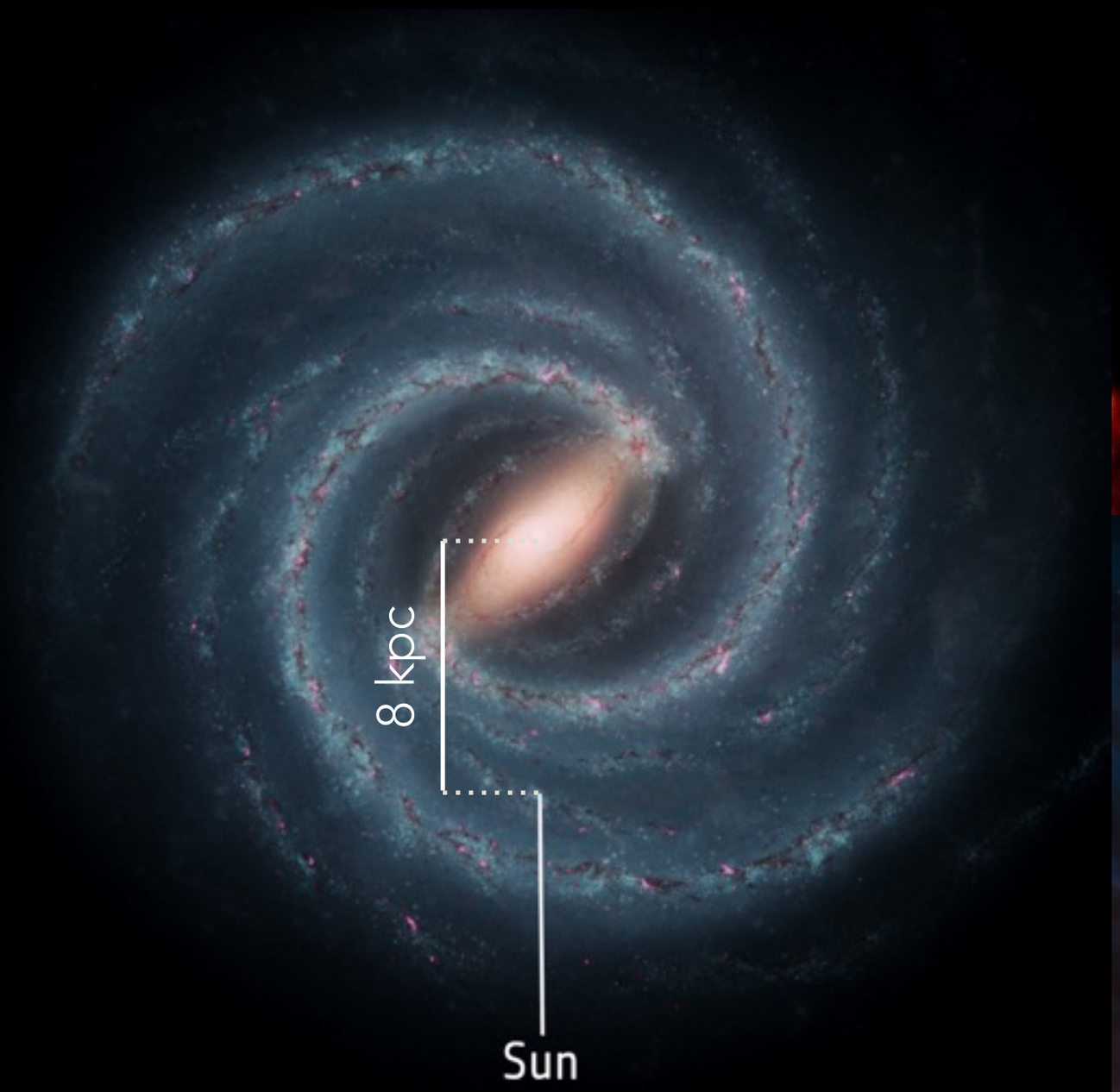
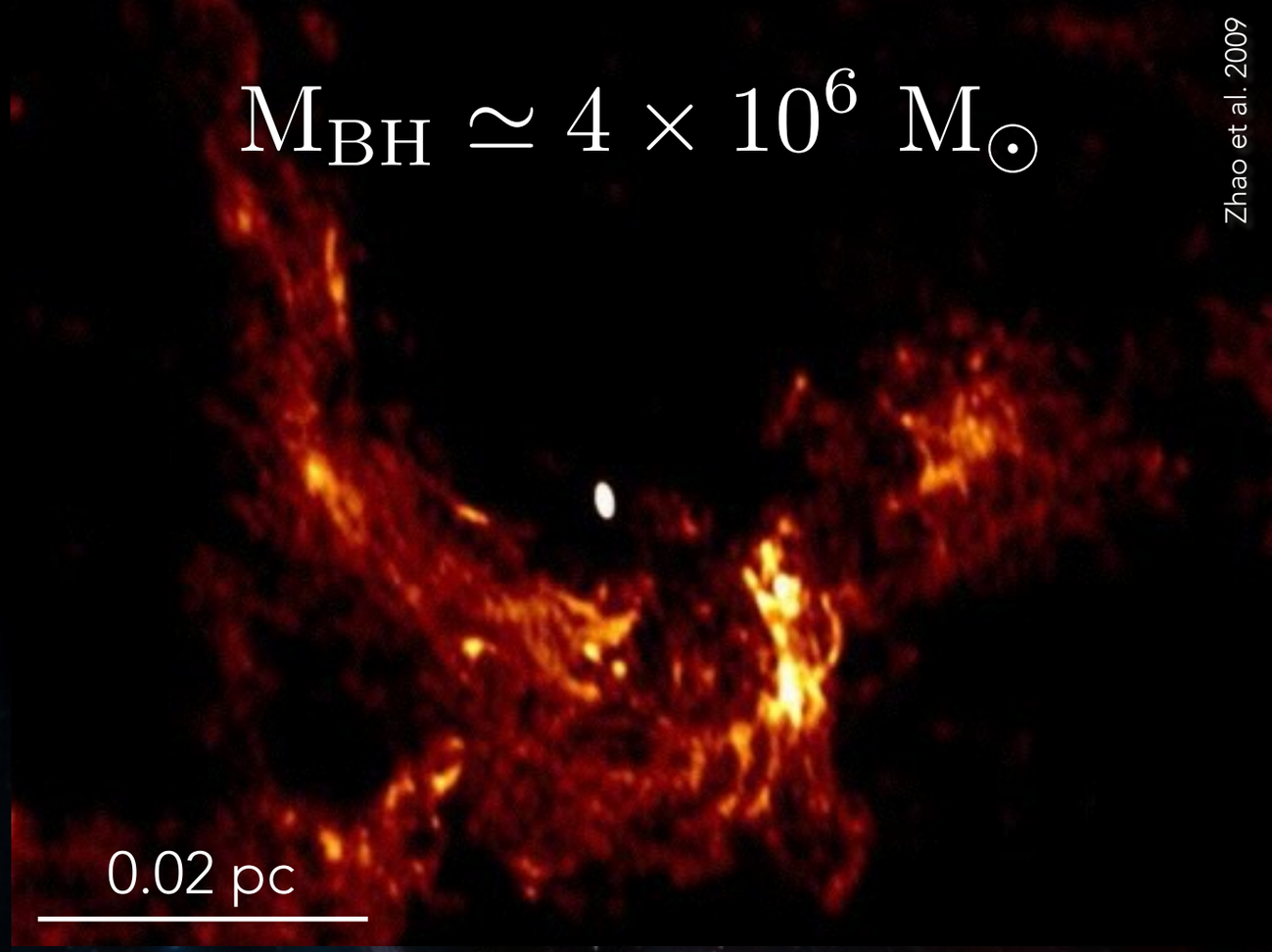
DIMITRI CHUARD (CEA/APC)

UNVEILING THE PAST OF THE GALACTIC NUCLEUS WITH X-RAY ECHOES

Journée des doctorants de l'APC – November 15, 2017



$$M_{BH} \simeq 4 \times 10^6\ M_\odot$$

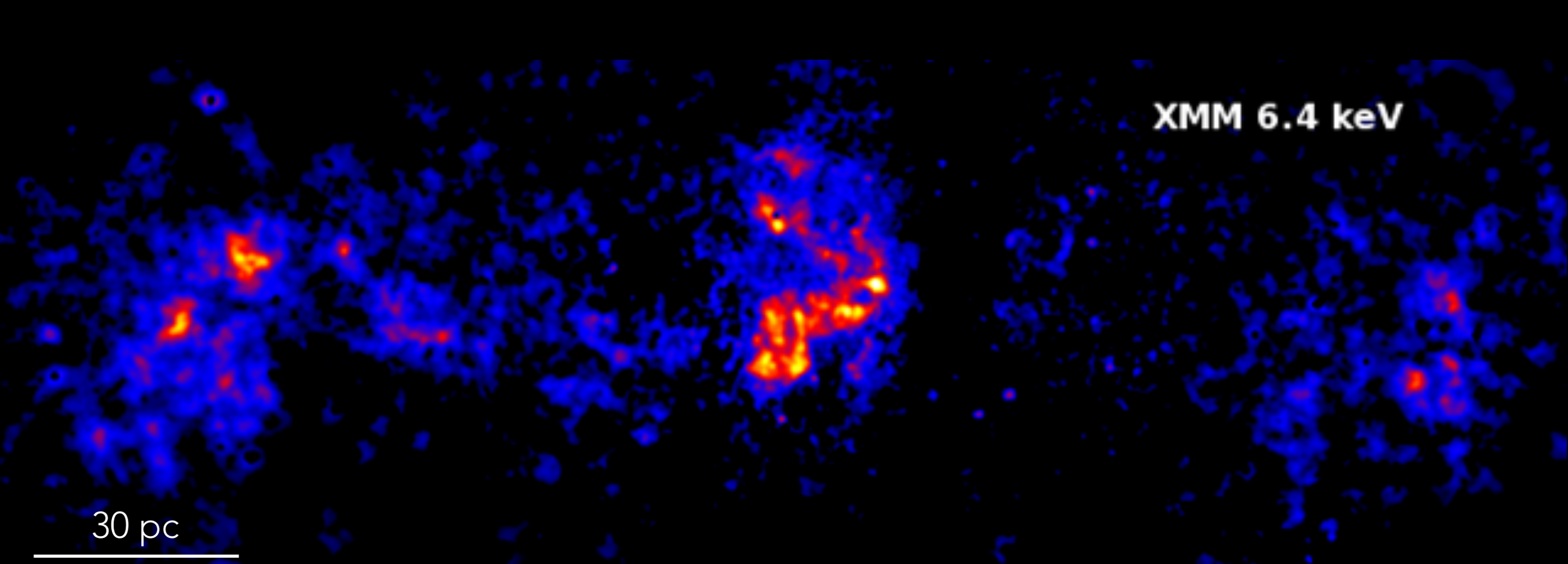


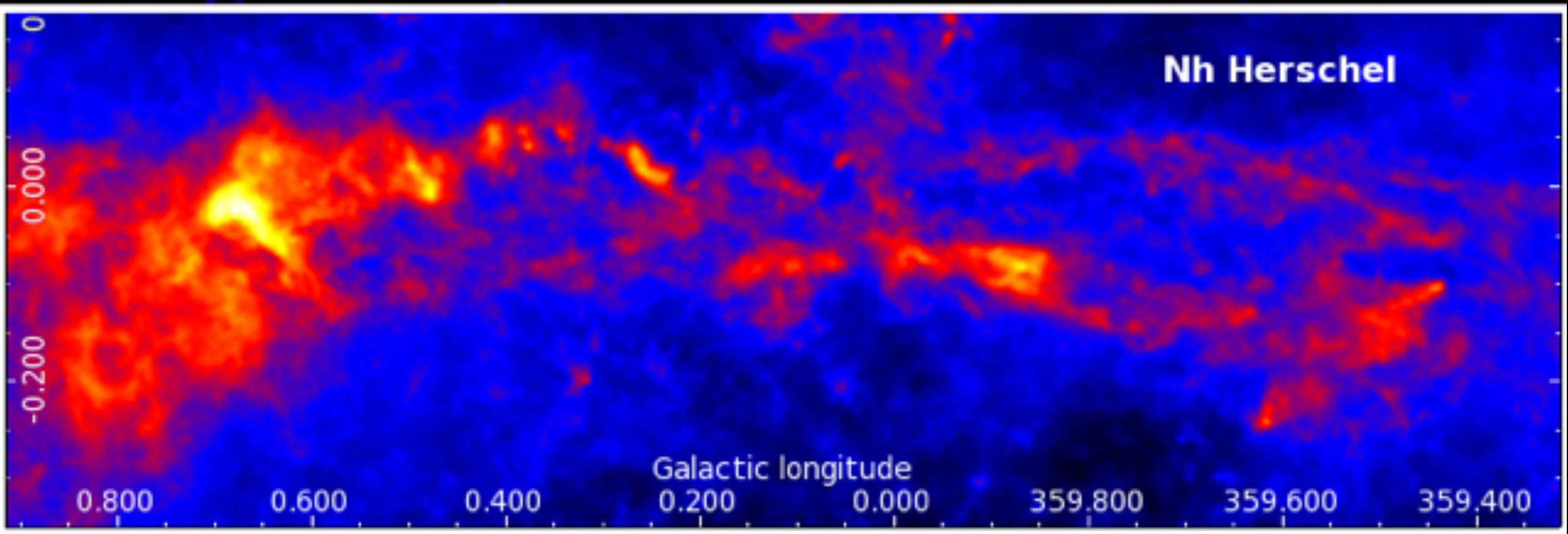
Zhao et al. 2009

$$L_{\rm Edd} \simeq 1.3 \times 10^{38} \left(\frac{M}{M_\odot}\right)\ {\rm erg \cdot s^{-1}}$$

$$L_{\rm bol}/L_{\rm Edd} \sim 10^{-10}$$

- Sgr A* is currently in a remarkable low luminosity state
- But it may have been much more luminous in the past
- Giant molecular clouds are key places for investigation

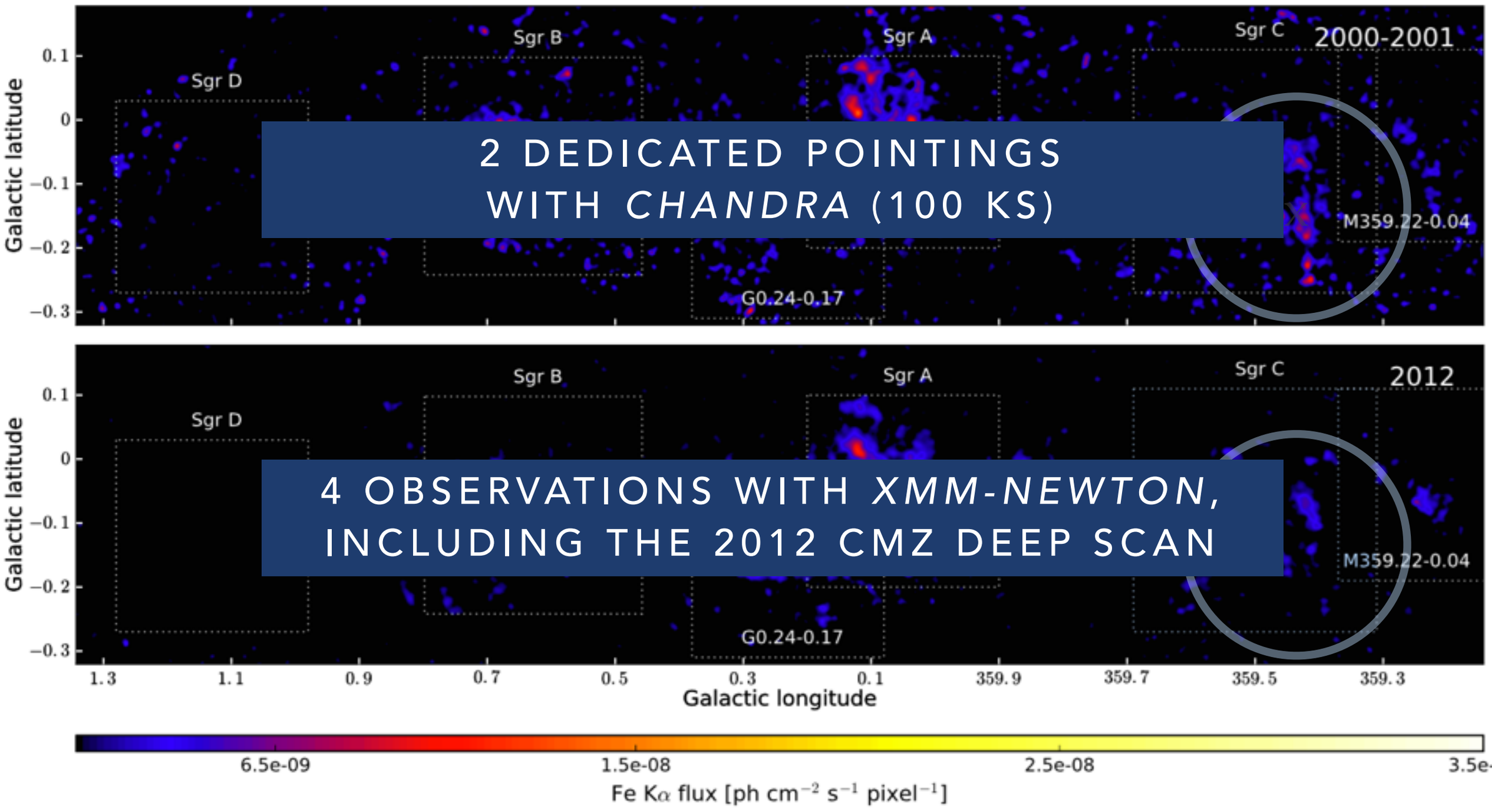

XMM 6.4 keV
30 pc


Nh Herschel
0
0.000
-0.200
Galactic longitude
0.800
0.600
0.400
0.200
0.000
359.800
359.600
359.400

- Sgr A* is currently in a remarkable low luminosity state
- But it may have been much more luminous in the past
- Giant molecular clouds are key places for investigation
- A competing mechanism: LECR irradiation
- Variability is a strong hint in favour of the reflection

EVIDENCE OF VARIABILITY

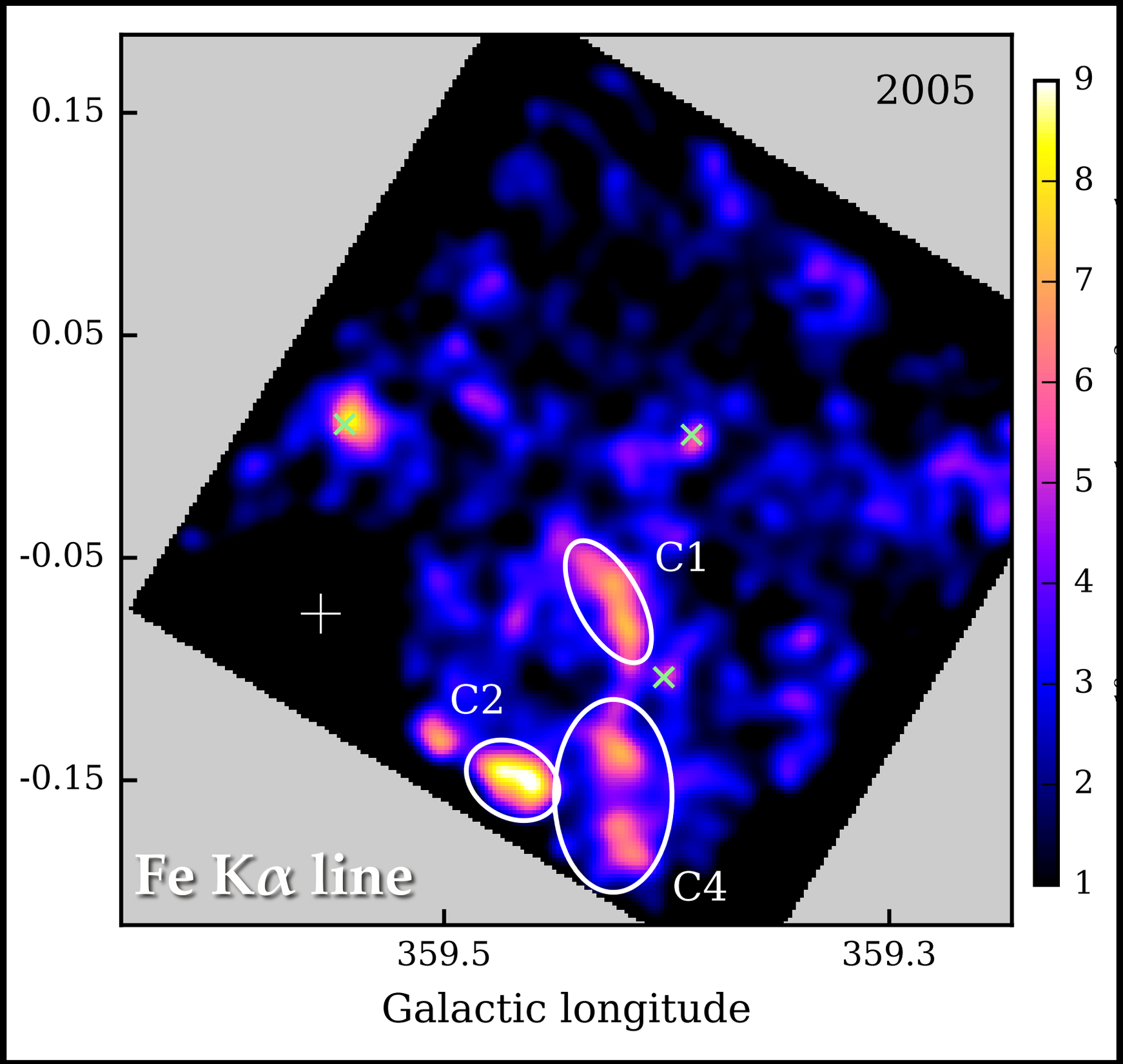
IN ALL CENTRAL MOLECULAR COMPLEXES

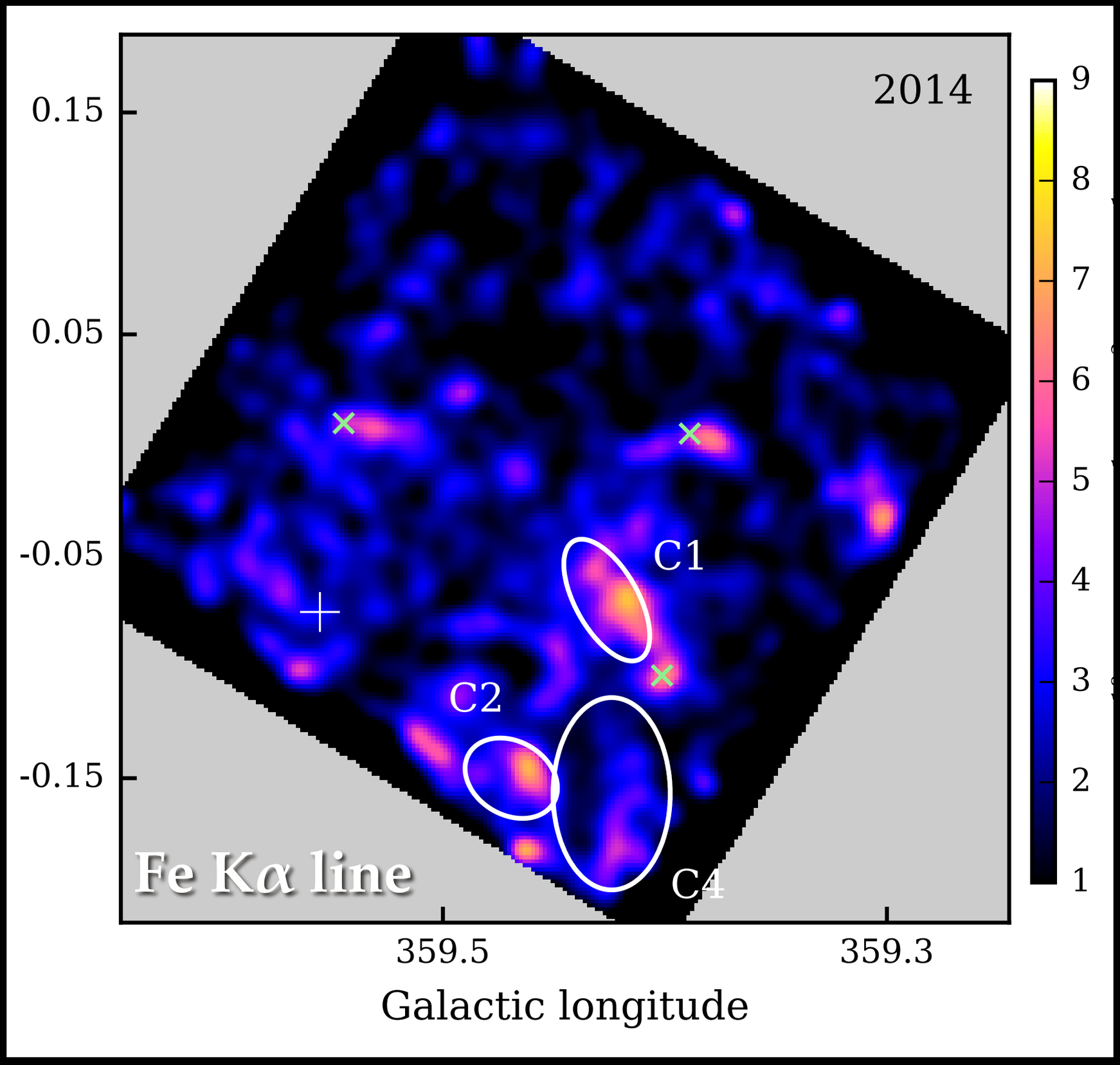


2 DEDICATED POINTINGS
WITH *CHANDRA* (100 KS)

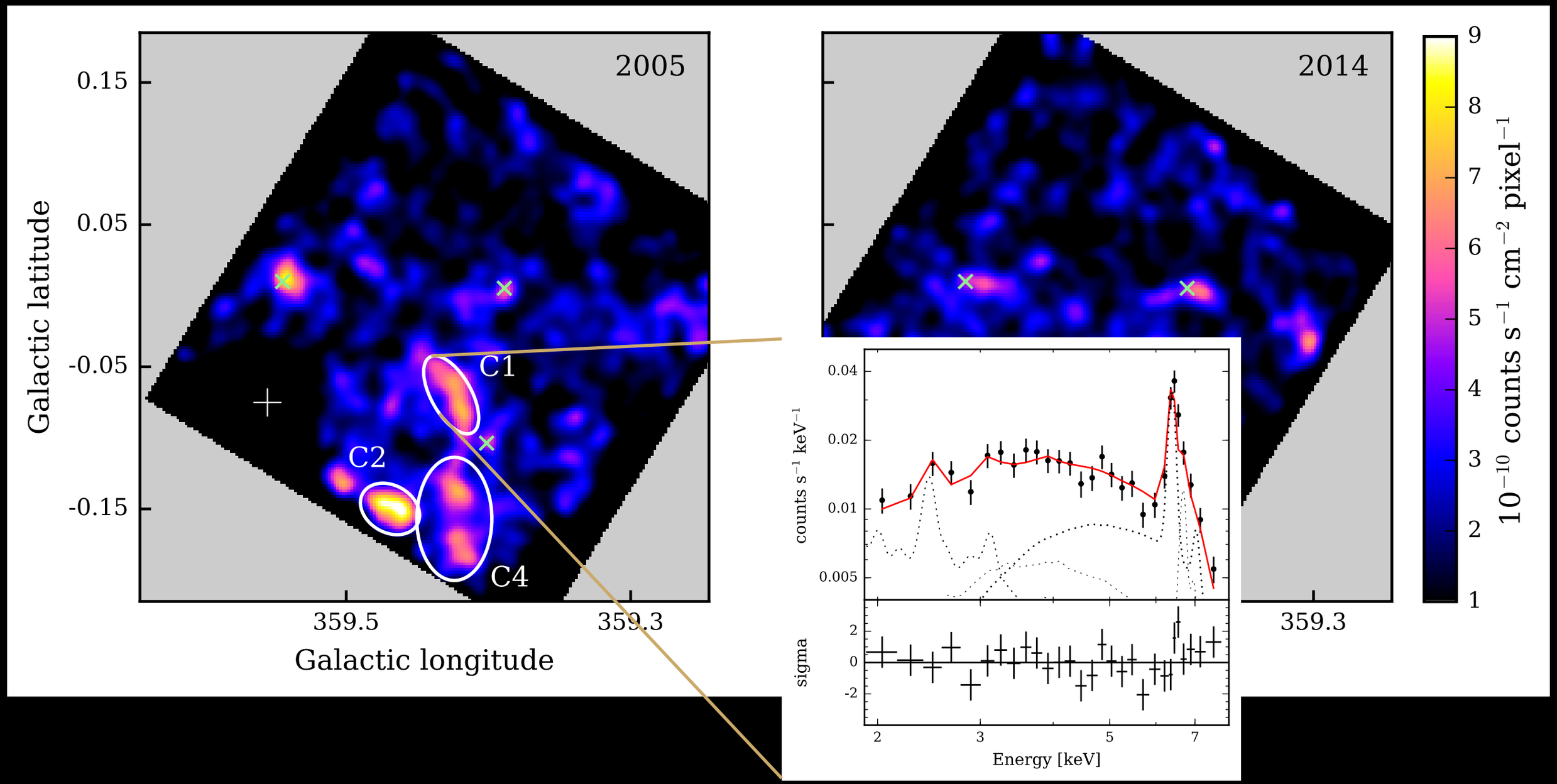
4 OBSERVATIONS WITH *XMM-NEWTON*,
INCLUDING THE 2012 CMZ DEEP SCAN

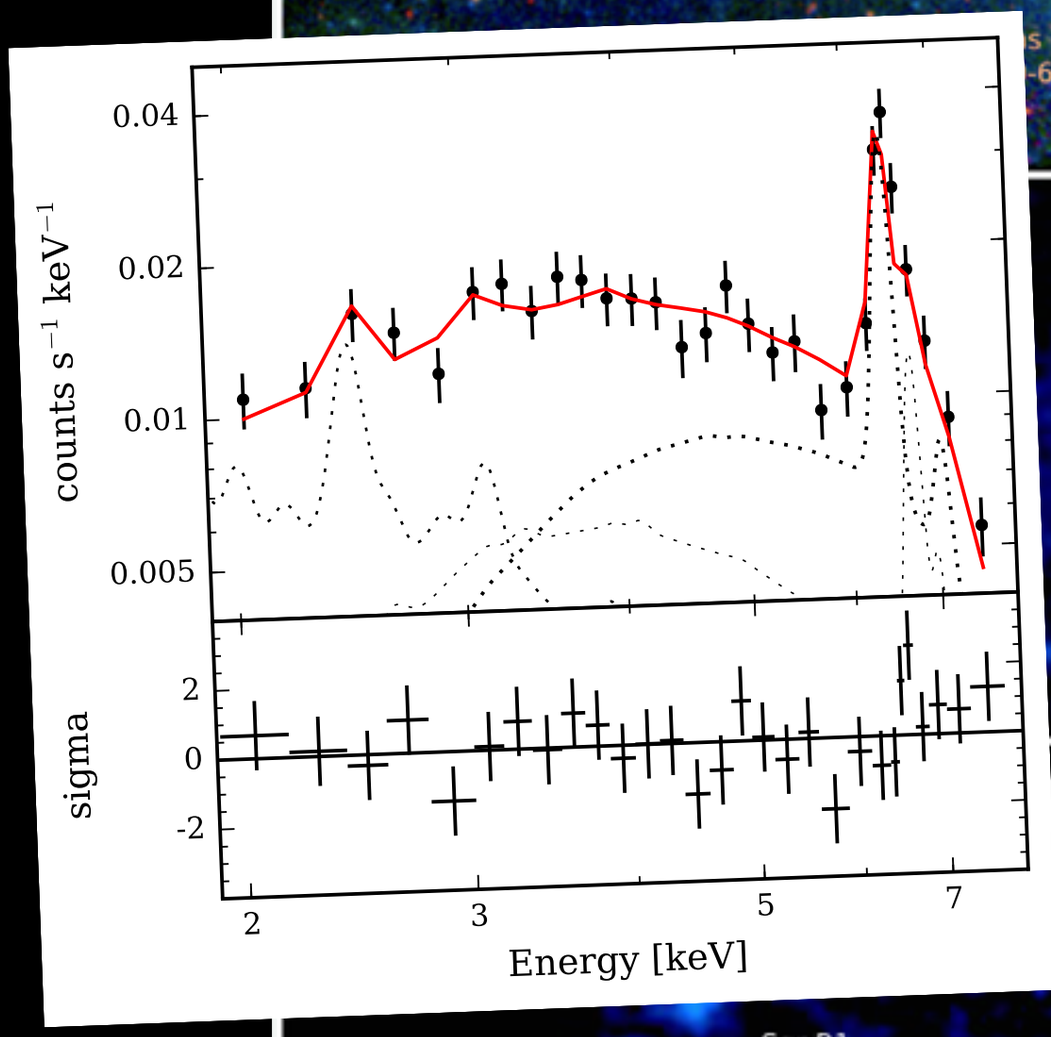
TERRIER+2017


2005
0.15
0.05
-0.05
-0.15
C1
C2
C4
Fe Kα line
359.5
359.3
Galactic longitude
9
8
7
6
5
4
3
2
1


2014
0.15
0.05
-0.05
-0.15
C1
C2
C4
Fe Kα line
359.5
359.3
Galactic longitude
9
8
7
6
5
4
3
2
1

VARIABILITY OF THE NON-THERMAL EMISSION





SOFT PLASMA

Amas DB00-58
GRS 1741.9-2853
SNR 0.9-0.1
Amas des Arches
IE 1743.1-2843
Sgr B2
Sgr B1
AX J1745.6-2901
Sgr C
Amas du Quintuplet
Sgr A
SAX J1747.0-2853
0.5 - 12 keV (RGB)

HOT PLASMA

Amas des Arches
Sgr A
6.7 keV

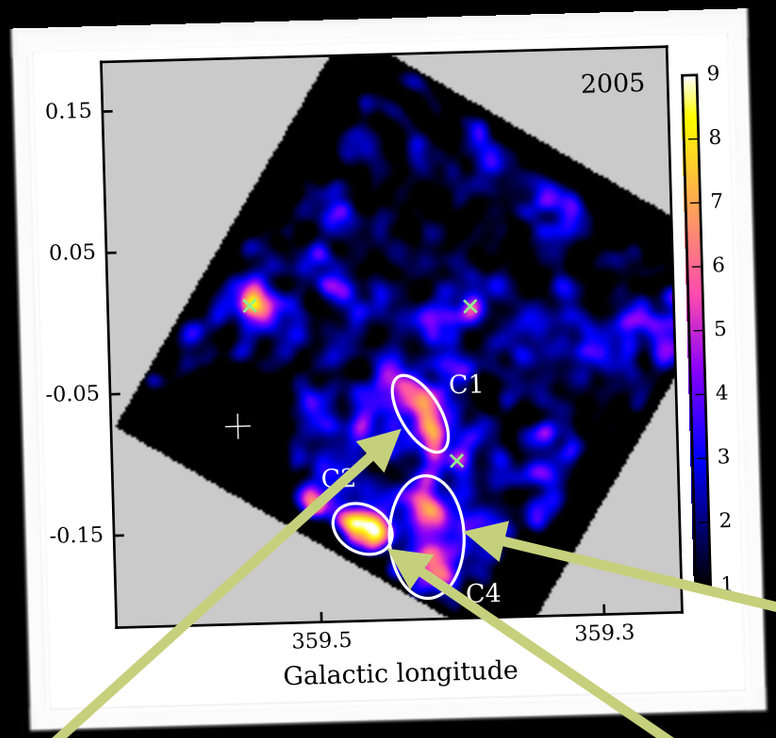
REFLECTION

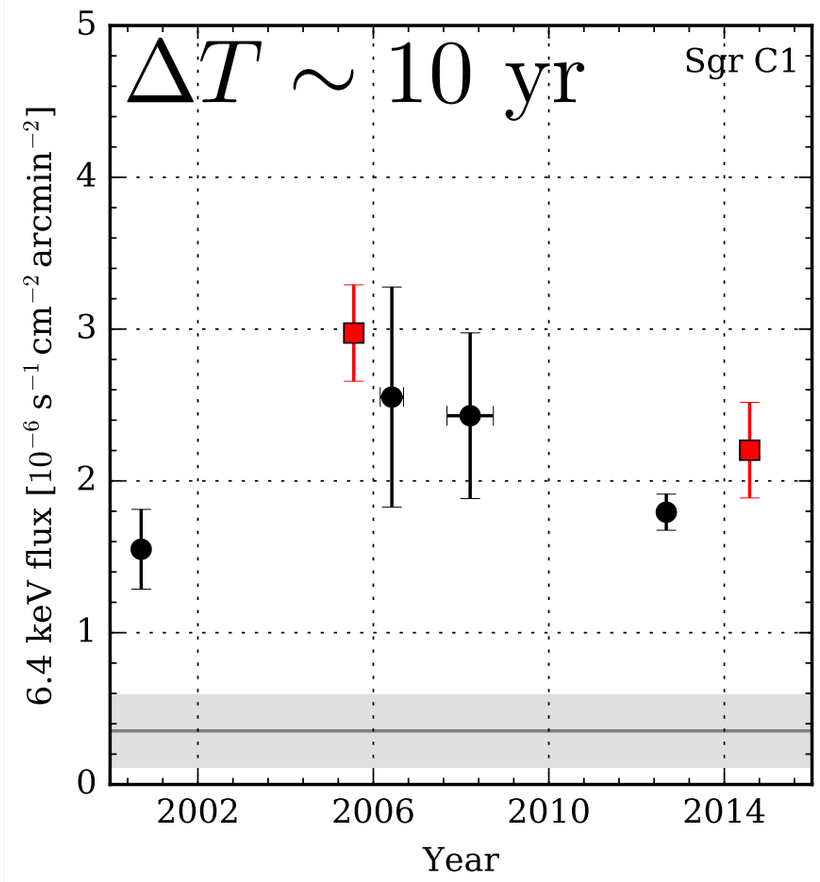
Nuage des Arches
AX J1745.6-2901
Sgr C
Sgr B1
Complexe Sgr A
Emission non thermique à 6.4 keV
6.4 keV

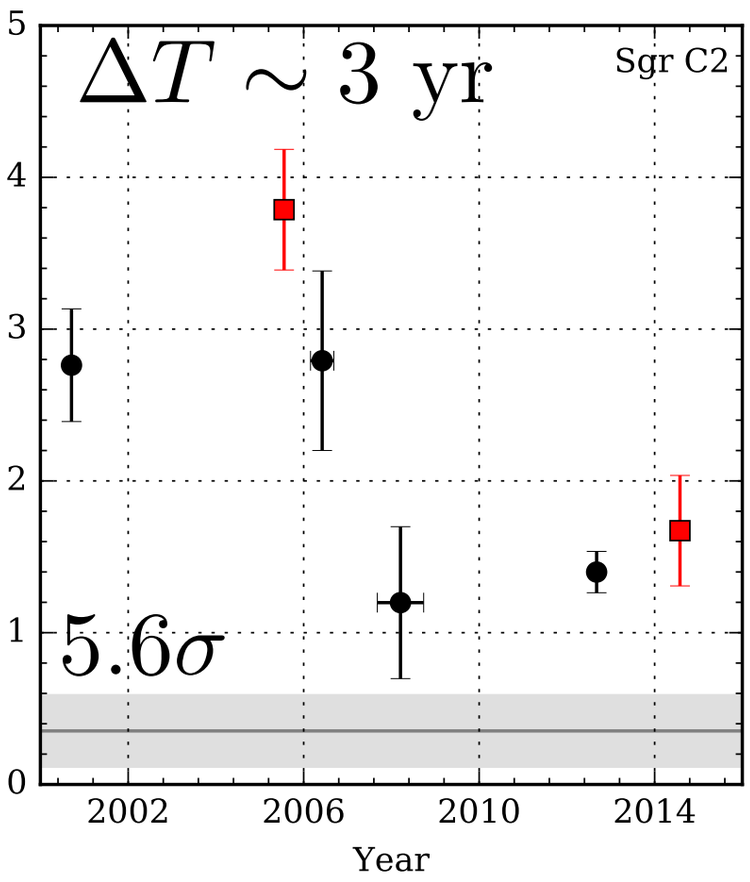
XMM-NEWTON (2000-2012)

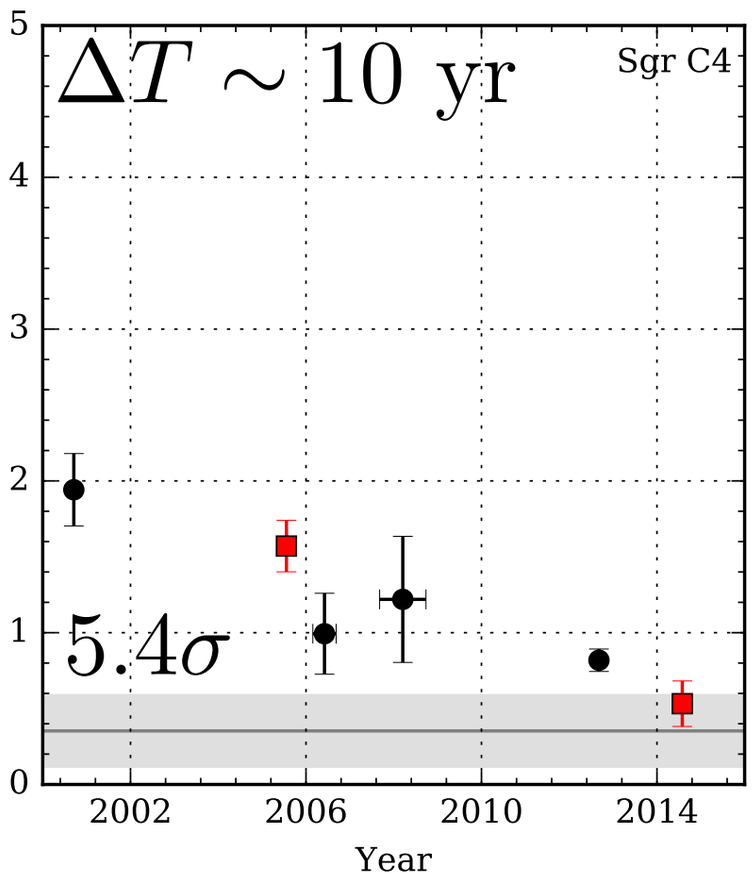
M. CLAVEL (PHD THESIS)

TWO TIME BEHAVIOURS









HOW TO INFER THE PAST LIGHTCURVE OF SGR A* FROM THE LIGHTCURVES OF THE CLOUDS?

HOW MANY EVENTS?
HOW LONG AGO?

X-RAY REFLECTION

VIEW FROM ABOVE

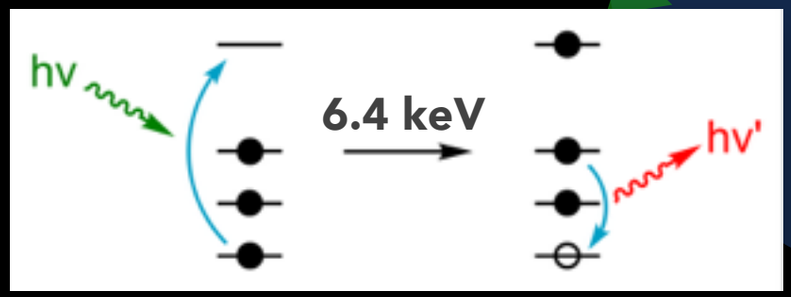
BH

$d = c\Delta t$

CLOUD

$t = t_0$

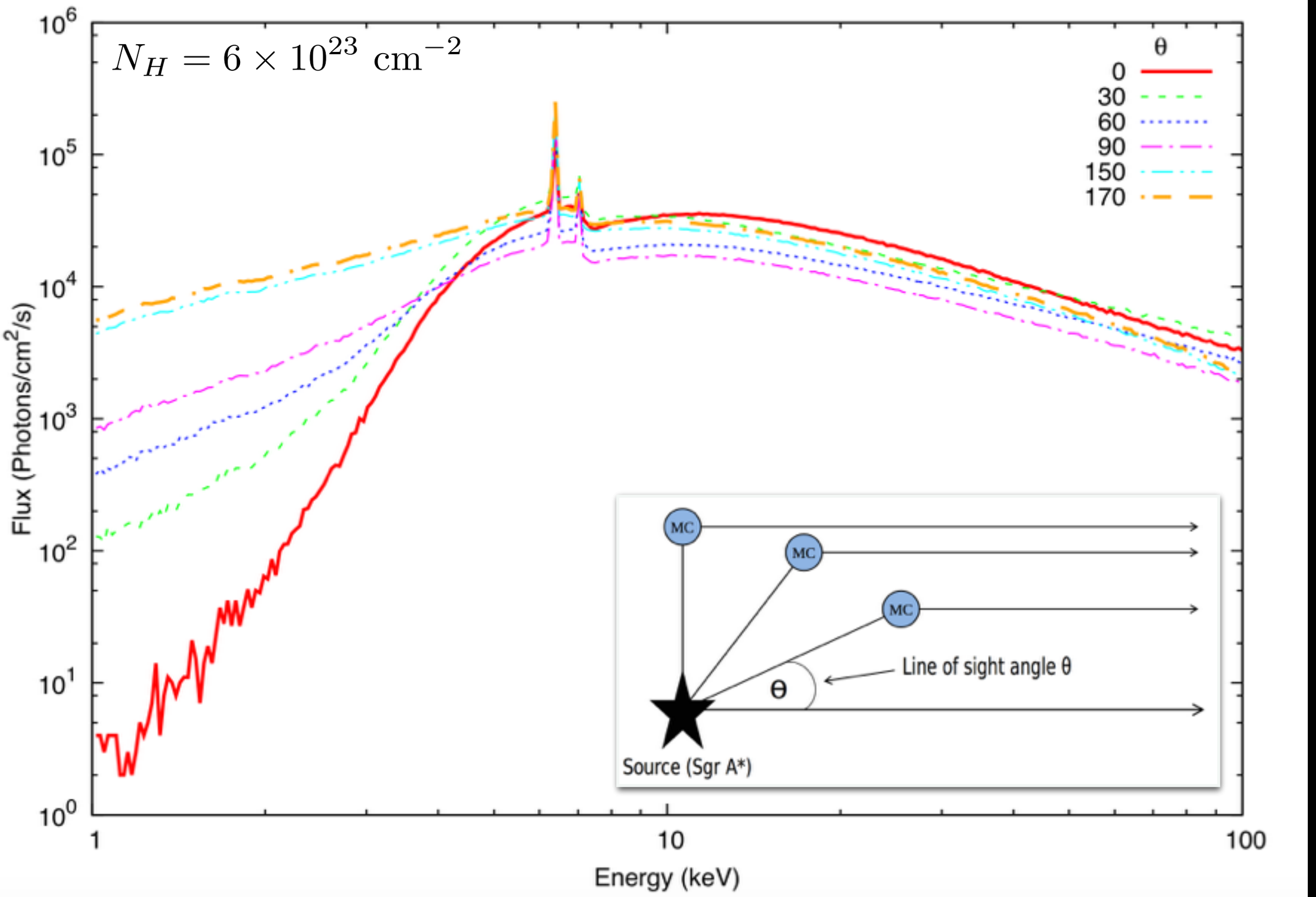
TO OBSERVER



+ COMPTON SCATTERING

$t = t_0 + \Delta t$

TO OBSERVER

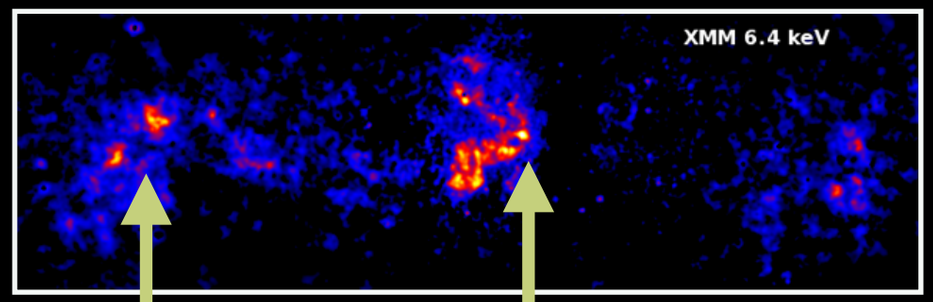

$N_H = 6 \times 10^{23}$ cm^{-2}
θ
0
30
60
90
150
170
Flux (Photons/cm^2/s)
10^6
10^5
10^4
10^3
10^2
10^1
10^0
1
10
100
Energy (keV)
MC
MC
MC
Line of sight angle θ
θ
Source (Sgr A*)

FITTING THE DATA WITH THE MODEL

XSPEC table model whose parameters are:

- the line-of-sight angle
- the cloud column density
- the photon index of the incident power-law spectrum (fixed at 2.0, following Terrier+2010)

Walls+2016 apply the model to Sgr B2 and find 64±8°.



VIEW FROM ABOVE

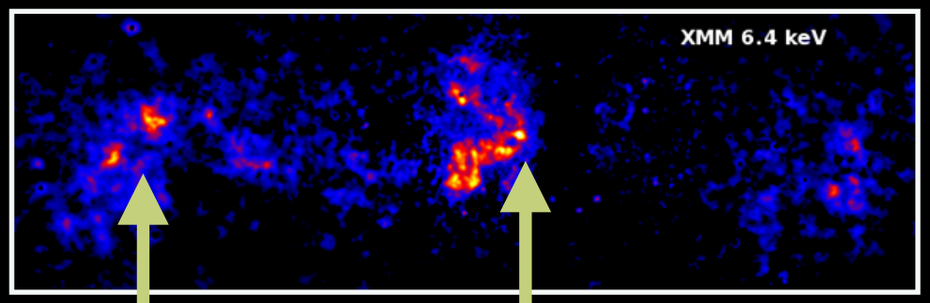
B2

$\Delta t = 205^{+41}_{-22}$ yr

z [pc]

x [pc]

150
100
50
0
−50
−100
−150



VIEW FROM ABOVE

B2

$\Delta t = 205^{+41}_{-22}$ yr

z [pc]

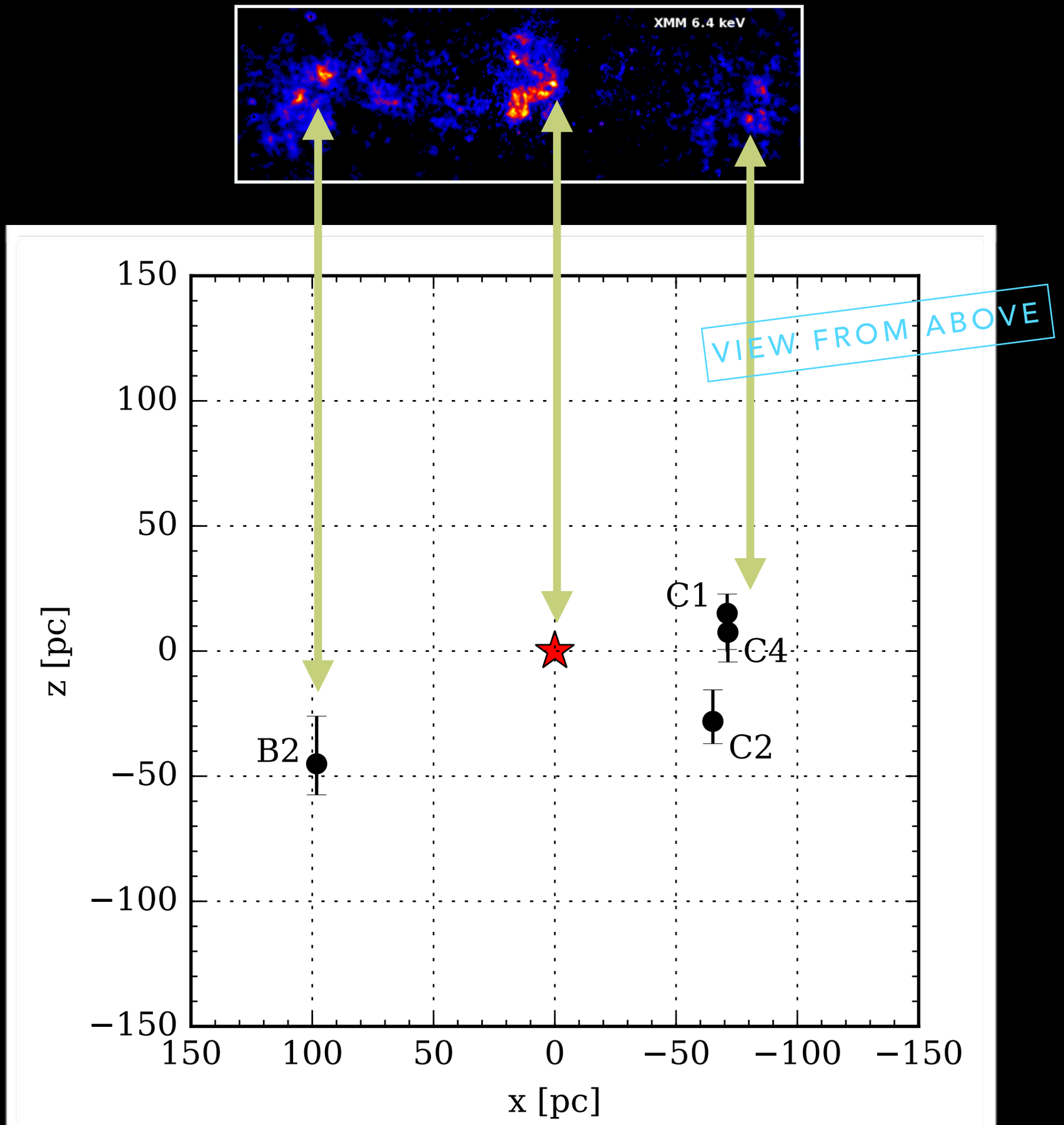
x [pc]

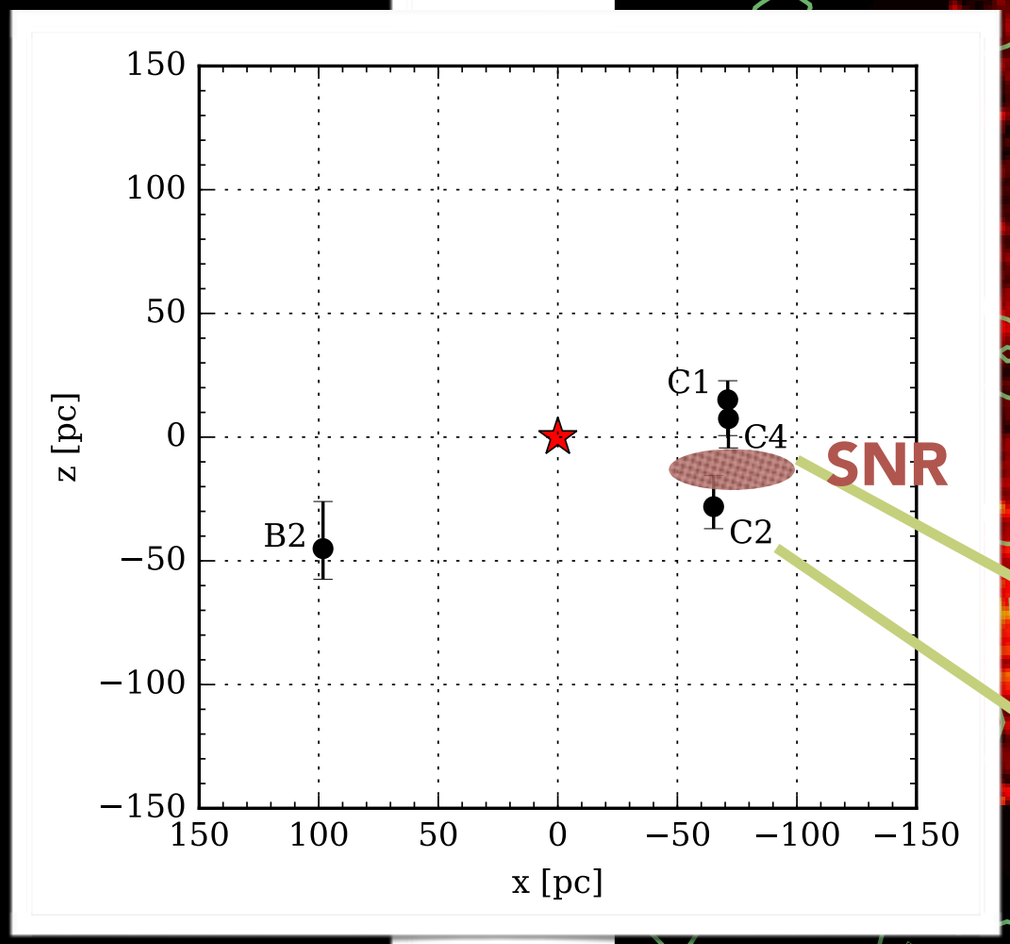
150
100
50
0
−50
−100
−150

APPLYING THE MODEL TO SGR C

Region	Angle (°)	N_H (10^{23}cm^{-2})	χ^2/d.o.f.
Sgr C1	$102.0^{+5.8}_{-11.5}$	$2.18^{+0.20}_{-0.37}$	423.6/372
Sgr C2	$66.7^{+9.9}_{-6.3}$	$7.0^{+1.2}_{-1.2}$	234.0/206
Sgr C4	$96.0^{+6.2}_{-9.5}$	$1.63^{+0.12}_{-0.13}$	436.2/420

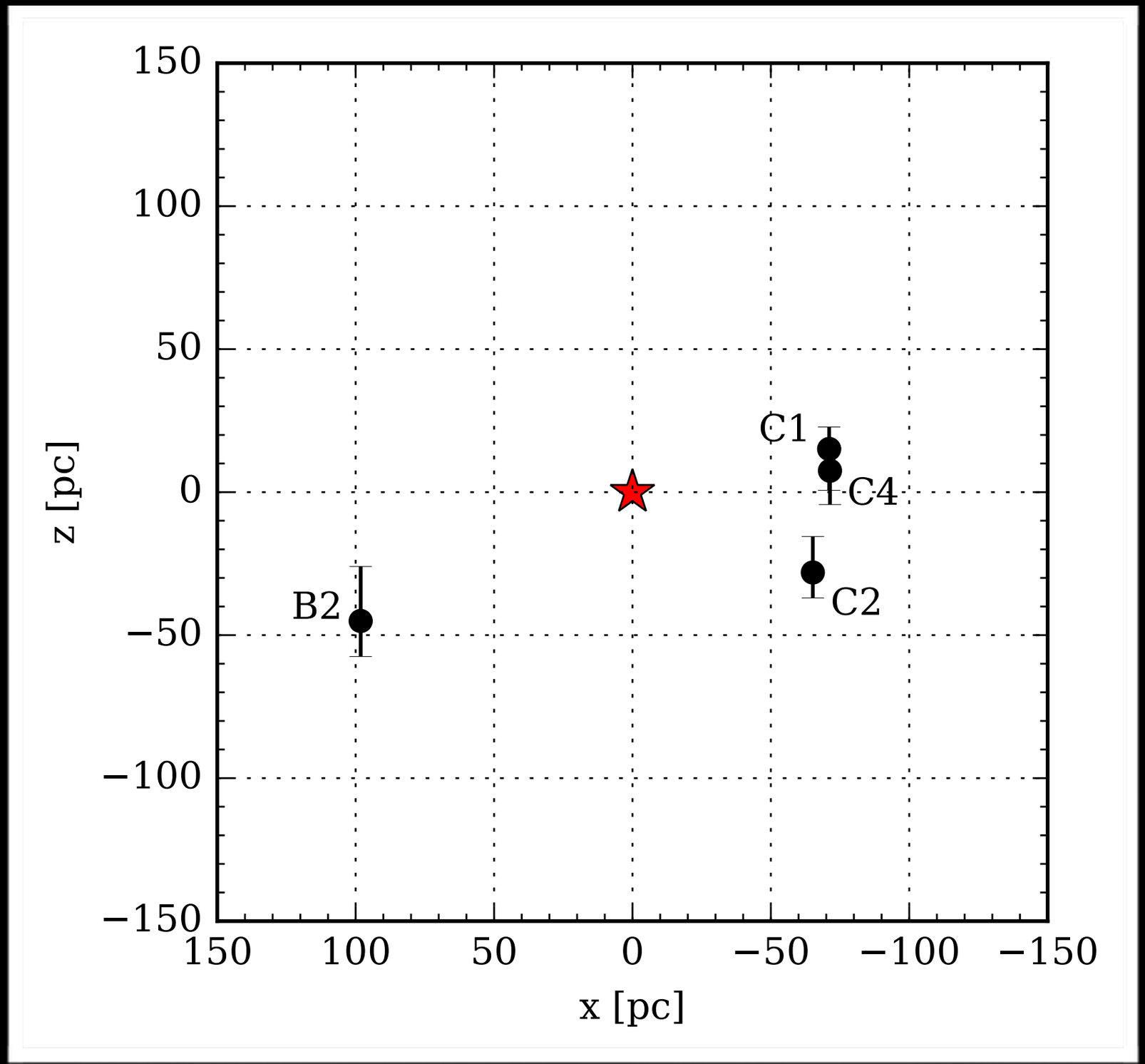
CHUARD+2017B (SUBM.)


XMM 6.4 keV
VIEW FROM ABOVE
150
100
50
0
−50
−100
−150
z [pc]
x [pc]
C1
C4
C2
B2


150
100
50
0
−50
−100
−150
z [pc]
150
100
50
0
−50
−100
−150
x [pc]
C1
C4
C2
B2
SNR

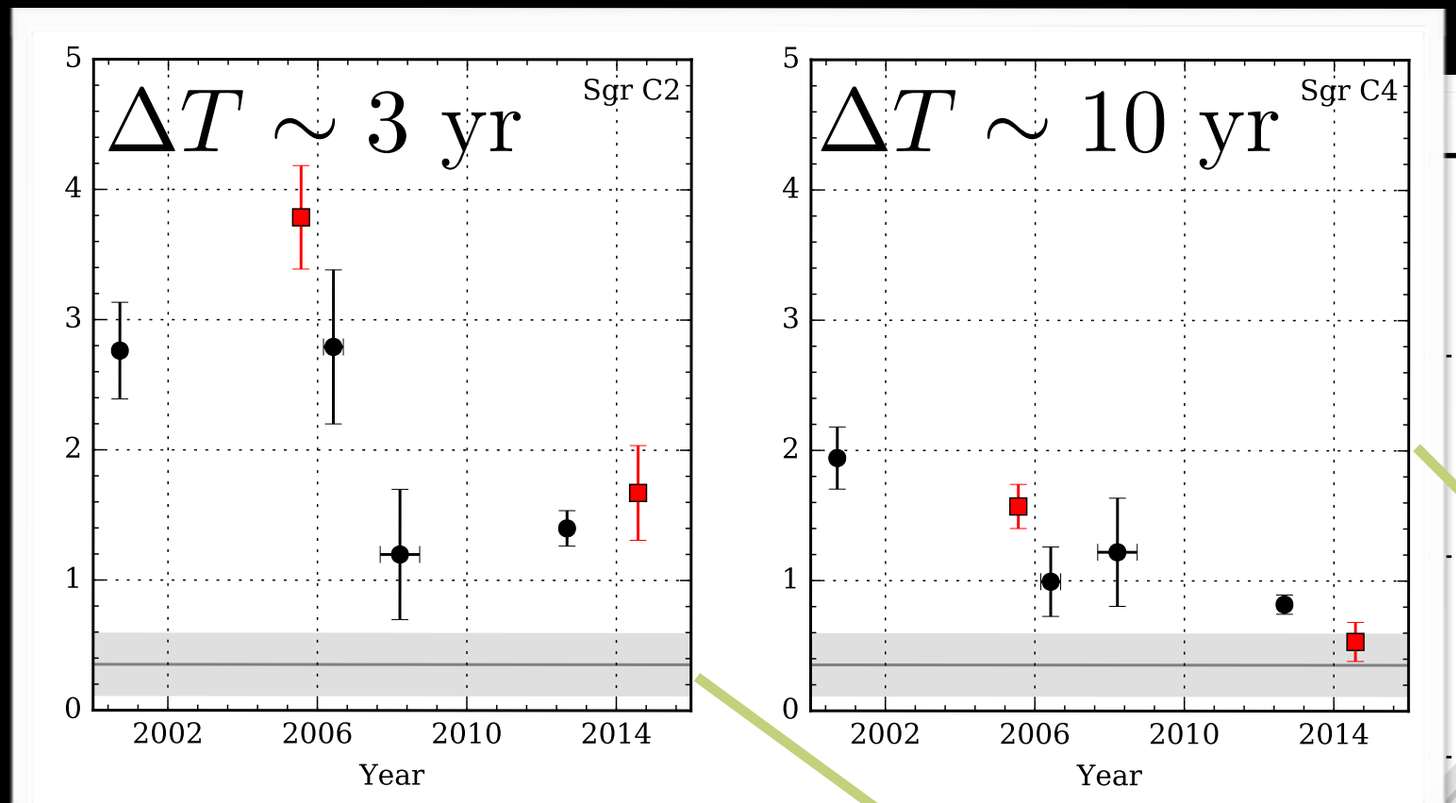
2.0 - 4.5 keV
0.15
359.5
359.3
Galactic longitude

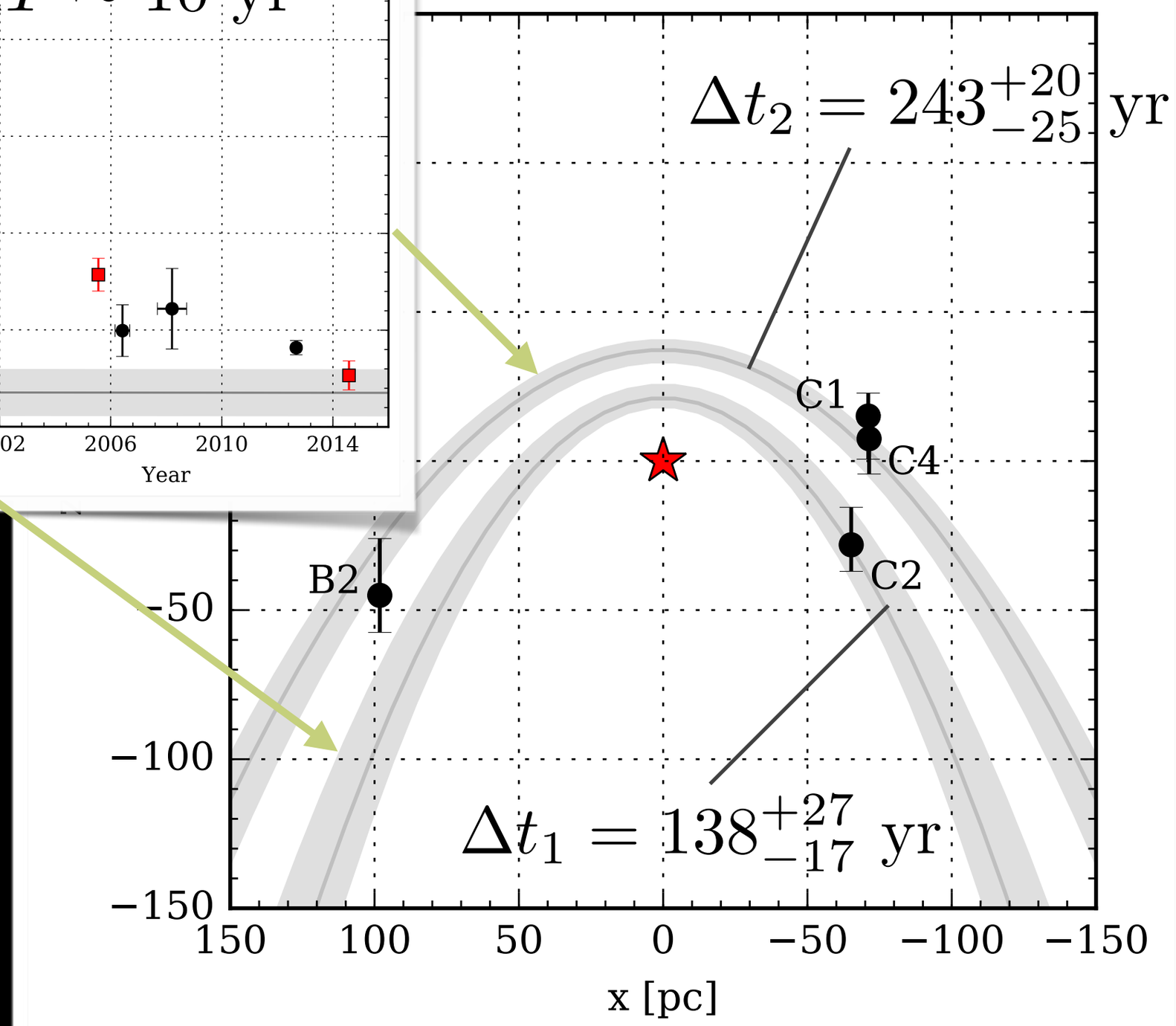
HOW MANY EVENTS?



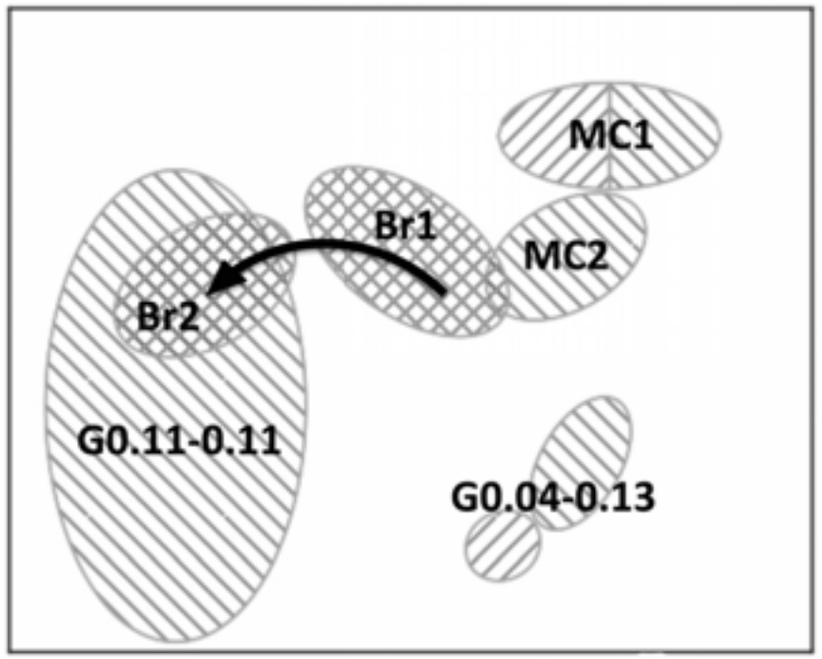
CHUARD+2017B (SUBM.)

HOW MANY EVENTS?





CHUARD+2017B (SUBM.)



10-year
Linear decrease

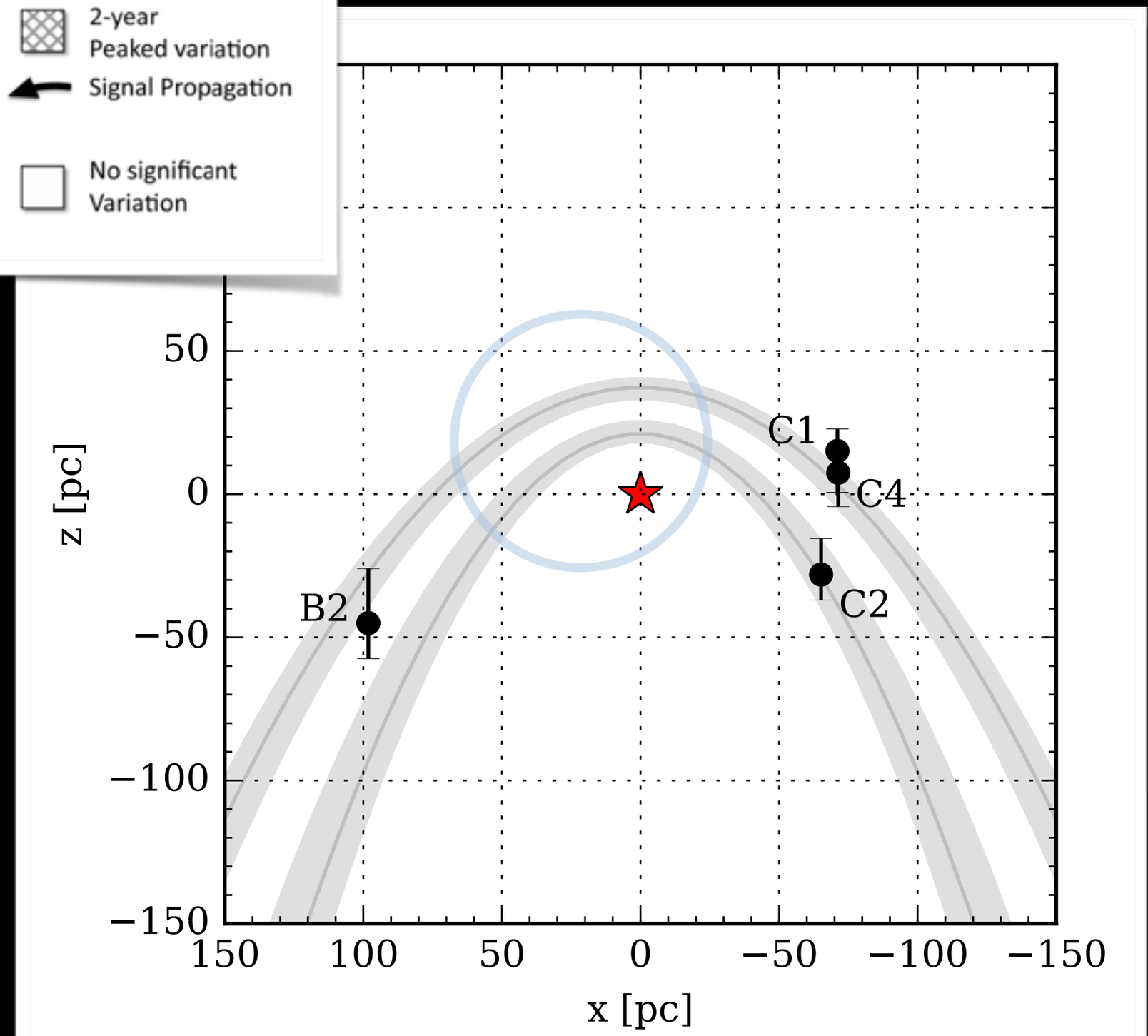
10-year
Linear increase

2-year
Peaked variation

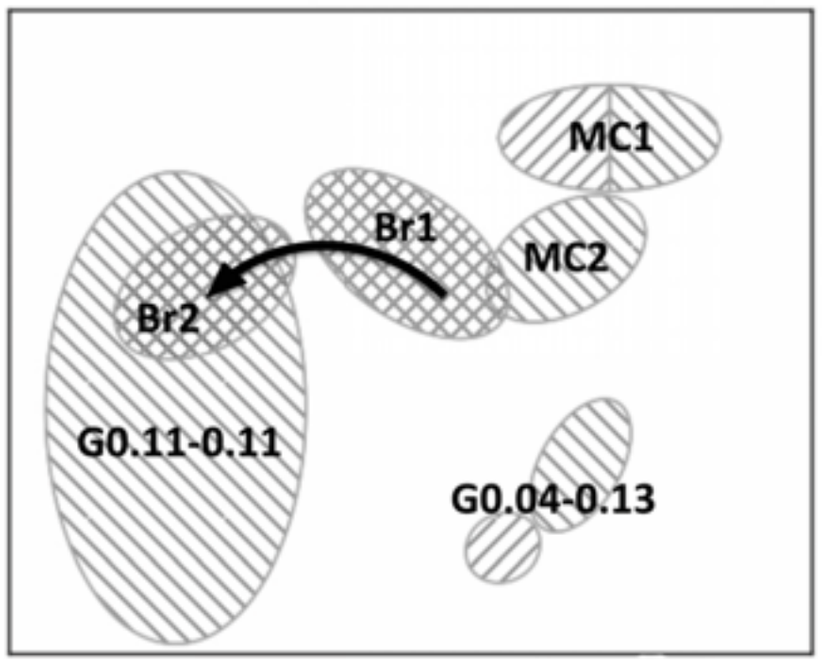
Signal Propagation

No significant
Variation

CLAVEL+2013



CHUARD+2017B (SUBM.)



10-year
Linear decrease

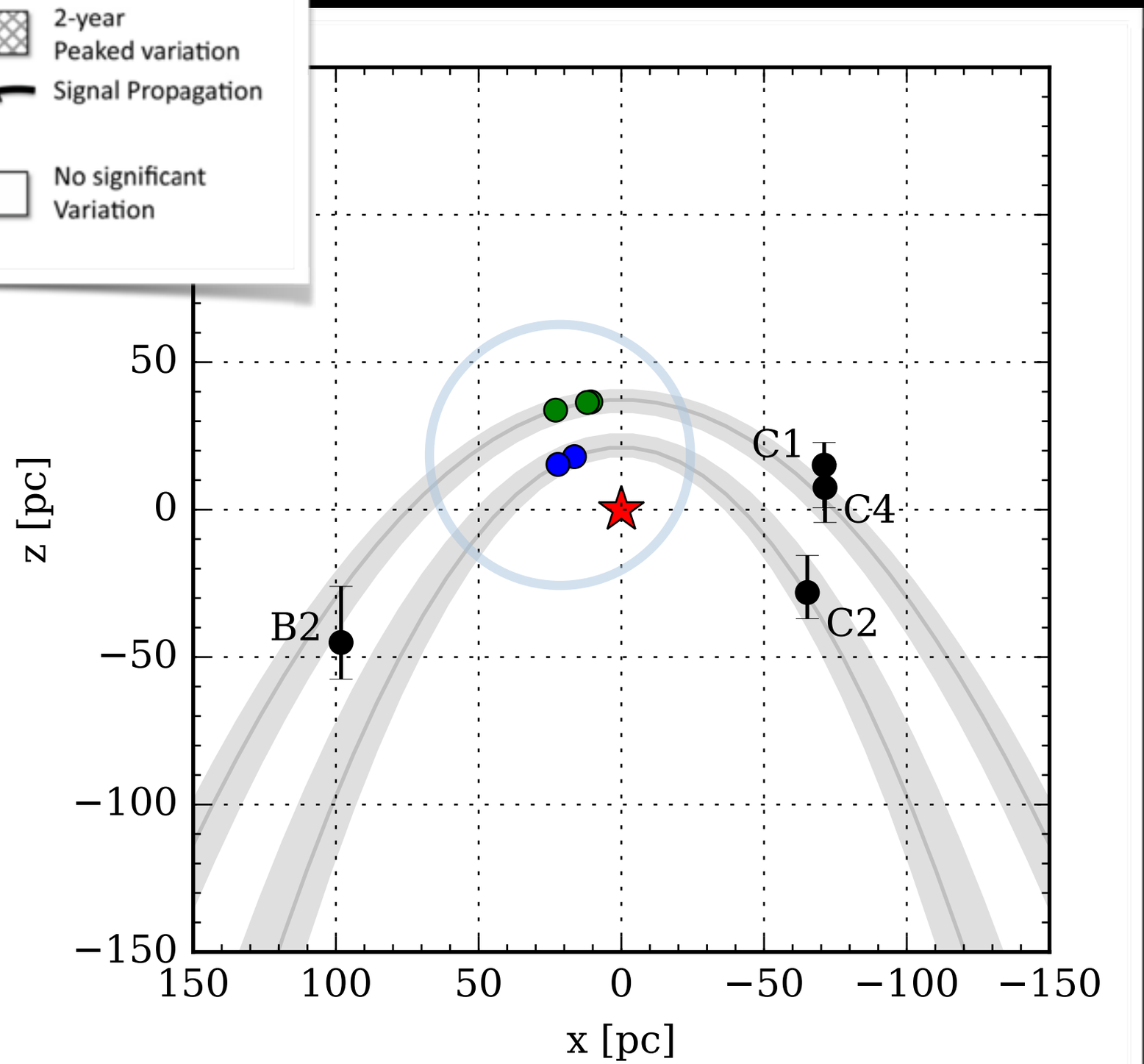
10-year
Linear increase

2-year
Peaked variation

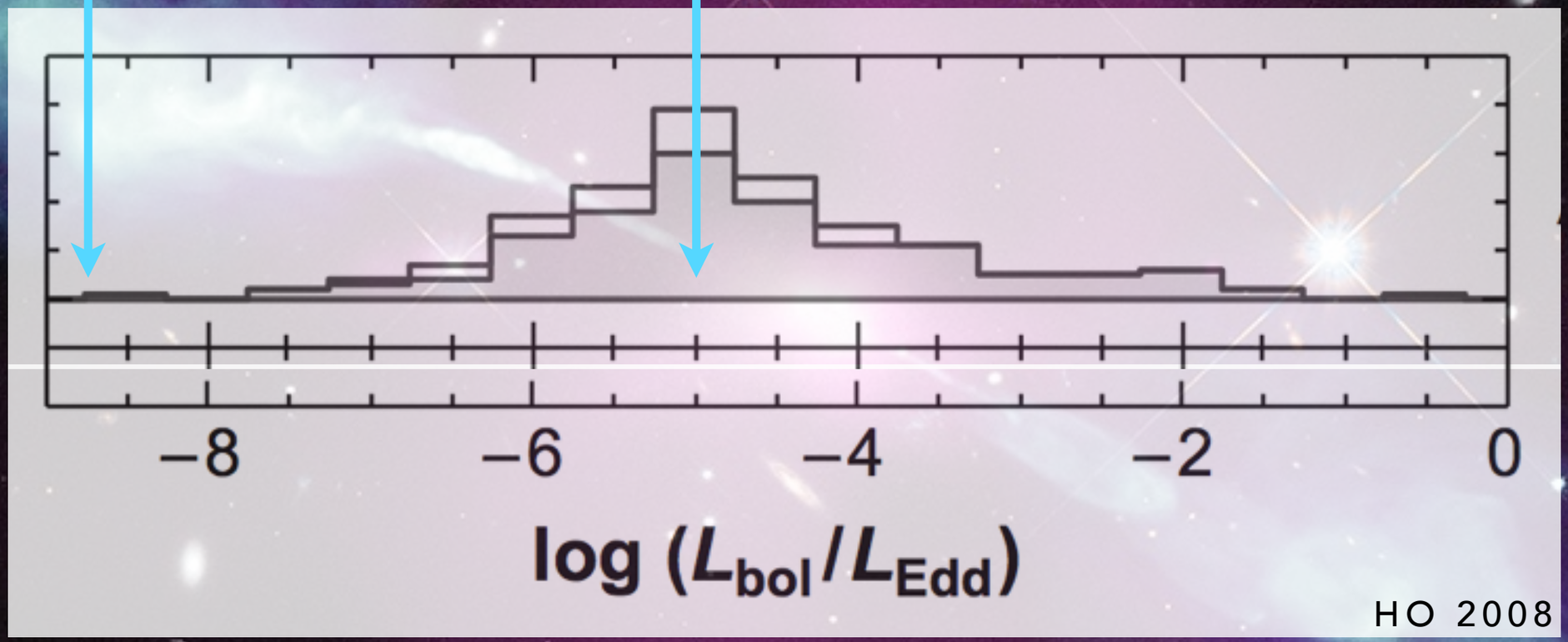
Signal Propagation

No significant
Variation

CLAVEL+2013



CHUARD+2017B (SUBM.)



HO 2008

PALOMAR SURVEY OF NEARBY GALAXIES

TAKE-HOME MESSAGES

- The variability of the 6.4 keV emission confirms the reflection scenario in Sgr C.

- The molecular cloud positions can be determined using the reflected spectra (consistently with the absorption).

- We provide quantitative evidence for the two-event scenario and we date both outbursts for the first time.

- Our Galaxy was probably in a LLAGN phase a few hundred years ago.