What are the radio outflows in gamma-ray binaries?

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High Energy Phenomena in Relativistic Outflows II
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Outline

Outline

Gamma-ray binaries

- PSR B1258$-$63: Be + young non-accreting pulsar + radio (Aharonian et al. 2005)
- LS 5039: O ms + pulsar or black hole + radio (Aharonian et al. 2005)
- LS I +61 303: Be + pulsar or black hole + radio (Albert et al. 2006; Acciari et al. 2008)
- Cygnus X-1: O Sg + black hole + radio (Albert et al. 2007)
- HESS J0632+057?: massive star? + pulsar or black hole? + radio (Hinton et al. 2009)

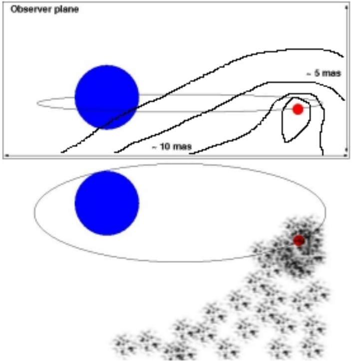
Is radio emission produced by a relativistic outflow?

Pair creation and radio emission

- Gamma-rays $\geq$ 100 GeV are absorbed by the stellar photons producing $e^{\pm}$ pairs.
- Pairs are quickly trapped in the stellar wind magnetic field.
- Radio and X-ray emission from the pairs in the wind may be relevant (Bosch-Ramon, Khangulyan & Aharonian 2008).
- Flux, lightcurve, and morphology in the radio band will be linked to the gamma-ray emitter and the stellar wind properties.

Outline

The basic picture



High-mass binary with VHE emission, $\gamma\gamma$ absorption and radio emission.

Estimates: Flux, spectra and morphology

- Flux: $L_{\rm radio} \sim N_{e^\pm}\,(E/t_{\rm sync})_{\rm 5\;GHz} \sim (L_{e^\pm}\,t_{\rm cool}/E_{\rm inj})(E/t_{\rm sync})_{\rm 5\;GHz}$ where $E_{\rm 5\;GHz}$ comes from $\dot{E}(r)$ ($\sim$ 10 mJy)
- Spectra: IC cooling ($F_\nu \propto \nu^{-1/2}$), adiabatic cooling (F_ν flat), free free absorption (F_ν harder)
- Size: IC cooling ($X_{\rm radio} \sim r_{\rm inj}$), adiabatic cooling ($X_{\rm radio} \sim r_{\rm inj}\,(E_{\rm inj}/E_{\rm 5\;GHz})^{2/3} \gg r_{\rm inj}$)

Detailed study

- Monte-Carlo calculations
- Photons are injected in the system and followed till absorbed in the stellar photon field.
- Pairs follow the magnetic field lines (adiabatic invariant approximation) or diffuse anisotropically.
- Pairs evolve suffering IC, synchrotron, adiabatic, relativistic Bremsstrahlung and ionization losses.

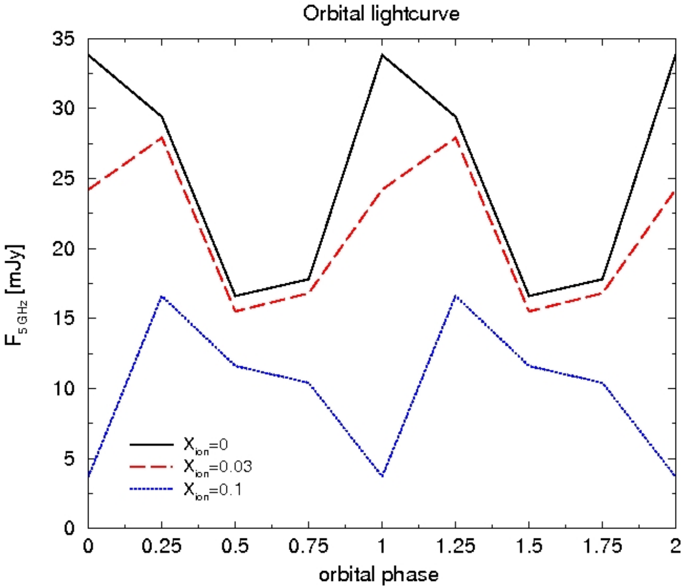
Outline

Particular case: LS 5039

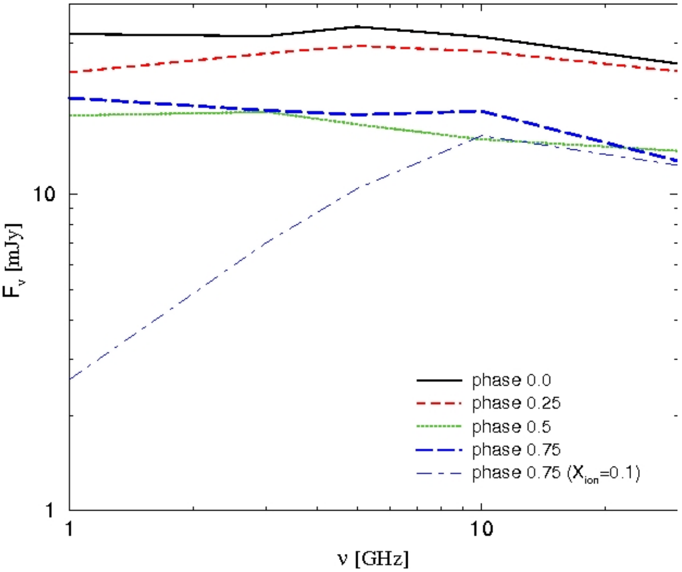
- $L_* = 7 \times 10^{38}$ erg s^{-1}, $T_* = 38000$ K, $R_* = 7 \times 10^{11}$ cm
- $e = 0.33$, $a = 2.2 \times 10^{12}$ cm
- $i \sim 30^\circ - 60^\circ \to 45^\circ$
- $v_{\mathrm{w}\infty} = 2.5 \times 10^8$ cm s^{-1}, $v_{\mathrm{tan}} = 0.1\, v_{\mathrm{w}\infty}$
- $\dot{M}_{\mathrm{w}} = 3 \times 10^{-7}\, M_\odot$ yr^{-1}
- $B_* = 200$ G, $B_{\mathrm{r}} = 200\,(R_*/r)^{-2}$ G, $B_\phi = 200\,(v_{\mathrm{tan}}/v_{\mathrm{w}\infty})\,(R_*/r)$ G
- $D = 0.01\, D_{\mathrm{Bohm}}$ $(\delta B(r_{\mathrm{g}}) = 0.1\, B)$
- $L_{\gamma\ >10\ GeV} = 10^{36}$ erg s^{-1} $(\tau \geq 1)$
- $\Gamma = 2.3$
- Gamma-ray emitter at the compact object location (0th order).

(Casares et al. 2005; Usov & Melrose 1992; Aharonian et al. 2006)

Phase 0.0, $\sim$ SUPC

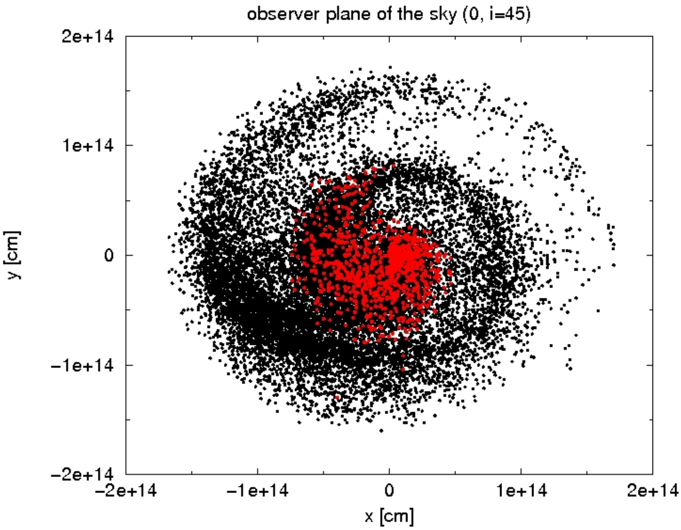


Spectral energy distribution along the orbit



Outline

Phase 0.0, $\sim$ SUPC; electrons



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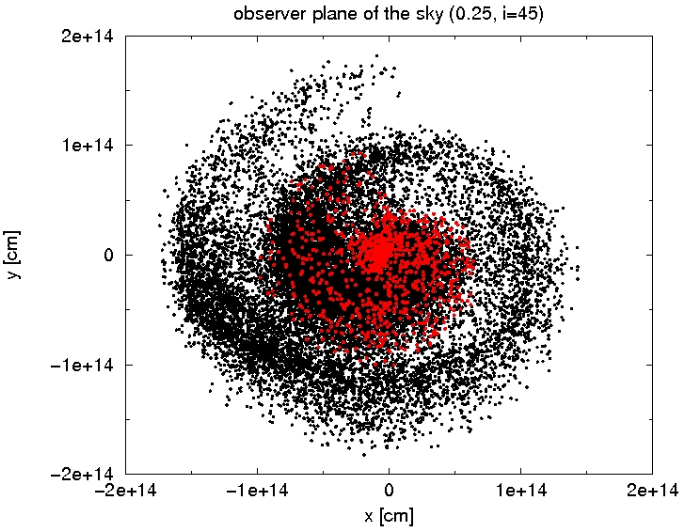
observer plane of the sky (0.25, i=45)
2e+14
1e+14
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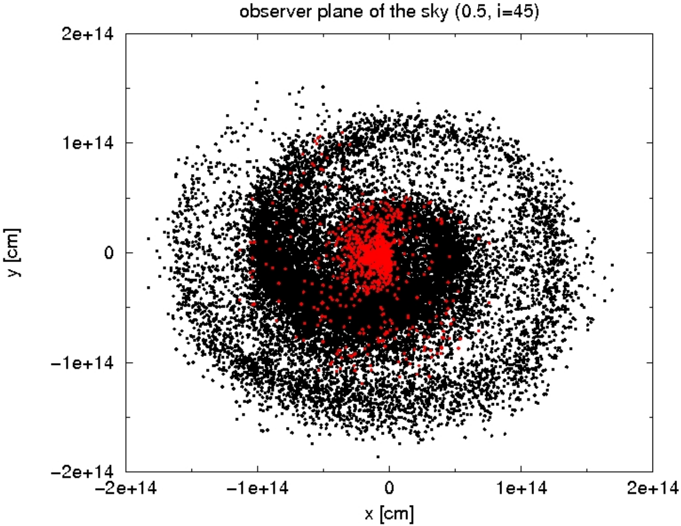
−1e+14
−2e+14
y [cm]
−2e+14
−1e+14
0
1e+14
2e+14
x [cm]

Phase 0.5



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1e+14
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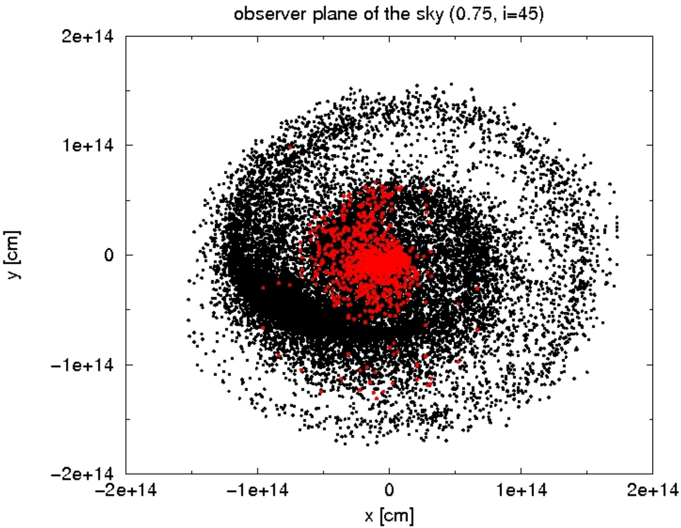
−1e+14
−2e+14
y [cm]
−2e+14
−1e+14
0
1e+14
2e+14
x [cm]

Phase 0.75, $\sim$ INFC



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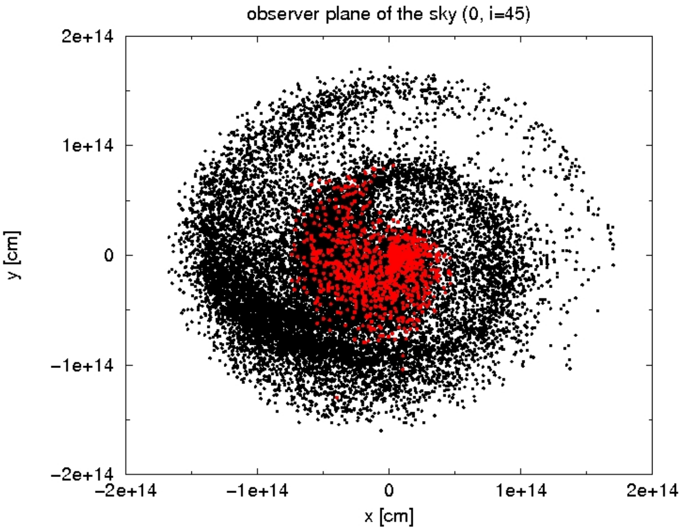

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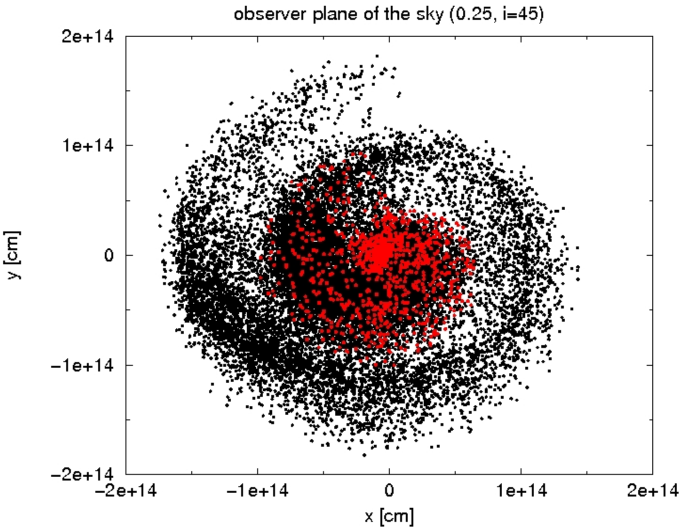

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1e+14
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−1e+14
−2e+14
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0
1e+14
2e+14
x [cm]

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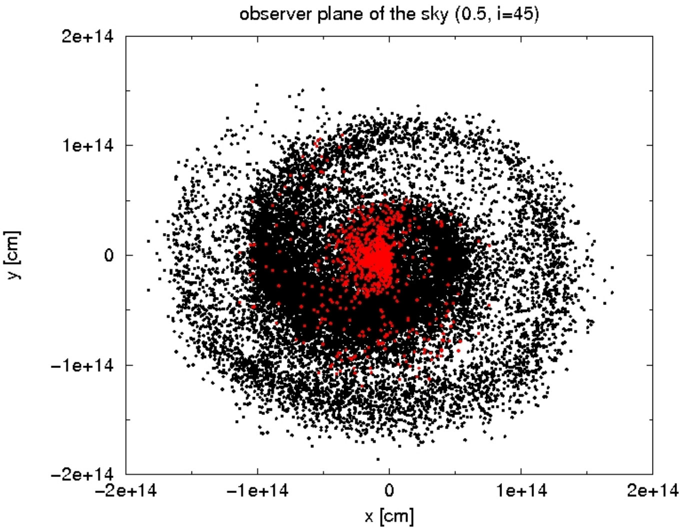

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1e+14
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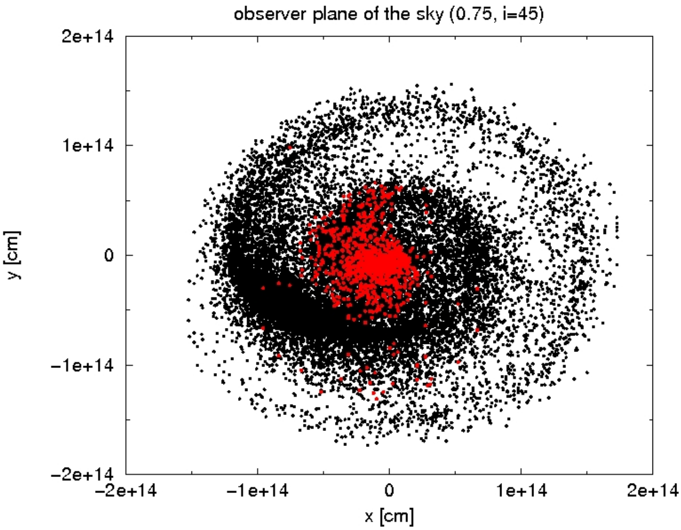
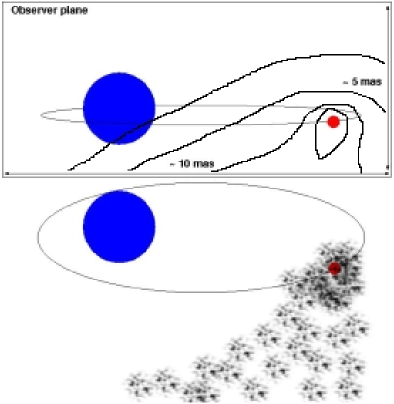
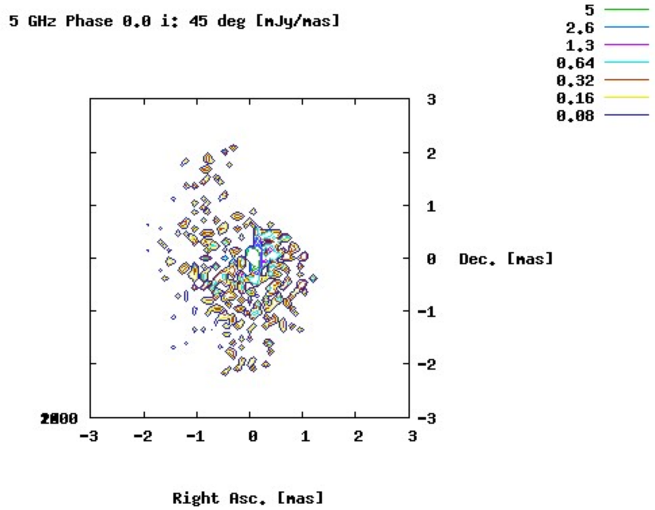


Imaging the system



Phase 0.0, $\sim$ SUPC; source



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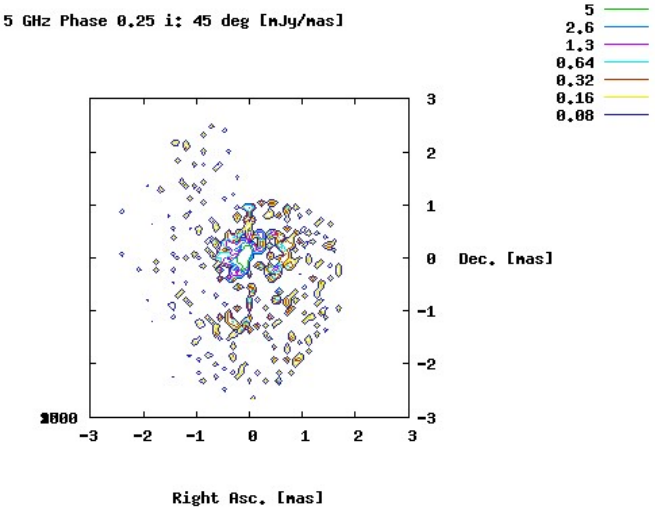

5 GHz Phase 0.25 i: 45 deg [mJy/mas]
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Dec. [mas]
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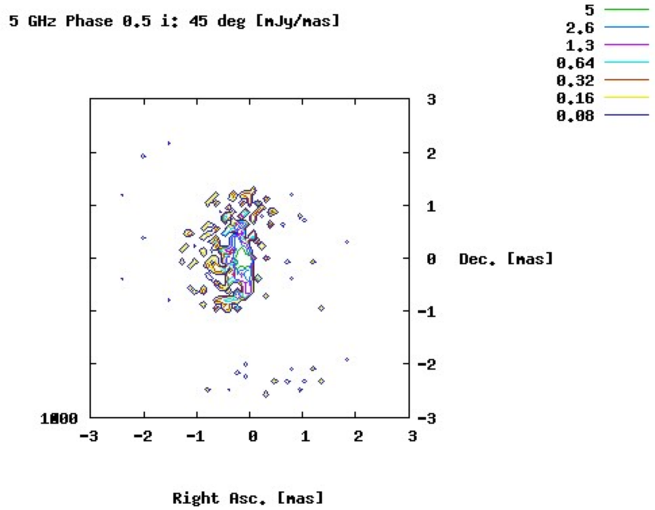
Right Asc. [mas]

Phase 0.5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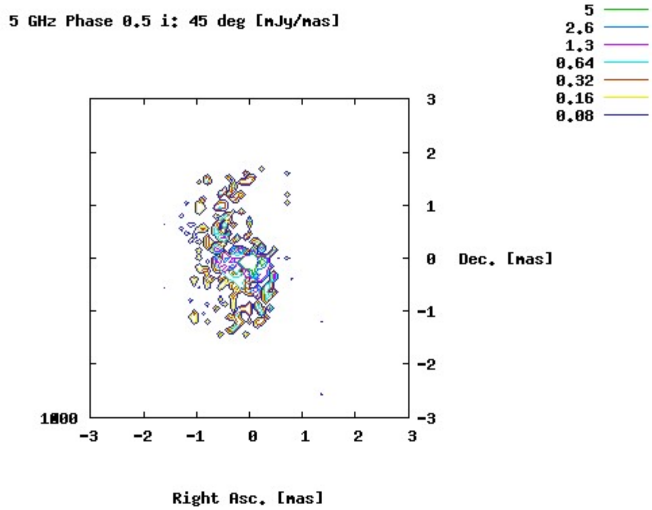
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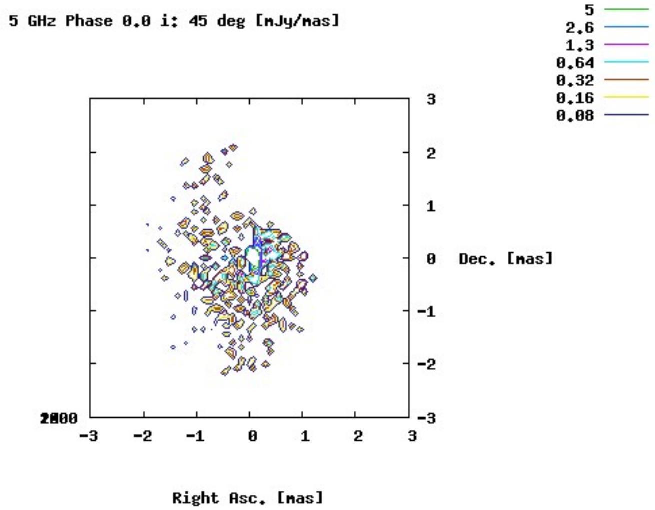

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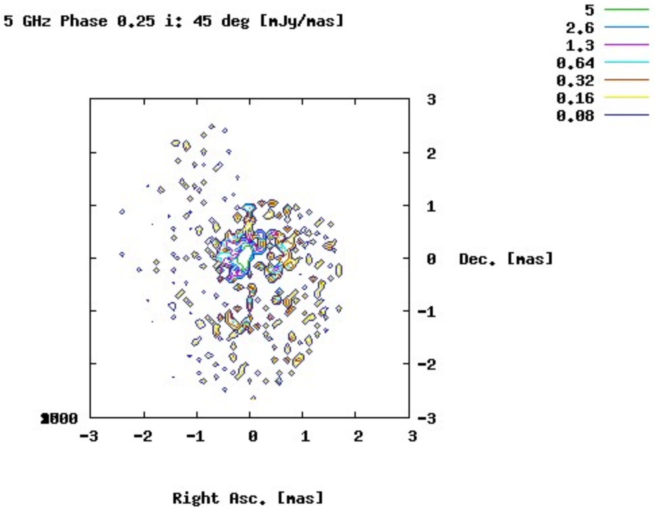

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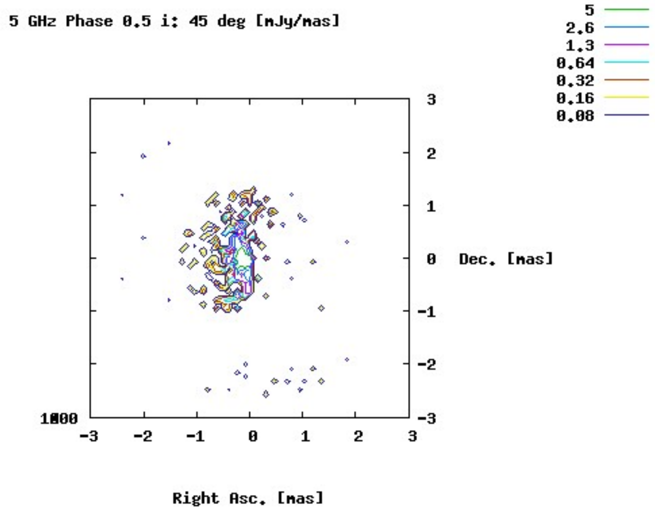

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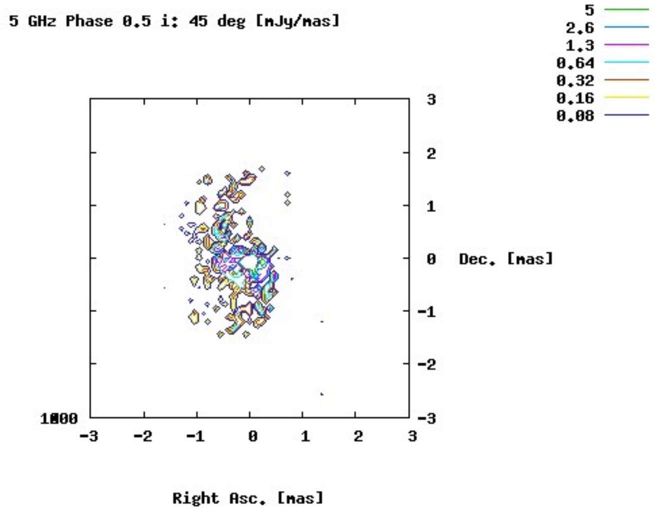
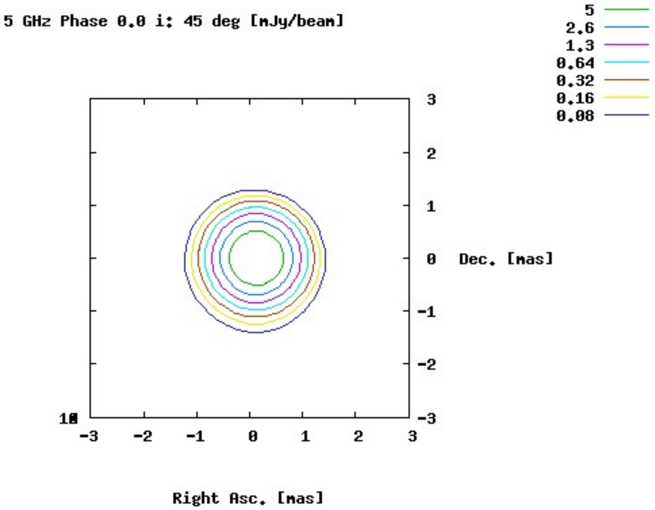
Phase 0.75, $\sim$ INFC





5 GHz Phase 0.0 i: 45 deg [mJy/beam]
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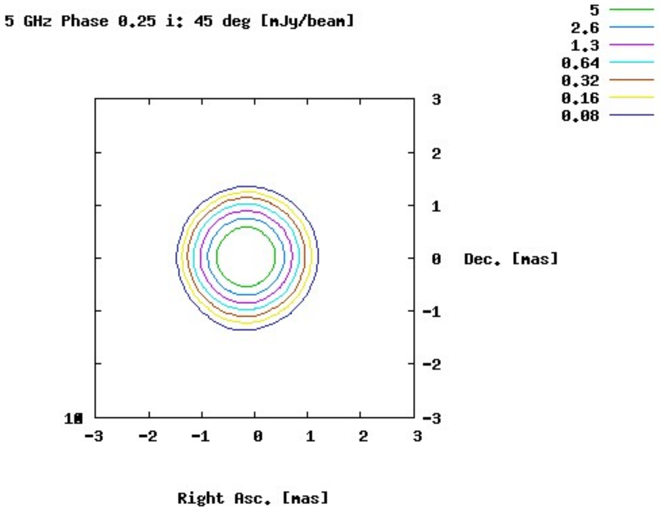
Phase 0.25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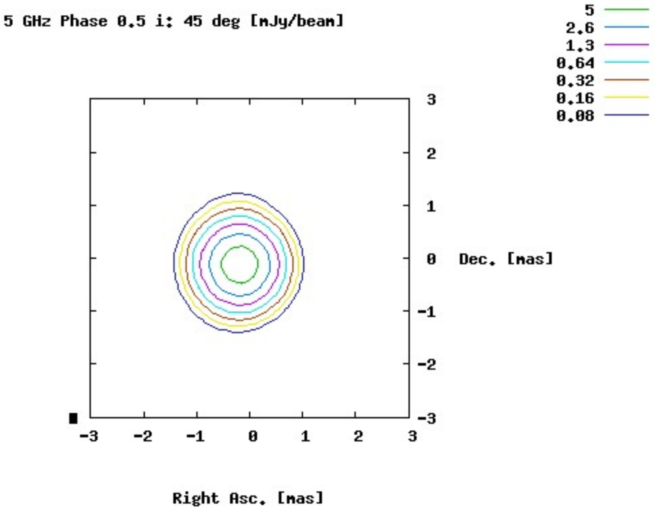
Phase 0.5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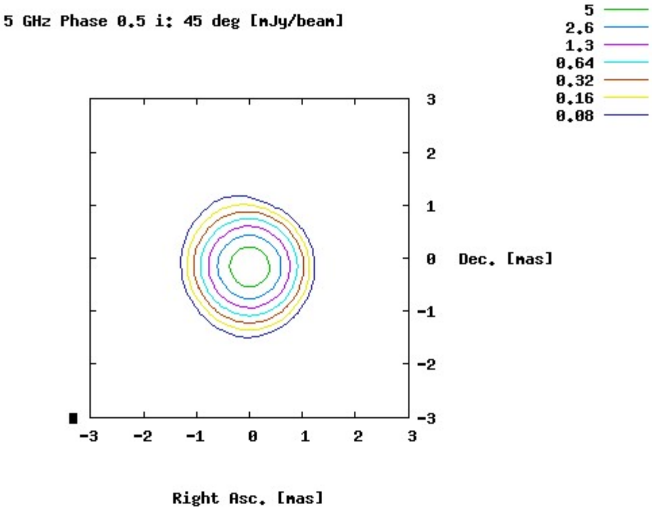
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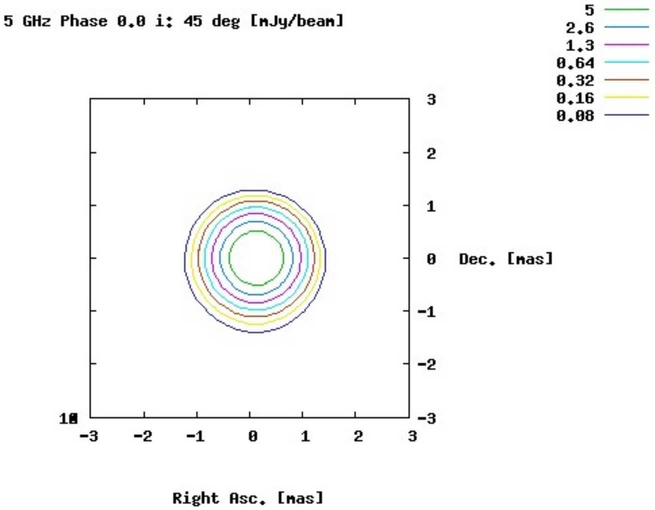
Phase 0.0, $\sim$ SUPC



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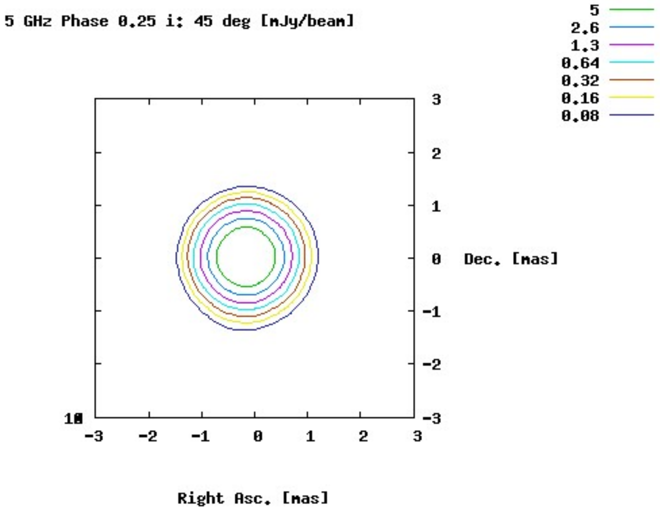

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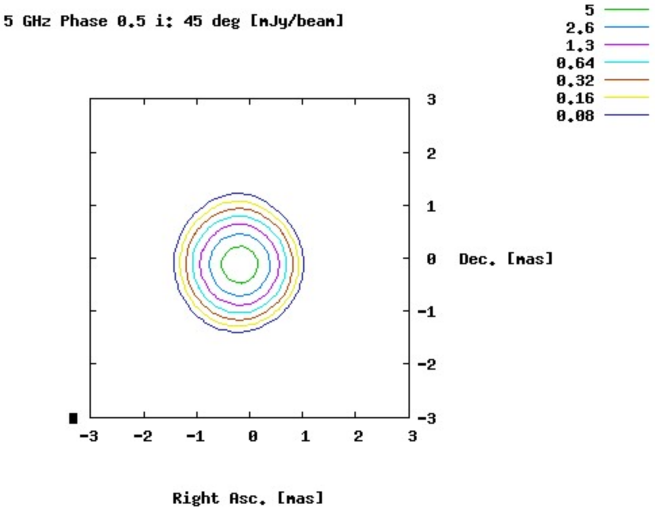

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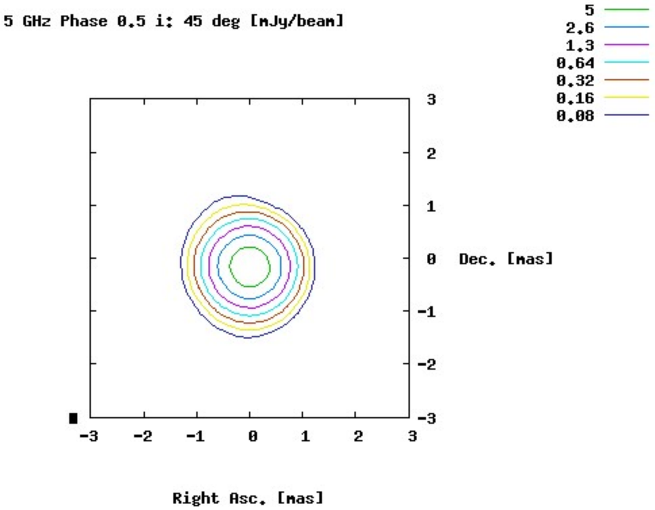
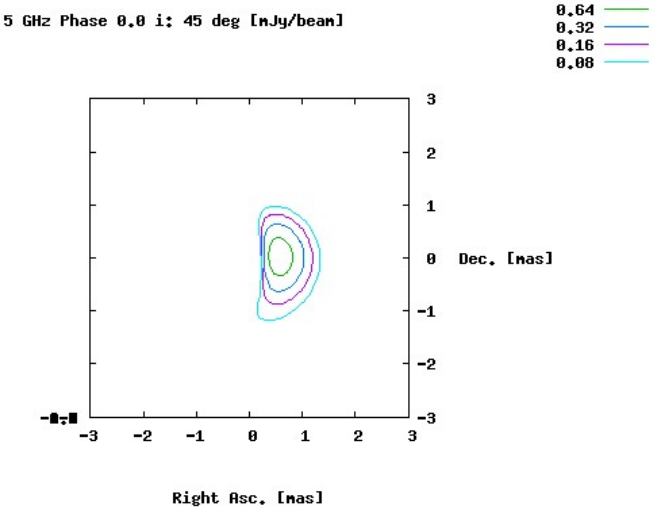


Phase 0.0, ∼ SUPC; residuals



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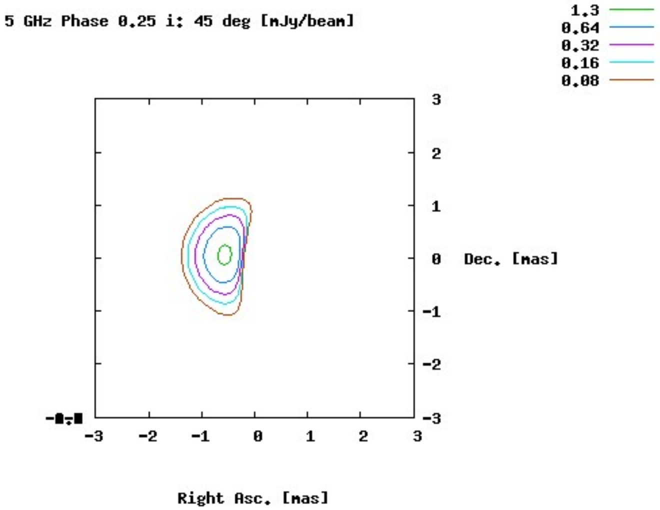

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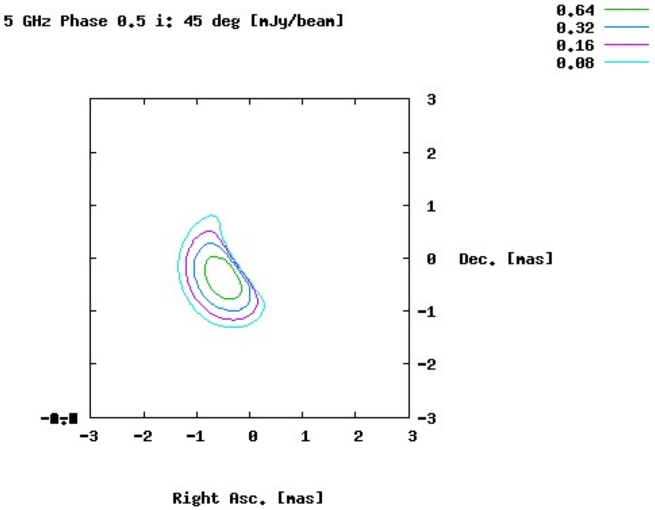

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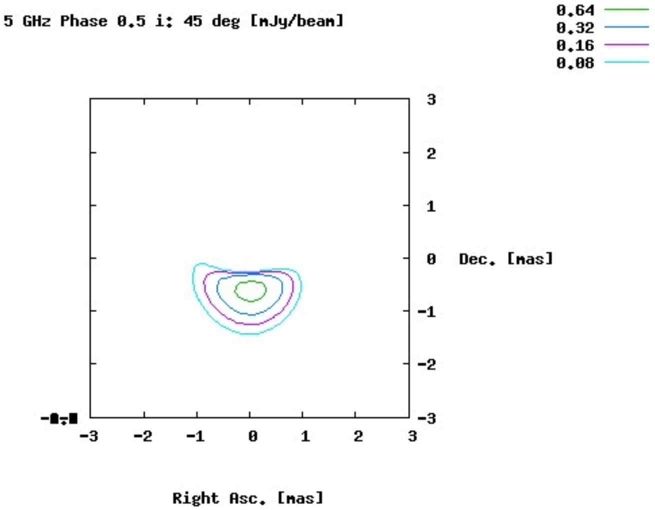

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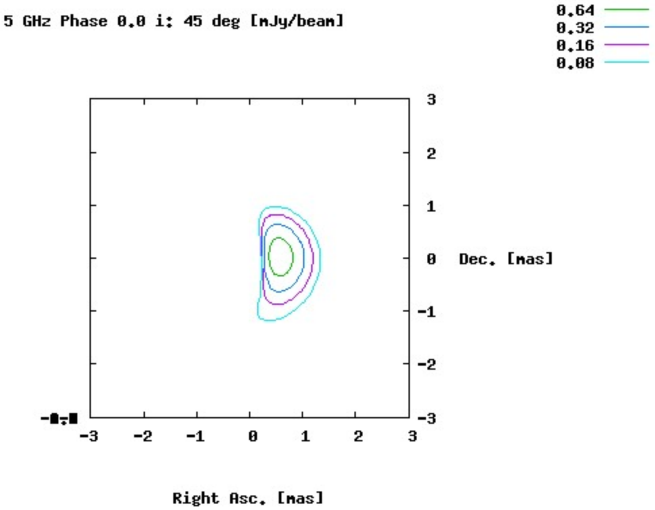

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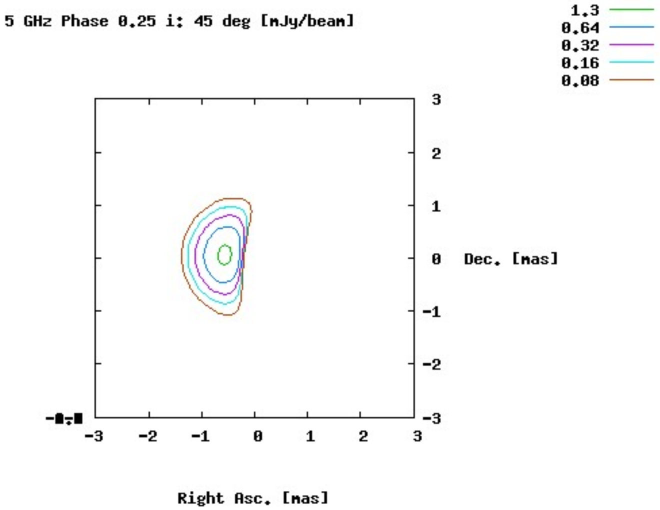
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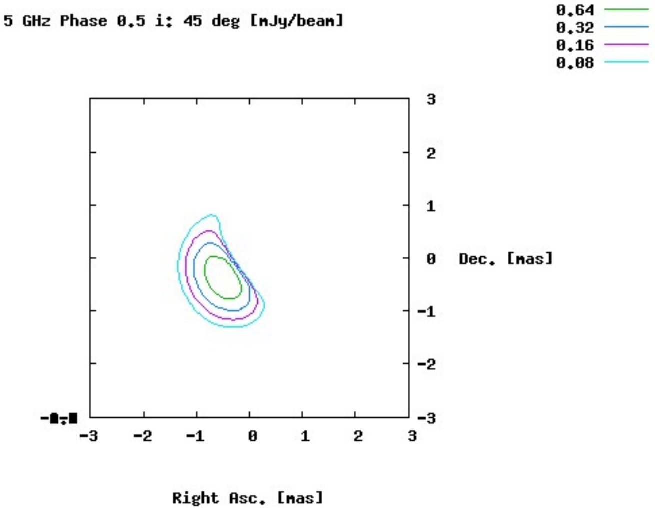

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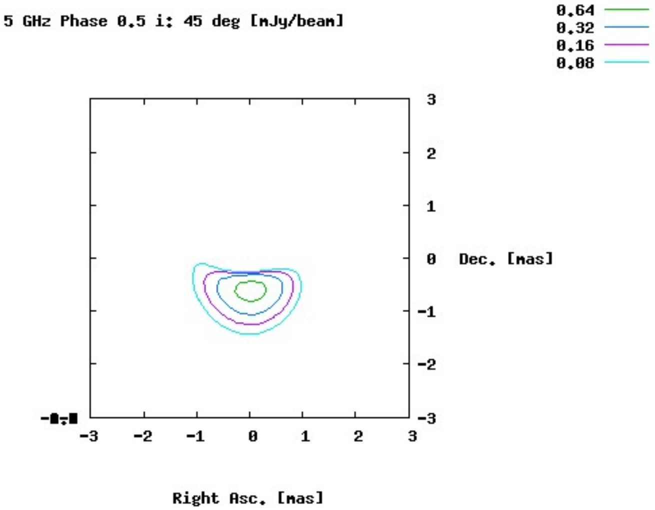

Outline

Summary

- The production of gamma-rays $\geq$ 100 GeV in massive gamma-ray binaries leads to $e^{\pm}$ creation.
- Pairs rapidly isotropize and radiate.
- Radio fluxes are detectable.
- Moderate amount of radio variability is expected.
- Radio spectra tend to be flat.
- The structures are resolvable and change significantly along the orbit.
- Important parameters are the magnetic field and the ionization of the wind.
- X-ray-to-radio flux ratios depend strongly on $B(r)$, $r_{\rm inj}$ and Γ.