Supernova remnants – a perspective from NAO Rozhen

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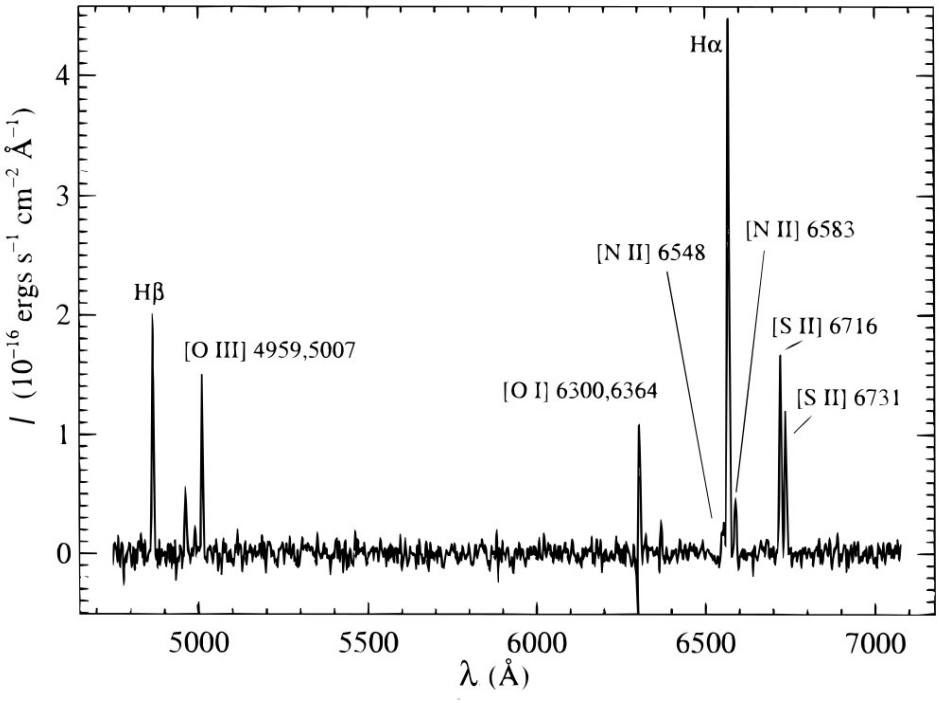
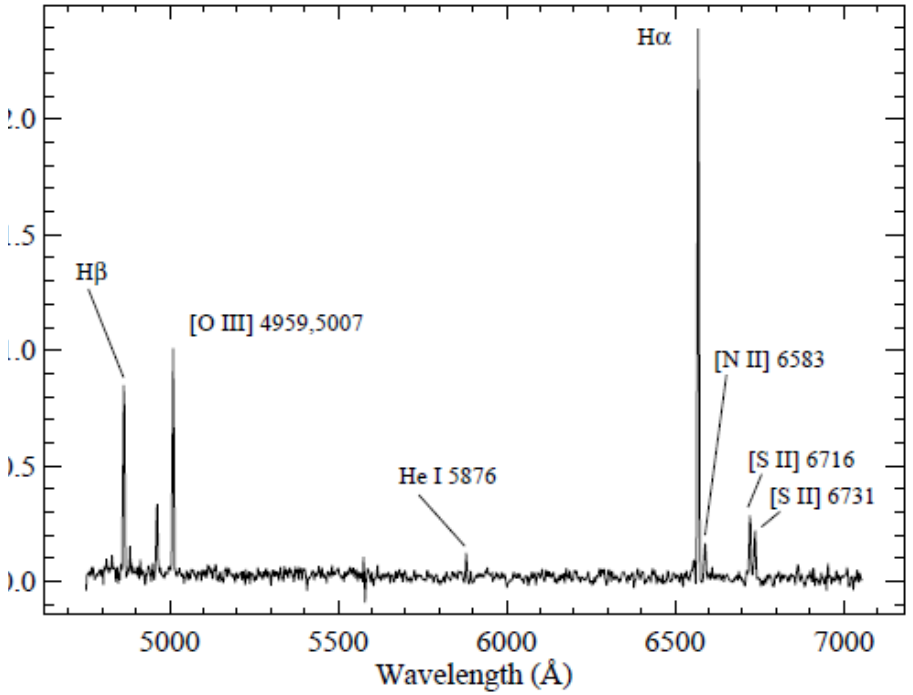
Optical detection of SNRs

- Mathewson & Clarke (1973) – SNRs in LMC (combination of radio and optical observations)
- [SII]/Hα emission line ratio
  - Shock heated SNRs > 0.4
  - Photoionized nebulae - HII regions < 0.4 (0.2)
  - (D'Odorico et al. 1978; Matonick & Fesen 1997; Blair & Long 1997)

SNR and HII region spectra comparison

(from Matonick & Fesen 1997)





- Spectroscopic, or some other band confirmation needed
- Data reduction difficulties
  - Low fluxes – long exposures – tracking problems
  - Continuum subtraction from emission-line filters
  - Absolute calibration with non-standard narrow-band filters

Galaxies observed for optical SNRs (Vučetić et al. 2015a)

Table 1. Data for galaxies which have been observed for optical SNRs.

Galaxy name	R.A. (J2000) (h:m:s)	Decl. (J2000) (d:m:s)	Distance (Mpc)	Distance reference	Major axis (arcmin)	Minor axis (arcmin)	Galactic latitude (°)	Incl.[a] (°)	Galaxy	B (mag)	A_B (mag)
LMC	05:23:34.5	−69:45:22	0.05	1	645	550	−32.9	35	SB(s)m	0.9	0.272
SMC	00:52:44.8	−72:49:43	0.06	2	320	185	−44.3	58	SB(s)m pec	2.7	0.134
NGC 6822	19:44:57.7	−14:48:12	0.50	1	15.5	13.5	−18.4	33	IB(s)m	9.31	0.855
NGC 185	00:38:58.0	48:20:15	0.62	3	11.7	10.0	−14.5	–	E3 pec	10.1	0.667
IC1613	01:04:47.8	02:07:04	0.65	4	16.2	14.5	−60.6	29	IB(s)m	9.88	0.090
IC342	03:46:48.5	68:05:47	3.30	5	21.4	20.9	10.6	25	SAB(rs)cd	9.1	2.024
NGC 253	00:47:33.1	−25:17:18	3.94	6	27.5	6.8	−87.9	85	SAB(s)c	8.04	0.068
M31	00:42:44.3	41:16:09	0.79	4	190	60	−21.6	78	SA(s)b	4.36	0.225
M33	01:33:50.9	30:39:37	0.84	4	70.8	41.7	−31.3	54	SA(s)cd	6.27	0.15
NGC 300	00:54:53.5	−37:41:04	2.0	4	21.9	15.5	−79.4	45	SA(s)d	8.95	0.046
NGC 4214	12:15:39.2	36:19:37	2.92	7	8.5	6.6	78.1	39	IAB(s)m	10.24	0.079
NGC 2403	07:36:51.4	65:36:09	3.22	4	21.9	12.3	29.2	57	SAB(s)cd	8.93	0.145
M82	09:55:52.7	69:40:46	3.53	8	11.2	4.3	40.6	69	I0 edge-on	9.3	0.567
M81	09:55:33.2	69:03:55	3.63	4	26.9	14.1	40.9	62	SA(s)ab	7.89	0.291
NGC 3077	10:03:19.1	68:44:02	3.82	9	5.4	4.5	41.6	38	I0 pec	10.61	0.243
NGC 7793	23:57:49.8	−32:35:28	3.91	6	9.3	6.3	−77.2	48	SA(s)d	9.98	0.053
NGC 4449	12:28:11.1	44:05:37	4.21	9	6.2	4.4	72.4	45	IBm	9.99	0.053
M83	13:37:00.9	−29:51:56	4.47	10	12.9	11.5	31.9	28	SAB(s)c	8.2	0.241
NGC 4395	12:25:48.8	33:32:49	4.61	9	13.2	11.0	81.5	34	SA(s)m?	10.64	0.063
NGC 5204	13:29:36.5	58:25:07	4.65	9	5.0	3.0	58.0	54	SA(s)m	11.73	0.045
NGC 5585	14:19:48.2	56:43:45	5.7	11	5.8	3.7	56.6	51	SAB(s)d	11.2	0.057
NGC 6946	20:34:52.3	60:09:14	5.9	12	11.5	9.8	11.7	32	SAB(rs)cd	9.61	1.241
M101	14:03:12.5	54:20:56	6.7	4	28.8	26.9	59.8	22	SAB(rs)cd	8.31	0.031
M74	01:36:41.7	15:47:01	7.3	13	10.5	9.5	−45.7	20	SA(s)c	9.95	0.254
NGC 2903	09:32:10.1	21:30:03	8.9	14	12.6	6.0	44.5	64	SAB(rs)bc	9.68	0.113

[a]From Tully (1988).

Number of detected SNRs (Vučetić et al. 2015a)

Galaxy name	No. of optical SNRs	Fraction surveyed	F_{SNRs} (erg cm^{-2} s^{-1}) $\times 10^{-14}$	δF_{SNRs} (per cent)	L_{SNRs} (erg s^{-1}) $\times 10^{38}$	[N II]/H α ratio	A_B (mag)	F_{gal} (erg cm^{-2} s^{-1}) $\times 10^{-12}$	L_{gal} (erg s^{-1}) $\times 10^{39}$	R (per cent)	δR (per cent)	Ref.
(1)	(2)	(3)	(4)	(5)	(6)	(7)[a]	(8)[a]	(9)[a]	(10)[a]	(11)	(12)	(13)
M31	156	1	371.9	–	2.8	0.54	0.18	360.4	26.9	1.0	12	1
M33	137	1	544.6	–	4.6	0.27	0.18	383.0	32.4	1.4	12	2
NGC 300	22	1	23.1	22	1.1	0.2	0.06	31.6	15.1	0.7	34	3
NGC 4214	92	1	178.0	2	18.2	0.16	0.05	15.2	15.5	11.7	14	4
NGC 2403	150	0.88	620.7	1	77.0	0.29	0.17	48.6	60.3	12.8	13	4,5
M82	10	0.07	2.7	5	0.4	0.3	0.4	78.8	117.5	0.1	17	6
M81	41	1	18.8	–	3.0	0.51	0.24	37.3	58.9	0.5	12	7
NGC 3077	24	1	28.3	6	5.0	0.38	0.25	5.5	9.5	5.2	18	4
NGC 7793	27	1	28.8	–	5.3	0.25	0.08	20.8	38.0	1.4	12	8
NGC 4449	71	1	121.6	2	25.8	0.23	0.04	24.2	51.3	5.0	14	4
M83	296	1	653.0	–	156.0	0.53	0.21	74.4	177.8	8.8	12	9,10,11
NGC 4395	47	0.73	27.2	3	6.9	0.19	0.04	4.5	11.5	6.0	15	4
NGC 5204	36	1	23.6	4	6.1	0.13	0.03	3.1	8.1	7.5	16	4
NGC 5585	5	1	6.9	–	2.7	0.18	0.03	2.1	8.1	3.3	12	7
NGC 6946	26	0.95	12.1	–	5.0	0.54	1.54	69.2	288.4	0.2	12	7
M101	73	0.98	35.0	–	19.2	0.54	0.02	39.8	213.8	0.8	12	7,12
M74	9	0.83	9.4	–	6.0	0.4	0.21	11.6	74.1	0.8	12	13
NGC 2903	5	1	4.9	–	4.6	0.56	0.1	12.4	117.5	0.4	12	14

[a]From Kennicutt et al. (2008).

REFERENCES: (1) Lee & Lee (2014); (2) Long et al. (2010); (3) Millar et al. (2011); (4) Leonidaki et al. (2013); (5) Matonick et al. (1997); (6) de Grijs et al. (2000); (7) Matonick & Fesen (1997); (8) Blair & Long 1997); (9) Dopita et al. (2010); (10) Blair et al. (2013); (11) Blair et al. (2014); (12) Franchetti et al. (2012); (13) Sonbas et al. (2010); (14) Sonbas et al. (2009).

Observations from NAO Rozhen, Bulgaria

- 2 m RCC telescope, FOV 5.45” × 5.35”, with FORERO 15” × 15”
- Narrowband photometry through Hα, [SII] and continuum filters (~30 A)

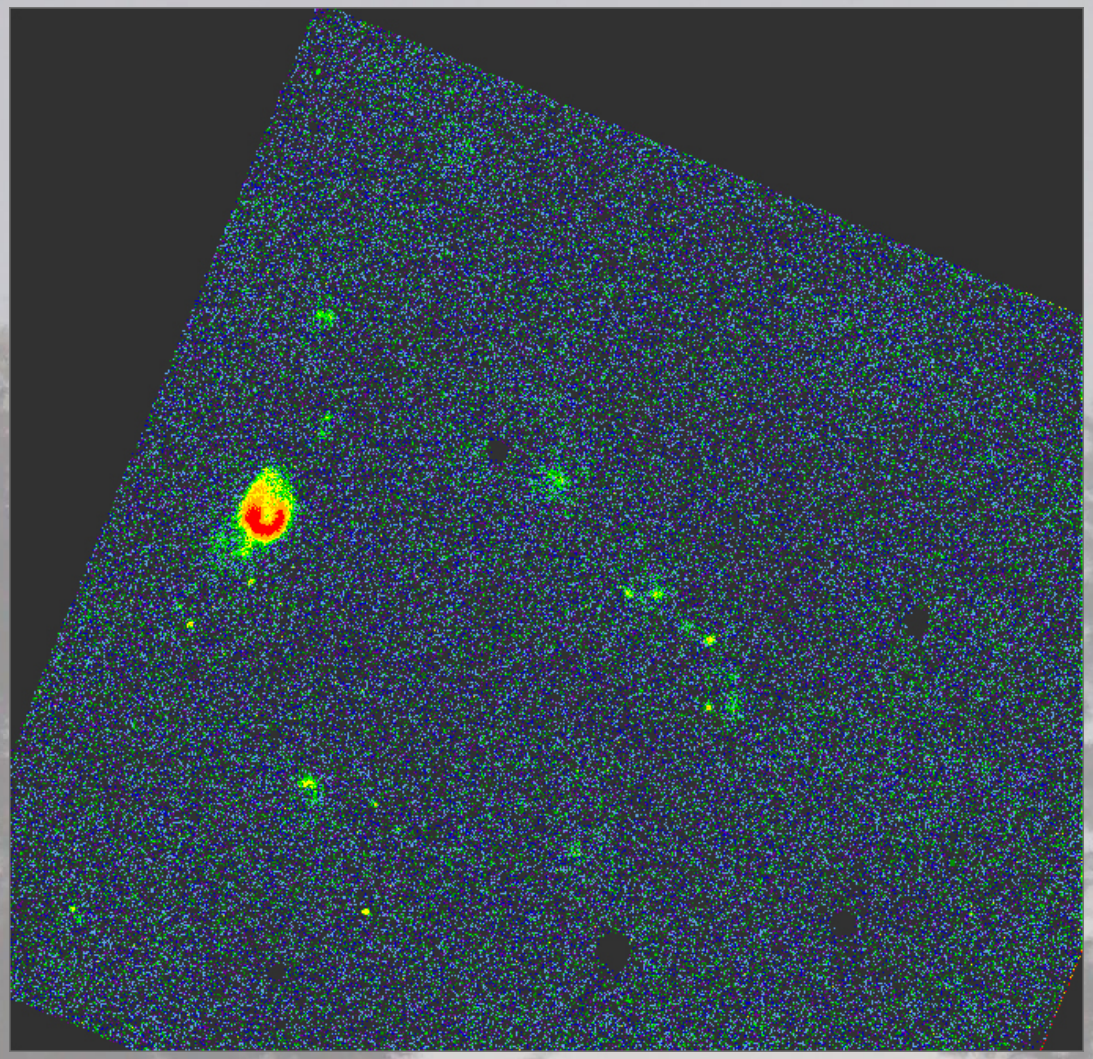
- Three joint projects between Serbian and Bulgarian Academies of Sciences “Optical search for supernova remnants and HII regions in nearby galaxies” since 2013 (PIs Urošević D., Arbutina B, Vučetić M.)

Observed galaxies

- **Holmberg IX** – ULX source Ho IX X-1 (Arbutina et al. 2009; Andjelić 2011)
- **IC342** – 203 HII regions (Vučetić et al. 2013); 16 new SNR candidates (Vučetić et al. 2015b); 28 new SNR candidates and 12 probable SNRs (Vučetić et al. in prep.)
- **NGC 3077** – 12 new HII regions (Andjelić et al. 2011)
- **NGC 1156** – 59 HII regions (Vučetić et al. 2018)
- **NGC 2366** – 2 SNRs, 3 superbubles, 64 HII regions (Vučetić et al. 2019a)
- **NGC 185** – 3 SNR candidates (Vučetić et al. 2019b)

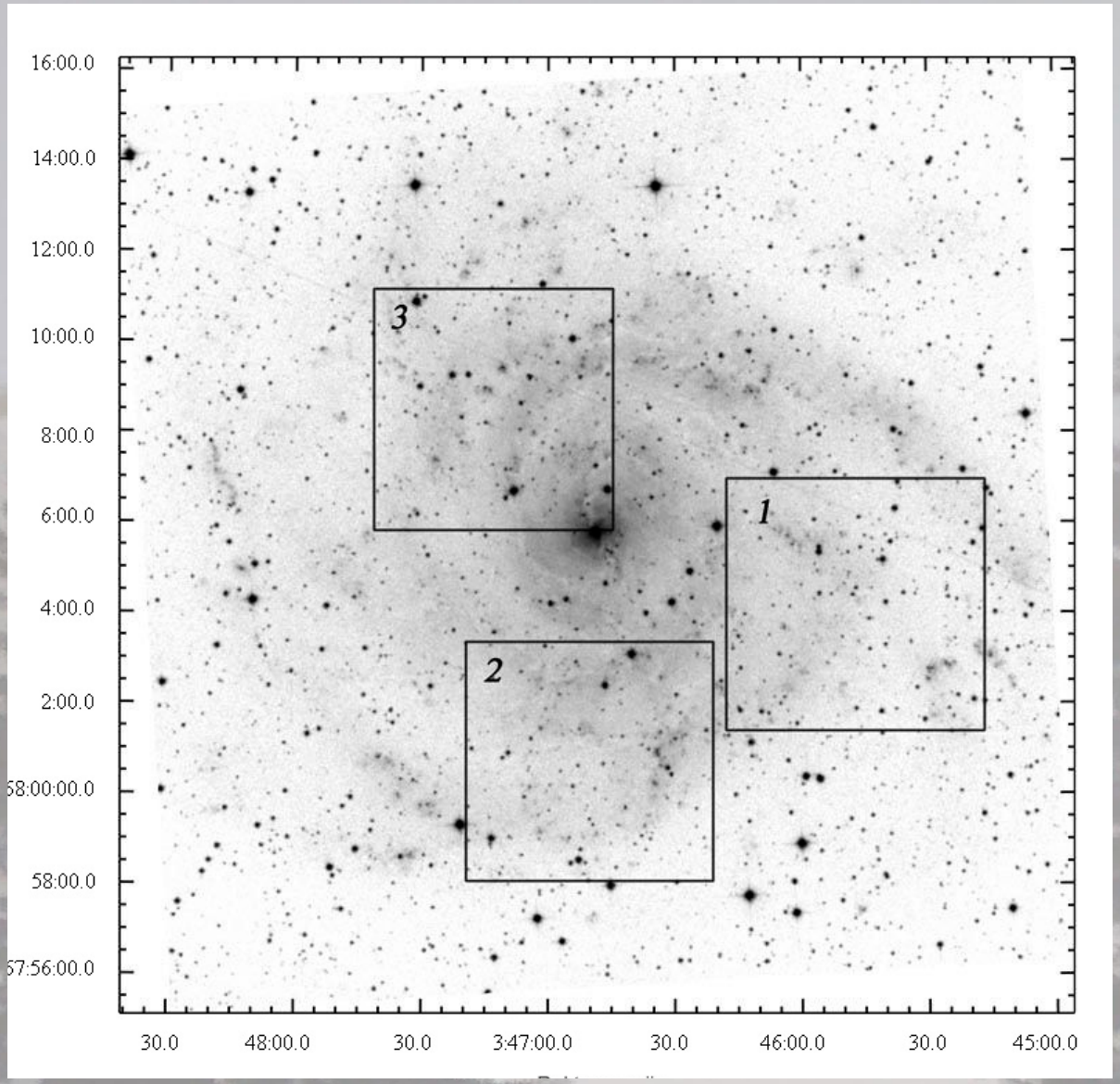
Holmberg IX galaxy

- **Observed from NAO Rozhen (Arbutina et al. 2009)**
- **140 mins exposure**
- **21 Hα emission line objects detected, 10 for the first time**
- **HolX X-1 – ULX object**

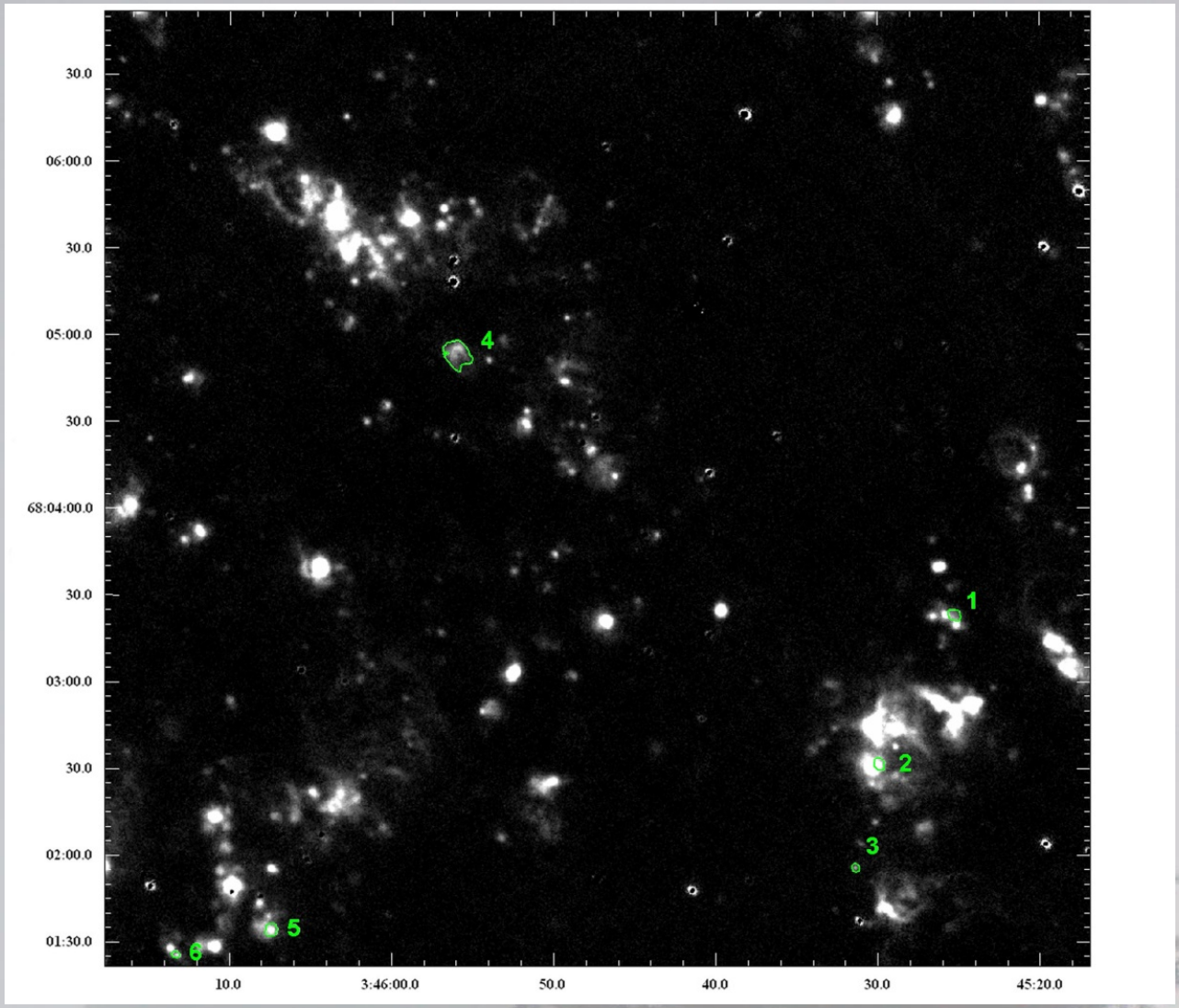


IC342 galaxy from NAO Rozhen

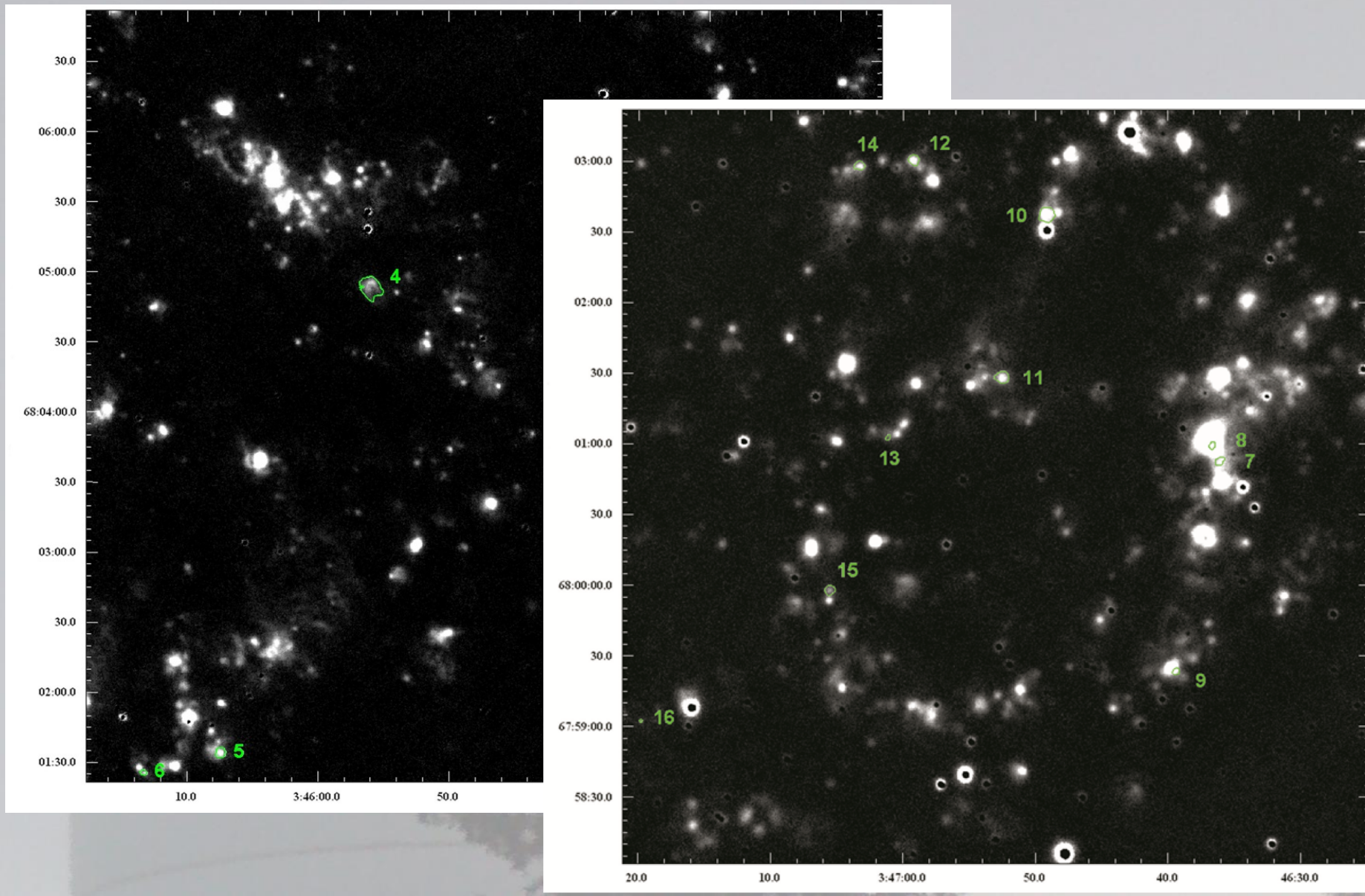
- **November 2011**
- **Exposure 45 mins**
- **Face-on spiral**
- **d = 3.4 Mpc**
- **Low Galactic latitude**



IC342 galaxy from NAO Rozhen

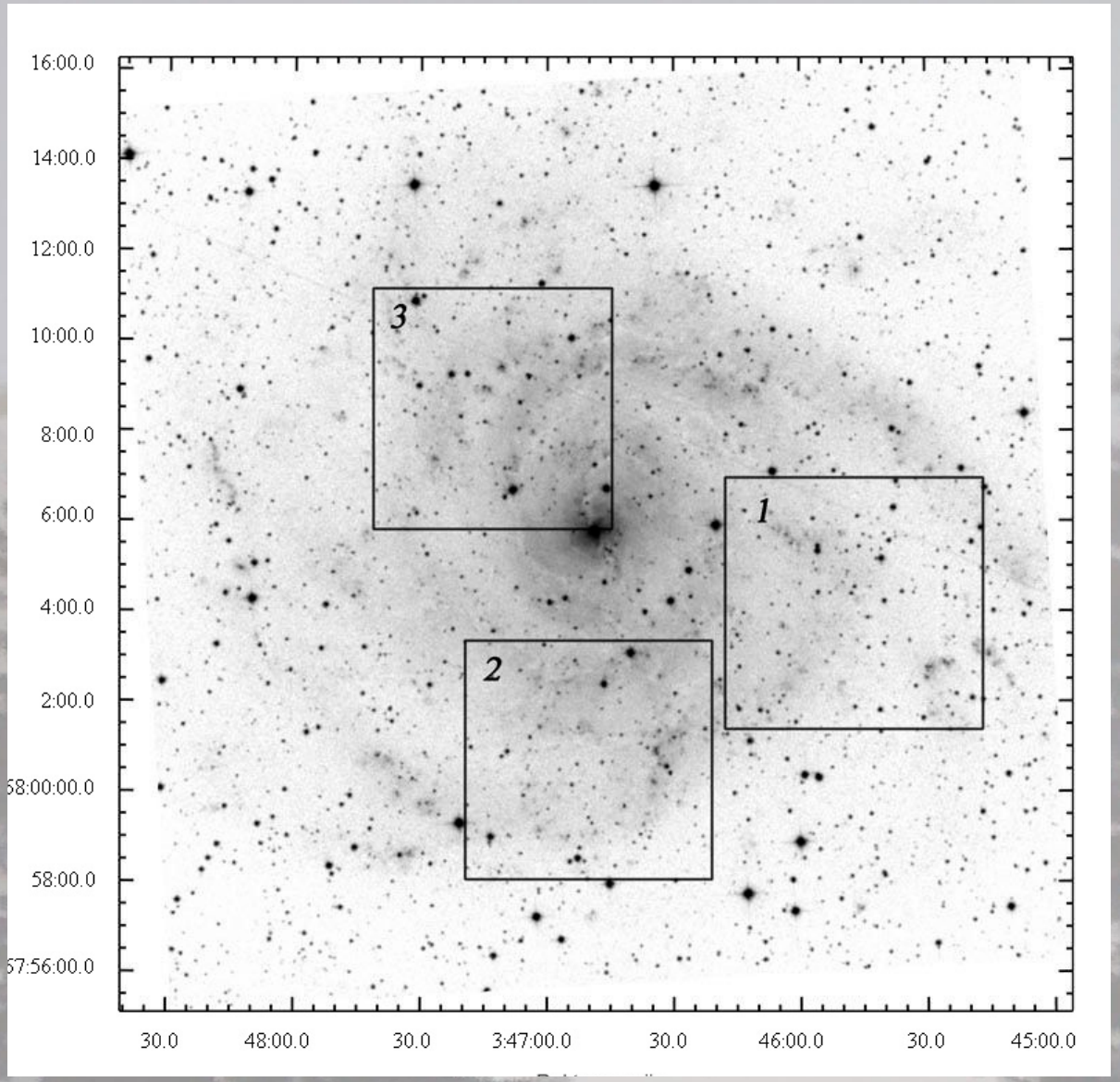


IC342 galaxy from NAO Rozhen



IC342 galaxy from NAO Rozhen

- **November 2011**
- **Exposure 45 mins**
- **16 SNR candidates**
- **203 HII regions**

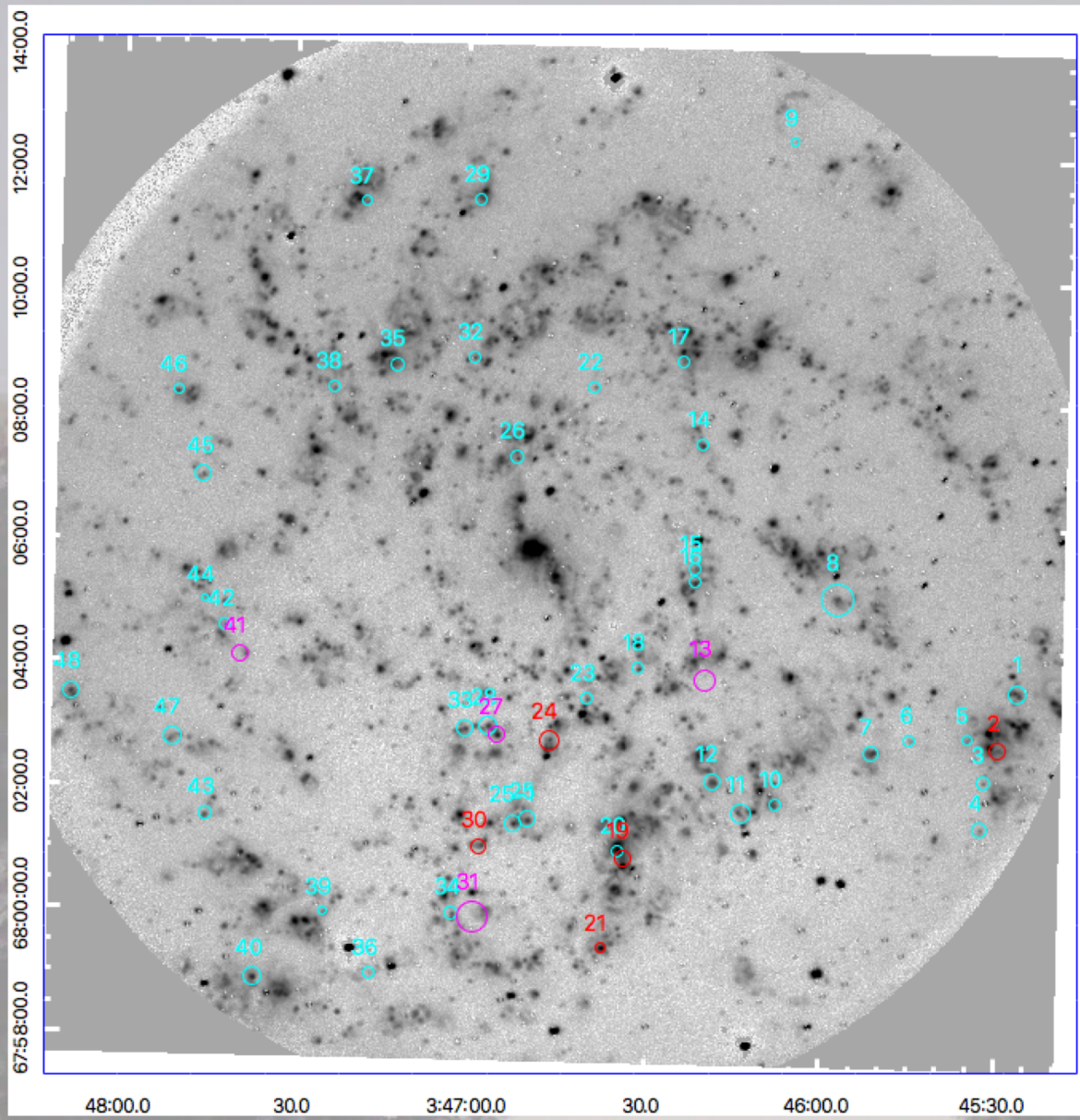


IC342 galaxy from NAO Rozhen

- **November 2021**
- **Exposure 110 mins**
- **FORERO FOV 15 arcmin**
- **28 are SNR candidates**
- **12 are probable SNR candidates**

(0.3<[SII]/Halpha <0.4)

- **5 not SNRs** in Vučetić et al. (2015)
- **4 are SII sources**



IC342 – archival radio and X-ray data

- X-rays
  - XMM Newton: 60ks exposure, energy band 0.4-5keV
  - Chandra: merged dataset has a total exposure of 149 ks

- Radio data:

VLA observations

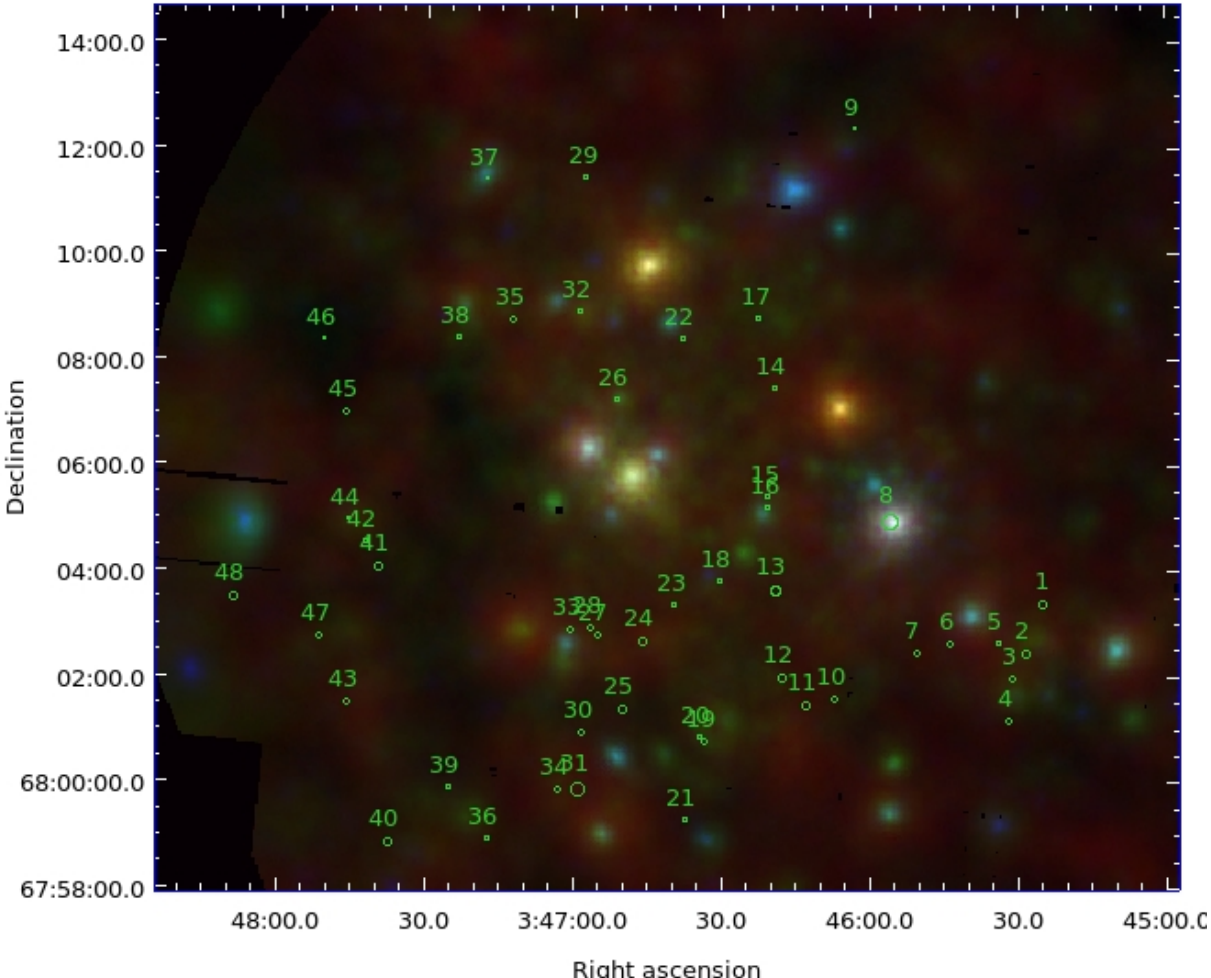
A configuration

20 cm (L band)

6 radio+optical+X

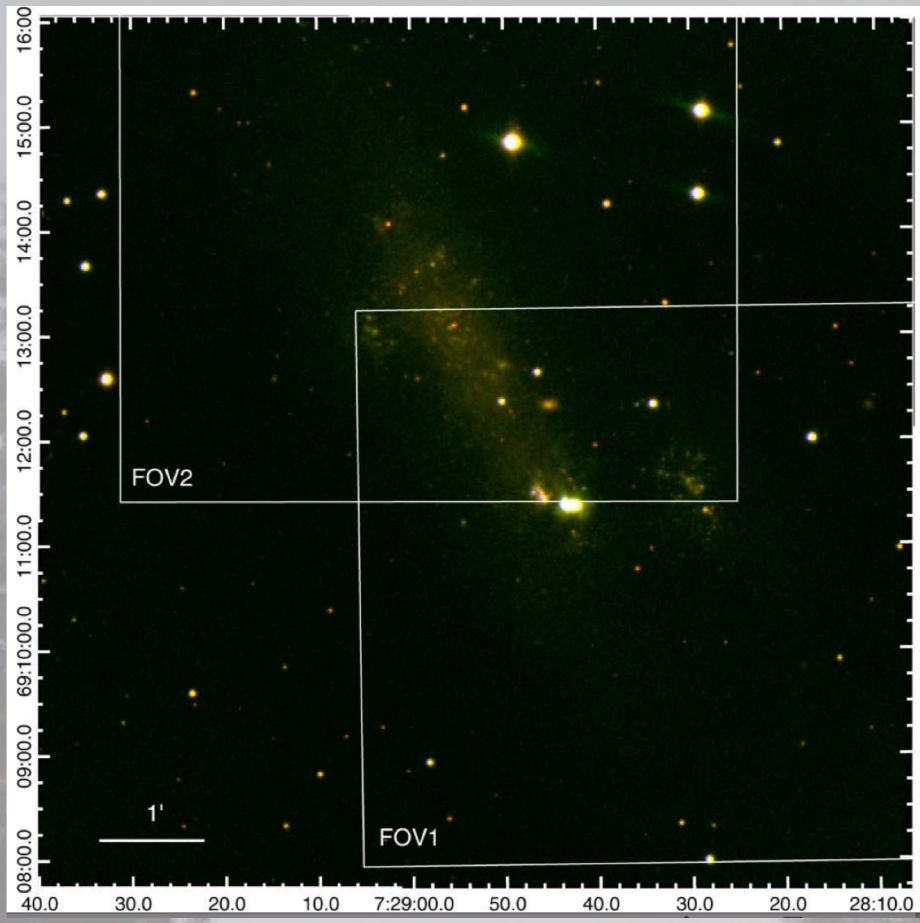
11 radio+optical

4 radio+X



NGC 2366 dwarf galaxy

- Dwarf galaxy, d=3.4 Mpc
- Previous VLA radio and XMM observations
- Observed from NAO Rozhen in 2015 and 2016
- 2 SNRs, 3 superbubbles, 64 HII regions (Vučetić et al. 2019a)
- 2 SNRs optical detected also in radio and X-rays
- 1 SNR in radio and X-rays



Comparison of HST and 2m telescope at NAO Rozhen :)

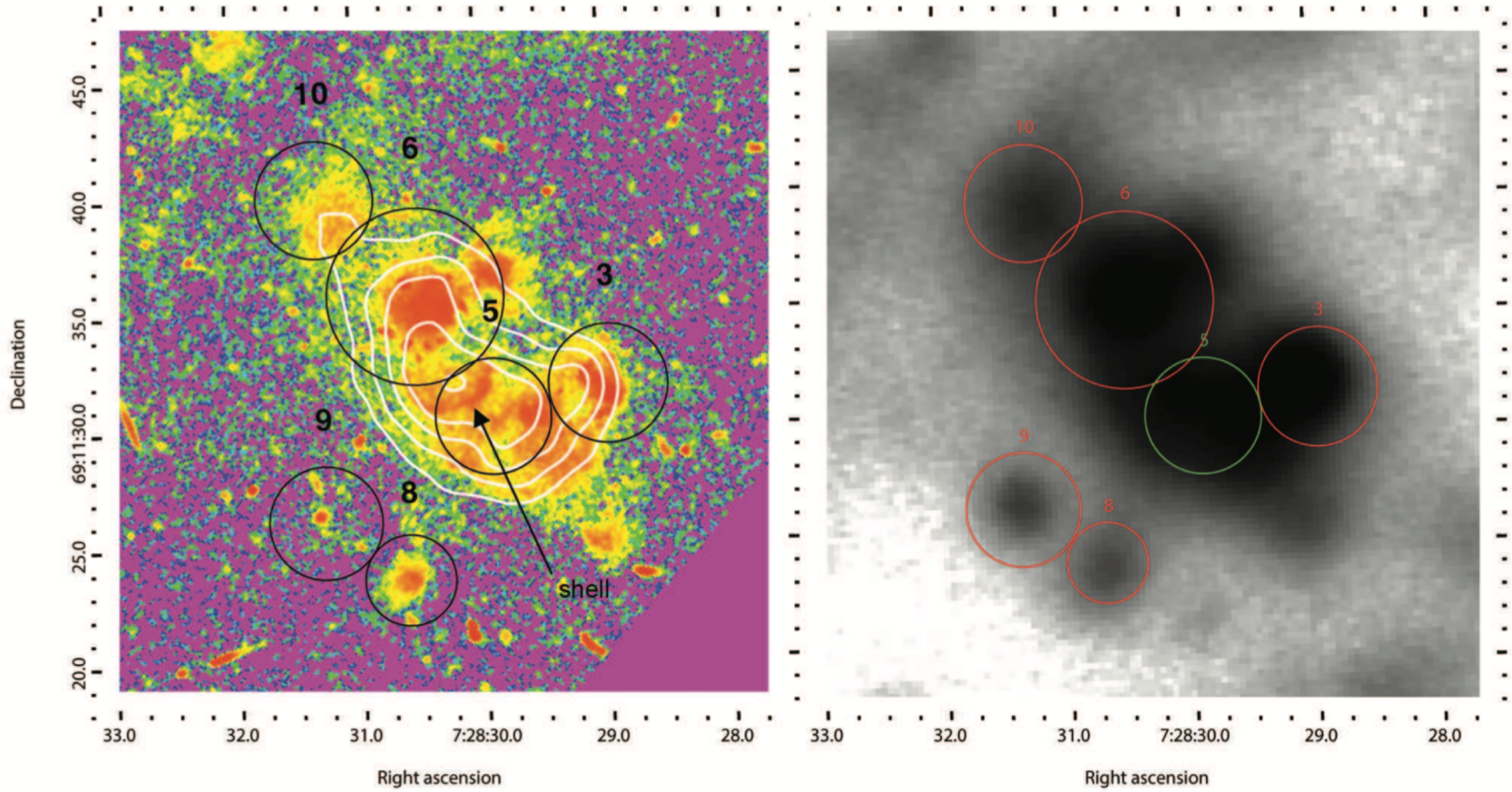
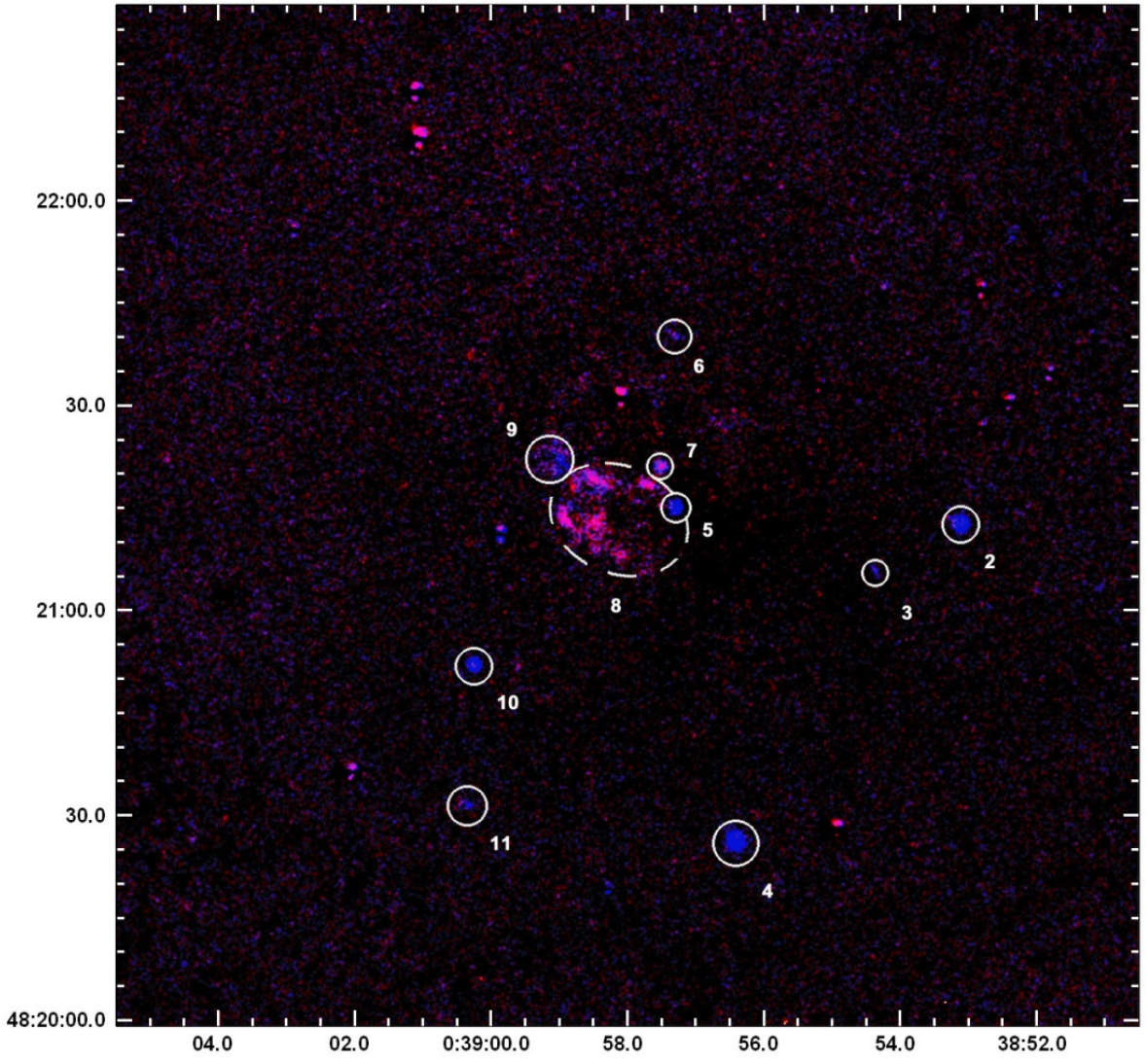


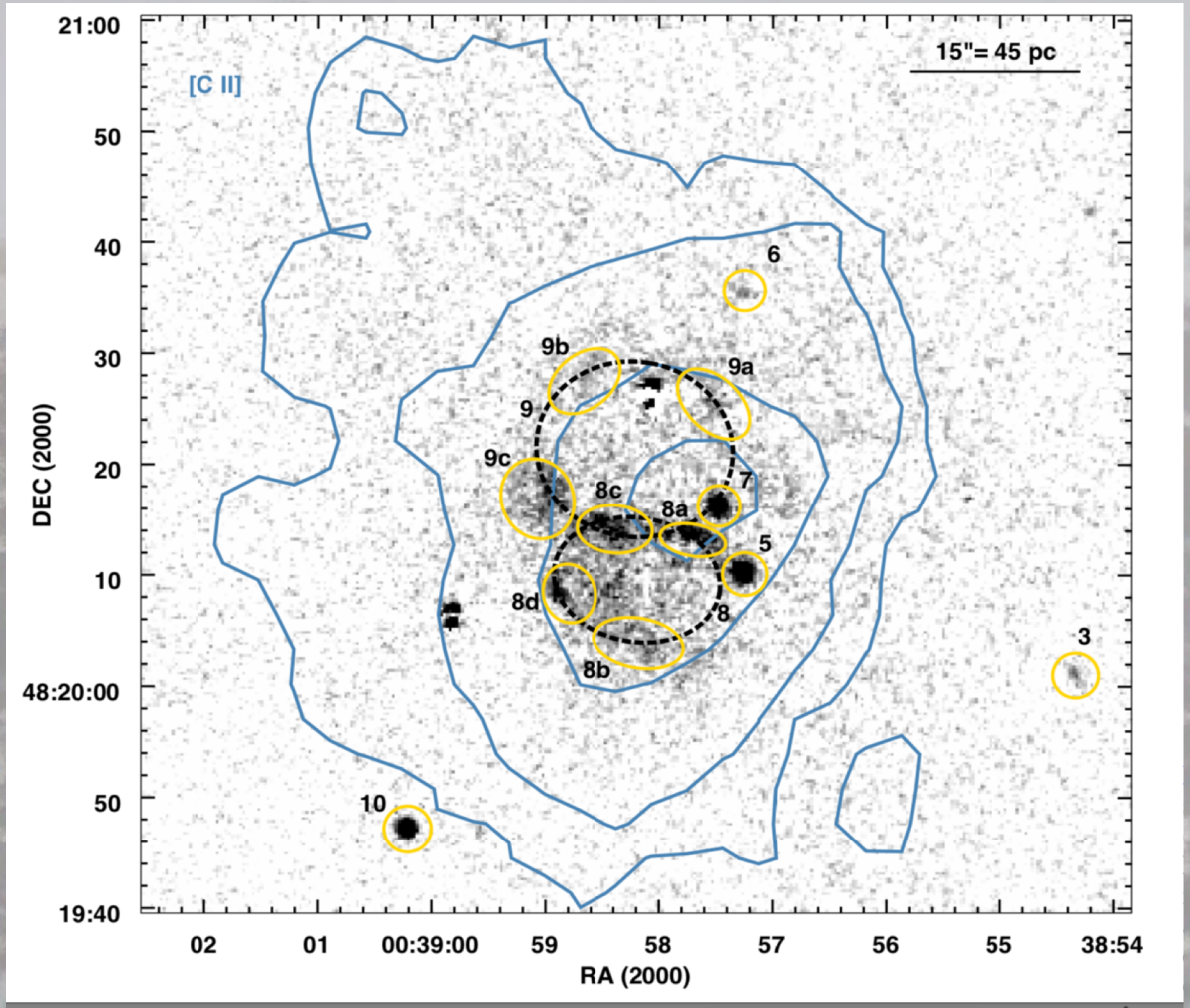
Fig. 6. *Left: HST WFPC2 F658N image with overlaid [S II] contours, centered on the starforming region near the object Vu19 5. The maximum of [S II]emission aligns with the partial Hα shell resolved with HST. Right: the same part of our Hα image. Seeing was 3″.25. The diameter of the SNR candidate Vu19 5 is 5″.0=85 pc.*

NGC 185 galaxy

- **Dwarf elliptical**
- **d=620 kpc**
- **Observed from NAO Rozhen, November 2015**
- **80 mins exposure**
- **6 PNe, 2 HII region candidates, 1 symbiotic star**
- **2 SNR candidates**
- **Low and high resolution spectra of central region from 6m BTA at Special Astrophysical Observatory (Russia)**

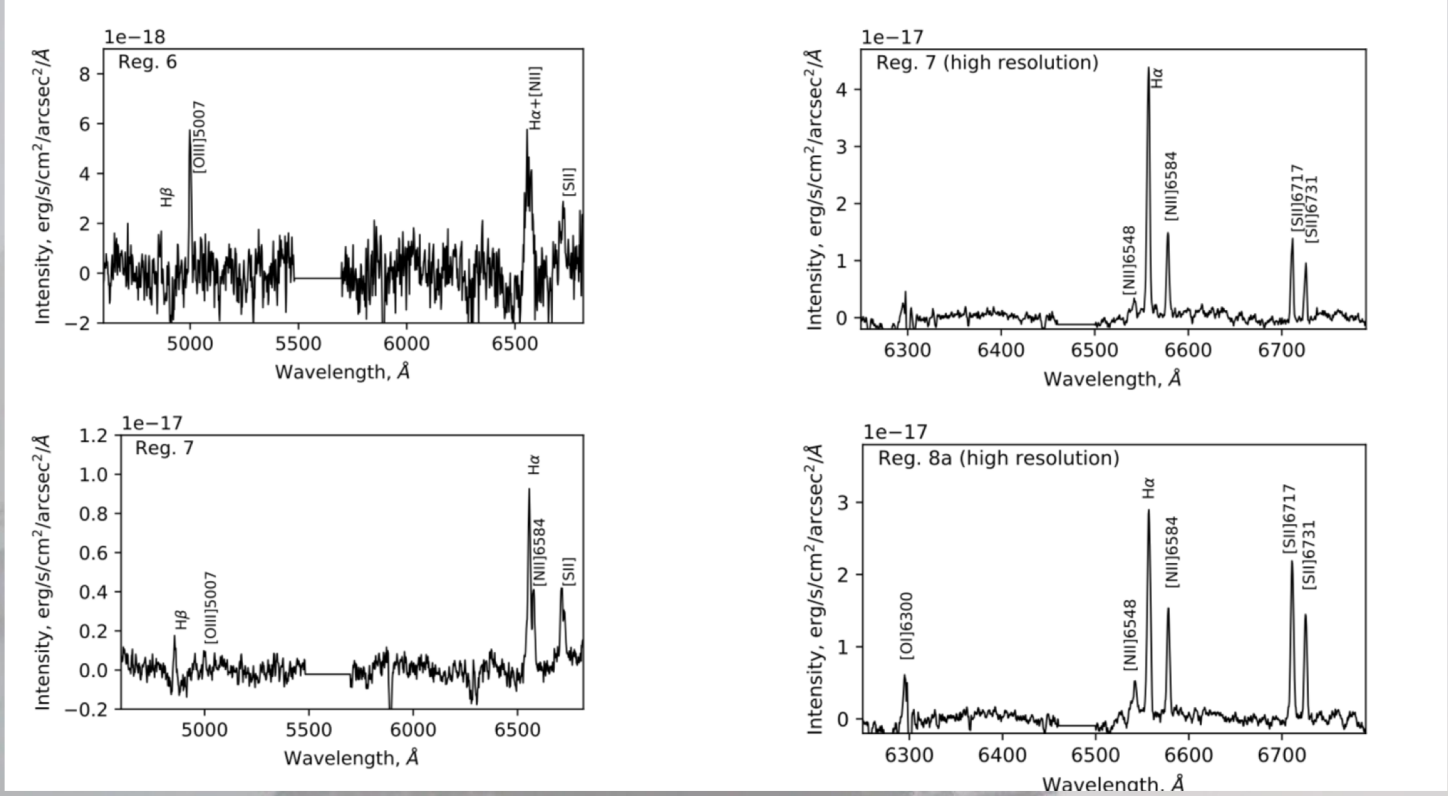


Why there are SNR(s) in dwarf elliptical galaxy?



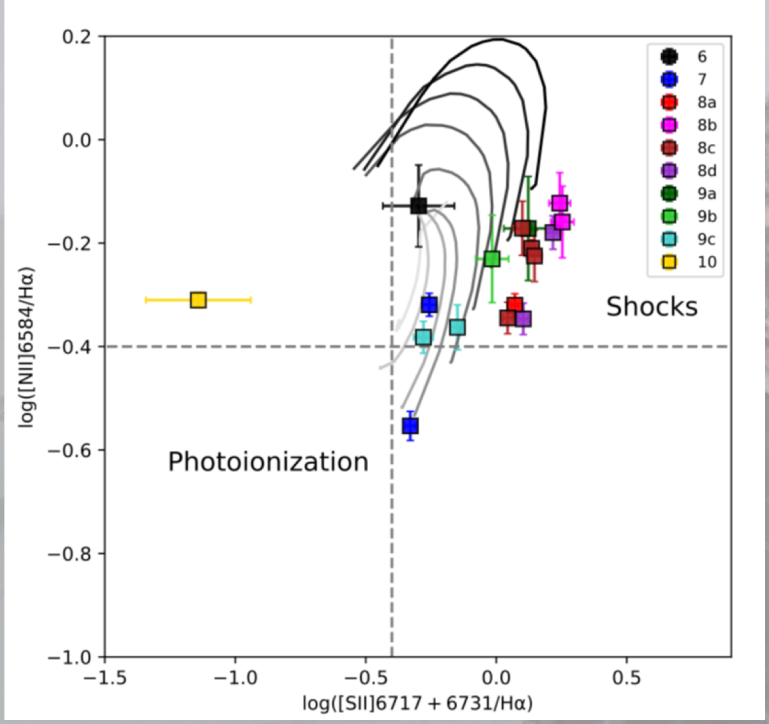
Continuum-subtracted Hα image of the center (∼1.5′ × 1.5′) of NGC 185 with *Herschel* [CII] contours, indicating the location of dense gas.

Low ($\delta\lambda$=14 A) and high ($\delta\lambda$=3.6 A) resolution spectra

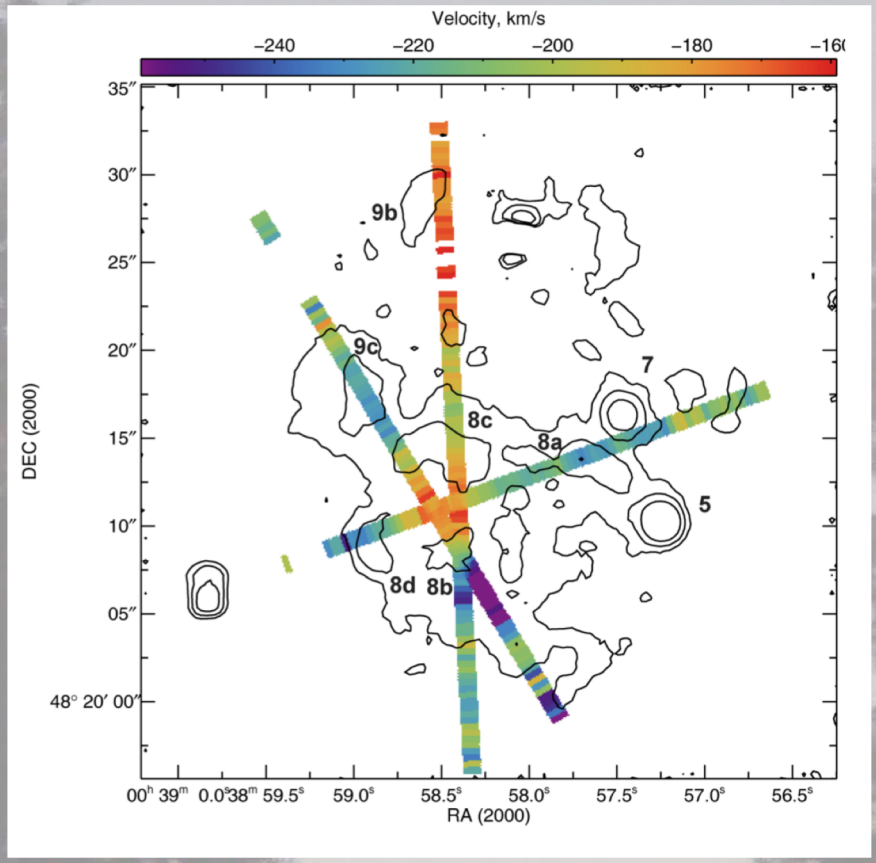


Possibilities with high-res spectroscopy

- estimation of electron density
- estimation of shell expansion
- age of an SNR
- construction of BPT diagrams



Two-dimensional velocity map in the Hα line of the central 40″ × 40″, constructed from three slit positions for high-resolution spectra



Summary

- Optical photometry observations need spectral or other band observations for confirmation of SNRs
- Obtaining better samples in already observed galaxies, rather than observing new galaxies
- Improvement of statistical analysis of SNRs sample