Ancora Supernova Remnant G288.8-6.3 in the context of multiwavelength observations

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#DIASdiscovers
dias.ie

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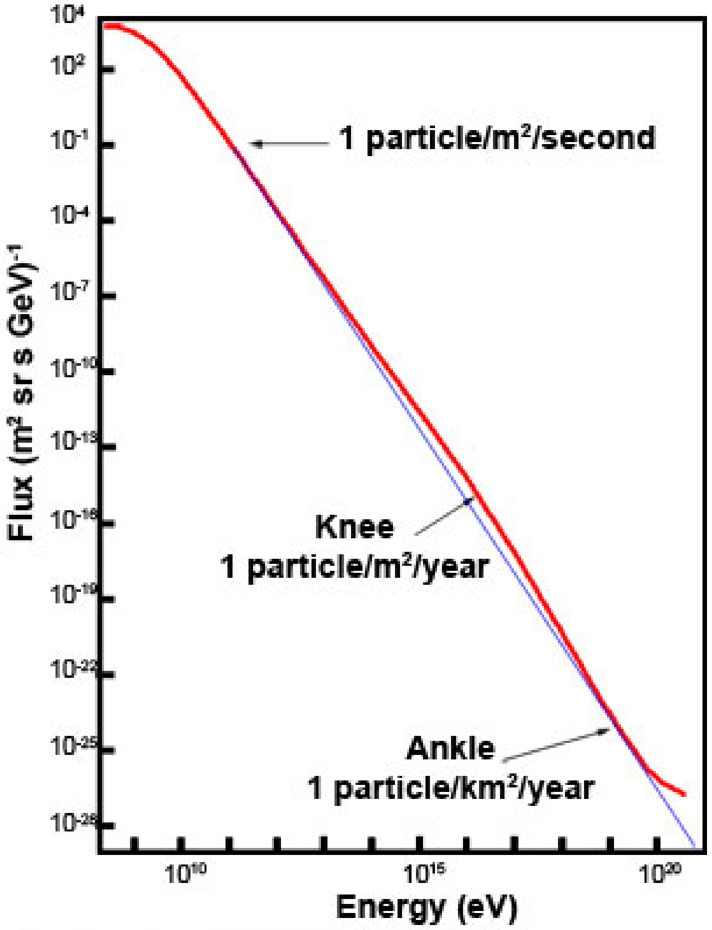
CTAO | Australia Meeting #2 2024 @Parramatta, NSW, Australia

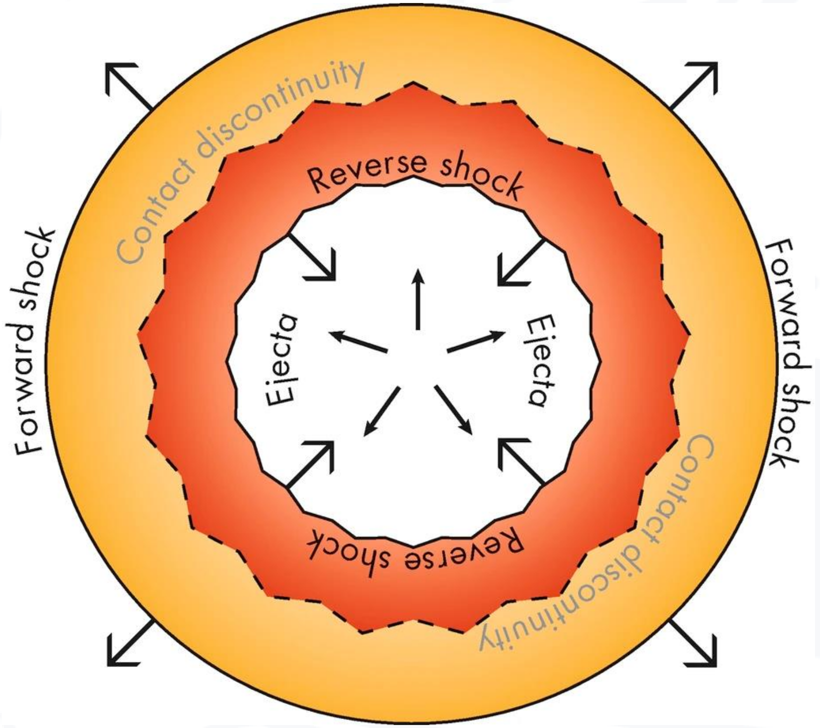
Cosmic rays (CRs)

Victor Hess 1914/15



Credit: Swinburne Centre for Astrophysics and Supercomputing

Supernova remnants



Source: SNR evolution, Vink 2020

- Hadronic
  - Pion decay
- Leptonic
  - Synchrotron radiation
  - Inverse Compton scattering

Phases:

- Free expansion phase
- Sedov-Taylor phase
- Radiative phase

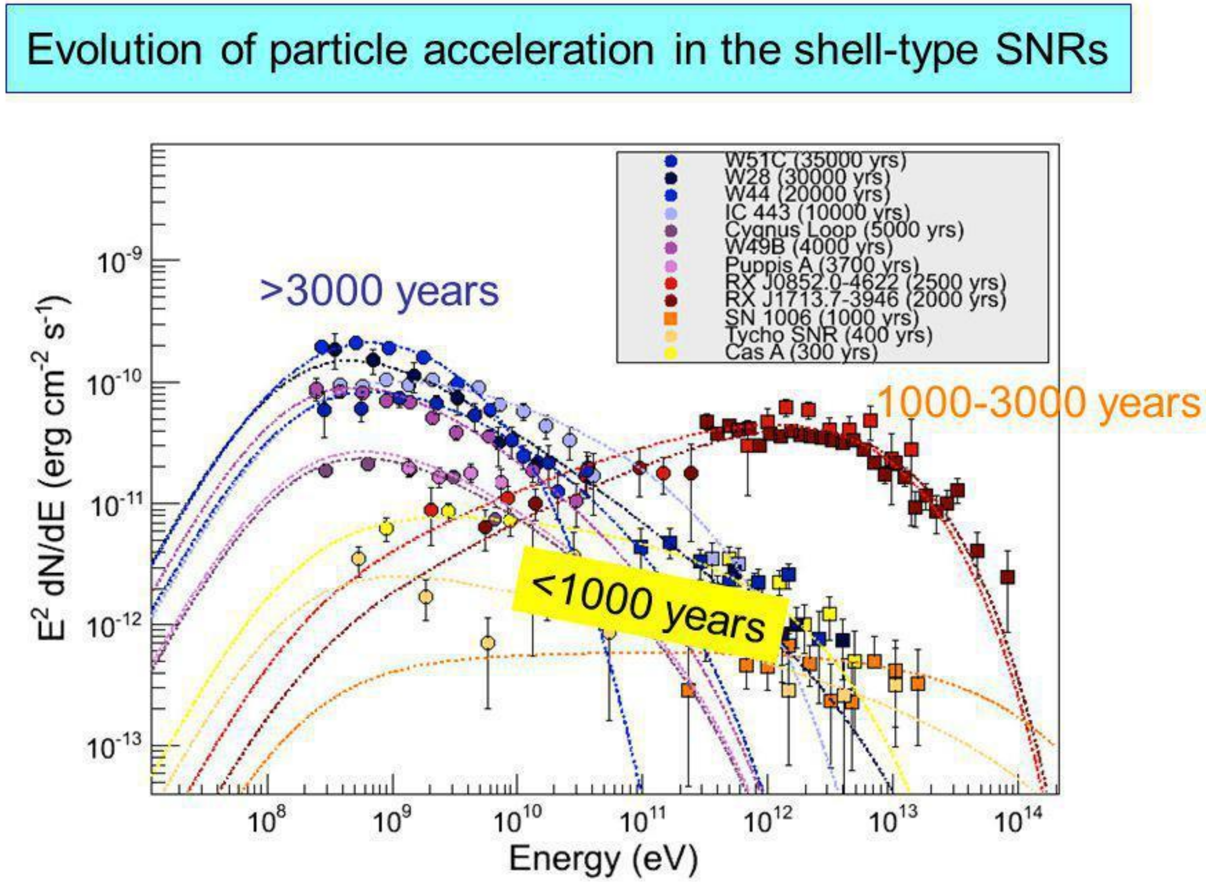
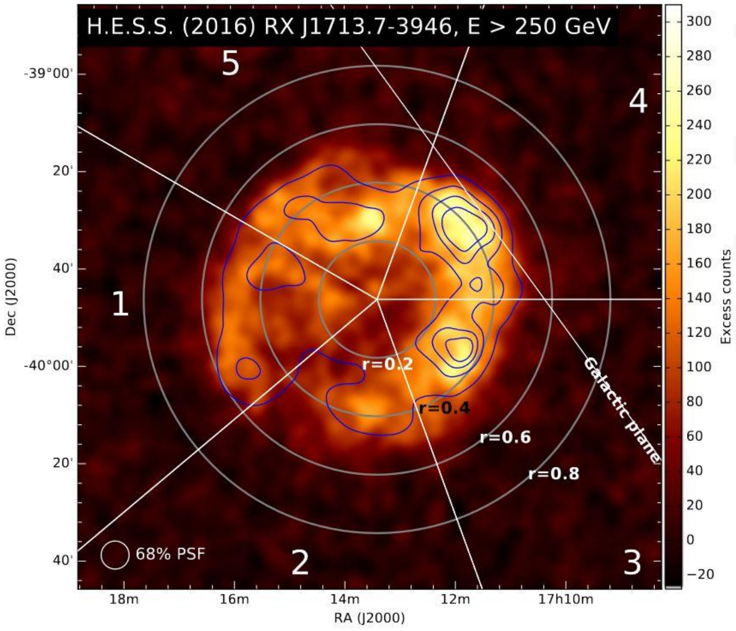


Figure: Gamma-ray flux from various SNRs (Funk, TeVPa 2011)

Credits: R. Brose, PASTO, 5-7 September 2022.



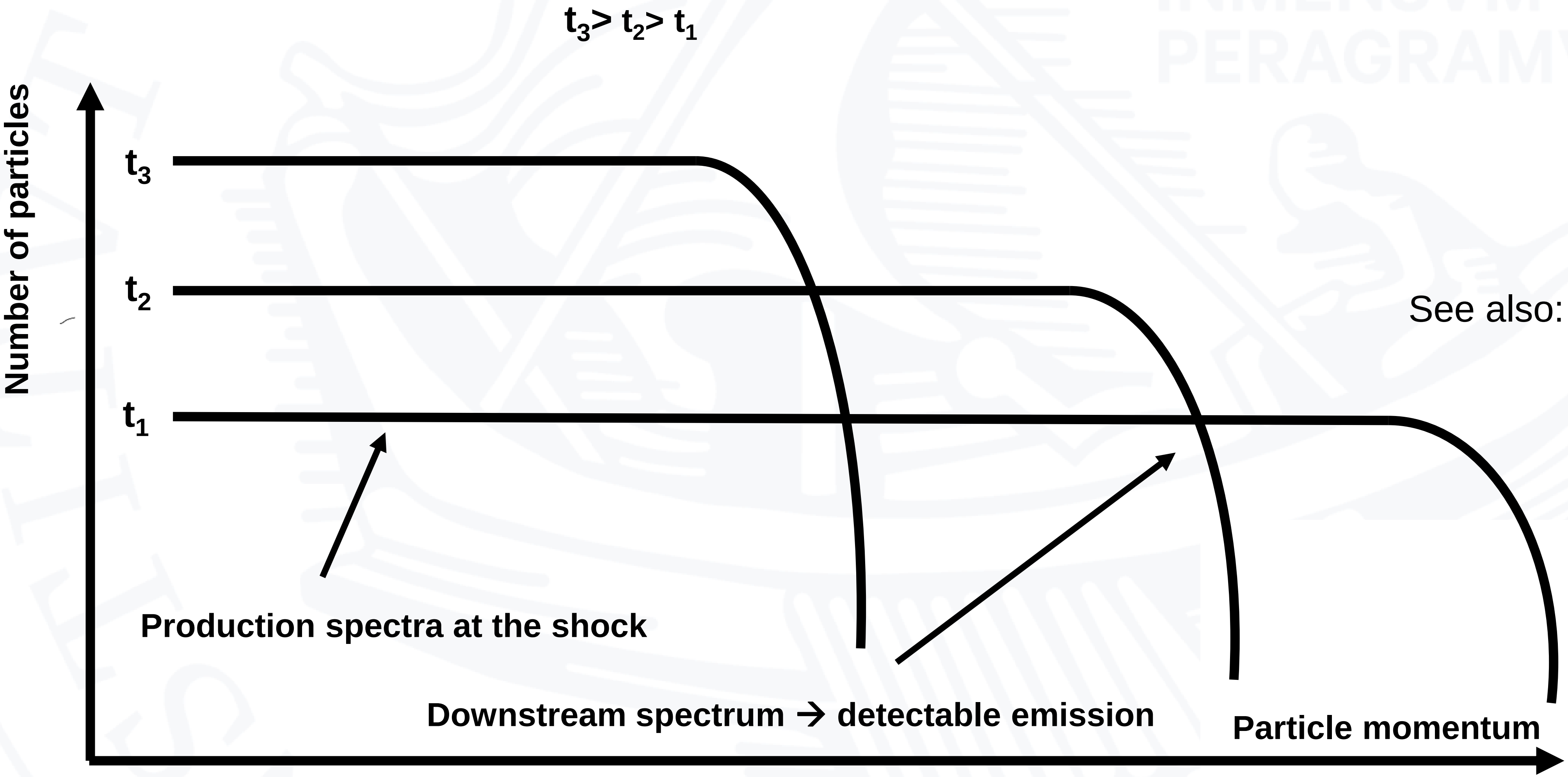
More and more observational constraints:

Models need to account for spectral evolution AND morphology

→ **Problem**: often complicated regions, interaction with gas/clouds etc.

Cosmic-ray escape

The mechanism

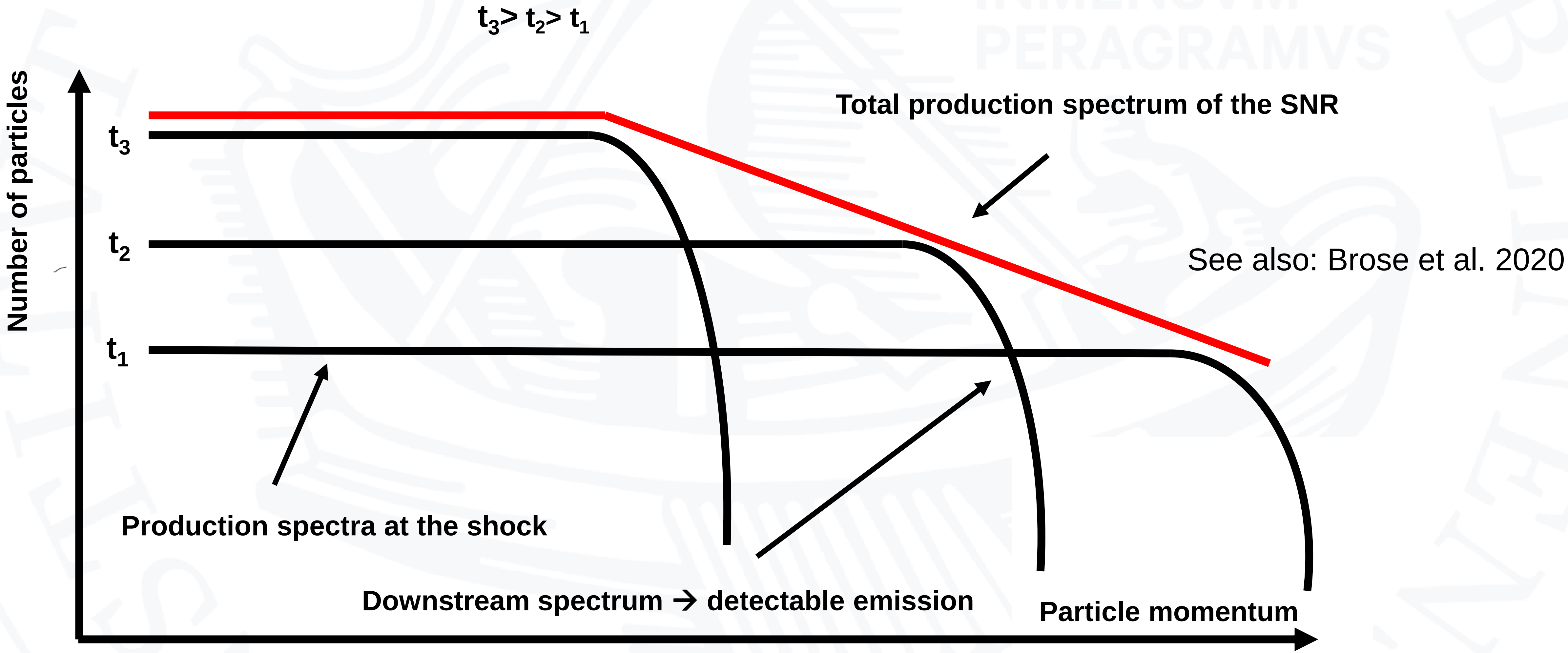


See also: Brose et al. 2020

Credits: R. Brose, PASTO, 5-7 September 2022.

Cosmic-ray escape

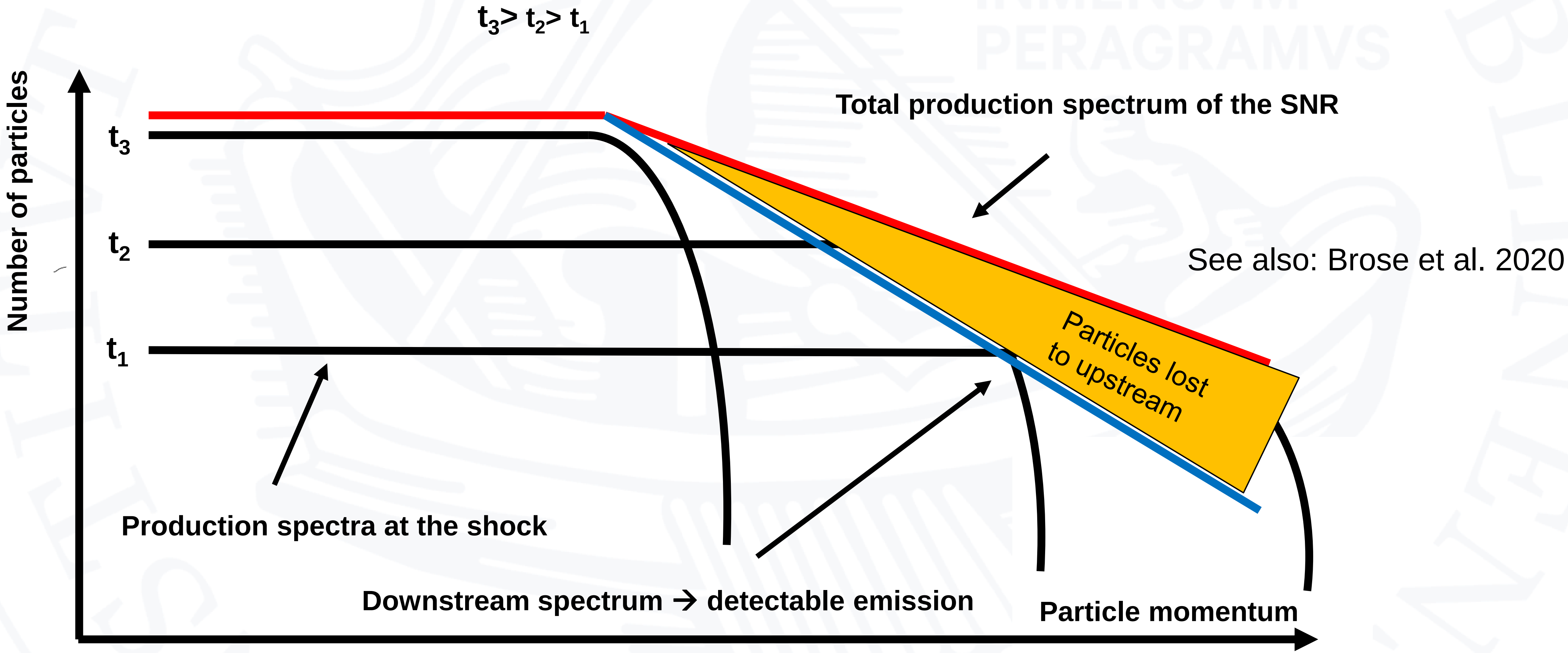
The mechanism



Credits: R. Brose, PASTO, 5-7 September 2022.

Cosmic-ray escape

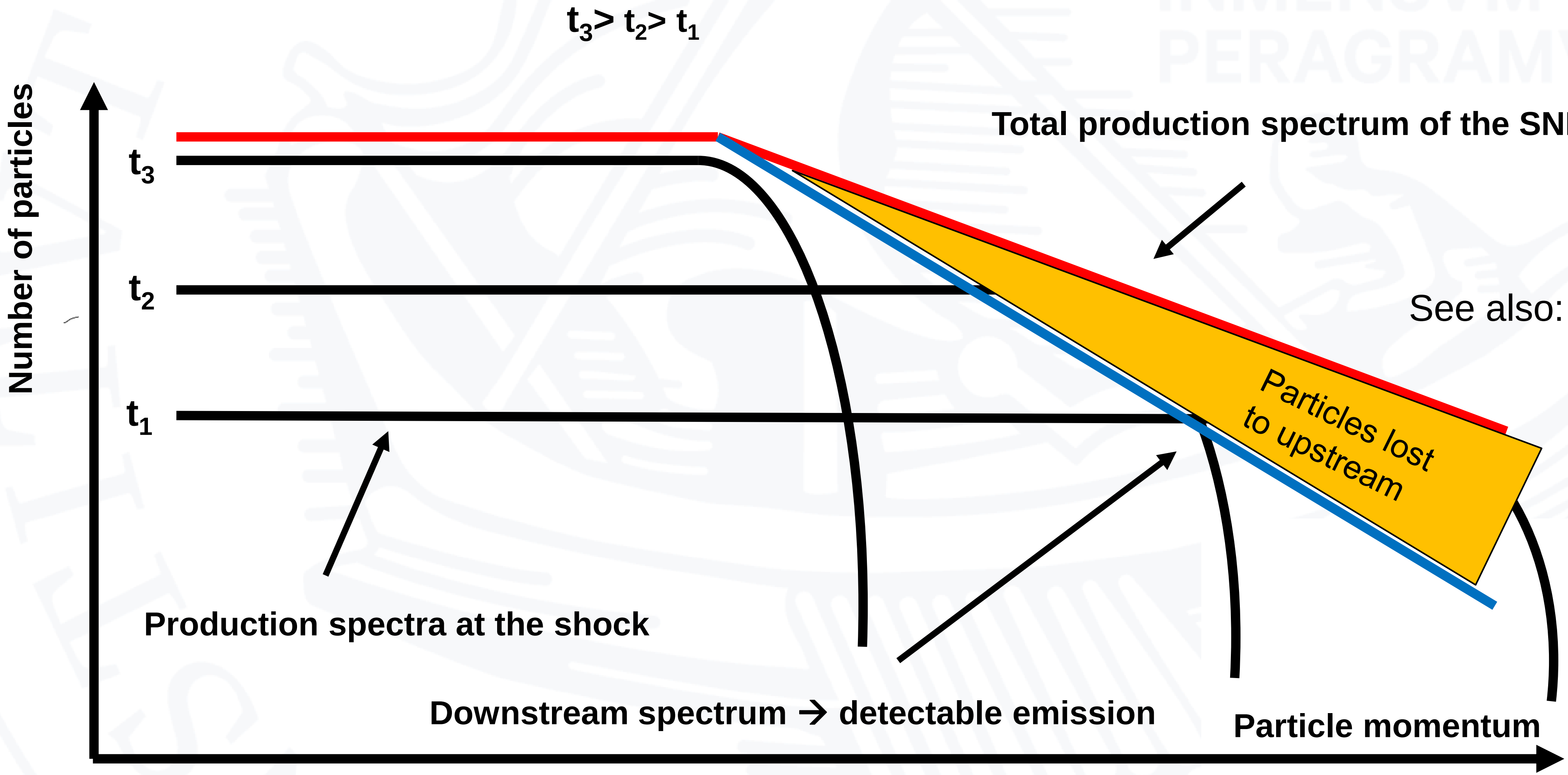
The mechanism



Credits: R. Brose, PASTO, 5-7 September 2022.

Cosmic-ray escape

The mechanism



See also: Brose et al. 2020

Credits: R. Brose, PASTO, 5-7 September 2022.

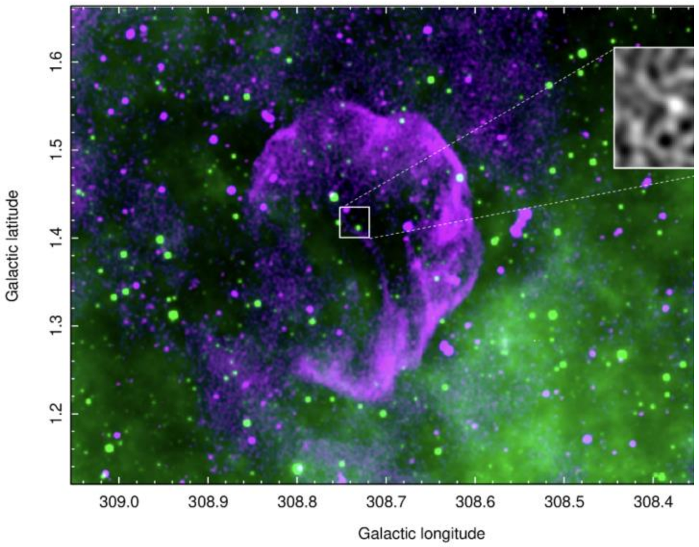
Detection of SNRs

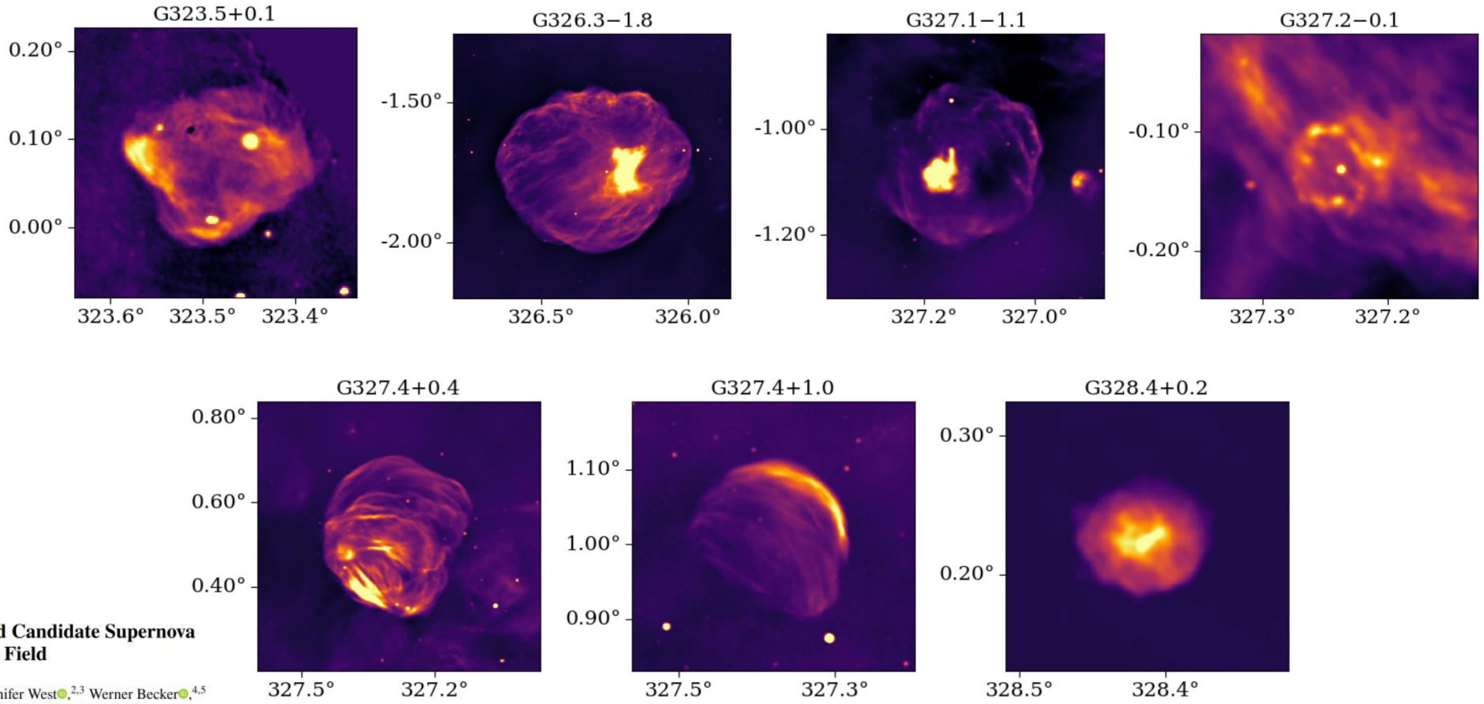
- Around 300 currently detected (see D. Green's catalogue)
  - Most of which at radio wavelengths first
  - Though non-thermal spectrum and shell-like morphology

- Around 10% of which are seen at gamma-ray energies
- Few in x-rays (~10)
- Few in optical
- Very few at very-high-energy (VHE) gamma-rays

Recent detections with ASKAP/EMU

G308.73+1.38 SNR candidate (Lazarevic et al. 2024)





A Catalogue of Radio Supernova Remnants and Candidate Supernova Remnants in the EMU/POSSUM Galactic Pilot Field

Brianna D. Ball,[1,*] Roland Kothes,[2,1] Erik Rosolowsky,[1] Jennifer West,[2,3] Werner Becker,[4,5] Miroslav D. Filipović,[6] B.M. Gaensler,[3] Andrew M. Hopkins,[7] Bärbel Koribalski,[8,6] Tom Landecker,[2] Denis Leahy,[9] Joshua Marvil,[10] Xiaohui Sun,[11] Filomena Bufano,[12] Ettore Carretti,[13] Adriano Ingallinera,[12] Cameron L. Van Eck,[14] and Tony Willis[2]

B. Ball et al. 2023

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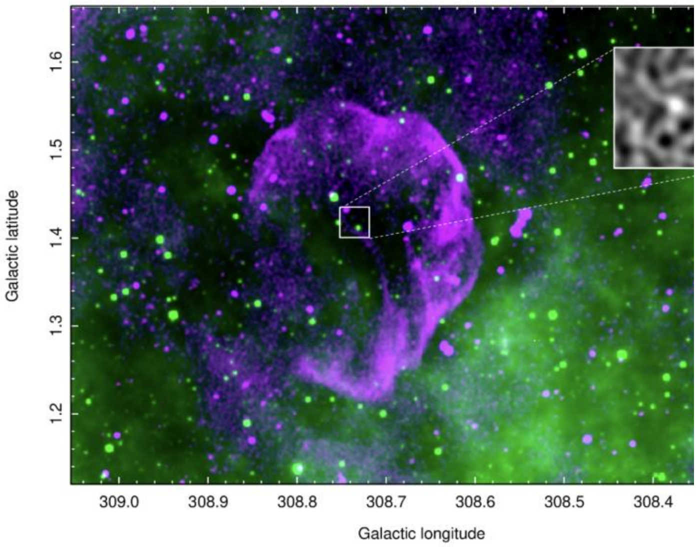

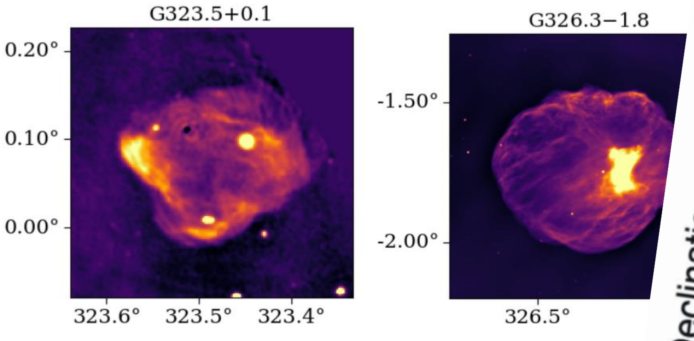

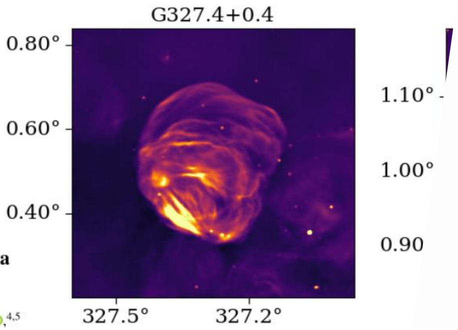

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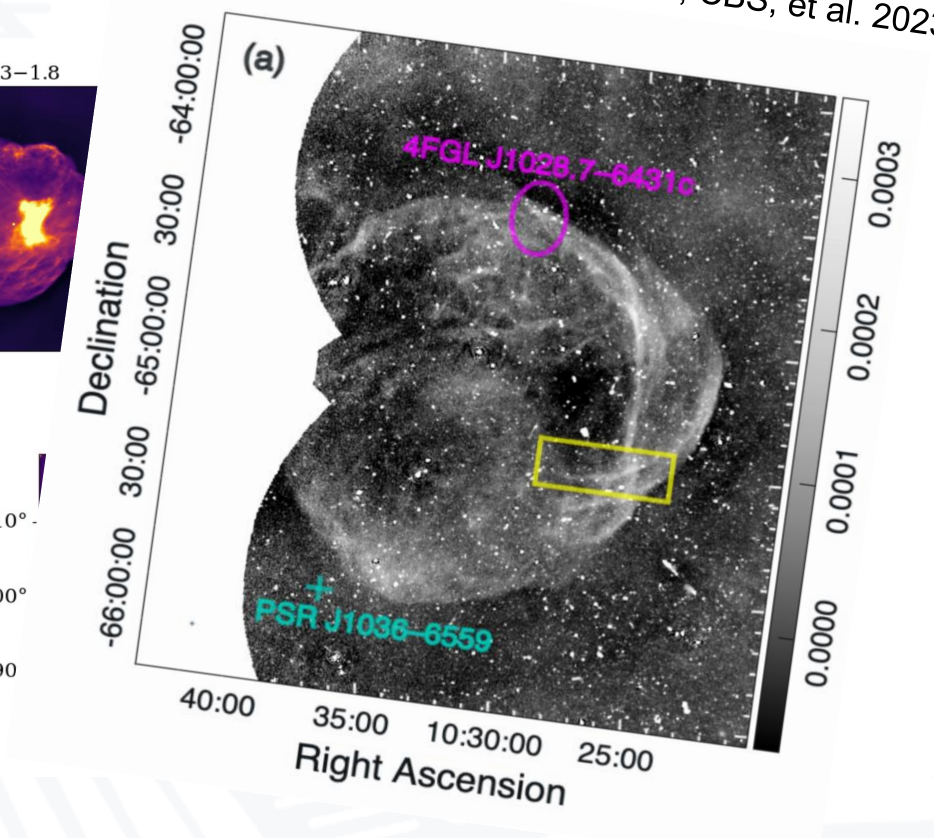
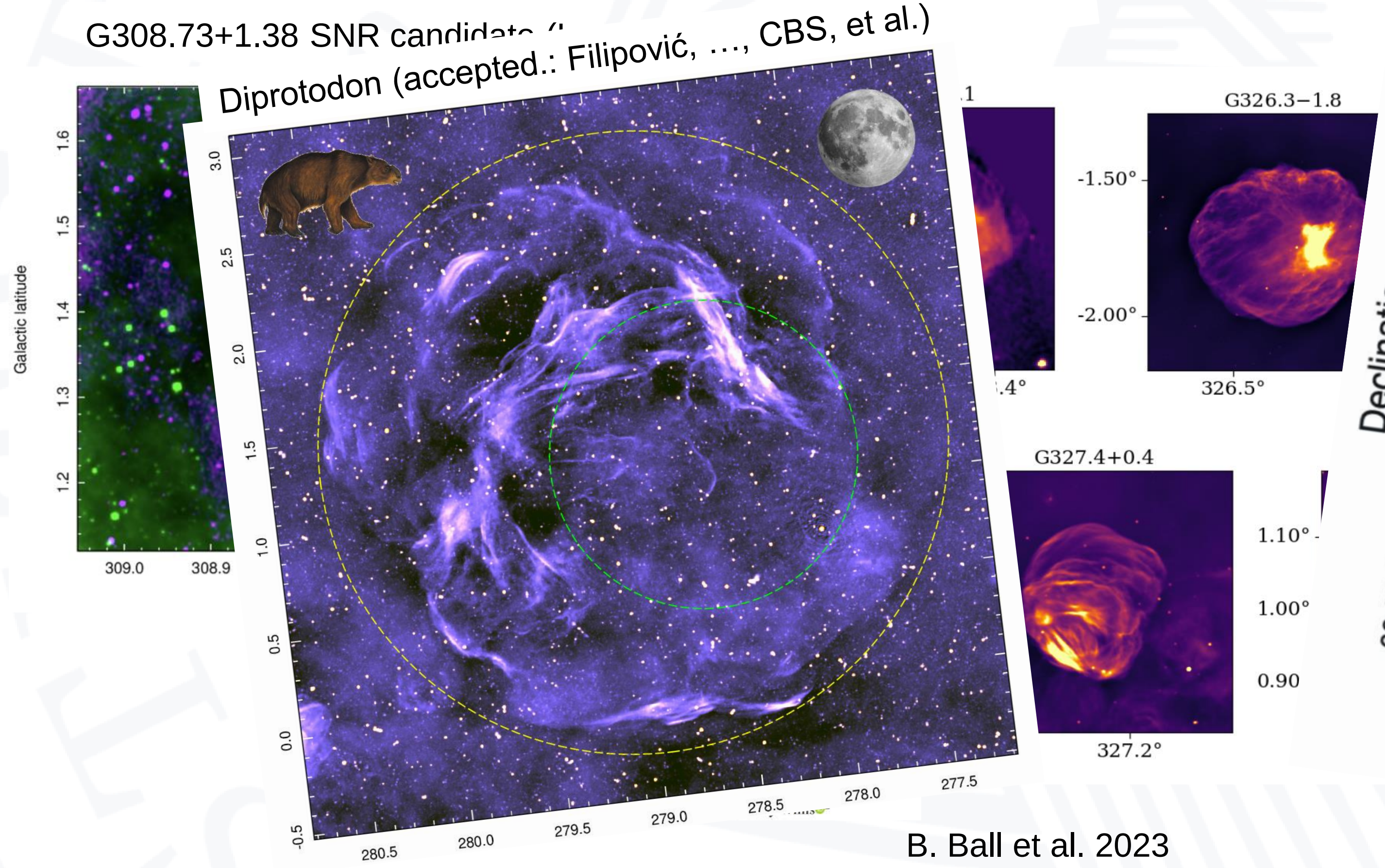
B. Ball et al. 2023

SNR G288.8-6.3 (Filipović, …, CBS, et al. 2023)



Recent detections with ASKAP/EMU



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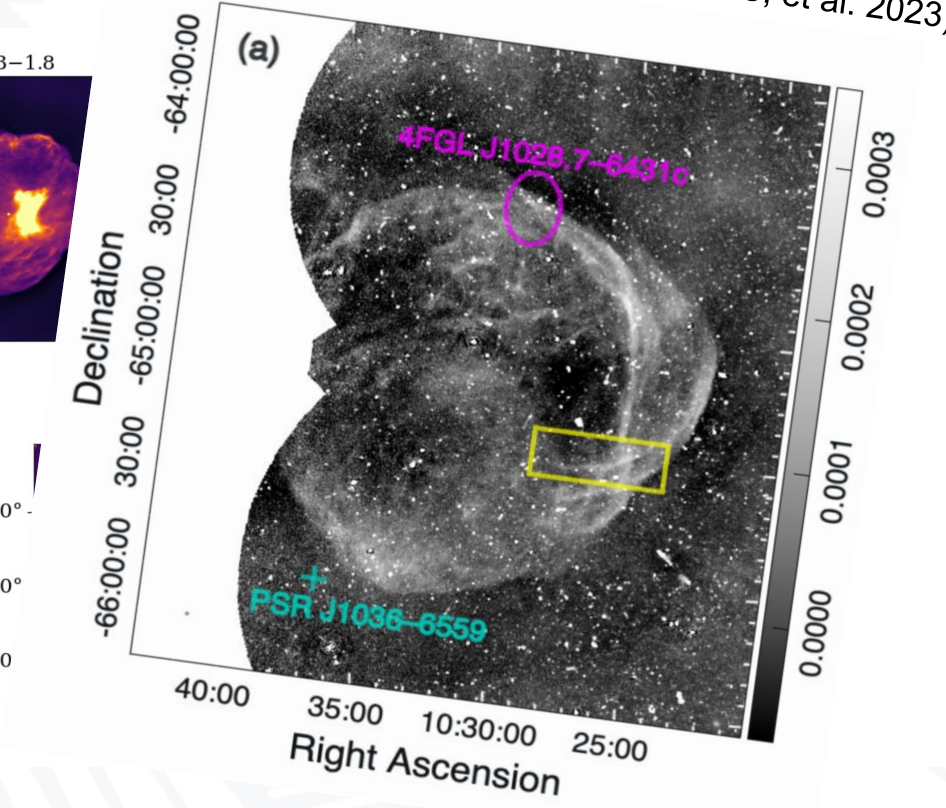
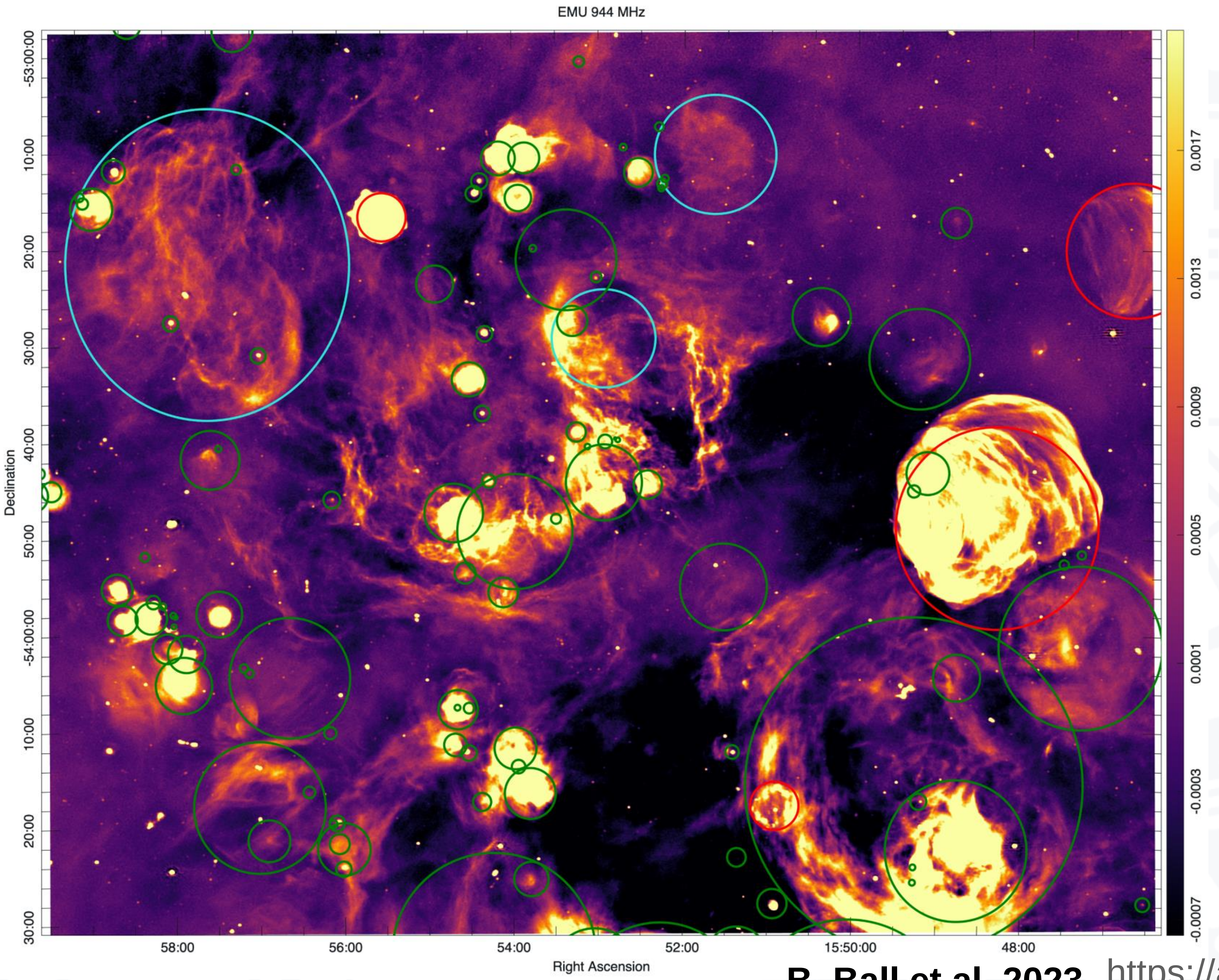


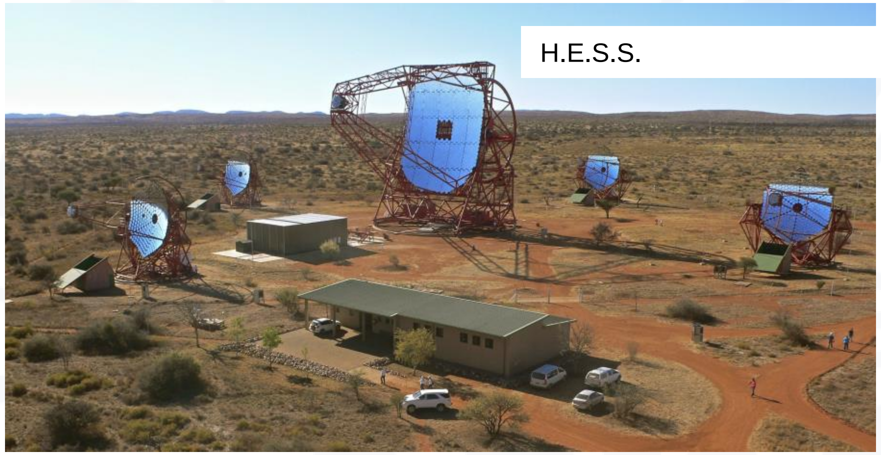
…. and many others on their way



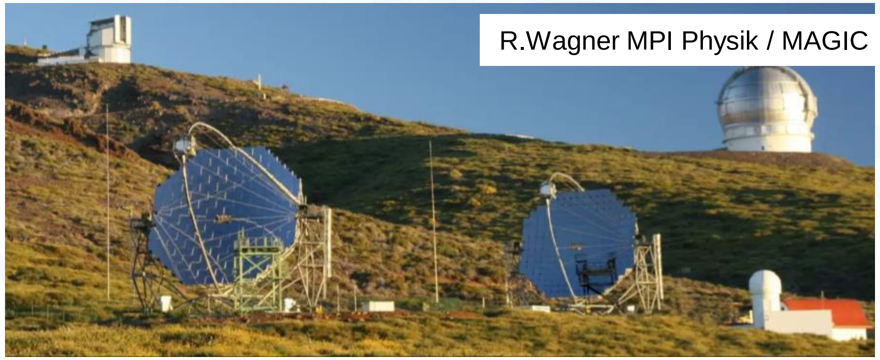
red circles: known SNRs
teal: SNR candidates
green: HII regions from the WISE catalogue.

B. Ball et al. 2023 https://arxiv.org/pdf/2307.01948

Gamma-ray astronomy


H.E.S.S.


VERITAS

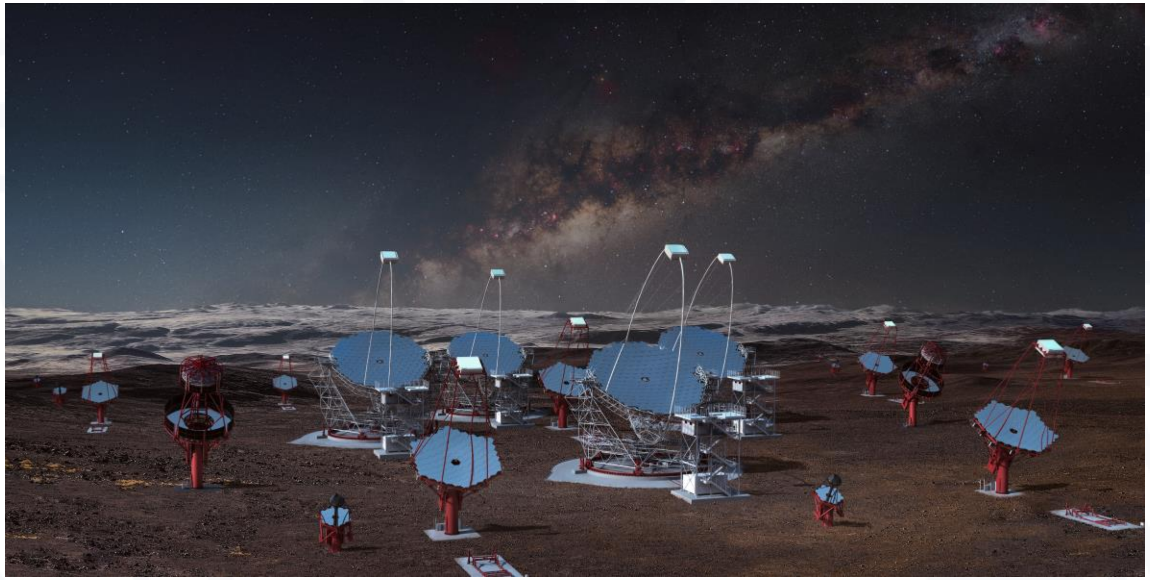

R.Wagner MPI Physik / MAGIC

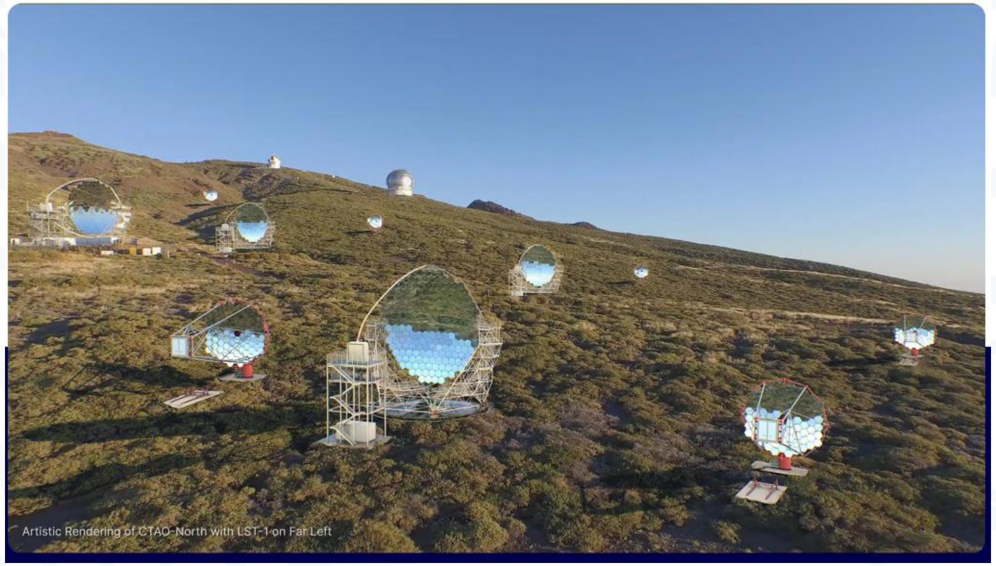

Credit: Fermi Collaboration


HAWC


LHAASO

Gamma-ray astronomy: CTAO





Research questions looking at High-Latitude SNRs

- What energies can cosmic rays be accelerated up to in SNRs?
  (constrain models of CR acceleration)

- Can we resolve morphological features in these SNRs? See Halos?

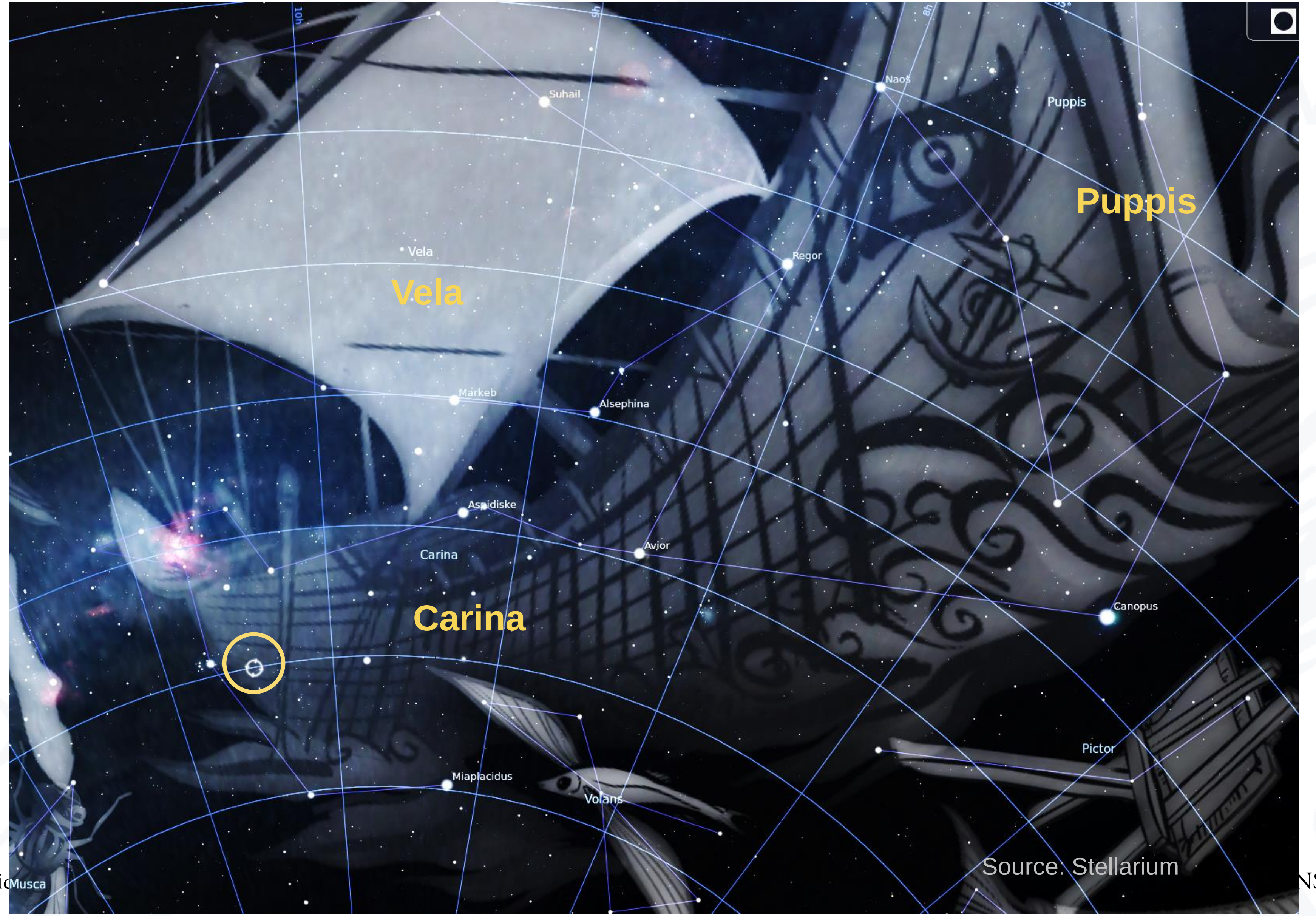
- Leptonic versus hadronic models

- Can we build the SNR population to get more insight?
  (currently around 30 at HE (7 high-lat), 10 at VHE)

Research questions (continued…)

- Impact of CRs on the ISM? Dynamics, drive outflows, CR heating, …
- Older SNRs → CR escape (Brose et al. 2020)
- Impact on habitability of planets

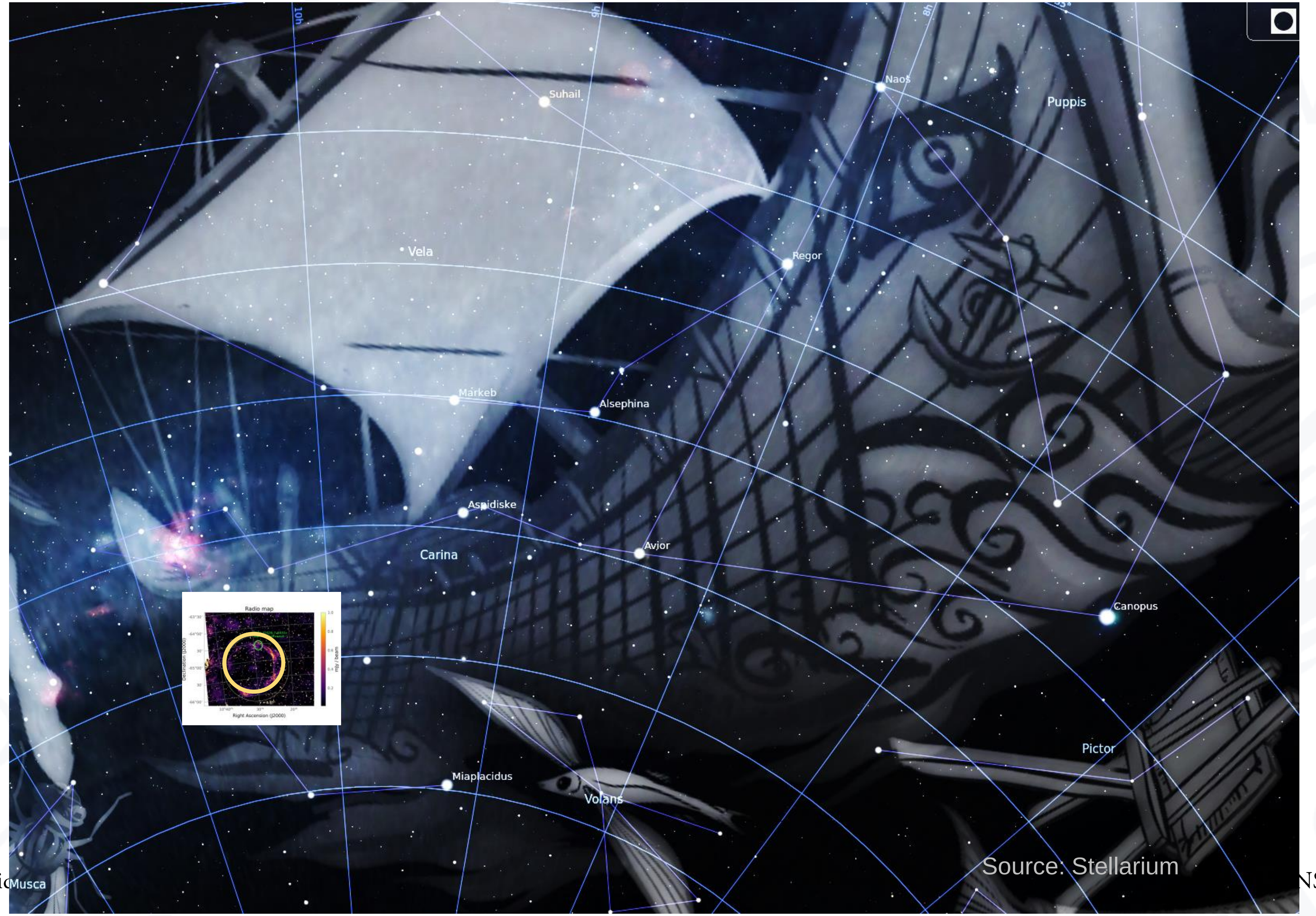
G288.8–6.3



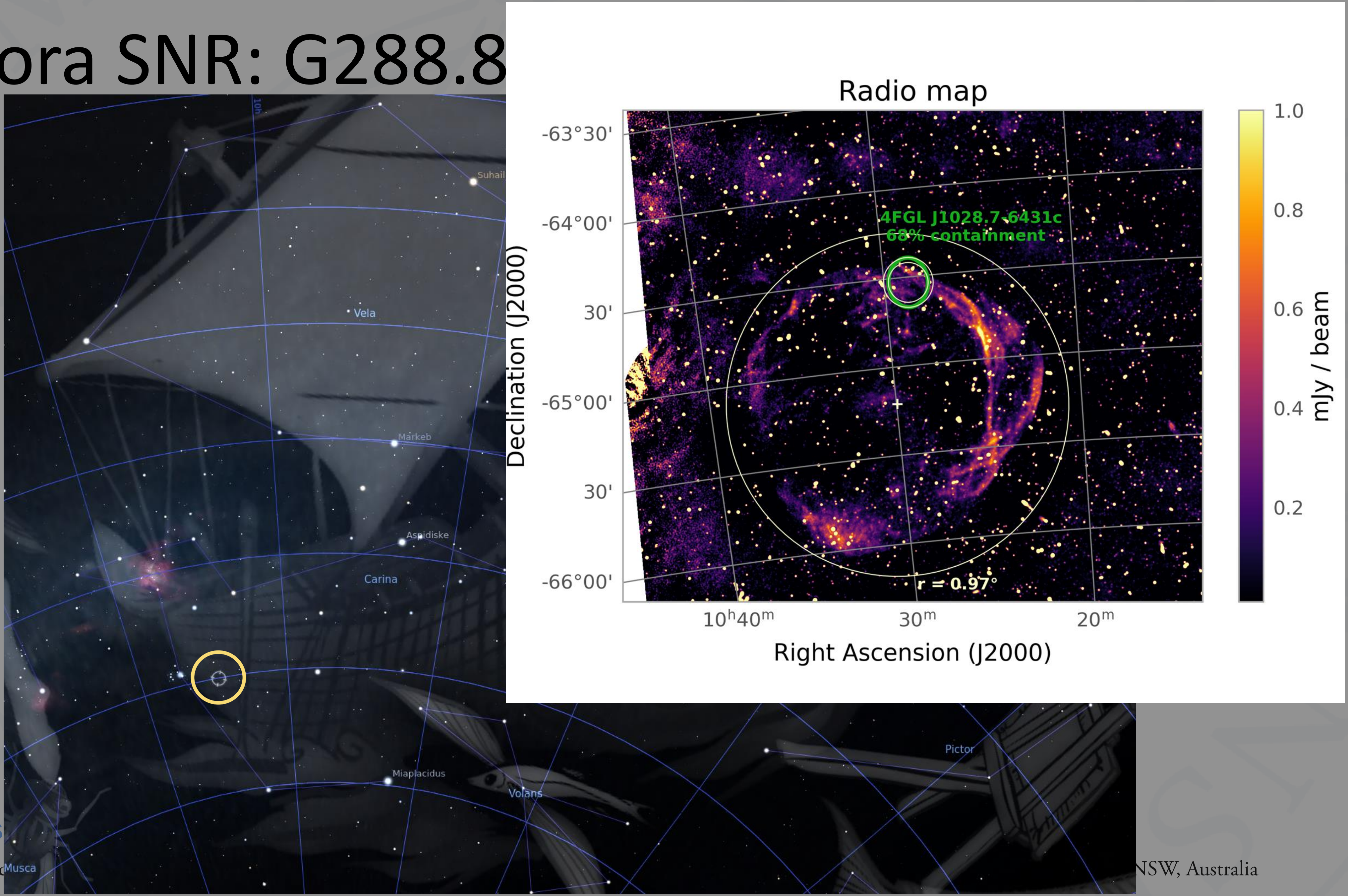
10h
9h
8h
Suhail
Naos
Puppis
Puppis
Vela
Vela
Regor
Markeb
Alsephina
Aspidiske
Carina
Avior
Carina
Canopus
Pictor
Miaplacidus
Volans
Musca
Source: Stellarium

Ancora SNR: G288.8–6.3

Ancora SNR: G288.8–6.3



Ancora SNR: G288.8



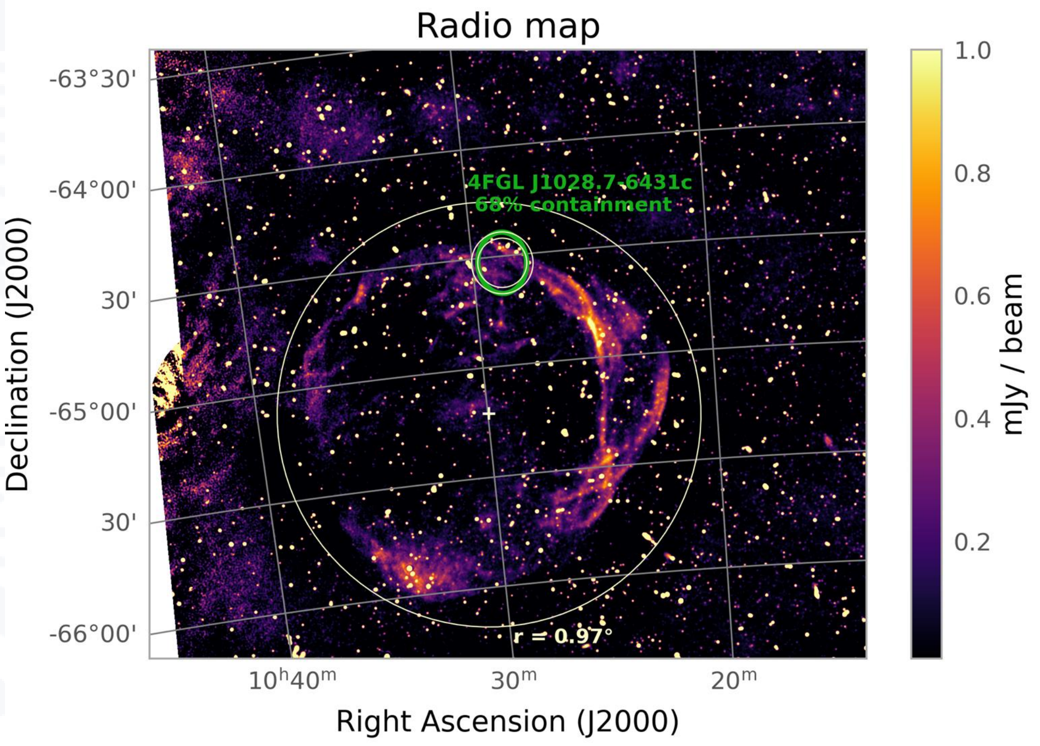
#DIASdis

SNR G288.8–6.3

- Coordinates:
  GLON/GLAT: 288.8°/-6.3°
  R.A./ Dec: 157.488°/−65.214°

Distances:
1.3 kpc
~140 pc from plane

Radio detection: ASKAP at 943MHz
Extension: ~0.8°
Spectral index α = −0.41 ± 0.12
Low surface brightness
Age (>13kyr?)



Filipović , …, CBS, et al. (2023)
https://arxiv.org/abs/2308.08716v1

SNR G288.8–6.3

Deep Optical Emission-Line Images of Nine Known and Three New Galactic Supernova Remnants

Robert A. Fesen,[1] Marcel Drechsler,[2] Xavier Strottner,[3] Bray Falls,[4] Yann Sainty,[5] Nicolas Martino,[6] Richard Galli,[7] Mathew Ludgate,[8] Markus Blauensteiner,[9] Wolfgang Reich,[10] Sean Walker,[11] Dennis di Cicco,[11] David Mittelman,[11] Curtis Morgan,[4] Aziz Ettahar Kaeouach,[12] Justin Rupert,[13] and Zouhair Benkhaldoun[14]

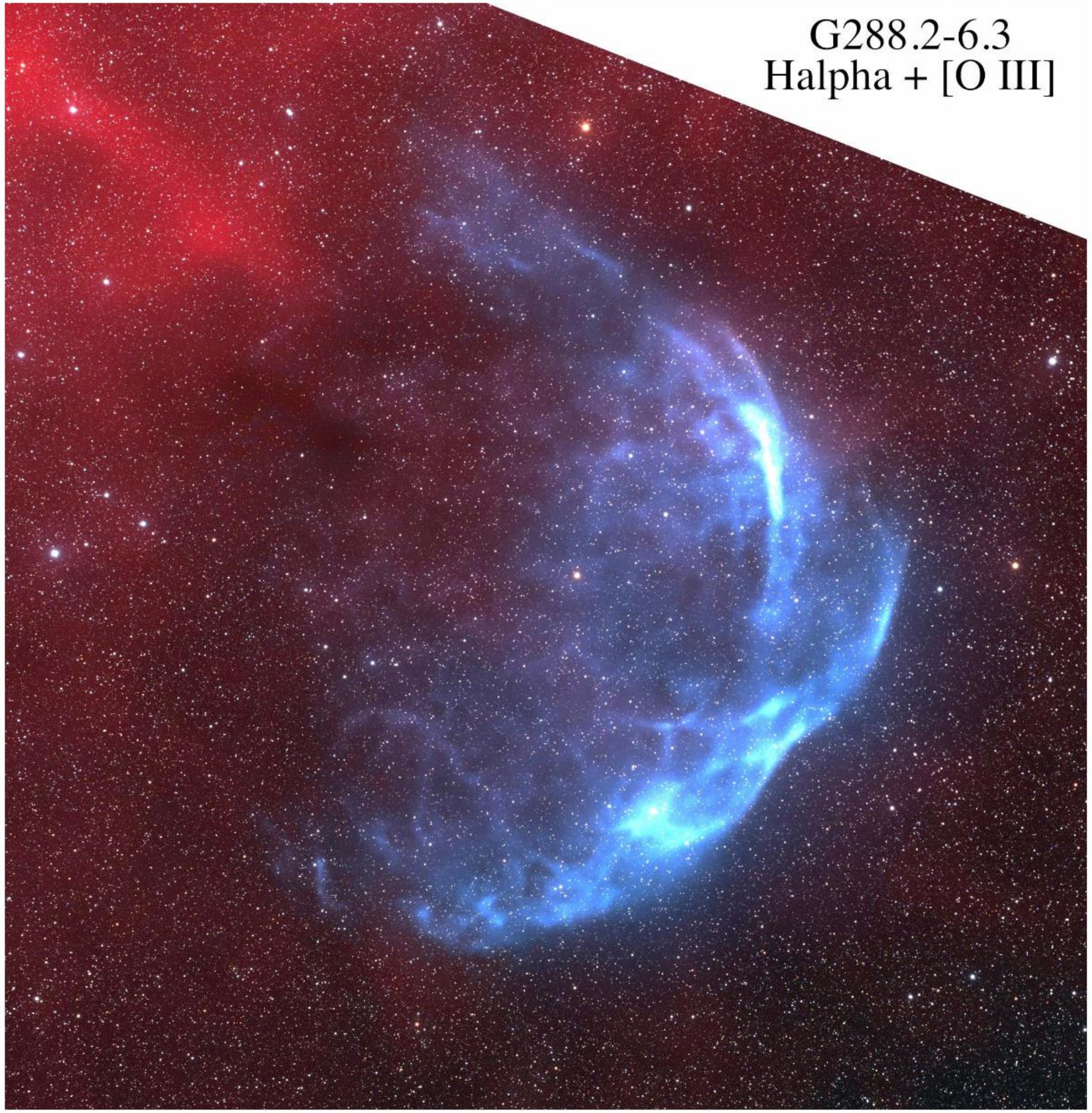


Figure 26. Top: Deep [O III] image (left) and composite [O III] + Hα (right) images of the SNR G288.8-6.3. Bottom: Color composite of [O III], Hα + RGB images of the G288.8-6.3

Fermi-LAT analysis

Credit: Fermi Collaboration

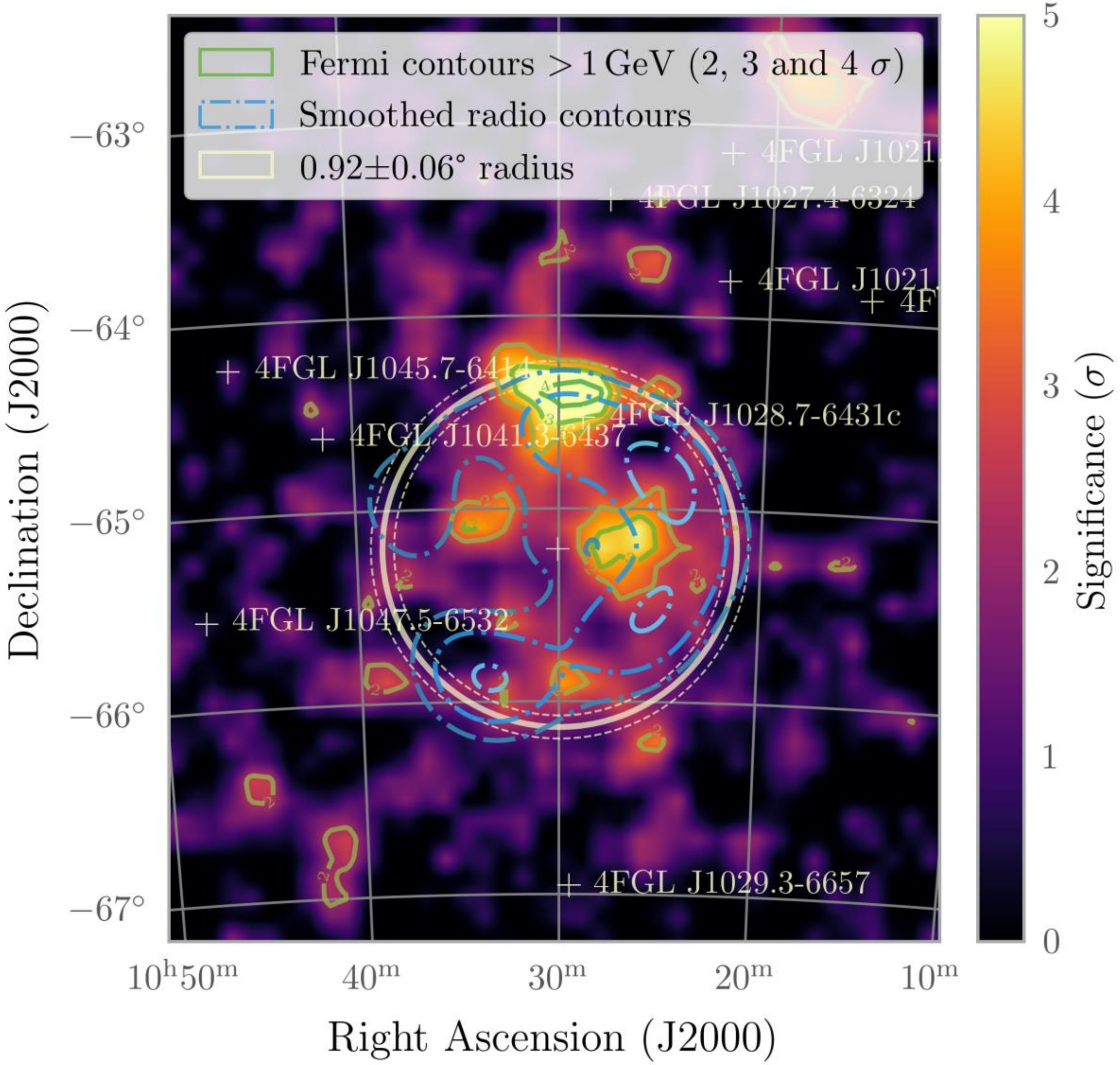
- Energy range (100 MeV – 1 TeV)
- FoV ~20% of whole sky

- Using Fermipy (v1.1.6) and Fermitools (v.2.2.0)
- 4FGL-DR3 Fermi catalogue (Abdollahi et al. 2022)

- 15 years of data (Aug 2008 – July 2023)
- Standard *binned maximum-likelihood analysis*

Fermi-LAT analysis

- Residual map with overlaid radio contours
- Several hotspots seen overlapping with radio



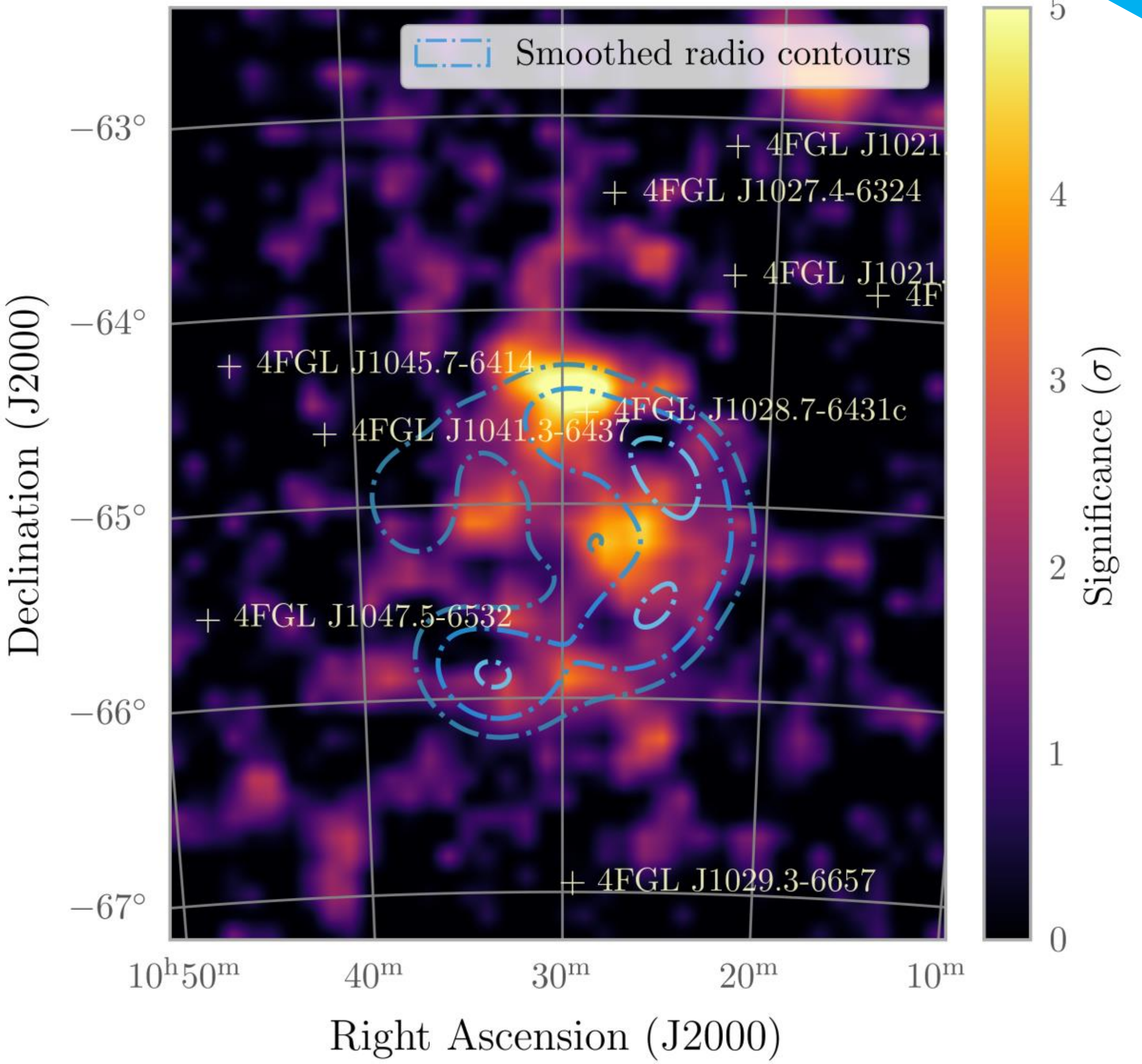
Fermi-LAT analysis

Table 1: List of different models and their relative log-likelihood values compared to the base model, with $\mathcal{L}_0 = 435708.381$, and $\Delta ln(\mathcal{L}) = ln(\mathcal{L}_\mathrm{i}) - ln(\mathcal{L}_0)$, and difference in model parameters compared to the base model ($\Delta k = k_\mathrm{i} - k_0$). The two best-fit models, both presented in this work, are marked in bold font.

Model Nº	J1028 incl.	Spatial model	Spectral model	$\Delta ln(\mathcal{L})$	Δk	ΔAIC
0	Y	—	—	0	0	0
1	N	—	—	−24.87	−5	39.74
2	**Y**	***RadialDisk***	***PowerLaw***	**16.50**	**5**	**−22.99**
3	**N**	***RadialDisk***	***PowerLaw***	**9.54**	**0**	**−21.08**
4	N	*RadialDisk*	*LogParabola*	9.80	1	−19.59
5	N	Radio template	*PowerLaw*	7.76	−1	−19.51

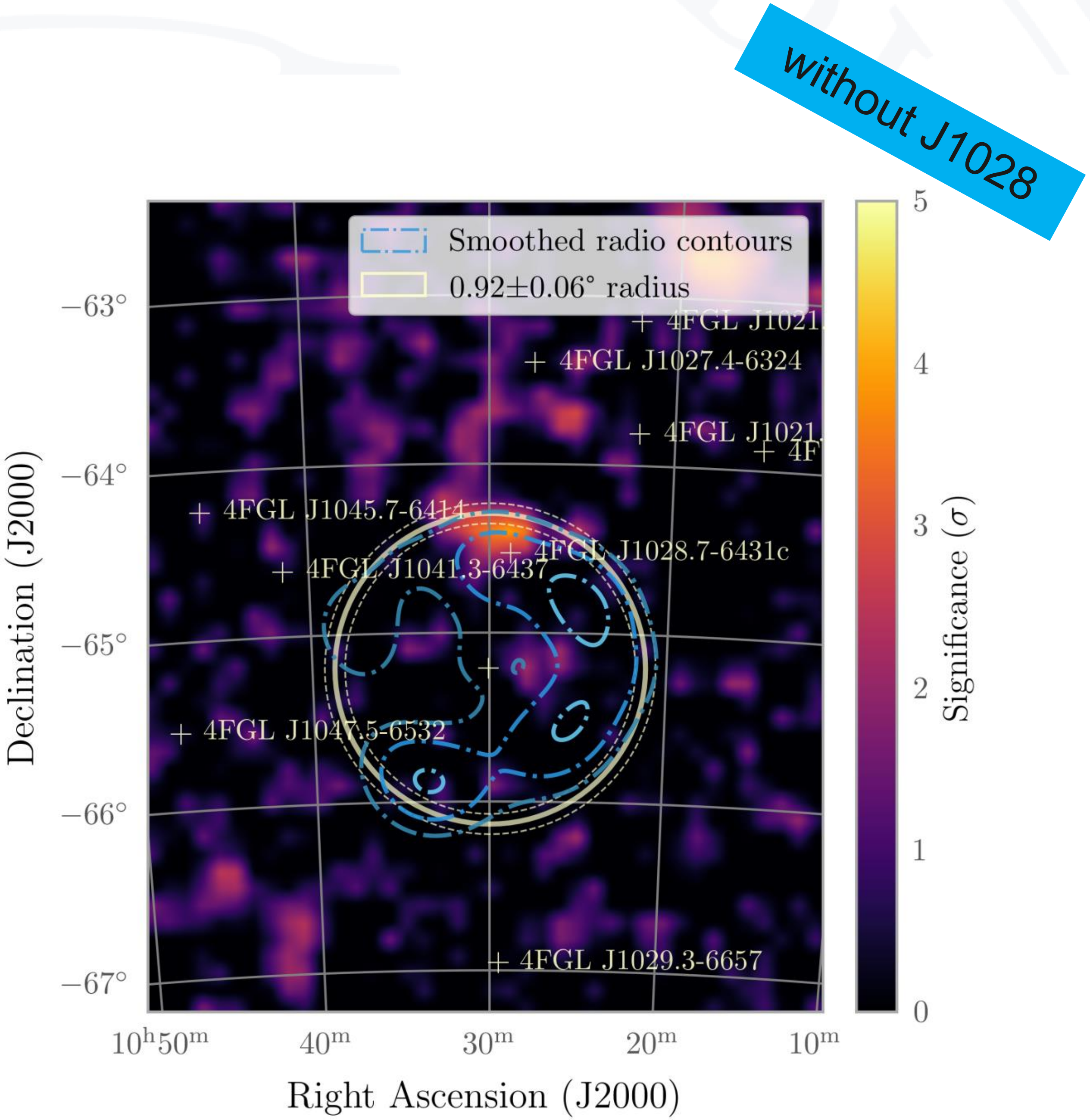
Fermi-LAT analysis

- Before modelling



Fermi-LAT analysis

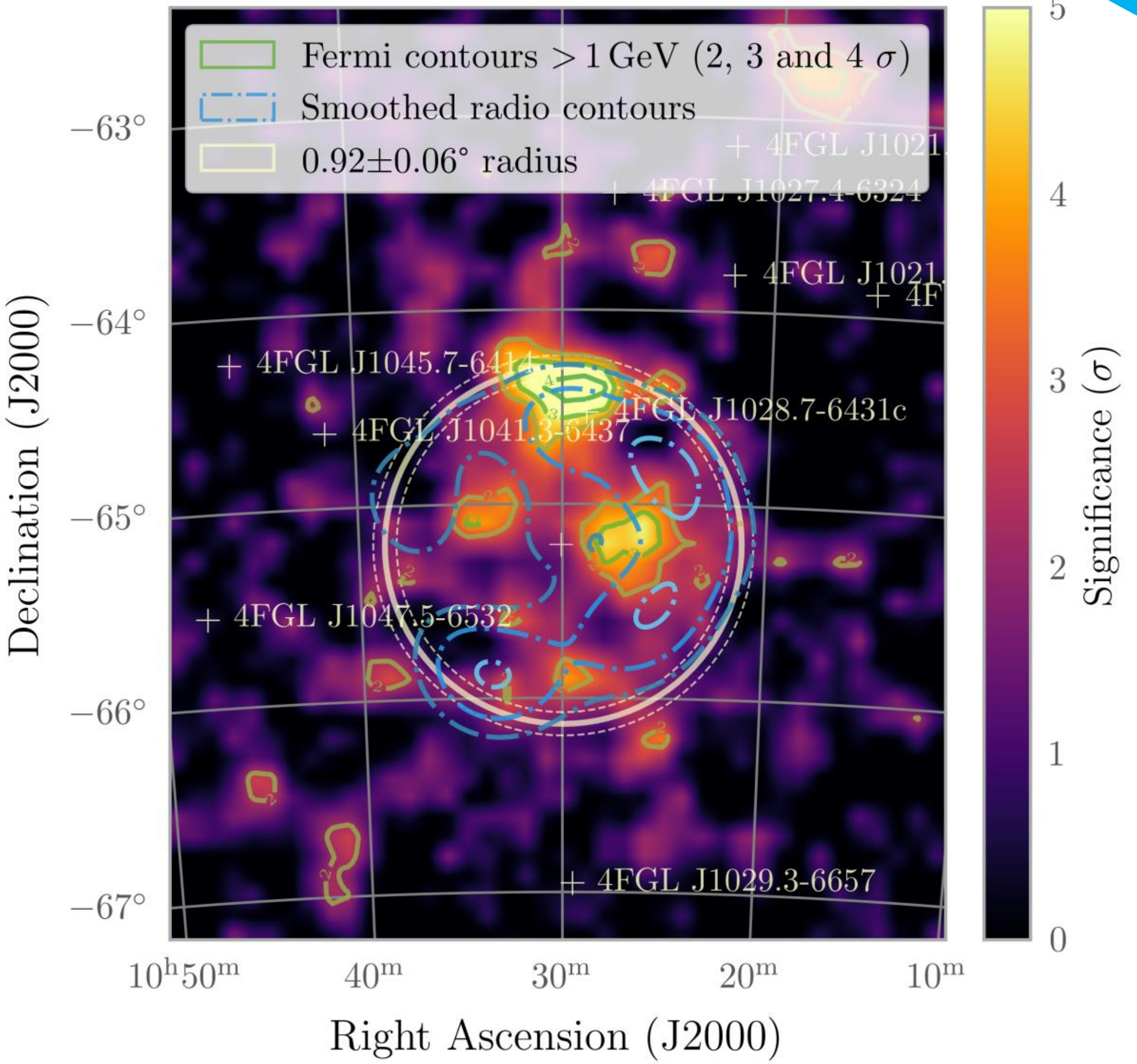
- After modelling with
  - RadialDisk
  - PowerLaw



Fermi-LAT analysis

without J1028

- Resulting map

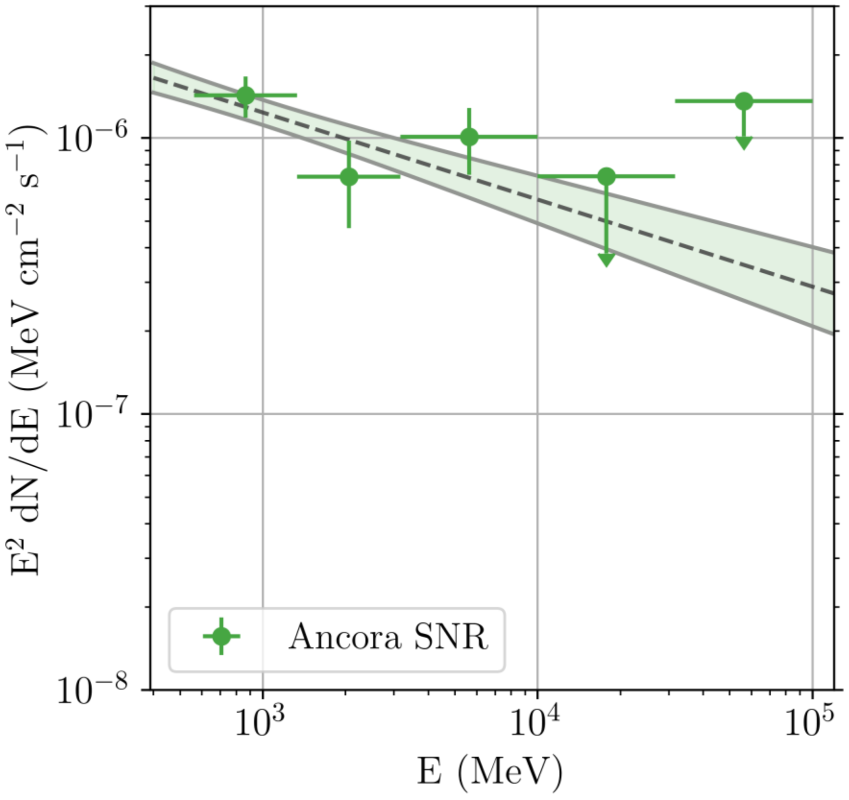


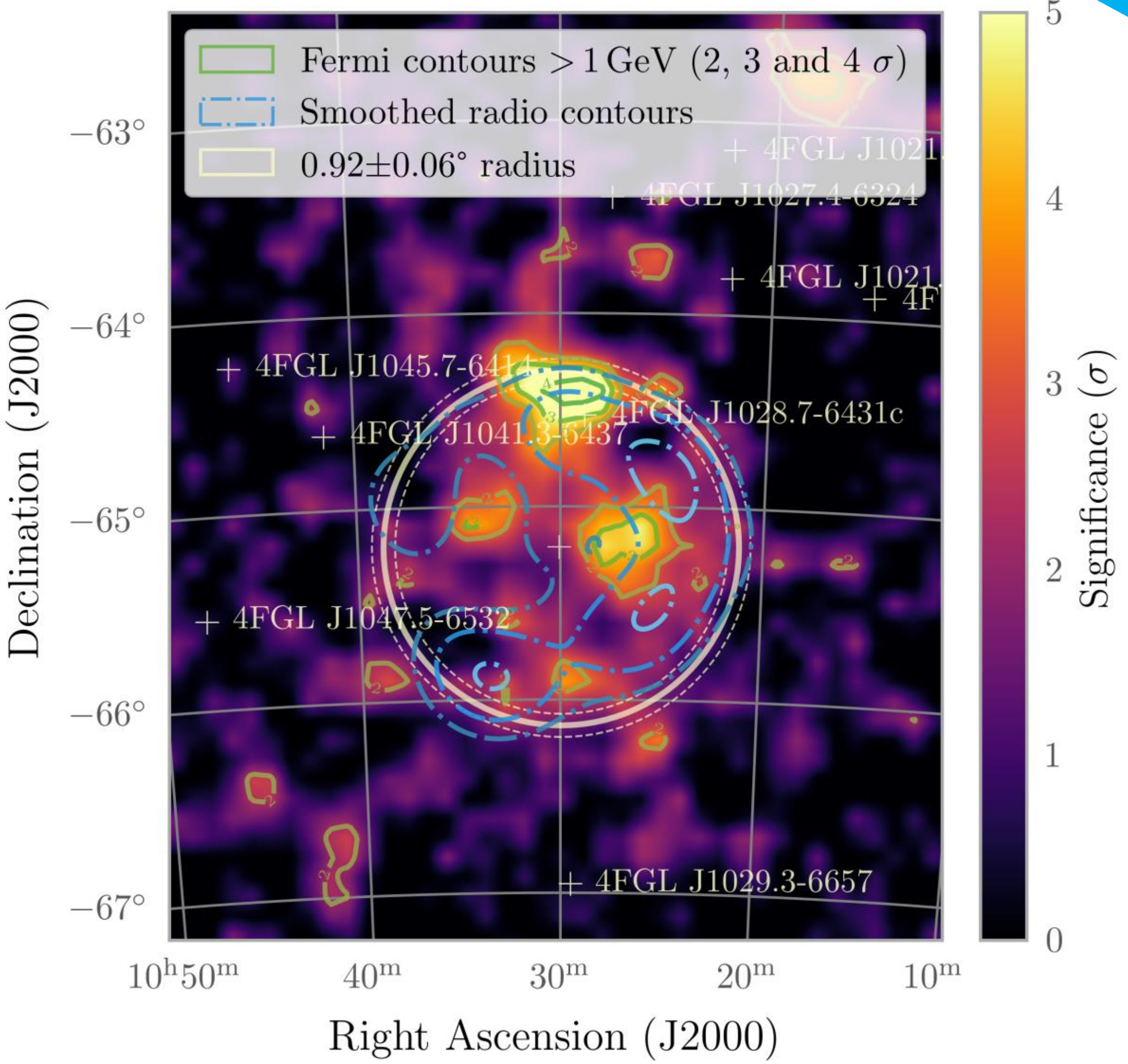
Fermi-LAT analysis

without J1028

- Resulting map

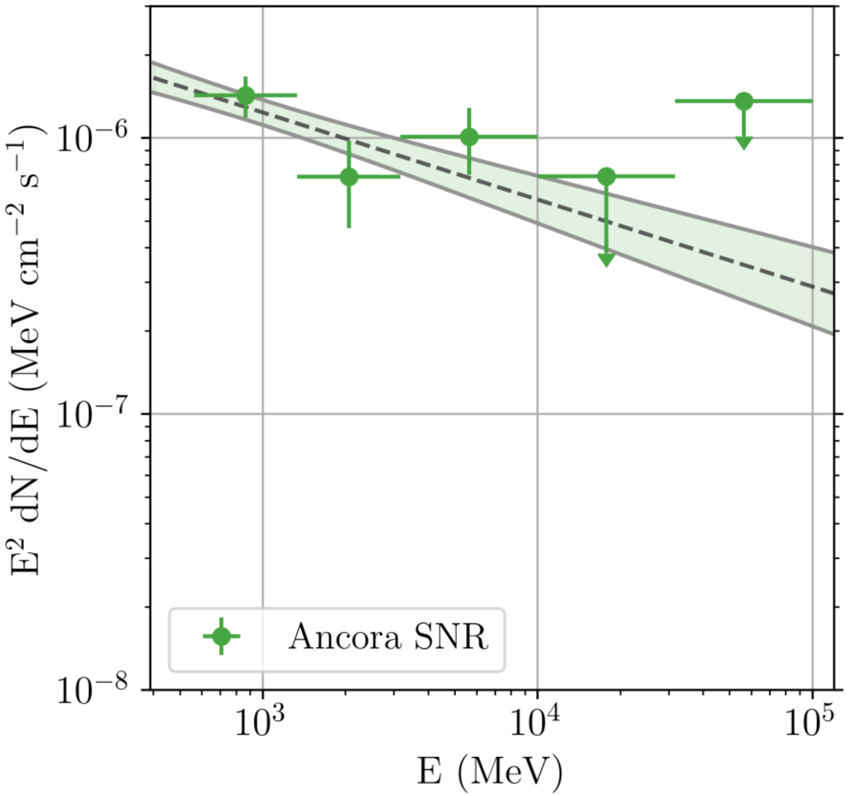
  … and SED





Burger-Scheidlin et al. (submitted)

Fermi-LAT analysis



A&A, 684, A150 (2024)
https://doi.org/10.1051/0004-6361/202348348

Astronomy & Astrophysics

Gamma-ray detection of newly discovered Ancora supernova remnant: G288.8–6.3

Christopher Burger-Scheidlin[1,2], Robert Brose[1,3], Jonathan Mackey[1,2], Miroslav D. Filipović[4], Pranjupriya Goswami[5,6], Enrique Mestre Guillen[7], Emma de Oña Wilhelmi[8], and Iurii Sushch[6,9,10]

Table 2: Best-fit parameters of the *RadialDi*
the spatial template derived from the radio s

Parameter	Unit			
Position				
R.A. / Dec	deg / deg		157.488 / -65.214	
GLON / GLAT	deg / deg		288.8 / -6.3	
Model N°		2	3	5
J1028 incl.		Y	N	N
Spatial model		*RadialDisk*	*RadialDisk*	*SpatialTemplate*
Spectral model		*PowerLaw*	*PowerLaw*	*PowerLaw*
TS	—	44.74	77.14	70.98
N° of predicted photons	—	978	1331	1174
Photon flux	ph cm^{-2} s^{-1}	$(2.29 \pm 0.45) \times 10^{-9}$	$(3.14 \pm 0.41) \times 10^{-9}$	$(2.74 \pm 0.37) \times 10^{-9}$
Energy flux	MeV cm^{-2} s^{-1}	$(4.29 \pm 1.03) \times 10^{-6}$	$(4.80 \pm 0.91) \times 10^{-6}$	$(3.62 \pm 0.68) \times 10^{-6}$
> 1 GeV (to 316 GeV)	MeV cm^{-2} s^{-1}	$(3.08 \pm 0.83) \times 10^{-6}$	$(3.29 \pm 0.78) \times 10^{-6}$	$(2.13 \pm 0.66) \times 10^{-6}$
Spectral parameters				
N_0	MeV^{-1} cm^{-2} s^{-1}	$(9.17 \pm 1.81) \times 10^{-13}$	$(1.23 \pm 0.16) \times 10^{-12}$	$(1.15 \pm 0.15) \times 10^{-2}$
Γ	—	2.21 ± 0.12	2.32 ± 0.11	2.41 ± 0.13
E_0	MeV	1000*	1000*	1000*
Spatial parameters				
Extension	deg	0.92 ± 0.07	0.92 ± 0.06	—
TS_{ext}†	—	33.92	52.56	—

* Parameter fixed
† Test statistic for the extension hypothesis against the null hypothesis of a point-like source

MWL

- Naima modelling (computation of non-thermal radiation from relativistic particle populations)
- Only upper limits for X-rays
- Observations needed for good constraints:
  - VHE
  - hard X-ray

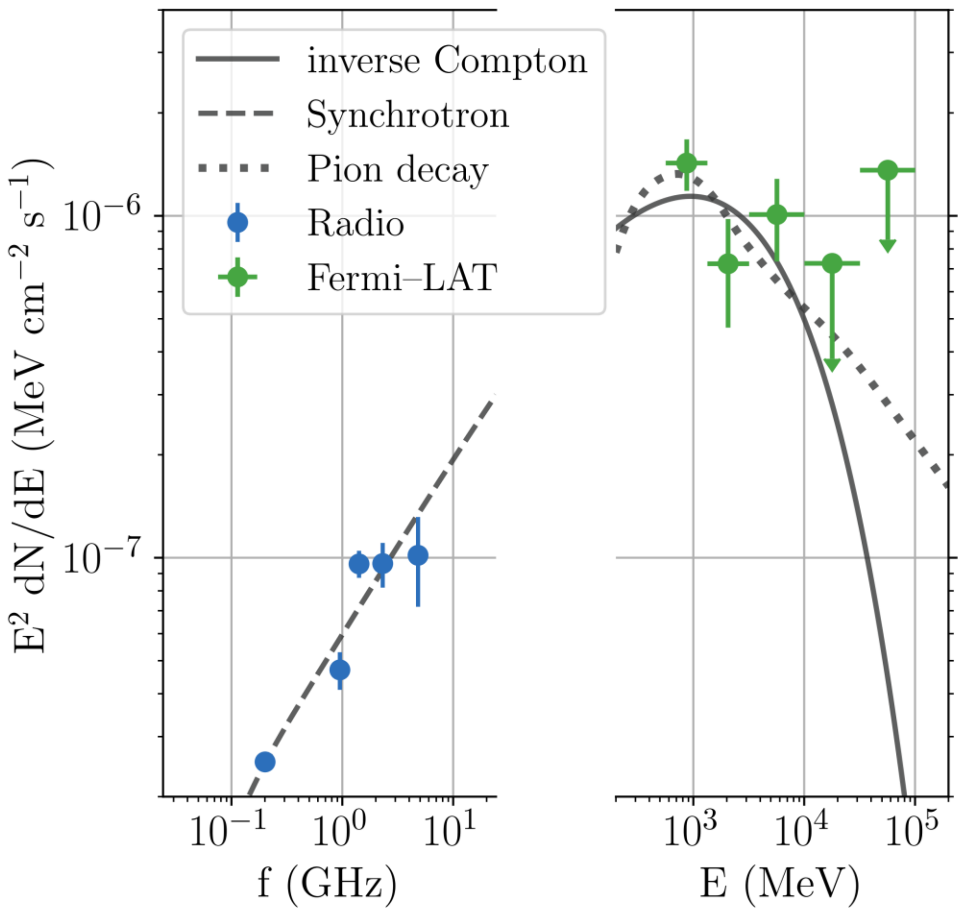


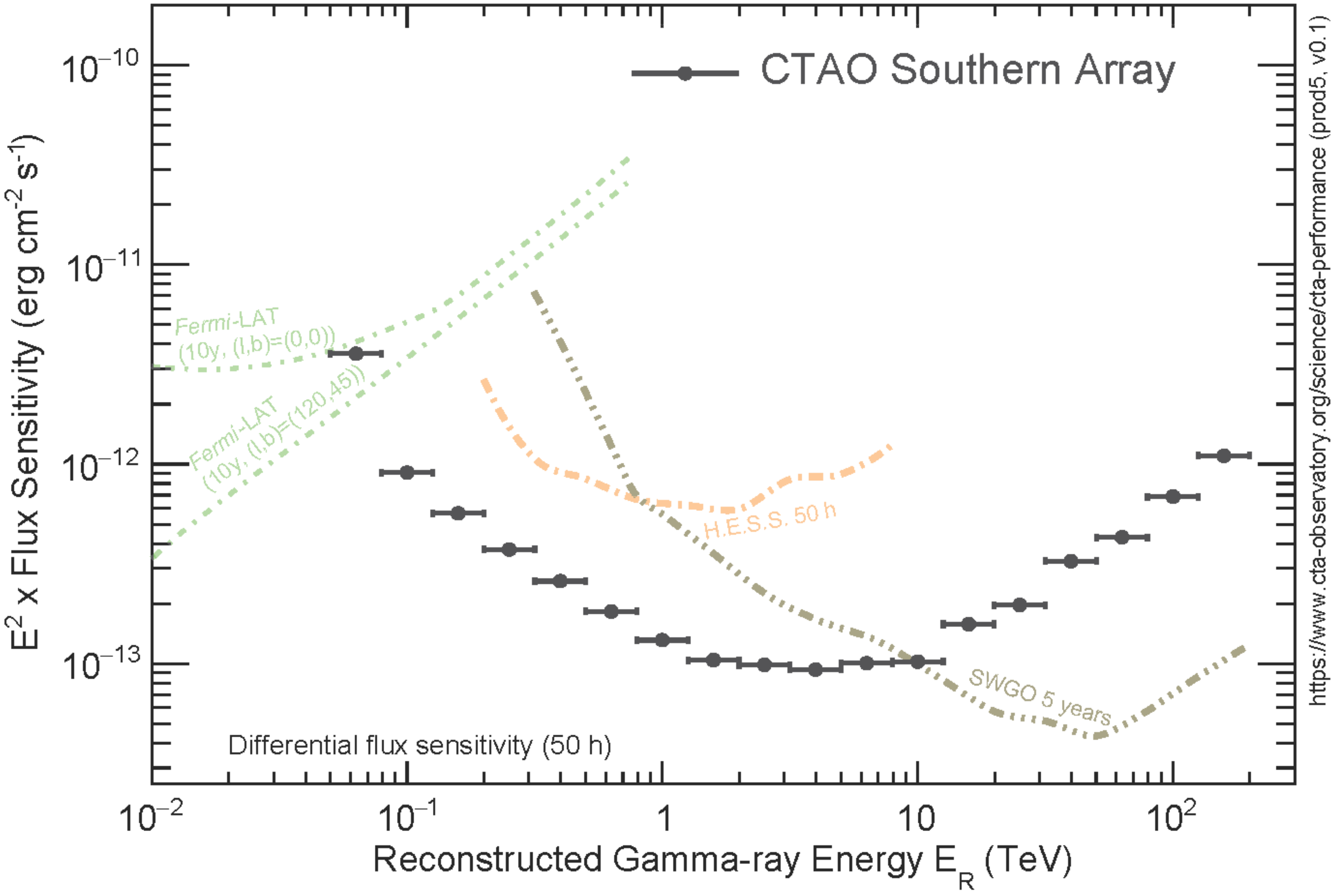
Table of high-latitude SNRs

Table 4. Comparison of Ancora SNR to fluxes and photon spectral indices of other known high-latitude SNRs detected at high energies, sorted by their total energy flux.

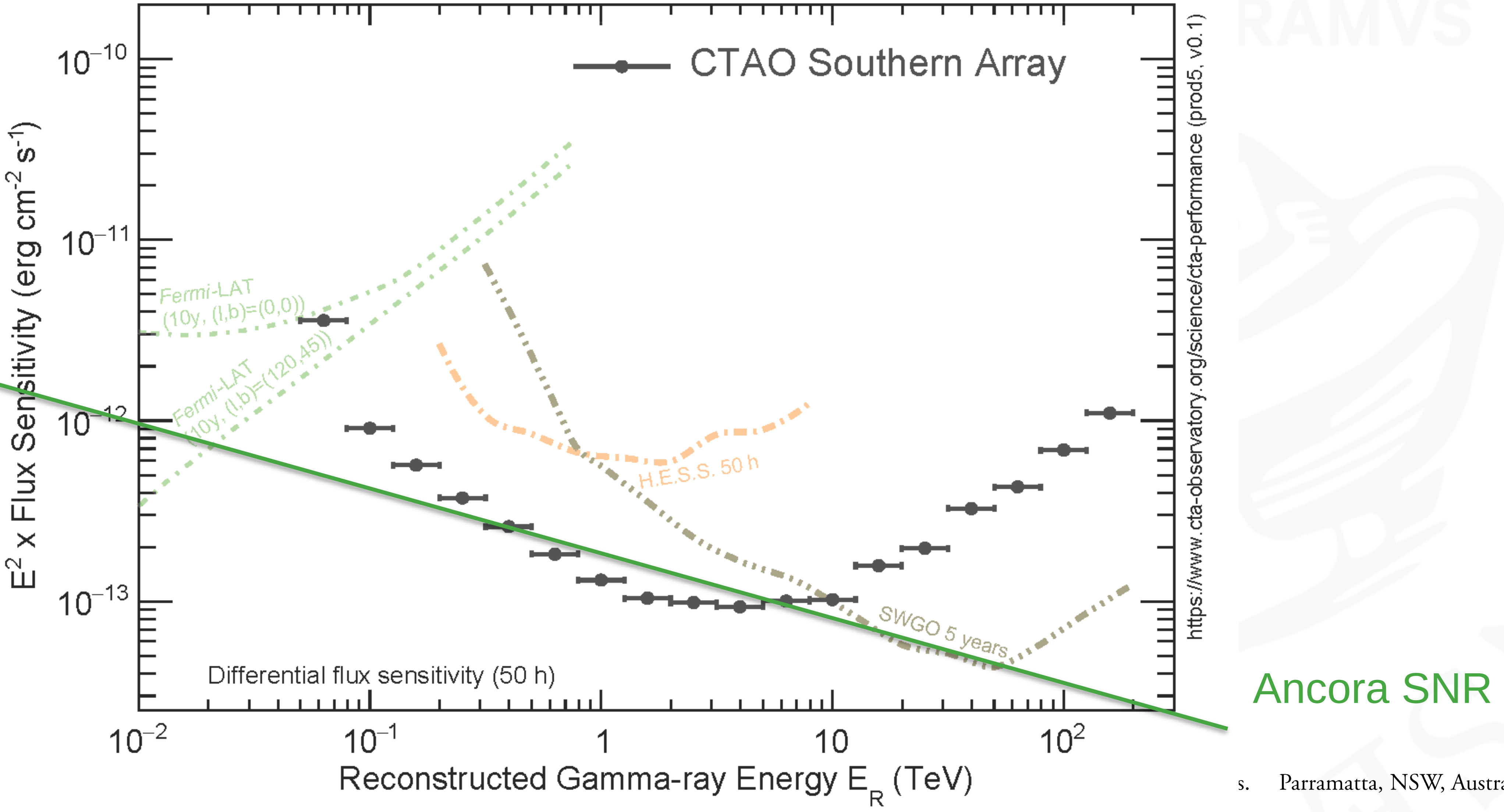
Source name	Extension (deg)	Energy flux ($\mathrm{MeV\,cm^{-2}\,s^{-1}}$) 1 GeV–1 TeV	Photon spectral index –	Reference	Radio extension (deg)
Ancora SNR/G288.8–6.3	0.92	$(3.29 \pm 0.78) \times 10^{-6(\perp)}$	$2.31 \pm 0.11^{(\perp)}$	This work	~0.8 (Filipovic et al. 2023)
G150+4.5	1.5	$5.20 \times 10^{-5(*)}$	$1.62 \pm 0.04_{stat} \pm 0.22_{sys}{}^{(\dagger)}$	Devin et al. (2020)	1.25-1.5 (Gao & Han 2014)
G17.8+16.7/ FHES J1723.5–0501	0.73	$(1.38 \pm 0.26) \times 10^{-5(\triangledown)}$	$1.83 \pm 0.02_{stat} \pm 0.05_{sys}$ $1.97 \pm 0.08_{stat} \pm 0.06_{sys}$	Araya et al. (2022) Ackermann et al. (2018)	~0.48 (Condon et al. 1998)
G296.5+10.0/FHES J1208.7–5229	0.7	$8.17 \times 10^{-6(**)}$ $(1.13 \pm 0.24) \times 10^{-5(\triangledown)}$	1.85 ± 0.13 $1.81 \pm 0.09_{stat} \pm 0.05_{sys}$	Araya (2013) Ackermann et al. (2018)	~0.7 (Milne & Hayes 1994)
SN 1006/G327.6+14.6	0.1	$(3.63 \pm 1.62) \times 10^{-6(\dagger\dagger)}$	1.57 ± 0.11	Condon et al. (2017)	~0.5 (Reynoso 2006)
Calvera SNR/G118.4+37.0	0.53	$3.06 \times 10^{-6(\triangledown\triangledown)}$	$1.66 \pm 0.10_{stat} \pm 0.03_{sys}$	Araya (2023)	~0.45 (Arias 2022)
G166+4.3	~0.3	$2.87 \times 10^{-6(**)}$	2.7 ± 0.1		0.6-0.9 (www.mrao.cam.ac.uk)

Notes. The list includes data from the SNR catalogue provided by Ferrand & Safi-Harb (2012). $^{(\diamond)}$`snrcat.physics.umanitoba.ca`; $^{(\perp)}$ values taken from `model 3`, energy range 1 GeV–316 GeV; $^{(*)}$calculated using data from Table 2 in Devin et al. (2020), and using results for the radial Gaussian model and log-parabola spectral model; $^{(\dagger)}$log-parabola model, α given in Table, $\beta = 0.07 \pm 0.02_{stat} \pm 0.02_{sys}$; $^{(\triangledown)}$ from FITS data provided with Ackermann et al. (2018); $^{(**)}$calculated using data from Table 2 in Araya (2013); $^{(\dagger\dagger)}$range is 1 GeV–2 TeV; $^{(\triangledown\triangledown)}$calculated using data from Araya (2023).

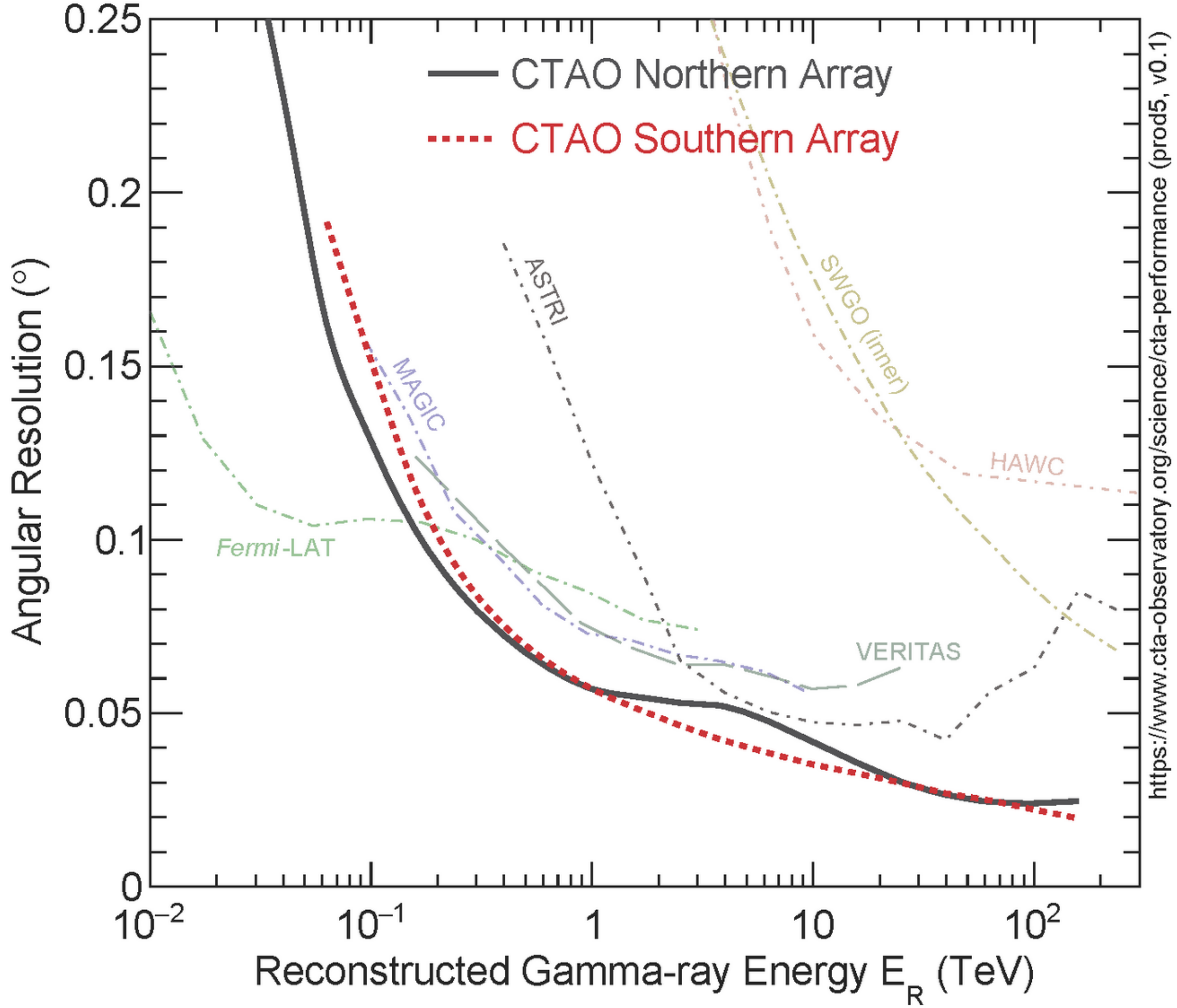
CTAO performance: Sensitivity



CTAO performance: Sensitivity



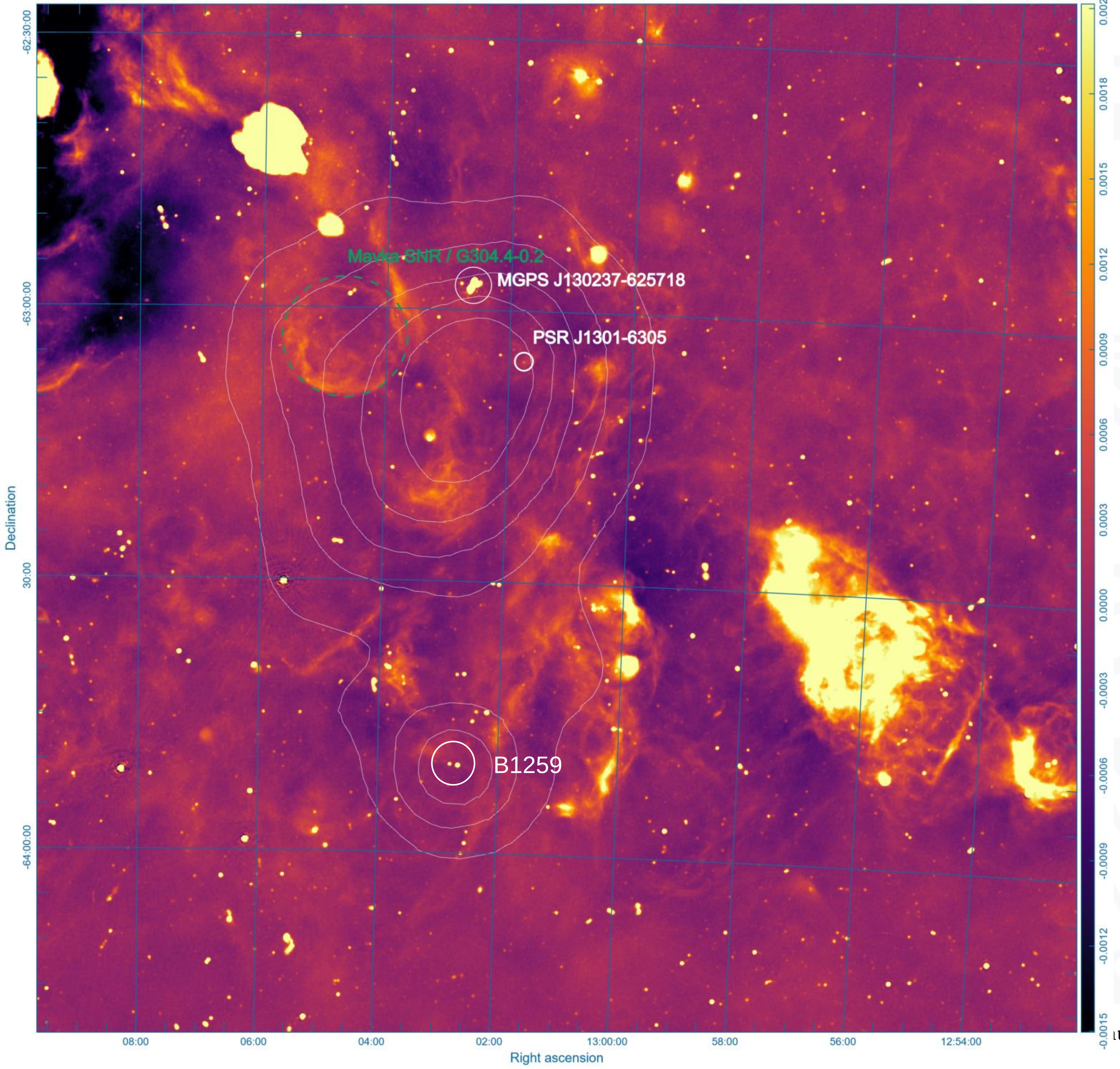
CTAO performance: Angular resolution



Conclusions/Outlook

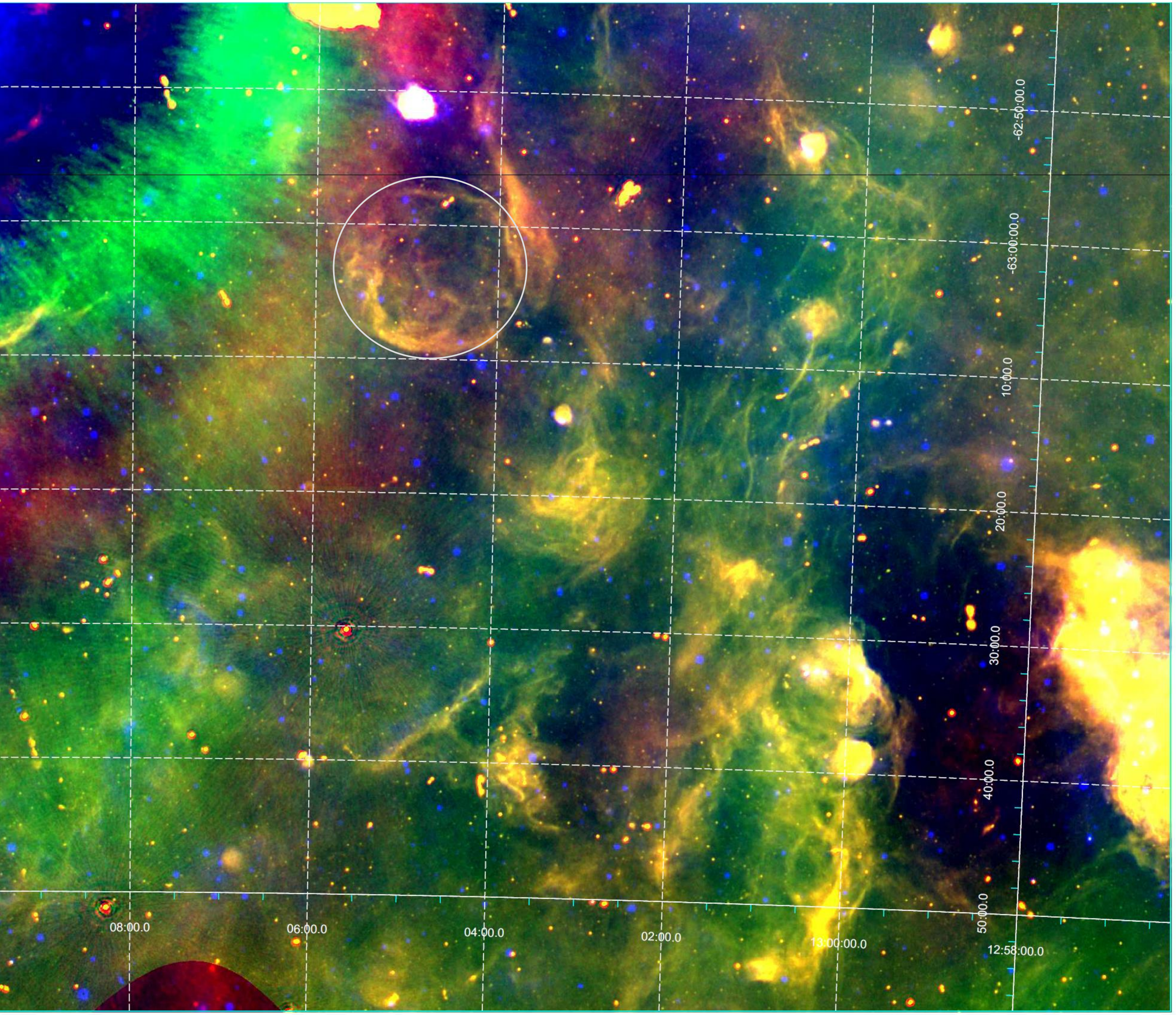
- MWL observations needed to constrain models of SNRs
- Radio SNRs are already increasing the number of SNRs, finding gamma-ray counterparts is important
- High Galactic SNRs are good objects because they expand in unperturbed environments, thus
  - less risk of source confusion
  - possibility to observe CR escape
- Fermi-LAT sensitive enough to detect, but not to answer the science questions
- Upcoming CTA will likely be capable of detecting many of them with good sensitivity/resolution, larger FoV

Part 2: G304.4-0.2



Part 2: G304.4-0.2

ASAKP-EMU colour map
White contours: H.E.S.S. Galactic Plane Survey



red: ASKAP-EMU
green: MeerKAT
blue: 12µm WISE

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Ancora Supernova Remnant G288.8-6.3 in the context of multiwavelength observations

Christopher Burger-Scheidlin

INSTITVTVM · STVD · SVP · DVBLINENSE · MCMXL · INMENSVM PERAGRAMVS

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13 Nov 2024
CTAO | Australia Meeting #2 2024 @Parramatta, NSW, Australia

Backup

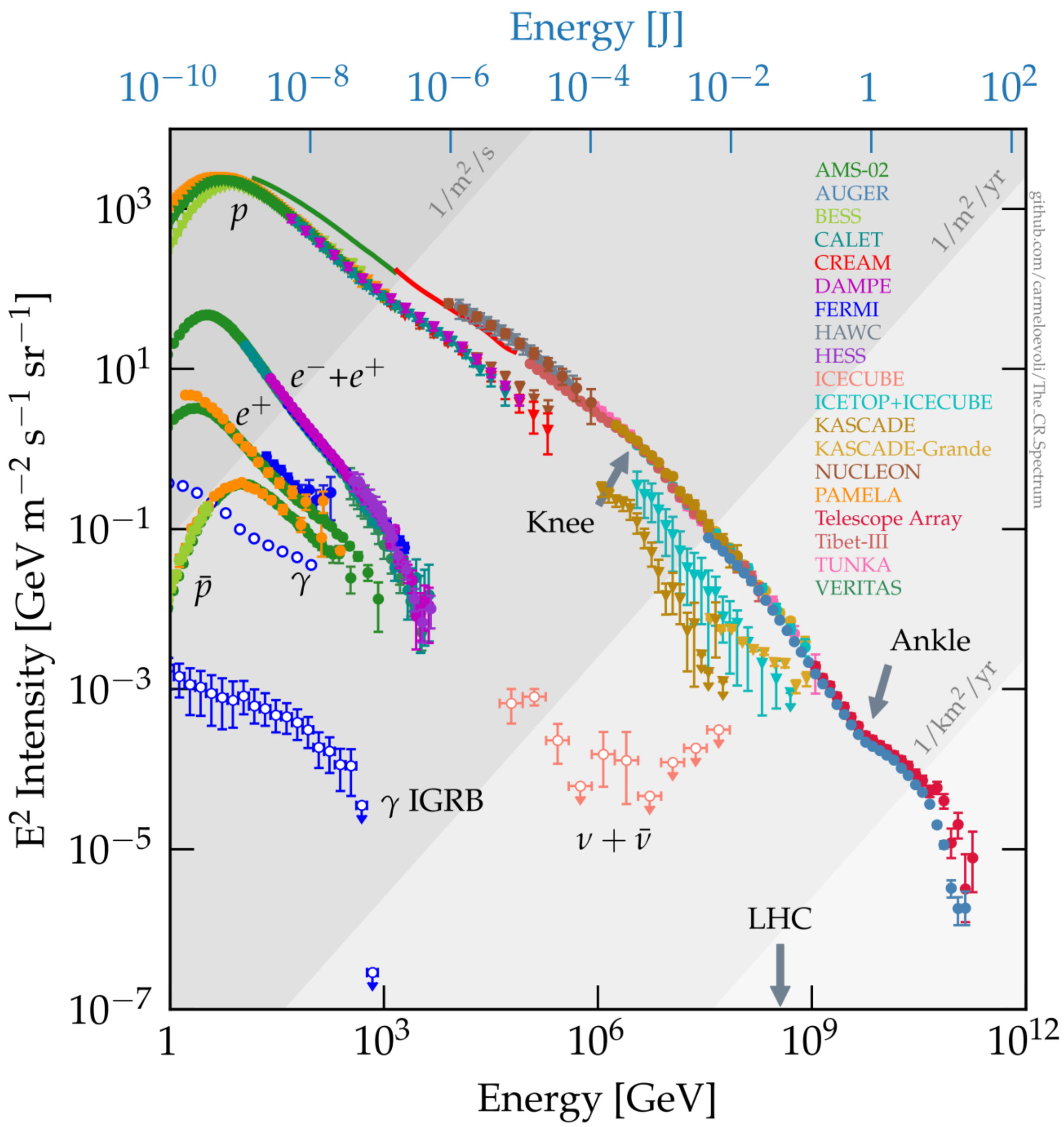
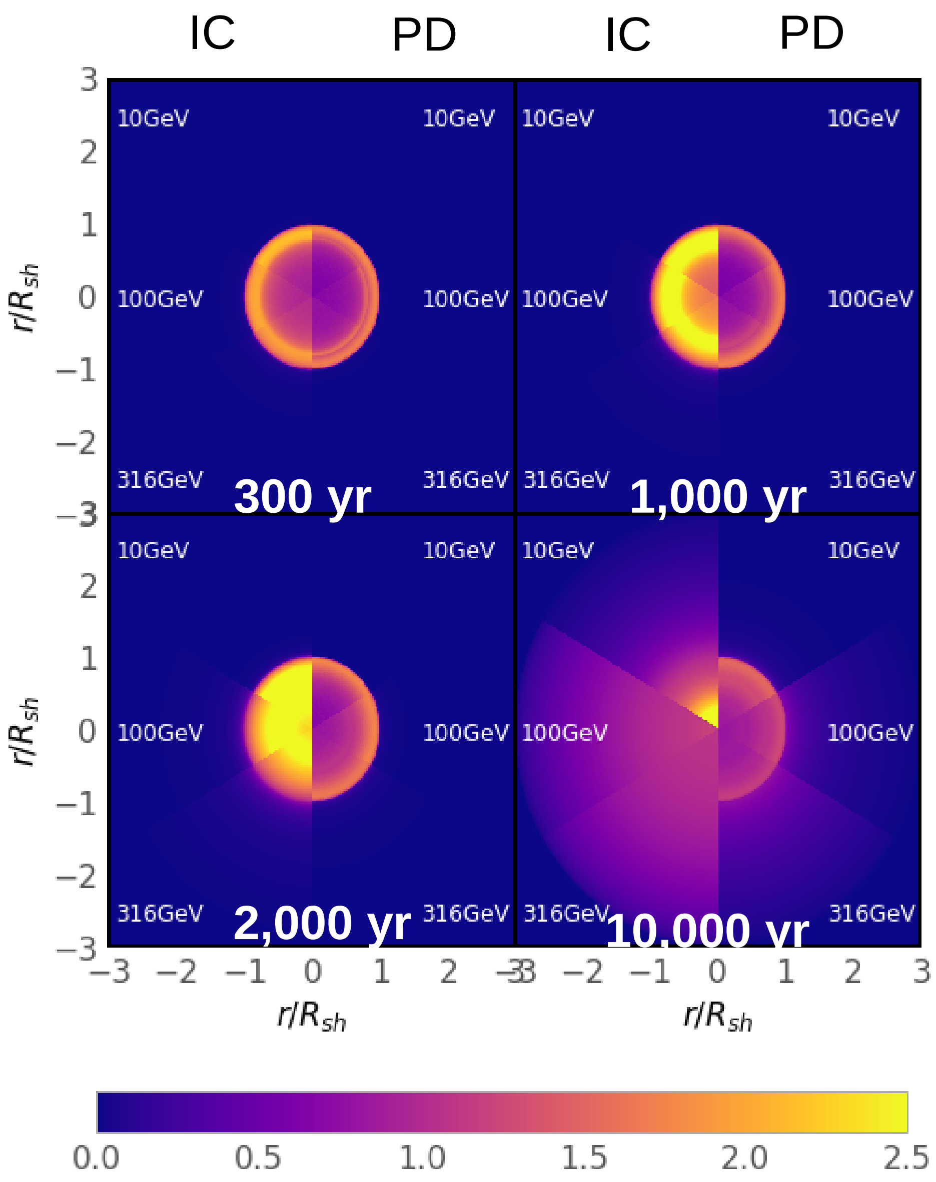


Figure: github.com/carmeloevoli/The_CR_Spectrum (2023)

Cosmic-ray diffusion

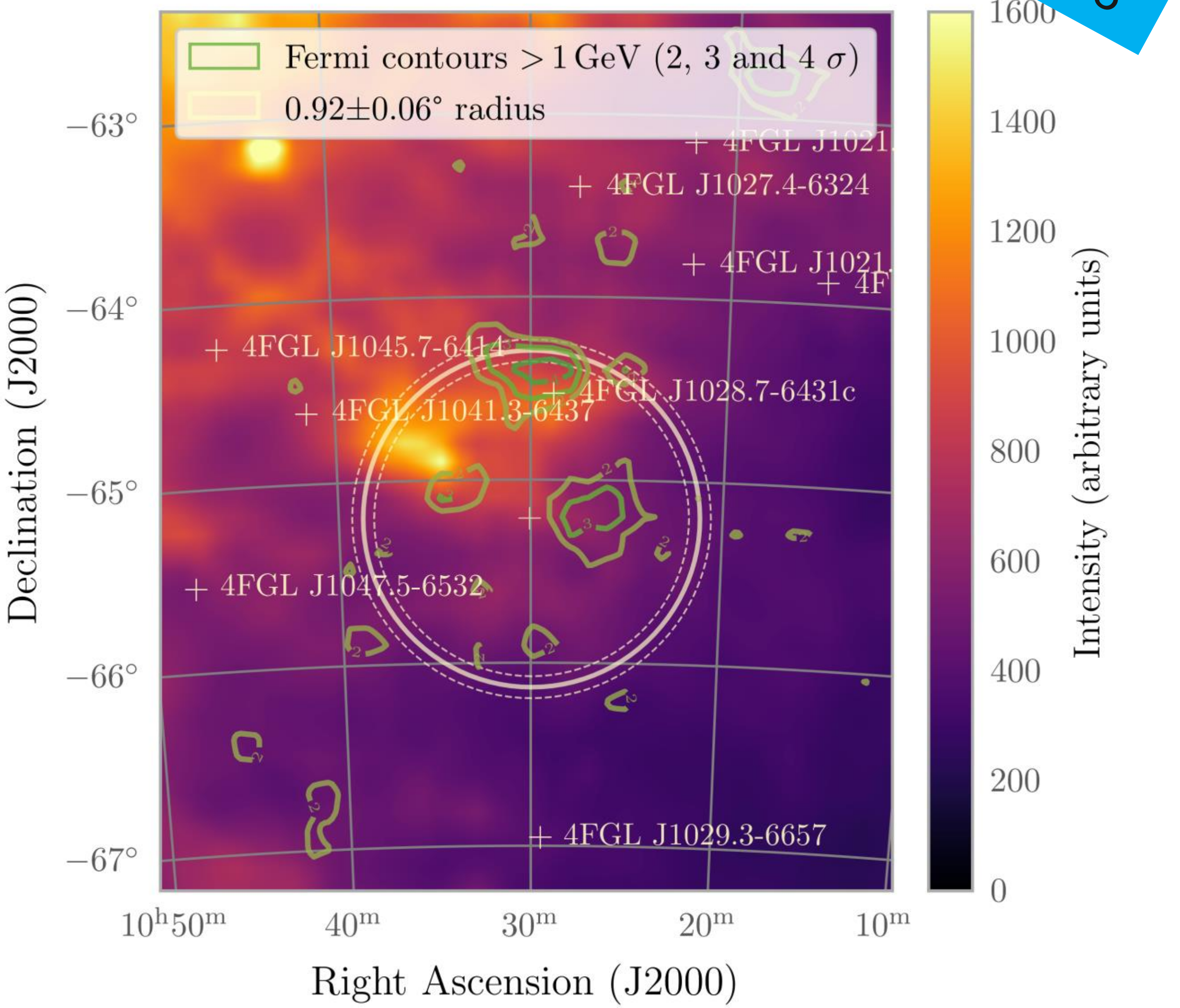
- Diffusion coefficient in SNRs many orders of magnitude smaller that the Galactic one (Drury 1983)
- But, according to theory, CR can drive some turbulence which create B-fields in the surroundings of the SNR → CR bubbles with intermediary diffusion coefficient (Ohira 2011, Brose 2021)



Source: Brose et al. 2021

Dust intensity in the region

- Thermal, unpolarised dust emission by *Planck*



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