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The Fireworks Galaxy, NGC 6946: Looking at the Fading Embers

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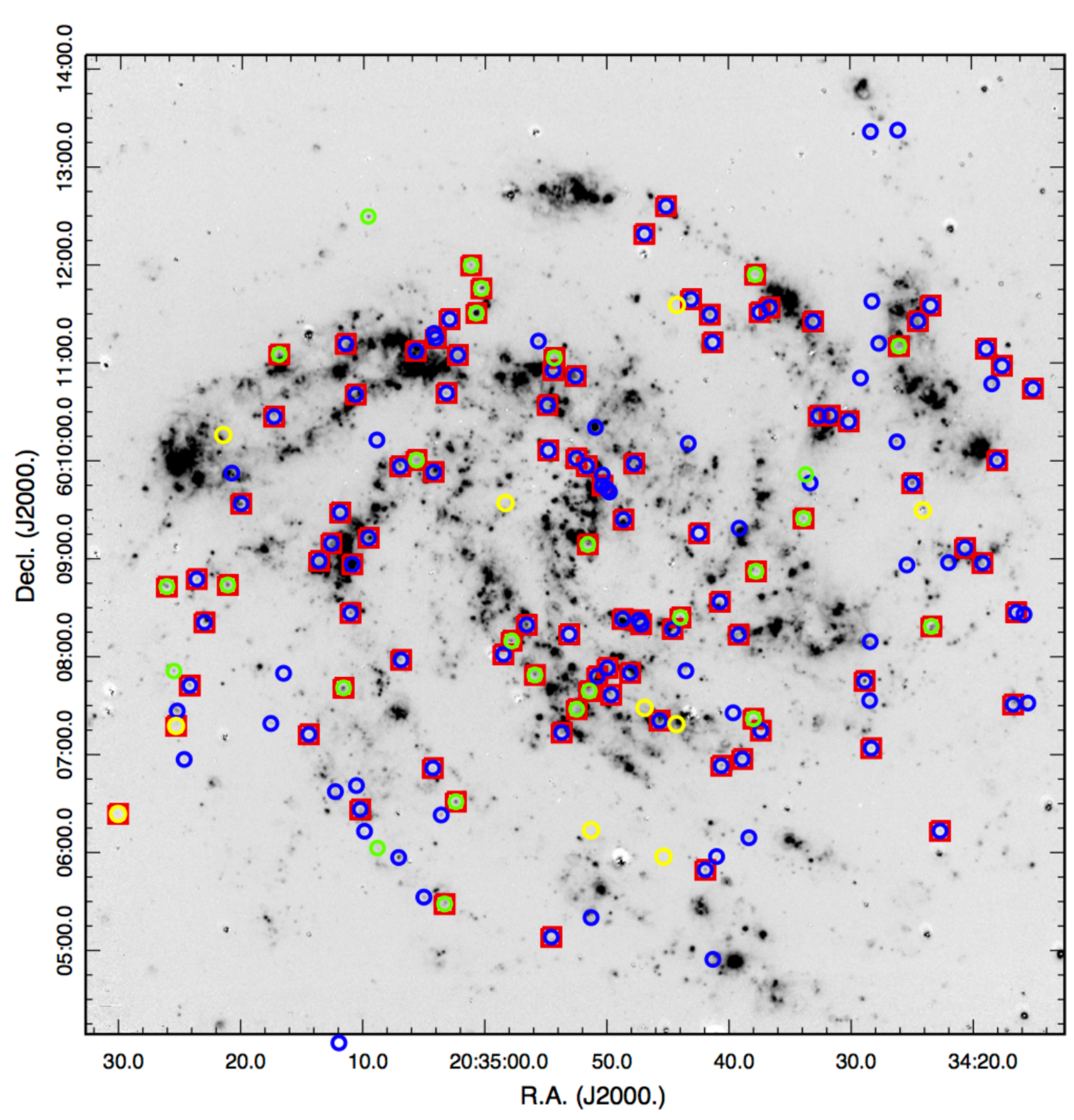
General Overview

- NGC 6946 has active star-formation in nuclear starburst and spiral arms. SF rate = 4-9 M_{sun}/year, depending on author. Published distances range from 5.1 – 7.9 Mpc (cf. Eldridge & Xiao 2019). We adopt distance=6.7 Mpc (1"=33 pc).
- NGC 6946 holds the record for production of observed supernovae, with some 10 in the last century (and four just since the turn of the millennium). Hence, it is a prime galaxy in which to study global SN remnant populations.
- New ground-based WIYN survey for SNRs (Long+2019) builds on Matonick & Fesen (1997): 147 optical SNR candidates from [S II]:Hα ratio; spectra confirming 89/102.
- HST/WFC3: 7 UVIS fields in Hα and [S II]; 9 IR fields in [Fe II] 1.64 μm and Paβ; HST ACS: deep 2-3 color broadband continuum filters to study underlying stellar populations (in progress).
- Archival *Chandra* X-ray data (173 ks; Fridricksson+2008), shows 90 point sources, only 8 of which align with optical SNRs.
- Radio: VLA at 6 and 20 cm used to identify 35 nonthermal `radio SNRs,' but very few overlap with optical SNRs (Lacey & Duric 2001); new deeper data are being processed.

Finding and characterizing SNRs in nearby galaxies is enhanced by having both ground-based and HST optical imaging data (see Figures to right). The former are typically more sensitive to lower surface brightness and somewhat extended objects, while the latter are far superior for deriving diameter and morphology information and finding objects that are in relatively confused regions of emission. We are currently using published X-ray and radio data to add the multiwavelength diagnostics at least for the brighter objects. The high foreground N(H) column toward NGC 6946 hampers detection of SNRs, which typically have soft spectra.

Interestingly, we still find that many of the brighter SNRs do not have corresponding radio counterparts (Lacey & Duric 2001), which has been a long-standing problem for NGC 6946 compared with other nearby galaxies.

HST WFC3 [Fe II] 1.64 μm data allow us to find objects in dusty regions as well as confirming many of the optical SNRs. The HST optical data permit diameter measurements of most of the optical SNR catalog, and allow us to study the global properties of the sample.

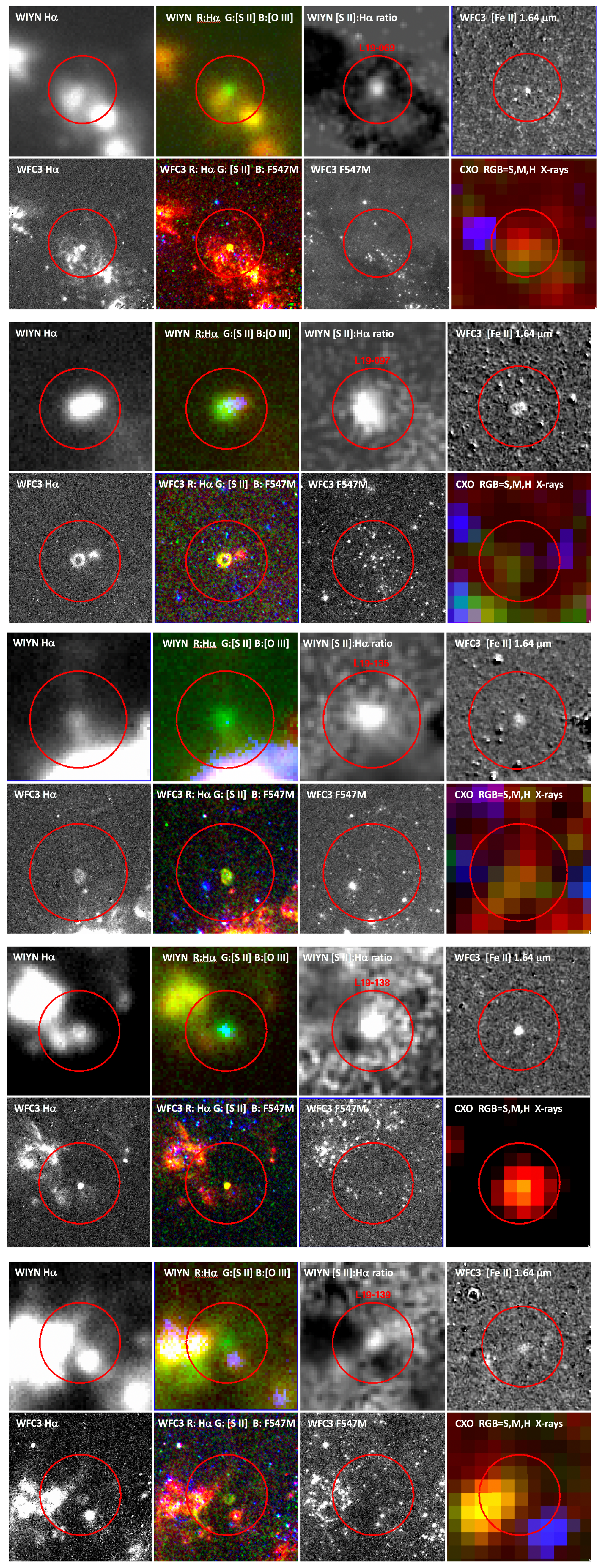


(Above) Image of NGC6946 in Hα after subtracting starlight. Green circles indicate the positions of SNRs and candidates from MF97; blue circles indicate the positions of our new [S II]-selected candidates; yellow circles indicate the positions of historical SNe. The red squares denote those objects for which we obtained GMOS spectra.

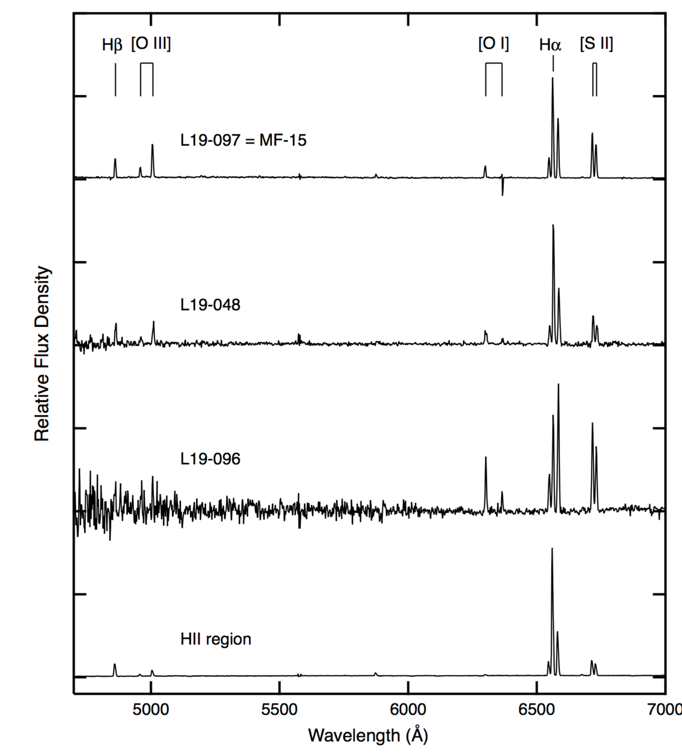
Table 1: NGC 6946 SNRs in Context with Other Nearby Face-On Spiral Galaxies

Galaxy	M33	M83	NGC 6946
Distance (Mpc)[a]	0.81	4.6	6.7
Scale (pc per arcsec)	4	22	35
R_{25} (arcmin)[a]	$37' \times 22.5'$	$7.7'$	$7'$
Absolute Magnitude, M_V^a	−19.4	−21.53	−20.10
Metallicity, $12 + \log(O/H)$[b]	8.78	9.16	9.06
Star Formation Rate ($M_\odot\,yr^{-1}$)[c]	0.45	5.0	9.1
Historical SNe[d]	0	6 (7)[e]	10
Optical SNRs	217[f]	300+[g]	147[i]
Spectral confirmations	170/197[f]	117/140[h]	89/102[i]
X-ray Detections	112	87[k]	8[m]
Radio Detections	155[j]	23[k]	7[n]
Fe II Total Detections	6[p]	121[q]	107[q]
Fe II SNR Detections	6/42[p]	∼88/273[q]	∼37/94[q]
Fe II-only Detections	(0)[r]	∼26[q]	∼70[q]

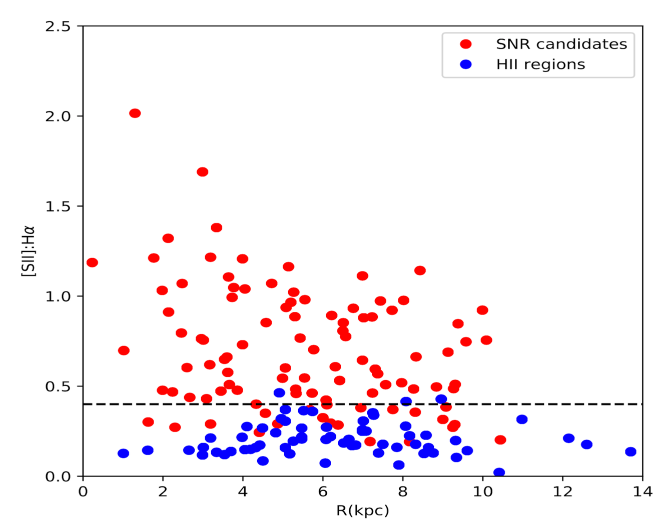
[a]NASA Extragalactic Database; [b]Zaritsky et al. 1994, ApJ, 420, 87, measured at r=0.4 R_{25}; [c]Lee et al. 2009, ApJ, 706, 599; [d]Asiago SN catalog, Barbon et al. 1999, A&AS, 139, 531 (15 Feb 2015 update); [e]7th is B12-174a, Blair et al. 2015, ApJ, 800, 118; [f]Long et al. 2018, ApJ, 855, 140; [g]Blair et al. 2012, ApJS, 203, 8; [h]Winkler et al. 2017, ApJ, 839, 83; [i]Long et al. 2019, arXiv 1903.01318; [j]White et al. 2019, arXiv 1903:04434; [k]Long et al. 2014, ApJS, 212, 21; [m]Fridricksson et al. 2008, ApJS, 177, 465; [n]Lacey & Duric 2001, ApJ, 560, 719; [p]Morel et al. 2002, MNRAS, 329, 398; [q]HST; [r]M33 has not been independently surveyed in [Fe II] in its entirety.



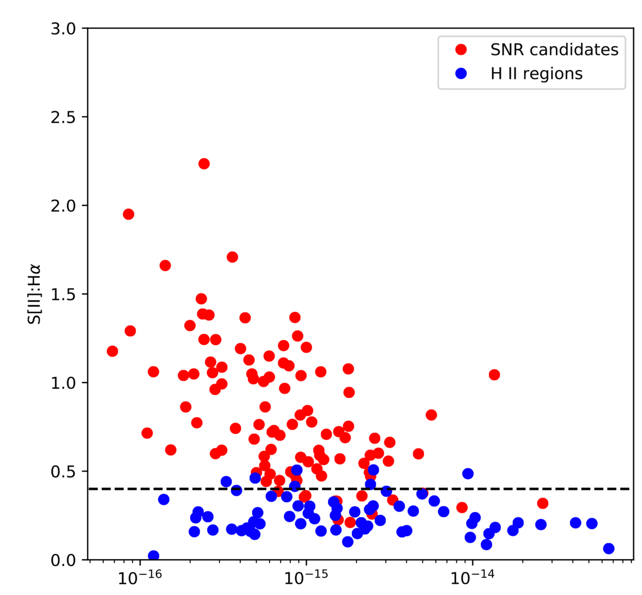
(Above): The five 8-panel figures above show a small selection of NGC 6946 SNRs in multiple ground-based and space-based observations, as indicated on each panel. Ground-based images from WIYN are effective at finding many SNR candidates, but HST resolution is needed to see their morphology and measure their sizes. Some of the objects have clear Chandra X-ray counterparts and others do not or are confused. All of these objects show some amount of [Fe II] emission, but this is not always the case (see Table 1).



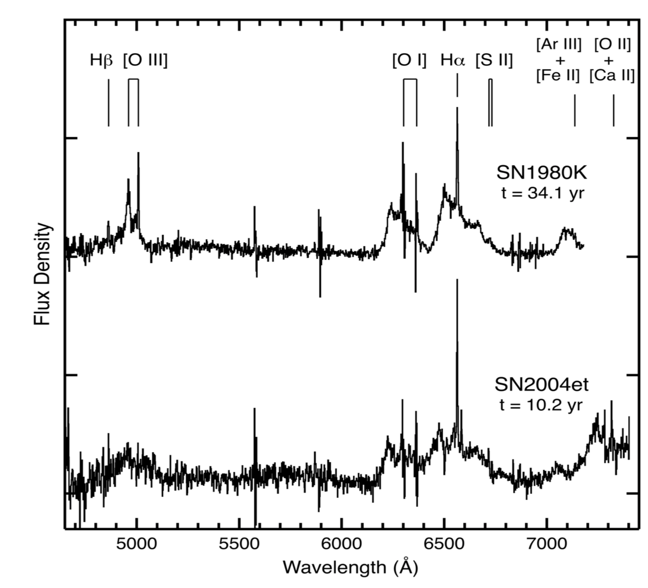
(Left) Examples of the spectra obtained for three representative SNR candidates and one H II region in NGC 6946, from our GMOS spectroscopy program. The three SNR spectra have been selected to illustrate the quality of the spectra for a bright, medium bright, and fairly faint candidate. (The traces have been scaled arbitrarily, and offset for clarity.) Note the strong [S II]:Hα and variable [N II]:Hα from the SNRs compared with the H II region. Also, the Hα:Hβ ratio indicates significant and variable extinction for all objects.

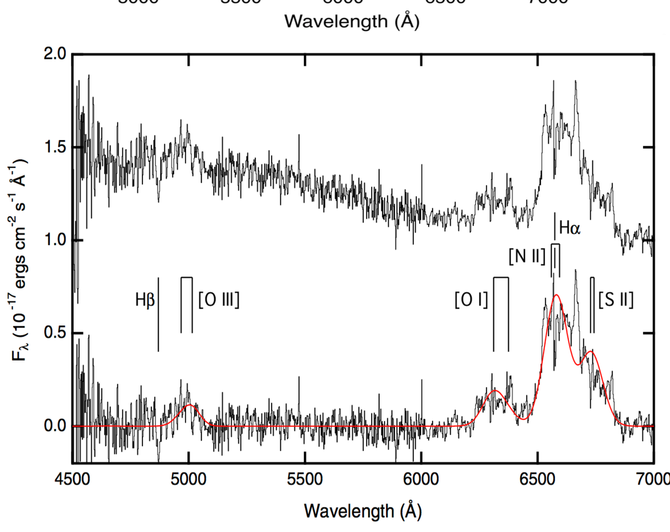


(Left) The [S II]:Hα ratio from GMOS spectra vs. galactic radius in NGC 6946. Somewhat higher average values at small galactic radius may be partially an abundance effect. There is some confusion near the nominal boundary of 0.4 in the ratio that separates shocks from photoionized regions, due mainly to difficulties subtracting H II region contamination.

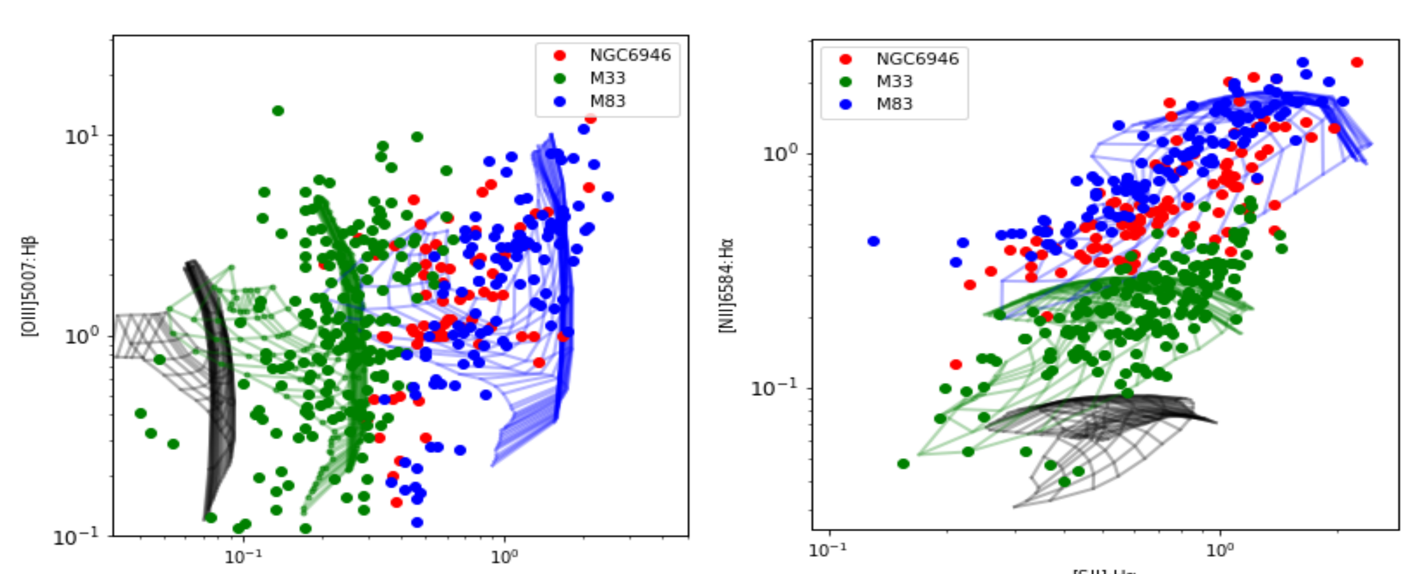


(Left) The [S II]:Hα ratio from GMOS spectra are shown here vs. the total Hα flux from each SNR (a surrogate for surface brightness). There is a tendency for higher values of the ratio at lower surface brightness, an effect that has also been seen in M33, M83, and other galaxies. To the extent that this effect also impacts H II regions, this contributes to the confusion near the dividing line.

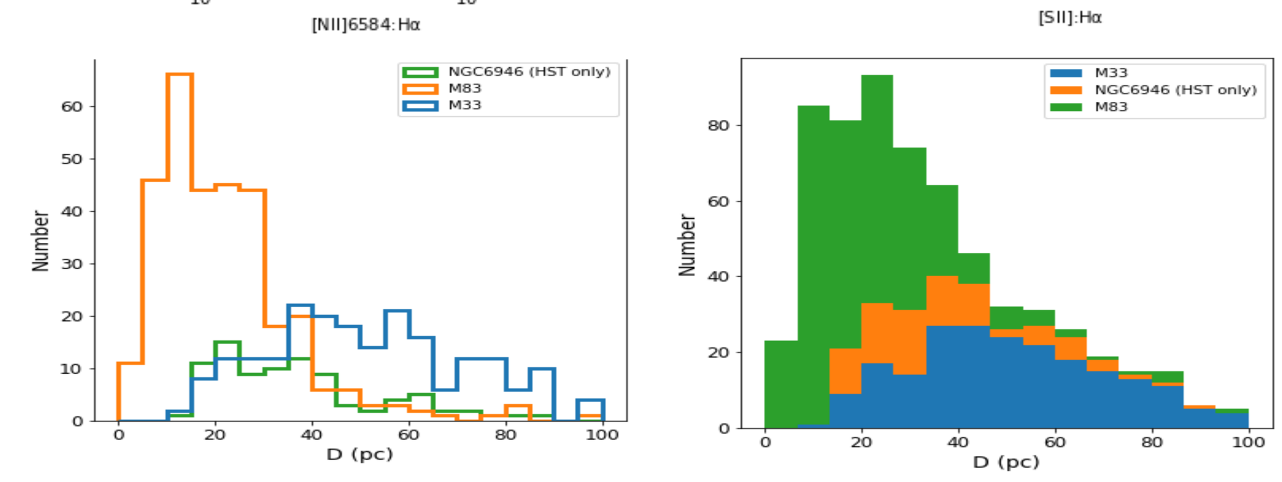




(Left and below-left) GMOS spectra of two historical SNe have been observed in NGC 6946. Both show the broad emission lines characteristic of young core-collapse SNRs where rapidly expanding ejecta interact with a circumstellar shell. (The spectra have been displaced vertically for clarity.) Below is the GMOS spectrum of a similar object called B12-174a identified by Blair+(2015) in M83. The spectrum is shown before and after subtraction of underlying emission from blue stars near the position.



(Two panels to left) Observed line ratios for SNRs in three galaxies are compared with shock model grids from Allen+ (2008), using the Mappings III program. The black, green, and blue meshes correspond to shock models with a range of shock velocities and pre-shock magnetic fields, and with metallicities corresponding to the SMC, LMC, and Milky Way, respectively. The offsets in mean abundances are clearly discerned.



(above) Two comparisons of the SNR diameter distributions for three galaxies. Left: regular histograms of the distributions; right: summed histogram with diameter. This highlights that M83 contains many small diameter SNRs in comparison to M33, and somewhat unexpectedly also NGC 6946. Note that for this comparison, only NGC 6946 SNRs within the region observed with HST are included, so small diameter SNRs should have been seen if present. However, our assessment for NGC 6946 is preliminary at this time.

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