VERY LARGE ARRAY SKY SURVEY

POLARIZATION (TOMOGRAPHY)

Lawrence Rudnick, University of Minnesota

Galactic Center (Survey) Multiwavelength Image
Credit: X-ray: NASA/UMass/D.Wang et al., Radio: N
RAO/AUI/NSF/NRL/N.Kassim, Mid-Infrared: MSX

Contributors:

Sui Ann Mao (MPIfR),
Julie Banfield (CASS, CSIRO),
Bryan Gaensler (Dunlap Institute, Toronto),
Lawrence Rudnick (U Minnesota),
Jeroen Stil (U Calgary),
Cormac Purcell (University of Sydney),
Rainer Beck (MPIfR),
Jamie Farnes (University of Sydney),
Shane O'Sullivan (UNAM, Mexico),
Dominic Schnitzeler (MPIfR),
Tony Willis (DRAO),
Xiaohui Sun (University of Sydney),
Ettore Carretti (Osservatorio Astr. Di Cagliari),
Tracy Clarke (NRL),
Klaus Dolag (U Munich),
Dmitry Sokoloff (Moscow State University),
Roland Kothes (DRAO),
Maik Wolleben (U Calgary),
George Heald (ASTRON),
Joern Geisbuesch (DRAO),
Tim Robishaw (DRAO),
Jose Afonso (Observatorio Astronomico de Lisboa),
Antonio Mario Magalhães (U São Paulo),
Britt Lundgren (U Wisconsin Madison),
Marijke Haverkorn (Radboud University Nijmegen),
Niels Oppermann (CITA),
Russ Taylor (U Capetown, U. Western Cape)

- **Survey Design & Technical Products**
- **Sample Science Cases**

DESIGN: PRODUCTS

- ***Goal: a unique, game-changing, polarization survey***
  - High frequency: probe depolarized population
  - High spatial resolution: Faraday maps for most sources
  - Large bandwidth: characterize Faraday complexity in beam & along line of sight; provide k-corrections
  - High sensitivity: [All-sky] increase background probes x6; [Deep] detect new galaxy population
  - Complementary to SKA-precursors
  - Legacy Science: ? ? ?

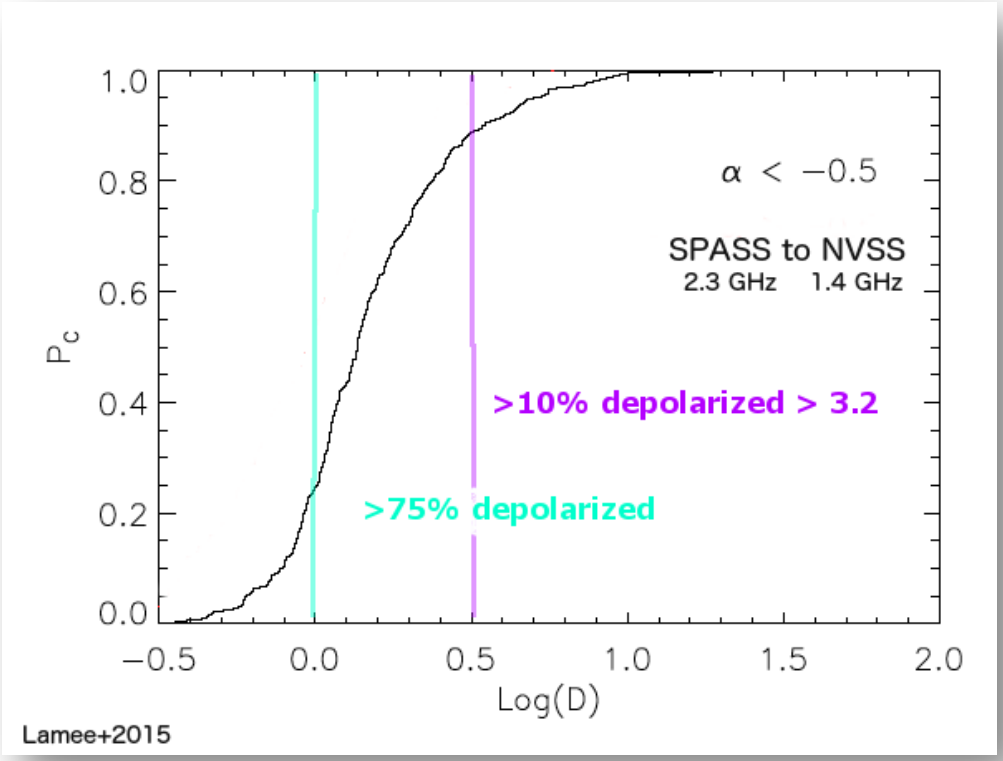
Probe depolarized population

Only ~3% sources polarized – why ?

Bandwidth Depolarization

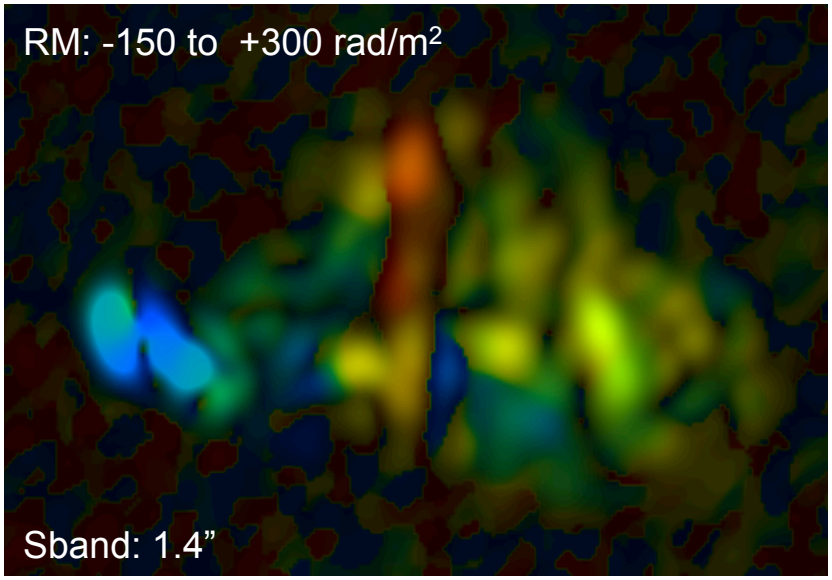
NVSS (full bandwidth)	|RM| max < 100 rad/m^2
NVSS (split bandwidth)	< 500 rad/m^2
VLASS	< 13000 rad/m^2

Physical Depolarization

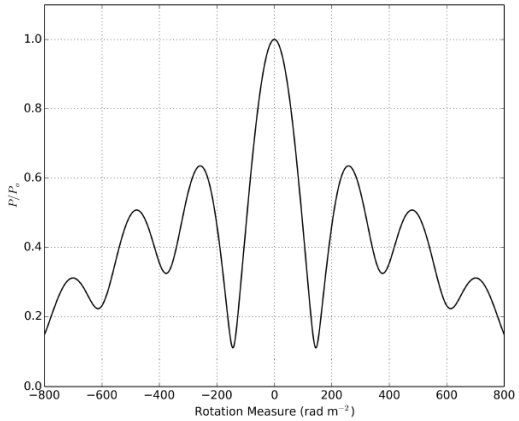


Sband optimal for physical depolarization (Faraday dispersion) of 50-100 rad/m^2 Arshakian & Beck 2011

Produce Faraday maps

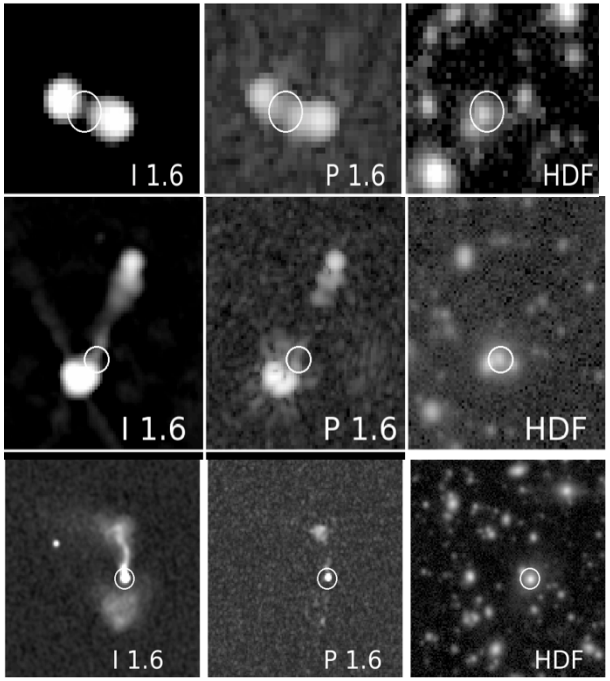


(A2256 Source A, Rudnick, Owen Eilek,



Faraday Transfer Function
RFI-free 2-4 GHz
Resolution=
200/[2*S/N] rad/m^2
3.8” resolution

Q IV. 5. **IF** lose all < 2.4 GHz,
350/[2*S/N] rad/m^2
3.2” resolution

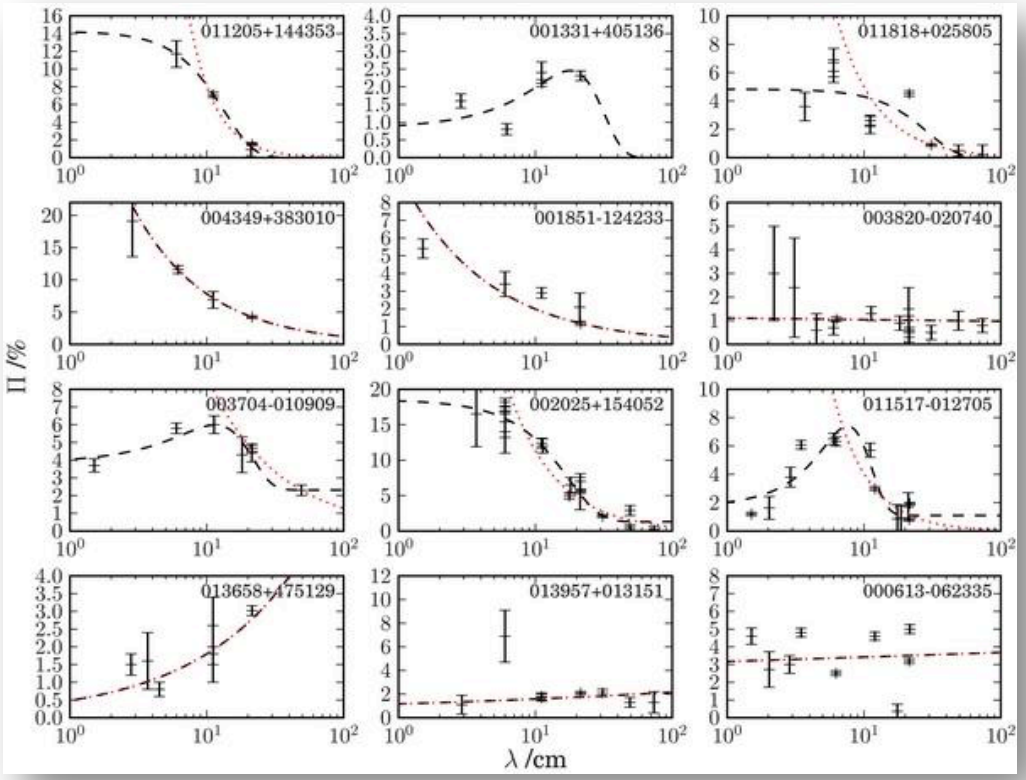


GOODS N, 1.4 GHz, 1.6” resolution
10 of 14 polarized sources resolved
Median size ~20”
Rudnick & Owen 2014

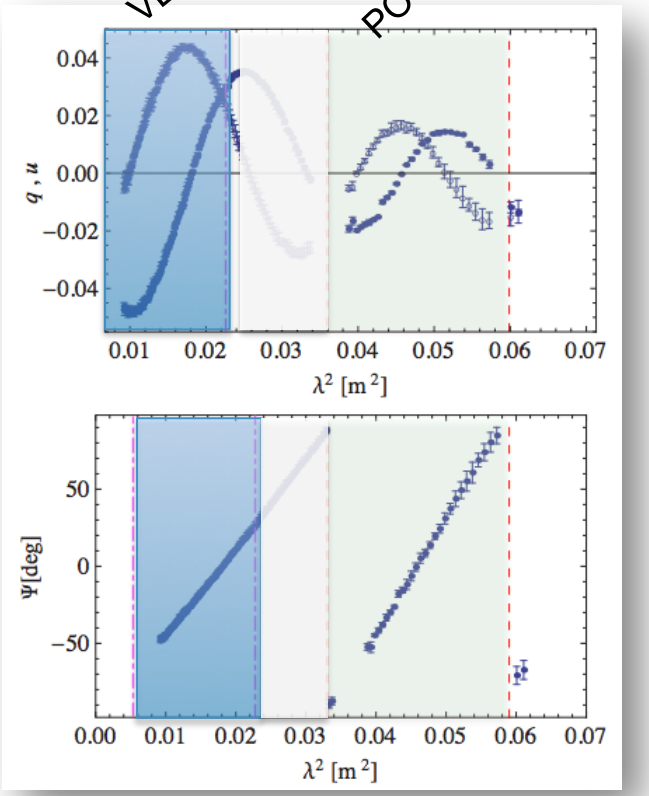
Characterize Faraday complexity

OLD: RM= ($d\chi / d\lambda^2$); $Q = Q_0 * \cos(2*RM*\lambda^2)$

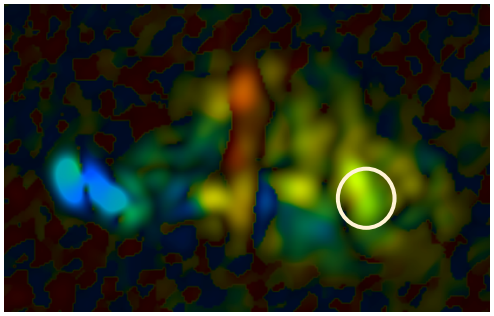
NEW: RM ≠ const; Q,U sum of multiple RMs
multiple "Faraday depths" → $F(\Phi)$

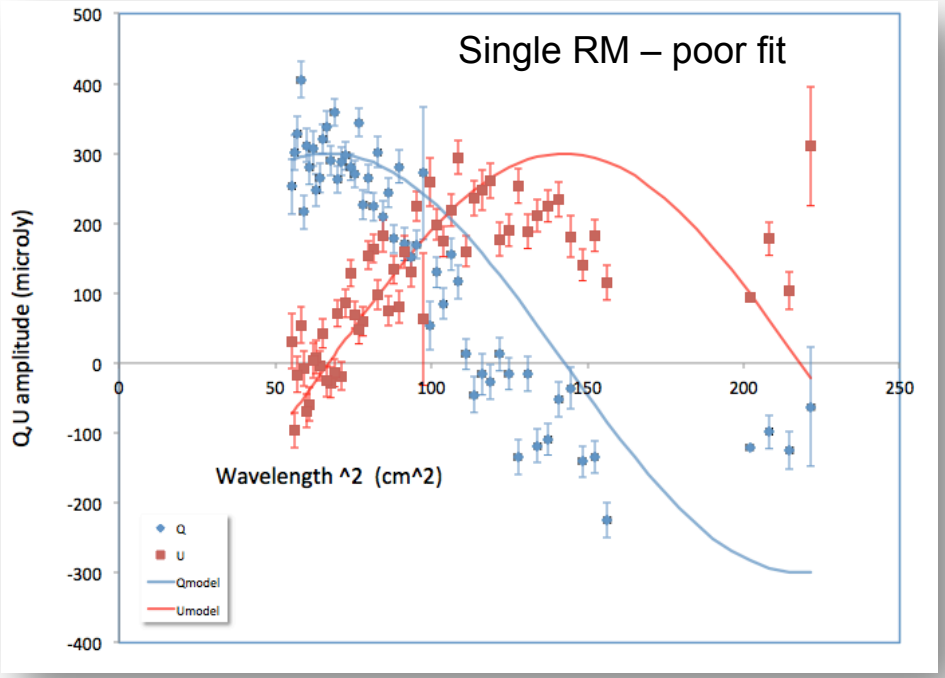


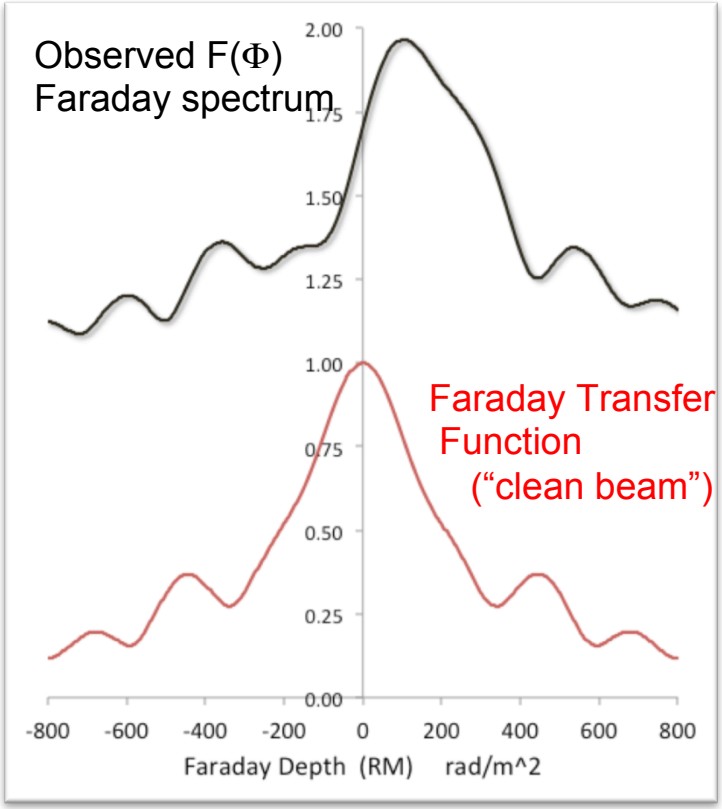
Broadband polarization, Farnes+2014



Characterize Faraday complexity

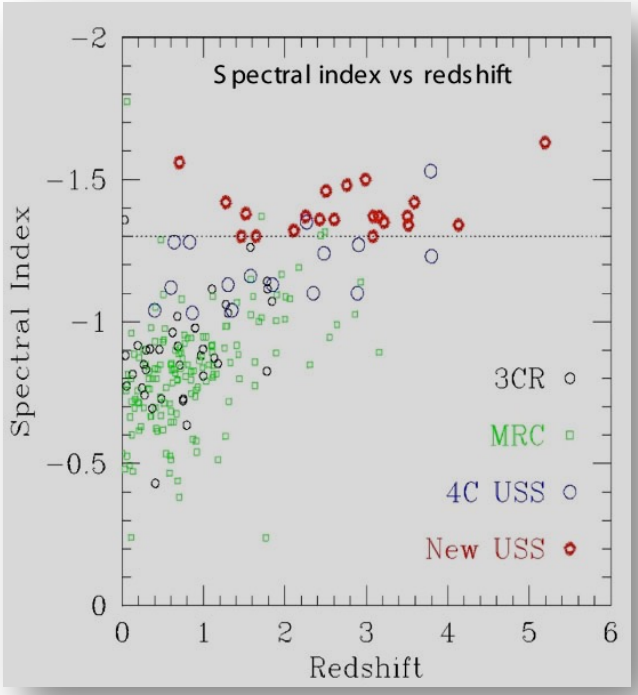




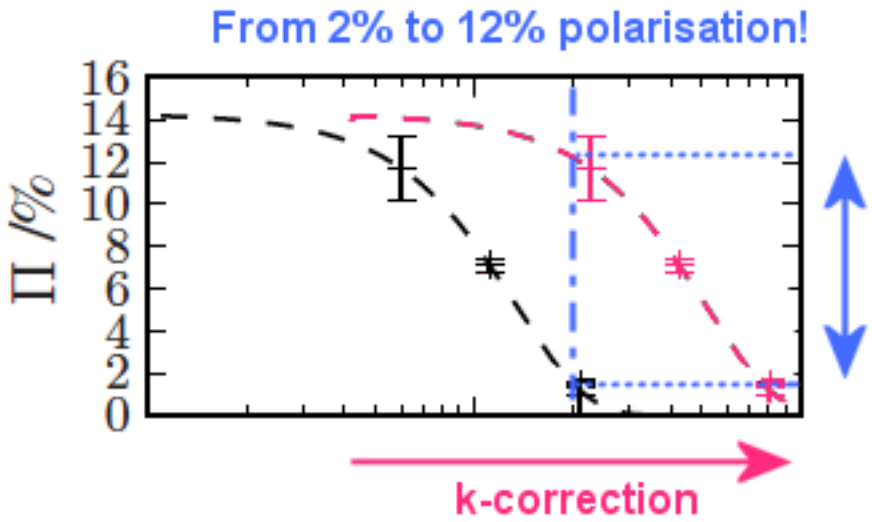


Enable "k"-corrections
(with SKA precursor Lband surveys)

Spectral k-correction: curvature + **evolution**



Polarization k-correction:
curvature vs **evolution**?

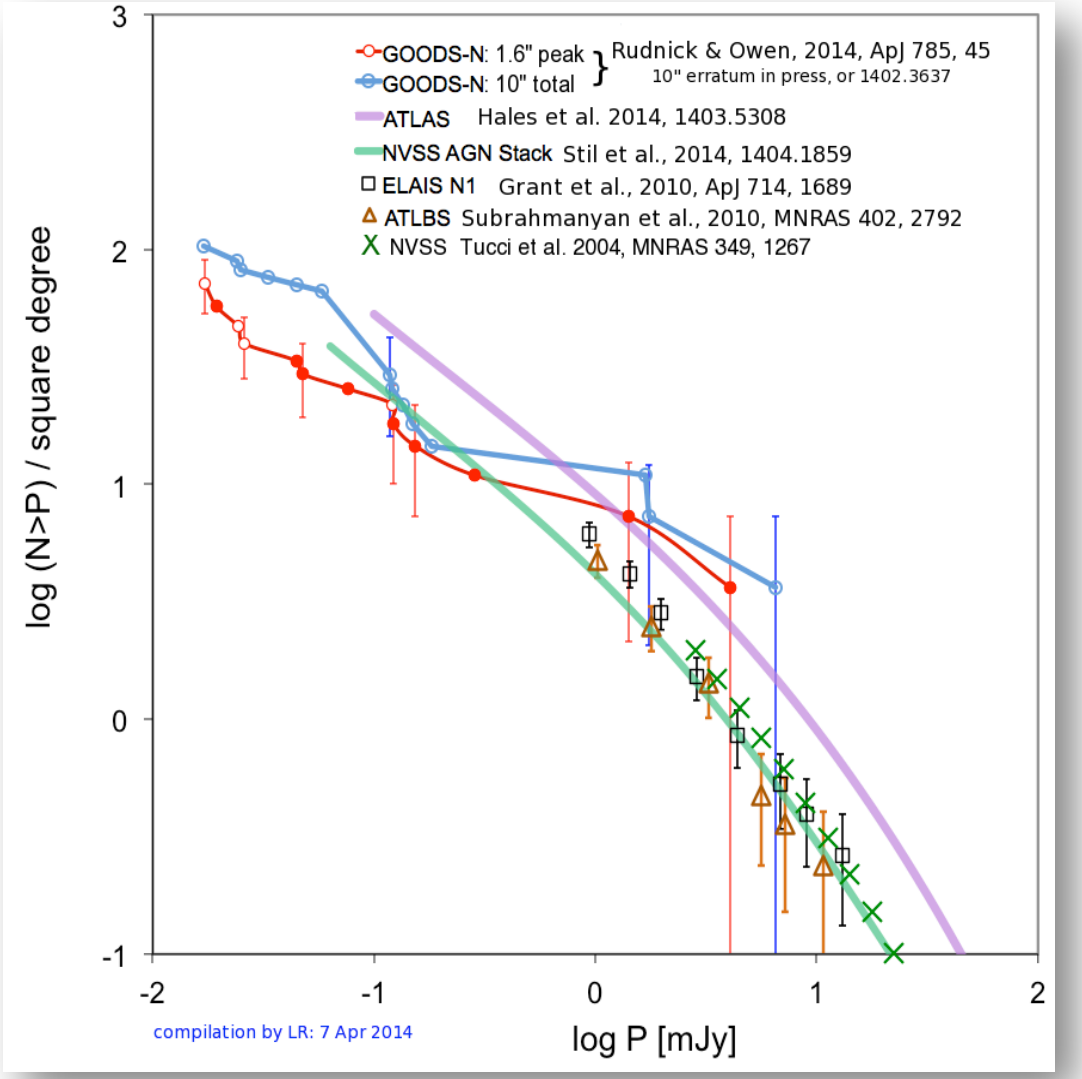


Most recently done with 62 sources (Kronberg+ 1972)!

VLASS: 20,600 sources!

correction up to z~1.9
(POSSUM, z~1.3)

Increase polarized counts



All-sky: foreground studies

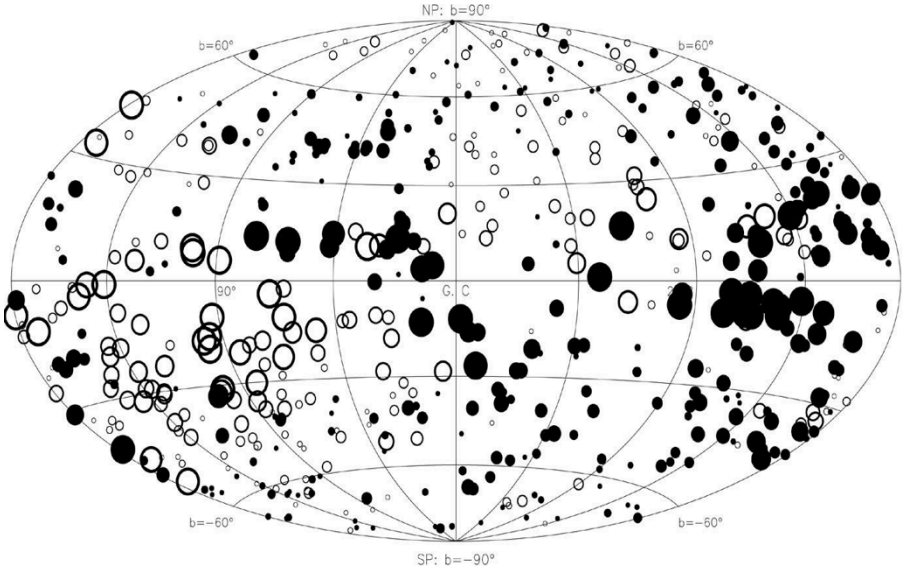
NVSS	VLASS	EMU
3×10^4	2×10^5	1×10^6

DEEP

AGNs: 10^2 per square degree
NEW: Disks- 10s per sq. deg

Q IV 5. Cumulative # of polarization sources a $P_{min}^{-0.6}$. Counts from 1.6", so will increase slightly at 3.2-3.8"

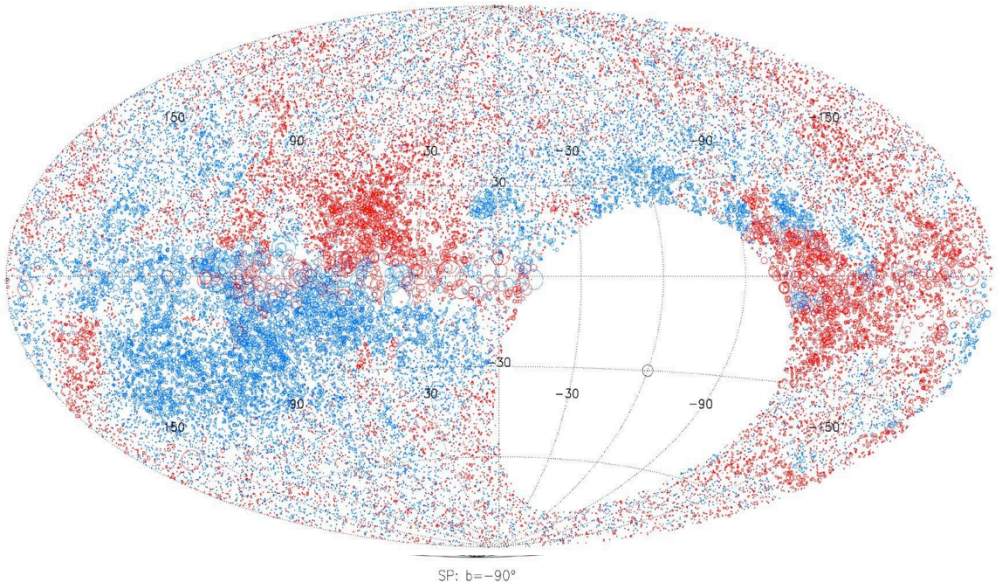
Increase polarized counts:
Evolution of the “RM Grid”



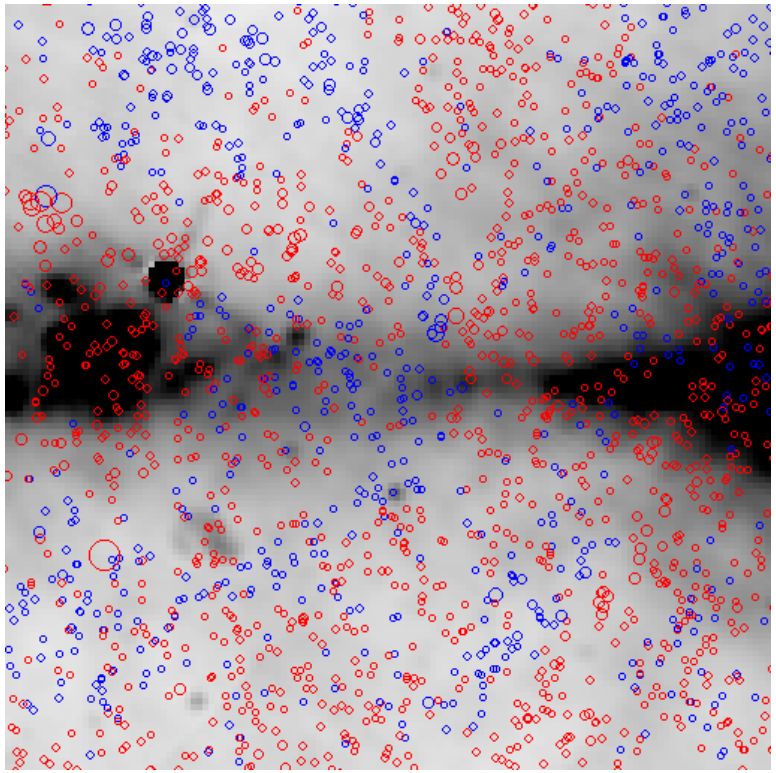
Han+ 1999

VLA SKY SURVEY

Increase polarized counts: Evolution of the "RM Grid"



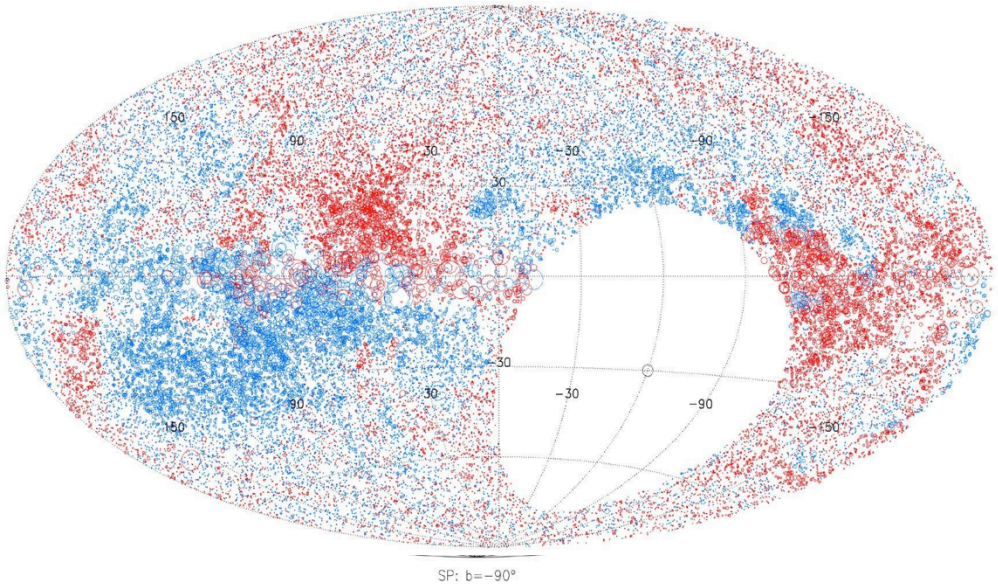
NVSS + Taylor, Stil, Sunstrum 2009

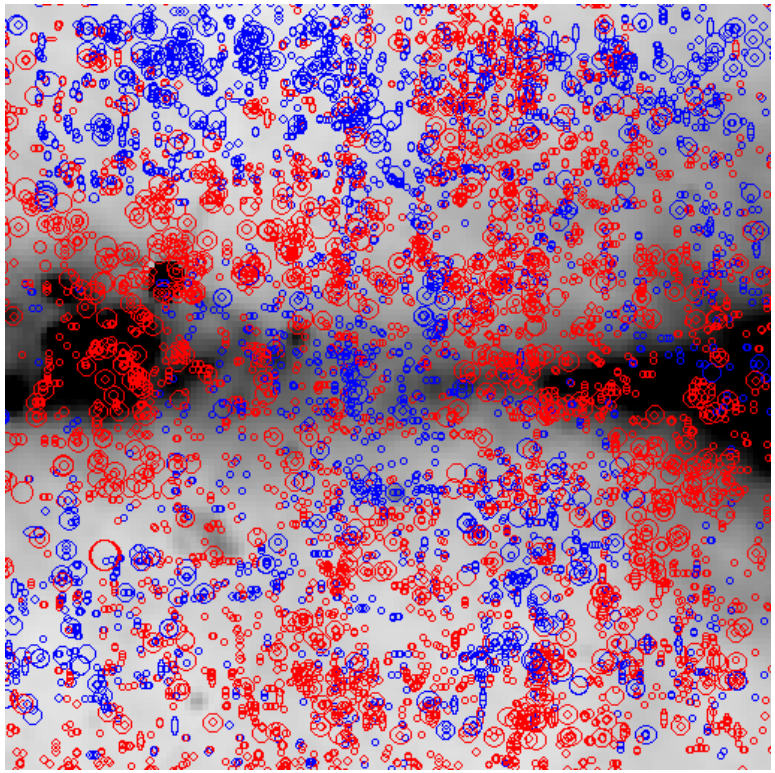


137 refs to date, including

- First determination of local "halo" field component
- Local nature of structures on 10s degree scales
- First estimate of extragalactic intrinsic RM magnitude

Increase polarized counts: Evolution of the "RM Grid"





VLASS

137 refs to date, including

- First determination of local "halo" field component
- Local nature of structures on 10s degree scales
- First estimate of extragalactic intrinsic RM magnitude

Complement the Precursor Surveys

	VLASS All-Sky	POSSUM/ WODAN	VLASS Deep (10sq deg)	MIGHTEE+ (35 sq deg)
Frequency	2-4 GHz	1.1-1.4 GHZ	2-4 GHz	0.9-1.67
Ang. Res.	3.2-3.8”	10-15”	1-1.2”	6.5”
Sensitivity	70 μJy/ bm	20 μJy/bm	1.5 μJy/bm	1 μJy/bm
** # pol srcs/ sq. deg	~ 6	15-20	60-100	~100
Max. range of Faraday Depths (scale)	560	71	560	97
Faraday Max	13,000	540	13,000	25000
Faraday Resolution	200-350	130	200-350	45
$(\lambda_{max} / \lambda_{min})^2$ *[complexity]*	2.6 - 4	1.6	2.6 - 4	3.4

** All numbers somewhat uncertain depending on effects of resolution, slope of polarized number counts, depolarization

Ground-breaking until pre-SKA

Ground-breaking after pre-SKA

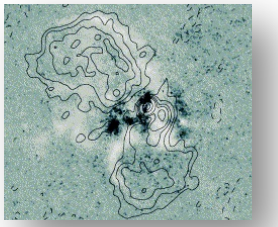
+ Tier 2, as per A. R. Taylor

SAMPLE SCIENCE: What is the interaction between AGN thermal and relativistic plasmas?

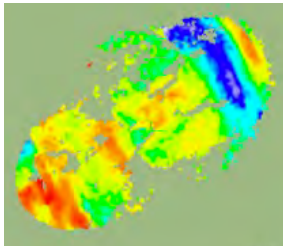
Some key physics:

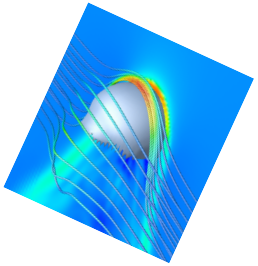
flow Mach numbers, plasma βs, field intermittency, extent of entrainment, mixing?

Current examples of interactions:



- Thermal gas around radio lobes



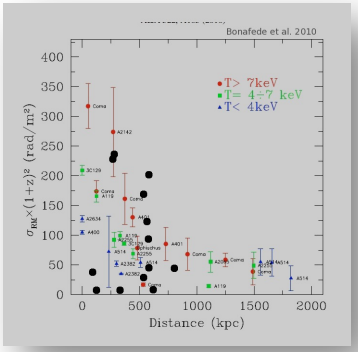


- Magnetic draping

Guidetti+11, Dursi,Pfrommer 07,08

- Influence of cluster ICM

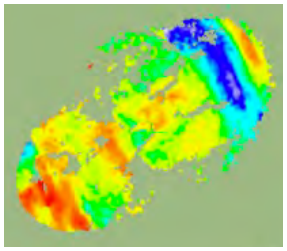
Bonafede+10



SAMPLE SCIENCE: What is the interaction between AGN thermal and relativistic plasmas?

Current RM maps in literature: ~ 50 - 100

Current Faraday structure maps in literature: ~ 2



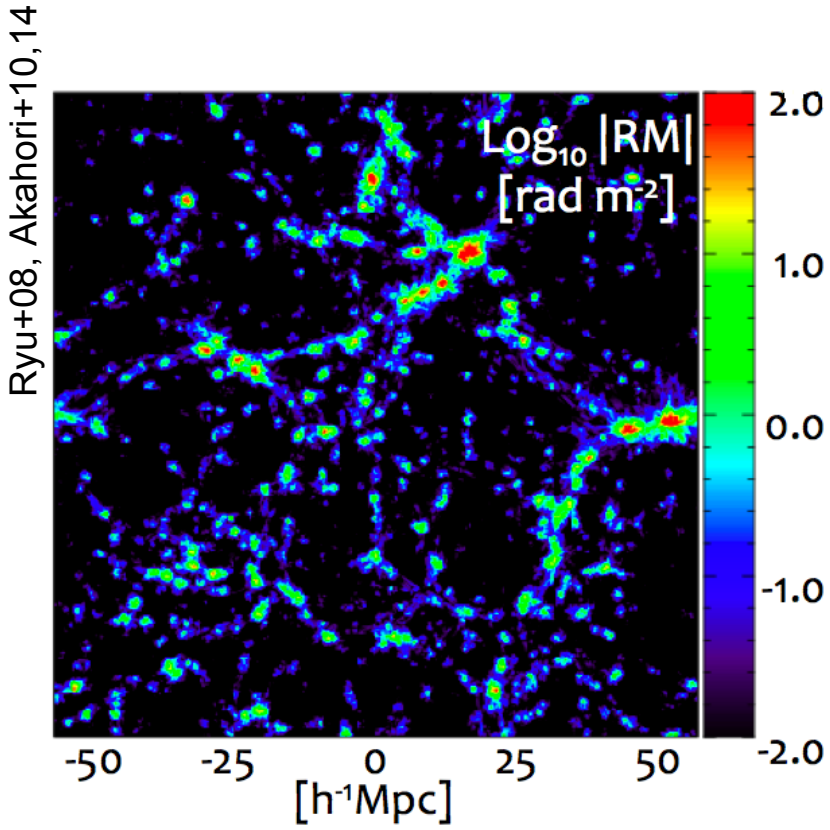
VLASS Projections for RM maps: >10,000* (conservatively)

Examine effects of:

- Source size, structure, luminosity, spectral index
- Host properties
- Environment
- Redshift

- $2x10^5$ sources * (brightest 10%) * (30-60% resolved)
  resolved estimated from GOODS-N (Rudnick & Owen 14), and ATLAS (C. Hales, private comm.)

SAMPLE SCIENCE: How do galactic & large scale fields evolve over cosmic time?



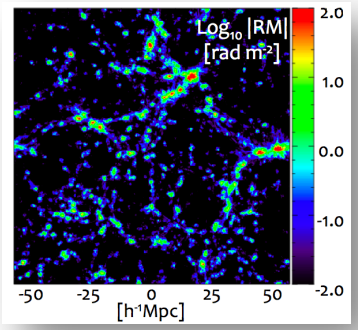
RM contributions from

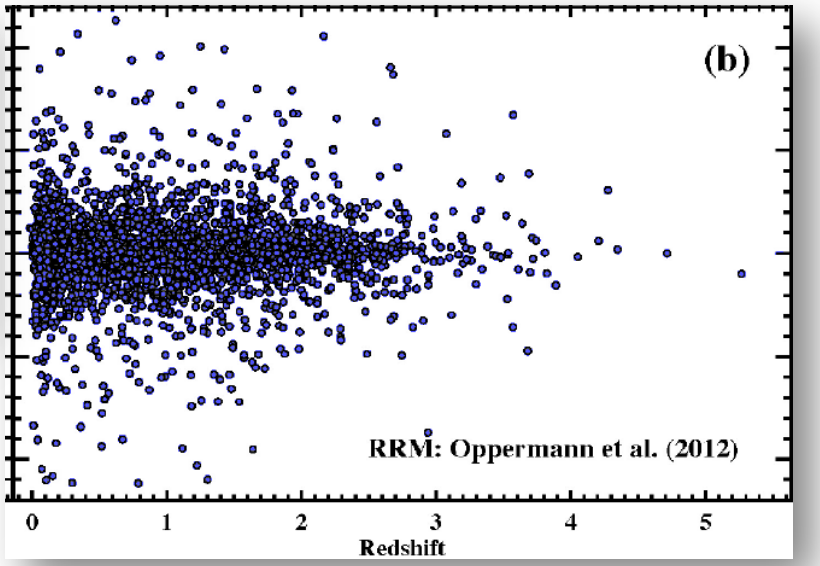
- Radio source (and Faraday complexity)
- Intervening clusters, groups, galaxies
- Milky Way
- COSMIC WEB

→ Study z dependence for both source astrophysics AND for large-scale structure

SAMPLE SCIENCE: How do galactic & large scale fields evolve over cosmic time?

Hammond+2012 NVSS pol & FIRST IDs

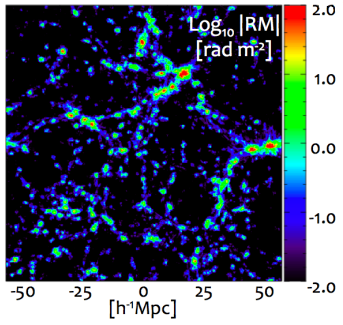




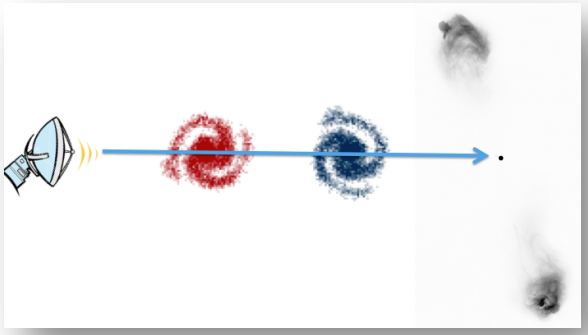
- Fractional polarization decreases at z>0.5
  ← change from galaxies to quasar cores
- No change in σ_{RM} with z (within populations)
- σ_{RM} ~10-15 rad/m^2 due to unknown intervenors

4003 sources w/z →
> 20,600, VLASS
+ polarization/RM maps

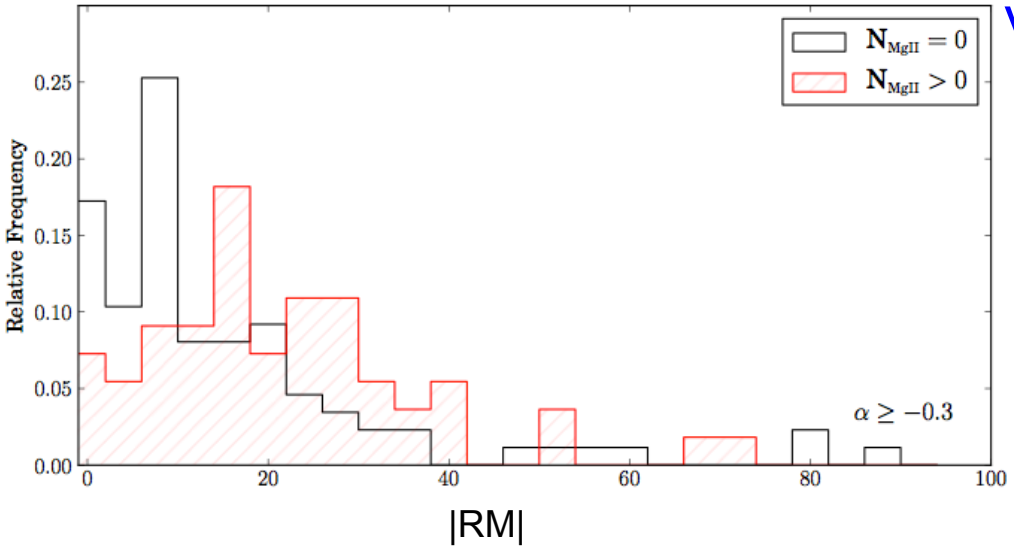
SAMPLE SCIENCE: How do galactic & large scale *(cosmic web)* fields evolve over cosmic time?



RMs for Mg II absorbers (Farnes+14)



Current status:
Polarized sources+SDSS spectra: 599
(400 being observed now on VLA)

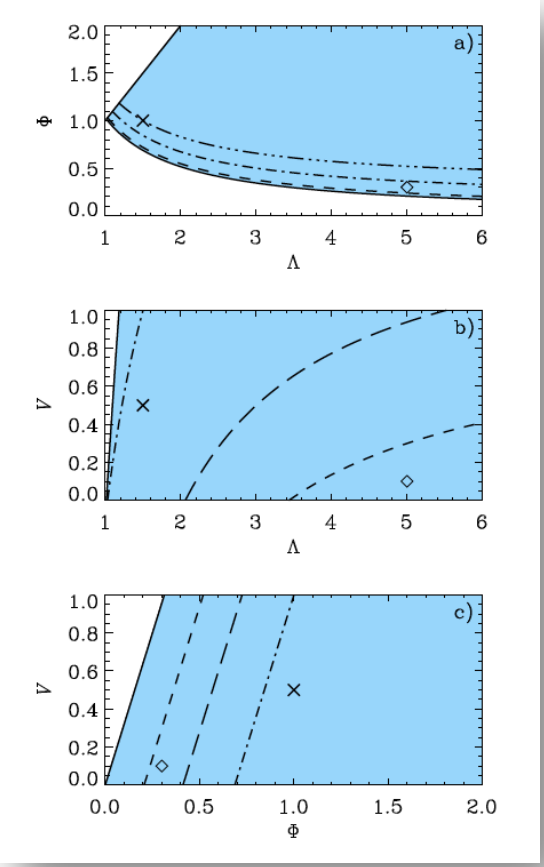


VLASS Projections: > 3000 sources
15 redshift bins +
angular size of absorber

SAMPLE SCIENCE: How do disk galaxy ordered magnetic fields evolve/relate to star formation?

Key physics:

under what conditions can galactic dynamos create large scale fields?



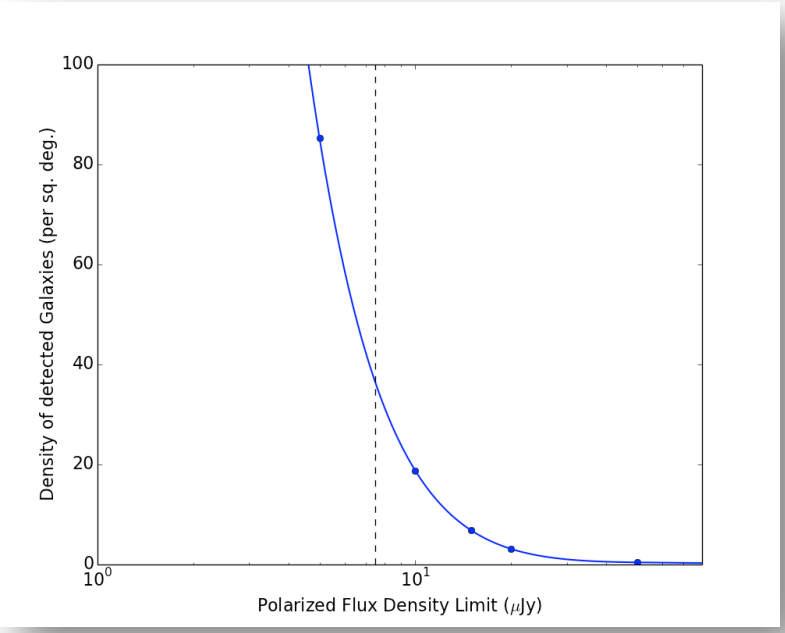
Shaded areas: growing solutions for dynamo
Chamandy, Taylor, Shukurov, in prep.

One useful set of dimensionless parameters:

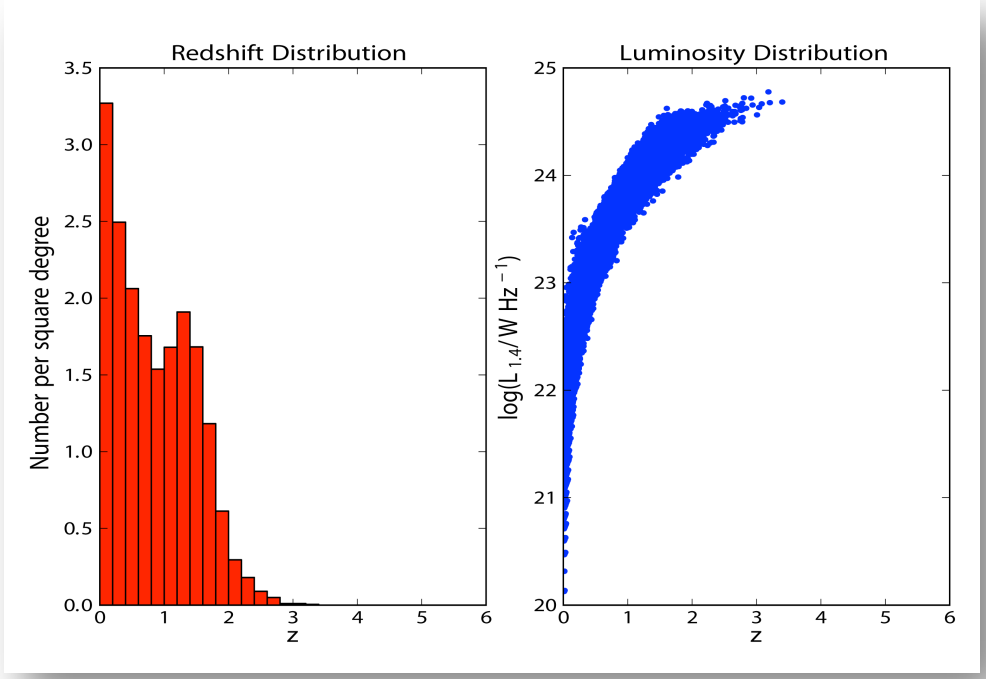
- Λ half thickness of disk in correlation lengths
- Φ ratio of Coriolis force / inertia
- V ratio of outflow / turbulent rms velocities

SAMPLE SCIENCE: How do disk galaxy ordered magnetic fields evolve/relate to star formation?

a DEEP problem



Polarized detections above 10 μJy



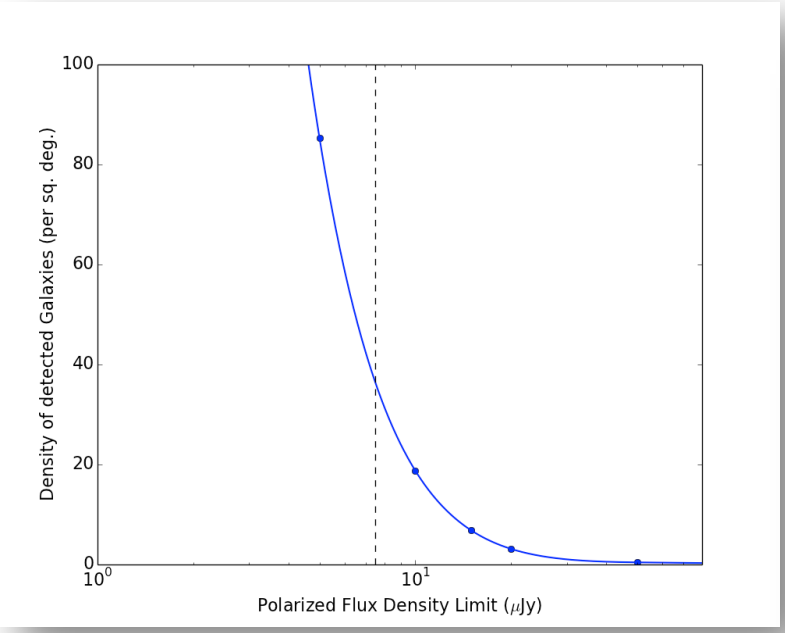
Courtesy Jeroen Stil

Sband Pol. – 3-4x higher than Lband
Direct detection: 10s per square degree

- Most SF disks likely slightly resolved, 1-2 beams
- Based on Lacy recovered flux simulations:
  some loss for z<0.25
- More quantitative study necessary (selection effects)

SAMPLE SCIENCE: How do disk galaxy ordered magnetic fields evolve/relate to star formation?

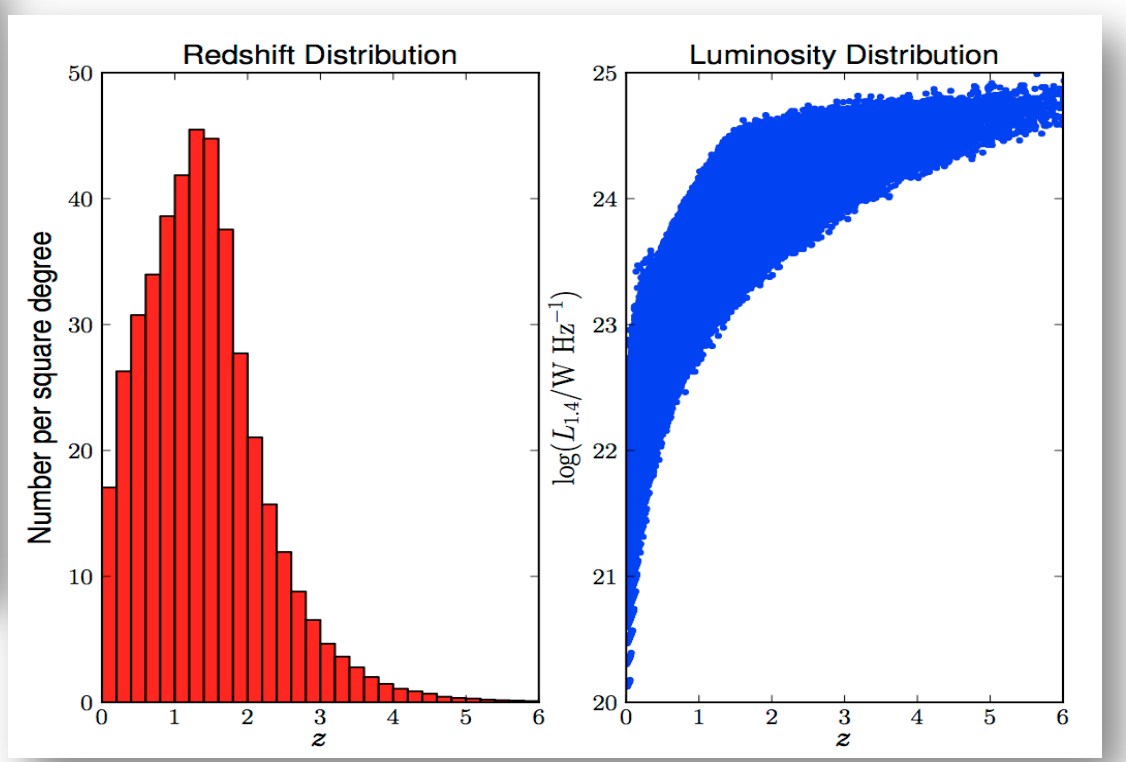
a DEEP problem



Stacking of >10^4 IR sources

Detection to ~1 μJy

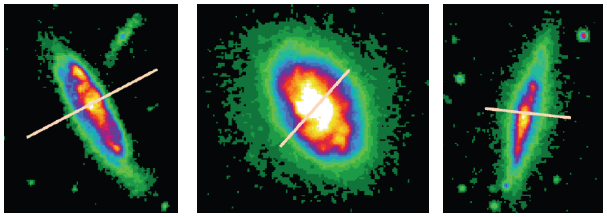
Polarized distributions above 1 μJy



Courtesy Jeroen Stil

SAMPLE SCIENCE: Weak Lensing

Polarization angle = minor axis; NOT affected by lensing



Effelsberg, 6 cm
= Sband@ z=0.5

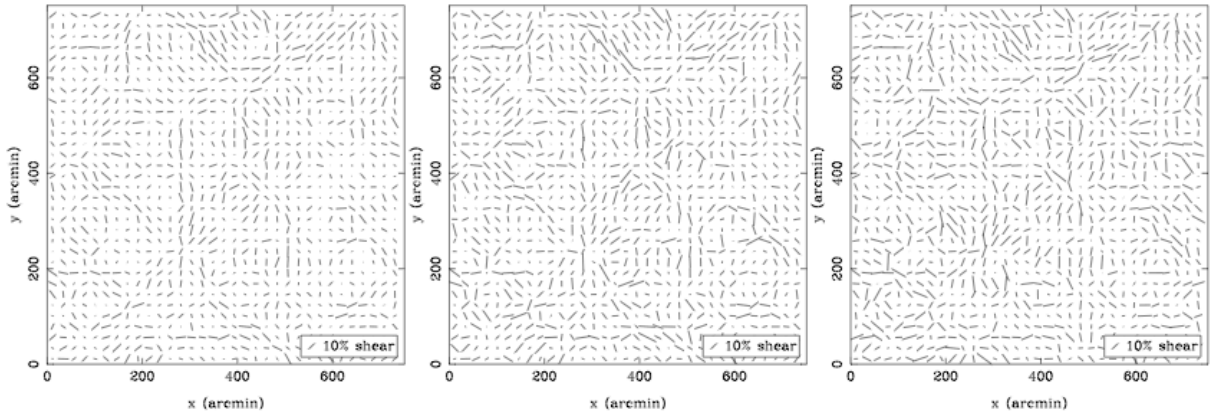
courtesy A. R. Taylor

→ Intrinsic disk angle need not be assumed isotropic

Input Shear

Derived : **6** /arcmin^2

Derived : **POL+ 0.6** /arcmin^2



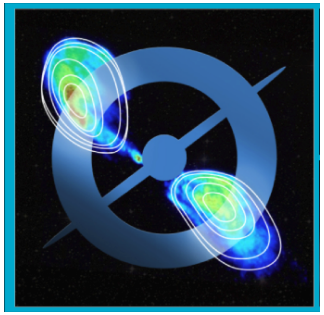
Brown & Battye 2011

VLASS DEEP: First demonstration of this technique

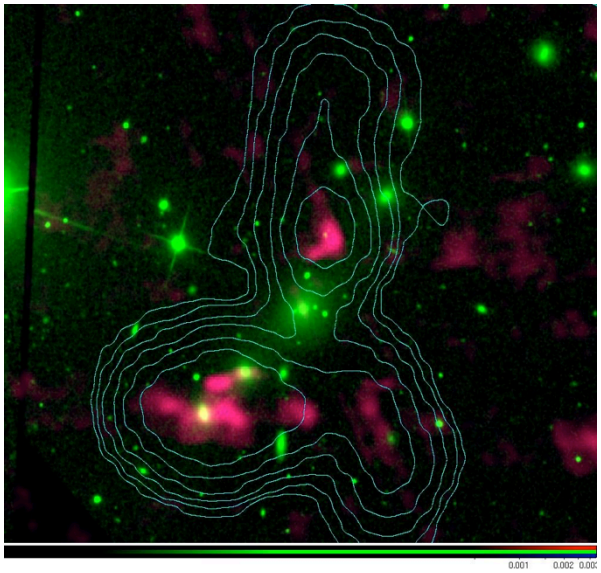
Q V.2 (d) re: polarization

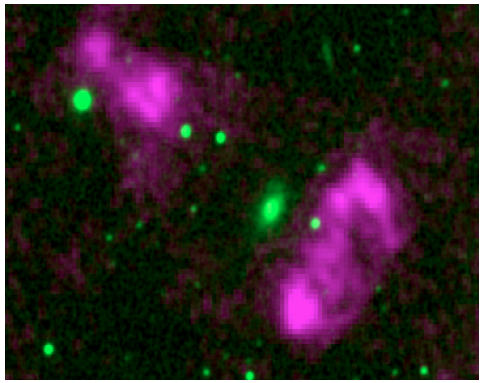
LEGACY SCIENCE:

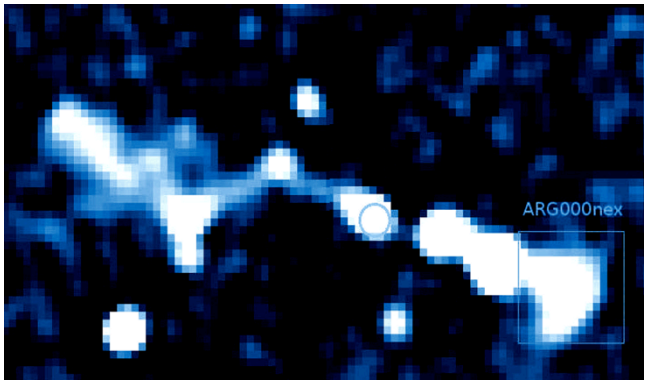
example(s) from Radio Galaxy Zoo
(see presentation Thurs. by S. Deustua)

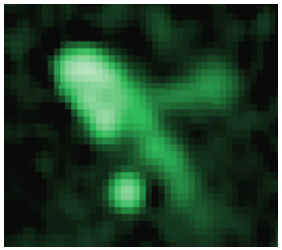


FIRST + WISE, > 10^6 classifications to date!
example: looking for ICM turbulence
VLASS, connect with RM structure









VLASS Polarization

- ***Goal: a unique, game-changing, polarization survey***
  - High frequency: probe depolarized population
  - High spatial resolution: Faraday maps for most sources
  - Large bandwidth: characterize Faraday complexity in beam and along line of sight; provide k-corrections
  - High sensitivity: [All-sky] increase background probes x6; [Deep] detect new galaxy population
  - Complementary to SKA-precursors

Addendum:

Responses to Condon review

• JC: There is no comparison with EMU

This is now included in this presentation; frequency and bandwidth and angular resolution are key VLASS advantages

• JC: Proposal conflates polarized flux and brightness

The counts were actually derived from 1.6” polarized counts, not from the NVSS as stated in the proposal, so are actually conservative estimates of flux/beam.

• JC: The DEEP surface brightness detection limit is too high to detect low-redshift Milky-Way type galaxies

Agreed. The plots in the current presentation show galaxies at all redshifts, but for $z<0.25$ the detection rate will be lower.