Feedback-driven superbubbles and triggering of star formation in nearby dwarf galaxies

Oleg Egorov

SAI MSU; SAO RAS (Russia)

In collaboration with

Tatiana Lozinskaya and Alexei Moiseev

VOLGA

View On the Life of GAlaxies

Feedback

Mechanical energy input

- Stellar winds from massive OB-stars
- Supernovae

Superbubbles…

Ionization

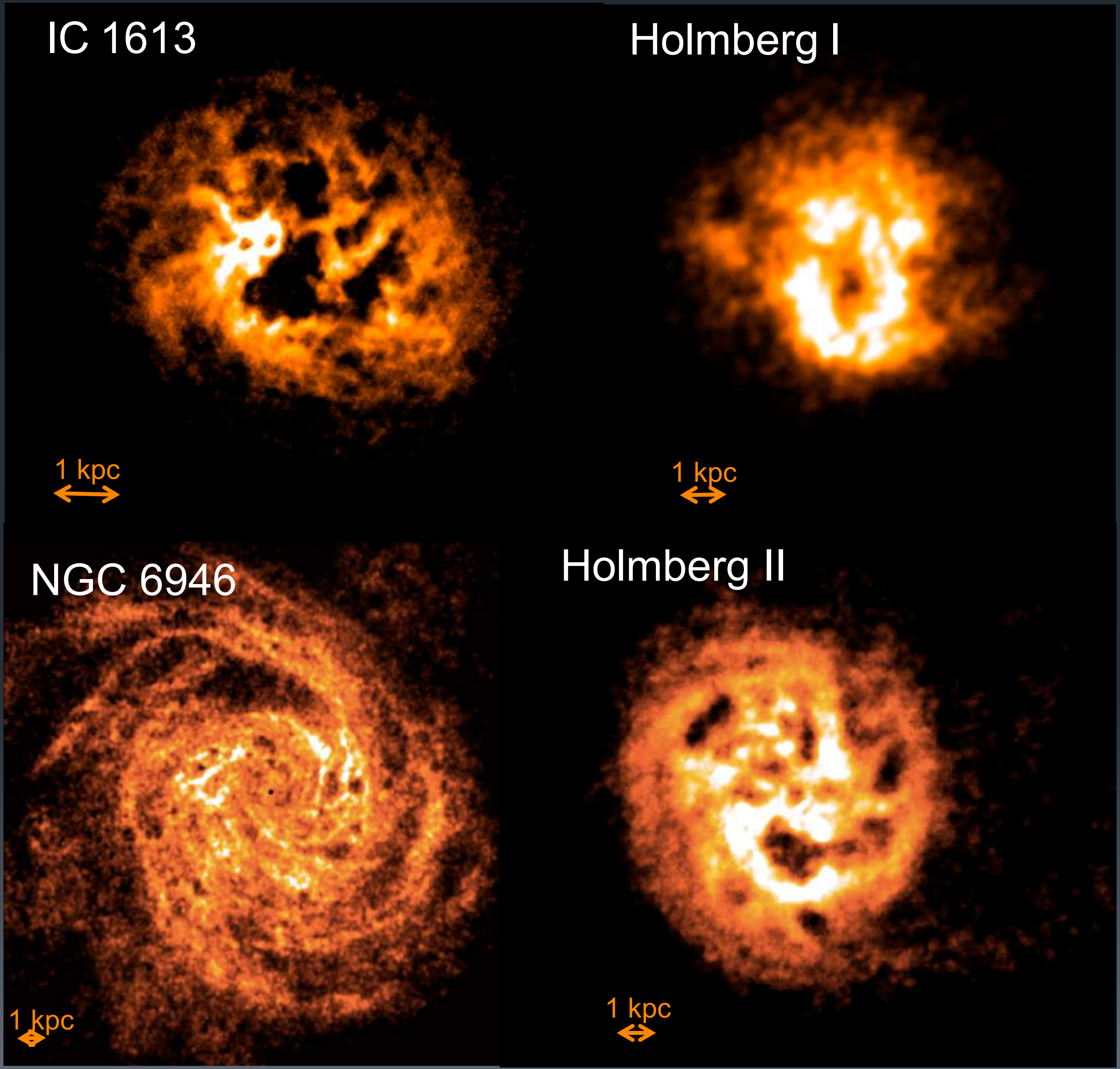
Young massive OB-stars:
LyC quanta escape from HII regions

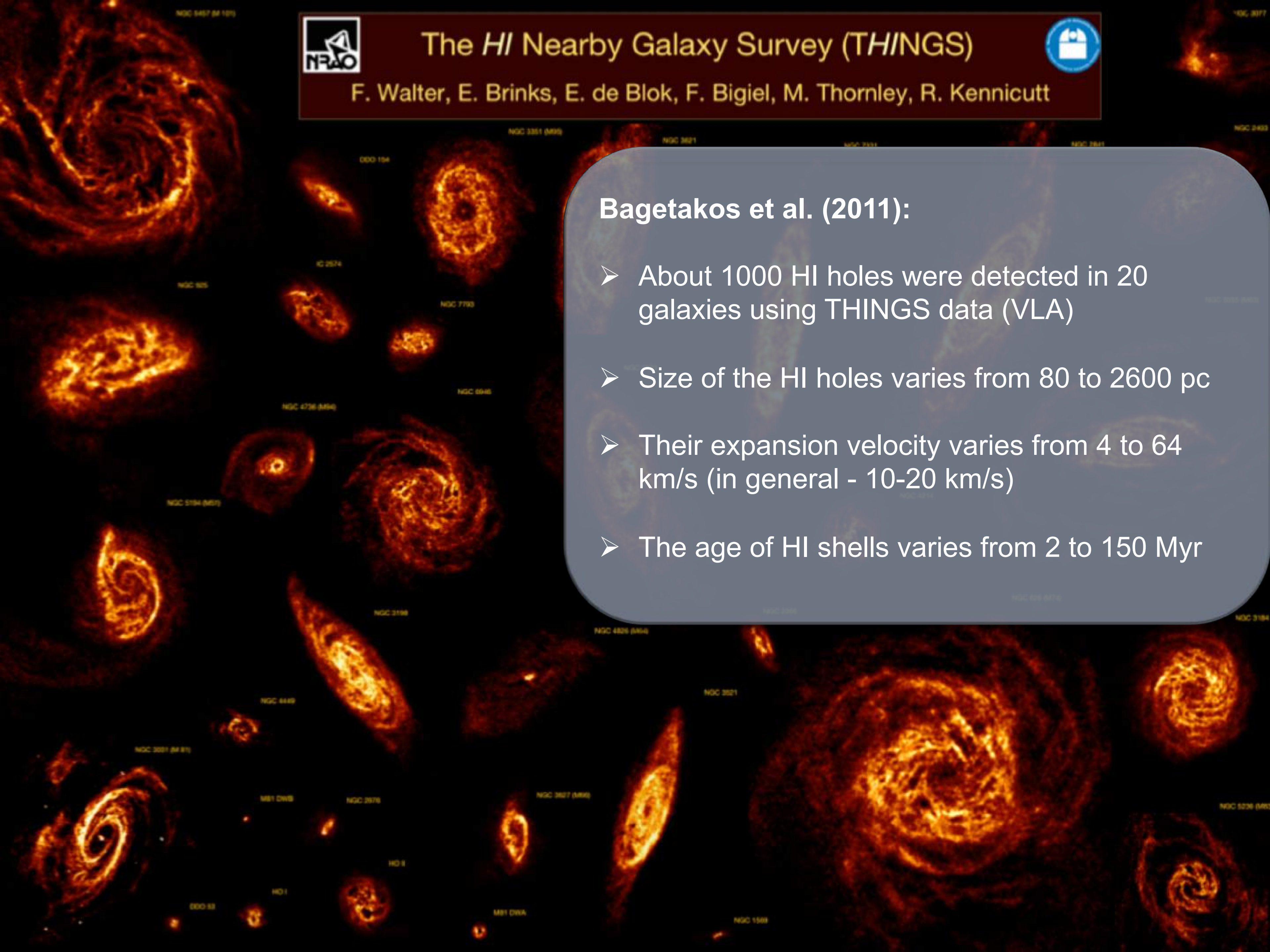
DIG…

Influence of supernovae and stellar winds on the ISM

Collective influence of young cluster’s massive stars and supernovae on the ISM creates supershells with sizes from several pc to 2-3 kpc.

HI 21 cm





Bagetakos et al. (2011):

- About 1000 HI holes were detected in 20 galaxies using THINGS data (VLA)
- Size of the HI holes varies from 80 to 2600 pc
- Their expansion velocity varies from 4 to 64 km/s (in general - 10-20 km/s)
- The age of HI shells varies from 2 to 150 Myr

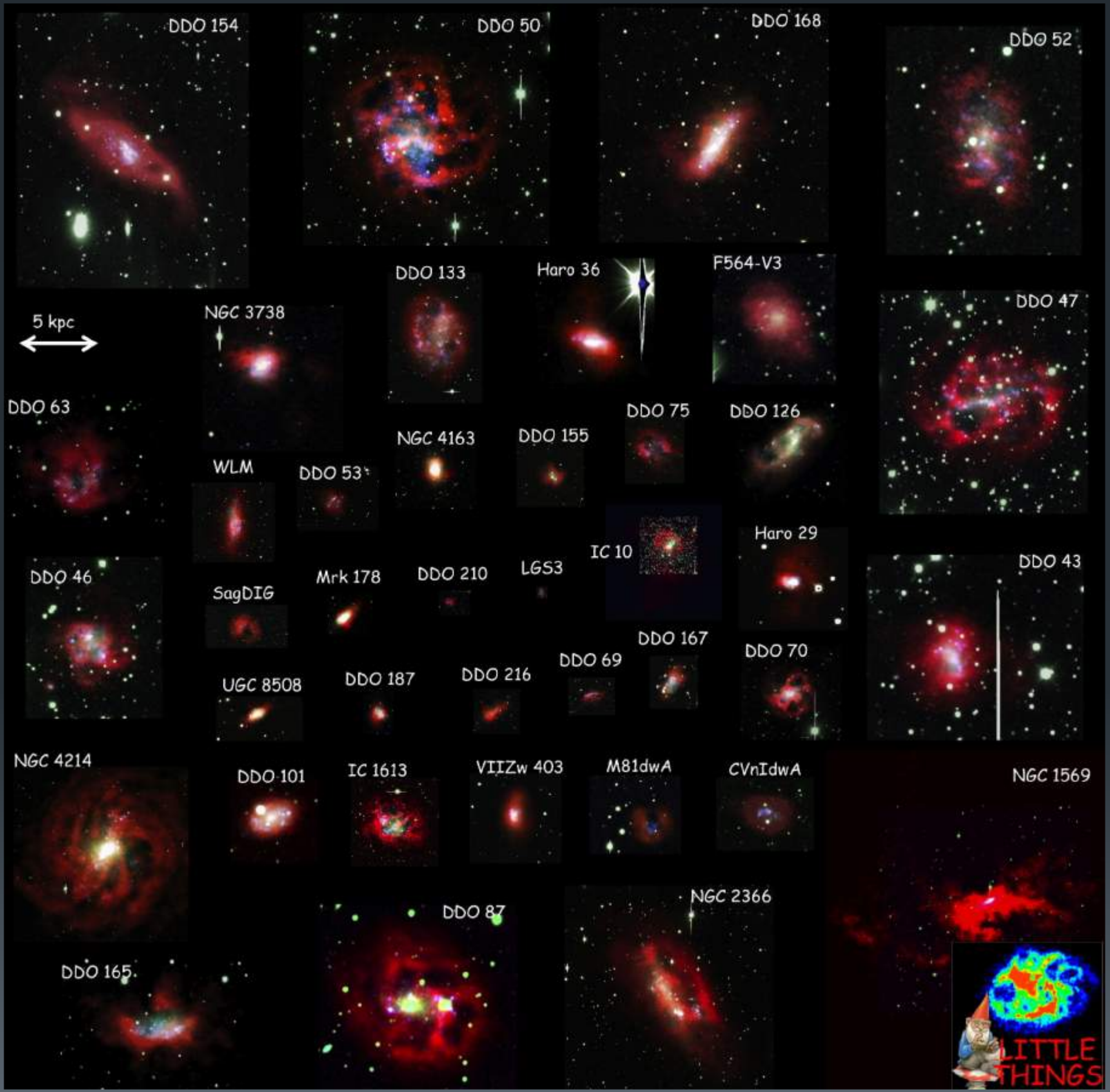
Supergiant shells (SGS) with sizes 1-3 kpc

Supershells result from the cumulative action of multiple stellar winds and supernova explosions
(Weaver et al. 1977)

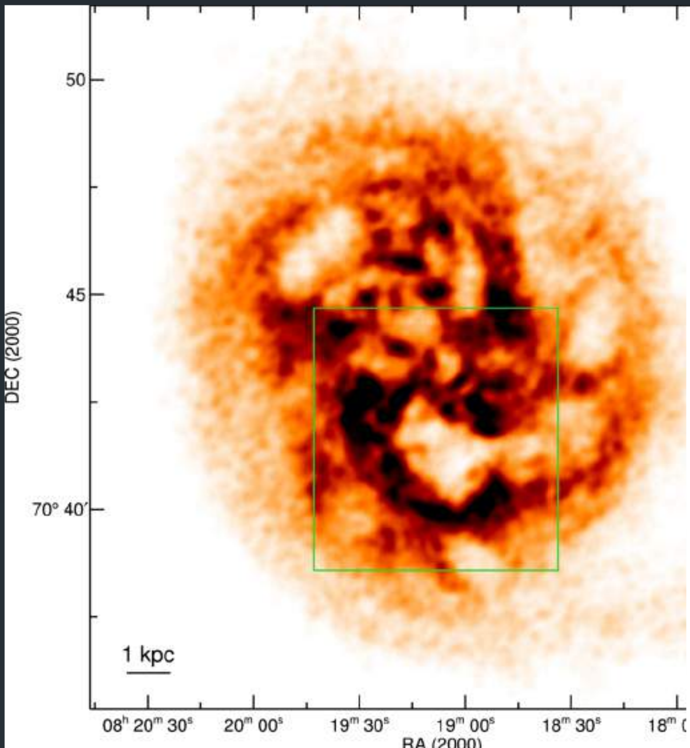
But: the mechanical energy input from the detected stellar cluster is insufficient for most of the SGSs.
(Tenorio-Tagle & Bodenheimer 1988, Silich et al. 2006 etc.)

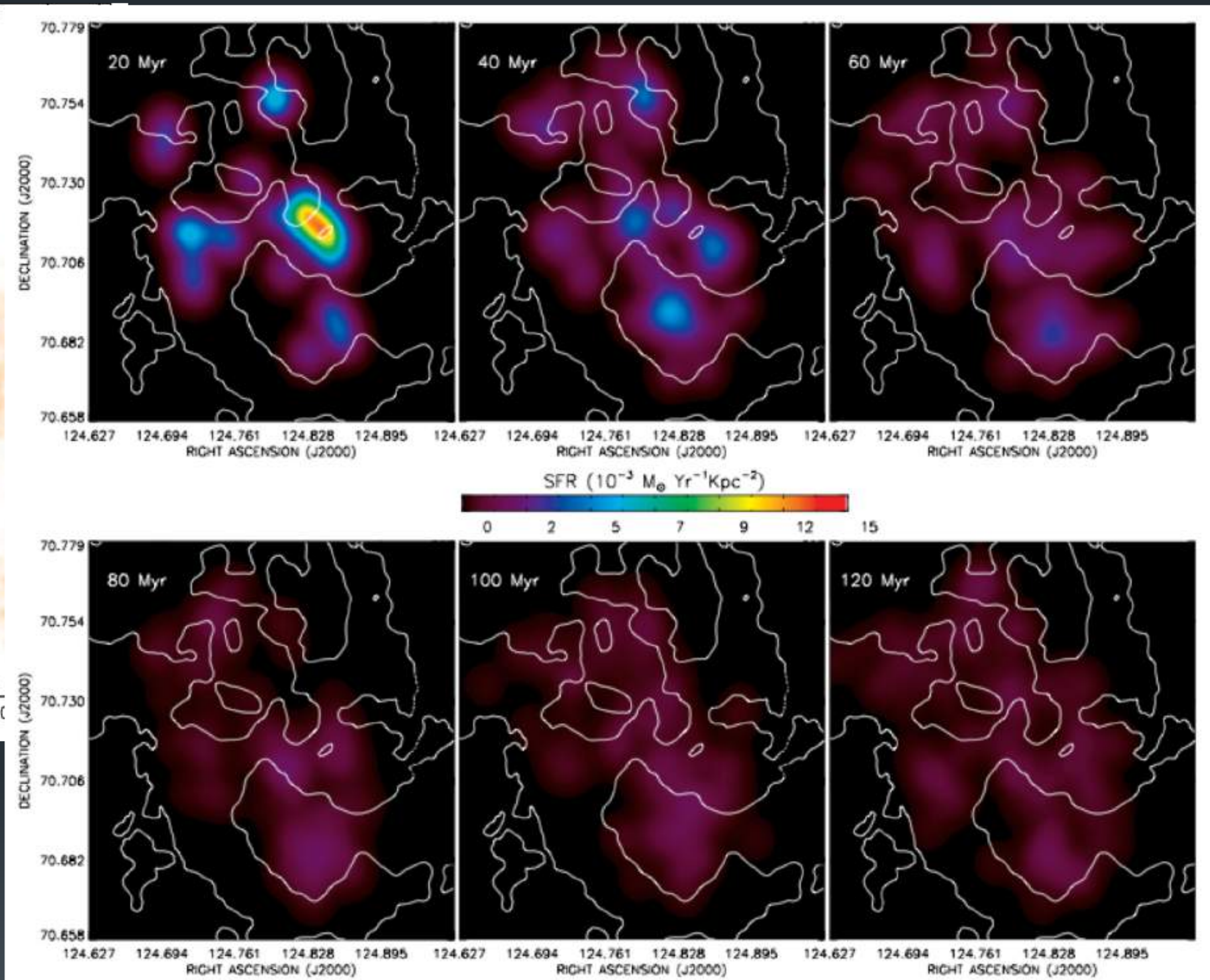
A lot of observed SGS have no any young stars inside.

Multiple generations of stars are responsible for the creation and driving of SGS
(Weisz et al. 2009,
Warren et al. 2011)



Holmberg II: star formation history

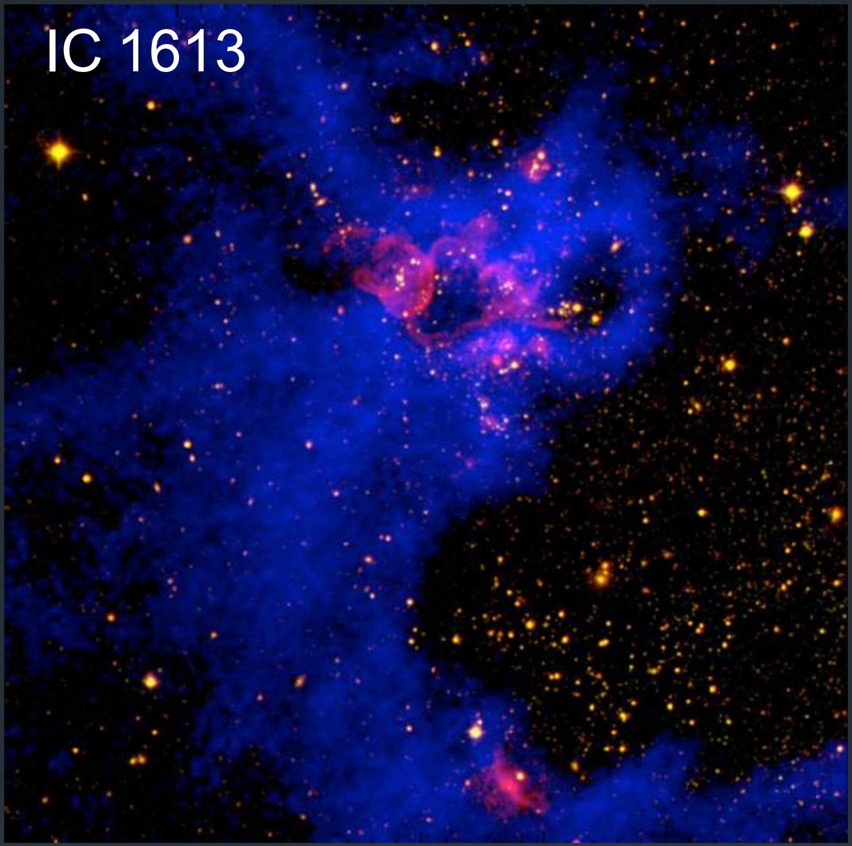


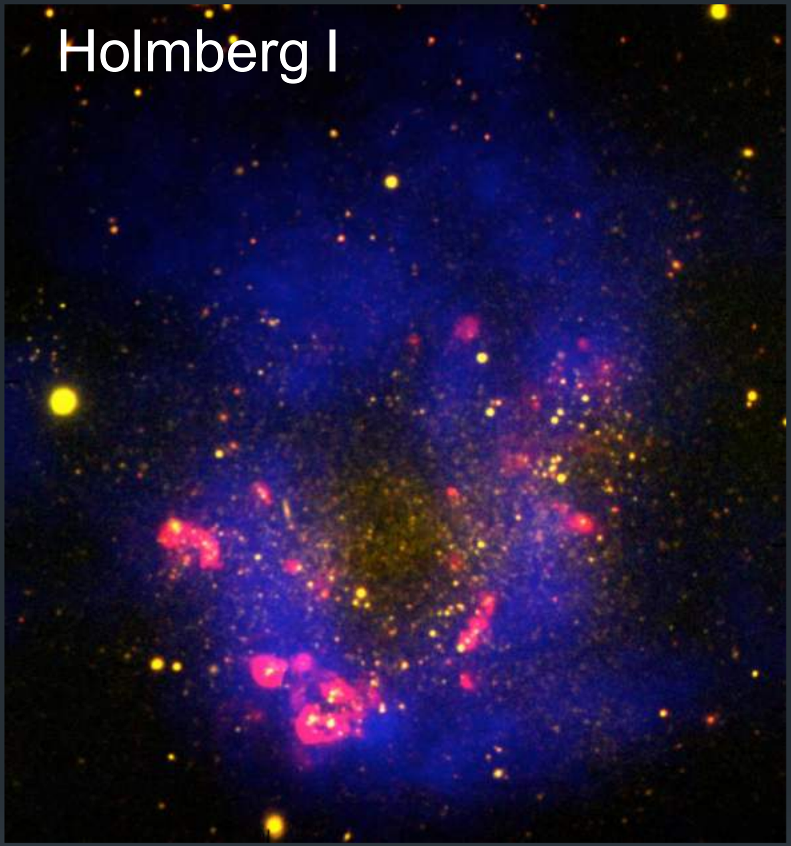


Mechanical energy input from stellar winds and supernovae integrated over the whole long period of star formation is enough to form most of the observed SGS

Weisz et al. (2009)

Star formation in the rims of HI supershells

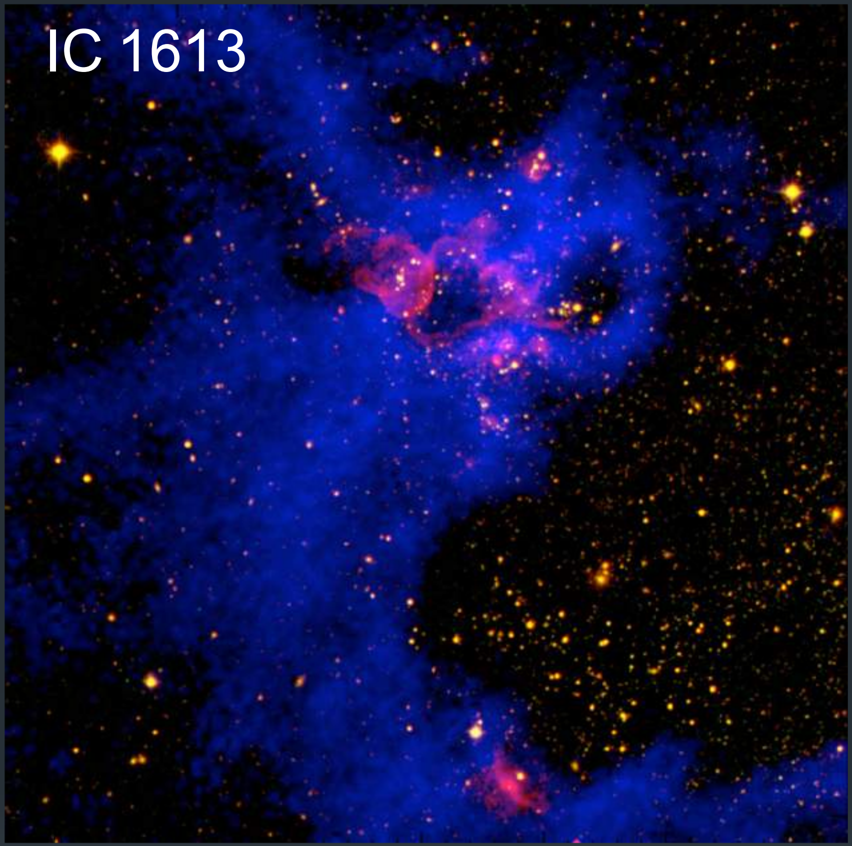


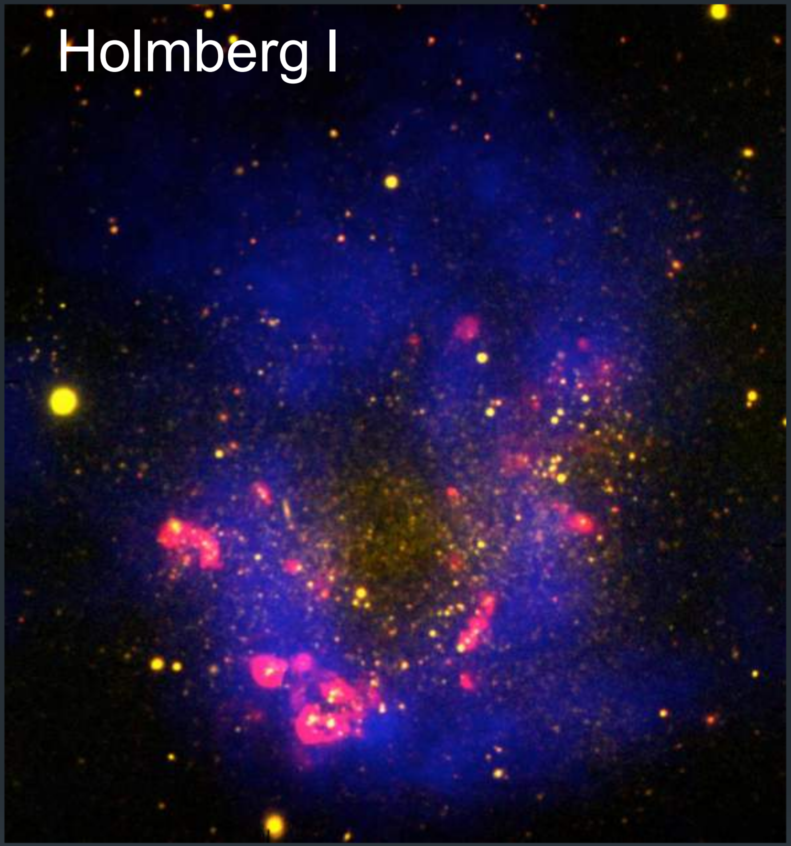


H-alpha + HI 21cm + stars

- What triggers the new episode of star formation and how it propagates through SGS?
- How these new episodes of star formation influence the “parent” SGS?

Star formation in the rims of HI supershells





H-alpha + HI 21cm + stars

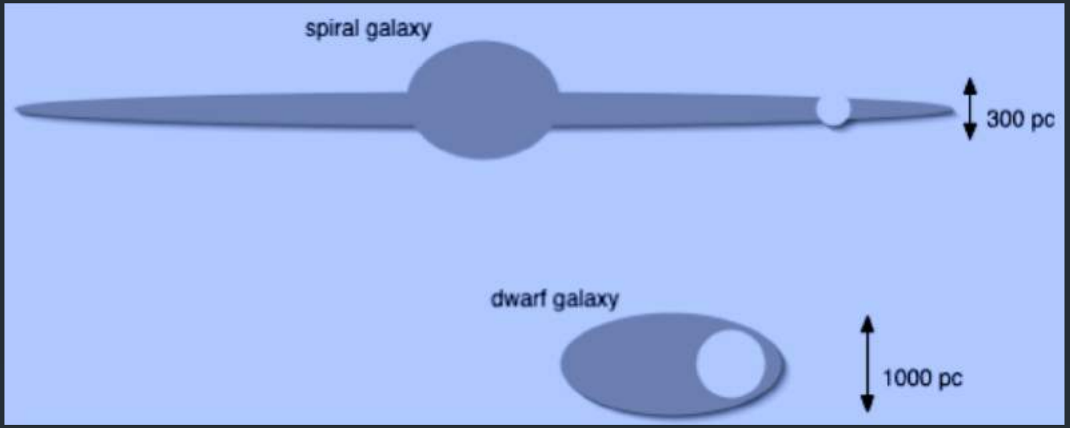
- What triggers the new episode of star formation and how it propagates through SGS?
- How these new episodes of star formation influence the “parent” SGS?

- Identification and analysis of supernovae remnants, nebulae around WR stars and other high-energy objects influencing on ISM

Dwarf Irr galaxies as a good laboratory

- They are gas rich
- Have a thick gas disc
- … a shallow potential
- … and a lack of spiral density

waves.



Due to that the stellar winds and supernovae may create a large (up to several kpc sized) long-lived complexes of multiple shells, supershells and filaments.

Hence dIrr galaxies provide a good opportunity to study the stellar feedback influence to ISM.

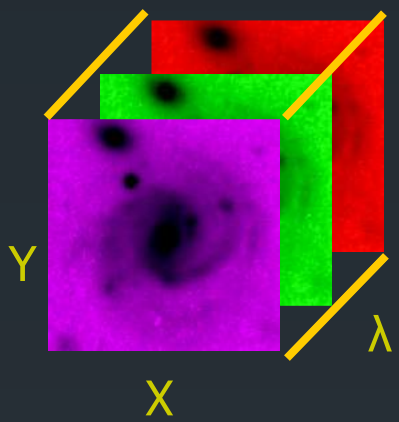
Observations: 6-m telescope BTA (SAO RAS)

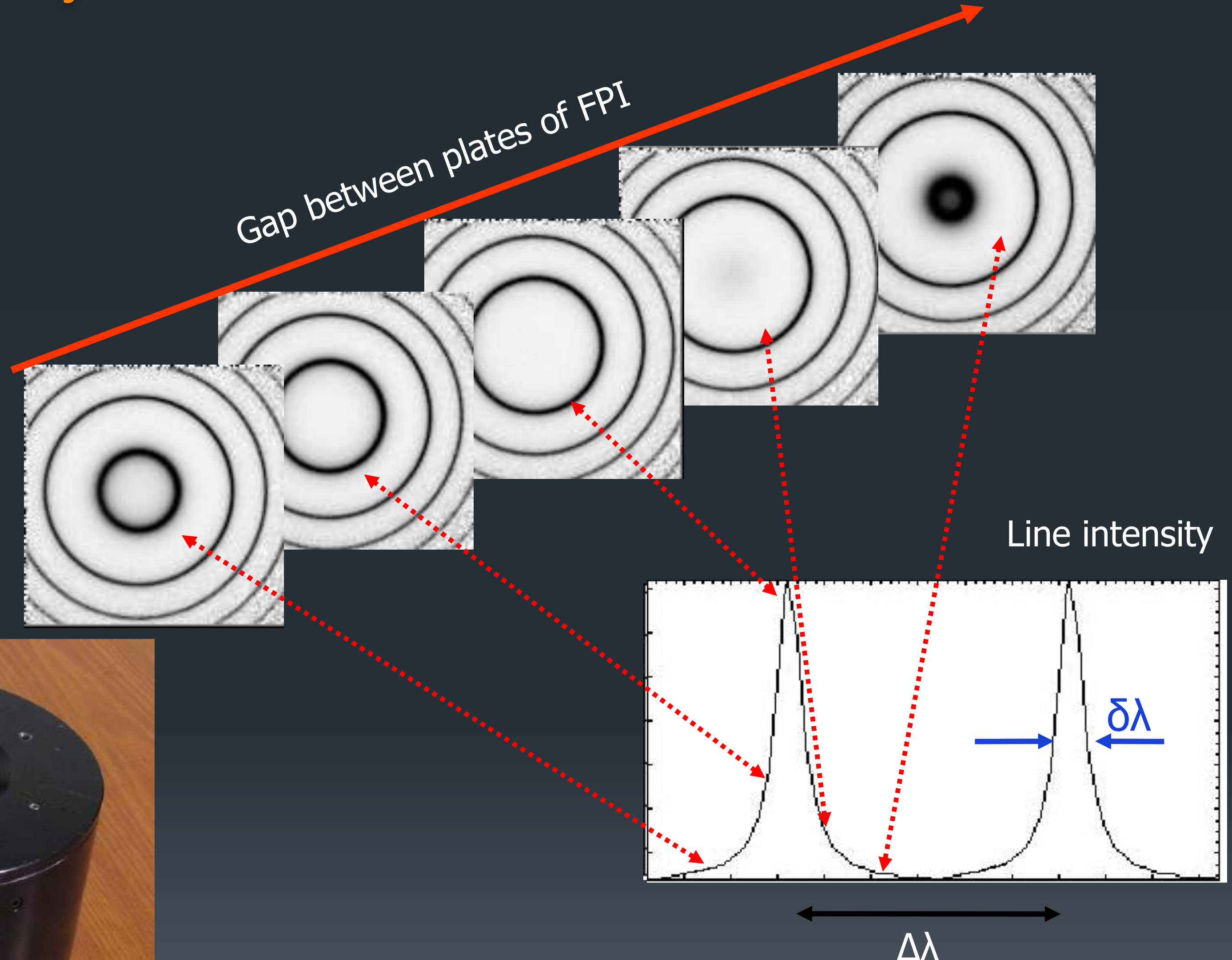
SCORPIO & SCORPIO-2 multi-mode focal reducers with scanning FPI (Afanasiev & Moiseev, 2005, 2011)

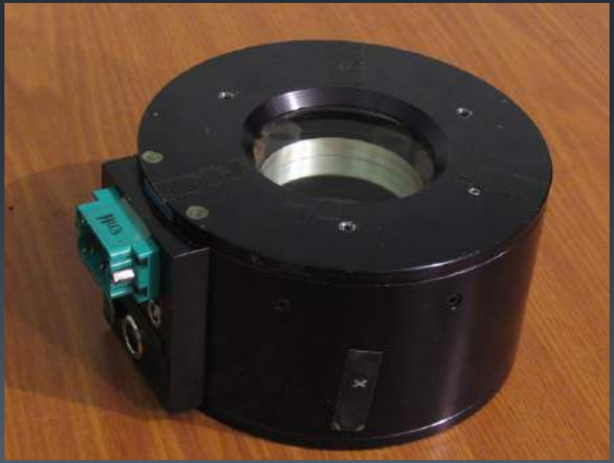
- Long-slit spectrograph with set of the grisms of different resolution and spectral range
- Set of broad-band and narrow-band optical filters
- Spectropolarimeter
- 3D-spectroscopy
    - Fabry-Perot interferometer
    - IFU spectrograph (Afanasiev, Egorov & Perepelitsyn 2018)

6-m telescope : www.sao.ru

Scanning Fabry-Perot Interferometer





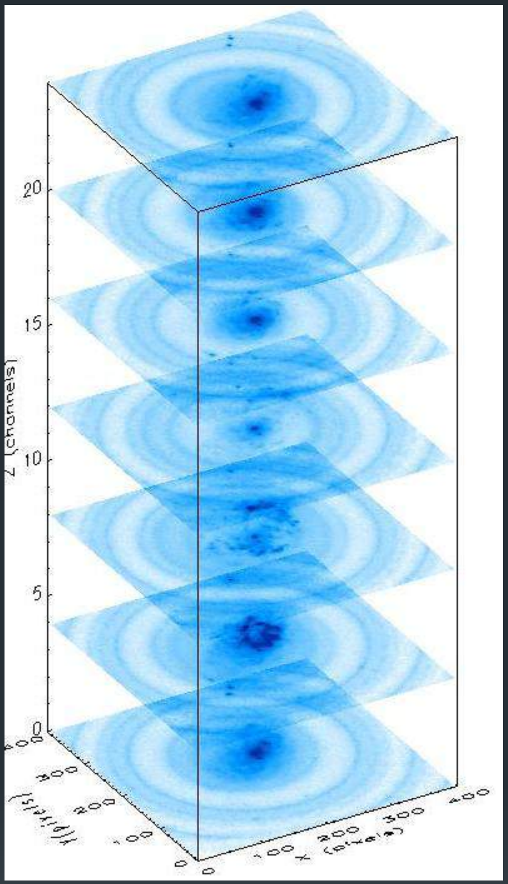


FPI ET-50
Queensgate Inc. (IC Optical System Inc.)

large field of view: 5-20 arcmin
high spectral resolution: δλ= 0.2…2Å
small spectral range: Δλ=λ/n=5…50 Å

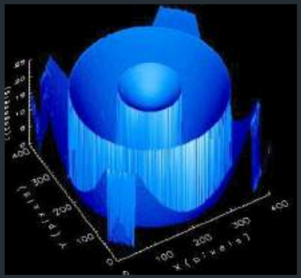
Scanning Fabry-Perot Interferometer

Z=channels

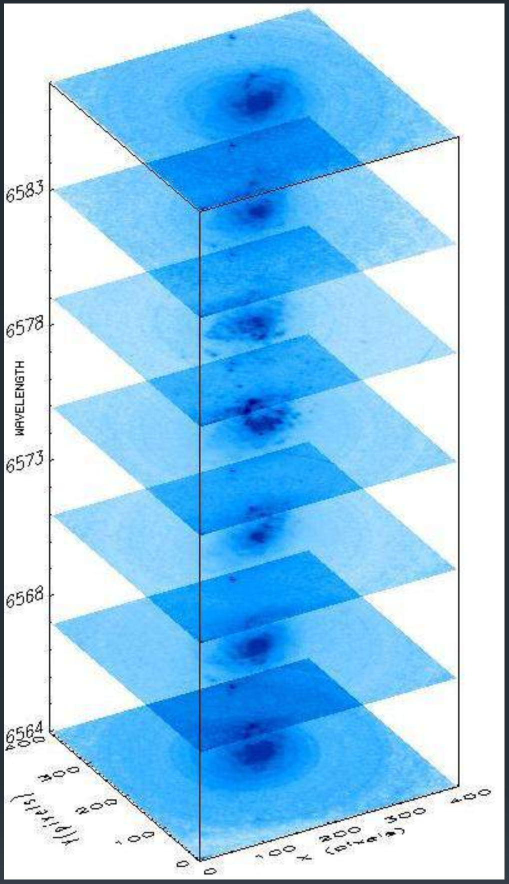


Data reduction:

Moiseev (2002)
Moiseev, Egorov (2008)
Moiseev (2015)



Z=Wavelength



Field of view: 6.1x6.1 arcmin

Spectral range: Hα, [NII], [OIII] and [SII] emission line

Spatial sampling: 0.35-0.70 arcsec/px

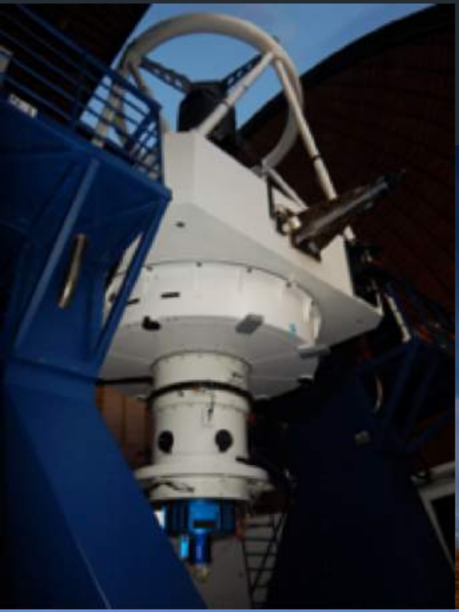
Spectral resolution:

R=4000 - 15000

σ= 8.5 - 30.0 km/s

Observations: 2.5-m telescope of SAI MSU

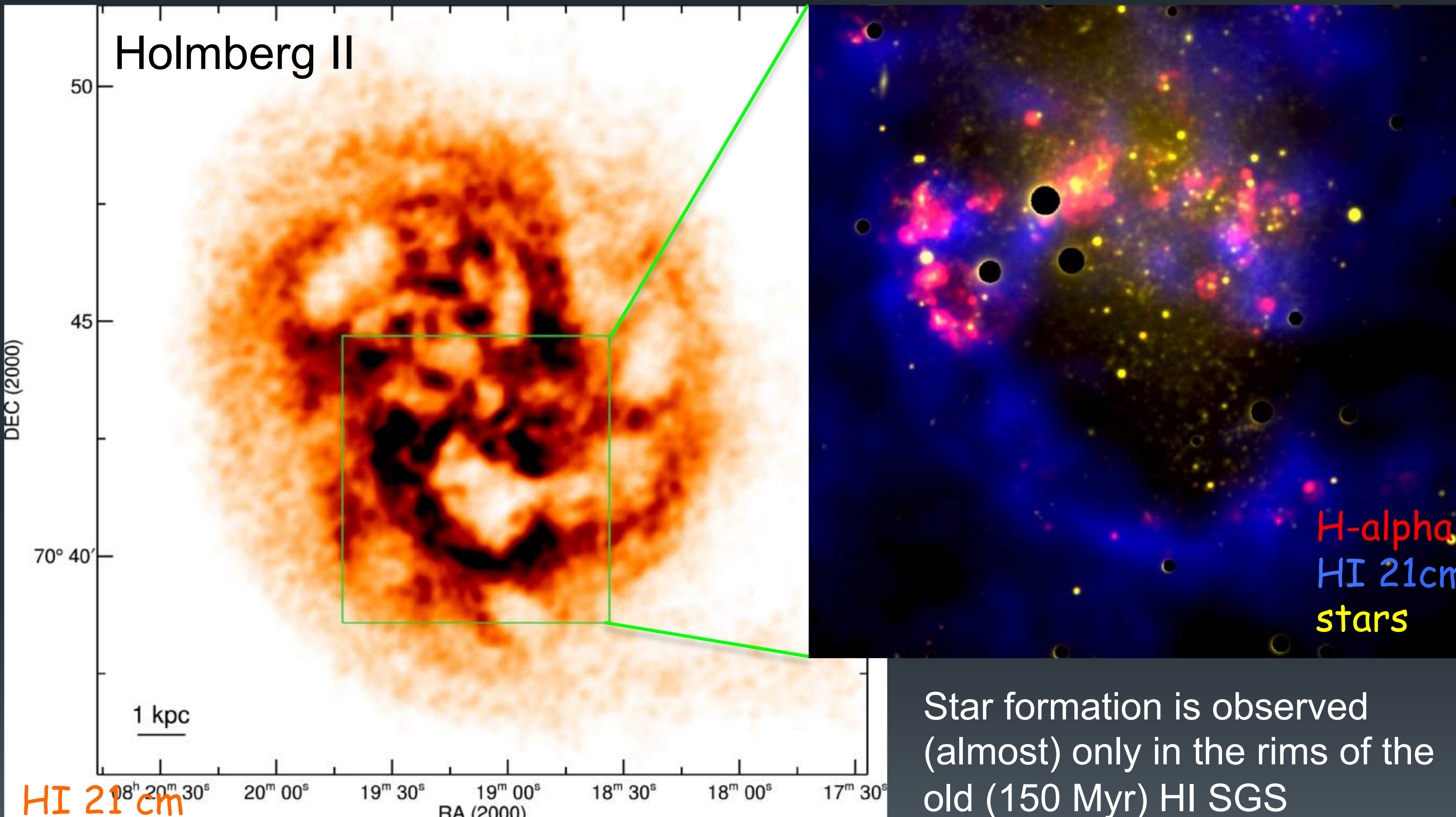
- New observatory: official opening ceremony was in Dec, 2015
- Currently working in technical mode



Available instruments:

- Optical CCD camera (10x10 arcmin) with set of broad-narrow-band filters (Halpha, [SII]6717,6731, [OIII]5007 and corresponding continuum)
- NIR photometer and spectrograph
- Speckle-polarimeter
- Photometer with tunable filter "MANGAL" (project of SAO-SAI)
- Optical spectrograph (in development)

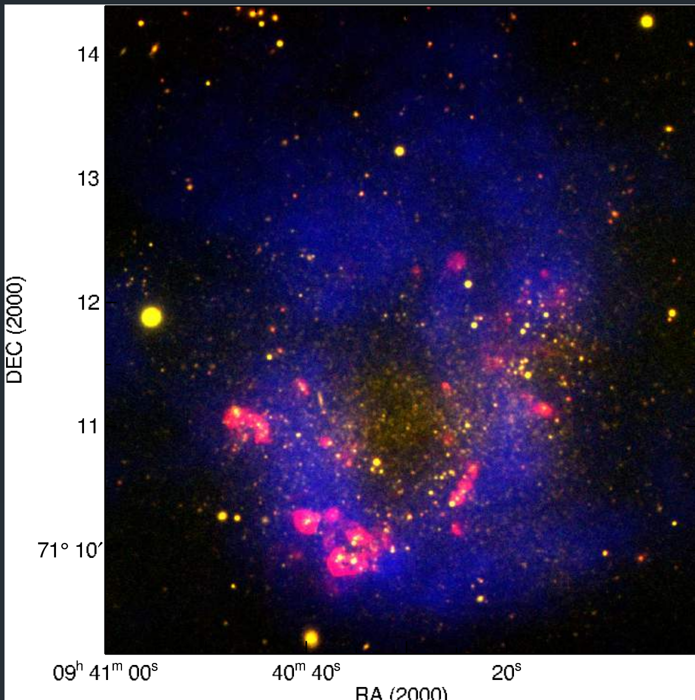
Holmberg II: star formation in the rims of the largest SGS (2.5 kpc)

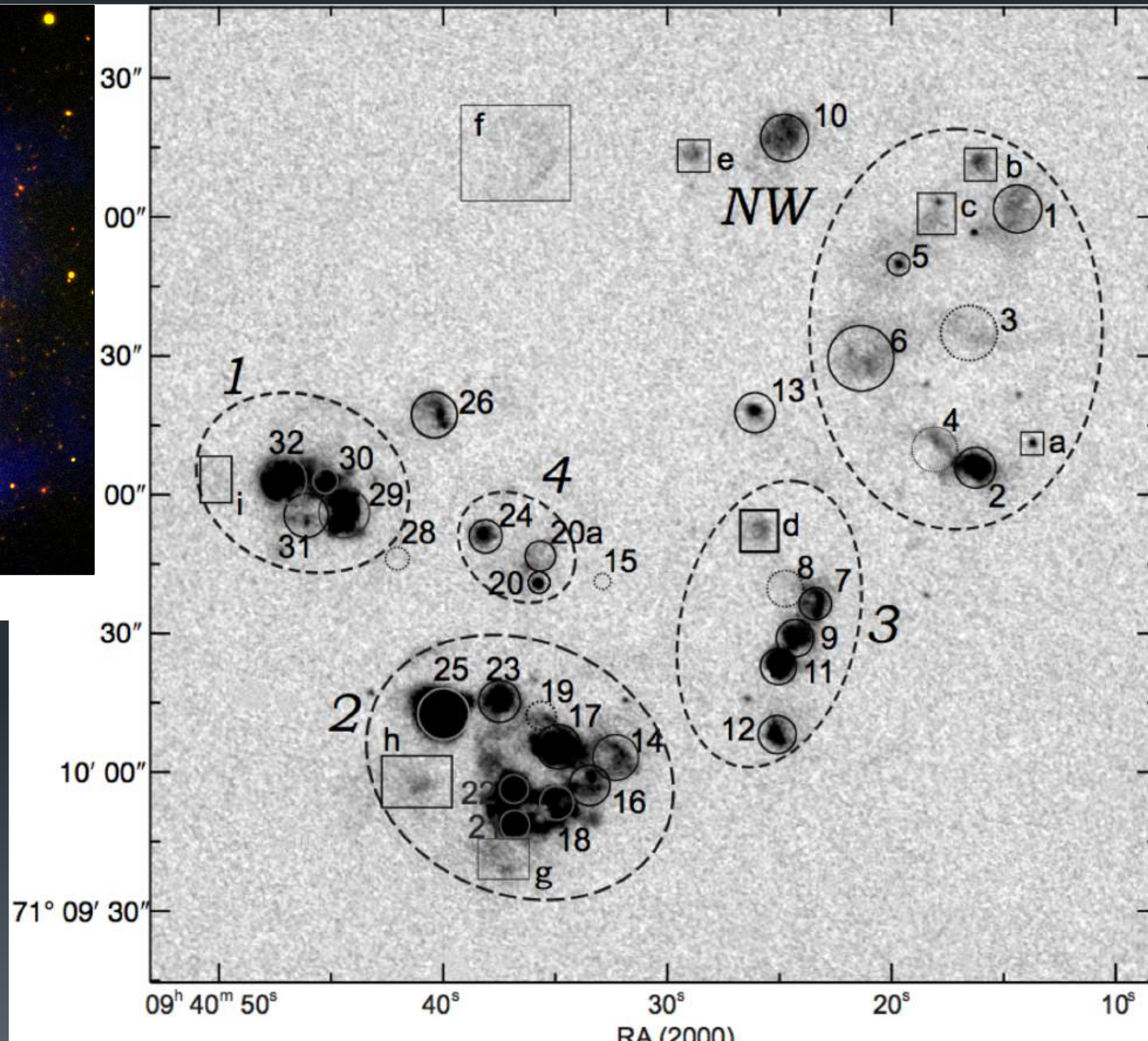


Star formation is observed (almost) only in the rims of the old (150 Myr) HI SGS

Egorov et al. (2017; MNRAS, 464, 1833)

Holmberg I: star-forming complexes in SGS

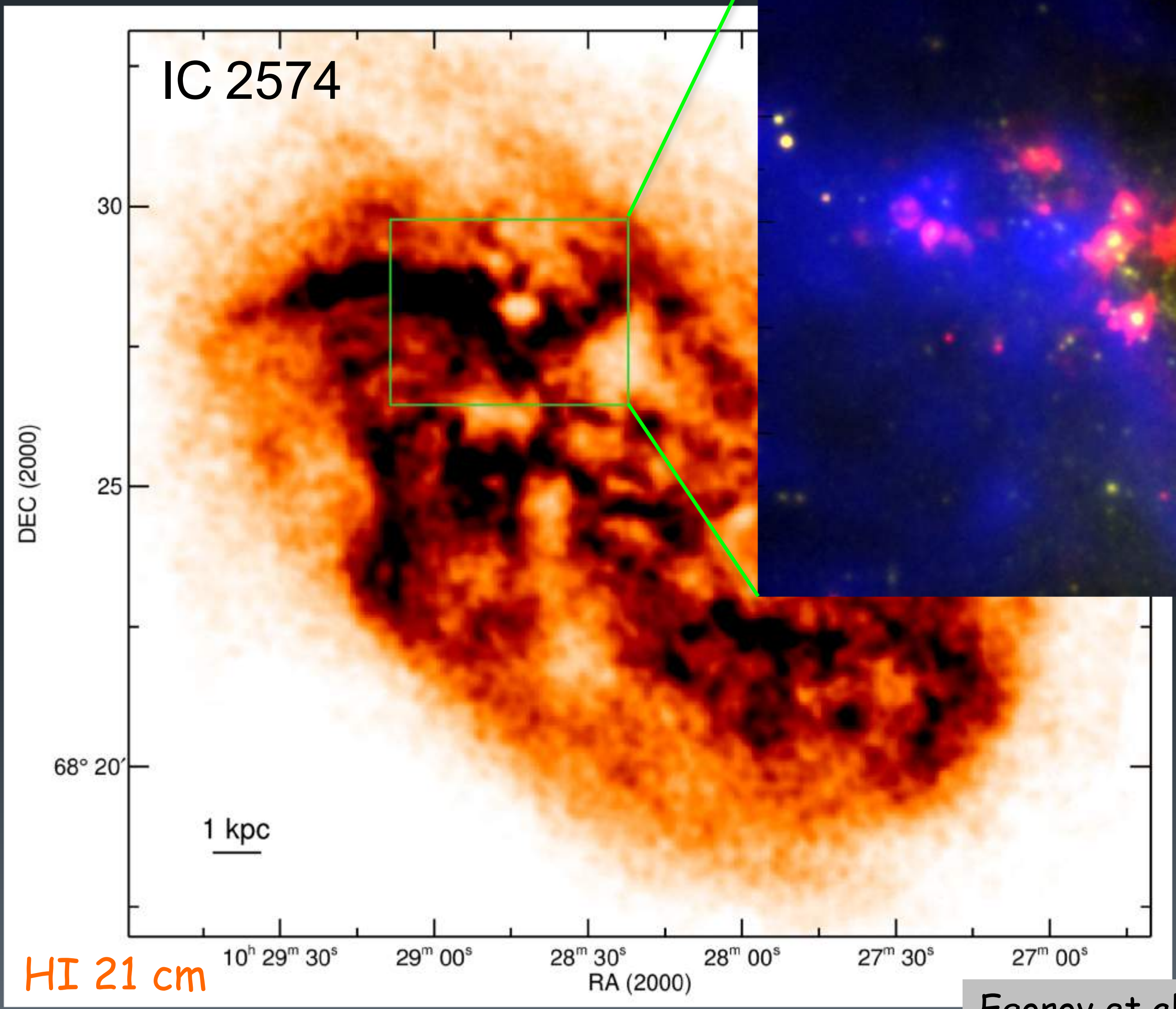


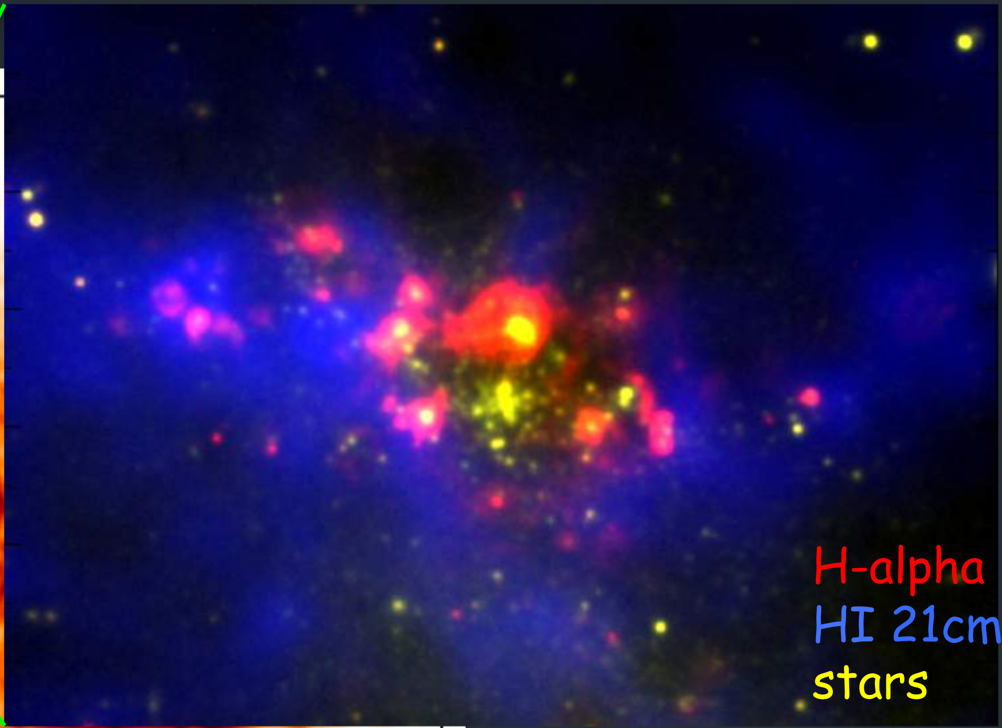


Star formation is localized in the complexes physically-related complexes of HII regions. Size of these complexes – hundreds of pc. Bright HII are tied each other with faint filaments of ionized gas. The complexes are surrounded by HI shells and demonstrate identical kinematical properties

Egorov et al. (2018, MNRAS, 478, 3386)

IC 2574: young HI SGS and star formation in its rims





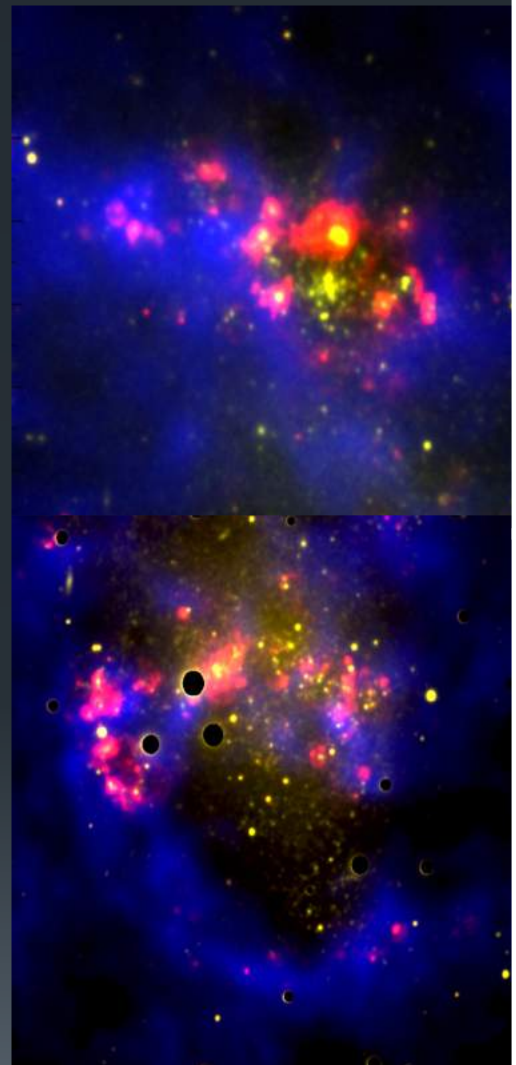
Intensive star formation is localized in the rims of young (14 Myr) HI SGS

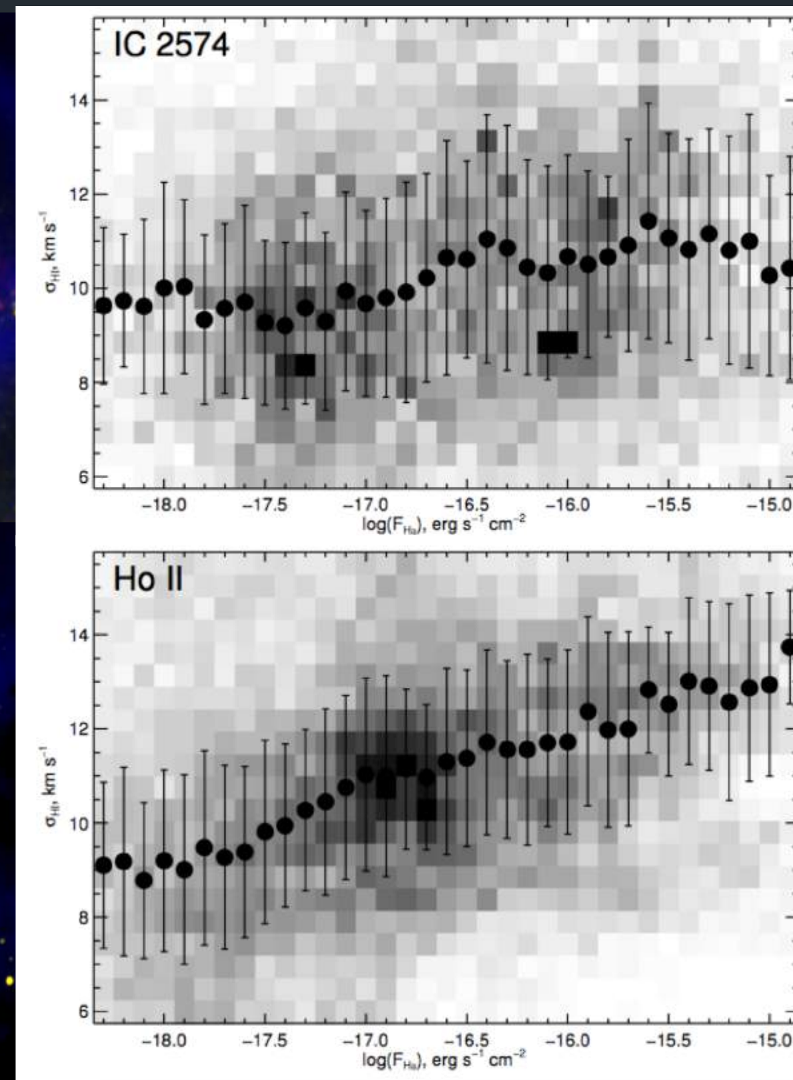
Egorov et al. (2014; MNRAS, 444, 376)

What triggers star formation in SGS?

IC 2574:
- Star formation was propagated from the center of SGS
- Turbulence of ISM doesn’t correlates with ΣSFR

Holmberg II:
- HI clearly correlates with ΣSFR
- Probably, current star formation was triggered by SGS collision HI



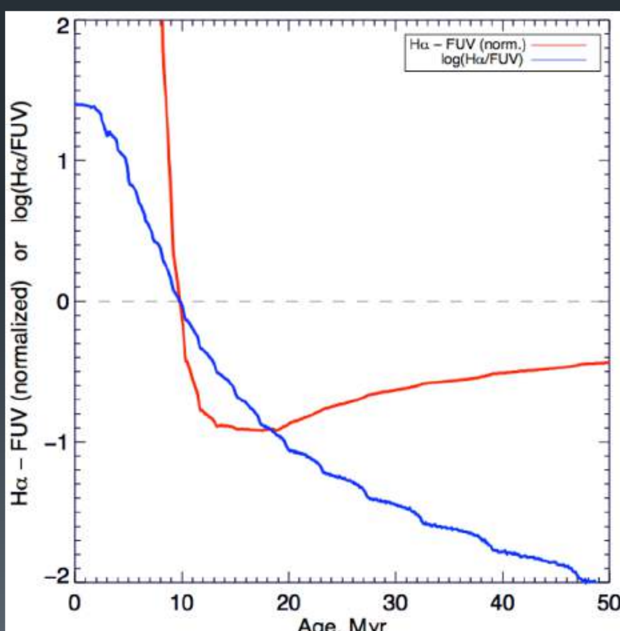


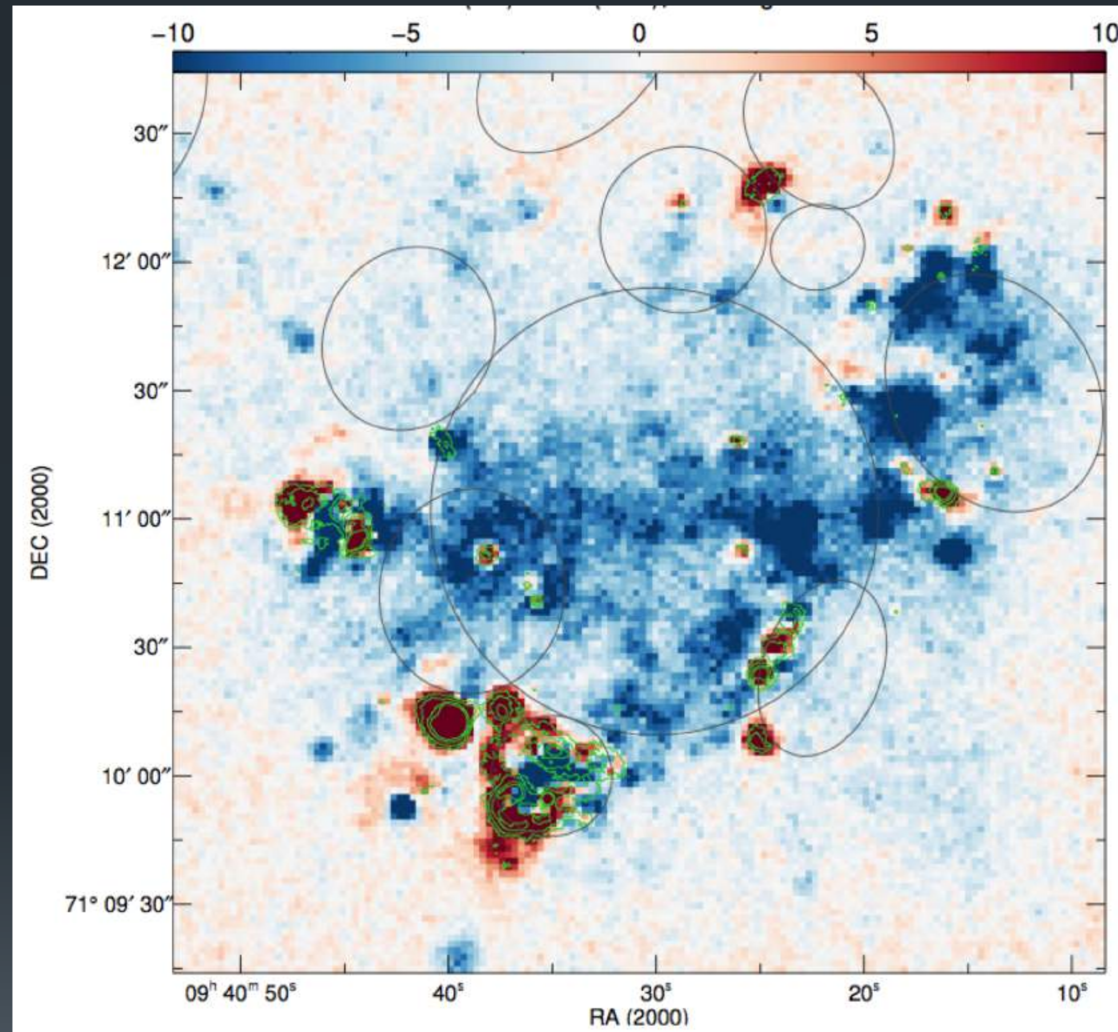
Egorov et al. (2017; MNRAS, 464, 1833)

Propagation of star formation in galaxies

Both FUV and H-alpha are indicators of star formation, but on different timescales: H-alpha observed on the scale of ~10 Myr, while FUV - ~100 Myr.

Starting from ~9 Myr FUV became brighter than H-alpha. Distribution of the flux difference Halpha – FUV demonstrates the propagating star formation

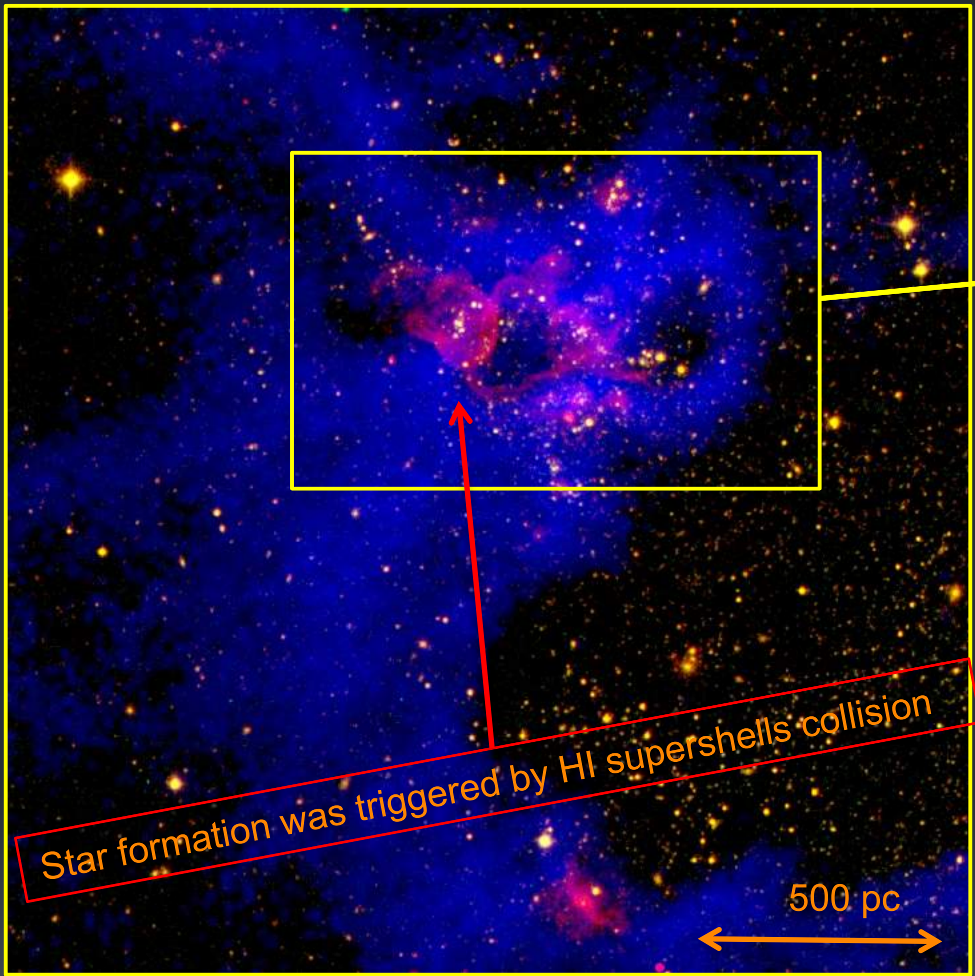


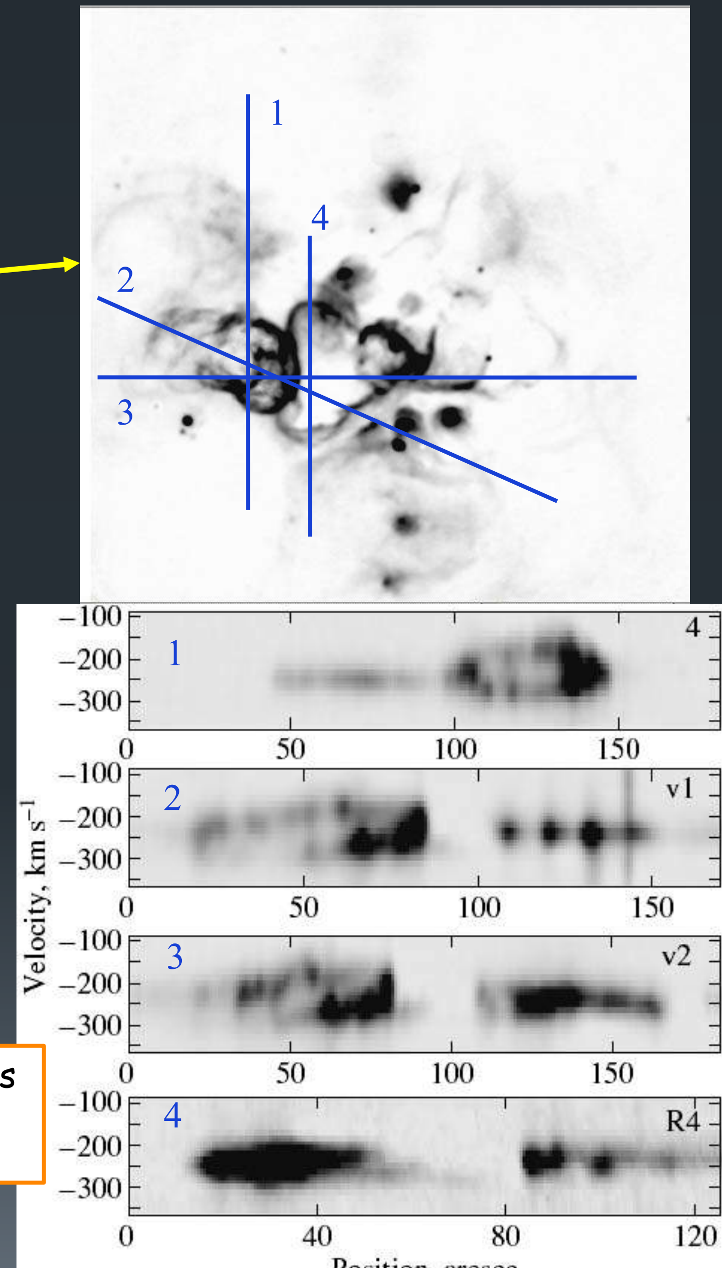


Regions of current and recent star formation

Egorov et al. (2018, MNRAS, 478, 3386)

IC1613: triggered star formation





H-alpha + HI 21 cm + continuum

See also modeling in Chernin et al. (1995); Kawata et al. (2014); Vasiliev et al. (2017)

Age of supershells
HI: 5.3-5.6 Myr,
HII: 0.6-2.2 Myr

Lozinskaya (2002, A&ATr, 21, 223)

Influence of star formation on the evolution of HI SGS

HI kinematics point to the probable gradual disruption of the HI SGS in Holmberg I

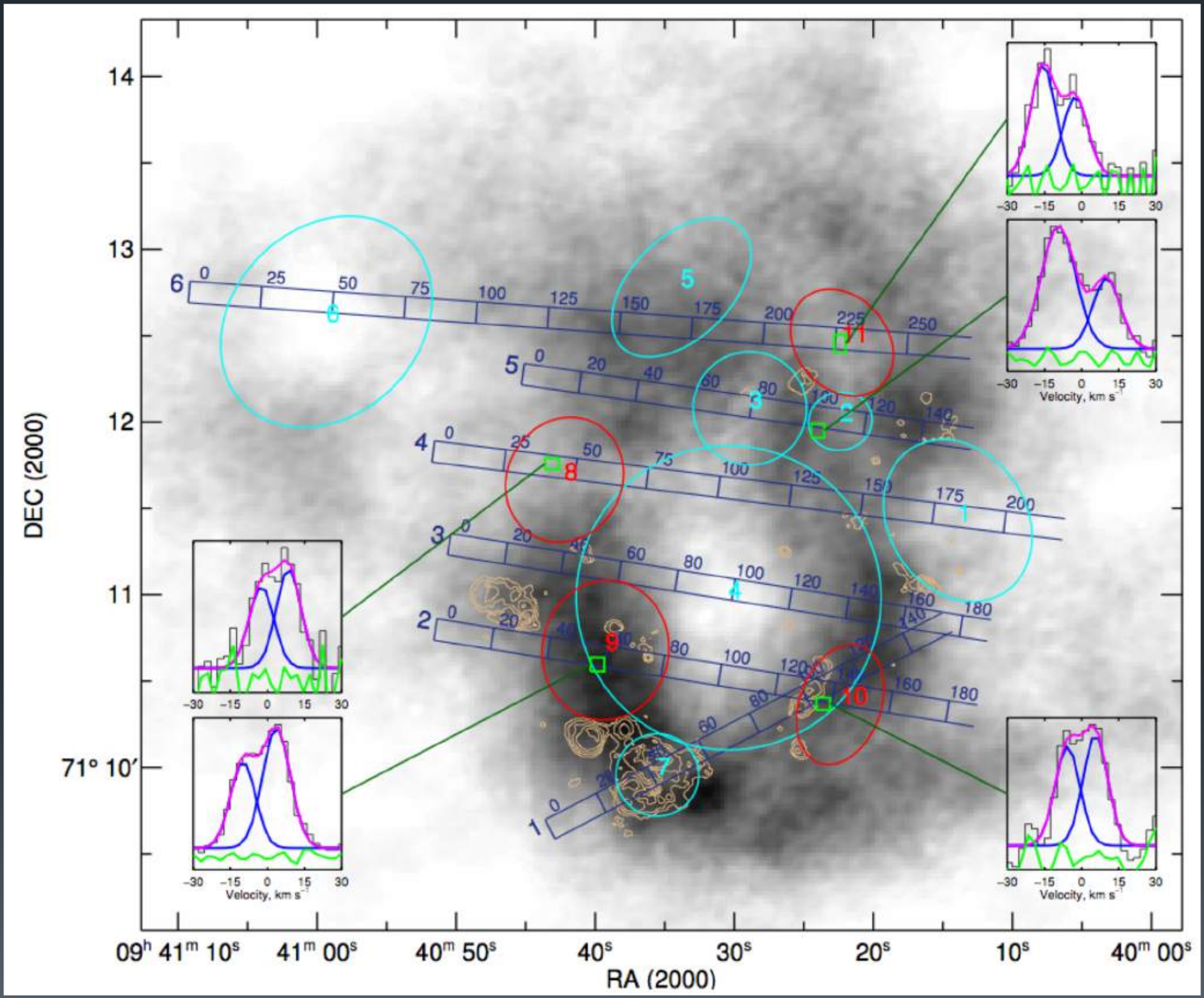


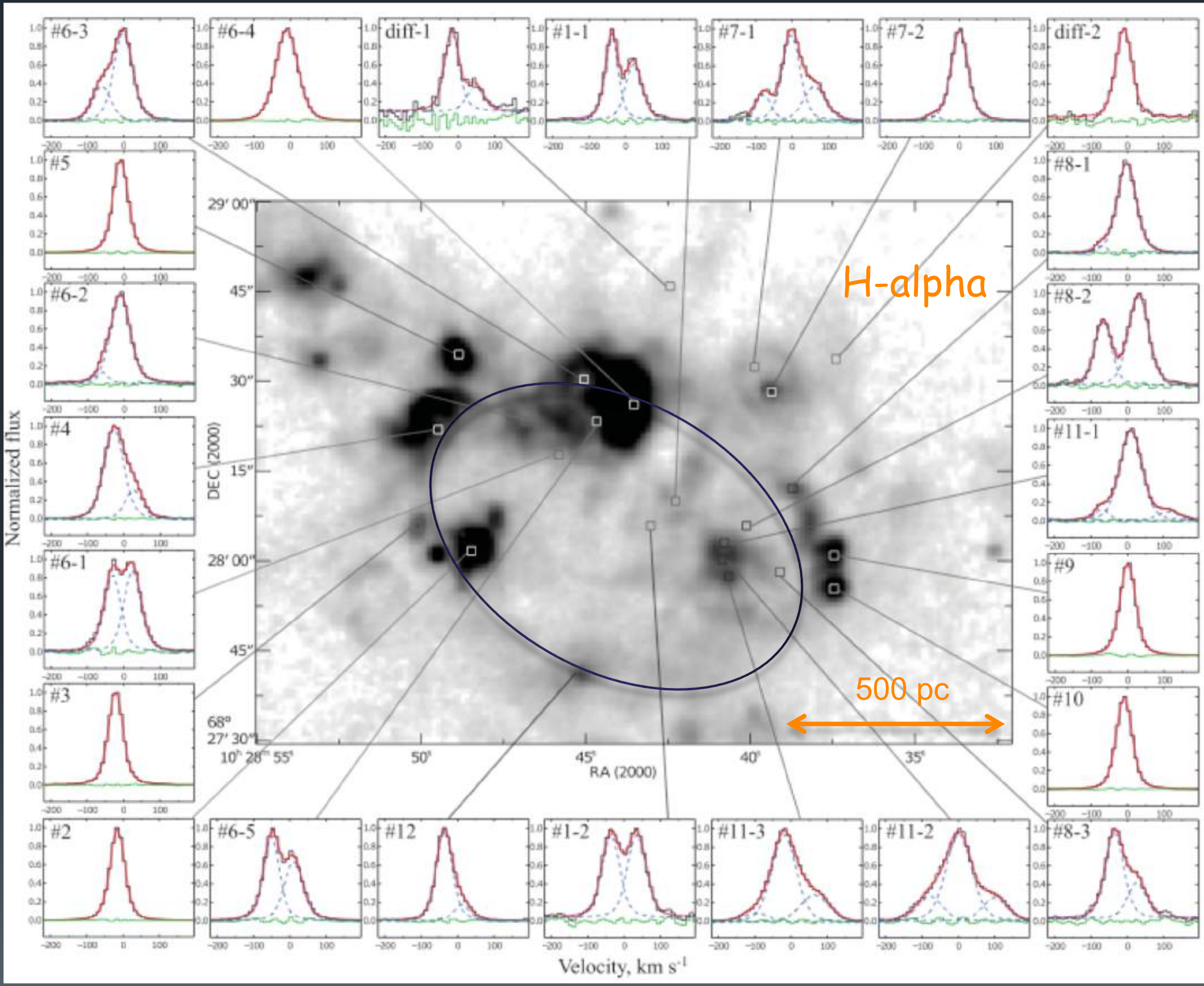
Image - HI 21 cm;
Contours – Halpha;
Ellipses – detected expanding HI supershells

Egorov et al. (2018, MNRAS, 478, 3386)

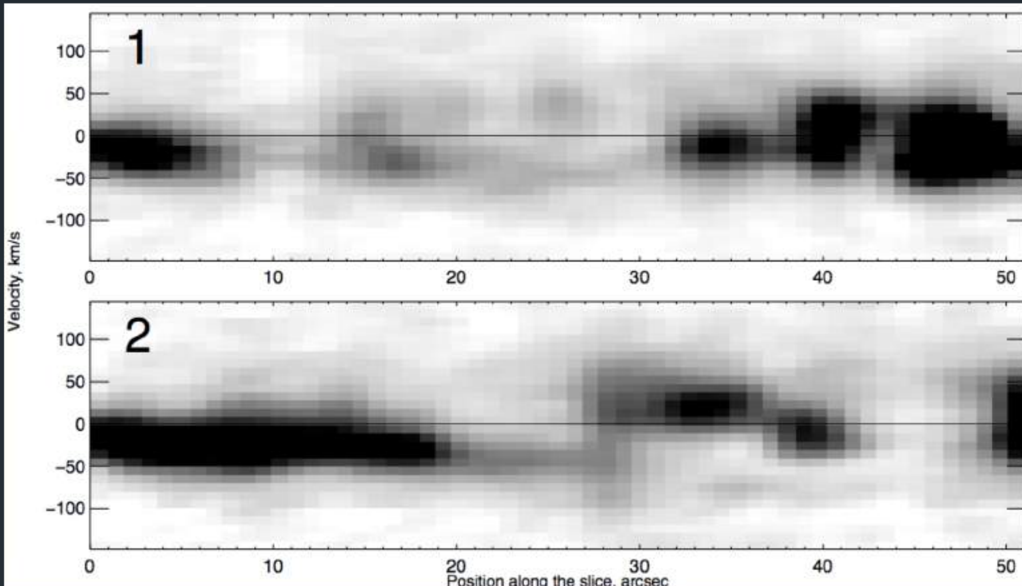
Influence of star formation on the evolution of HI SGS

- Perturbed kinematics of both ionized and neutral gas in the rims of the HI SGS

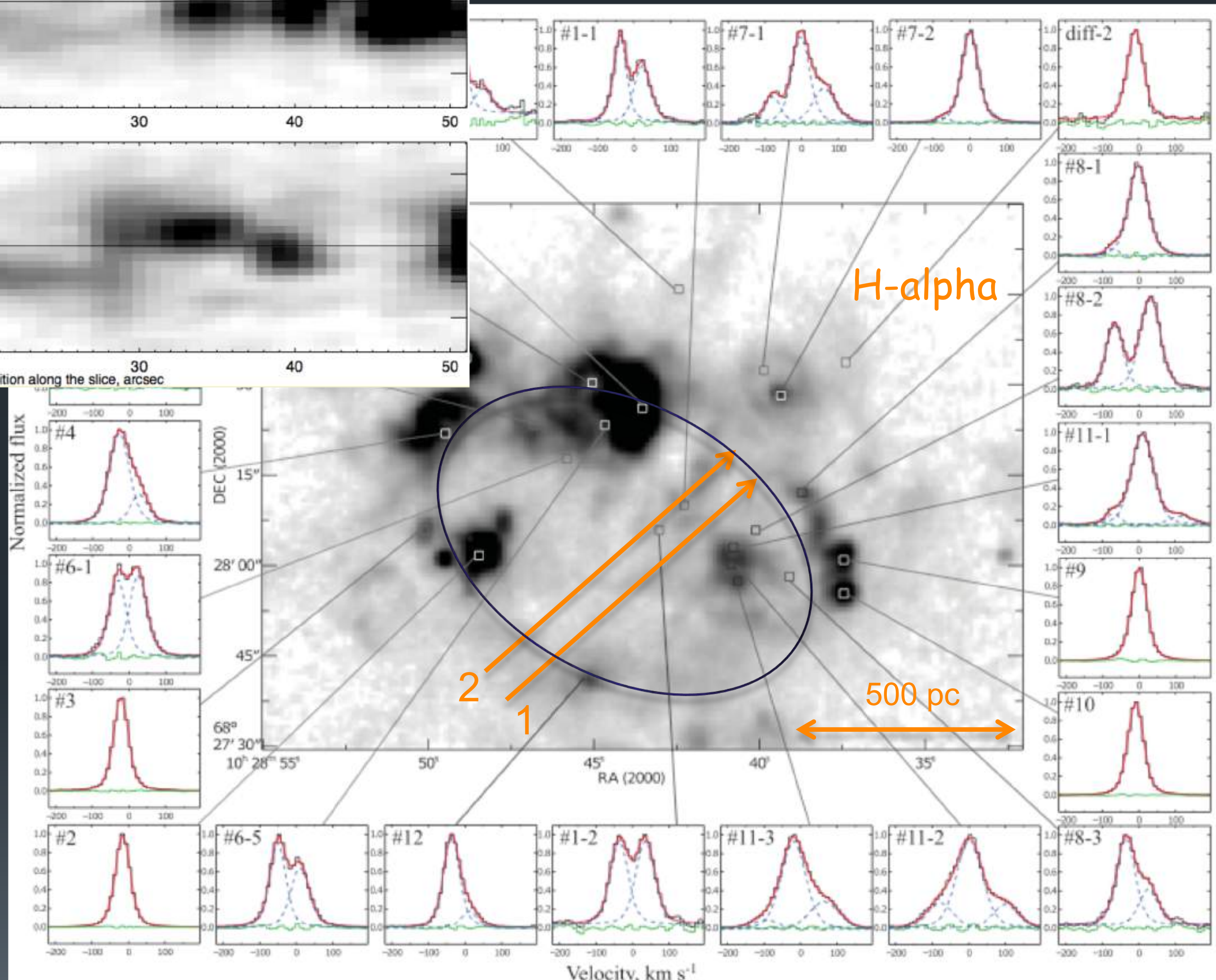
- Faint expanding kpc-sized H-alpha superbubble coincides with the inner wall of the SGS. Shock waves and leakage of hard UV quanta are probably responsible for ionization of the superbubble



Egorov et al. (2014; MNRAS, 444, 376)



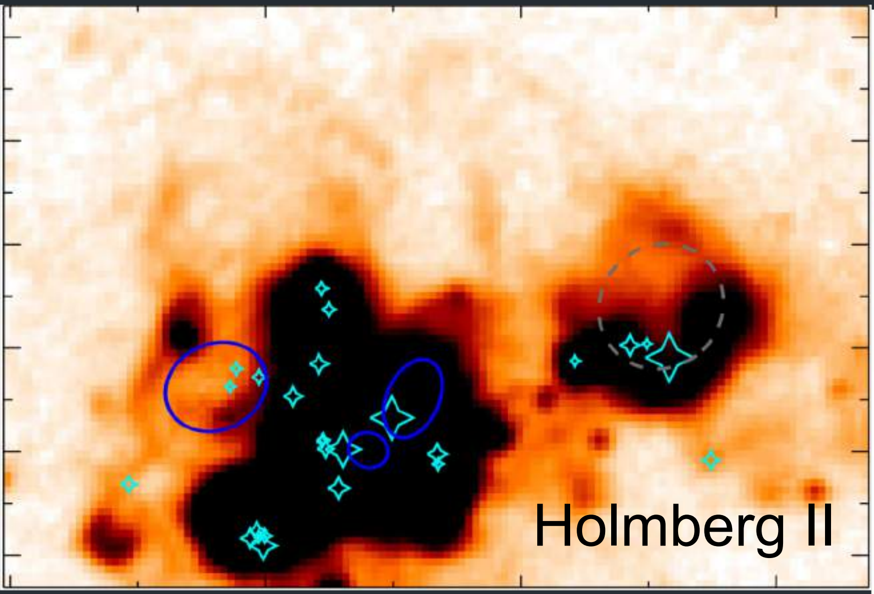
on of HI SGS

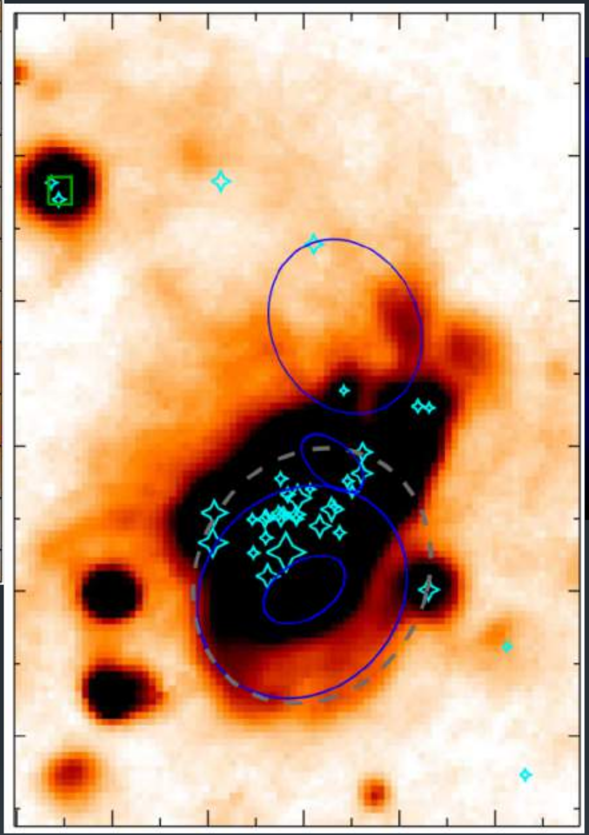


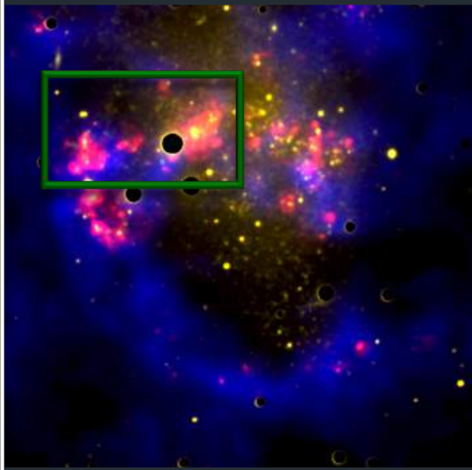
- Faint expanding kpc-sized H-alpha superbubble coincides with the inner wall of the SGS. Shock waves and leakage of hard UV quanta are probably responsible for ionization of the superbubble

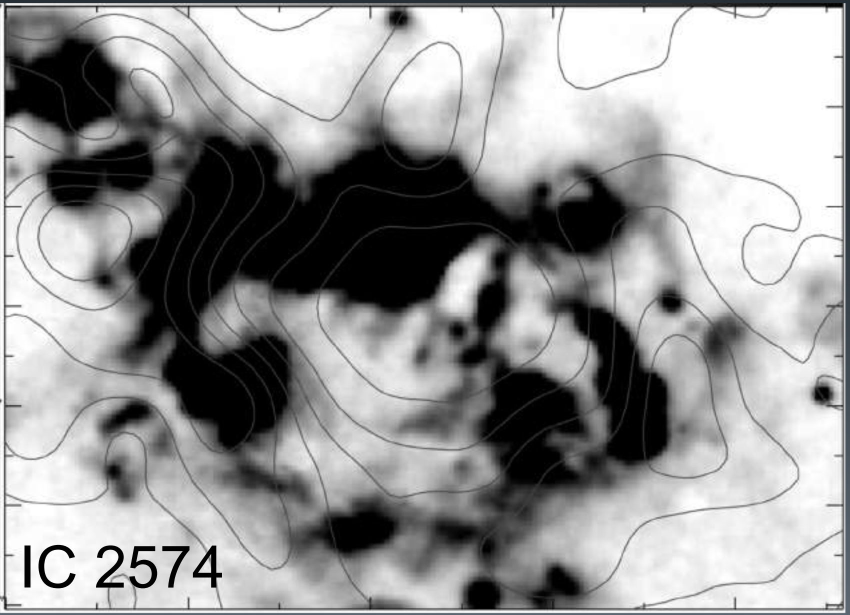
Egorov et al. (2014; MNRAS, 444, 376)

Influence of star formation on the evolution of HI SGS









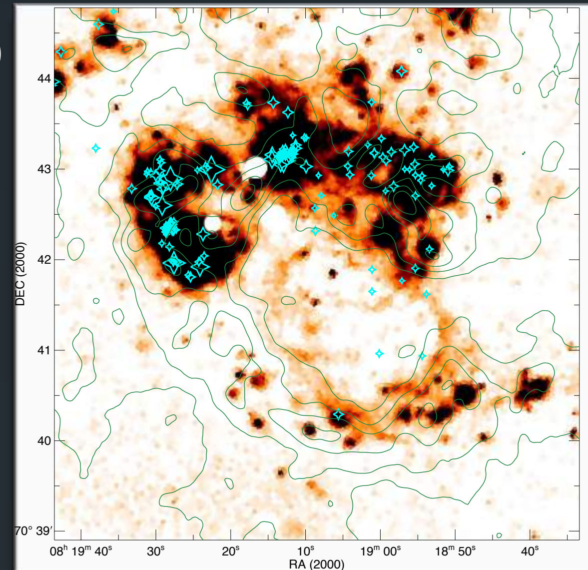
Subsequent destruction and merging of HI SGSs is probable

Egorov et al. (2014, 2017)

«Leakage» of ionizing quanta from the regions of star formation

NGC 2366 (2.5-m telescope of SAI MSU)

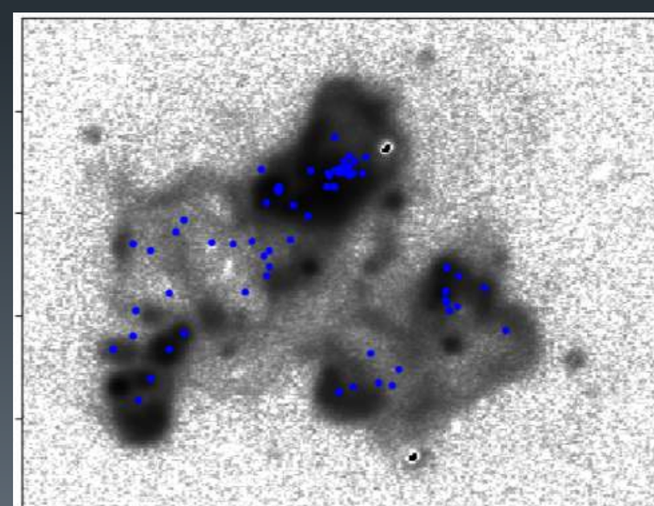
H-alpha + [OIII] + [SII] + continuum



Holmberg I & II:

- Star forming regions are localized in the rims of SGS
- Fraction of «leaking» LyC-quanta ~ 50-60%.

(Egorov et al., 2017, 2018)



DDO 53:
No leaking LyC-quanta detected

IC 2574: energetic balance

Whether the energy of winds from stellar population is sufficient for creation and driving the expansion of observed ionized shells?

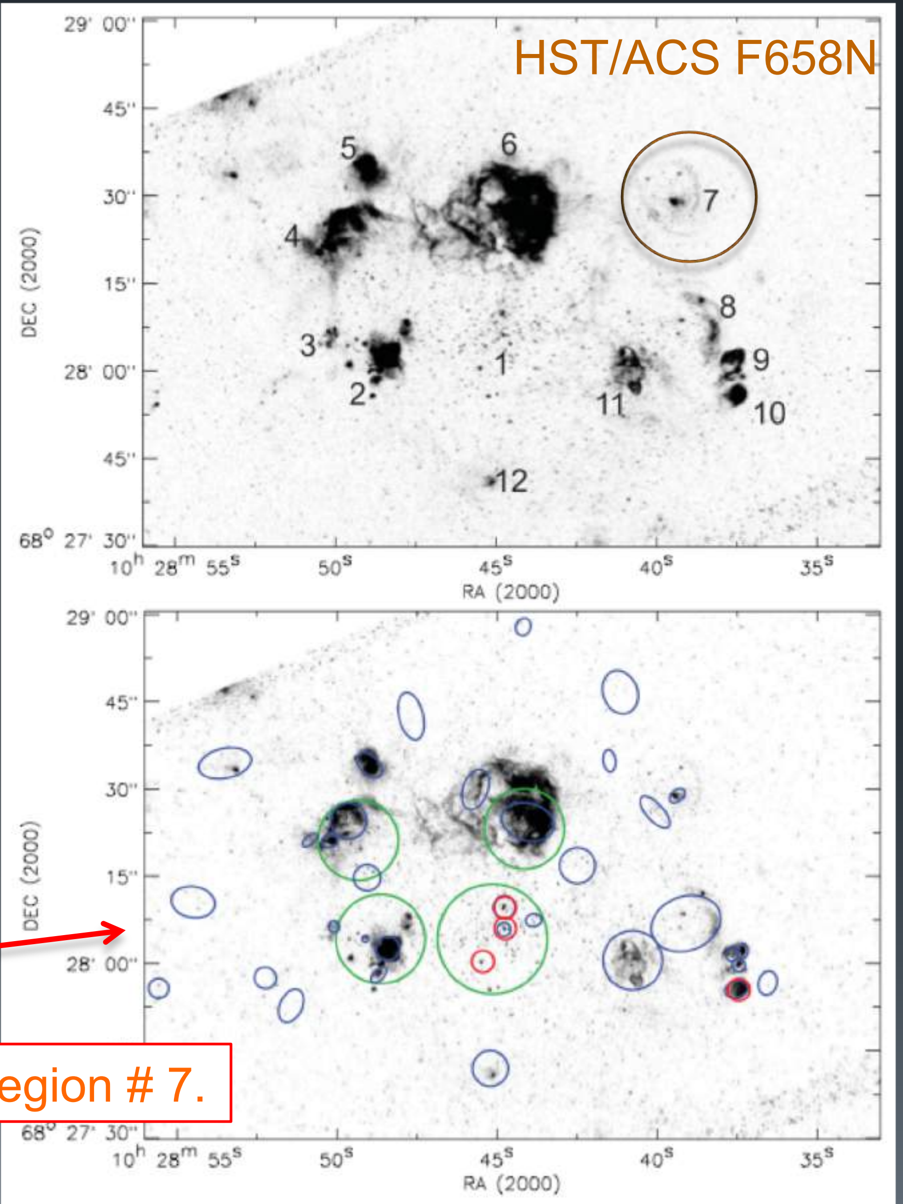
According to Mac Low & McCray (1988):

$$R_s(t) = \left(\frac{125 L_w}{154\pi\rho_0}\right)^{1/5} t^{3/5} = 67 \left(\frac{L_{38}}{n_0}\right)^{1/5} t_6^{3/5} \text{ pc}$$

$$v_{exp}(t) = \frac{0.6 R_s}{t} = 39.4 \left(\frac{L_{38}}{n_0}\right)^{1/5} t_6^{-2/5} \text{ km s}^{-1}.$$

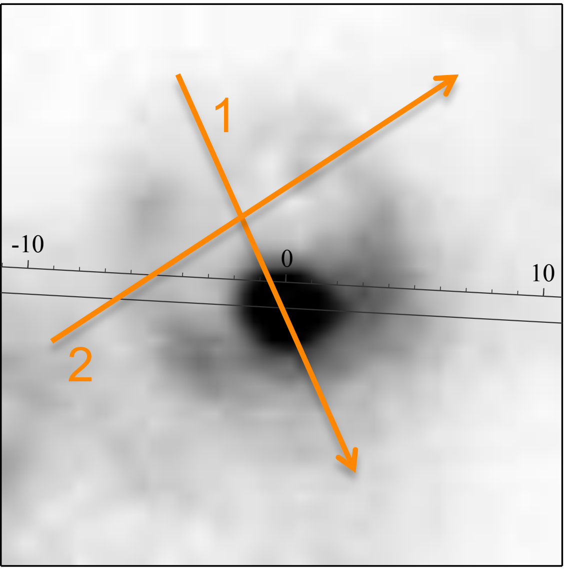
Using our Fabry-Perot observations => obtain kinematic age and necessary energy input. Comparing it with energetics of star clusters from Stewart & Walter (2000) and Yukita & Swartz (2012) =>

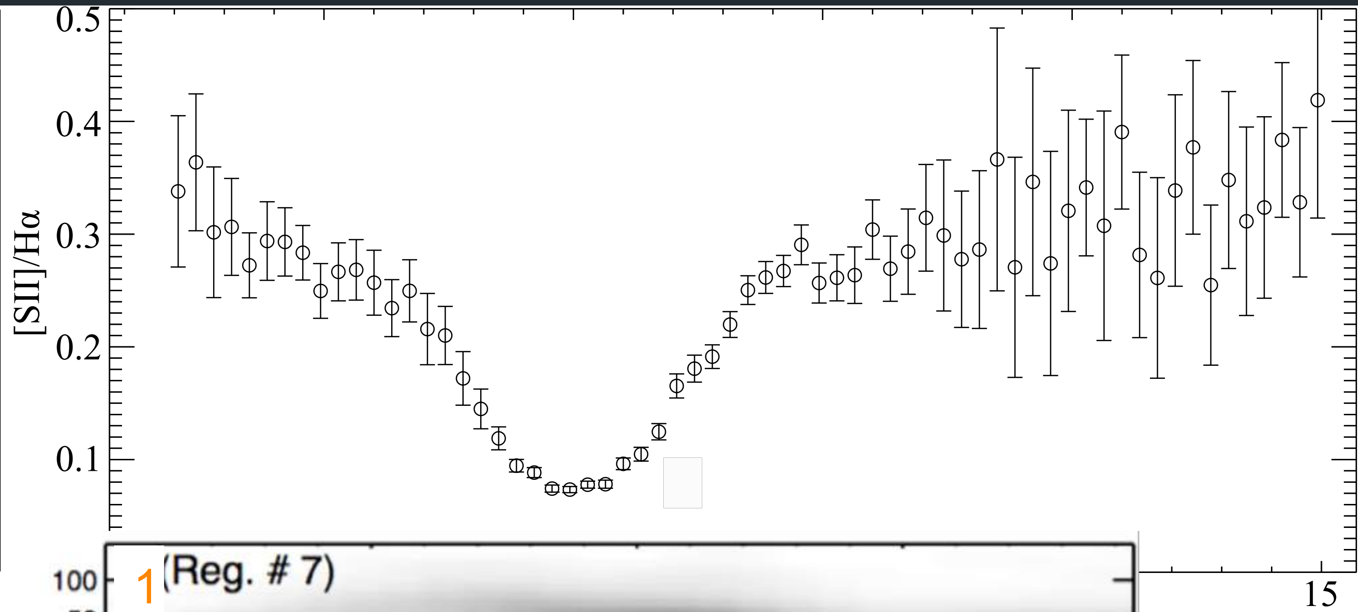
Yes, but the region # 7.

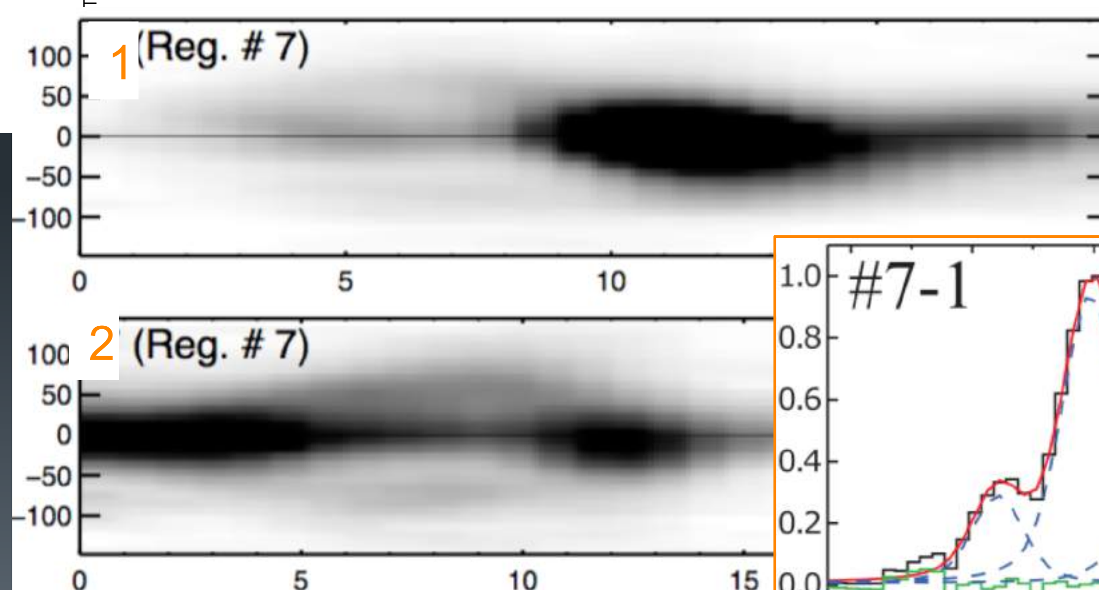


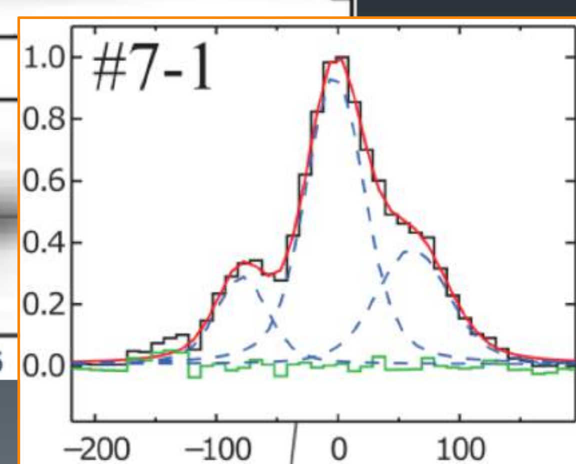
Egorov et al. (2014; MNRAS, 444, 376)

IC 2574: energetic balance









The youngest region in the area

t_{kin} = 1 Myr

V_{exp} = 65 km/s

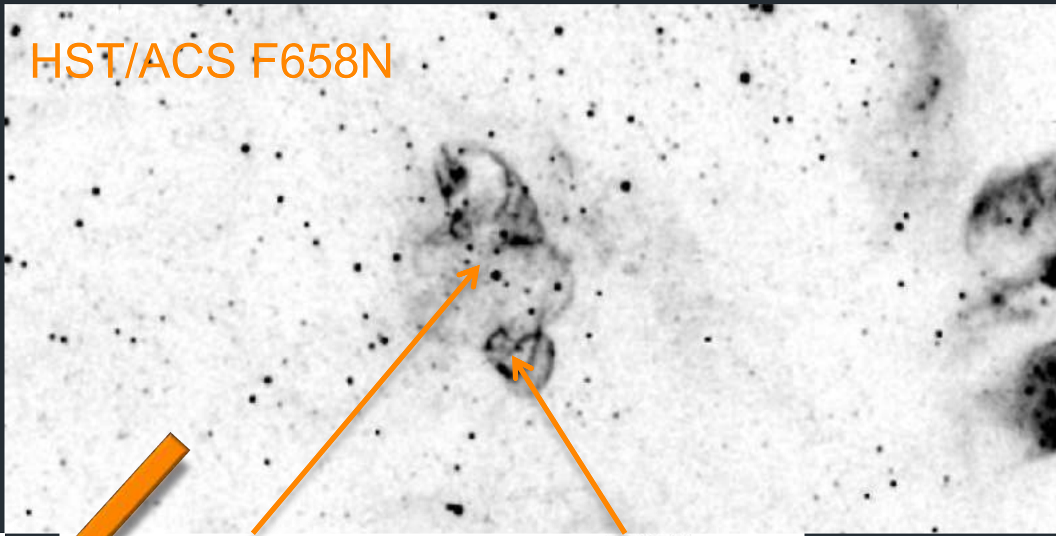
Size = 210 pc

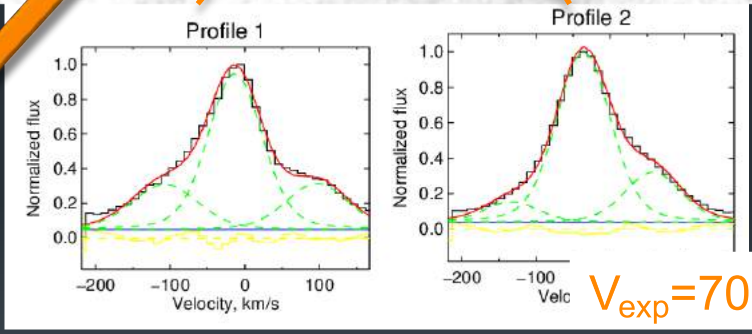
Egorov et al. (2014; MNRAS, 444, 376)

Old SNR in IC 2574

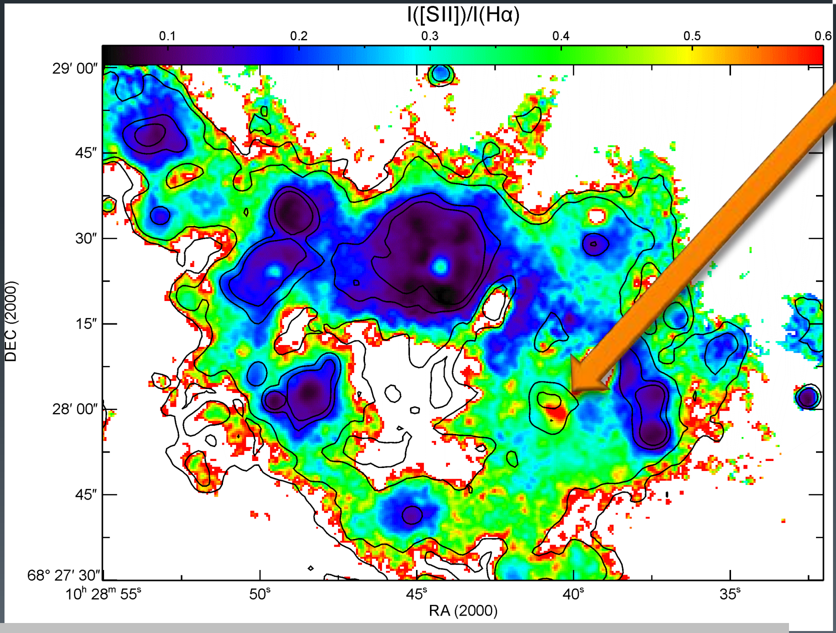
- Walter et al. (1998) proposed this nebula to be a supernova remnant.

- Our study of spectrum and kinematics confirmed this suggestion





V_{exp}=70-80 km/s



Following Sedov (1946) self-similar solution

$$R_s = 13.5(E_{51}/n_0)^{0.2}(t/10^4\ \mathrm{yr})^{0.4}\ \mathrm{(pc)}$$

$$v_{exp} = 0.4 R_s/t$$

Age = 0.3 Myr

Egorov et al. (2014; MNRAS, 444, 376)

Searching for expanding ionized superbubbles

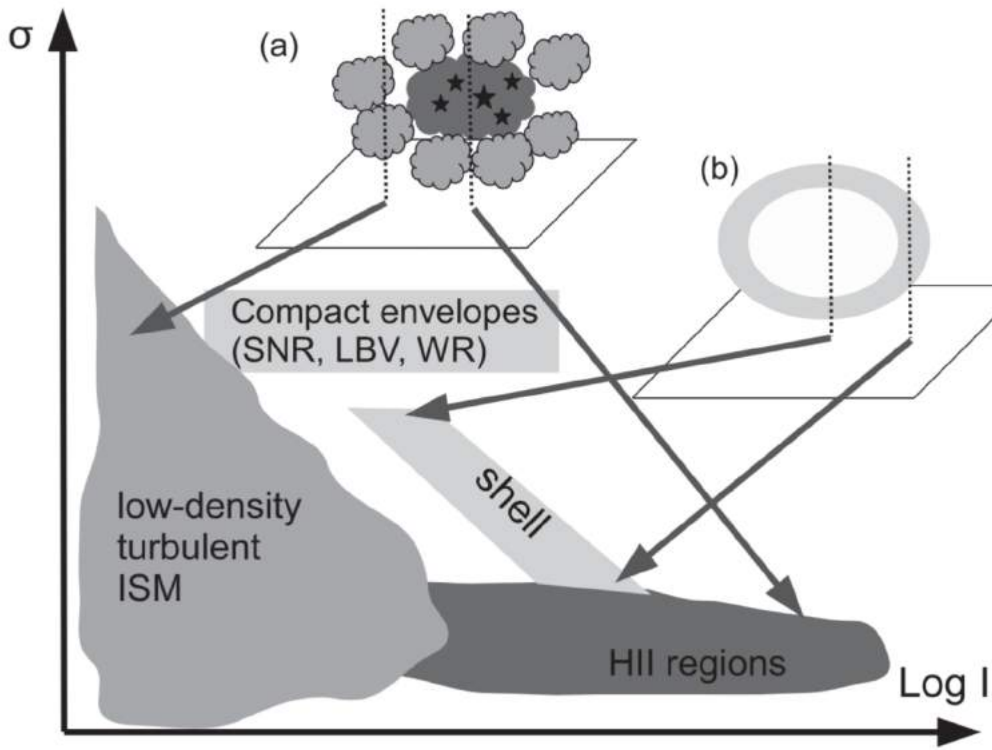
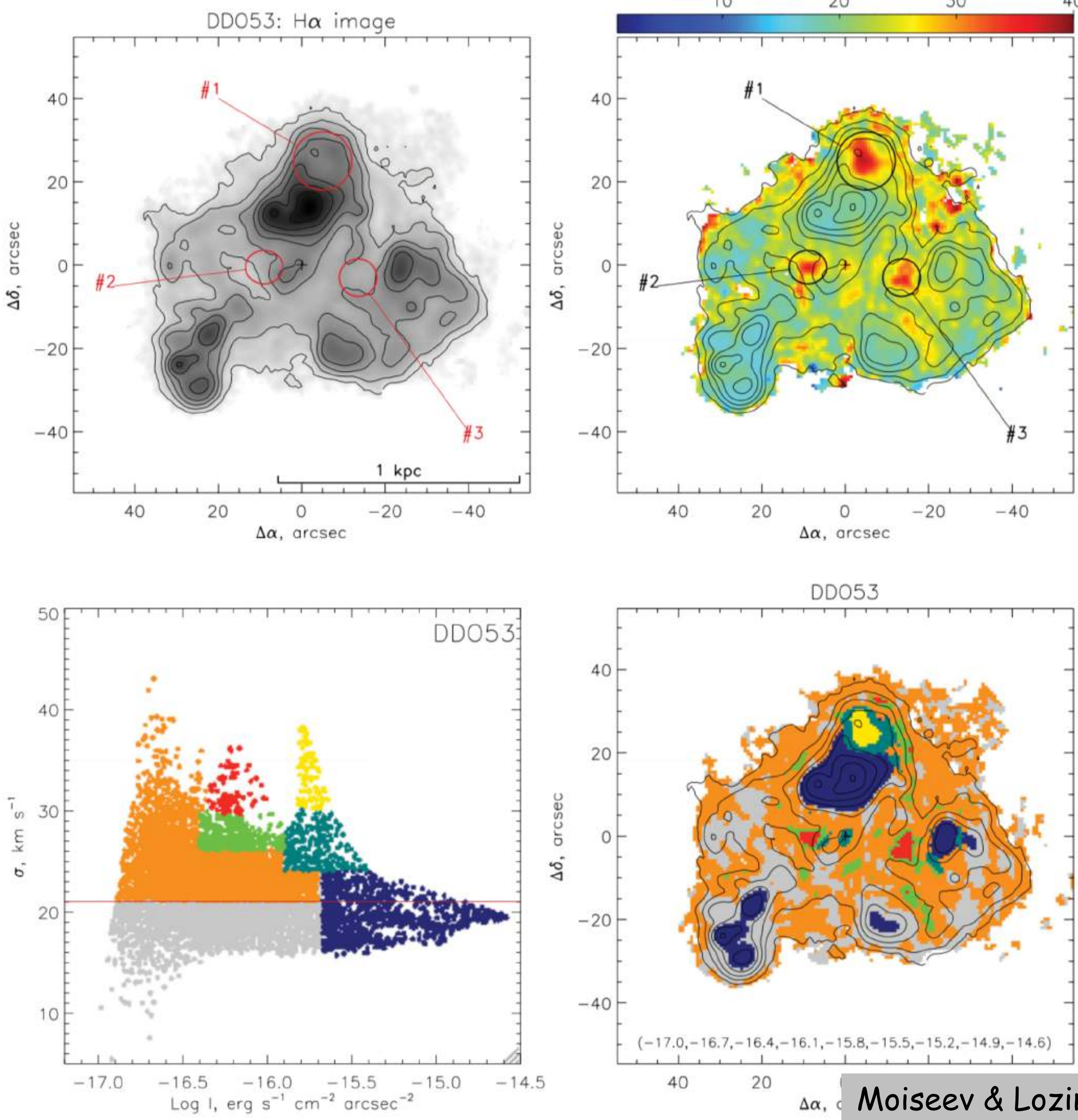
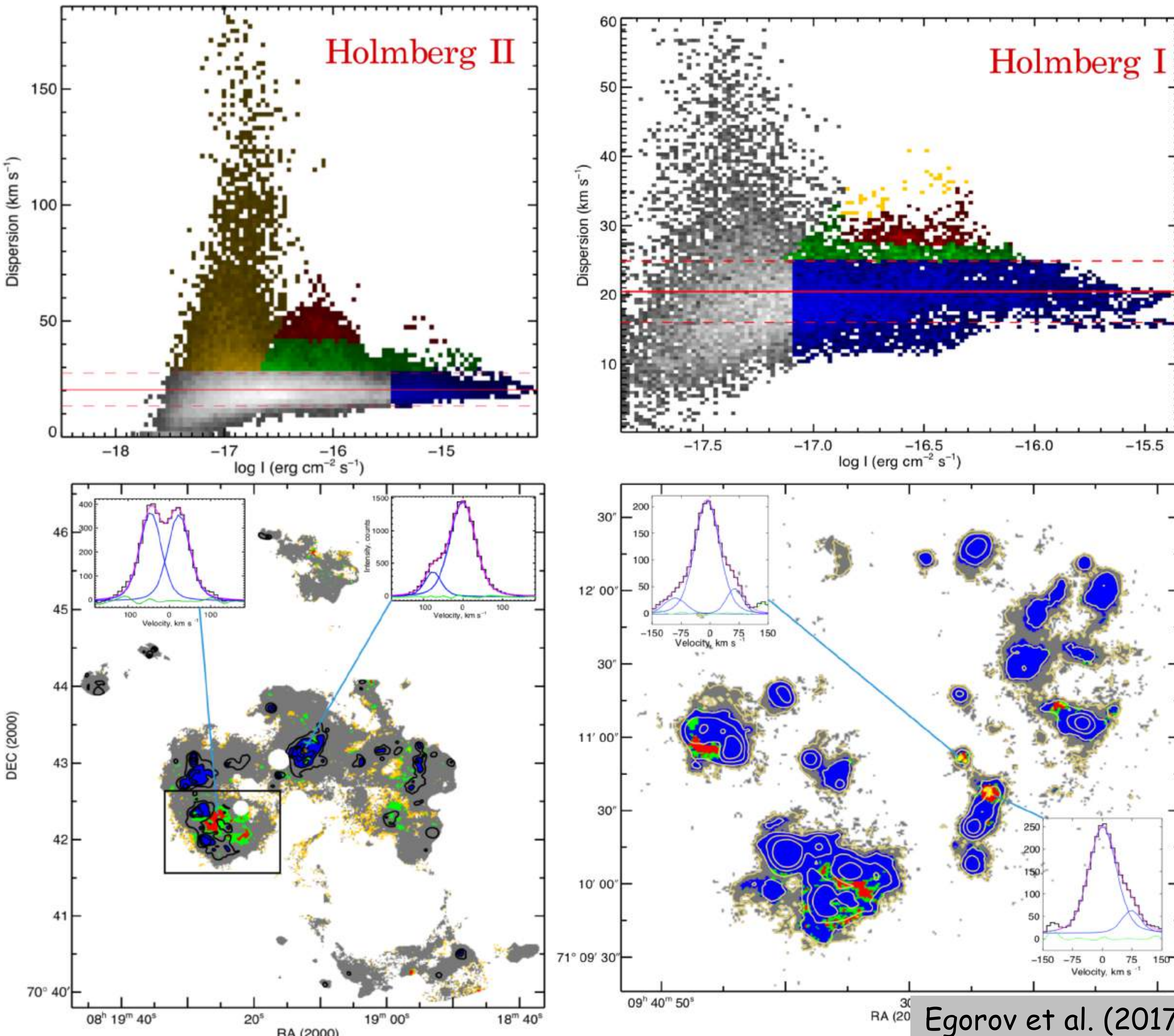


Figure 6. The scheme illustrating the location of points on the $I-\sigma$ diagram. The insets show how we projected on to the sky plane the surface brightness distribution and velocity dispersion (a) from dense H II regions, surrounded by low-density gas with considerable turbulent motions, and (b) from the expanding shell within the model by Muñoz-Tuñón et al. (1996). The dotted line shows the lines of sight passing through different spatial regions.

Moiseev & Lozinskaya (2012)

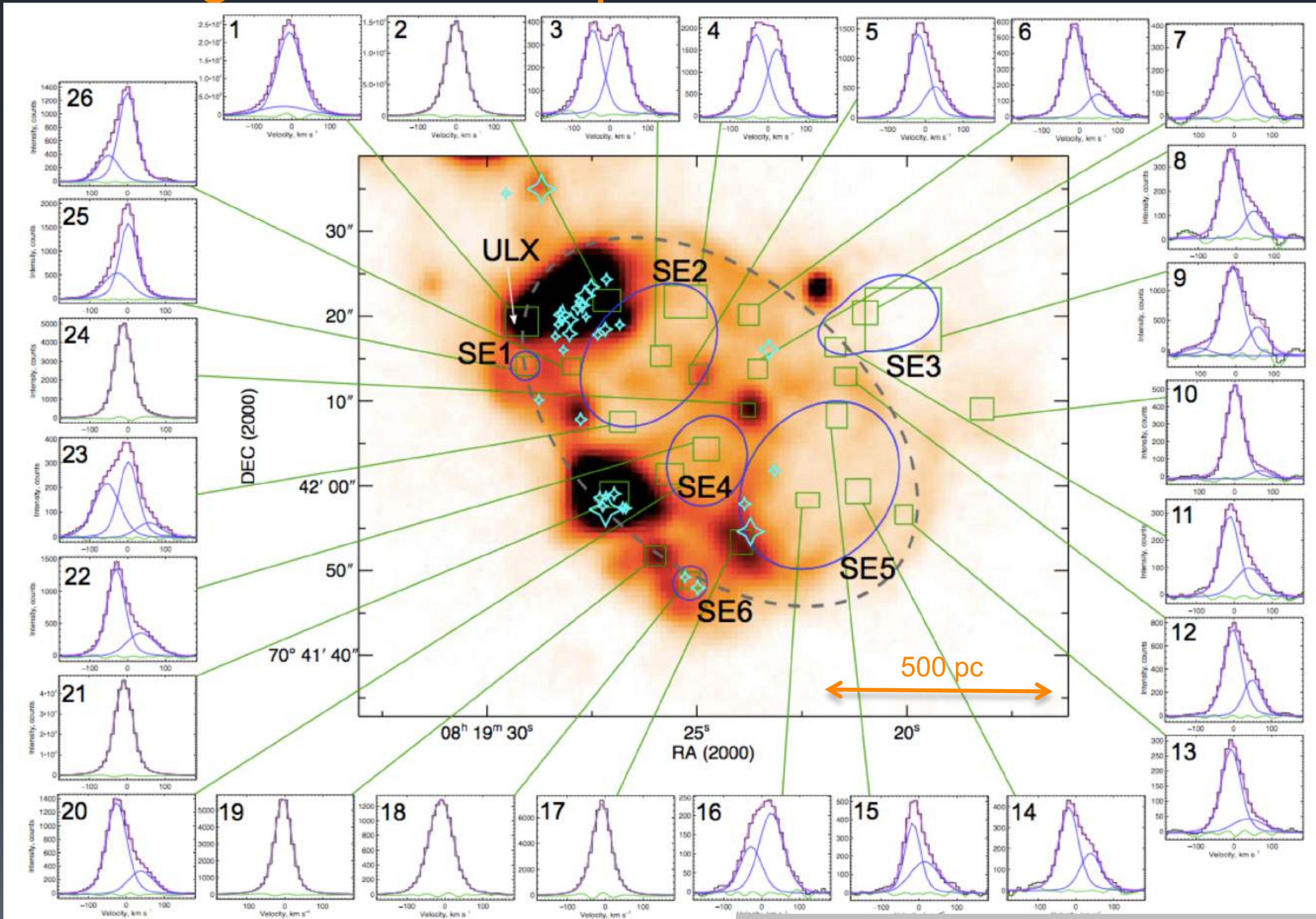


Moiseev & Lozinskaya (2012)



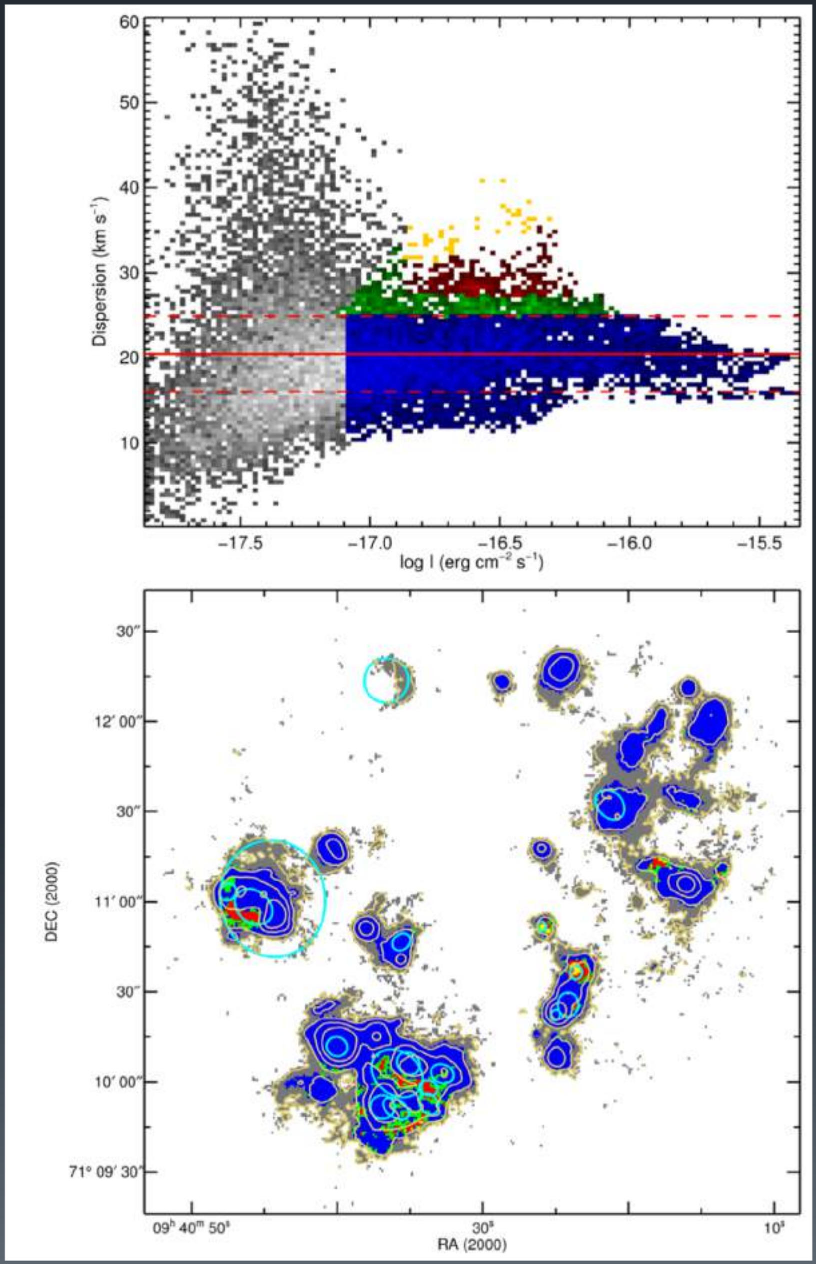
Egorov et al. (2017, 2018)

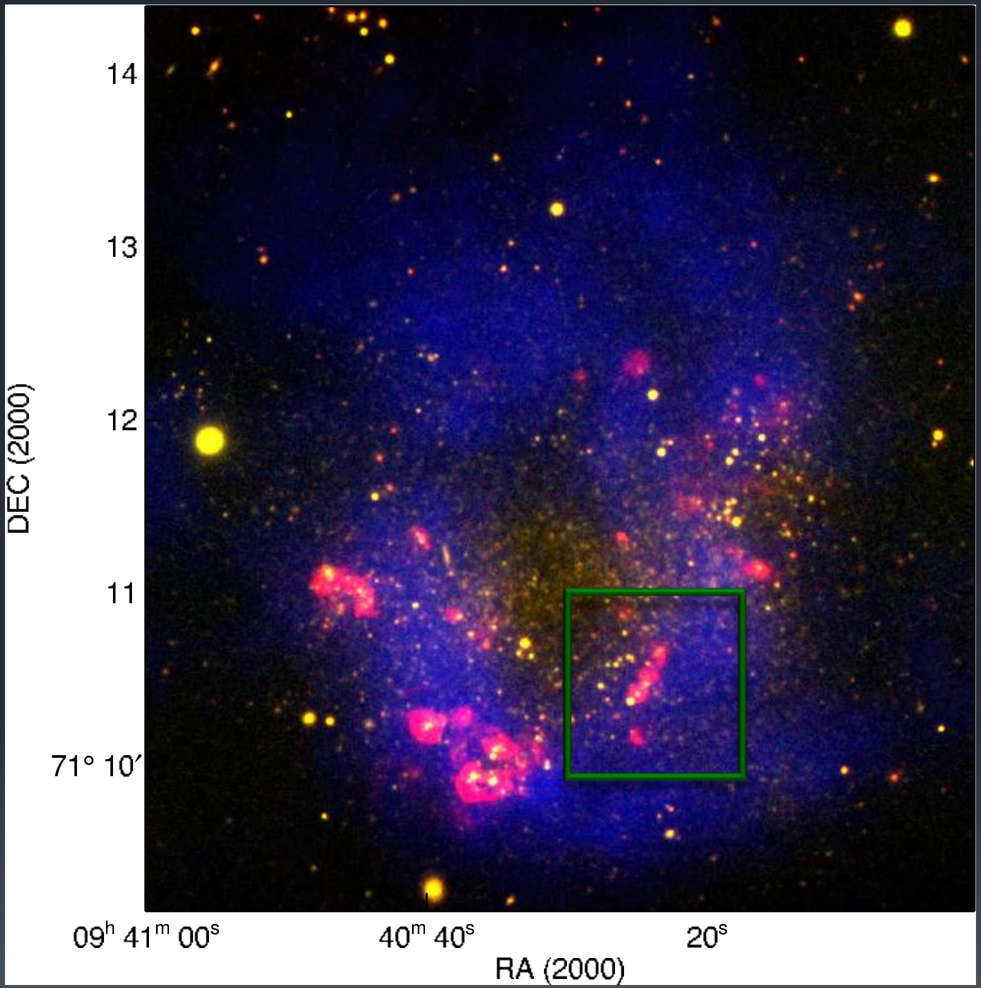
Holmberg II: ionized superbubbles



Egorov et al. (2017; MNRAS, 464, 1833)

Holmberg I: SNRs?





Egorov et al. (2018, MNRAS, 478, 3386)

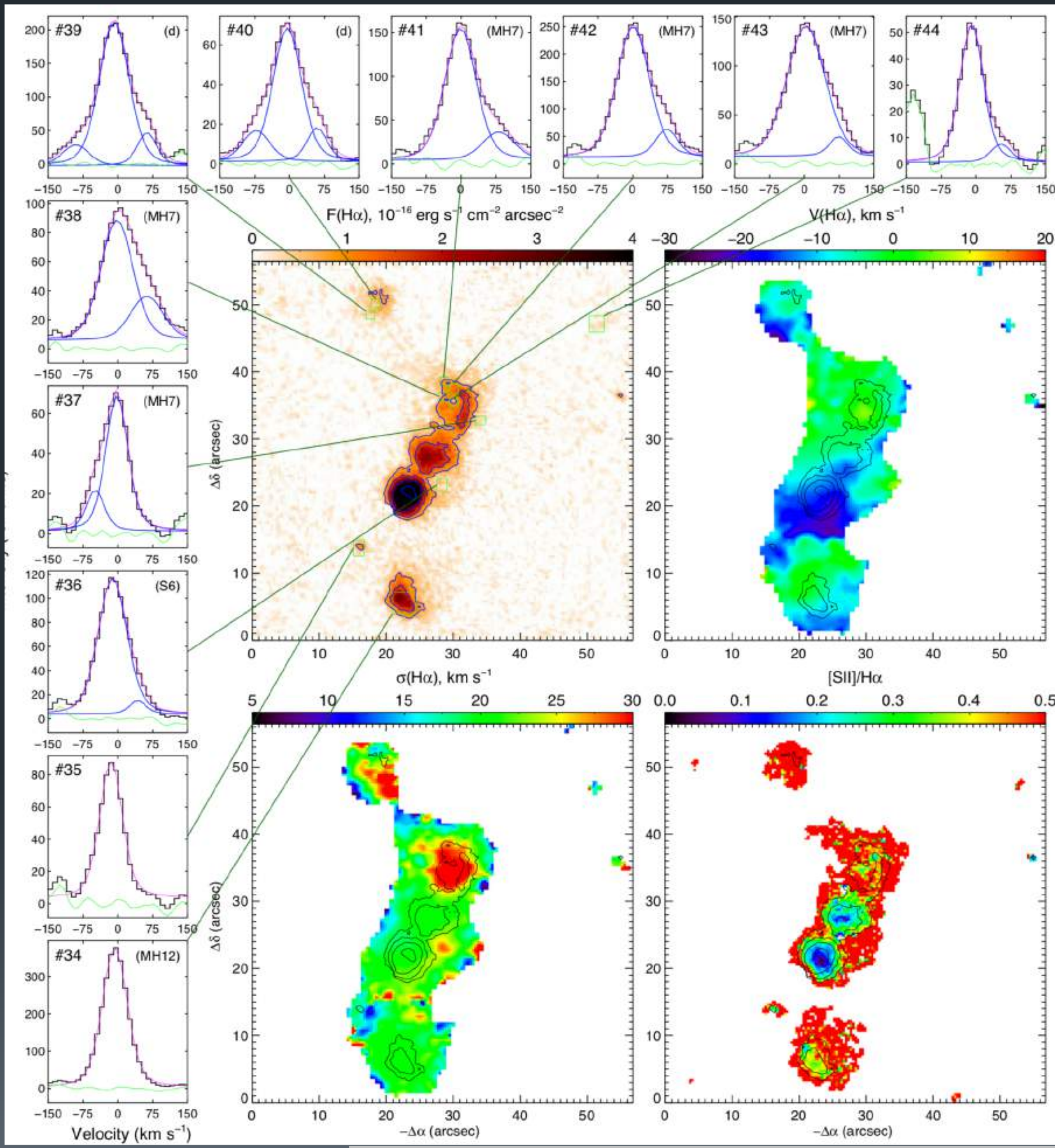
Holmberg I: SNRs?

- High expansion velocities (74 and 85 km/s)
- [SII]/Ha = 0.36 – 0.49
- Kinematic age: 0.2-0.3 Myr

- Low energy of explosion:

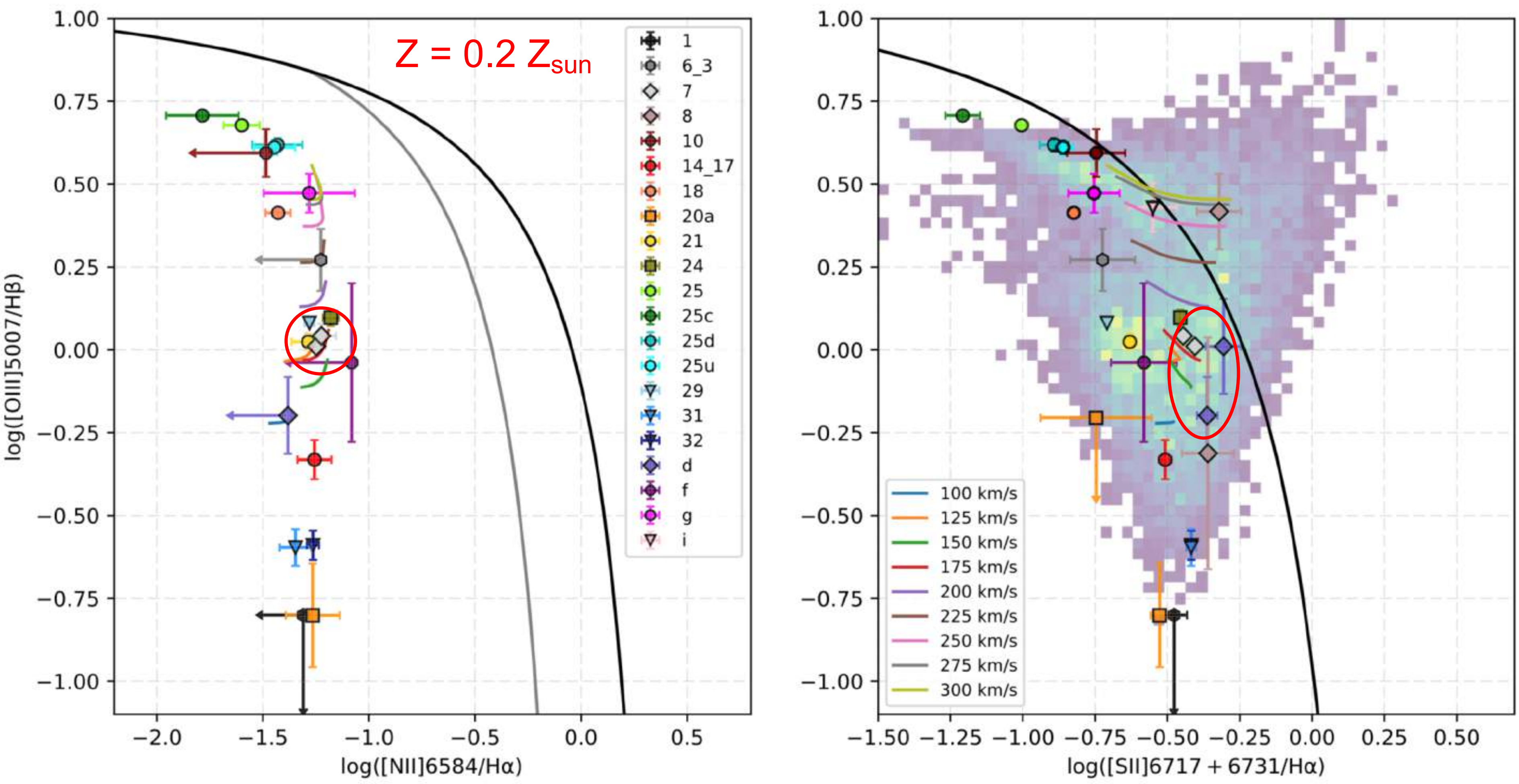
E=0.07-0.25 foe if adiabatic phase;
E=0.4-0.9 foe if post-adiabatic.

High radiation loses? (Sharma et al. 2014)



Egorov et al. (2018, MNRAS, 478, 3386)

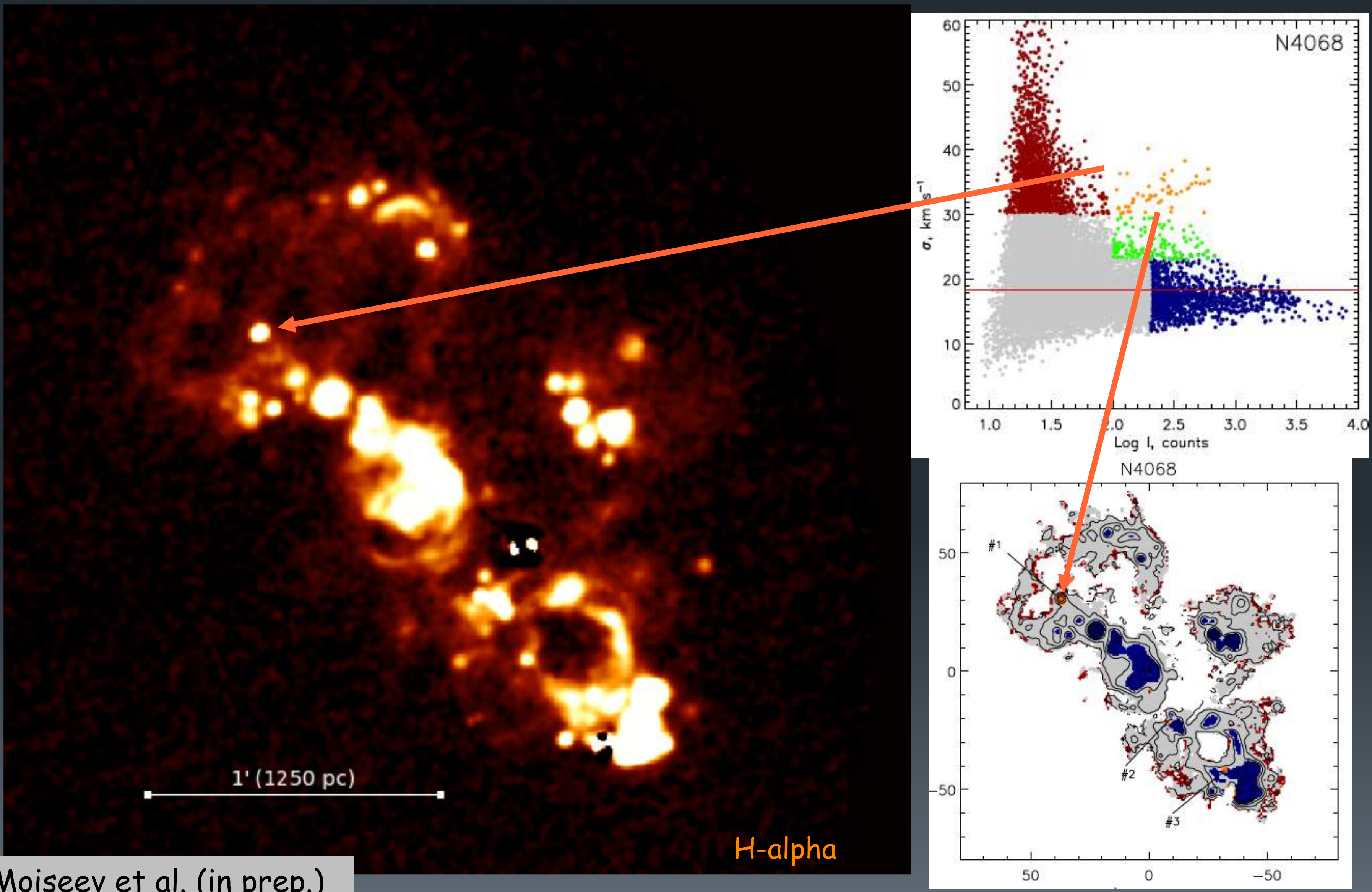
Holmberg I: SNRs?



Generally accepted criteria for SNR identification ([SII]/Ha>0.4) might underestimate a number of SNRs at low metallicity.

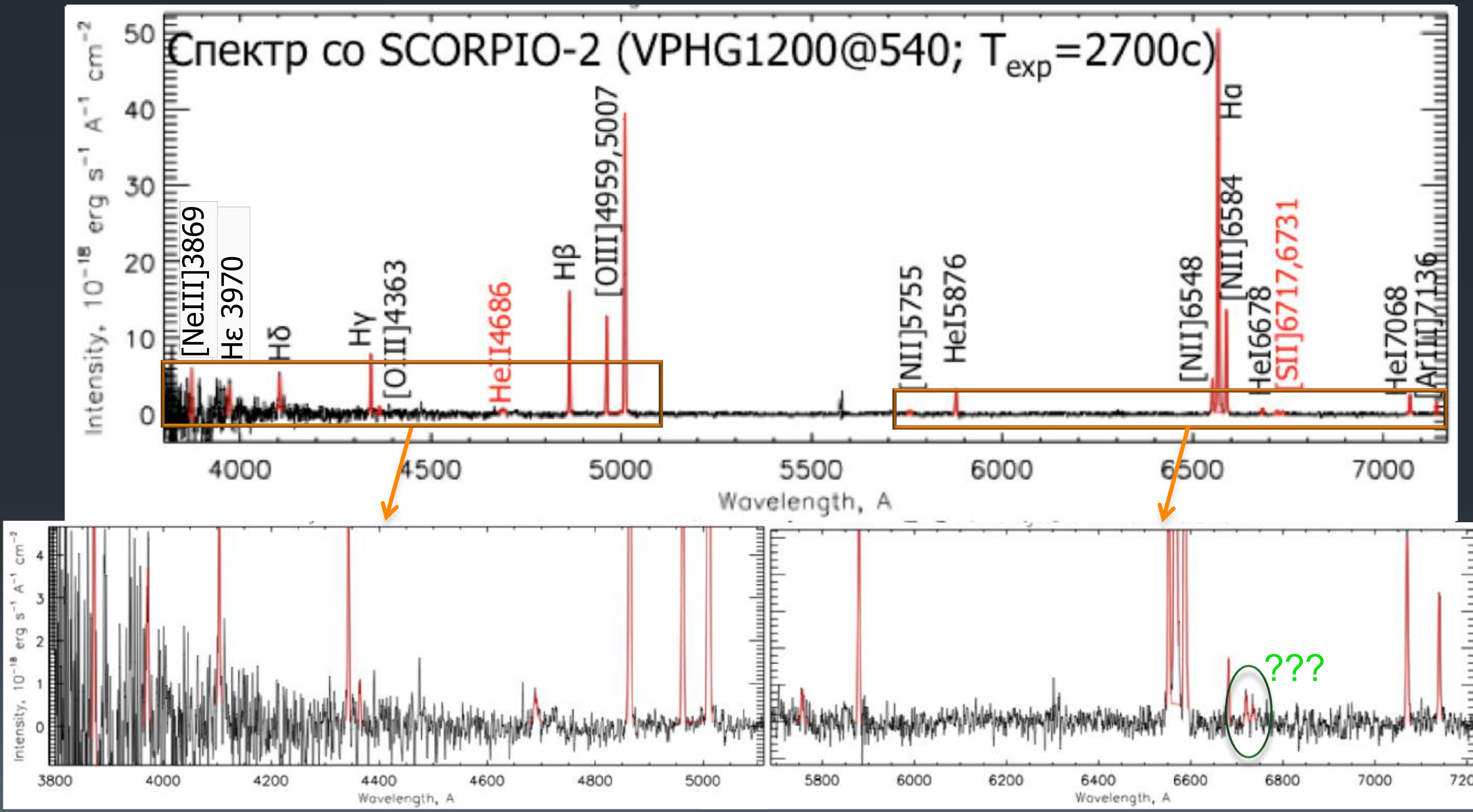
Egorov et al. (2018, MNRAS, 478, 3386)

Peculiar emission object in NGC 4068 (WNL star?)



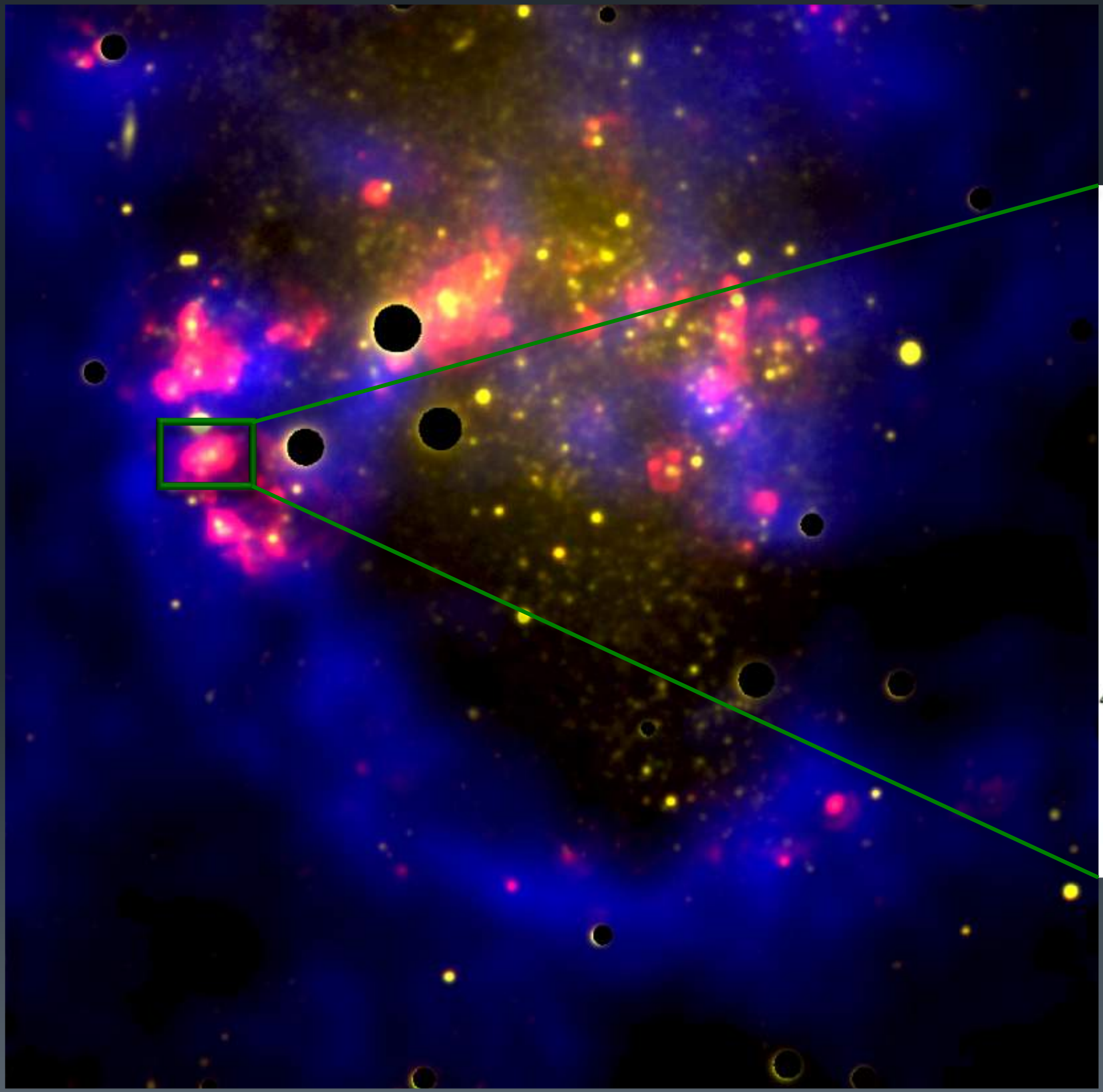
Moiseev et al. (in prep.)

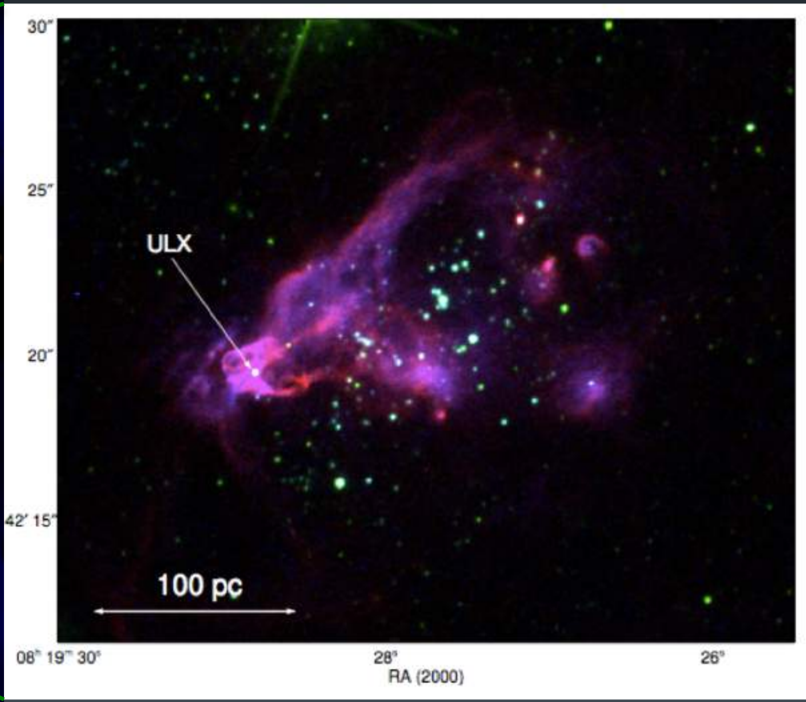
Peculiar emission object in NGC 4068 (WNL star?)



Moiseev, Egorov et al. (in prep.)

Holmberg II: first kinematical evidence of ULX escape from star cluster





ULX = Ultraluminous X-ray source ($L_X \sim 10^{41}$ erg/s)

Egorov et al. (2017; MNRAS, 467, L1)

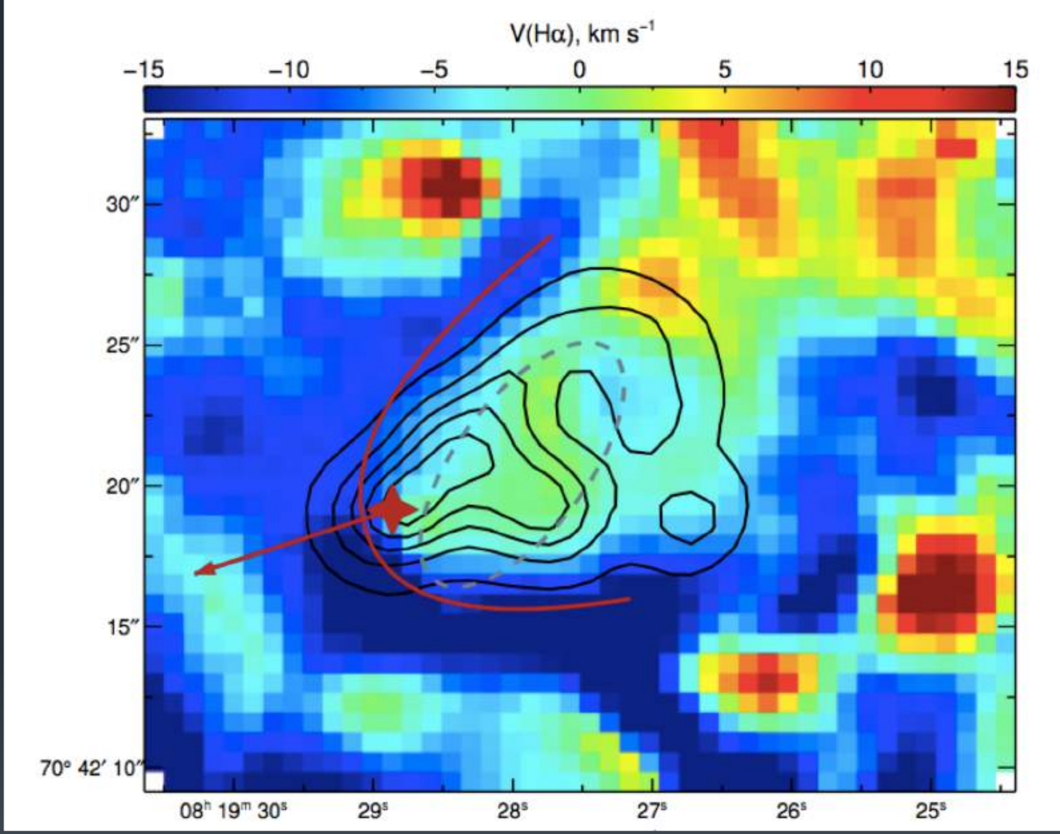
Holmberg II: first kinematical evidence of ULX escape from star cluster

- ULXs are often observed close to young star clusters, but outside of them.
- We have detected the structure in the velocity field in H-alpha, [SII] and [OIII] lines that looks like bow-shock.
- Following the Wilkin (1996) analytical solution we have computed the shape of ULX's bow-shock in the case of its moving from the center of nearby cluster

$$R = R_0 \csc\theta \sqrt{3(1 - \theta \cot\theta)}.$$

$$R_0 = \sqrt{\frac{\dot{M}_w v_w}{4\pi \rho_{AMB} v_{ULX}^2}}$$

H-alpha velocity field observed with FPI



The structure observed in the velocity field could be explained as bow-shock created by ULX escaping from the nearby young star cluster

Egorov et al. (2017; MNRAS, 467, L1)

Summary

- Supergiant shells (SGS) of HI are observed in many nearby galaxies and might be even a dominating feature of their ISM

- Most probable scenario of SGS formation is feedback from several generations of stars over the long period of star formation inside a SGS

- Star formation take place in the rims of only part of the ISM and might be induced by energy input from previous generation of stars, or by collision of neighboring SGS.

- Star formation in the rims of HI SGS leads to their gradual disruption

- Scanning FPI is very useful for searching and analysis of expanding superbubbles, including SNRs and nebulae around WR stars

хвала на пажњи