Non-thermal Hard X-ray Emission from Colliding Wind Binary Systems

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Abstract: ***Colliding-wind massive star binaries are known to produce strong shocks in their wind-wind interaction regions. The interaction region is the scenario of several physical processes, including strong thermal X-ray emission and in several cases particle acceleration up to relativistic energies. The latter process is still poorly understood in these environments, and deserves a particular attention in stellar astrophysics. The investigation of particle acceleration is a critical aspect of high-energy astrophysics, especially at energies above 10 keV where non-thermal emission processes dominate. We discuss the possibility to detect the hard X-ray emission from WR147, a well-known particle accelerator, using Astro-H Hard X-ray Telescope (HXT) and Soft Gamma-Ray Detector (SGD), and to probe the particle acceleration process at work in its colliding-wind region.***

Colliding wind system WR 147

We focus here on the colliding wind binary WR 147. Among other colliding wind binary systems, known to accelerate particles, this system is exceptional due to its bright radio emission and very nearby location, at about 650 pc from Earth. Also thanks to the large projected star separation distance of $6\cdot10^{15}$ cm this system has been resolved in X-rays (ref. 2), and this is currently the only case for colliding wind binary systems. Its X-ray spectrum has been intensively studied below 10 keV (ref. 3 and ref. 4), and INTEGRAL/ISGRI observations provided an upper limit on the flux above 10 keV (ref. 5).

The radio emission from this source is dominated by the non-thermal component, related to a population of relativistic electrons accelerated in its wind-wind interaction region (Fig. 2 and ref. 6). Thus, it is likely that systems similar to WR 147 are capable to produce non-thermal emission also at energy bands higher than radio. Indeed, in the presence of relativistic electrons accelerated through the diffusive shock acceleration mechanism, UV photons from the bright stars in the system could be up-scattered to the high-energy domain through inverse Compton scattering, producing non-thermal X-rays and gamma rays. In particular, such a scenario is most probably responsible for the hard X-ray tail that has been detected with Suzaku in the case of the emblematic colliding-wind binary system WR 140 (ref. 7).

For a general overview of the non-thermal processes taking place in massive binary systems we refer to the De Becker et al. Poster (this Session, ref. 1).

Non-thermal emission from WR 147

Our aim is to develop a radiation model that is consistent with the hydrodynamical structure of the the interacting winds in colliding wind binary systems. Thus, first we have developed a hydro code suitable for a rough description of the flow structure. The result of the calculations is presented in Fig. 1, where the computed density distribution is shown.

On top of the obtained hydrodynamical solution we apply a kinetic code, which computes the distribution of the non-thermal particles. The kinetic part extensively uses the results obtained via hydrodynamical modelling. In particular,

(1) The non-thermal particles were assumed to be accelerated at the wind termination shocks. The properties of the shock obtained in the hydrodynamical modeling were used to determine the initial spectrum of the non-thermal particles assuming that the acceleration is governed by the Fermi I process

(2) The non-thermal particles were assumed to propagate downstream along the flow current lines, and particle evolution was computed consistently with the local photon field, adiabatic loss rate (which was calculated on the base of the hydrodynamical solution), and the magnetic field (which was calculated adopting the froze-in condition in the hydrodynamical part)

This allowed the derivation of the spartial-energy distribution of the non-thermal particles to be calculated. Finally, we have computed the synchrotron and inverse Compton radiation produced by these particles. The broadband spectral energy distribution is shown in Fig. 3.

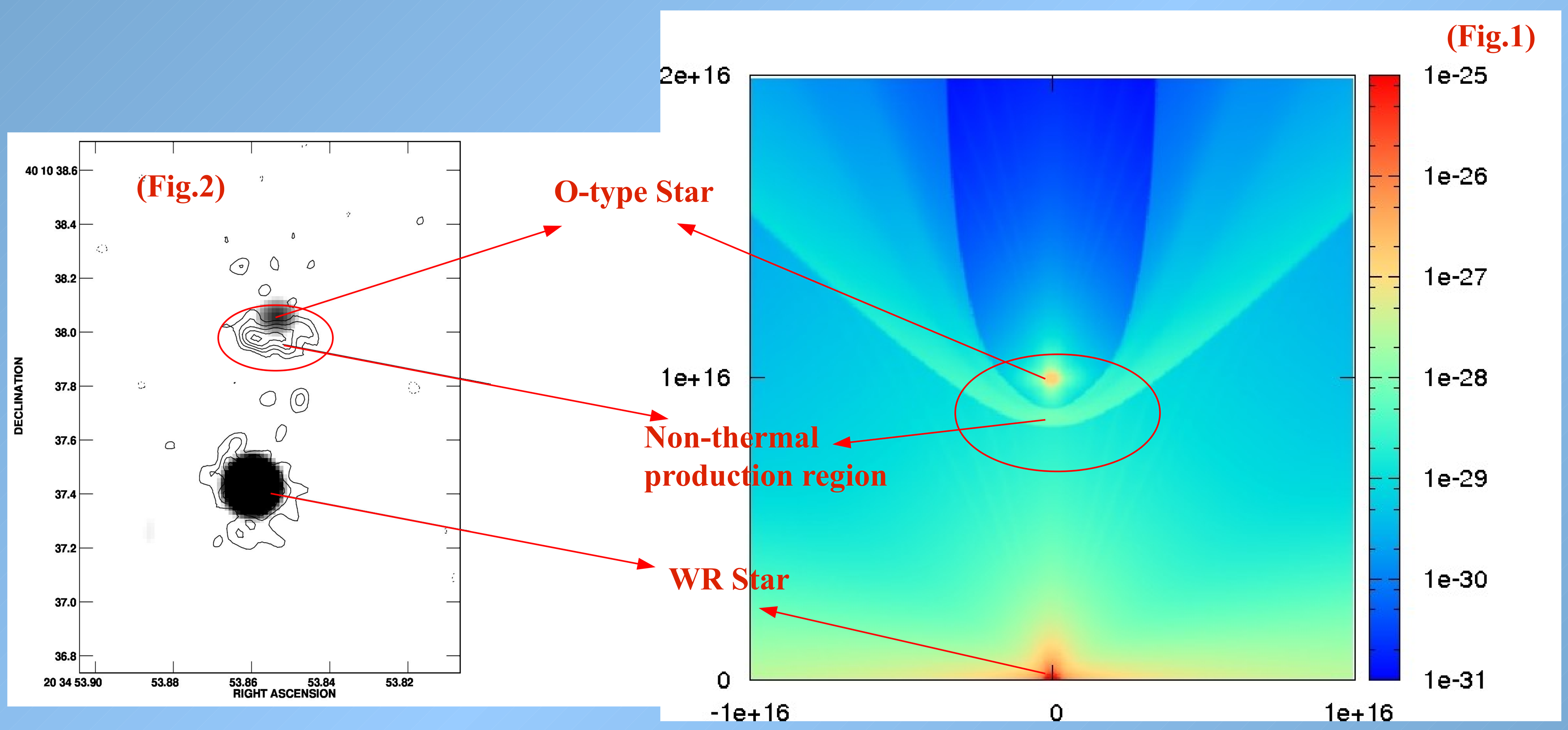

Fig. 1 : Distribution of density (in cgs units) in the wind collision region of WR 147 obtained via hydrodynamical numerical modelling. **Fig. 2:** Overlay of an infrared image of WR 147 with radio coutours. The position of the non-thermal radio emission is coincident with that of the expected stagnation point between the two winds of the components in the system. The Fig.2 is adopted from **Ref.6**

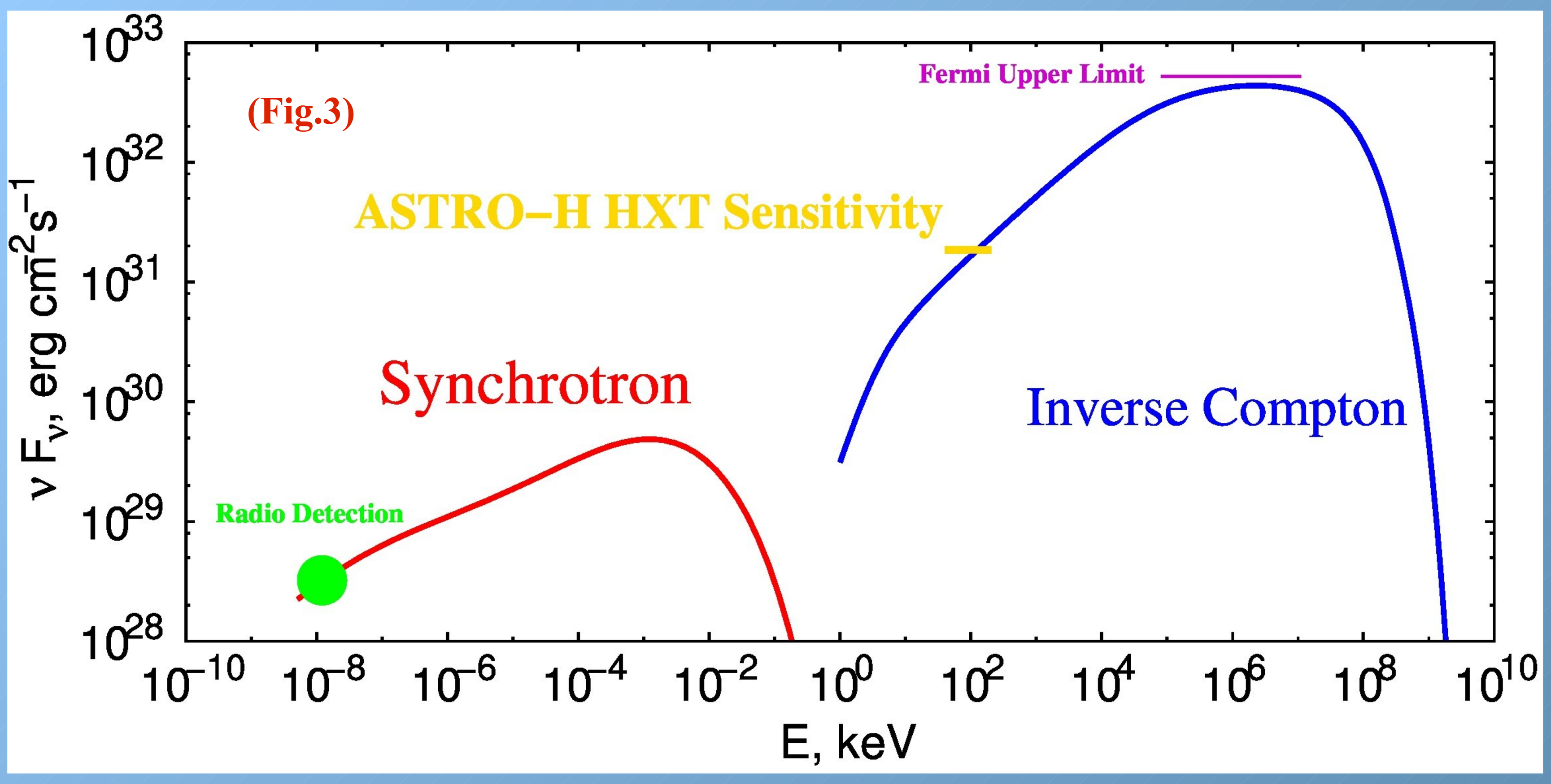

Fig. 3 : Broad band spectral energy distribution of the synchrotron and inverse Compton radiation. The computation of the emission was performed consistently with the hydrodynamical calculations shown in Fig. 1. It was assumed that the non-thermal particles obtained 0.1% of the kinetic luminosity of the winds injected into the interaction region. Regarding the magnetic field it was assumed that downstream its stregth is determined by the froze-in conditions, and in the upstream region $B=10^{-3}(R_*/10^{-15}\ \mathrm{cm})^{-2}$G, where R_* is the distance to the corresponding star. The target photon field for the inverse Compton scattering was provided by the optical stars. It can be seen that while the synchrotron component is responsible for the radio emission, the inverse Compton component is dominant in the X- and gamma-ray energy bands.

References

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Concluding remarks:

(1) Hydrodynamical modelling of the wind interaction in colliding wind binary systems revealed that conditions on the wind termination shock **are** suitable for acceleration of ultrarelativistic particles with energies up to 100GeV

(2) Two distinct emission components are expected from the system. The synchrotron radiation is emitted from radio to UV, and the inverse Compton component dominates from hard X-rays to gamma ray energies

(3) The found WR 147 non-thermal radio fluxes allow to normalize the intensity of the synchrotron component, which appears detectable only at radio frequencies independently on the magnetic field strength

(4) The relative intensity of the inverse Compton emission depends on the particle distribution energy, and thus on the strength of the magnetic field (through the radio data), in the stellar winds, being the latter at present not robustly determined. While for magnetic fields of $B>>10^{-3}$ G at the distance of 10^{15} cm from the star, the hard X-ray emission should remain undetectable with ASTRO-H, smaller intensities of the B-field ($B<<10^{-3}$ G) lead to gamma-ray fluxes above the *Fermi*/LAT upper limits (for detail see **ref.8**)

(5) For $B\sim10^{-3}$ G, the inverse Compton component should not violate the Fermi/LAT upper limits and be detectable with HXT of ASTRO-H