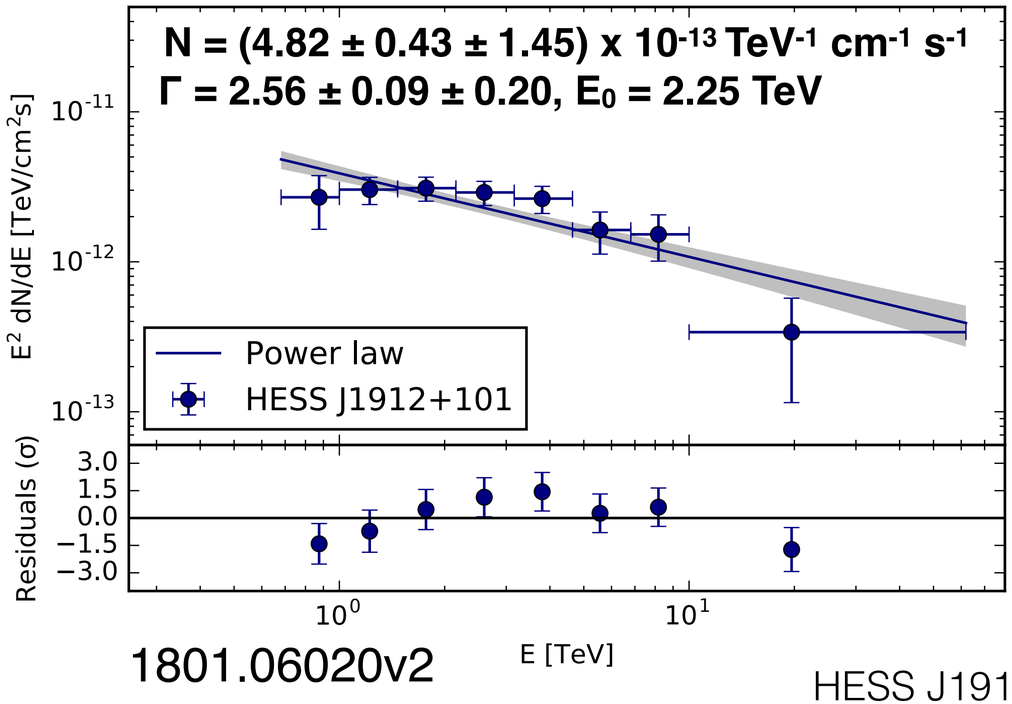
Gamma-ray emission from HESS J1912+101 observed by MAGIC and *Fermi*-LAT

Tsutomu Nagayoshi[1], David Green[2]*, Francesco de Palma[3]
On behalf of the MAGIC and Fermi-LAT Collaborations
*damgreen@mpp.mpg.de

[1]Institute for Cosmic Ray Research
[2]Max Planck Institut für Physik
[3]Istituto Nazionale di Fisica Nucleare Torino

What is HESS J1912+101?

- Unassociated extended TeV source discovered by H.E.S.S in 2008
- No associated radio or x-ray emission



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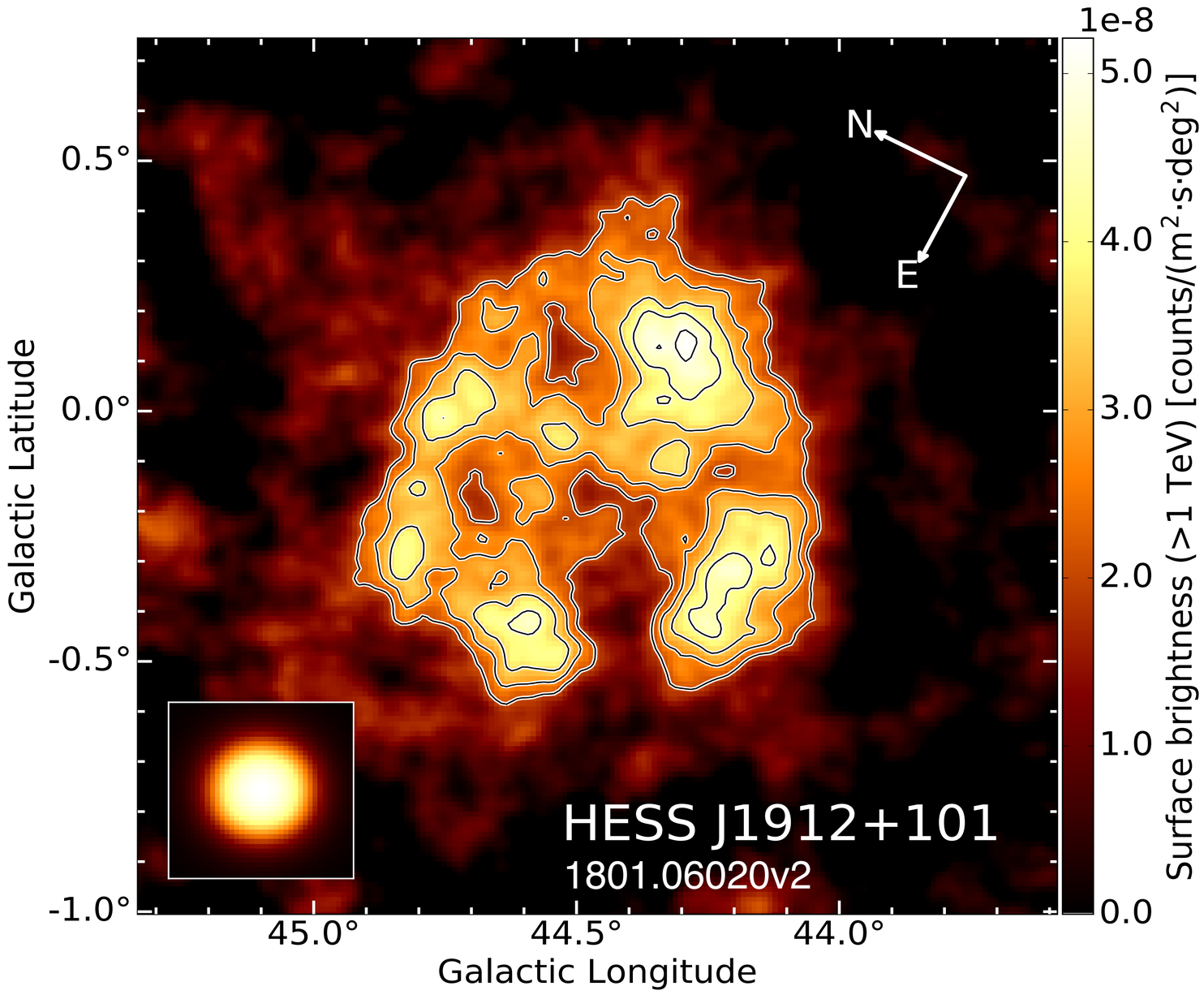
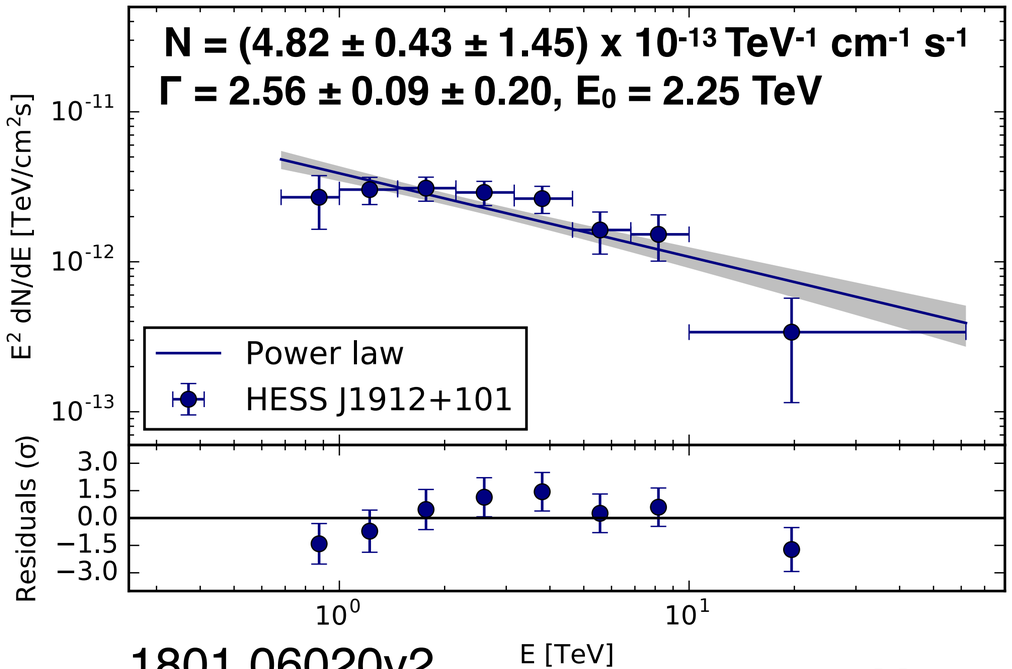


What is HESS J1912+101?

Projected Shell:

$$M(R) = A \times \begin{cases} \sqrt{R_2^2 - R^2} - \sqrt{R_1^2 - R^2} & R < R_1 \\ \sqrt{R_2^2 - R^2} & R_1 < R < R_2 \\ 0 & R > R_2 \end{cases}$$



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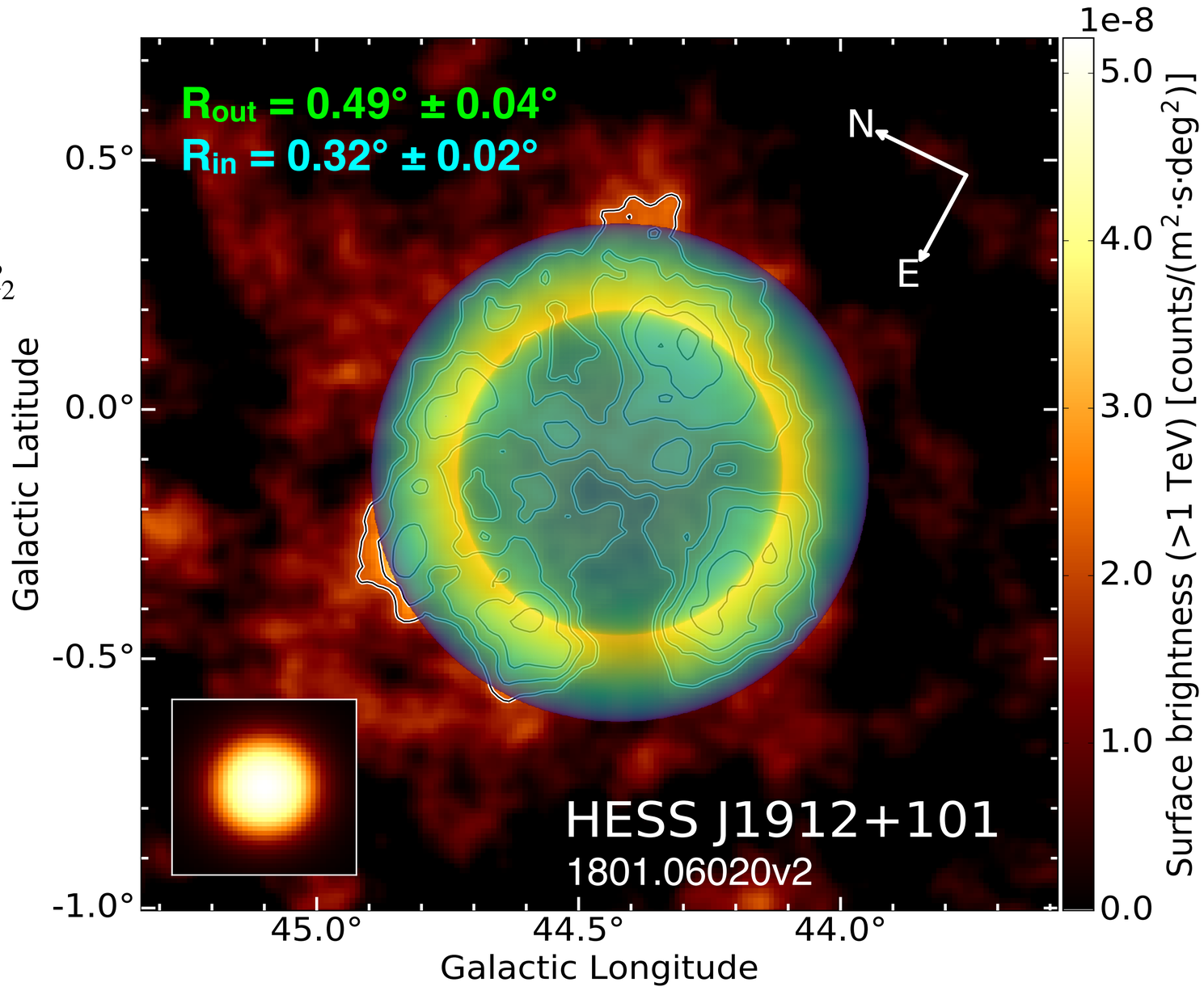
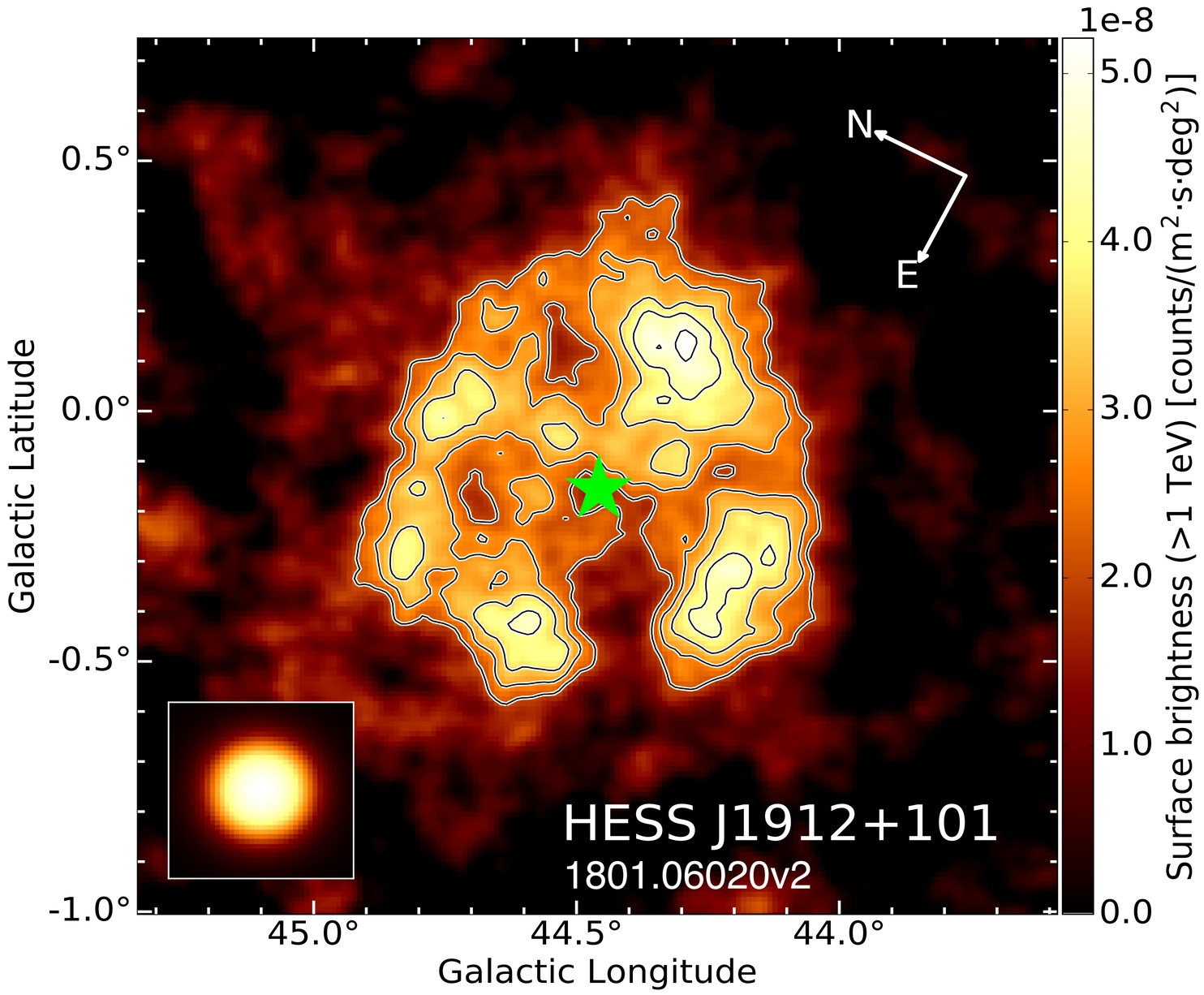


What is HESS J1912+101?

- PSR J1913+1011 is found at center of HESS J1912+101
  - Dist = 4.6 kpc
    Age = 1.69 x 10^5 yr
    Edot = 1.4 x 10^{35}
    Implies R ~ 38 pc
- Will interpret this source as a SNR candidate
  - PWN cannot be ruled out



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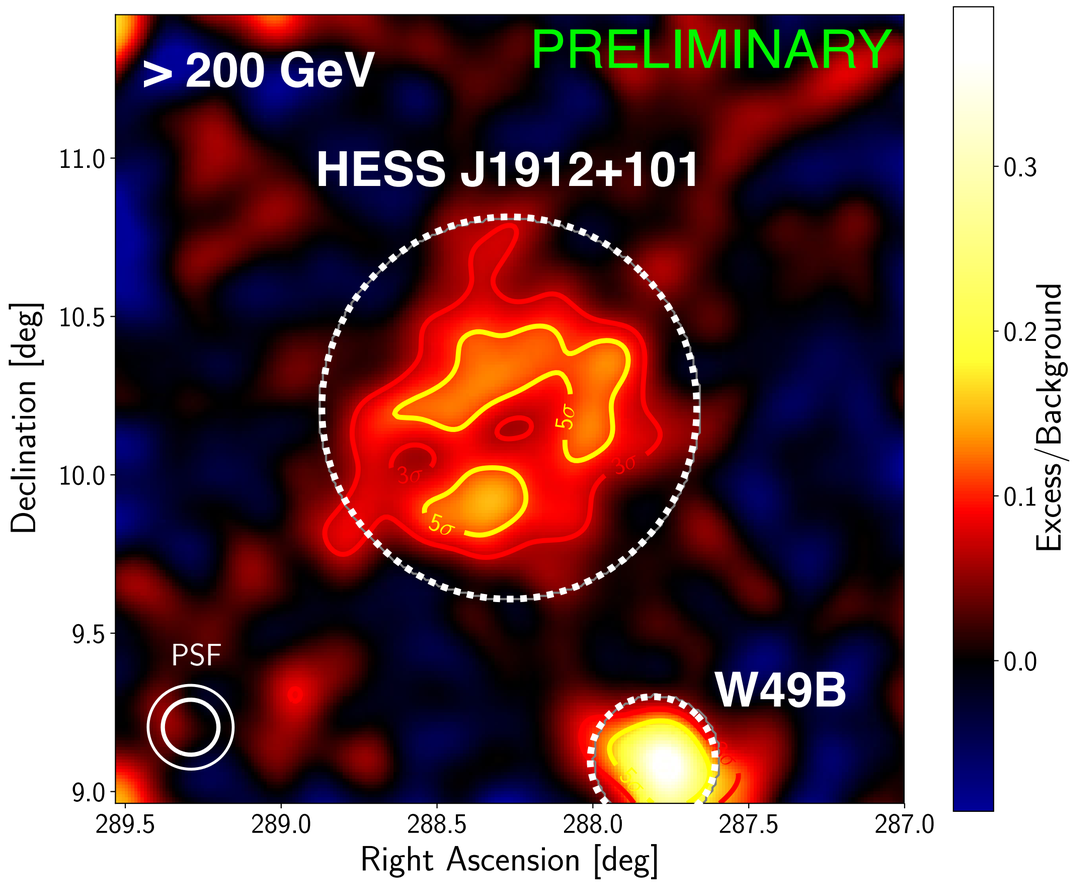
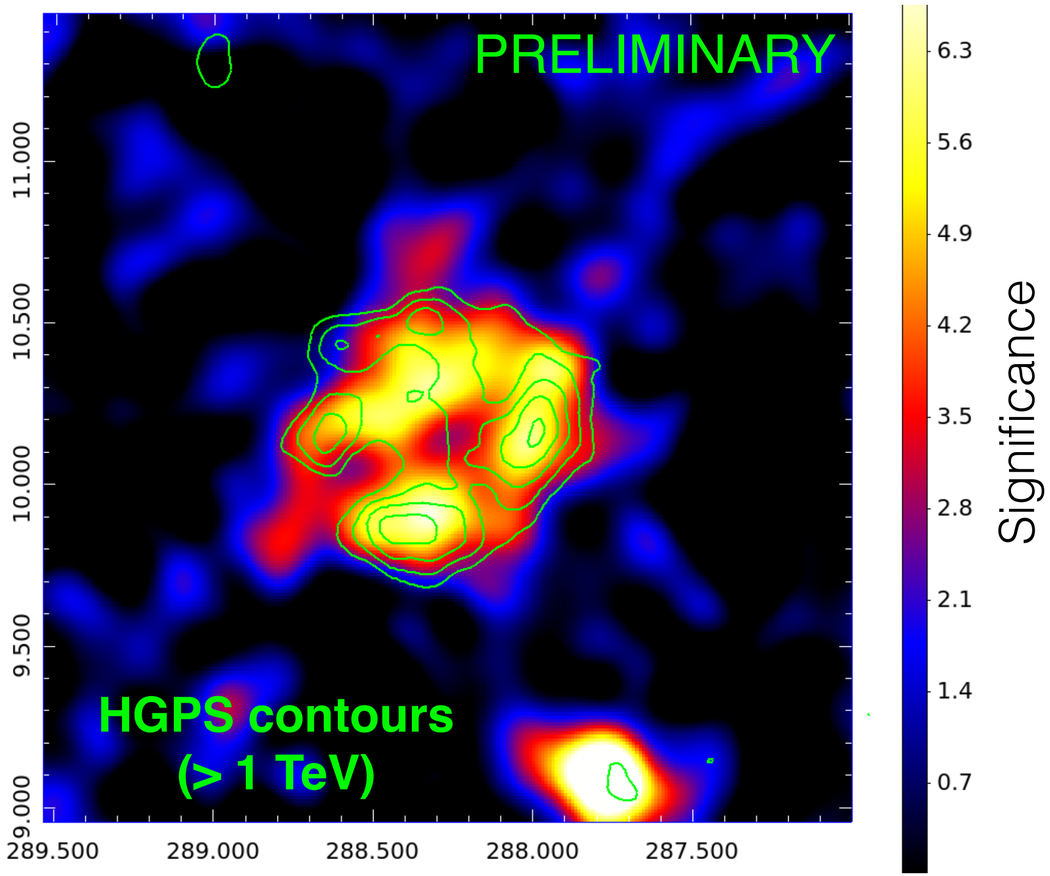
MAGIC Observations

- 86 hours of MAGIC data
- Clear detection > 200 GeV (>11σ)
- Very similar to the morphology obtained by H.E.S.S. Collaboration et al. 2018 (>1 TeV)

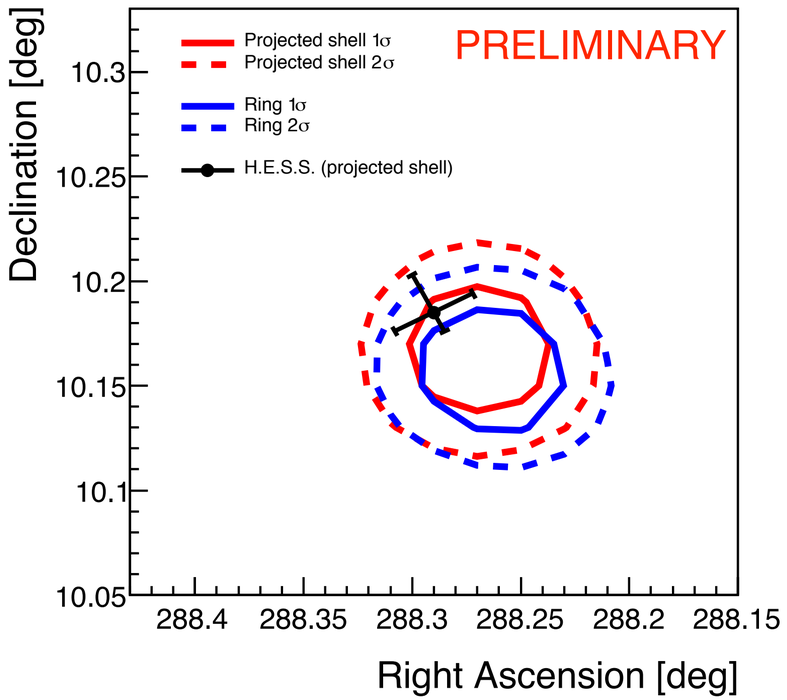


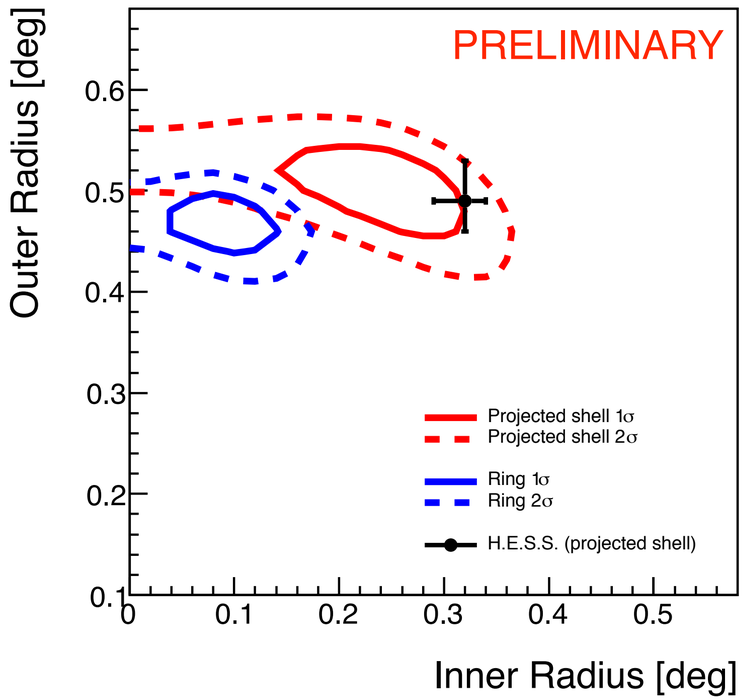


MAGIC Morphology

- To characterize morphology use *SkyPrism* (A&A 619, A7 (2018))
- Uniform ring is preferred model
- If using Projected Shell, MAGIC morphology consistent with H.E.S.S. result

Spatial Model	RA [°]	DEC [°]	R_1 [°]	R_2 [°]	TS
Gaussian	288.27±0.03	10.17±0.03	-	0.47±0.04	194.03
Ring	288.27±0.03	10.17±0.03	0.10±0.03	0.46±0.02	207.1
P Shell	288.27±0.03	10.17±0.03	0.26±0.05	0.50±0.03	205.80

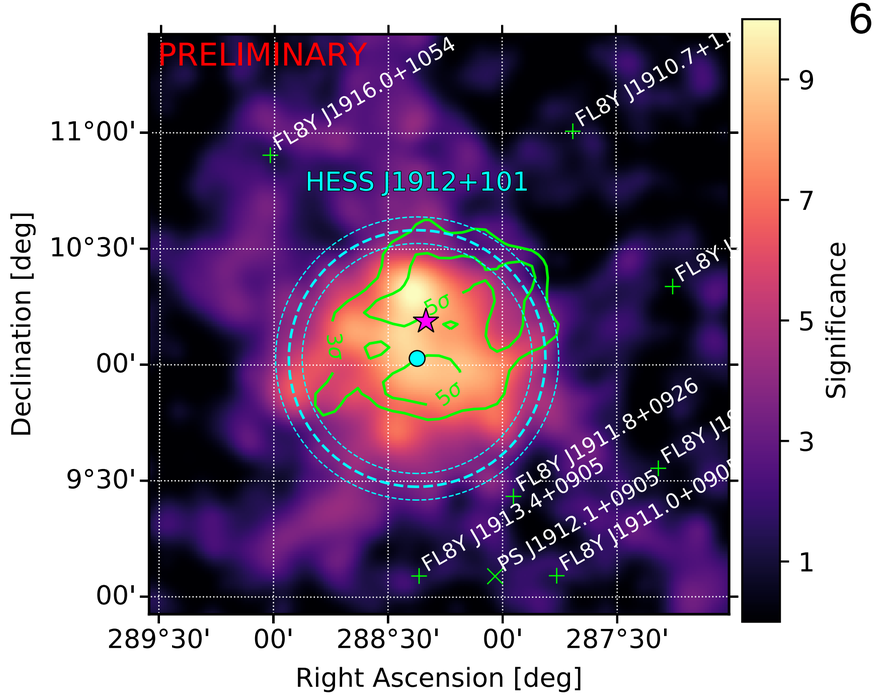


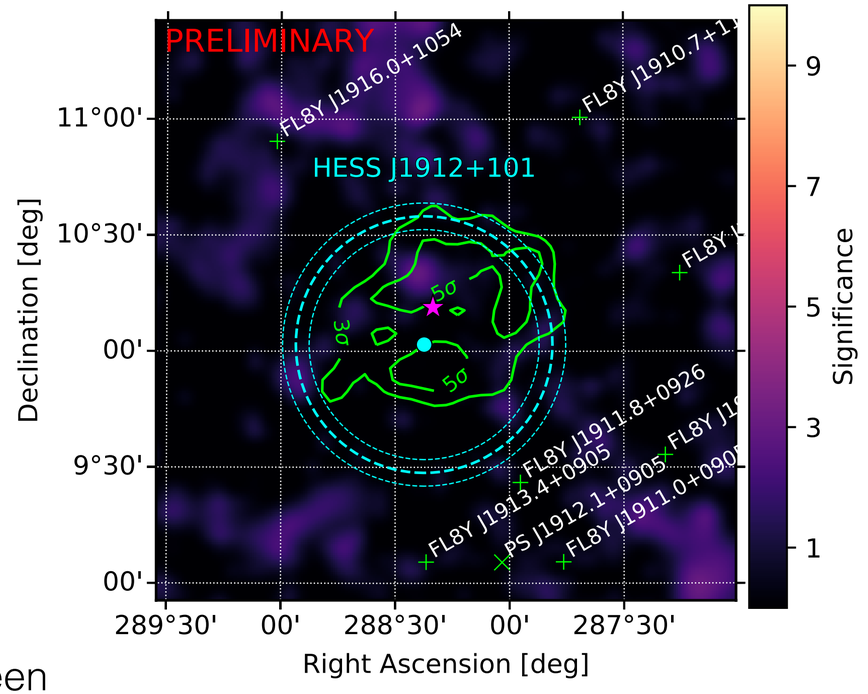


Fermi-LAT Morphology

- Test for extension from 1 GeV - 2 TeV using binned joint maximum likelihood
- Gate PSR J1913+1011 found at center of HESS J1912+101
- Three source found in contours of HESS J1912+101 and removed from ROI:
  - FL8Y J1913.3+1018, FL8Y J1912.7+0959, FL8Y J1914.6+1009
- Radial Gaussian preferred over other spatial models

Spatial Model	RA [°]	DEC [°]	R_{68} [°]	TS	TS_{EXT}
PS	288.34±0.03	10.03±0.02	-	192.66	
Gaussian	288.37±0.04	10.03±0.04	0.55±0.06±0.01	294.32	101.66
Disk	288.39±0.03	9.99±0.03	0.45±0.03±0.01	284.56	91.9
Map	288.28	10.18	-	252.51	59.85





Fermi-LAT SED

- Spectral analysis from 100 MeV - 2 TeV using binned joint maximum likelihood
- Using Radial Gaussian model from extension analysis
- 8 alternative interstellar emission models (aIEMs) estimate the systematic uncertainties in the SED
  - Combined using: $\sigma_{\mathrm{sys},w} = \sqrt{\frac{1}{\sum_i^M w_i} \sum_i^M w_i \left(P_i - P_{\mathrm{STD}}\right)^2}$ (2016, APJS, 224, 8)
- Best spectral model a simple PowerLaw:
  - Prefactor = $(2.88 \pm 0.34_{\mathrm{stat}} \pm 1.01_{\mathrm{sys}}) \times 10^7$ TeV^{-1} cm^{-2} s^{-1}
  - Index = $2.15 \pm 0.03_{\mathrm{stat}} \pm 0.01_{\mathrm{sys}}$

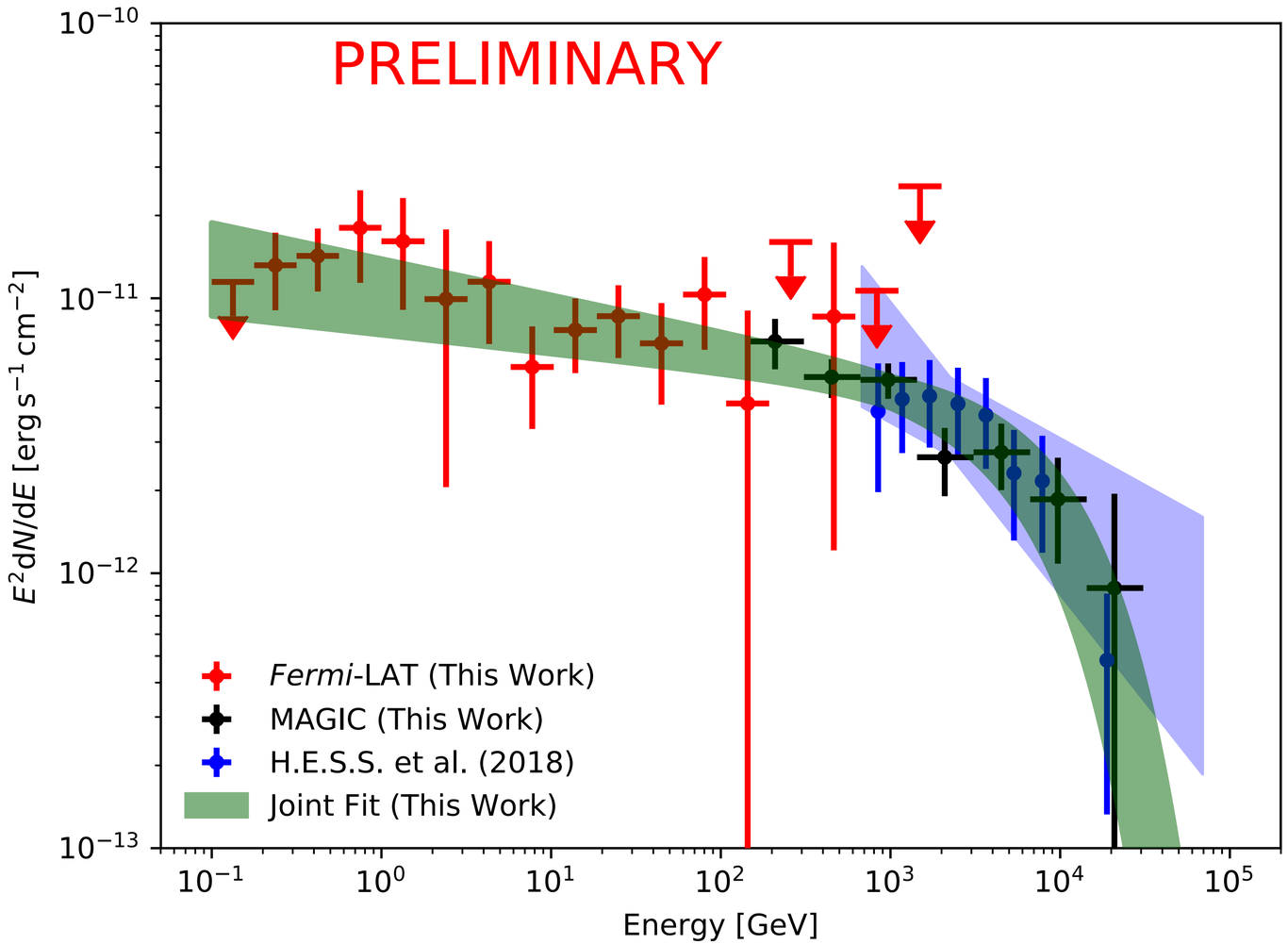
Joint Spectrum

- Using best models from *Fermi*-LAT and MAGIC
- Joint fit using instruments' responses
- Fluxes are smoothly connected

$$\mathrm{PL}: \frac{dN}{dE} = f_0 \left(\frac{E}{E_0}\right)^{-\Gamma}$$

$$\mathrm{ECPL}: \frac{dN}{dE} = f_0 \left(\frac{E}{E_0}\right)^{-\Gamma} \exp\left(-\frac{E}{E_{cut}}\right)$$

Spectral Model	f_0 [cm^{-2} s^{-1} TeV^{-1}]	Γ	E_{cut} [TeV]	χ^2/NDF (p-value)
PL	$\left(2.06^{+0.15}_{-0.14}\right) \times 10^{-12}$	$2.20^{+0.02}_{-0.02}$	-	82.47/30 $\left(8.65 \times 10^{-7}\right)$
ECPL	$\left(3.17^{+0.33}_{-0.31}\right) \times 10^{-12}$	$2.09^{+0.04}_{-0.02}$	$9.59^{+3.48}_{-2.47}$	34.09/29 (0.24)

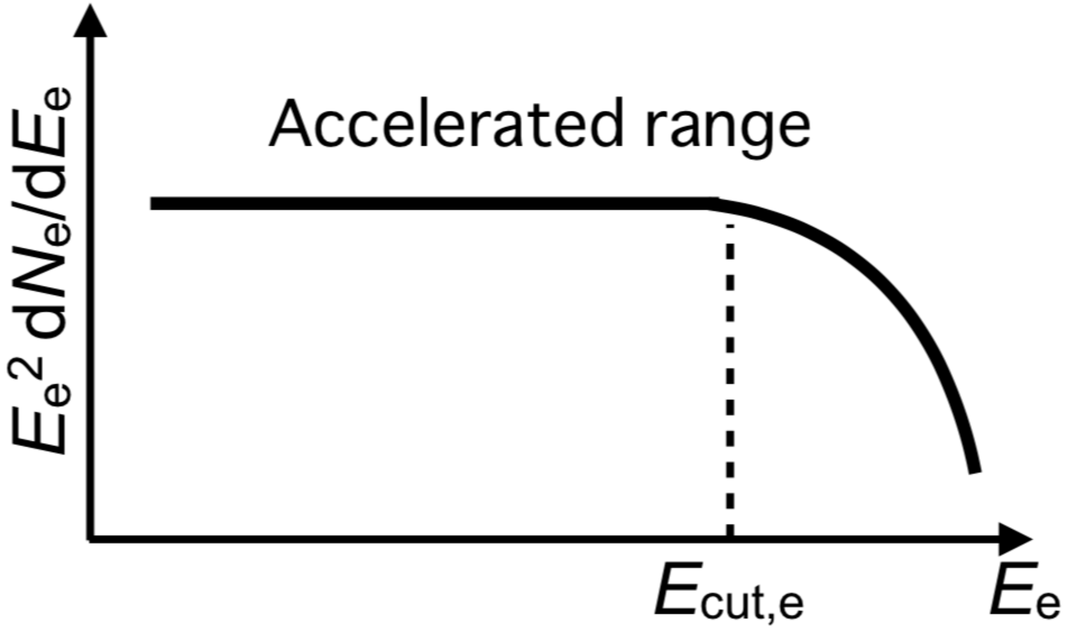


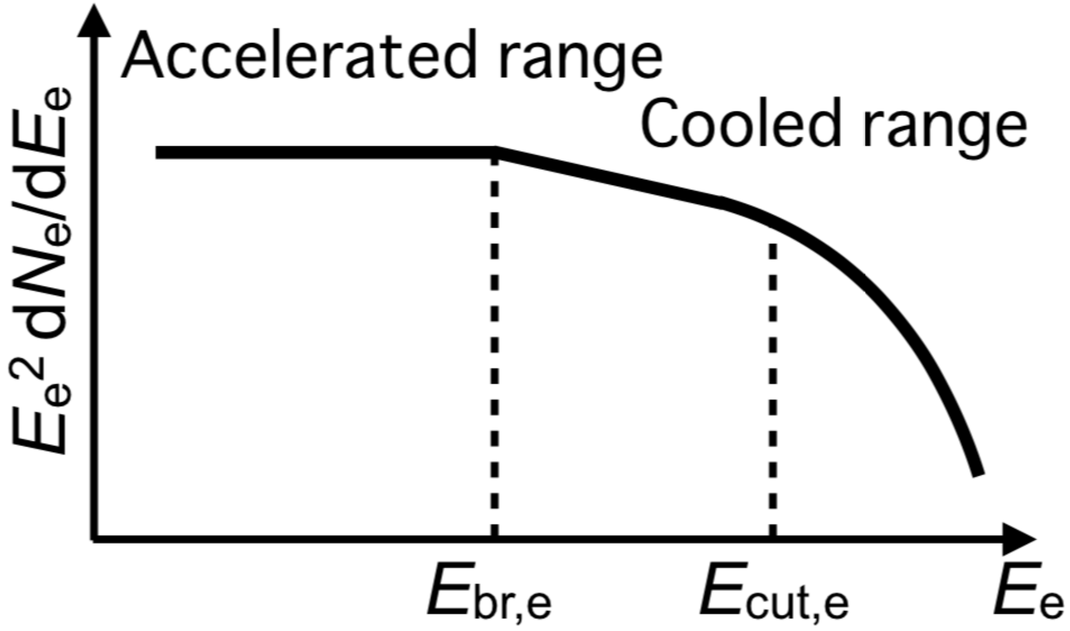
Spectral Modeling - Leptonic

- Fitting done with Naima (1509.03319)
- One-zone leptonic model
  - Dist = 1.5 kpc, B = 10 μG
- S_e (e^- index) generally outside DSA predictions (1.4 - 2.4)
  - Indicative of cooled electrons and an old SNR

n [cm^{-3}]	S_e	$E_{cut,e}$ [TeV]	W_e (E_e > 1GeV) [erg]	BIC
0.1	$2.85^{+0.03}_{-0.05}$	$49.72^{+33.07}_{-18.32}$	$1.65^{+0.31}_{-0.43} \times 10^{49}$	25.49
1.0	$2.63^{+0.03}_{-0.03}$	$25.73^{+9.71}_{-6.86}$	$4.01^{+0.53}_{-0.64} \times 10^{48}$	26.41
10.0	$2.41^{+0.03}_{-0.05}$	$20.12^{+7.00}_{-5.31}$	$7.19^{+0.89}_{-1.17} \times 10^{47}$	25.42

$$E_{\mathrm{br,e}} = 128\ \mathrm{TeV} \left(\frac{\mathrm{B}}{10\mu\mathrm{G}}\right)^{-2} \left(\frac{t_{\mathrm{age}}}{1\ \mathrm{kyr}}\right)^{-1}$$





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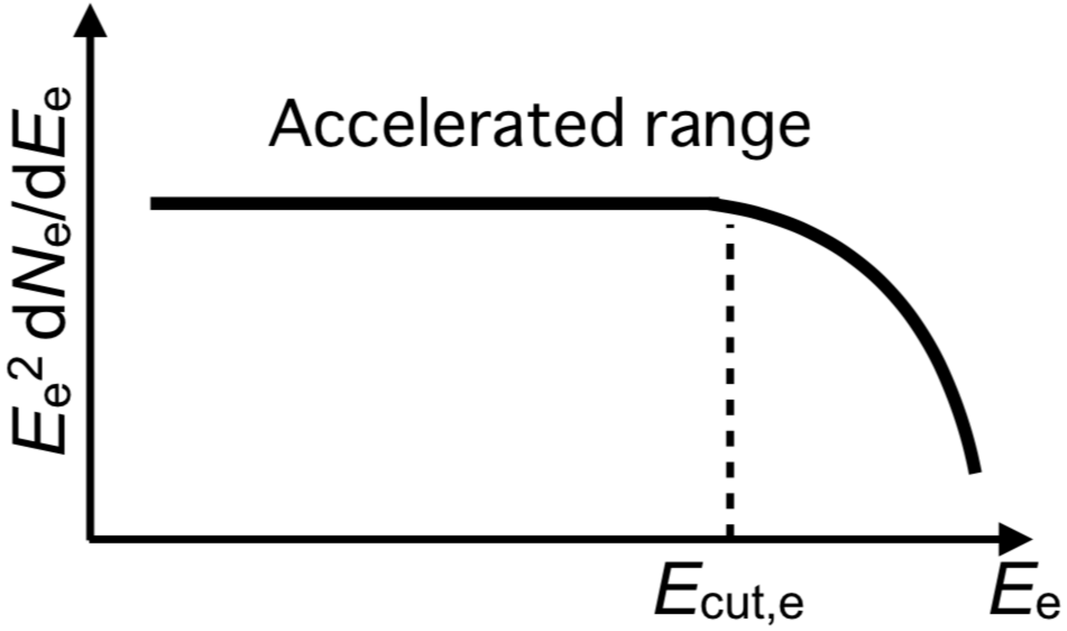
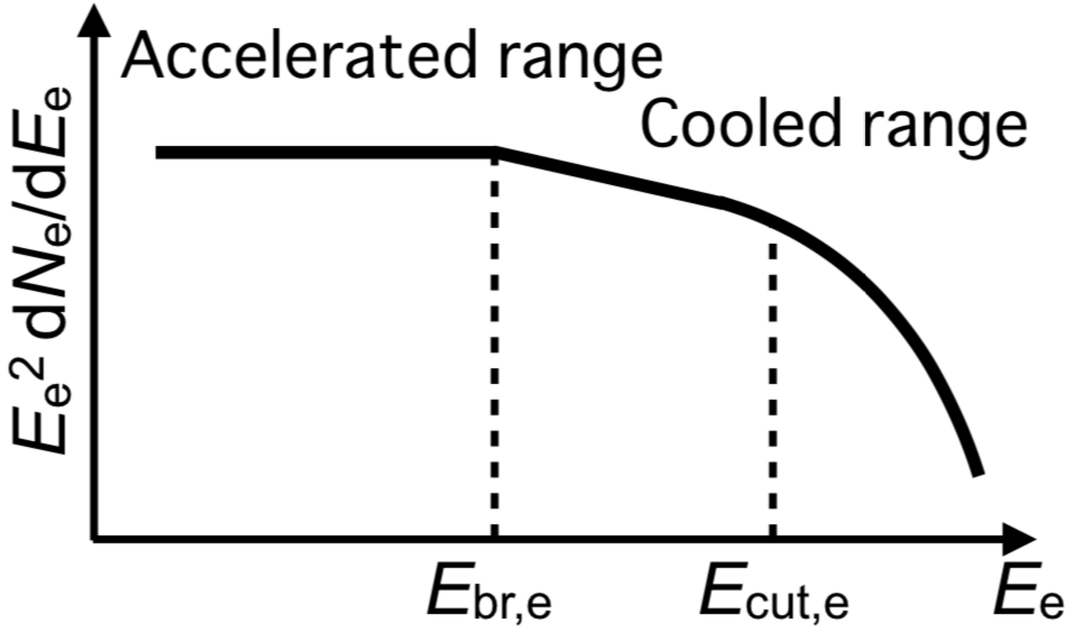
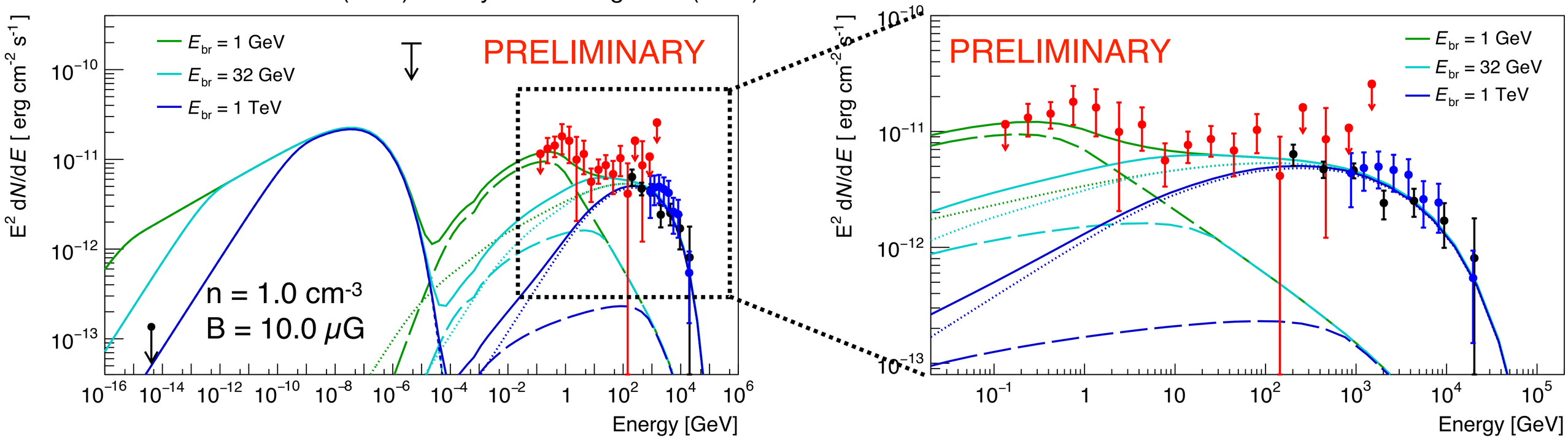




Spectral Modeling - Leptonic

Radio UL : Reich & Sun (2018) X-ray UL : Chang et al. (2008)



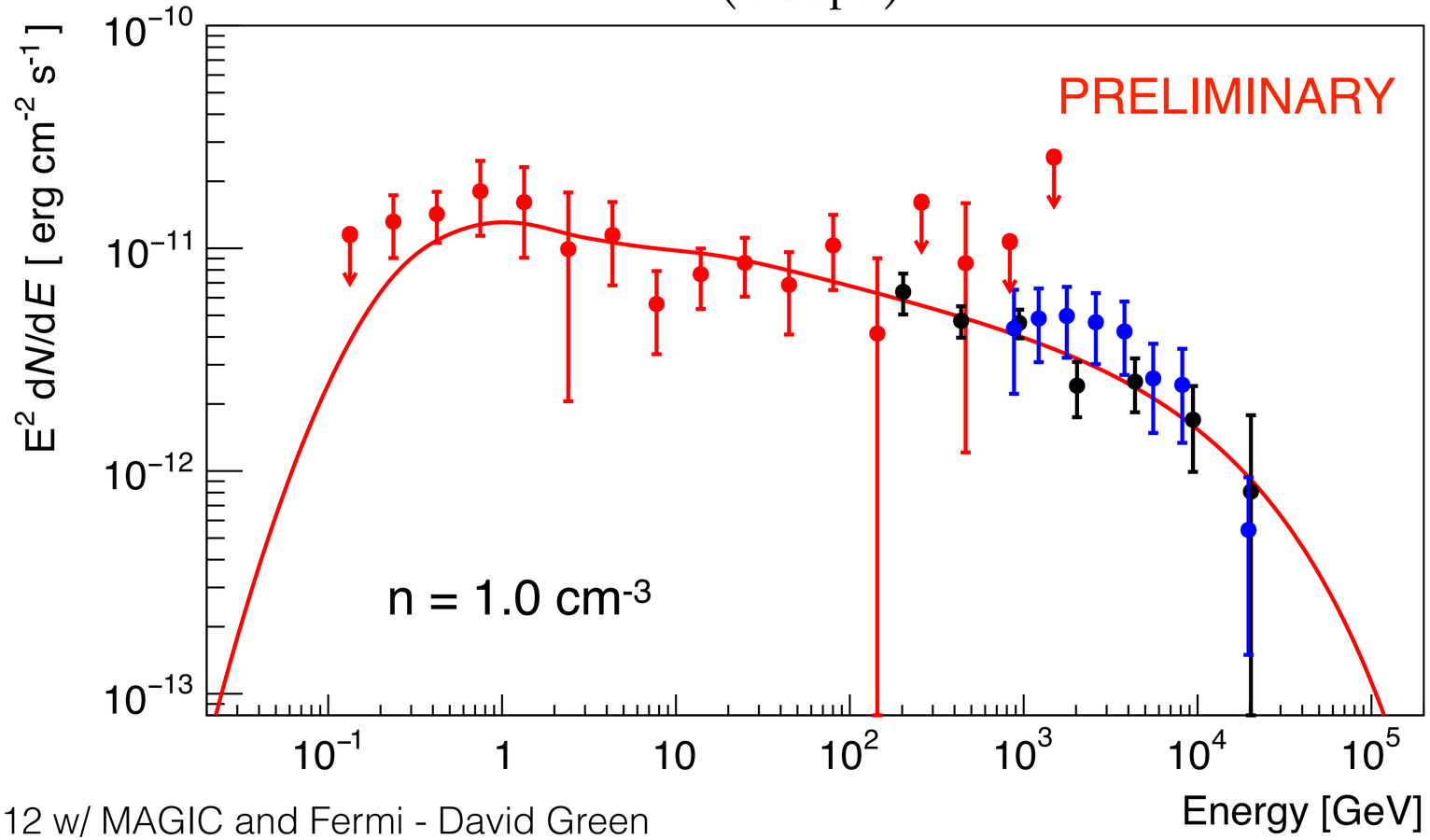
- To represent data, $E_{br,e}$ ~1 GeV is required
  - t_{age} ~1.28 x 10^8 yr, very old
- Additionally, conflict between GeV data and lack of radio detection
- Motivation for additional X-ray observations

Spectral Modeling - Hadronic

- Using a one-zone hadronic model
- For Dist = 1.5 kpc (R = 12.4 pc):
  - W_P ~ 15% E_{SN}
  - t ~ 1x10^4 yr and V_{sh} ~ 500 km/s
  - $E_{cut,P}$ ~ 15 TeV (too low)
- Old SNR associated w/ PSR J1913+1011?
  - Dist = 4.6 kpc (R = 38 pc)
  - $E_{cut,P}$ decreases with shock speed
  - At age ~ 160 kyr (close to PSR), $E_{cut,P}$ ~ 2.3-8.0 TeV (too low)

n [cm^{-3}]	S_P	$E_{cut,P}$ [TeV]	W_P (E_P > 1GeV) [erg]	BIC
1.0	$2.25^{+0.04}_{-0.04}$	$215.32^{+286.47}_{-98.96}$	$1.42^{+0.21}_{-0.19} \times 10^{50}$	26.10

$$W_P = 1.42 \times 10^{50}\ \mathrm{erg} \left(\frac{d}{1.5\mathrm{kpc}}\right)^2 = 0.14 E_{\mathrm{SN}}$$



Interpretation & Conclusions

- Difficult to conclude nature of HESS J1912+101 without further MWL observations
- Morphology and spectrum look like an SNR, but…
- One-zone leptonic models require a softer, than typical DSA, spectral index (>2.4)
  - Modeled with cooled electrons with $E_{br,e}$ ~1 GeV with an age ~ 1.28 x 10^8 yr
  - Conflict between GeV break and lack of radio detection
- One-zone hadronic models also in conflict with DSA
  - $E_{cut,p}$ ~ 200 TeV difficult to reconcile with age and radius estimates
- Pulsar Wind Nebula interpretation still be finalized

BACKUP SLIDES

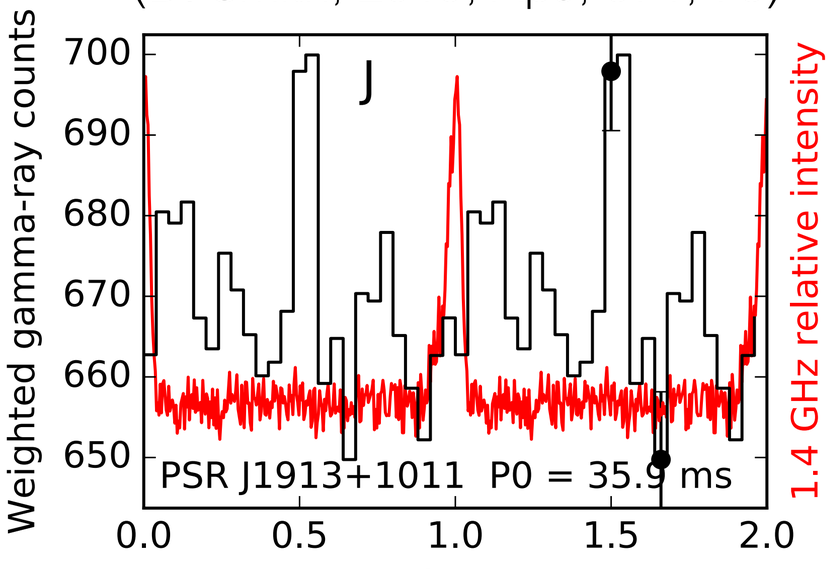
PSR J1913+1011

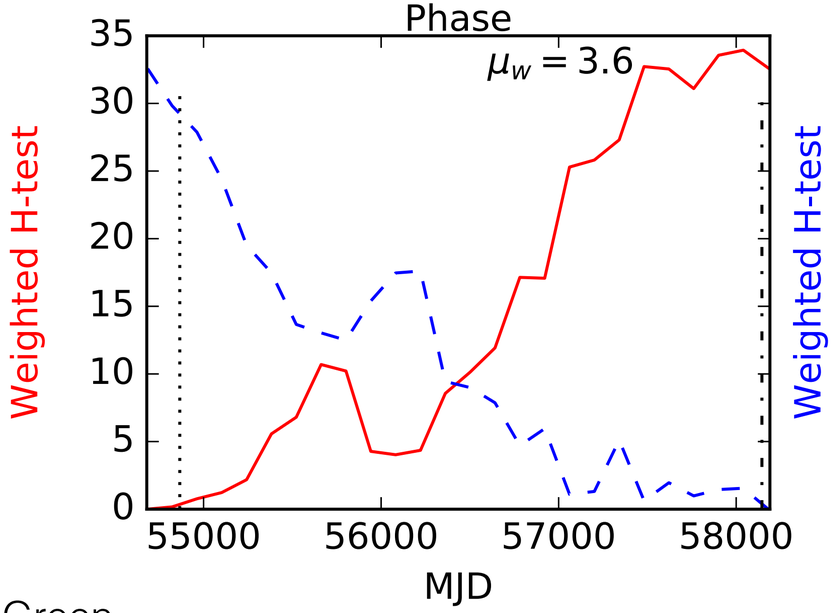
- PSR J1913+1011 is found at center of HESS J1912+101

Name	RA [°]	DEC [°]	Age [yr]	Dist [kpc]	Edot [erg/s]
PSR J1913+1011	288.33475	10.18971	1.69×10^5	4.61	1.4×10^{35}

- Recently discovered gamma-ray pulsar (D. Smith, 2019, ApJ, 871, 78)
- Performed a phased analysis with ephemerides provided by Jordell Bank Observatory
- Removed strongest peak

(D. Smith, 2019, ApJ, 871, 78)





Comparing FL8Y to Extended Source

- We can use AIC to determine best model

$$\mathrm{AIC} = 2k - 2\log\mathscr{L}$$

- ΔAIC between Radial Gaussian and collection of PS:
  - ΔAIC = 39.36
- Radial Gaussian is strongly preferred over collection of PS

Source Name	RA [°]	DEC [°]	Offset [°]	TS
FL8Y J1913.3+1018	288.34	10.31	0.15	38.77
FL8Y J1912.7+0959	288.18	10.00	0.20	123.16
FL8Y 1914.6+1009	288.65	10.16	0.37	41.64
PS J1915.6+0953	288.91	9.90	0.69	41.90

Spatial Model	RA [°]	DEC [°]	R_{68} [°]	TS	TS_{EXT}
PS	288.34±0.03	10.03±0.02	-	192.66	
Gaussian	288.37±0.04	10.03±0.04	0.55±0.06±0.01	294.32	101.66
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