Search for VHE Emission from PSR J0218+4232

Sidika Merve Colak[1], Alessia Spolon[2], B. Limyansky[3], P. M. Saz Parkinson[3,4,5] **For the MAGIC and *Fermi*-LAT Collaborations**

[1]IFAE, Campus UAB, E-08193 Bellaterra, Spain, [2]Università di Padova and INFN, I-35131 Padova, Italy, [3]SCIPP, Santa Cruz, CA 95064, USA, [4]HKU, Pokfulam Road, Hong Kong, China, [5]LSR, Hong Kong, China

Introduction

- ★ Millisecond pulsar (MSP) with P_spin=2.32ms, P_orbital=2d
- ★ High magnetic field strength at Light Cylinder
  - (B_LC~3.2x10^5 G)
- ★ **One of the youngest and most energetic MSP**
- ★ Bright in radio and X-rays [1]. Detected by EGRET[2] , and Fermi-LAT[3]
- ★ Possibly aligned rotator with ~50% unpulsed component
- ★ **Hints for pulsed emission >10 GeV [4] and >25 GeV [5]**

Data Analysis

***Fermi*-LAT**

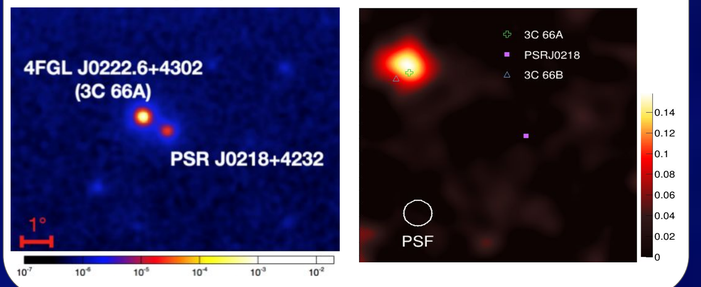
- ★ Data: **11.5 years** (2008 - 2020)
- ★ P8R3_SOURCE_V3
- ★ Energy range: **100 MeV - 870 GeV**

MAGIC

- ★ Data: **87 hours** (2018 - 2019)
- ★ **Sum-Trigger-II system[6]** : high performance at sub-100 GeV
- ★ Energy Range: **>20 GeV**
- ★ Zenith range = 13°-30°

Results - Skymaps

Fermi-LAT Skymap > 1 GeV | **MAGIC Skymap >20 GeV**



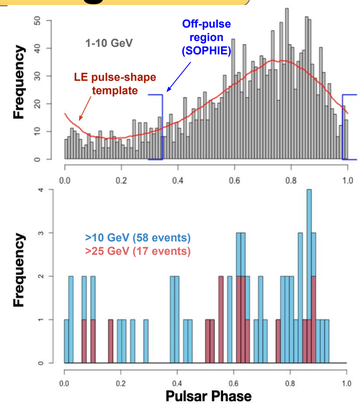
References

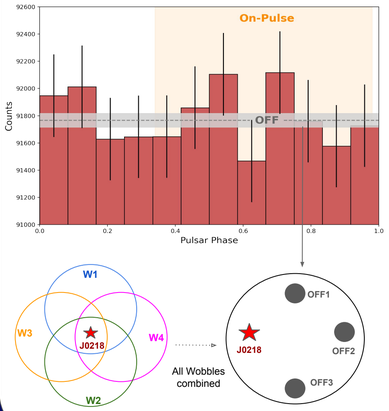
[1] Gotthelf et al., 2017, ApJ, 845, 159
[2] Kuiper et al., 2000, A&A, 336, 545
[3] Abdo et al., 2009, Science, 325, 848
[4] Ackermann et al., 2013, ApJS, 209, 34
[5] Saz Parkinson et al., 2017, in Proceedings Of 7th International Fermi symposium, 1
[6] Dazzi et al., 2021, IEEE, 1
[7] Harding et al., 2015, ApJ, 811, 63
[8] Torres et al., 2019, MNRAS, 489, 5494
[9] Acciari et. al , 2021, submitted to ApJ

Results - Phaseograms

***Fermi*-LAT**

- ★ High Energy (HE) search for pulsed emission
- ★ Likelihood ratio test (LRT) method
  - Low-Energy: 1-10 GeV **(pulse-shape red template)**
  - High-Energy: >10 GeV
- ★ Results:
  - **>10 GeV p_value: 10^{-4}**
  - **>25 GeV p_value: 10^{-2}**
  - **>30 GeV p_value > 0.05**





MAGIC

- ★ Very High Energy (VHE) search for pulsed emission : **20 - 200 GeV**
- ★ Method 1 : LRT **(Fermi-LAT LE template)**
  - **p_value > 0.05**
- ★ Method 2 : Li&Ma
  - ON: [0.34-0.98 phase], OFF: mean **3 source-free reflected regions**
  - **0.057 σ**
- ★ Method 3 : region-indep. signal tests
  - **χ^2 : 5.54/11 dof**
  - **H-test : 0.05 σ**

Discussion

- ★ *Fermi*-LAT
  - **Pulsed emission significant > 10 GeV , marginal >25 GeV, no evidence > 30 GeV**
- ★ MAGIC
  - **No significant emission > 20 GeV (neither pulsed nor unpulsed)**
- ★ Theory:
  - **Data is in better agreement with Synchro-curvature Model**
  - No VHE emission is predicted, agreement with MAGIC results
- ★ **Stay tuned for the publication[9]**

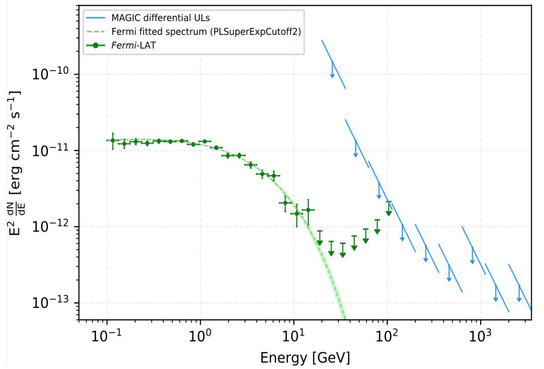
Results - SED & Theoretical Models

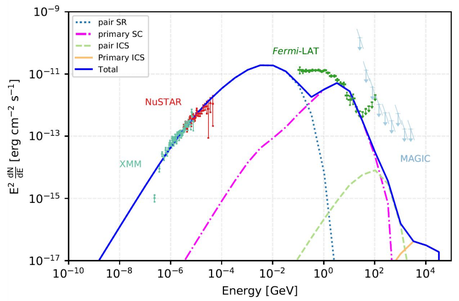
***Fermi*-LAT**

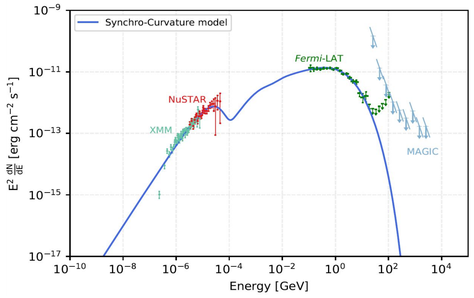
- ★ Power-law with exponential cut-off, steep > 10 GeV
- ★ **Significant emission up to 20 GeV**

MAGIC

- ★ Power-law with Γ=4.5 (from Fermi-LAT data)
- ★ ON: [0.34-0.98 phase]
- ★ **No significant detection, only upper limits**







Force-free Magnetosphere Model[7]

- ★ Computation of individual particle trajectories (Particle-In-Cell simulations)
  - Injected **at neutron star surface**
  - Two populations of particles :
    - Primary e^-/e^+: accelerated by $E_{||}$ (current sheet)
    - Secondary e^-/e^+: from polar cap pair cascade (no accelerating E field)
  - Emission: **Synchro-Curvature and Inverse Compton**

Synchro-Curvature Model[8]

- ★ Computation of particle trajectories
  - Particles accelerated by $E_{//}$ **around Light Cylinder**
  - Emission: **Synchro-Curvature radiation**
- ★ Remarks:
  - Estimated magnetic gradient > normal pulsars
    - Could be due to higher B_{LC} and smaller R_{LC}