Traces of past activity in the Galactic Centre

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Cosmic rays in star forming environments - arXiv:1210.3034

Was Sgr A brighter in the past?*

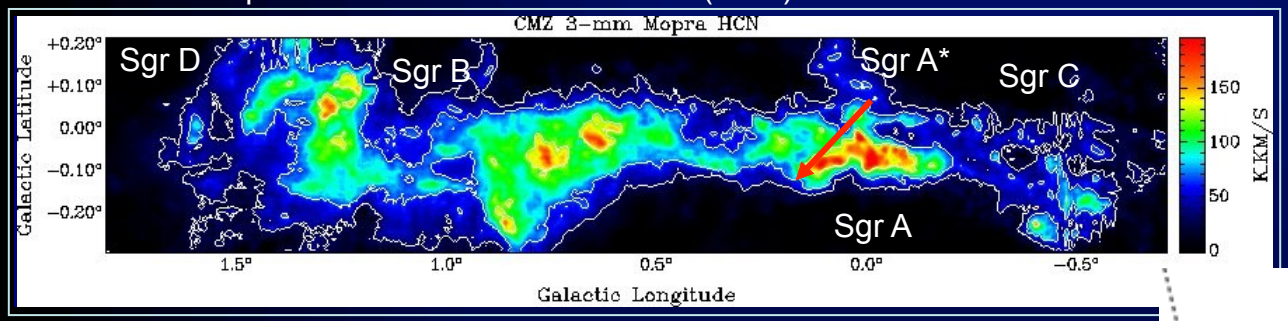
L_{SgrA*}~3×10^{33} - 10^{35} erg s^{-1}
L_{Edd} = 5×10^{44} erg s^{-1}

M_{SgrA*}=4.4×10^{6} M_{Sun}

➔ Smallest Eddington ratio BH (η~$10^{-9,10}$)

Was Sgr A* brighter in the past?

Map of the Central Molecular Zone (CMZ) in HCN transition



Jones et al. 2012
MOPRA CMZ project

~300 pc

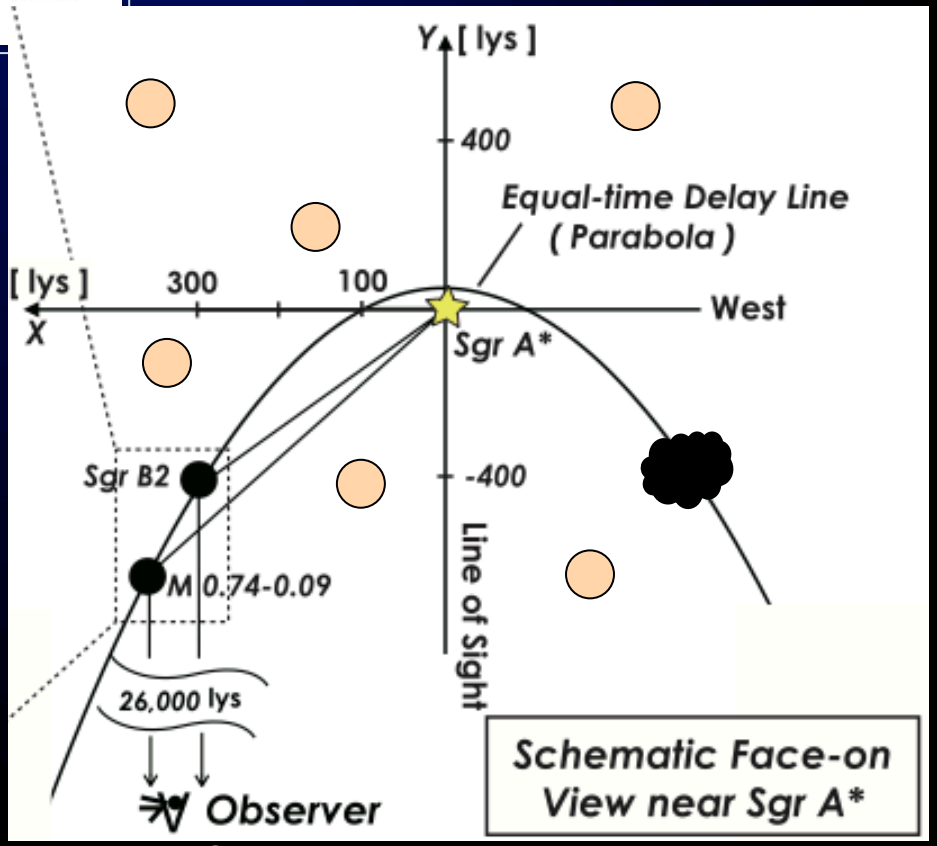
Sgr A* sits on Central Molecular Zone (CMZ) centre

10^{7}-10^{8} M_{Sun} of gas in the central 300 pc

➔ MC tool to trace GC past X-ray activity!

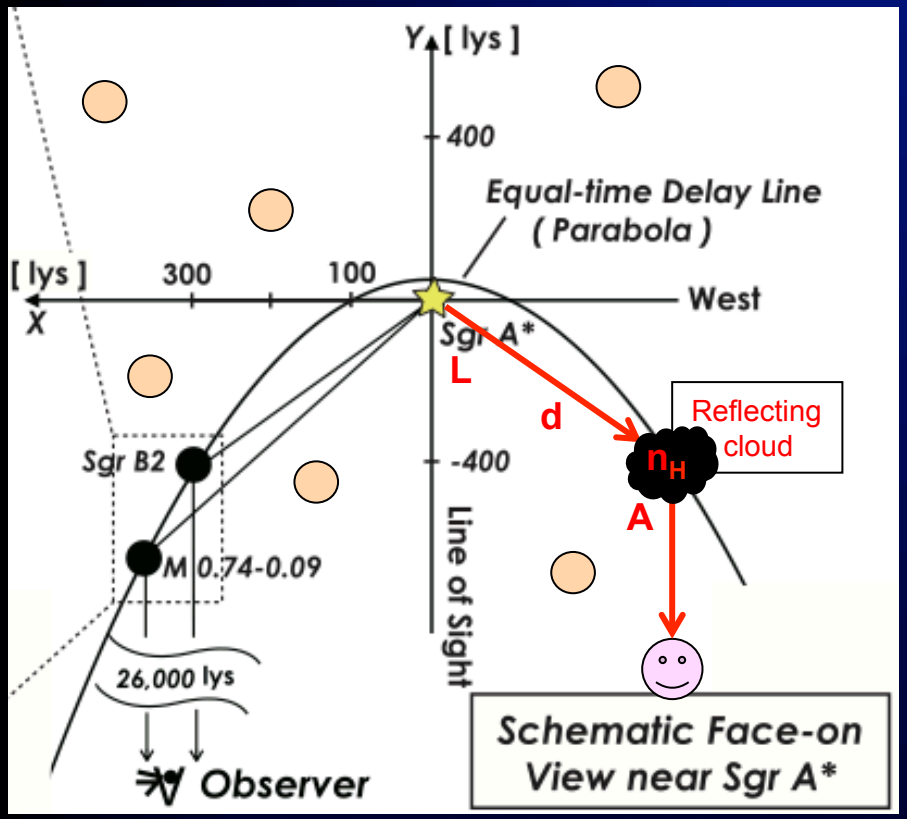
➔ Correlated variations if clouds along same light front

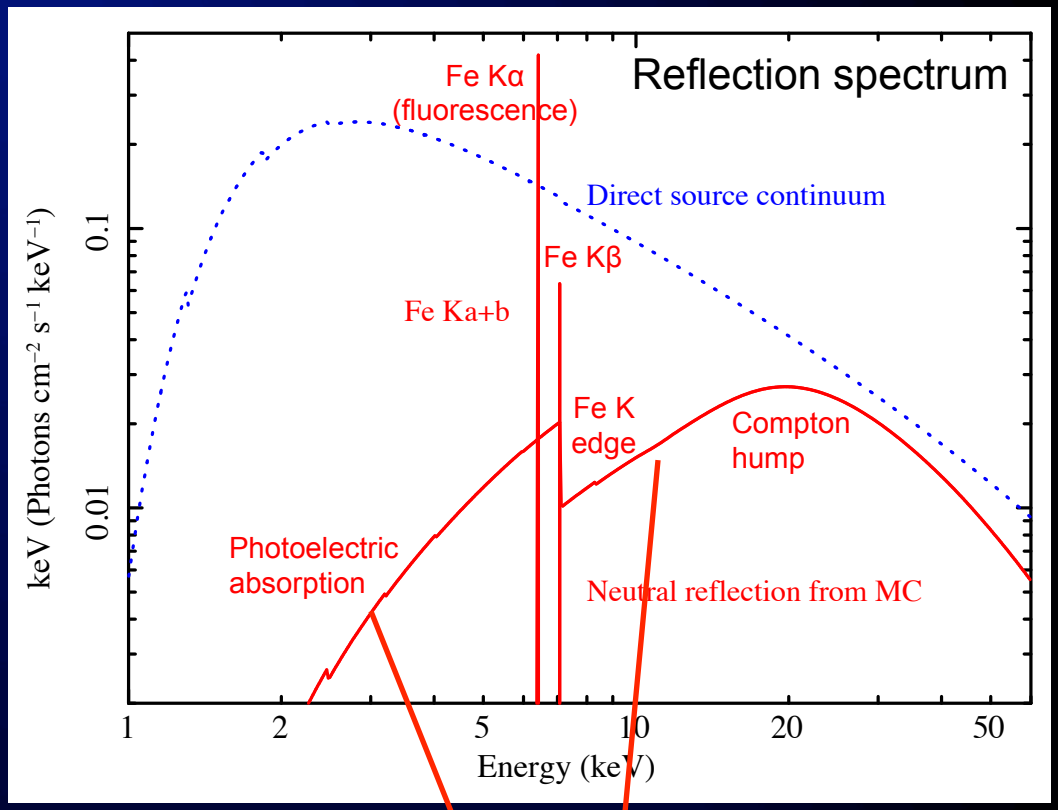
➔ Tomography of cold gas distribution!



Sunyaev et al. 1993; 1998; Ponti et al. 2010; 2013; Nobukawa et al. 2011; Capelli et al. 2012; Ryu et al. 2013

Clouds to trace Galactic Centre past activity:





Related to cloud N_H + los absorption

See e.g. Ryu et al. 2013

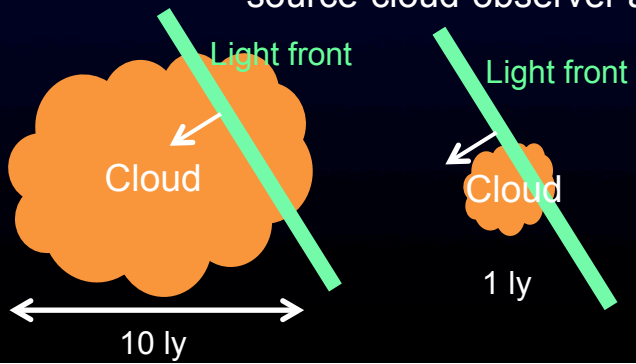
➔ Link between source incident flux and reflection intensity

Compton scattering depends on source-cloud-observer angle ➔ info on geometry

See e.g. Capelli et al. 2012

$$L_{SgrA*} \propto \frac{n_H \times A \times I_{\mathrm{FeK}}}{d^2}$$

Measure of $d_{\text{line of sight}}$ ➔ L_{source} & t_{flare}



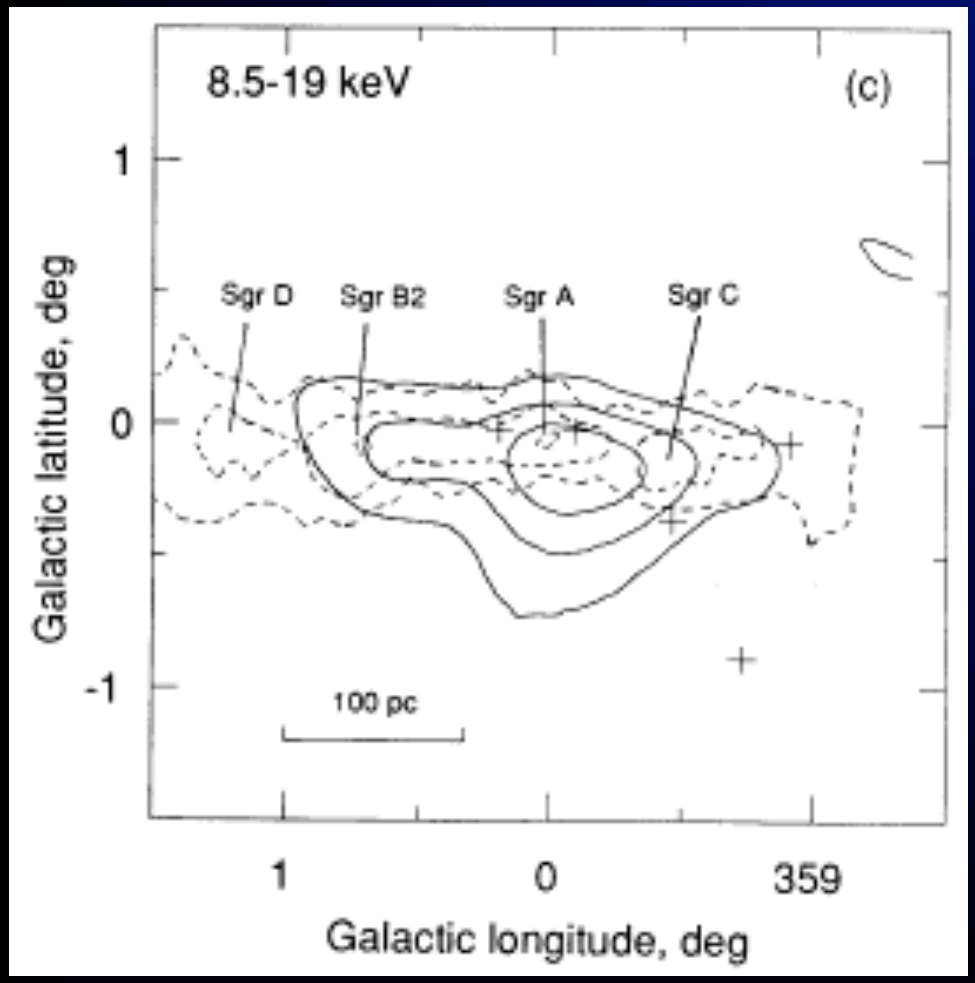
➔ Reflection variability modulated by cloud light crossing time

➔ Smaller clouds tests faster variability

FeK & Hard X-ray emission from MC

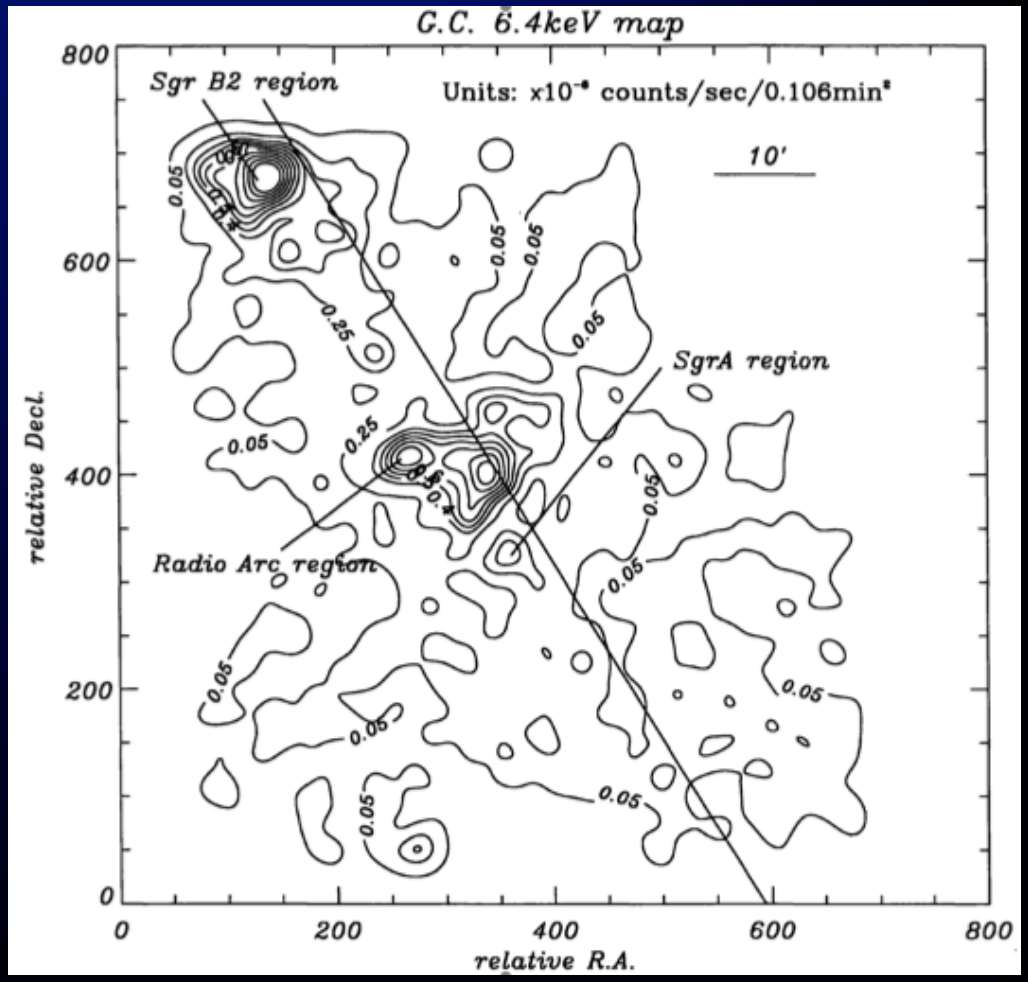
Which is the origin of the Hard X-ray emission from MC?

GRANAT: Hard X-ray/MC



Sunyaev et al. 1993

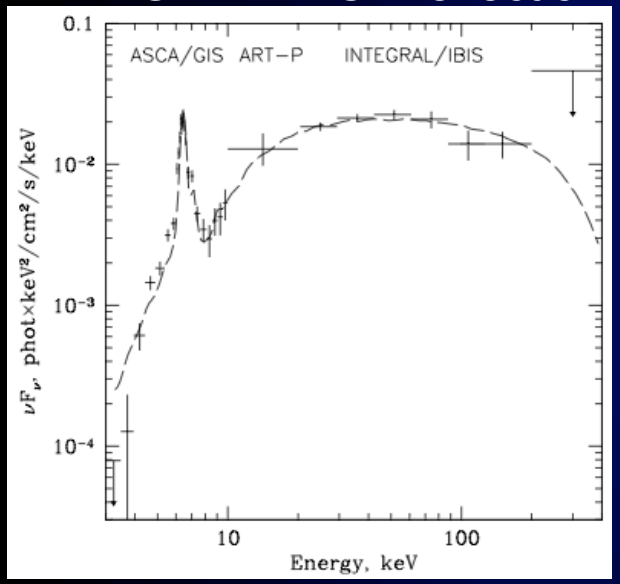
ASCA: Fe Kα from some MC



Koyama et al. 1996

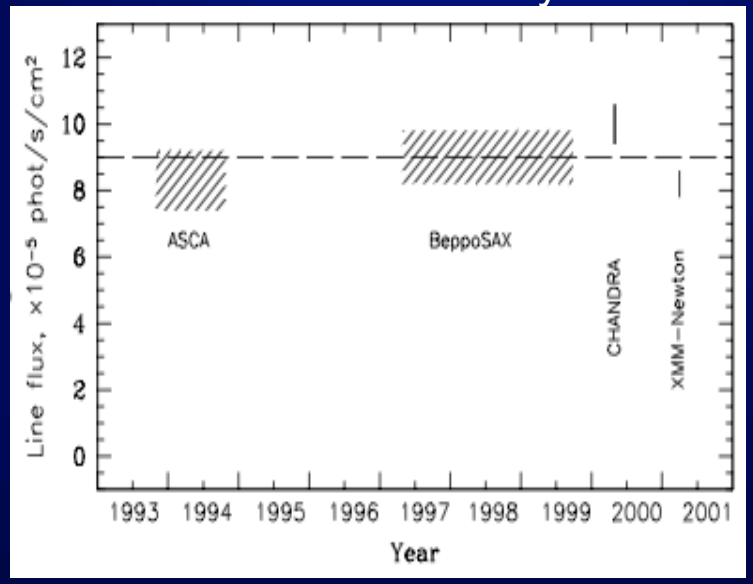
Are MC reflecting GC radiation?

INTEGRAL: MC - reflection



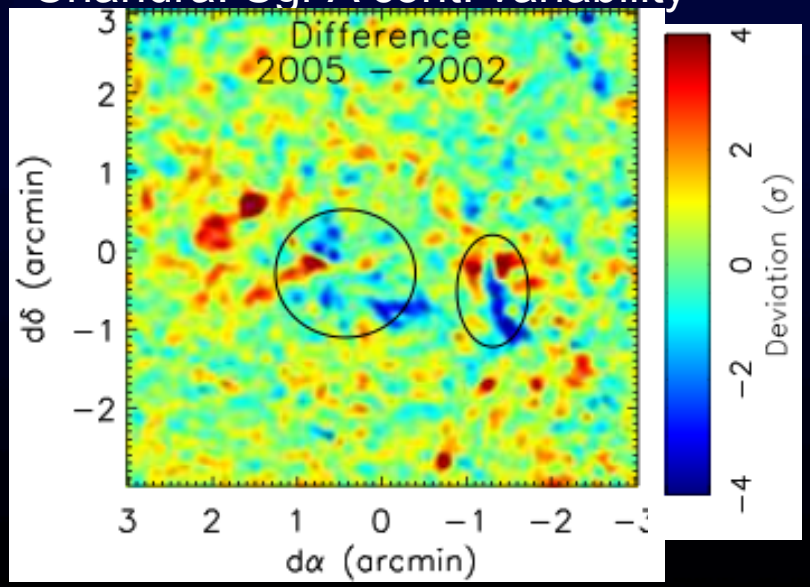
Revnivtsev et al. 2004

FeKα: constant intensity!



Spectrum:
Sgr B2 consistent with reflection
Luminous event ➔ X-ray binary unlikely

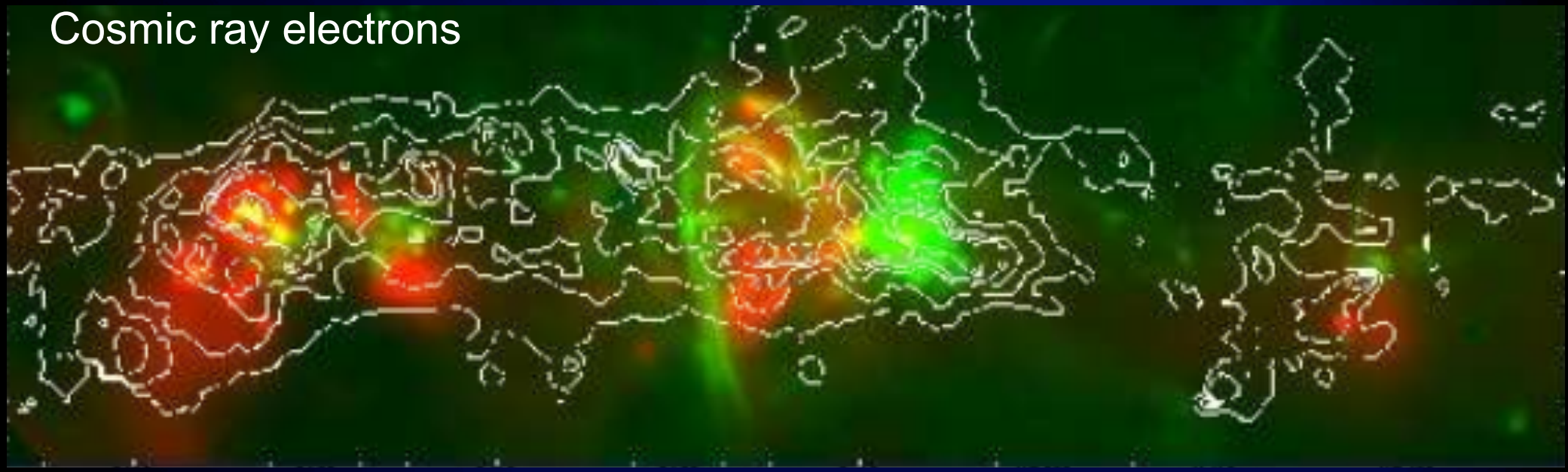
Chandra: Sgr A cont. variability



Muno et al. 2007

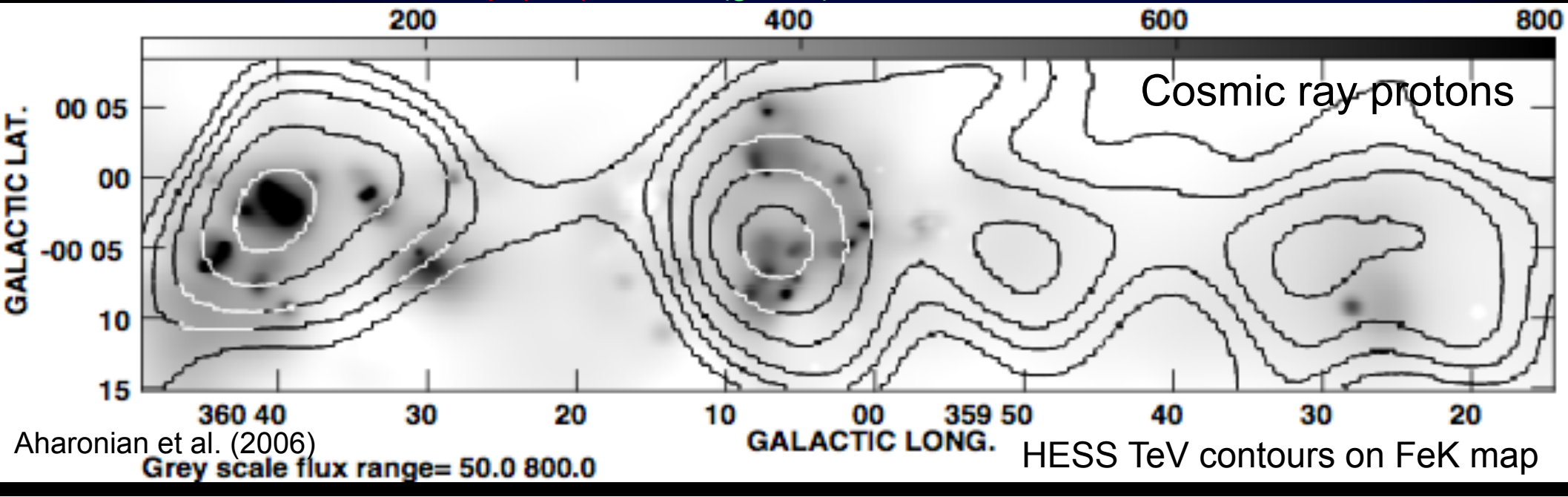
But weak detection of variability!!

Alternatives to reflection: Cosmic Rays



Contours 850-micron; FeK map (red); 20 cm (green)

Yusef-Zadeh et al. 2002; 2007; 2013



Aharonian et al. (2006)

HESS TeV contours on FeK map

X-ray from MC: Reflection or Cosmic Rays?

⇒ Low energy cosmic ray electrons or protons

Low energy cosmic ray electrons: Yusef-Zadeh et al. 02; 07; 13 Valinia et al. 00;
Low energy cosmic ray protons: Dogiel et al. (2009)
Supernovae ejecta: Bykov 02

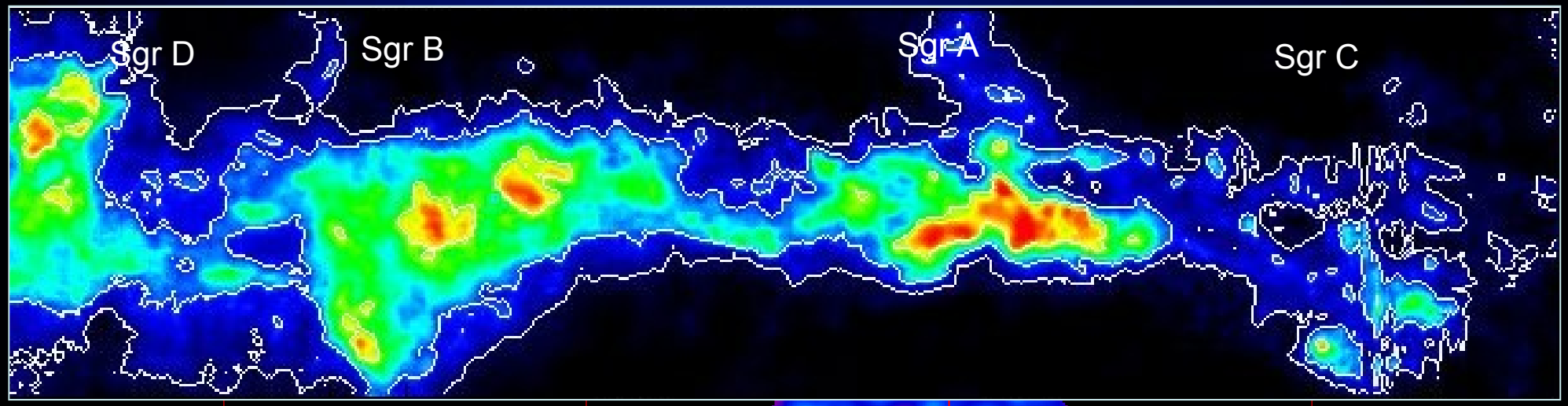
⇒ Sgr A* flare ~1.5×10^{39} erg s^{-1} ~ 100 yr ago

Internal source

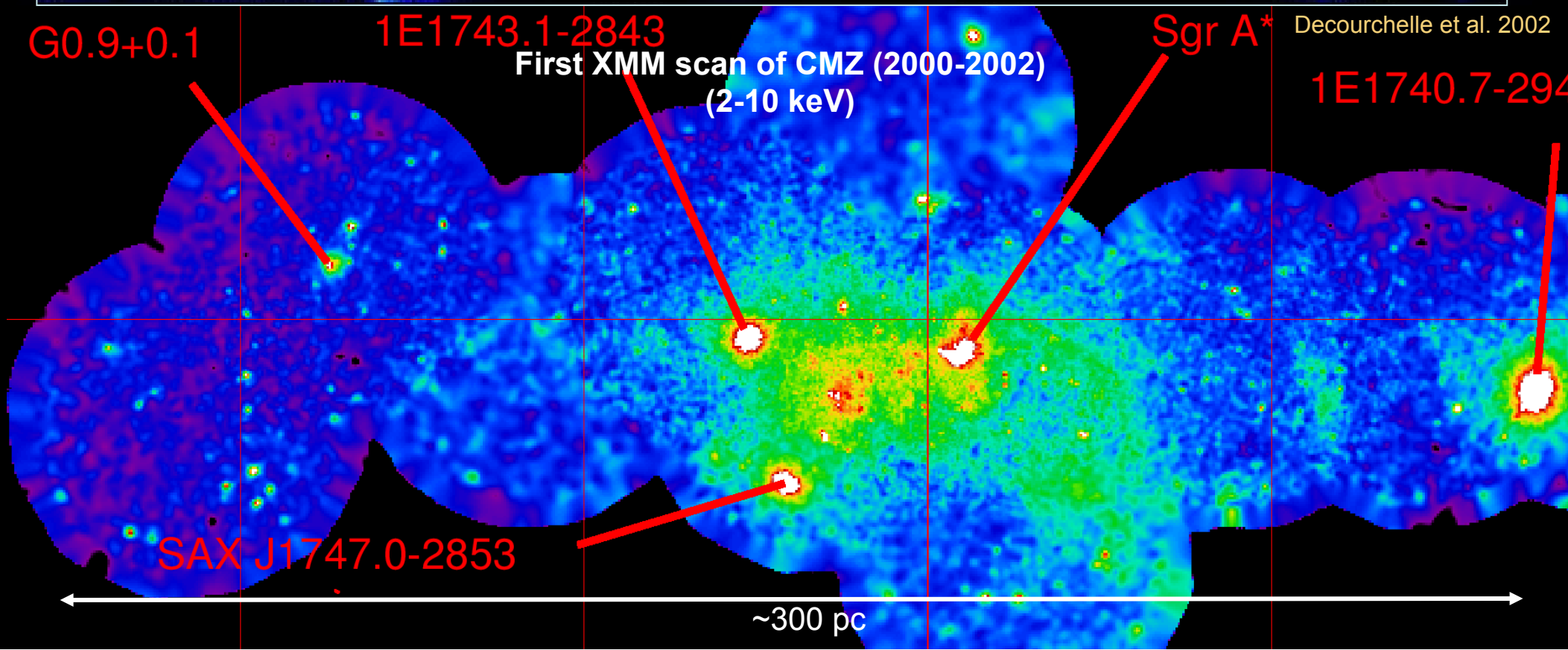
External source: Sgr A*, X-ray binary, Magnetar, Sgr A East

The XMM view of the Galactic Centre

Jones et al. 2012
MOPRA CMZ project



Decourchelle et al. 2002



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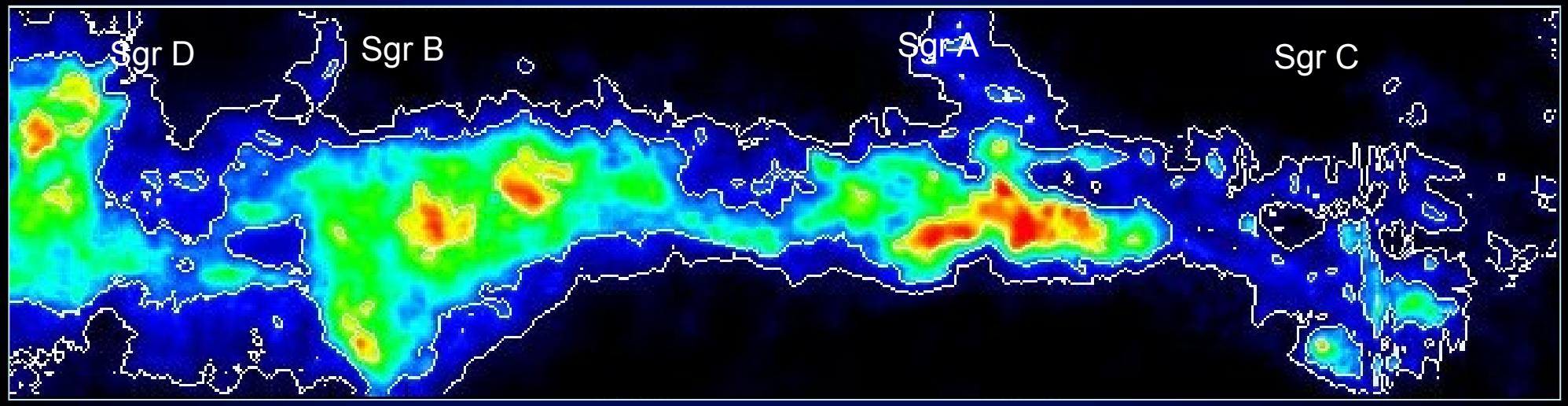
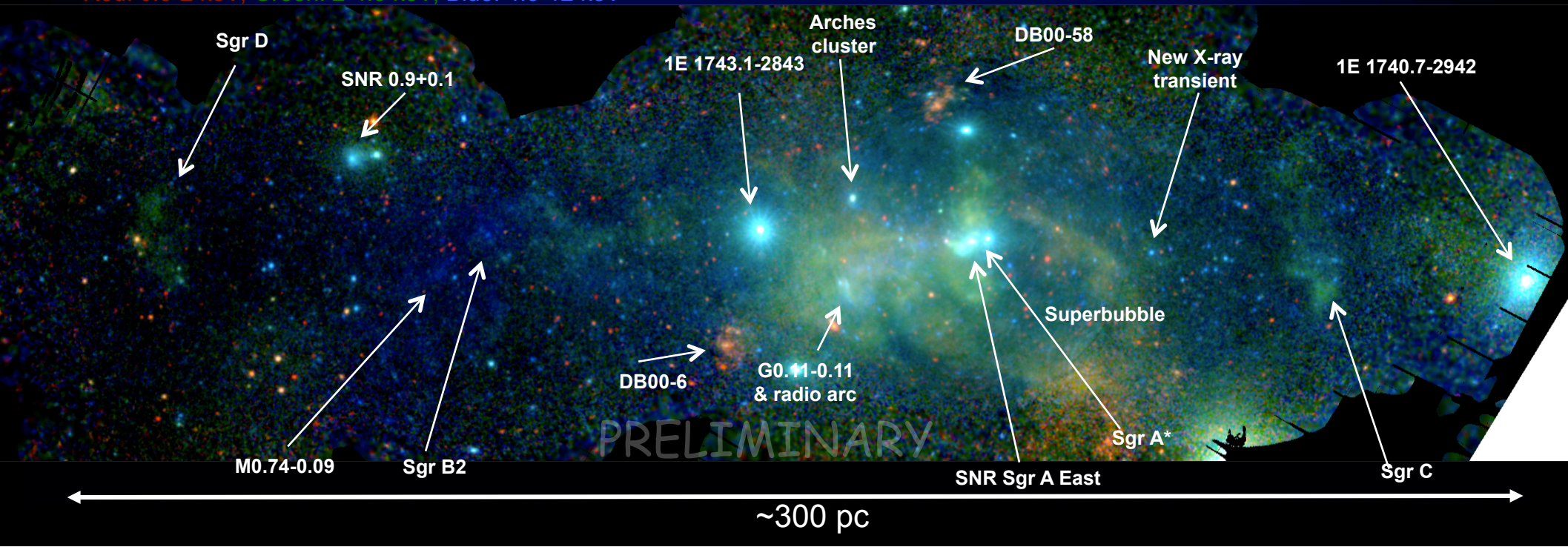


New XMM scan of CMZ (2012)
(continuum)

Red: 0.5-2 keV; Green: 2-4.5 keV; Blue: 4.5-12 keV

Ponti et al. in prep.



The XMM view of the Galactic Centre

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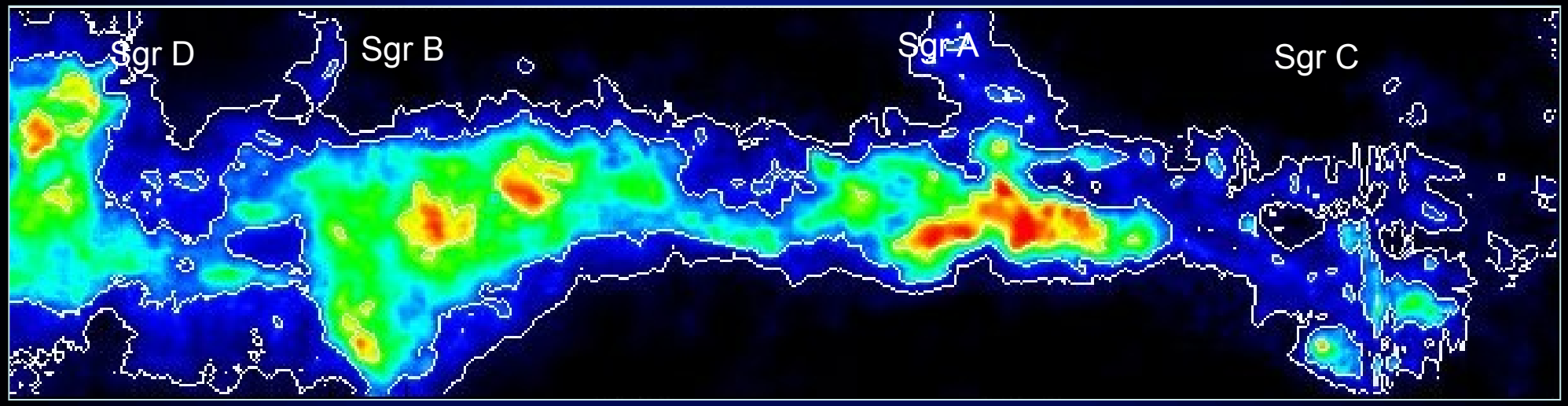
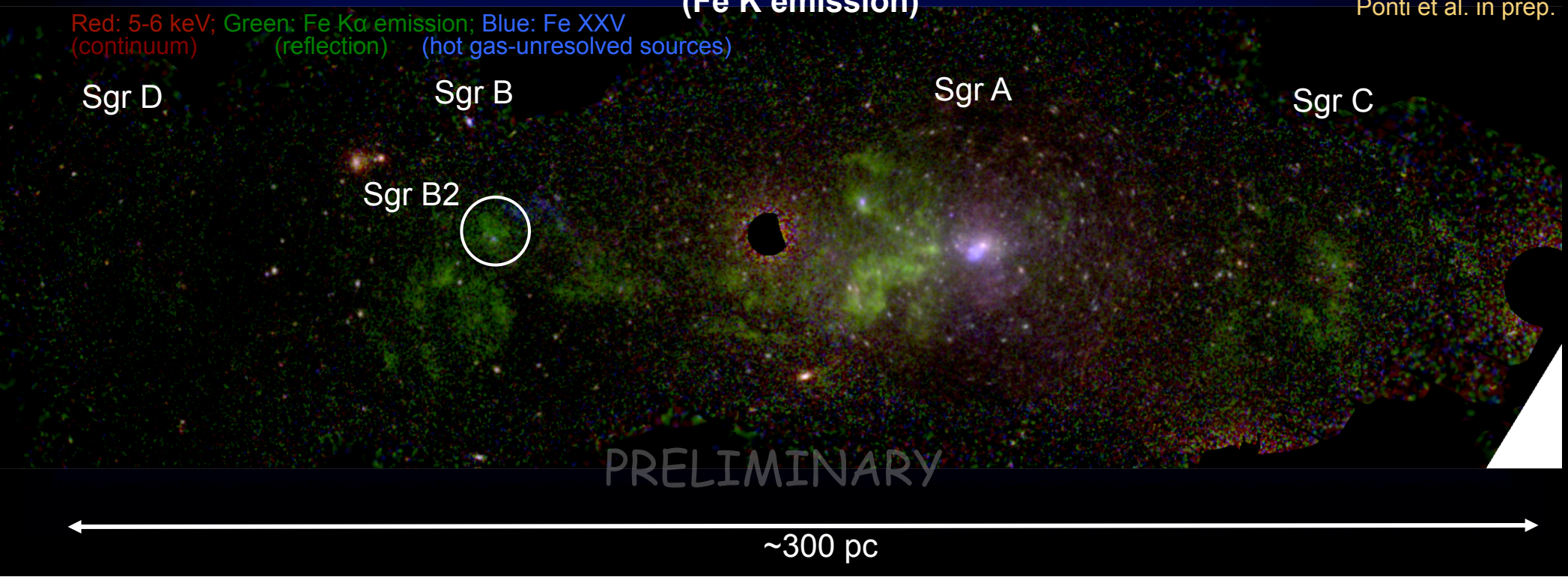
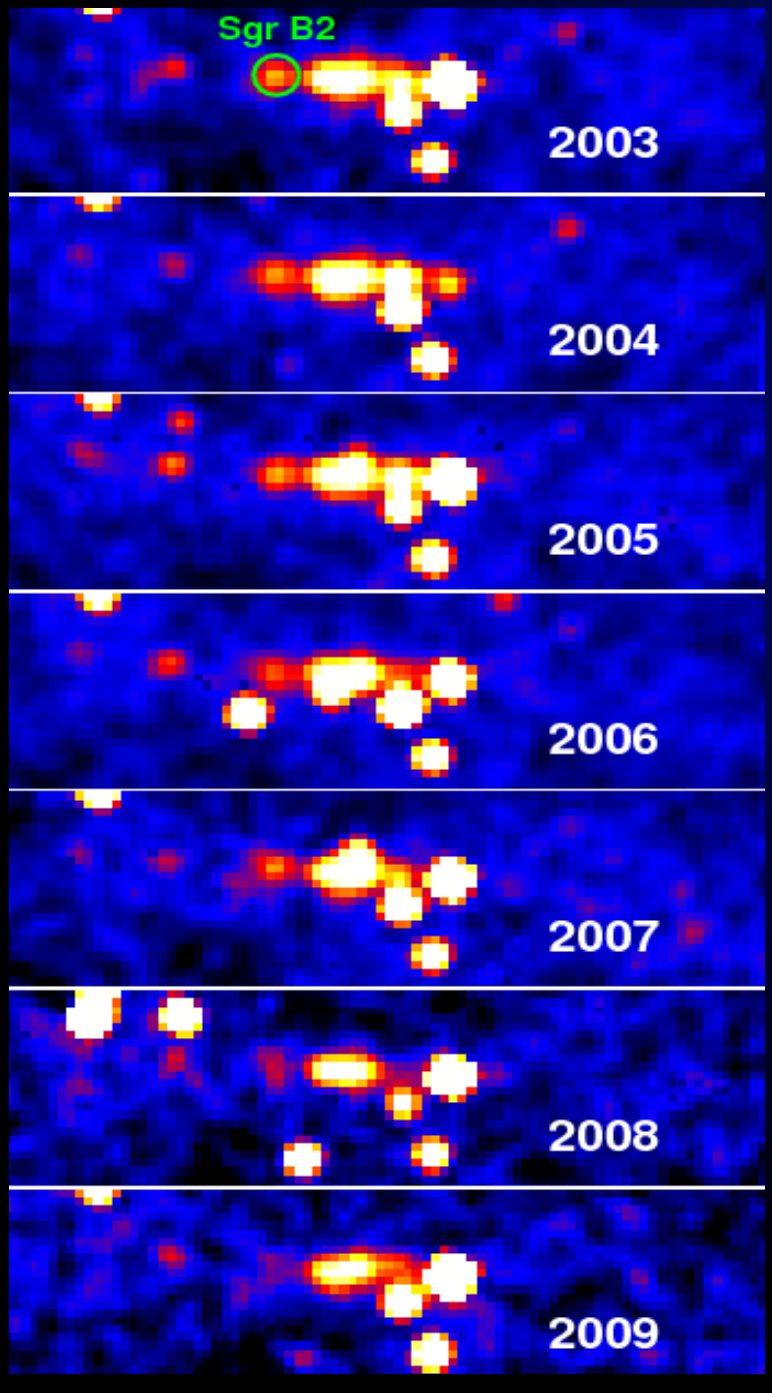


New XMM scan of CMZ (2012)
(Fe K emission)

Ponti et al. in prep.

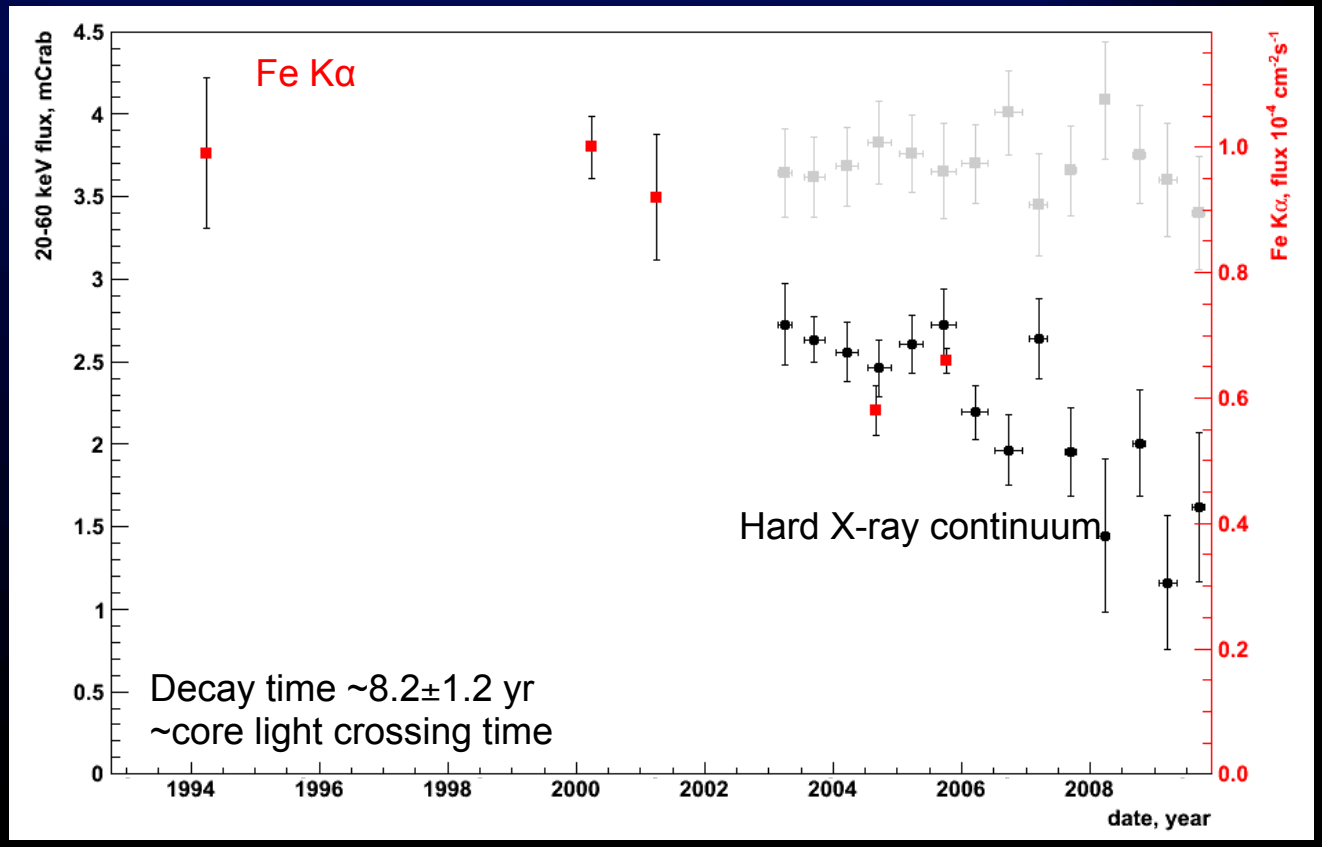


The X-ray view of Sgr B2

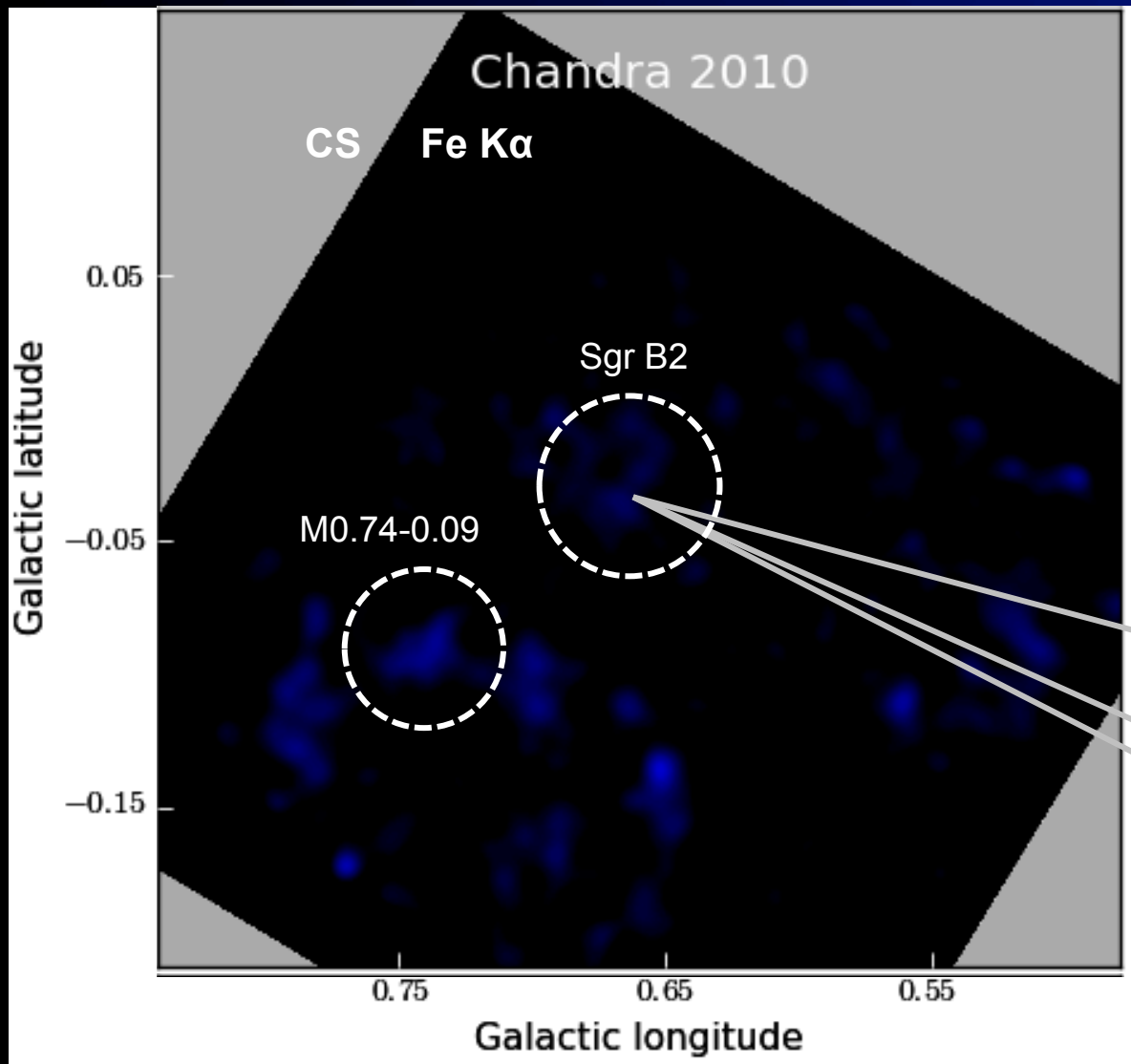


Inui et al. 2009

Terrier et al. 2010

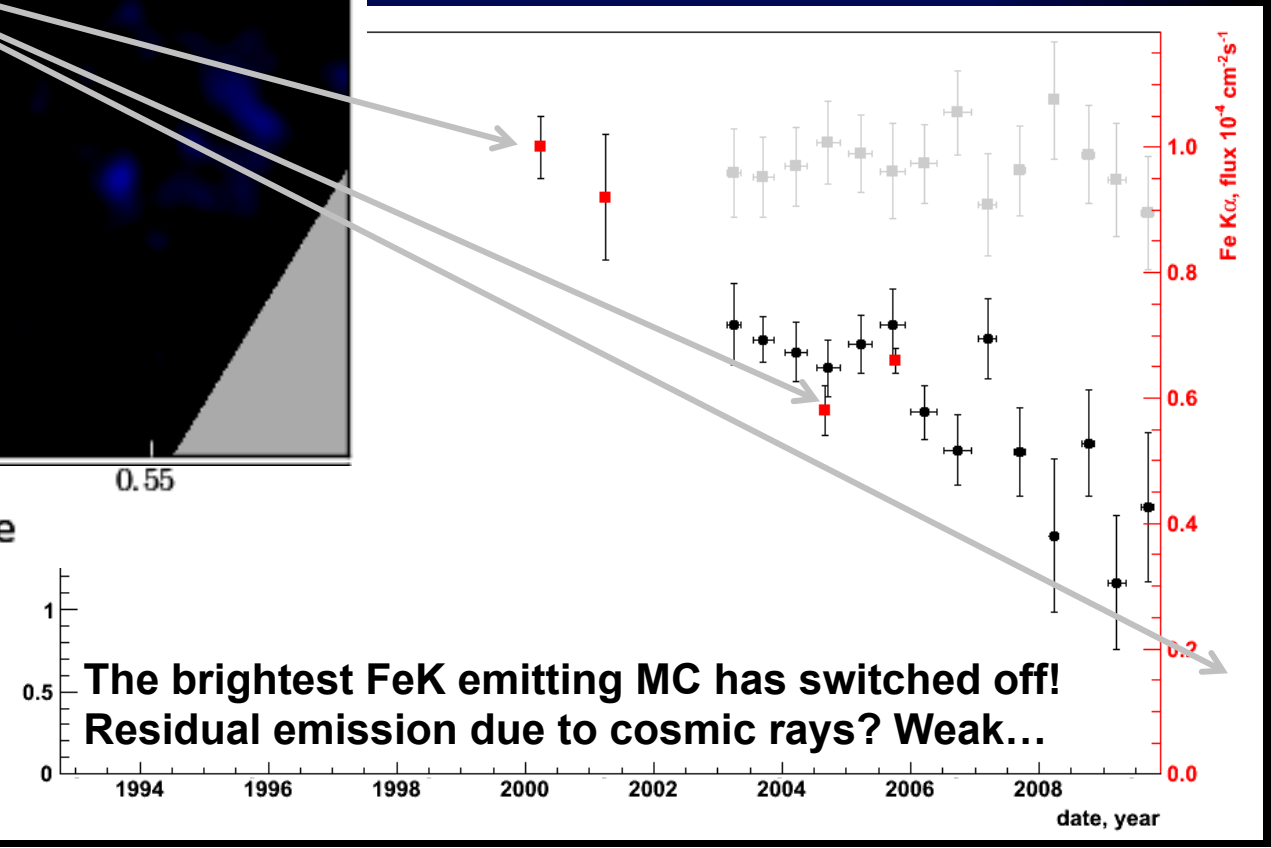


The Chandra-XMM view of Sgr B2



Terrier et al. sub.

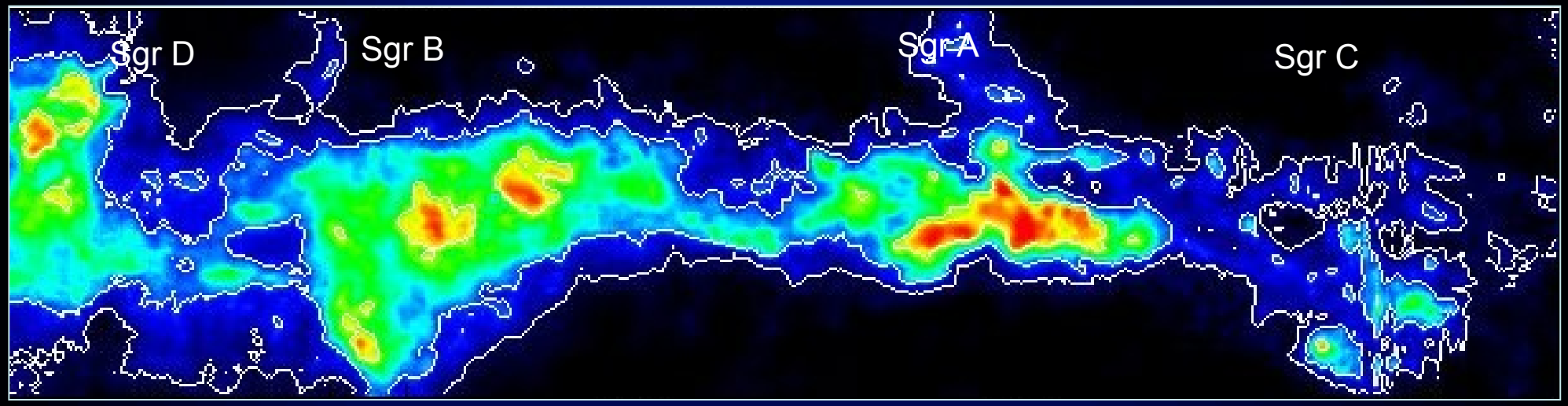
- ➔ Luminosity > 10^{39} erg s^{-1} for more than 10 years
- ➔ X-ray binary unlikely



The brightest FeK emitting MC has switched off!
Residual emission due to cosmic rays? Weak…

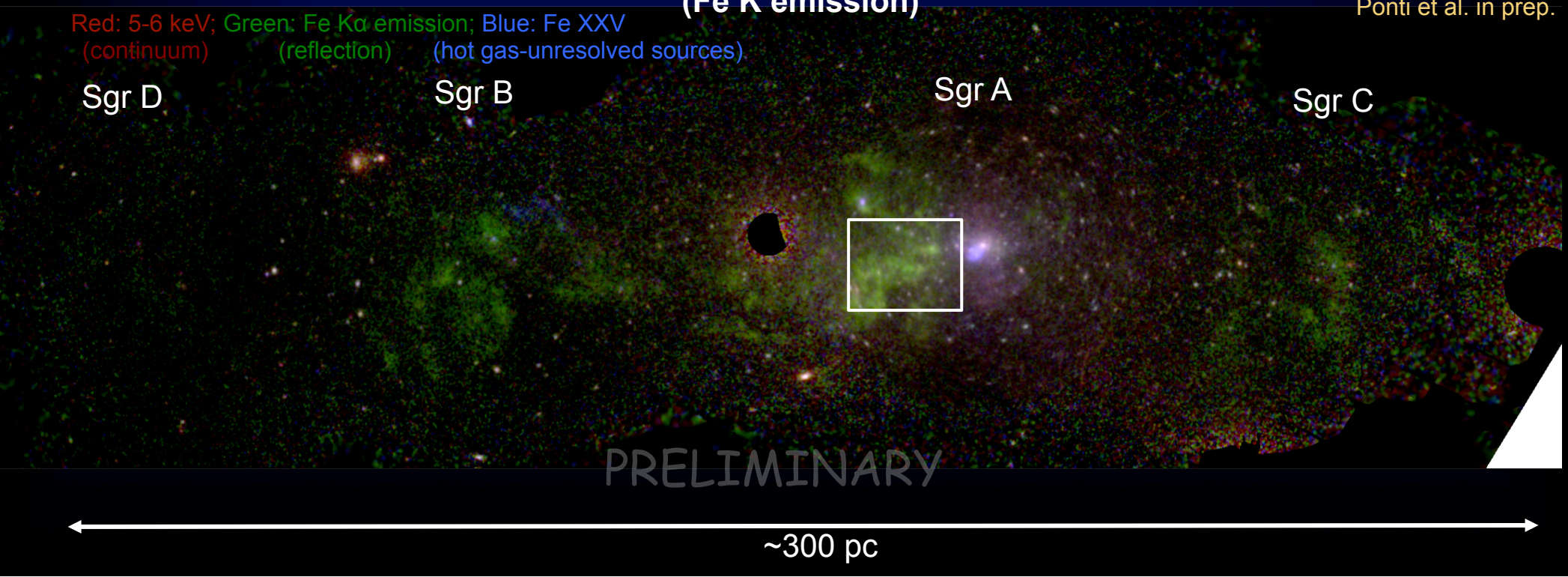
The XMM view of the Galactic Centre

Jones et al. 2012
MOPRA CMZ project

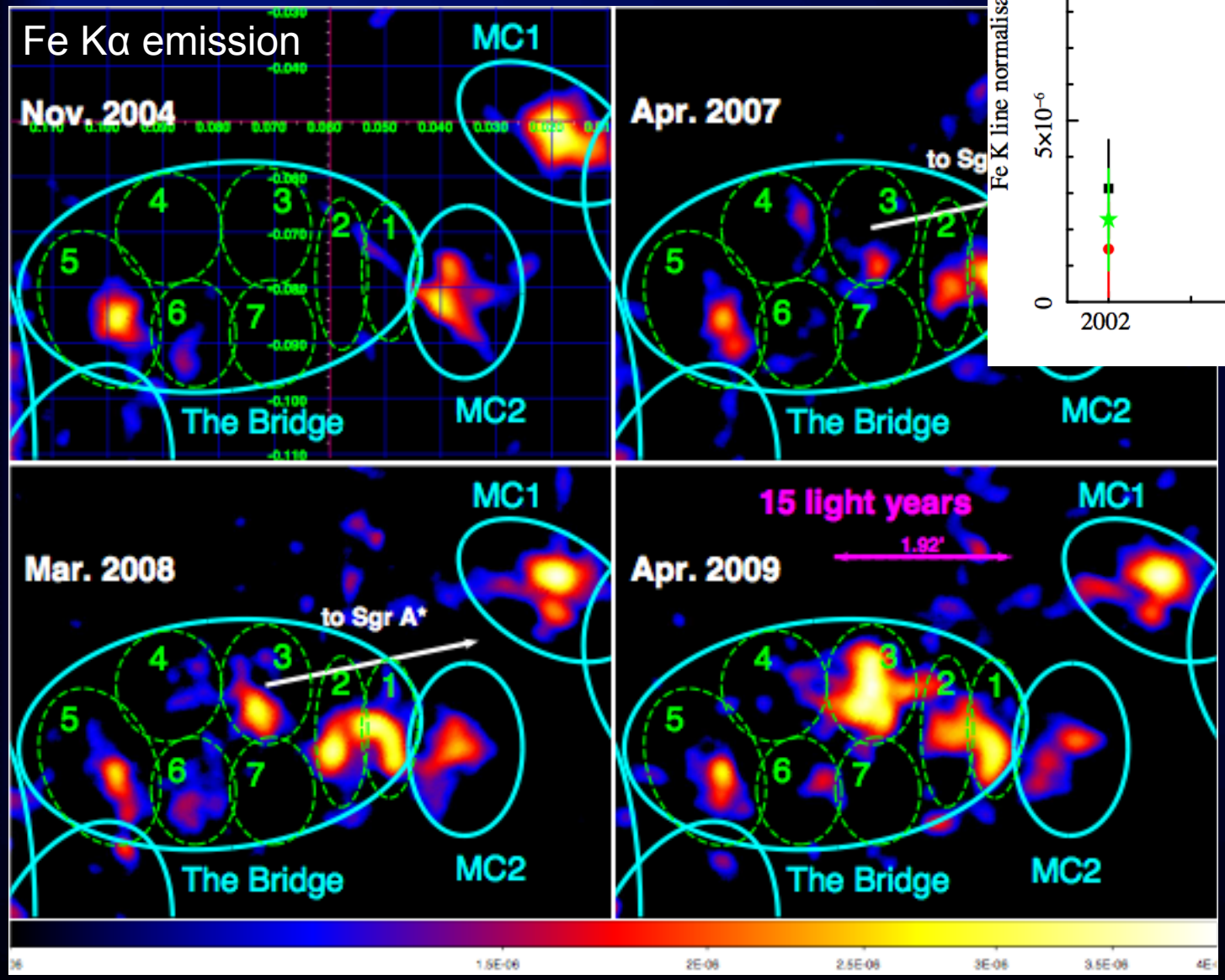


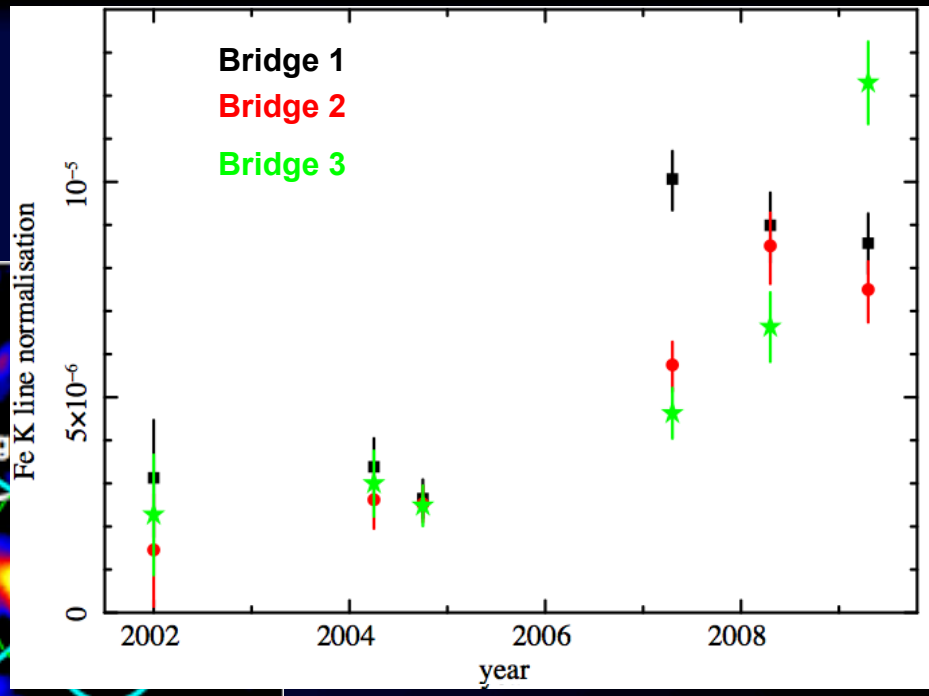
New XMM scan of CMZ (2012)
(Fe K emission)

Ponti et al. in prep.



Super-luminal motion?





Direction toward Sgr A*

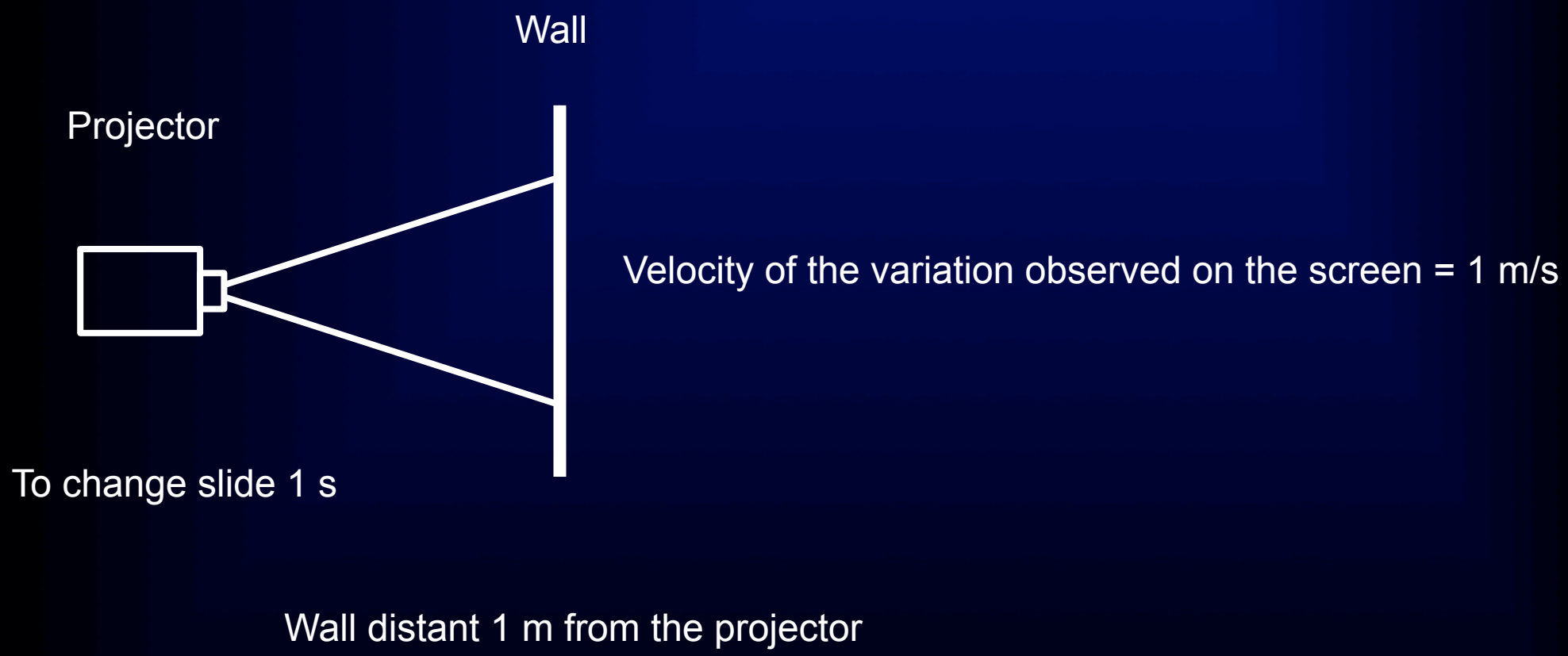
Ponti et al. 2010

Regions causally disconnected!!

➔ No propagation of single event ➔ Cosmic ray - internal source excluded!

➔ External illumination!

How can a superluminal echo happen?



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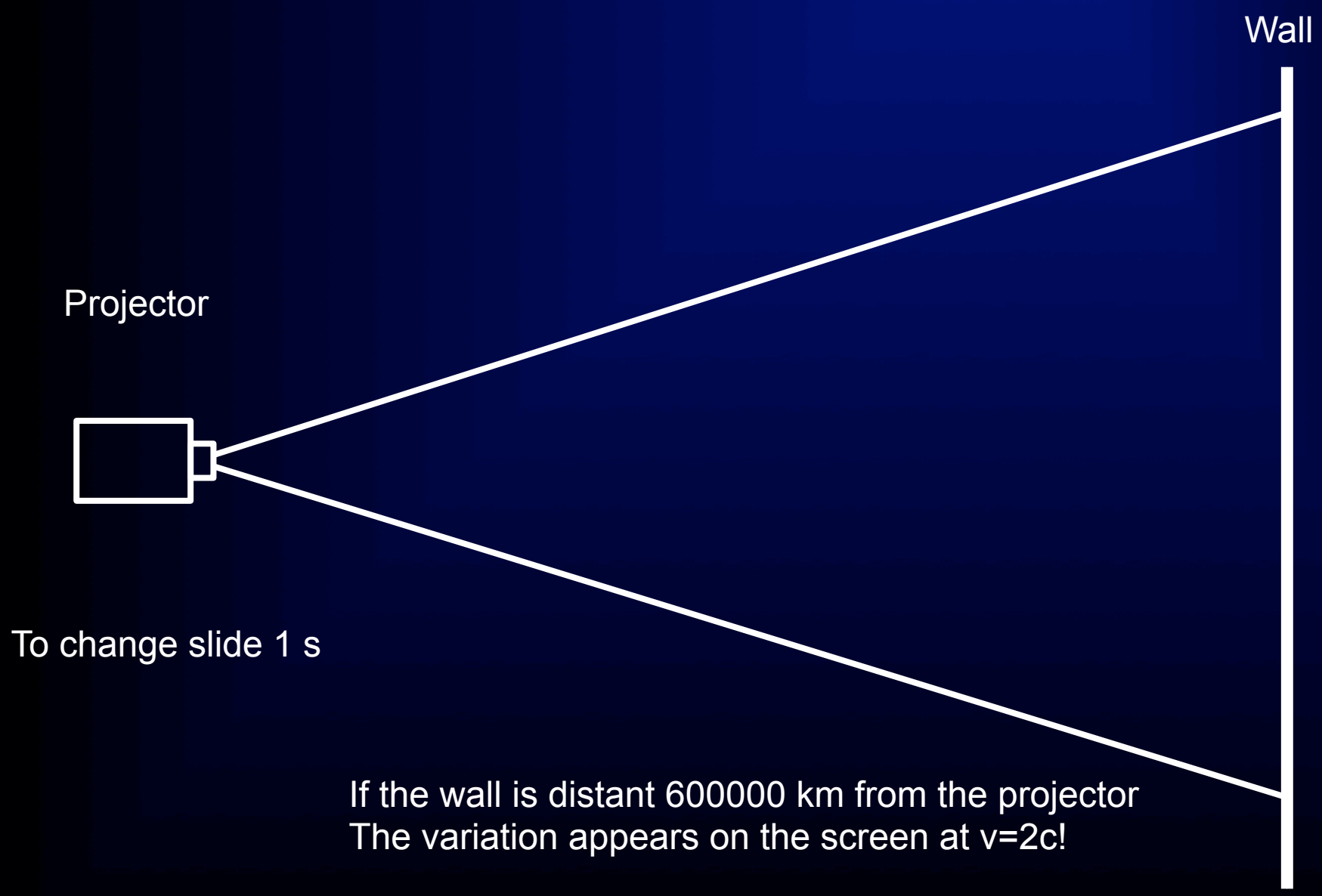


If the wall is distant 600000 km from the projector
The variation appears on the screen at v=2c!

Because the real “physical” variation happens at the level of the projector and not of the wall

Possible past activity of Sgr A…*

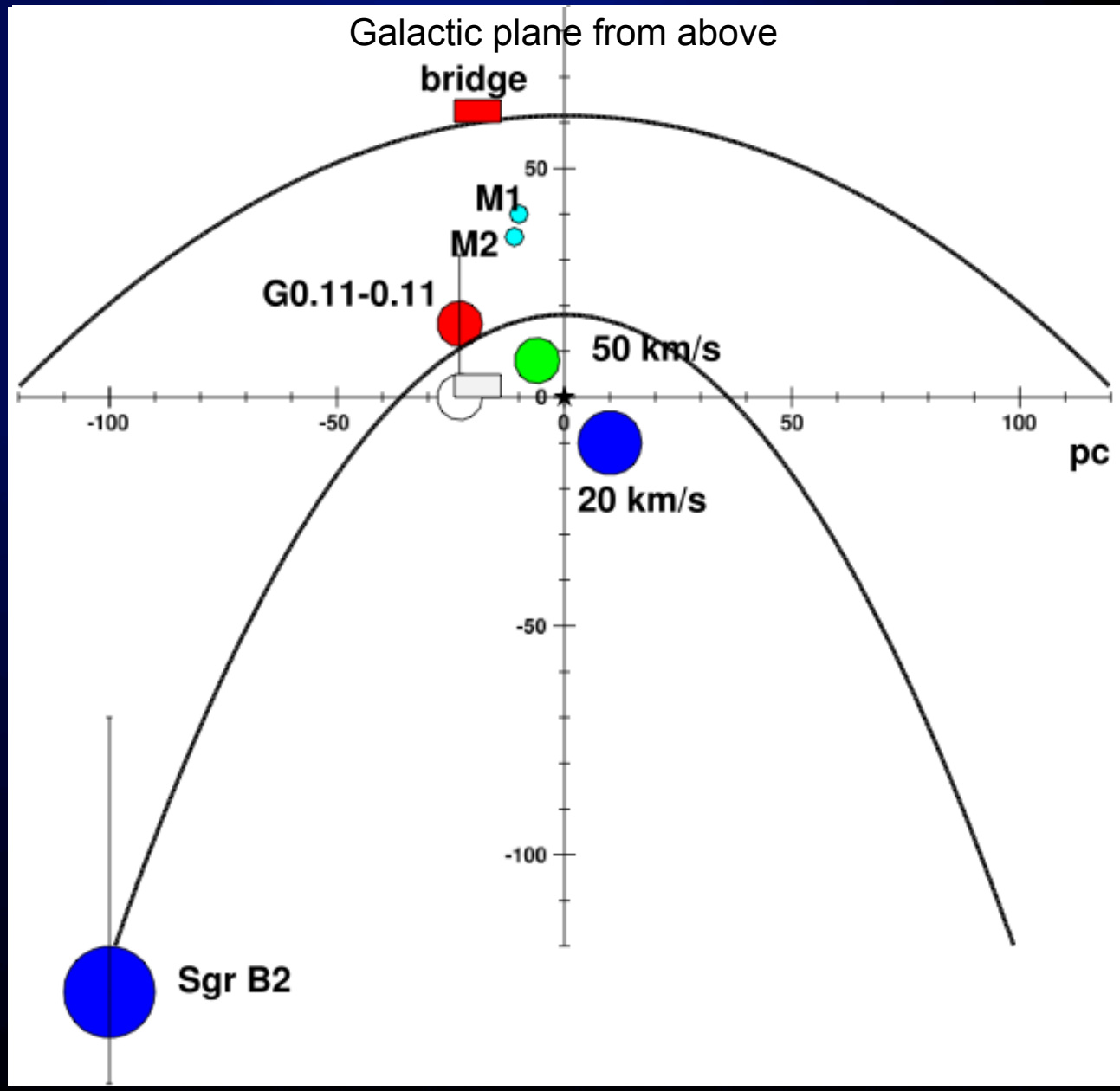
Sgr A* past activity

$$L_{SgrA*} \propto \frac{n_H \times A \times I_{\mathrm{FeK}}}{d^2}$$

50 km s^{-1}: (No FeK line)
$L_{SgrA*} < 10^{36}$ erg s^{-1} past 60-90 yr

Sgr B2 - G0.11-0.11:
$L_{SgrA*} \sim 1.4\times10^{39}$ erg s^{-1} ~100 yr ago

Basic unknown: MC distance!



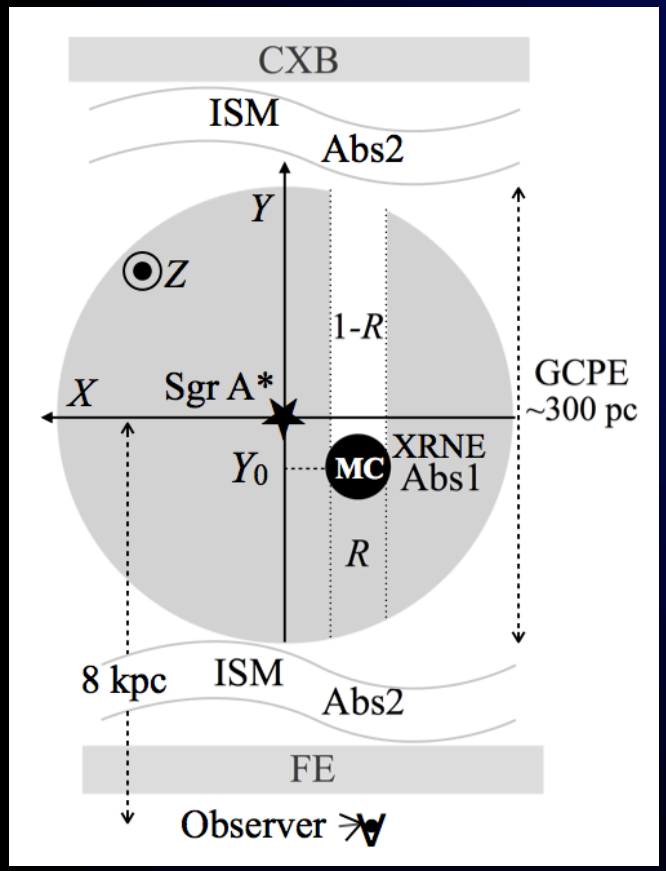
Ponti et al. 2010

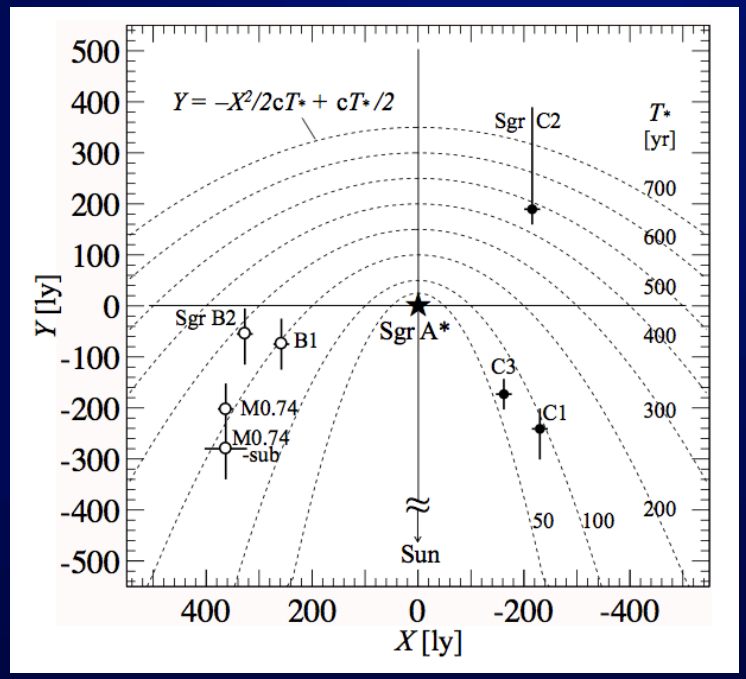
Another possible Sgr A* light curve

Sgr C:

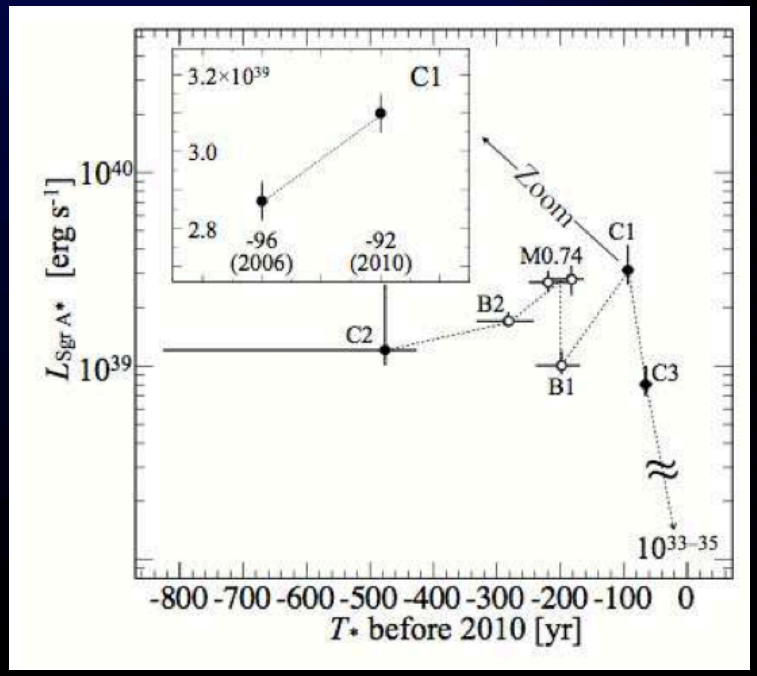
Ryu et al. 2013

Line of sight distance through X-ray absorption (absorption uniformly distributed)





3-d distribution of molecular clouds



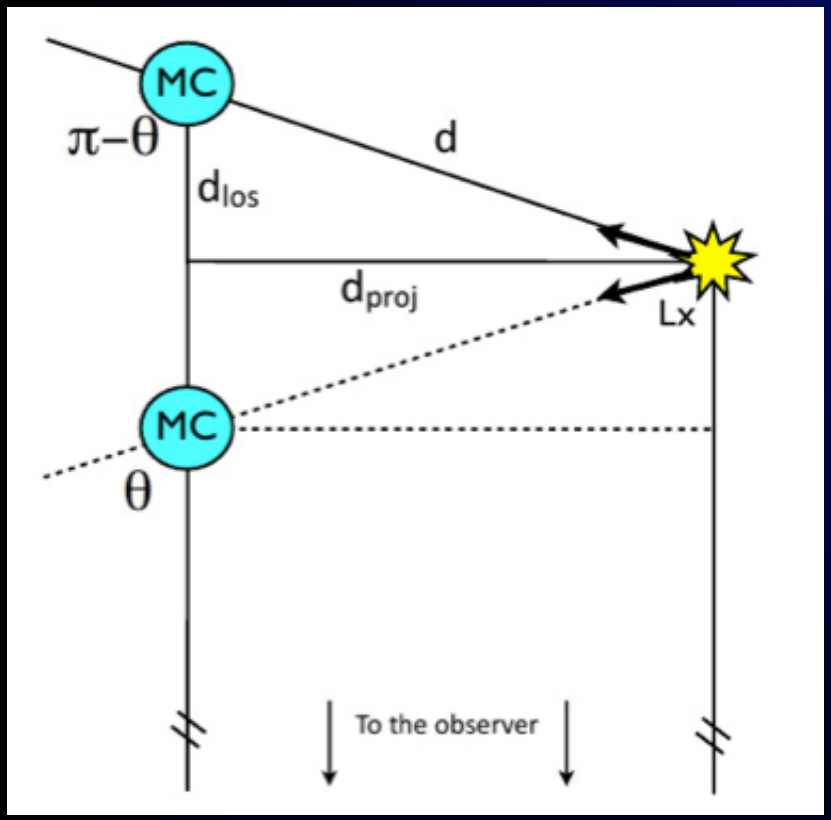
$L_{Sgr\ A^*}$ ~10^{39} erg s^{-1} for ~400 yr
$L_{Sgr\ A^*}$ <10^{35} erg s^{-1} last 100 yr

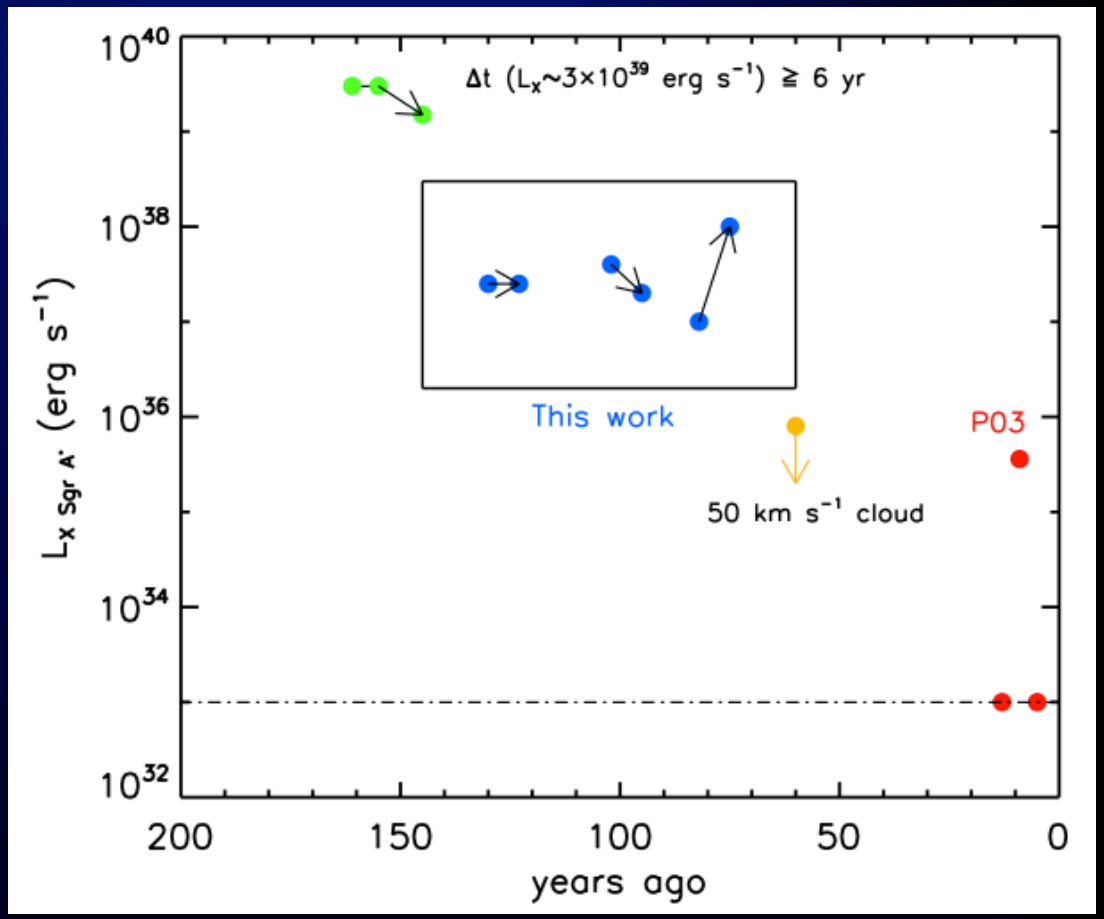
Another possible Sgr A* light curve

Sgr A:

Capelli et al. 2012

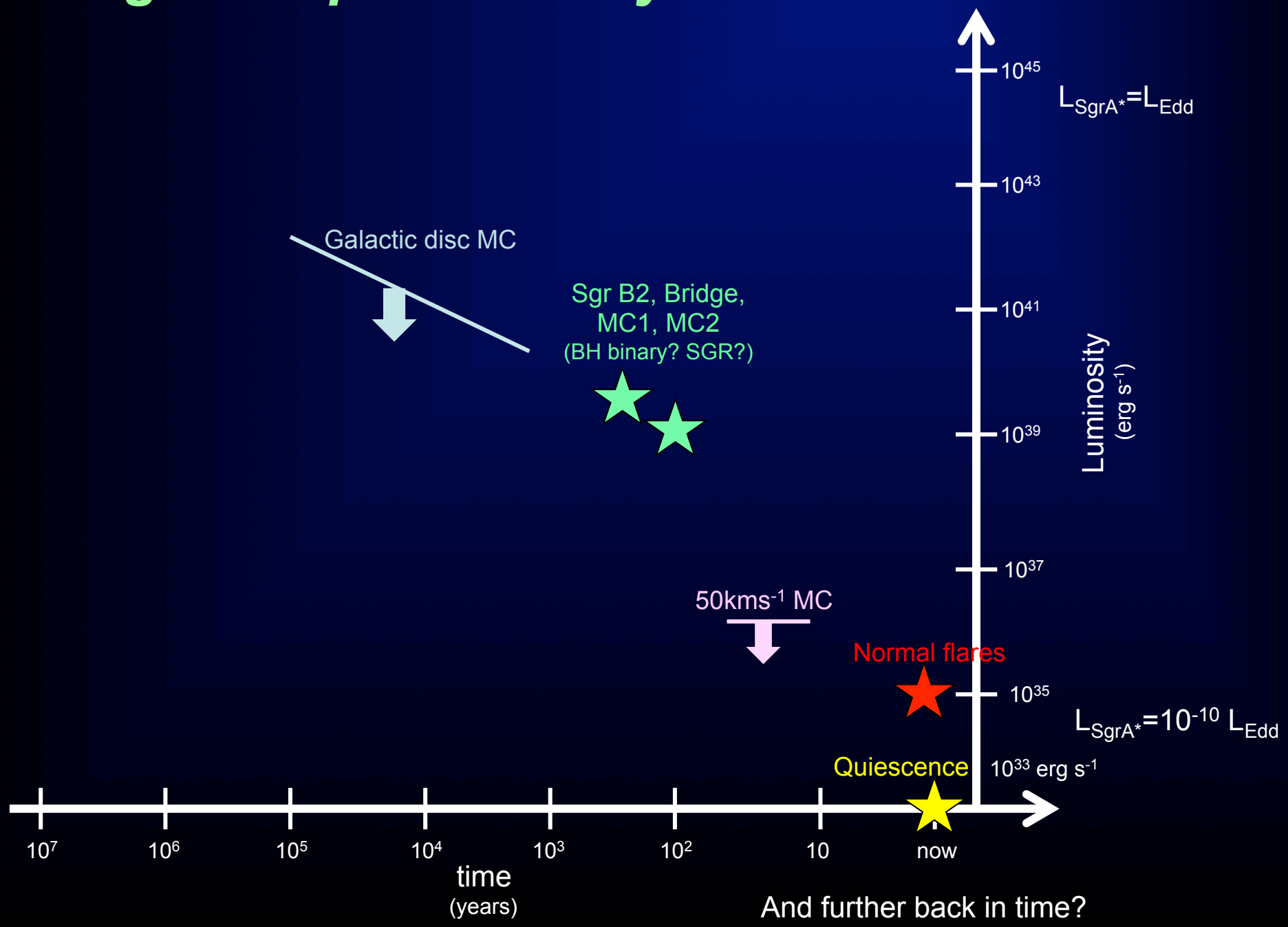
Line of sight distance through Fe Kα line equivalent width



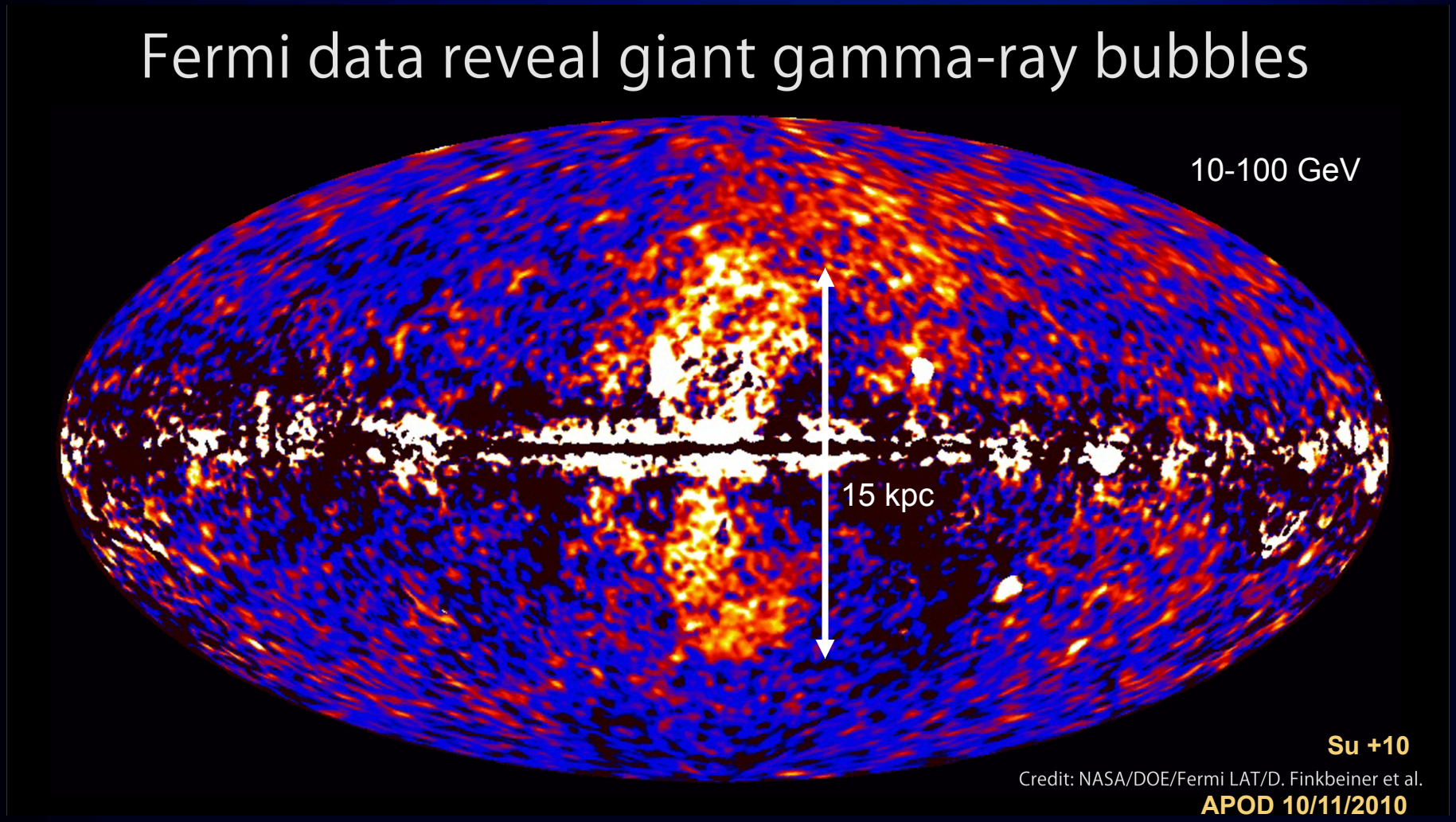


A trend of decreasing luminosity in past 150 yr,
Several flares?
$L_{Sgr\ A^*}$ <10^{35} erg s^{-1} last 100 yr

Sgr A*'s past activity



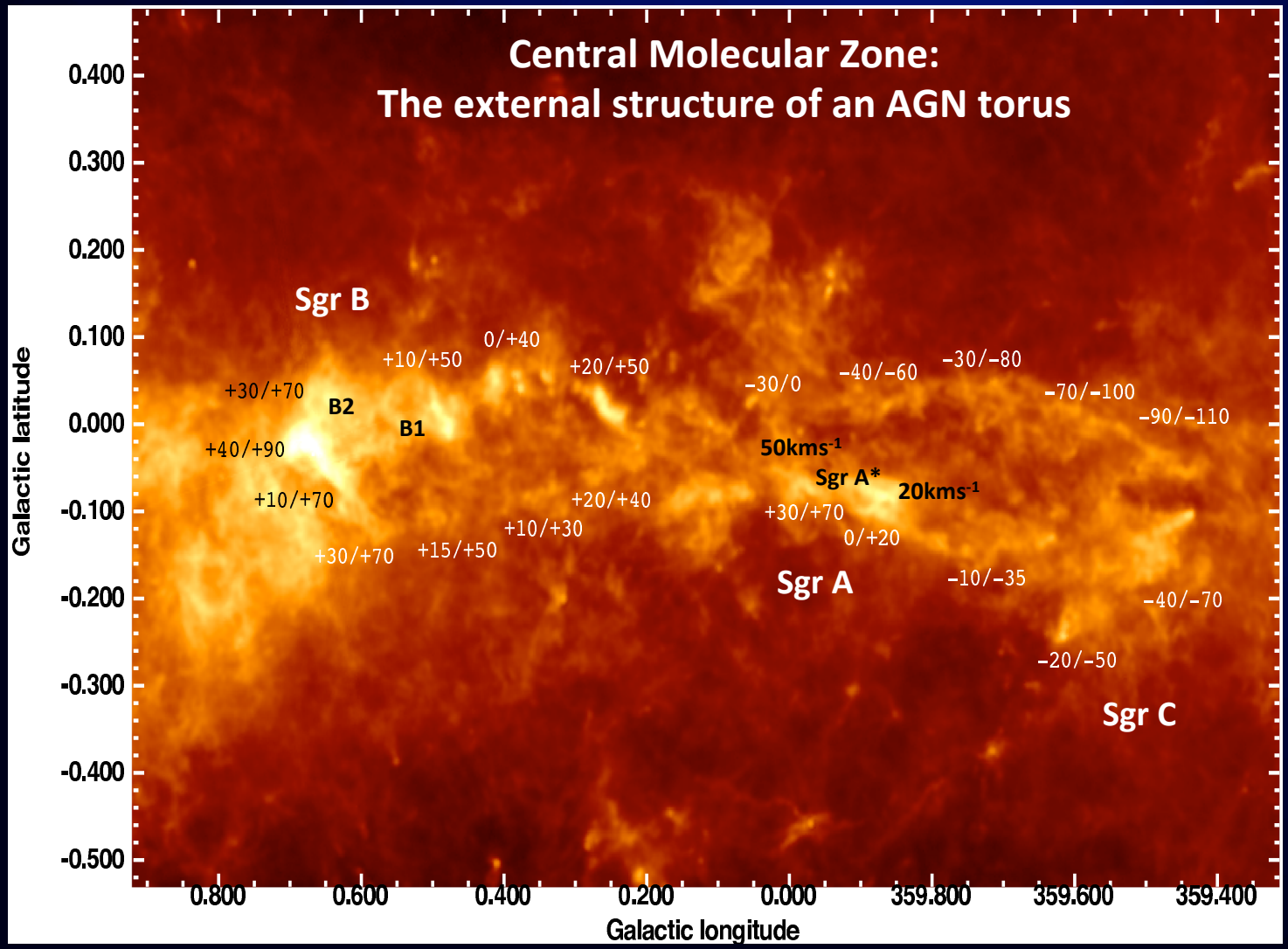
A past major outburst of Sgr A?*



- Energy release $>10^{55}$ erg
- ~ few 10^6 yr ago

Origin:
i) a past accretion event onto Sgr A*
ii) or a nuclear starburst

An AGN torus in our backyard?



adapted from Molinari et al. 2011

CMZ obscured Sgr A* equatorial view with up to $N_H \sim 10^{24}$-10^{25} cm^{-2}

Typical MC core with v~10^2 km s^{-1} at 100 pc has $t_{orbit}=10^7$ yr ➔ AGN torus structure preserved!

To power AGN phase 2×10^3 M_{Sun} accreted < 0.1 M_{CND} ➔ CND can feed Sgr A* again (clumpy CND structure suggest episodic feeding)

Limit cycle of recurrent nuclear activity: Viscous disc evolution $r_{in\ CND}$ shrinks ➔ Accretion generate shocks/gas compression ➔ Trigger star formation ➔ Star winds clear gas from GC creating a cavity ➔ After 107 yr stellar winds fade ➔ $r_{in\ CND}$ shrinks

Morris +99

Summary:

Sgr A*:
At present is extremely under-luminous

Echo of recent (10^2 yr) **past weak** (10^{39} erg s^{-1}) **activity from MC of CMZ:**
i) Super-luminal FeK variations ➔ external illumination ➔ **correlated (delayed) cloud variations**

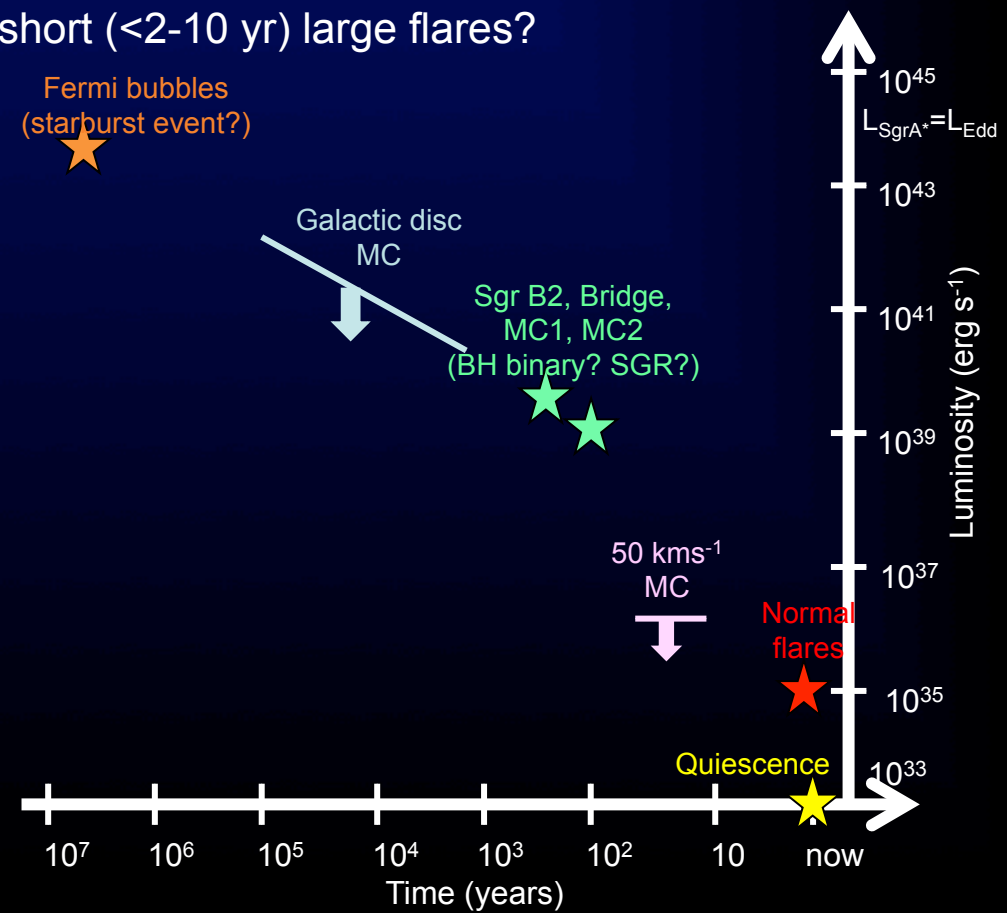
➔ Tool to determine the GC past (10^3 yr) X-ray activity
➔ Tool to determine the cloud distribution within the CMZ

Sgr A* outburst:
one long (~10^2 yr) highly variable event or several short (<2-10 yr) large flares?

Mechanism for such outburst?
(accretion from star winds, asteriod-planet, interstellar medium blob, partial tidal disruption, Sgr A East, gas supply via star tidal interaction)

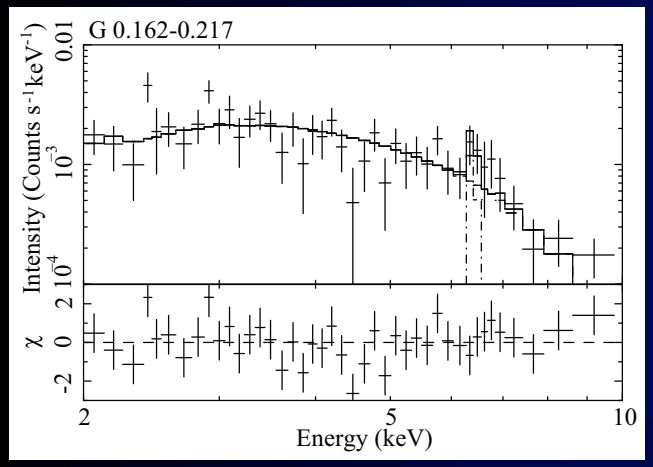
AGN activity ~6×10^6 yr ago:

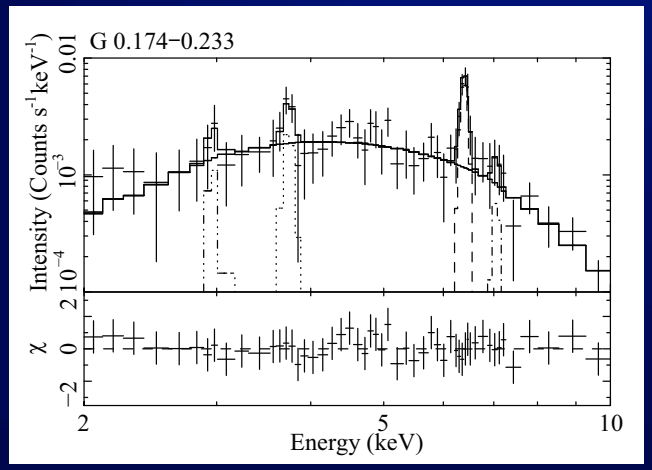
Is the (outer) CMZ a relic AGN torus?

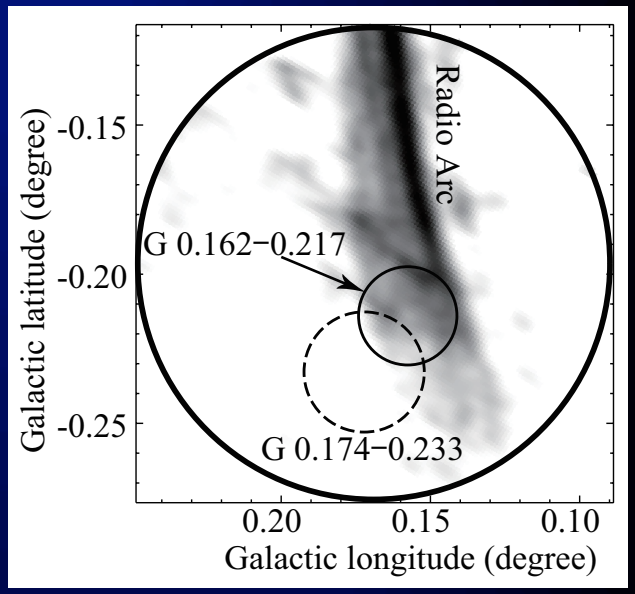


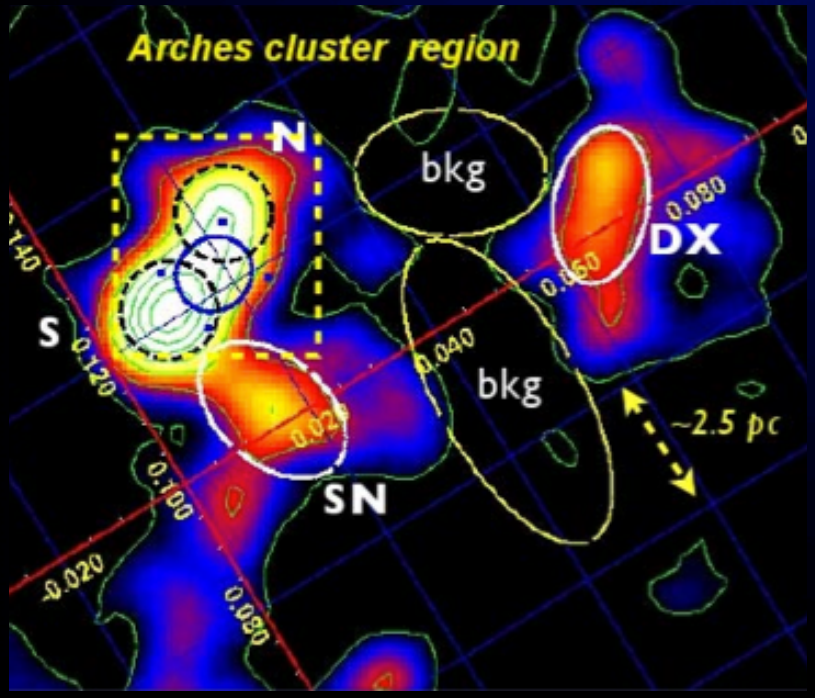
Can irradiation from external sources explain the emission from ALL MC?

Fukuoka et al. 2009









G0.174-0.233 ➔ EW FeK = 950 eV ➔ Reflection

G0.162-0.217 ➔ EW FeK = 360 eV ➔ LECRE

Regions S&N FeK ➔ Cosmic Ray protons!

Other regions variable FeK emission ➔ X-ray binary

Capelli et al. 2011; Tatischeff et al. 2012

Outburst from a magnetar

April 25th Swift detects L=1.6 10^{35} erg s^{-1} at Sgr A* position

Degenaar et al ATEL5006

April 26th source still at L=1.7 10^{35} erg s^{-1} at Sgr A* position

Dwelly, GP ATEL5008

SGR-like flare from Sgr A* position (Swift-BAT)

Kennea et al ATEL5009

NuSTAR detects spin period of 3.76 s

Mori et al ATEL5020

Chandra locates the new magnetar at 3" from Sgr A*

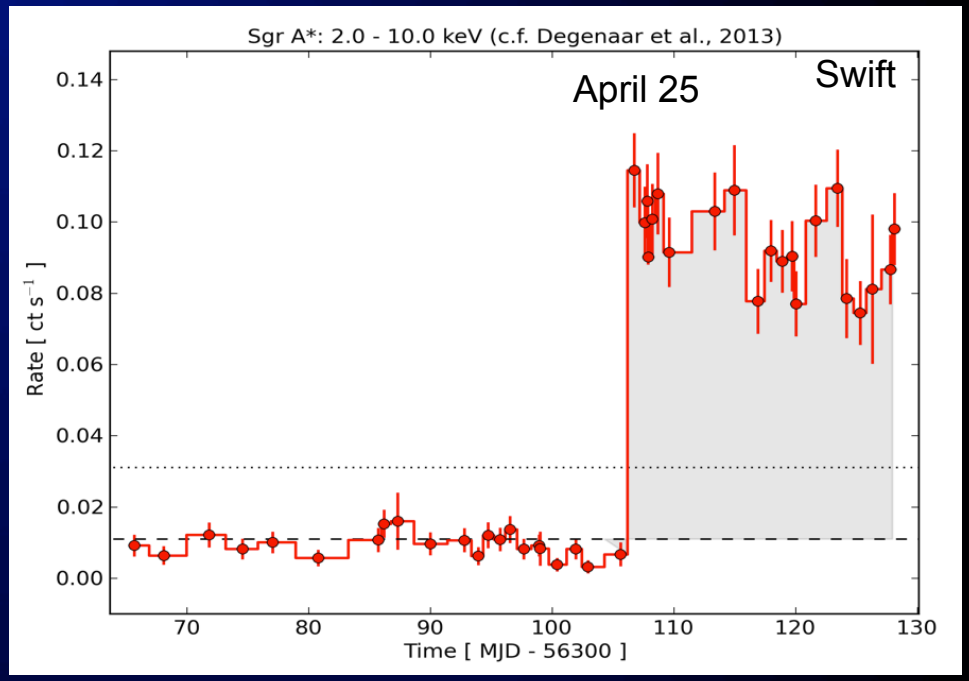
Rea et al ATEL5032

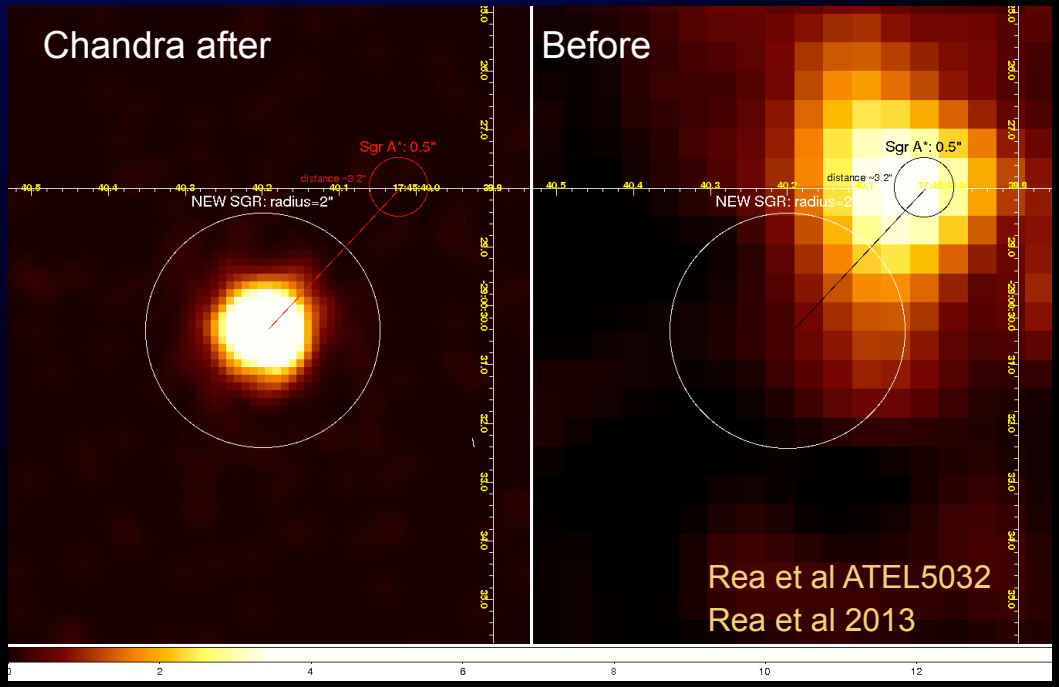
Spin down period ➔ magnetic field B=3 10^{14} G

Gotthelf et al ATEL5046

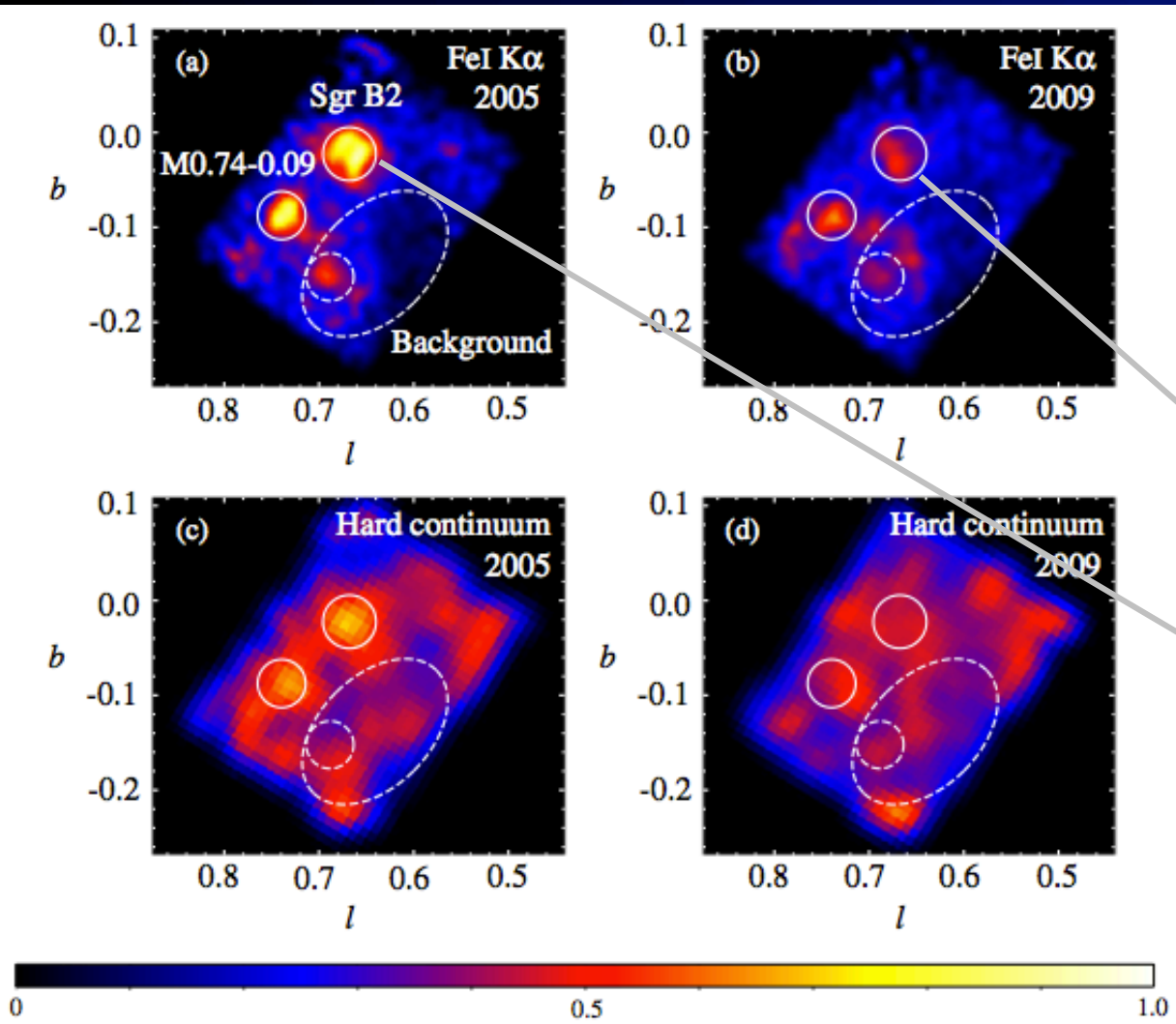
➔ New magnetar!

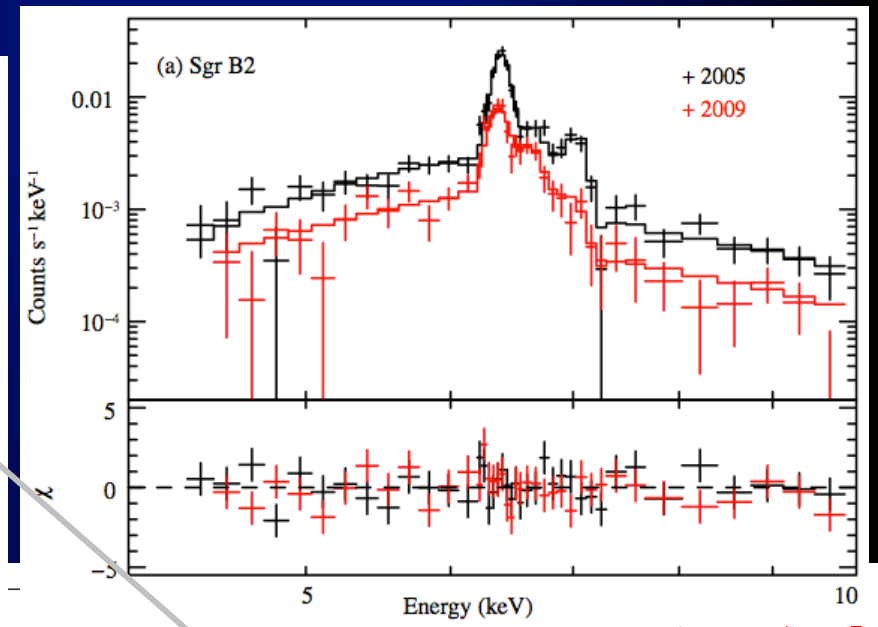
Nature News; Mori et al 2013; Kennea et al 2013; Rea et al 2013; Eatough et al. 2013; Bower et al. 2013; Spitler et al. 2013

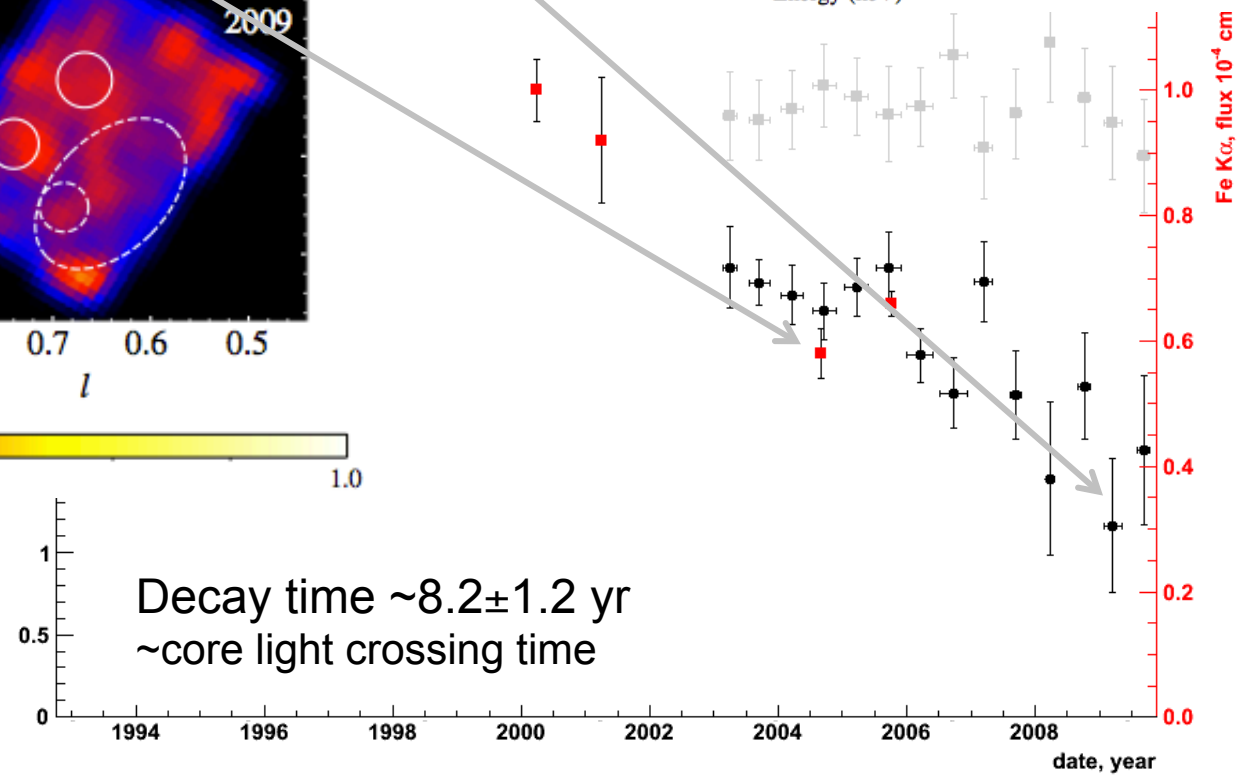




The Suzaku view of Sgr B2







Decay time ~8.2±1.2 yr
~core light crossing time

Nobukawa et al. 2011