Particle acceleration in colliding-wind massive binaries: a relevant science case for ASTRO-H

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Abstract: ***The strong stellar winds of massive stars in binary systems interact through shocks responsible for several phenomena, including significant particle acceleration up to relativistic energies. The existence of this relativistic particle population is mainly revealed through detection of bright synchrotron radio emission in the case of a few tens of systems. More recently, Suzaku observations revealed the existence of non-thermal X-rays in the case of two colliding-wind binaries (CWBs), confirming the prediction that inverse Compton scattering should be at work in these objects. In this context, the ASTRO-H mission constitutes the ideal tool to investigate non-thermal phenomena in hard X-rays (above 10 keV), where the well-known thermal emission from the shocked winds should not be significantly present. This poster gives an overview of this science case, and provides clues for the expected input of ASTRO-H in the study of these objects.***

Colliding-winds in massive binaries

The stellar winds of the infividual components in CWBs interact, producing strong shocks responsible for a rise of the temperature of the post-shock plasma up to several tens of MK. Such a hot plasma is able to produce X-rays, in the form of emission lines on top of a free-free continuum, i.e. thermal emission spectrum *(ref.1,2)*.

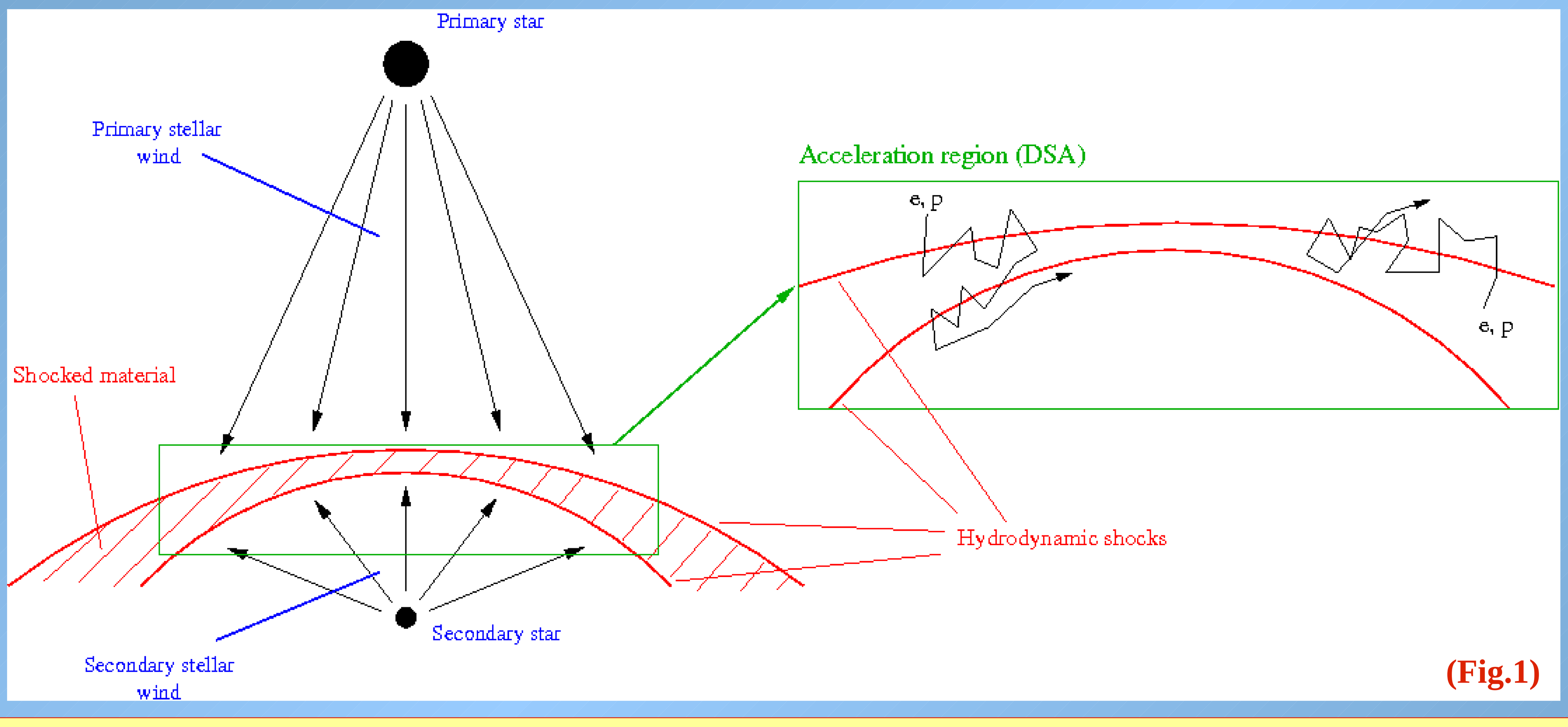
• The properties of the soft X-ray spectrum are intimately related to the physical properties of the wind interaction region. The complex hydrodynamics of colliding winds can therefore be studied through a detailed investigation of the X-ray spectrum they produce.

Particle-accelerating colliding-wind binaries (PACWBs)

• Beside the production of thermal X-rays, a fraction of the energy injected in colliding-winds can be channelled to particles that are accelerated up to relativistic energies. In the presence of strong shocks, Diffusive Shock Acceleration (DSA) is likely to be at work.

• Observational support for this scenario comes from two facts :

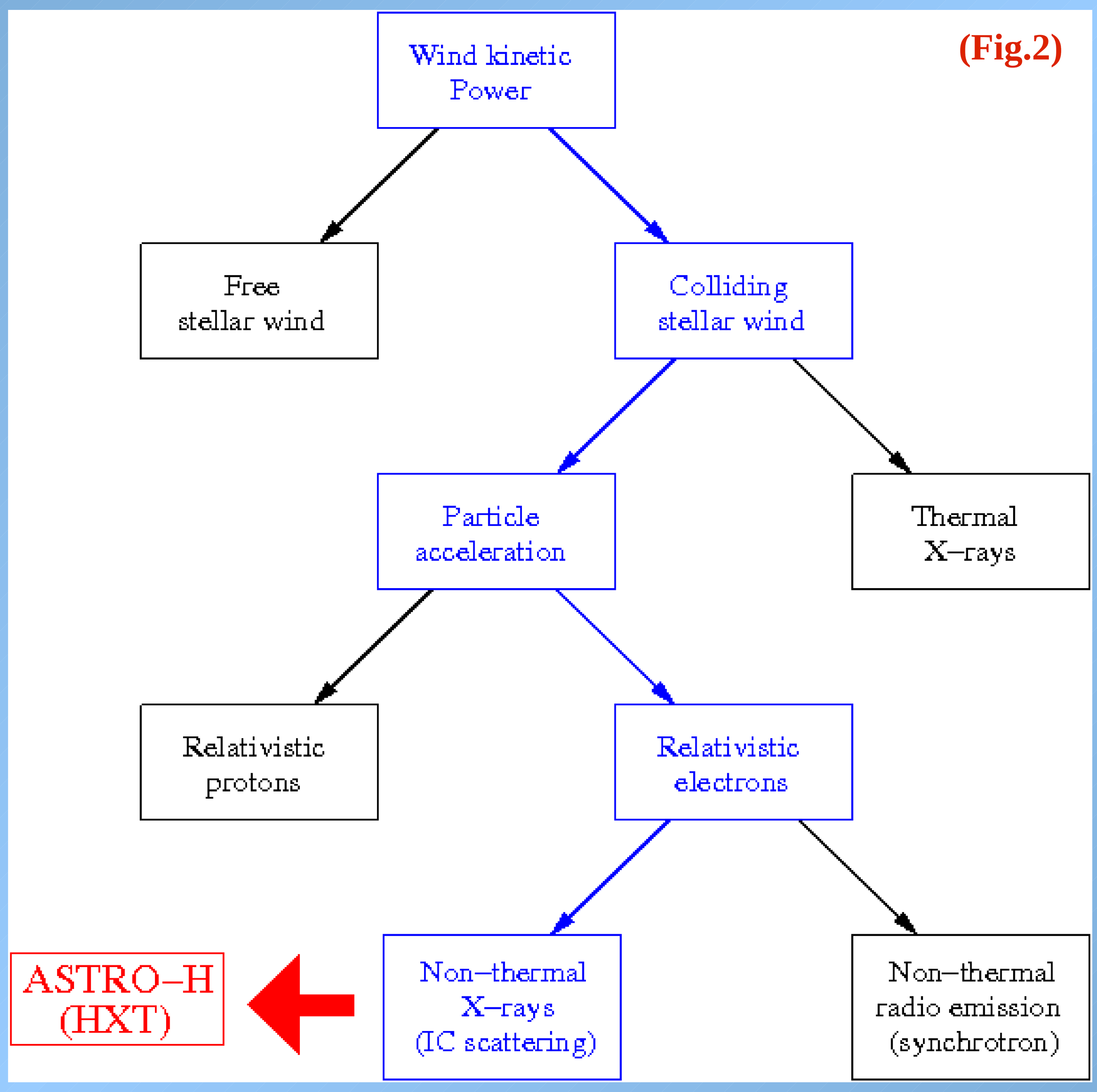
1. Synchrotron radio emission has been firmly identified for about 40 massive stars *(ref.3,4)*, among which about 85% are at least suspected - and most which confirmed - binaries. Synchrotron radiation implies the existence of a population of relativistic electrons.
2. In the case of 2 CWBs, non-thermal radiation has also been unambiguously detected in the high energy regime. These systems are WR140 and Eta Carinae, both detected in hard X-rays using Suzaku *(ref.5,6)*. In addition, Eta Carinae has also been identified as a gamma-ray emitter thanks to AGILE and Fermi observations *(ref.7,8)*.



(Fig.1)

Schematic view of a colliding-wind massive binary system made of two stars producing stellar winds with different strengths (e.g. a WR + O binary). DSA occurs at the shocks, with significant acceleration of electrons and protons. Depending on the mean free path of accelerated particles, their acceleration may potentially involve both shocks. Electrons may interact with the magnetic field to produce the synchrotron radio emission, or with the photon field from the stellar photospheres (inverse Compton scattering) to be up-scattered to the high energy domain (hard X-rays or even gamma rays). These processes involving electrons are referred to as **leptonic processes** The interaction of relativistic protons with ambient thermal material may also generate neutral pions that decay to produce gamma rays. The latter case is referred to as a **hadronic process**.

The role of ASTRO-H in the context of the study of PACWBs



(Fig.2)

• In a CWB, the energy involved in particle acceleration is taken from the kinetic power of the stellar winds. In an asymmetric system as illustrated in *Fig.1*, let us consider that most of the kinetic power comes from the primary :

$$P_{kin} = \frac{1}{2}\dot{M}\,V_{\infty}^{2}$$

The fundamental parameters defining the available energy are the mass loss rate ($\dot{M}$) and the terminal velocity (V_{∞}) of the stellar wind.

A fraction of this energy is involved in the wind-wind interaction, and at most a few % is transferred to relativistic particles, mainly electrons and protons (*Fig.2*). IC scattering, the most efficient cooling process for electrons, is responsible for the production of non-thermal X-rays in the hard X-ray domain *(ref.3,9,10)*.

• In the context of this science case, the strong advantage of ASTRO-H is its **unprecedented sensitivity in the hard X-ray domain (HXT)**, i.e. where the strong thermal emission from the colliding-winds is not anymore dominating the spectrum, to detect a priori rather faint hard X-ray sources *(ref.11)*

→ measurement of the energy content of relativistic electrons can be performed with the Hard X-ray Telescope on-board ASTRO-H (only a very small fraction of that energy is injected in synchrotron emission)

• The non-thermal X-ray spectrum should be a power law. The determination of the spectral index is pivotal to understand the physics of particle acceleration in CWBs. We refer to the Khangulyan et al. Poster (this Session, *ref.12*) for more quantitative estimates relevant to one PACWB in particular : WR147.

• Other instruments on-board ASTRO-H should also simultaneously provide important information about the physical conditions in PACWBs : SXT in soft X-rays to improve hydrodynamical models of colliding-winds, and SGD to allow a detection of soft gamma-rays in some cases, revealing further information about the particle acceleration process.

References

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Concluding remarks:

(1) CWBs are privileged targets for the study of many physical processes in relation with the interaction of stellar winds, including particle acceleration physics in a part of the parameter space somewhat different from that of supernova remnants, pulsar wind termination shocks, Galactic and extragalactic jets.

(2) The Hard X-ray Telescope on board ASTRO-H constitutes an unprecedented tool to investigate non-thermal phenomena in the high energy domain, and in particular to investigate the physics of particle acceleration in colliding-wind binaries.

(3) So far, about 40 systems have been indentified, covering a wide parameter space. Observational strategies coud be easily defined to observe some of them with ASTRO-H, and lift some part of the veil covering these objects.

(4) The strong complementarity with gamma-ray facilities (to study the high-energy electron cutoff and probe hadronic processes) will allow the determination of the non-thermal energy budget in CWBs, and locate these objects in the broader context of the production of Galactic Cosmic-Rays. Because of the high energetics involved, PACWBs are indeed good candidates to provide a contribution to low energy Galactic Cosmic-Rays.