RUHR-UNIVERSITÄT BOCHUM

RUB

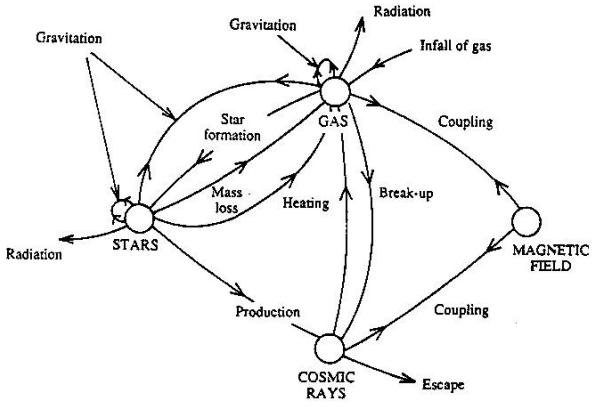
A fresh look on cosmic rays and magnetic fields in disc galaxies

Ralf-Jürgen Dettmar, Ruhr-University Bochum

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

Processes in the interstellar medium

(from Taylor, Cambridge Univ. Press)



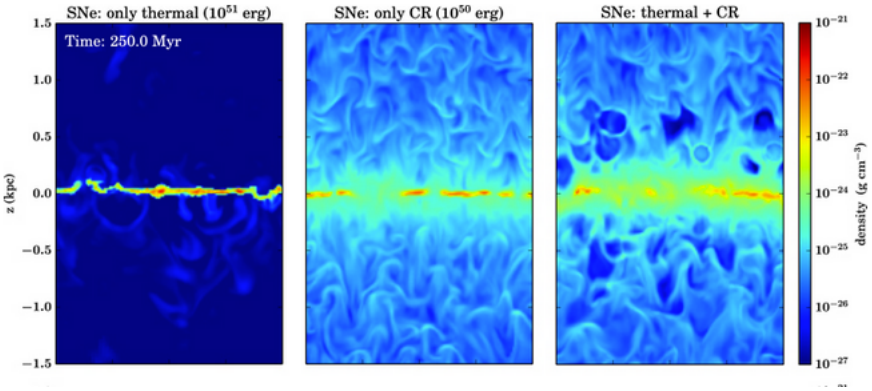
Magnetic Fields and Cosmic Rays contribute significantly to the energy density:

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

LAUNCHING COSMIC-RAY-DRIVEN OUTFLOWS FROM THE MAGNETIZED INTERSTELLAR MEDIUM

Philipp Girichidis[1], Thorsten Naab[1], Stefanie Walch[2], Michał Hanasz[3], Mordecai-Mark Mac Low[4,5], Jeremiah P. Ostriker[6], Andrea Gatto[1], Thomas Peters[1], Richard Wünsch[7], Simon C. O. Glover[5], Ralf S. Klessen[5], Paul C. Clark[8], and Christian Baczynski[5] — Hide full author list

Published 2016 January 6 • © 2016. The American Astronomical Society. All rights reserved.
The Astrophysical Journal Letters, Volume 816, Number 2



RUHR-UNIVERSITÄT BOCHUM

RUB

recognition in cosmological context

Magnetic fields in cosmological simulations of disk galaxies

R. Pakmor, F. Marinacci, V. Springel

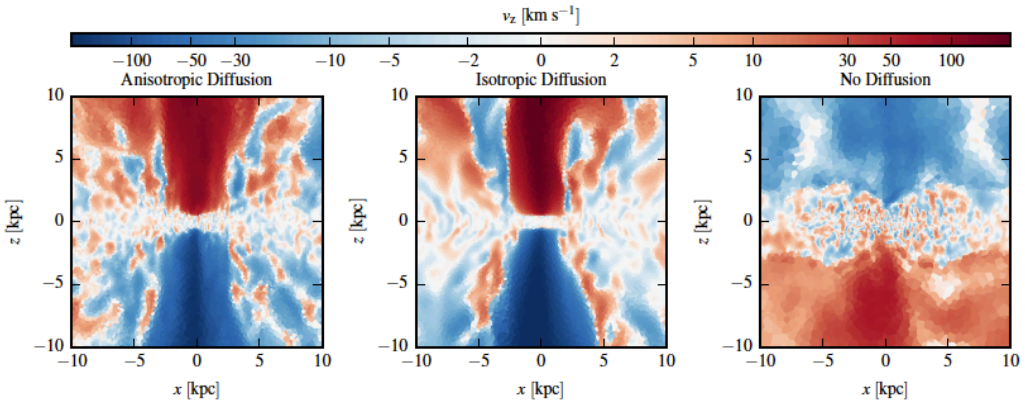
(Submitted on 9 Dec 2013 (v1), last revised 3 Feb 2014 (this version, v2))

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.

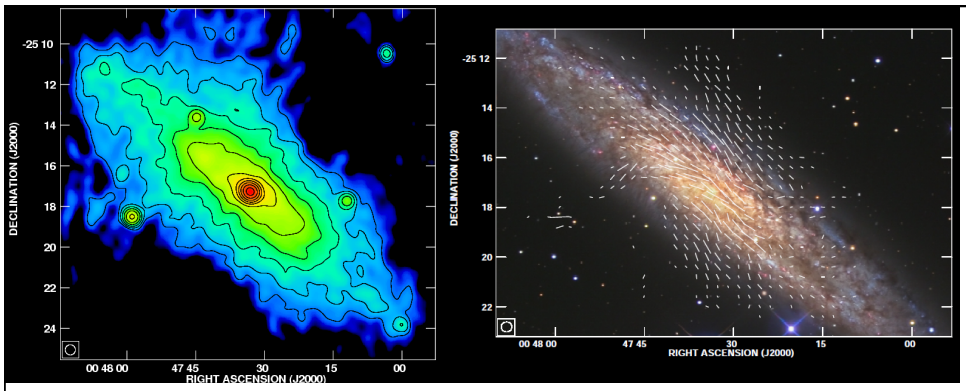
ApJ 783, L20 (2014)

RUHR-UNIVERSITÄT BOCHUM

RUB



Pakmor, Pfrommer, Simpson, Springel (2016)



NGC 253 radiocontinuum study at 3, 6, 20, 90 cm (Heesen, Krause, Beck, Dettmar 2009 A&A)

What we can measure:

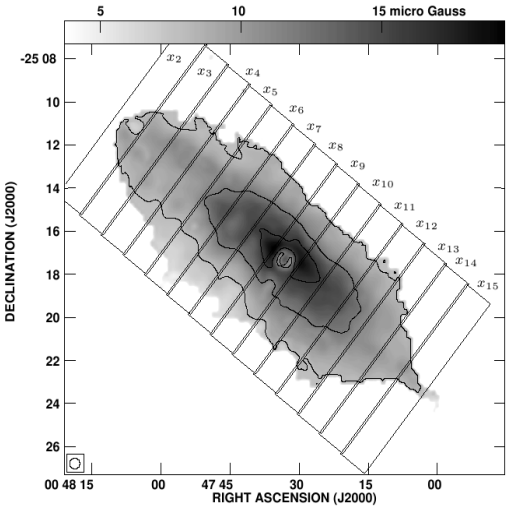
Polarized emission (and angles):

$I \propto \int n_{CR} B_{\perp}^{1+\alpha} dl$

Faraday rotation measures of the diffuse polarized emission:

$RM \propto \int n_e B_{\parallel} dl$ and $\chi(\lambda) = \chi_0 + RM \cdot \lambda^2$

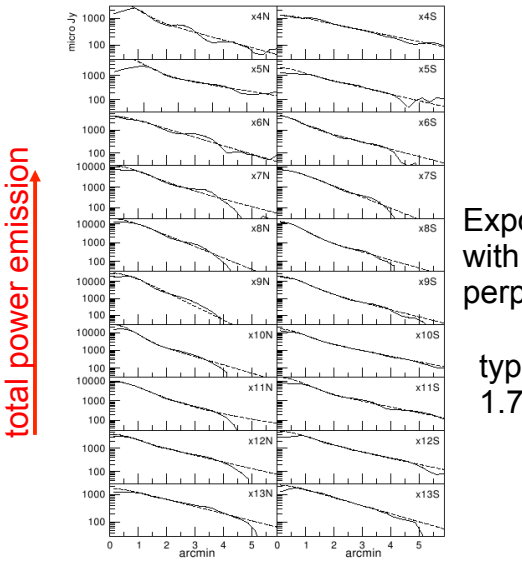
Total magnetic field strength



local magnetic field strength

local Synchrotron-lifetime

equipartition magnetic field strength: $B \propto L_\nu^{1/(3+\alpha_{\rm nt})}$



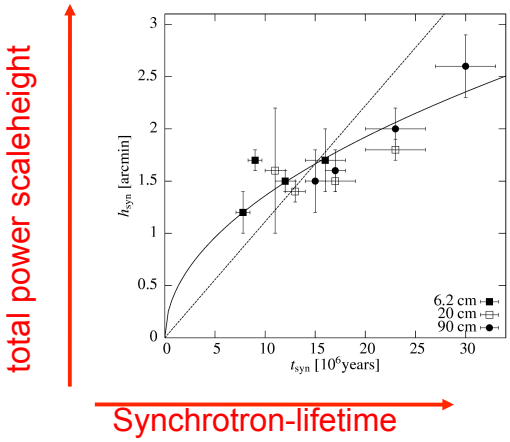
total power emission

Exponential distribution with scaleheight: h perpendicular to disk: z

typical scaleheight ~ 1.7 kpc

distance from the major axis: z

Scaleheight vs. Synchrotron- lifetime



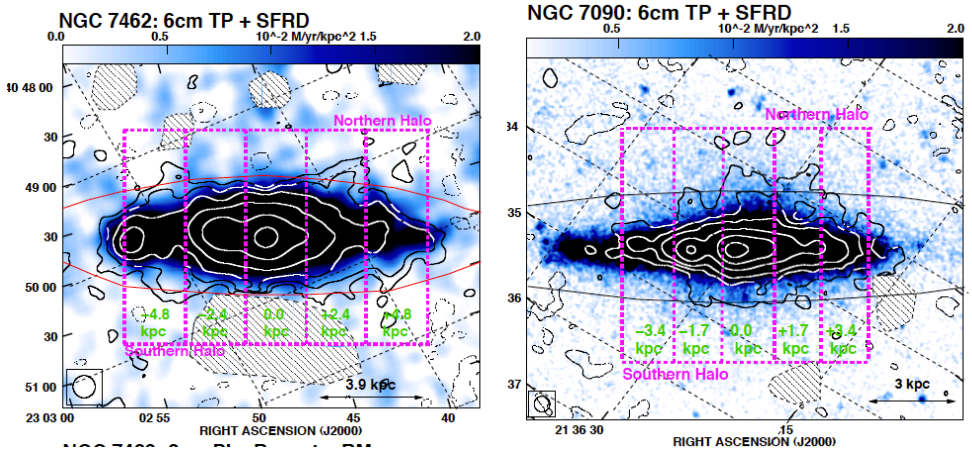
Cosmic ray propagation

$$v_{\rm e} = \frac{3+\alpha_{\rm nt}}{2}\frac{\Delta h_{\rm e}}{\Delta t_{\rm Syn}}$$

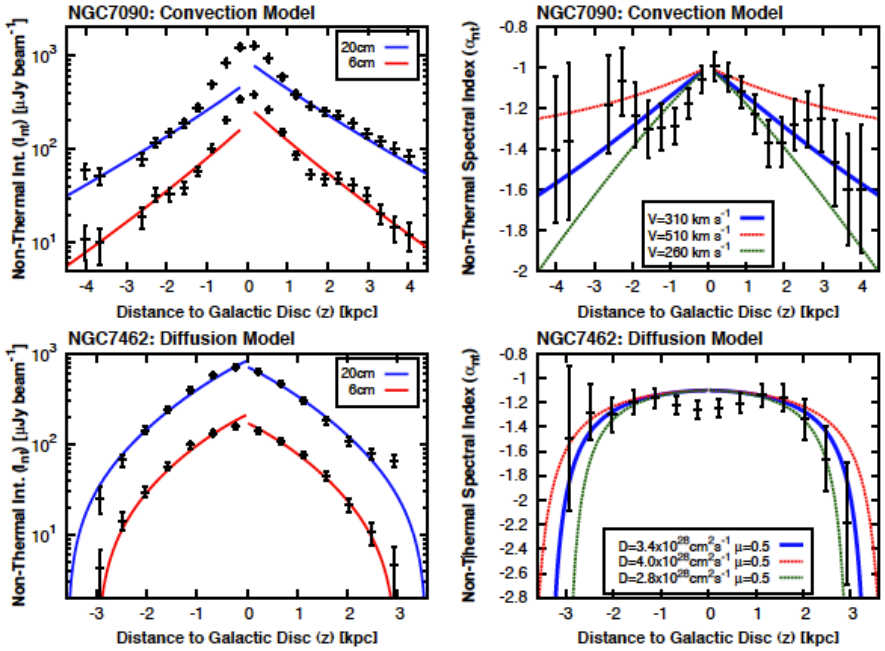
$$\bar{v}_{\lambda 6.2} = (280 \pm 40)\ {\rm km\,s^{-1}}$$

close to escape velocity!

analysis of CR transport (ATCA 6&20cm)



Heesen, Dettmar, Krause et al. 2016 MNRAS 458, 332



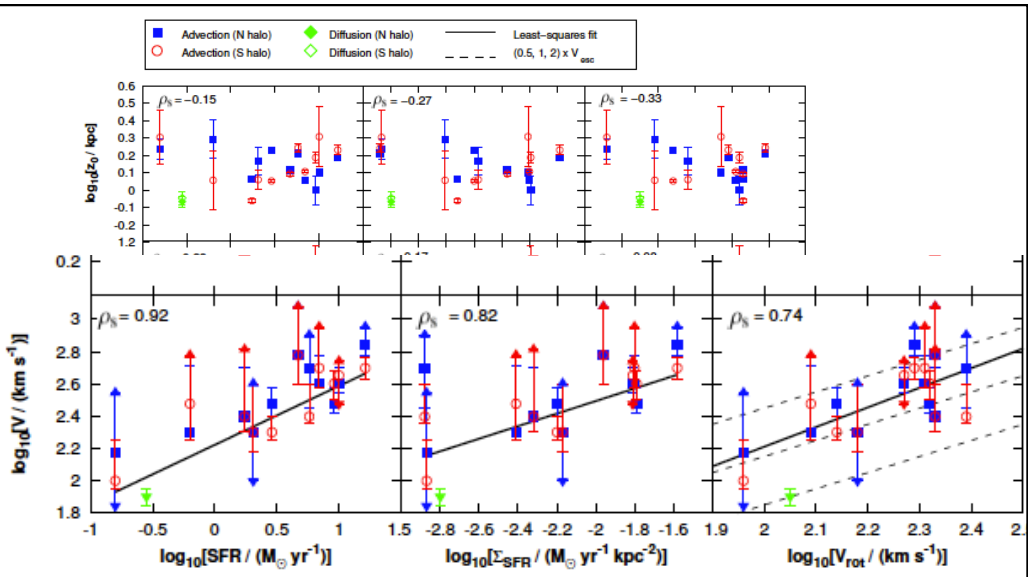


Figure 5. Parameter studies in log–log diagrams as function of SFR, SFR surface density (Σ_{SFR}) and rotation speed V_{rot}. *Top panels:* non-thermal intensity scale height (z_0) at 5 GHz (8.5 GHz for NGC 5775) of the thick radio disc. *Middle panels:* magnetic field scale height (h_{B2}) of the thick radio disc. *Bottom panels:* Advection speed (V), where solid lines show least-squares fits. In the bottom right panel the dashed lines show (0.5, 1, 2)×V_{esc}. In each panel, we also present Spearman's rank correlation coefficient, ρ_S, which we derived from values that have both an upper and lower limits.

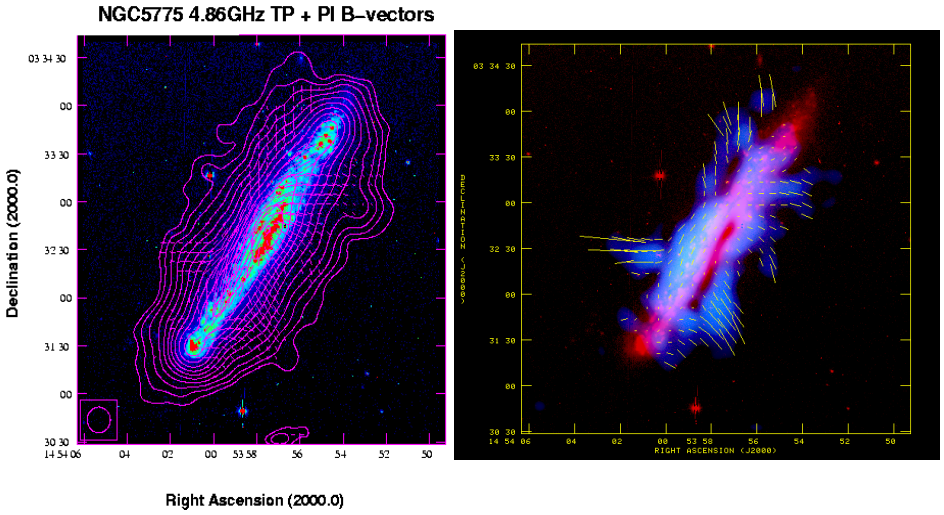
:

Heesen+ MNRAS 476,158 (2018)

RUHR-UNIVERSITÄT BOCHUM

RUB

NGC 5775 comparison at three wavelengths



Soida, Krause, Dettmar, Urbanik A&A 2011

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

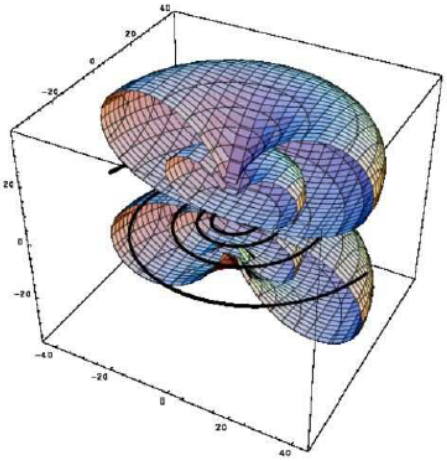
very important step:

solution by quadrupol halo field

The Westerbork SINGS survey II

Global magnetic field topology

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



RUHR-UNIVERSITÄT BOCHUM

RUB

and even more general description:

Analytical models of X-shape magnetic fields in galactic halos

Katia Ferrière[1] and Philippe Terral[1]

[1] IRAP, Université de Toulouse, CNRS, 9 avenue du Colonel Roche, BP 44346, F-31028 Toulouse Cedex 4, France

Received ; accepted

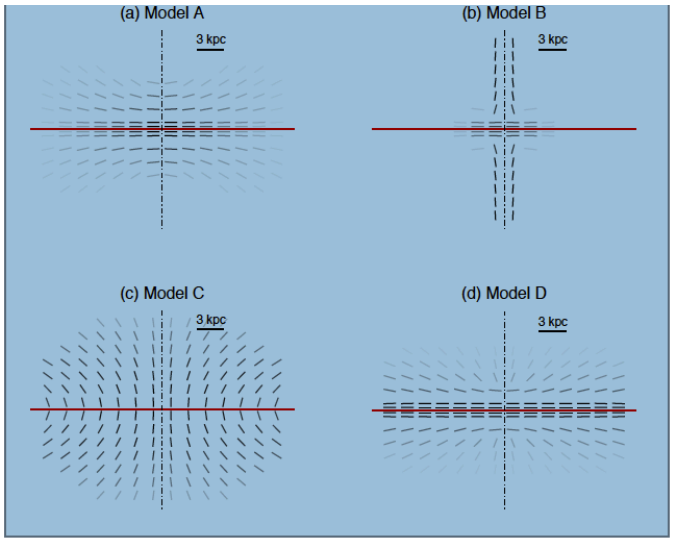
ABSTRACT

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.

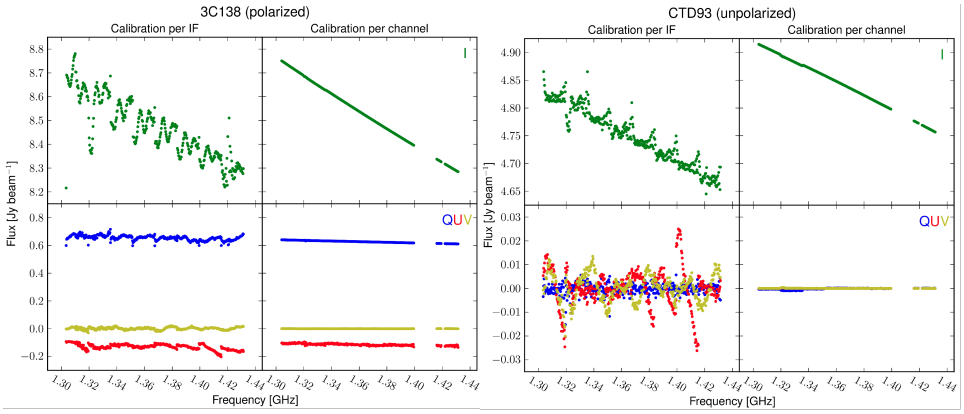
Key words. Galaxies: magnetic fields – galaxies: halos – galaxies: spirals – Galaxy: halo – Galaxy: disk – ISM: magnetic fields

RUHR-UNIVERSITÄT BOCHUM

RUB



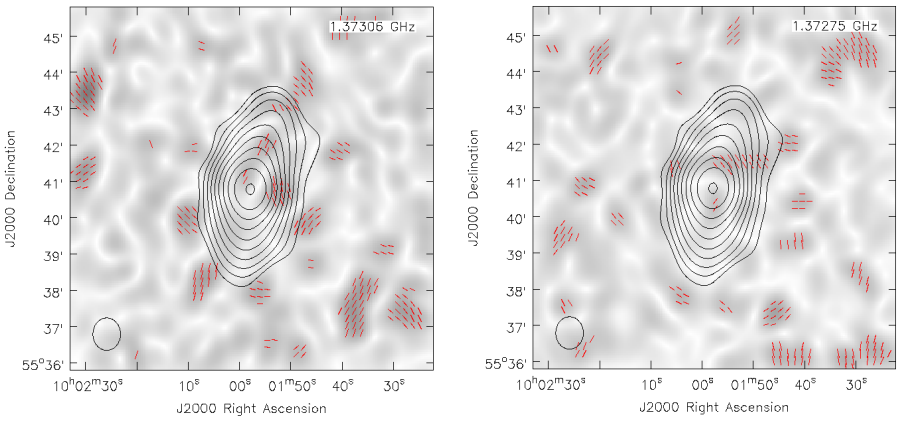
„fresh look“ through the latest generation of multi-channel broad-band receiver systems example: WSRT multichannel receiver



(Björn Adebahr, PhD thesis, Bochum 2013)

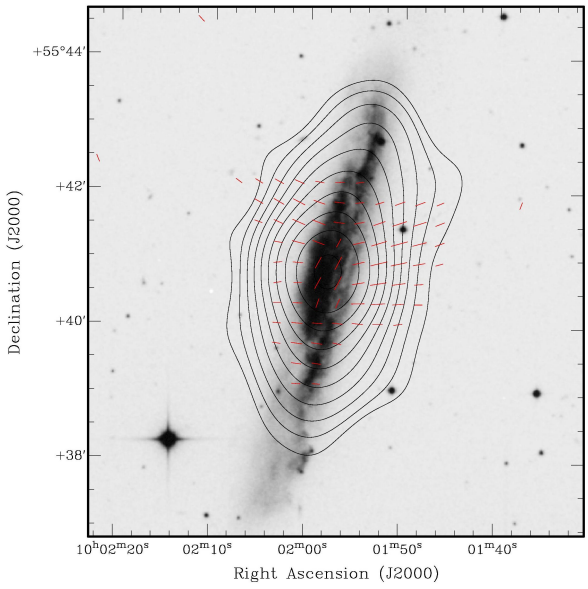
New technique: Rotation Measure Synthesis

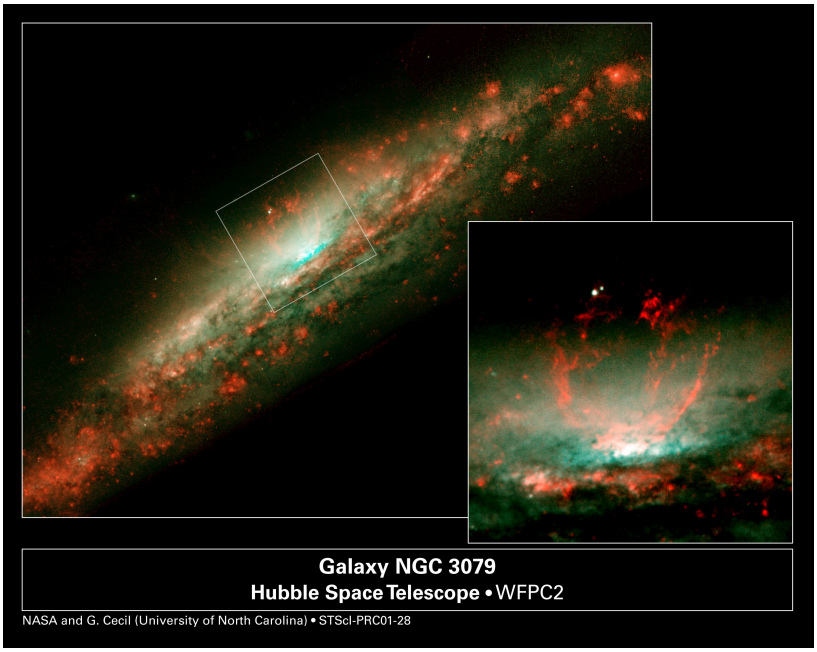
WSRT observations of NGC3079



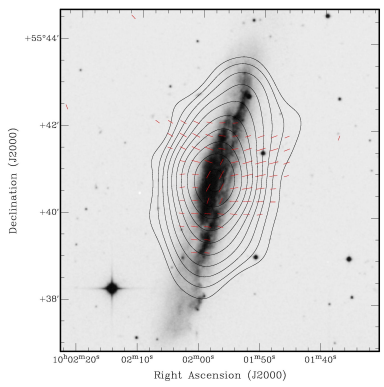
Carlos Sotomayor (PhD Bochum 2014)

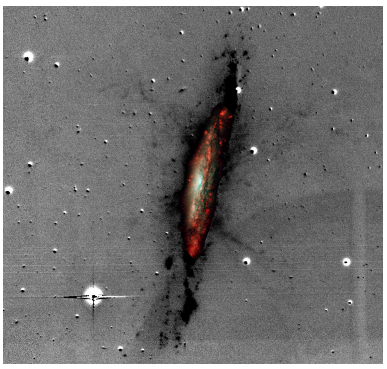
WSRT observations of NGC3079





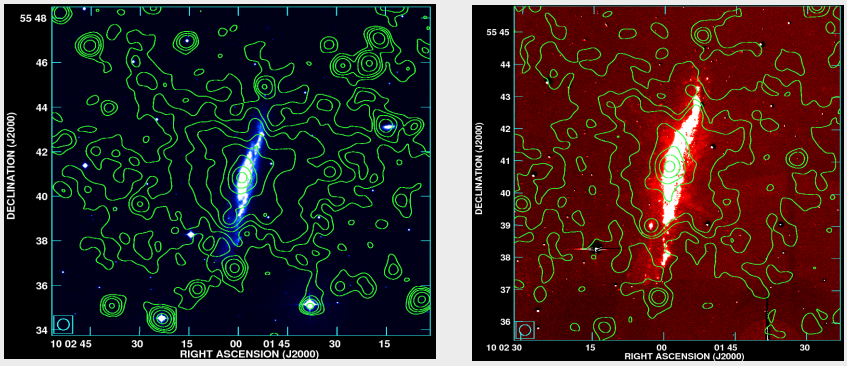
N3079 (WRST)





Carlos Sotomayor (PhD Bochum 2014)

X-ray emission
Starburst galaxy NGC 3079



NGC 3079 soft X-ray image based on XMM-Newton archives.

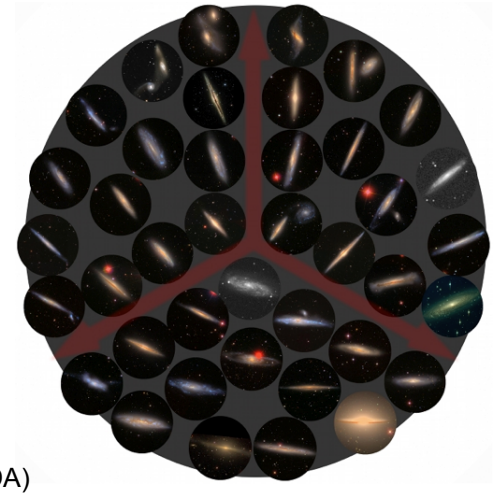
18 ks of clean pn data allows detailed spectral analysis.

Making use of the JVLA

CHANGES:
Continuum HAlos in Nearby Galaxies
- an Evla Survey

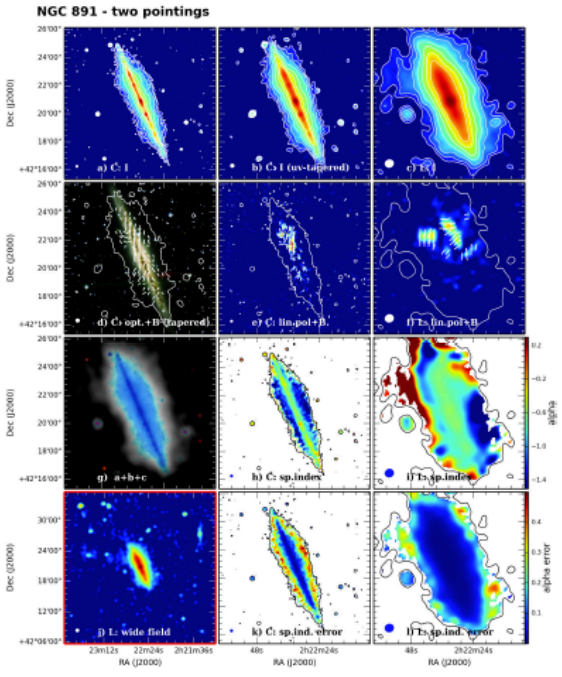
35 edge-on galaxies

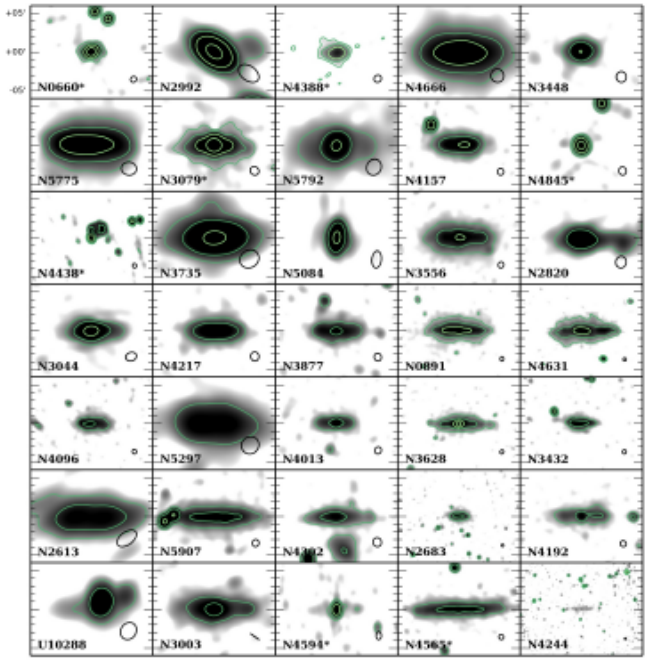
inclination > 75 deg
DEC > 25 deg
4 arcmin > D < 15 arcmin
flux > 23 mJy



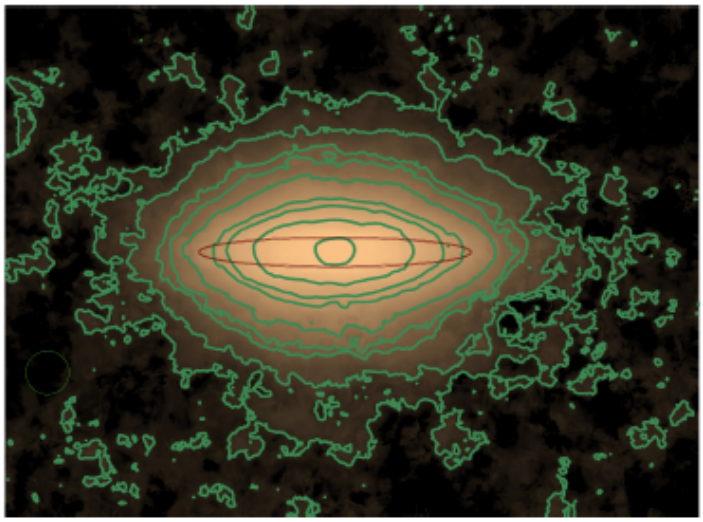
PI: Judith Irwin, Kingston (ONT/CANADA)

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





„averaged“ radio continuum halo



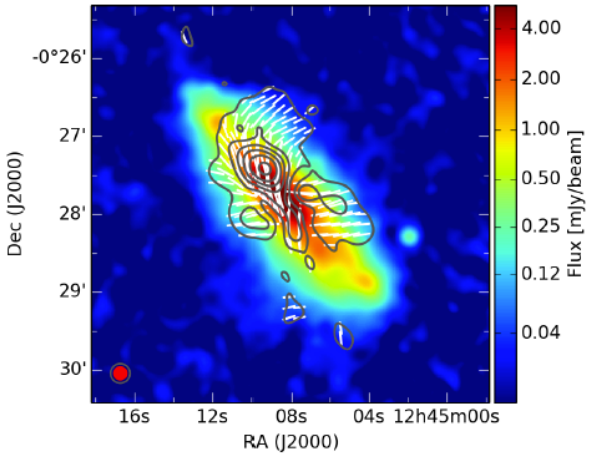


Fig. 3. Total intensity image of NGC 4666 from C-band (robust zero, beam of 10" × 10", σ is 11 μJy/beam) with gray polarisation contours from RM-synthesis at 3, 6, 9, 12, 15, 18 σ level with a σ of 20 μJy/beam. The robust parameter was set to zero, no tapering was used. The corre-

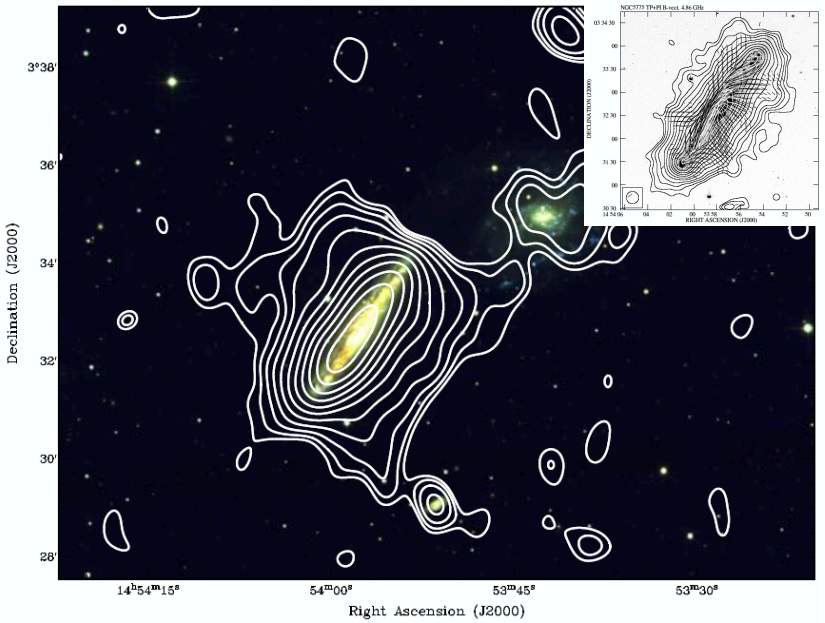
Stein, PhD Bochum 2017

RUHR-UNIVERSITÄT BOCHUM

RUB

LOFAR HBA at Jülich (FZ Jülich- RU Bochum)

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



RUHR-UNIVERSITÄT BOCHUM

RUB

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 are likely to 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

RUHR-UNIVERSITÄT BOCHUM

RUB

NGC 6946

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

polarization asymmetry