Stellar Feedback in Giant H II Regions: a Case Study of M101

Wei Sun

Purple Mountain Observatory, CAS

Mar. 27, 2018

collaborators: Y.-H. Chu (ASIAA), Q. D. Wang (UMASS), R. Chen (Bonn), L. Ji. (PMO), Y. Chen (NJU)

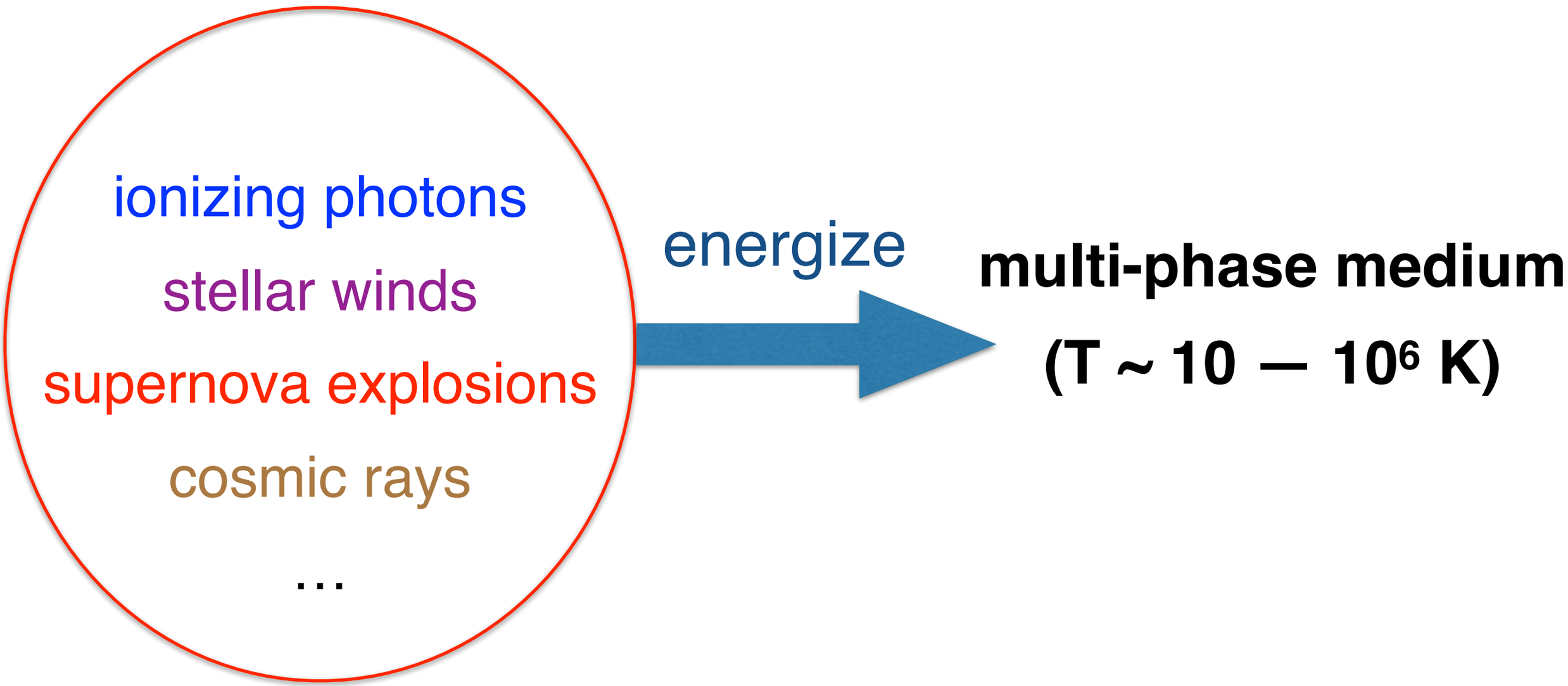
ISM2018@Bamberg

Outline

- Motivation
- Targets and observations
- Results
  - kinematics of 10^4 K ionized gas;
  - tallying mechanical energy in multi-phase medium;
- Discussion: case of H1105 downtown

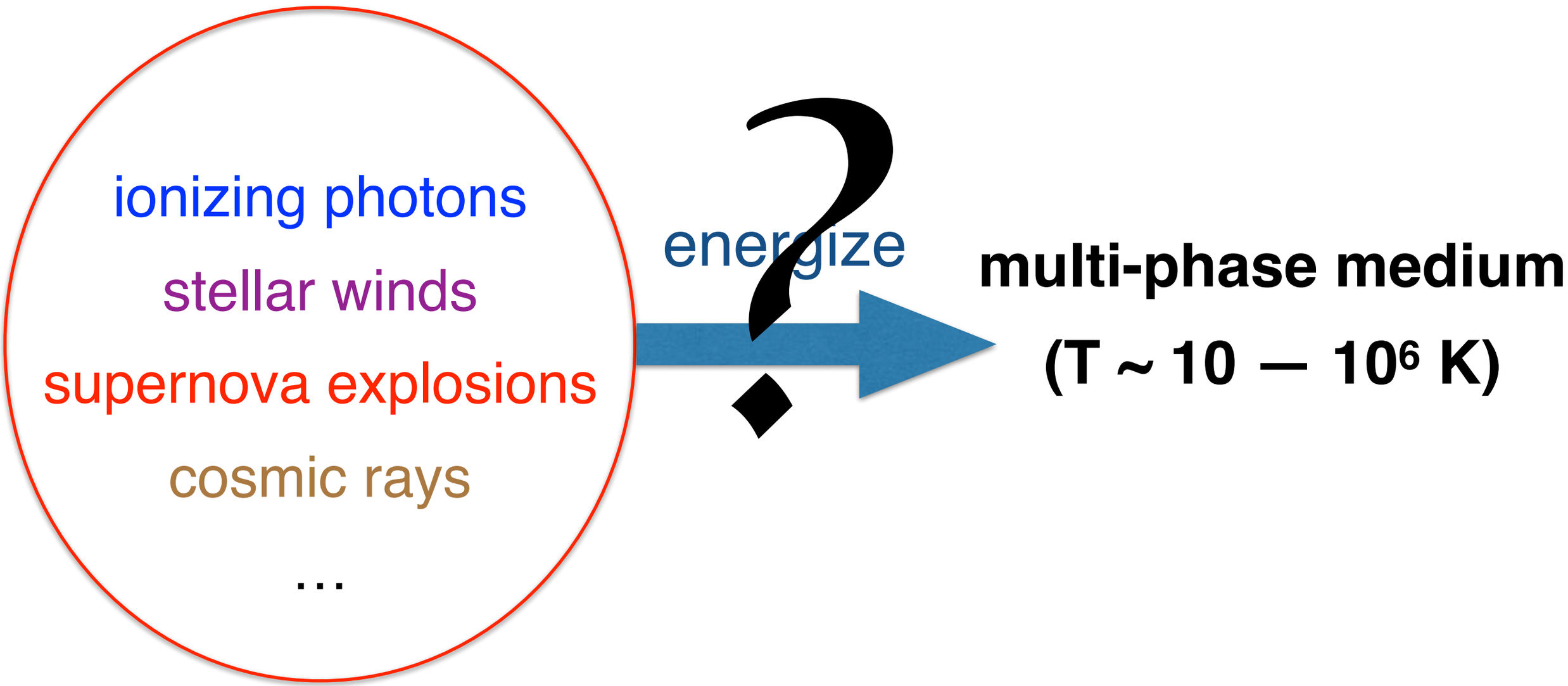
Motivation

- ✦ Stellar feedback plays an important role in the evolution of host galaxies;



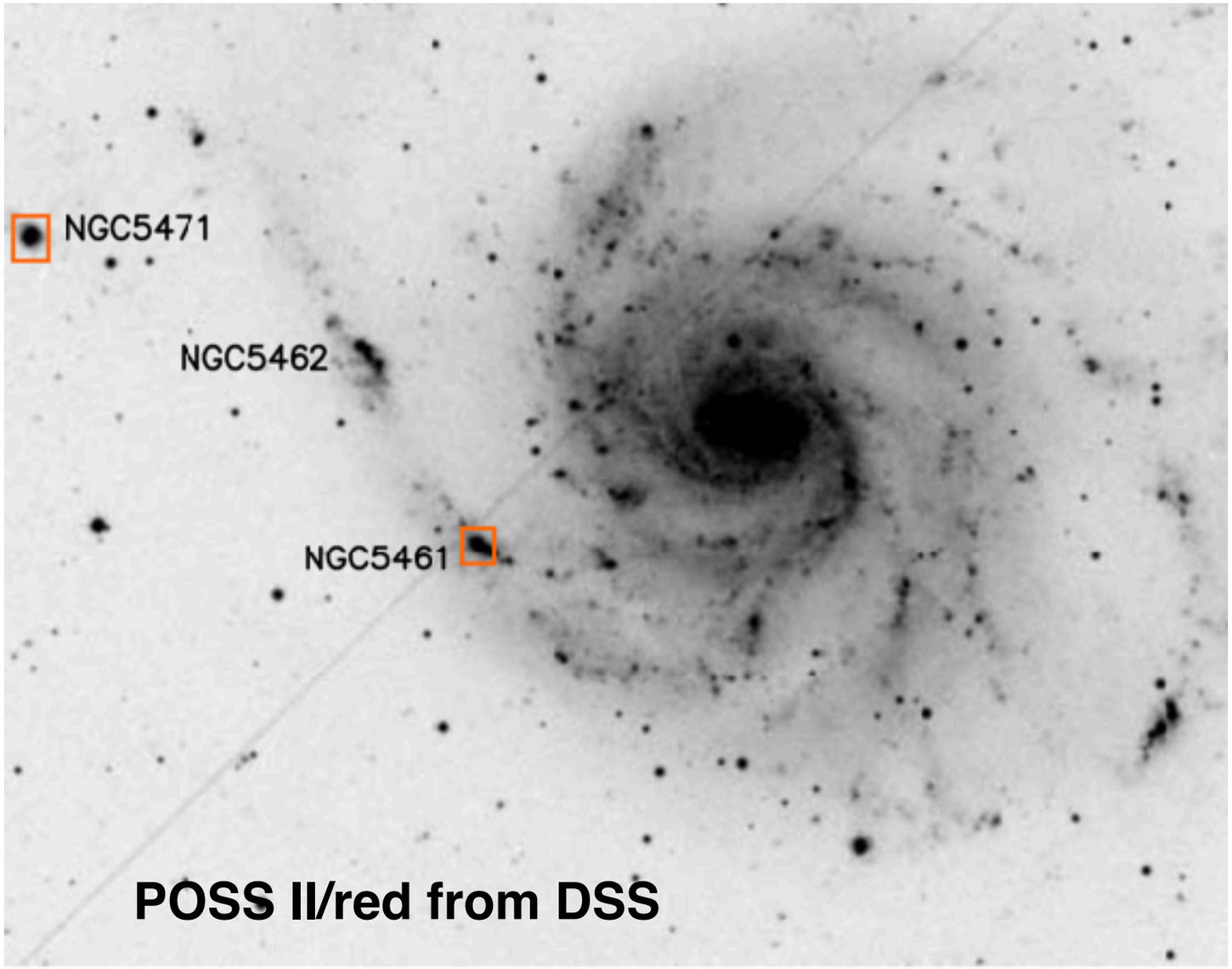
Motivation

- ✦ Stellar feedback plays an important role in the evolution of host galaxies;



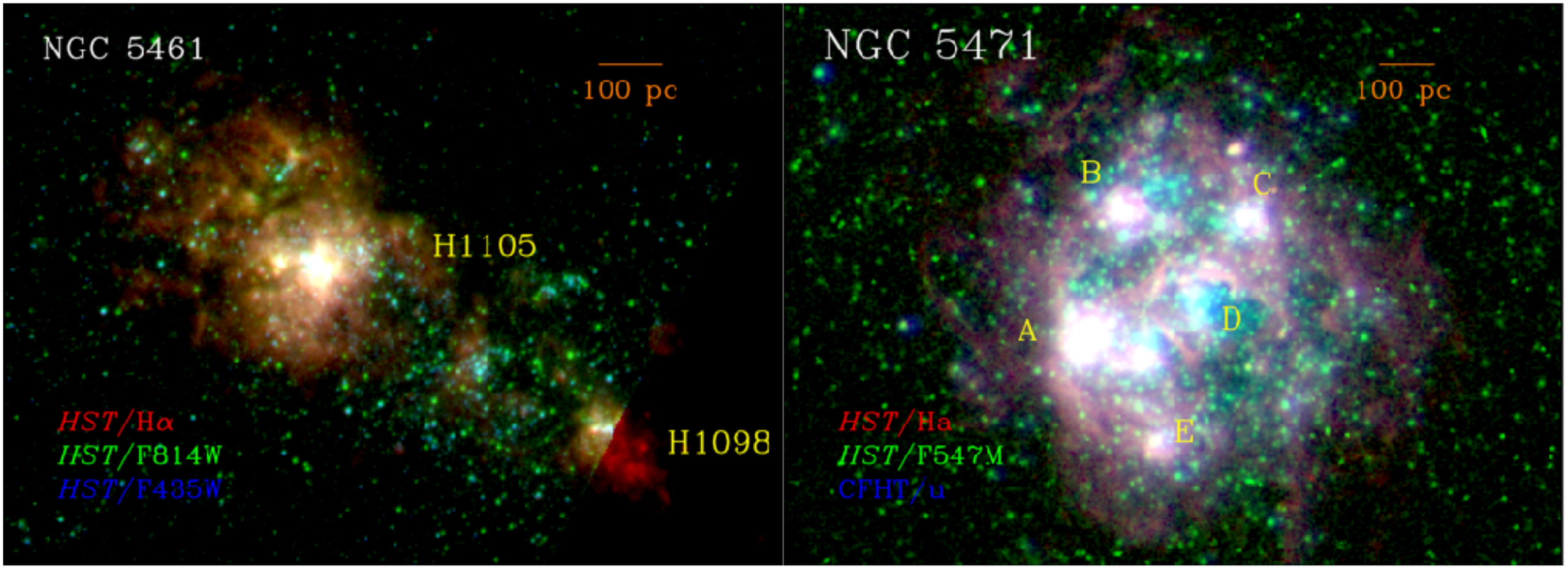
Our approach

- Tallying the mechanical energy reserved in multi-phase gas, in two giant H II regions, NGC 5461 and NGC 5471, in M101 (d=6.8 Mpc)



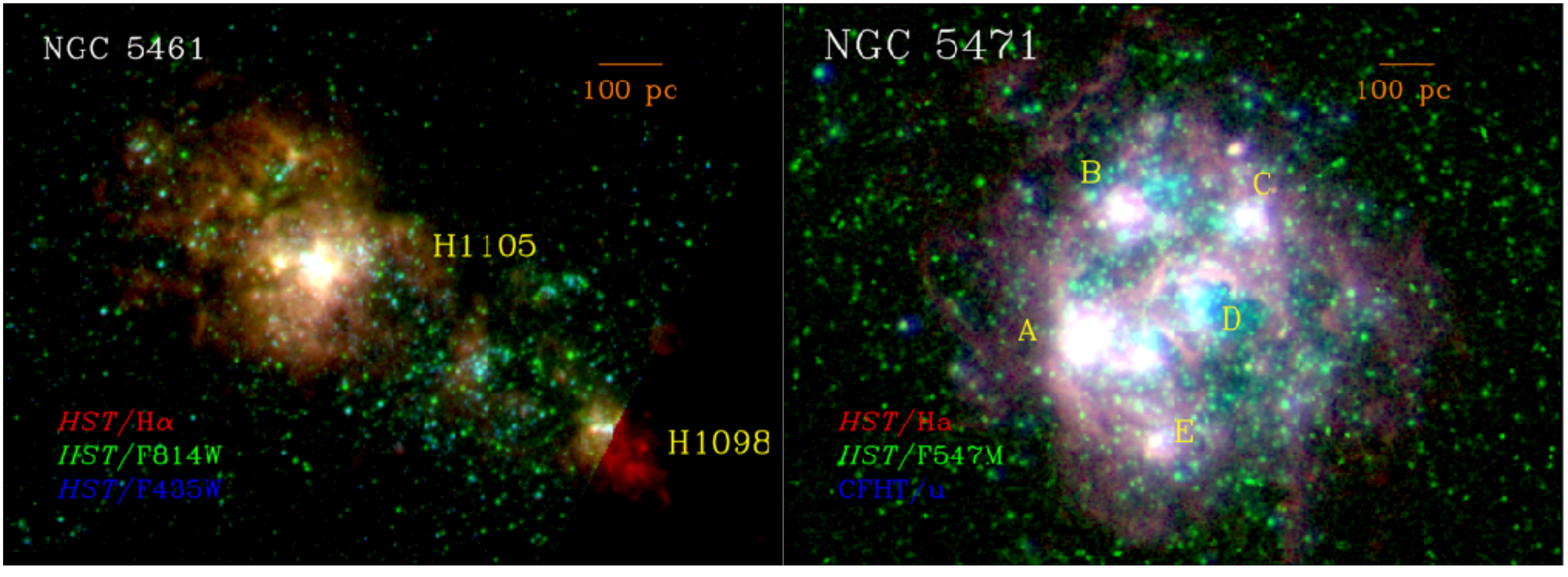
Target information

- Tallying the mechanical energy reserved in multi-phase gas, in two giant H II regions, NGC 5461 and NGC 5471, in M101 (d=6.8 Mpc)



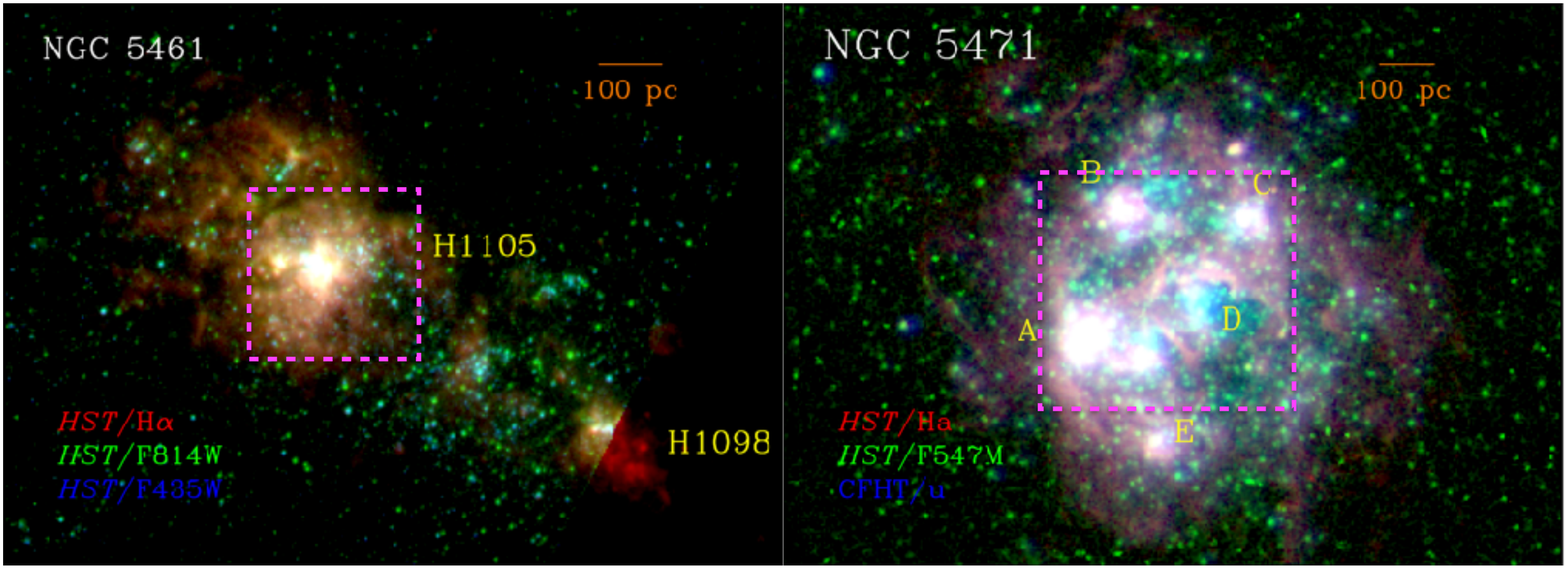
Target information

- Tallying the mechanical energy reserved in multi-phase gas, in two giant H II regions, NGC 5461 and NGC 5471, in M101 (d=6.8 Mpc)
  - most luminous ones in nearby galaxies ($L_{H\alpha}$~10^{41} erg s^{-1}), requires ionizing power of ~2000 O5V stars.



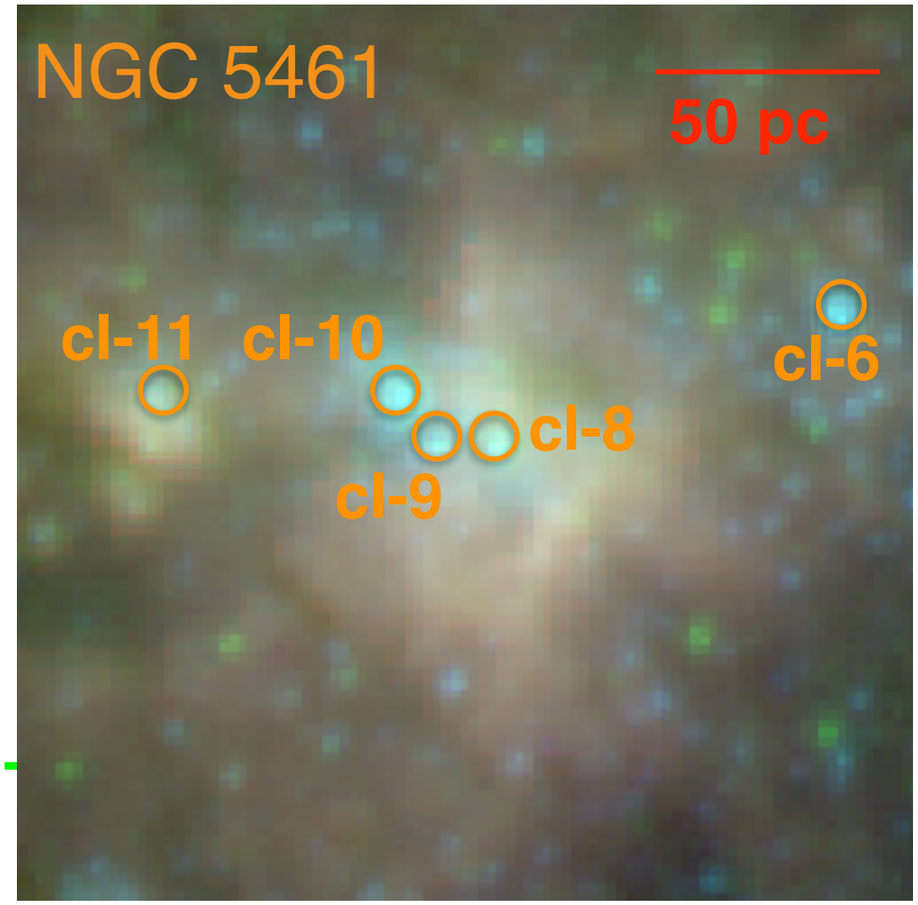
Target information

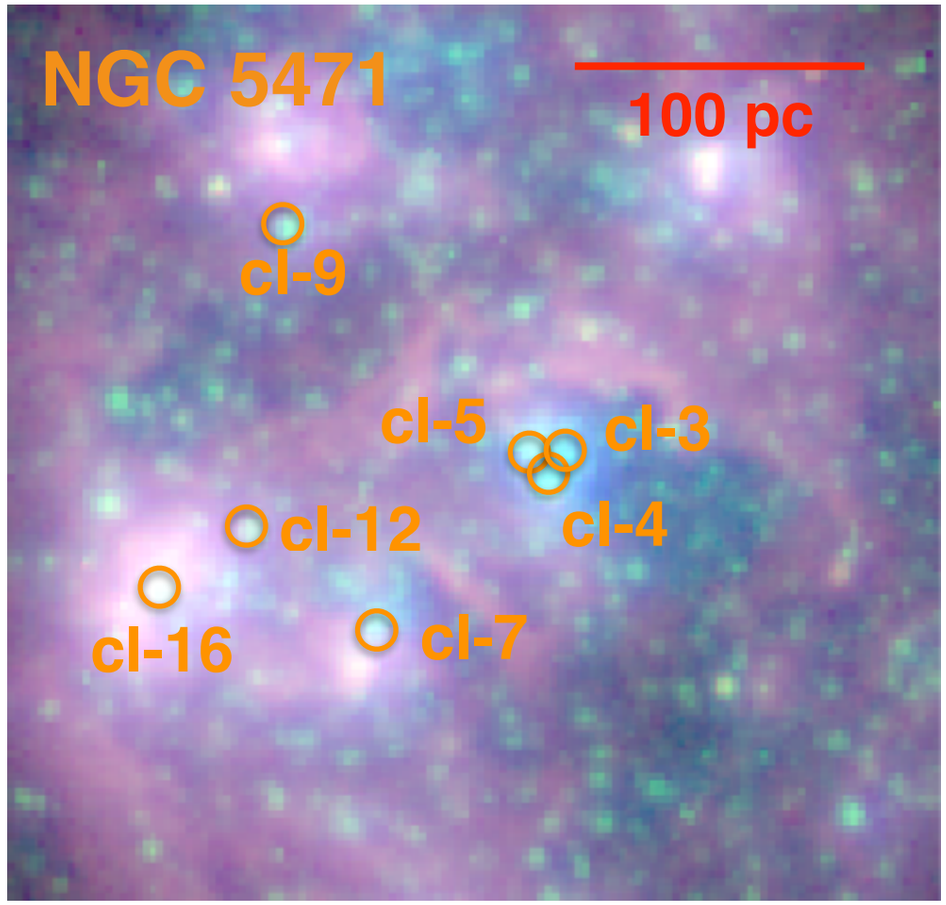
- Tallying the mechanical energy reserved in multi-phase gas, in two giant H II regions, NGC 5461 and NGC 5471, in M101 (d=6.8 Mpc)
  - most luminous ones in nearby galaxies ($L_{H\alpha}$~10^{41} erg s^{-1}), requires ionizing power of ~2000 O5V stars.



Target information

- Tallying the mechanical energy reserved in multi-phase gas, in two giant H II regions, NGC 5461 and NGC 5471, in M101 (d=6.8 Mpc)
  - most luminous ones in nearby galaxies ($L_{H\alpha}$~10^{41} erg s^{-1}), requires ionizing power of ~2000 O5V stars.
  - harboring 5 and 7 10^4 M_{sun}-class clusters (Chen+2005), most of them are younger than 5 Myr.





Data sets

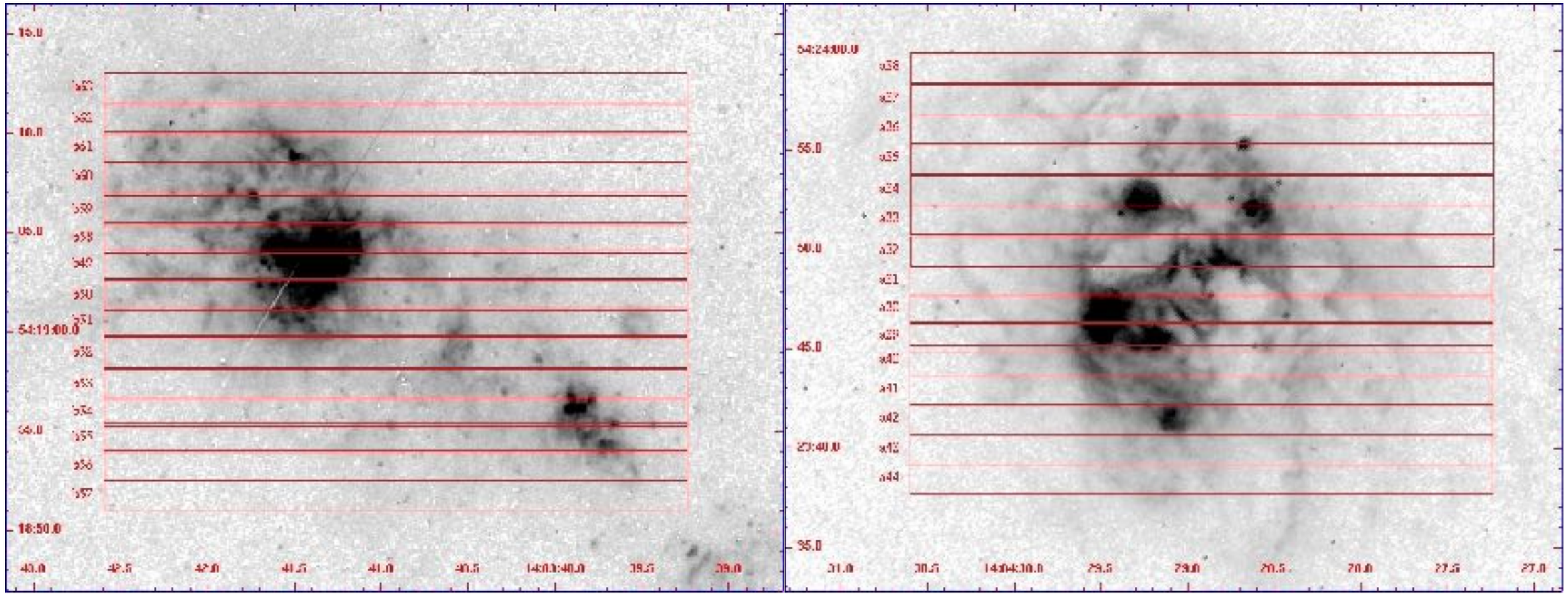
- **Cold neutral gas:** H I 21-cm data cube from THINGS survey (Walter+2008);

- **10^4 K ionized gas**: Hα profiles taken by KPNO Mayall telescope echelle spectrograph + *HST*/WFPC2 narrow band image;

- **10^6 K hot gas**: *Chandra* M101 Ms Project (Kuntz+ 2010, covering NGC 5461, but not NGC 5471);

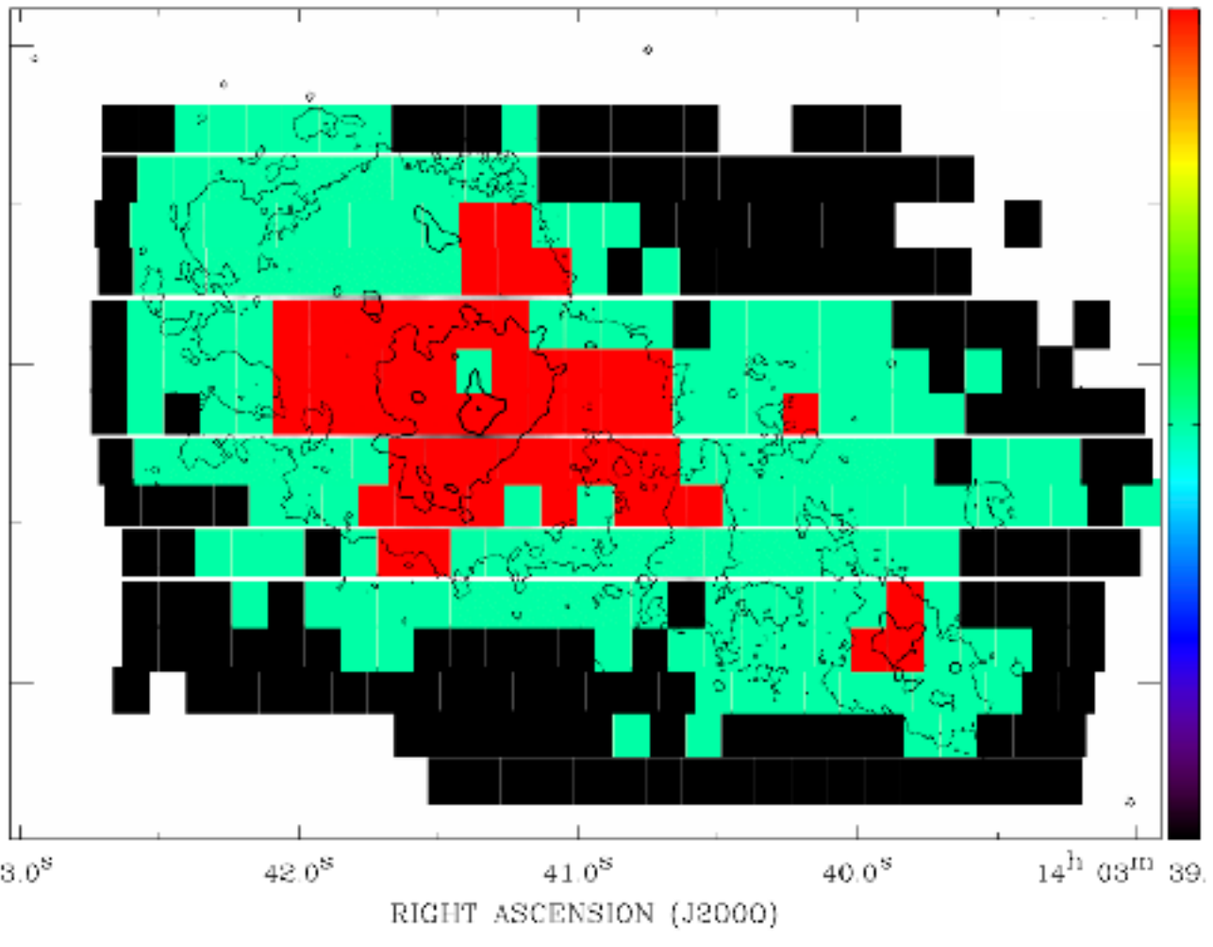
Data sets

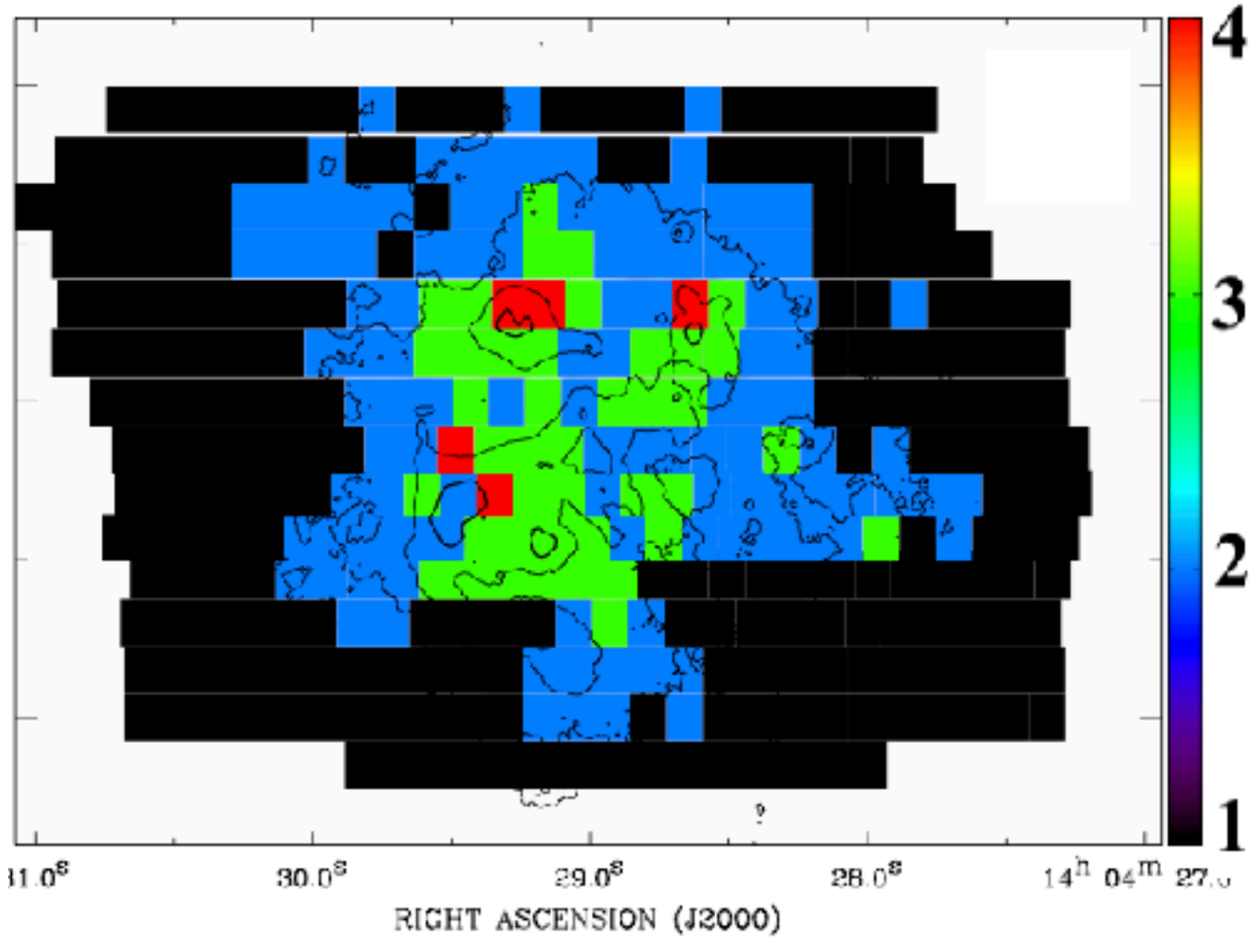
- KPNO Mayall 4m slit-covering echelle spectra
  - taken on Jun 1999 (PI: You-Hua Chu); covering Hα and [N II] λλ6548,6583;
  - slit-width: 1.4”; instrumental FWHM=14.6 km/s; *R*~80,000

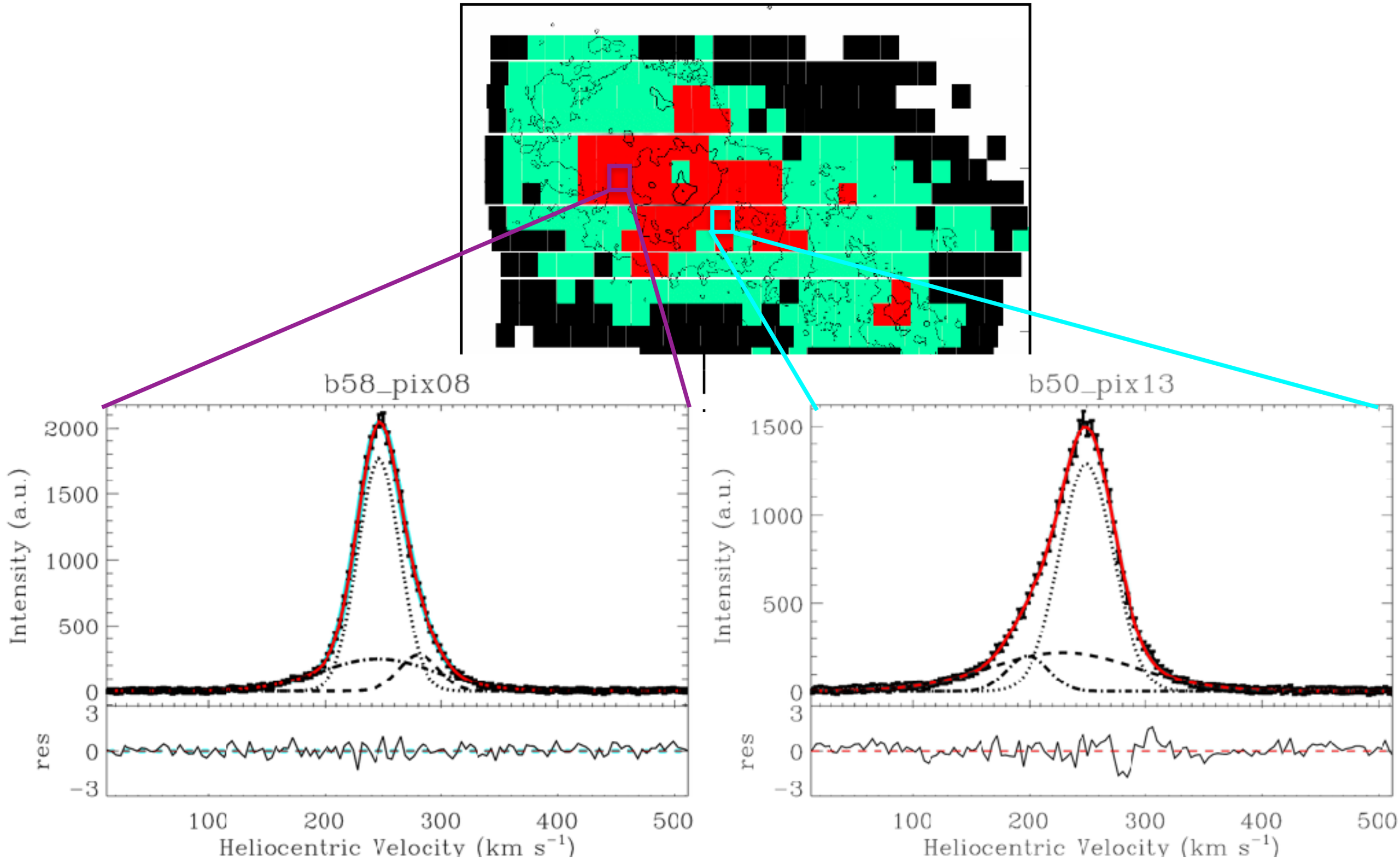


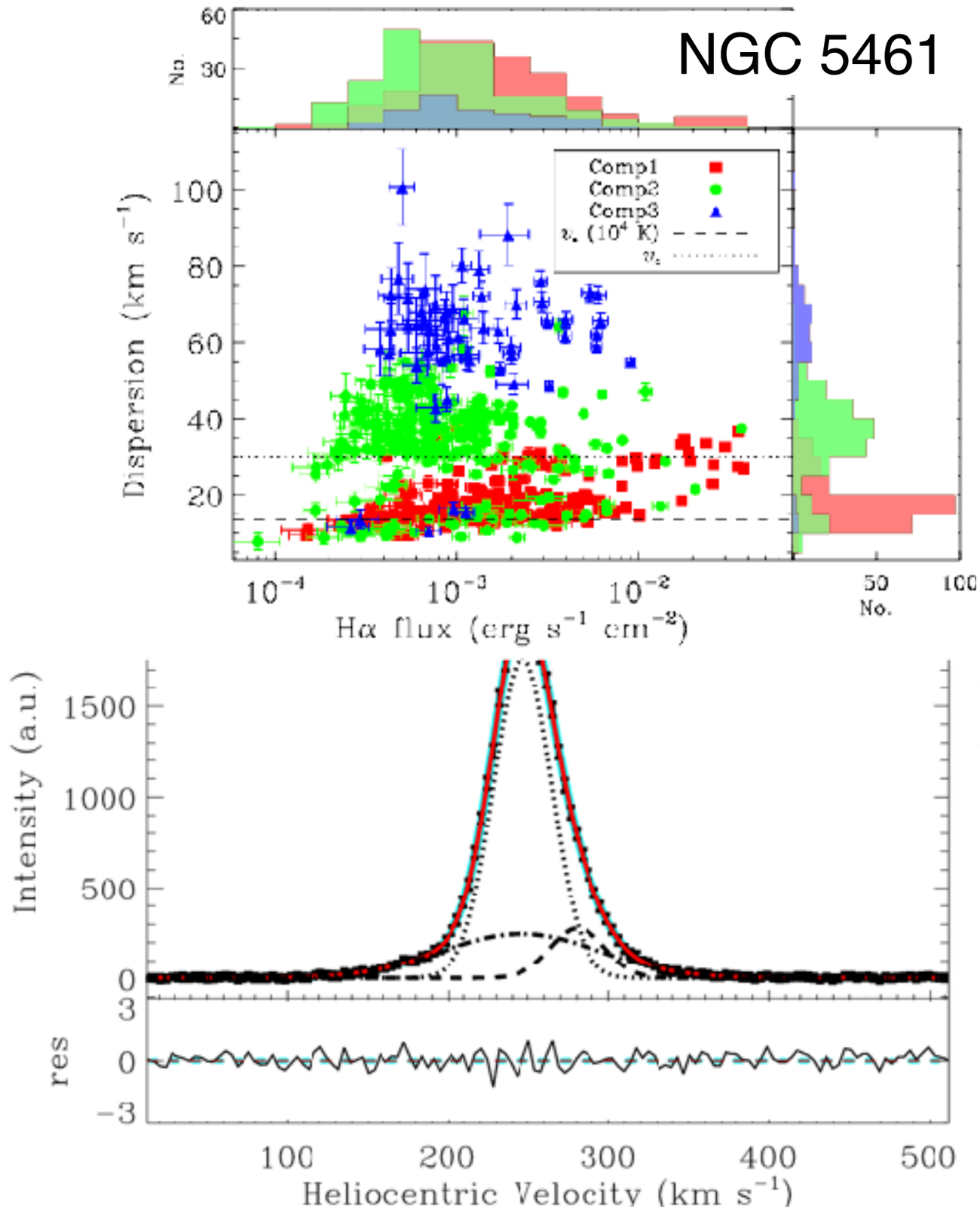
Analysis of the KPNO echelle spectra

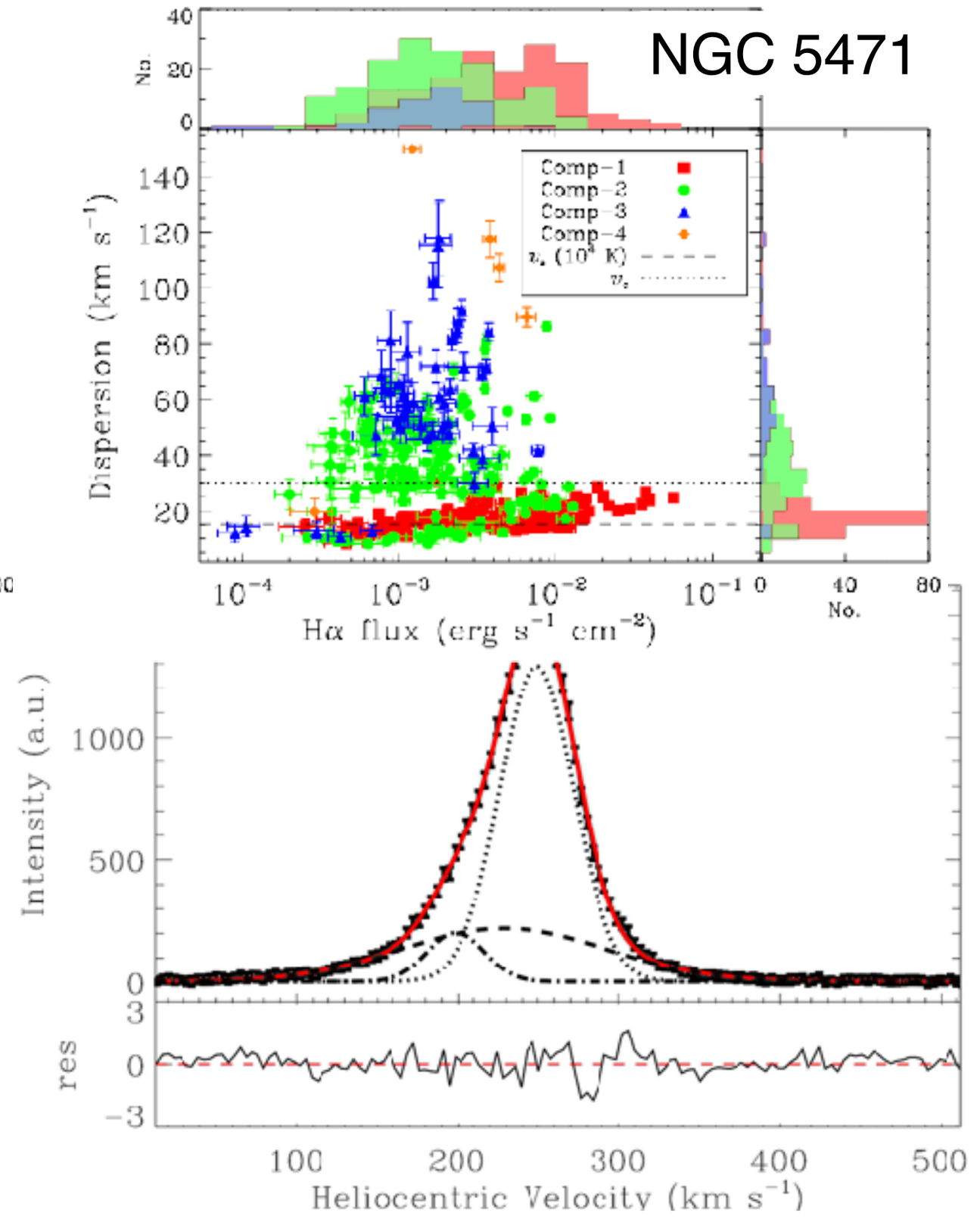
- Extract spectra from every 1.14”x1.4” apertures;
- Fit the Hα profiles with multiple Gaussians;
- Add extra components by F-test (with *p*-value=10^{-3}).

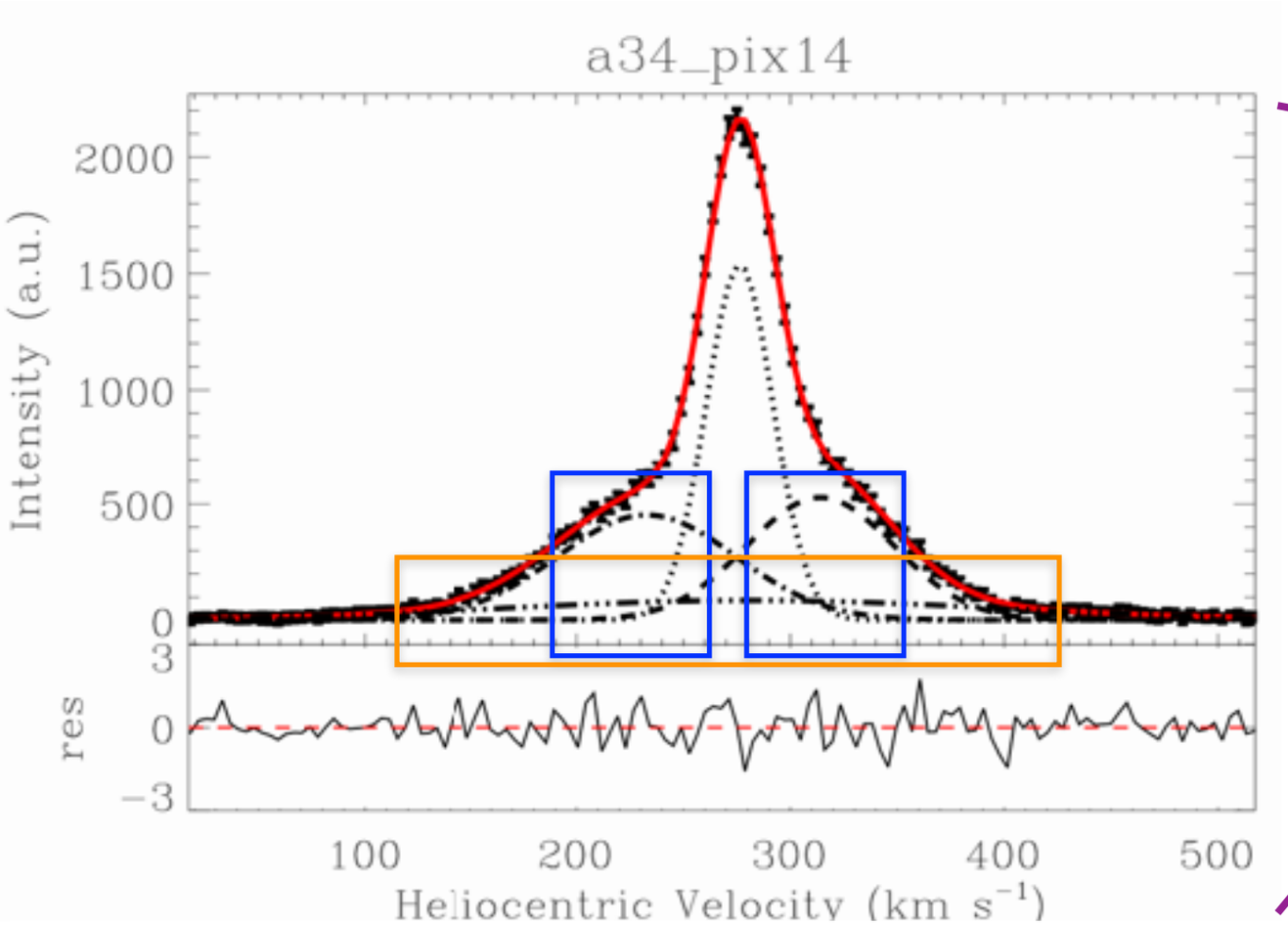


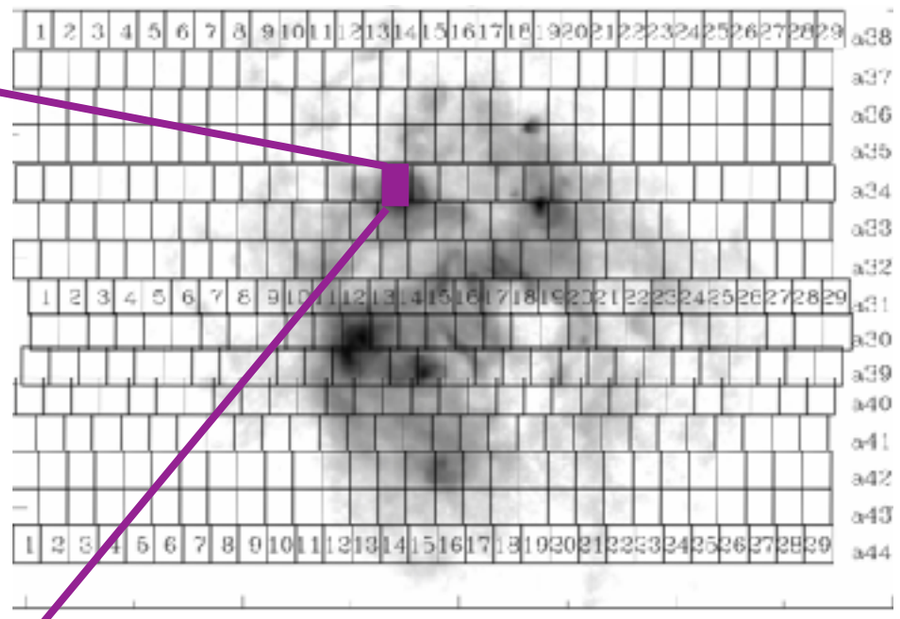


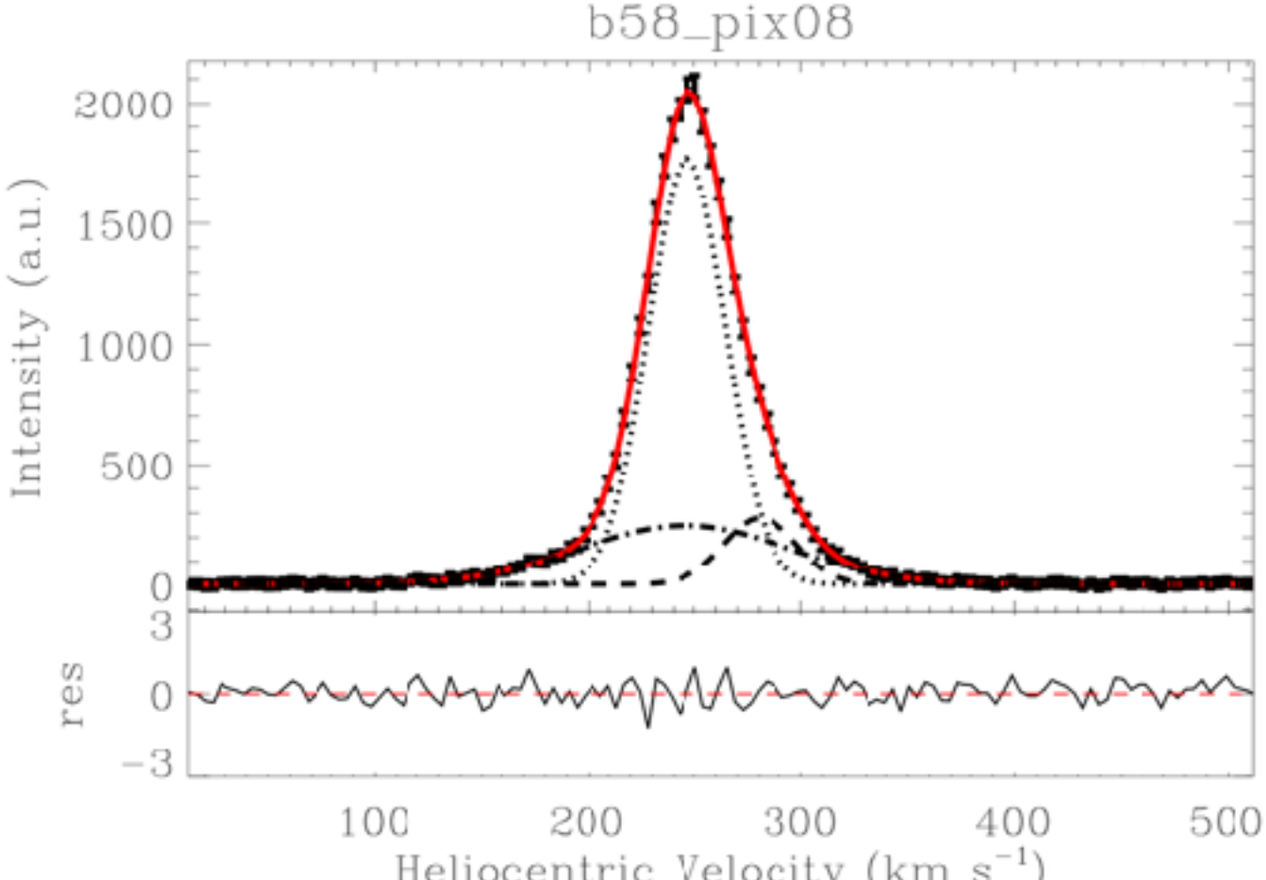

b58_pix08
b50_pix13
Intensity (a.u.)
res
Heliocentric Velocity (km s^{-1})

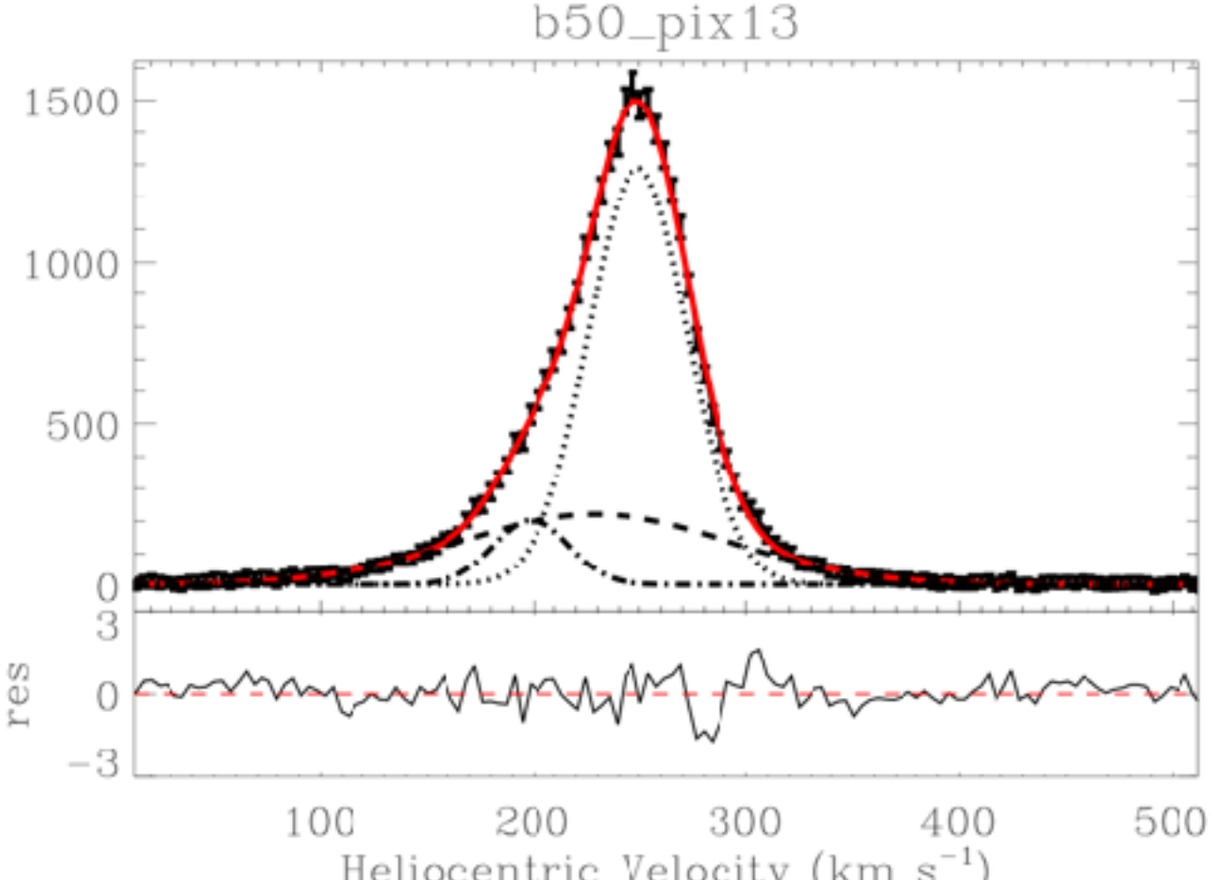

NGC 5461
Comp1
Comp2
Comp3
Dispersion (km s^{-1})
Hα flux (erg s^{-1} cm^{-2})
Intensity (a.u.)
res
Heliocentric Velocity (km s^{-1})


NGC 5471
Comp−1
Comp−2
Comp−3
Comp−4
Dispersion (km s^{-1})
Hα flux (erg s^{-1} cm^{-2})
Intensity (a.u.)
res
Heliocentric Velocity (km s^{-1})


a34_pix14
Intensity (a.u.)
2000
1500
1000
500
0
3
0
−3
res
100
200
300
400
500
Heliocentric Velocity (km s^{-1})

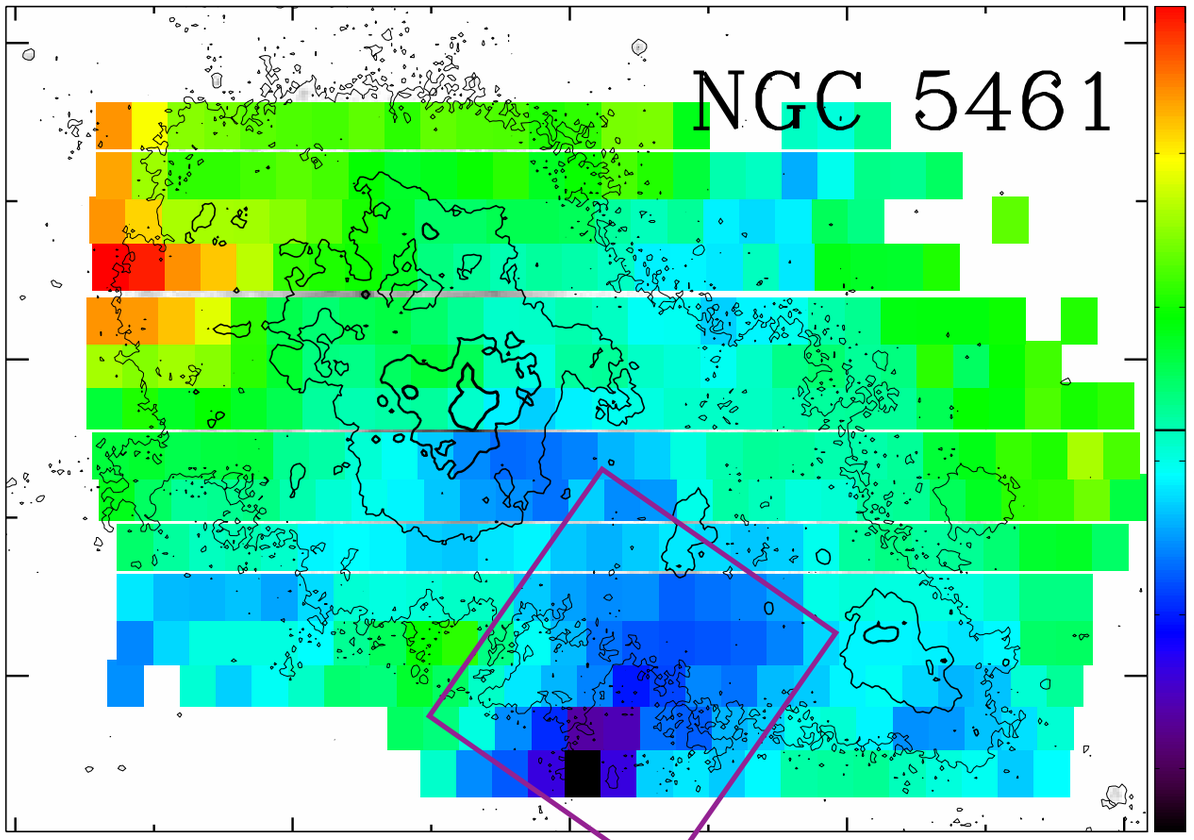


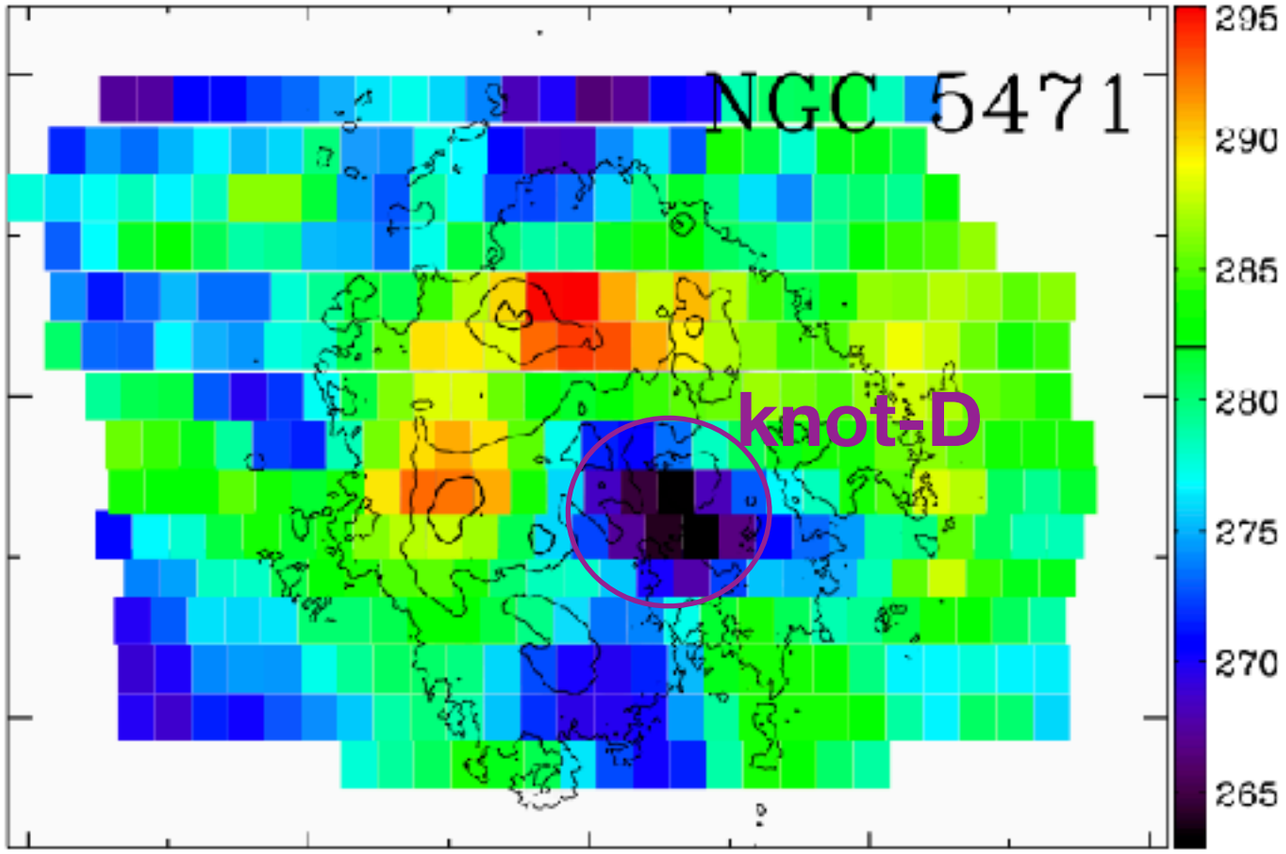

b58_pix08
Intensity (a.u.)
2000
1500
1000
500
0
3
0
−3
res
100
200
300
400
500
Heliocentric Velocity (km s^{-1})

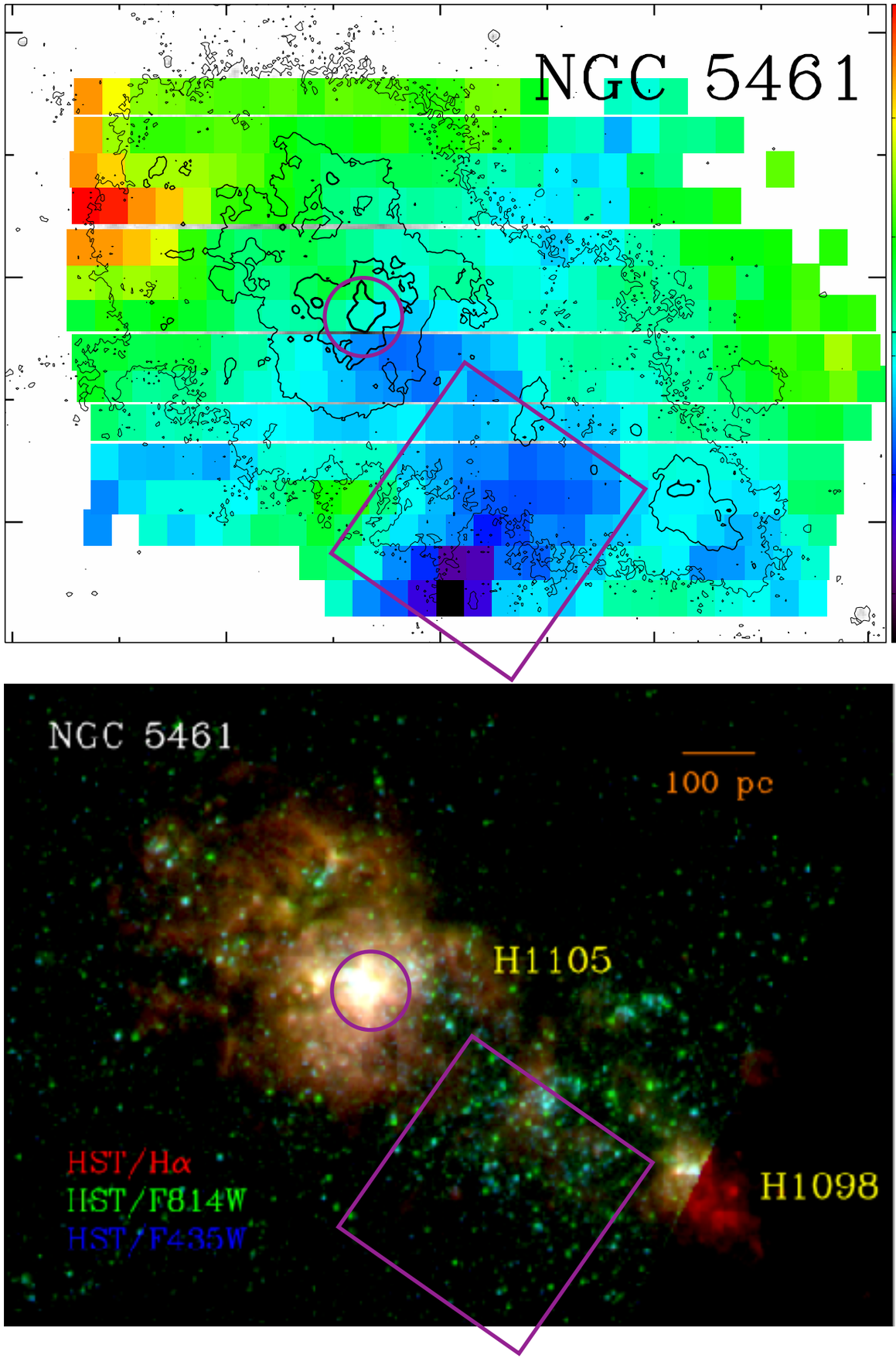

b50_pix13
1500
1000
500
0
3
0
−3
res
100
200
300
400
500
Heliocentric Velocity (km s^{-1})

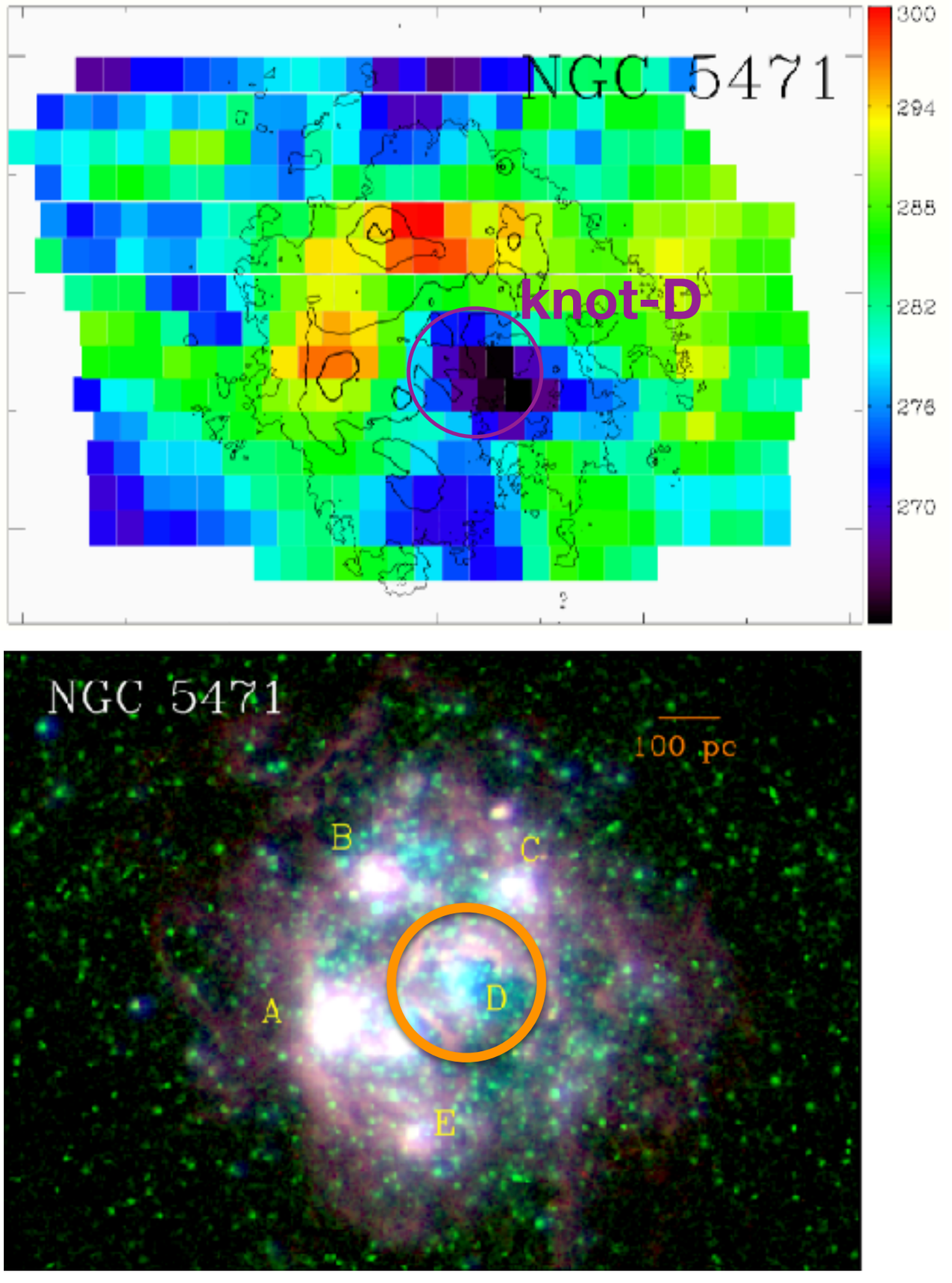
Interpretation of the Gaussian fitting

- **Kinematics of the ionized gas**: modest blueshift at the southwestern outskirt of H1105 and NGC 5471D





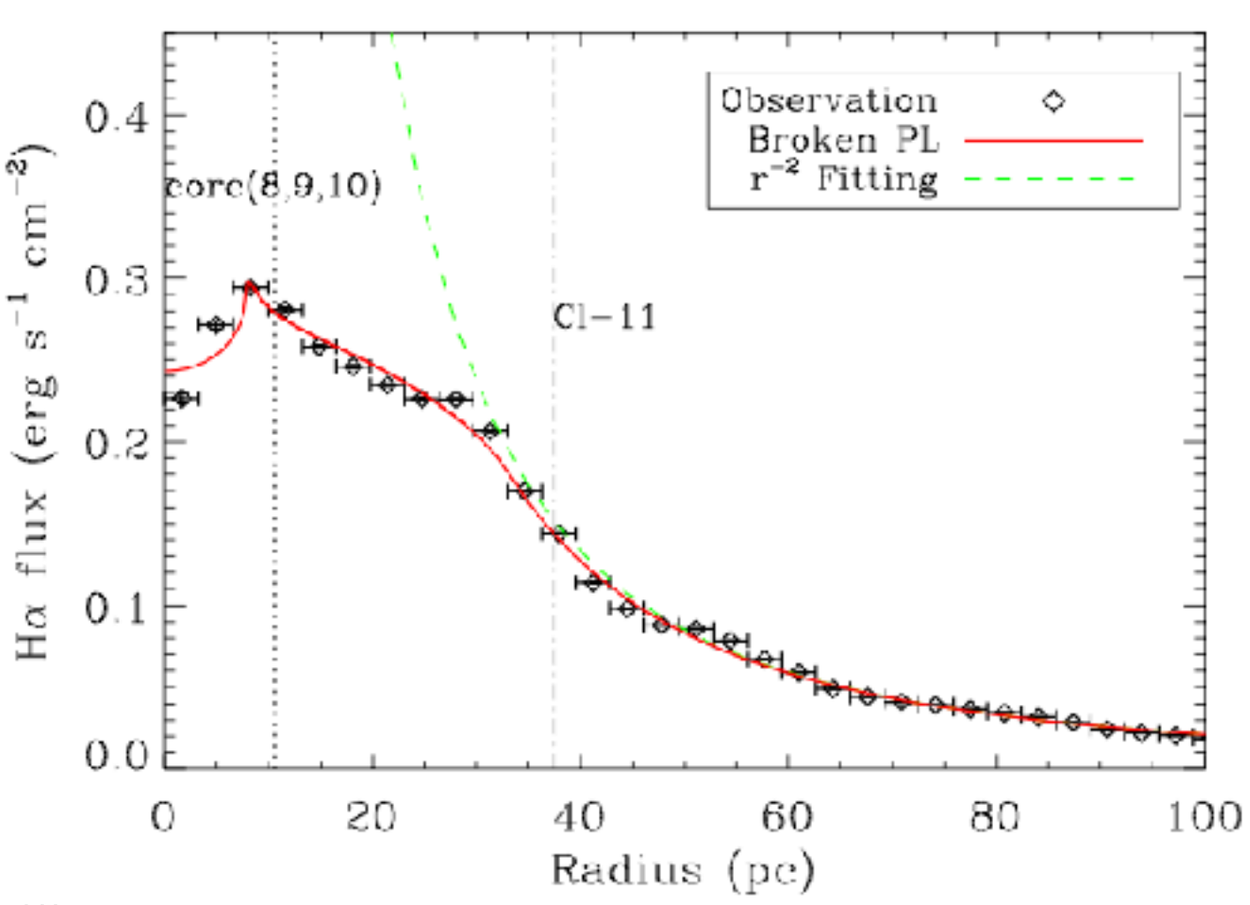

NGC 5461
280
270
260
250
240
NGC 5461
100 pc
H1105
H1098
HST/Hα
HST/F814W
HST/F435W


NGC 5471
knot-D
300
294
288
282
276
270
NGC 5471
100 pc
A
B
C
D
E

Interpretation of the Gaussian fitting

- Kinetic energy of turbulent motion: $E_k = \frac{3}{2}\Sigma_{\mathrm{H\,II}}(\sigma^2_{\mathrm{obs}} - \sigma^2_{\mathrm{instr}} - \sigma^2_{\mathrm{th}})$
- Geometry
  - **NGC 5461**: broken power-law
  - **NGC 5471**: uniform line-of-sight distribution length of 5 pc

$$\frac{n_{\mathrm{H}}}{\mathrm{cm}^{-3}} = \begin{cases} 0, & < 8 \text{ pc}; \\ 490, & 8 - 33.5 \text{ pc}; \\ 490\left(\frac{r}{33.5 \text{ pc}}\right)^{-1.46}, & > 33.5 \text{ pc}. \end{cases}$$



Interpretation of the Gaussian fitting

- Kinetic energy of turbulent motion: $E_k = \frac{3}{2}\Sigma_{\mathrm{H\,II}}(\sigma^2_{\mathrm{obs}} - \sigma^2_{\mathrm{instr}} - \sigma^2_{\mathrm{th}})$
- Geometry
  - **NGC 5461**:

    broken power-law
  - **NGC 5471**:

    uniform line-of-sight distribution length of 5 pc

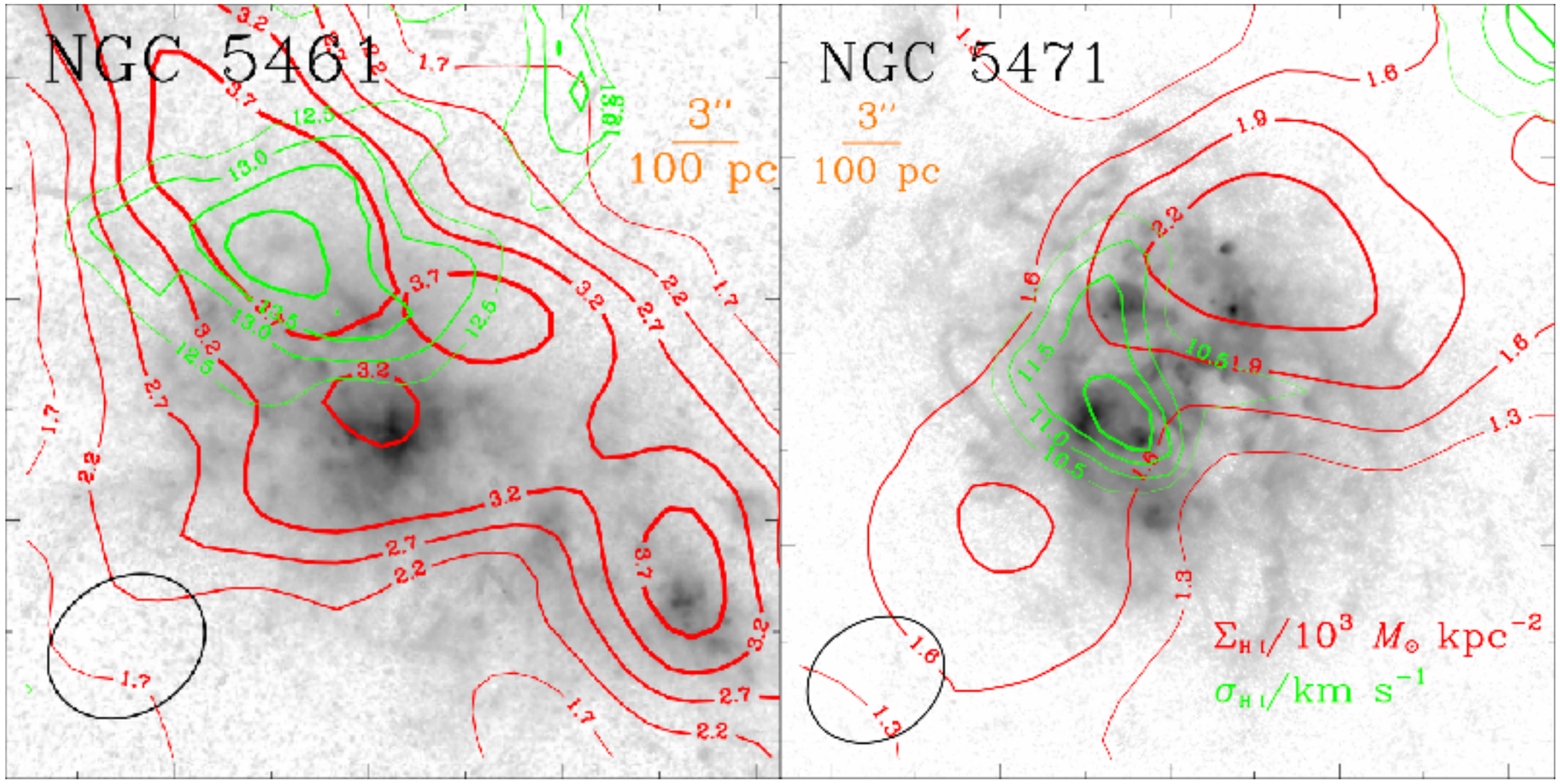
10^4 K ionized gas

	NGC 5461	**NGC 5471**
Mass (10^6 M_{sun})	**2.1**	**1.6**
$E_{\mathrm{k,turb}}$ (10^{52} ergs)	**5.7**	**3.6**

Complementary information

- Kinetic energy of the turbulent neutral atomic gas: derived from H I 21-cm data cube in the THINGS survey

$$E_k = \frac{3}{2}\Sigma_{\mathrm{H\,I}}(\sigma^2_{\mathrm{obs}} - \sigma^2_{\mathrm{out,\,turb}})$$



Complement information

- Kinetic energy of the turbulent neutral atomic gas: derived from H I 21-cm data cube in the THINGS survey

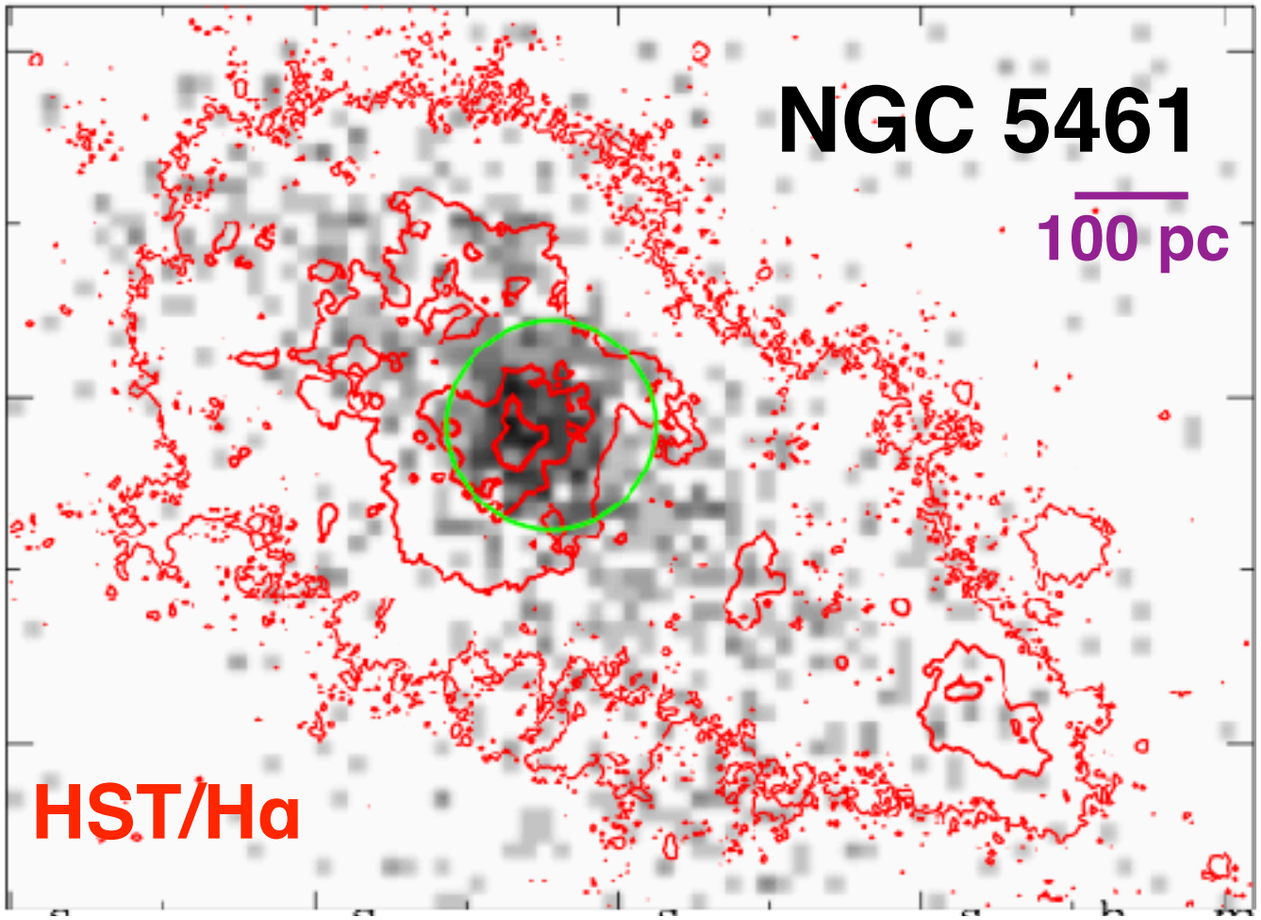
$$E_k = \frac{3}{2}\Sigma_{\mathrm{H\,I}}(\sigma^2_{\mathrm{obs}} - \sigma^2_{\mathrm{out,\,turb}})$$

H I gas **NGC 5461** **NGC 5471**

Mass (10^6 M_{sun})	**35**	**15**
$E_{\mathrm{k,turb}}$ (10^{52} ergs)	**4.9**	**0.6**

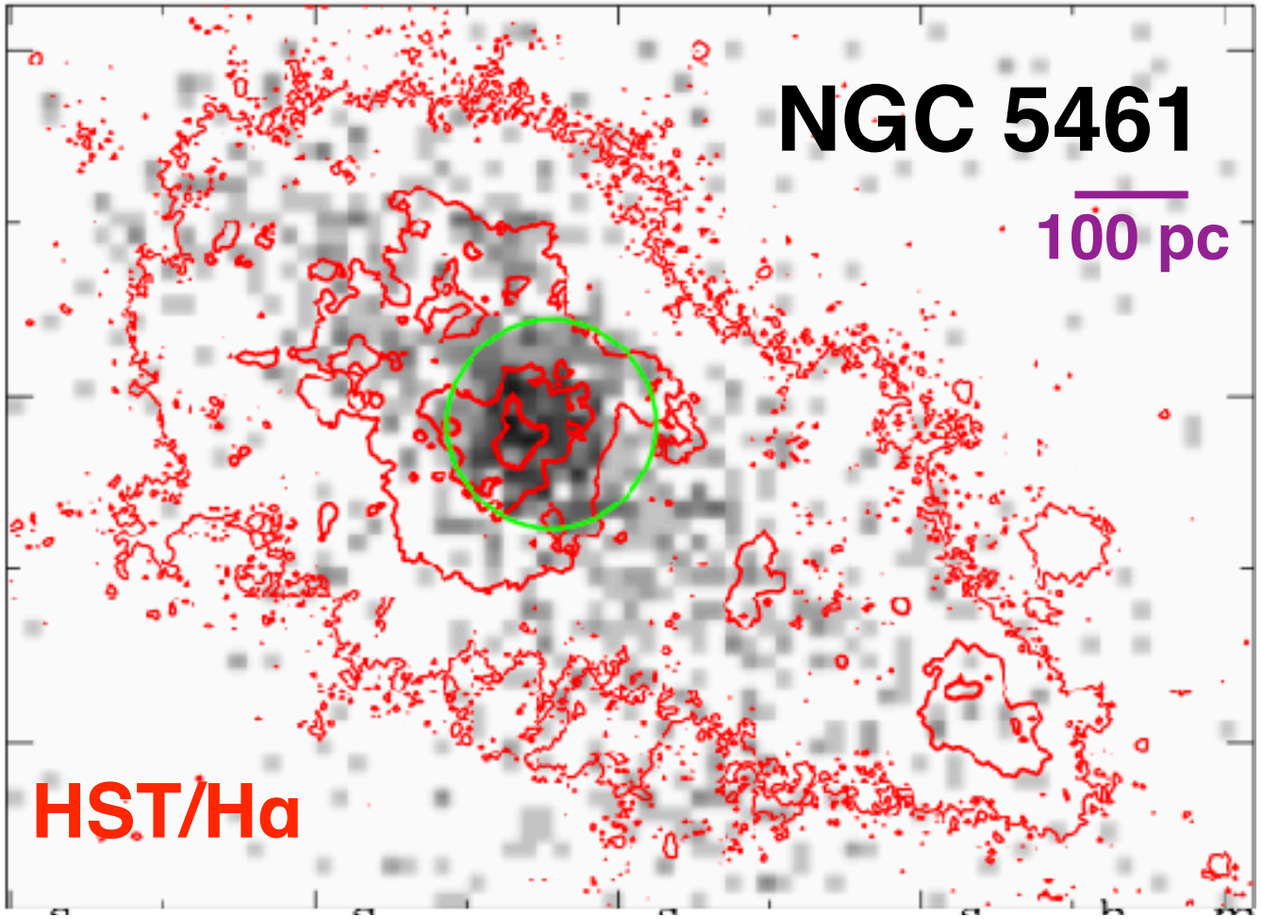
Complementary information

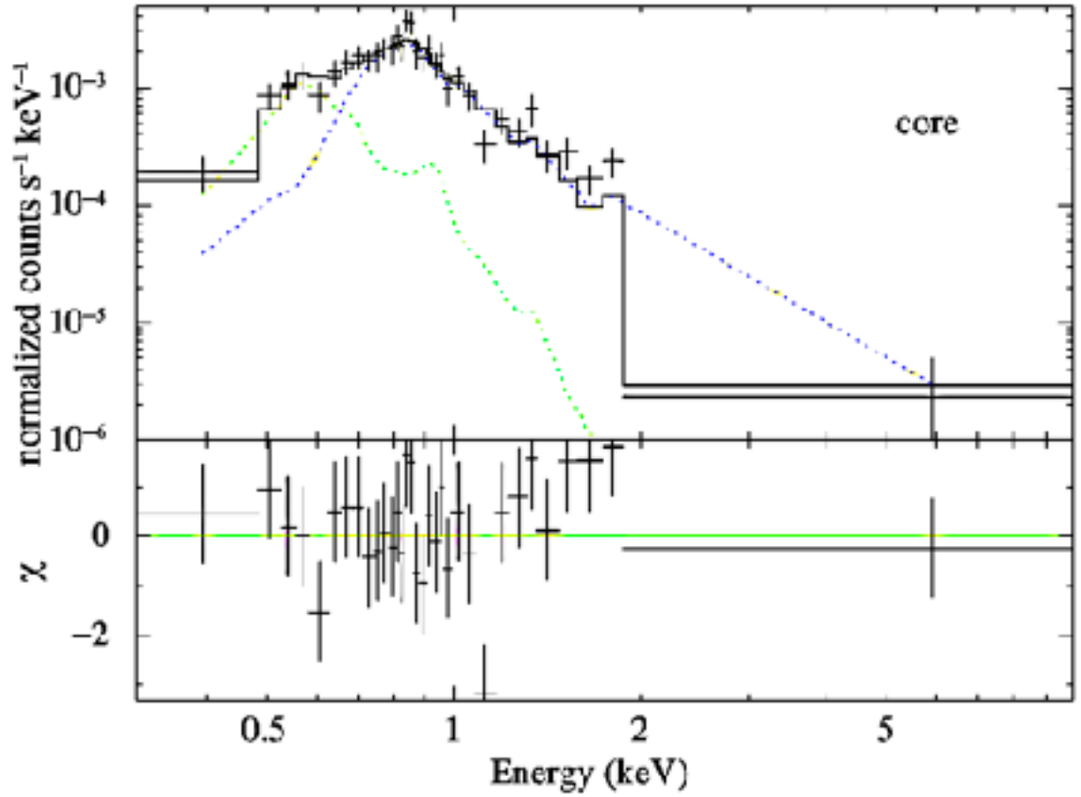
- Thermal energy of 10^6 K hot gas in the core of H1105: derived from *Chandra* observation



Complementary information

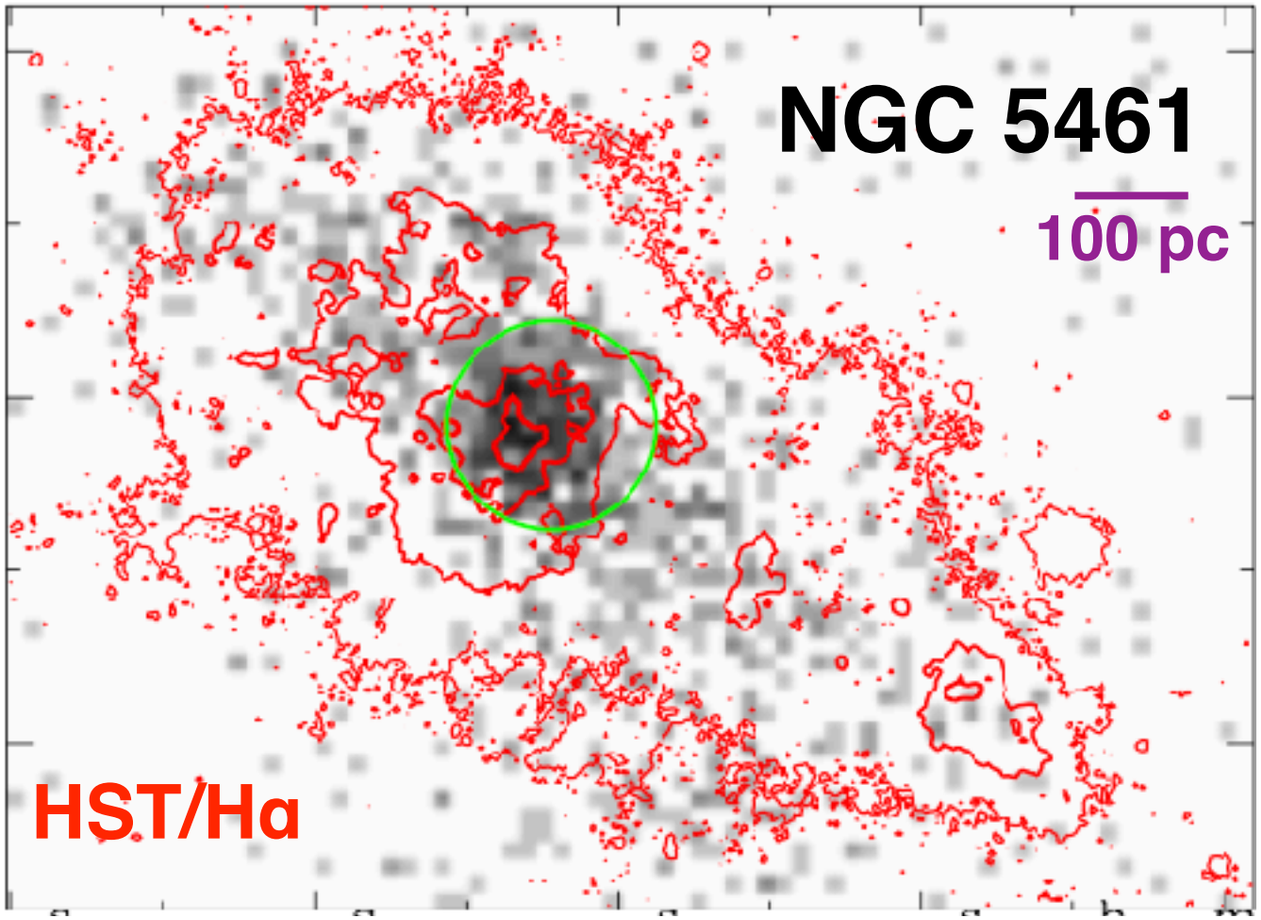
- Thermal energy of 10^6 hot gas in the core of H1105: derived from *Chandra* observation

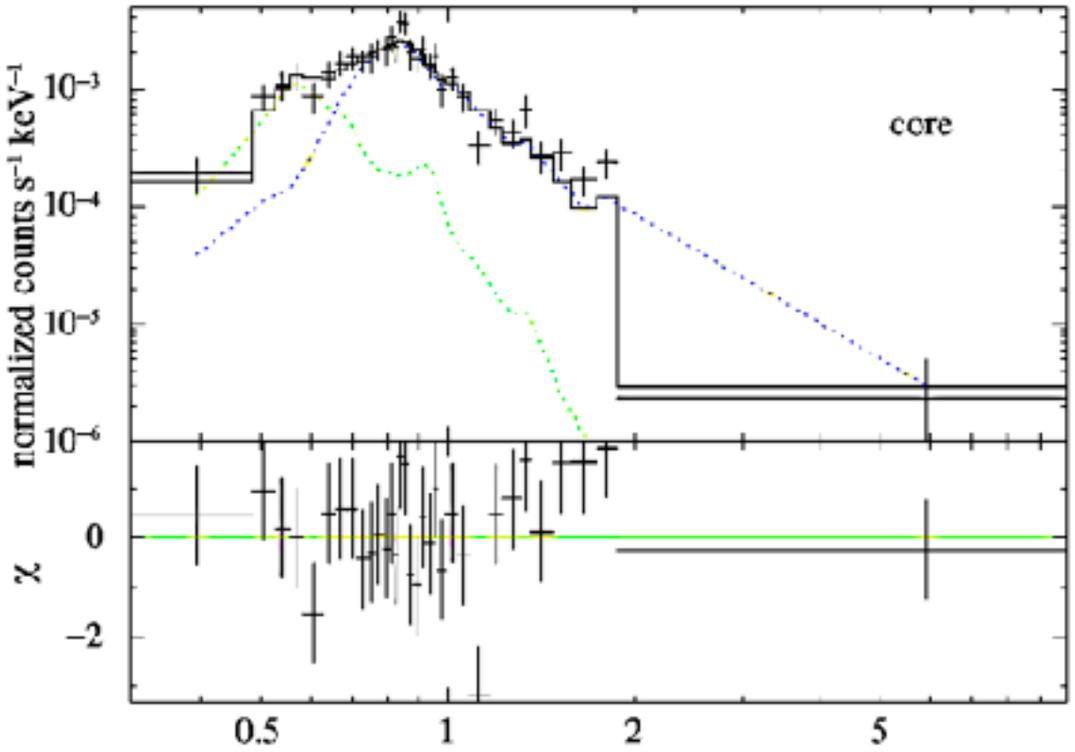




Complementary information

- Thermal energy of 10^6 hot gas in the core of H1105: derived from *Chandra* observation



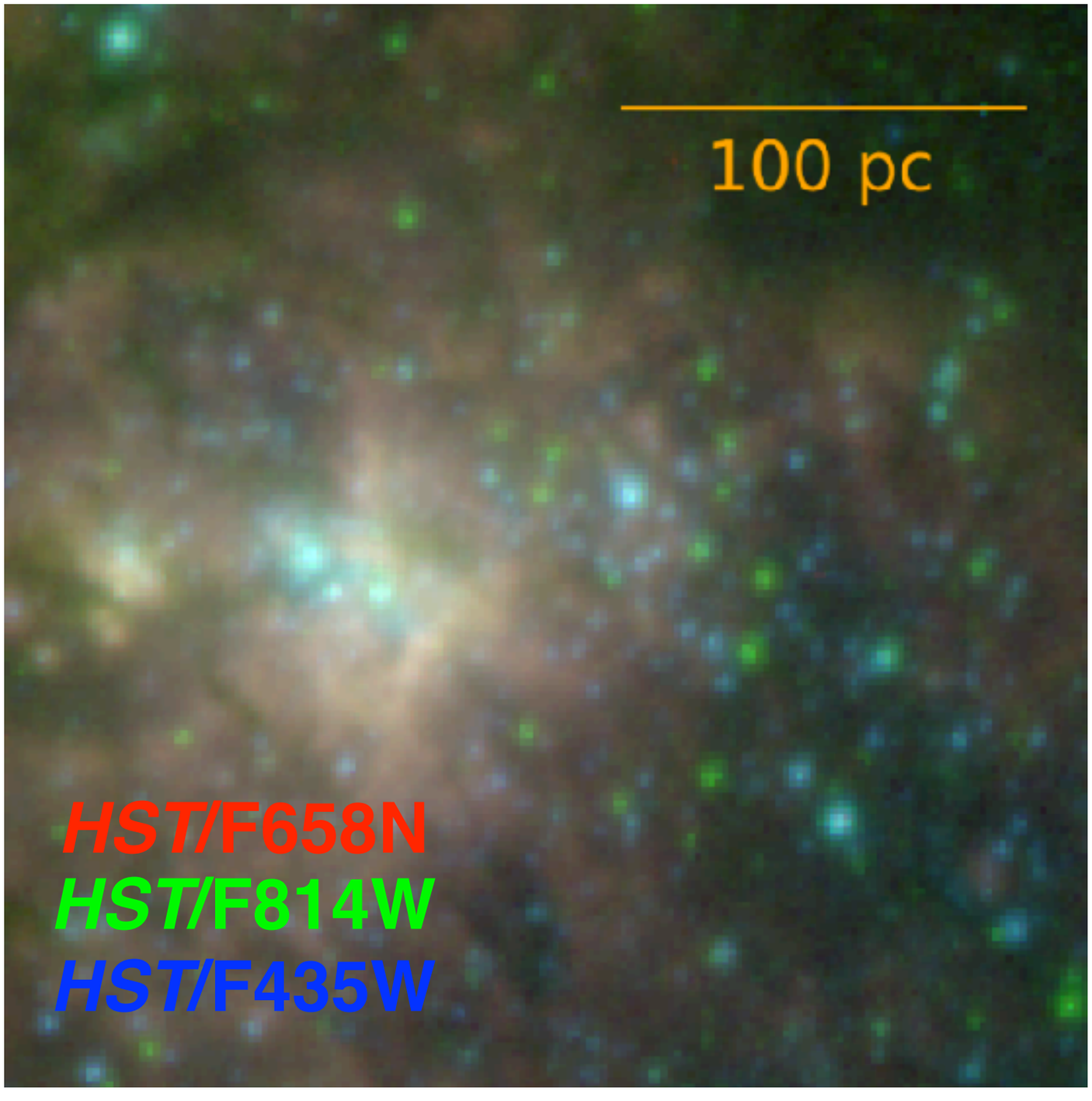


10^6 K hot gas	H1105
Mass (10^6 M_{sun})	0.1
E_{th} (10^{52} ergs)	19

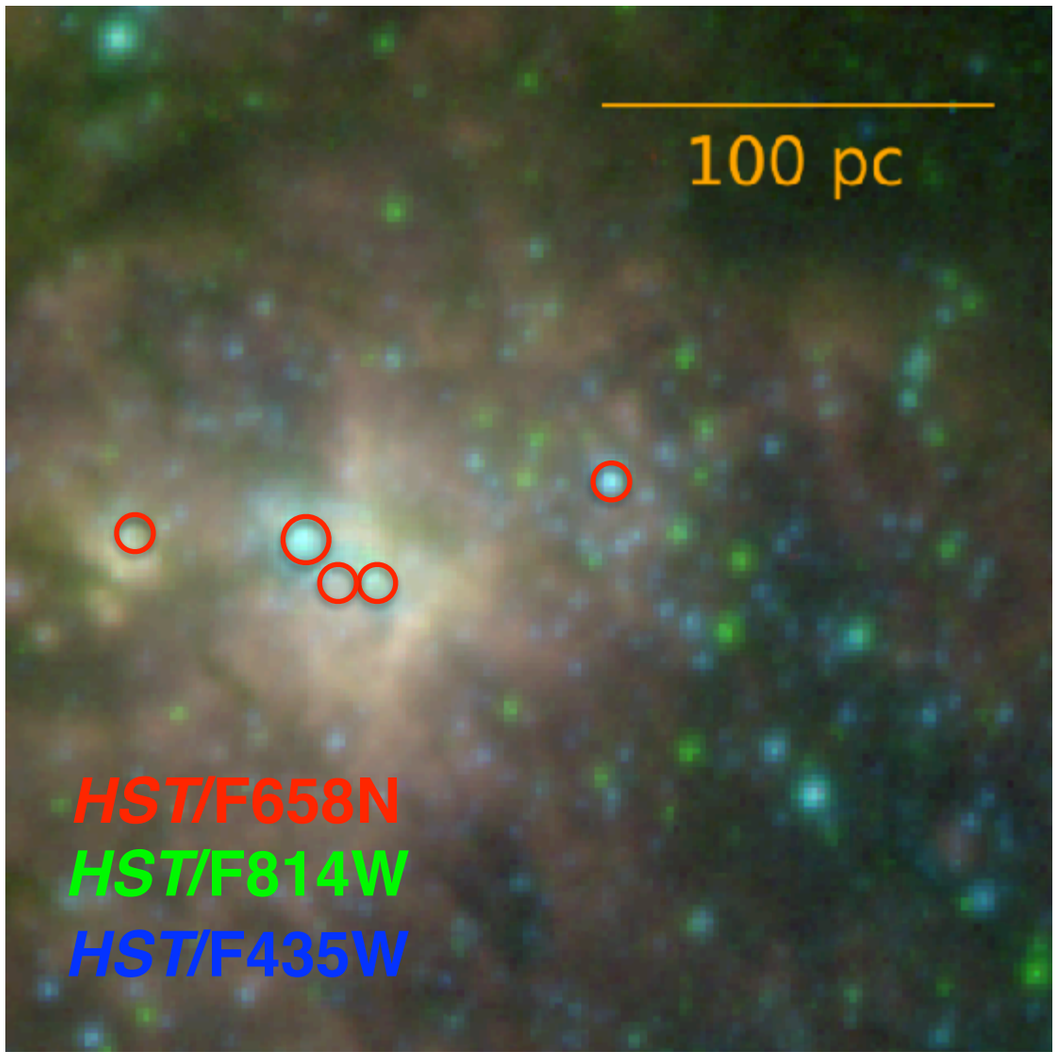
Census of mechanical energy in multi-phase gas

	10^6 K hot gas		10^4 K ionized gas		neutral atomic gas	
	Mass (10^6 M_{sun})	E_{th} (10^{52} ergs)	Mass (10^6 M_{sun})	E_k (10^{52} ergs)	Mass (10^6 M_{sun})	E_k (10^{52} ergs)
NGC 5461	0.1	19	2.1	5.7	35	4.9
NGC 5471	…	…	1.6	3.6	15	0.6

Downtown of H1105

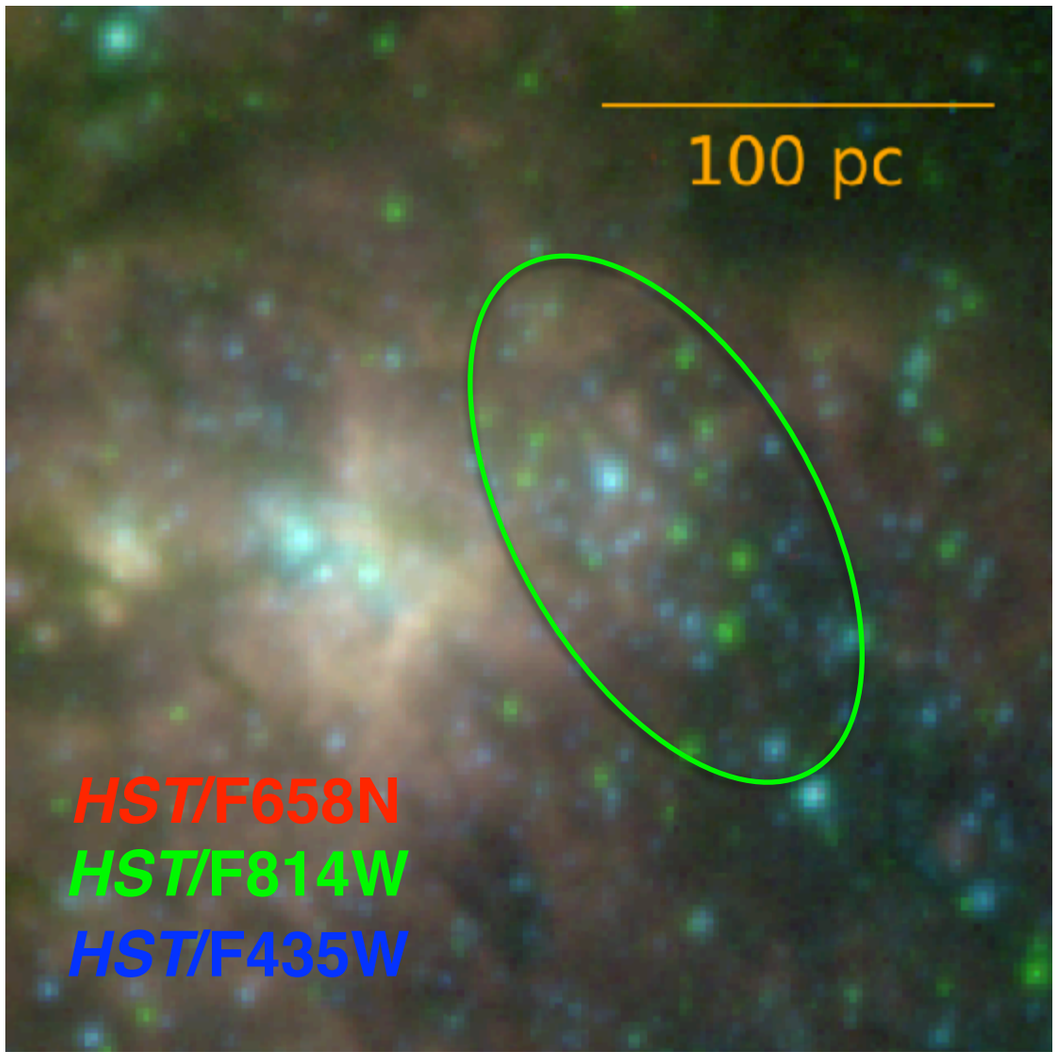


Downtown of H1105



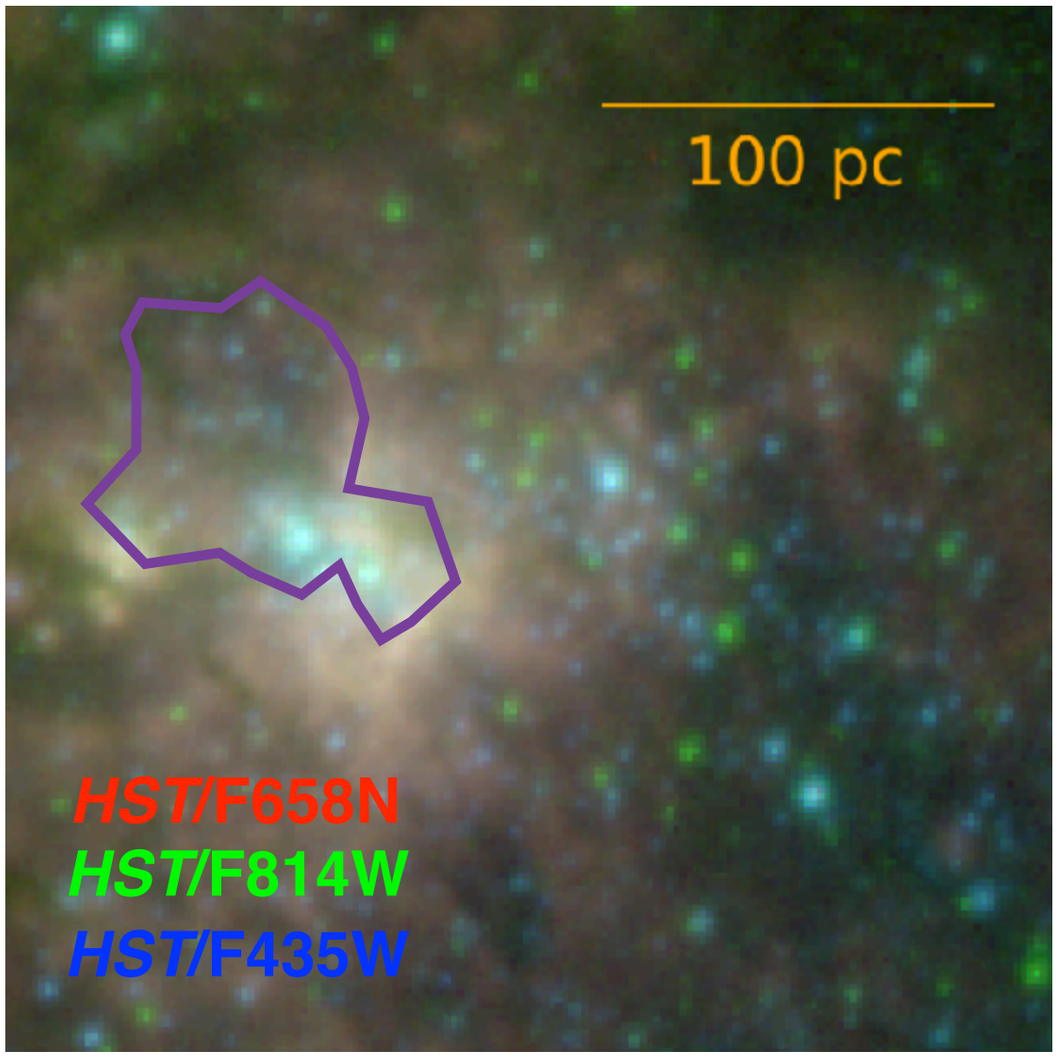
- E_{mech} from identified clusters: (0.3—30)x10^{52} ergs v.s. ~30x10^{52} ergs in multi-phase medium

Downtown of H1105



- E_{mech} from identified clusters: (0.3—30)x10^{52} ergs
- massive clusters are crowded by star clouds

Downtown of H1105



- E_{mech} from identified clusters: (0.3—30)x10^{52} ergs
- massive clusters are crowded by star clouds
- Hα bubble around the central three, like 30 Doradus

Summary

- We analyzed multi-band observations toward multi-phase gas in NGC 5461 and NGC 5471, and found

  - In NGC 5471B, ionized gas shows kinematic features of expanding shell and outflow;

  - At the southwestern outskirt of H1105 and NGC 5471D, the ionized gas is modest blueshifted — consistent with modest evolved populations in those portions;

  - An investigation of feedback efficiency requires more information on the stellar contents.

Thank you for your attention!

Property of young popupations: SED fitting of synthesized photometry

Starburst99 → stellar spectrum

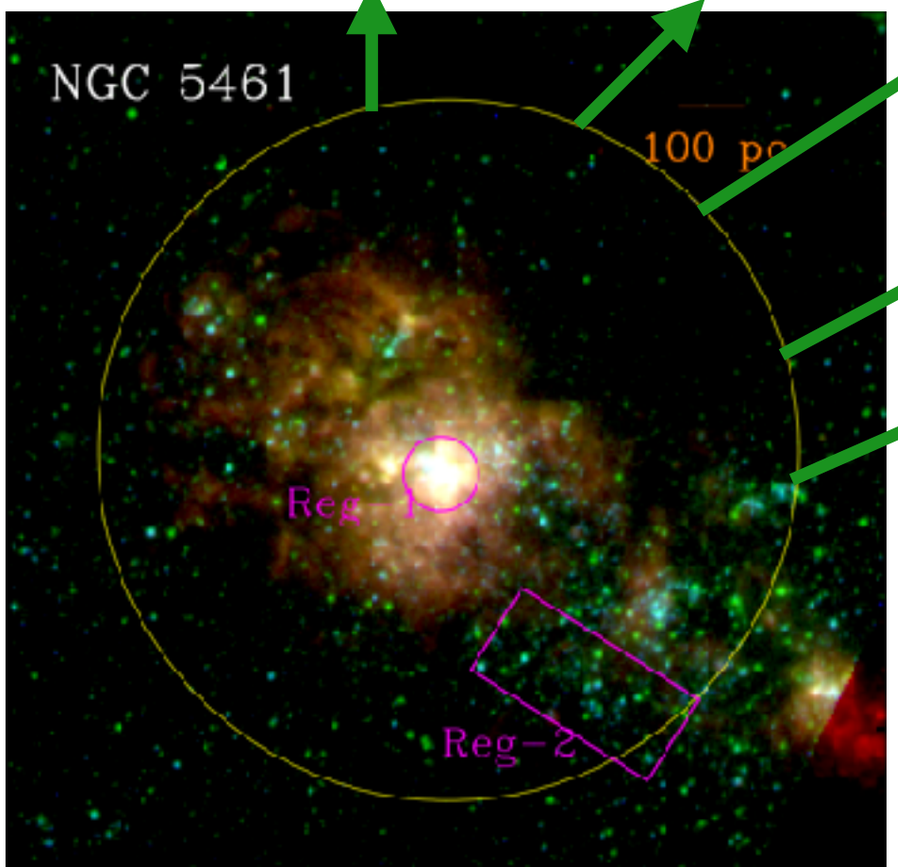
CLOUDY → nebula spectrum

stellar spectrum + nebula spectrum → SYNPHOT package

nebula spectrum → $f_{H\alpha}$

SYNPHOT package → f_λ under

F336W F435W F555W F675W F814W



Extinction curve: following Cardelli, Clayton, & Mathis 1989, ApJ

Property of young popupations: SED fitting of synthesized photometry

Starburst99 → stellar spectrum

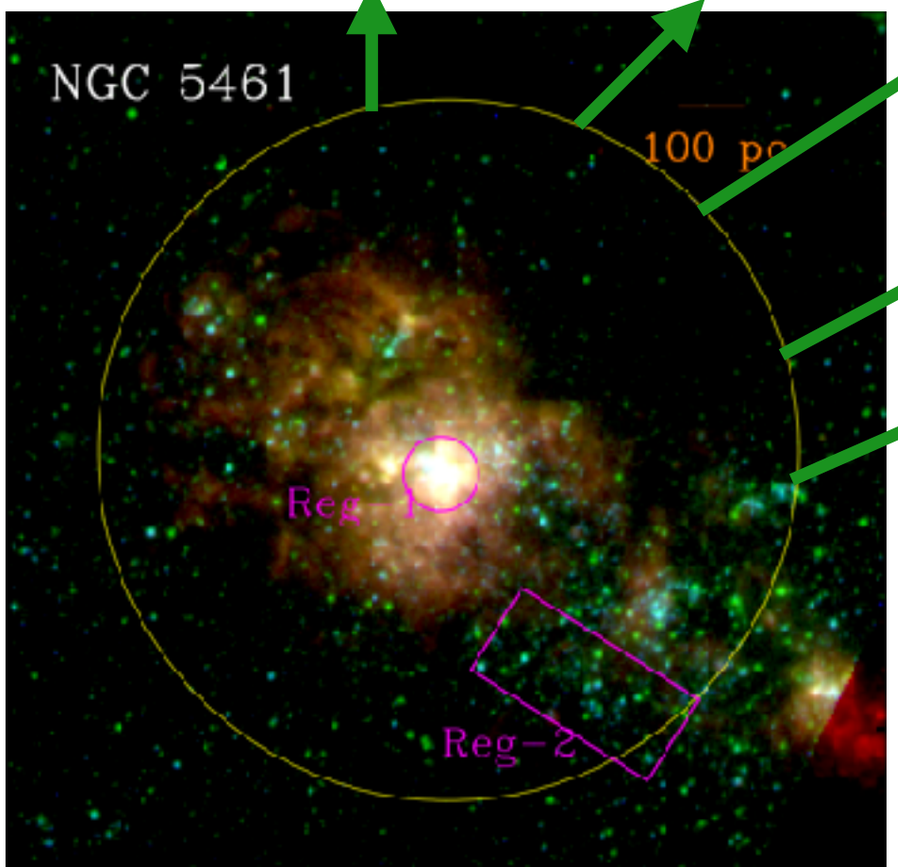
CLOUDY → nebula spectrum → $f_{H\alpha}$

Cluster Age

SYNPHOT package

f_λ under

F336W F435W F555W F675W F814W

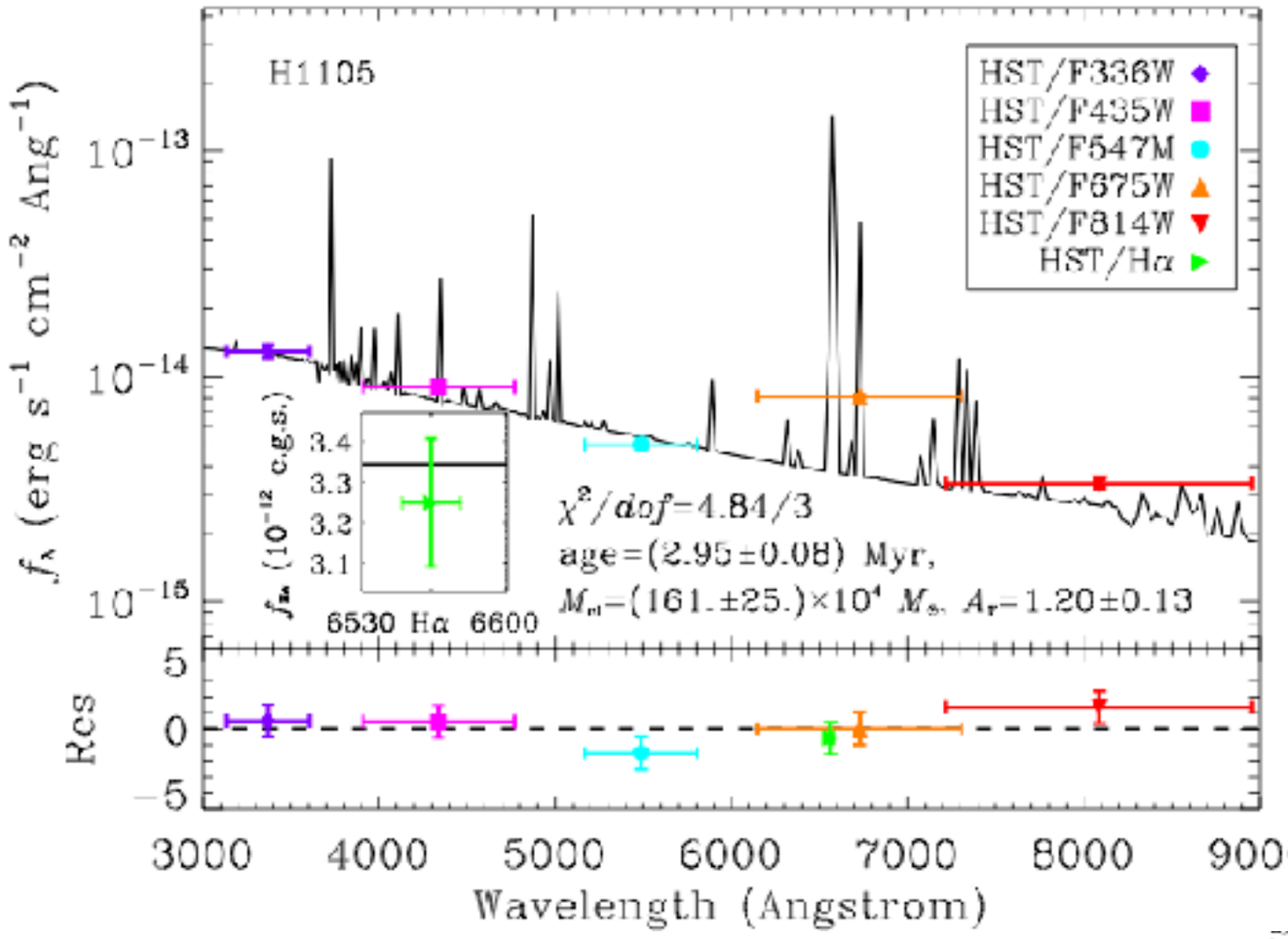


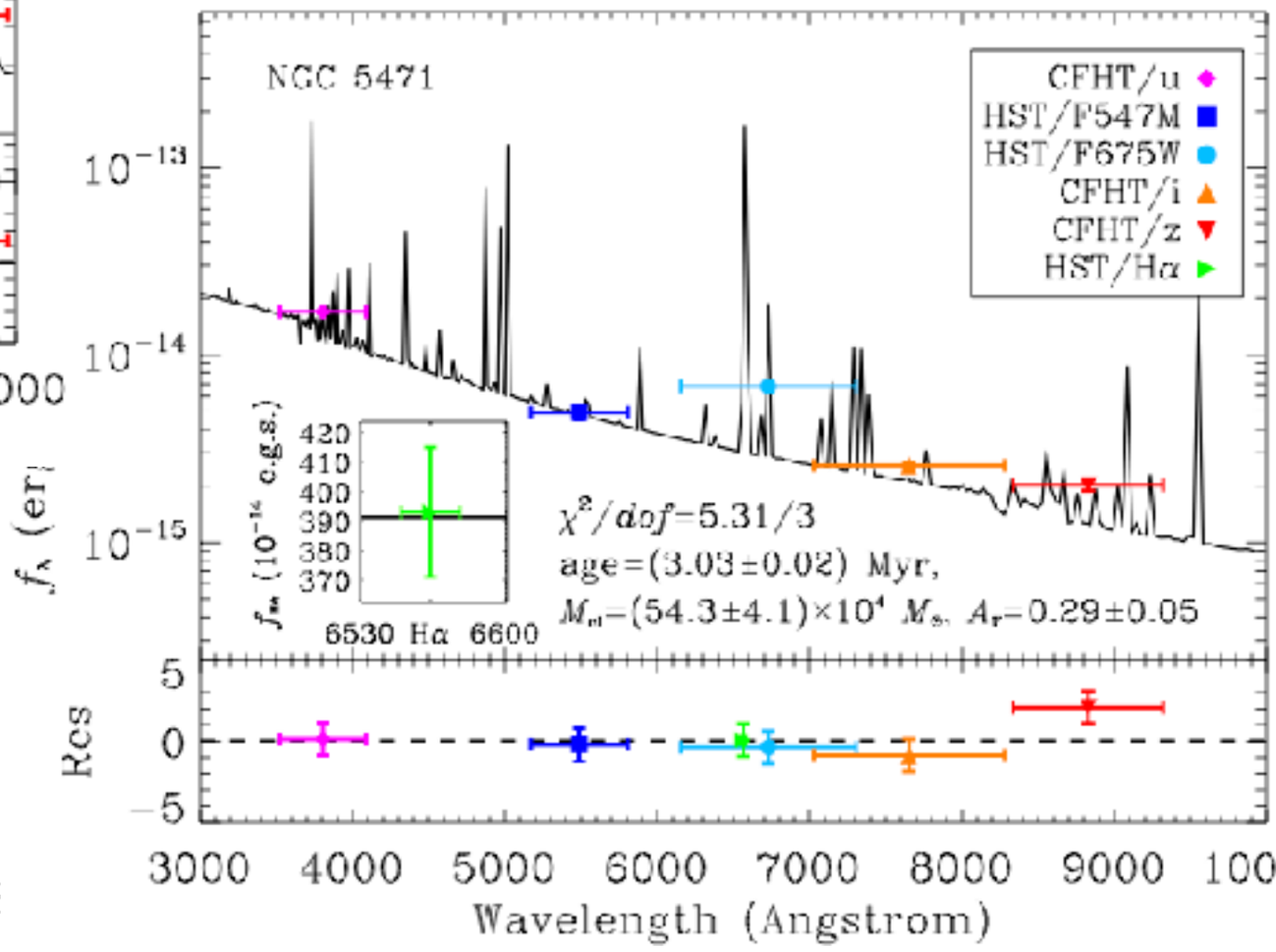
Cluster Mass

Extinction curve: following Cardelli, Clayton, & Mathis 1989, ApJ

A_V

Examples of SED fitting



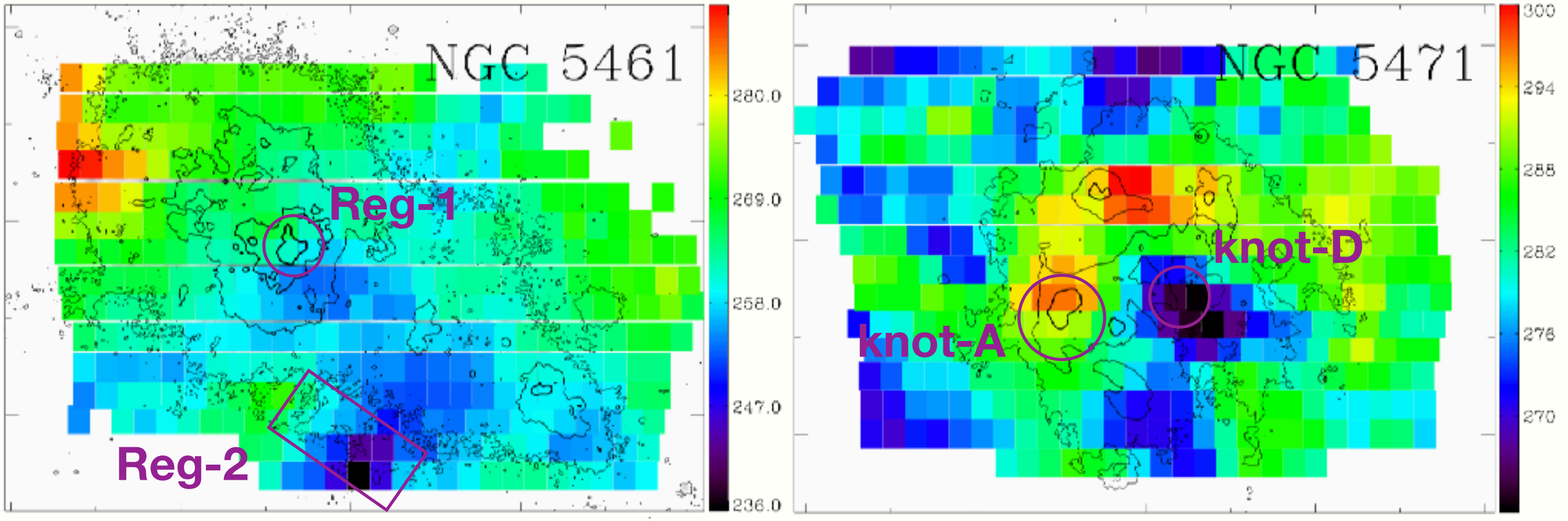


Census of mechanical energy in multi-phase gas

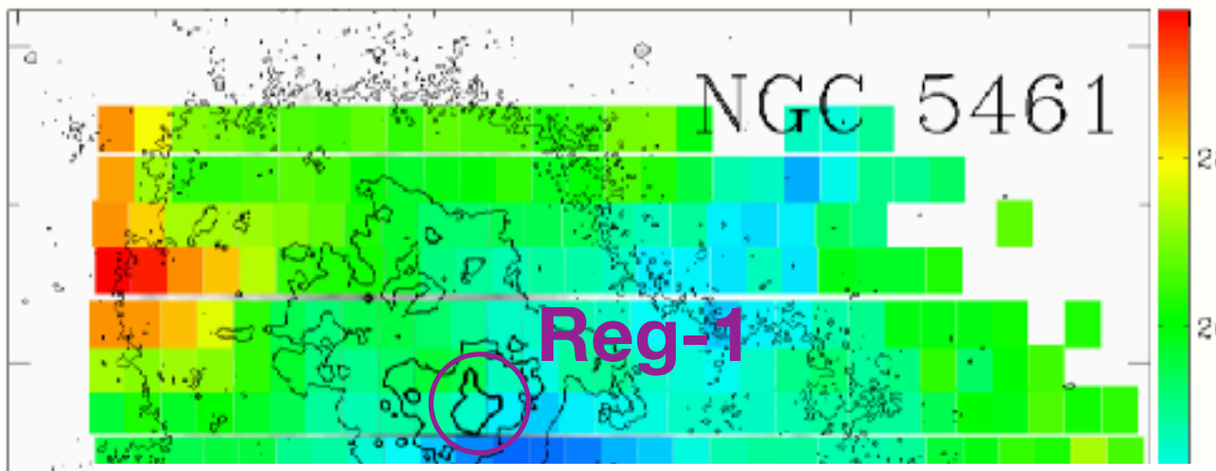
	hot gas	Ionized gas	neutral gas	mechanical energy
	E_{th} (10^{52} erg s^{-1})	E_k (10^{52} erg s^{-1})	E_k (10^{52} erg s^{-1})	E_{mech} (10^{52} erg s^{-1})
NGC 5461	**19**	**5.7**	**4.9**	**242**
NGC 5471	**…**	**3.6**	**0.6**	**75**

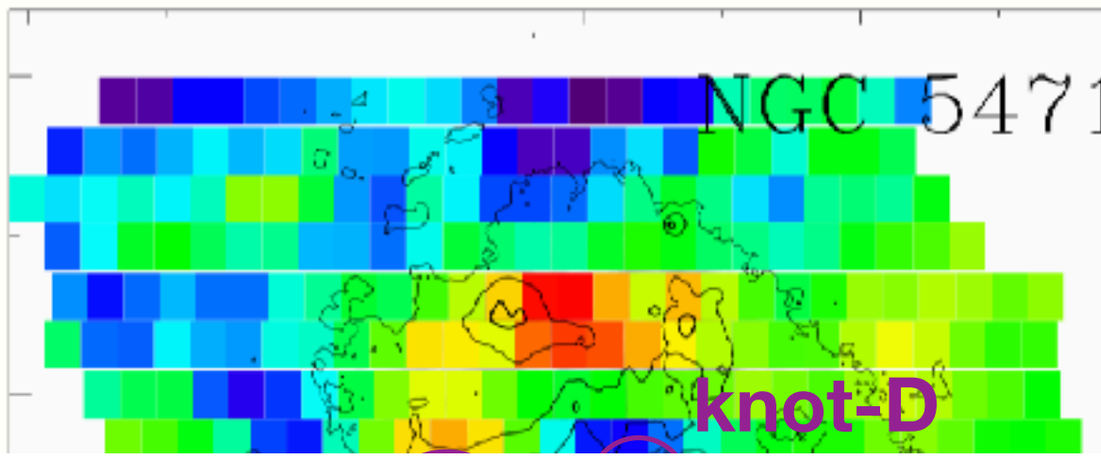
- **~10%** v.s. superbubble model's prediction (Weaver+1977): **55/77**
- much more kinetic energy could be reserved in tenuous gas (e.g., Wood+2015): **still too low**
- **low feedback efficiency!**

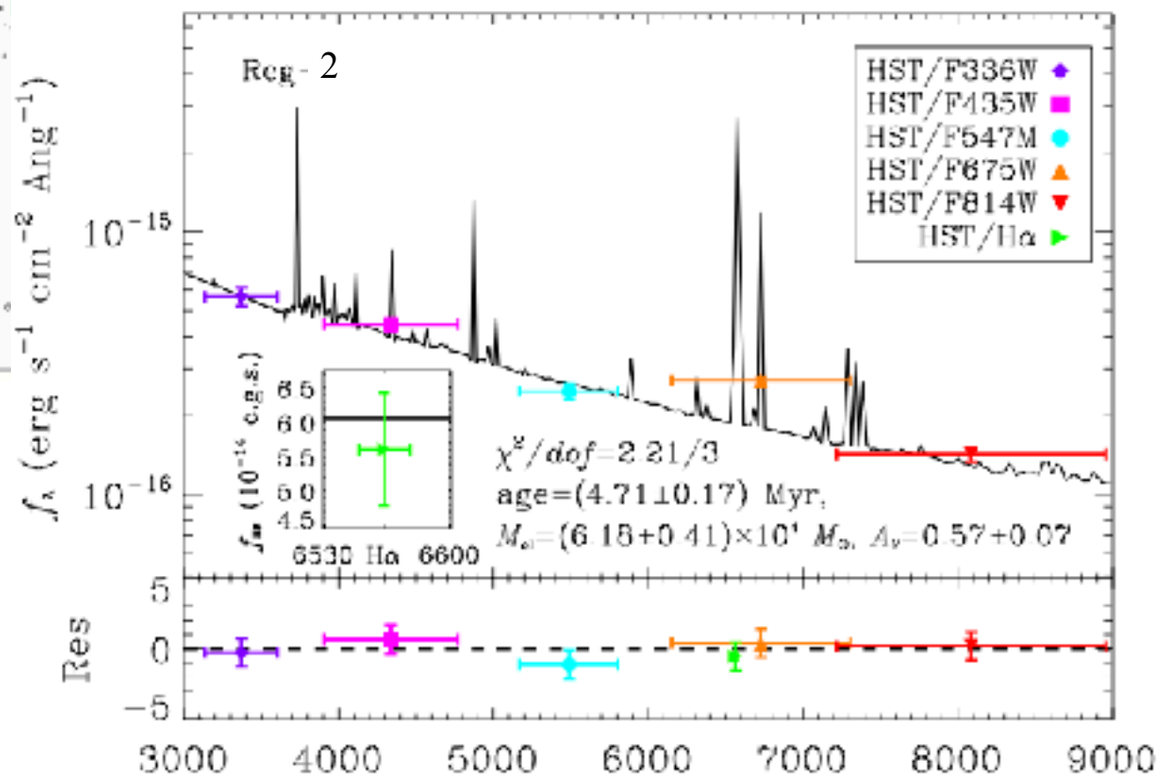
Young stars v.s. motion of ionized gas

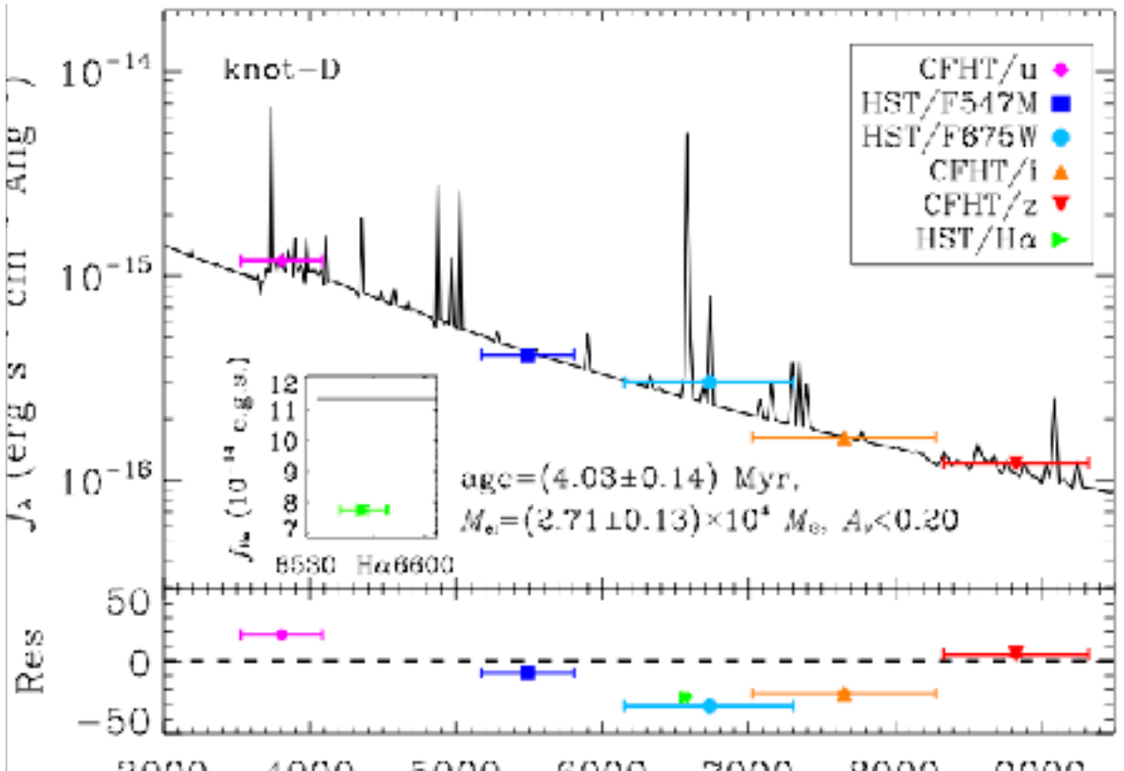


Young stars v.s. motion of ionized gas

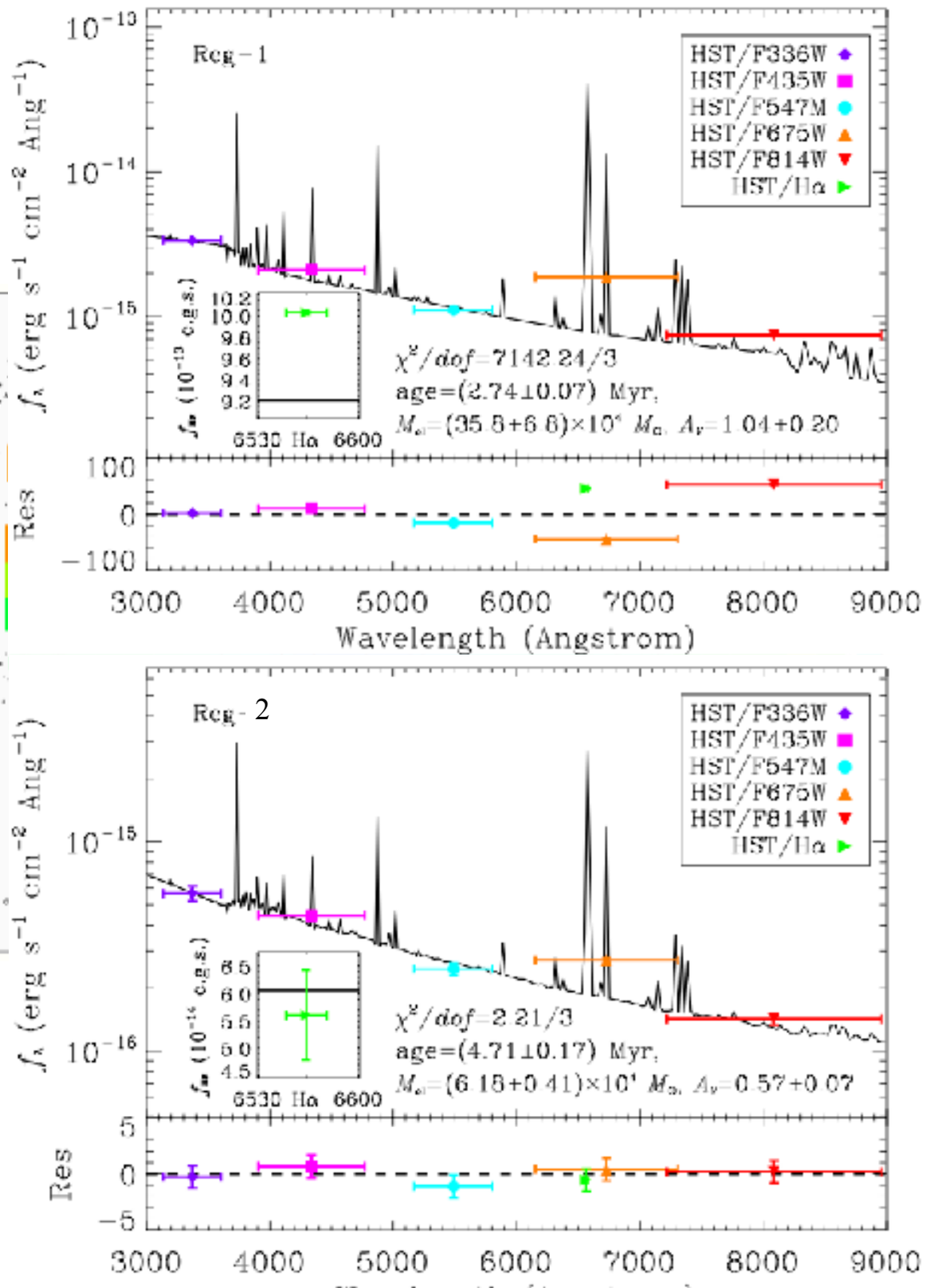


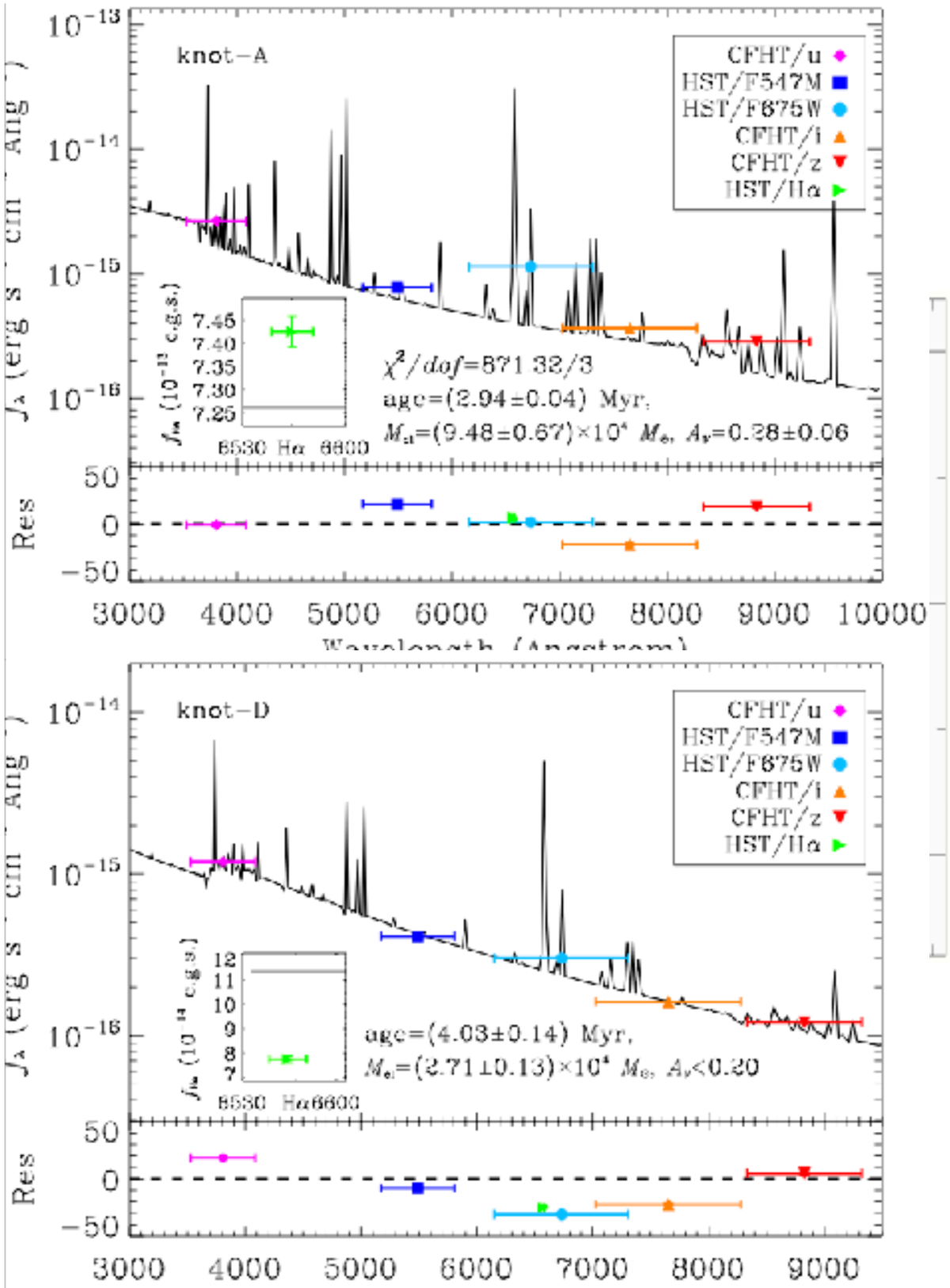




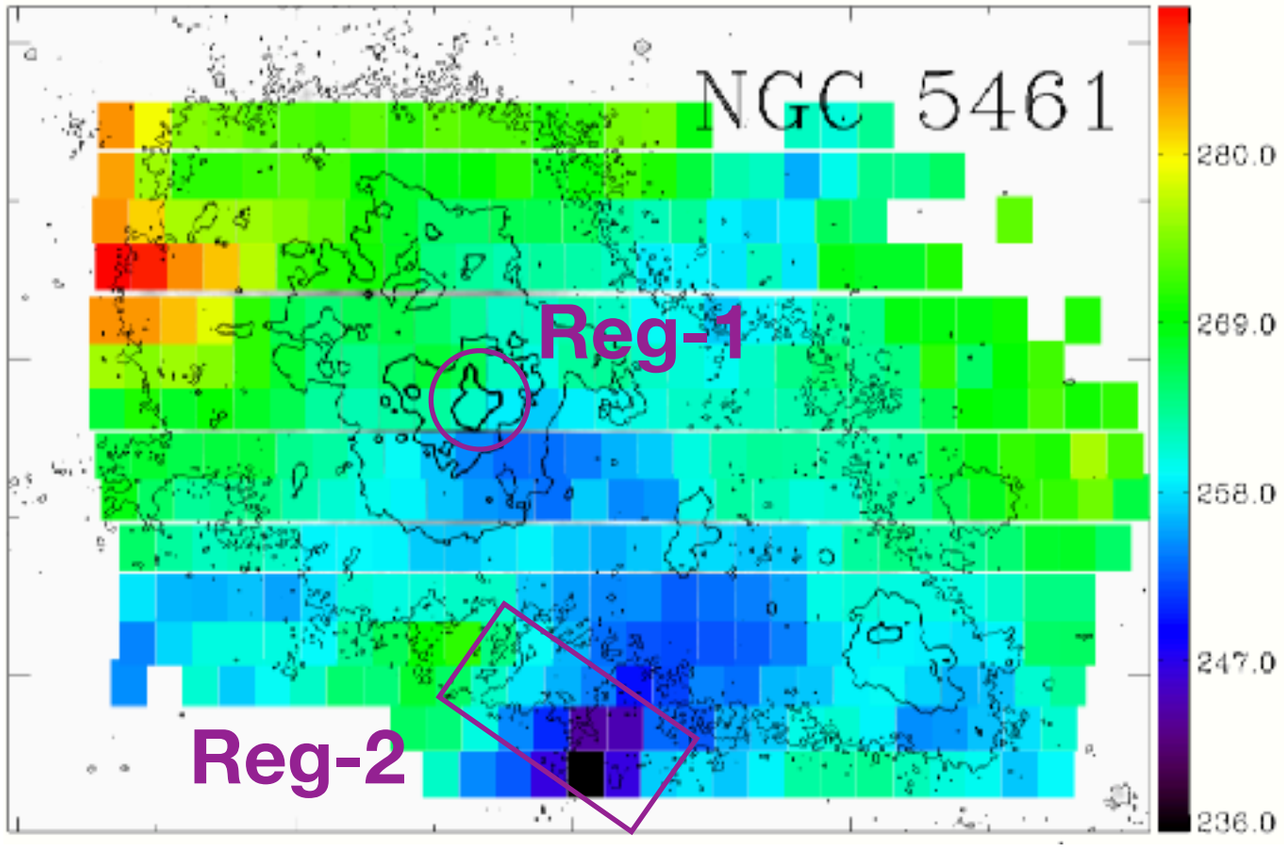


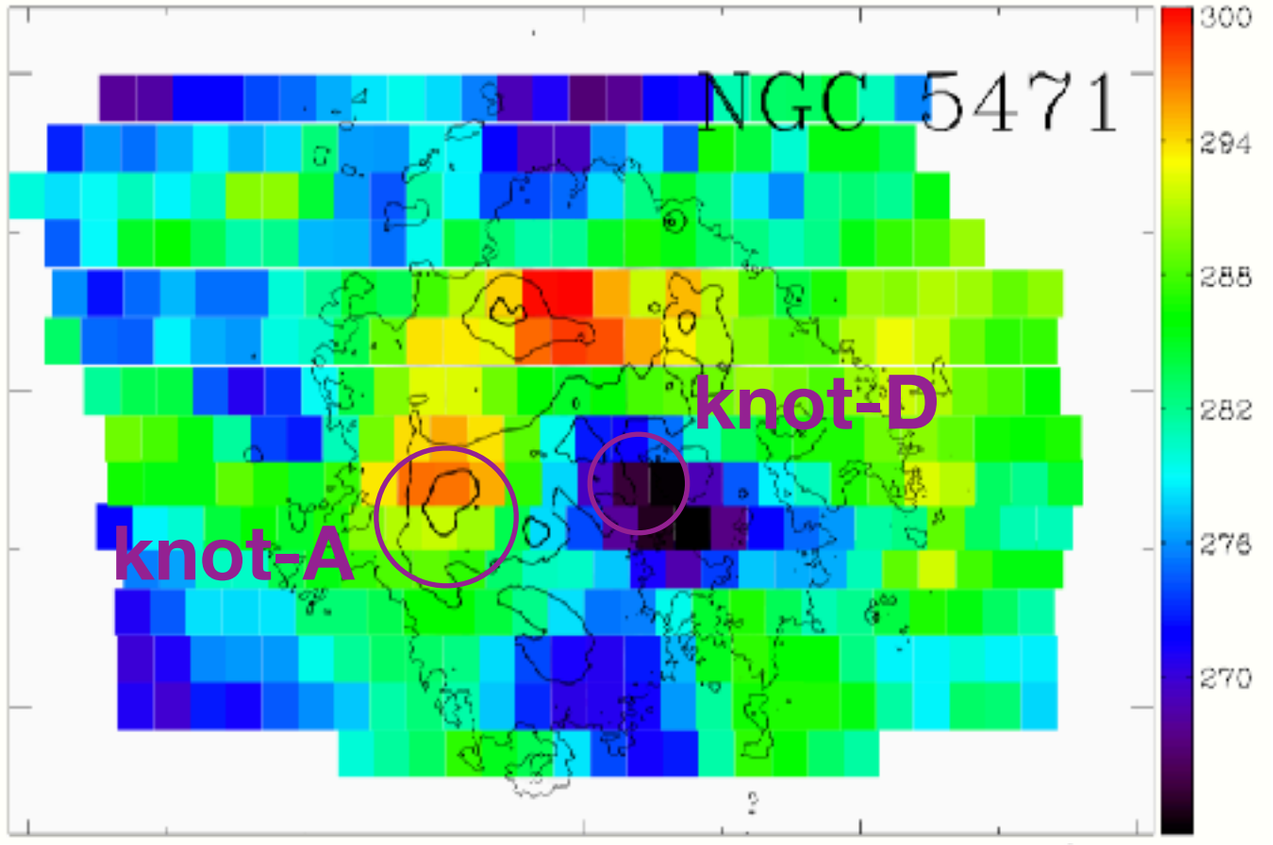
Young stars v.s. motion of ionized gas





Young stars v.s. motion of ionized gas





	Reg-1	Reg-2	knot-A	knot-D
Age (Myr)	2.74 (0.07)	4.71 (0.17)	2.94 (0.04)	4.03 (0.14)
A_V	1.04 (0.20)	0.57 (0.07)	0.28 (0.06)	<0.20