Search for VHE Emission from the MSP PSR J0218+4232

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For the MAGIC Collaboration and *Fermi*-LAT Collaboration

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Introduction

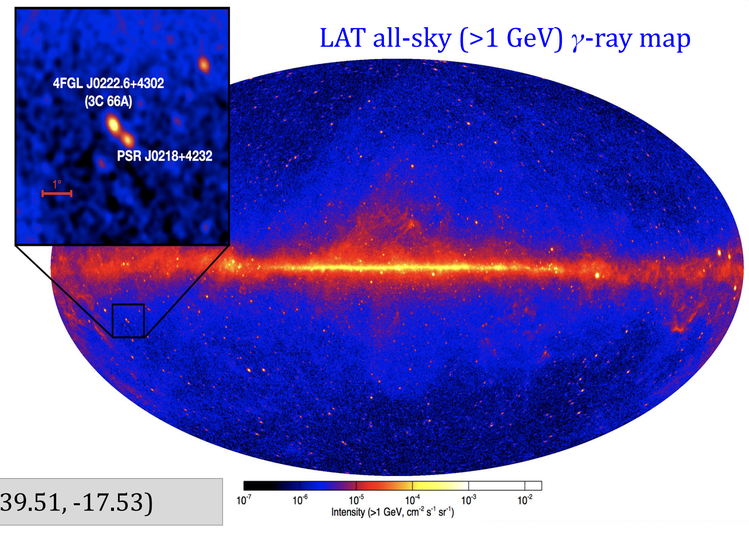
PSR J0218+4232 is one of the most energetic millisecond pulsars (MSPs) known and has been considered one of the best candidates for Very High Energy (VHE) gamma-ray emission (E>100 GeV). We analyze 11.5 years of *Fermi*-LAT data (100 MeV-870 GeV) + ~90 hours of MAGIC data (20 GeV -20 TeV). We find evidence for pulsed emission above 25 GeV based on *Fermi*-LAT data, but no evidence of VHE emission with MAGIC. We give an overview of the theoretical models that can interpret the lack of VHE emission.

Overview of PSR J0218+4232

- 2.32 ms pulsar (VLBI parallax)
- MSP + white He dwarf (~ $0.2M_{\odot}$)
- 2 day orbital period
- Distance d ~ 3kpc
- Characteristic age τ <0.5 Gyr
- Spindown power 2.4×10^{35} erg s^{-1} } One of the **youngest & most energetic** MSPs
- Bright in Radio, X-rays, hard X-rays (non-thermal emission) [1]

Motivation for VHE Observation:
- 1st detection of GeV γ-ray pulsations by Fermi-LAT [2]
- Hints of **pulsed emission >10 GeV** in 1FHL catalogue [3]
- Hints of **pulsed emission >25 GeV** [4]

→ STRONG motivation to observe PSR J0218 +4232 at Very High Energies → ground-based telescopes.



Galactic coord. (L, B)	(139.51, -17.53)

Fermi-LAT Analysis

11.5 years of data (August 2008 - February 2020).
★ Energy range: 100 MeV - 870 GeV
★ Region of Interest (RoI): 15° x 15°

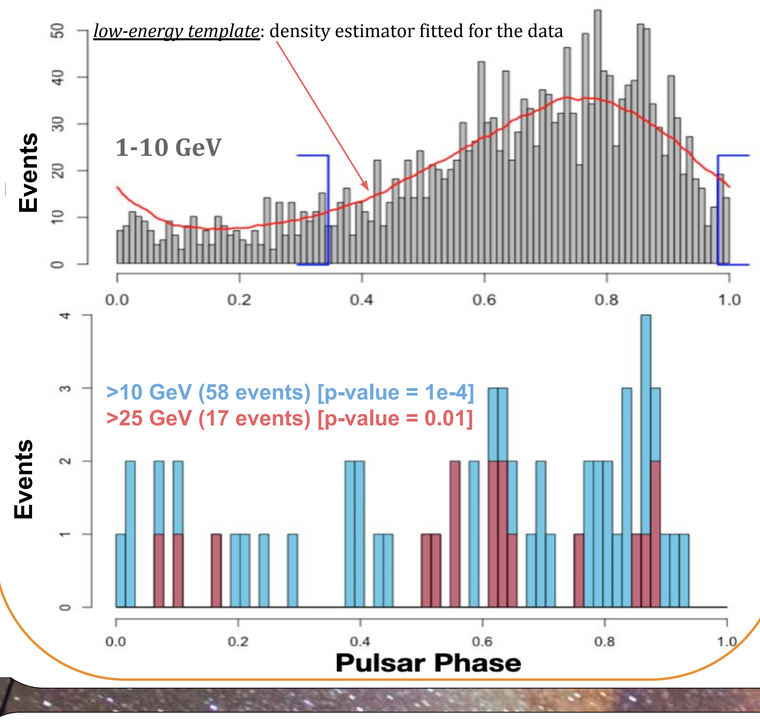
Fermi-LAT Phaseogram

ON phase: 0.34-0.98
OFF phase: 0.0-0.34 ∪ 0.98-1.0
[from radio + gamma-ray observation]

Search for Pulsed emission > 1 GeV:

Probability Density Function (PDF) { PDF_{LE} : 1-10 GeV; PDF_{HE} : >10 GeV

Likelihood Ratio test: determine if HE events have ~ distribution as LE template.
Null Hypothesis: NO pulsation (in HE range)
Test Statistic (TS) → p-value (p<0.05: pulsed emission)



Power Law with Exponential Cutoff

$$\frac{dN}{dE} = N_0\left(\frac{E}{E_0}\right)^{\gamma} exp(-aE^b)$$

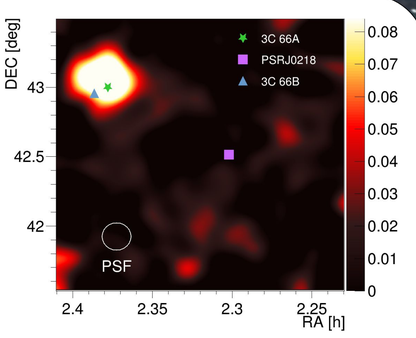
γ: -1.85±0.04
a: (5.9±0.5)x10^{-3}
b: 0.6667
E_0: 821.6 MeV
N_0: (1.9±0.1)x10^{-11} [ph cm^{-2} s^{-1} MeV^{-1}]

LAT Spectrum
- Falls steeply (Γ=4.5) at E>10 GeV
- Extracted from the whole phase range.
- E>20 GeV: Upper limits only

MAGIC Analysis

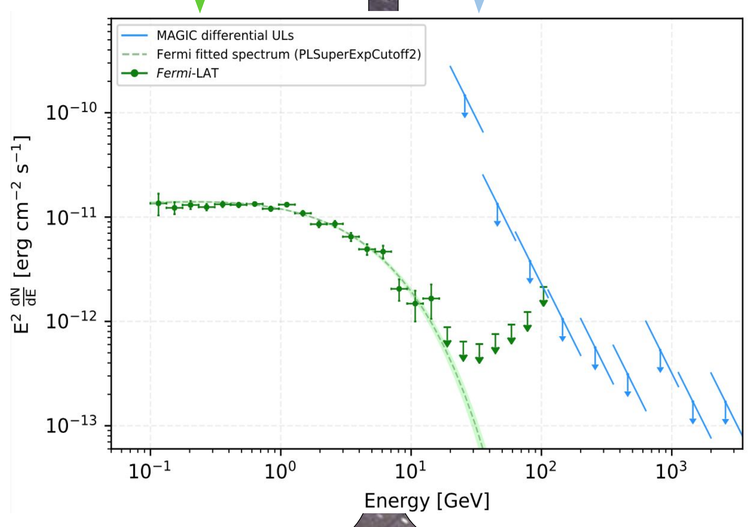
87 hours of data (Nov. 2018- Nov. 2019).
★ Stereoscopic mode with **Sum-Trigger-II** system [5]
★ Zenith range = 13°-30°
★ Atmospheric Transmission > 0.85

Improves the performance of MAGIC in the sub-100 GeV range.

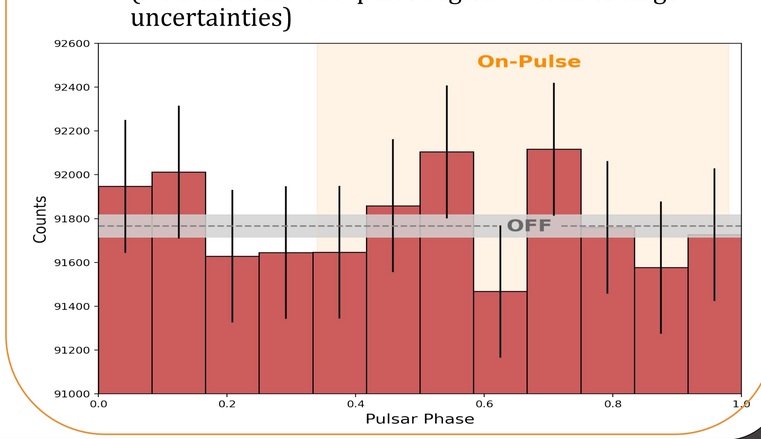


Relative flux Skymap (calculated by the excess events divided by the background events)

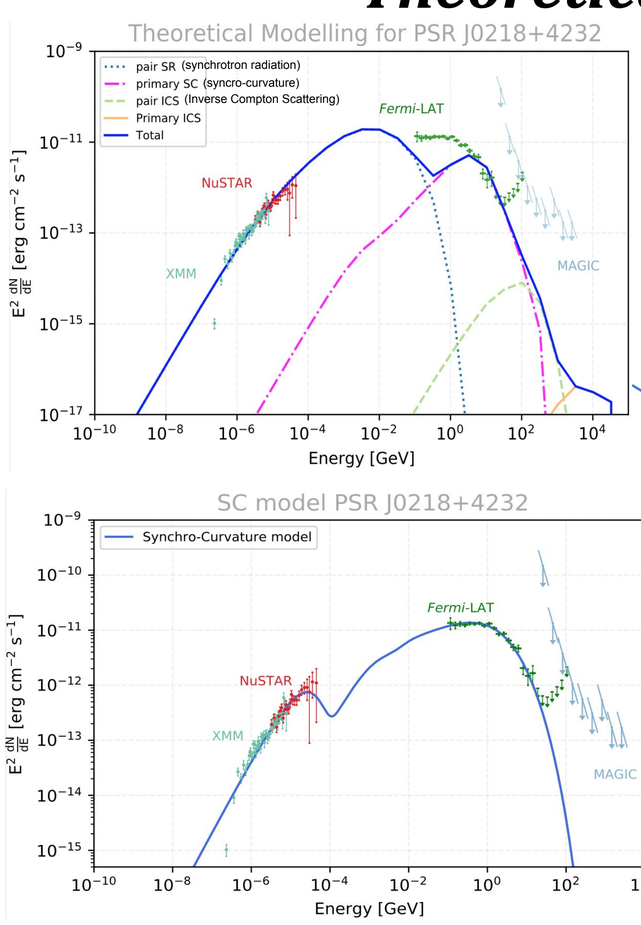
MAGIC Spectrum
E_threshold = 20 GeV
Power-law model => Γ=4.5 (E >10GeV)
Upper limits only



MAGIC Phaseogram
- Energy range = 20 -200 GeV
- NO evidence of Pulsation
- Background estimation: 3 source-free reflected regions (NOT used the OFF-pulse region → lead to large uncertainties)



Theoretical Modelling



Force-free magnetosphere Model [6]
★ trajectories of particles injected at neutron star surface
  - From UV to VHE γ-ray
  - 2 populations of particles
    - Primary e^-/e^+: accelerated by $E_{||}$
    - Secondary e^-/e^+: from polar cap pair cascade
★ Emission: Synchro-Curvature and Inverse Compton
★ Although the model can account for the detected X-ray emission, it fails to predict the correct level (and spectral shape) of the LAT-detected GeV emission, suggesting that further refinements are required.

LACK of VHE emission (MAGIC)
-Consistent with theoretical models:
Models do not predict VHE emission.
-We are searching for a second component of charged and accelerated particles able to emit VHE emission.

Synchro-Curvature model [7]
★ Particles trajectories around the light cylinder (pulsar's magnetosphere) threaded by an $E_{||}$.
★ *b* (magnetic gradient) is larger than for normal pulsars
  - maybe B_{lc} of MSPs is larger
  - smaller R_{lc} → region of emission ≪1km
★ Agreement between model and data (X-ray and *Fermi*-LAT)
  - the fractional residual errors are of order ~10%

Conclusions

We performed a new and deep analysis on the MSP J0218 using 11.5 years of LAT data + 87 hours of MAGIC data:

★ Pulsed emission E> 25 GeV (*Fermi*-LAT) 🙂 → SC model
★ No Pulsed/Unpulsed Emission in MAGIC data (E>100 GeV)
★ No detection of PSR J0218 at VHE
★ Theoretical Models:
  - HE emission: well described by the Syncro-curvature model.
  - VHE emission: not predicted by applied models.

References

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