Ram-pressure stripped ionized gas found in Suprime-Cam/Subaru narrow-band imaging

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Hα emitting objects

Hα is a recombination line of ionized hydrogen gas. $\lambda=6562.8$ Å (rest; air)

Hα emitting objects are...
- HII region (star-forming region)
- AGN, planetary nebulae,
- shock, turbulence, etc.

and sometimes intergalactic ionized gas.
NGC4388 in Virgo

Blue: [OIII]
Green: V
Red: Hα

Hα@659nm (z~0.005)

Yoshida+2002
Extended Ionized Gas (EIG) Hα emission out of galactic disk.

To keep shining in Hα, some ionizing source/mechanism is needed (and last for the age of the EIG).

Meanwhile, if ionization is too strong, the gas will be fully ionized plasma (evaporated), and stop Hα emission.
EIGs from Hα images

(I'm sorry if incomplete)

Perseus (Conselise+2001)
Norma (Sun+2007,2010, Fossati+2016)
A851,CL0024+0017 (Yagi+2015)
A2420, A2597 (Yagi+ in prep.)
EIG is not always RPS

Hickson Compact Group 92
(Stephan's quintet)
B,R,NB671
(Hα@z=0.02)

Tidally stripped gas is ionized by shock and young stars.
(Though RPS may work as well)
NGC4388 in Virgo

[OIII], V, Hα

Active Galaxy NGC 4388

Suprime-Cam (OIII, V, Hα)

Subaru Telescope, National Astronomical Observatory of Japan

April 15, 2002

Yoshida + 2002
NGC 4388 in Virgo

[OIII], V, Hα

RPS

~35 kpc

Outflow

Active Galaxy NGC 4388

Suprime-Cam (OIII, V, Hα)

Subaru Telescope, National Astronomical Observatory of Japan

April 15, 2002

Yoshida + 2002

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EWASS 2017
Our strategy

Wide field narrow&broad band (NB&BB) imaging of galaxy clusters to detect EIGs (candidates).
- Hα emitting gas out of galaxies is less affected by continuum
- in cluster of galaxies, many objects exist at the redshift so that Hα is at the NB center.
Subaru Telescope & Suprime-Cam

Subaru: 8.2m telescope @ Maunakea, Hawaii
Suprime-Cam: a wide-field imager.
Decommissioned last month (2017 May).
Hyper Suprime-Cam succeeds.
Suprime-Cam covers full moon size

5x2 of 2k x 4k CCDs

Moon image is taken from NAOJ WWW.
... supermoon is larger

Moon image is taken from NAOJ WWW.
Narrow-band imaging

NB – BB shows Hα strong regions.

Spectrum from SDSS.
Part of the Coma Cluster image (NB671) used in Yagi+2007,2010
NB671-R(NB-BB) 100kpc (3.5arcmin)
They were spectroscopically confirmed to have the redshift of the Coma (Yagi+2007, Yoshida+2012, Yoshida+ in prep.)
In case of an NB filter (NB671; Hα@z=0.02), blue continuum makes NB-BB flux negative, while red continuum makes NB-BB positive. ⇒ false Hα excess at red continuum object.
EIG detection

Visual inspection of NB-BB image and 3-color composites, to reject:
- continuum residual
- optical ghosts
- debris of moving object
- noises, blooming, flat errors, etc. etc.

In Coma, false detection was 0% (0/14)
#completeness is unknown...
EIGs from Hα images
Using Subaru Suprime-Cam Imaging

Perseus (Conselise+2001)
Norma (Sun+2007,2010,Fossati+2016)
A851,CL0024+0017 (Yagi+2015)
A2420,A2597 (Yagi+ in prep.)
EIGs from H\(\alpha\)@Subaru

Selection of the target cluster depends on available narrow-band filters.

<table>
<thead>
<tr>
<th>Cluster</th>
<th>(z)</th>
<th>Filter</th>
<th>Area (arcmin(^2))</th>
<th>Number of EIGs</th>
<th>Notes</th>
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<tr>
<td>Virgo</td>
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<td>NA659</td>
<td>1000</td>
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<td>2200</td>
<td>12((+3)?)</td>
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<td>NA671</td>
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<td>14((+9)?)</td>
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</table>

Number of EIGs per cluster is various, but in most of the clusters, EIGs exist, and rare.
Our strategy

The role of wide-field NB and BB imaging is to DETECT candidates of EIGs. Such candidates are rare; 0~7 in dithered 35'x28' field.

Blind NB&BB survey, and then, targetted spectroscopy.
Two interesting (strange) objects in the Leo(A1367)
Long tail from BIG

Star-forming blobs

Blue Infalling Group (BIG)

Yagi+2017
Orphan clouds

Isolated Hα clouds
~35x10 kpc
No apparent parent galaxy;
no giant within 80kpc.

Where are they from?
What keeps them ionized??

Yagi+2017
Probable star formation

Magenta color implies Hα and young stars = star formation.
Need spectroscopic confirmation.

EWASS 2017

Yagi+2017
Spectroscopic follow-up is \textbf{VERY IMPORTANT}
NB vs redshift

vr=4200km/s

vr=6600km/s

vr=9000km/s

accurate Hα flux estimation requires spectral information (at least redshift)

Yagi+2017

EWASS 2017
Follow-up spectroscopy

- Confirmation of the redshift.
- Velocity gradient (Deceleration)
- Diagnostitic line ratios.

Wide-field IFS is desirable!
... but because of telescope time accessibility, we used MOS (FOCAS/Subaru and LRIS/Keck) for Coma EIGs.
Deceleration

RB199(GMP4060) in Coma

Yoshida+2008
Yagi+2010

cluster velocity
deceleration
Deceleration

10 Coma EIGs
distance from the parent galaxy vs. recession velocity

Yoshida+ in prep.
Line ratios

Coma EIGs
(Yoshida+2012, Yoshida+ in prep.)

$\frac{[\text{NII}]}{\text{H}\alpha}$ vs $\frac{[\text{OIII}]}{\text{H}\beta}$

Similar to HII regions rather than AGNs.
Line ratios

Coma EIGs (Yoshida+2012, Yoshida+ in prep.)

\[ \frac{[\text{OI}]}{H\alpha} \] is sometimes larger than theoretical HII regions' ratio.

⇒ shock? but not always
Summary 1/3

- Ram pressure stripped (RPS) gas is sometimes ionized and seen clearly in Hα.

- Narrow-band Imaging at the redshifted Hα are useful for searching the intergalactic ionized gas (not always RPS)
- Subaru Telescope is a power tool for detecting Hα cloud (extended ionized gas; EIG) candidates.

- Spectroscopic follow-up is necessary in most cases. (e.g., for an accurate Hα surface brightness measurement)
Summary 3/3

- Questions still remain about EIGs e.g.,
  - Ionizing source
  - Fate of the stripped gas
  - Key parameter of the variety among systems and among clusters