Shock heating and acceleration by RCW 86

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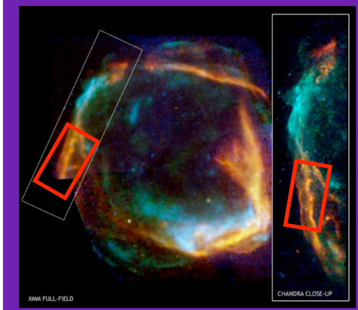

Fig 1: Combined XMM and Chandra image of RCW 86. The red boxes indicate the position of the central image of this poster, which is made in the $H\alpha$ band.

Slit of Southern spectrum

Introduction

Supernova remnant RCW 86 is a remnant with two faces. The South-Western part has a mostly thermal X-ray spectrum [1] and is very bright in optical. Shock velocities of this part are around 700 km/s [2], which disagrees with the remnant originating from the supernova of 185 A.D., recorded by Chinese astronomers. In the North-East side, the X-ray spectrum is dominated by synchrotron radiation [3]; a sign for efficient shock acceleration. Moreover, X-ray synchrotron can only be established for shock velocities higher than 2000 km/s [4], which makes the association with SN185 more probable. How fast is the shock and how efficient is the cosmic ray acceleration in the North-East of RCW 86?

Theory

According to the Rankine Hugoniot jump conditions, the temperature behind a shock is related to the shock velocity via $kT_i = 3/16 m_i v^2$. So, measuring the temperature behind a shock gives us a measure for the shock velocity. More specific, a shock velocity of 2000 km/s corresponds with a kT of 7.8 keV.

RCW 86 shows in the NE side non-radiative $H\alpha$ emission. This means that it has a spectrum which consists of a small and a broad peak at 656.3 nm; $H\alpha$ [5]. The narrow peak is caused by neutral hydrogen swept up by the shock, which gets excited and emits a photon afterwards. This has the thermal velocity distribution of the ISM and hence gives a narrow emission peak.

The broad peak is also emitted by neutral hydrogen swept up by the shock, however, now the neutral hydrogen first exchanges an electron with a proton which already has the temperature of the post-shock plasma, when this neutral hydrogen atom now gets excited and emits a photon, we get a broad emission peak, from which we can determine the downstream temperature of the shock.

If a shock is efficiently accelerating cosmic rays, a substantial part of the energy is absorbed by this process and the pressure behind the shock is partly caused by cosmic ray pressure. This changes the temperature in such a way, that for the same shock velocity, there is a lower T [6].

Observations

We took spectra with the VLT at two locations along the Eastern rim. The Southern pointing (central image) coincides with an X-ray spectrum which also shows thermal line emission. The X-ray spectrum of the Northern pointing is non-thermal. We extracted the spectrum and fitted two Gaussian line profiles, convolved with the PSF to the spectra (Fig. 2). Since the width of the 2.5'' slit translates into a spectral resolution of 340 km/s, we only determine the FWHM of the broad Gaussian, which is 1020 ± 30 km/s (1.9 keV) for the Southern pointing and 1270 ± 60 km/s (3.1 keV) for the Northern pointing.

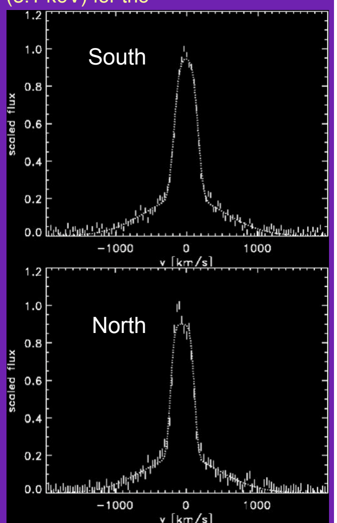

Fig 2: Spectra of both pointings; 0 km/s corresponds with 656.3 nm ($H\alpha$).

Conclusions/Future work

- The temperature in the North West of RCW 86 is significantly higher than in the East, but still significantly lower than 7.8 keV; the temperature for a 2000 km/s shock.
- There are two possible explanations for this:
  1. Either the shock has recently slowed down and the X-ray synchrotron we see is emitted by electrons accelerated in the past (less than 500 years ago).
  2. Or the shock velocity is indeed 2000 km/s and the temperature is low because of efficient cosmic ray acceleration.

We can discriminate between these two options by measuring the true shock velocity. We have Chandra observations of this rim taken in 2004 and 2007. A shock velocity of 2000 km/s comes down to 0.5'' in 3 years at a distance of 2.8 kpc. A difference which can be resolved by Chandra.

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[1] Rho et al., 2002
[2] Ghavamian et al., 2001
[3] Vink et al., 2006
[4] Aharonian & Atoyan,1999
[5] Chevalier et al., 1980
[6] Ellison et al., 2005