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. λ=6562.8 Å (rest;air)

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

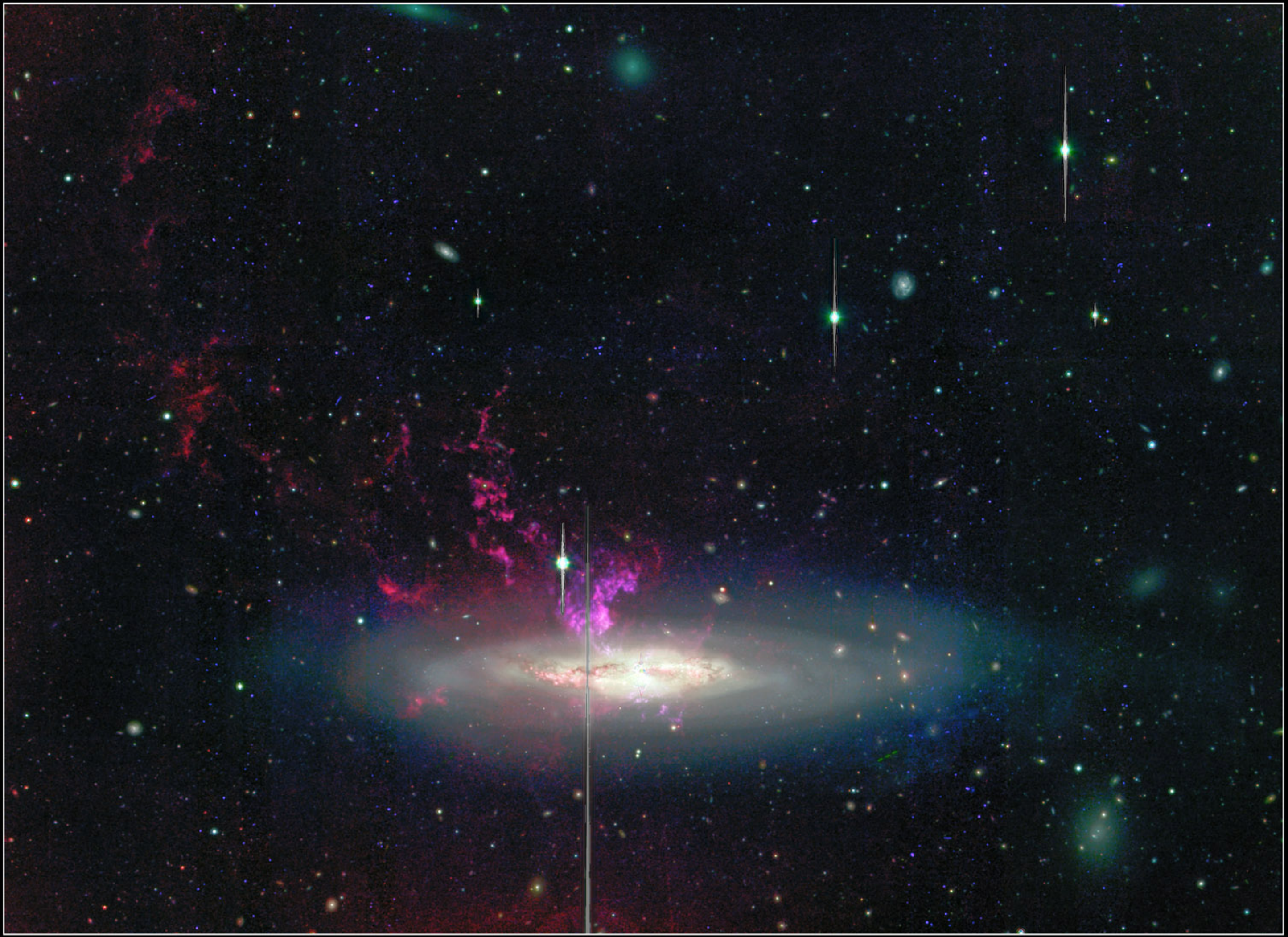
and sometimes intergalactic ionized gas.

NGC4388
in Virgo

Blue:[OIII]
Green: V
Red: Hα

Hα@659nm
(z~0.005)

Yoshida+2002



Active Galaxy NGC 4388 Suprime-Cam (OIII, V, Hα)

Subaru Telescope, National Astronomical Observatory of Japan April 15, 2002

Extended Ionize Gas

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(evapolated), and stop Hα emission.

EIGs from Hα images

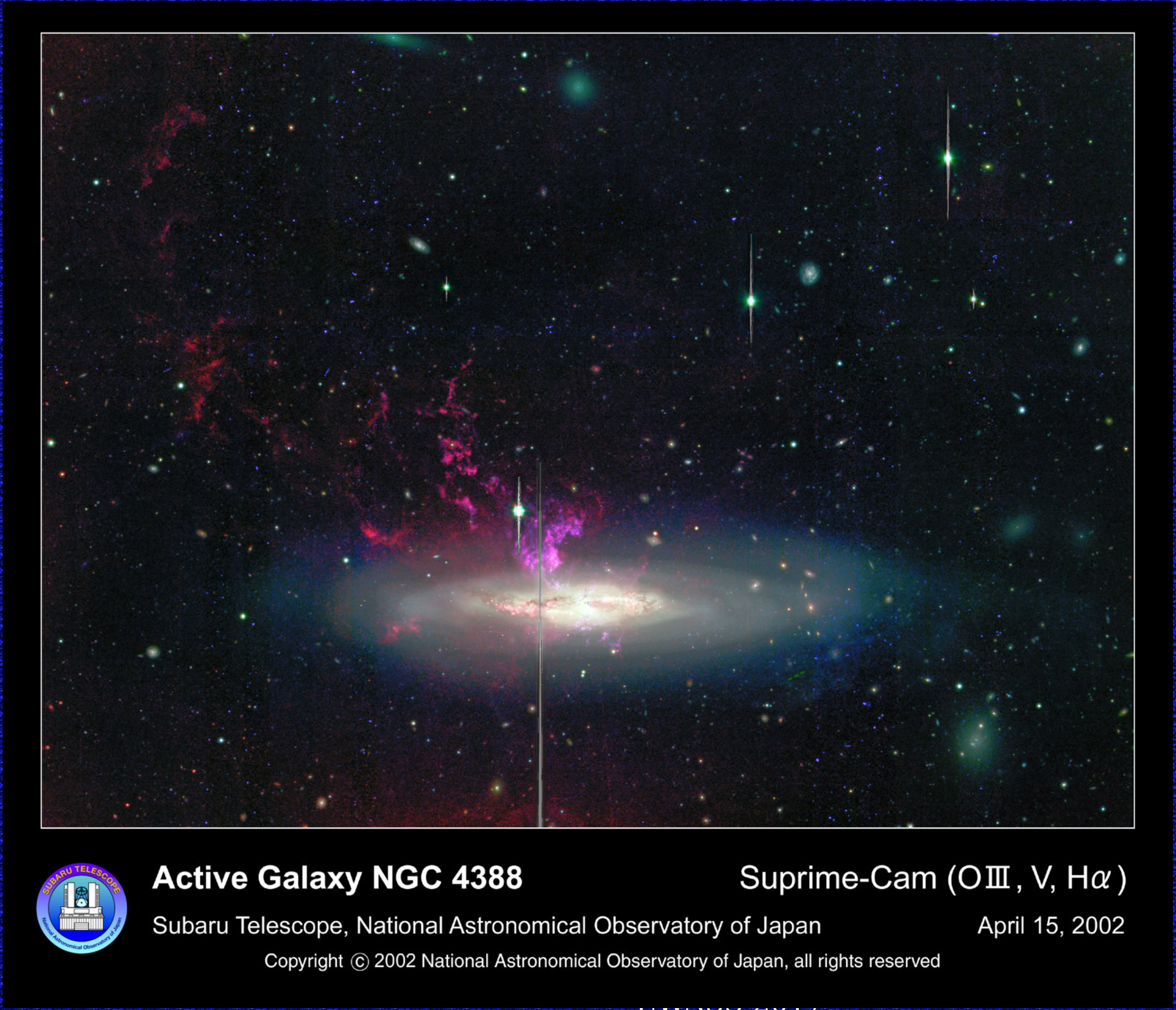
(I'm sorry if incomplete)

Virgo (Kenney+1995,1999,2008,2014,Chemin+2005,
Yoshida+2002,Yagi+2013,Boselli+2016)
Leo (Gavazzi+1995,2001,Cortese+2006,Yagi+2017)
Perseus (Conselise+2001)
Norma (Sun+2007,2010, Fossati+2016)
Coma (Yagi+2007,2010,Yoshida+2008,Fossati+2012)
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)



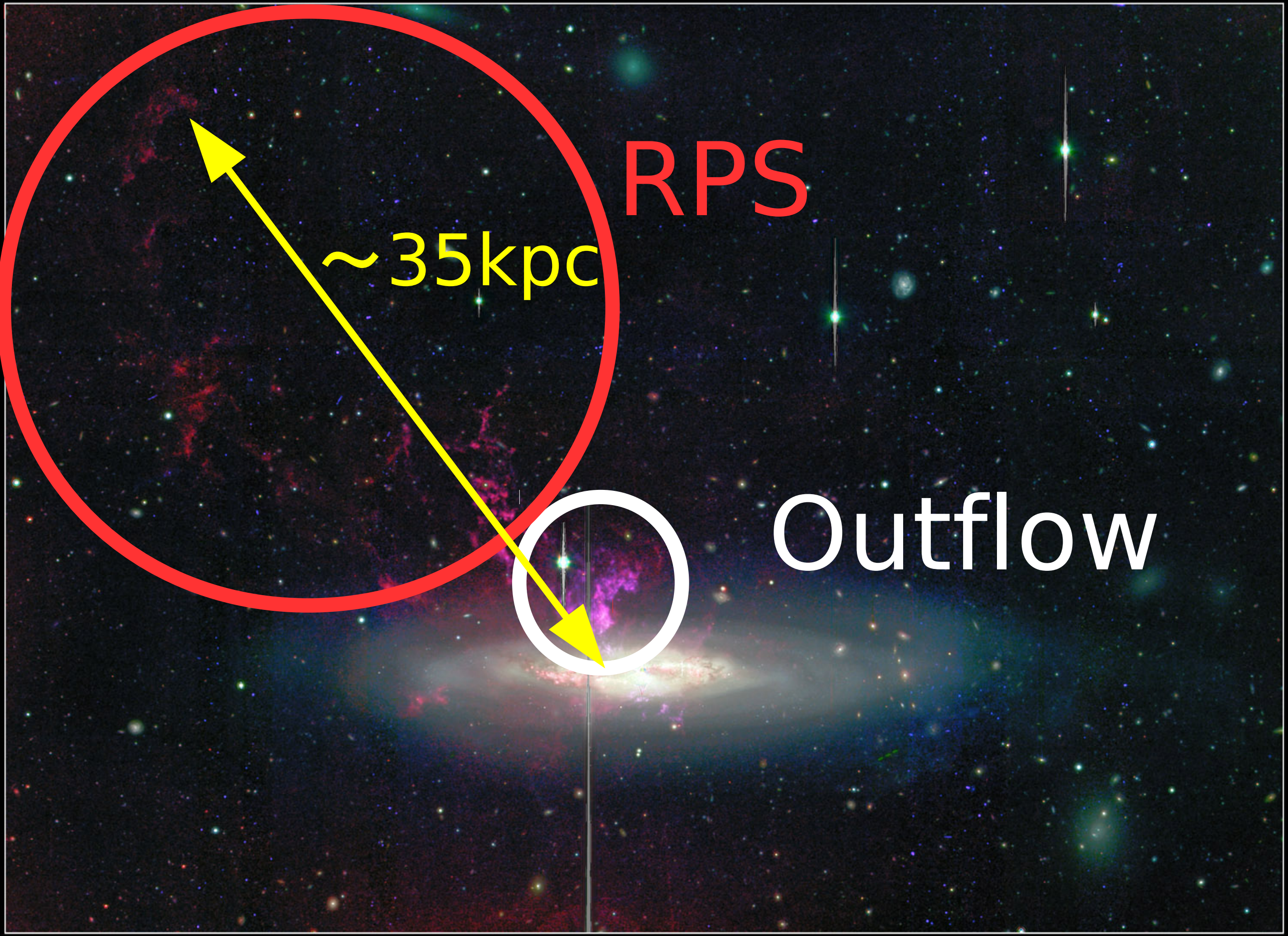
NGC4388 in Virgo

[OIII],V,Hα

Yoshida+2002

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

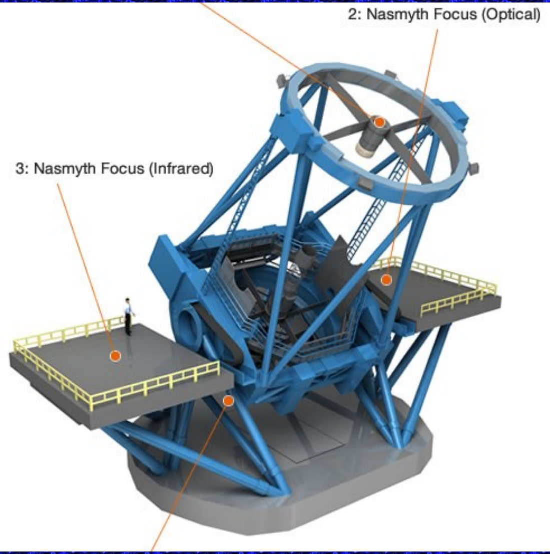
Yoshida+2002

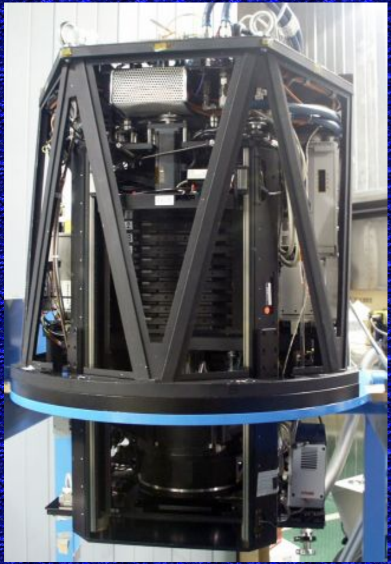
Our strategy

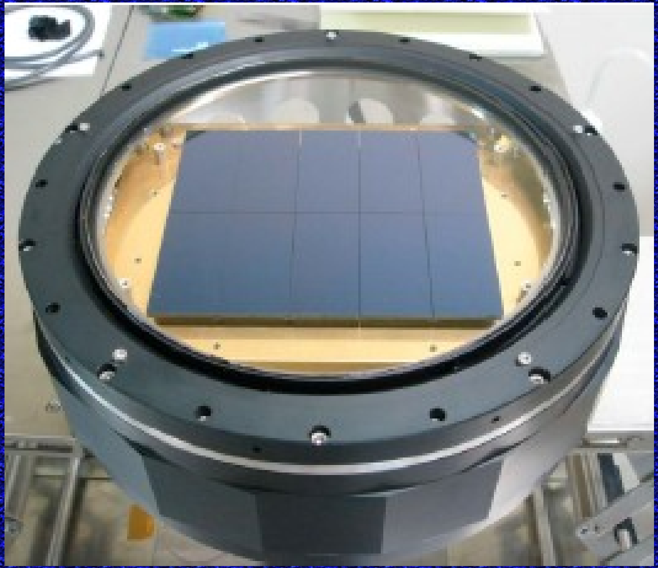
Wide field narrow&broad band (NB&BB) imaging of galaxy clusters to detect EIGs (candiates).
- Hα emitting gas out of galaxies is less affected by continuum
- in cluster of galaxies, many objects exist at the redshift so that Hα is at the NB center.

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.







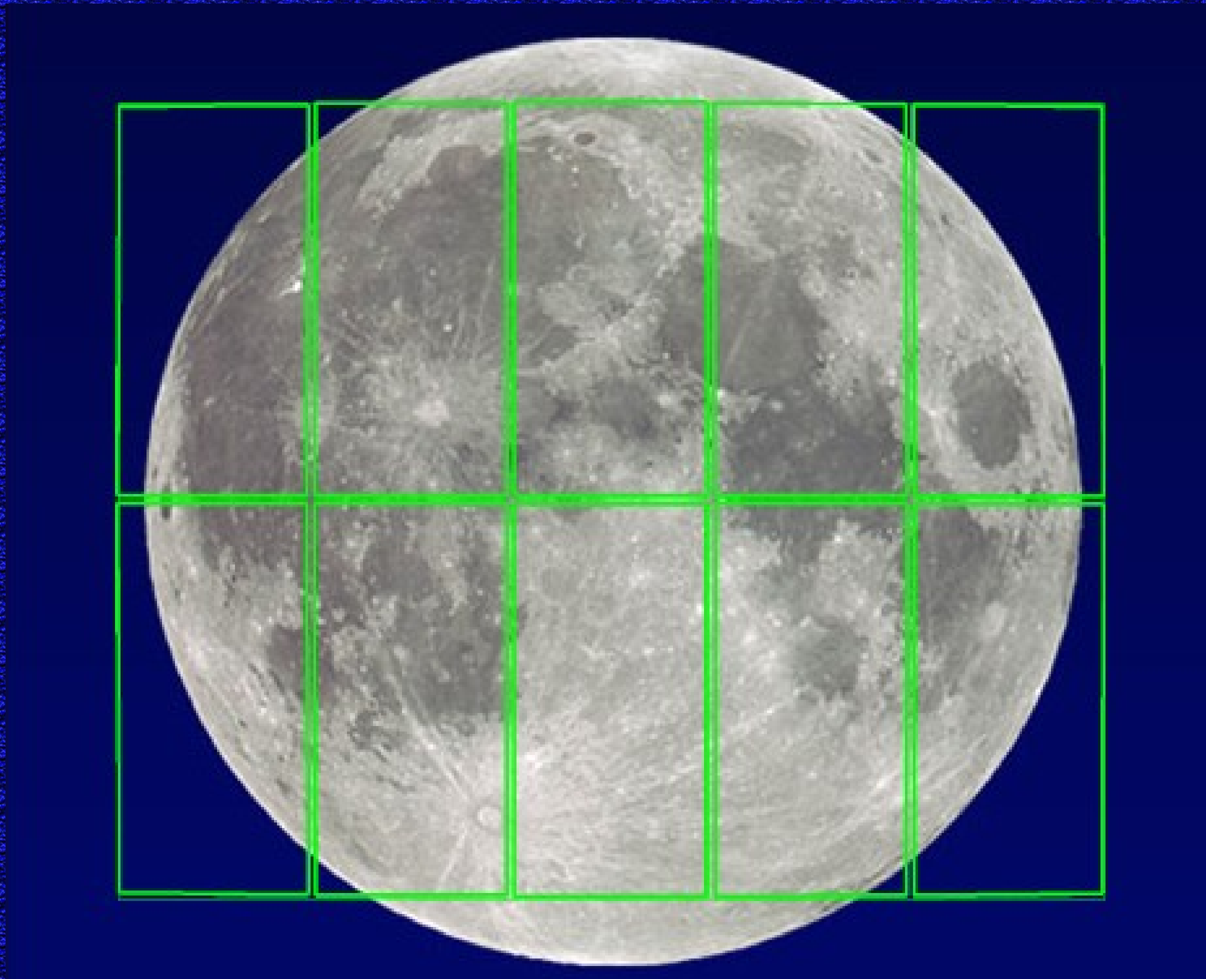
Images from Subaru Telescope

Suprime-Cam covers fullmoon size

5x2 of
2k x 4k
CCDs

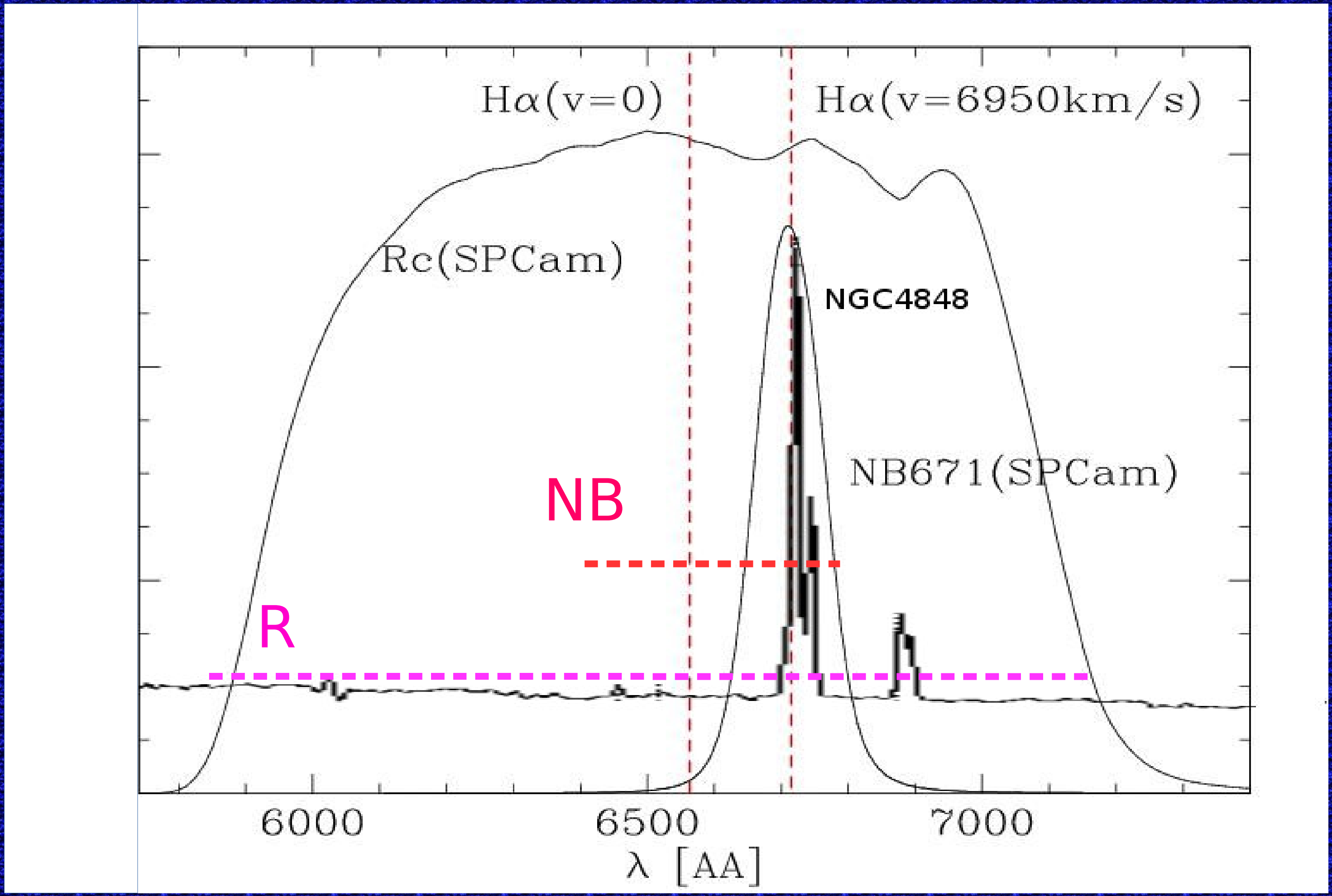
Moon image is
taken from NAOJ WWW.

… supermoon is larger



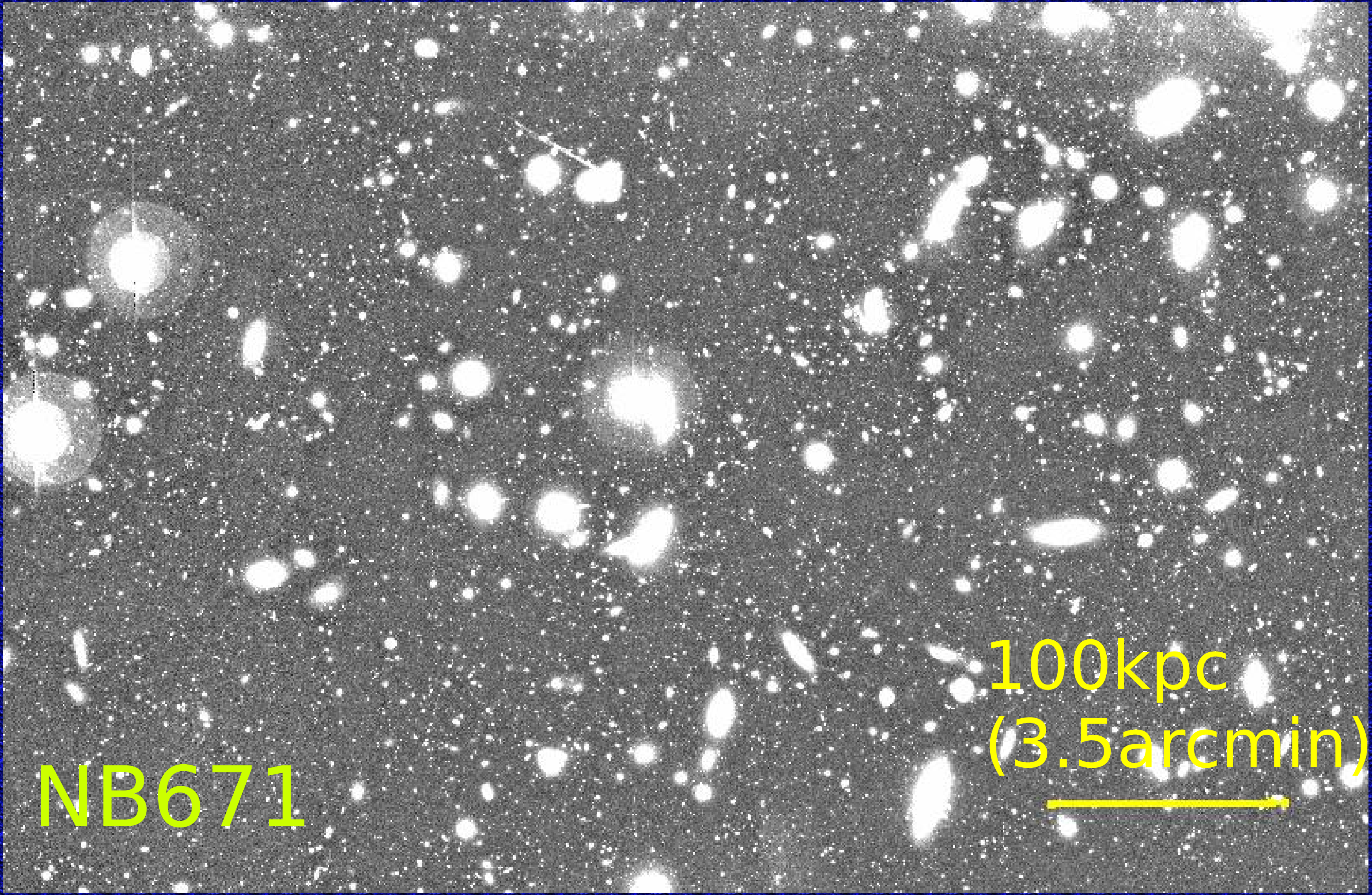
Moon image is
taken from NAOJ WWW.

Narrow-band imaging

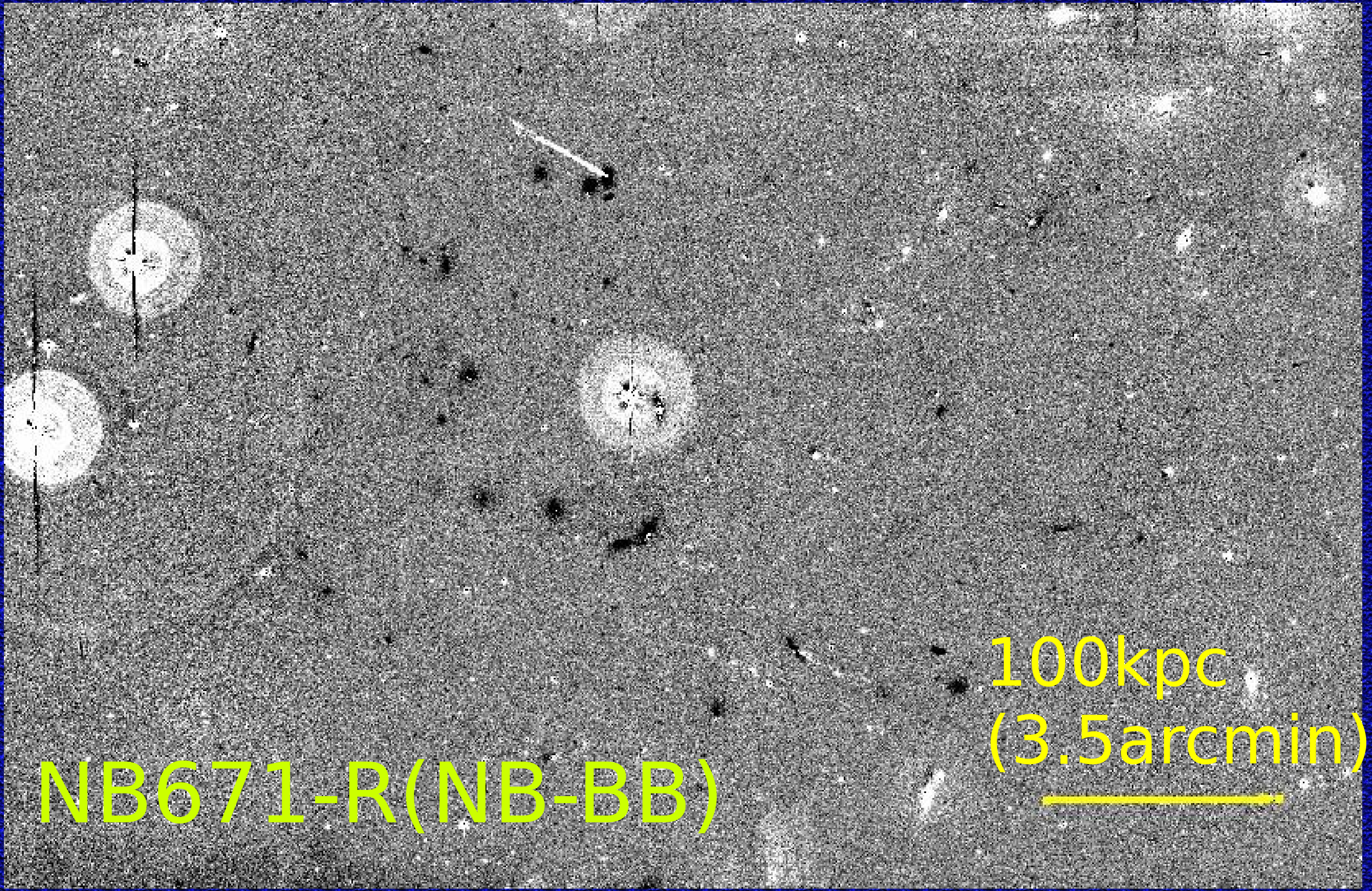


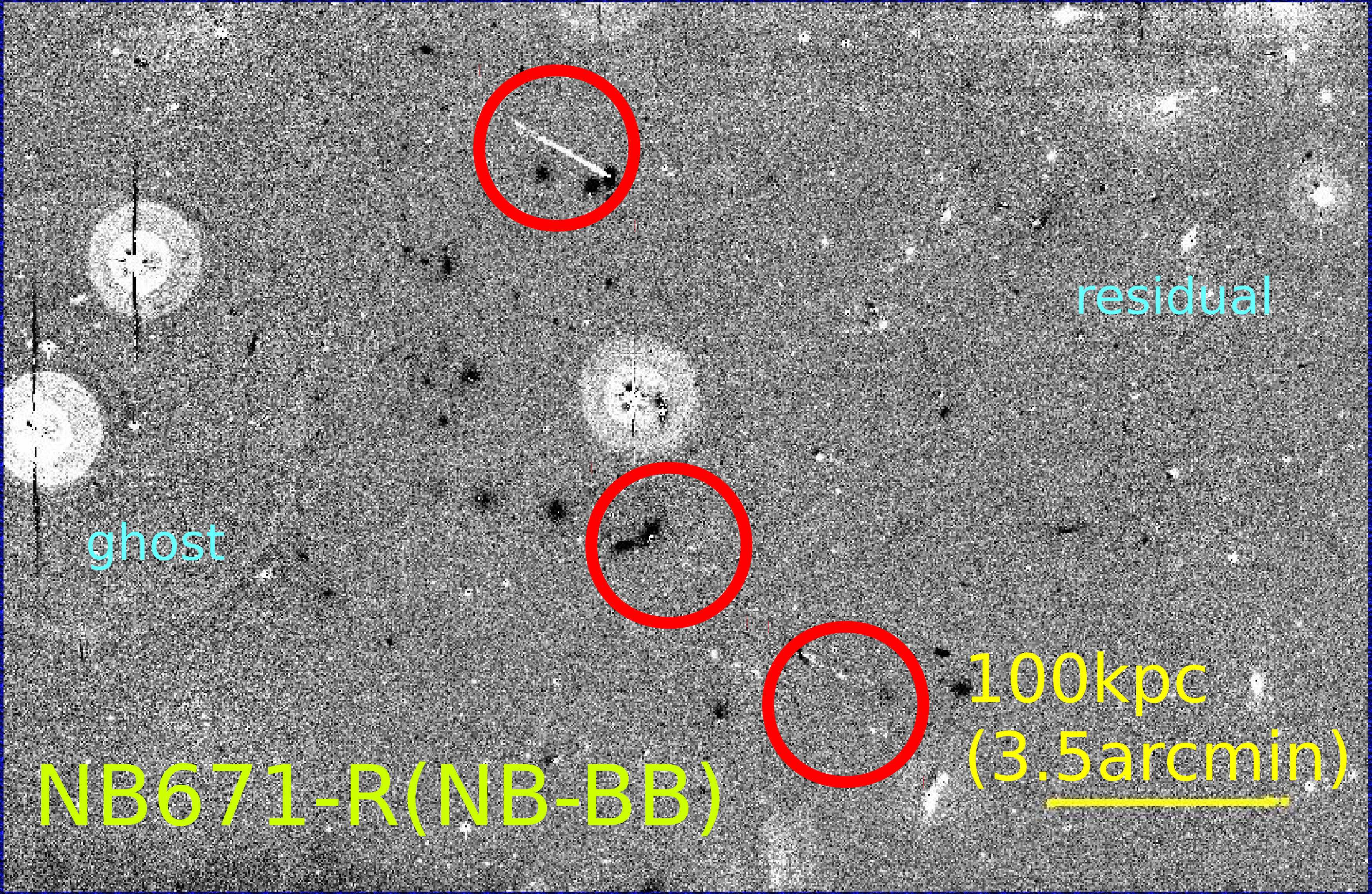
NB – BB shows Hα strong regions.

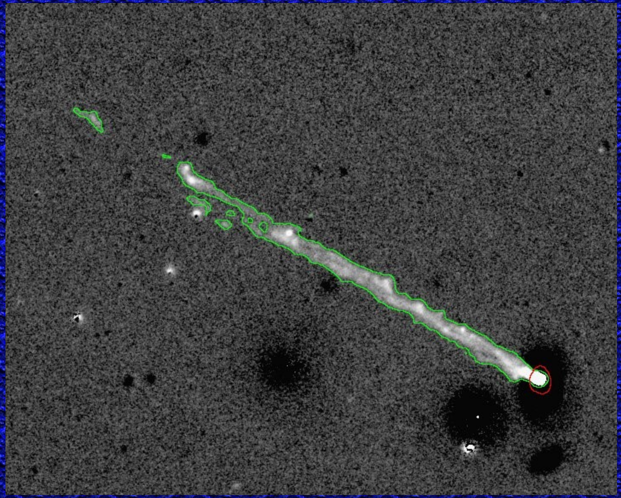
Spectrum from SDSS.

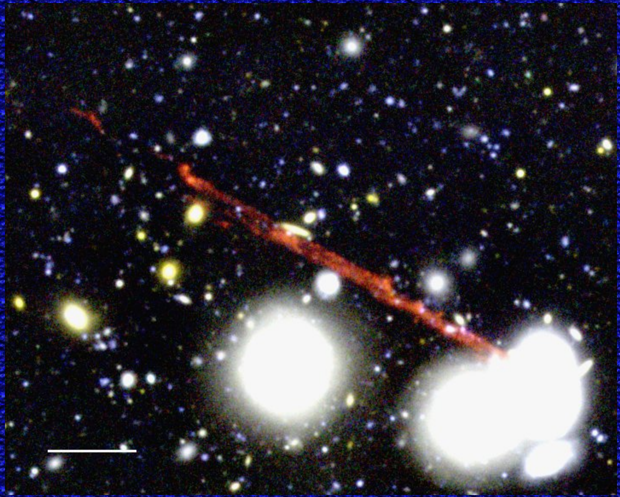


Part of the Coma Cluster image (NB671) used in Yagi+2007,2010


NB671-R(NB-BB)
100kpc
(3.5arcmin)

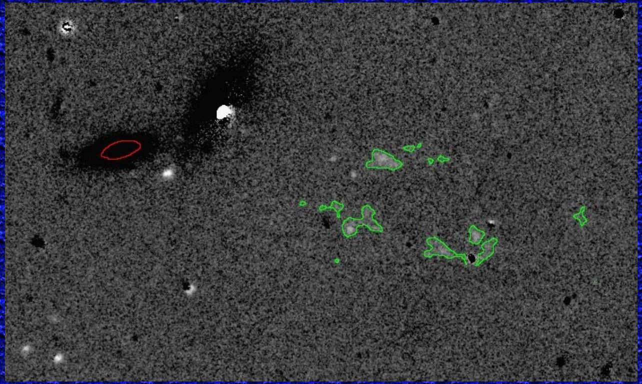

residual
ghost
100kpc
(3.5arcmin)
NB671-R(NB-BB)

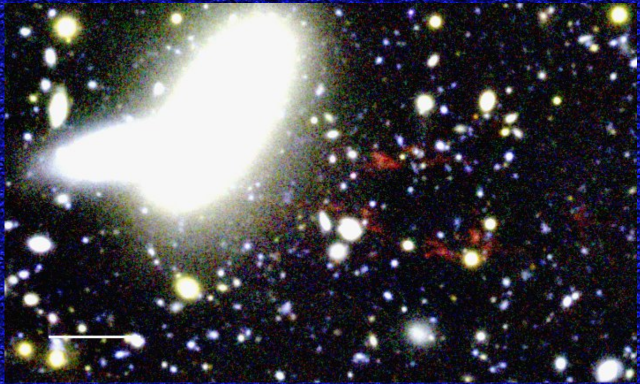


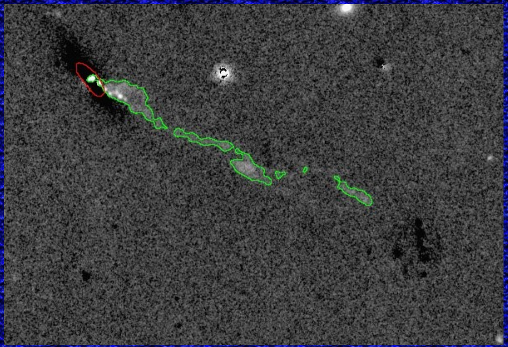


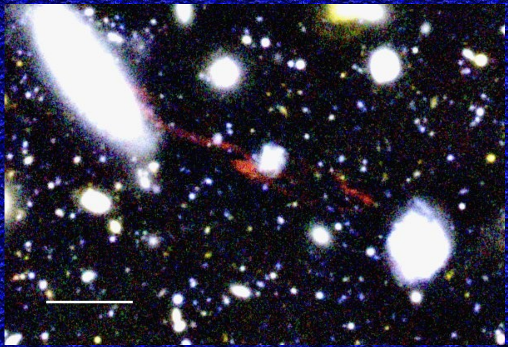
NB-BB (left)

3color composite
B,R,NB (right)



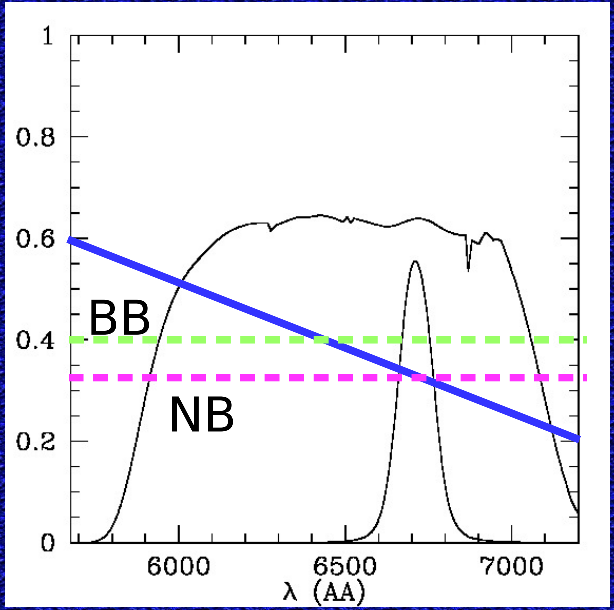


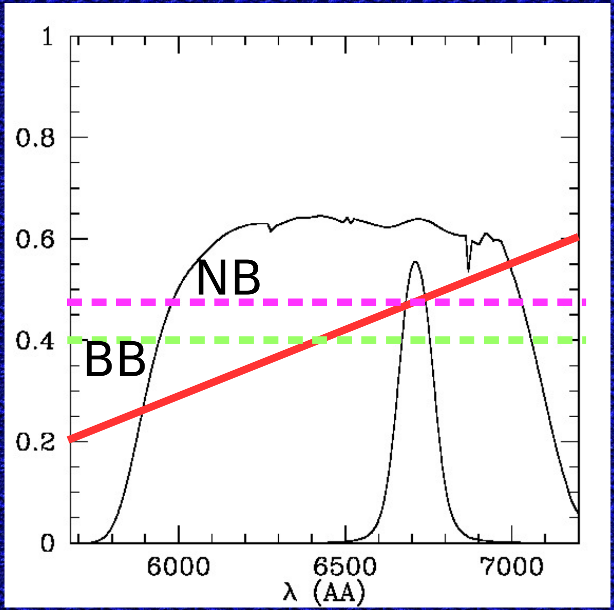




They were spectroscopically
confirmed to have
the redshift of the Coma
(Yagi+2007,Yoshida+2012,
Yoshida+ in prep.)

NB-BB of continuum





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

Virgo (Kenney+1995,1999,2008,2014,Chemin+2005,
Yoshida+2002,Yagi+2013,Boselli+2016)
Leo (Gavazzi+1995,2001,Cortese+2006,Yagi+2017)
Perseus (Conselise+2001)
Norma (Sun+2007,2010, Fossati+2016)
Coma (Yagi+2007,2010,Yoshida+2008,Fossati+2012)
A851,CL0024+0017 (Yagi+2015)
A2420,A2597 (Yagi+ in prep.)

EIGs from Hα@Subaru

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

			Area arcmin^2	EIGs from Subaru Hα	
Virgo	z=0.004	NA659	1000	(1)	(+more)
Leo	z=0.023	NA671	2200	12(+3?)	
Coma	z=0.023	NA671	1600	14(+9?)	(+more)
A2420	z=0.085	NB711	1000	2	
A2597	z=0.085	NB711	1000	4	
CL0024	z=0.390	NB912	1000	0	
A851	z=0.405	NB921	1000	9	

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

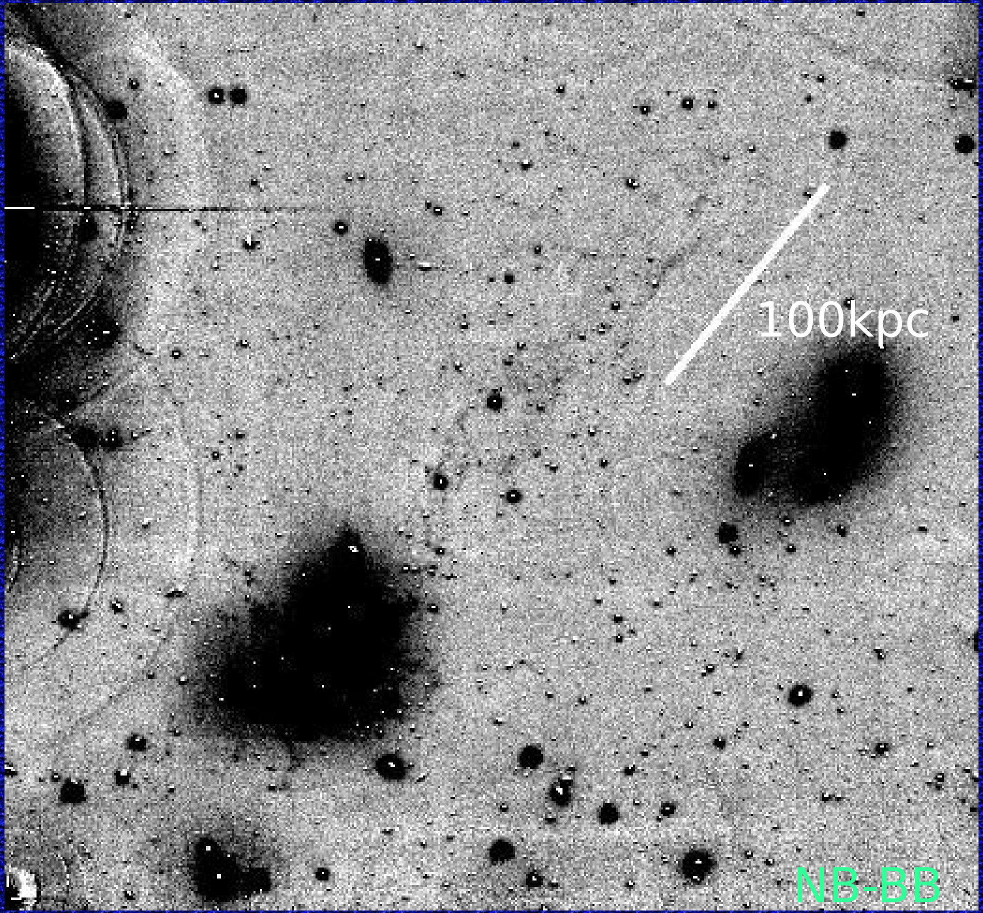
Our strategy

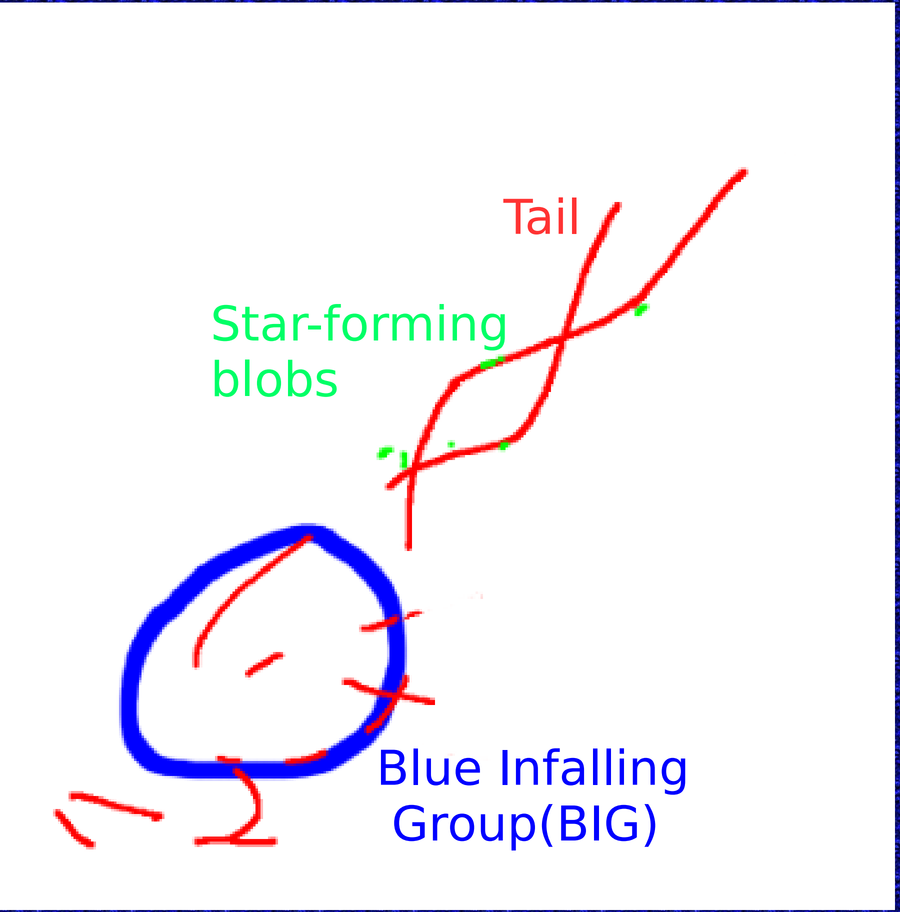
The role of wide-field NB and BB imaging is to DETECT candidates of EIGs. Such candidates are rare; 0~7 in dithered 35'x28' field.

Blind NB&BB survey, and then, targetted spectroscopy.

Two interesting (strange) objects in the Leo(A1367)

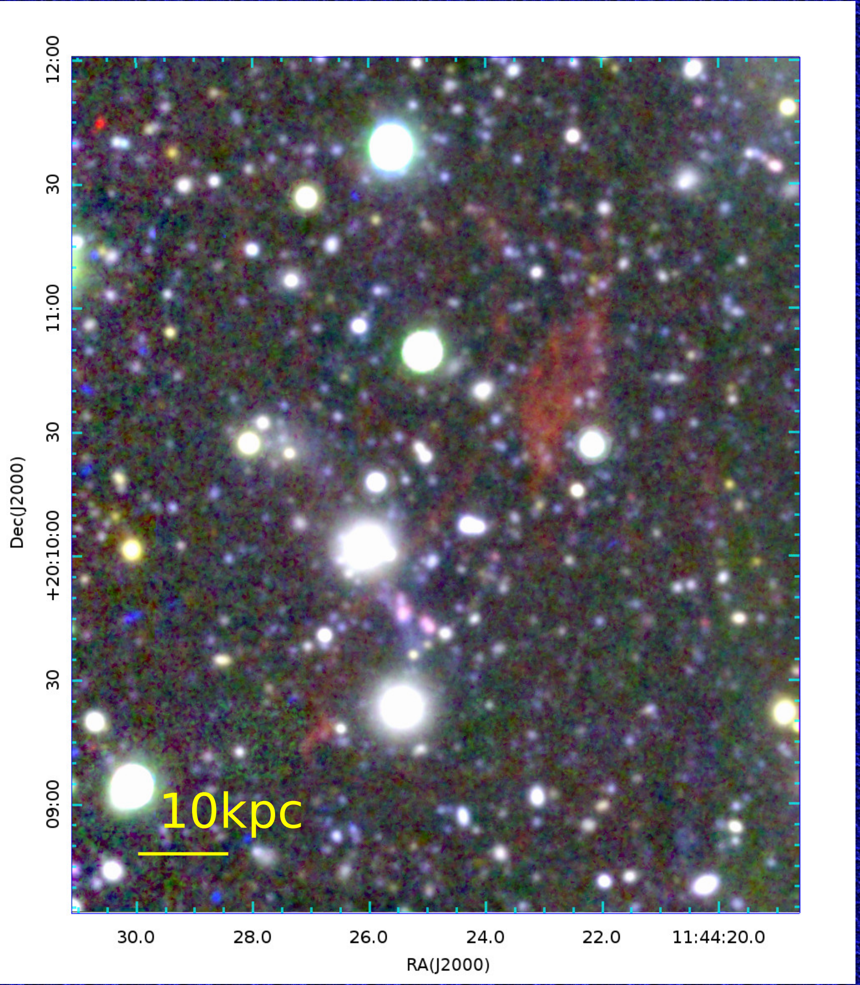
Long tail from BIG





Yagi+2017

Orphan clouds

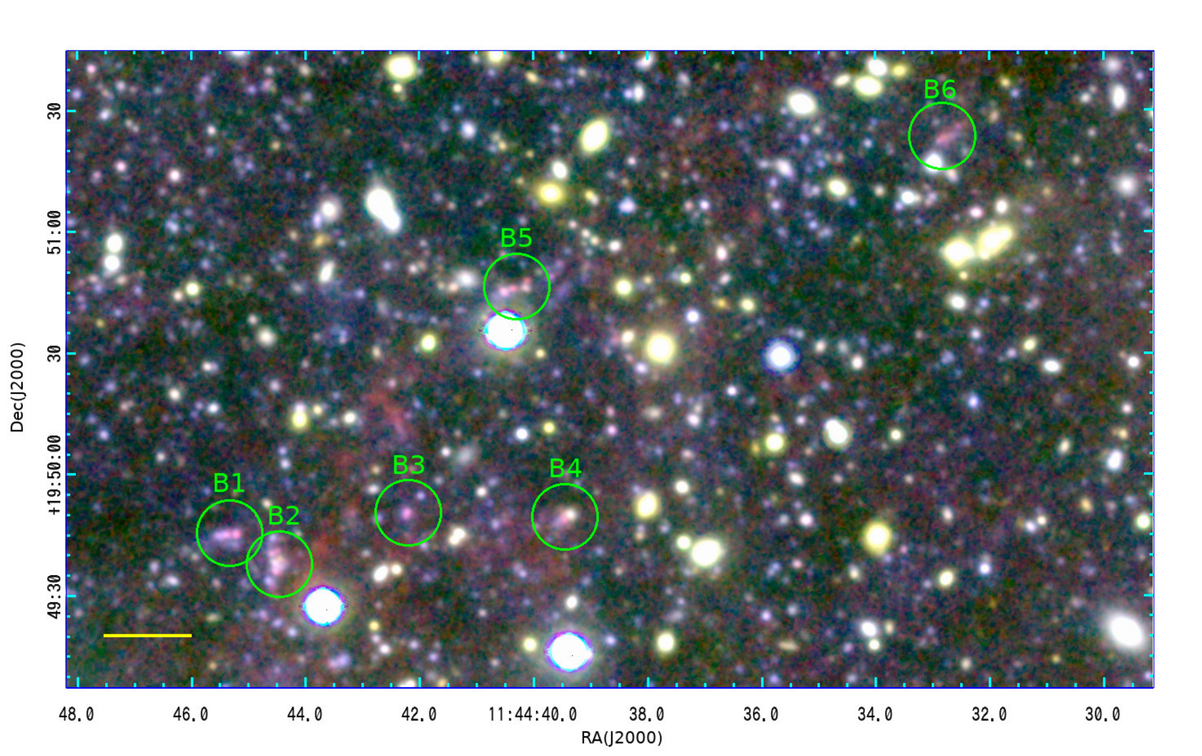


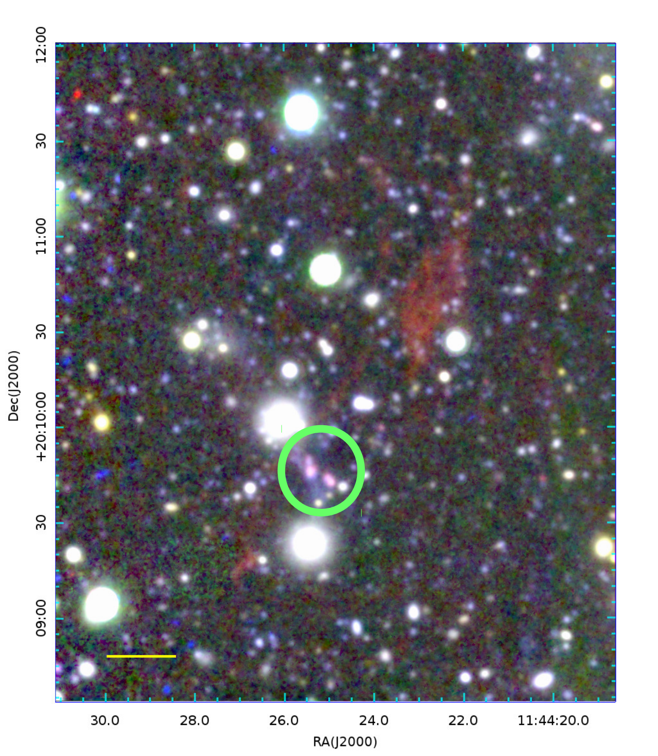
Yagi+2017

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

Where are they from?
What keeps them ionized??

Probable star formation





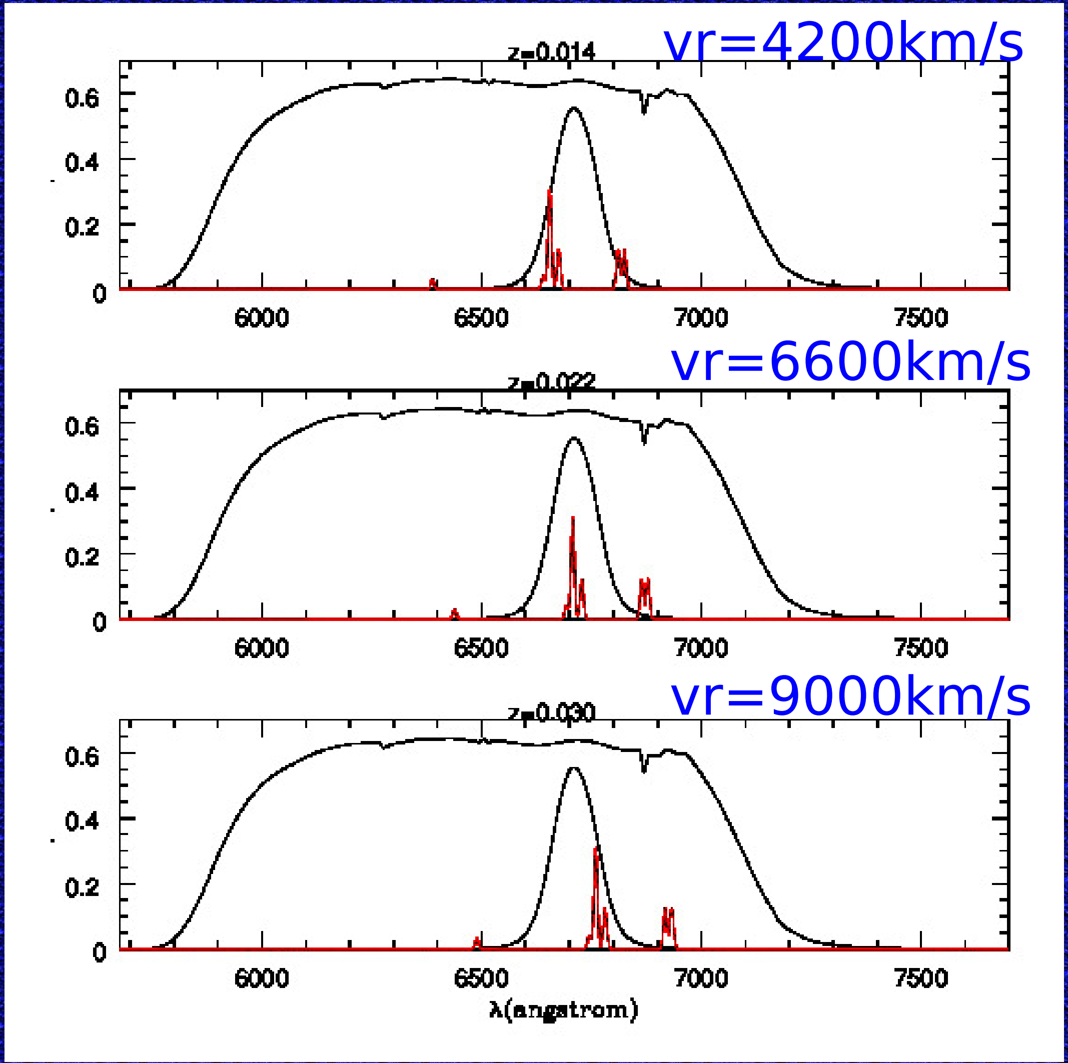
Magenta color implies Hα and young stars = star formation.

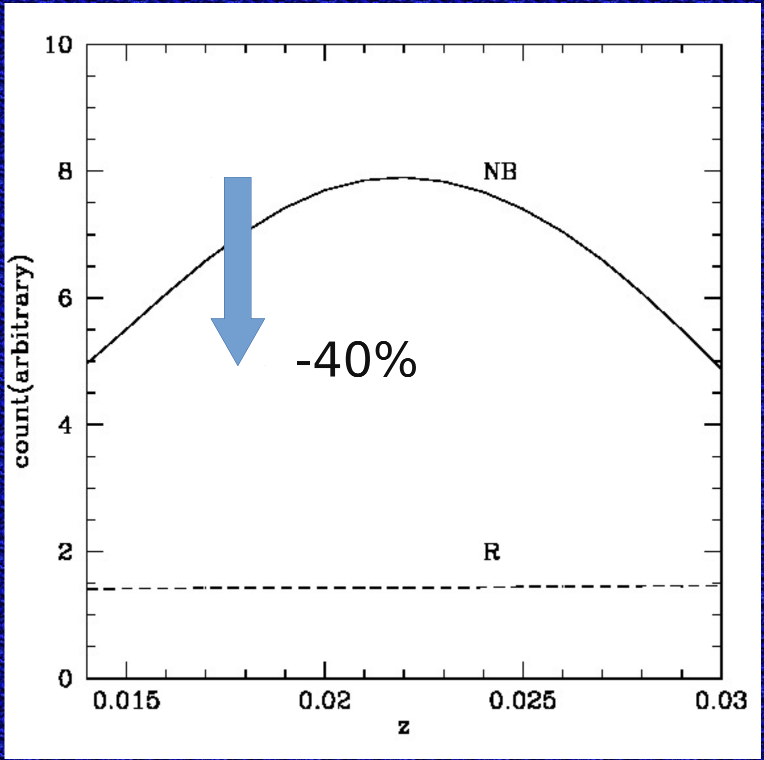
Need spectroscopic confirmation.

Yagi+2017

Spectroscopic follow-up is VERY IMPORTANT

NB vs redshift





Yagi+2017

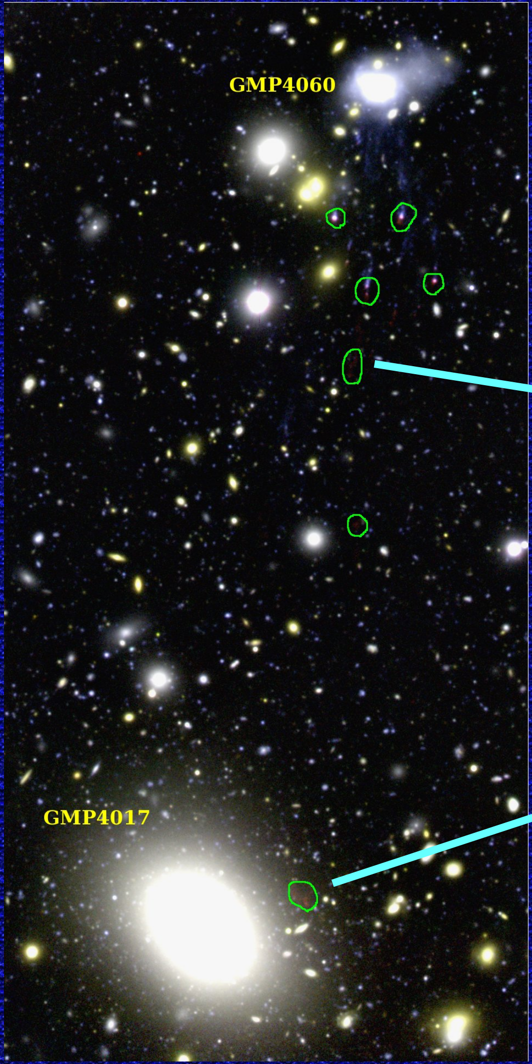
accurate Hα flux etimation requires spectral information (at least redshift)

Follow-up spectroscopy

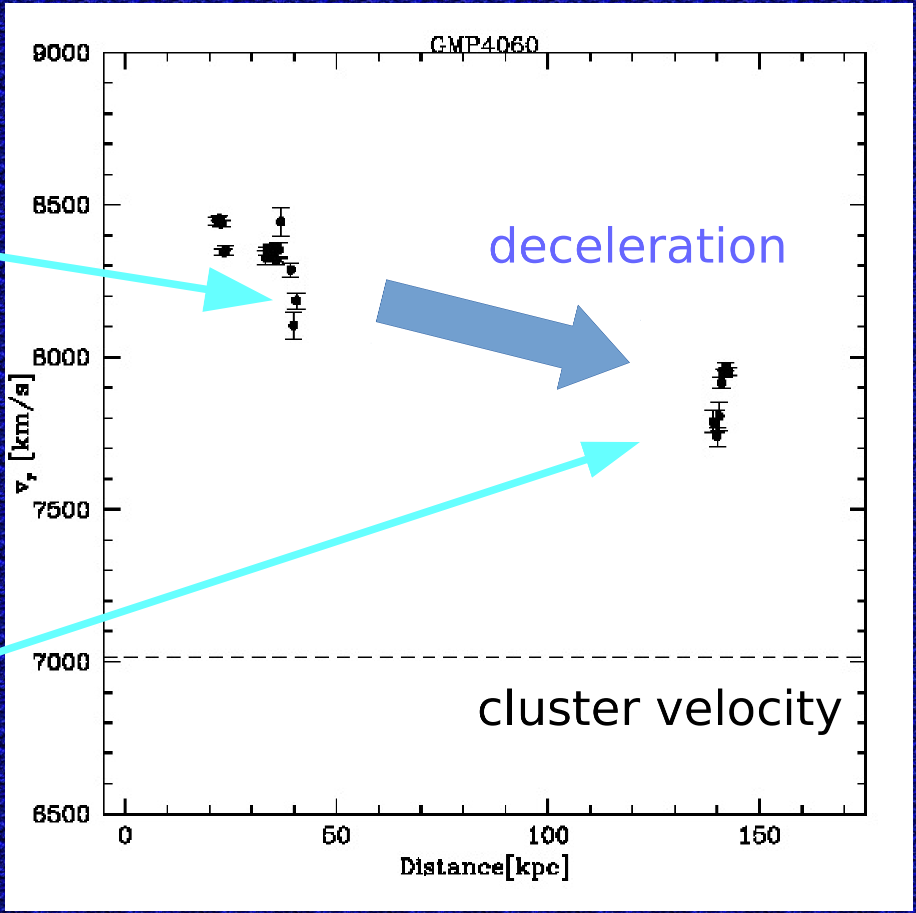
- Confirmation of the redshift.
- Velocity gradient (Deceleration)
- Diagnositic line ratios.

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

Deceleration

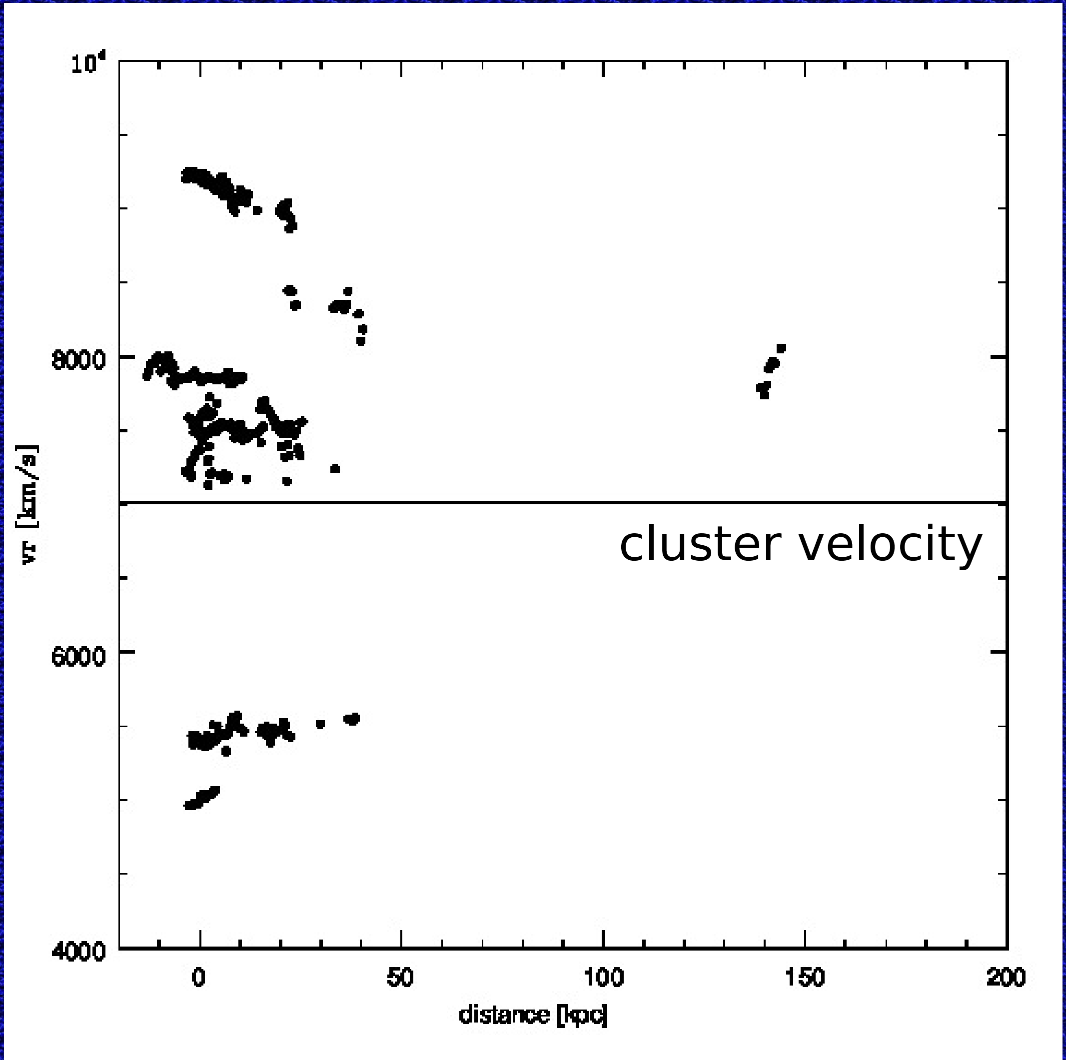


RB199(GMP4060) in Coma



Yoshida+2008
Yagi+2010

Deceleration

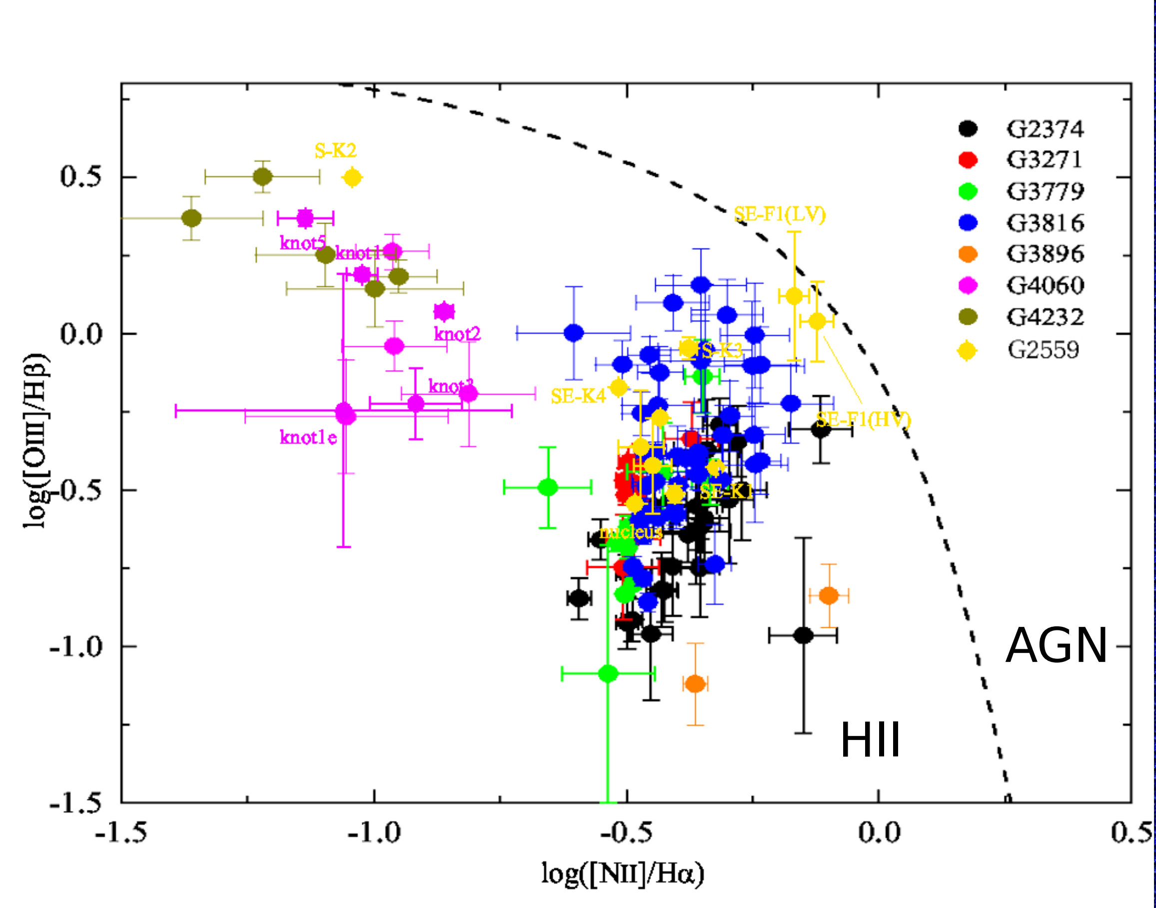


10 Coma EIGs

distance from
the parent galaxy
vs.
recession velocity

Yoshida+ in prep.

Line ratios

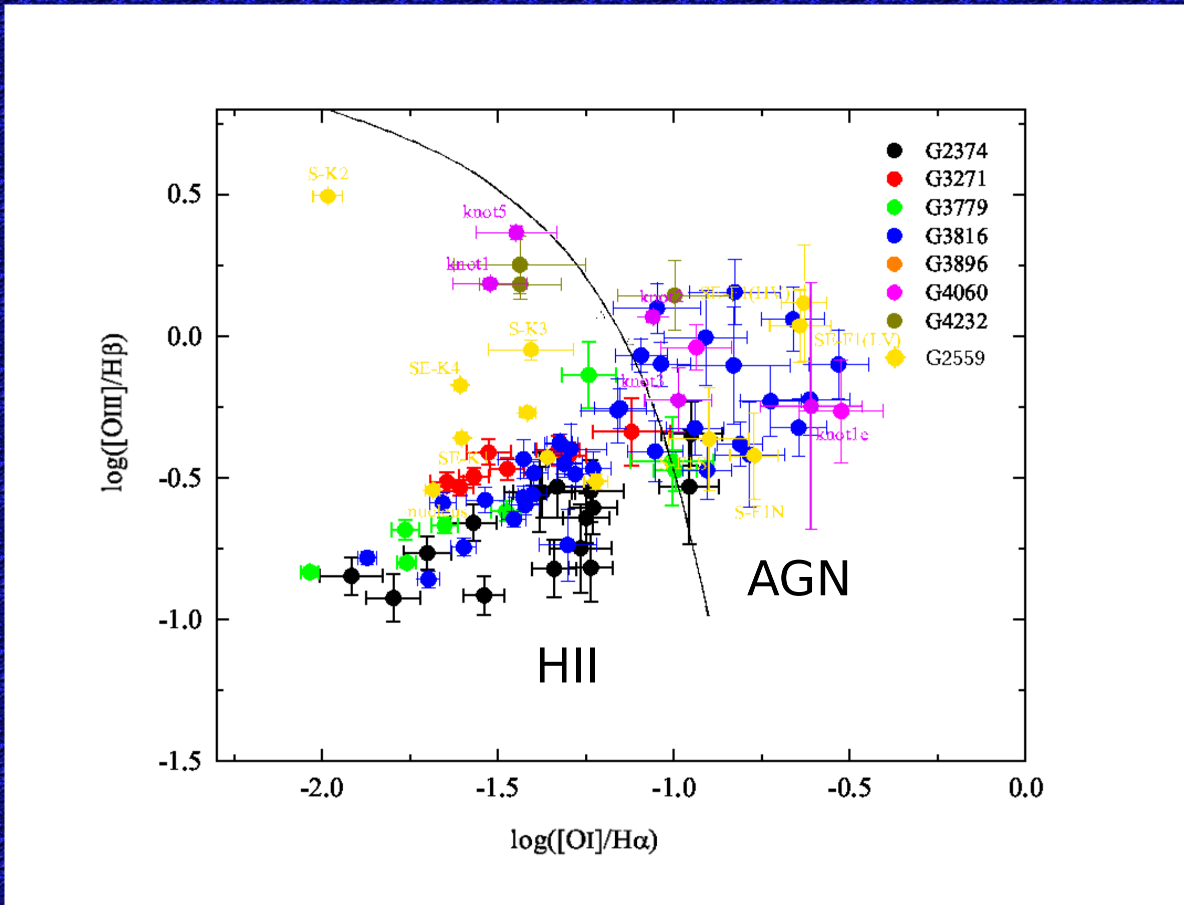


Coma EIGs
(Yoshida+2012,
Yoshida+ in prep.)

[NII]/Hα vs
[OIII]/Hβ

Similar to
HII regions
rather than AGNs.

Line ratios



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

[OI]/Hα 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)

Summary 2/3

- 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
    variery among systems
    and among clusters