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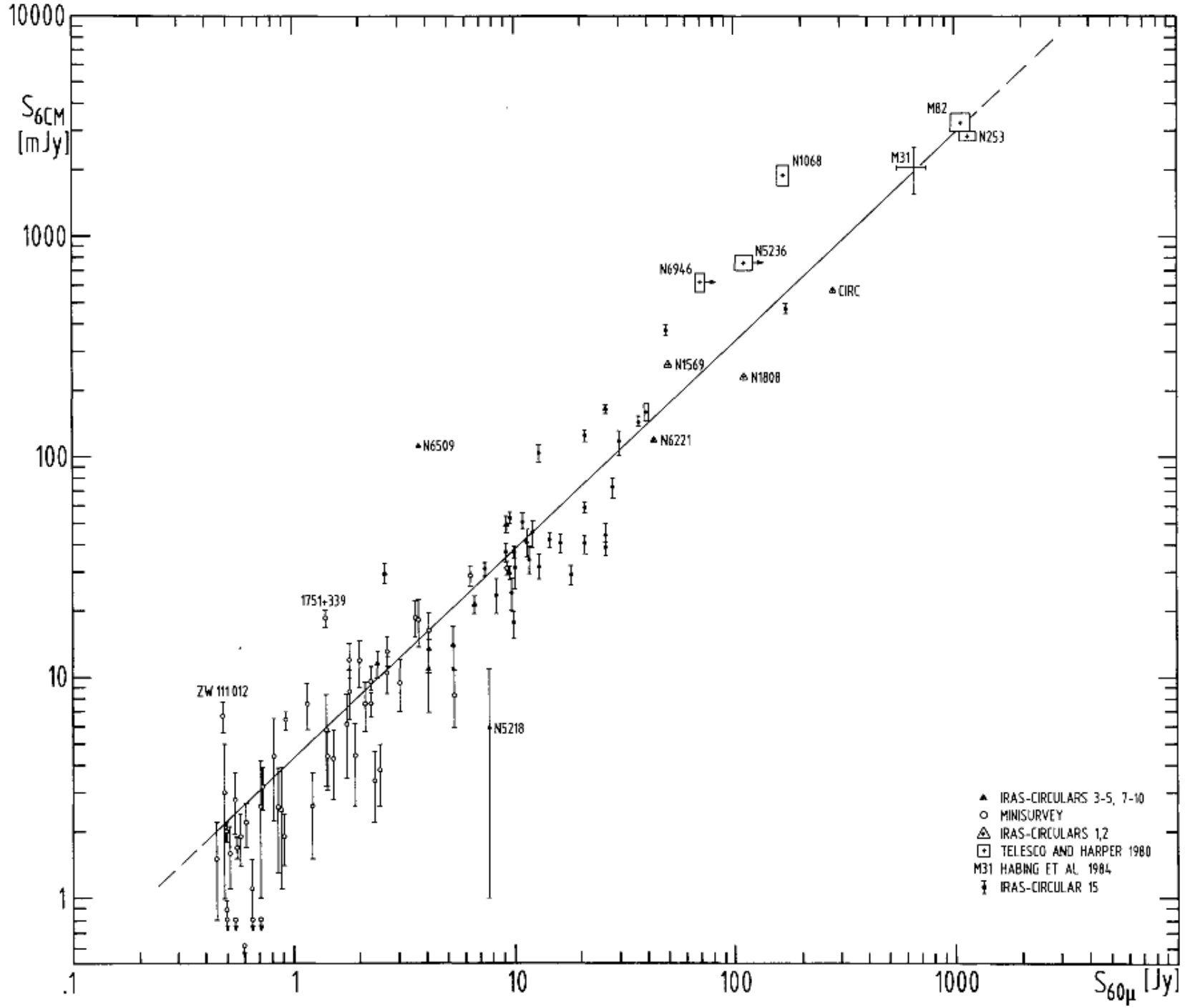
Probing cosmic rays in nearby dwarf irregular galaxies with deep radio continuum observations

Motivation

- RC as an extinction free SF tracer
  - Do dwarfs lie on the radio–FIR correlation?
- Do dwarfs have (ordered) magnetic fields?
  - Amplification by galactic dynamo
  - Thermally / non-thermally dominated?
- Dwarf galaxies as "building blocks"
  - Magnetization of the early Universe

Outline

- **Resolved RC–SFR correlation**
- Dwarf irregular galaxy IC10
  - RC emission as SF tracer
  - Magnetic fields



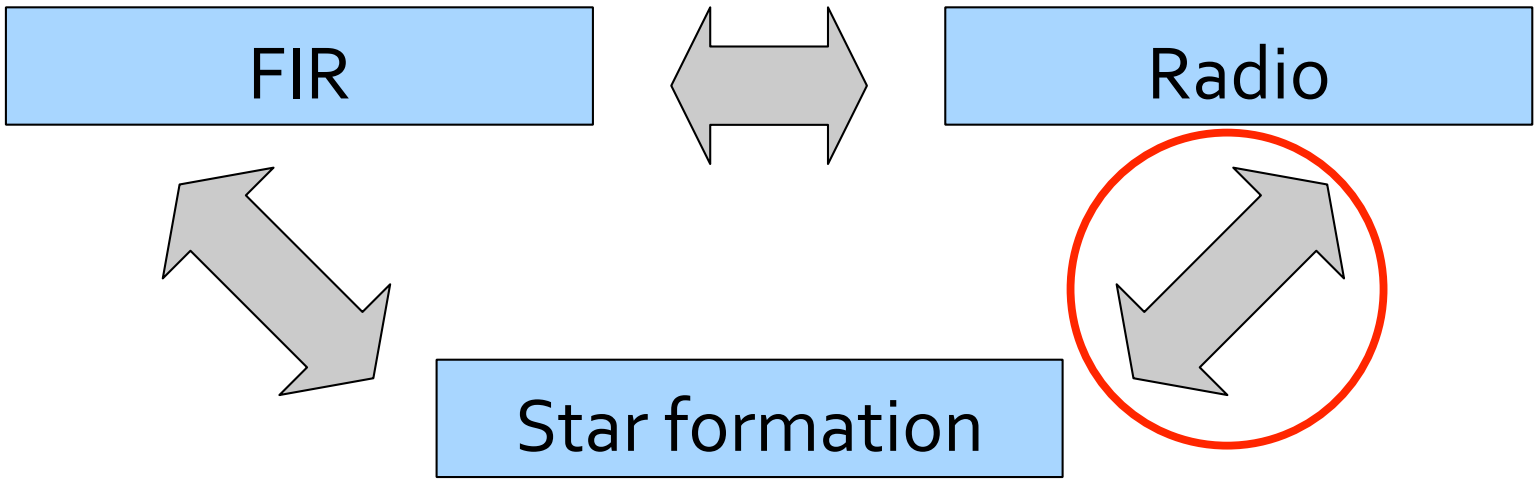
6 cm radio continuum flux density

60 µm mid-infrared flux density

de Jong et al. 1985

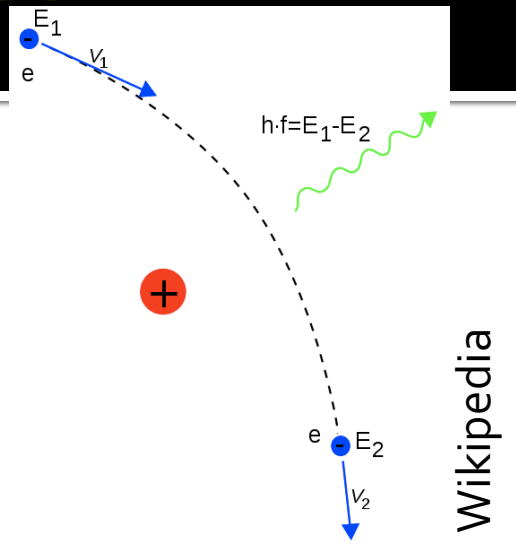
Radio–SFR correlation

- Break up the RC–FIR correlation into
  - RC–SFR correlation
  - FIR–SFR correlation

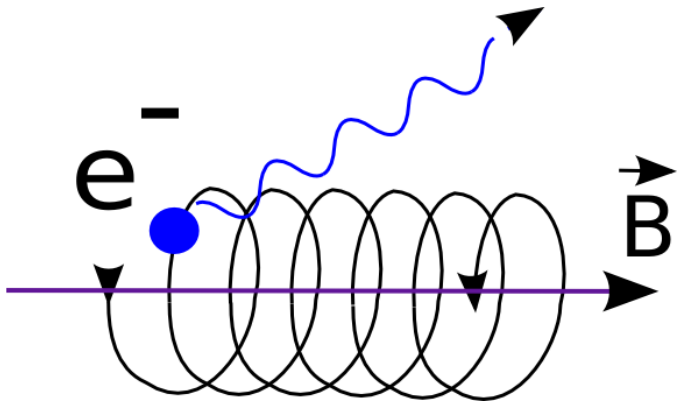


Radio emission in galaxies

- Thermal emission
  - UV-photons ionize gas
  - Free-free radio emission
  - Can use Halpha as tracer
- Non-thermal emission
  - Cosmic-ray electrons
  - Magnetic fields
  - Synchrotron emission

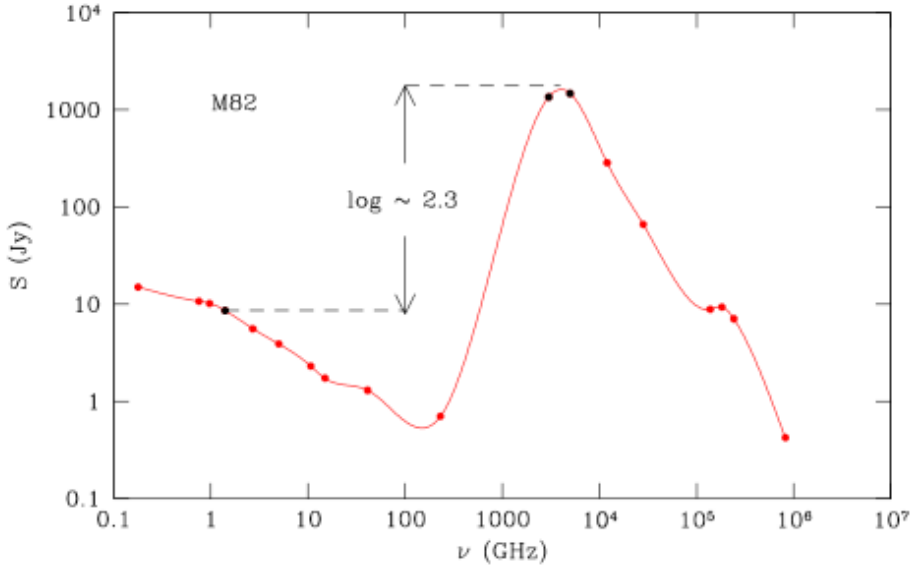


Massive stars



RC–SFR correlation

- Radio continuum (RC)
- Thermal RC ideal SFR tracer
- Non-thermal emission dominates ∝ SFR
- Resolved study
- Separate AGNs
- Condon's relation



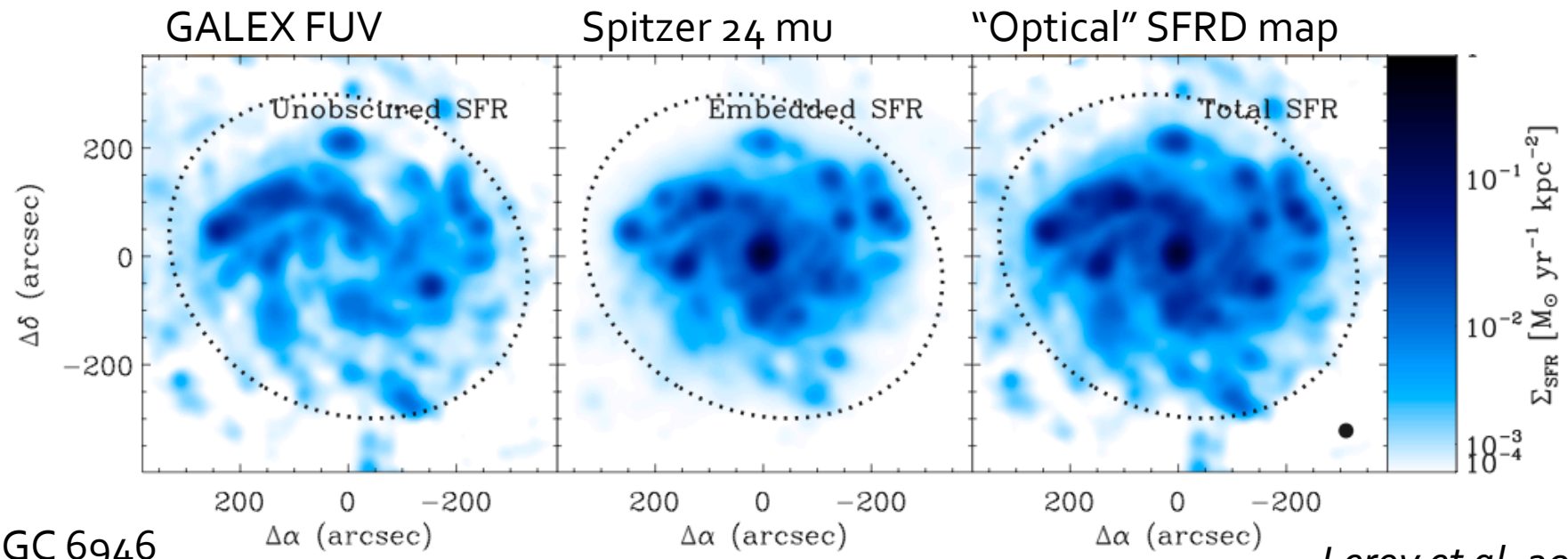
J. Condon

$$\left(\frac{\mathrm{SFR}}{\mathrm{M_\odot\,yr^{-1}}}\right)_{>0.1\,M_\odot} = 1.2\times10^{-21}\left(\frac{L_{1.4\,\mathrm{GHz}}}{\mathrm{W\,Hz^{-1}}}\right)$$

Condon (1992)

"Optical" star-formation tracers

- GALEX FUV: young massive stars
- *Spitzer* 24 μm: dust emission (SF regions)
- SFR density maps (Leroy et al. 2008, 2012)

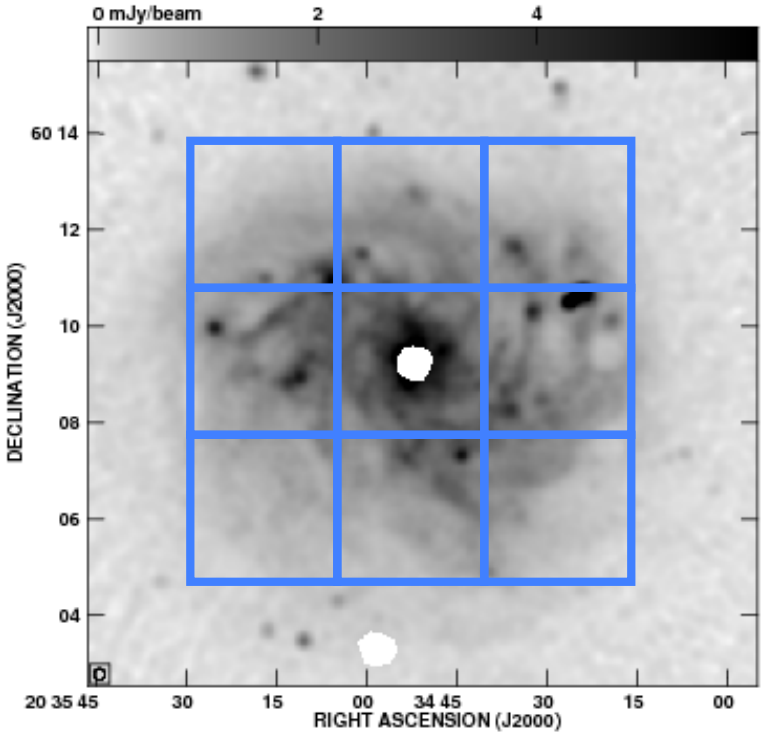


NGC 6946

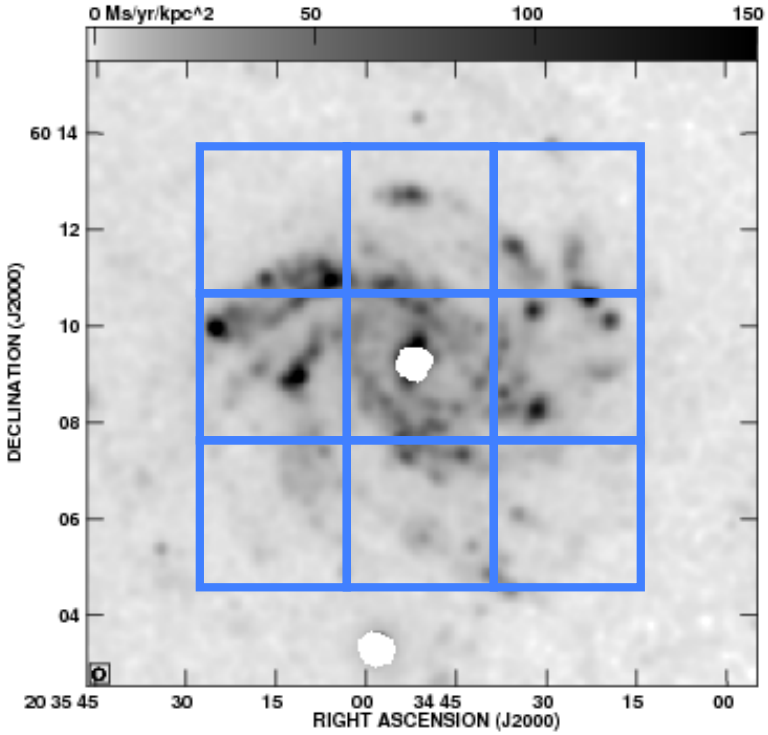
Leroy et al. 2008

Resolved SFRDs – NGC 6946

Radio 22 cm

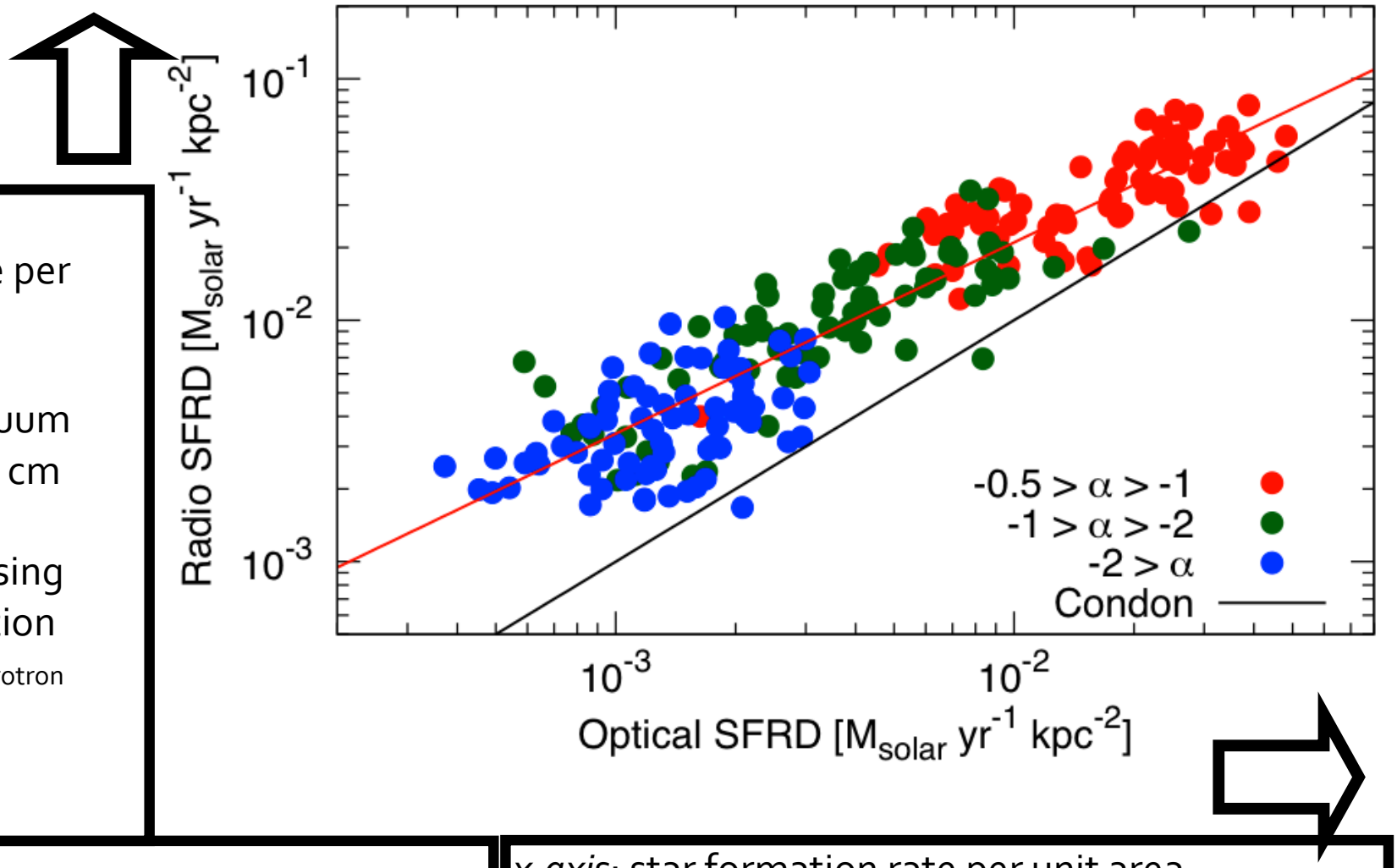


SFR density



Grid not to scale!

- RC is smoothed SFRD map



y-axis: star formation rate per unit area

- Radio continuum emission at 22 cm

- Converted using Condon's relation

Non-thermal synchrotron and thermal free-free emission

Flat radio spectral index

Intermediate radio spectral index

Steep radio spectral index

x-axis: star formation rate per unit area

Ultraviolet (GALEX FUV)

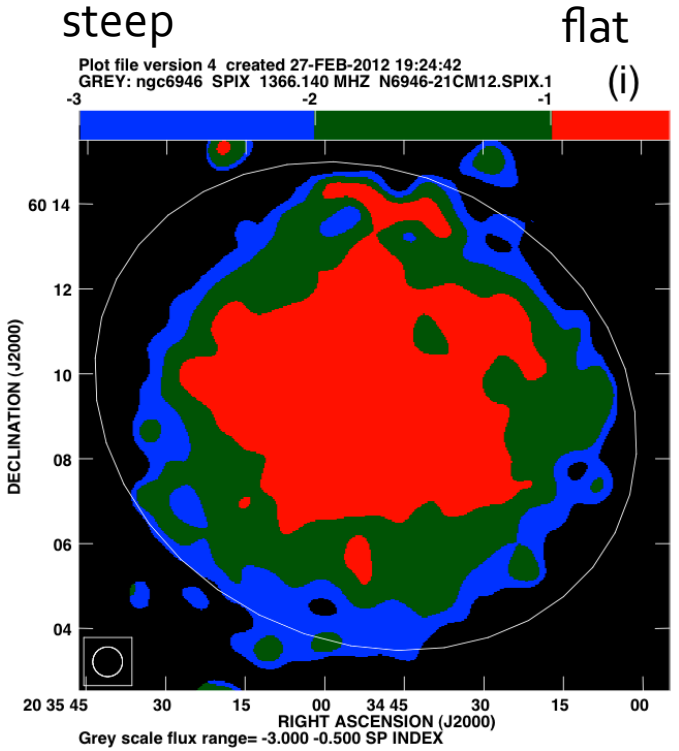
Unobscured young (O and B) stars.

Infrared (*Spitzer* 24μm)

Dust enshrouded young stars.

Local RC–SFR correlation

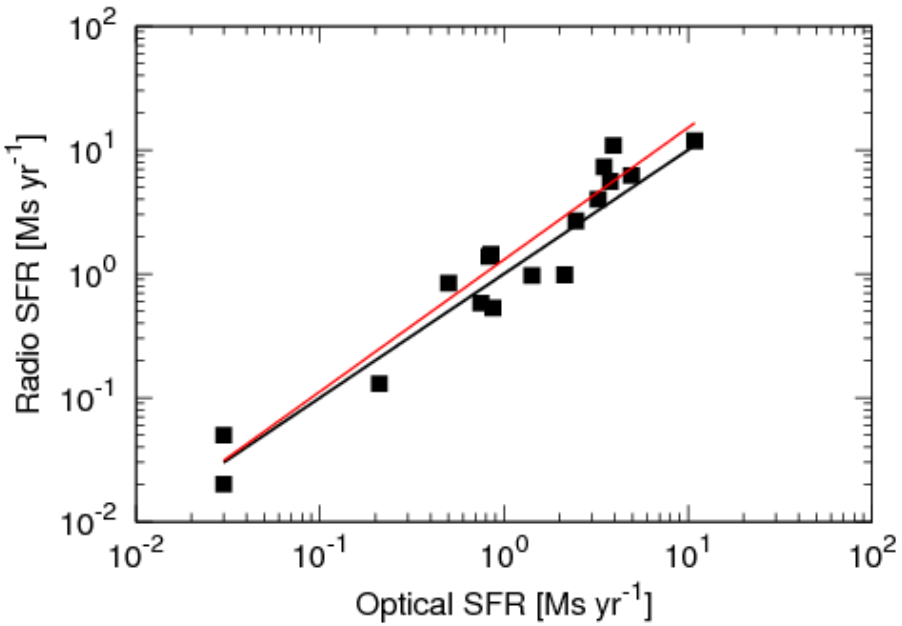
- Local correlation
  - $\log(RC) = \zeta \times \log(SFRD)$
    $(\zeta = 0.63 +/- 0.25)$
- Steep/flat spectral index
  - Radio bright/dim
- Cosmic-ray transport!

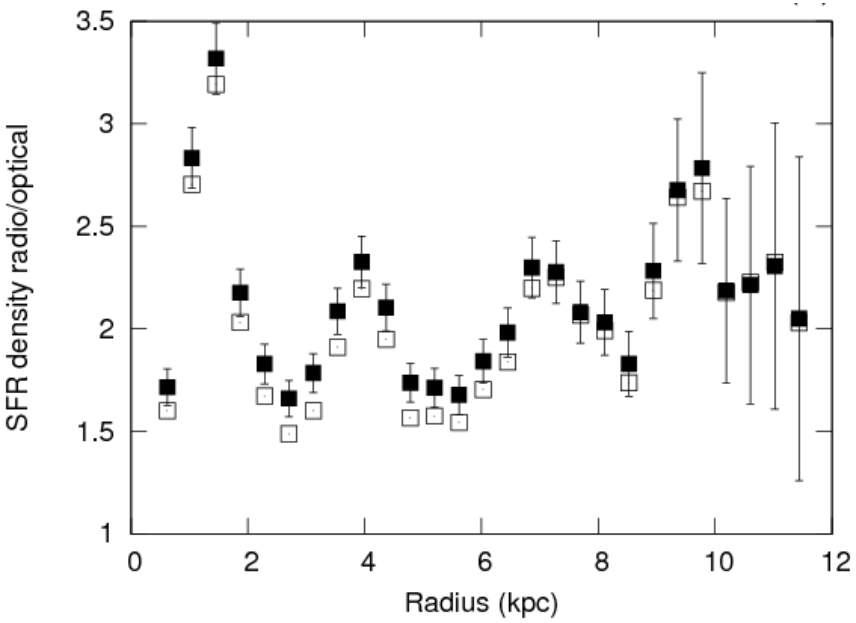


NGC6946
WSRT spectral index 22/18 cm
1.2 kpc resolution

Resolved RC–SFR correlation

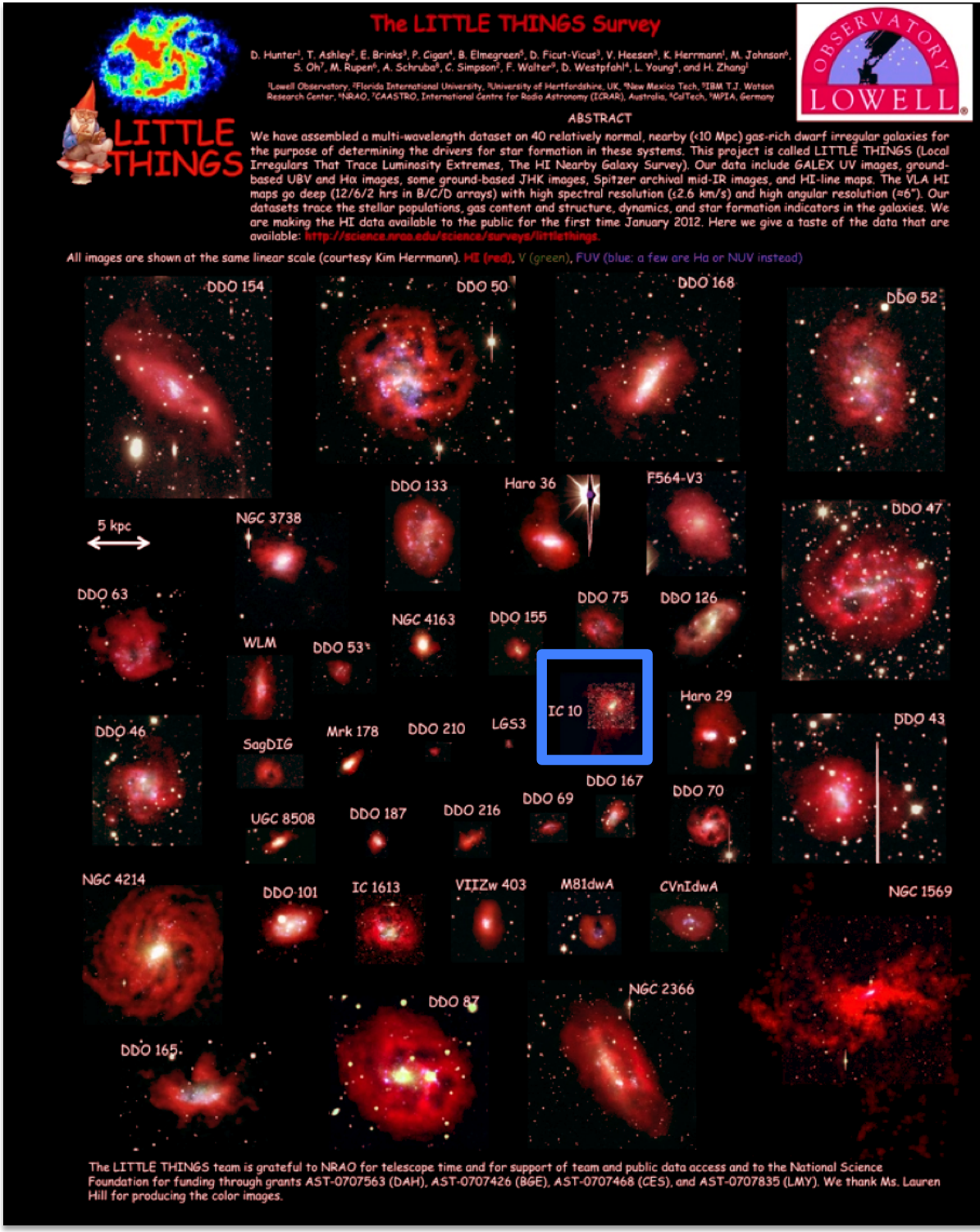
- Condon's relation confirmed
- RC/optical SFRD = 1.2 +/- 0.6
- No strong correlation with global parameter
- Non-thermal RC is good SF tracer!





Outline

- Resolved RC–SFR correlation
- Dwarf irregular galaxy IC10
  - **RC emission as SF tracer**
  - Magnetic fields

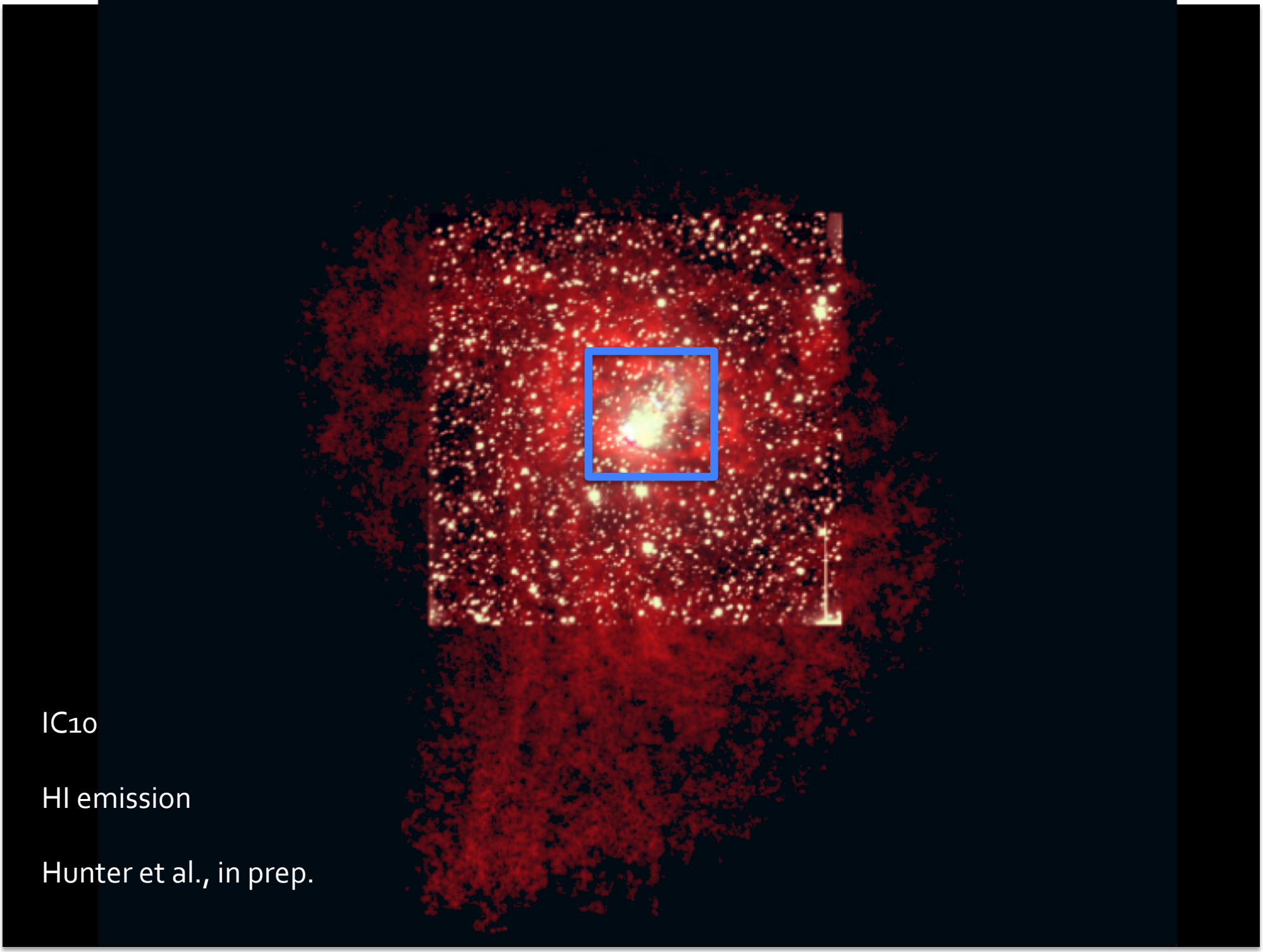


EVLA observations

IC10 + IC1613 at 20, 6, 3, 1 cm

Entire sample at 6 cm

See poster by Ged Kitchener



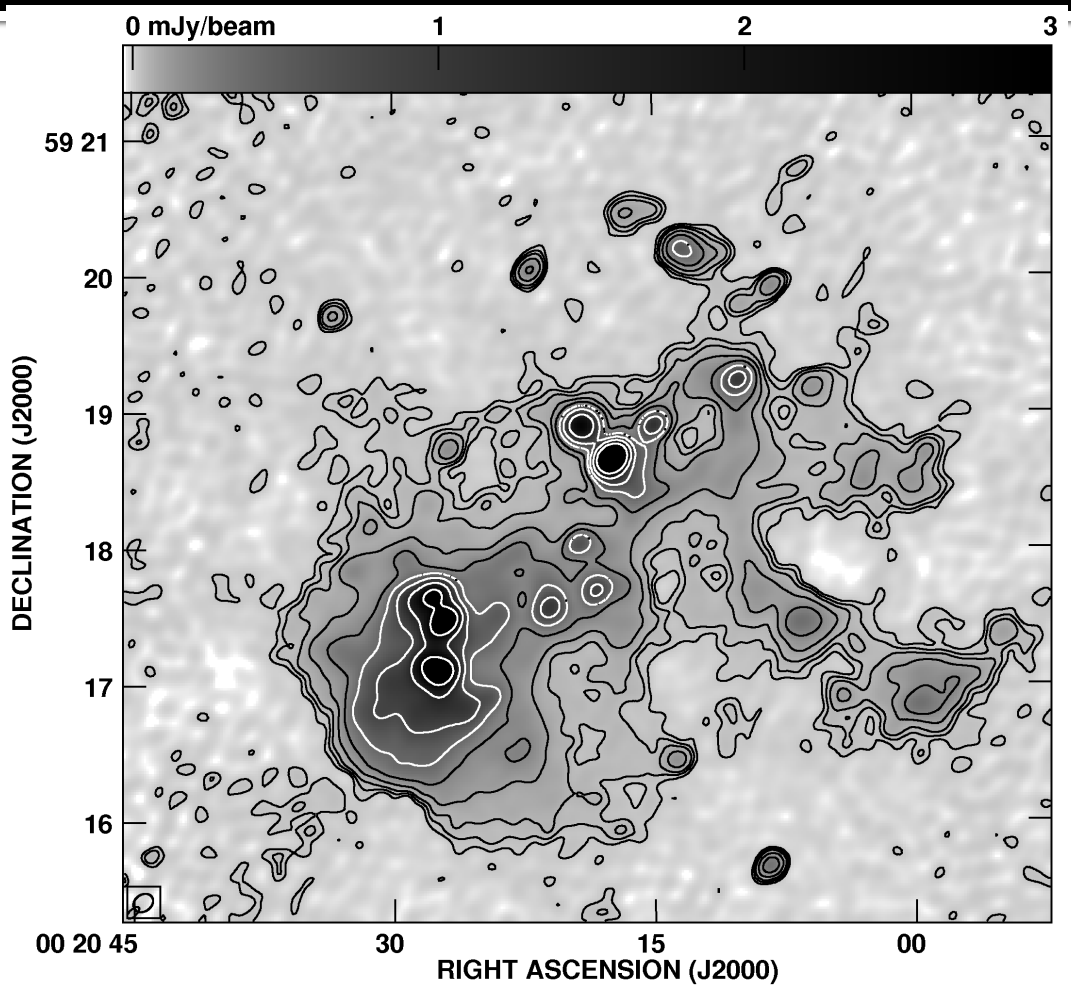
IC10

HI emission

Hunter et al., in prep.

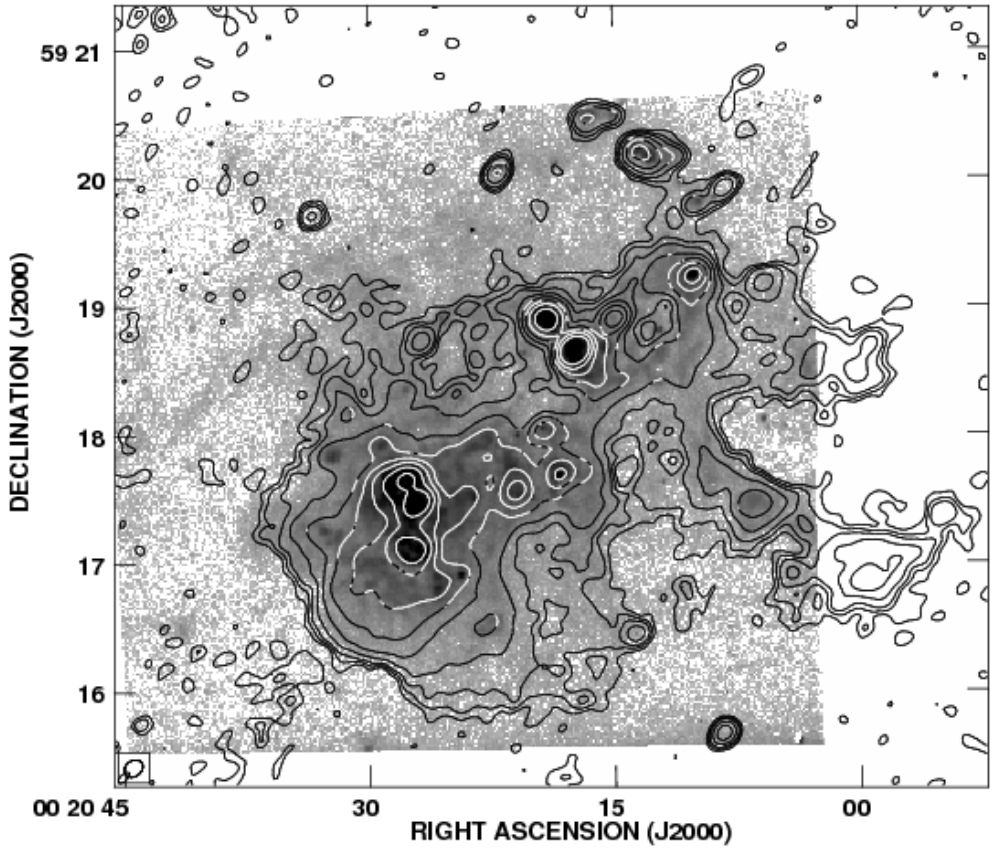
EVLA observations

- 4h D-configuration at 6cm
- 5 μJy/beam rms noise
- Only 20% higher than theoretically expected

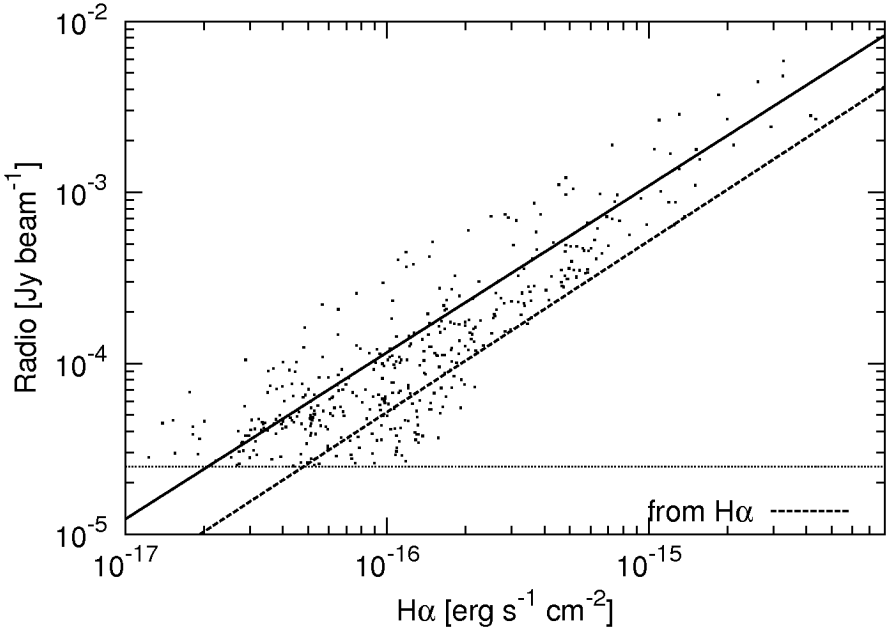


6 cm total power
Contours: 2^n x 3 sigma

RC – Hα at 50 pc resolution



RC – Hα correlation
50 pc resolution



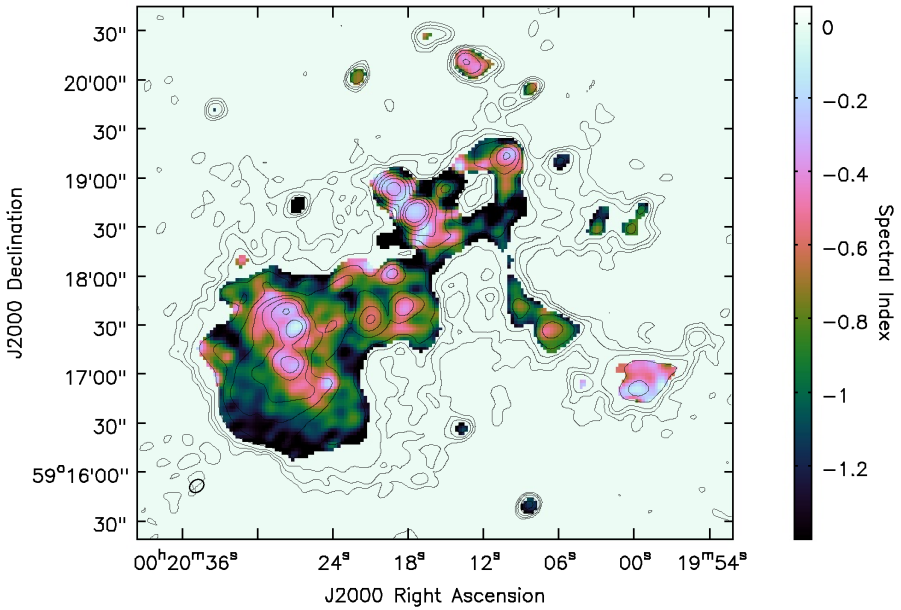
- 50% thermal RC emission
- Radio dim by factor 2–3 (Kennicutt 1998)

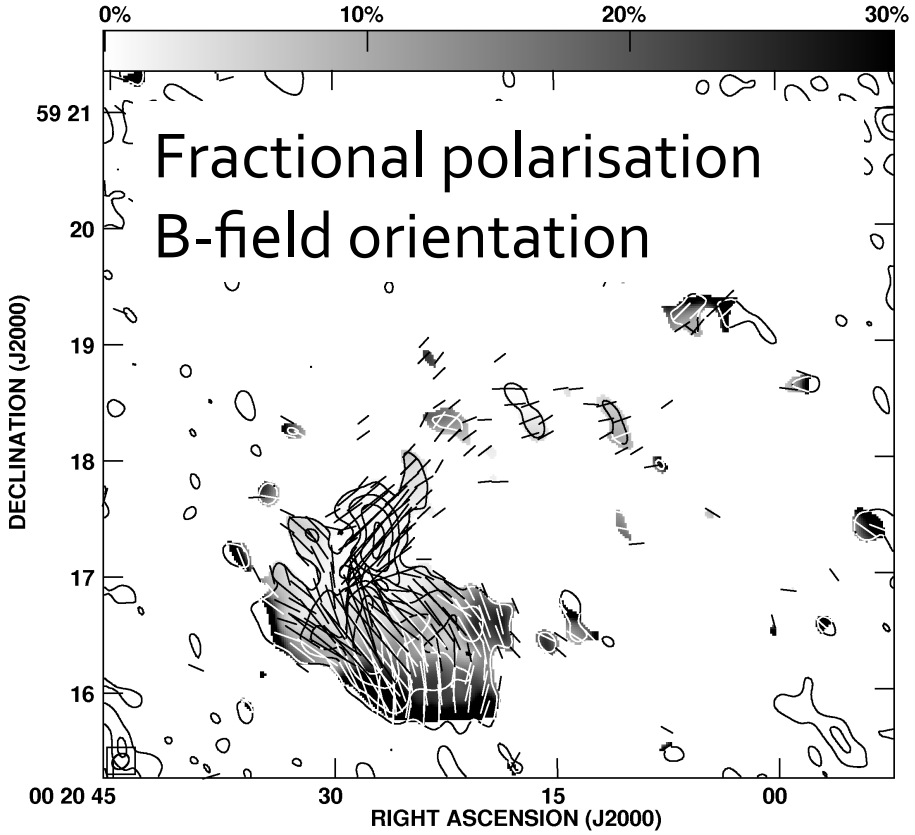
Outline

- Resolved RC–SFR correlation
- Dwarf irregular galaxy IC10
  - RC as SF tracer
  - **Magnetic fields**

Magnetic fields in IC10

Radio spectral index





- Non-thermal bubble
- Fractional polarization 10–20%
- Possibly compression by shock waves

Conclusions

- Resolved RC–SFR correlation
  - Condon's relation works!
- Dwarf irregular galaxy IC10
  - High thermal RC fraction
  - Radio dim (compared to SFR)
  - Locally amplified B-fields

Thank you!