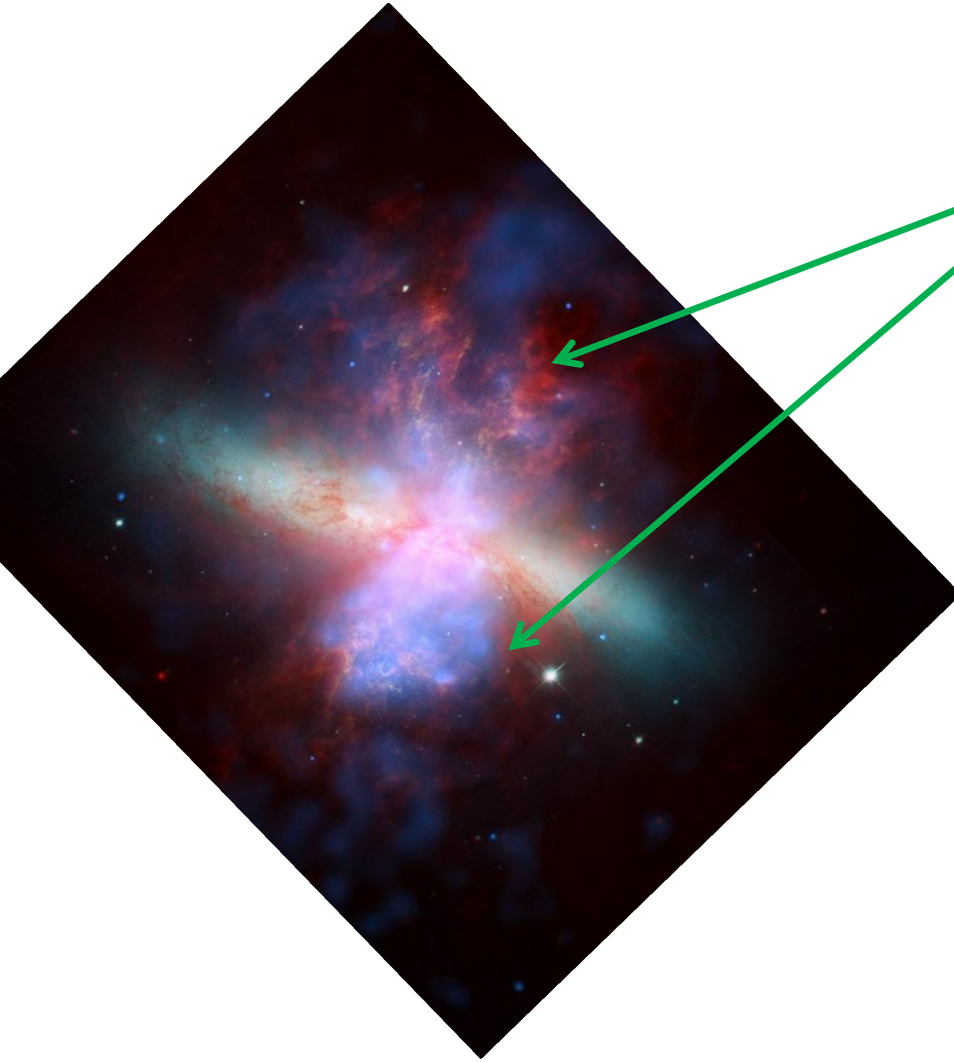
# Ionization Source of the M82 Cap Region Investigated by Optical Line Ratio Maps

Kazuya Matsubayashi (Ehime University)

Hajime Sugai, Atsushi Shimono, Takashi Hattori,
Shinobu Ozaki, Tatsuhito Yoshikawa, Yoshiaki Taniguchi,
Tohru Nagao, Masaru Kajisawa, Yasuhiro Shioya,
Laurie Riguccini, Joss Bland-Hawthorn

# Superwind (Galactic wind)



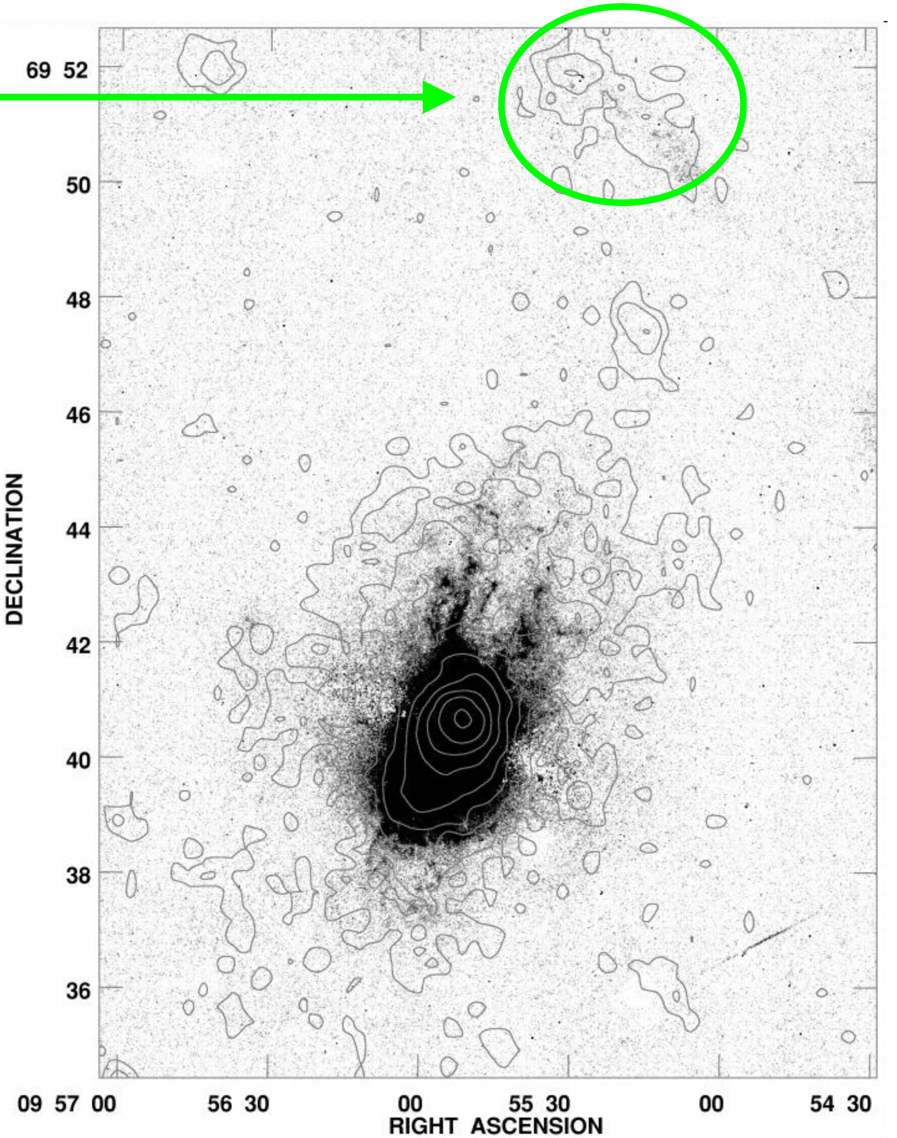
M82 (NASA)

galaxy scale outflow

- is occurred by supernovae or AGN
- quenches the star-formation activity (feedback)
- A part of superwind becomes intergalactic medium.

# M82 cap

- a gas cloud 11’ (= 11.6 kpc) from the M82 center
- detected in X-ray and Hα (Devine & Bally 1999; Lehnert et al. 1999)
- origin of hot gas is type-II supernovae (Tsuru et al. 2007)




grayscale: Hα
countour: X-ray

# Emission mechanism

(Devine & Bally 1999; Lehnert et al. 1999)

- X-ray: $k_B T$ = 0.80 keV (~ $10^7$ K)
  - heated by shock ($v_{shock}$ ~ 800 km/s) between the M82 superwind and halo gas clouds
- Hα: FWHM ~ 100 km/s
  - photoionized by the M82 nuclear starburst region?
  - another shock ($v_{shock}$ ~ 100 km/s)？

# Motivation

Line ratios are powerful to distinguish the ionization source of the cap.

- [NII]/H$\alpha$ > 1.0 → fast shock
- [NII]/H$\alpha$ < 0.5 → photoionization

We measured [NII]/H$\alpha$ and [SII]/H$\alpha$ line ratios of the cap with Subaru telescope.

# Observation

- object: M82 cap
- date: 2011/Nov/22 26:40 – 28:50 (HST)
- telescope/instrument: Subaru/Kyoto3DII Fabry-Perot mode
- target lines: H$\alpha$, [NII]$\lambda\lambda$6548,6583, [SII] $\lambda\lambda$6716, 6731
- wavelength resolution: $R$ = 348, $\Delta\lambda = 19$ Å
- spatial resolution: 0".9
- exposure time: 4200 s (H$\alpha$+[NII]), 1500 s ([SII]), 600 s (continuum)

# Result

(a) flux(cont.)

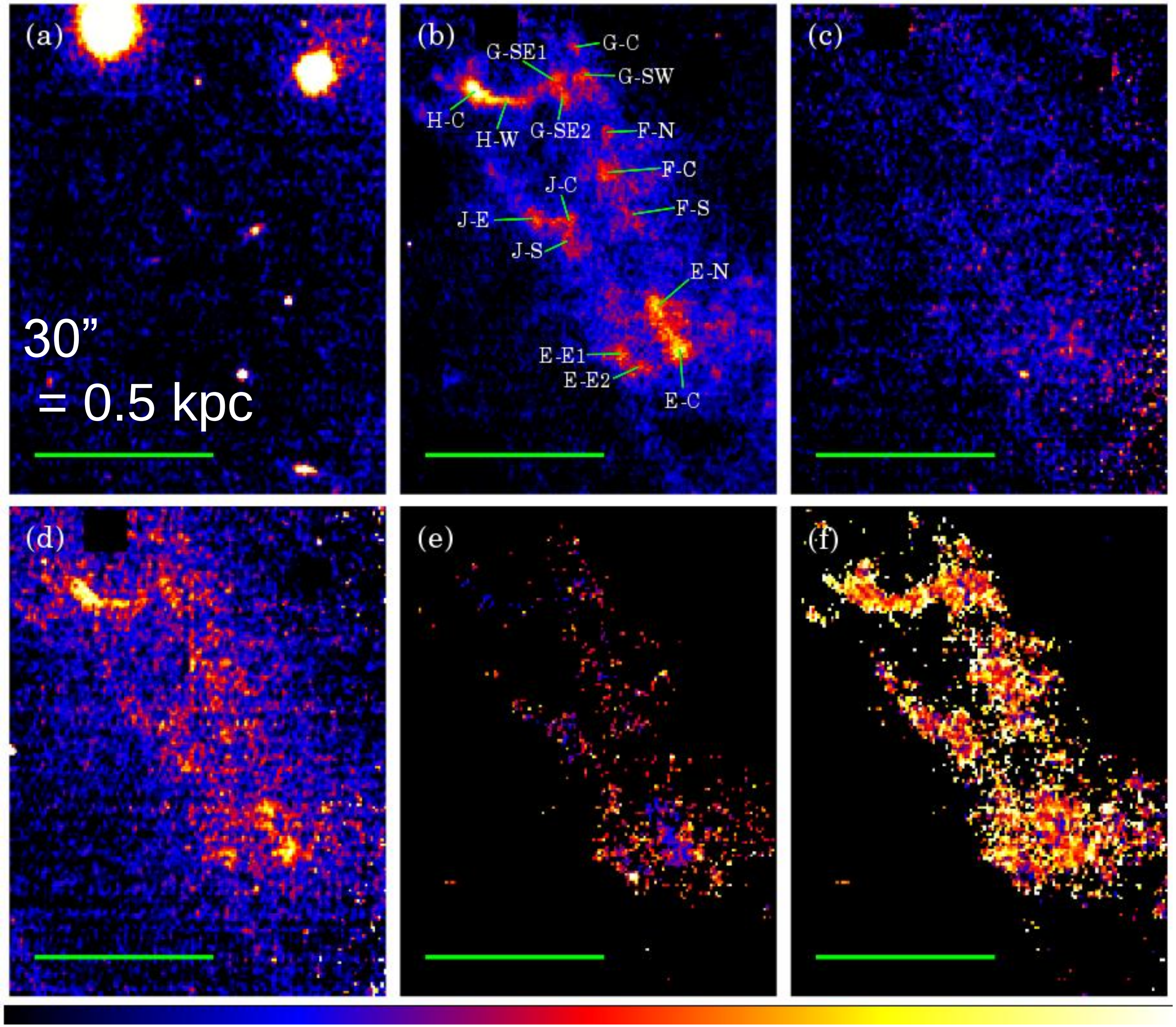
(b) flux(Hα)

(c) flux([NII])

(d) flux([SII])

(e) [NII]/Hα

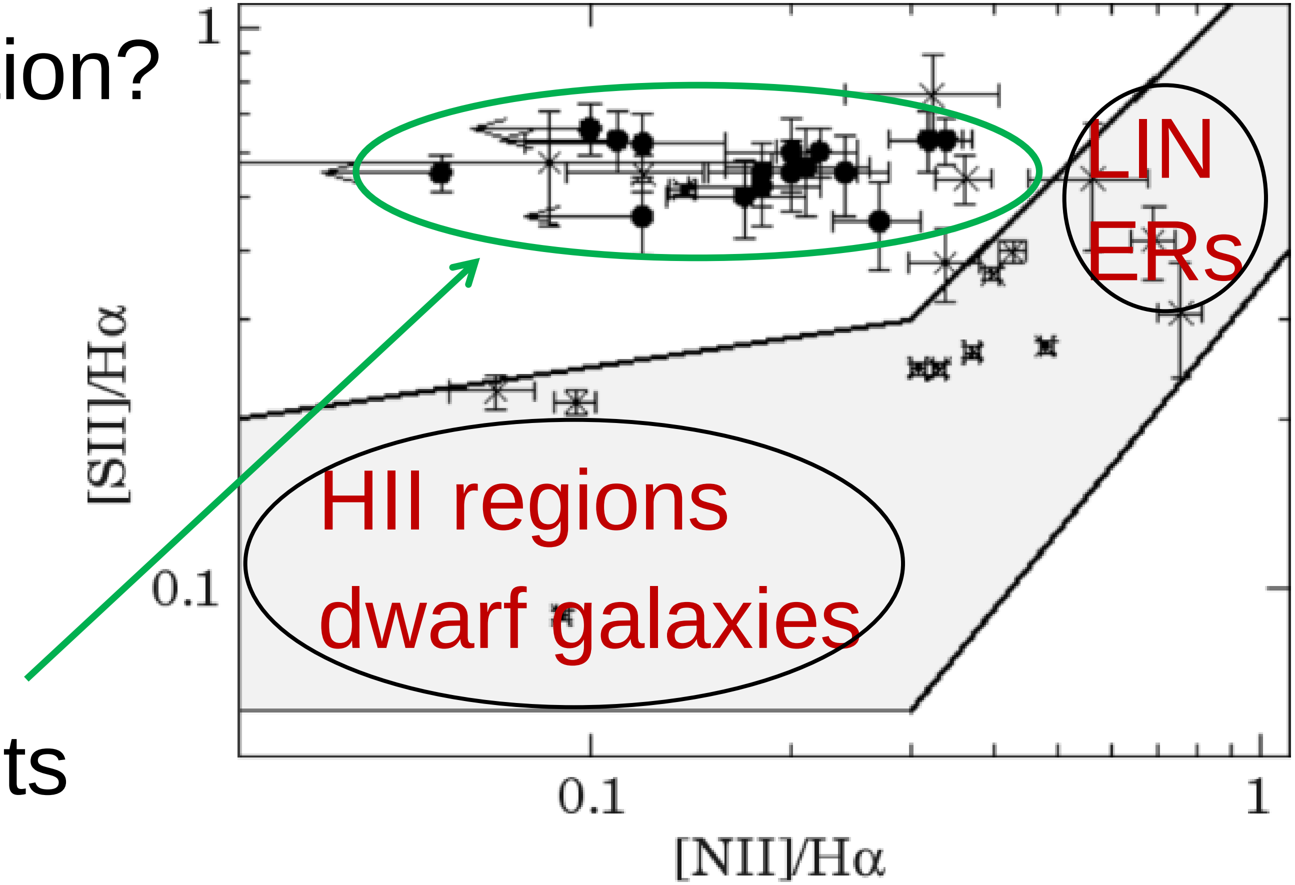
(f) [SII]/Hα



# [NII]/Hα vs [SII]/Hα of knots

- [NII]/Hα = 0.10 – 0.35, [SII]/Hα = 0.45 – 0.65

→ phoionization?




filled circles:
M82 cap knots

[SII]/Hα ratios of M82 cap knots are larger than those of HII regions by ~0.3 dex.

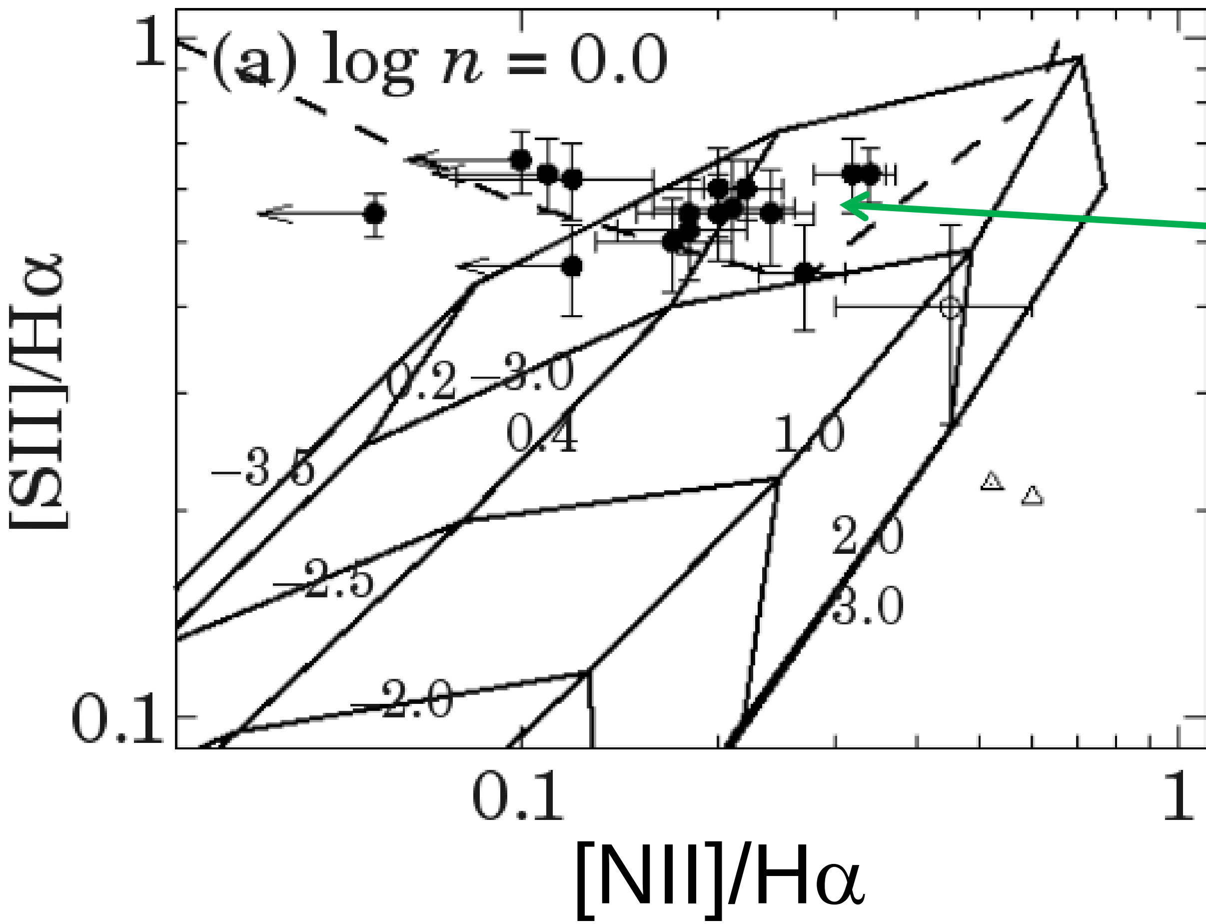
# Compare with models

We compare the observed ratios at M82 cap with model predicted values.

- photoionization: UV photons from OB stars ($0.05 \le Z/Z_{sun} \le 3$, $-3.5 \le \log U \le -1.5$) (Cloudy; Ferland et al. 1998)
- slow shock ($Z_{sun}$, 40 km/s $\le v_{shock} \le$ 130 km/s) (Shull & McKee 1979)
- fast shock ($Z_{sun}$, 200 km/s $\le v_{shock} \le$ 1000 km/s, various $B$) (Allen et al. 2008)

# Photoionization

- solid lines: photoionization model
- Photoionization can explain observed ratio.

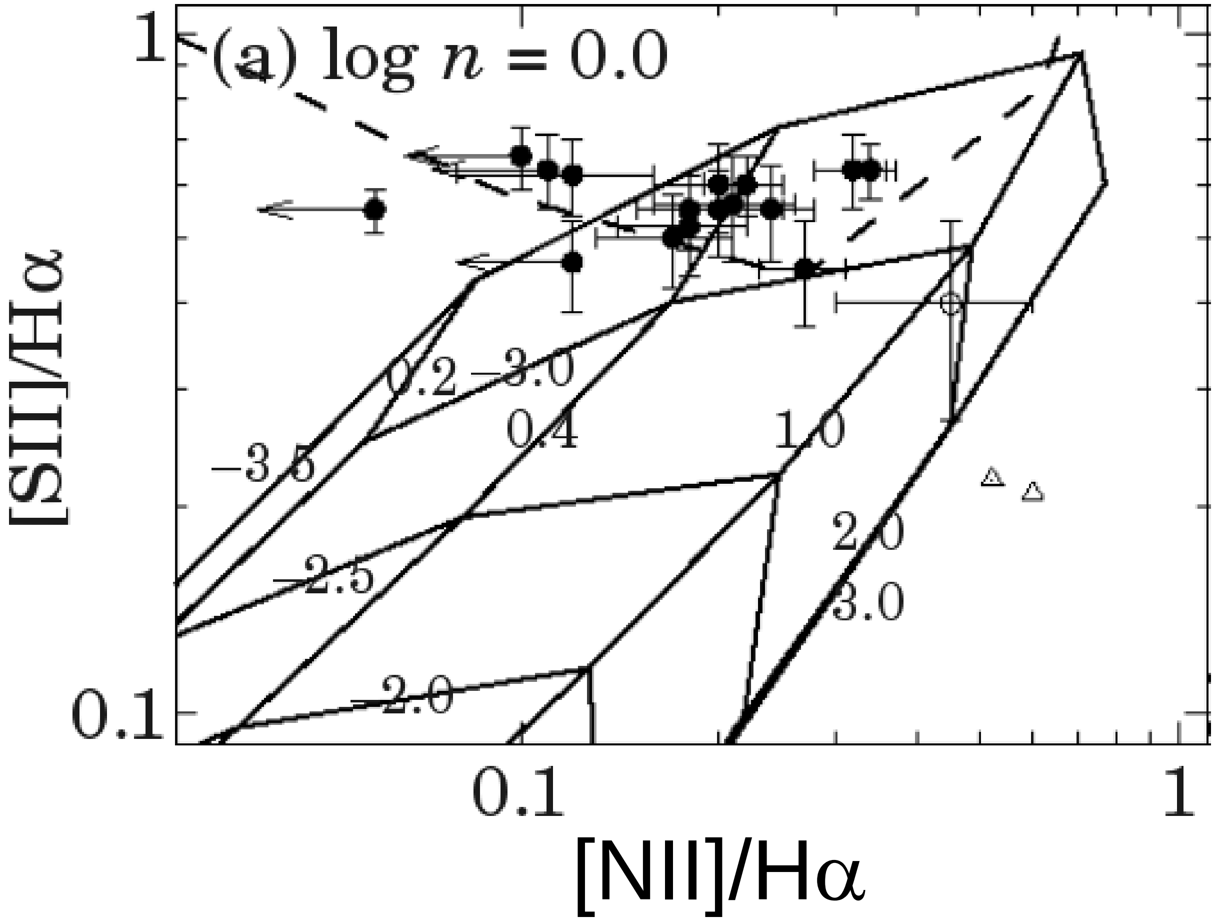



M82 cap knots (filled circles)

best fit: $U \sim 10^{-3.5} - 10^{-3.0}$, $Z \sim 0.4\, Z_{\rm sun}$

# Slow shock

- dashed line: slow shock model
- Slow shock also can explain observed ratios.

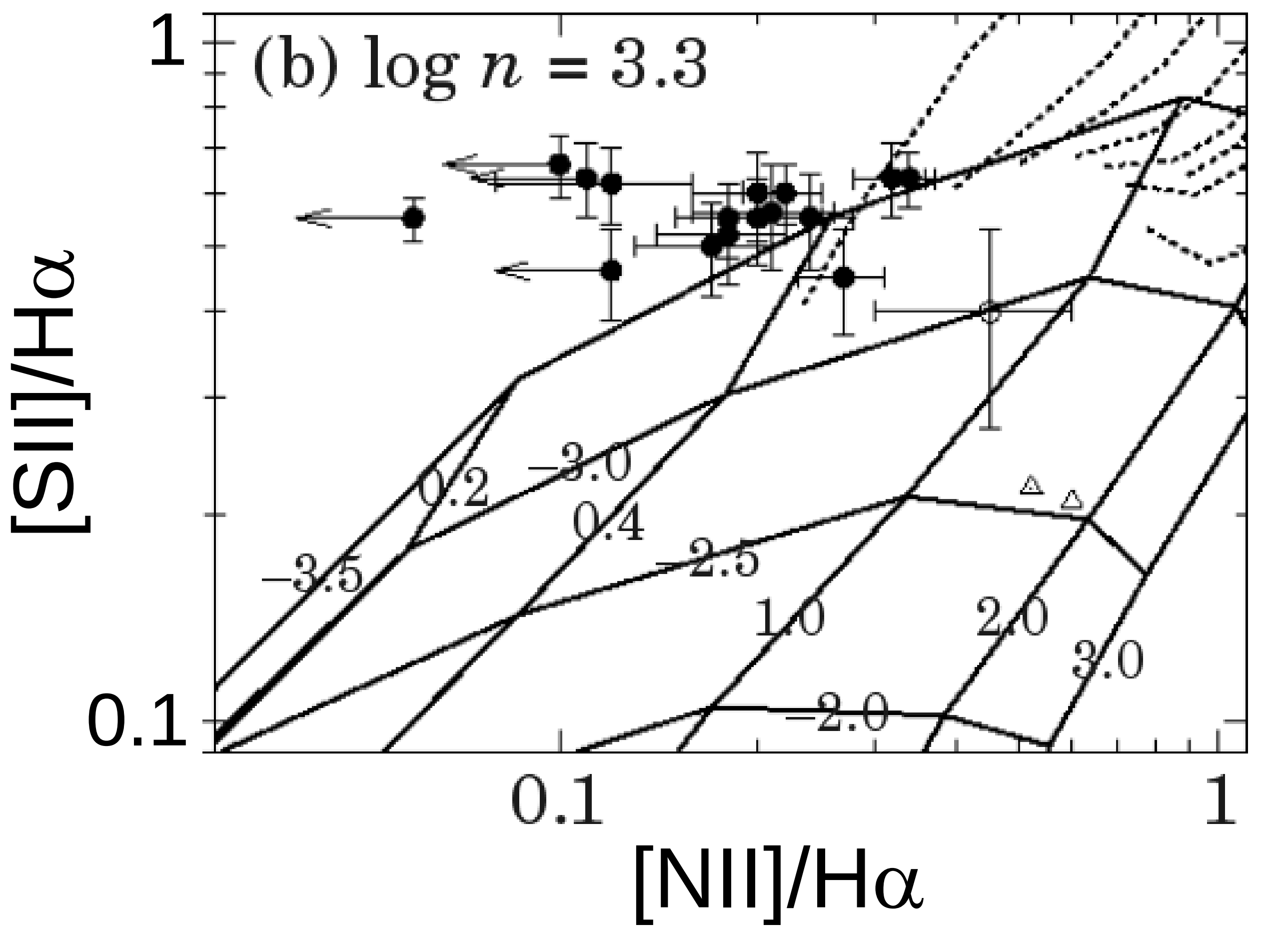



shock velocity

best fit: 60 – 80 km/s ($Z_{sun}$)

# Fast shock

- dotted line: fast shock model
- Fast shock cannot explain the observed ratios.

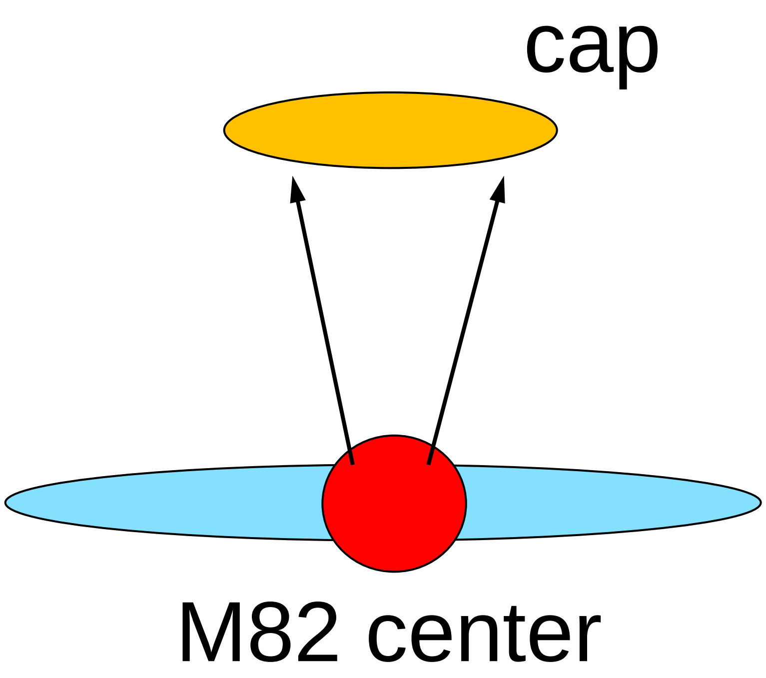



shock velocity

# Heating mechanism of hot gas

- Hot gas was considered to be heated by fast shock at the cap (Lehnert te al. 1999).
- But our data indicates no fast shock there.

Hot gas was produced at the M82 center, blown out by superwind, and moved to the present place?



# Ionized gas origin

- halo gas cloud photoionized by OB stars
  - ionized and hot gas happen to coincide
- part of superwind is photoionized
  - ionized gas metallicity (~0.4 $Z_{sun}$) is slightly different from hot gas one (~$Z_{sun}$) (Tsuru et al. 2007)
- **Slow shock between superwind and halo gas can avoid these problems.**

# Summary

- We observed the M82 cap, a gas cloud 11.6 kpc from the center, in order to understand the ionization source.
- The observed ratios are [NII]/H$\alpha = 0.10$ – 0.35 and [SII]/H$\alpha = 0.45$ – 0.65.
- Photoionization and slow shock can explain the observed ratios, but fast shock cannot.
- It is possible that hot gas heated at the M82 center was transported by superwind, and slow shock produces ionized gas.