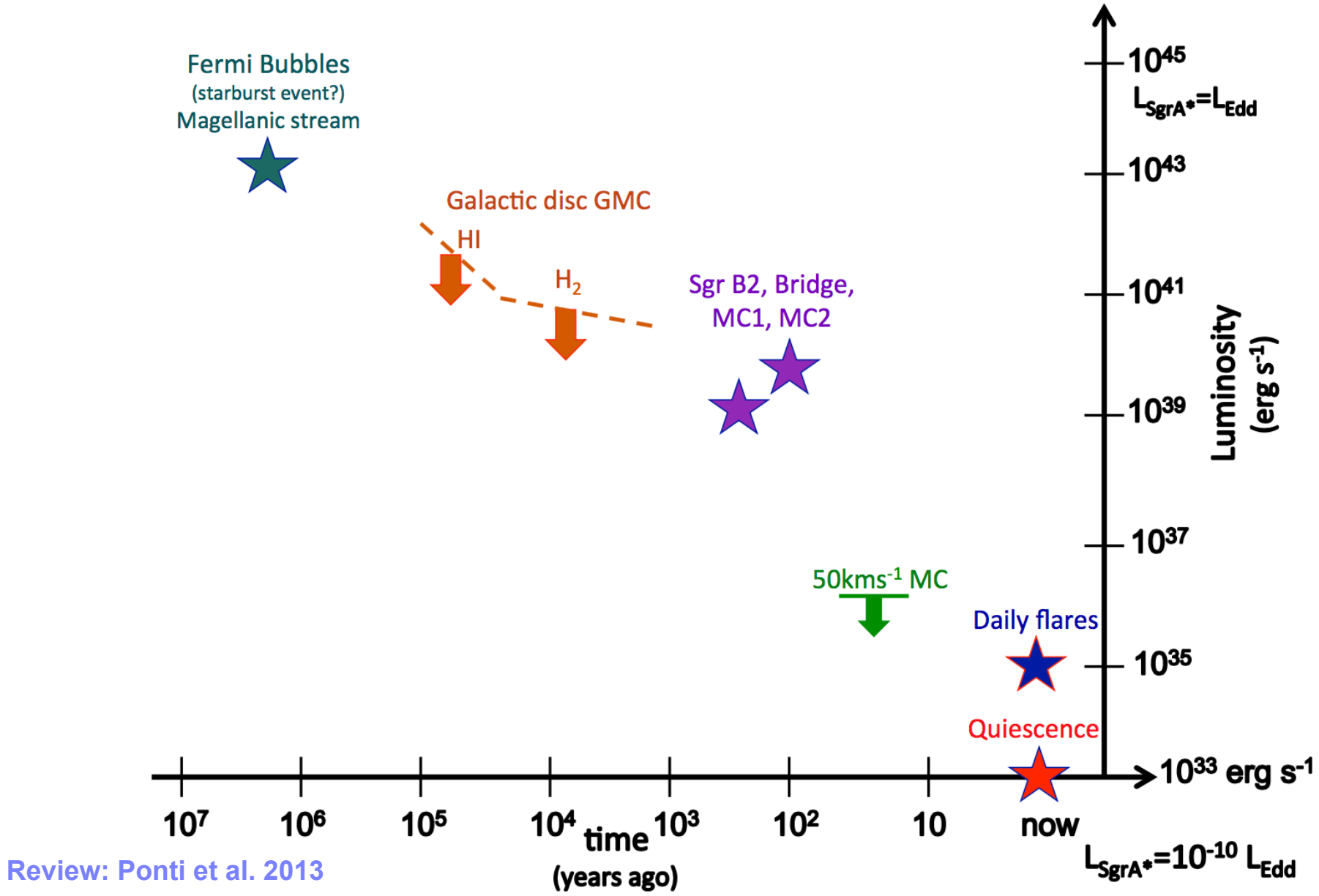
Past Galactic center activity



Review: Ponti et al. 2013

Gabriele Ponti (MPE Garching)

Morris, Terrier, Goldwurm

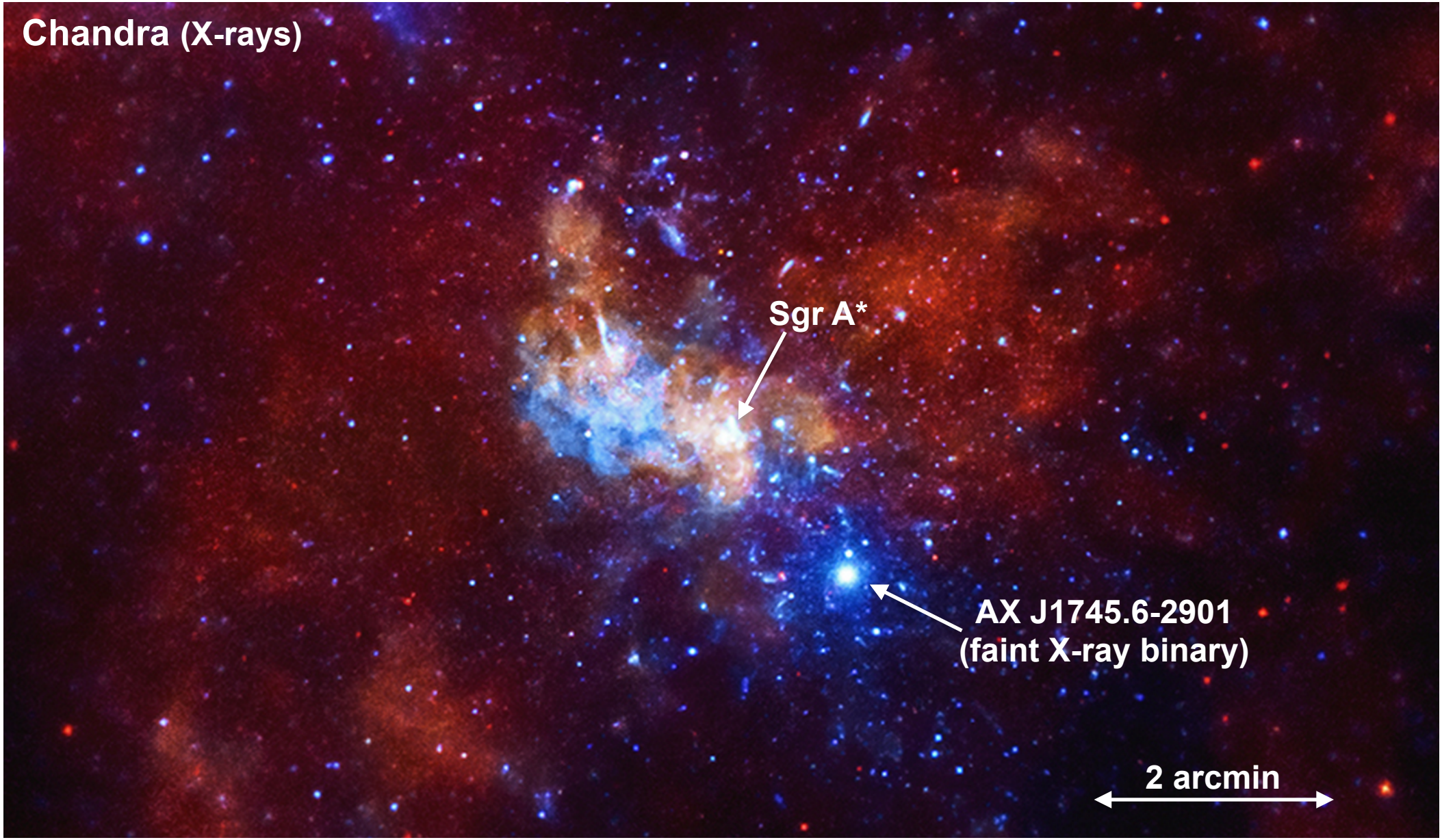
Sgr A today: a dormant AGN*

$M_{Sgr\ A^*} = 4.4 \times 10^6\ M_{Sun}$

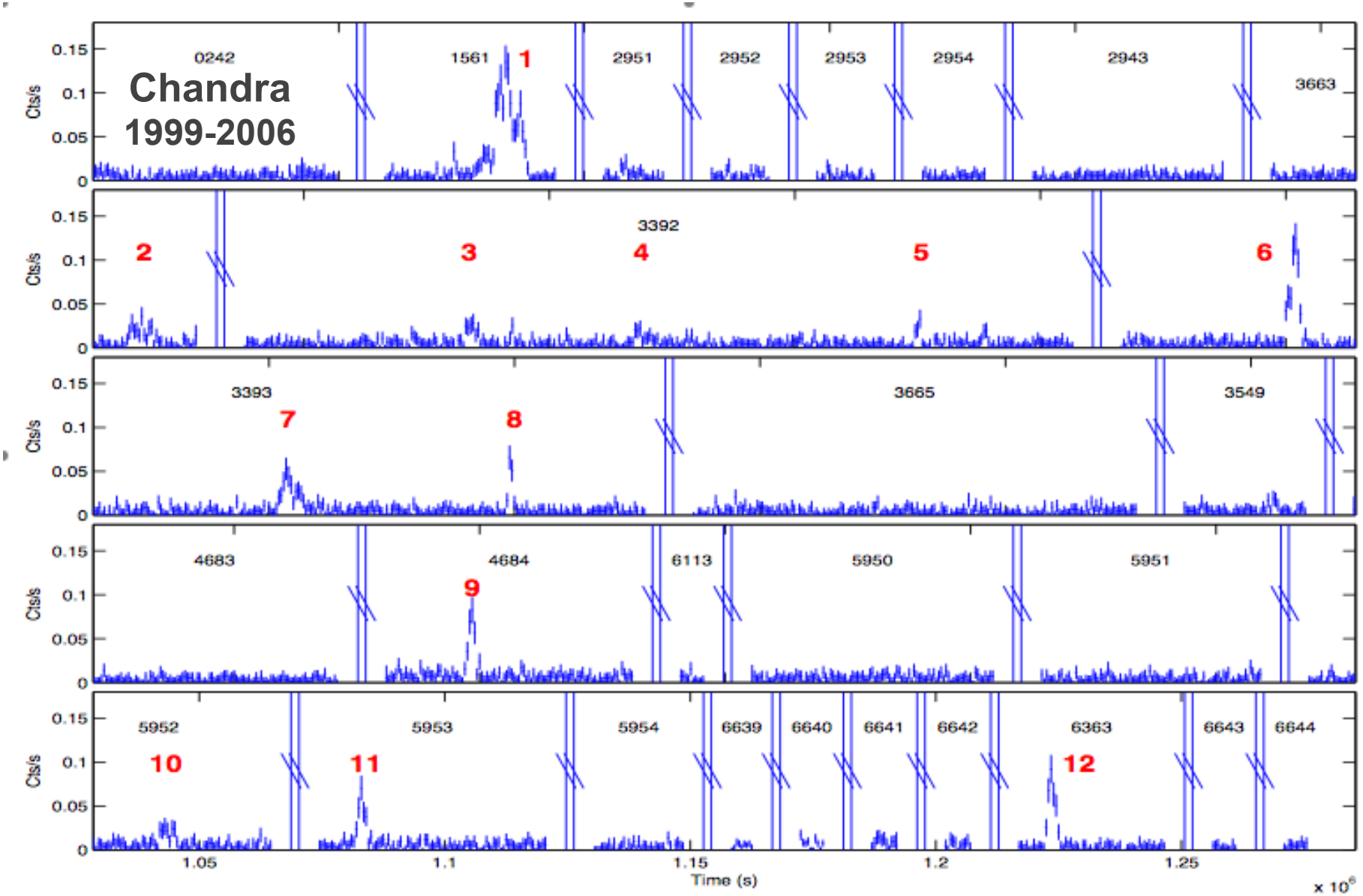
$L_{Sgr\ A^*} = 3 \times 10^{33} - 10^{35}\ erg\ s^{-1}$

$L_{Edd} = 5 \times 10^{44}\ erg\ s^{-1}$

$\eta \sim 10^{-9}$



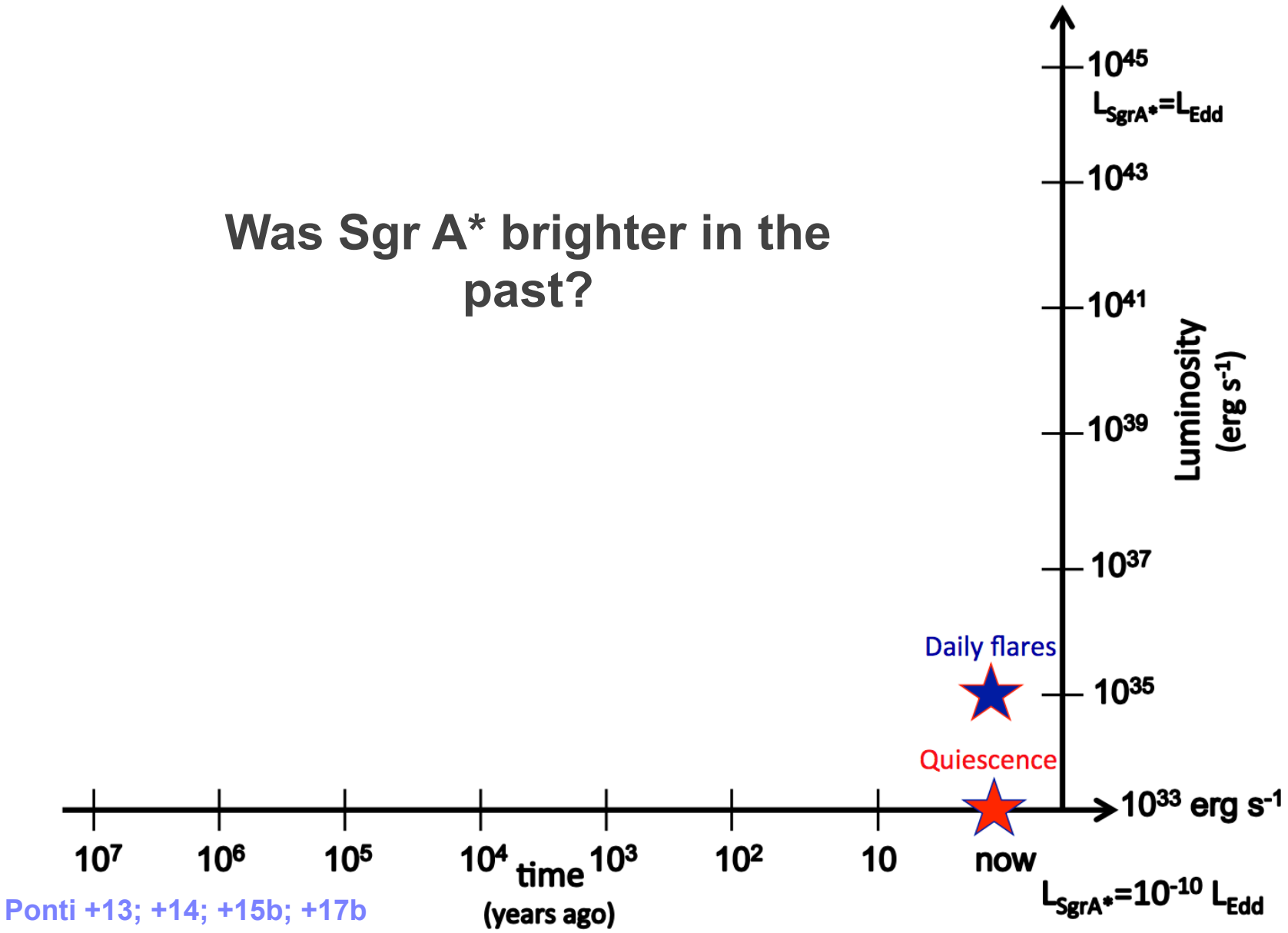
*X-ray light curve of Sgr A**



Baganoff +01; Goldwurm +03; Porquet +03; 08; Nowak +12; Neilsen +13; Barriere +14

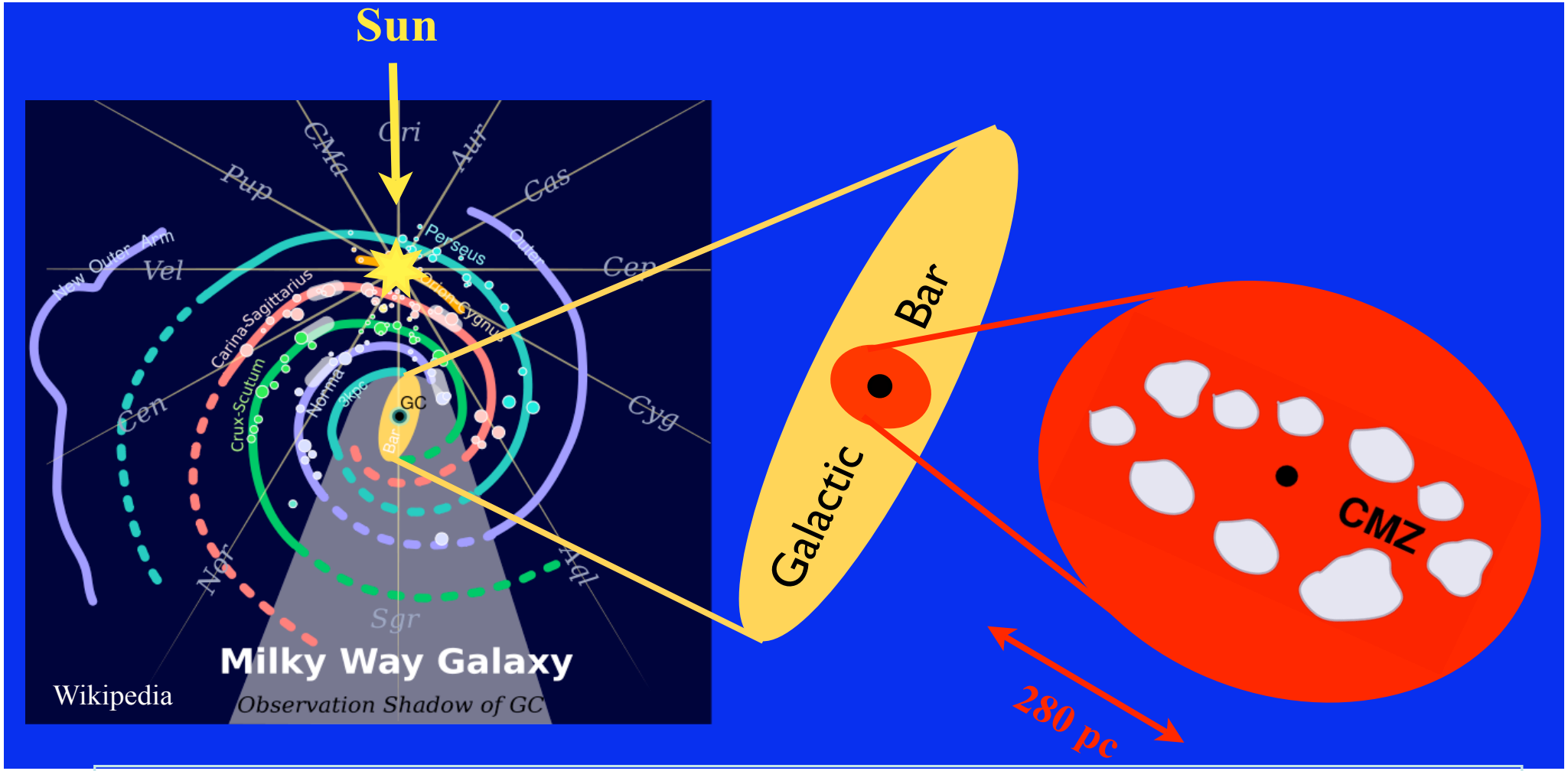
X-ray flares: • up to 100 fold • ~ 1 day^{-1} • up to few hours ➜ Few r_g from BH

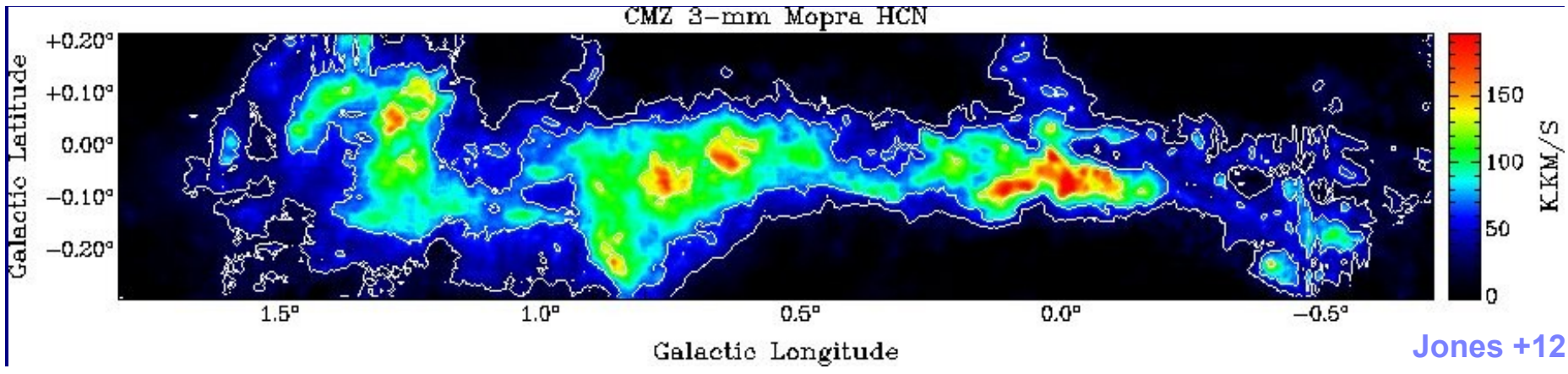
Sgr A's activity*



The Central Molecular Zone

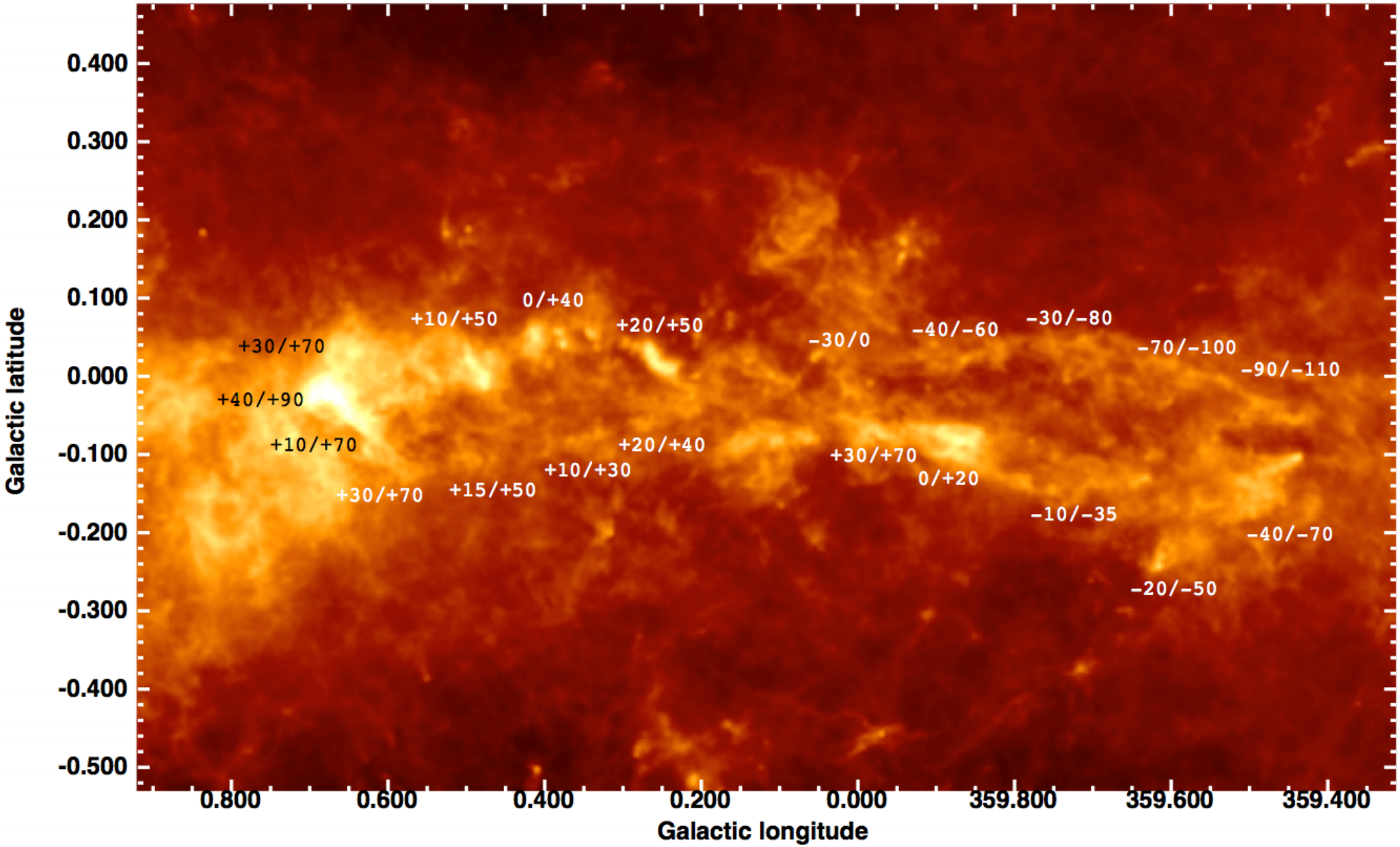
Wikipedia





Herschel map of the CMZ

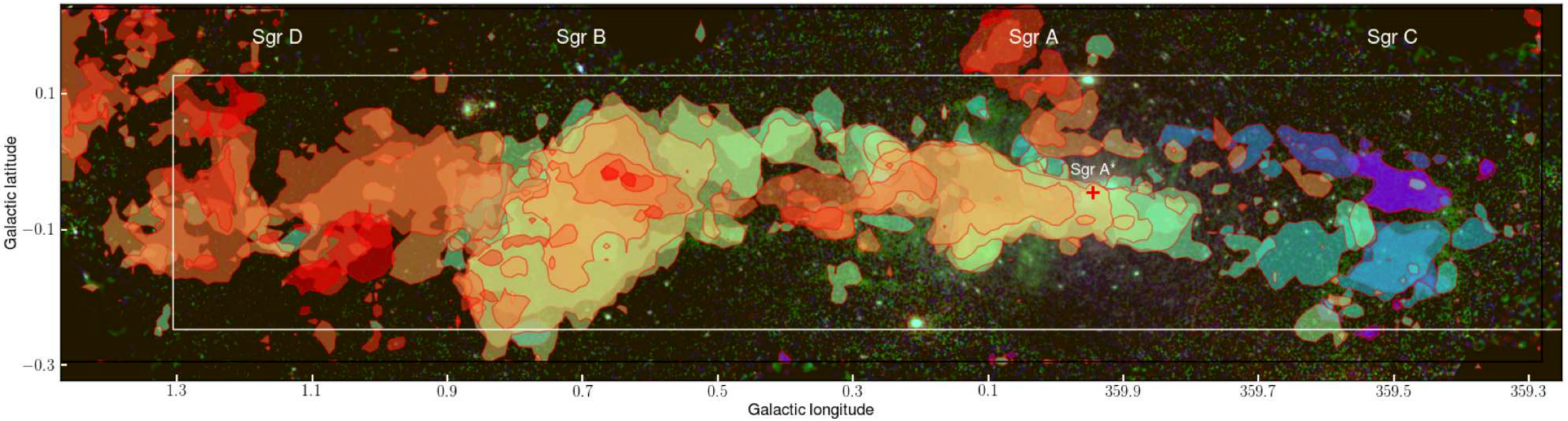
Molinari +11



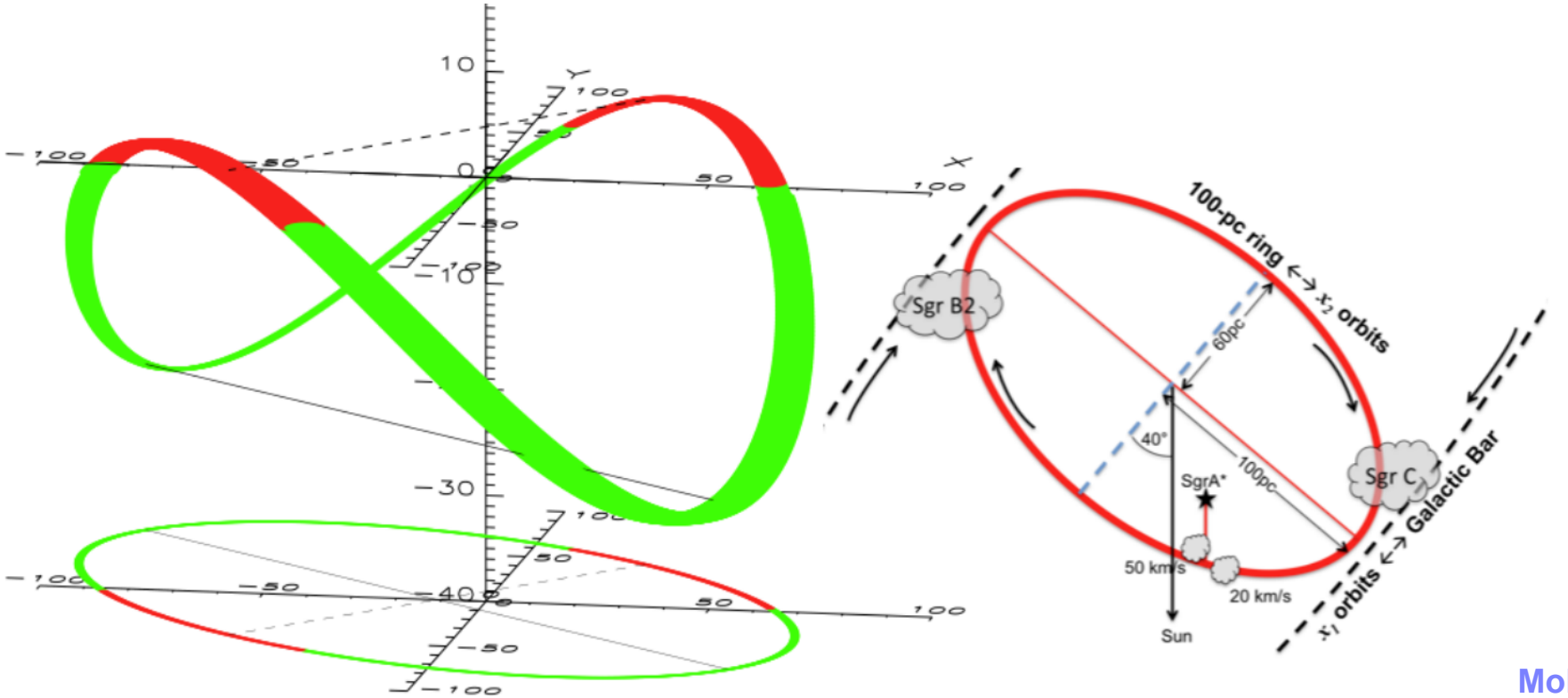
Atomic hydrogen column density map of GC
from 4×10^{22} to 4×10^{25} cm^{-2}

Coherent pattern of line of sight velocities

Ponti +14



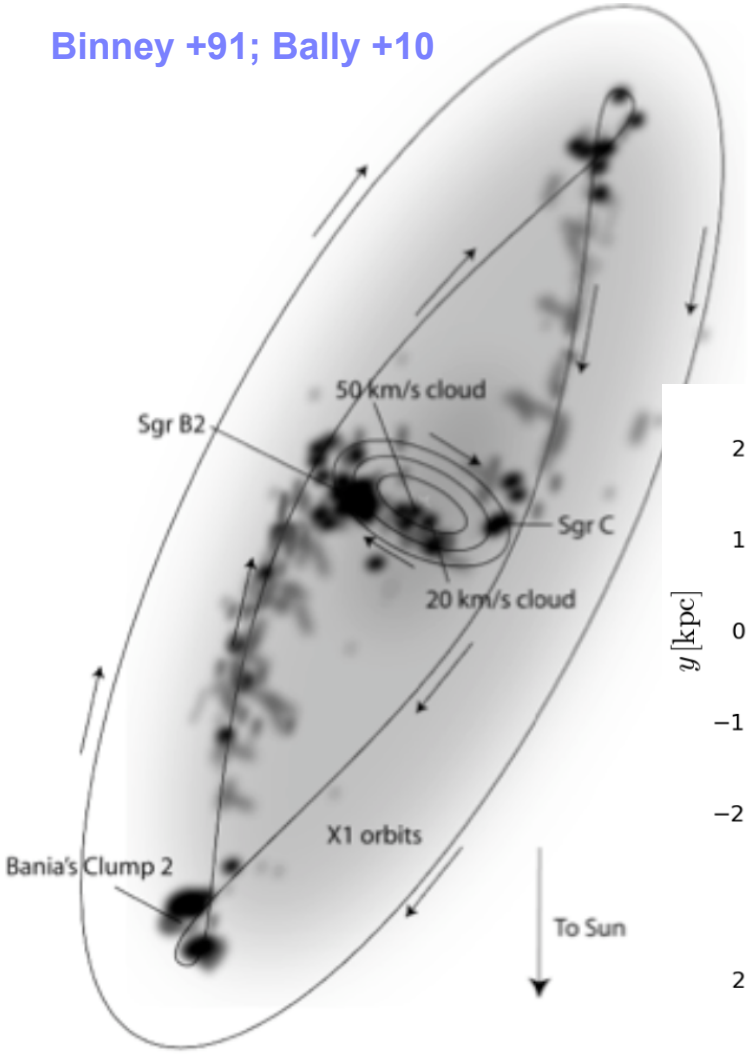
A 100 pc elliptical and twisted ring of molecular clouds



Molinari +11

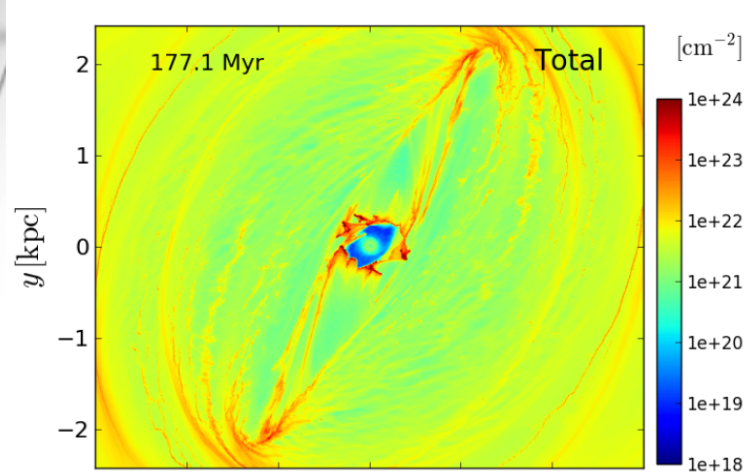
Gas motion at the Galactic center

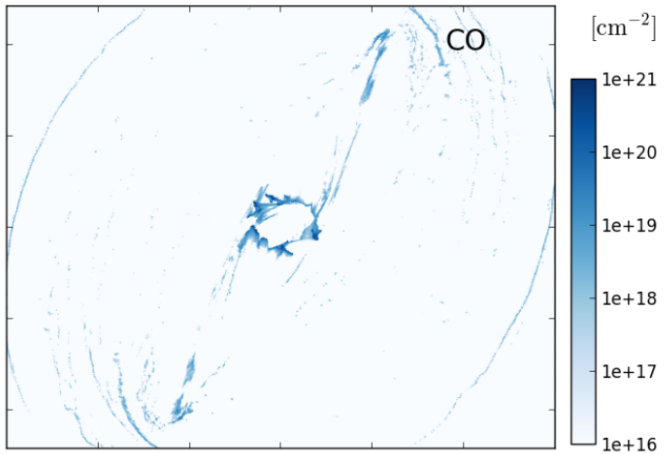
Binney +91; Bally +10

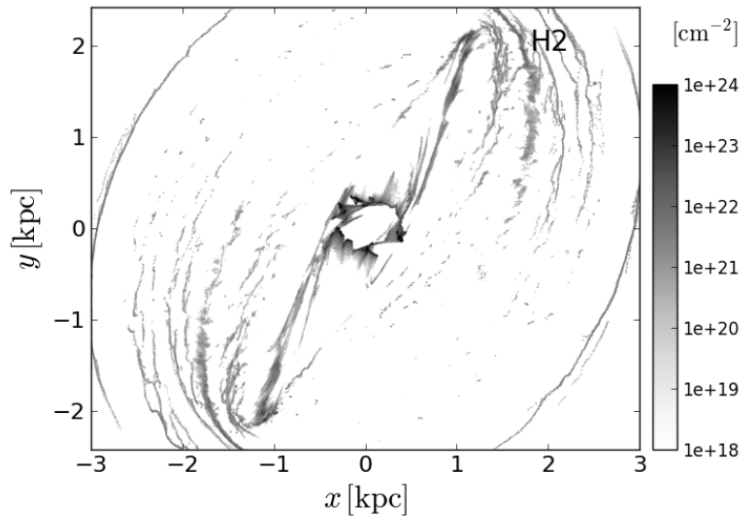


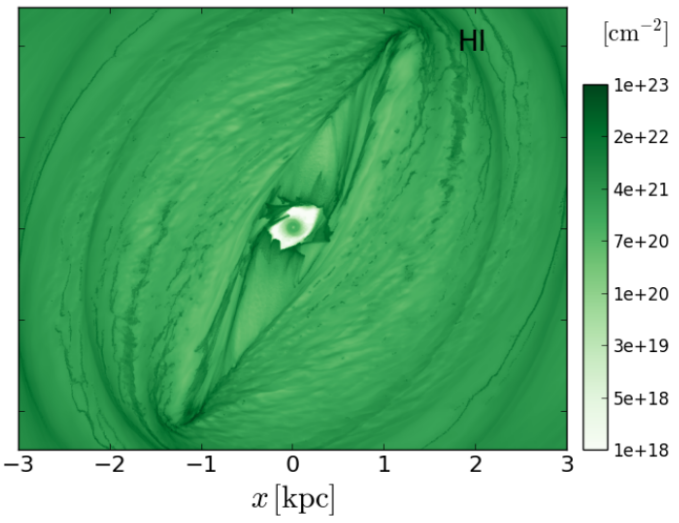
Gravitational potential ➜ Galactic bar
Gas motion determined by stars

Ridley +17







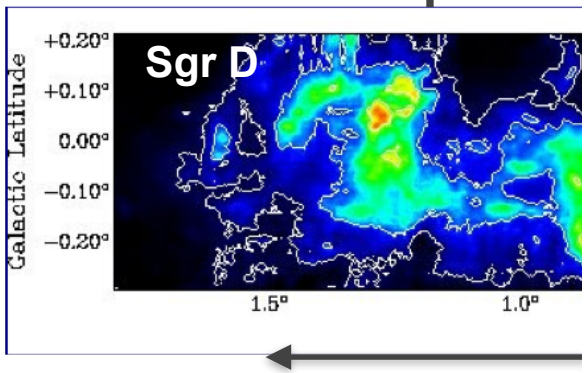


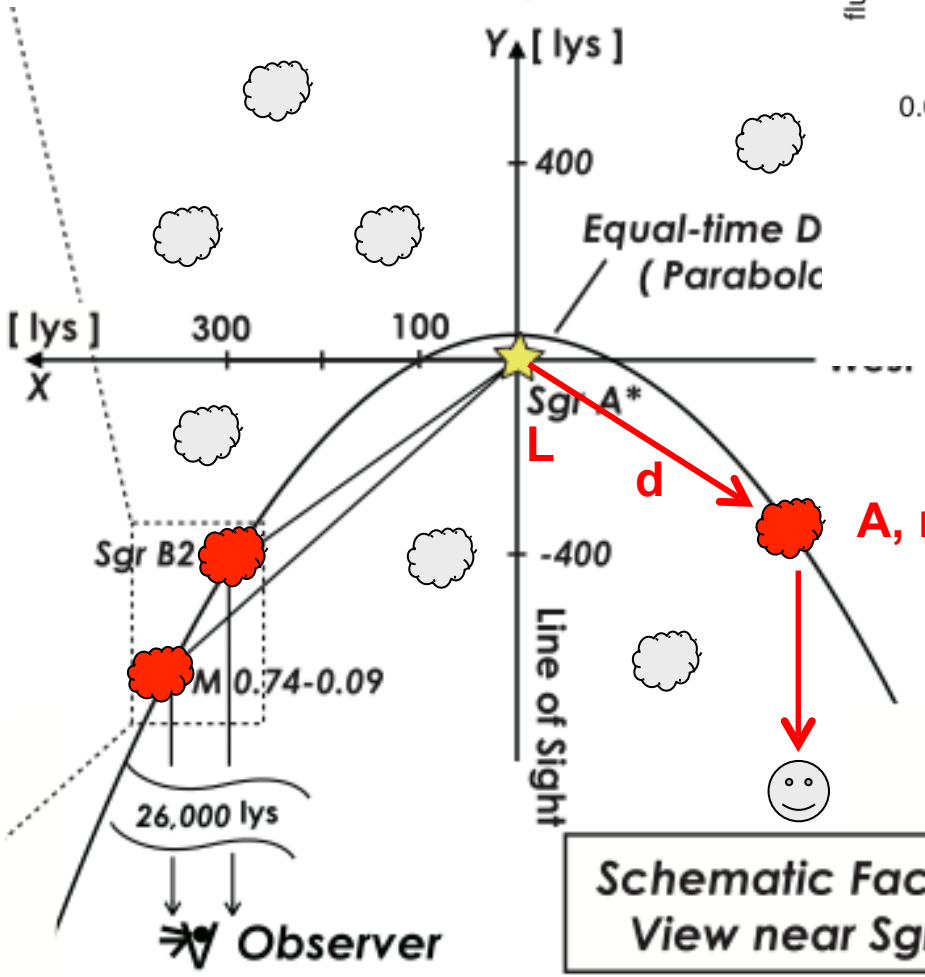
Numerical simulation of gas motion in the Galactic center

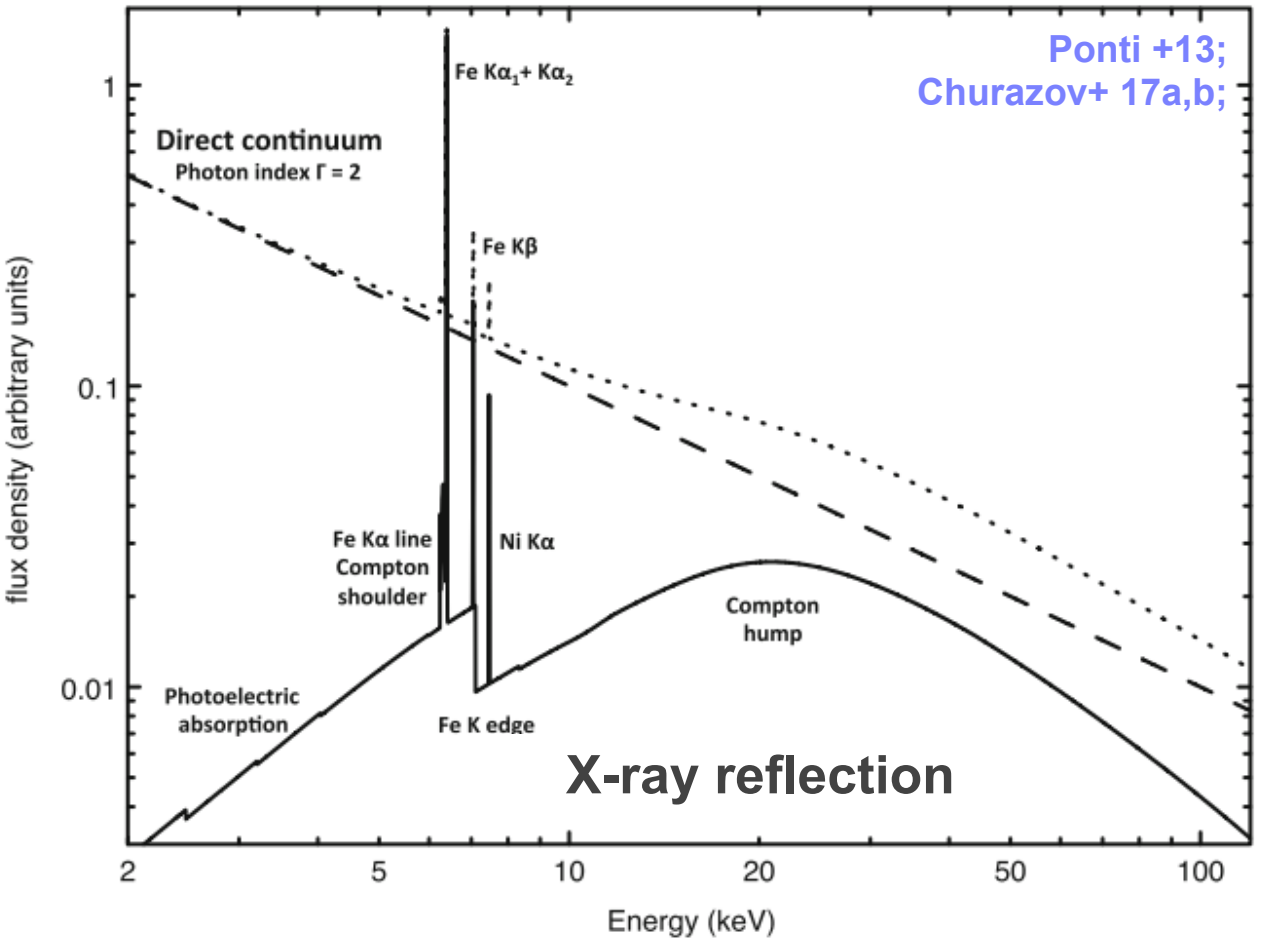
Was Sgr A brighter in the past?*

Clouds to trac

Map of C







MC ➜ Tool to study past activity

➜ Tomography of cloud distribution

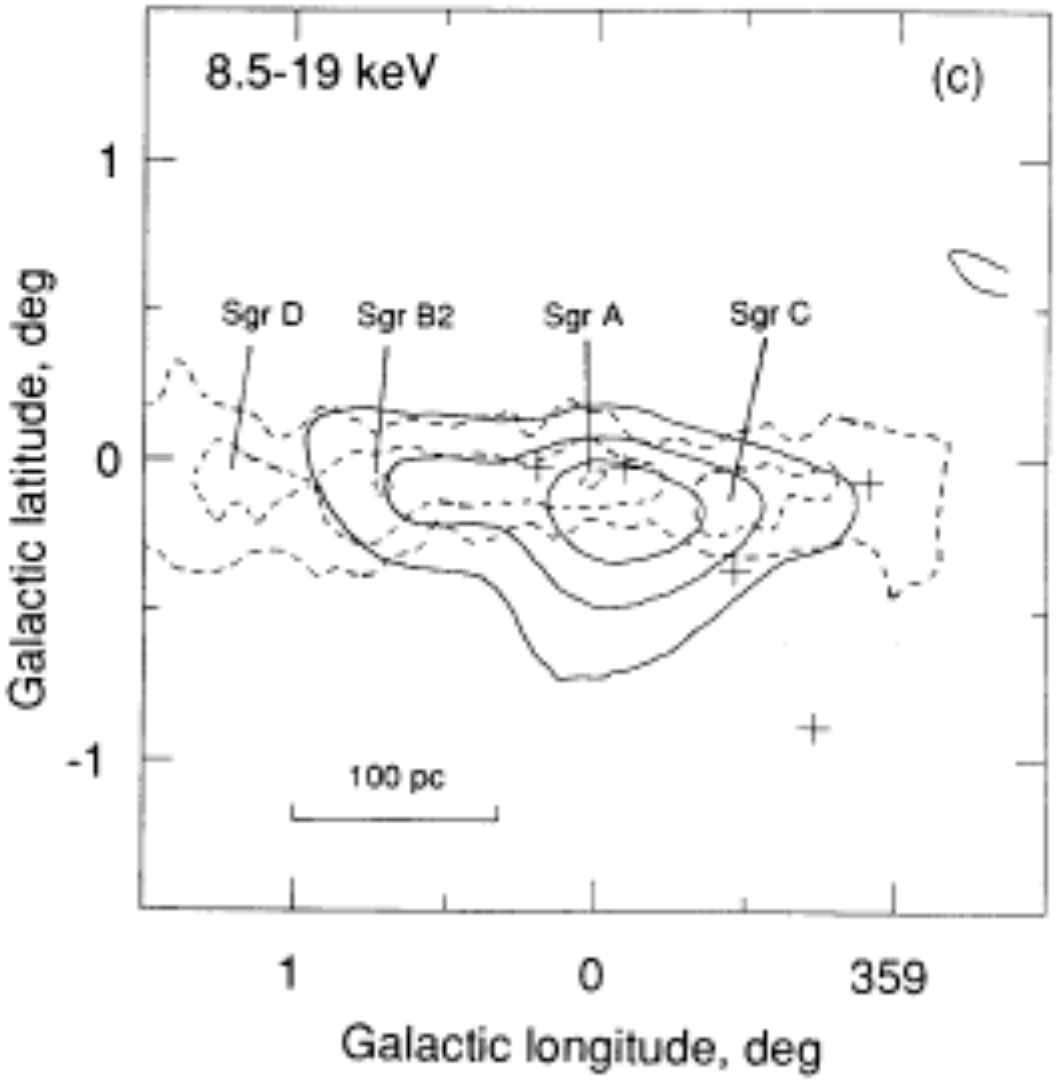
$$L_{SgrA*} \propto \frac{n_H \times A \times I_{\mathrm{FeK}}}{d^2}$$

Sunyaev +93

FeK & Hard X-ray emission from MC

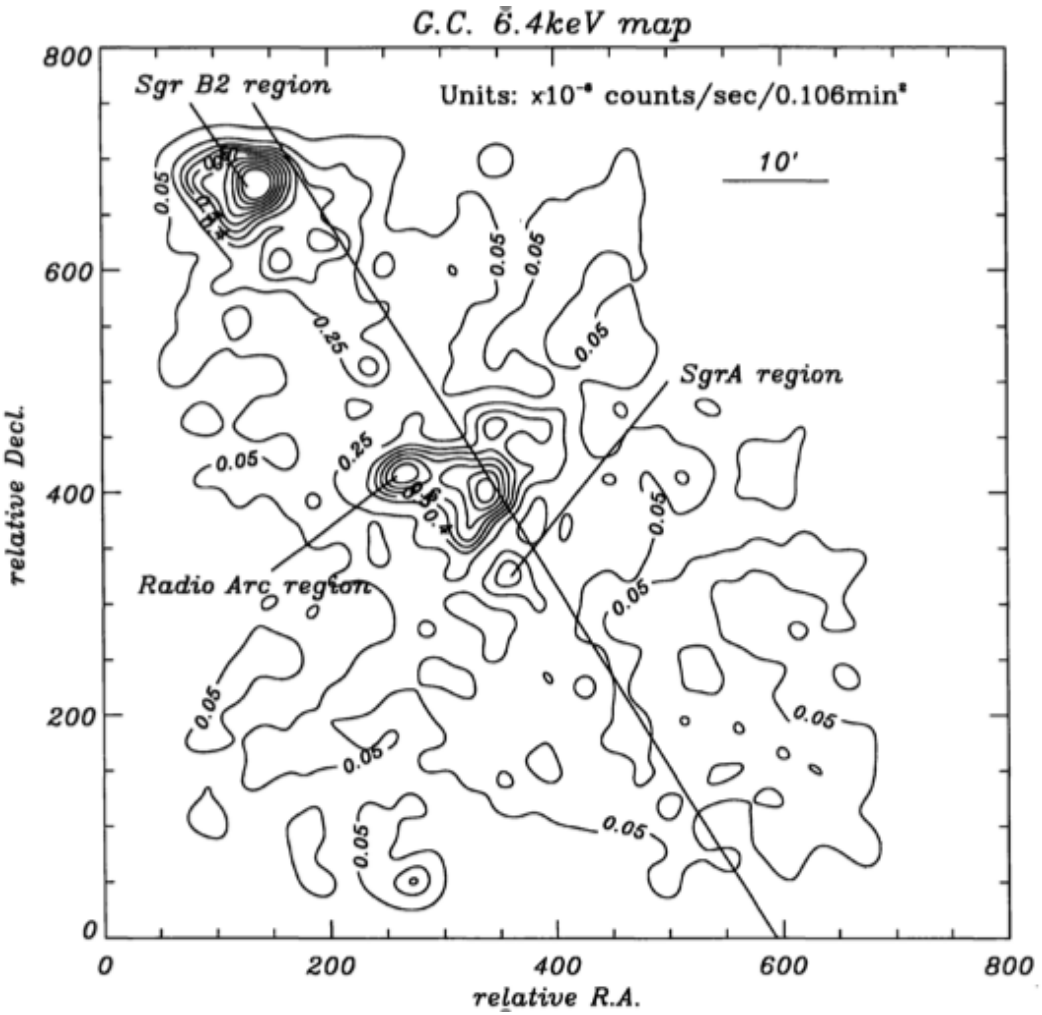
Origin of hard X-ray emission?

GRANAT: Hard X-ray/MC



Sunyaev +93

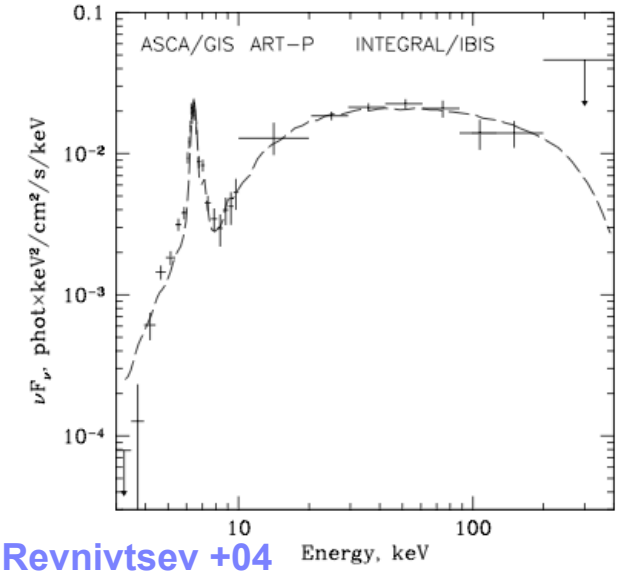
ASCA: FeKα from some MC



Koyama +96

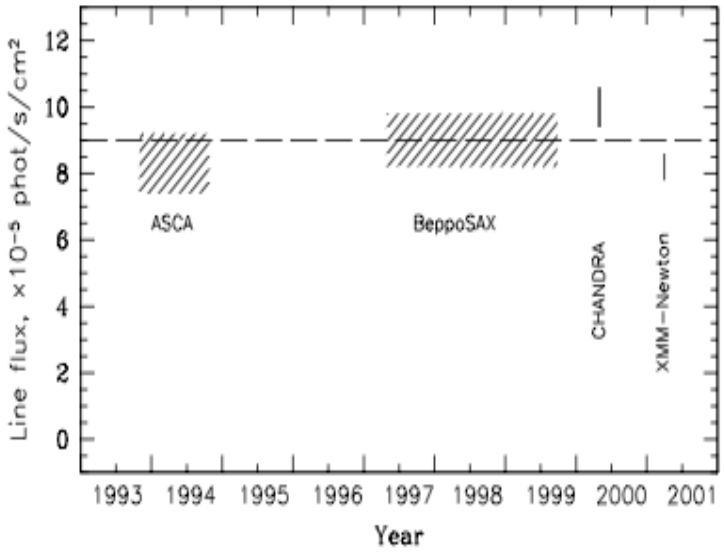
Are MC reflecting GC radiation?

INTEGRAL: MC - reflection



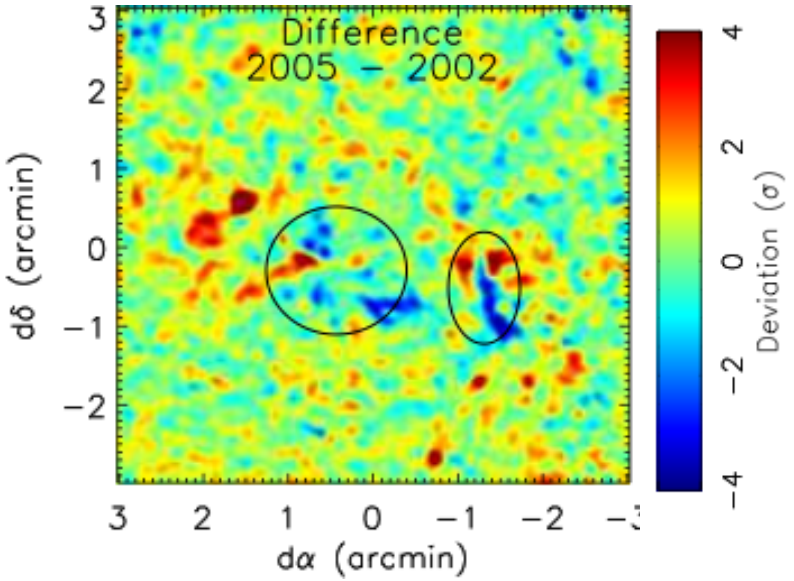
Revnivtsev +04

FeKα: constant intensity!



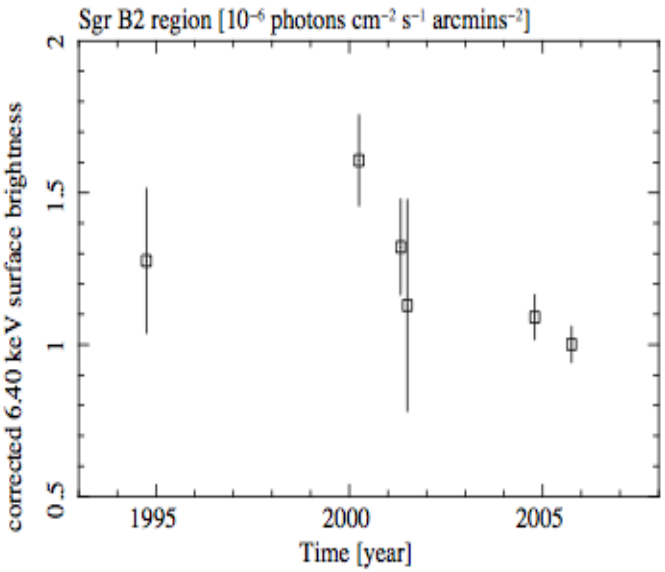
Reflection spectrum
➜ but constant!

Chandra: Sgr A cont. variability



Muno +07

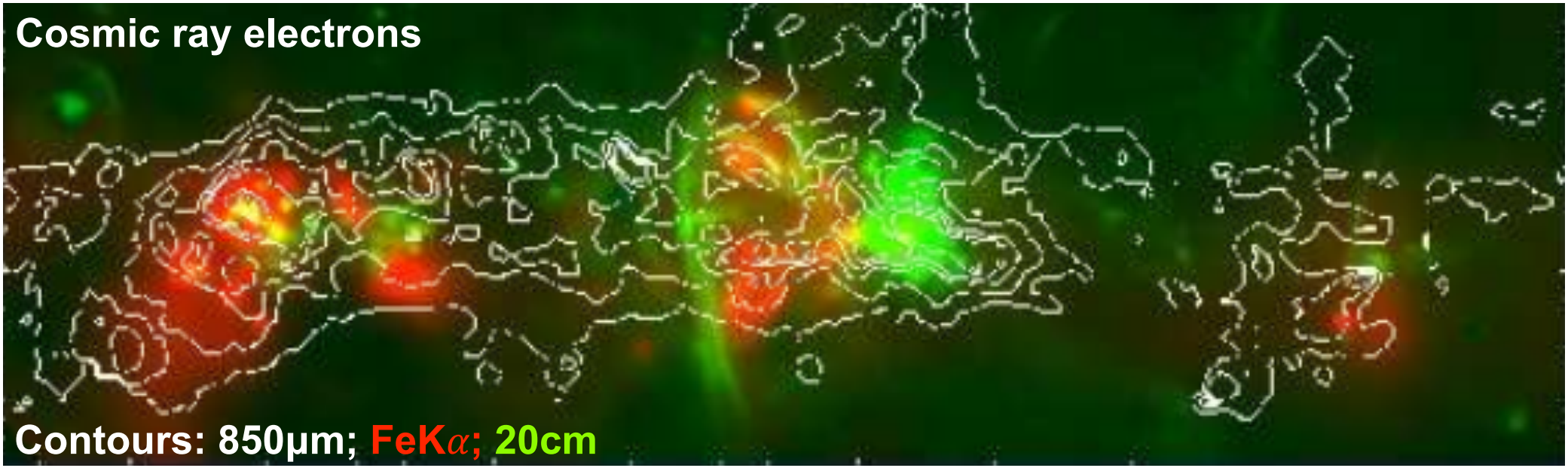
Multi-instruments: Sgr B2 variability



Inui +09

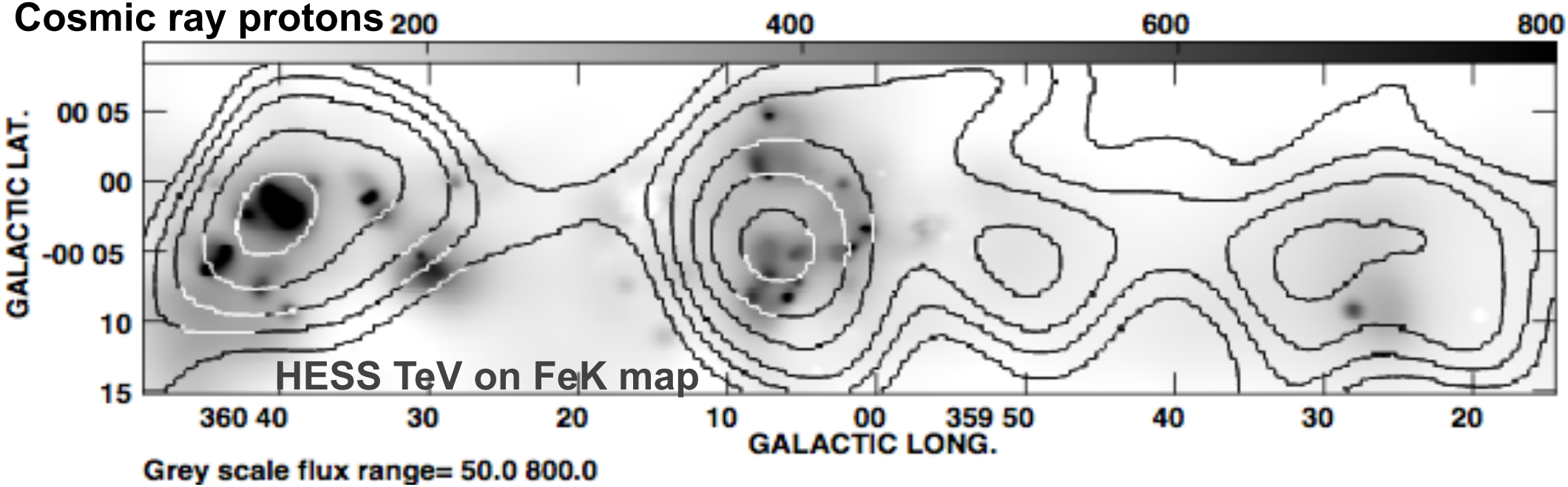
Variable?
➜ weak detections

Are MC reflecting GC radiation?



Yusef-Zadeh +02+07

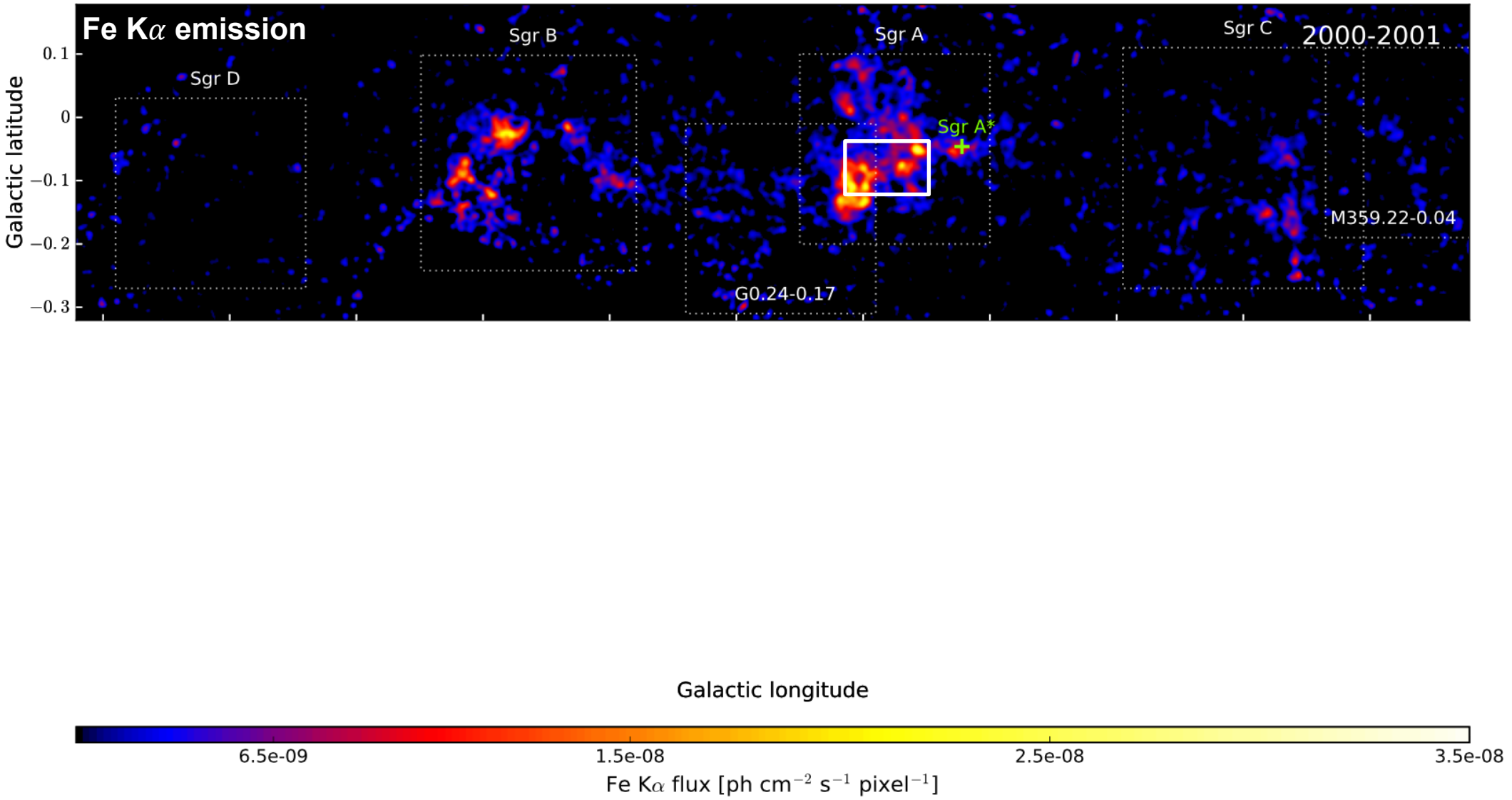
Cosmic ray protons



Aharonian +06

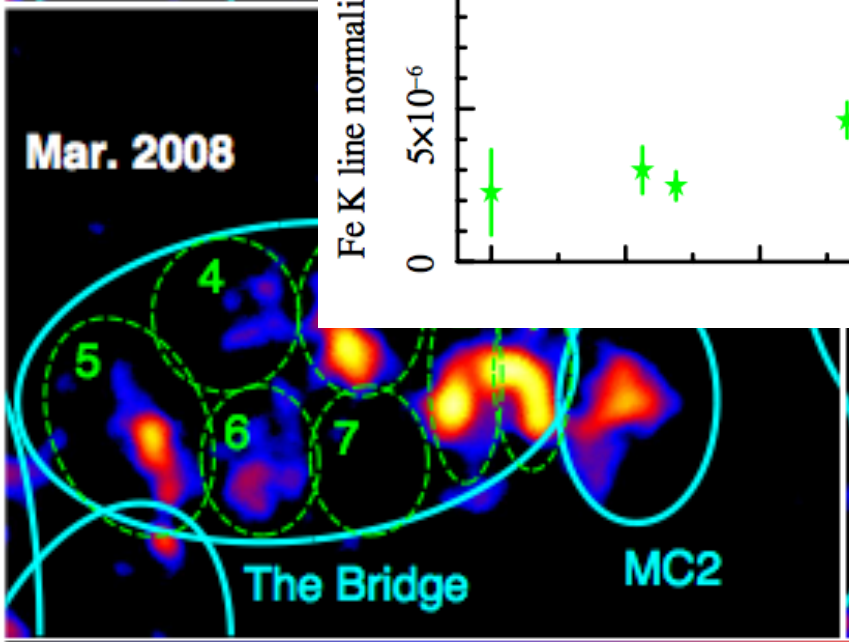
Fe K emission from GC

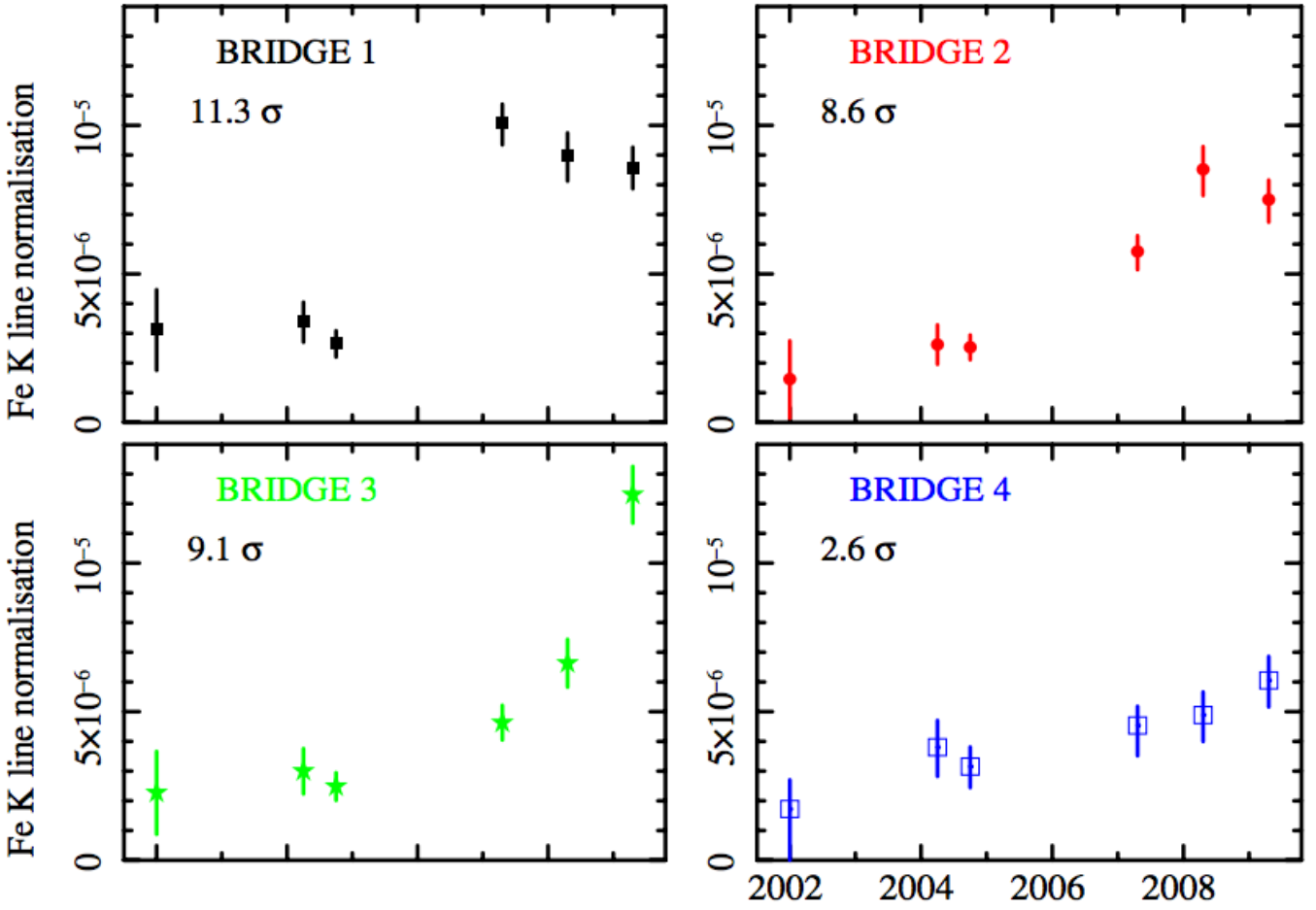
Ponti +14; Terrier +17

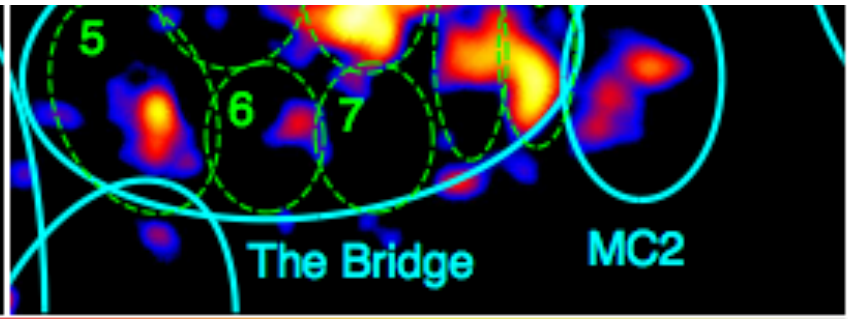


Super-luminal variation?

XMM: Fe Kα emission







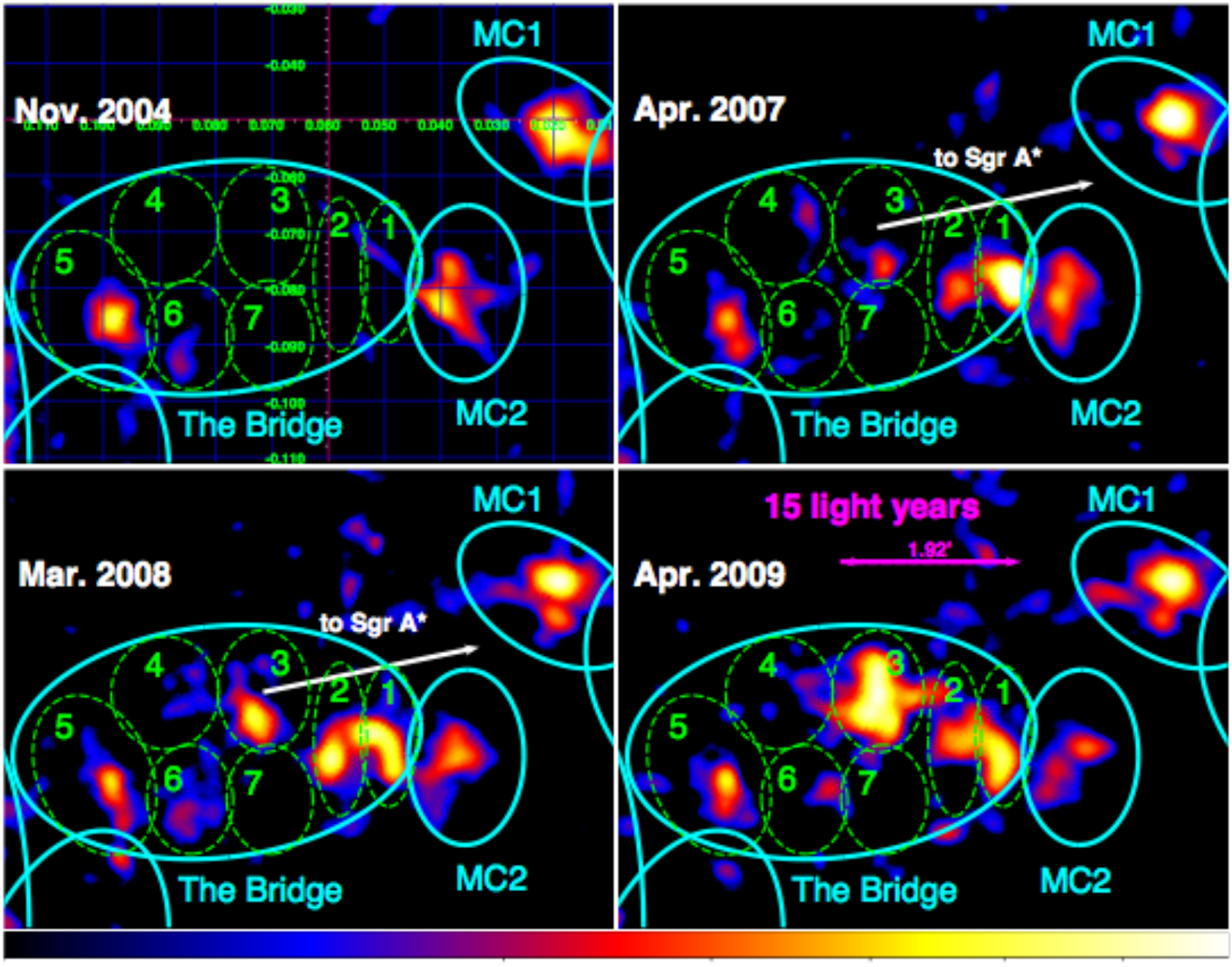
Ponti +10

Significant variation of the Fe Kα emission

e.g. Ponti +10;+13

Super-luminal variation?

XMM: Fe Kα emission



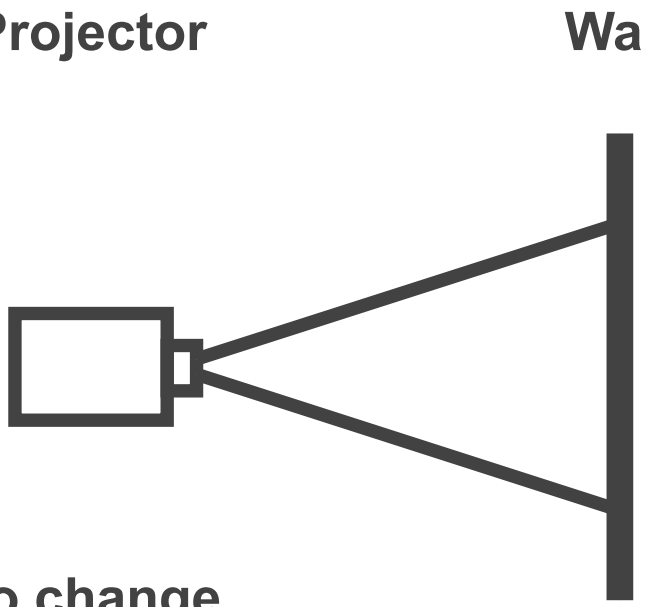
Ponti +10

Super-luminal Fe Kα propagation

➜ Rule out cosmic rays or internal source

e.g. Ponti +10;+13

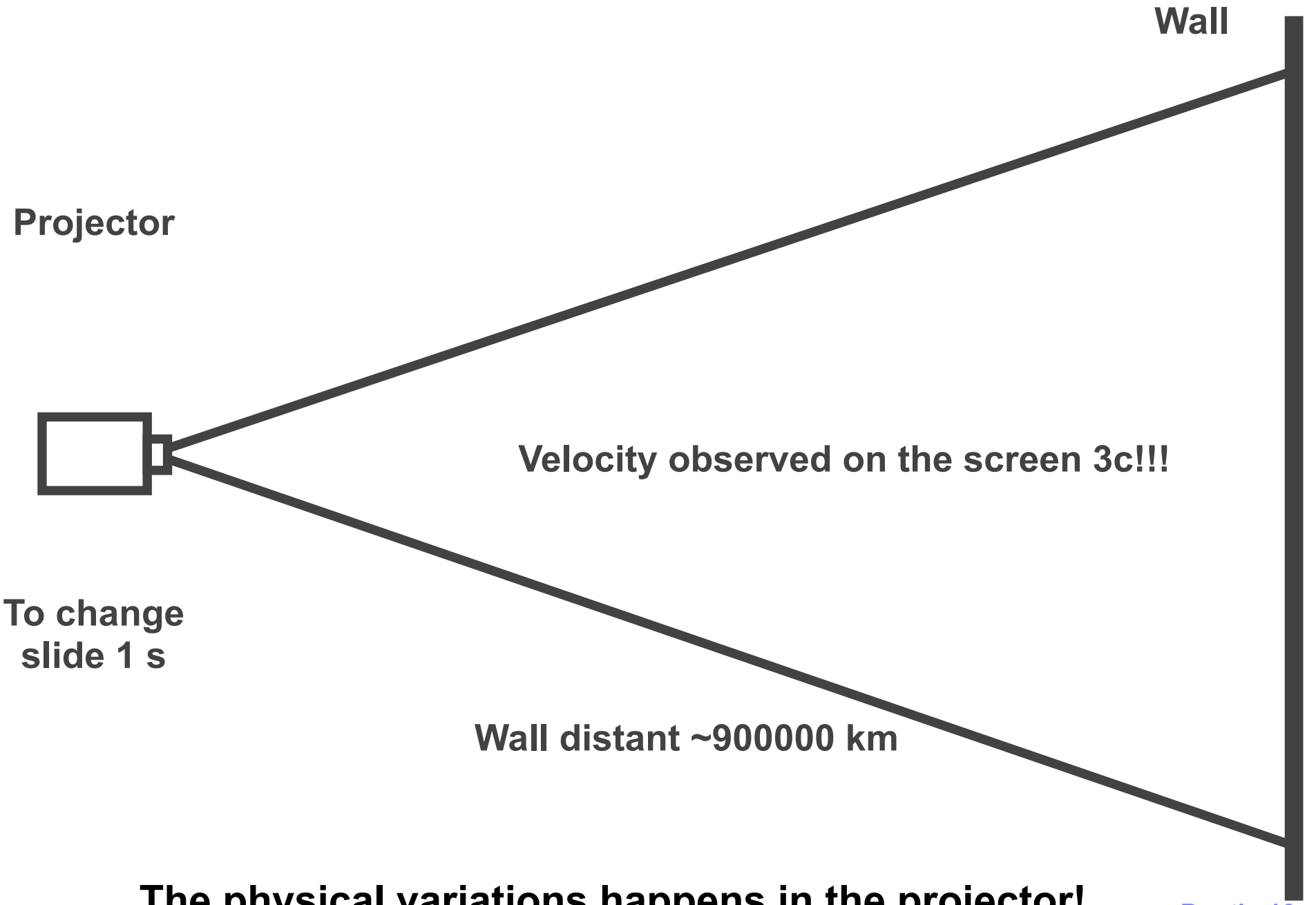
How can a super-luminal echo happen?



Velocity observed on the screen 1m/1s

e.g. Ponti +10;+13

How can a super-luminal echo happen?

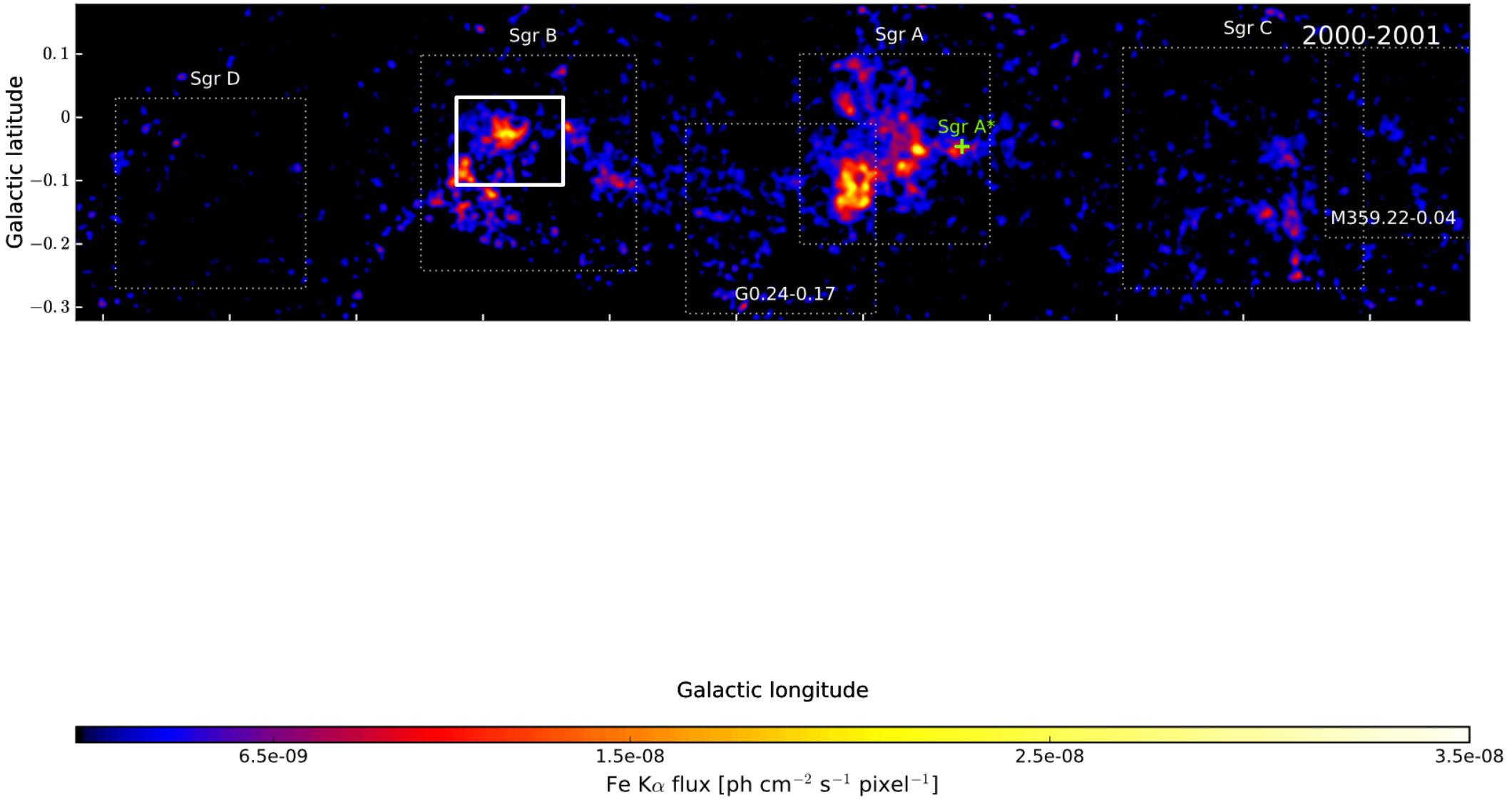


The physical variations happens in the projector!

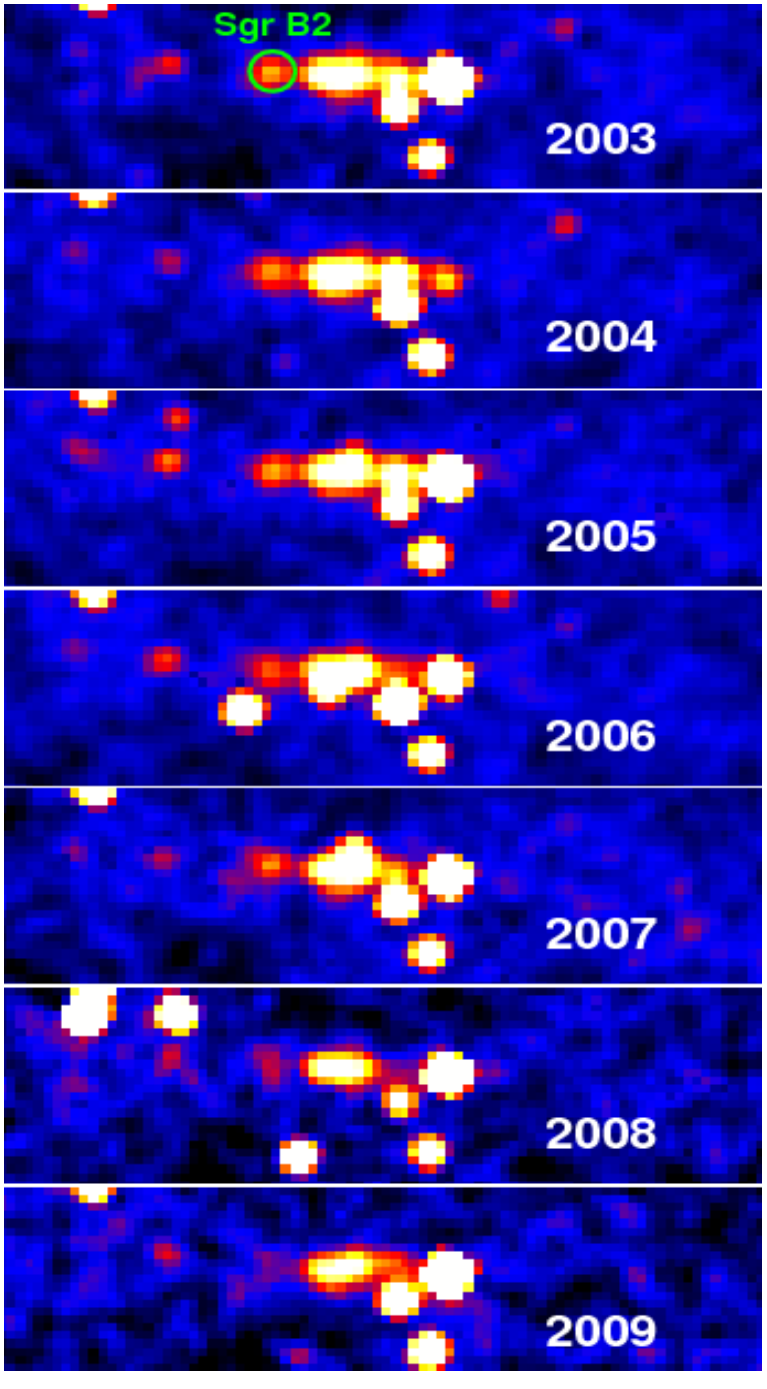
e.g. Ponti +10;+13

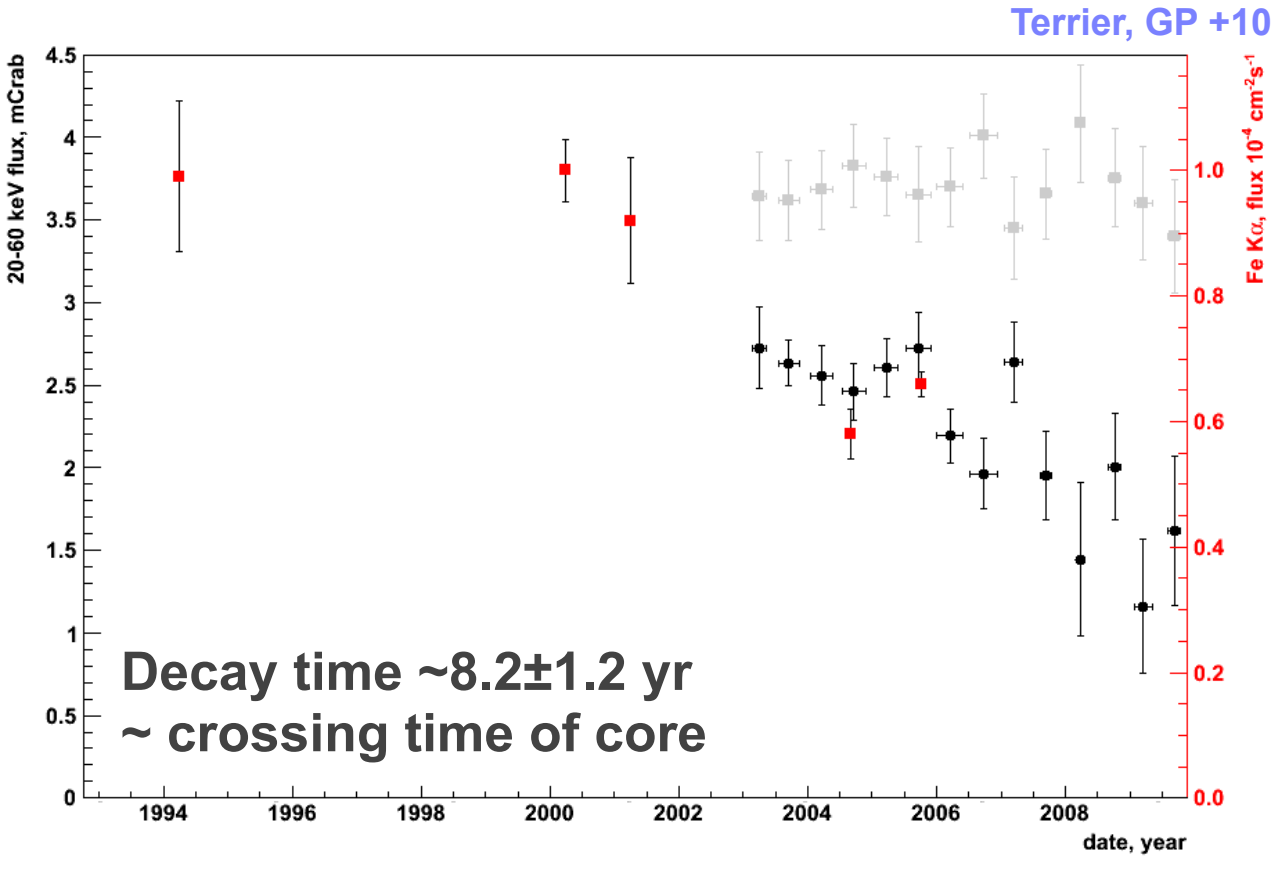
Fe K emission from GC

Ponti +14; Terrier +17



The INTEGRAL view of Sgr B2





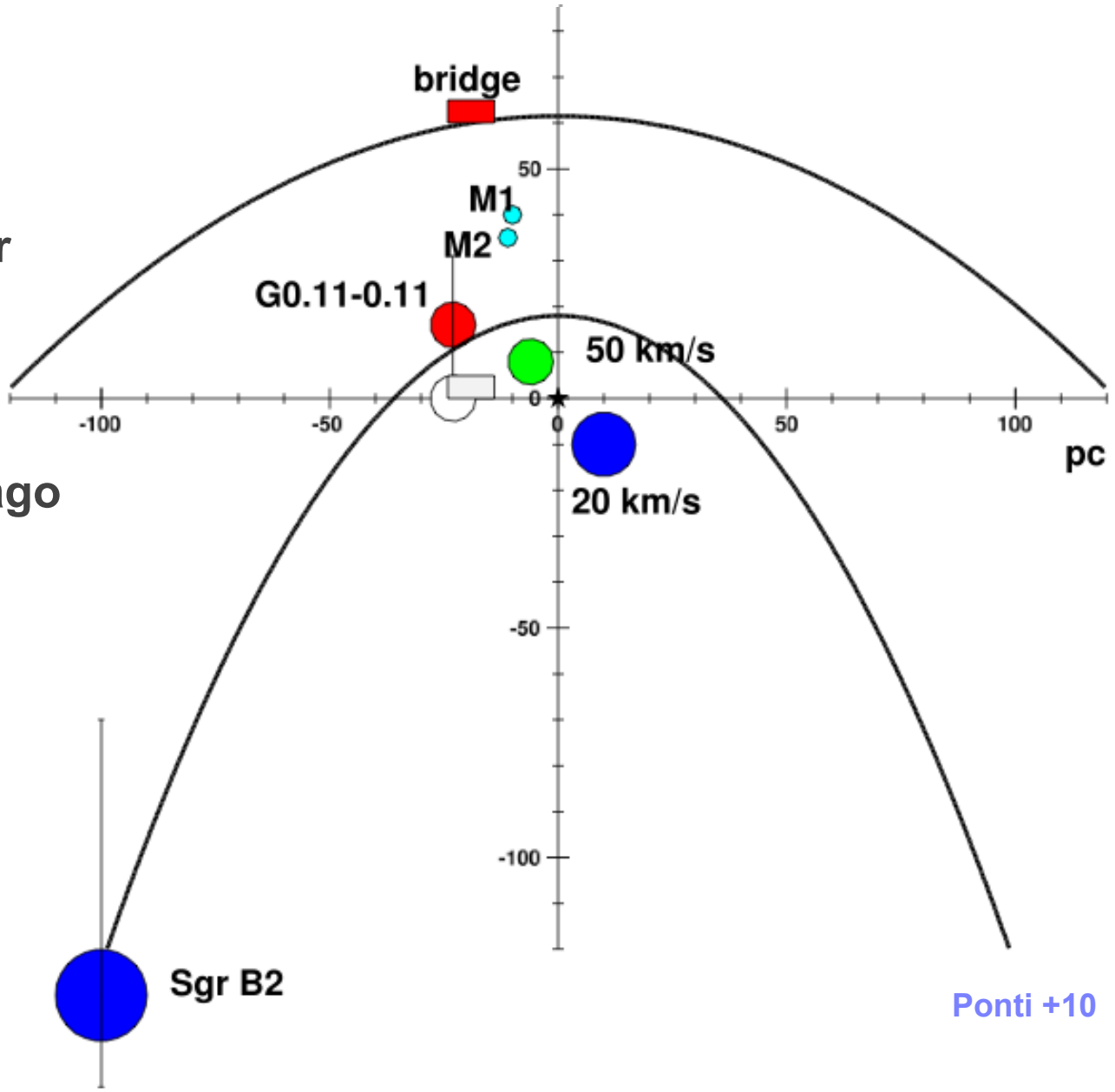
*Possible past activity of Sgr A**

50 km s^{-1} MC: No Fe K line
$L_{Sgr\ A^*} < 10^{36}$ erg s^{-1} past 70-80 yr

Sgr B2 - G0.11-0.11:
$L_{Sgr\ A^*} < 1.4\ 10^{39}$ erg s^{-1} ~100 yr ago

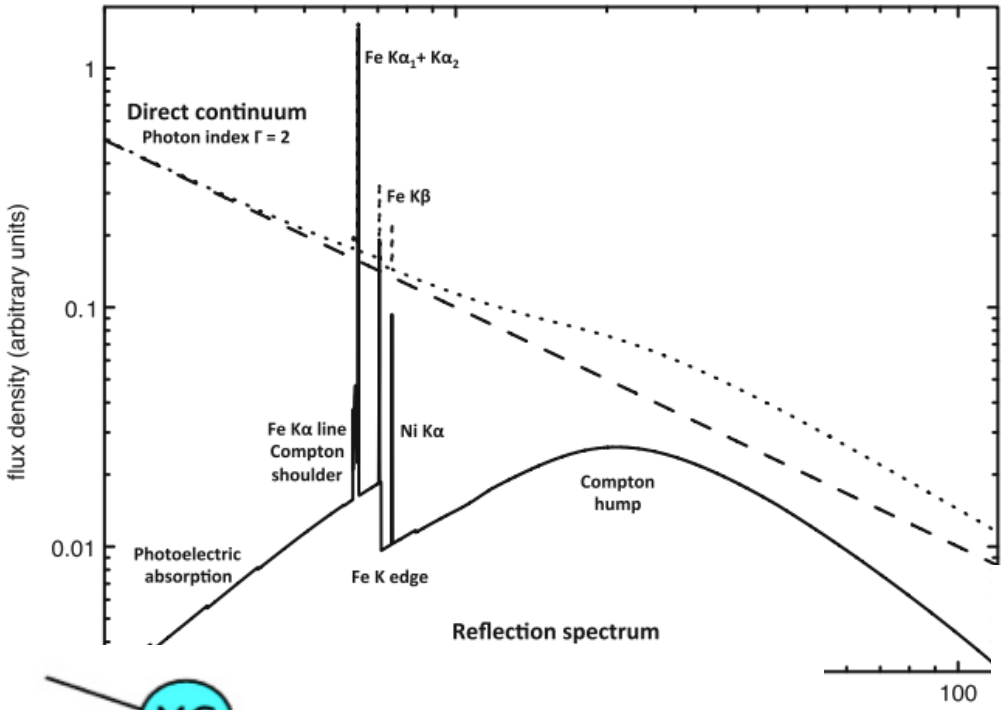
Main limitation ➜ los distance!

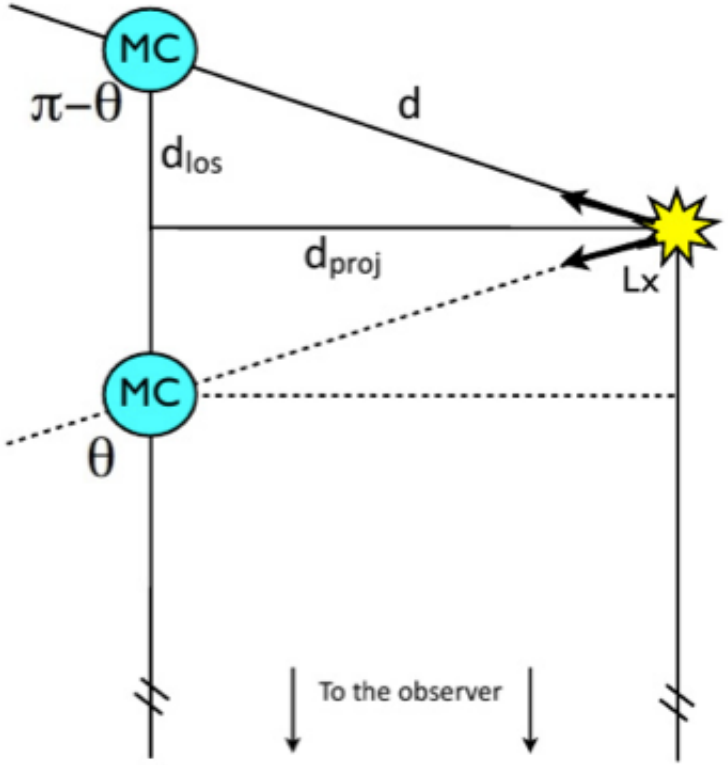
Galactic plane seen from the pole



Ponti +10

Los distance from Fe Kα equivalent width?





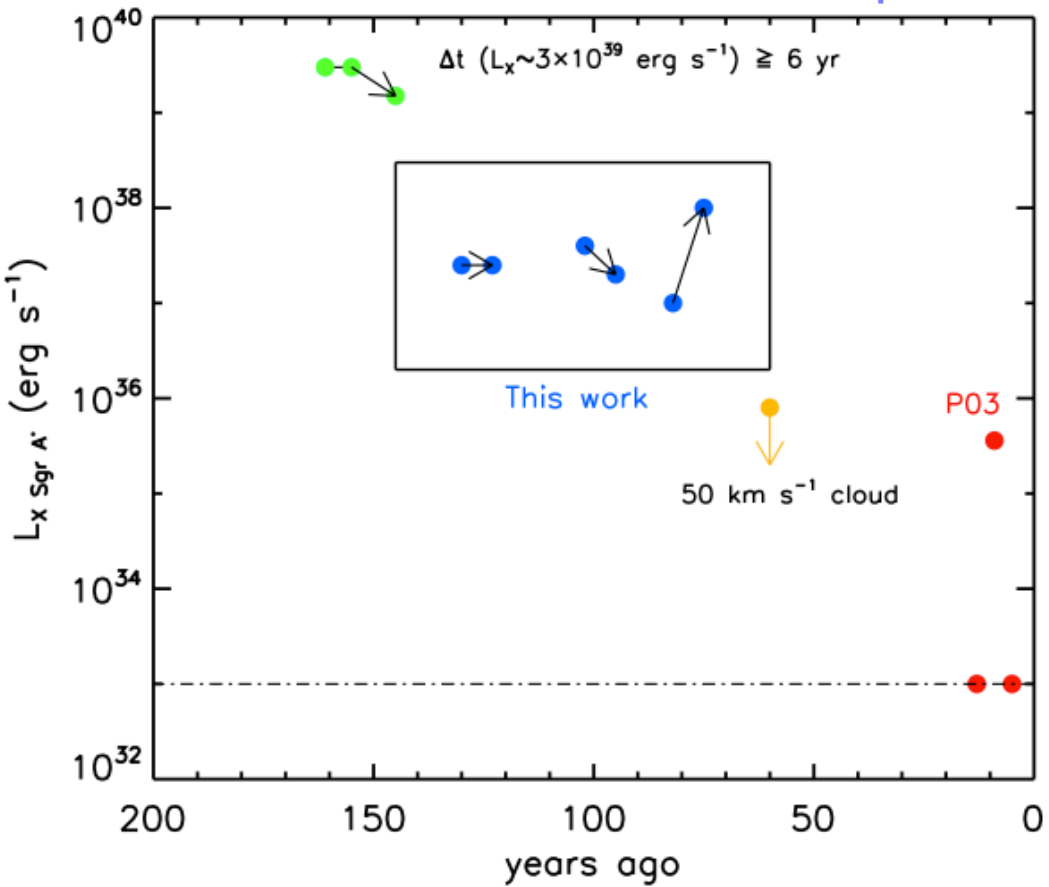
Reflection continuum ➜ Compton effect ➜ Angular dependence

Fe Kα ➜ No angular dependence

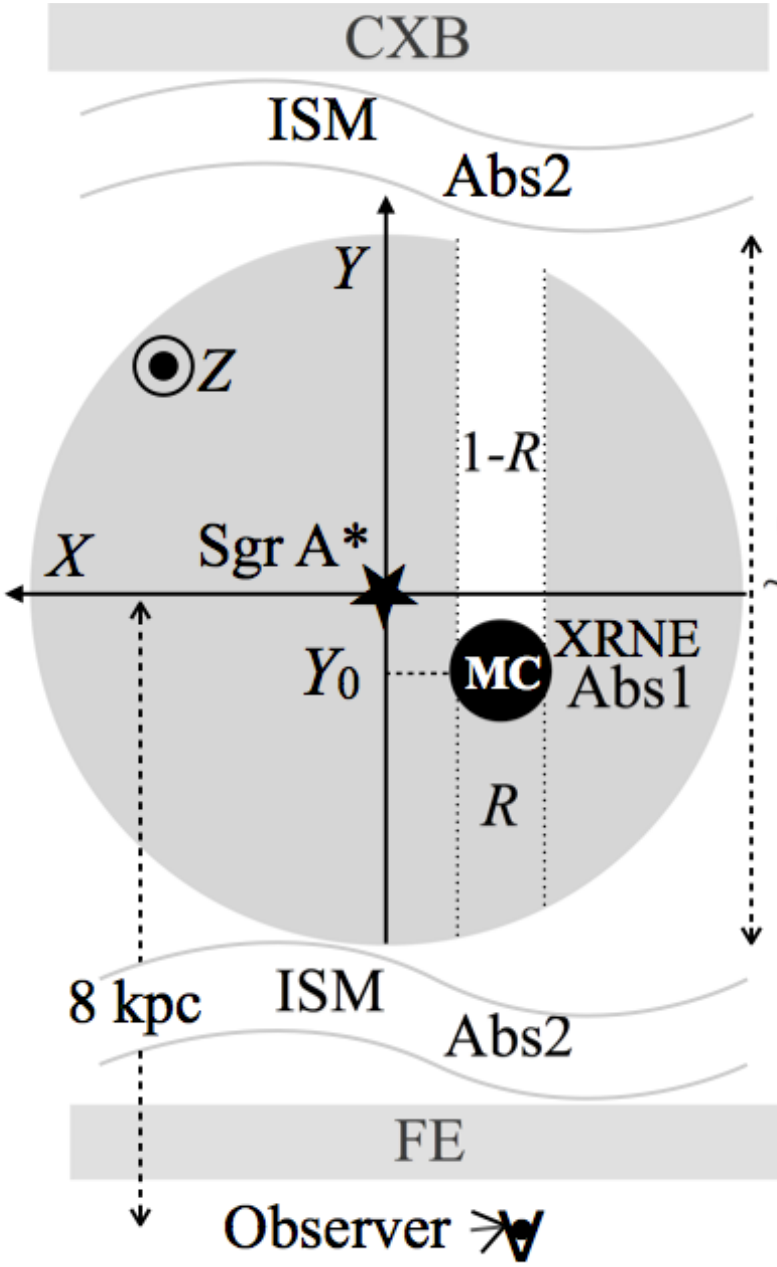
Capelli +12

Bridge closer to Sgr A* ➜ Decreasing trend past 100 yr

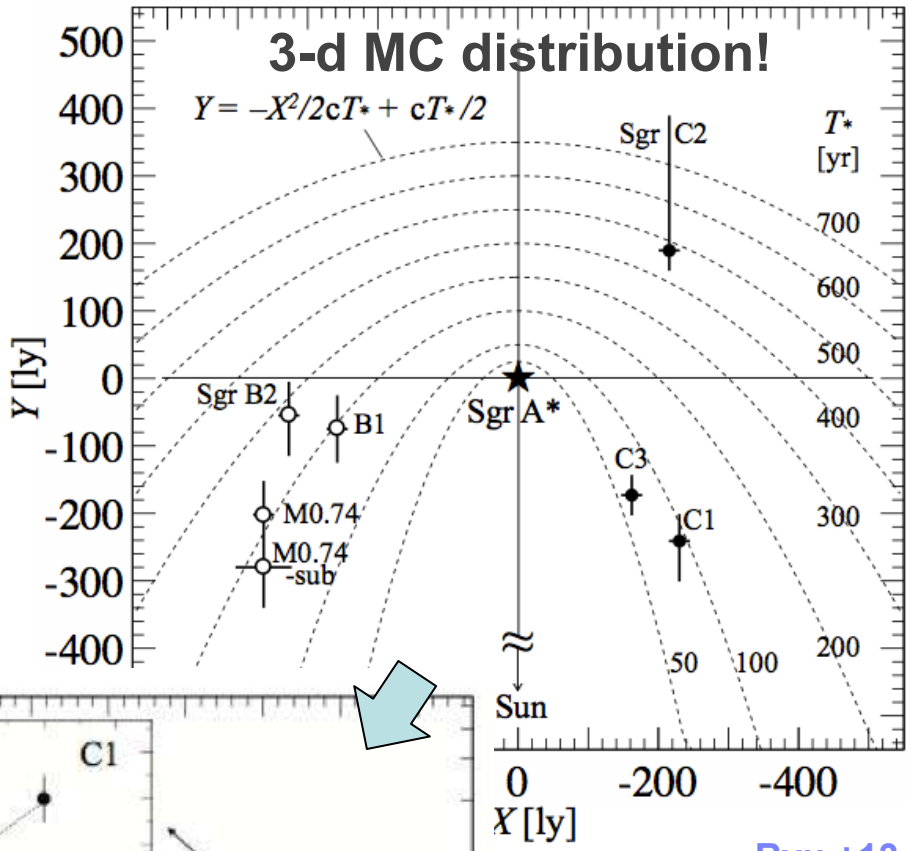
Capelli +12



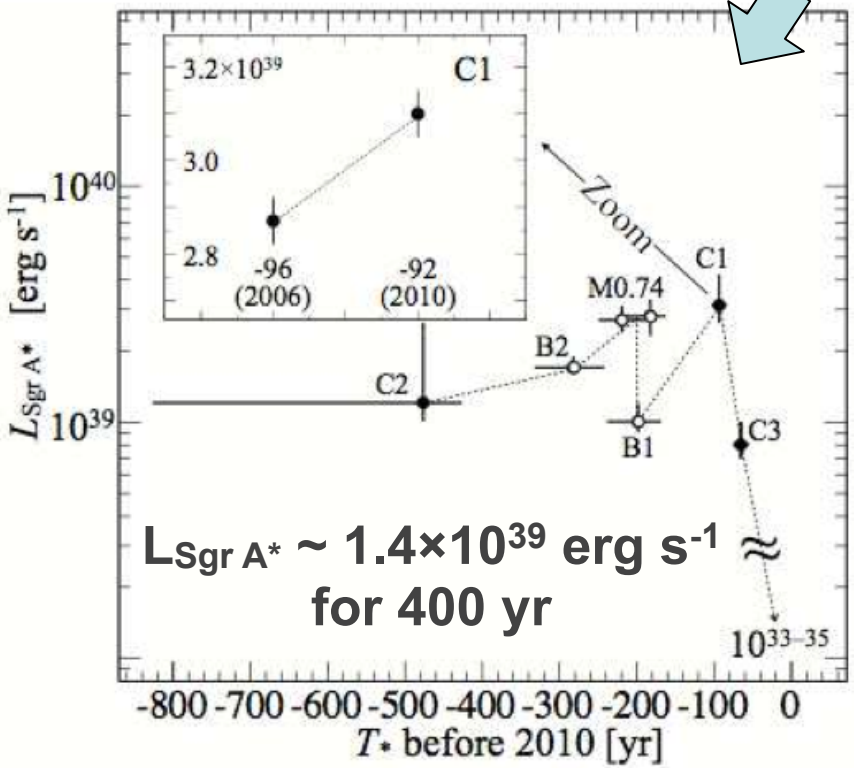
Los distance from X-ray absorption?



Ryu +13



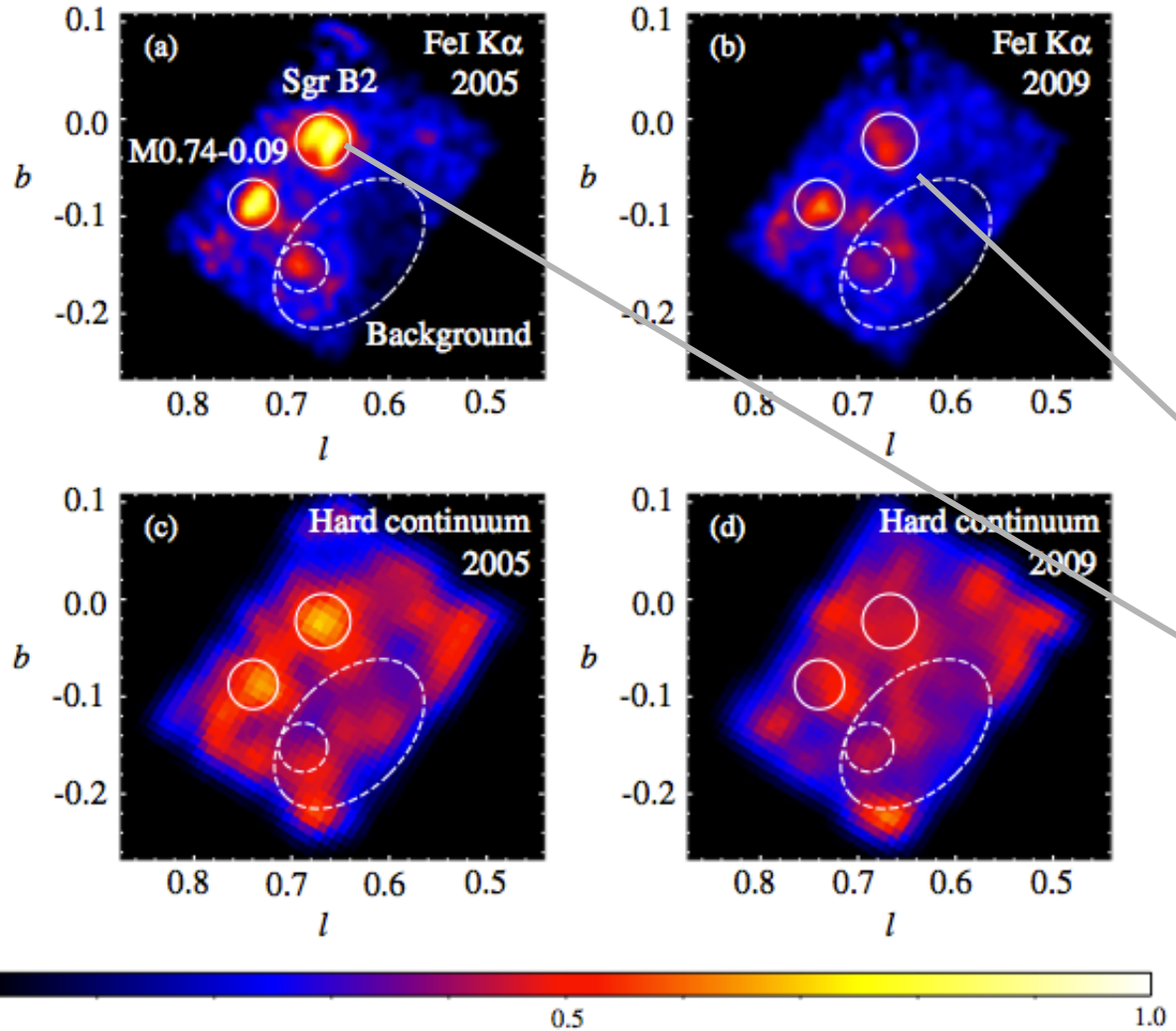
Ryu +13



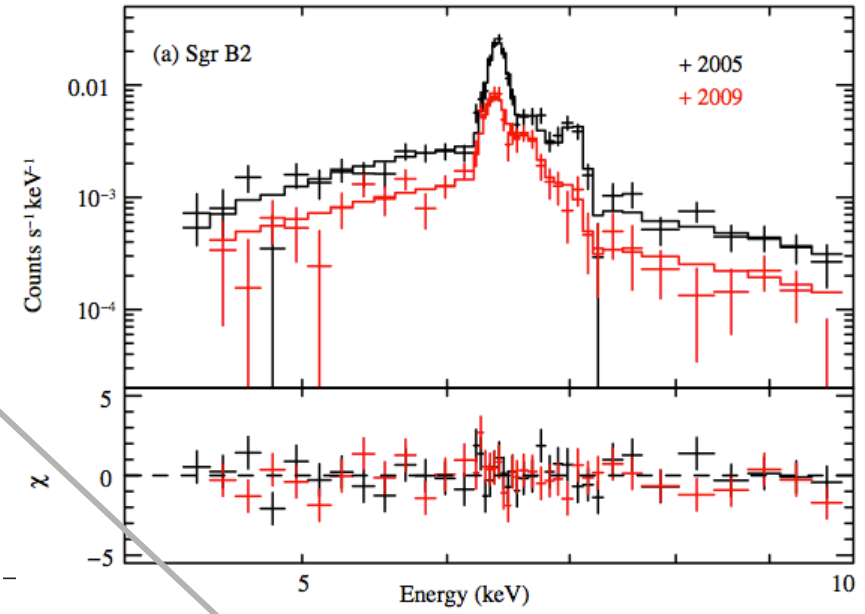
$L_{Sgr\ A^*}$ ~ 1.4×10³⁹ erg s⁻¹ for 400 yr

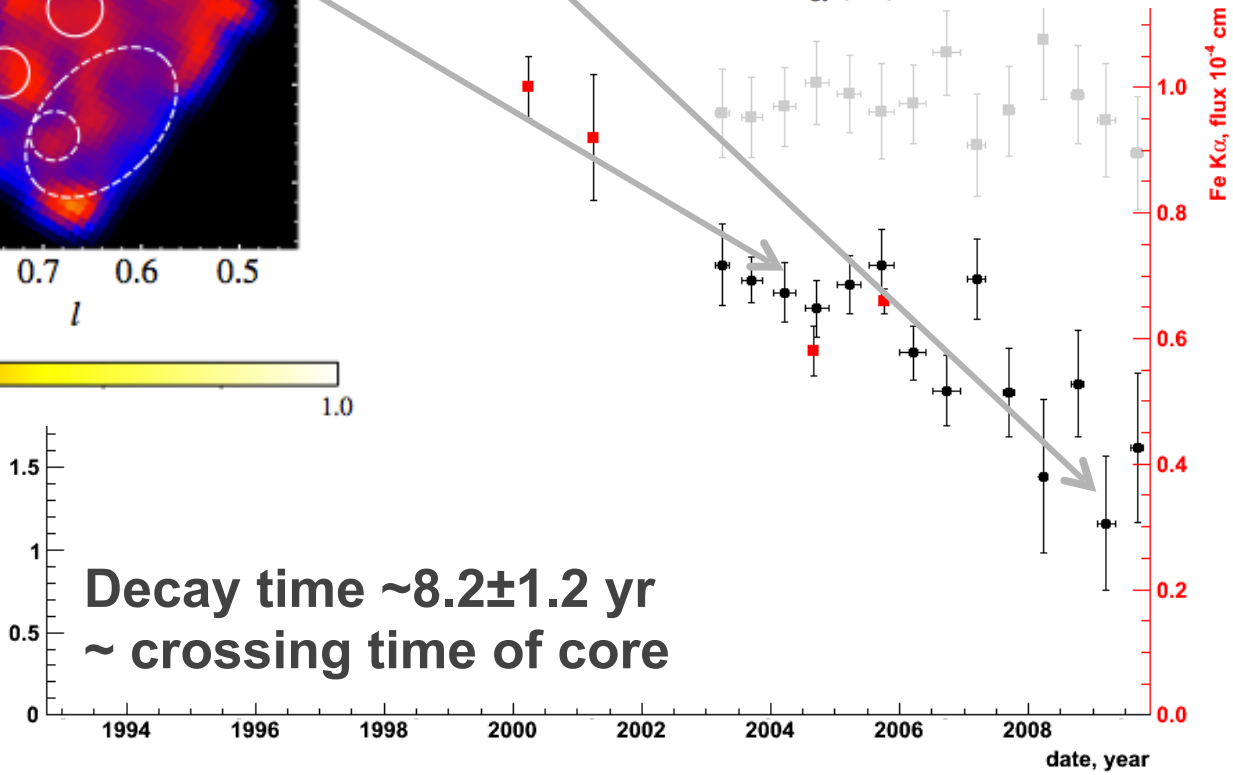
Measure X-ray absorption
➜ assume uniform absorber
➜ LOS distance

The Suzaku view of Sgr B2



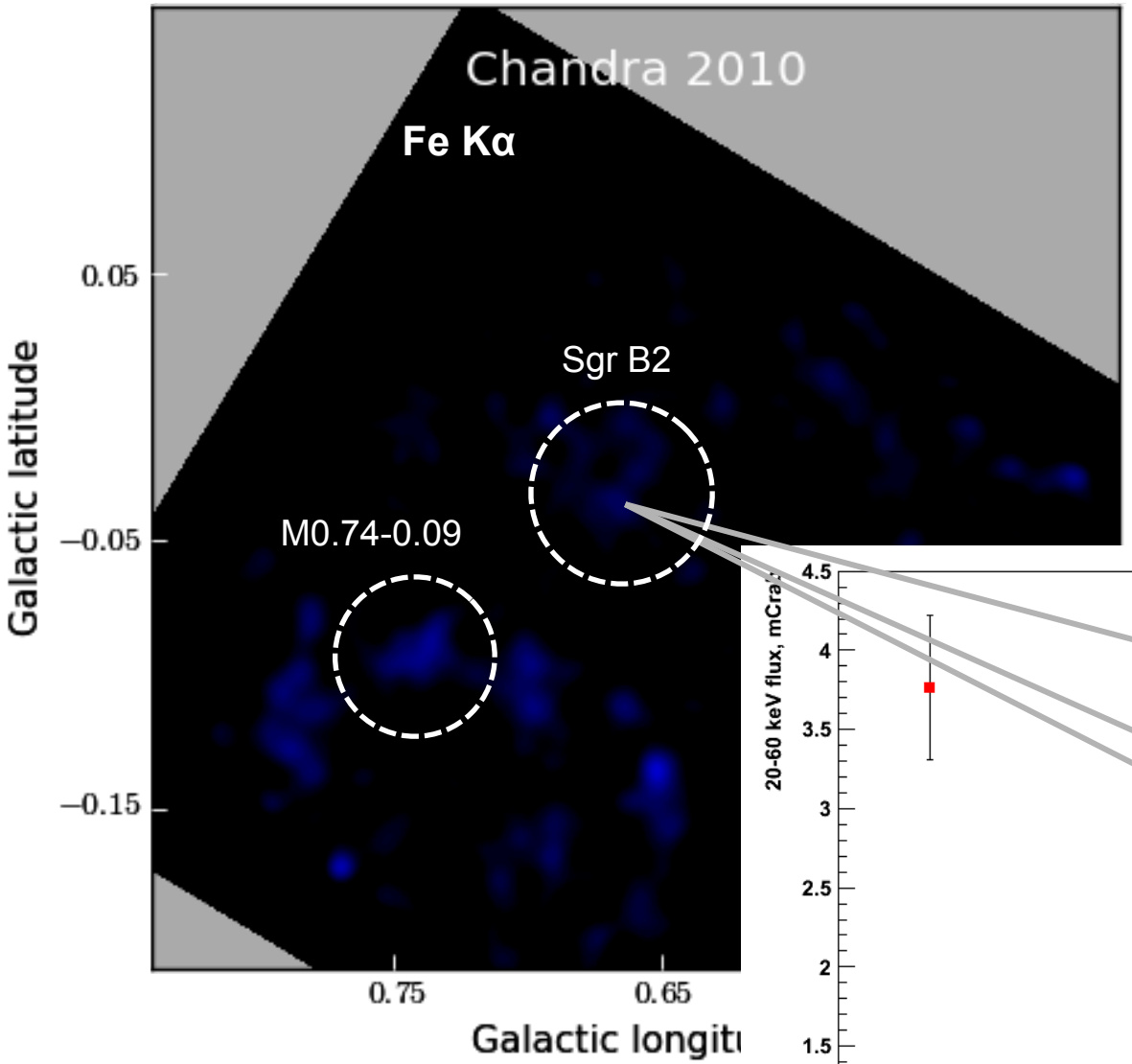
Nobukawa +11





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

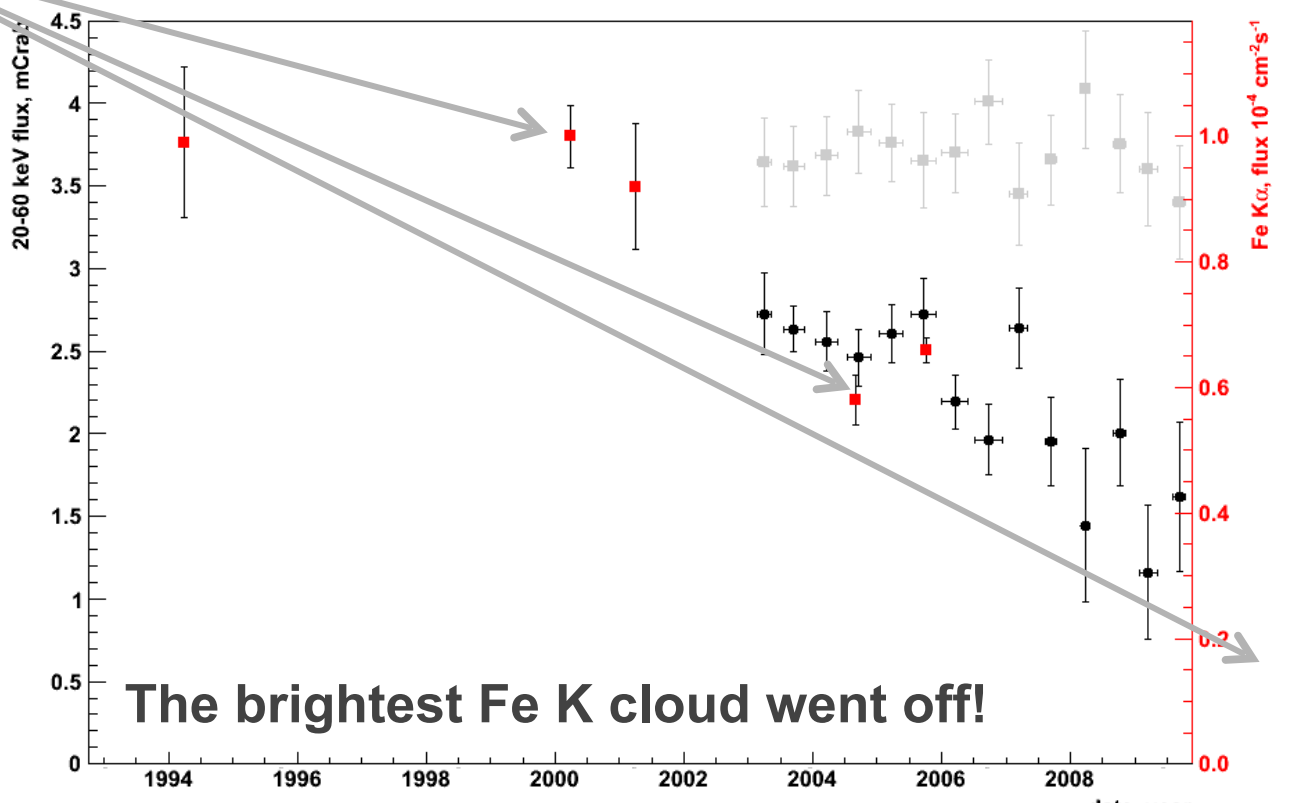
Sgr B2 faded away!



➜ Strong indication for irradiation

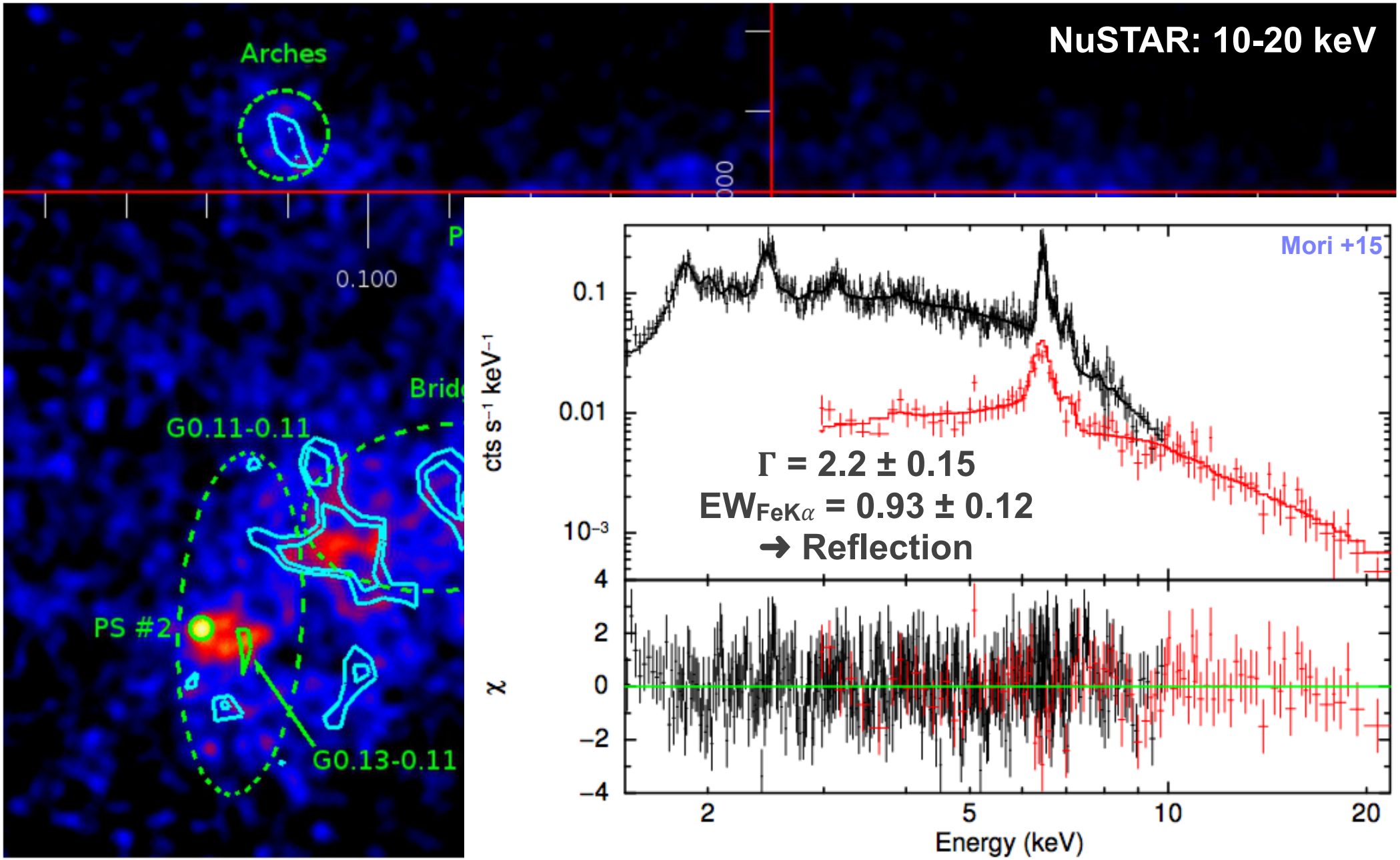
Residual emission due to cosmic rays ➜ Weak

Terrier, GP in prep

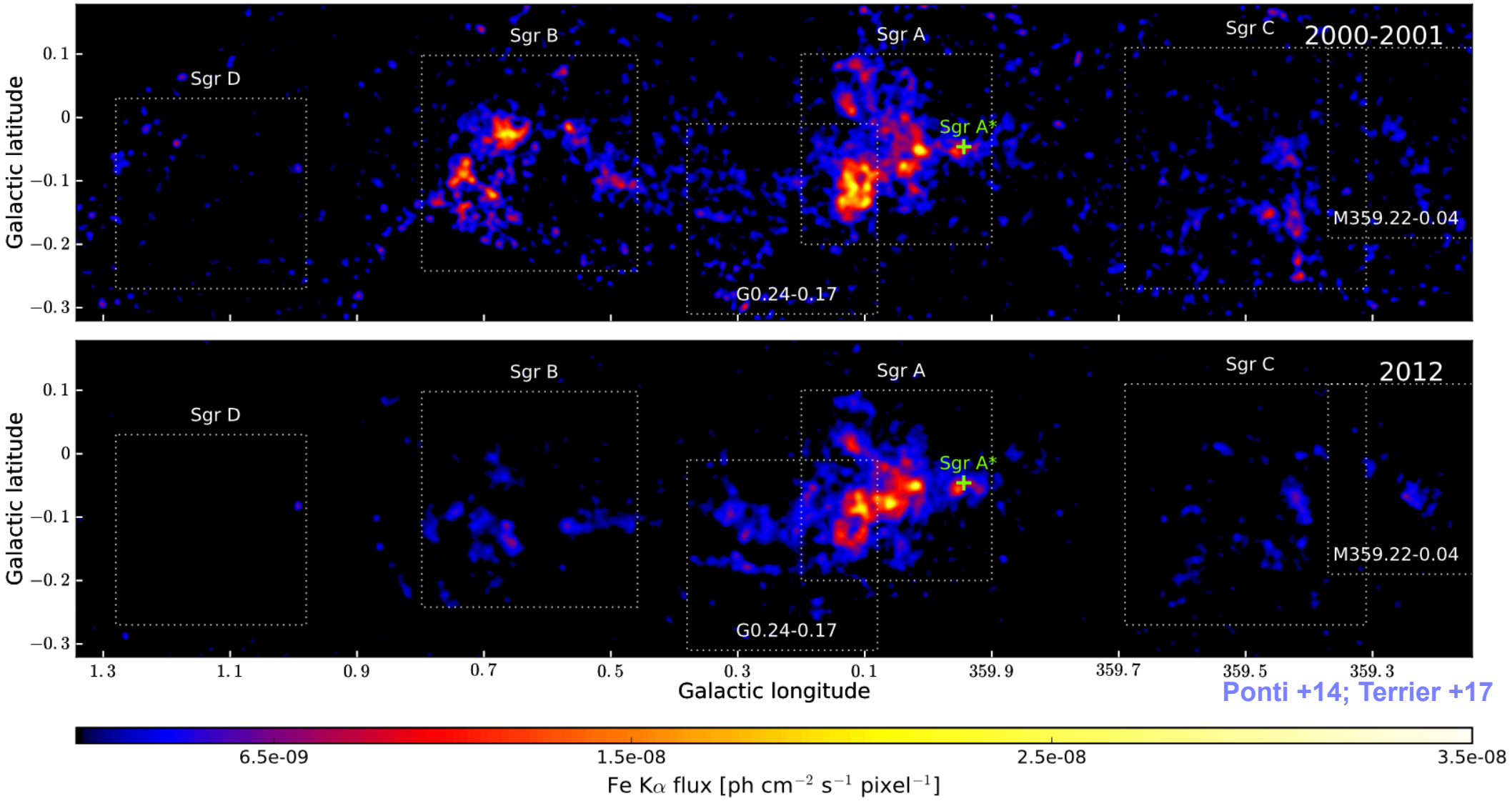


NuSTAR: hard X-ray emission!

Mori +15

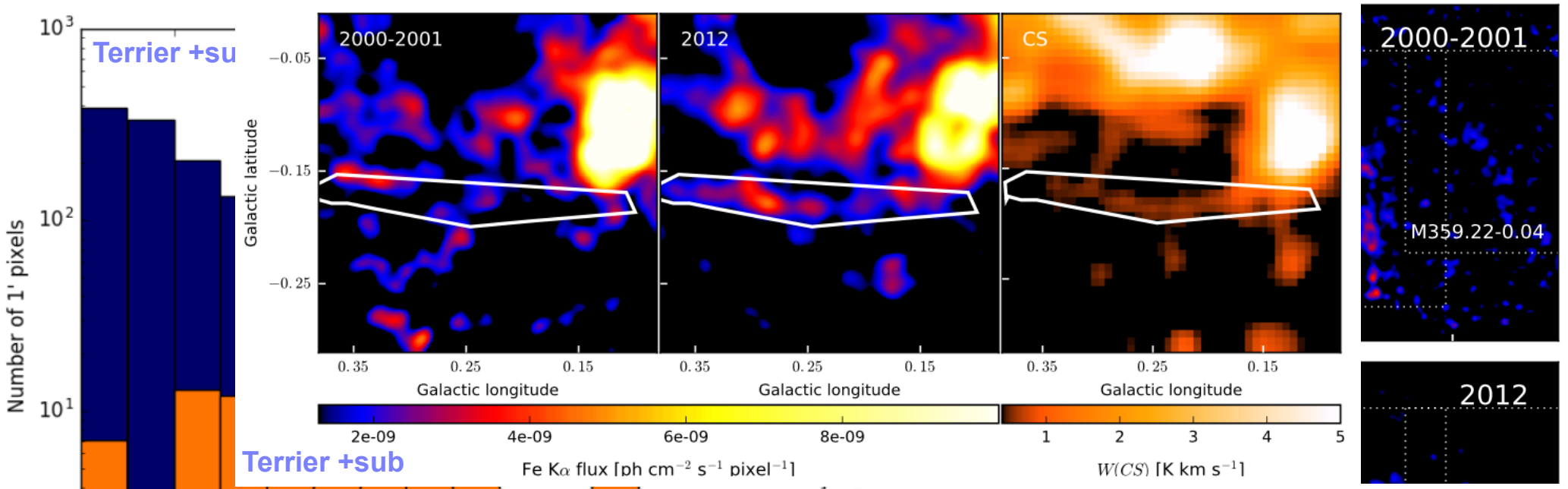


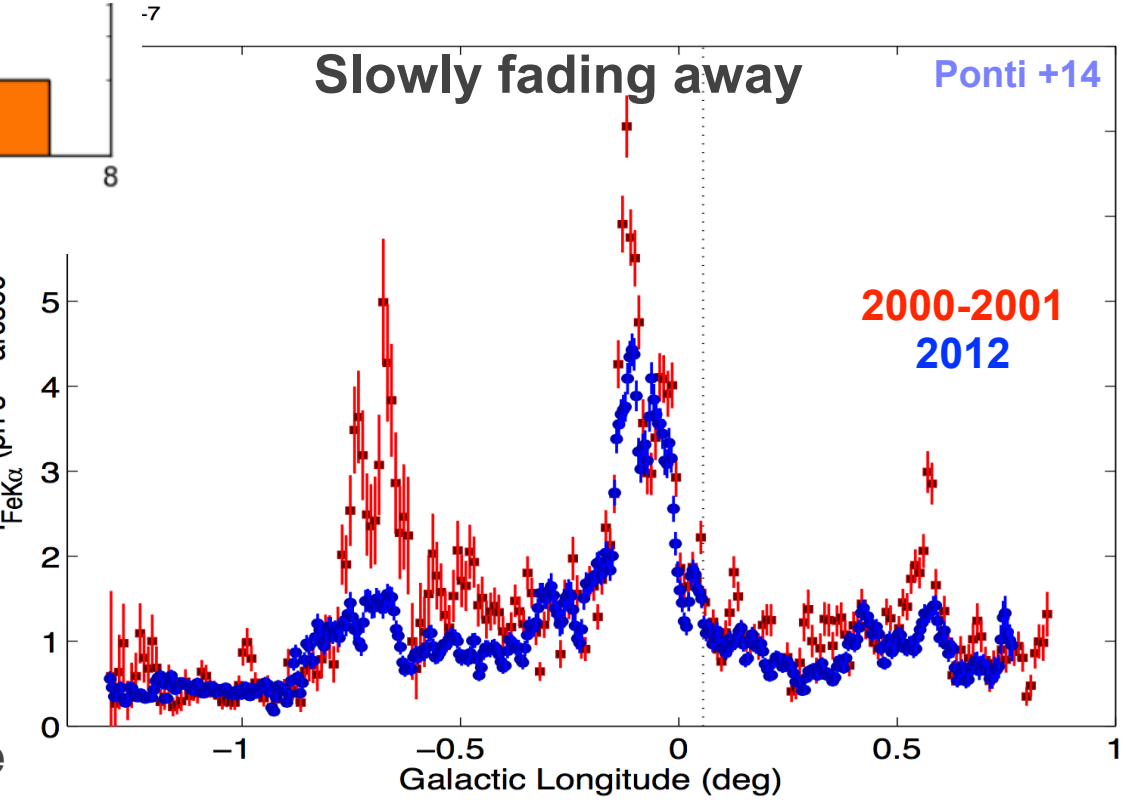
Fe K emission from GC



Ponti +14; Terrier +17

Fe K emission from GC





Reflection faded in 10 yr Ponti +14

All Fe K bright clumps are variable

➜ no century long flare Terrier +sub

Illumination of 25 pc long feature in 10 yr

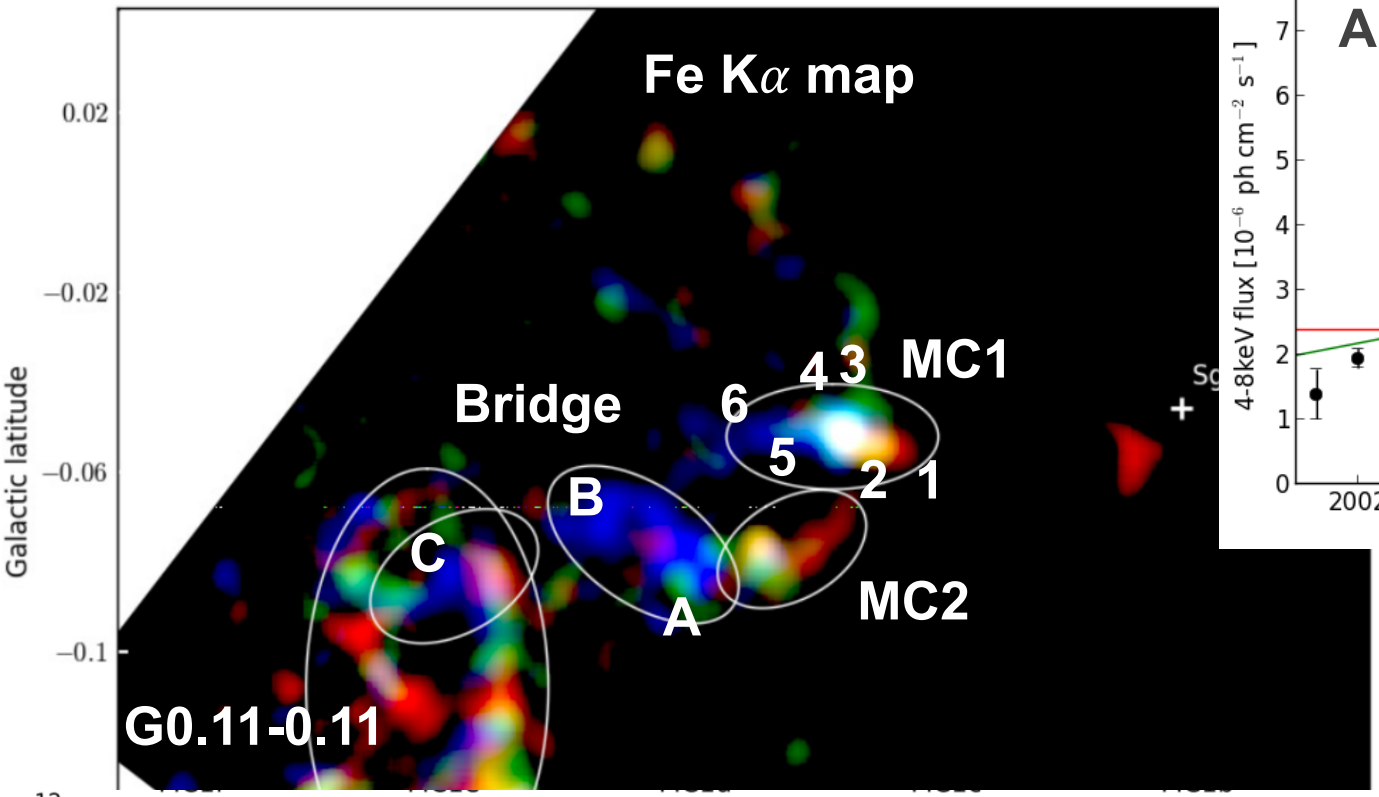
➜ External irradiation Terrier +sub

➜ Smaller clumps vary faster ➜ short flare

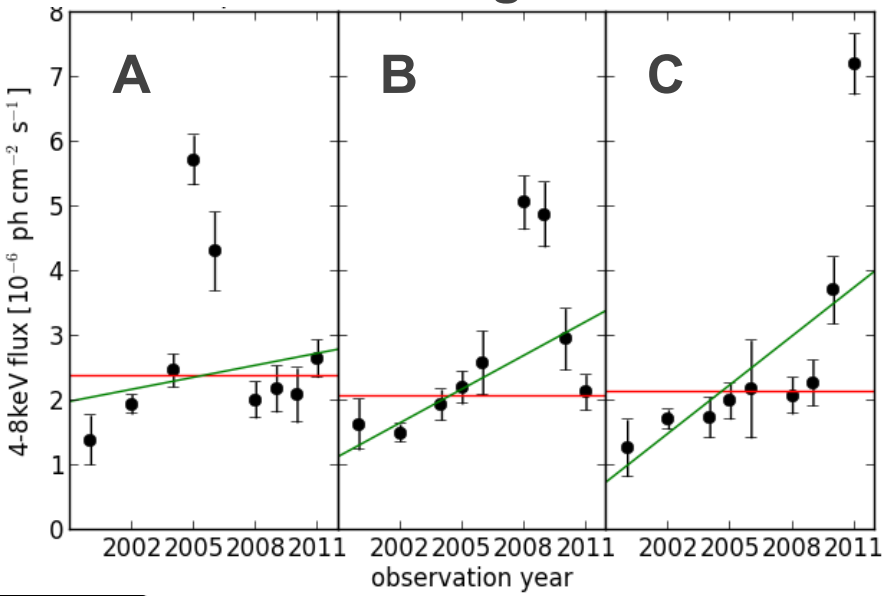
Multiple outbursts from Sgr A?*

Chandra: Smaller regions ➜ vary faster
(due to cloud light crossing time)

Clavel +13

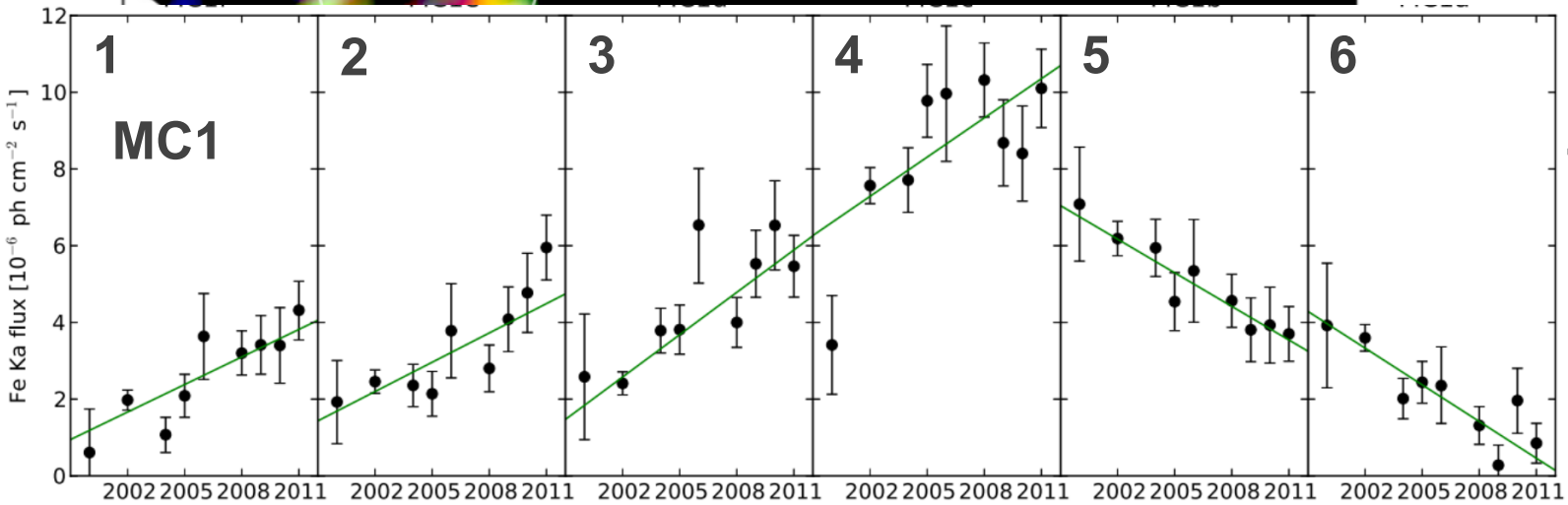


Bridge



Super-luminal echo confirmed

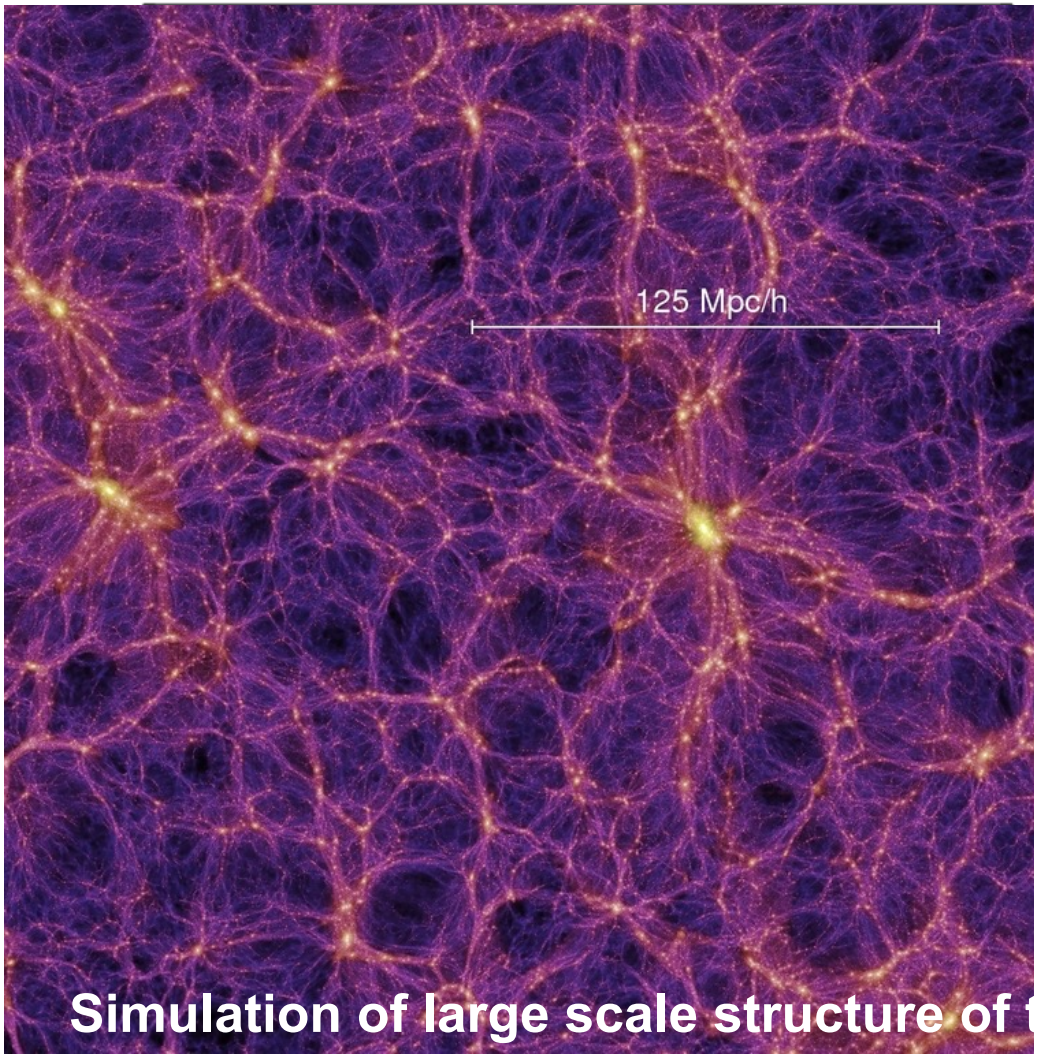
extending further

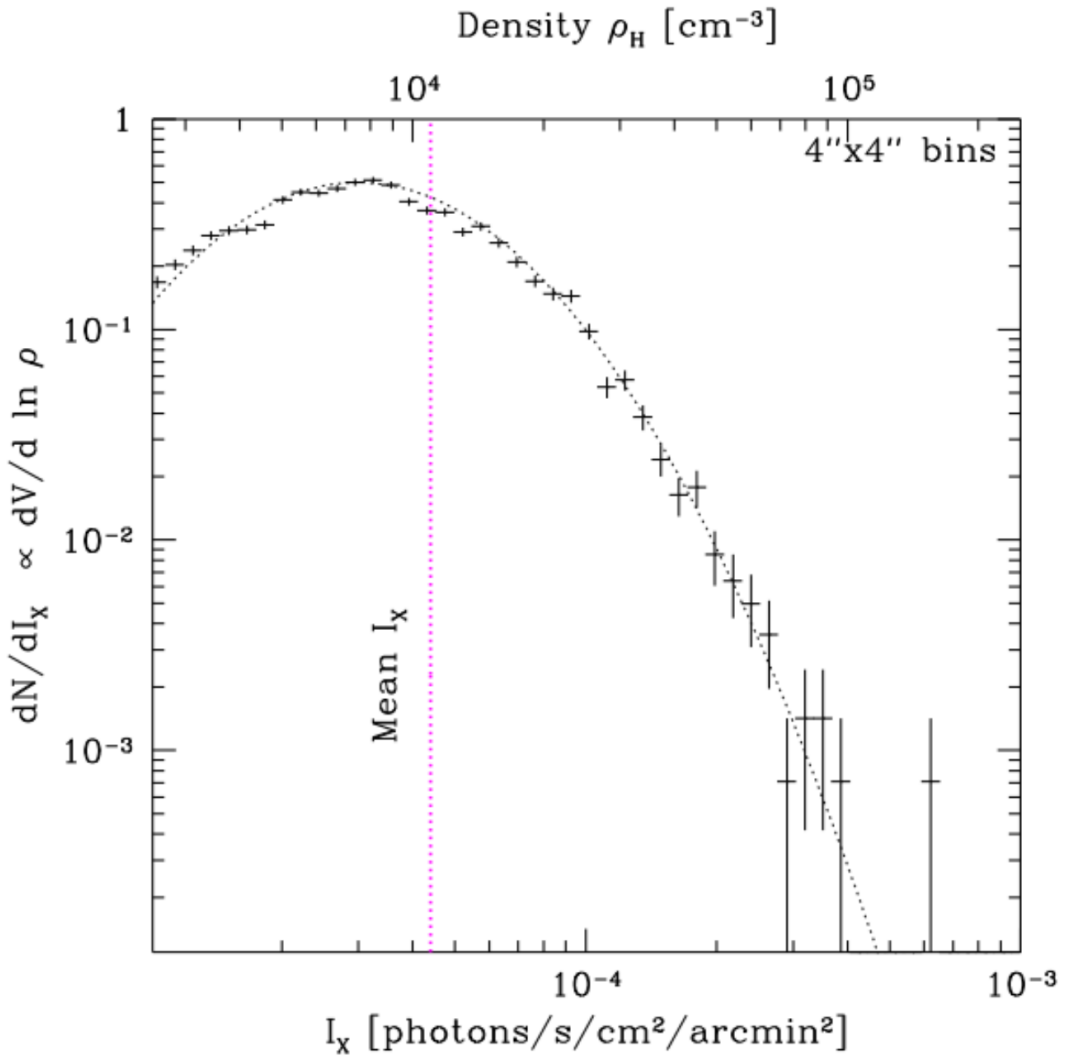


Two different events illuminate Bridge and MC1

Clavel +13

Can echoes reveal PDF of gas densities?





Churazov +17

Short echo ➜ reveal internal structure of clouds

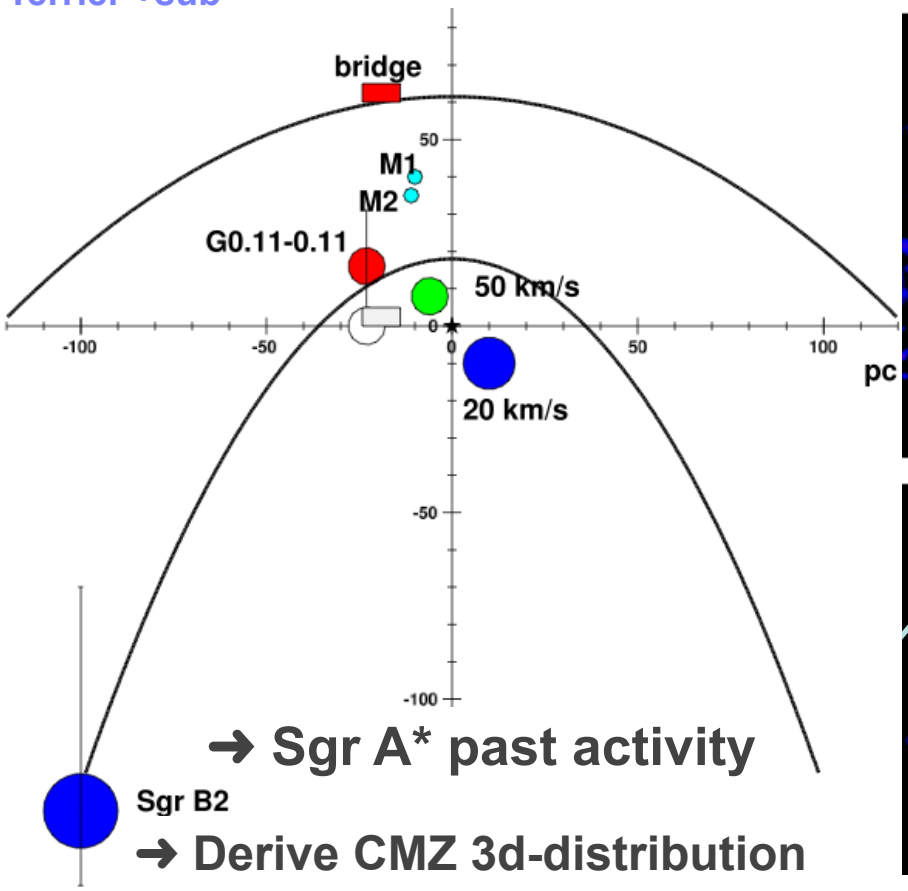
➜ Voids and walls structures

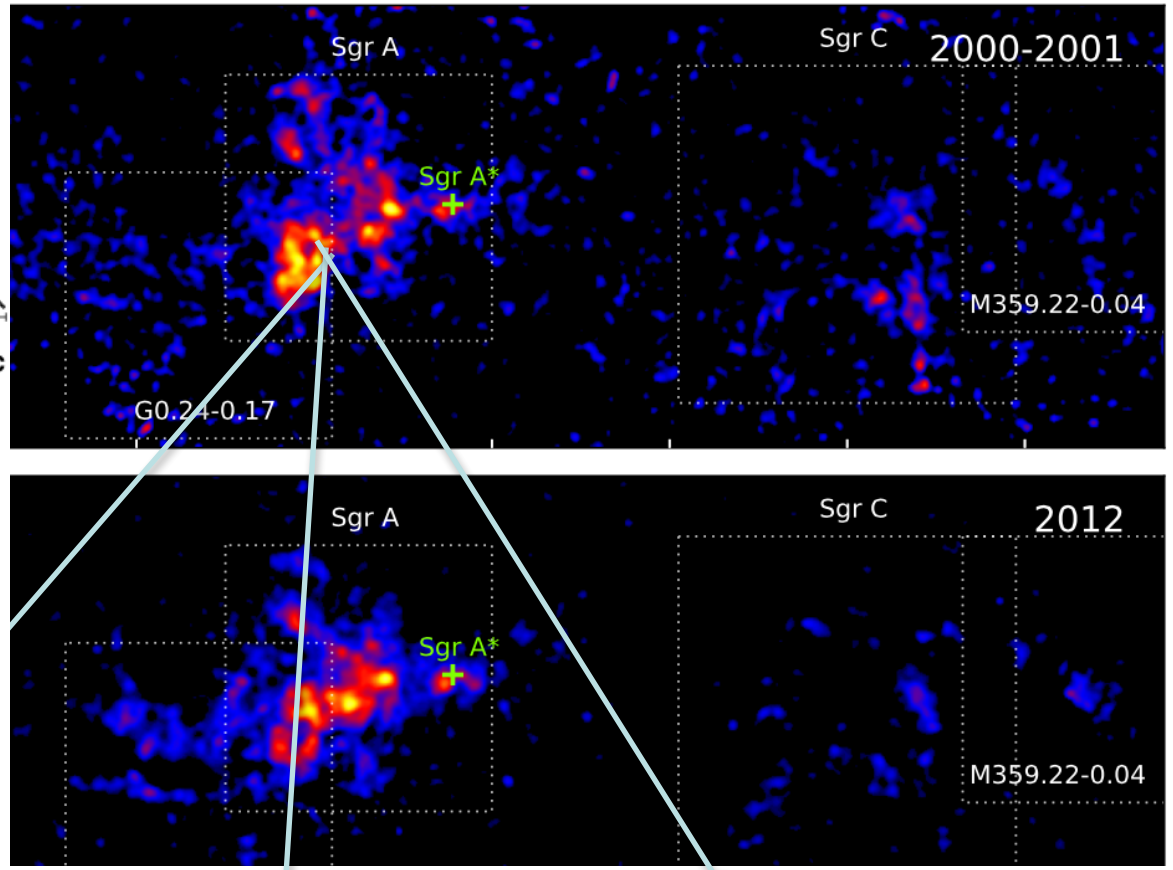
➜ Unbiased probe of mass/density distribution ➜ Star formation!

➜ Athena will measure gas velocities ➜ cloud velocity field structure function

Future prospects: Correlated variations

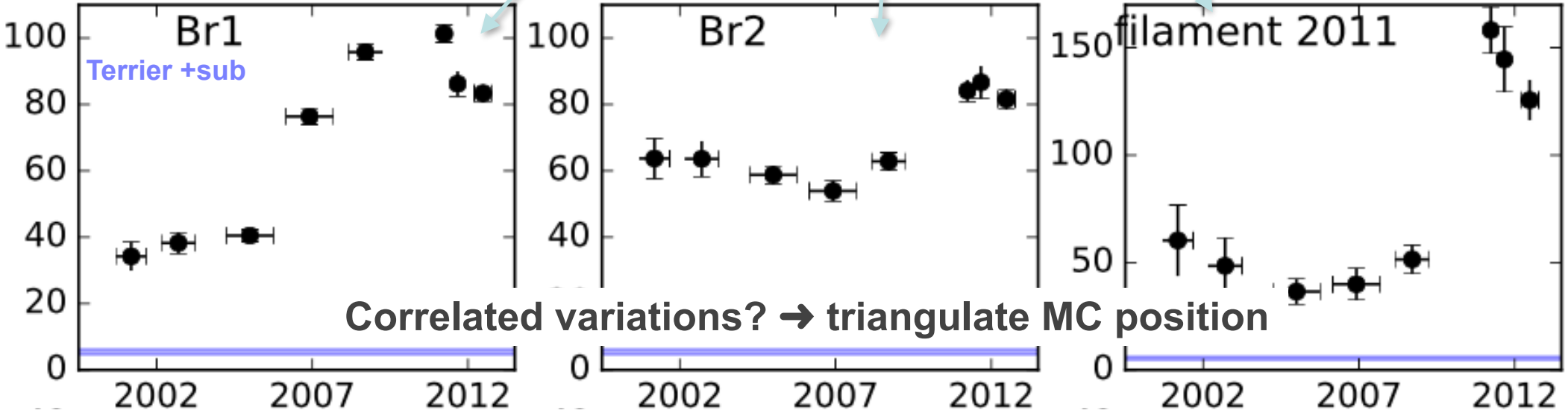
Terrier +sub





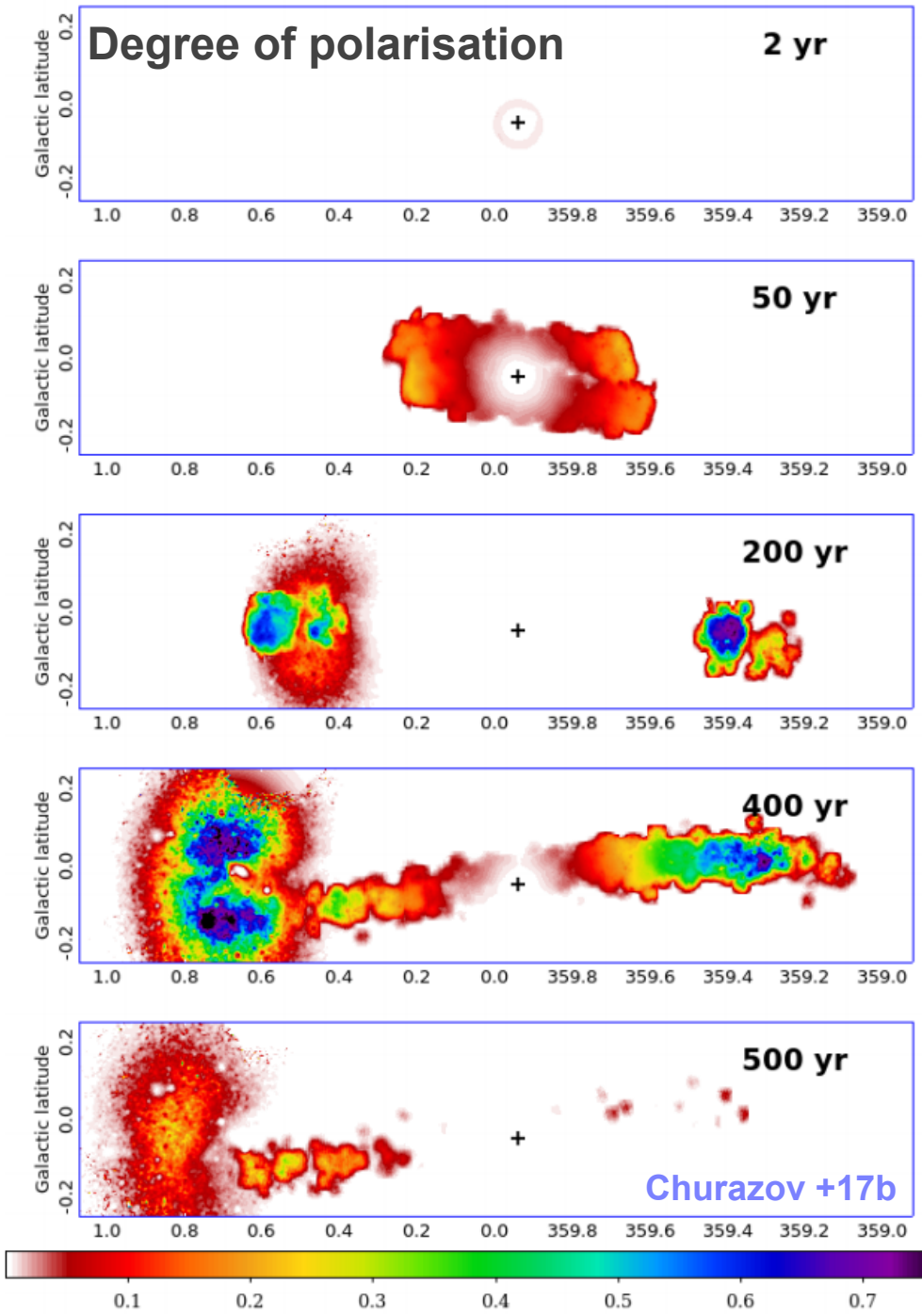
➜ Sgr A* past activity

➜ Derive CMZ 3d-distribution



Correlated variations? ➜ triangulate MC position

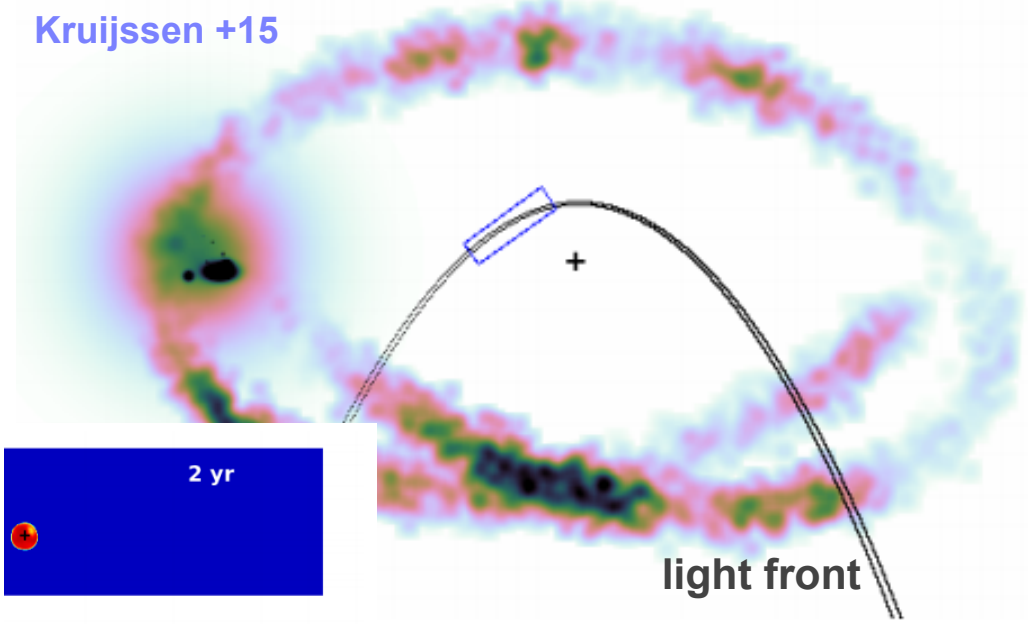
Future prospects: Polarisation

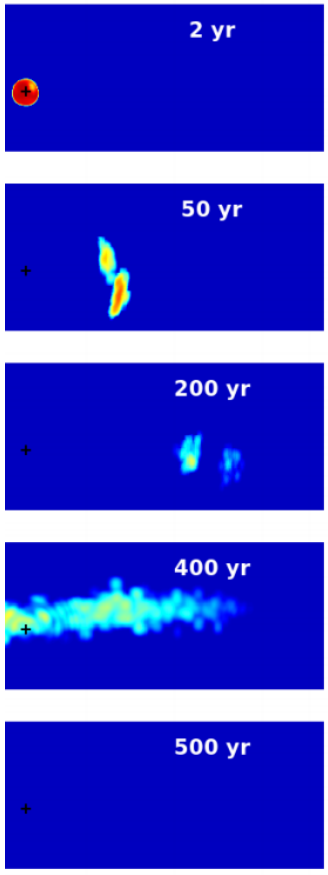


Central Molecular Zone

Kruijssen +15

Churazov +17b





Churazov +17b

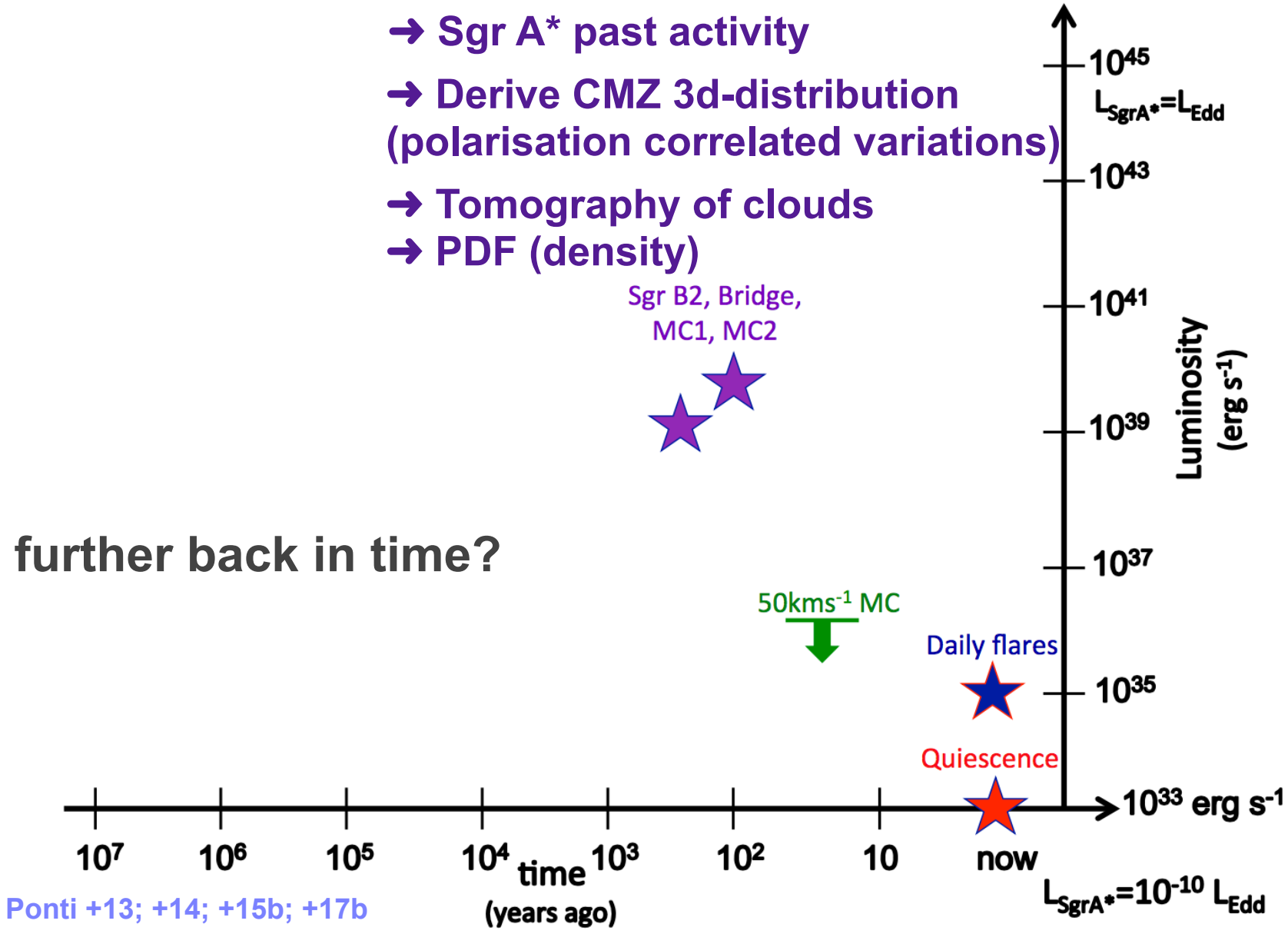
Time evolution of Fe Kα

Degree of polarisation

➜ Reconstruct 3-d distribution

➜ Achievable with XIPE

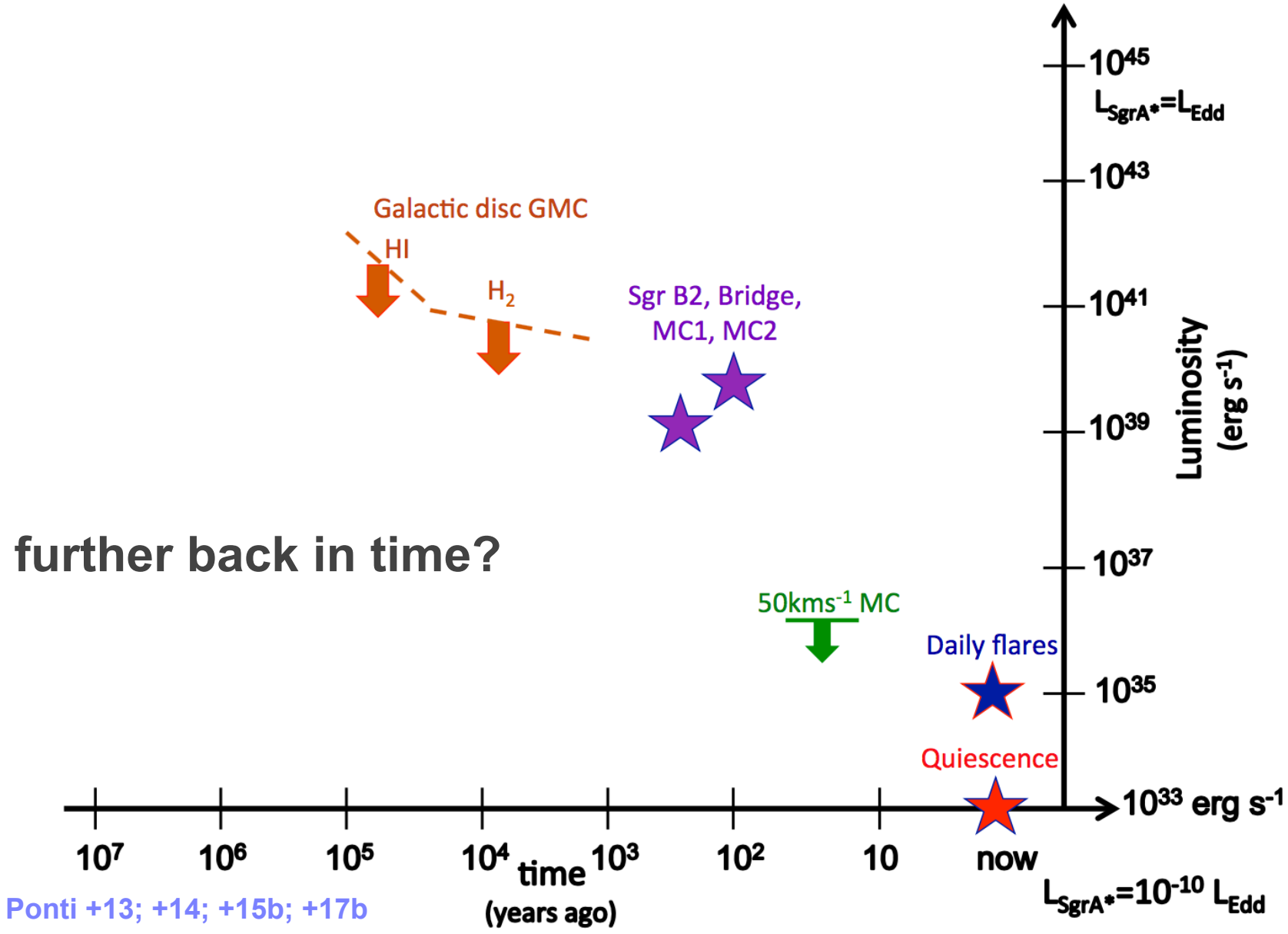
Sgr A's present and past activity*



And further back in time?

$L_{Sgr\ A^*} \sim 10^{39}$ erg s^{-1} ~ 10^2 years ago

Sgr A's present and past activity*



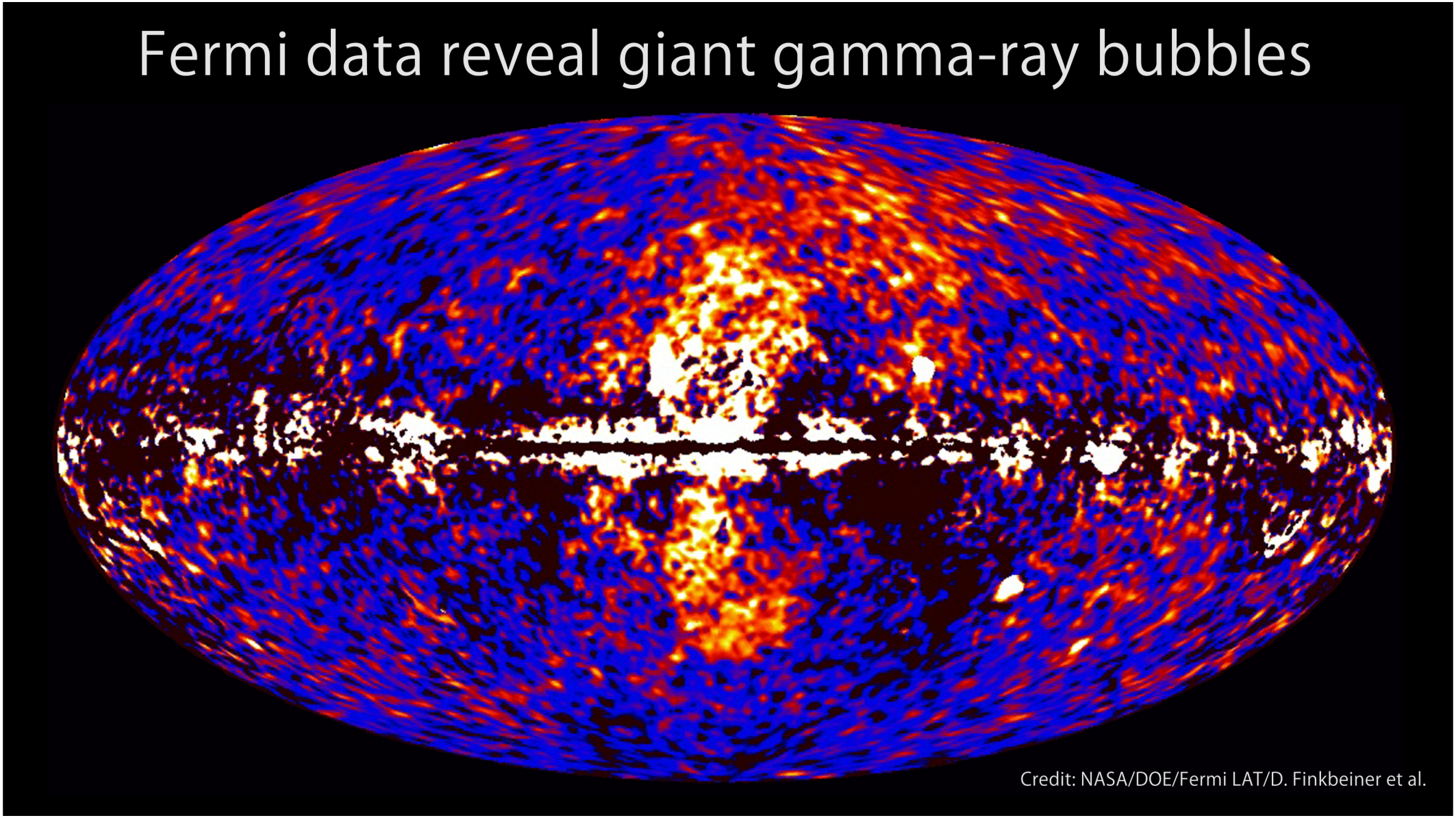
And further back in time?

Ponti +13; +14; +15b; +17b

$L_{Sgr\ A*} \sim 10^{39}$ erg s^{-1} ~ 10^2 years ago

FERMI bubbles

Su +10



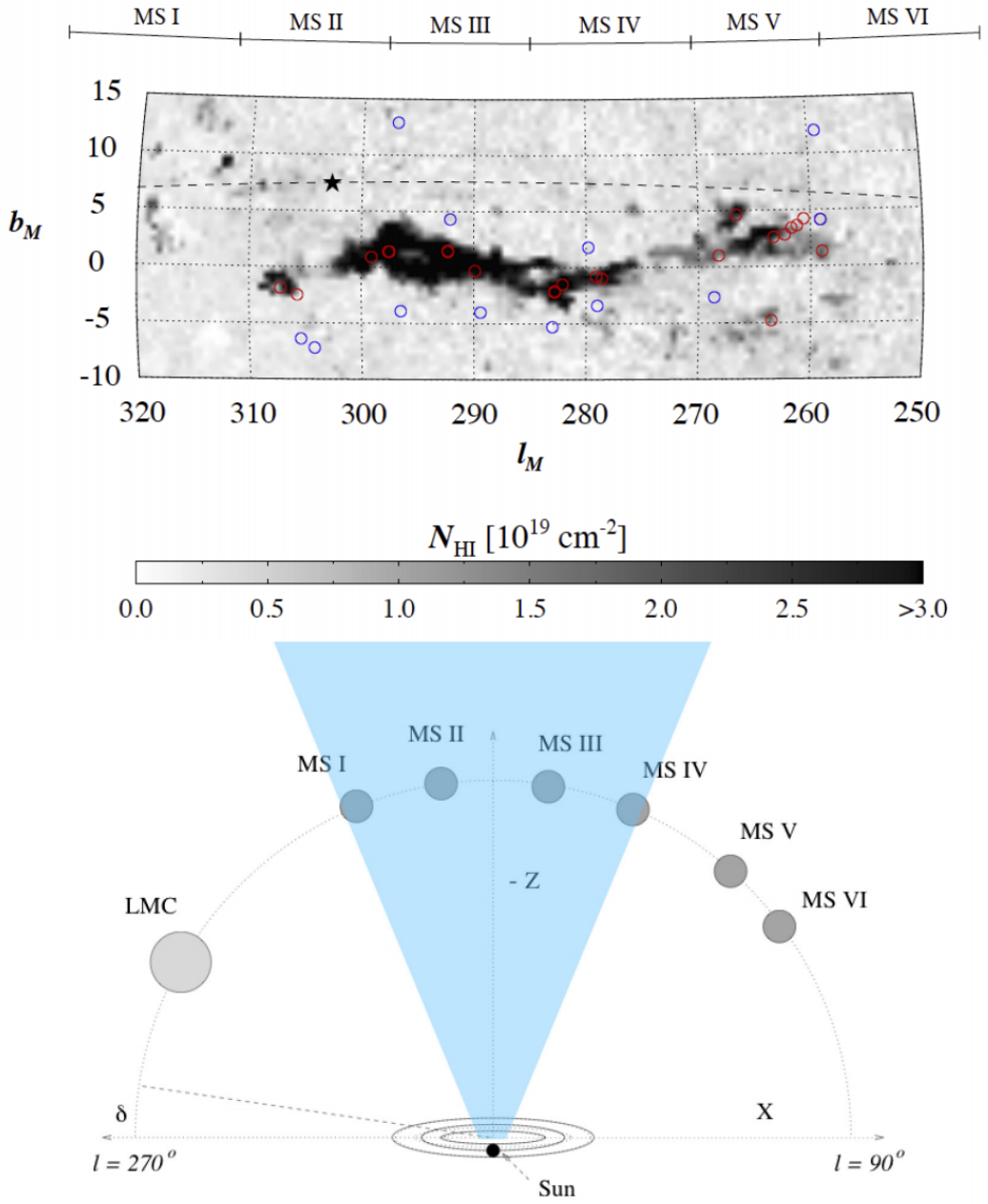
Energy release > 10^{55} erg **Few > 10^{6} yr ago**

Origin

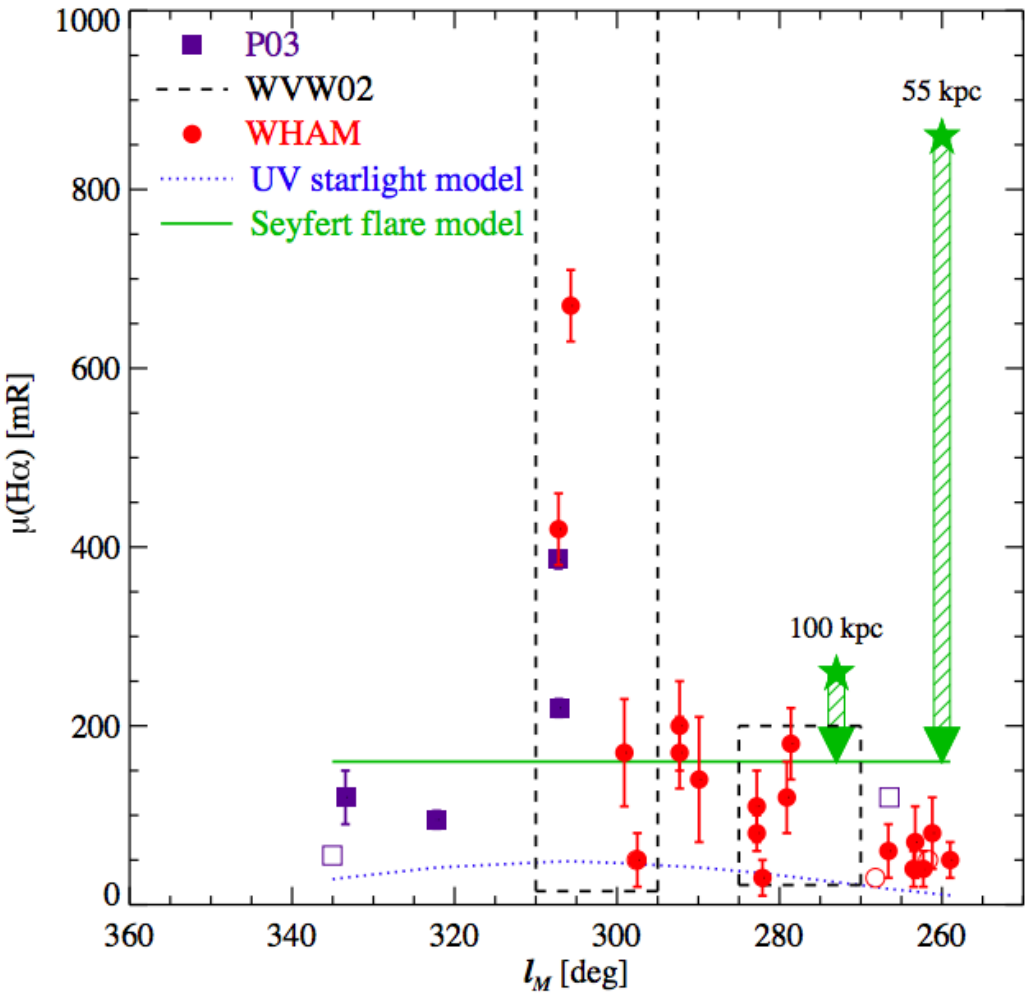
Past accretion event onto Sgr A*

Nuclear starburst

Reflection from the Magellanic stream



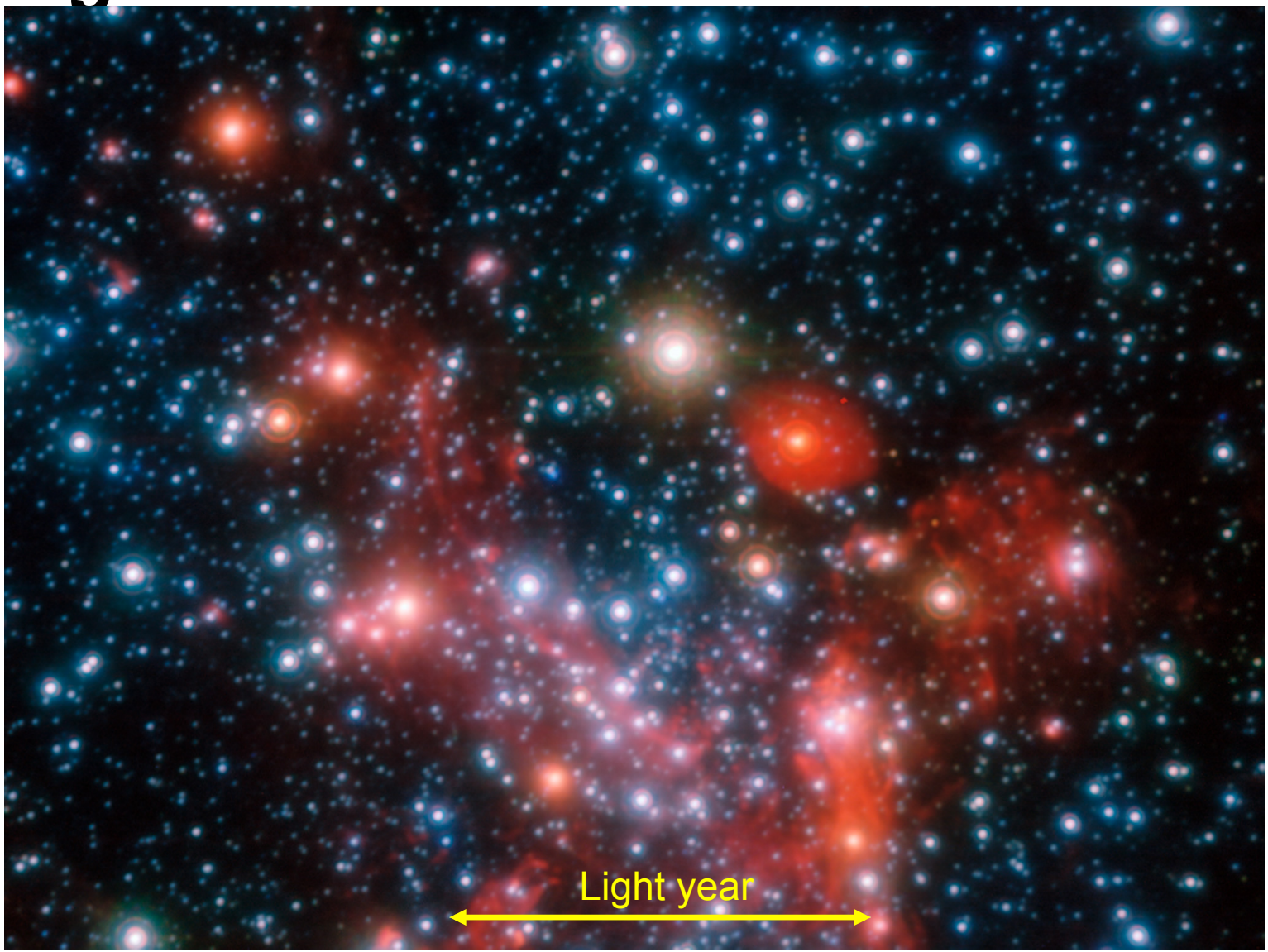
Bland-Hawthorn +13



➜ **Enhanced H emission along the Magellanic stream**

➜ **Sgr A* was an AGN (e.g., a Seyfert) few 10^6 yr ago**

Young star cluster at the Galactic center



> 200 young (few 10^6 yr) stars in the central parsec ➜ Sgr A* too close ➜ No star formation

Paradox of youth Morris +93; Ghez +03

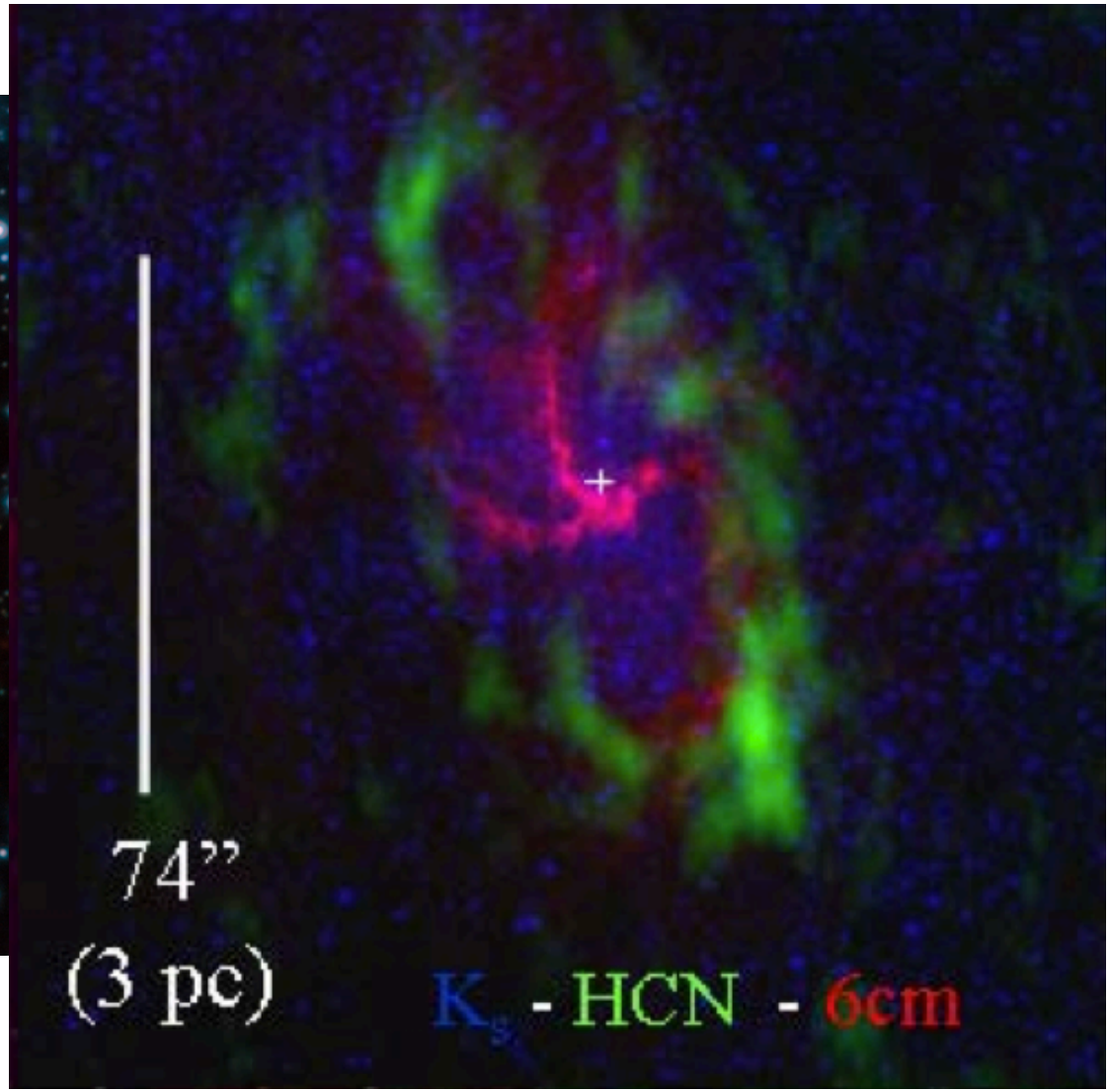
Stars rejuvenated by mergers (unlikely) Gerhard +01

Formed far away and funnelled inward (unlikely) Davies +05

Star formed in accretion disc! Nayakshin +07

Circum-nuclear disc

Genzel +10

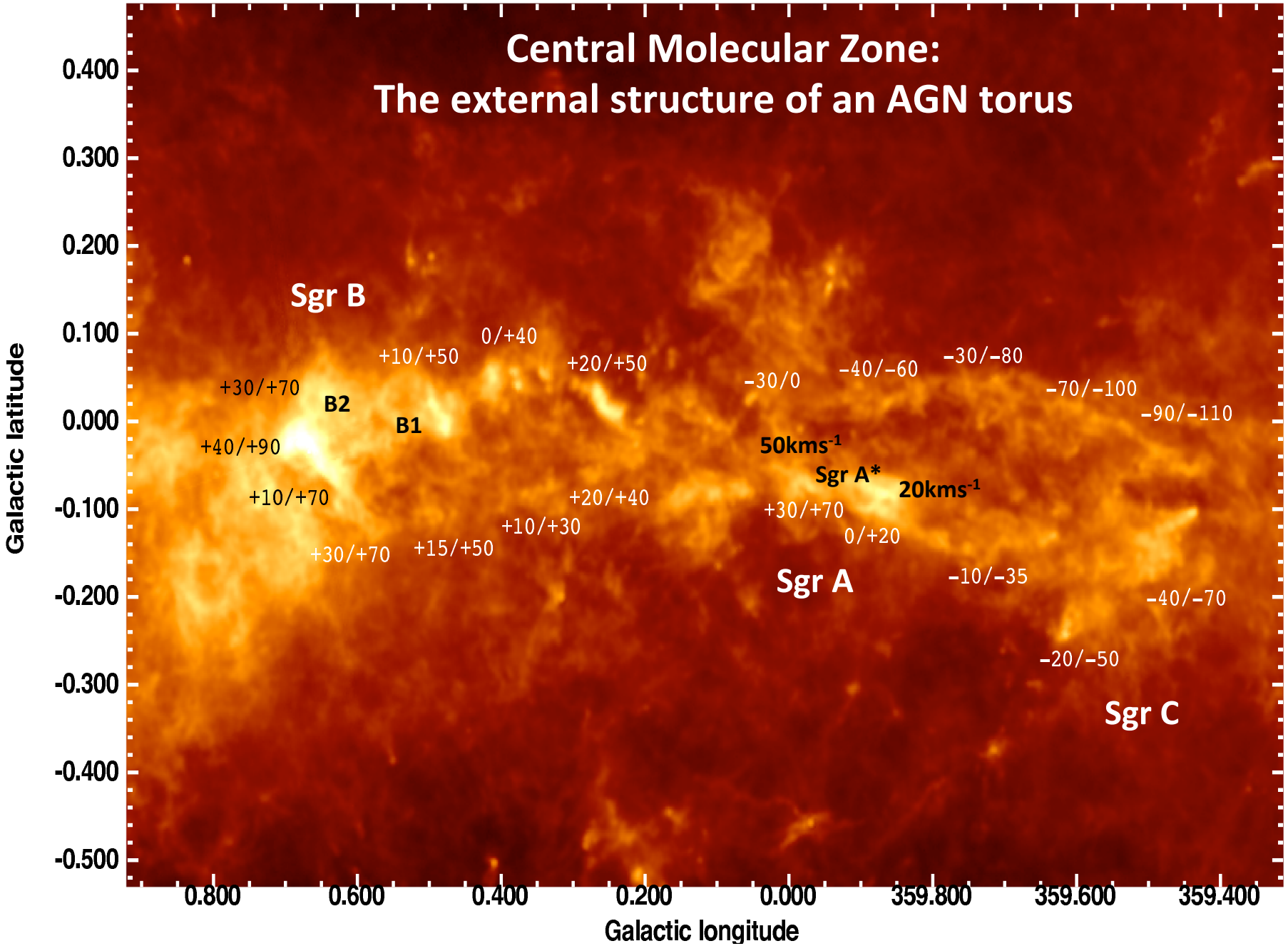


CND configuration similar to rotating disc or set of filaments

Transient nature or energetic disruption of a stable disc

Accretion event?

Was the CMZ a torus?

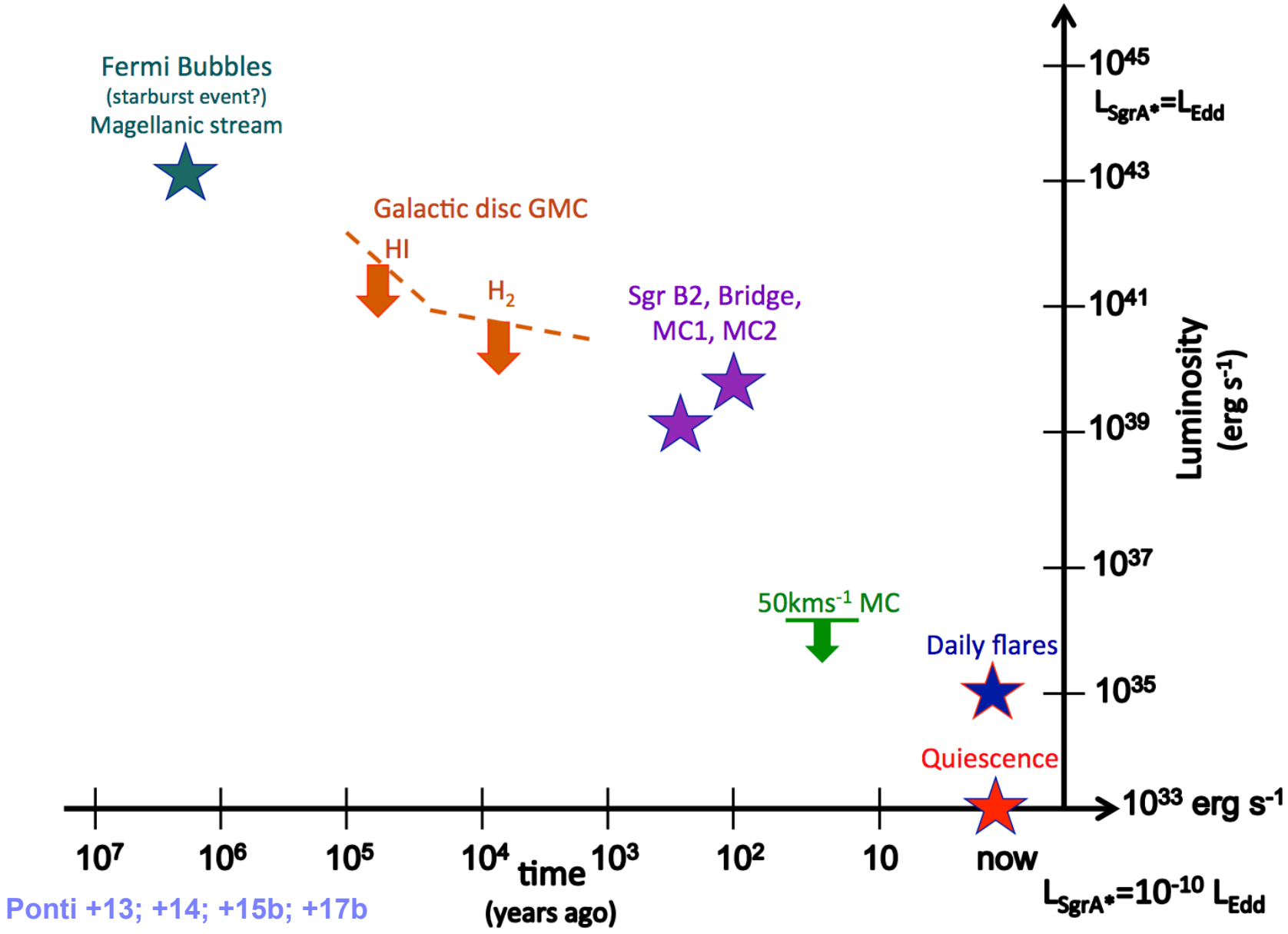


The CMZ would have looked like a torus to an external observer

Structure preserved ($t_{orb} \sim 10^7$ yr)

Ponti +13

Sgr A*'s present and past activity



Ponti +13; +14; +15b; +17b

$L_{Sgr\ A*} \sim 10^{39}$ erg s^{-1} ~ 10^2 years ago

$L_{Sgr\ A*} \sim 10^{44}$ erg s^{-1} ~ 10^6 years ago