X-ray, Optical, (and Radio) Properties of the Extensive Supernova Remnant Population in M83

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See also Long et al., poster S1.12, “X-ray Properties of SNRs in M51, M83, and M101”
Kopsacheili et al., poster S1.11, “New Candidate SNRs in Nearby Galaxies”

Many Collaborators

- Knox Long, STScI
- Frank Winkler, Middlebury College
- Michael Dopita, Australian National University
- Roberto Soria, & Thomas Russell, ICRAR, Curtin University, Australia
- Paul Plucinsky, SAO
- Kip Kuntz, JHU
- Brad Whitmore, STScI
- Hwihyun Kim, University of Texas at Austin
- Rupali Chandar, University of Toledo
- Chris Stockdale, Marquette University
- Leith Godfrey, Dwingeloo, The Netherlands
- Ben Williams, University of Washington

Take home points

- As expected from observed SN rate, there are LOTS of SNRs in M83!
- *HST/WFC3* and *Chandra* have allowed us to uncover the young SNR population in M83, but...
- ***Very few appear to be obviously in the ejecta-dominated state.***
- Possible reasons include:
  - Rapid evolution due to higher density/pressure in the general ISM?
  - High CSM densities due to enhanced mass loss from progenitors?
- Some additional young SNRs may remain to be discovered via additional spectroscopy.

M83 Data Sets

- Magellan 6.5 m IMACS ground-based images
  - Blair et al. 2012, ApJS, 203, 8 (>225 optical SNR candidates)
- Chandra X-ray Observatory (730 ks)
  - Long et al. 2014, ApJS, 212, 21 (>440 pt X-ray sources)
- HST WFC3 Cy19 Imaging of 5 (+2 ERS) fields
  - Blair et al. 2014, ApJ, 788, 55 (63 SNRs <11 pc in size)
- Gemini South/GMOS Spectroscopy (7 masks; ~100 objects); (line ratios and kinematics)
  - Winkler et al. (2016, in preparation)
- EVLA and ATCA radio surveys
  - ATCA (2011) reported in Long et al. 2014, ApJS, 212, 21
  - New ATCA(2015) and EVLA data still being processed

Multi-wavelength Overviews of M83

Magellan 6.5m Imagery

D=4.6 Mpc (1" = 22 pc)

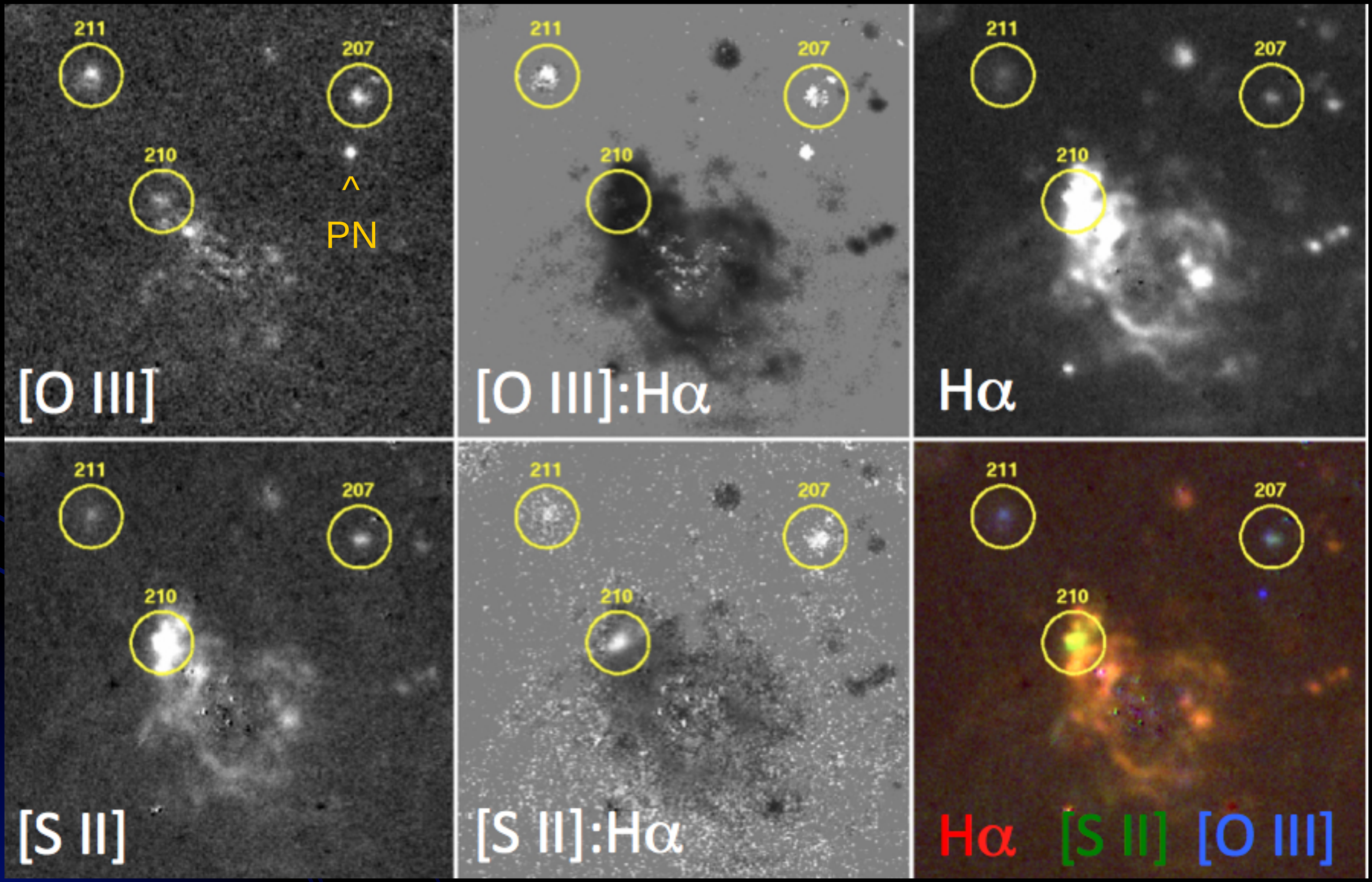
Chandra X-ray Observatory

Red: $H\alpha$ (w/stars)
Green: V-band
Blue: B-band
Also [S II] and [O III]

Six SNe observed since 1923 →
~70 SNRs < 1000 years old!
(Many core collapse SNe expected due to all the star formation)

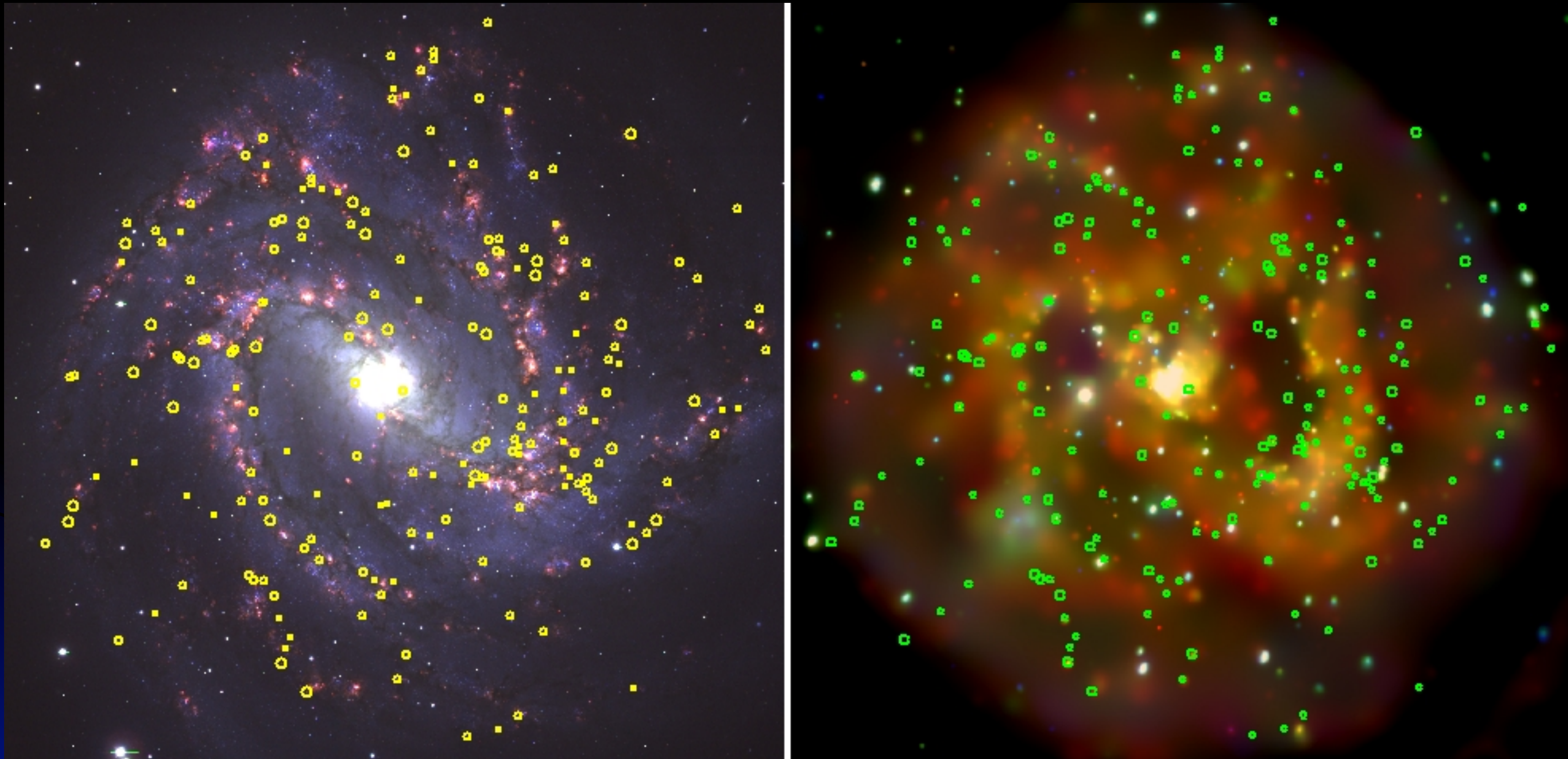
729 ks, ACIS-S
Red: 0.5 – 1.1 keV (soft)
Green: 1.1 – 2.4 keV (med)
Blue: 2.4 – 8 keV (hard)

Magellan Data Example
(27'' FoV)



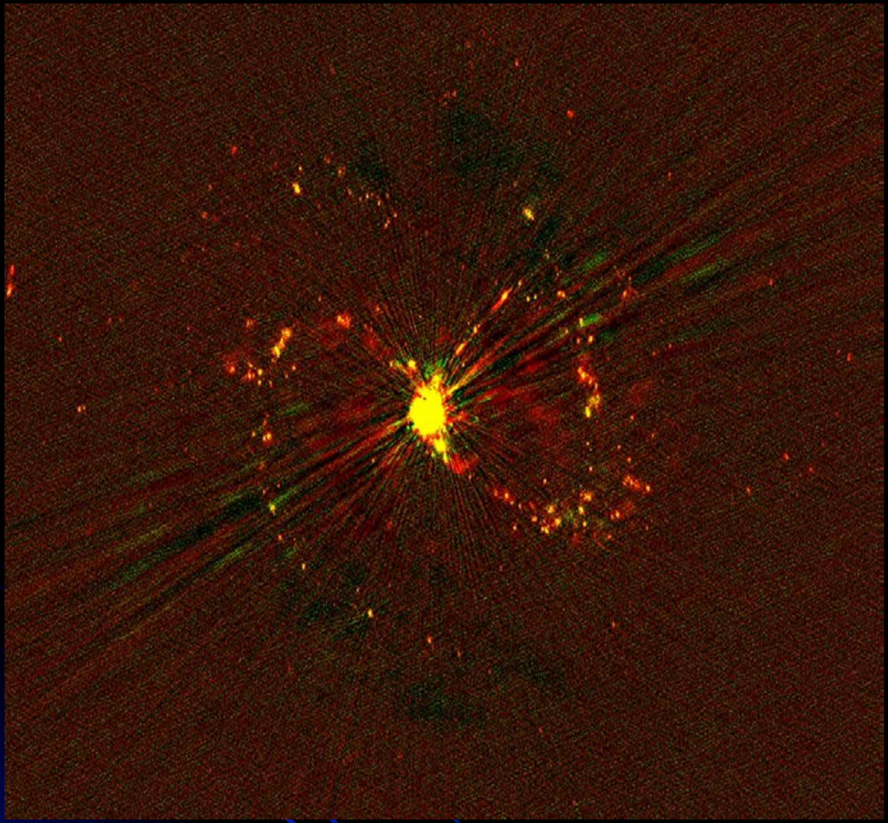
Magellan/IMACS SNR Survey*

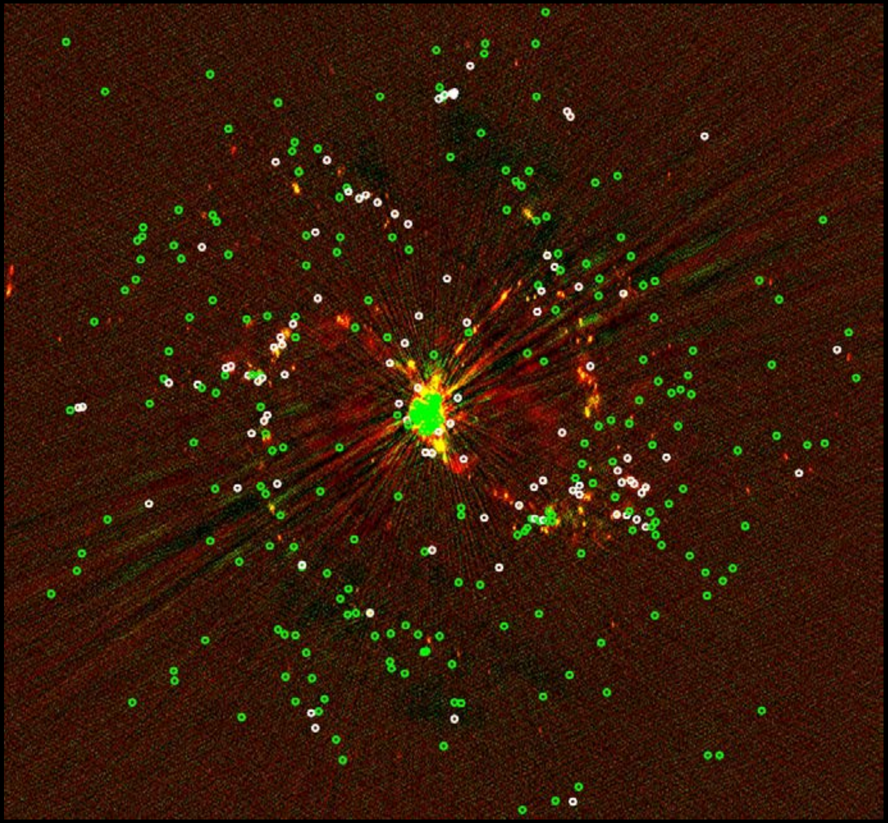
* Blair et al. 2012, ApJS, 203, 8



- >225 ISM-dominated SNRs identified! (87 with *Chandra* counterparts)
- 46 relatively strong [O III] emitters (possible ejecta-dominated SNRs) have NOT panned out. (More later…)

ATCA 2015 maps

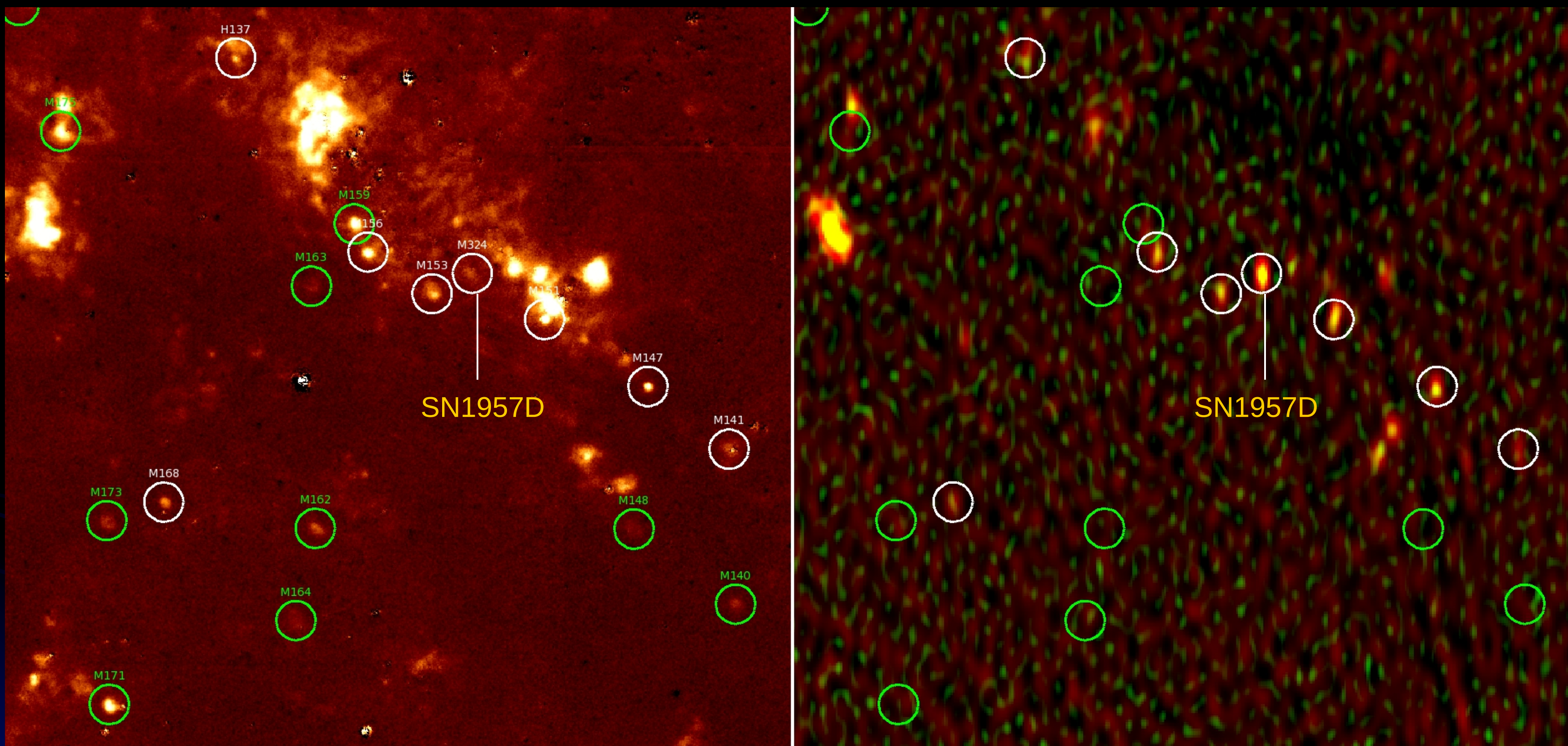




Red: 5 GHz   Green: 9 GHz
>180 sources not incl. nucleus

Optical SNRs (85 in white have obvious radio)

Magellan-ATCA 2015 Comparison

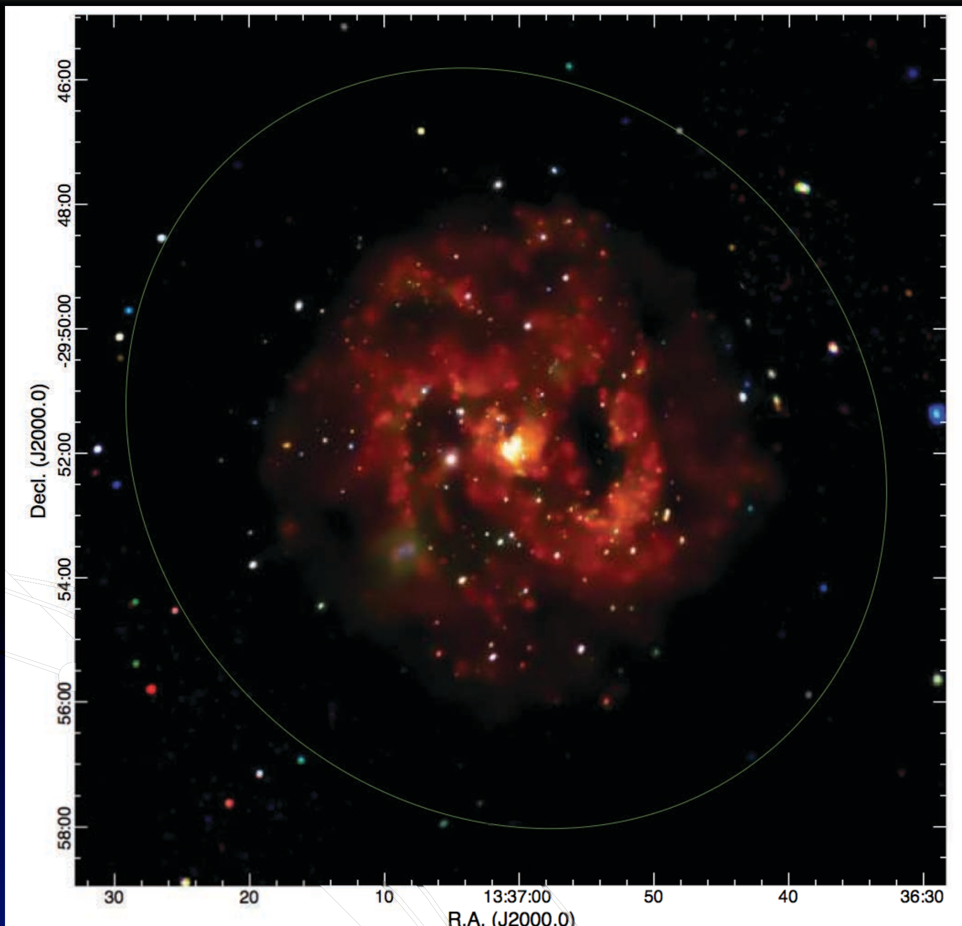


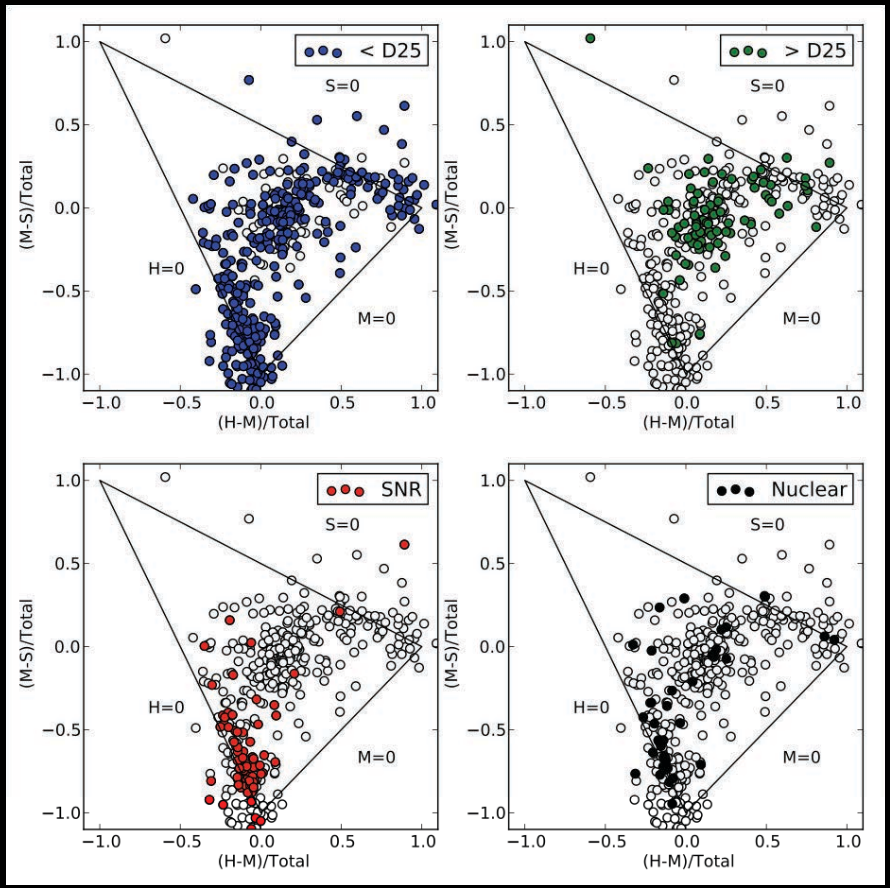
Magellan [S II] continuum subtracted

Optical SNRs (white have radio)

(75 arcsec region of northern spiral arm is shown)

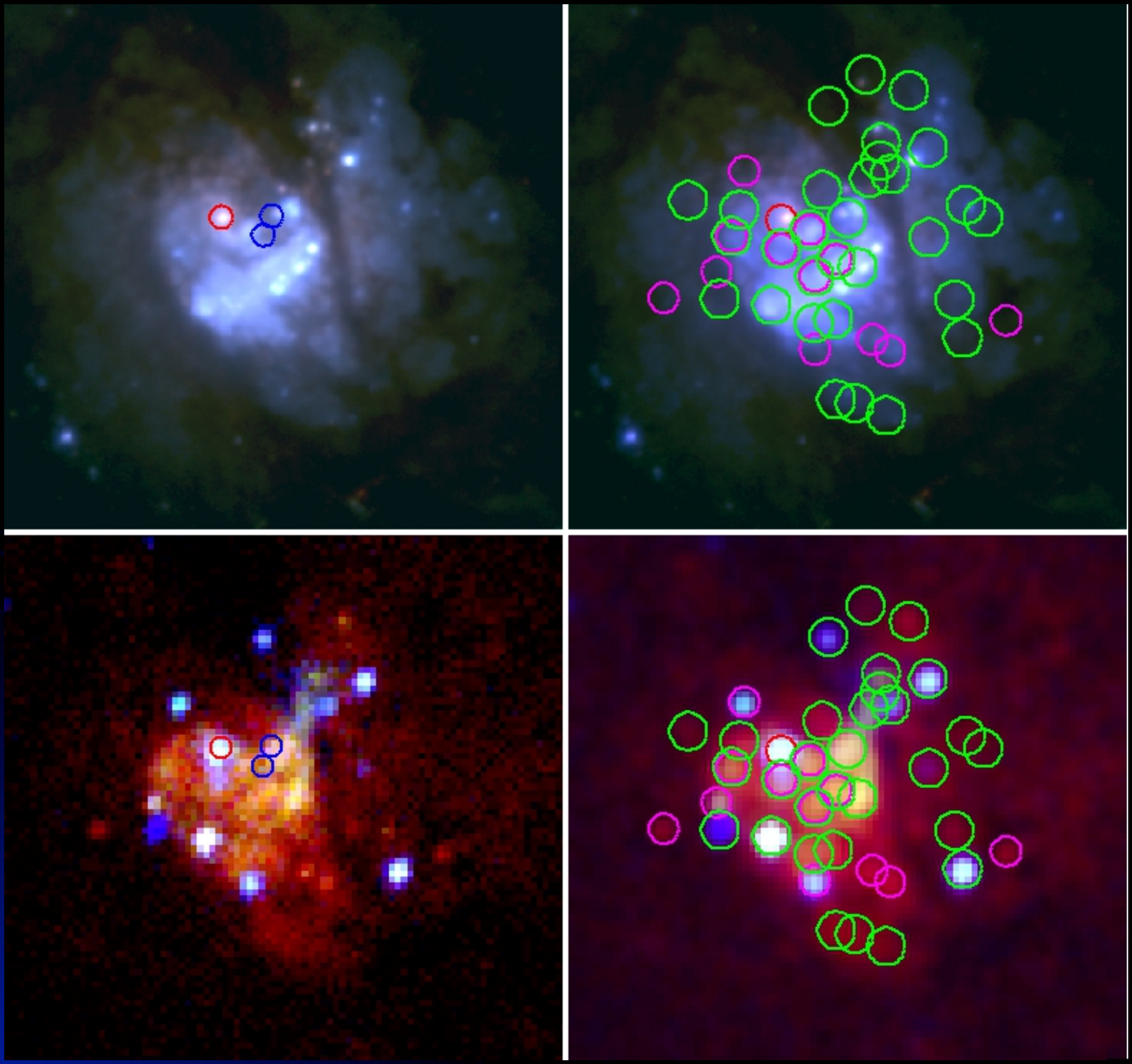
M83 *Chandra* Summary





Long et al. 2014, ApJS, 212, 21 >450 point sources plus strong diffuse X-ray gas.
Points to hot, high pressure ISM, especially in arms.
At least 87 X-ray sources align with optical SNRs.

M83 Complex Nuclear Region



Top: Magellan continuum
Bottom: Chandra RGB

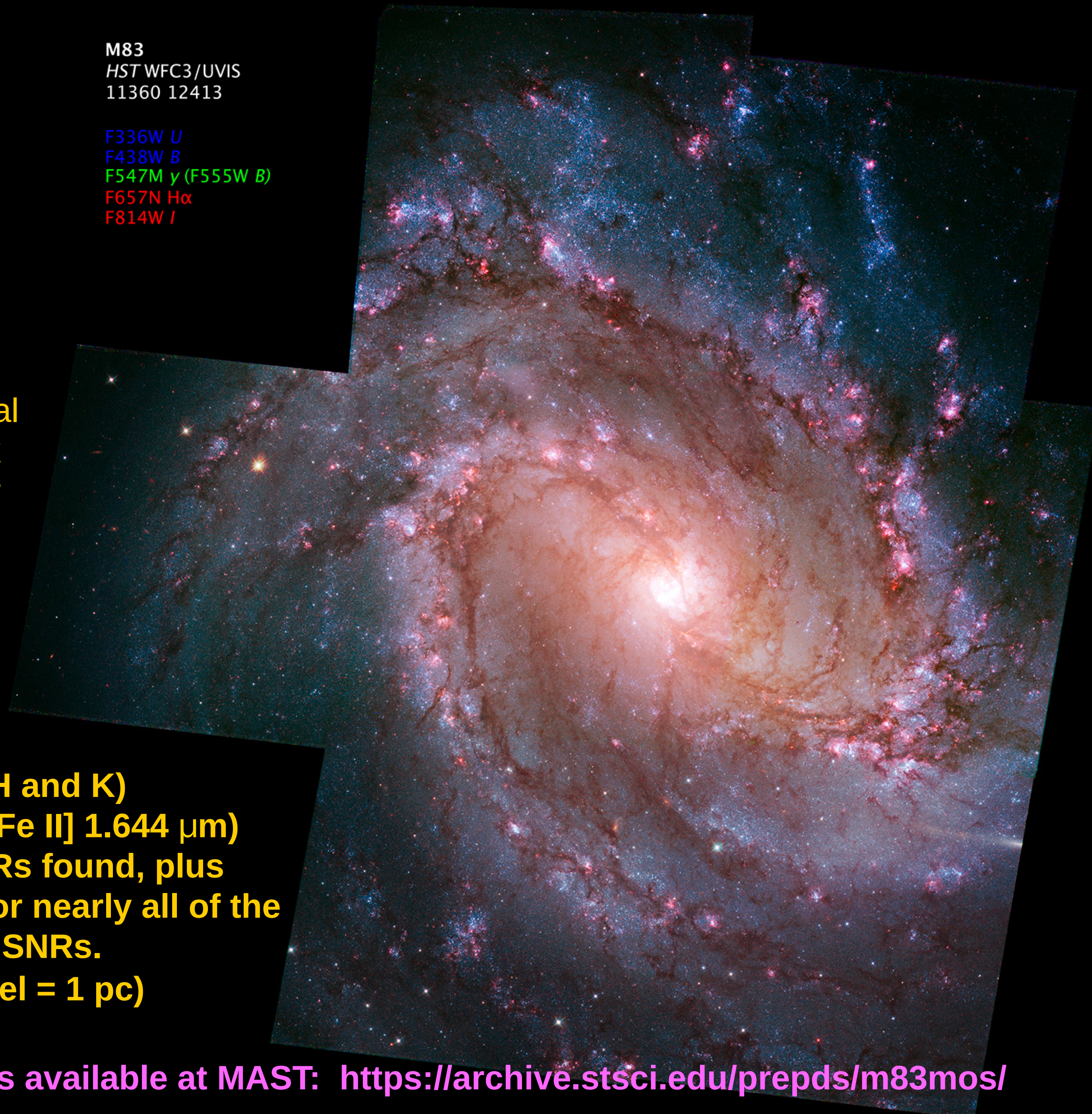
Green circles: XRBs
Magenta circles: HST SNRs

Circles in left panels are the optical nucleus and two different assessments of the dynamical center.

All Seven WFC3 Fields

Alignment and astrodrizzle of individual fields thanks to Derek Hammer and Jennifer Mack, STScI

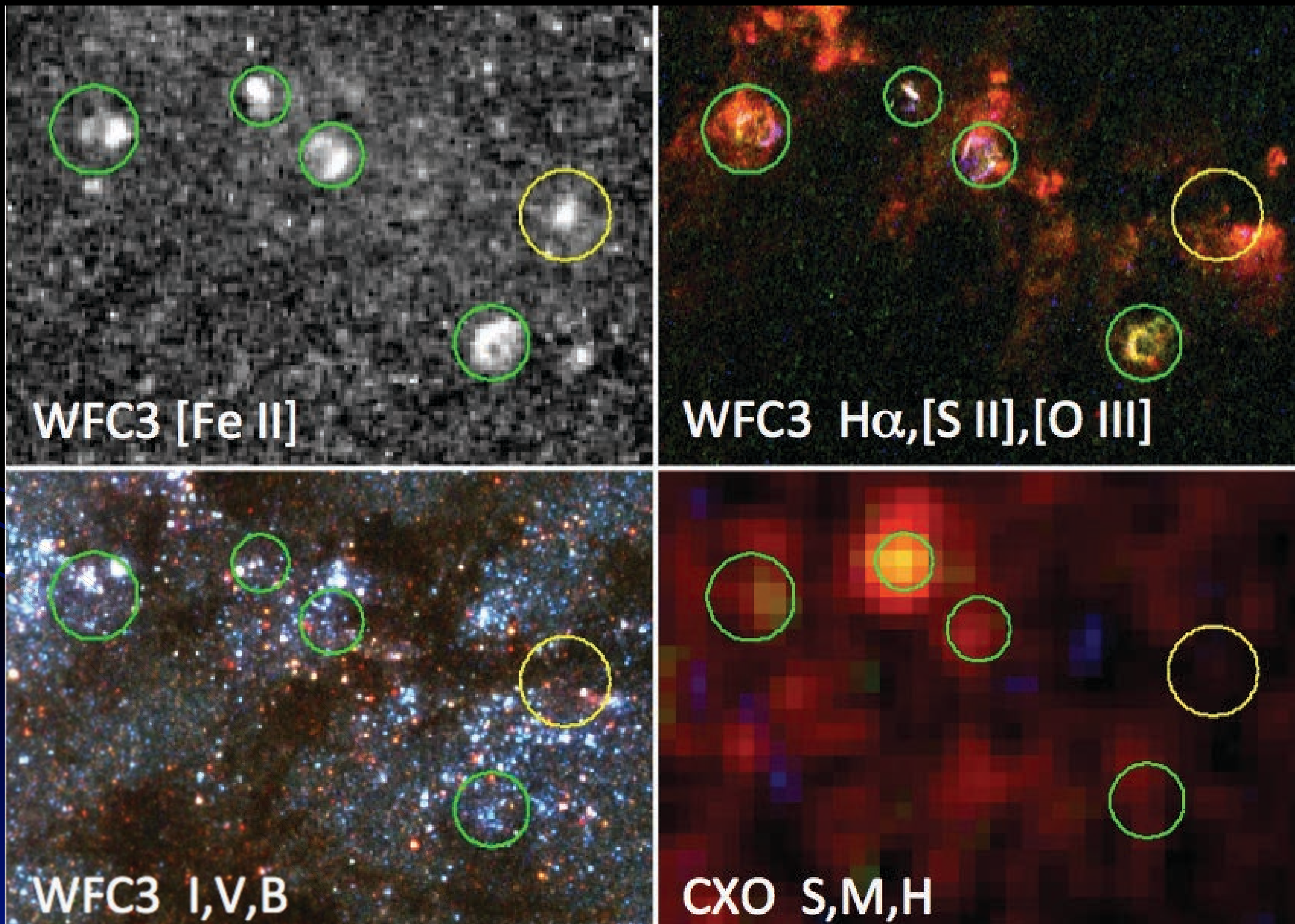
Seven field mosaic thanks to Zolt Levay, STScI.



U, B, V, I, (H and K)
Hα, [S II], [O III], ([Fe II] 1.644 μm)
46 additional SNRs found, plus accurate diameters for nearly all of the Magellan SNRs.
(1 WFC3 pixel = 1 pc)

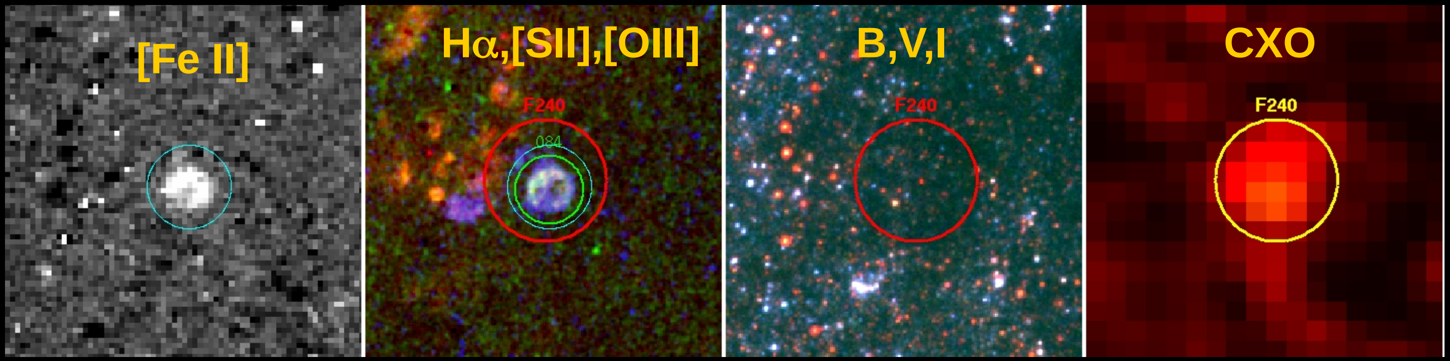
Full aligned mosaics available at MAST: https://archive.stsci.edu/prepds/m83mos/

Five SNRs in One 15''x20'' FoV



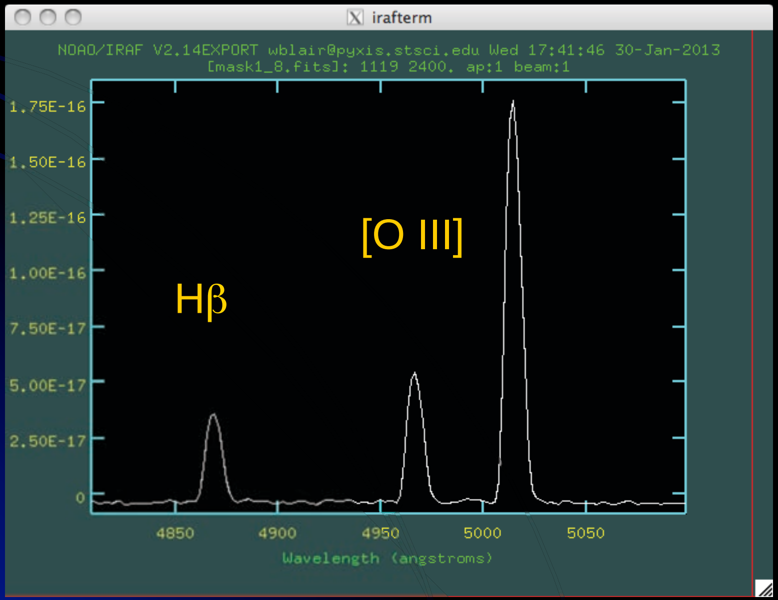
A "Cygnus Loop" in M83

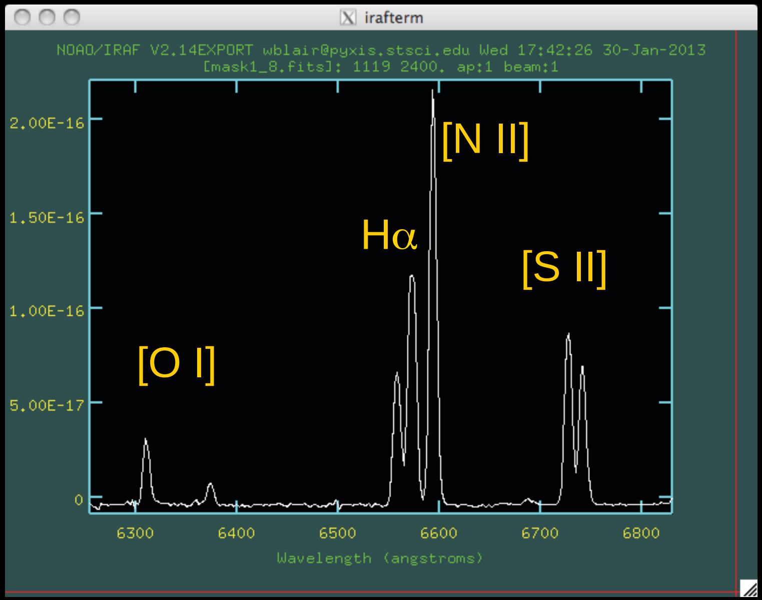
(B12-84, similar in size to the Cygnus Loop)



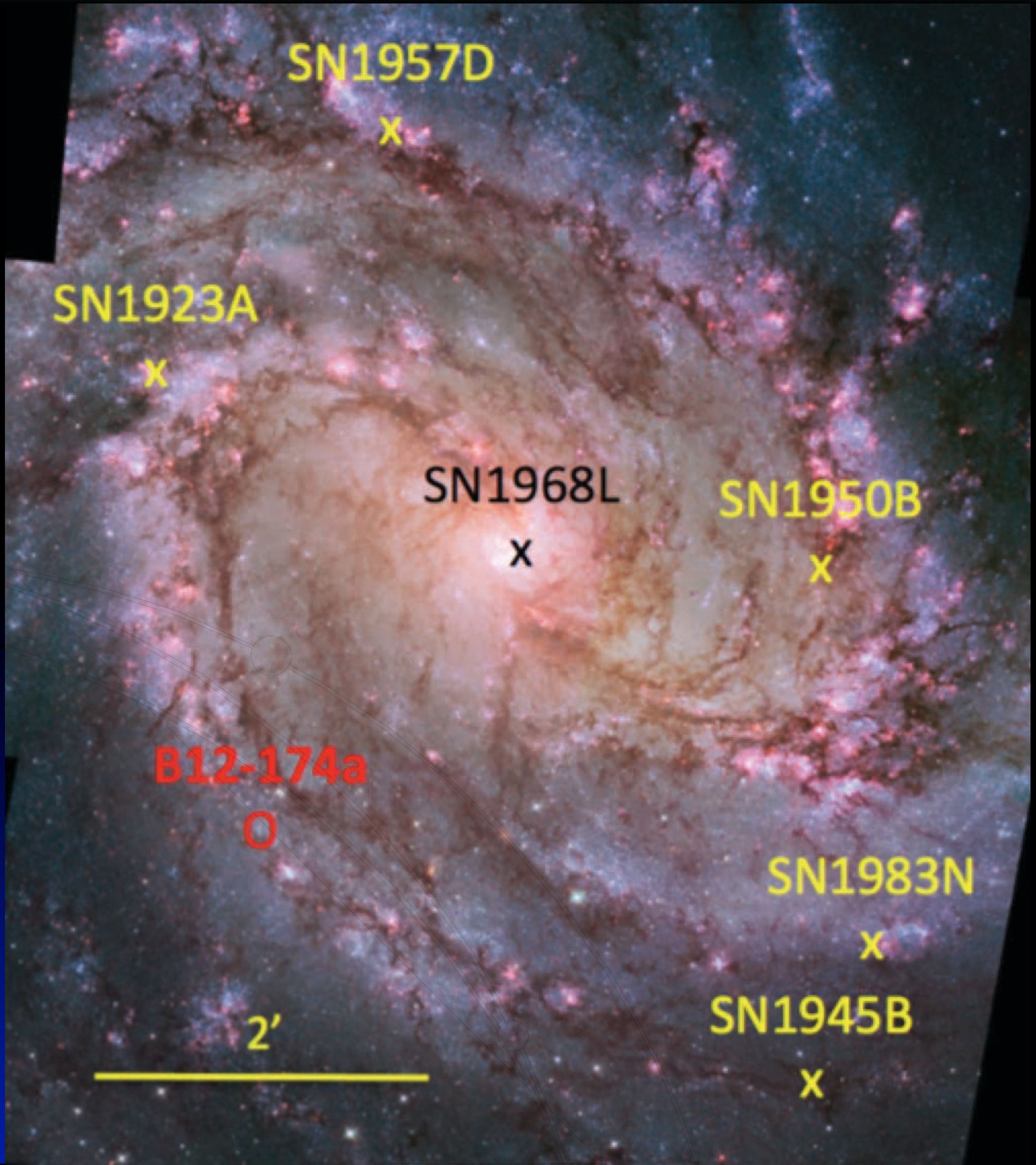
(Large circle is 3")

Gemini-S GMOS Spectra





6 (7?) Historical SNe in M83



SN ID	Type
SN1923A	II P:
SN1945B	?
SN1950B	?
SN1957D	II
SN1968L	II P
SN1983N	Ic
B12-174a	(C-C)

(Types from Asiago catalog)

With this many SNe in last century, expect 60-70 SNRs <1000 years post-explosion.

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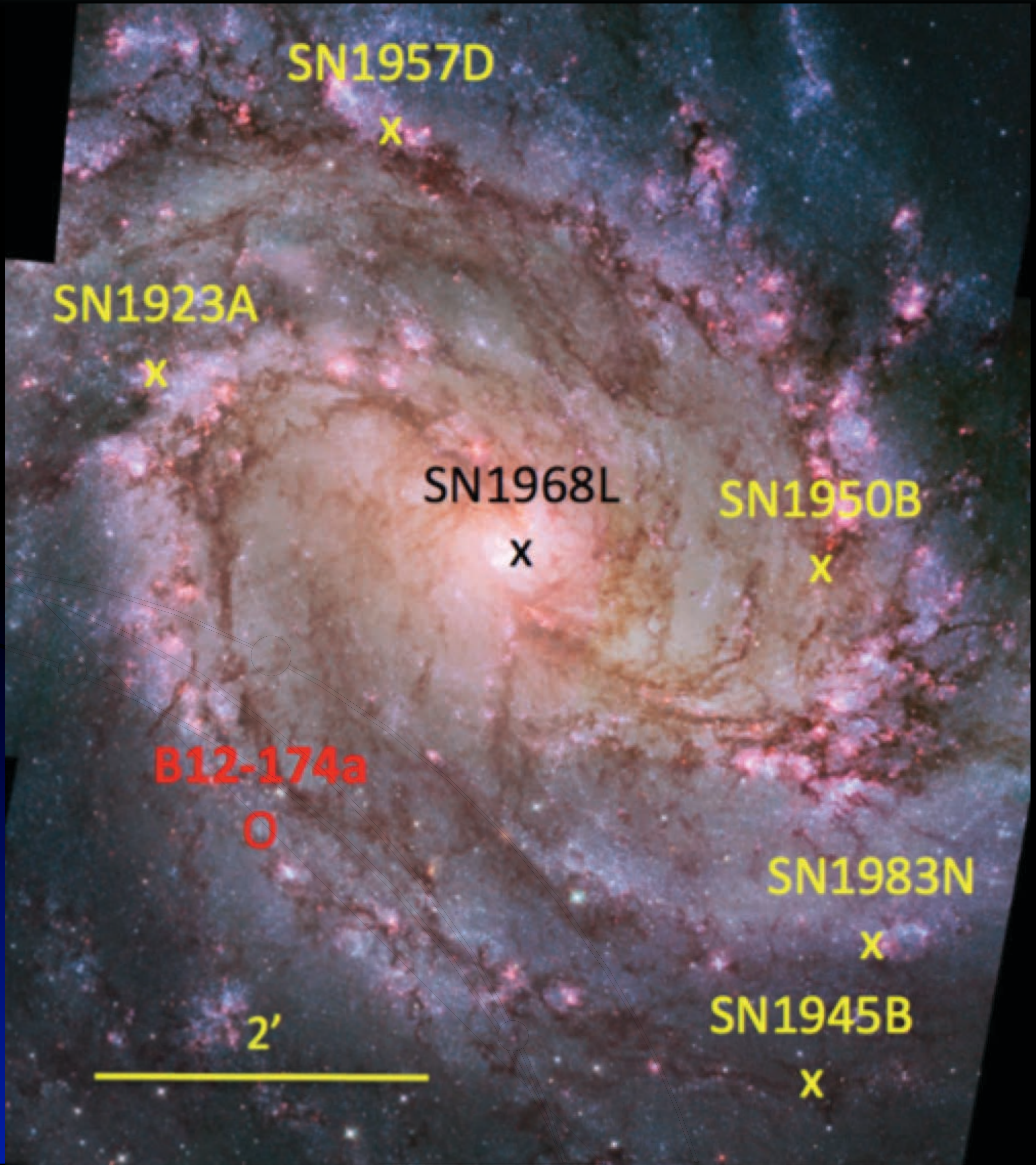

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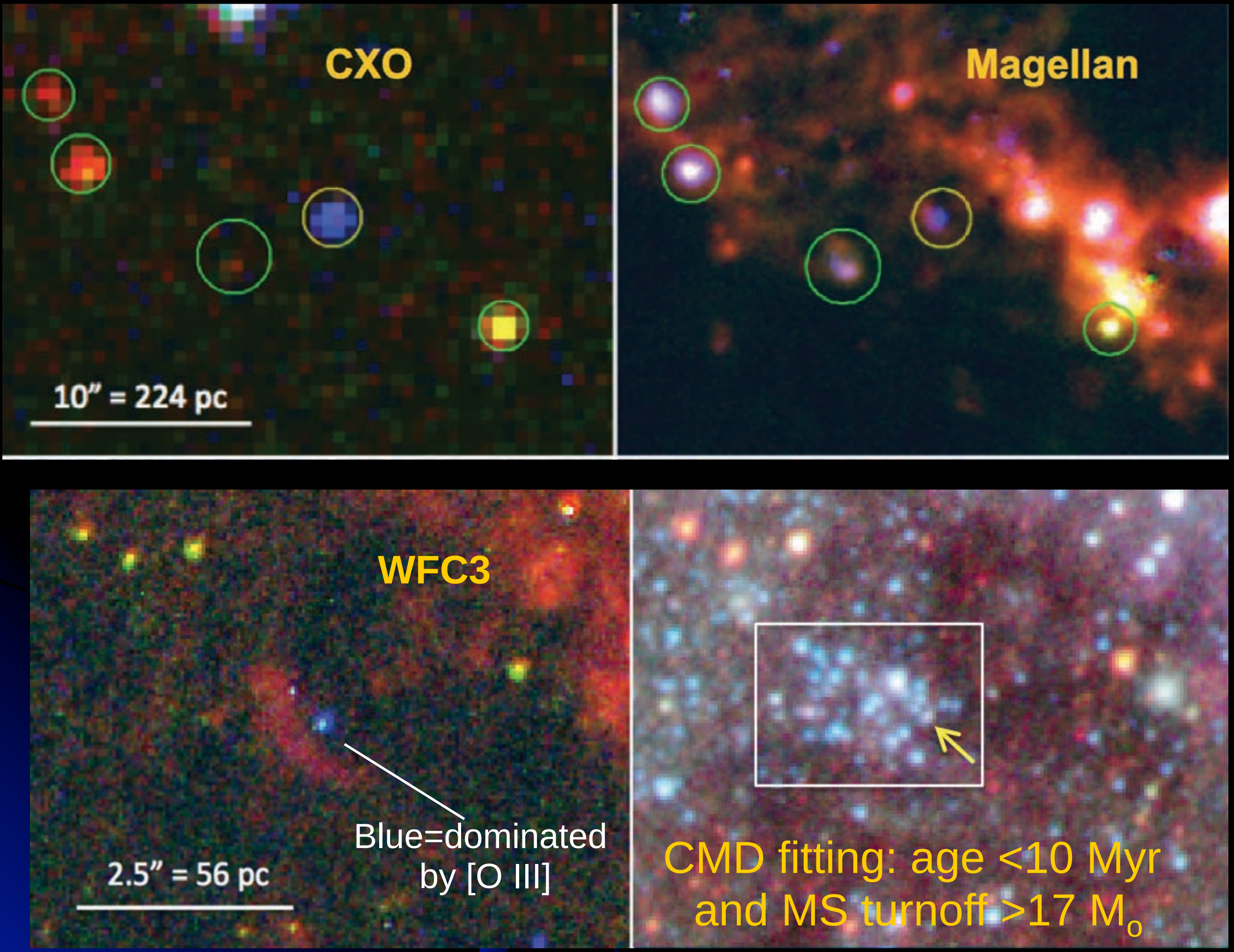
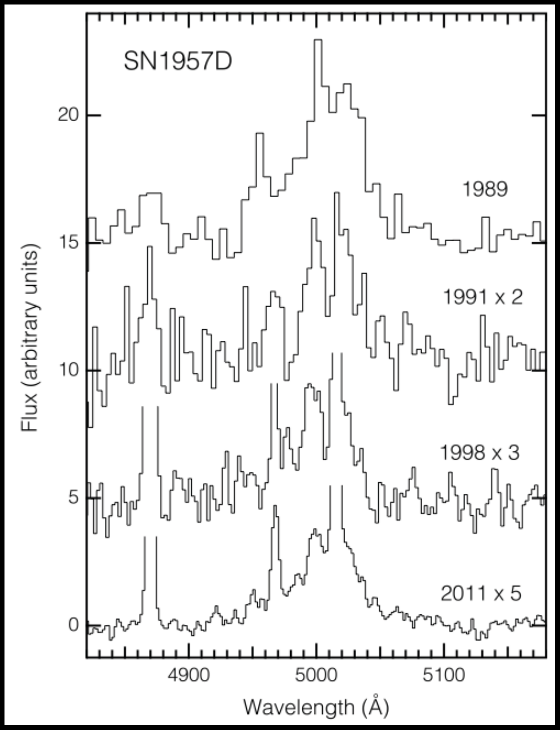
X-ray & Optical Counterpart of SN 1957D

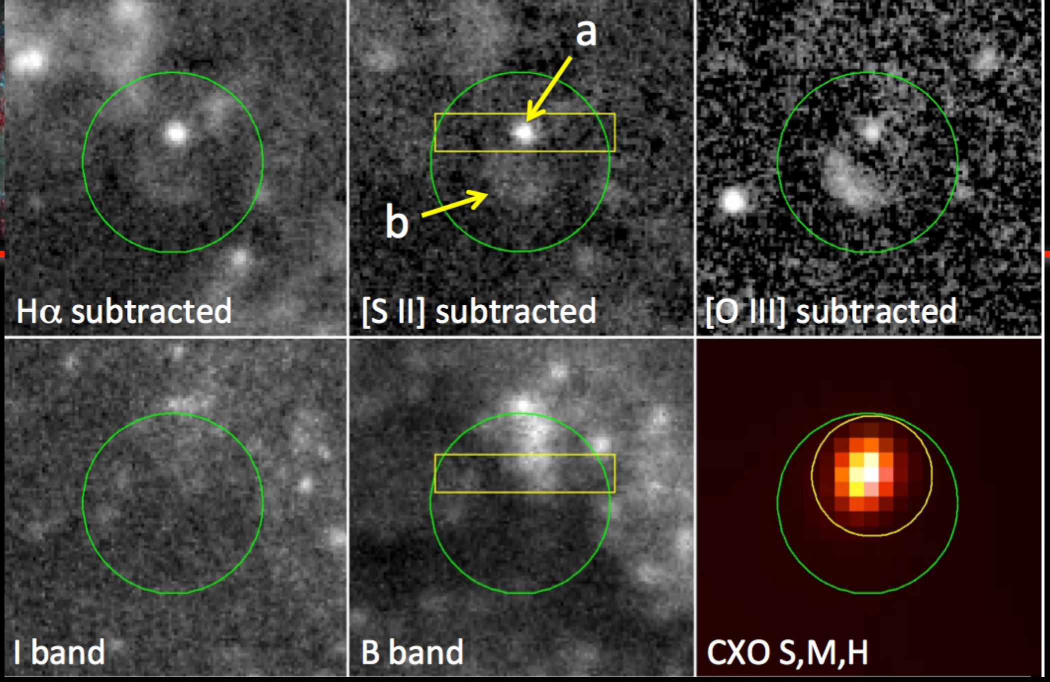
(A very young ejecta-dominated SNR)



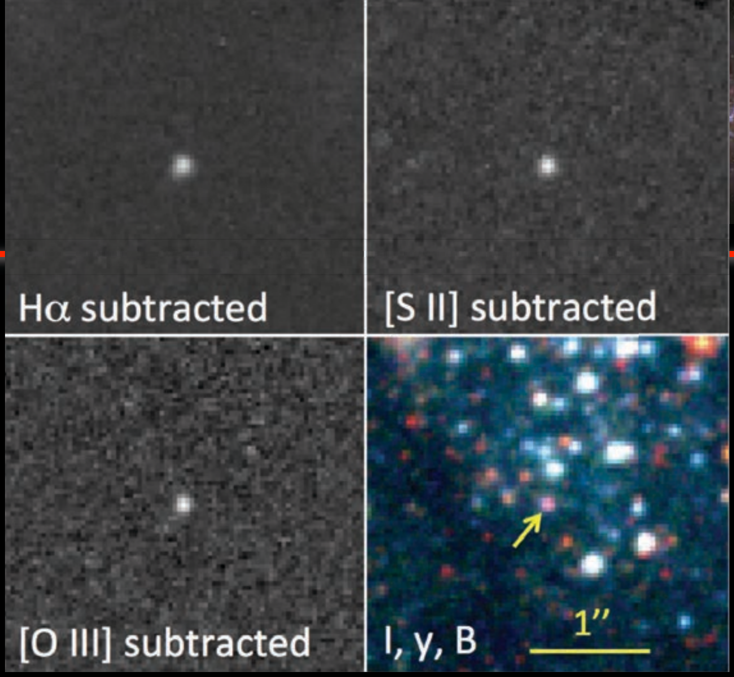


Broad ejecta lines, but decreasing in intensity rapidly over time… (A clue?)

Long et al. 2012, ApJ, 756, 18

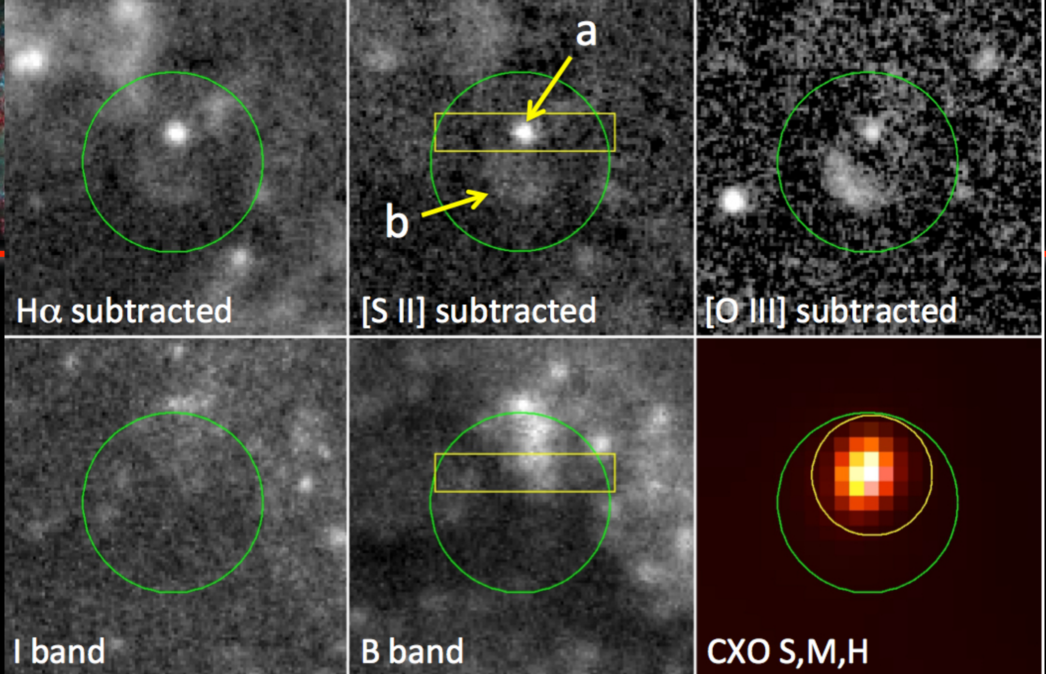


Magellan images, 10” FoV

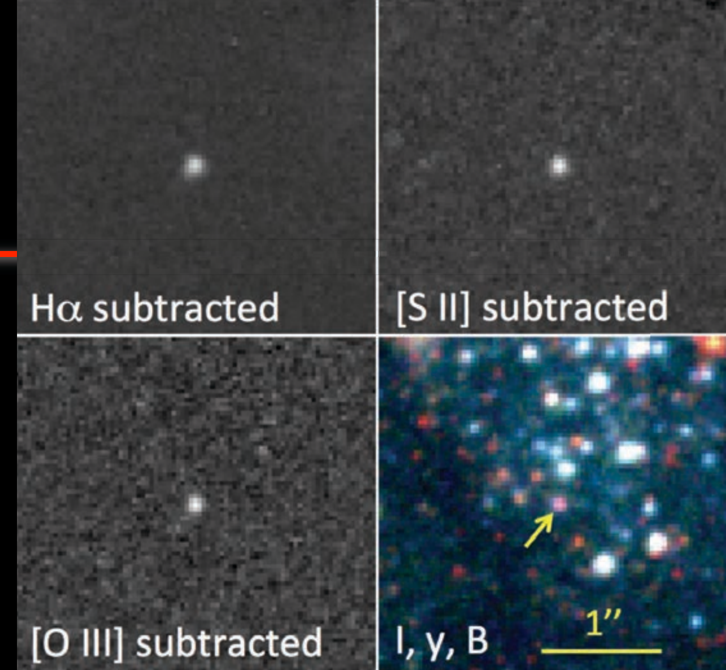


HST WFC3 images, 3” FoV

B12-174a: A newly recognized very young SNR in M83



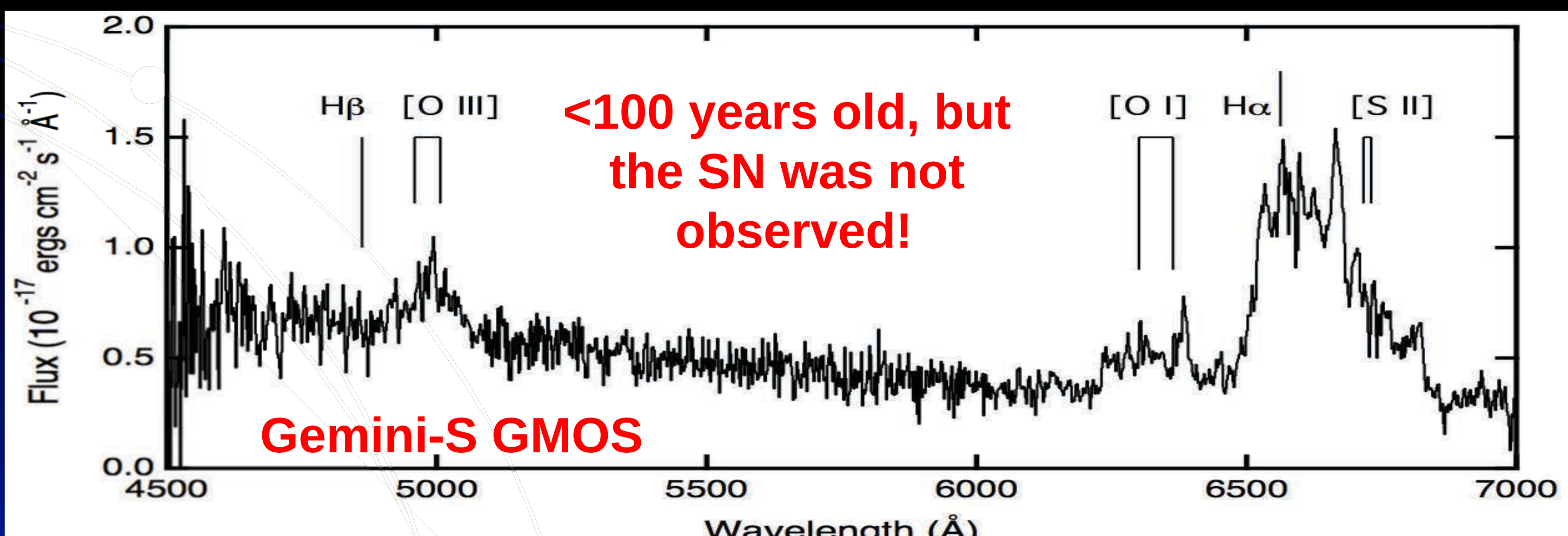
Magellan images, 10” FoV



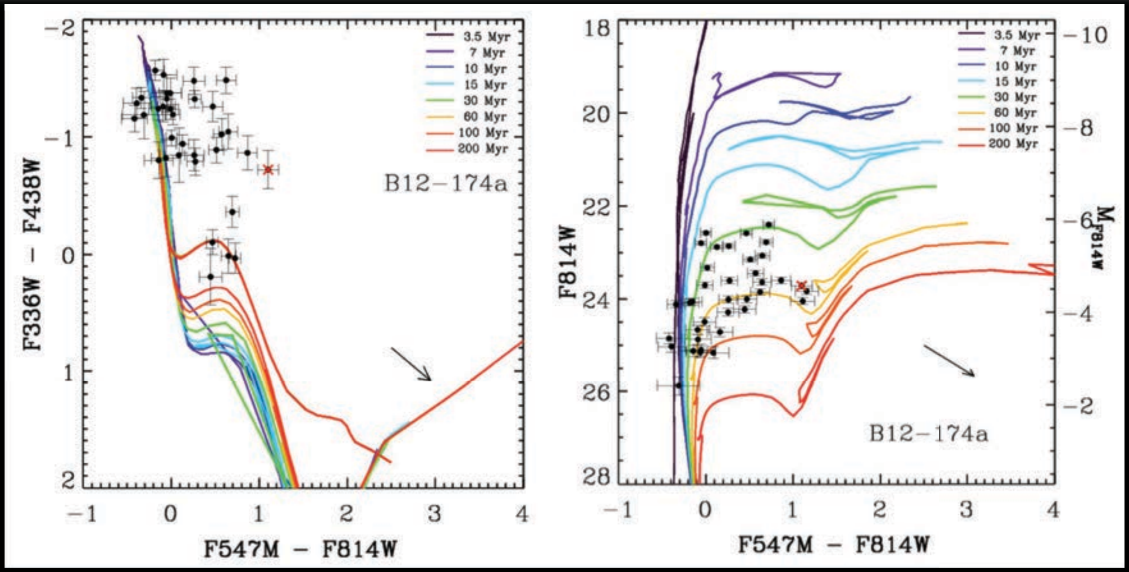
HST WFC3 images, 3” FoV

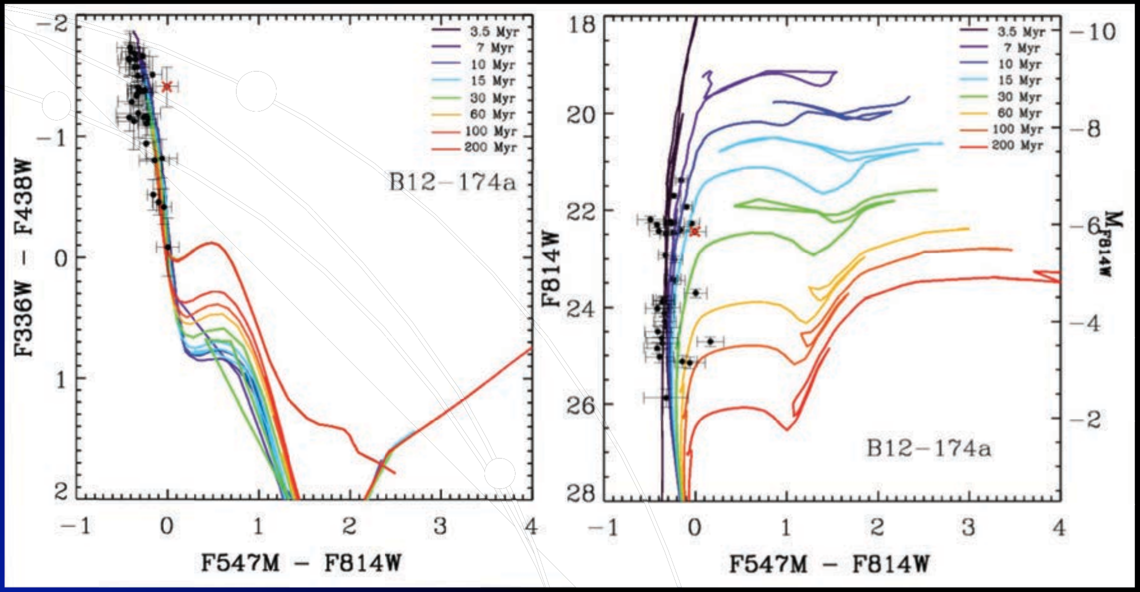
B12-174a: A newly recognized very young SNR in M83

Blair et al. (2015)



M83 B12-174a Photometry





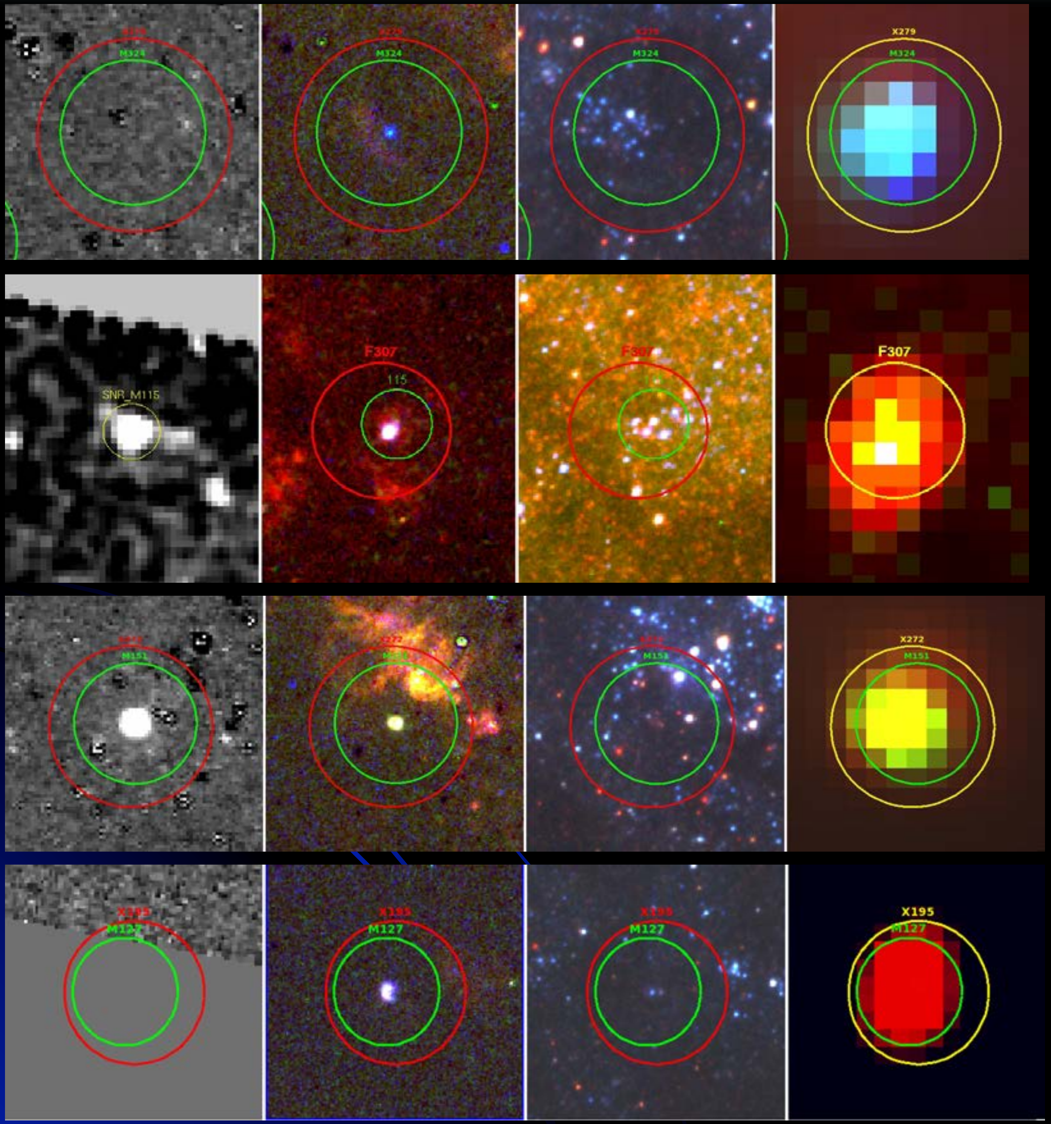
Observed photometry for cluster near B12-174a.

Reddening-corrected stars cluster on the youngest isochrones, indicating a population age of <10 Myr and a MS turnoff >17 M_o

(Note: SN1957D region is essentially identical to this.)

(See Blair et al. 2015, ApJ, 800, 118)

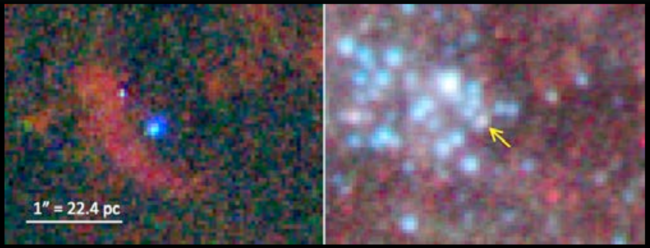
The Binarity Issue — Possible Companions?



B12-115

B12-151

B12-127



SN 1957D

These are some of the best examples, but there are numerous other possible cases to investigate.

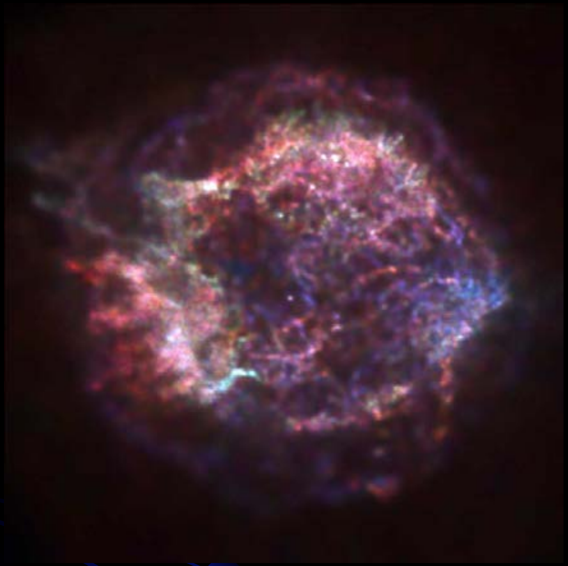
B12-174a

Young (Small) SNR Summary

- 63 SNR candidates with diameters below 0.5" (or 11 pc).
  - 37/63 were previously known SNR candidates but there small sizes were unknown prior to HST.
  - 26/63 were newly discovered with HST.
- 32 have *Chandra* X-ray counterparts.
- But only three objects look to be ~similar to our expectations of the "ejecta-dominated" paradigm.

Where are all the “Cas A’s”?

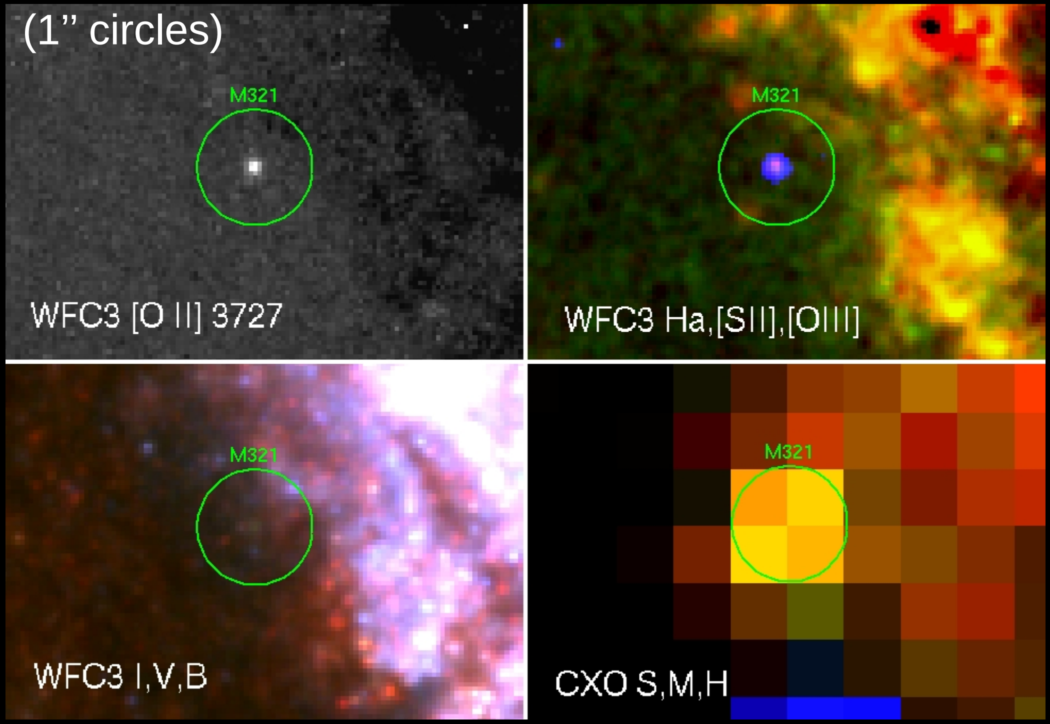
Cas A -- 340 years



Expected signature: a small diameter optical nebula dominated by [O III] (and possibly [S II] emission), coincident with a soft X-ray source.

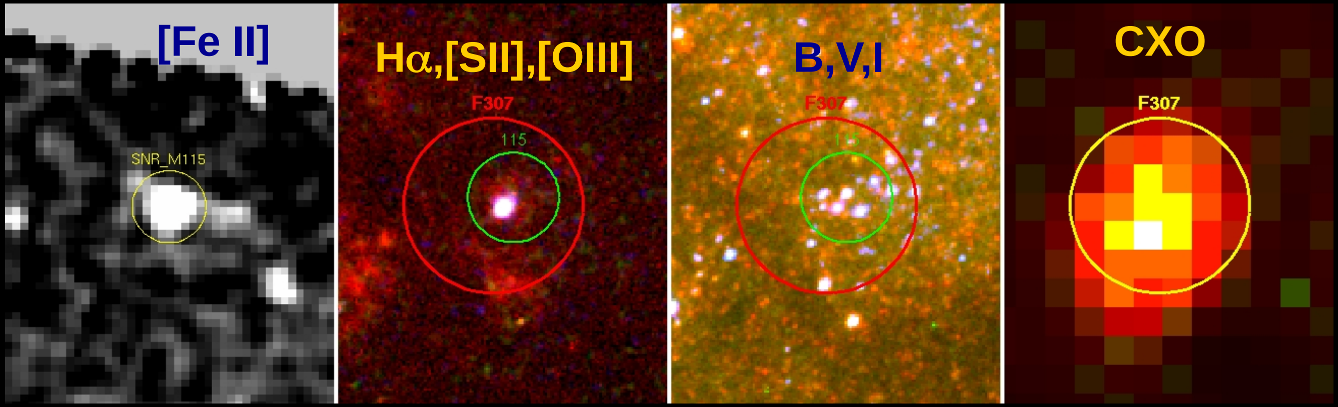
If such objects stay visible for ~1-2000 years (like E0102), one might have expected ~50-100 such objects in the M83 WFC3 fields.

So far, we found THREE examples: SN 1957D, B12-174a, and the object shown here, and even they are “different” from Cas A in significant ways!



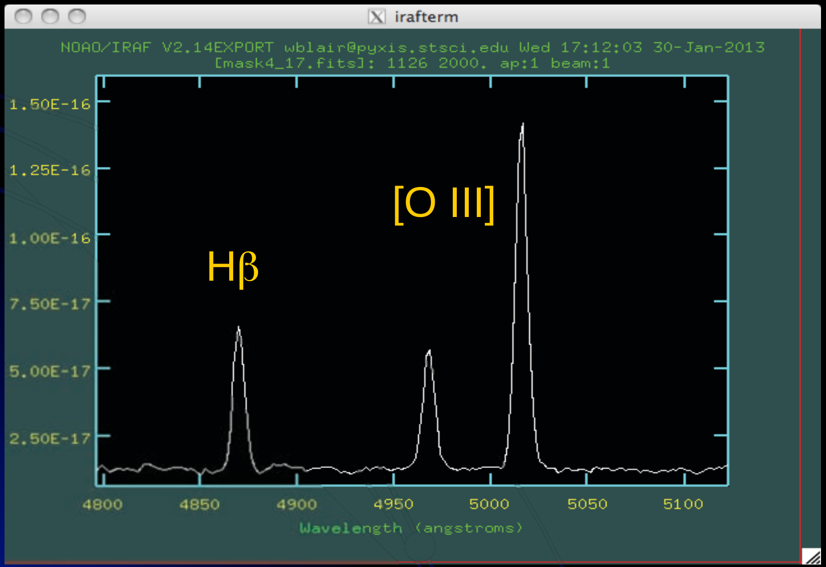
A "typical" young M83 SNR

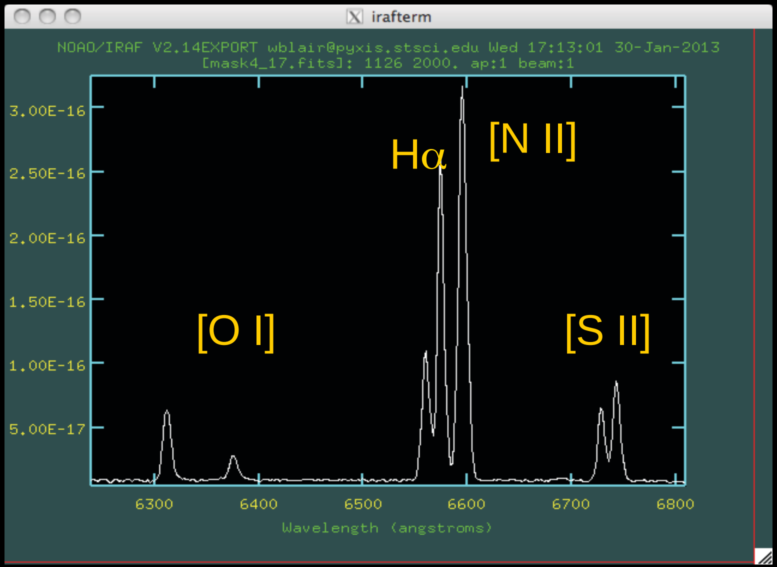
(B12-115; diameter=5.3 pc)



(Large circle is 3" or ~65 pc)

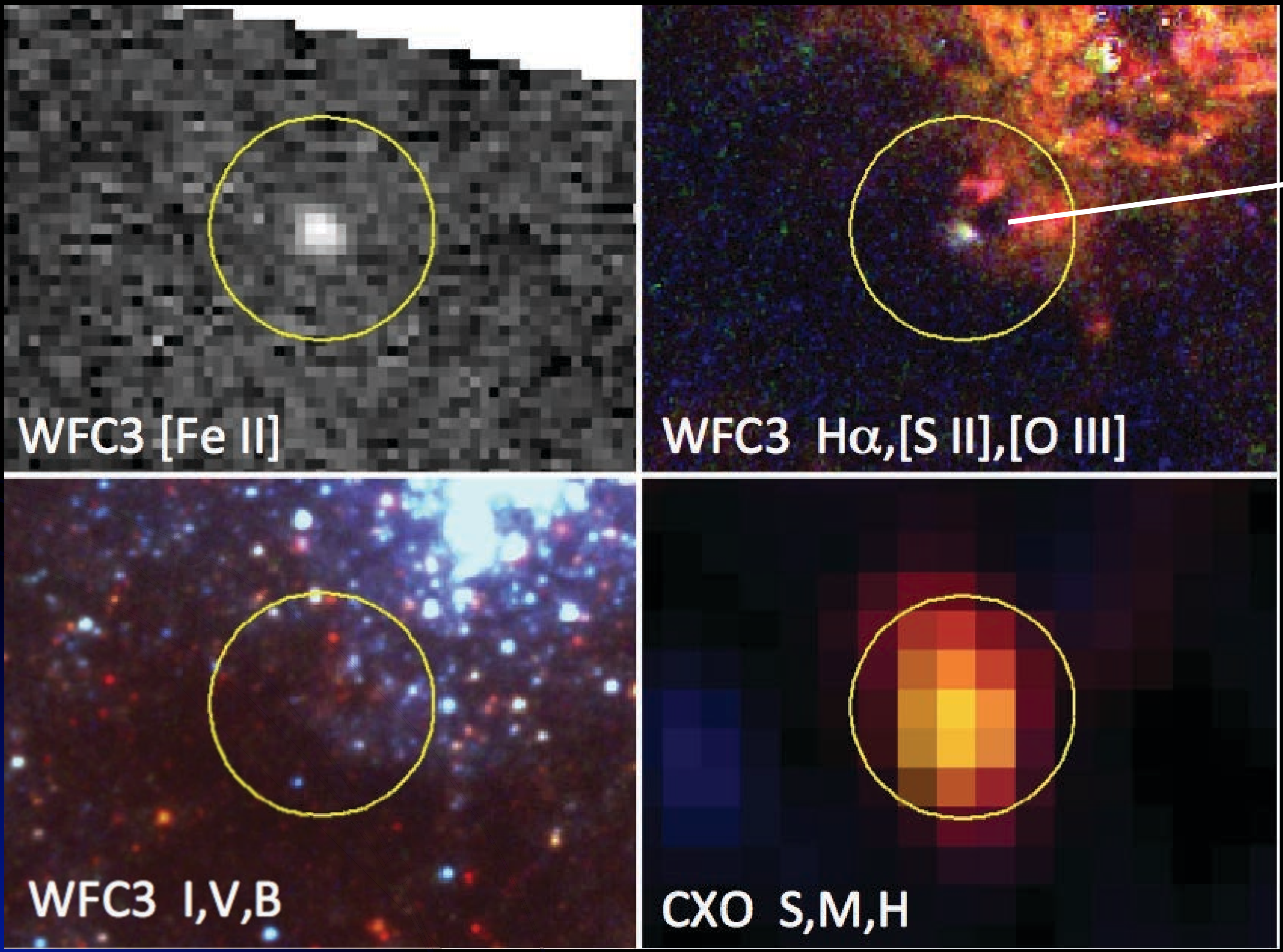
Gemini-S GMOS Spectra





Looks like the Cygnus Loop, except small Diam and high [S II] density…

A Newly Discovered SNR from HST/WFC3
(Circle is 3")

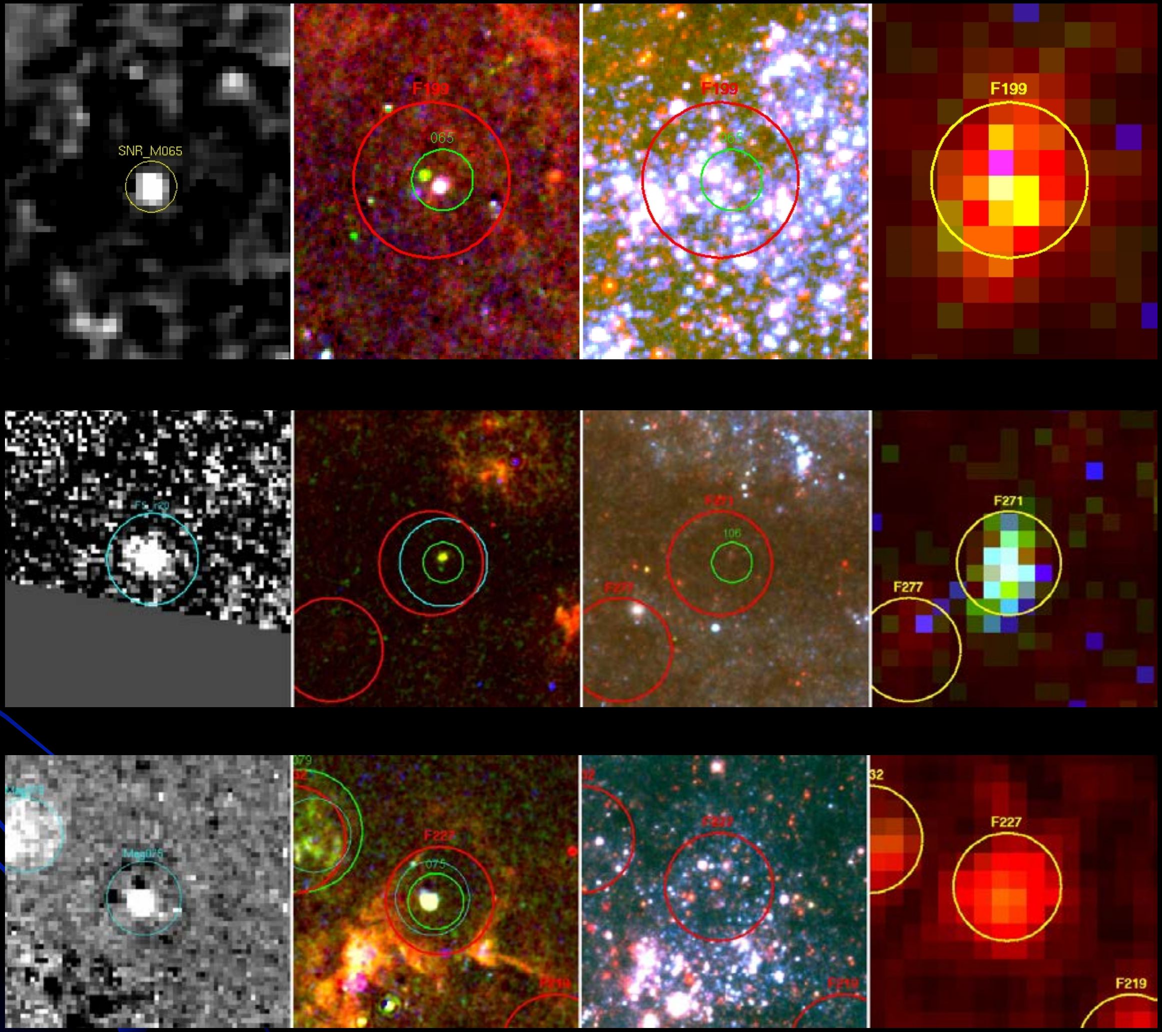


White means strong in all three bands,

=

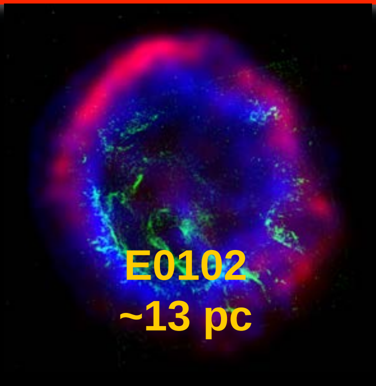
Radiative shock emission!

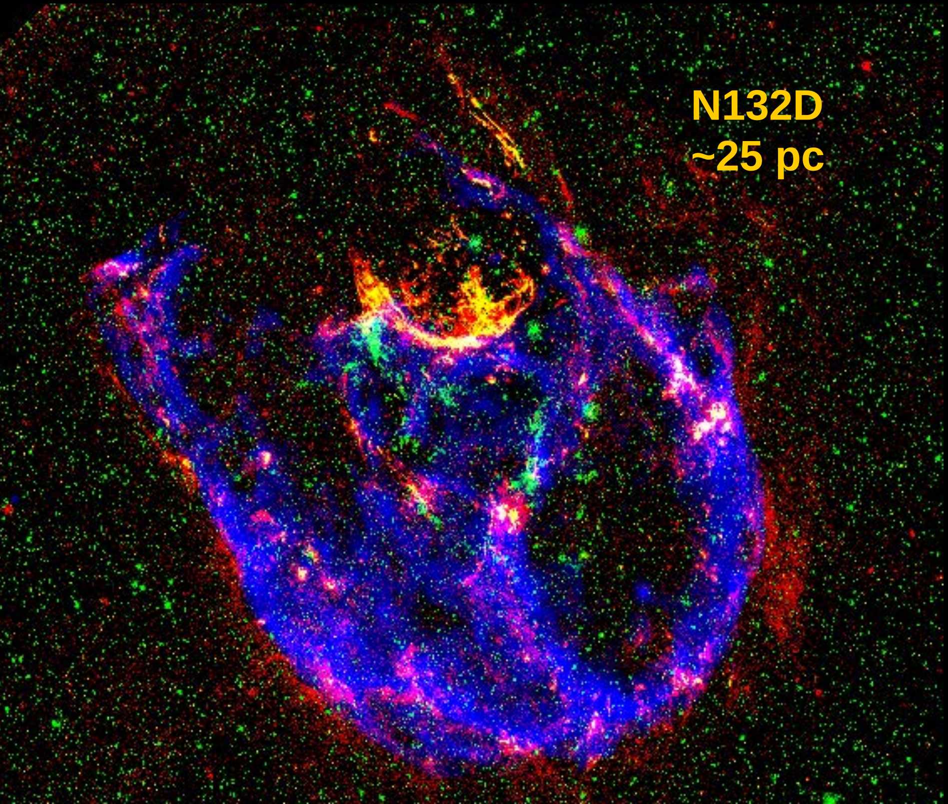
Many other young SNRs are basically similar…

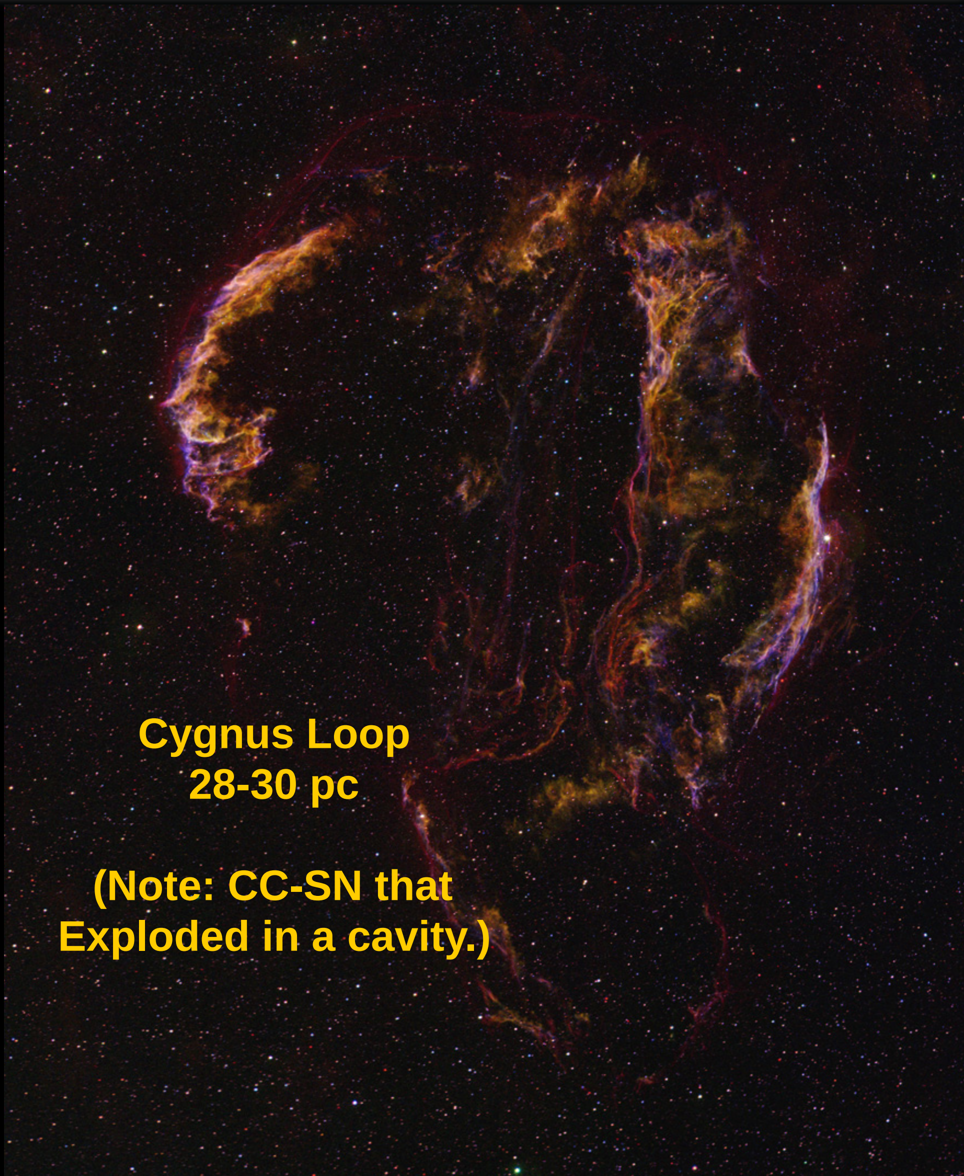


(Believe, me, I could bore you with many more…)

The CC-SNR Paradigm
(Approximate relative sizes shown)





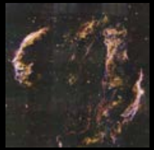


M83 SNRs are "different"

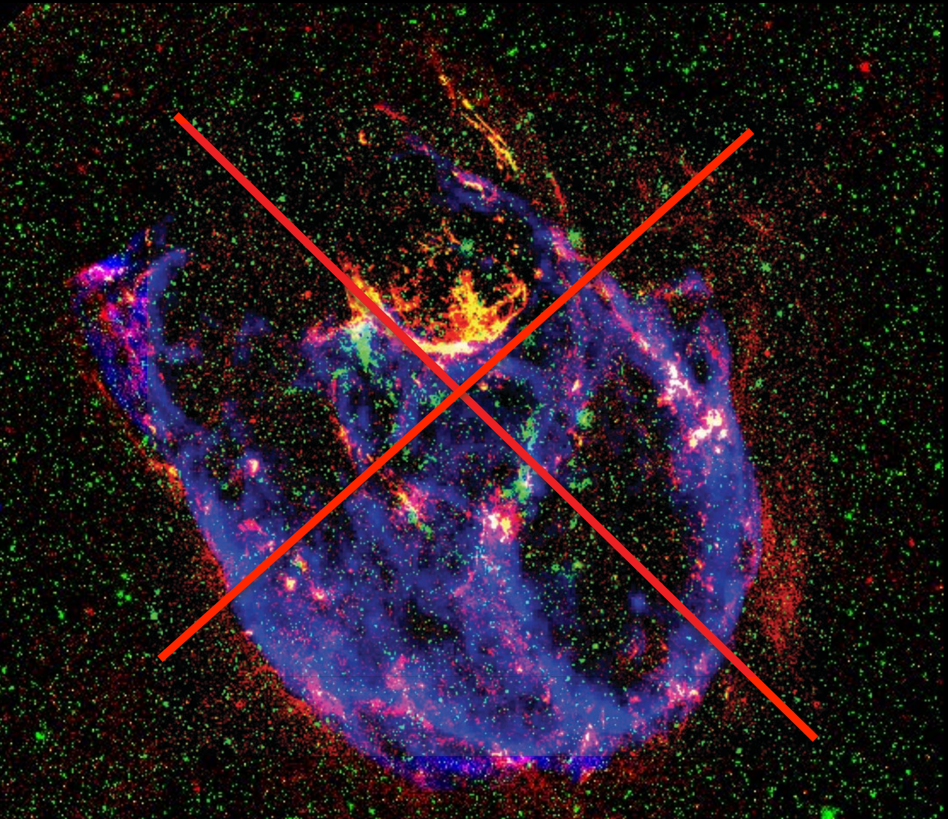
Cas A
5.6 pc

Crab
5x7 pc

E0102
~13 pc pc



Bright, radiative
"Cygnus Loops"
At diameters < 10 pc!



M83 SNRs are evolving very quickly into the radiative phase

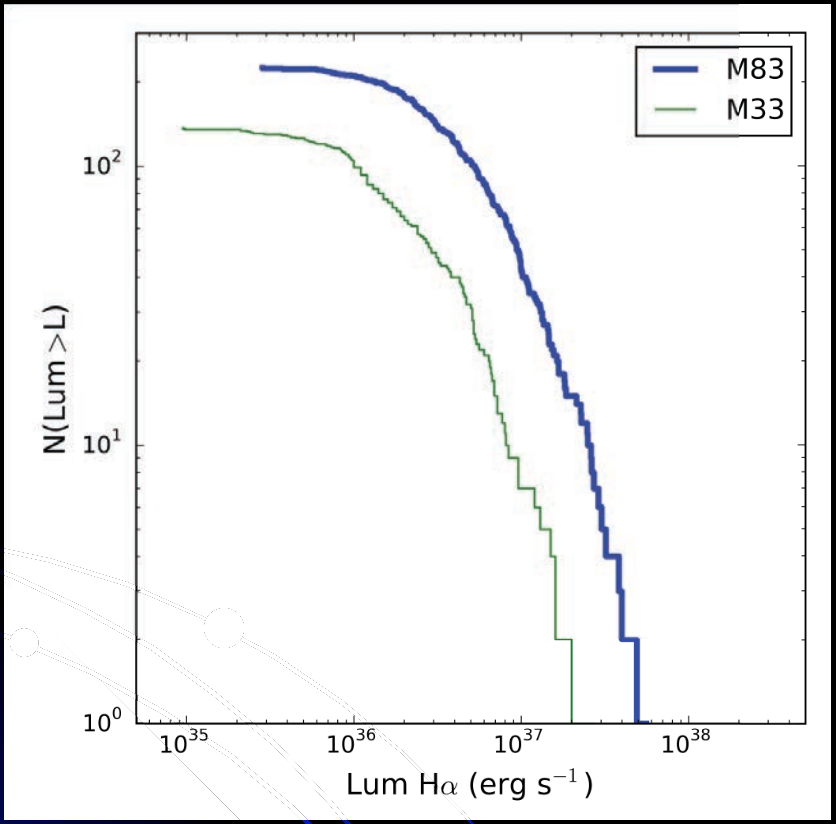
So what's going on??
(Possibilities…)

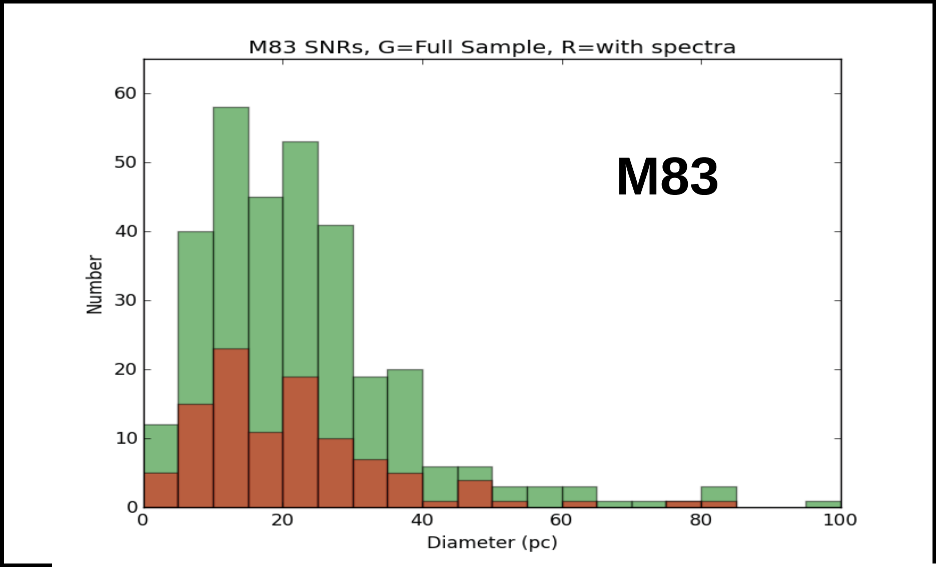
1. M83 has unusually high ISM pressures and densities.

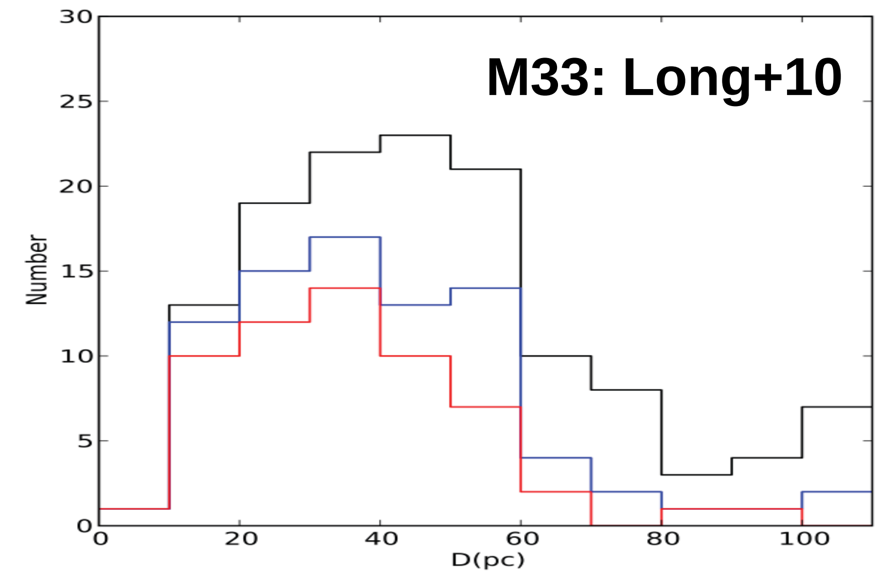
2. High abundances in M83 allow significantly higher stellar winds/ mass loss from SN progenitors; high density CSM around progenitors causes young SNRs to evolve quickly beyond the ejecta-dominated stage.

3. Some combination of 1. and 2.

M83 – M33 Comparison

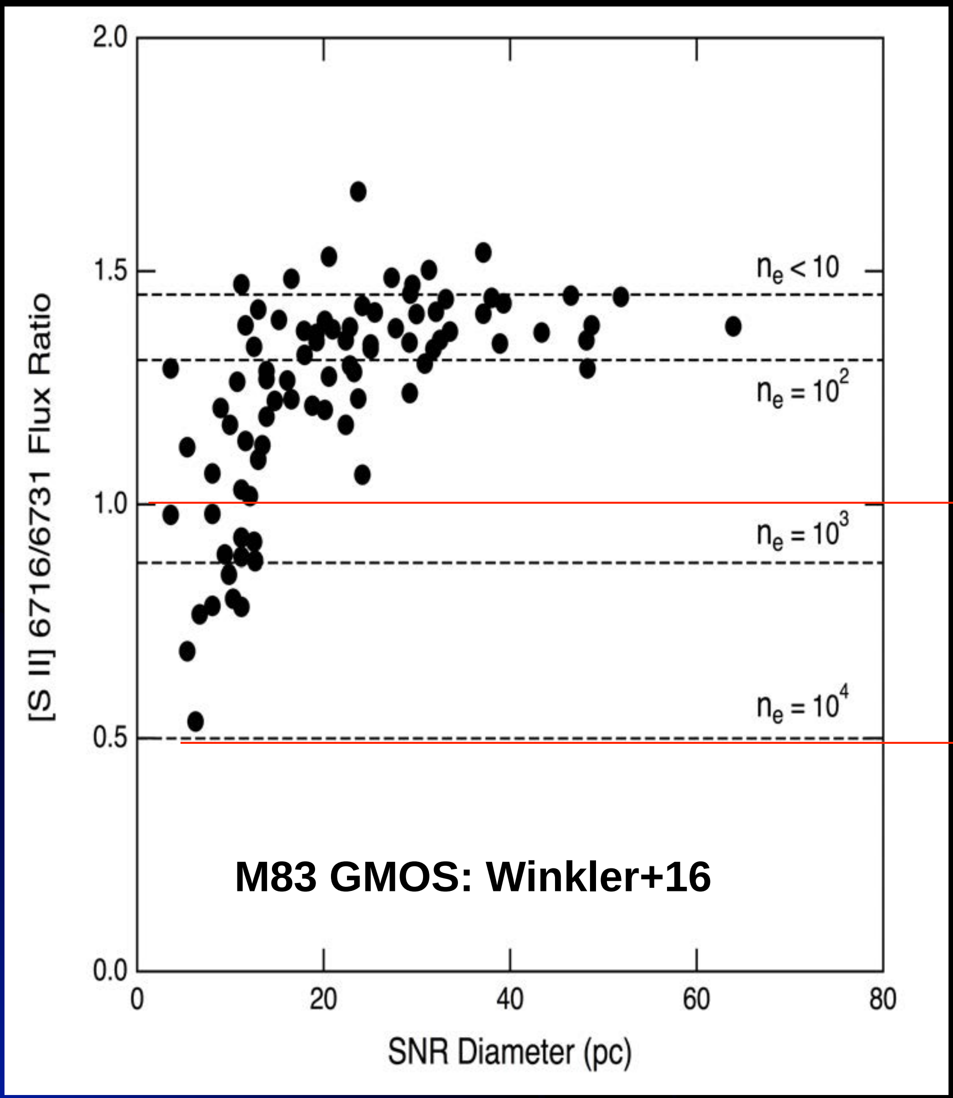




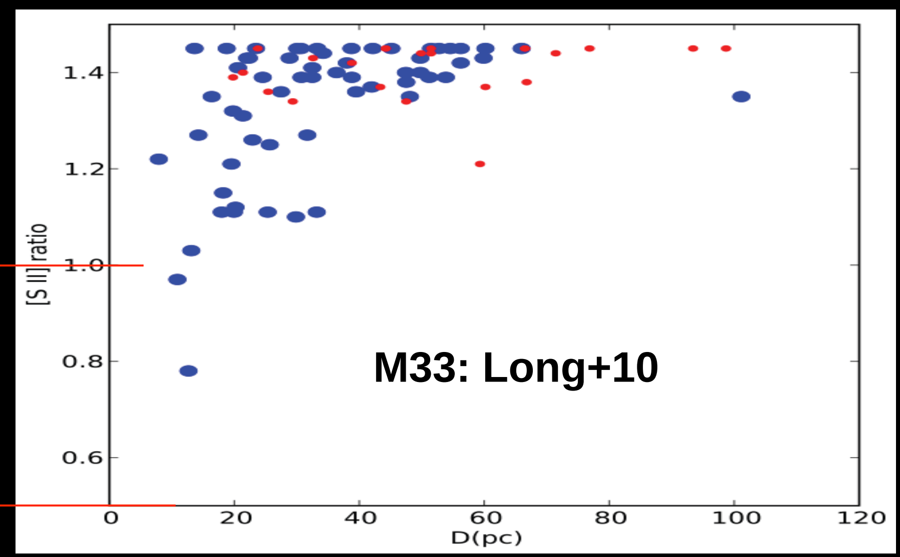


M83 SNRs are skewed toward smaller Diameters and higher Luminosities

M83 – M33 Comparison-II

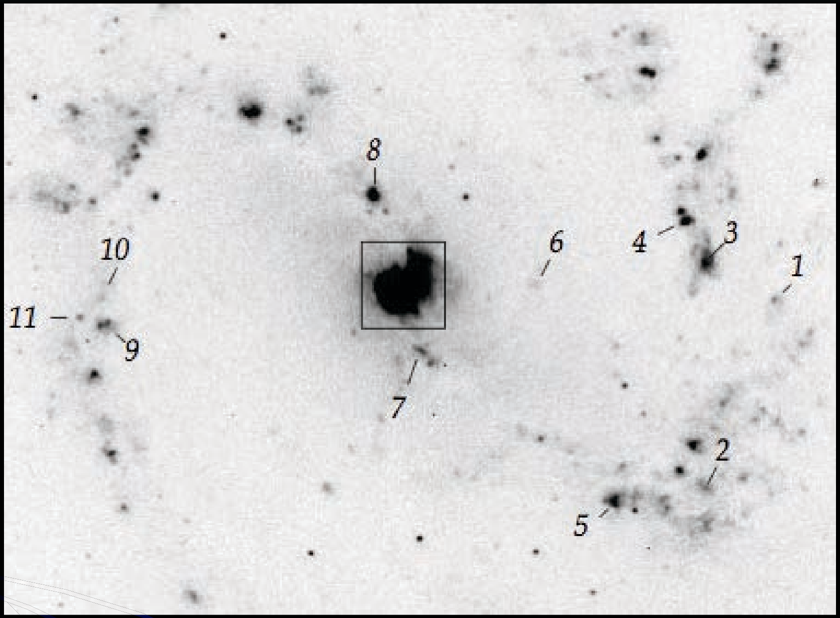


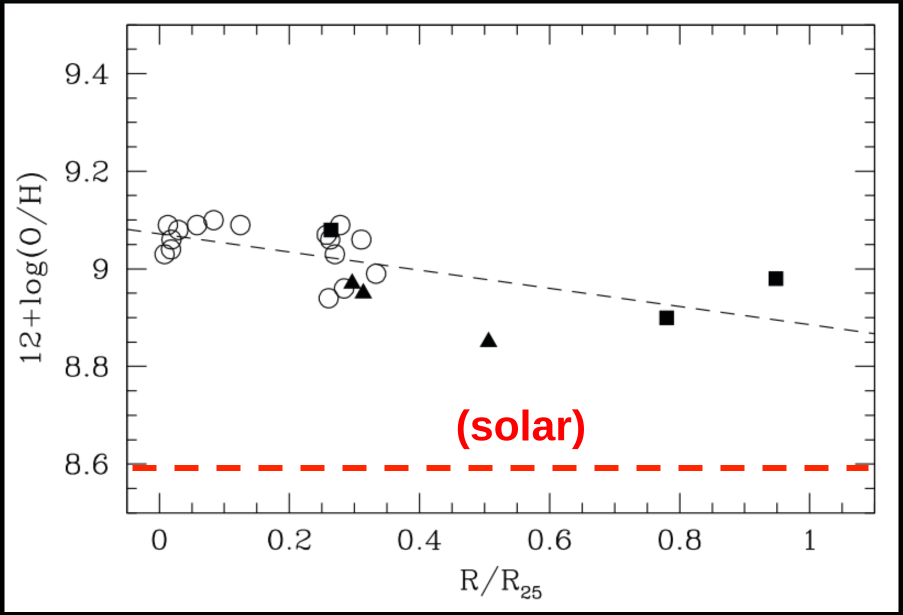
[S II] electron densities



M83 has larger fraction at lower ratios (=higher densities)

M83 Abundances and Gradients

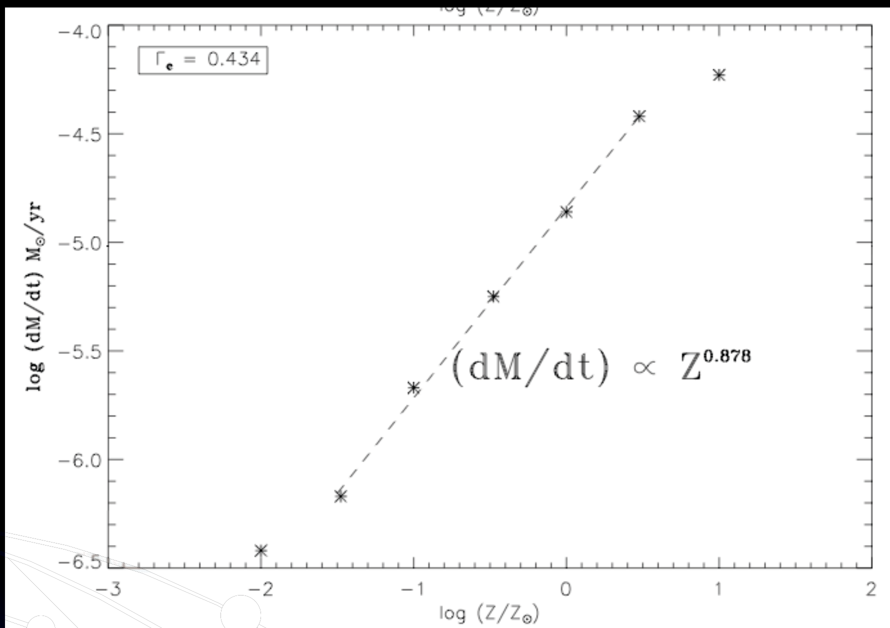


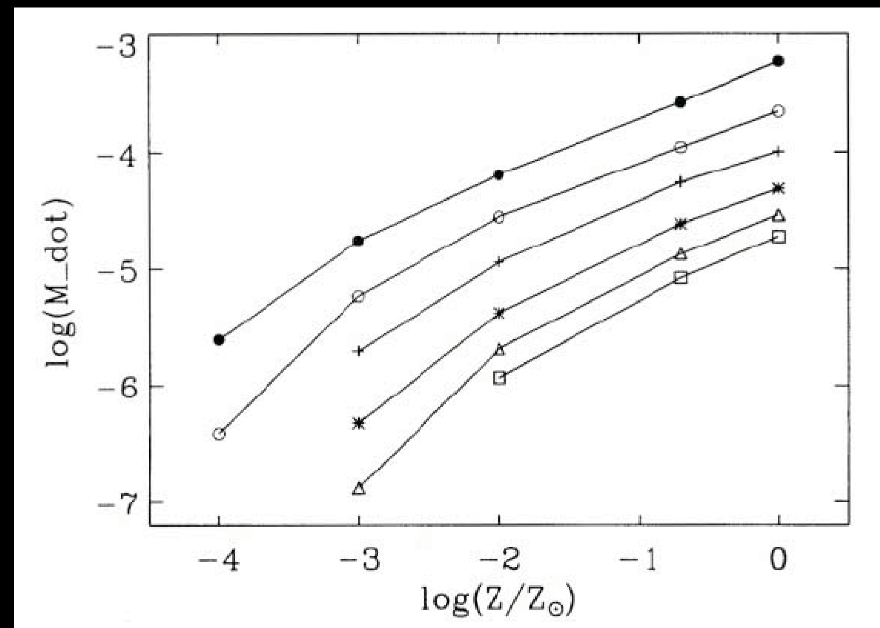


H II region spectral analyses show a modest abundance gradient, but very high (super-solar) abundances over the entire bright optical disk.

(Bresolin & Kennicutt 2002, ApJ, 572, 838; Note: R_{25} = 6.74')

Mass Loss and Metallicity: Models



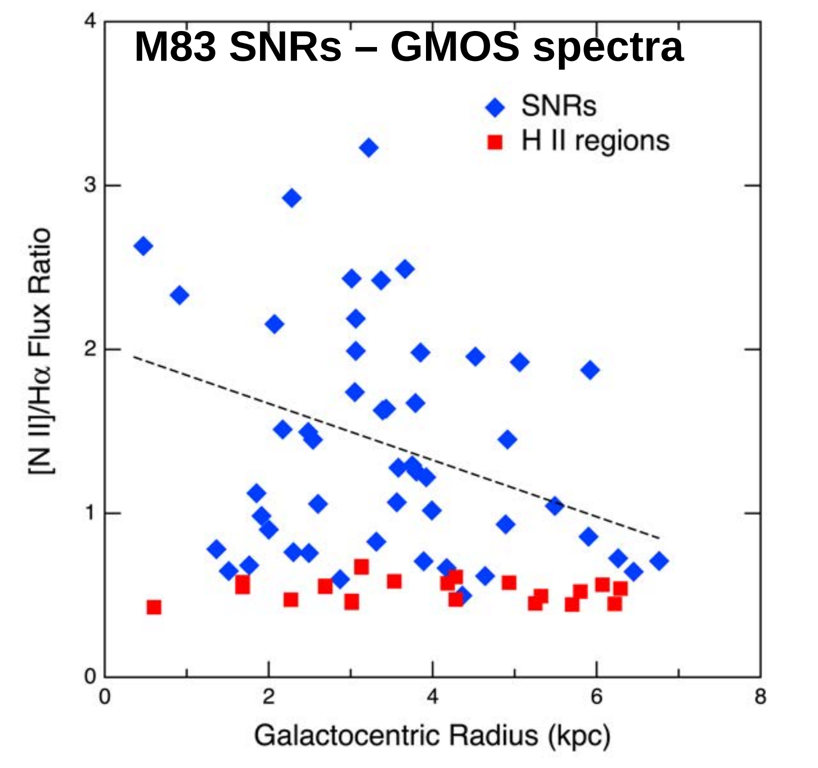


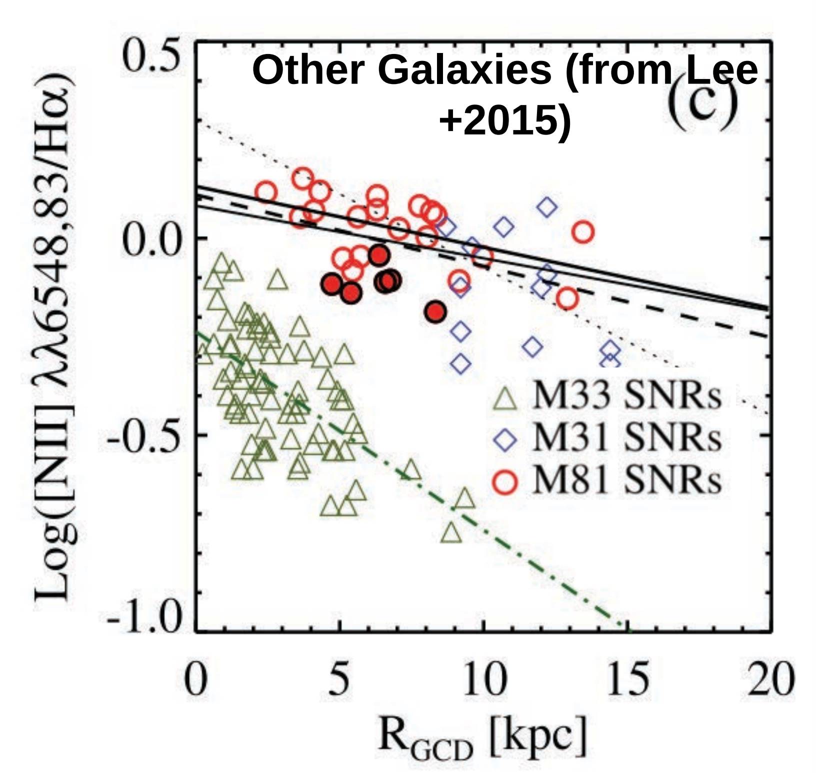
Vink, de Koter, & Lamers 2001, A&A, 369, 574. T=50,000 K, and constant V_{inf}/V_{esc} for these models.

Kudritzki 2002, ApJ, 577, 389. Models go from early O (top) to late O (bottom) and only up to solar abundance.

Higher metallicity → higher stellar wind mass loss

Does [N II]:Hα provide a clue?





- [N II]/Hα is primarily an N/H abundance indicator
- Even in galaxies where an abundance gradient is indicated, there is large scatter
- Is the huge variation at a given GCD indicative of strong and variable pre-SN mass loss?

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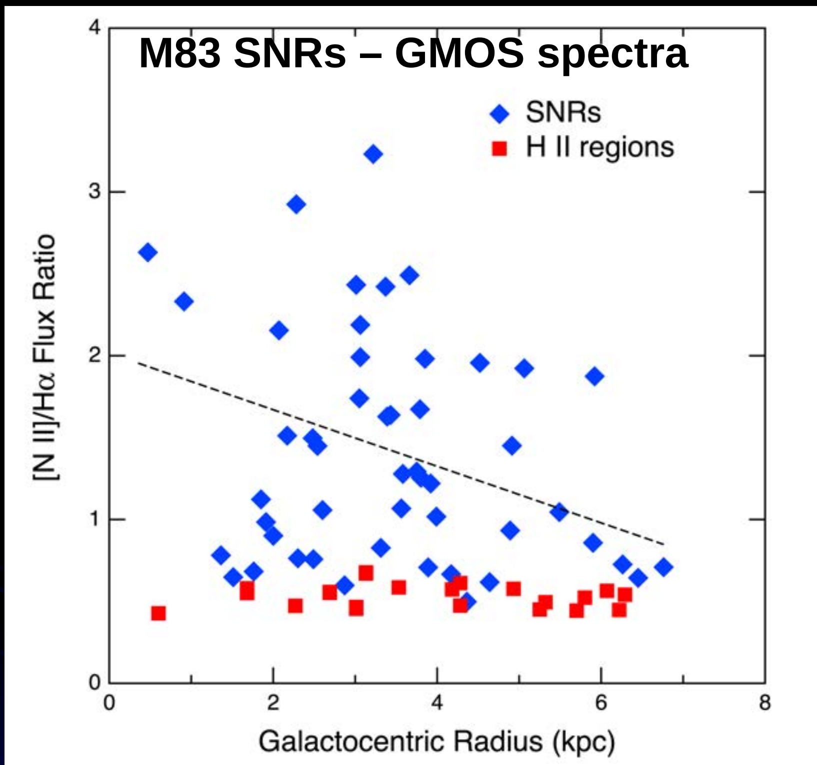

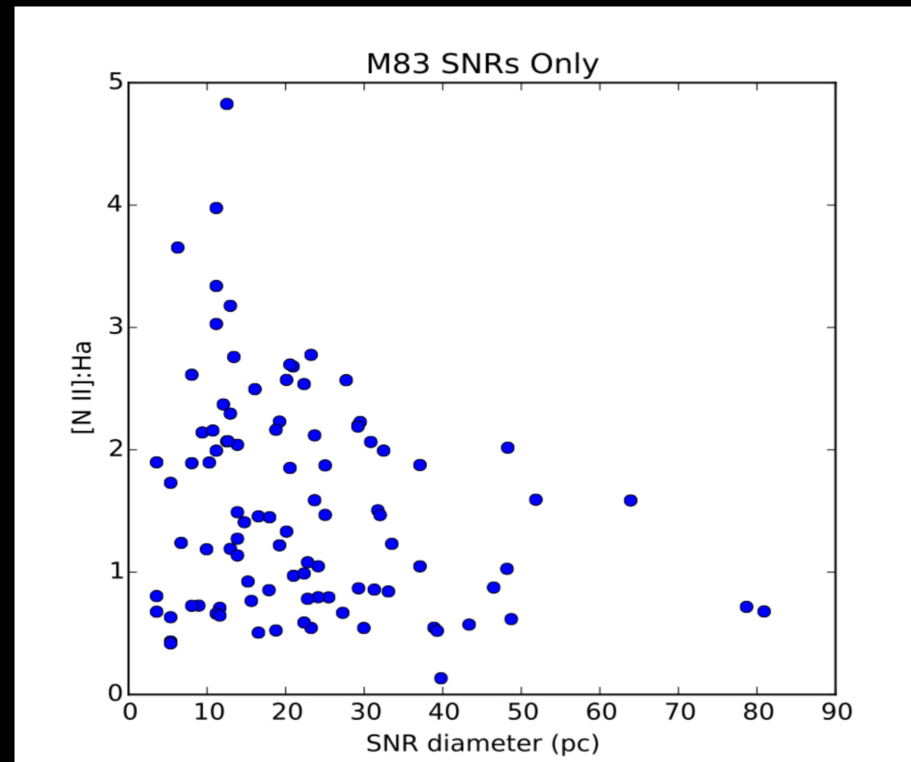

- [N II]/Hα is primarily an N/H abundance indicator
- Even in galaxies where an abundance gradient is indicated, there is large scatter
- Is the huge variation at a given GCD indicative of strong and variable pre-SN mass loss?
- Is the stronger [N II]:Hα at small diameters indicative of local enrichment?
- Is there a connection to binarity here?

Summary

- As expected from observed SN rate, there are LOTS of SNRs in M83!
- *HST/WFC3* and *Chandra* have allowed us to uncover the young SNR population in M83, but...
- Very few appear to be obviously in the ejecta-dominated state.
- Possible reasons include:
  - Rapid evolution due to higher density/pressure in the general ISM?
  - High CSM densities due to enhanced mass loss from progenitors?
- Some additional young SNRs may remain to be discovered via additional spectroscopy.