A SEARCH FOR MAGNETIC FIELDS *AROUND* DISK-LIKE GALAXIES AT Z~0.5

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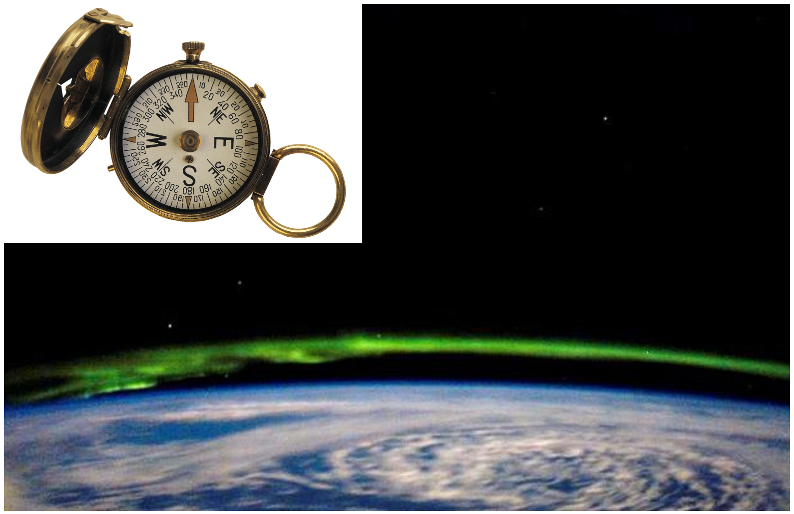
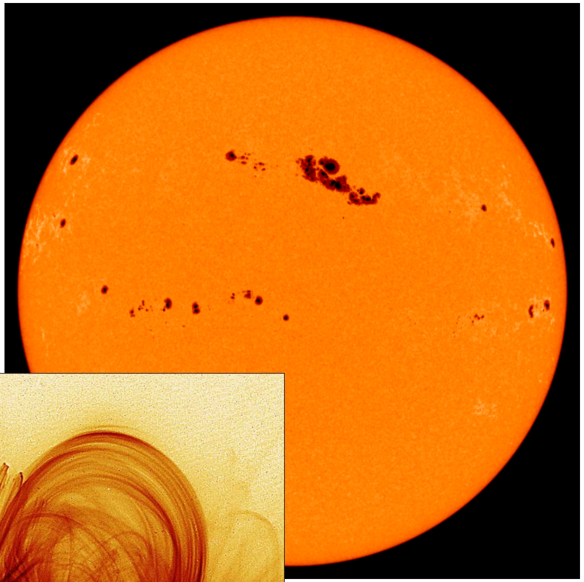
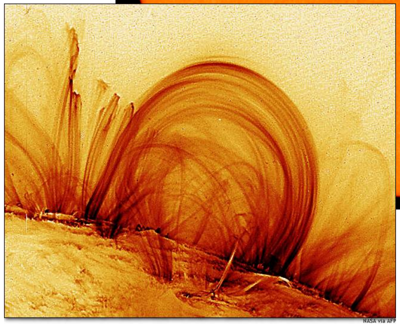
Why study magnetic fields?

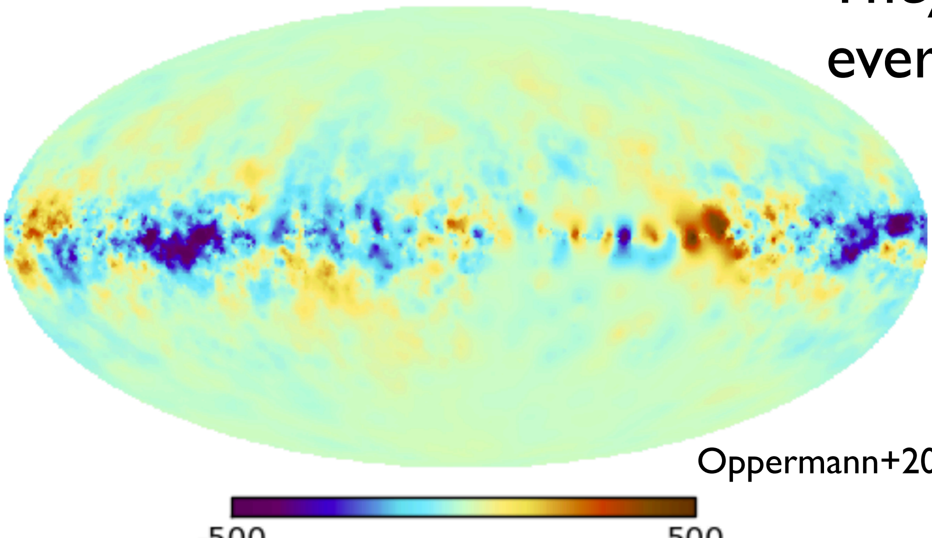




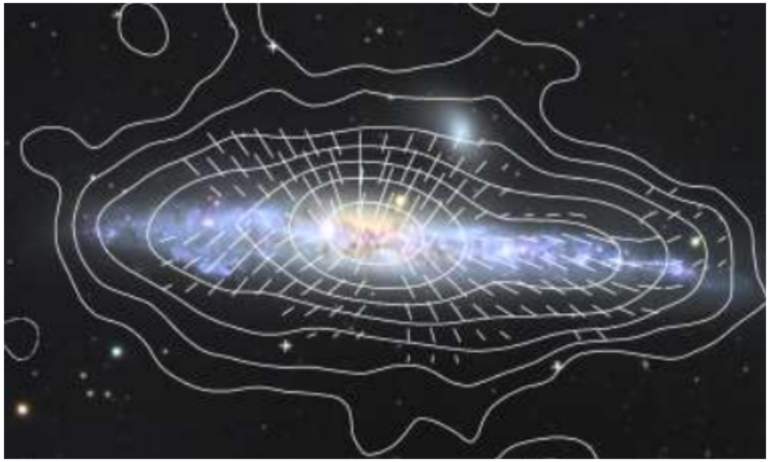


SOHO-NASA,ESA

They are everywhere!



Oppermann+2015



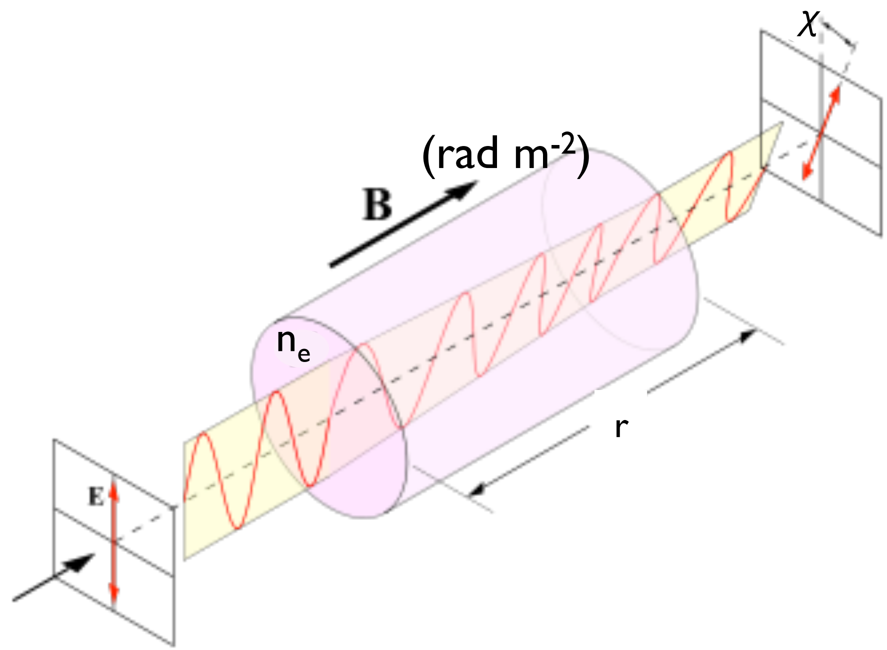
Krause+2012

Outstanding Questions

- Origin
  - How and when did the first magnetic fields form in the universe?
- Growth and amplification
  - How do the strength and structure of magnetic fields evolve with redshift?
- Dynamics
  - (How) Do magnetic fields affect astrophysical processes that in turn define the evolution of galaxies?
- Beyond galaxies
  - Are there magnetic fields in the IGM? If so, how did they get there and what are their strengths?

Observing Magnetic Fields

- Synchrotron emission
  - B in plane of sky, radio
- Polarized dust emission
  - B in plane of sky, IR and submm
- Zeeman Effect
  - B along line of sight, radio and submm
- Faraday Effect
  - B along line of sight, radio



$$\phi(r) = 0.81 \int_{there}^{here} n_e \vec{B} \bullet d\vec{r}$$

n_e = cm^{-3}, **B**= μ G, **dr**=parsec

Simplest case: ϕ = RM = $\Delta \chi / \Delta \lambda^2$

Faraday Rotation

$$\phi(r) = 0.81 \int_{there}^{here} n_e(z) B_{\parallel}(z) \frac{1}{(1+z)^2} \frac{dl}{dz} dz$$

Observer in Milky Way

Magnetized stuff in between

Source of linearly polarized emission

How to study RM in distant galaxies

- Theories predicted

(e.g., Parker 1979)

  - μ G strength fields to be a relatively recent phenomenon
  - Galactic magnetic fields would be substantially weaker at z~2.0
  - Should see change in RM as function of redshift

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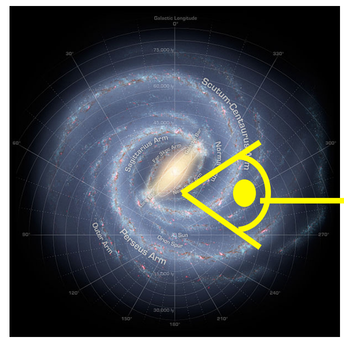

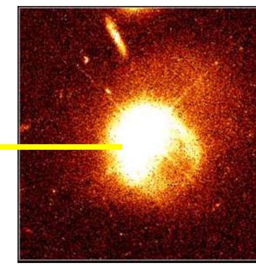

Control:

$RM_{Obs.} = RM_{MW} + RM_{IGM} + RM_{QSO} + \sigma$

How to study RM in distant galaxies

- Theories predicted (e.g., Parker 1979)
  - μ G strength fields to be a relatively recent phenomenon
  - Galactic magnetic fields would be substantially weaker at z~2.0
  - Should see change in RM as function of redshift
- Observational RM experiments were designed with control and target samples (e.g., Oren & Wolfe 1995, Bernet +2010)

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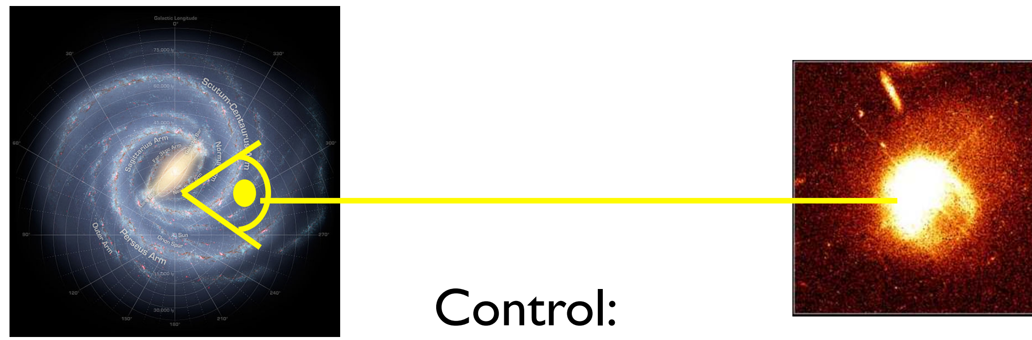

Control:

$RM_{Obs.} = RM_{MW} + RM_{IGM} + RM_{QSO} + \sigma$

Target:

$RM_{Obs.} = RM_{MW} + RM_{INT} + RM_{IGM} + RM_{QSO} + \sigma$

Recent Work:

Bernet +2010

268 QSOs (from Kronberg+2008)

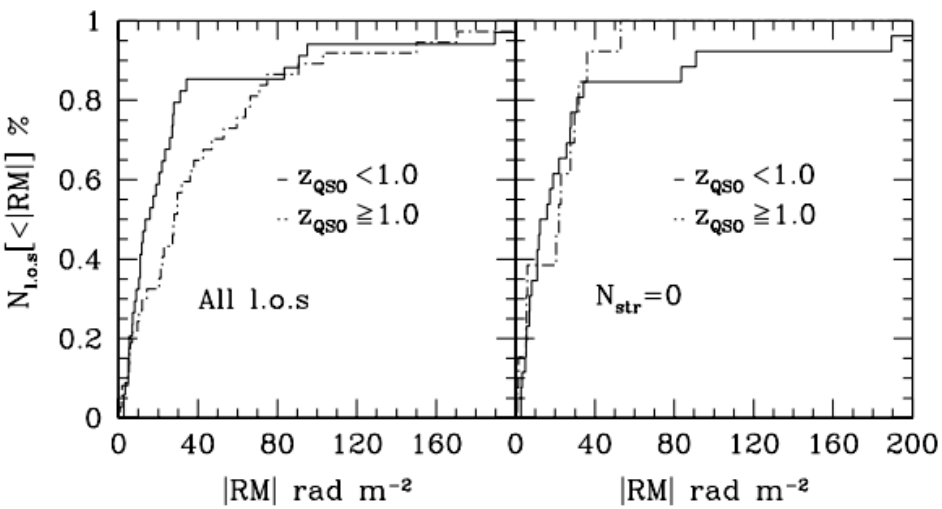

Fig. 8: Distributions of QSOs split into two redshift bins. All observed QSOs (left), QSOs without strong MgII absorption (right).

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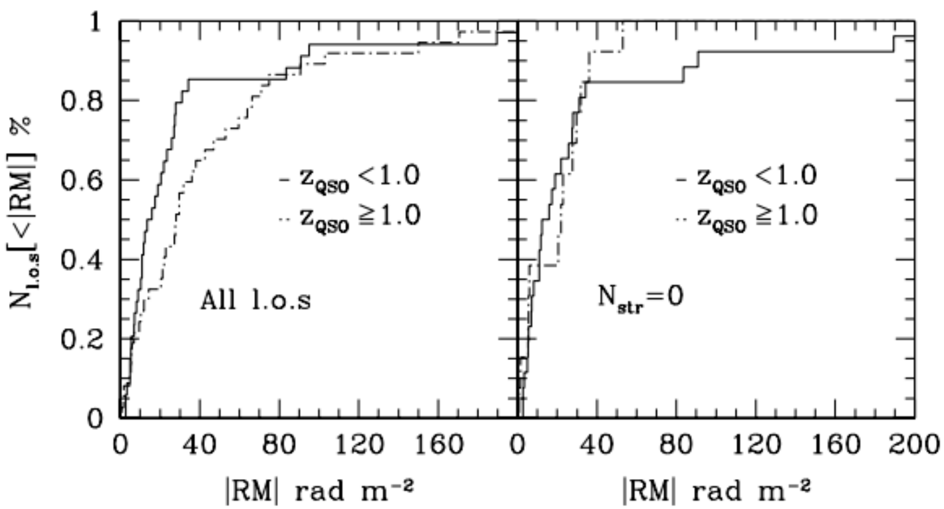

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Bernet +2013

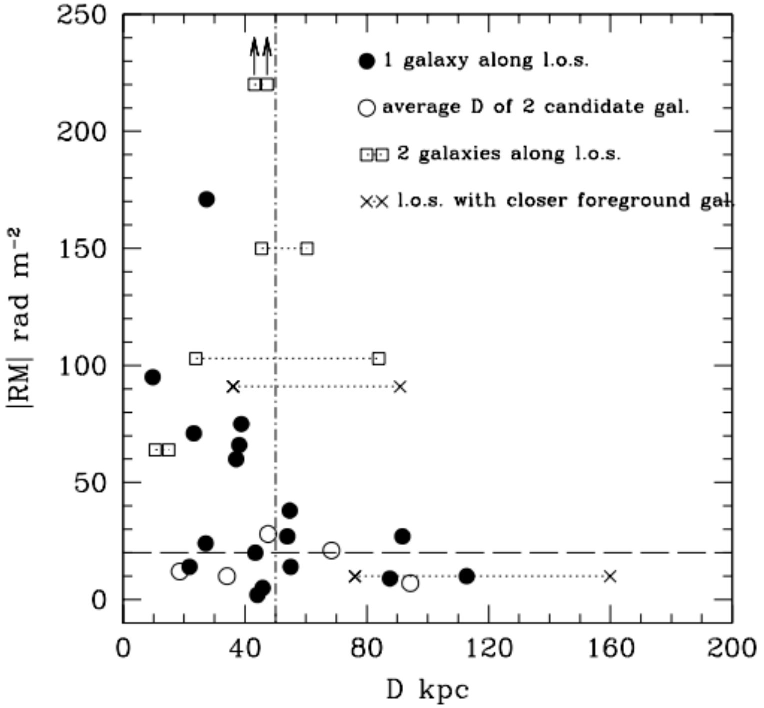


Fig. 2: |RRM| vs impact parameter of MgII absorber

Infer B~10uG

Supports FIR-radio correlation and magnetized outflows

Recent Work: Farnes+2014

- 599 MgII absorption systems with polarized background radio sources (cross-matched Farnes+2014 radio catalog with Zhu&Menard 2013 MgII catalog)
- Looked at spectral index of absorbers
  - Difference between steep ($\alpha \leq$-0.7) and flat spectrum ($\alpha \geq$-0.3) radio sources
  - Flat spectrum (core) sources probe same region at optical
- Detect RM contribution of 24rad/m^2

(k-corrected) due to MgII absorbers in flat spectrum sources → 1.8±0.4uG

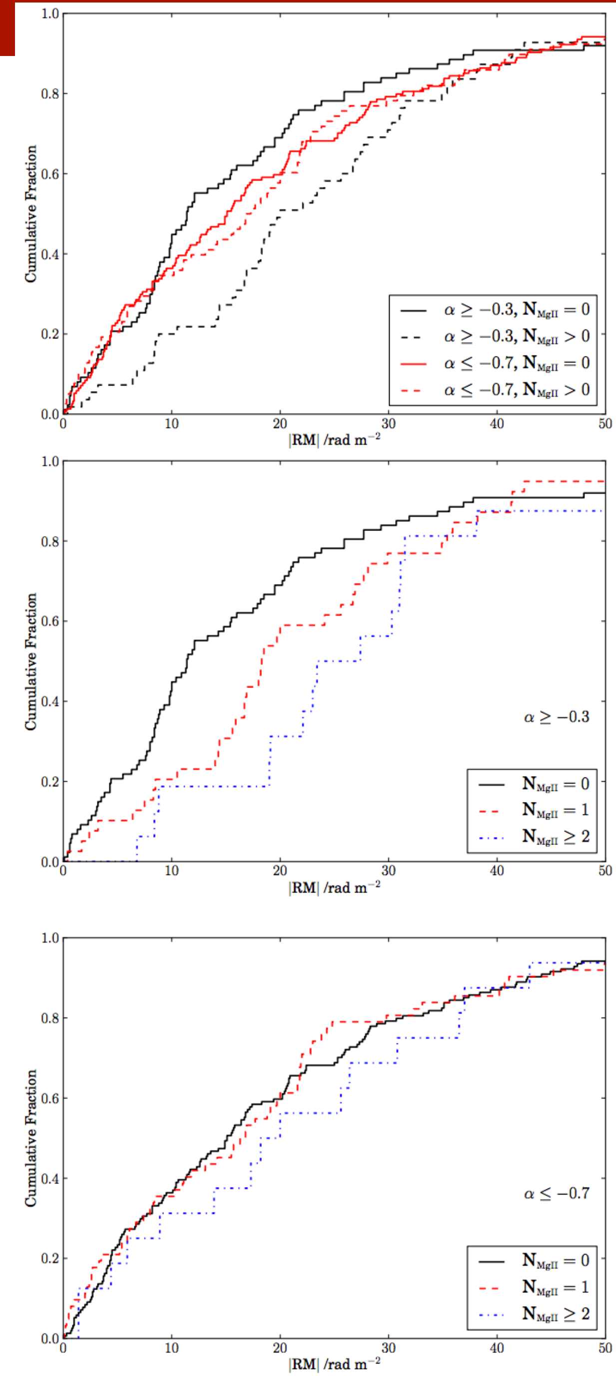
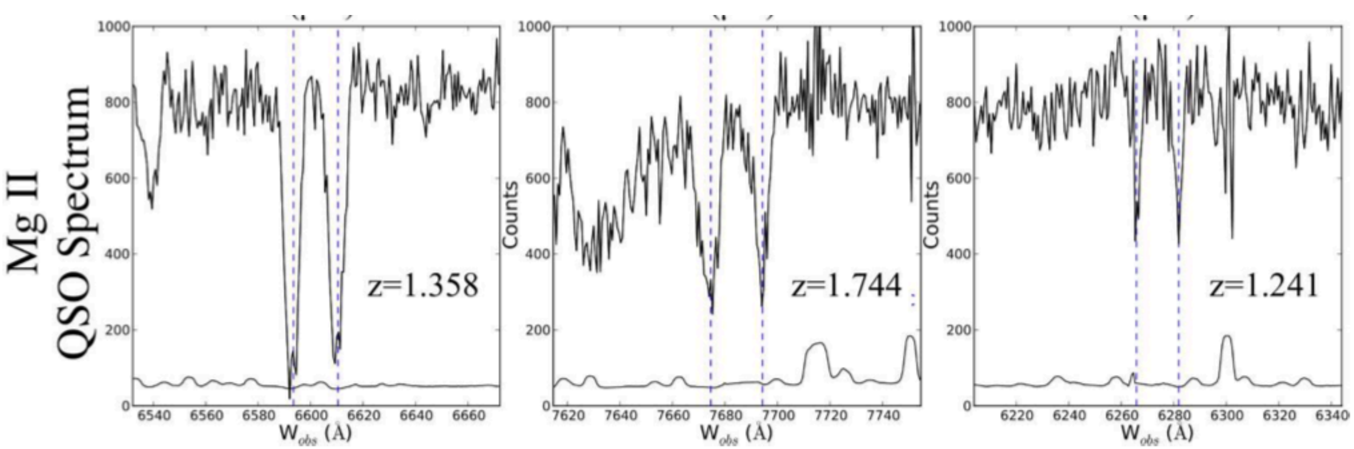


Fig. 5

Why MgII absorbers?

- Traces HI
  - $10^{18} < N(HI)\ cm^{-2} < 10^{22}$ (e.g., Rao+2006), $T \sim 10^4$ K (e.g., Charlton+2003)
- Photo-ionized gas clouds associated with galaxies: disks, halos, HVCs, dwarf galaxies, or galactic outflows
- Probe conditions in and around evolving galaxies

What are the magnetic field properties in these environments?

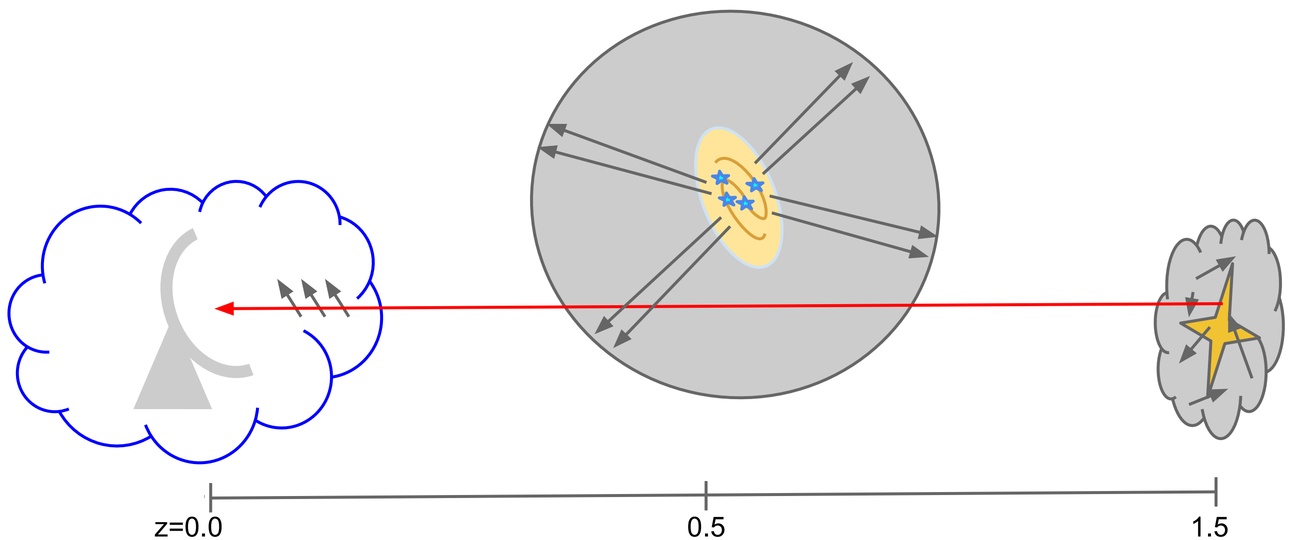


Lundgren +2012 DEIMOS spectra of high-z QSO with MgII absorption systems

Our VLA Study: Building off these results

Idea:

1) Find QSOs with *single*, strong MgII absorption in SDSS
2) Check list of objects against previous radio surveys (NVSS and FIRST)
3) Build control sample, radio sources *without* strong absorption features
4) Observe with VLA!



Observer in the Milky Way
Homogeneous magnetic field along the line of sight

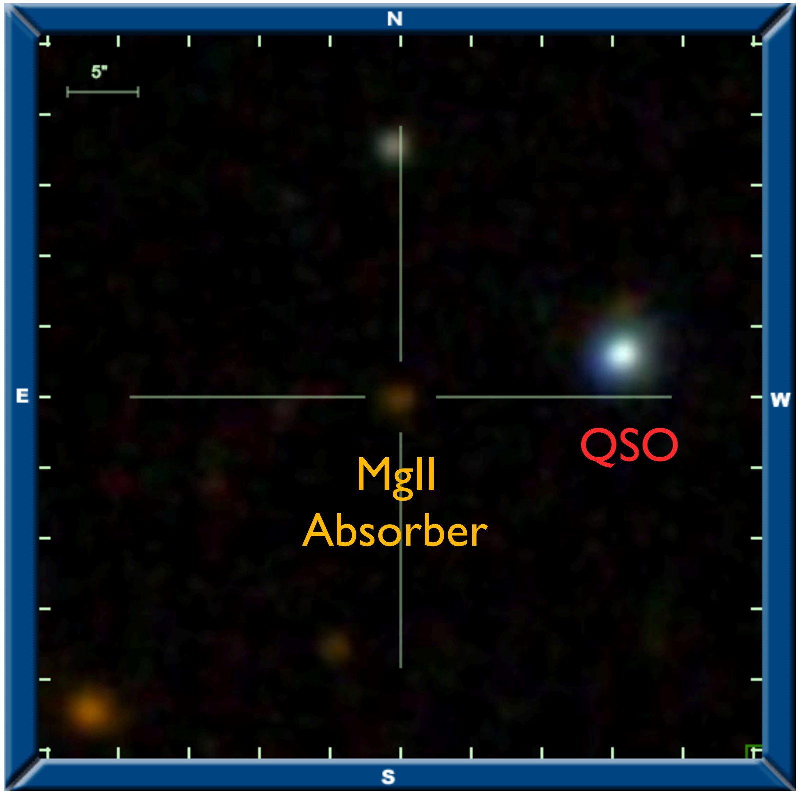
Intervening System
Homogeneous magnetic field in or near the MgII absorbing system

Intrinsic RM system
Inhomogeneous magnetic field near or inside the emitting region

VLA Observations taken during 2014 & 2015

- 38 QSO sightlines with single MgII absorption feature AND photometric detection for absorber!
  - Within 70kpc of QSO
  - $0.38 < z_{MgII} < 0.65$
  - $0.65 < z_{QSO} < 1.9$
- 112 Control sightlines with roughly same distribution in RA and redshift
- S-band (2-4GHz)
  - Mitigate depolarization
  - Broadband for RM synthesis & Q-, U-fitting
- VLA A- & BnA- Configurations
  - Resolve our radio sources!

SDSS Image of one target



Preliminary results!

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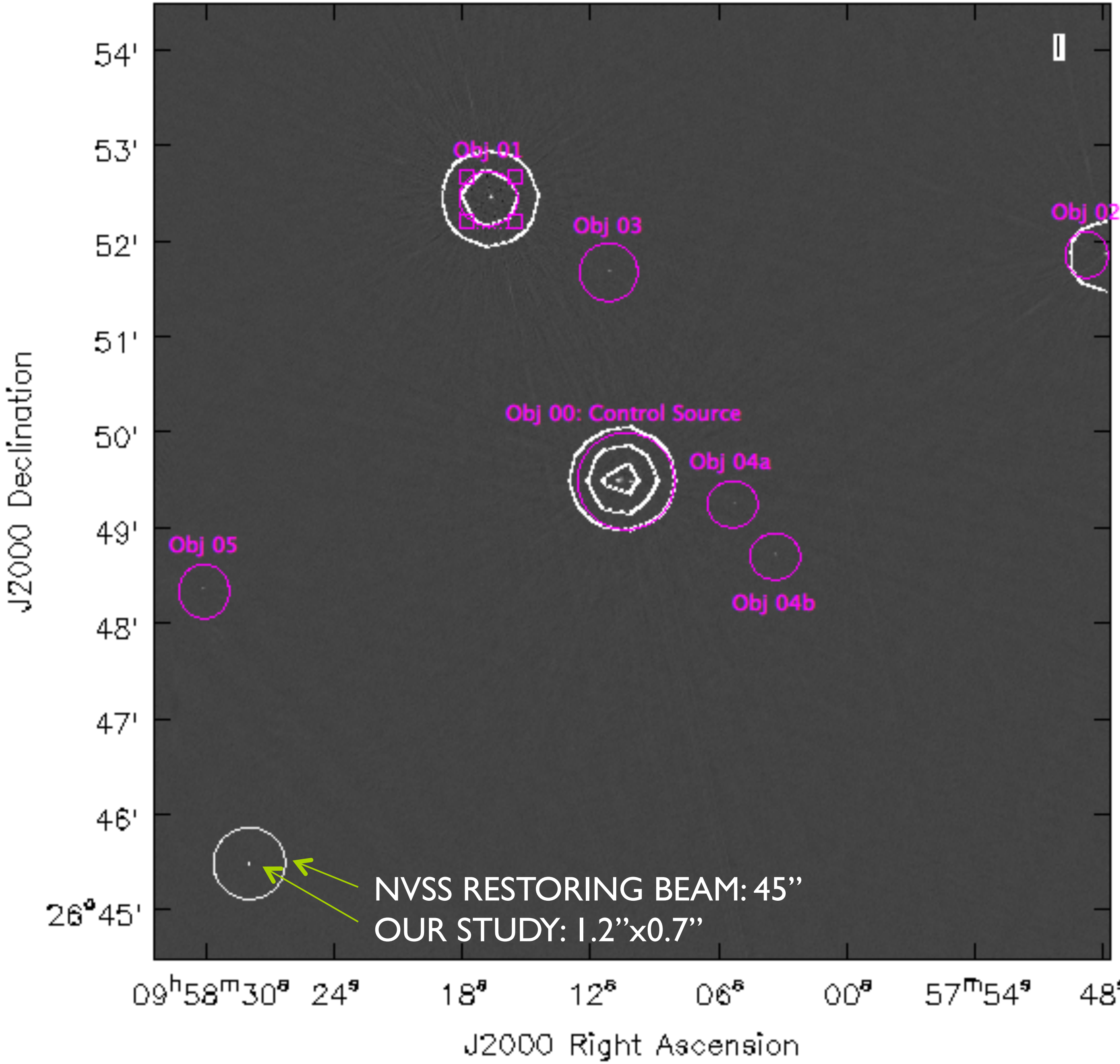
Primary beam ~15'
Pixels are 0.2"
20uJy rms



Preliminary results!

Primary beam ~15'
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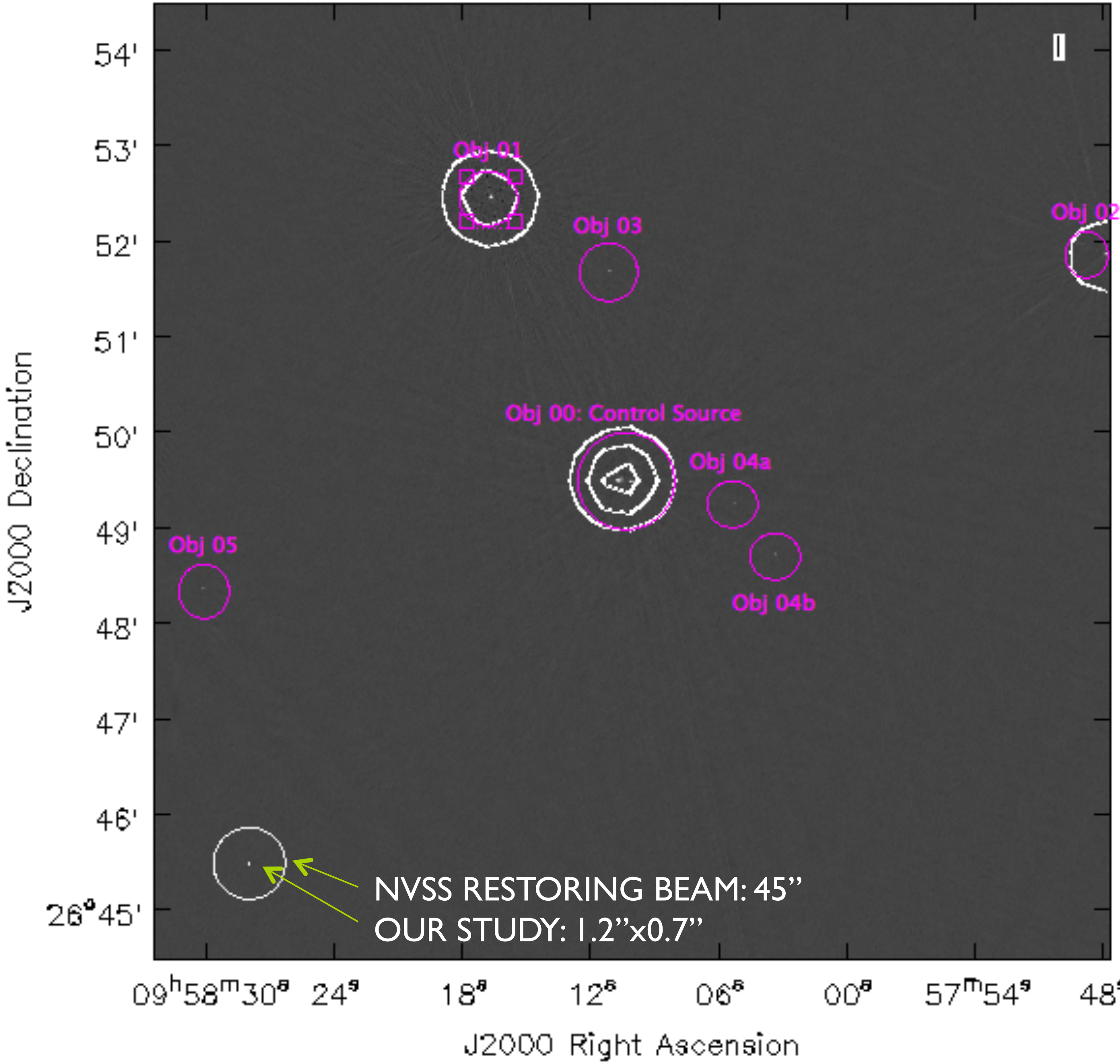
20uJy rms

We want to determine RM 3 ways:

1) Fit slope of PA vs. λ^2
2) RM Synthesis
3) Q-,U-fitting



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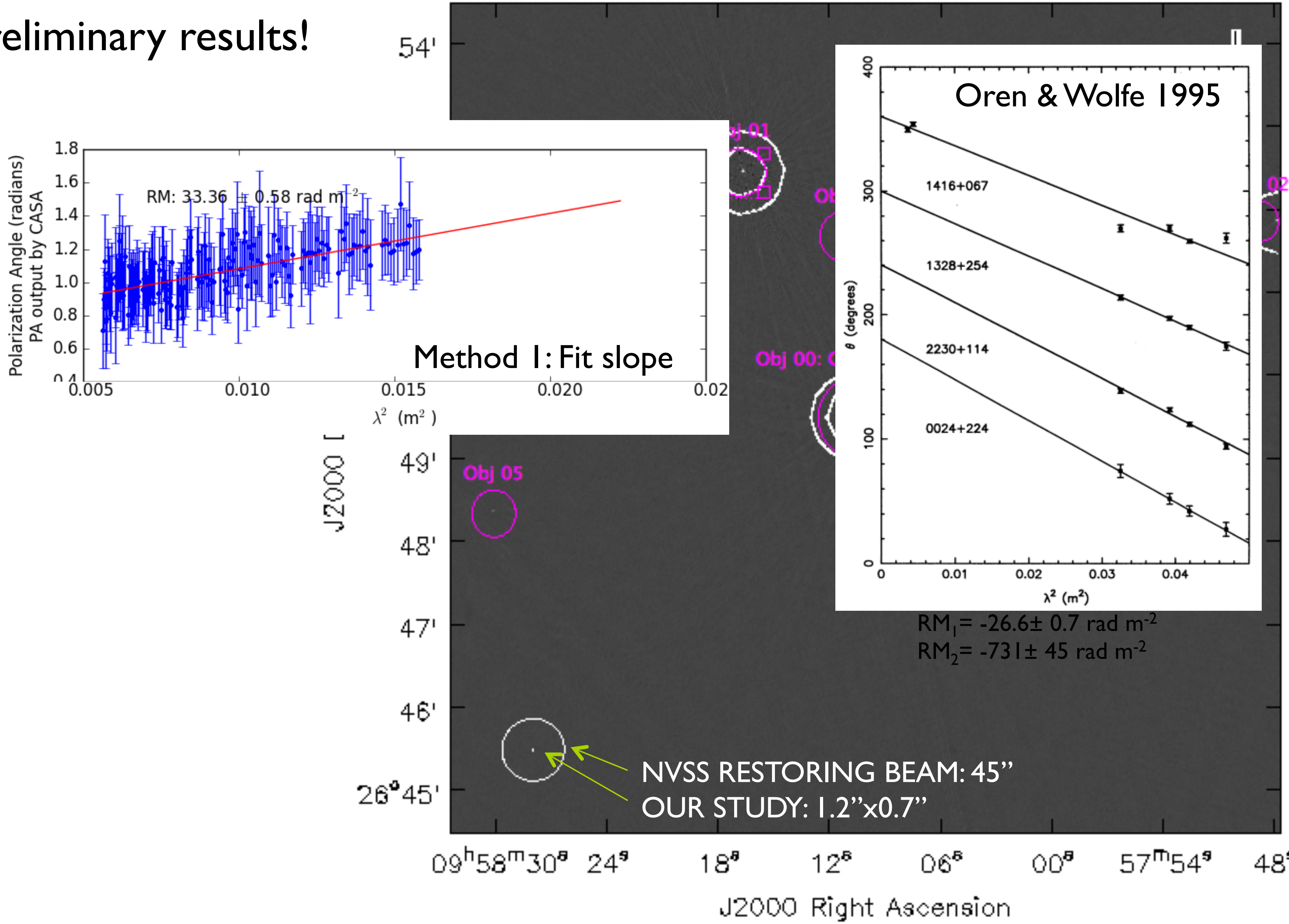

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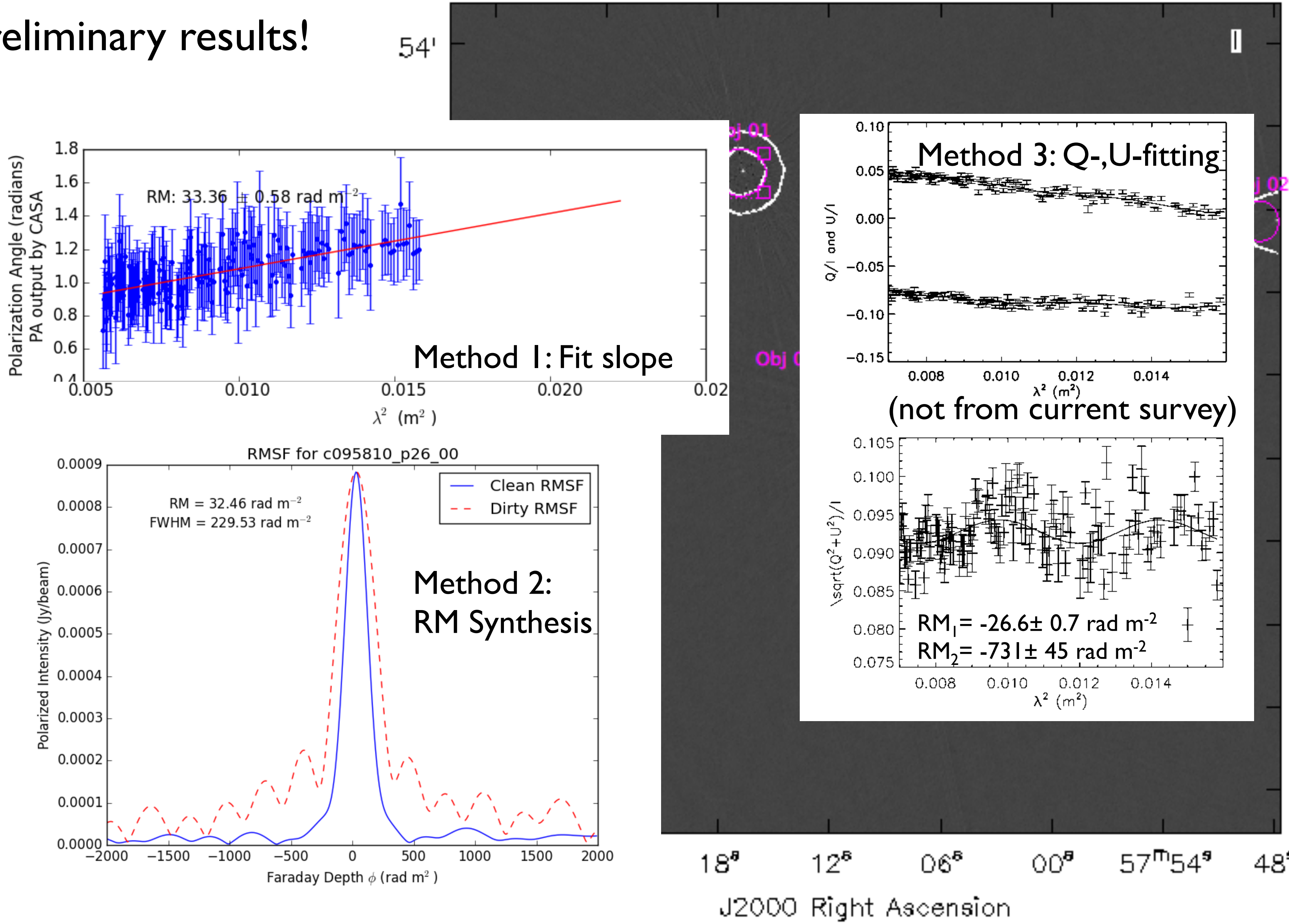

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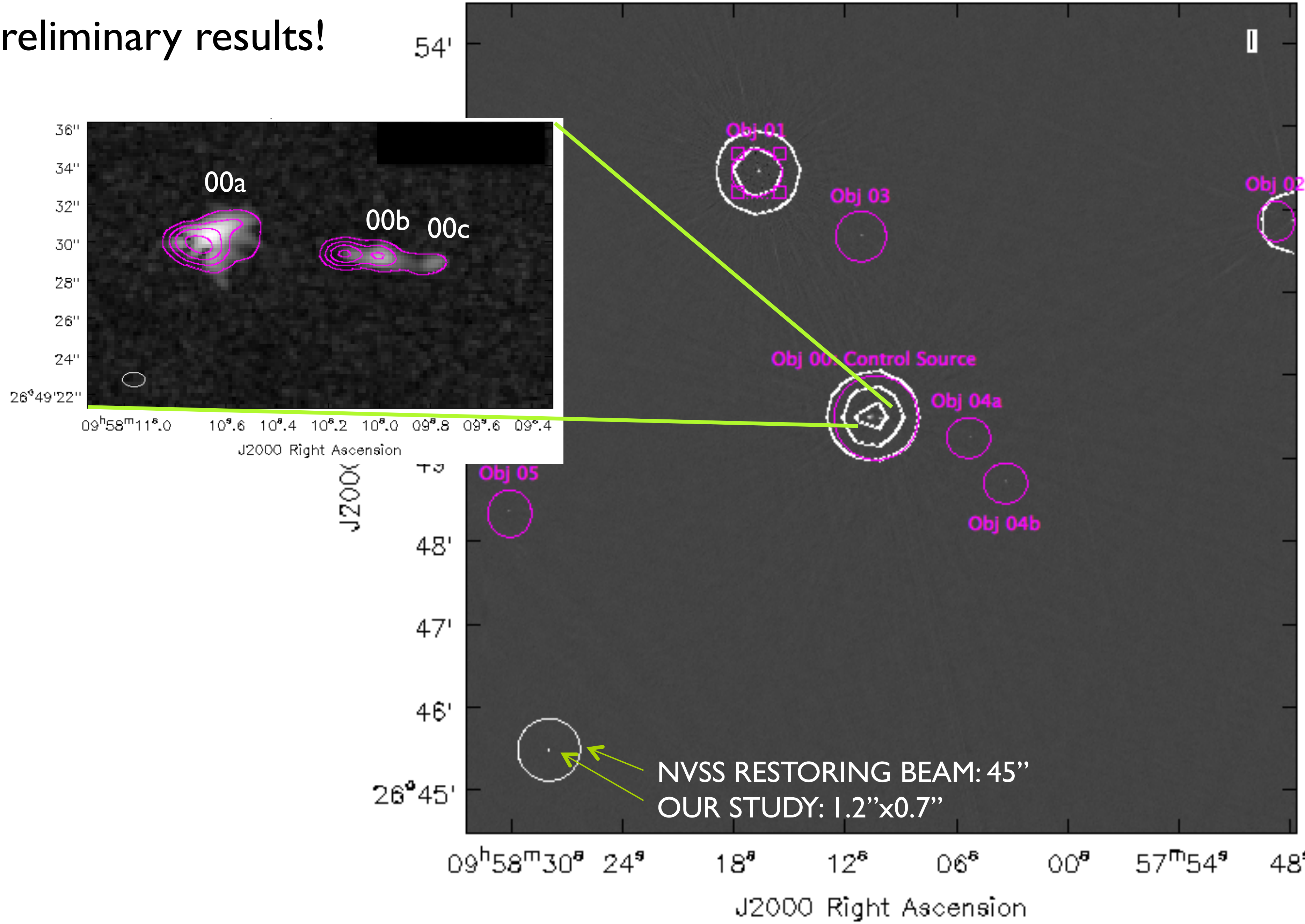

Preliminary results!

Obj	SDSS z	α	Pol.	Pol. S/N	% Pol	RM_{obs}		NVSS Pol.	NVSS % Pol	NVSS RM_{obs}
			(mJy/ beam)			(rad/ m^2)		(mJy/ beam)		(rad/ m^2)
00a	1.5	-0.98	0.88	49	19.5%	+33 ±2.5		3.88 ±0.24	4.01%	+44.1 ±13.1
00b	1.5	-0.82	0.36	20	12.2%	+30 ±5.5		3.88 ±0.24	4.01%	+44.1 ±13.1
00c	1.5	-1.05	0.19	10	19.5%	+40 ±10.6		3.88 ±0.24	4.01%	+44.1 ±13.1
01	0.678 (?)	-1.12	0.12	6.8	0.6%	+141 ±16.3		-	-	-
02	(?)	+0.13	0.12	6.7	1.0%	+7 ±16.5		-	-	-
03	0.317	-0.64	0.08	4.6	6.3%	+44 ±25.0		-	-	-

RMS~20uJy

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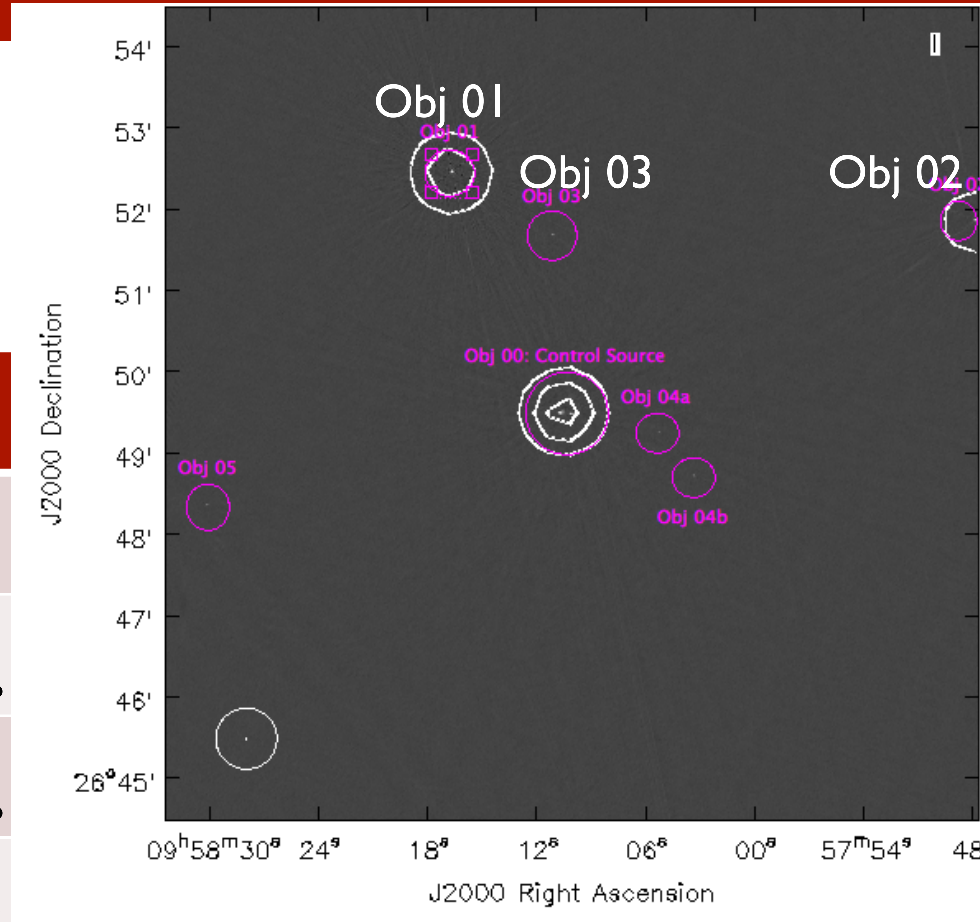

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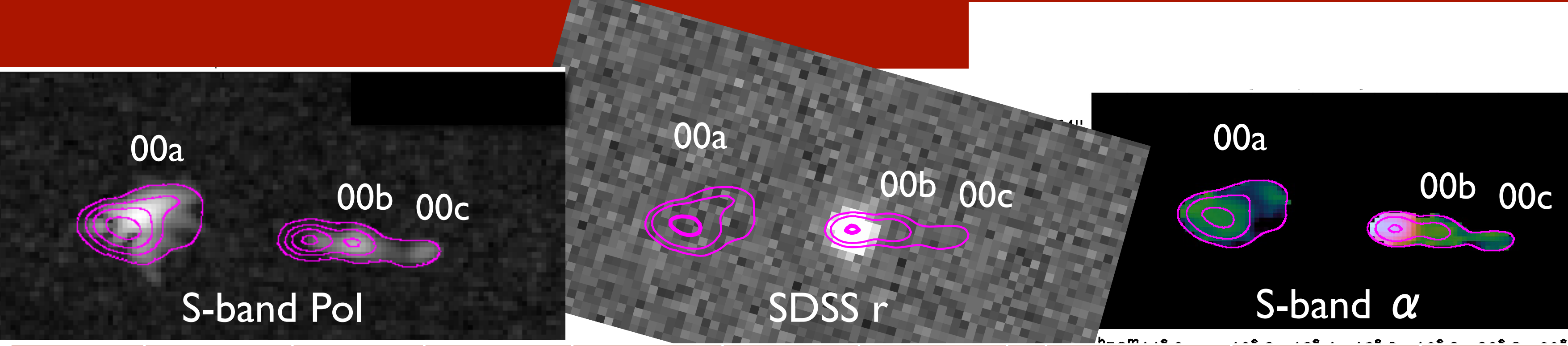
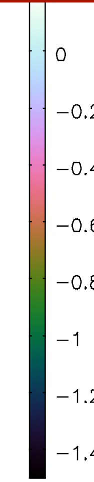
New polarization detections!

RM

RMS~20uJy





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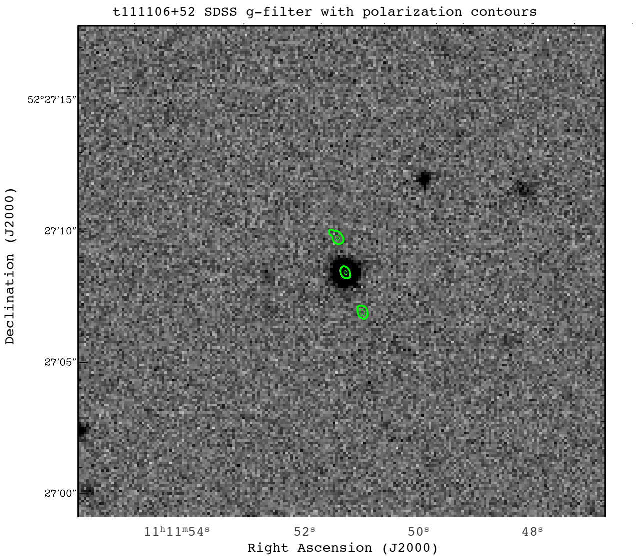
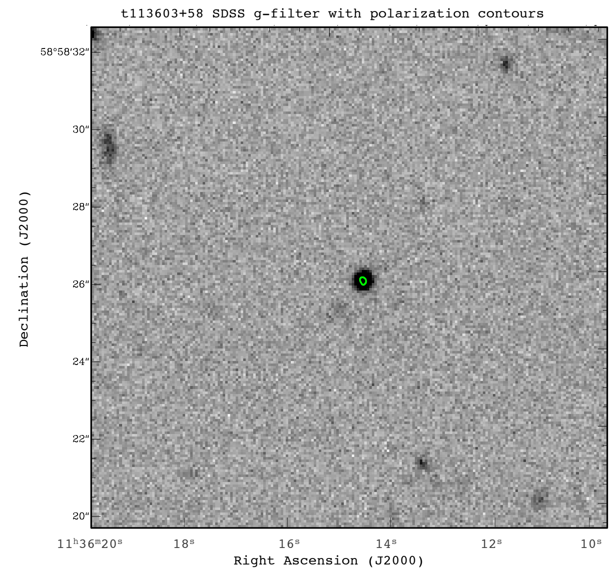
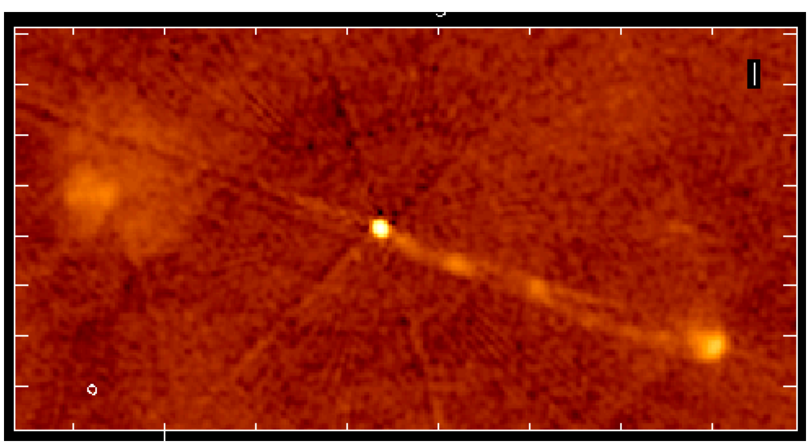
RMS~20uJy

Teaser of what is to come

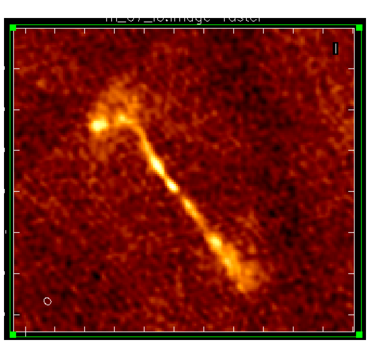


Example target QSOs
←RM~21.1 rad/m^2
RM~4.2 rad/m^2 →





← Target QSO
Field AGN→



Summary

Current best estimates for magnetic fields in and around young, disk-like galaxies is 1.8±0.4um (Farnes + 2014) using a broadly sampled data set (599 QSOs with $N_{MgII} \geq 1$, $z(MgII)_{median} \sim 0.8$)

Our Study	Observations	Goals
+38 MgII absorbers ($W \geq 0.3$Å, $z_{MgII} \sim 0.5$), +112 Control (similar z_{QSO} as MgII sample)	+S-band (2-4GHz) +VLA A, BnA configurations (1-2" resolution)	+Determine RMs, compare target vs. control samples +RM vs Impact Parameter +RM vs MgII Eq. width (W) +RM vs z_{MgII} +RM vs other photometric properties

+This is still small-scale, future surveys will improve statistics for sample comparison and our understanding of foreground (Milky Way) effects

+Wideband observations are vital for us to understand source of polarization and magnetic field structure

Remaining challenges:

RM_{MW} estimates, k-corrections, understanding polarized beam-shape, managing and accessing data locally…

Thank you!