Constraining leptonic emission scenarios for the PeVatron candidate HESS J1702-420 with deep XMM-Newton observations

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HESS J1702-420

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7th Heidelberg International Symposium on
High Energy Gamma-Ray Astronomy
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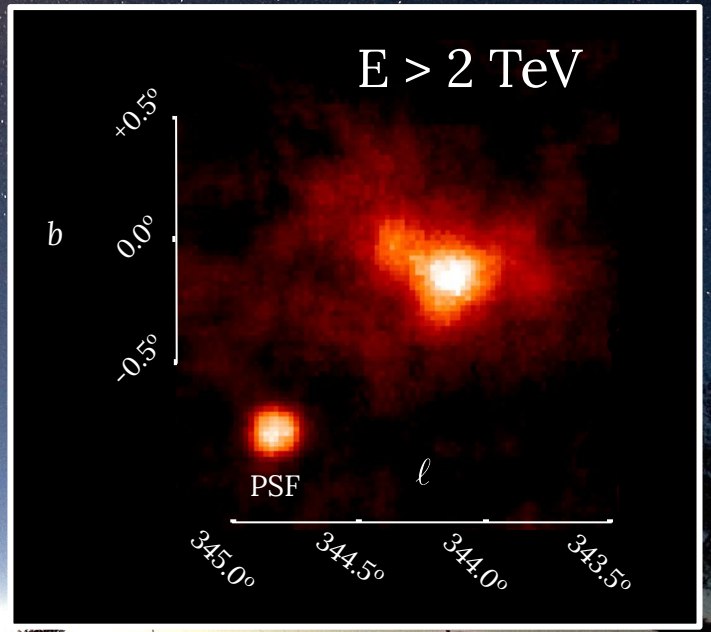
H.E.S.S. Collab. 2021



HESS J1702-420:

- First detection: H.E.S.S. Collab. 2006
- ***It is completely unidentified***
- All searches for counterparts have failed

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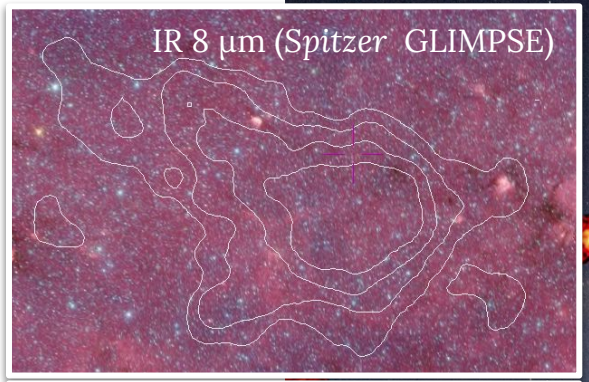
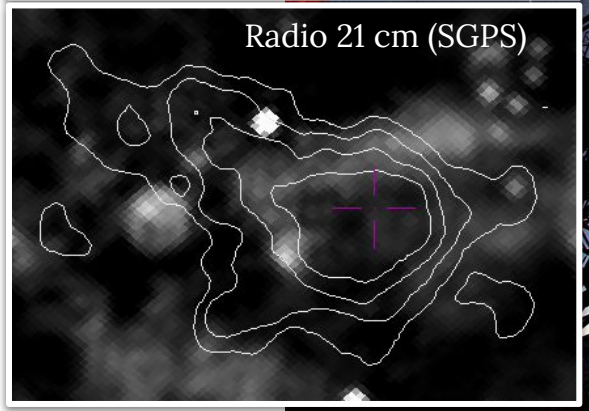
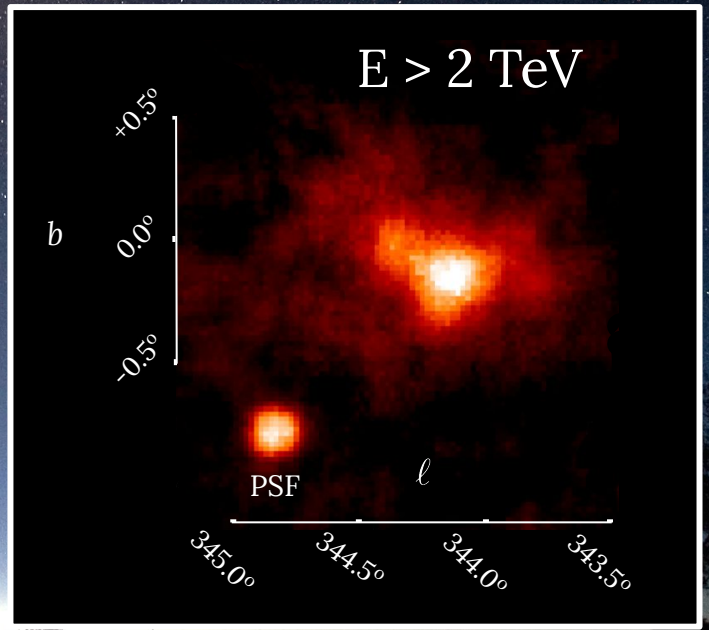




H.E.S.S. Collab. 2021



H.E.S.S. Collab. 2021 (Lead author L. Giunti):

- Discovery of a new TeV emission zone: **HESS J1702-420A**
- Small-sized: $R = 0.06 \pm 0.02_{stat} \pm 0.03_{syst}$ deg
- Hard spectrum: $\Gamma = 1.53 \pm 0.19_{stat} \pm 0.20_{syst}$
- ***Hadronic (PeVatron) or PWN?***

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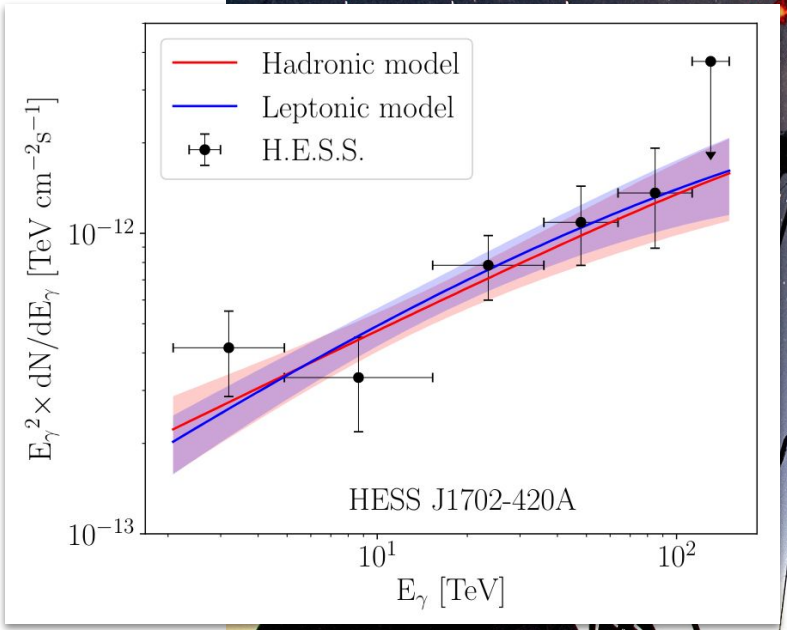
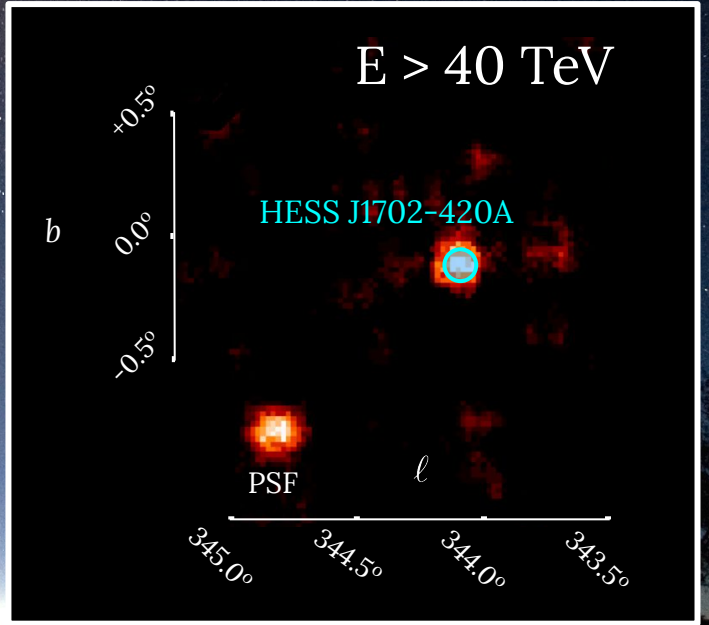


H.E.S.S. Collab. 2021



Suzaku Src B:

- Unidentified X-ray point source
- ***Is it a leptonic (pulsar) counterpart of HESS J1702-420A?***
- Poor statistics + high systematics
  → no X-ray spectrum
  → no search for extension (PWN)

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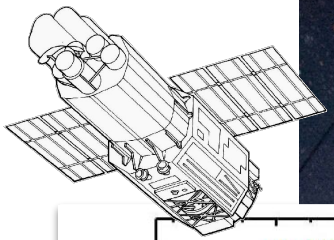
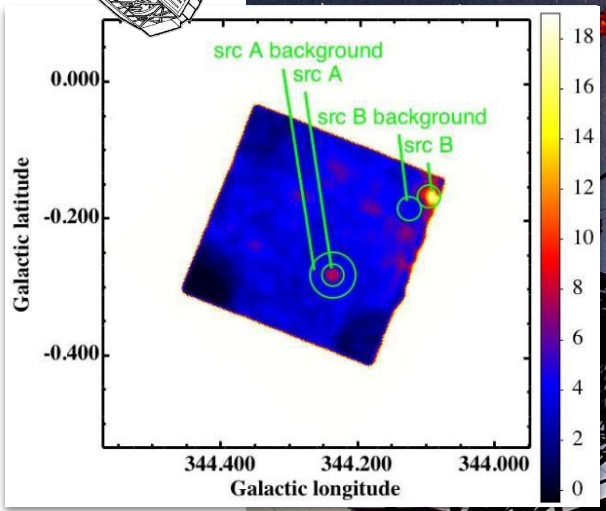
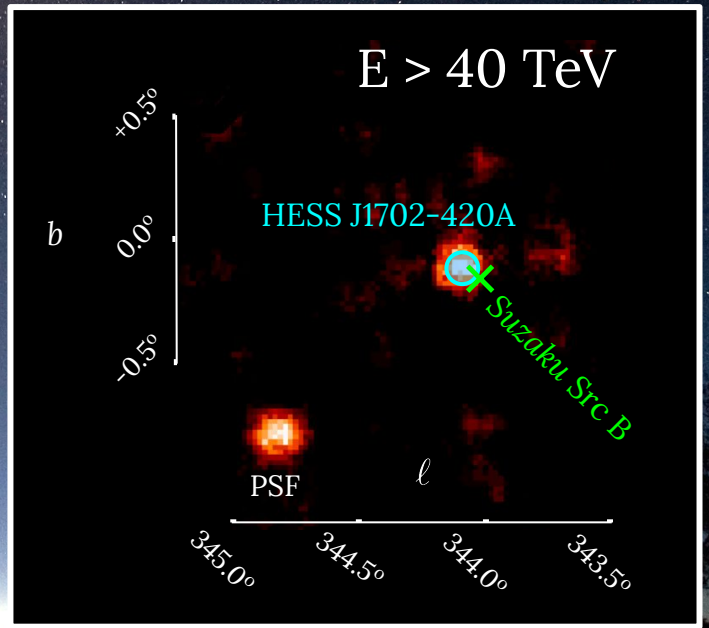


Fujinaga+2011



H.E.S.S. Collab. 2021



A new deep X-ray observation with XMM-Newton

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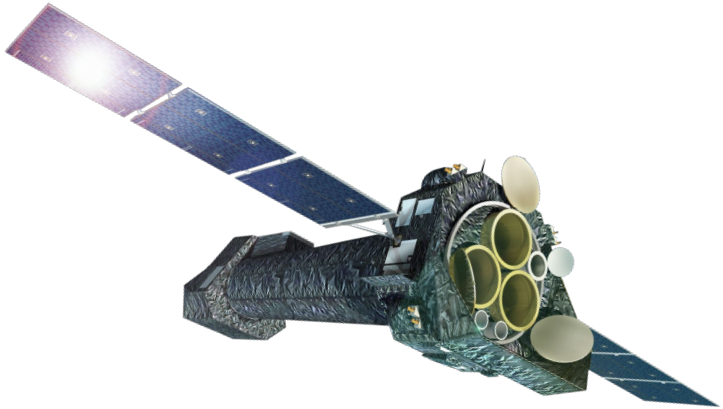
Details:

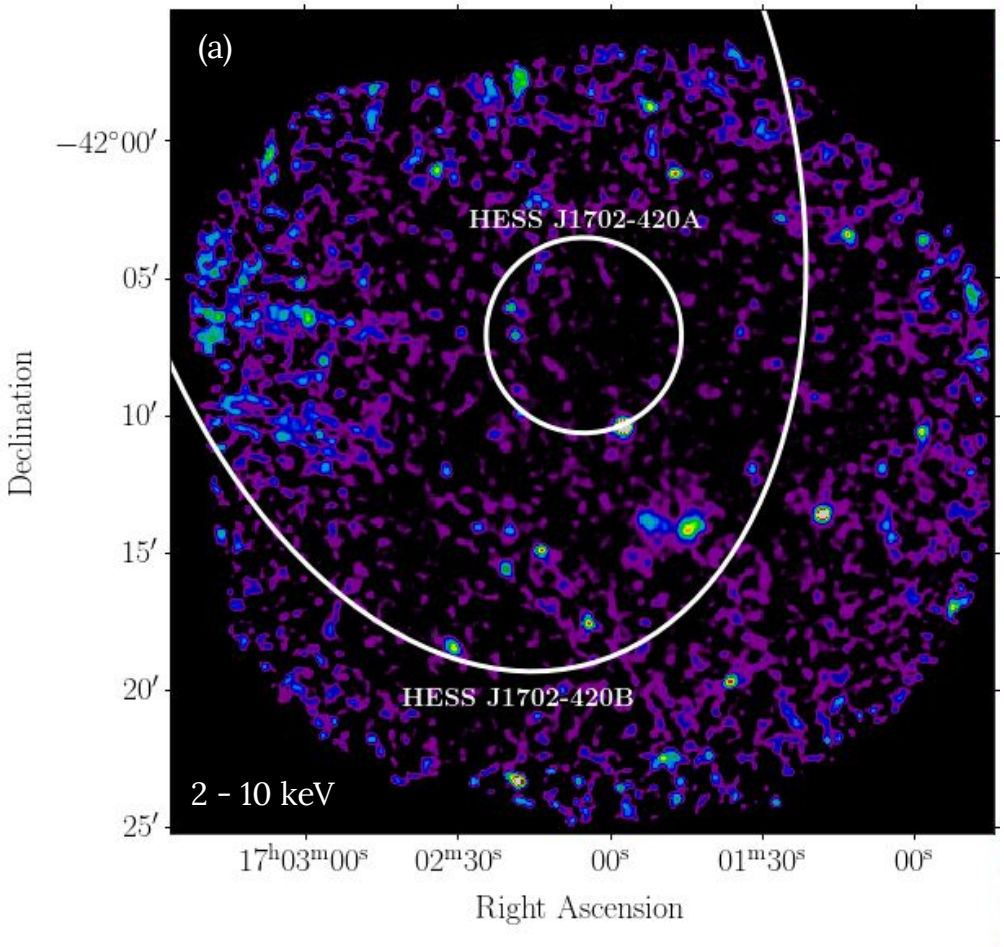
- Livetime: **72 ks**
- Date: September 26th 2021
- Centered on *Suzaku* Src B: l=344.1º, b=−0.17º
- All EPIC cameras (M1, M2, PN) in Full Frame mode



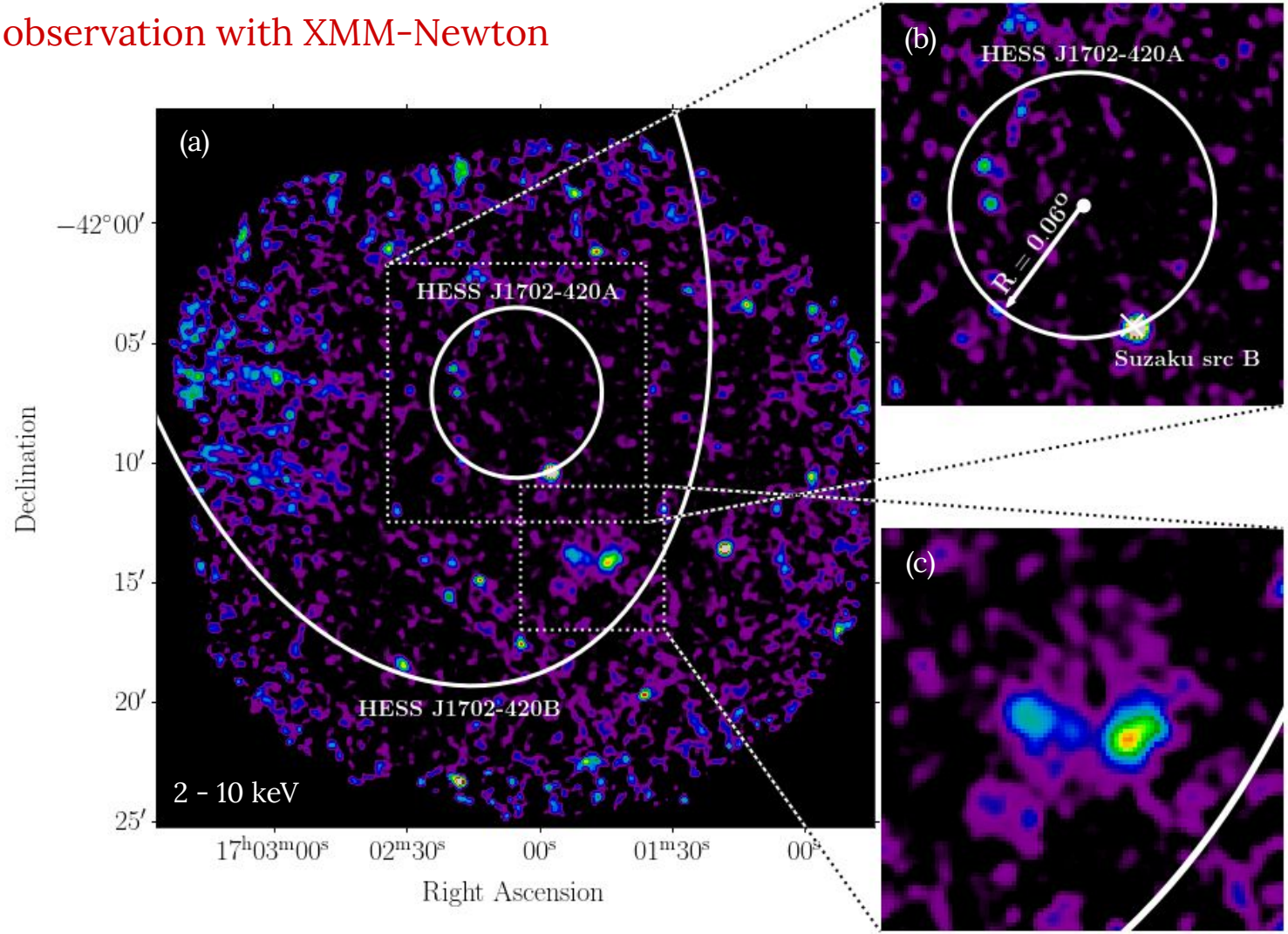
Objectives:

- Look for an X-ray counterpart of HESS J1702-420A to **probe leptonic TeV emission scenarios**
- **Characterize *Suzaku* Src B**, to understand if it is a pulsar associated with HESS J1702-420A
- Estimate the level of on the **diffuse X-ray emission and $\vec{B}$** in the HESS J1702-420A region

A new deep X-ray observation with XMM-Newton



A new deep X-ray observation with XMM-Newton



1) Characterization of *Suzaku* Src B with new XMM data

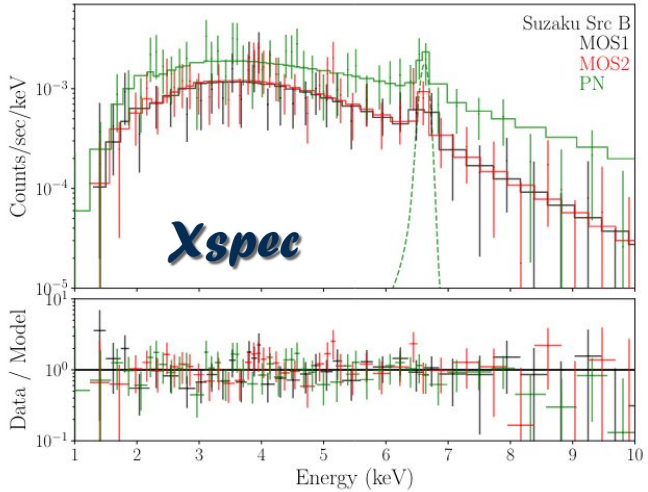
Power law model:

- **Hard index**: $\Gamma = 1.51 \pm 0.30$
- **Heavily absorbed**: $N_h = (5.1 \pm 1.0) \times 10^{22}$ cm^{-2}
  $\Rightarrow$ distance $\gtrsim 7$ kpc
- F(2-10 keV) $= (2.2 \pm 0.2) \times 10^{-13}$ erg cm^{-2}

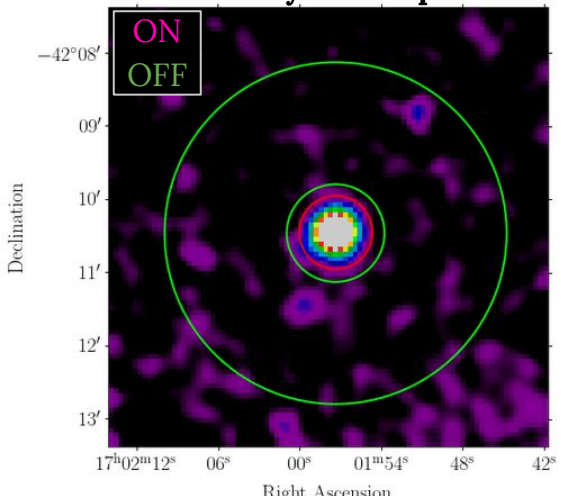
A Fe spectral line:

- Gaussian centered at (6.62 ± 0.6) keV
- Significance: 3.3σ

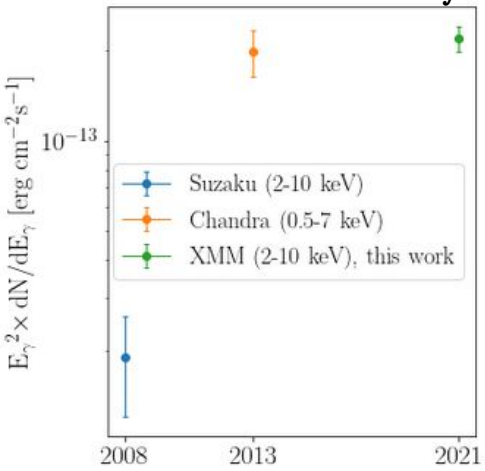
Best-fit model



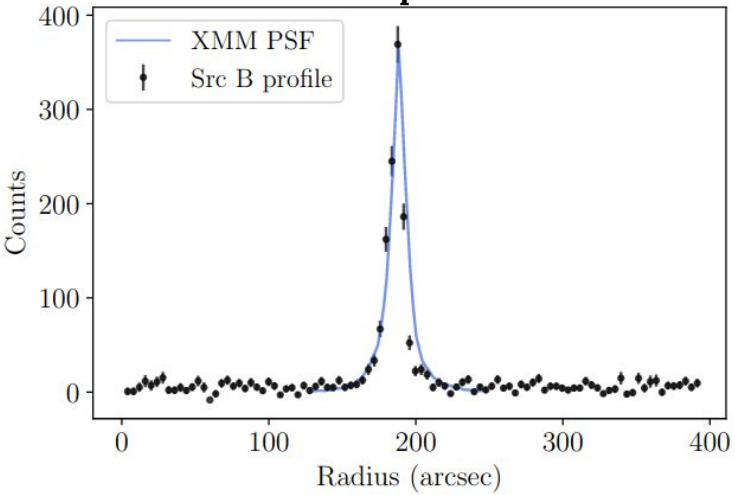
Analysis setup



Evidence of variability



Emission profile



Power law model:

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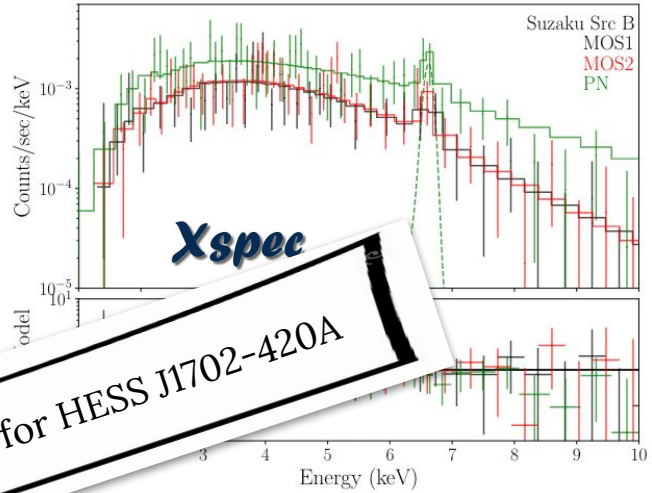
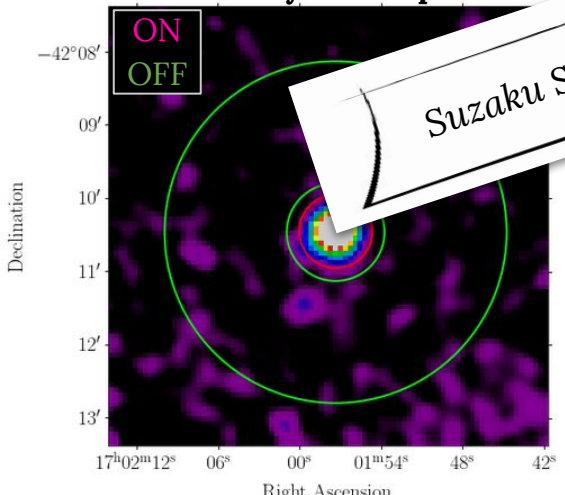
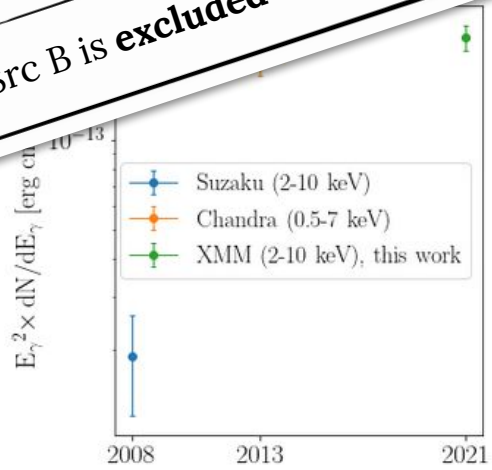


Xspec

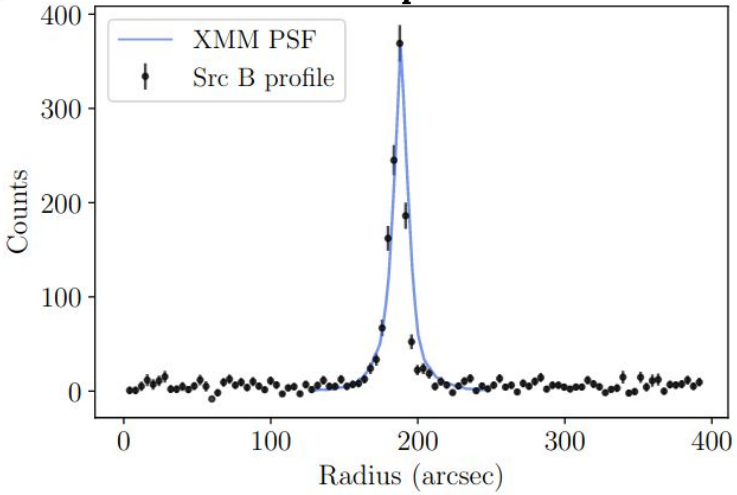
Suzaku Src B is **excluded** as a counterpart for HESS J1702-420A

Analysis setup





Emission profile



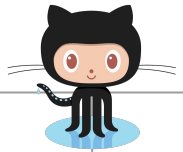
2) Spectral analysis of the HESS J1702-420A region

We want to estimate an upper limit on

1. the **diffuse X-ray emission**
2. the **average $\vec{B}$**

in the HESS J1702-420A region

Approach: Compute a likelihood profile for a model describing a signal in the HESS J1702-420 region

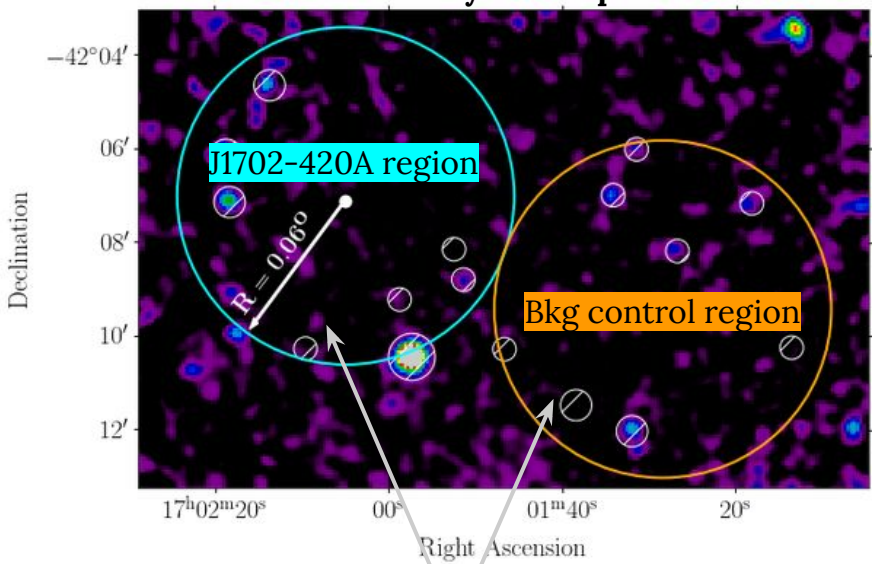


Main analysis | **Crosscheck**

A **Python** package for **gamma-ray** astronomy

Sherpa

Analysis setup



Joint fit of the astrophysical background

Goal 1: Upper limit on the HESS J1702-420A diffuse X-ray flux

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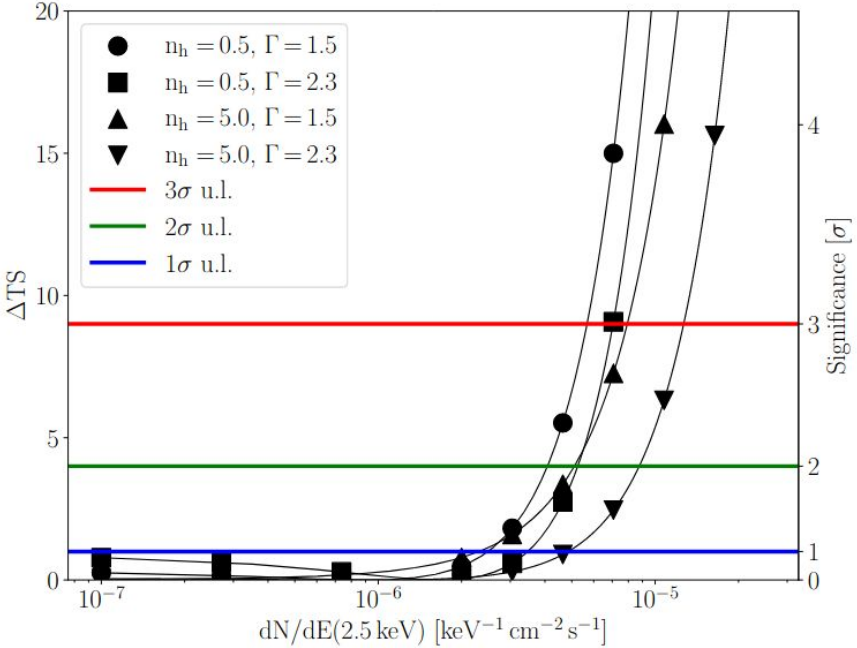
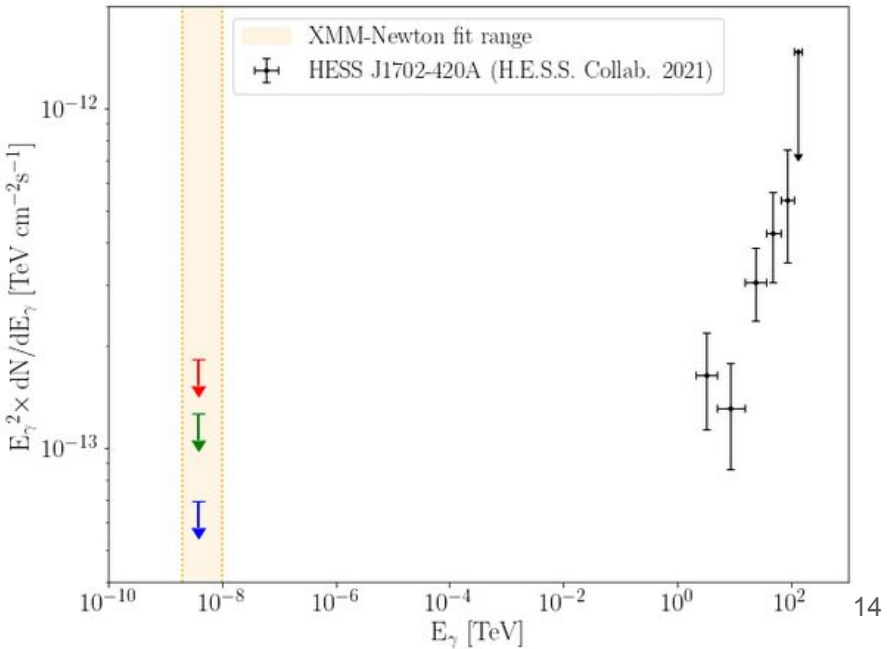
- Background and signal are both modeled with absorbed (`tbabs`) power laws
- All nuisance parameters are left free to vary

Likelihood profiles for the signal amplitude



H.E.S.S. SED with XMM upper limits

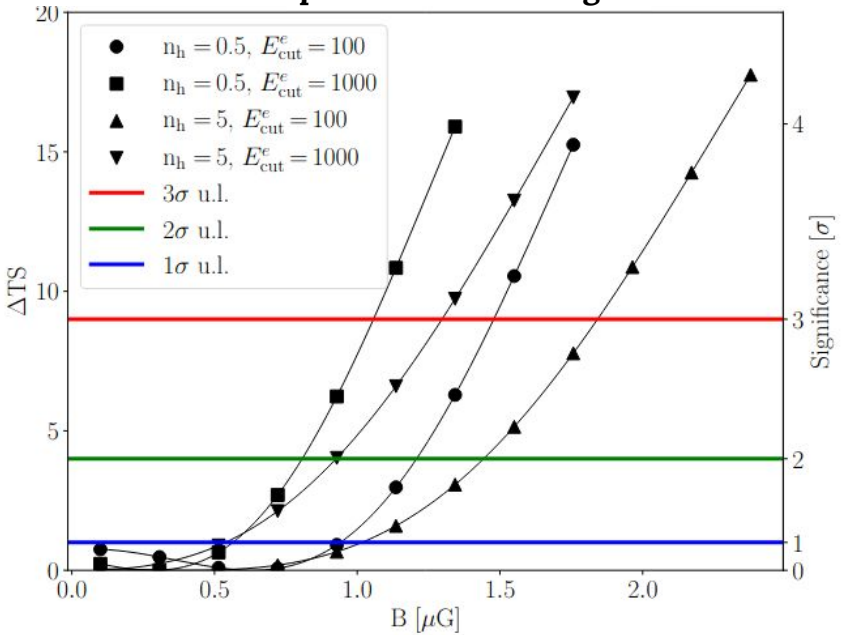


Goal 2: Upper limit on the HESS J1702-420A average magnetic field

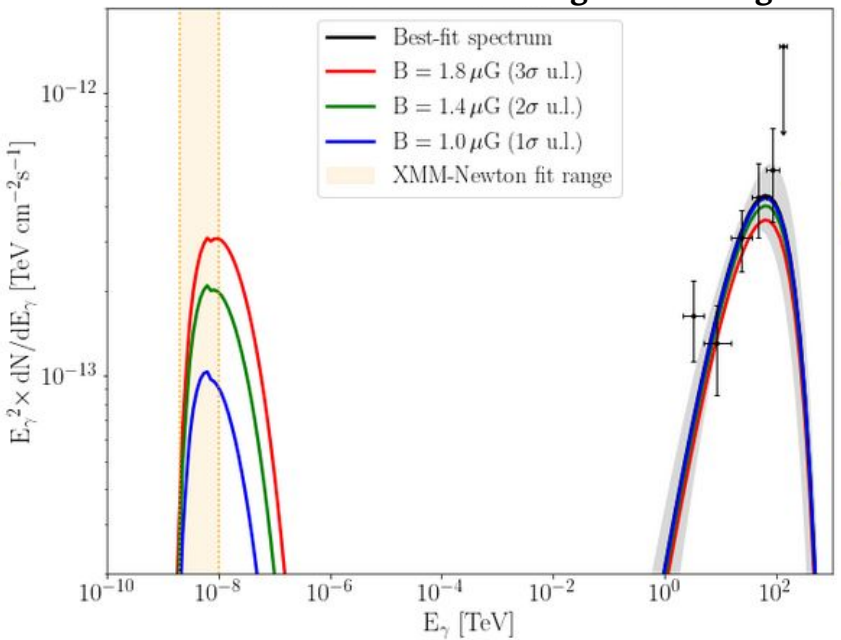
- The signal is described by an **absorbed electron synchrotron model**
- **Joint X-ray (synchrotron) and TeV (inverse-Compton) modeling under one zone assumption**
- population emits γ-rays via synchrotron and inverse-Compton
- 3σ (2σ, 1σ) magnetic field upper limits:

$$B \lesssim 1.8\ (1.4,\ 1.0)\ \mu G$$

Likelihood profiles for the magnetic field



One-zone multi-wavelength modeling

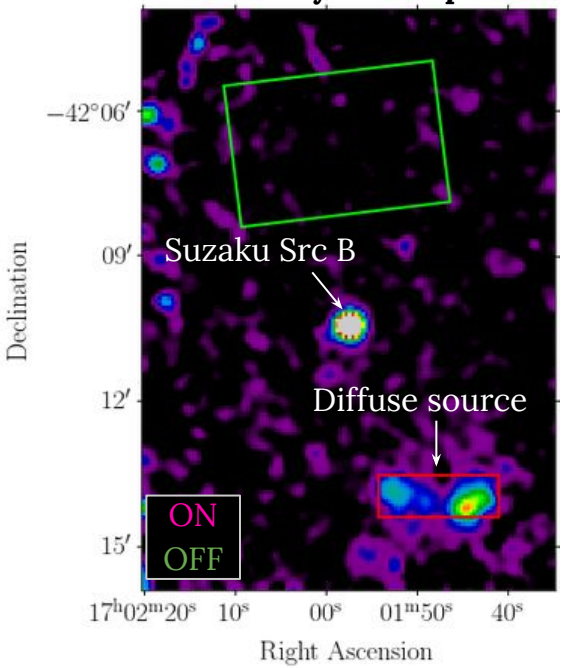


3) The new diffuse X-ray source

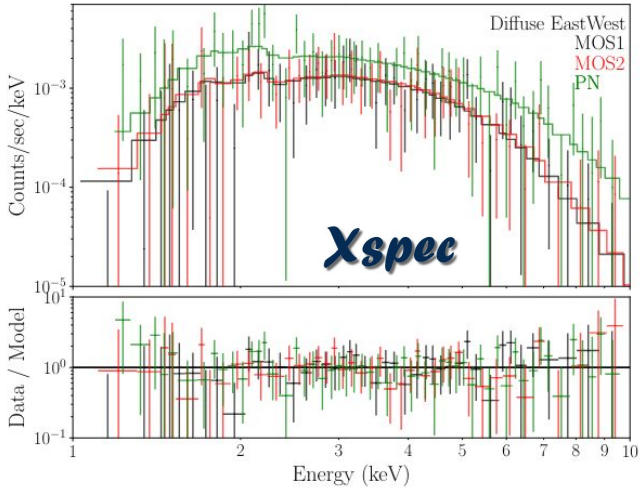
Power law model:

- Hard index: $\Gamma = 1.99 \pm 0.45$
- $N_h = (3.5 \pm 1.0) \times 10^{22}\ cm^{-2}$
- $F(2\text{-}10\ keV) = (1.25 \pm 0.15) \times 10^{-13}\ erg\ cm^{-2}$

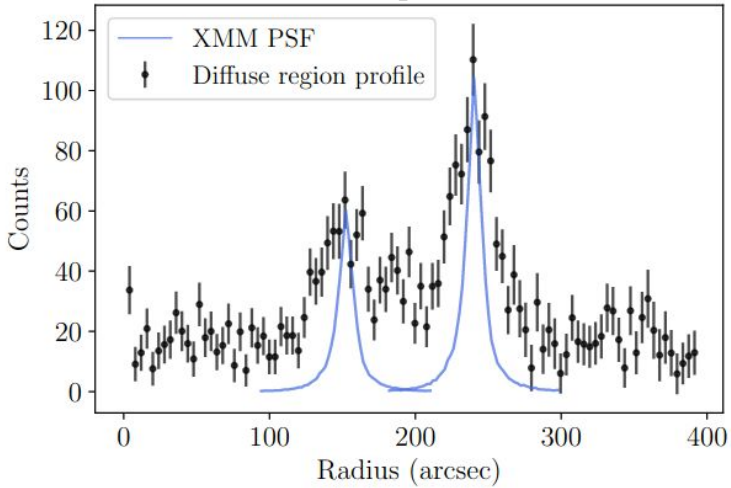
Analysis setup



Best-fit model

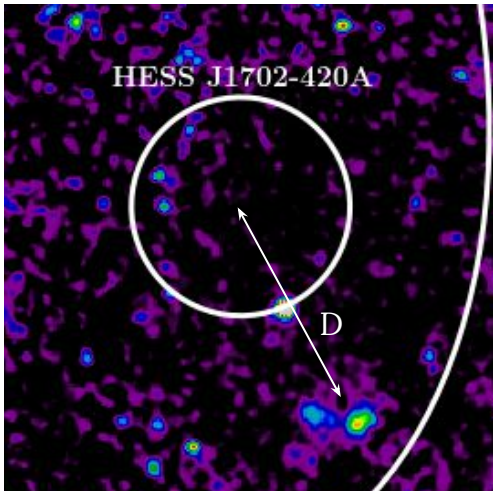


Emission profile



A runaway PWN associated with HESS J1702-420A?

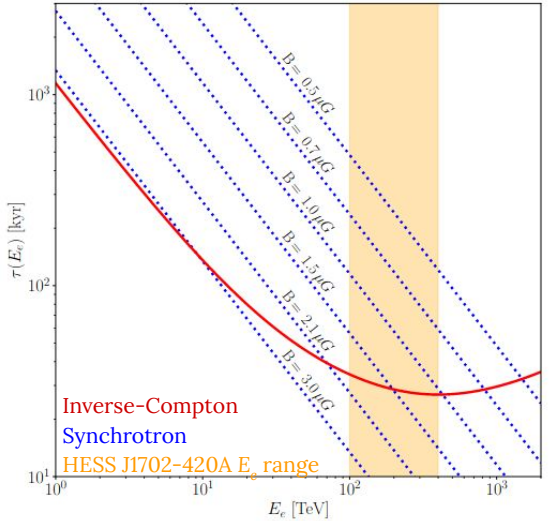
Distance from HESS J1702-420A:



Assuming a d = 1—5 kpc l.o.s. distance:

D = d tan(0.12°) = 2—10 pc

Electron cooling time:



Assuming B = 1 μG (IC dominated cooling):

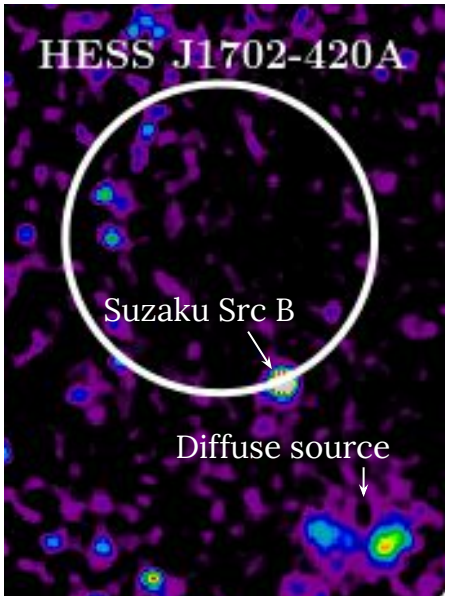
τ_{loss} ≈ 30 kyr

$v_{PWN} \geq D/\tau_{loss} = 70—350$ km s^{-1}

An association with HESS J1702-420A cannot be excluded

Conclusions:

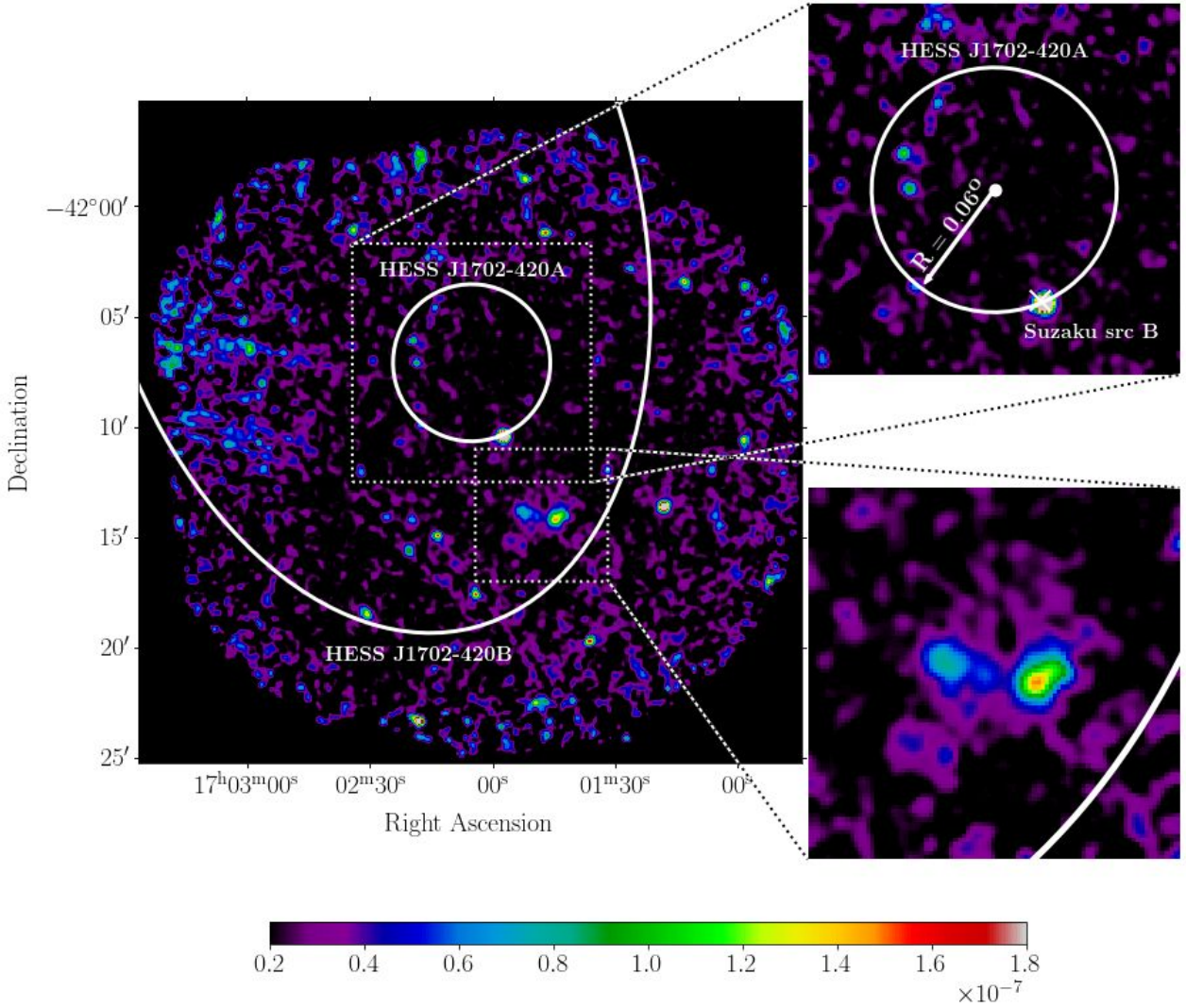
- A **deep 72 ks XMM-Newton observation** was used to **explore leptonic emission scenarios for HESS J1702-420A**
- The X-ray source ***Suzaku* Src B is excluded as a possible counterpart**
- The absence of an X-ray counterpart and the tight magnetic field upper limits **strengthen the classification of HESS J1702-420A as a PeVatron candidate**
- **A new diffuse X-ray source with hard spectral index** was discovered:
  - no counterparts for this object were found
  - a runaway PWN associated with HESS J1702-420A? Not excluded



Remarks:

- This work contains the **first joint X-ray and TeV modeling done with Gammapy**
- The paper (in preparation) will be submitted shortly after the conference

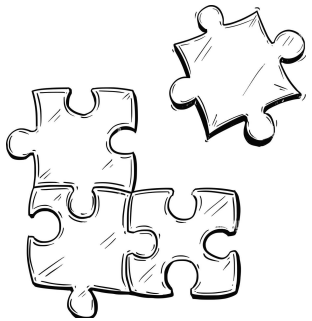
Backup


HESS J1702-420A
R = 0.06°
Suzaku src B
HESS J1702-420A
HESS J1702-420B
−42°00′
05′
10′
15′
20′
25′
Declination
17h03m00s
02m30s
00s
01m30s
00s
Right Ascension
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
×10−7

Suzaku Src B

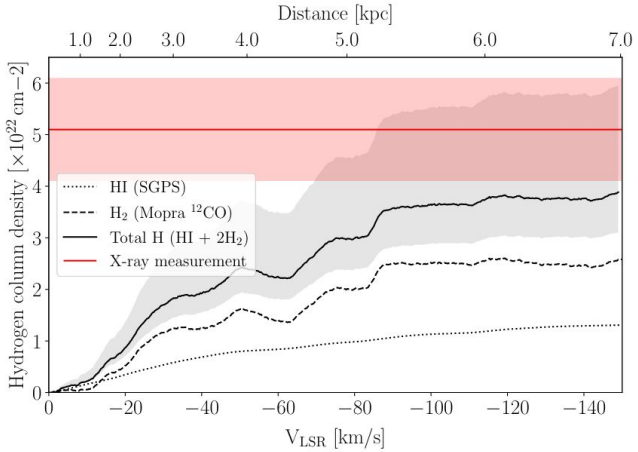
Is likely not a powerful isolated PSR:

- Point-like morphology (no extended X-ray PWN)
- Fe spectral line (suggesting the presence of an accretion disk)
- Evidence of spectral variability
- Possible GLIMPSE (IR) counterpart



Is too far away for H.E.S.S.:

- N_h-based distance: $\gtrsim 7$ kpc



Suzaku Src B is **excluded** as a counterpart for HESS J1702-420A

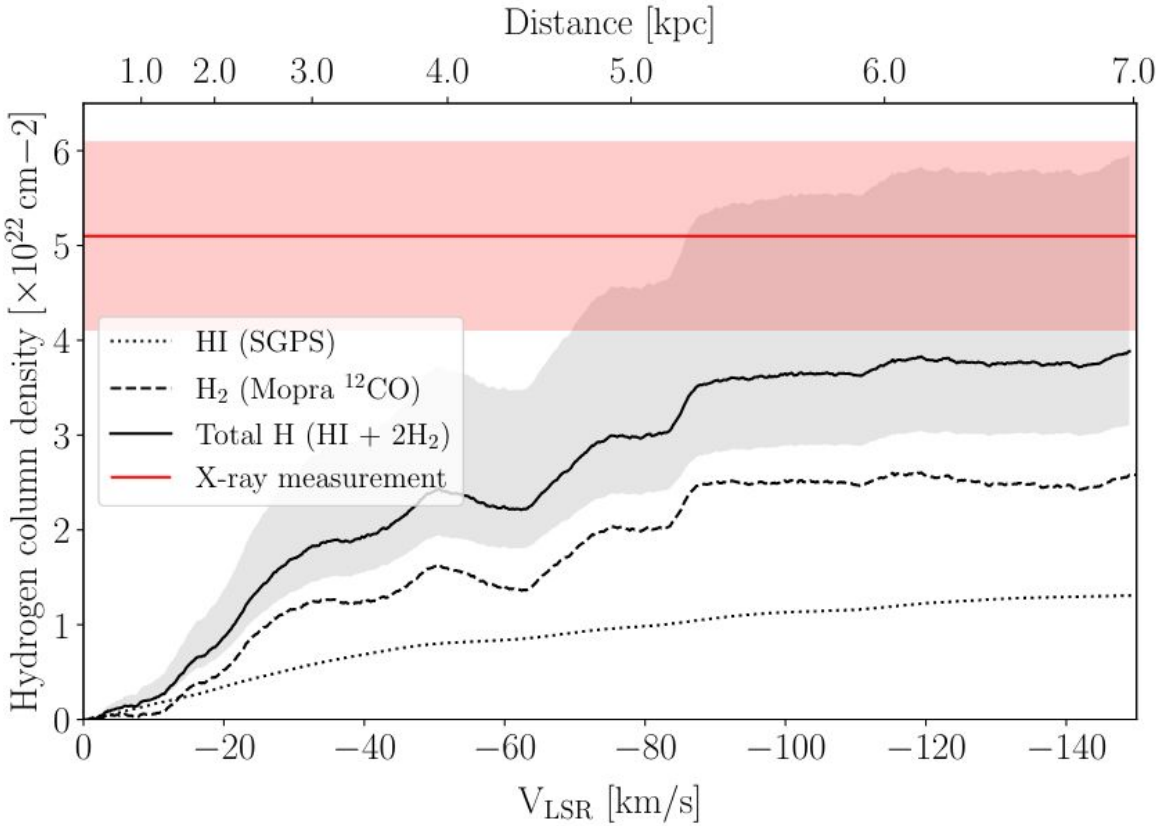
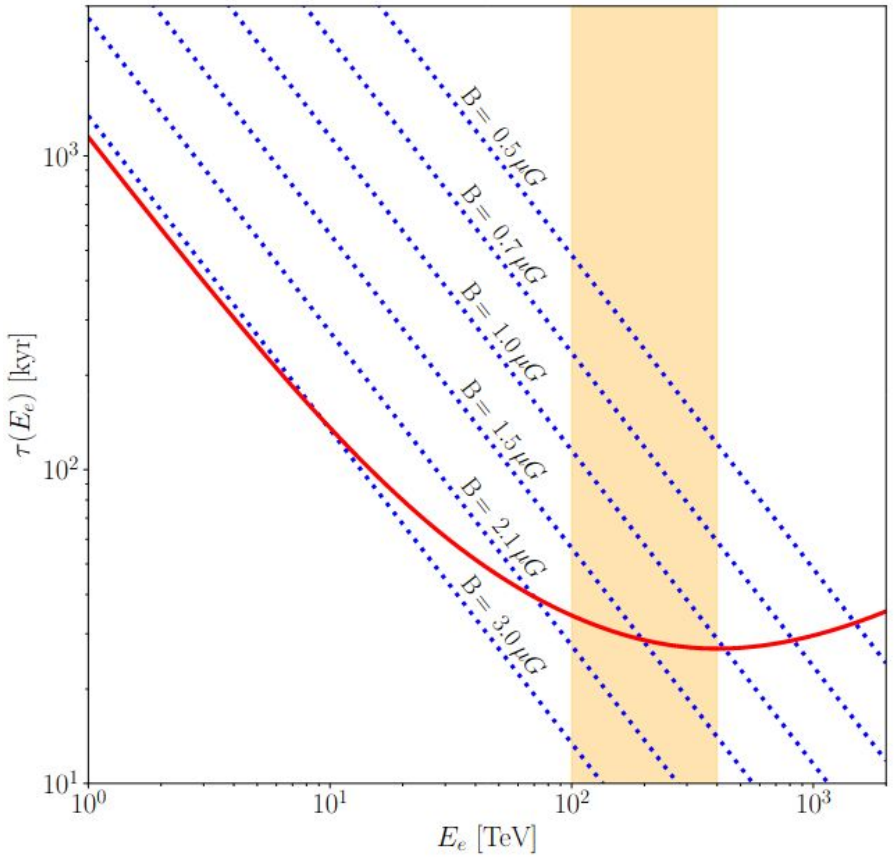
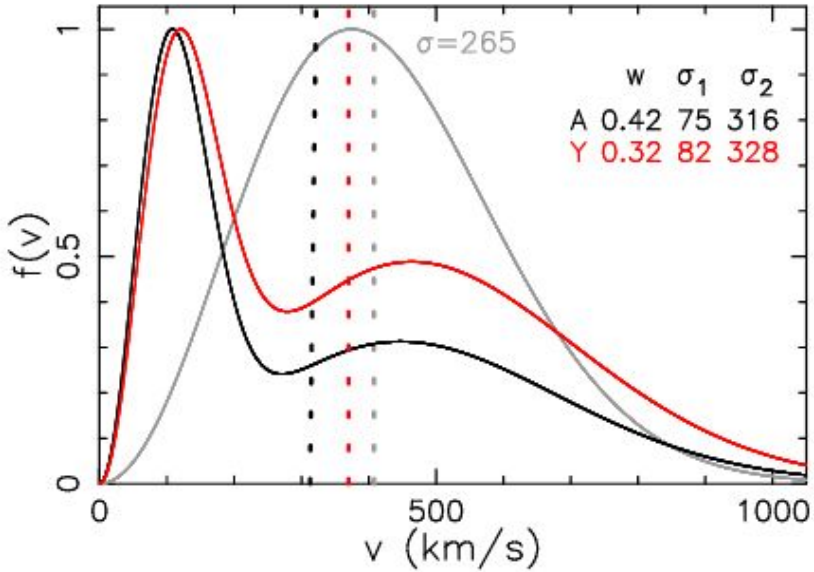

Distance [kpc]
1.0
2.0
3.0
4.0
5.0
6.0
7.0
Hydrogen column density [$\times 10^{22}$ cm-2]
0
1
2
3
4
5
6
HI (SGPS)
H_2 (Mopra ^{12}CO)
Total H (HI + $2H_2$)
X-ray measurement
0
−20
−40
−60
−80
−100
−120
−140
V_{LSR} [km/s]

Table 4. Flux ratio of VHE gamma-ray objects

Name	$F_{\rm TeV}{}^{*}$	$F_{\rm X}{}^{\dagger}$	$F_{\rm TeV}/F_{\rm X}$	Type	References
Crab nebula	5.6	2.1×10^{5}	2.7×10^{-3}	PWN	[1] [2]
G0.9+0.1	0.2	58	0.3	PWN	[3]
RX J1713–3946	3.5	5400	0.06	SNR	[4] [5]
HESS J1813–178	0.9	70	1.3	SNR	[6] [7]
HESS J1616–508	1.7	< 3.1	> 55	dark	[6] [8]
HESS J1745–303	0.52	< 2.1	> 25	dark (SNR?)	[6] [9]
HESS J1804–216	1.0	< 8.0	> 13	dark	[6] [10]
HESS J1702–420	3.1	< 27	> 12	dark	[11] this work

* In units of 10^{-11} erg s^{-1} cm^{-2} in the 1–10 TeV band.
† In units of 10^{-13} erg s^{-1} cm^{-2} in the 2–10 keV band.
[1] Aharonian et al. (2004a), [2] Willingale et al. (2001), [3] Aharonian et al. (2005b)
[4] Aharonian et al. (2004b), [5] Slane et al. (2001), [6] Aharonian et al. (2006)
[7] Brogan et al. (2005), [8] Matsumoto et al. (2007), [9] Bamba et al. (2009),
[10] Bamba et al. (2007), [11] Aharonian et al. (2008).


B = 0.5 μG
B = 0.7 μG
B = 1.0 μG
B = 1.5 μG
B = 2.1 μG
B = 3.0 μG
10^3
10^2
10^1
$\tau(E_e)$ [kyr]
10^0
10^1
10^2
10^3
E_e [TeV]


σ=265
w σ1 σ2
A 0.42 75 316
Y 0.32 82 328
f(v)
0
0.5
1
0
500
1000
v (km/s)

Comparison of X-ray and VHE gamma-ray fluxes

3σ (2σ, 1σ) flux upper limits :

$$F(2-10\,\mathrm{keV}) = \int_{2\,\mathrm{keV}}^{10\,\mathrm{keV}} E\frac{dN}{dE}dE < 8.1\,(5.4,\,3.3) \times 10^{-5}\,\mathrm{keV\ cm^{-2}\ s^{-1}}$$

$$\frac{F^{\mathrm{H.E.S.S.}}_{1-10\,\mathrm{TeV}}}{F^{\mathrm{XMM}}_{2-10\,\mathrm{keV}}} \gtrsim 3.2\,(4.8,\,7.8)$$

Analysis setup

Region	OFF	Models
BKG	Archival filter wheel closed observations	Astro background
SPEC		Astro background + Signal