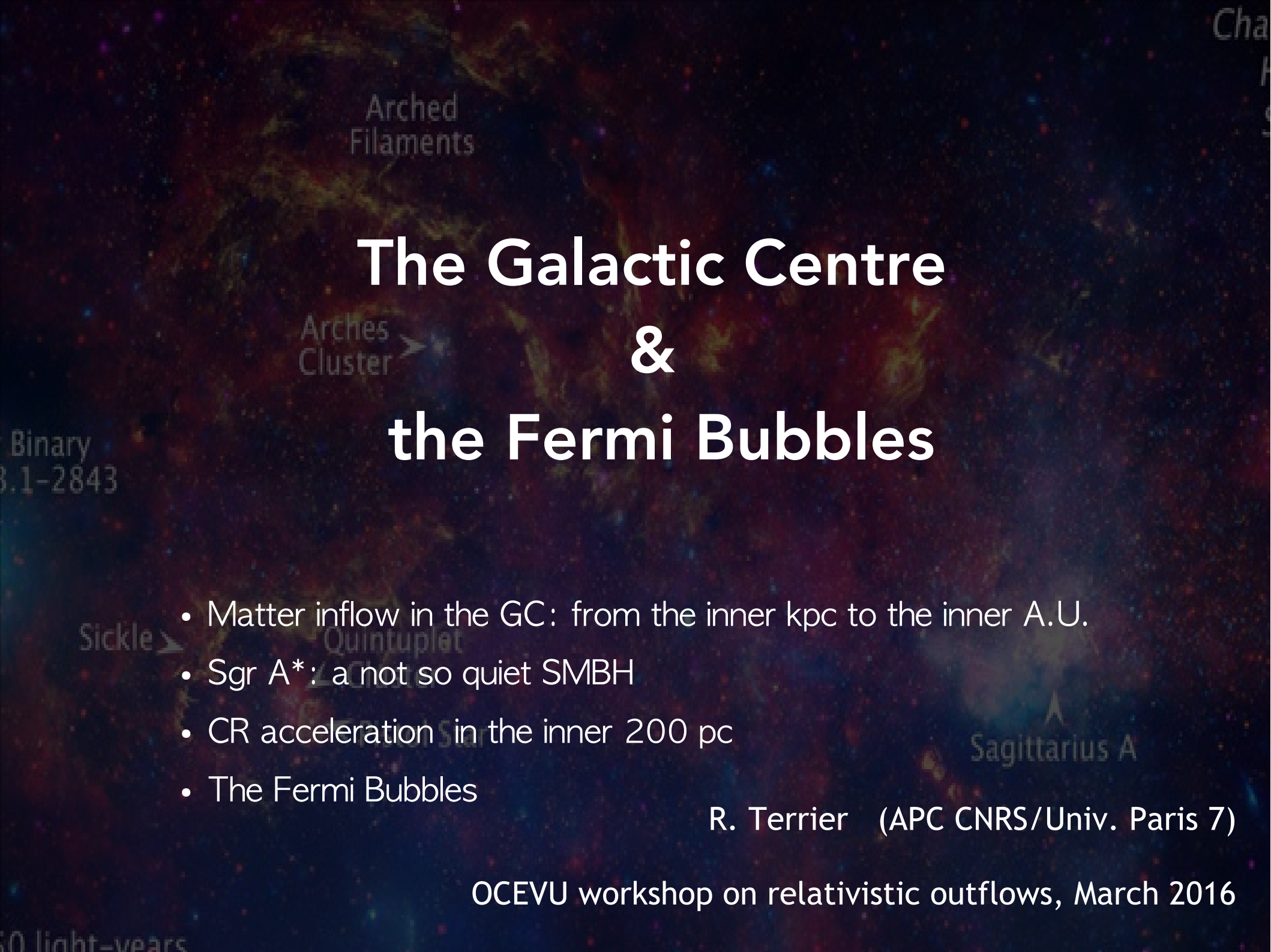


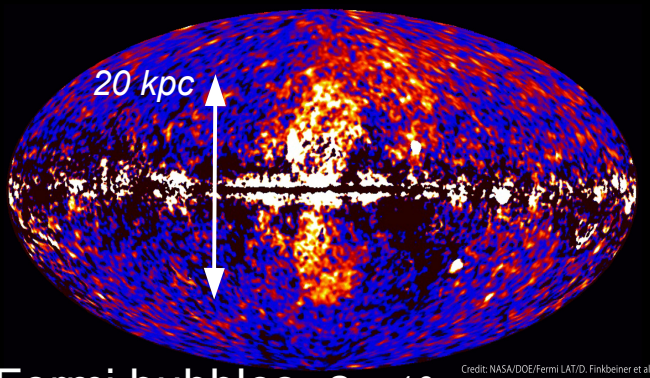
The Galactic Centre & the Fermi Bubbles

- Matter inflow in the GC: from the inner kpc to the inner A.U.
- Sgr A*: a not so quiet SMBH
- CR acceleration in the inner 200 pc
- The Fermi Bubbles

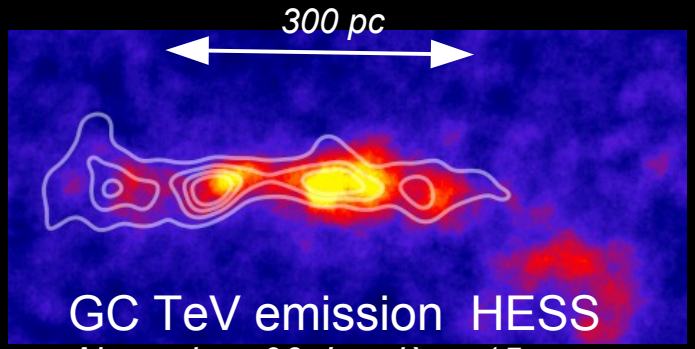
R. Terrier (APC CNRS/Univ. Paris 7)

OCEVU workshop on relativistic outflows, March 2016

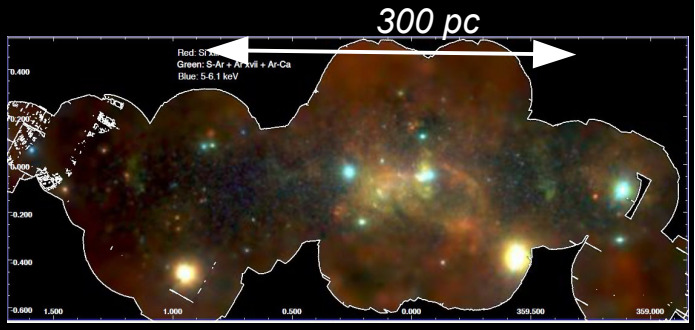
Energetic phenomena the GC region



Fermi bubbles *Su+10*



Aharonian+06, Lemière+15

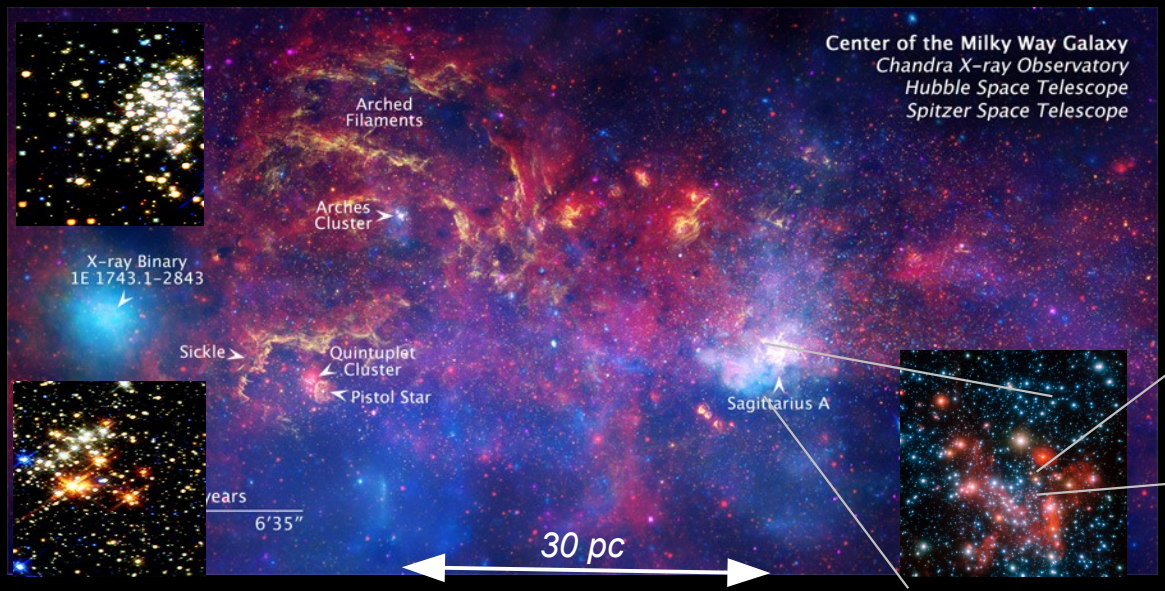


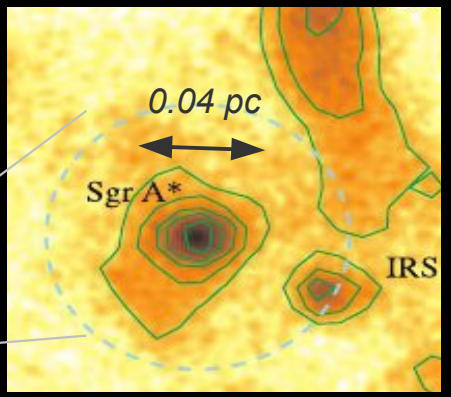
GC soft plasma kT~ 1 keV

Kaneda+97, Muno+04, Heard+13, Ponti+15

What is the impact of the intense star formation at the GC

and of the SMBH past activity?





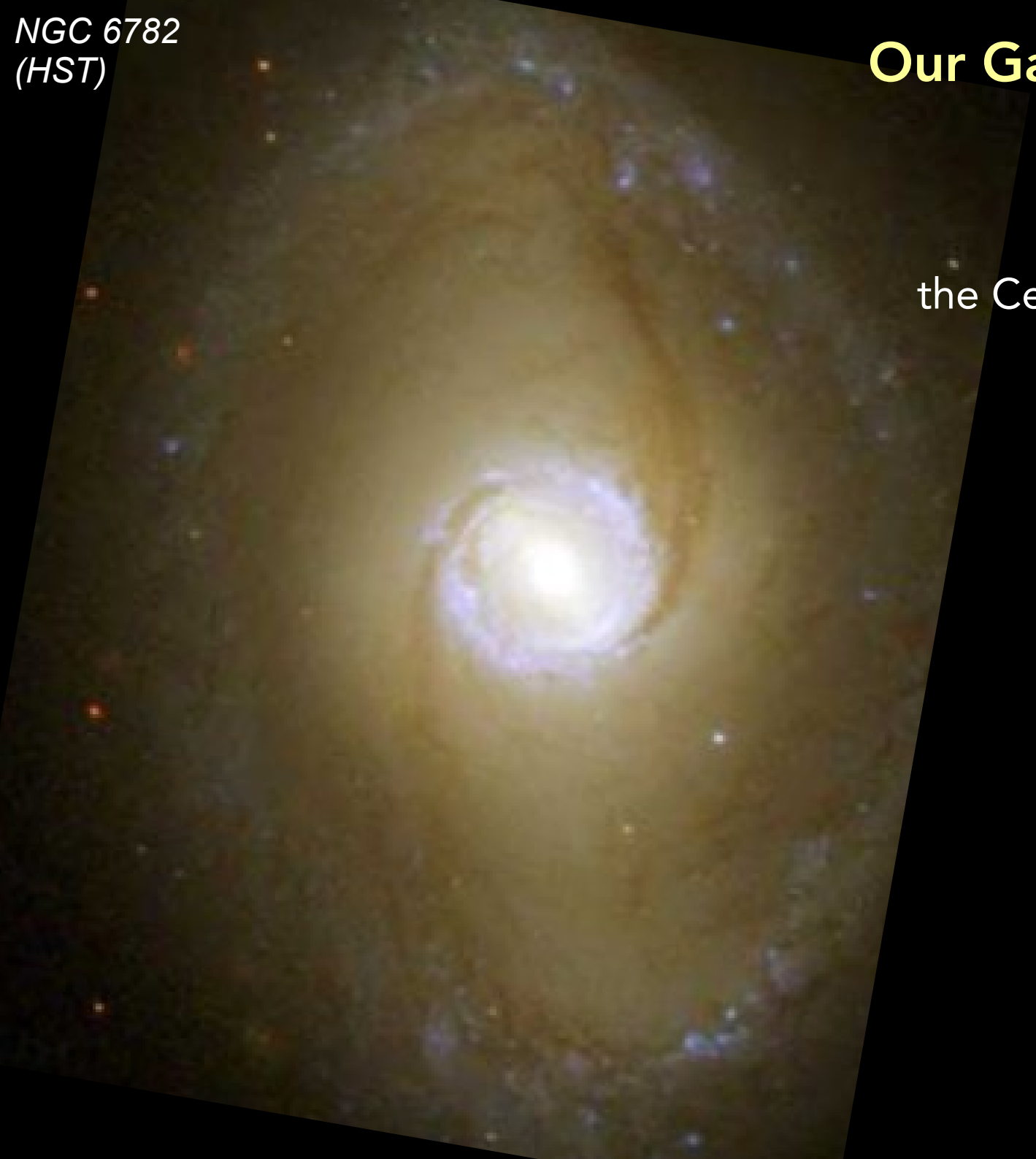
Chandra XVP Wang+13

Sgr A*:

Quiescence

$L_X \sim 10^{33}$ erg/s

$L_{edd} \sim 10^{44}$ erg/s



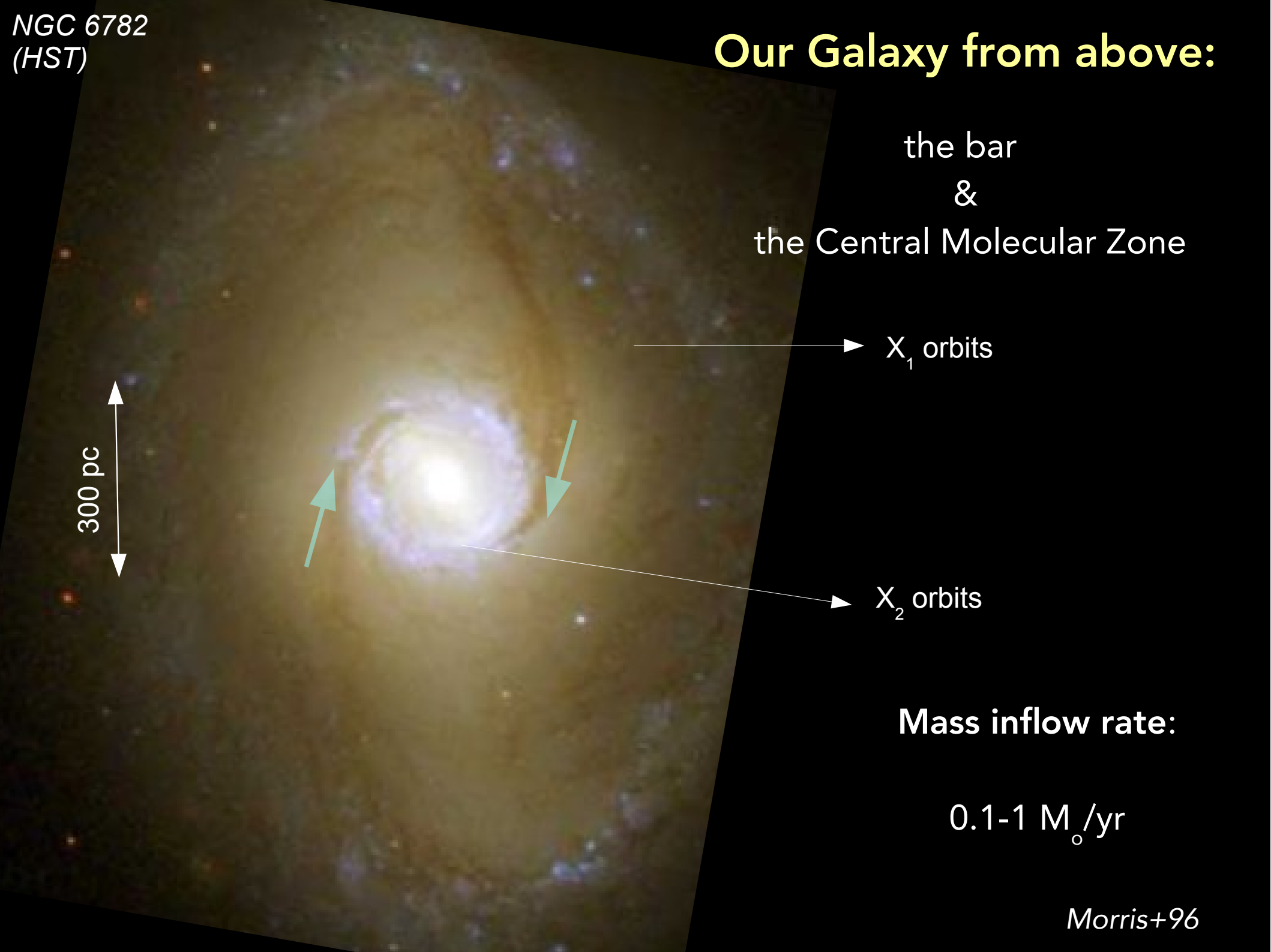
NGC 6782
(HST)

Our Galaxy from above:

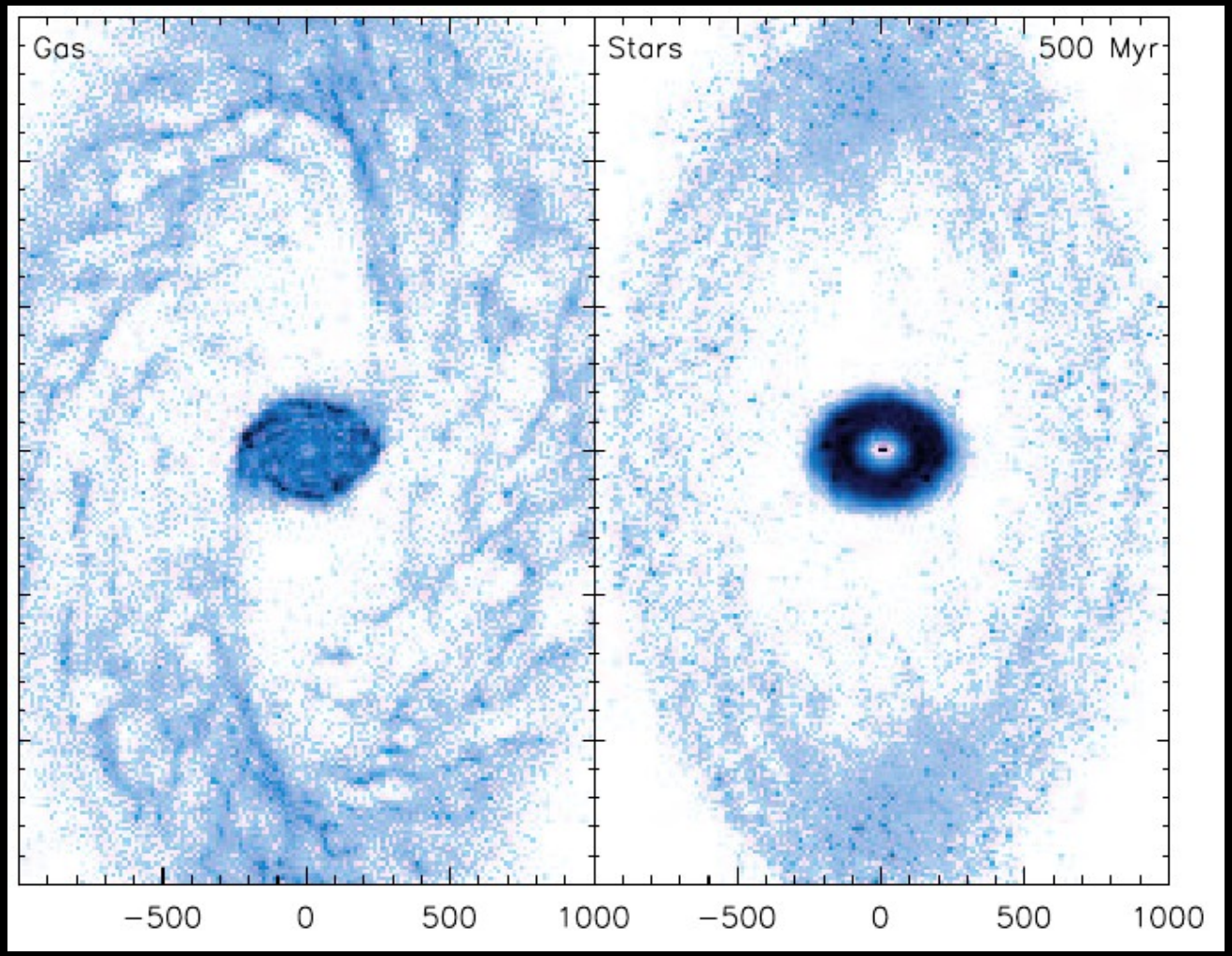
the bar

&

the Central Molecular Zone


NGC 6782
(HST)
Our Galaxy from above:
the bar
&
the Central Molecular Zone
X1 orbits
300 pc
X2 orbits
Mass inflow rate:
0.1-1 Mo/yr
Morris+96

Inflow triggers intense star formation in the central 200 pc



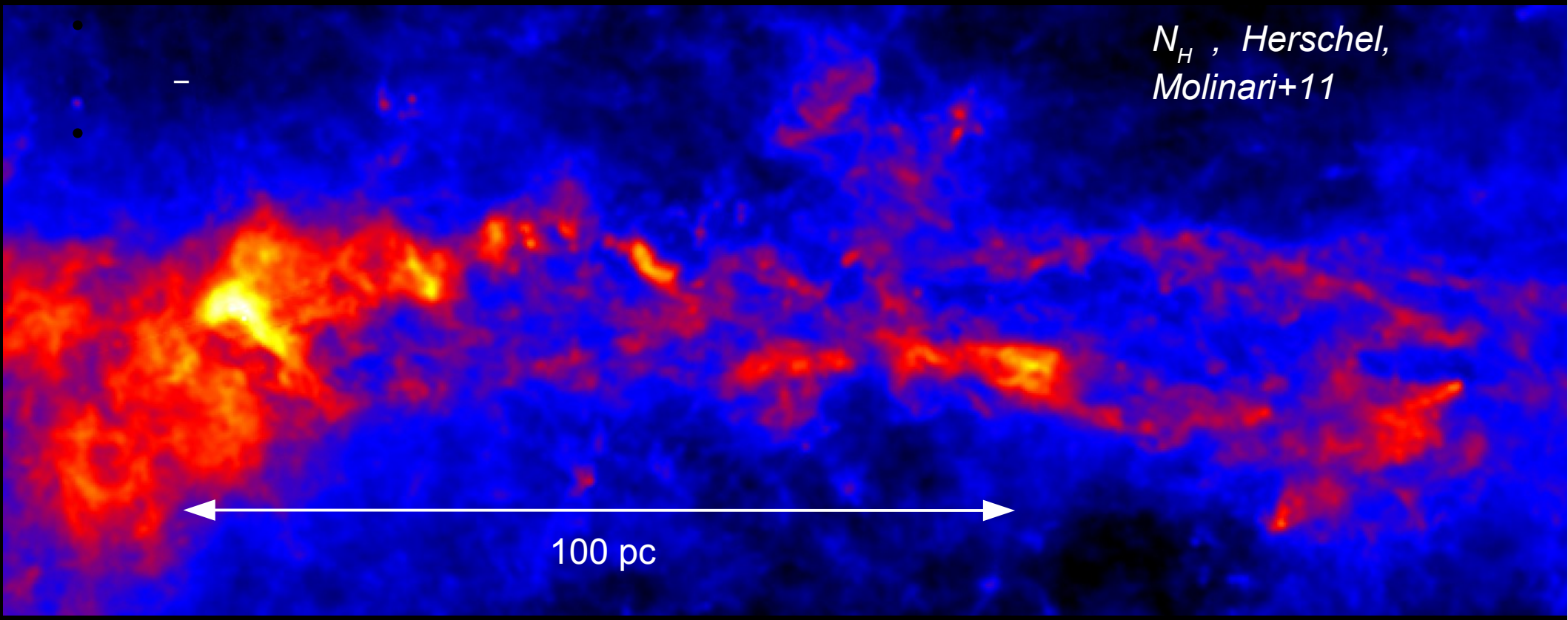
From Kim+11

Intersection of X1 and X2 orbits: compression and intense star formation

Star formation rate in the CMZ: 0.03-0.15 $M_\odot$/yr

Ponti+15, see also Longmore+14 and many more

Star formation in the central 200 pc



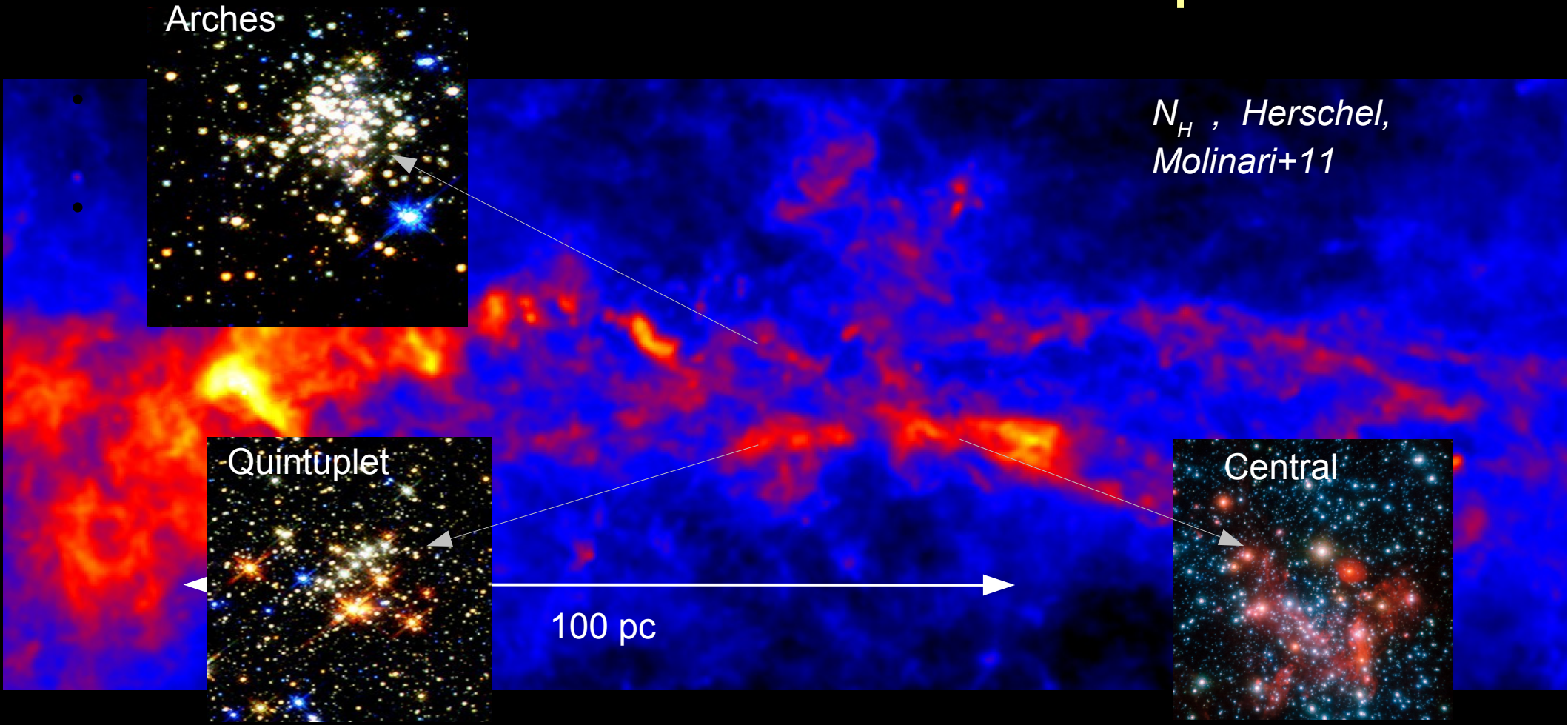
Central Molecular Zone (CMZ) contains 2-6 10^7 M_o of molecular matter

Tsuboi+99, Molinari+11 etc

In form of massive molecular clouds and a diffuse molecular component (100 cm^{-3})

Oka+05,Geballe12

Star formation in the central 200 pc

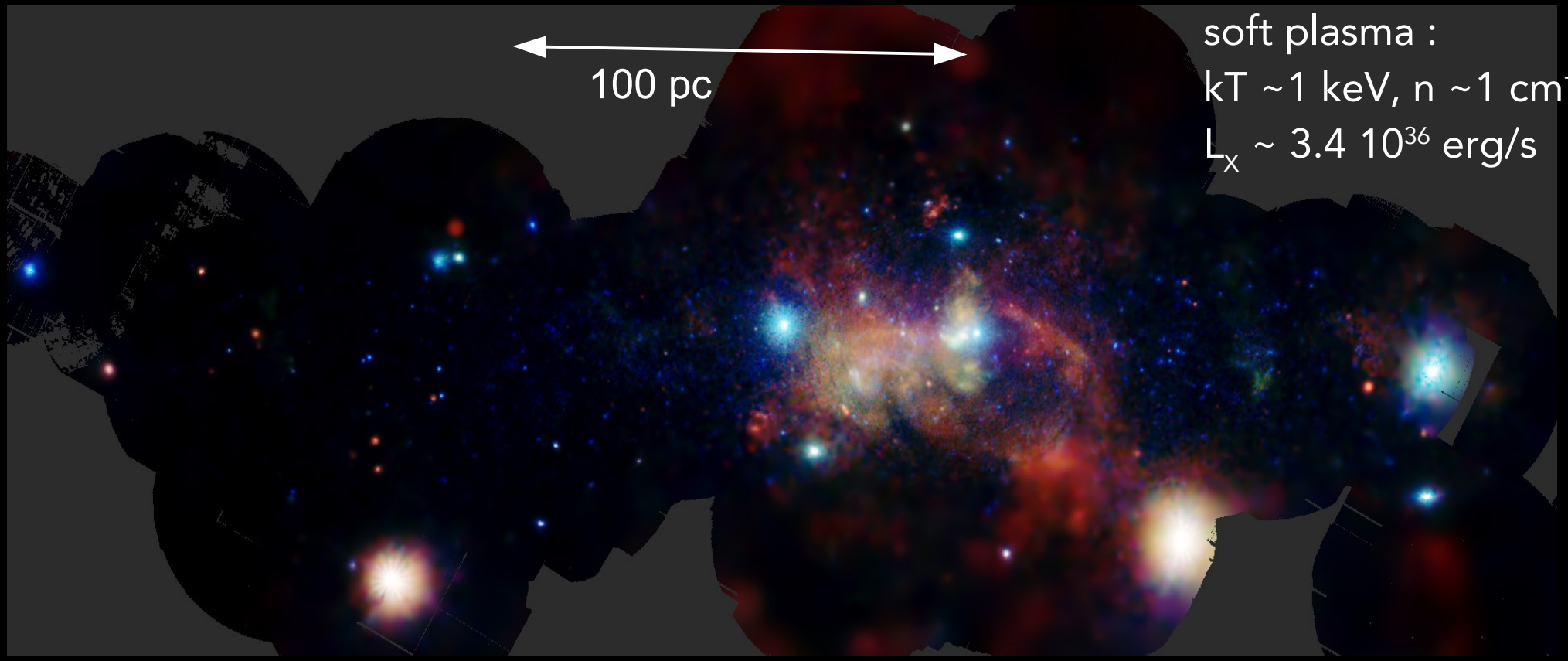


Young massive star clusters in the central 30 pc:

- Central: ~150 O & WR stars *Did it form there? paradox of youth*
- Arches: ~ 2Myr, central density up to 10^5 $M_o.pc^{-3}$
- Quintuplet : ~ 4 Myr, harbors the pistol star

Star formation through thermal X-ray emission

Through thermal lines: Si xiii, S xv, Ar xvii



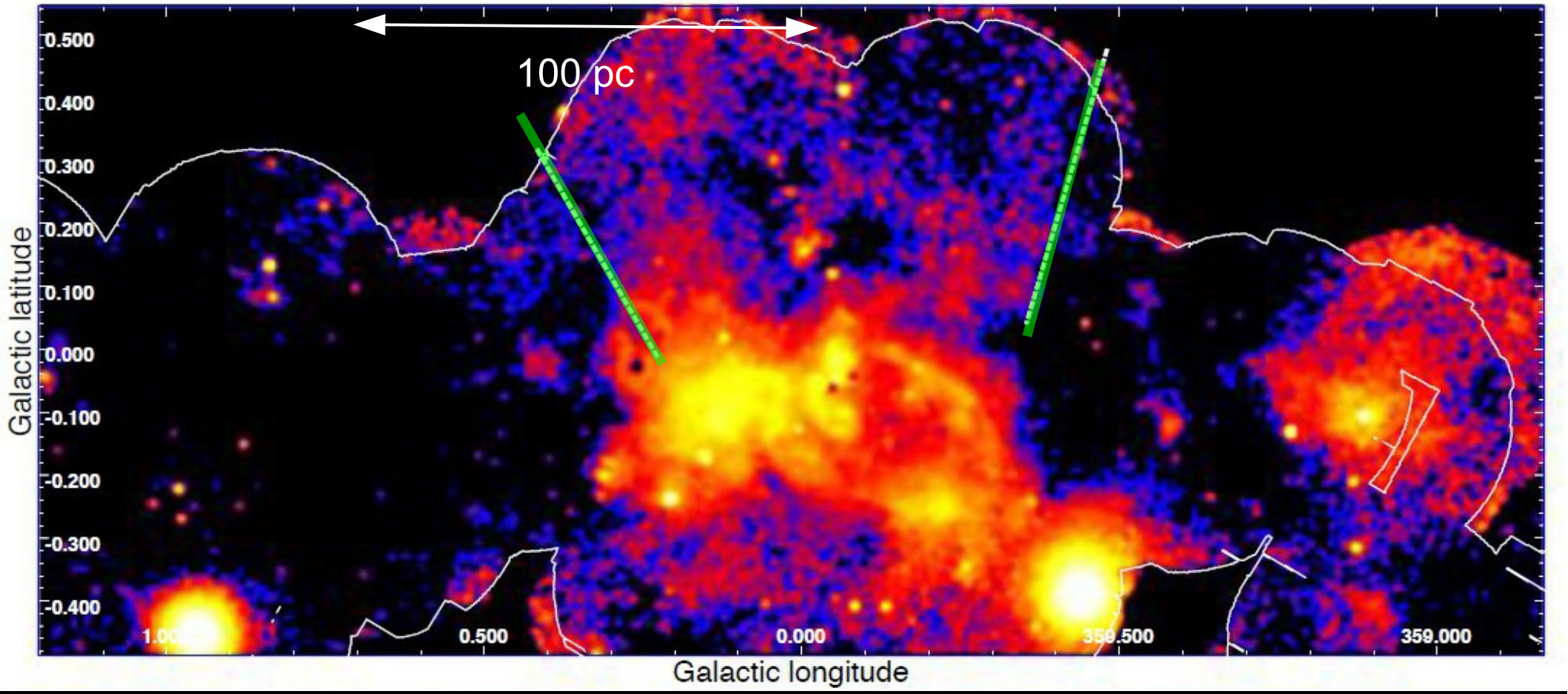
SN rate: from 0.3 x 10^{-3} to 1.5 x 10^{-3} yr^{-1}

Ponti+15

Kinetic energy released: 0.9 – 5 x 10^{40} erg/s

CR acceleration? outflows?

Star formation & large scale outflow ?



Indication of plasma emission extending at higher latitudes (at least up to 0.5° - 70 pc)

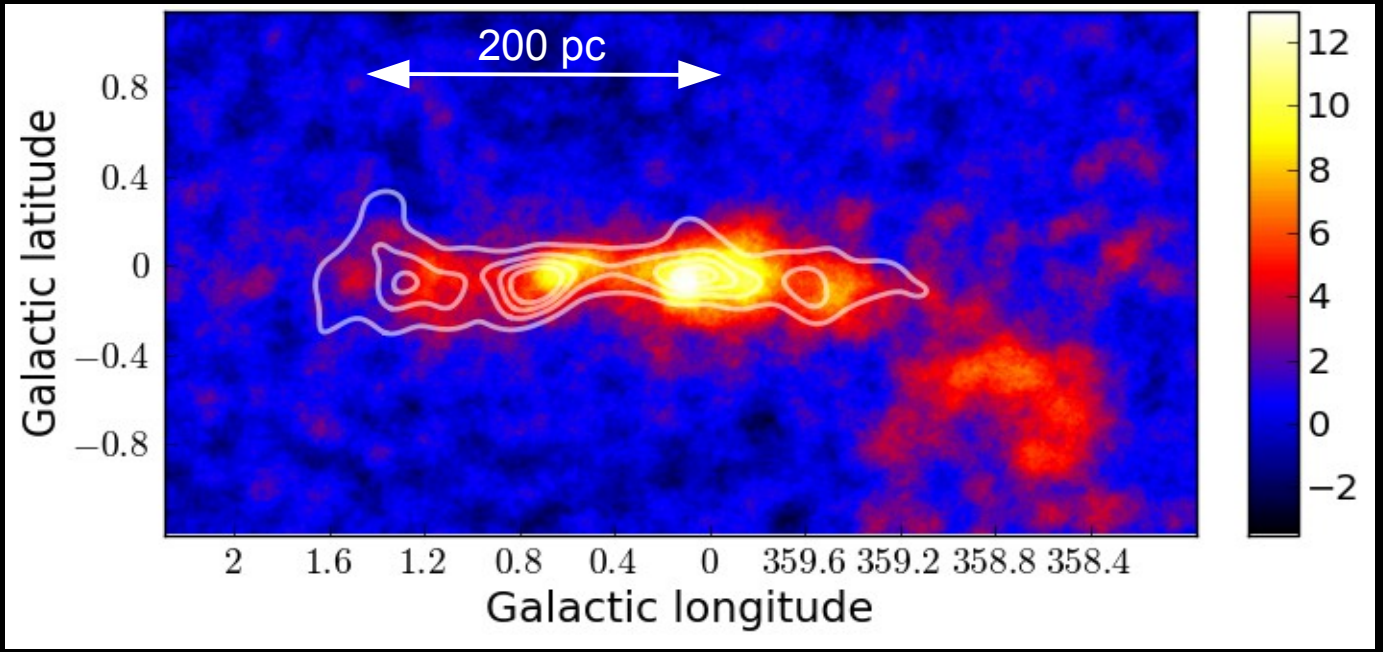
Real edges? Exposure effect?

Extension along latitude? Connection with larger structures?

A high latitude survey to be performed this year with XMM

Intense CR acceleration in the inner 200 pc?

HESS
> 250 GeV



Lemière+15

Diffuse VHE gamma-ray luminosity: L_{VHE} = 3 - 4 10^{35} erg/s

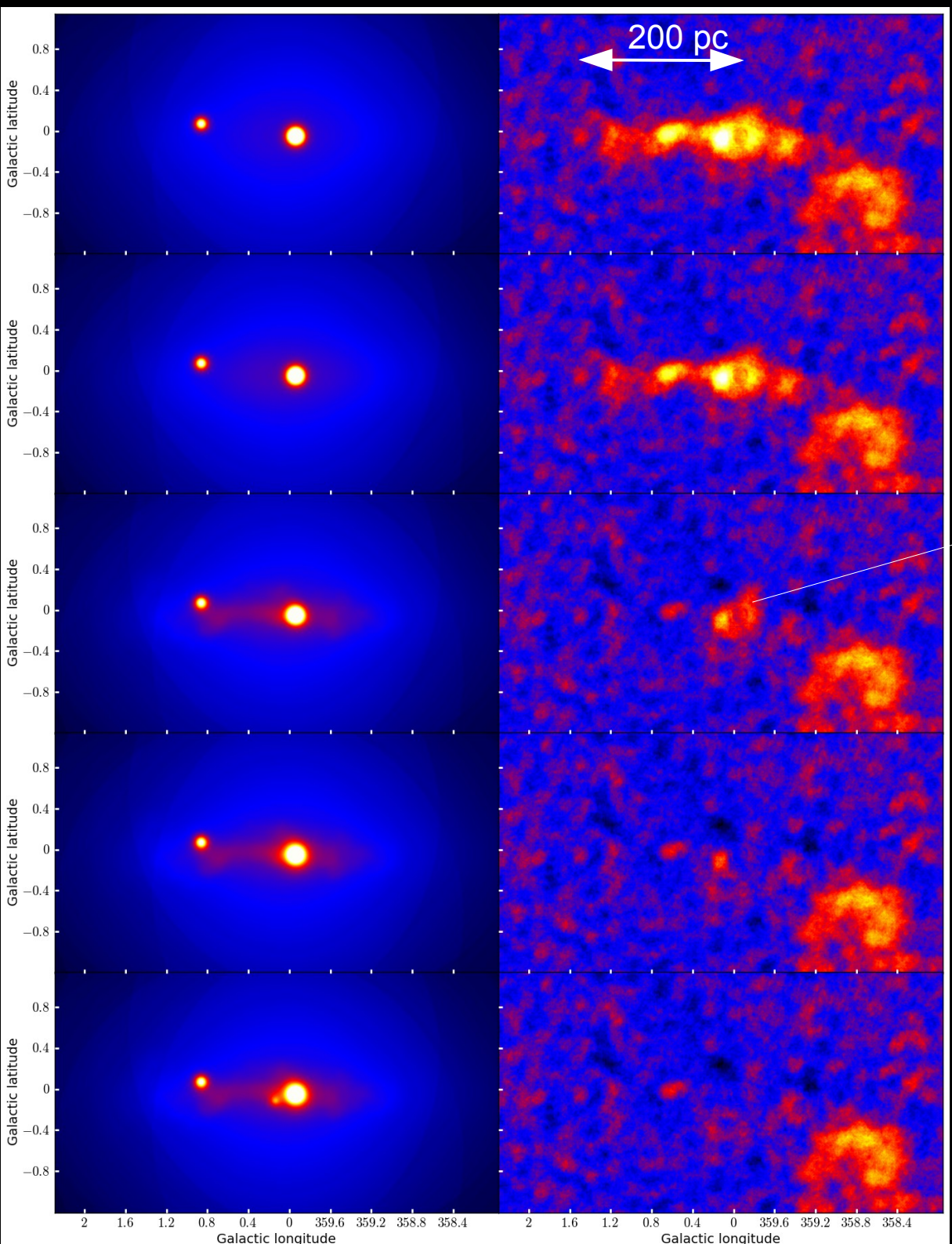
A (small) excess of 6-9 w.r.t. local CR density

HESS collab. 2006

If CMZ is calorimetric to CR : expected L_{VHE} ~ 1 - 5 10^{37} erg/s

There must be efficient particle escape from the central region

- Advection by ~1000 km/s wind? *Crocker+11, Lacki+14, Yoast-Hull+14*
- Diffusive escape to the halo? *Jouvin+15*



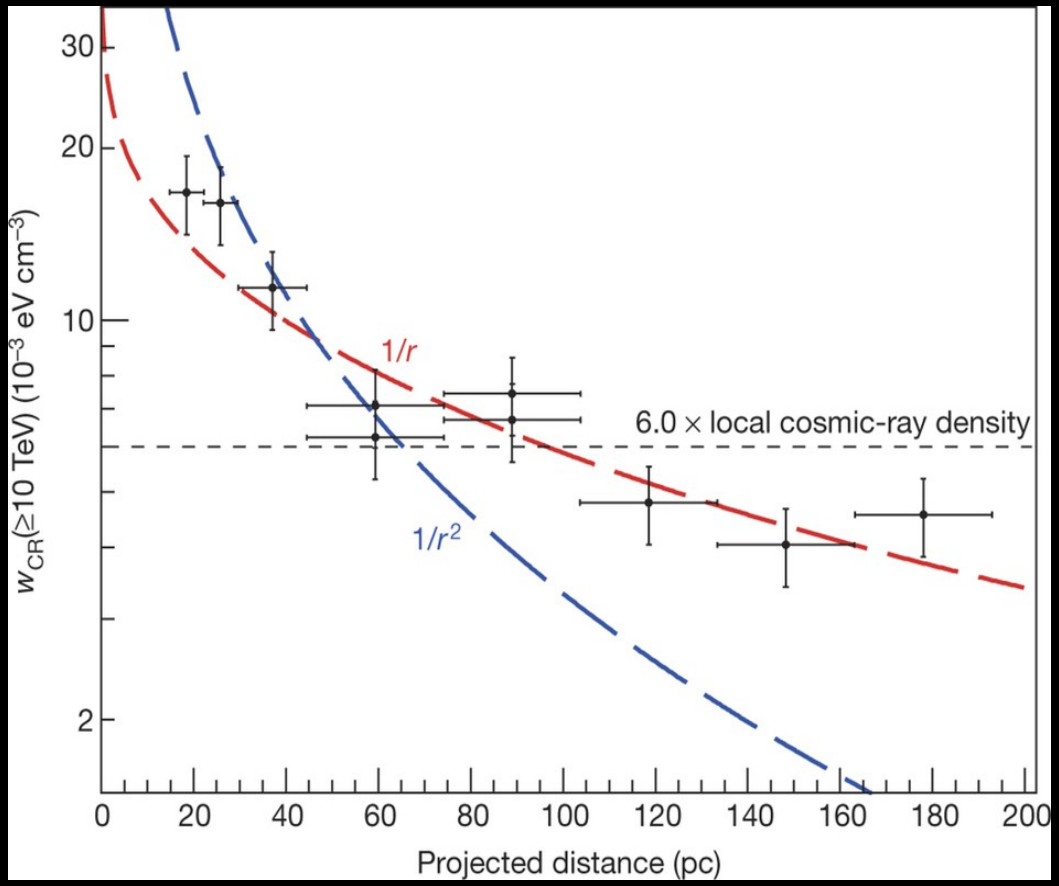
A CR excess in the central 30 pc?

HESS, > 250 GeV

Iterative component fitting requires 30 pc feature centered on Sgr A*

Lemière+15

A CR excess in the central 30 pc

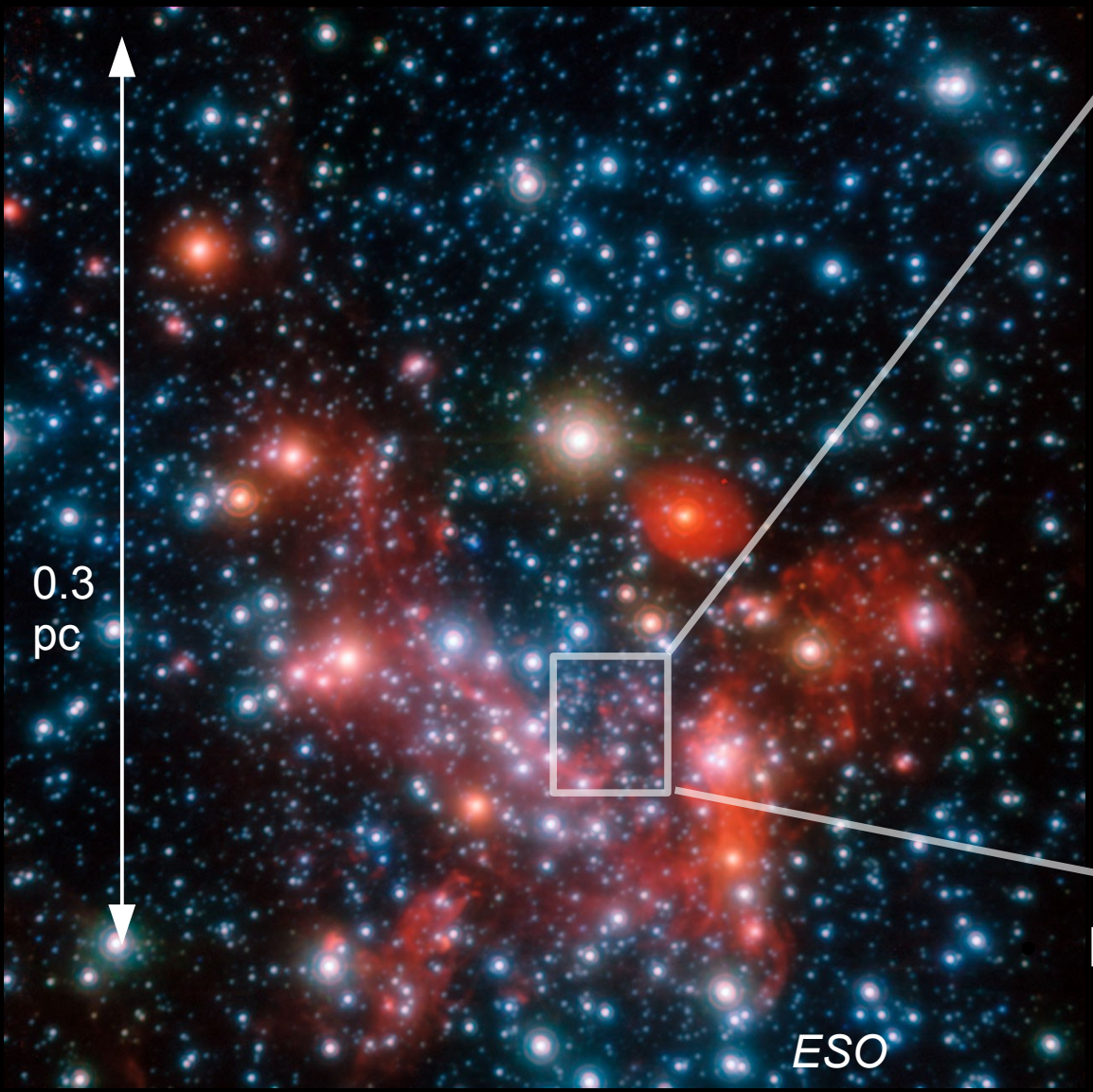


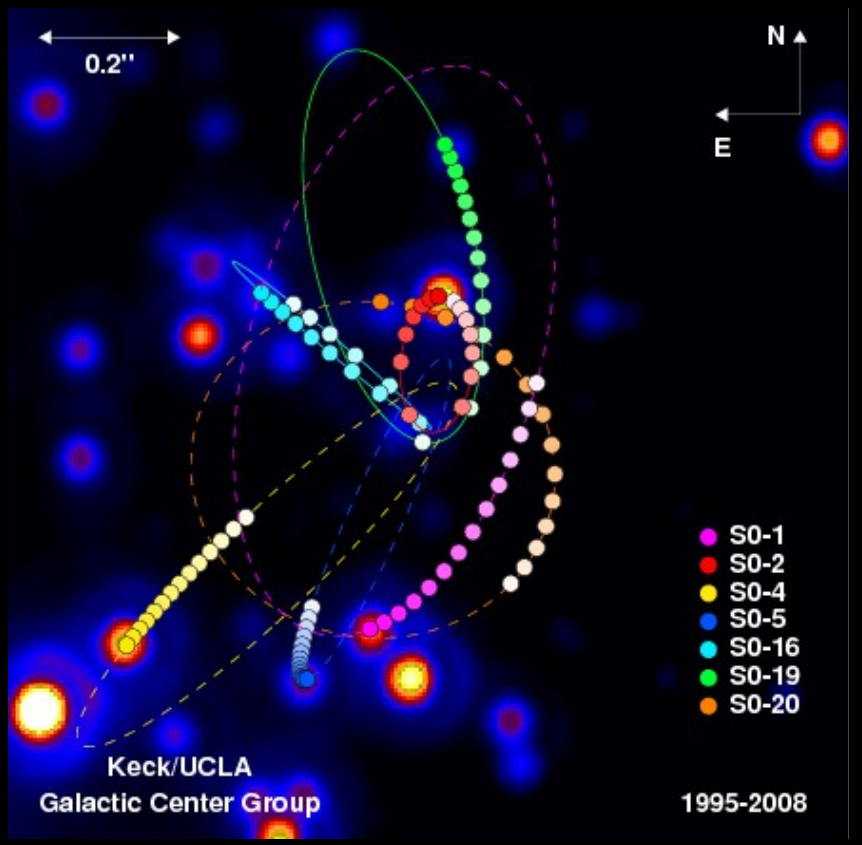
Apparent CR density profile consistent with integrated 1/r profile:

a **steady CR source at the GC. Sgr A*?**

HESS collab. 2016

Sgr A*: a SMBH in quiescent state





Faint Galactic Centre source Sgr A*
powered by a 4 10^6 $M_\odot$ SMBH!

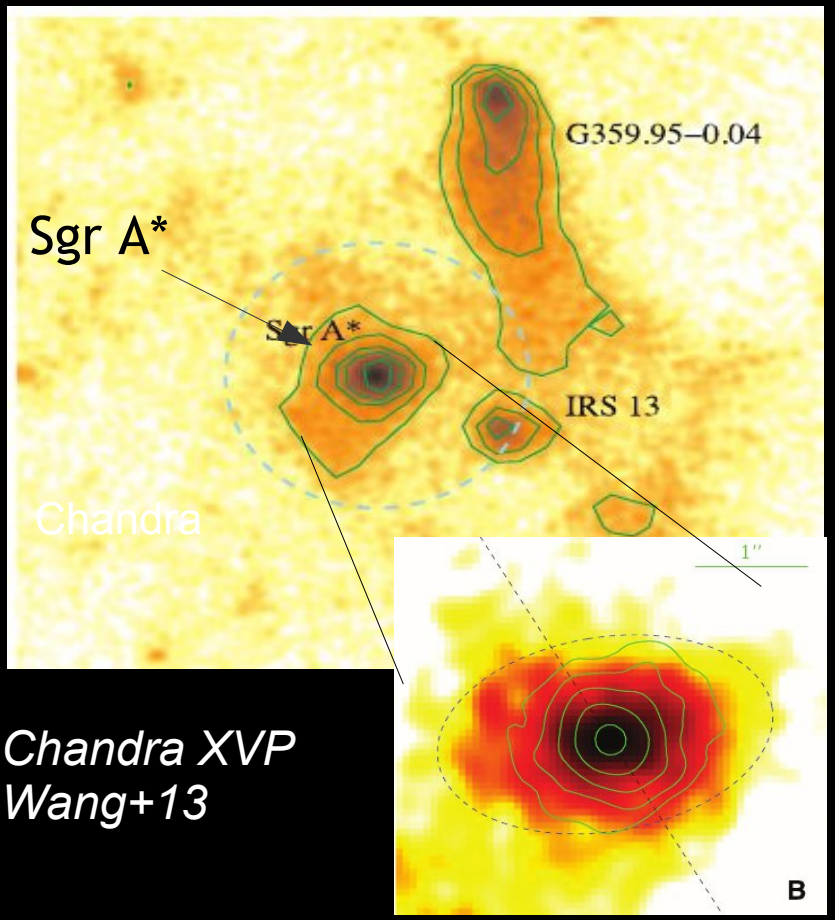
(Ghez+08, Gillessen+09)

Central (1pc) cluster of old stars + disk of young massive stars (< 6 Myr)

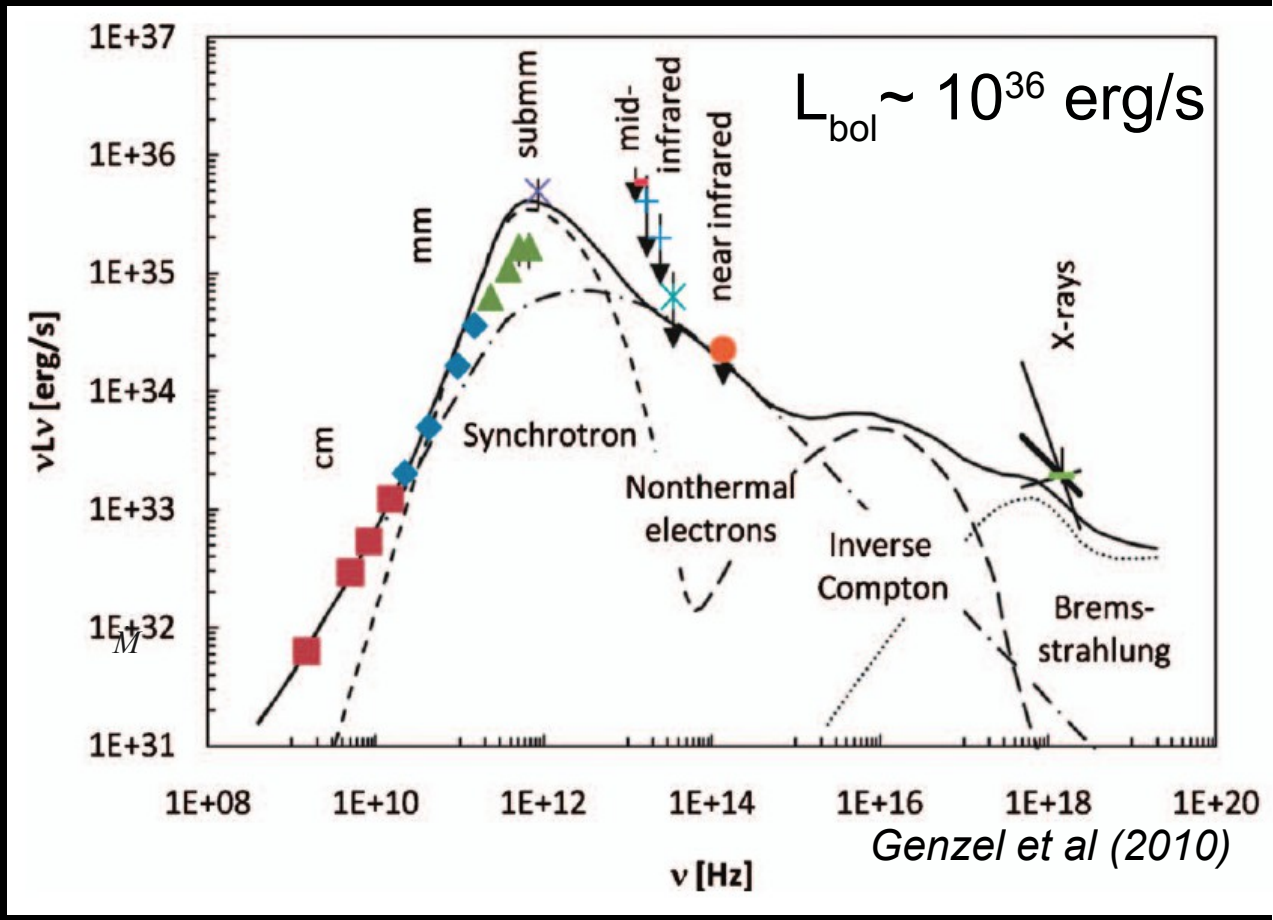
Paradox of youth?

Genzel+10

Sgr A*: a SMBH in quiescent state



Chandra XVP
Wang+13



Genzel et al (2010)

Accretion driven by massive stars wind: accretion rate at Bondi radius: 10^{-5} M_o/yr

(Baganoff+03)

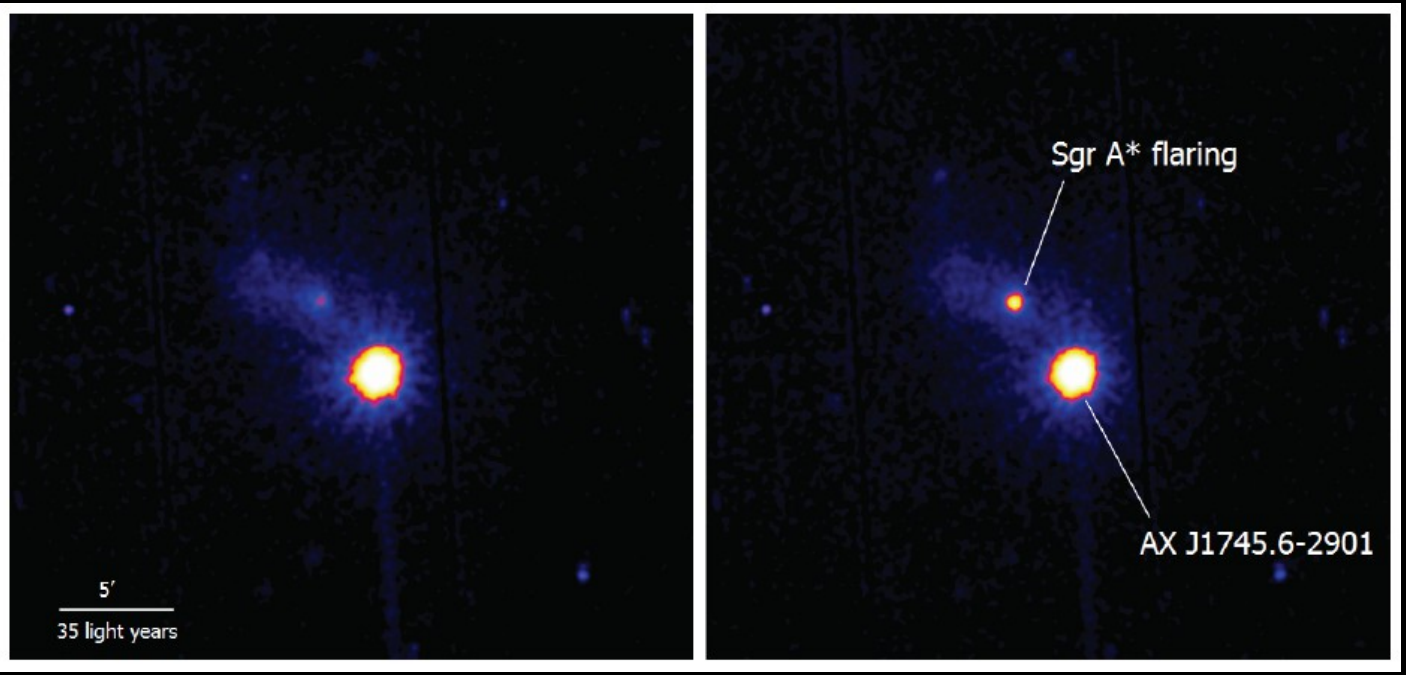
Accretion rate at the SMBH: 10^{-9} M_o/yr < M_{dot} < 10^{-7} M_o/yr

(Marrone+07)

Advected power (outflows) ~ 10^{39} erg/s

(Wang+13)

Sgr A* experiences faint but regular flares



XMM-Newton
Apr. 2007

Trap+10

Sgr A* exhibits flaring activity in X-rays

Flare frequency: 1.1± 0.2 day^{-1} Typical duration: ~ 1 ks

$dN/dL \propto L^{-1.9}$

Neilsen+13

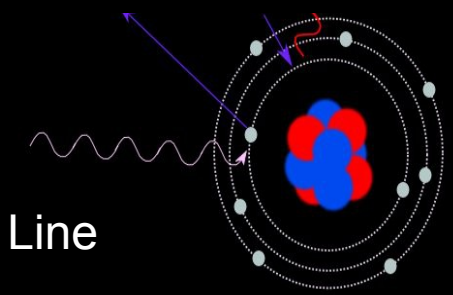
Most intense flares detected at L_X ~ 5 10^{35} erg/s

(e.g. Porquet+08, Nowak+12)

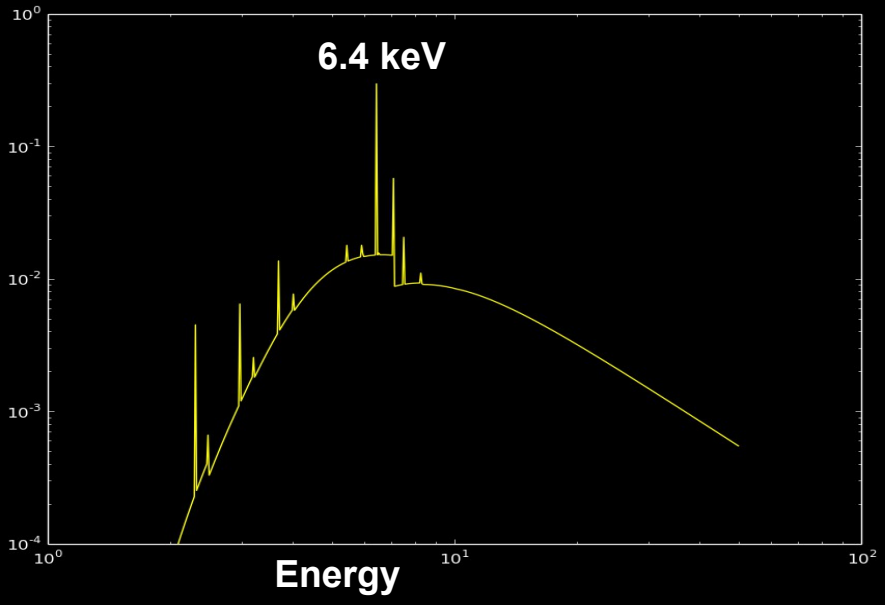
A change in the flaring rate? Induced by G2 pericentre passage?

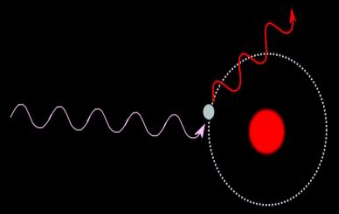
Ponti+15

Hard X-ray echo of past activity



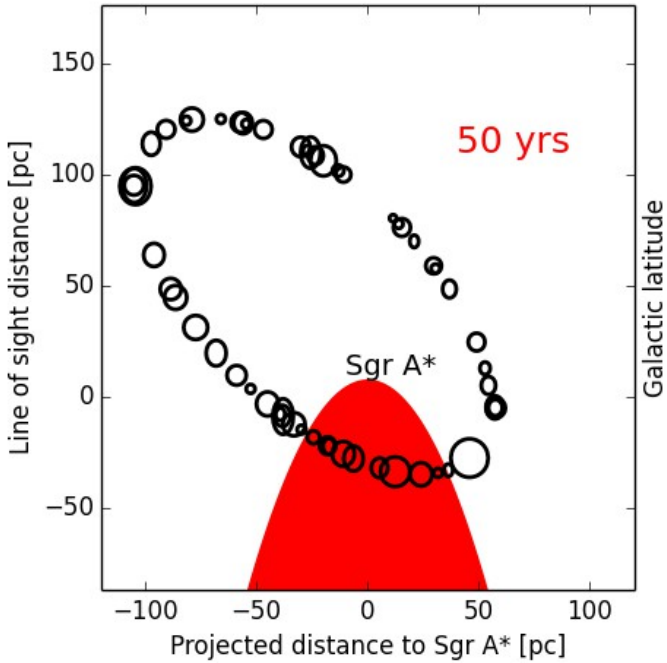
Line

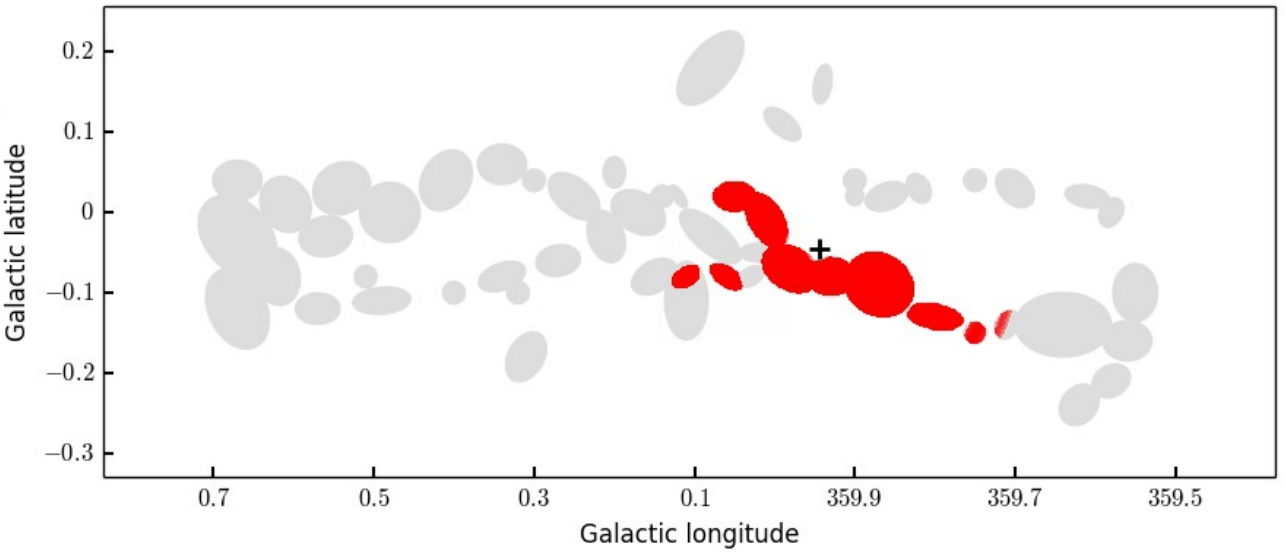




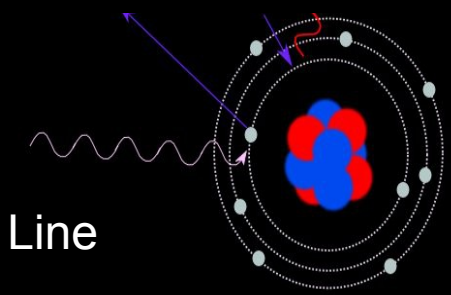
Continuum

Clavel+14

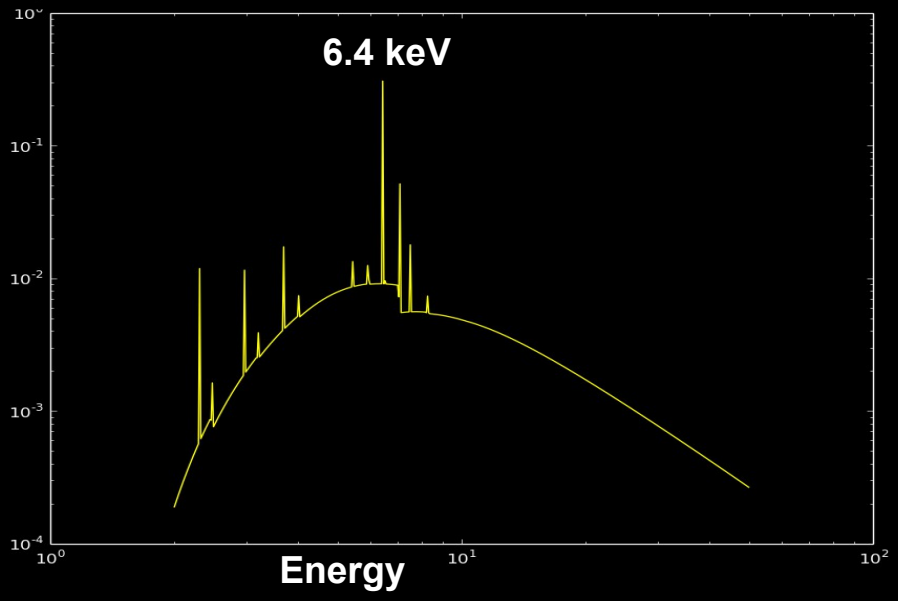


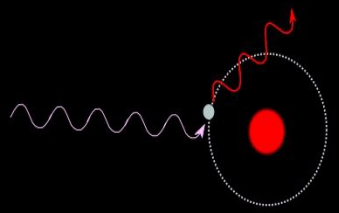


Hard X-ray echo of past activity



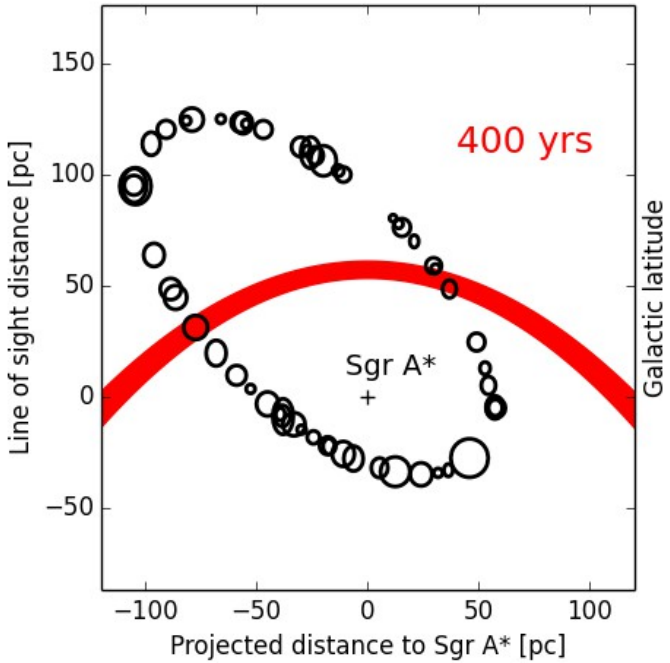
Line

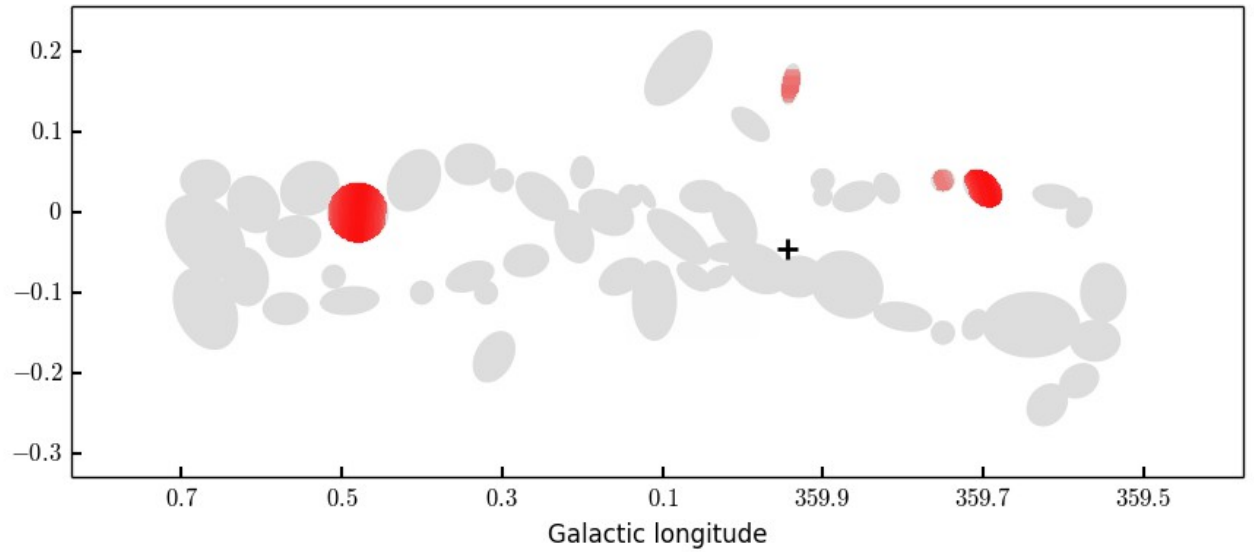




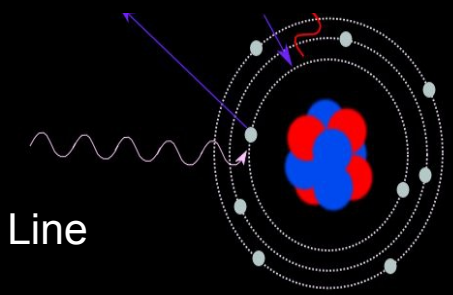
Continuum

Clavel+14





Hard X-ray echo of past activity



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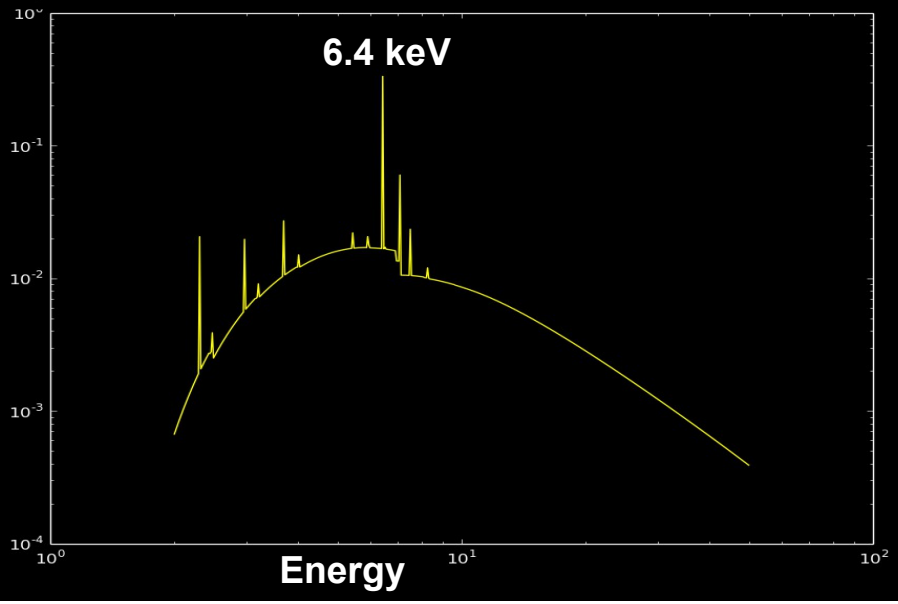
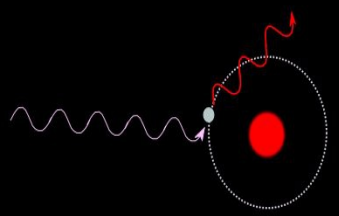
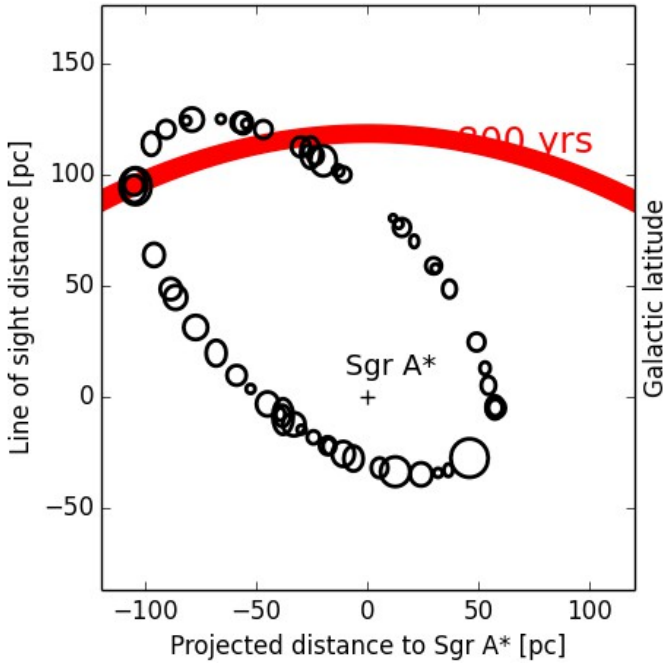
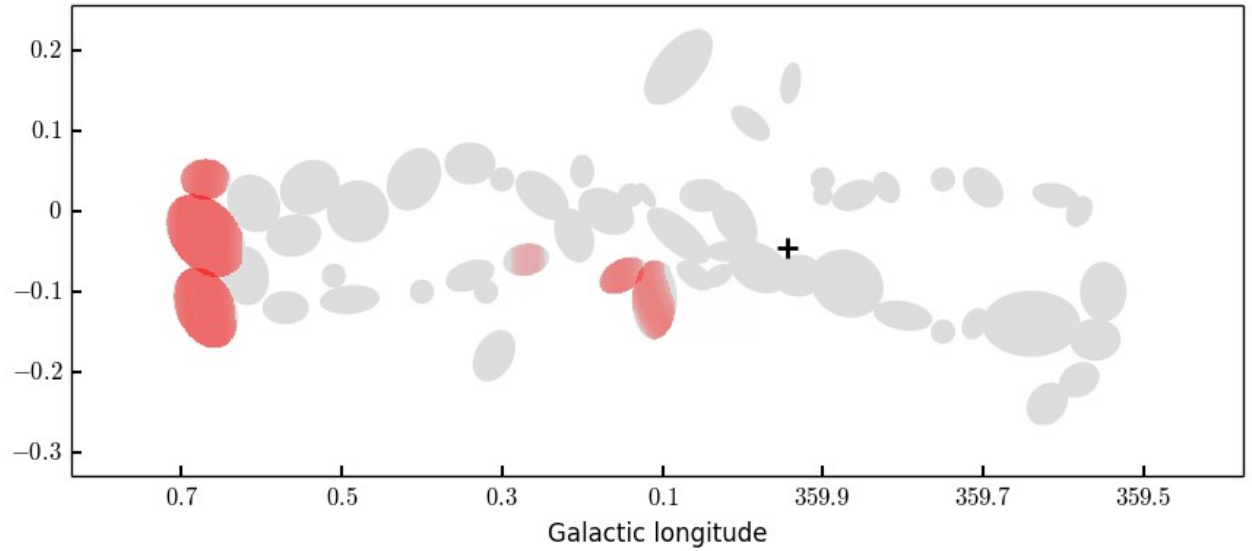




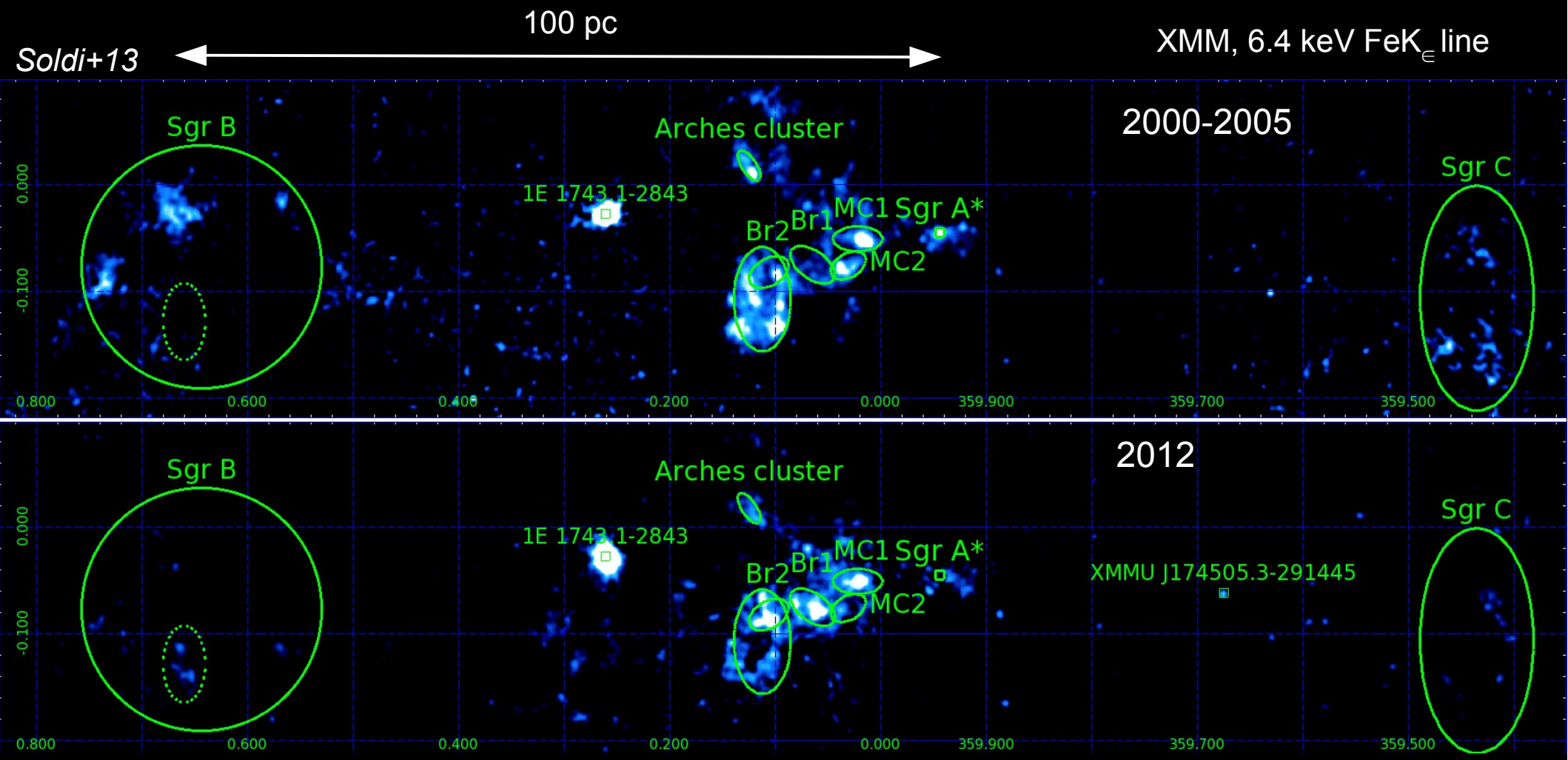
Continuum

Clavel+14





The Fe K_α emission of the CMZ 10 years apart



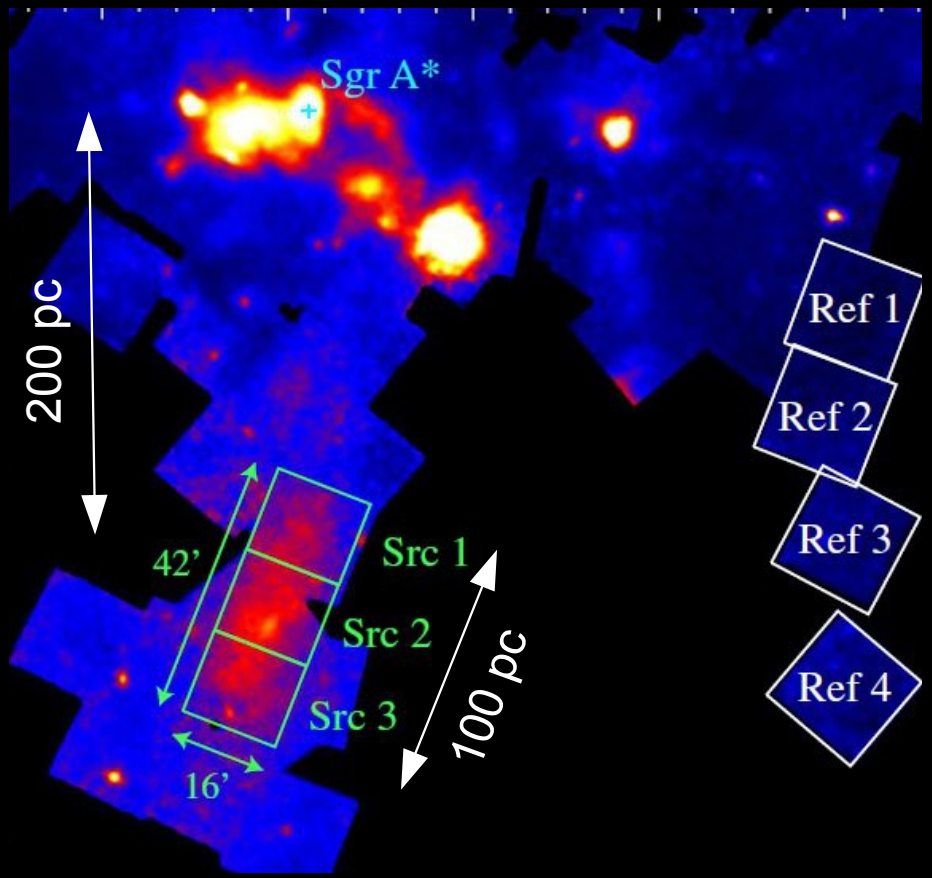
Large scale variations of 6.4 keV Fe K_α emission:

At least 2 distinct flares with $L_X \sim 10^{39}$ erg/s O(100 yr) ago

Ponti+10, Terrier+10, Nobukawa+11, Clavel+13, Soldi+14

A relic of a 100 kyr old event?

Nakashima+13 have discovered large region of recombining plasma emission 1.5° south of Sgr A*



Thermal energy content:

1.6×10^{51} erg

Relaxation timescale ~ 100 kyr

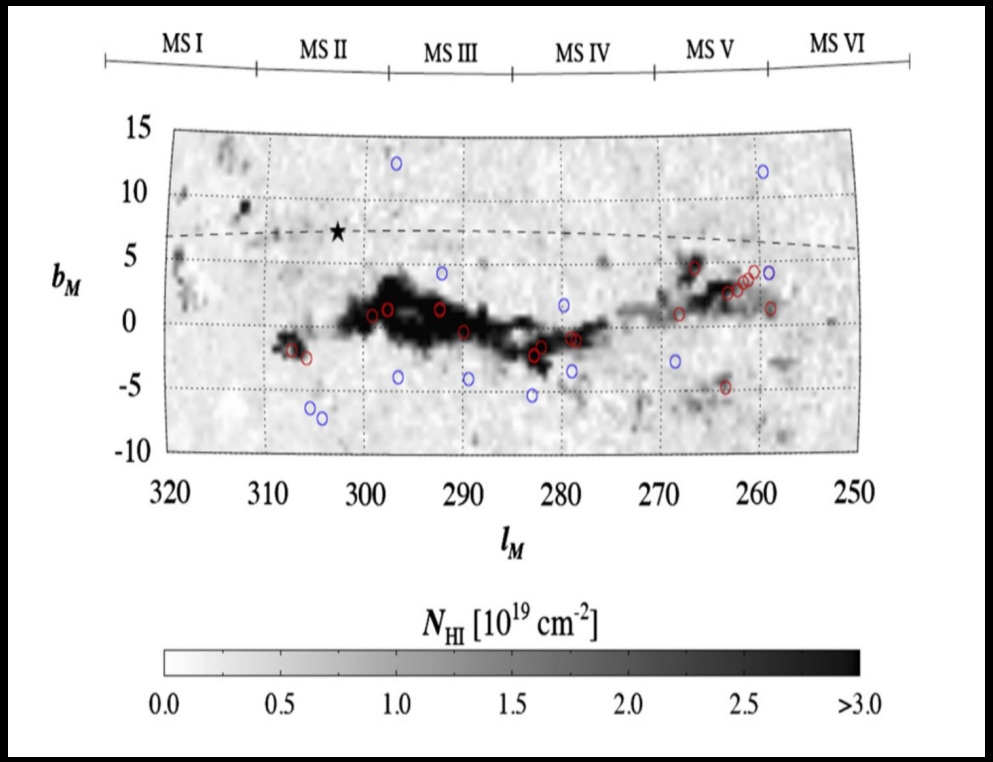
Origin?:

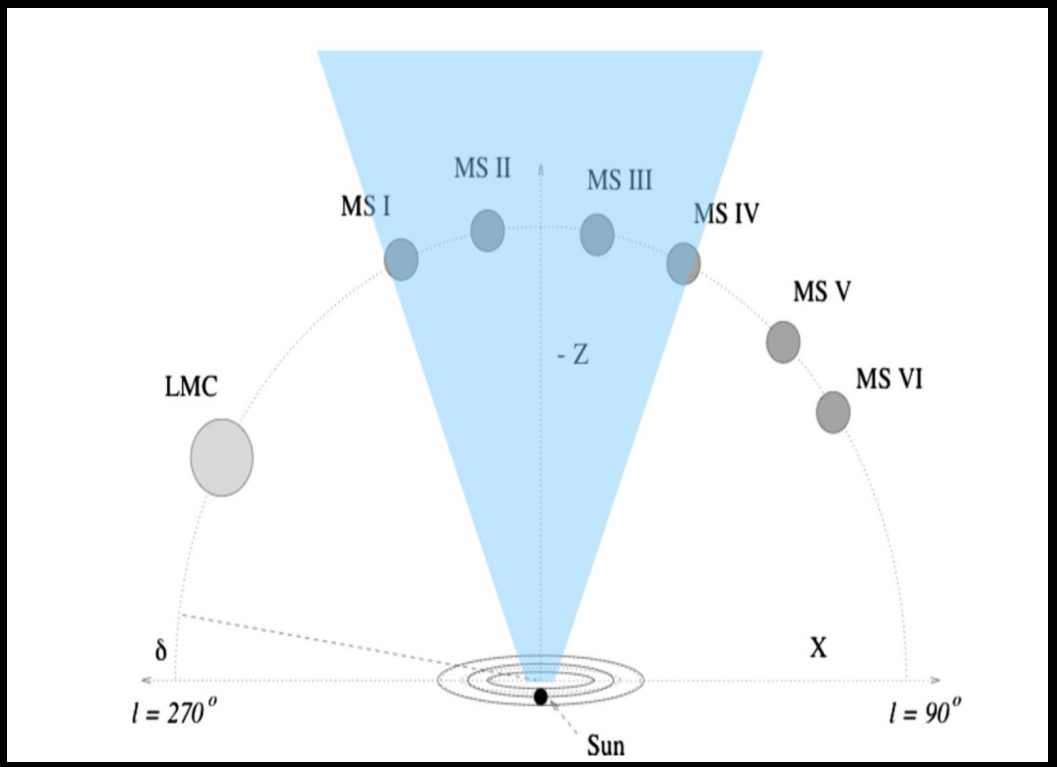
- Past star forming activity?
- Bipolar outflow from Sgr A*?
- Photo-ionization by jet emission from Sgr A*?

Nakashima+13

A Myr old Seyfert activity?

Balnd-Hawthorn+13 have found large ionization levels in a region of the Magellanic stream located below the south Galactic Pole



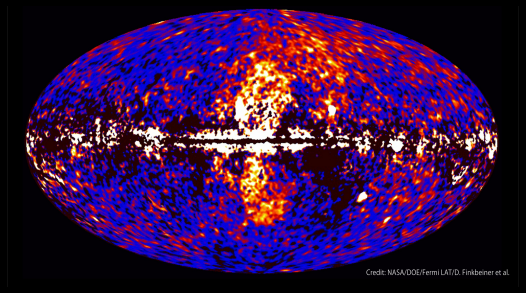


Steady disk ionization level too small.

Enhanced GC emission required: ~0.1 L_{edd}

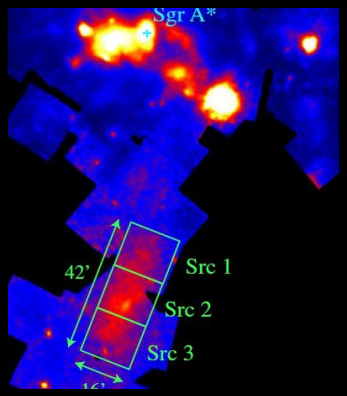
Bland-Hawthorn+13

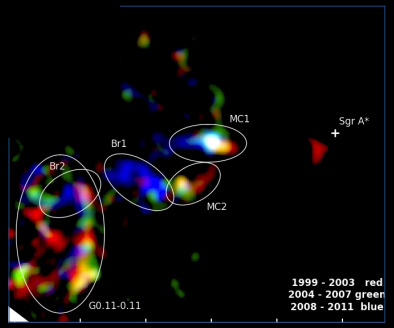
Sgr A* past activity ?



Fermi bubbles?

High latitude plasma?





Hard X-ray echoes

Normal flares

Quiescence

$L_{SgrA*}=L_{Edd}$

$L_{SgrA*}=10^{-10}\ L_{Edd}$

Luminosity (erg s-1)

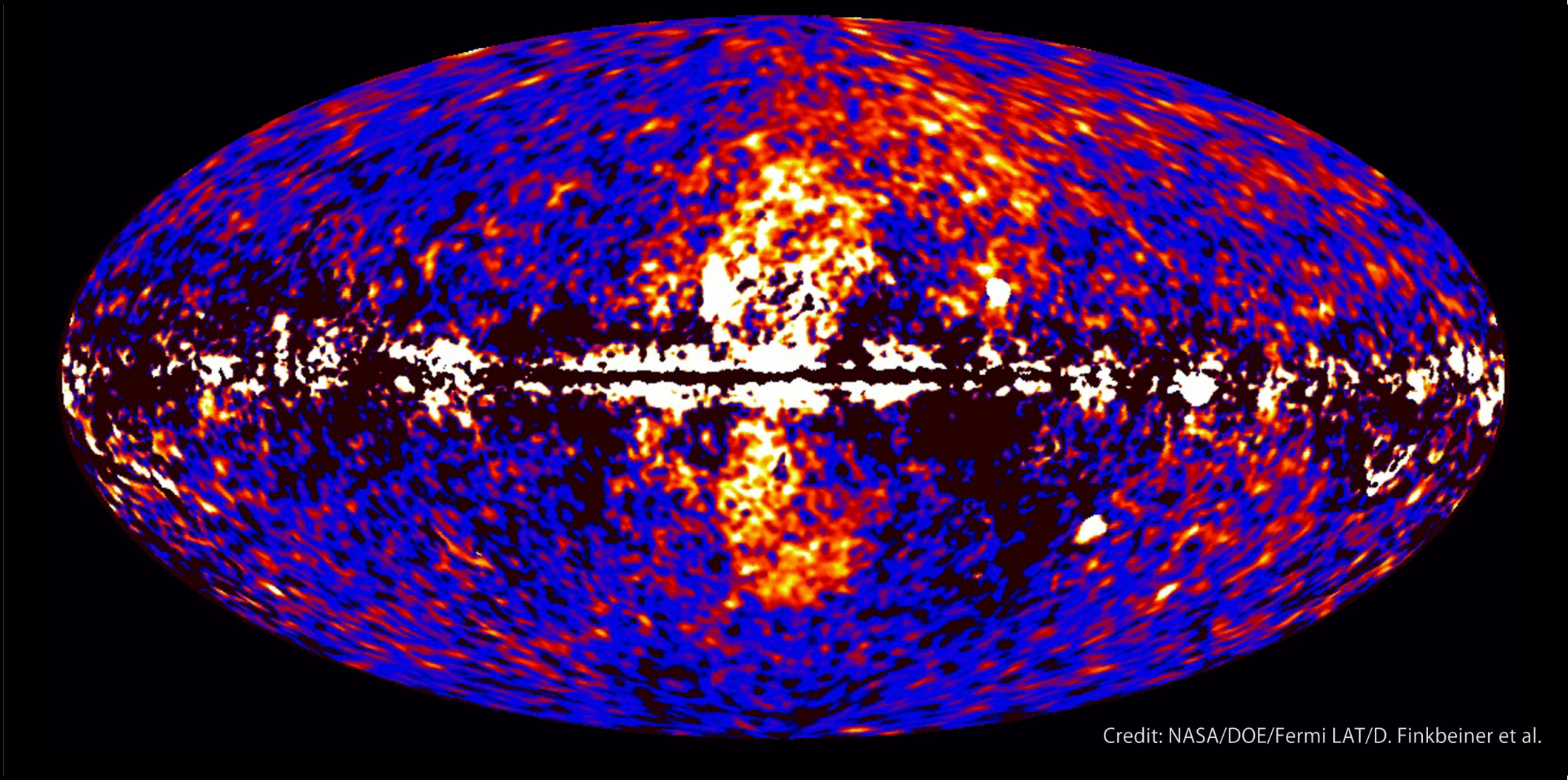
10^{45} 10^{43} 10^{41} 10^{39} 10^{37} 10^{35}

10^{7} 10^{6} 10^{5} 10^{4} 10^{3} 10^{2} 10 now

Time (years)

From Ponti+13

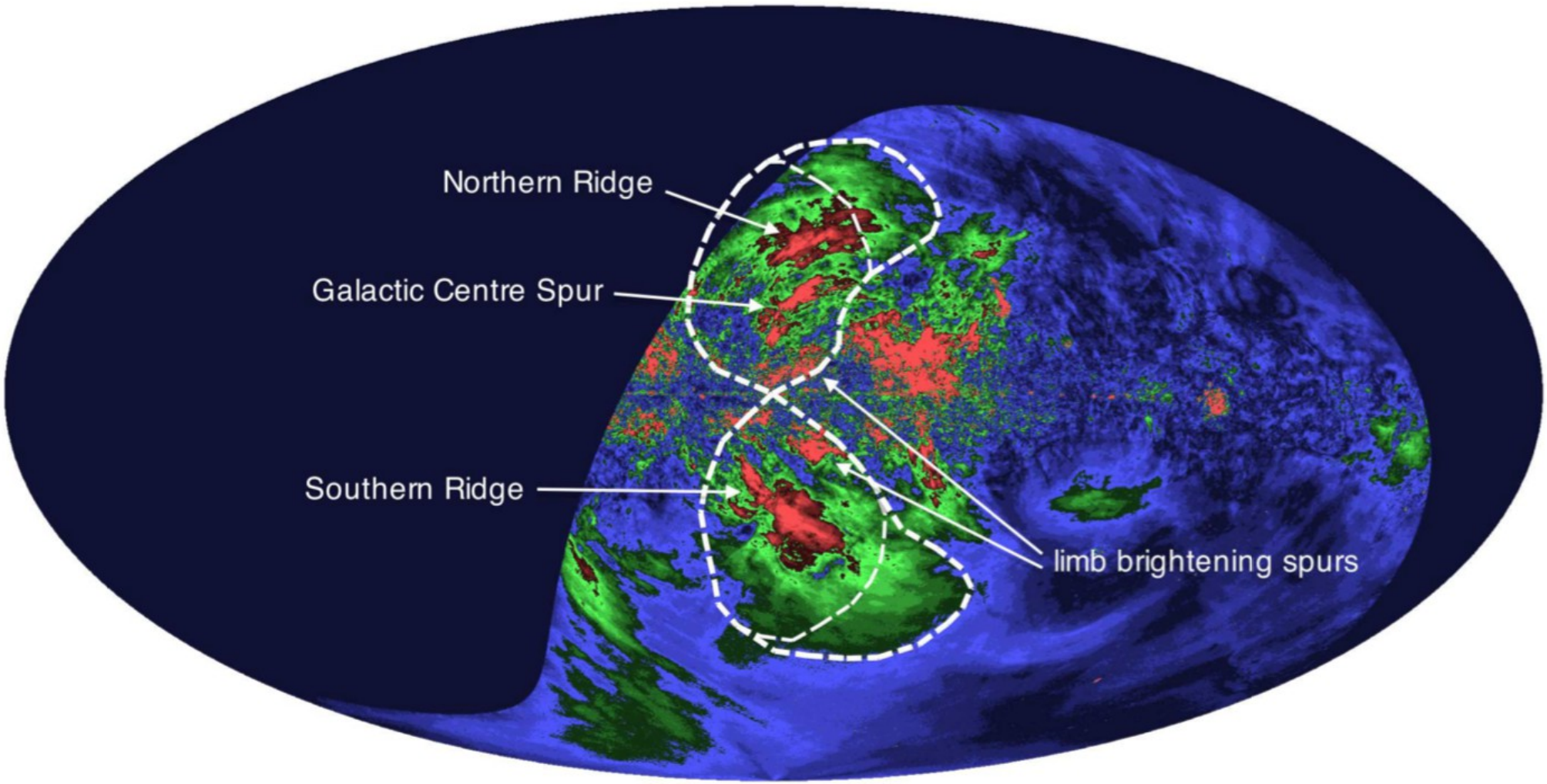
Large scale outflows from the GC



Credit: NASA/DOE/Fermi LAT/D. Finkbeiner et al.

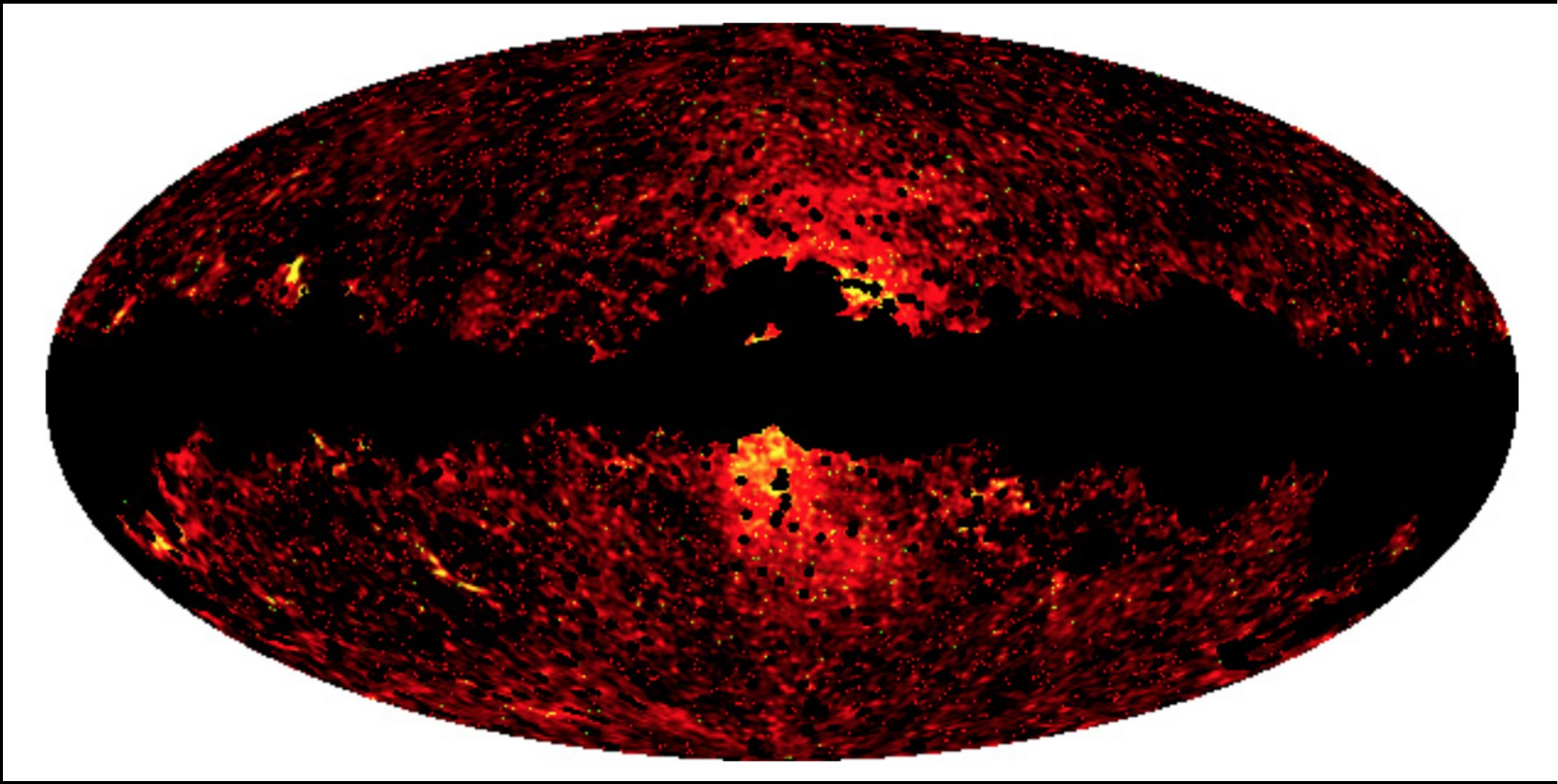
1- 5 GeV emission seen by Fermi *Su+10*

Large scale outflows from the GC



Linearly polarized radio emission at 2.3 GHz *Carretti+13*

Large scale outflows from the GC



Haze emission at 40 GHz

Planck collab, 2013

The Fermi Bubbles

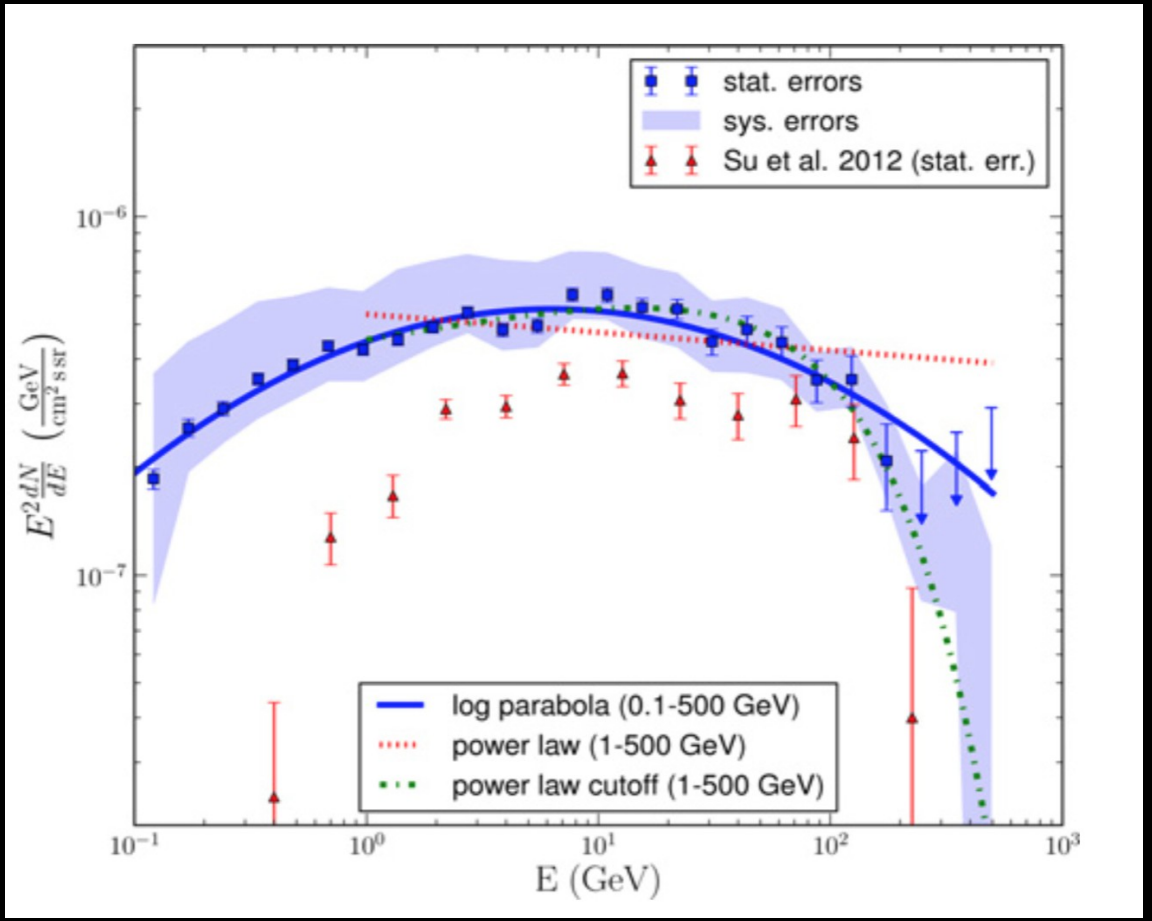
$L_\gamma = 4.4 \times 10^{37}$ erg/s

Hard spectrum $\Gamma = 1.9$

Cutoff energy ~ 110 GeV

No clear spectral evolution with latitude

Spectrum compatible with both electrons & protons



Flat structure with sharp edges: thickness ~ 3 - 4°

Ackermann+14

The Fermi Bubbles

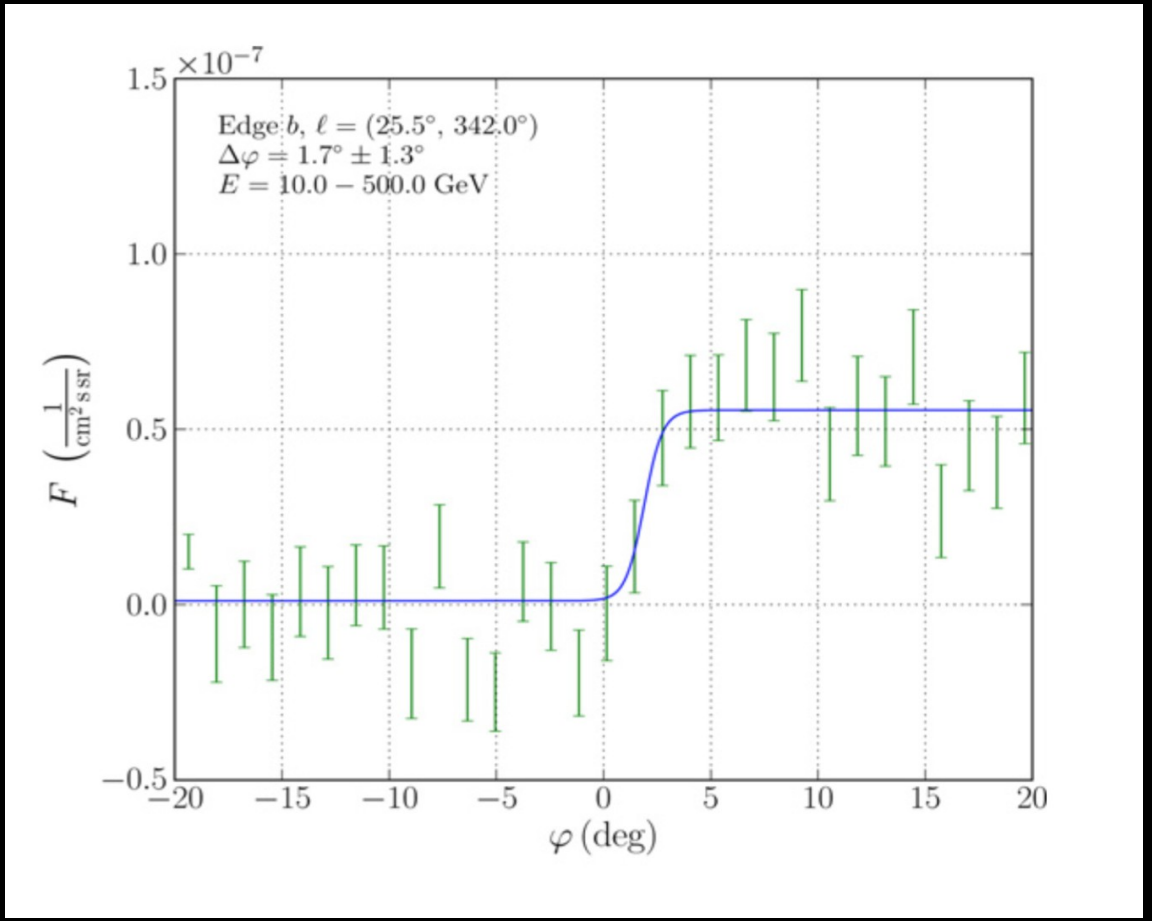
$L_\gamma = 4.4 \times 10^{37}$ erg/s

Hard spectrum $\Gamma = 1.9$

Cutoff energy ~ 110 GeV

No clear spectral evolution with latitude

Spectrum compatible with both electrons & protons



Flat structure with sharp edges: thickness ~ 3 - 4°

Ackermann+14

Fermi bubbles: radiation process?

IC of TeV electrons

- Livetime O(1 Myr)
- Energy requirement ~10^{52} erg
- Implies recent injection and rapid propagation
  - e.g. *Zubovas+12, Guo+12*
  - Consitent with no spectral evolution?
- Or (re)-acceleration in the bubbles
  - Distributed, e.g. *Mertsch+11*, termination shock, *Lacki14*

Hadronic interactions

- Low density in the halo implies large livetime: O(10 Gyr)
- Energy requirement ~10^{55} erg

Fermi bubbles: mechanism?

Past AGN activity (in the last 10 Myr)

- Jet model — *Guo+12 etc.*
- Spherical outflow powered by luminous quasar — *Zubovas+12*
  - Collimation in biconical outflow by CMZ
- Winds from increased hot accretion flow — *Mou+14*

Recurrent Sgr A* activity

- Regular tidal disruption events ($10^{-4\text{-}5}$ yr^{-1}) — *Cheng+11,15*

Steady state star formation

- Emission from integrated population of CR accelerated by GC activity
  $L_p \sim 10^{39}$ erg/s. Requires 5 Gyr of confinement time!

  Crocker+11, Crocker12
- Confinement of CR in gas condensation reduce cooling time to 100 Myr.

  Crocker+14, Crocker+15

Summary

Mass inflow on GC region powers sustained star forming activity

- Up to 3 10^{40} erg/s released
- CR induced gamma-ray emission lower than expected
- A strong wind? Escape?

Presence of a CR density excess in the inner 30 pc

- Profile consistent with steady diffusive source at the GC
- Hard to explain with SNR acceleration only. Sgr A*?

Sgr A* is currently very inactive:

- Large power is advected out of the accretion flow: CRs?
- Evidences of various levels of increased activity in the past

Large outflows from GC region extending 10 kpc in the halo: Fermi Bubbles

- Signatures from radio to gamma-rays (100 GeV)
- SMBH activity? Starburst winds? Steady state/transient? Leptonic/hadronic?