(Subaru UM 2013/1/17)

Ionization Source of a Minor-Axis Cloud in the Outer Halo of M82

(Matsubayashi et al. 2012, ApJ, 761, 55)

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Galactic winds

M82 image. *B*, *V*, and Hα are in blue, green, and red. (NAOJ)

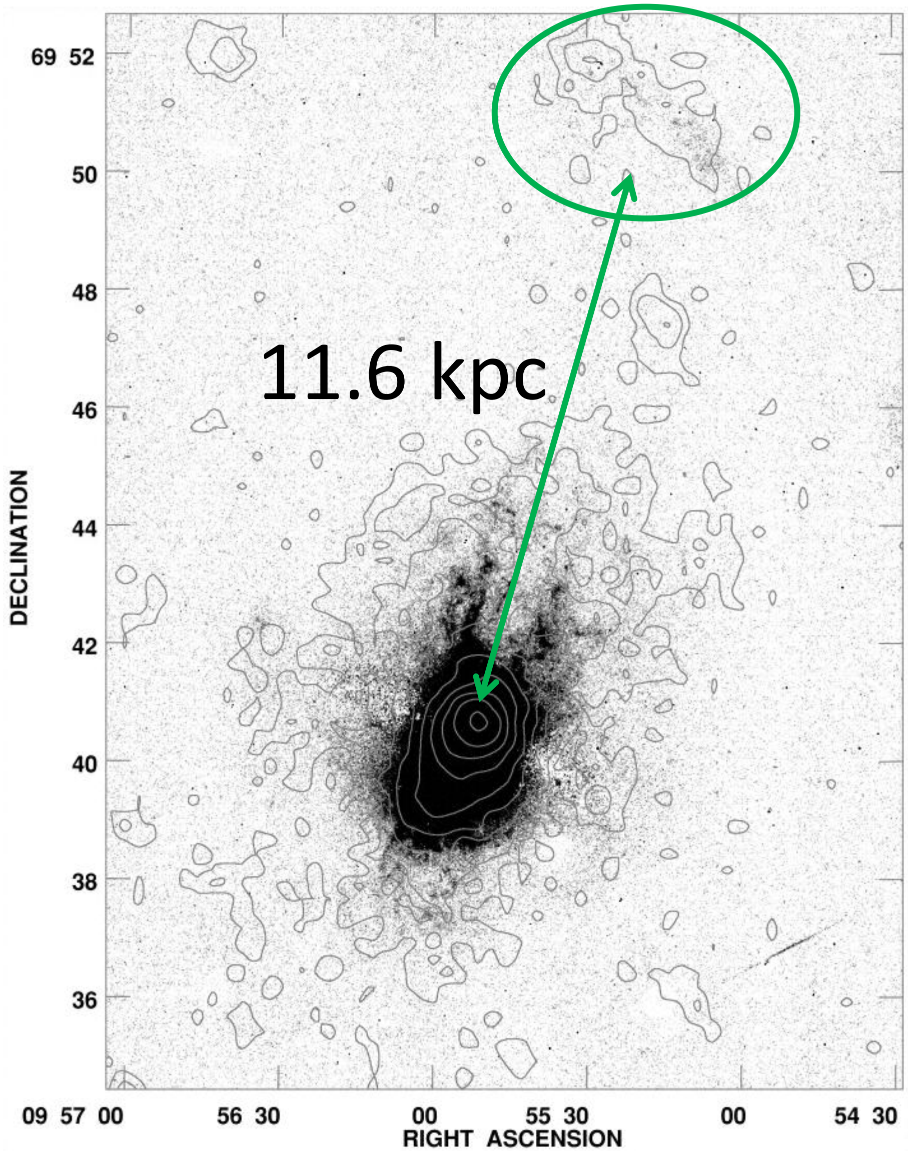
- Large-scale gas outflows from galaxies.
- Caused by supernovae in nuclear starburst regions or active galactic nuclei (AGNs).
- May have large impacts on galaxy evolution and inter-galactic medium.

Galactic winds

Basic properties are not fully understood yet.

- How old is the wind?
- Is it powered by radiation pressure or wind pressure?
- Is the source of energy impulsive or sustained over many dynamical times?
- Is most of the outflowing material swept up or entrained from the disk?
- Does the wind material escape the galaxy or fall back to the disk?
- How far does the wind expand?

M82 `Cap'



- The most distant gas cloud in M82.
- Does the wind reach the cap?
  - Ionized by shock or UV photons from the starburst regions?

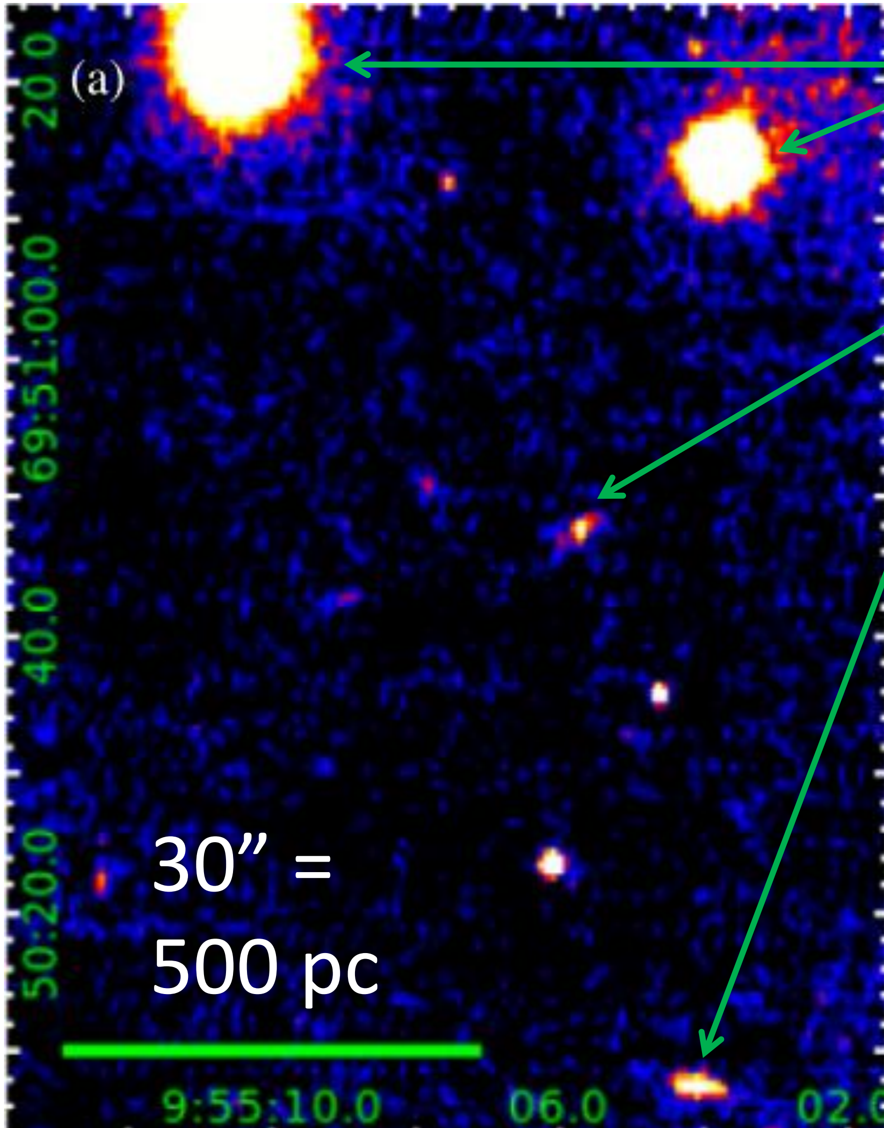
gray scale: Hα
contour: X-ray
(Lehnert et al. 1999)

Observation

- Date: Nov. 22, 2011
- Telescope: Subaru
- Instrument: Kyoto3DII Fabry-Perot mode

- Target lines: Hα, [NII]$\lambda\lambda$6548,6583, [SII]$\lambda\lambda$6716,6731 (+ continuum 6650 Å)
- Spatial resolution: ≤ 0".9
- Spectral resolution: 19 Å
- Exposure: 300 seconds / frame, 21 frames

Continuum map



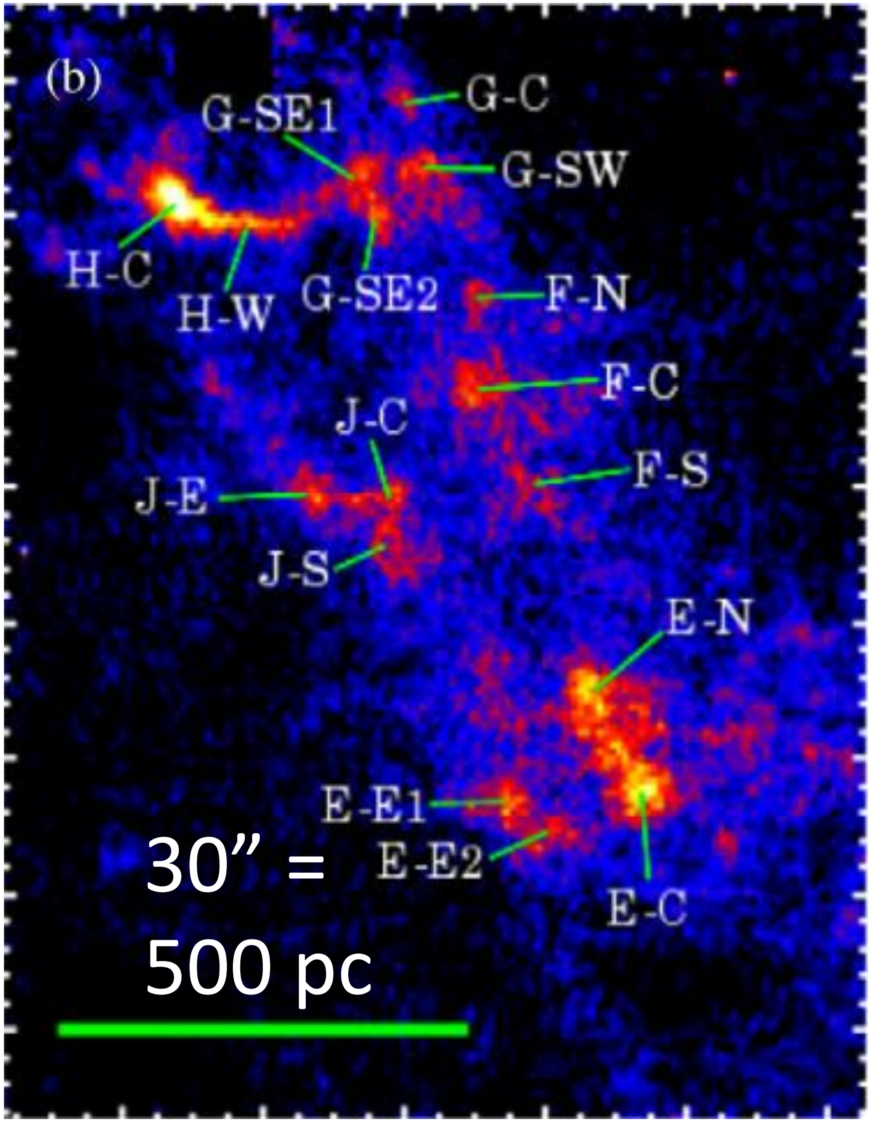
stars in the Galaxy

distant galaxies

- No continuum emission from the cap is detected.

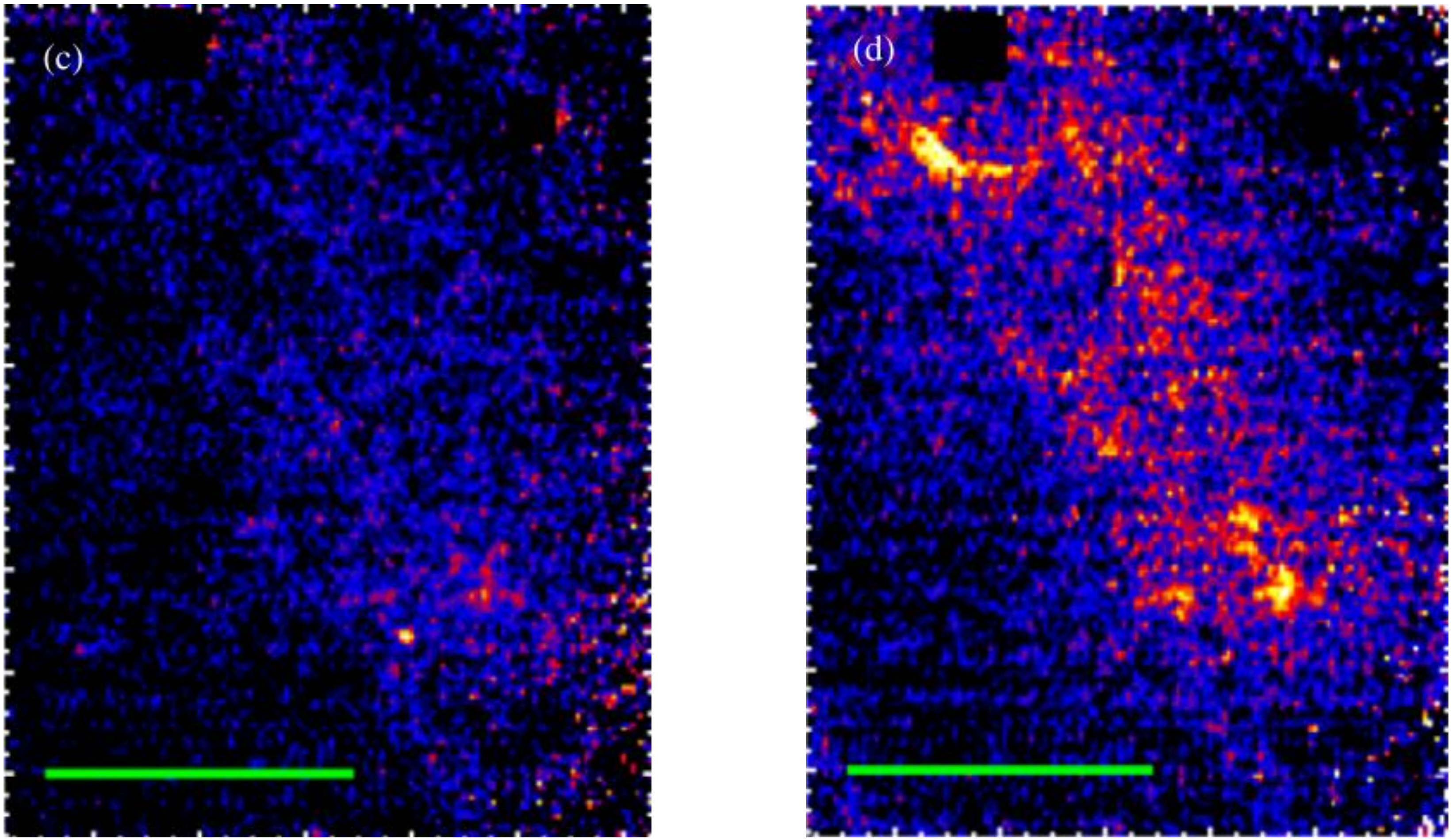
-> The cap is not a dwarf galaxy.

Hα map



- Clumpy and filamentary structures are clearly detected.
- Typical size of knots is 5” – 10” (= 90 – 180 pc).
- Electron density of the brightest knot (H-C): 1.0 cm^{-3}
  - estimated from Hα surface brightness

[NII] and [SII] maps



[NII] map [SII] map

Hα fluxes and line ratios of knots

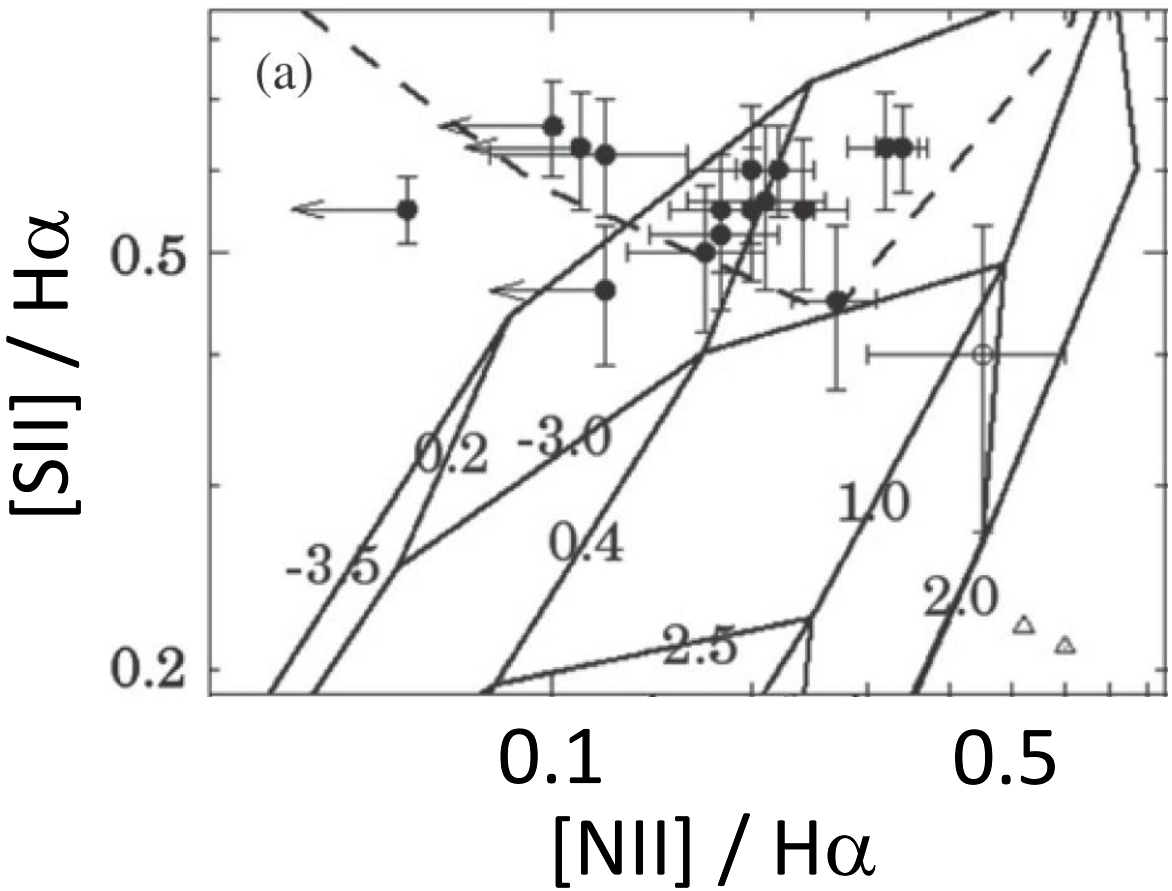
Table 2
Observed Hα Flux and Line Ratios at each Knot

Knot ID	Hα Flux (10^{-16} erg cm^{-2} s^{-1})	[N II]λ6583/Hα	[S II]λλ6716,6731/Hα
E-C	4.3 ± 0.1	0.34 ± 0.03	0.63 ± 0.06
E-N	4.0 ± 0.1	0.22 ± 0.03	0.60 ± 0.06
E-E1	3.3 ± 0.1	0.32 ± 0.04	0.63 ± 0.08
E-E2	2.8 ± 0.1	0.27 ± 0.04	0.45 ± 0.08
F-C	3.2 ± 0.1	0.18 ± 0.03	0.55 ± 0.07
F-N	2.6 ± 0.1	0.20 ± 0.04	0.60 ± 0.09
F-S	2.5 ± 0.1	0.20 ± 0.05	0.55 ± 0.08
G-C	2.3 ± 0.1	0.21 ± 0.05	0.56 ± 0.10
G-SE1	3.1 ± 0.1	<0.11	0.63 ± 0.08
G-SE2	3.1 ± 0.1	0.12 ± 0.04	0.62 ± 0.08
G-SW	2.9 ± 0.1	0.18 ± 0.04	0.52 ± 0.08
H-C	5.7 ± 0.1	<0.06	0.55 ± 0.04
H-W	3.3 ± 0.1	<0.10	0.66 ± 0.07
J-C	2.8 ± 0.1	0.24 ± 0.04	0.55 ± 0.09
J-E	2.9 ± 0.1	<0.12	0.46 ± 0.07
J-S	2.6 ± 0.1	0.17 ± 0.04	0.50 ± 0.08

Notes. The aperture sizes are 2.″25 × 2.″25. Uncertainties are in 1σ levels, while upper limits are in 3σ.

- [NII]/Hα = 0.1 – 0.3
- [SII]/Hα = 0.45 – 0.65

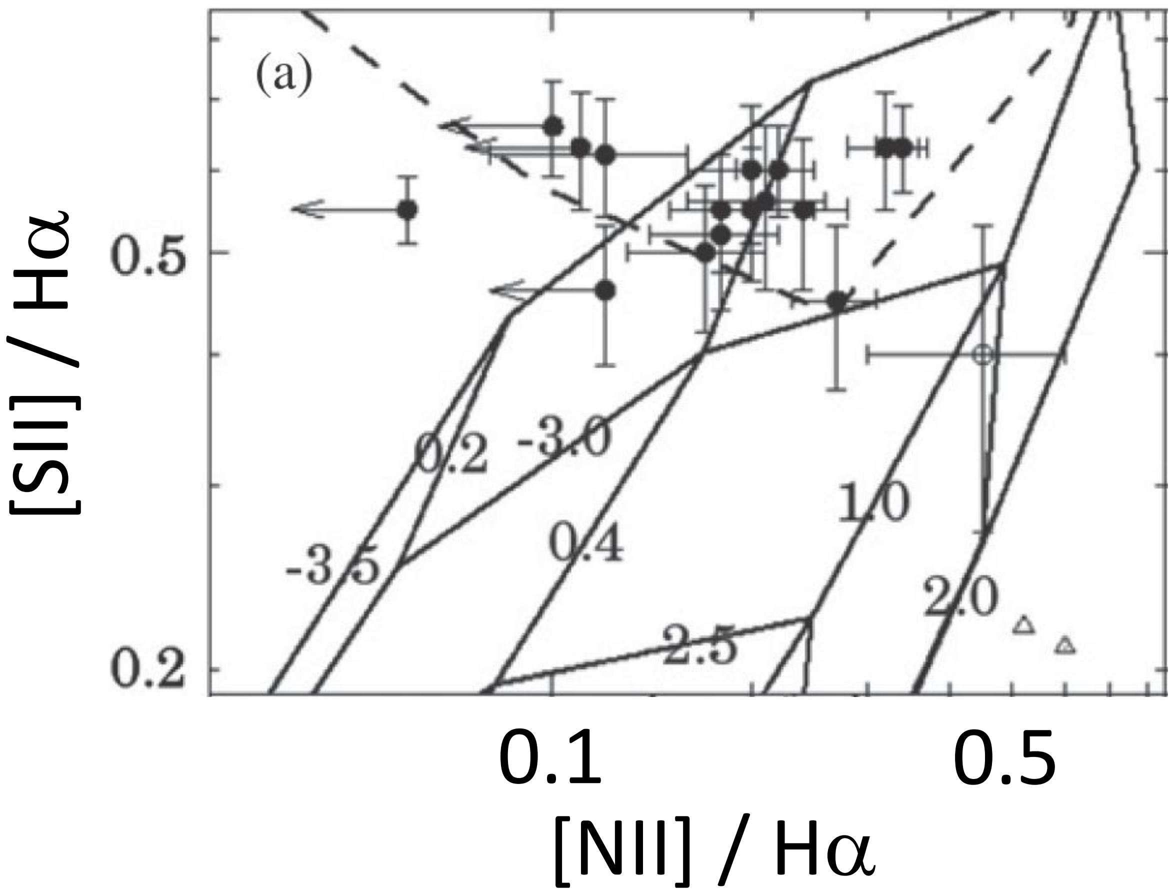
Photoionization model



- filled circle: cap
- solid line: photo-ionization model (Cloudy)
  - at various metallicities and ionization parameters

Observed ratios can be explained by photo-ionization model.

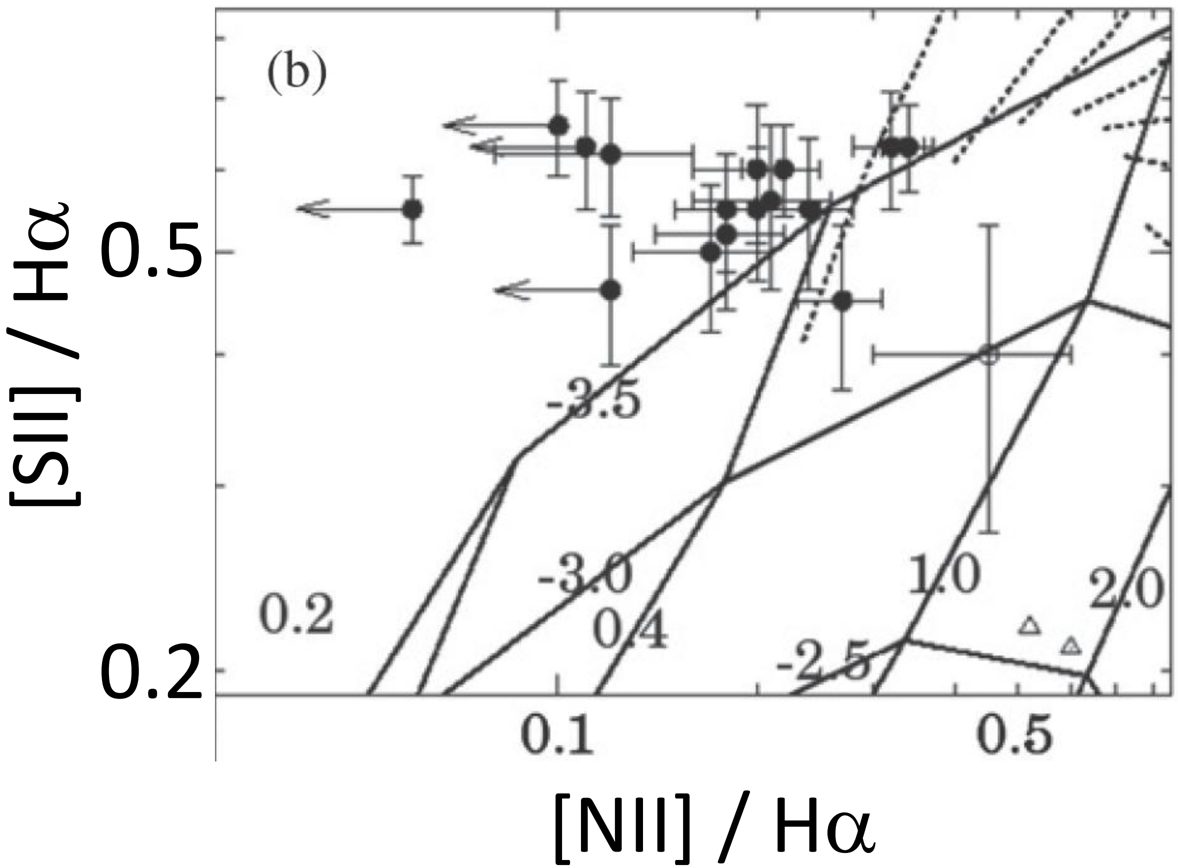
Slow shock model



- filled circle: cap
- dashed line: slow shock model (Shull & McKee 1979)
  - shock velocity = 40 – 100 km/s

Observed ratios can also be explained by slow shock model.

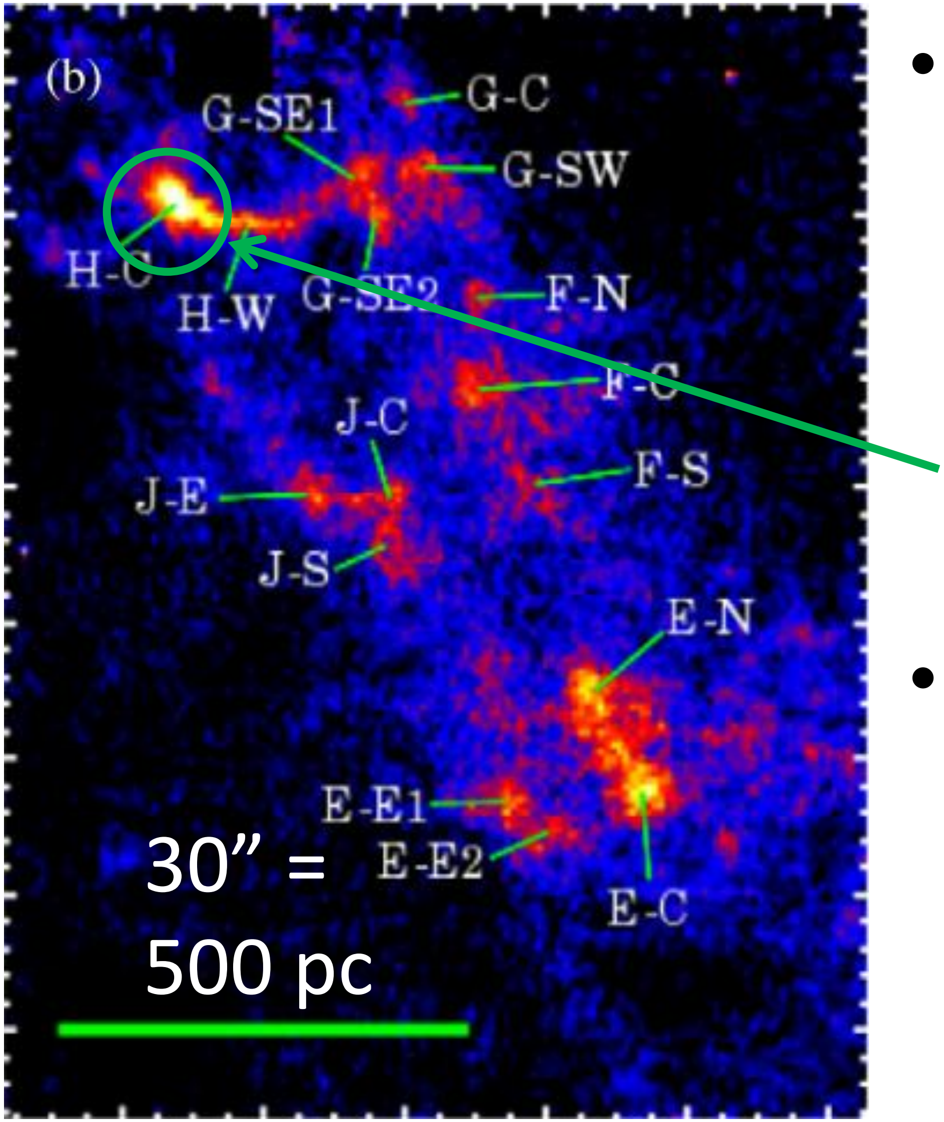
Fast shock model



- filled circle: cap
- dotted line: fast shock model (Allen et al. 2008)
  - shock velocity = 200 – 1000 km/s

Observed ratios cannot be explained by fast shock model.

Another diagnosis



- Can photoionization or slow shock models explain the Hα surface brightness of the brightest knot?
- We assume that the knot is a 90-pc diameter sphere.

Enough ionizing photons?

- Ionizing photon flux from M82 starburst regions: 10^{54} photons s^{-1} (McLeod et al. 1993)
- Escape fraction of ionizing photons = ~6 %

-> Photon flux at cap = 3.6×10^{6} cm^{-2} s^{-1}

- Observed Hα surface brightness = 1×10^{-16} erg cm^{-2} s^{-1} $arcsec^{-2}$ (2.25" x 2.25" aperture)

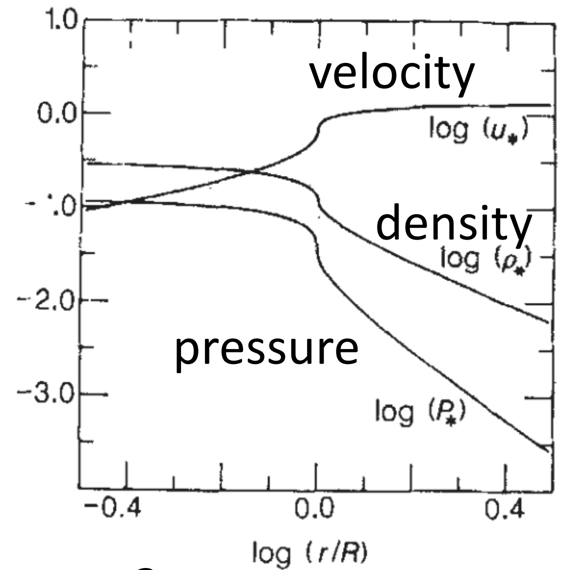
-> Required photon flux = 3.7×10^{7} cm^{-2} s^{-1}

-> It is difficult to explain with photoionization, unless the escape fraction is extremely large, 60 %.

Enough pressure by the wind?

- Galactic wind model
  - Chevalier & Clegg (1985)

-> Ram pressure at 11.6 kpc = 2.1×10^{-12} dyne cm^{-2}



- Electron density of knot H-C = 1.0 cm^{-3}
- Assumed electron temperature = 10^4 K

-> Thermal pressure = 2.8×10^{-12} dyne cm^{-2}

-> Model and observed pressure are well balanced.

-> It is likely that <u>the cap is ionized by slow shock</u>.

Summary

- In order to investigate whether the galactic wind reach the cap, we observed the M82 cap with Kyoto3DII Fabry-Perot mode.

- It is quite likely that the cap is ionized by slow shock and therefore the galactic wind can reach the distance of the cap, 11.6 kpc.
- More distant clouds?