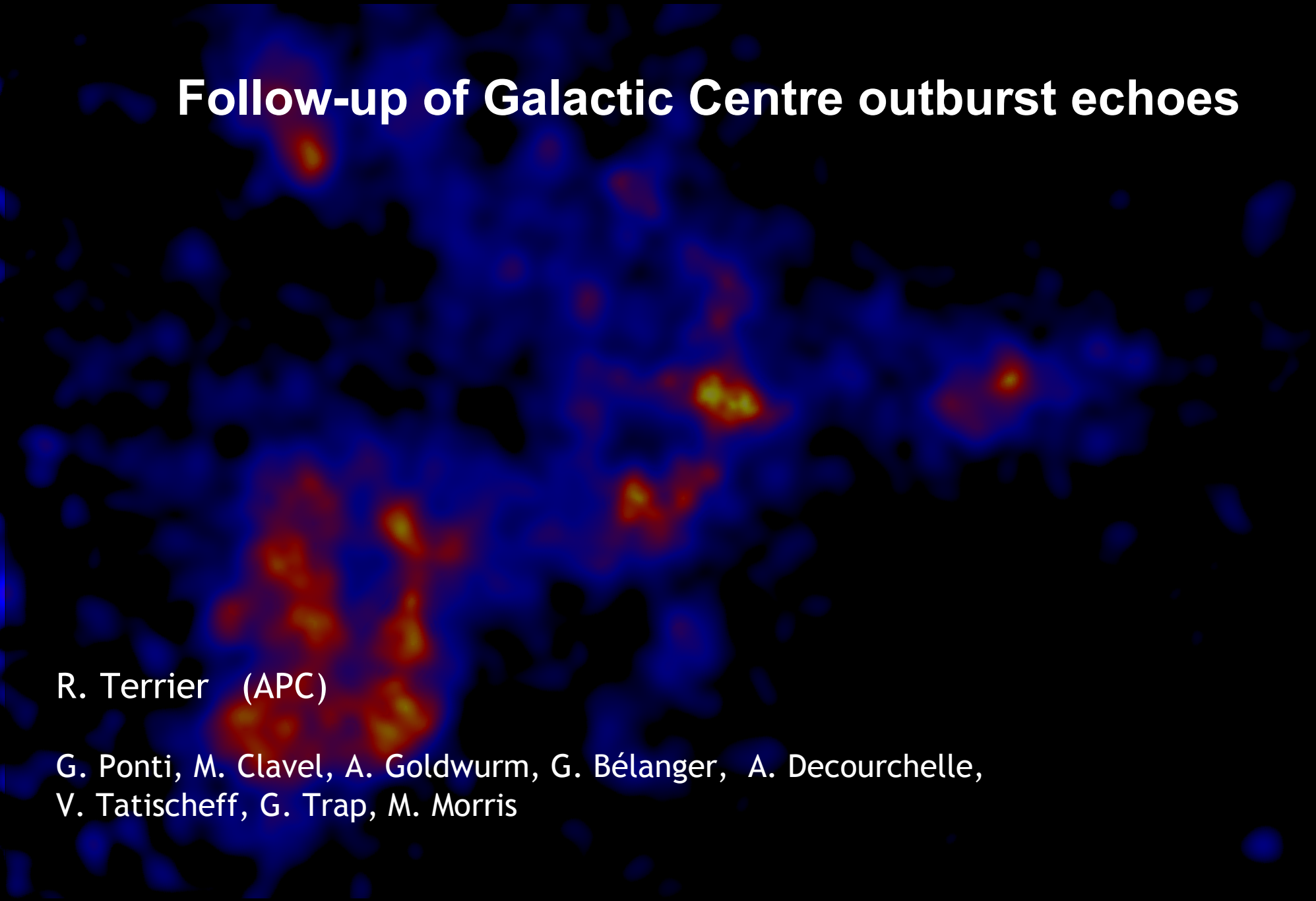
Follow-up of Galactic Centre outburst echoes

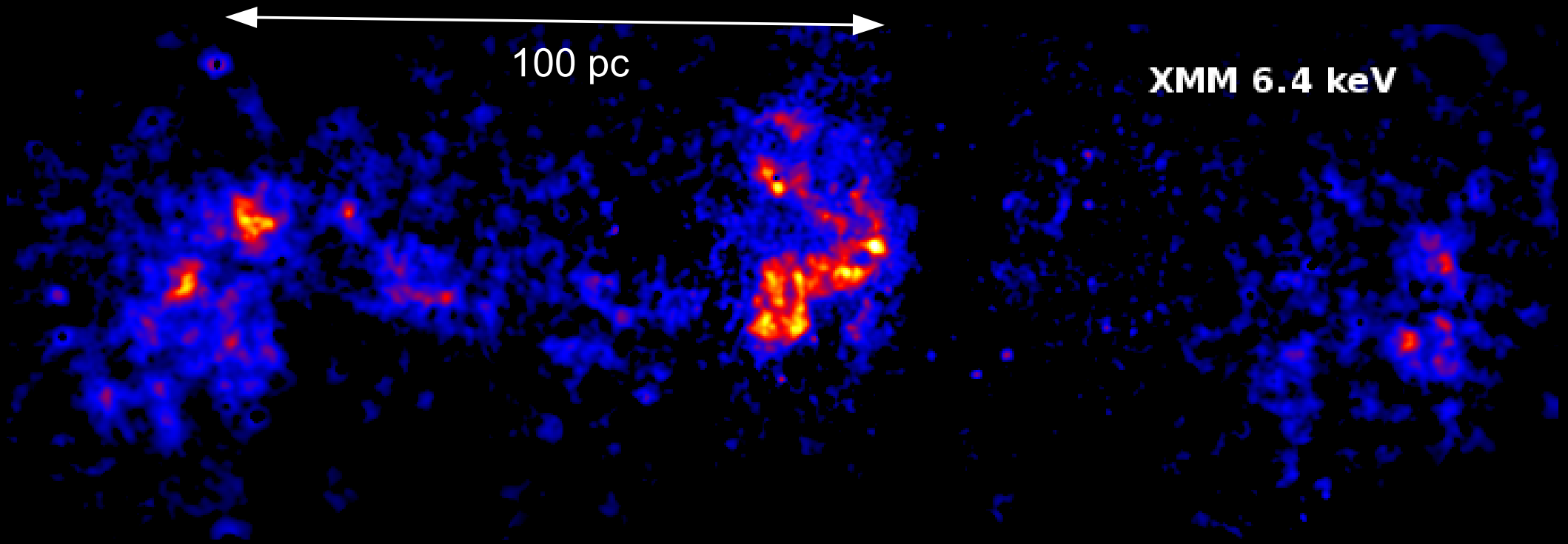


R. Terrier (APC)

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

Gamma 2012
Heidelberg

Fe Ka 6.4 keV line in the central 200 pc



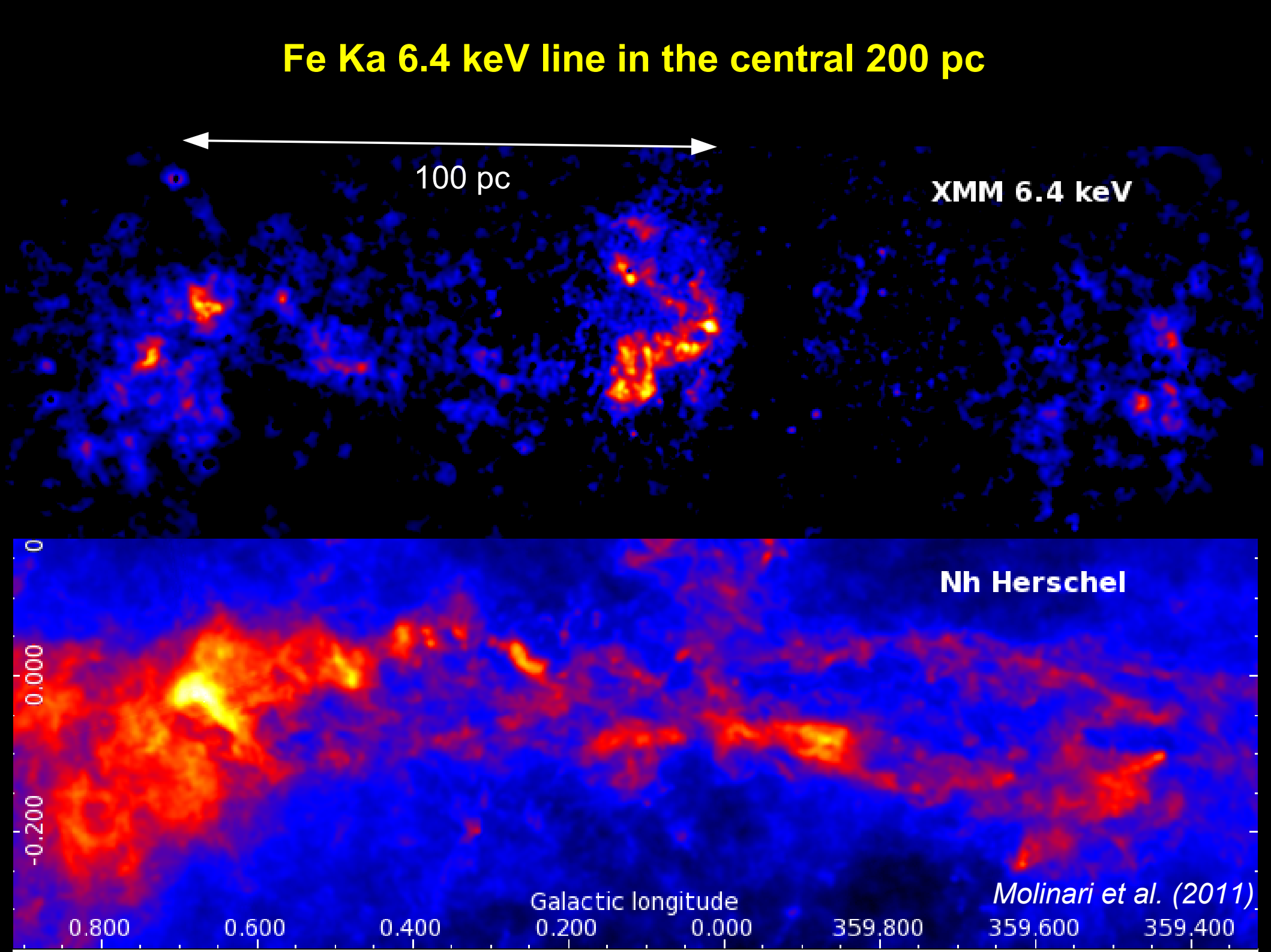
Intense & large EW 6.4 keV emission from GC molecular clouds

Sunyaev et al. (1993), Koyama et al. (1996), Park et al (2004) etc

Integral detection of hard X-ray emission (>20 keV) from Sgr B2 GMC

(Revnivtsev et al. 2004)

Fe Ka 6.4 keV line in the central 200 pc

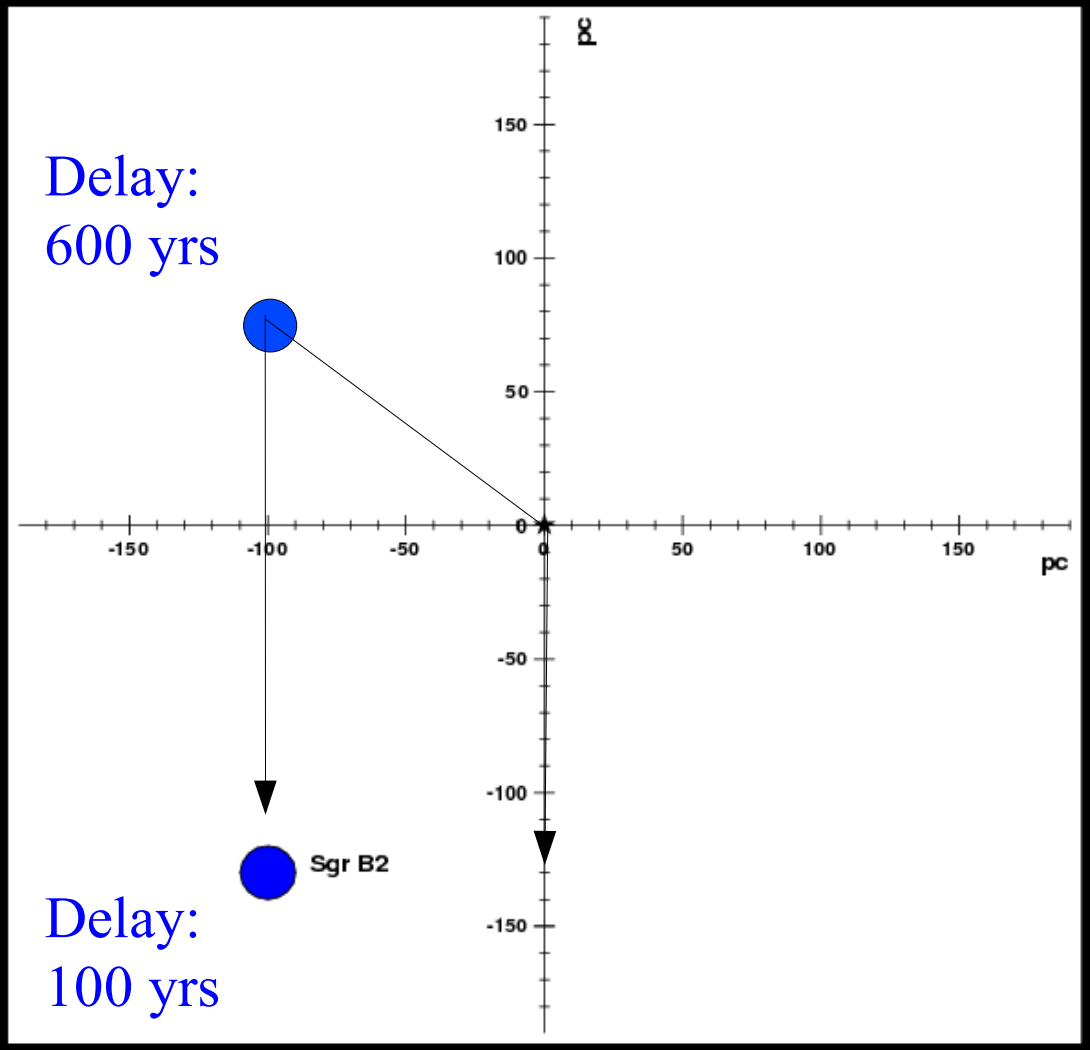


Origin : XRN/Compton echo ?

X-Ray Nebula – Compton echo:

Fluorescence and Compton scattering of bright source : Sgr A*?

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



Photons absorbed and scattered by cloud electrons

Fraction of absorbed photons above K-edge are reemitted in fluorescence line

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

Time variable!

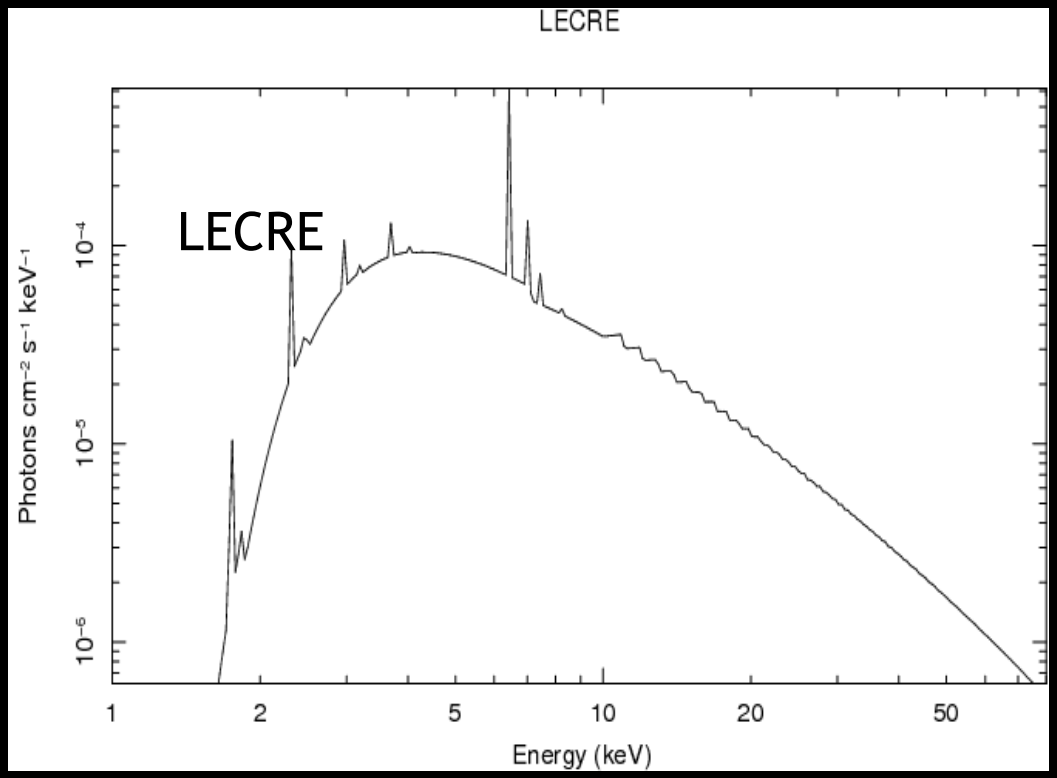
Origin : irradiation by Cosmic Rays?

Bremsstrahlung emission of low energy CR electrons (LECRE)

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

Inverse bremsstrahlung emission from sub-GeV protons in the CMZ

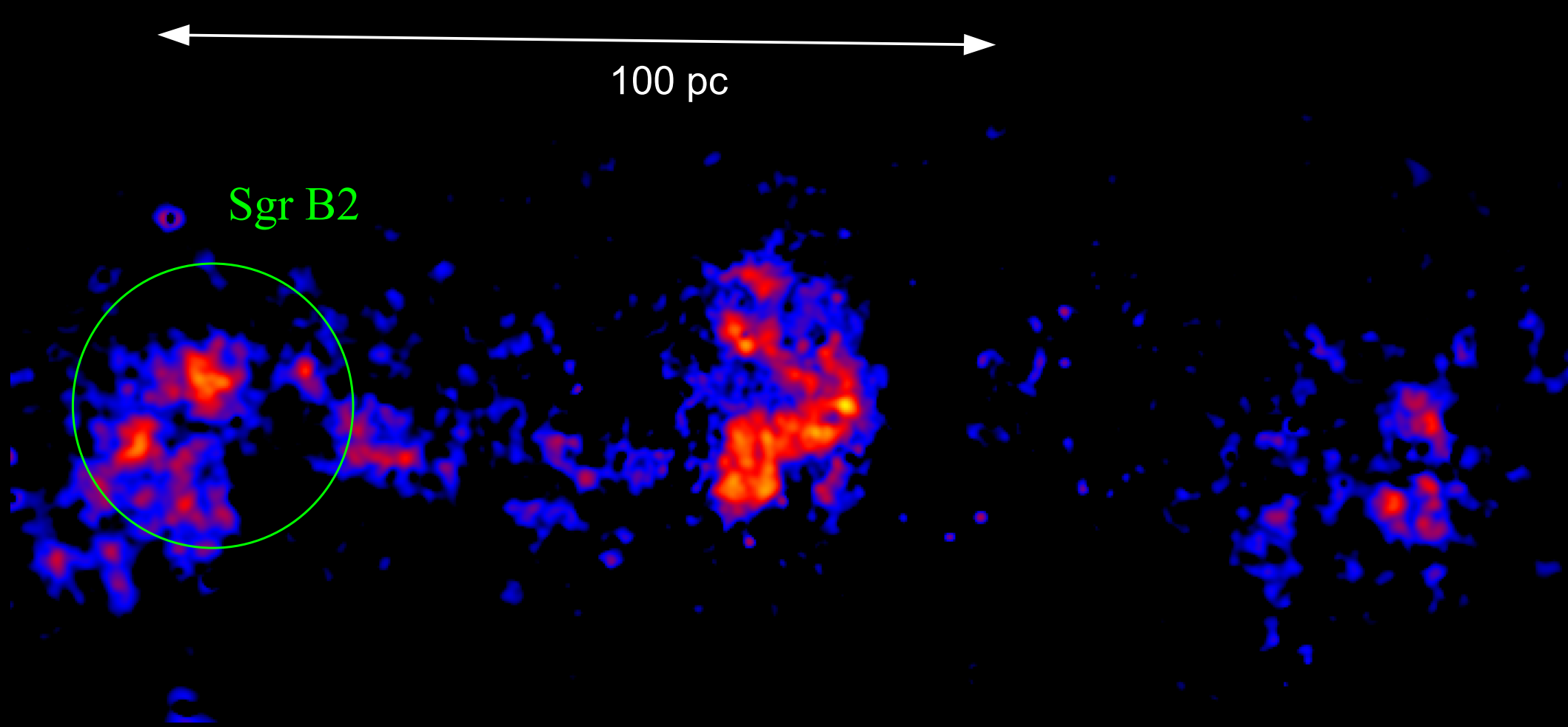
e.g. Dogiel et al (2009)



- Much lower 6.4 keV line EW than observed (~2 keV in Sgr B2)
  Requires large metallicities
- Small K edge

See F. Yusef-Zadeh talk this afternoon

Non-thermal emission from the CMZ



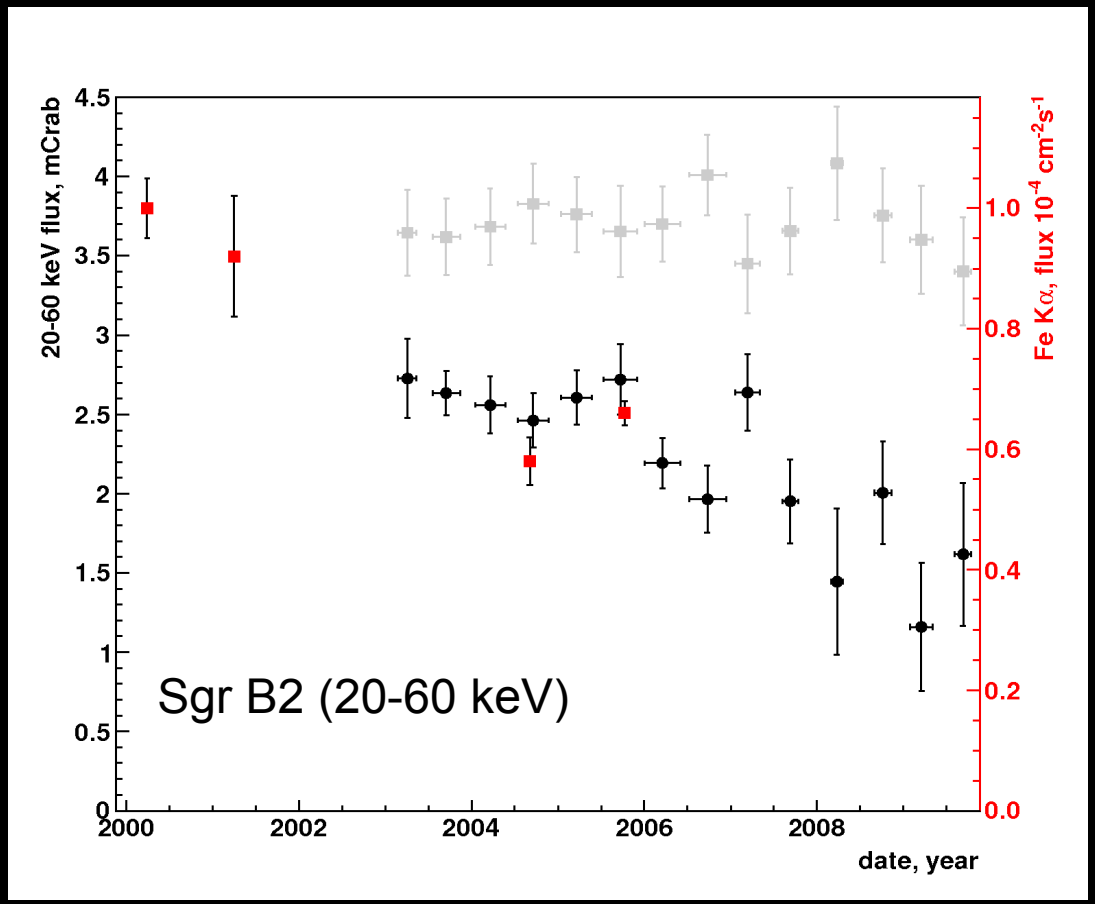
Time variability in the Sgr B2 cloud?

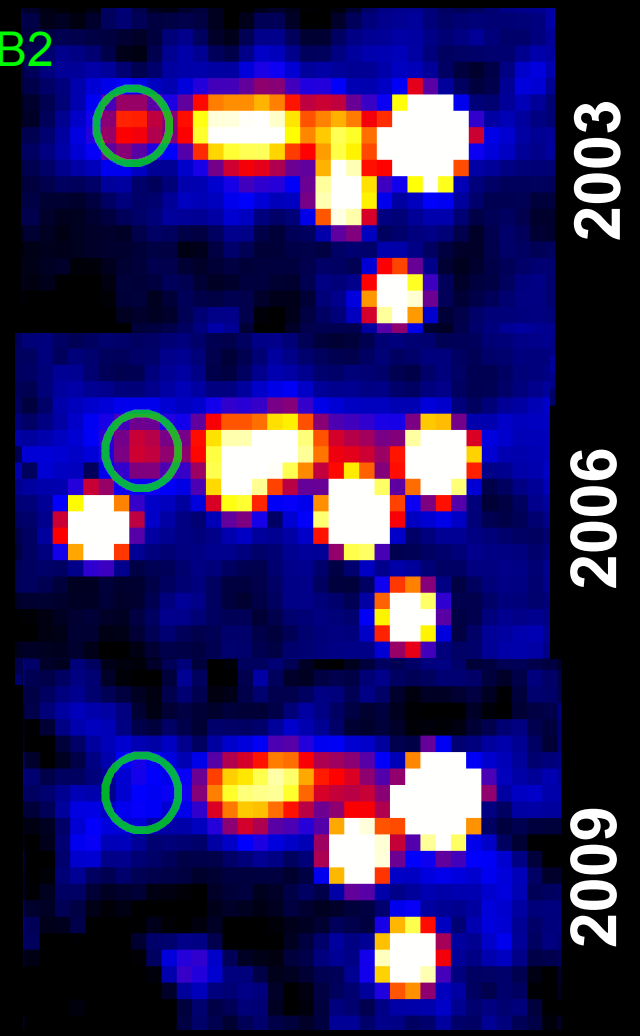
Hard X-ray emission from Sgr B2 is fading!

Flux has decreased by ~40% in 7 years

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

Illumination by Sgr A* requires $L \sim 10^{39}$ erg/s for 5-10 yrs





Integral IBIS/Isgri : 20-60 keV

Fe Kα from Inui et al (2009)

Terrier et al. (2010)

Hard X-ray emission from Sgr B2 is fading!

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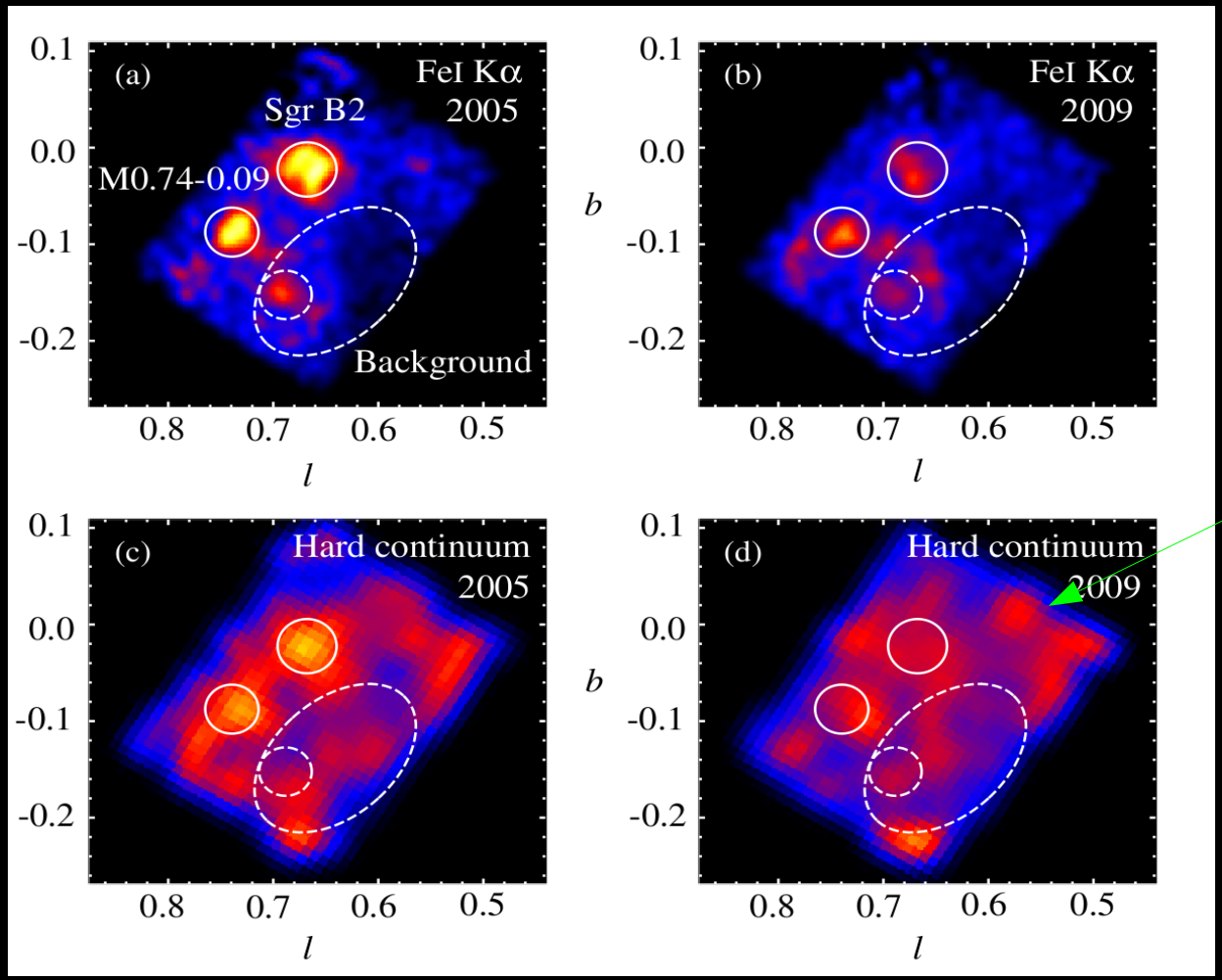
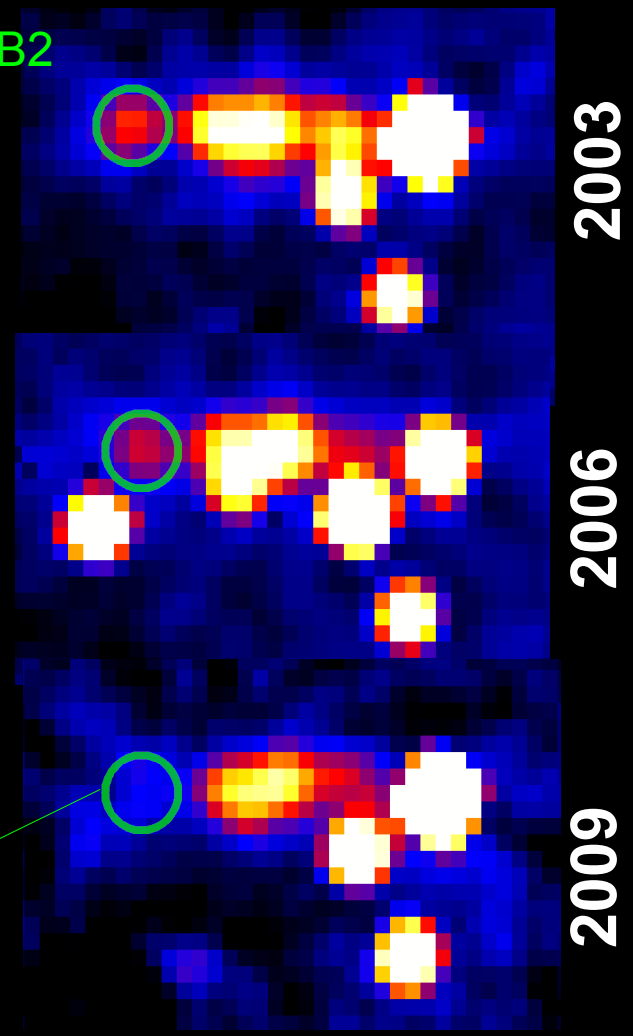
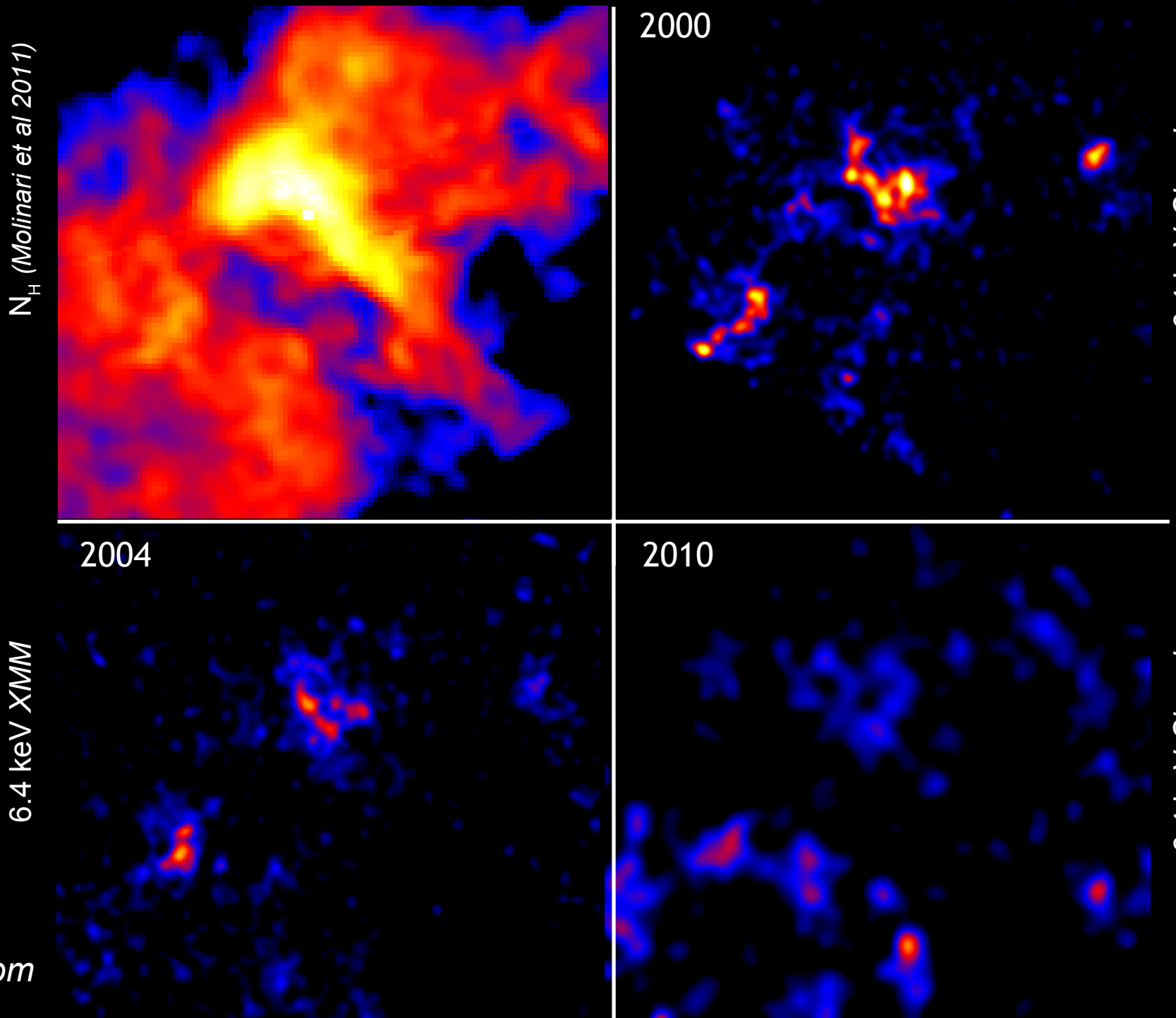




Integral IBIS/Isgri :
20-60 keV

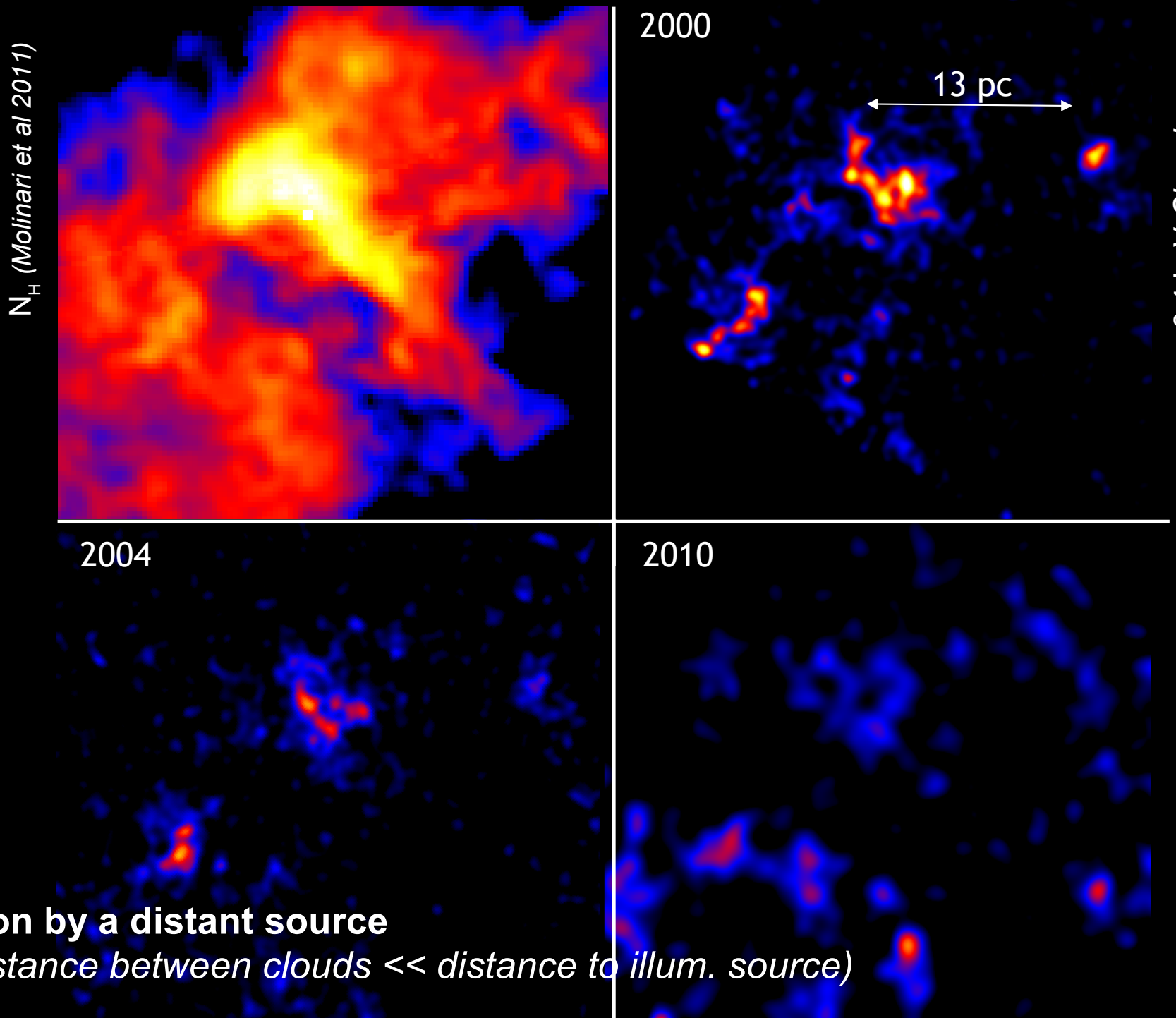
Suzaku
Nobukawa et al. (2011)

Resolving Sgr B2 Fe Kα emission over 10 yrs



Terrier et al. subm

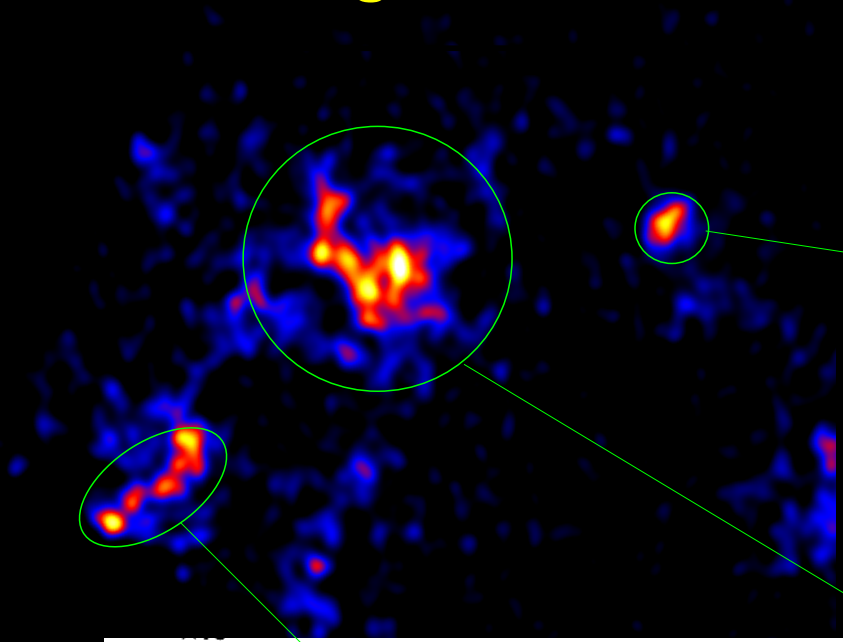
Fe Kα decay in regions separated by more than 20 pc

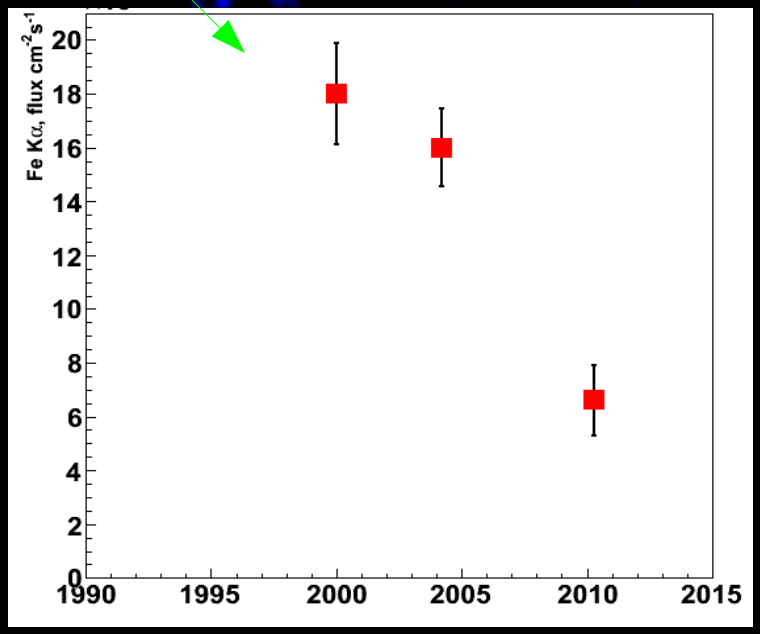


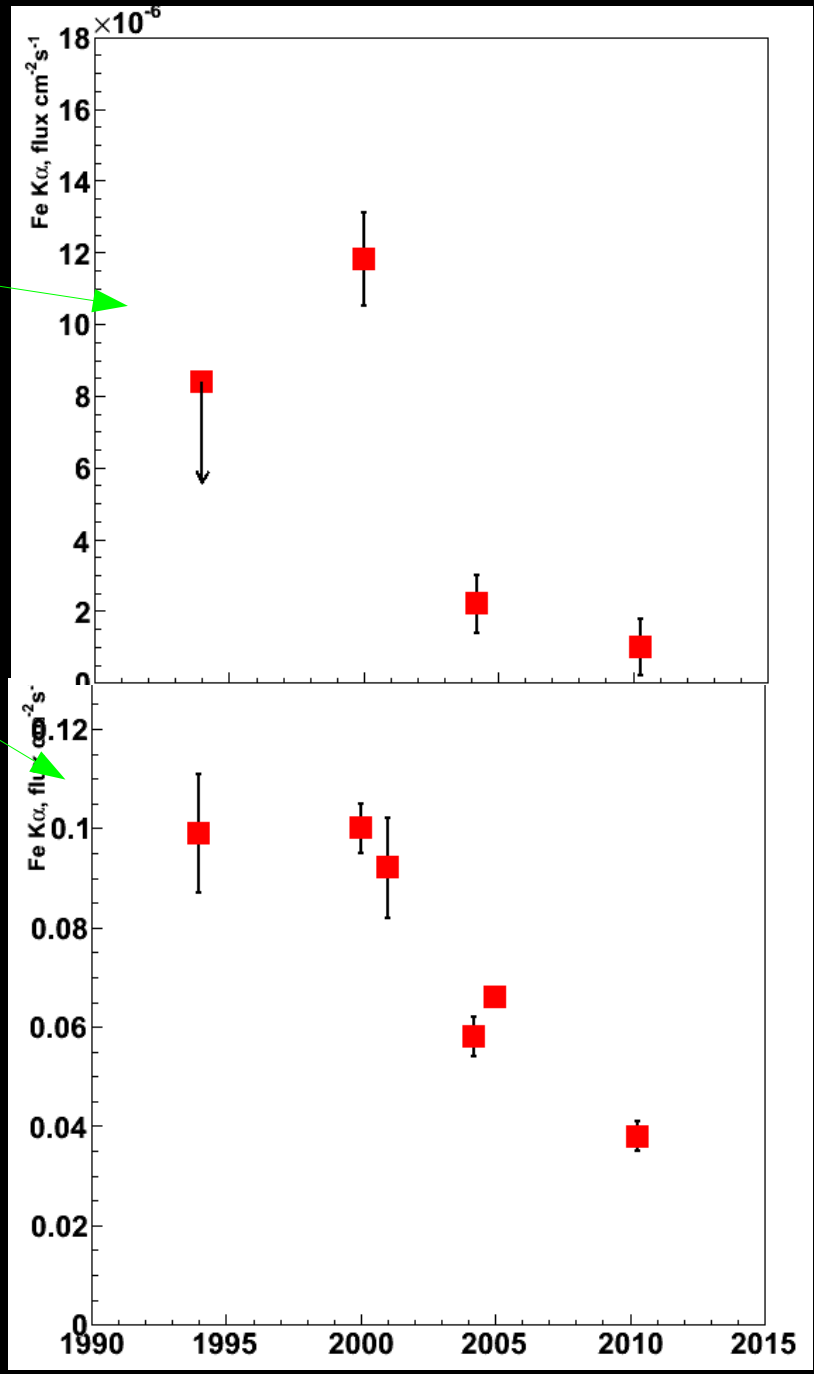
Illumination by a distant source

(i.e. typical distance between clouds << distance to illum. source)

Sgr B2 Fe Kα emission over 10 yrs







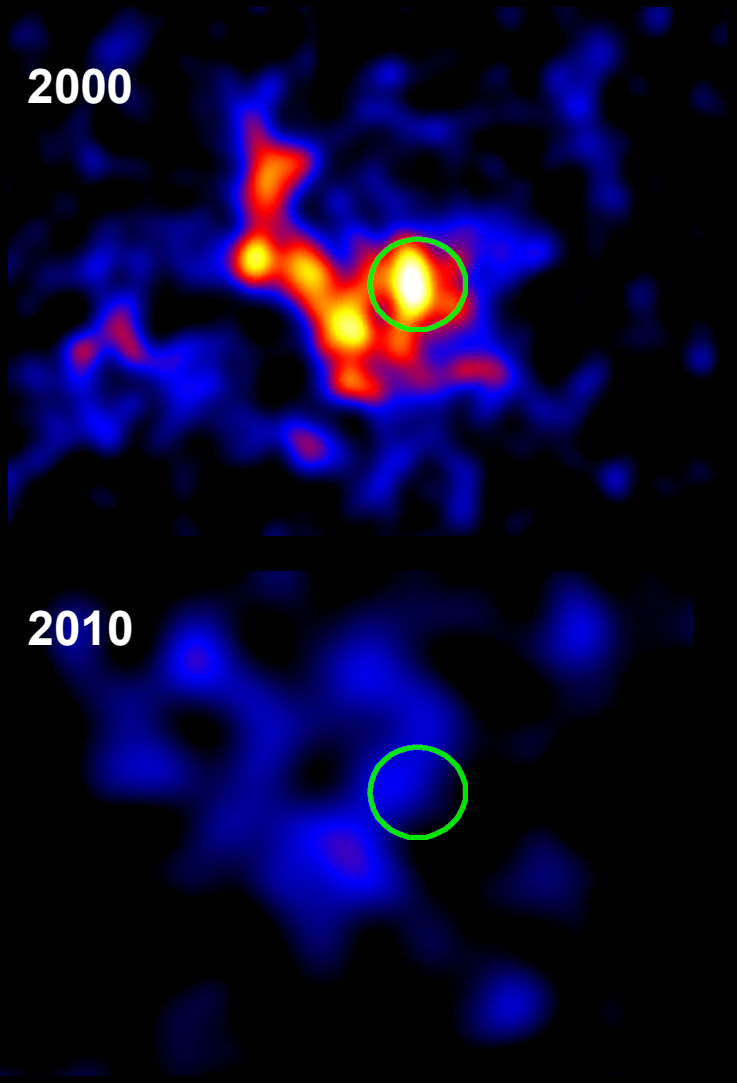
The regions closer to the GC decay earlier

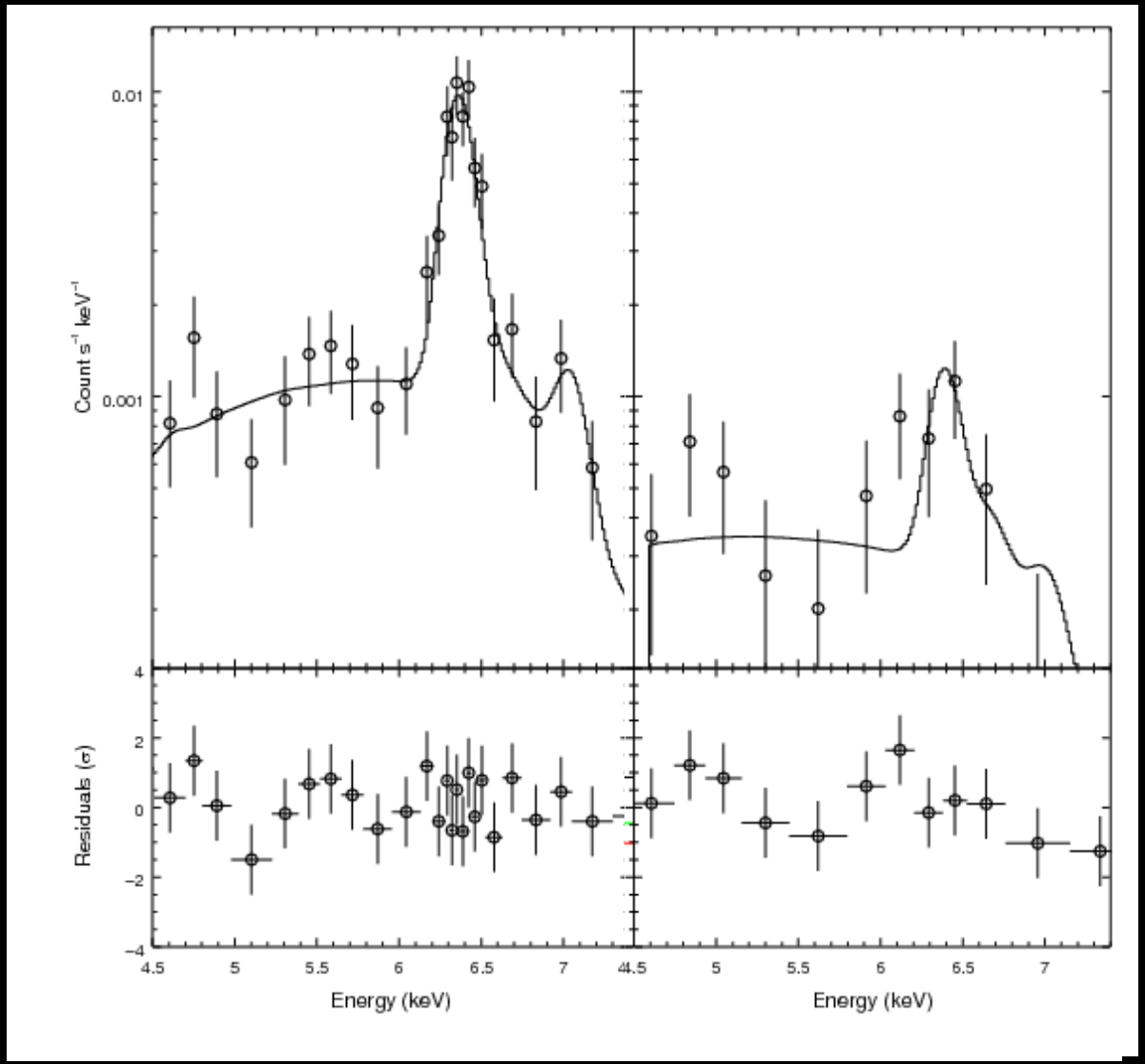
Illumination comes from the inner GC regions

Rapid small scale variations in Sgr B2 core

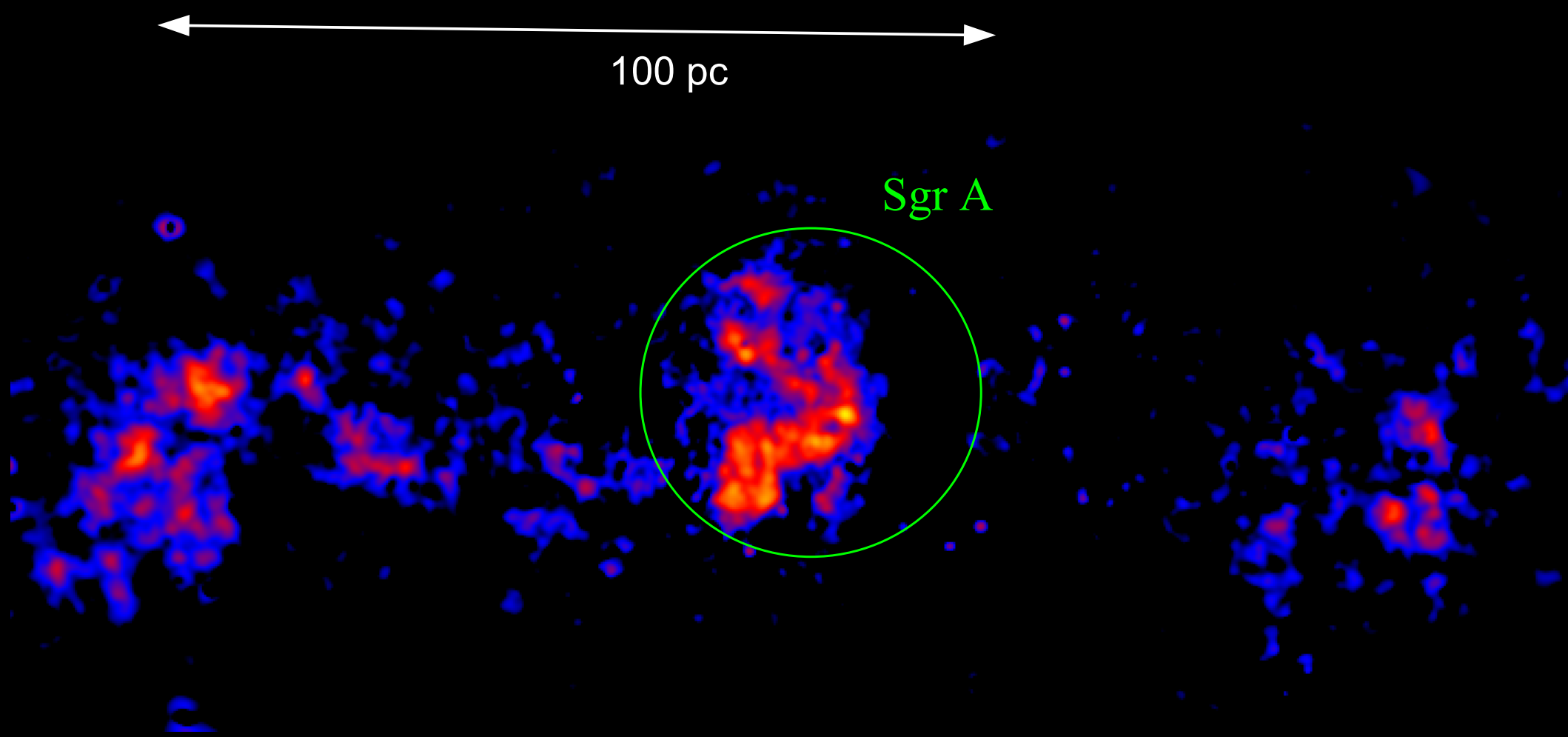
Flux decay in small (1', ~ 2 pc) regions up to a factor of 8 in 10 yrs

Rapid flux decay of the illuminating source





Non-thermal emission from the CMZ



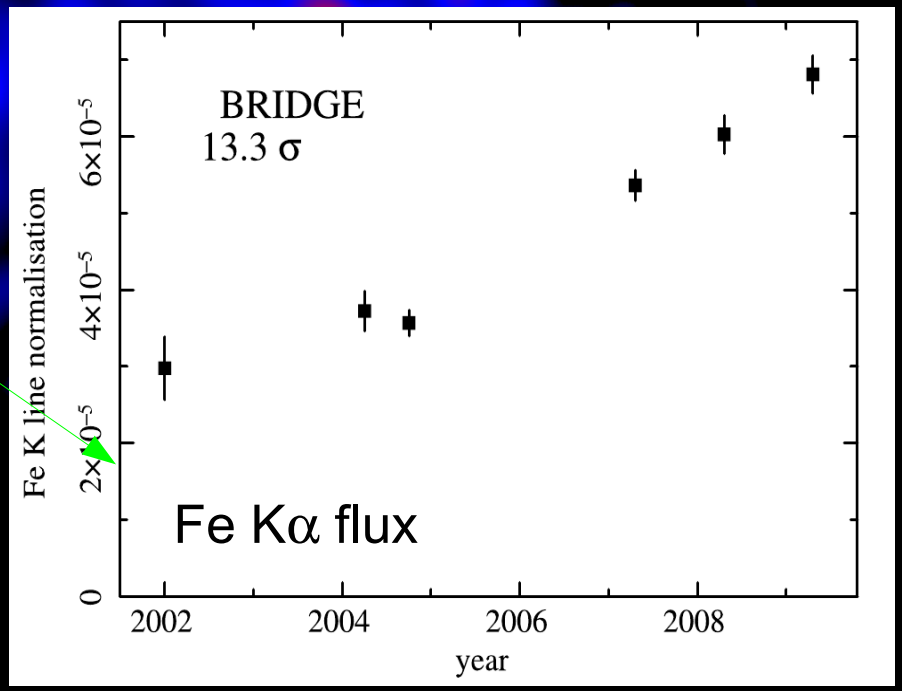
Time variability in the Sgr A complex?

Variations in the Sgr A complex

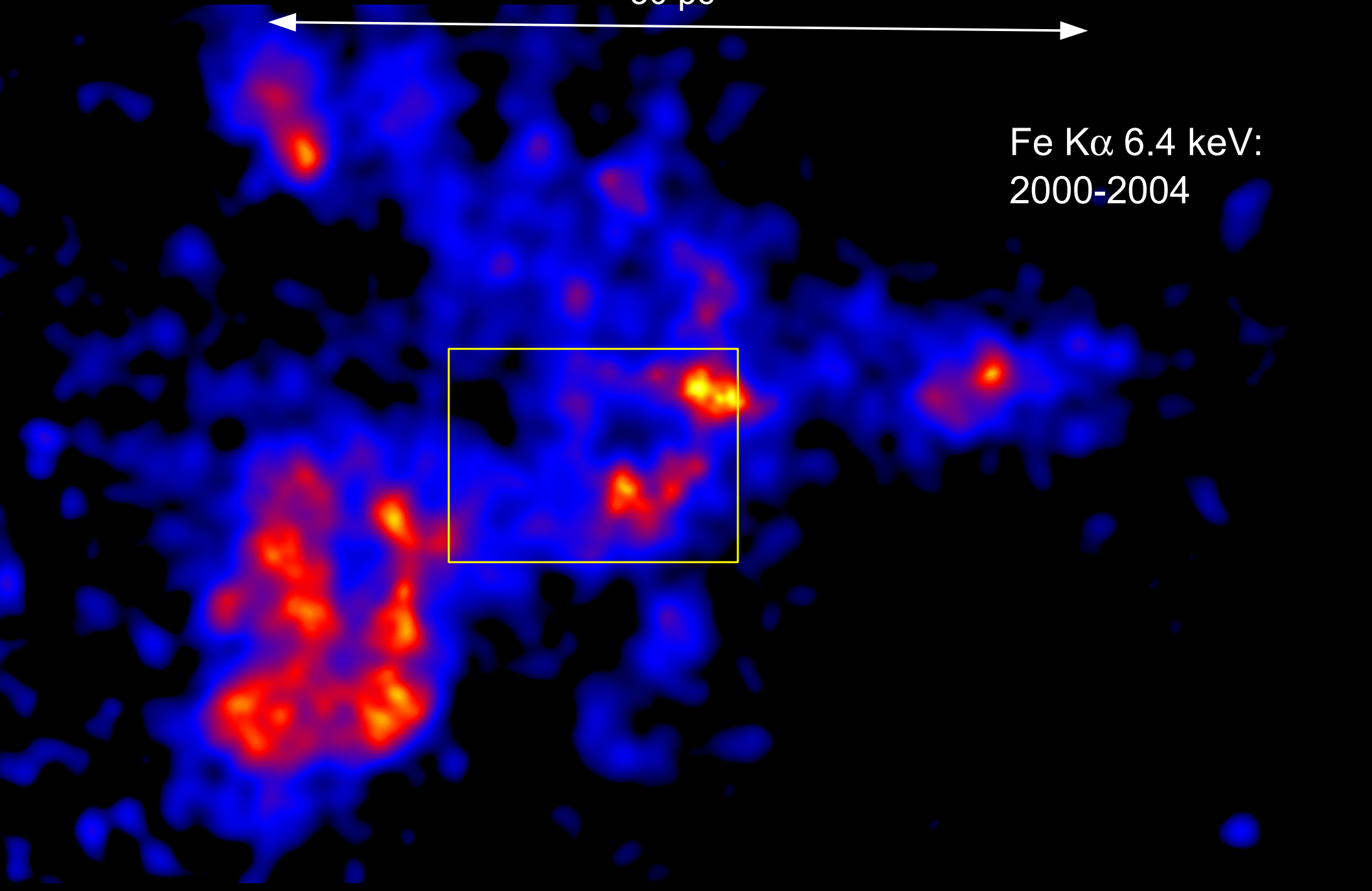
30 pc

Fe Kα 6.4 keV:
2000-2004

Bridge



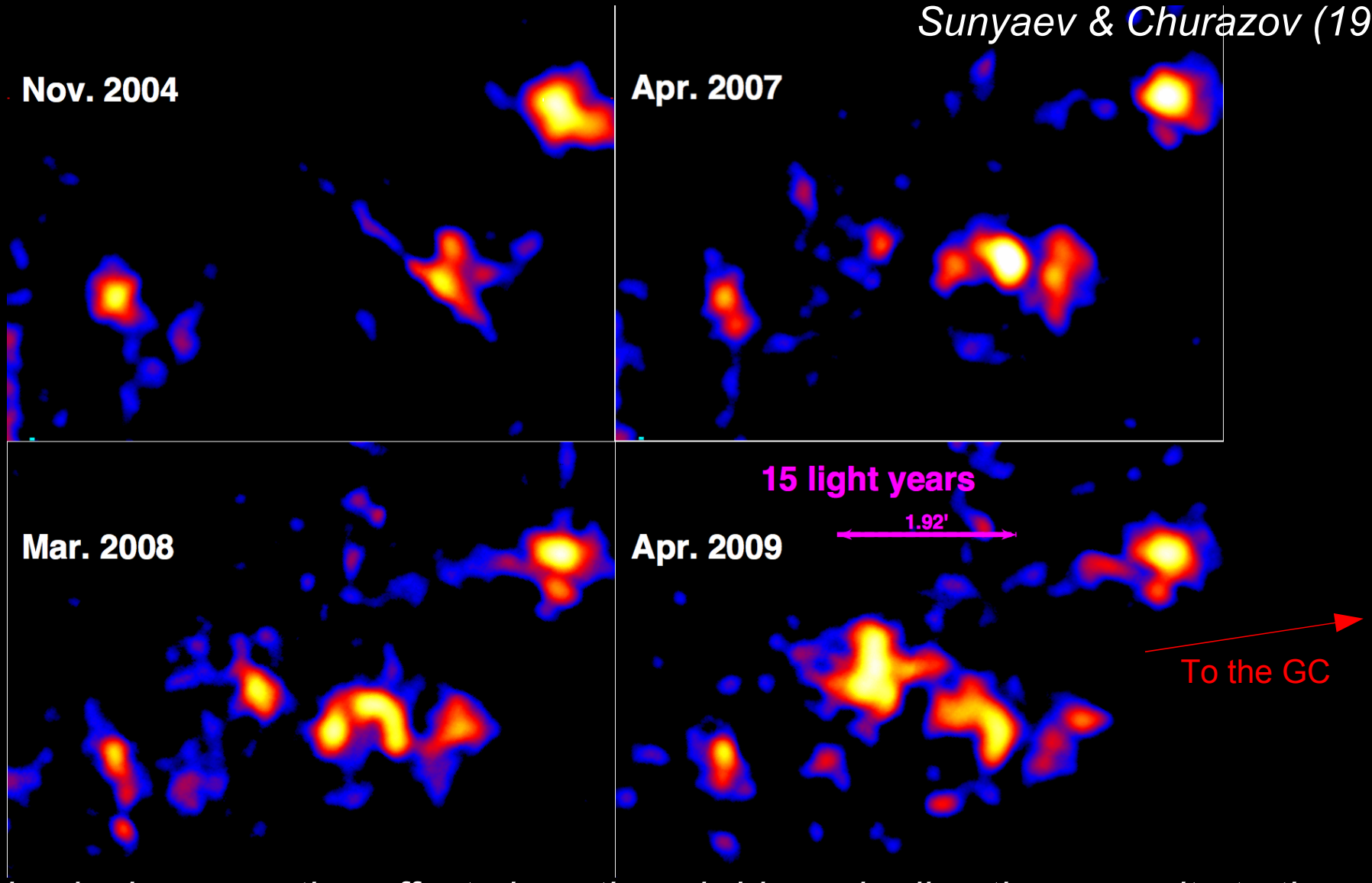
Some propagation effects?



Apparent superluminal motion

Apparent superluminal effects expected in XRN

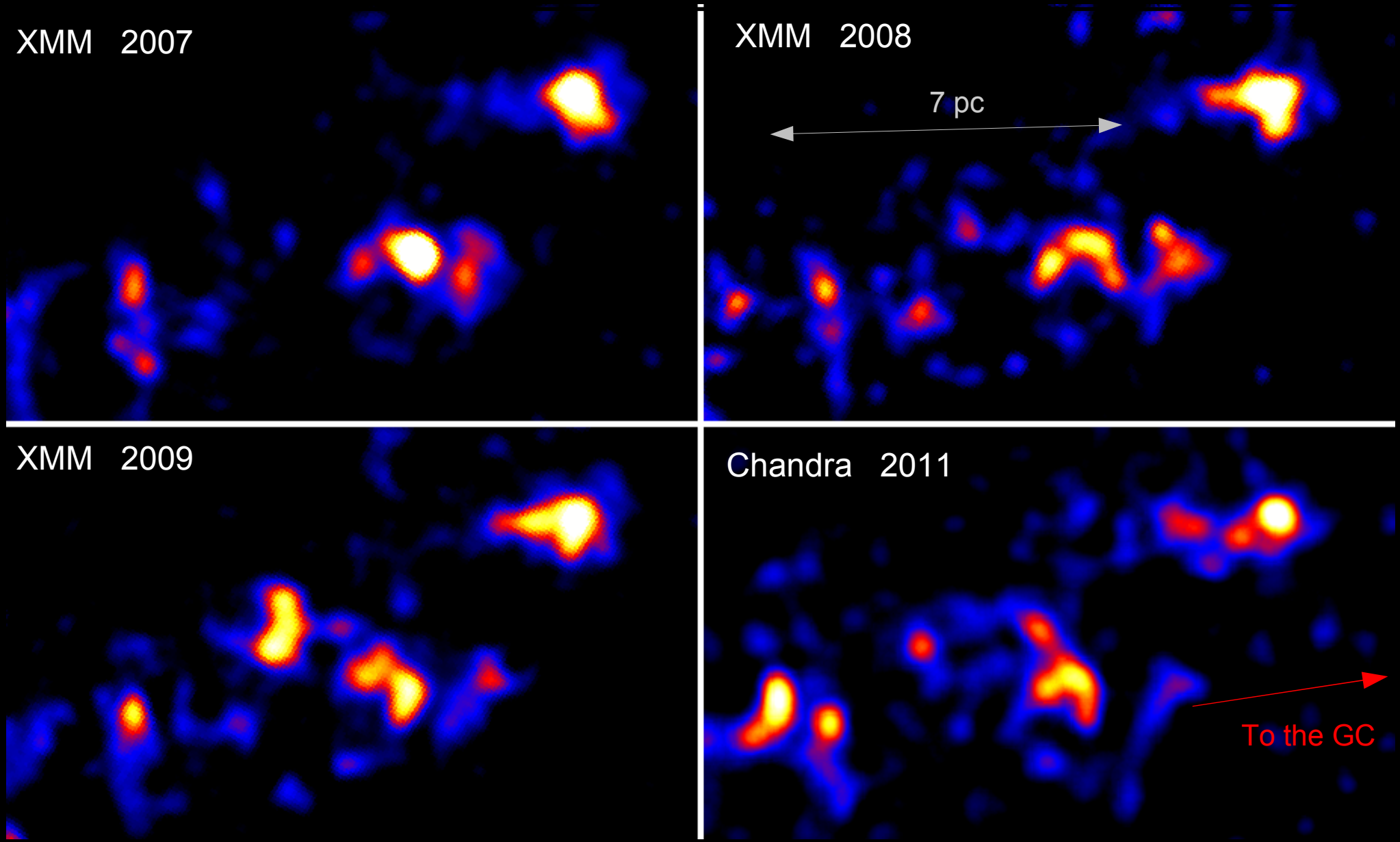
Sunyaev & Churazov (1998)



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

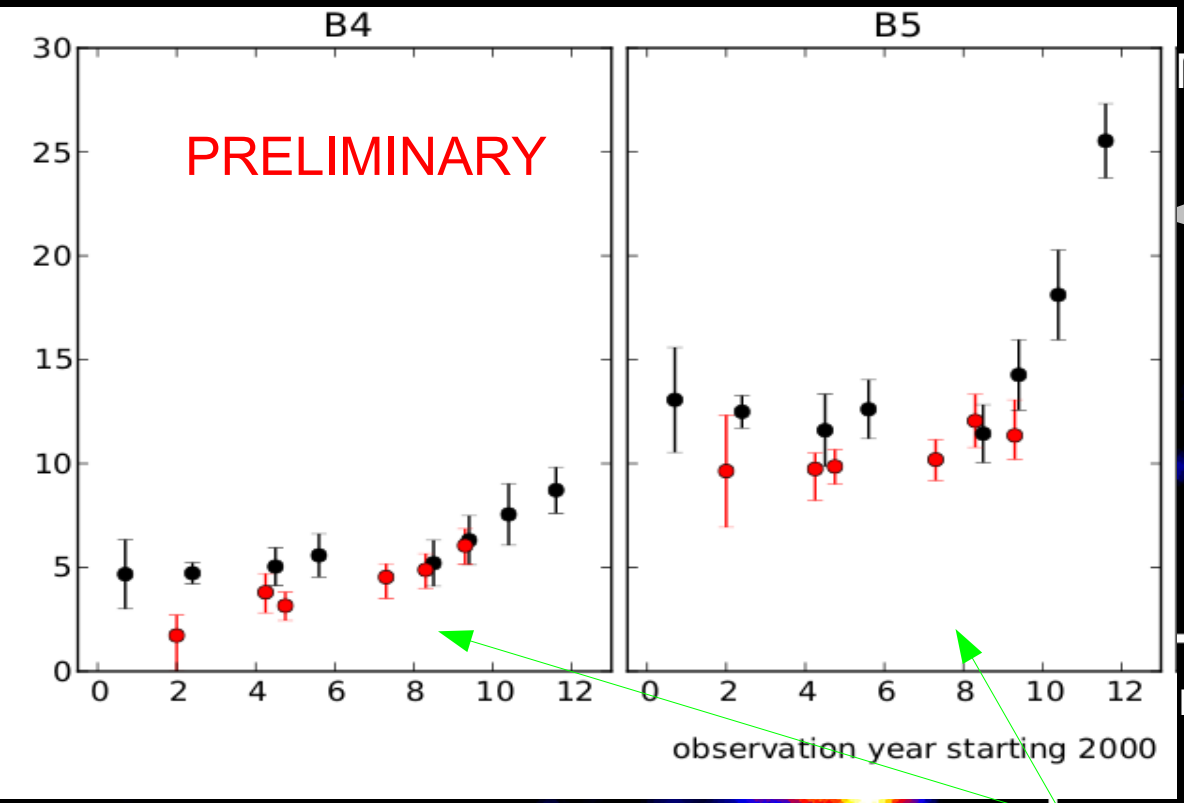
Ponti et al. (2010)

Sgr A bridge region with Chandra in 2011



Propagation along bridge structure confirmed

Sgr A bridge region with Chandra in 2011



M 2008

7 pc

ndra 2011

To the GC

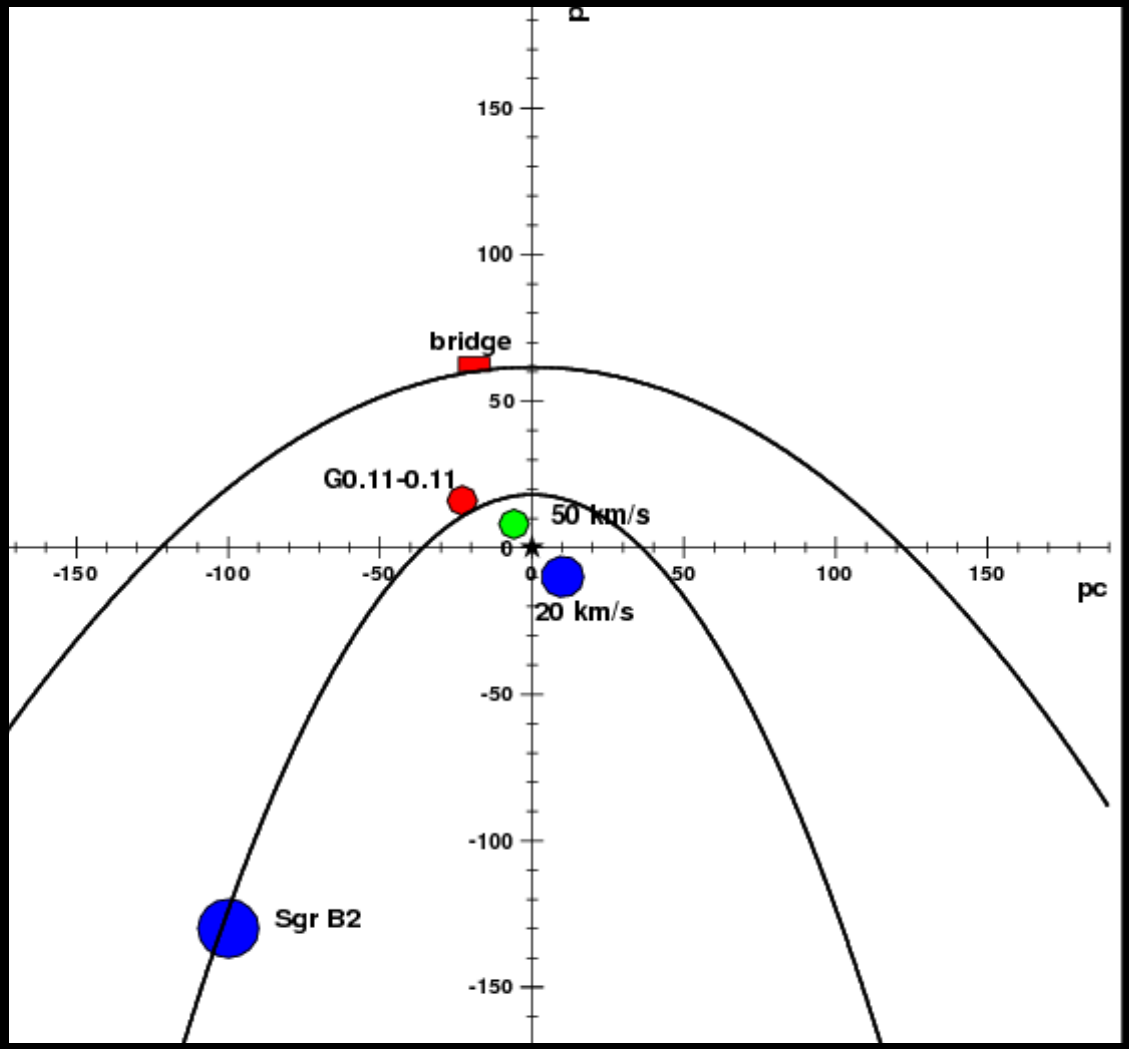
Propagation along bridge structure confirmed

Clavel et al. in prep

A possible scenario

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.

N_H~9 10^{22} cm^{-2}



Ponti et al. (2010)

One or several flares? see Capelli et al (2012)

Conclusions

- **Fe Kα 6.4 keV line emission in the CMZ is highly variable:**
  - Strong correlated decrease in several Sgr B2 clouds
  - Superluminal apparent propagation effect in the « bridge » confirmed
  - **GC molecular clouds reflect a past bright (~10^{39} erg/s for at least 10 yrs) period of activity from an object close to the GC: Sgr A*!**

- **Nature of stable emission in several regions?**
  - Illumination of the clouds less dense enveloppes?
  - Low energy cosmic-rays e.g. Near Arches cluster

(see Capelli et al., 2011, Tatischeff et al. 2012)

- **Sgr A* was more than 10^5 time brighter 100 ago**
  - Sgr A* was in a luminosity state similar to LLAGNs e.g. M81* $L_X = 10^{-5} L_{edd}$
  - Rapid decay ~ 100 yrs ago. Duration of the flare?
  - Impact in other energy ranges?

- **3D matter distribution is main uncertainty on Sgr A* lightcurve**
  - Are all 6.4 keV clouds illuminated by same event?
  - One or several flares?

e.g. Ponti et al. (2010), Capelli et al (2012)

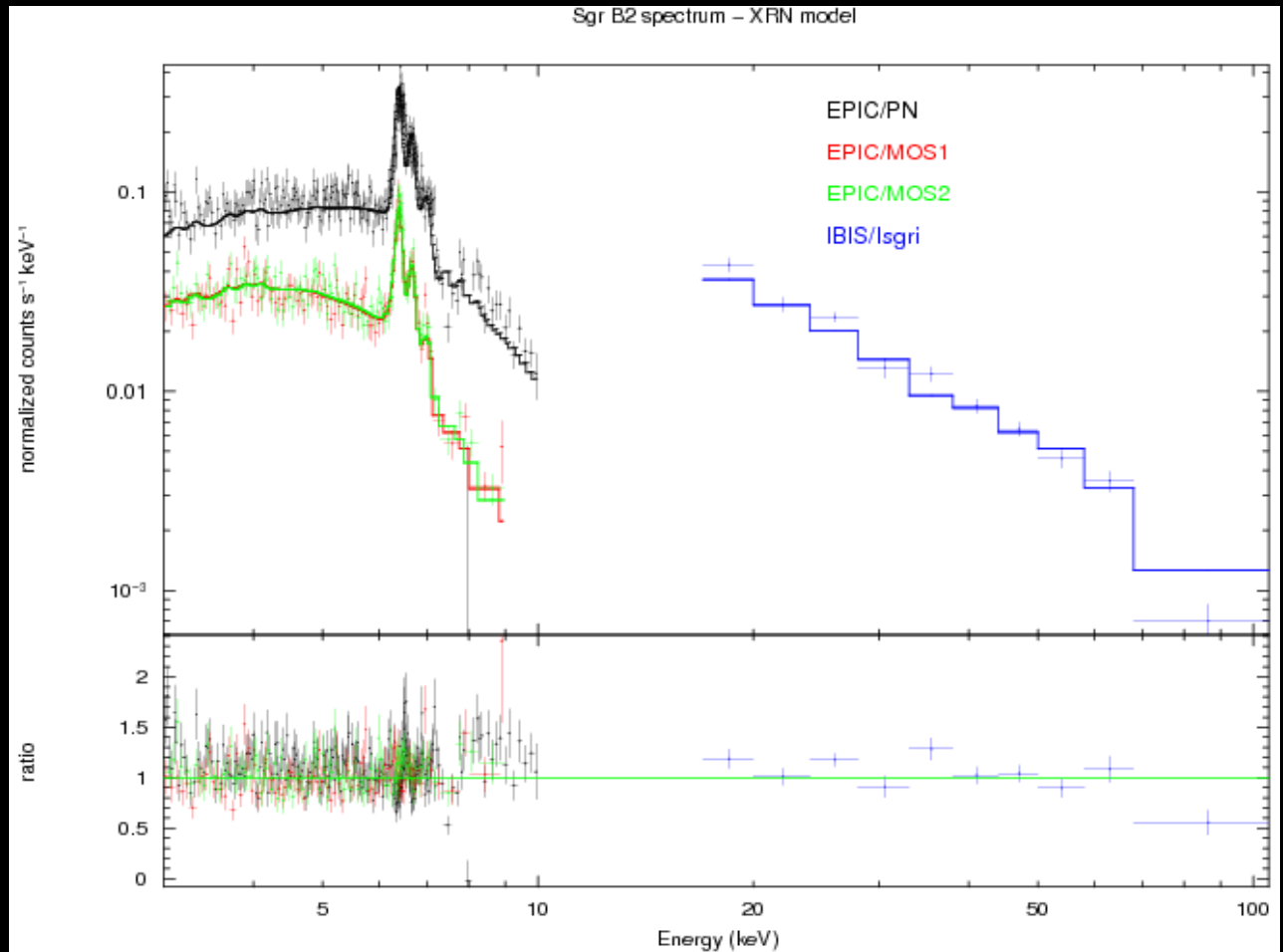
Sgr B2 : XMM/Integral spectrum (2004-2005)

Fit with XRN model using Lis & Goldsmith density profile

Γ =2 ± 0.2 *illuminating source spectral index*

A = 1.3 ± 0.1 *cloud metal abundance w.r.t. solar*

L_{rad} = 1.1 10^{39} (d/100 pc)^2 erg/s *illuminating source luminosity*



L_γ (20-100 keV) = 2 10^{35} erg/s

Some clouds see a flux decrease

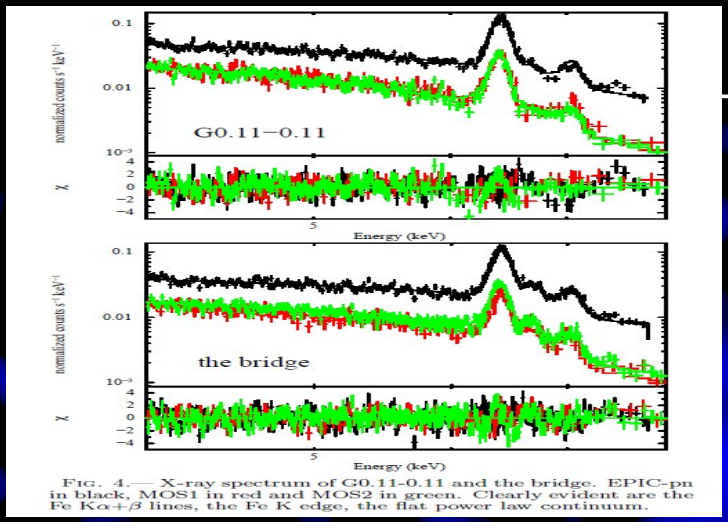
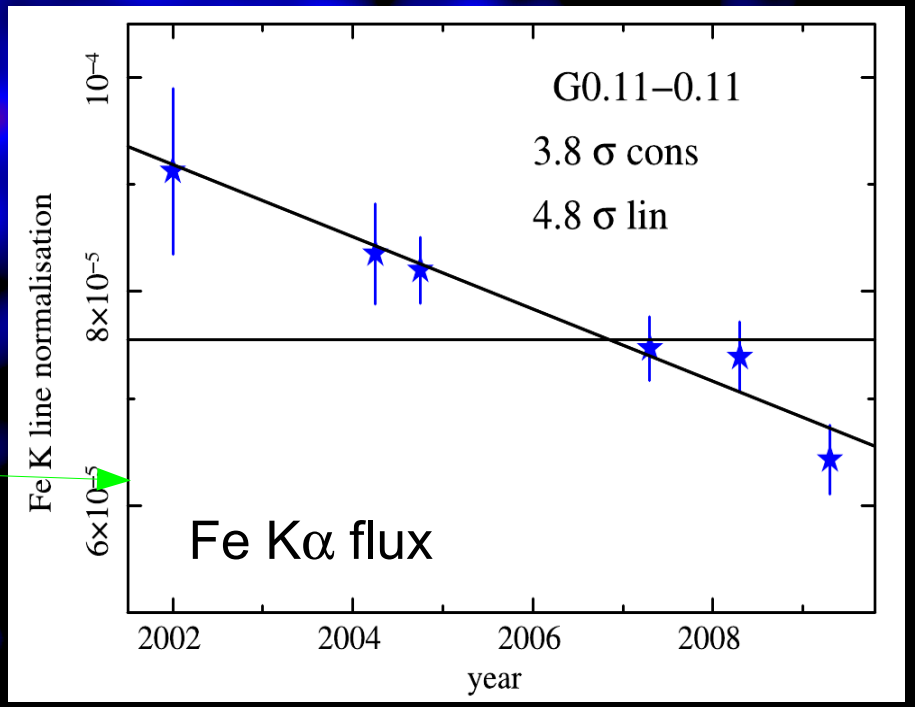


FIG. 4.— X-ray spectrum of G0.11-0.11 and the bridge. EPIC-pn in black, MOS1 in red and MOS2 in green. Clearly evident are the Fe Kα+β lines, the Fe K edge, the flat power law continuum.

30 pc

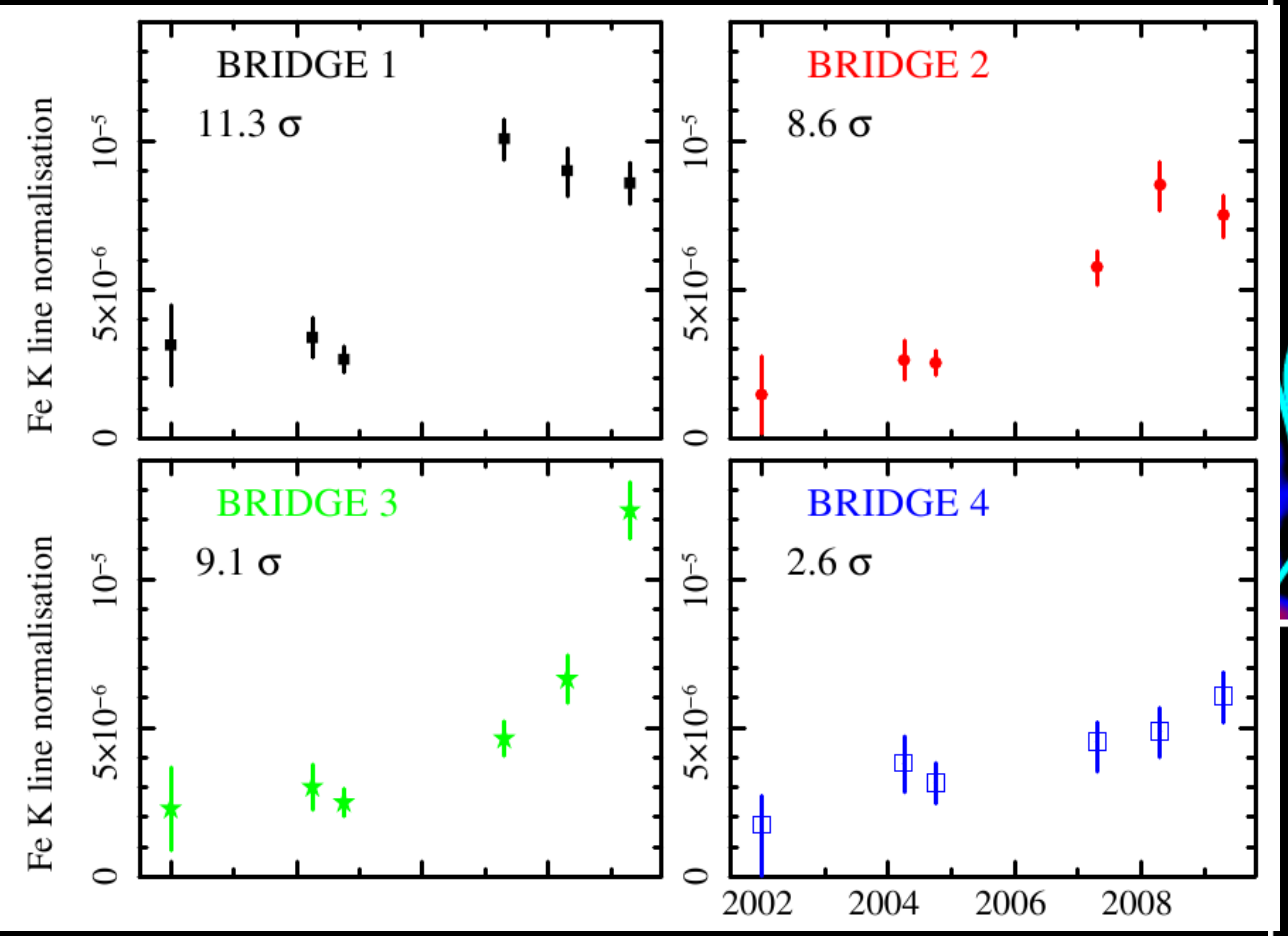
Fe Kα 6.4 keV:
2000-2004

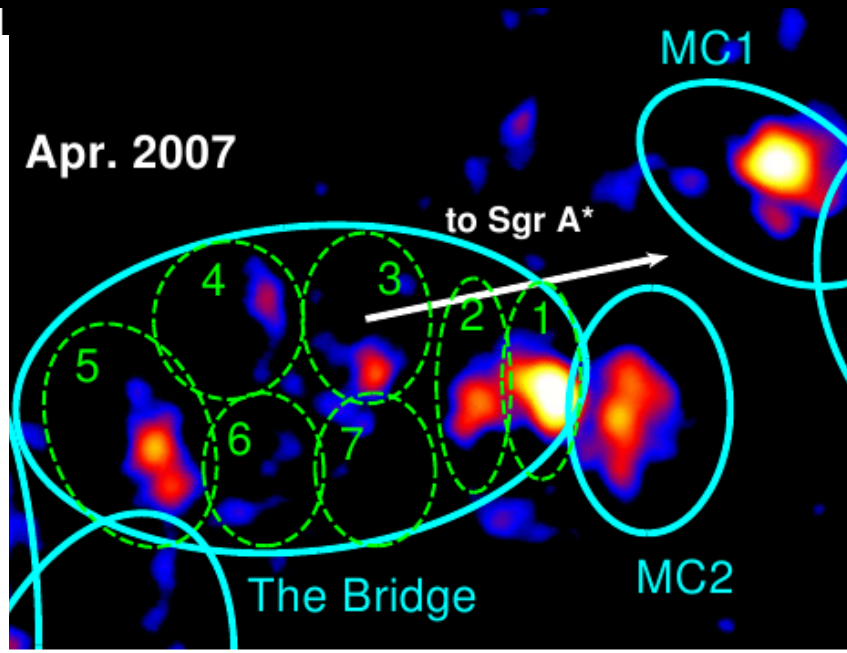
G0.11-0.11

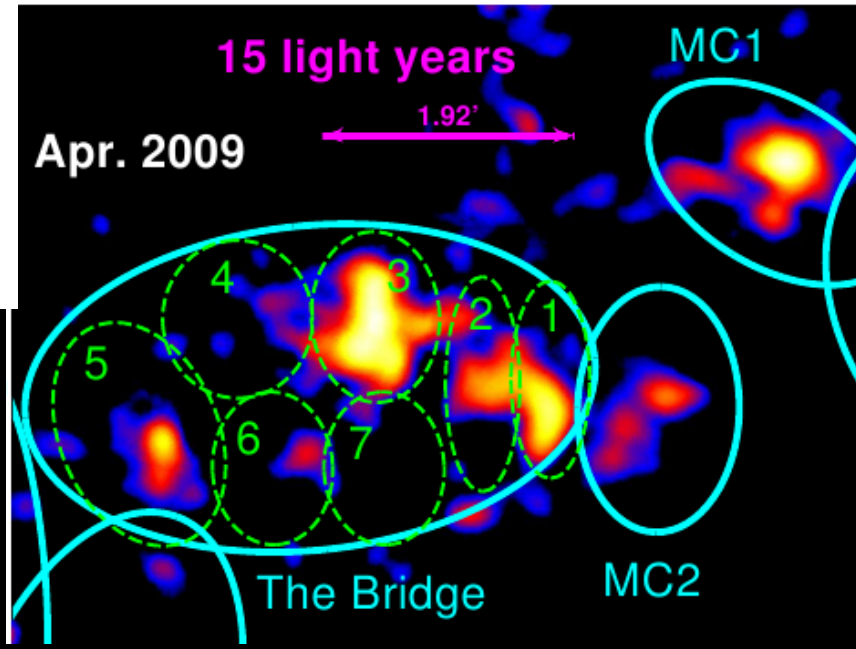


Spectral model: wabs(apec + edge*(PL + gaus + gaus))

Apparent superluminal motion







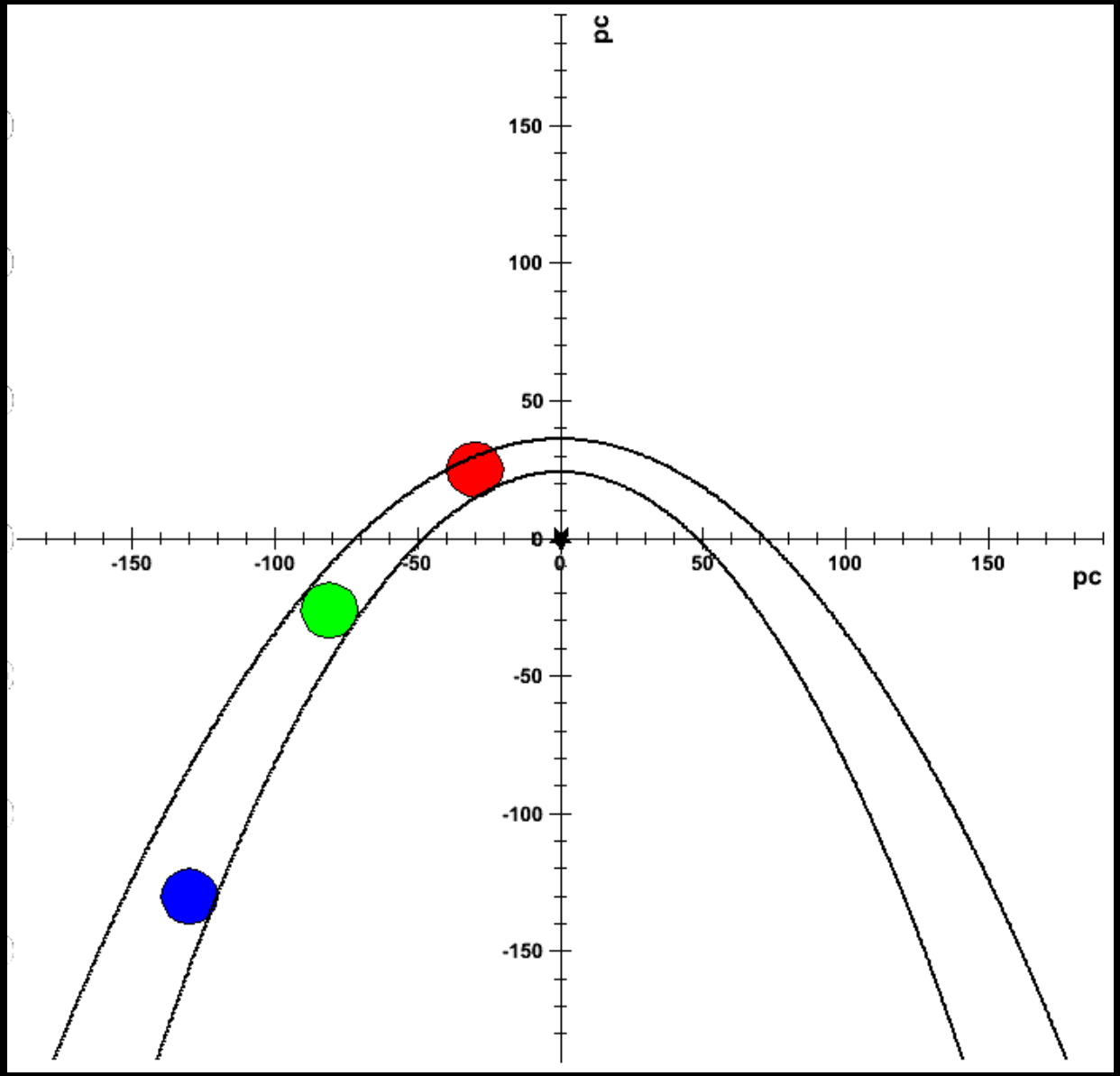
Propagation effect along the « bridge » in direction opposite to the Galactic centre.

Ponti et al. (2010)

Apparent superluminal motion?

Effect discussed by Sunyaev & Churazov (1998)

Curves of constant delay (isochrons) : parabola



Apparent light crossing times:

120 yrs
70 yrs
45 yrs