Kinematics of the ram pressure stripped ionized gas of two galaxies in the Coma cluster

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We report the results of deep optical spectroscopy of very extended Hα emitting clouds associated with two member galaxies, IC4040 and RB199, in the central region of the Coma cluster. The clouds have elongated filamentary morphology and extend over ~60 – 80 kpc. Our spectroscopy revealed that several bright blue knots in the clouds show intensive star-forming activity. The velocities of the clouds increase monotonically with the distance from the galaxies and the relative velocities reach up to ~600 km/s at 60 kpc from the galaxies. These findings suggest that the disk gas of IC4040 and RB199 were stripped by ram pressure caused by high-speed collision between the galaxies and the intra-cluster medium and inter-galactic star-formation occurs in the stripped gas.

1. Extended Hα clouds in the Coma cluster

The Coma cluster: nearby (z=0.0231; D=95 Mpc) massive rich cluster

Serendipitous discovery of many large extended Hα clouds around the member galaxies (Yagi et al. 2010)

Characteristics of the clouds
• One-sidedness morphology
• Size: ~10 – 100 kpc
• Consist of ionized gas and blue stellar knots
• Distributed further than 0.2 Mpc from the cluster center

What are they? (Yagi 2007; Yoshida 2008)
• ram pressure stripped gas?
• tidal stripped gas?

We witness rapid gas stripping phenomena in a rich cluster. ➔ Important clues for understanding the gas removal in clusters

2. Target Objects

IC4040:
Spiral galaxy. cz=7840 km/s
Large Hα clouds extending toward the south

RB199:
E+A galaxy. cz=8500 km/s
Complex of narrow filaments consisting of ionized gas and young stars (“fireballs”: Yoshida et al. 2008)

Fig. 1 Extended Hα clouds found around the member galaxies of the Coma cluster: Left panels are false color images made from B(blue), Re(green) and Hα(red) images. Right panels are net Hα images. The scale bar (right bottom) shows 40 kpc.

3. Observation

Subaru Telescope + FOCAS
Date 2009/5/25
Targets: RB199, IC4040
Method: MOS spectroscopy
slit width ~ 0.8 arcsec
2 slit masks for each galaxy
300 grooves/mm grating
Spectral resolution: R=7000
Wavelength range: 4000Å~8000Å
Exposure time: 60 min. for each mask

Fig. 2 False color (B, Re, Hα) images of IC4040 (left) and RB199 (right).

Fig. 3 Positions of IC4040 and RB199 in the central region of the Coma cluster

Fig. 4 Slit positions for IC4040 spectroscopy overprinted on the net Hα image.

Fig. 5 Slit positions for RB199 spectroscopy overprinted on the Hα + continuum image.

Fig. 6 Spectra of the extended Hα clouds of IC4040 and RB199. Examples of star-forming bright knots are shown in the upper panels. Examples of shock heating-like spectra seen in diffuse filaments and bright knots are shown in the lower panels.

4. Results

4.1. Emission-line Spectra and Excitation of the Ionized Gas

• Spectra of bright blue knots (upper panels of Fig.6)
  * strong Hα
  * weak [NII], [SII], [OII]
  * relatively strong [OIII]
  * blue continuum
  ➔ low metal star-forming region

• Spectrum of diffuse ionized gas (lower left panel of Fig.6)
  * strong [OII]
  * weak [OIII]
  ➔ shock heating

• Part of the bright knots show hybrid spectra of star-formation + shock (lower right panel)

Fig. 7 Emission-line intensity ratio diagrams. Blue dots and red dots represent the data of IC4040 and those of RB199, respectively. Dotted lines are loci of radiative shock model of Dopita and Sutherland (1995)

4.2. Velocity Field

• The relative velocities (outflow velocity) of the extended Hα clouds monotonically increase with the distance from the galaxy with a rate of ~70 km/s/kpc.
• SE filament of IC4040 has very high velocity (~1300 km/s).

Comparison the observed velocity field with a ram pressure stripping model by Tonesson et al. (2010):
• The observed data are in good agreement with the model calculation.
  • smooth acceleration with the distance from the parent galaxy
  • high velocity component near the parent galaxy

Primary formation mechanism of the extended Hα clouds is ram pressure stripping (RPS) ➔ Extended ionized gas is a good probe to investigate rapid gas removal in cluster center region.

Fig. 8 The velocity field of the extended Hα clouds of IC4040 (left) and RB199 (right).

Fig. 9 Comparison the velocity field of the extended Hα clouds of IC4040 (orange and red lines: the inclination angle of the flow is assumed to be 45°) with an RPS model calculations (gray scale: Tonesson 2010).

Summary
• We performed deep optical spectroscopy of the extended Hα clouds around IC4040 and RB199 in the Coma cluster.
• Bright blue knots in the clouds have spectra similar to low metalicity star-forming regions. ➔ Active inter-galactic star-formation.
• Shock heating plays an important role in excitation of part of the diffuse filaments in the clouds.
• The outflow velocities of the clouds increase monotonically with the distance from the galaxies. ➔ Ram pressure stripping is the most plausible candidate for formation mechanism of the clouds.

References