

# Tenth International Fermi Symposium

9th-15th October 2022



## Implications from 3-dimensional modeling of gamma-ray signatures in the Galactic Center

Julien Dörner \*

J. Becker Tjus, P. S. Bloomenkamp, H. Fichtner,  
A. Frankowiak, M. Hoerbe, E. M. Zaninger

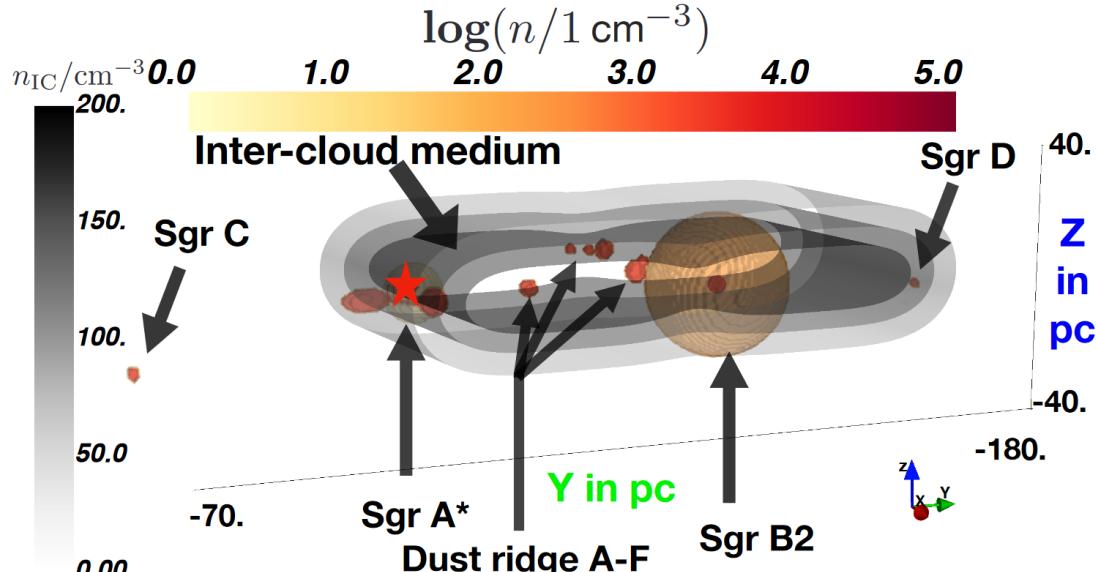
[arXiv:2207.08097](https://arxiv.org/abs/2207.08097)

\* [julien.doerner@ruhr-uni-bochum.de](mailto:julien.doerner@ruhr-uni-bochum.de)

# Galactic Center the environment

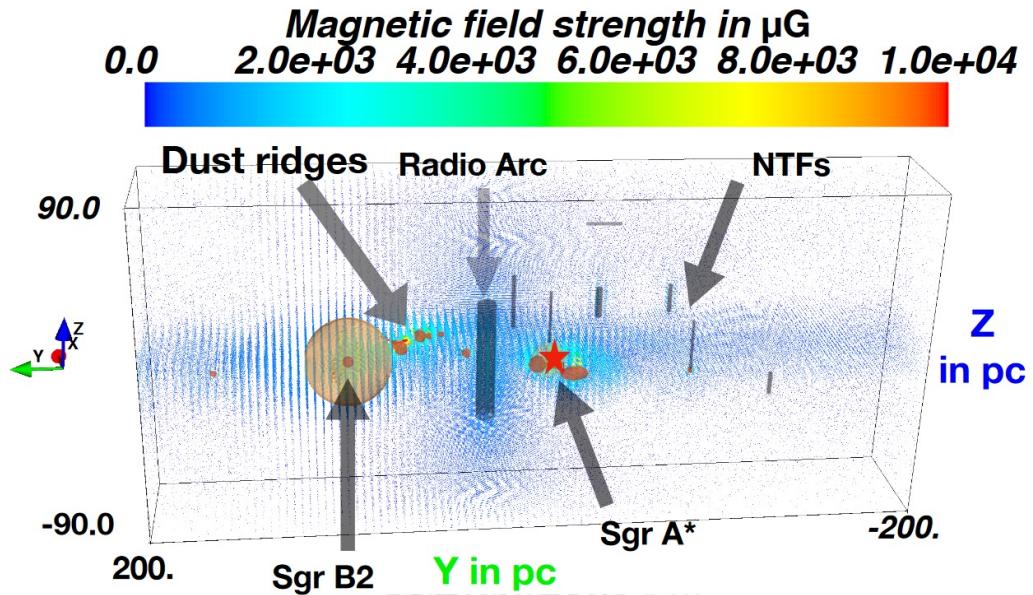
# Galactic Center environment – gas distribution

- 13 molecular clouds  
(Guenduez et al. (2020))
- Central 10 pc structure  
(Ferriere et al. (2012))
- diffuse intercloud  
component  
(Ferriere et al. (2007))



# Galactic Center environment – magnetic field

- 13 molecular clouds
- 7 non-thermal filaments
- Radio arc
- Inter-cloud component



Guenduez+ A&A 644 (2020) A71

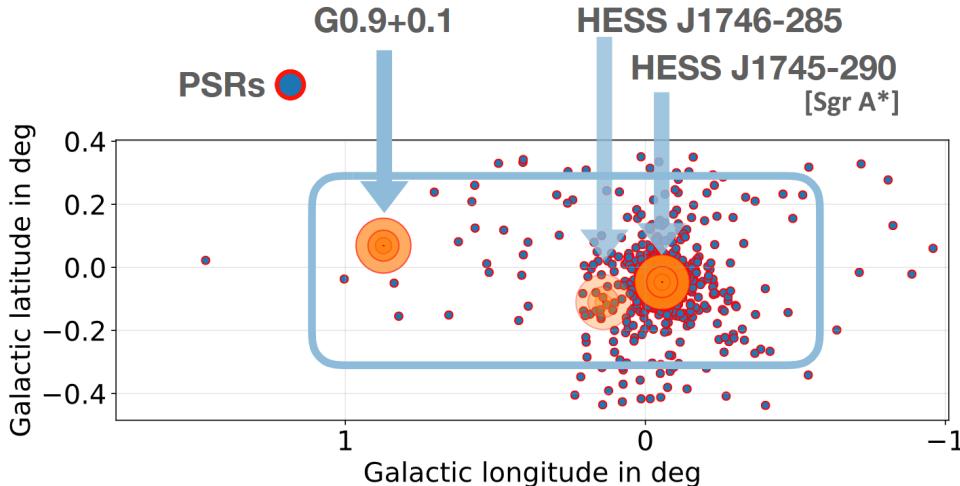
# sources of cosmic rays

Testing different source setups:

- **Sgr A\*** (HESS J1745-290)
- **3sr** three point sources
- **uPSR** unresolved pulsar

$$dn/dr = k \cdot r^{-\alpha}$$

- **3sr + uPSR**
- **hom** homog. cylinder



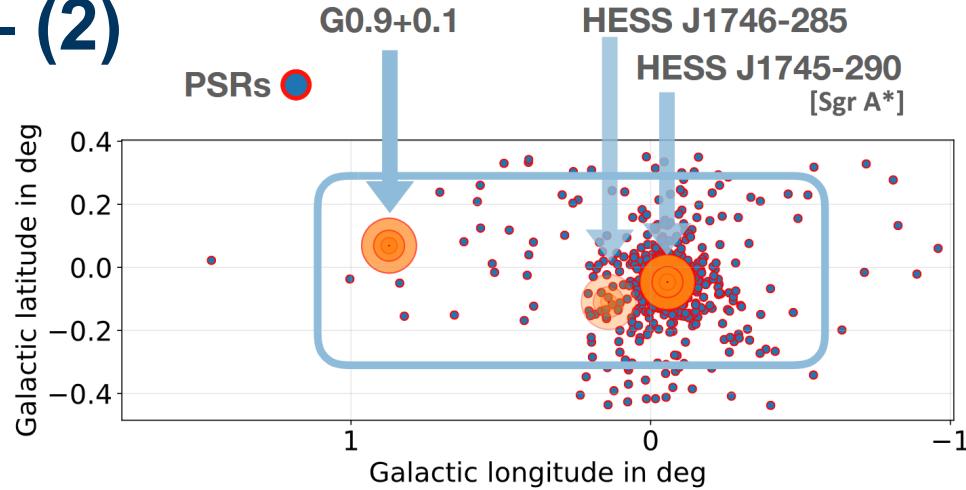
Source	Contribution [3sr]	Contribution [3sr + uPSR]
HESS J1745-290	72 %	58 %
HESS J1746-285	6 %	5 %
G0.9+0.1	22 %	18 %
uPSR	-	19 %

# sources of cosmic rays – (2)

- CR protons
- Energy range 1 TeV – 1 PeV
- Simulated source Injection

$$\left. \frac{dN}{dE} \right|_s \propto E^{-2.0}$$

- Reweighted for source index  
[-2.0; -2.4]



# Galactic Center the transport model

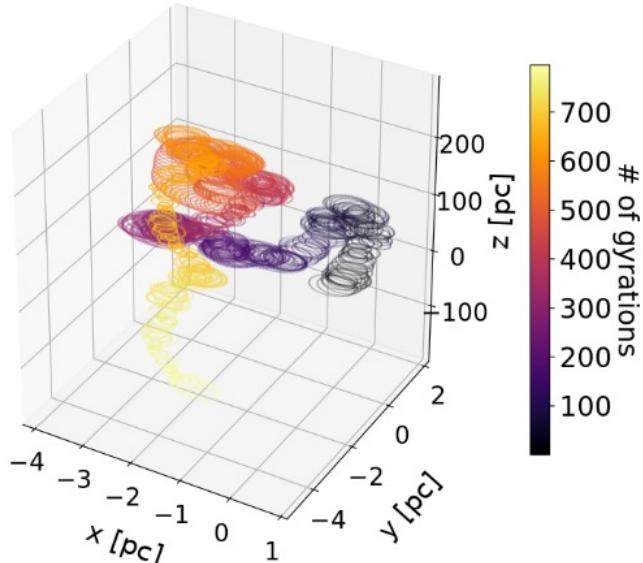
# transport model

$$\frac{\partial n}{\partial t} = \nabla \cdot (\hat{\kappa} \nabla n) + \frac{\partial}{\partial E} \left[ \frac{\partial E}{\partial t} n \right] + S(\vec{r}, E)$$

## Diffusion:

- anisotropic in local magnetic field system
- $\hat{\kappa} = \text{diag}(\kappa_{\perp}, \kappa_{\perp}, \kappa_{\parallel}) = \kappa_{\parallel} \cdot \text{diag}(\epsilon, \epsilon, 1)$   
for  $\vec{B} = B \vec{e}_z$
- spatially constant
- Quasi-linear theory:  $\kappa_{\parallel} = \kappa_0 \cdot \left( \frac{E}{4 \text{ GeV}} \right)^{\frac{1}{3}}$

**CR** 



J. Becker Tjus, L. Merten, Physics Reports **872** (2020)

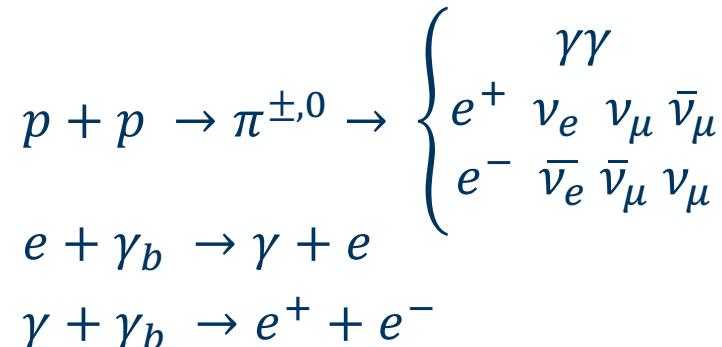
# transport model – (2)

**CR** 

$$\frac{\partial n}{\partial t} = \nabla \cdot (\hat{\kappa} \nabla n) + \frac{\partial}{\partial E} \left[ \frac{\partial E}{\partial t} n \right] + S(\vec{r}, E)$$

## Energy loss:

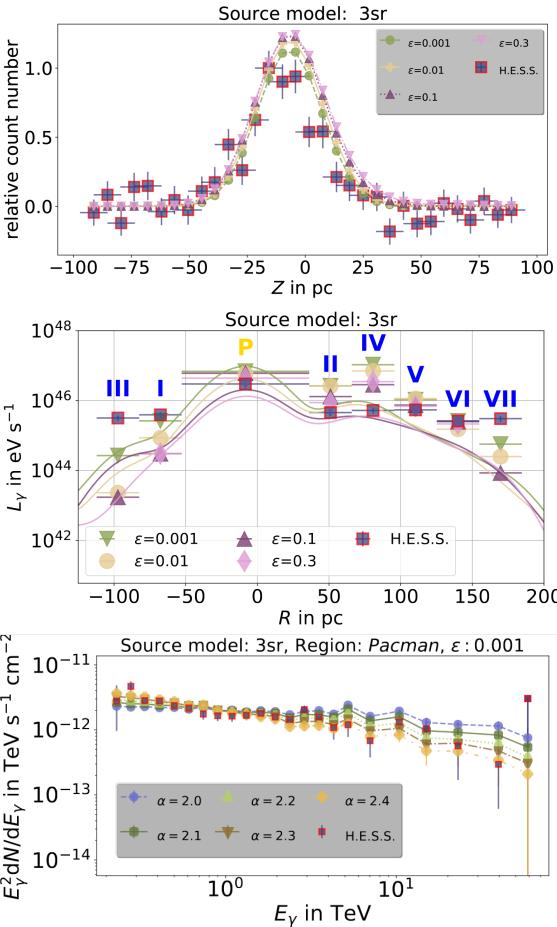
- Hadronic Interaction
- Inverse Compton
- EM pair production



# Galactic Center determining the model parameter

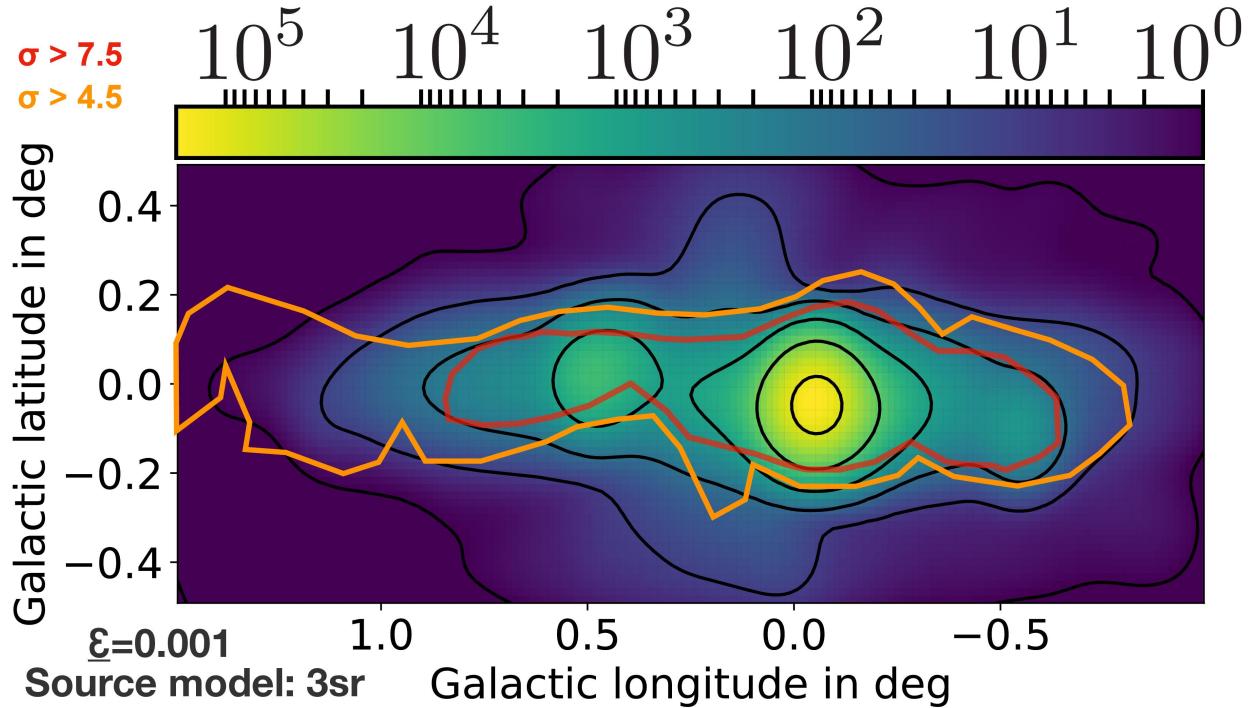
# Find the best source model

- Compare model output to H.E.S.S data
- Latitudinal and longitudinal countmaps
  - Most sensitive to the source model → **3sr**
- Total luminosity in the distinct regions
  - Most sensitive to the anisotropy of the diffusion tensor →  $\epsilon \sim 0.001$
- Spectral shape of the  $\gamma$ -ray emission
  - Most sensitive to the source spectrum →  $E^{-2.3 \pm 0.05}$



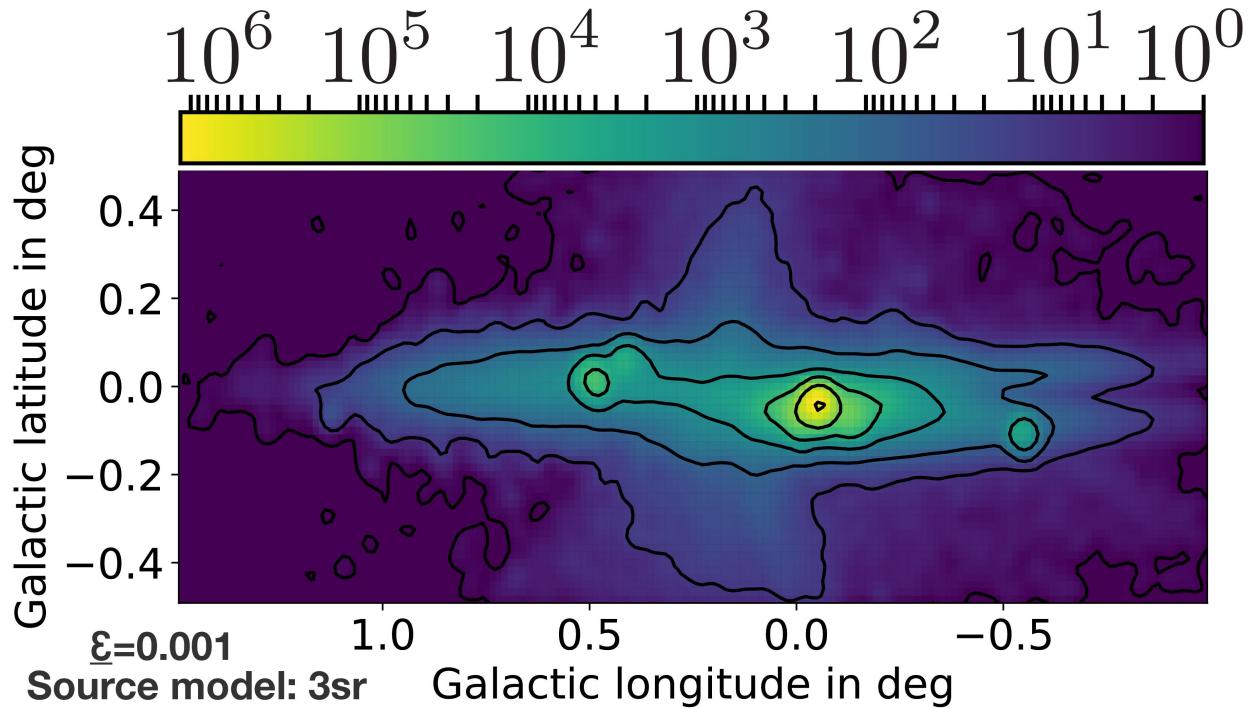
# Galactic Center resulting messengers

# Countmap for H.E.S.S.



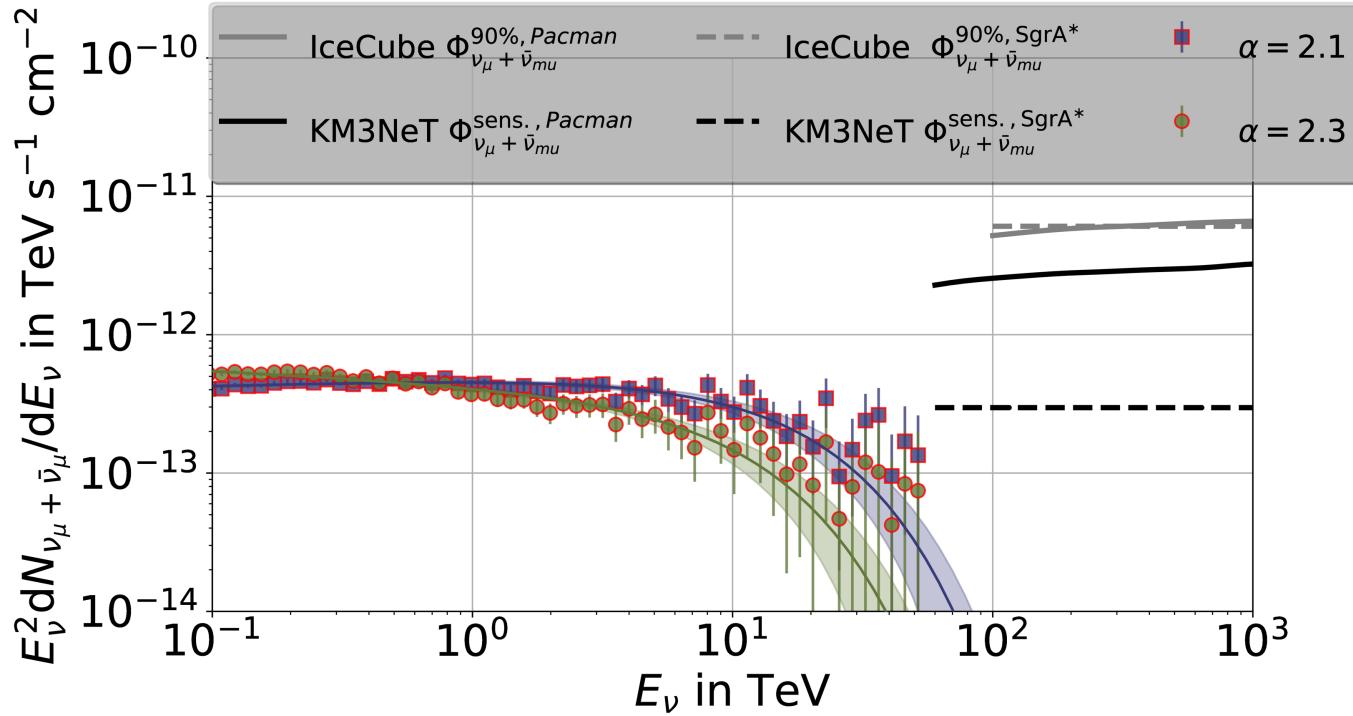
H.E.S.S. resolution  
 $\sigma = 0.077^\circ$

# Countmap for CTA



CTA resolution  
 $\sigma = 0.03^\circ$

# Neutrino flux



# Galactic Center summary

# Conclusion

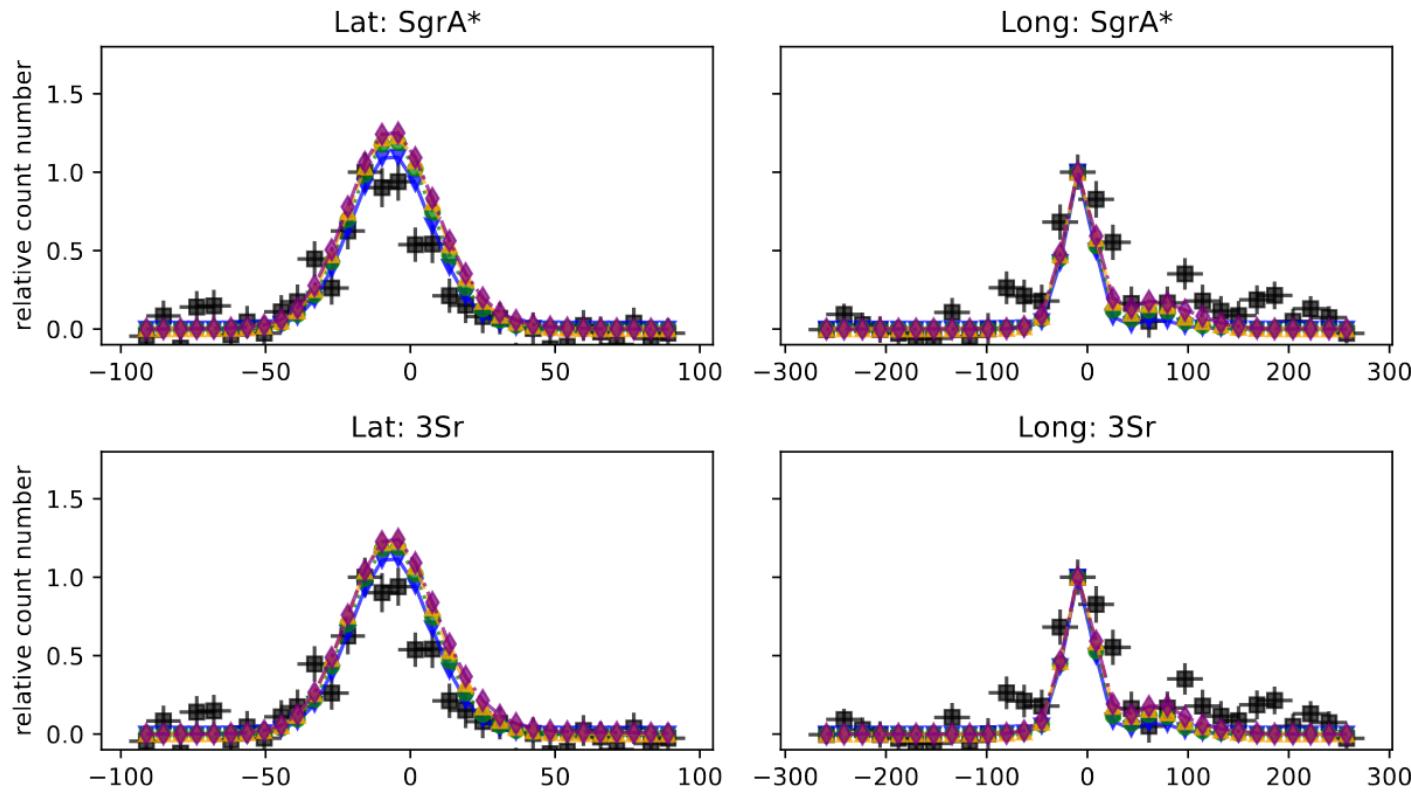
- 3 dominant sources - no pulsars in VHE  $\gamma$ -ray
- We expect dominating parallel diffusion  $\kappa_{\perp}/\kappa_{\parallel} = 0.001$
- Some unresolved small-scale features → more detailed gas map
- Neutrino detection unlikely

# Outlook

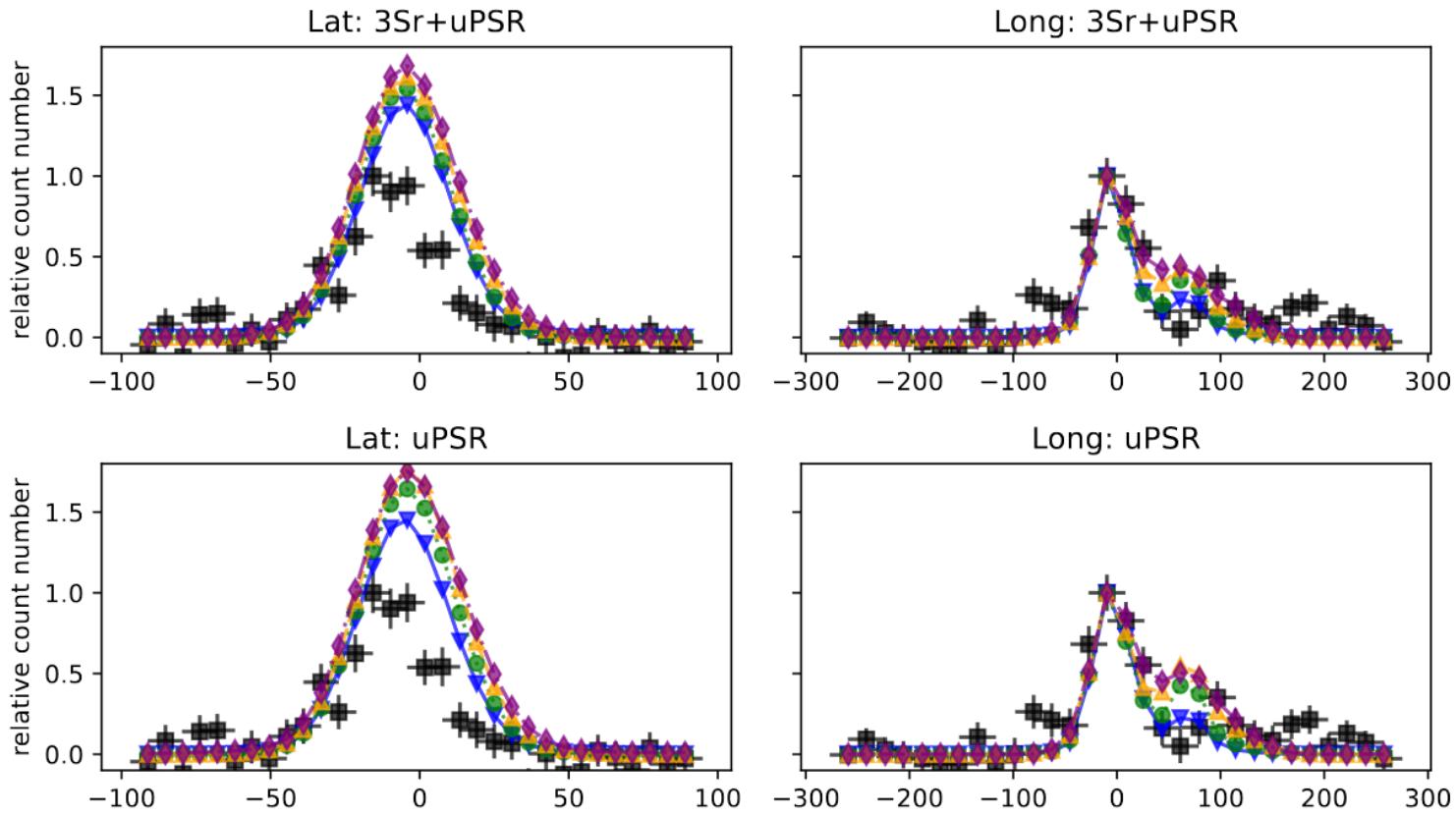
- Outflow structure (advection)
- Lower energy → direct compare to Fermi-LAT data

# Back up

⊕ H.E.S.S.    ▾  $\varepsilon = 0.001$     ⋅ ⋅ ⋅  $\varepsilon = 0.01$     ▲ ▲  $\varepsilon = 0.1$     ⋆ ⋆ ⋆  $\varepsilon = 0.3$



■ H.E.S.S.     $\downarrow$   $\varepsilon = 0.001$      $\cdots \bullet \cdots$   $\varepsilon = 0.01$      $- \triangle -$   $\varepsilon = 0.1$      $- \diamond -$   $\varepsilon = 0.3$



# Optimal source distribution

$\chi^2$  values:

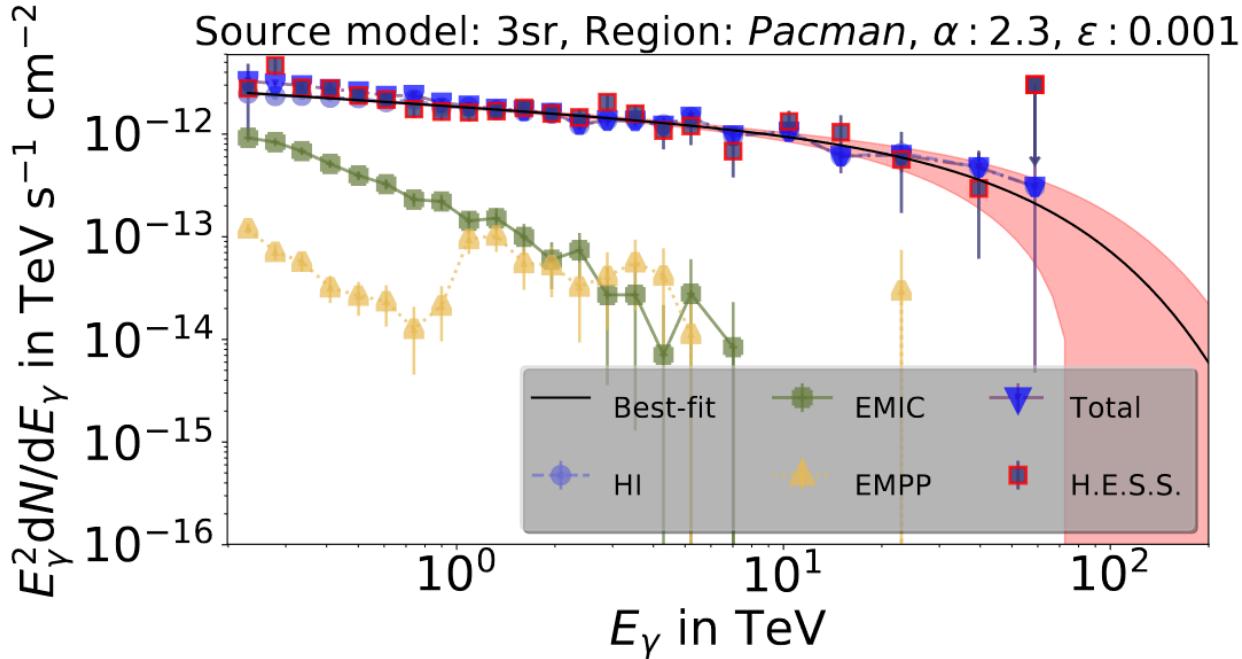
longitudinal profile

$\epsilon$ /Source	[SgrA *]	[3sr]	[3sr + uPSR]	[uPSR]	[hom]
0.3	2.12	2.16	4.91	6.37	9.37
0.1	2.25	2.24	4.62	7.17	7.31
0.01	2.44	2.48	3.71	4.70	6.50
0.001	2.6	2.65	2.56	2.45	5.11

latitudinal profile

$\epsilon$ /Source	[SgrA *]	[3sr]	[3sr + uPSR]	[uPSR]	[hom]
0.3	1.83	1.95	11.34	15.41	17.09
0.1	1.49	1.444	8.56	12.57	12.64
0.01	0.93	0.91	5.14	7.79	7.35
0.001	0.46	0.52	3.65	4.02	5.46

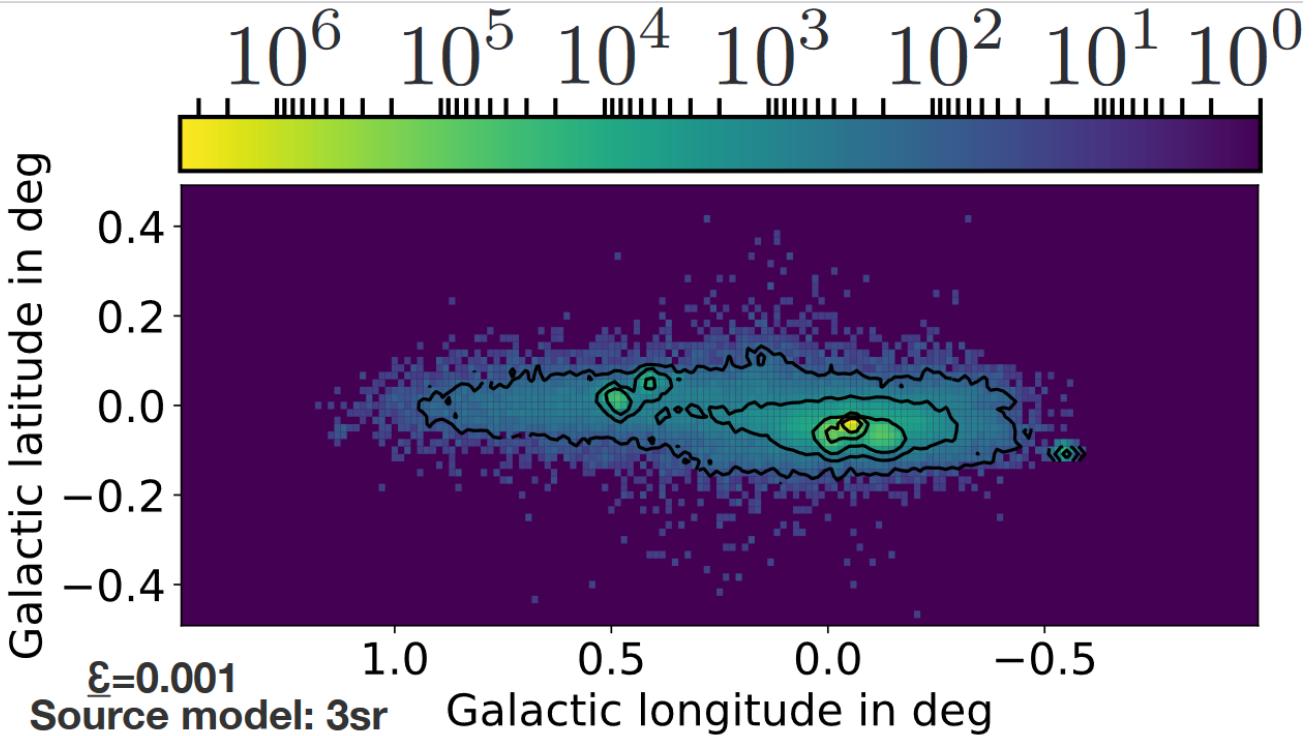
# Gamma-ray by secondaries and absorption



# Optimal spectral index ( $\chi^2$ results)

$\epsilon/\alpha$	2.0	2.05	2.1	2.15	2.2	2.25	2.3	2.35	2.4
0.3	3.5	3.1	2.8	2.8	2.9	3.3	3.5	4.2	4.7
0.1	6.4	4.7	3.7	3.0	2.5	2.6	2.6	2.9	3.3
0.01	6.8	4.7	3.6	2.6	2.2	2.0	2.5	2.5	2.5
0.001	8.5	5.9	4.4	3.3	2.5	2.1	1.9	2.1	2.3

# Neutrino emission – raw data



# Neutrino emission – IceCube resolution

