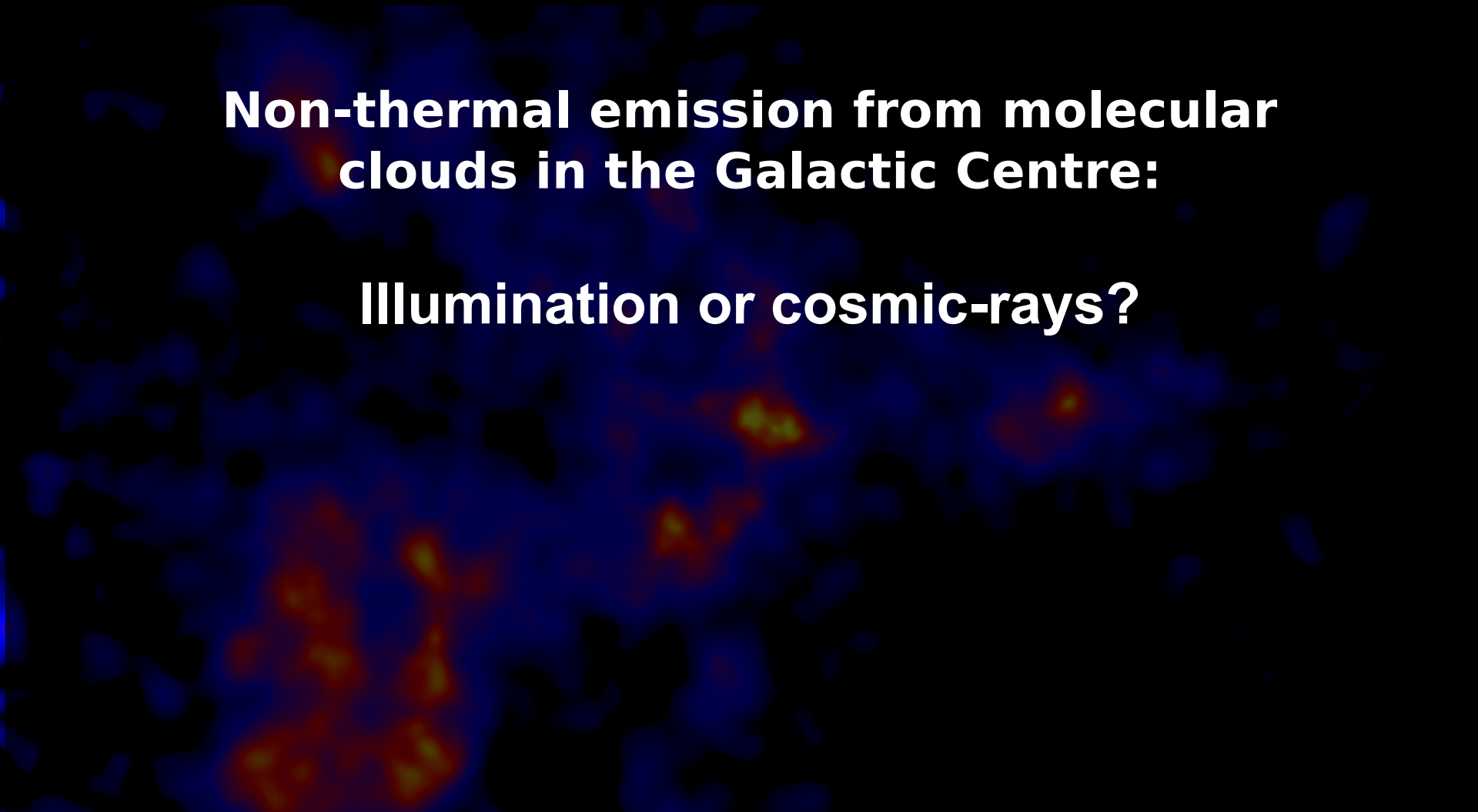
Non-thermal emission from molecular clouds in the Galactic Centre:

Illumination or cosmic-rays?

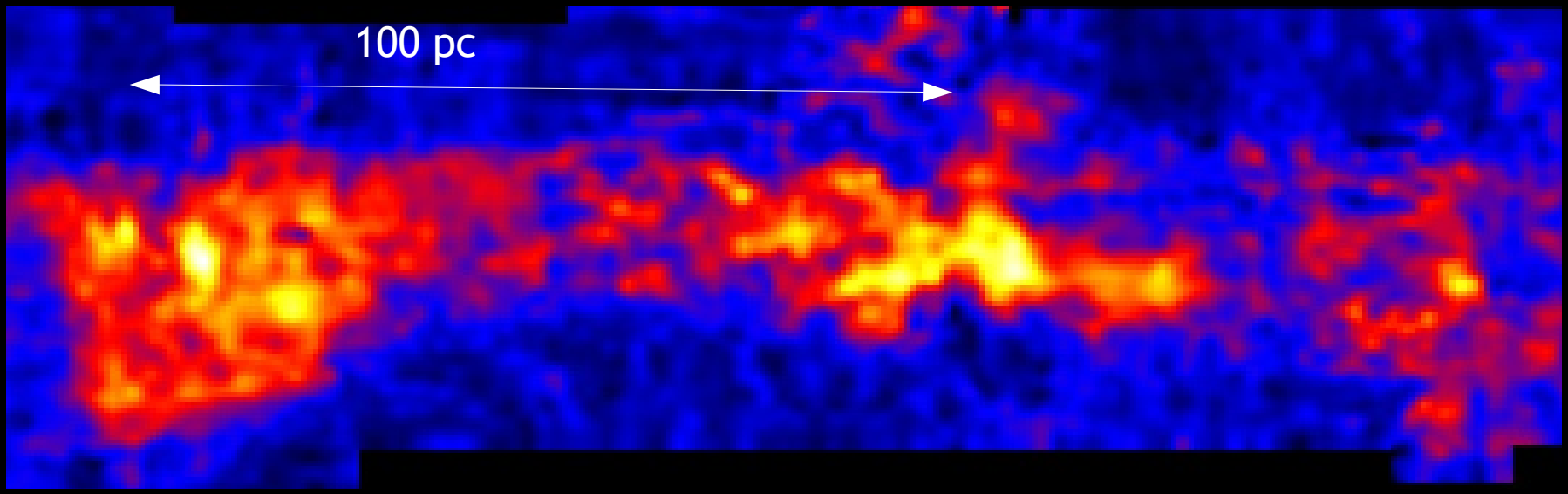


R. Terrier (Astroparticule et Cosmologie - CNRS/Univ. Paris 7)

G. Ponti, A. Goldwurm, G. Bélanger, A. Decourchelle,
V. Tatischeff, G. Trap, M. Morris, R. Warwick

CRISM
Montpellier 2011

The Central Molecular Zone



CS (49 GHz) *Tsuboi et al. (1998)*

Central Molecular Zone (CMZ) : the central 200 pc

It contains ~ 10% of Galaxy molecular matter

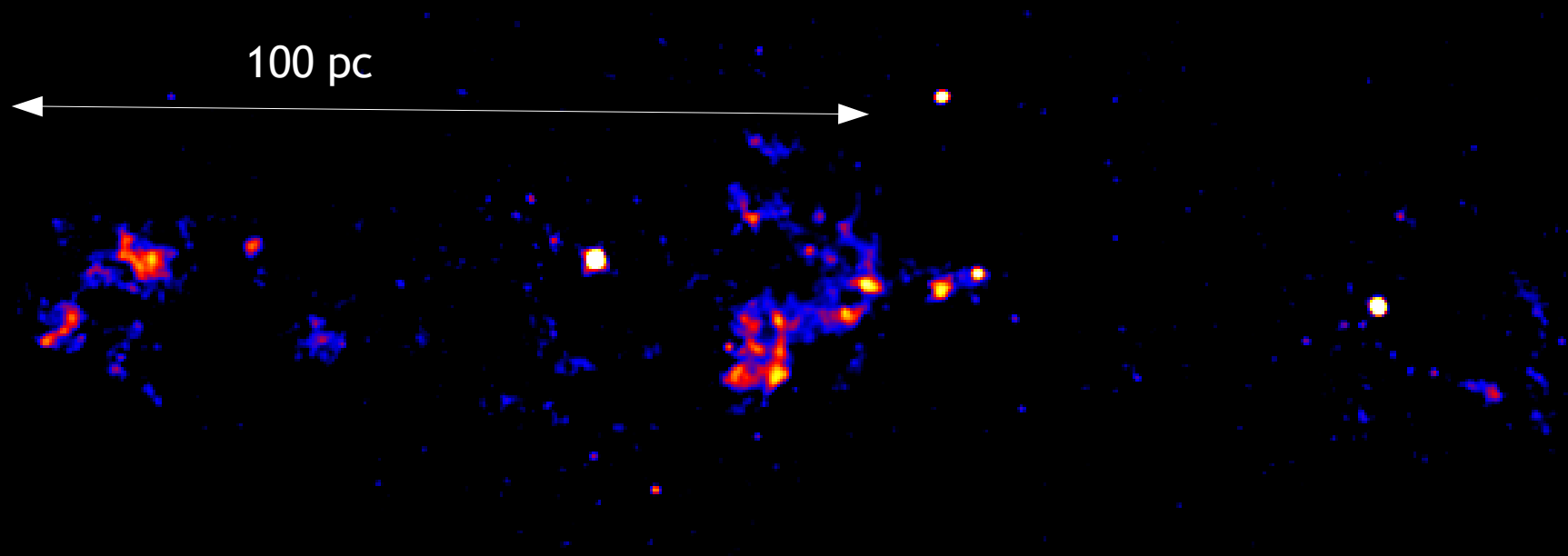
~ 10^7 M_o of molecular matter

Morris & Serabyn (1996)

Massive star clusters and intense star forming activity:

Arches, Central, Quintuplet clusters, Sgr B2 MoC

Hard X-ray emission from the CMZ



Chandra 6.4 keV (Fe Kα)

Discovery of diffuse Fe Ka 6.4 keV line from molecular clouds in the GC

Sunyaev et al. (1993)

Koyama et al (1996)

Integral detection of hard X-ray emission from some molecular clouds

Sgr B2 *(Revnivtsev et al. 2004)*

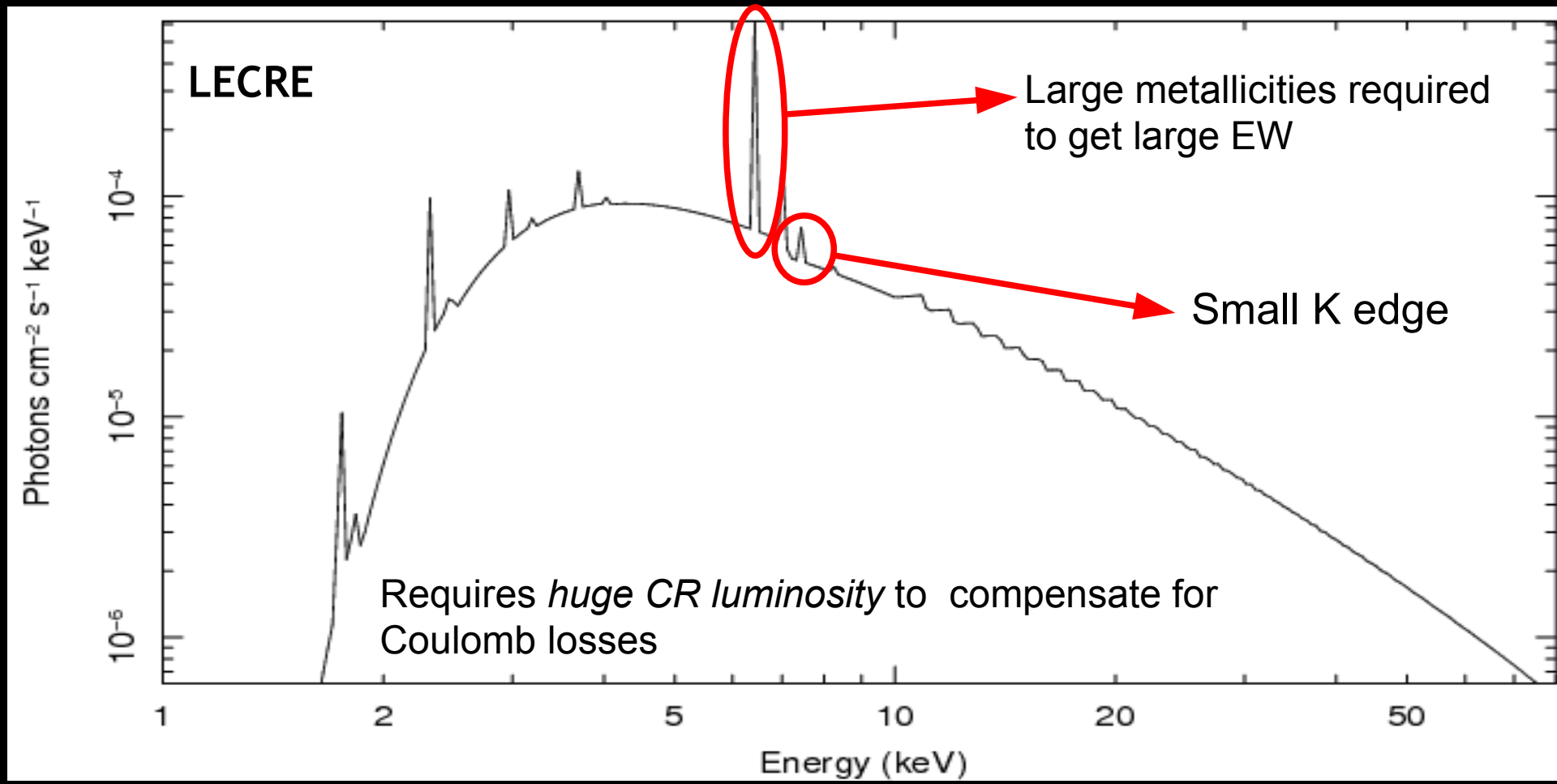
Sgr A region *(Belanger et al. 2006)*

Origin : irradiation by Cosmic Rays?

Bremsstrahlung emission of low energy CR electrons (LECRE)

e.g. Valinia et al (2000), Tatischeff et al (2001), Yusef-Zadeh et al. 2002 & 2007

Electrons energy ~100 keV



Origin : irradiation by Cosmic Rays?

Bremsstrahlung emission of low energy CR electrons (LECRE)

e.g. Valinia et al (2000), Tatischeff et al (2001), Yusef-Zadeh et al. 2002 & 2007

Electrons energy ~100 keV

bremstrahlung to Coulomb losses ratio ~ 10^{-4}

Requires *huge CR luminosity* to compensate for Coulomb losses

Inverse bremsstrahlung emission from sub-GeV protons in the CMZ

e.g. Dogiel et al (2009 & 2011)

Produced by ~ 100 MeV protons

Lifetime of ~ 10^4 yrs in dense CMZ regions

Origin : XRN/Compton echo ?

X-Ray Nebula – Compton echo:

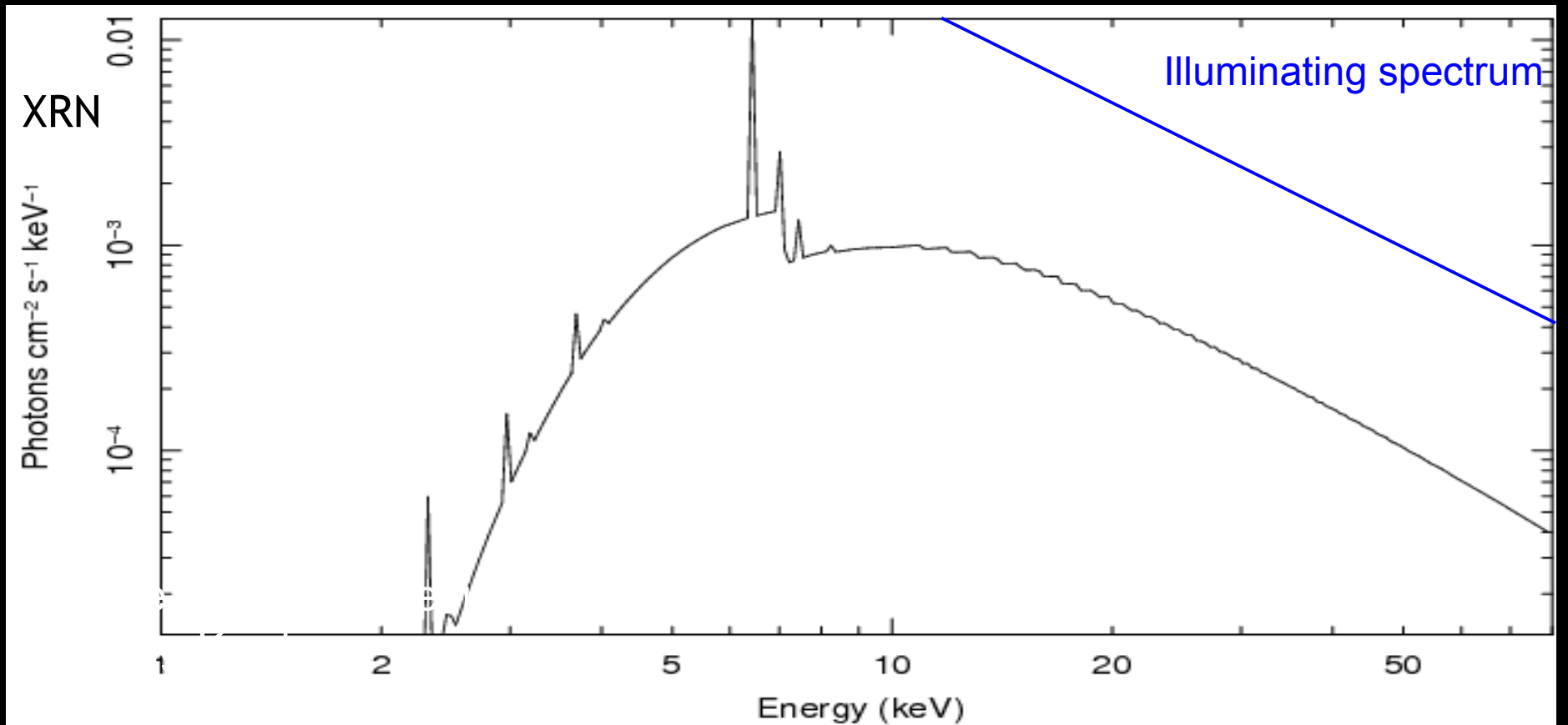
Fluorescence and Compton scattering of bright source

e.g. Koyama et al. (1996), Sunyaev & Churazov (1998), Murakami et al (2000)

$$F \propto L_X N_H \left(\frac{r_{cloud}}{R} \right)^2$$

Sgr B2:

$L_X \sim 10^{37}$ erg/s required for R = 10 pc



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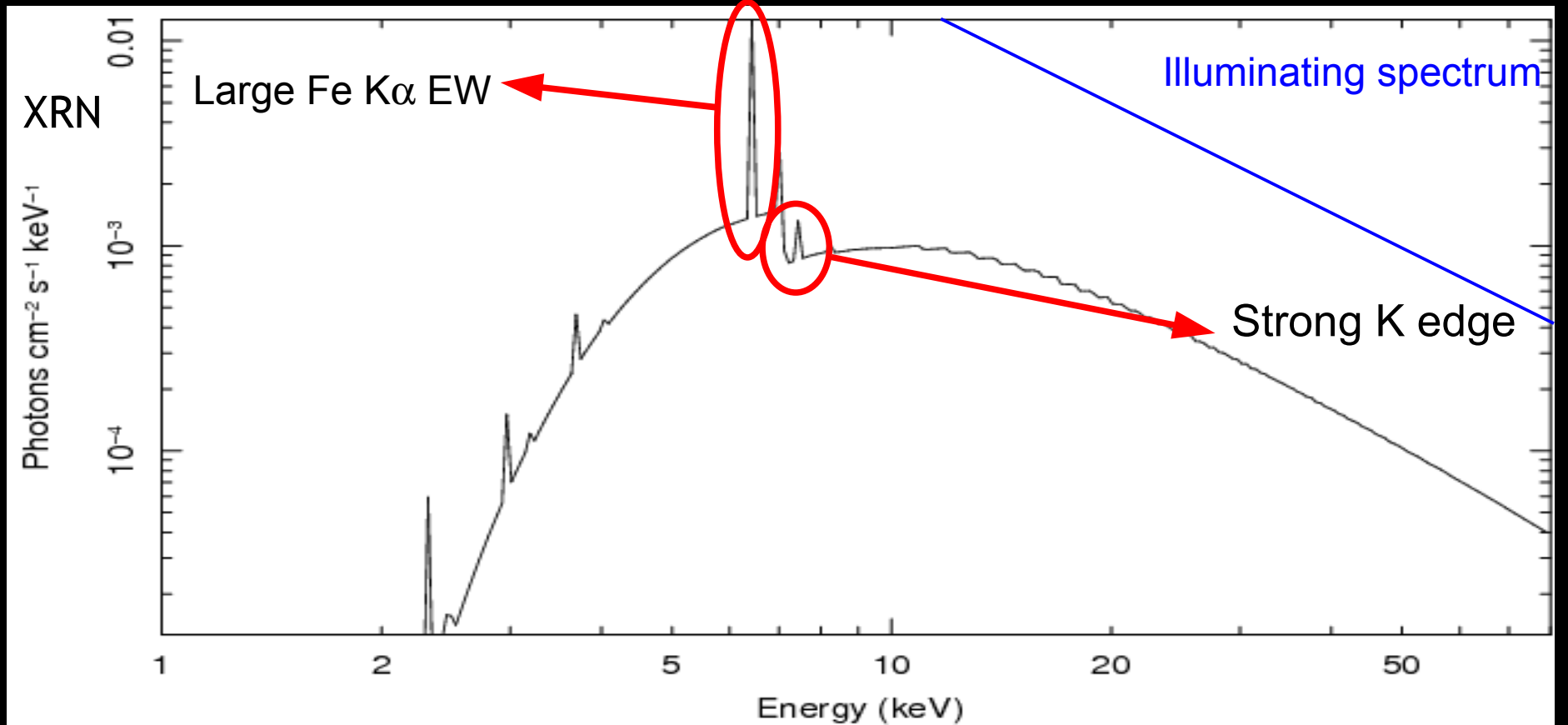
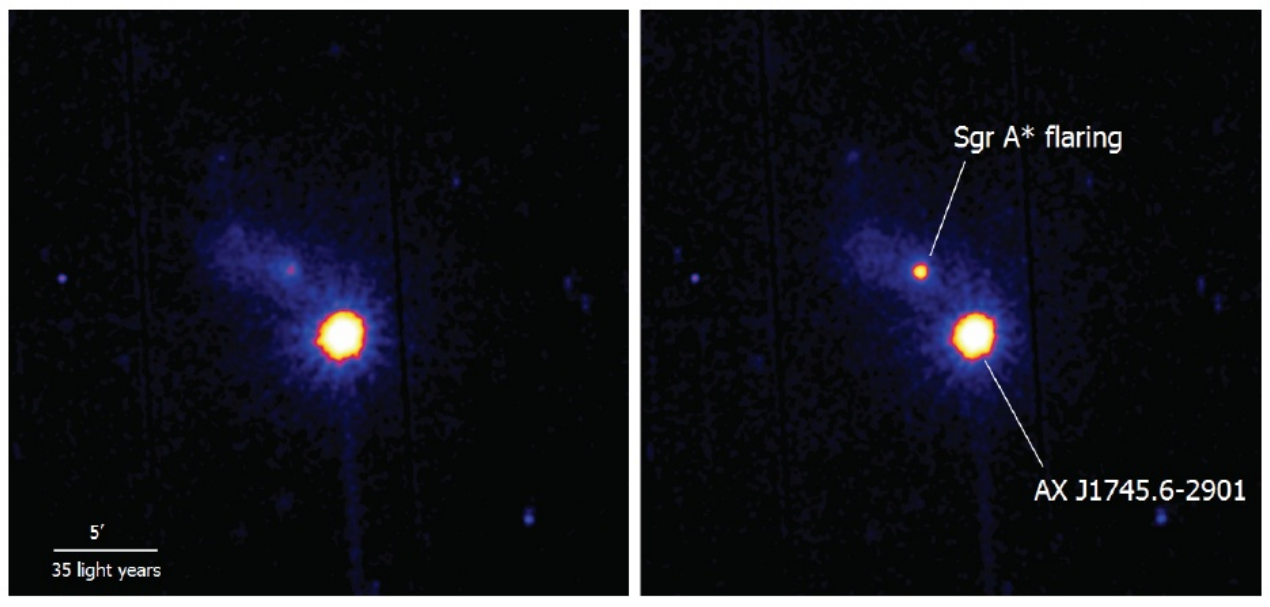


Illumination from Sgr A*?



XMM-Newton
Apr. 2007

Galactic Centre harbors a 4 10^6 M_o black hole: Srg A*

Sgr A* very inactive in X-rays : $L_X \sim 10^{33} - 10^{35}$ erg/s $< 10^{-9} L_{Edd}$!

(e.g. Porquet et al. , 2008)

Periods of stronger activity in the past?

A past $L_X \sim 10^{39}$ erg/s a few 100 yrs ago?

Koyama et al. (1996), Revnivstev et al (2004)

Can we distinguish between CR/XRN?

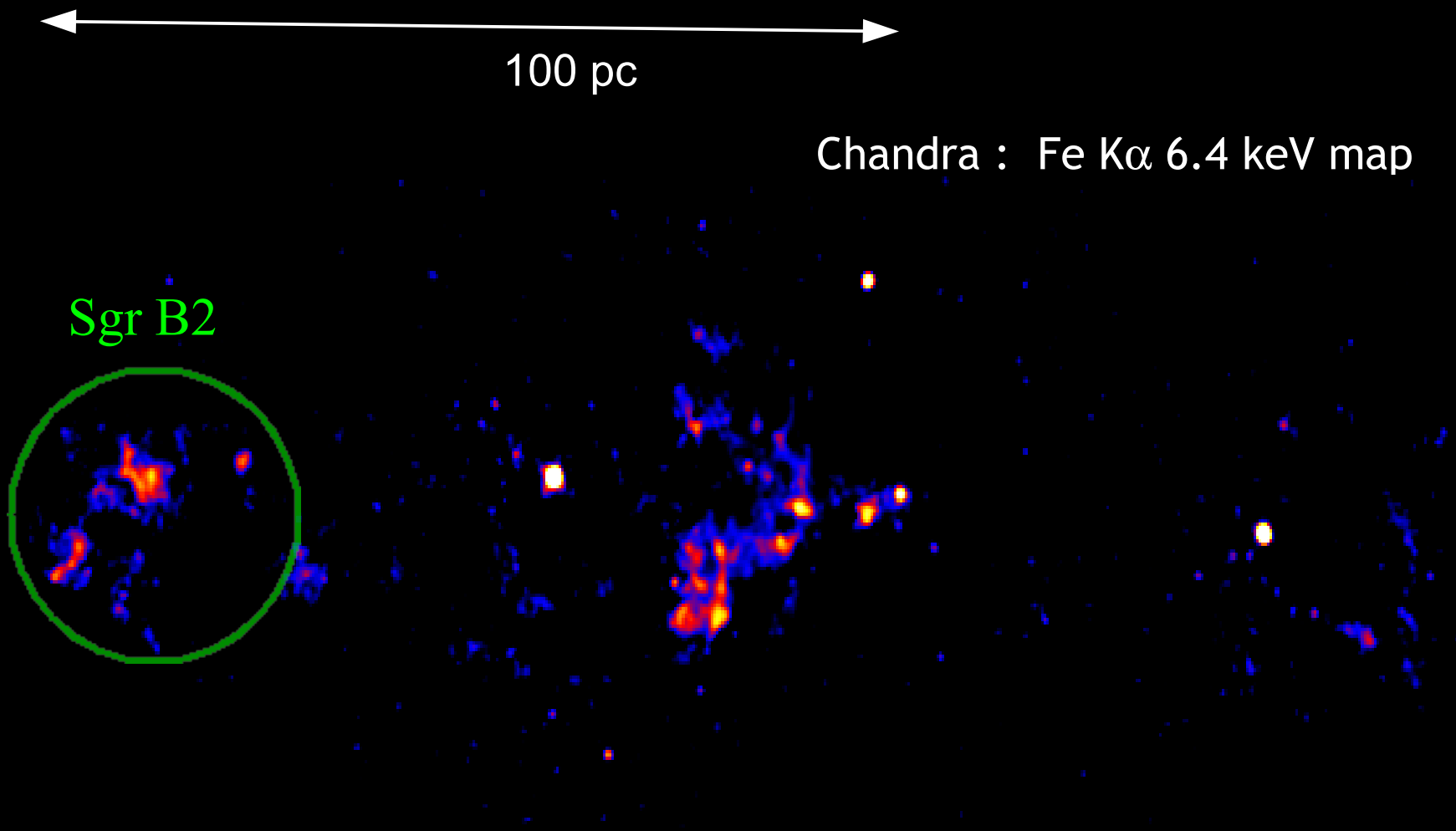
- Constraints from spectra:
  - Fe Kα EW
  - Hard X-ray continuum slope
  - Energetics

- Variability of diffuse emission for XRN scenario:
  - No bright enough source today to explain GMC emissions
    - Illumination from a past bright transient source
  - **XRN emission has to be variable!**

•Indications of variability:

Muno et al (2007), *Inui et al (2009)*

Non-thermal emission from the CMZ



Time variability in the Sgr B2 cloud?

Sgr B2 broad band spectrum

LECRE

s =1.5

Abund = 3.1 ± 0.2

E_{max} = 200 ± 50 keV

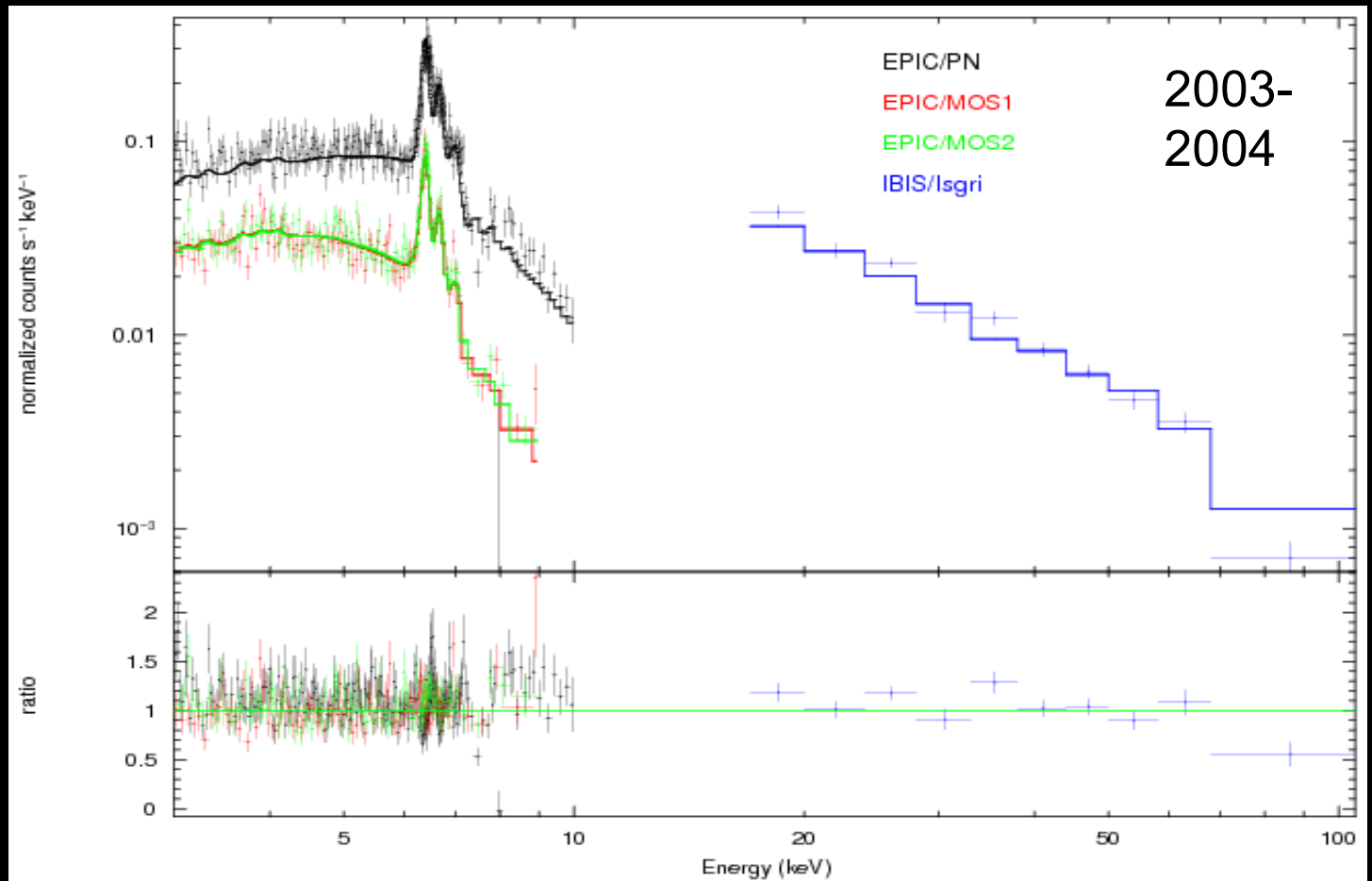
$L_{CR} = 8.9 \pm 1.3\ 10^{39}$ erg/s

XRN

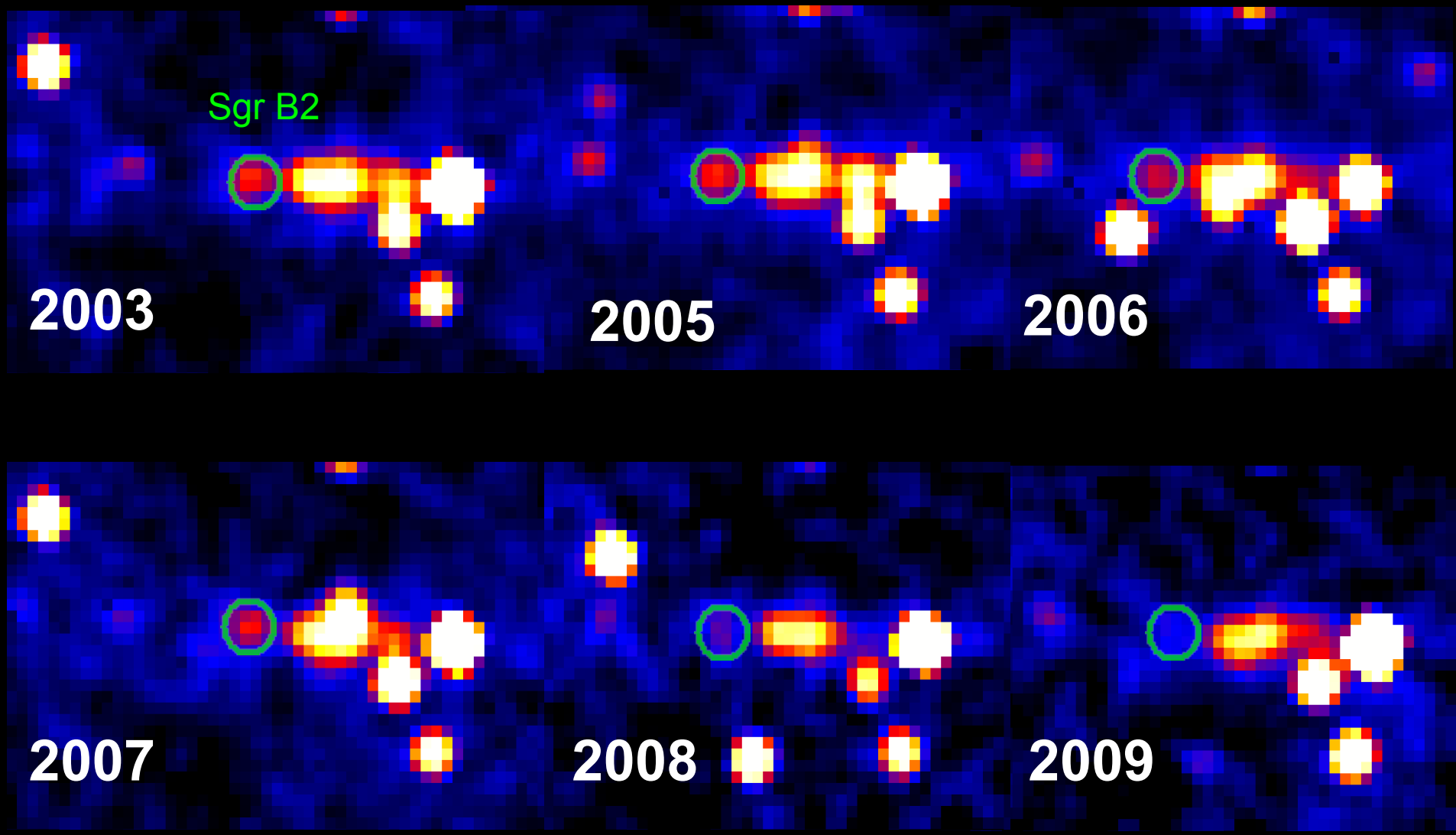
Γ =2 ± 0.2

Abund = 1.3 ± 0.1

$L_{rad} = 1.1\ 10^{39}\ (d/100\ pc)^2$ erg/s



Time dependence of the hard X-ray GC emission

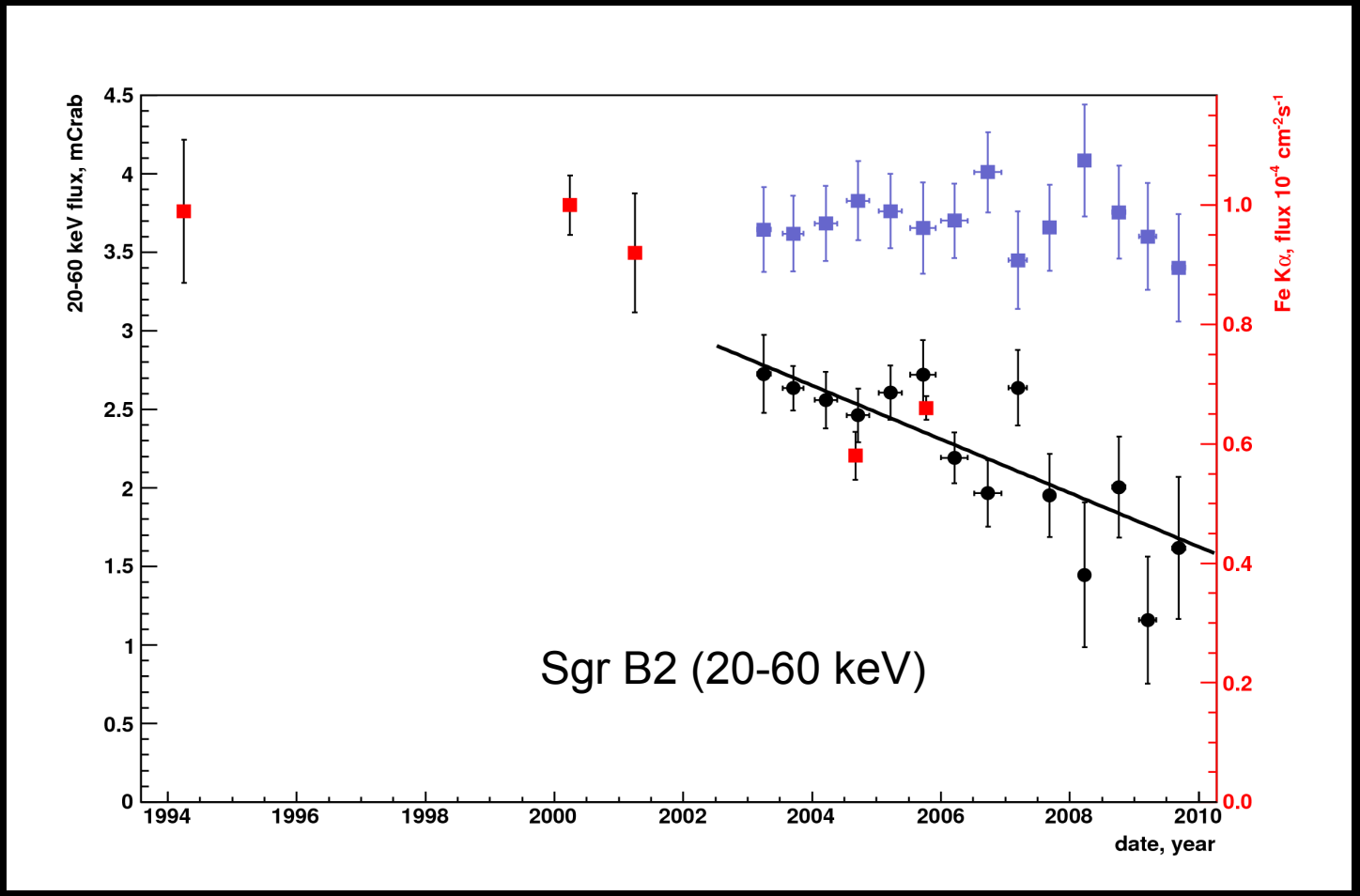


Integral IBIS/Isgri : 20-60 keV

Hard X-ray emission from Sgr B2 is fading!

Flux has decreased by ~40% in 7 years

Characteristic half decay time $\tau = 8.2 \pm 1.7$ yr

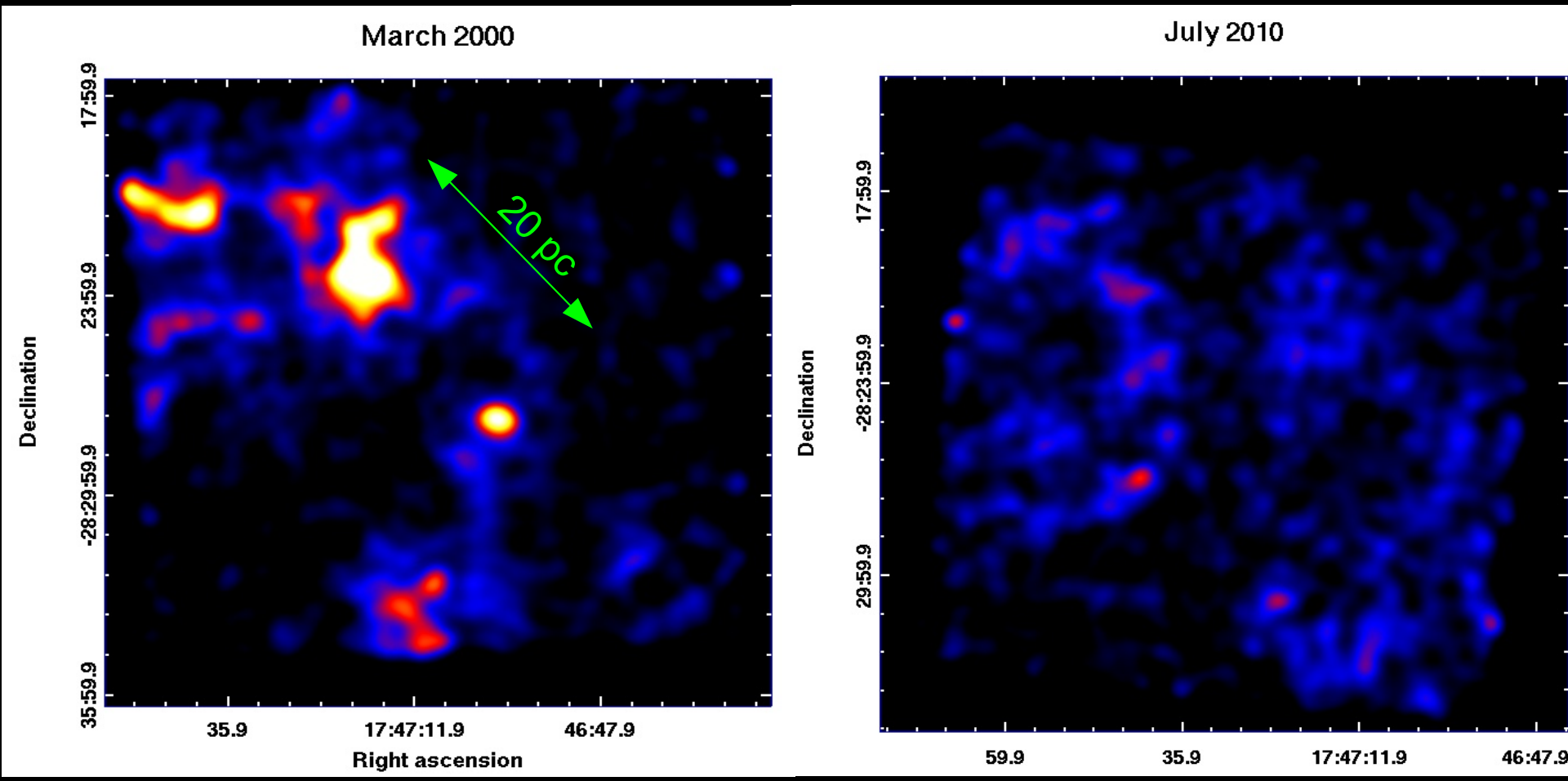


Oph cluster (20-60 keV)

Fe Kα from Inui et al (2009)

Terrier et al. (2010)

Sgr B2 variability seen with Chandra



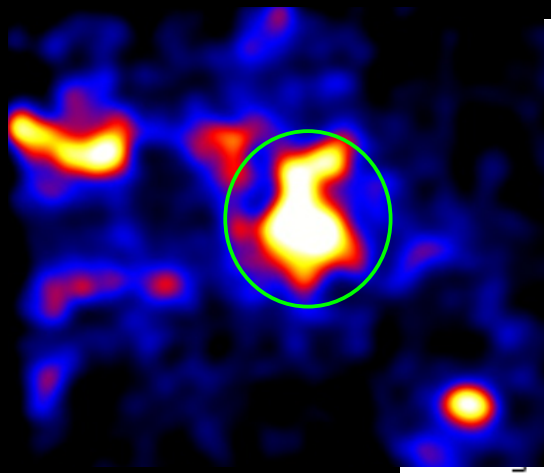
FeKα flux images

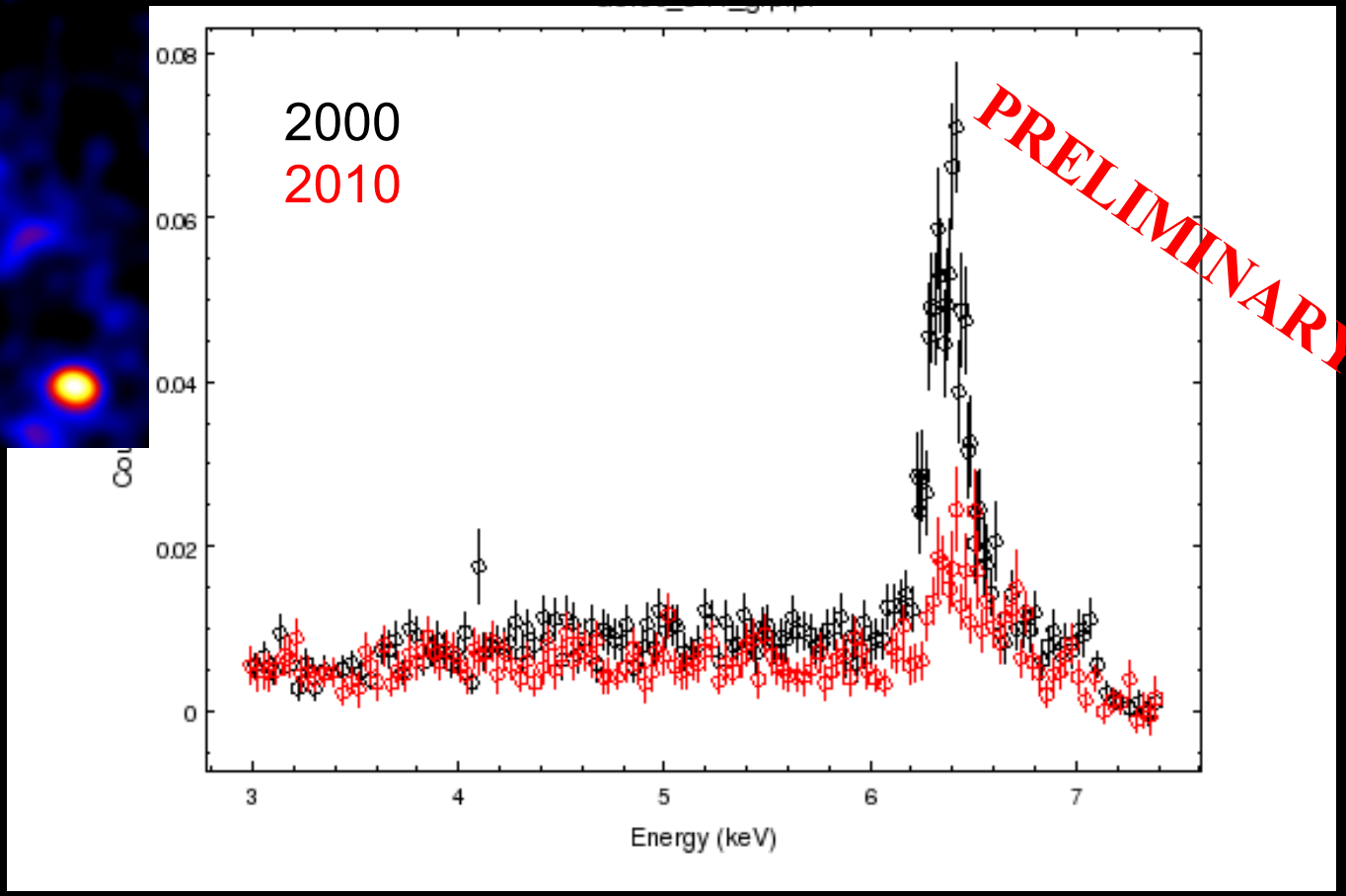
Very significant flux decay all over the Sgr B2 complex (>20 pc)

Some structures completly vanished

Terrier et al. (2011)

Sgr B2 variability seen with Chandra



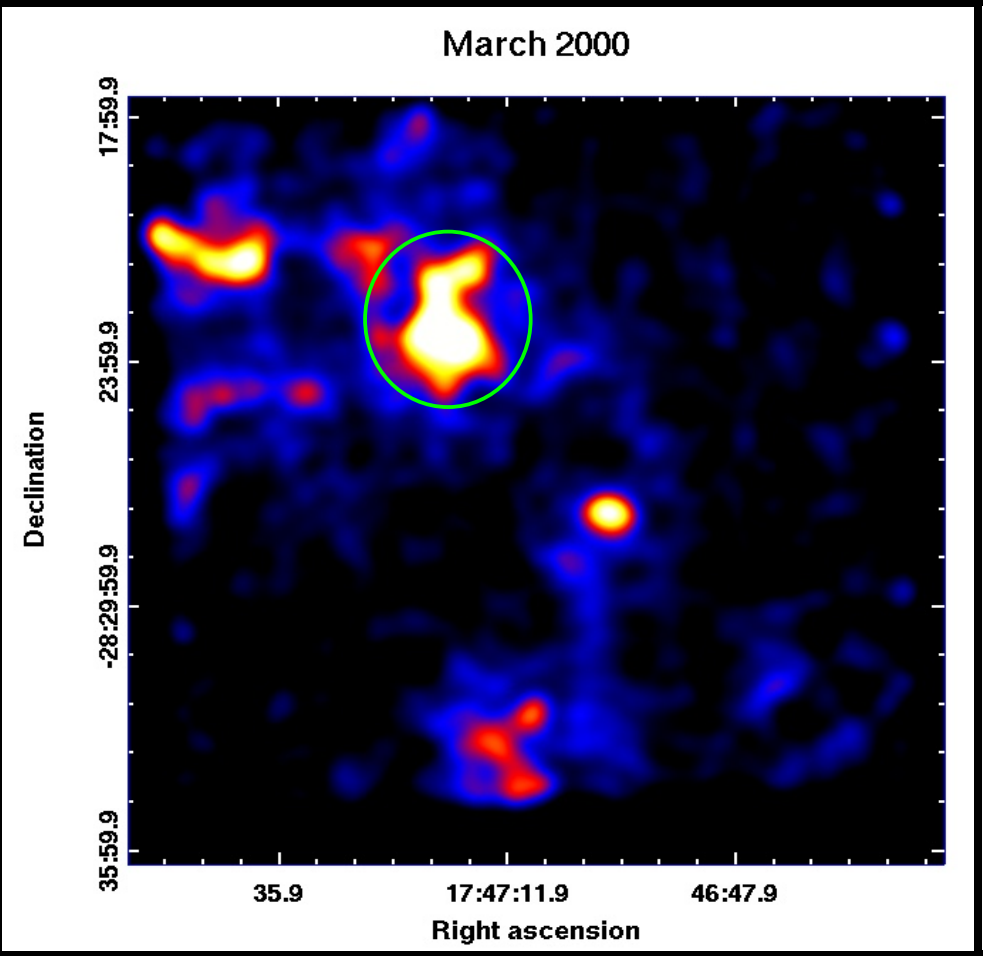


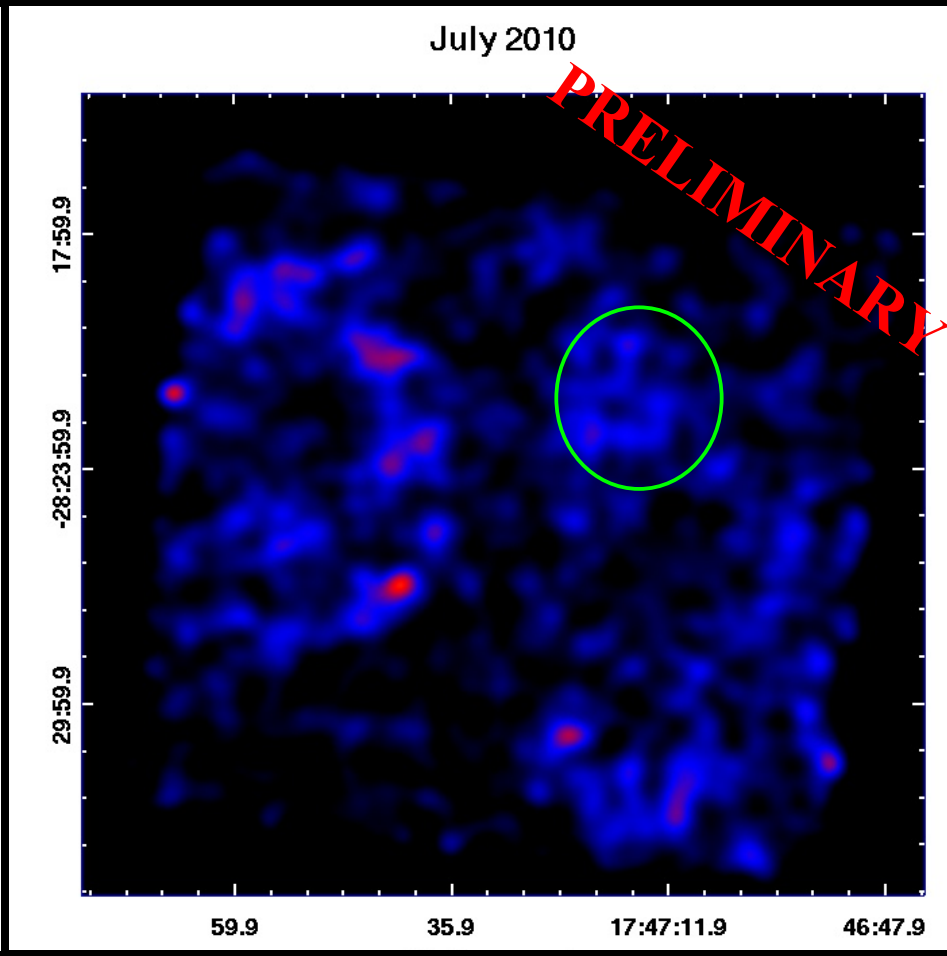
FeKα flux in the central 2' of Sgr B2 divided by 3-4 in 10 yrs

EW in 2010 is still large (~1 keV)

Terrier et al. (2011)

Sgr B2 variability seen with Chandra





Rapid variations on small scales (from the cores of Sgr B2 with densities of $>10^5$ cm^{-3})

No strong variations in more diffuse regions: reflections in the cloud enveloppe?
(with densities of ~10^3 cm^{-3} *Lis & Goldsmith 1991*)

Terrier et al. (2011)

Nature of Sgr B2 emission

Sgr B2 FeKα and hard X-ray emission is fading:

- Factor of 3-4 flux decrease in 10 years
- Characteristic timescale comparable with light crossing timescale of the cloud core (~2.5pc)
-

Fast time variability rules out CR as the dominant contribution

Sgr B2 is a reflection nebula:

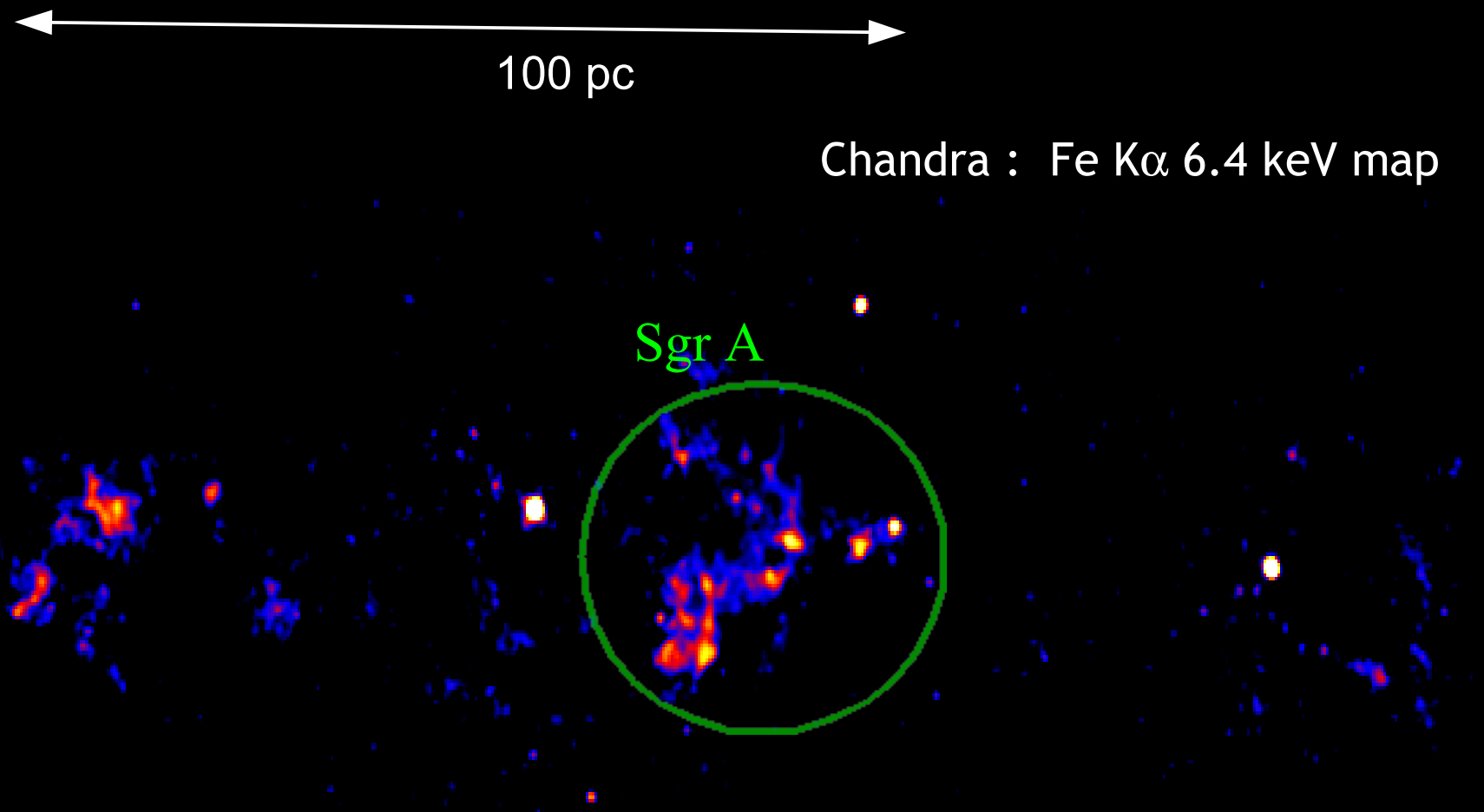
- A past 10^{39} erg/s mean activity period from Sgr A*?

Small scale variations in densest regions are stronger

Variation more limited in more diffuse regions: a steady component?

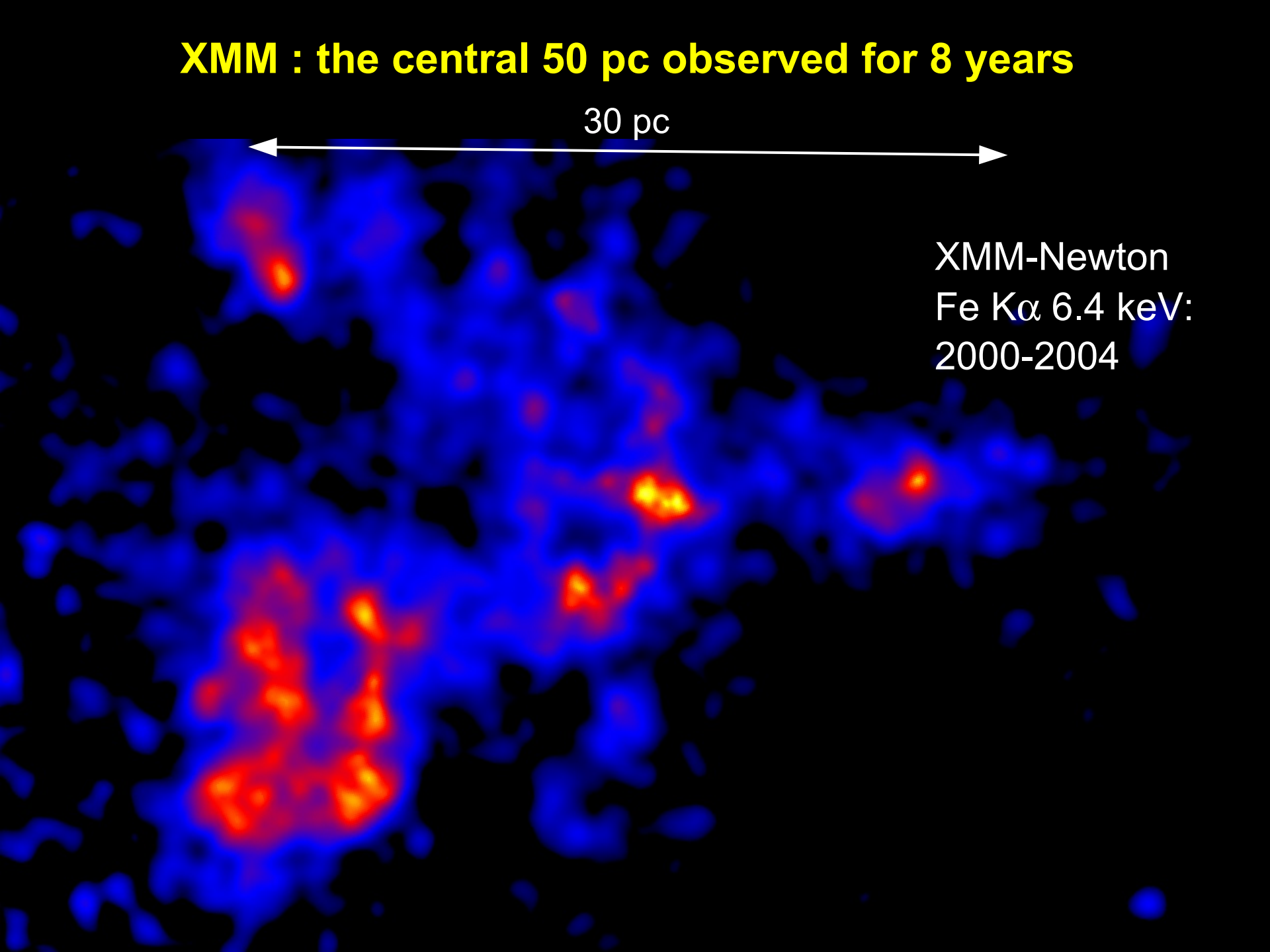
Reflection by large scale cloud enveloppe

Non-thermal emission from the CMZ

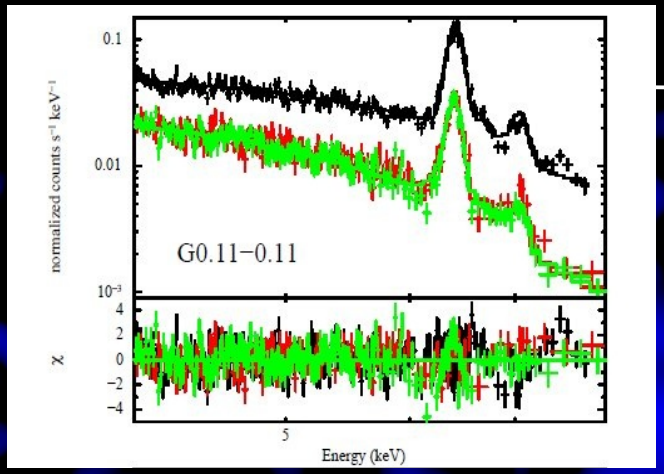


Time variability in the Sgr A complex?

XMM : the central 50 pc observed for 8 years



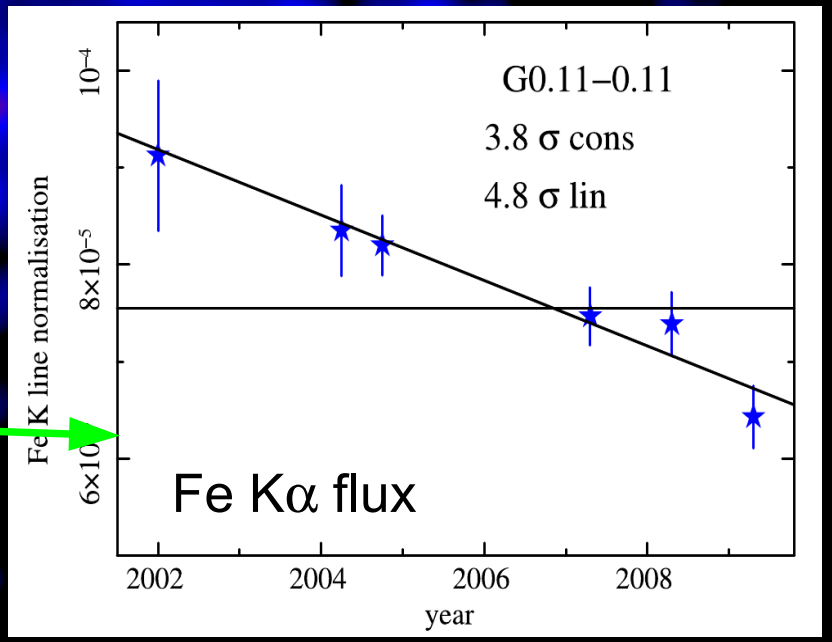
Some clouds see a flux decrease



30 pc

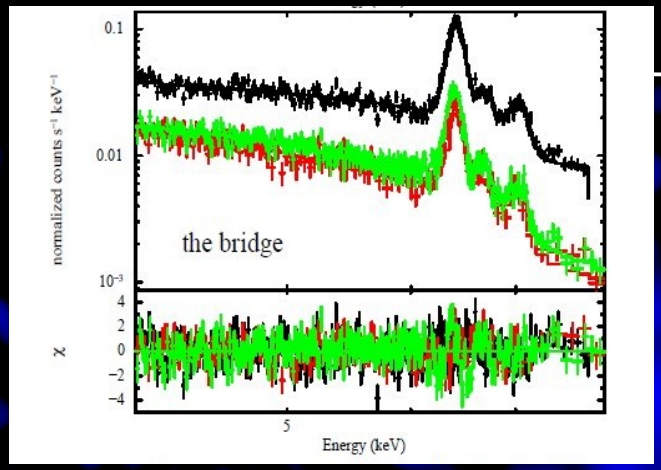
Fe Kα 6.4 keV:
2000-2004

G0.11-0.11



Spectral model: wabs(apec + edge*(PL + gaus + gaus))

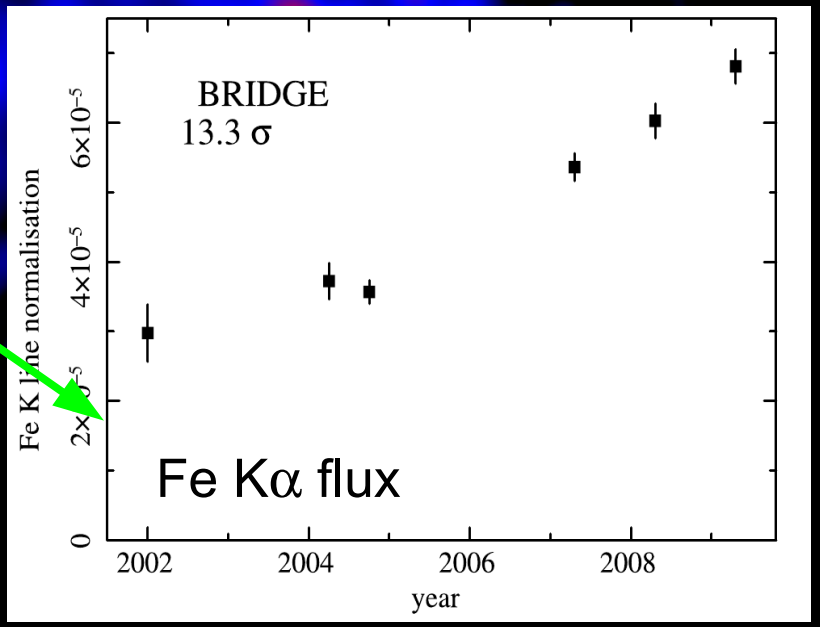
Some see an increase



30 pc

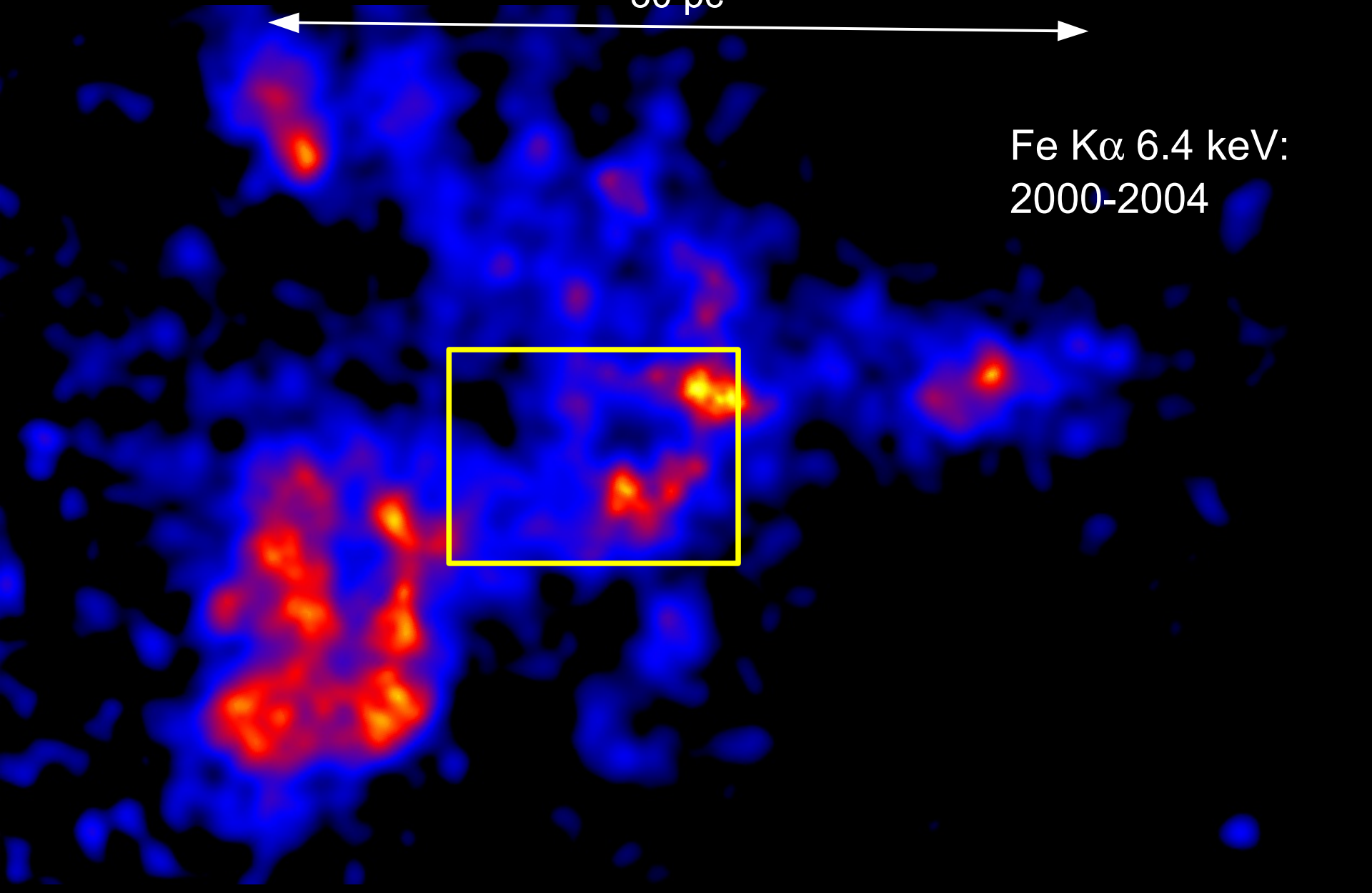
Fe Kα 6.4 keV:
2000-2004

Bridge



Spectral model: wabs(apec + edge*(PL + gaus + gaus))

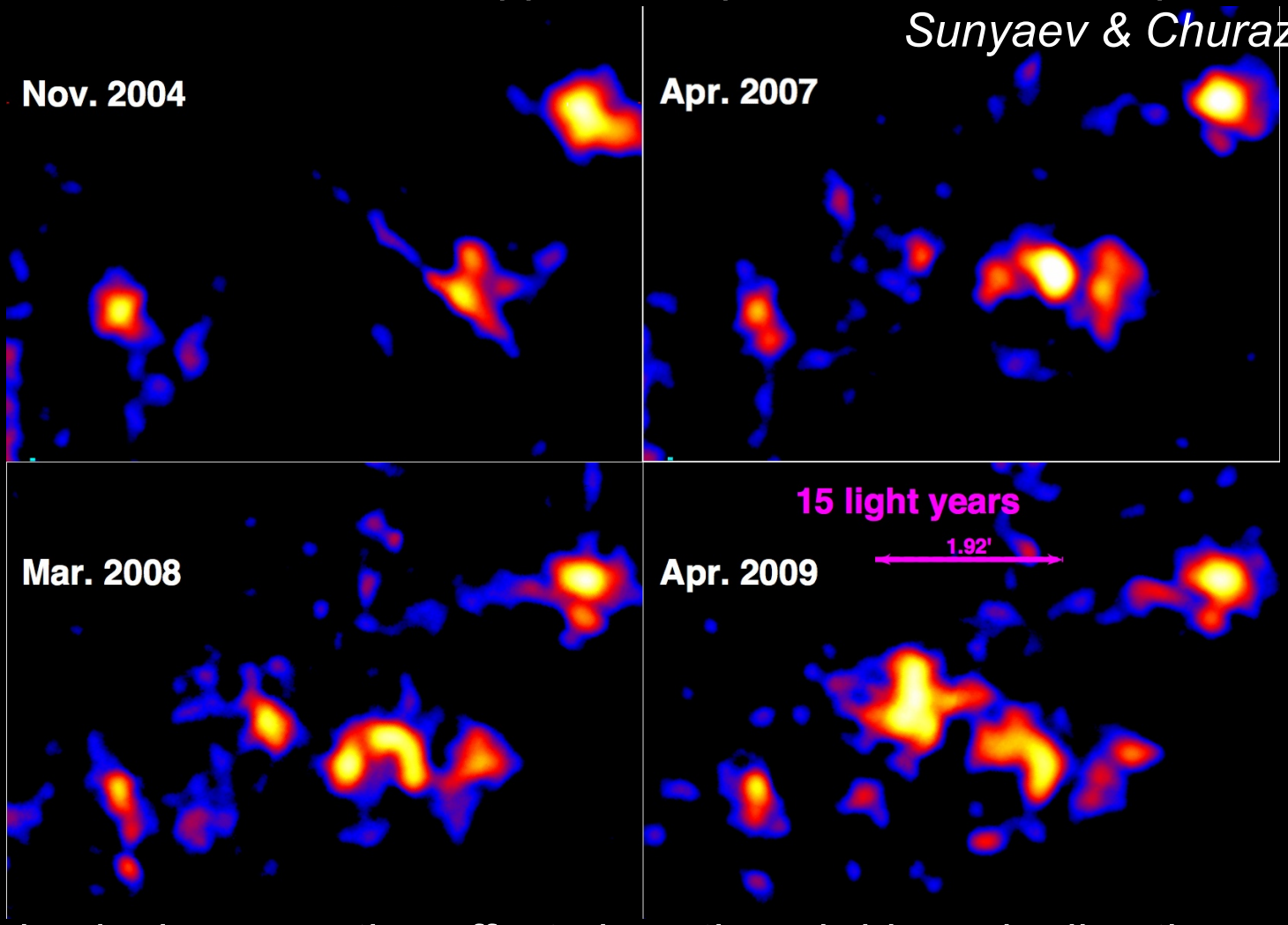
Some propagation effects?



Apparent superluminal motion

Apparent superluminal effects expected in XRN

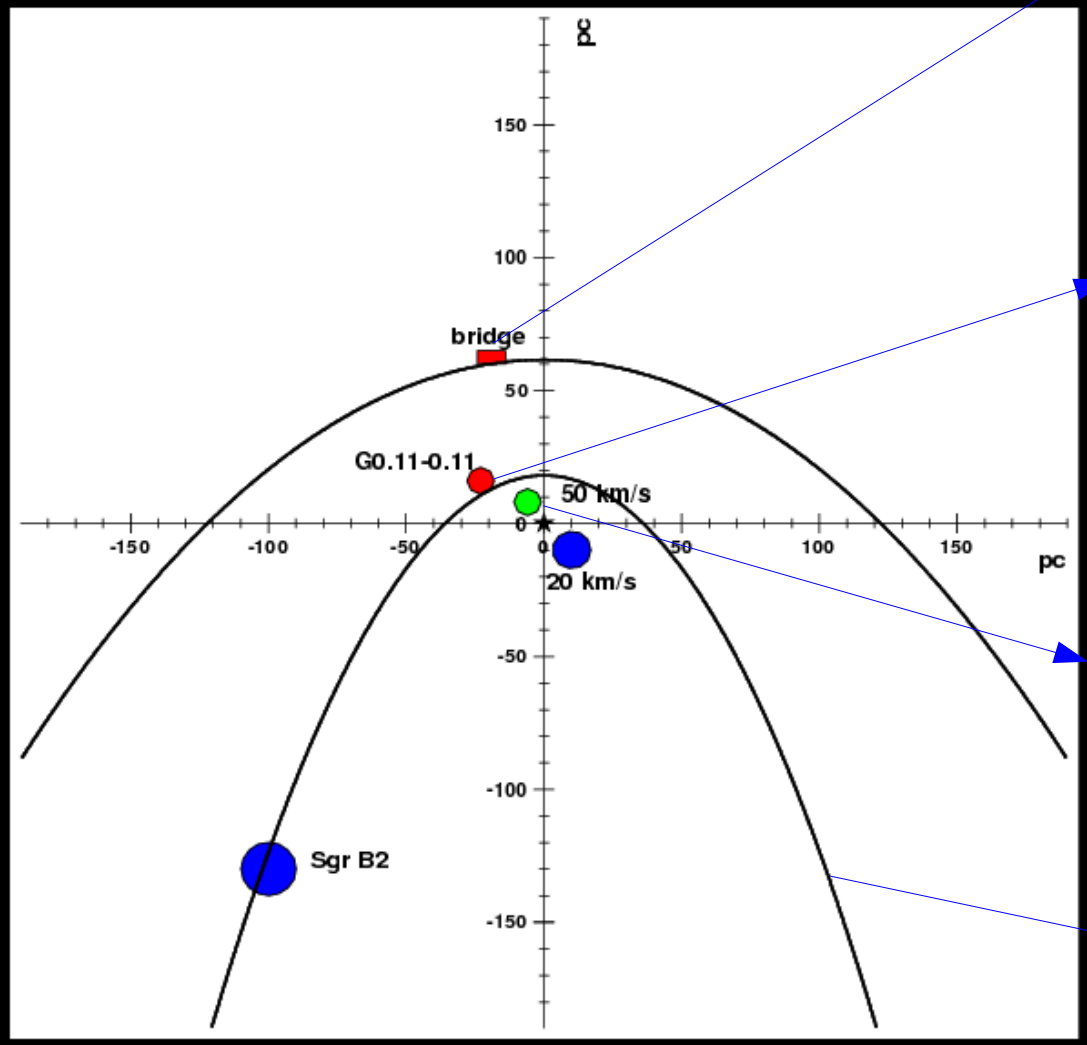
Sunyaev & Churazov (1998)



Superluminal propagation effect along the « bridge » in direction opposite to the GC

Ponti et al. (2010)

A plausible scenario: face on view



Does the bridge reflect the same event? Beginning of the flare?

G0.11-0.11 & Sgr B2 are reflecting the end of the same flare (10^{39} erg/s)

No recent activity reflected by 50 km/s

Isochron: parabola

Ponti et al. (2010)

Conclusions

- **Clear signatures of illumination by a bright transient source in the GC**
  - Discovery of fast variability in several molecular clouds
  - Apparent superluminal propagation effect in one of them
  - **GC molecular clouds reflect a past bright (~10^{39} erg/s) period of activity from a single object close to the GC: Sgr A*!**

- **Bulk of hard X-ray emission in the CMZ not due to CR bombardment**
  - Possible existence of a steady contribution: CR?
  - Reflection by more diffuse medium *must* also be present
    - Long variation timescales expected

- Search for CR in specific regions. See R. Capelli talk

Conclusions

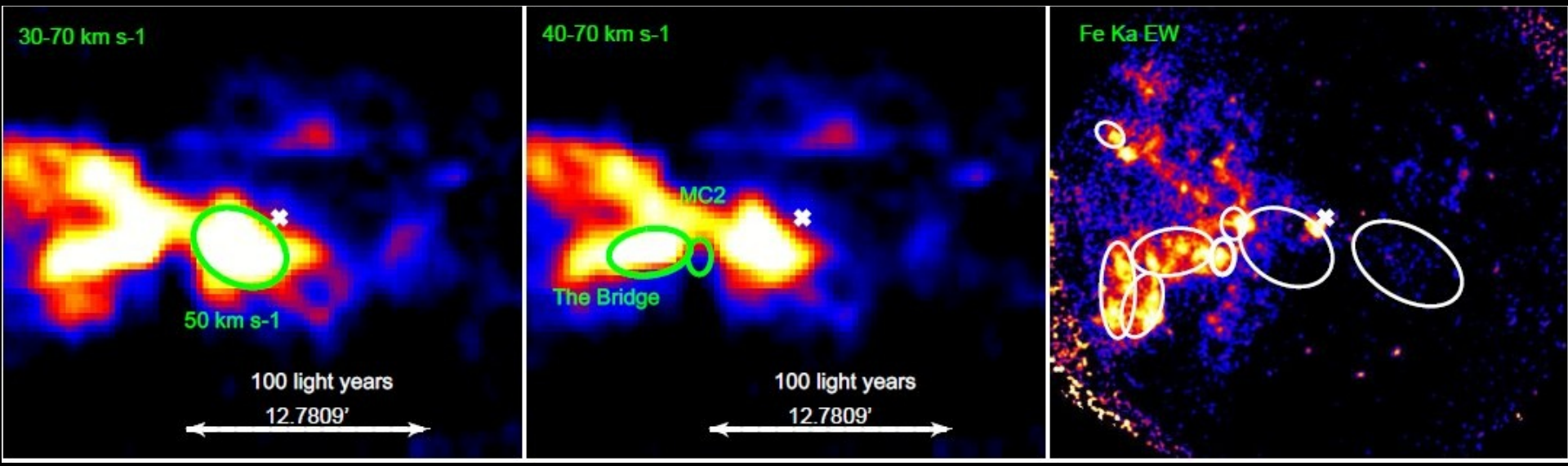
- **Sgr A* was more than 10^5 time brighter ~100 years ago**
  - Emission then decayed quickly
  - Emission was less than 10^{36} erg/s, ~ 60 yrs ago
  - Duration of the flare?
    - More detailed observations to constrain the duration

- **Sgr A* was in a luminosity state similar to LLAGNs**
  - e.g. M81* $L_X = 10^{-5} L_{edd}$
  - Duty cycle and mechanisms of such flares?

Construction of a plausible scenario

Different & distant clouds varying at the same time

→ 1 bright illuminating source : Sgr A* is the most likely candidate



Reconstruct past activity using emission from GC MoC:

For MoC with known positions use measured flux or U.L. to constrain activity at given time

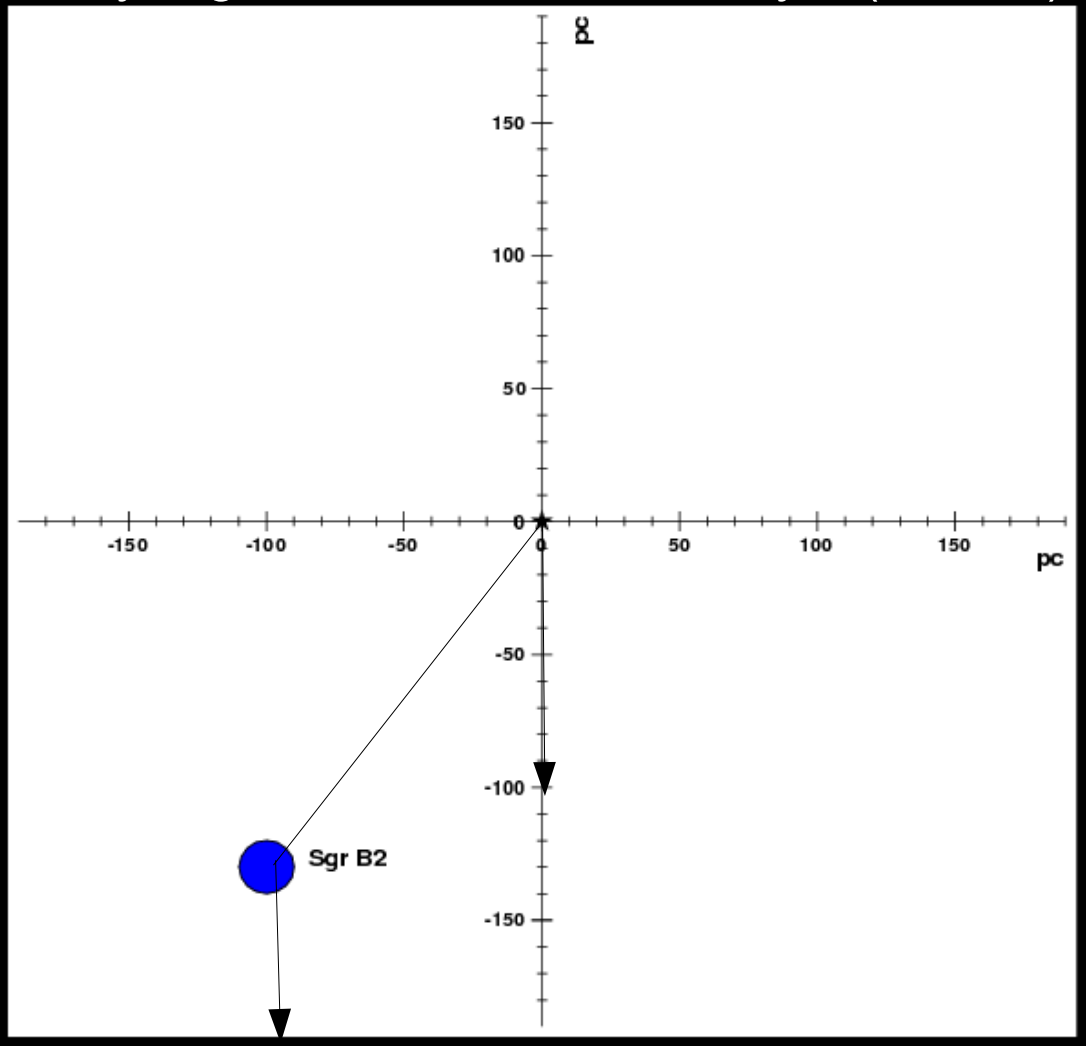
For illuminated MoC with unknown positions: assume Sgr A* luminosity at 10^{39} erg/s to determine their position

Face on view of the phenomenon

Parallax measurement : Sgr B2 is 130 ± 60 pc in front of Sgr A*

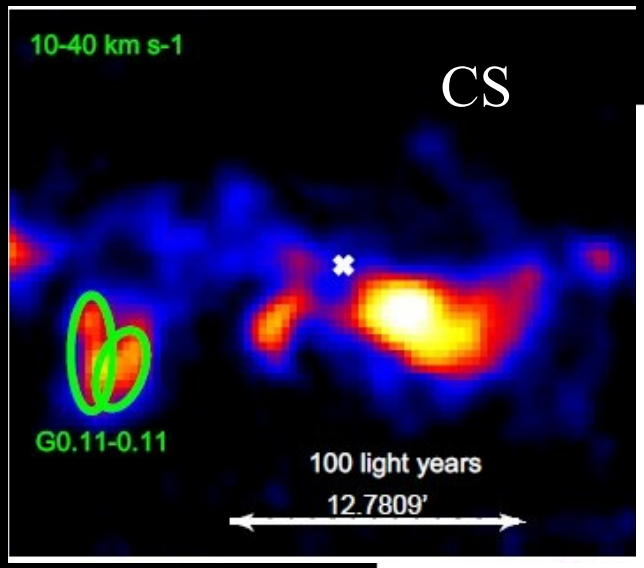
(H_2O maser, VLBI, Reid et al, 2009)

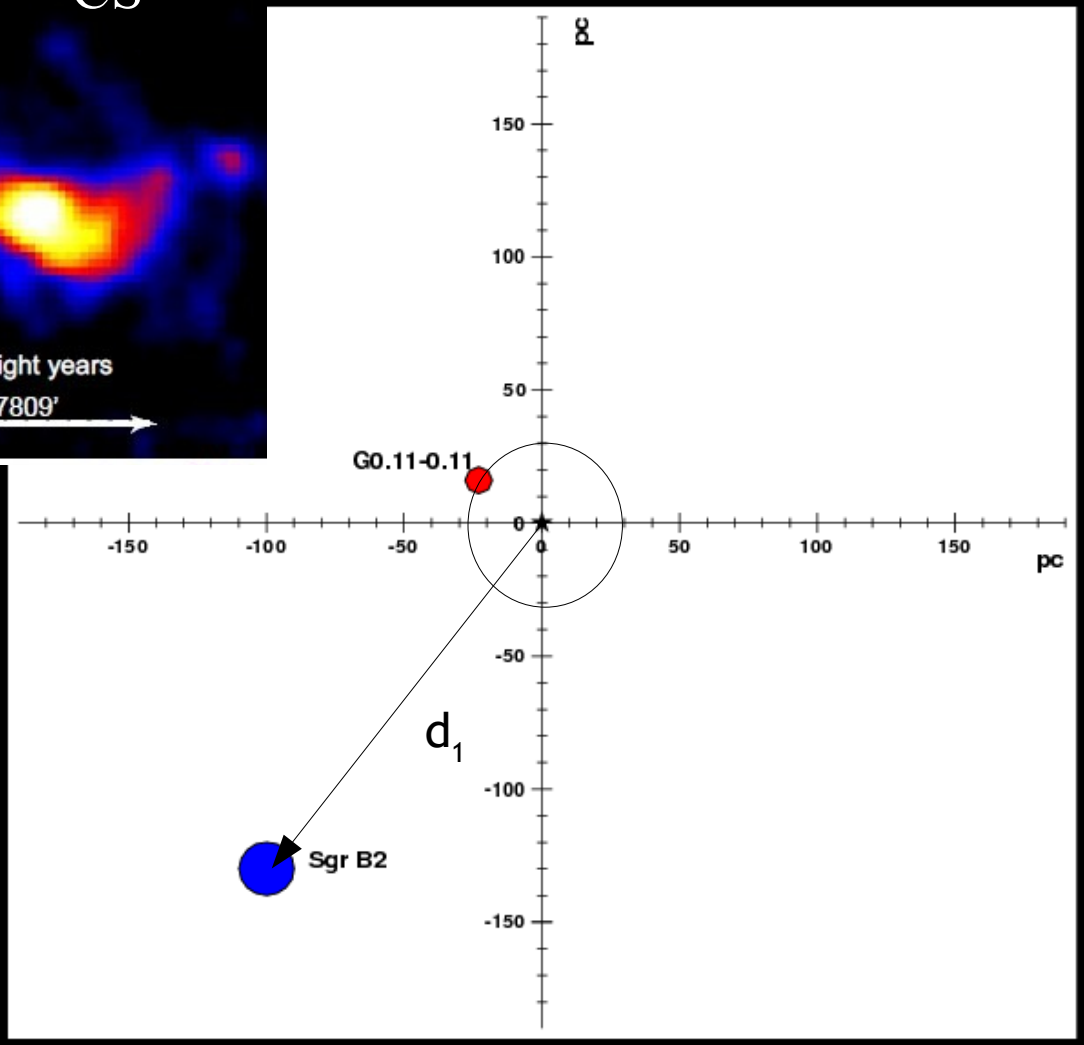
Photons scattered by Sgr B2 were emitted 100 yrs (70-150) ago by Sgr A*



Face on view of the phenomenon

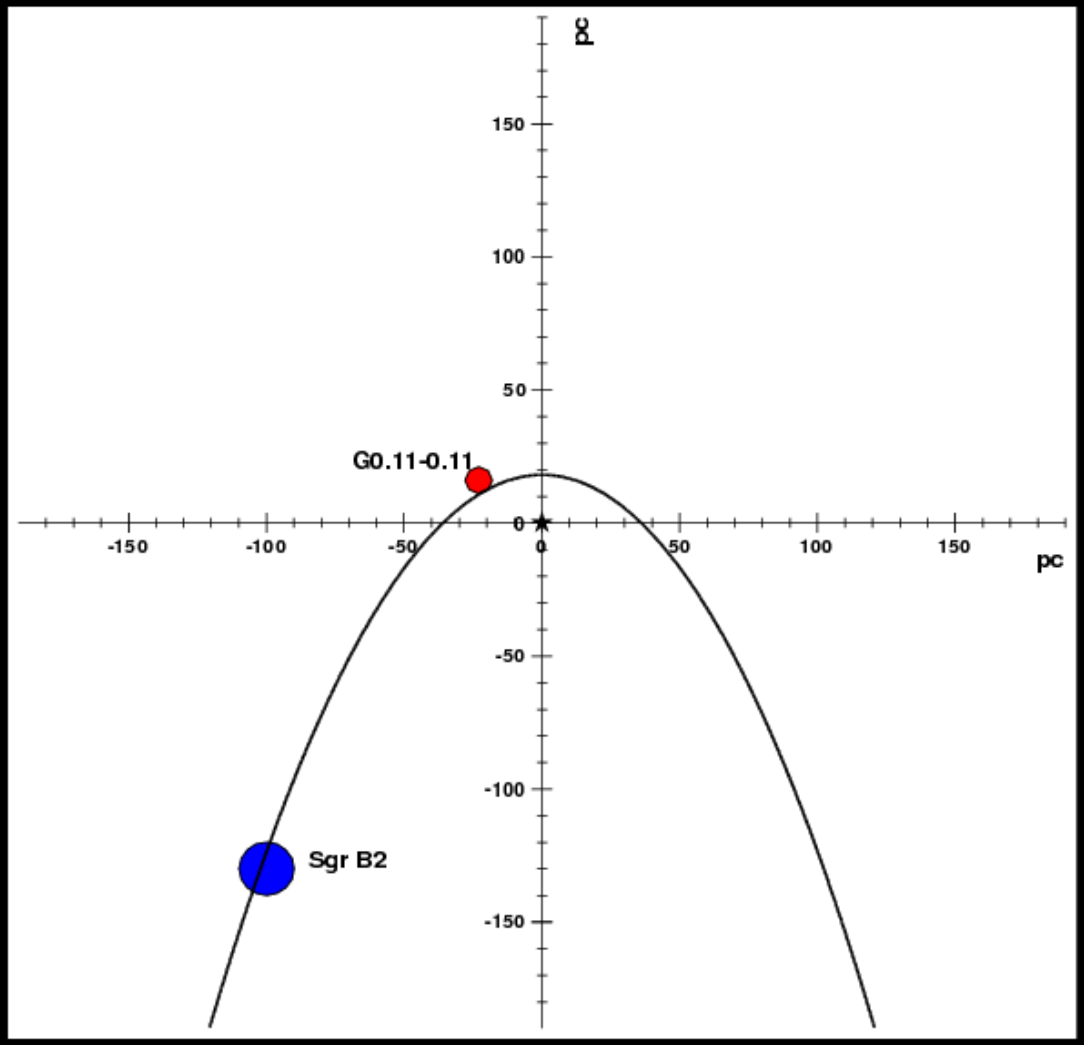
If G0.11-0.11 & Sgr B2 are illuminated by the same event:





Face on view of the phenomenon

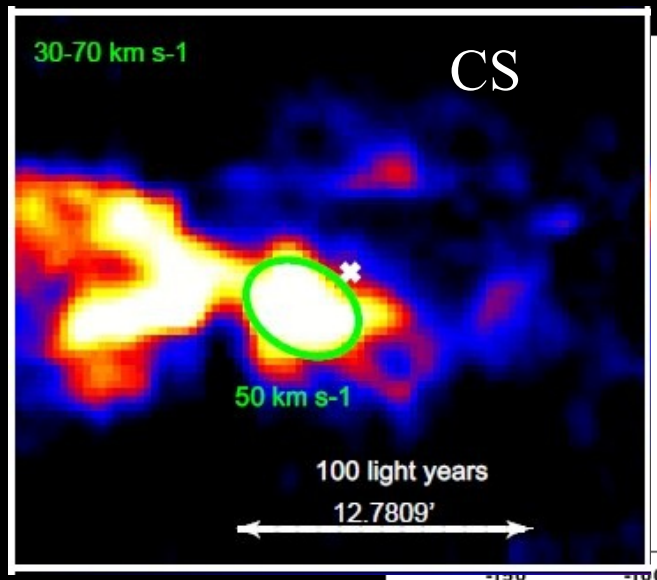
G0.11-0.11 & Sgr B2 are on the same isochron (parabola)
Both reflect the end of Sgr A* flare

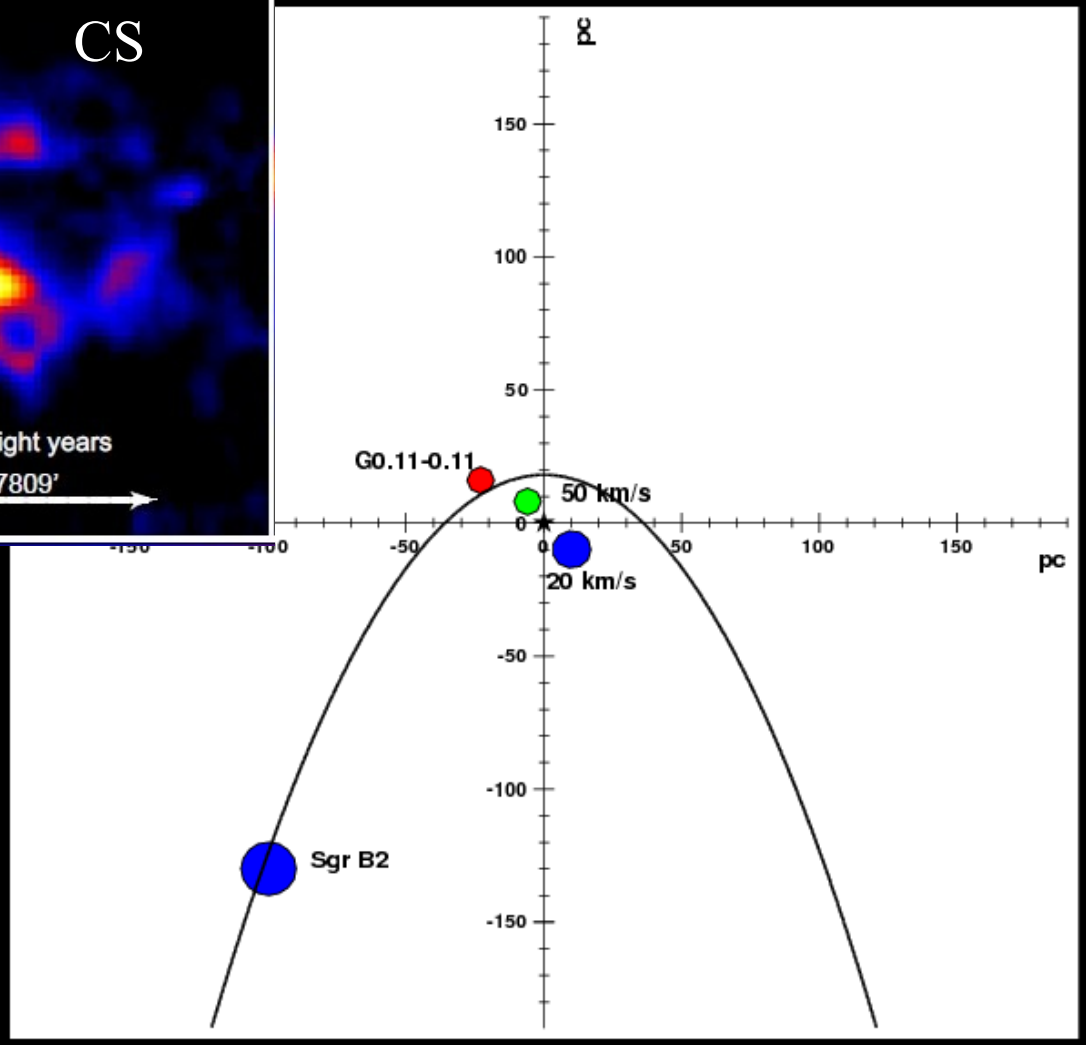


Face on view of the phenomenon

20 & 50 km/s clouds are not illuminated:

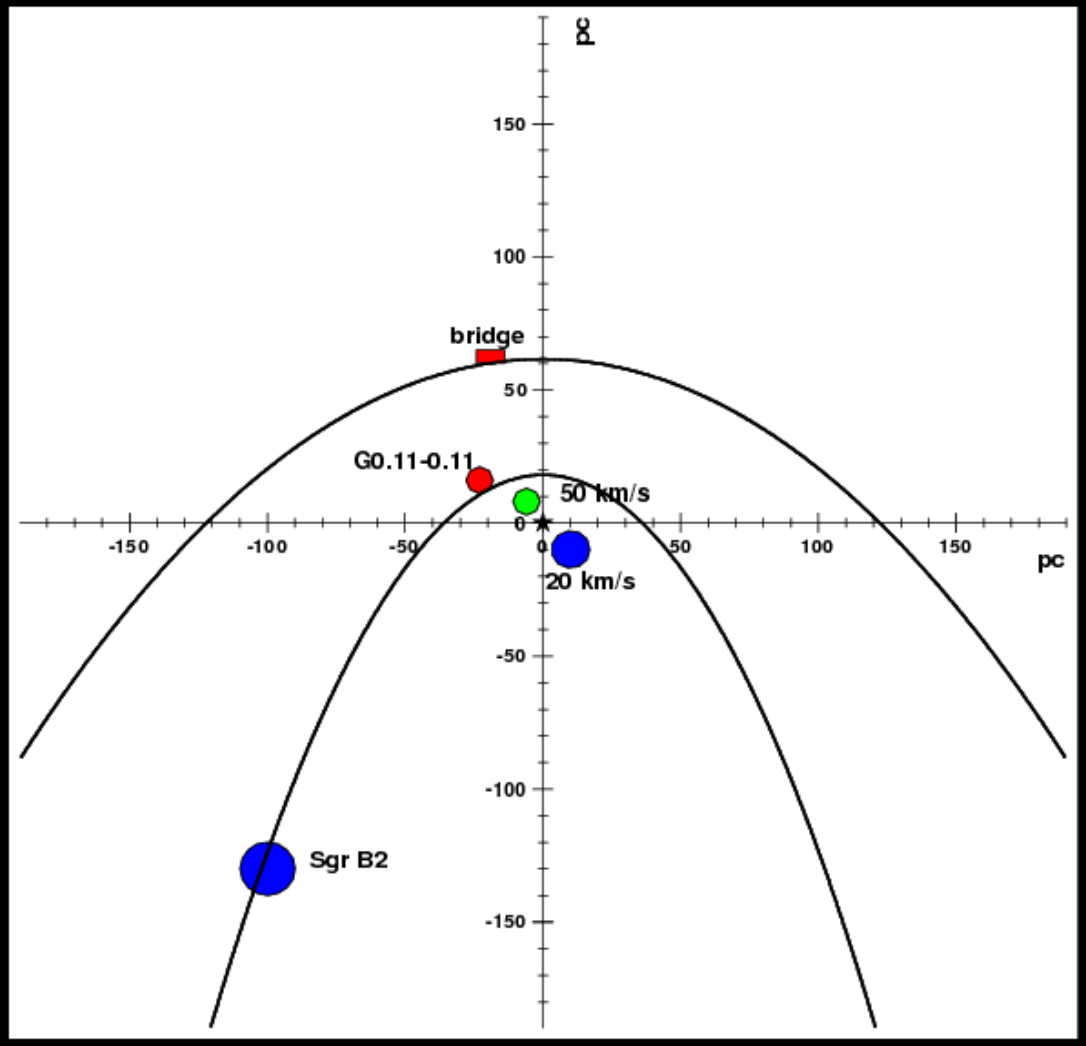
Sgr A* activity low during last 60-90 yrs ($L_X < 10^{36}$ erg/s)





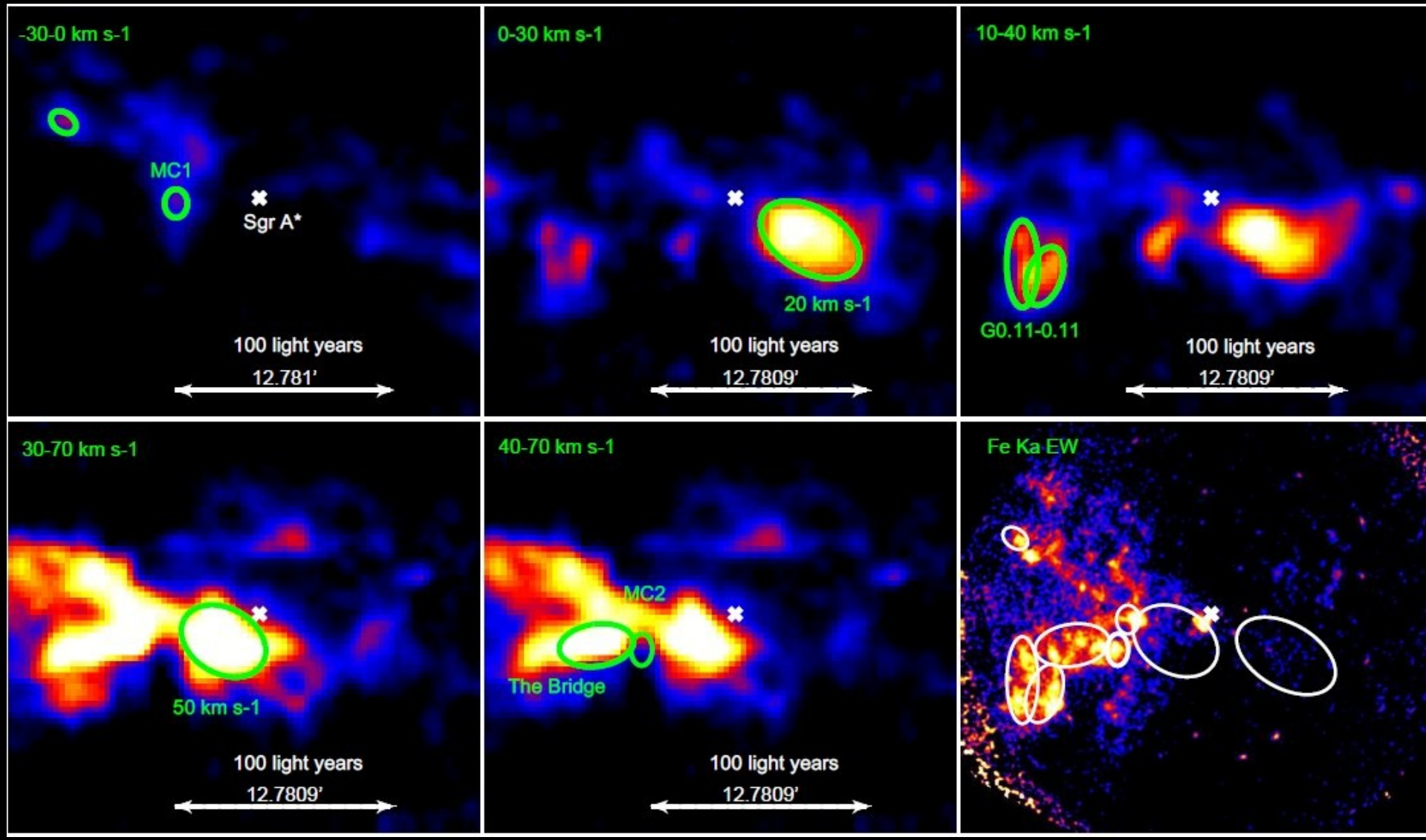
Face on view of the phenomenon

If the « bridge » and Sgr B2 are illuminated by the same flare (10^{39} erg/s):
Bridge located 60 pc behing Sgr A* & flare began 400 years ago?

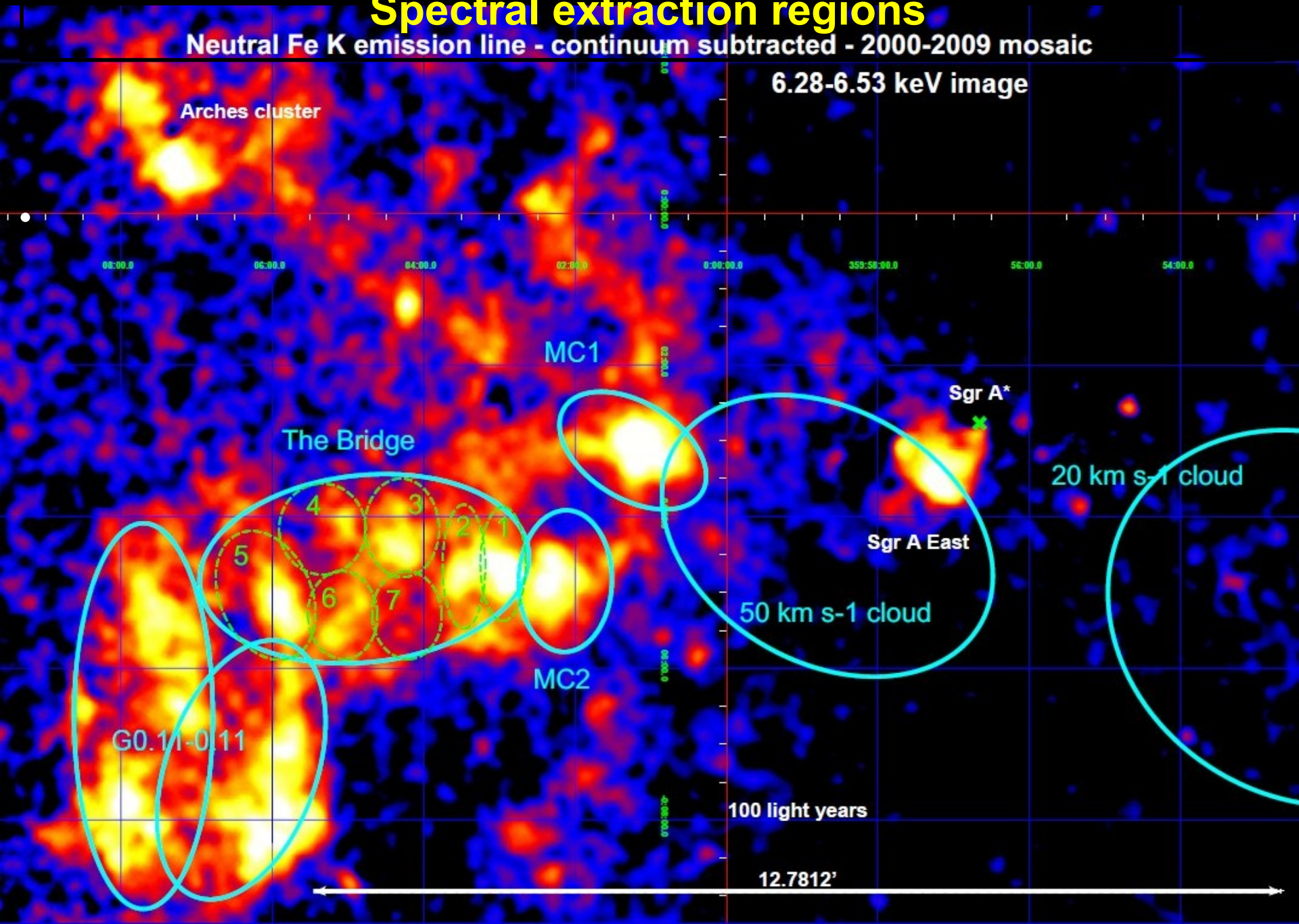


Ponti et al. (2010)

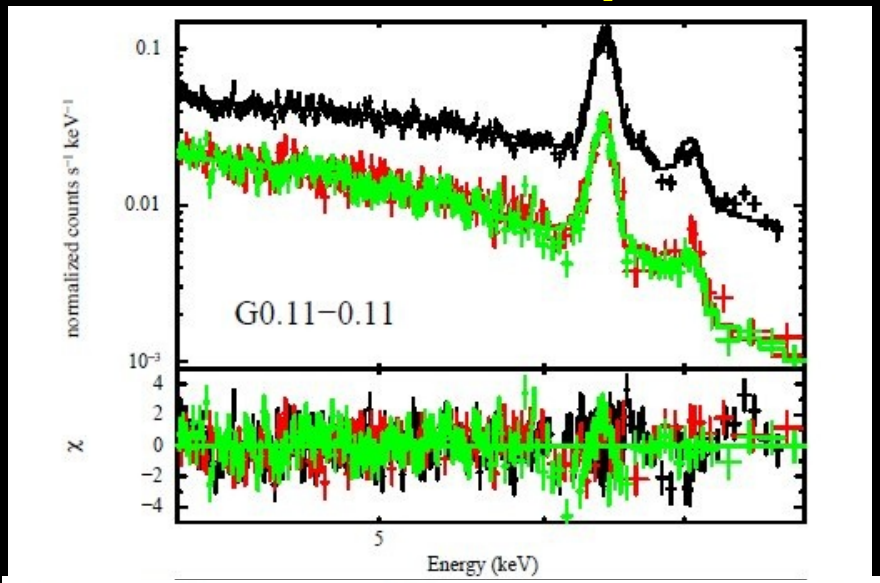
Molecular clouds traced by CS emission

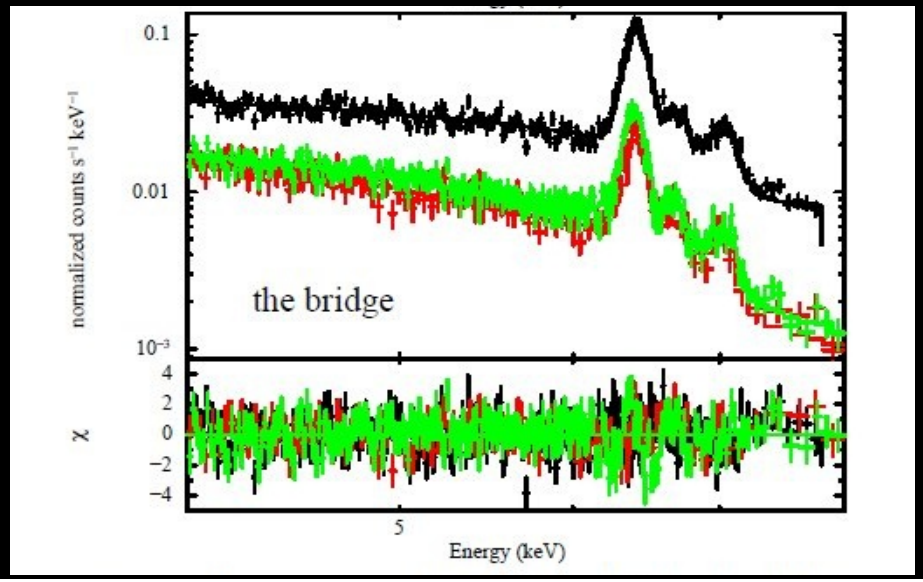


Spectral extraction regions



Spectral extraction results





Model: wabs × (apec + edge × (power-law + Gaus + Gaus))

name	nh 10^{22} (cm^{-2})	τ	E (keV)	σ (eV)	norm$_{Ga}$ 10^{-5} (ph. cm^{-2} s^{-1})	Γ	norm$_{pl}$ 10^{-5} (ph. keV^{-1} cm^{-2} s^{-1})	EW (eV)	χ^2/dof
Bridge	4±3	0.26±0.12	6.409±0.002†	28±4††	$4.7^{+0.3}_{-0.2}$	$1.0^{+0.4}_{-0.3}$	26^{+22}_{-13}	750	1175.1/1121
G0.11-0.11	7±4	$0.03^{+0.11}_{-0.03}$	6.411±0.002	28±5	7.5±0.5	$1.9^{+0.3}_{-0.4}$	250^{+200}_{-130}	955	1302.0/1175
MC1	10^{+1}_{-2}	0.32±0.07	6.410±0.005	< 18	$1.87^{+0.18}_{-0.06}$	$0.8^{+0.4}_{-0.5}$	10^{+10}_{-5}	684	780.3/780
MC2	5^{+5}_{-4}	$0.36^{+0.2}_{-0.15}$	6.411±0.004	30^{+7}_{-10}	$0.98^{+0.17}_{-0.09}$	$0.9^{+0.1}_{-0.5}$	$6.3^{+0.5}_{-2}$	715	755.1/615

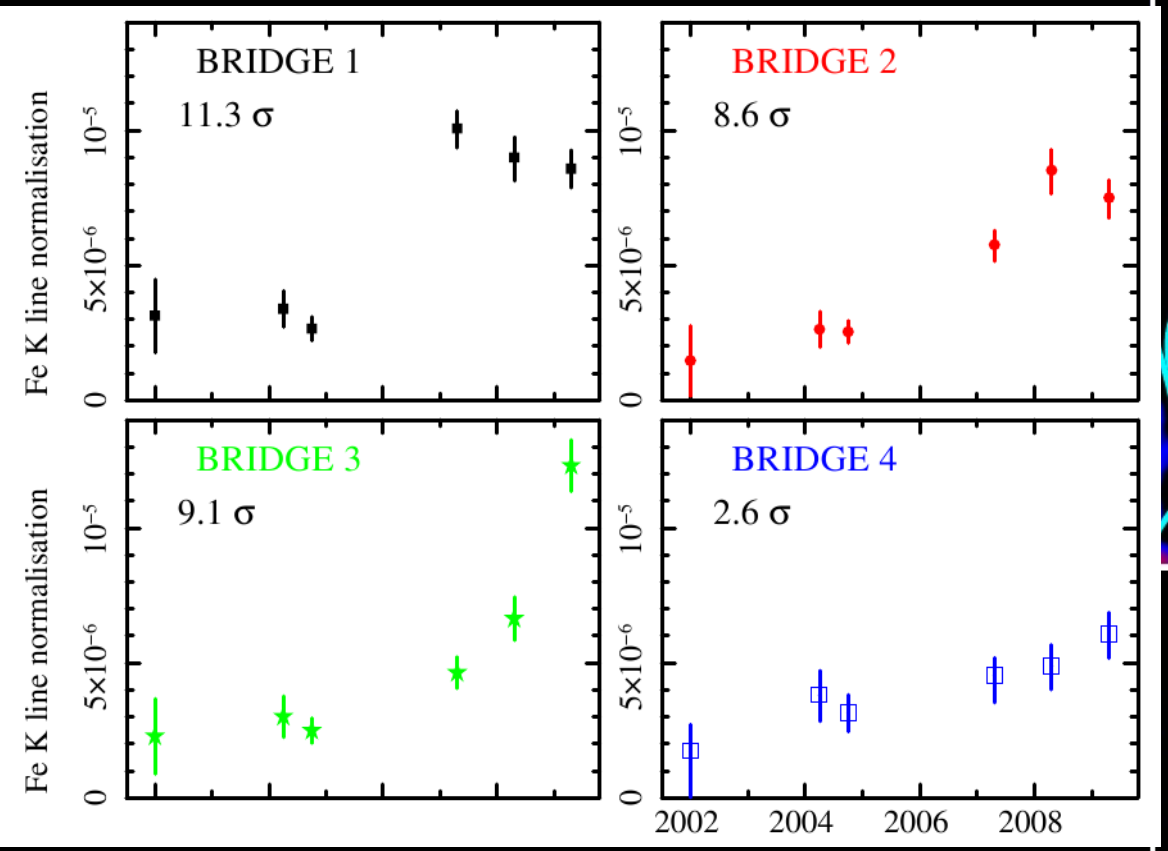
Model: wabs × (power-law + apec + pexrav+ Gaus + Gaus)

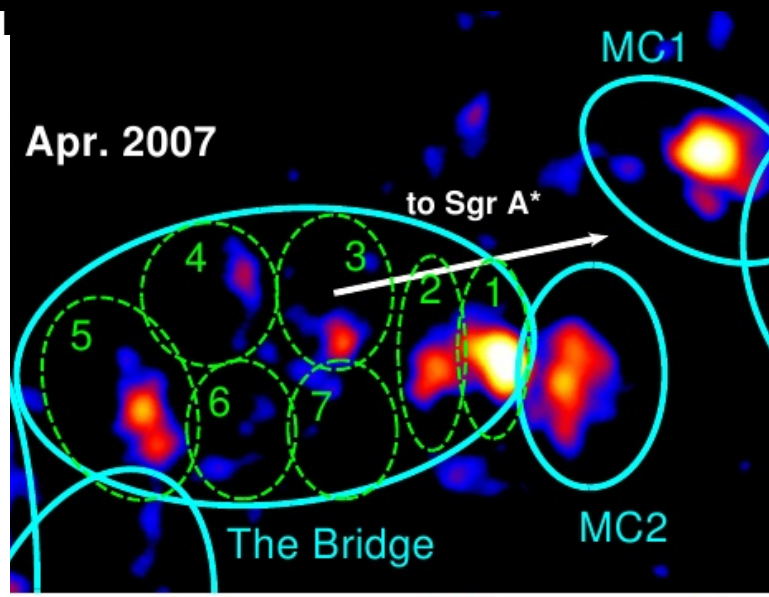
name	nh	E	σ	norm$_{Ga}$	Γ	norm$_{pl}$	χ^2/dof
Bridge	4±3	6.409±0.002	26±5	4.6±0.2	2.1±0.1	78^{+55}_{-34}	1179.7/1122
G0.11-0.11	6^{+2}_{-3}	6.411±0.002	27±5	$7.1^{+0.4}_{-0.3}$	2.4±0.2	420^{+160}_{-130}	1309.5/1176
MC1	9^{+2}_{-4}	6.410±0.005	< 20	1.9±0.07	1.9±0.1	28^{+24}_{-15}	781.8/781
MC2	8^{+6}_{-5}	6.409±0.004	23±10	1.2±0.1	2.1±0.2	35^{+18}_{-10}	760.0/615

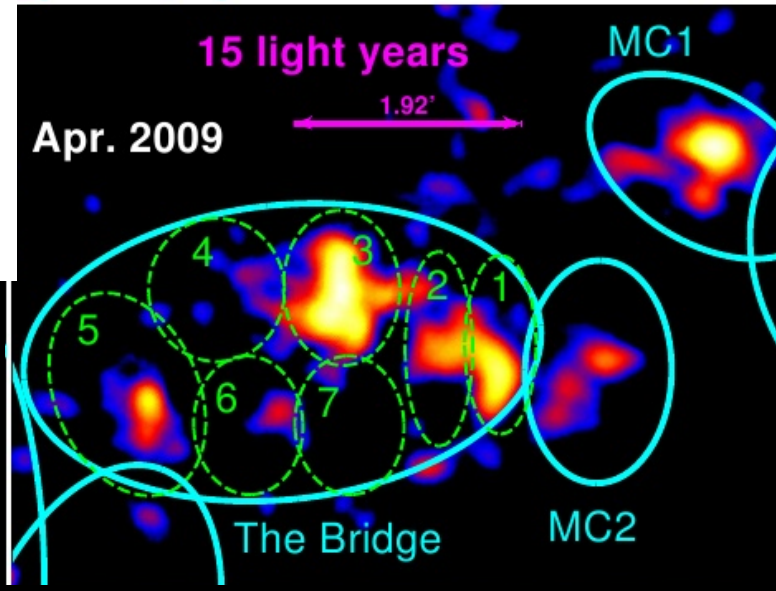
TABLE 3

Best fit results of the fit of the mean spectra of the different MC. EPIC-pn and MOS data are fitted simultaneously. *(Upper panel)* Fit

Apparent superluminal motion







Propagation effect along the « bridge » in direction opposite to the Galactic centre.

Ponti et al. (2010)