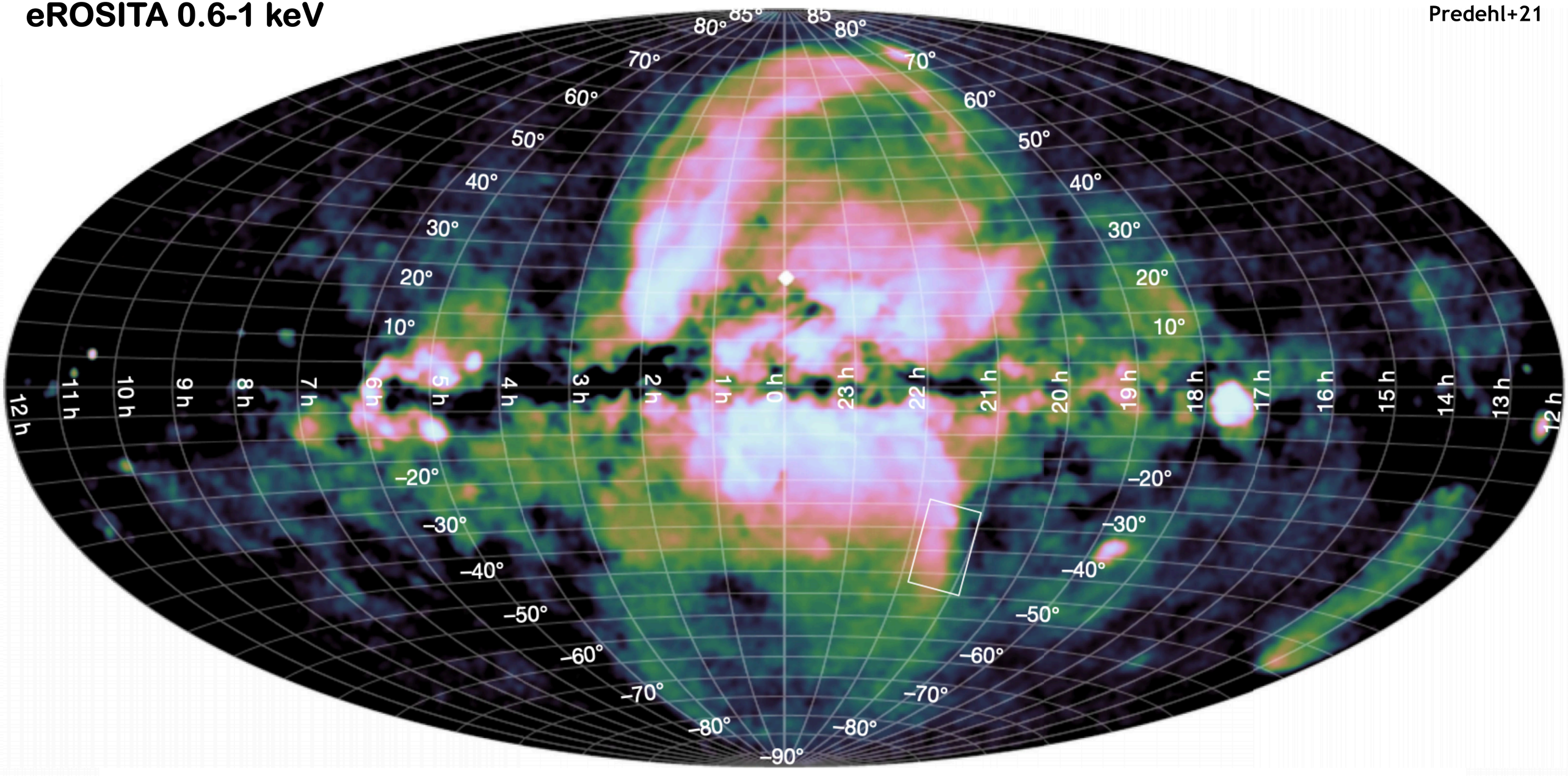


Su+10; Kataoka +18

Discovery of the eROSITA bubbles!

eROSITA 0.6-1 keV

Predehl+21



Sgr A* at very high and lower energies…

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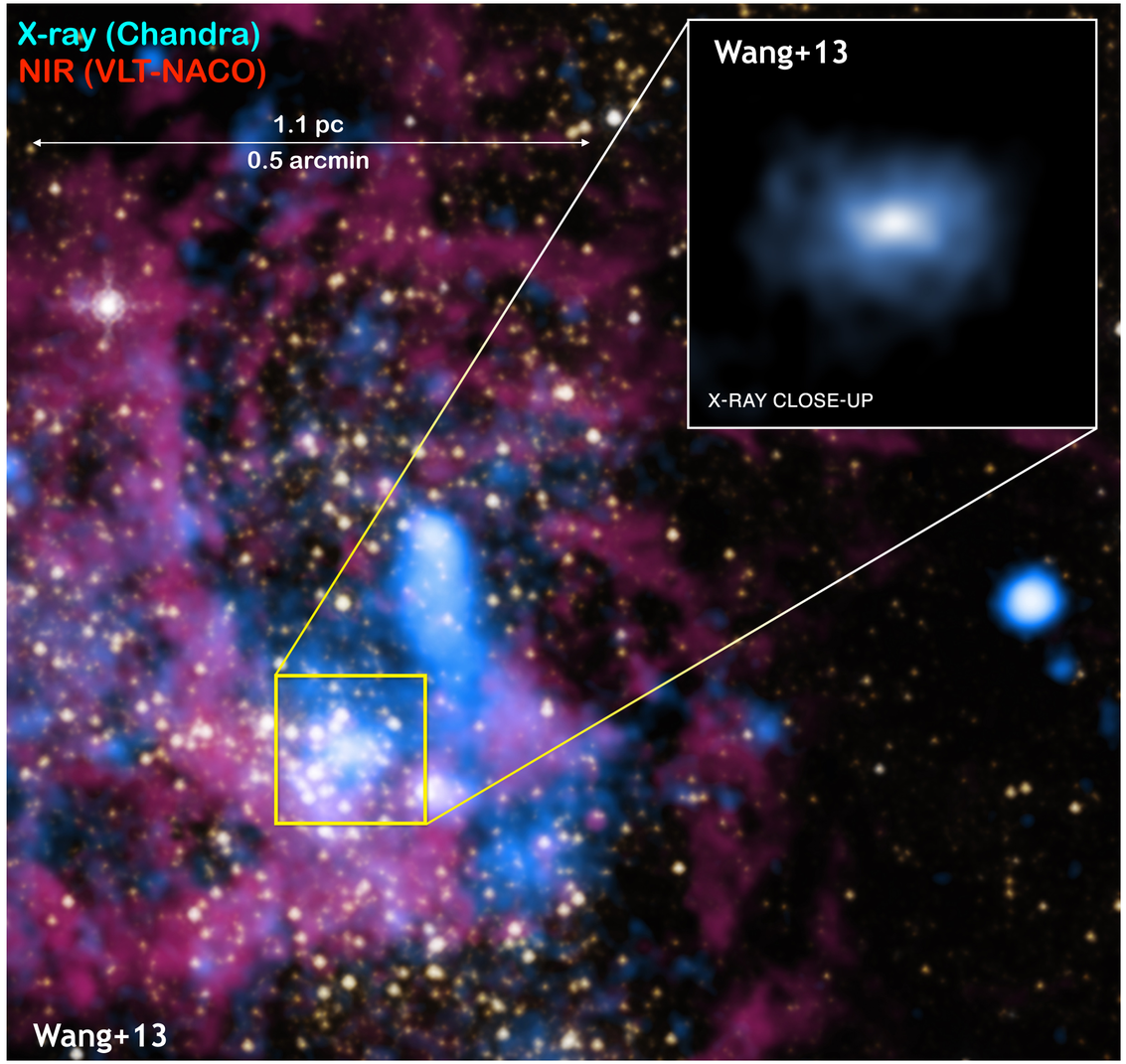

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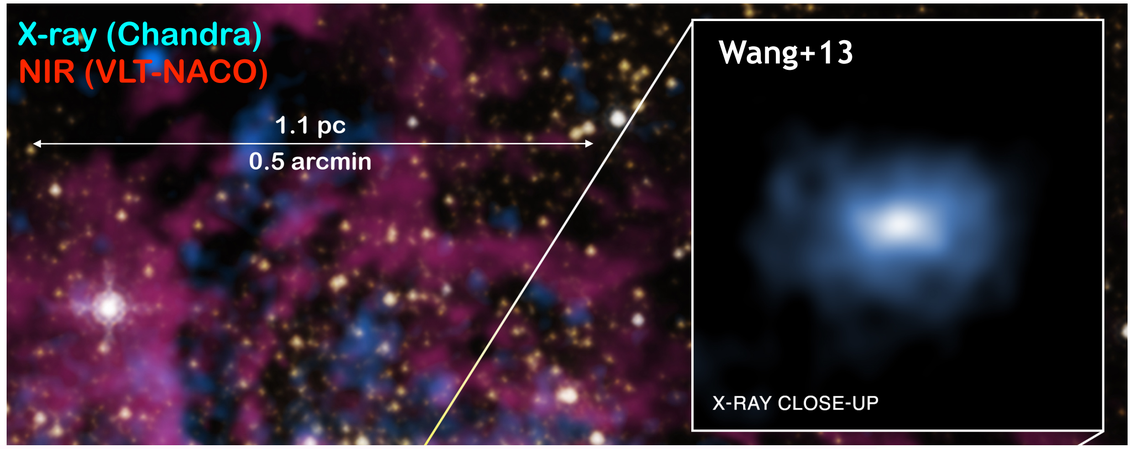
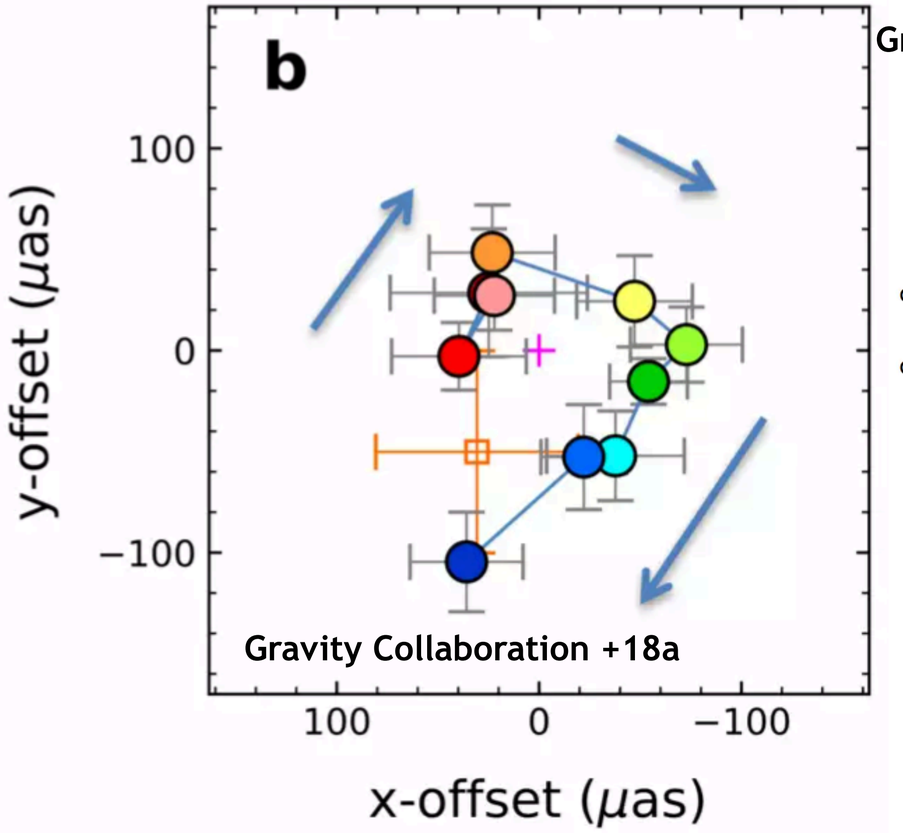
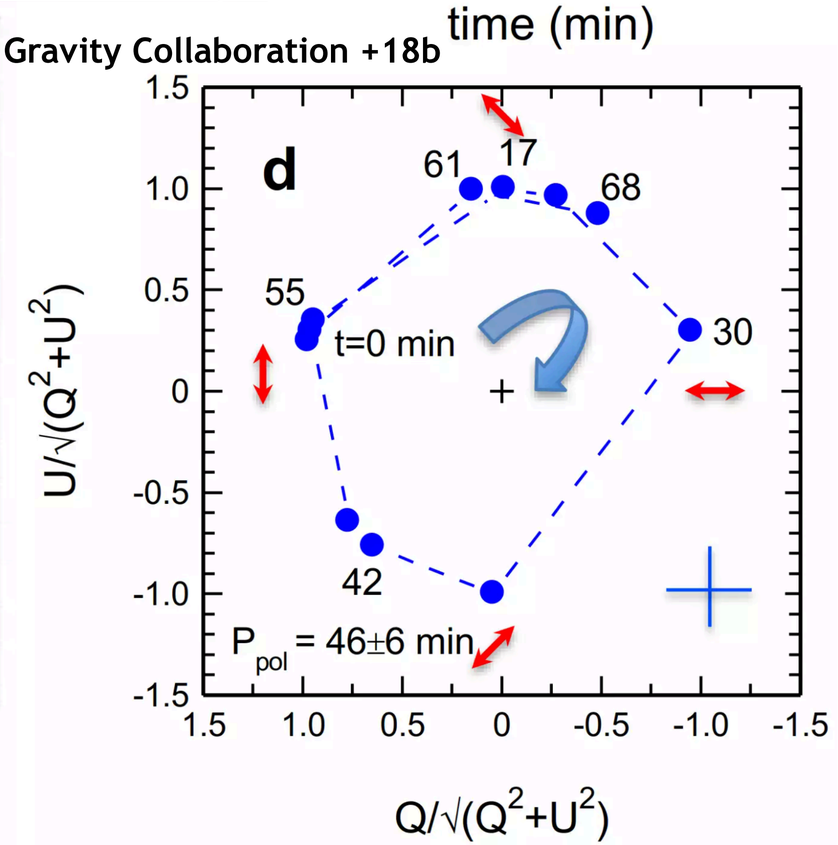


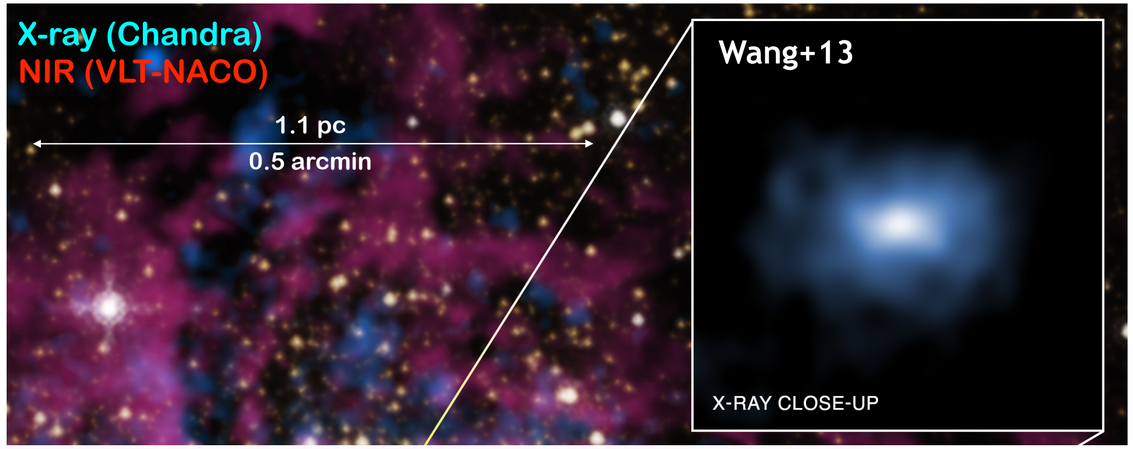


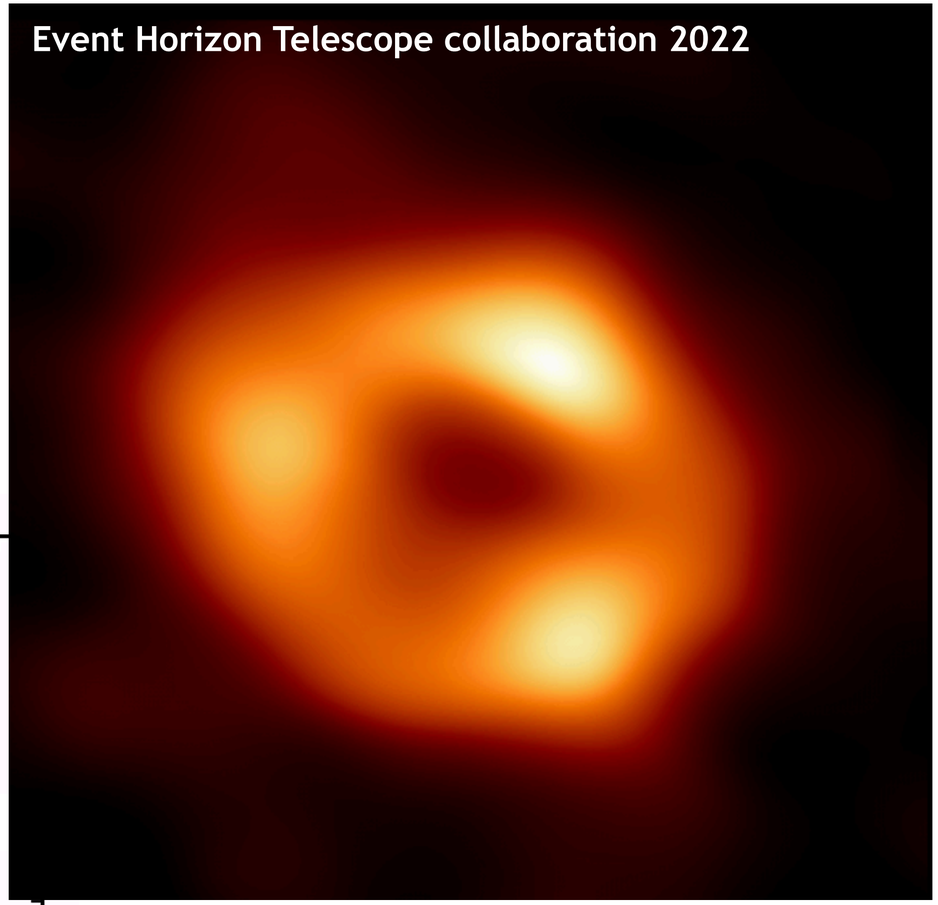
Gravity Collaboration +18b

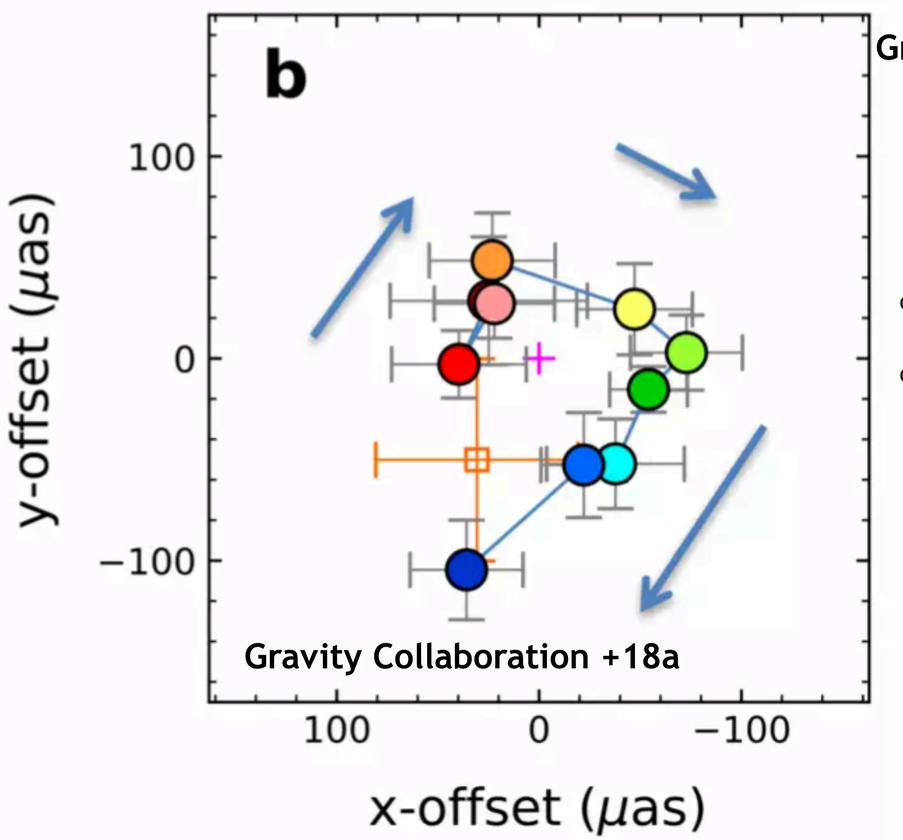


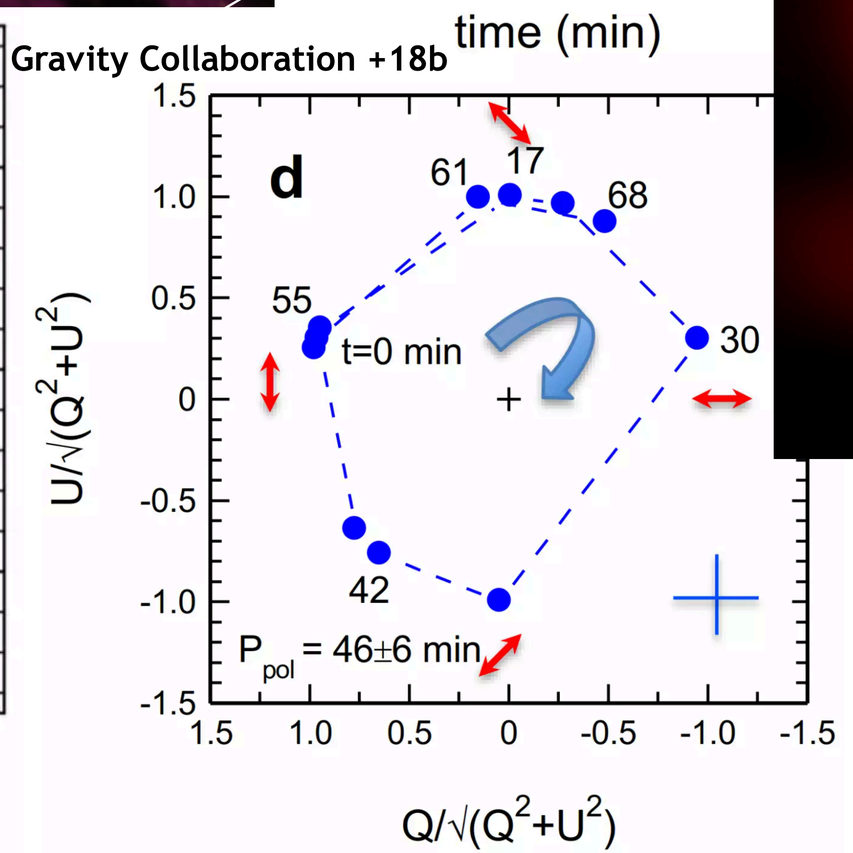
Orbital motion around BH!

Sgr A* at very high and lower energies…









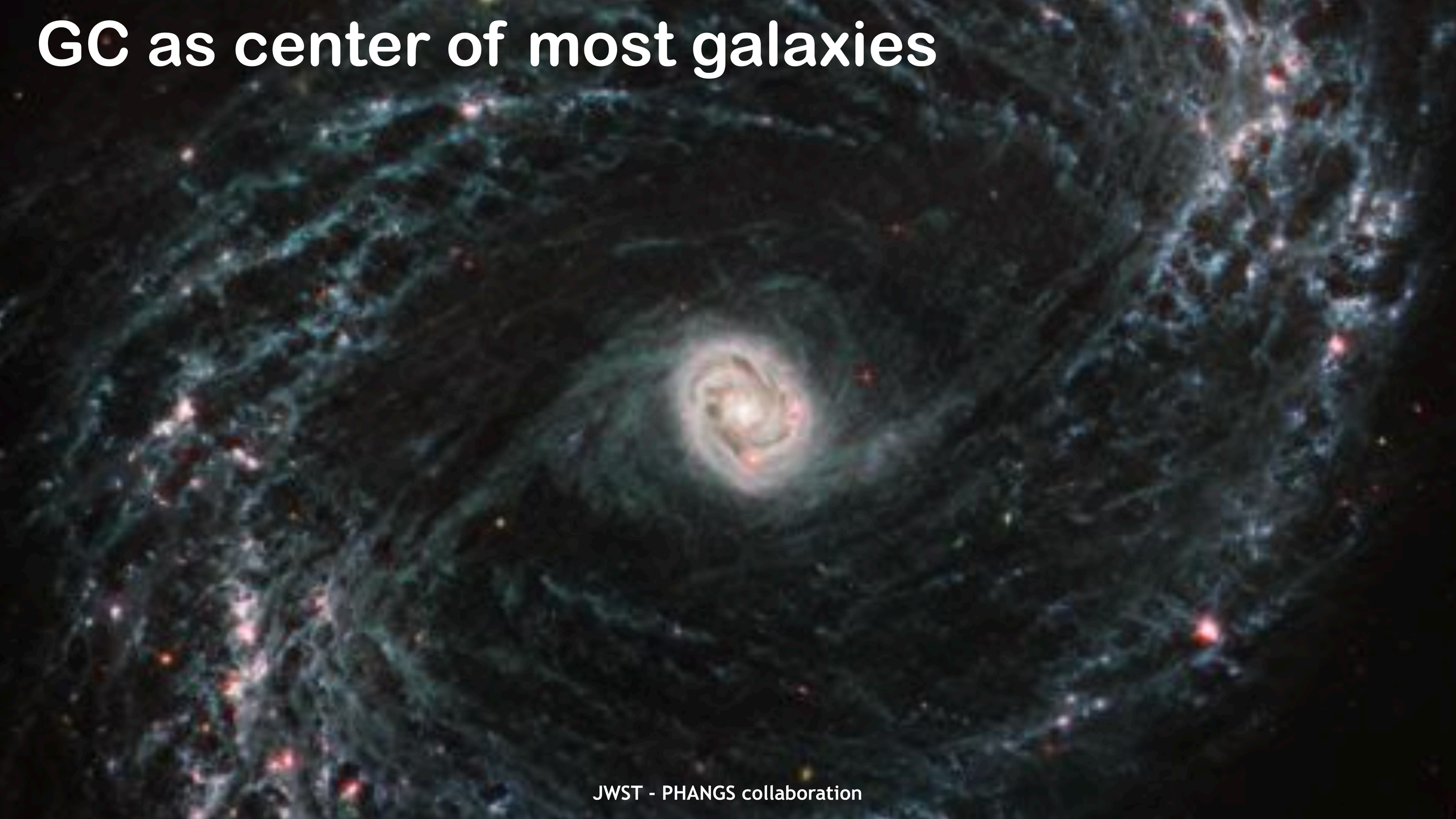
Orbital motion around BH!

The Galactic center is a peculiar environment

The Galactic center is a peculiar environment

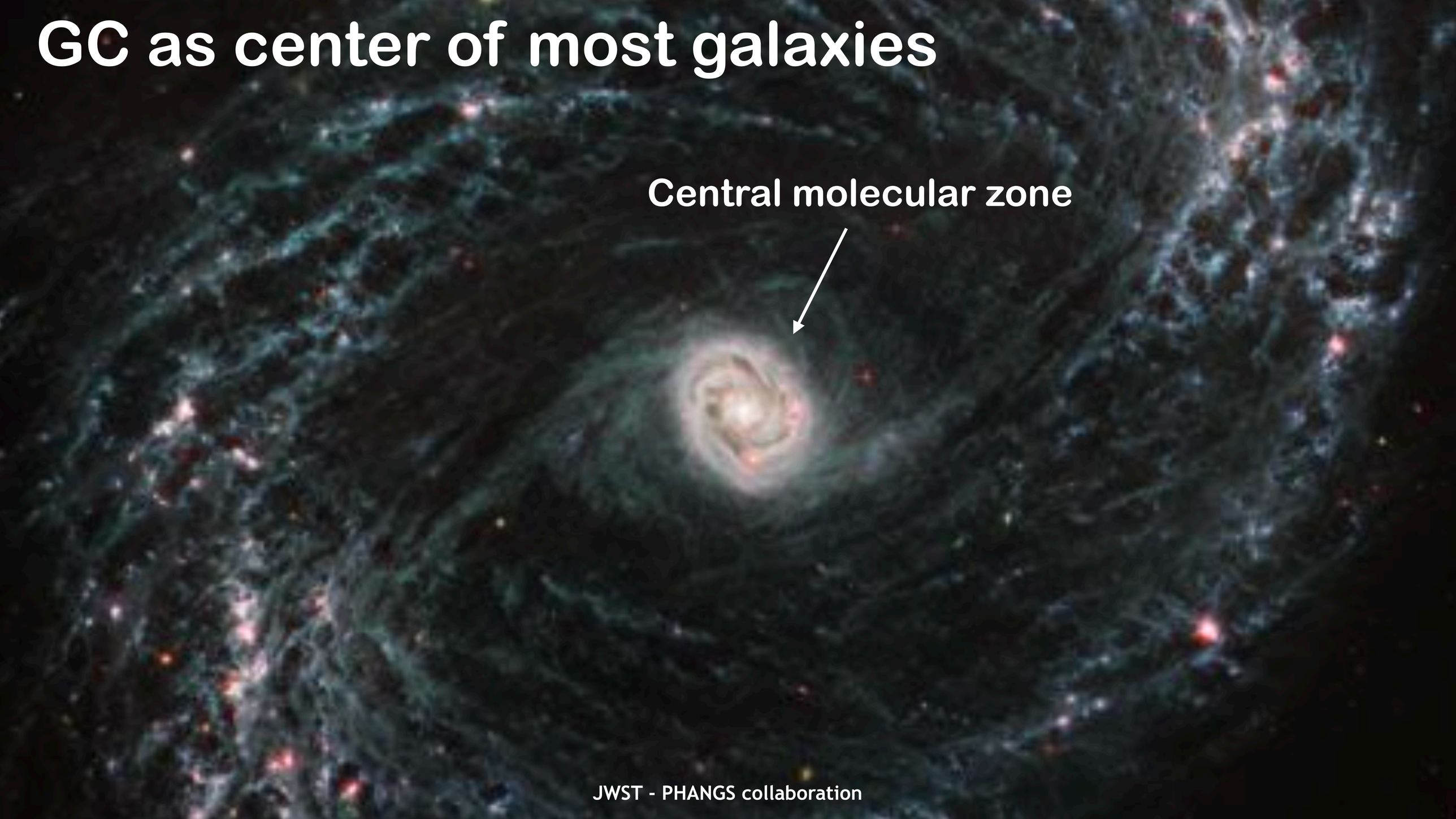
➜ but similar to the center of many galaxies

GC as center of most galaxies



JWST - PHANGS collaboration

GC as center of most galaxies



JWST - PHANGS collaboration

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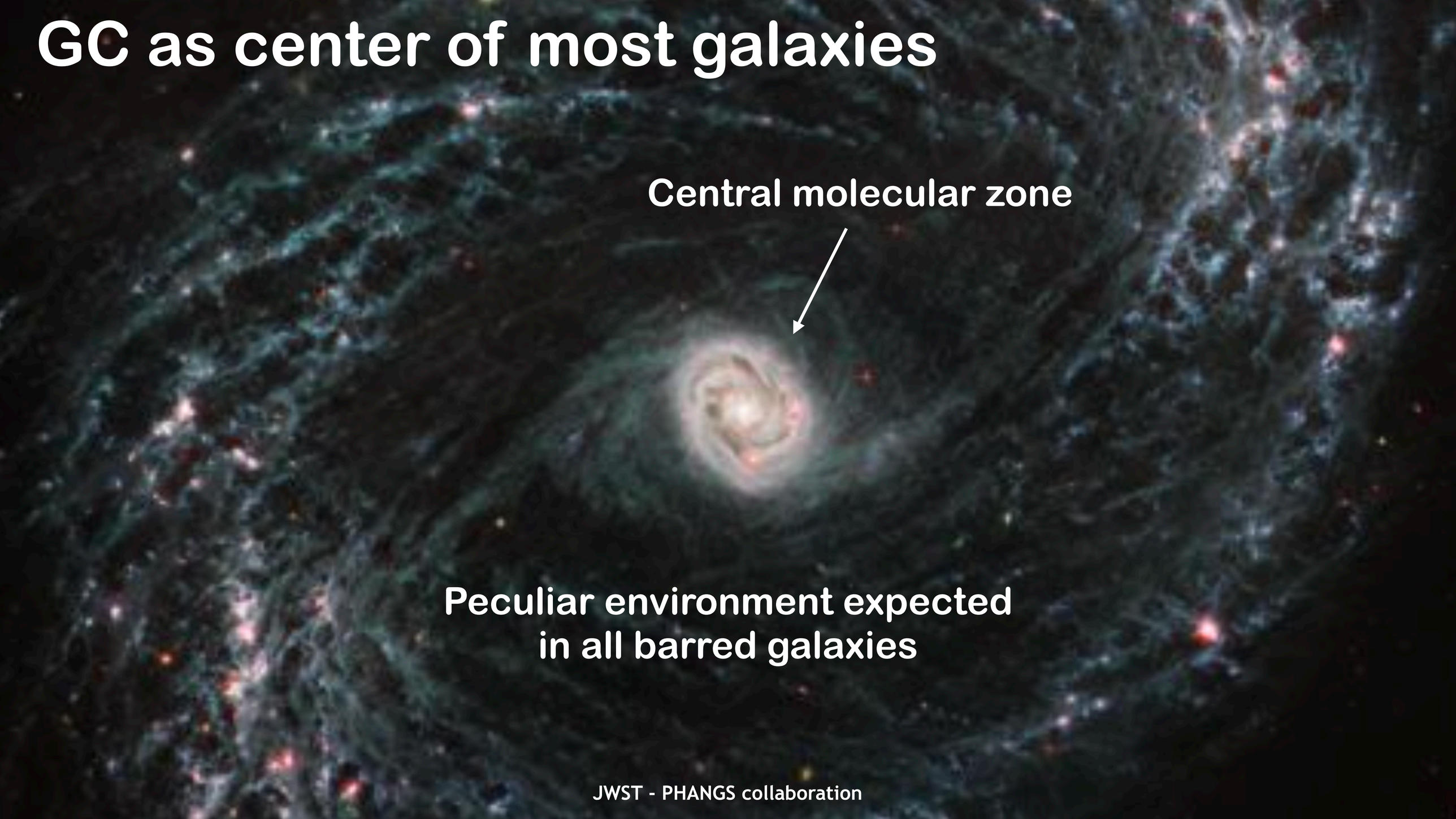
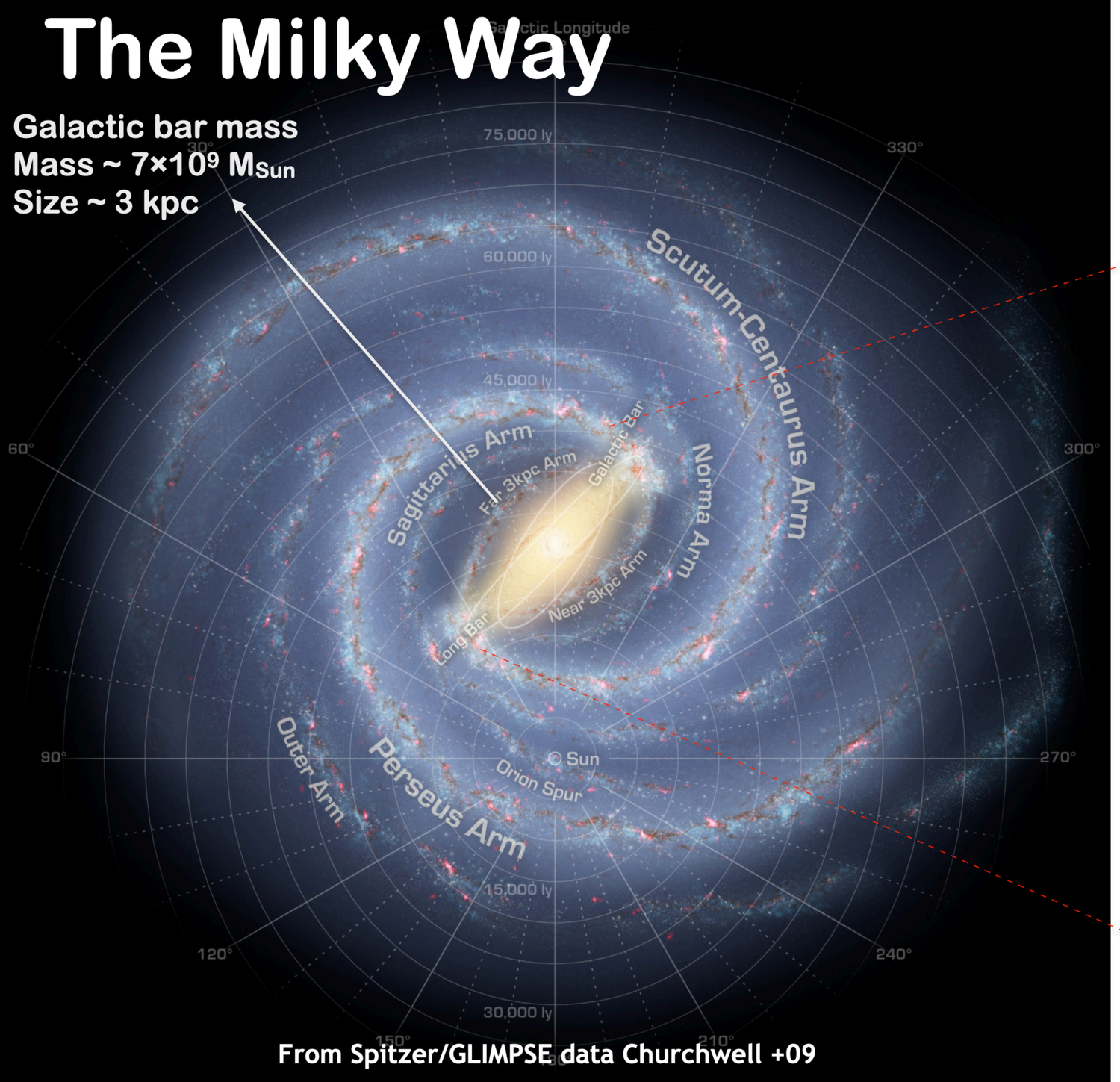
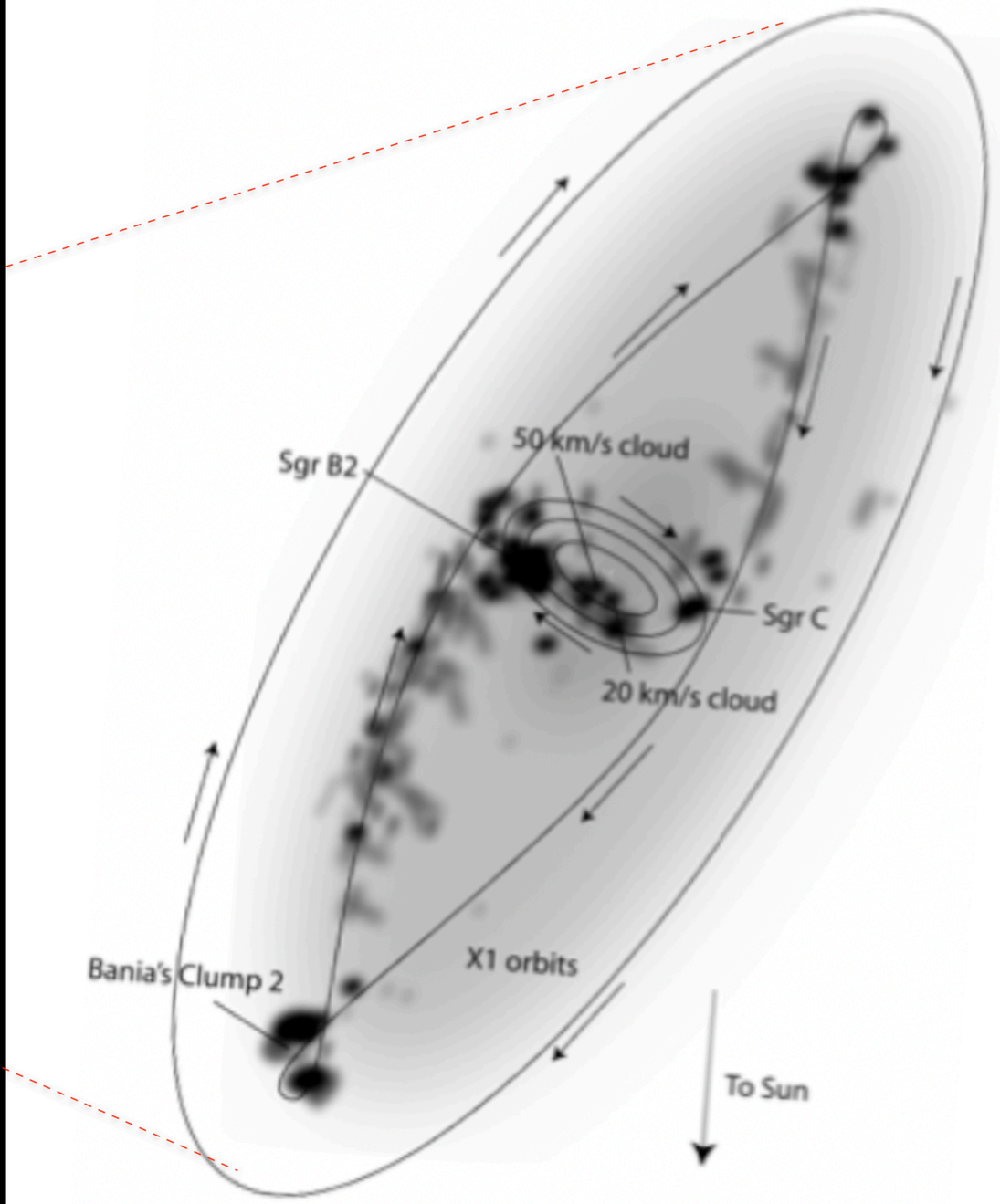


The Milky Way

Galactic bar mass
Mass ~ 7×10^9 M_{Sun}
Size ~ 3 kpc



From Spitzer/GLIMPSE data Churchwell +09



What would I love to do with CTA?

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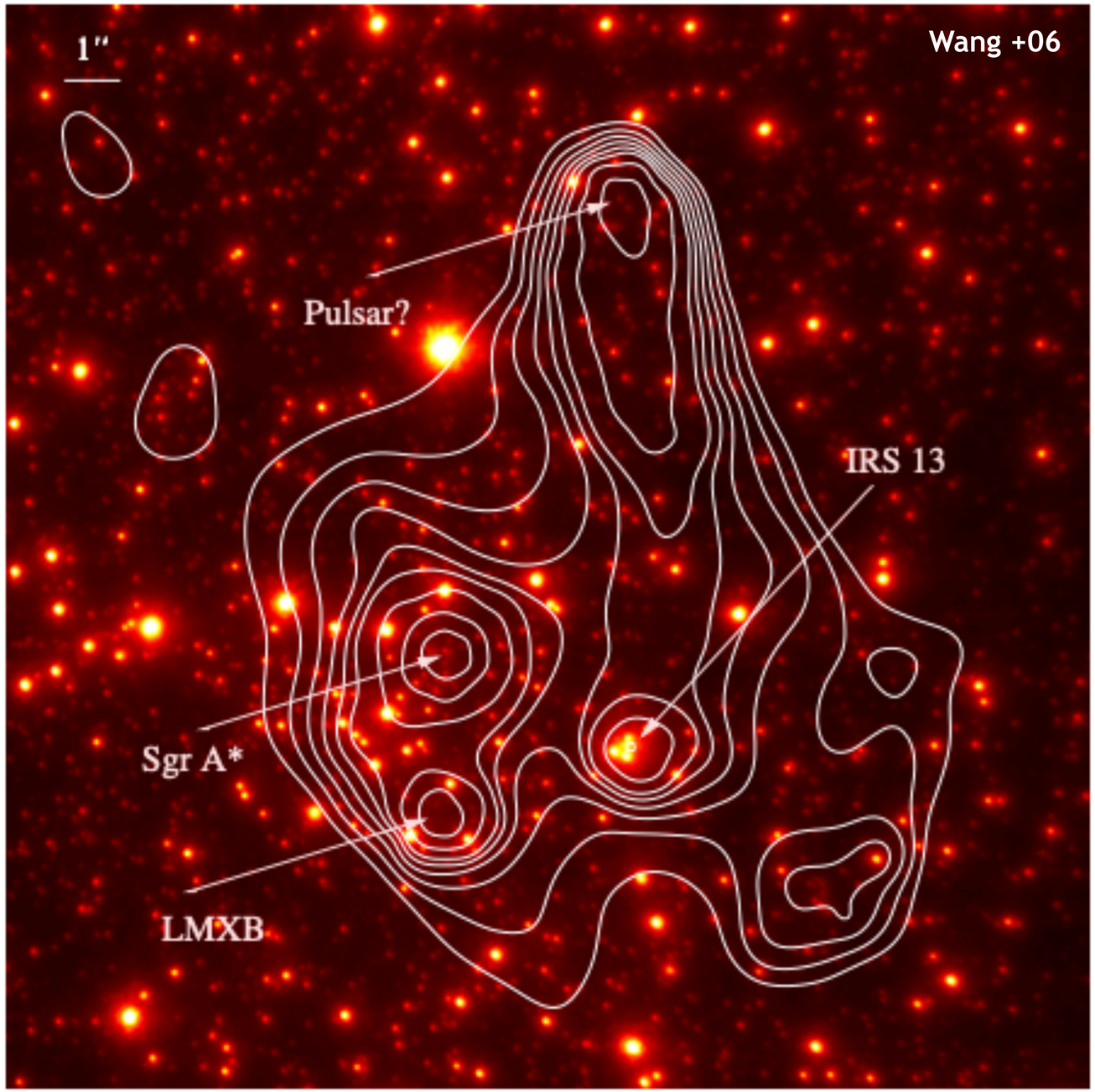
➜ Localisation of GC TeV source



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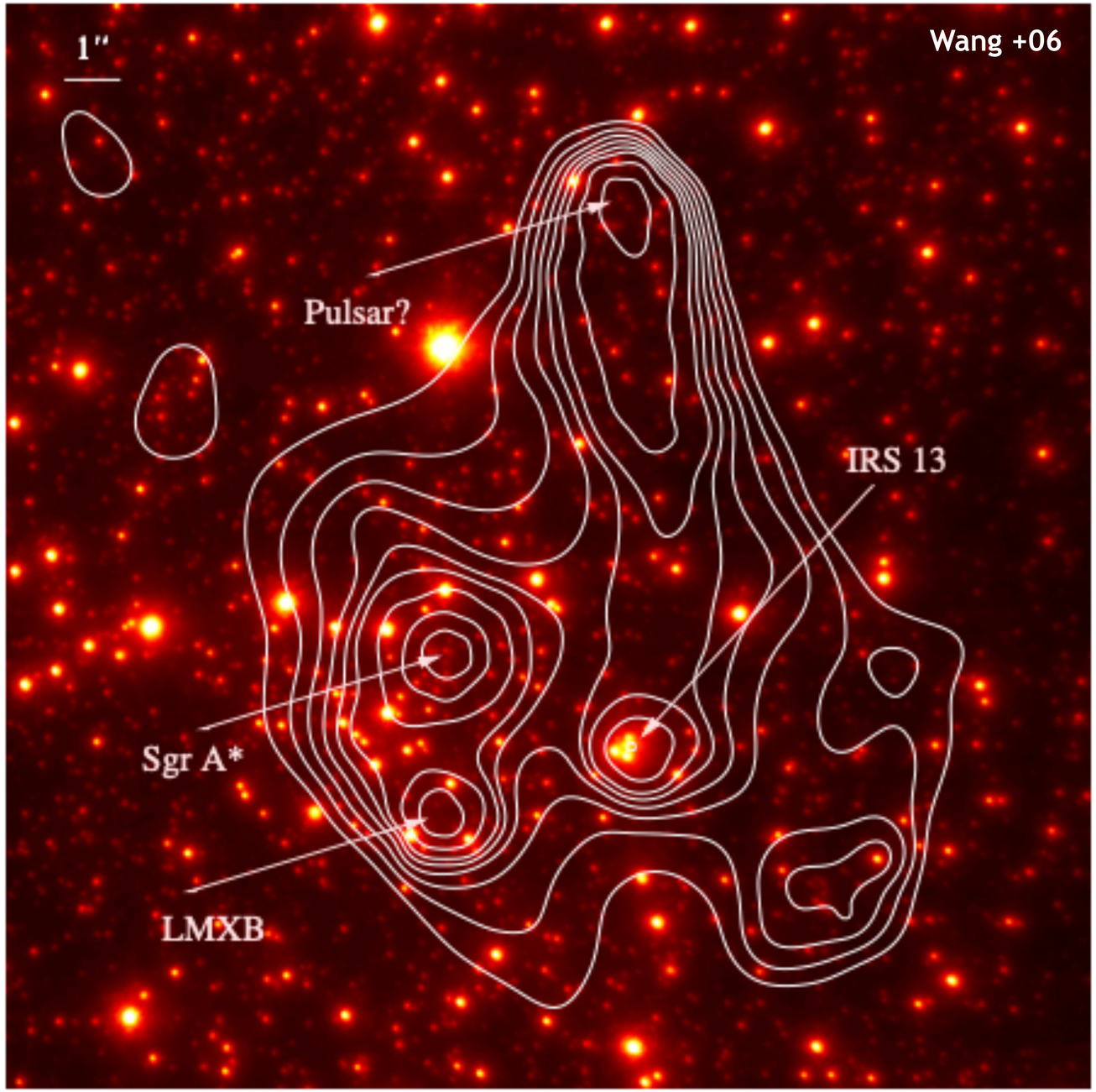
➜ Localisation of GC TeV source

Sgr A*? PWN?
Star cluster? Other?



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➜ Nature of GC PeVatron

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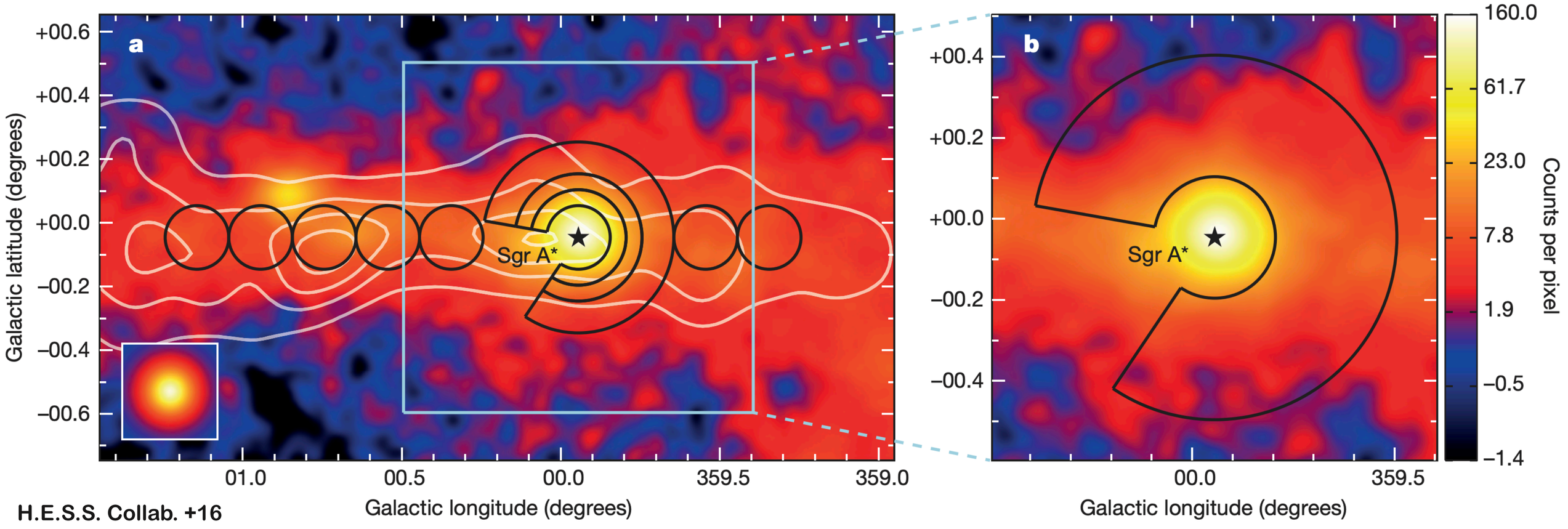

H.E.S.S. Collab. +16

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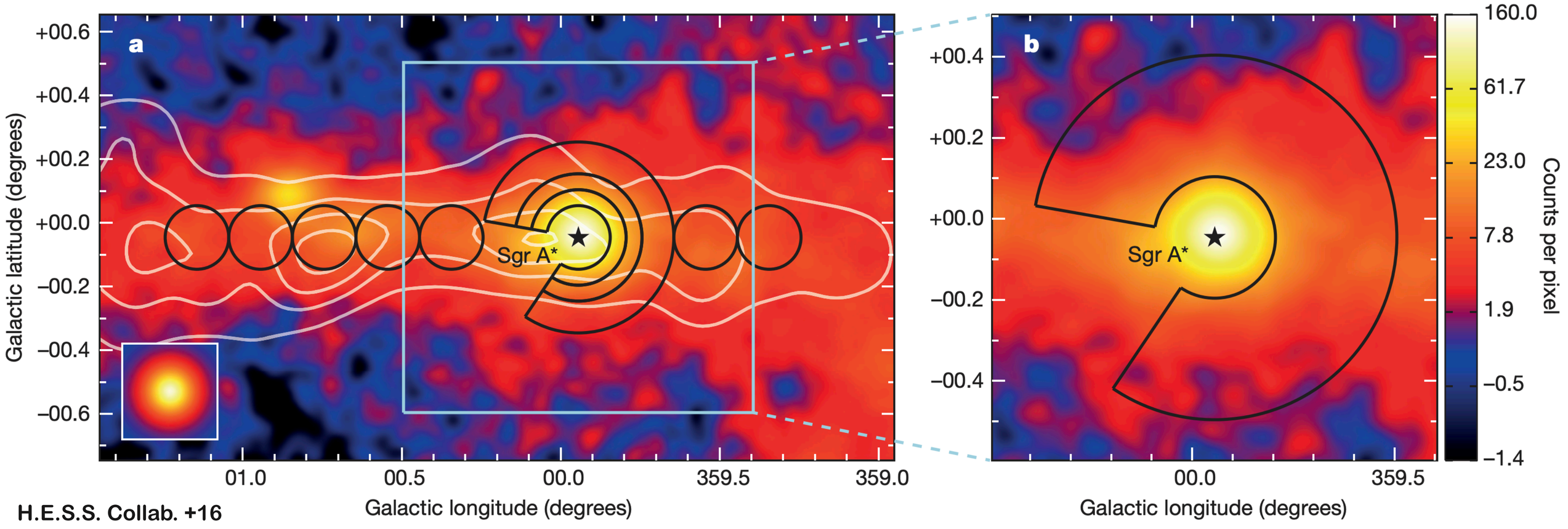
➜ Nature of GC PeVatron

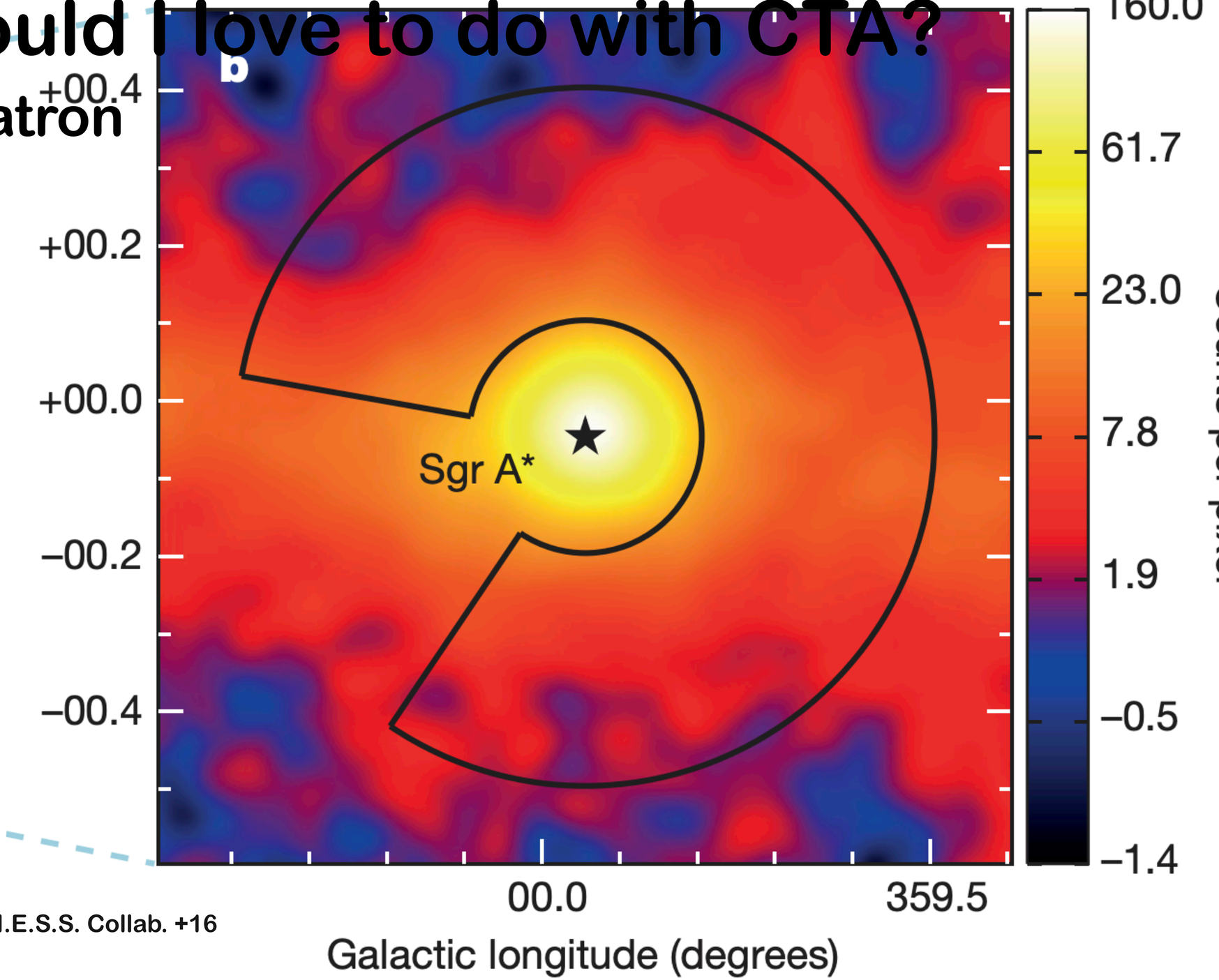


H.E.S.S. Collab. +16

Sgr A*? Young star clusters? Other?

What would I love to do with CTA?

➜ Nature of GC PeVatron



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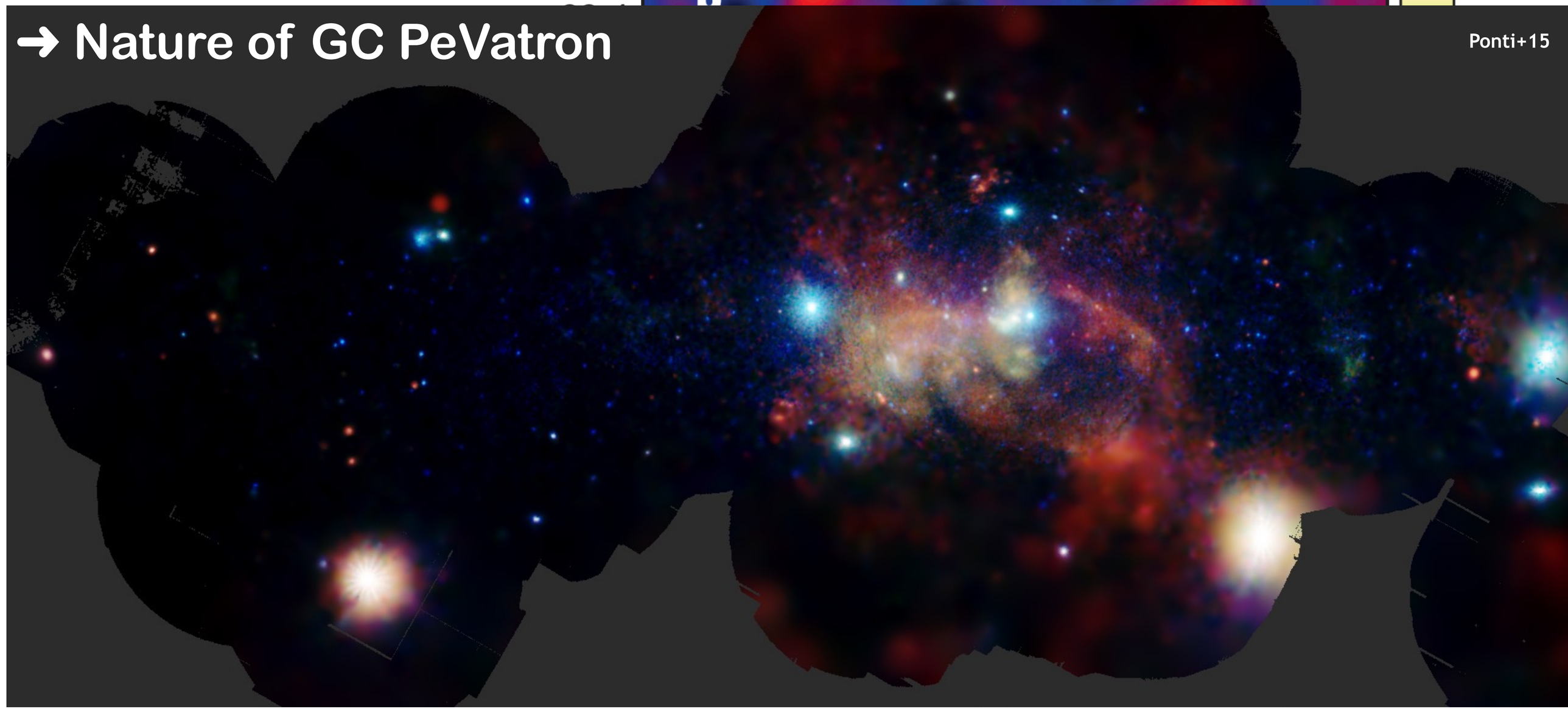

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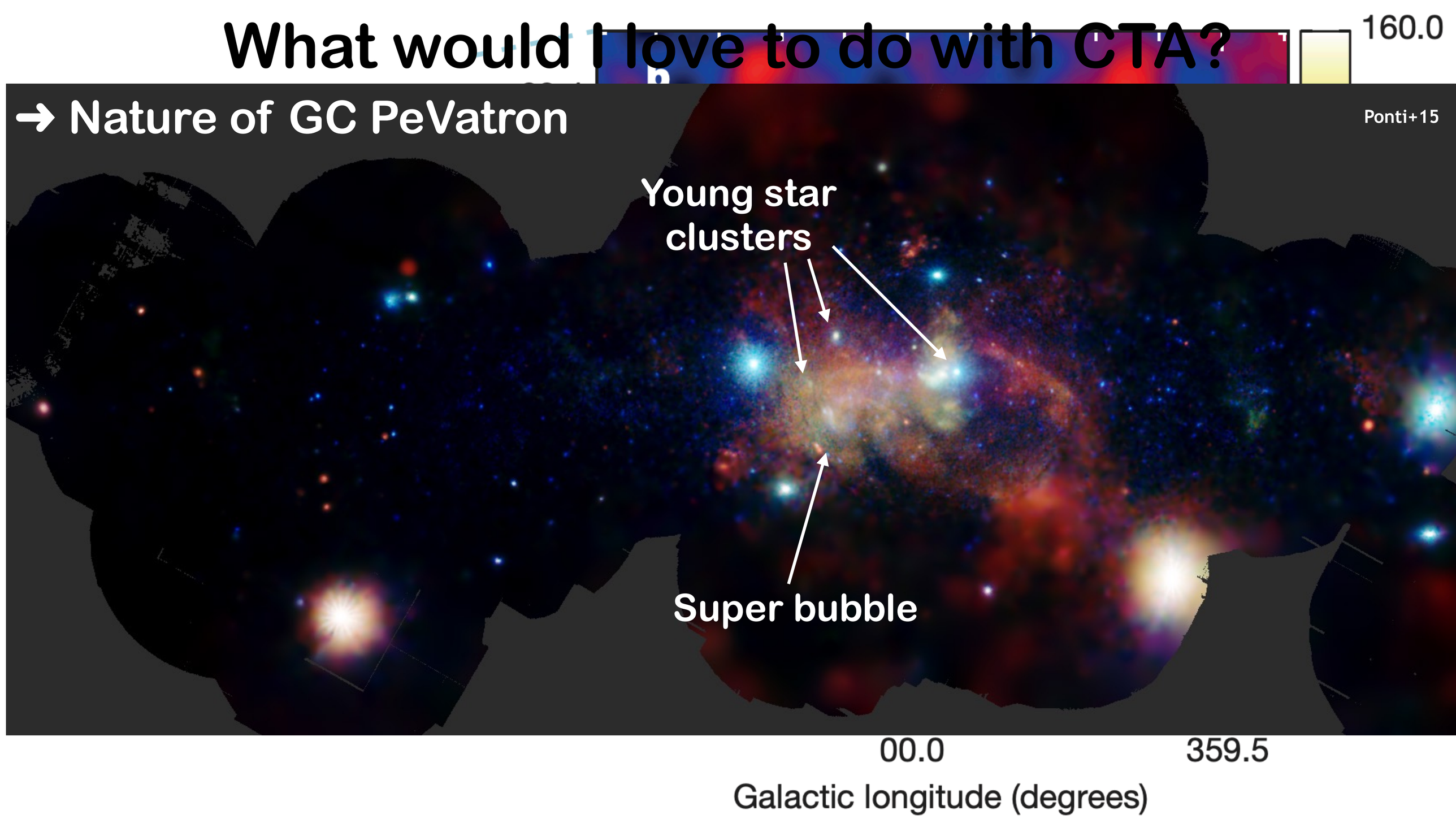

What would I love to do with CTA?

➜ Cover the base and edges of
the Galactic outflow!

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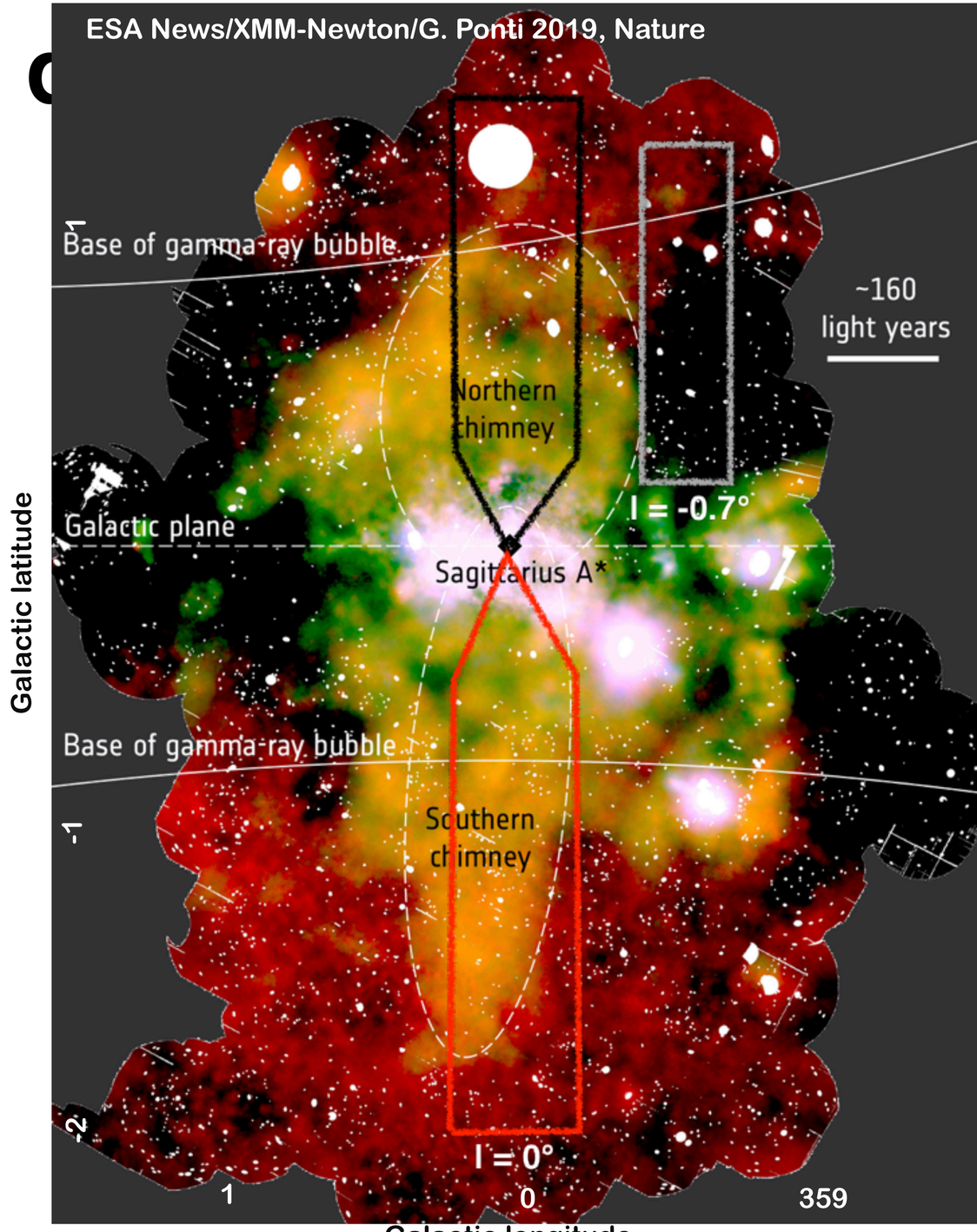

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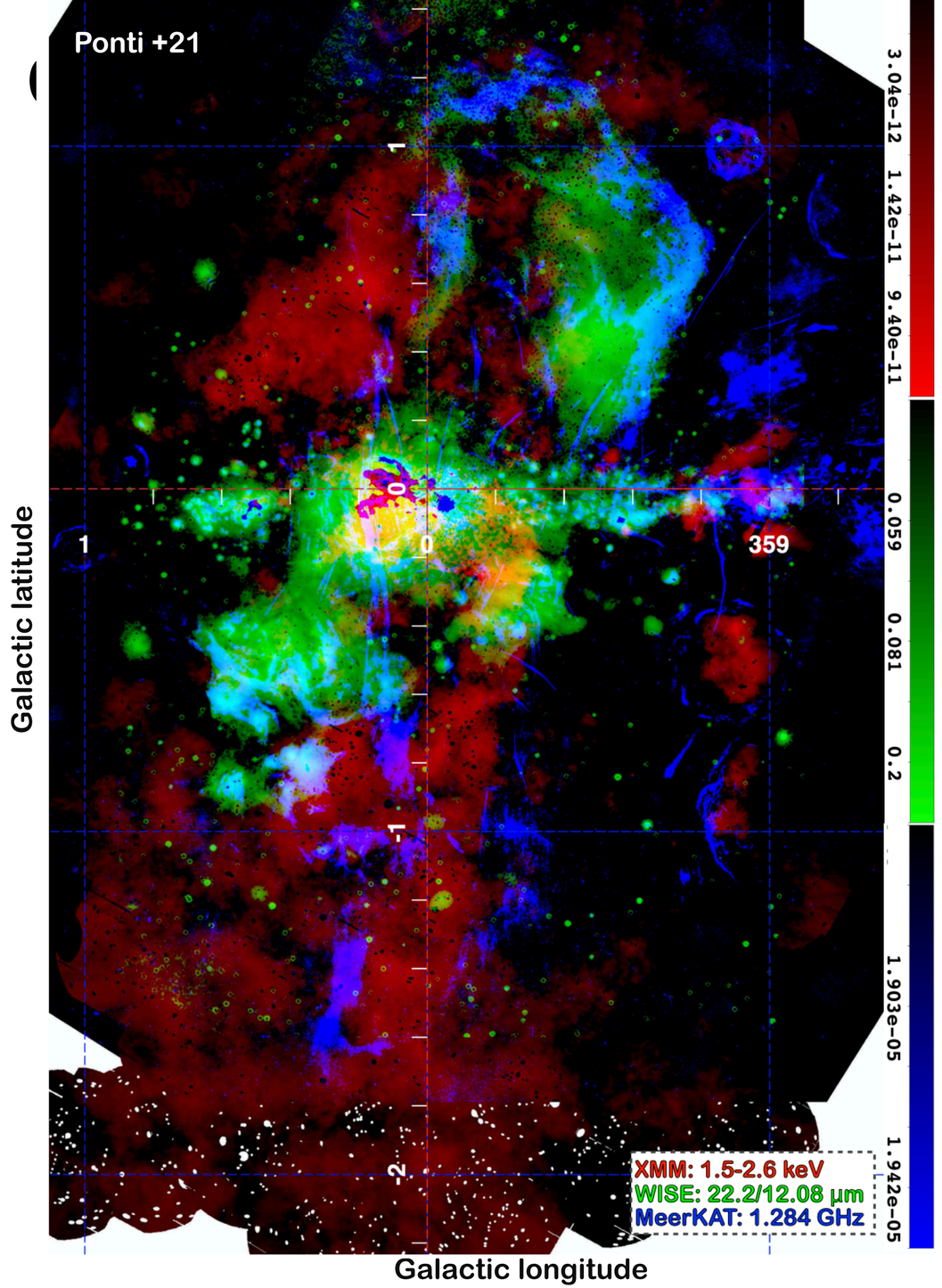

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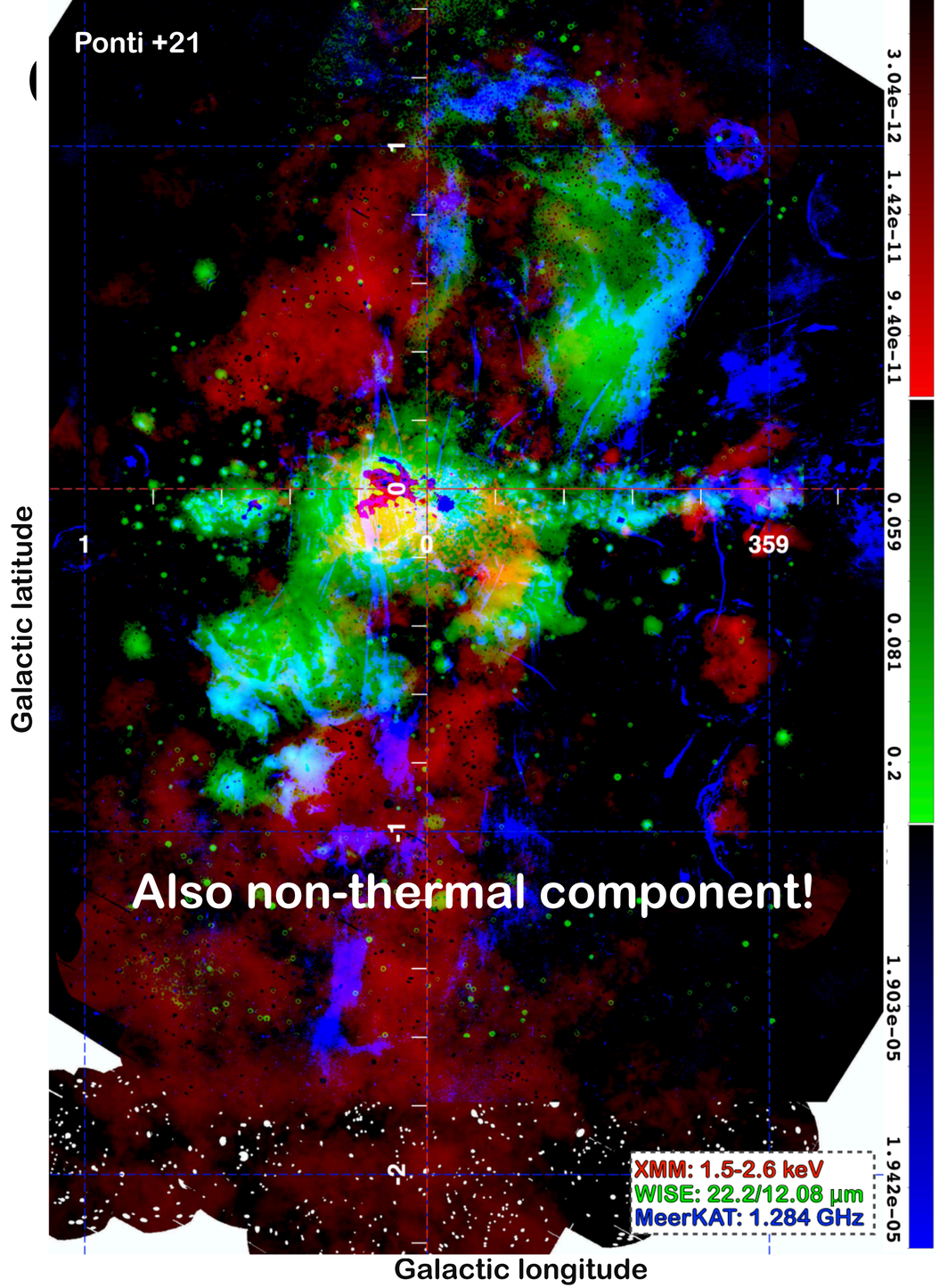

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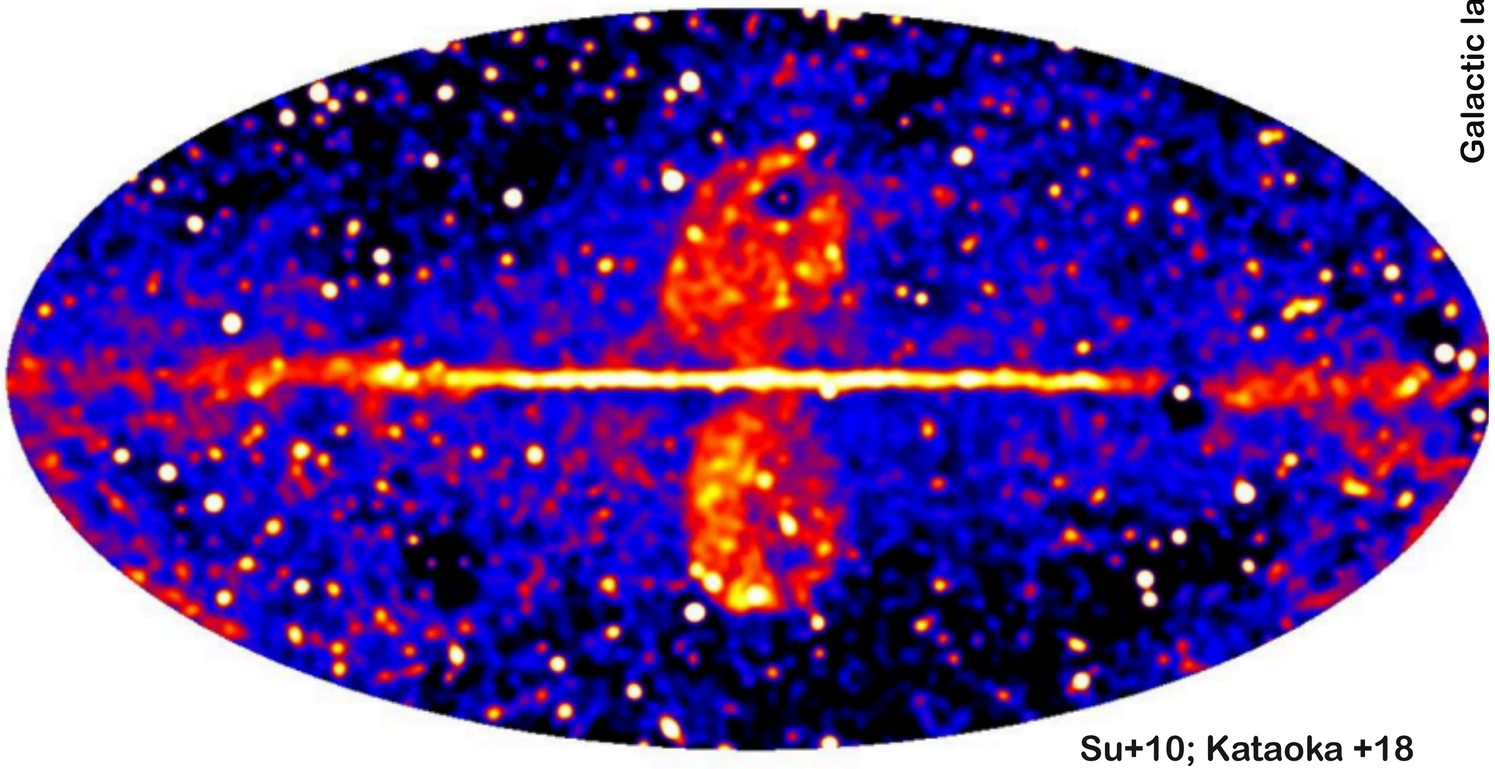
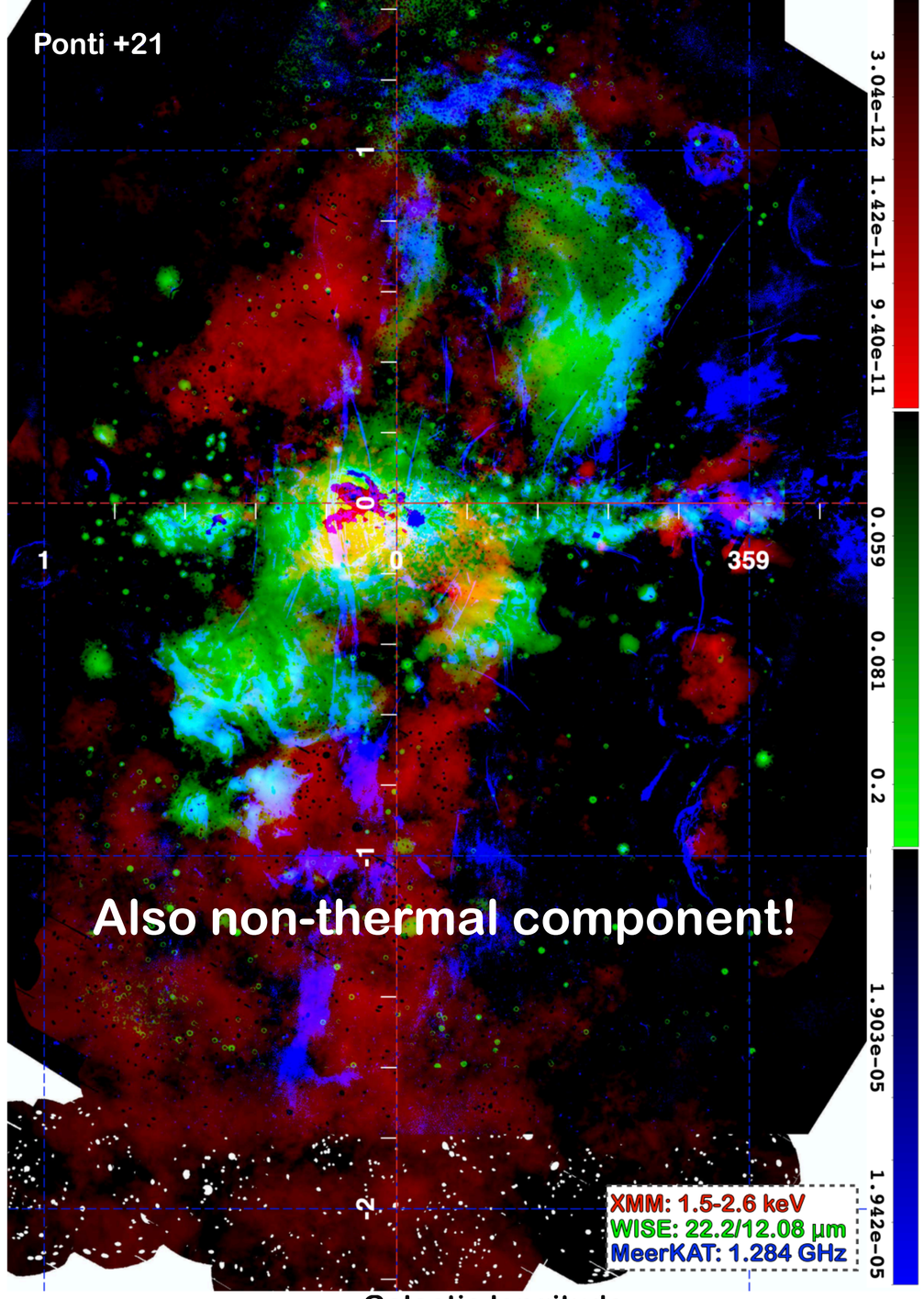


Su+10; Kataoka +18



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➜ Sgr A*'s emission during flares

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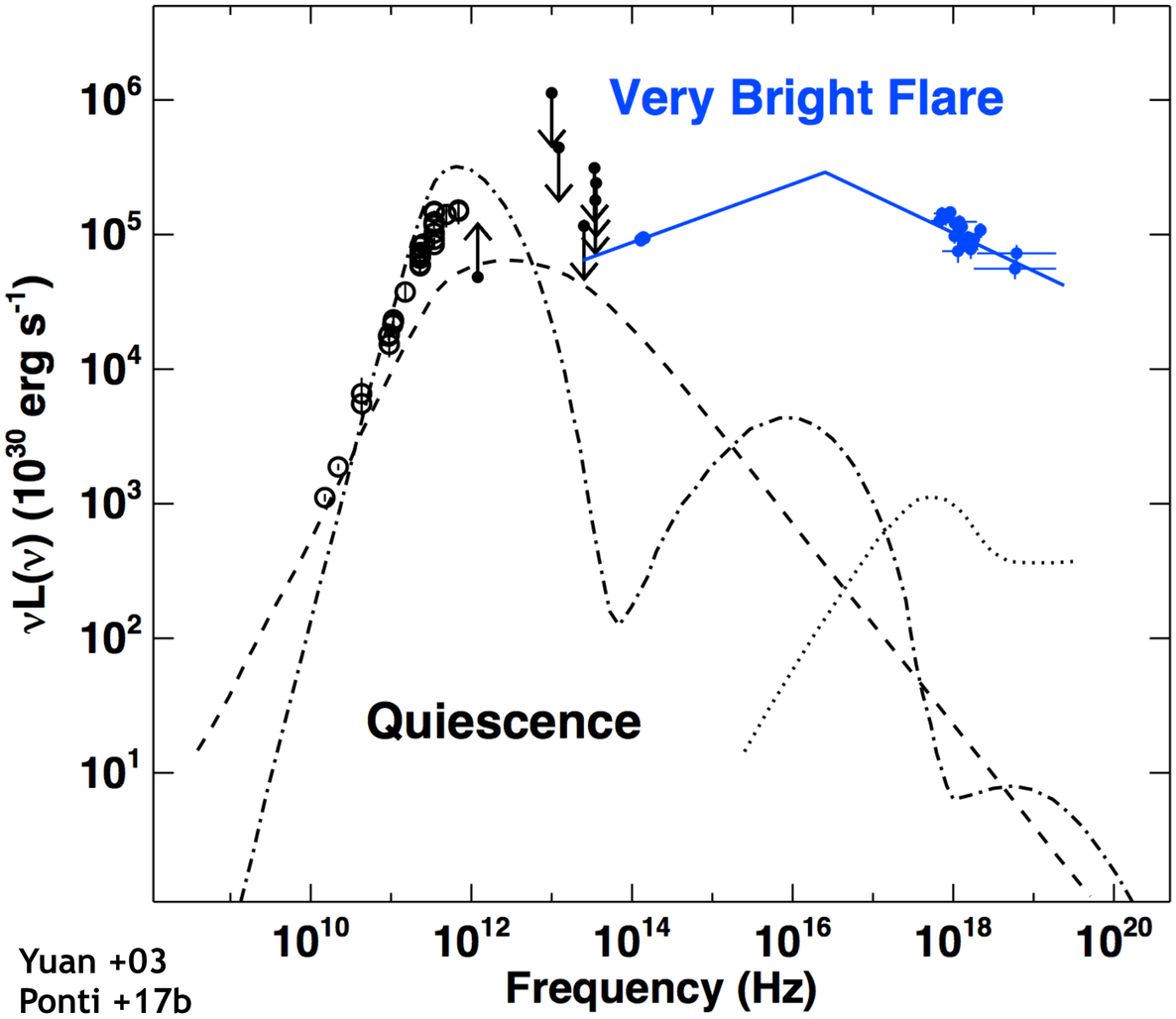

Yuan +03
Ponti +17b

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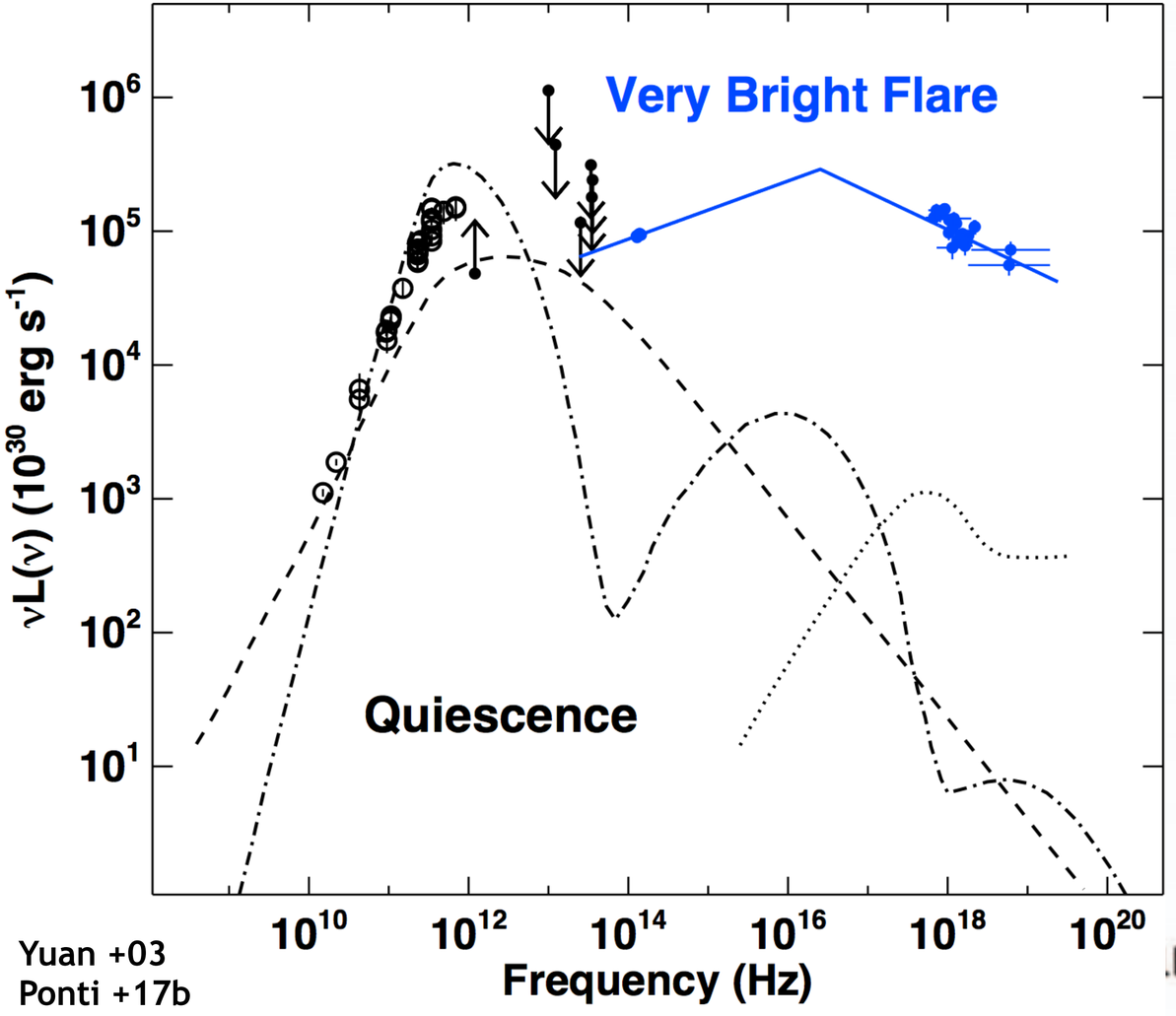

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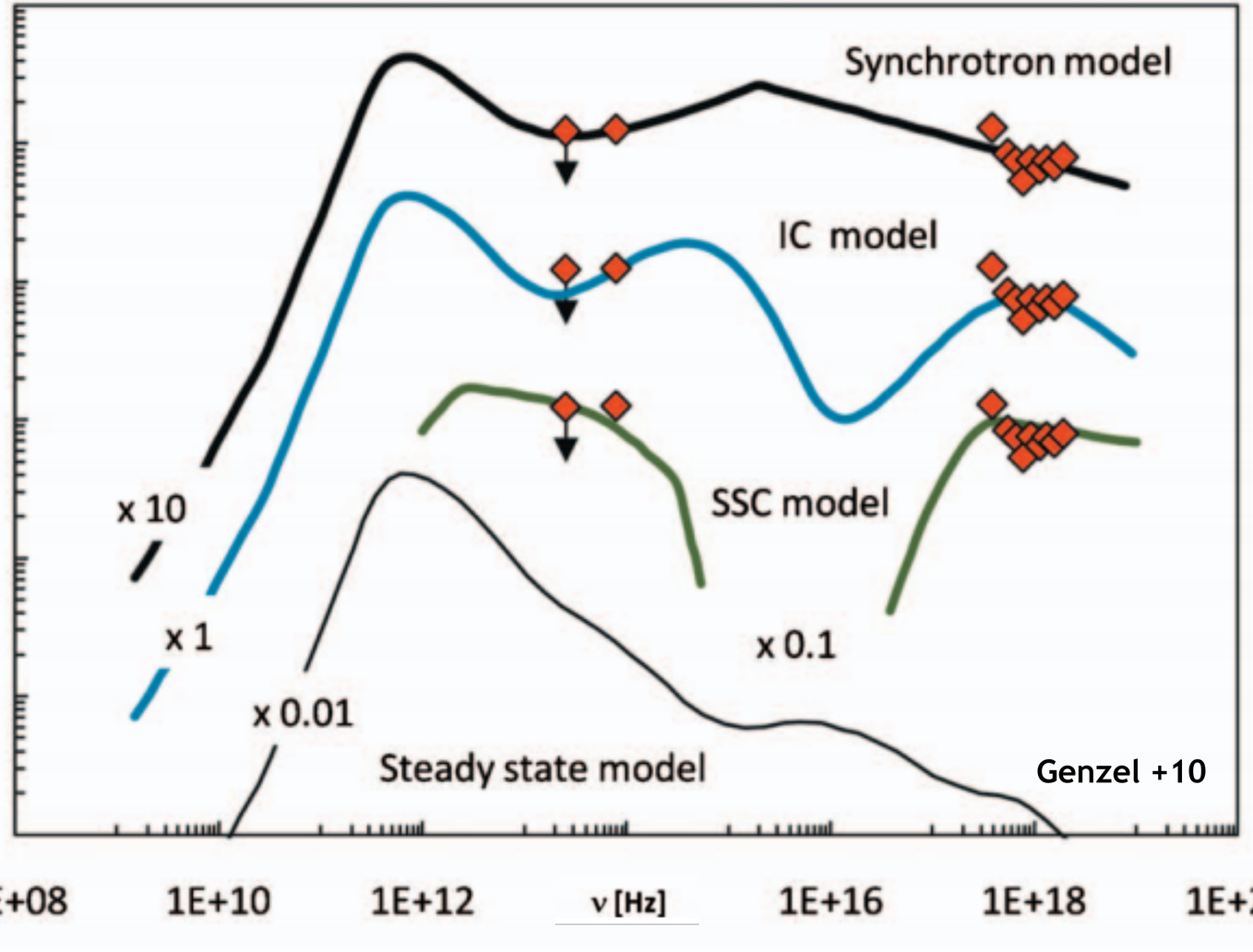

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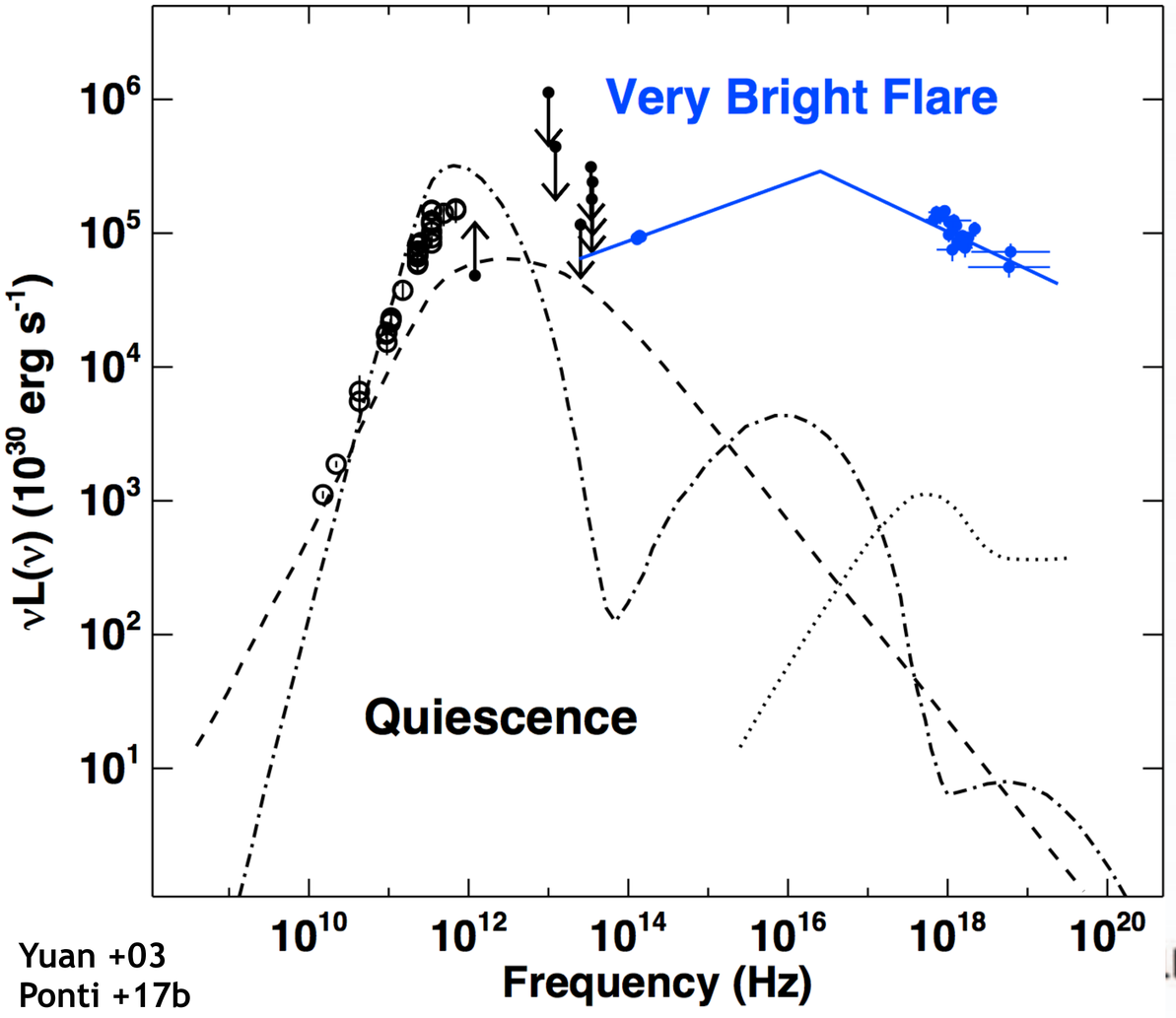

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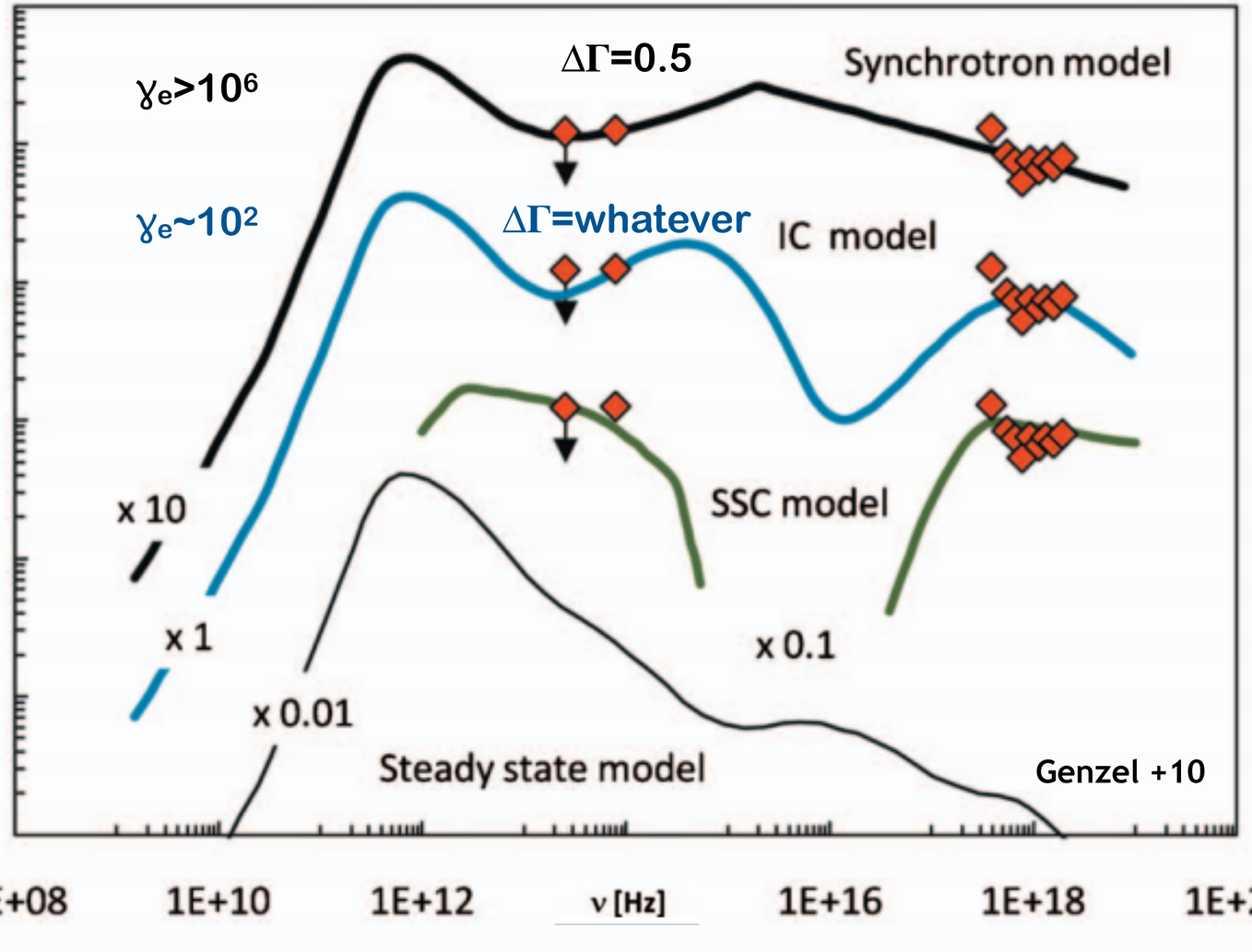
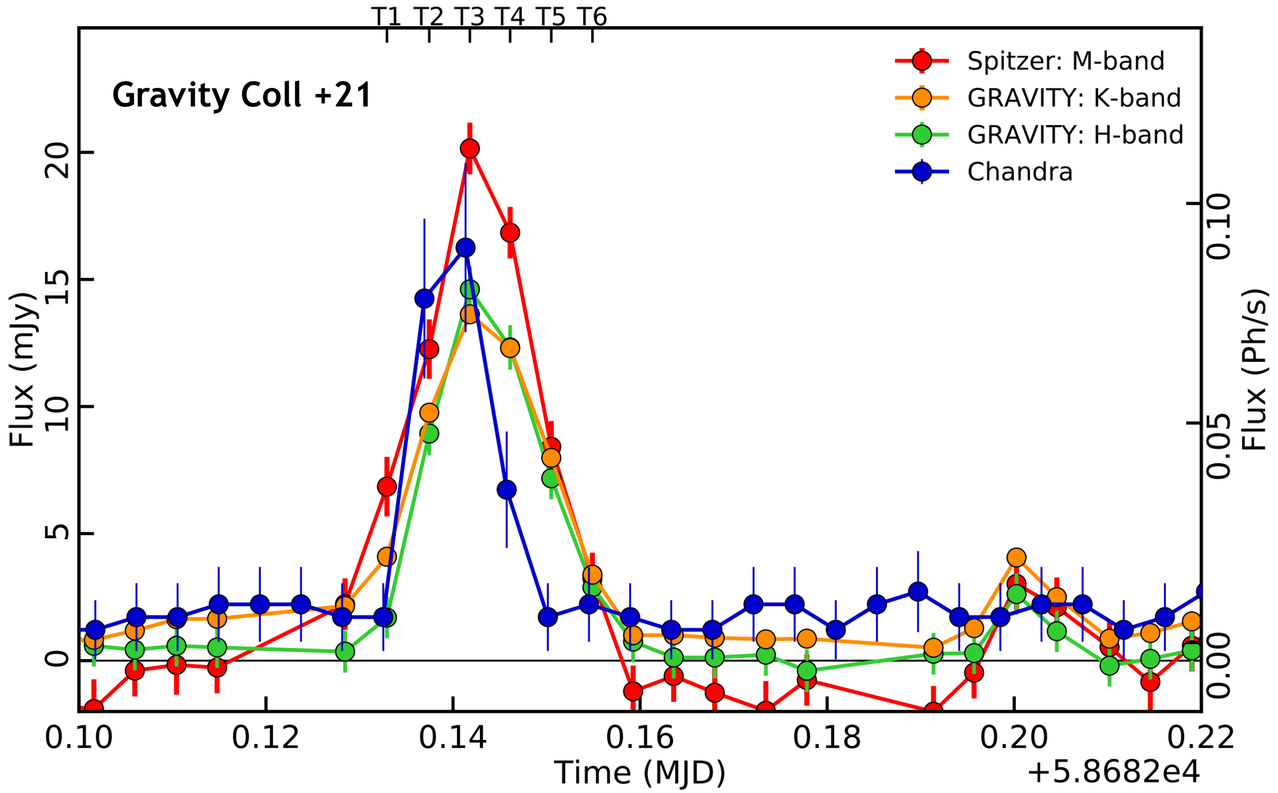
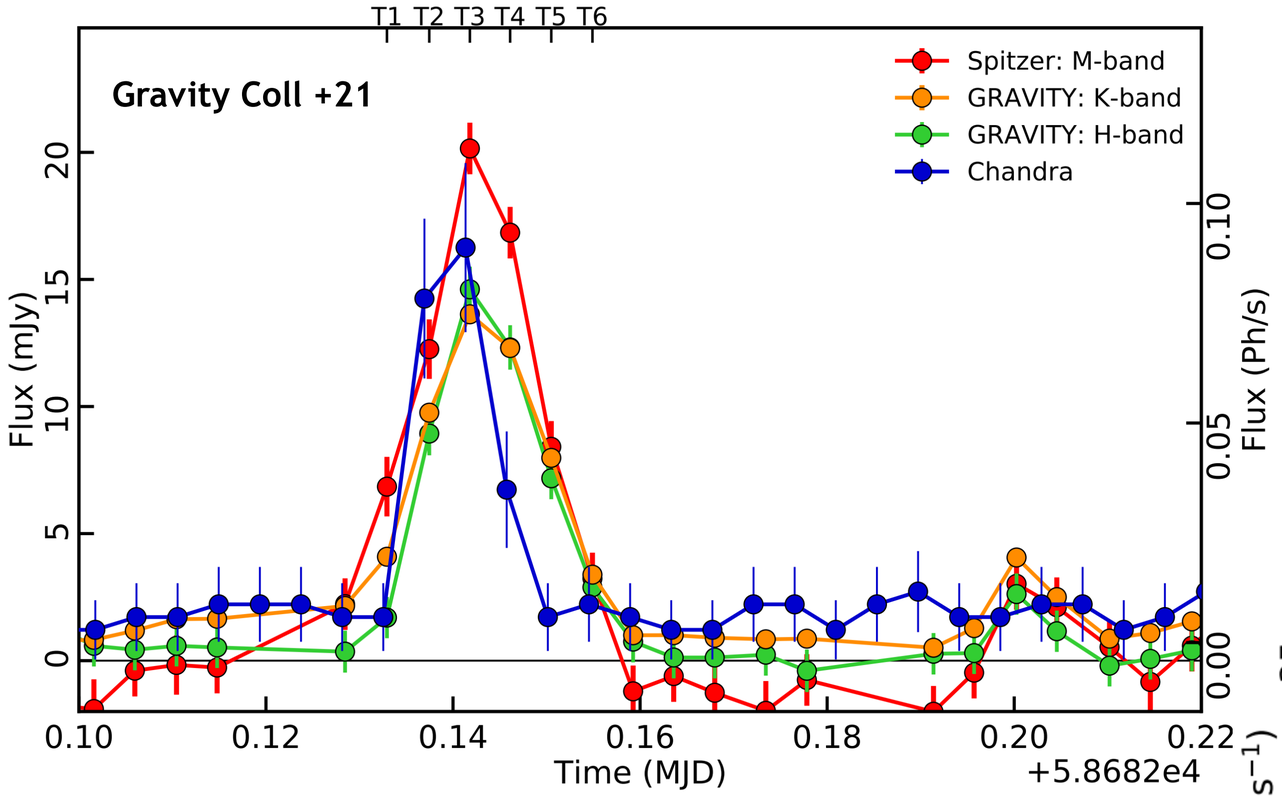


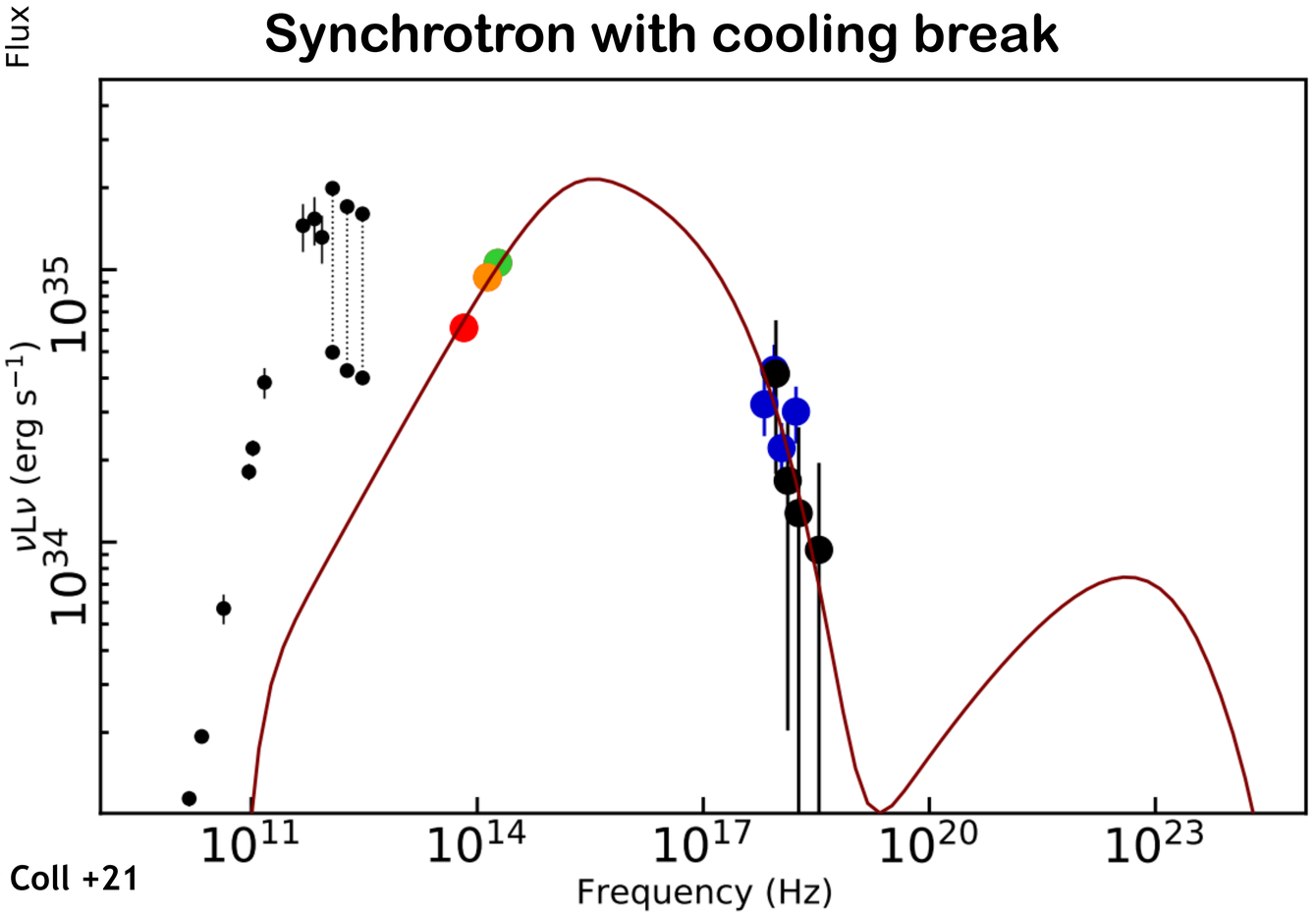
Most recent multi-wavelength flare of Sgr A*



$\gamma_e \sim 5 \times 10^4$

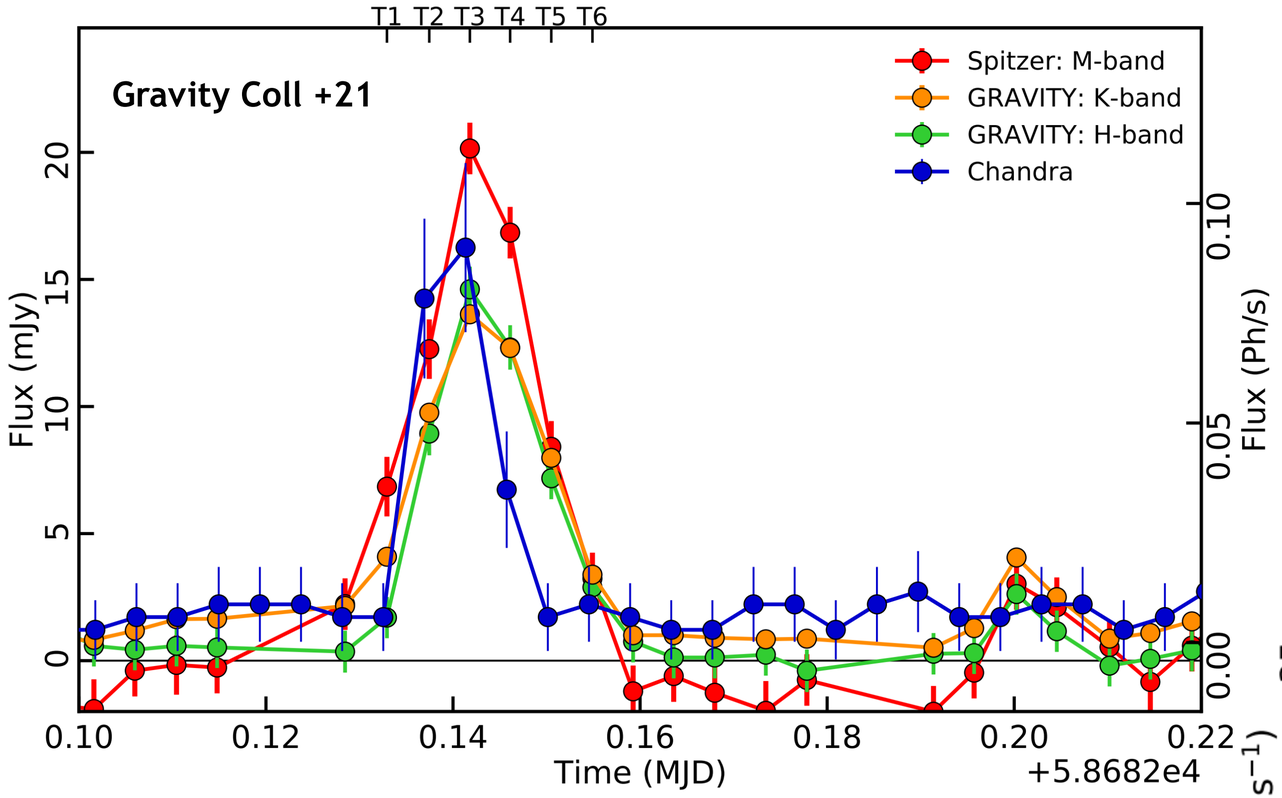
Most recent multi-wavelength flare of Sgr A*

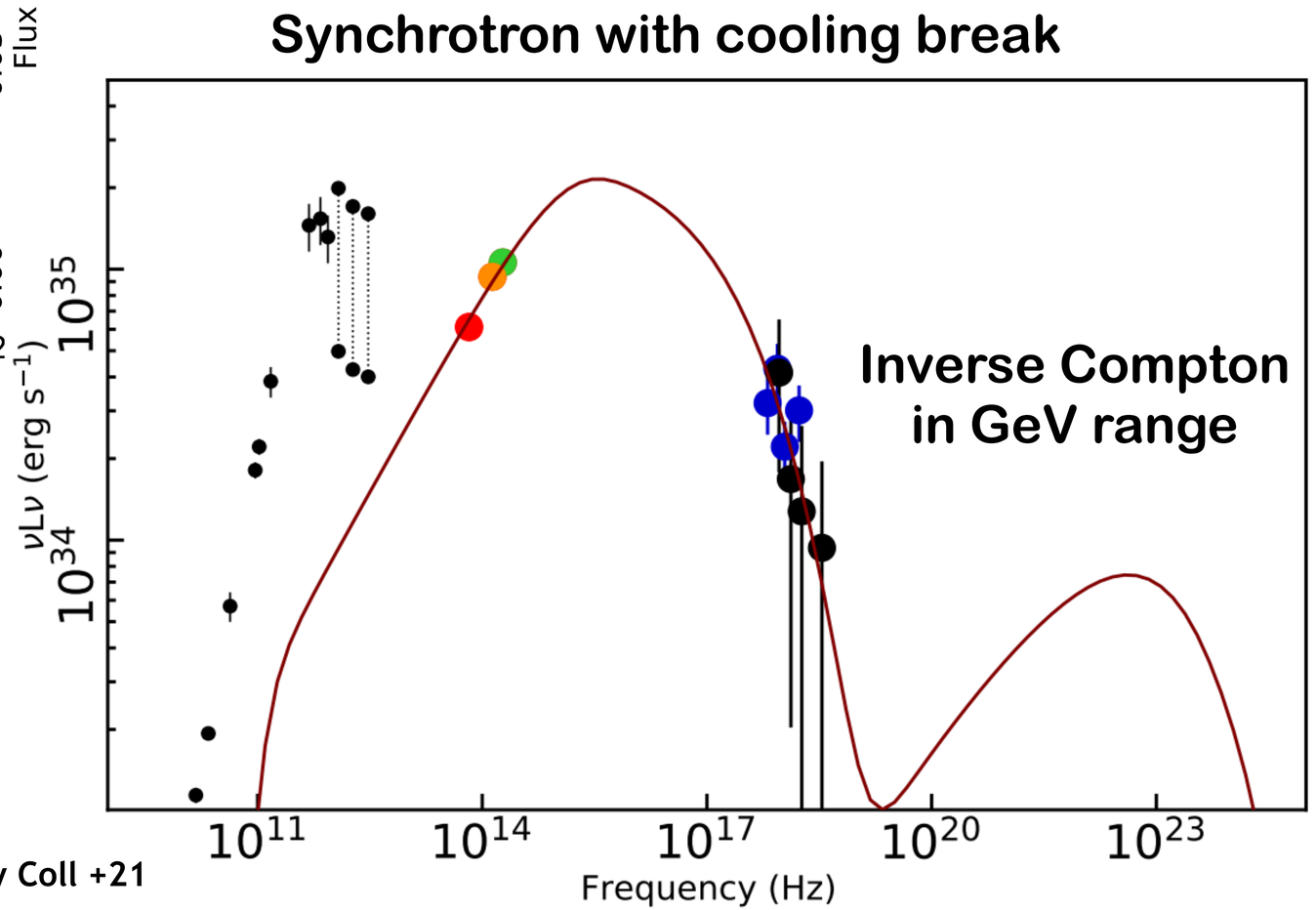




Gravity Coll +21

Most recent multi-wavelength flare of Sgr A*





Gravity Coll +21

What would I love to do with CTA?

➜ Use molecular clouds as calorimeters for cosmic rays

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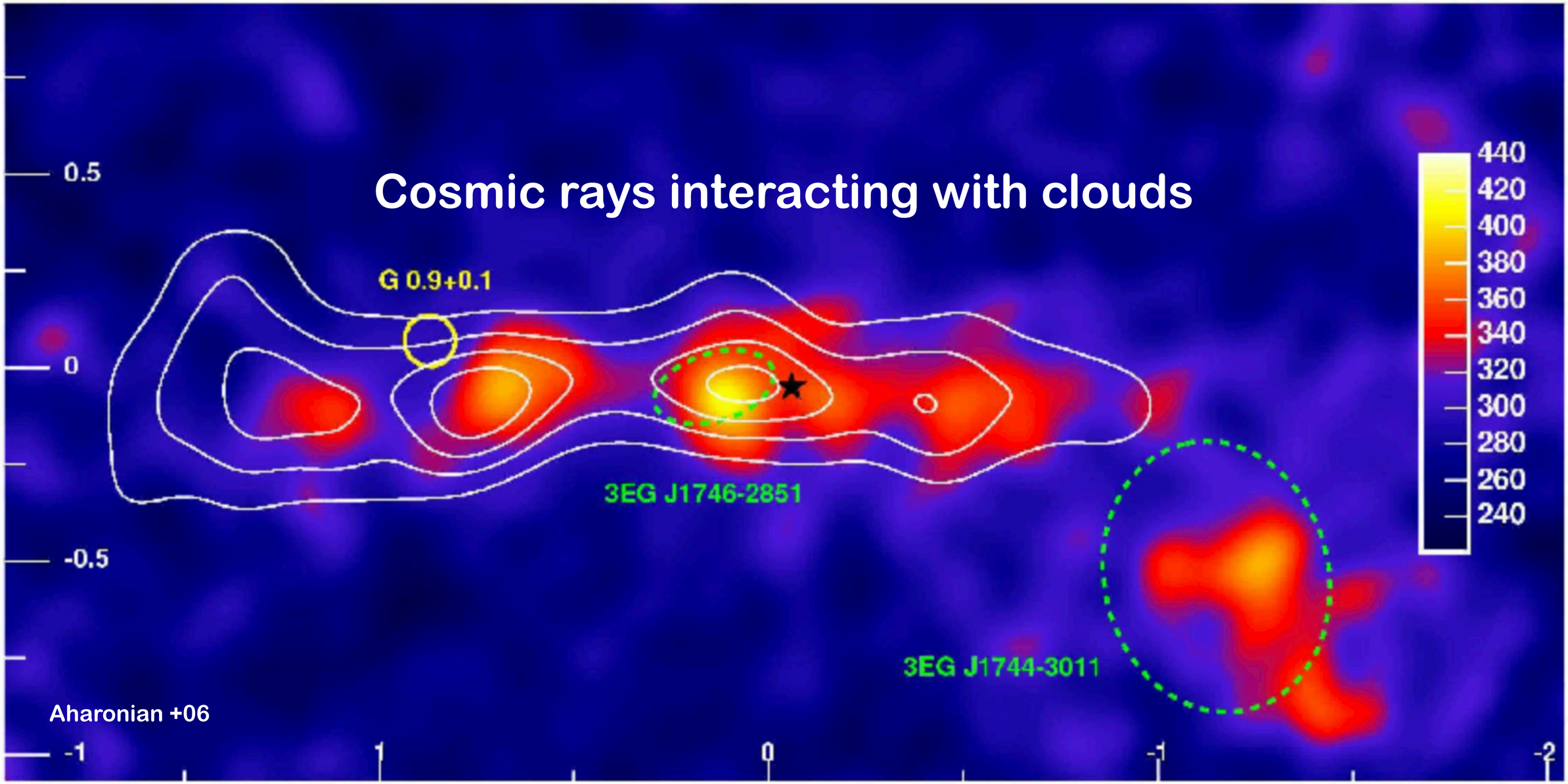

What would I love to do with CTA?

➜ Check TeV emission from filaments and B configuration

Fast escape of cosmic rays?

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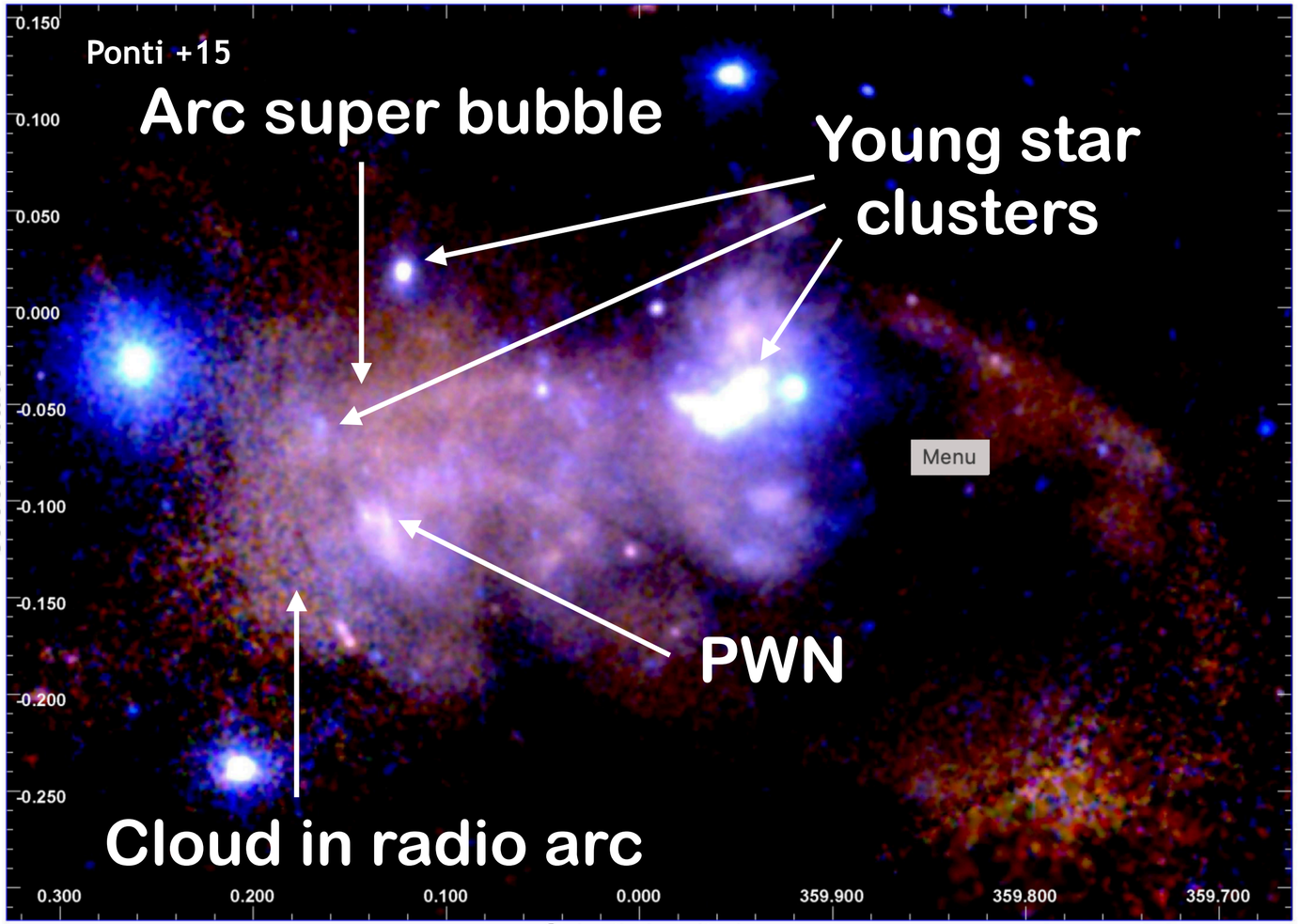

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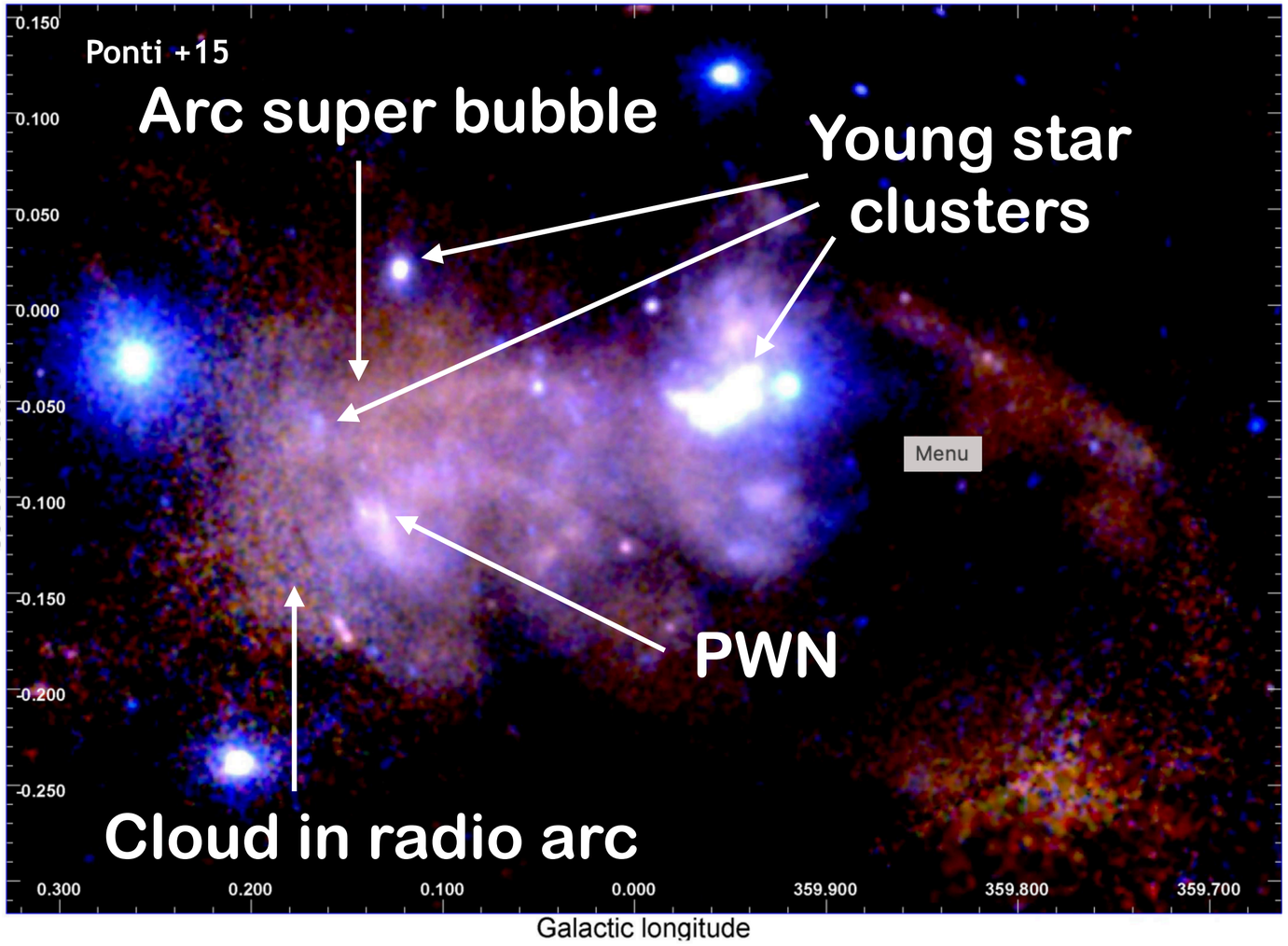

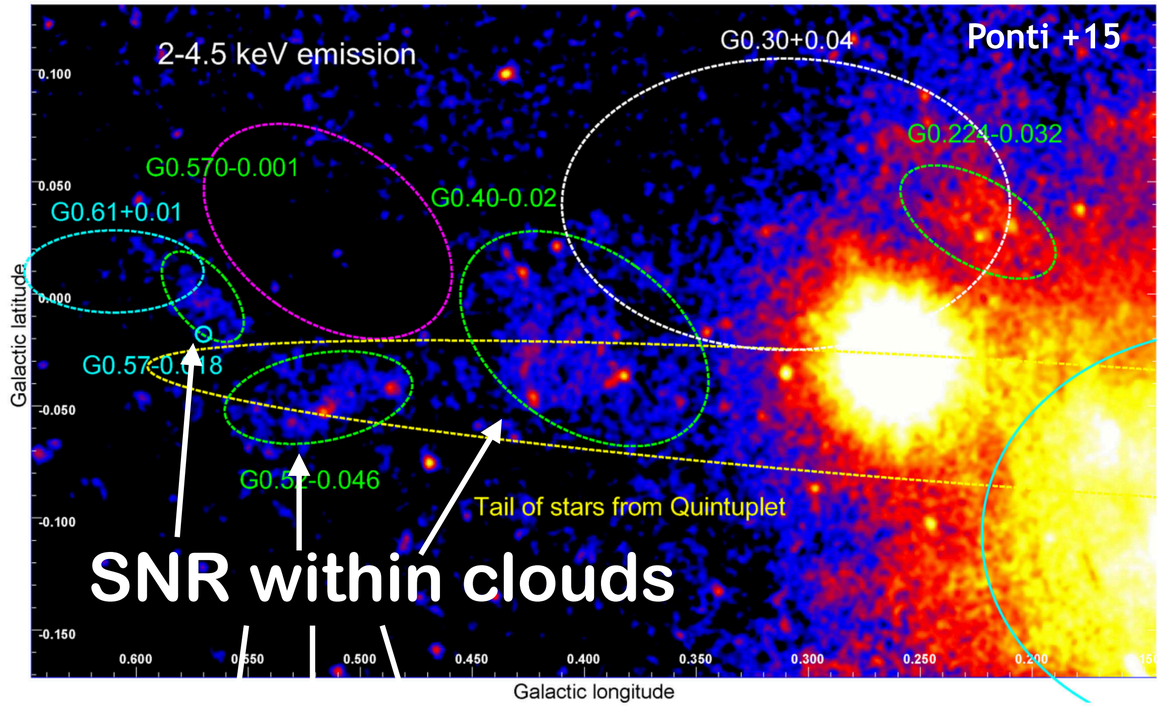

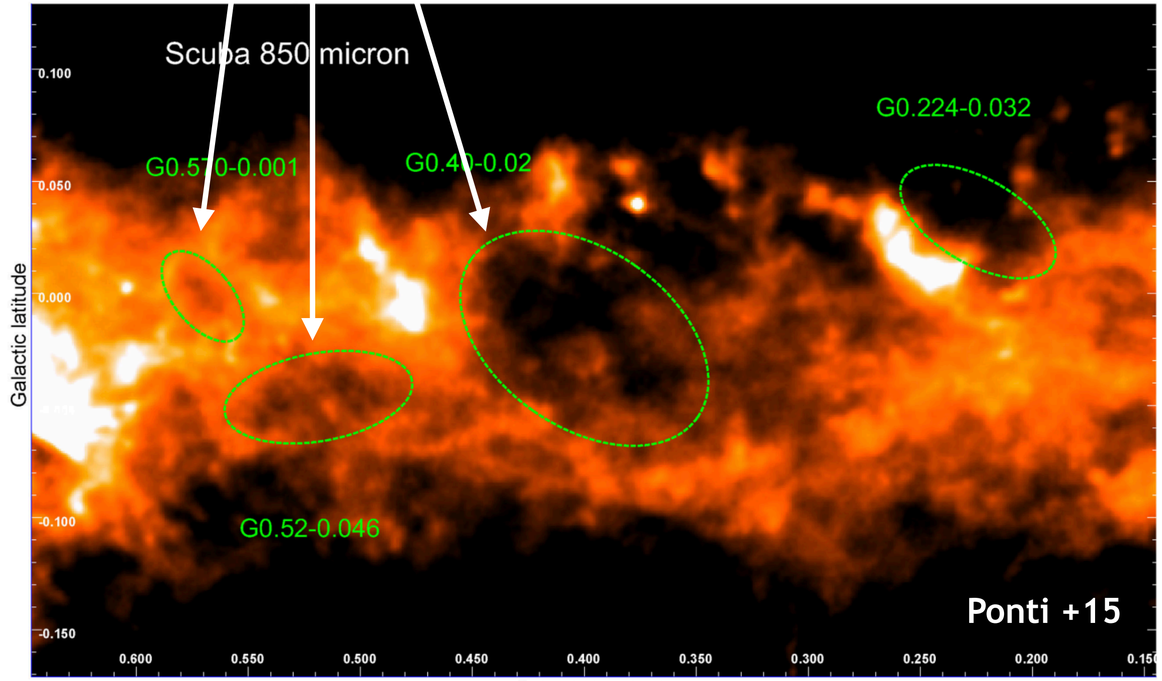

Preparing for the work ahead…

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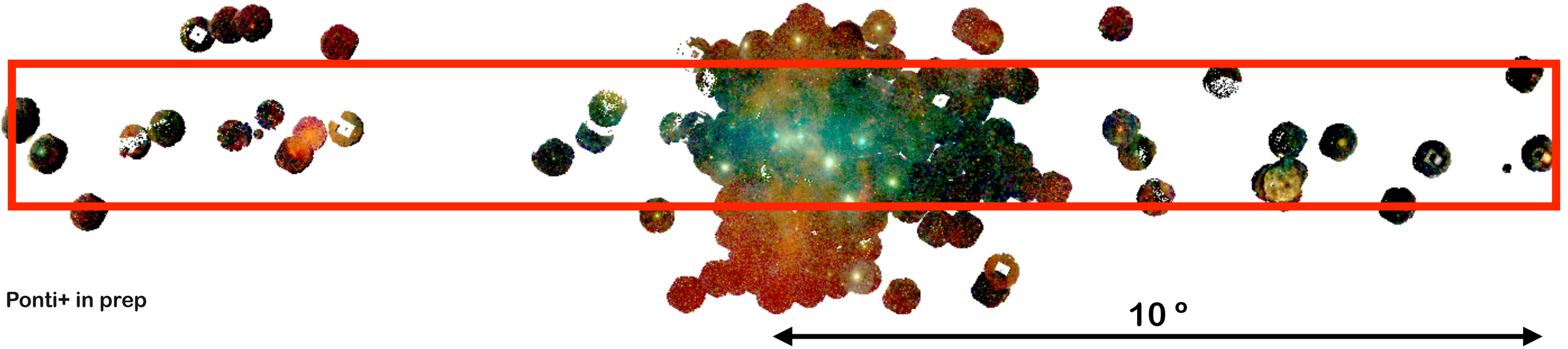

Ponti+ in prep

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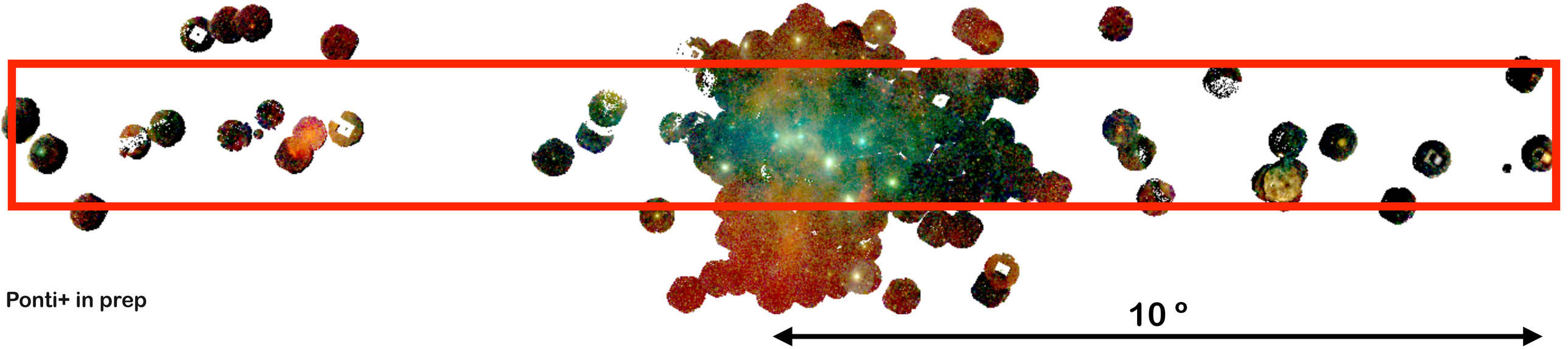

Ponti+ in prep

10 °

Scan of the plane with XMM and Chandra

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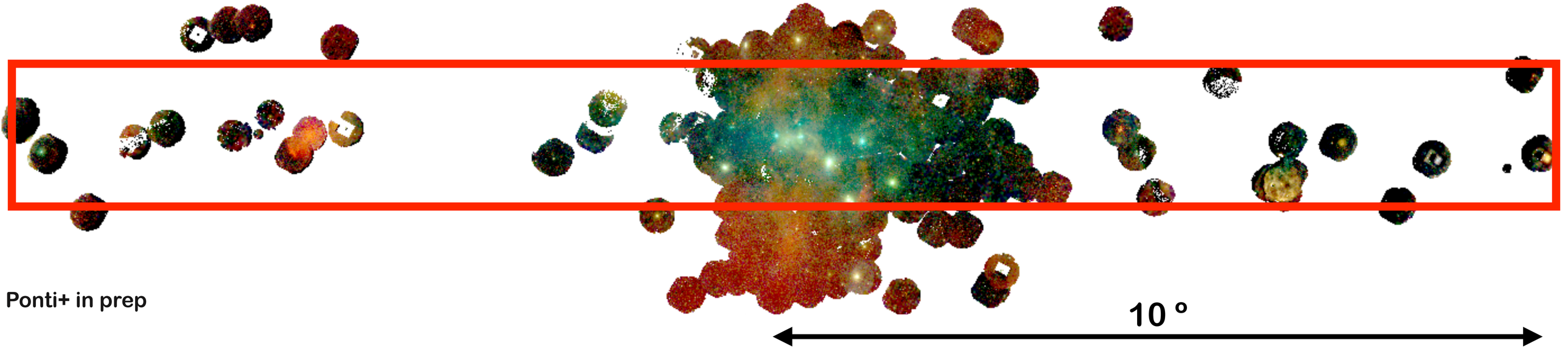

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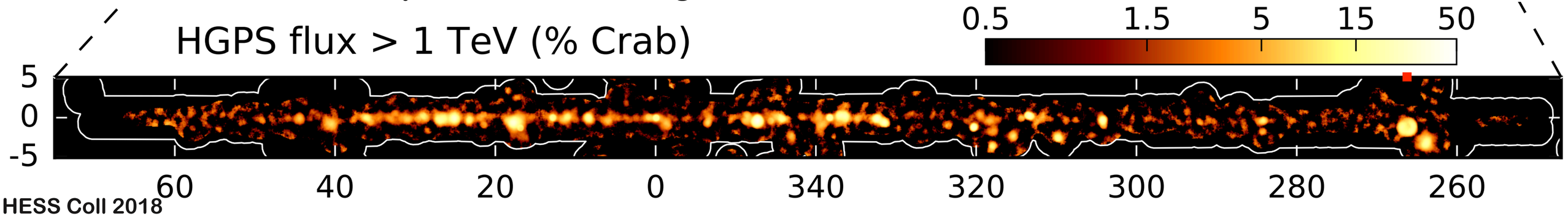
Scan of the plane with XMM and Chandra

HESS Galactic plane survey



HESS Coll 2018

Conclusions

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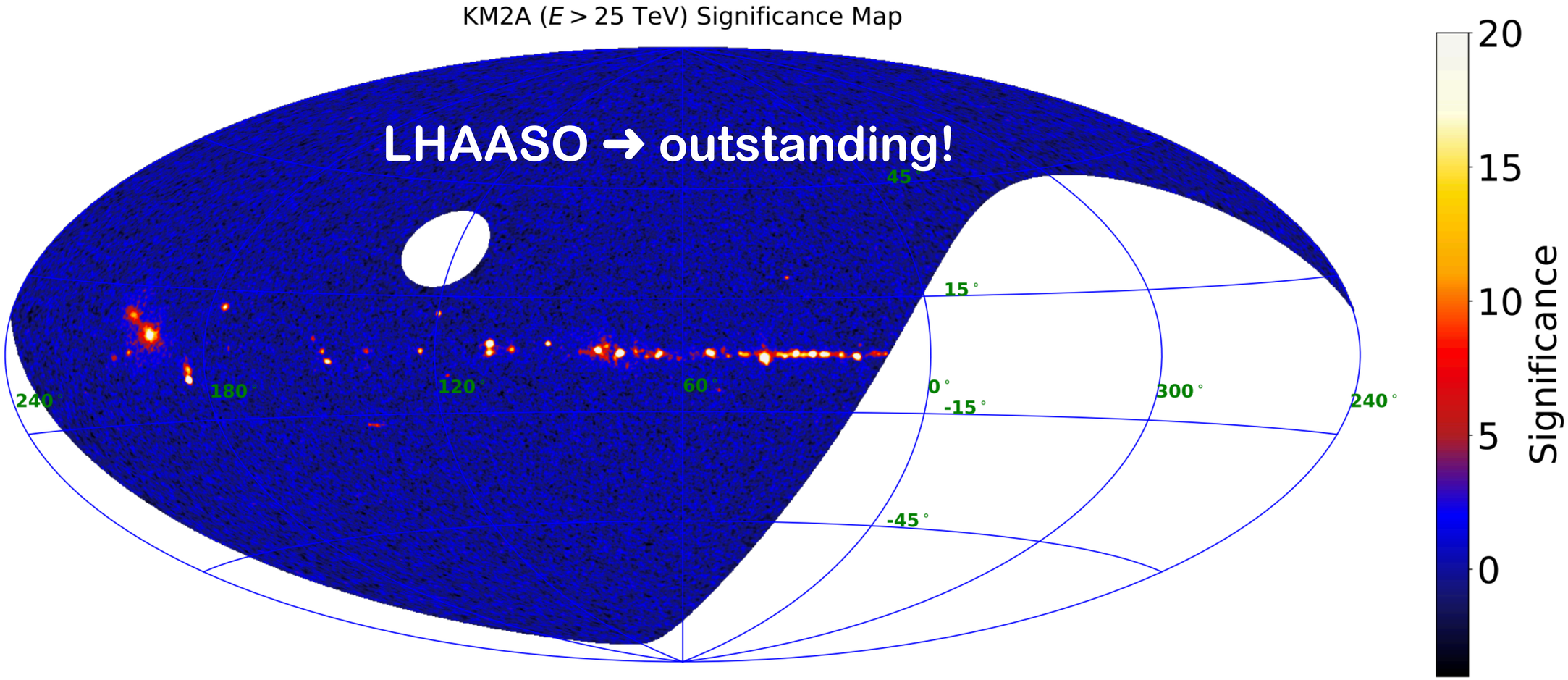

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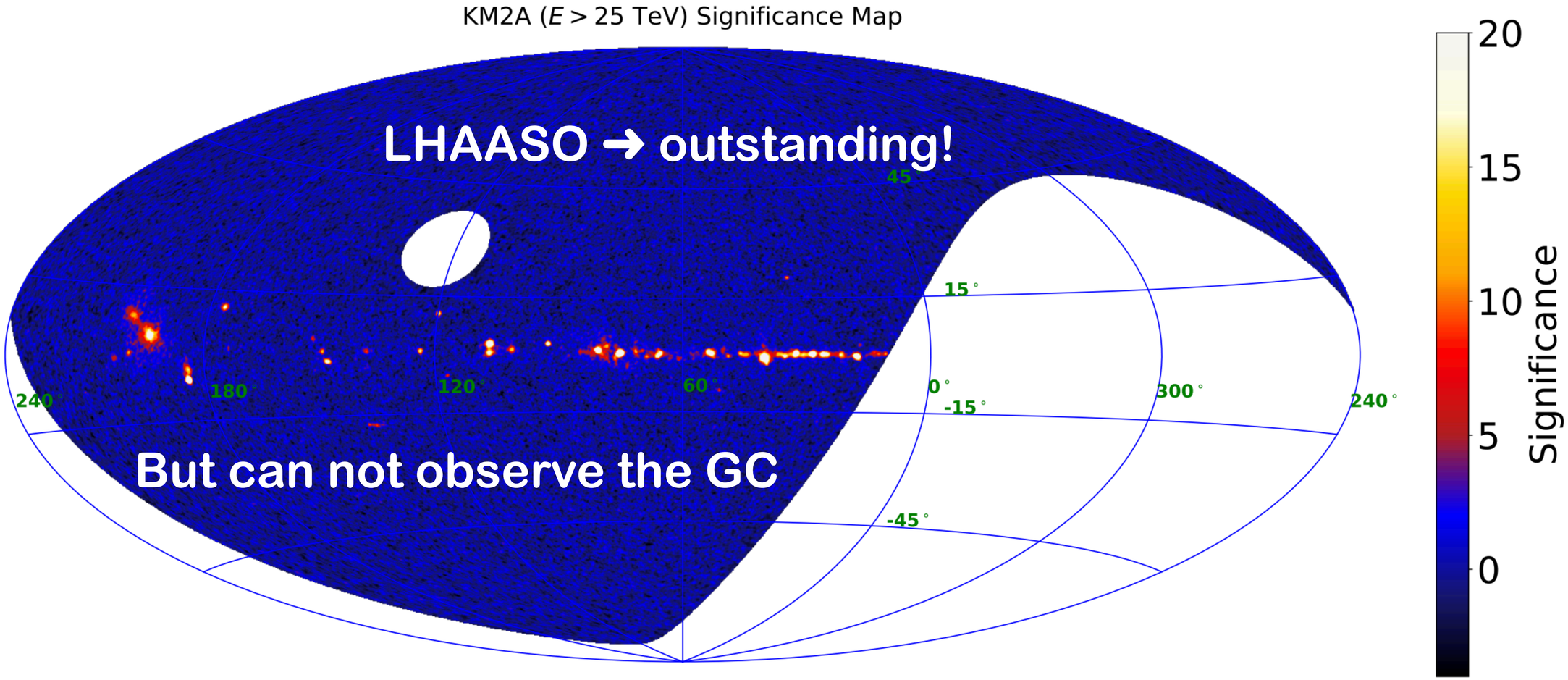
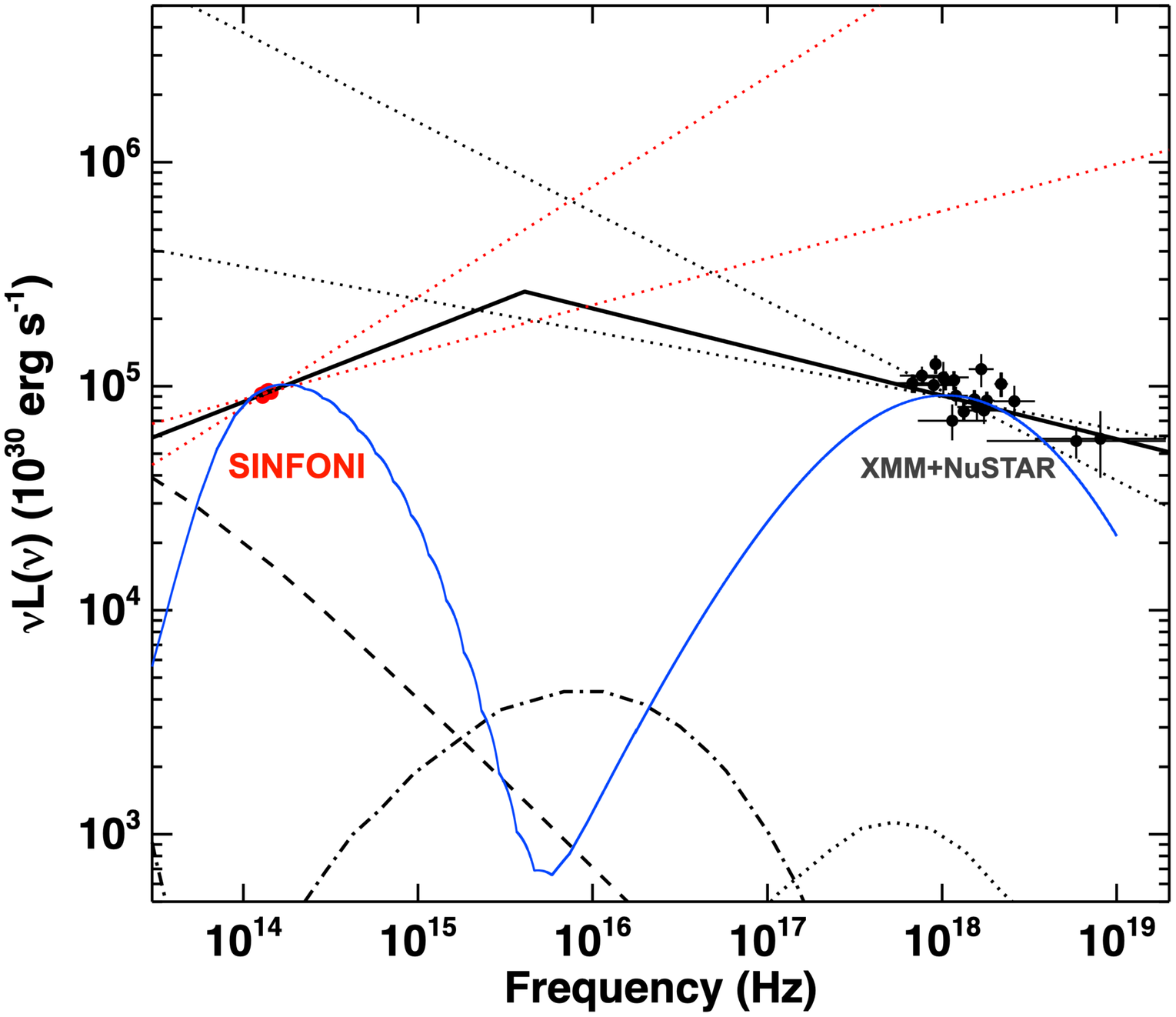


First NIR and X-ray spectrum of a flare



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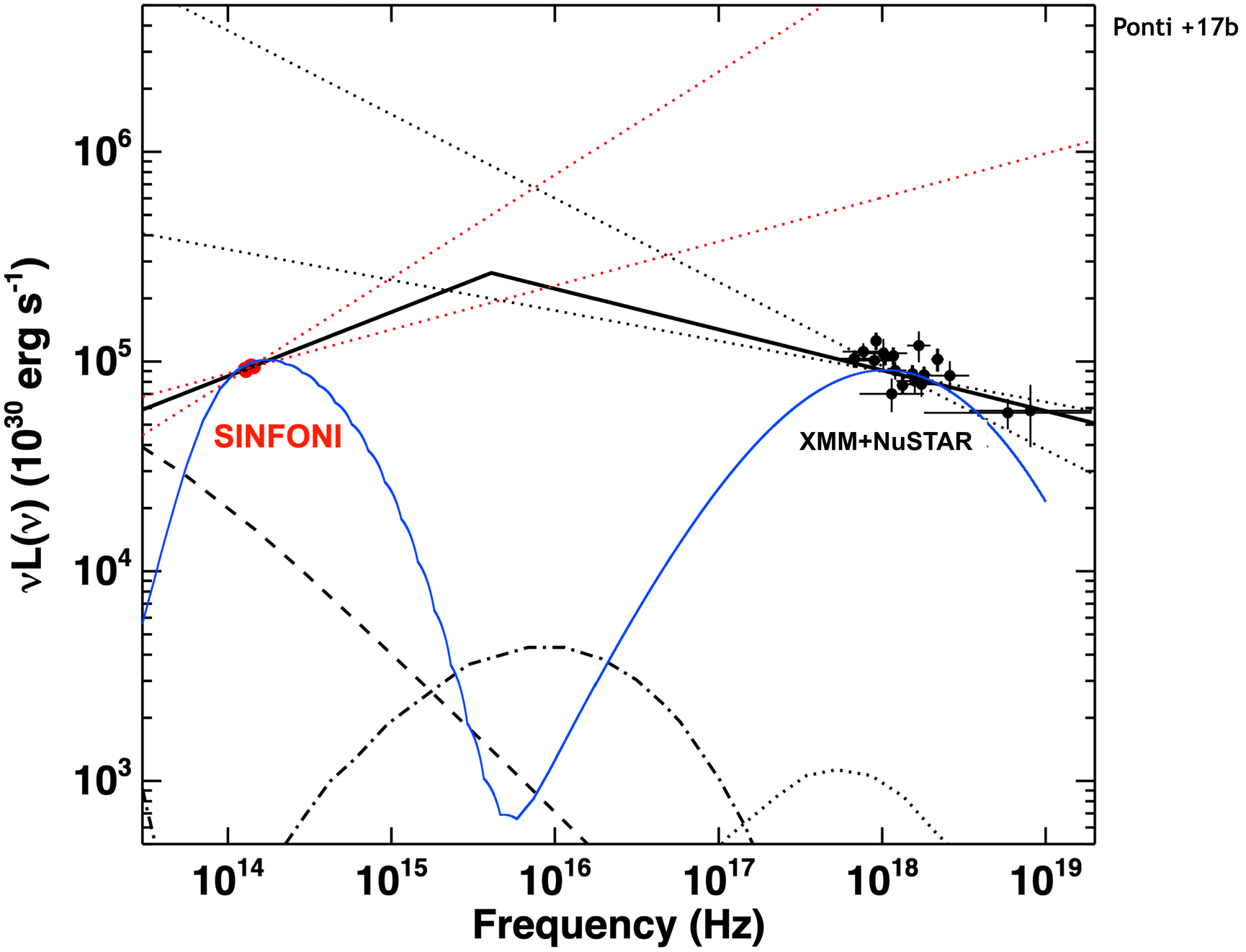

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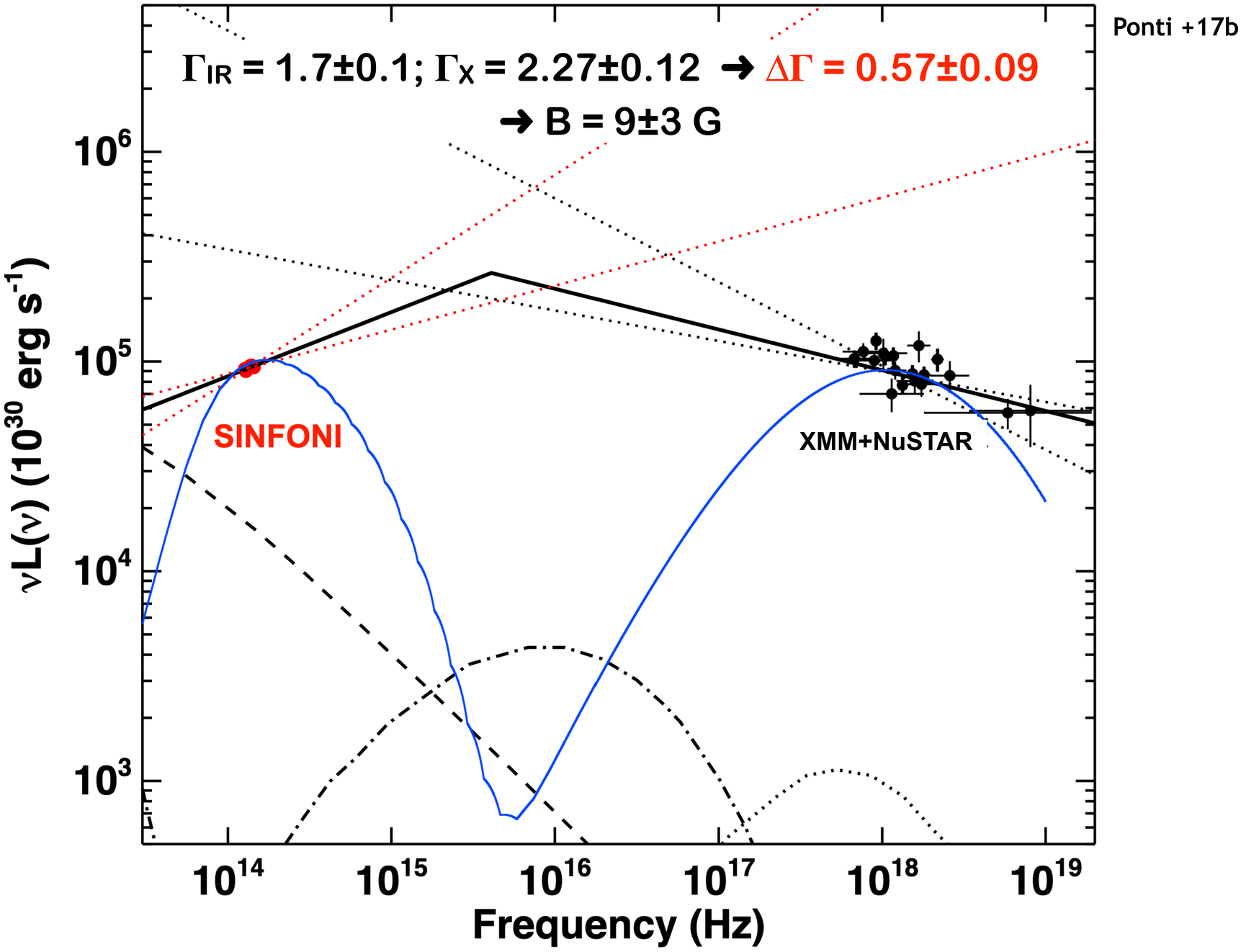

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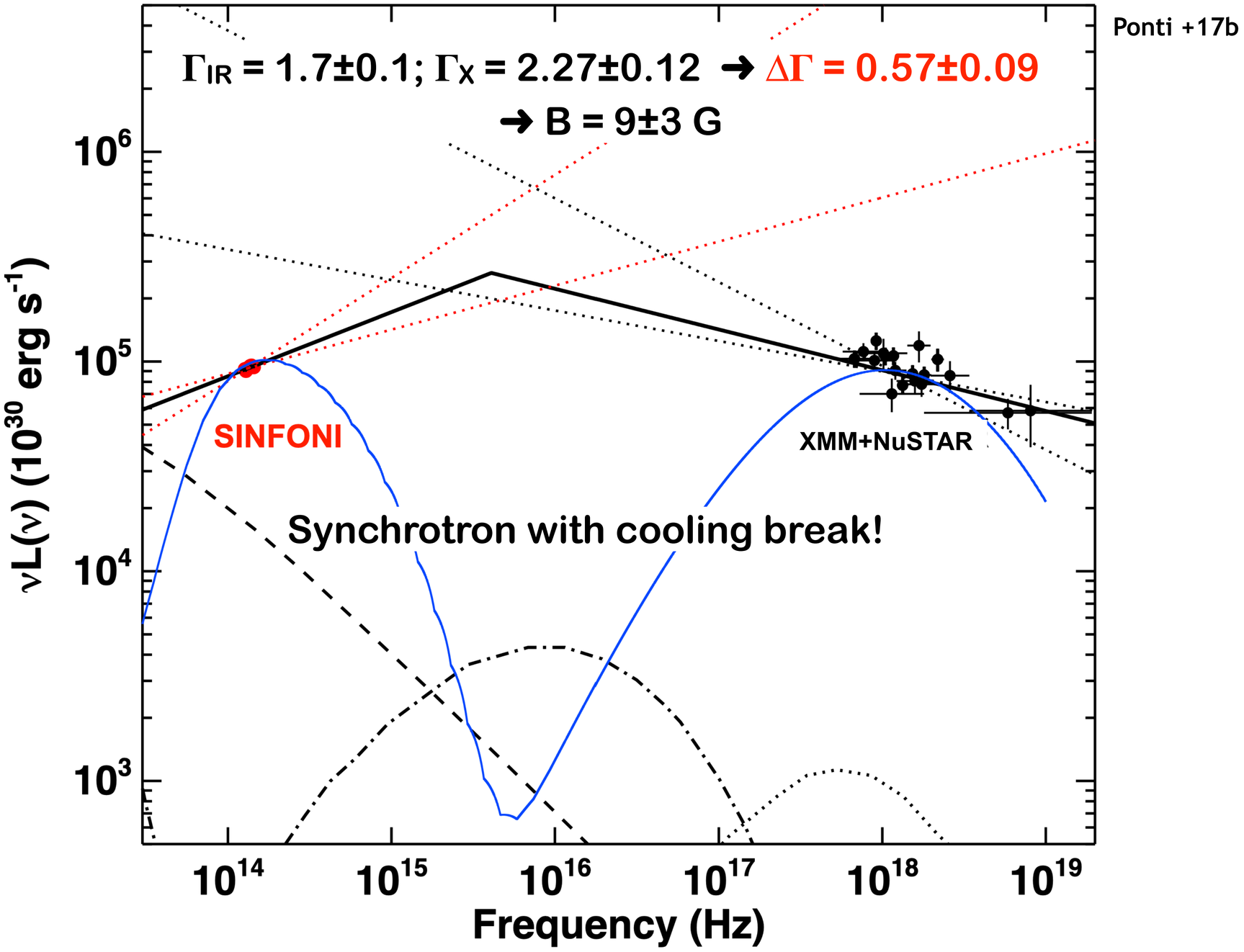

First NIR and X-ray spectrum of a flare