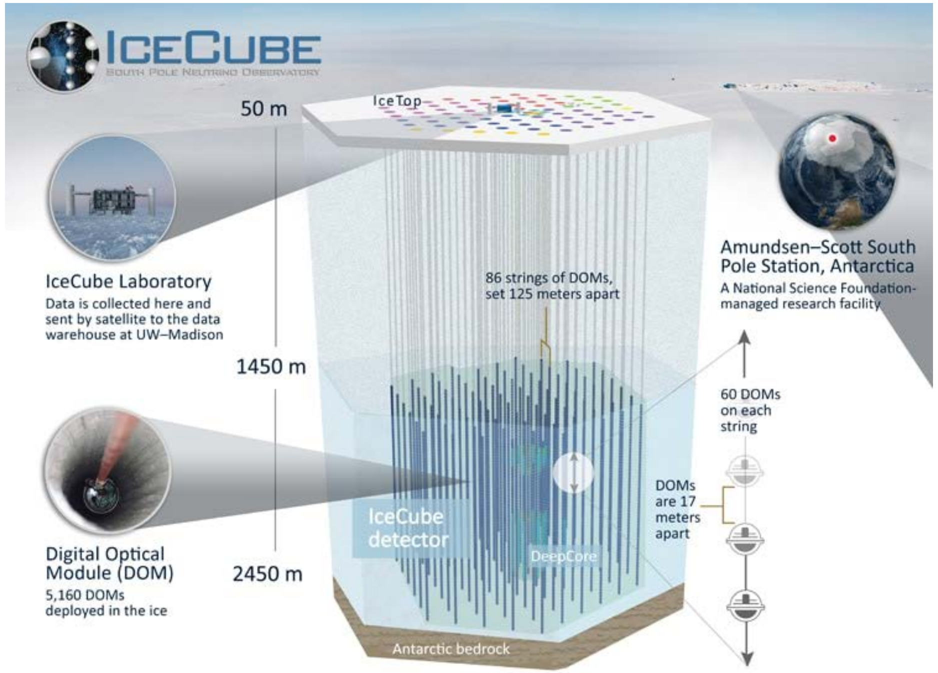
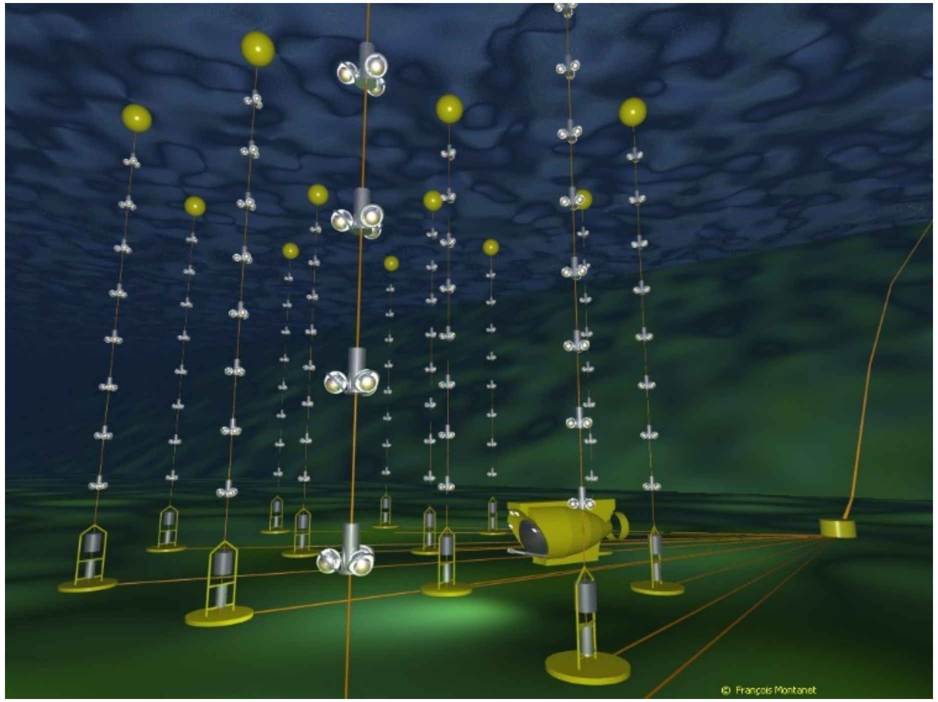
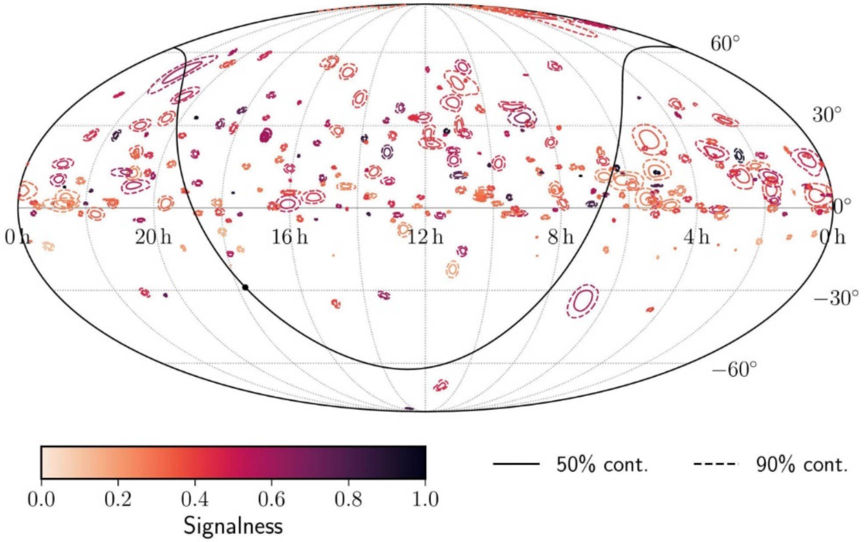
Neutrinos from binaries

A.M.Bykov, A.E.Petrov, M.E.Kalyashova (Ioffe), M.Falanga (ISSI), S.V.Trioitsky (INR)

Neutrino experiments. Galactic sources







Albert et al (2018): Galactic sources < 15%

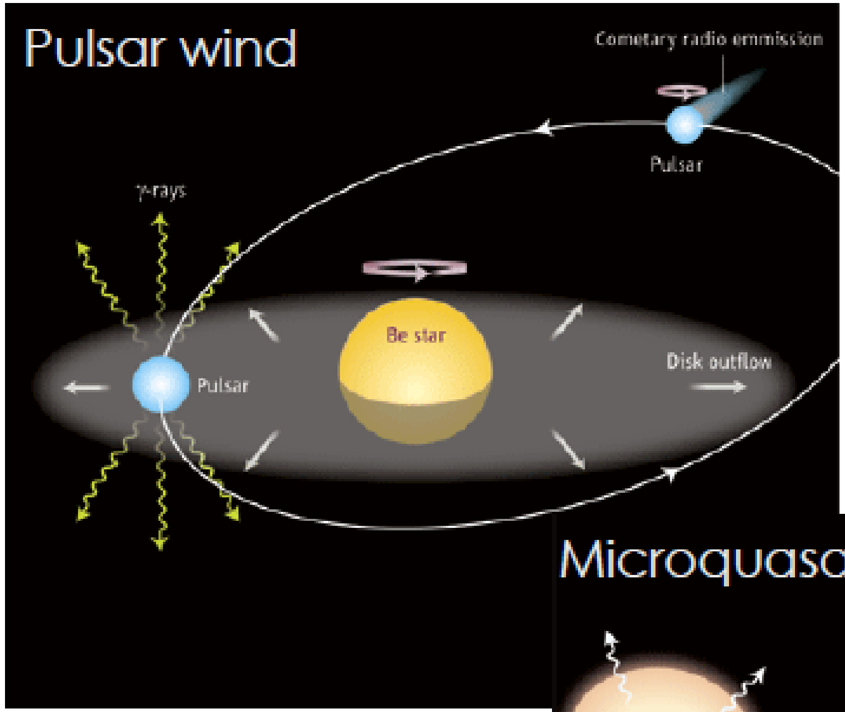
Aartsen et al. (2019): indications of Galactic sources

Abbasi et al. (2021): explain tension between different measurements

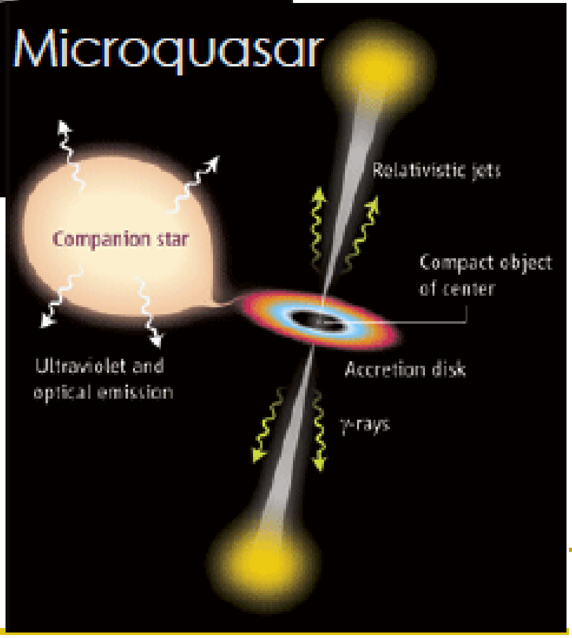
Neronov & Semikoz (2015) Galactic contribution

Credit: IceCube Collaboration, ANTARES collaboration

Binaries as gamma-ray and neutrino sources: microquasars and pulsars



Mirabel 2006

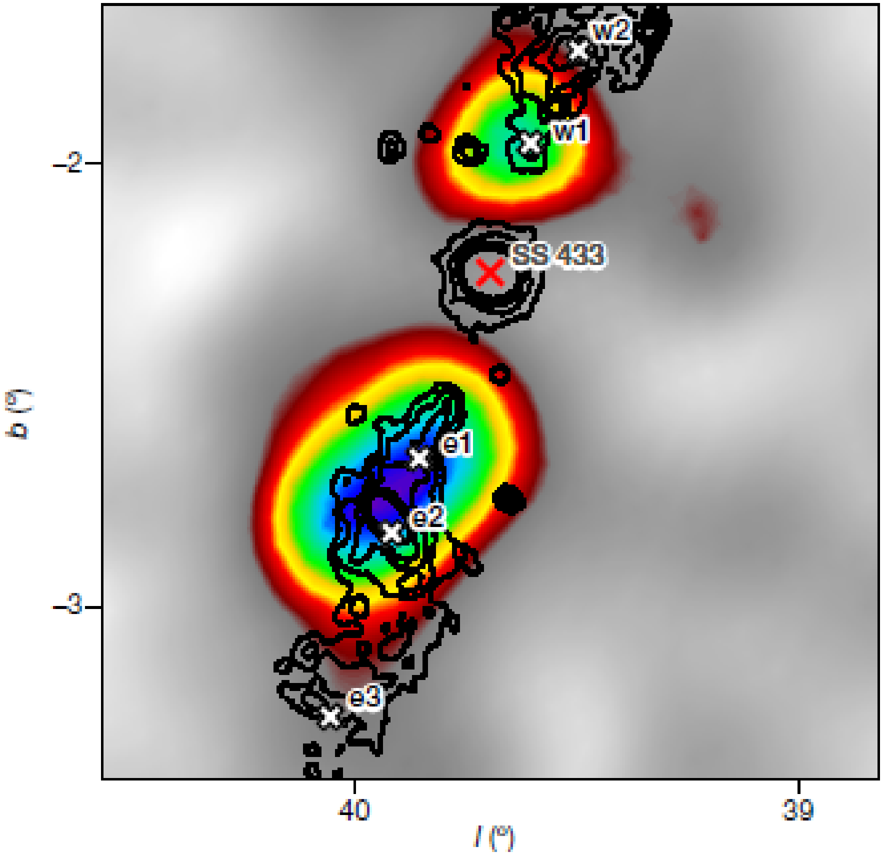


Skilton et al, 2009

PSR B1259-63
PSR J2032+4127
LS 5039
LSI 61 303
Cyg X-3

Distefano,Guetta, Waxman, Levinson ‘02
Bednarek 2005
Neronov & Ribordy 2008
Sahakyan,Piano3,Tavani 2014

Microquasars



Credit: Abeysekara et al. (2018)

Levinson & Waxman (2001)
Distefano et al. (2002)

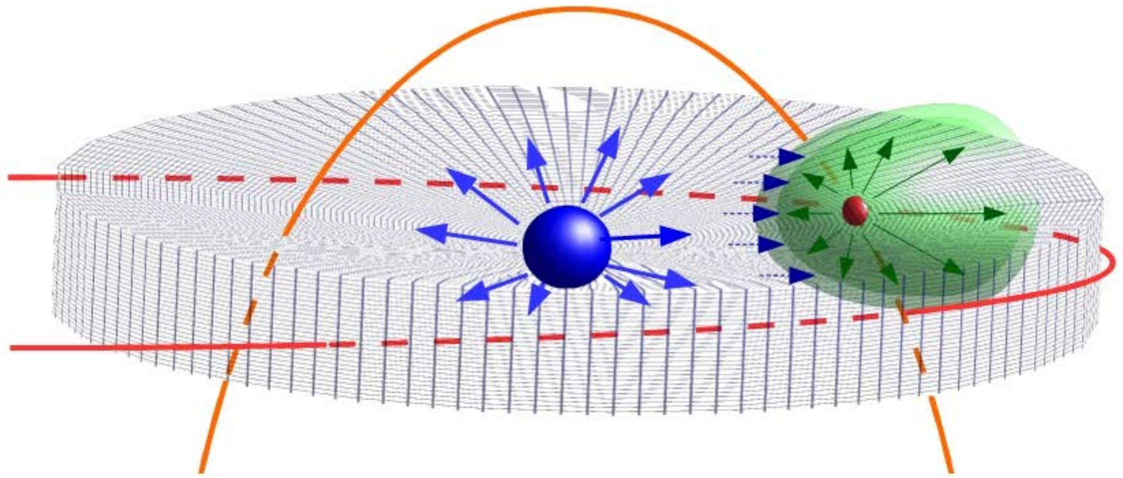
- Jet composition – unknown. Pairs or e-p?
- Doppler-shifted Halpha may indicate e-p (SS 433)
- Neutrino may indicate e-p composition, if detected

- Internal shocks in jet: protons acceleration upto PeV!

- X-ray photons: disk and synchrotron
- Photomeson process: threshold at ~ 300 TeV for 1 keV photons
- Large optical depth for protons exceeding threshold ->
    - 1) efficient conversion to neutrions
    - 2) neutrino spectrum similar to proton

- May be detected by 1 km(2) telescopes…

Colliding wind binaries



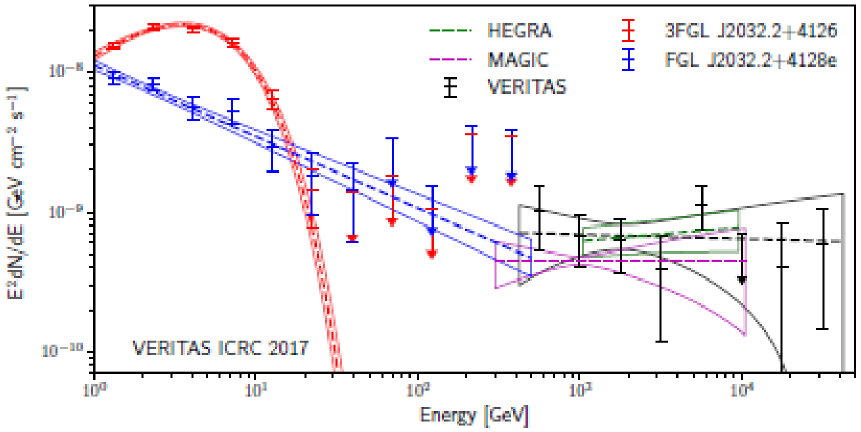
System	Star spectral type	Compact object	Porb [days]	HE emission	VHE emission
PSR B1259-53	Be	48ms pulsar	1236.72	yes	yes
LS 5039	O	-	3.91	yes	yes
LS I +61 303	Be	-	26.49	yes	yes
HESS J0632+057	Be	-	315.50	yes	yes
FGL J1018.6-5856	O	-	16.58	yes	yes
LMC P-3	O	-	10.2	yes	yes
PSR J2032+4127	Be	143 ms pulsar	50 years	yes	yes

From O.Blanch 2019

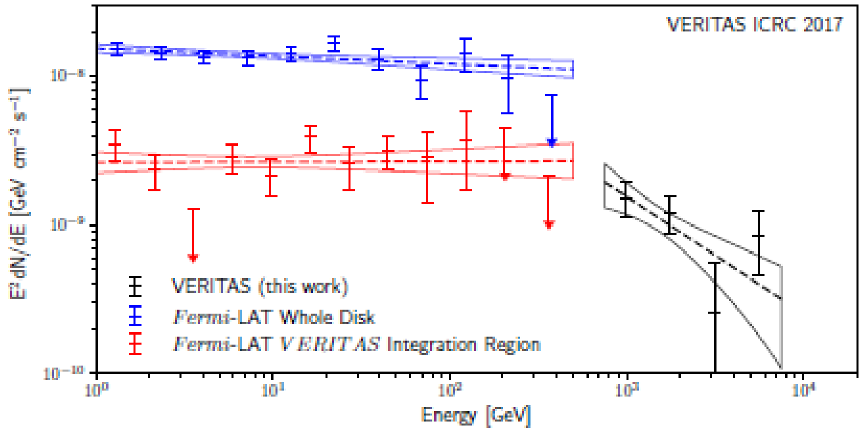
In the Cygnus region there are compact TeV sources

VERITAS spectra of some sources in Cygnus

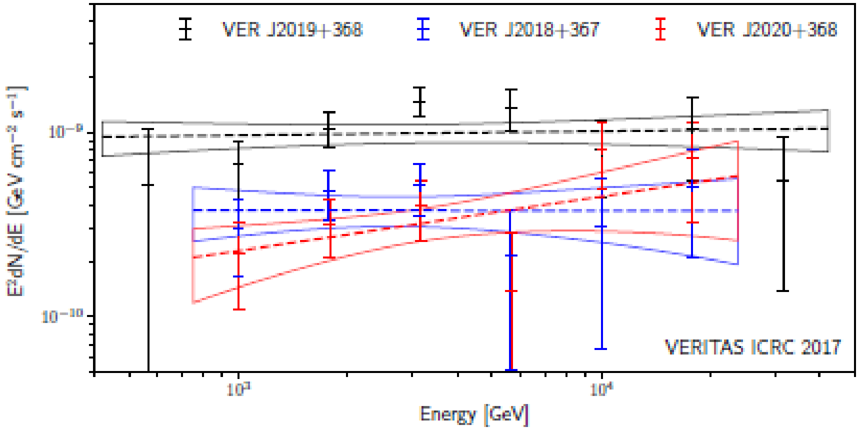
VERITAS observations of the Cygnus Region Ralph Bird



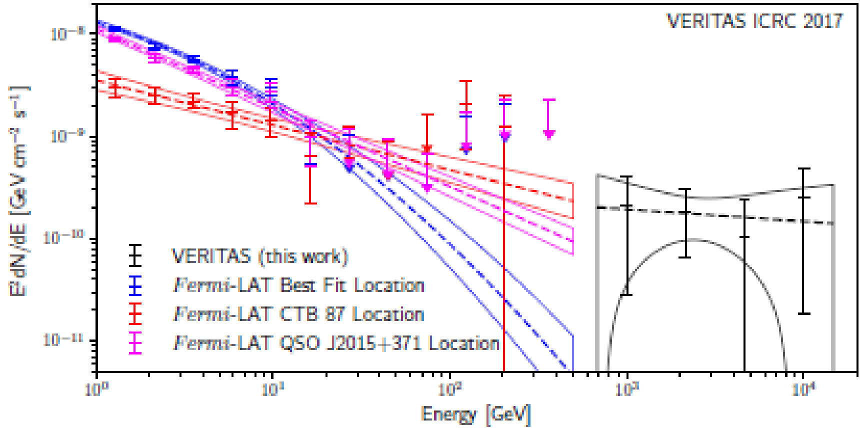
(a) TeV J2032+4130 region.



(b) Gamma Cygni region.



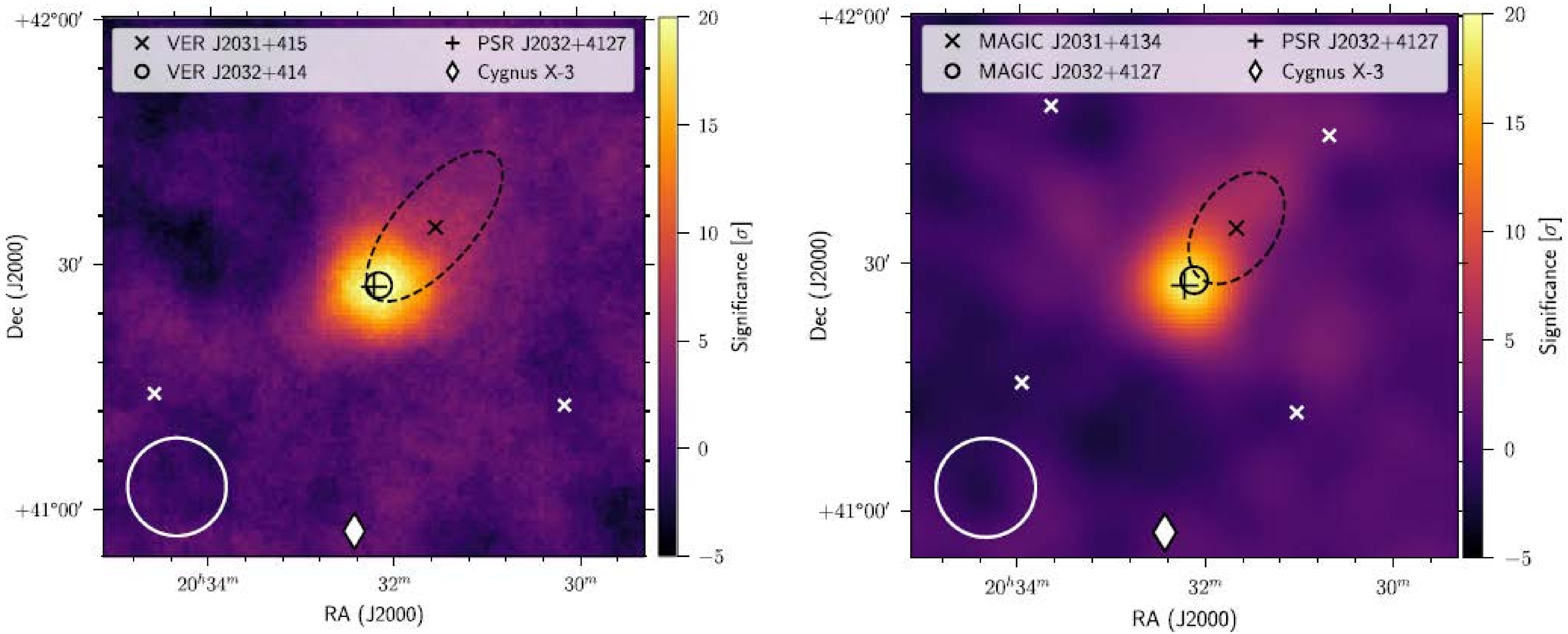
(c) MGRO J2019+37 region.



(d) CTB 87 region.

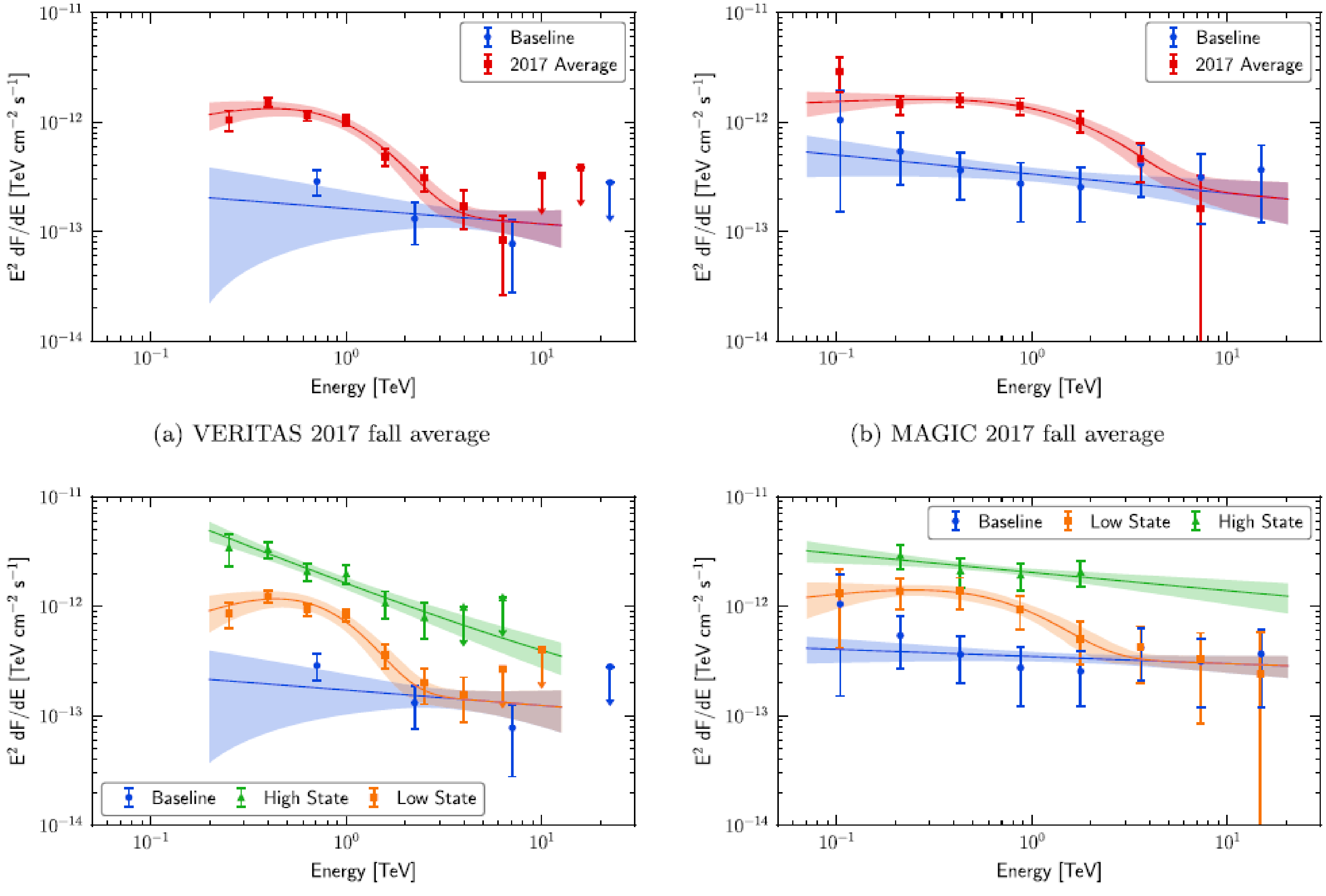
VERITAS ICRC 17

VERITAS MAGIC maps of a crowded region in Cygnus
TeV emission PSR J2032+4127/MT92 213 @ periastron



VERITAS & MAGIC teams The Astrophysical Journal Letters, 867:L19, 2018

VERITAS MAGIC at different orbital phases of PSR 2032



(a) VERITAS 2017 fall average

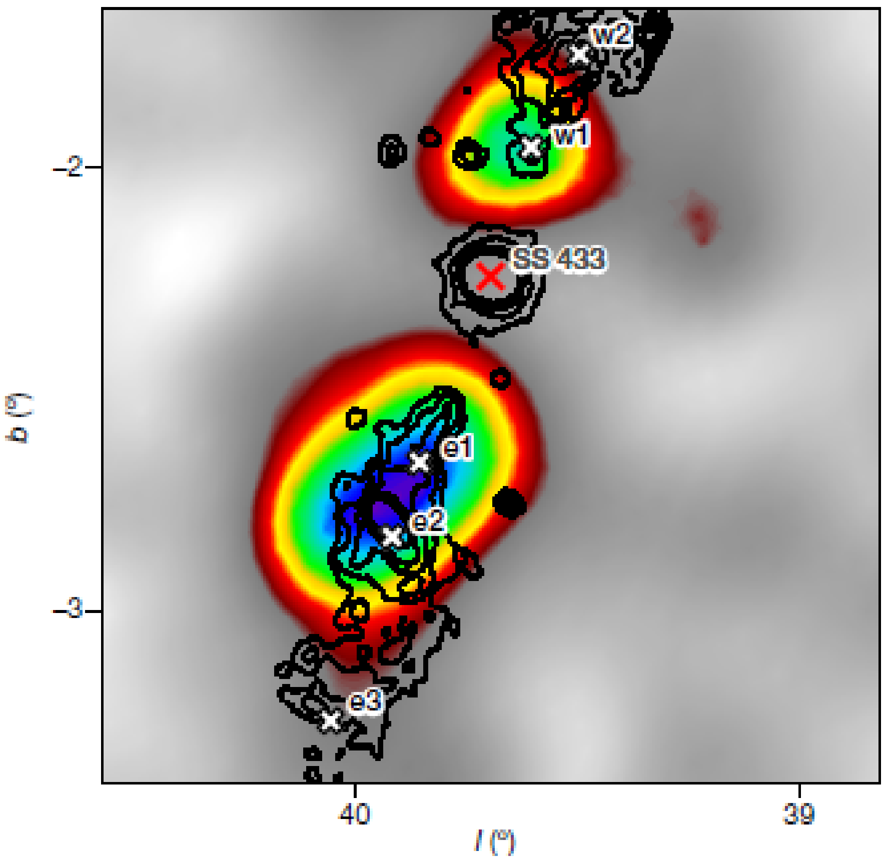
(b) MAGIC 2017 fall average

(c) VERITAS high & low states

(d) MAGIC high & low states

VERITAS & MAGIC teams The Astrophysical Journal Letters, 867:L19, 2018

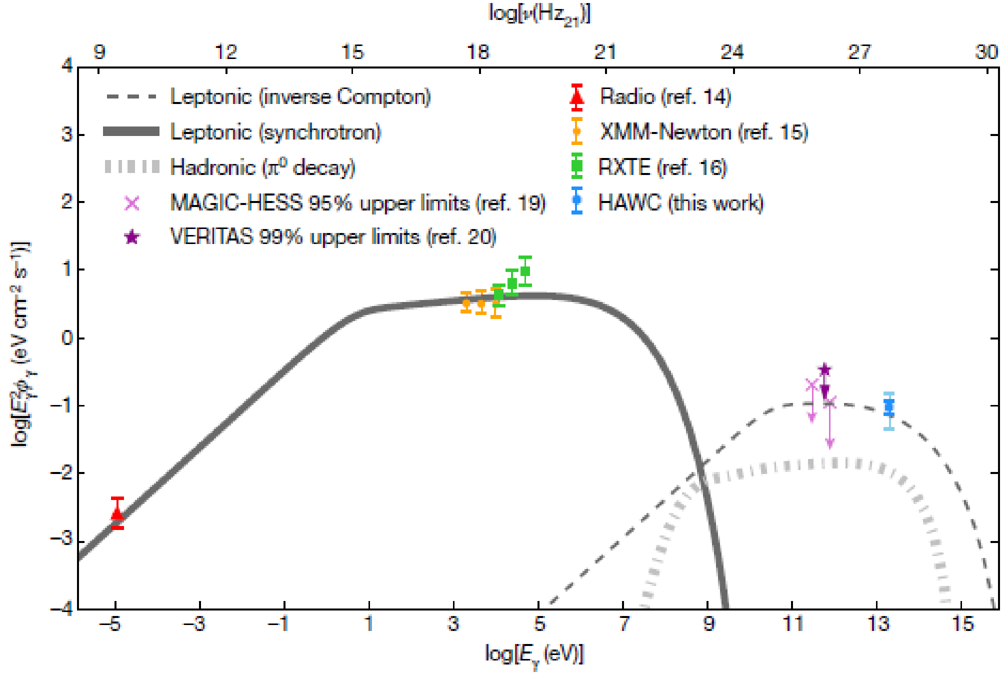
SS 433



First microquasar
Supercritical accretion ~ 10-4 MΘ/yr
Orbital period 13d (precession 126d)

Mx/Mv > 0.6 black hole Mx ~ 8-10 MΘ + A supergiant
(MNRAS 485, 2638, 2019)
Jets 0.26 c, power ~ 10^{39} эрг/с (baryonic?)

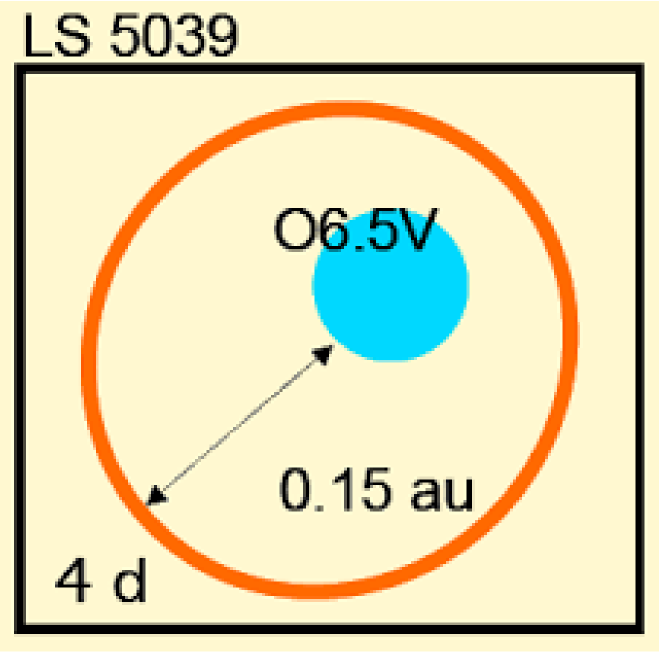
remnant CH W50

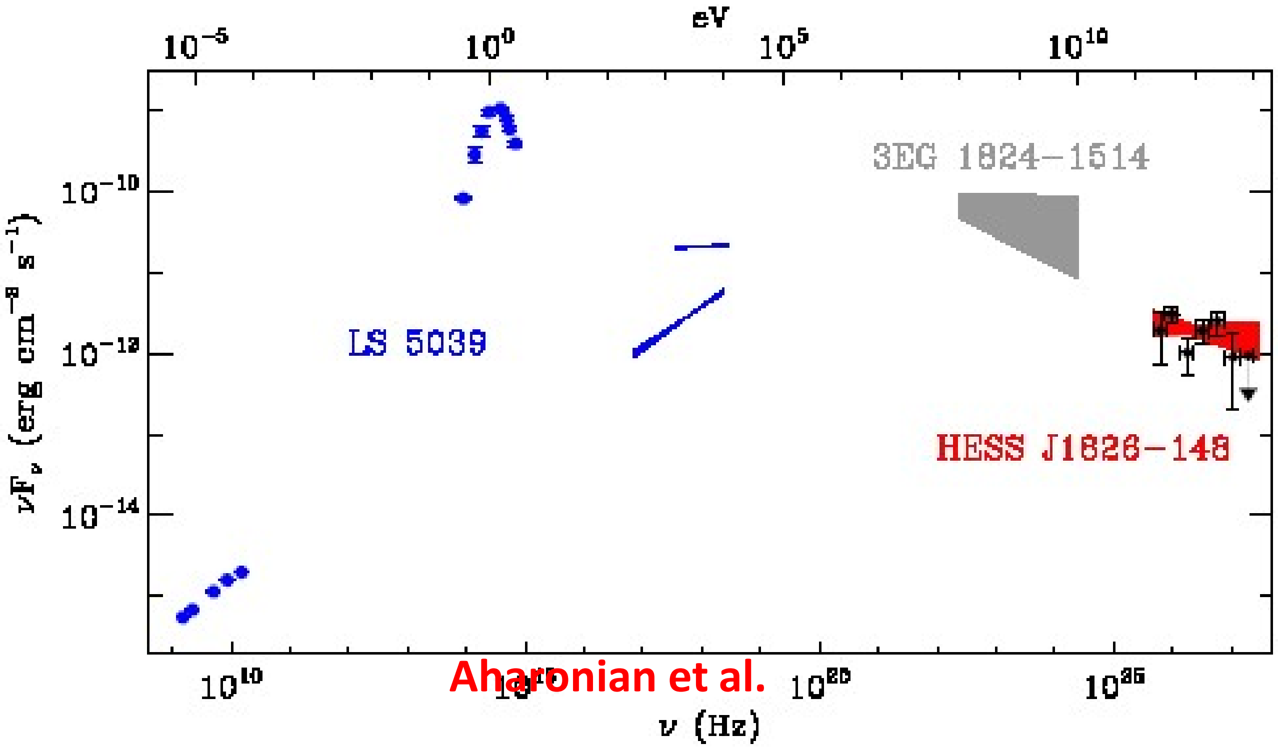


HE/VHE emission (Bordas 2015, HAWC 2018) L ~ 10^{32} erg/s

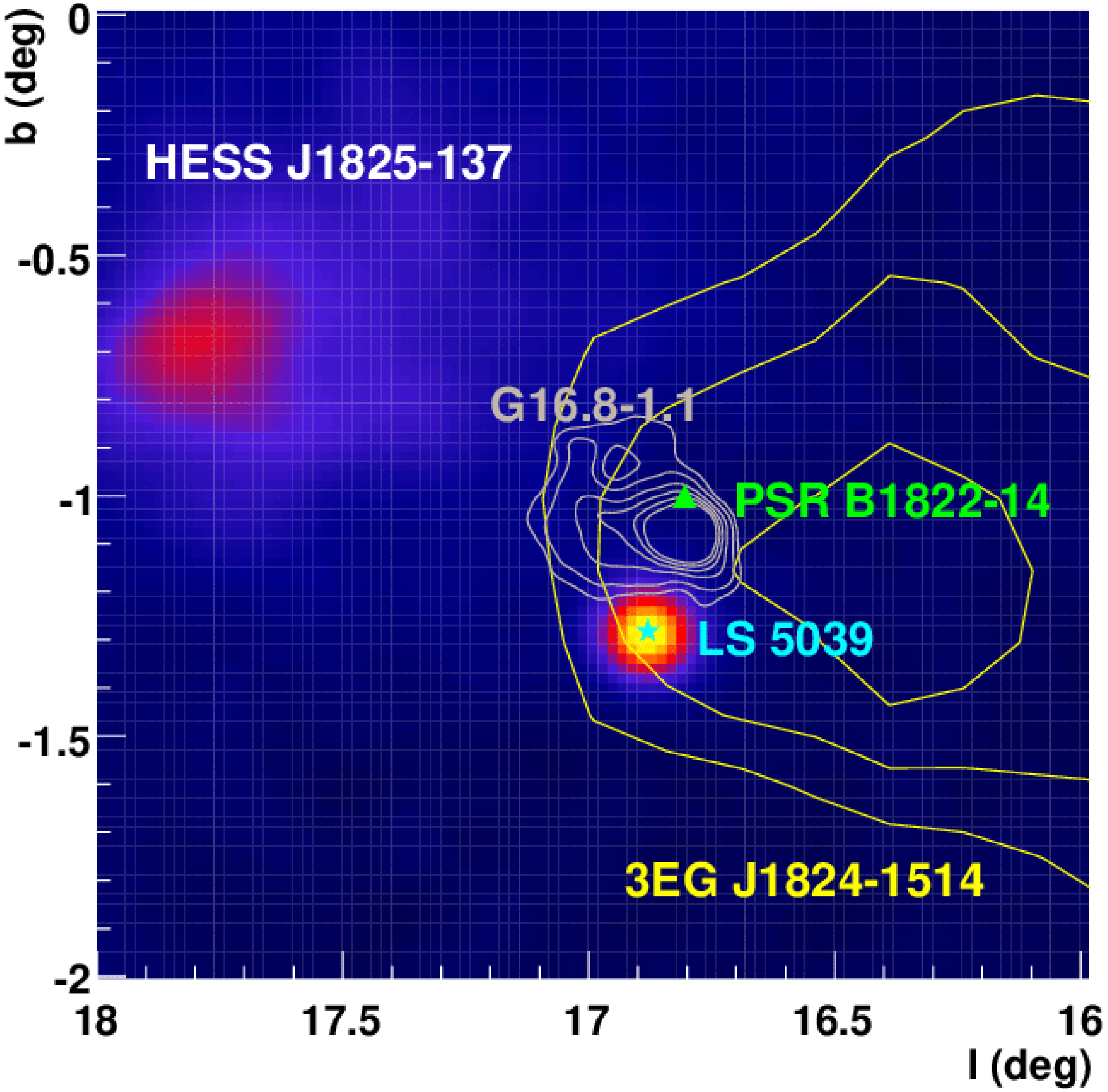
Possibly from jet-medium interaction, no VHE central source, photons upto 20 TeV…

Bordas 19

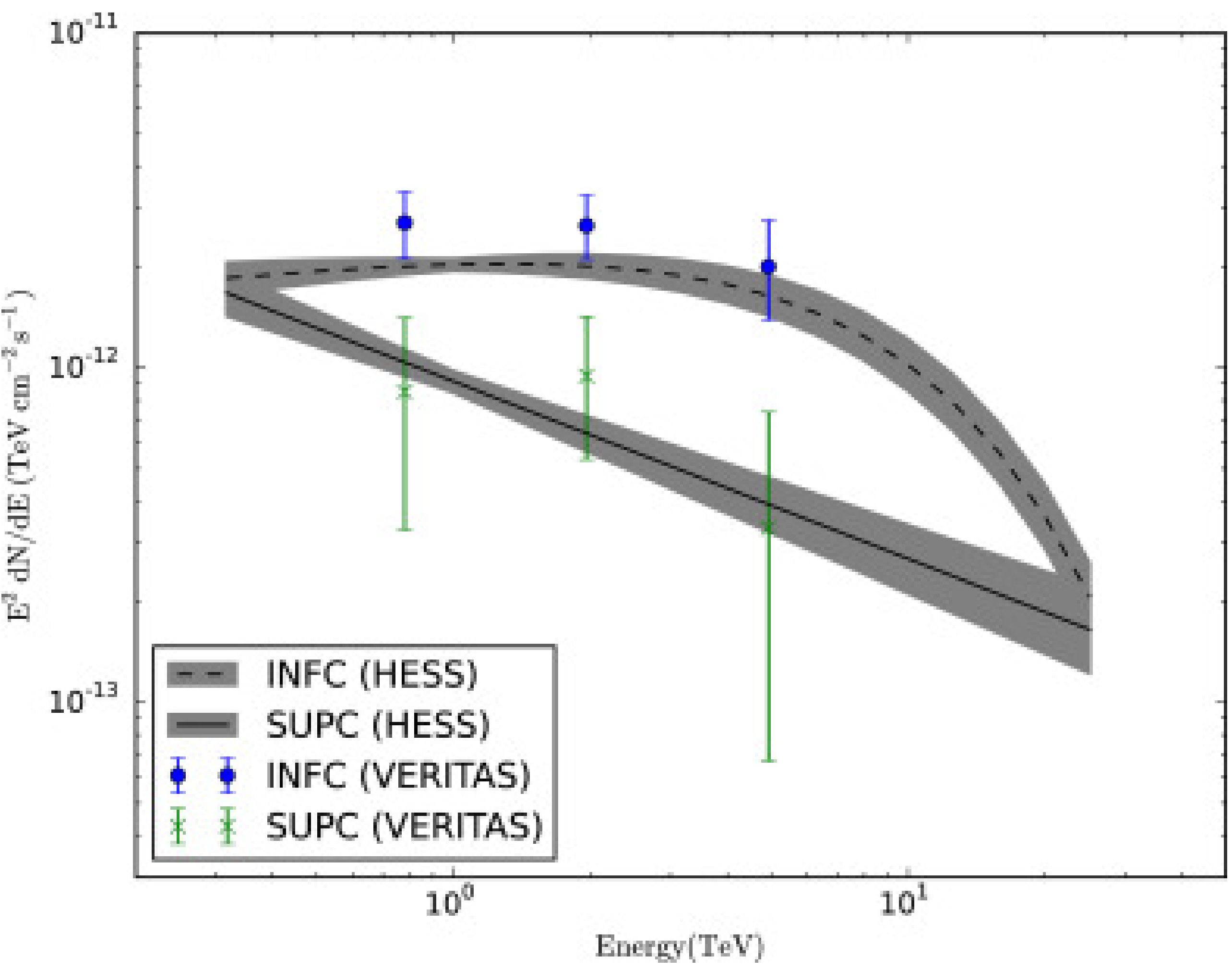


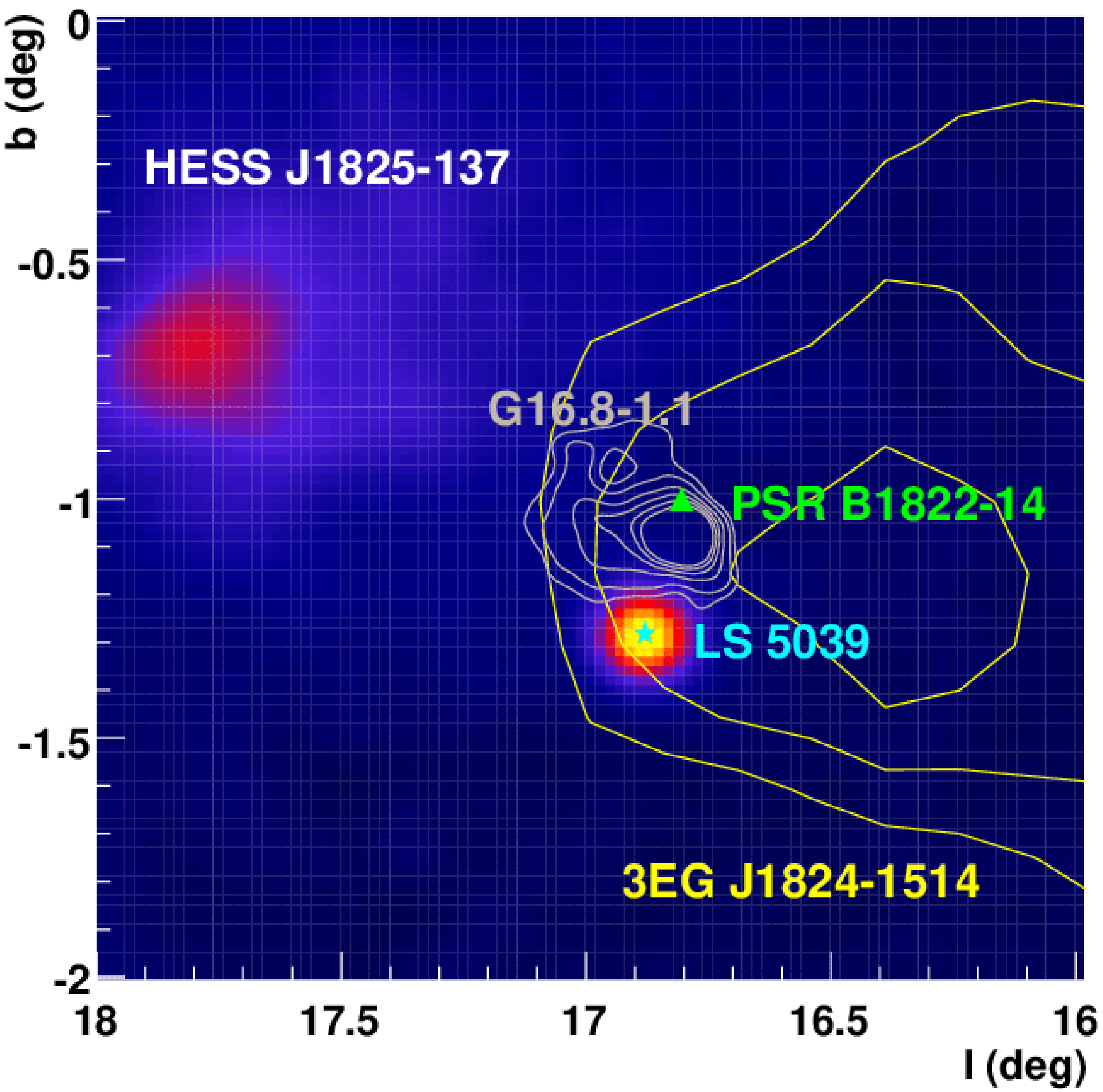


Aharonian et al.



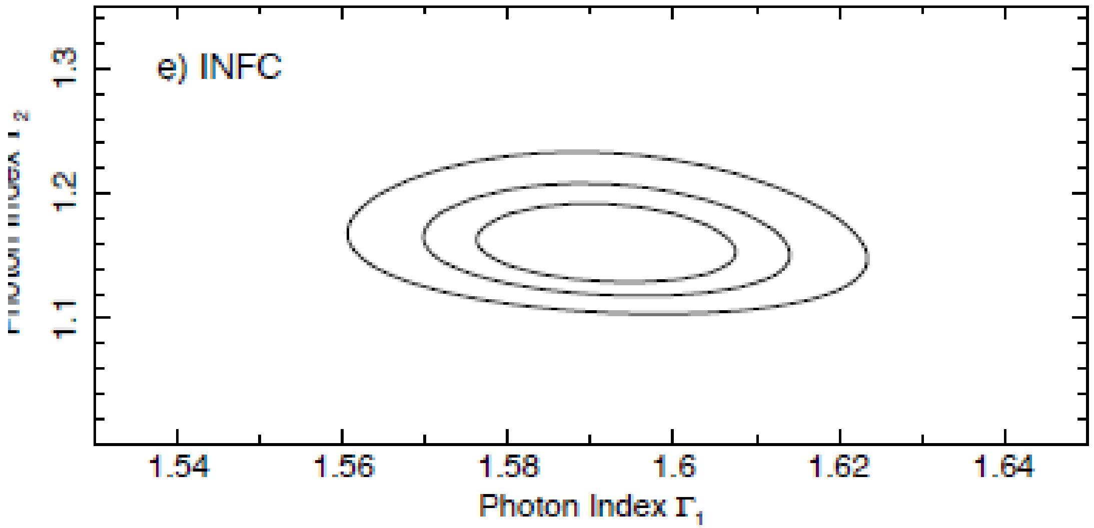
Spectra H.E.S.S. & VERITAS

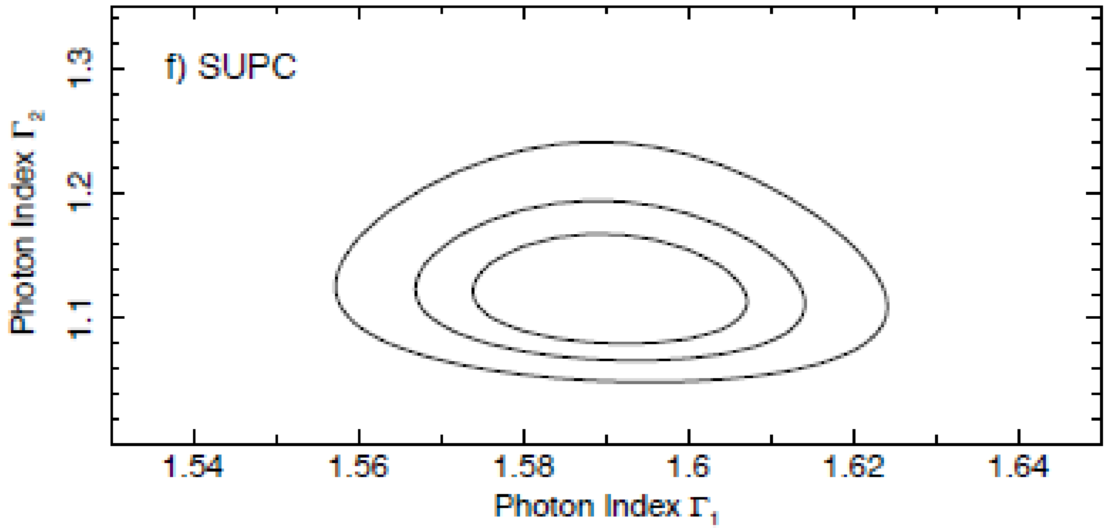




Leptonic scenario in Klein-Nishina regime?

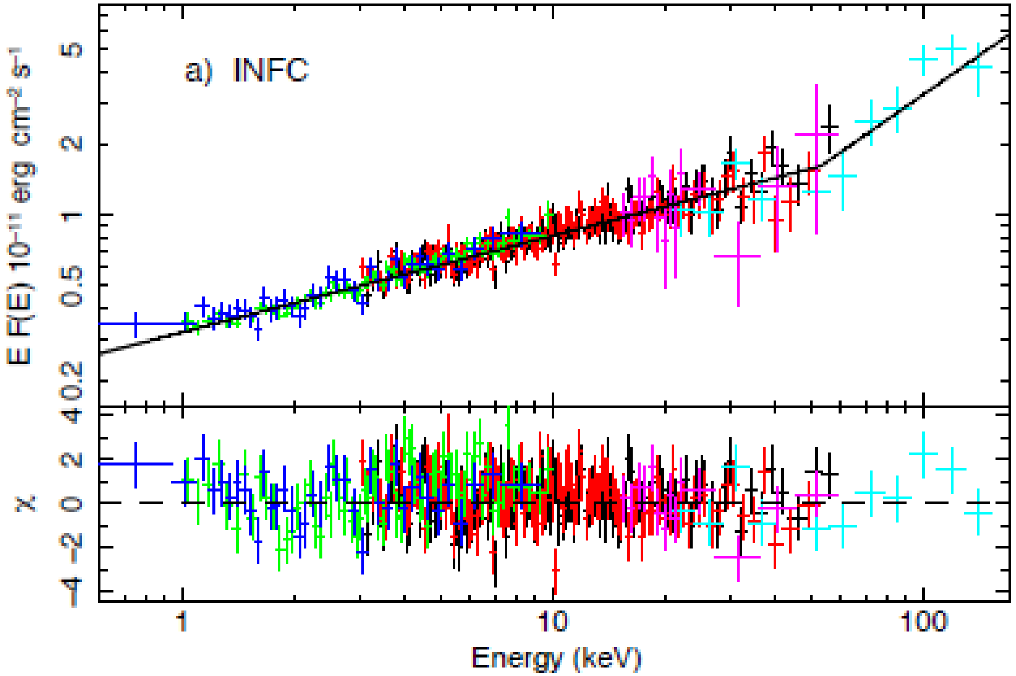
Hard synchrotron spectra of LS 5039





XMM-Newton, Suzaku, NuSTAR

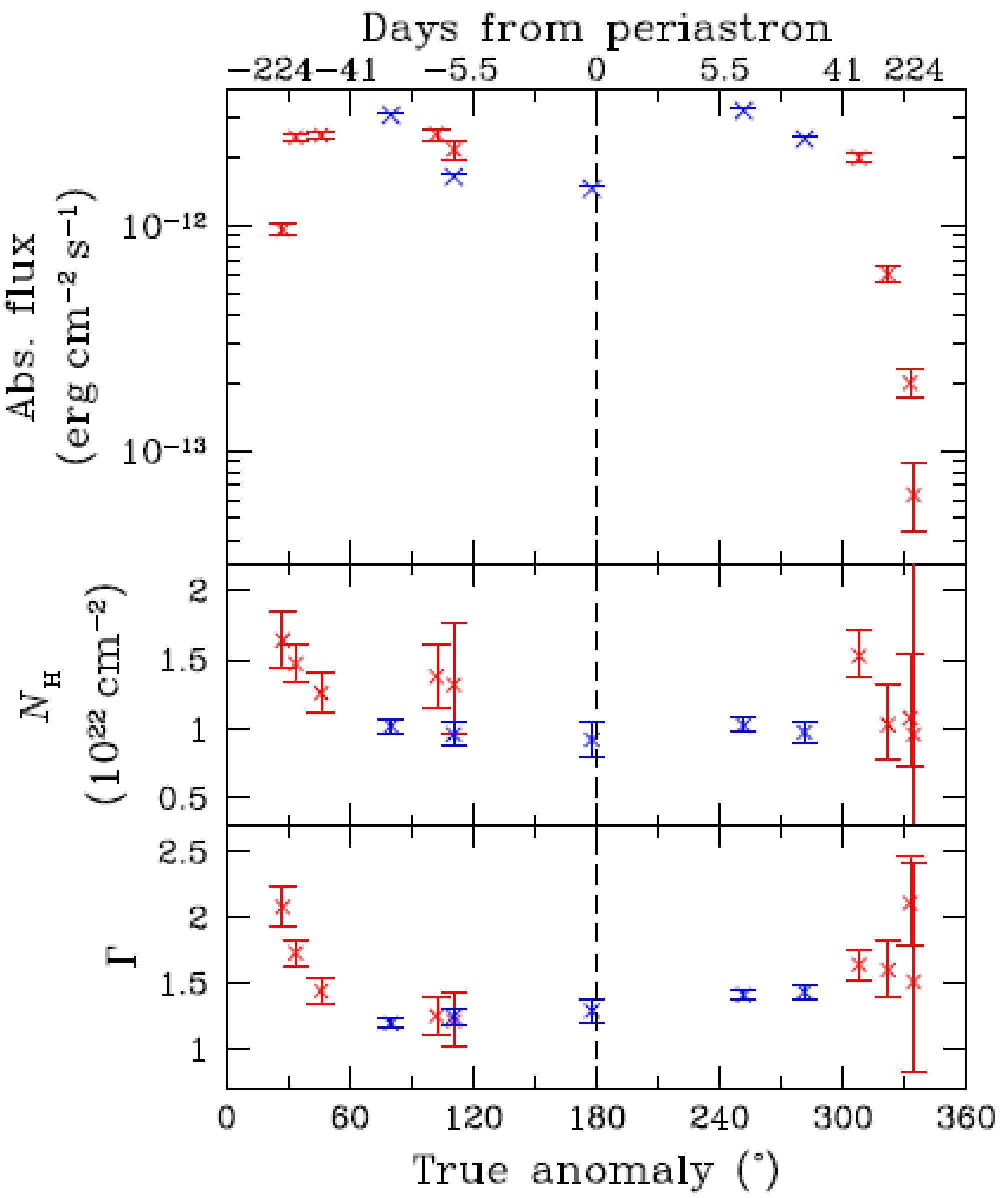
INTEGRAL ISGRI

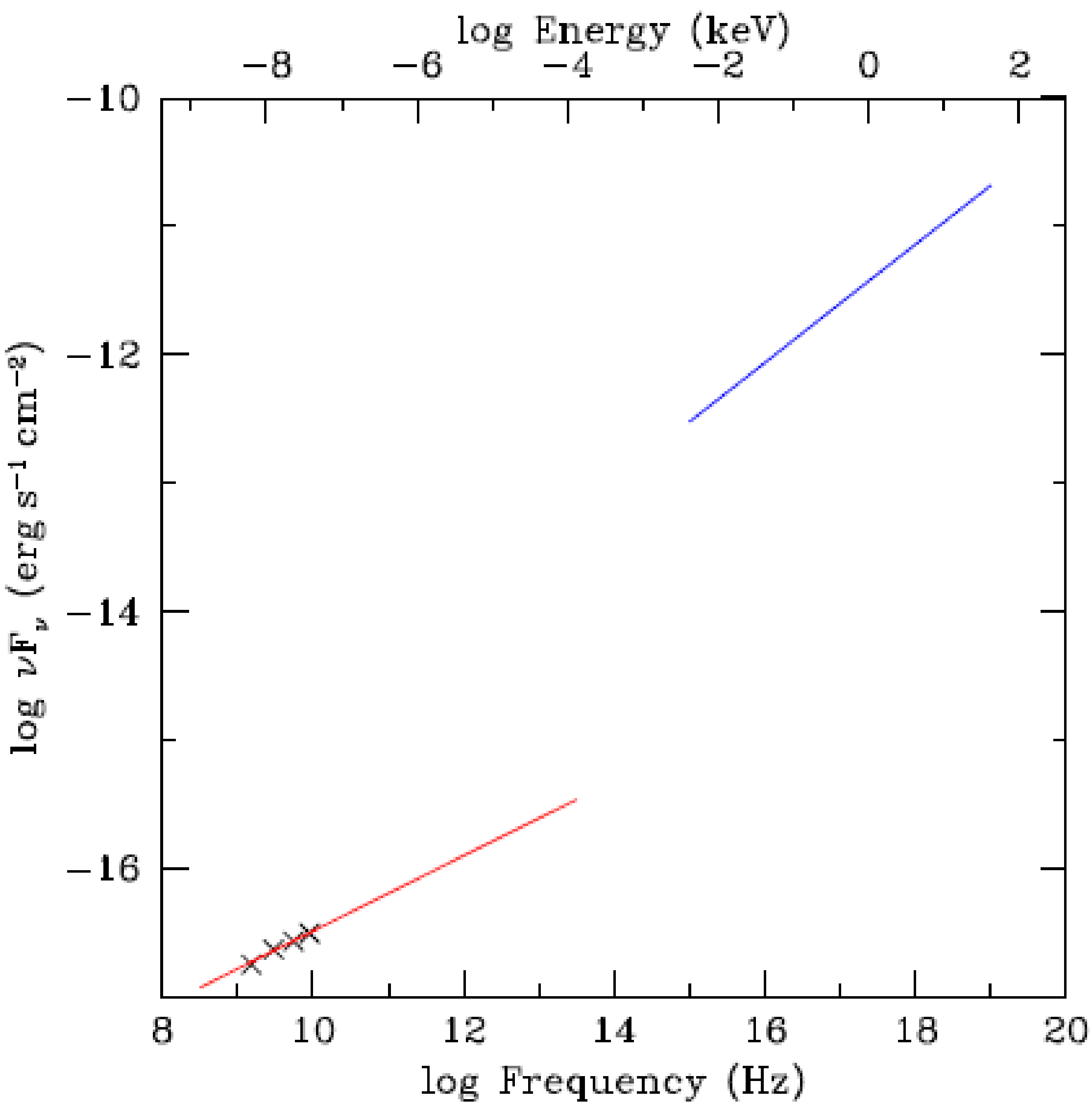


Colliding winds model predicts very hard particle index Γ ~ 1.0 - 1.2, see Space Sci. Rev. v. 207, 235, 2017

Astron. Astroph. V.654, A127, 2021

Chandra XMM-Newton NuSTAR PSR 2032 (SED a week after periastron)

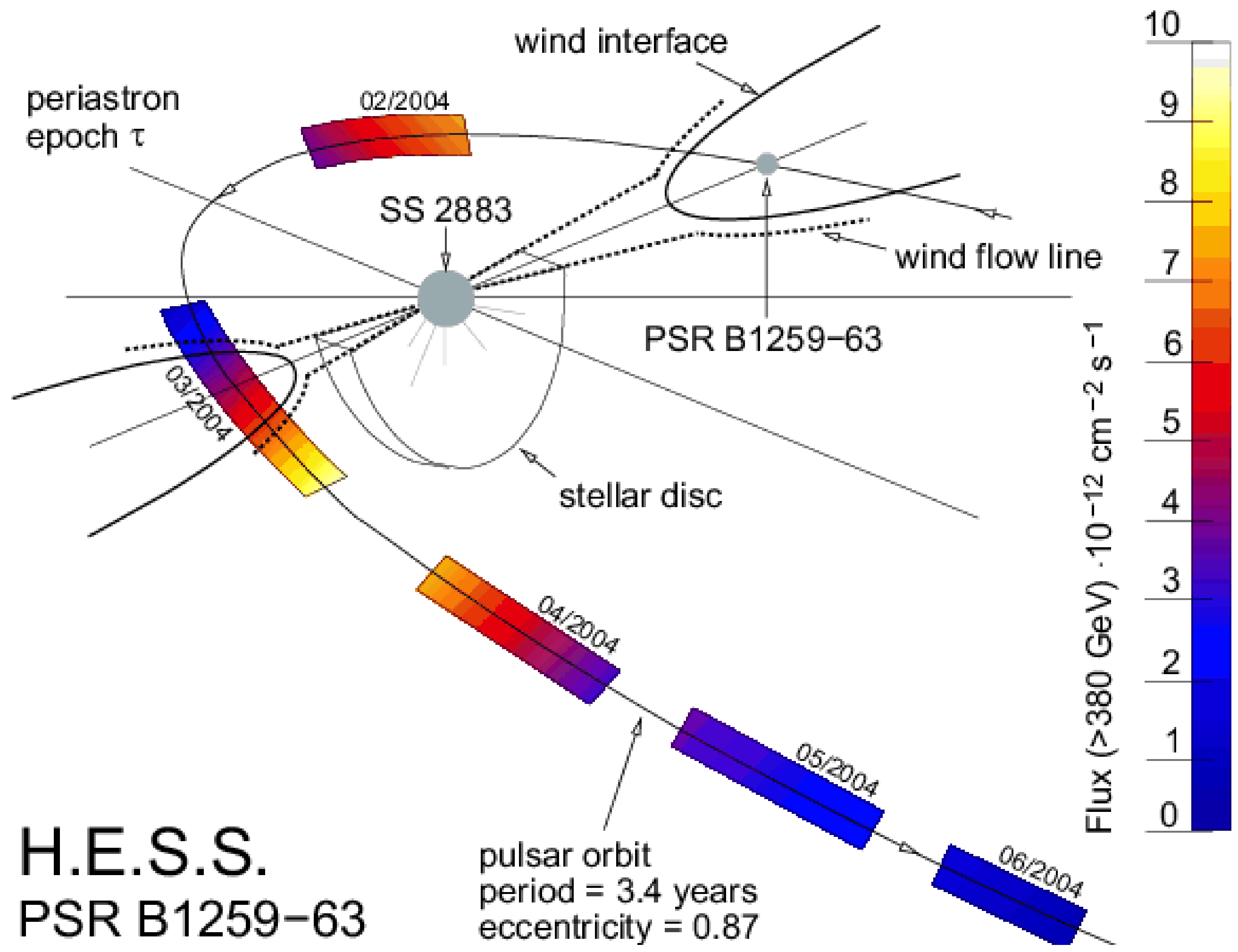




Note the very hard spectrum!!!

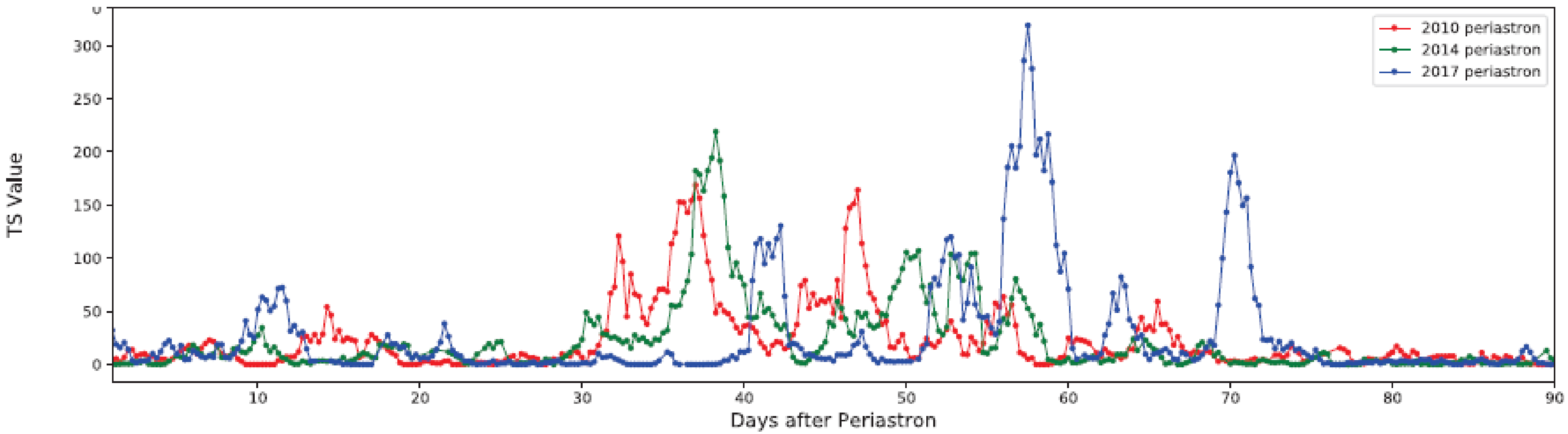
Ng + The Astrophysical Journal v.880, 147,2019

TeV gamma-ray source PSR B1259-63 – Be star



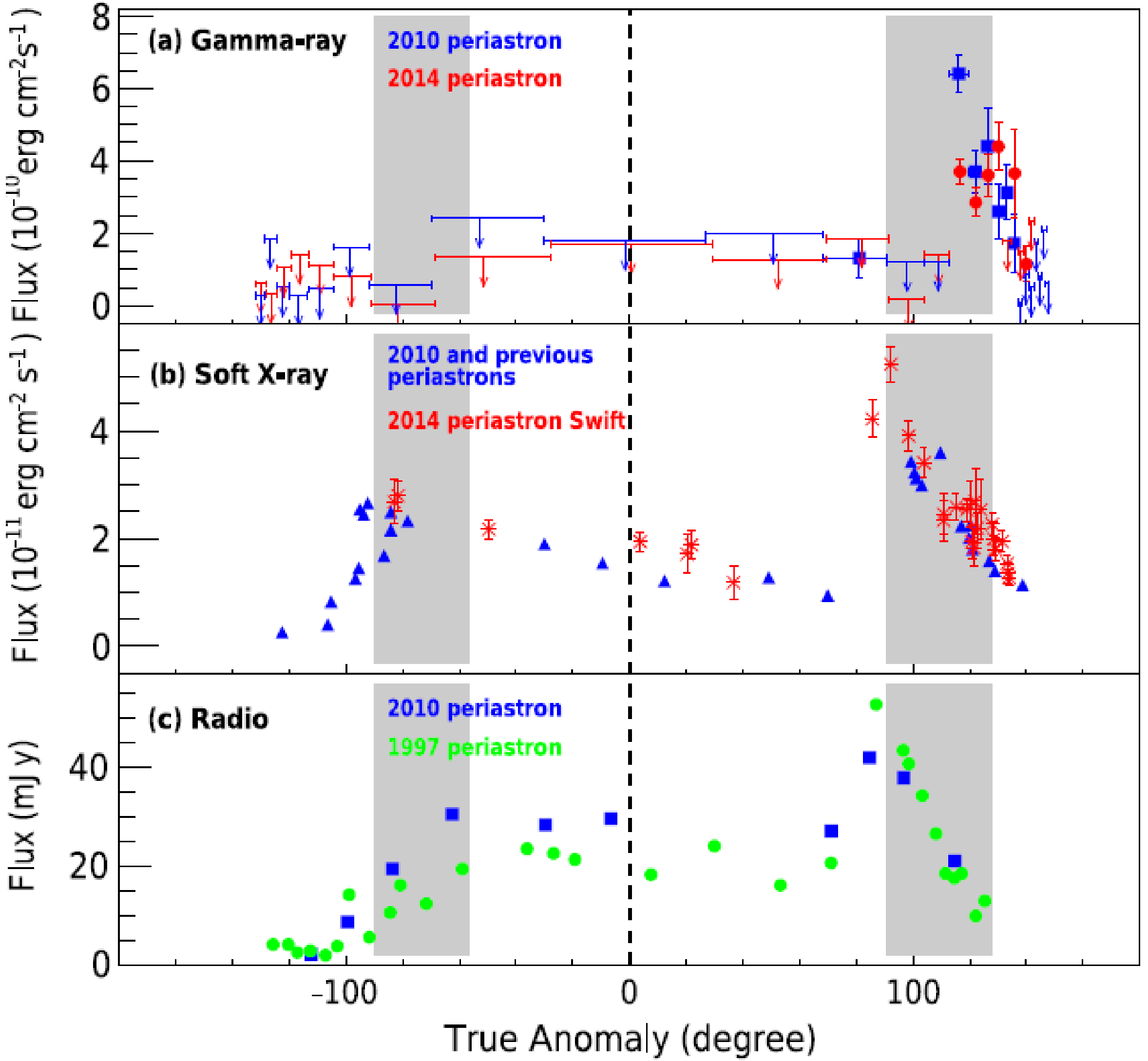
Aharonian et al. A&A 2005

HE flares from PSR B1259-63



Chang+ 2018

- Unexpected flares observed at HE gamma-rays with LAT in 2010 **Abdo+ 2011**
- Flares starting 30 days (40 days) after t_p in 2010 and 2014 (in 2017), and lasting for more than 50 days (70 days in 2017)
- luminosities almost reaching $L_\gamma \sim L_{sd}$ **Abdo+ 2011, Caliandro+ 2015**
- No counterpart at radio, X-rays or VHEs **Chernyakova+ 2014**



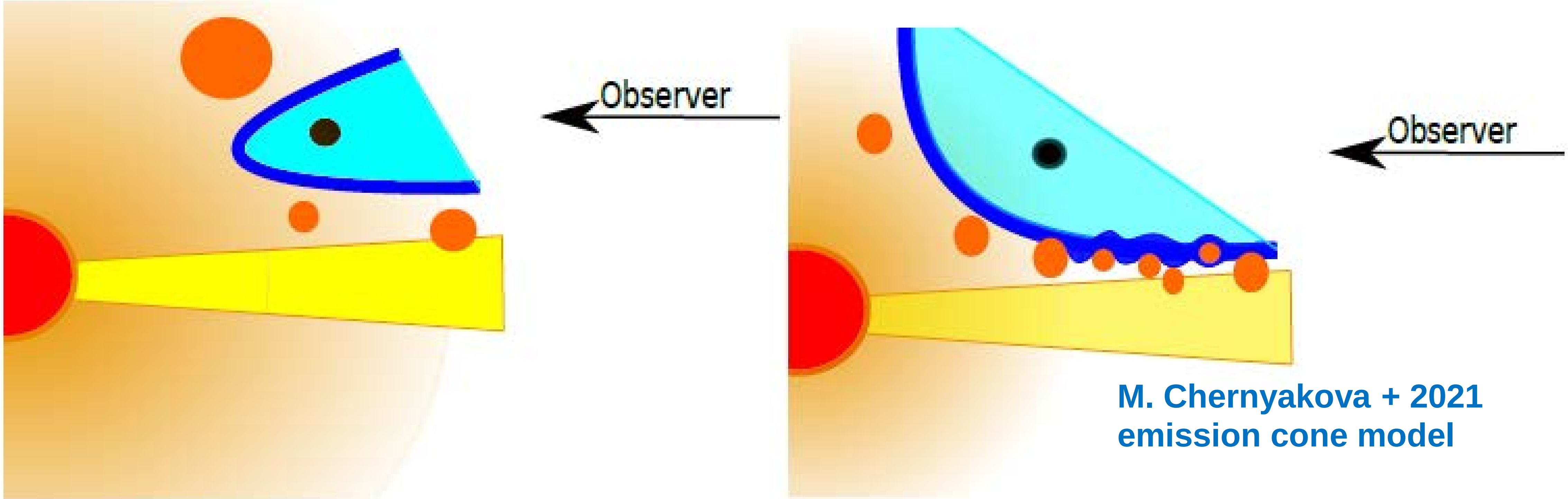
On the efficiency of PSR B1259–63 spin-down conversion in gamma-rays.

Observed fluxes (daily averaged) in 2014 periastron correspond to **isotropic** gamma-ray luminosity in Fermi band **~ 4.5 10^{35} erg s^{-1}** ,

Meanwhile, **spin-down power of the pulsar ~ 8.3 10^{35} erg s^{-1}**

Caliandro + Astrophys. J., v.811:68, 2015

Strong wind inhomogeneities (blobs) and PWN anisotropy can be important for understanding observed flux and variability of PSR B1259 across the spectrum



M. Chernyakova + 2021
emission cone model

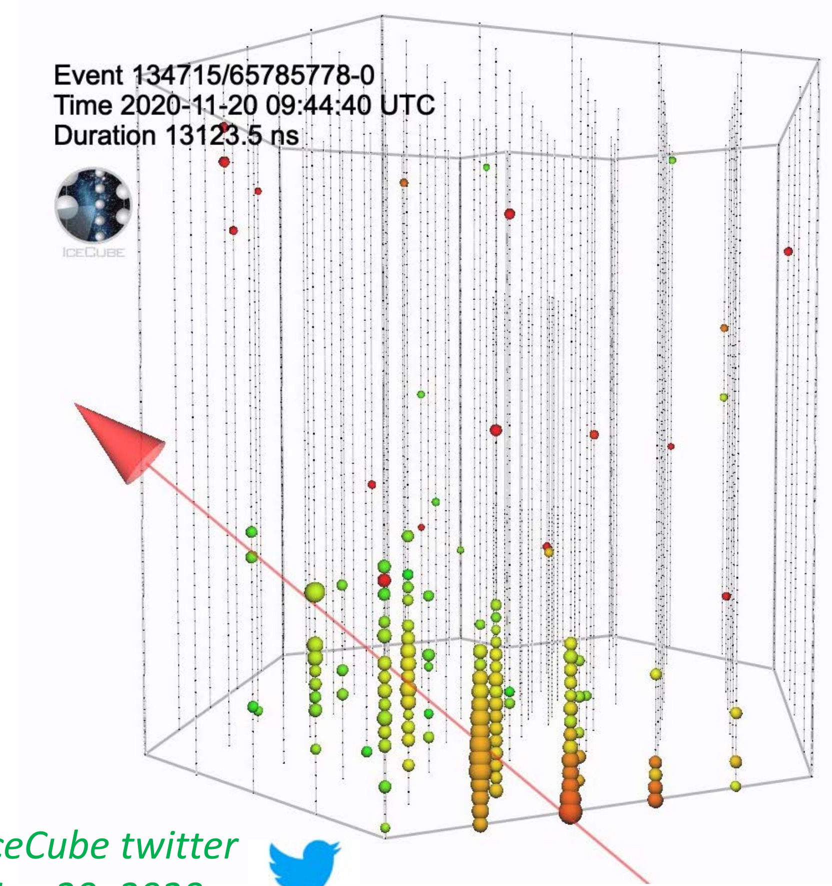
Multi-Wavelength Properties of the 2021 Periastron Passage of PSR B1259-63

Universe 2021, 7, 242.

Maria Chernyakova [1,2,*], Denys Malyshev [3], Brian van Soelen [4], Shane O'Sullivan [1], Charlotte Sobey [5], Sergey Tsygankov [6,7], Samuel Mc Keague [1], Jacob Green [1], Matthew Kirwan [1], Andrea Santangelo [3], Gerd Pühlhofer [3] and Itumeleng M. Monageng [8,9]

PeV gamma-ray & neutrino flares from binaries?

IceCube neutrino from Cygnus Cocoon



IceCube twitter
Nov 20, 2020

//

TITLE: GCN CIRCULAR
NUMBER: 28927
SUBJECT: IceCube-201120A: IceCube observation of a high-energy neutrino candidate event
DATE: 20/11/20 13:57:56 GMT
FROM: Cristina Lagunas Gualda at DESY <cristina.lagunas@desy.de>

The IceCube Collaboration (http://icecube.wisc.edu/) reports:

On 20/11/20 at 09:44:40.56 UT IceCube detected a track-like event with a moderate probability of being of astrophysical origin. The event was selected by the ICECUBE_Astrotrack_Bronze alert stream. The average astrophysical neutrino purity for Bronze alerts is 30%. This alert has an estimated false alarm rate of 0.295 events per year due to atmospheric backgrounds. The IceCube detector was in a normal operating state at the time of detection.

After the initial automated alert (https://gcn.gsfc.nasa.gov/notices_amon_g_b/134715_65785778.amon), more sophisticated reconstruction algorithms have been applied offline, with the direction refined to:

Date: 20/11/20
Time: 09:44:40.56 UT
RA: 307.53 (+ 5.34 - 5.59 deg 90% PSF containment) J2000
Dec: 40.77 (+ 4.97 - 2.80 deg 90% PSF containment) J2000

Due to the topology of this event, with a short distance traversed through the detector, the updated angular uncertainty is significantly larger than average error contours.

We encourage follow-up by ground and space-based instruments to help identify a possible astrophysical source for the candidate neutrino.

There are several Fermi-LAT 4FGL sources inside the 90% localization region. The closest source is 4FGL J2028.6+4110e (Cygnus Cocoon) located at RA 307.17 deg and Dec 41.17 deg (J2000), at a distance of 0.484 degrees from the best-fit location.

The IceCube Neutrino Observatory is a cubic-kilometer neutrino detector operating at the geographic South Pole, Antarctica. The IceCube realtime alert point of contact can be reached at roc@icecube.wisc.edu

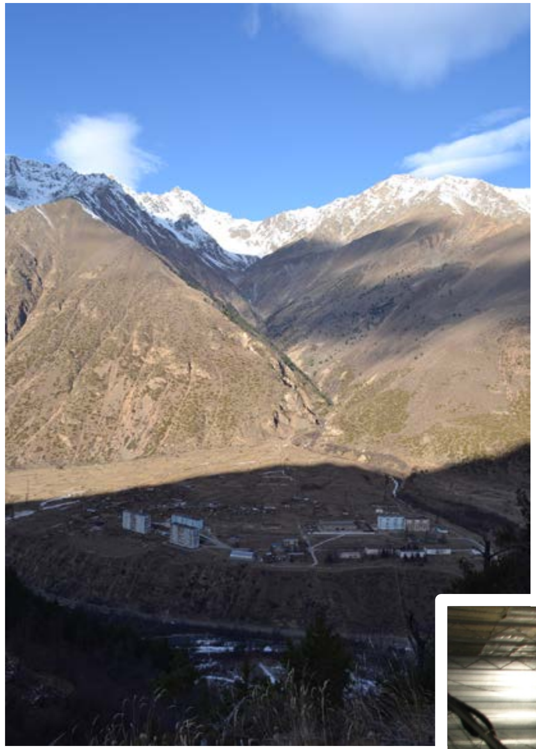
GCN #28927

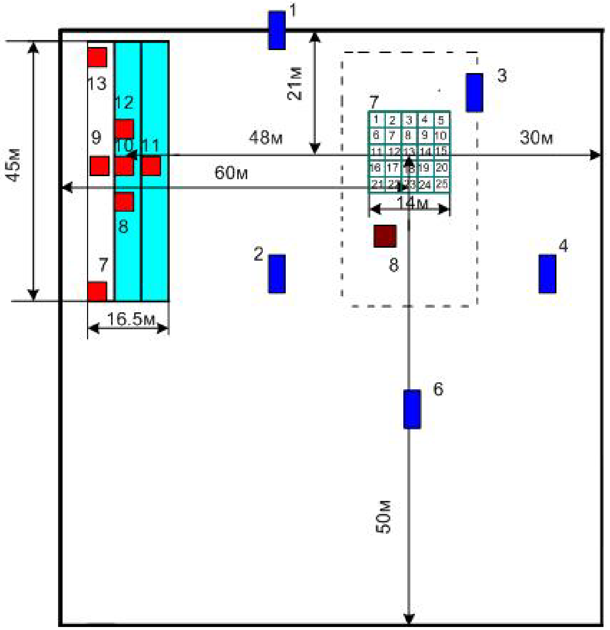
despite poor localization, this event is exceptional:
the first neutrino alert associated with a plausible Galactic source

Carpet-2: EAS+muon detector installation

@ Baksan Neutrino Observatory, INR RAS

- ✓ surface scintillator detector
- ✓ 175 m^2 muon detector (E_μ>1 GeV)
- ✓ ~10 live years of data 1999-2011
- ✓ 2018-2020: “photon-friendly” trigger





Standard alert procedure:
(test fixed circle (6.15°) centered at the best-fit neutrino direction)

- ±1000 sec (**just outside FOV this time**)
- ±12 h (**no excess**) ATel #14237
- ±15 days (**2 events**) ATel #14255

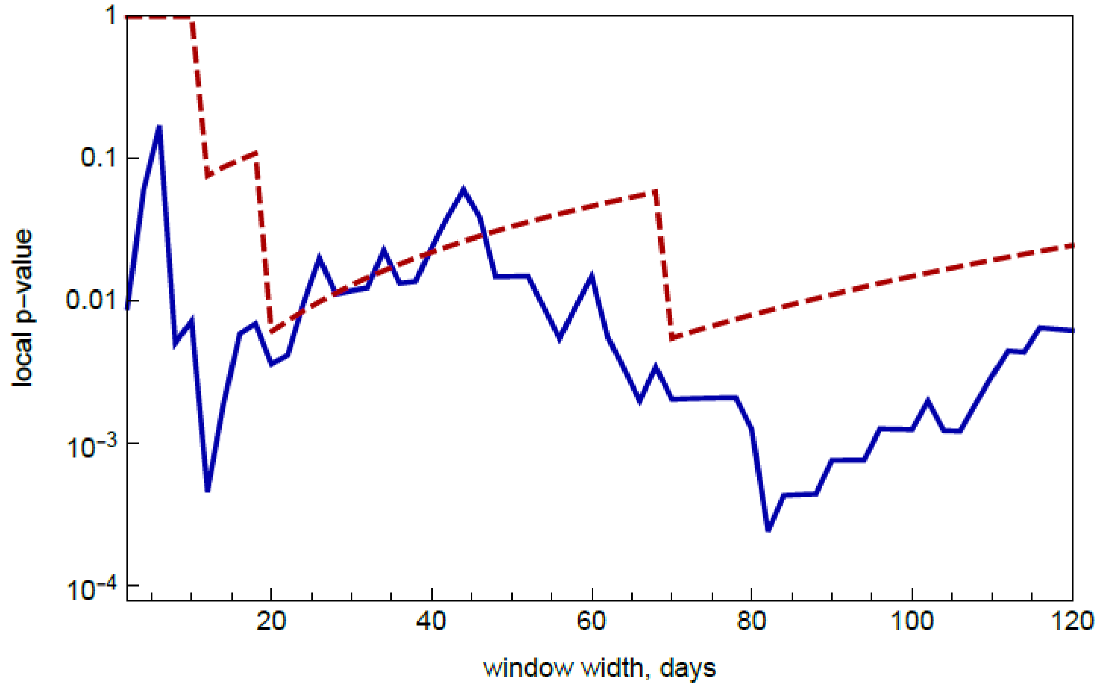
[Previous | Next | ADS]

Carpet-2 observation of two E>100 TeV photon-like events associated with the IceCube 201120A neutrino alert in the Cygnus Cocoon

ATel #14255; *D. Dzhappuev, A. Kudzhaev, V. Petkov, S. Troitsky on behalf of the Carpet-2 group (INR RAS)*
on ***9 Dec 2020; 12:27 UT***
Credential Certification: Sergey Troitsky (st@ms2.inr.ac.ru)

Related

14255	Carpet-2 observation of two E>100 TeV photon-like events associated with the IceCube 201120A neutrino alert in the Cygnus Cocoon
14237	Carpet-2 limits on E>100 TeV gamma rays associated with the IceCube 201120A neutrino alert in the Cygnus Cocoon



Cygnus Cocoon test:
4.7° centered at the Fermi LAT Cygnus Cocoon center:

- Total 346 events
    - Best window width is 82 days
- 5 are "photon median candidates“
    - Best window width is 70 days

V.Romanenko,
for the Carpet-3 Collaboration

The statistical significance of a flare

V.Romanenko,
for the Carpet-3 Collaboration

Pre-trial probability:

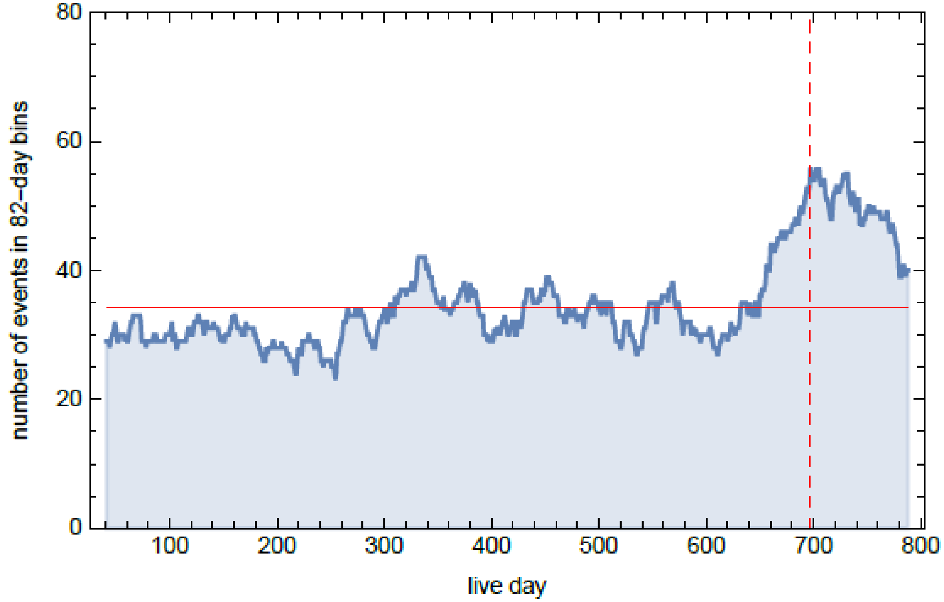
- Full set, 5.5×10-4 (**3.67 σ**)
- Photon candidate, 5.8×10-3 (**2.78 σ**)

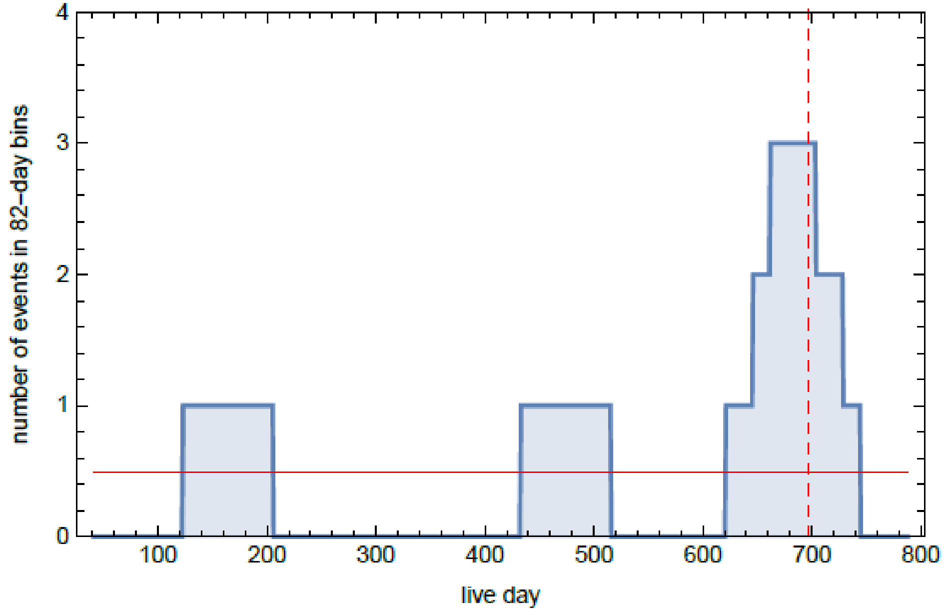
Post-trial probability:

- Full set, 3.7×10-3 (**3.17 σ**)
- Photon candidate, 9.8×10-3 (**2.55 σ**)

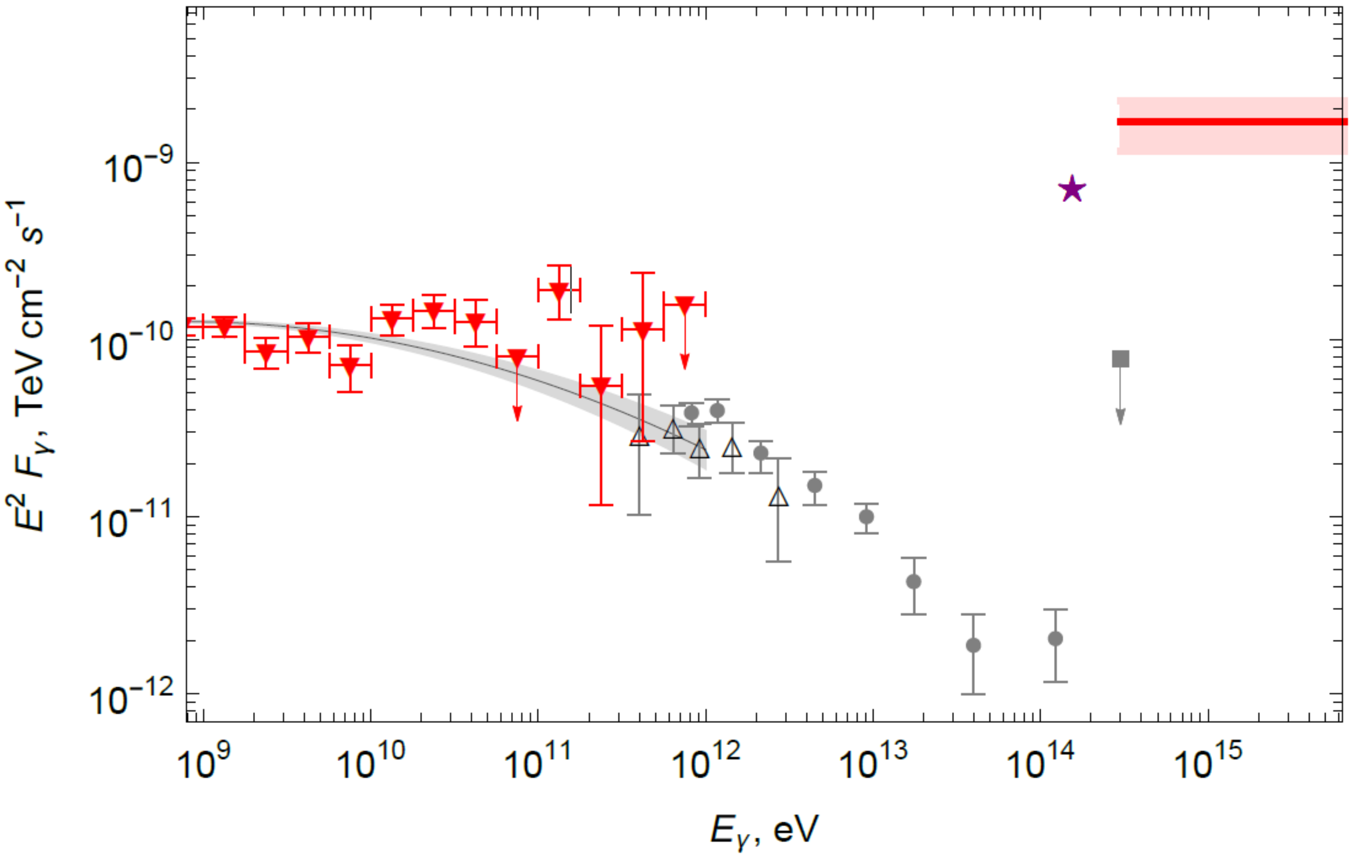
the line indicates the neutrino arrival time;

the line indicates the expectation for the constant arrival rate.





Spectral energy distribution of Cygnus Cocoon above 1 GeV.



Spectral energy distribution averaged over the same d = 82-day period around the neutrino arrival using publicly available data of the Fermi Large Area Telescope (Fermi-LAT)

Time-averaged

4FGL flux model (Abdollahi et al. 2020)

ARGO (Bartoli et al. 2014)

HAWC (Abeysekara et al. 2021)

Carpet-2, this work

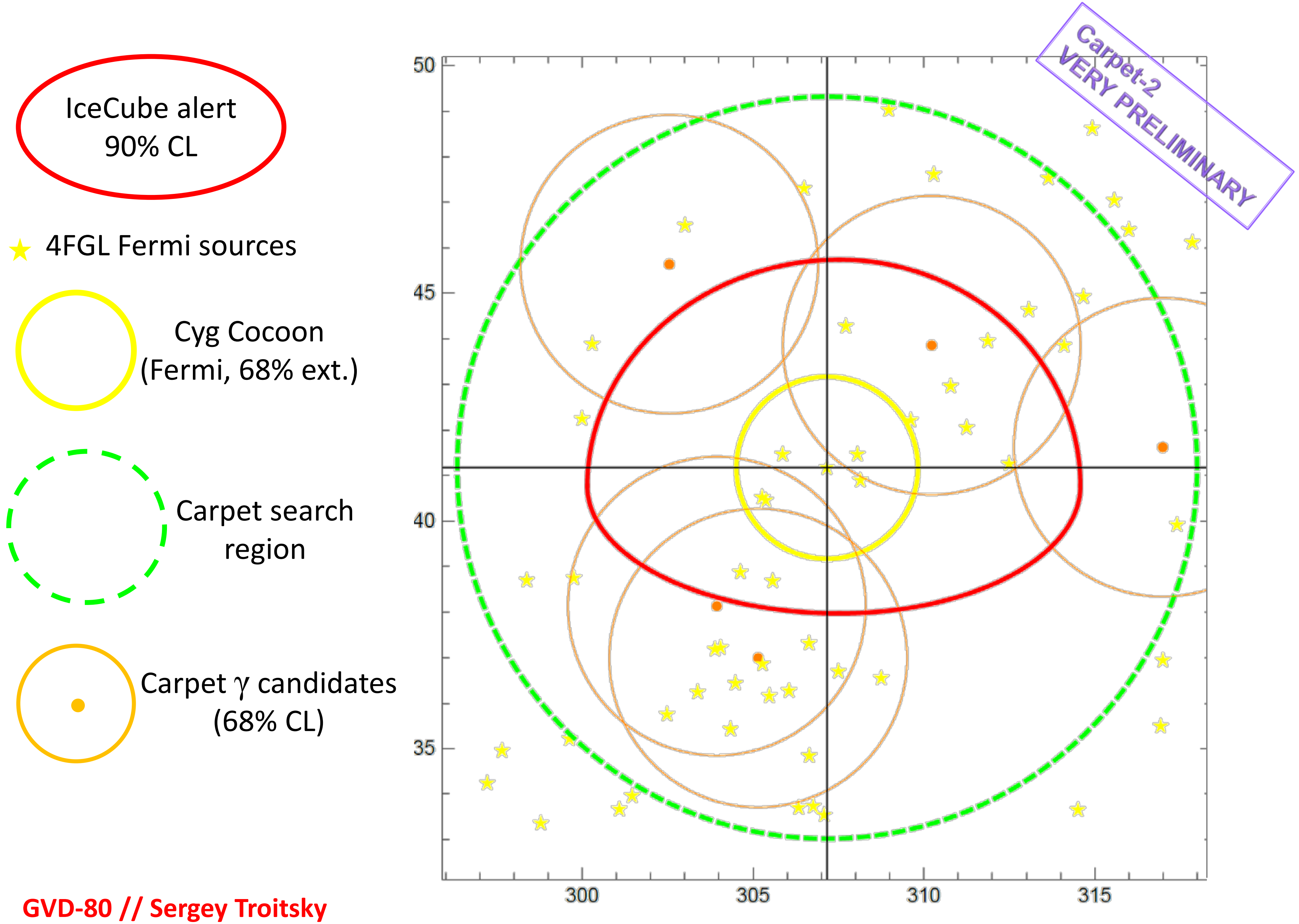
Flare

Fermi LAT

Carpet-2, this work

Estimate of the IceCube neutrino fluence

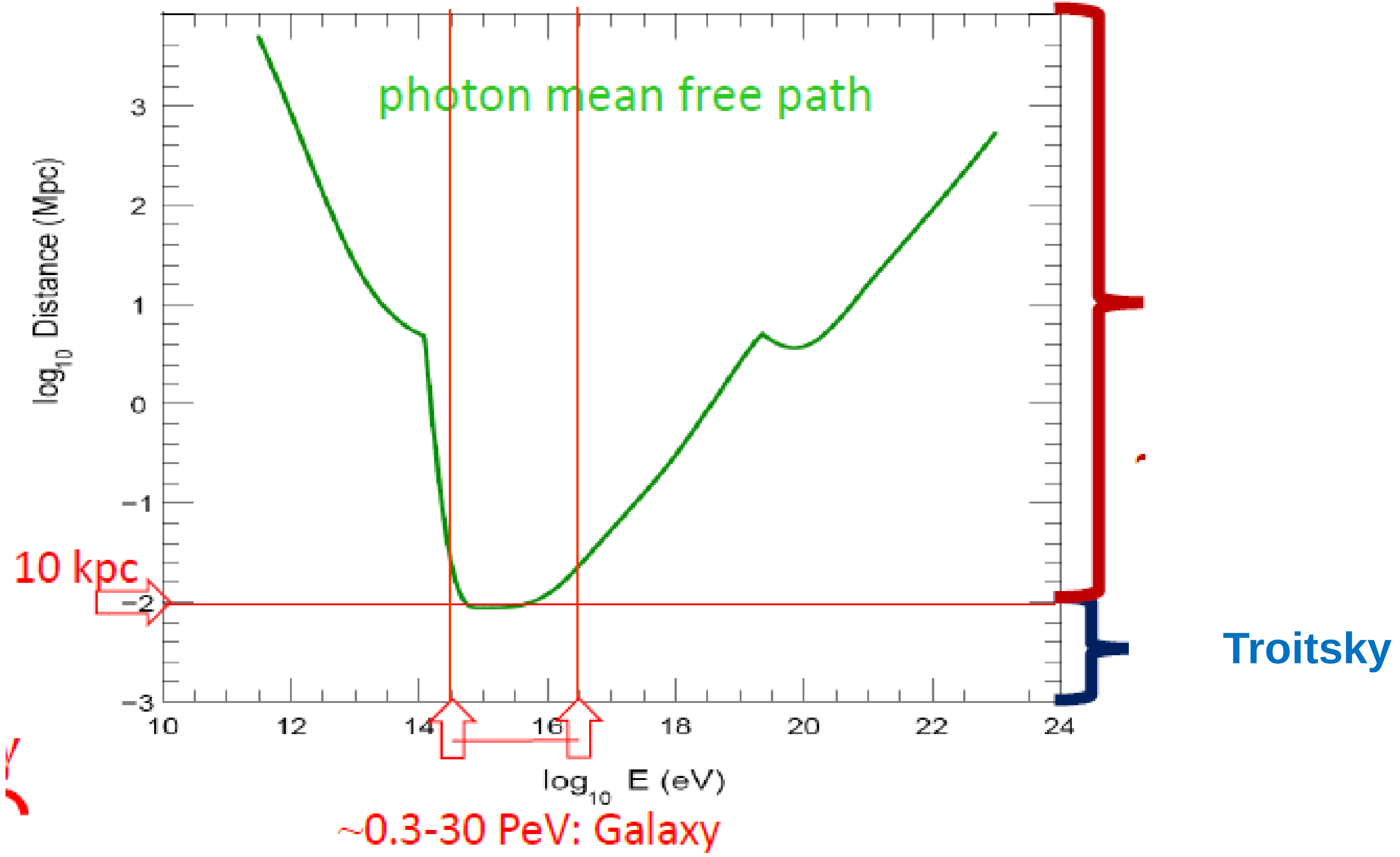
V.Romanenko,
for the Carpet-3 Collaboration

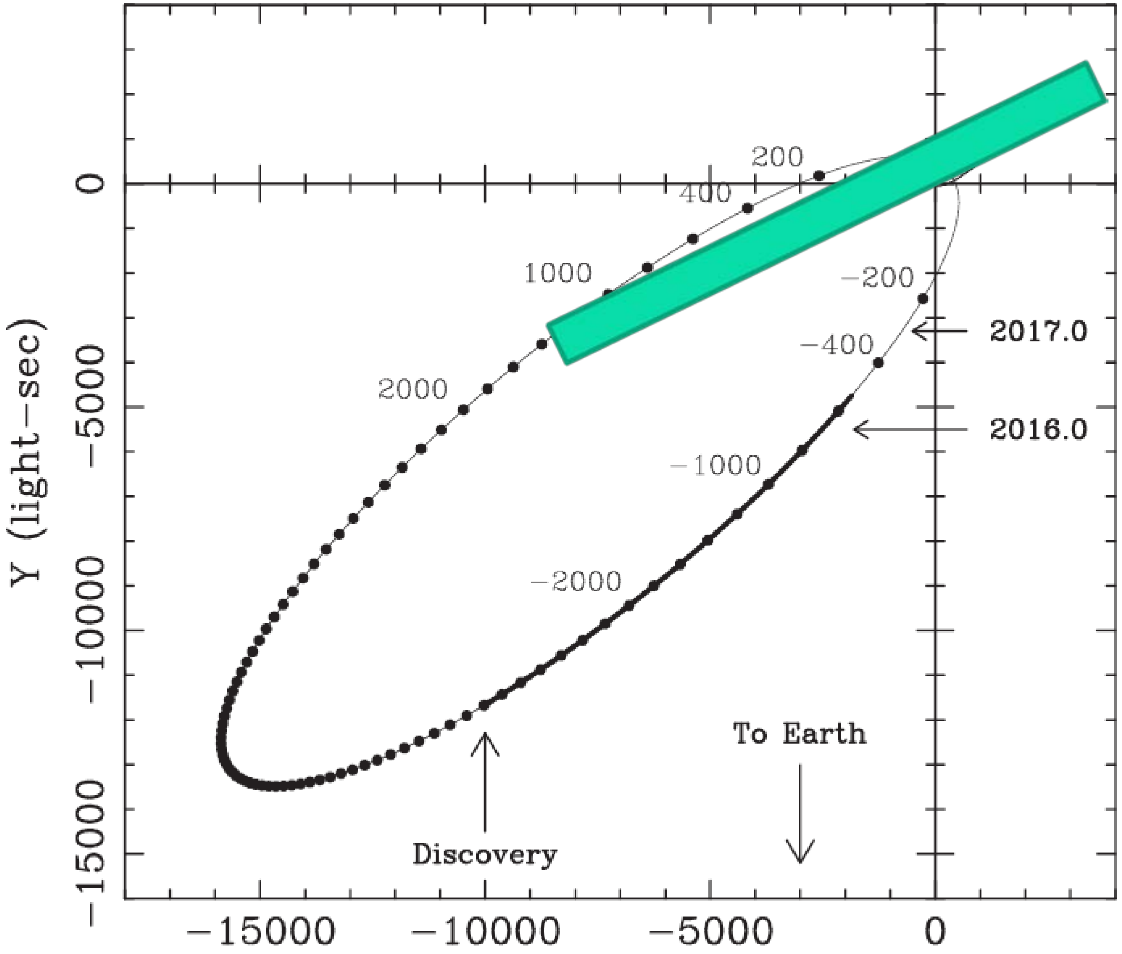

IceCube alert
90% CL
4FGL Fermi sources
Cyg Cocoon
(Fermi, 68% ext.)
Carpet search
region
Carpet γ candidates
(68% CL)
Carpet-2
VERY PRELIMINARY
50
45
40
35
300
305
310
315

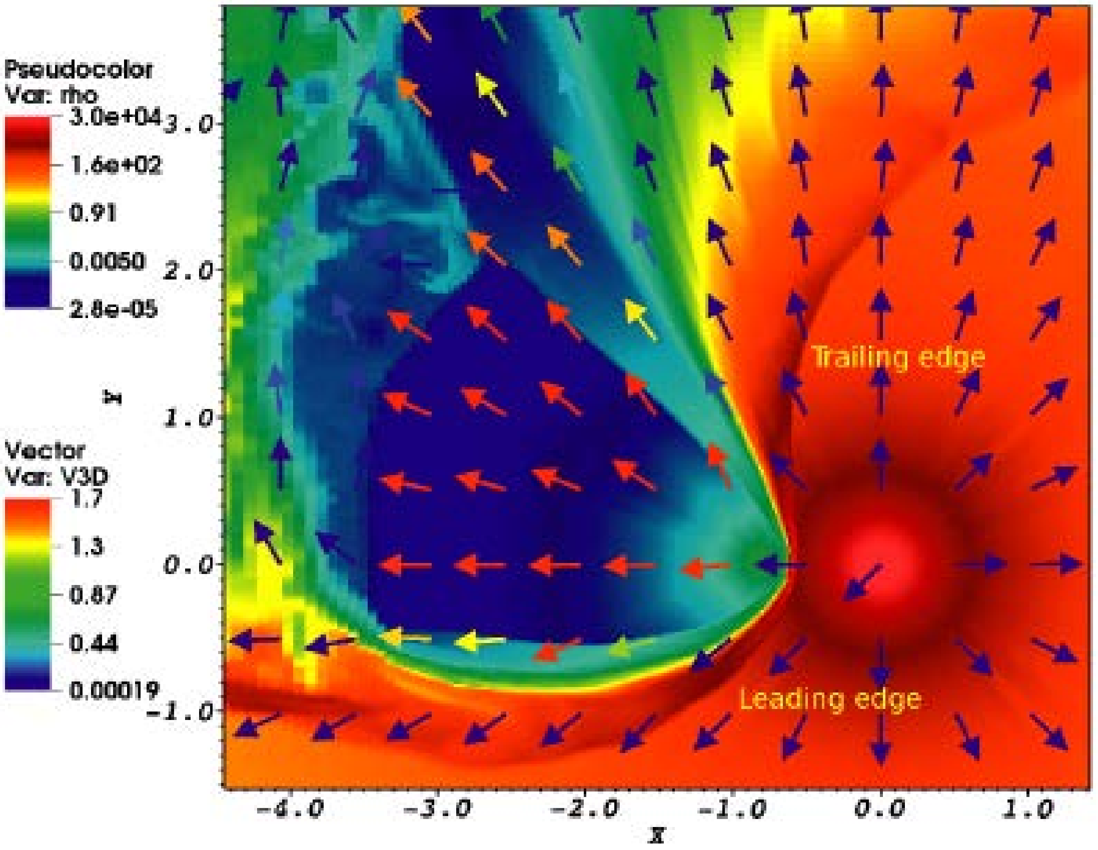
Galactic binary PSR J2032+4127
At distance ~1.4 kpc, companion – Be star MT91 213 (B0Vp)
P ~50 yr (Ho et al. 2017).
spin-down power ~ 3 10^{35} erg s^{-1} (Camilo et al. 2009).
Multichannel observations of PSR J2032+4127
In periastron 2017 Ng + (ApJ v.880, 147, 2019)
Chernyakova et al. (MNRAS v.495, 365, 2020).

If PSR J2032+4127 binary produces
PeV photons (Carpet-2) and neutrino (IceCube) than very efficient mechanism should convert system power to PeV energies (i.e., produce very hard proton spectra) to explain simultaneously Data of VERITAS MAGIC and Carpet 2.

Gamma-ray flare at energies above 300 TeV, duration about 2 months From the Cygnus Cocoon region was detected in 2020 by Carpet-2 (Dzhappuev + Ap.J Lett 916, L22, 2921). It is associated with contemporaneous 150 TeV IceCube (IceCube Collaboration 2020) neutrino. Isotropic gamma-ray luminosity ~ 2 10^{35} erg s^{-1} (at 1.5 kpcs).

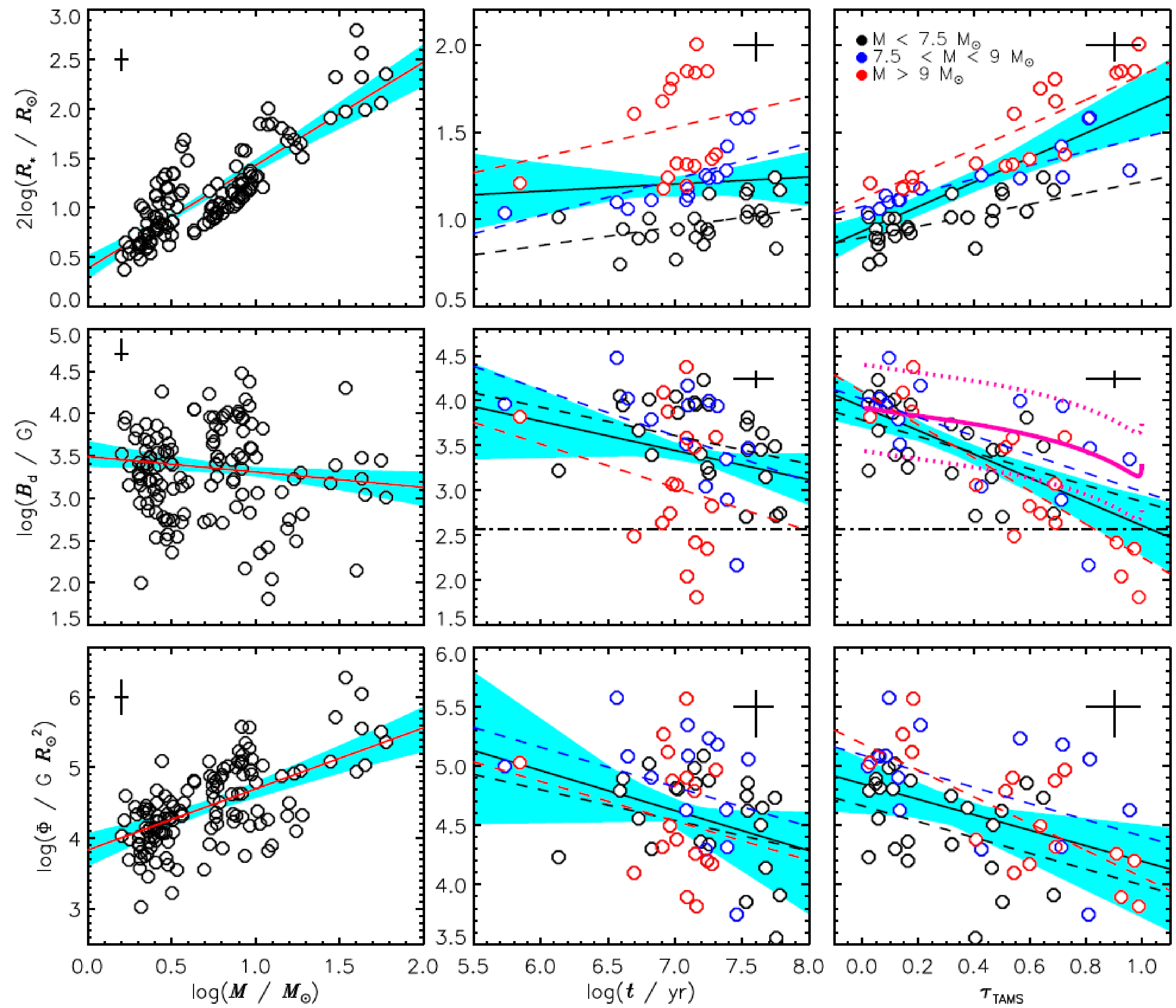






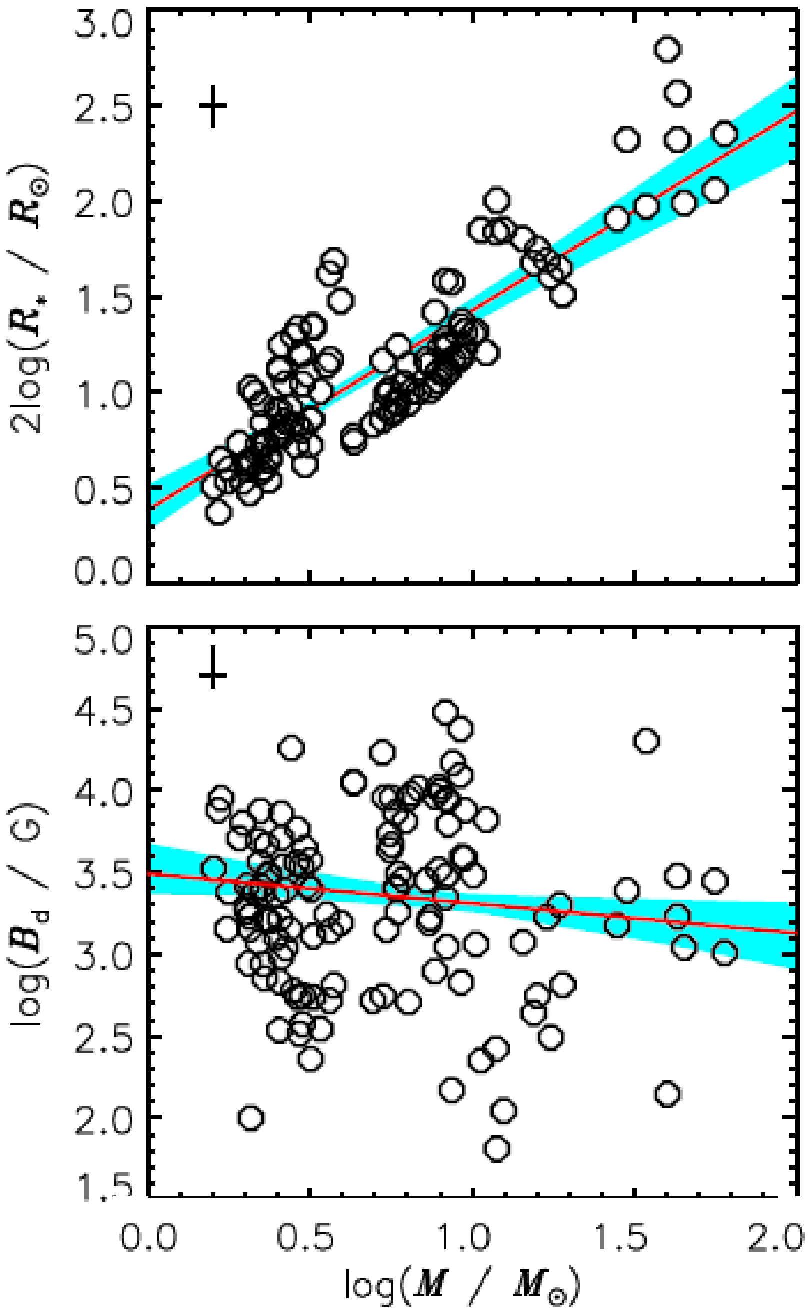
Bosch-Ramon Barkov Perucho A&A 577, A89 (2015)

Ho + MNRAS 464, 1211, 2017

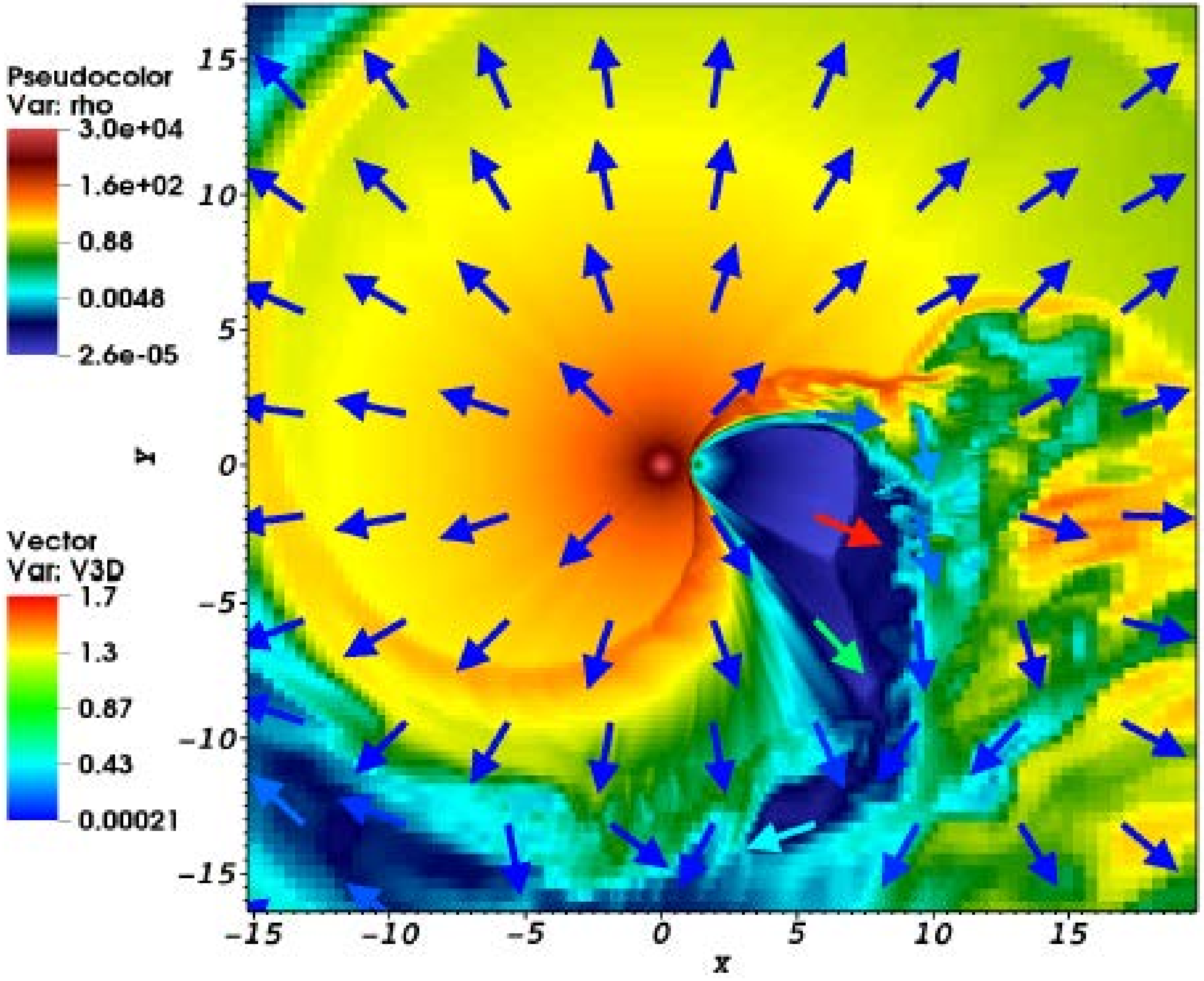


The magnetic early B-type stars - III. A main-sequence magnetic, rotational, and magnetospheric biography

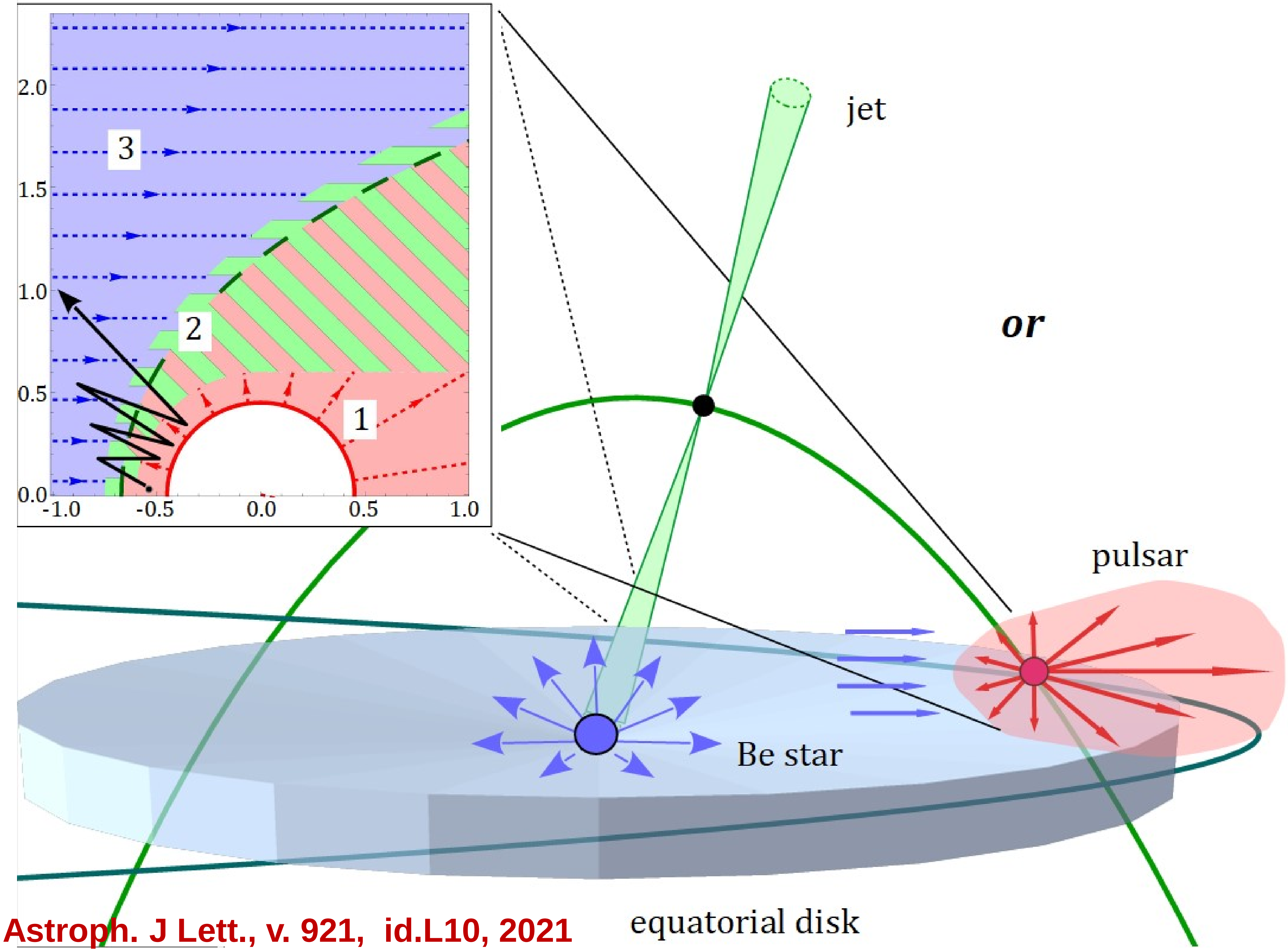
Shultz + MNRAS v.490, 247, 2019



Shultz + MNRAS v.490, 247, 2019



Bosch-Ramon Barkov Perucho A&A 577, A89 (2015)



Bykov + Astroph. J Lett., v. 921, id.L10, 2021

Colliding wind flows acceleration– the most efficient Fermi I process (gives VERY hard spectra)

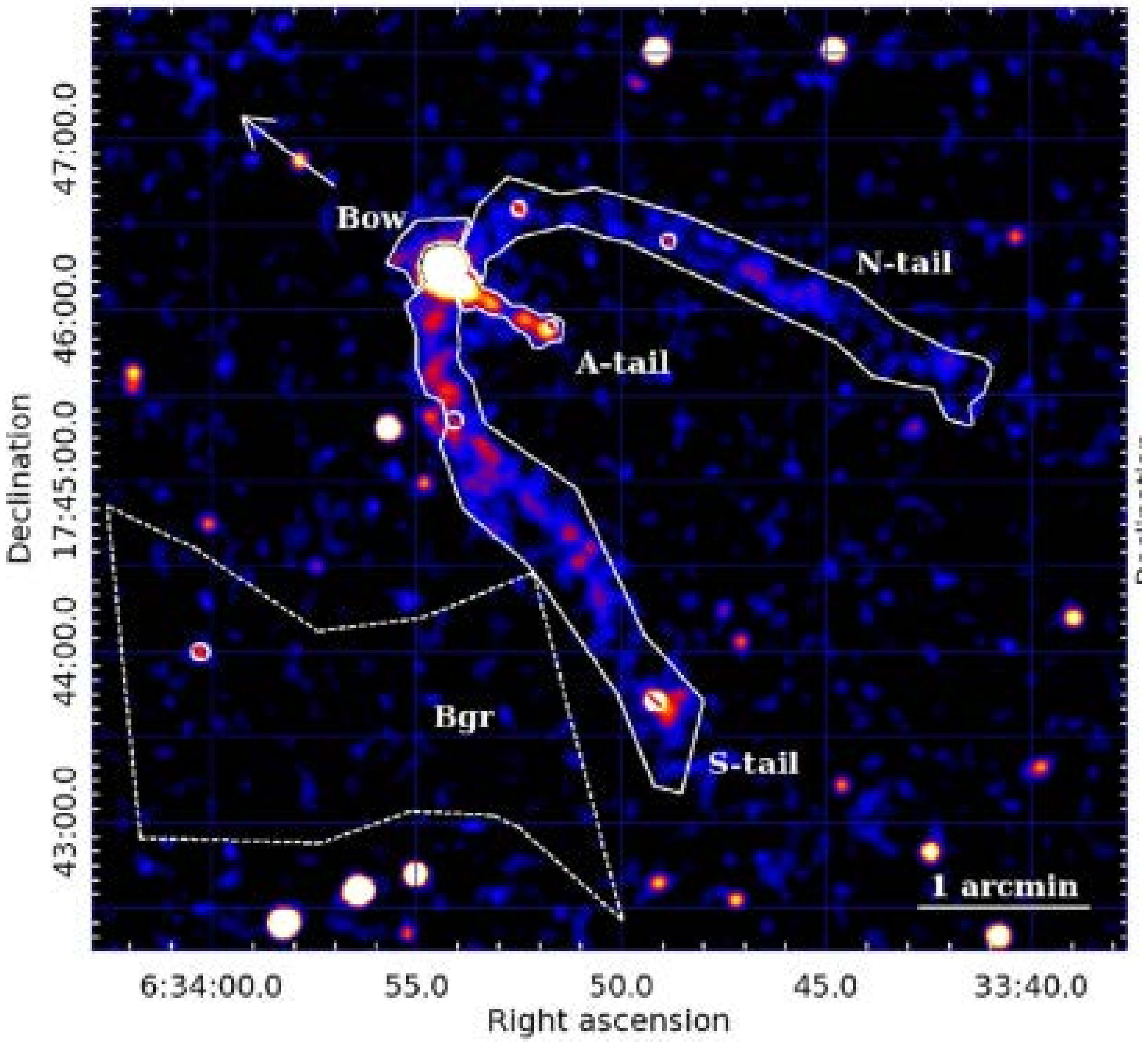
The maximum energies of protons accelerated by outflows with frozen-in magnetic fields of a kinetic/magnetic luminosity $\mathcal{L}_K$ can be estimated from the equation:

$$E_{\max} \approx \frac{f(\beta_{\mathrm{f}})}{\Gamma_{\mathrm{f}}\Omega}\left(\frac{\mathcal{L}_K}{5\times10^{34}\ \mathrm{erg\ s^{-1}}}\right)^{1/2}\ \mathrm{PeV}, \quad (1)$$

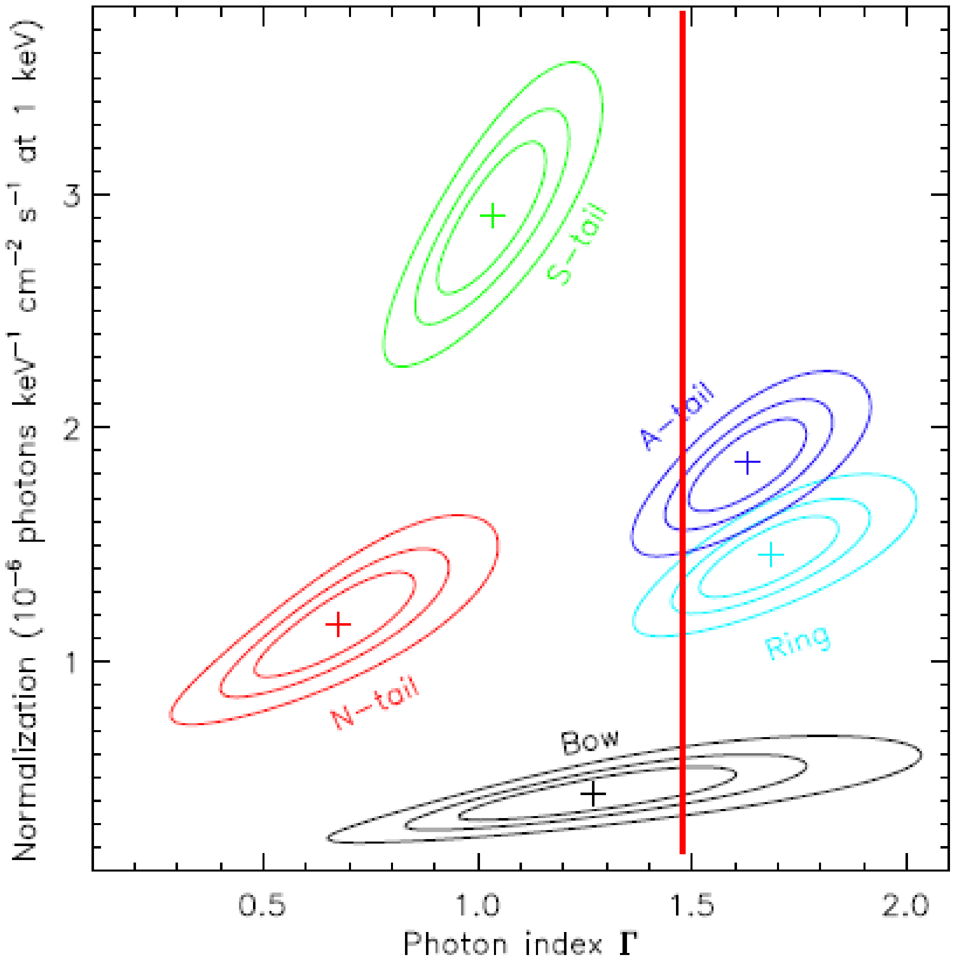
Hard synchrotron indexes of Geminga PWN: Chandra 0.5- 8 keV

Photon indexes Γ ~ 1

The Astrophysical Journal, 835:66 (19pp), 2017 January 20

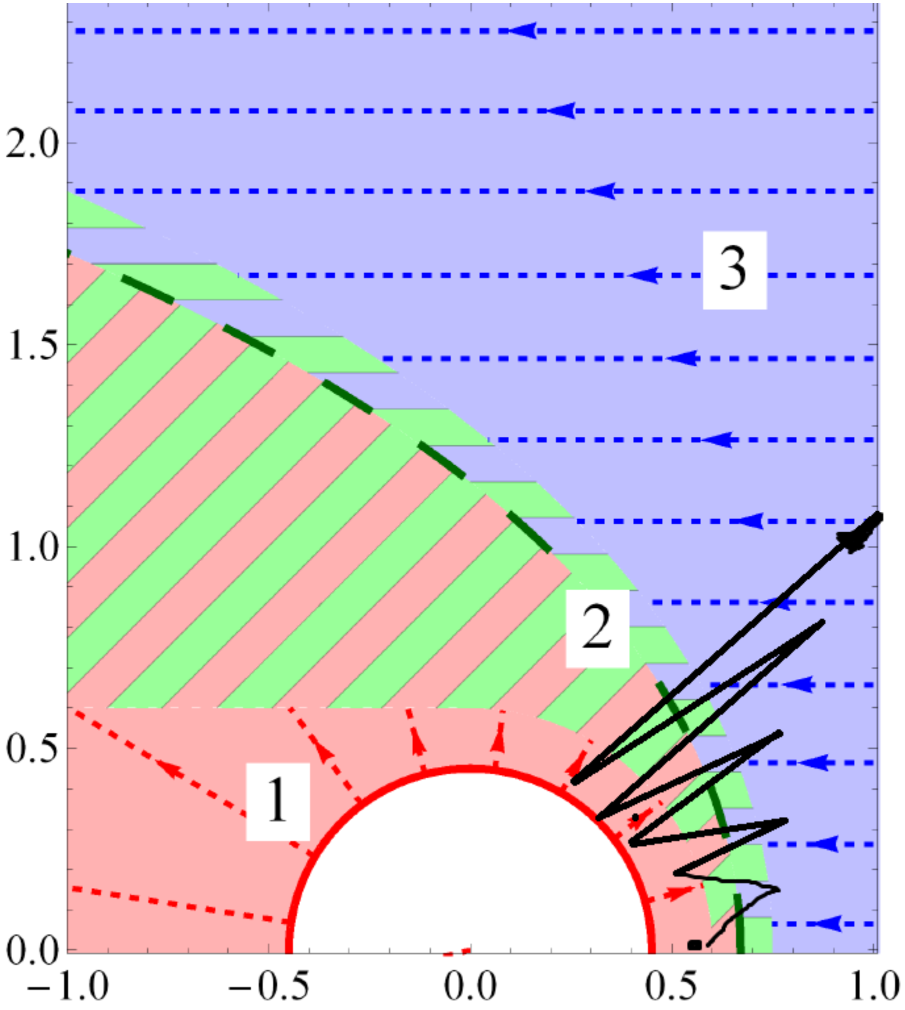


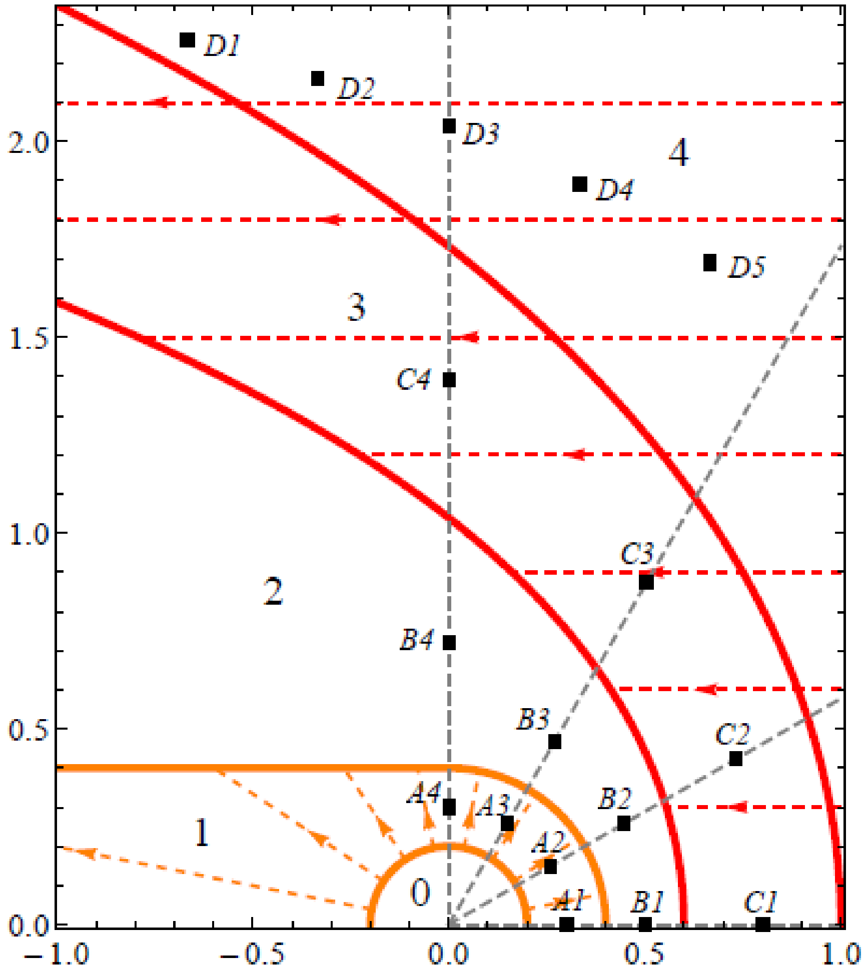
The Astrophysical Journal, 835:66 (19pp), 2017 January 20



Posselt + Ap J, v.835:66, 2017

Particle spectra: Monte-Carlo in PWN geometry



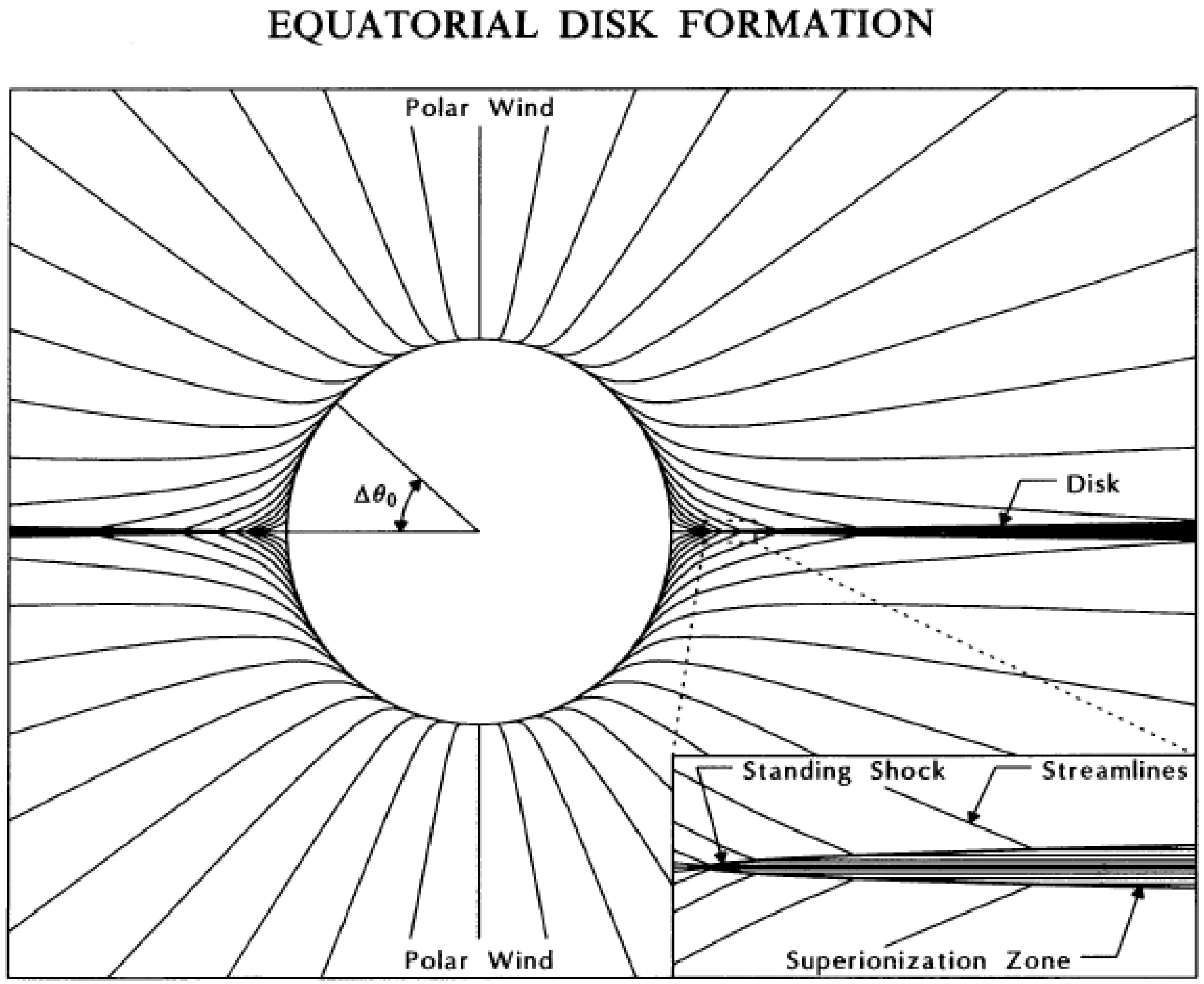


The numbers 1- 3 (for left panel) label the regions with different transport regimes: 1 is the cold PW, 2 is the shocked wind, 3 is the B-star wind.

AB+ Astroph. J Lett., v. 921, id.L10, 2021

AB+ Space Sci. Rev v.207 p.235, 2017

Be star equatorial decretion disk

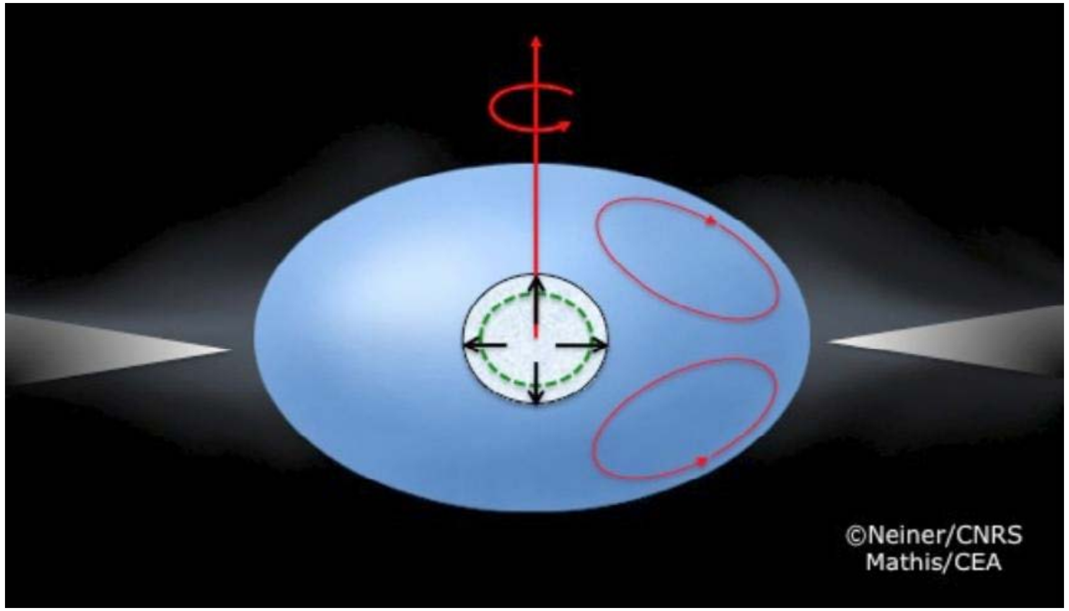


$$\rho(r,z) = \rho_0 \left(\frac{r}{R_e}\right)^{-n} \exp\left(-\frac{z^2}{2H^2}\right),$$

$$H(r) = H_0 \left(\frac{r}{R_e}\right)^{3/2},$$

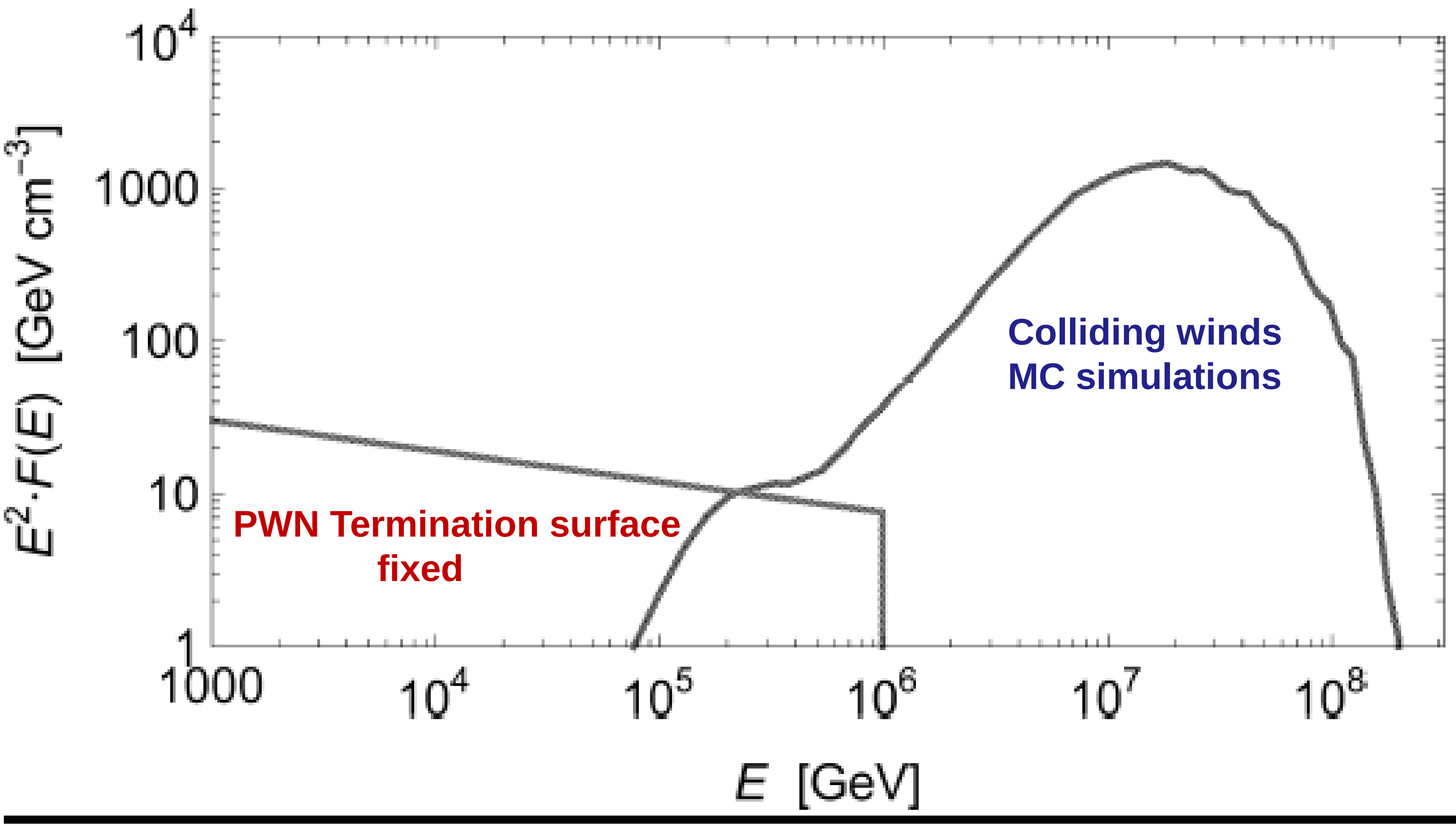
where $H_0 = c_s v_{\rm orb}^{-1} R_e$

e.g. Klement + A&A 601, A74, 2017

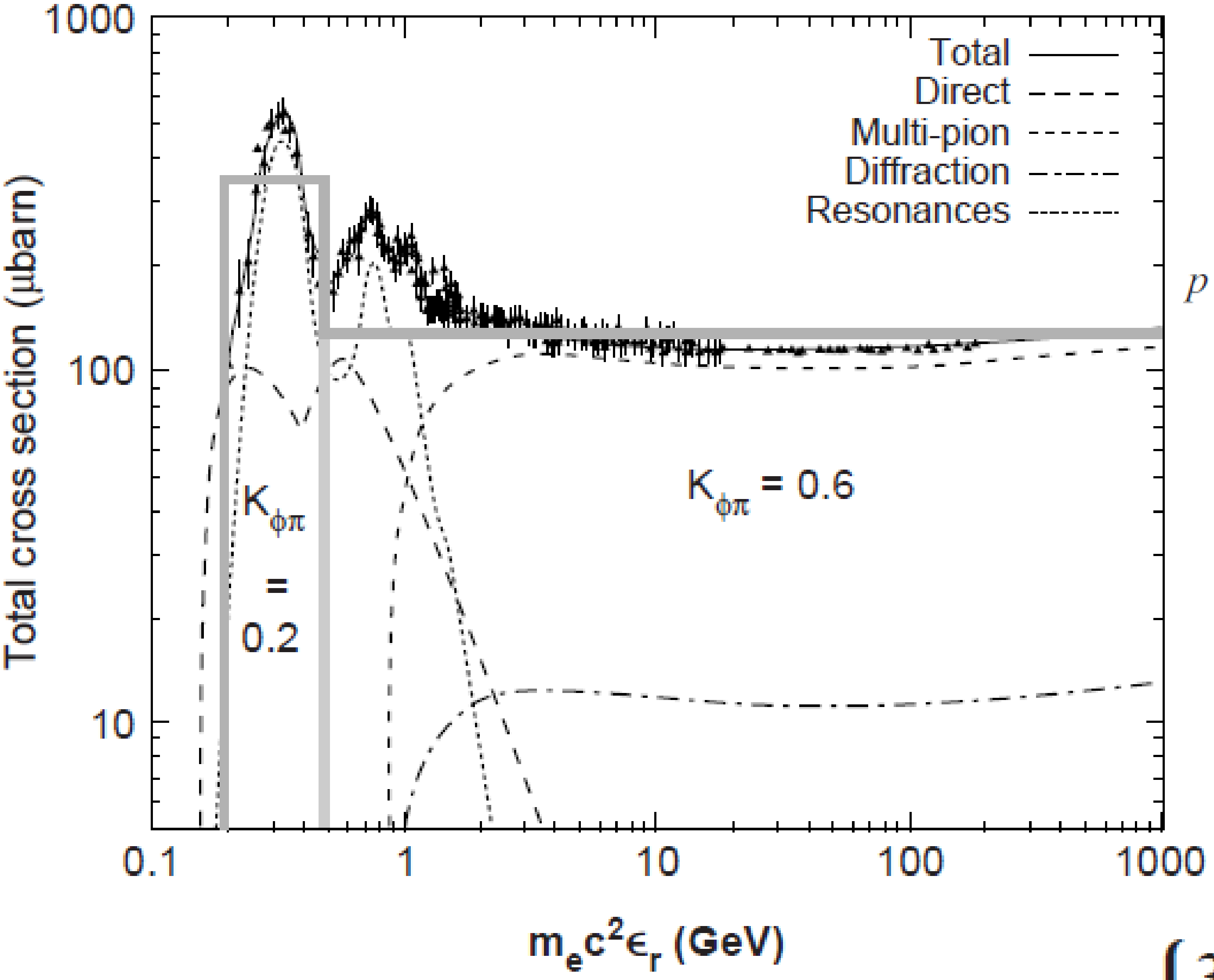


Bjorkman & Casinelli 93; Klement + 2017; Bogovalov + 2021

Proton spectra in the colliding MHD flows PSR 2032 – Be star winds



AB+ Astroph. J Lett., v. 921, id.L10, 2021



from Dermer & Menon 2009

Photo-hadron

Single pion resonance: inelasticity K=0.2

$$p+\gamma \to \Delta^+ \to \begin{cases} p+\pi^0 \to p+2\gamma, \\ n+\pi^+ \to n+e+3\nu \to p+2e+4\nu, \end{cases}$$

Multi pion channel: Inelasticity K=0.6

In this channel 60% of proton energy is divided equally between

$$\pi^0, \pi^+, \text{ and } \pi^-$$

$$\sigma_{\phi\pi}(\epsilon_r) = \begin{cases} 340\ \mu\text{b}, & \epsilon_{\text{thr}} = 390 \le \epsilon_r \le 980, \\ 120\ \mu\text{b}, & \epsilon_r \le 980, \end{cases}$$

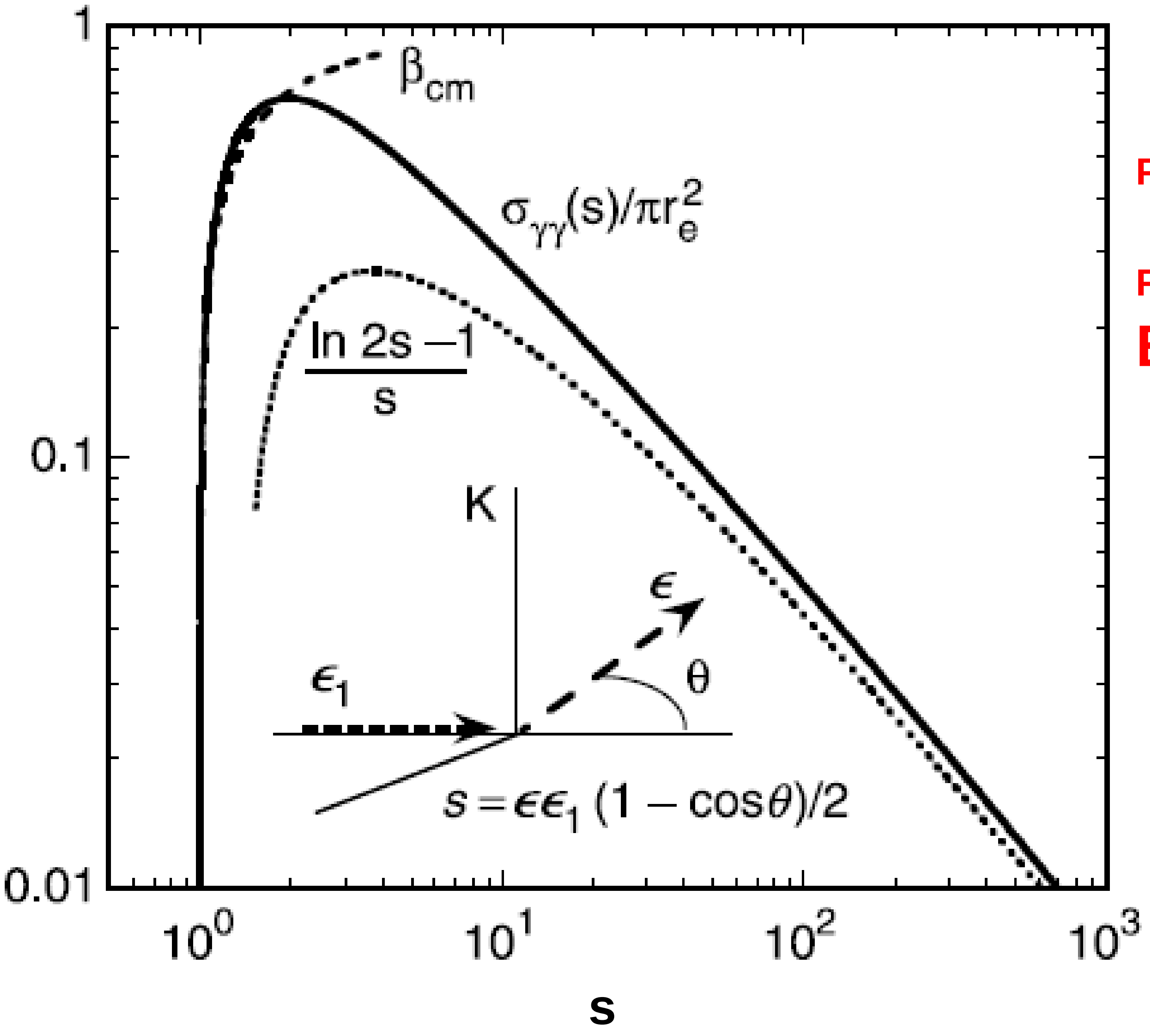
A convenient reference frame to discuss photonuclear interactions is the nuclear rest frame, in which the photon energy $\epsilon_r = E\,\varepsilon\,(1 - \cos\theta)/m_j$ depends on the energy of the relativistic nucleus E and the photon energy ε in the observer's or (cosmological) comoving frame. The pitch angle θ is the angle between incident photon and nucleus such that $\cos\theta = -1$ represents head-on collisions, and ϵ_r is related to the center-of-mass energy by $s = m_j^2 + 2m_j\epsilon_r$ where m_j is the mass of the nucleus. The photonuclear interaction rate and the interaction cross section σ are related as

$$\Gamma(E) = \int \mathrm{d}\varepsilon \int_{-1}^{+1} \frac{\mathrm{d}\cos\theta}{2} (1 - \cos\theta) n_\gamma(\varepsilon, \cos\theta)\, \sigma(\epsilon_r), \qquad (2.1)$$

where n_γ is the photon number density and the rate is expressed in units of inverse length. Depending on the type of source or environment, the photon spectrum can extend from sub-eV up to TeV energies, and its shape can contain peaked (thermal) or power-law (non-thermal) components.

s

from Morejon + 2019



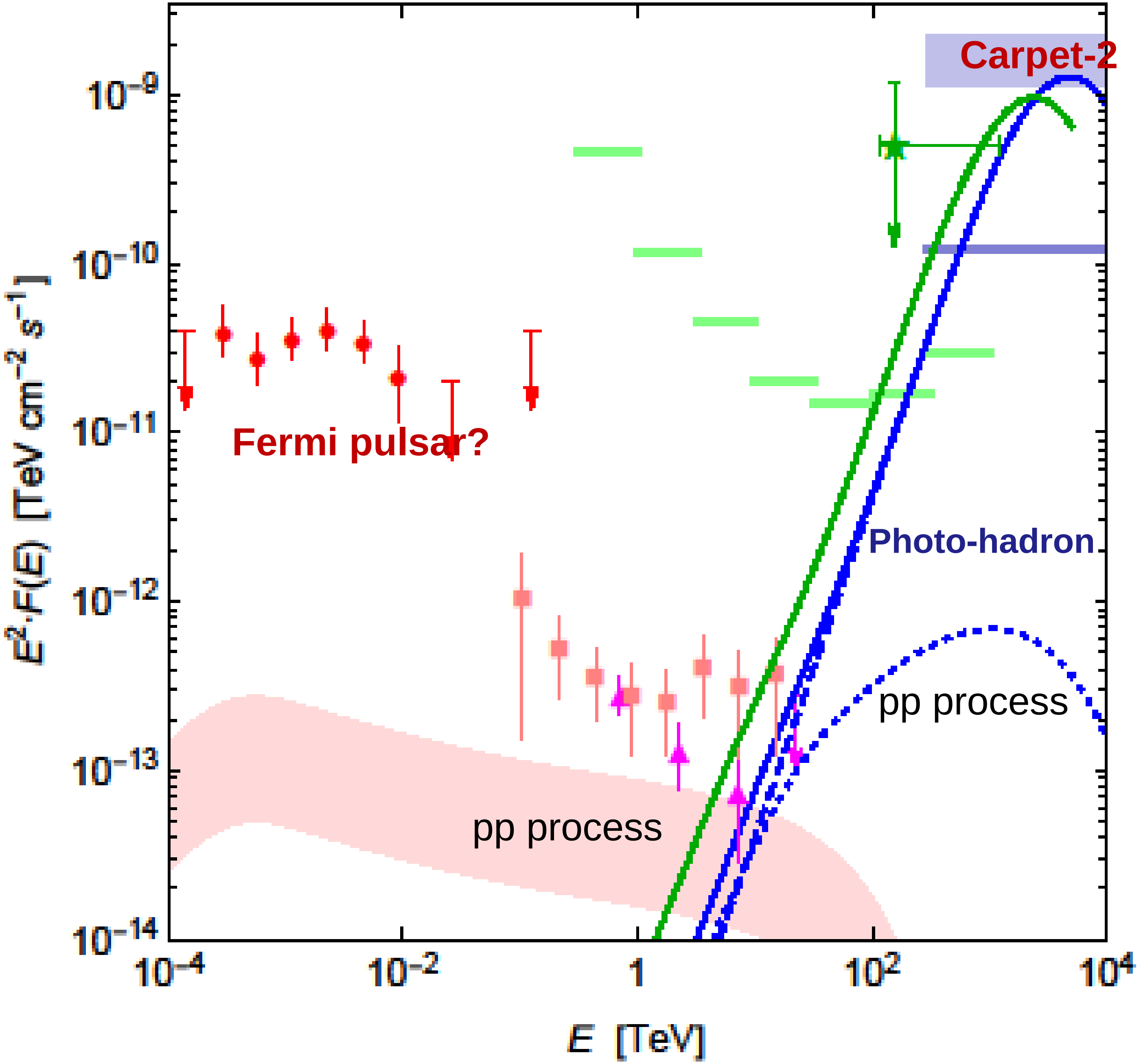
Pair production at photons collision

For estimates – cross-section maximum at:

$E_\gamma \sim 10^{11}$ (E_{opt} /5 эВ)$^{-1}$

Above 300 TeV
Pair production cross-section is less, than photo-hadron quant production

from Dermer & Menon 2009



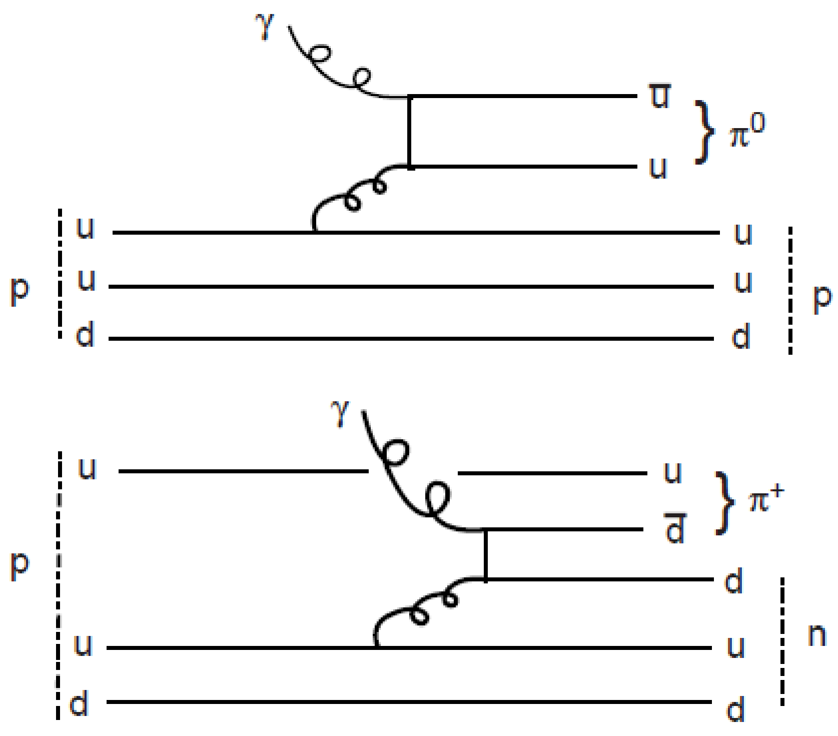


Photo-hadron cross-sections are from Kelner Aharonian PhRvD, 78, 034013

Bykov+ Astroph. J Lett., v. 921, id.L10, 2021

Thank you for your attention!

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