PWNe at the Galactic Centre

or

some GC stuff @ MODE workshop - season 3 ep. 1

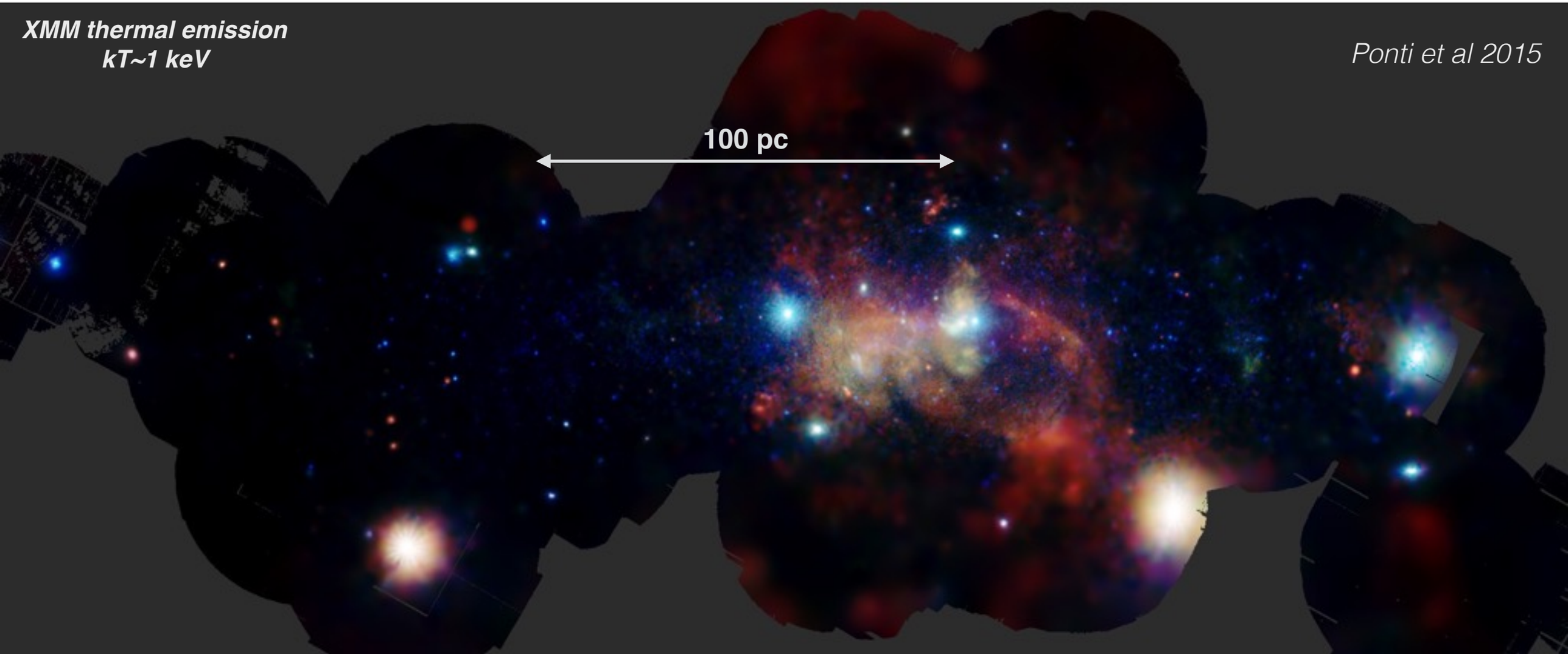
R. Terrier, A. Lemière, L. Jouvin et al.
APC

PWN in the inner 200 pc

- Sustained star formation activity: 0.03-0.1 M_o/yr *(Crocker+11, Longmore+13,Ponti+15)*
- Associated SNR rate : 10^{-3} - 3 x10^{-4} yr^{-1}
- Expected number of PWNe produced in 100 kyr: 30 - 100
- Expected number of PWNe in the inner 20 pc (neglecting kicks): ~ 20

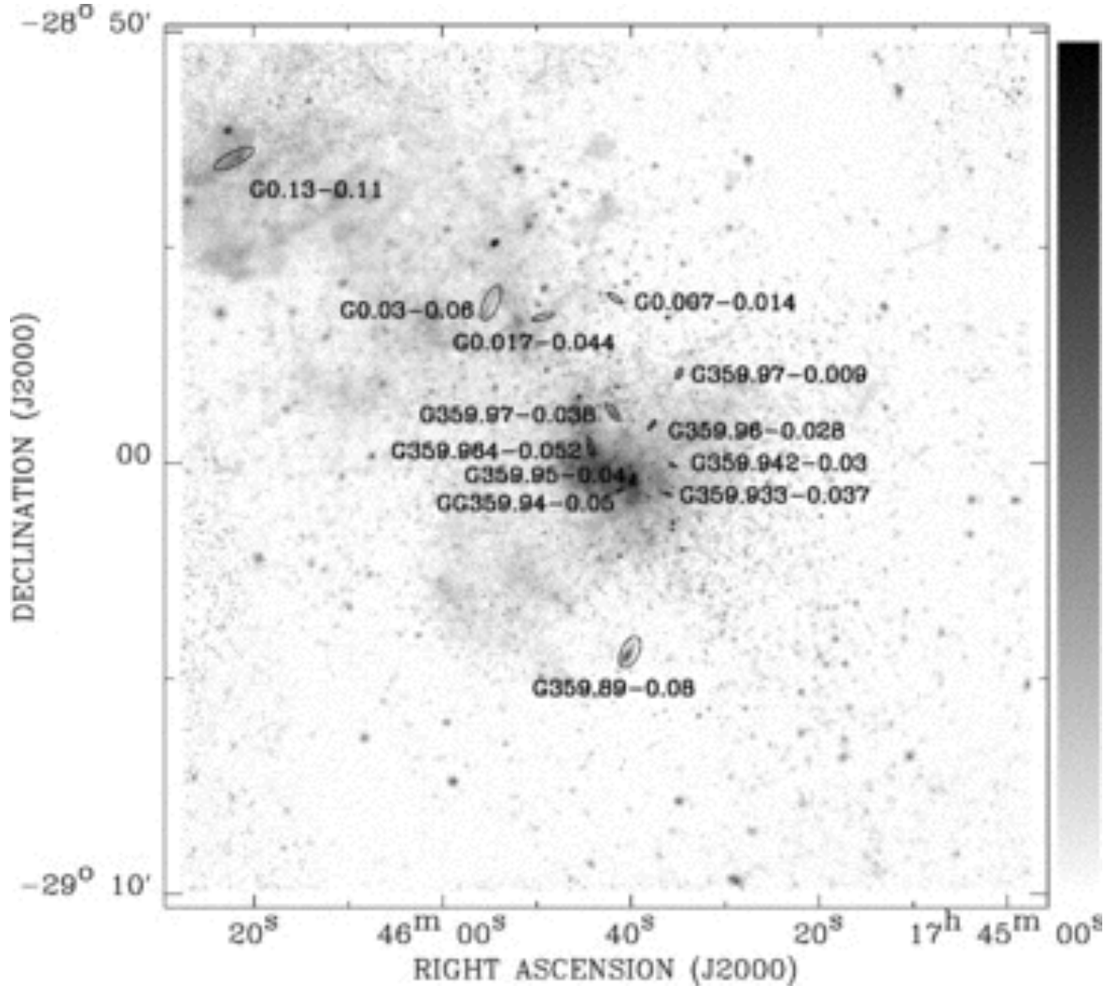
XMM thermal emission kT~1 keV

Ponti et al 2015



PWN candidates seen by Chandra

- Chandra survey of the GC : 34 non thermal filaments in X-rays
- Up to 20 PWNe candidates *Muno et al. (2008), Johnson et al. (2009)*
- Most are found in the inner 30 pc



Johnson et al. (2009)

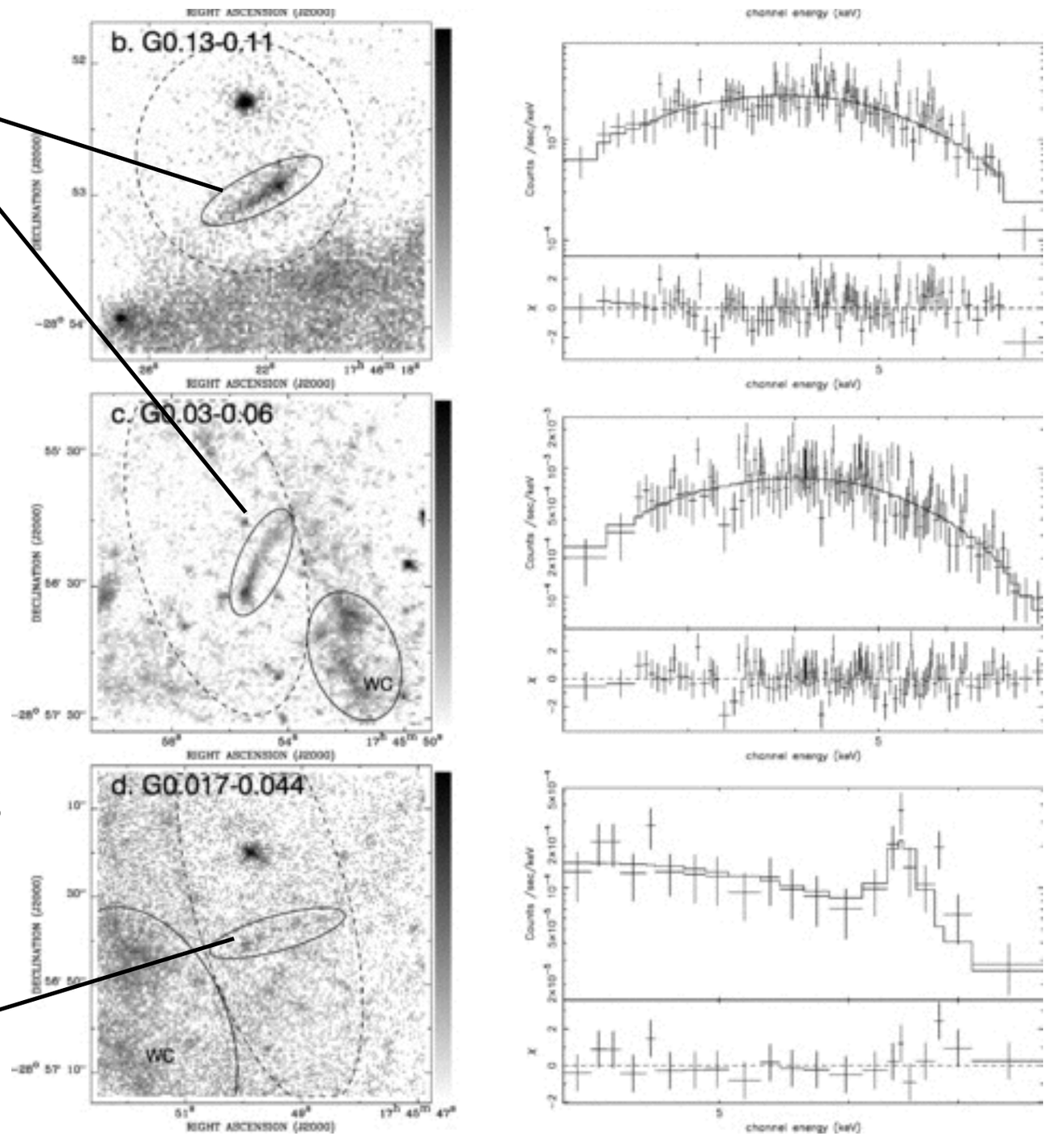
PWN candidates seen by Chandra

- Most PWN candidate show clear head/tail morphology

- Ram pressure confined nebulae?
  - PSR kicks?
  - GC outflow?

- Luminosities: $L_X = 10^{32–34}$ erg/s

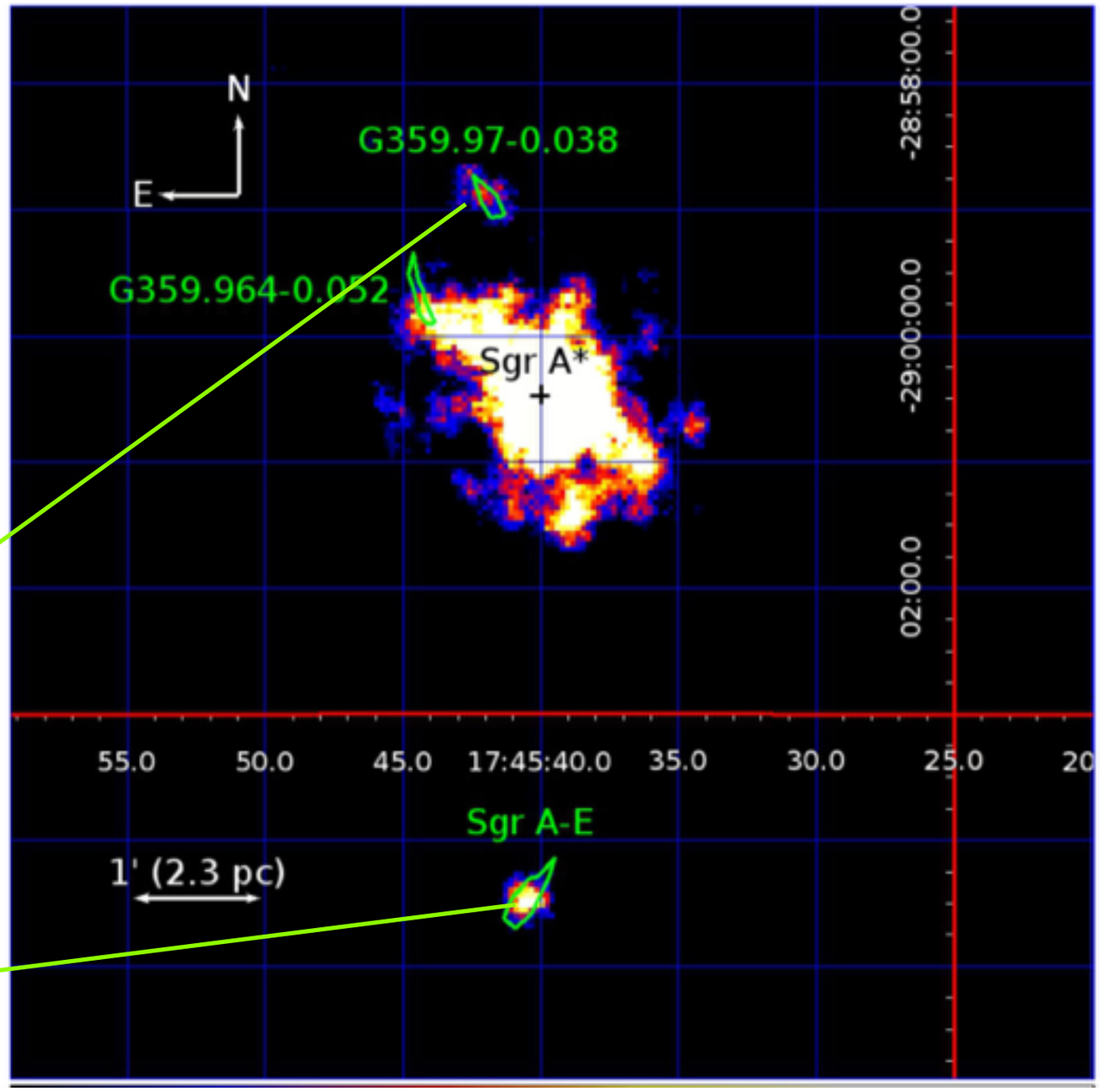
- Some display 6.4 keV line: X-ray reflection nebulae in disguise



Johnson et al. (2009)

PWN candidates seen with NuSTAR

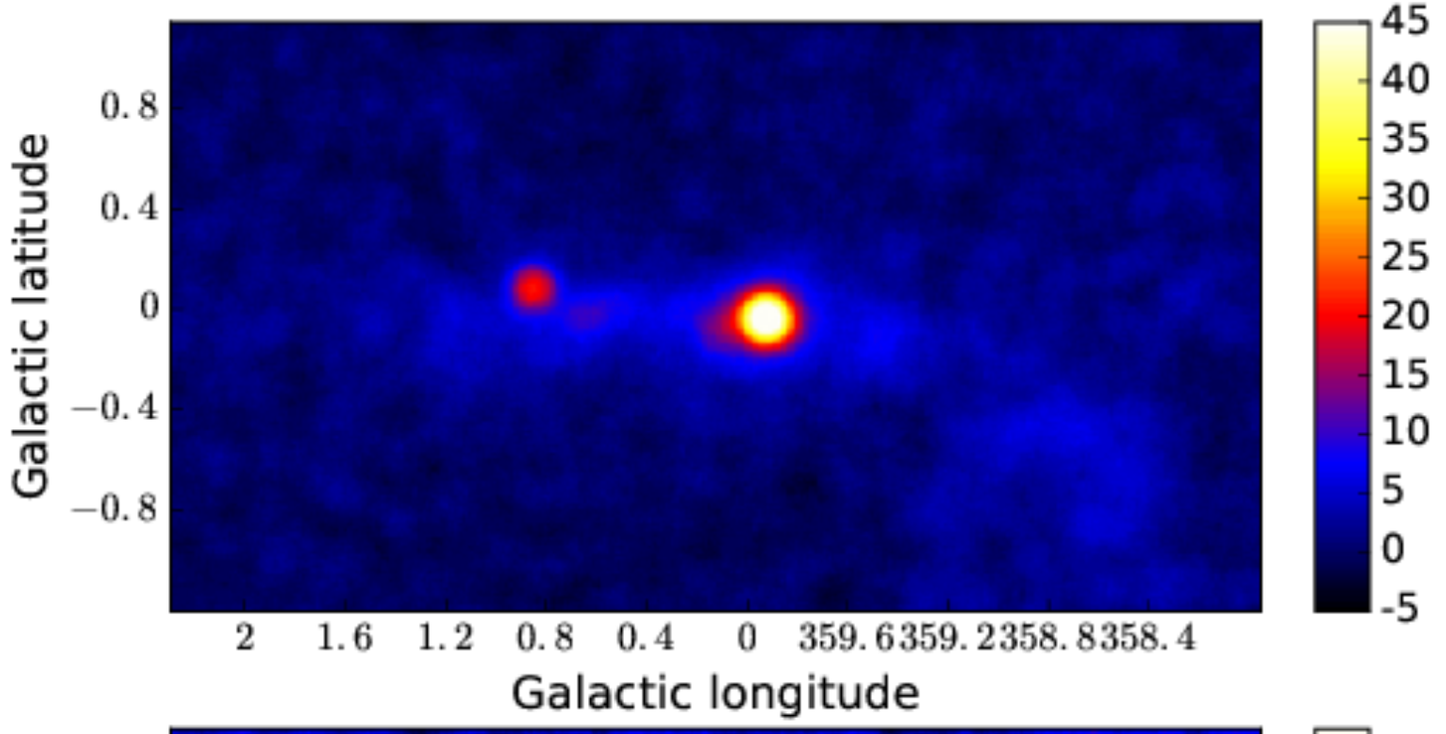
- 3 PWN candidates detected above 40 keV!
- Unlikely PWN:
  - electron lifetime ~few years
- Interacting SNR shock?
  Nynka et al (2015)
- Magnetic flux tube
  Zhang et al (2015)



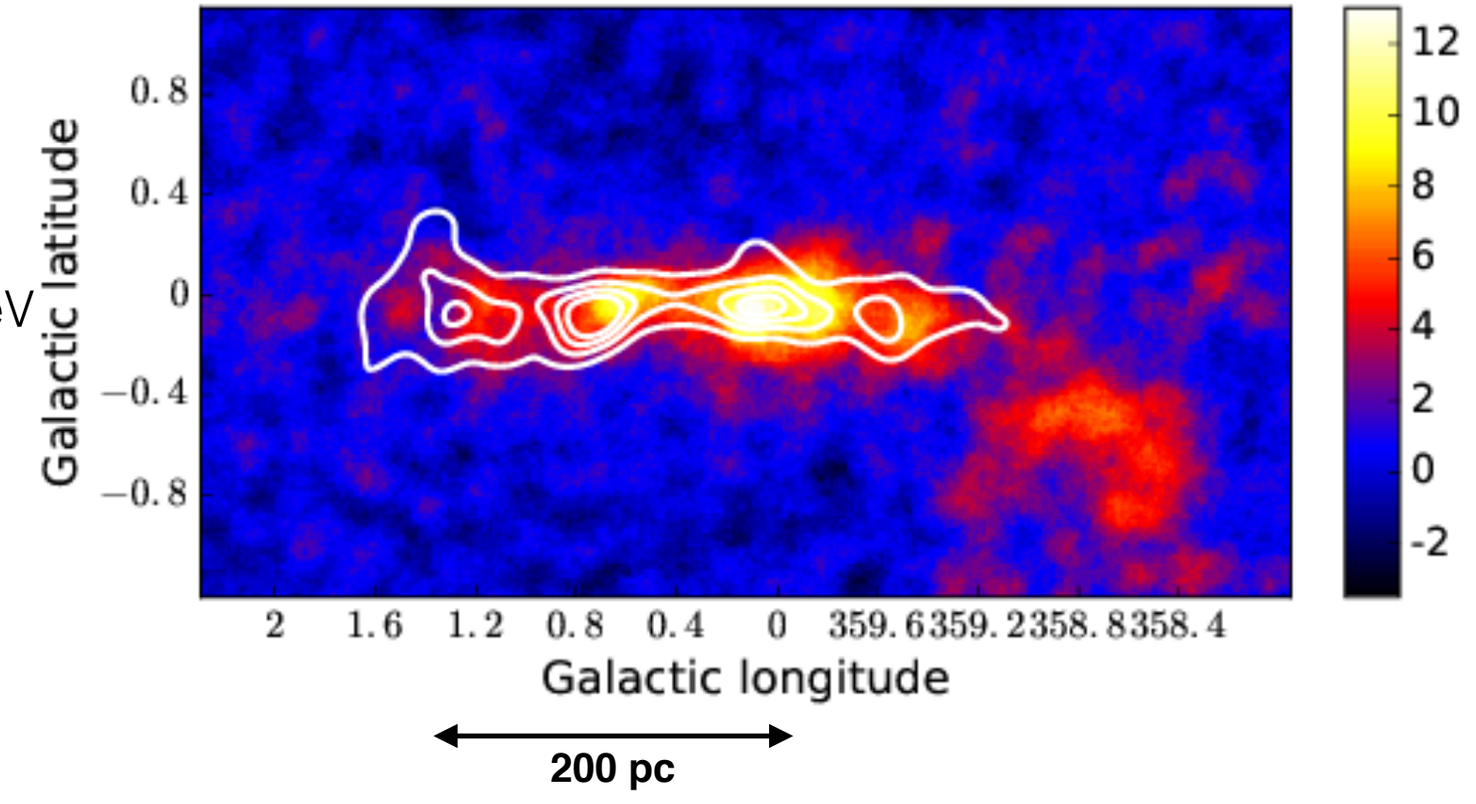
Mori et al. (2015)

TeV PWN in the GC?

VHE γ-rays > 200 GeV



diffuse γ-rays > 200 GeV

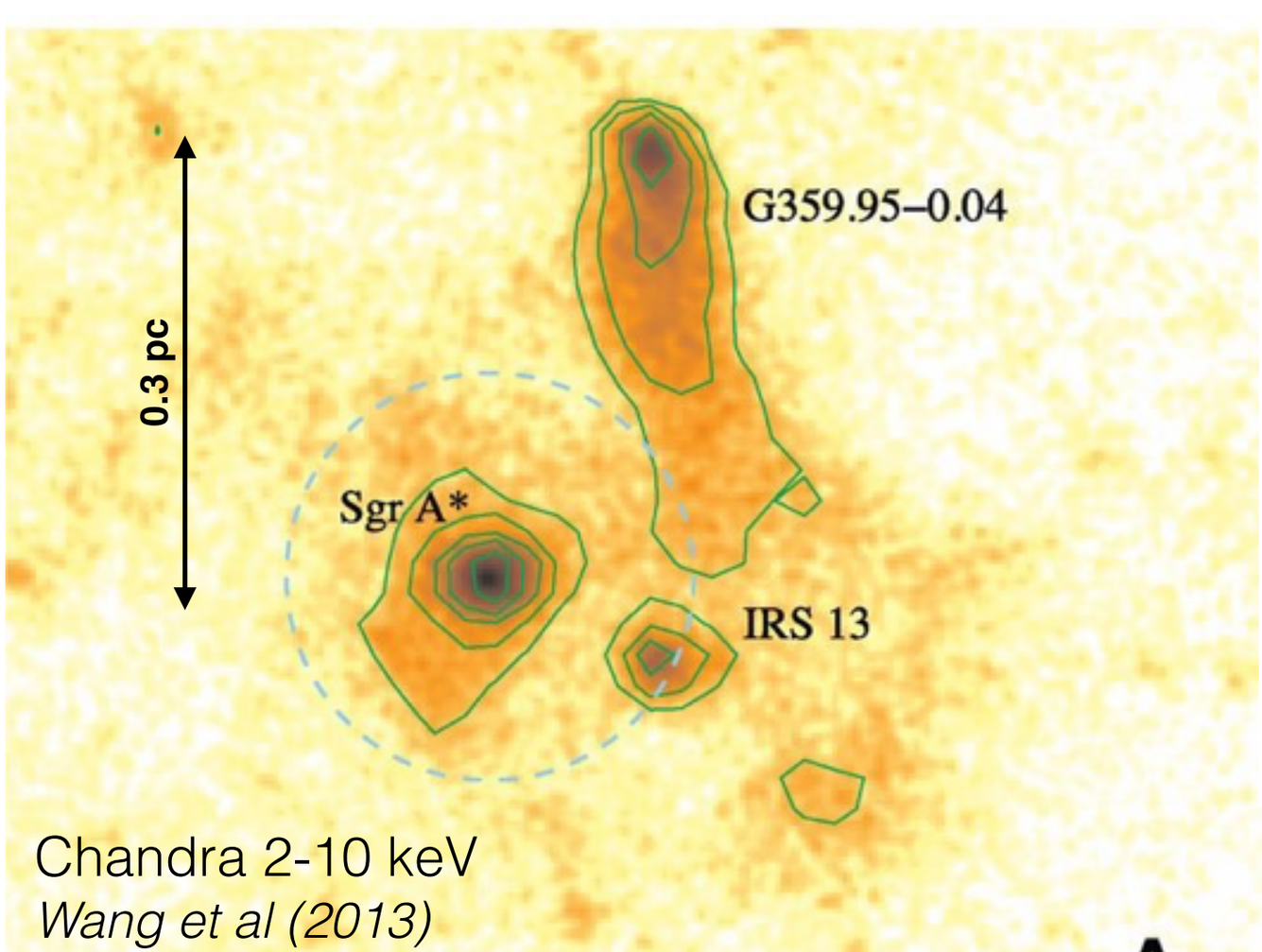


G359.95-0.04 & HESS J1745-290?

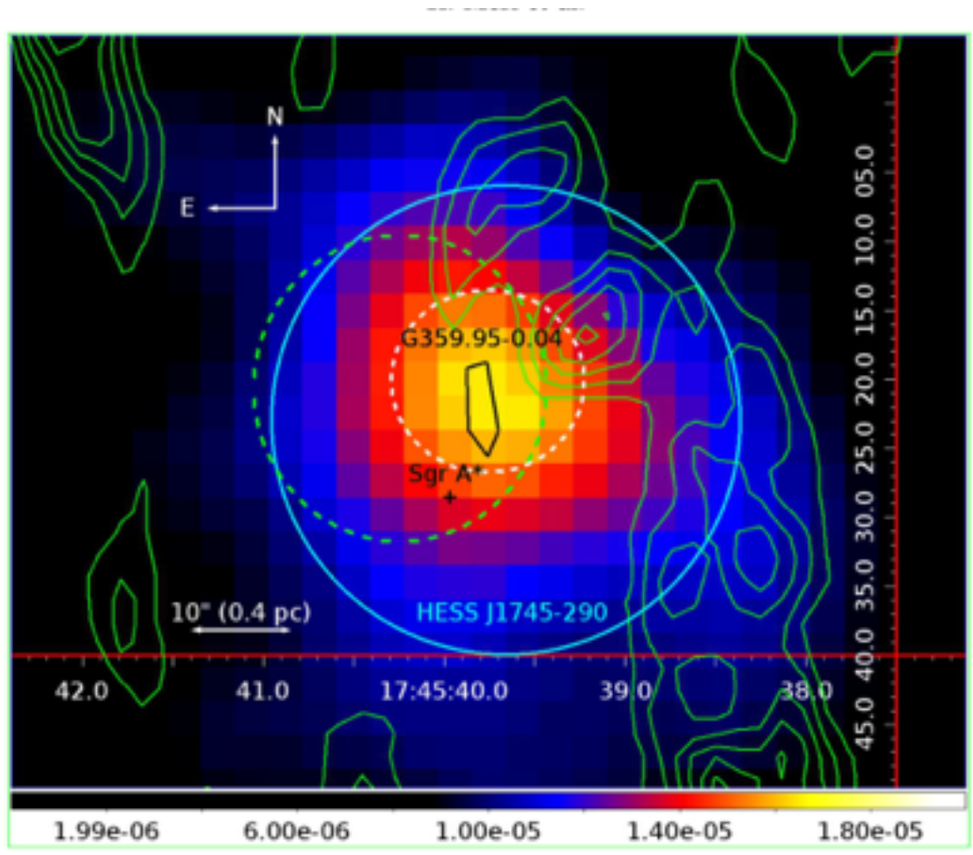
- HESS J1745-290 position consistent PWN candidate G359.95-0.04 located at 0.7'' (0.3 pc) from Sgr A*

Wang et al. (2006), HESS collab (2010)

- Can it power the TeV source?



Chandra 2-10 keV
Wang et al (2013)



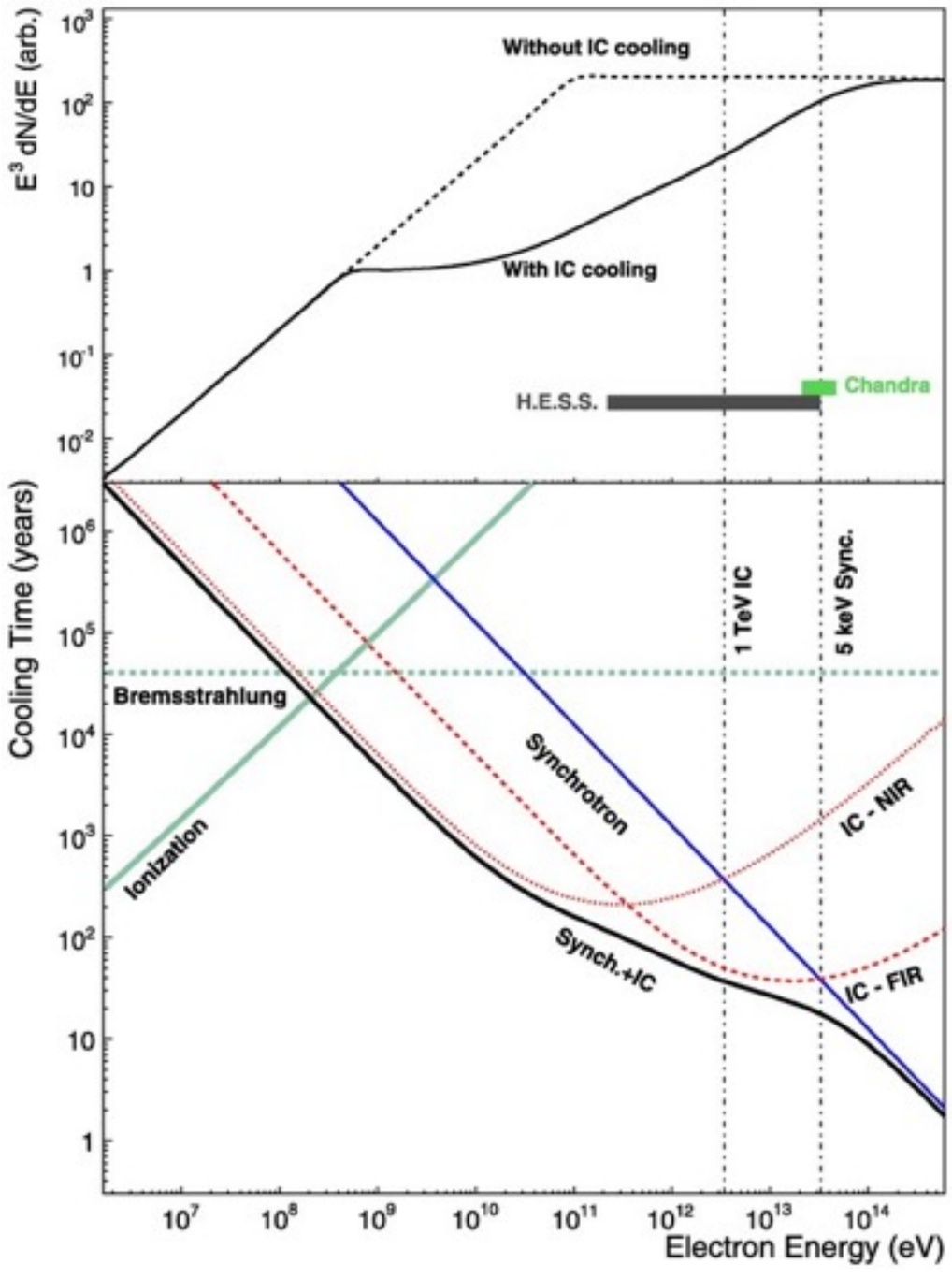
NuSTAR 20-40 keV
Mori et al (2015)

IC dominated PWNe

- If radiation energy density is large compared to magnetic energy density, radiative losses are dominated by IC

- Energy dependent losses due to Klein-Nishina effects will alter the electron spectrum

- X-ray spectra harder than TeV ones



from Hinton & Aharonian (2007)

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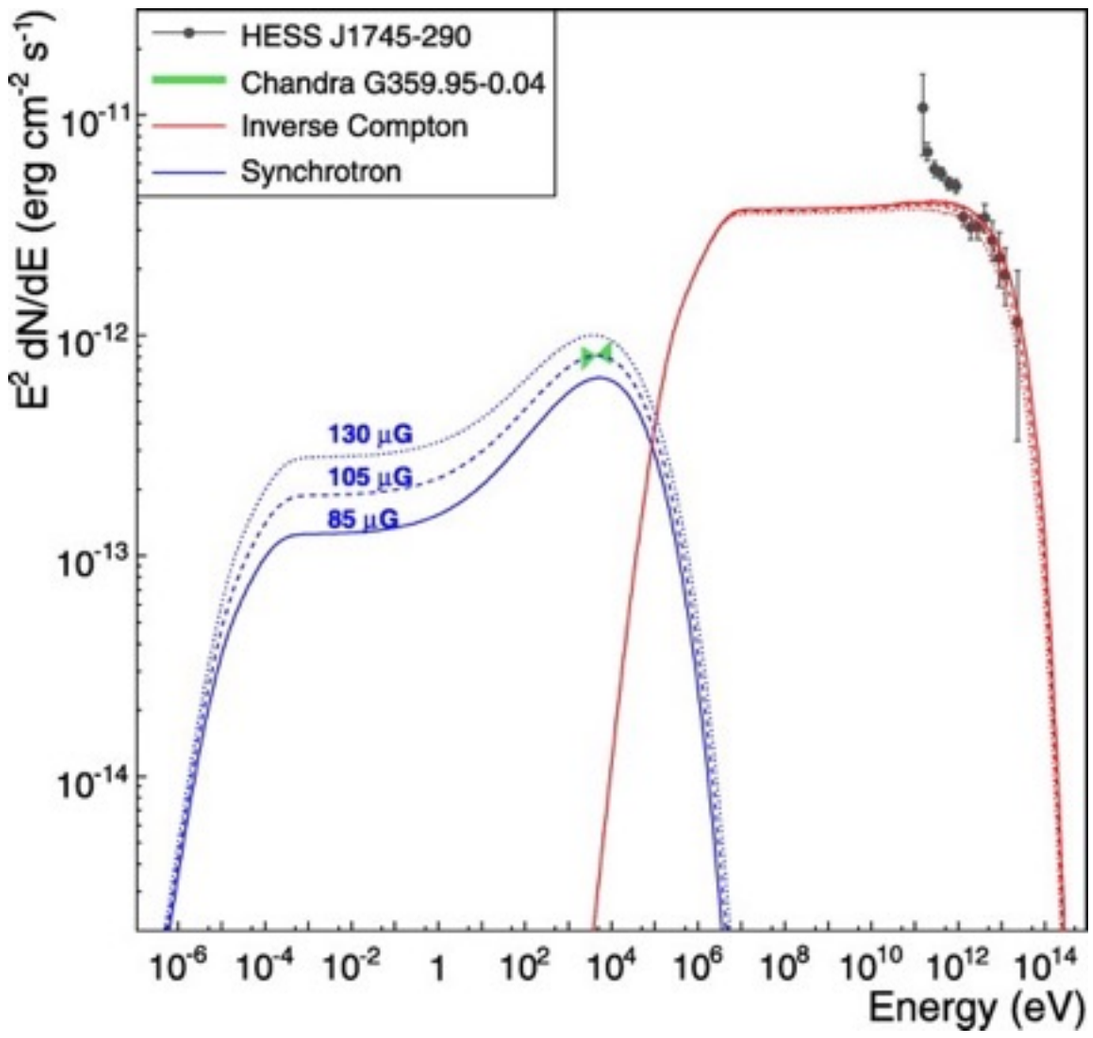
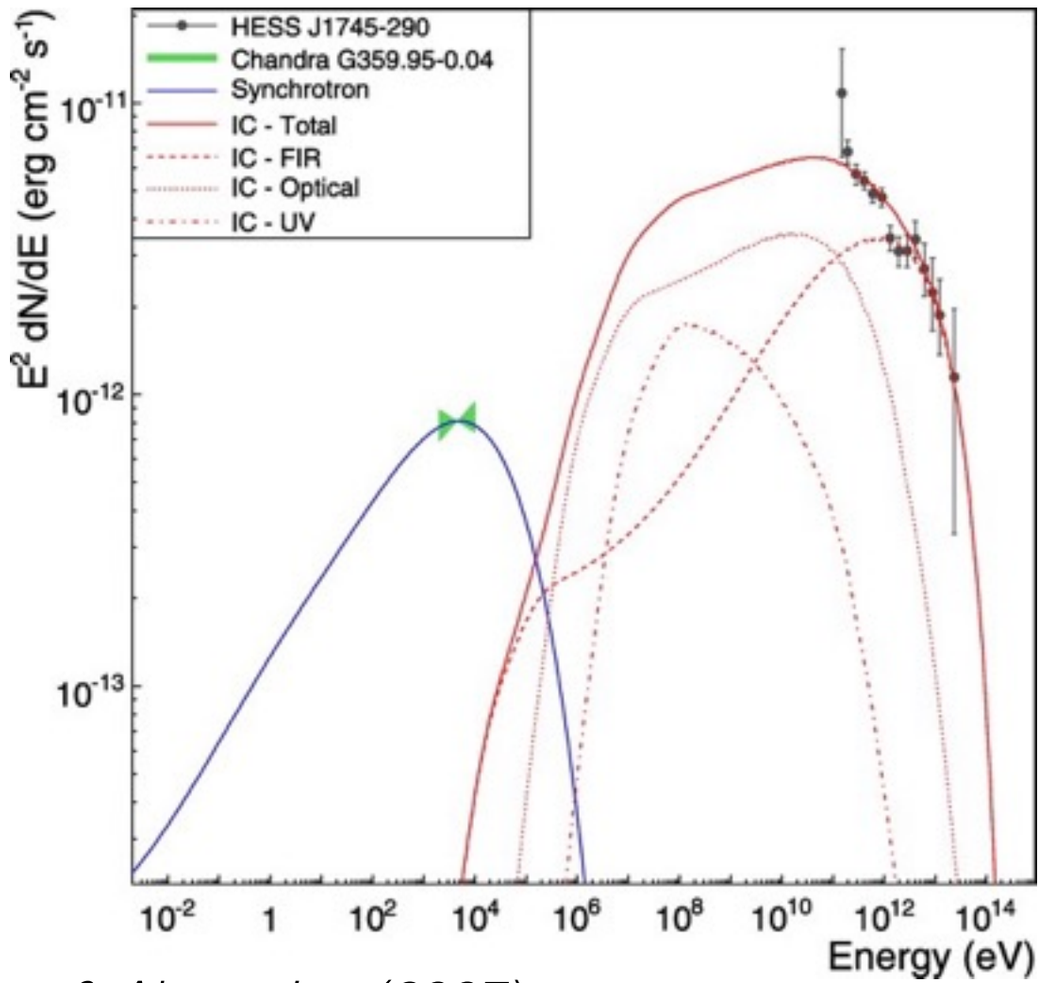


from Hinton & Aharonian (2007)

G359.95-0.04 & HESS J1745-290?

- At 0.3pc from Sgr A*, inside central star cluster ($L > 10^{41}$ erg/s)
- Huge radiation energy density:
  - 5000 eV/cm^3 FIR field, 5 x 10^4 eV/cm^3 opt/UV field *(e.g. Kistler 2015)*



Hinton & Aharonian (2007)

SED well reproduced with a 105 μG field

Hinton & Aharonian (2007)

But ambient magnetic field deduced from magnetar Faraday rotation: B > 1mG @ 0.3 pc

Eatough et al (2013)

Cannot recover correct SED by moving PWN position along line of sight

Kistler (2015)

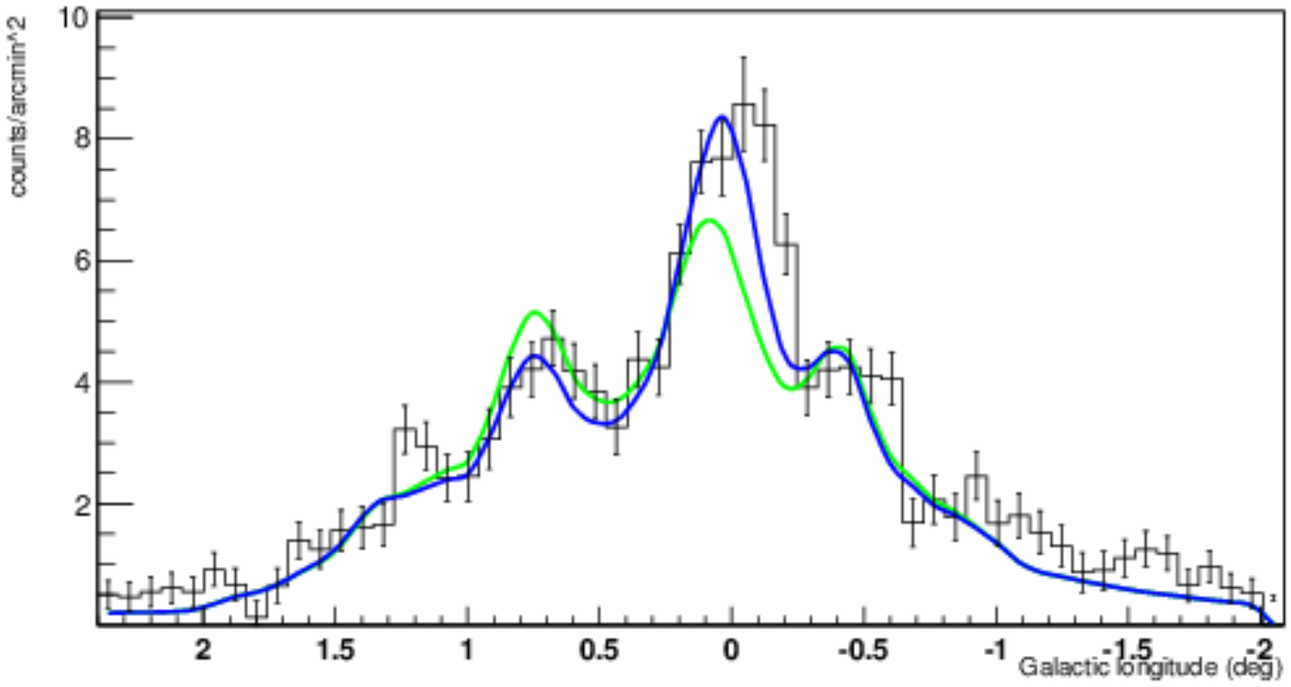
Note that Faraday rotation can take place in lower density medium: B > 50 μG

Kravchenko et al (2015)

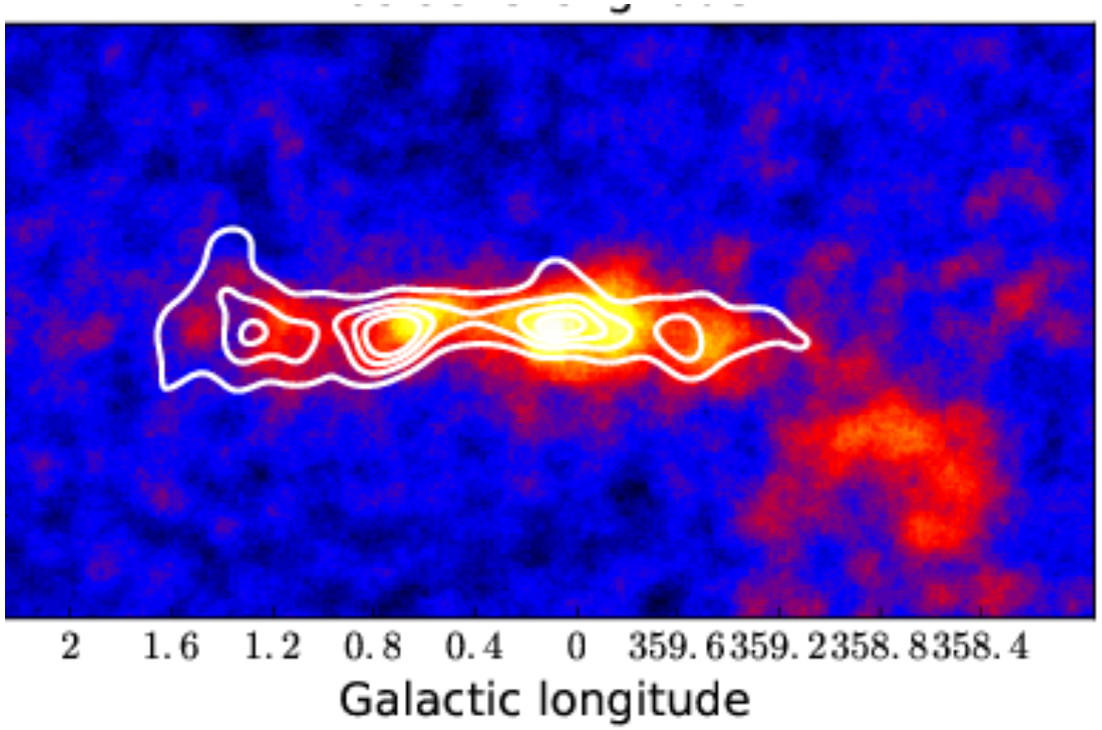
Diffuse VHE emission in the inner 200 pc

- Emission from the bright molecular complexes and peak around GC
- Produced by excess of > TeV CRs in the region
- A gradient of CR peaking at the GC position
- Injection of CRs by a stationary source at the GC ? *HESS collab (2016)*

See presentation by L. Jouvin



γ-ray profile after subtraction of GC source and G0.9+0.1



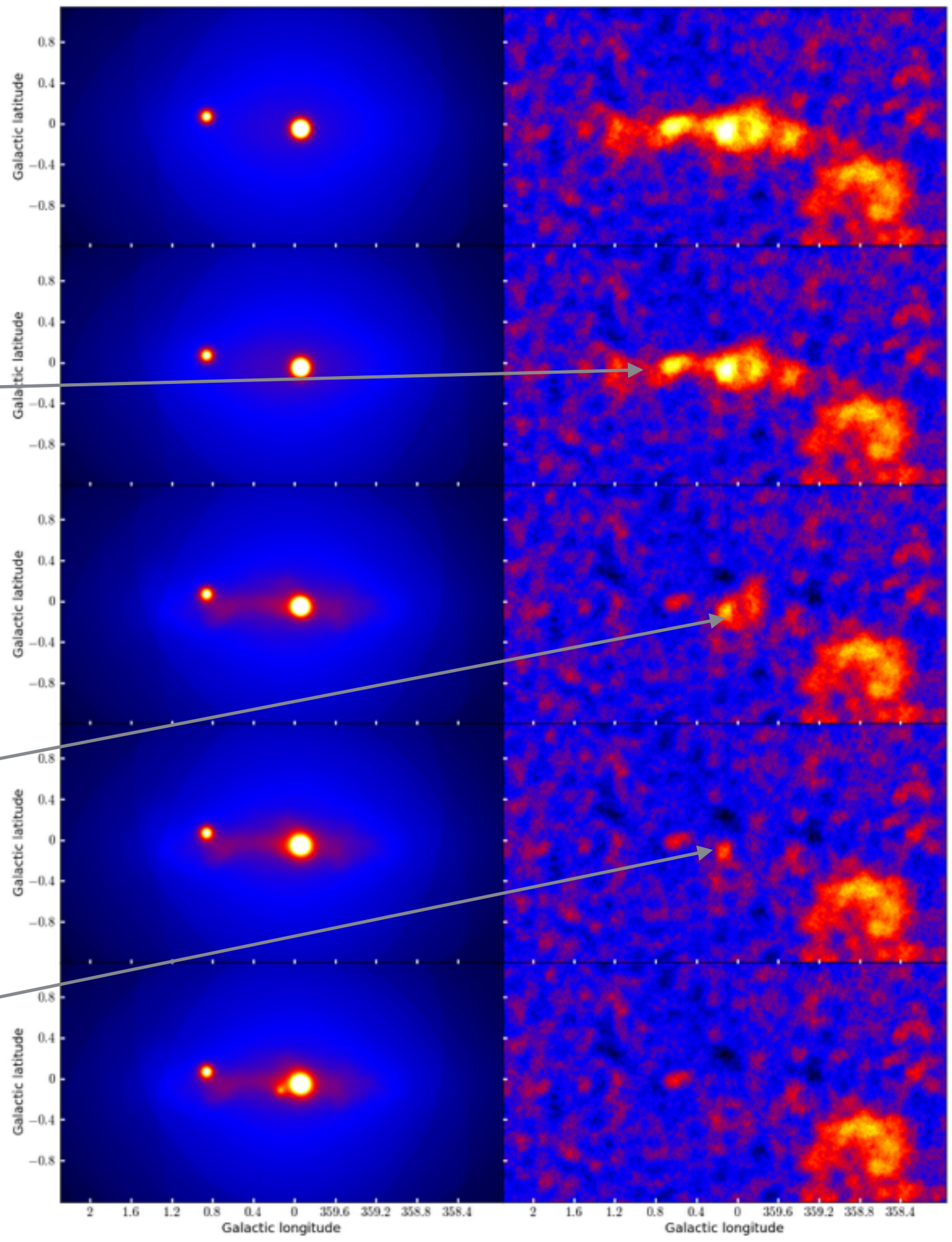
HESS collab (under review)

Iterative fitting of VHE emission

Components included:

- **CMZ***:* CS x gaussian (53% flux, ~150 pc extension)
- Large Scale gaussian with larger latitude coverage (33% flux)
- **Central Component** (CC) 0.1° gaussian at GC position (12% flux, ~15 pc ext)
- **Pointlike source** HESS J1746-285

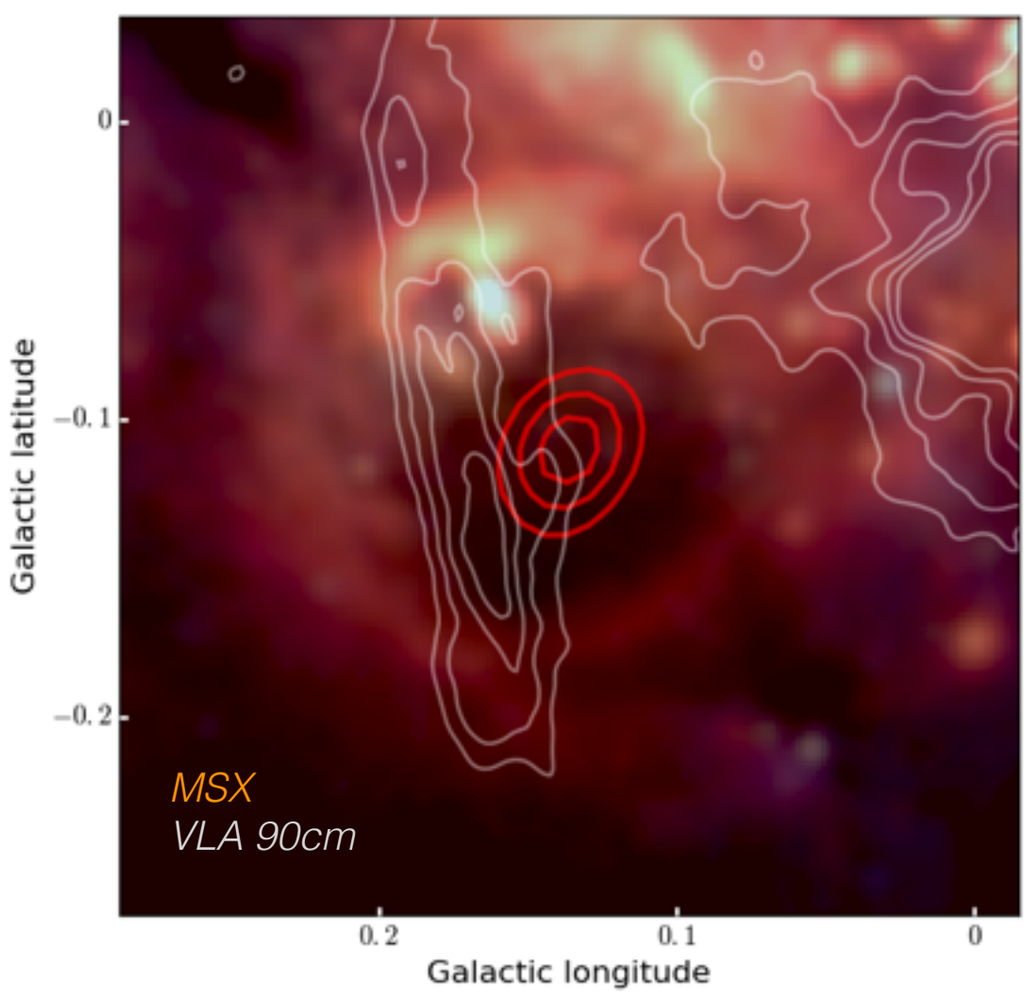
HESS collab (under review)

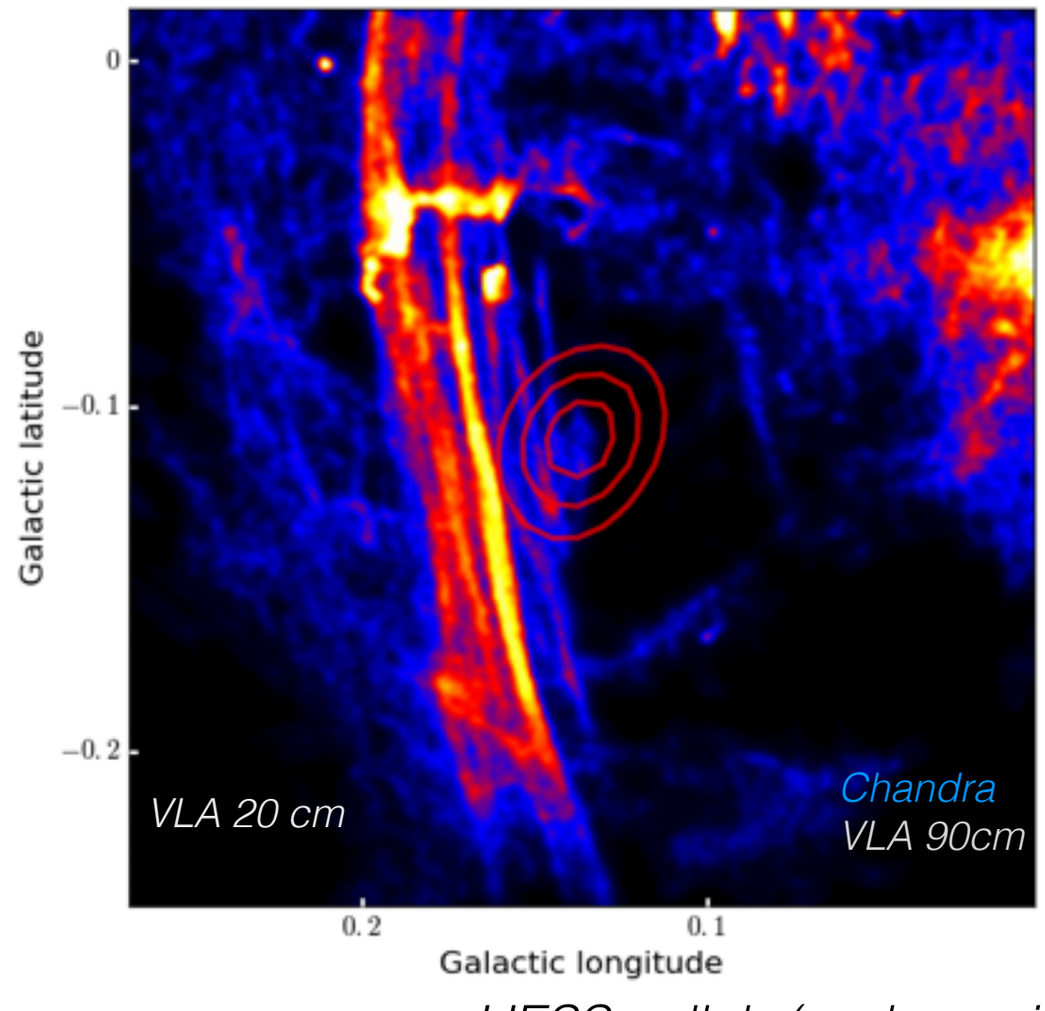


HESS J1746-285: a TeV PWN in the GC?

- Point source HESS J1746-285 located at the centre of the radio arc IR bubble and I on the edge of the radio arc

- Arc bubble: a kind of super bubble associated to the Quintuplet cluster?

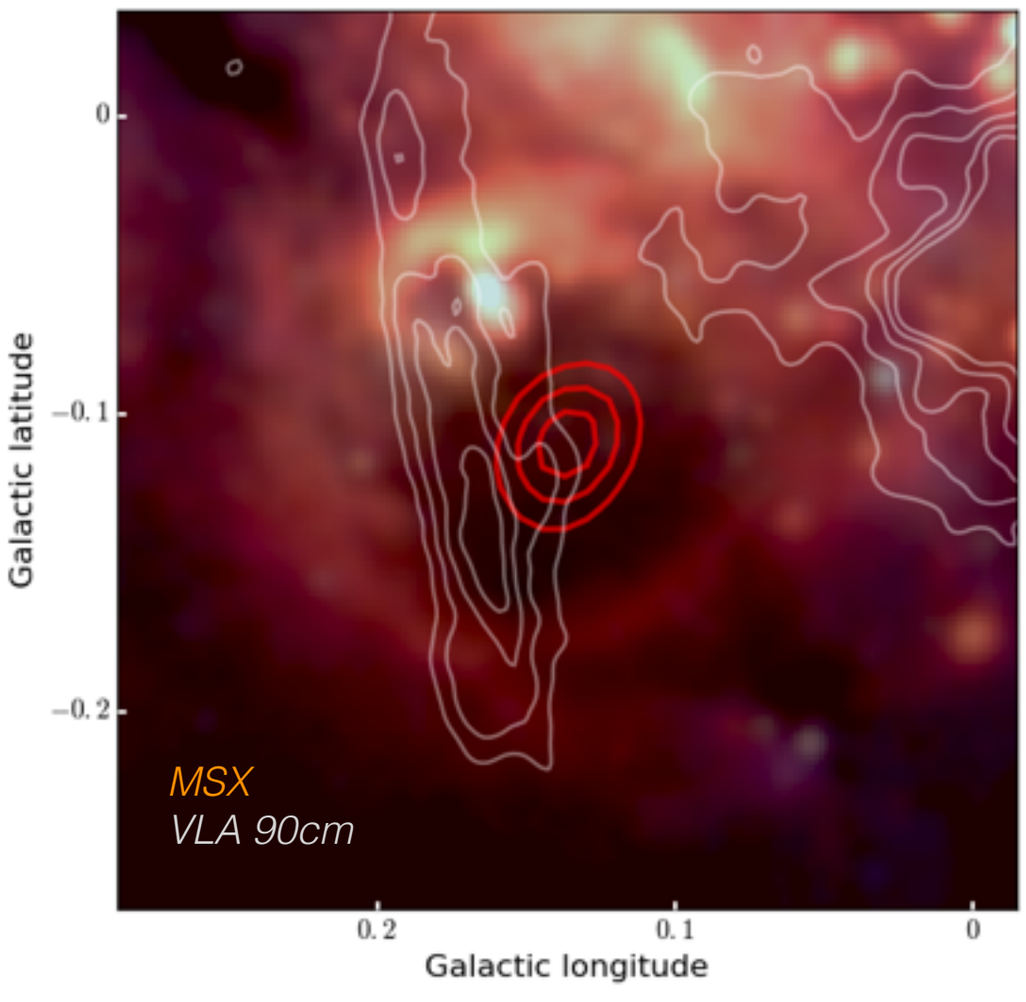


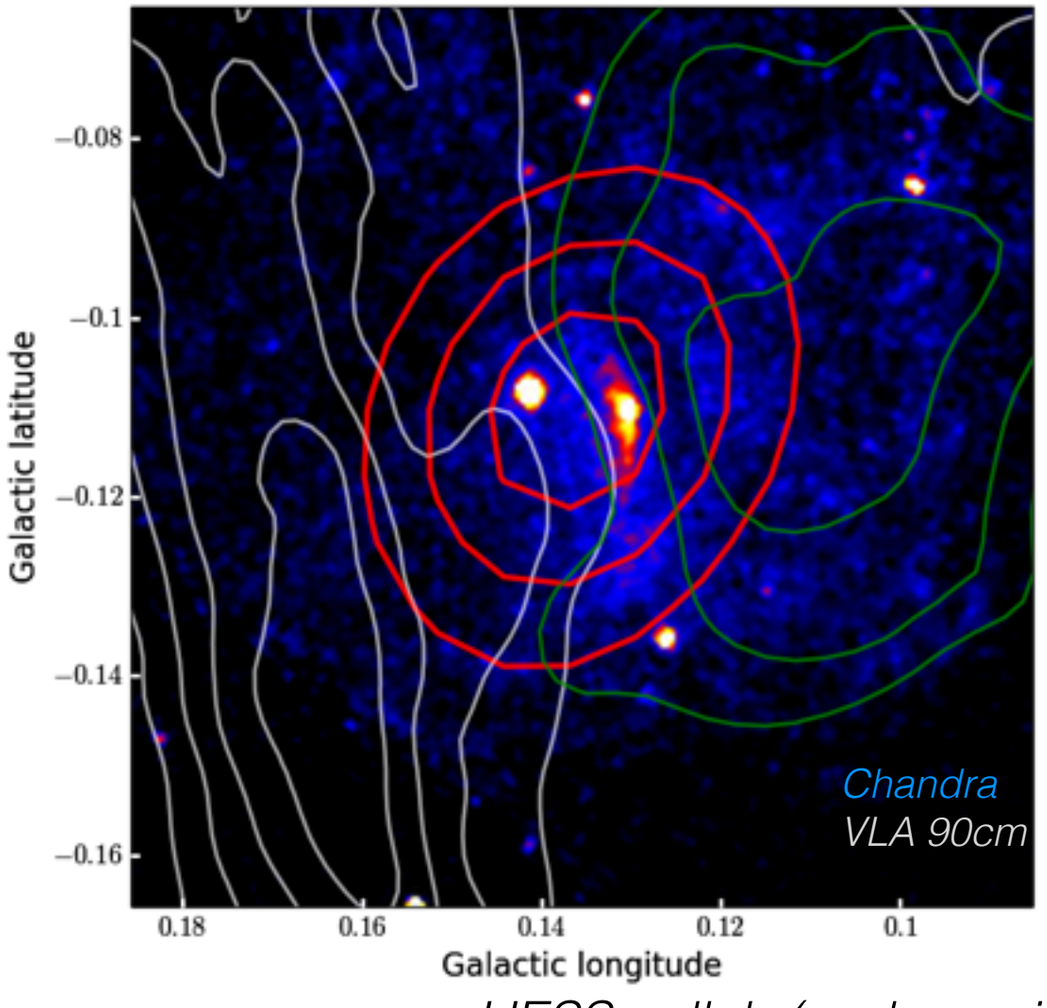


HESS collab (under review)

HESS J1746-285: a TeV PWN in the GC?

- Point source HESS J1746-285 well coincident with PWN candidate G0.13-0.11
  - Centre of IR bubble: progenitor connected to Quintuplet cluster (at 10 pc)
- PWN has to be illuminated by cluster and ionized material in the bubble



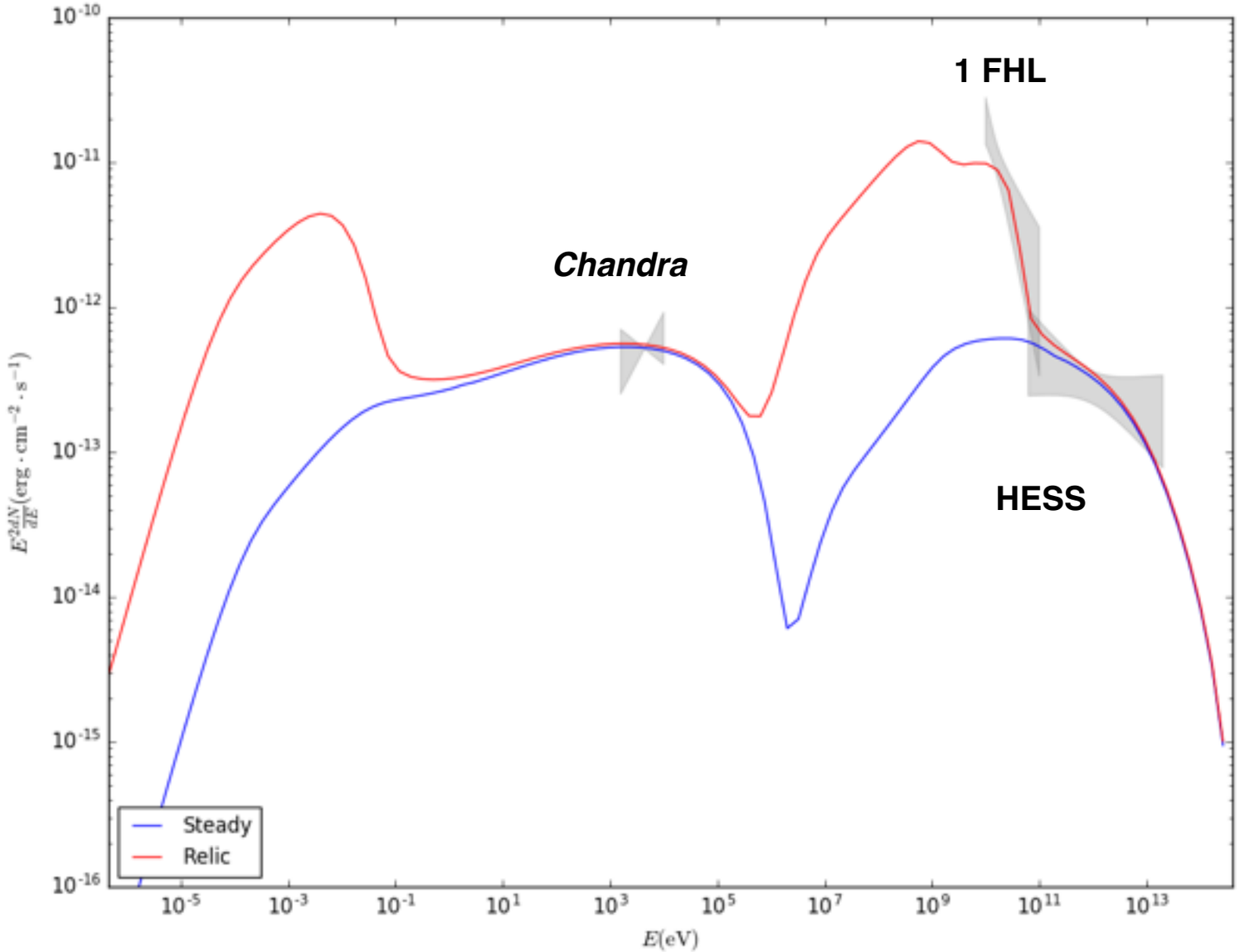


HESS collab (under review)

HESS J1746-285: a TeV PWN in the GC?

- Estimated radiation field: opt ~200 eV/cm^3 IR ~ 50-100 eV/cm^3
- Hard spectrum in X-rays because of energy dependent IC cooling
- X-rays & TeV well reproduced for a steady $\dot{E} = 2\ 10^{35}$ erg/s injection with ambient B ~ 50 μG

Steady injection



HESS J1746-285: a TeV PWN in the GC?

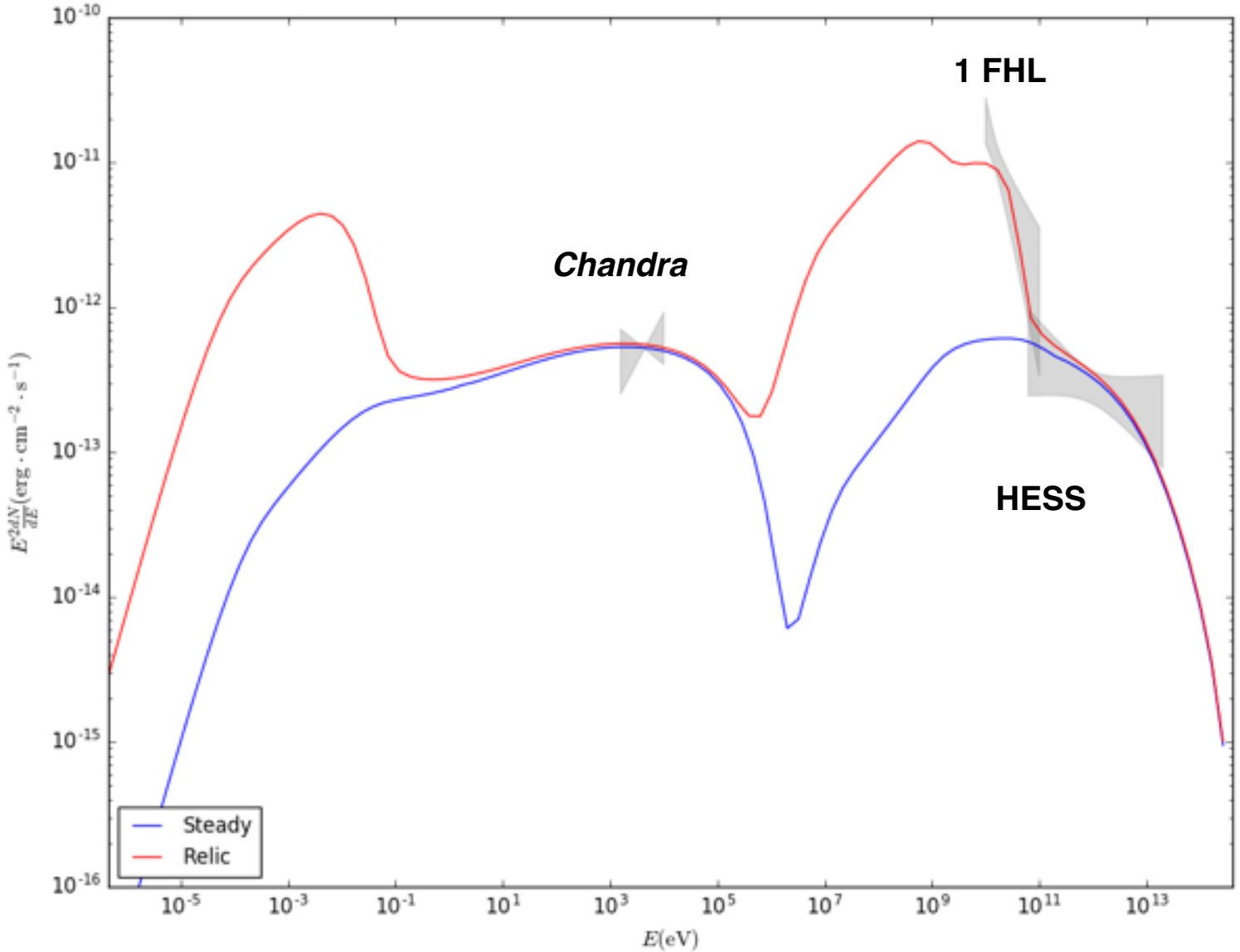
- Relic scenario with $\dot{E}_0 = 7\ 10^{38}$ erg/s, $\tau_0 = 500$ yr and age 30 kyr reproduces only partly GeV spectrum

- Origin of GeV emission?

    - Pulsar? Underlying SNR? Diffuse emission?

Steady injection

Relic model

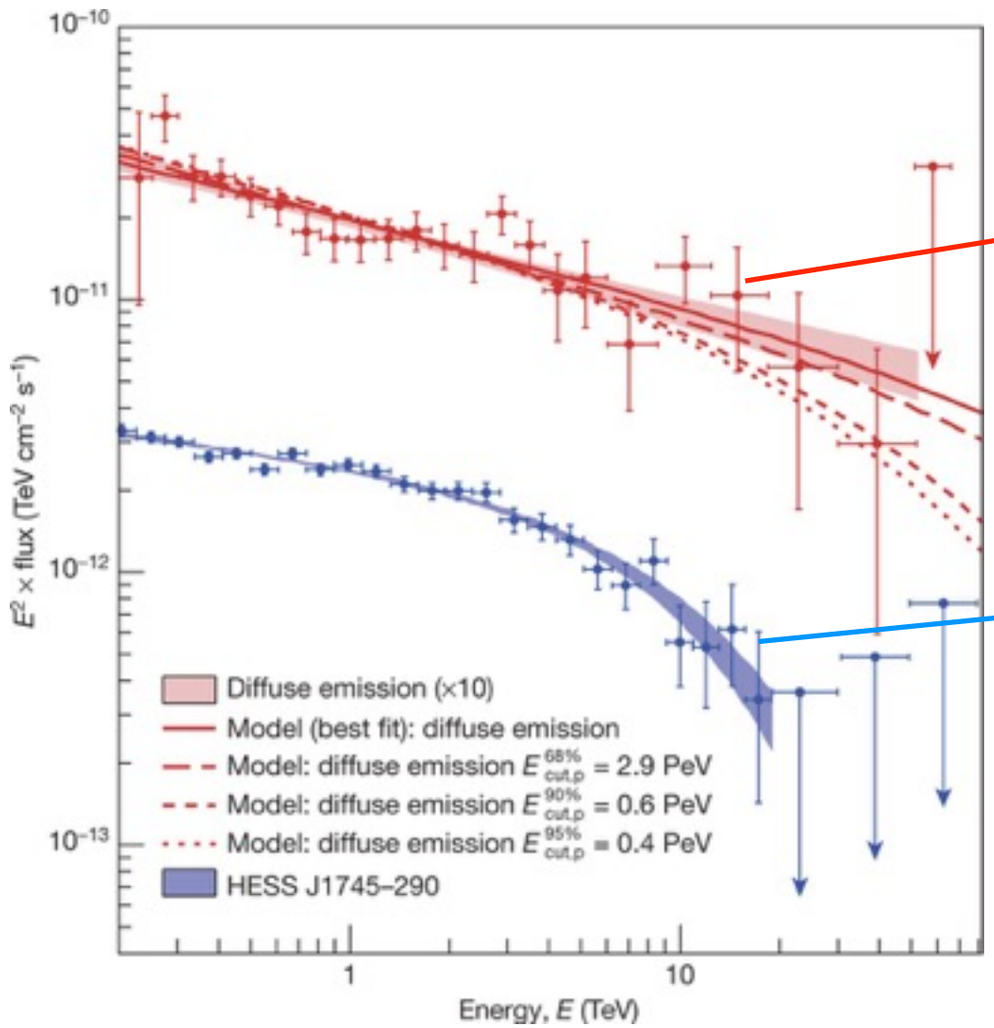


Contribution of PWNe to VHE diffuse emission?

- If GC environment is such that evolved PWNe have typical ratios of $L_\gamma/L_X \sim 2$ (as G0.13-0.11),
  - **What is their total contribution to diffuse emission?**
- ~15 PWNe in the inner 15 pc radius:
  - total expected luminosity $L_\gamma \sim 5\ 10^{34}$ erg/s
  - Central Component luminosity $L_\gamma = 4.5\ 10^{34}$ erg/s
- Good luminosity match but strong KN losses expected: **spectrum should show sharp cutoff above a few TeV**

Contribution of PWNe to VHE diffuse emission?

- No such spectral cutoff is visible in the inner regions
- No strong contribution of PWNe to diffuse emission
- Is G0.13-0.11 a special case?



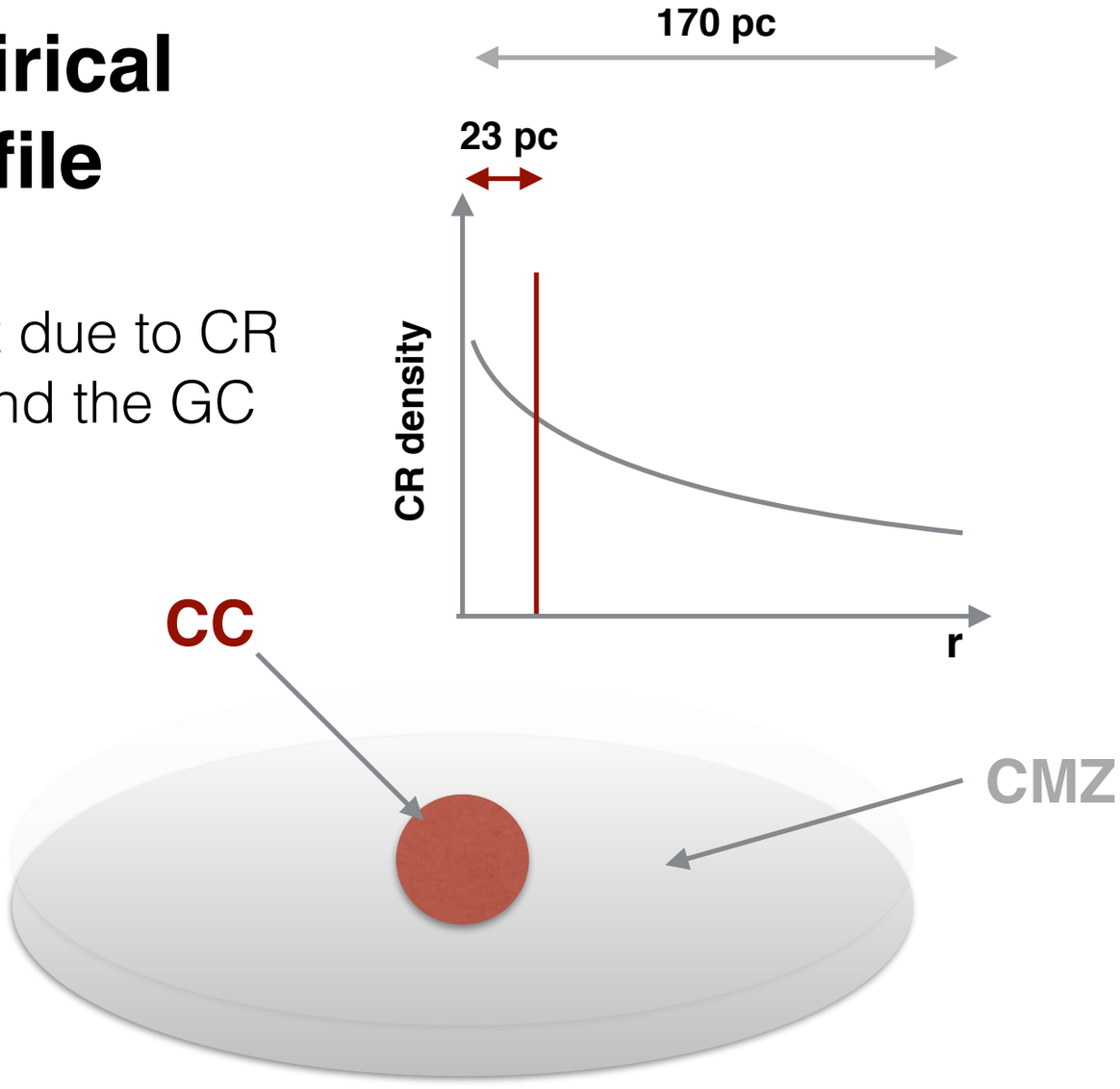
spectrum from 0.15°-0.4° region

spectrum from GC source

from HESS collab (2016)

Consistency of empirical model with 1/r profile

If CMZ & central component due to CR compute over density around the GC



Measured intensity ratio:

CC / total ridge = 0.12

Expected intensity ratio (for a 1/r CR distribution and uniform gas):

CC / total ridge = 0.10

$$\int dV\ 1/r$$

Central Component (~15 pc radius) is well explained by gradient of CR in ISM (with ~1/r profile): a stationary CR source at the GC?

Conclusions

- Up to 20 PWNe candidates in the GC (most in the inner 30pc)
  - X-ray morphology: ram pressure confined?
- Because of high radiation field environment, several should be bright at TeV
- The TeV GC source is a possible case (although the ambient B field might be too high)
- The radio Arc PWN G0.13-0.11 is detected on top of diffuse emission by H.E.S.S.
  - Consistent with emission from $\dot{E} \sim 2 \times 10^{35}$ erg/s pulsar
  - Coincident GeV emission does not seem to be connected with PWN itself
- Combined VHE emission of all PWNe might contribute significantly to excess of diffuse emission visible in the central 30 pc
- But this would imply a sharp cutoff at multi-TeV energies that is not observed