Magnetised wind and synchrotron halo of IC 10

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

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

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

- 3 out of 12 dlrrs are radio detected at 2.64 GHz (IC 10, NGC 6822, IC 1613)
- Undetected: give upper limits of B
- Weak fields: typical $B \sim 4 \mu G$

Starburst dwarf IC10 has stronger fields

(see also Jurusik et al. 2014)


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Basic properties of IC 10

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

Strong SF (starburst), many W-R stars

$M_*=8.6 \times 10^6$, $M_{\text{HI}}=9.8 \times 10^7$

20x less massive than NGC 4449

Complex HI velocity field

(merged with another dwarf, accreting gas filaments, Ashley et al. 2014)

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

Synchrotron envelope of IC 10

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

$B_{\text{tot}}$
Degree of field order:
$B_{\text{ord}}/B_{\text{ran}}$

HII complex
tangle region

7 (1.4GHz)
Whole 14

K. Chyży
Cargèse
8.10.2015
Magnetic X-structure

PI+B
VLA+EFF
4.86 GHz
45”x45”
+opt image
(Massay & Olsen)
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?
Magnetised wind
Estimation of CRs bulk speed in IC 10

Scale length: \( h_{\text{syn}} \approx 0.3 \) kpc

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

From equipartition: scale length of CRe

\[
h_e = \frac{3 + \alpha_{\text{nth}}}{2} h_{\text{syn}}
\]

Synchr. cooling time

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

Wind velocity

\[
V_w \approx h_e / t_{\text{syn}} \approx 60 \text{ km/s}
\]

\[
v_{\text{esc}} \approx \sqrt{2} v_{\text{max}} = 40 \text{ km/s}
\]

(MI – 30 km/s Wilcots & Miller 1998)

### 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

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 $4 \mu G$.

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 $30 \mu G$.
• The scale length of radio emission is about $0.3 \text{ kpc}$. Estimated bulk speed of CRs is $\sim 60 \text{ km/s}$ 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.