Inverse Compton pulse profiles inferred from global PIC simulations

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Collaborators :

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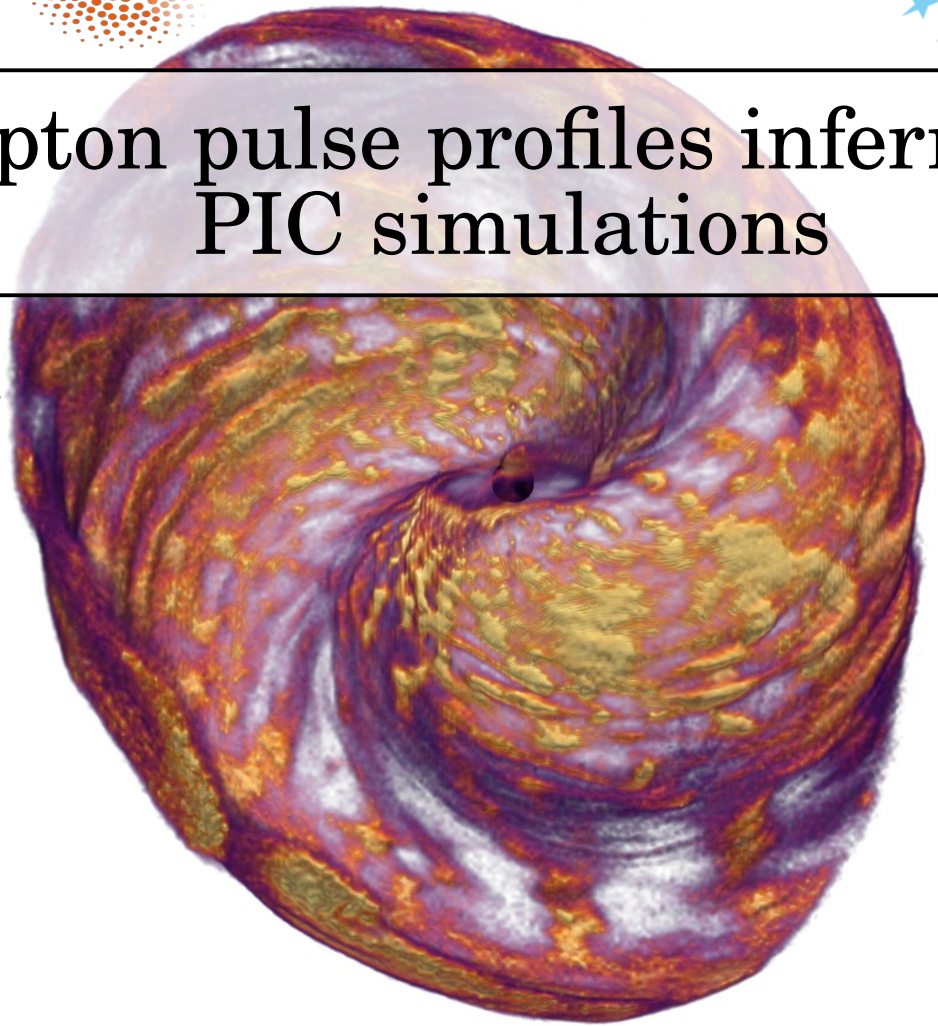
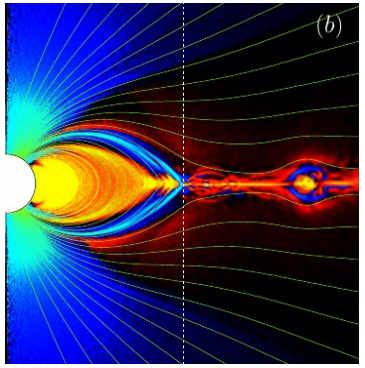
A. Soudais (Grenoble)



Cerutti et al., submitted
Soudais et al., A&A, 2024

3rd HONEST workshop, November 28, 2024

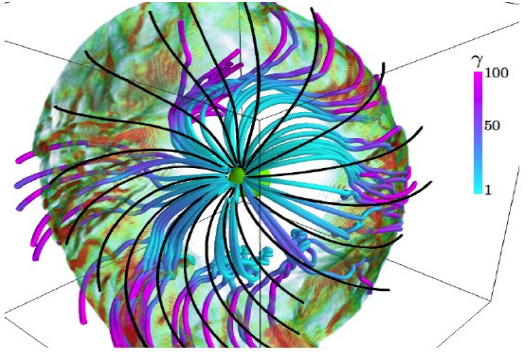
Global PIC model (2014-): A mini-revolution in the field



Columbia

Andrei Beloborodov
Alex Chen
Rui Hu

Code : Aperture



Princeton/UMD

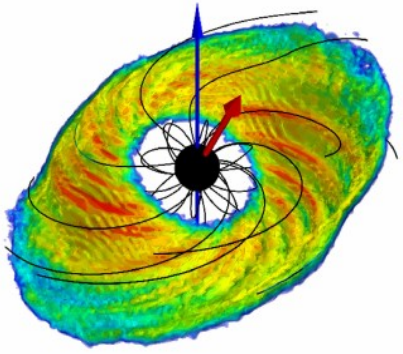
Sasha Philippov
Anatoly Spitkovsky
Hayk Hakobyan

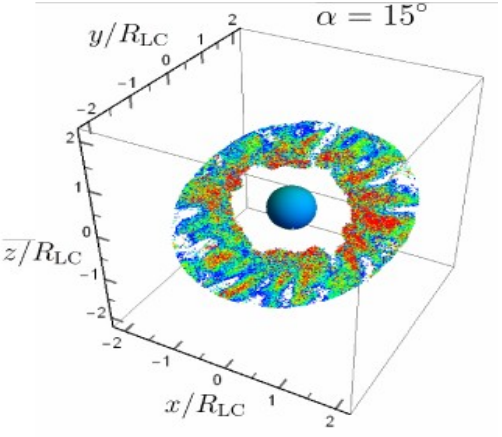
Code : Tristan

Grenoble

Benoît Cerutti
Guillaume Dubus
Enzo Figueiredo
Claire Guépin
Valentina Richard-Romei
Adrien Soudais

Code : Zeltron





NASA/UMD

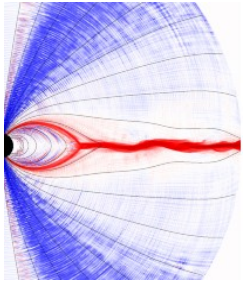
Brambilla
Alice Harding
Konstantinos Kalapotharakos
Andrei Timokhin

Code : C-3PA

Lisbon

Fabio Cruz
Thomas Grismayer
Luis Silva
Rui Torres

Code : Osiris

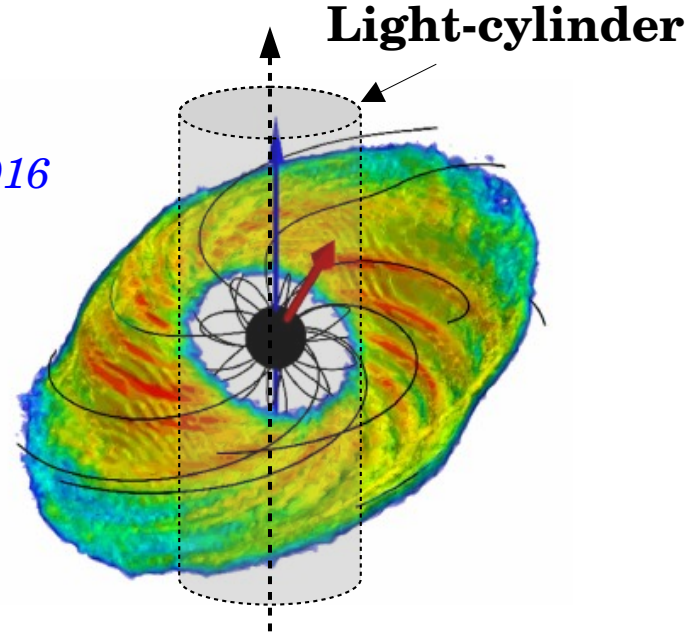


<u>Consensus :</u> γ-rays originate from the wind current sheet

Global PIC model: reconnection-powered pulses

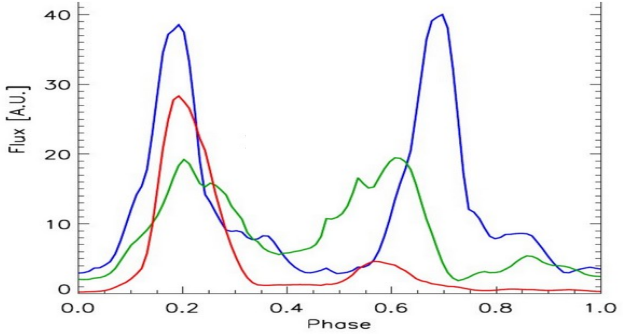
2016

Cerutti et al. 2016



Synchro-curvature

Synthetic pulse profiles



Global PIC model: reconnection-powered pulses

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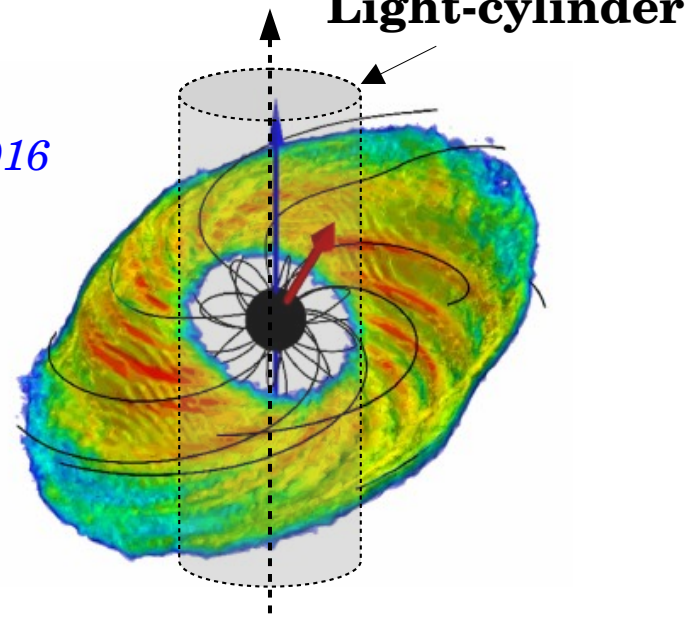
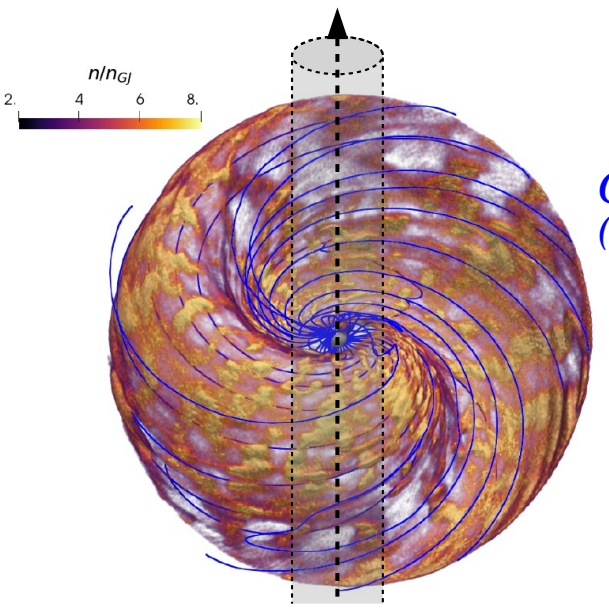
Cerutti et al. 2016



This work

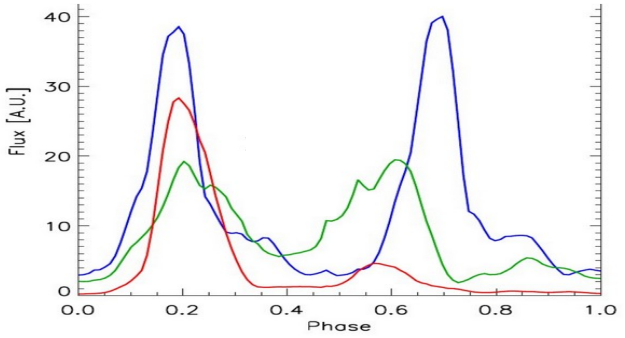
2024



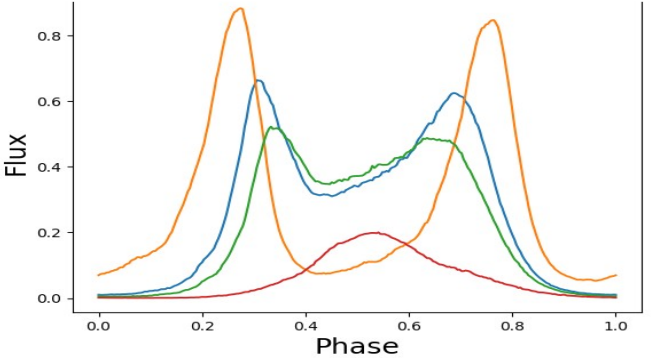
Cerutti et al. (submitted)

Synchro-curvature

Synthetic pulse profiles



Synchro-curvature + Inverse Compton

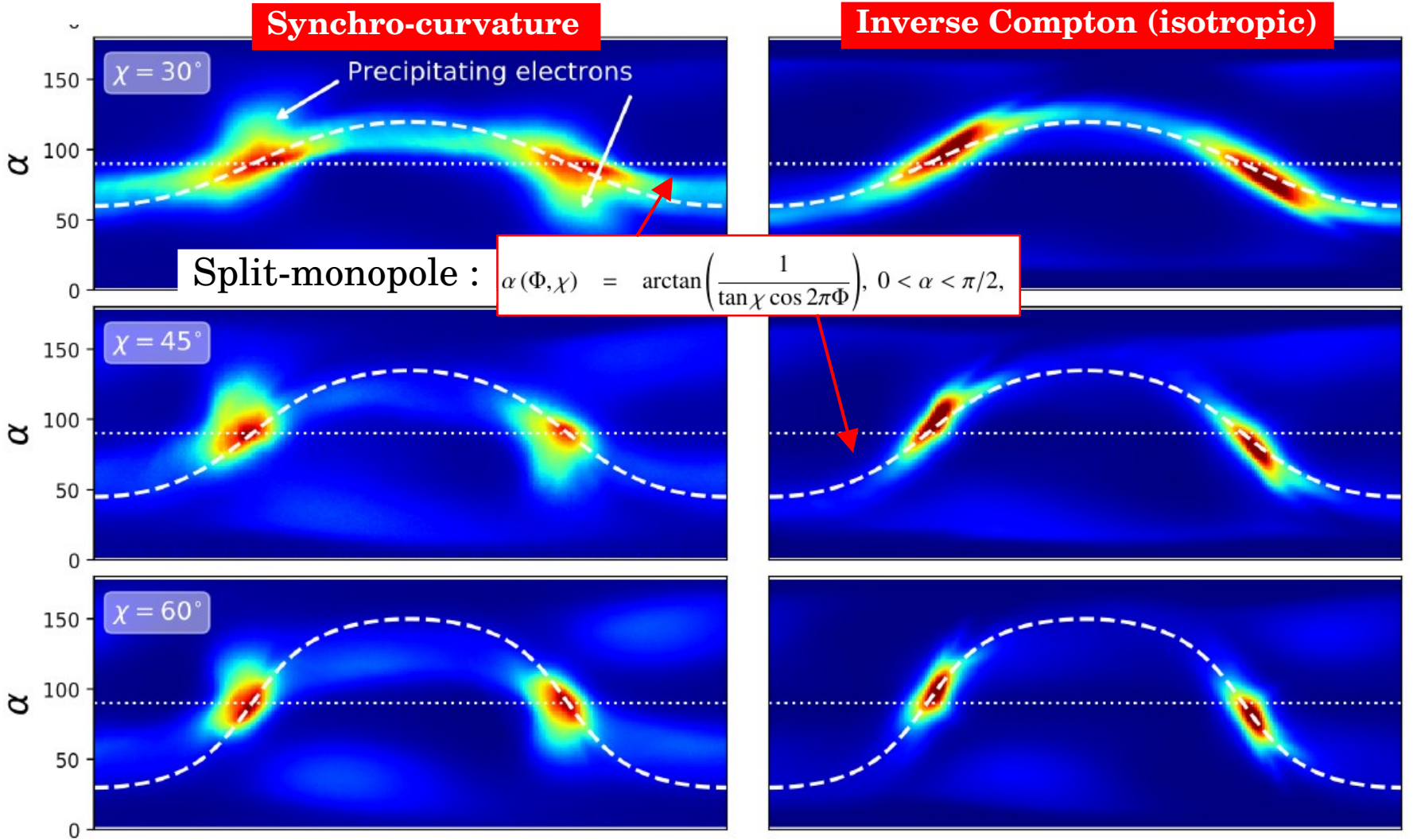


Target photons :

1. Isotropic
2. Radial

(IC cooling negligible)

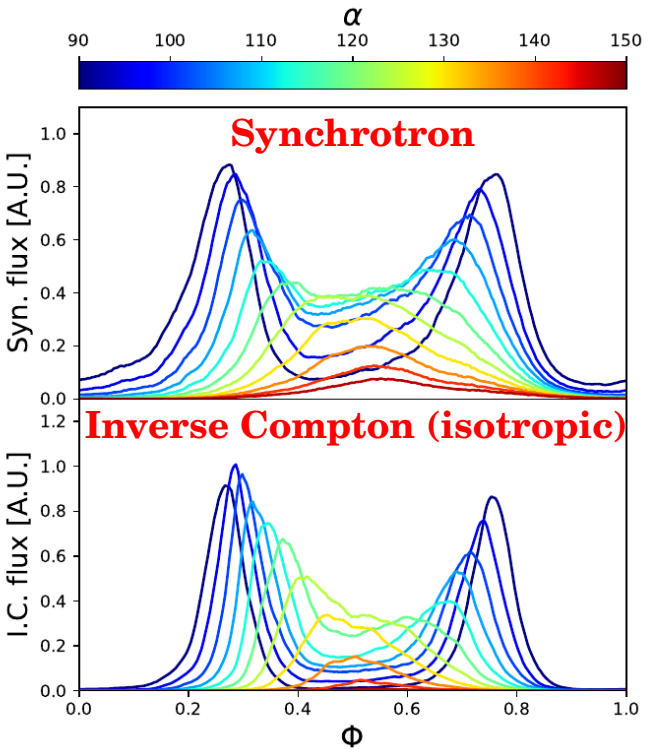
Ab-initio modeling of emitted skymaps



Cerutti et al. (submitted)

The model can reproduce generic feature of *Fermi* pulse profiles

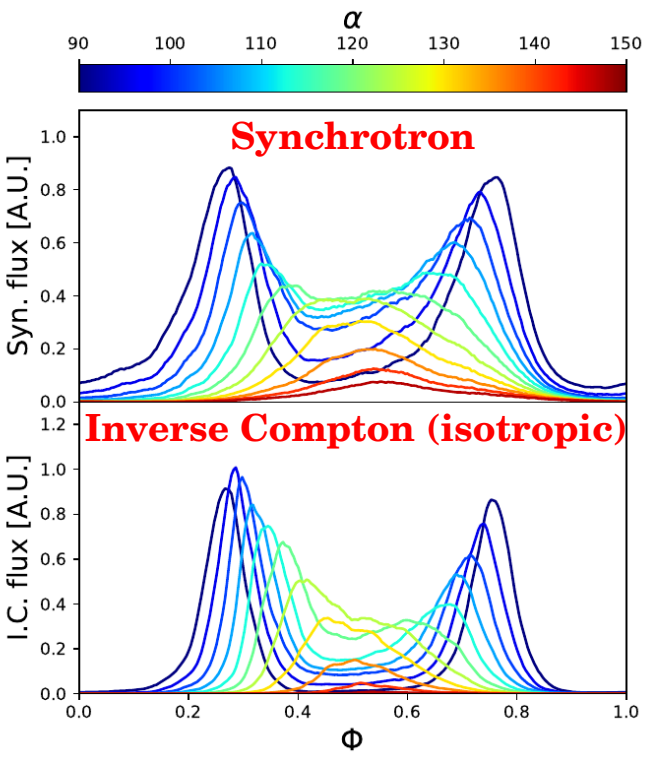
Synthetic skymap



IC lightcurves (TeV) thinner but similar to synchrotron (GeV)

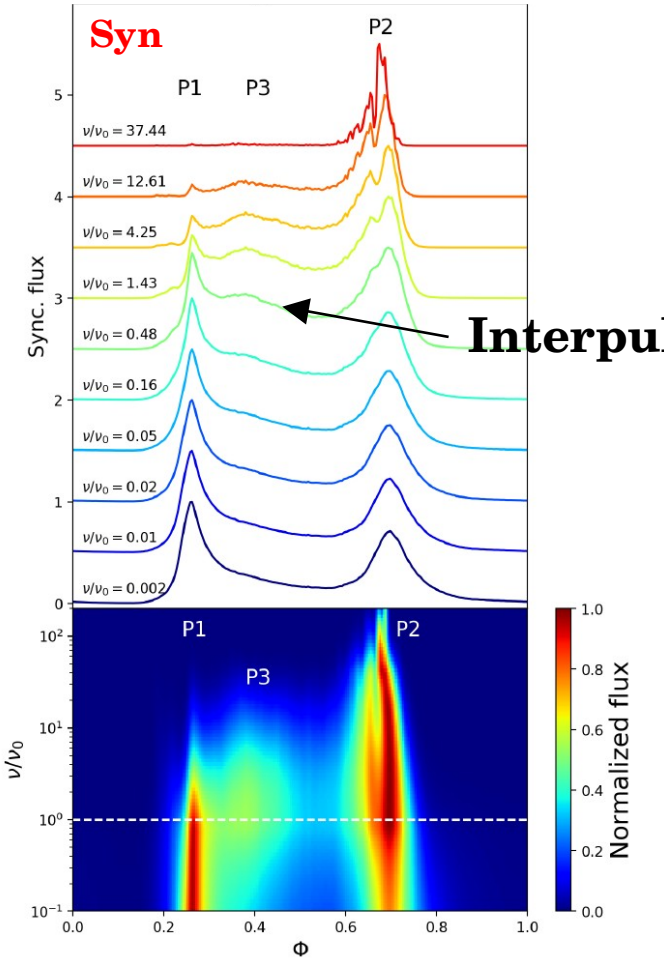
The model can reproduce generic feature of *Fermi* pulse profiles

Synthetic skymap



IC lightcurves (TeV) thinner but similar to synchrotron (GeV)

Energy evolution for Vela-like pulsar



Interpulse !

The model can reproduce generic feature of *Fermi* pulse profiles

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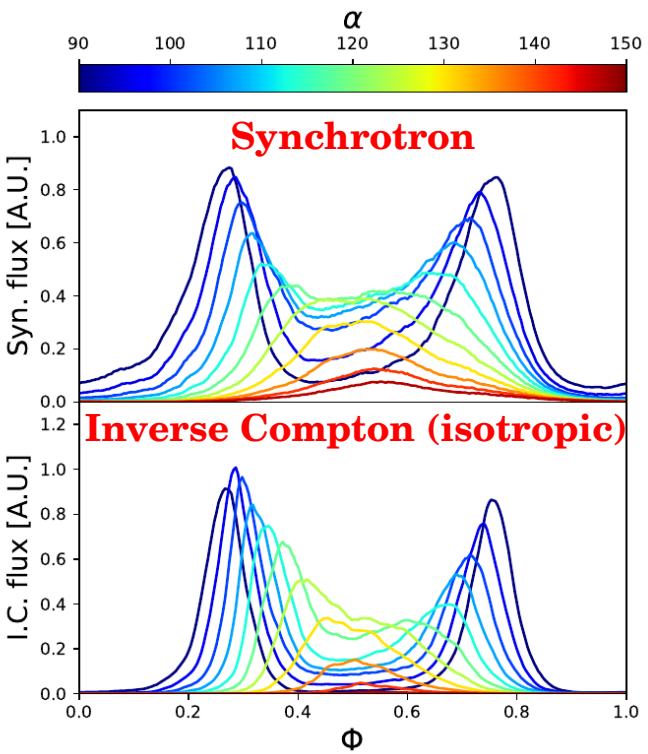

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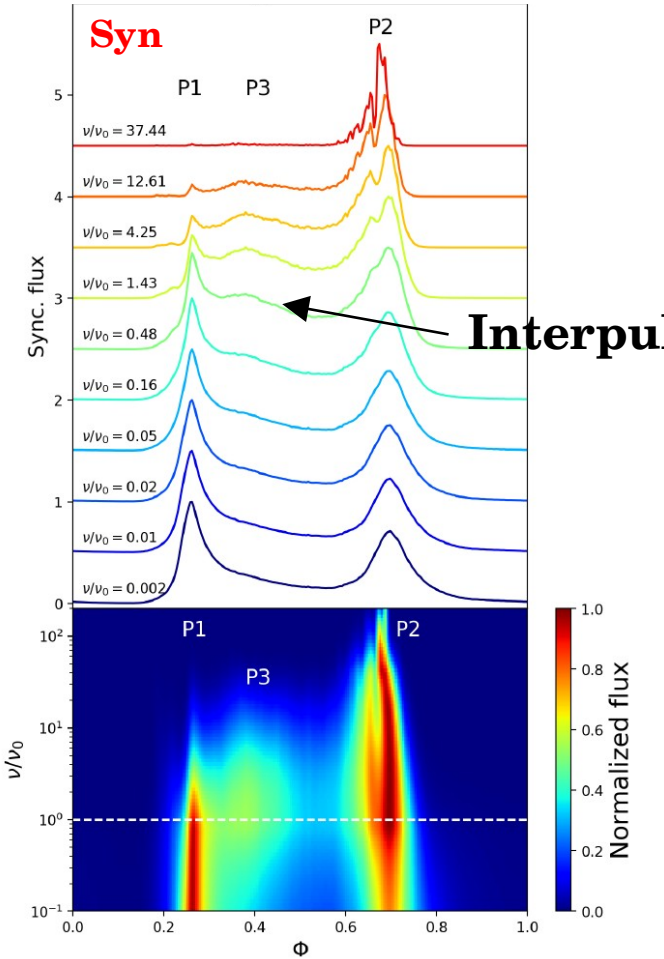
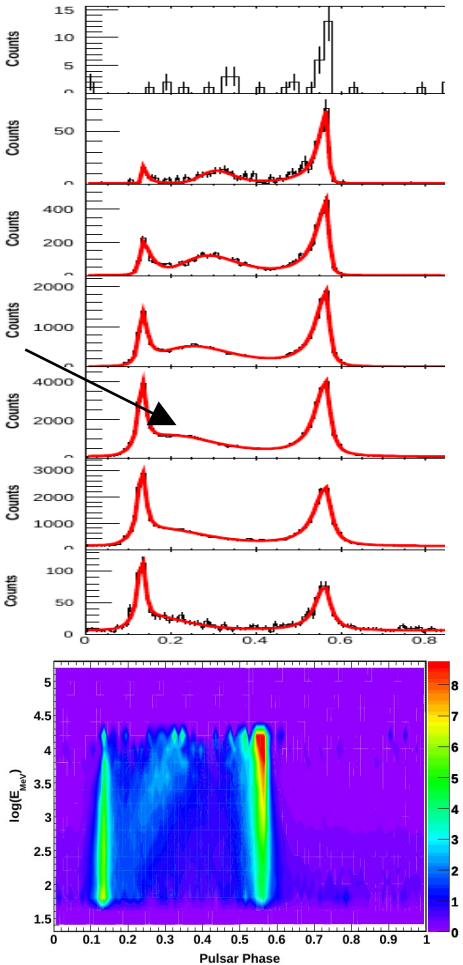


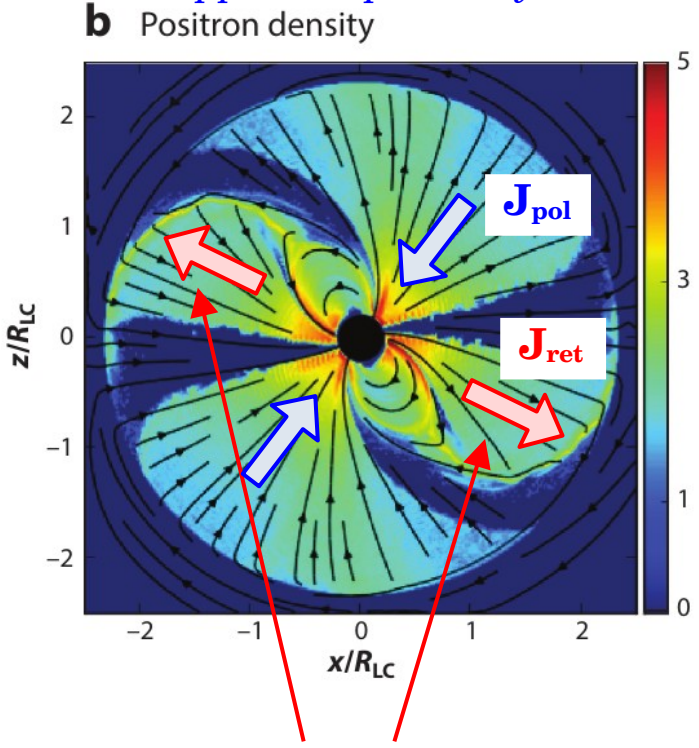
Interpulse !

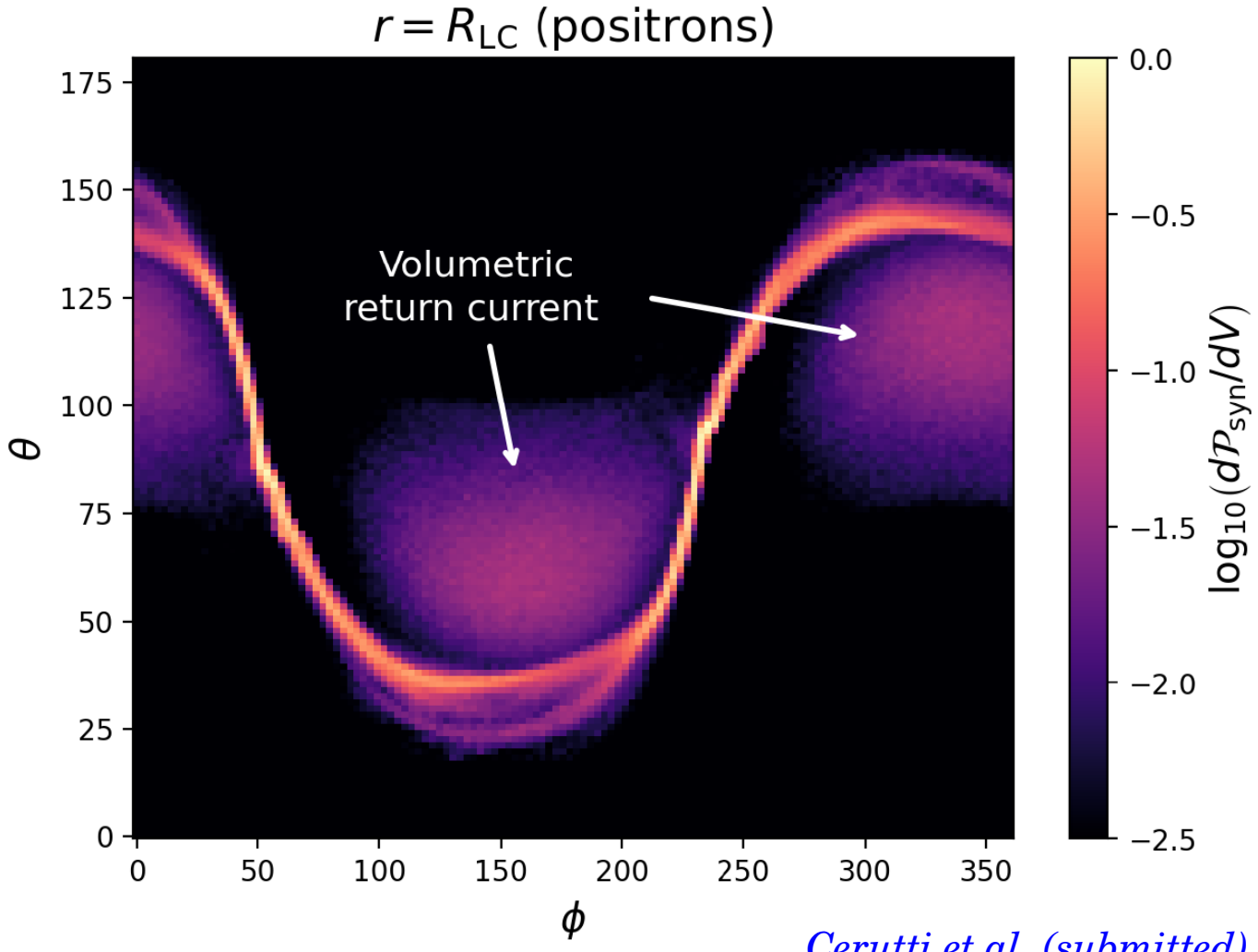
Vela *(Abdo+2010)*



Origin of the Vela-like third peak

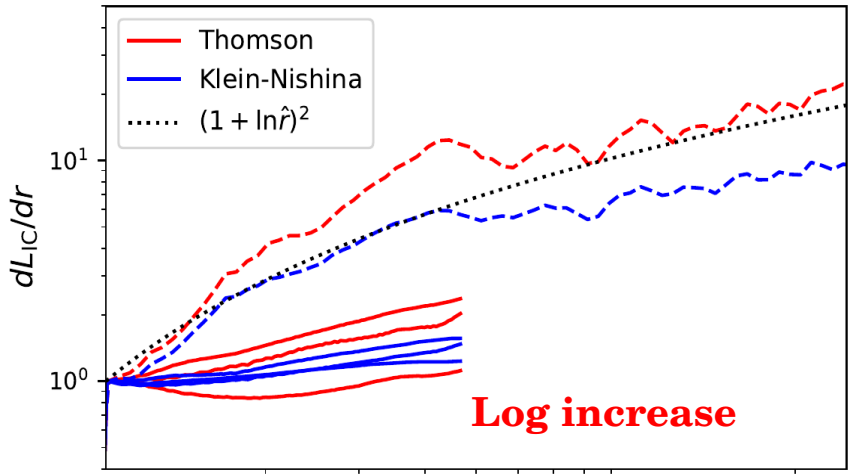
(Philippov & Spitkovsky+2018)



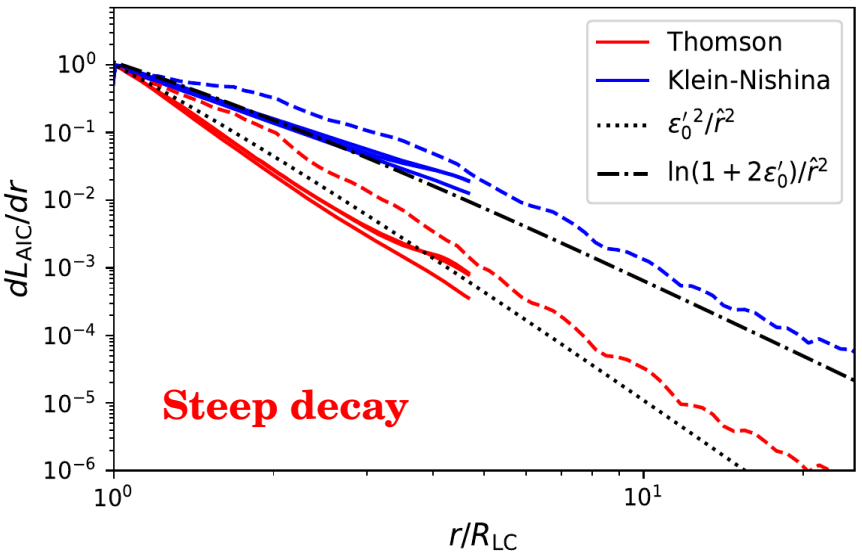


Cerutti et al. (submitted)

Radial VS isotropic photon field

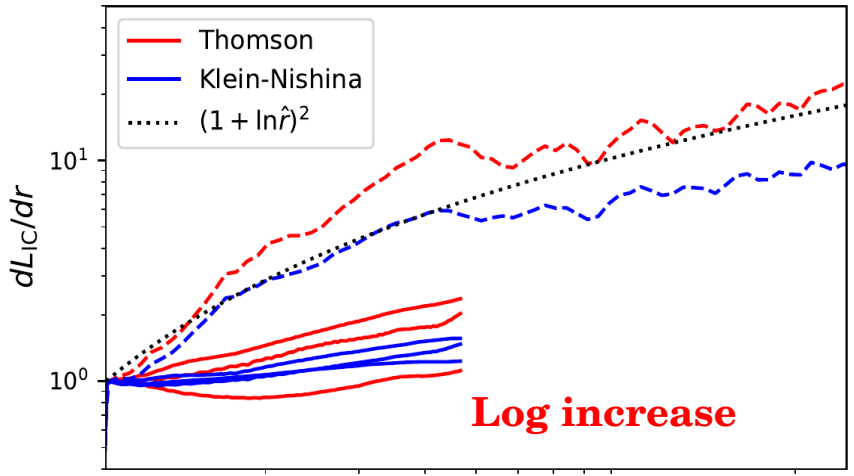


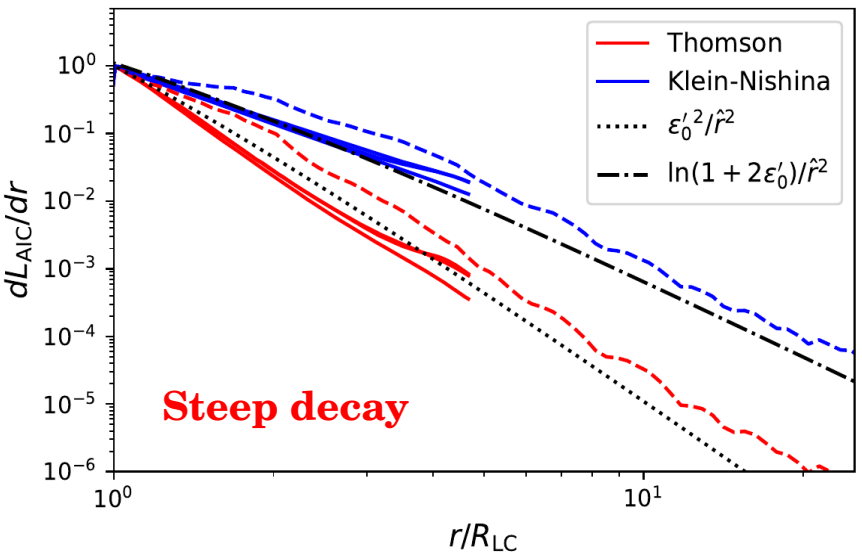
Homogeneous Isotropic



Radial field

Radial VS isotropic photon field

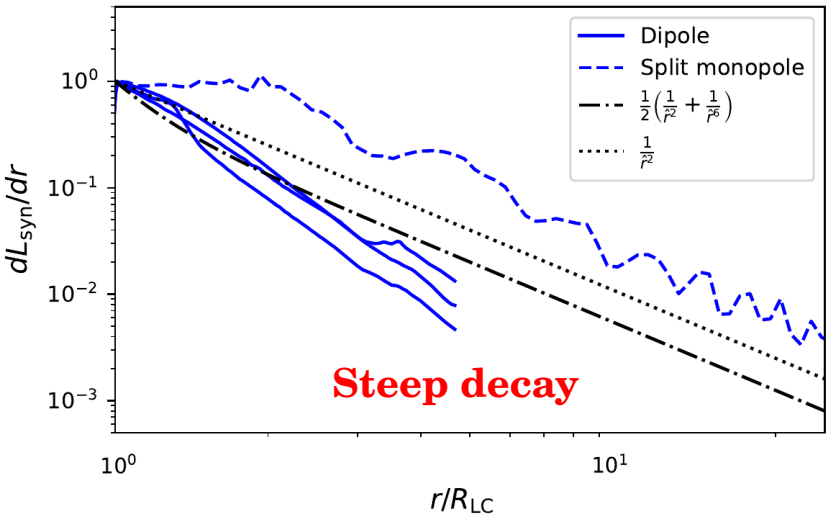




Homogeneous Isotropic

Radial field

Synchrotron power distribution

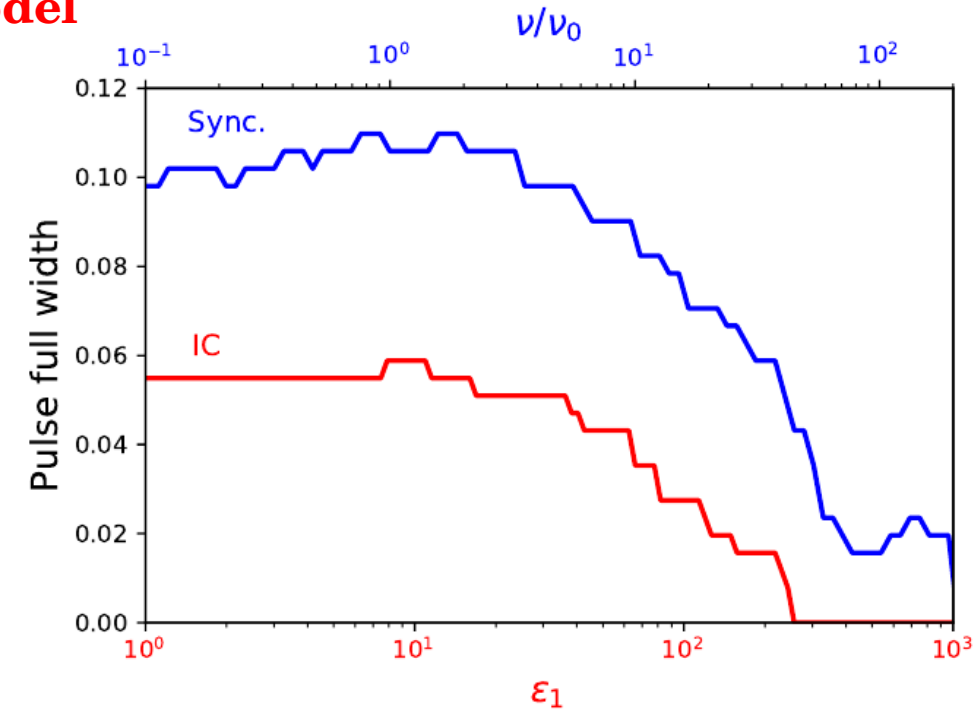


In Vela, the need to push the accelerating zone away from the light cylinder disfavors a radial photon field

=> Pulse width may tell us about the photon distribution

Origin of pulse width: radial and energy evolutions

Model

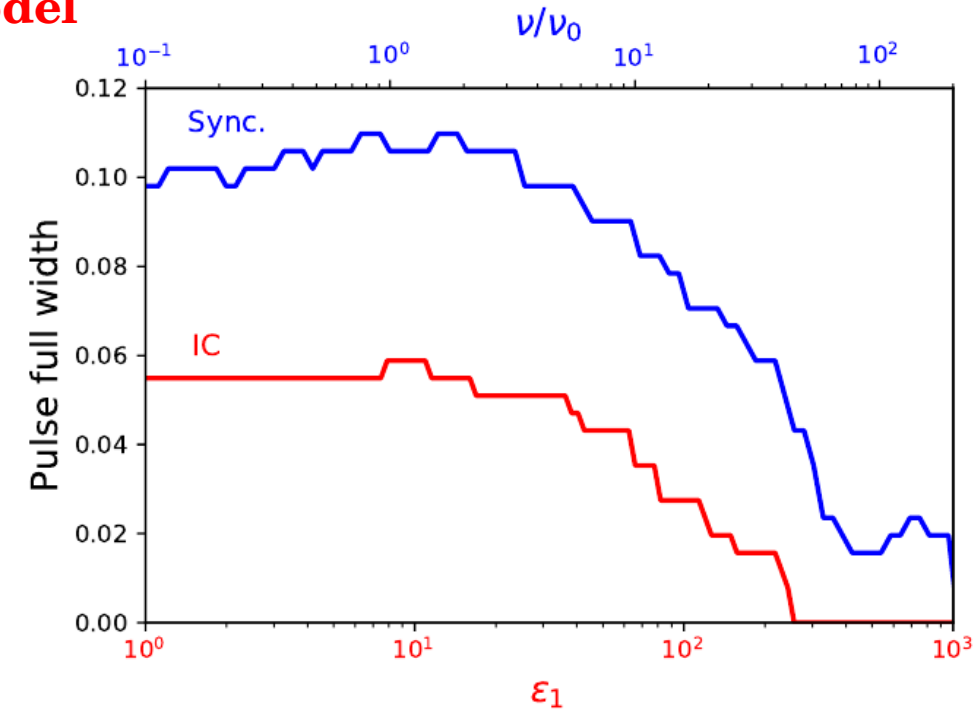


Pulses become thinner at higher energies

=> Higher energies are produced further away where the wind is more relativistic (stronger beaming)

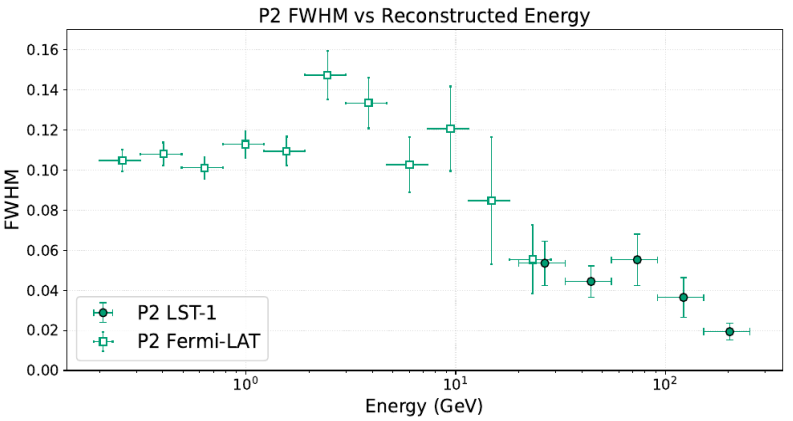
Origin of pulse width: radial and energy evolutions

Model

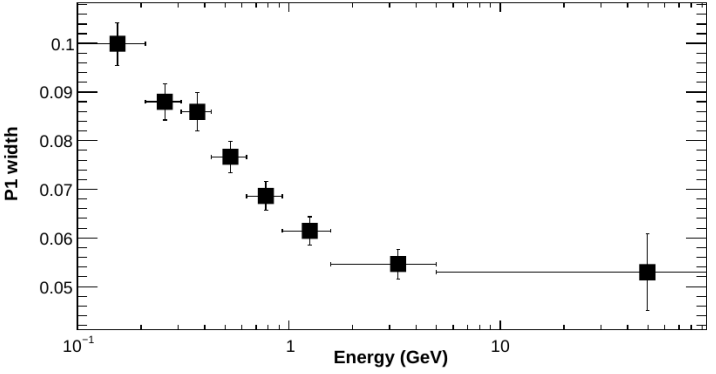


HE-VHE observations

Crab *(Abe+2024)*



Geminga *(Abdo+2010)*



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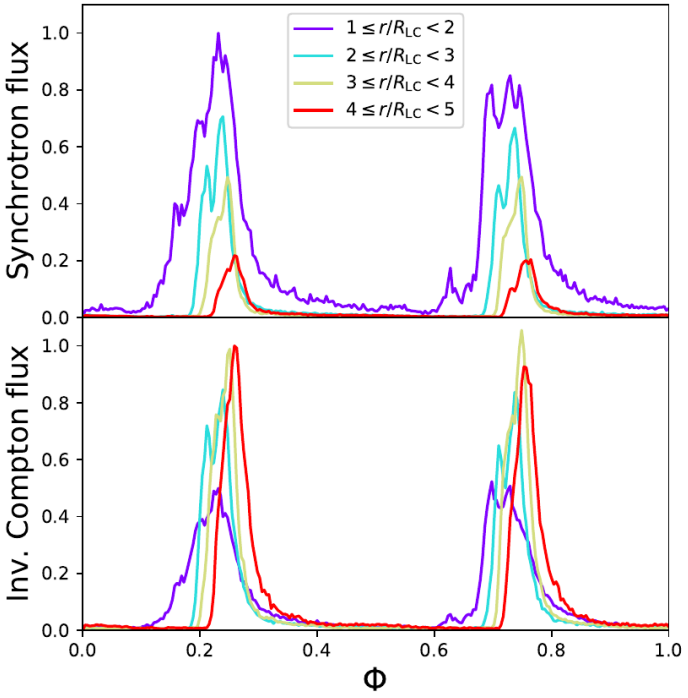
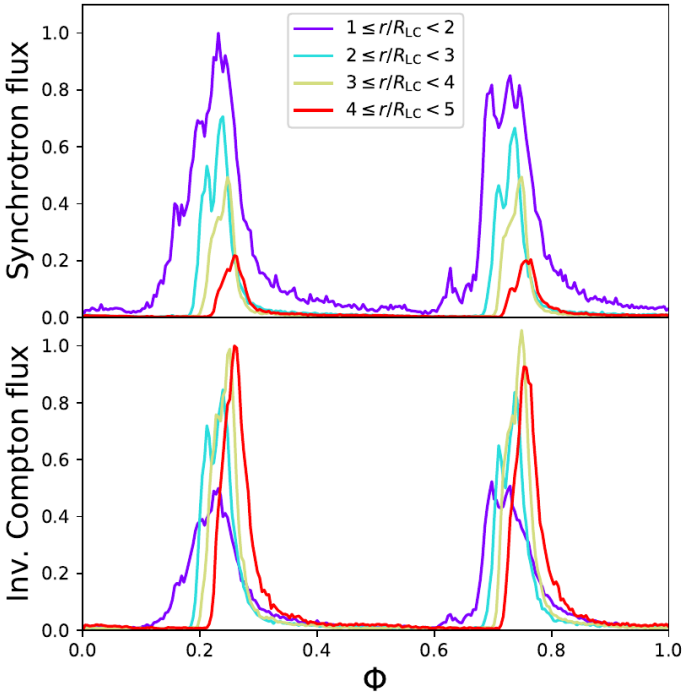
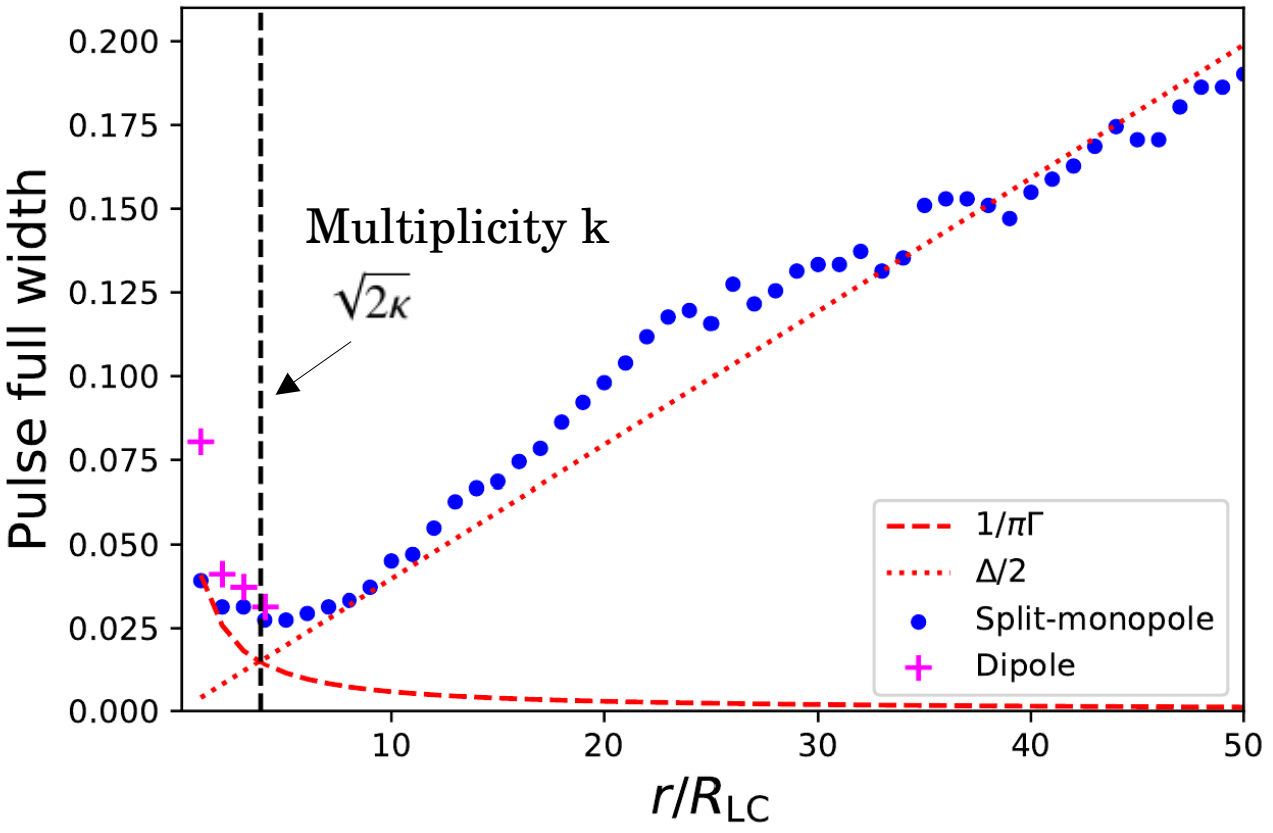
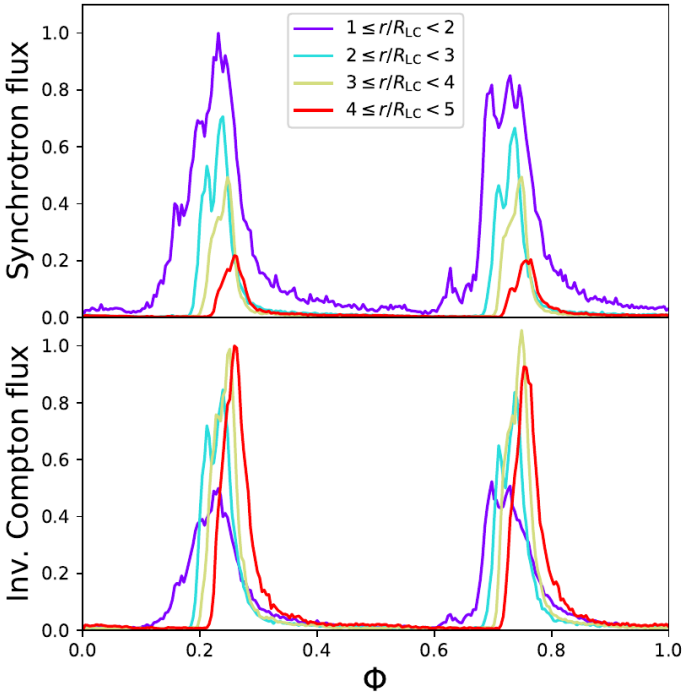


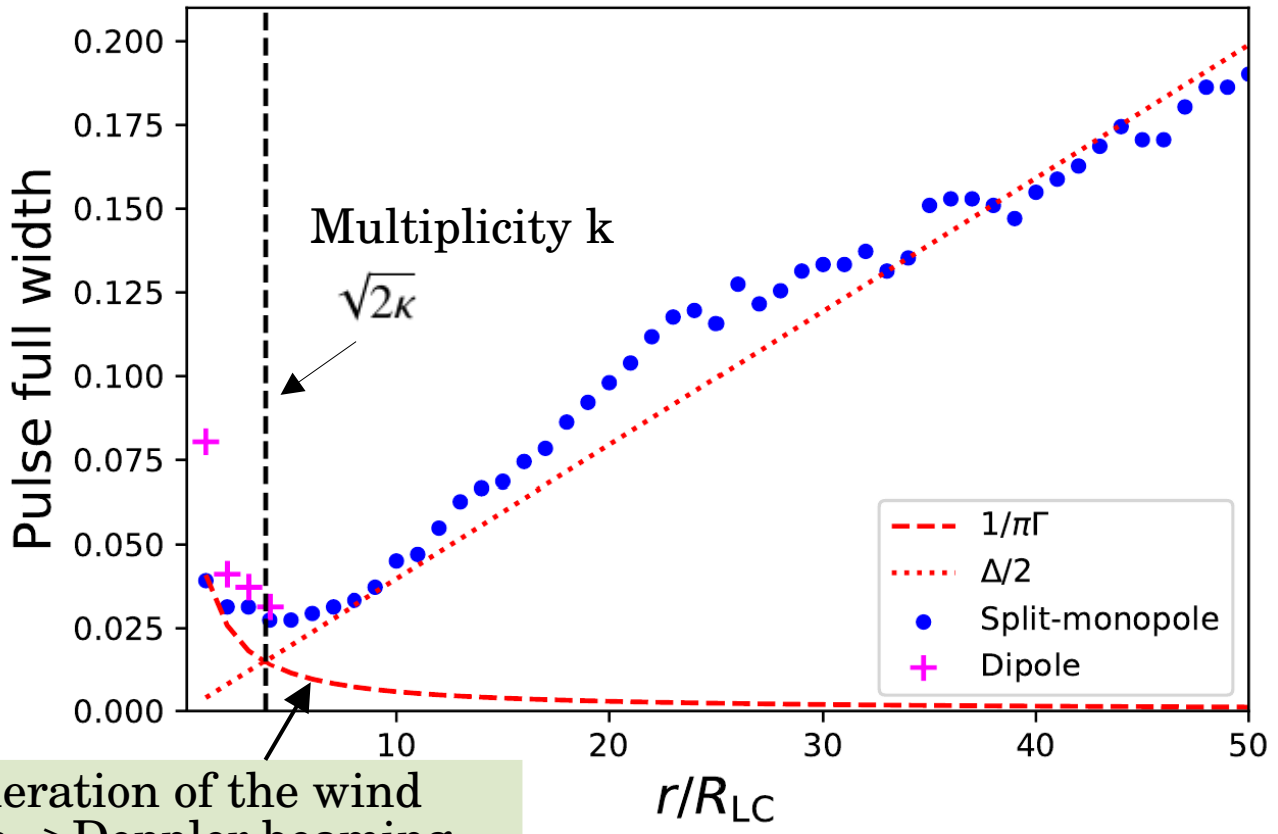
Origin of pulse width: radial and energy evolutions





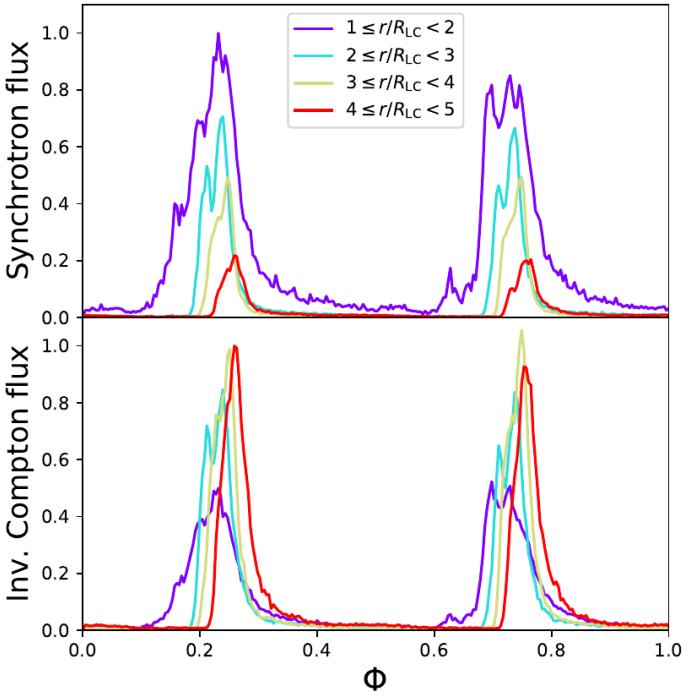
Origin of pulse width: radial and energy evolutions

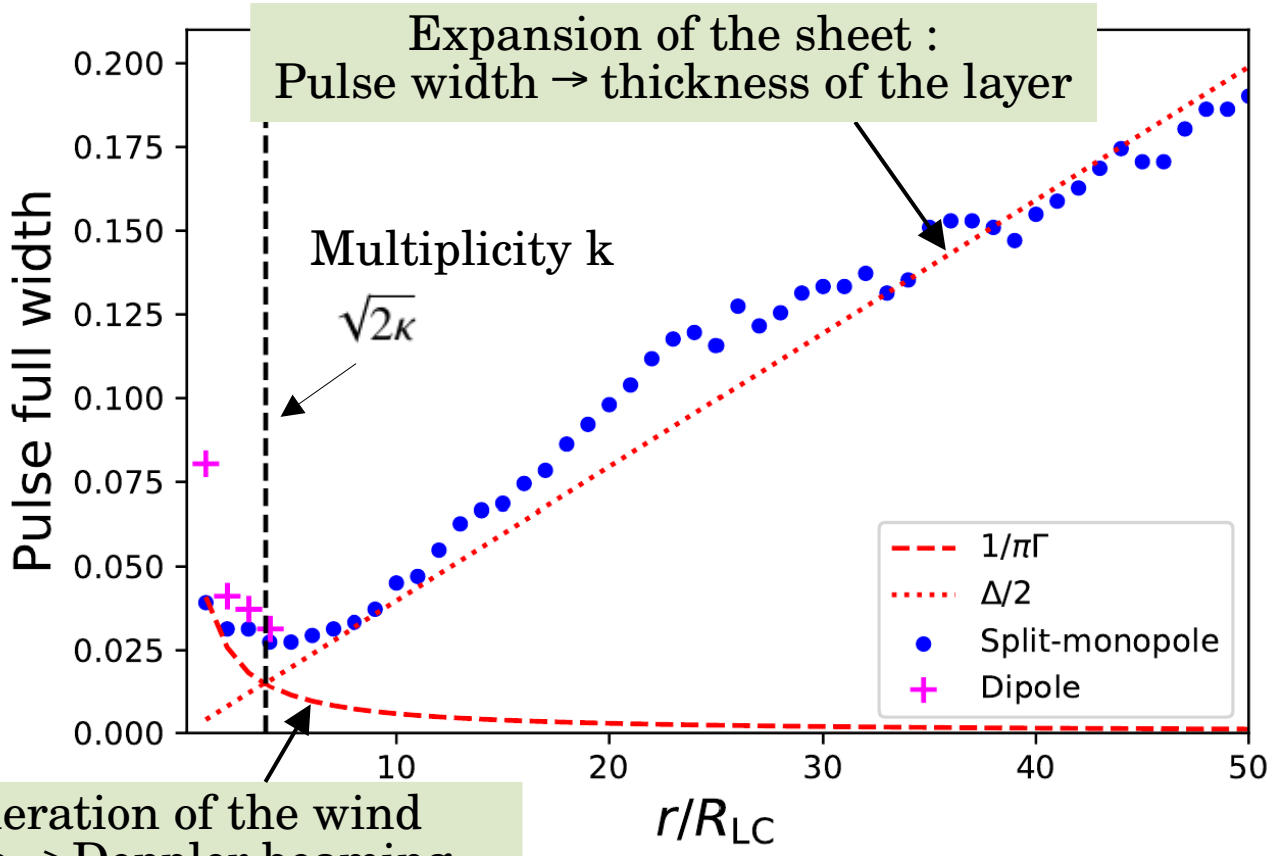




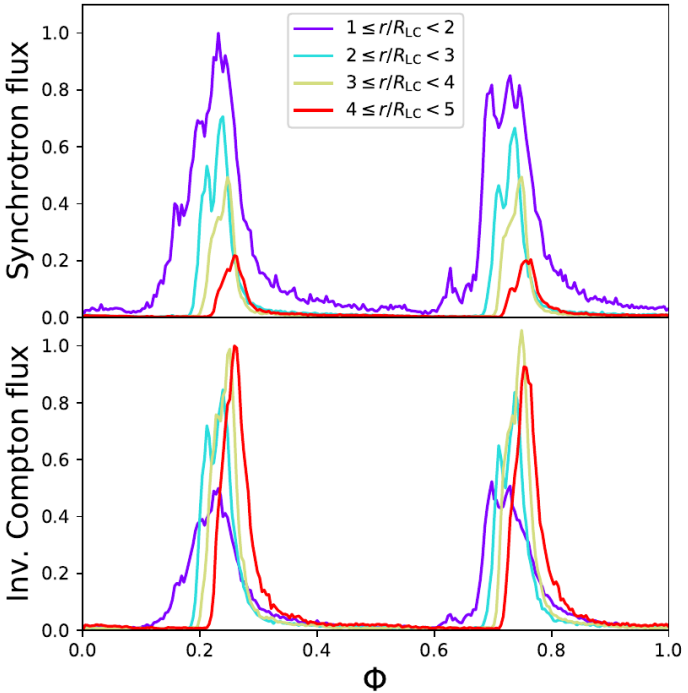
Bulk acceleration of the wind
Pulse width → Doppler beaming

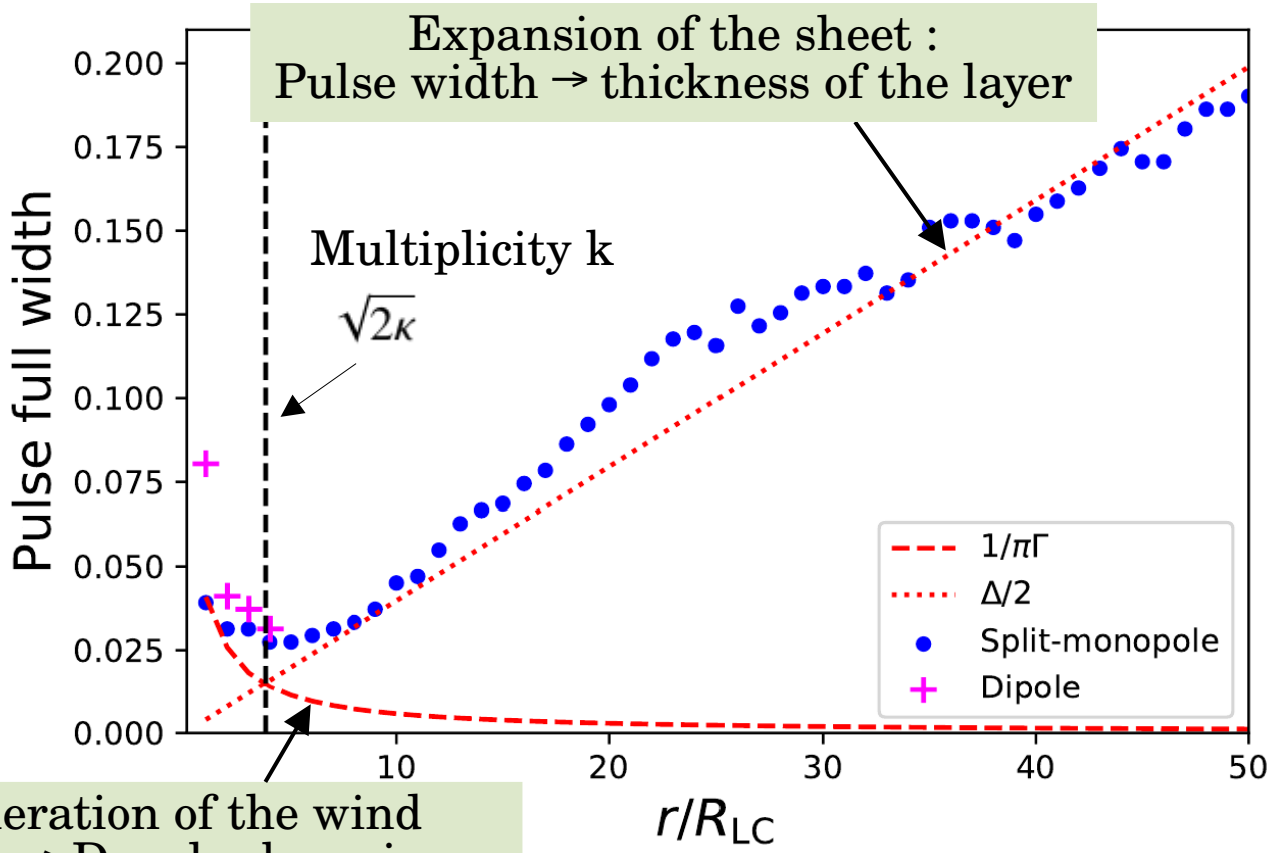
Origin of pulse width: radial and energy evolutions





Origin of pulse width: radial and energy evolutions





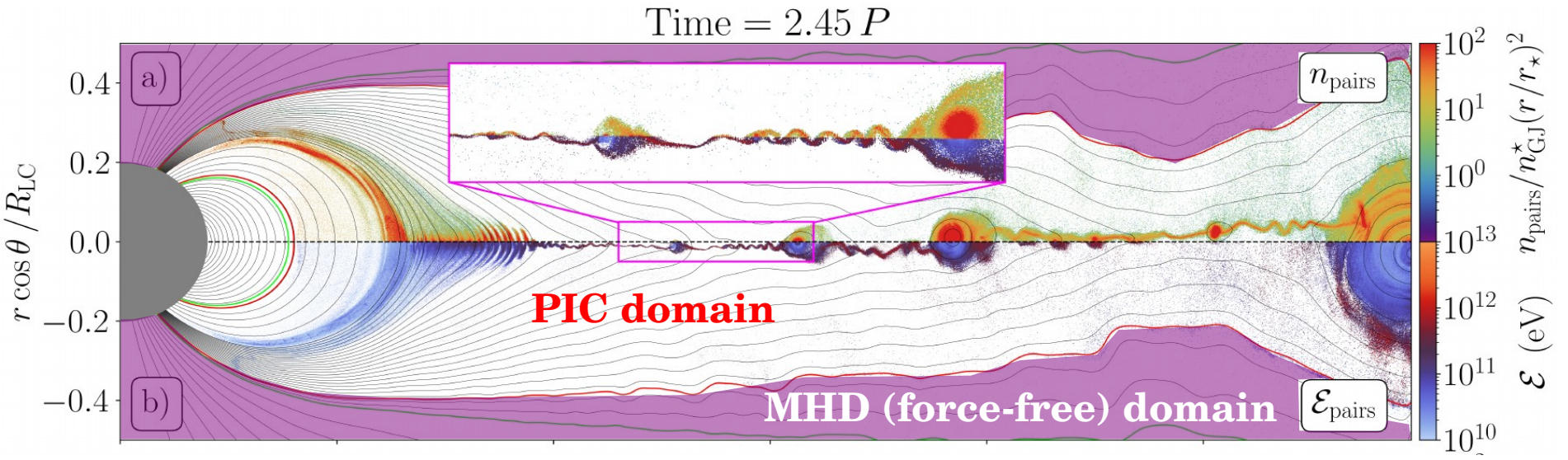
Implications :

- **The TeV emission in Vela probably shifted away from the light cylinder, but within ~10-100 R_{LC}**
- **Photon bath cannot be nebular, must be local, SSC from secondary pair emission ?**

Hybrid PIC/MHD model: a (weak) ms *Fermi* pulsar in a box

(Soudais et al. 2024)

Pulsar period : **1ms**
Surface magnetic field : **10^7 G** **(no rescaling)**



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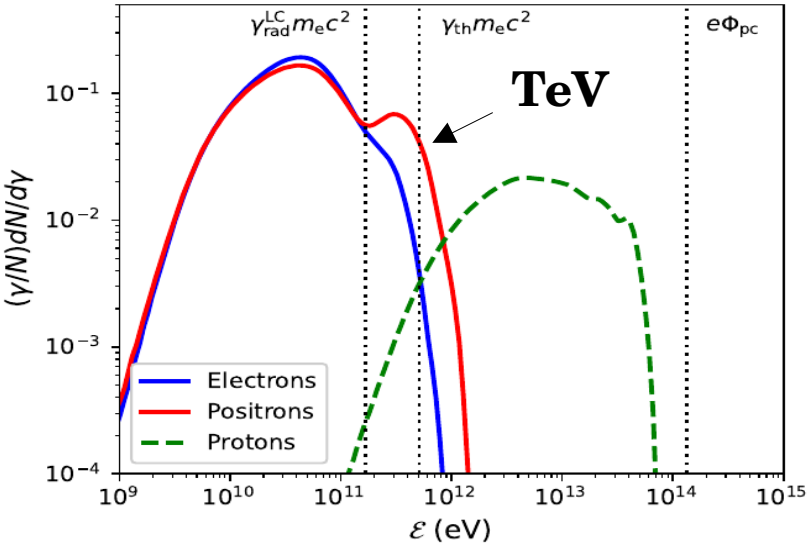
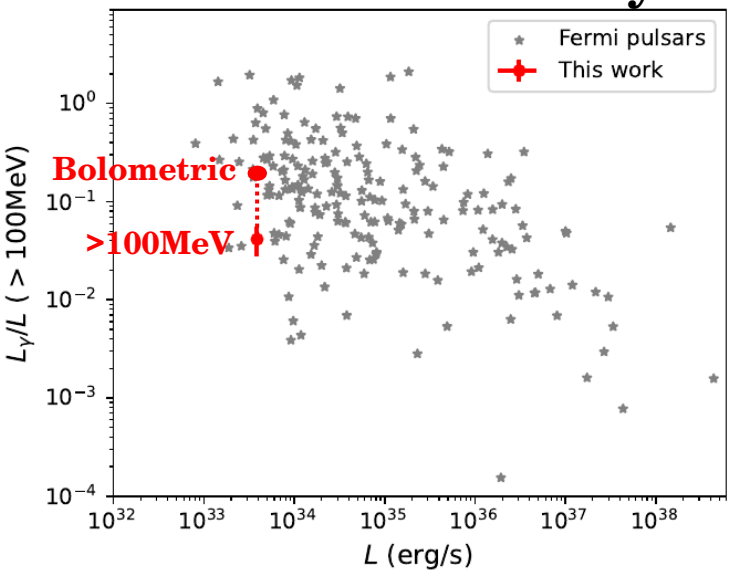
Pulsar period : **1ms**
Surface magnetic field : **10^7 G** **(no rescaling)**

Particle acceleration

Pairs : TeV
Protons : >10TeV



Radiative efficiency



Canonical (10^8-10^9G) millisecond pulsars could be TeV emitters
Narrow TeV spectral feature ?

Where to go next?

- **Scale separation problem** : Need to scale simulations up !
  Develop innovative methods :
  - GPU acceleration and exa-scale computing => large $10{,}000^3$ grid cells simulations, and broader exploration of the parameter space in 3D
  - Hybrid methods => MHD + PIC, MHD + subgrid models + test particles

- We need to better understand **how pairs are created at light cylinder scales**
  - Along field lines carrying the volumetric return and super-GJ currents?
  - Local photon field emitted by secondary pairs, spatial and energy distribution ? Include SSC in global PIC models.

MAIN MENU

- Home
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- Registration
- Venue and practical information
- List of Participants
- News

HELP

- @ Contact

Overview

This workshop aims at bringing together world experts in the field of relativistic plasma astrophysics to discuss recent progress in the understanding of magnetized plasmas surrounding neutron stars and black holes and related astrophysical phenomena from an observational, theoretical and computational perspectives.

Important dates

Conference dates: Sunday April 6, 2025 - Friday April 11, 2025.

Application and abstract submission: September 16, 2024 - December 1, 2024.

Notification to all applicants: December 15, 2024.

Registration fee

The registration fee is fixed to a flat rate of **300**€ (taxes included). It will cover all expenses during your stay in Les Houches (meals and accommodation). Payment can be made by credit card, bank transfer or purchase order. A link to the online payment platform (Azur-Colloque) will be available soon.

Confirmed invited speakers

- Andrei Beloborodov, Columbia University, USA
- Roger Blandford, Stanford University, USA
- Arache Djannati-Ataï, APC/CNRS, France
- Gwenael Giacinti, Tsung-Dao Lee Institute, China
- Hayk Hakobyan, Columbia University, USA
- Yuri Lyubarsky, Ben-Gurion University of the Negev, Israel
- Monika Mościbrodzka, Radboud University, Netherlands
- Kohta Murase, Penn State, USA
- Cherry Ng, LPC2E/CNRS, France
- Nanda Rea, CSIC-ICE, Spain
- Bart Ripperda, CITA-University of Toronto, Canada
- Dmitri Uzdensky, University of Oxford, UK
- Alexandra Veledina, University of Turku, Finland
- Yajie Yuan, Washinton Univeristy, USA

Preregistration closes on Dec 1!

SOC :
- B. Cerutti (chair)
- B. Crinquand
- N. Globus
- C. Guépin
- A. Levinson
- K. Parfrey
- A. Philippov

https://r-magnetosphere.sciencesconf.org/