Study of the very high energy gamma-ray diffuse emission in the central 200 pc of our galaxy with H.E.S.S.

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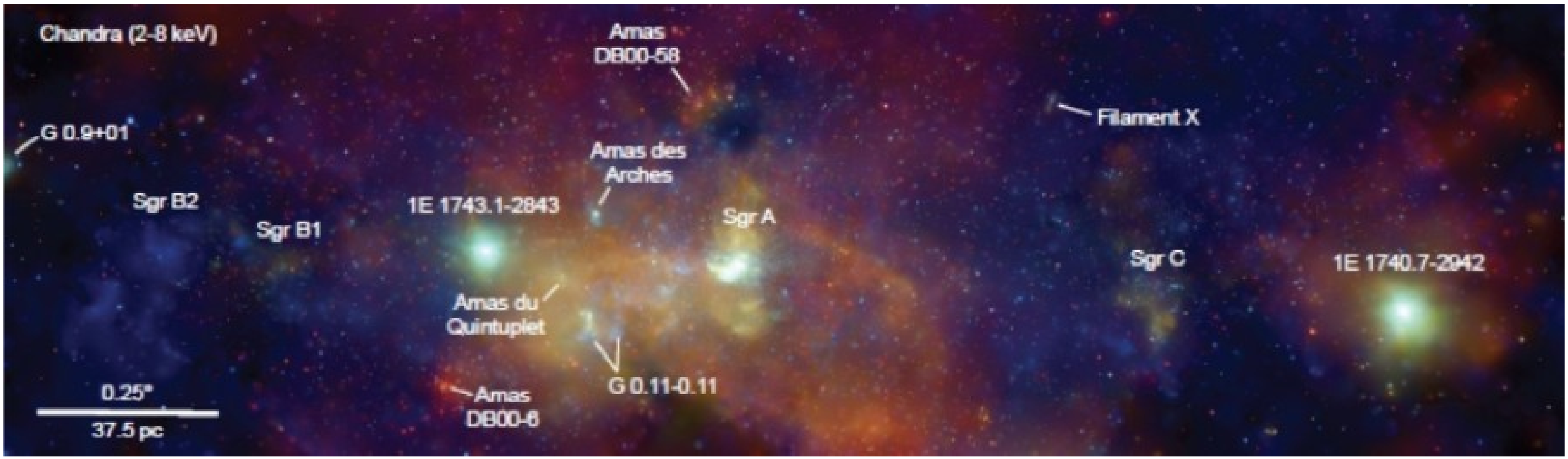
For the H.E.S.S. Collaboration

TeVPA , Kashiwa, 26-30/10/2015

H.E.S.S.

Central 200 pc : The Galactic Center Ridge

Muno et al. 2008



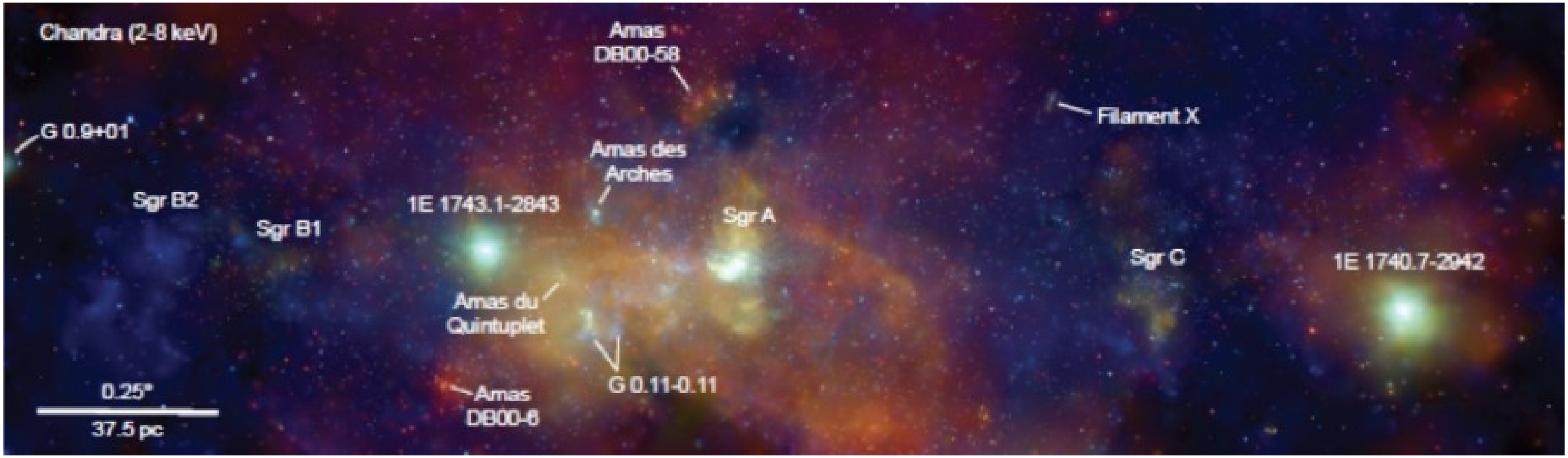
- Central Molecular Zone (CMZ) contains up to 5 10^7 M_{sun} of molecular matter
  In form of massive molecular clouds and a diffuse molecular component(100 cm^{-3})

- 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...

Central 200 pc : The Galactic Center Ridge

Muno et al. 2008

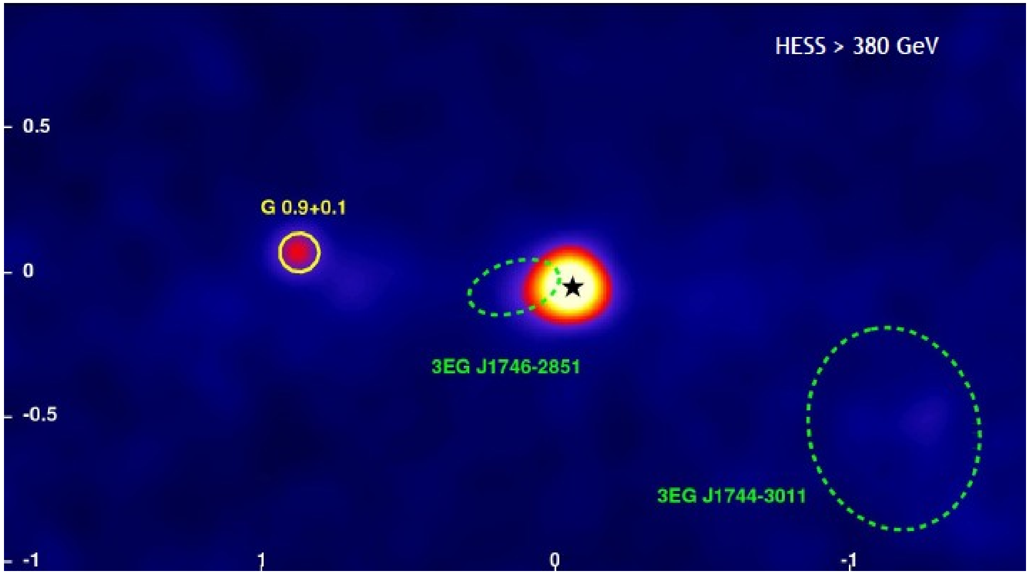


- SgrA* : M~ 4.10^6 M_{sun} *(Ghez et al. (2000) and Gillesen et al. (2009))*

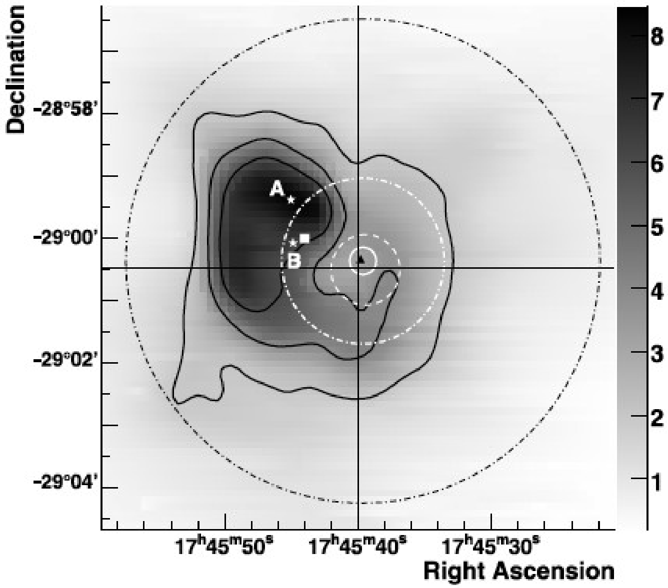
- Sgr A east: bright and compact mixed morphology SNR (radio shell & thermal X-ray core).The likely result of a single SN ~ $10^{3\text{-}4}$ yrs ago (*Sakano et al (2004), Park et al (2005), Koyama et al (2007))*

- Chandra resolves >20 diffuse, non-thermal structures in the central 30 pc. About 20 pulsar wind nebulae expected during the last 100 kyr in the region *(Muno et al., 2008, Johnson, Lu et al., 2009, Dong & Wang, 2010)(Wang et al ,2013)*

The TeV view of the Galactic Centre



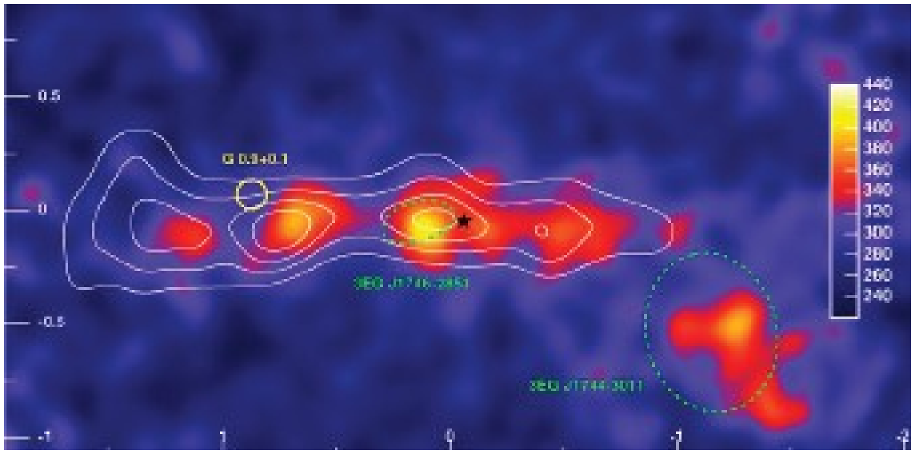
HESS collab. 2006

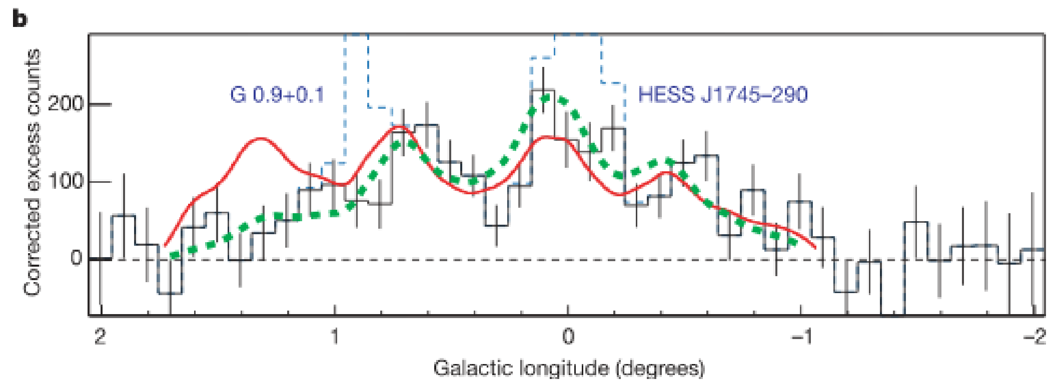


HESS collab. 2010

- 2 point-like sources:
  - HESS J1745-290 compatible with GC :
    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) ***(HESS collab. 2010)***
  - Composite SNR G0.9+0.1
- Extended source associated with unid 3EG J1744-3011

The TeV Galactic Centre diffuse emission





from Aharonian et al (2006)

- After point source subtraction: discovery of diffuse emission correlated with dense gas tracer CS with 90 hours of data:ɣ produced through p-p collisions

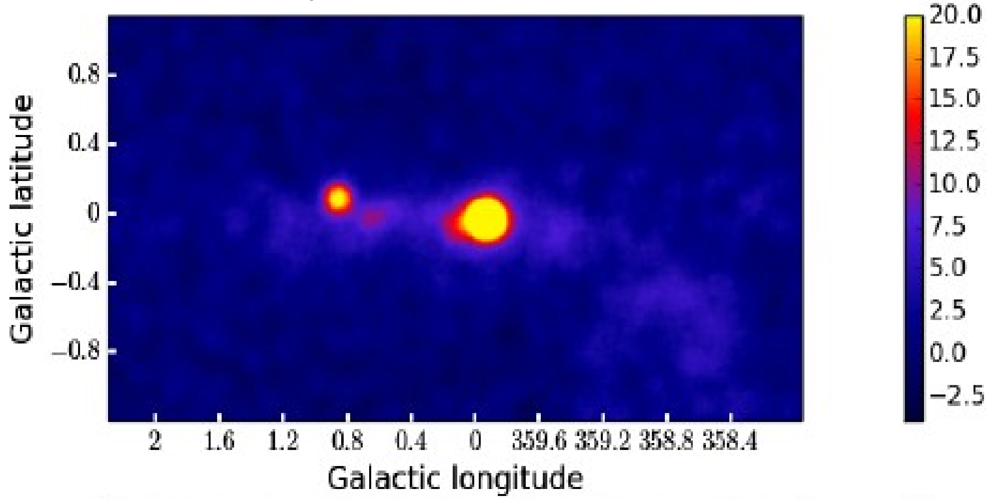
- Deficit of emission at **l** =1.3° suggest gradient of cosmic-ray with 0.8° scale: diffusion of CR injected in a recent period (i.e."~ 10 kyr) ?

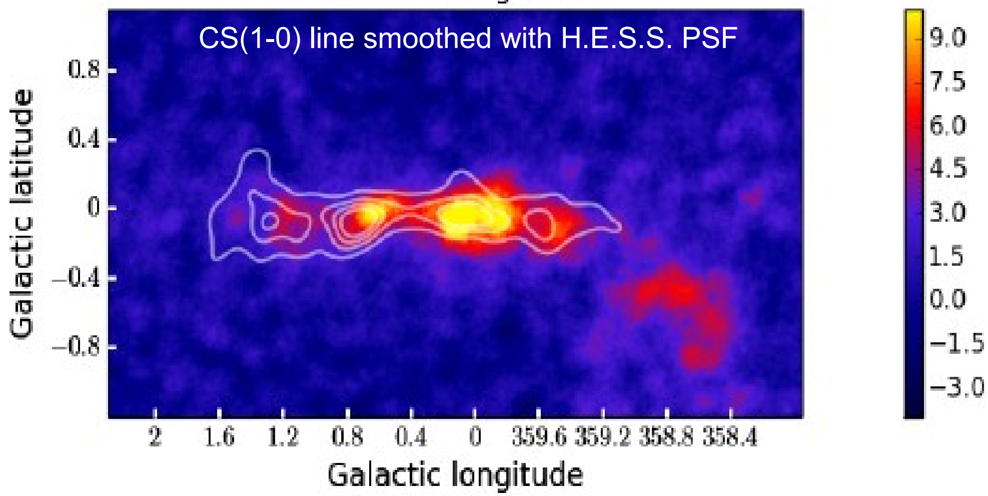
- Diffuse emission spectrum similar to HESS J1745-290: Γ = 2.3 ± 0.1
Not compatible with spectrum expected from local CR
spectral distribution → Existence of a local cosmic-ray accelerator

The TeV Galactic Centre 7 years later

- Full H.E.S.S.I data set from 2004-2013
- 250 hours of livetime after data quality selection (734 runs)
- Data analysis performed using MVA analysis with 80 p.e. selection
- Background obtained with adaptative ring background technique

Excess map smoothed with H.E.S.S. PSF





Excess map point-sources subtracted, smoothed with H.E.S.S. PSF

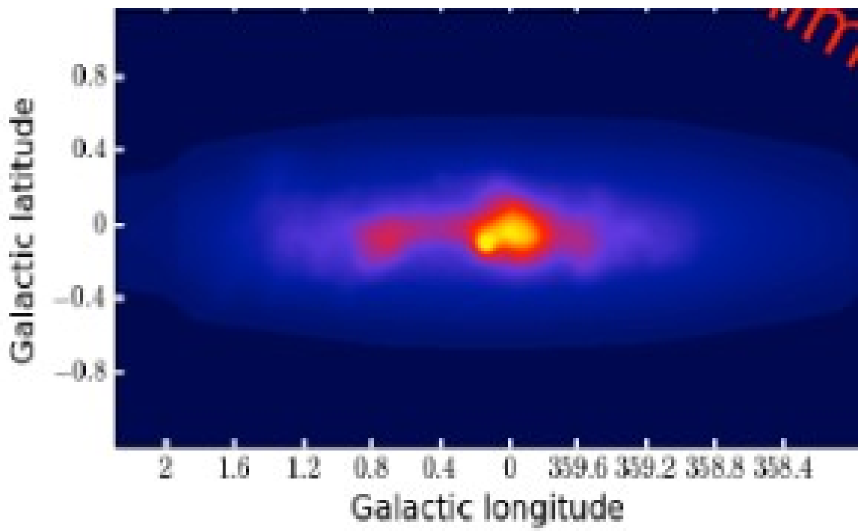
H.E.S.S.

Morphology Study

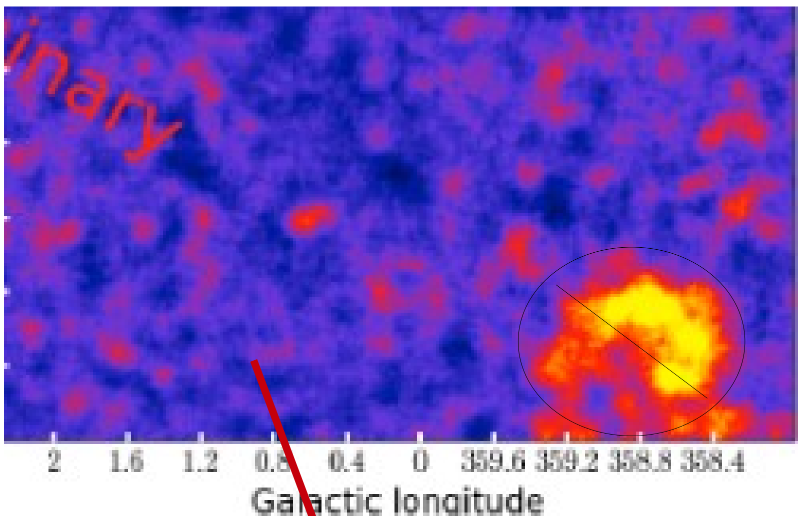
- Point source subtraction and diffuse emission studies performed with a 2D maximum likelihood using sherpa :
  - PSF modeled assuming a 2.3 spectral index
  - Gamma-ray acceptance included
  - Region of Interest: full CMZ.. Exclude region around HESS J1745-303
  - Fit point source at position of Sgr A* and G0.9+0.1 PWN
  - Galactic Diffuse Emission included *(Cf HGPS)*
  - Diffuse emission fitted with gas tracers and CR distribution gaussian templates convolved with PSF
  - Other gaussian components may be added in order to improve the model, depending on the features seen in the residual map obtained at each step of the process.

Quantifying the Goodness of fit

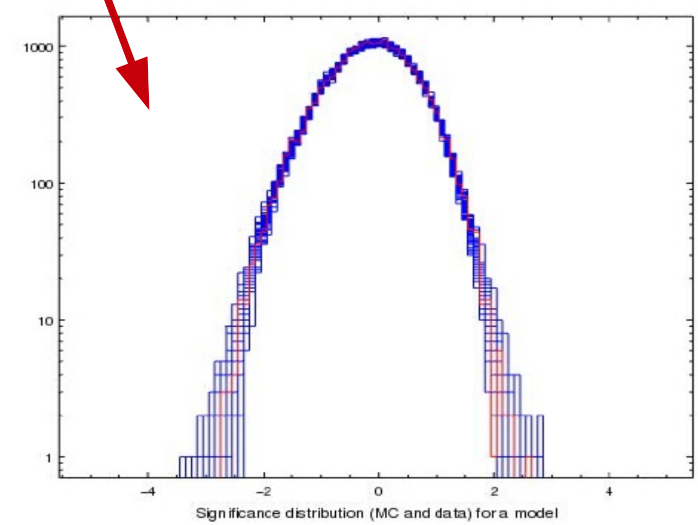
Full Model ON map for the Ridge emission



Significance map of the residuals

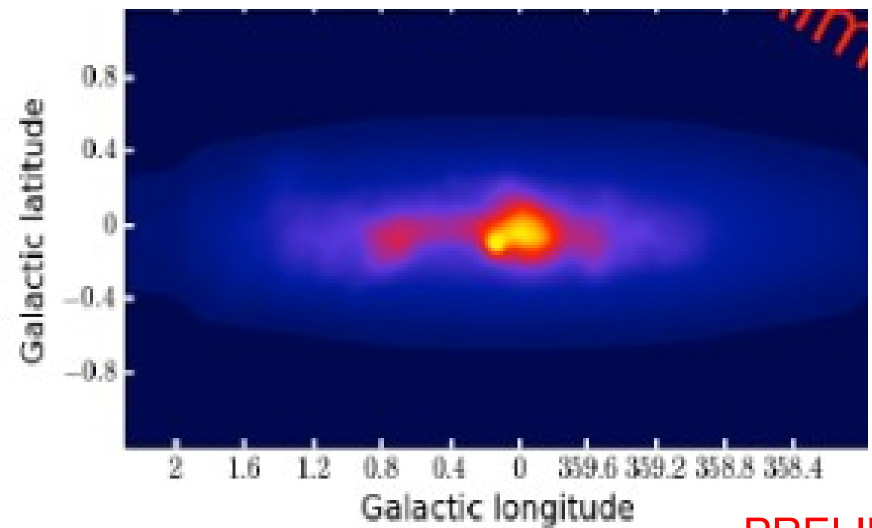


- Compute the distribution of statistical significance of the residuals at each position of the map (Li&Ma) (Red)
  - On map : number of detected events
  - Model : number of expected events
- Compare with those expected from a large number of MC poissonien simulations following the model (150). (blue)



GC VHE diffuse emission components

- **Half of GC ridge emission is distributed like dense gas tracers.**
  → hadronic CRs interacting with dense gas.
  → dip in ɣ-ray emission beyond 100-150 pc is likely the result of a combination of decreasing CR density with distance to the GC and the matter distribution along the line-of-sight.



PRELIMINARY

- **A large scale (LS) component extending ±30 pc in latitude and ±150 pc in longitude.**
  → does not correlate with dense gas tracers; in particular, its latitudinal extension is larger.
  → origin unclear:
  - A diffuse gas component not well accounted for by dense gas tracers such as CS, might be responsible.
  - Unresolved sources not significant enough to be detected individually can contribute as well.

step	Model components	Parameter values	ΔTS /d.o.f. significance	CSTAT /d.o.f.
1	LS	$\sigma_x = 0.65 - 0.19° + 0.21°$, $\sigma_y = 0.13° \pm 0.06°$	1574/ 3 22.9 σ	1.05
2	LS CS×Gauss	$\sigma_x = 0.60° - 0.16° + 0.2°$, $\sigma_y = 0.19° \pm 0.05°$ $\sigma = 1.02° \pm 0.2°$	160/3 16.5 σ	1.044
3	LS CS×Gauss CC	$\sigma_x = 1.050° - 0.017° + 0.02°$, $\sigma_y = 0.25° \pm 0.05°$ $\sigma = 0.98° \pm 0.19°$ $\sigma = 0.12° \pm 0.02°$	66.6/2 8 σ	1.041
4	LS CS ×Gauss CC ArcSource	$\sigma_x = 0.91° - 0.01° + 0.02°$, $\sigma_y = 0.21° \pm 0.05°$ $\sigma = 1.10° \pm 0.20°$ $\sigma = 0.10° \pm 0.01°$ $l = 0.140° \pm 0.013°$, $b = -0.114° \pm 0.021°2$ $\sigma_x = 0.033° \pm 0.031°$, $\sigma_y = 0.01° \pm 0.015°$	45/5 6.32 σ	1.039

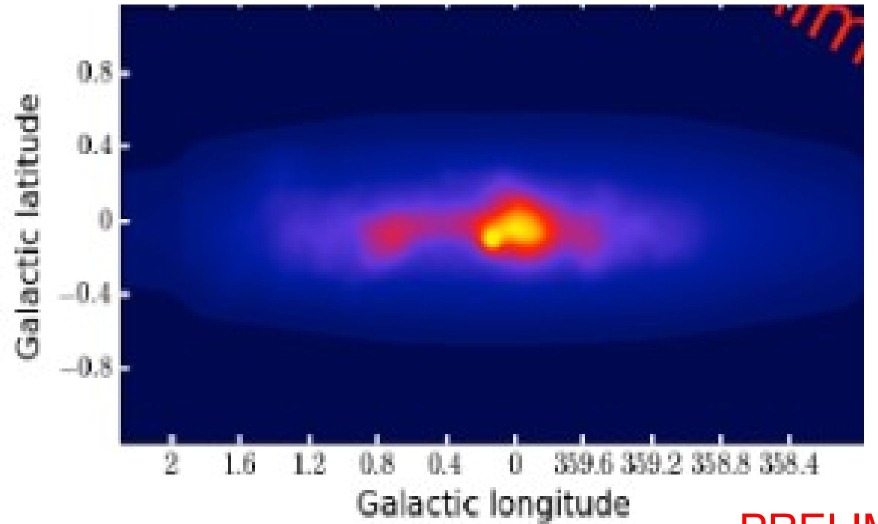
GC VHE diffuse emission components

- **An additional component (CC), centered on the GC, with an intrinsic extension 0.1°(or 14 pc) and a flux of 15% of the total ridge emission .**

→ Signature of a radial gradient of CRs in the CMZ. Central excess similar to an integrated 1/r 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.



PRELIMINARY

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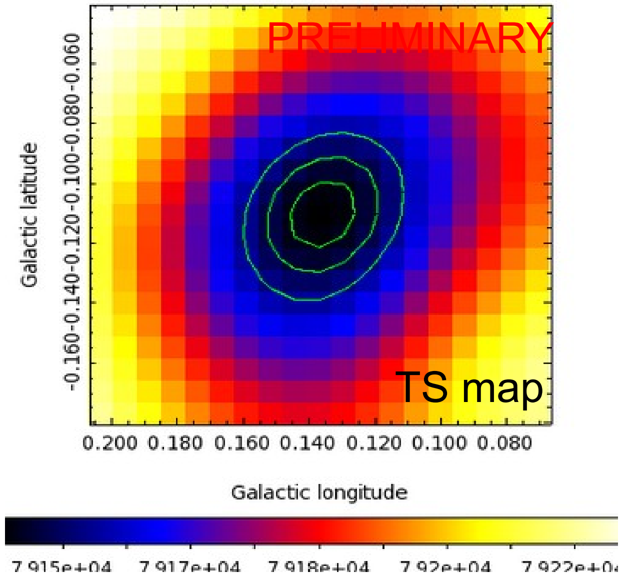
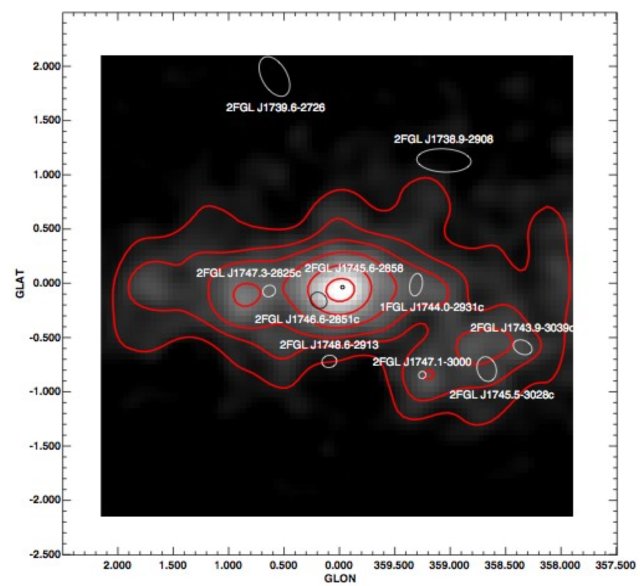
The VHE radio Arc source HESS J1746-285

- 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 :
    $F(1TeV) = (1.8 \pm 0.33)10^{-13} cm^{-2} s^{-1} TeV^{-1}$
    index = 2.19±0.16
    luminosity of $L = 2\text{-}3\ 10^{33} erg\ s^{-1}$ at 8 kpc



- Position compatible with the soft (3.2±0.3) Fermi source 1FHLJ1746.3-2851.
  → Same physical origin ?

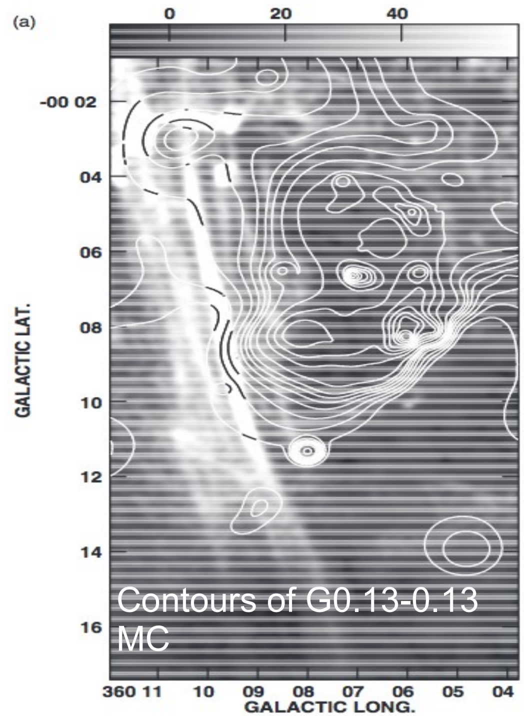


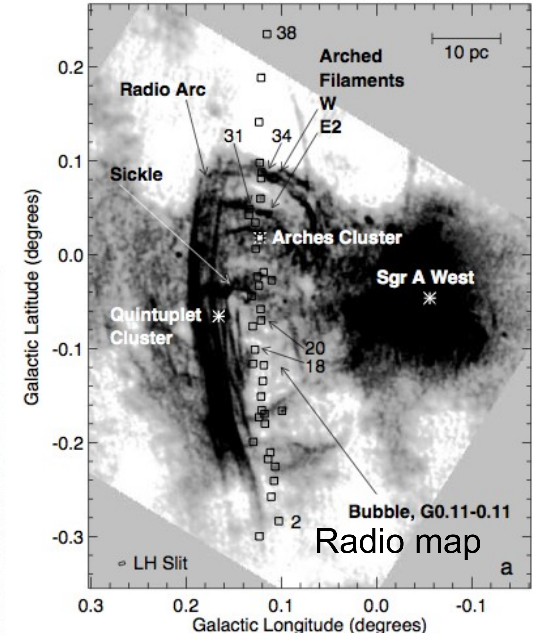
The VHE radio Arc source HESS J1746-285

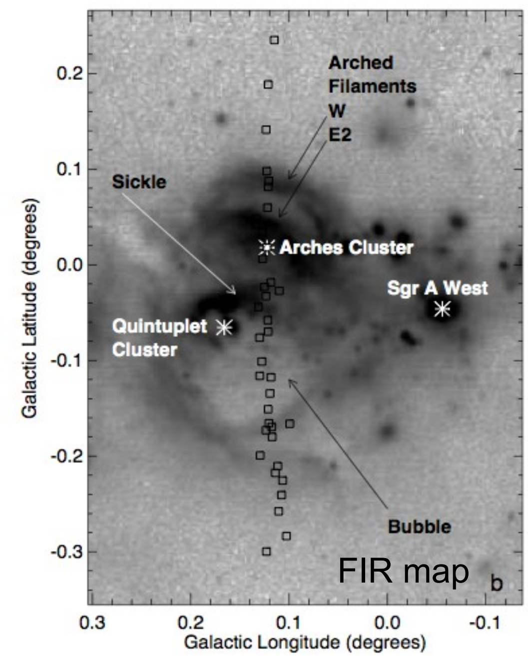
- Close to the non-thermal filaments of the Radio Arc : prominents linear filaments perpendicular to the Galactic plane near l = 0.2°, a high magnetic field (>50µG) expected.

- Lies just next to the dense molecular cloud called G0.13-0.13 believed to be expanding into this Radio Arc.

- Lies in the low density Radio-Arc Bubble





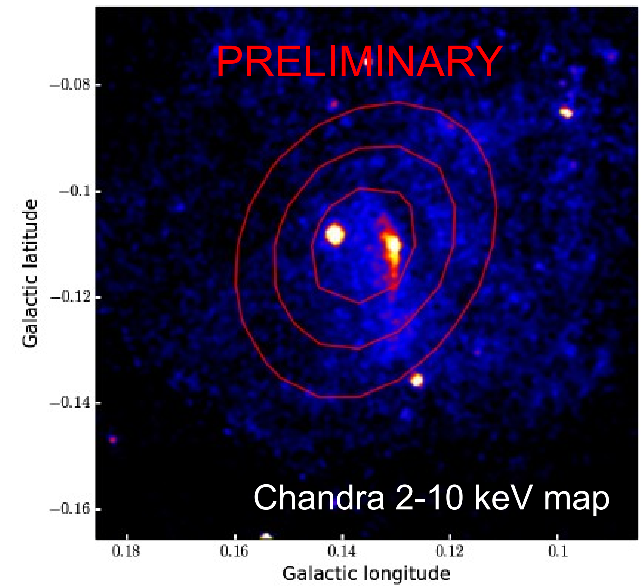


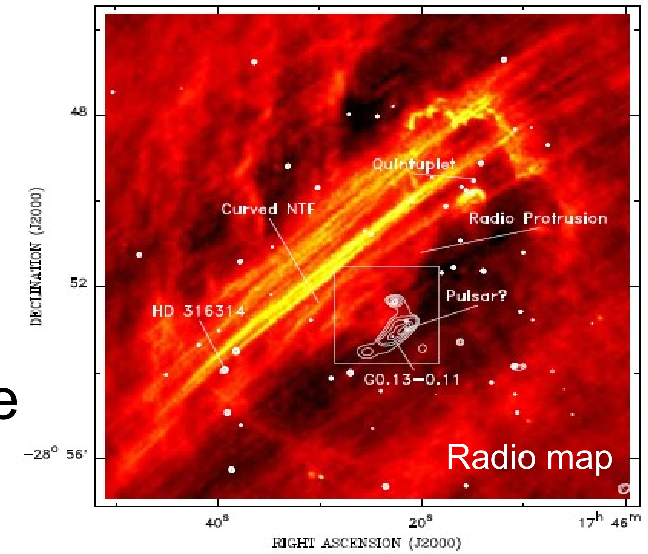
The VHE radio arc source HESS J1746-285

X-ray filament is likely a PWN

- Presence of a pointlike feature in Chandra maps *(Lang+02)*
- Filament morphology:
  interaction with neighbouring molecular cloud?
- L(2-10 keV)= 3 10^{33} erg/s, Γ_X ~1.4-2.5
- A PWN in high B field?
  - Magnetic field estimation from interaction between NTFs and MC : B~100-1000 μG
  - X-ray synchrotron lifetime : l~40" → B<300μG

- VHE emission from the pulsar wind nebula (PWN) candidate G0.13-0.11 ?
  L_X / L_γ ~ 1, in the range of observed Galactic PWNe



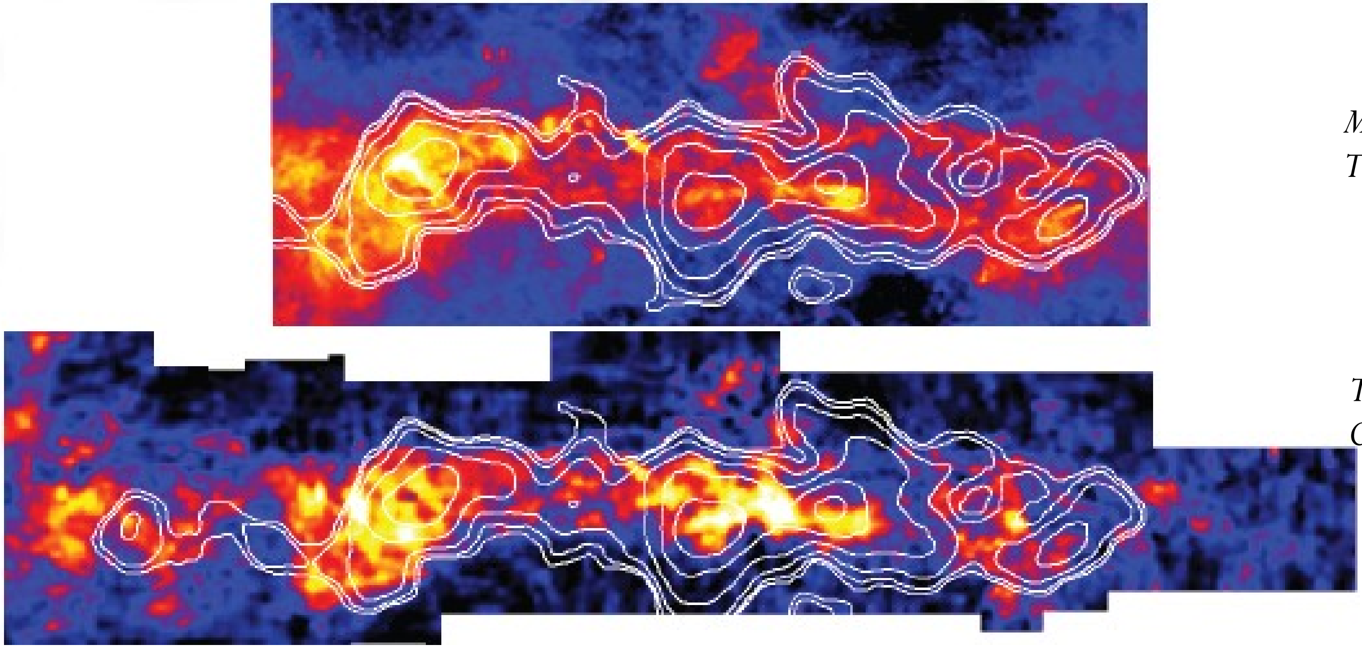


Conclusion

- Half of GC ridge emission is distributed like dense gas tracers over a projected distance of 140 pc and fades beyond.
- A large scale emission that does not correlate with dense gas tracers is required. The result of unresolved sources and/or a gas component in a diffuse phase not seen by gas tracers ?
- A central component extending over ~15 pc could be the signature of an excess of CR around the GC and the result of a radial gradient of CRs in the CMZ (expected e.g. if CR are accelerated by the SMBH itself).
- A new source HESS J1746-285 spatially coincident with the Fermi Arc source and the X-ray PWN candidate G0.13-0.13. Position and γ-ray luminosity suggest a physical association with the PWN.
  Very complex and highly magnetized environment of the object need further studies to conclude.

Tracers of dense gas

- 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.



Molinari et al 2011
Total NH

Tsuboi et al 1998
CS

0.07° smoothed contours of TeV diffuse emission on Herschel and CS maps

GC VHE diffuse emission components

PRELIMINARY

Model :

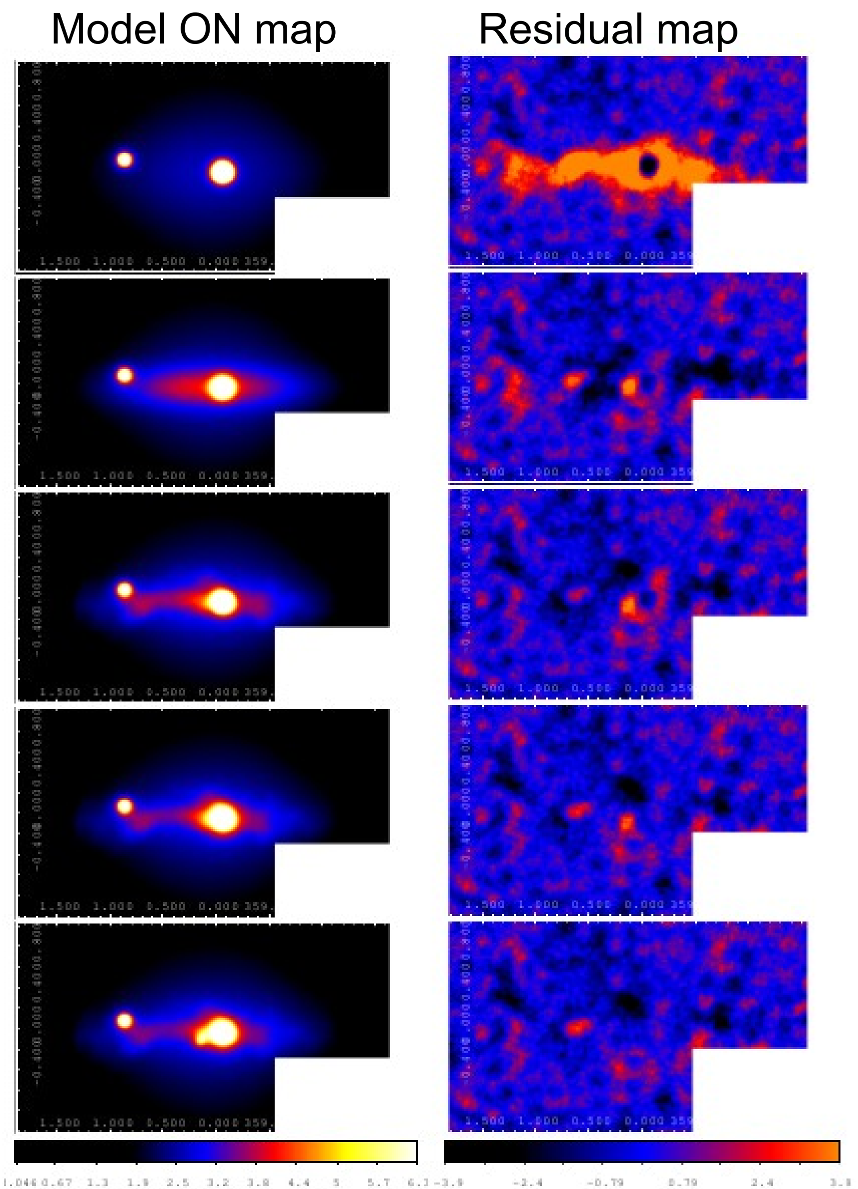
$a_1 S_1 + a_2 S_2 +$ OFF + GalDiff

$+ \alpha_{LS}\, LS(\boldsymbol{\sigma x}, \boldsymbol{\sigma y}, \mathbf{l_c}, \mathbf{b_c})$

$+ \alpha_{CR}\,(Gauss(\boldsymbol{\sigma x}, \boldsymbol{\sigma y}, \mathbf{l_{=0}}, \mathbf{b_{=0}}) \times Templ) * PSF$

$+ \alpha_{CC}$ Central Compo$(\boldsymbol{\sigma}, \mathbf{l_c}, \mathbf{b_c})$

$+ a_3 S_3(l,b)$



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