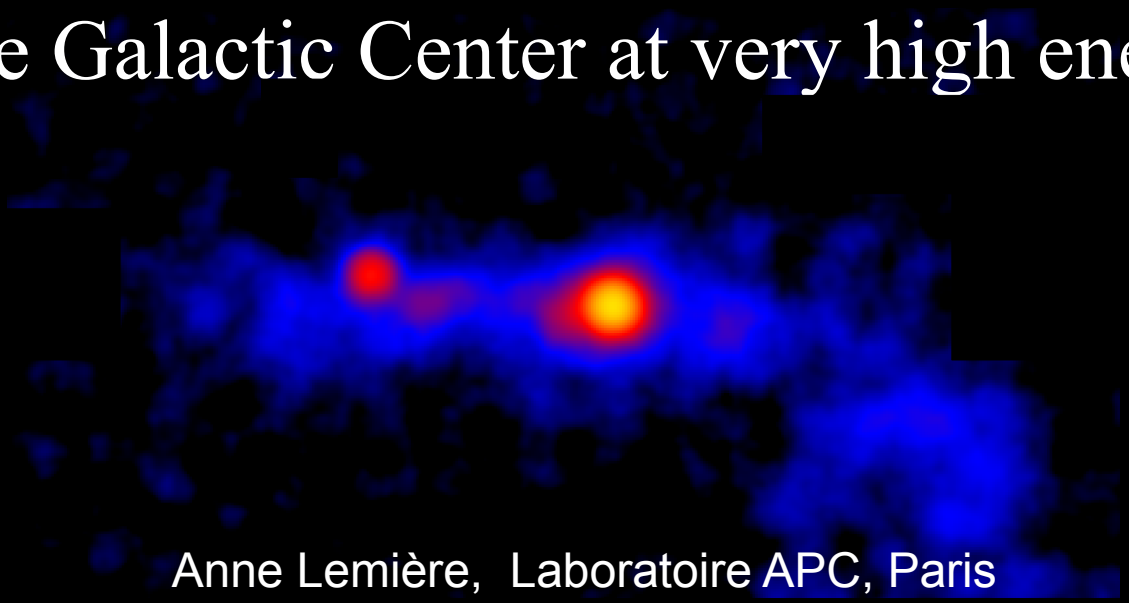
TeVPA 2018

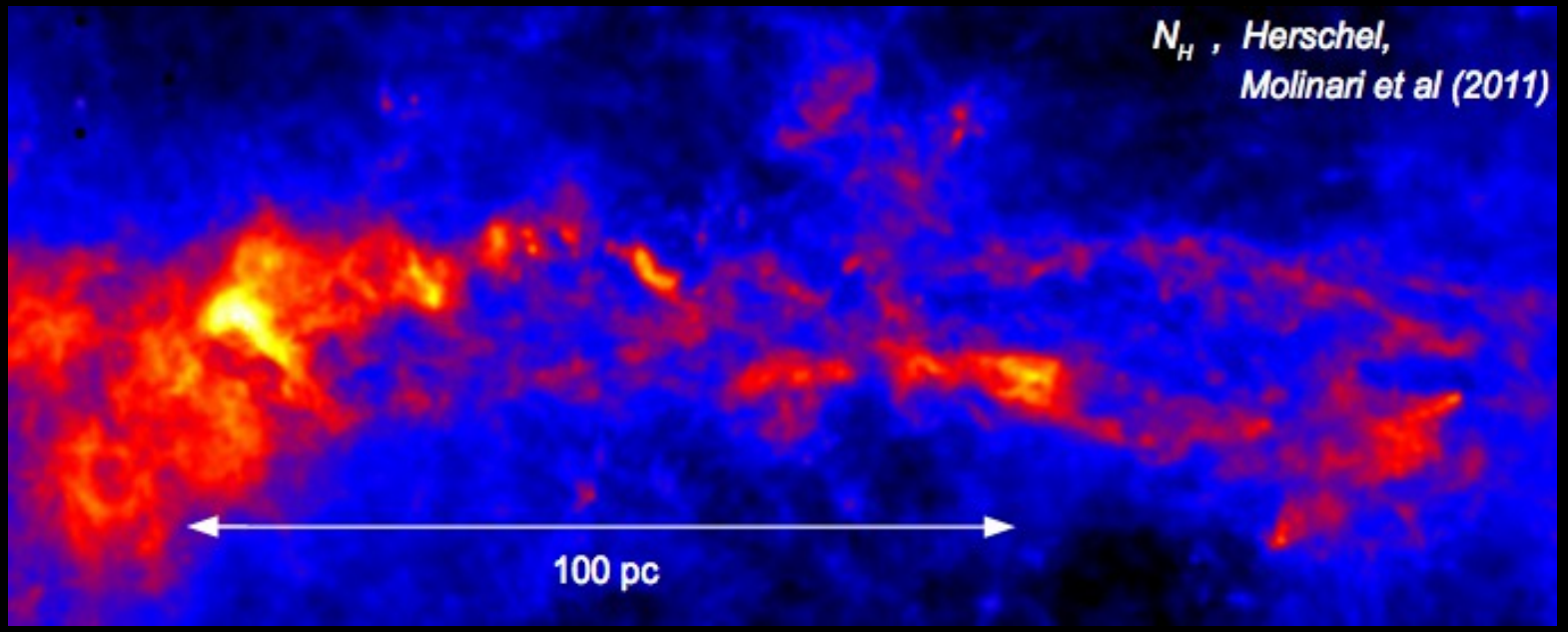
The Galactic Center at very high energy



Anne Lemière, Laboratoire APC, Paris

Collaborators : L.Jouvin, R.Terrier, S.Gabici, A. Viana, B.Khelifi,... & the H.E.S.S. collaboration

Central 200 pc : The Galactic Center Ridge



- Super massive BH SgrA* : M~ 4.10^6 M_{sun}
- 10% of the total molecular mass (CMZ) of the Galaxy in in 10^{-6} of its volume !
- Large fraction of young massive star clusters located in the GC : 10% of massive star forming activity in the CMZ
- Many accelerators : Superbubles candidates,SNRs candidates, ect...

GC Ridge observed by ground based telescopes

- CANGAROO-II (2001-2004)

  Very steep spectrum: photon index ~ 4.6 up to 2 TeV

- Whipple (1995-2003, LZA)

  GC emission evidence (3.7σ signal)

- H.E.S.S. (2004, 2006,2009,2016,2017)

  first clear GC TeV source detection-Spectrum with photon index ~2.2,

- MAGIC (2006, 2016)

  165GeV<E<10 TeV detection of HESS J1745-290

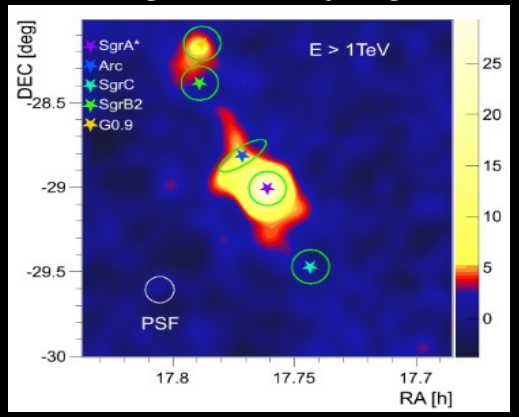
  2006 :confirm H.E.S.S. measurements

  2016 : Detect diffuse emission

- VERITAS (2011, 2016)

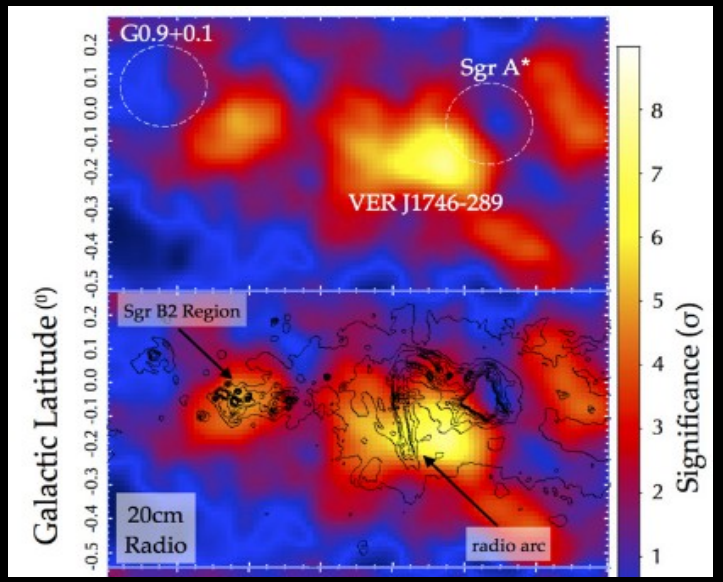
  Diffuse emission detection, Arc Source

MAGIC >1 TeV gamma-ray significance map



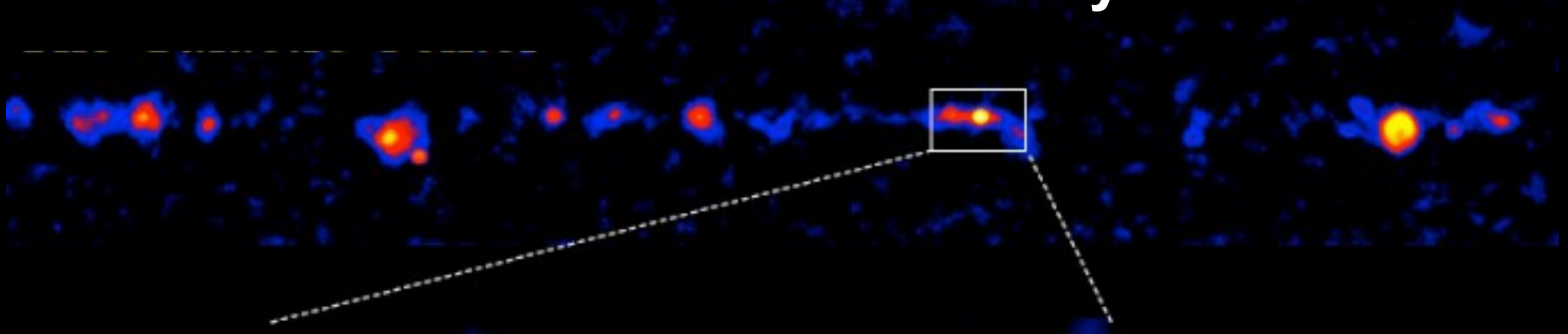
~ 80 hr livetime

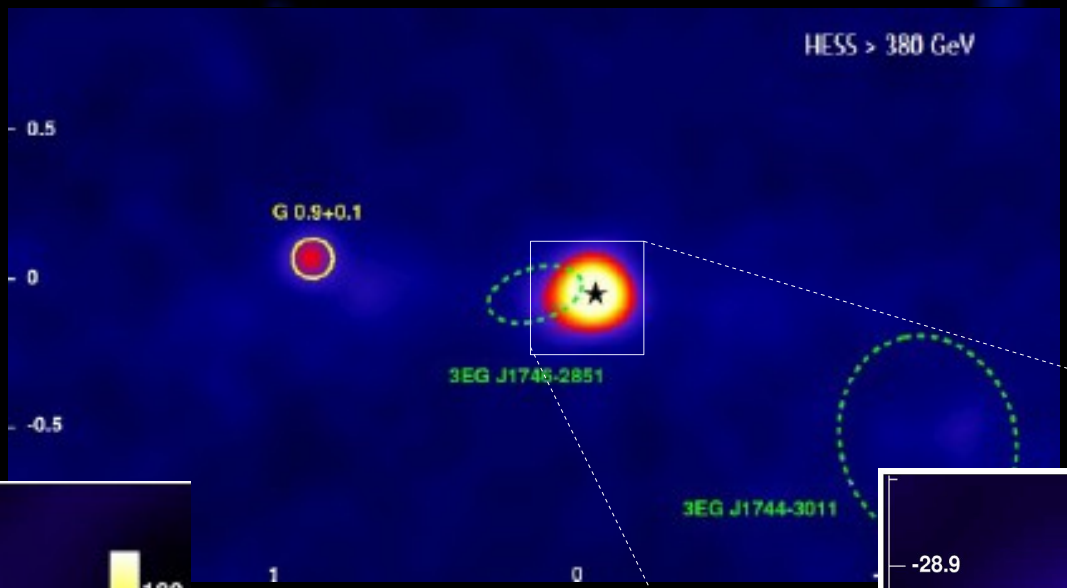
VERITAS >2 TeV gamma-ray significance maps



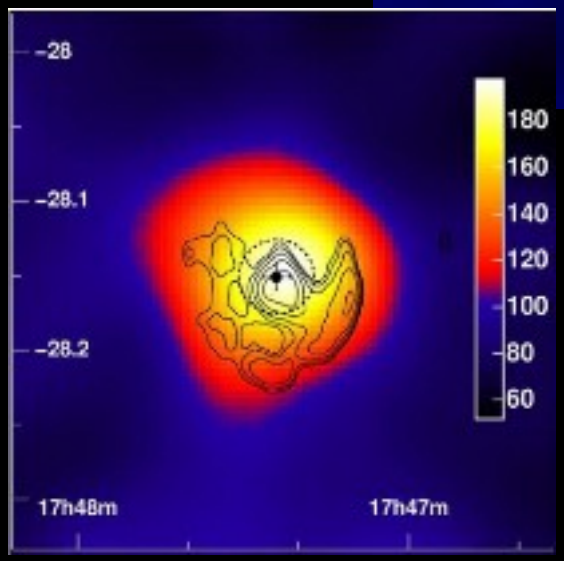
~ 85 hr livetime

The Galactic Center as seen by HESS

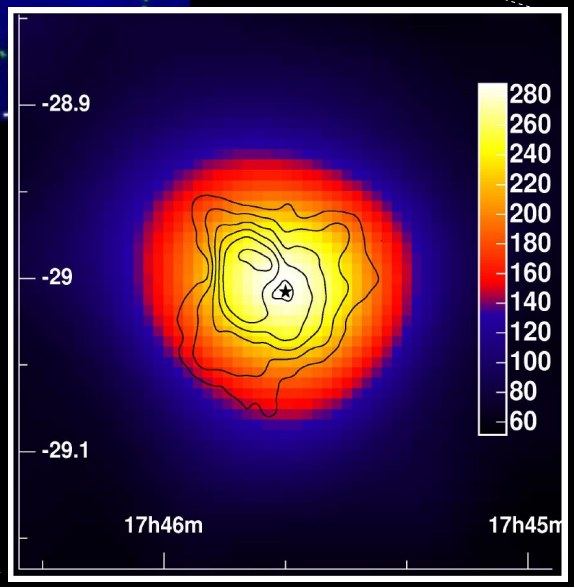




Composite SNR
G0.9+0.1



HESS J1745-290
compatible with GC



HESS J1745-290 Spectrum

- Significant deviation from a power-law :

  spectral index ~ 2.2

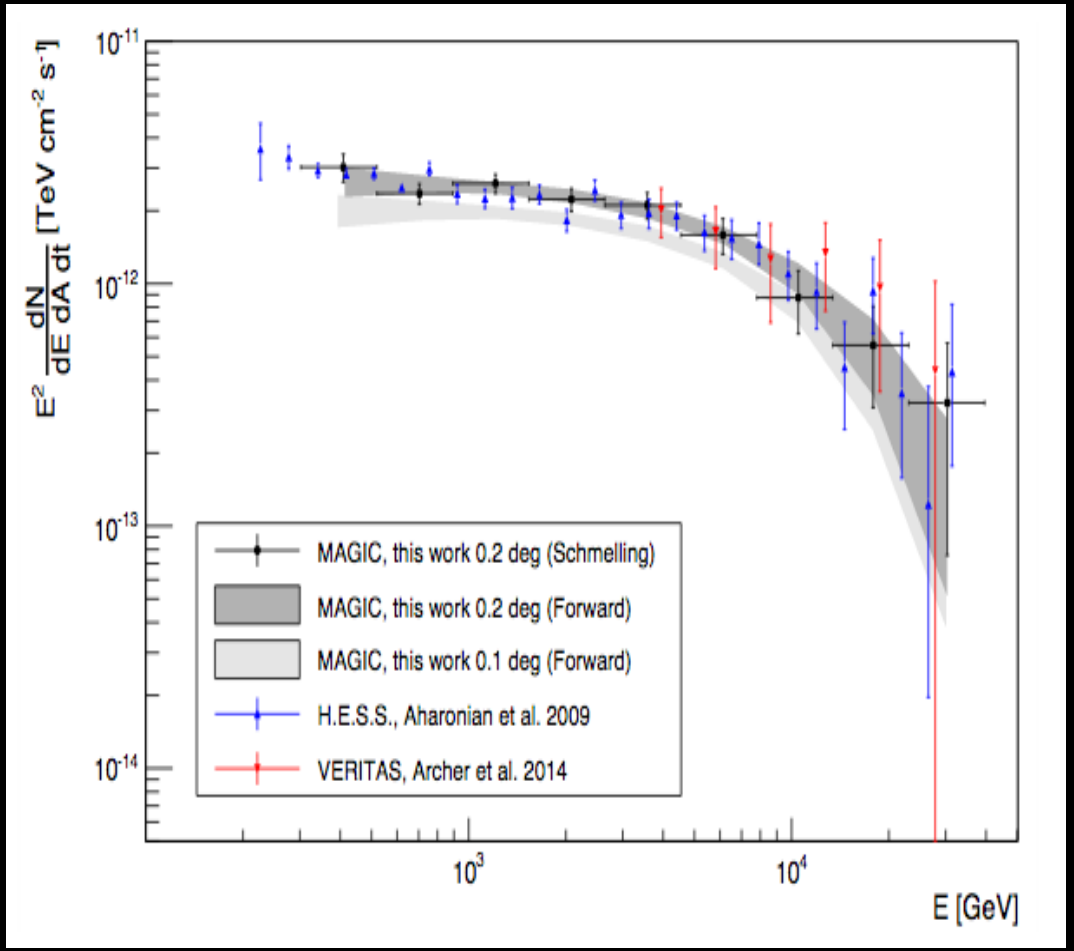
  exp cut-off at E~15 TeV

  $F(1TeV) = 2.5\ 10^{-12}\ cm^{-2}.s^{-1}.TeV^{-1}$

- Steady source :

no variation found despite simultaneous Chandra observations with X-ray flare (2005).

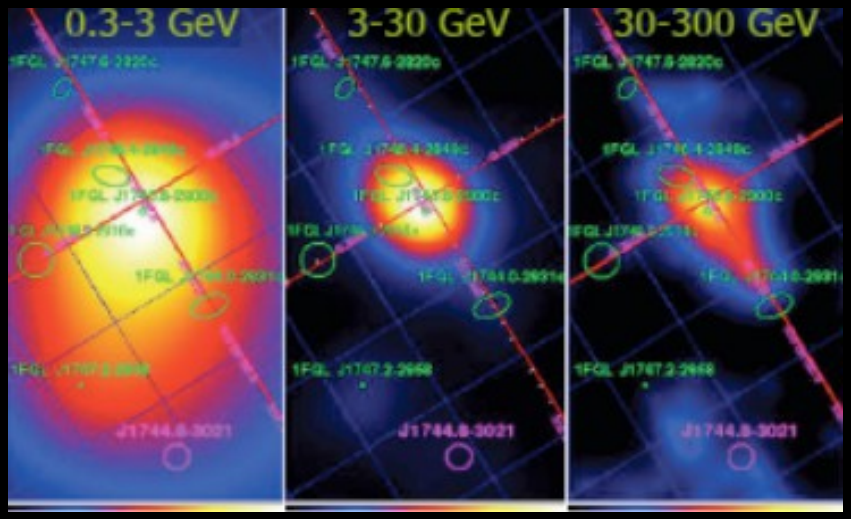
(factor 2 increase excluded at 99%CL)



FERMI LAT point source at the GC

One point-source at the GC : *(Chernyakov et al. 2011)*

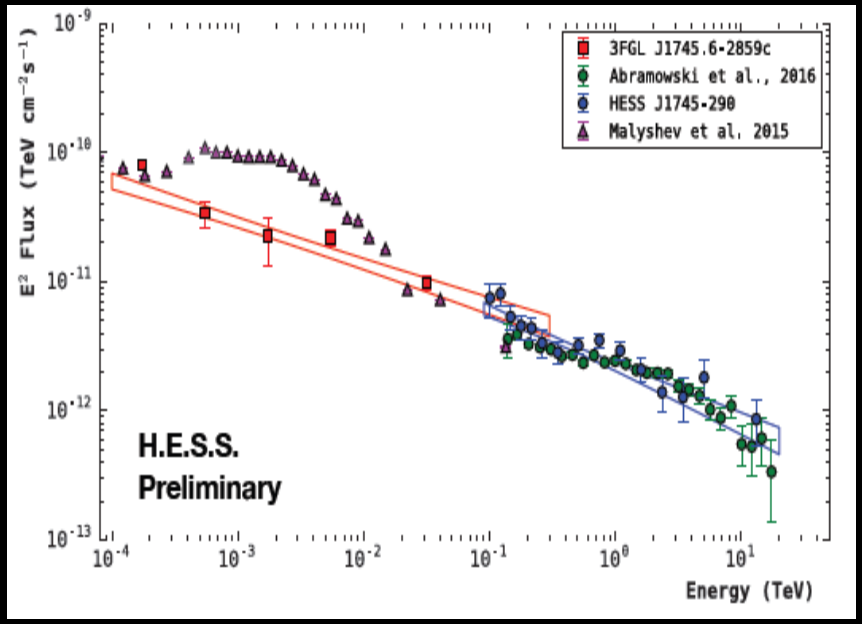
- Centroid seems to be consistent with SgrA* at high energy : 2' +- 1' offset in the 2FGL
  index1 = 2.2 (<5GeV)
  index2=2.7 (>5GeV)



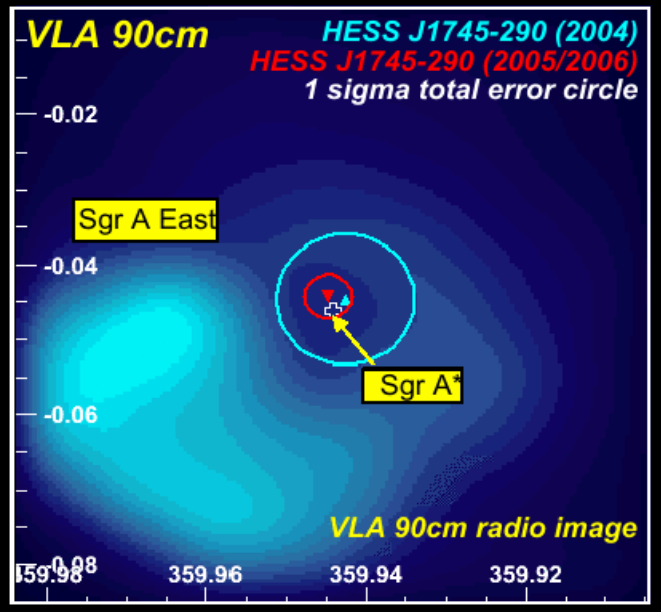
Two sources at the GC : *(Acero et al. 2015)*

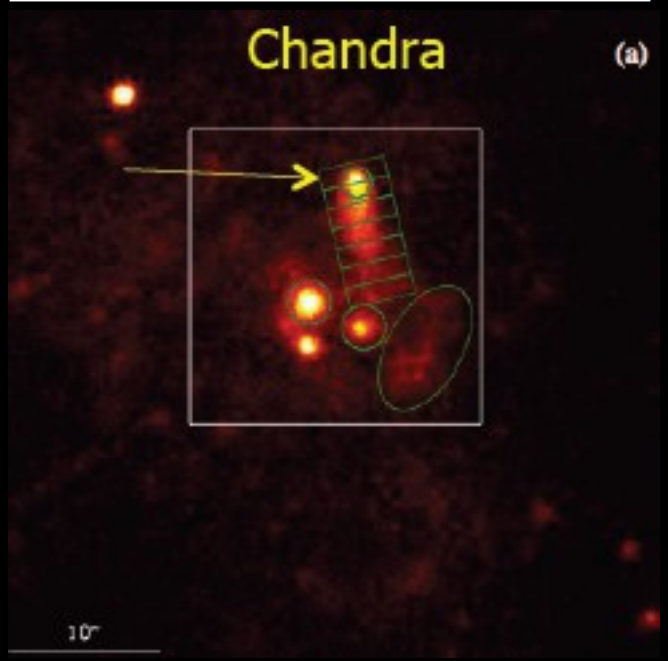
- 3FGL1745.6-2859c:
  compatible with GC PWL spectrum
  Γ = 2.32 ±0.034
  Flux(1-10 GeV)=2.18±0.2 10^{-8} γ/cm^2/s

- 3FGL J1745.3-2903c :
  second source at 6' for SgrA* with curved spectrum



Counterparts for HESS J1745-290





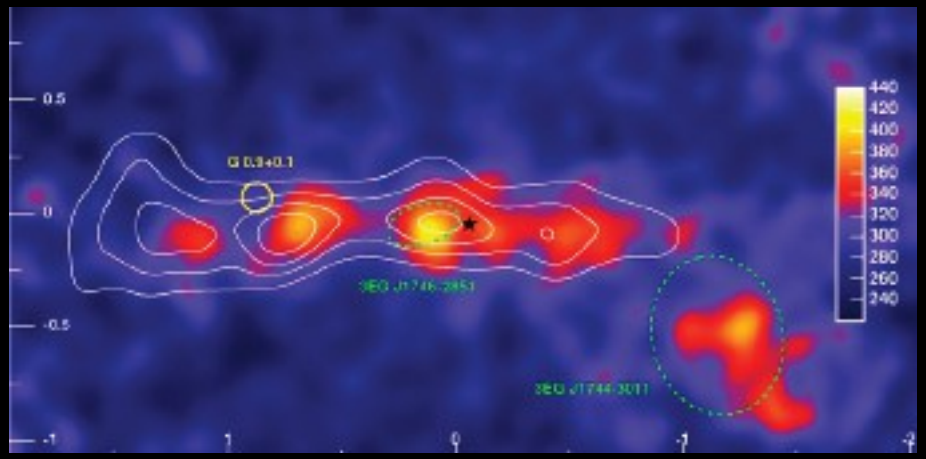
HESS collab. 2010 :

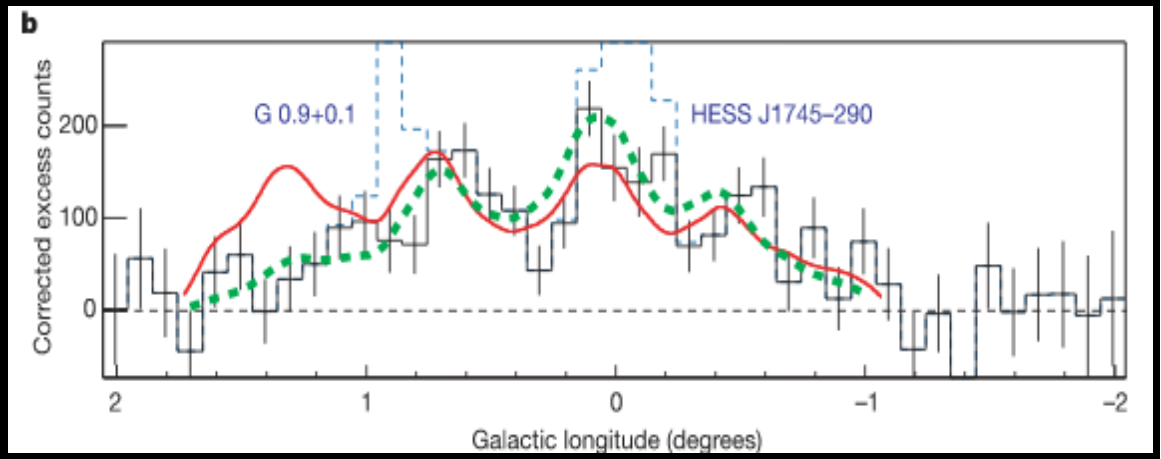
- Maximal source extension <1.3' (95% CL) i.e. < 3pc
  Excludes Sgr A East as a plausible counterpart
- Source within 6" of Sgr A* (after pointing accuracy improvements)

Nature of the emission ?

- Sgr A East SNR : excluded
- Sgr A* :
  TeV particles accelerated in the vicinity of the SMBH, diffuse and interact with the dense circum-nuclear disk.
- The PWN G359.95-0.04 at only 7" (0.3pc) of SgrA*
  (Hinton et al. 2006)

The TeV Galactic Centre diffuse emission





Aharonian et al (2006)

- Discovery of diffuse emission correlated with dense gas tracer CS with 90 hours of data: ɣ produced through p-p collisions

- Diffuse emission spectrum : $\Gamma = 2.3 \pm 0.1$, L_γ (>4TeV)= 5.10^{34} erg/s

  Not compatible with spectrum expected from local CR spectral distribution → Existence of a local cosmic-ray accelerator

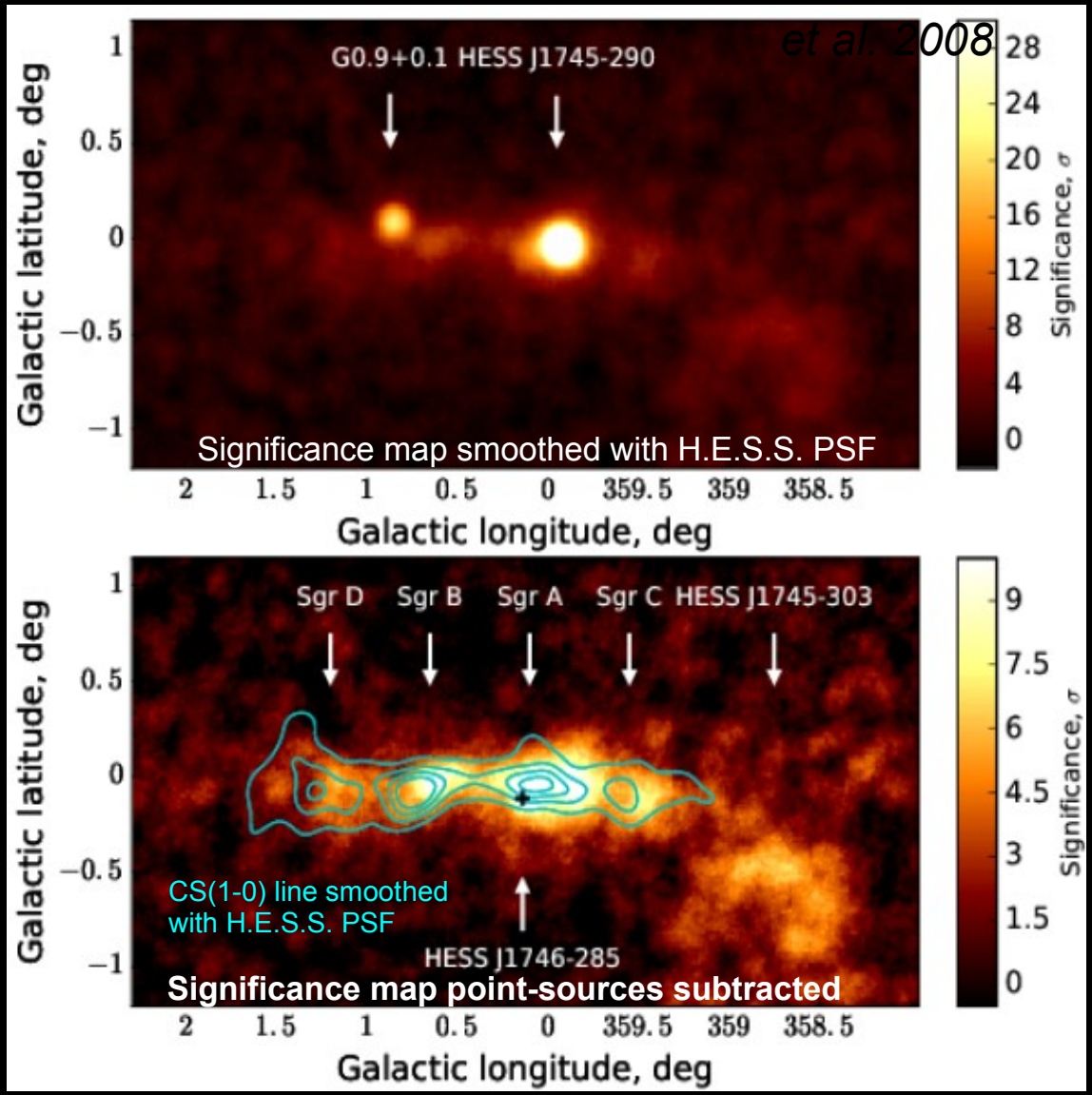
- Deficit of emission at l =1.3° suggest gradient of cosmic-ray on 0.8° scale: diffusion of CR injected in a recent period (i.e.~ 10 kyr) ?

The TeV Galactic Centre 10 years later

•**Dataset :** ~10 years H.E.S.S.I data set from 2004-2014 : 250 hours of livetime

Data analysis:

- More sensitive multivariate type analysis
- Residual background estimation tools at the limit of validity domain.
- Wide range of observations conditions implies a careful estimation of systematics
- Point source subtraction and diffuse emission studies performed with a 2D maximum likelihood using sherpa



GC VHE diffuse emission components

Model

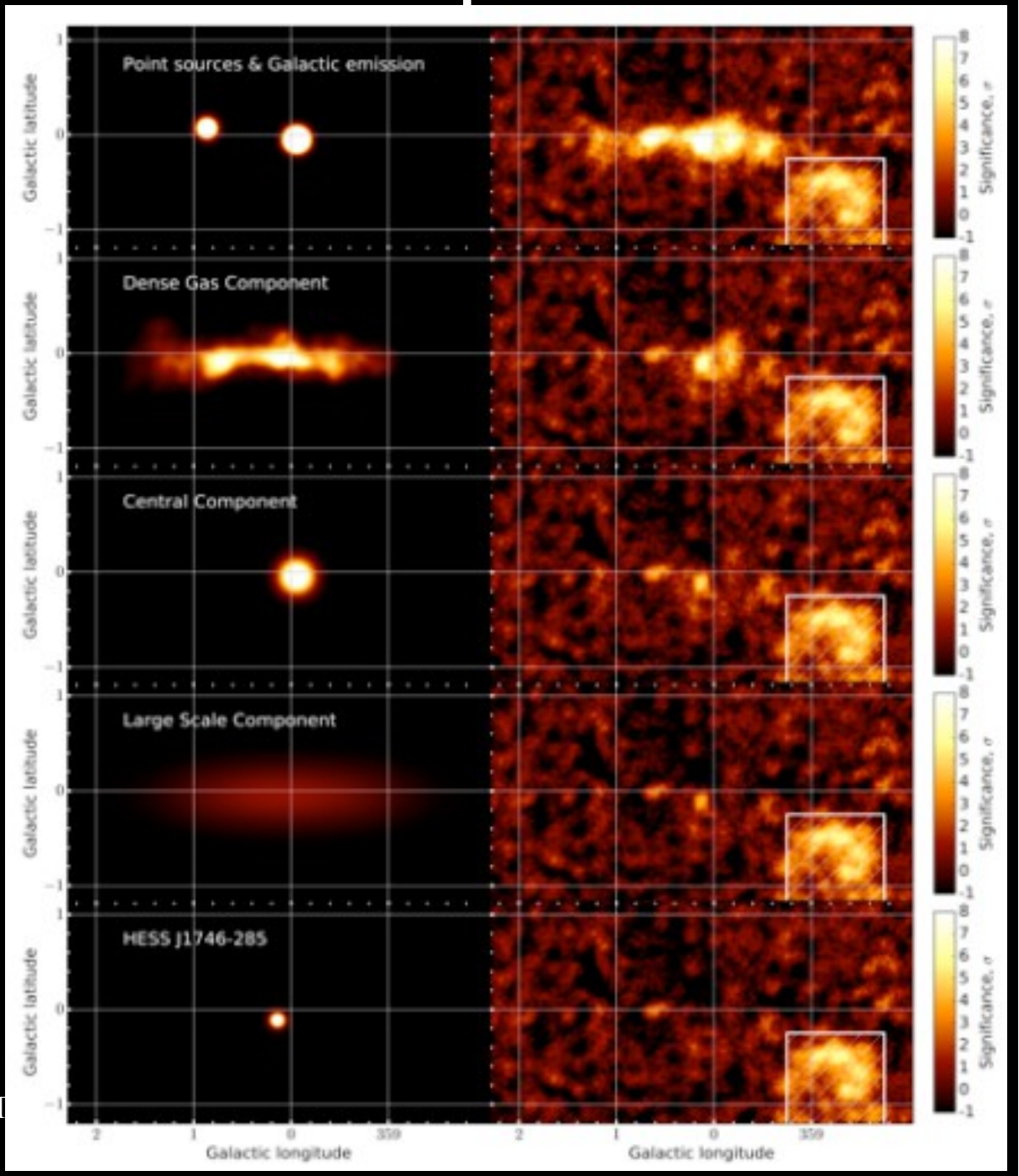
$a_1 S_1 + a_2 S_2 +$ OFF + GalDiff

$+ \alpha_{CR}$ (Gauss(**σx, σy**) x CS) * PSF

$+ \alpha_{CC}$ Central Compo(**σ**)

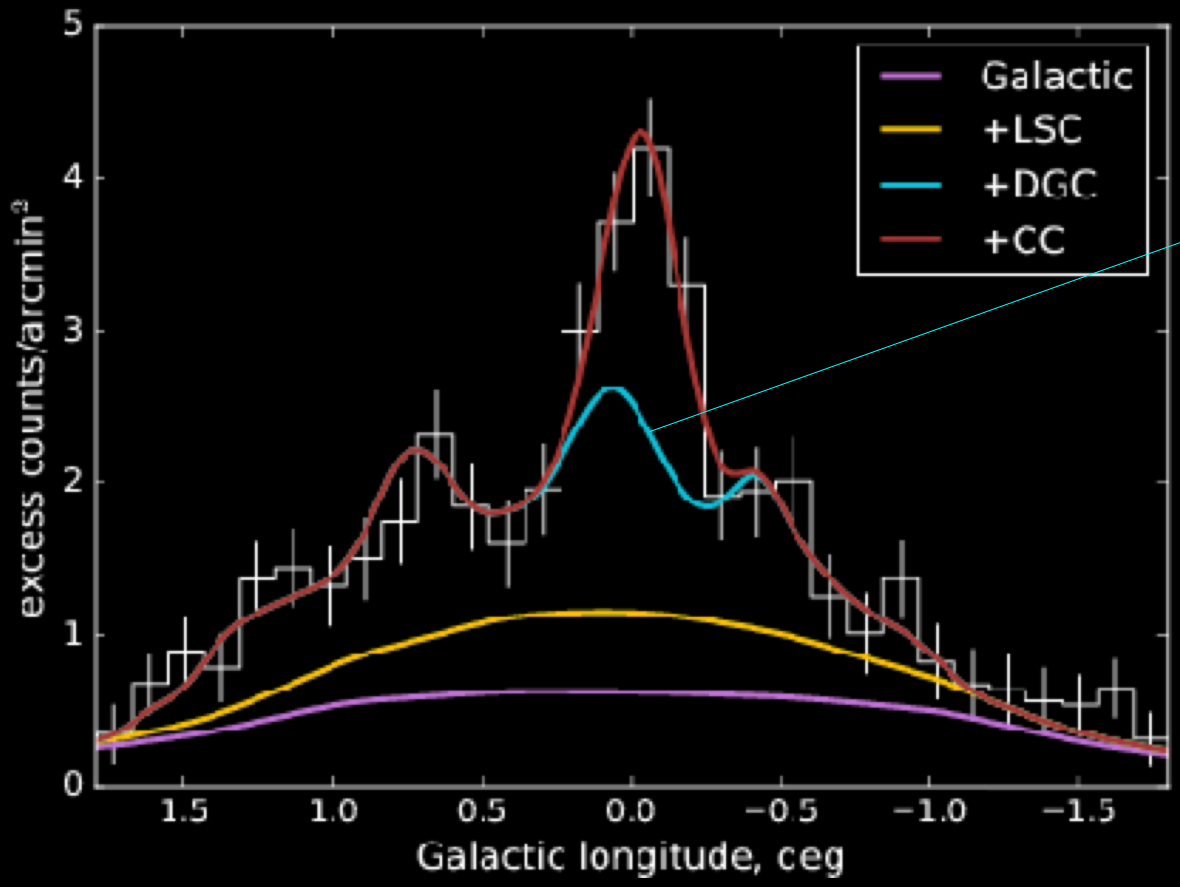
+ α_{LS} LargeScale(**σx,σy**)

+ $a_3 S_3(l,b)$



GC VHE diffuse emission components

Longitude profile of the emission



- Half of GC ridge emission is distributed like dense gas tracers

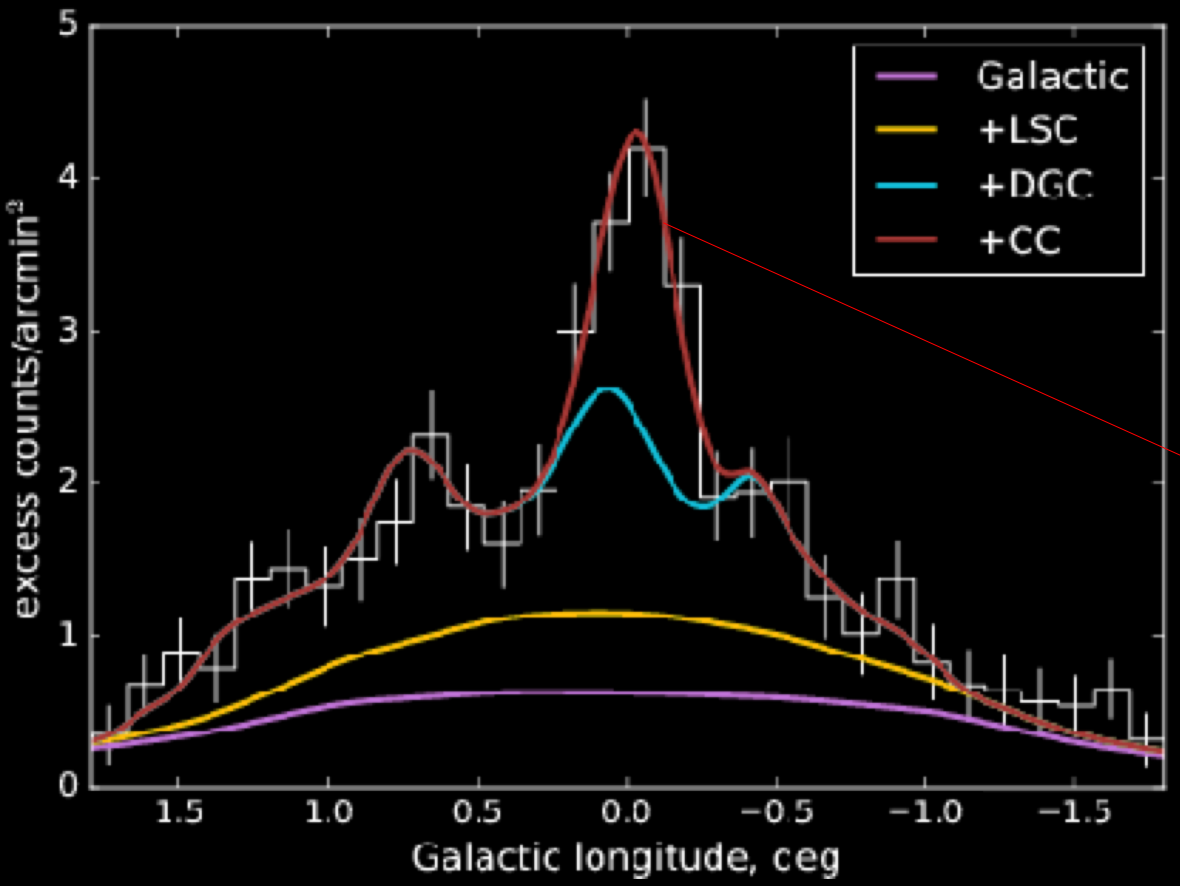
  → signature of protons interacting with the CMZ

- CR gaussian extension of ~0.9° confirmed by 2D fit

  → CR distribution not homogeneous : enhancement near the center

GC VHE diffuse emission components

Longitude profile of the emission



- Central component centered on the GC, 0.1°(or 14 pc) extension and 15% of the total ridge emission.

→ Signature of a radial gradient of CRs in the CMZ., profile expected when a stationary source of CRs is present.

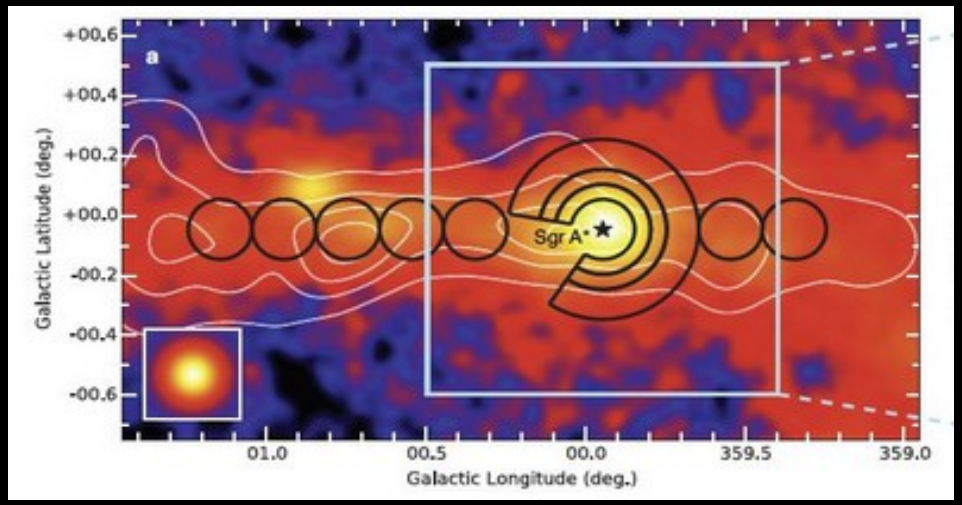
→ Evidence that a fraction of CRs pervading the CMZ is accelerated at the GC, possibly around the SMBH itself.

CR density profile integrated on the line of sight

- Compute Gamma-ray luminosity L

  in several regions

- Derive CR energy density : L / M

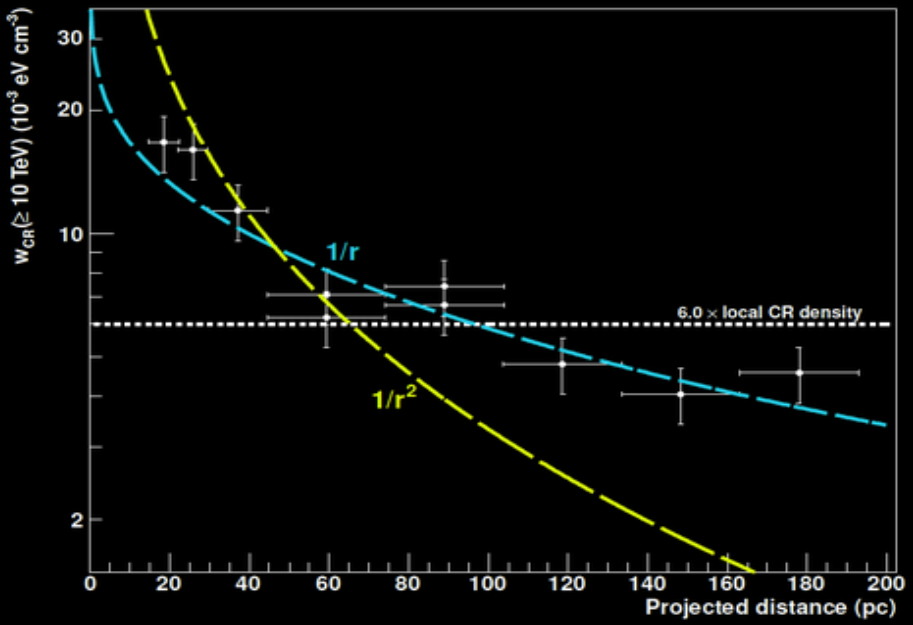


- Build CR density radial distributions :

  $1/r^2$ Wind-driven or ballistic propagation

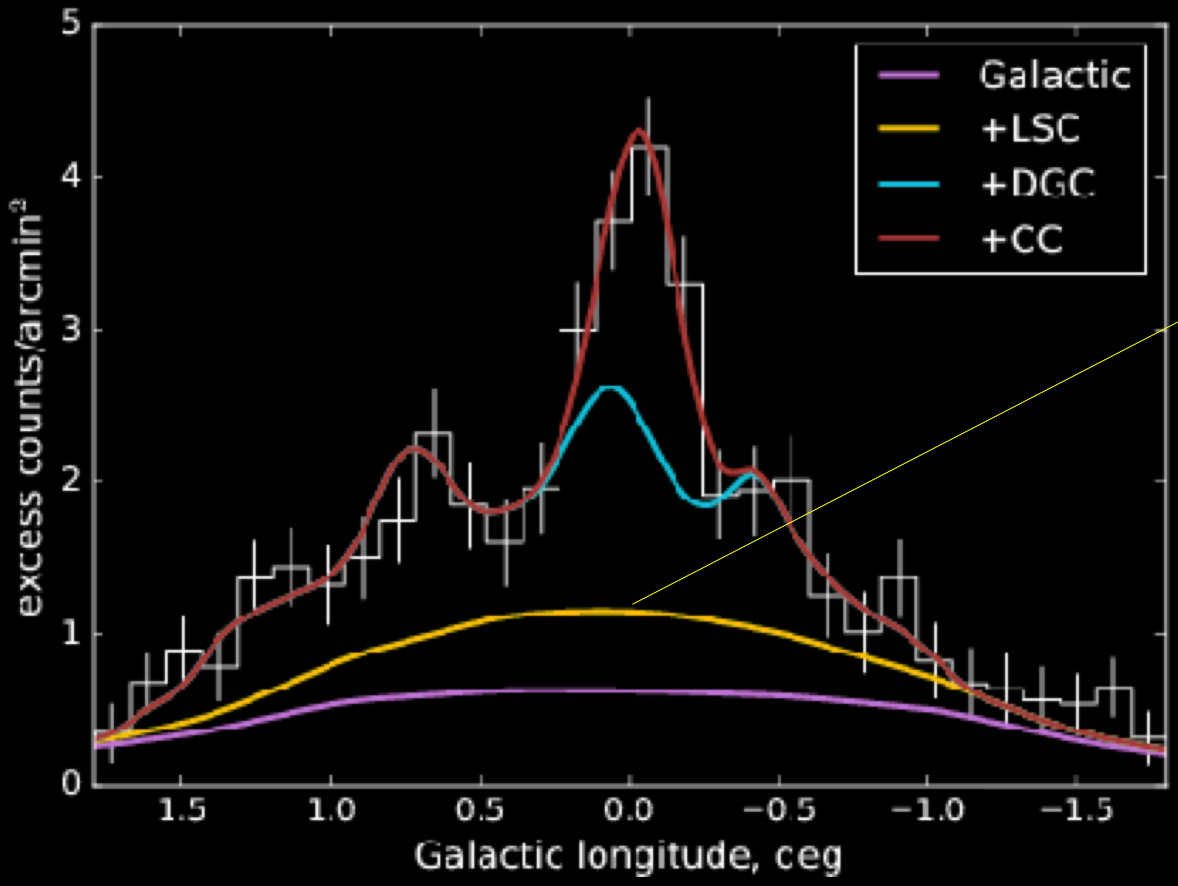
  1/r continuous injection and diffusive propagation

→ Homogeneous/Constant-Impulsive injection of CRs and diffusive propagation



GC VHE diffuse emission components

Longitude profile of the emission



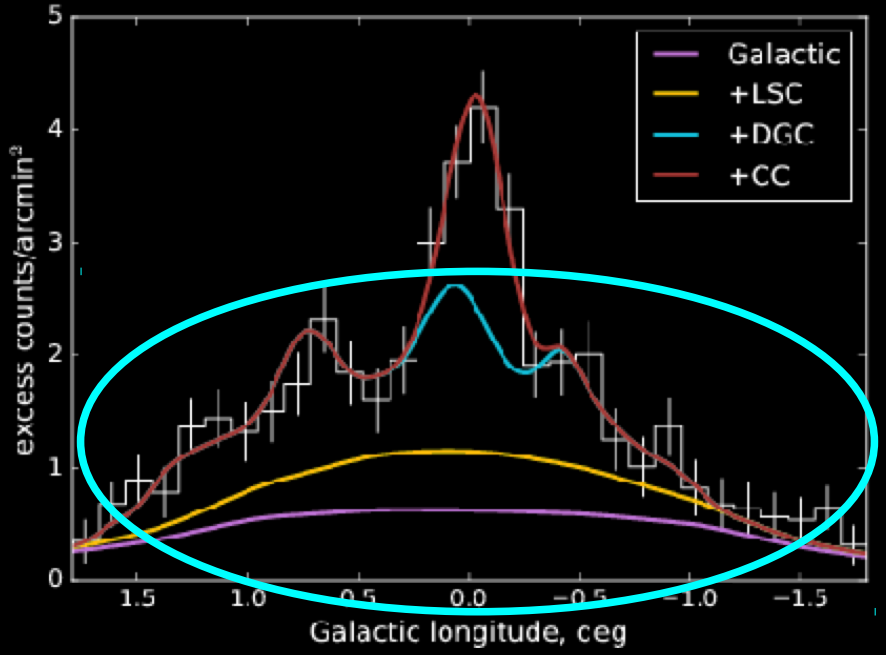
- A large scale component extending:
  ±30 pc in latitude
  ±150 pc in longitude
- Origin uncertain :

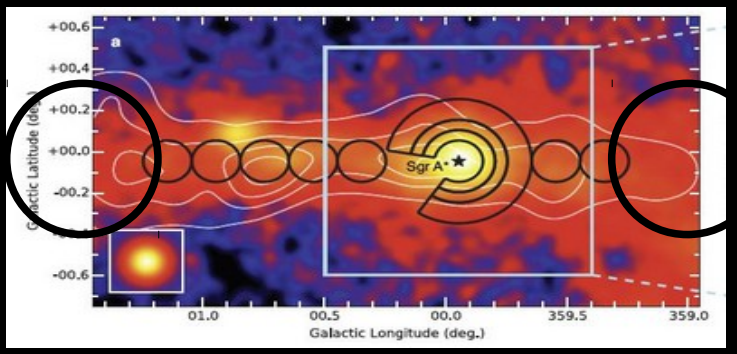
  → Diffuse gas component not seen in tracers ?

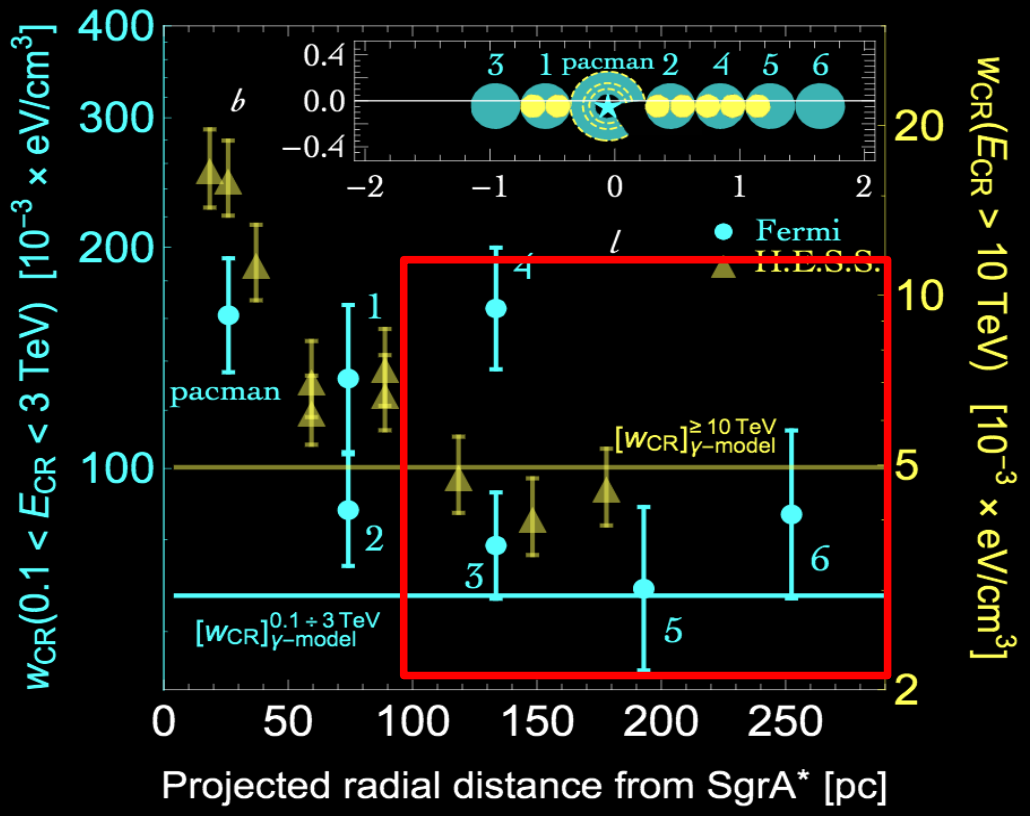
  → Unresolved TeV sources ?

  → Diffuse features at high latitude ?

Is there an exces of CRs in the GC ?







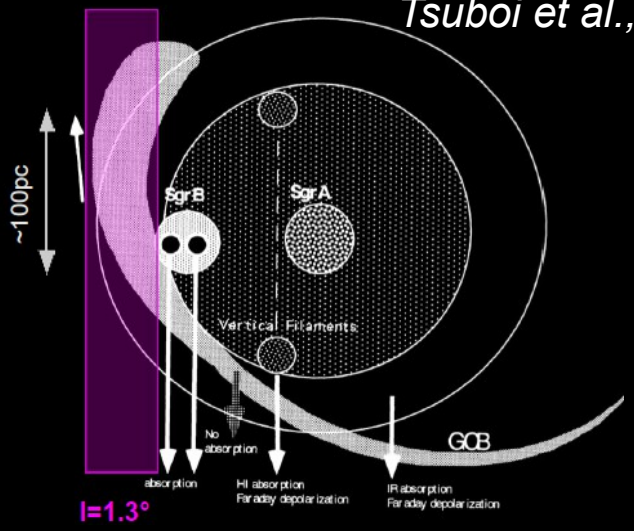
Gaggero et al. 2017 claim R>100 pc Galactic ridge emission can be reproduced by the interaction of diffuse steady state Galactic CR sea with the CMZ.

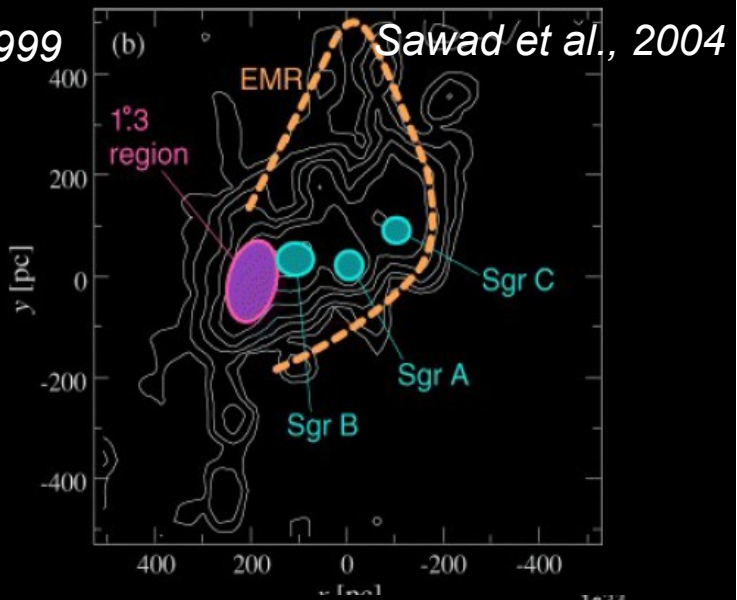
But what happens at larger longitudes ?

A deficit of gamma-ray emission at l=1.3°

A face-on view of the CMZ :

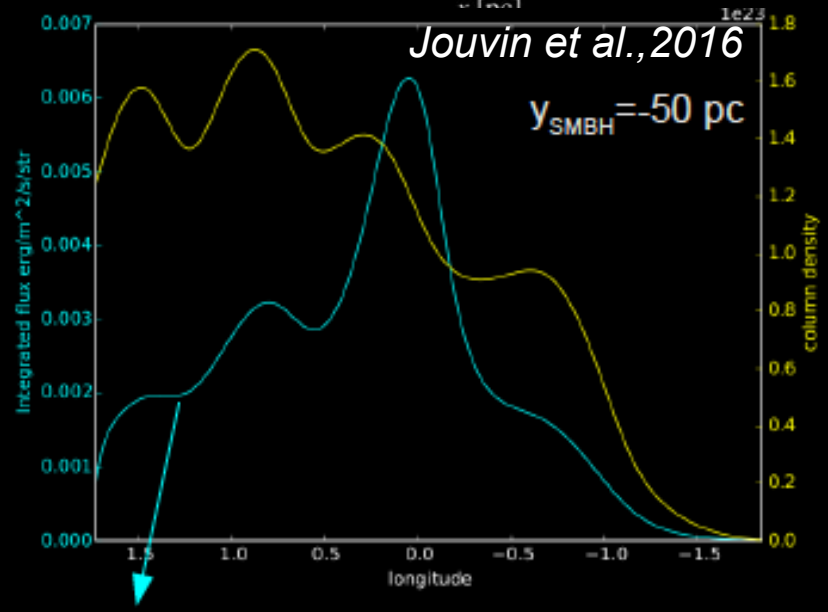
- l=1.3° feature is the tangent point of a large arc of gas
- Gas is more distributed and spread along the line of sight





Enough to explain the lack of TeV emission at 1.3°
→ Test the 1/r CR profile in a 3D model using 3D CMZ

- Factor of 2 enhancement towards inner region is clearly visible
- Decrease at l=1.3° is there. Profile is broadly consistent with data

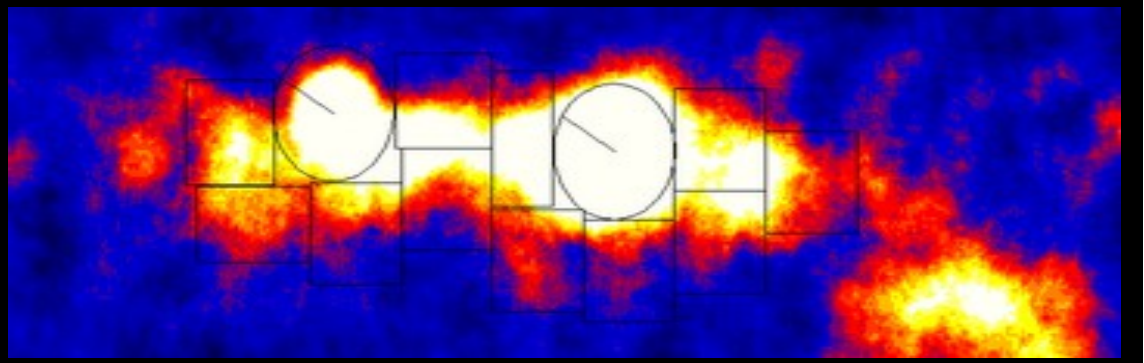


Gamma-ray profile

Gas column density

Spectrum of diffuse emission

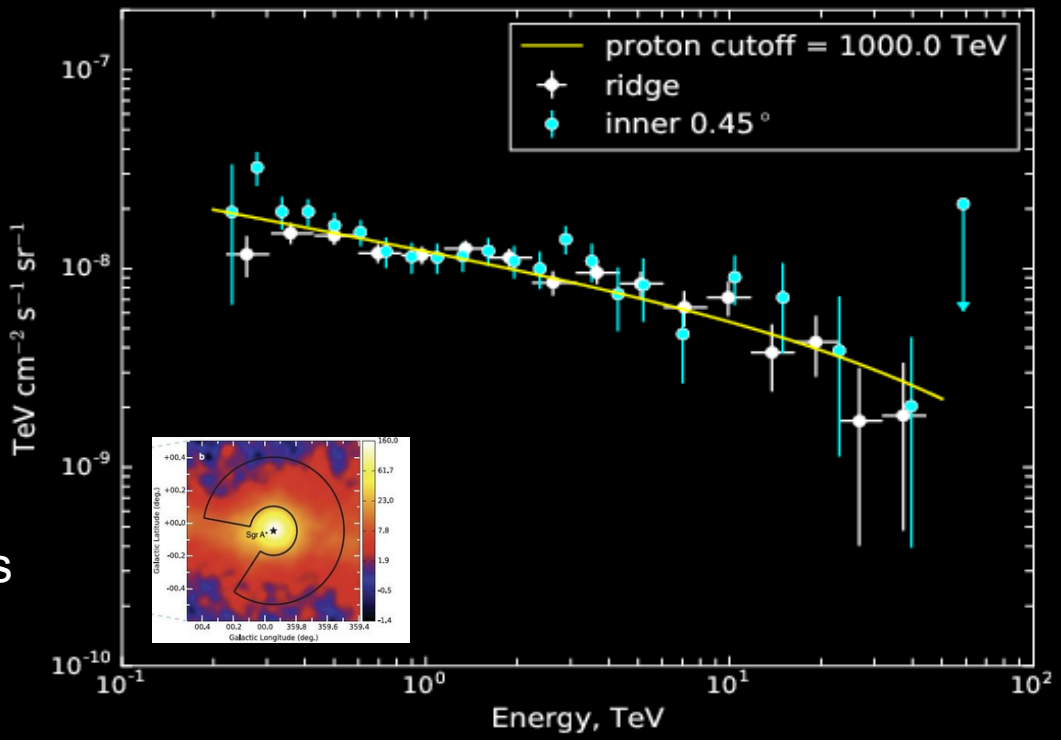
- Power-law with index 2.3 compatible with previous spectrum
- Spectrum extending up to 50 TeV without any detected energy cut-off



Parent proton injection spectrum should :

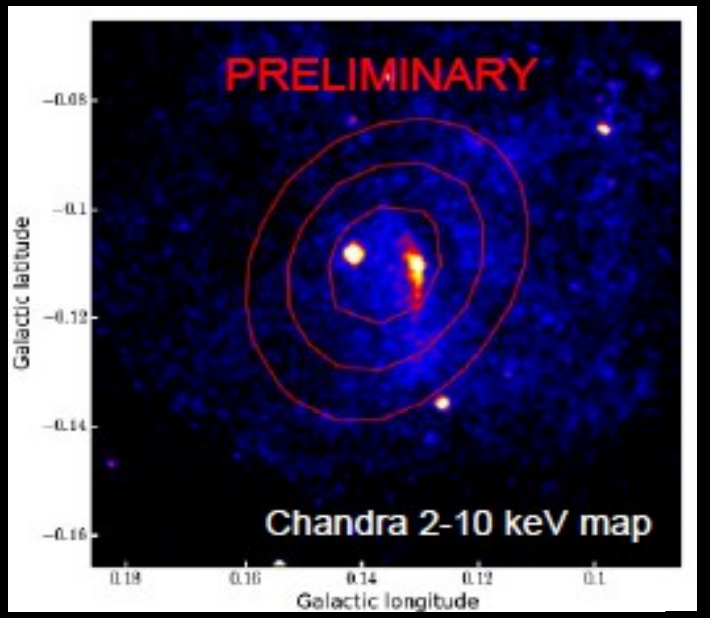
- extend to PeV energies : PeVatron !
- fill the entire CMZ

- Quasi-continuous injection lasting over ~10^4 years
- Total CR power injected at the GC ~10^{38} erg/s

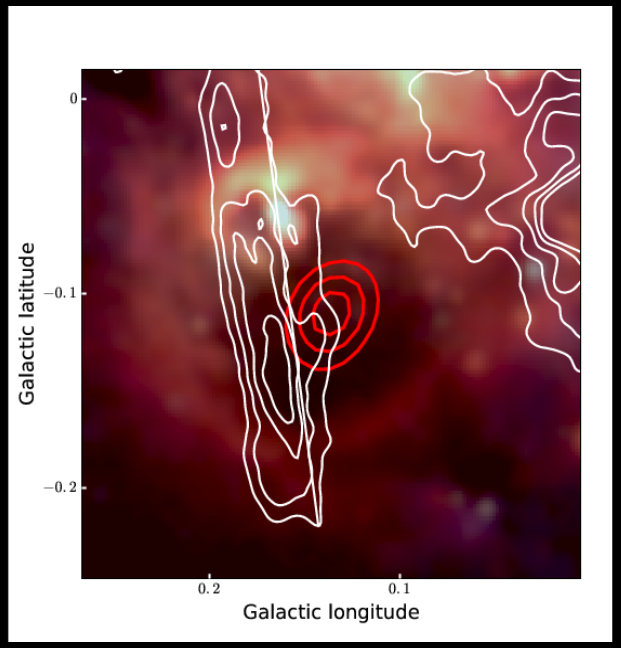


The VHE radio arc source HESS J1746-285

A new point-source is detected at more than 6σ :
Index = 2.19±0.16
L = 2-3 10^{33}erg s^{-1} at 8 kpc



- Position compatible with the soft (3.2±0.3) Fermi source 1FHLJ1746.3-2851
- Lies in the low density Radio-Arc Bubble : an IR cavity field with soft plasma
- Coincident with X-ray filament G0.13-0.11
  - L(2-10 keV)= 3 10^{33} erg/s, Γ_x ~1.4-2.5
  - A PWN in high B field?
    Interaction NTFs /MC : B~100-1000 μG
    X-ray synchrotron lifetime : l~40" → B<300μG
    L_x / L_γ ~ 1, in the range of observed Galactic PWNe



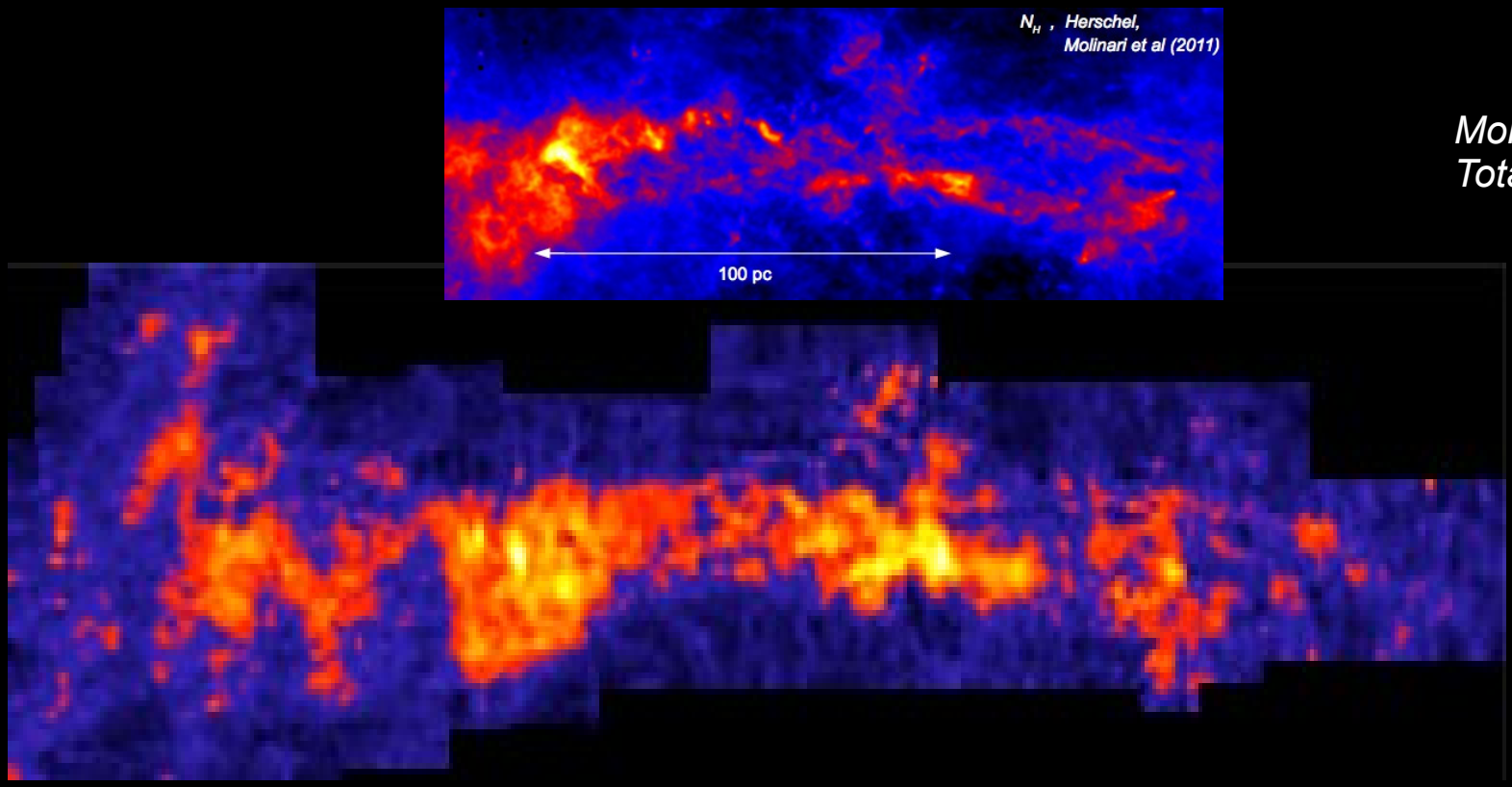
Conclusion

- We observe a radial gradient of CRs in the CMZ compatible with the shape expected if CR are accelerated by a steady source at the GC.
- PeV protons fills the entire CMZ and emit gamma-rays: the GC accelerator is a Pevatron
- PWNe of the CMZ in high magnetic field can be TeV emitters

But a lot of open questions !

- Which relation with the central point-source ?
- Which connection with the Fermi bubbles ?
- Why don't we see emission from the SNRs (very high rate !)
- What is the contribution of all the 30 PWN detected by Chandra in the central 30pc ?
- ...

Tracers of dense gas



Molinari et al 2011
Total NH

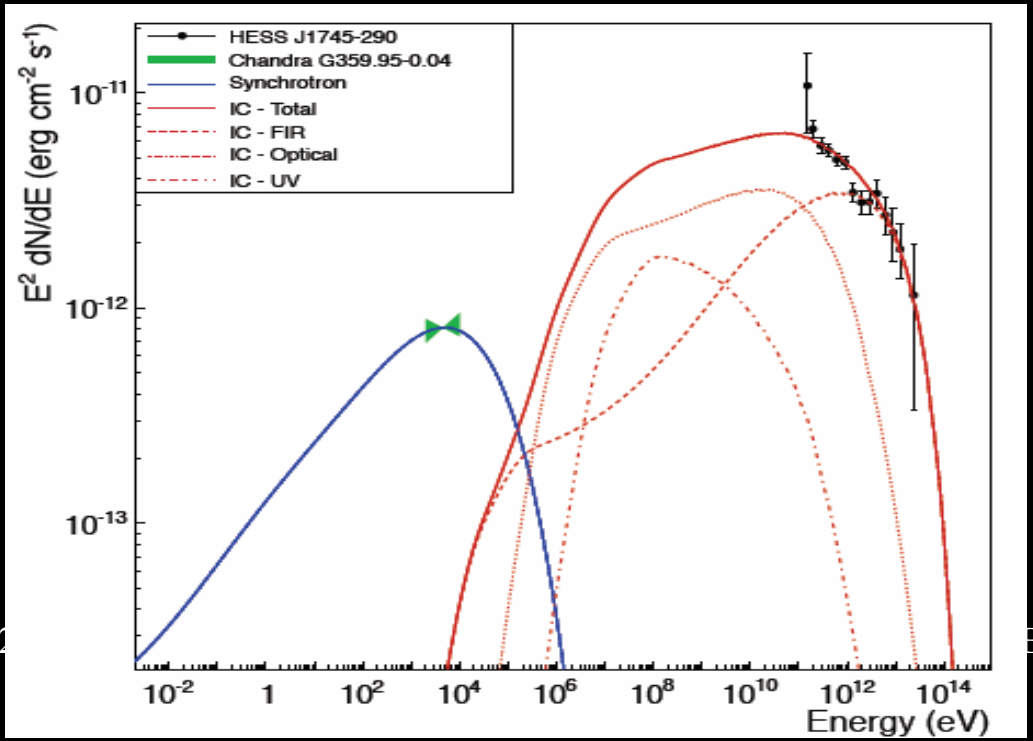
Tsuboi et al
1998
CS

- CS is an effective tracer of dense gas, but suffers from self-absorption in very dense regions (Full CMZ : (-1. 5°< l < 1. 5°))
- HCN has similar density distribution than CS (Full CMZ)
- Molinari et al (2011) total **NH** map (-0. 8°< l < 0. 8°) :
  Dust temperature and column density maps deduced from multi-frequencies **Herschel** observations : total gas column density is deduced multiplying by a constant gas-to-dust ratio.

Nature of HESS J1745-290

Hadron scenario:

- Reflects the energy cut-off in the primary proton spectrum at Ep ~100 TeV
- diffusion of protons to outside of the center: competition between injection and escape of protons



Leptonic scenario:

IC emission from Very high energy electrons(up to 100TeV) of the PWN

Energetically possible given high local radiation field and if B~few 10 of μG (Hinton et al. XX)

But recent magnetar measurement constrain B~100 of μG (XX)

The VHE radio Arc source HESS J1746-285

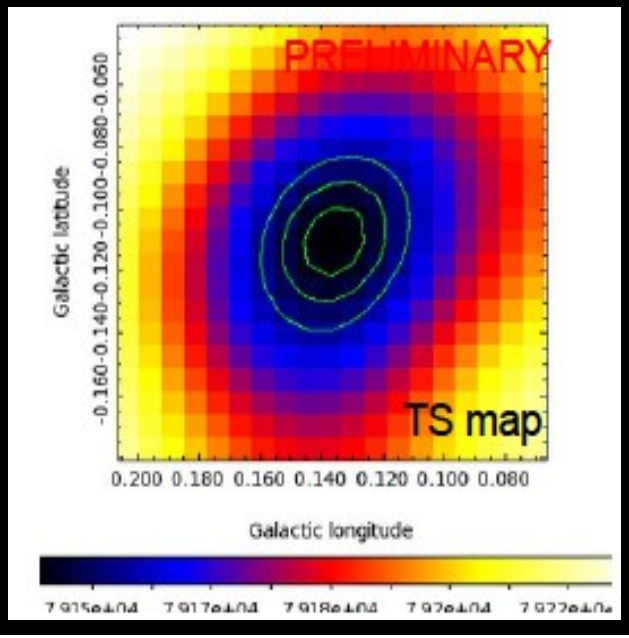
A new source is detected at more than 6**σ** :

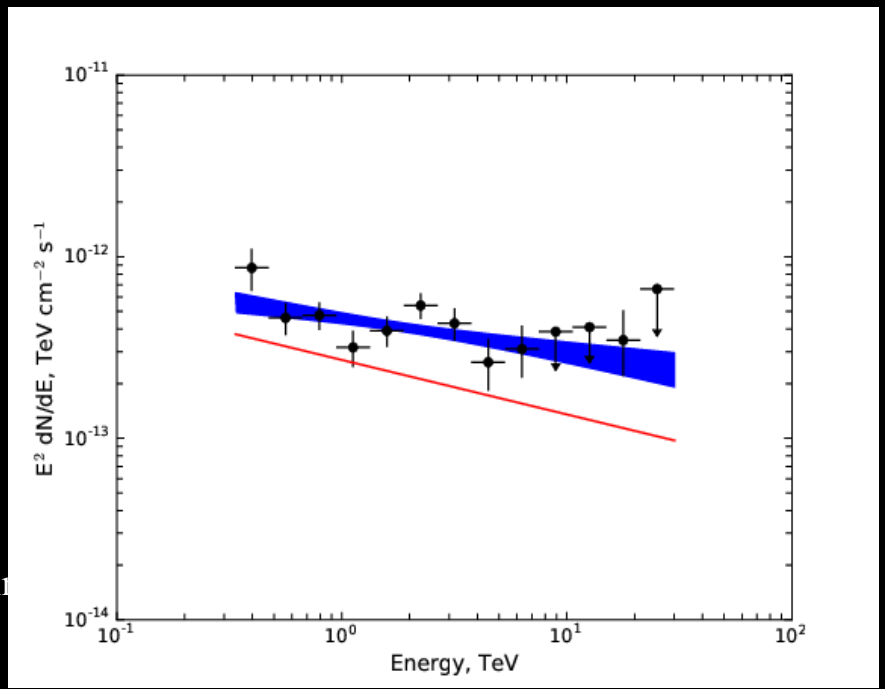
- compatible with a point-source
- lying at Galactic position : l = 0.14° ±0.013°
  b = -0.114° ±0.02°
- *Intrinsic* spectrum :

F(1TeV) = (1.8±0.33)10^{-13}cm^{-2}s^{-1}TeV^{-1}

index = 2.19±0.16

luminosity of L = 2-3 10^{33}erg s^{-1} at 8 kpc

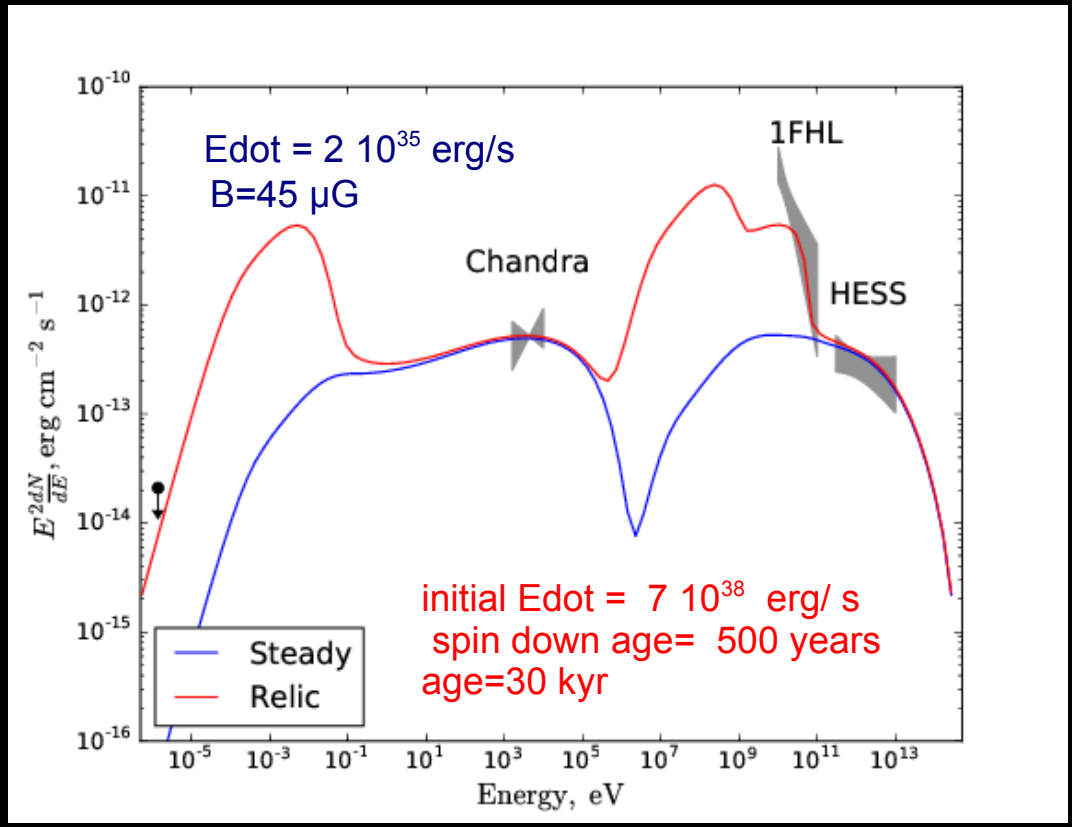




Is HESSJ1746-285 associated with the X-ray PWN ?

Local fields energy density :
IR radiation ~ 50 eV/cm^3
Optical radiation ~ 250 eV/cm$^{3.}$

Large radiation densities:
evolution of the nebula driven by IC losses
→ can explain the hard X- ray spectrum observed by Chandra .



Compute the spectrum radiated by electrons injected by the putative pulsar as a function of time taking into account pulsar braking and energy dependent losses

GAMERA package to compute the time evolution of the electron population (Hahn 2015)