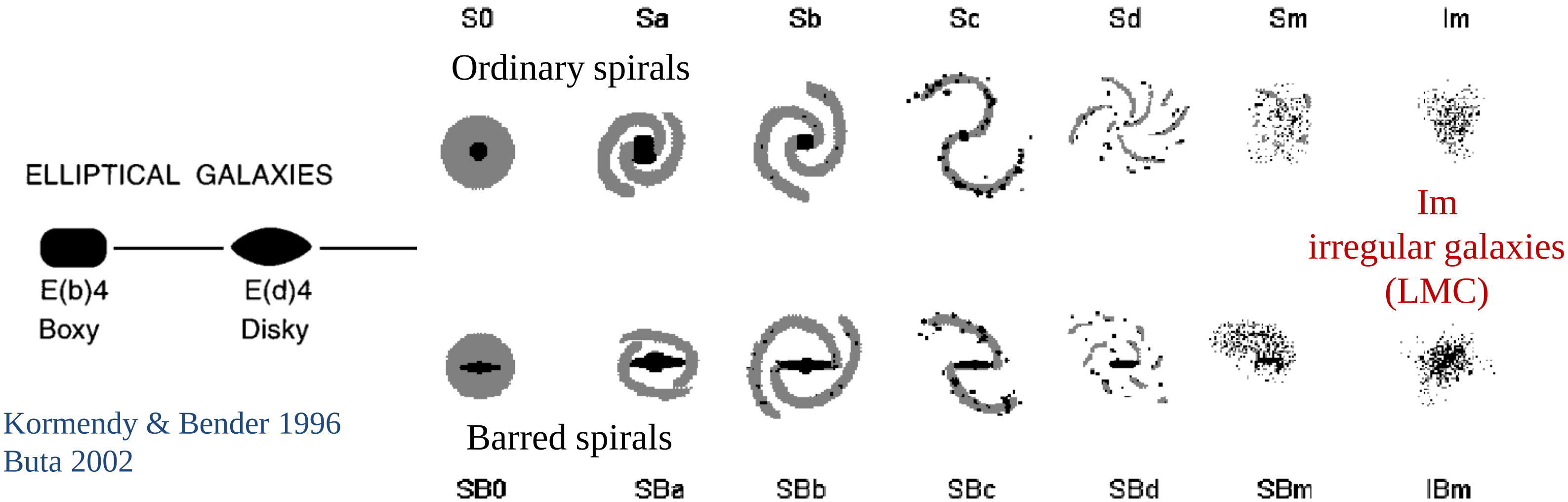
Magnetised wind and synchrotron halo of IC 10

Krzysztof T. Chyży
Jagiellonian University
Kraków, Poland

In collaboration with
Robert Drzazga, Rainer Beck, Marek Urbanik, Volker Heesen, Dominik Bomans, Wojciech Jurusik, LOFAR MKSP

IC10 X-1,Credit: Aurore Simonnet/Sonoma State University/NASA

Dwarf galaxies



Kormendy & Bender 1996
Buta 2002

Dwarf galaxies - $M_V > -18^m$ (McConnachie 2012, Grebel 2003)
or $M_* < 10^{9.5}$ or small size

- **dIrr** – gas-rich, ongoing star forming (SMC) - **magnetic fields?**
- **dE** – little or no gas, no current SF, M_*: 10^7-10^9, 1-10 kpc
- **dSph** – no SF, gas-poor, no buldge, M_*: 10^7-10^8, 0.1-0.5 kpc
- **UFD** – ultra-faint (mainly dSph), oldest population of stars, $M_V > -8^m$, $M_* < 10^6$, <300 pc (McConnachie 2012)

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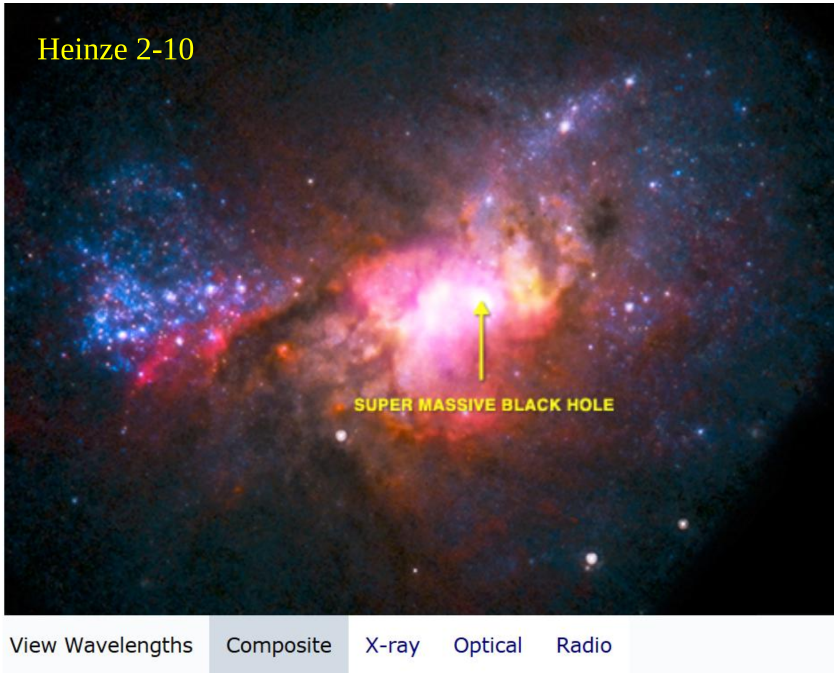
Why investigate dwarfs?

- This type of galaxies is the **most abundant** in the universe (but difficult to detect) – test for the formation and evolution of structures (ΛCDM)
- The **most dark matter** dominated stellar systems
- UFD - fossil **remnants of the first galaxies** that finished forming stars before the epoch of reionization (Jang & Lee 2014).
- **Black holes found** in dwarfs ($10^5 < M_* < 10^6$) e.g. in a BCD galaxy Heinze 2-10. Was BH formed before the galaxy spheroid (Reines et al. 2011, 2013, 2015)?

- In dwarfs with star formation (dIrr) we can investigate the existence of **magnetic fields, test the dynamo concept.** How MFs evolve and are connected to other ISM phases without density waves? Could low-mass galaxies magnetise the IGM?



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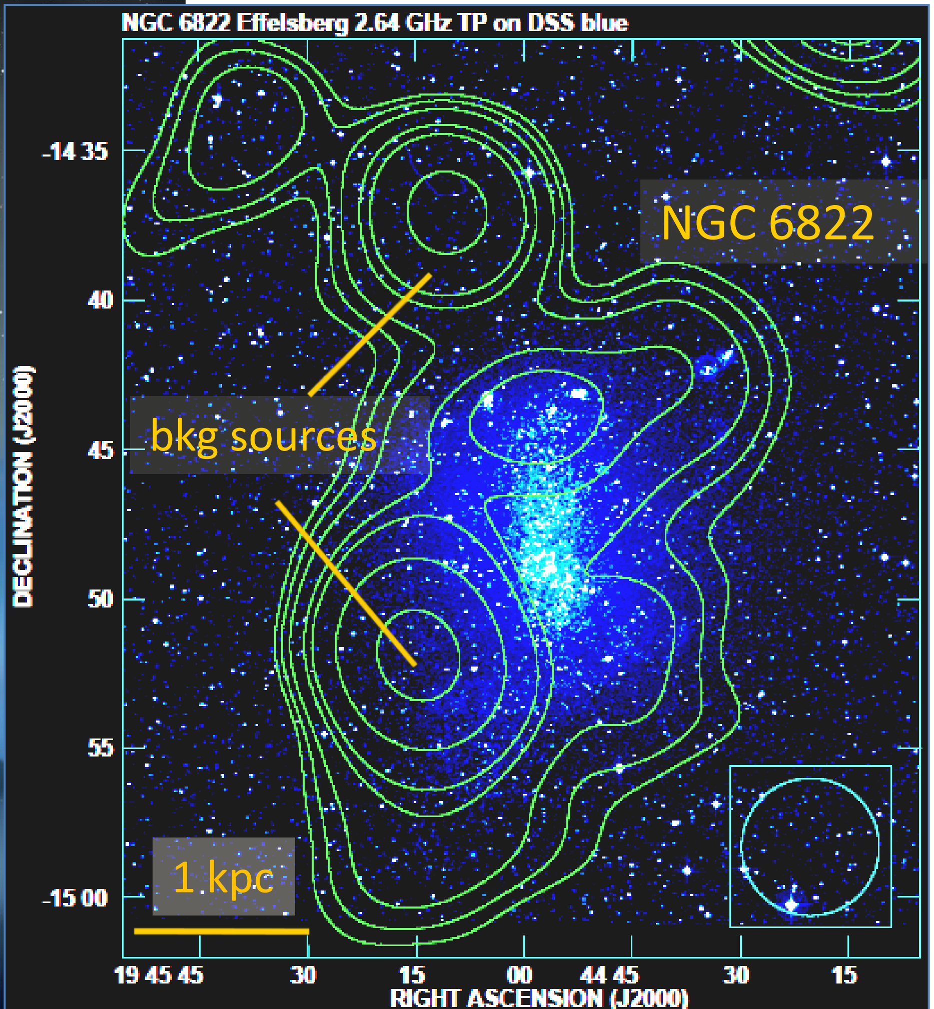
Radio detections of dIrrs in the Local Group



Chyży et al. 2011, A&A 529, A94

(see also Jurusik et al. 2014)

Mateo (1998), Salvadori & Ferrara (2009)

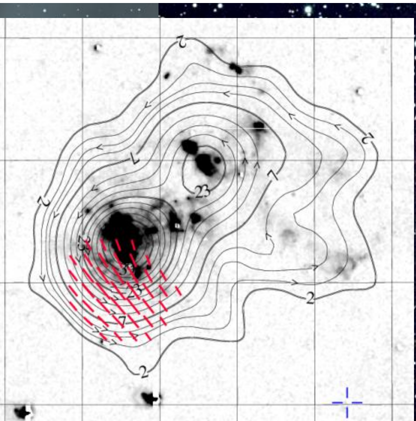
S	Irr	dwarfs			
		dIrr	dE	dSph	UFD
3	7	14	2	15	≈20

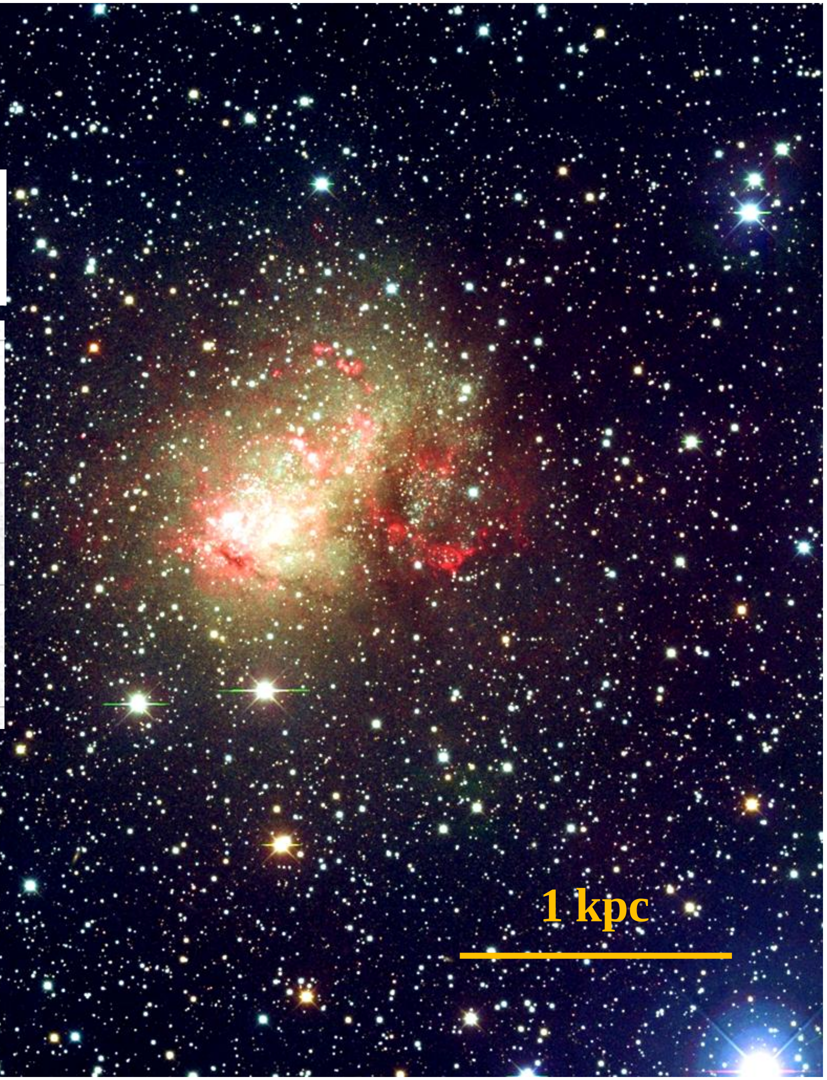
12 dIrrs with some star formation attainable from Effelsberg

- **3 out of 12 dIrrs are radio detected at 2.64 GHz** (IC 10, NGC 6822, IC 1613)
- Undetected: give upper limits of B
- Weak fields: typical B~4μG

Starburst dwarf IC10 has stronger fields

Basic properties of IC 10





B-V-Hα Massay et al. 2006

IC10 – LG dIrr, **irregular morphology** without spiral arms (1.6 kpc optical extent)

Strong SF (starburst), many W-R stars

M_{*}=8.6x10^{6} , M_{HI}=9.8x10^{7}

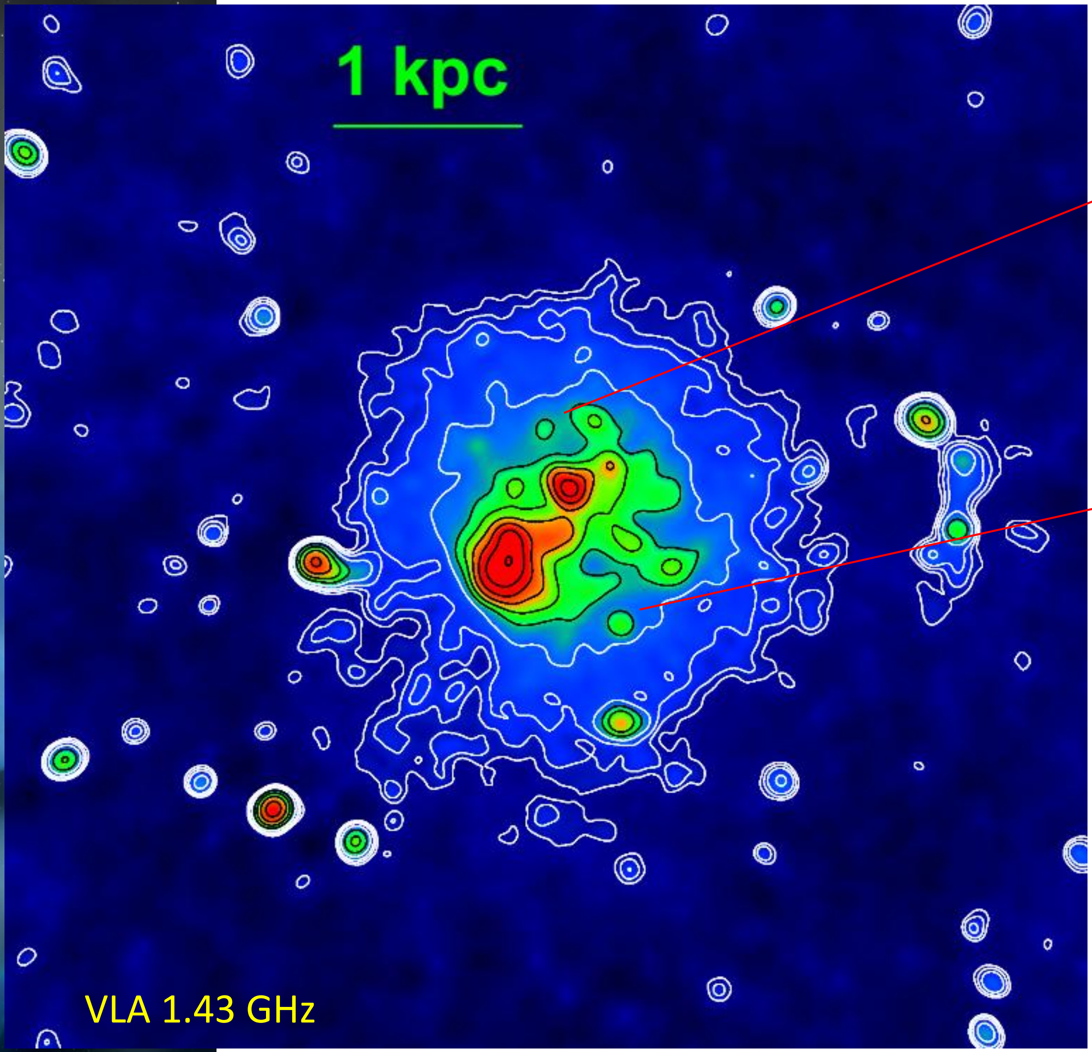
20x less massive than NGC 4449

Complex HI velocity field (merged with another dwarf, accreting gas filaments, Ashley at al. 2014)

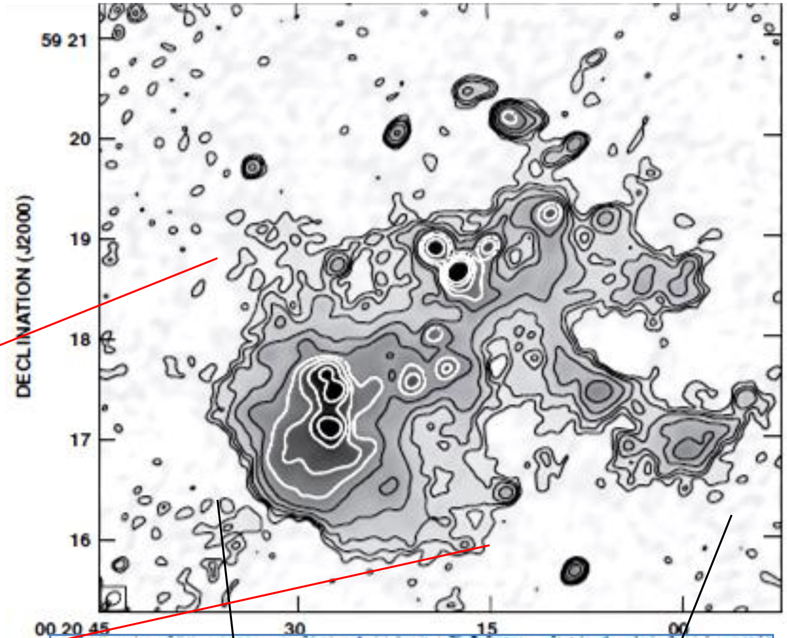
We performed VLA + Eff radio polarimetric observation at 1.43, 4.85, 8.46 GHz

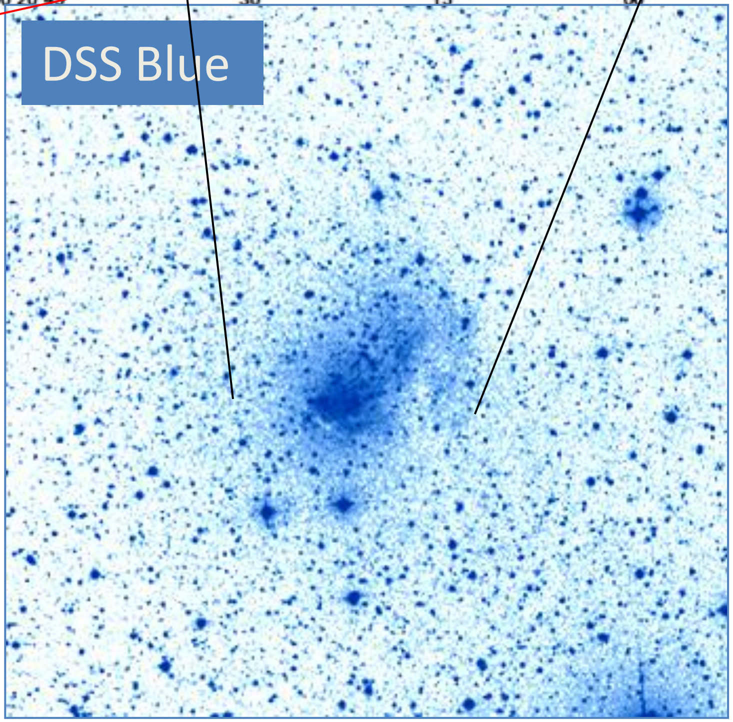
Chyży et al. ApJ submitted

Synchrotron envelope of IC 10



4.8 GHz JVLA, Heesen et al. 2012





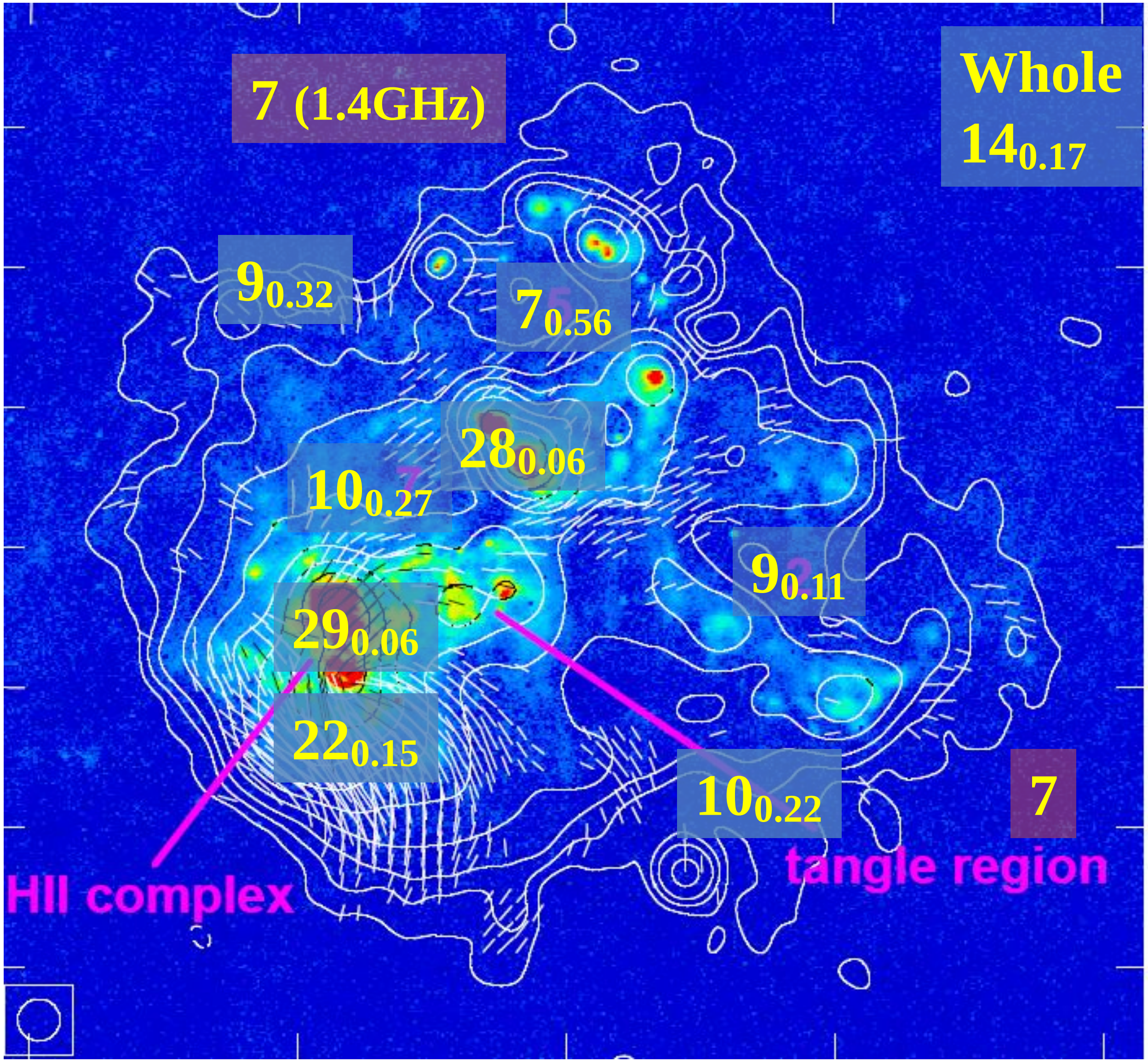
Radio halo (3 kpc in diameter)
Symmetric – blown up by wind?

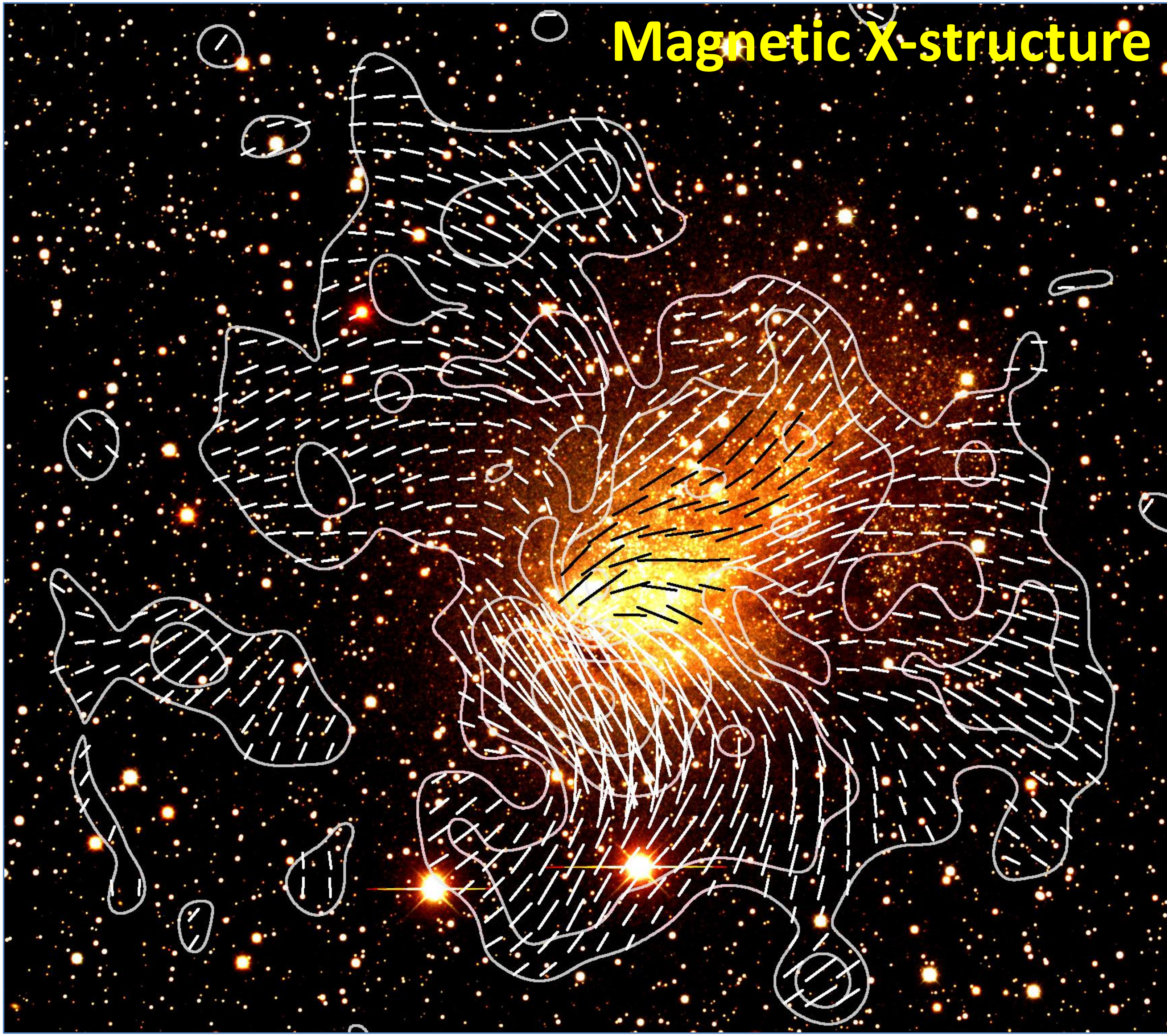
Magnetic field strength

VLA+EFF
4.86 GHz 18”x18”
Hα - Gil de Paz et al. 2003

B_{tot}

Degree of field order:
B_{ord}/B_{ran}





PI+B
VLA+EFF
4.86 GHz
45”x45”
+opt image
(Massay &
Olsen)

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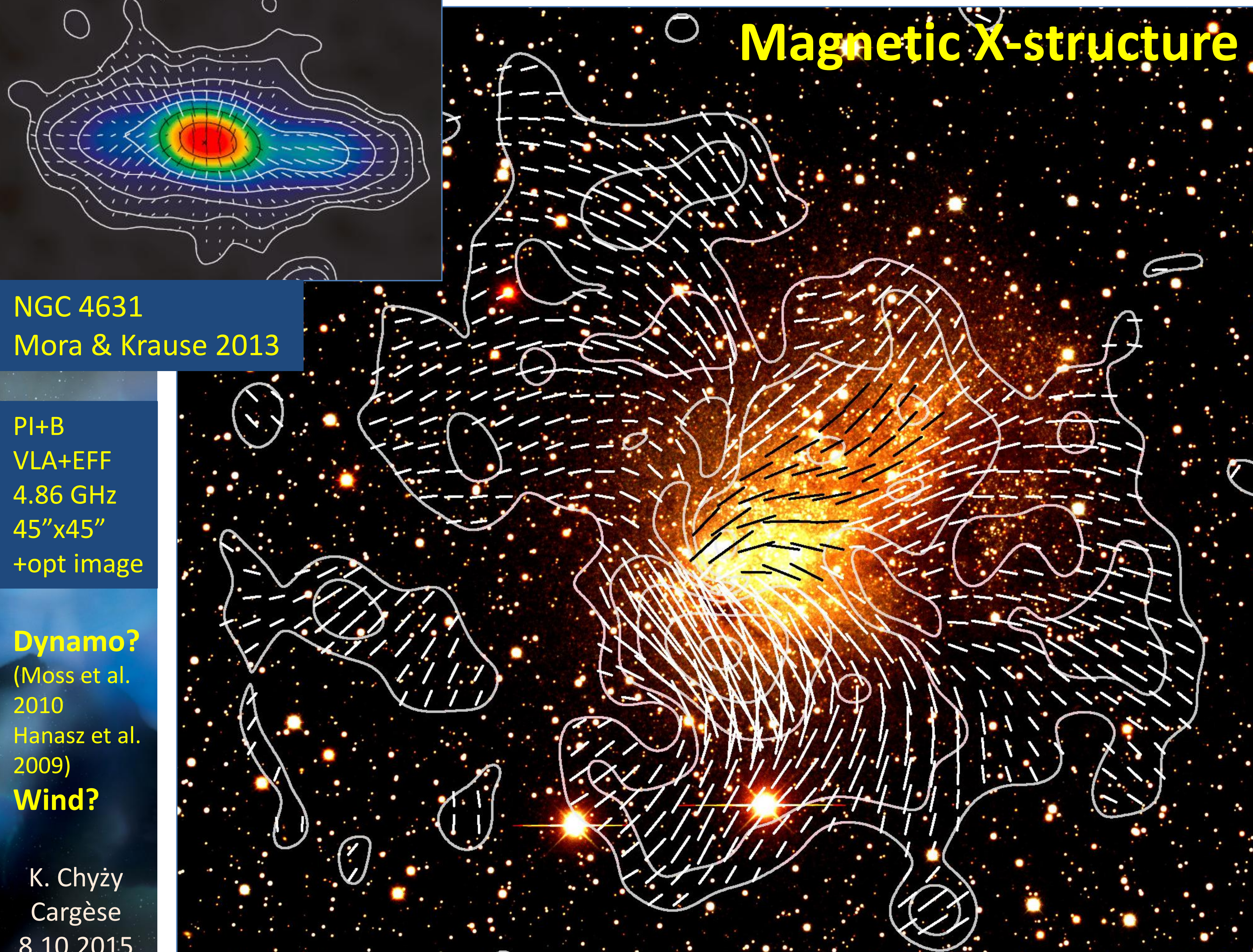
Magnetic X-structure



NGC 4631
Mora & Krause 2013

PI+B
VLA+EFF
4.86 GHz
45"x45"
+opt image

Dynamo?
(Moss et al. 2010
Hanasz et al. 2009)
Wind?

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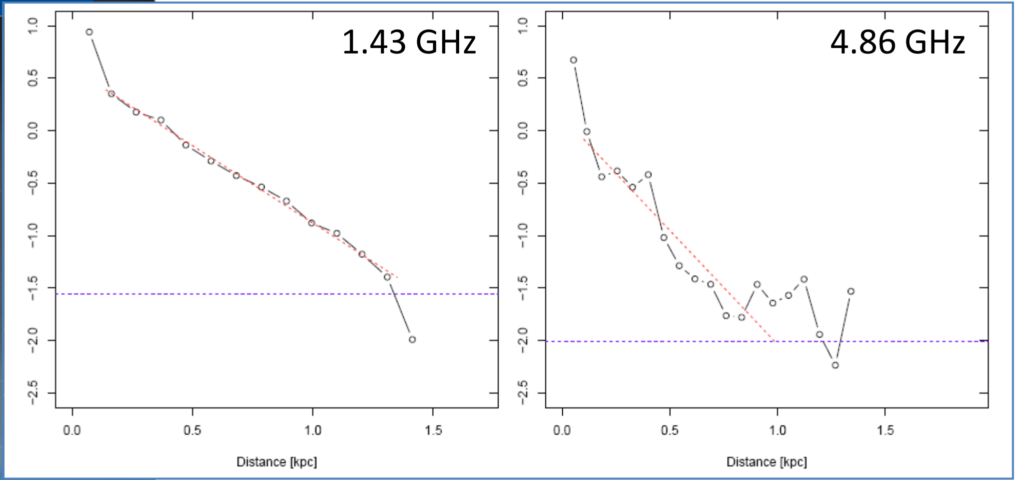
Magnetised wind

Estimation of CRs bulk speed in IC 10

Radio profiles



From equipartition: scale length of CRe

$$h_e = \frac{3+\alpha_{nth}}{2} h_{syn}$$

Synchr. cooling time

$$\frac{t_{syn}}{yr} = 8.352 \times 10^9 \left(\frac{E}{GeV}\right)^{-1} \left(\frac{B}{\mu G}\right)^{-2}$$

Wind velocity

$$\boldsymbol{V_w \cong h_e / t_{syn} \approx 60 \text{ km/s}}$$

$$v_{esc} \cong \sqrt{2}\, v_{max} = 40 \text{ km/s}$$

(HI – 30 km/s Wilcots & Miller 1998)

Scale length: $h_{syn} \approx$ **0.3 kpc**

1.7 kpc for NGC 253 (Heesen et al. 2009)

Direction	Scale length kpc	B_{tot} μG	t_{syn} Myr	V_w km s^{-1}
	1.43 GHz			
All	0.26	13.5	17.9	26 ± 4
NE ($PA = 35°$)	0.25	13.5	17.9	25 ± 4
NE from N H II complex	0.29	20.0	9.9	52 ± 8
	4.86 GHz			
All	0.19	13.5	9.7	35 ± 5
NE ($PA = 35°$)	0.17	13.5	9.7	30 ± 5
NE from N H II complex	0.20	20.0	5.4	66 ± 10

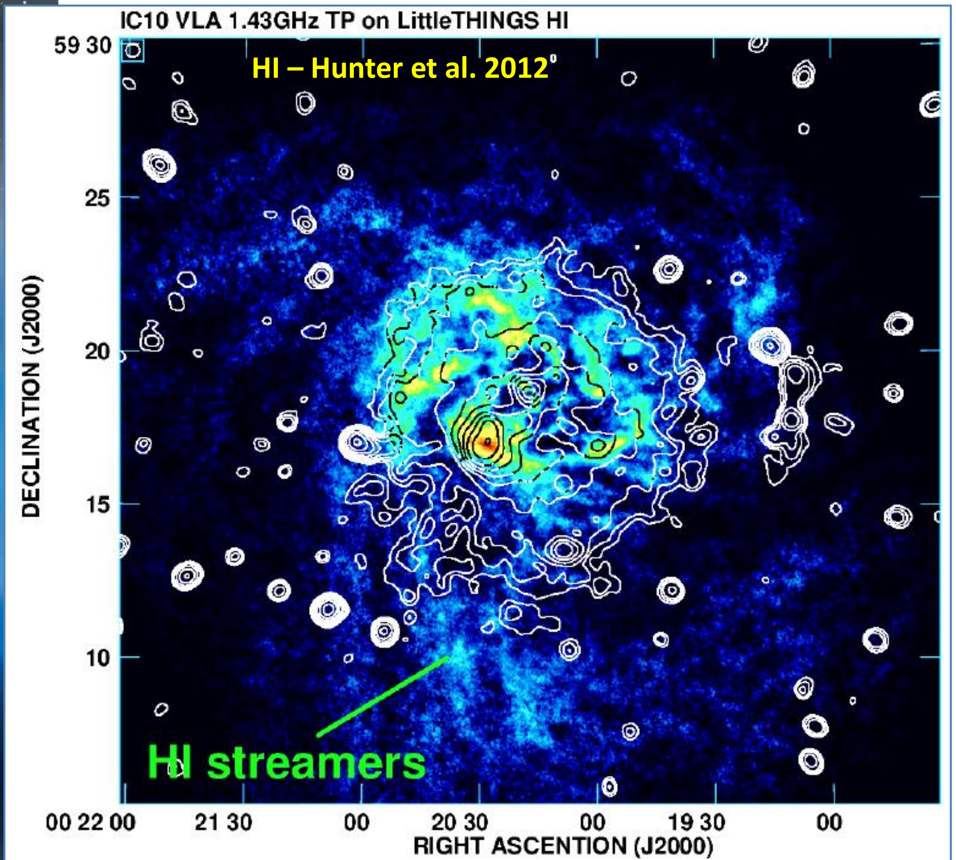
Magnetised galactic winds

↓

Synchrotron halo (1.43 GHz)
Magnetic X-structure (4.86 GHz)

Cosmological implications

Grav. Inter. induce-> large-scale turb.-> trigger burst of SF -> small-scale turb. -> gener. MF -> feed-back on IGM



Idea: primordial magnetic field - MF spread-out into IGM by galactic winds from low-mass galaxies (Kronberg et al. 1999, Bertone 2006, Chyży et al. 2011, etc.)

Test: look for extensive synchrotron envelopes around nearby dwarf galaxies

IC10 – this is it!

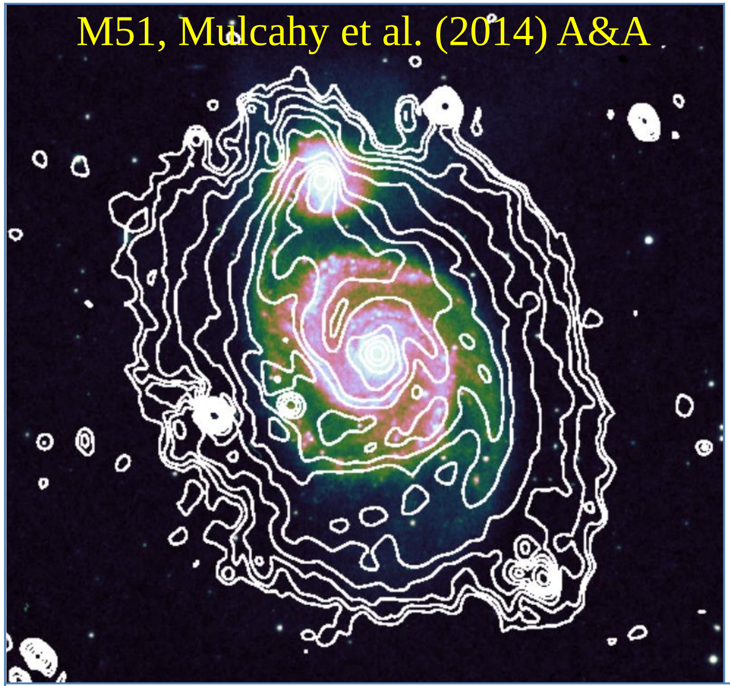
IC 10 can seed the IGM with random and ordered magnetic fields

Maybe the radio (magnetic) envelope is even larger

Low-frequency studies with LOFAR

(Magnetism Key Science Project)

- M51: The radial scale length is greater at 151 MHz than at 1.4 GHz
- We expect the same for dwarfs
- Studies of dwarfs (and other galaxies) with LOFAR are in progress



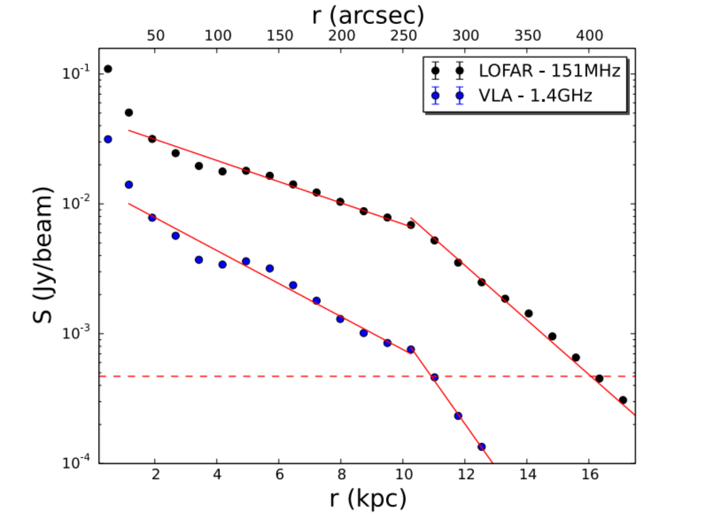
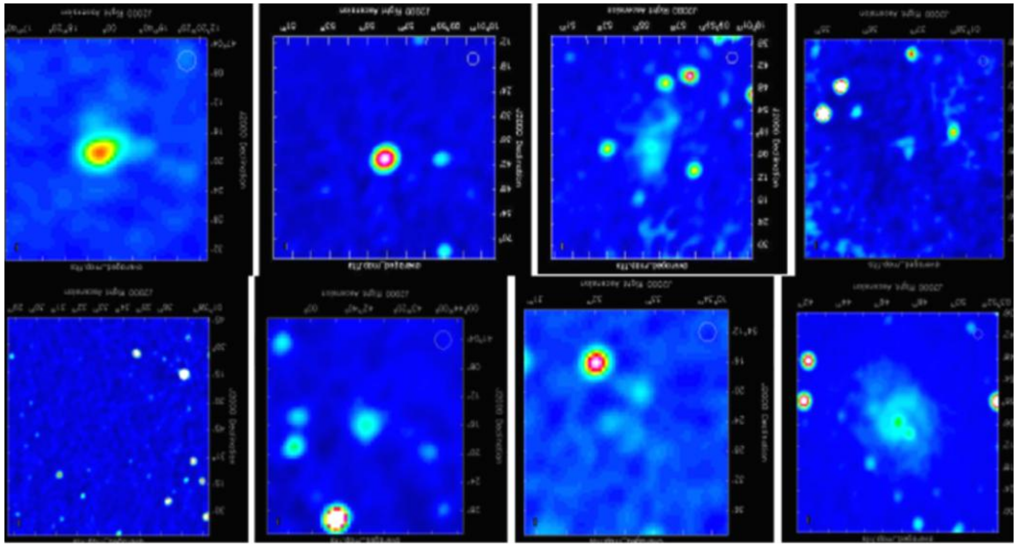


Fig. 11. Radial profile of M 51 at 151 MHz and 1.4 GHz. The horizontal red line shows the sensitivity limit (3σ) of the 151 MHz image. Errors are too small to be seen at this scale.



LOFAR MSSS survey

Summary

Observations of low-mass galaxies

- **Only 3 out of 12 dIrrs of the Local Group are radio detected.**
  Production of magnetic energy is low, typical B strength is 4 μG.

Radio observations of IC 10

- We detect large and **symmetric radio synchrotron halo**.
- Magnetic structure is of **X-shape** topology, observed so far in edge-on spiral galaxies. B is up to **30 μG**.
- The **scale length** of radio emission is about **0.3 kpc.** Estimated bulk speed of CRs is **~60 km/s** and implies the **magnetised galactic wind.**

Cosmological implications

- IC 10 can seed the IGM with random and ordered magnetic fields.
- The full extent of the radio halo - with LOFAR at low frequencies.

Dwarf galaxies constitute an important link between the nearby universe, which we can study relatively easily, and the most distant objects.