Deep observations of the starburst galaxy M82 by the VERITAS gamma-ray observatory

Martin Pohl

for the VERITAS collaboration

Introduction

- New analysis of the entire VERITAS data set
- Modeling the entire SED
    - Assume that all we see is diffuse emission and not sources
    - Ignore spatial variations (one-zone modeling)
    - Concentrate on starburst core

New SED

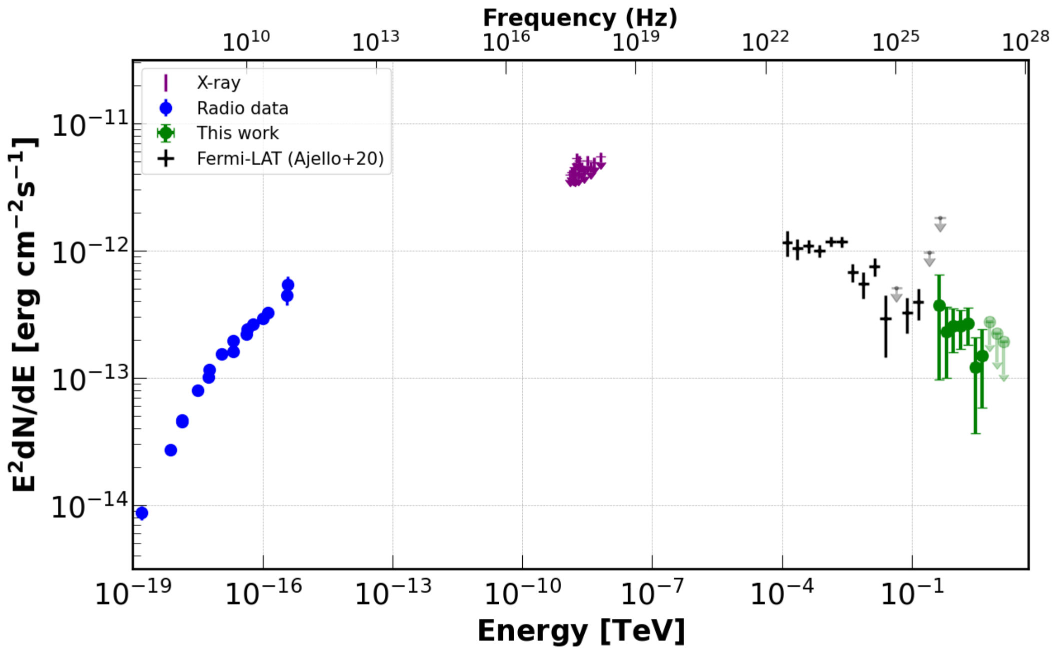
All data

4 telescopes only

254h after cuts

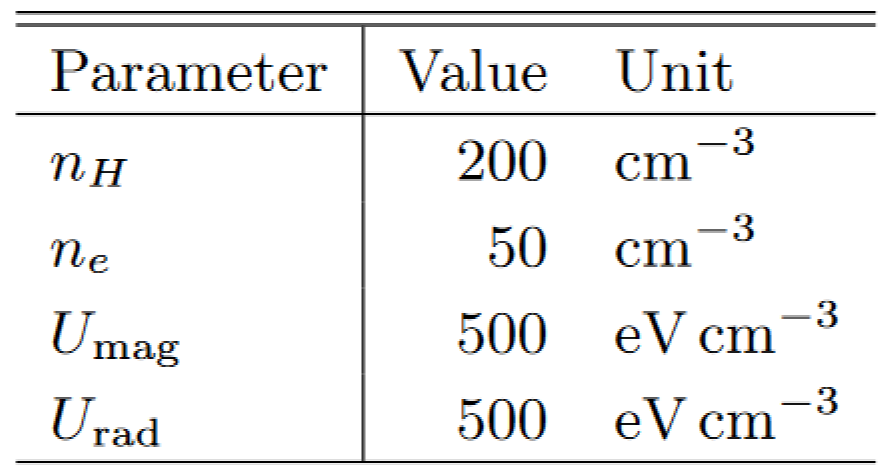
Significance 6.5σ

X-ray sources subtracted



Modeling

New fiducial parameters



Parameter	Value	Unit
n_H	200	cm^{-3}
n_e	50	cm^{-3}
U_{mag}	500	$\mathrm{eV\,cm}^{-3}$
U_{rad}	500	$\mathrm{eV\,cm}^{-3}$

Leptonic scenario

Energy loss rate

$$-b(E) = C_1 + C_2\,E + C_3\,E^2$$

$$\begin{aligned}
C_1 &= \left(3.7\cdot 10^{-16}\ \mathrm{GeV\,s^{-1}}\right)\ (n_H + 1.54\,n_e)\\
C_2 &= \left(10^{-15}\ \mathrm{s^{-1}}\right)\ (n_H + 0.95\,n_e)\\
C_3 &= \left(10^{-16}\ \mathrm{GeV^{-1}\,s^{-1}}\right)\ (U_{\mathrm{mag}} + U_{\mathrm{rad}})\ .
\end{aligned}$$

Lifetime a factor 100 shorter than starburst duration → calorimetry

Two spectral breaks, at 0.4 GeV and at 2.5 GeV

$$N(E) = \frac{1}{|b(E)|}\int_E dE'\ Q(E')$$

Leptonic scenario

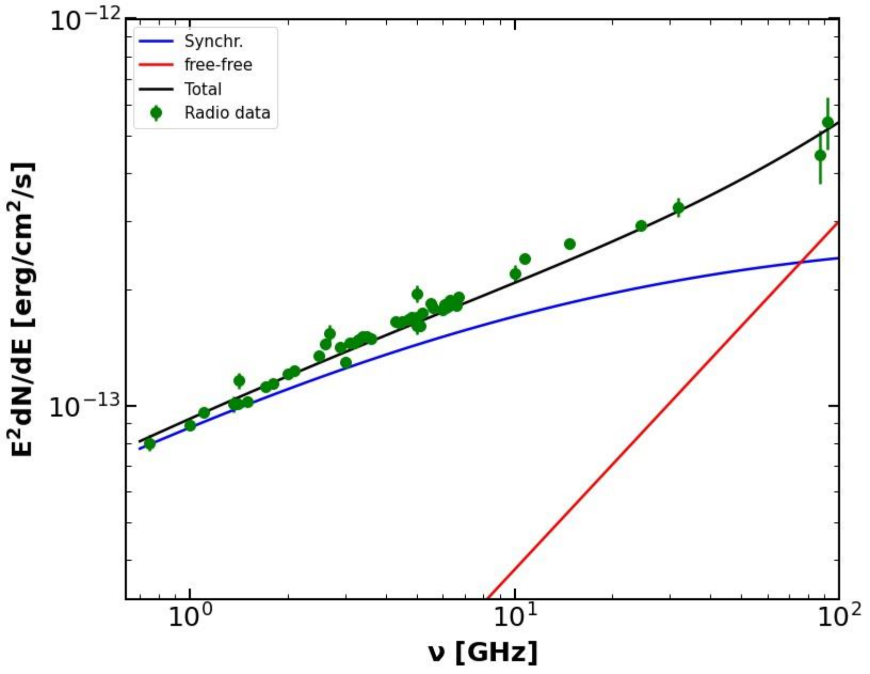
Radio spectrum

Electron injection
with Q~E$^{-2.25}$

Free-free emission fits to absorption cut-off at 300 MHz

Soft GeV-scale bremsstrahlung

Weak GeV-scale inverse-Compton



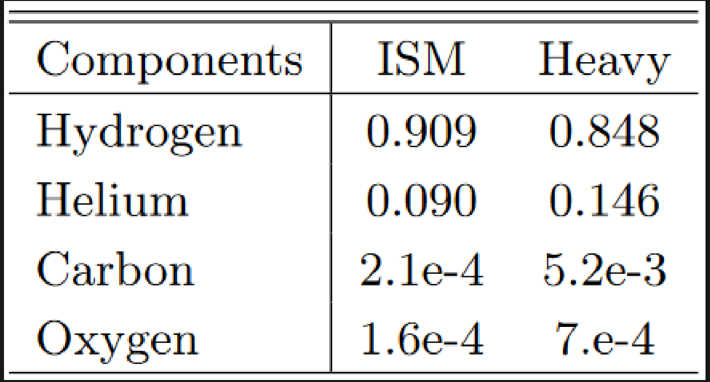
Hadronic scenario

Assume particle spectrum is a power law in momentum

Gamma-ray production calculated with DPMJET III (Bhatt et al. 2020)

Two different compositions

(target and cosmic rays)

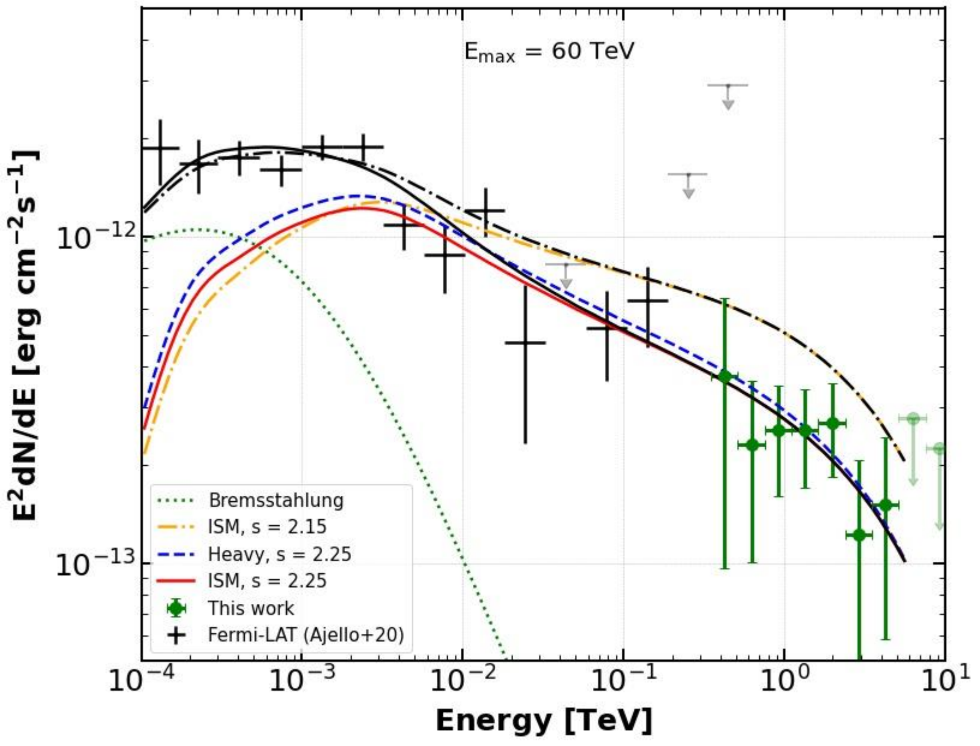


Components	ISM	Heavy
Hydrogen	0.909	0.848
Helium	0.090	0.146
Carbon	2.1e-4	5.2e-3
Oxygen	1.6e-4	7.e-4

Hadronic scenario

Significant flux at 200 MeV

Electron/ion ratio
large at a few GeV



Hadronic scenario

Heavy composition give more sub-GeV gamma rays.

No conclusions possible

Spectral index s=2.25 provides a good match, s=2.15 does not.

The maximum energy is poorly constrained

Calorimetry: luminosity directly measures the cosmic-ray source power

Secondary electrons

Production rate, $Q_e(E)$, computed with DPMJET III

$$\frac{\partial}{\partial E}\left(b(E)\,N\right)+\frac{N}{T}=Q_e(E)$$

Solve balance equation

$$N(E,t)=\int_E^{\infty}dE'\;\frac{Q_e(E')}{|b(E)|}\;\exp\left(-\int_E^{E'}\frac{du}{T\,|b(u)|}\right)$$

Convolve with synchrotron emissivity

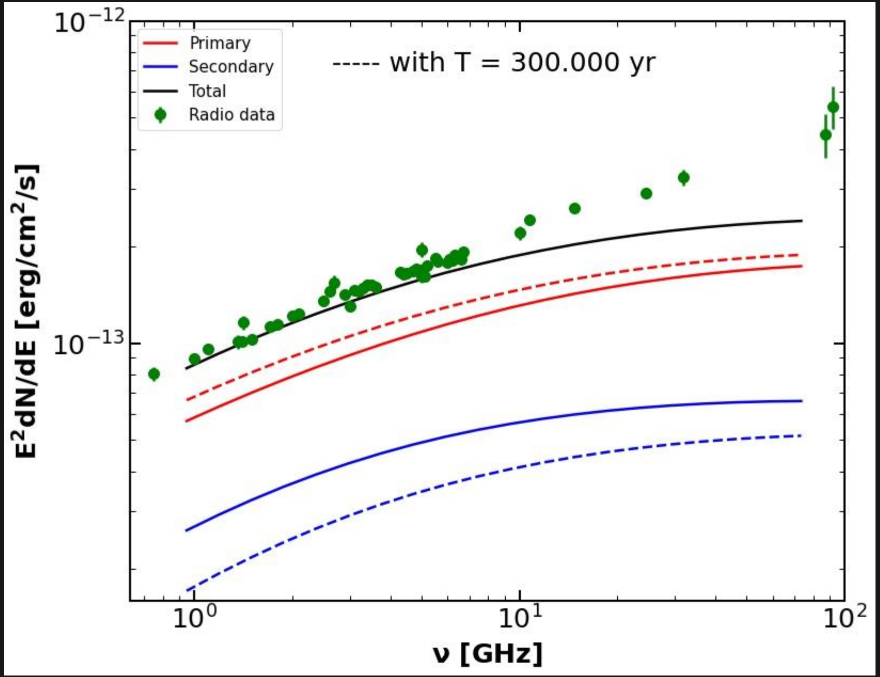
$$P_{E_\gamma}=\frac{E^2}{(10^{16}\ \mathrm{GeV\,s})}\,U_{\mathrm{mag}}\,\delta\left(E_\gamma-aE^2\right)$$

Secondary electrons

Secondary synchrotron flux high

unless n_H/U_{mag} is large
But then too much 100-MeV flux

Situation relaxes with
catastrophic losses by,
e.g., escape in the wind.



Summary

Hadronic scenario clearly preferred

CR source spectrum has index s=2.25 (similar to SNRs)

Strong bremsstrahlung flux below 500 MeV → large N_e/N_i

Strong secondary synchrotron flux at a few GHz

Catastrophic losses by, e.g., advective escape possible