On the Physics at the Highest Energies of Gamma-Ray Emitting Binaries (LS 5039)

Valenti Bosch-Ramon;

In collaboration with M. Barkov, E. Derishev, D. Khangulyan

Universitat de Barcelona, ICCUB

Variable Galactic Gamma-Ray Sources VII

Universitat de Barcelona-ICCUB, May 6-8, 2025

Outline

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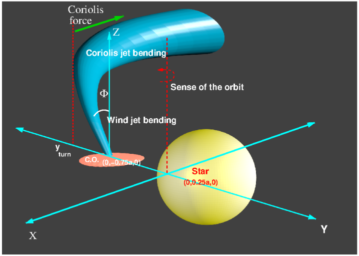
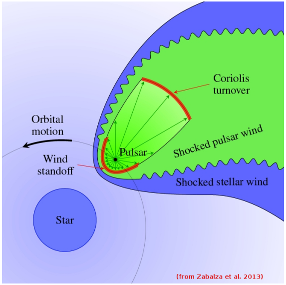
High-mass, relativistic, γ-ray emitting binaries

- **High-mass, relativistic γ-ray emitting binaries are efficient complex accelerators and powerful high-energy sources.**
- **Important elements common to most of these sources:**
  - **Magnetized relativistic outflow: wind, jet. (BINARY SCALES)**
  - **Dense radiation field and radiation reprocessing.**
  - **Substantial and structured stellar wind (clumps, disk...).**
  - **Shocks, instabilities, turbulence, mixing...**
  - **Orbit, eccentricity, disruption. (BEYOND BINARY SCALES)**
  - **Interactions on large scales, medium, proper motion...**



(B-R & Barkov 2016 -MQ-)



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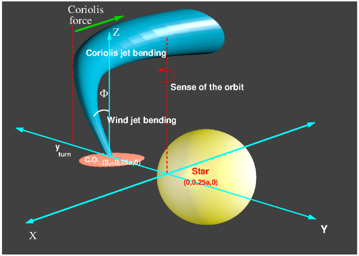

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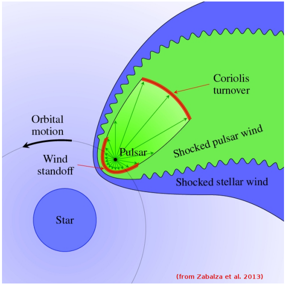

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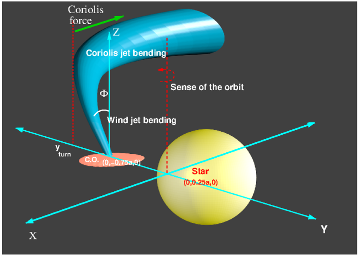

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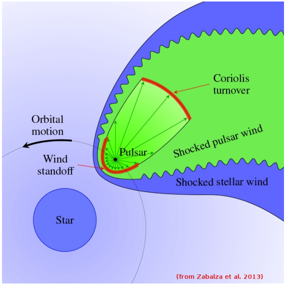

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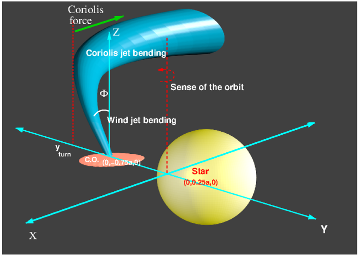

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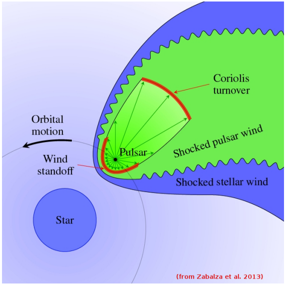

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- Jet likely structured (spine+sheath); B-role, content, velocity are unclear.
- Jet gets recollimation shock, mixing, non ballistic helical motion due to wind+orbit.
- **Ultrarelativistic pulsar winds form from a rotating magnetosphere at light cylinder.**
- Pulsar wind expected to be magnetized and striped, anisotropic, ultrarelativistic...
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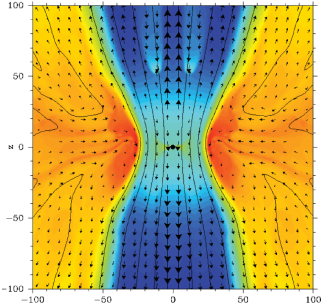

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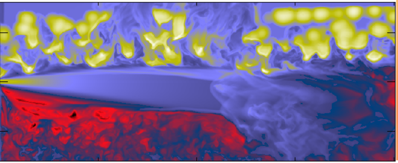

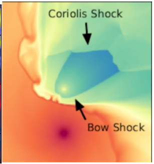

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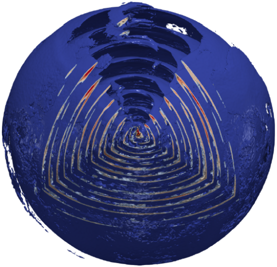

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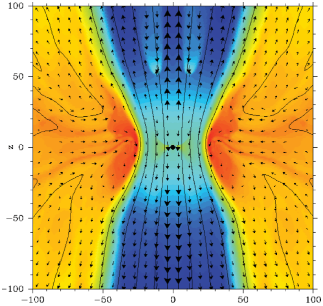

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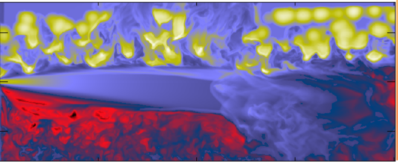

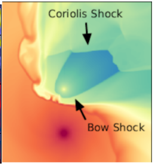

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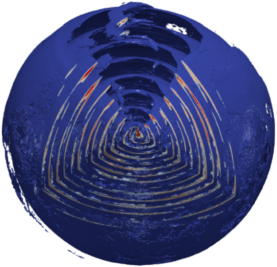

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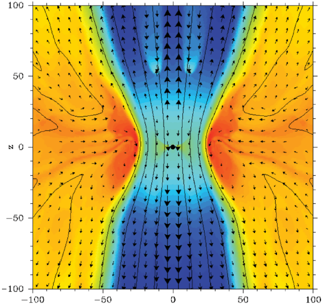

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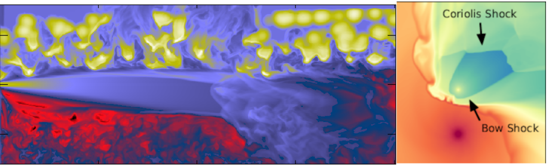

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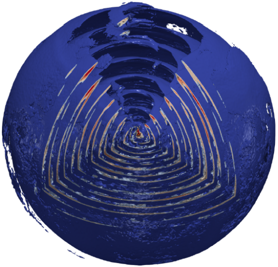

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A case of study: LS 5039

- **LS 5039 is a binary system with an O6.5V star and a compact object of unknown nature.** (e.g. Casares et al. 2005)
- **More compact and less eccentric than other (likely) non-accreting gamma-ray binaries, it is well studied and useful to understand.**
- **LS 5039 presents extended jet-like radio, and orbitally modulated X-ray, GeV, TeV and UHE emission, likely synchrotron and IC.**
  (e.g. Paredes et al. 00; Bosch-Ramon et al. 05; Aharonian et al. 06; Paredes, B-R & Romero 06; Khangulyan et al. 08; Dubus et al. 08; Takahashi et al. 09; Hadasch et al. 12; Moldón et al. 12; Alfaro et al. 25)
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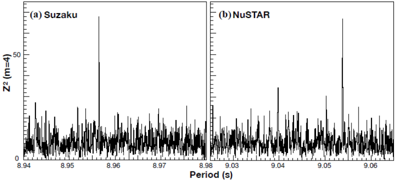

- This pulse evidence, if true, could indicate that a young highly magnetized NS is powering the non-thermal activity.
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- A magnetar may imply a very young source (~ 500 yr), but there is no evidence of a nearby young SNR. (Ribó et al. 2002; Moldón et al. 2012)
- LS I +61 303, showing sporadic 269 ms radio pulses and similar to LS 5039, has also been proposed to host a magnetar-like NS.

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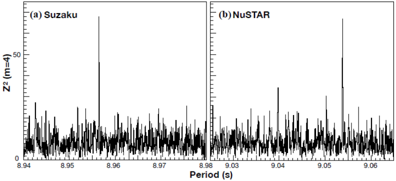

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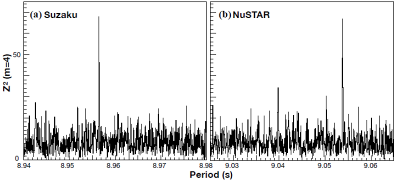

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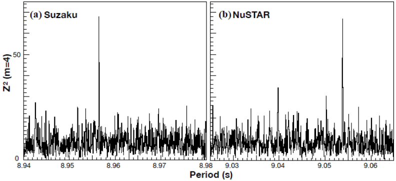

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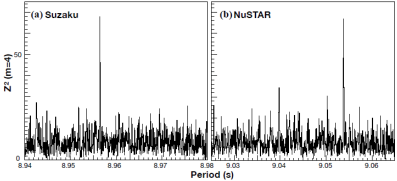

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- **For a weak wind:** $r_{\rm cd} \sim \eta^{1/2} R_{\rm orb}/(1+\eta^{1/2}) \sim 2\times 10^{10}\,\eta_{-4}^{1/2}$ **cm.**
- If $r_{\rm cd} \lesssim r_{\rm lc} \approx 4\times 10^{10}$ cm for $P=9$ s, the stellar wind can potentially interact and tap energy from the magnetosphere. (Yoneda et al. 2020)
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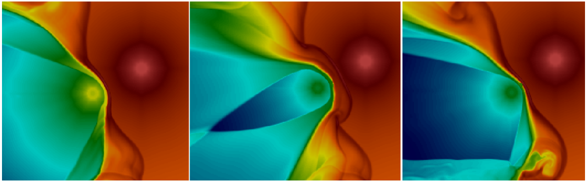

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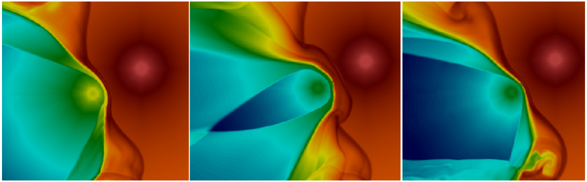

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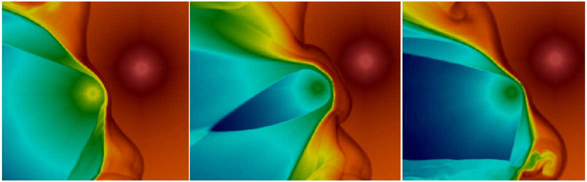

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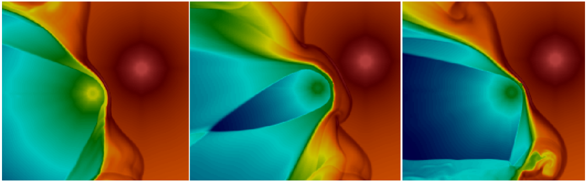

Linking magnetospheric and non-thermal activity

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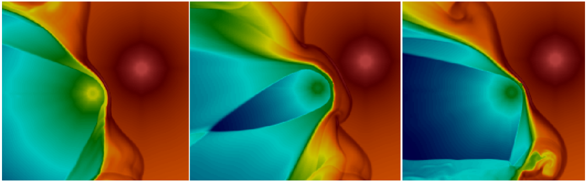

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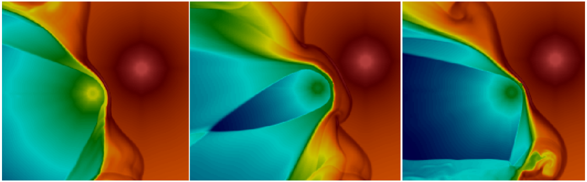

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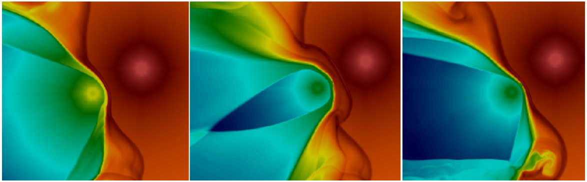

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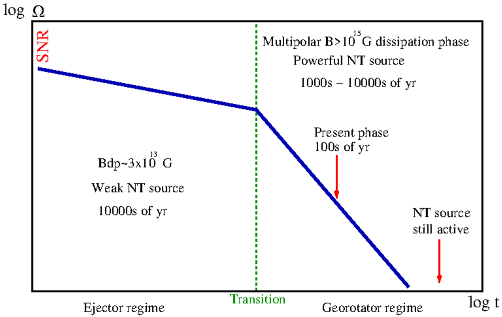

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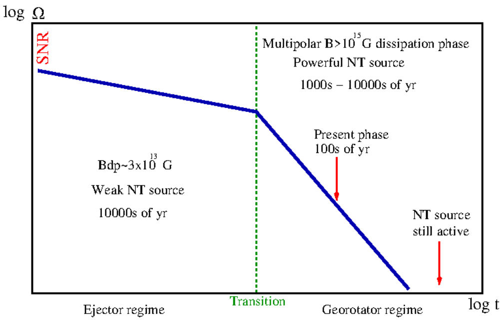

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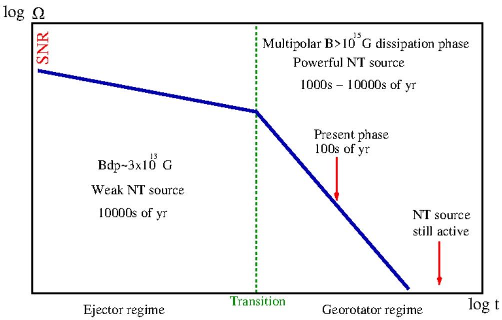

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Outline

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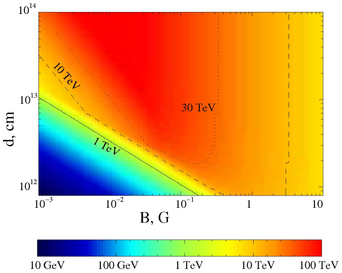

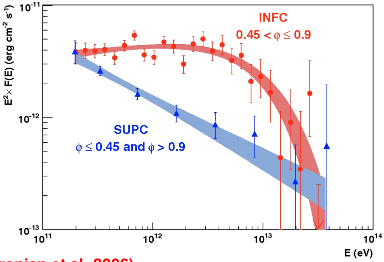

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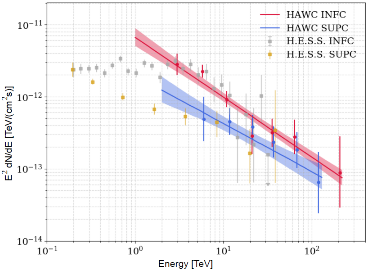

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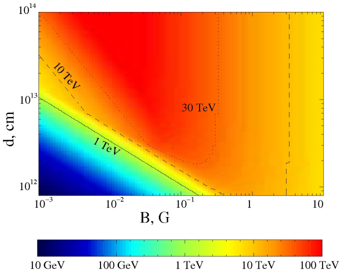

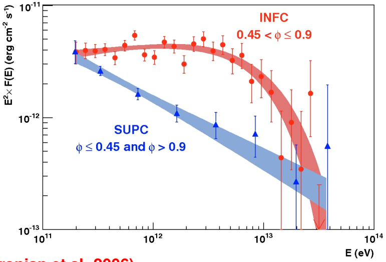

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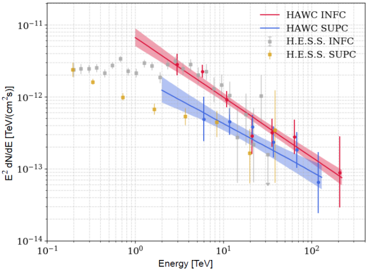

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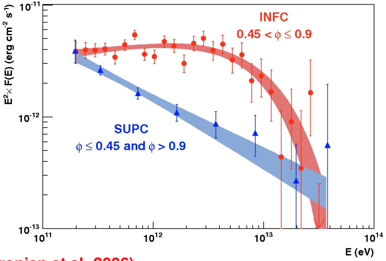

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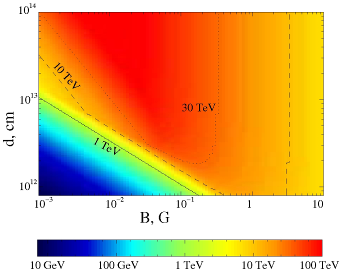

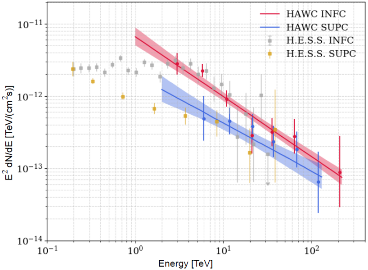

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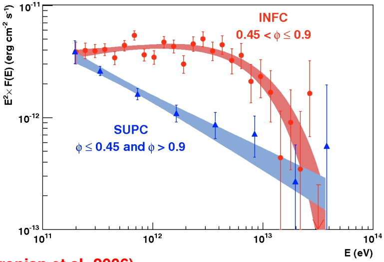

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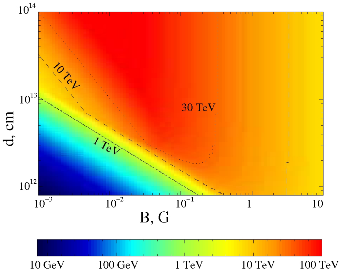

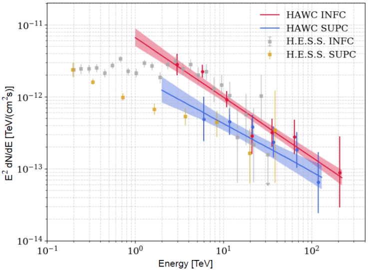

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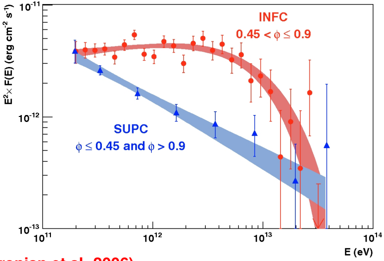

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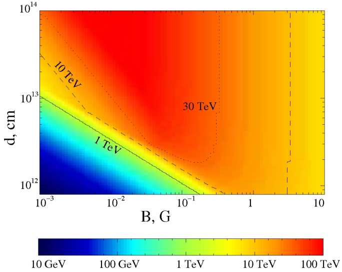

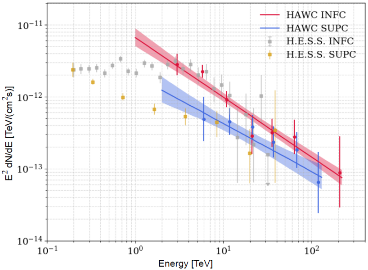

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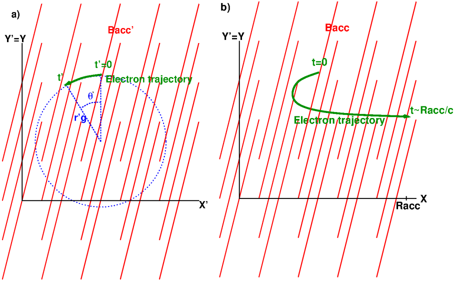

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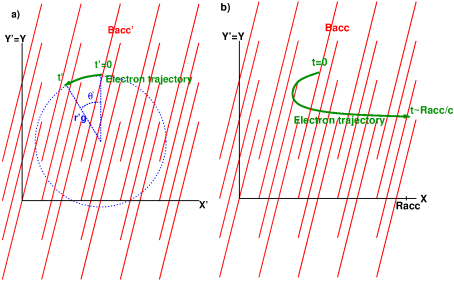

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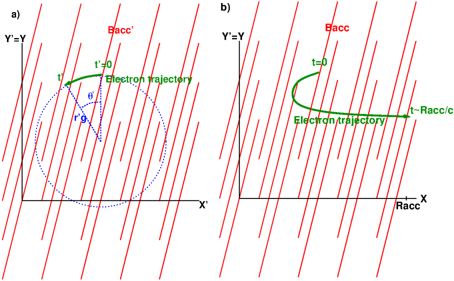

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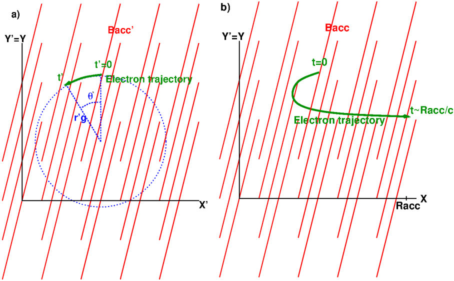

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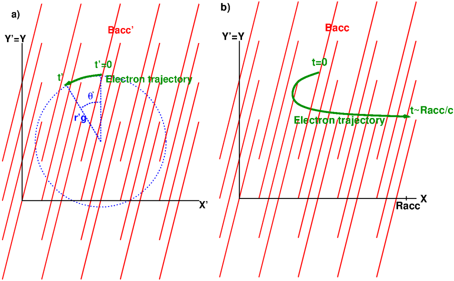

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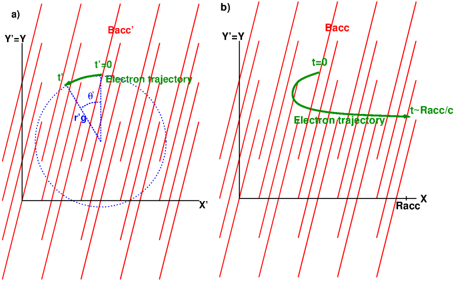

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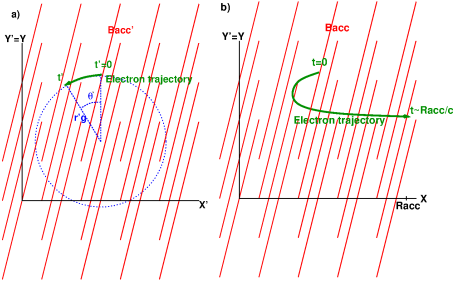

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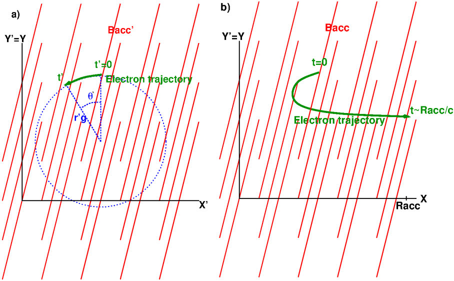

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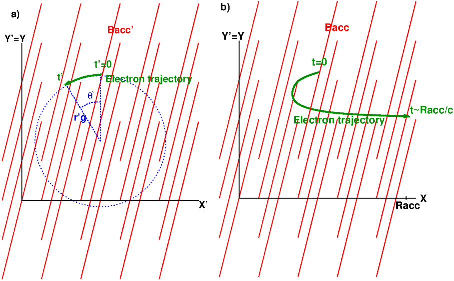

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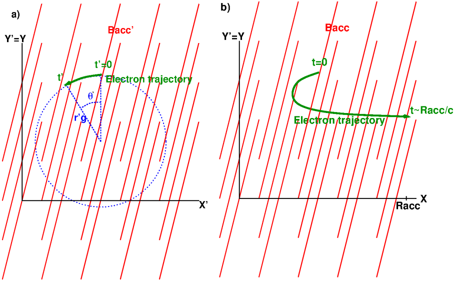

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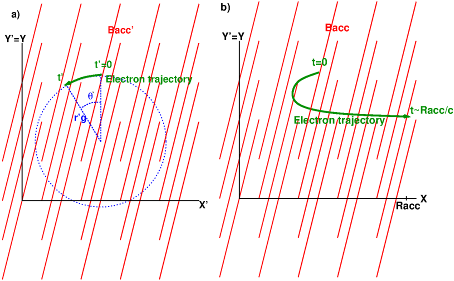

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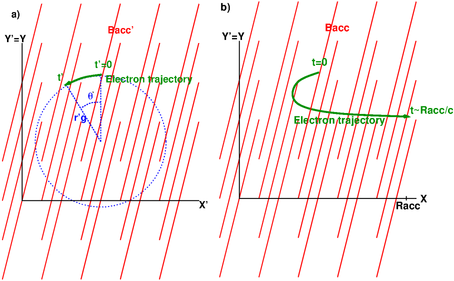

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Outline

1. Introduction
2. Power source
3. Variable UHE photons from LS 5039
4. Conclusions

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