An XMM X-ray and Molecular Line Study of Supernova Remnant Kes 78

Ping Zhou & Yang Chen
Department of Astronomy, Nanjing University, Nanjing 210093, P.R.China

Abstract

We have performed an XMM-Newton X-ray spectroscopic study for the northeastern (NE) edge of the Galactic supernova remnant (SNR) Kesteven 78 (Kes 78) and investigated the molecular environment of the remnant. The X-rays arising from the northeastern radio shell are emitted by underionized hot (1.5 keV), low-density (0.1 cm^{-3}) plasma with solar abundance, and the plasma may be of intercloud origin. Kes 78 seems to interact with the molecular clouds (MCs) at a systemic local standard of rest(LSR) velocity of 81 km s^{-1}, which may be responsible for the 1720 MHz OH maser at LSR velocity of 86 km s^{-1}. The SNR is also consistent in extent with a molecular cavity,. The SNR-MC association places the SNR at a kinematic distance of 4.8 kpc. The age of the remnant is inferred to be some 6 kyr.

XMM-Newton X-rays from the northeastern boundary

We extracted the on-SNR X-ray spectra from two regions (labeled with "A" and "B"), which cover the hard (green) and soft (orange) portions.

A double background subtraction method was used, as the X-ray source region is located near the edge of the FOV and is not very bright relative to the instrumental background,

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The X-rays from the radio brightness peak (region "A"), which along molecular strip appears to connect (see Figure 3), suffers a heavier absorption than those from other part along this XMM-observed section of the shell.

The ionization age of the X-ray emitting gas for region A t_i~4.4 kyr.

The thermal pressures of the X-ray emitting gas along the shell is lower than the magnetic pressure in the OH maser region by up to two order of magnitudes.

Table 1. Spectral fitting results for the Northern shell of Kes 78 with 90% confidence ranges and estimates of the gas density.

Regions	A	B
Net Count Rate (10^{-2} cts s^{-1})	3.61 ± 0.11 (MOS) 8.52 ± 0.27 (PN)	2.79 ± 0.10 (MOS)
χ^2_ν (d.o.f.)	1.04 (318)	1.17 (137)
N_H (10^{22} cm^{-2})	$1.04^{+0.09}_{-0.08}$	$0.70^{+0.12}_{-0.09}$
kT_x (keV)	$1.51^{+0.34}_{-0.50}$	$1.30^{+1.57}_{-0.65}$
$n_e t_i$ (10^{10} cm^{-3} s)	$1.82^{+0.89}_{-0.32}$	$2.03^{+4.88}_{-0.72}$
$f n_e n_H V/d_5^2$ (10^{56} cm^{-3})	$1.12^{+0.31}_{-0.25}$	$0.58^{+0.69}_{-0.29}$
Flux(10^{-12} erg cm^{-2} s^{-1})^a	$3.41^{+0.94}_{-0.77}$	$1.82^{+2.19}_{-0.92}$
$n_H/f^{-1/2}d_5^{-1/2}$ (cm^{-3})^b	$0.11^{+0.01}_{-0.01}$	$0.10^{+0.05}_{-0.02}$

Fig. 1. X-ray image of the NE part of Kes 78. Red: 0.5–1.0 keV, Green: 1.0–2.0 keV , Blue: 2.0–8.0 keV . 1.4 GHz radio contours are overlaid.

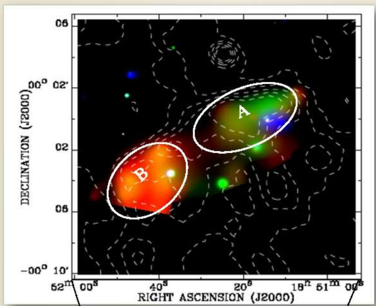
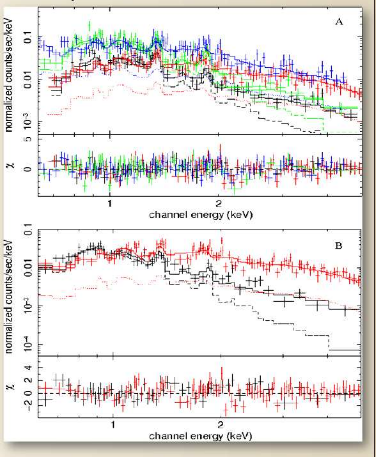


Fig. 2. XMM-Newton EPIC spectra of regions A and B defined in Fig. 1. The on-SNR spectra (*black* solid lines for EPIC-MOS and *green* solid line for EPIC-PN) are fitted as a sum of the diffuse background emission and the net SNR emission. The on-SNR diffuse backgrounds (*red* dotted lines for MOS and *blue* dotted line for PN) are scaled from the off-SNR spectra (*red* solid lines for MOS and *blue* solid line for PN), which are mimicked by an absorbed *nei* + *blackbody* model.



Millimeter molecular line observations and results

^{12}CO(1-0), ^{13}CO(1-0) and ^{12}CO(2-1) observations toward SNR Kes 78 were made with 13.7-meter millimeter-wavelength telescope of the Purple Mountain Observatory at Delingha (hereafter PMOD) and KOSMA.

Kes 78 seems to evolve in an interstellar environment of molecular gas with systemic velocity ~81 kms^{-1} :

1.**Morphological correspondence**:
the SNR is in the side of some dense MCs and is consistent in extent with a cavity of ^{12}CO gas (Figure 4).

2.**The velocity and location of the 1720MHz OH maser:**
at the velocity of 81 km s^{-1}, the SNR expands into a cloudy dense region in the east, where the 1720 MHz OH maser emission arises. The velocity offset between the OH maser and the main-body molecular cloud is as low as 5 km s^{-1}.

3.**Broadened ^{12}CO lines and relative enhancement of ^{12}CO J=2–1 to ^{12}CO J=1–0 in the maser region.**

For the clumpy molecular arc in the western boundary (indicated in figure 4), we also found broadened ^{12}CO line profiles at the clump cores and elevated ^{12}CO 2–1/1–0 ratios at the clump sides.

The association of SNR Kes 78 with the 81 kms^{-1} MC, together with the HI absorption along the line-of-sight places the SNR at a kinematic distance of 4.8 kpc.

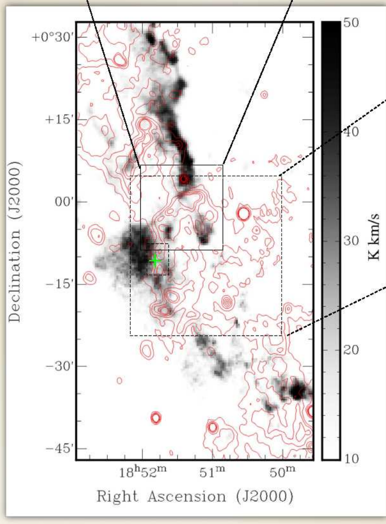


Fig. 3.Molecular environment of Kes 78 in 80–84 km s^{-1} interval (the BU-FCRAO GRS ^{13}CO (J=1–0) observation). The plus sign denotes the OH maser point.

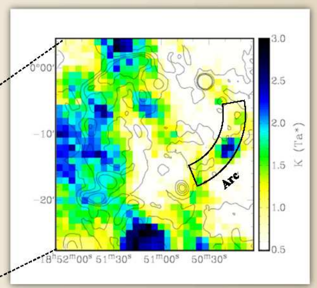


Fig. 4. Intensity maps of ^{12}CO (J=2-1) at V_{LSR}= 81 kms^{-1}.

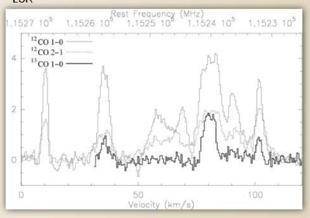


Fig. 5. The spectra of three CO transitions at the OH maser point defined in Fig. 3.

Global evolution

The velocity of the blast wave $v_s=[16kT_x/(3\mu m_H)]^{1/2}$ ~1.1 × 10^3 km s^{-1}.
The SNR radius r_s ~17pc . <= curvature radius of the eastern radio shell 12' .
The dynamical age of the remnant $t=2r_s/(5v_s)$ ~6.1 kyr
(derived with the Sedov evolution law. The ionization timescales ti~4.4kyr).
The explosion energy E ~4.7 × 10^{50} erg.

The dubious radio ridge

The north-south oriented radio continuum ridge west to the bright shell is suggested to be irrelevant with the SNR, but related to ~100 kms^{-1} CO branch at the tangent point, which is correspondent to IR bright, low-[SII]/H_α ratio star formation region(s).

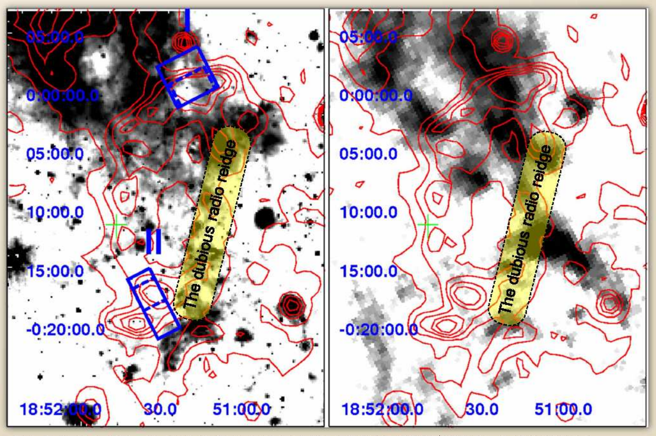


Fig. 5. Spitzer 24 μm map (left panel) and BU-FCRAO GRS ^{13}CO (J=1–0) antenna temperature map integrated from 99 km s^{-1} to102 km s^{-1} (right panel), both of the maps are overlaid with 1.4 GHz radio emission.