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Magnetic fields and CRs in the disk-halo interface of spiral galaxies

Ralf-Jürgen Dettmar, Ruhr-University Bochum

with V. Heesen, B. Adebahr, R. Beck, M. Krause, M. Soida, M. Wezgowiec, M. Urbanik, LOFAR MKSP & CHANGES teams

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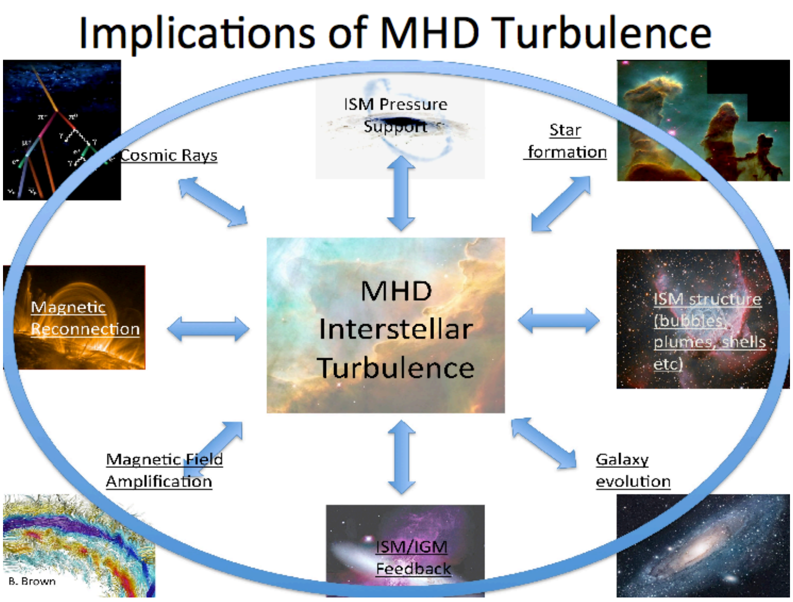
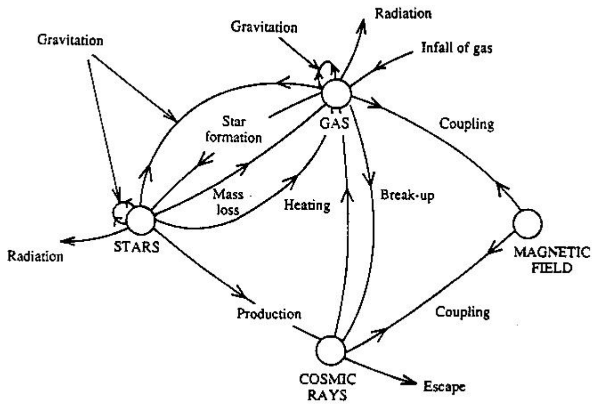
B-field & CRs possibly important...
(e.g., talks by Burkhart, McClure-Griffiths)



Processes in the interstellar medium

(from Taylor, Cambridge Univ. Press)



Magnetic Fields and Cosmic Rays contribute significantly to the energy density:

$U_{rad} \sim U_{B} \sim U_{CR} \sim U_{kin}$

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recognition in cosmological context

Magnetic fields in cosmological simulations of disk galaxies

R. Pakmor, F. Marinacci, V. Springel

(Submitted on 9 Dec 2013 (v1), last revised 3 Feb 2014 (this version, v2))

Observationally, magnetic fields reach equipartition with thermal energy and cosmic rays in the interstellar medium of disk galaxies such as the Milky Way. However, thus far cosmological simulations of the formation and evolution of galaxies have usually neglected magnetic fields. We employ the moving-mesh code \textsc{Arepo} to follow for the first time the formation and evolution of a Milky Way-like disk galaxy in its full cosmological context while taking into account magnetic fields. We find that a prescribed tiny magnetic seed field grows exponentially by a small-scale dynamo until it saturates around $z=4$ with a magnetic energy of about 10% of the kinetic energy in the center of the galaxy's main progenitor halo. By $z=2$, a well-defined gaseous disk forms in which the magnetic field is further amplified by differential rotation, until it saturates at an average field strength of $\sim 6 \mu G$ in the disk plane. In this phase, the magnetic field is transformed from a chaotic small-scale field to an ordered large-scale field coherent on scales comparable to the disk radius. The final magnetic field strength, its radial profile and the stellar structure of the disk compare well with observational data. A minor merger temporarily increases the magnetic field strength by about a factor of two, before it quickly decays back to its saturation value. Our results are highly insensitive to the initial seed field strength and suggest that the large-scale magnetic field in spiral galaxies can be explained as a result of the cosmic structure formation process.

ApJ 783, L20 (2014)

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ApJ 777, L16 (2013)

SIMULATIONS OF DISK GALAXIES WITH COSMIC RAY DRIVEN GALACTIC WINDS

C. M. Booth[1]. Oscar Agertz[2,1]. Andrey V. Kravtsov[1,3,4]. and Nickolay Y. Gnedin[5,1,3]

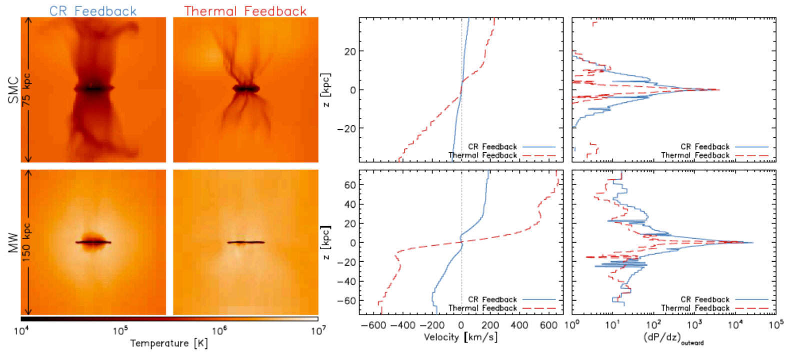
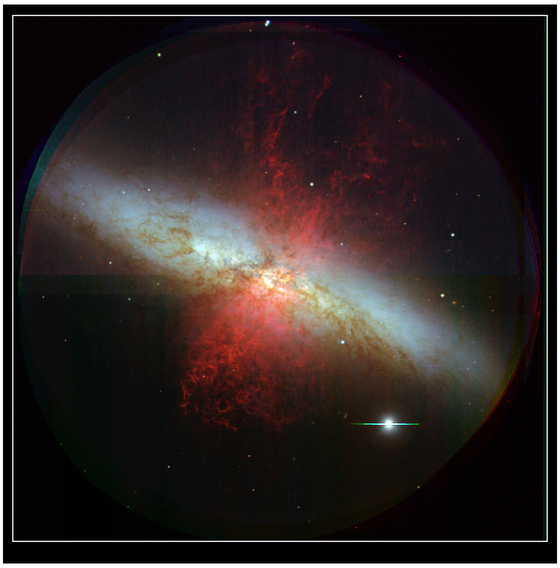


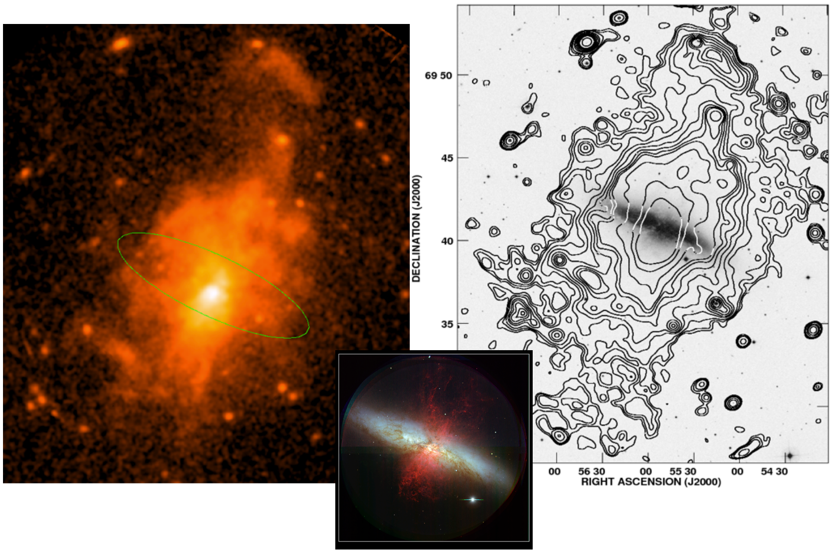
Fig. 3.— Edge-on maps of the temperature in a thin slice around the MW (*top panels*) and SMC galaxies (*bottom panels*) for both the thermal feedback *left panels*) and CR feedback (*right panels*). CR feedback has a large effect on the temperature structure of the halo gas. The plots show the median velocity (*left panels*) and outward pressure force (*right panels*) as a function of height from the disk for the same two simulations. All quantities are calculated in a cylinder of radius 3kpc, centered on the galactic disk. It is clear that the effect of the CRs is to increase the outward pressure forces in the halo by a factor of 3-5 at all z. This pressure gradient slowly accelerates the wind into the halo. The wind in the thermal feedback simulations is accelerated abruptly from the disk and maintains a constant velocity thereafter.

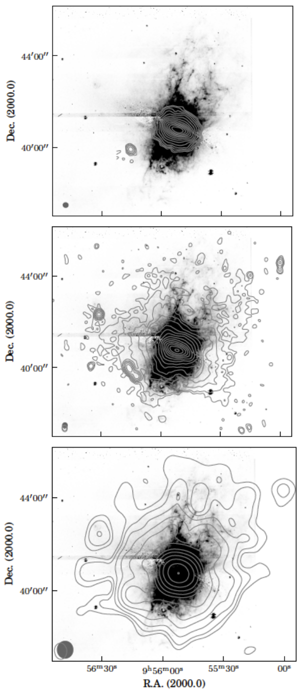
the prototypical galactic wind M82 (?)



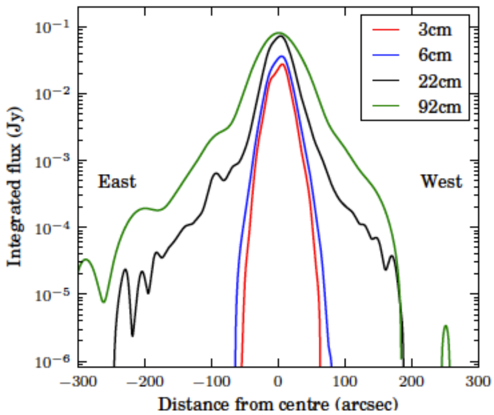
Subaru

M82 in X-rays / XMM (Wezgowiec, et al. in prep.)



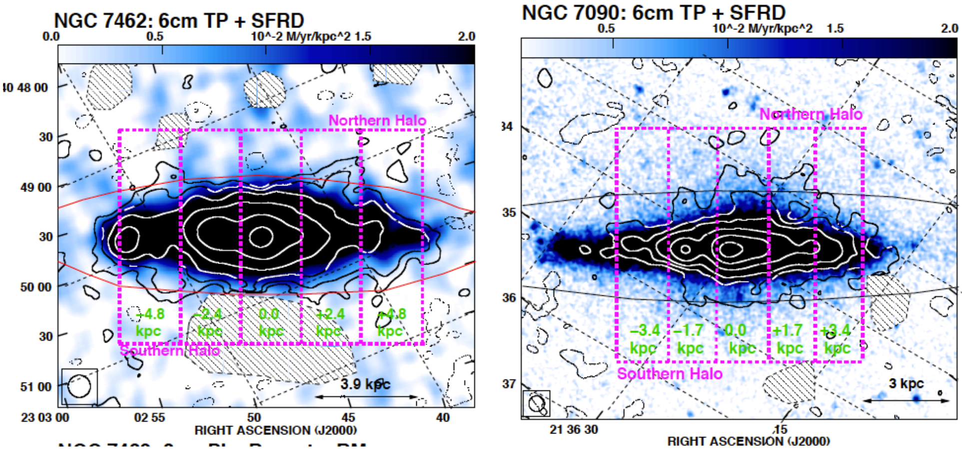


cosmic ray transport in M82

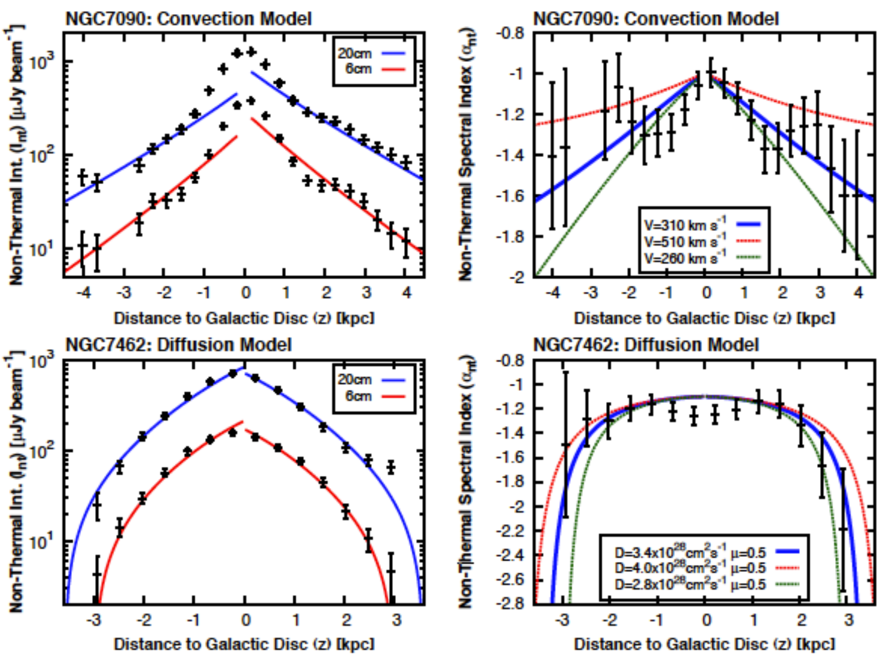


Adebahr et al. 2013, A&A

analysis of CR transport (ATCA 6&20cm)



V. Heesen, R.-J. Dettmar et al. in prep.



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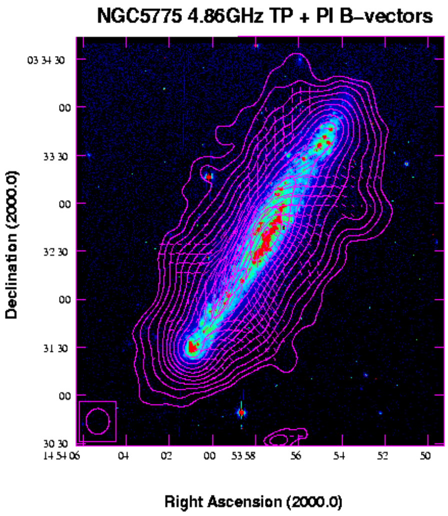
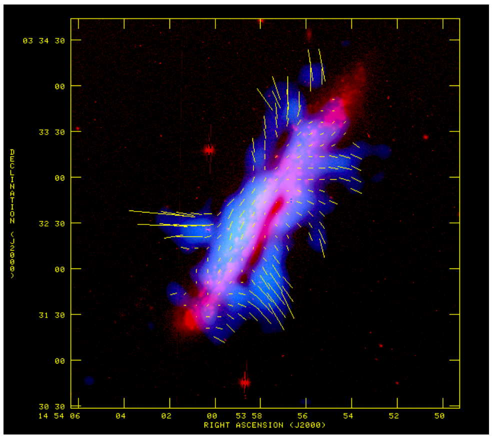
NGC 5775 comparison at three wavelengths





Soida, Krause, Dettmar, Urbanik A&A 2011
Tüllmann, Dettmar, Soida, et al. A&A, 2000 364,L36

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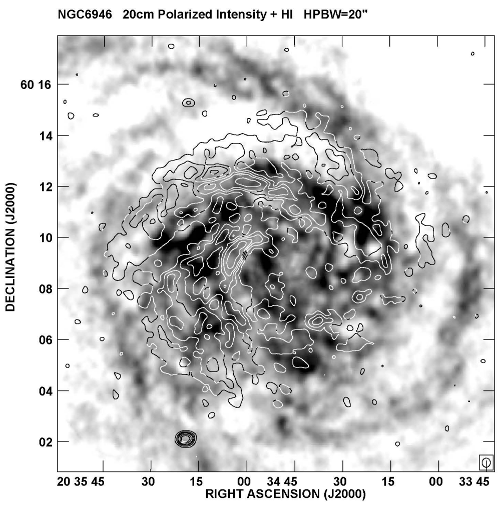
NGC 6946

6cm VLA+Effelsberg
Polarized intensity
on HI
(Beck 2007)

polarization asymmetry



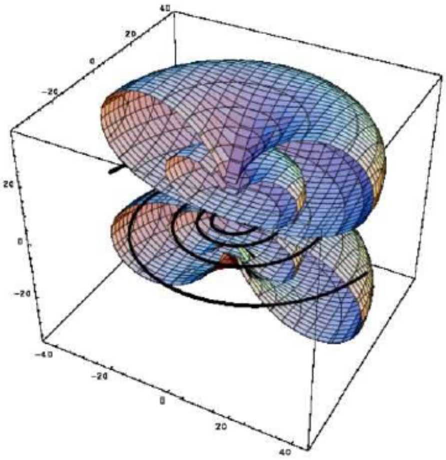
very important step:

solution by quadrupol halo field

The Westerbork SINGS survey III

Global magnetic field topology

R. Braun[1], G. Heald[2], and R. Beck[3]



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and even more general description:

Analytical models of X-shape magnetic fields in galactic halos

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Received ; accepted

ABSTRACT

Context. External spiral galaxies seen edge-on exhibit X-shape magnetic fields in their halos. Whether the halo of our own Galaxy also hosts an X-shape magnetic field is still an open question.
Aims. We would like to provide the necessary analytical tools to test the hypothesis of an X-shape magnetic field in the Galactic halo.
Methods. We propose a general method to derive analytical models of divergence-free magnetic fields whose field lines are assigned a specific shape. We then utilize our method to obtain four particular models of X-shape magnetic fields in galactic halos. In passing, we also derive two particular models of predominantly horizontal magnetic fields in galactic disks. All our field models have spiraling field lines with spatially varying pitch angle.
Results. Our four halo field models do indeed lead to X patterns in synthetic synchrotron polarization maps. Their precise topologies can all be explained by the action of a wind blowing outward from the galactic disk or from the galactic center. In practice, our field models may be used for fitting purposes or as inputs to various theoretical problems.

Key words. Galaxies: magnetic fields – galaxies: halos – galaxies: spirals – Galaxy: halo – Galaxy: disk – ISM: magnetic fields

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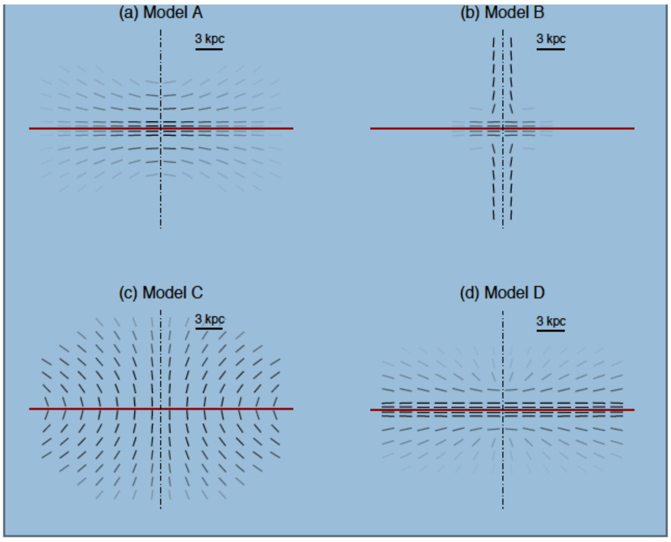
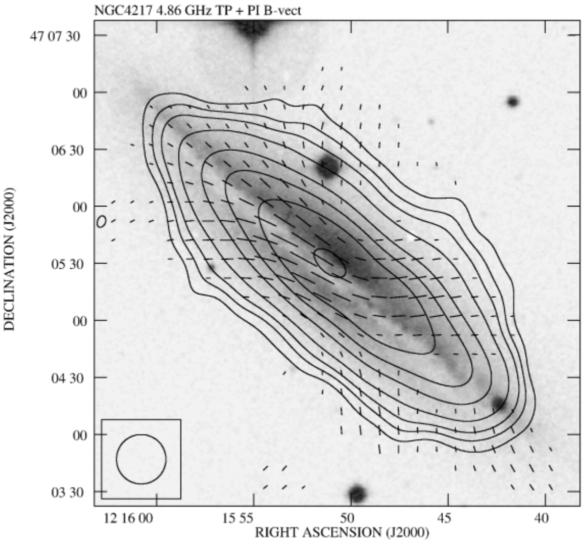


that‘s what is observed:

large scale magnetic field structure in halos

the global magnetic fields in disk galaxies typically have a significant poloidal component (based now on 6+ cases studied, Dettmar & Soida 2006, Soida 2005)

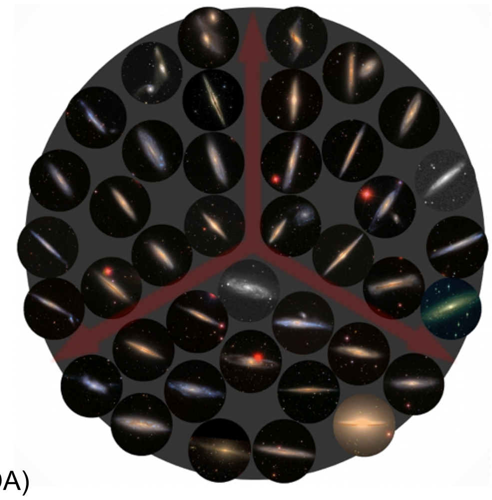


Making use of the JVLA

CHANGES:
Continuum HAlos in Nearby Galaxies
- an Evla Survey

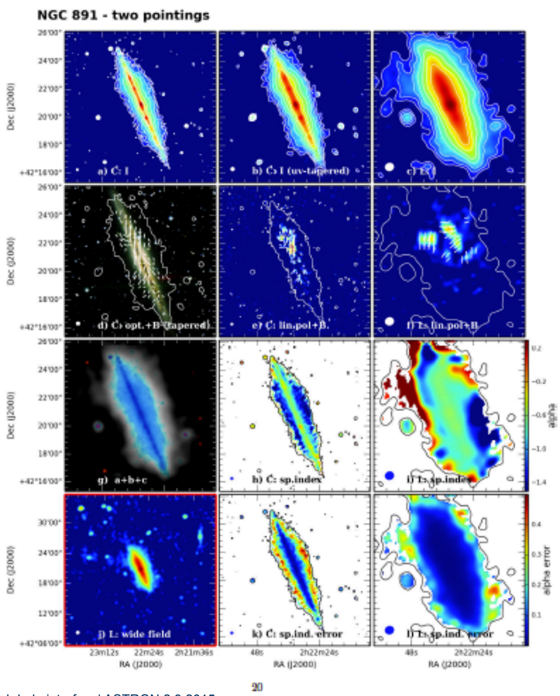
35 edge-on galaxies

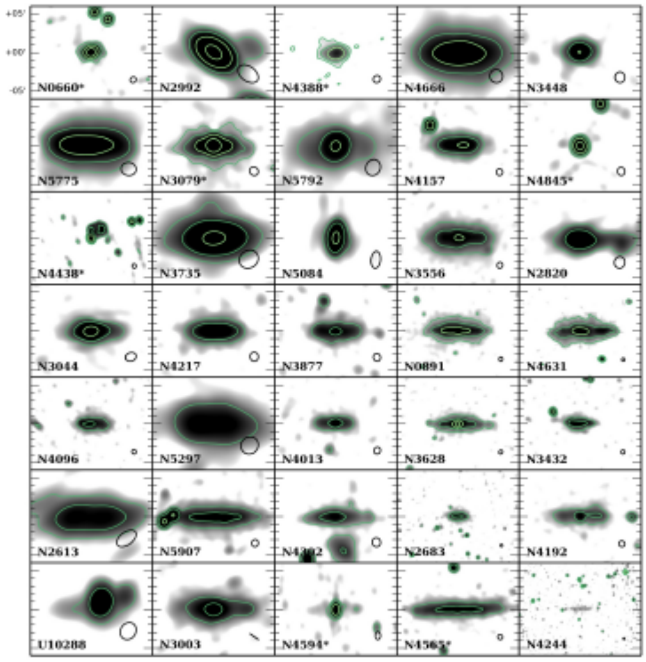
inclination > 75 deg
DEC > 25 deg
4 arcmin > D < 15 arcmin
flux > 23 mJy



PI: Judith Irwin, Kingston (ONT/CANADA)

Wiegert et al. AJ 150, 81 (2015) D-array C & L band





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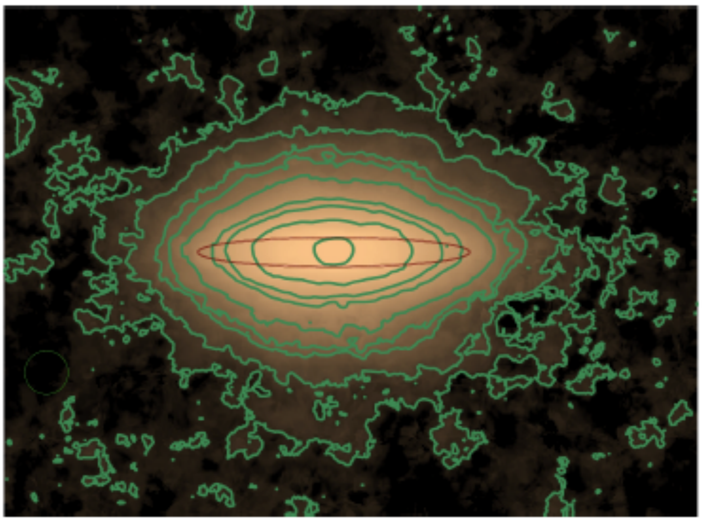
„averaged“ radio continuum halo



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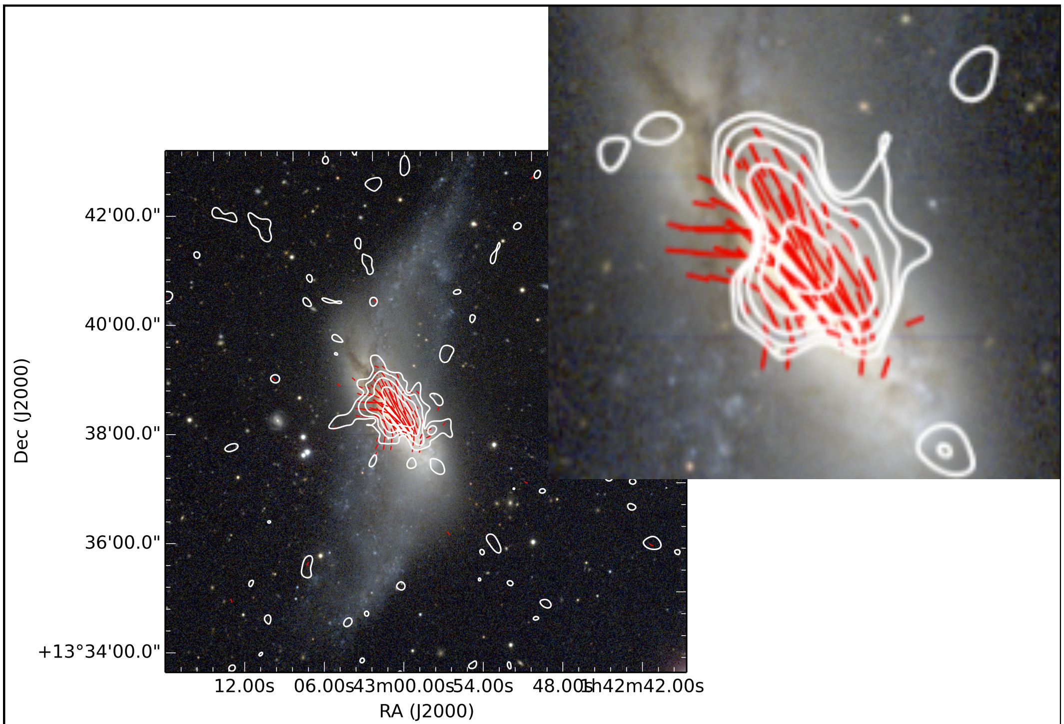

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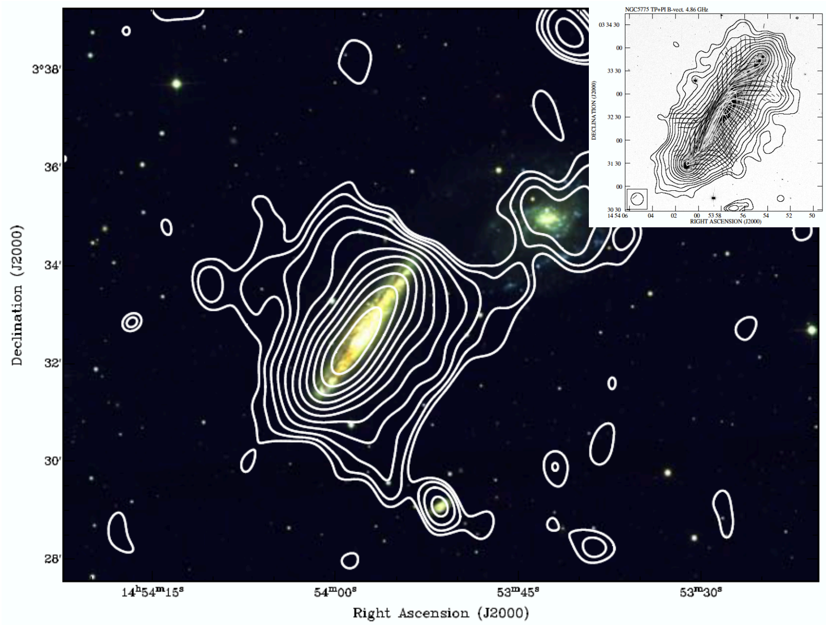
HBA at Jülich (FZ Jülich- RU Bochum)

LOFAR HBA 10hrs 118-192 MHz (Heald, Shridar + MKSP)



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Summary:

- Halos of spiral galaxies have a significant poloidal magnetic field component (quadrupol field)
- New broad-band multichannel receivers provide higher sensitivity and allow for new analysis techniques such as Rotation Measure Synthesis
- CR driven winds could be important for the evolution of galaxies
- Surveys aiming at measurements of magnetic fields and CRs in halos of a larger number of objects are underway

Thank you for your attention