Magnetic fields in spiral galaxies

including first results from the CHANG-ES survey of edge-on galaxies

Marita Krause

Max-Planck-Institut für Radioastronomie Bonn

Magnetic fields in galaxies – observations of face-on and edge-on galaxies galaxies

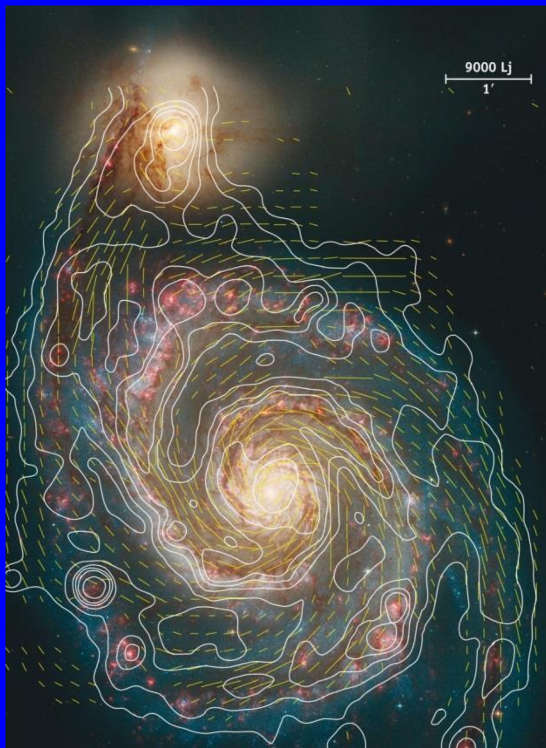
– X-shaped field structure in halos

CHANG–ES Project and first results

– results for **UGC10288**

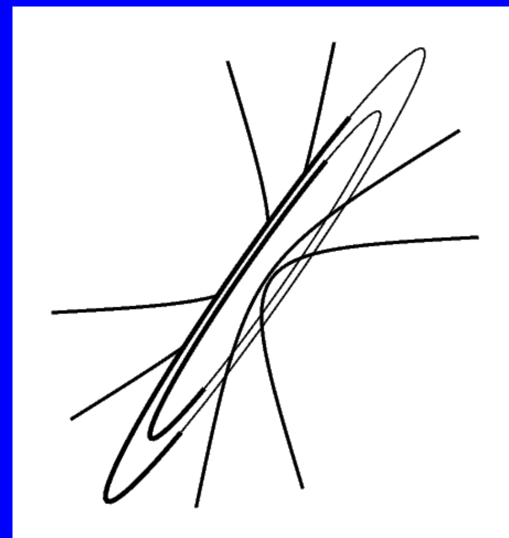
Magnetic fields in spiral galaxies

M51

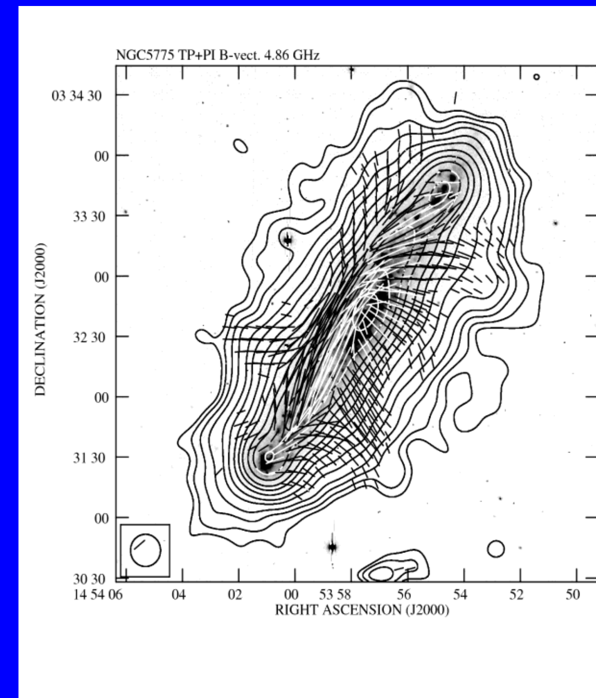


Fletcher et al. 2010

Scetch of toroidal disk field and halo field



NGC5775 i = 86°

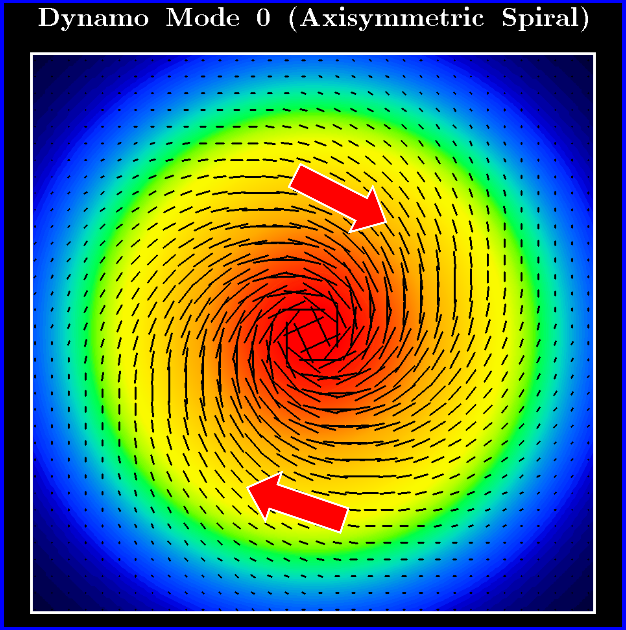


Soida, Krause, Dettmar, Urbanik 2011

Face-on galaxies show a spiral magnetic field along the disk → disk-parallel field in edge-on galaxies

Large-scale field strength in the halo comparable to disk field strength

A dynamo generated large-scale magnetic field in the disk



courtesy to R. Beck

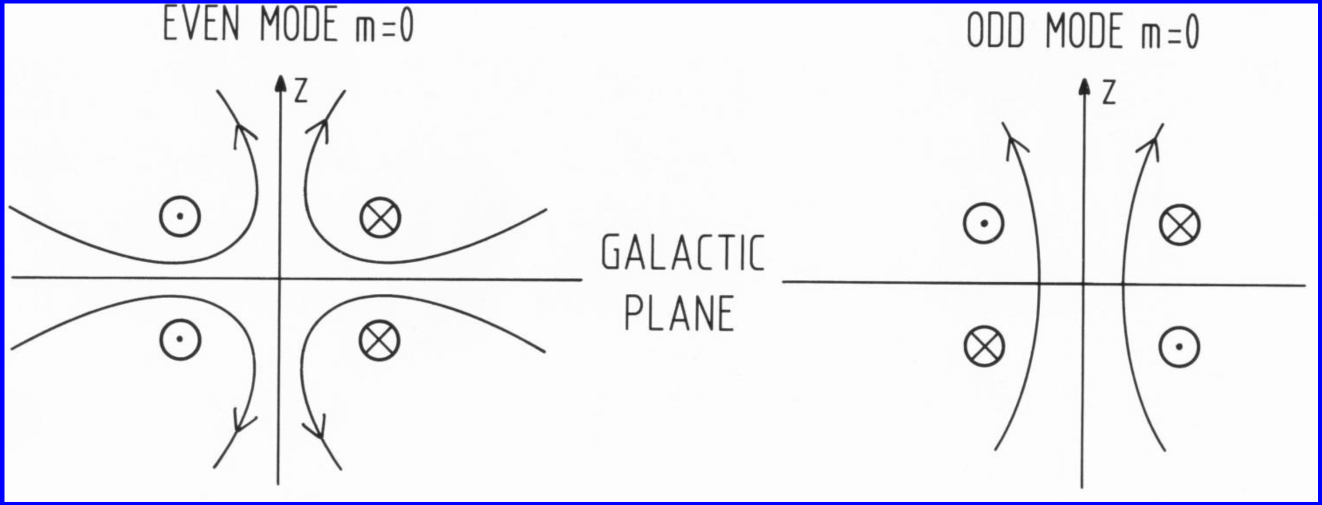
→ASS disk-field

Large-scale RM-pattern indicates an ASS disk-field. Its poloidal component alone cannot explain the observed halo fields.

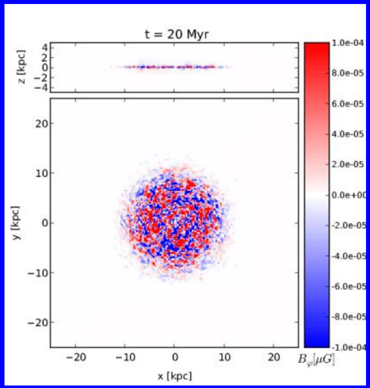
→ **dynamo action in the halo**

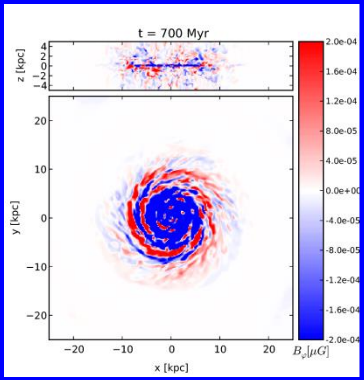
or

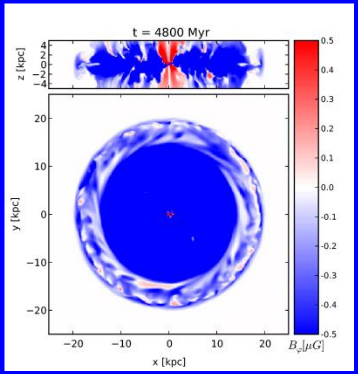
galactic wind needed

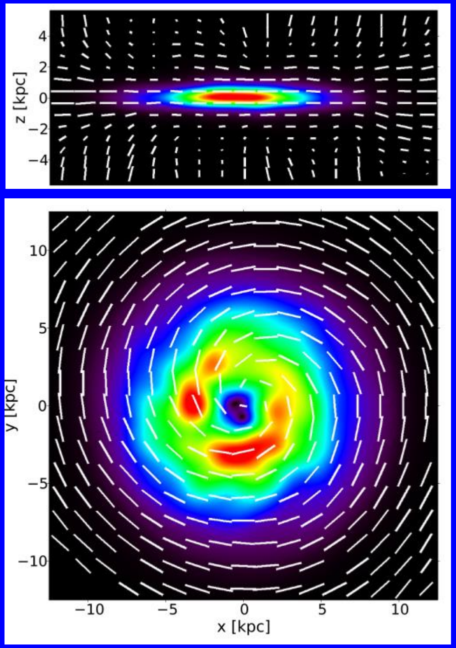


Global galactic-scale MHD simulations **of the** **CR-driven dynamo** (Hanasz et al. 2009):









→ horizontal spiral field &

large lobes of field in vertical direction

→ **X-shaped field structure and vertical fields**

helical magnetic fields?

importance of **galactic wind:**

vertical transport of magnetic flux and helicity

Cosmological simulations

- Quasi-**cosmological simuations** of isolated disk galaxies **with and without magnetic fields** (Pakmor & Springel 2013)

  → Magnetic field **reduces star formation** rate at later times (>1 Gyr), reduces the prominence of individual spiral arms, **causes weak outflows of gas and magnetic fields**

- Similar to results in simulations of Kotarba et al. 2009, A. Beck et al. 2012

- First **hydrodynamical cosmological simulations of a present-day disk galaxy** in which **dynamics of magnetic field** have been included (Pakmor, Marinacci, Springel, 2014):

  → **Strength and shape of magnetic field agrees with observations**

  Small-scale magnetic field first amplified, later (z=2) further amplified and ordered by differential rotation in the disk after it formed.

  Large-scale field can be understood as a result of structure growth alone

…back to observations

11 edge-on galaxies

high SFR or starburst

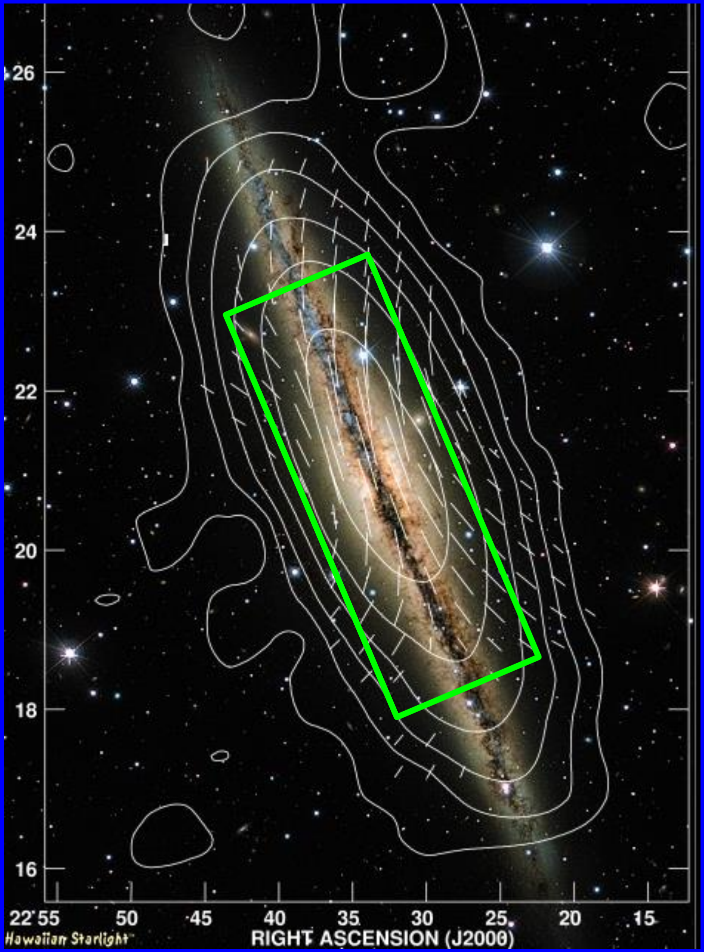
	SFR(IR) [$M_\odot$/yr]	SFE [$L_\odot$/ $M_\odot$]	i	type
M82	1.8	22	79°	(Irr) SBc
N253	6.3	14	78°	Sc
N891	3.3	5.0	88°	Sb
N4631	2.1	9.9	86°	SBcd
N4666	1.9	2.1	80°	Sc
N5775	7.3	6.1	86°	Sbc

low SFR

	SFR(IR) [$M_\odot$/yr]	SFE [$L_\odot$/ $M_\odot$]	i	type
M104	1.2	4.2	84°	Sa
N3628	1.1	4.9	89°	Sb pec
N4217	1.4		86°	Sb
N4565	1.3	3.2	86°	Sb
N5907	1.3	4.0	87°	Sc

NGC891

3.6cm Effelsberg **85″**

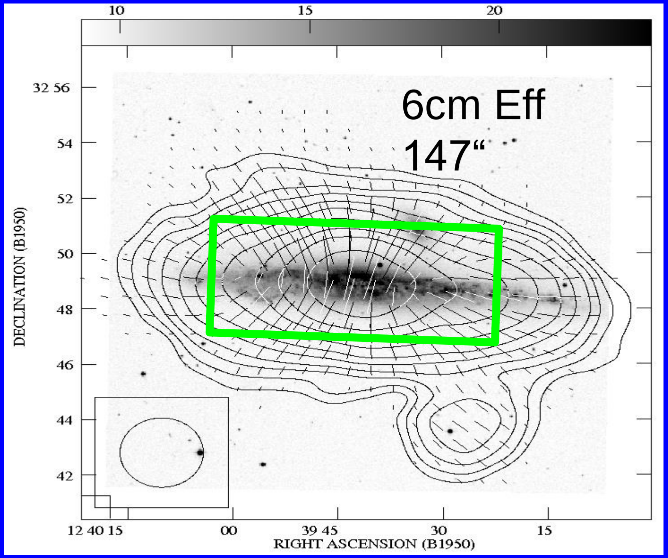


Krause 2009

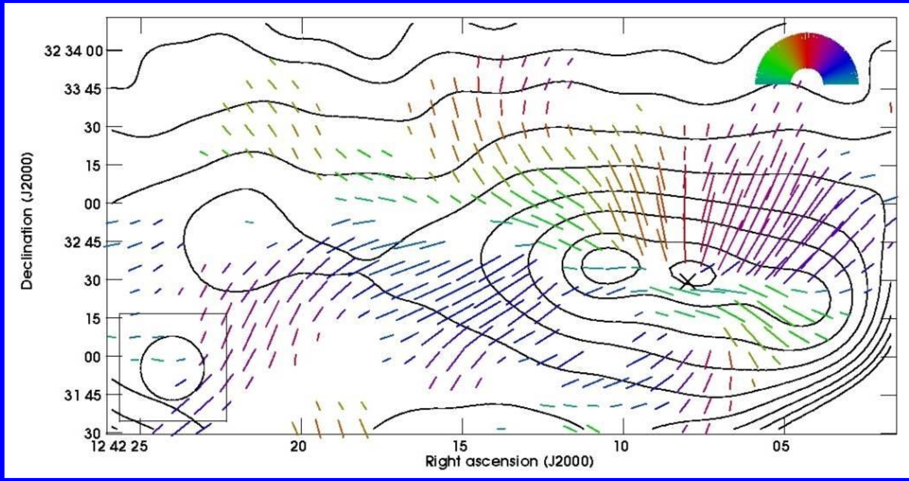
disk-parallel field & X-shaped halo field for both galaxies

NGC4631

6cm Effelsberg **147″**



3.6cm VLA **25″ B-field**

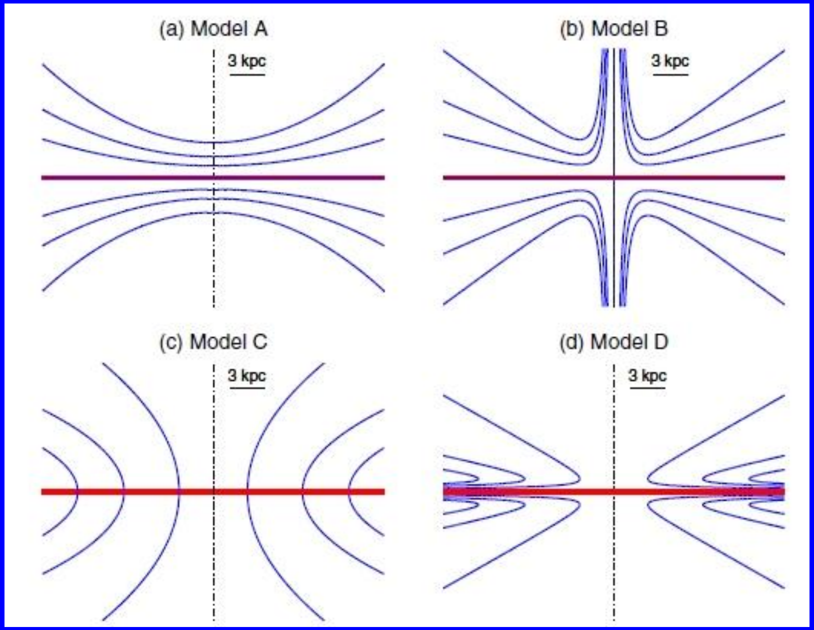


Mora & Krause 2013

Models of X-shaped magnetic fields in galactic halos

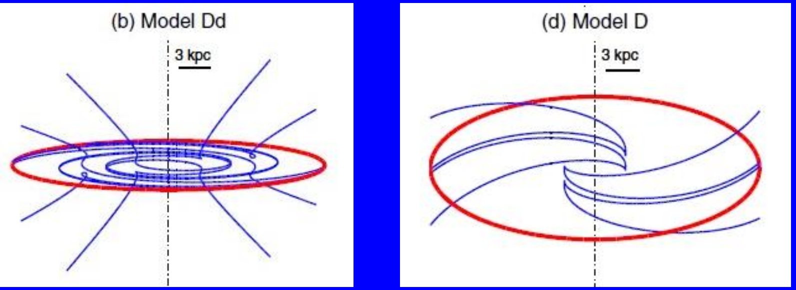
by Ferrière & Terral 2014

X-shaped halo field



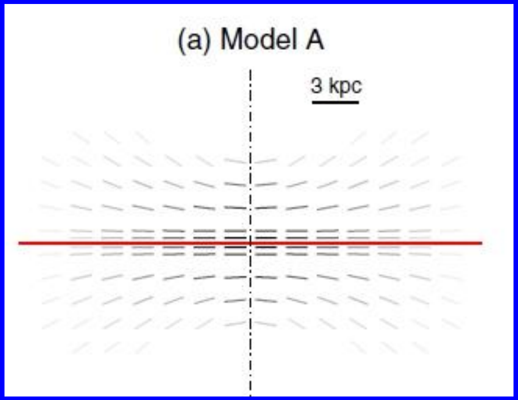
Analytical descriptions of divergence free X-shaped halo fields

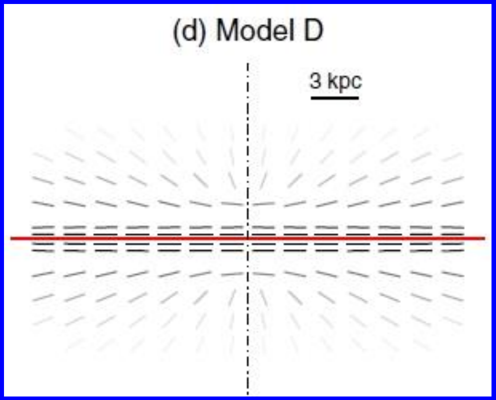
X-shaped halo field with toroidal field



→ **helical field**

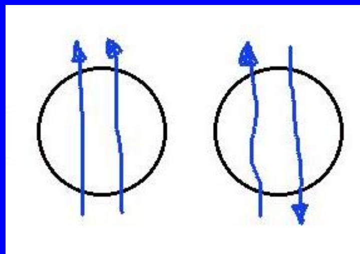
predicted observations of B-vectors from model A and D





Models A and D agree best with our radio observations of spirals

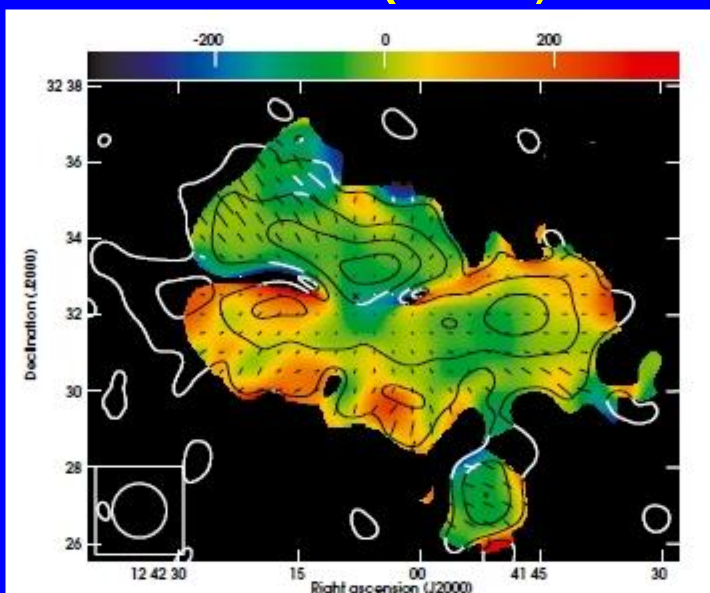
Are halo magnetic fields coherent or anisotropic?



courtesy A.Fletcher

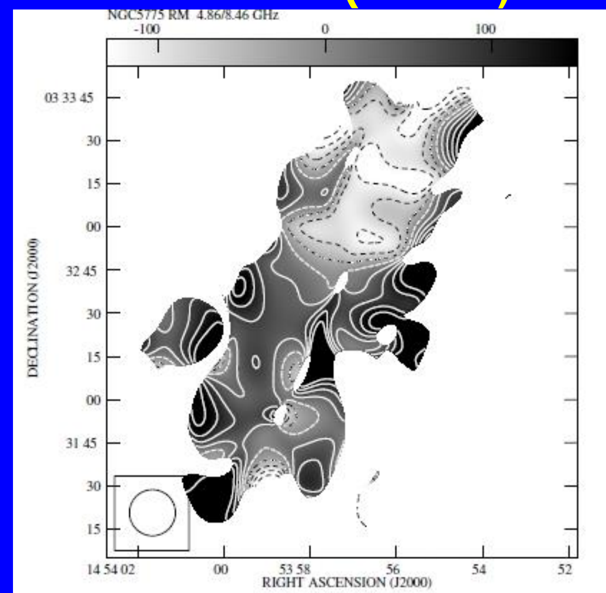
Both give **PI**, only coherent field yield **RM**

NGC4631 RM(6-3cm) 85″



Mora & Krause 2013

NGC5775 RM(6-3cm) 16″



Soida, Krause et al. 2011

No clear large-scale RM-pattern deteted up to now, however: **│RM│ does not generally decrease with z**

→ **indication of coherent field**

→Probably both: **coherent fields** in NGC253 (Heesen, Krause et al. 2009)
significant anisotropc field in M51 (Fletcher et al. 2010)

more observations needed…

Continuum
HAlos in
Nearby
Galaxies – an
EVLA
Survey
→ **CHANG-ES**

35 galaxies

1.5 GHz, 6 GHz
in B,C,D-array

405 hours

Probing CRs and magnetic fields at the interface between galaxies and the IGM

The consortium (31 members at present, 8 PhDs)

Judith Irwin, Queen's University (**PI**), Kingston, Canada
Rainer Beck, Max-Planck-Institut für Radioastronomie, Bonn
Robert Benjamin, University of Wisconsin
Ancor Damas, Max-Planck-Institut für Radioastronomie
Ralf-Jürgen Dettmar, Ruhr-Universität Bochum,
Jayanne English, University of Manitoba, Canada
George Heald, Netherlands Institute for Radio Astronomy
Richard Henriksen, Queen's University, Kingston, Canada
Megan Johnson, CSIRO, Epping, Australia
Amanda Kepley, National Radio Astronomy Observatory
Marita Krause, Max-Planck-Institut für Radioastronomie
Jiang-Tao Li, University of Massachusetts
Zhiyuan Li, Nanjing University (NJU), China
Arpad Miskolczy, Ruhr-Universität Bochum
Silvia Carolina Mora, Max-Planck-Institut für Radioastronomie, Bonn
Eric Murphy, Spitzer Science Center, Calteh, Pasadena
Tom Oosterloo, Netherlands Institute for Radio Astronomy
Elena Orlando, Stanford University
Troy Porter, Stanford University, Palo Alto
Richard Rand, University of New Mexico
D. J. Saikia, National Centre for Radio Astrophysics, Pune, India
Philip Schmidt, Max-Planck-Institut für Radioastronomie, Bonn
Carlos Sotomayor, Ruhr-Universität Bochum
Yelena Stein, Ruhr-Universität Bochum
Andrew Strong, Max-Planck-Institut für extraterrestrische Physik, Garchng
Carlos Vargas, New Mexico State University, Las Cruces PhD
Rene Walterbos, New Mexico State University, Las Cruces
Daniel Wang, University of Massachusetts, Amherst
Marek Wezgowiec, Ruhr-Universität Bochum
Theresa Wiegert, Queen's University, Kingston, Canada
Yang Yang, Nanjing University (NJU), China

Galaxy list & criteria

from Nearby Galaxies Catalog:

- inclination > 75 °
- 4 ≤ d_blue isophotal ≤ 15 arcmin
- δ > -25 °
- 1.4 GHz fluxes > 20 mJy
- plus N4244, N4565, N5775

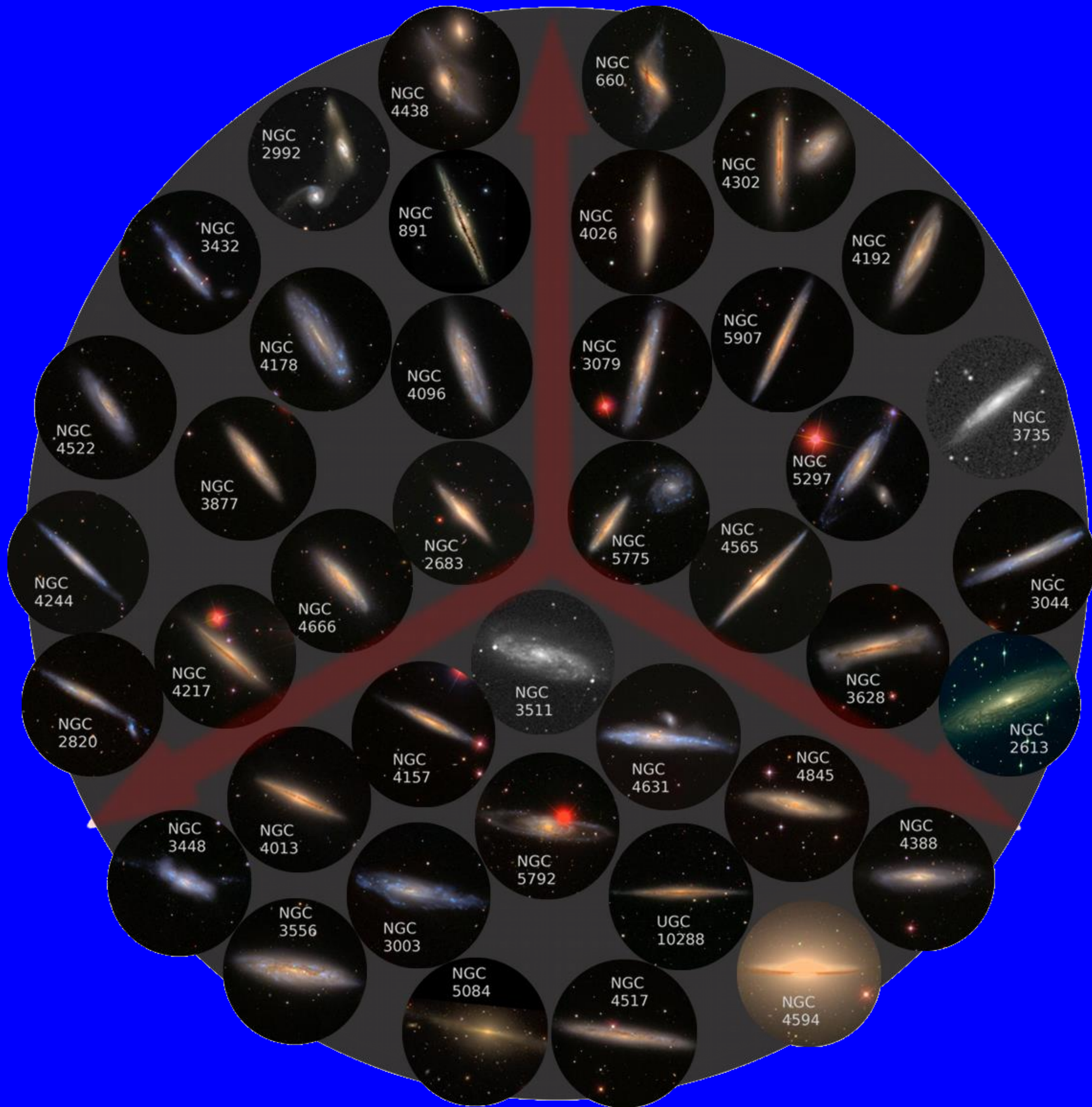
→ **35 galaxies in total**,
mixture of AGN, LINERs,
SFR, interacting






N660
N891
N2613
N2683
N2820
N2992
N3003
N3044
N3079
N3432
N3448
N3511
N3556
N3628
N3735
N3877
N4013
N4026
N4096
N4157
N4178
N4192
N4217
N4244
N4302
N4388
N4438
N4517
N4522
N4565
N4631
N4666
N4845
N4594
N5084
N5297
N5775
N5792
N5907
U10288

Sky orientation is correct



Logo Created by Jayanne English

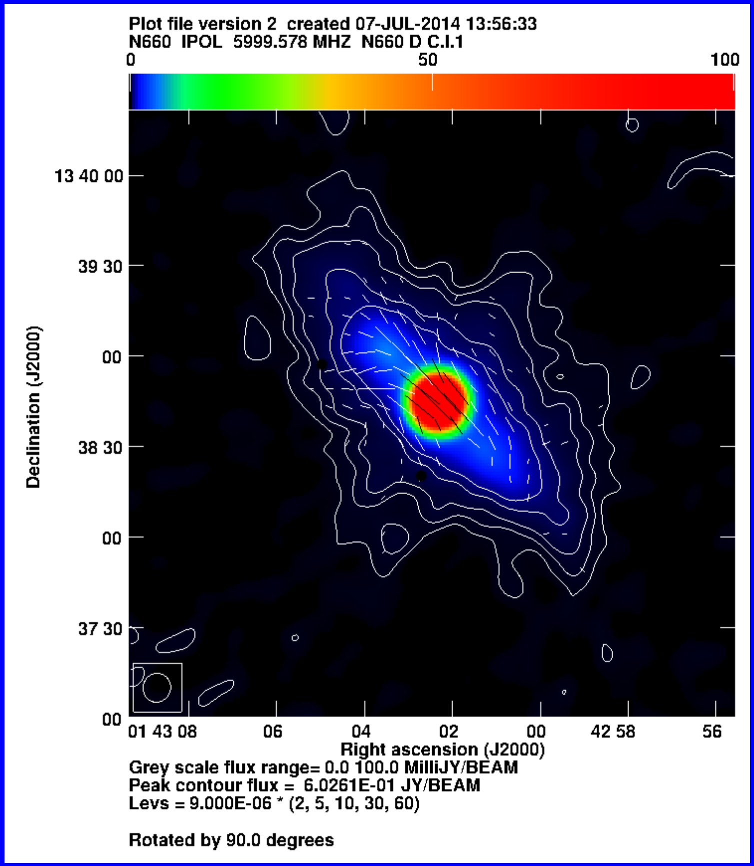
Galaxy selection out of the CHANG-ES sample

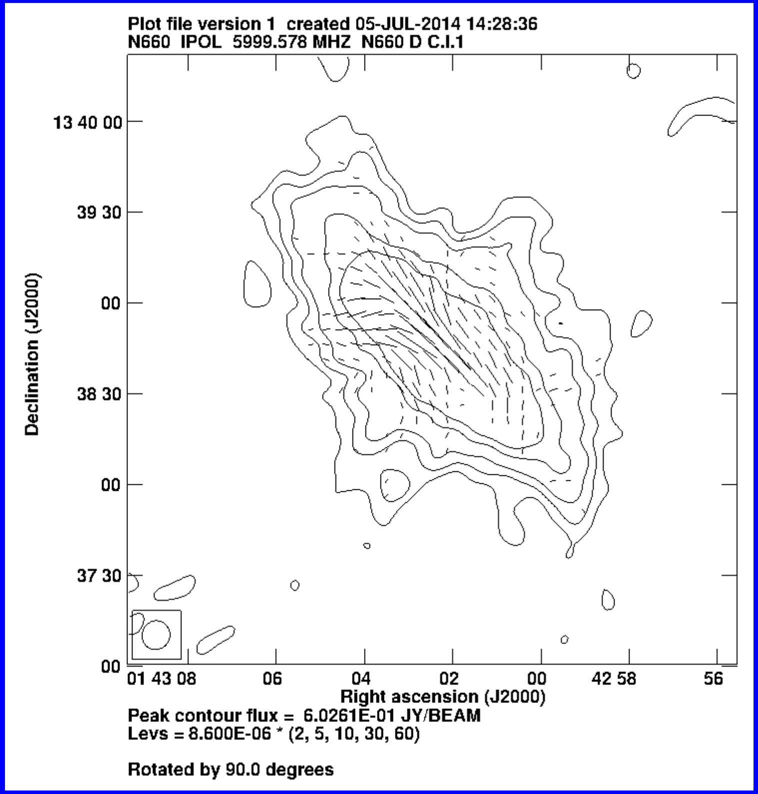
- 35 galaxies in total
- 15 galaxies are part of PhD thesis
- Excluding the ‚well-known' galaxies NGC3628, NGC4217, NGC5775
- **UGC 10288** considered separately (CHANG-ES Paper III)
- From the remaining 16 galaxies I looked at **5 galaxies with extended PI**

				$[M_\odot/yr]$		
NGC 660	SBa	i=77°	12 Mpc	SFR=2.7	d_{25}=7.'2	polar ring, LINER
NGC 2683	Sb	i=79°	6.3Mpc	SFR=0.09	d_{25}=9.'1	LINER, Sy2
NGC 3044	SBc	i=90°	20 Mpc	SFR=0.95	d_{25}=4.'4	
NGC 3556	SBc	i=81°	14 Mpc	SFR=2.2	d_{25}=7.'8	
NGC 4157	SABb	i=90°	16 Mpc	SFR=1.3	d_{25}=7.'0	

NGC 660 SBa i=77° 12.3Mpc SFR=5.7 $M_\odot$/yr d_{25}=7.'2

polar ring galaxy, LINER





Merger?

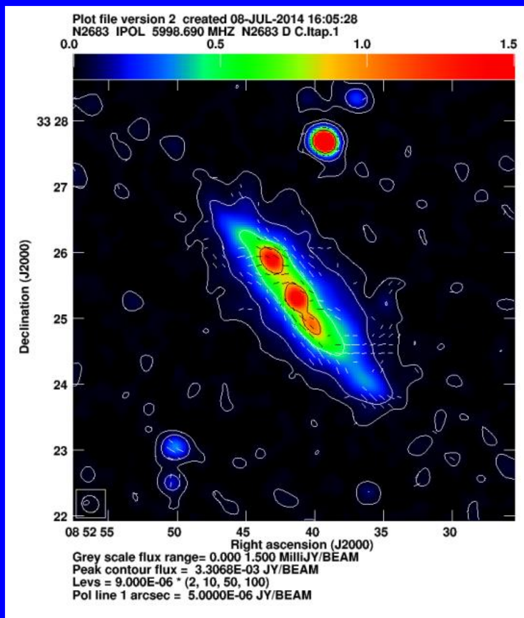
Disk-field:
plane-parallel

Halo-field:
X-shaped

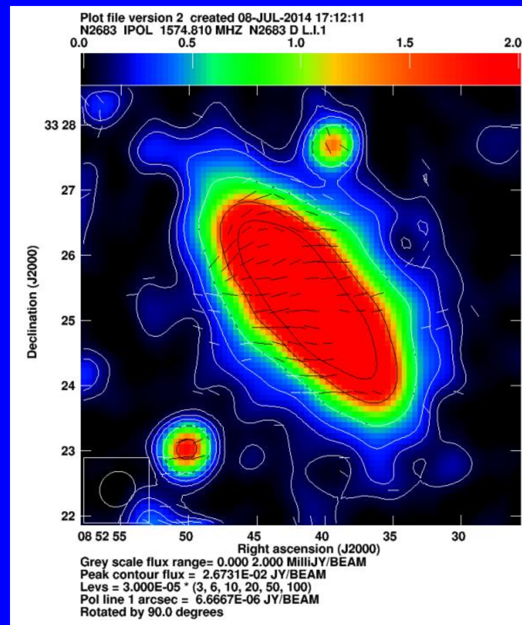
C-band, D-array, no taper
9.5“ x 9.1“ HPBW

D-array, L-band: strongly depolarized within the disk with 40“ x 39“ HPBW

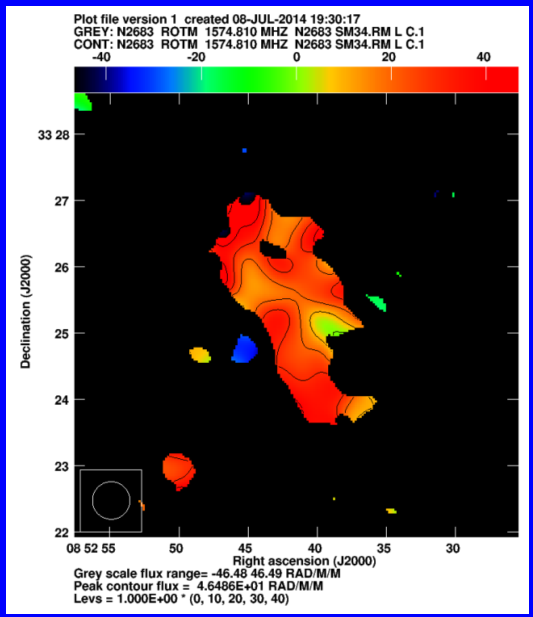
NGC 2683 Sb i=79° 6.3Mpc SFR=0.36 $M_{\odot}$/yr d_{25}=9.'1 Sy2



C-band, D-array, taper
16“ x 15“ HPBW



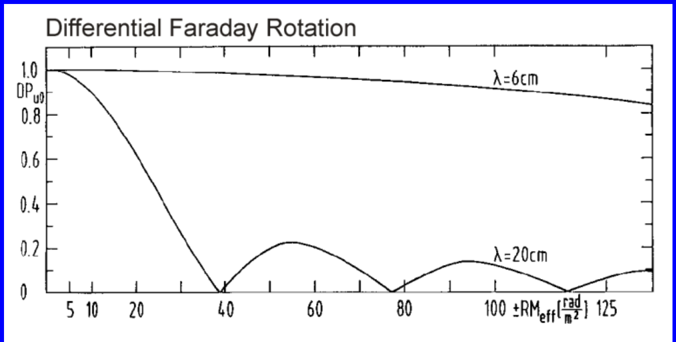
L-band, D-array, no taper
34“ x 31“ HPBW



RM C-D-band
34“ x 31“ HPBW

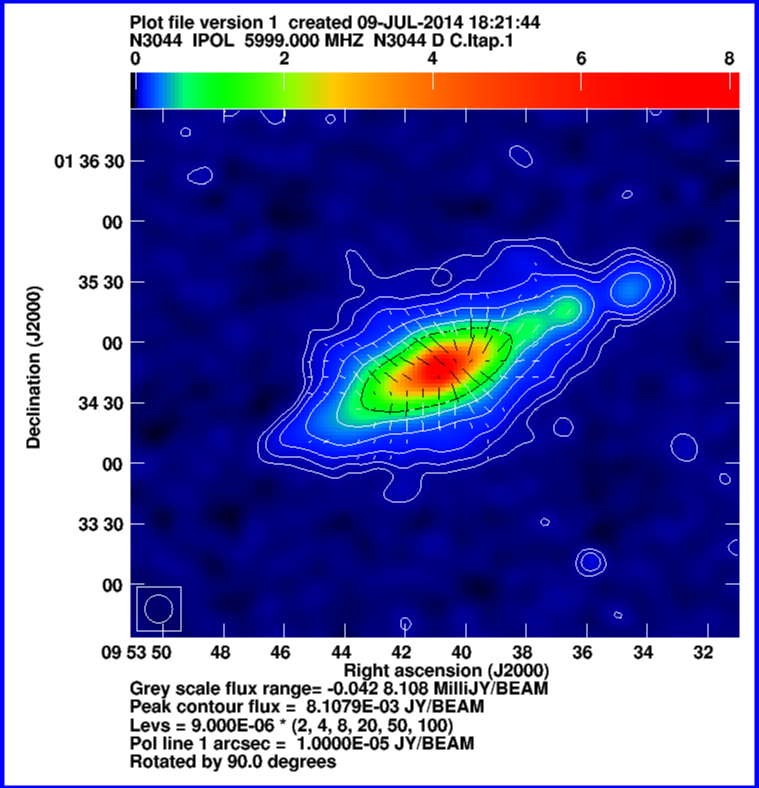
3% < P < 20%
Indication of
spiral arms?

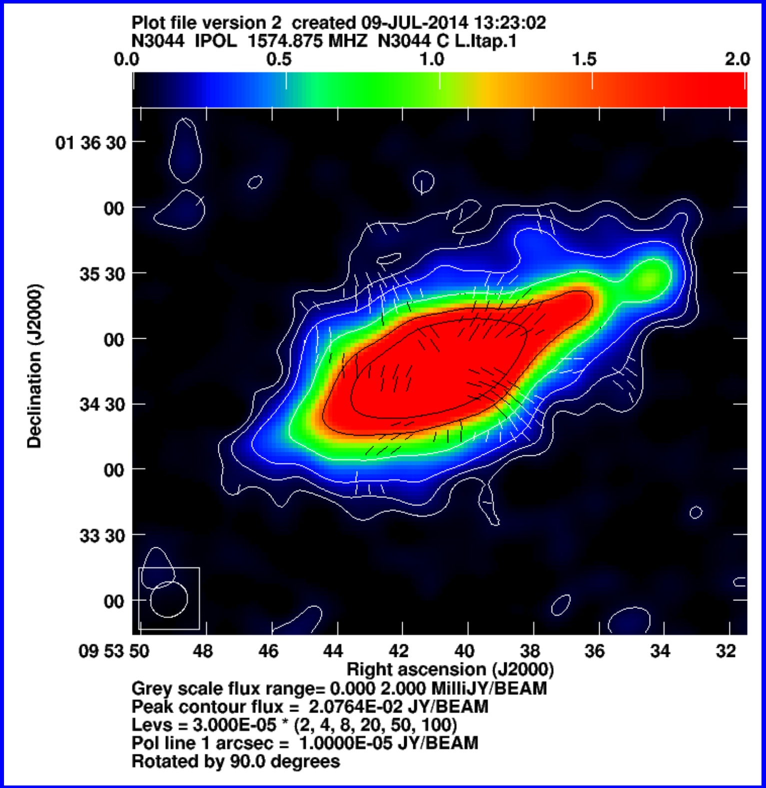
Asymmetric
depolarization
along disk



In **L-band not Faraday thin** → only layer in front side

NGC 3044 SBc i=90° 20 Mpc SFR=2.6 $M_\odot$/yr d_{25}=4.'4





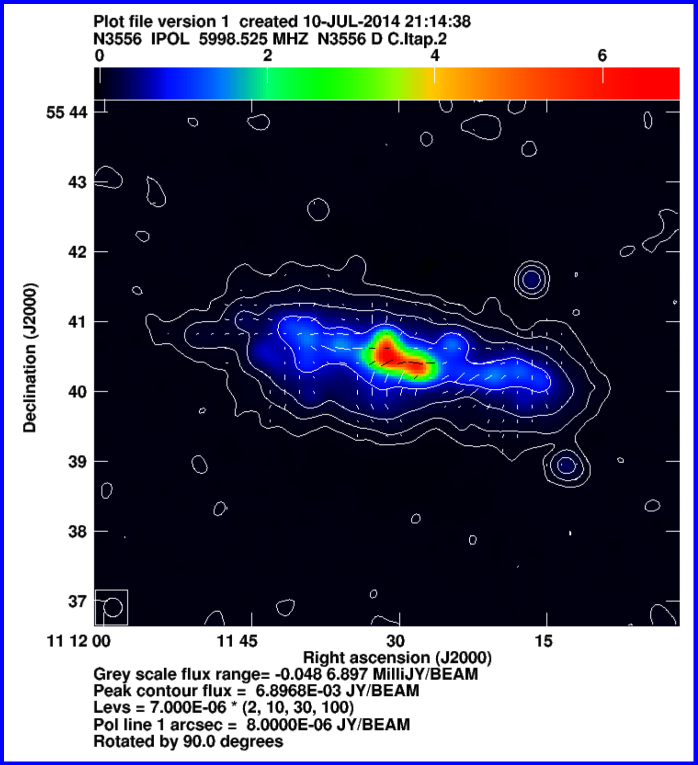
C-band, D-array, taper 13.8“ x 13.6“ HPBW

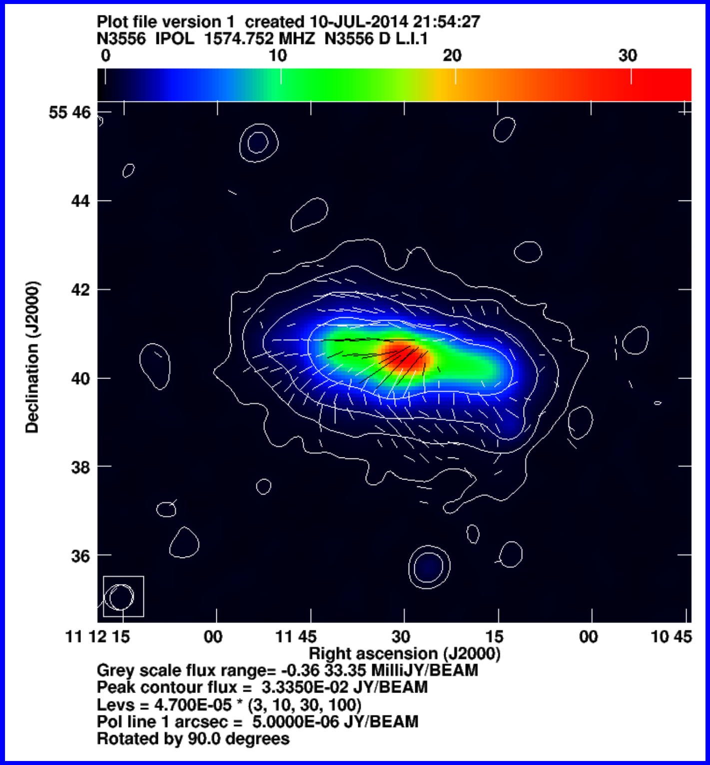
Comparable resolution!

L-band, C-array, taper 17.3“ x 16.0“ HPBW

Strong depolarization along the disk plane also in C-band, similar to NGC4631(?):
- TP asymmetric along radius
- strong vertical fields
- SFR is lower, however also extended over inner disk

NGC 3556 SBc i=81° 14 Mpc SFR=4.9 $M_{\odot}$/yr d_{25}=7.'8



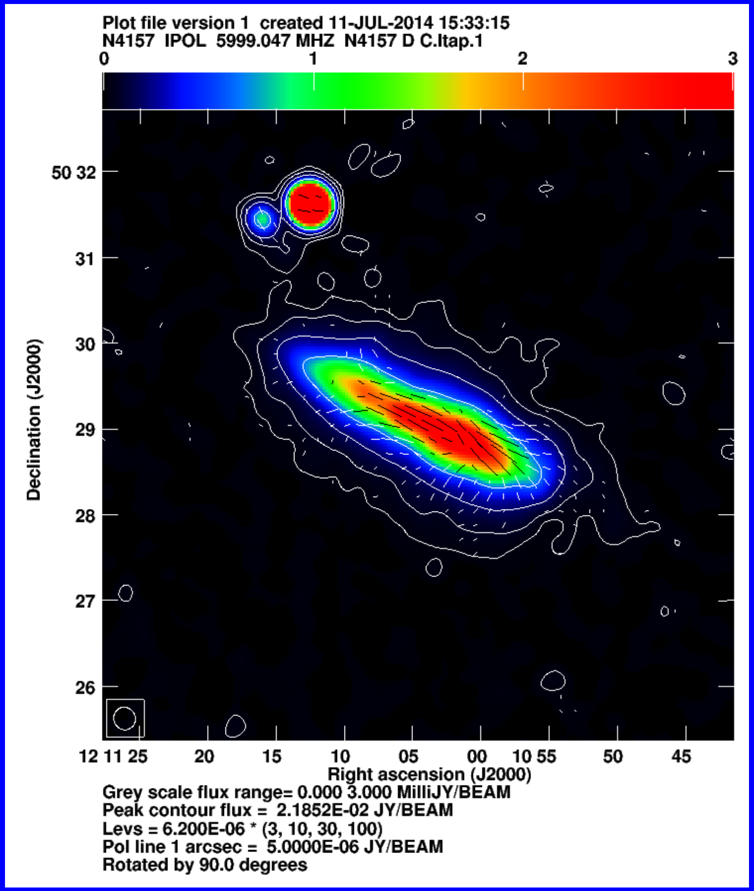


C-band, D-array, taper
16“ x 15“ HPBW
σ(PI) = 5.6 μJy/beam

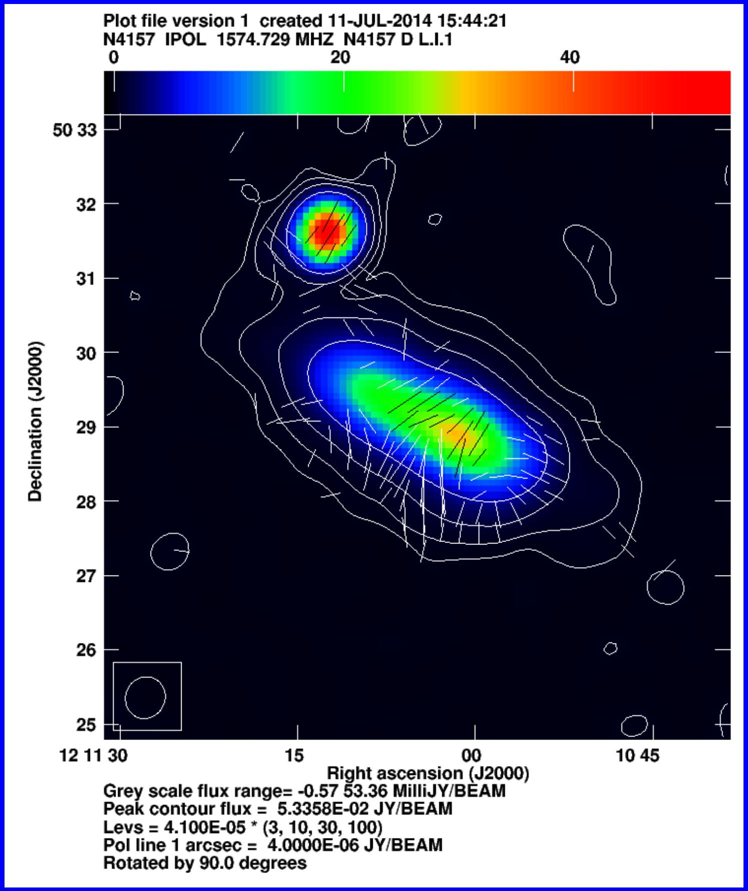
L-band, D-array, no taper
34“ x 31“ HPBW

Asymmetric depolarization along disk

NGC 4157   SABb   i=90°   16 Mpc   SFR=3.8 $M_\odot$/yr d_{25}=7.'0



C-band, D-array, taper
16“ x 15“ HPBW



L-band, D-array, no taper
34“ x 31“ HPBW

Asymmetric depolarization along disk

Conclusions from this part

First look to CHANG-ES galaxies confirm the present picture of B in galaxies:

- **Parallel disk field, X-shaped halo** field for edge-on galaxies
- **Asymmetric depolarization** in one half of the galaxy (also observed in face-ons (Braun, Heald, Beck 2010))
- Sample of all galaxies already now significantly extended (**11→16**)
- Sample will further increase, especially weighting with **rob=2** will increase the detection of galaxies with extended polarized emission
- **RM synthesis** allows determination of **B-vectors** within C-band alone

UGC 10288

Sc   i=90°   34.1Mpc   SFR=0.4-0.5$M_\odot$/yr d_{25}=4.'9
1" ↔ 165pc

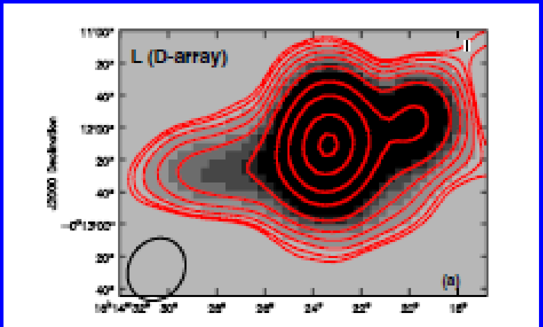
CHANG-ES III UGC 10288 – an edge-on galaxy with a background double-lobed radio source
or
Two Galaxies for the Price of one

Judit Irwin, Marita Krause, Jayanne English, Rainer Beck, Eric Murphy, Theresa Wiegert, George Heald, Rene Walterbos, Richard Rand, Troy Porter

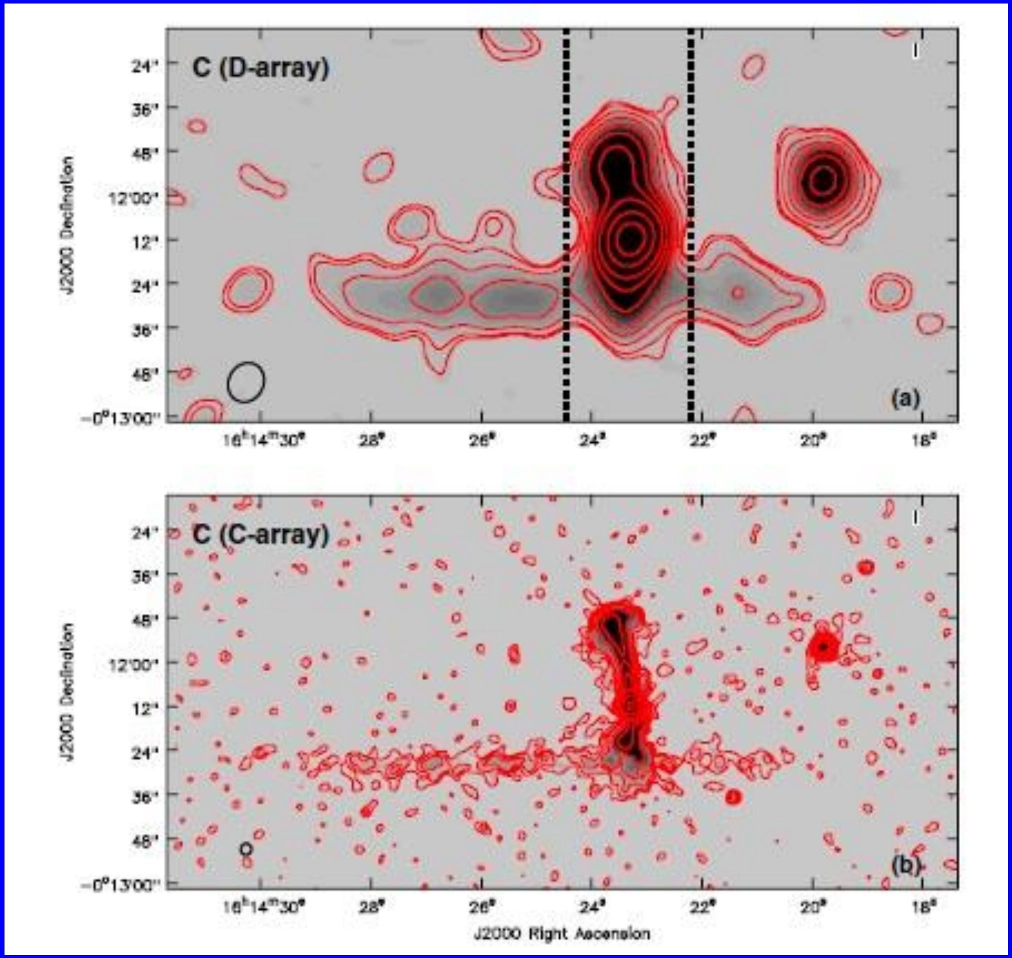
- AJ 146, 164 2013, December
- Press release December 3rd, 2013

UGC 10288 Total intensity

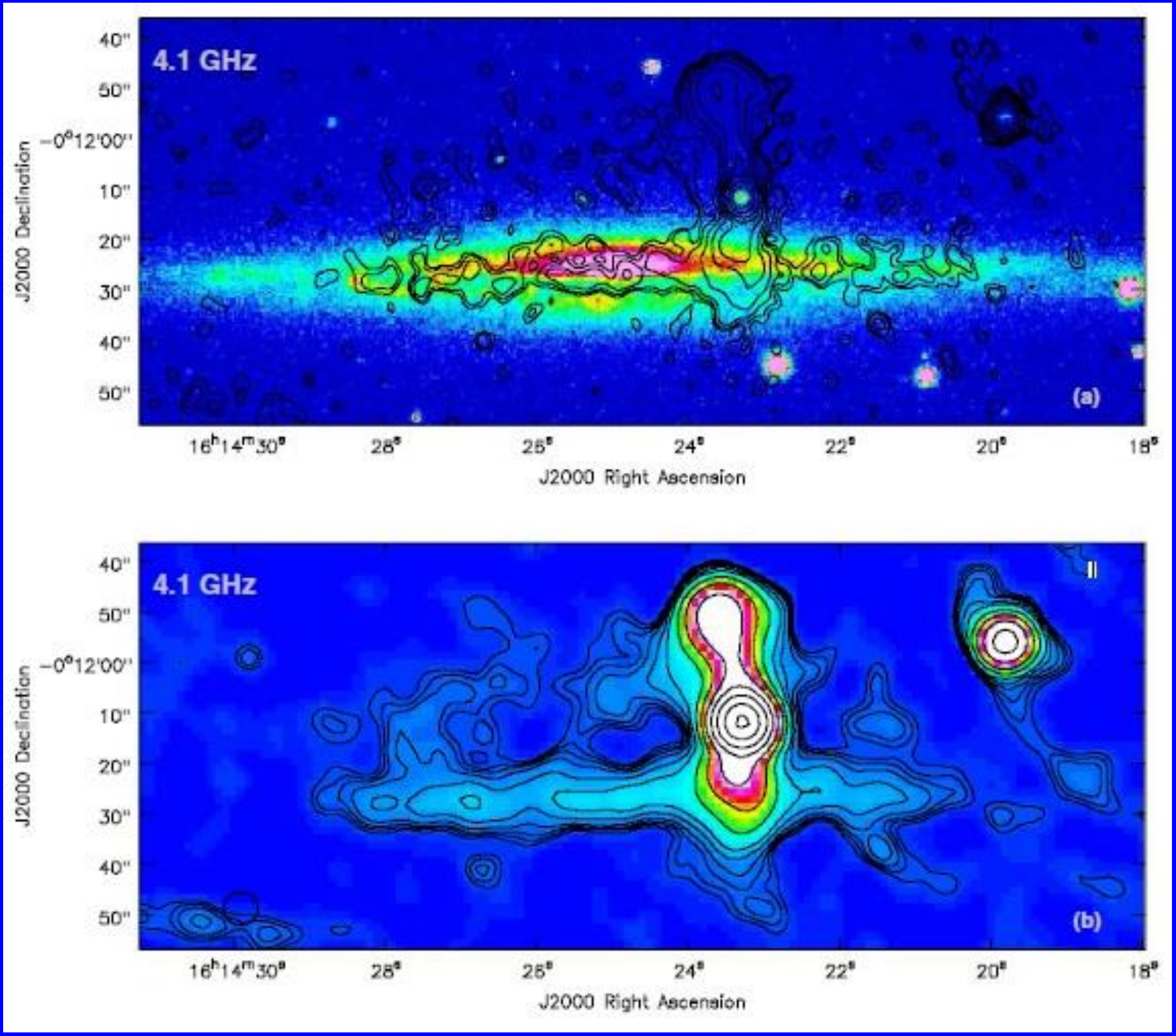
L-band (20cm)



C-band (5cm)



Total intensity combined (all arrays, both bands)



3.″5 HPBW

over SDSS r-band color image

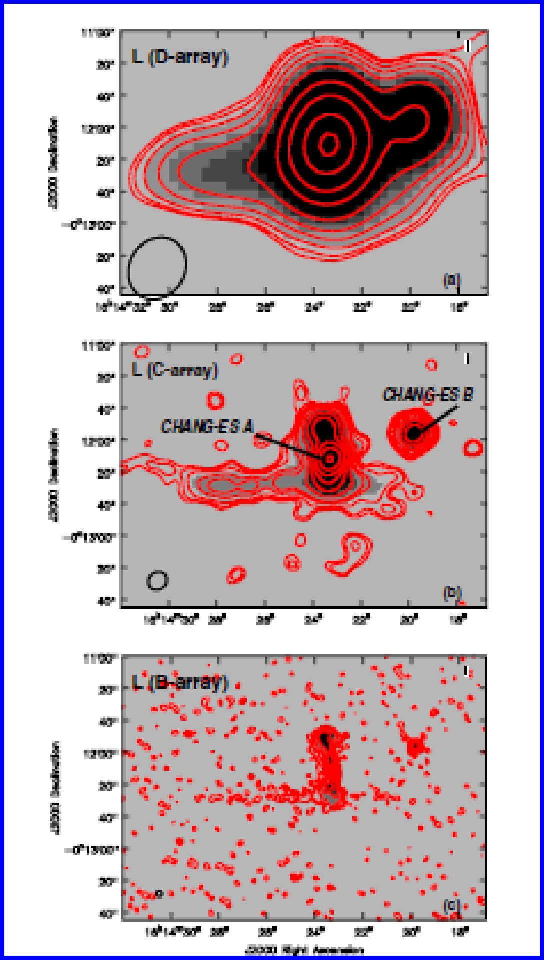
double-lobed EGR
optical point source at center, listed as galaxy with z = 0.388 ± 0.026

→ Changes A

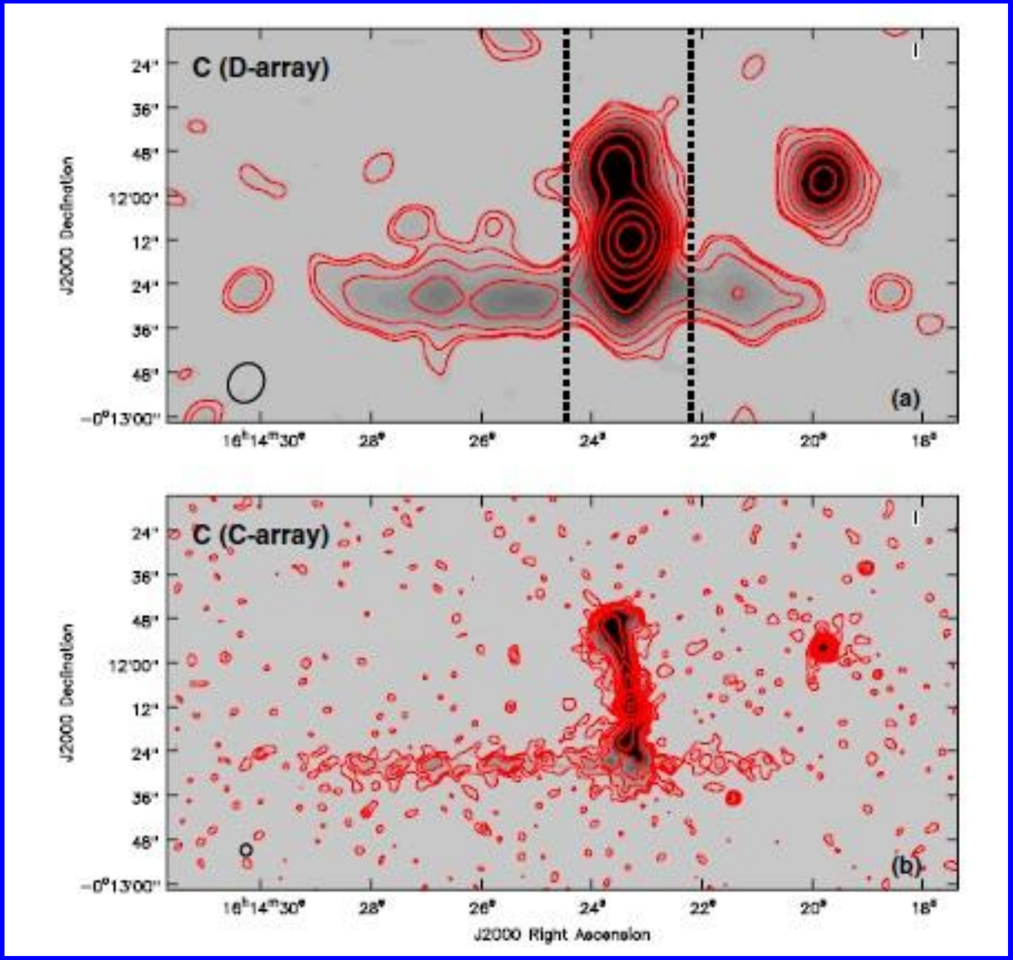
6.″5 HPBW

UGC 10288 (and Changes A, B)
Total intensity

L-band (20cm)



C-band (5cm)



Cyan: C-band C-array total intensity
Darker cyan: combined all-array, all frequency total intensity
Orange: WISE 12 μm
Yellow: Spitzer 3.6 μm
Rose: Hα
Blue: SDSS r-band
Purple: SDSS g-band
Spatial resolutions vary and have been chosen for visual effects

Vertical scales heights

determined from maps with 7" HPBW

Table 7
Disk Exponential Scale Heights

Strip #	BCD+CL (4.1 GHz)	Hα	*WISE* λ12 μm
1 (North)	7.9 (1.3)	2.3 (0.38)	6.4 (1.1)
(South)	5.1 (0.85)	5.1 (0.84)	7.7 (1.3)
2 (North)	5.2 (0.86)	3.2 (0.54)	6.8 (1.1)
(South)	2.8 (0.46)	4.0 (0.66)	6.8 (1.1)
4 (North)	8.6 (1.4)	2.9 (0.47)	7.5 (1.2)
(South)	6.7 (1.1)[a]	4.0 (0.66)	7.1 (1.2)

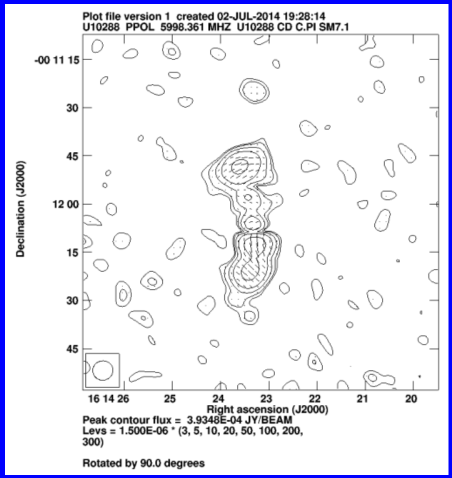
values in arcsec, with kpc in parantheses

Small radio scale heights ≈ 1kpc (usually 1.8 ± 0.2 kpc)
→ **UGC10288 has no global radio continuum halo**

Low SFR (0.4 – 0.5 M⊙/yr) **with high thermal fraction** (44% at 6GHz)

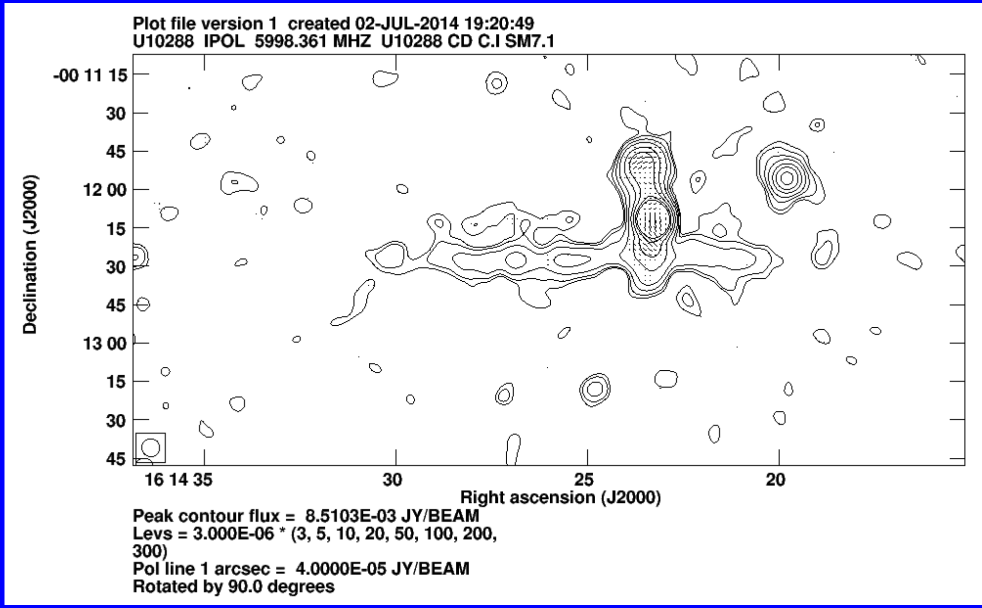
Magnetic field in UGC10288

PI(C-band) CD



for UGC 10288: **B ≈ 10 μG** (minimum energy assumption)

Total intensity C-band CD and E+90 vectors

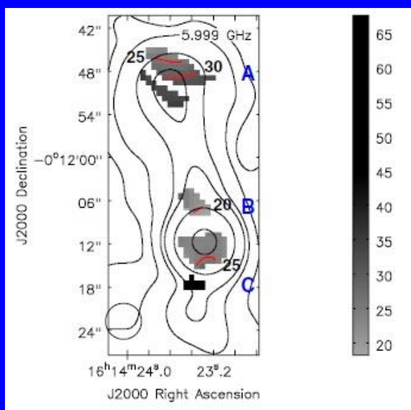


Changes A can be used as background candle for the magnetic field in the halo (and disk) of UGC10288.

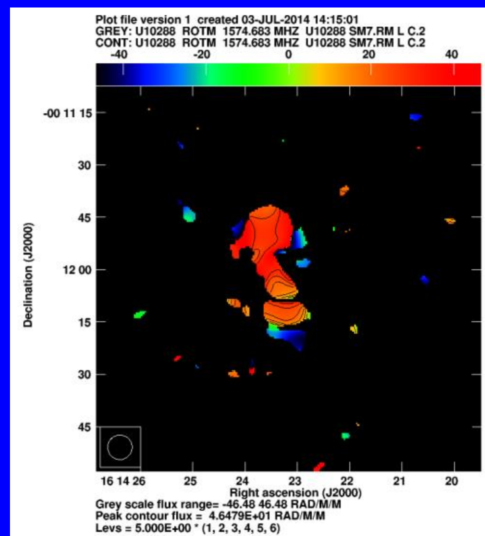
$RM_{fg} = 10 \pm 10\ rad/m^2$

Comparison of different RM determinations

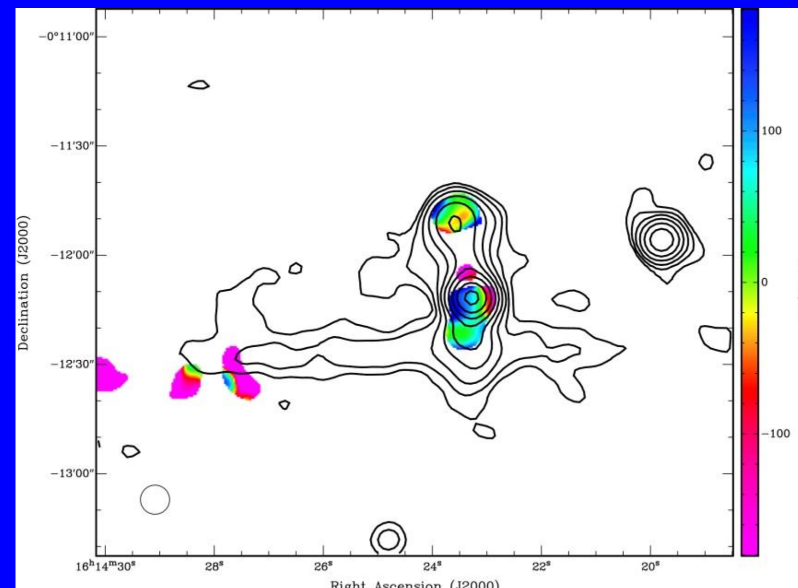
CHANG-ES paper
(1 array each)



RM (C- and L-band)
(2 arrays combined)



RMsynthesis of C-band rob=2



RM_{fg} = 10 ± 10 rad/m^2

→ **No information** about **B_{reg} in UGC10288** from RM in CHANGES A up to now

Conclusions (related to UGC10288)

- Discovery of a background double-lobed EGRS → **CHANG-ES A**
- **UGC10288** would not have been in the CHANG-ES survey without beeing blended with CHANG-ES A (factor of 5 below the survey flux limit)
- **Low SFR** (0.4 – 0.5 M⊙/yr) with **high thermal fraction**
- Small radio scale heights ≈ 1kpc (usually 1.8 ± 0.2 kpc)
- →**UGC10288 has no global radio continuum halo**
- **Background radio galaxy** can be used to **study the halo** of the faint spiral galaxy UGC10288 – as soon as we can determine RM along southern jet

THE ASTRONOMICAL JOURNAL

2013 December – No. 1896

Published for the
American Astronomical Society
by
IOP Publishing