Cloud-Scale GMRT Survey of M33: Unveiling the Low-Frequency Properties of the ISM

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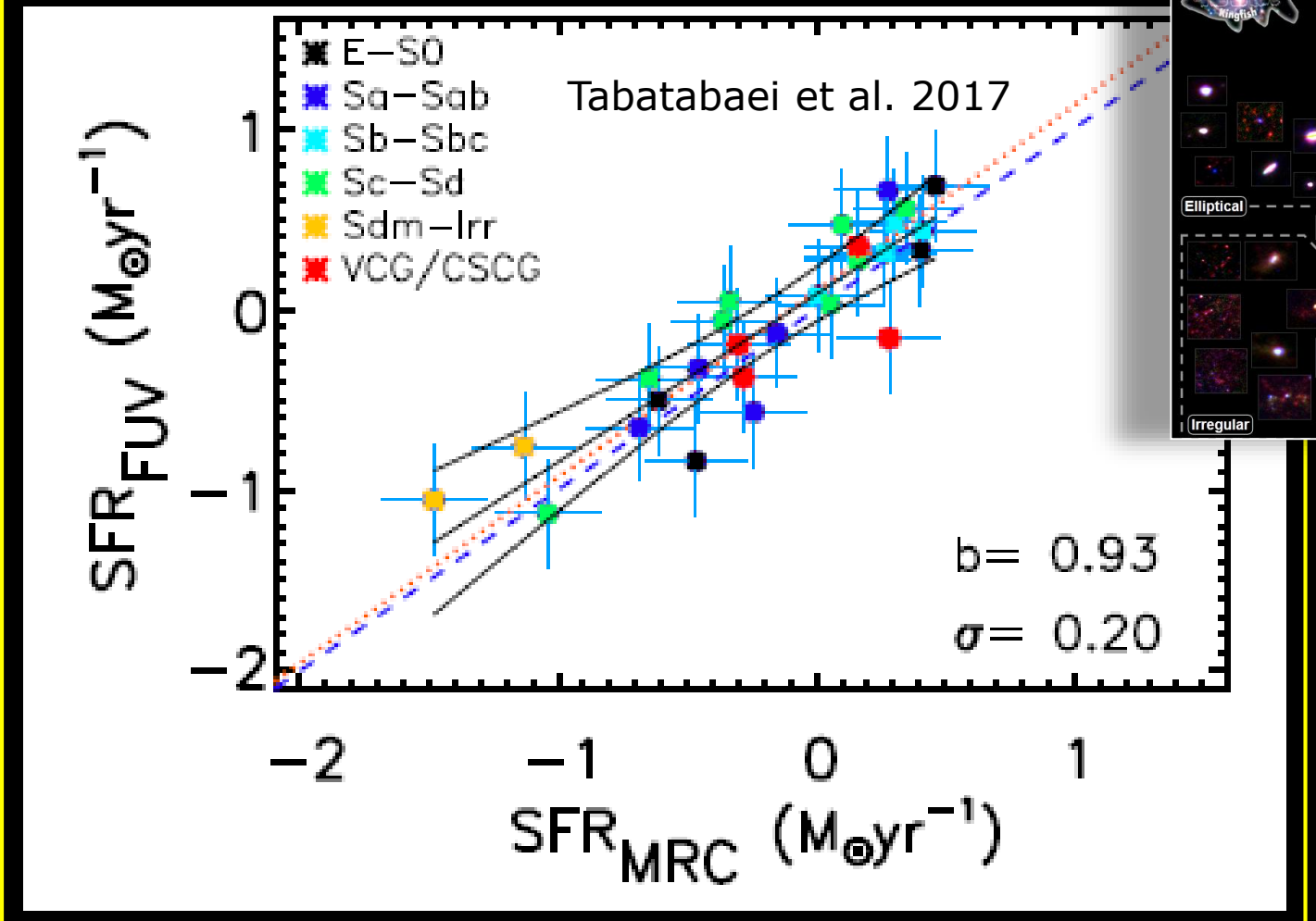
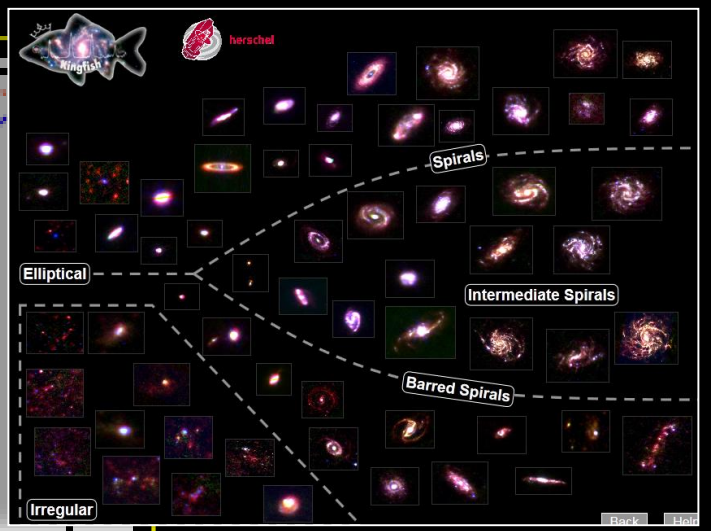
RC an extinction-free SFR tracer

Mid-radio continuum (MRC: 1-10GHz) the most precise measure of SFR





→ How precise is to measure SFR at lower frequencies?

Low Frequency RC Ideal Tracer of SF History

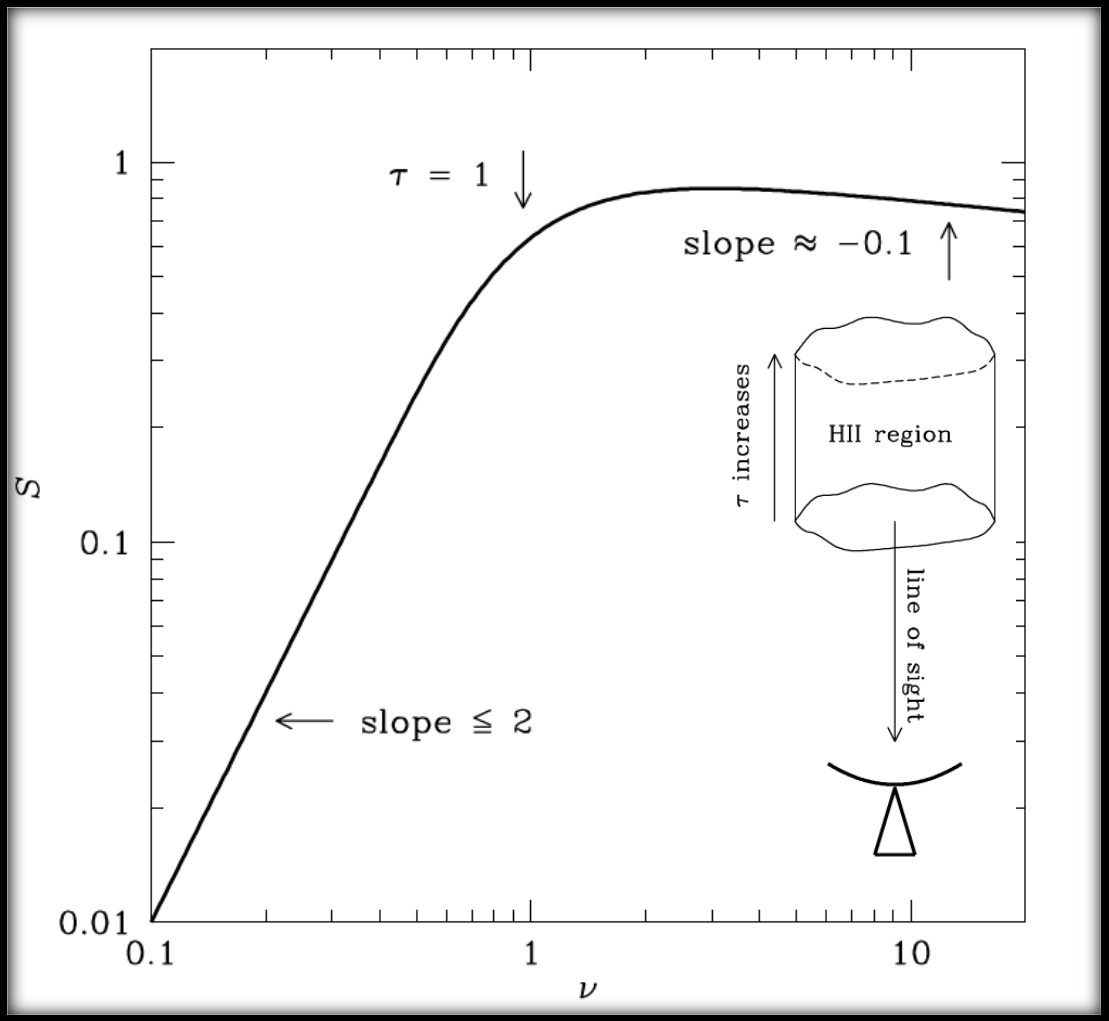
Ideal tracer of old cosmic ray electrons (CREs):

→ star formation history
→ galaxy evolution

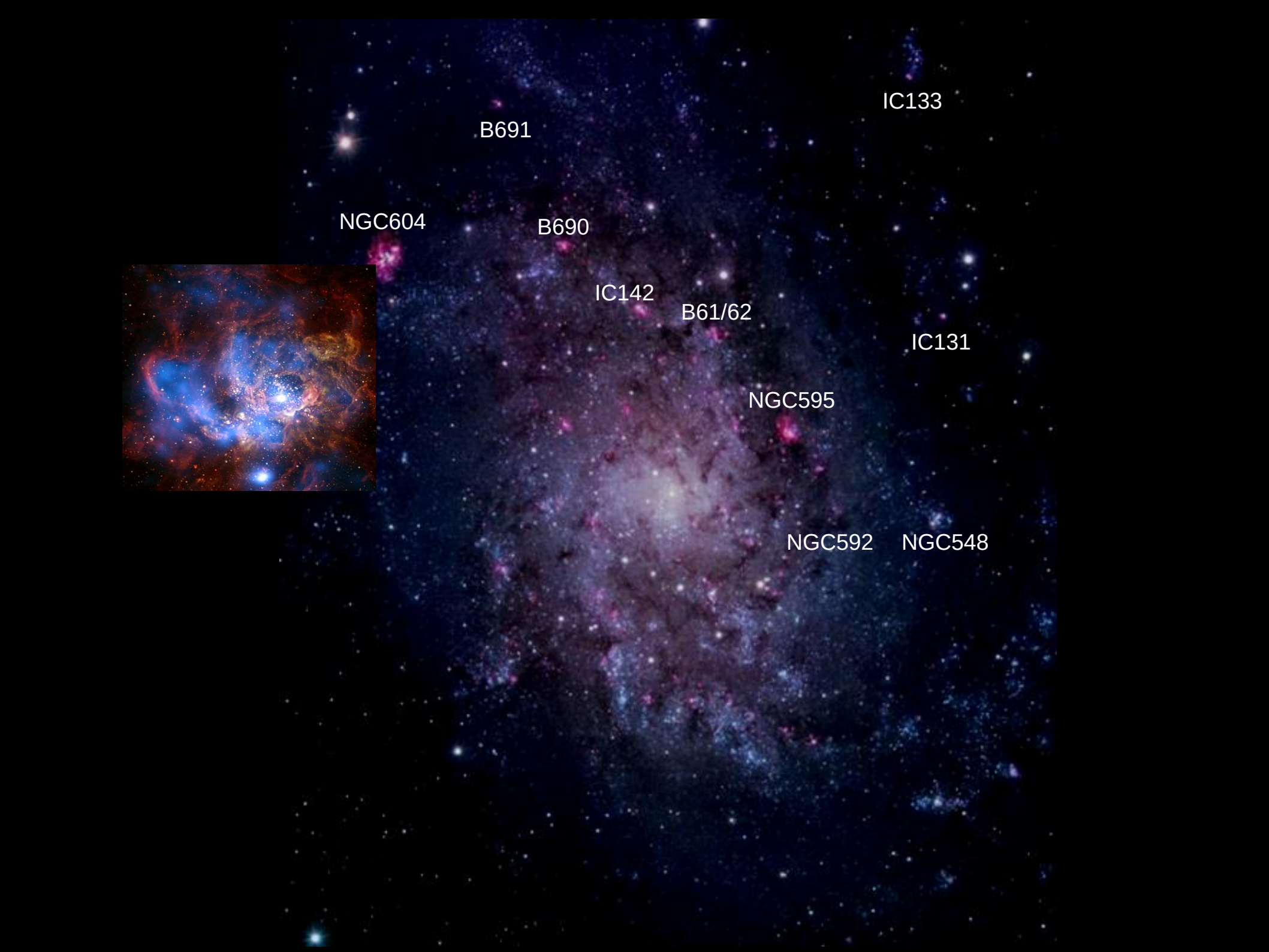
ISM studies mostly in the MW (e.g. Kassim 1990, Brogan 2003)

What if the ISM condition differs from that in the MW?
→Giant HII regions?

Radio Spectrum of an idealized HII region



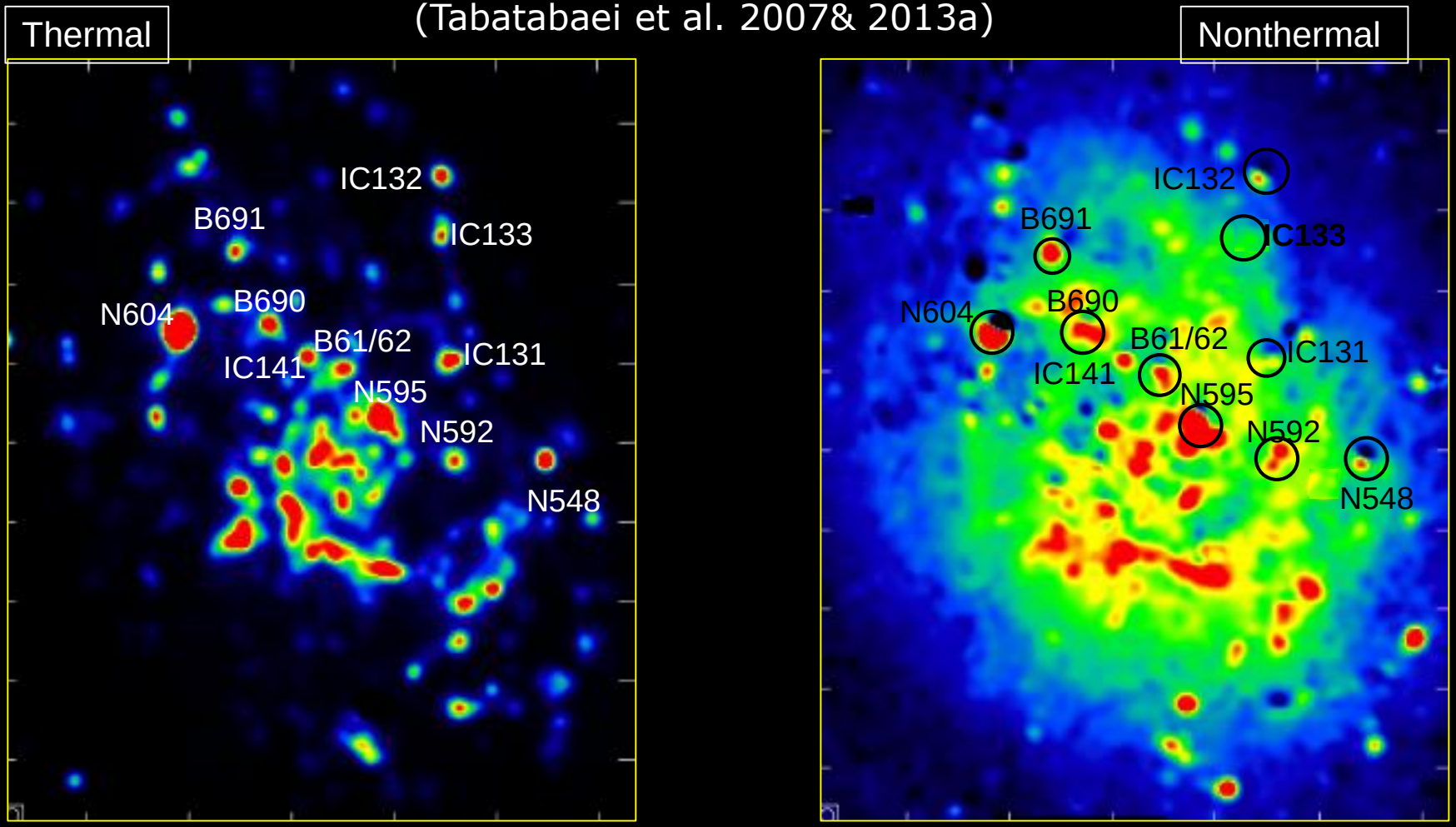
Tomography of CR emissivity using opaque HII regions (Kassim 1990)


IC133
B691
NGC604
B690
IC142
B61/62
IC131
NGC595
NGC592
NGC548

Mid-Radio: GHz Thermal & Nonthermal Emission @ 200-pc resolution

TRT Separation Technique:

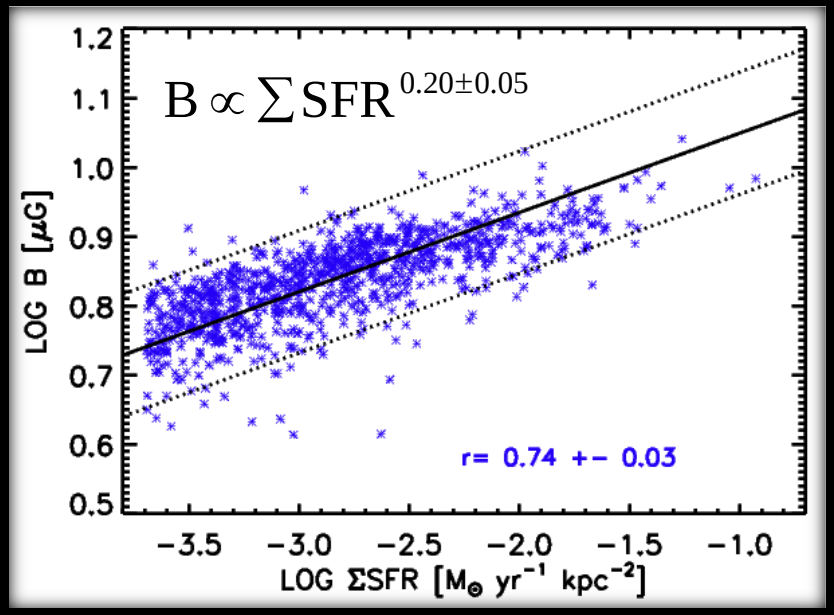
Synchrotron spectral index varies in the disk
as CREs experience various energy losses
(Tabatabaei et al. 2007& 2013a)



Synchrotron emission is extended, yet strong near SF regions

→ enhanced magnetic field/fresh CREs?

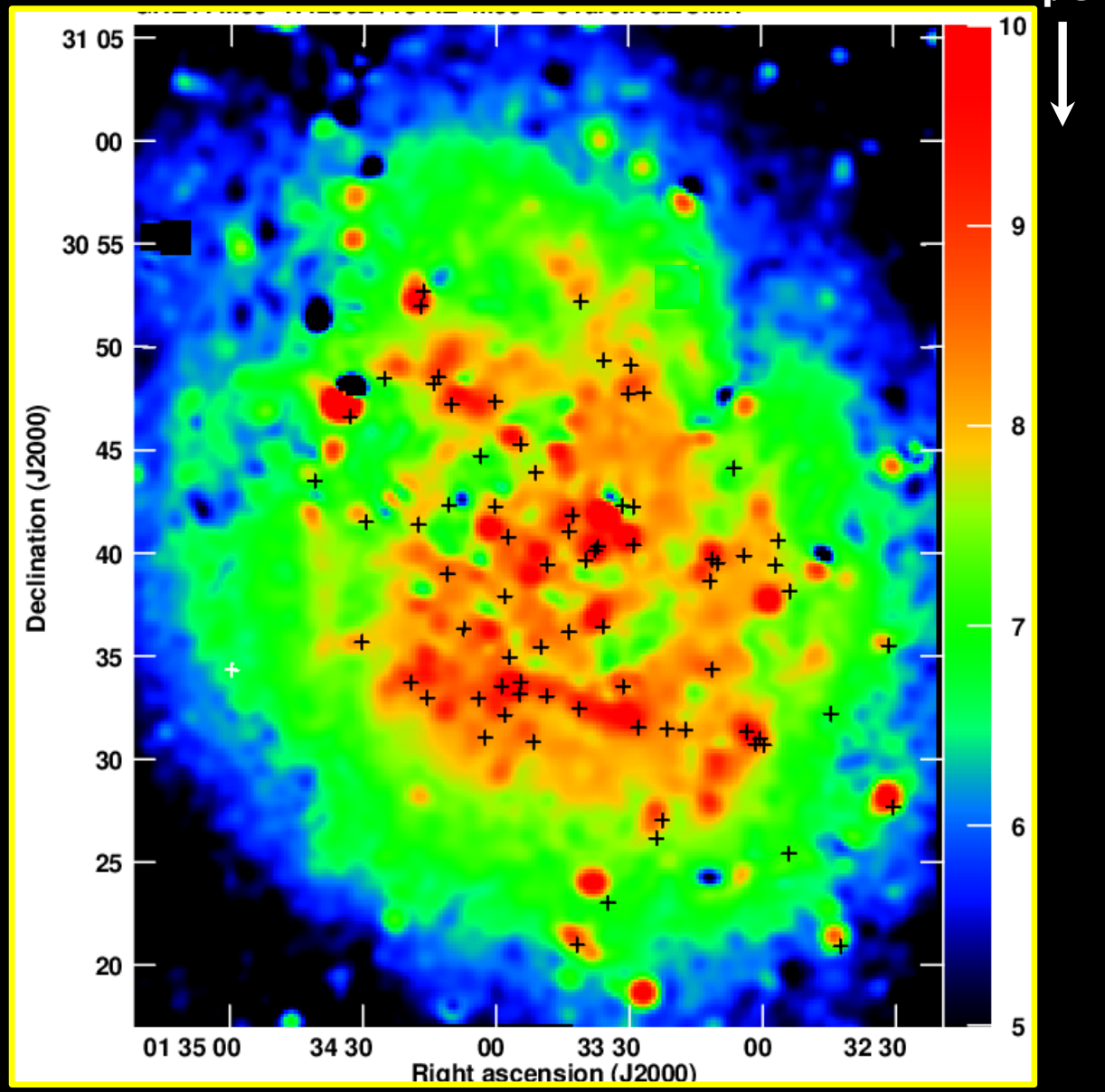
Amplification of Magnetic Fields in SF Regions



B - SFR correlation agrees with supernova-driven dynamo models (Gressel+2000)

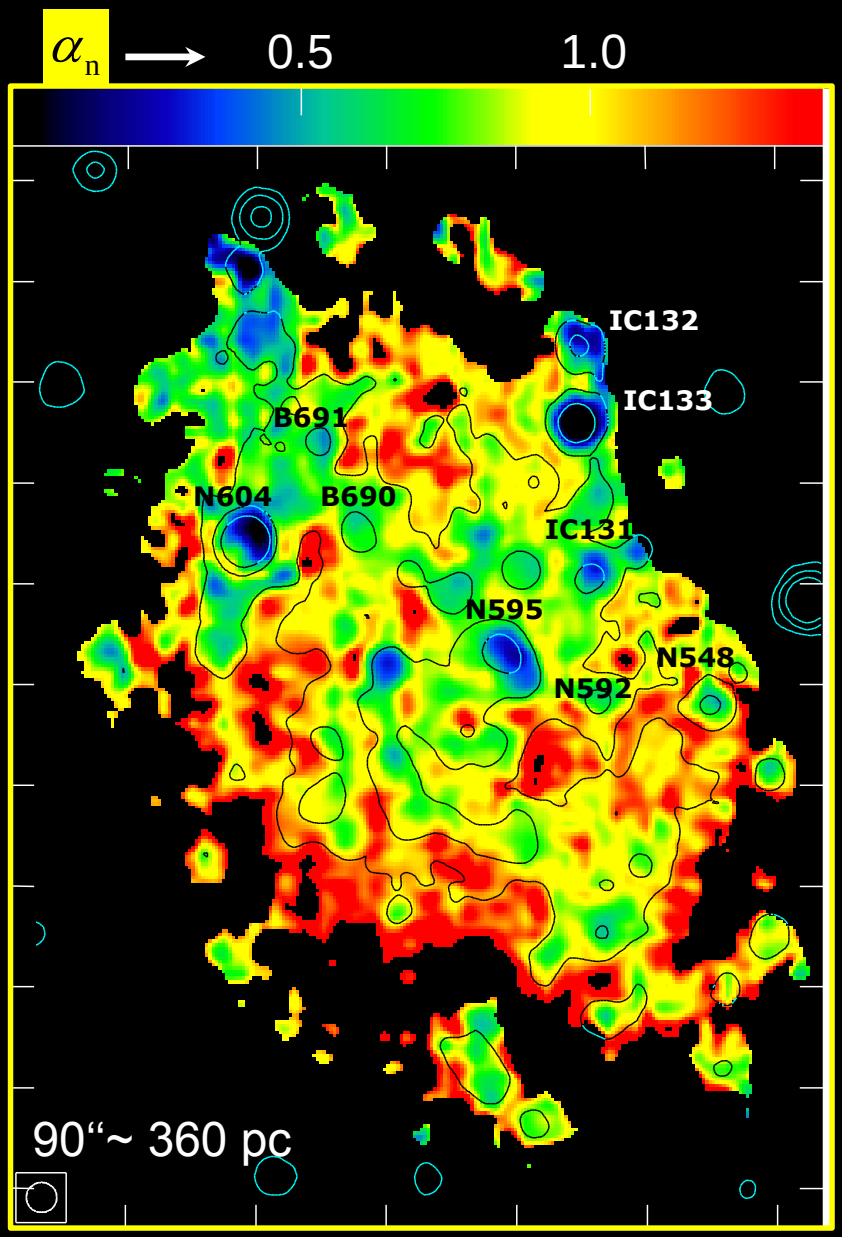
Global studies: Chyzy+2008,09, Heesen+2014, FT+2017

Magnetic Field (color) & SNRs (+)



Tabatabaei et al. 2013

Injection of Cosmic Rays in SF Regions



Tabatabaei+2007

$$S_\nu \propto \nu^{-\alpha_n}$$

- α_n=1.0 ±0.1 in between the arms and the outer parts
→ Inverse Compton +synchrotron energy loss

- α_n≈0.5 in star forming regions: injection of CREs

- Even flatter in giant HII regions→ different acceleration regimes?

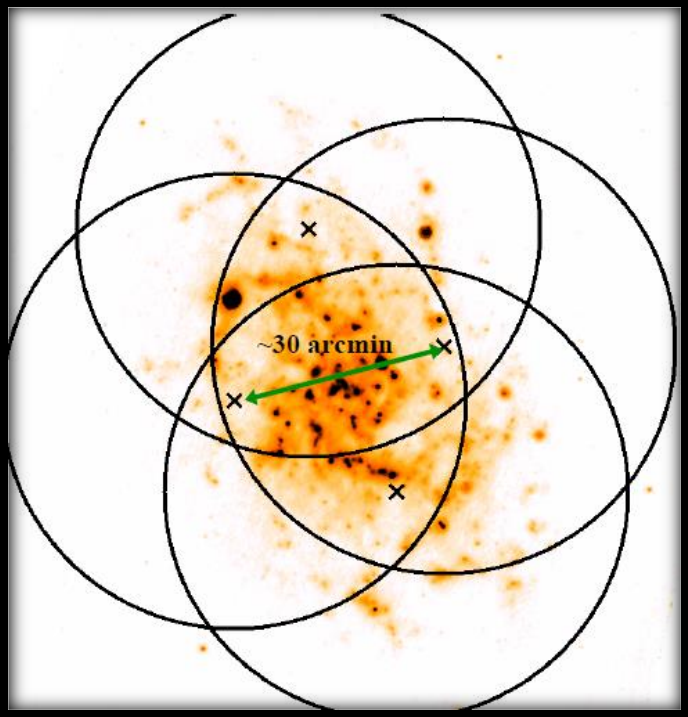
→ High-resolution surveys

Cloud-Scale Surveys of SF & ISM in M33 (≥ 40pc resolution)

~ same res. as HerM33es and CO/HI observations

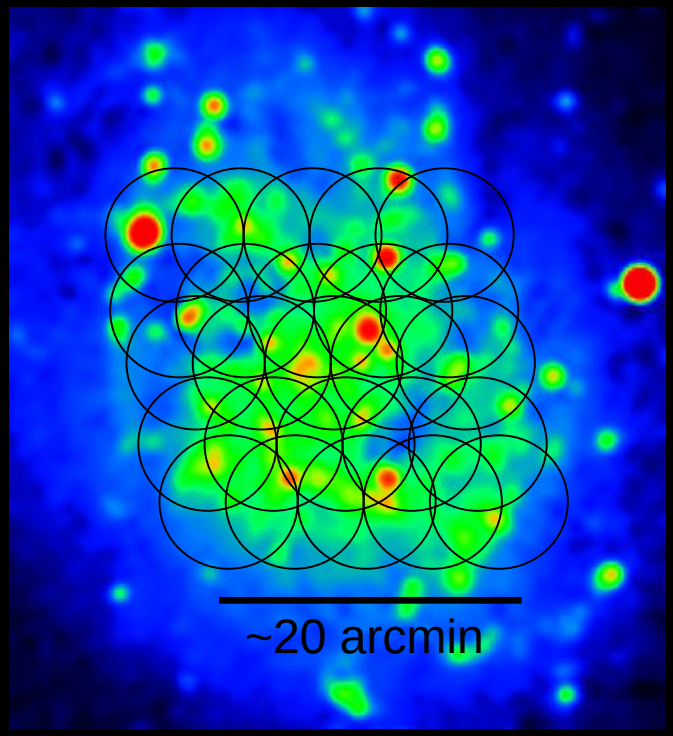
The GMRT 320 MHz Survey

(4 ponit.)



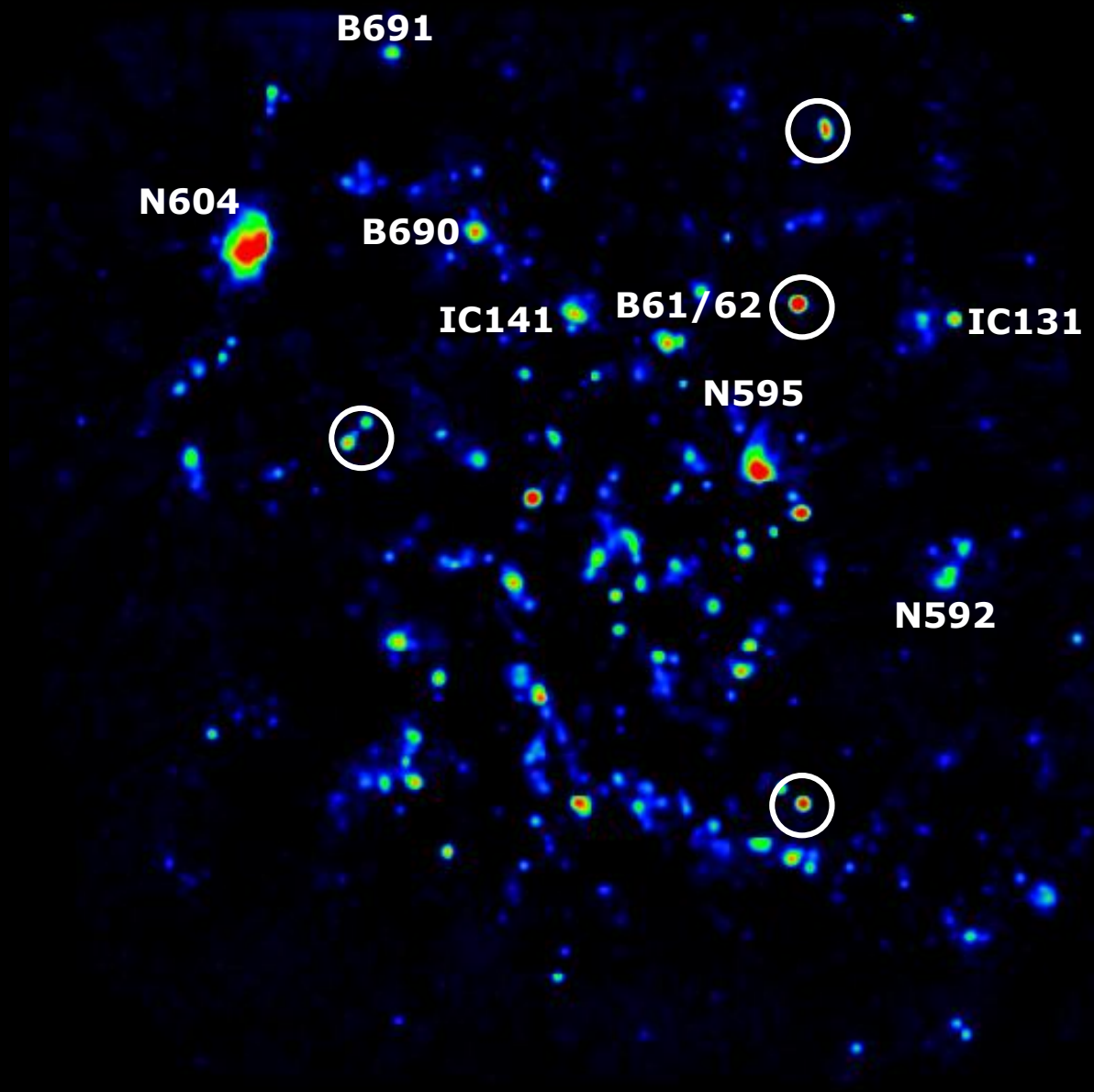
The JVLA Surveys:

L-band (12 point.), C-band (25 point.)

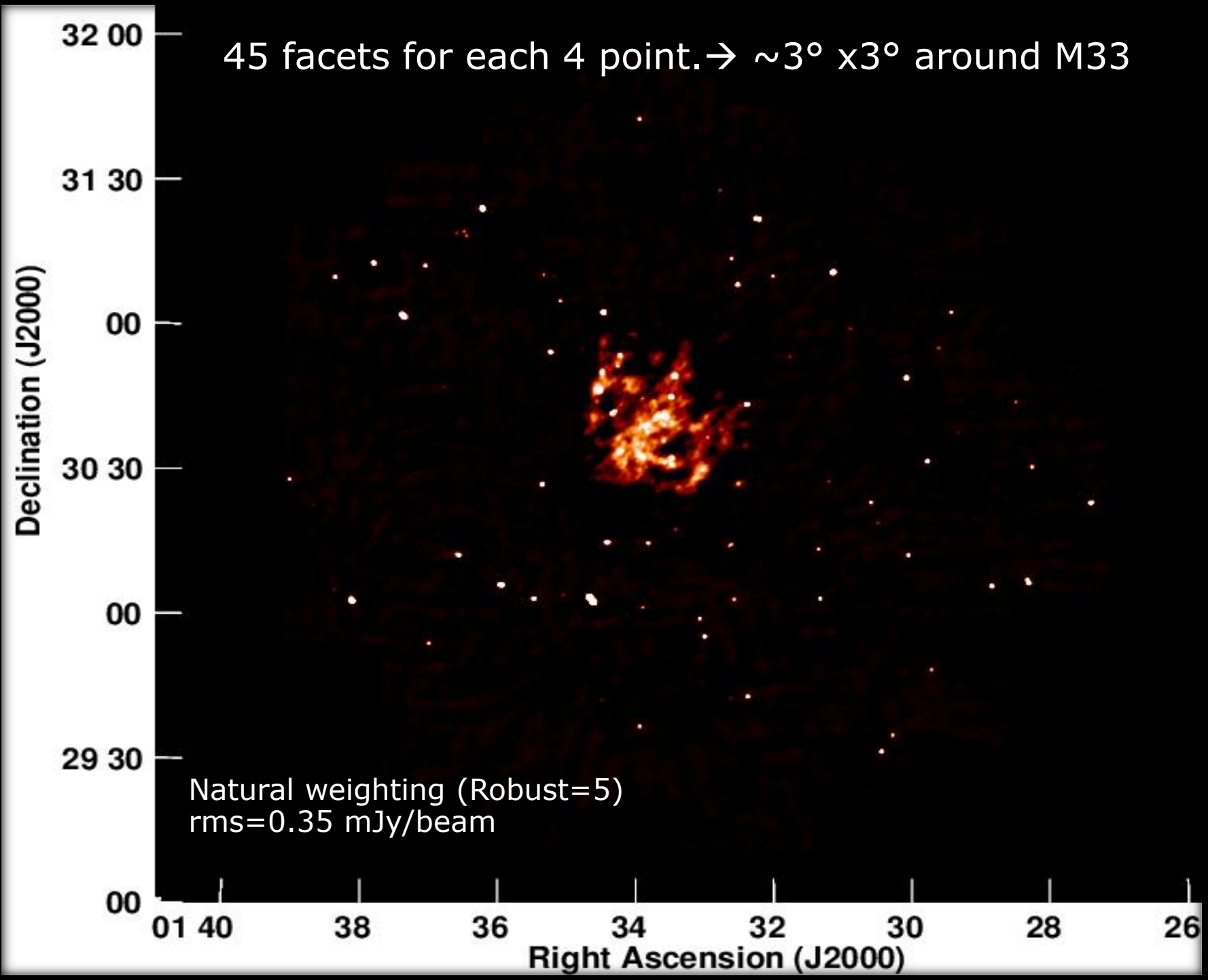


The JVLA Observations (6.3 GHz)

resolution= 10″ ~ 40pc
rms=7 μJ/beam



The GMRT Observations



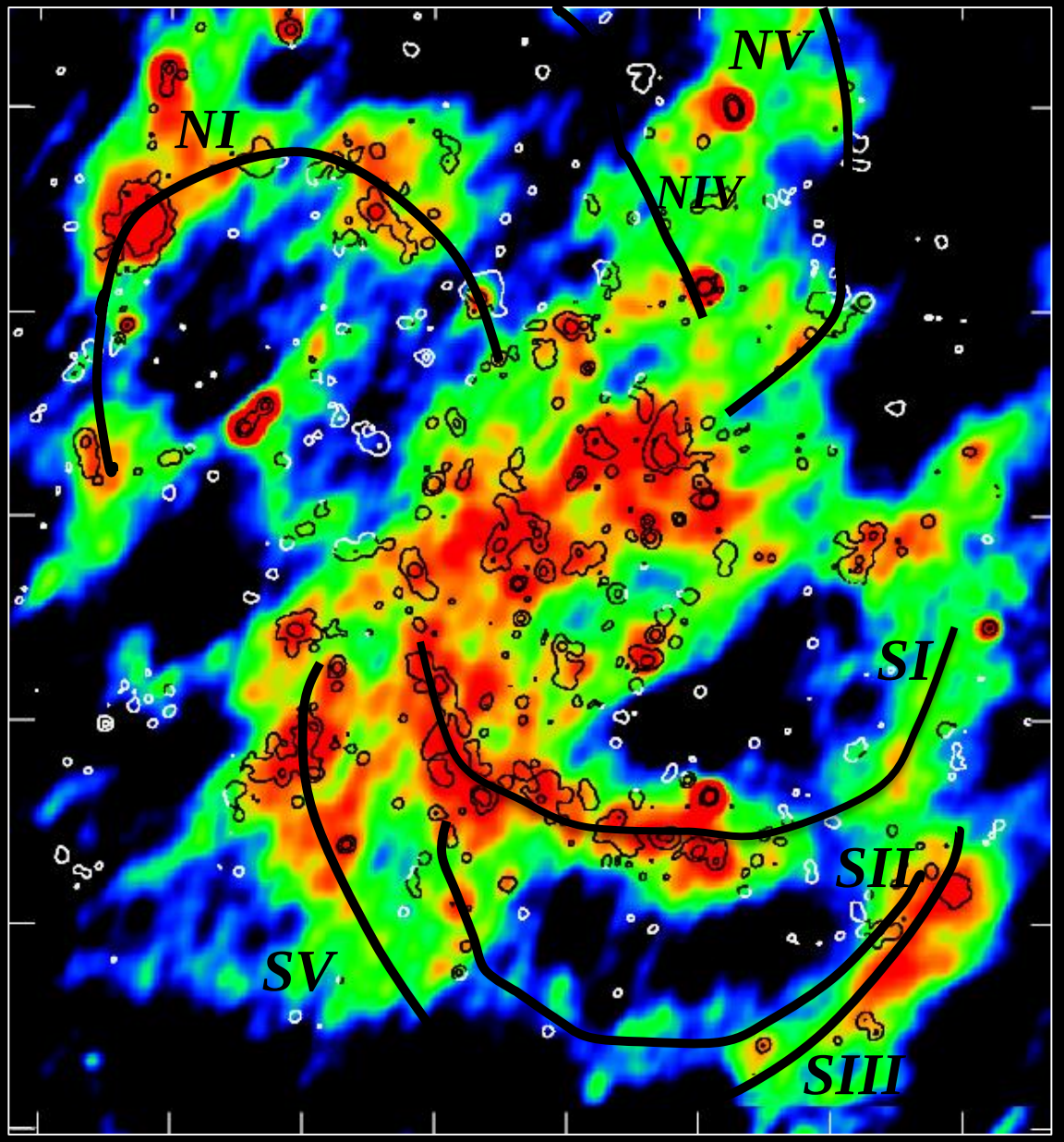
M33 at 320 MHz: 25”~ 100pc resolution

Robust=5, rms=0.35 mJy/beam

Contours: JVLA 6GHz
Color: GMRT 320 MHz

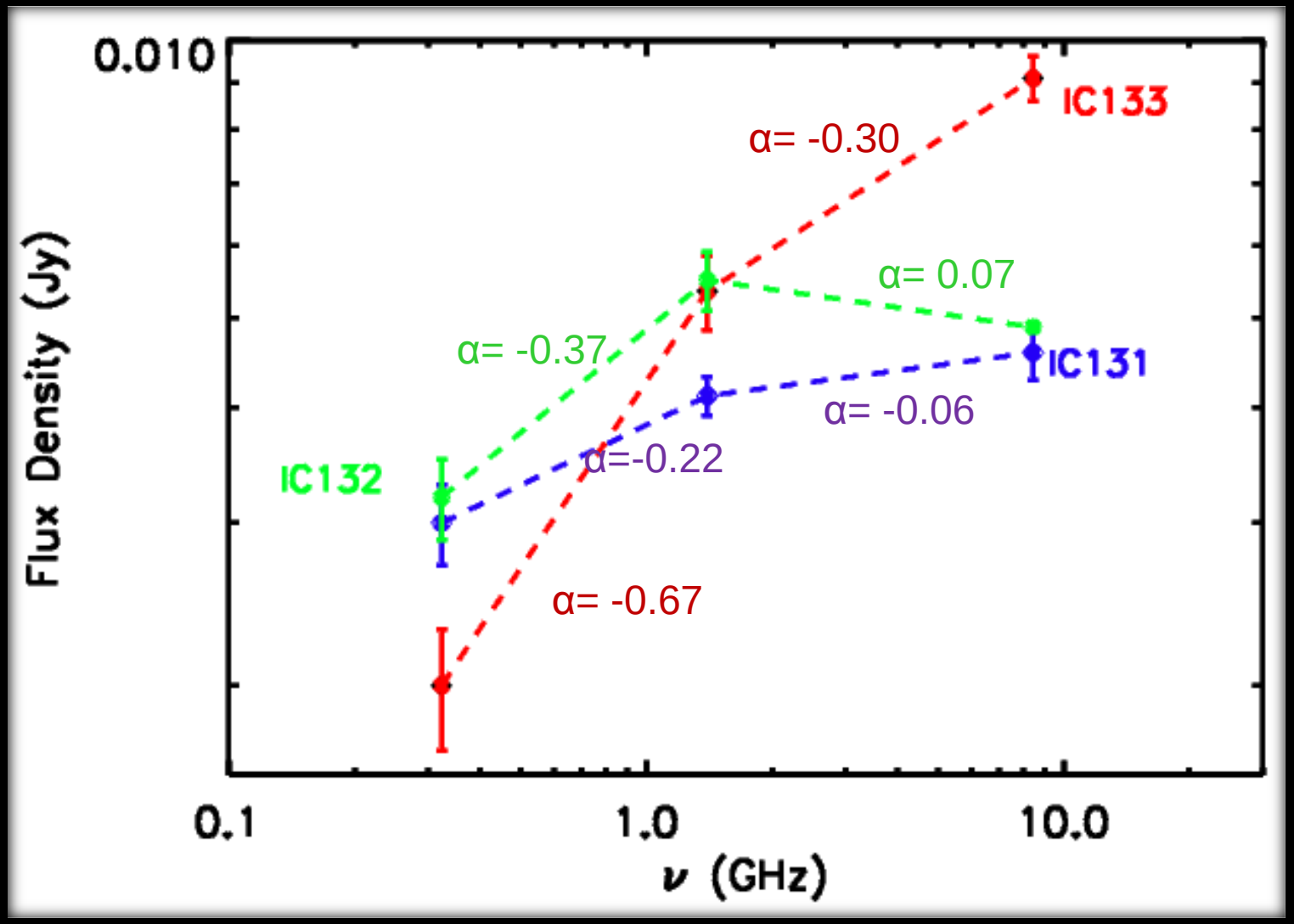
<u>Galaxy Structures:</u>

- The Galaxy center
- Inner 3kpc bright
- The spiral arms NI, SI, SII
- Segments of other arms
- SF regions?



Absorption in Some Regions

SEDs of the HII regions



...And Globally?

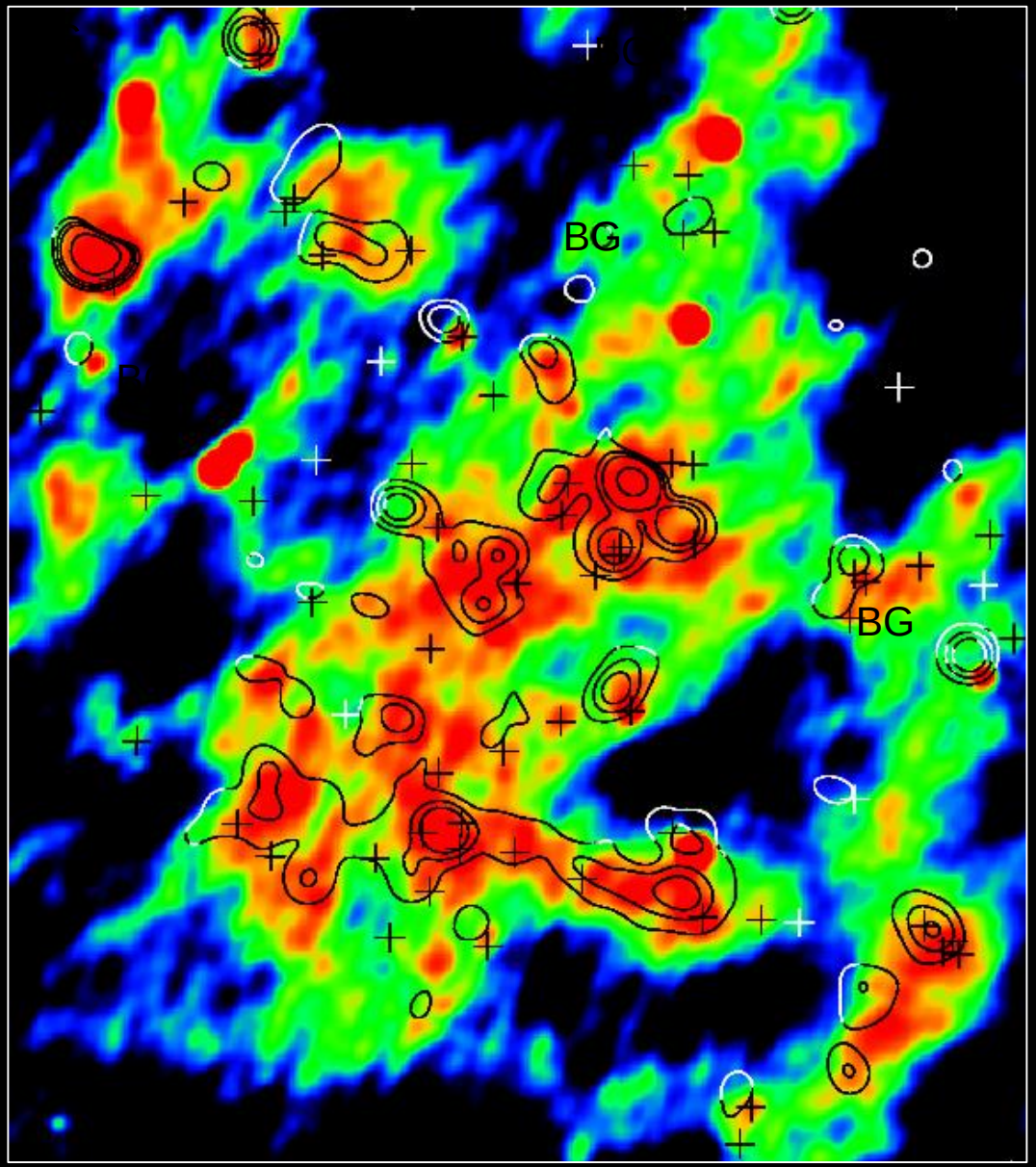
General trend:

Bright 320MHz emission where the GHz nonthermal emission is bright

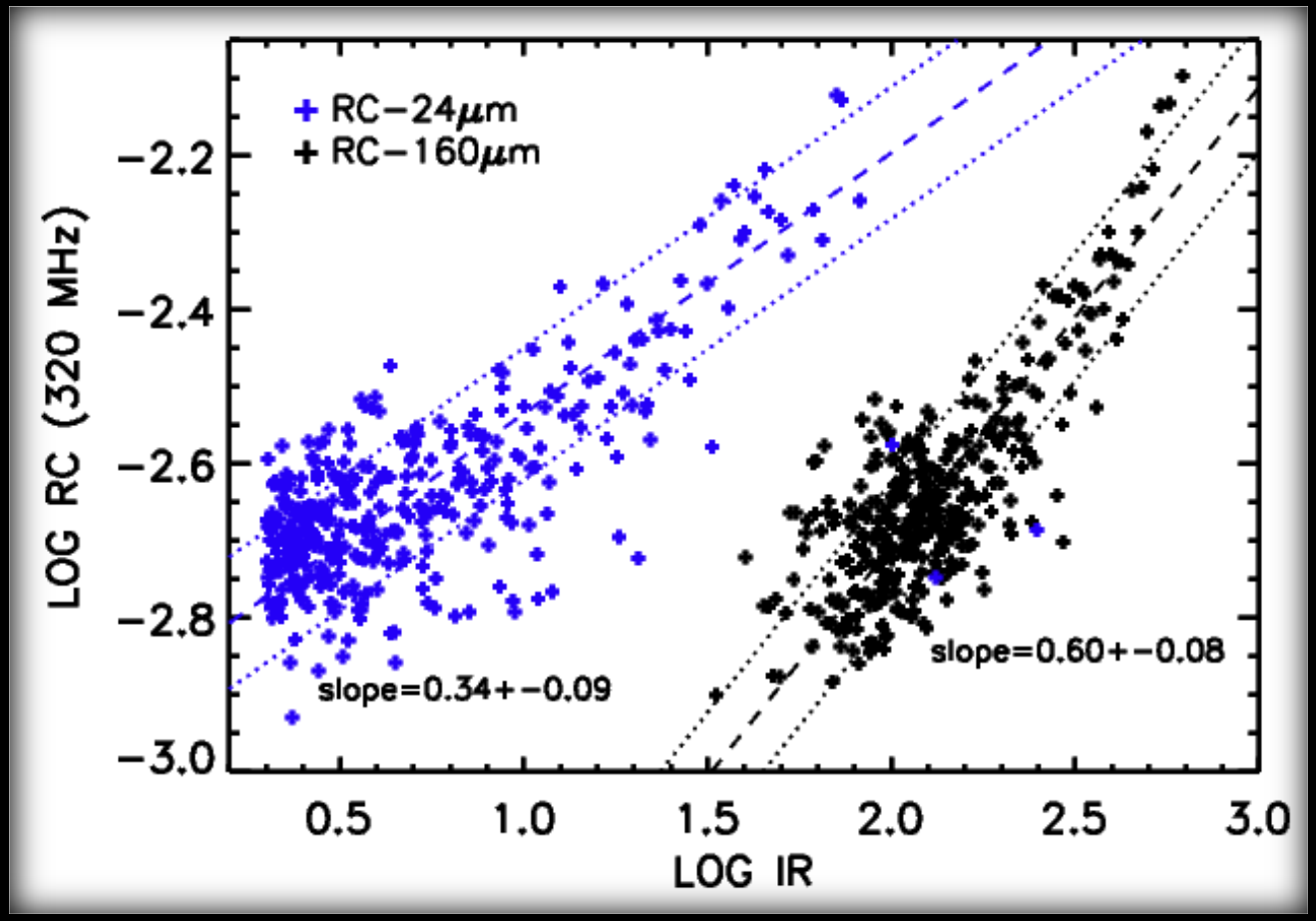
The radio spectrum of giant HII:

Steeper at υ<1 GHz, as the thermal emission is absorbed → indicative of pure SNRs, or the nonthermal ISM (enhanced B due to SF feedback)

Contours: Nonthermal 1.4 GHz
(separated using TRT method, Tabatabaei+ 2013)



Radio - IR Correlation



320 MHz RC:
better correlated with 160μm than with 24μm

Summary

- Giant HII regions/SF complexes show up as bright sources at low-frequncies mostly due to their nonthermal emission as first indicated at GHz using the TRT separation in M33.

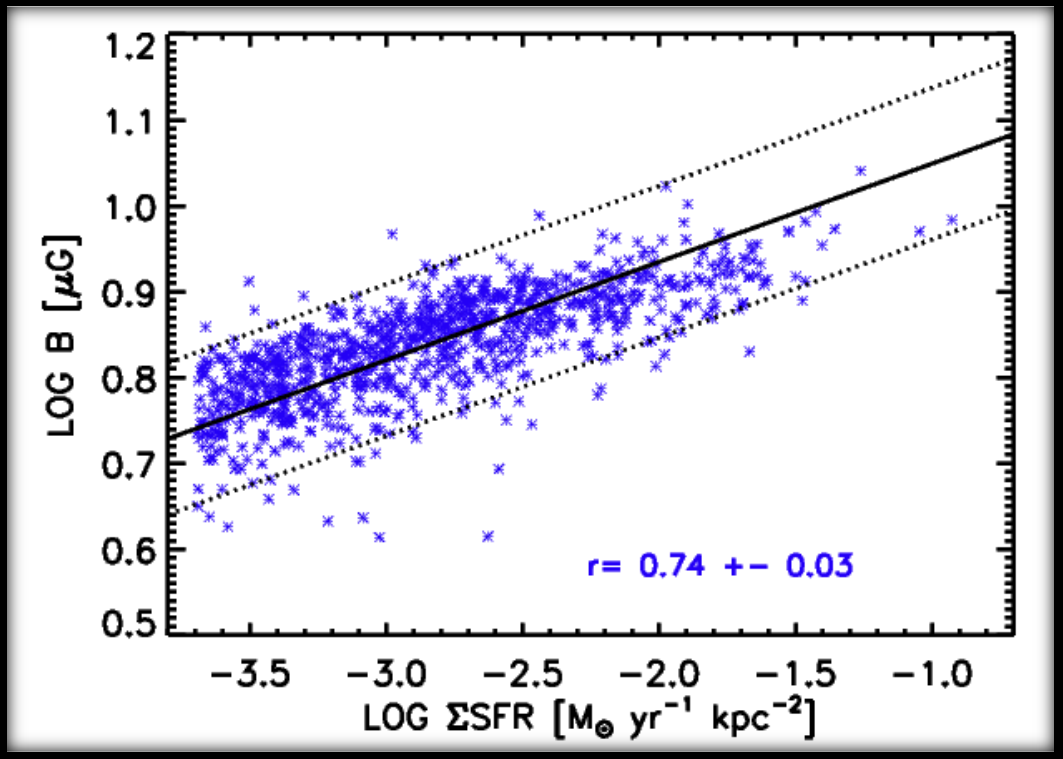
- The 320MHz and CO correlated but weaker than GHz-CO correlation possibly due to free-free absorption in a cold ionized gas.

- The 320MHz-IR correlation is better with colder dust traced by 160μm than with warmer dust.

- The absorption effects should be taken into account measuring SFR at low-frequencies.

Amplification of the magnetic field in SF regions

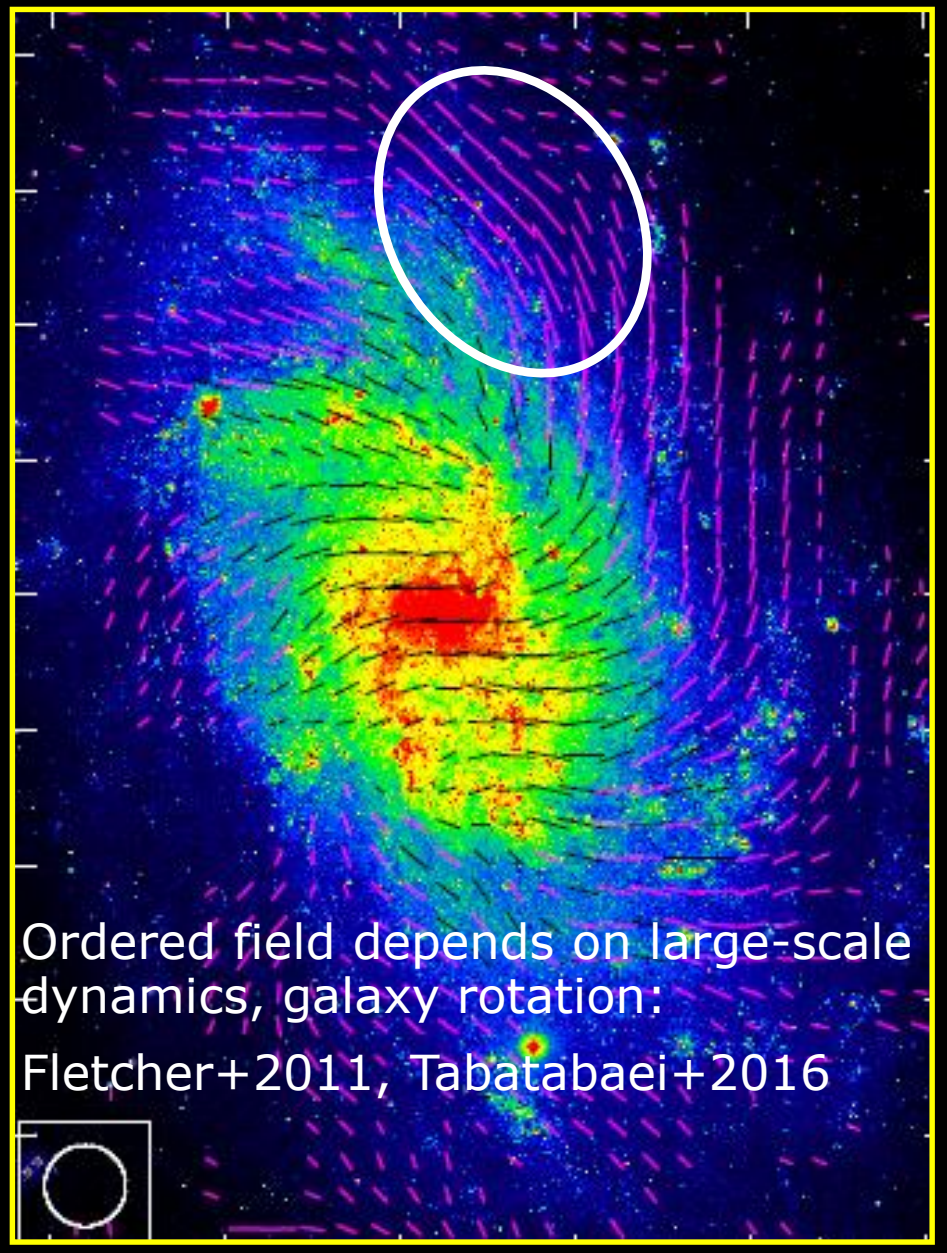
The total B strength and SFR correlated



$$B \propto \sum SFR^{0.20\pm0.05}$$

Agrees with Supernova-driven dynamo models (Gressel+2000, see also Chyzy+2008,09, Heesen+2014)

Ordered Magnetic Field



Tabatabaei+2008