Excess of VHE cosmic rays in the central 100 pc of the Milky way

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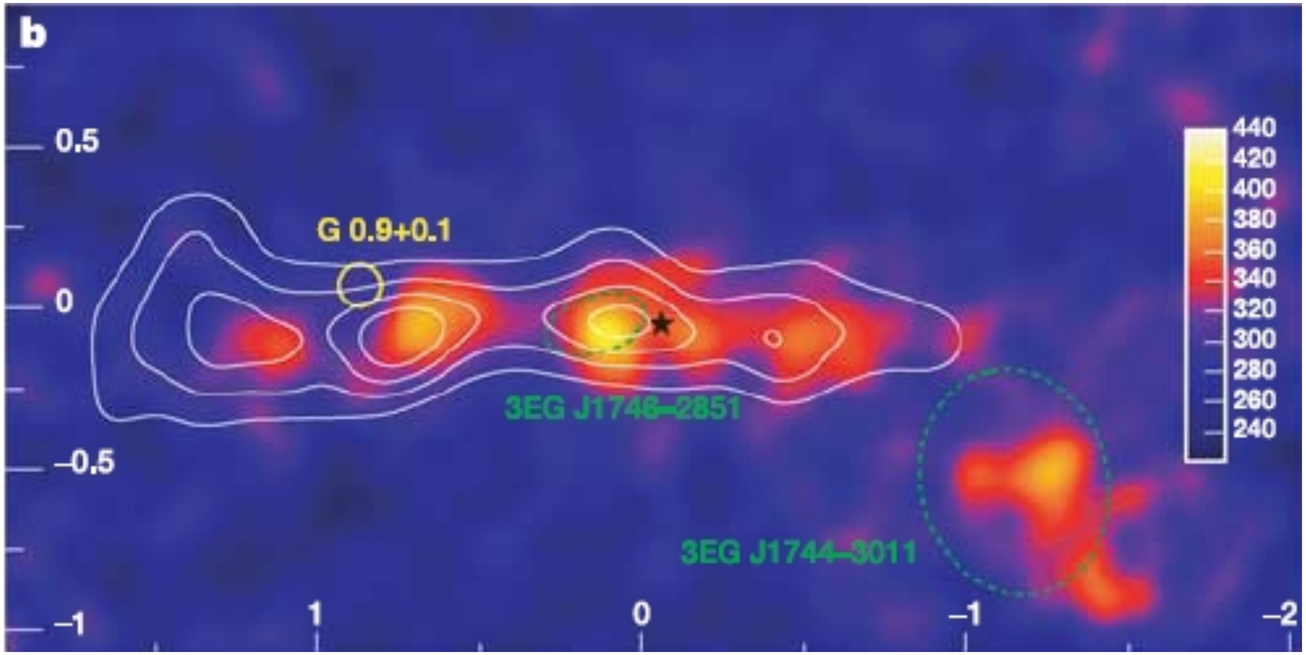
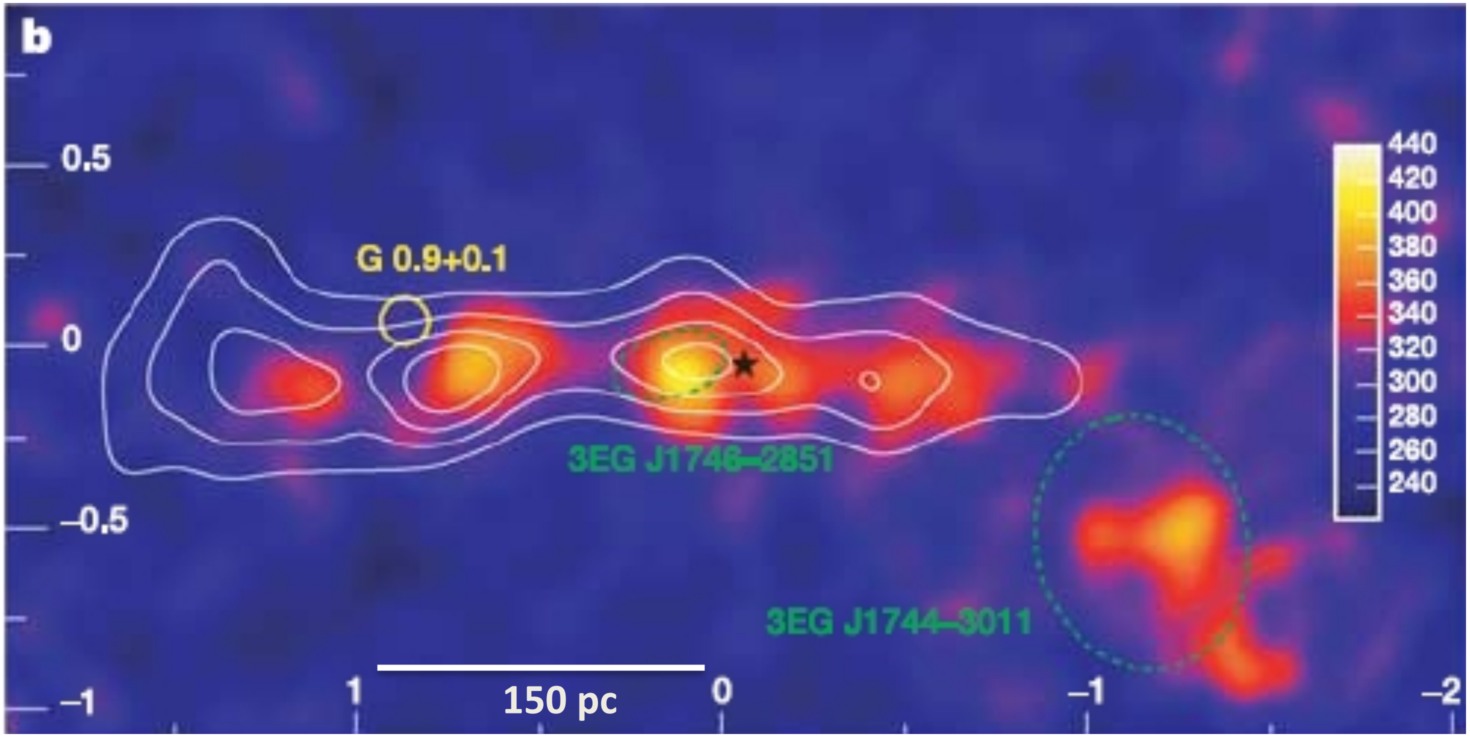


ICRC
The Astroparticle Physics Conference
34th International Cosmic Ray Conference
July 30 - August 6, 2015
The Hague, The Netherlands

Excess of VHE Cosmic rays (CRs)

Diffuse emission seen by H.E.S.S. (2004-2006):

γ-ray count map



Credits: H.E.S.S. collaboration
Aharonian et al., 2006

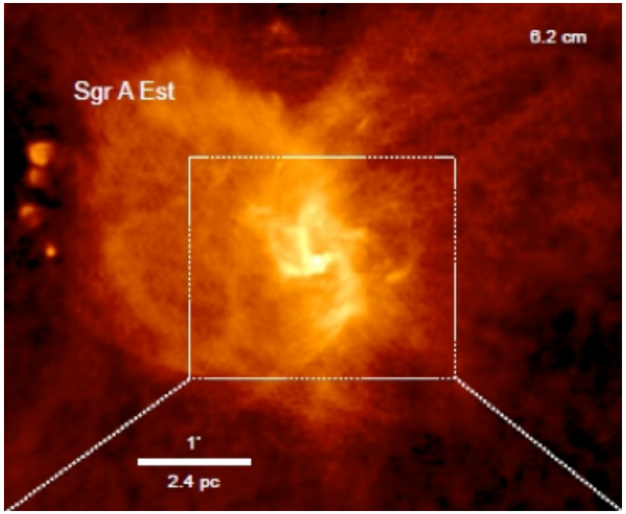
After subtracting the brightest TeV sources:

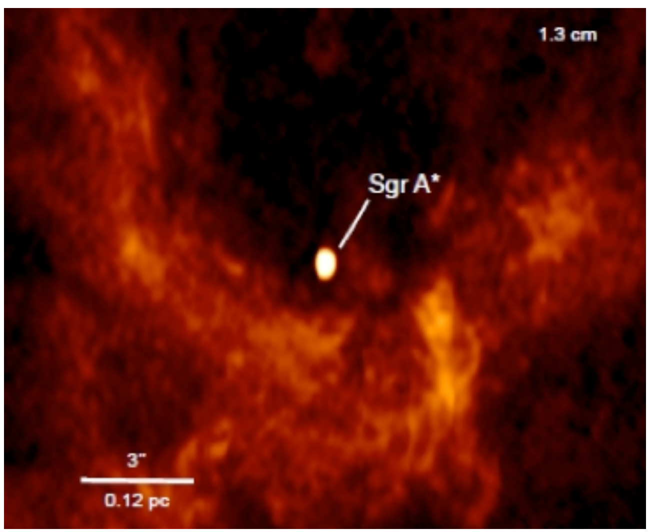
-> diffuse emission

-> Emission very correlated to the matter distribution → hadronic origin

-> CRs energy density: 3-9 times higher than the one measured on Earth and harder spectrum (Γ=2.3)

A unique CR accelerator in the central pc ?





Credits: F. Yusef-Zadeh

Impulsive source:

SgrA East (Aharonian et al., 2006):
-Supernovae remnant
- located at ~ 2 pc from SgrA*
- explosion ~ 10 000 years

Stationary source:

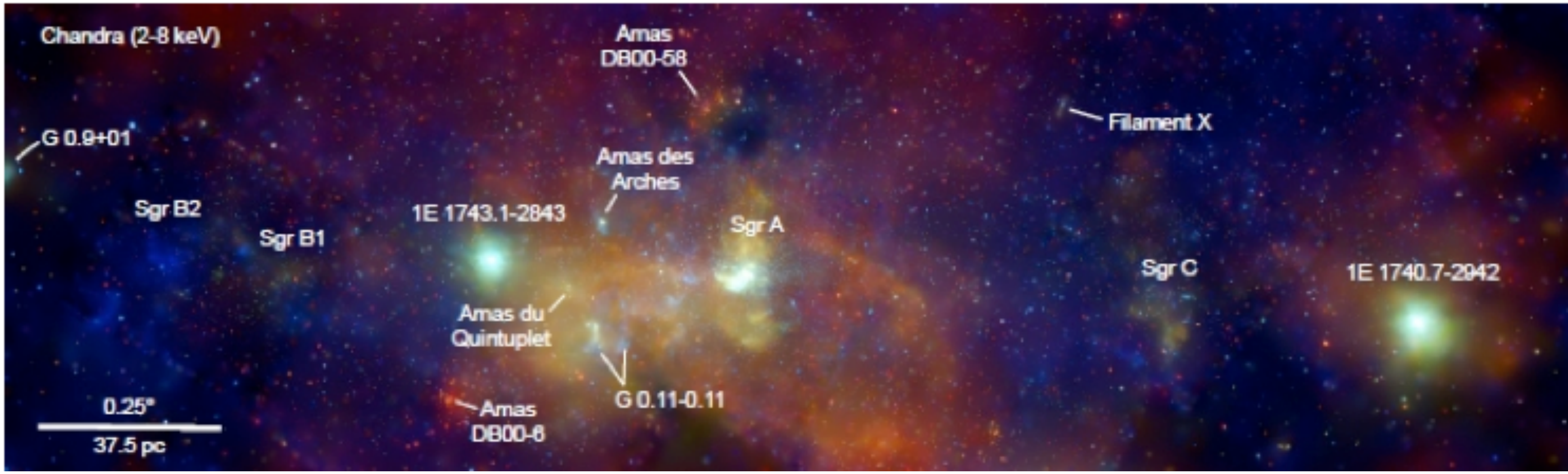
SgrA* as a CR accelerator (Liu et al (2006), Chernyakova (2011), Aharonian and Neronov (2005), Macias (2014)):

- **M :** 4×10^{6} M_{sun}
(Ghez et al. (2000) and Gillesen et al. (2009))
- $L_{bolometric}$ **:** 10^{36} erg

- **Bondi radius :** $\tau_{accretion}$ $\sim10^{-5}$ M_{sun}/an
(Baganoff et al., 2003)
- **Intern radius :** $\tau_{accretion}$ $\sim10^{-7}$ M_{sun}/an
(Marrone et al (2007)

- **Bondi accretion power:** 10^{39} ergs^{-1} (Wang et al , 2013)

Multiple CR impulsive injections ?



Multiple X observations detected SNRs (Ponti G., 2015)
1keV plasma (red): can be heated to this high temperature by SNs

Credits: M. Muno, Chandra observations (few central degrees)

<u>Temporal distribution:</u>
- Crocker et al (2011): central value on 0.04 SN per century
- Large uncertainties ([0.02:0.08] SN per century)

<u>Spatial distribution:</u>
- Uniform: presence of a high number of isolated stars (Mauerhan, 2010)
- Three compact and massive cluster in the GC: the Quintuplet (3-5 Myrs), the Arches (2-3 Myrs) and the Central Cluster (4-6 Myrs)

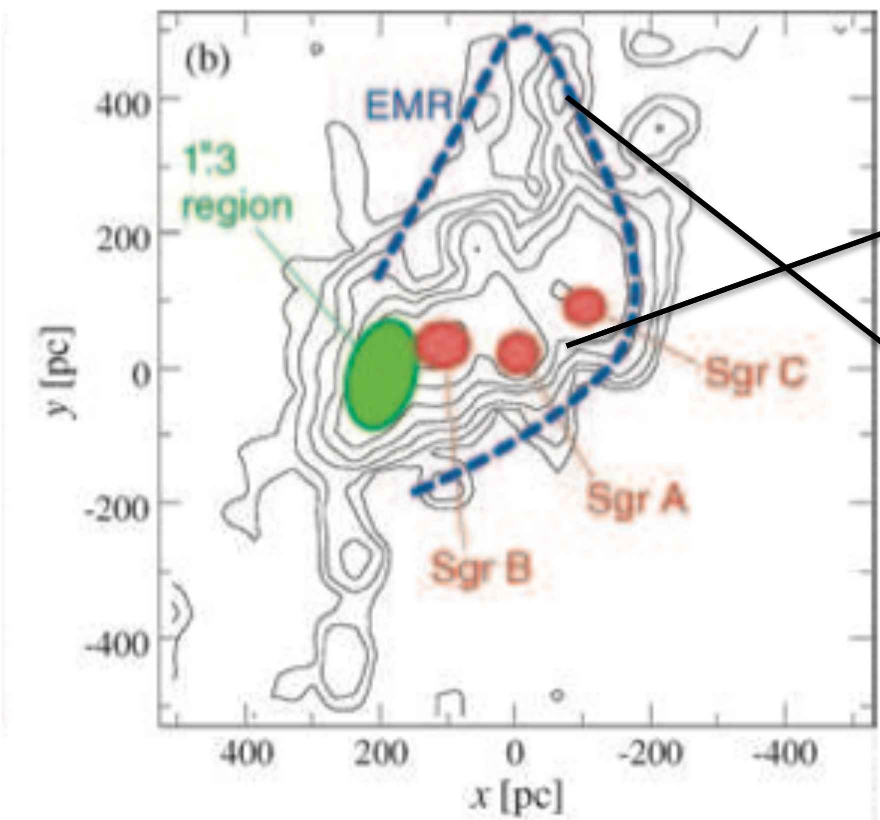
<u>Energy released:</u>
*CR acceleration:*10% of E_k released by a SN (10^{51} erg) and *SN rate:* 0.04 per century ➔ 10^{39} erg s^{-1}

3D modeling of the CR propagation and Y-ray photons production

3D matter distribution

Sawada (2004)

- No kinematical model
- **OH/CO ratio carries information on the position of the gas along the line of sight relative to the continuum source**
- **M_{tot}=20×10^6 M_{sun} (ferriere K. 2007): lower edge of total mass estimations**



Well known gas structure in the center

Larger spread along the line of sight

CR diffusion

- ➢ <u>Injection:</u> Power law Q= $\mathbf{N_o E^{-2}}$
- ➢ <u>Propagation:</u> Transport equation

$D=D_{10TeV}\,(E/10\ \mathrm{TeV})^{0.3}$, $\mathbf{D_{10TeV}=5\times10^{29}\ m^2s^{-1}}$ (interstellar medium value):

- High value compare to other studies that rule out the possibility of individual localized accelerators (Wommer et al, 2008)
- High diffusion coefficient ➔Neglecting the convection ➔ diffusion equation

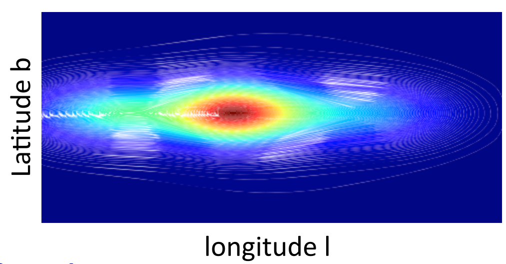
$$\frac{\partial f}{\partial t} + \cancel{(\vec{u}\cdot\vec{\nabla})f} + \vec{\nabla}\vec{J} = Q \qquad \vec{J} = -D\vec{\nabla}f$$

- Two solutions: impulsive (SNR) and stationary (SgrA*)

- ➢ <u>3D box:</u> 500pc × 500pc × 50pc
- ➢ E_{CR}: 1 TeV to 1 PeV

By summing over all the energies of the incident protons ➔ ϒ-ray spectrum

2D map (l,b)



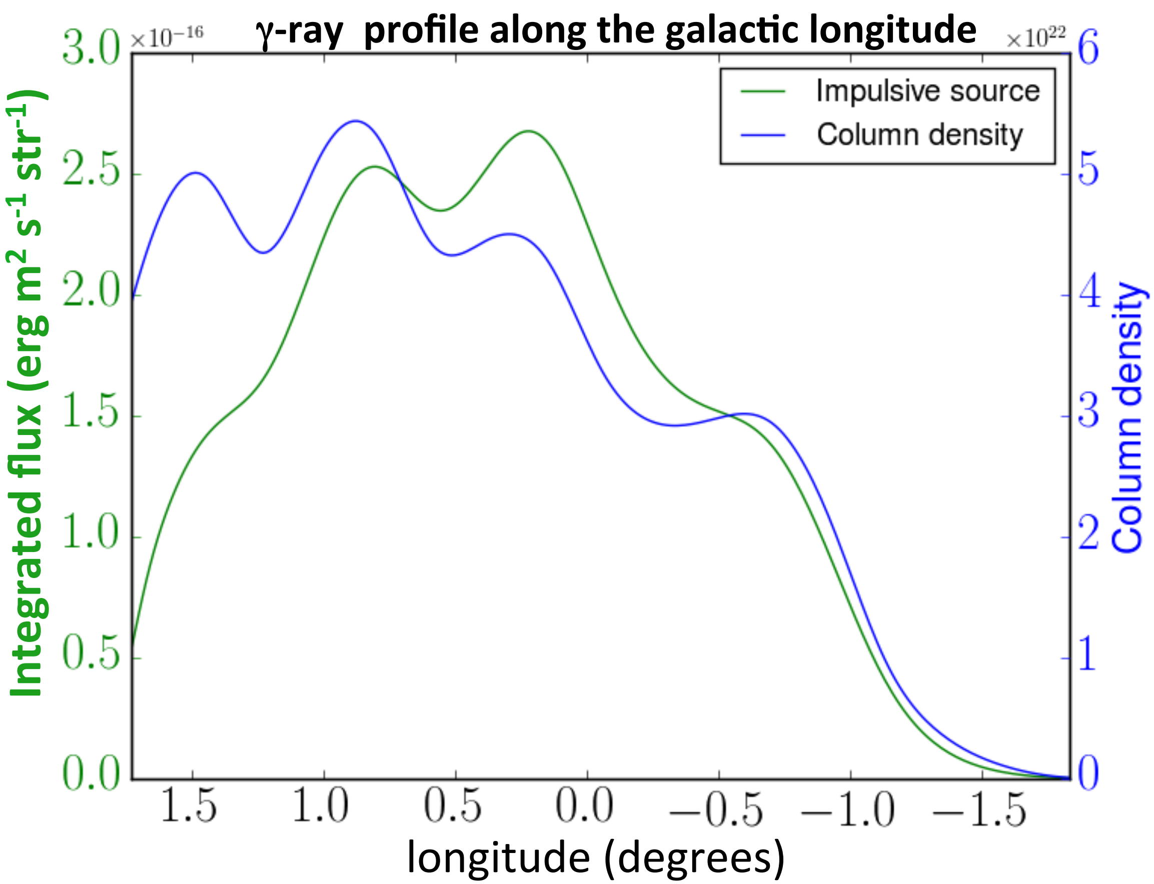
Integration along the line of sight

Comparison data/model on 1D VHE γ profile

Single accelerator at the CG

Stationary or impulsive?

- Impulsive source that exploded 10 kyrs ago (SgrA East)
- Stationary source (SrgA*)



Impulsive source: CR emitted 10 kyrs ago ➔flat CR profile ➔γ-ray emission follows the matter distribution

Stationary source:

- profile more peaked on the source itself
- Profile decreases at large distances due to a more spread ISM

Single accelerator at the CG

Stationary or impulsive?

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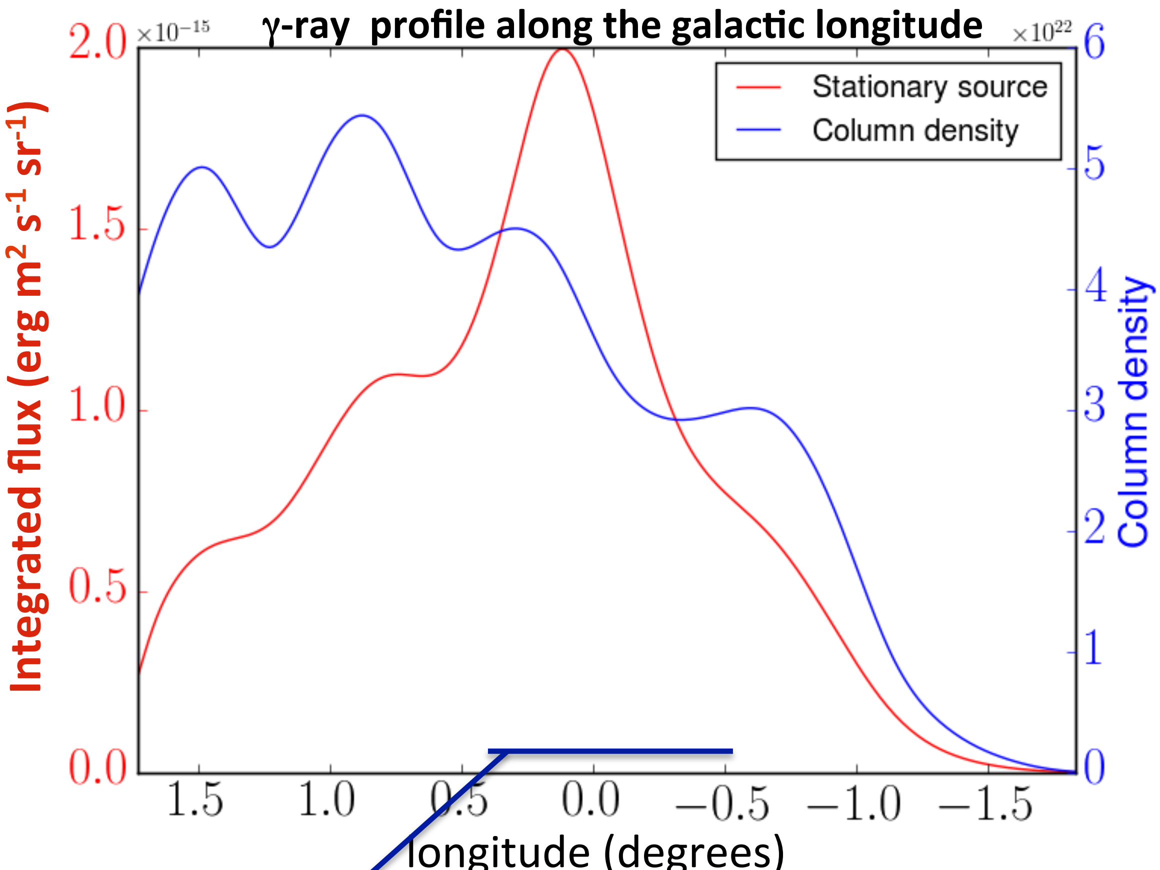


r<mean free path ➔ ballistic regime

Impulsive source: CR emitted 10 kyrs ago ➔flat CR profile ➔γ-ray emission fallows the matter distribution

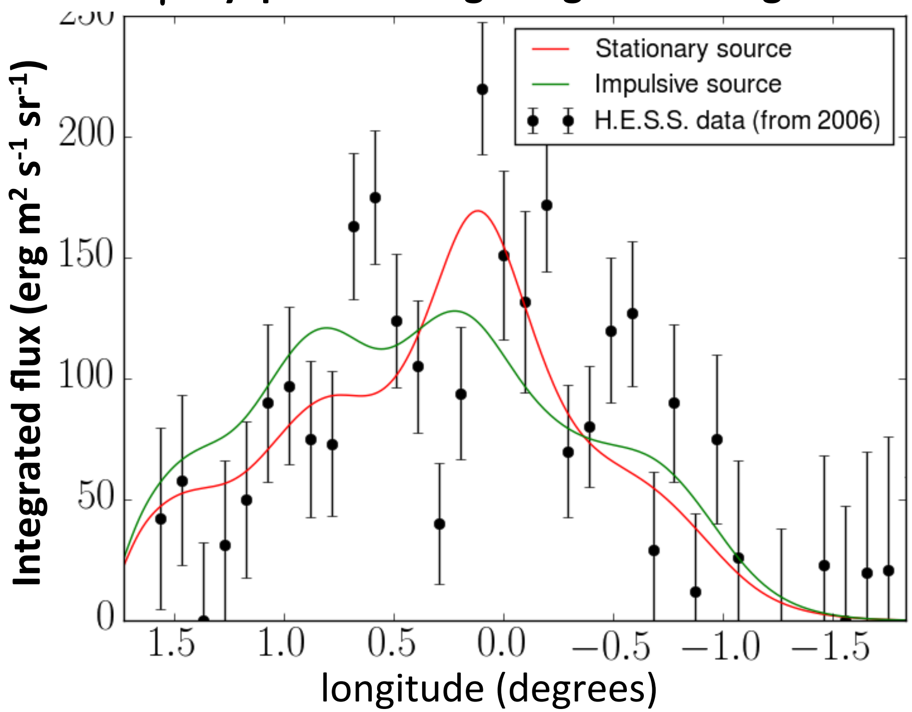
Stationary source:

- Profile more peaked toward the source
- Profile decreases at large distances due to a more spread ISM

Single accelerator at the CG
Stationary or impulsive?

- Impulsive source that exploded 10 kyrs ago (SgrA East)
- Stationary source (SrgA*)

γ-ray profile along the galactic longitude



- ➢ **Given the low statistic available so far, neither the impulsive or stationary hypothesis may still be excluded**
- ➢ Stationary source: Intrinsic power needed for CR acceleration $\approx 3\times10^{38}$ erg s^{-1} (30% of the Bondi accretion power)
- ➢ Impulsive source: 10% of E_k for CR acceleration requires a higher total mass

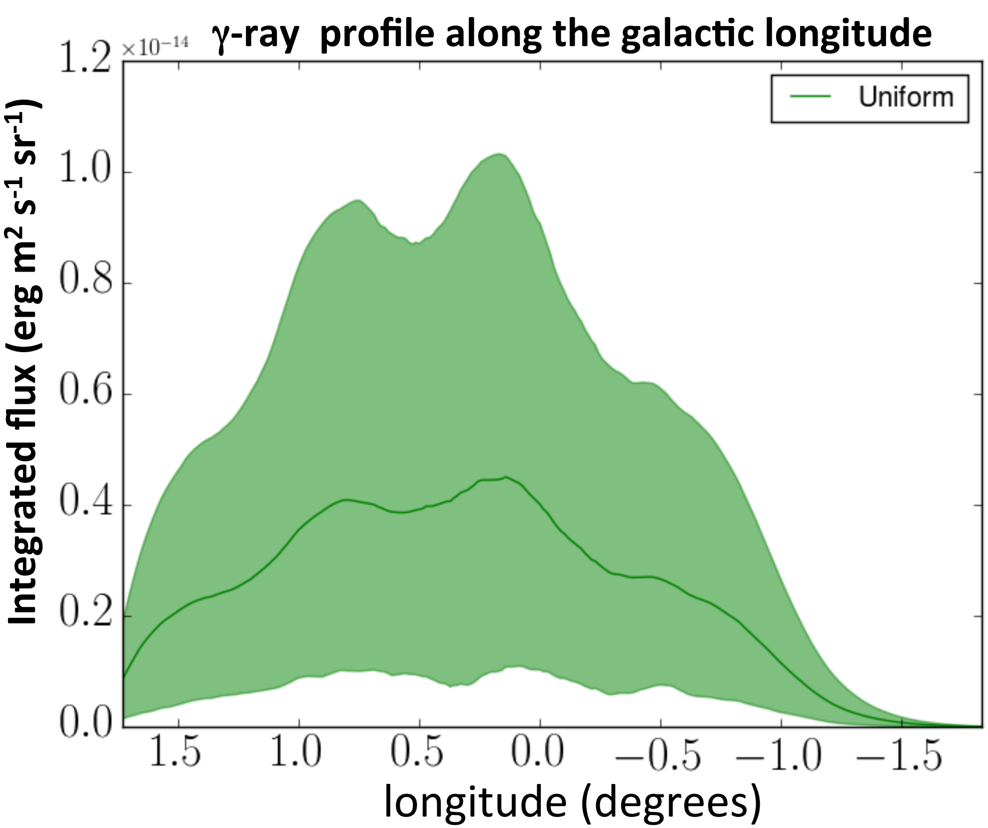
SNRs in the region

Temporal distribution: Poisson law of recurrence time=2500 yrs, t_{SNR}>1 kyrs and <100 kyrs.

Spatial distribution: 1)homogeneous cylinder (r=150 pc and z=-10 to 10 pc) and 2)homogeneous cylinder + concentration of the SNs in the two cluster: Quintuplet and Central

100 temporal and spatial distributions

Solid line: median of the γ ray profiles + spread around this median



- Profile highly dependent on each SNs spatial and temporal distribution
- More realistic distribution of SNRs (with the two clusters): makes the distribution peaked on the GC

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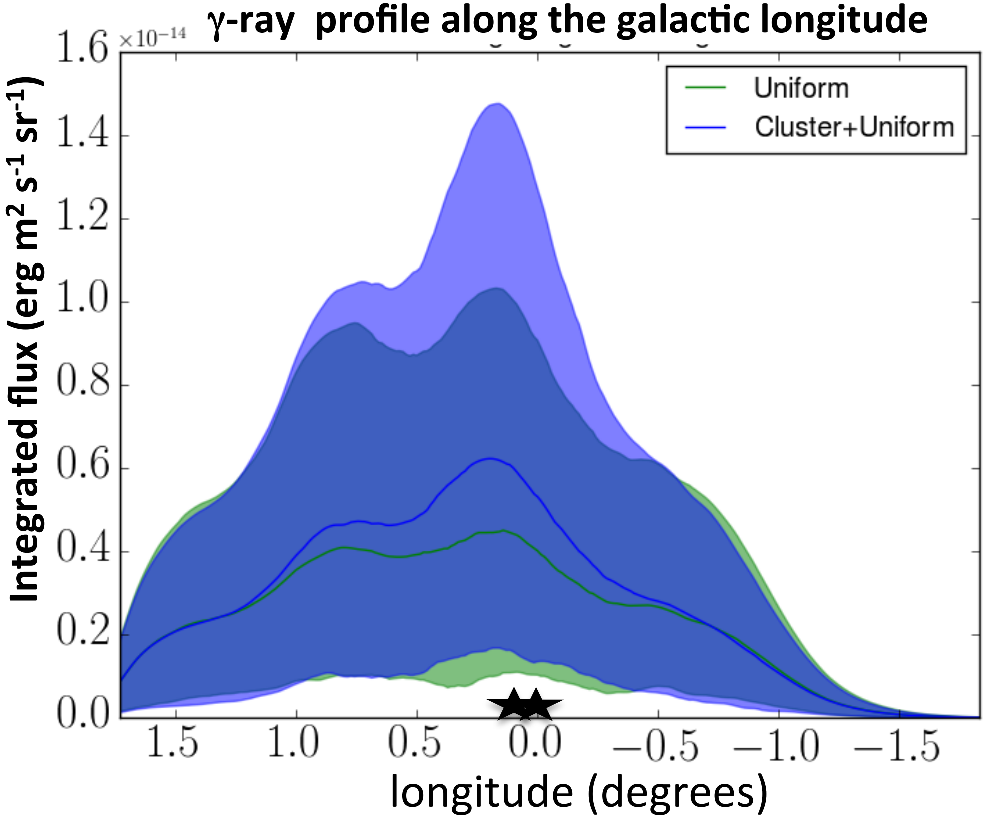
γ-ray profile along the galactic longitude

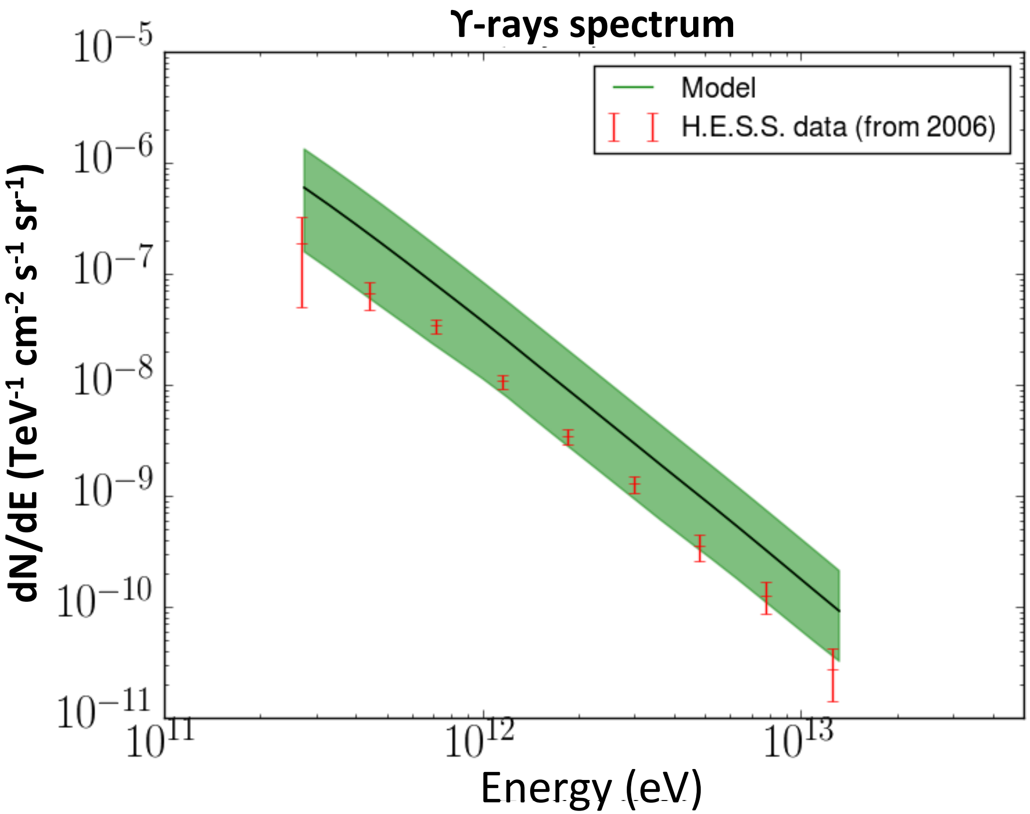


- Profile highly dependent on each SNs spatial and temporal distribution
- More realistic distribution of SNRs (with the two clusters): makes the distribution peaked toward the GC

SNRs contribution to the total flux

100 temporal and spatial distributions
Solid line: median of the γ ray profiles + spread around this median

SNRs can reproduce the total flux



In order not to overproduce the flux:

- Higher recurrence time ?
- Lower efficiency for CR acceleration?

Very hot medium ➔shock weakly supersonic

- Propagation

-Advection

-Anisotropic diffusion?

Conclusions

- Single accelerator at the center (stationary or impulsive): both can explain the existing H.E.S.S. data (2004-2006).

- SNRs contribution can not be neglected:
  - Already re(over)produce the total flux
    -> SNR rate?
    -> SNR efficiency?
    -> Propagation?
  - An excess toward the GC is expected regarding the spatial distribution

- Is the single source accelerator at the GC necessary?

Thanks for your attention

Ballistic propagation vs diffusion

When $r_{larmor} \approx \lambda$

-> Diffusion characterized by a random walk of mean free path l=3D/c :

E=1 TeV -> l≈ 7 pc

E=10 TeV -> l≈ 15 pc

E=100 TeV -> l≈ 30pc

E=1 PeV -> l≈ 60 pc

L_{box}=250pc

$D=D_o E^d$

➔ d=0.3

➔ $D_o = 5*10^{29}$ $cm^2 s^{-1}$

<u>How to model the CRs propagation and γ rays production for r < l (ballistic regime)?</u>

Diffusion vs advection

SNR in filling the Galactic center region:

Crocker et al (2011), Tova M. Yoast-Hull (2014): high speed wind (v = 400 - 1000 kms^{-1})

$H_{advection}$=50 pc → $\tau_{advection} = H_{advection}/v$ = **50 000 yrs**

H_{diff}=50 pc → $\tau_{diffusion} = H_{diff}^2/D$:

- E=1 TeV -> $\tau_{diffusion} \approx$ 1000 yrs
- E=10 TeV -> $\tau_{diffusion} \approx$ 500 yrs
- E=100 TeV -> $\tau_{diffusion} \approx$ 200 yrs
- E=1 PeV -> $\tau_{diffusion} \approx$ 100 yrs

Advection doesn't seems to play a major role for the H.E.S.S energy, how to evacuate the CRs injected by the SNRs?

-SNR rate ?

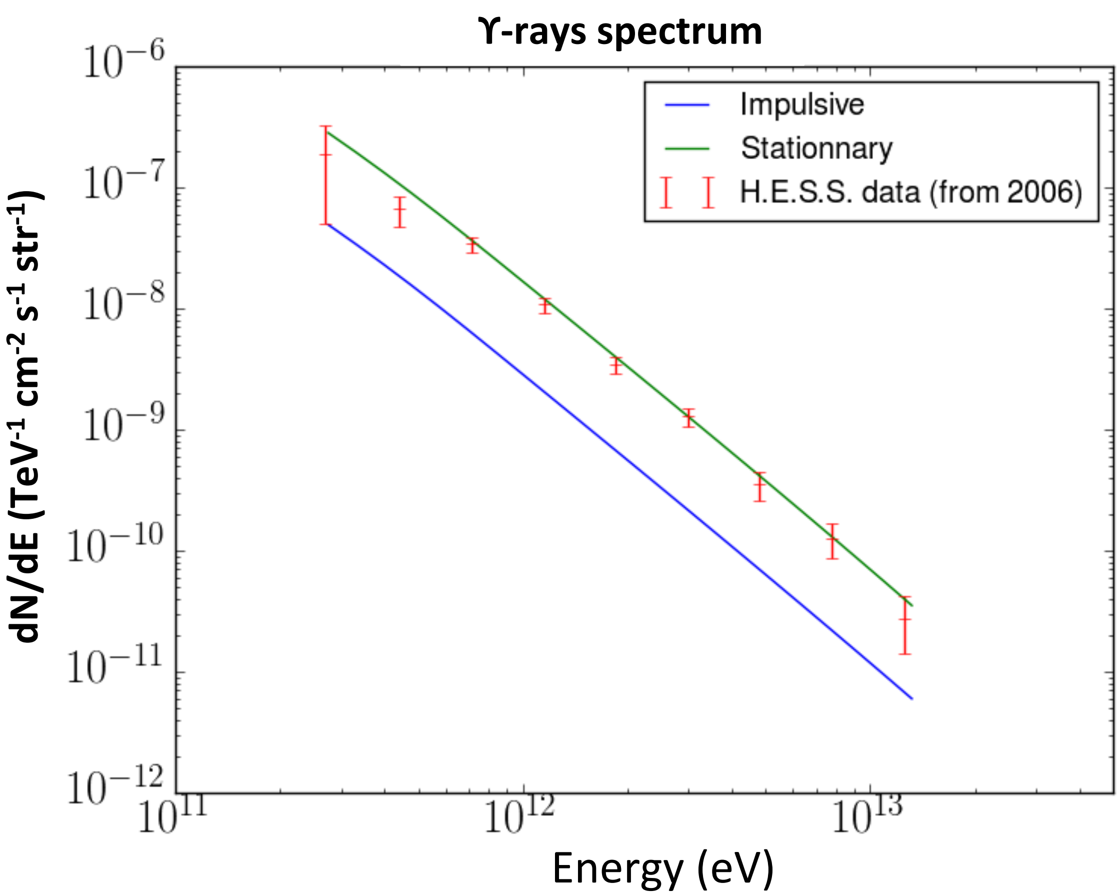
-efficiency?

-Diffusion ?

Single accelerator at the CG

Stationary or impulsive?

- Impulsive source that exploded 10 kyrs ago (SgrA East)
- Stationary source (SrgA*)



- $D=D_{10TeV}\,(E/10\ \text{TeV})^{0.3}$ to reproduce the hard spectrum observed with HESS

- <u>Stationary source</u>

Intrinsic power needed for CR acceleration ≈3×10^{38} erg s^{-1} (30% of the Bondi accretion power)

- <u>Impulsive source:</u>

The assumed total mass of 20×10^{6} M_{sun} for the matter is not enough