Galactic Centre - astrophysical foregrounds, DM distribution

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2nd DMNet International Symposium

Big thanks to Jim Hinton, Julia Djuvsland

Take Home Messages

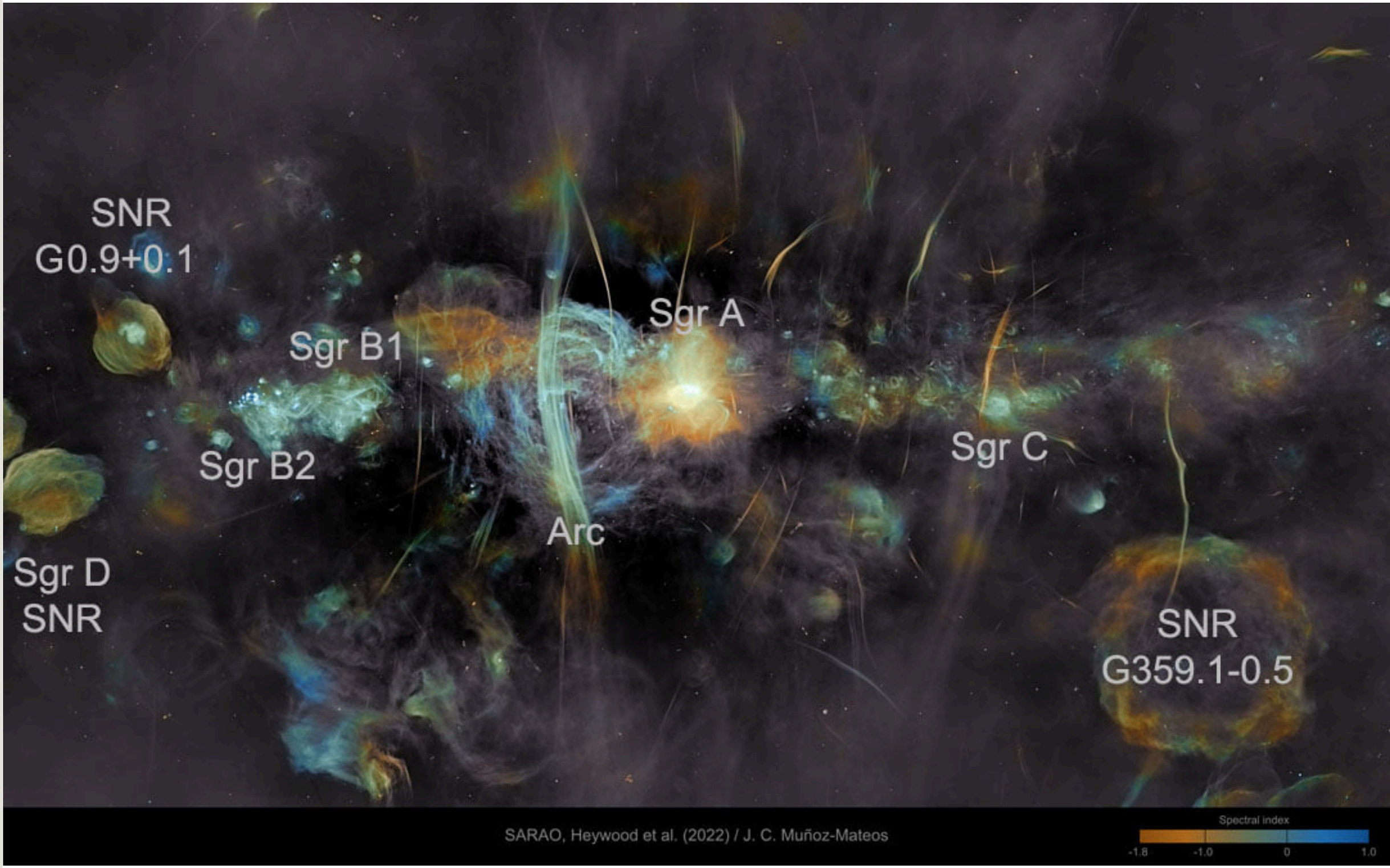
- **Astrophysical foregrounds are a fascinating nuisance**

- **Our understanding of CRs, their sources and transport, is by no means complete**

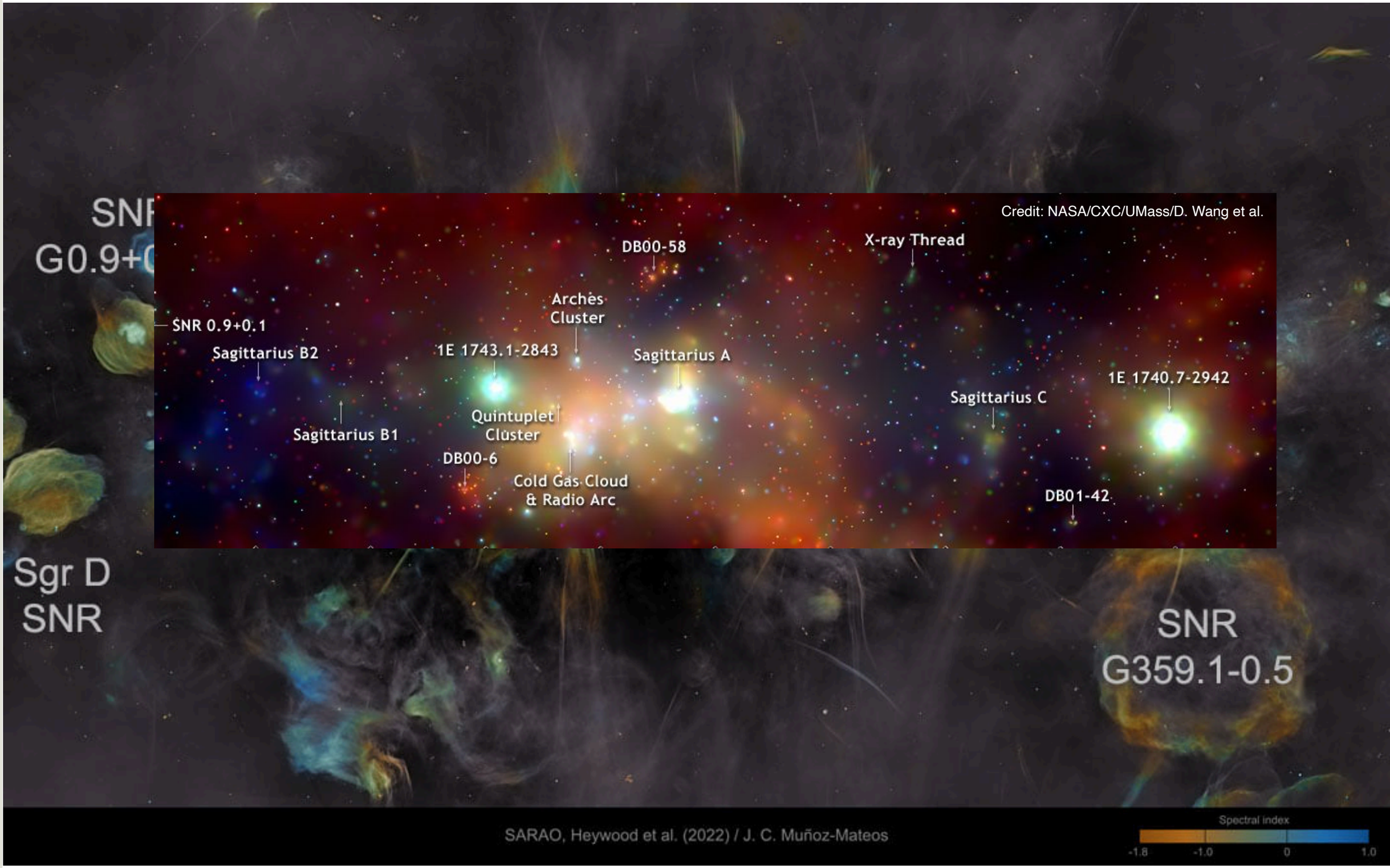
- **Energetic particle transport can have a measurable impact on indirect DM detection efforts**

A brief multi-wavelength view of the Galactic Centre

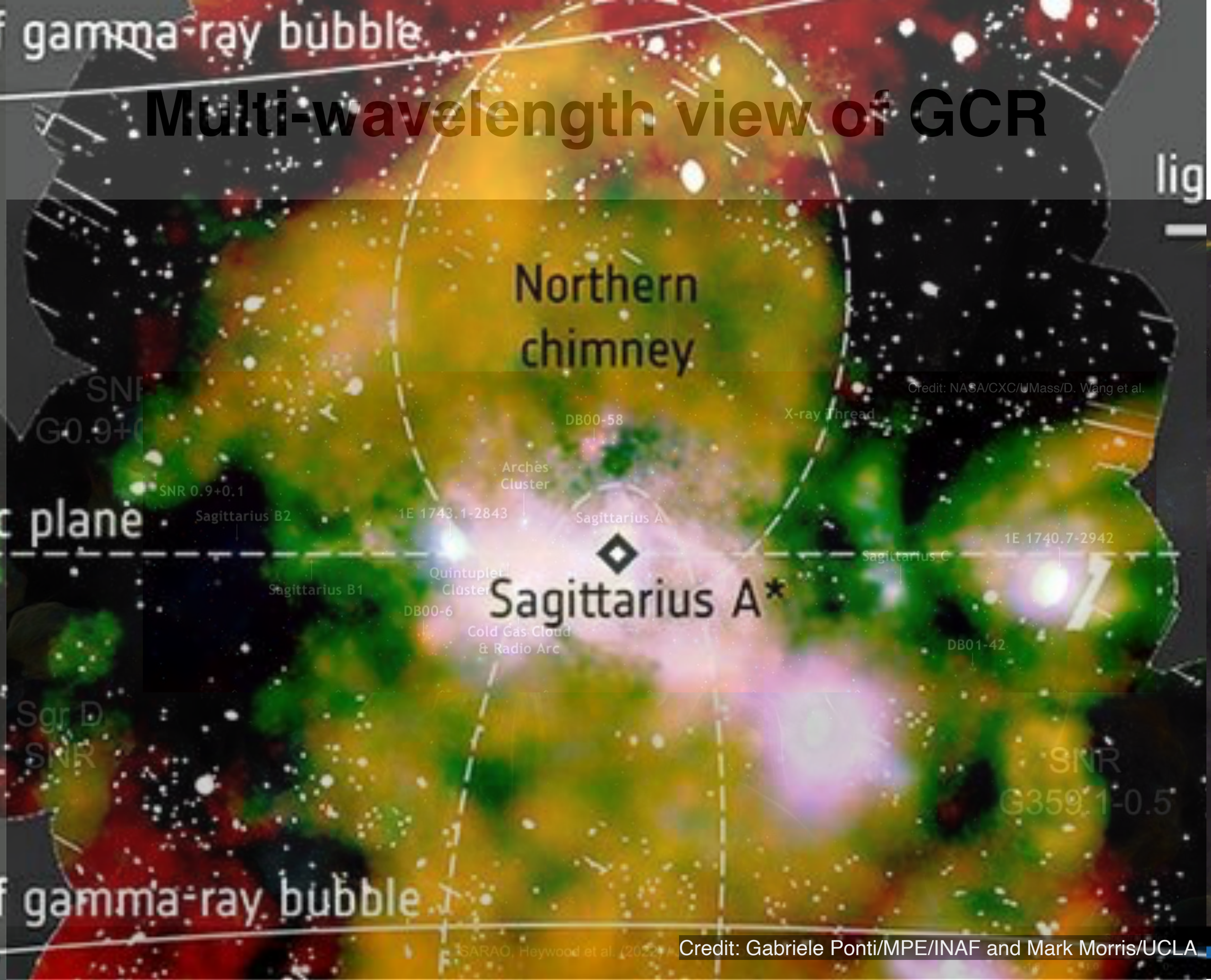
Multi-wavelength view of GCR



Multi-wavelength view of GCR



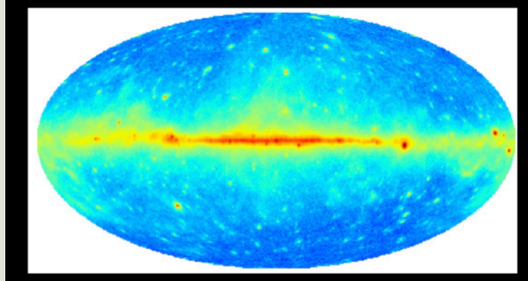
Multi-wavelength view of GCR

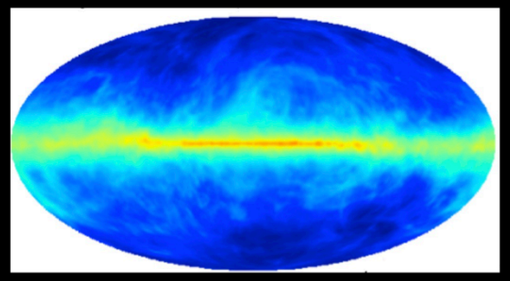


Multi-wavelength view of GCR

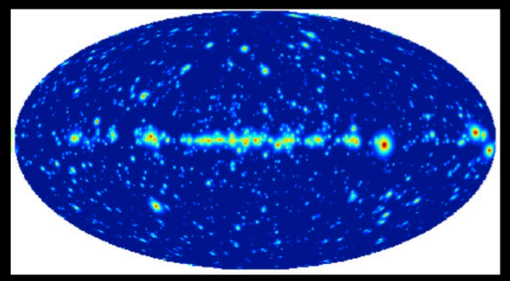
Excess relative to what?

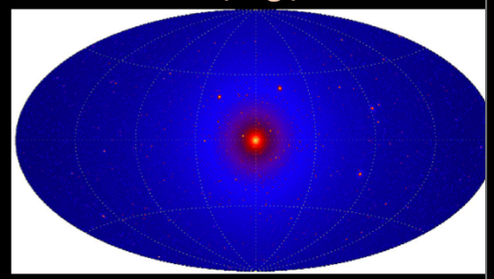
Data = Cosmic-ray related emission +





Known sources + New sources, e.g., dark matter





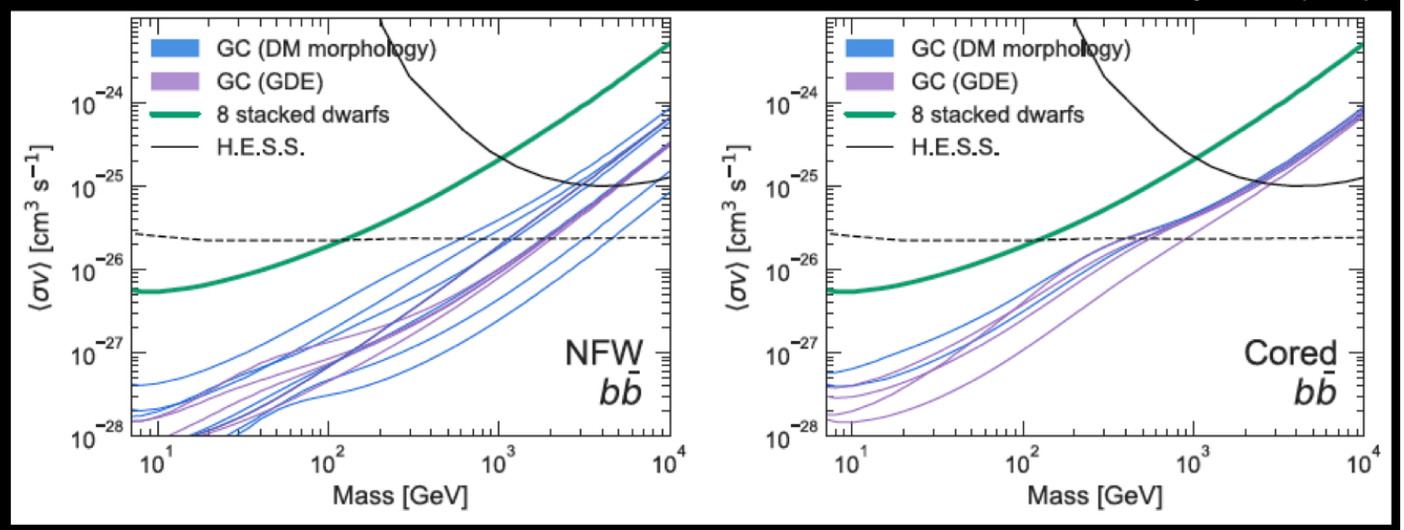
Shunsaku Horiuchi (Virginia Tech)

Dark matter implications

Perhaps we found a physically-motivated, *better astrophysical model* which provides a better explanation of the data than DM annhilation

➔ **Constrains thermal dark matter up to ~500 GeV**

Abazajian et al (2020)

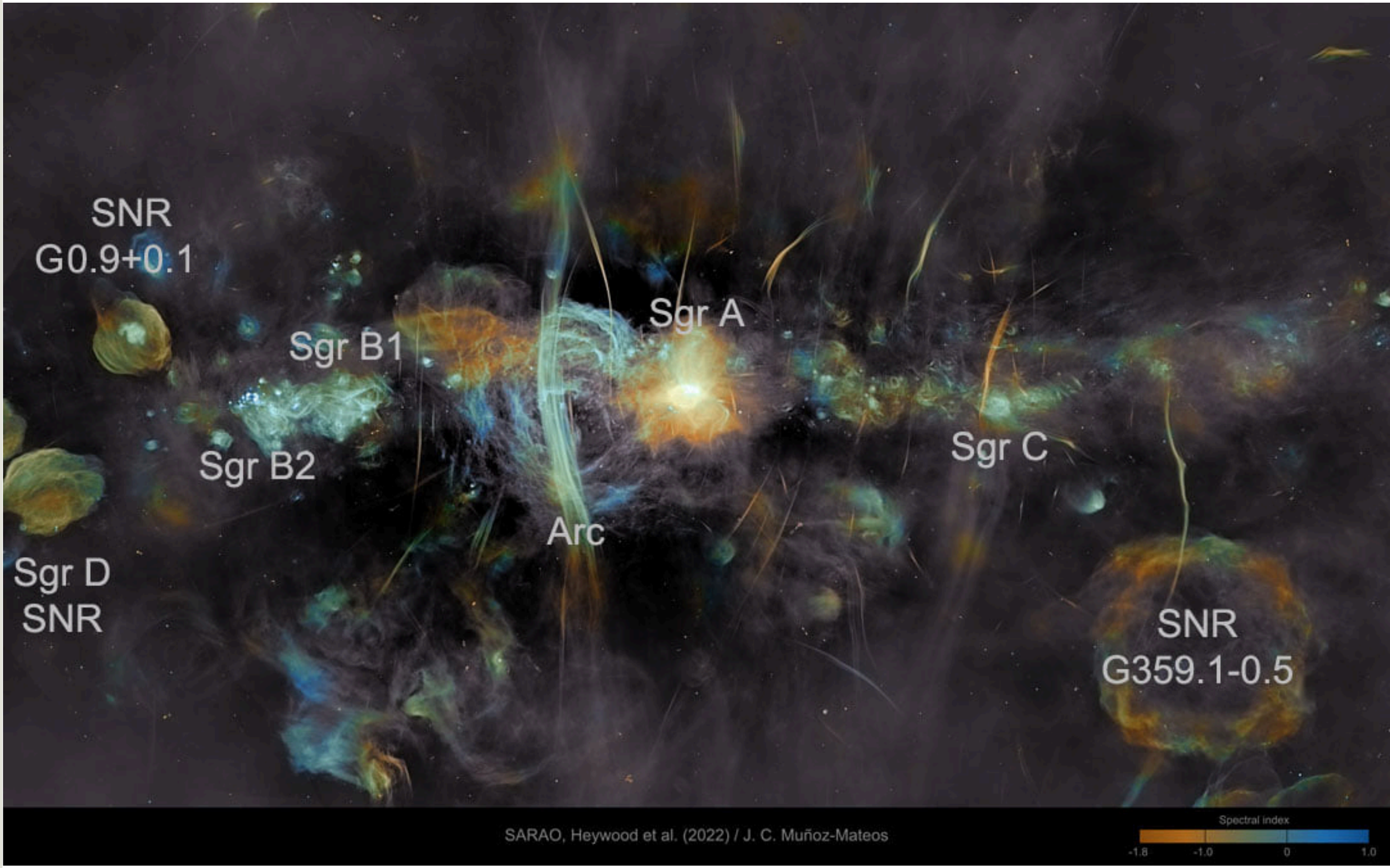


- Impacts of NFW slope [0.5,1.5] & sphericity
- Impacts of background modeling
- Impacts of core (1 kpc) & sphericity
- Impacts of background modeling

Shunsaku Horiuchi

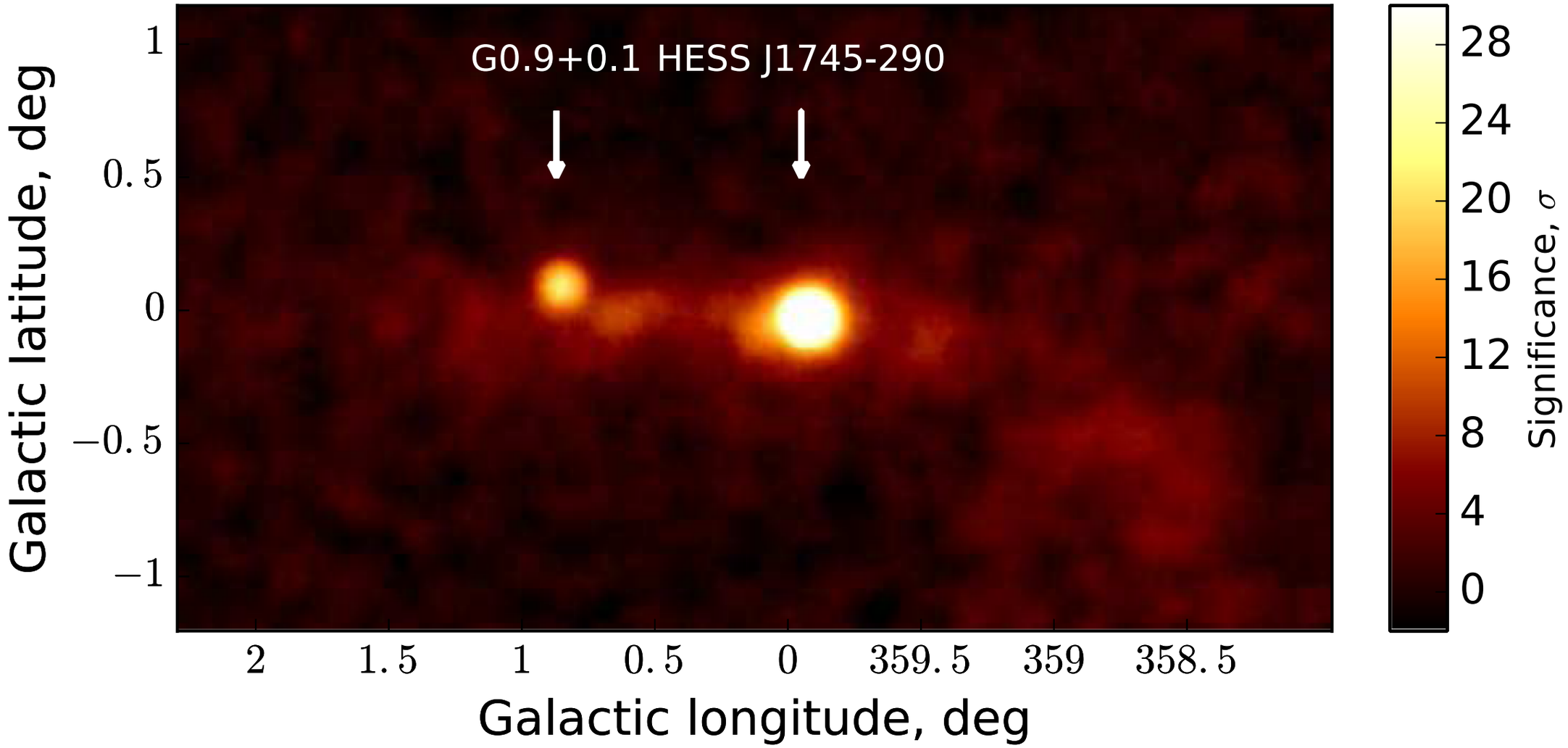
Shunsaku's talk yesterday.

Multi-wavelength view of GCR



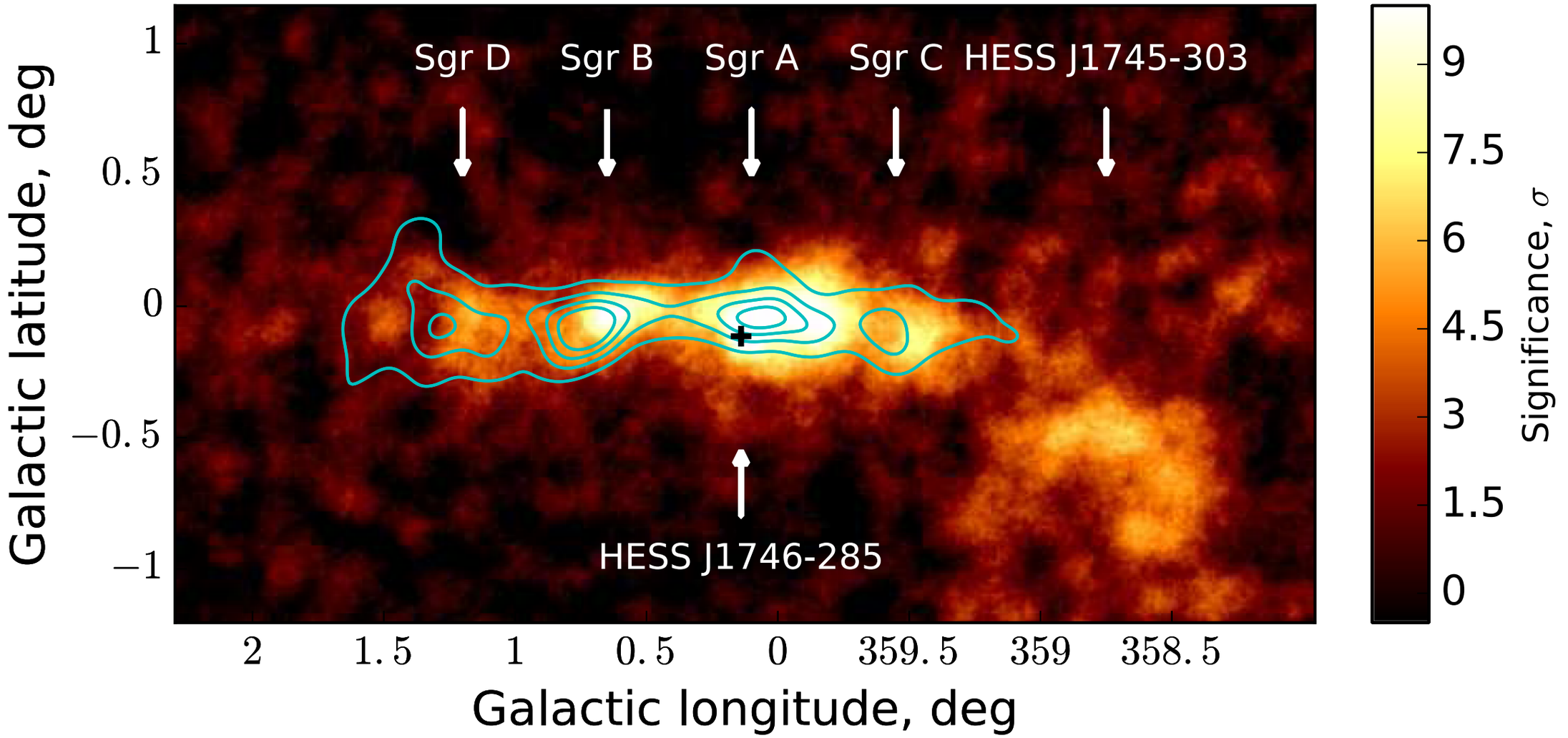
Multi-wavelength view of GCR

Diffuse TeV emission in inner Galaxy



H.E.S.S. view of the inner 200 pc - A&A 2018

Diffuse TeV emission in inner Galaxy



H.E.S.S. view of the inner 200 pc - A&A 2018

Removing point sources reveals a diffuse component closely correlated with gas distribution - hadronic origin preferred

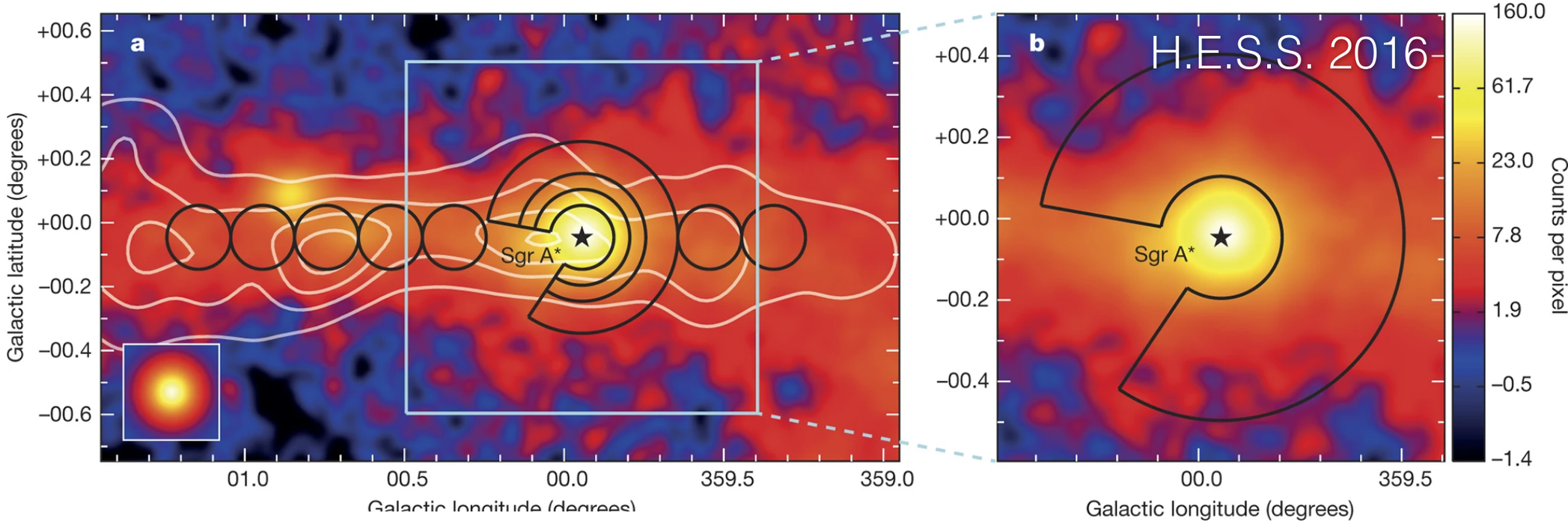
Sources and Distribution of CRs in Galactic Centre

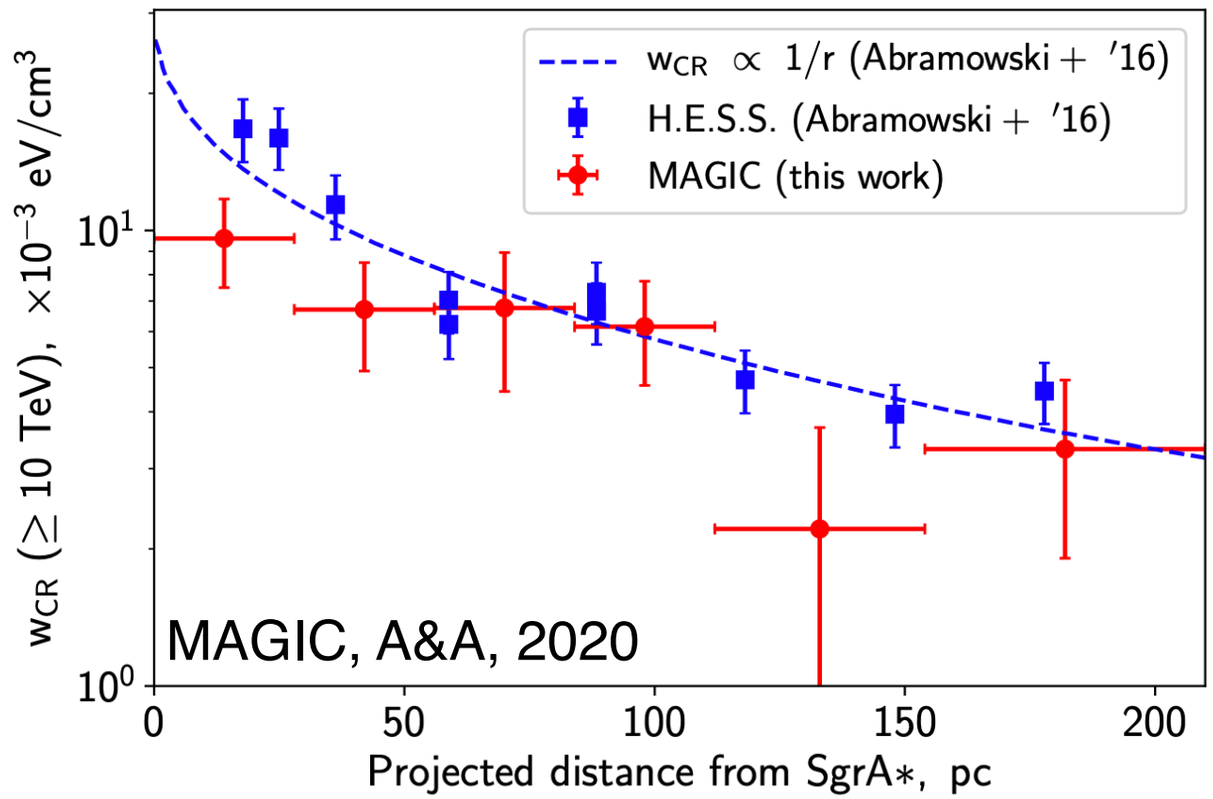
Galactic Sources of >TeV particles

- **Pulsars + their winds & nebulae (mostly $e^{\pm}$)**
- **Binary systems (massive stars, μ-quasars, etc.)**
- **Nova & Supernova Remnants**
- **Sgr A***
- **Massive Stellar Clusters / Superbubbles**

Credit: NASA/CXC/UMass/D. Wang et al.

Diffuse TeV emission in inner Galaxy





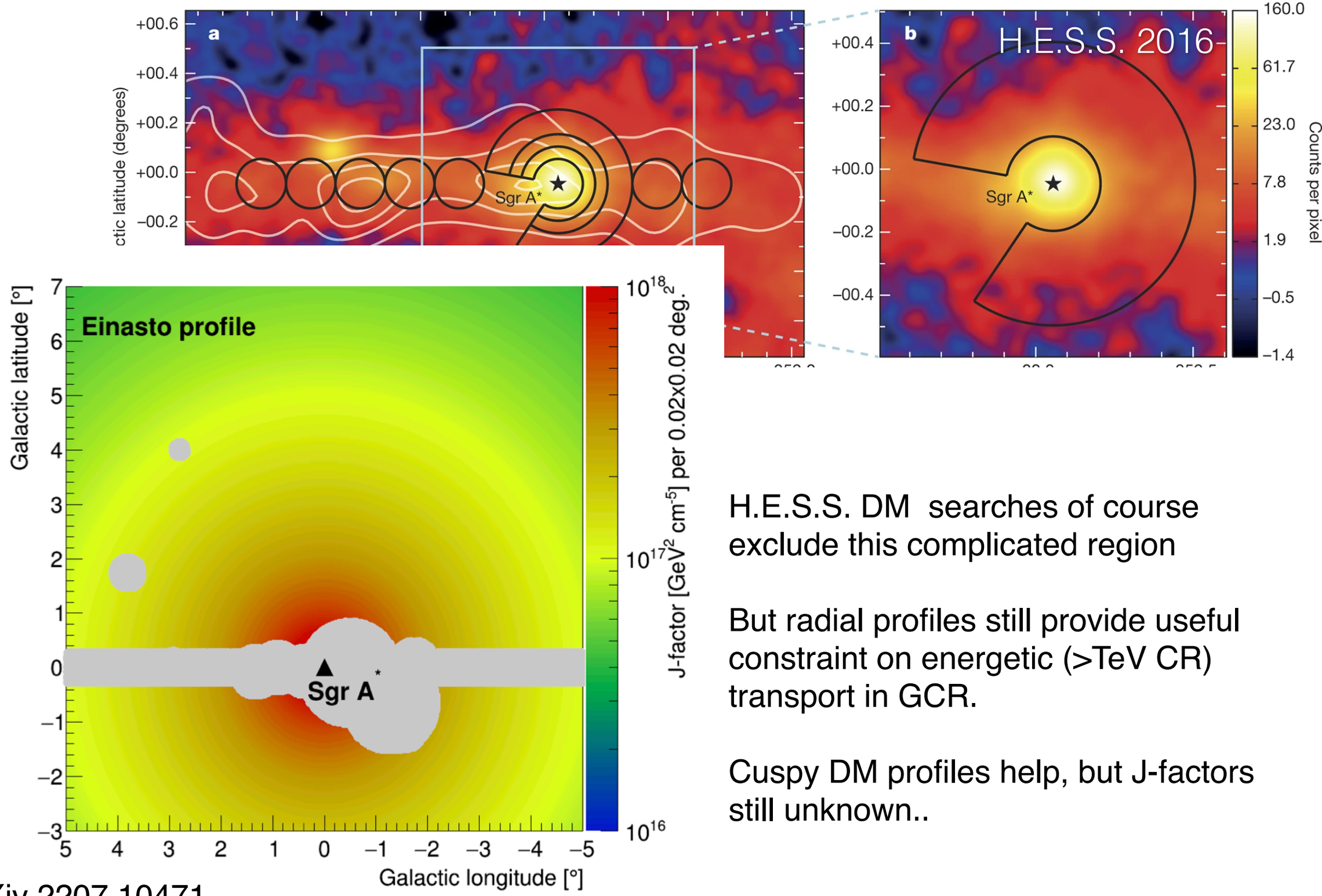
Gas correlation favours Hadronic origin of TeV emission

Profile suggests a central source of >> TeV CRs (possibly from Sgr A*?)

Can be used to place upper limit on the "effective" diffusion coefficient in the GCR

$$D_r(E) \ll Lc$$

Diffuse TeV emission in inner Galaxy



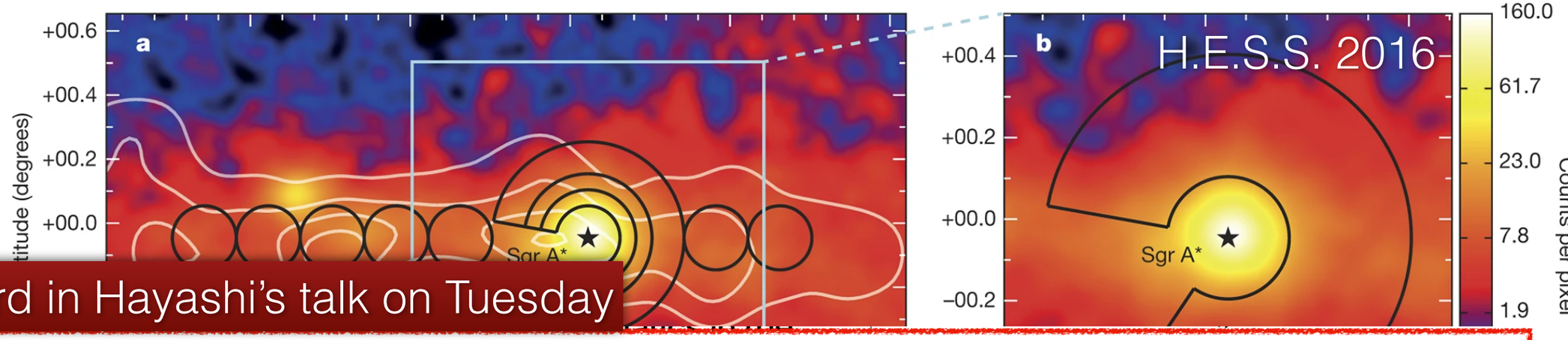
arXiv 2207.10471

H.E.S.S. DM searches of course exclude this complicated region

But radial profiles still provide useful constraint on energetic (>TeV CR) transport in GCR.

Cuspy DM profiles help, but J-factors still unknown..

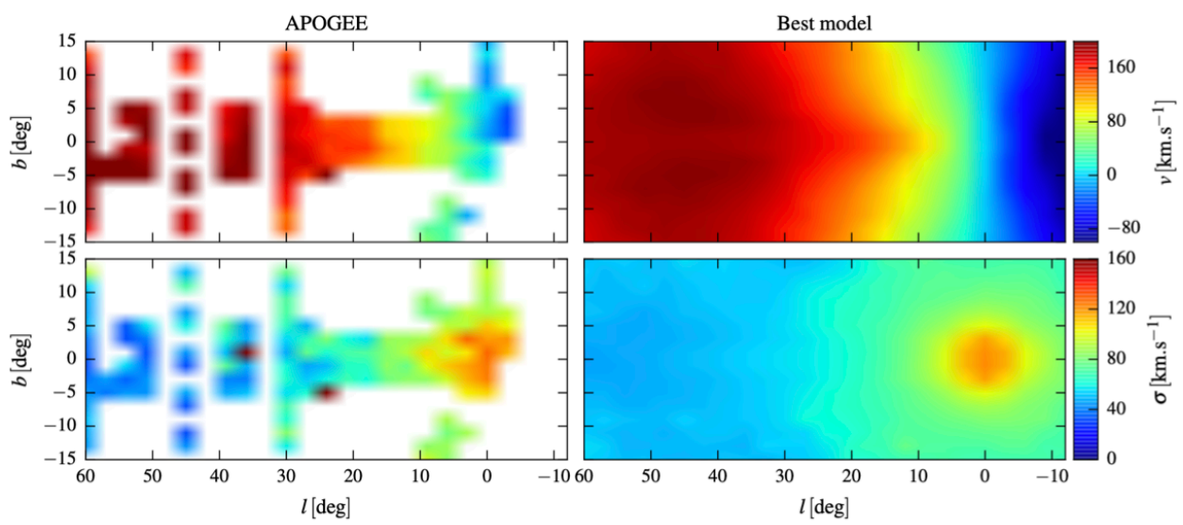
Diffuse TeV emission in inner Galaxy



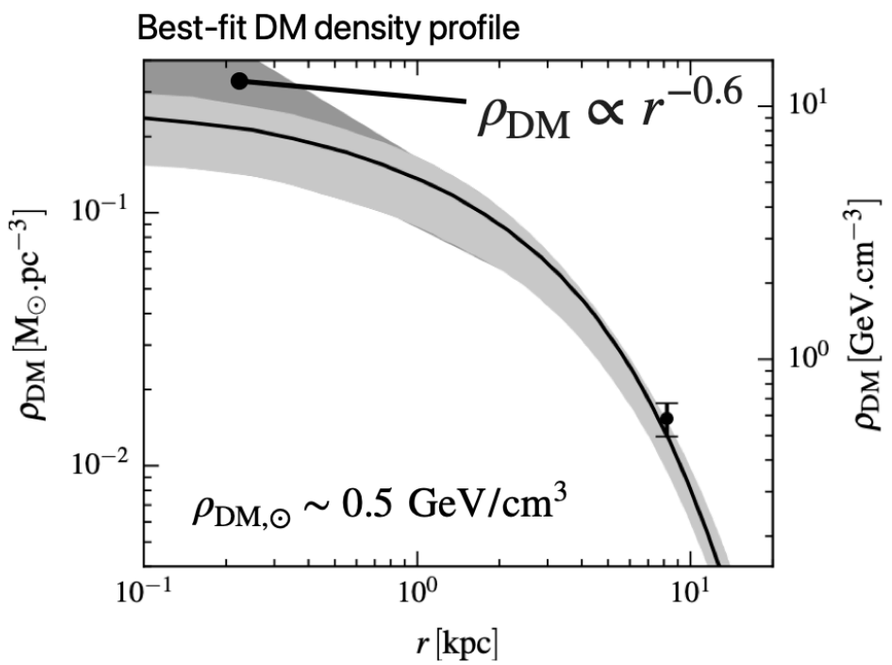
As we heard in Hayashi's talk on Tuesday

DM density inner slope of the MW is still unknown, although there are many efforts to estimate it...

- From the analysis, DM density favors shallower cusped or cored density inner slope.

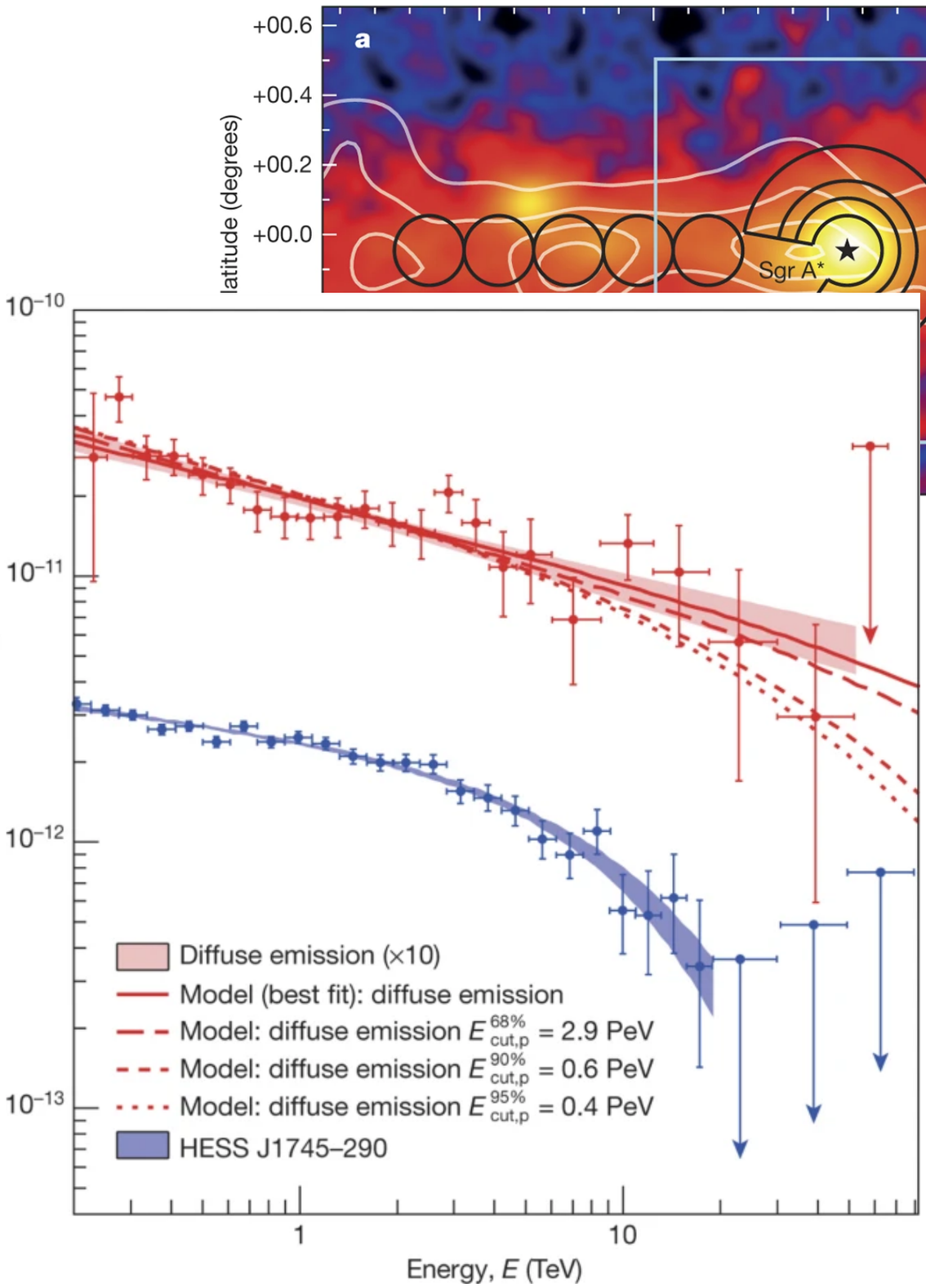


The mean velocity and velocity dispersion maps from the best fit model.



Portail et al. (2016, 1608.07954)

Diffuse TeV emission in inner Galaxy



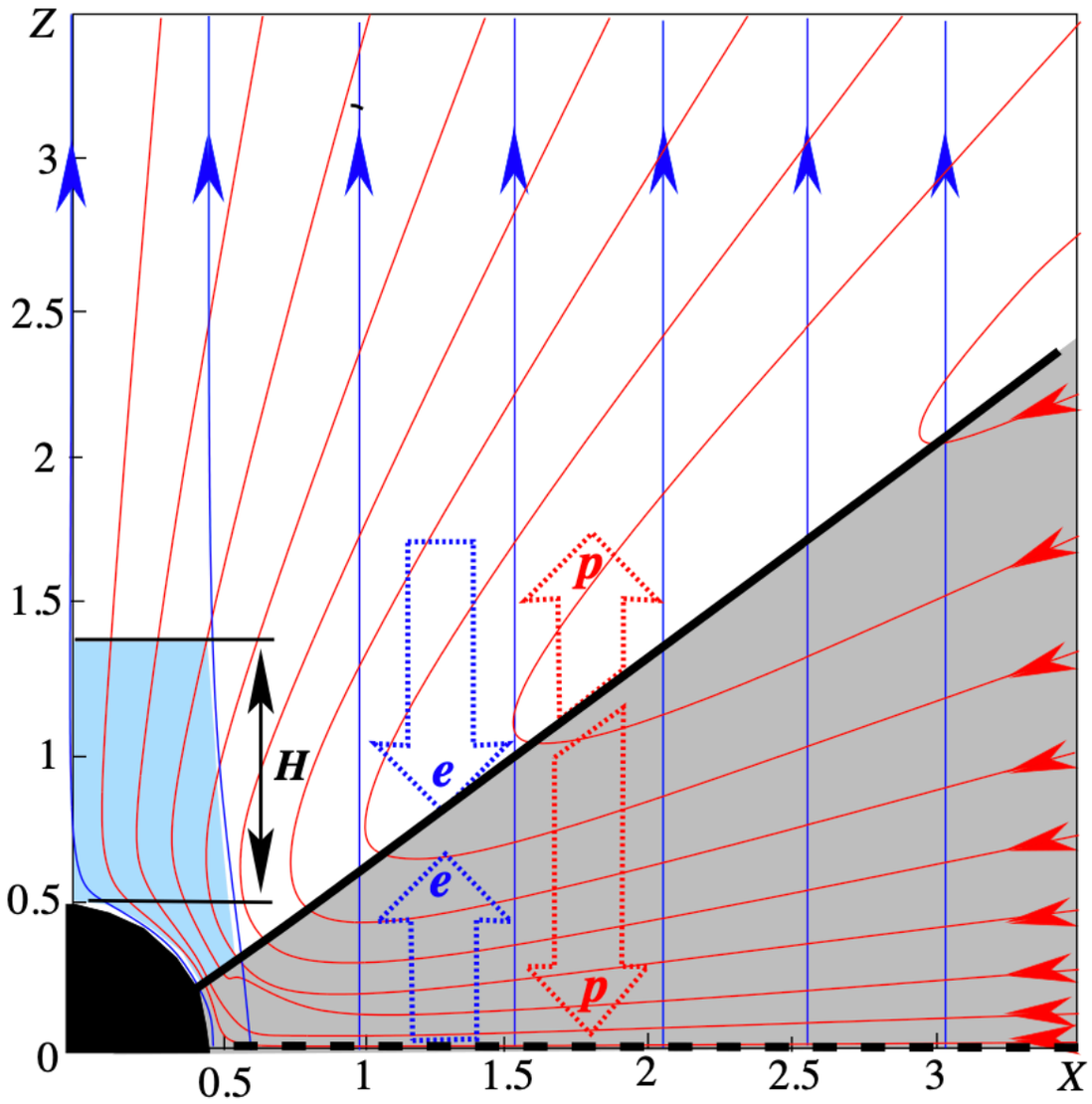
Diffuse emission is consistent with a power law (harder than local CR spectrum)

No clear high-energy turnover.

Is Sgr A* feeding this emission?

Are there other unresolved candidate sources in GCR?

Tapping into the Gap potential



CRs “leak” into gap (Nerenov et al. NJP, ’09)

Steady gap profiles:

- Cross gap potential $\propto \dot{m}^{-1}$
- Gap Luminosity $\propto \dot{m}^{-0.6}$

PV cross gap potential possible at current accretion rate.

Katsoulakos et al., ApJL, 2020

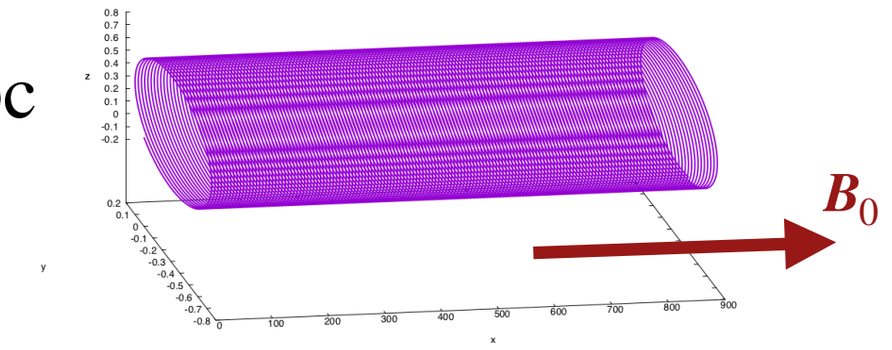
Bottom line : steady models of Sgr A* predict narrow particle distributions in GCR!
Observed spectrum however will depend on time history and subsequent transport

Magnetic fields and particle transport in the Galactic Centre

A digression into CR transport

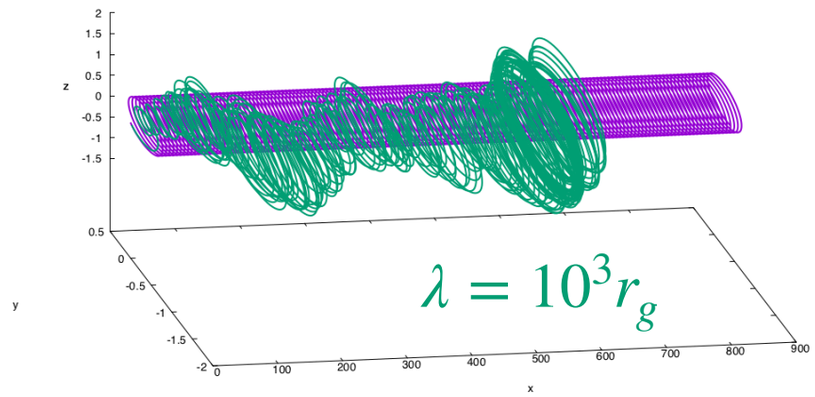
- We seek a better understanding of ~TeV particles' transport properties. What are the key length scales?

$$r_g \approx 10^{-4} \left(\frac{\langle B \rangle}{10\ \mu\mathrm{G}} \right) \left(\frac{E}{\mathrm{TeV}} \right) \ \mathrm{pc}$$



- Galactic average (a la GALPROP) would suggest a mean free path

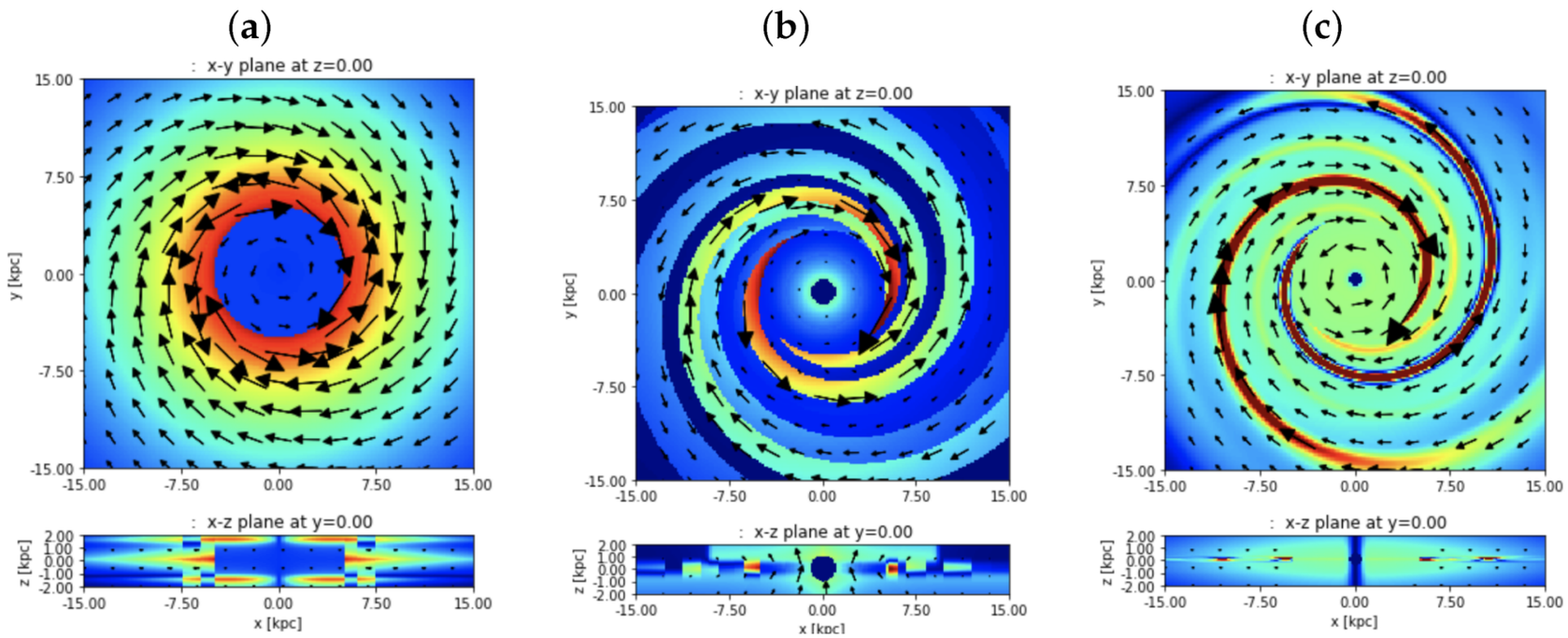
$$\lambda \approx 10 \left(\frac{E}{\mathrm{TeV}} \right)^{1/3} \ \mathrm{pc}$$



- If this is indeed the case, particles will spiral around field lines to distances of 10s of pc. (But what do the field lines do?)

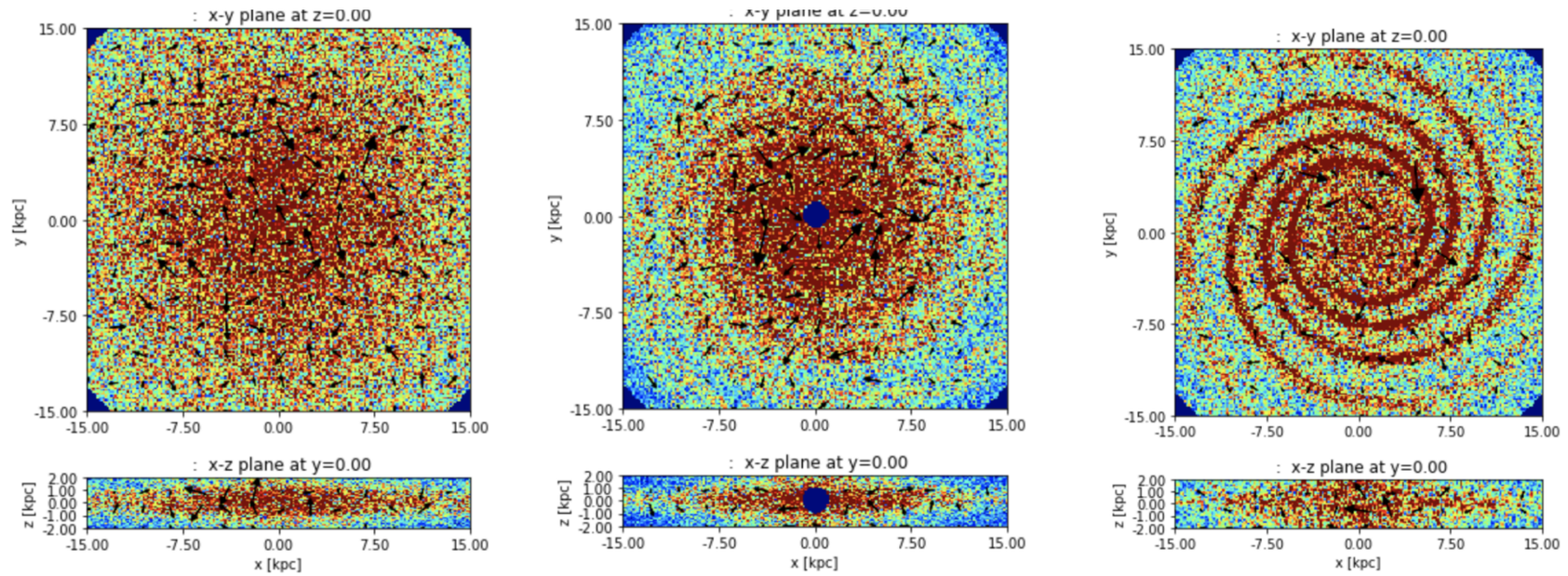
(Note, the outer scale of ISM turbulence is ≈ 100 pc. For GC radii, r < 100 pc, the field structure/statistics are very poorly constrained)

Magnetic Fields on galactic scales



Coherent fields

Sun et al. Jansson & Farrar Jaffe et al.

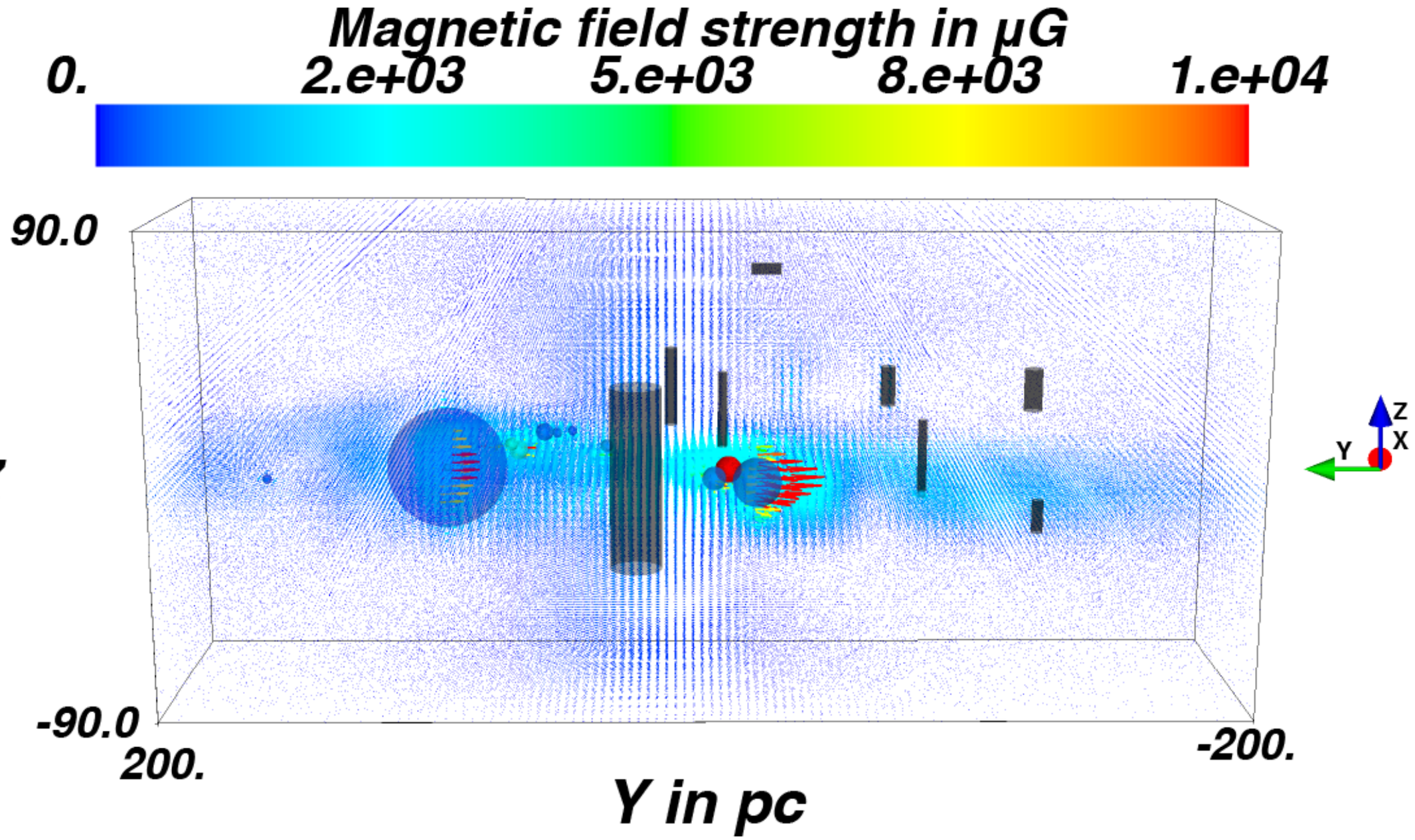


Isotropic fields

Jaffe, Galaxies, 2019

Big uncertainties still exist in all aspects of galactic magnetic field

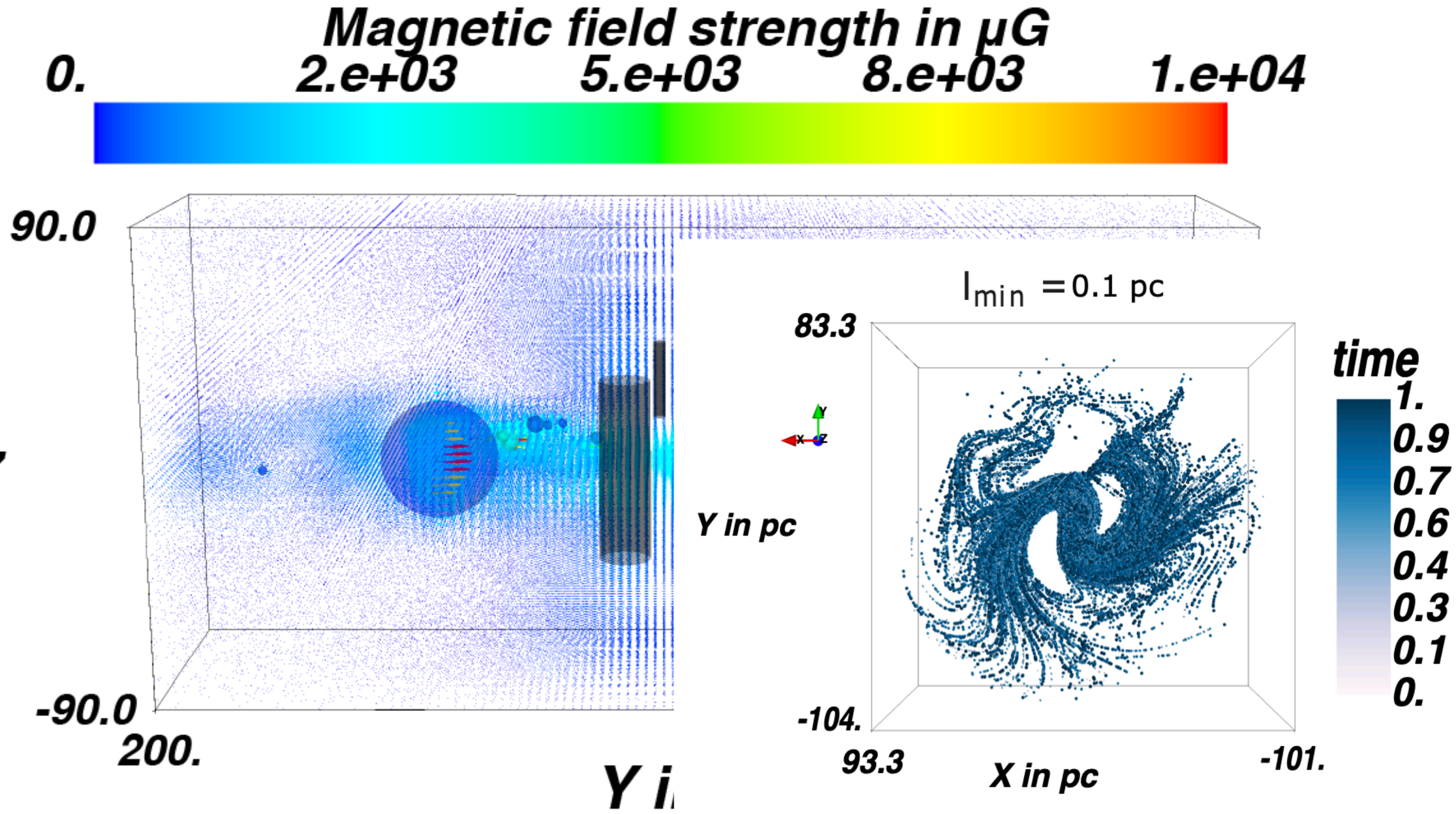
Magnetic fields in inner 200pc



Fields added component wise to match different observables

Guenduez et al (2020)

Magnetic fields in inner 200pc



arXiv 2207.08097

Fields added component wise to match different observables

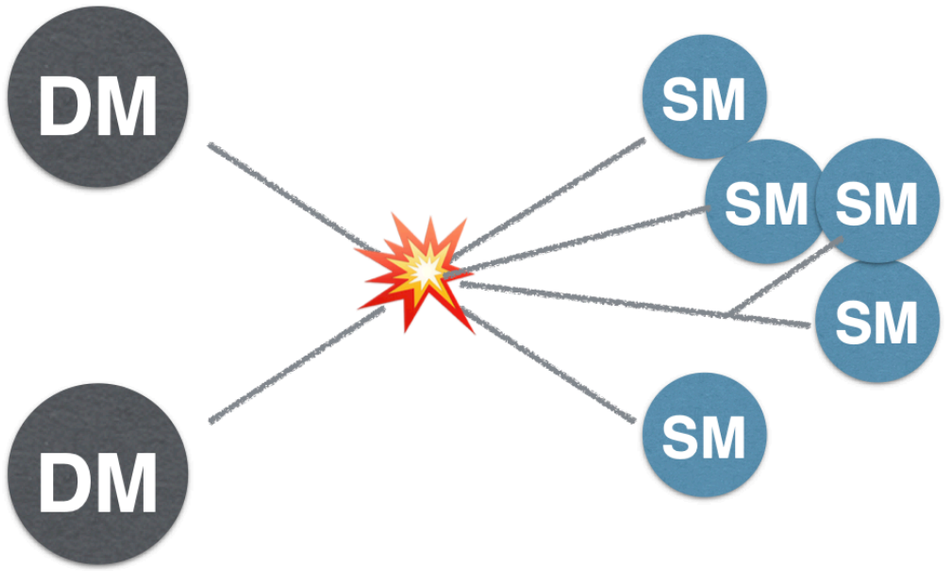
Guenduez et al (2020)

How can this impact DM searches?

Indirect searches for DM in GCR

Dark Matter annihilation

Prompt gamma rays

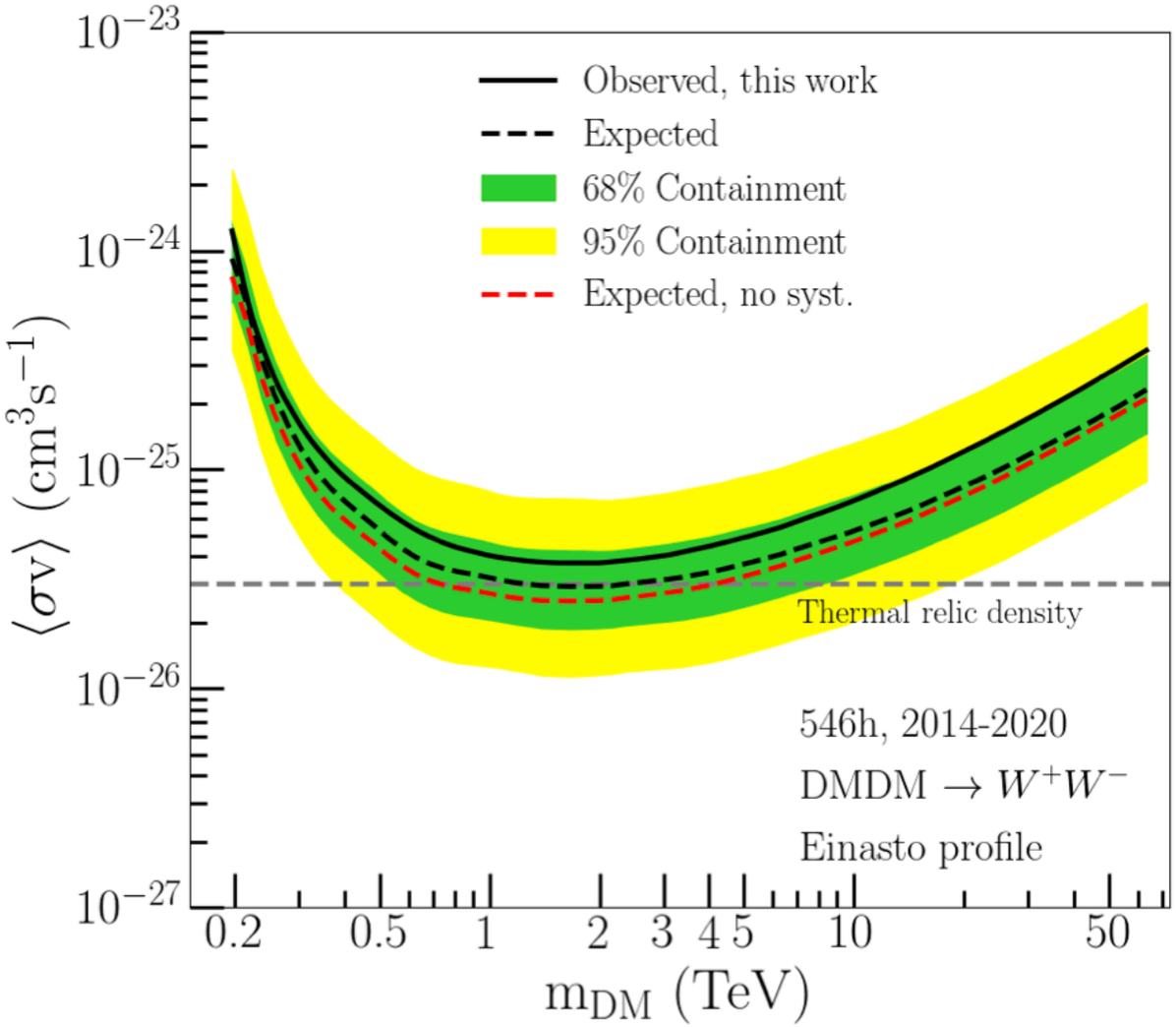


Appropriated from Martin Vollmann's talk yesterday

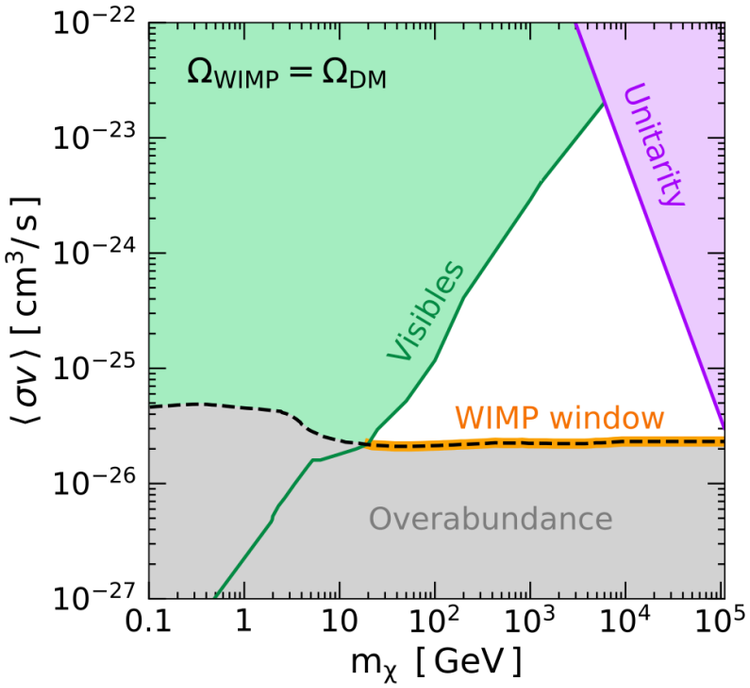
The role of "direct" and "delayed" leptonic products has been discussed, but a detailed treatment requires knowledge on electron transport in Central Galaxy (Lacroix et al. PRD '14)

Searching for WIMPs

- **TeV mass WIMP still popular.**



H.E.S.S. Coll., arXiv 2207.10471

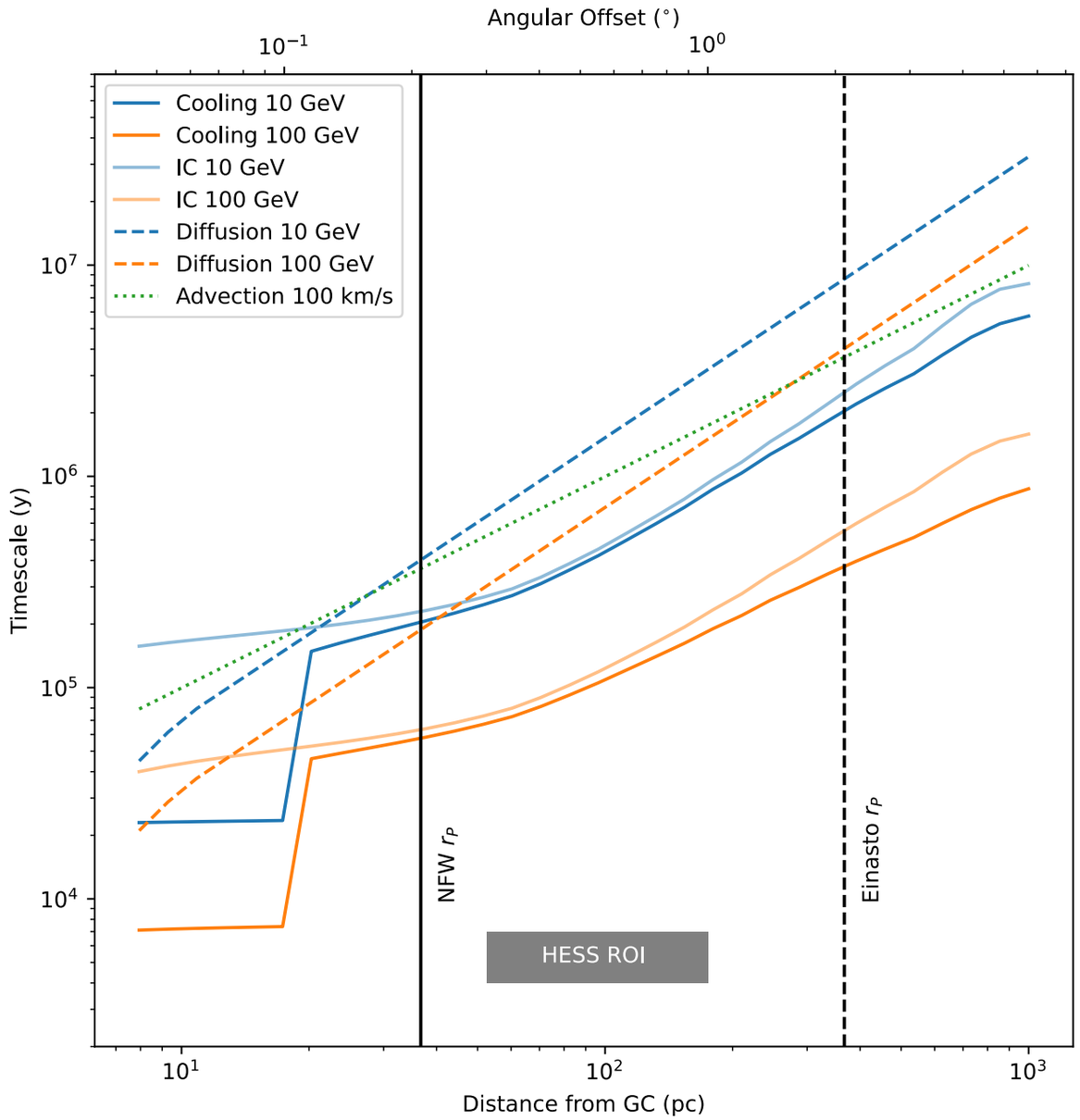


R. Leane, et al., arXiv:1805.10305

- **Latest H.E.S.S. measurements constrain the velocity-weighted annihilation cross section of Majorana WIMPs (for cuspy profiles)**

A TeV WIMP puts $e^{\pm}$ products in an interesting energy range for γ-ray instruments

$e^{\pm}$ cooling times in inner Galaxy



Here we exploit the limits on diffusion from γ-ray observations $D \sim D_{ISM}/10$

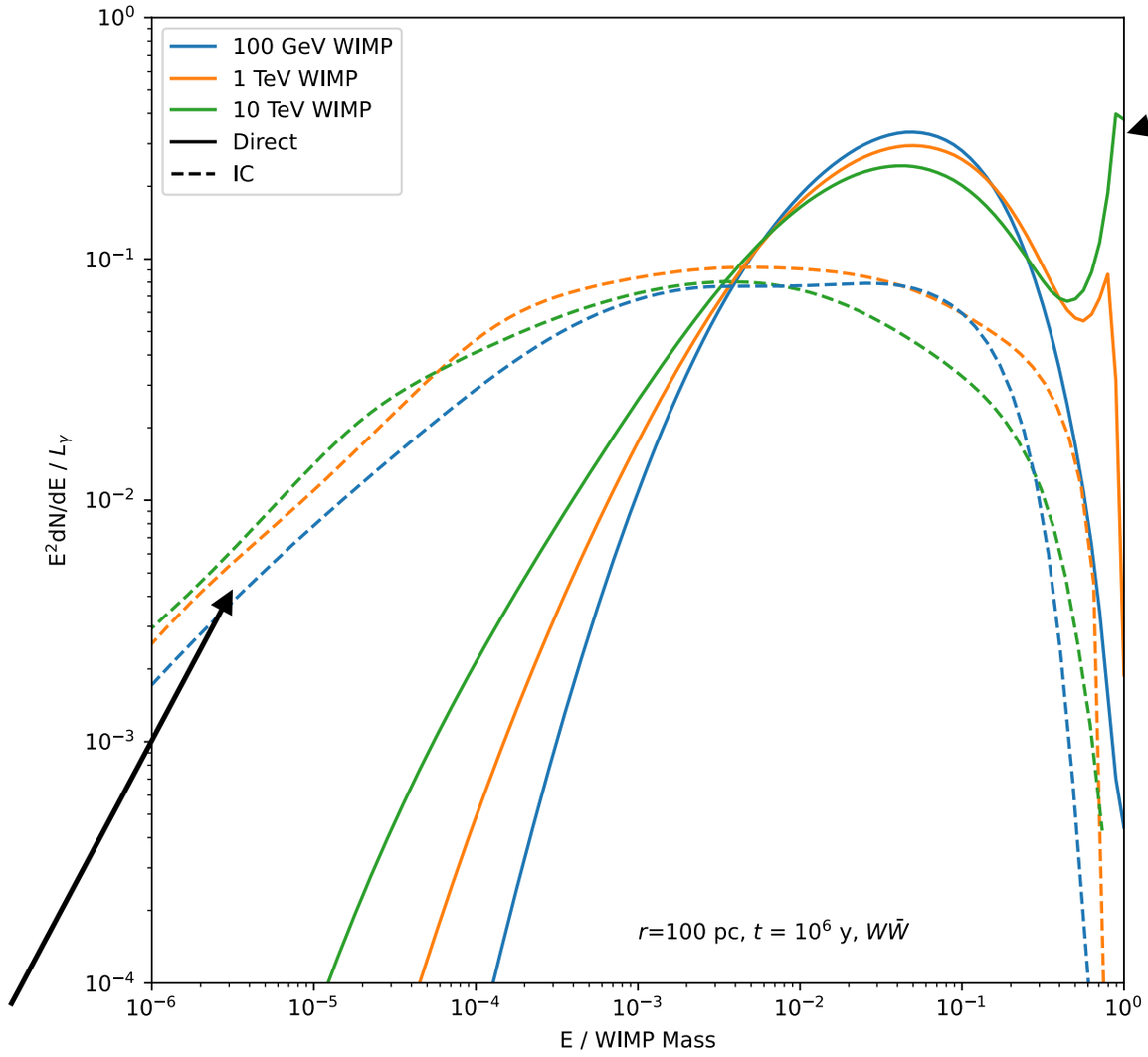
- $t_{\rm cool} \approx t_{\rm diff}/10 \propto D^{-1}$
- Key point: ***Electrons cool in-situ***
- IC emission from pairs produced as products of DM annihilation

Photon targets from Popescu et al (2017)
Fields from Jansson & Farrar (2012)

Julia's poster on Monday
- Djuvsland et al. (To be submitted)

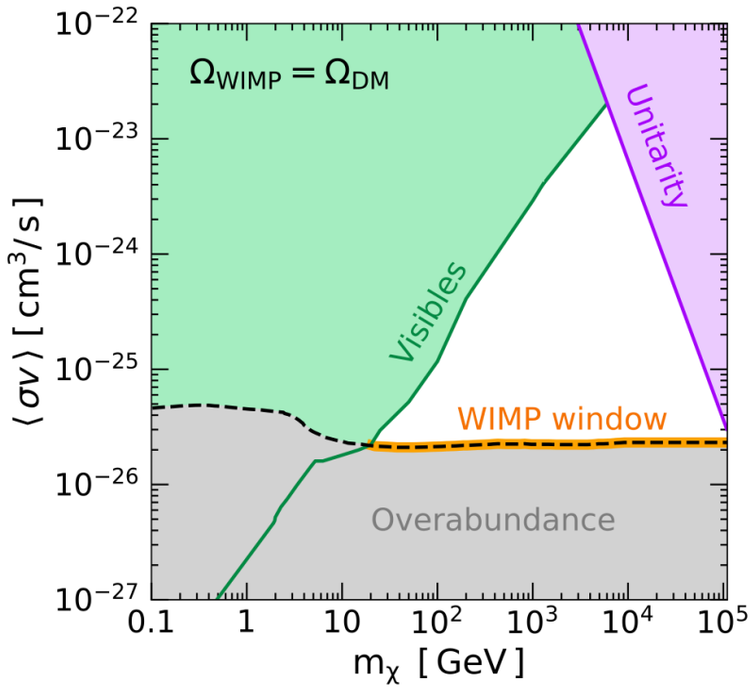
Direct vs delayed photon spectrum

Djuvsland et al.



Direct

Delayed



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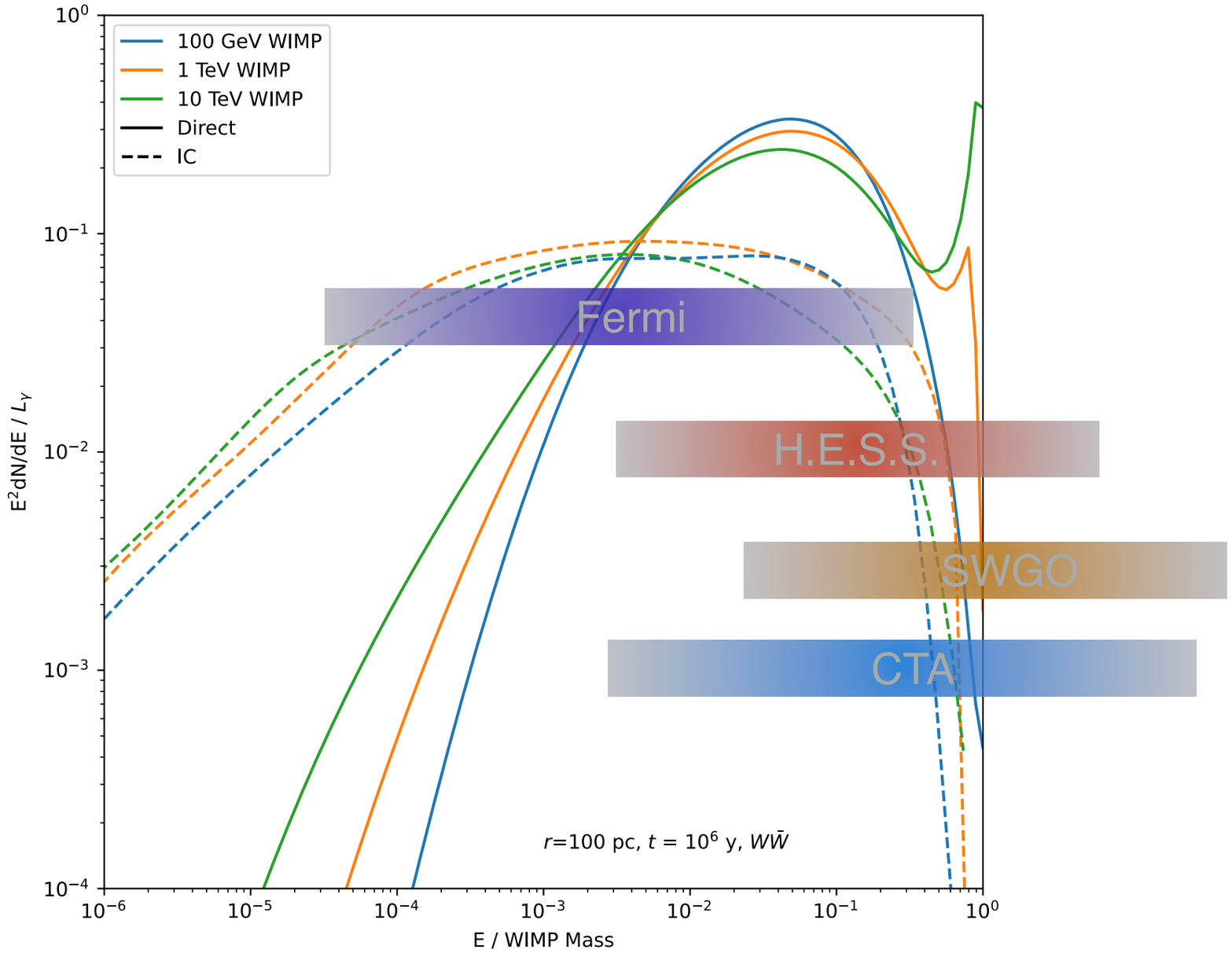
Direct photons and pairs taken from DM Cook-book (Cirelli et al. JCAP 2011)

IC emission from GAMERA† library

† github.com/libgamera/GAMERA/

Prospects for signals from 3 TeV WIMP



A more sophisticated multi-dimensional model needed for template
But a clear impact for Fermi DM searches is evident

Take Home Messages

- **Astrophysical foreground is important**
  - **CTA/SWGO will improve on current limits of TeV DM WIMP**
- **Our understanding of CRs, their sources and transport, is incomplete**
  - **Improved theoretical input much needed**
- **Energetic particle transport plays an important role**
  - **Delayed emission provides a novel approach to improve sensitivity**

Thank you