Supershells: What drives them & what role do they play in galaxies?

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What drives supershells in the ISM?
OB associations & Young Stellar Clusters: nurseries of Supernovae

* Aim: investigate role of stellar feedback in determining energetics & evolution of supershells in nearby spiral galaxies
* OB Assoc. contain even thousands of O & B stars (massive stars) w. short lives ~10^6 yr. Associations live a few x 10^6 yr, since stars exhaust
* SNe from these stars pressurize and churn ISM
* Supershells form & evolve due to continuous mech. energy injection of SNe & stellar winds
* Outer shocks of superbubbles sweep up ambient ISM into a thin cool shell ⇒ "Supershell"
* An Expanding HI supershell in M101: VLA data

Example:

Puche et al 1992: combined HI imaging with Halpha

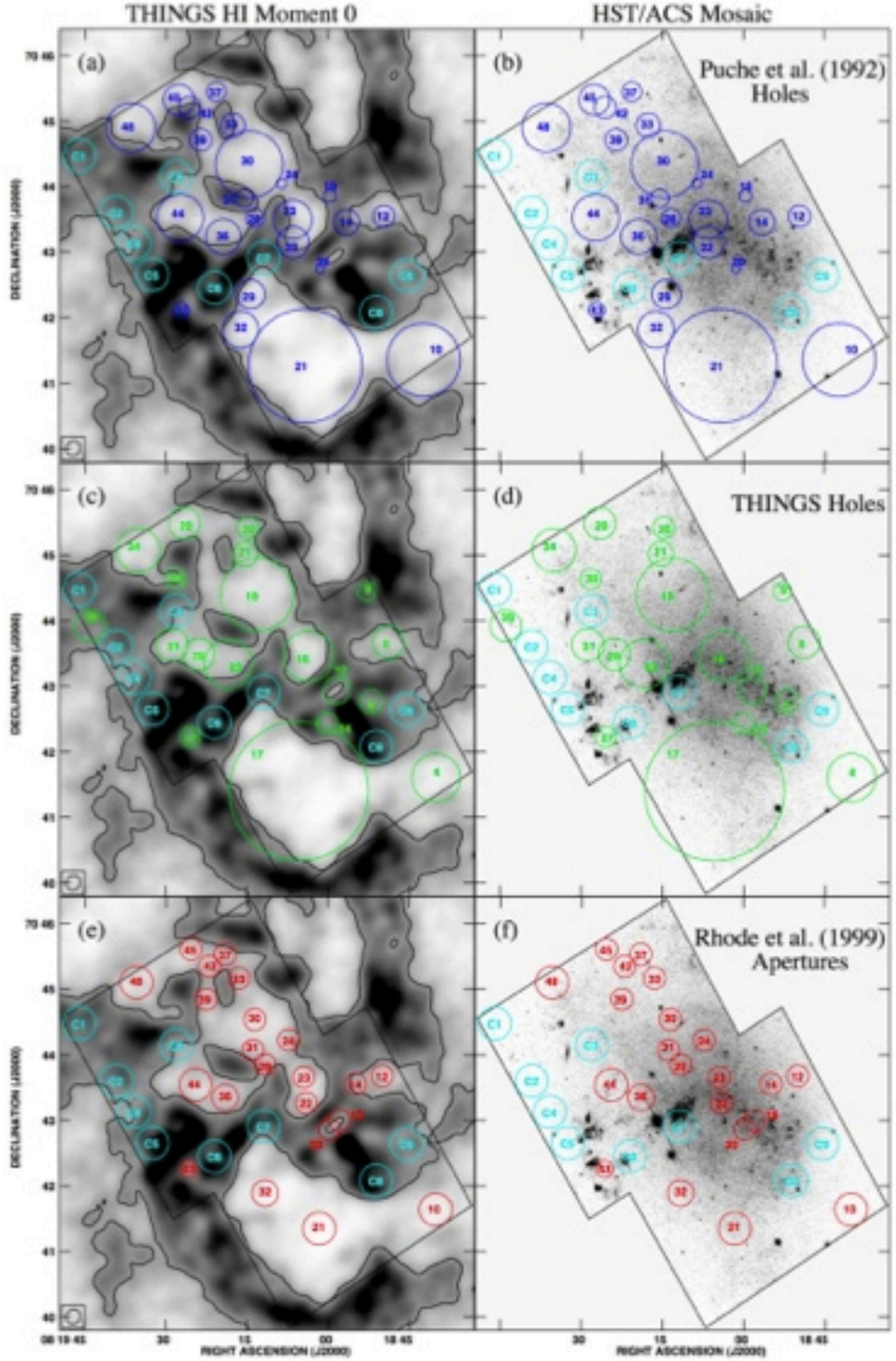


Figure 2. (a) THINGS processed H I image of Ho II (Walter et al. 2008) with a contour of 10^{-21} cm^{-2} overlaid and (b) ACS drizzled image of Ho II with Puche et al. (1992) holes in blue and control fields in cyan; (c) and (d) THING holes catalog (I. Bagetakos et al. 2009, in preparaion) in green and control fields in cyan; (e) and (f) Rhode et al. (1999) apertures in red and control fields in cyan.

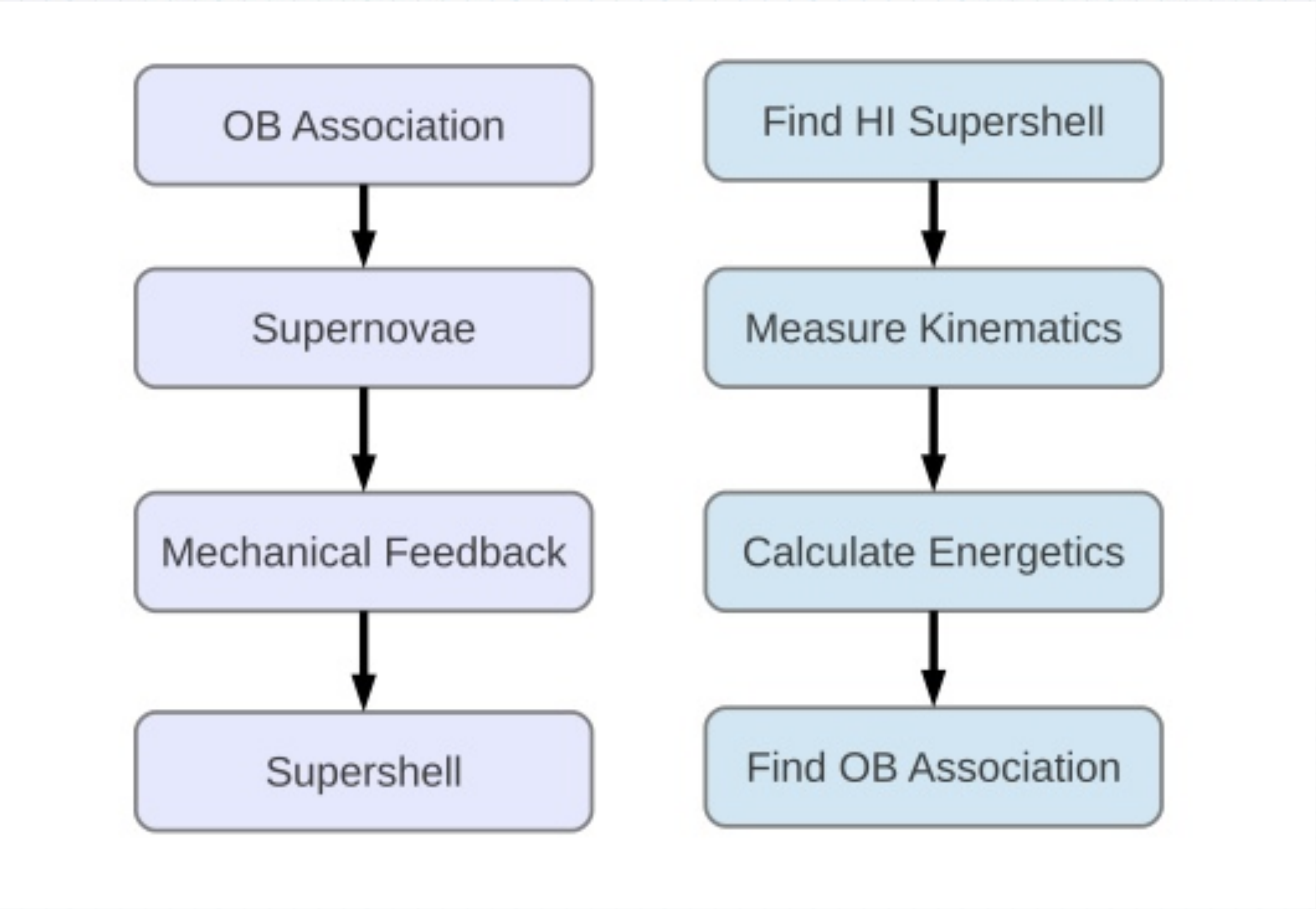
Rhode et al 1999: combined HI imaging with B, V, R data

Weisz et al 2009 ApJ Holmberg II

Evidence for expansion necessary

* Cavities of Neutral Hydrogen found in several nearby galaxies (Bagetakos et al 2011, Tenorio-Tagle & Bodenheimer 1988), including M101 (Kamphuis et al 1991).
* Cavity alone is insufficient evidence for paradigm: SN driven Supershell. Cavity (HI surface density) may simply indicate a low density region created by turbulent gas
* If supershells are SNe driven, evidence of young clusters or recent star formation in cavities: Pitfalls of listing of cavities as supershells: Puche etal (1992) in Holmberg II vs. Rhode etal (1999). Latter did not find young clusters.
* Showing expansion velocities essential for HI cavities supershells. Measured vel. should be sufficiently large compared to RMS vel of ISM.

Testing the paradigm of supershell formation



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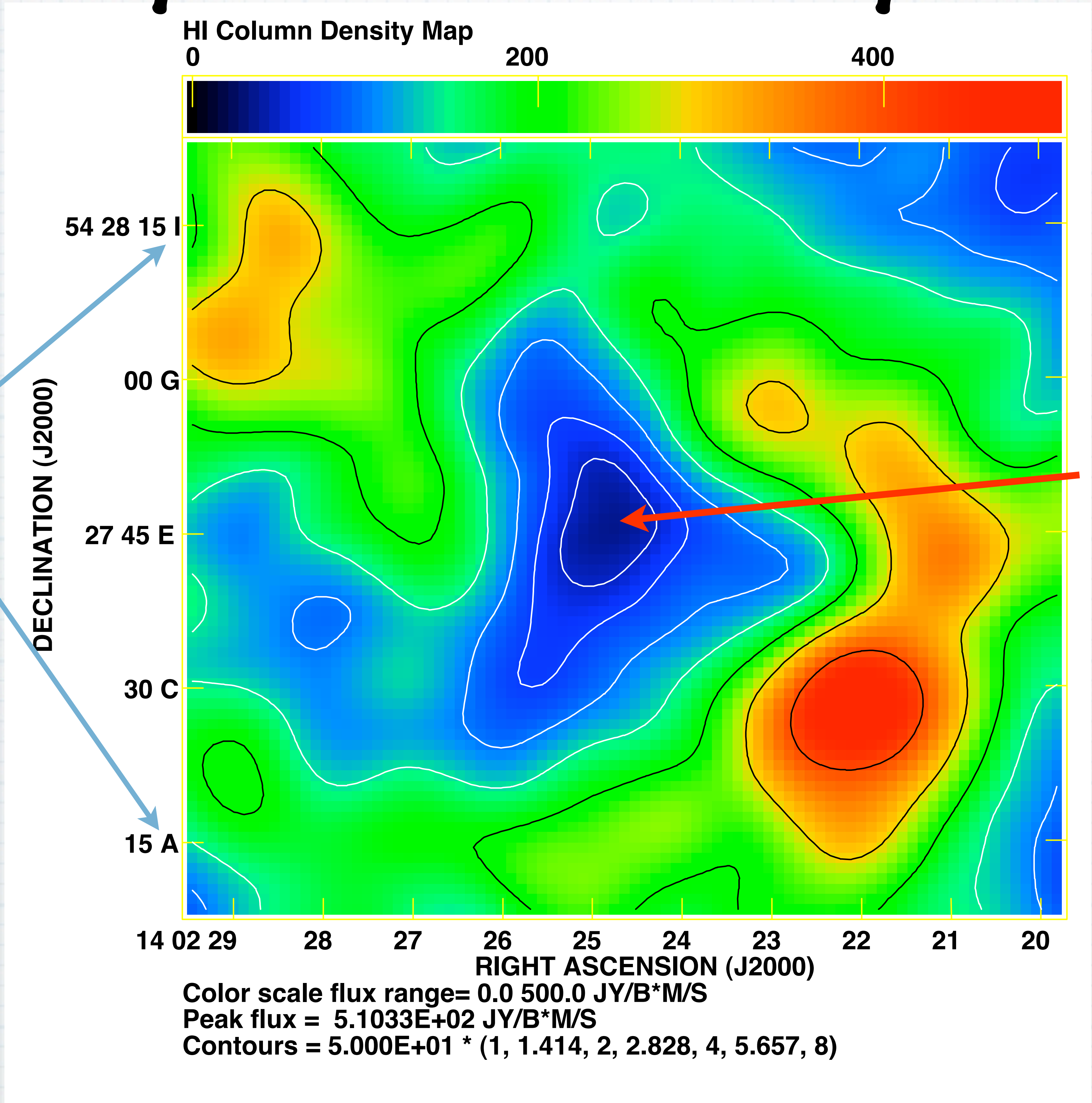
HI Supershell in M101 in VLA THINGS data

* THINGS = The HI Nearby Galaxy Survey undertaken by NRAO Very Large Array to study 21cm emission in nearby galaxies
* High angular resolution (≈7") maps and high spectral resolution (5 km/s).
* Data in Image cubes (RA, DEC, recssion velocity) after background continuum subtraction. For each triad, cube gives the HI line flux density.
* a) Supershell radii > 24 pc ($\theta_{10''}$ $D_{1\ Mpc}$) to have it larger than the projected beamsize. b) Two velocity components can be resolved only if V > spectral resolution. c) Limited by sensitivity in the beam: ≈ 10^{20} atoms/cm^2 .

A newly found HI cavity in M101

Alphabets A-I denote the positions of the DEC slices in the P-V diagram



Hole in the gas?

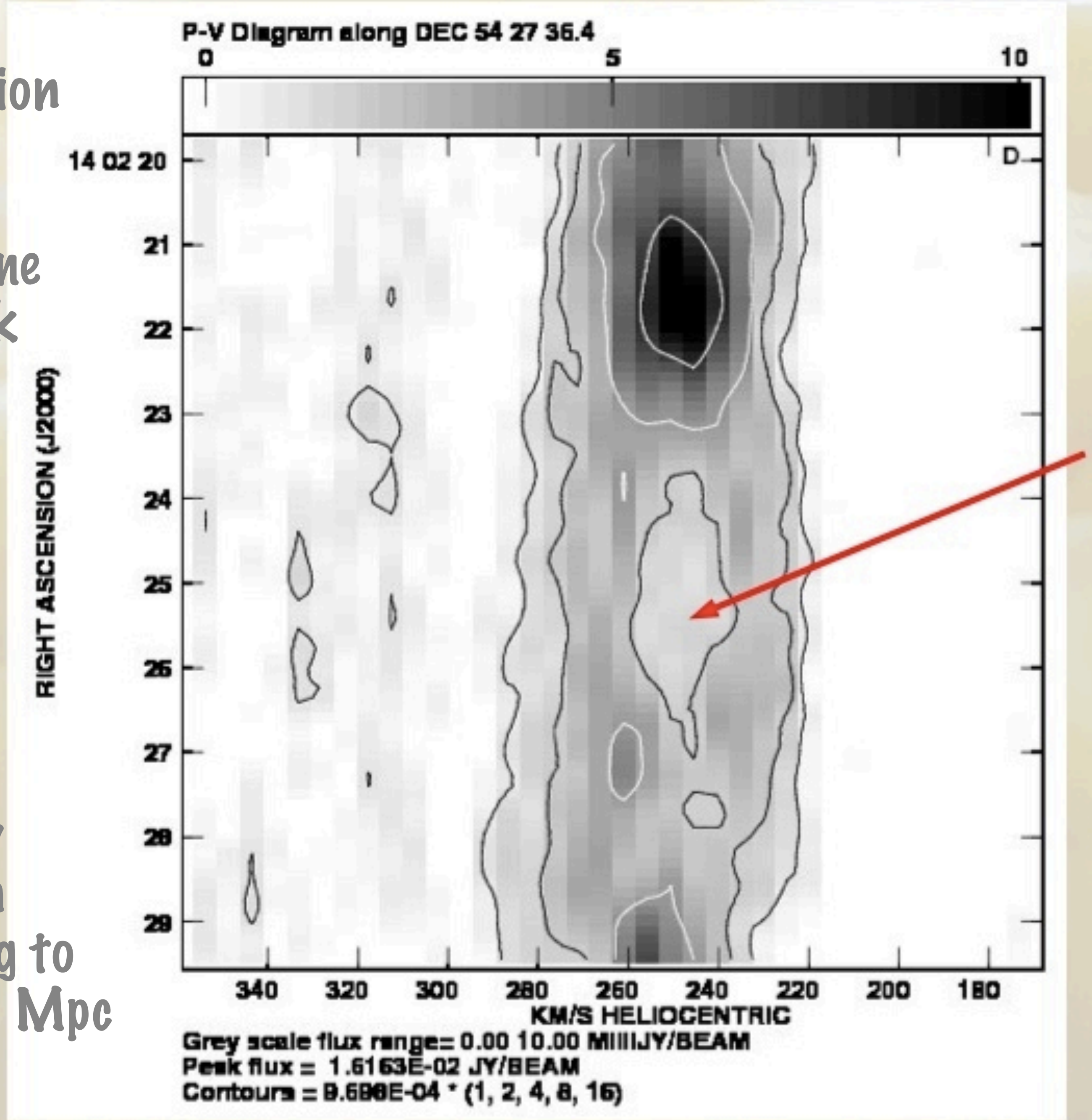
Yes ! See the column density map

Beamsize = 10"

Chakraborti & Ray 2011 ApJ 728, 24

Is the gas in the hole expanding?

HI under-dense region characterized by reduced emission from the rest frame velocity of the disk



Look at P-V diagrams
Answer: Yes!

Diameter of cavity lacking HI emission ≈30" corresponding to R_s ≈ 500pc @ 6.85 Mpc

Difference in velocity of two components in Panel D is ≈ 40 km/s. This is twice the expansion velocity of the supershell V_s ≈ 20 km/s

McCray & Kafatos (1987)

* Pressure driven phase of the supershell terminates when R_S becomes comparable to HI scale height
* Thereafter, if V_{shell} (@ one scale height) > V_{RMS} (HI), then parts of the shell going perpendicular to disk, accelerate into the halo & fragment & discharge the int. pressure into the Corona.
* Portion moving along the disk enters the pressureless snowplough phase & evolves slowly ($R_S \propto t^{1/4}$). → Radii of largest observed HI holes are slightly larger than the HI scale height.

McCray & Kafatos (1987): expanding HI supershell driven by multiple SNe

SNe rate in a cluster of typical IMF varied only slightly over the first 50 Myr

Continuous energy injection powering the Supershell over this timescale.

Radius and velocity of the expanding supershell are:

$$R_S = 97\ \mathrm{pc}\ (N_* E_{51}/n_0)^{1/5}\ t_7^{3/5}$$

$$V_S = 5.7\ \mathrm{km\ s^{-1}}\ (N_* E_{51}/n_0)^{1/5}\ t_7^{-2/5}$$

Model is invertible: R_S & V_S are observable from HI data:

$$t_7 = (R_S/97\ \mathrm{pc})(V_S/5.7\ \mathrm{km\ s^{-1}})^{-1}$$

$$(N_* E_{51}/n_0) = (R_S/97\ \mathrm{pc})^2 (V_S/5.7\ \mathrm{km\ s^{-1}})^3$$

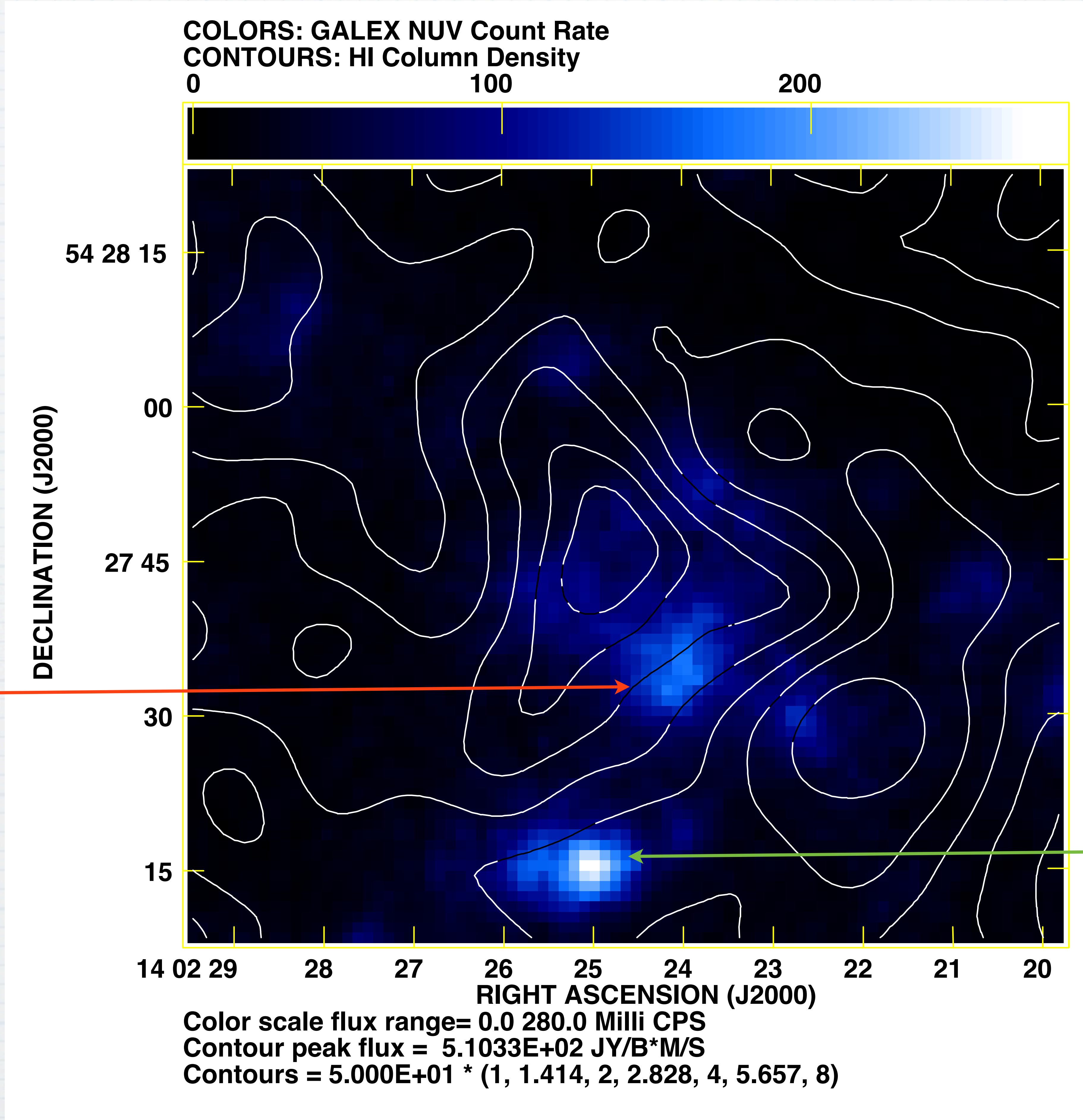
Evolution of M101 supershell

* With the McCray & Kafatos model, our measurement of the Radius and Velocity of the supershell gives:
* $t = 15$ Myr & $(N_* E_{51}/n_0) \approx 1100$
* Assuming $E_{51} \approx 1$ & $n_0 \approx 0.5$, the driving cluster should be massive enough sto harbor $N_* \approx 550$ supernova yielding massive stars
* McKee & Williams (1997): total mass of stars required to produce each CC SN= 196 M_{SUN} . Thus our cluster is of initial mass 10^5 M_{SUN} driving the Supershell for last $\approx$ 15 Myr . Only < 15% of the energy from already exploded SNe by t= 15 Myr needs to be in the kinetic energy of the Supershell

GALEX Nearby Galaxies Survey

* UV emission: a tool to identify young stellar associations --may host core collapse SNe supplying energy for expanding supershells
* NUV & FUV cts/s for each (RA,DEC) pair
* Use info @ both HI distrib & young stellar populations to search for neutral hydrogen shells powered by SNe.
* Association hosting SN 1970G (found in UV) is located on high column density HI ring in M101
* We have found a cavity in HI surface density hosting a young stellar pop w. NUV m_{AB} = 17.37 surrounded almost completely by higher HI density

GALEX NUV image at 5" FWHM overlaid on HI contours

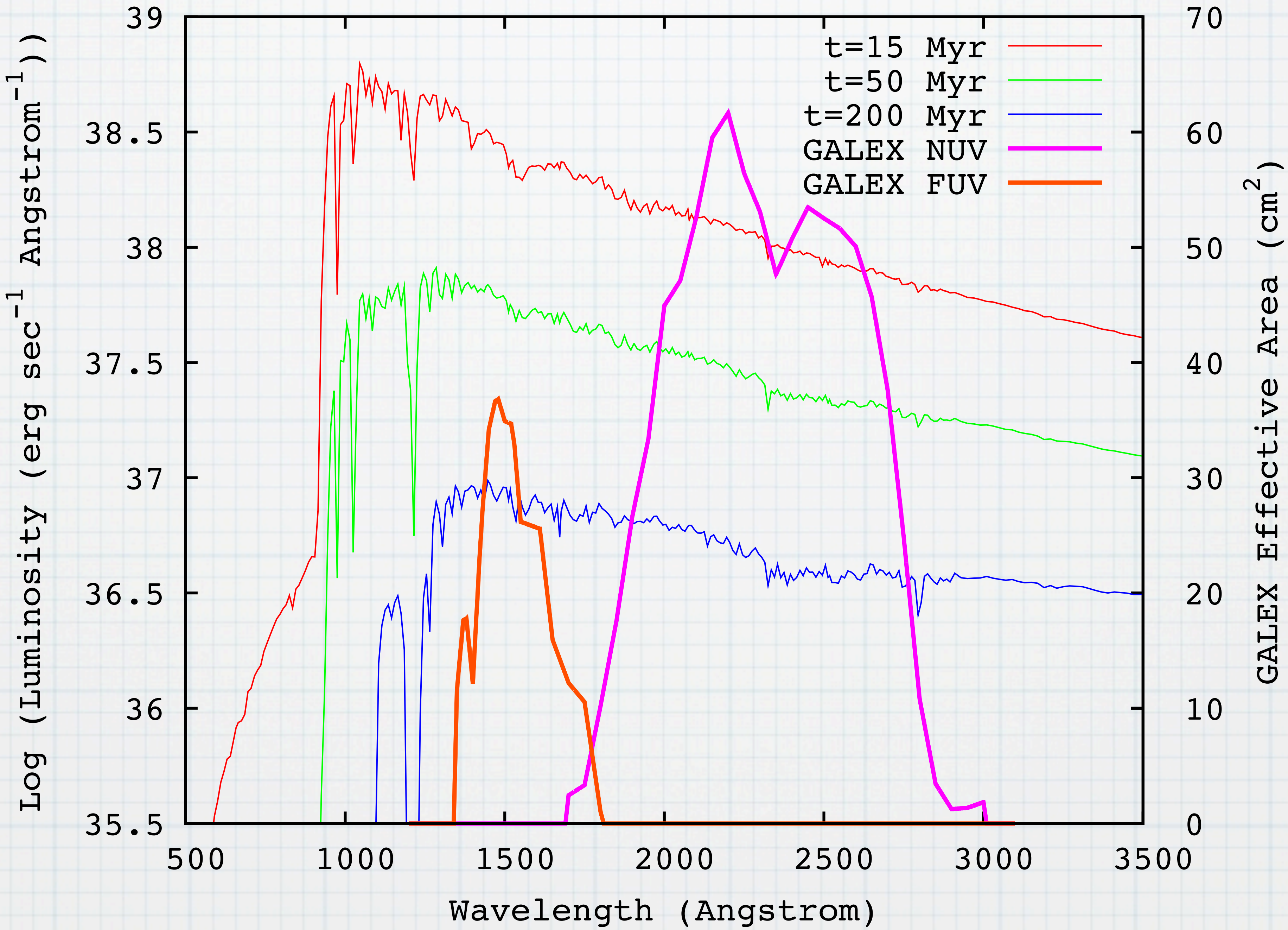


Star cluster inside HI cavity

Star cluster on the swept up shell in the south

Spectral Energy Distribution of a 10^6 M_{Sun} association with Salpeter IMF and solar metallicity at 15, 50, & 200 Myr using Starburst99 code (Leitherer et al 1999)

Note: Flux in GALEX NUV & FUV bands fall by > order of magn in the range of ages



Chakraborti & Ray 2011 ApJ 728, 24

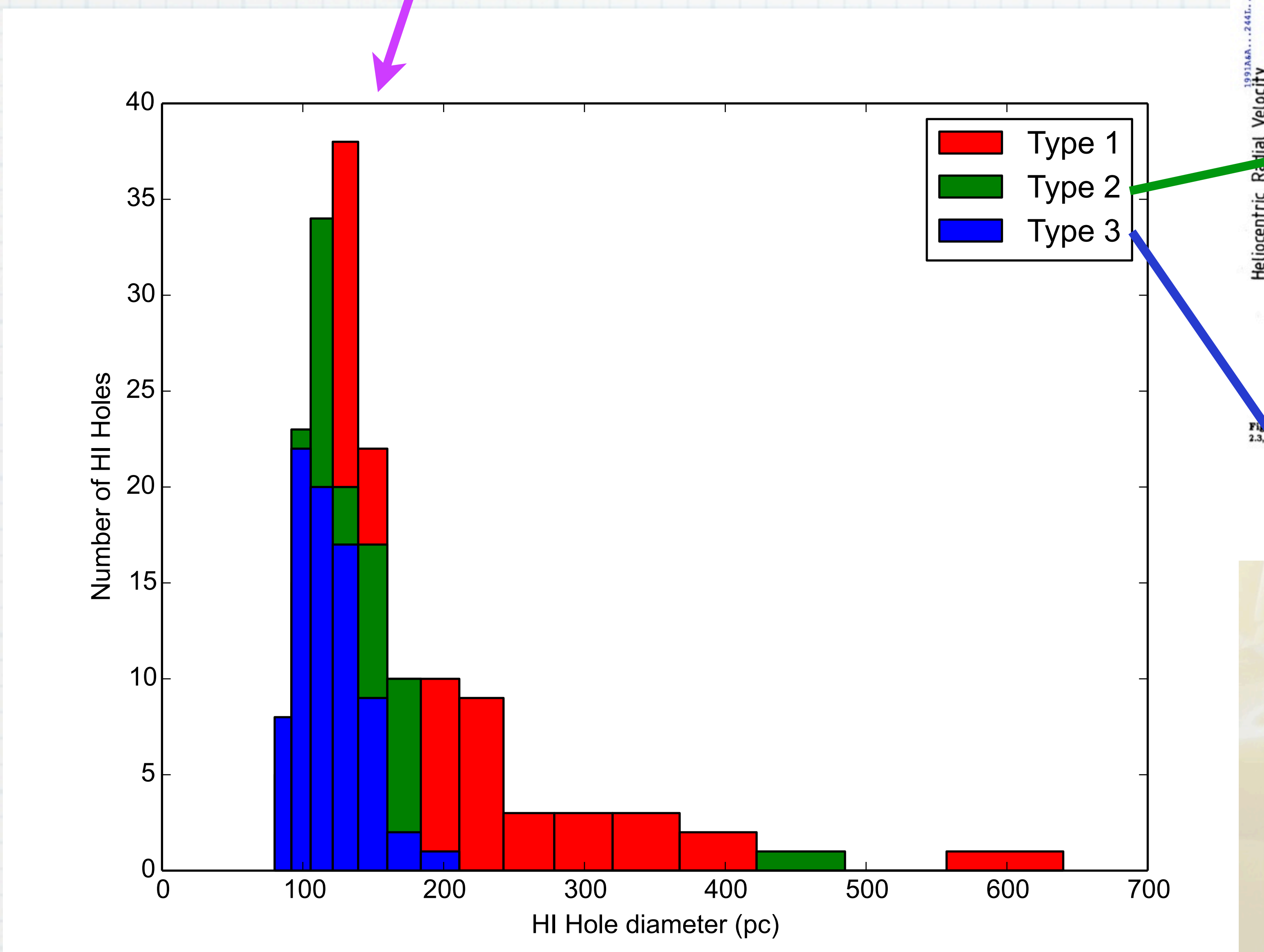
UV diagnostics for cluster mass

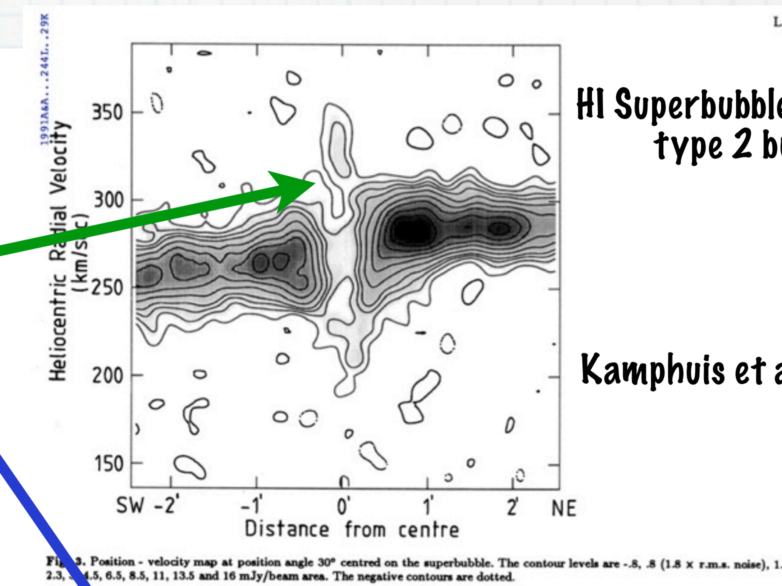
- Our **measured NUV** emission of cluster inside the HI cavity: **m_{AB}= 17.37 +- 0.08** in GALEX archival data
- Galactic extinction: A_V = 0.028 → A_{NUV} = 0.083 (using Cardelli et al for a Milky way like total to selective absorption R_V = 3.1)
- For d=6.85 Mpc, **GALEX NUV** measurement gives: **1.5 10^{37} erg/s/A**
- Compare with S99, NUV flux → stellar assoc. had an original mass ~**1.3 10^5 M_{Sun}**. Consistent w. minimum

  mass derived from energy requirement derived from McCray Kafatos model

Diameters of HI Bubbles in M81

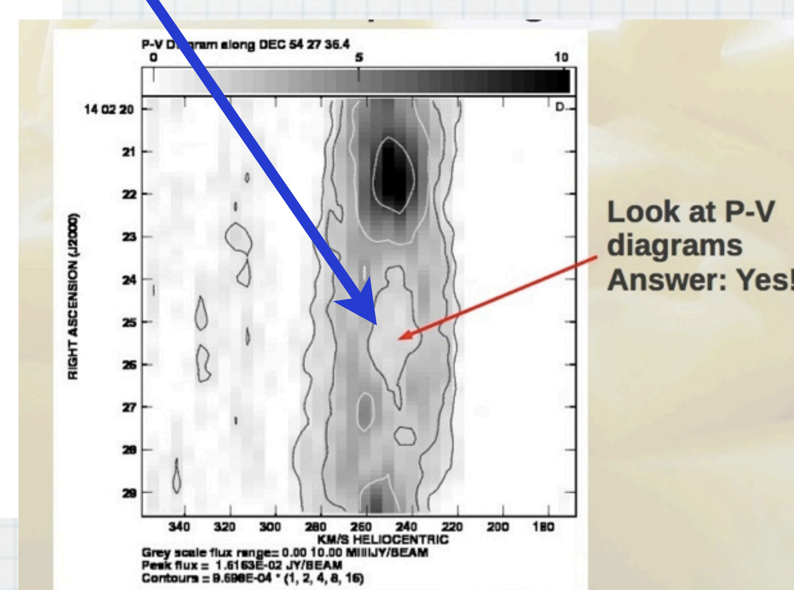
Data from: Bagetakos et al 2011





HI Superbubble in M101
type 2 bubble

Kamphuis et al 1991

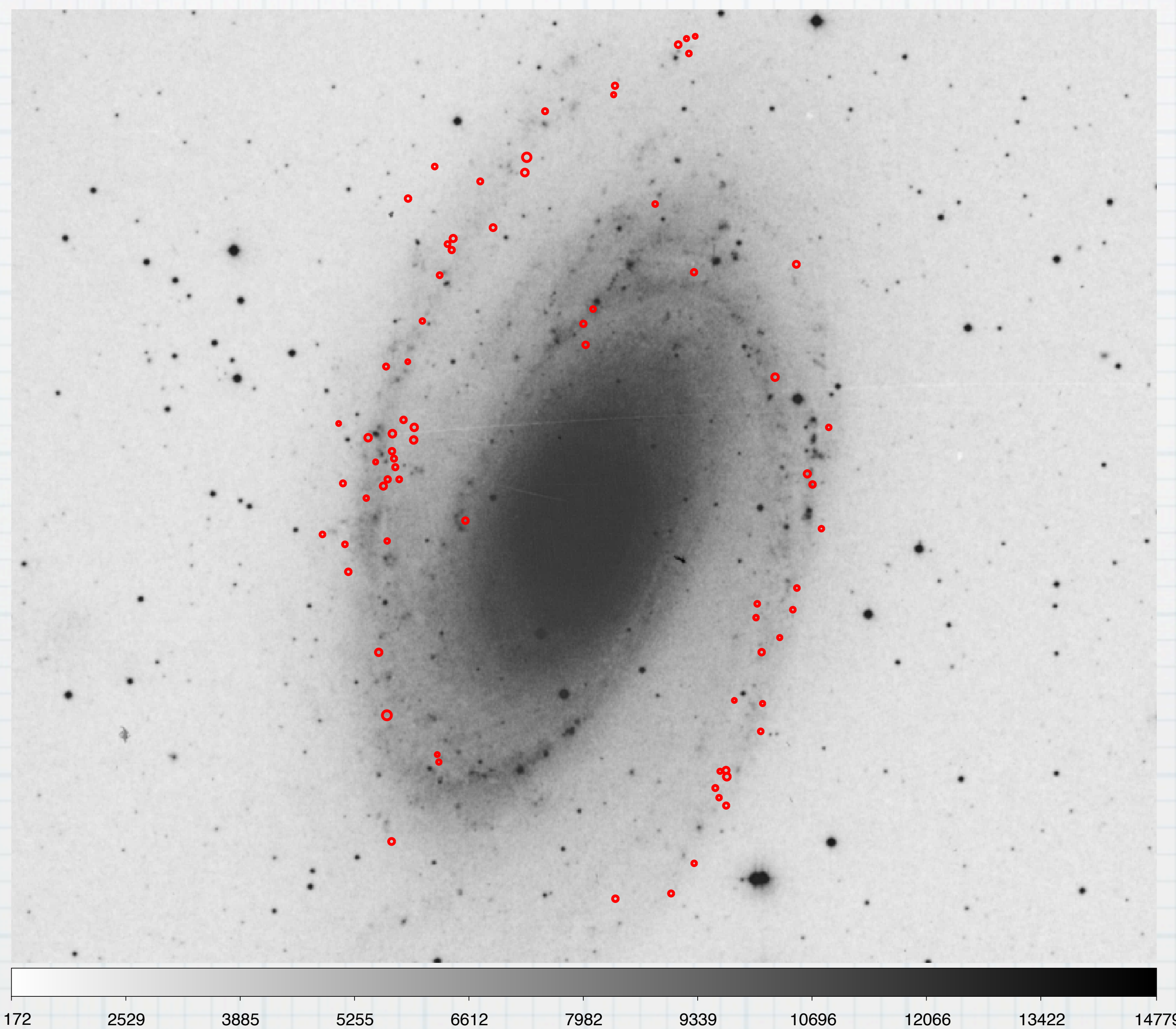


Chakraborti & Ray 2011

Many HI Holes in 20 Nearby Galaxies: Bagetakos et al 2011

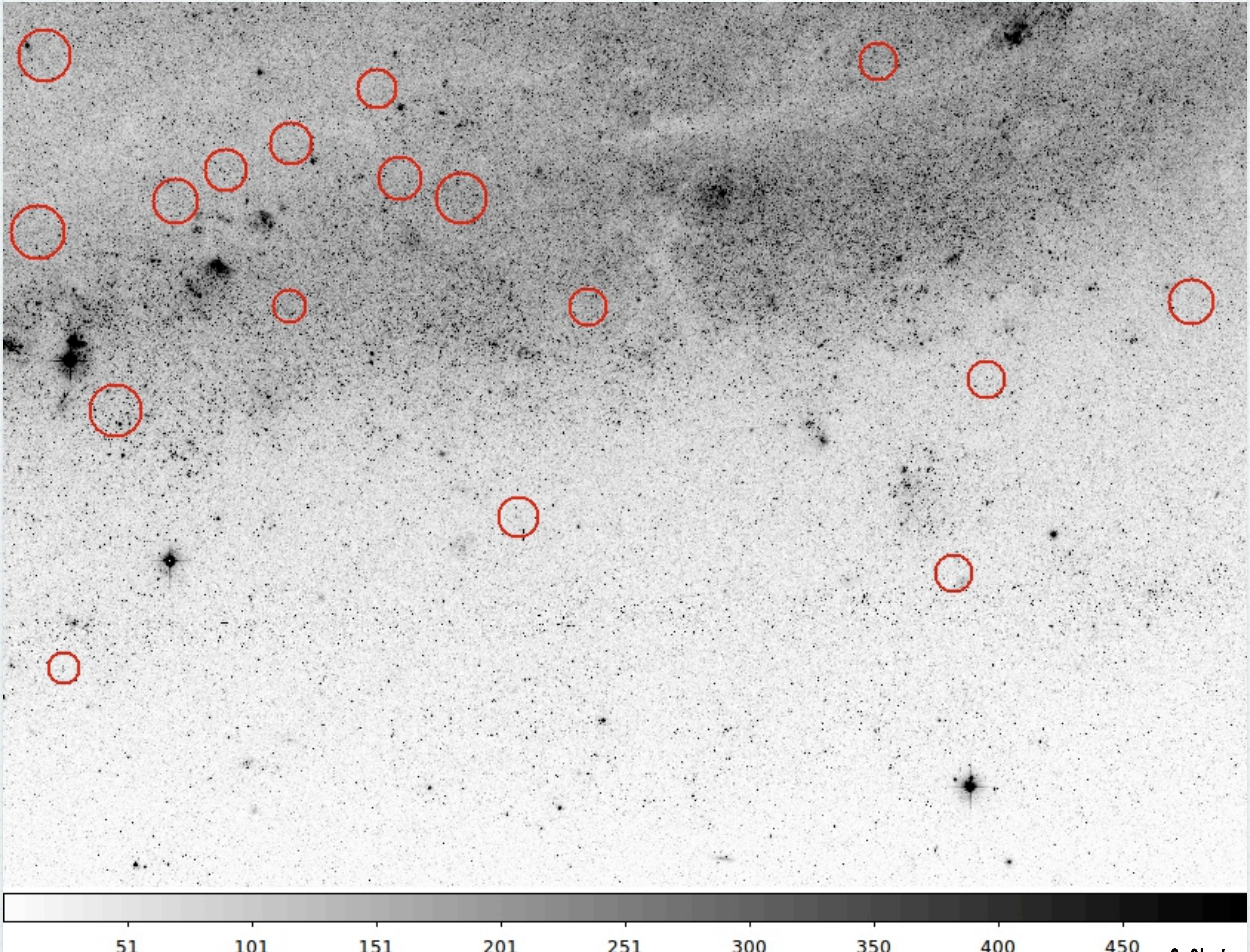
Example: Position & size of Type-3 HI Bubbles in M81

Red circles (positions from Bagetakos et al 2011) marked on Palomar POSS image



S. Chakraborti et al 2015, in preparation

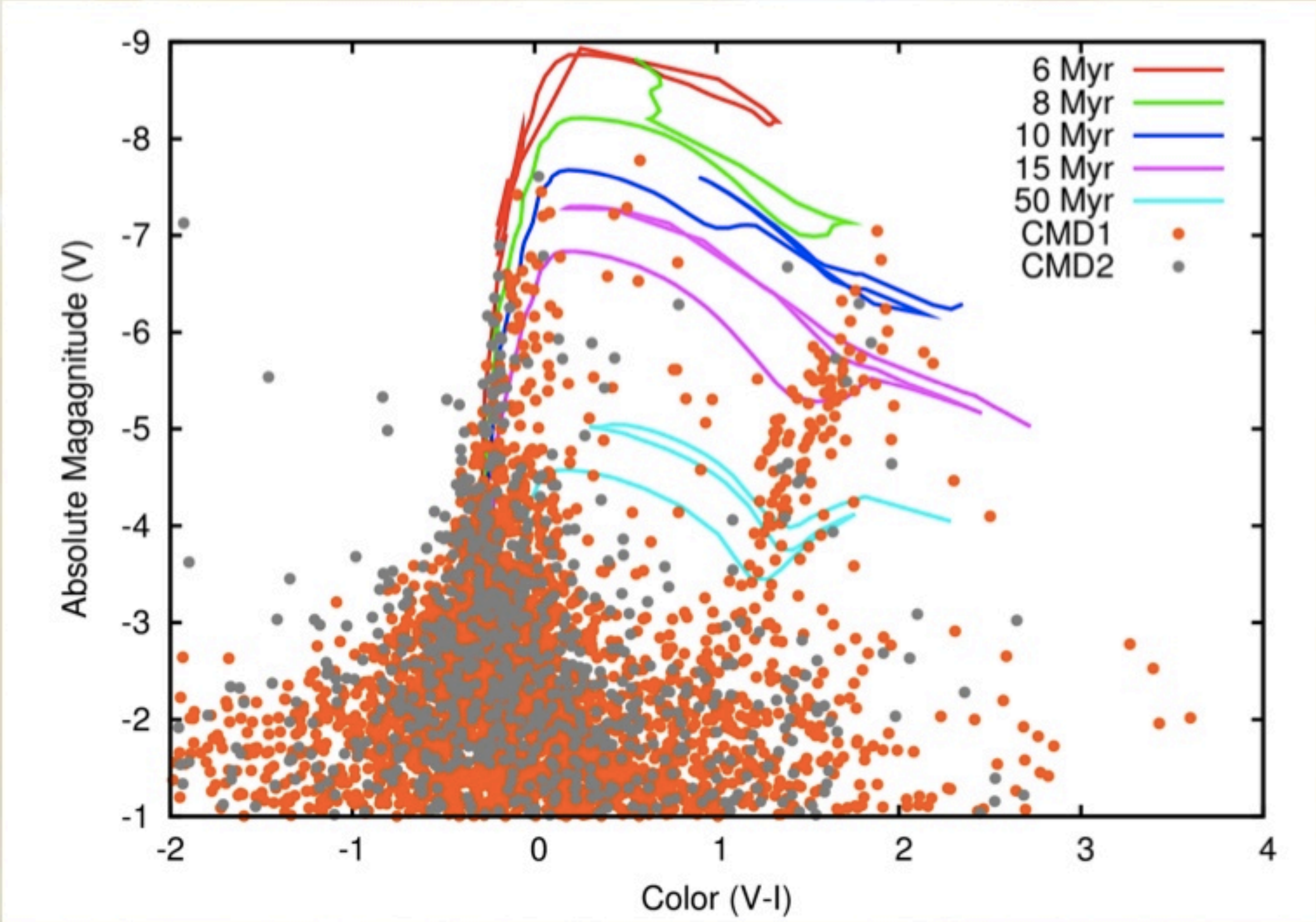
Type-3 HI holes marked on a HST/ ACS field in M81



S. Chakraborti et al 2015, in preparation

Color-Magnitude digram for 2 regions of M101 Supershell with superposed isochrones

- Count stars with HST



Sayan Chakraborti & Ben Shapee (work in progress): no clear evidence about sequential star formation in massive star cluster near the edge of the M101 supershell; have to await EW measures of Halpha in two clusters

Outlook with TMT

- Research in with "Resolved stellar populations as tracers of galaxy evolution": Sec 7.8.4 of TMT Detailed Science Case 2015 (W. Skidmore & ISDT)
- With HST resol can study stellar populations in galaxies out to few Mpc (e.g. Holmberg II a Dw Irr galaxy at d=3.4 Mpc, Weisz et al 2009) by sampling resolved stellar populations and decomposing the colour-magnitude diagram to constituent stellar types and obtain star formation history (SFH)
- Large collecting power TMT & high ang resolution w. AO (NFIRAOS res= 0.0055" @ 0.8 um, res= 0.017" @2.4um <=> compare HST/ACS res = 0.05") can extend such studies to >10 Mpc, & for several hundreds of galaxies.
- But have to beat: stellar crowding. DSC 7.8.5 suggests that TMT will resolve individual stars in crowded regions with crowding lim in K-band: 19 mag arc sec^{-2} in galaxies out to 15 Mpc with point source mag lim K_{lim} = 28.5.
- Spectroscopic observations of Blue and Red Supergiants at OIR bands (0.5 -1.2 um) with WFOS, HROS & NIRES will be possible typically to 8-10 Mpc (Table 7-1 DSC 2015)


The End
Thank You