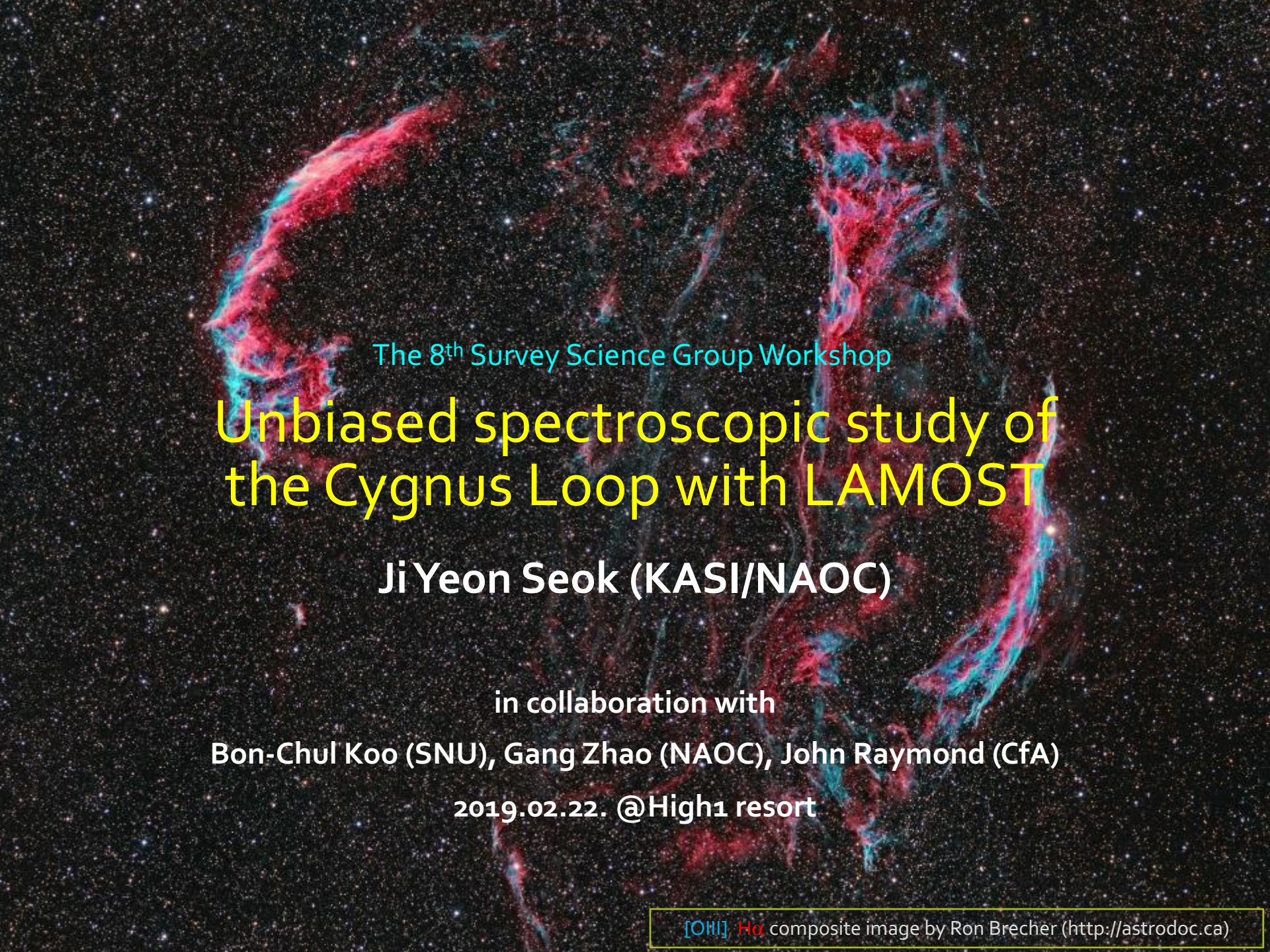

The 8th Survey Science Group Workshop

Unbiased spectroscopic study of the Cygnus Loop with LAMOST

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in collaboration with

Bon-Chul Koo (SNU), Gang Zhao (NAOC), John Raymond (CfA)

2019.02.22. @High1 resort

[OIII], Hα composite image by Ron Brecher (http://astrodoc.ca)

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The Large Sky Area Multi-object Fiber Spectroscopic Telescope (LAMOST) Quasar Survey: The Fourth and Fifth Data Releases

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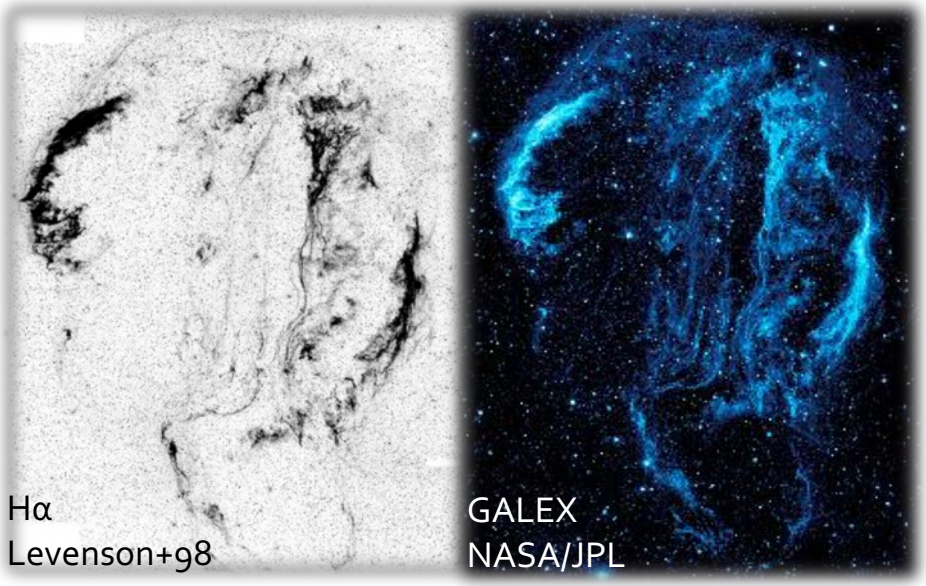
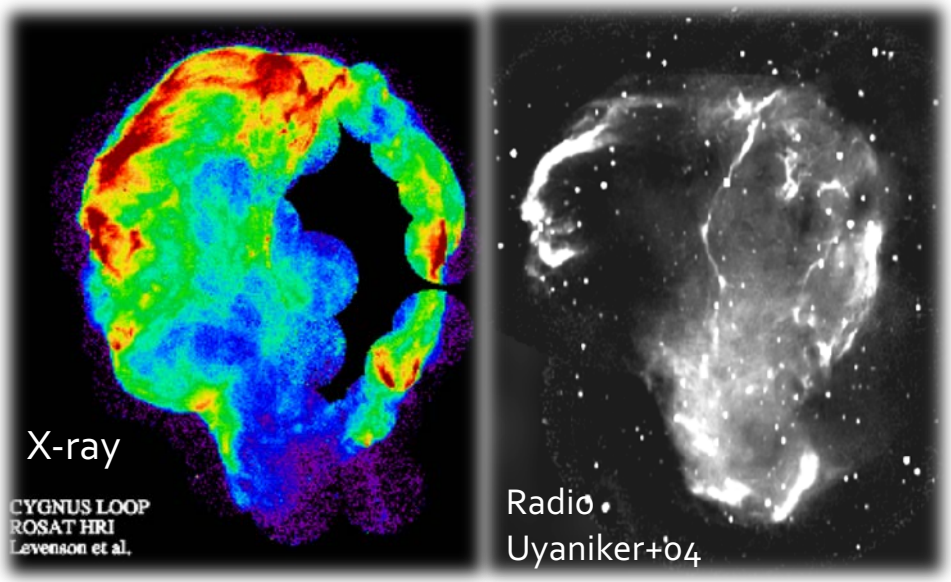
Abstract

We present Data Releases 4 and 5 of the quasar catalog from the quasar survey by the Large Sky Area Multi-object Fiber Spectroscopic Telescope (LAMOST), which includes quasars observed between 2015 September and 2017 June. There are a total of 19,253 quasars identified by visual inspections of the spectra. Among them, 11,458 were independently discovered by LAMOST, in which 3296 were reported by the SDSS DR12 and DR14 quasar catalog after our survey began, while the remaining 8162 are new discoveries of LAMOST. We provide the emission line measurements for Hα, Hβ, Mg II, and/or C IV for 18,100 quasars. Since LAMOST does not have absolute flux calibration information, we obtain the monochromatic continuum luminosities by fitting the SDSS photometric data using the quasar spectra, and then estimate the black hole masses. The catalog and spectra for these quasars are available online. This is the third installment in the series of LAMOST quasar surveys that has released spectra for ~43,000 quasars to date. There are 24,772 independently discovered quasars, 17,128 of which are newly discovered. In addition to this great supplement to the new quasar discoveries, LAMOST has also provided a large database (overlapped with SDSS) for investigating quasar spectral variability and discovering unusual quasars, including changing-look quasars, with ongoing and upcoming large surveys.

Key words: catalogs – quasars: general – surveys

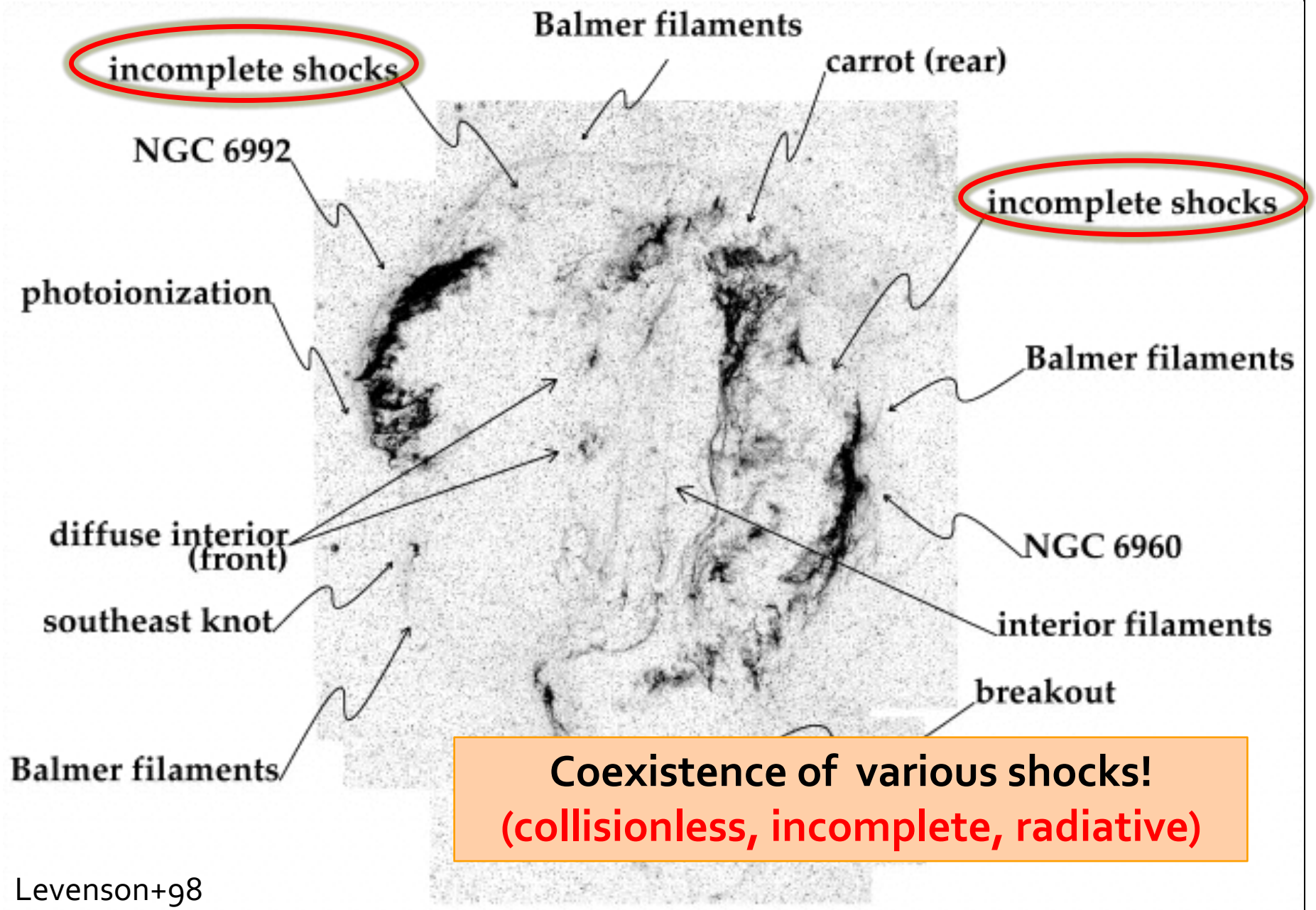
Supporting material: machine-readable table





The Cygnus Loop
(a.k.a. Veil Nebula)

- Prototype of middle-aged SNRs (~20,000 year)
- Among the brightest, best-studied Galactic SNRs in multi-wavelengths
- Large in angular size (~3° x 3.8°): ~38x51 pc at 735±25 pc (Fesen+18)
- Low extinction: E(B-V)≈0.08 mag (Parker 67)
- Its structure and physical properties resulting from a SN-generated shock wave interacting with the surrounding ISM (e.g., Fesen+82)

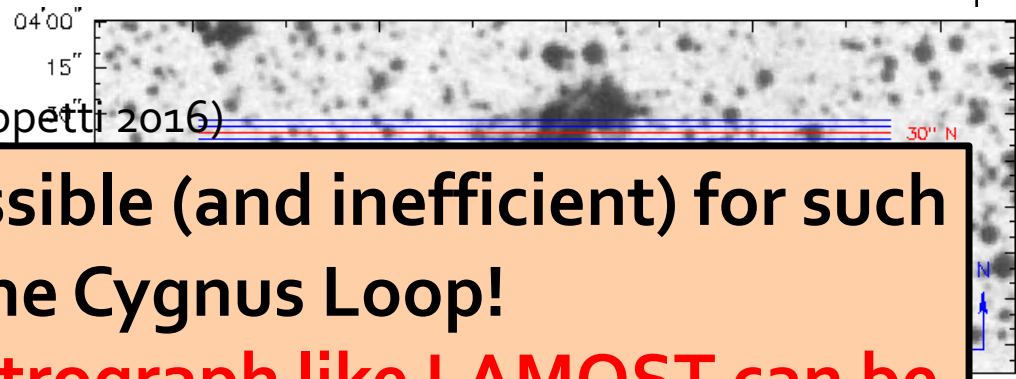


Coexistence of various shocks!
(collisionless, incomplete, radiative)

Levenson+98

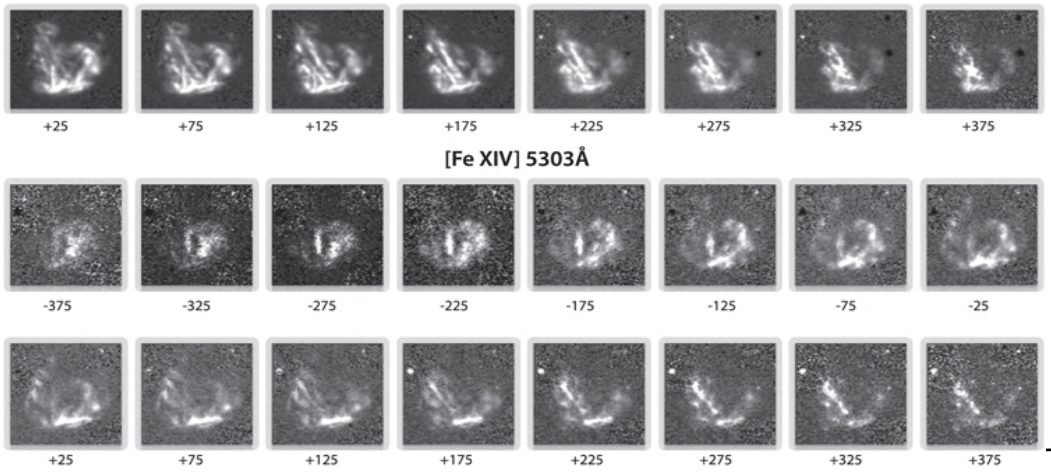
Spectral Mapping on SNRs

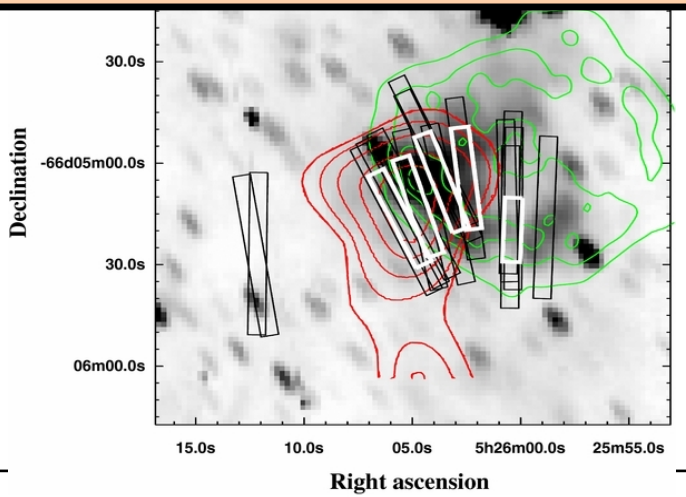
- **N49** (1.5′×1.3′): one of the best studied in the LMC
- Spectroscopic studies
  - Long-slit mapping (e.g.,Pauletti & Copetti 2016)



Spectral mapping is impossible (and inefficient) for such a large Galactic SNR like the Cygnus Loop!

Instead, multi-object spectrograph like LAMOST can be a perfect and unique technique!

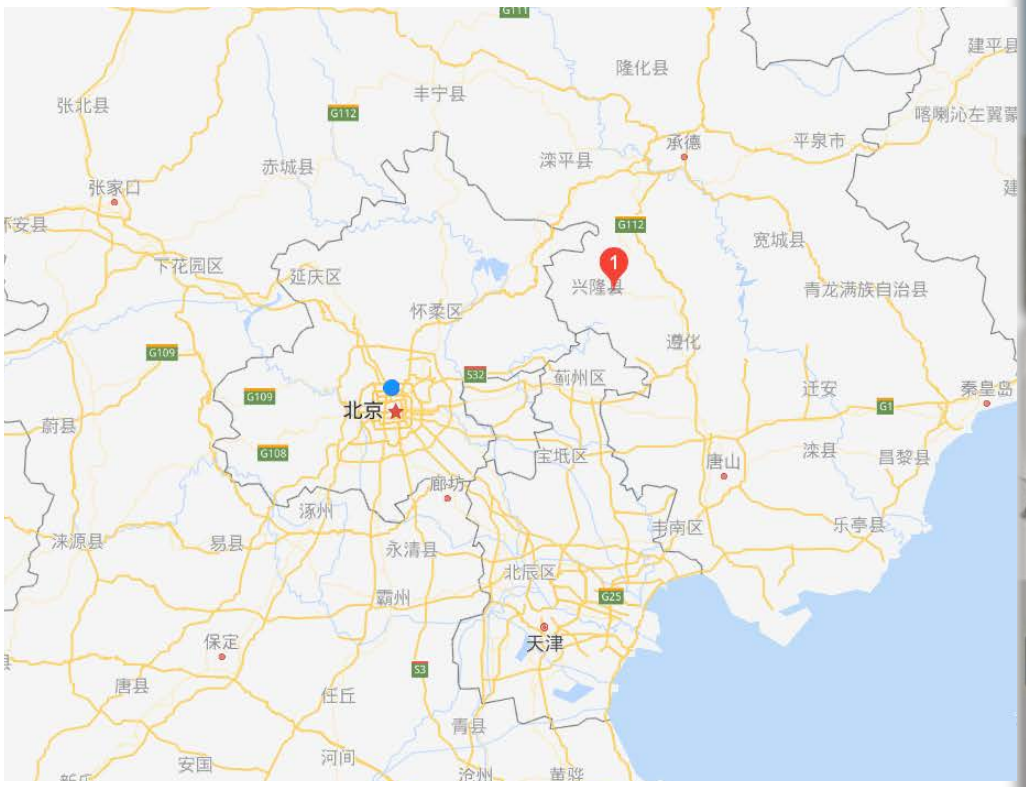


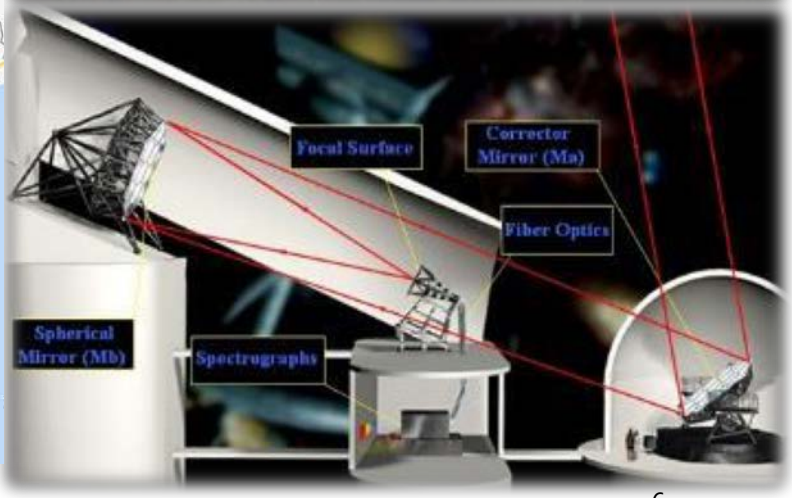


LAMOST

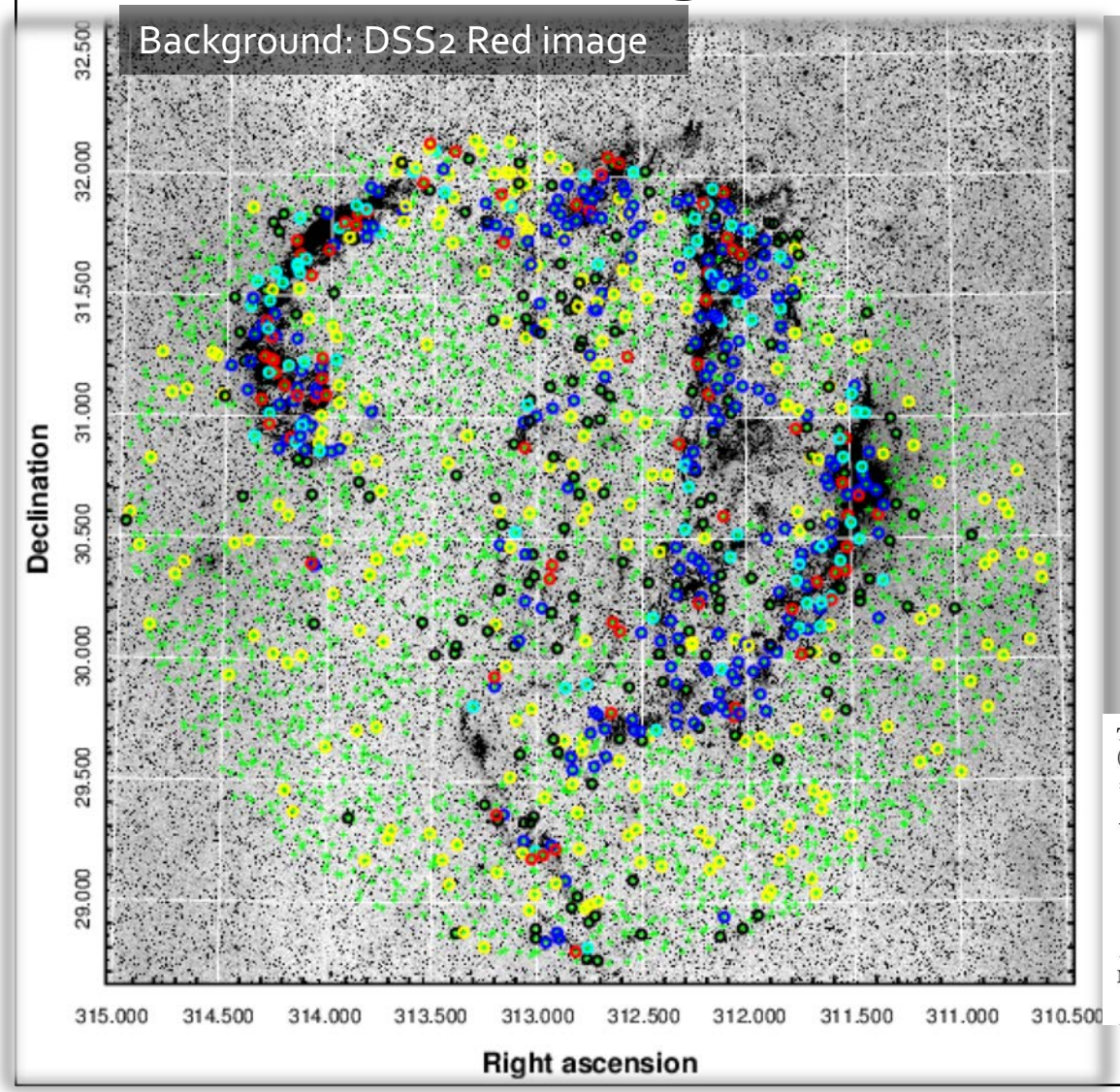
Large Sky Area Multi-Object Fiber Spectroscopic Telescope

- Located in Xinglong station of NAOC, Hebei province





Spatial Distribution of LAMOST Spectra toward the Cygnus Loop



In total, **2747 spectra in DR5** are found in the field (green crosses).

Classification for **778 spectra** after first screening (circles)

Group I: SNR-dominated (**75**)

Group IIa: strong SNR+ stellar (**79**)

Group IIb: weak SNR + stellar (**214**)

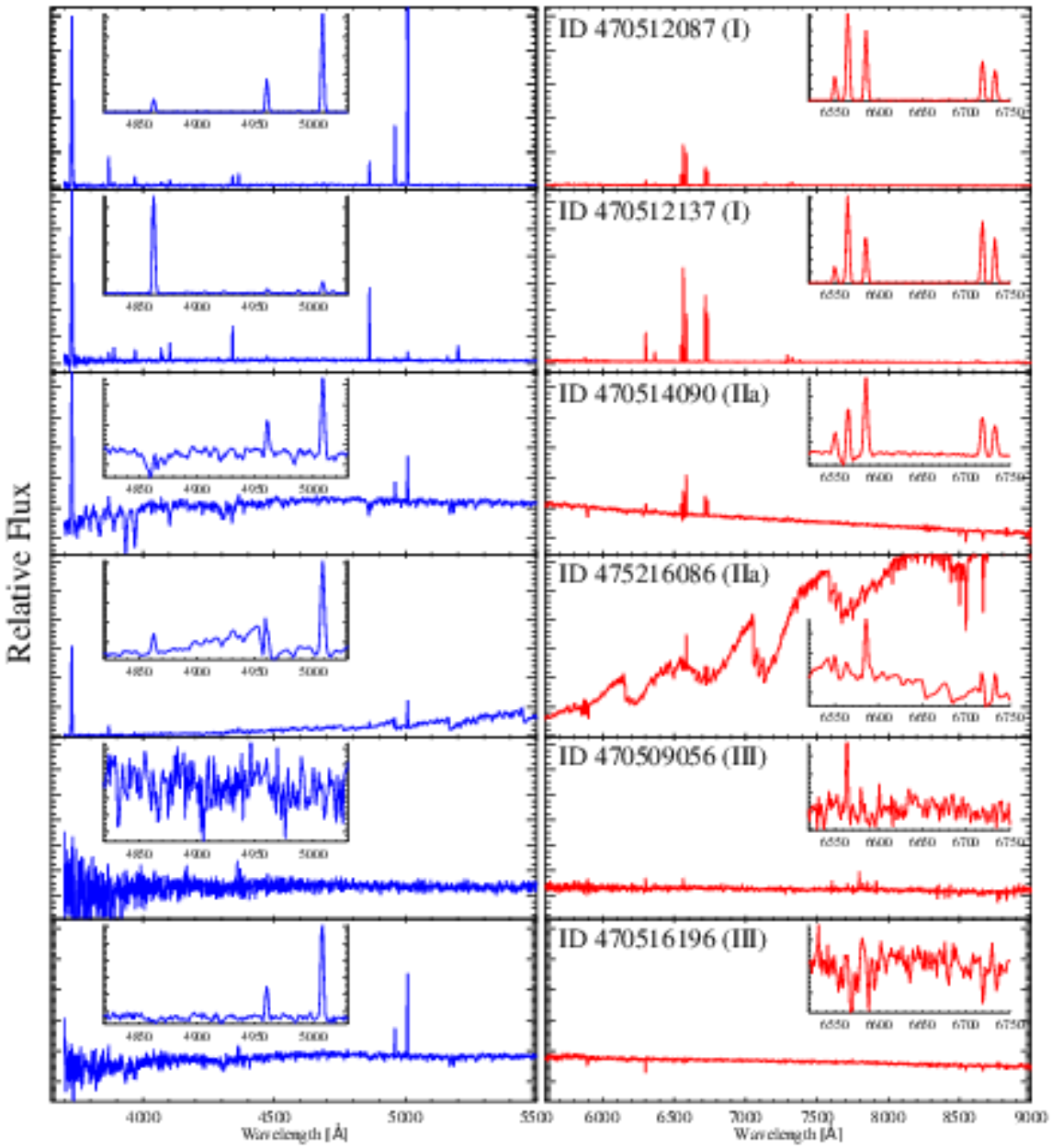
Group III: stellar with weak SNR or ambiguous association with the SNR (**176**)

Group IV: stellar only (**370**)

Table 2. Spectrum Classification for 778 Spectra after the first screening (ver07.13.2018)

Group	Number	Note	Symbol Color[a]
I	75	SNR-dominated	red
IIa	79	(strong) SNR+stellar	cyan
IIb	214	(weak) SNR+stellar	blue
III	176	Ambiguous, possibly Balmer-dominated	black
IV	234	Stellar-dominated	yellow

NOTE—Group I and IIa are mostly used for analysis in Section 3, and IIb is only used to estimate n_e (see Section 3.2.1).



Exemplary Spectra

Group I

- ✓ Line dominated
- ✓ high [SII]/Hα indicative of shocked emission

Group IIa

- ✓ Stellar features (continuum, absorption features, etc.)
- ✓ Emission lines from the SNR

Group III

- ✓ Only Balmer lines
- ✓ Only [OIII] lines

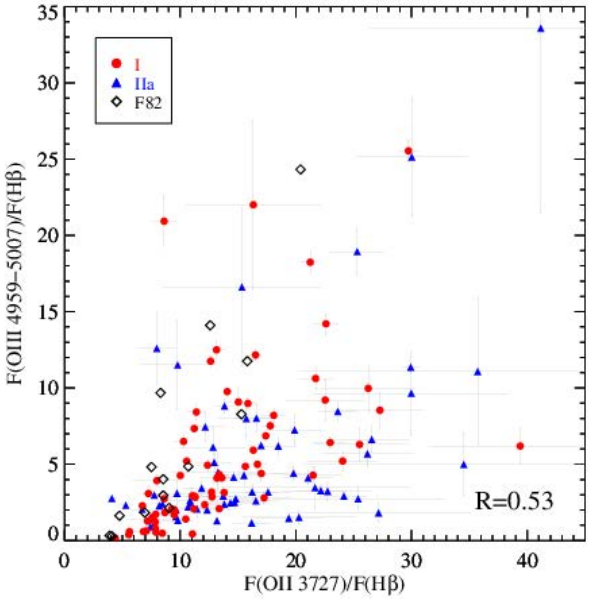
Variation of Line Ratios

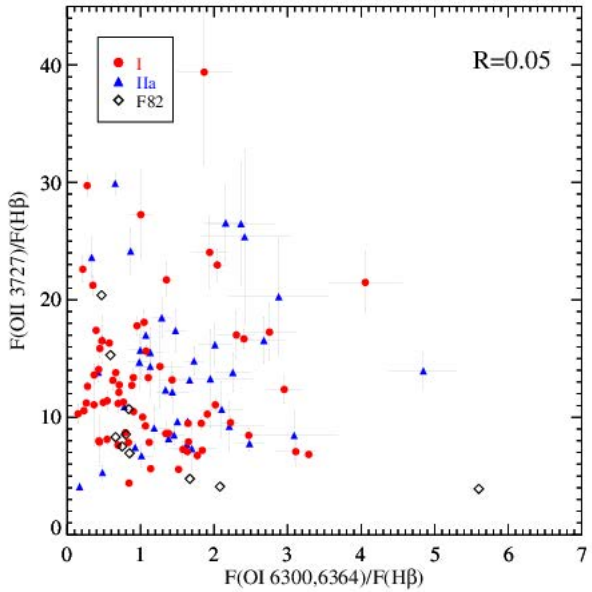
17 spectra taken by Fesen+82

154 spectra (this work)

Comparison between different transitions

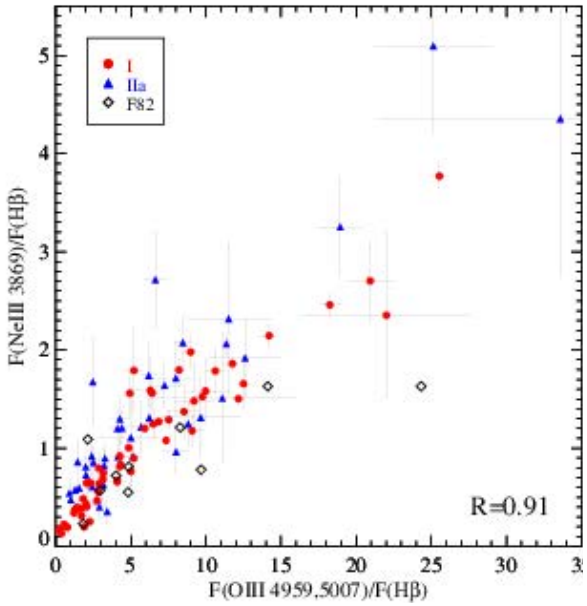
✓ Positive correlation between high ionization and negative correlation between ionized and neutral level

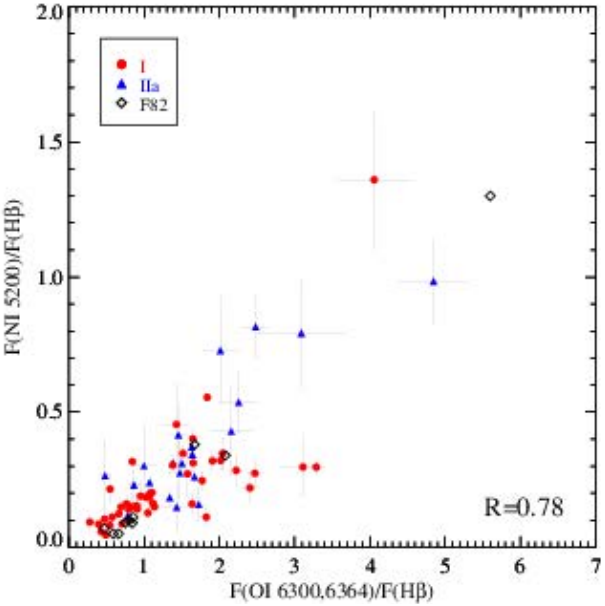




Comparison between different elements

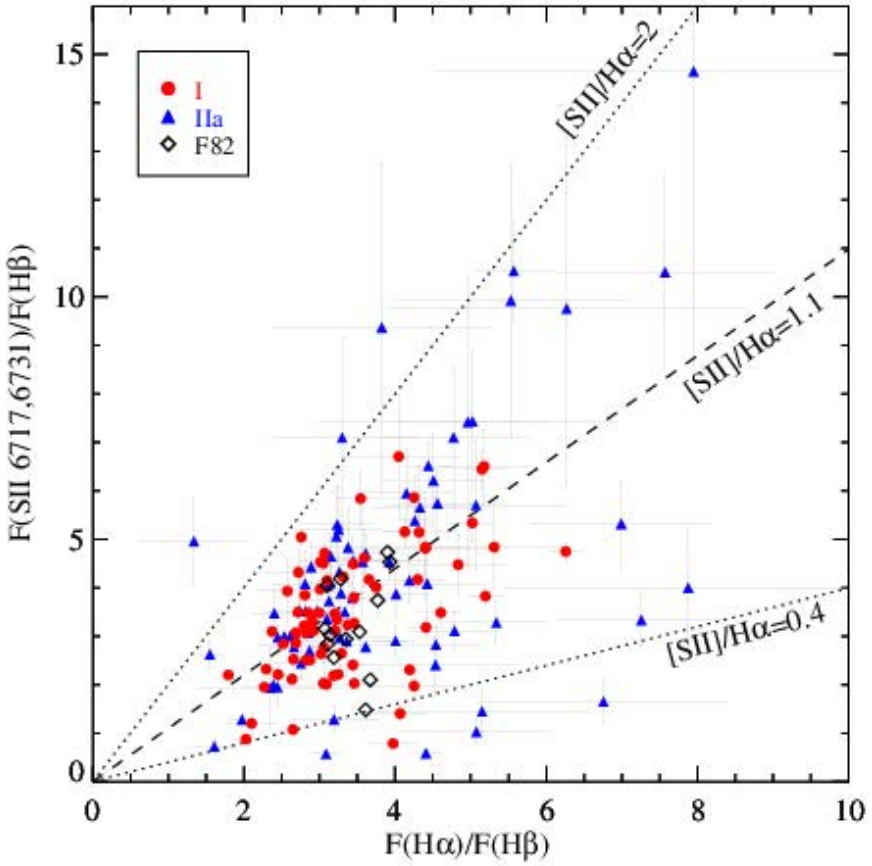
✓Good correlation between elements with the same ionization level

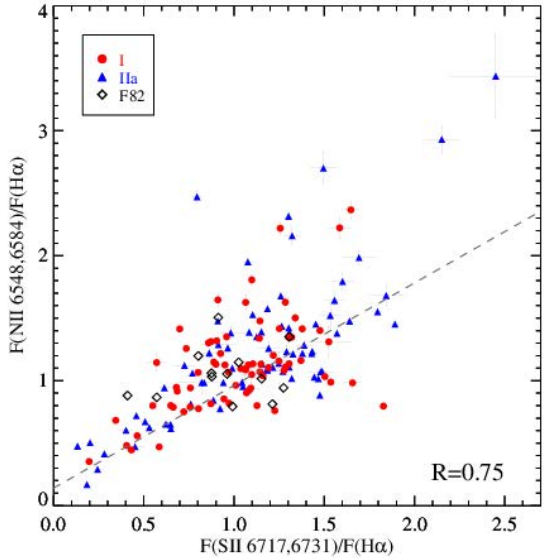


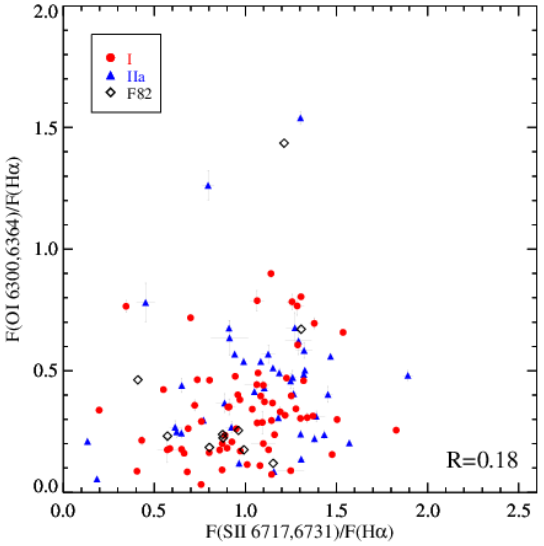


Variation of Line Ratios (II)

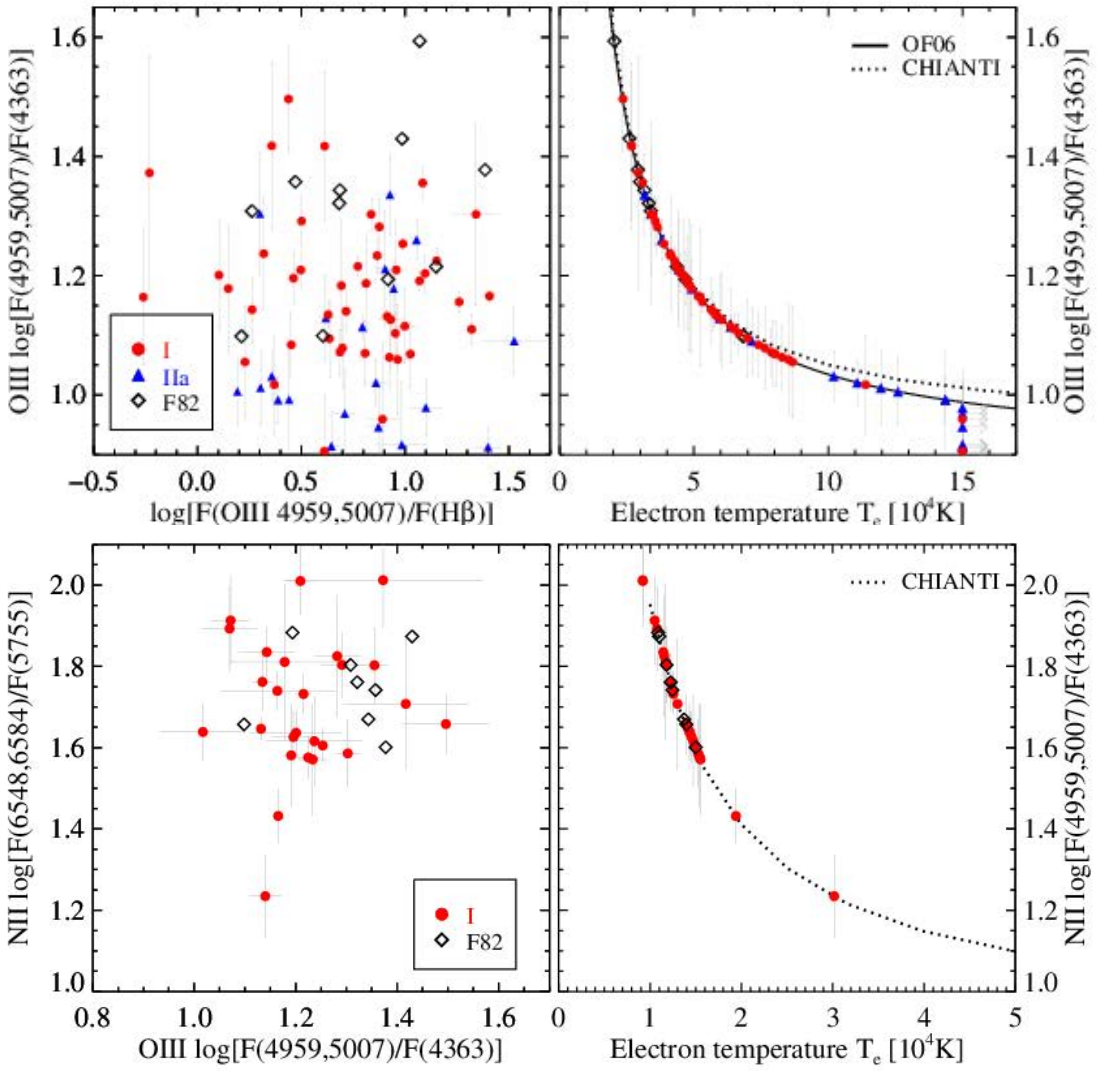
- Comparison between shock tracers







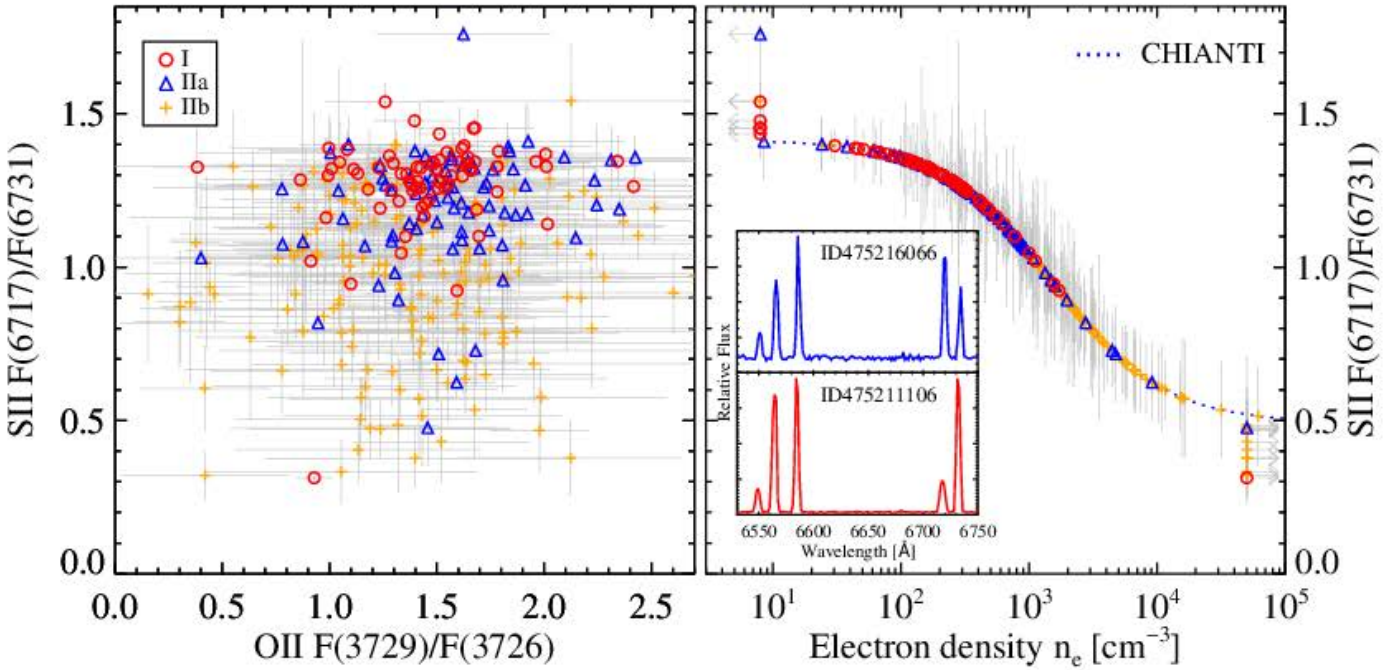
Electron Temperature



- [O III] T_e~3-8x10^4 K
  - Previous estimate of T_e: ~2-7x10^4 K with [OIII] (e.g.,Miller74, Fesen+82)
  - [O III] ratios ≤10: presence of higher T_e (≥10^5 K)

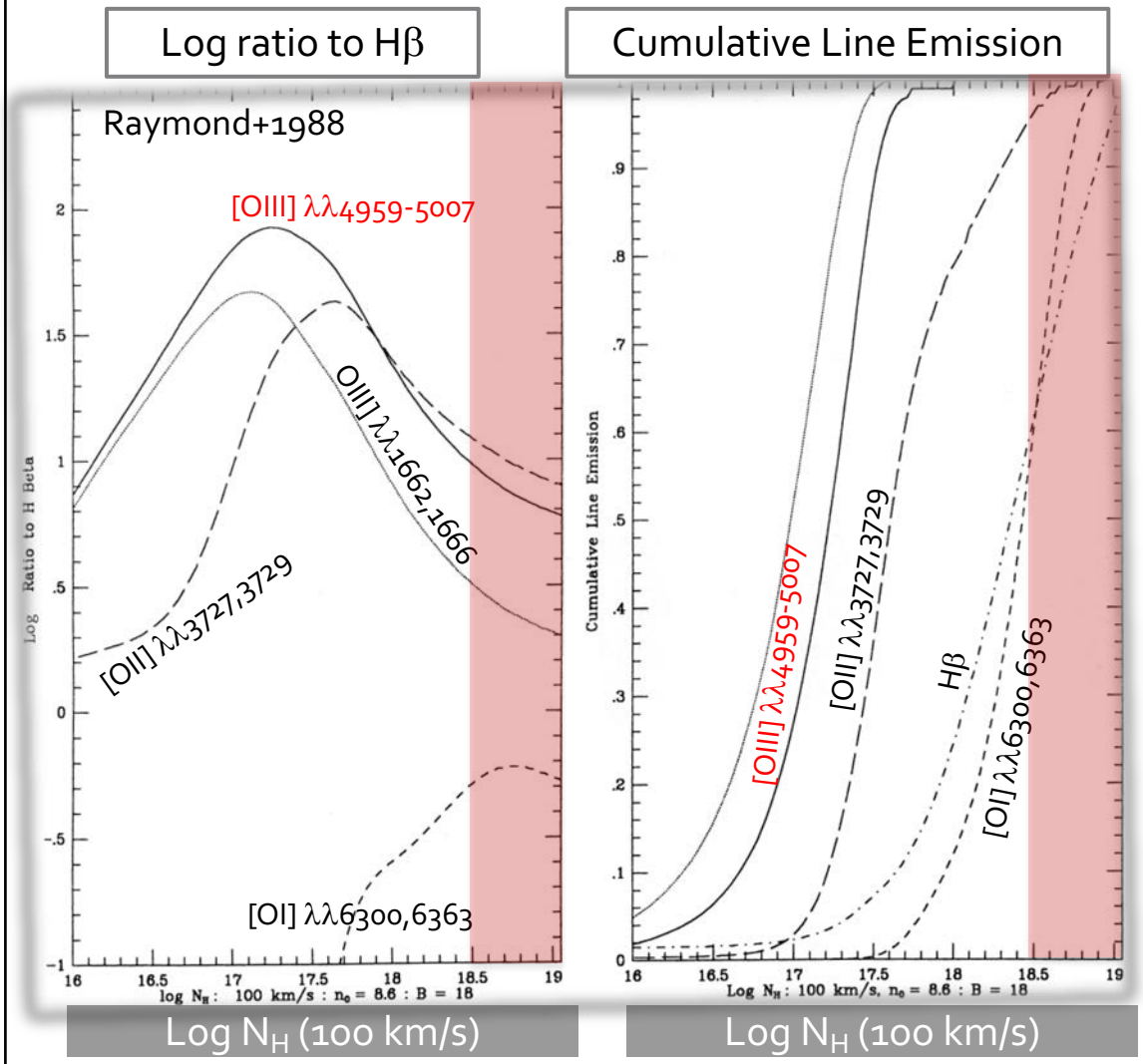
- [NII] T_e (only group I used)
  - T_e~1-1.5x10^4 K: much lower than [O III] T_e
  - No correlation with [O III] T_e
  - Natural consequence of cooling and recombination in the radiative zone.

Electron Density



- Estimate of n_e: ~20 to 500 cm^{-3}
  - Consistent with previous estimates of n_e (~100 to 1000 cm^{-3}; Miller74, Fesen+82)
- LAMOST data also show the presence of $n_e > 10^4$ cm^{-3} and $n_e < 10$ cm^{-3}.

Incomplete (or truncated) Shock



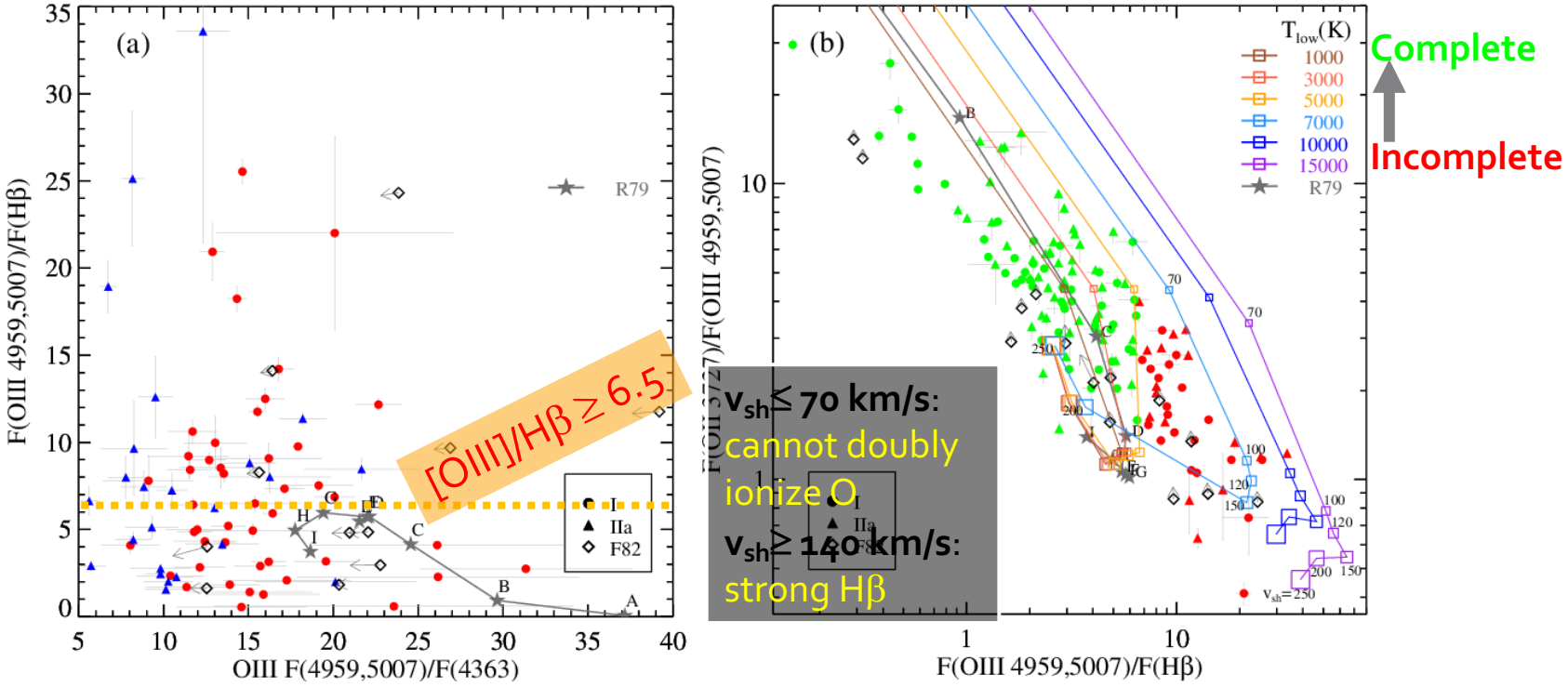
A shock that has *NOT* propagated long enough to become radiative (Draine & McKee 93)

- Its emission spectrum is different from those emitted by complete radiative zone.
- Shocks younger than the cooling time to ~10^4K will be incomplete.

Comparison with shock models (I)

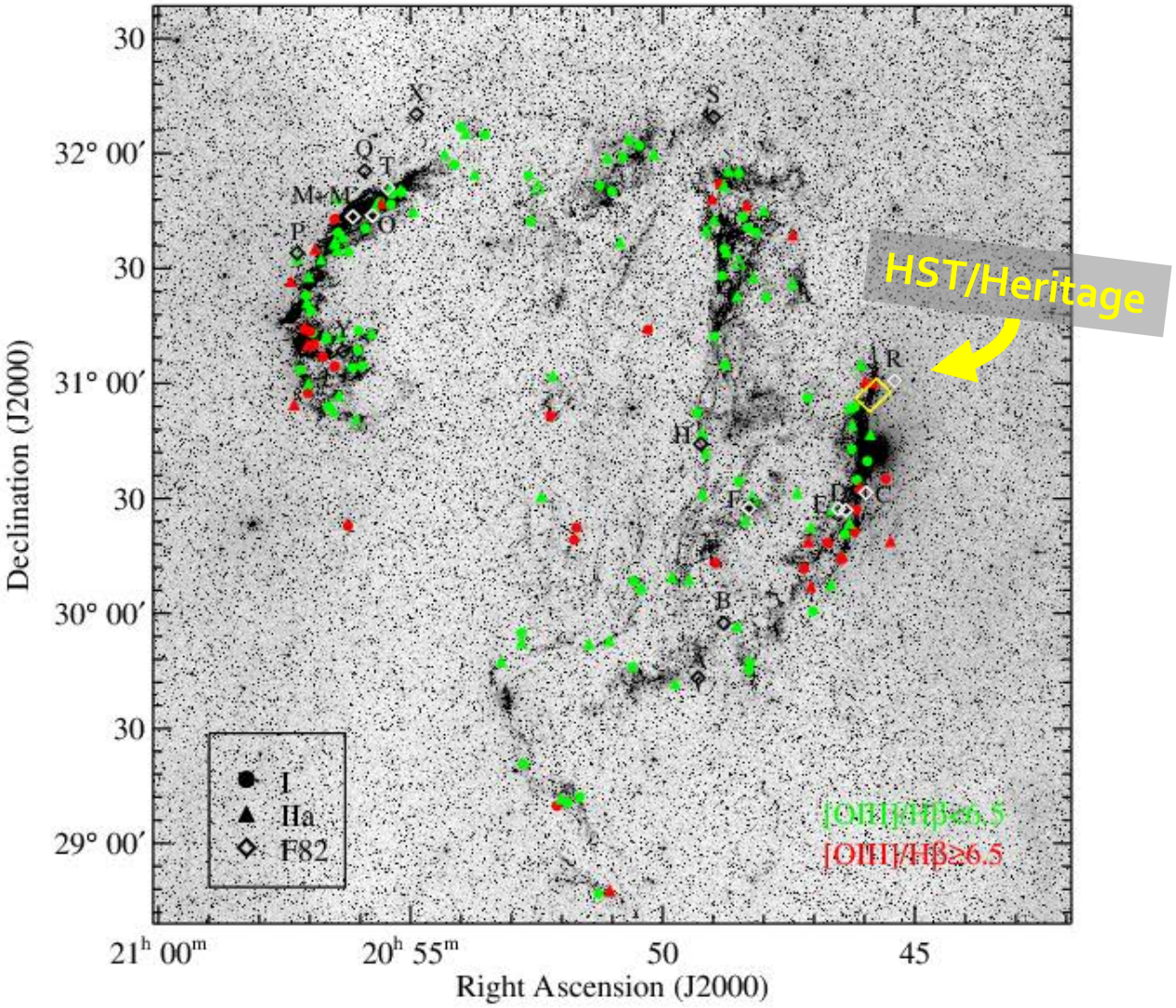
- New calculations taking incompleteness into account by introducing T_{low}
  - v_{shock}=50-250 km/s, n_o=3 cm^{-3}, T_{low}=1,000-15,000 K
  - Compared with Raymond 1979 (v_{shock}=50-250 km/s, n_o=10 cm^{-3})

v_{sh} tracer

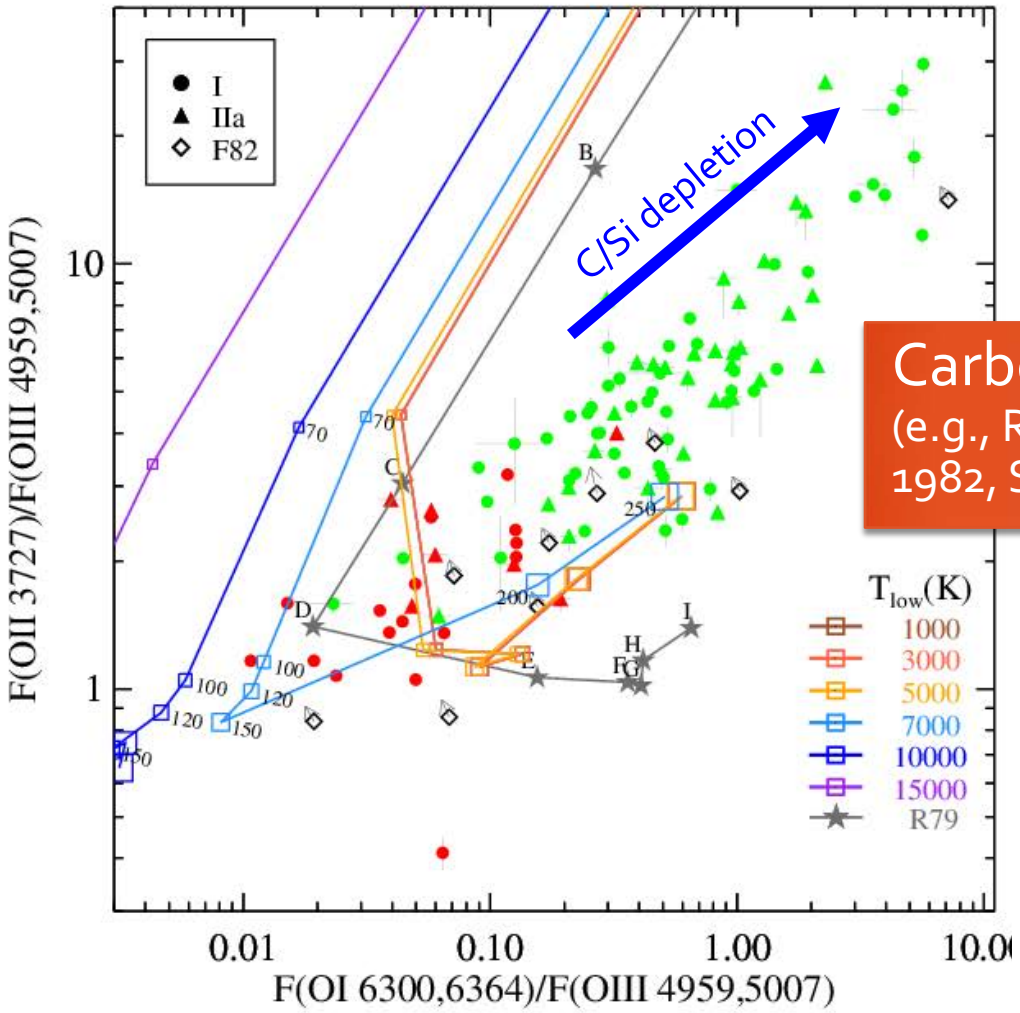


Line ratios associated with incomplete shocks well explained by 5,000K $\leq T_{low} \leq$ 7,000K

Spatial distributions of [OIII]/Hβ ≥ 6.5



Comparison with shock models (II)



[O II]/[O III]

[O I]/[O III]

Carbon and silicate depletion
(e.g., Raymond+1980, Contini & Shaviv 1982, Sankrit+2014)

Summary & Future Prospect

- Using the LAMOST DR5, **an *unbiased* spectroscopic study of the Cygnus Loop** is carried out.
- Signature of incomplete shock (high [OIII]/Hβ) is found in various positions, indicating complex shock structures (i.e., coexistence of collisionless, radiative, or incomplete shocks) within a single SNR.
- Physical properties of the SNR could be even more diverse than what we currently thought (e.g., wider range of n_e, etc.).
- There are more Galactic SNRs covered by the LAMOST survey. Stay tuned!