SKA contribution to multi-band and multi-scale studies of nearby galaxies

Rosita Paladino (INAF-IRA Bologna)

LOFAR Nearby Galaxies working group: Kris Chyzy, John Conway, Volker Heesen, Michael Stein, Cathy Horellou, Rainer Beck, Dominik Bomans, Fatemeh Tabatabaei, Lovorka Gajovic et al.

PHANGs-MeerKAT team: Anna Dignan, D.J. Pisano, E. Murphy, E. Schinnerer, A. Leroy, et al.

Why Nearby Galaxies?

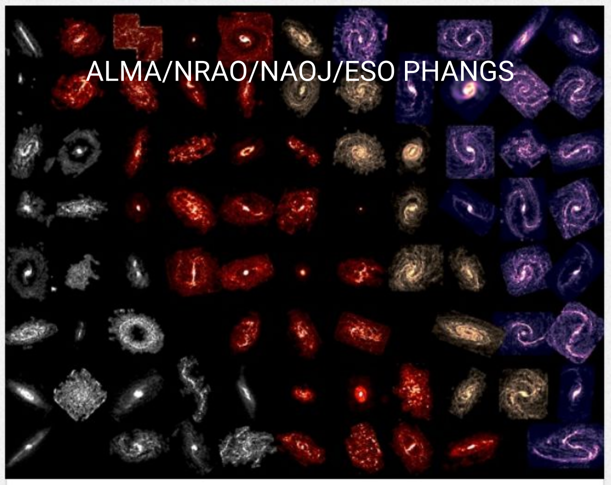
"Nearby" @ < 30 Mpc

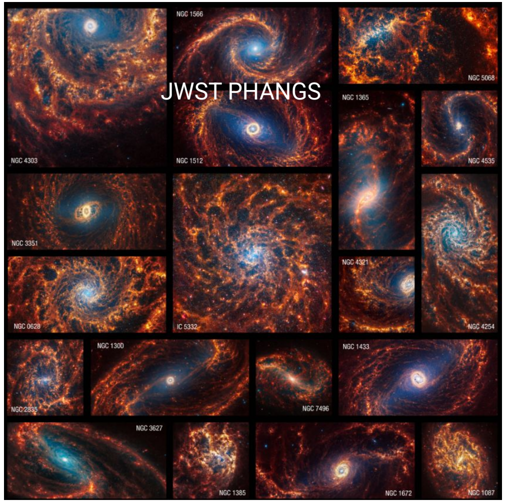
- Multiwavelength coverage

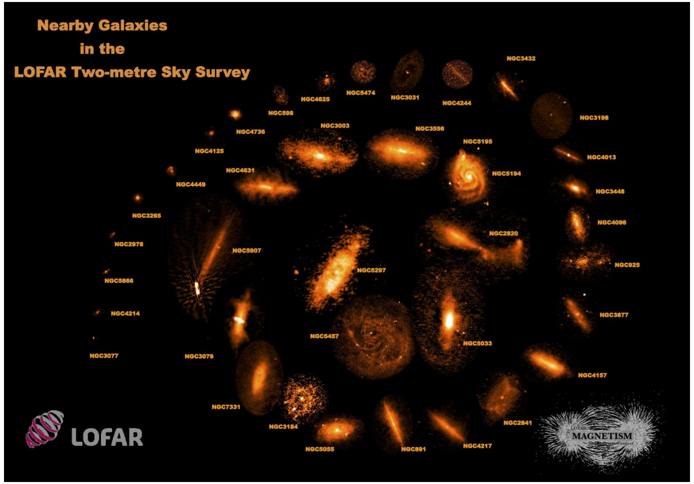
- Large scale + details

- Ideal to study multi-scale processes

Why at radio frequencies?







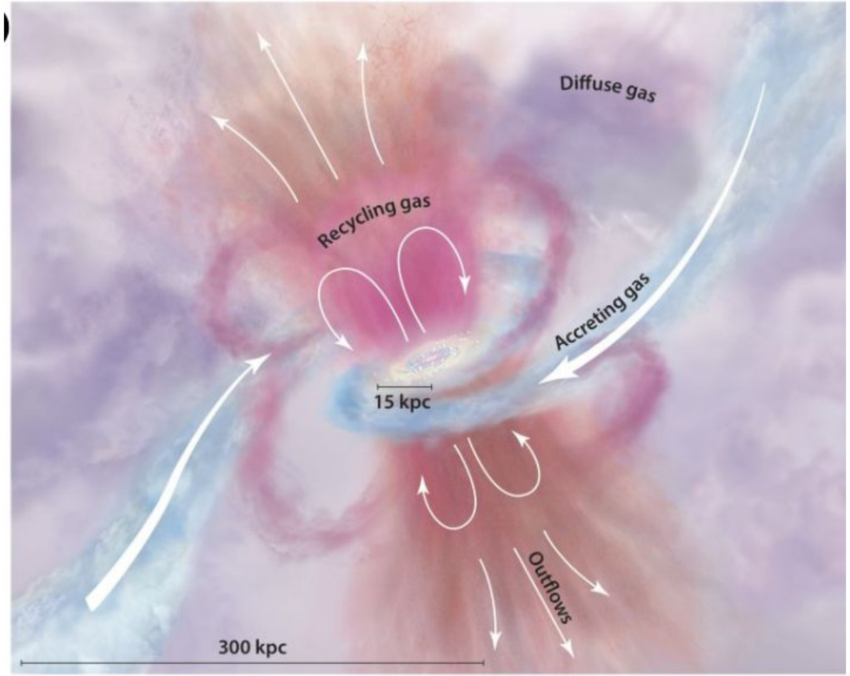
The role of relativistic phase (cosmic rays and magnetic field) in galaxy evolution

Need to add CR and B-field in this picture

Ruskowski & Pfrommer (2023):

“CRs accelerated at SNR shocks provide an efficient feedback mechanism [...]

CR cooling times are typically longer than those of thermal gas and CRs are well coupled to the plasma”



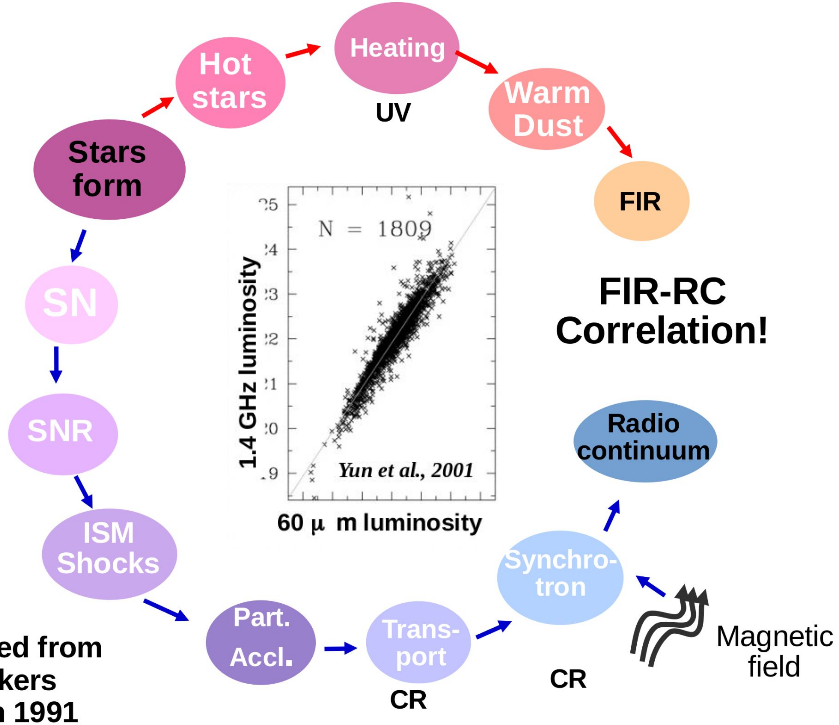
Tumlinson 2017

The role of relativistic phase (cosmic rays and magnetic field)

in star formation processes

The tight correlation between 1.4 GHz radio continuum and FIR emissions (e.g. Yun et al.2001)

motivated the use of RC as **dust unbiased SFR tracer** (e.g. Condon, 1992; Tabatabaei et al 2007; Murphy et al, 2011).

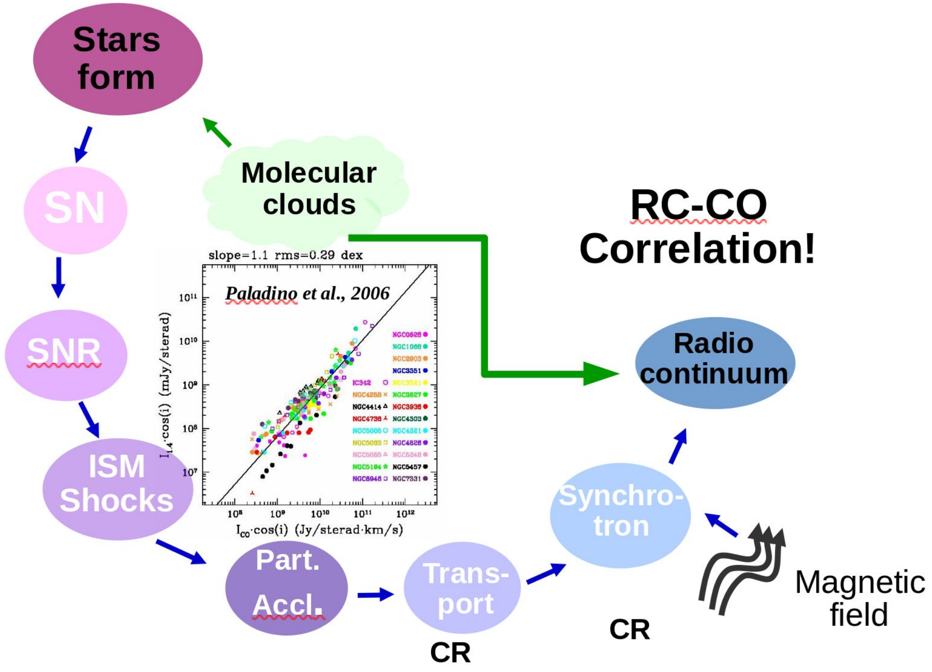


Adapted from Ron Ekers sketch 1991

The role of relativistic phase (cosmic rays and magnetic field) in star formation processes

Further confirmation
global and spatially resolved correlations between RC and molecular emission

(Murgia et al., 2005, Paladino et al, 2006,2008, Schinnerer et al. 2013, Liu et al., 2015, Orellana-Gonzales, 2020)



Complex physics to be clarified

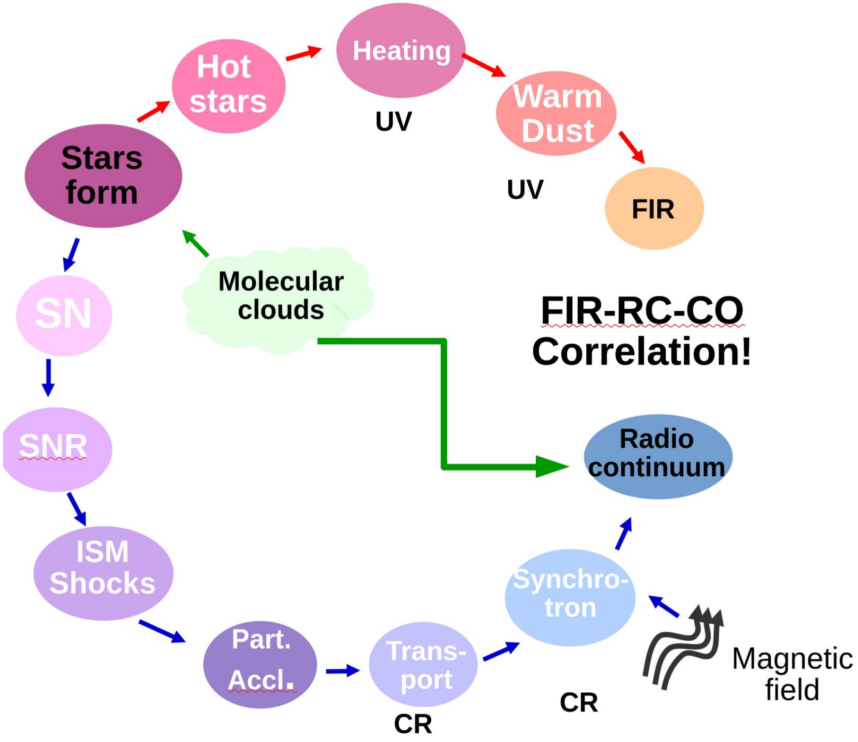
Calorimetric model (Voelk 1989, Lisenfeld 1996)

Magnetic field-gas coupling (Helou & Bicay, 1993, Niklas & Beck, 1997)

Hydrostatic pressure (Murgia 2005)

Proton calorimeter (Lacki, 2010)

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



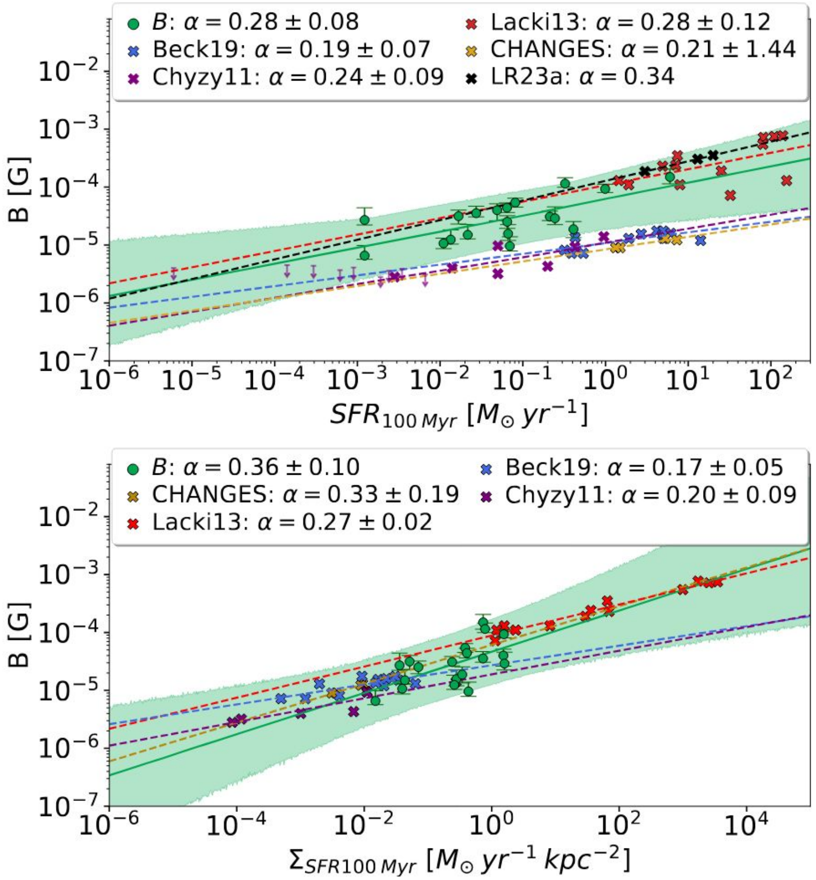
MHD models

Reproduce both global and local relations consistent with small scale dynamo

$$B \propto \Sigma^{0.3}_{SFR}$$

where SN-driven turbulence is the main

B-field amplification mechanism.



Belfiori et al. 2025, submitted

LOFAR results

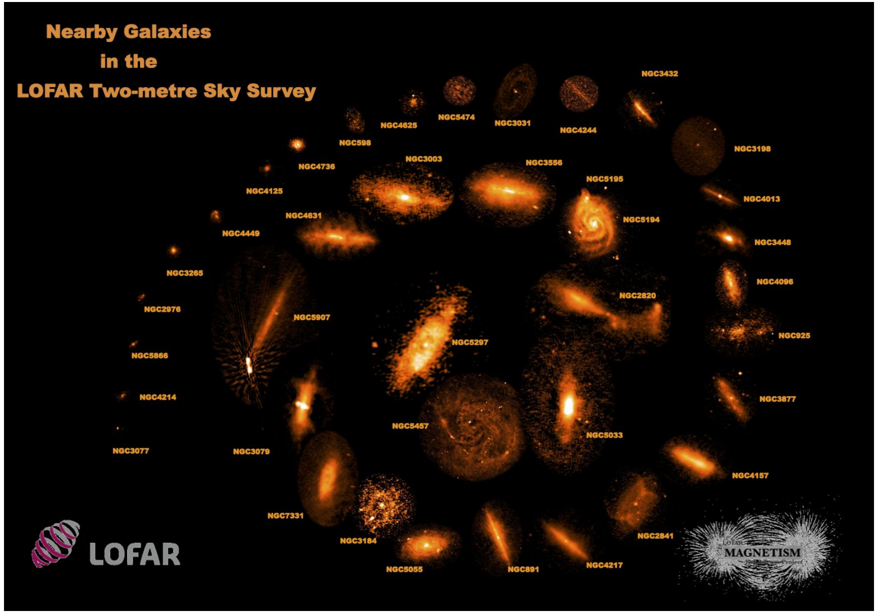
First LOFAR image of M51

(D. Mulcahy 2012)

LoTSS

LOFAR two-metre Sky Survey

Shimwell et al., 2017, 2019



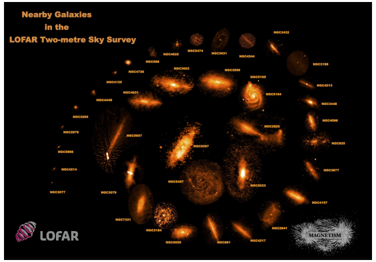
45 galaxies < 30 Mpc

Heesen et al.:

- I. Non linearity of RC-SFR relation (2022)

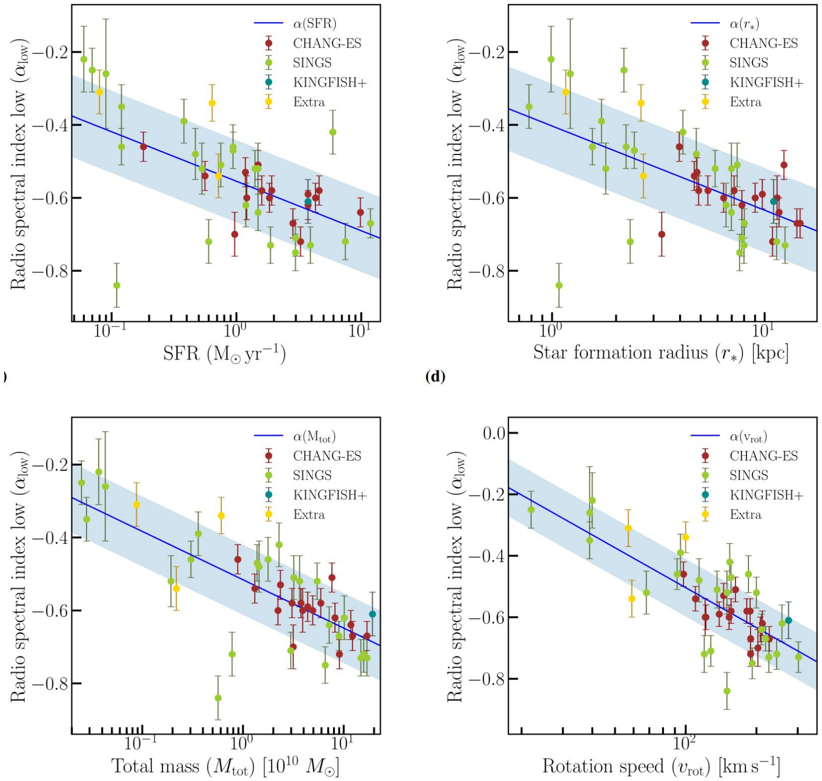
- II. Magnetic field - gas relation (2023)

- III. Influence of cosmic-ray transfer on the RC-SFR relation (2024)



Non linearity of RC-SFR relation

Global spectral index α_{low} vs SFR, r_*, M_{tot}, v_{rot}



In words:
steeper spectrum

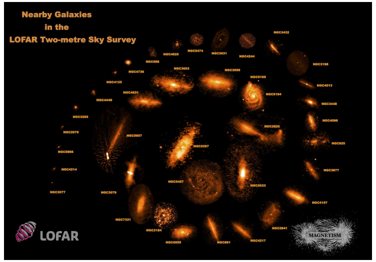
- **higher SFR**
- **larger radii**
- **larger mass**
- **highly rotating galaxies**

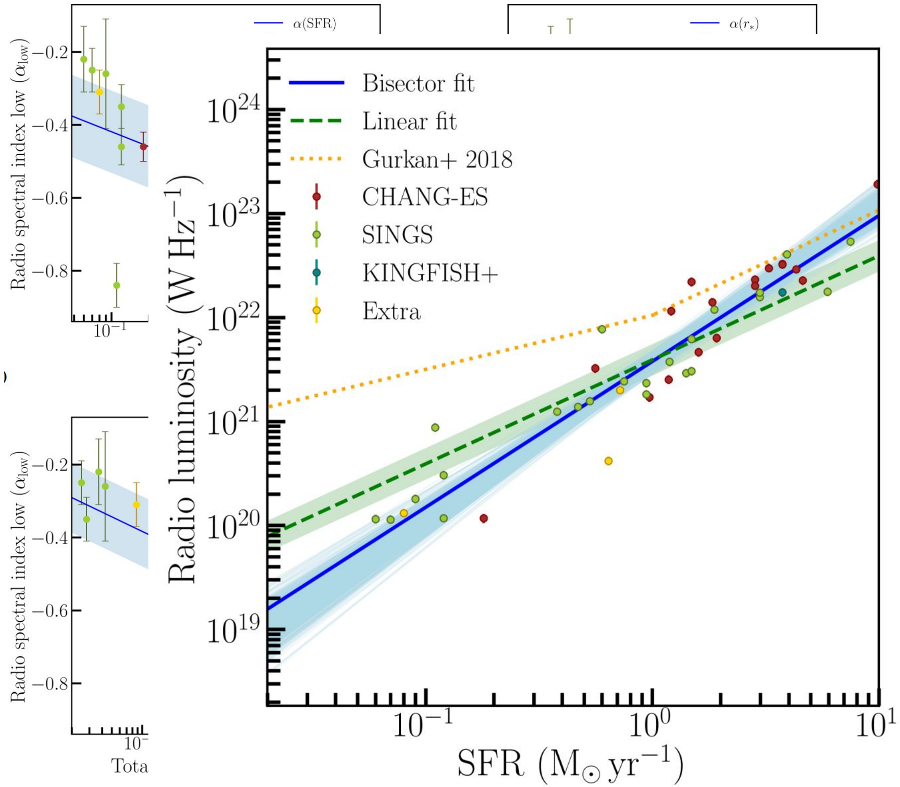
Cosmic rays loose larger fraction of energy due to synchrotron losses

Heesen et al. 2022

Non linearity of RC-SFR relation

Global spectral index α_{low} vs SFR, r_*, M_{tot}, v_{rot}





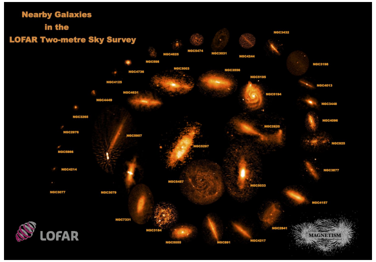
In words:
steeper spectrum
- higher SFR
- larger radi
- large
- galaxies

Cosm ys loose larger fraction of energy due to synchrotron losses

Super linear global radio-SFR relation

Heesen et al. 2022

Influence of cosmic rays in RC-SFR relation

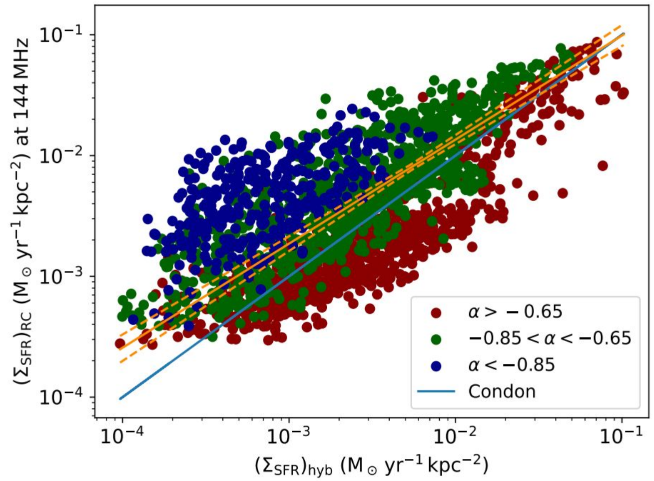


Sub-linear local radio-SFR relation @ 144 MHz

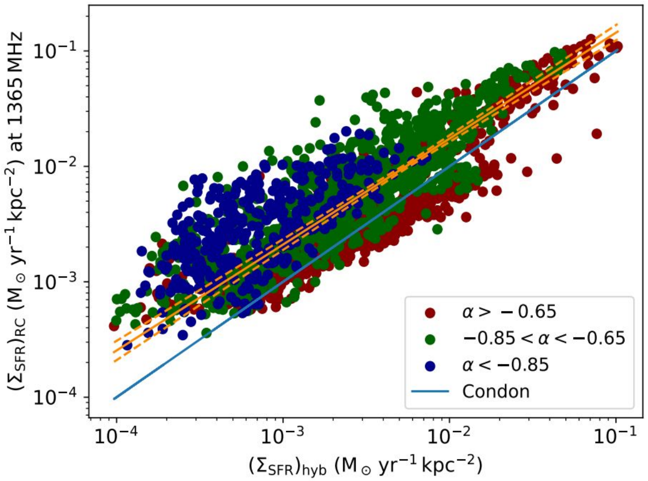
144 MHz

1.4 GHz

(b)

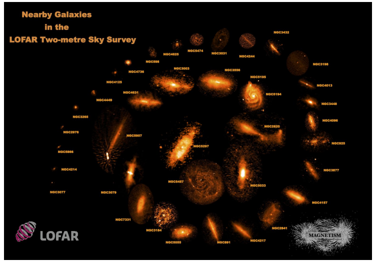


0.86



0.92

Influence of cosmic rays in RC-SFR relation

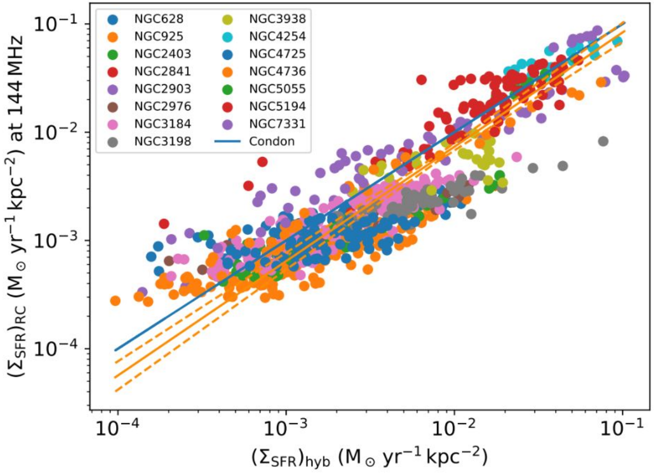


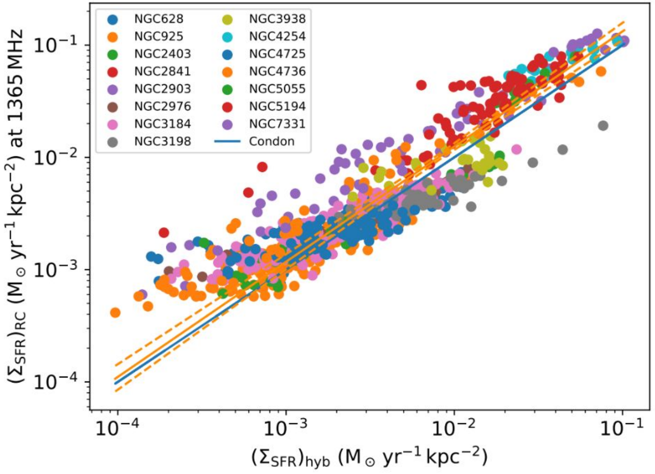
Only young cosmic rays (α > - 0.65)

144 MHz

1.4 GHz

(d)



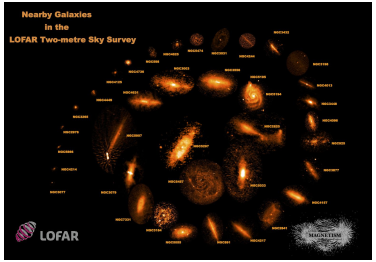


1.06

1.03

cosmic rays transport and spectral ageing play a role

Influence of cosmic rays in RC-SFR relation



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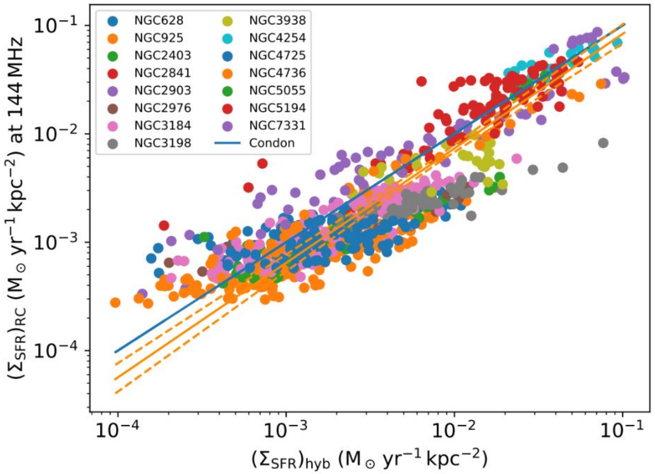
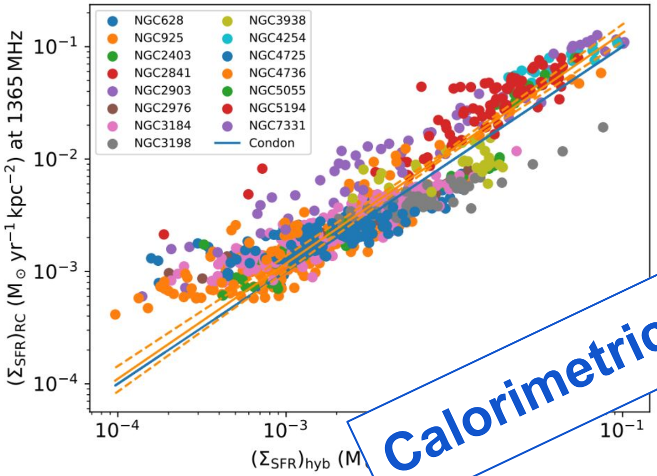


(d)

1.4 GHz



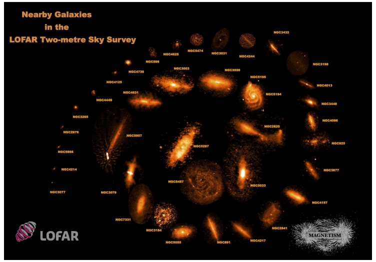
Calorimetric efficiency

1.06

1.03

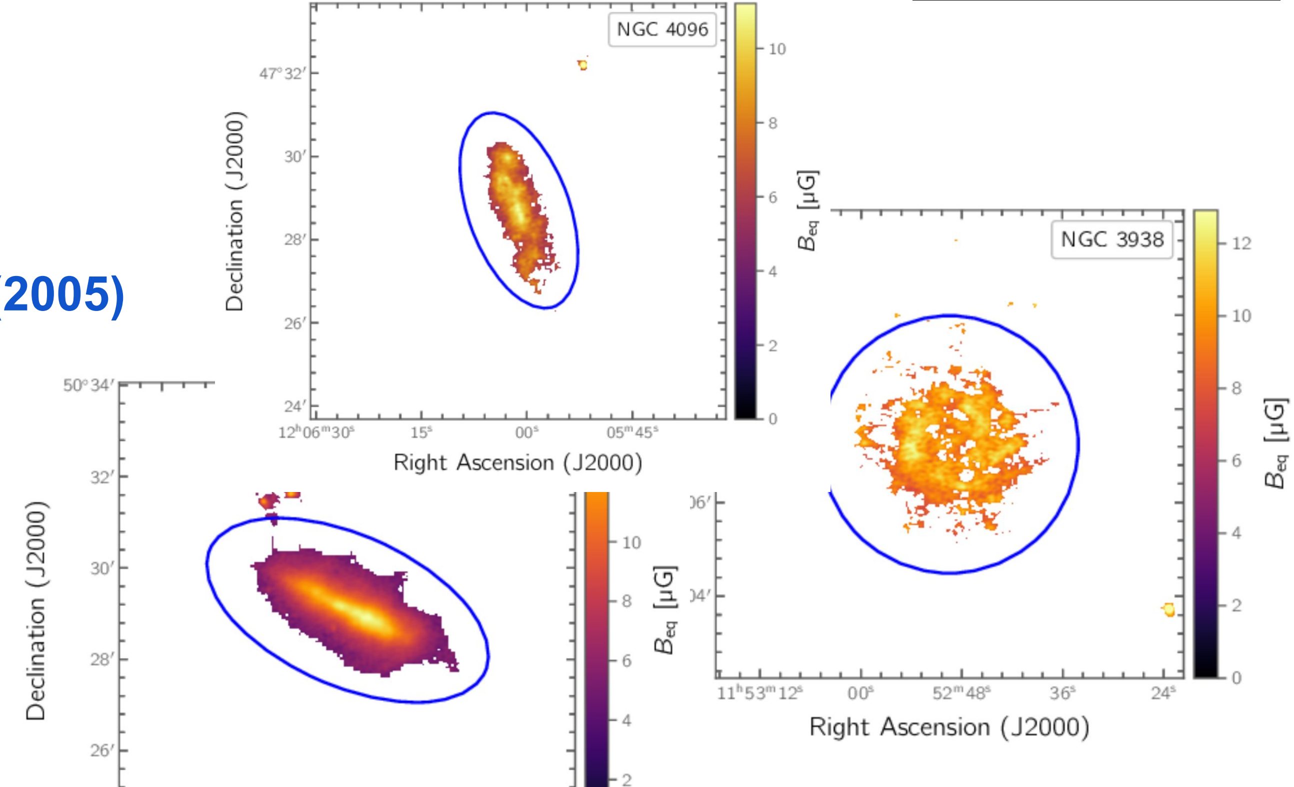
Magnetic field - gas relation

Spatially resolved equipartition B-field

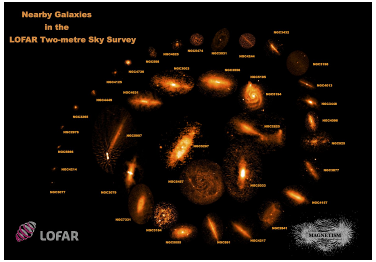


$B_{eq,\perp}$

using Beck & Krause (2005) revised formula

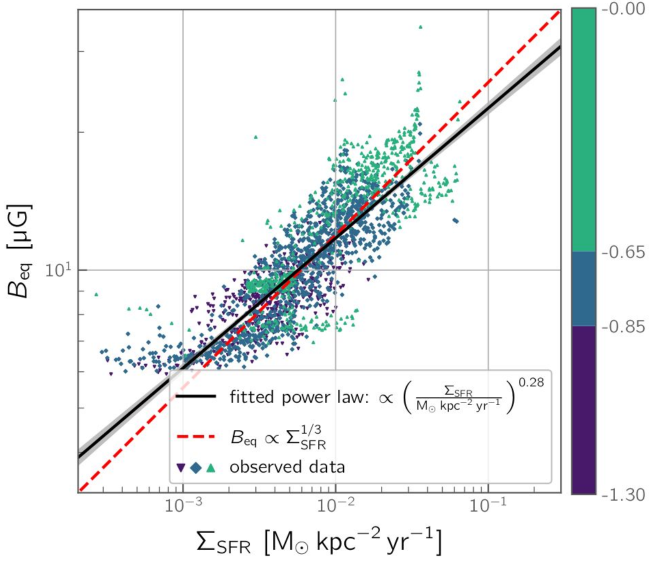


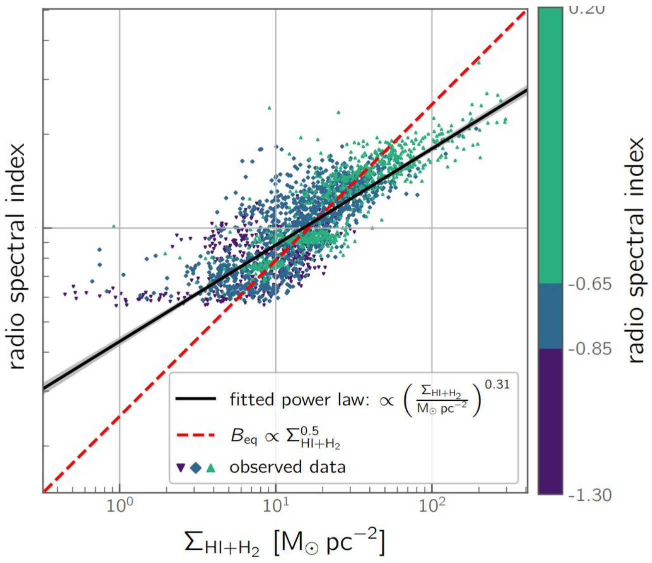
Magnetic field - gas relation



Spatially resolved comparison with

$B_{eq} \approx \Sigma_{SFR}^{0.28}$ $B_{eq} \approx \Sigma_{HI+HII}^{0.3}$





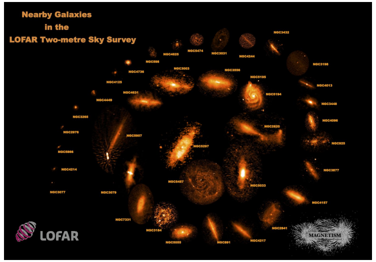
Both consistent with saturated small-scale dynamo

(Beck et al., 2015)

accounting for CR transport

Magnetic field - gas relation

Spatially resolved comparison with



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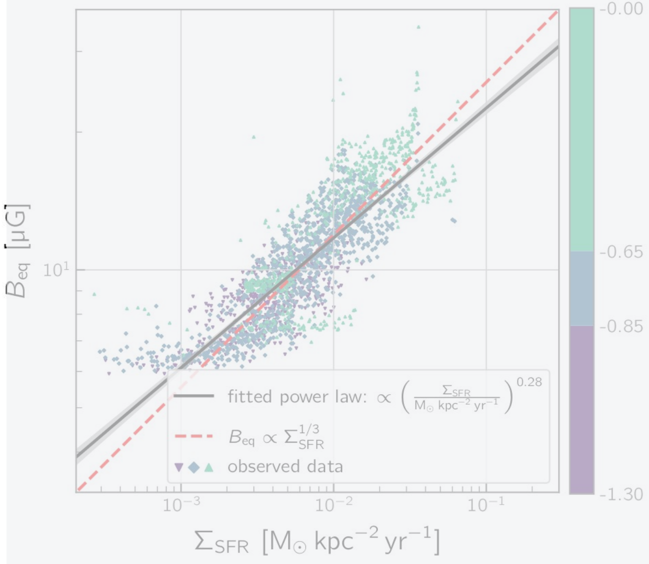

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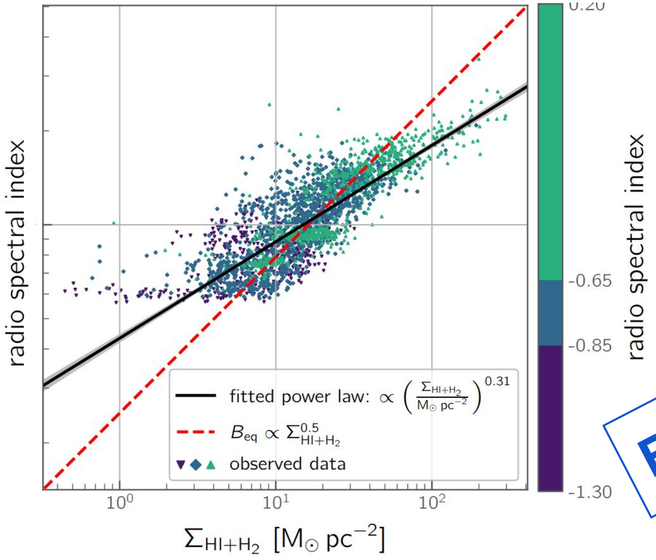

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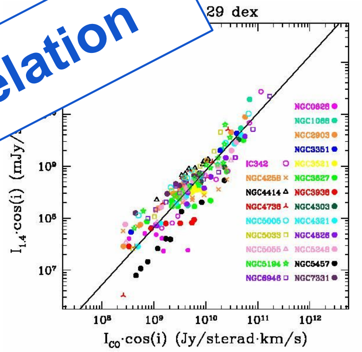
(Beck et al., 2015)

B-ϱ relation

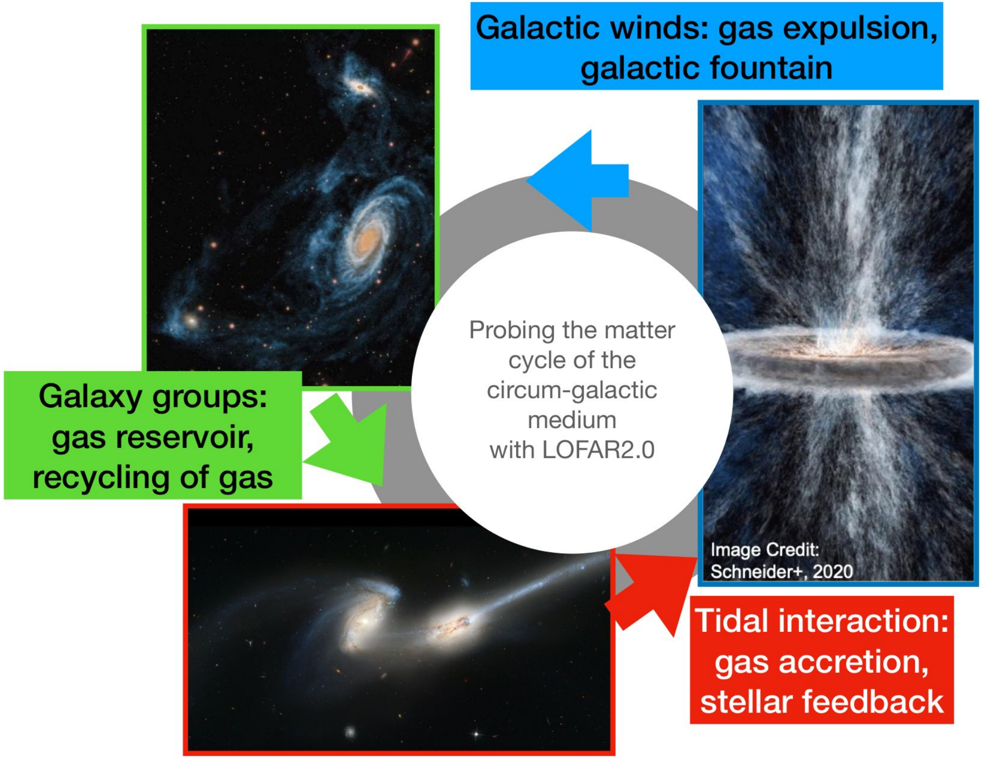


Near future: LOFAR 2.0

Nearby galaxies as laboratories for galaxy evolution with LOFAR2.0

Main goals:

- Role and fate of cosmic rays in galactic wind
- Structure of magnetic field in the circumgalactic medium



Very near future: MeerKAT

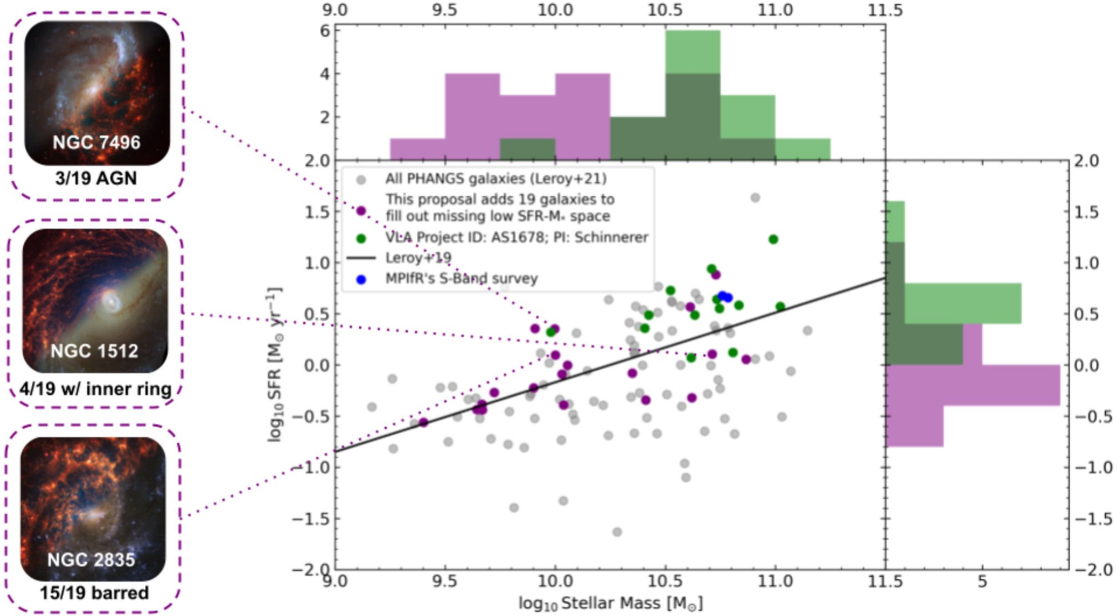
High resolution S-Band imaging of 19 PHANGS-ALMA galaxies (PI: A. Dignan)

80 hrs with MeerKAT band S

19 galaxies covering an essential parameter space of low SFR and low M_*

Main goals:

- **Resolved investigation of FIR-RC relation**
- **connecting non-thermal emission to SF**



Future: SKA

- **SKA-LOW**
  will allow to extend LOFAR results to higher resolution
  (up to ~2 arcsec with the most extended AA*)
  in the southern hemisphere

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  will allow to extend LOFAR results to higher resolution
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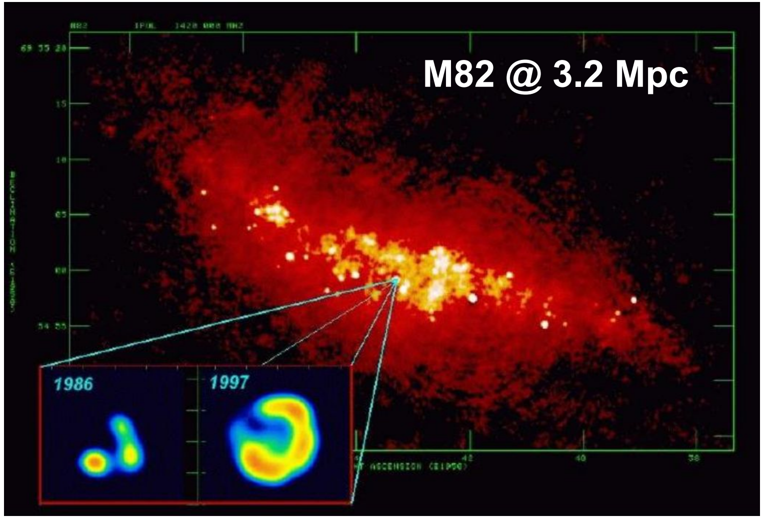
  in the southern hemisphere

- **SKA-MID**
  will map in few hrs nearby galaxies
  with < 40 pc resolution up to 20 Mpc
  disentangling thermal and non-thermal
  compact sources
  (from young HII regions,
  to SSCs, to SNe and their environments)



5GHz observations @ 0.75 pc
Muxlow et al., 1994 - Fenech et al. 2008