ECAP Astroparticle School 2022

eROSITA X-ray Analysis of the PeVatron Candidate Westerlund 1

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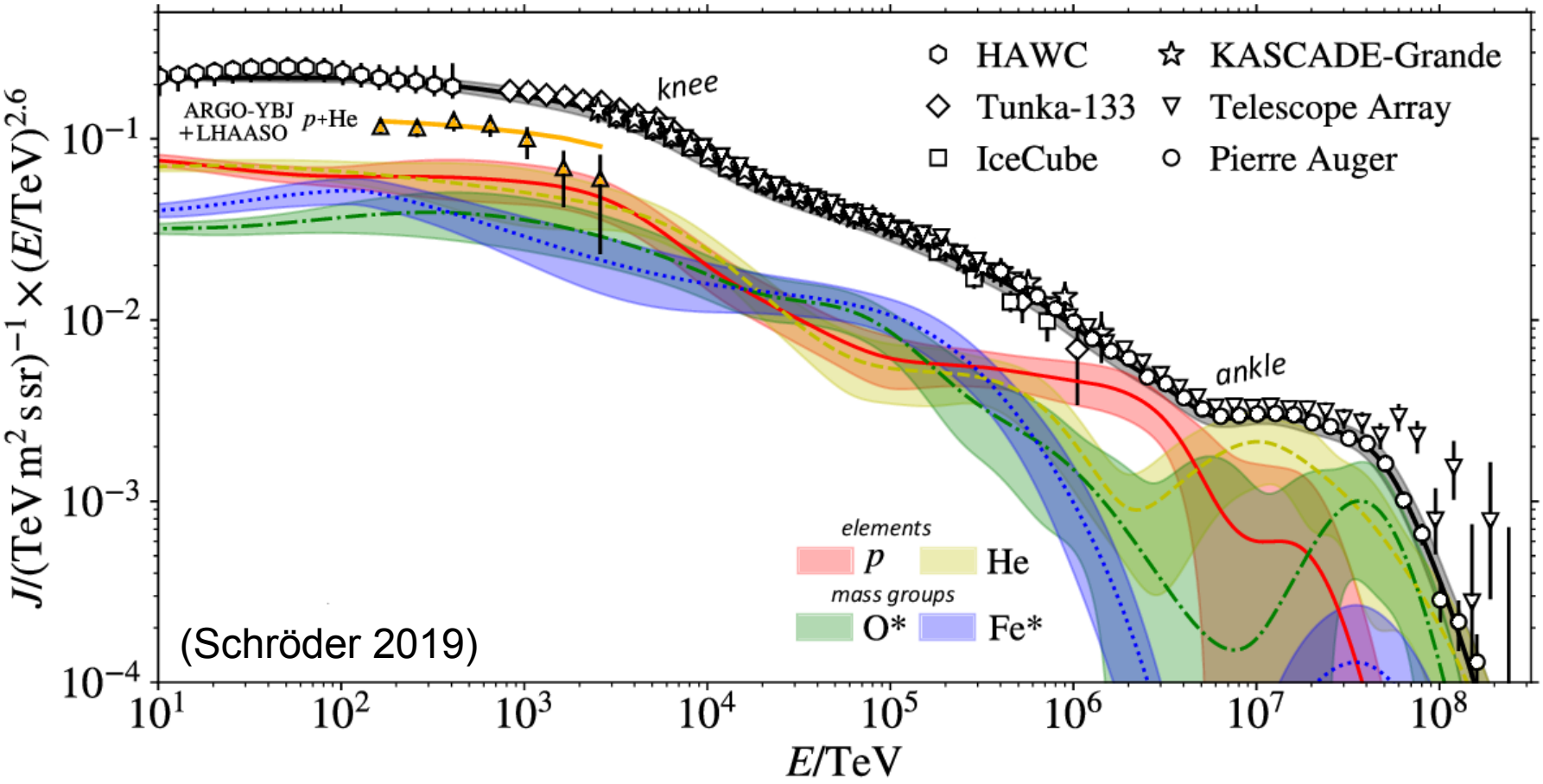
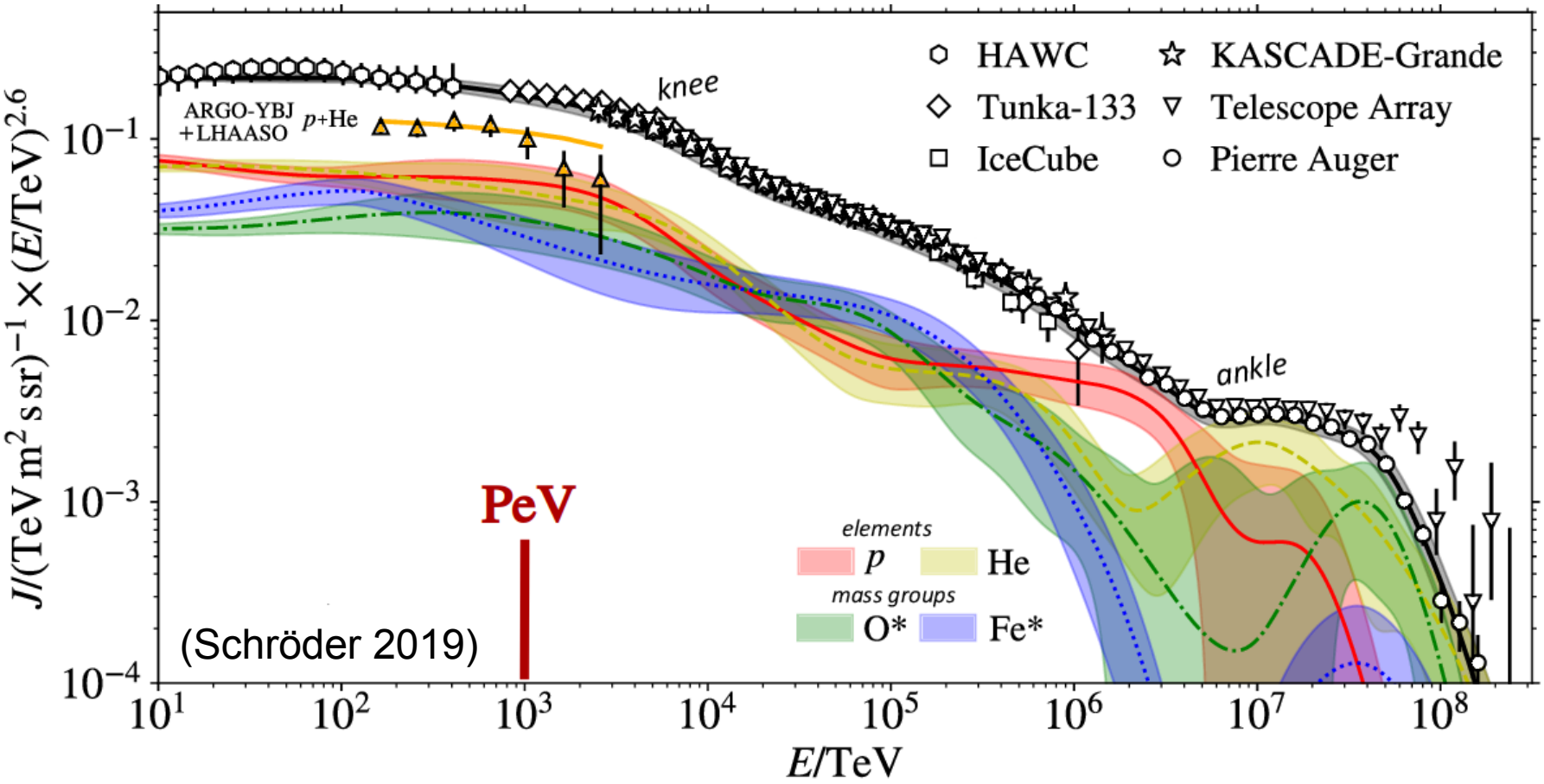
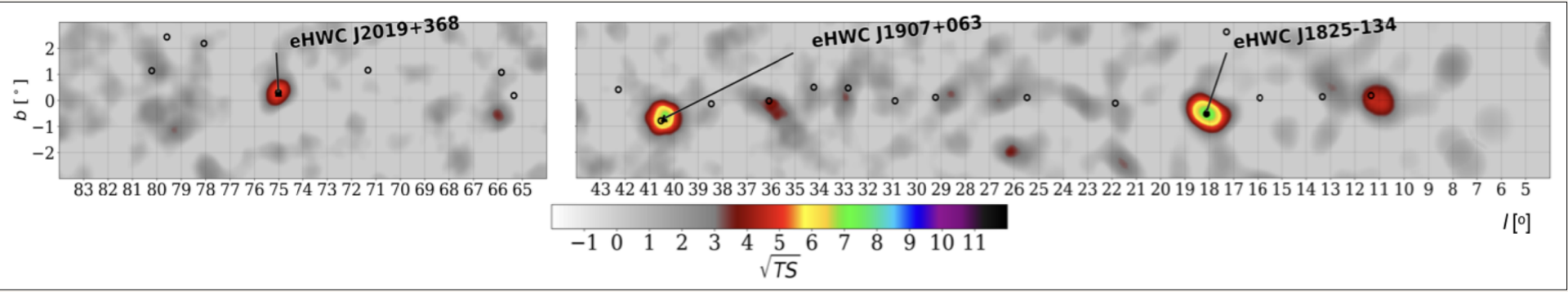
Spectrum of Cosmic Rays



Spectrum of Cosmic Rays



PeVatron Sources in Gamma-rays



Significance map of the Galactic plane for > 100 TeV emission (HAWC 2020)

Signatures of a PeVatron:

- **Gamma rays above 100 TeV**
- **No cut-off**

Shock Acceleration in Supernova Remnants

”Standard scenario” for cosmic ray acceleration

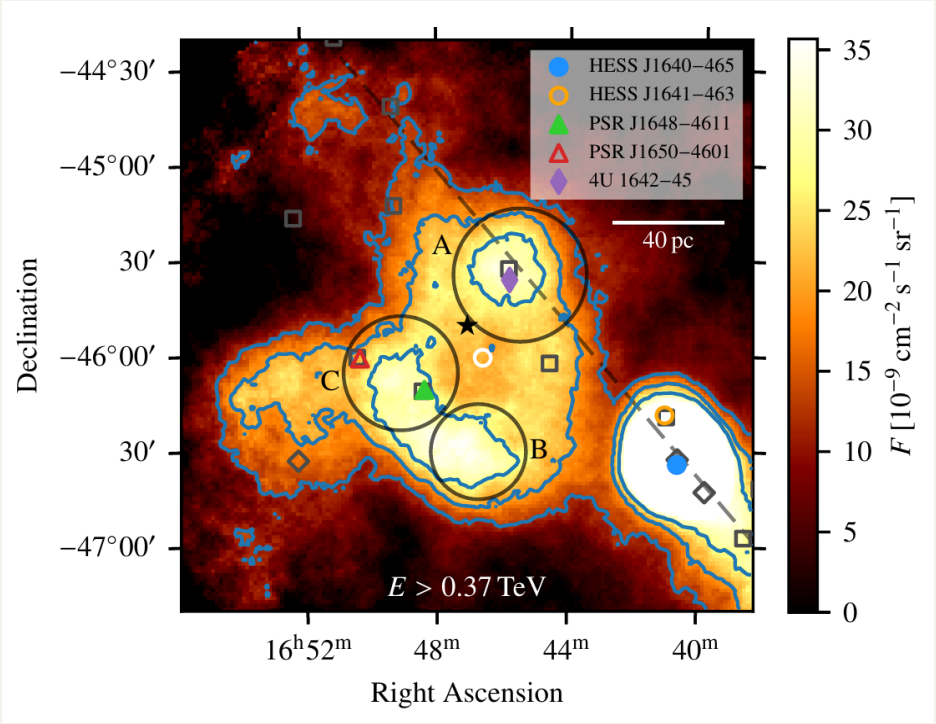
Theoretical and observational problems as PeVatron candidates

Cassiopeia A in X-rays (NASA/CXC/SAO)

Star Clusters as PeVatron Candidates

Detections of several star clusters in very-high-energy gamma rays (Wd 1, Wd 2, Cygnus OB2, 30 Dor)

Might accelerate particles at colliding stellar wind shocks or cluster wind termination shock



Flux map of Wd 1 above 0.37 TeV (HESS 2022)

Star Cluster Westerlund 1

- Optical radius: 3 arcmin
- Distance: 2 – 5 kpc
- Mass: ~ 10^5 Solar Masses
- OB giants/supergiants, Wolf-Rayet stars, red supergiants, yellow hypergiants, one magnetar...

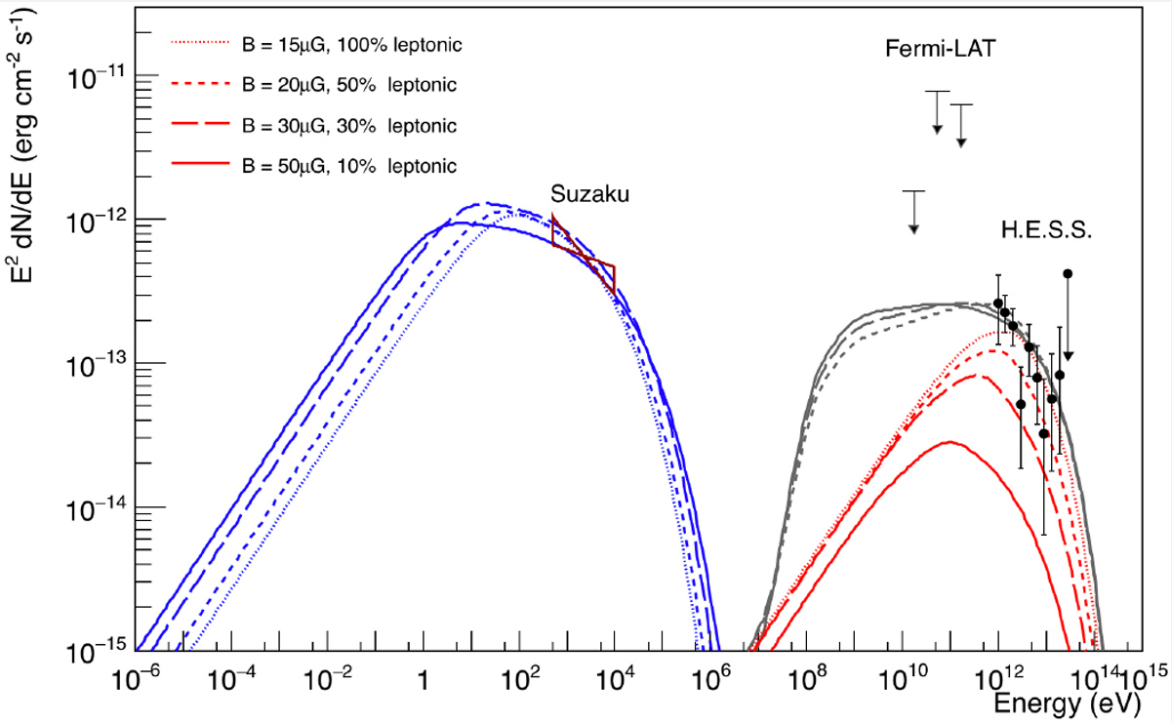
Optical image (ESA/Hubble and NASA)

Detection via Secondary Emission

X-rays from synchrotron emission

Gamma rays from inverse Compton and pion decay

Figure: Spectrum of the superbubble 30 Dor C (Kavanagh 2019)

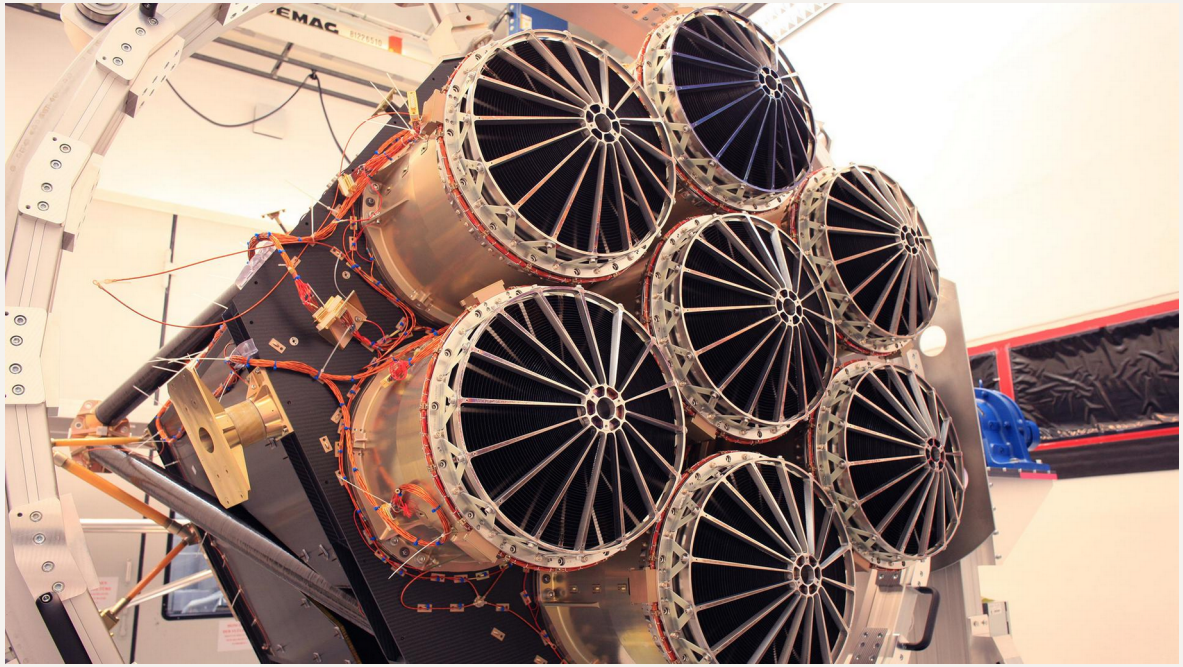


eROSITA

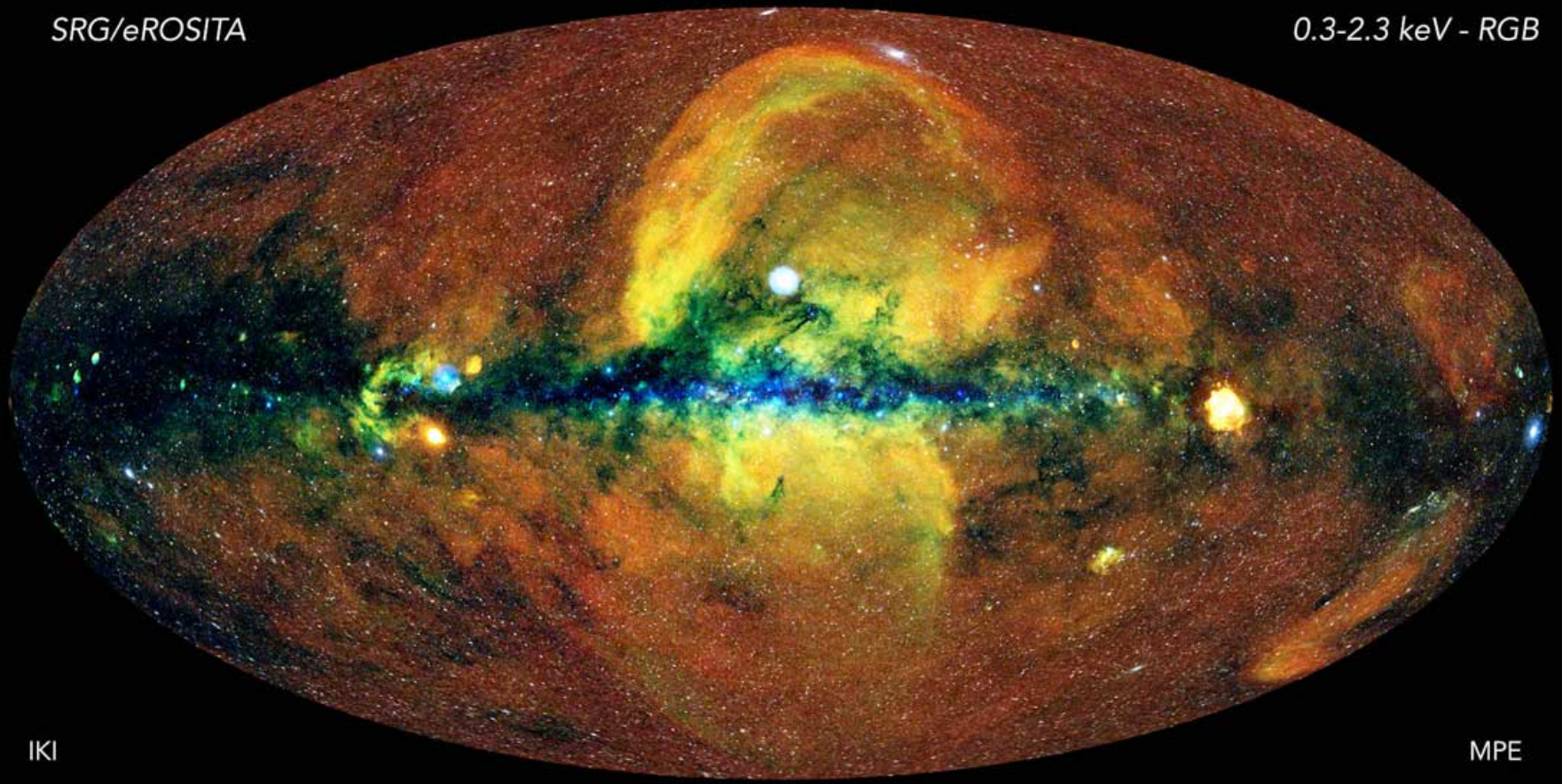
All-sky surveys from 0.2 to 10 keV

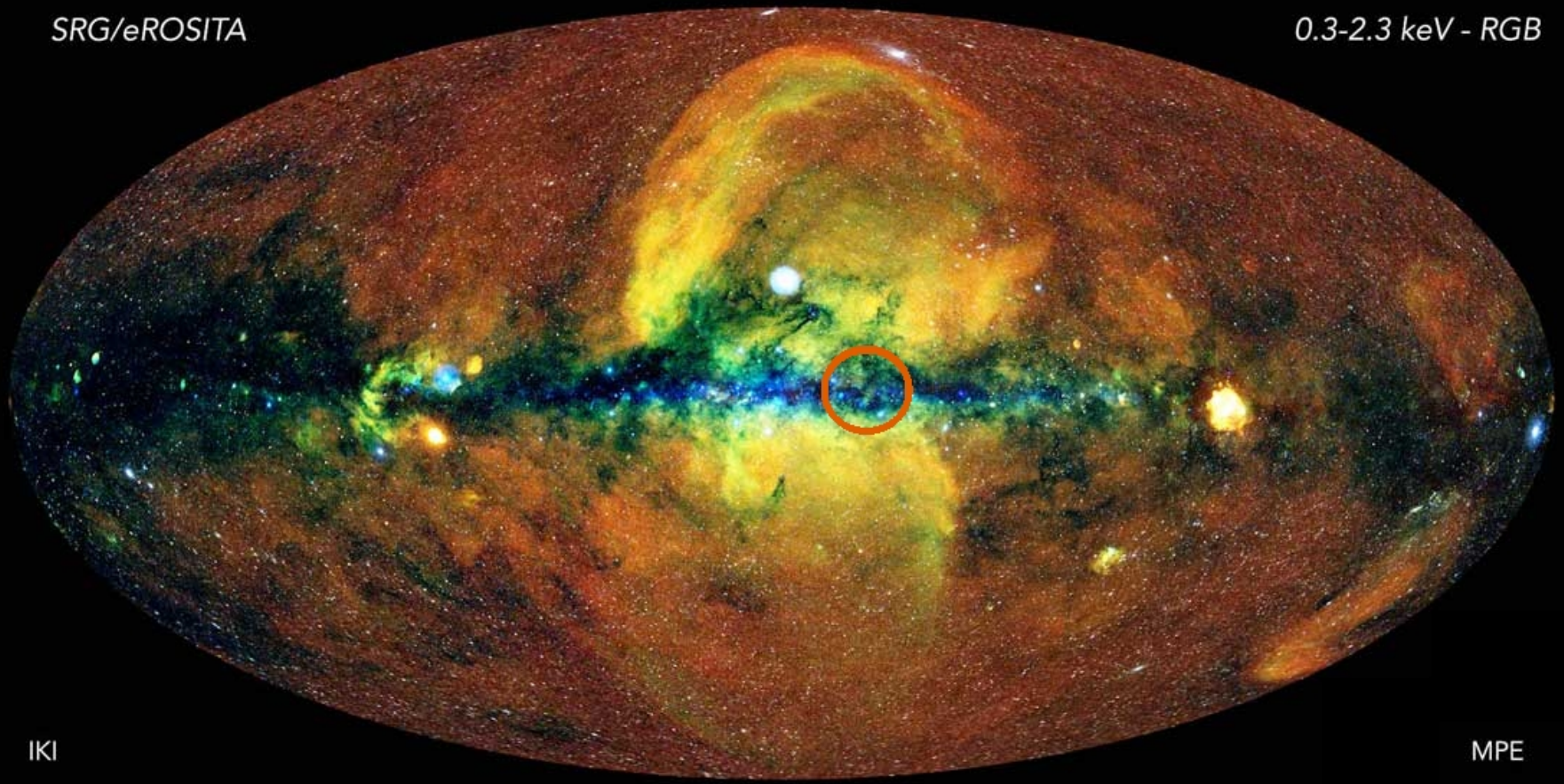
Angular resolution: 15 arcsec at 1.5 keV

Energy resolution: 50 – 180 eV



(MPE)


SRG/eROSITA
0.3-2.3 keV - RGB
IKI
MPE

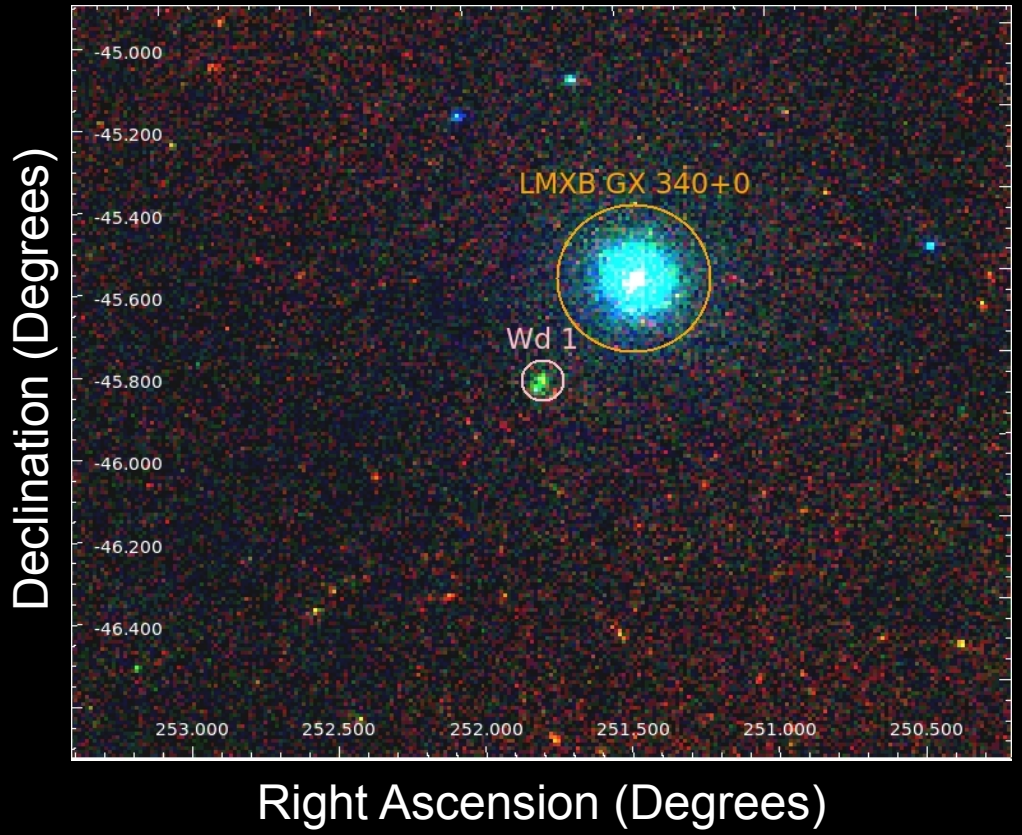

SRG/eROSITA
0.3-2.3 keV - RGB
IKI
MPE

eROSITA's View of Westerlund 1

Westerlund 1 marked with pink circle

Low Mass X-ray Binary GX 340+0 (blue)

Red: 0.7 – 1.1 keV
Green: 1.1 – 2.3 keV
Blue: 2.3 – 8.0 keV

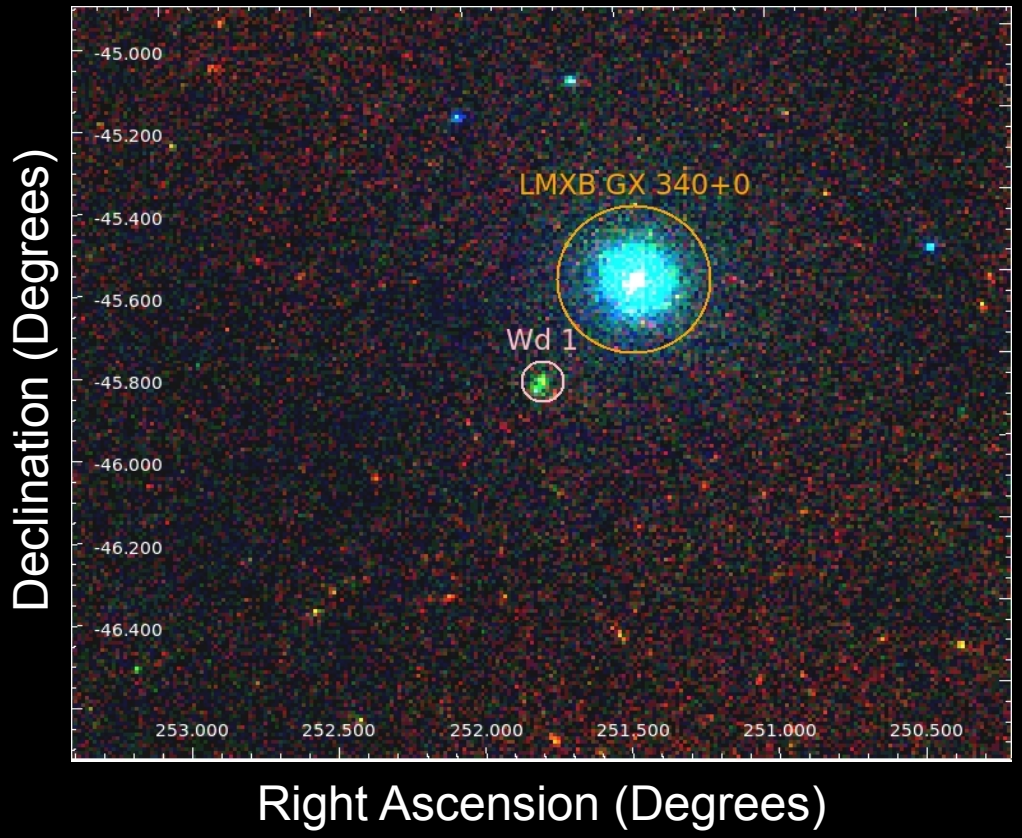


Aims

Taking X-ray spectra at Westerlund 1 and around it

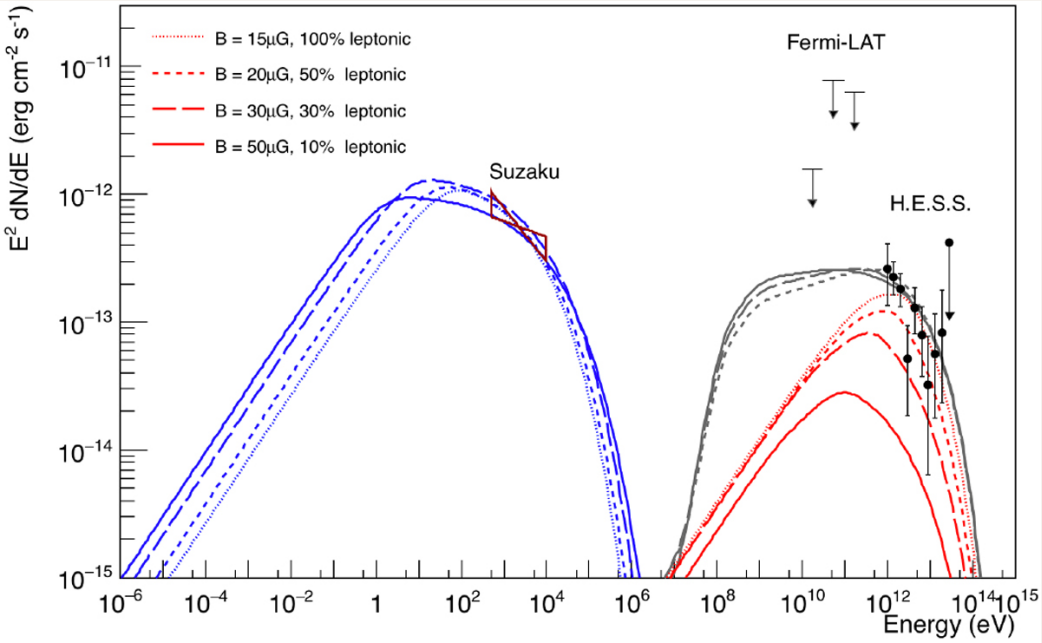
Possible detection of nonthermal radiation

=> Potential to help identifying Wd 1 as a PeVatron



What to take away

- **Evidence for population of PeVatron sources**
- **Exact nature of sources still unknown**
- **Star cluster as promising candidates**
- **X-ray data might reveal more information, i.e., on acceleration type**

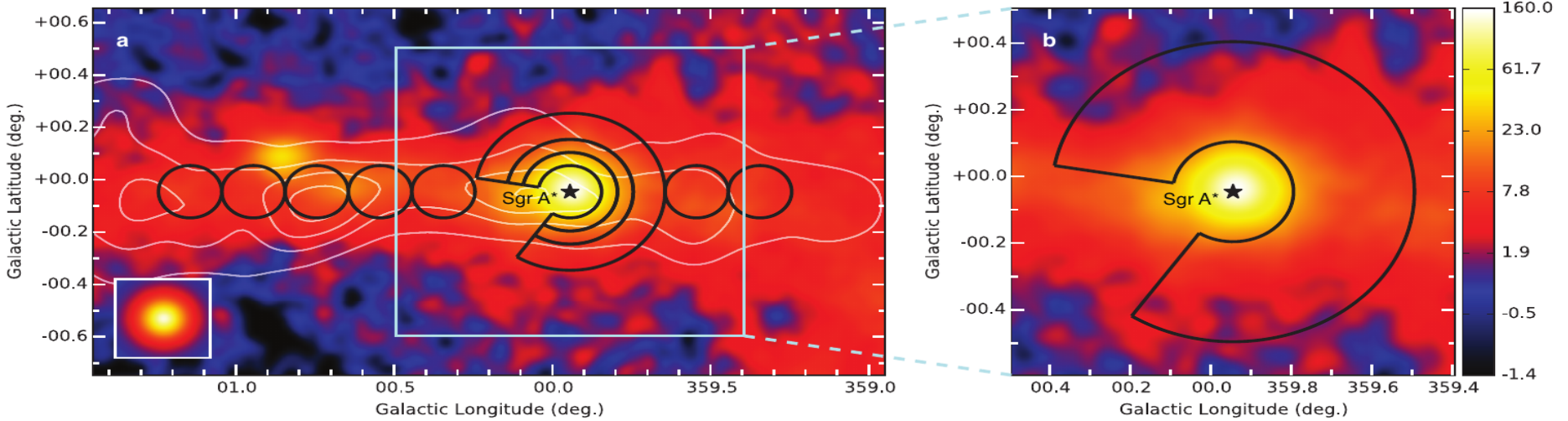


Spectrum of the superbubble 30 Dor C (Kavanagh 2019)

Image Sources

- Schröder 2019, BAAS 51(3) 131
- HAWC 2020, Phys. Rev. Lett. 124, 021102
- NASA/CXC/SAO: Chandra X-ray Center,
- Smithsonian Astrophysical Observatory
- Mohrmann 2021, arXiv:2207.10921
- ESA/Hubble and NASA
- Kavanagh 2019, A&A 621, A138
- MPE: Max Planck Institute for Extraterrestrial Physics

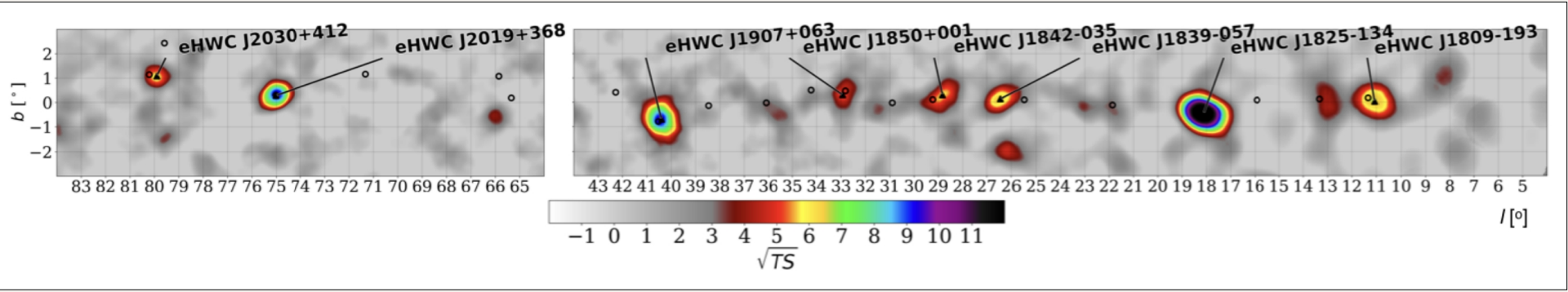
Other PeVatron Detections



Very-high-energy gamma rays from the galactic central region (HESS 2016)

Sgr A*, Crab Nebula (TibetAS 2019), star clusters, SNRs (Fang 2022)

HAWC Sources above 56 TeV



Significance map of the Galactic plane for > 56 TeV emission (HAWC 2020)

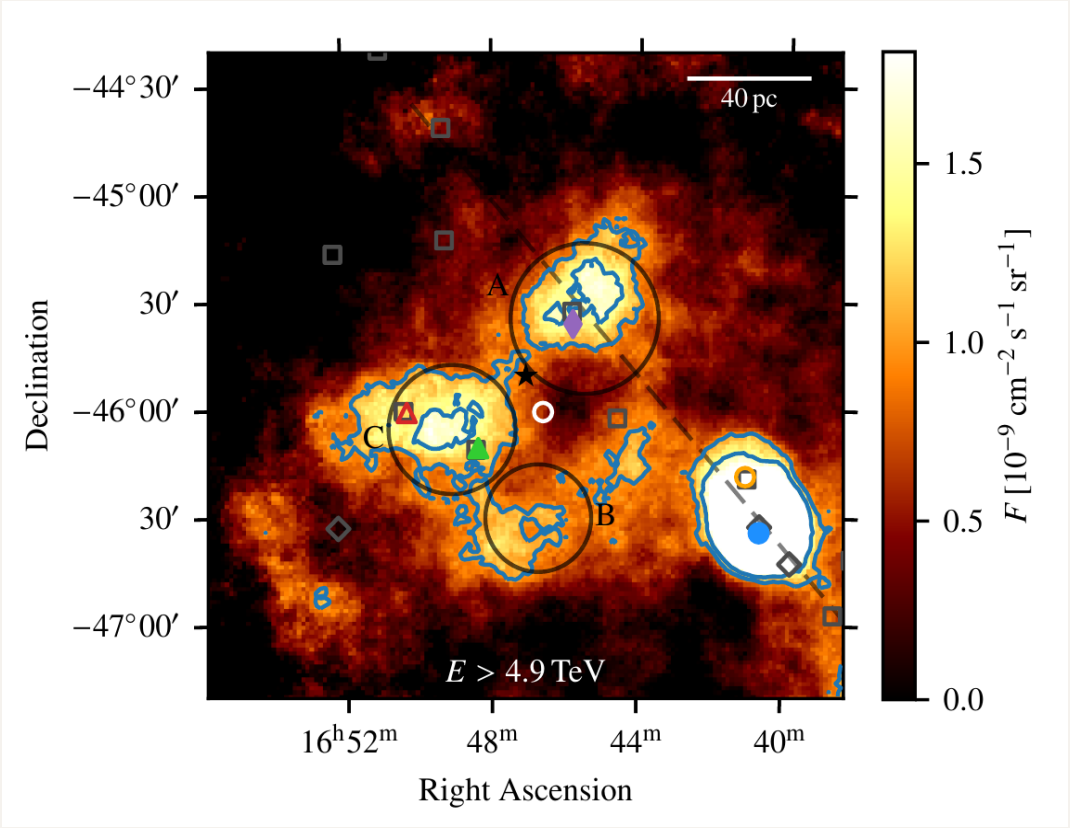
Signatures of a PeVatron:

- **Gamma rays above 100 TeV**
- **No cut-off**

Westerlund 1 above 4.9 TeV

Might accelerate particles at colliding stellar wind shocks or cluster wind termination shock

Figure: Flux map of Wd 1 above 4.9 TeV (HESS 2022)



Distance to Westerlund 1

Conflicting values for the distance depending on study and method:

- Color-magnitude diagrams: 5.0 kpc (Westerlund 1987), 1.0 kpc (Piatti 1998)
- Yellow hypergiants: 2 to 5.5 kpc (Clark 2005)
- WR photometry: 5.5 kpc (Crowther 2006)
- Main sequence fitting: 4.4 kpc (Hosek 2018)
- Gaia parallaxes: 2.8 kpc (Aghakhanloo 2021), 4.05 ± 0.20 kpc (Navarete 2022)

=> Assumed distance has consequences for luminosity and age estimates

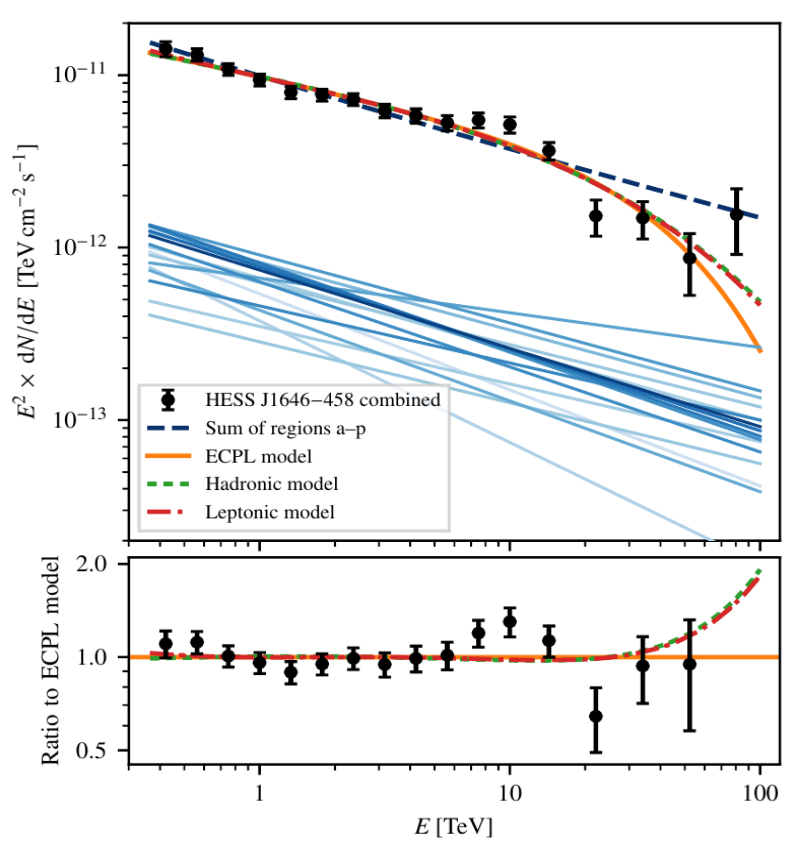
Gamma-ray Spectrum of Westerlund 1

Cut-off powerlaw with:

- Index $\Gamma = 2.30 \pm 0.04$
- Cut-off $E \approx 44$ TeV

=> Nevertheless no clear indication of a cut-off due to unreliable high-energy data

Figure: (HESS 2022)



X-ray Observations of Westerlund 1

Muno 2006: Possible nonthermal emission detected with Chandra

Kavanagh 2011 (Figure): Confirmed as thermal using XMM

Only looked at inner 2' radius of Westerlund 1