# SKA continuum observations to study star formation in nearby galaxies

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Some still open questions about star formation:

- Importance of local (disk or cloud instability)
versus global effects (spiral density waves, tidal forces, magnetic fields)
in triggering SF.

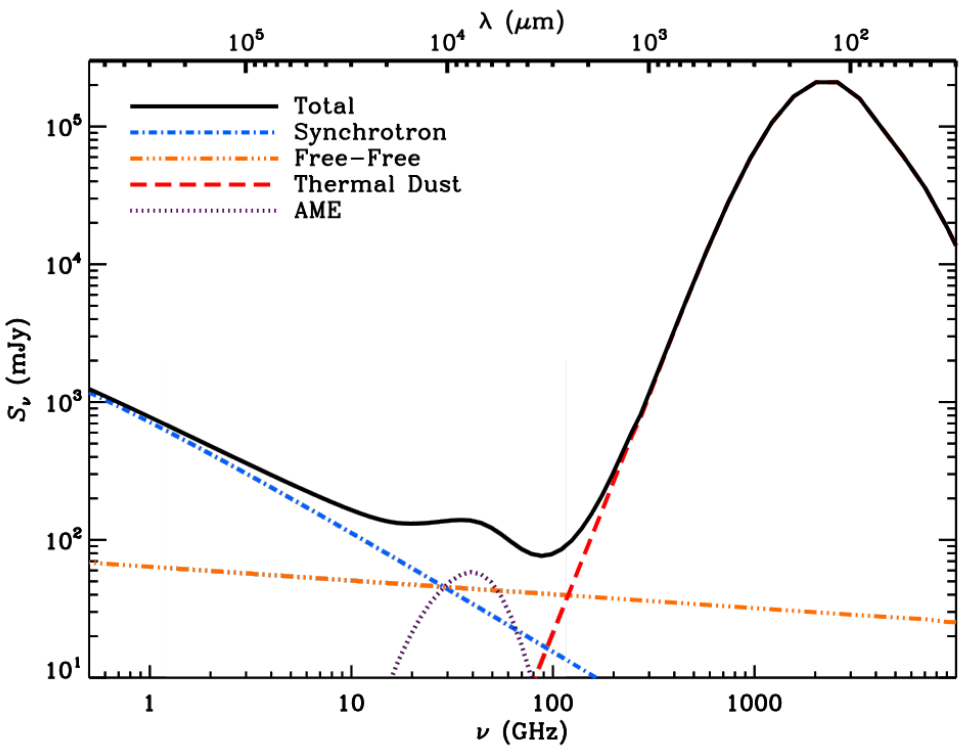
- How the properties of SF depend on various environmental parameters

- How SF might differ in nuclear regions or in burst and quiescent modes

- Which is the role of the relativistic phase (cosmic rays and magnetic field)
in SF processes

**Nearby galaxies are crucial to answer!**

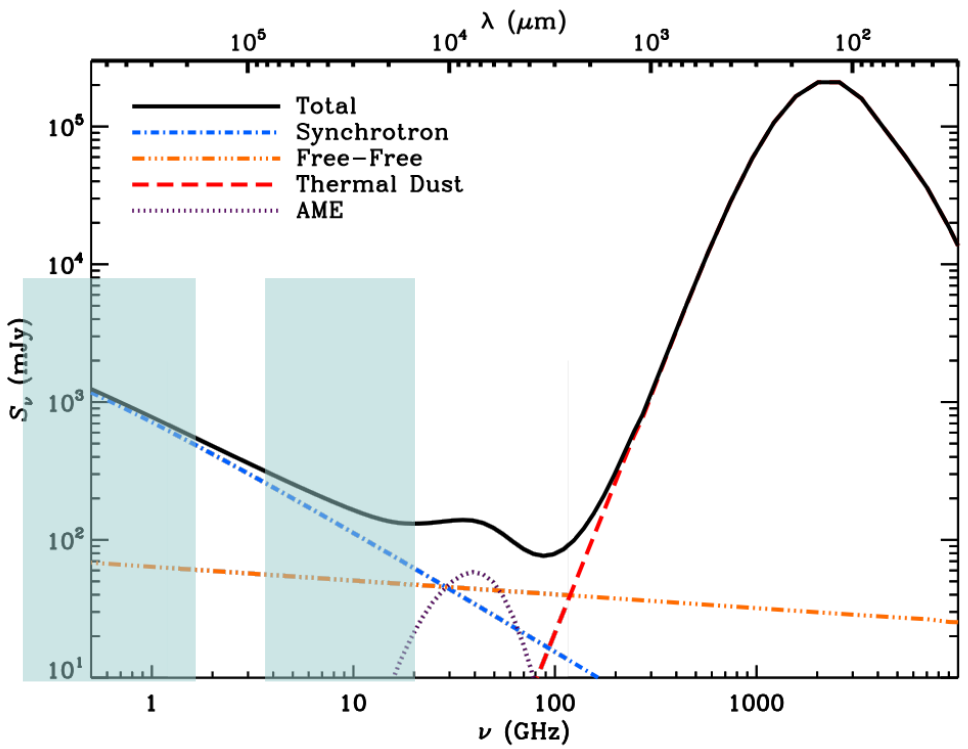
# Radio – FIR spectral energy distribution




Radio continuum emission from galaxies

- Synchrotron
- Free-free
- AME
- Thermal dust > 100 GHz

# Radio – FIR spectral energy distribution



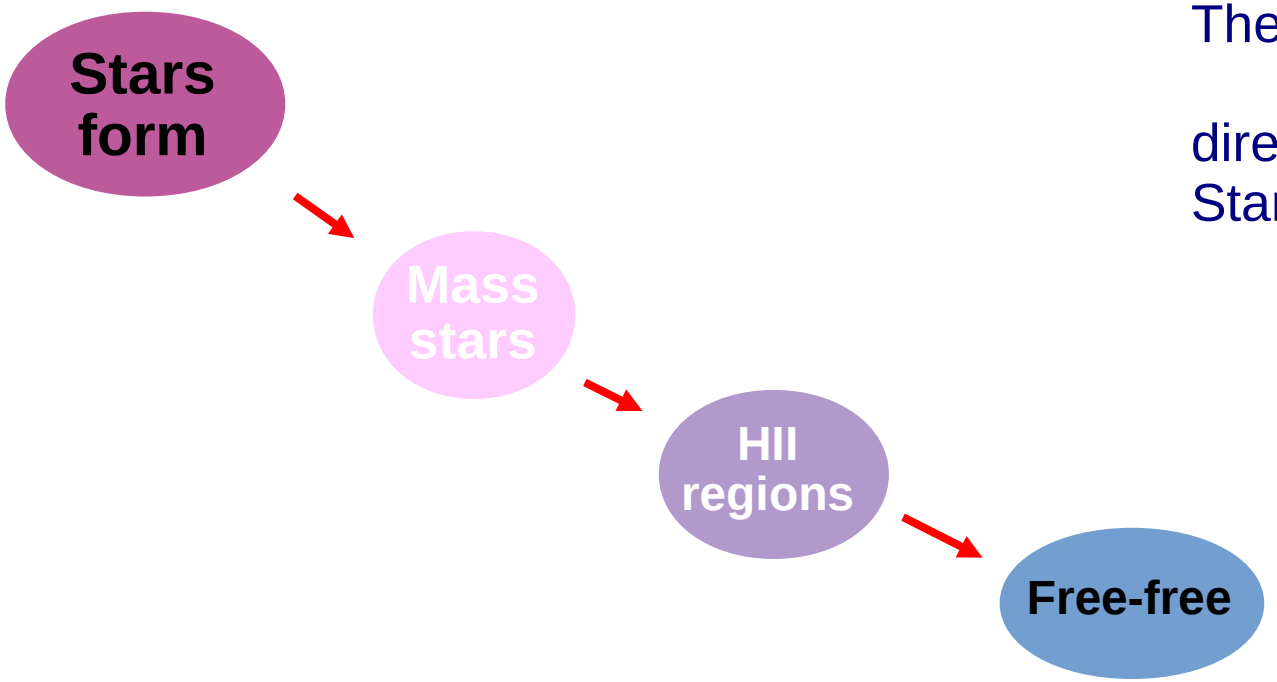

**SKA-1 ν bands**

Radio continuum emission from galaxies

- Synchrotron
- Free-free
- AME
- Thermal dust

**Spectral index to identify their nature**

# Bremsstrahlung (free-free) emission




Thermal emission

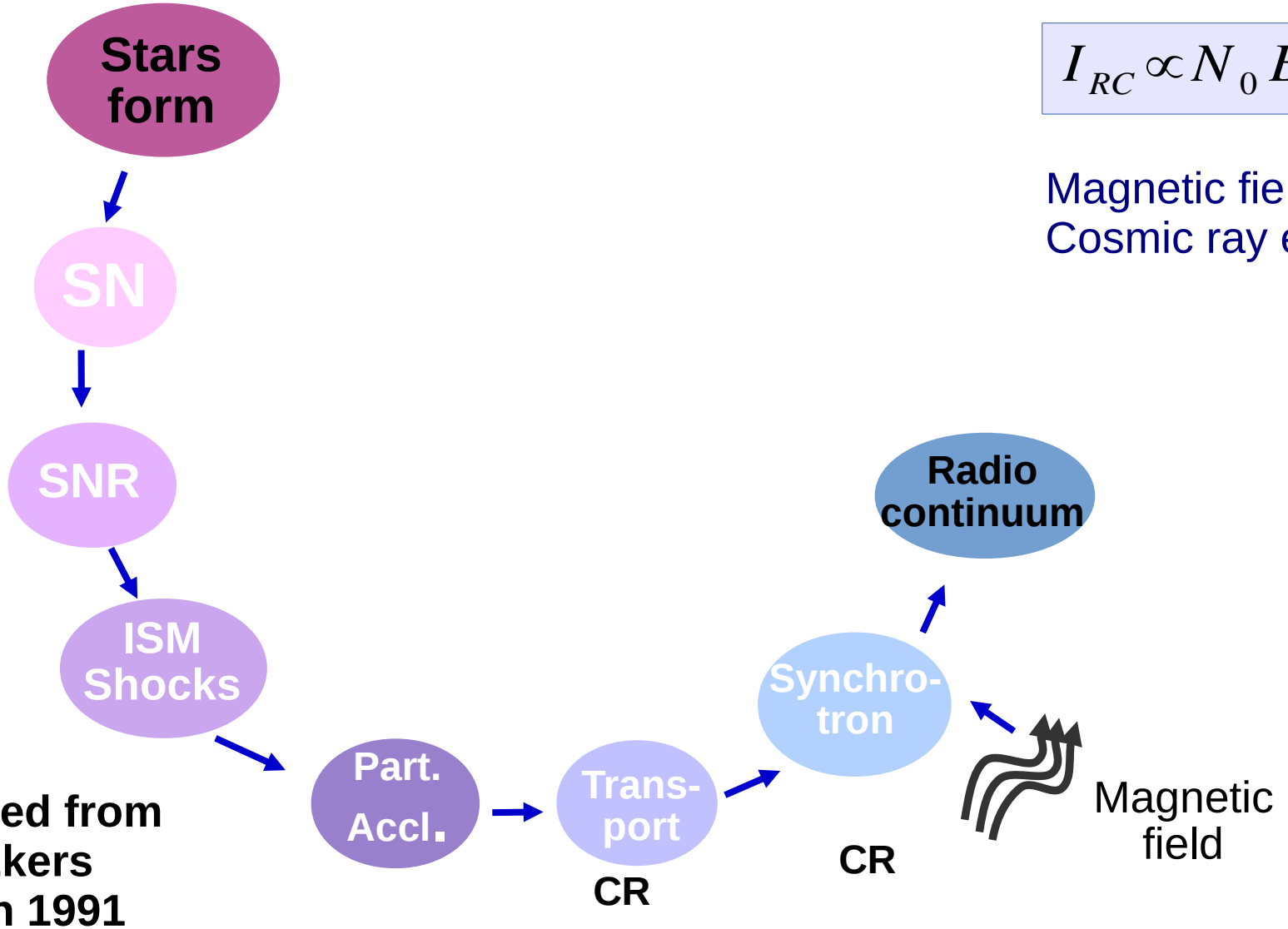
directly connected to Star formation

# Synchrotron emission

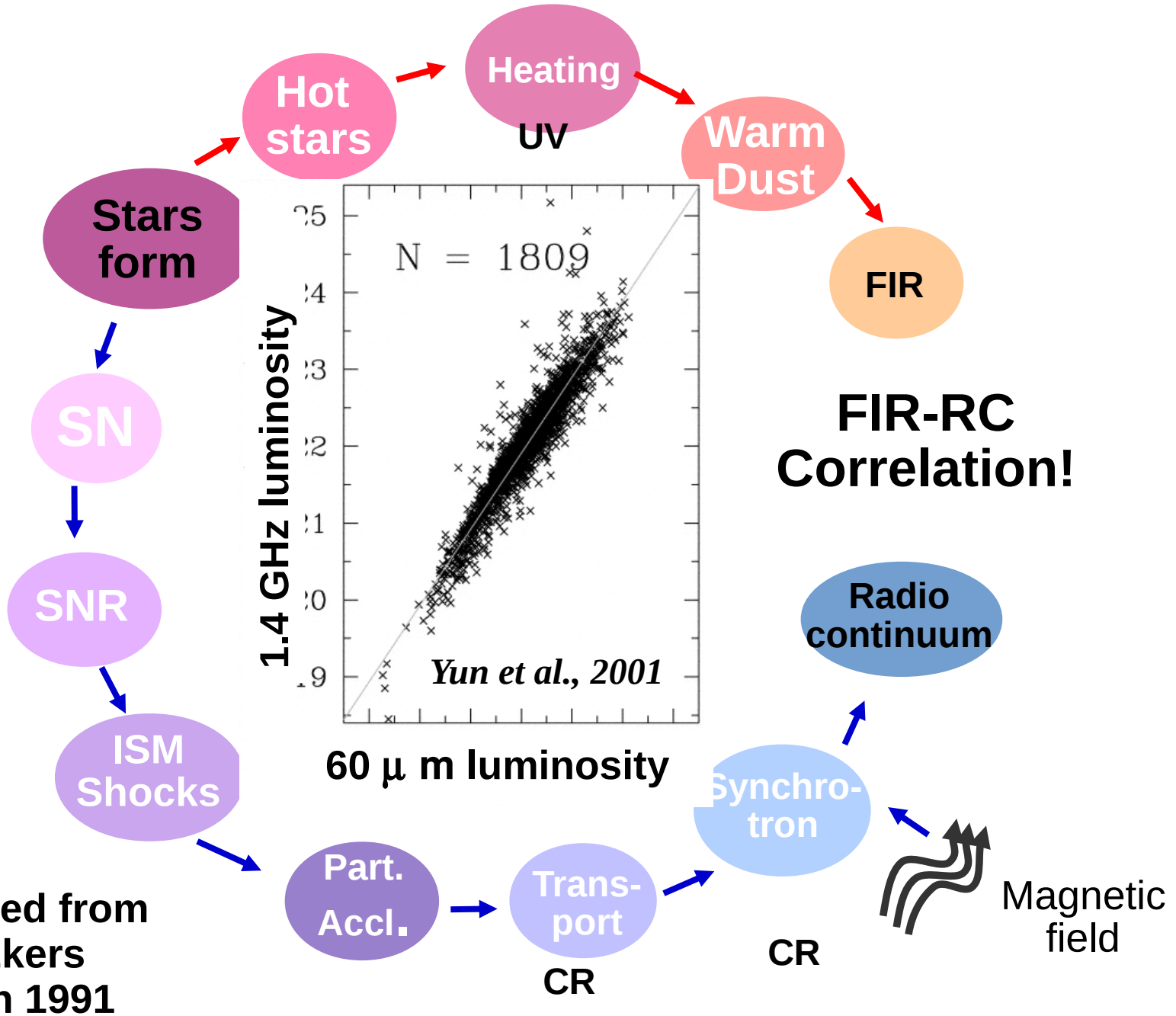
Non-thermal

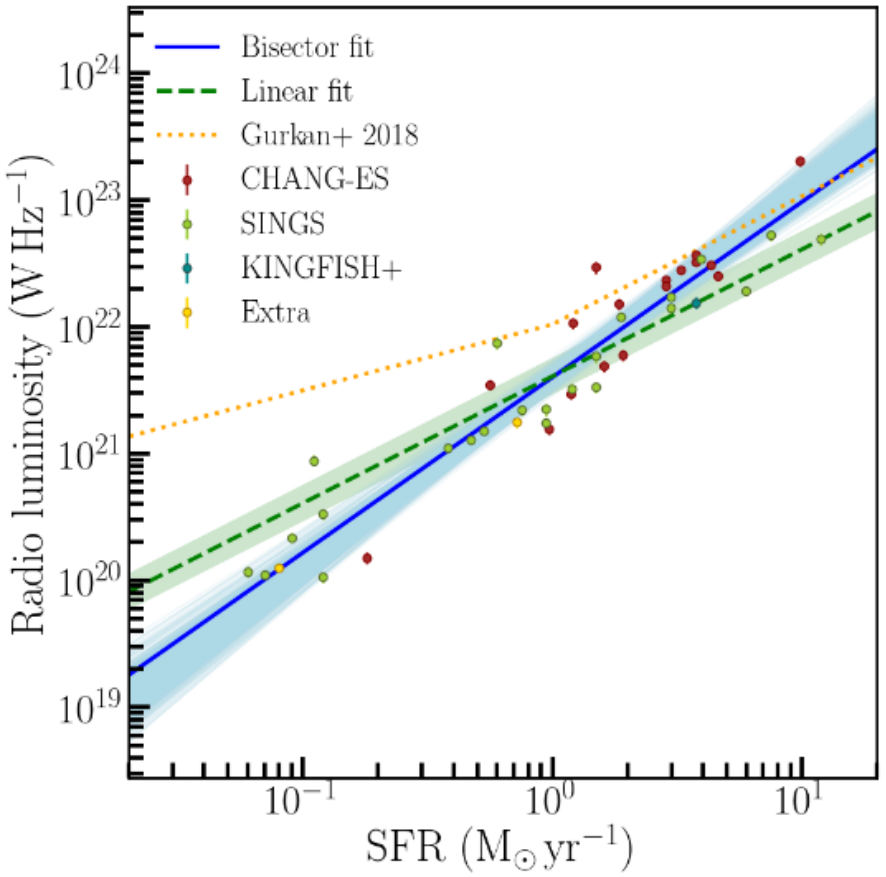
$$I_{RC} \propto N_0 B^{\alpha+1} \nu^{-\alpha}$$

Magnetic field
Cosmic ray electrons



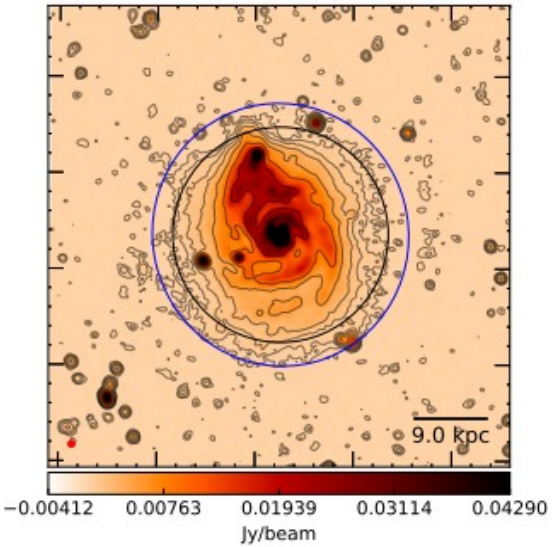

Adapted from Ron Ekers sketch 1991

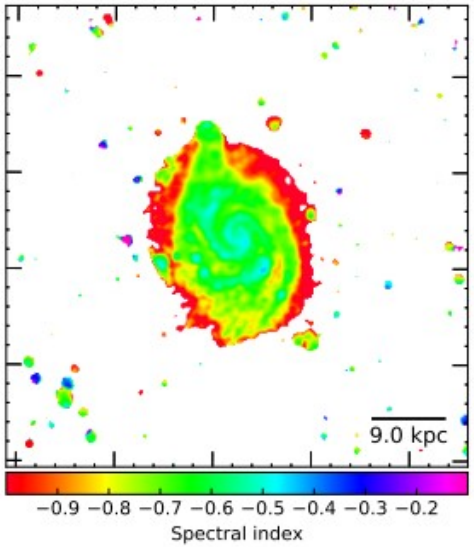

Hot stars
Heating
UV
Warm Dust
FIR
Stars form
SN
SNR
ISM Shocks
Part. Accl.
Trans-port
CR
Synchro-tron
CR
Magnetic field
Radio continuum
N = 1809
1.4 GHz luminosity
60 μ m luminosity
Yun et al., 2001
FIR-RC Correlation!
Adapted from Ron Ekers sketch 1991




Global RC-SFR correlation
for neaby galaxies @ < 30Mpc

**LOFAR 0.144 GHz data**
**Heesen et al. ~ submitted**



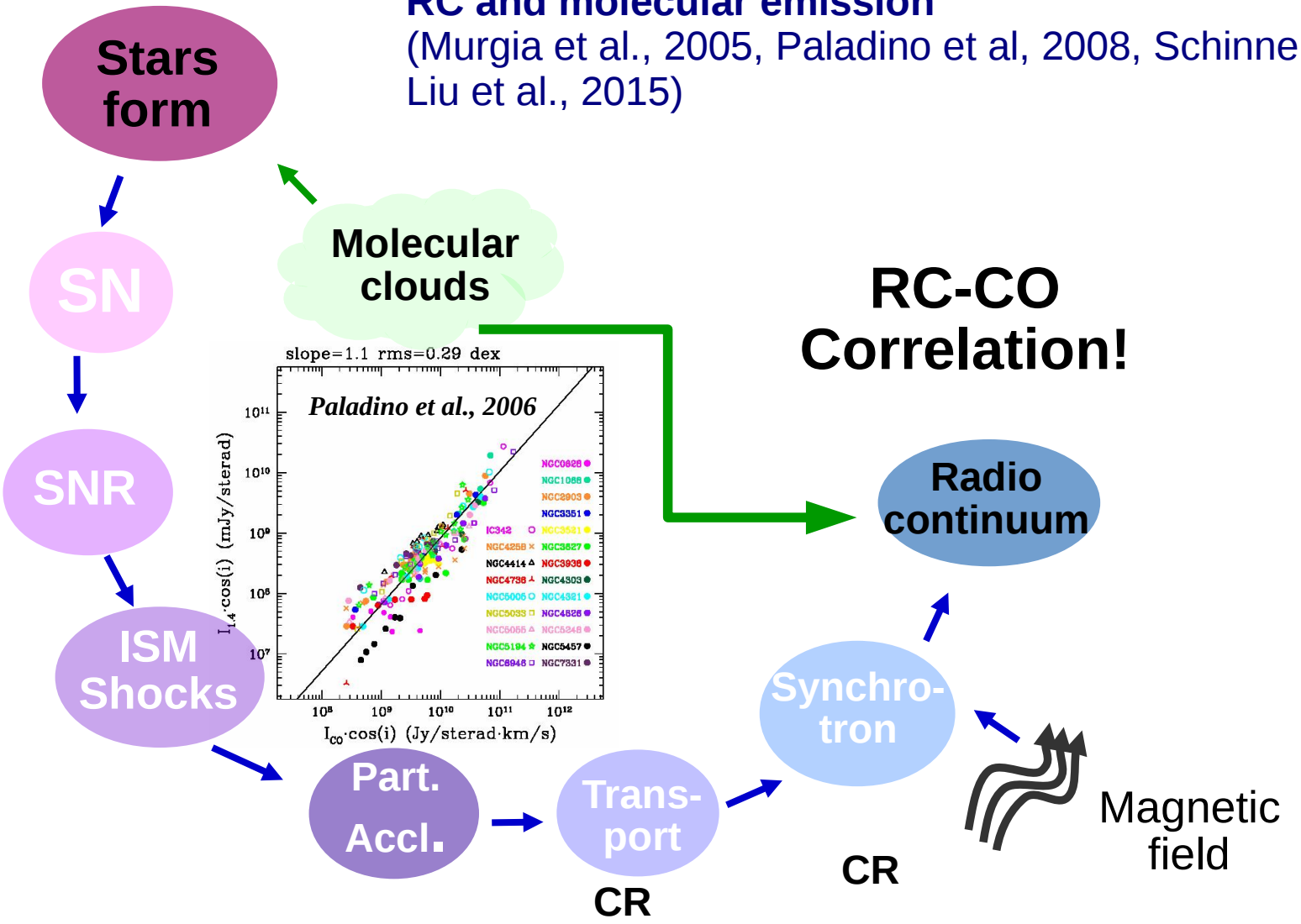




Images @ 20 “ resolution

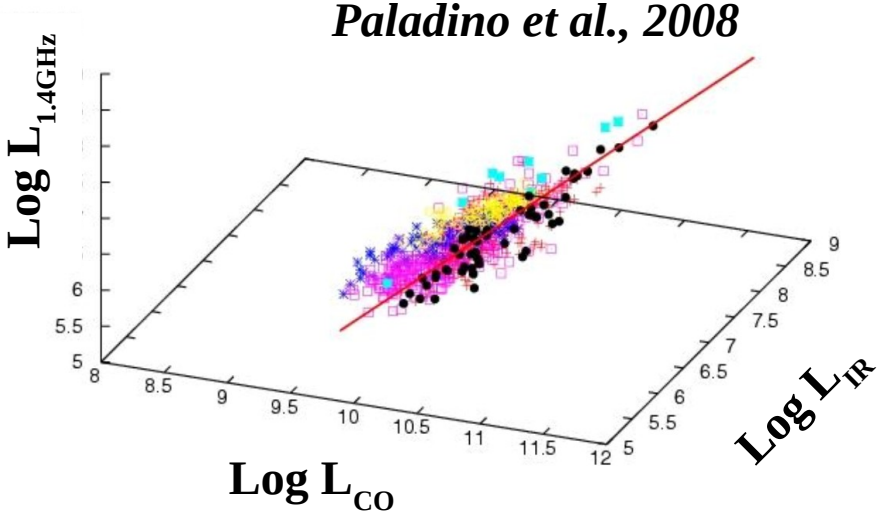
- ν dependent slope of the correlation due to electron diffusion
- Dependence of the spatially resolved spix on SFR

Higher spatial resolution (~6”) studies are ongoing

**Further confirmation**
Studies on nearby galaxies have revealed both global and spatially resolved correlations between
**RC and molecular emission**
(Murgia et al., 2005, Paladino et al, 2008, Schinnerer et al., 2013, Liu et al., 2015)



*Paladino et al., 2008*



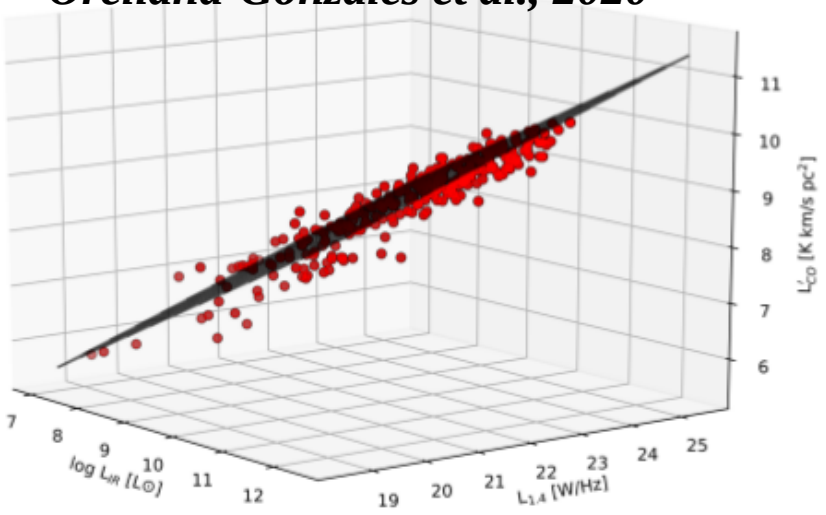

**It is actually a 3D correlation**

Complex physics to be clarified

**FIR-RC-CO Correlation!**

Calorimetric model (Voelk 1989, Lisenfeld 1996)
Magnetic field-gas density coupling (Helou & Bicay, 1993; Niklas & Beck 1997)
Hydrostatic pressure (Murgia 2005)
Proton calorimeter (Lacki, 2010)

*Orellana-Gonzales et al., 2020*




Warm Dust

JV

FIR

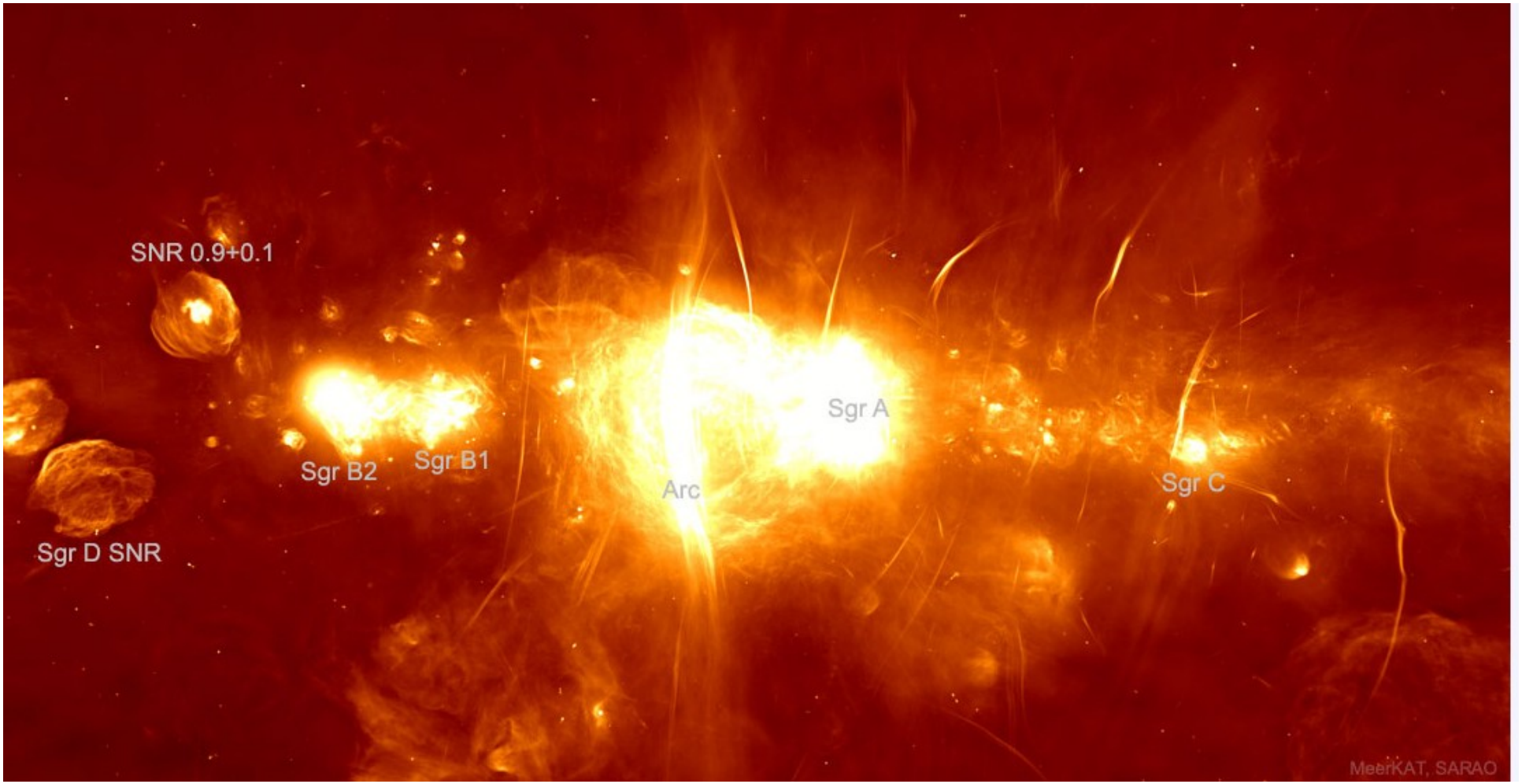
SNR

ISM Shocks

Magnetic field

- The complex physics behind the correlations is not completely understood
  - CR acceleration and transport
  - Magnetic field amplification
  - Dependence on galaxies environments
- To calibrate radio emission as SF tracer
  **we would like to have a census of compact SF products (from young HII regions, to SSCs, to SNe and their remnants)**

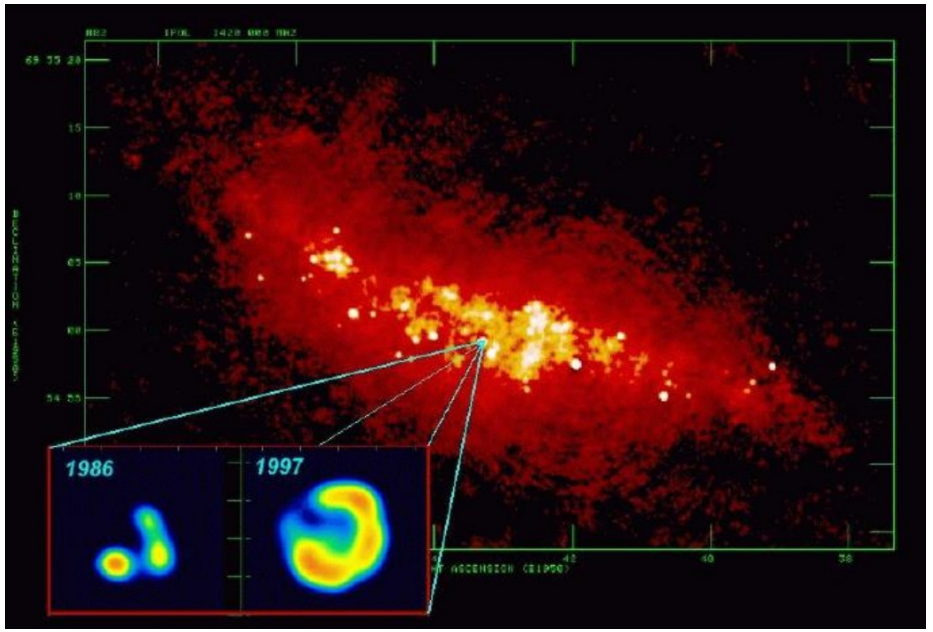
## The dream!




Galactic Center
Meerkat image @ 1.4 GHz --- 6” resolution → ~ **0.23 pc**
**Heywood 2019**

## The reality!

## This kind of studies can be done in very few nearby objects




**M82 @ 3.2 Mpc**

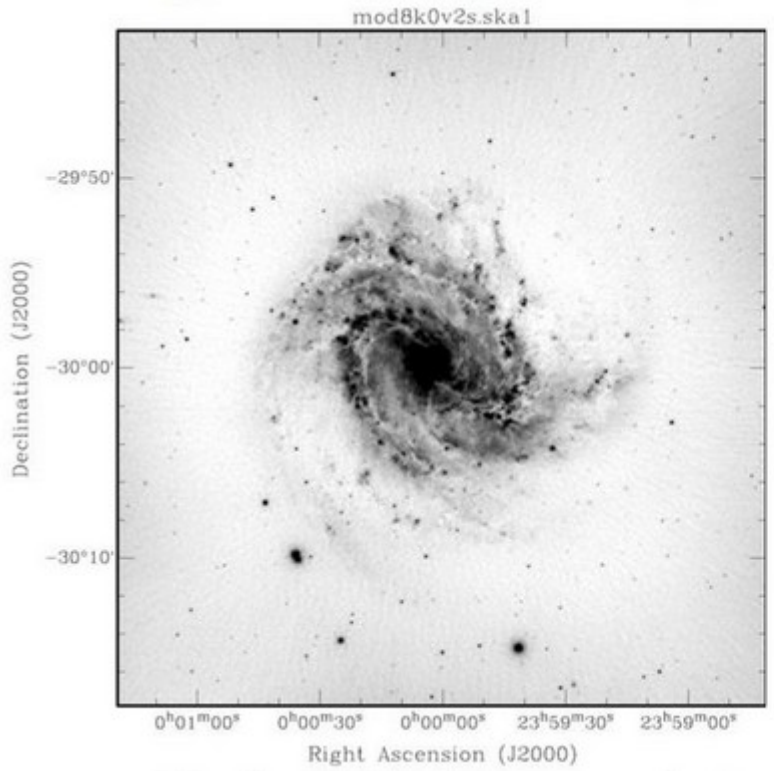
**Starburst galaxy**

5GHz observations @ 0.75 pc scale
e-MERLIN+VLA

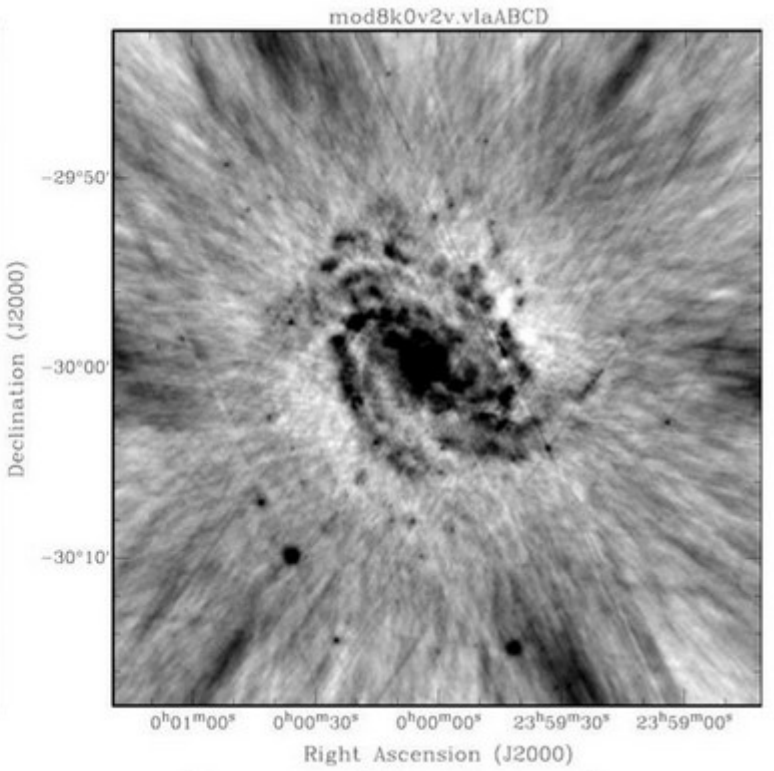
**Muxlow et al., 1994, Fenech et al, 2008**

- SKA-1 mid imaging improvement compared to current VLA (A+B+C+D configuration)

**1 snapshot**



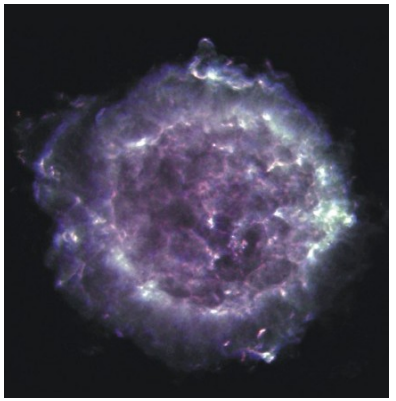

**Combination of snapshots**

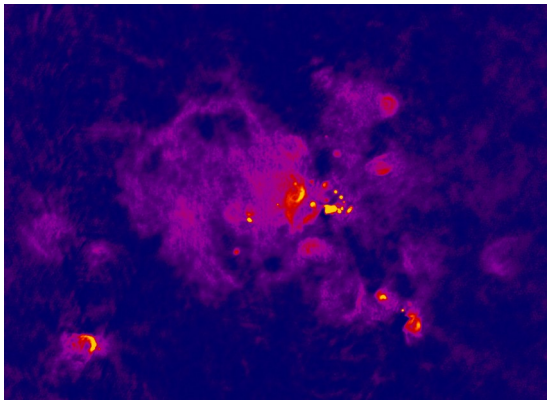



**Braun's slides @ skaengcon16**

- Expected radio emission from a typical non-thermal source **(Cas A)** and a thermal one (**W49 A**)

**SNR Cas A**
**@ 2.8 kpc**





**W49 A**
**@ 14.1 kpc**

| Distance | Cas A ($\mu$Jy) | | | W49A ($\mu$Jy) | | |
|---|---|---|---|---|---|---|
| Mpc | 1.4 | 5 | 8 GHz | 1.4 | 5 | 8 GHz |
| 10 | 177 | 58 | 48 | 93 | 114 | 131 |
| 25 | 28 | 9 | 8 | 15 | 18 | 21 |
| 50 | 7 | 2.3 | 2 | 3.7 | 4.6 | 5 |
| 75 | 3 | 1 | 0.8 | 1.7 | 2 | 2.3 |
| 100 | 2 | 0.6 | 0.5 | 0.9 | 1.1 | 1.3 |

**Paladino et al. 2015**

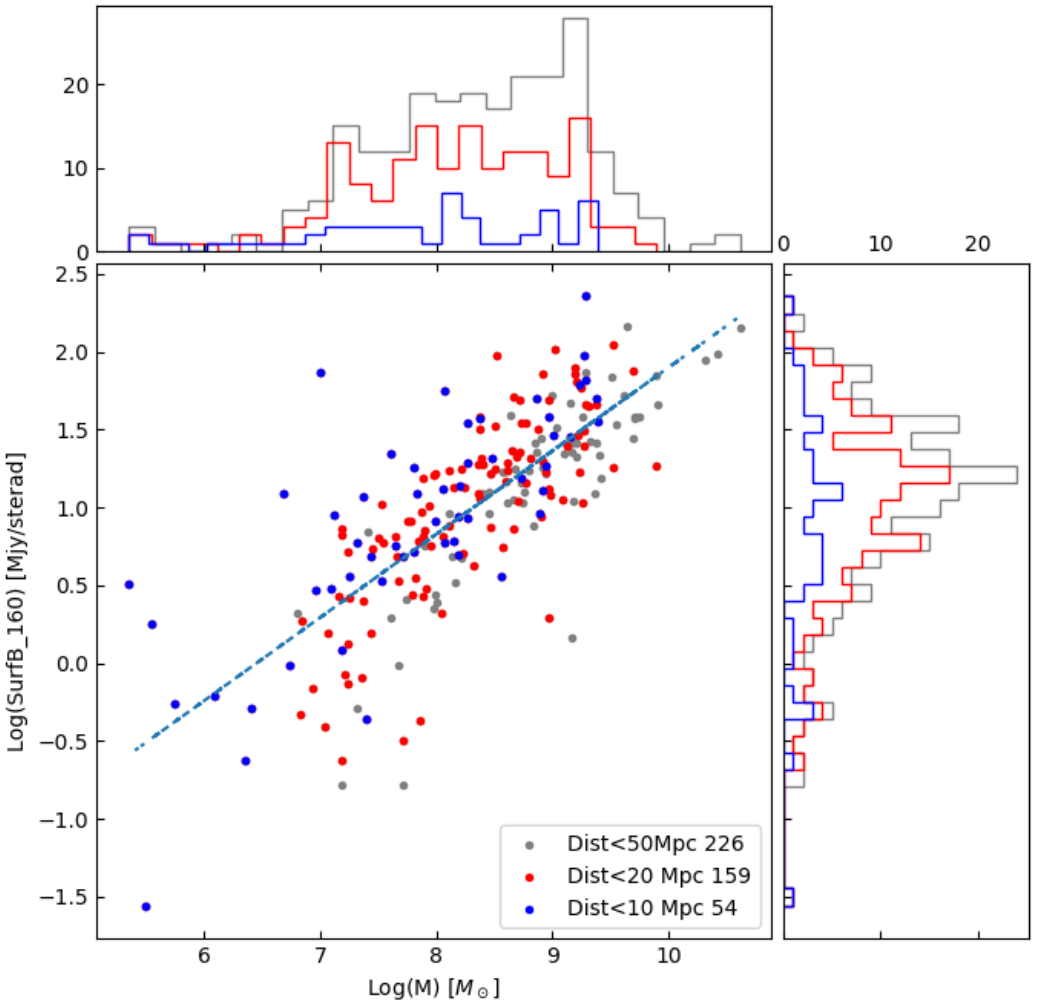
- Expected radio emission from a typical non-thermal source (**Cas A**) and a thermal one (**W49 A**)

| Band | Freq (MHz) | Max res (arcsec) | rms, 1hr (μJy/beam) |
|---|---|---|---|
| SKA-1 low | | | |
| | 0.05-0.35 | 4 | 14 |
| SKA-1 mid | | | |
| 1 | 350-1050 | 0.7 | 4.4 |
| 2 | 950 - 1760 | 0.4 | 2 |
| 5a | 4600 - 8500 | 0.08 | 1.3 |
| 5b | 8300-15300 | 0.04 | 1.2 |

**https://www.skatelescope.org/technical/info-sheets/**

| Distance | Cas A (μJy) | | | W49A (μJy) | | |
|---|---|---|---|---|---|---|
| Mpc | 1.4 | 5 | 8 GHz | 1.4 | 5 | 8 GHz |
| 10 | 177 | 58 | 48 | 93 | 114 | 131 |
| 25 | 28 | 9 | 8 | 15 | 18 | 21 |
| 50 | 7 | 2.3 | 2 | 3.7 | 4.6 | 5 |
| 75 | 3 | 1 | 0.8 | 1.7 | 2 | 2.3 |
| 100 | 2 | 0.6 | 0.5 | 0.9 | 1.1 | 1.3 |

# Galaxies with Diam > 120 arcsec @ distances up to 50Mpc from z0MGs (Leroy et al., 2019)




**< 50 Mpc 226**

**< 20 Mpc 159**

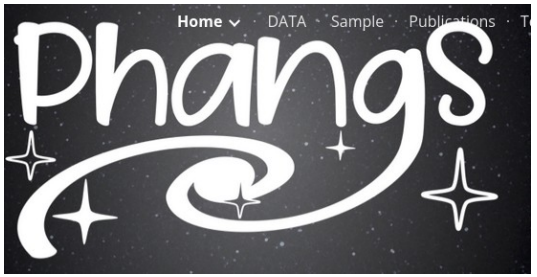
**< 10 Mpc 54**

- SKA-1 MID spatial scales achievable @ distances up to 50Mpc

| | Max res (arcsec) | Scale (pc) | | |
|---|---|---|---|---|
| | | **@10 Mpc** | **@20 Mpc** | **@50 Mpc** |
| 700 MHz | 0.7 | **34** | **68** | 169.7 |
| 1.4 GHz | 0.4 | **19.4** | **38.8** | **97** |
| 6.7 GHz | 0.08 | **3.9** | **7.8** | **19.4** |
| 12.3 GHz | 0.04 | **2** | **4** | **9.7** |

**Far from the dream!**

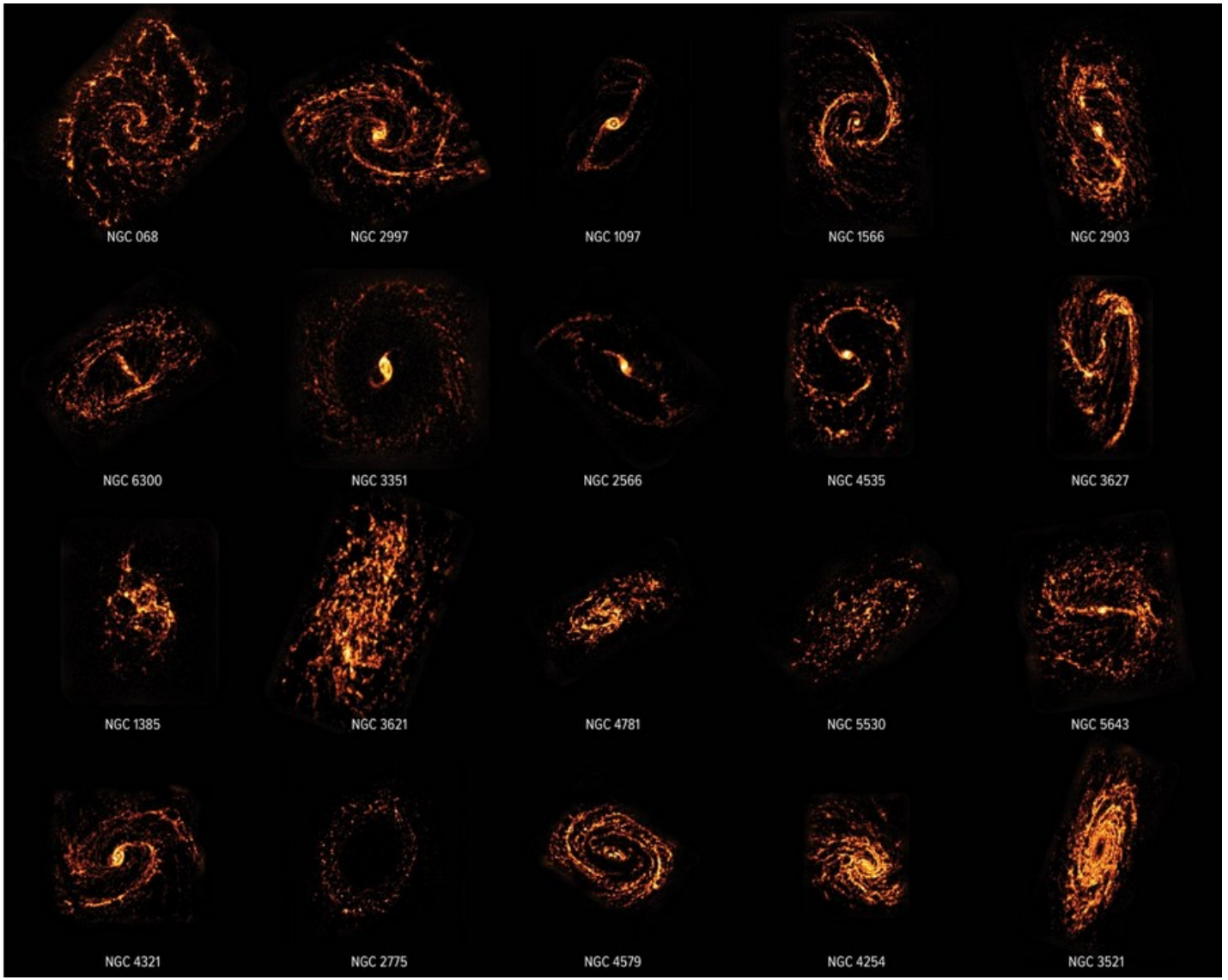
But > enough to identify and resolve GMC




https://almascience.eso.org/alma-data/lp/PHANGS/

74 galaxies (< 30 Mpc)
@ resolution < 100 pc

**ALMA large program**
Pis:
Schinnerer, Blanc, Hughes, Leroy, Rosolowsky, Schruba




Credit: ALMA (ESO/NAOJ/NRAO)/PHANGS, S. Dagnello (NRAO)

## Conclusions

- SKA-1 will provide the sensitivity and resolution to observe in few hours at different frequencies nearby galaxies, identifying and resolving GMC, up to 50 Mpc
- ~ 226 galaxies < 50 Mpc spanning ranges of masses, type, morphology
- Complementary multifrequency data
- ngvla will complement observing the northern sky targets