

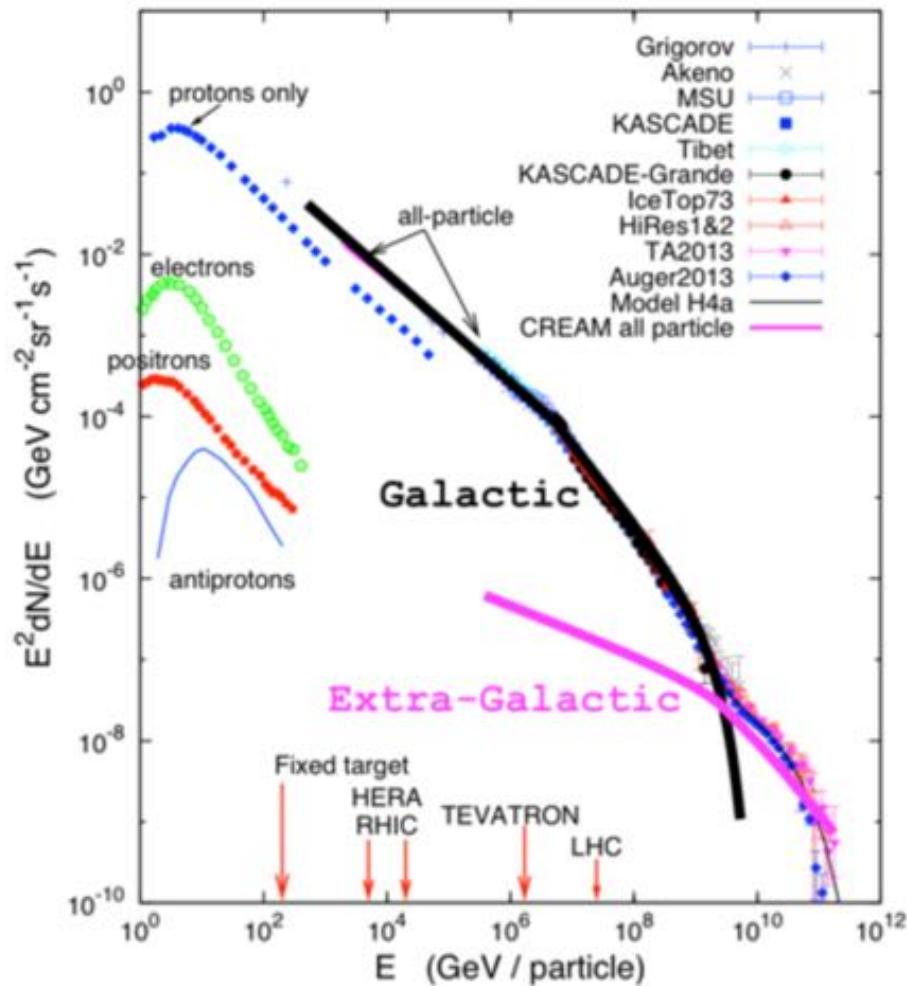


New constraints on galactic CRE transport from radio continuum observations

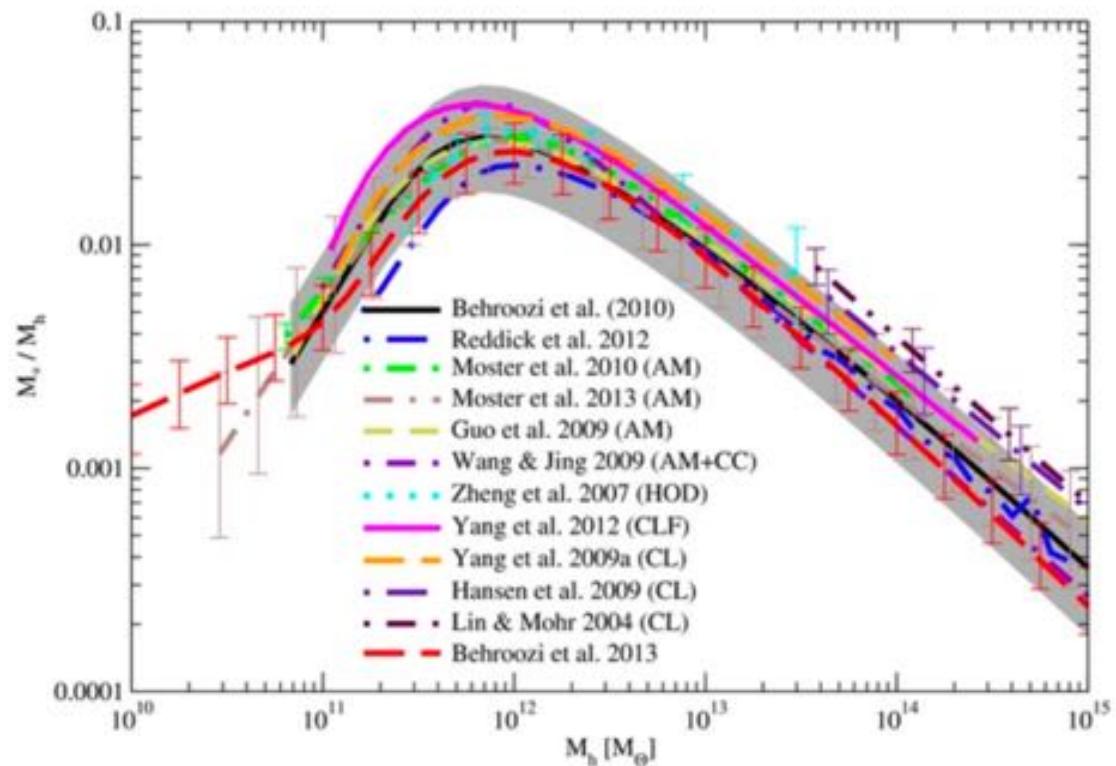
Ralf-Jürgen Dettmar, Ruhr-University Bochum

with V. Heesen, A. Miskolczi, Y. Stein, & the CHANG-ES team

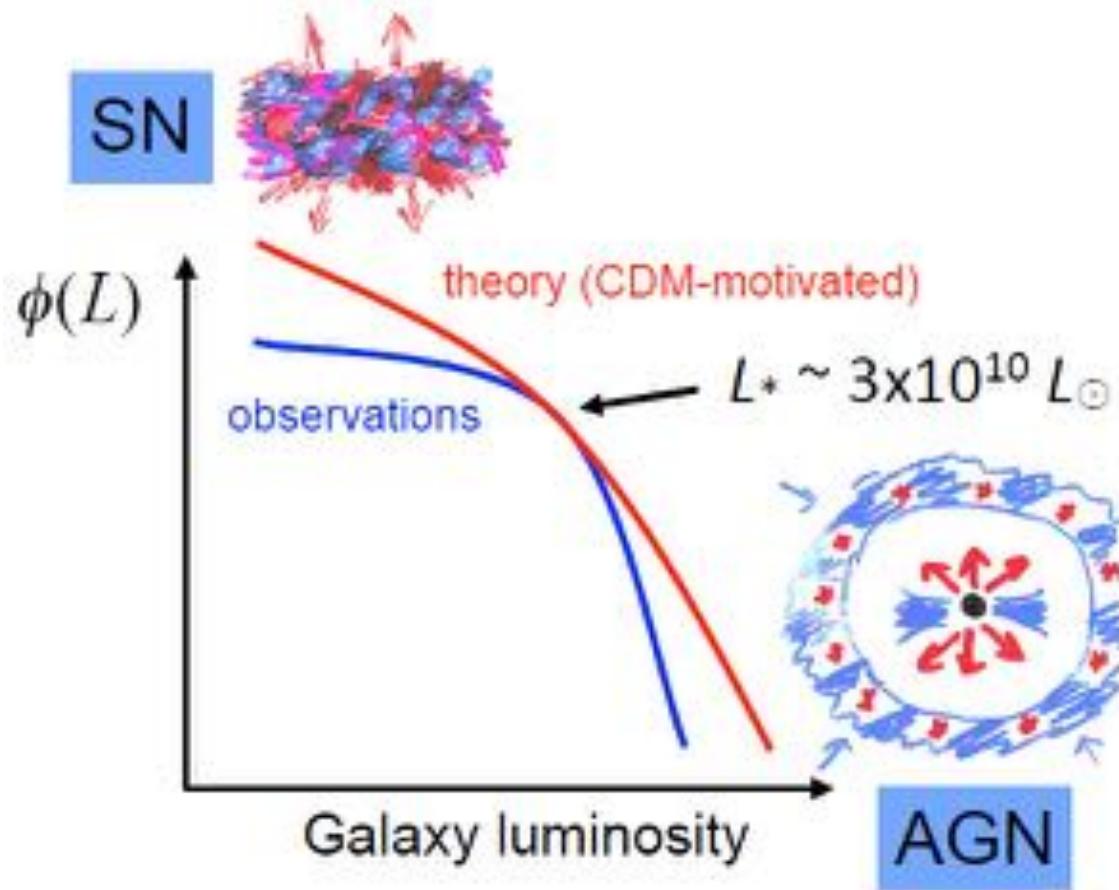
Energies and rates of the cosmic-ray particles



„IceCube Masterclass“



Behroozi+ 2013



Silk 2013

Cosmic ray-driven winds:

Magnetic Fields and Cosmic Rays contribute significantly to the energy density, i.e. pressure:

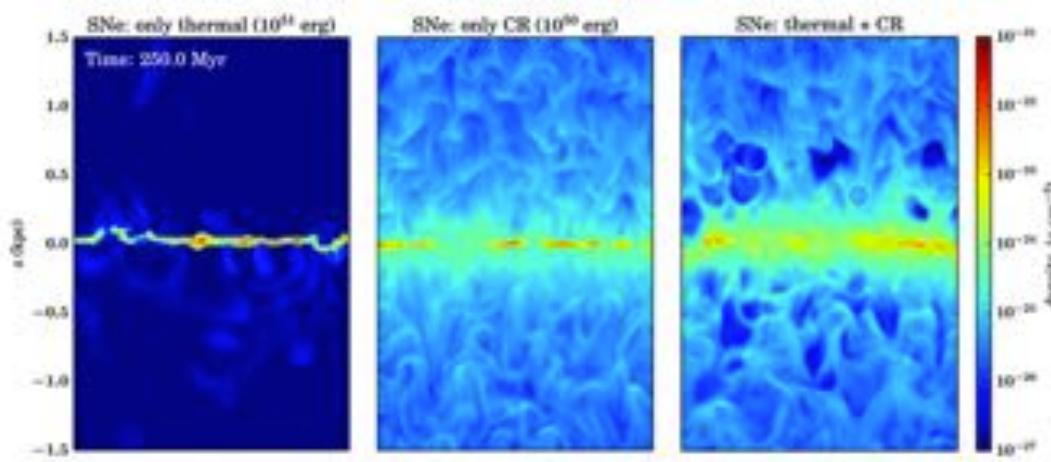
$$U_{\text{rad}} \sim U_B \sim U_{\text{CR}} \sim U_{\text{kin}}$$

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

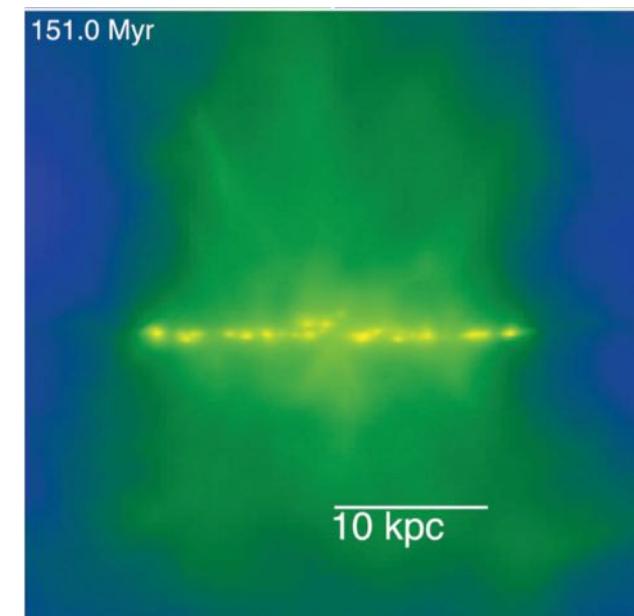
Philipp Girichidis¹, Thorsten Naab¹ , Stefanie Walch² , Michał Hanasz³ ,
Mordecai-Mark Mac Low^{4,5} , Jeremiah P. Ostriker⁶ , Andrea Gatto¹ , Thomas Peters¹,
Richard Wünsch⁷ , Simon C. O. Glover⁵, Ralf S. Klessen⁵ , Paul C. Clark⁸, and
Christian Baczynski⁵ — Hide full author list

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[The Astrophysical Journal Letters](#), Volume 816, Number 2

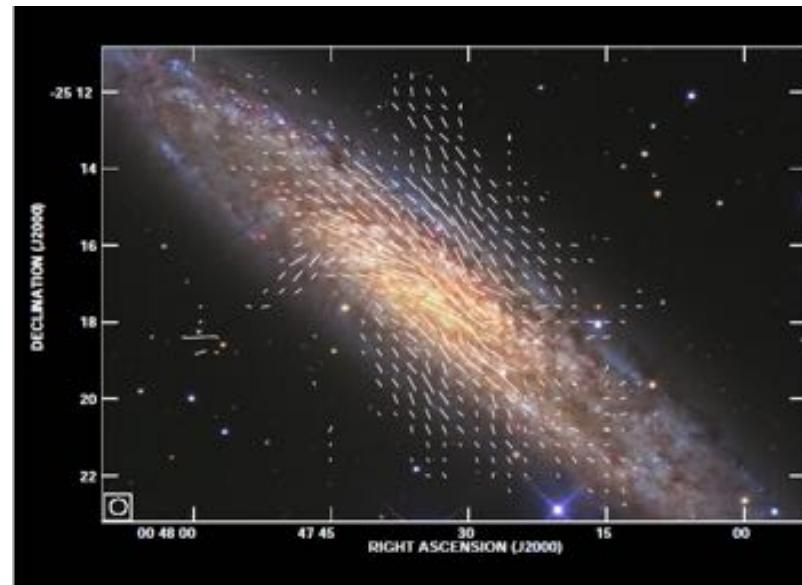
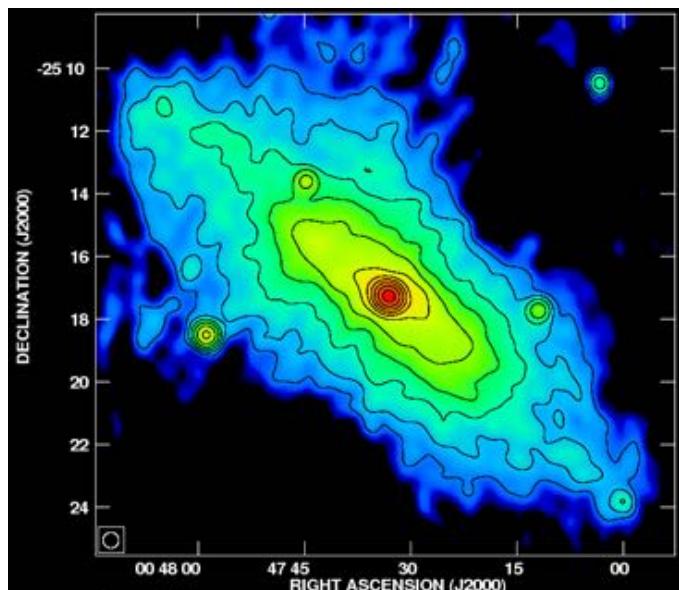


R.-J. Dettmar | CRE transport from radiocontinuum | ICRC2019 Madison, WI



Salem & Bryan (2014)

What we can measure: synchrotron emission from CR Electrons



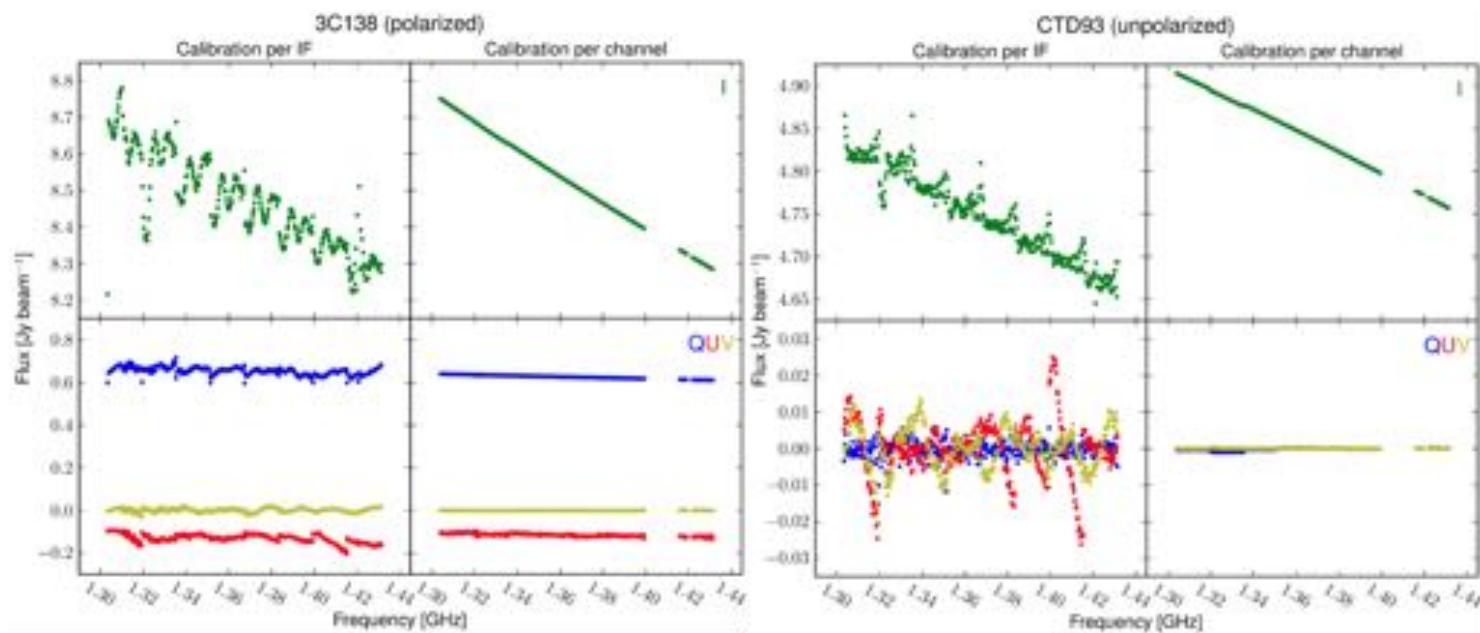
Polarized emission (and angles):

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

Faraday rotation measures of the diffuse polarized emission:

$$RM \propto \int n_e B_{\parallel} dl$$

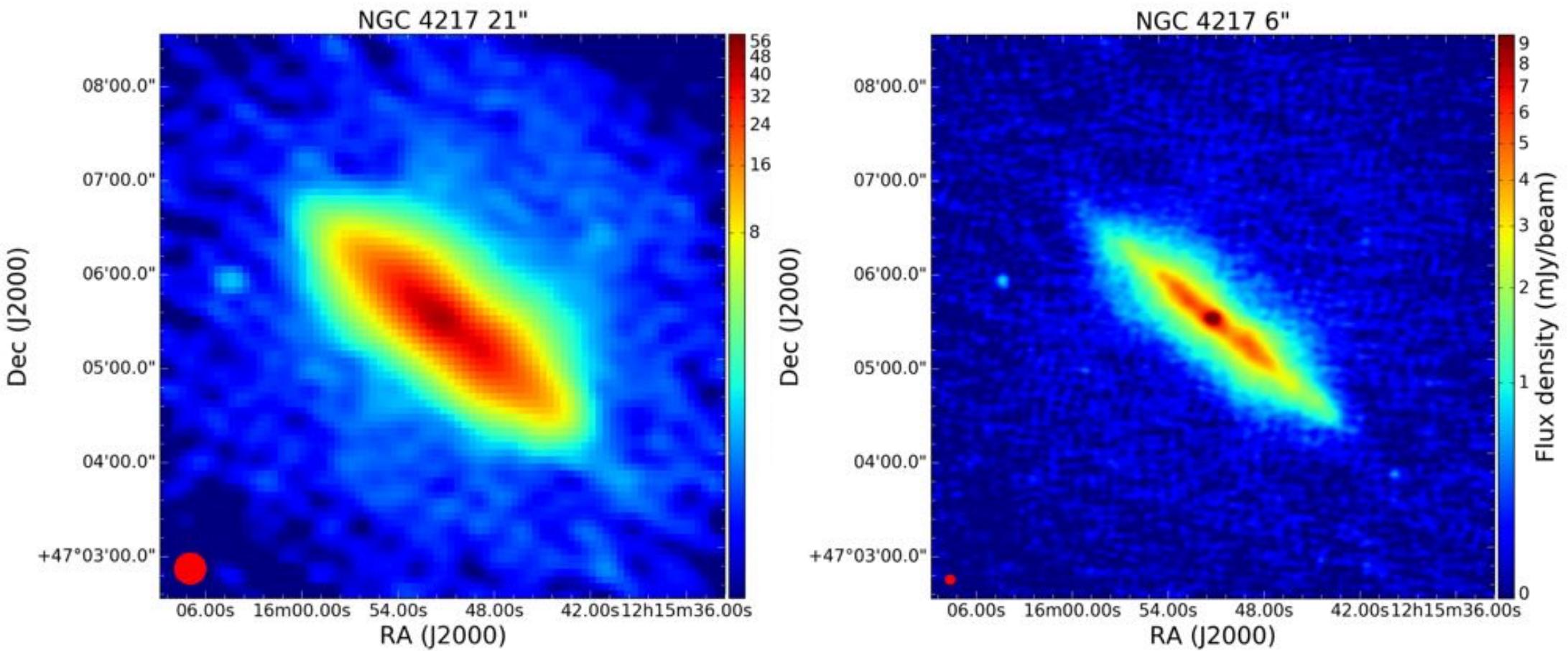
„new constraints“ due to the latest generation of multi-channel broad-band receiver systems



example: WSRT multichannel receiver

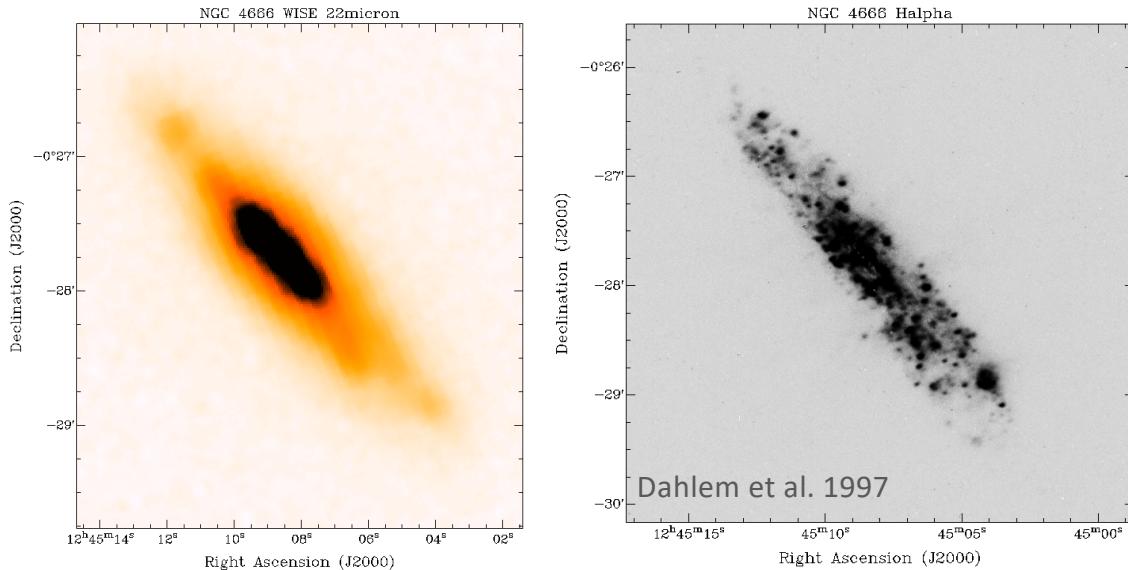
(Björn Adebarh, PhD thesis, Bochum 2013)

example LOFAR: LoTSS survey



~0.1 mJy rms noise, 0.46 Jy total flux (A. Miskolczi)

auxiliary data: thermal/non-thermal separation



Vargas+ 2018,
CHANG-ES X: Spatially Resolved Separation of Thermal Contribution
from Radio Continuum Emission in Edge-on Galaxies

Dust corrected H α image as thermal emission:

- WISE (22 μ m) and H α (in erg/s)
- Smoothing, regridding
- Calculating thermal Flux based on Calzetti et al. 2007

$$F_{\text{thermal}} = C (L_{H\alpha} + 0.04 L_{\text{WISE}})$$

“clean non-thermal emission”: 1D Modelling of CR–Transport

$N(E, z)$: Cosmic Ray Electron number (column) density

Advection:
$$\frac{\partial N(E, z)}{\partial z} = \frac{1}{V} \left\{ \frac{\partial}{\partial E} [b(E)N(E, z)] \right\}$$

Diffusion:
$$\frac{\partial^2 N(E, z)}{\partial z^2} = \frac{1}{D} \left\{ \frac{\partial}{\partial E} [b(E)N(E, z)] \right\}$$

CRe losses:
$$-\left(\frac{dE}{dt} \right) = b(E) = \frac{4}{3} \sigma_{TC} \left(\frac{E}{m_e c^2} \right)^2 (U_{\text{rad}} + U_B)$$

iC losses

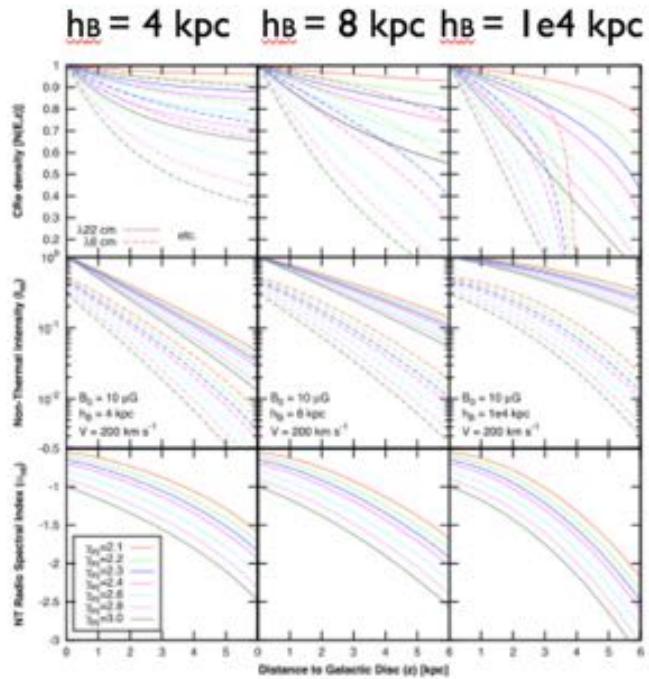
synchrotron
radiation

Advection models

$N(E,z)$

$I_{\text{nt}}(z)$

α_{nt}

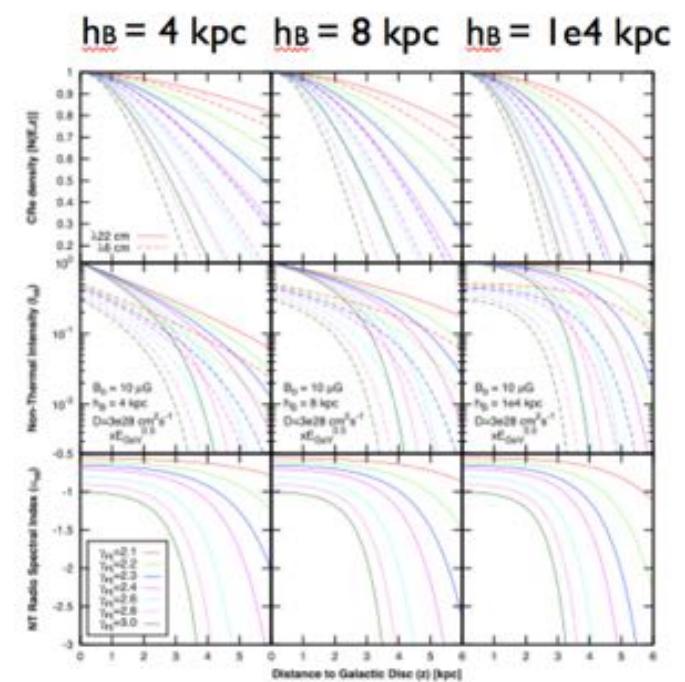


Diffusion models

$N(E,z)$

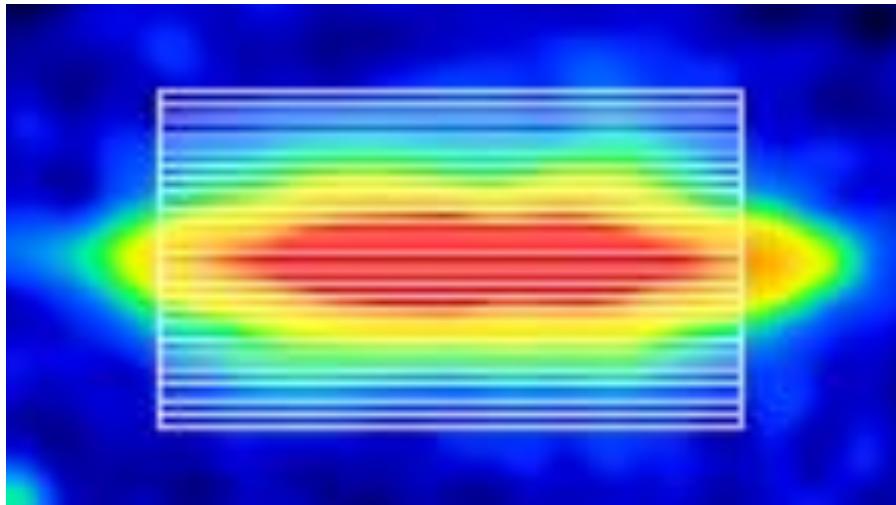
$I_{\text{nt}}(z)$

α_{nt}

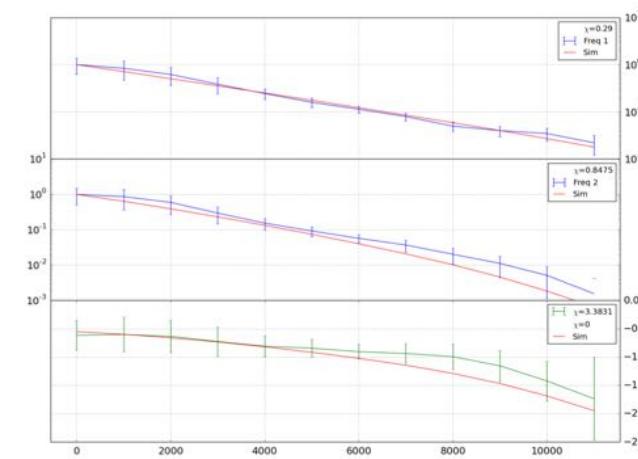


(V. Heesen)

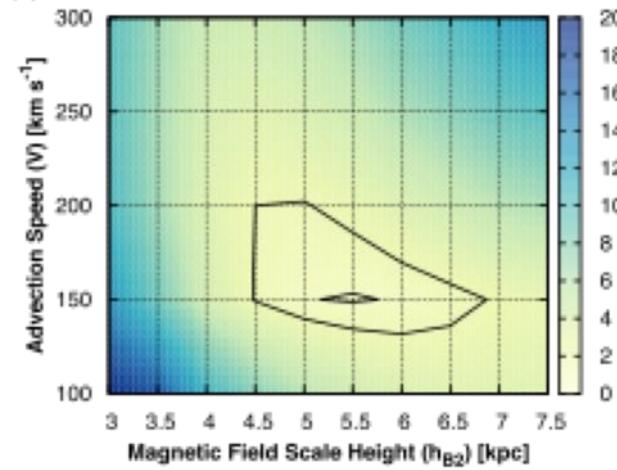
Cosmic Rays: 1-D Transport Model



Fitting of non-thermal intensity profiles with
SPINNAKER by V. Heesen based on advection or
diffusion equation



(a) Reduced chi²: NGC 7090 Northern Halo



CHANGES: Continuum HALos in Nearby Galaxies - an Evla Survey

PI: Judith Irwin, Kingston (ONT/CANADA)

35 edge-on galaxies

inclination > 75 deg

DEC > 25 deg

4 arcmin > D < 15 arcmin

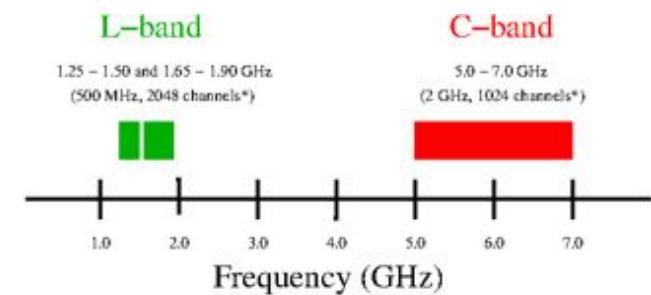
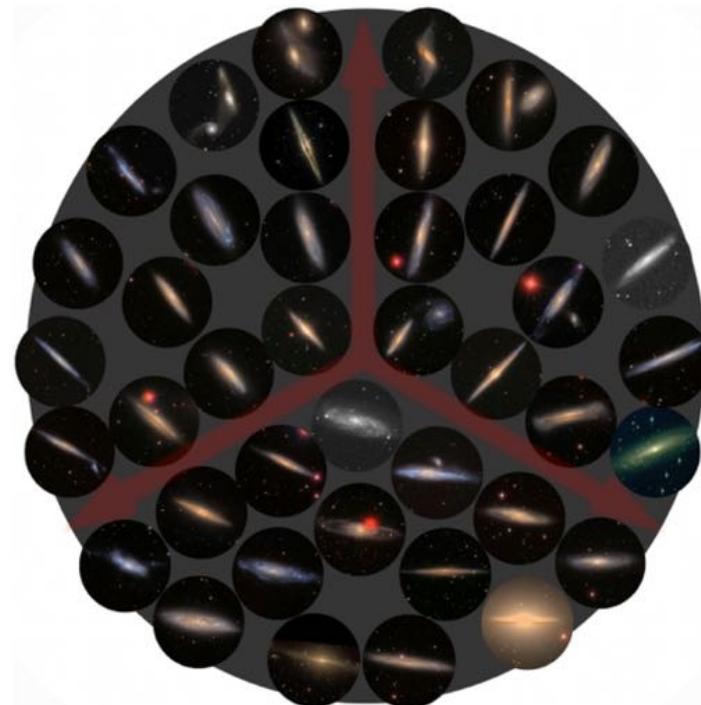
flux > 23 mJy

+ a few well studied larger object

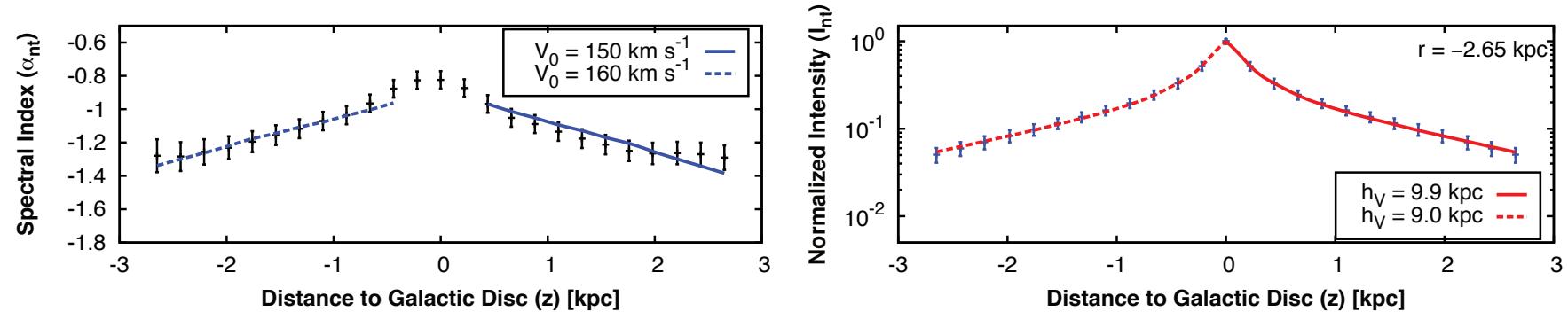
Large proposal 405 hours granted (RSRO)

Irwin+, 2012, AJ, 144, 44

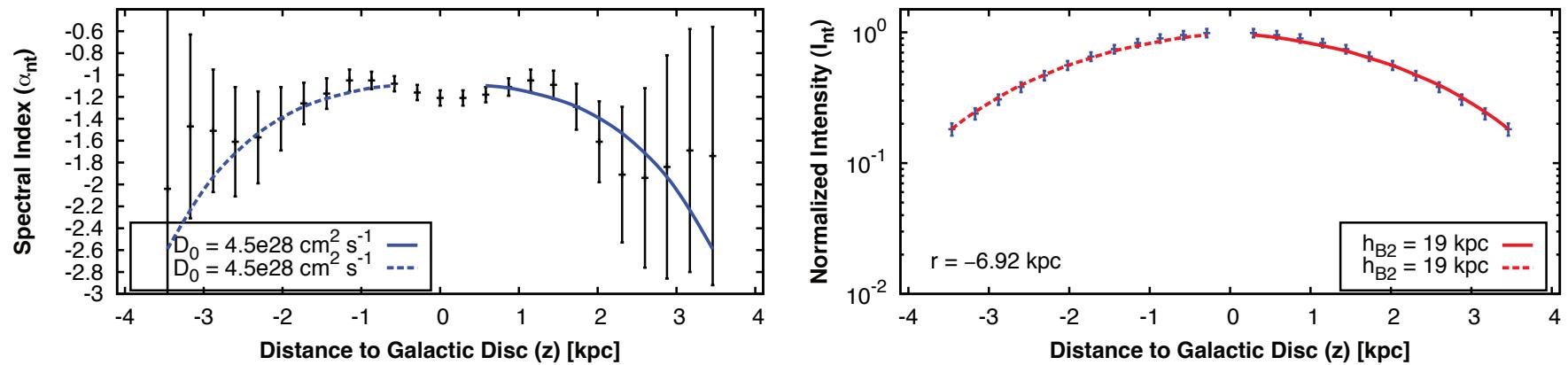
Wiegert+, 2015, AJ, 150, 81



NGC 891: advection model



NGC 4565: diffusion model



Schmidt+ arXiv : 1907.03789

NGC4565 seen with LOFAR: a diffusive CRE halo Heesen+, arXiv:1907.07076

V. Heesen et al.: Diffusive radio halo around NGC 4565

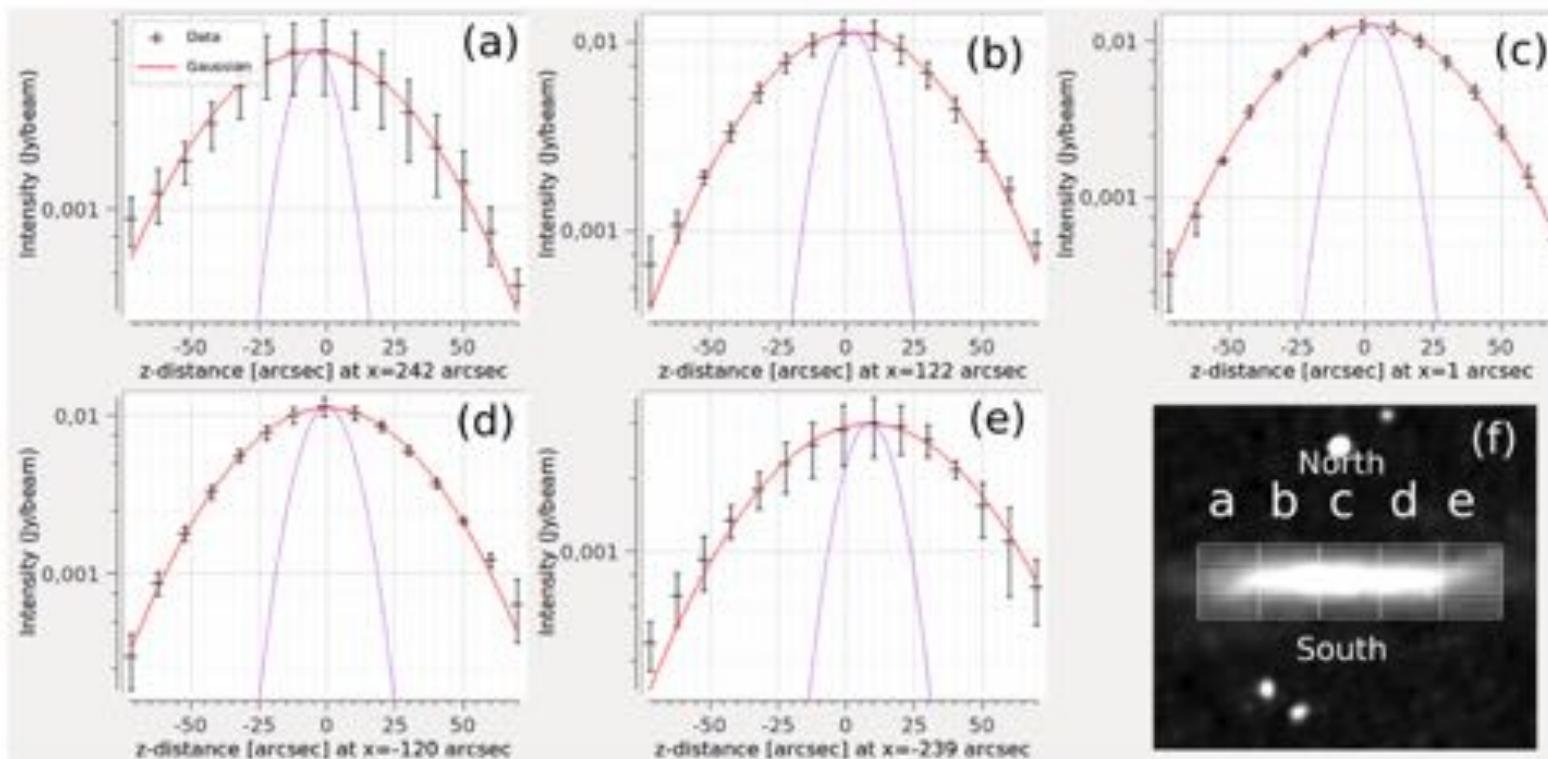


Fig. 2. Vertical profiles of the non-thermal radio continuum emission at 144 MHz in strips at various offsets along the major axis [panels (a)–(e)] and the position of the strips [panel (f)]. Red solid lines show Gaussian model fits to the data, and purple solid lines show the Gaussian synthesised beam (FWHM = 20 arcsec). Vertical tick marks are at 2.5 \times , 5 \times , and 7.5 \times the next labelled tick value below. In the profiles, south is to the left and north is to the right.

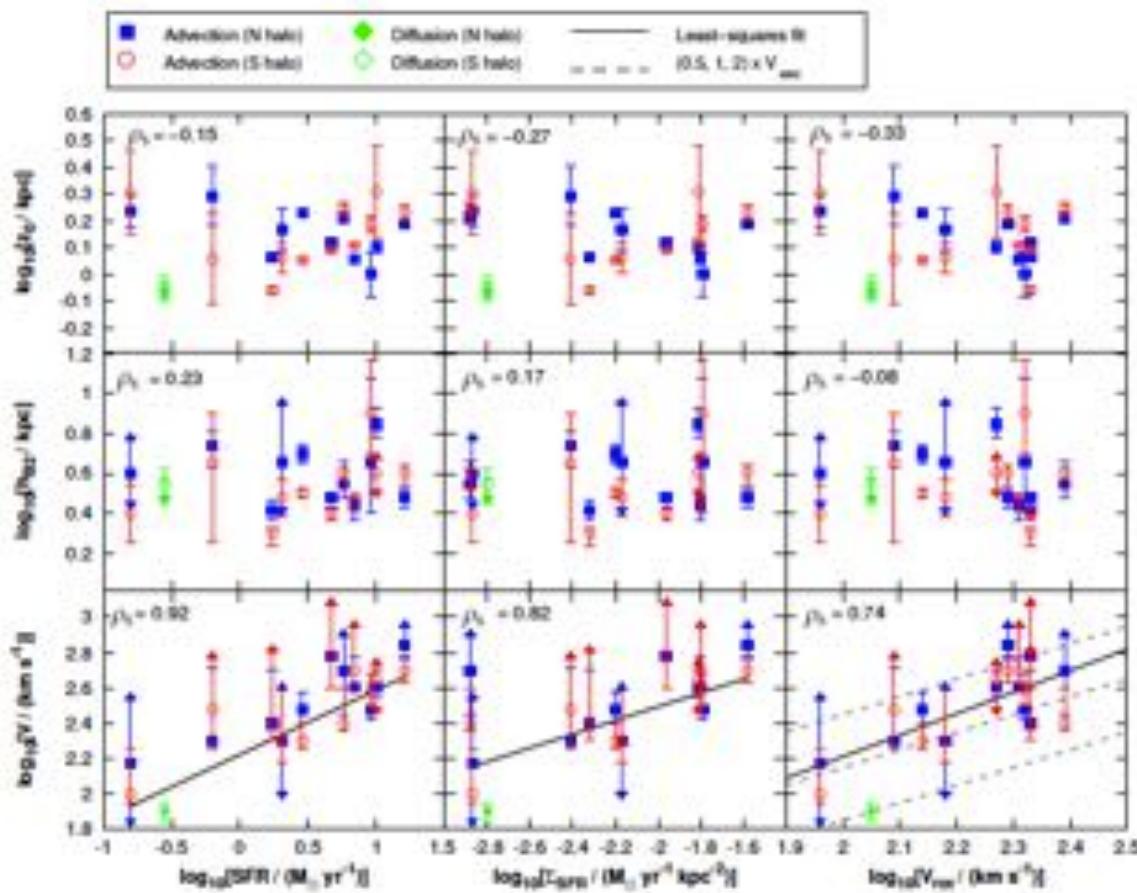
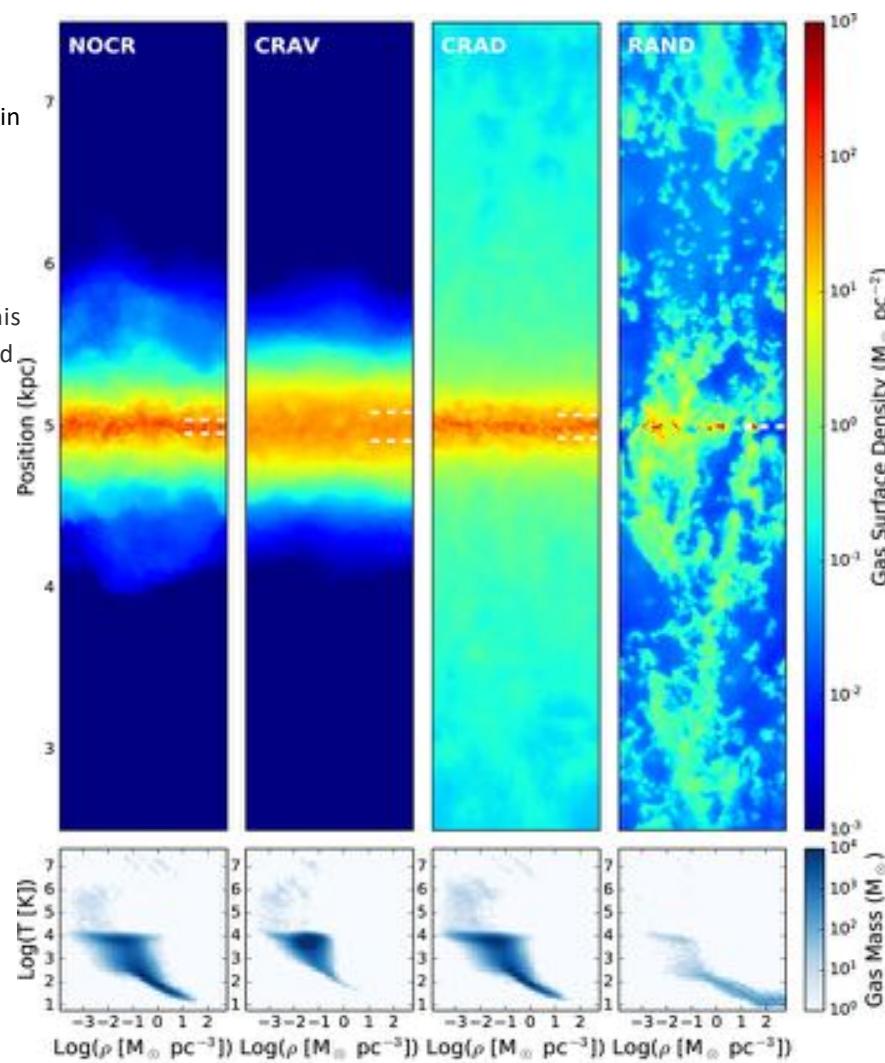


Figure 8. Parameter study in log-log diagrams as function of SFR, SFR surface density (Σ_{SFR}) and rotation speed V_{rot} . Top panels: non-thermal intensity scale height (I_{5GHz}) at 5 GHz (8.5 GHz for NGC 5248) of the thick radio disc. Middle panels: magnetic field scale height (B_{5GHz}) of the thick radio disc. Bottom panels: Advection speed (V), where solid lines show least-squares fits. In the bottom right panel the dashed lines show $(0.5, 1, 2)V_{\text{rot}}$. 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 limit.

Heesen+ MNRAS 476, 158 (2018)

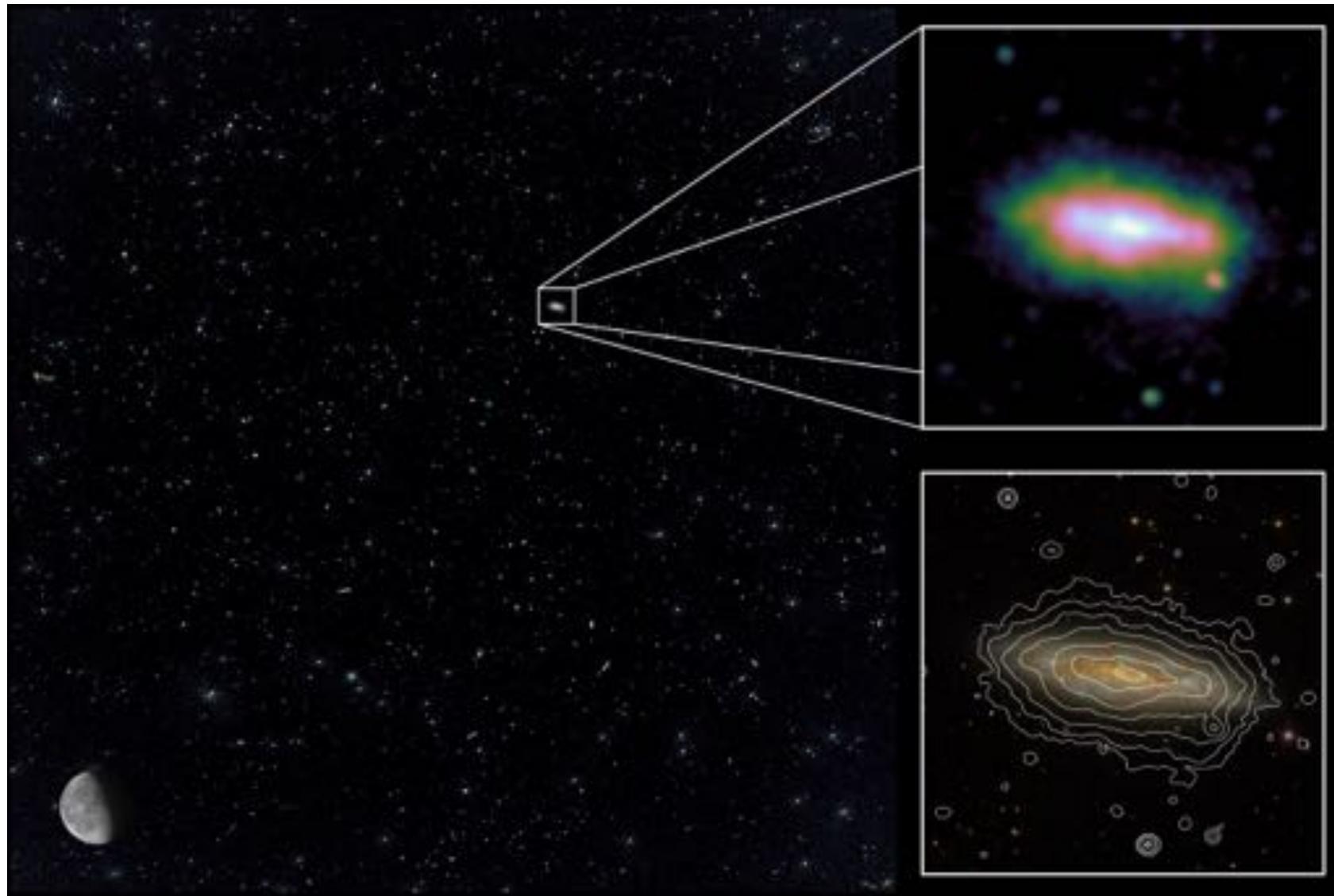
CRAV (identical to NOCR but 10% of the SN energy in CR energy. The remaining 90% is added as thermal energy. The CR energy can advect with the gas

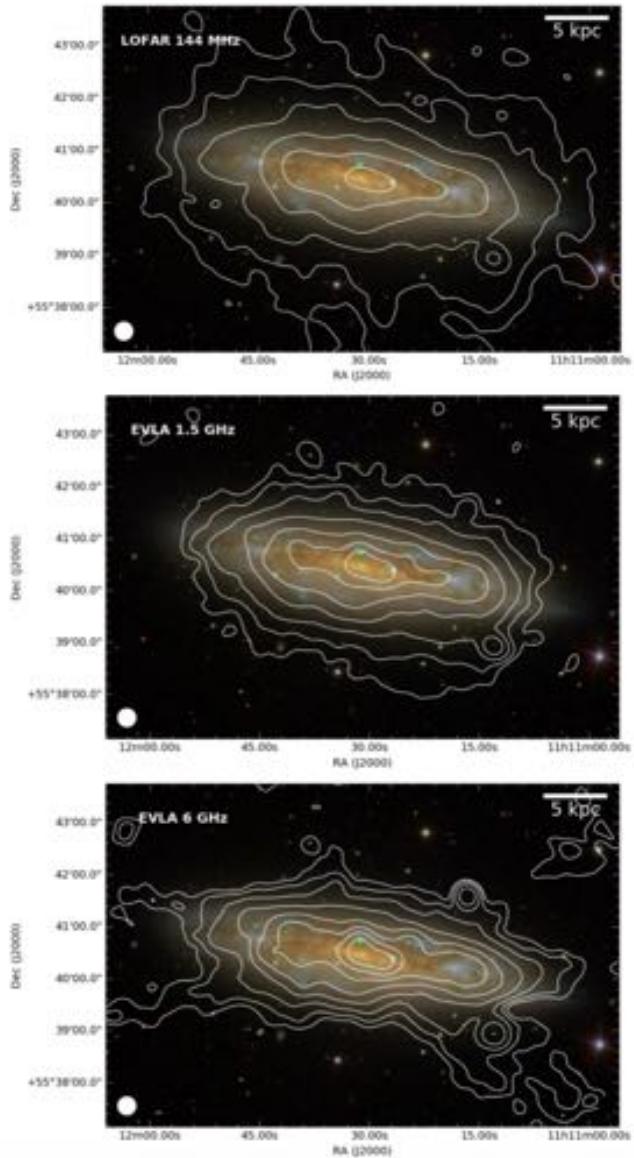
CRAD is identical to CRAV, but with *anisotropic* instead of isotropic CR diffusion (Pakmor et al. 2016a). The diffusion coefficient in this model is $\kappa = 10^{28} \text{ cm}^2 \text{ s}^{-1}$ parallel to the magnetic field and zero in all transverse directions.



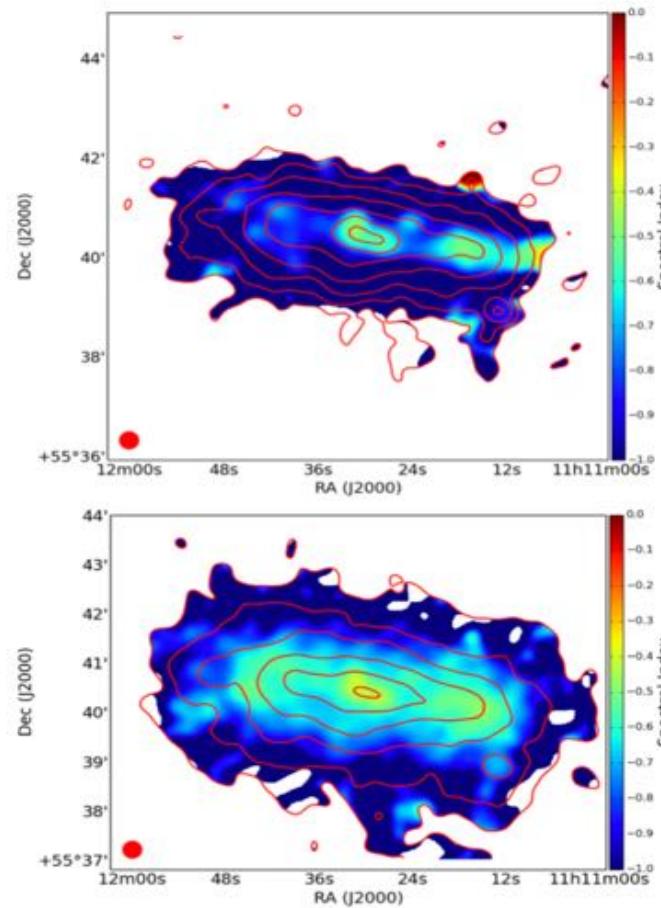
Christine M. Simpson et al. 2016 ApJL 827 L29

LOTSS
NGC3556
(A. Miskolczi)





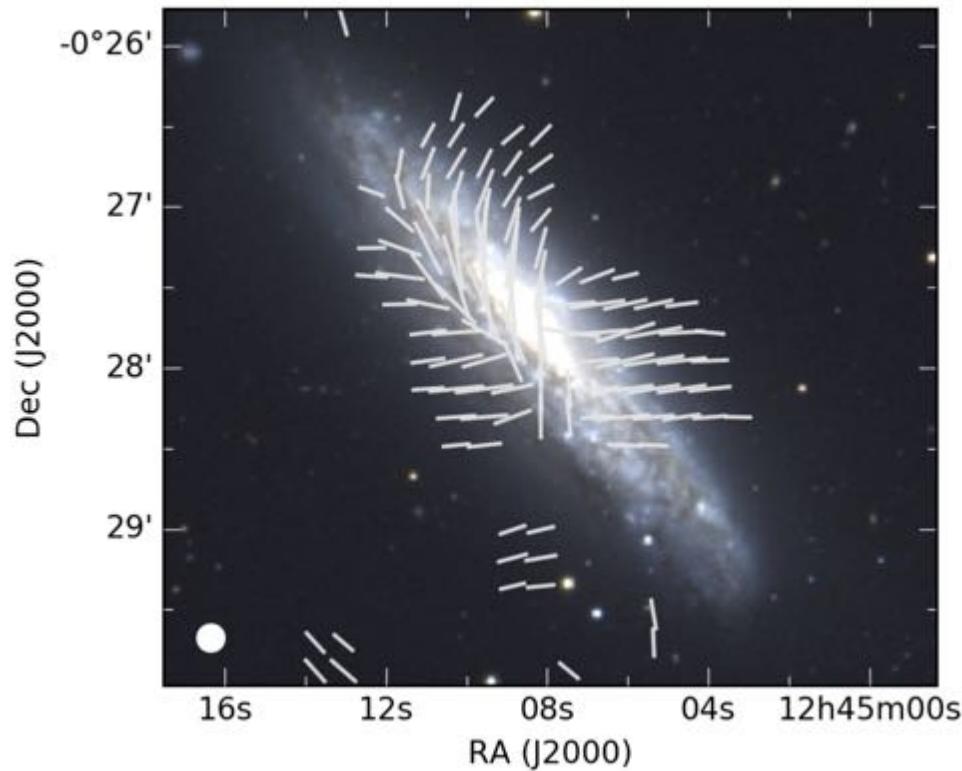
CHANGES XII: N3556 (Miskolczi+, 2019)



spectral index
much better
described using
a wind profile for v

$$v(z) = v_0 \left(1 + \left(\frac{z}{h_v} \right)^\beta \right)$$

Outlook: magnetic field structure



NGC4666

Stein+, A&A (2019), 623, A33

The large scale magnetic field of disk galaxies with a certain level of star formation has a significant poloidal (X-shape) component.



Summary:

- CRE transport into galactic halos seems to be dominated by advection in most star forming disk galaxies
- LOFAR observations allow us to study the low energy and „old“ population of CREs
- Surveys aiming at measurements of magnetic fields and CRs in halos of a larger number of objects are underway (e.g., CHANG-ES)
- Star-forming disk galaxies have a significant poloidal halo (X-shaped) component of the magnetic field

Thank you



NGC 46666 Credit: Y. Stein, J. Englisch, A. Miskolczi

GEFÖRDERT VOM

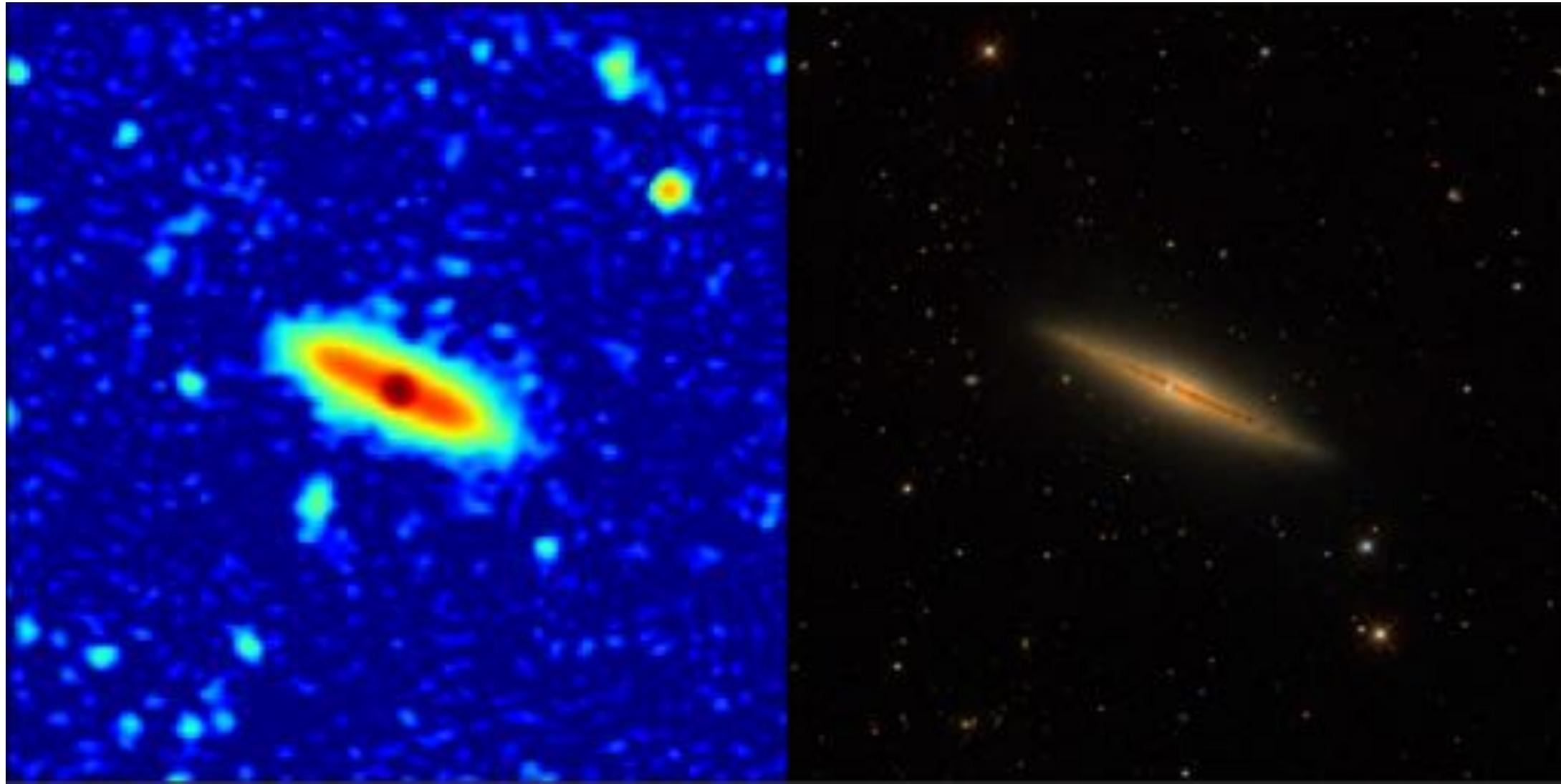


Bundesministerium
für Bildung
und Forschung

LOTSS 20"

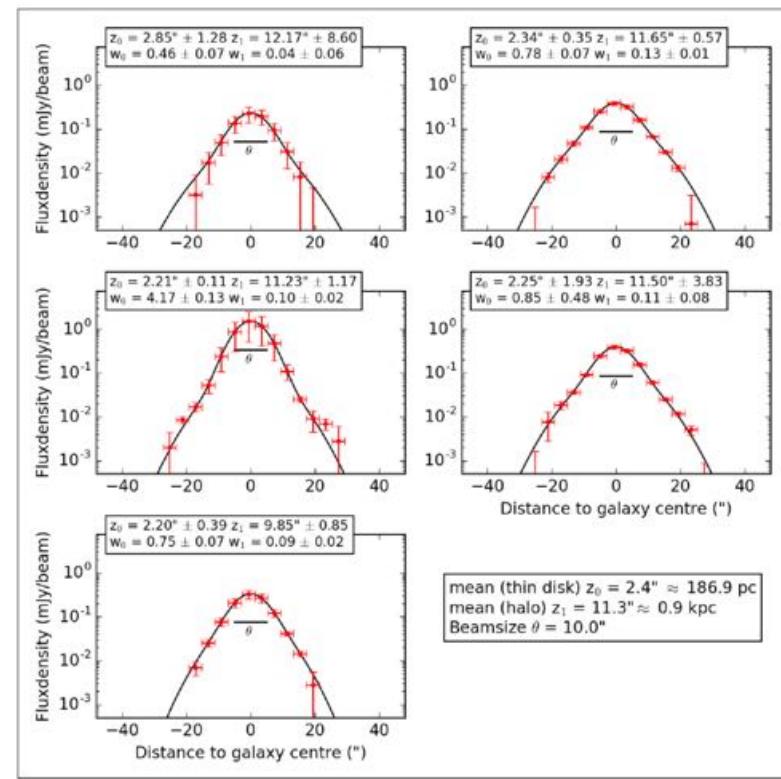
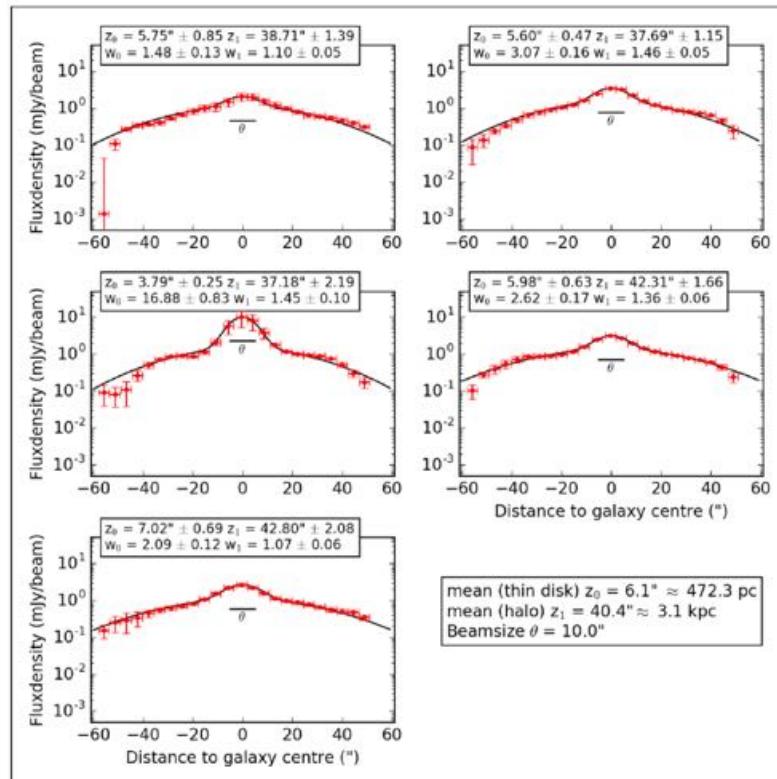
NGC4013

SDSS

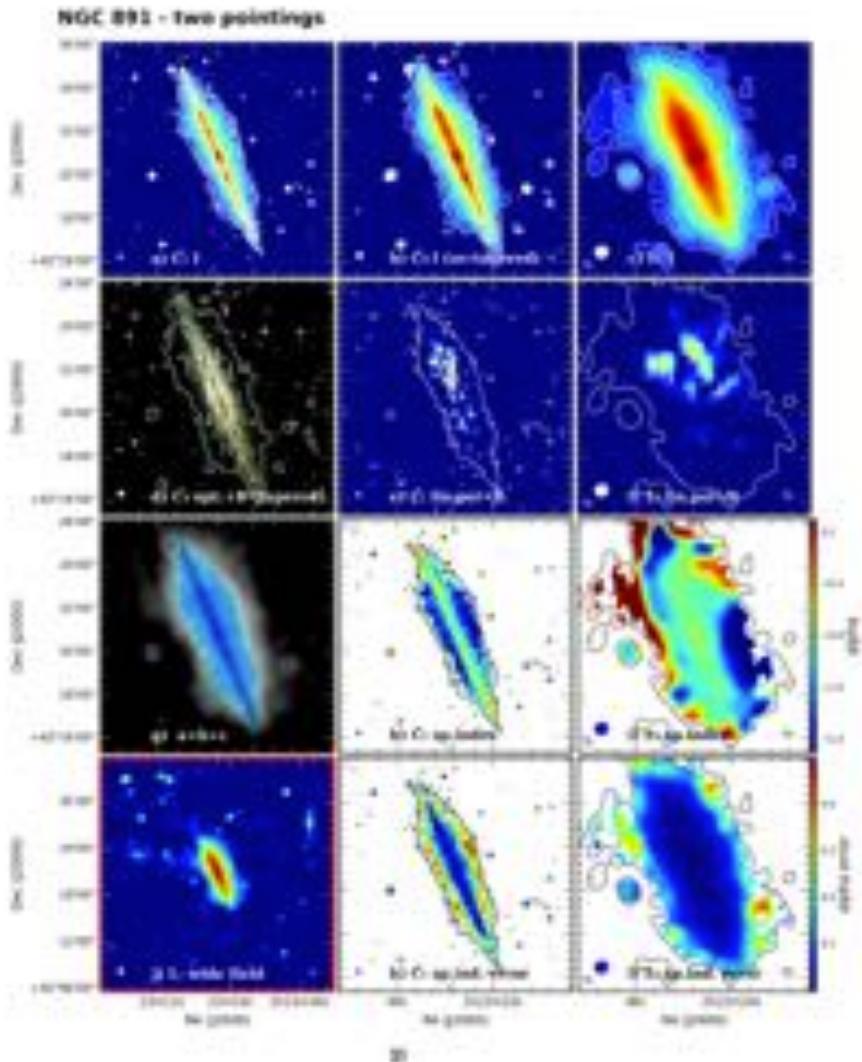


NGC 4013 LOTSS/JVLA C-Band

(Y. Stein+, 2019 A&A)



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



queensu.ca/changes

Queen's University



Welcome to the CHANG-ES data release web site.

Data Release 1 (DR1) is now available consisting of all images from the D configuration of the Very Large Array. NEW (May 10, 2017): The VLA has updated its primary beam (PB) parameters. Tests have shown that this makes no difference to our L-band data and only small differences to our C-band data, mostly within the errors as quoted in Wiegert et al. 2015 with the exception of the large angular size galaxies. Therefore, all C-band PB-corrected data (including spectral index maps) on this website have now been corrected to the new PBs as described in EVLA Memo 195.

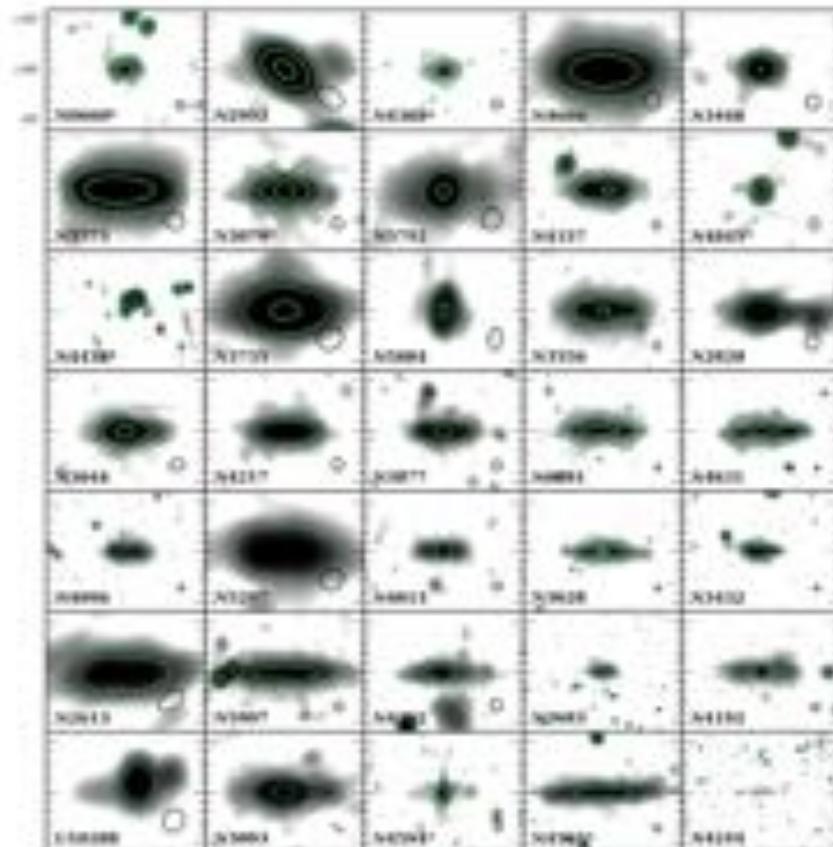
Clicking on the optical image of any galaxy will take you to its data release page. Please explore our project web site by clicking on the main navigation bar above. If you use these data, we would appreciate an appropriate citation. For example, "The CHANG-ES project is described in Irwin et al. 2012, AJ, 144, 43 and details about this first data release are provided by Wiegert et al. 2015, AJ, 150, 81."



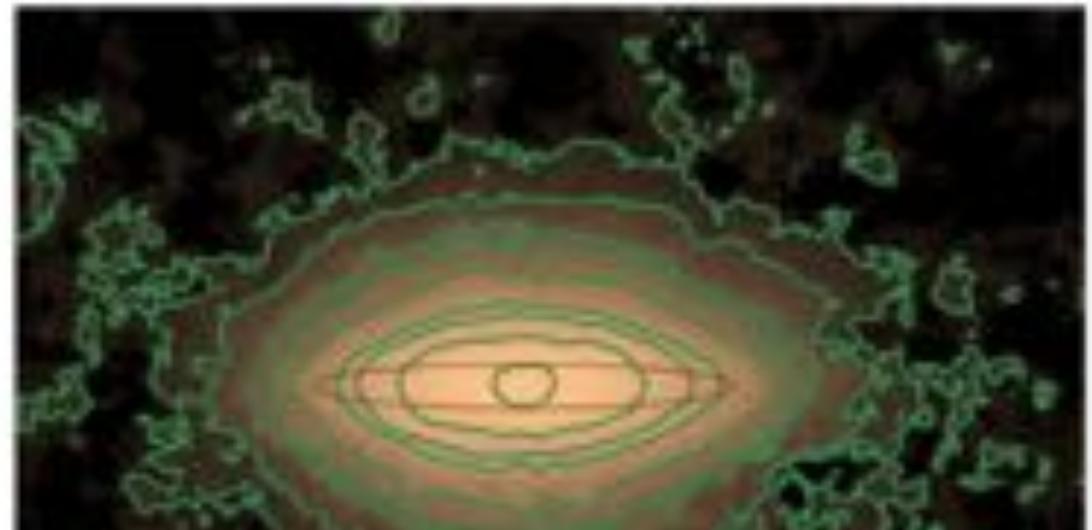
The images above were produced by Jiangtao Li (University of Michigan) for the CHANG-ES consortium using data from the Sloan Digital Sky Survey (<http://www.sdss.org>) and the Digitized Sky Survey (<http://www2.cadc-ccda.hia-iha.nrc-cnrc.gc.ca/dss2>). CHANG-ES has been support by the Natural Sciences and Engineering Research Council of Canada.

Web site design by Suzanne Oew-Daigneau. All fits files prepared for the web by Michael Radac.
Remaining images (C array B array) are just released

sorted by SFR at common distance



„averaged“ radio continuum halo



THE ASTROPHYSICAL JOURNAL LETTERS, 799:L10 (6pp), 2015 January 20
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doi:10.1088/2041-8205/799/L10

AXIAL RATIO OF EDGE-ON SPIRAL GALAXIES AS A TEST FOR BRIGHT RADIO HALOS

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Received 2014 August 28; accepted 2014 December 24; published 2015 January 19

ABSTRACT

We use surface brightness contour maps of nearby edge-on spiral galaxies to determine whether extended bright radio halos are common. In particular, we test a recent model of the spatial structure of the diffuse radio continuum by Subrahmanyan & Cowsik which posits that a substantial fraction of the observed high-latitude surface brightness originates from an extended Galactic halo of uniform emissivity. Measurements of the axial ratio of emission contours within a sample of normal spiral galaxies at 1500 MHz and below show no evidence for such a bright, extended radio halo. Either the Galaxy is atypical compared to nearby quiescent spirals or the bulk of the observed high-latitude emission does not originate from this type of extended halo.

Key words: Galaxy: halo – radio continuum: galaxies