

# Cluster Magnetic Fields: The Rest of the Story

Lawrence Rudnick  
Minnesota Institute for Astrophysics



- How will we separate **intrinsic** & **local** RG effects from **global** cluster fields?
- How will we create **clean samples** of background RMs?
- How will we use Faraday structure to study **RG physics**?

Some collaborators in these projects:  
*(don't blame them for my arguments!)*

Heinz Andernach (Large source %p)  
Jean Eilek (Abell 2256)  
Avery Garon (RGZ bending, %p)  
Mikel Jakaj (Size vs. %p)  
Tom Jones (overall punditry)  
Mehdi Lamee (SPASS depolarization)  
Shane O'Sullivan (Large source %p)  
Frazer Owen (Abell 2256, p counts)

POSSUM team  
Radio Galaxy Zoo team  
VLASS team

With support from the U.S.  
Nat'l Science Foundation



- How will we separate **intrinsic** & **local** RG effects from **global** cluster fields?
- How will we create **clean samples** of background RMs?
- How will we use Faraday structure to study **RG physics**?

RGs & RMs

Global Cluster B

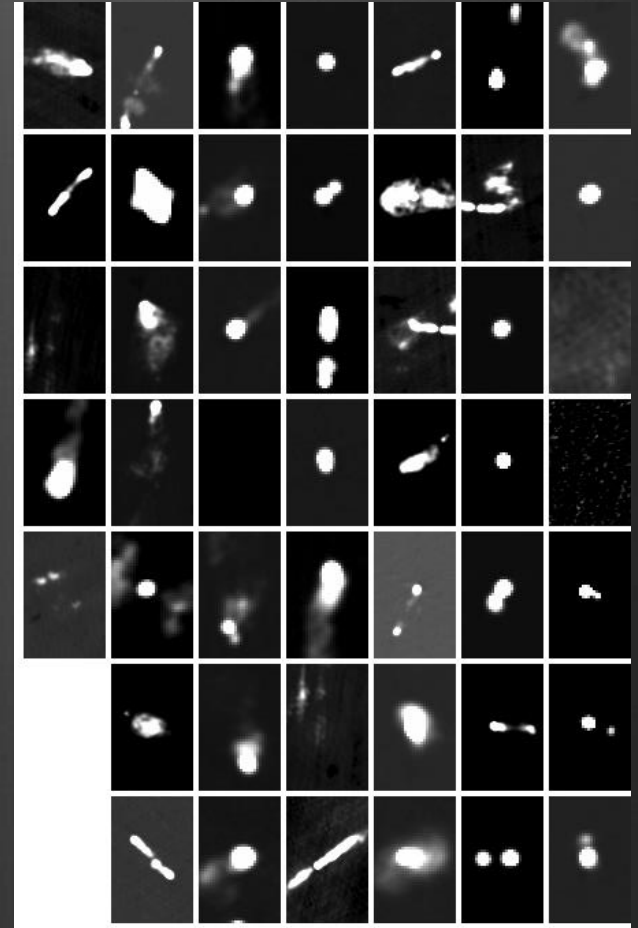
What's Next

RGs & RMs

Global B

What's next

(200) Brightest NVSS sources  
overlapping with FIRST



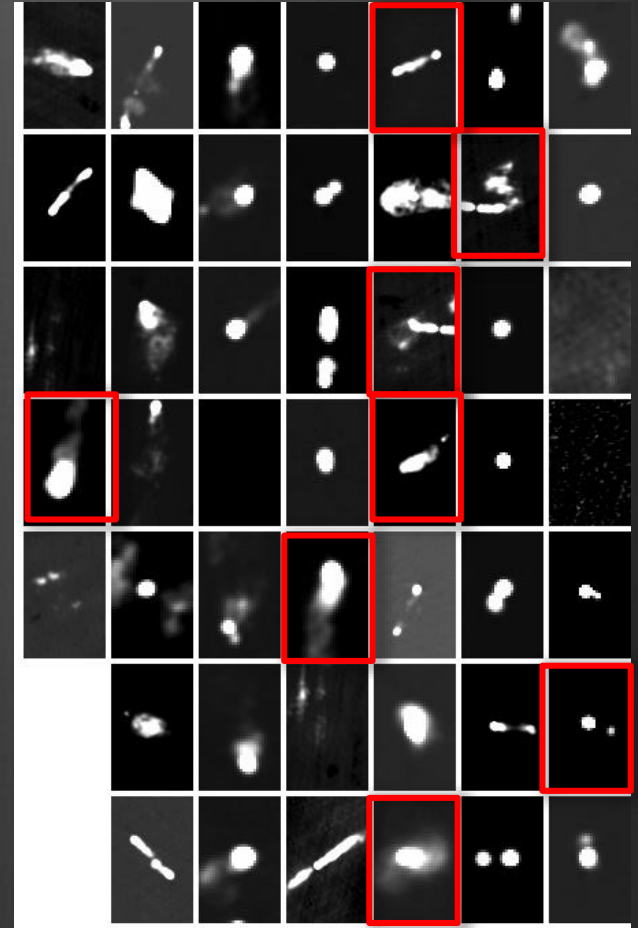
47 highest fractional polarization

RGs & RMs

Global B

What's next

(200) Brightest NVSS sources  
overlapping with FIRST



47 highest fractional polarization

RGs & RMs

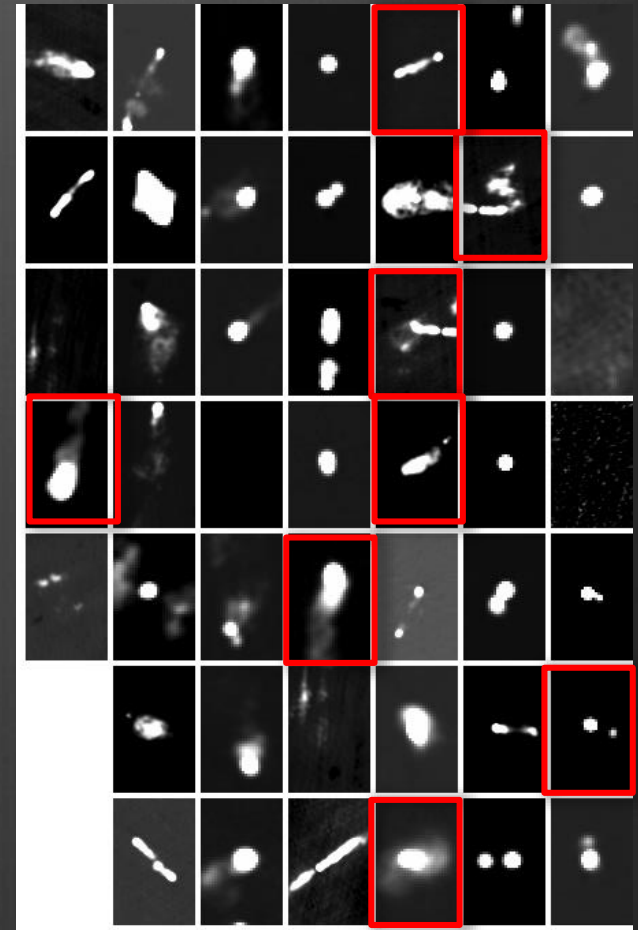
Global B

What's next

(200) Brightest NVSS sources  
overlapping with FIRST

How will lowest % polarization differ?

- A. More distorted sources – clusters
- B. Larger angular size – random screen
- C. Smaller angular size – host galaxy screen
- D. Smaller angular size – redshift
- E. No change – hidden variable, e.g., Luminosity



47 highest fractional polarization

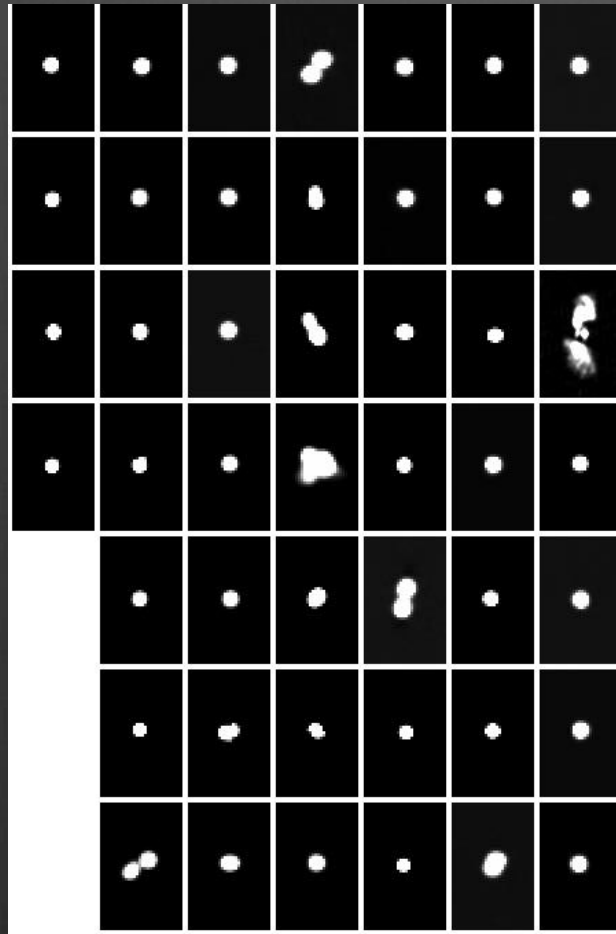


RGs & RMs

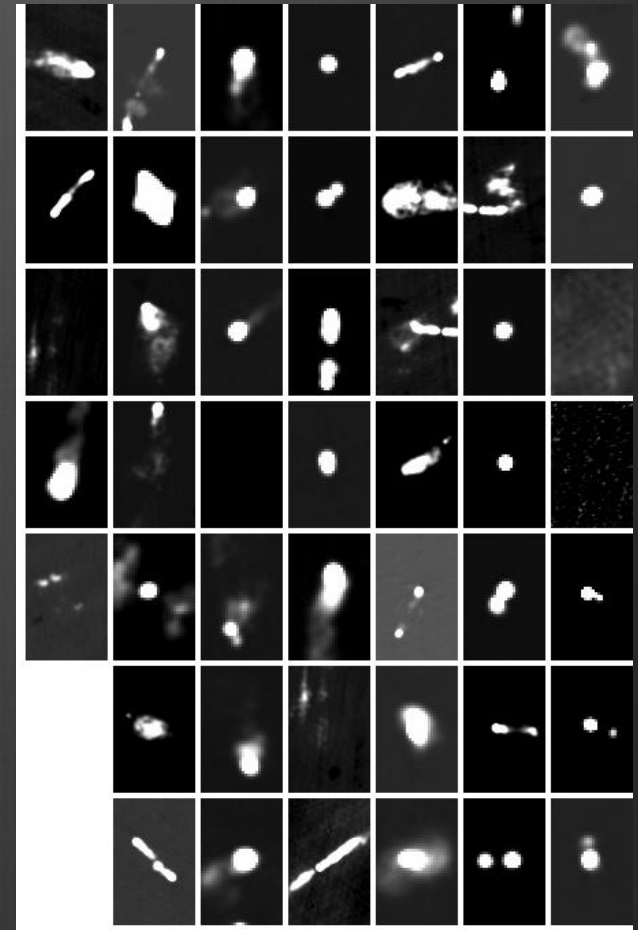
Global B

What's next

(200) Brightest NVSS sources  
overlapping with FIRST



46 lowest % polarization



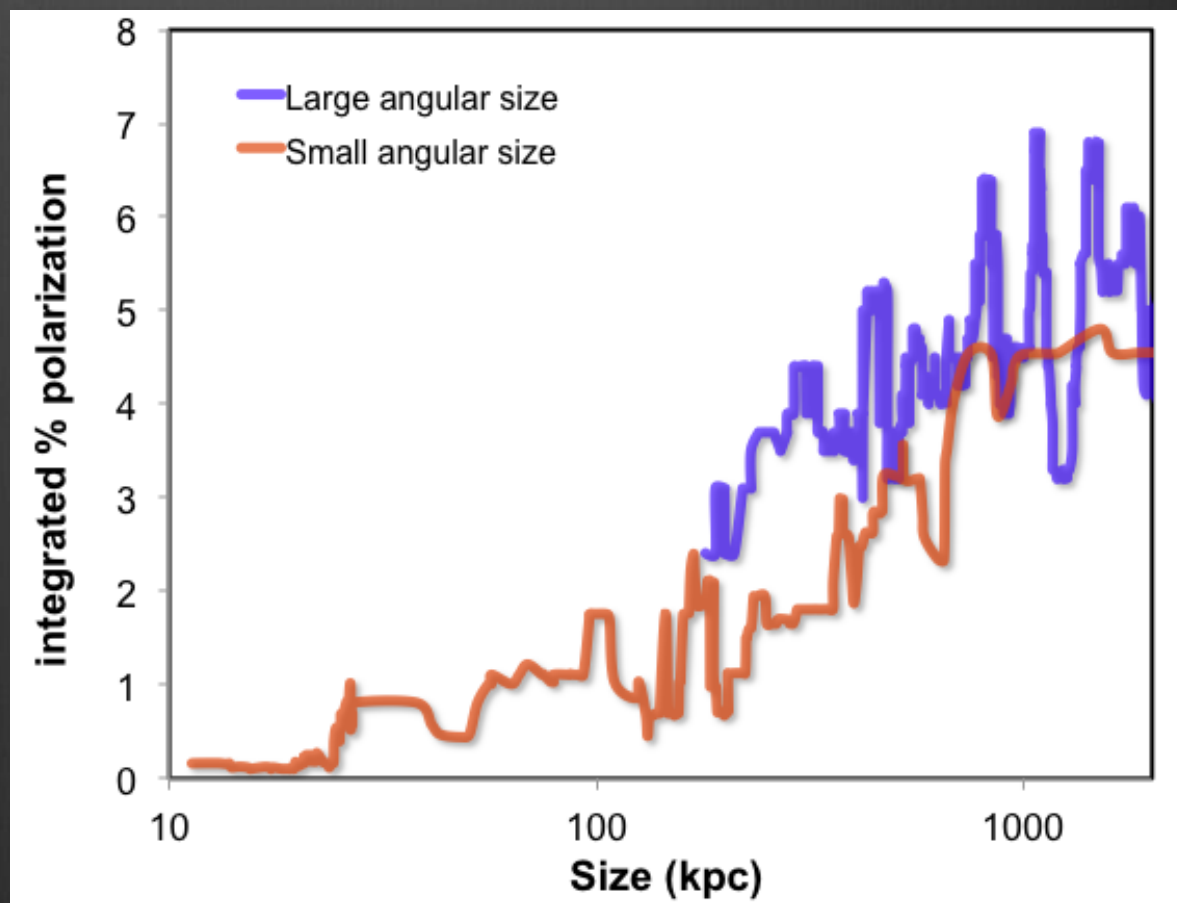
47 highest % polarization

# Size and polarization

NVSS polarizations

FIRST sizes (unresolved NVSS)

NVSS > 5' (Andernach, O' Sullivan)



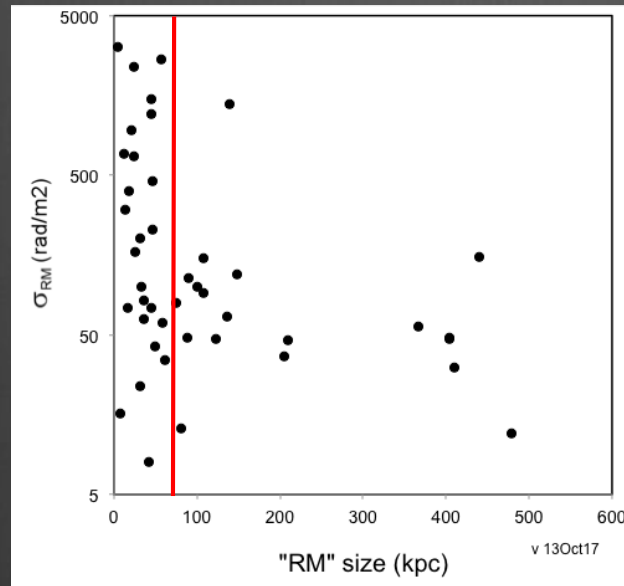


RGs & RMs

Global B

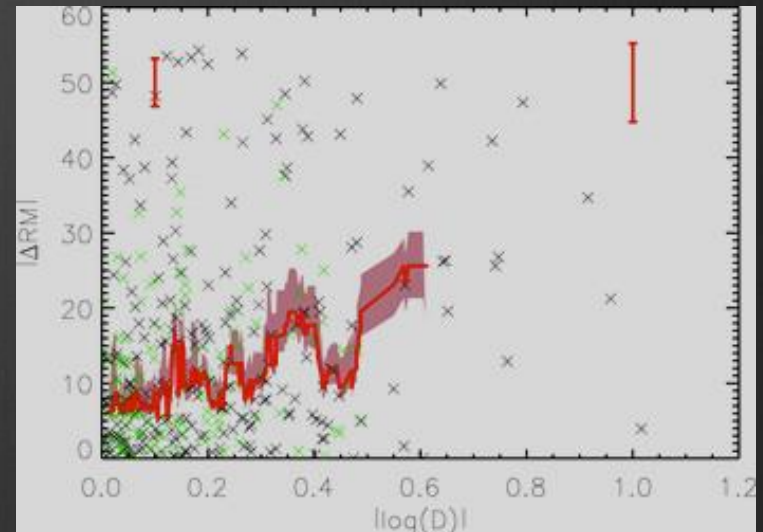
What's next

# %pol, $\sigma_{\text{RM}}$ , $\Delta_{\text{RM}}$ , Size



Literature,  $\sigma_{\text{RM}}$  vs. size

Non- $\lambda^2$  ( $\Delta_{\text{RM}}$ ) vs. Depolarization  
Lamee+16

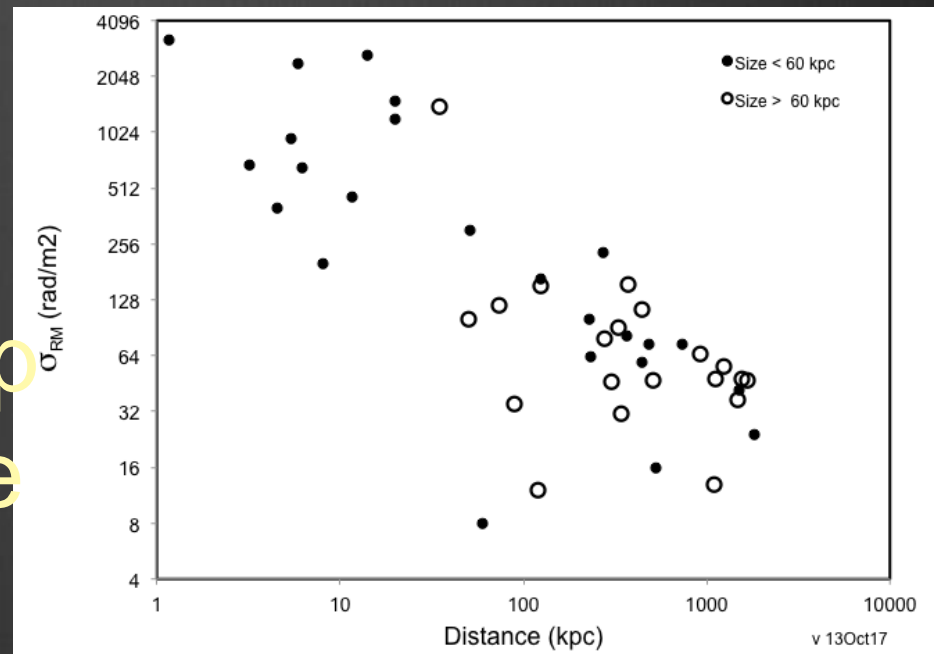




# Lesson 1

Size,  $\sigma_{RM}$ ,  $\Delta_{RM}$ , %pol are all correlated and will confuse measurements of cluster global B

To study clusters, need large, high %p sources, but they're rare



RGs & RMs

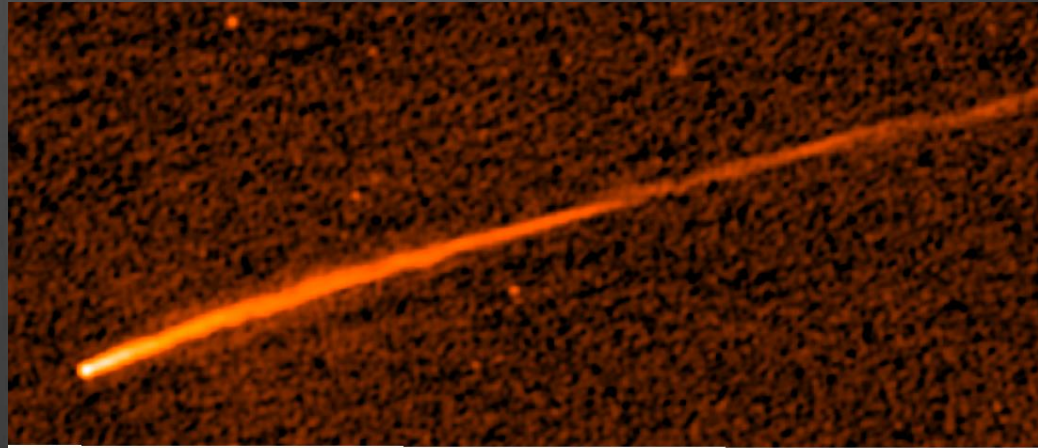
Global B

What's next

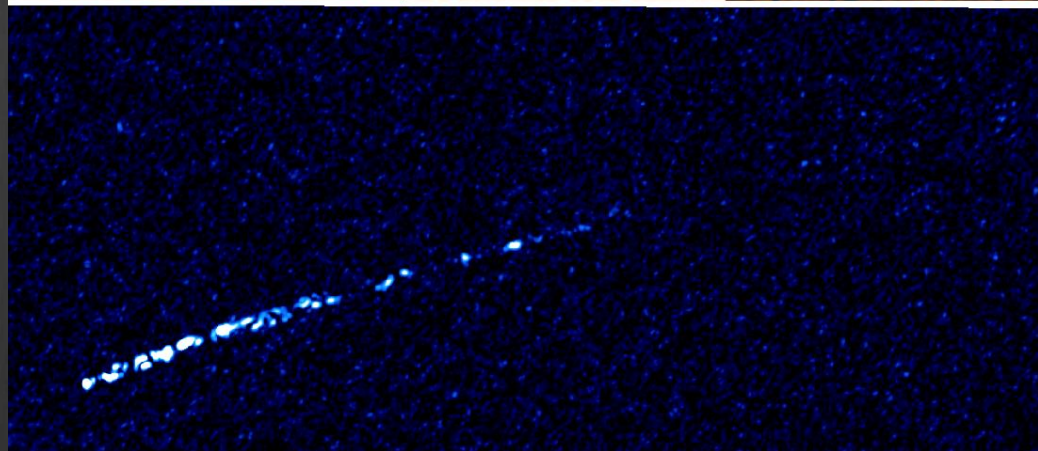
# RG RMs: what's local?

Long tail – Abell 2256 (Sband), 1.5''

Total intensity



Polarized intensity



RGs & RMs

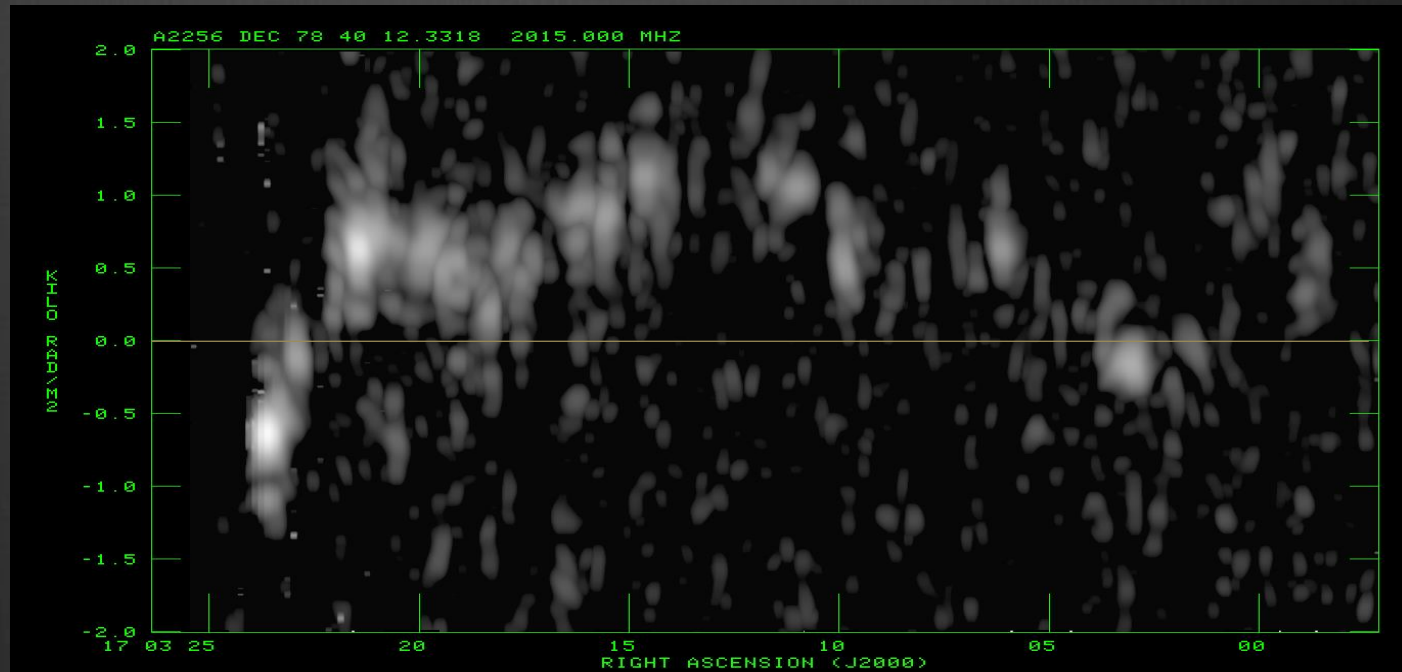
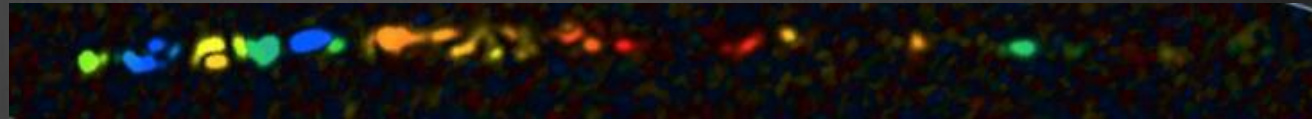
Global B

What's next

# RG RMs: what's local?

Long tail – Abell 2256 (Sband), 1.5''

Faraday depth, -600 to +1100



RGs & RMs

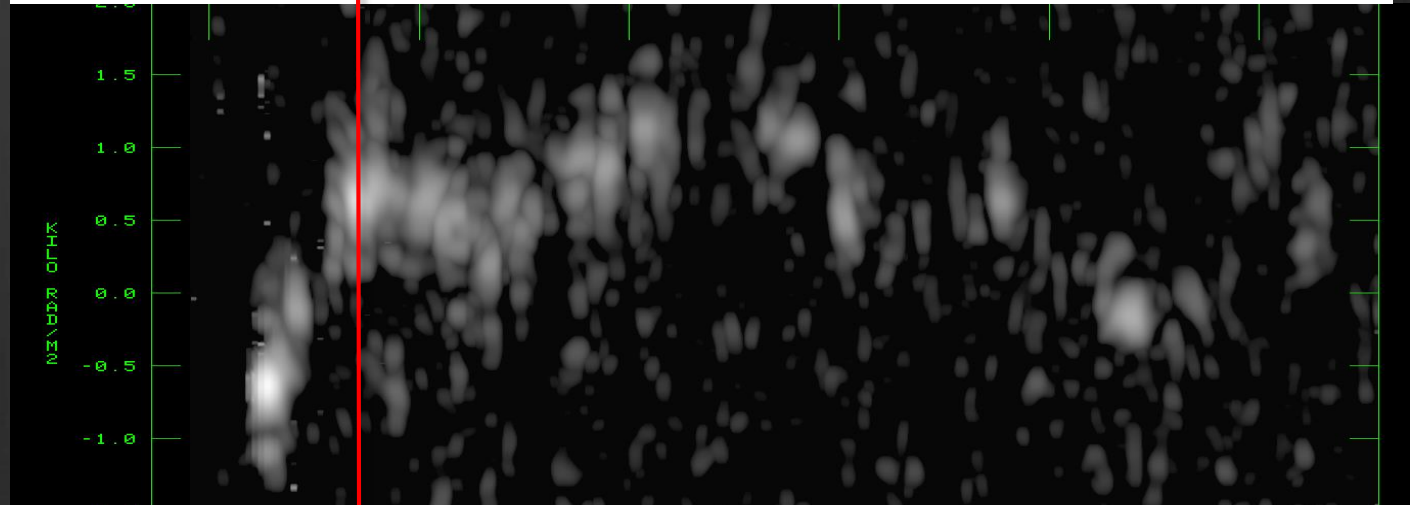
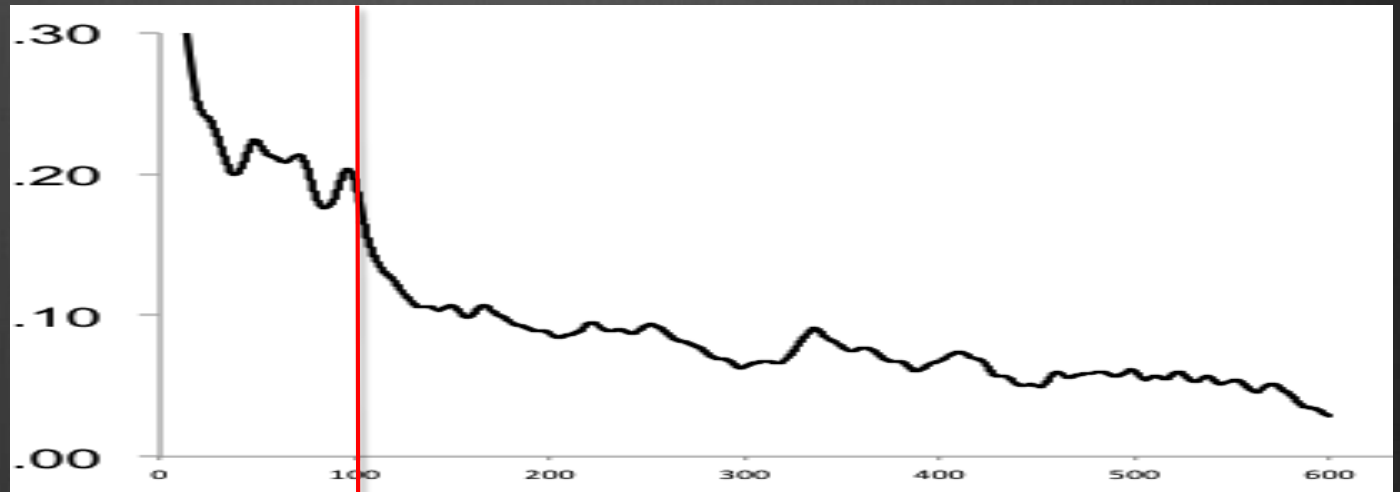
Global B

What's next

# RG RMs: what's local?

Long tail – Abell 2256 (Sband), 1.5''

Faraday depth, -600 to +1100

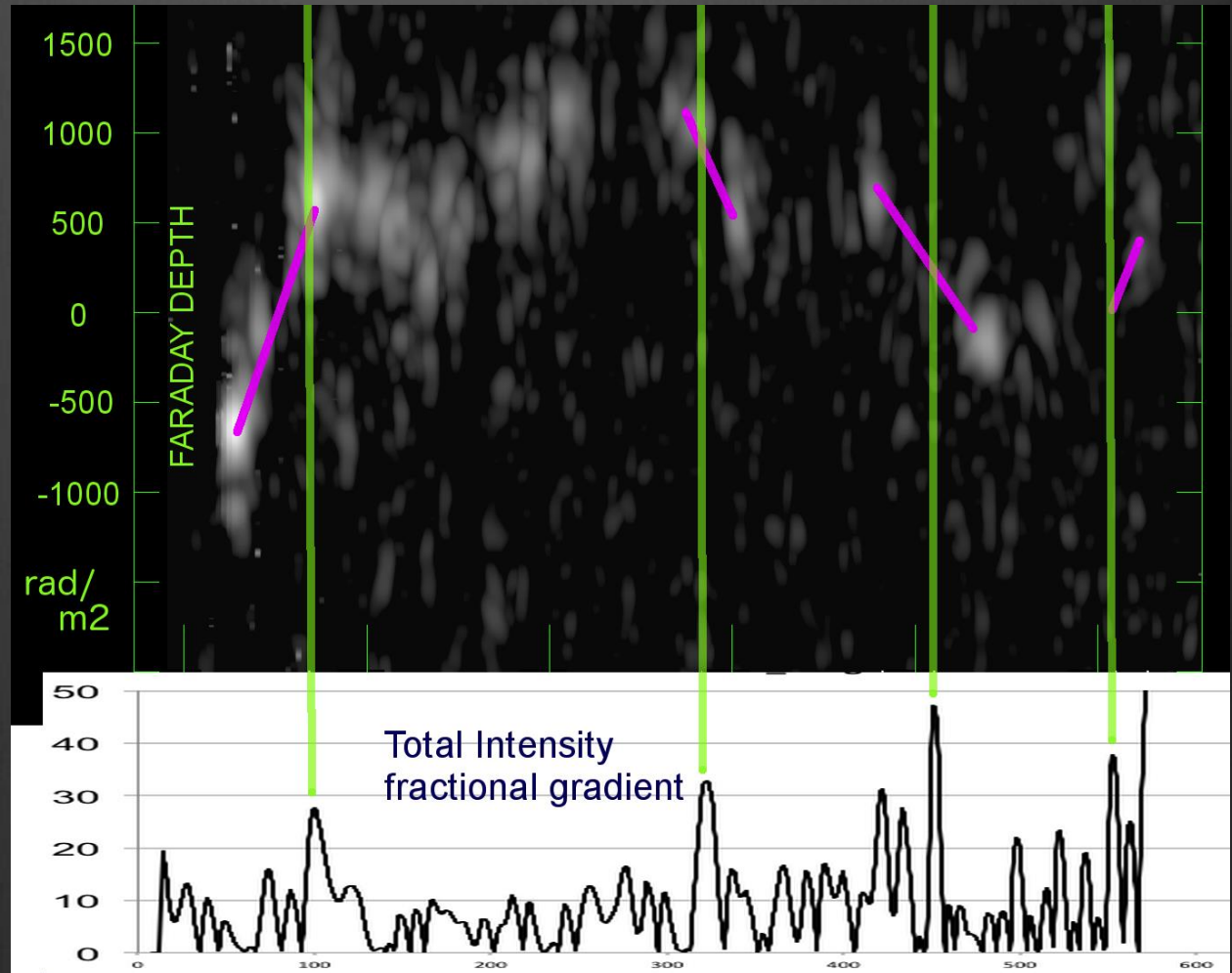




# RG RMs: what's local?

Long tail – Abell 2256 (Sband), 1.5"

Faraday depth, -600 to +1100



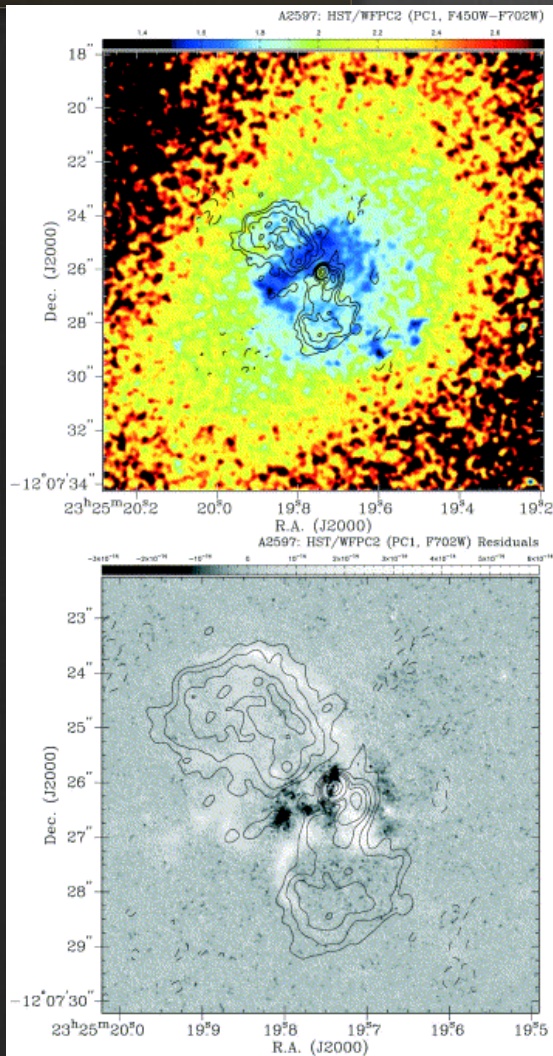


RGs & RMs

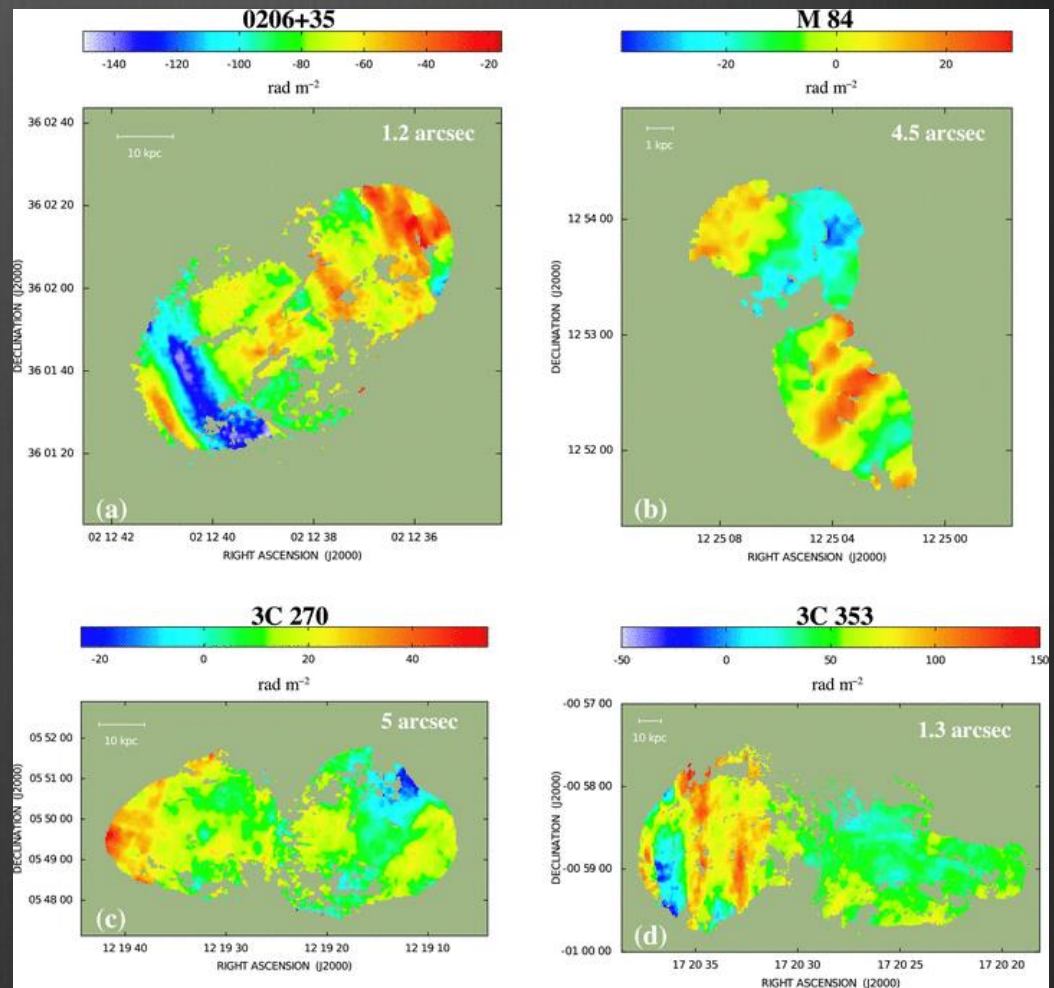
Global B

What's next

# RG RMs: what's local?



D. Guidetti et al. MNRAS 2011, 413:2525-2544



# RG RMs: what's local?

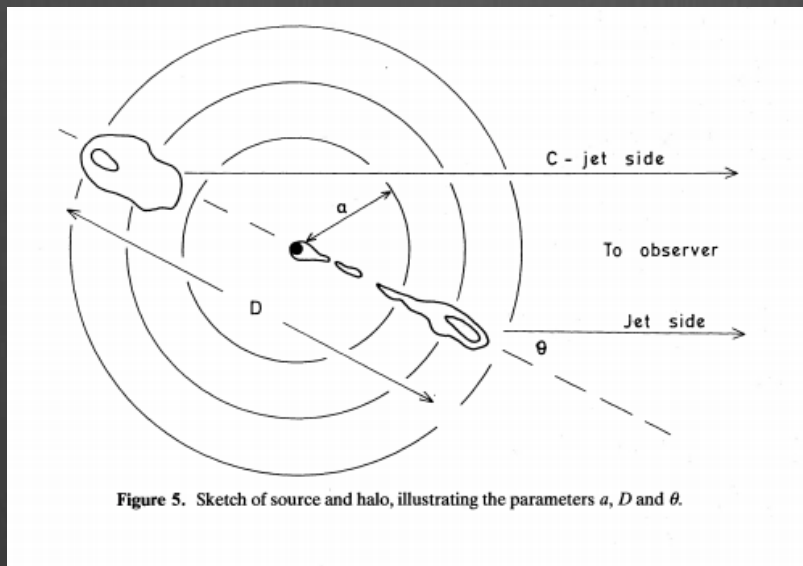


Figure 5. Sketch of source and halo, illustrating the parameters  $a$ ,  $D$  and  $\theta$ .

*some ancient history – Laing-Garrington effect*

Garrington+91

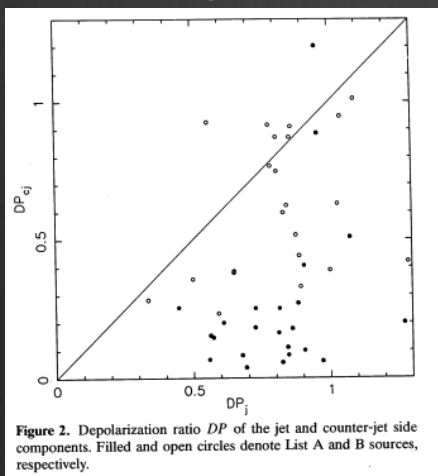


Figure 2. Depolarization ratio  $DP$  of the jet and counter-jet side components. Filled and open circles denote List A and B sources, respectively.

Morganti+97, low luminosity

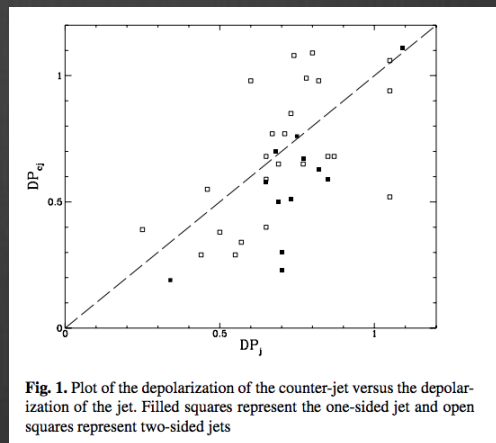


Fig. 1. Plot of the depolarization of the counter-jet versus the depolarization of the jet. Filled squares represent the one-sided jet and open squares represent two-sided jets



RGs & RMs

Global B

What's next



## Lesson 2

There is Faraday structure local to,  
and sometimes connected to the RG

This is exciting for RG physics, but  
confuses cluster B measurements

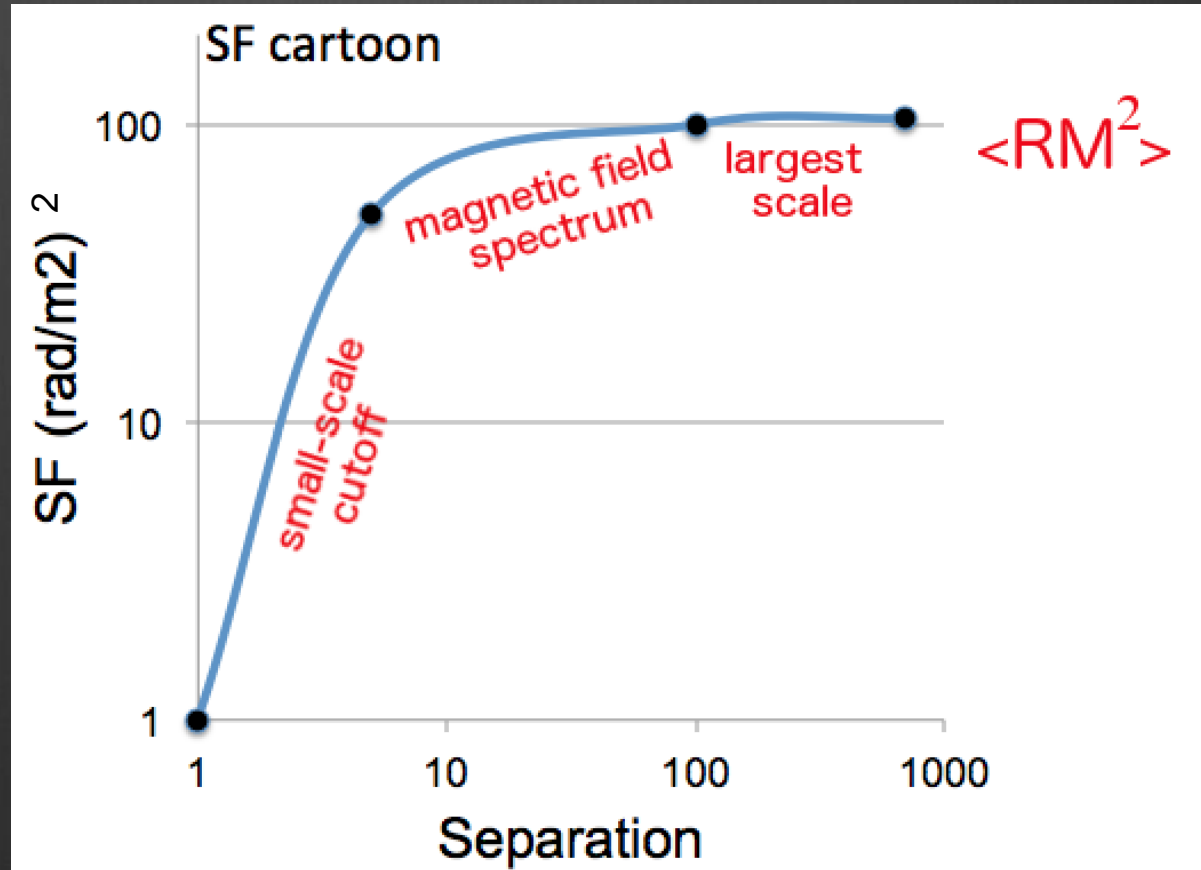
RGs & RMs

Global B

What's next

# Structure functions – characterizing the global cluster B field

$$SF(\text{sep}) = \langle [RM(x) - RM(x+\text{sep})]^2 \rangle$$

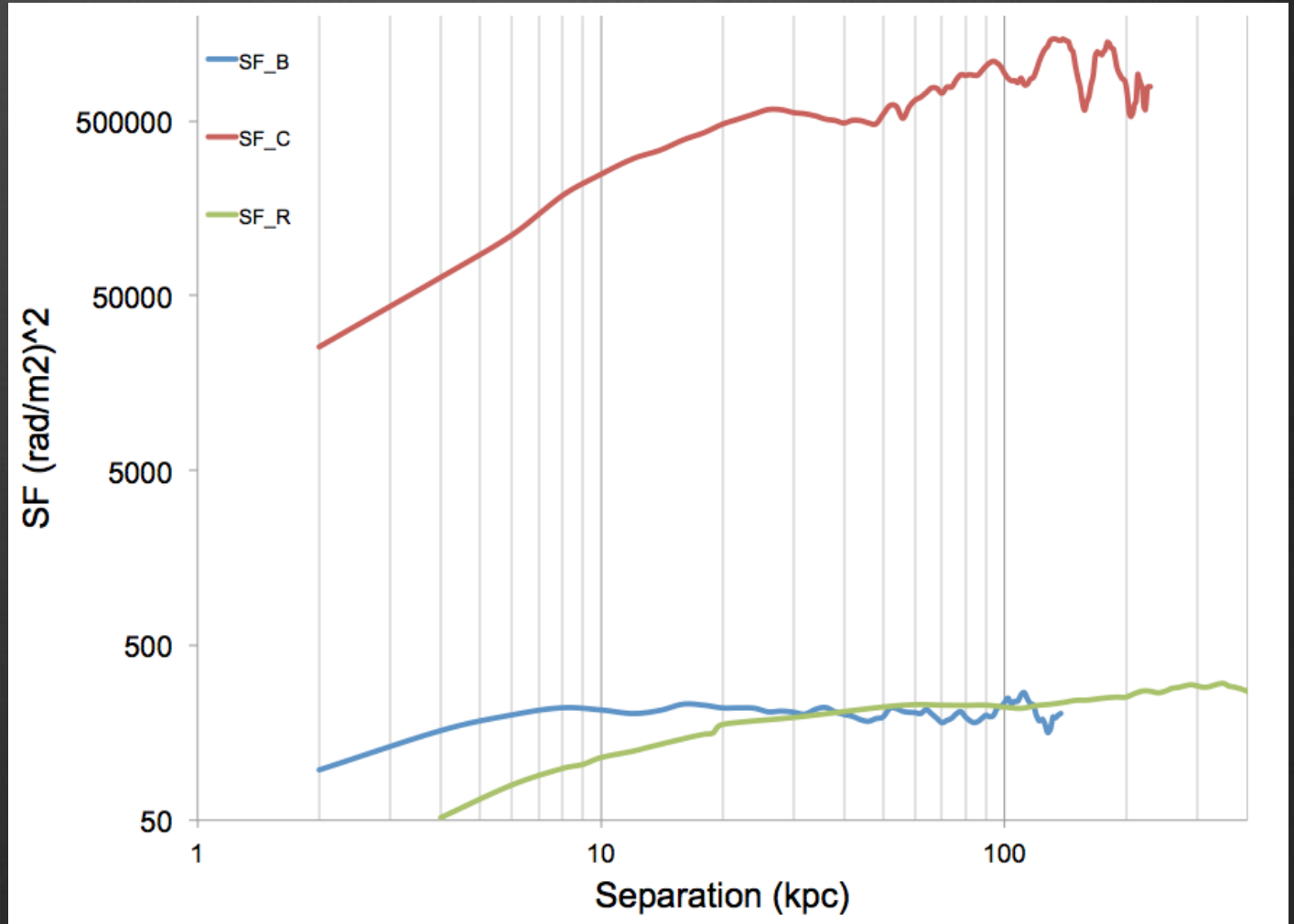


RGs & RMs

Global B

What's next

# Quick read of SFs

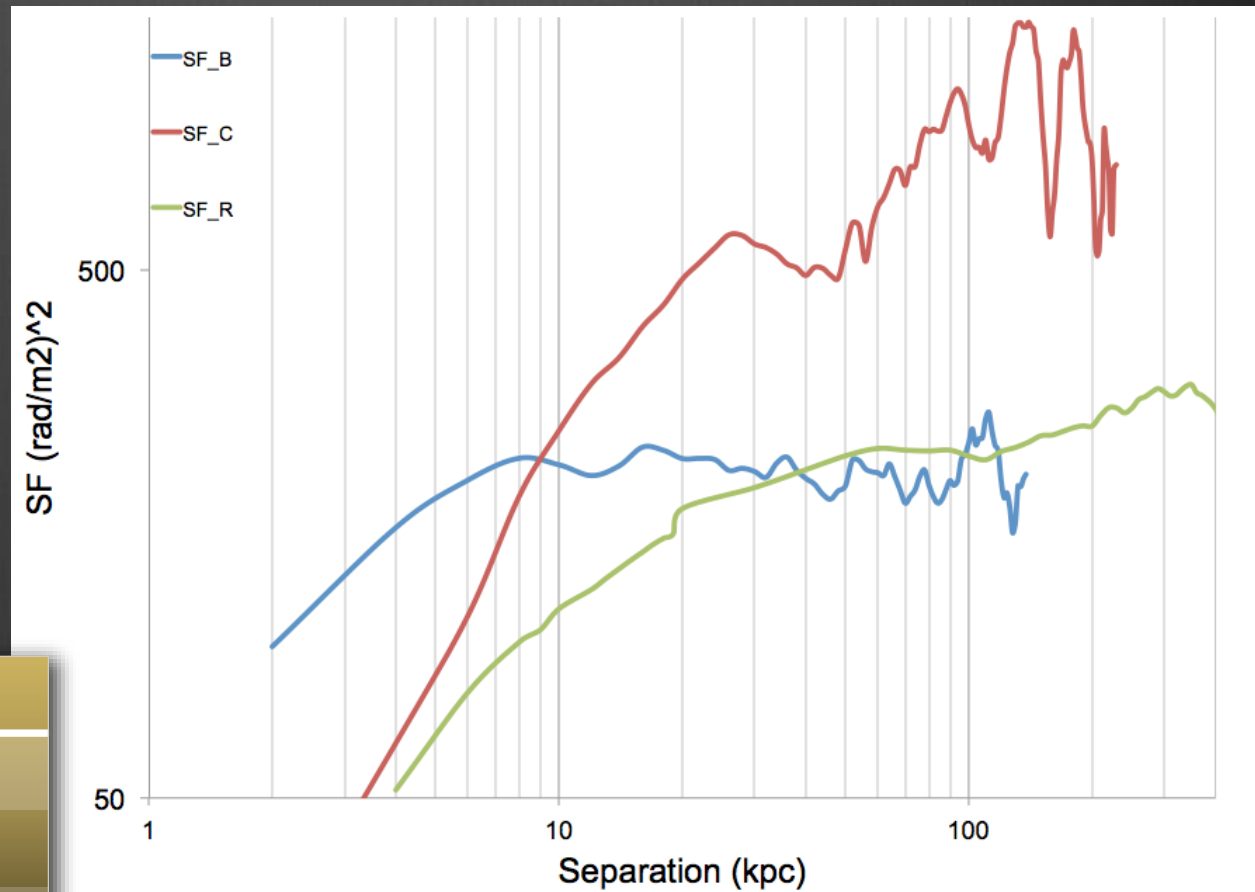
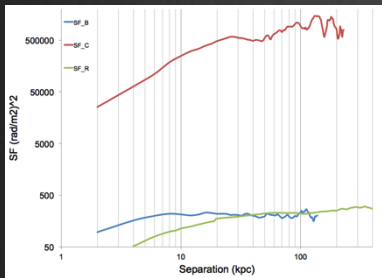


RGs & RMs

Global B

What's next

# Quick read of SFs



|   | Min | Max | RM <sup>2</sup> |
|---|-----|-----|-----------------|
| B |     |     |                 |
| C |     |     |                 |
| R |     |     |                 |

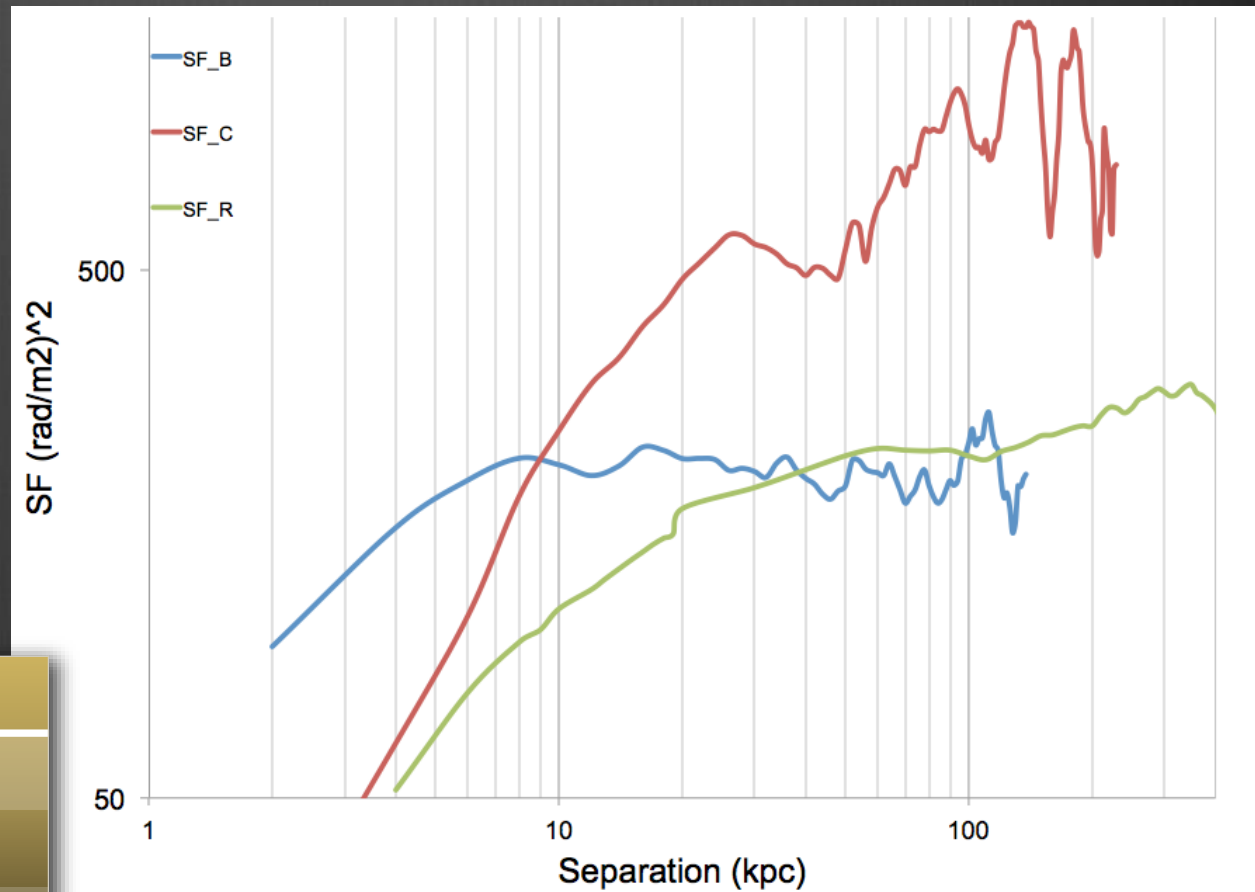
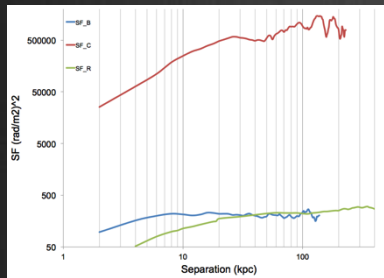


RGs & RMs

Global B

What's next

# Quick read of SFs



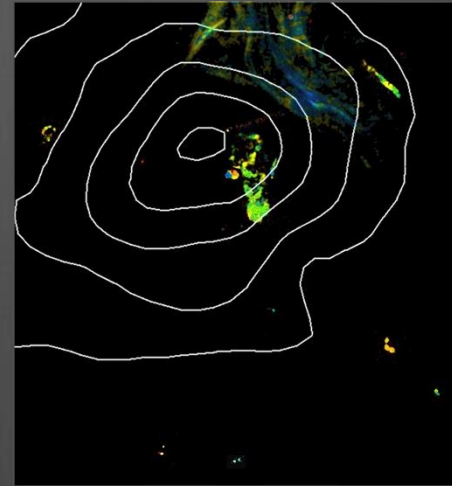
|   | Min | Max  | RM <sup>2</sup> |
|---|-----|------|-----------------|
| B | -   | 8    | 6e5             |
| C | -   | 20   | 150             |
| R | -   | >100 | >~200           |

RGs & RMs

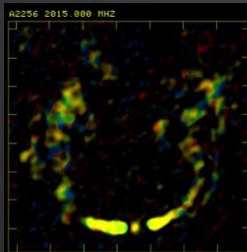
Global B

What's next

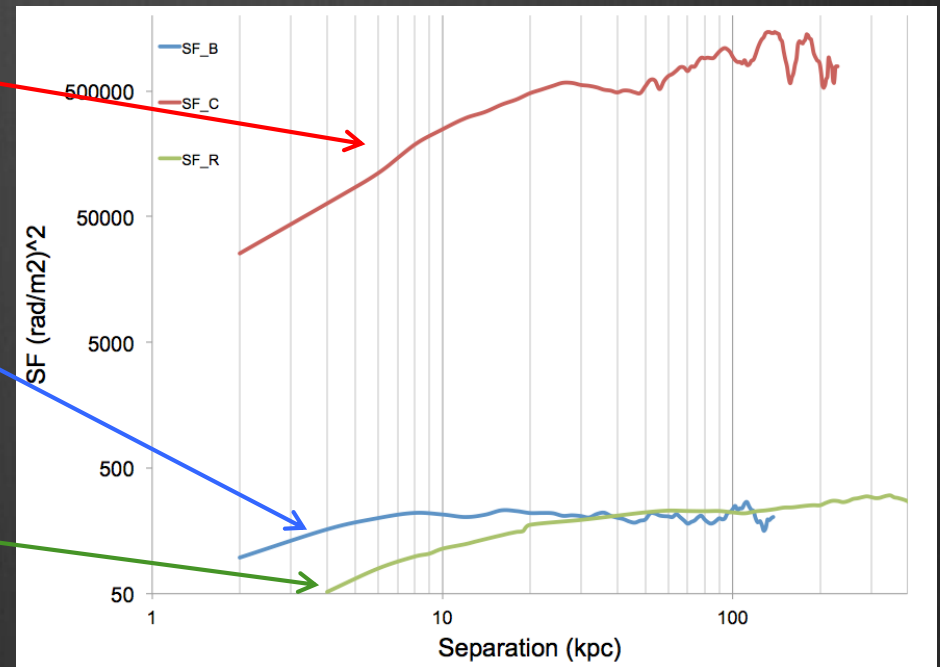
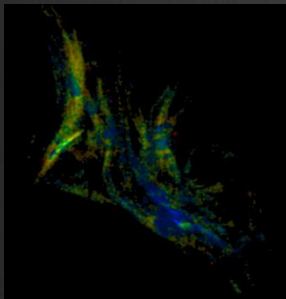
# Quick read of SFs



B



R

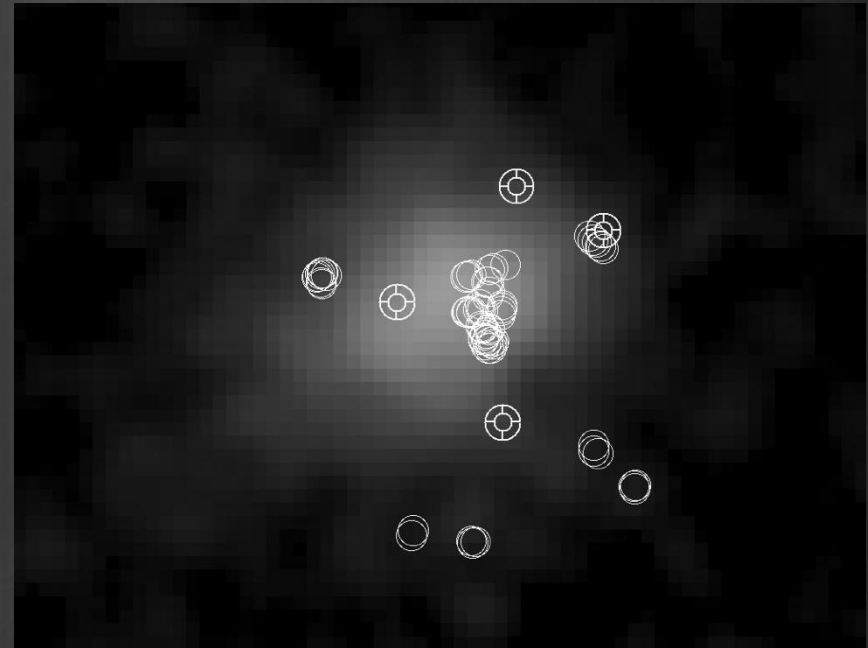
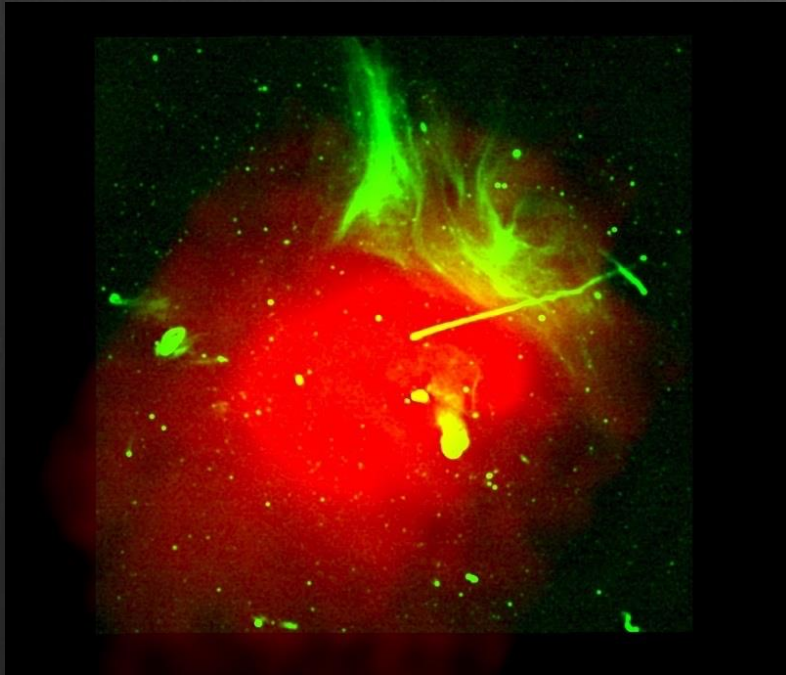


RGs & RMs

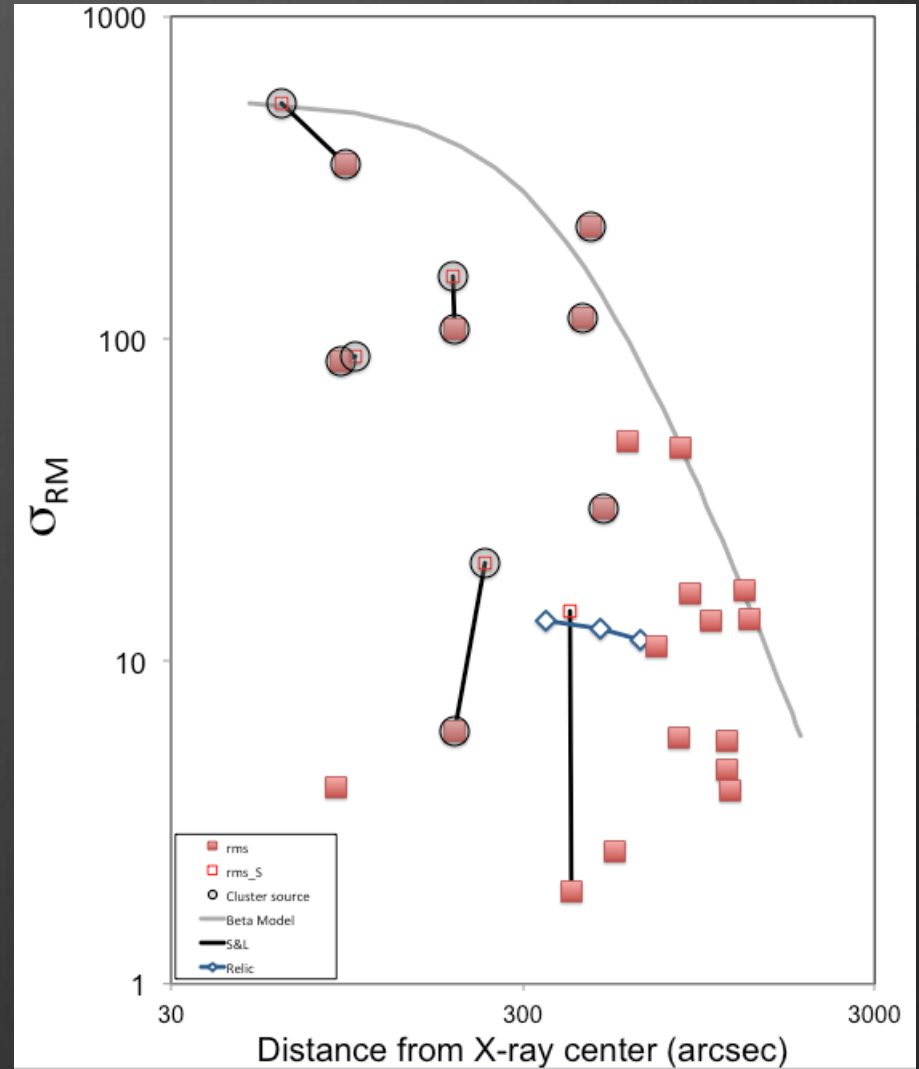
Global B

What's next

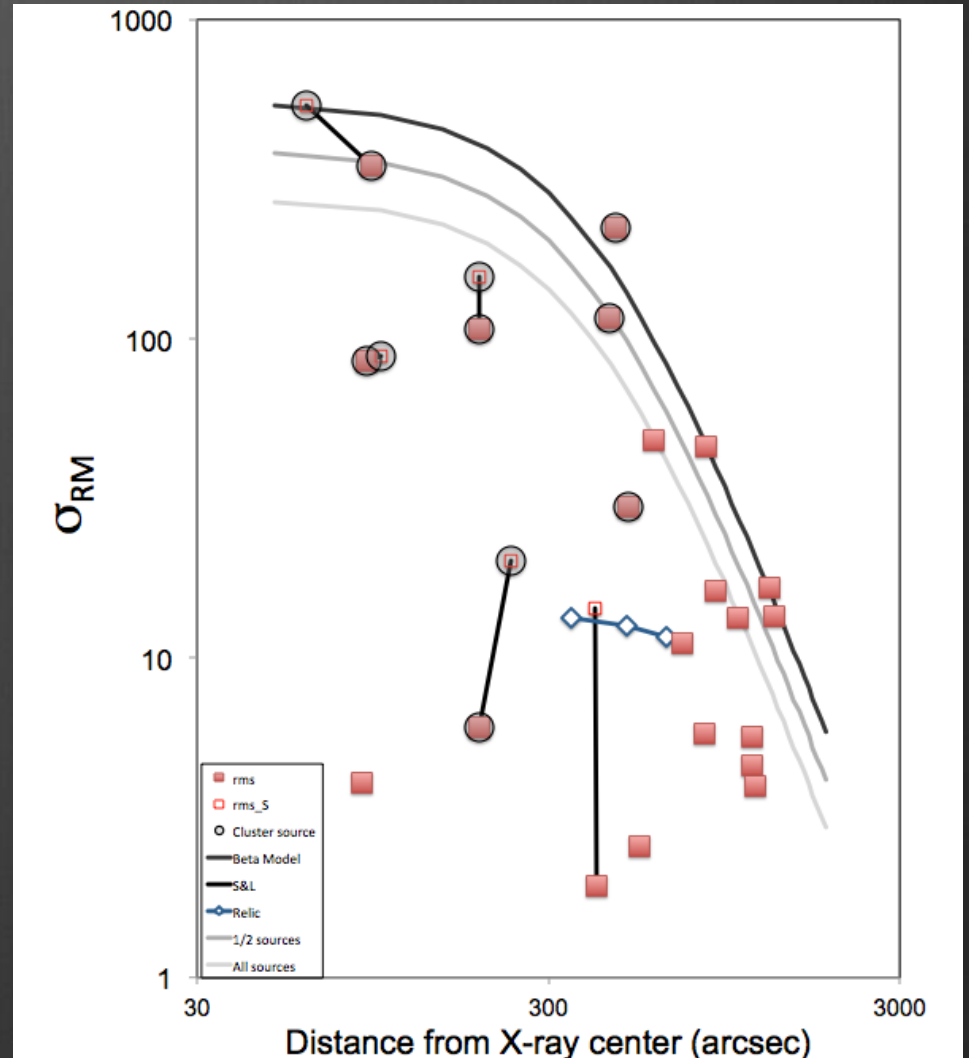
# A robust global B?



# A global model?



# A global model?



RGs & RMs

Global B

What's next



## Lesson 3

At least in Abell 2256, where we have the most extensive measurements of Faraday structure, there is not any simple global B .





# Lessons

1. Size,  $\sigma_{RM}$ ,  $\Delta_{RM}$ , %pol are all correlated and will confuse measurements of cluster global B
2. There is Faraday structure local to, and sometimes connected to the RG
3. At least in Abell 2256, where we have the most extensive measurements of Faraday structure, there is not any simple global B .

RGs & RMs

Global B

What's next

# Coming soon...

# RGZ, POSSUM, VLASS

The screenshot shows the Galaxy Zoo Radio website interface. At the top, there are navigation links: CLASSIFY, SCIENCE, TEAM, PROFILE, TALK, and BLOG. The main header features the 'GALAXY ZOO RADIO' logo. The central article is titled 'In Search of Erupting Black Holes' with a sub-headline: 'Help astronomers discover supermassive black holes observed by the KG Jansky Very Large Array (NRAO) and the Australia Telescope Compact Array (CSIRO)'. Below the title is a section 'Search for Black Holes' with a paragraph of text and a 'Begin Hunting' button. To the right of the text is an image of two black holes with jets of material. At the bottom of the image, there is a small credit line: 'NASA, ESA, S. Baum and C. O'Dea (RTT, R. Perley and W. Cotton (NRAO/JAIVE/SF), and the Hubble Heritage Team (STScI/AURA)'.

## In Search of Erupting Black Holes

Help astronomers discover supermassive black holes observed by the KG Jansky Very Large Array (NRAO) and the Australia Telescope Compact Array (CSIRO)

### Search for Black Holes

Black holes are found at the center of most, if not all, galaxies. The bigger the galaxy, the bigger the black hole and the more sensational the effect it can have on the host galaxy. These supermassive black holes drag in nearby material, growing to billions of times the mass of our sun and occasionally producing spectacular jets of material traveling nearly as fast as the speed of light. These jets often can't be detected in visible light, but are seen using radio telescopes. Astronomers need your help to find these jets and match them to the galaxy that hosts them.

[Begin Hunting](#)

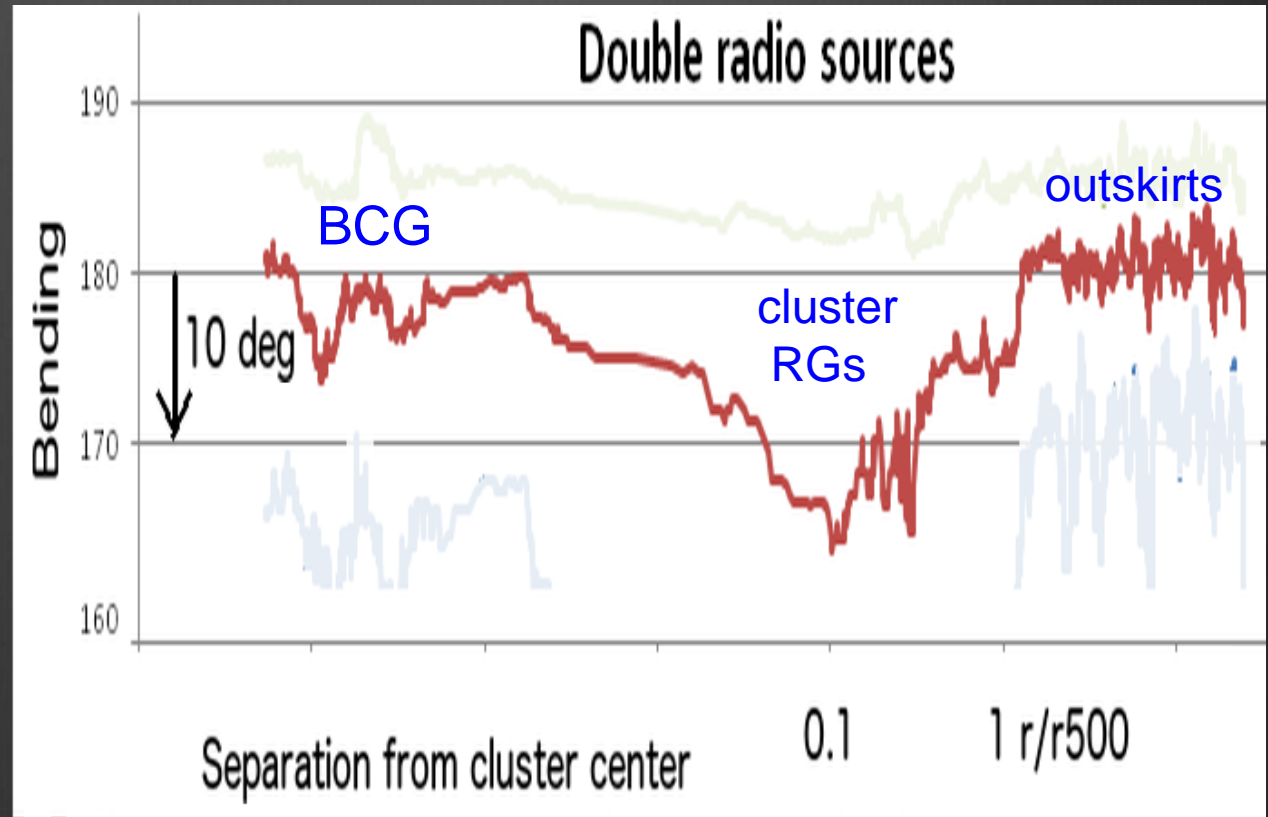


RGs & RMs

Global B

What's next

# RGZ: cluster effects

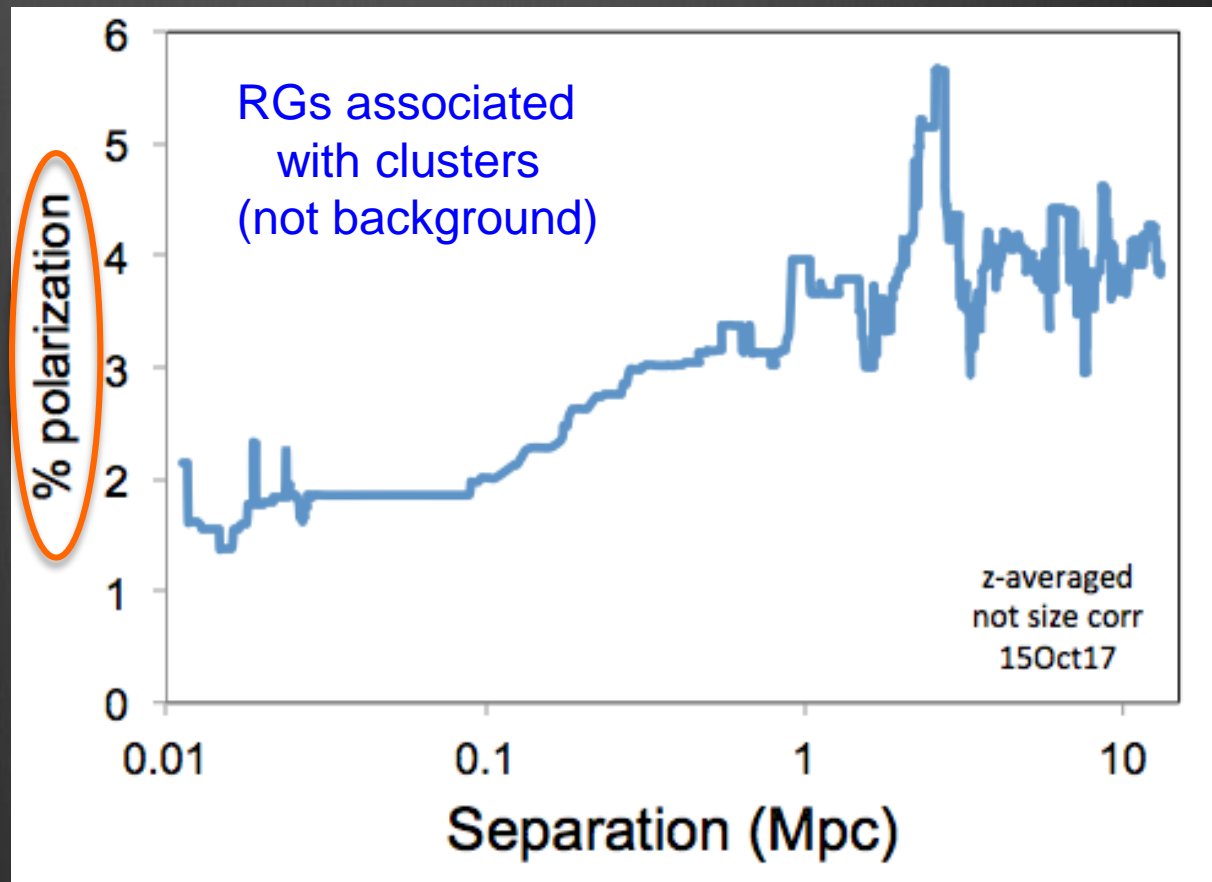
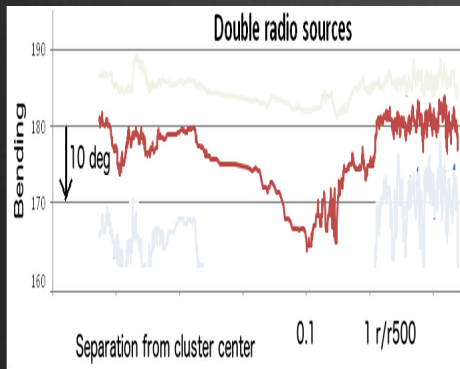


RGs & RMs

Global B

What's next

# RGZ: cluster effects



VLASS, “all sky,” 2-4 GHz, 70  $\mu$ Jy,  $\sim 3.5''$ , 2017-24

- 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

## POSSUM/ EMU/ ASKAP

“all sky,” 1.1-1.4 GHz, 15-40  $\mu$ Jy,  $\sim 15''$ -40''

- RM grid – galaxy & cluster “gold standards”
- Diffuse cluster mapping – relics, filaments, halos

| NVSS            | VLASS           | POSSUM          |
|-----------------|-----------------|-----------------|
| $3 \times 10^4$ | $2 \times 10^5$ | $1 \times 10^6$ |

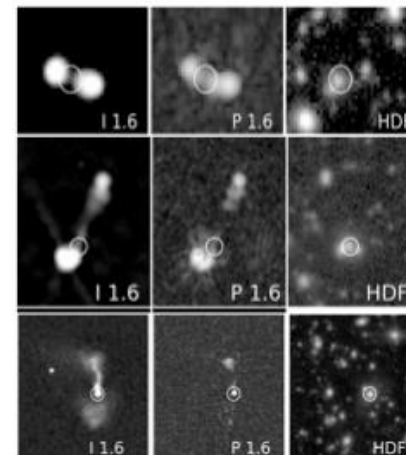
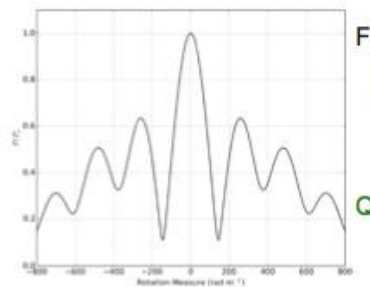
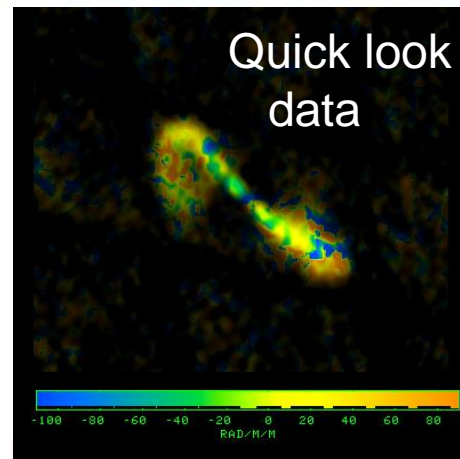
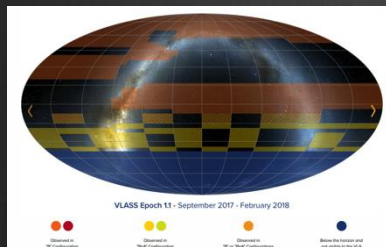
RGs & RMs

Global B

What's next

# VLASS

## Produce Faraday maps



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





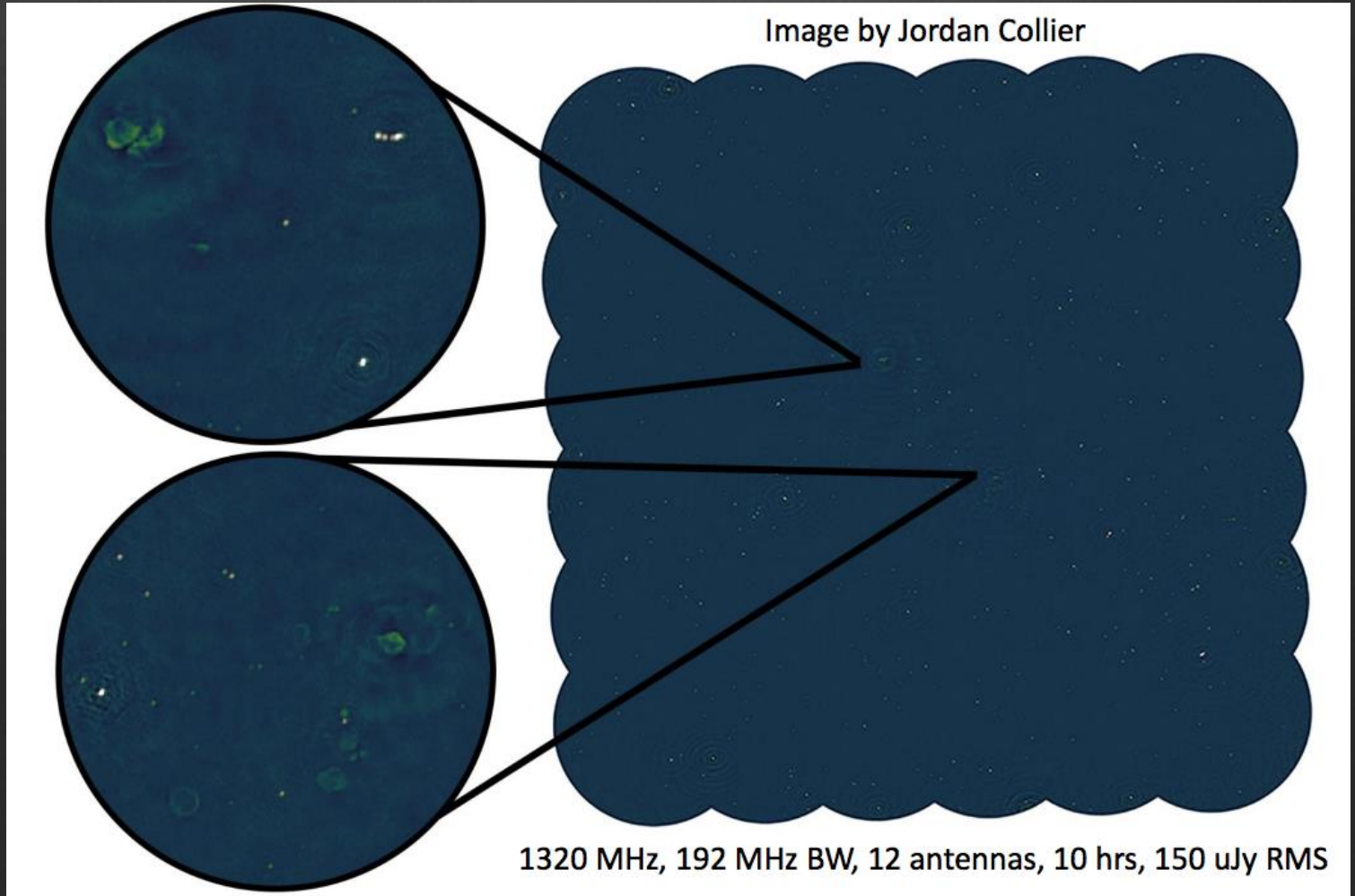
RGs & RMs

Global B

What's next

# POSSUM

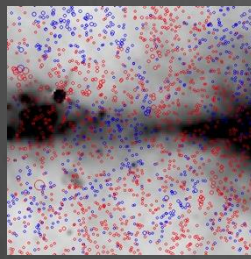
Early Science / Validation Sept 2017



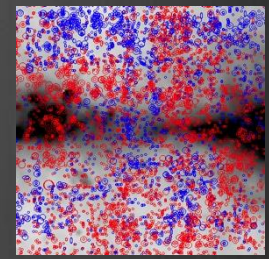
RGs & RMs

Global B

What's next

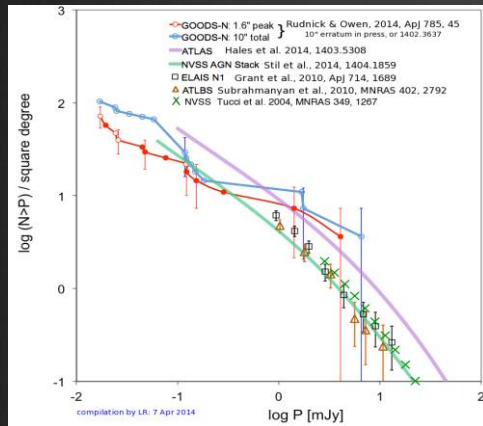


# POSSUM



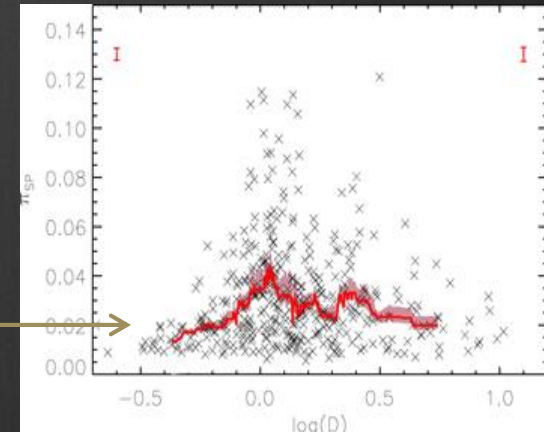
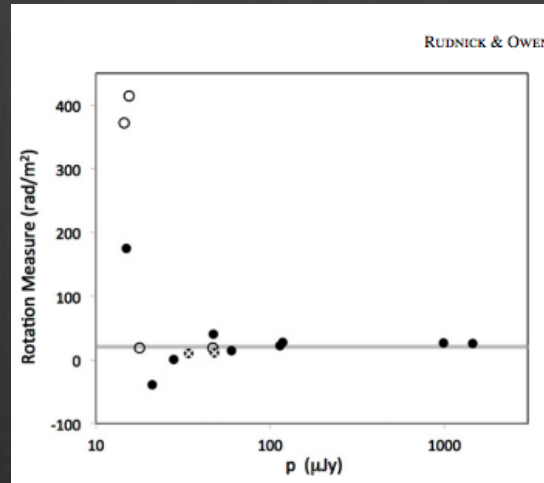
Counts increasing slowly

## How will we construct clean samples for background RM grid?



GOODS-N: high p, or %p  
→ low  $\sigma_{RM}$

%pol highest for non-depolarized sources





- How will we separate **intrinsic** & **local** RG effects from **global** cluster fields?
- How will we create clean samples of background RMs?
- How will we use Faraday structure to study RG physics?

RGs & RMs

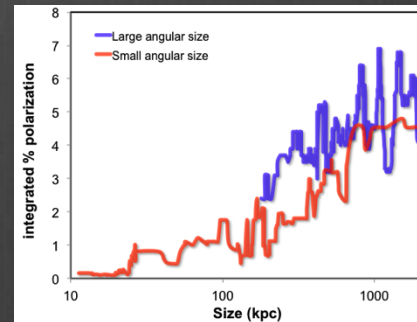
Global Cluster B

What's Next

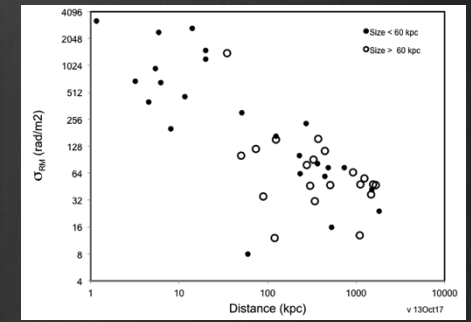
# How will we separate intrinsic & local RG effects from global cluster fields?

- Statistically characterize & remove size dependence, including morphology, etc.

Polarization and size are related



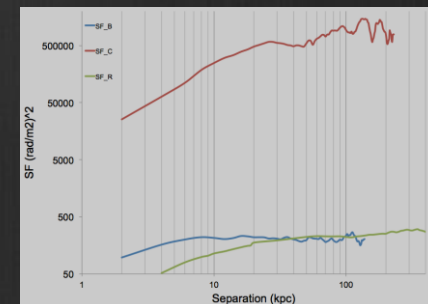
Cluster trends include effects of source size



- Ensure robustness ,e.g., SF, before claiming global.

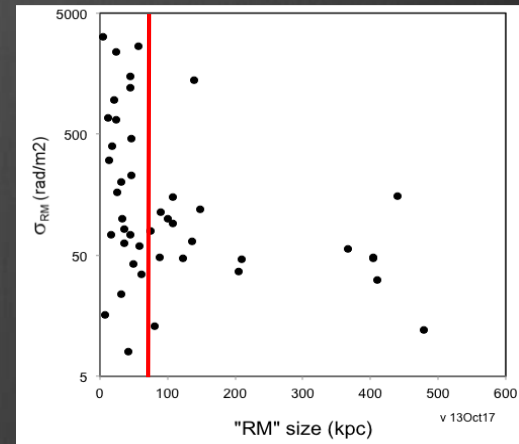
- Develop more sophisticated models informed by X-ray variations, radio morphology, etc.

Structure functions are not robust

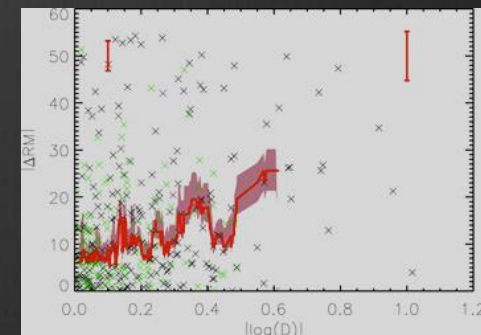


# How will we create clean samples of background RMs?

Literature,  $\sigma_{\text{RM}}$  vs. size



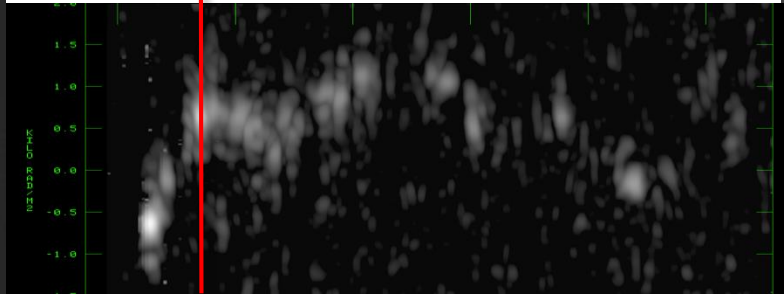
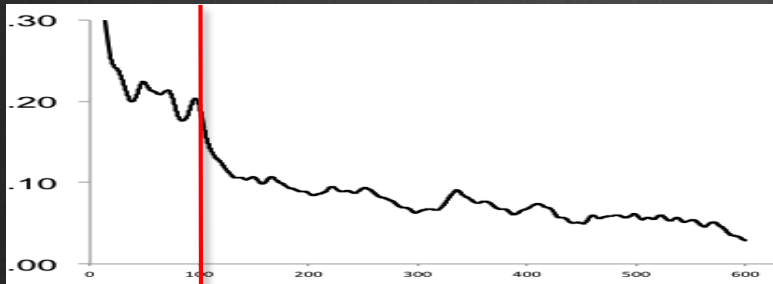
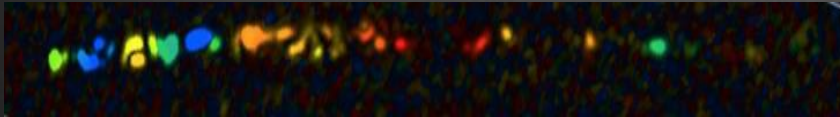
Non- $\lambda^2$  ( $\Delta_{\text{RM}}$ ) vs.  
Depolarization; Lamee+16



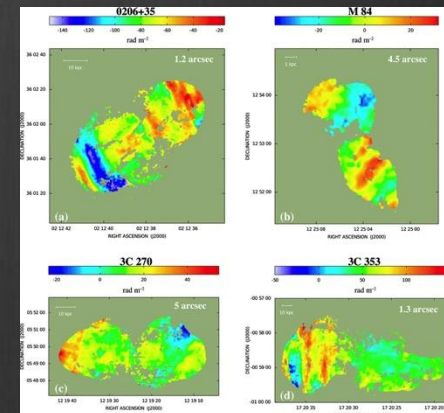
- Full Bayesian analysis based on properties of each background source, as well as foregrounds



# How can we use Faraday behavior to study RG physics?

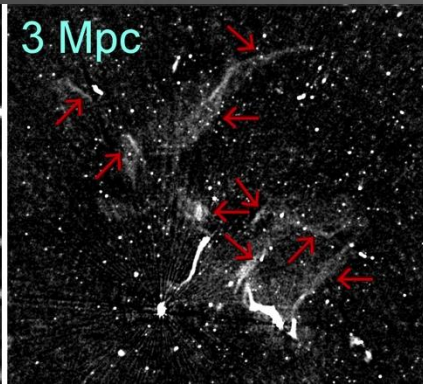
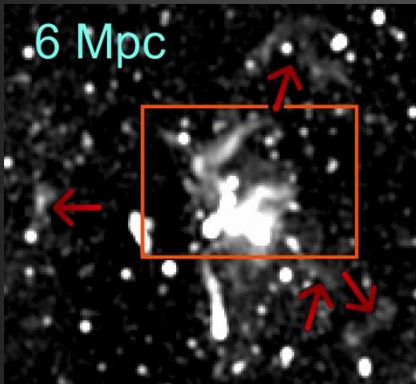


- Utilize extensive new VLASS, POSSUM data
- Simulations to reproduce obs & connect with physics

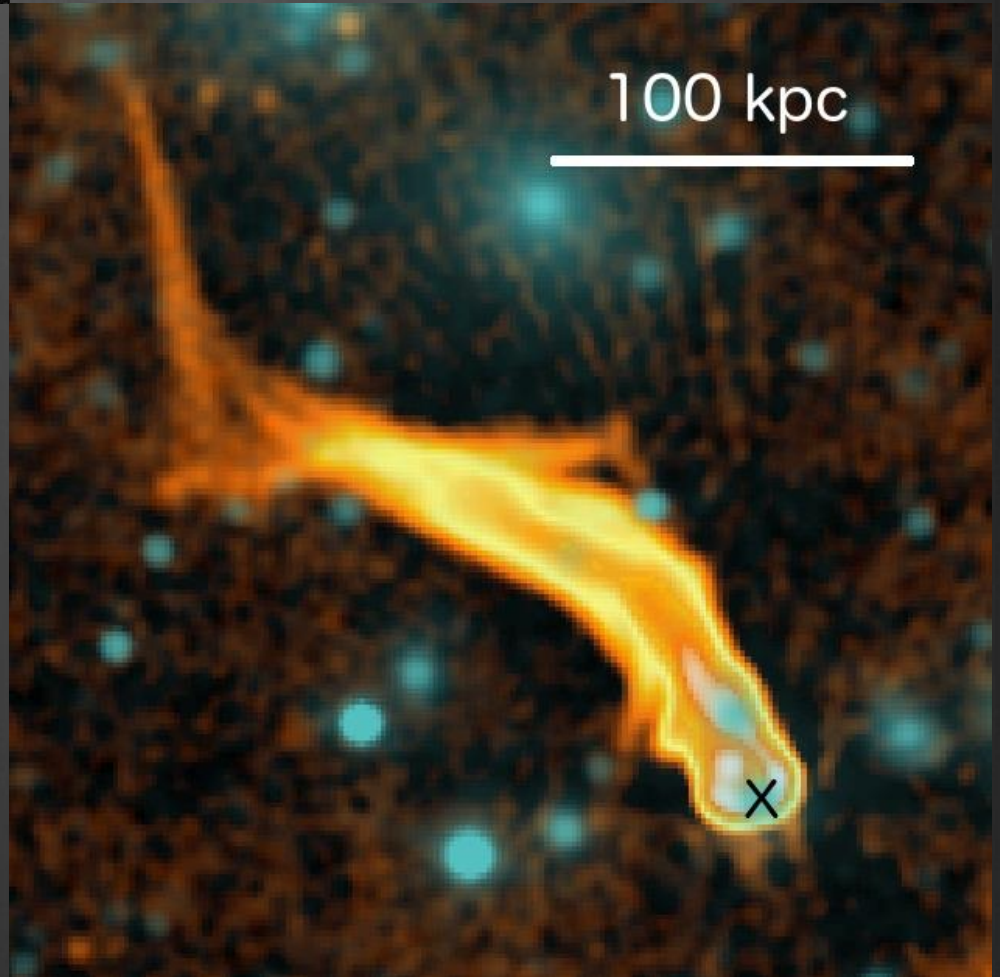






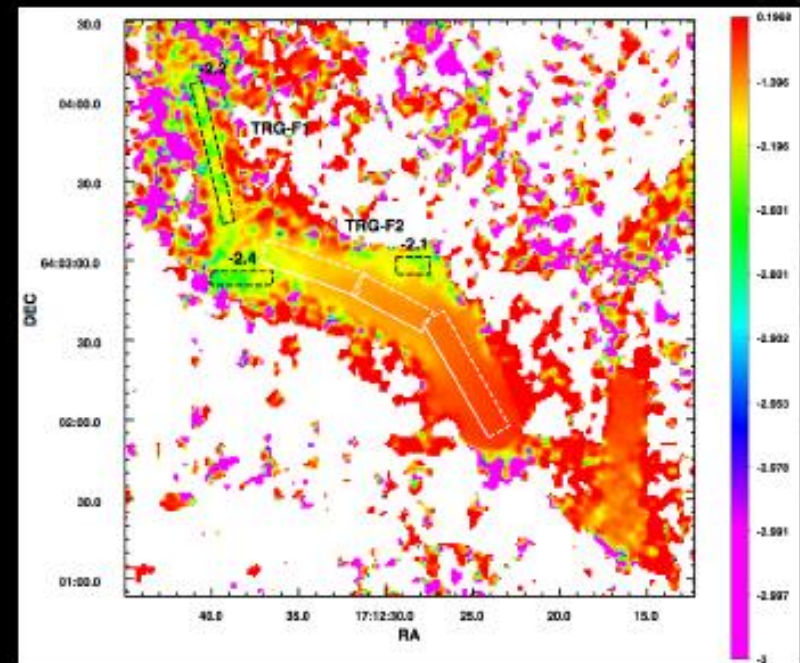
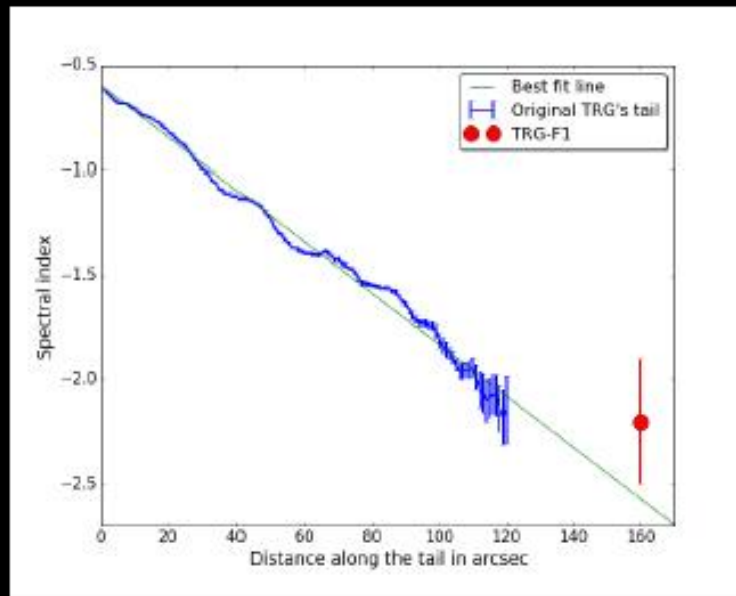
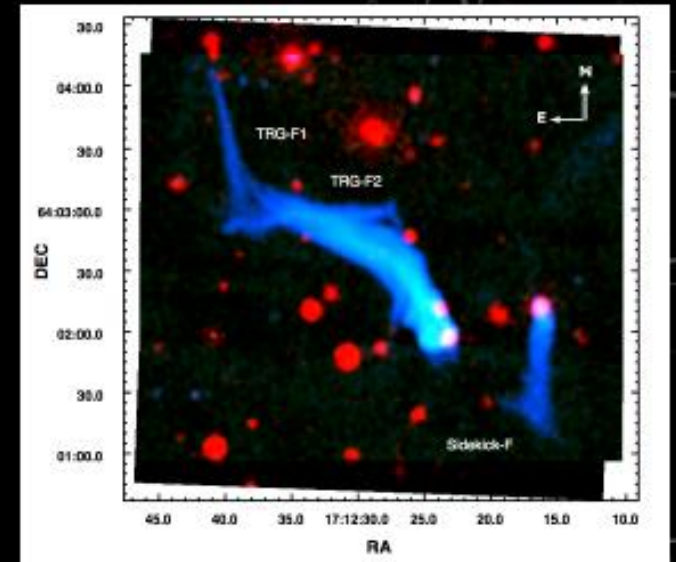


# A2255

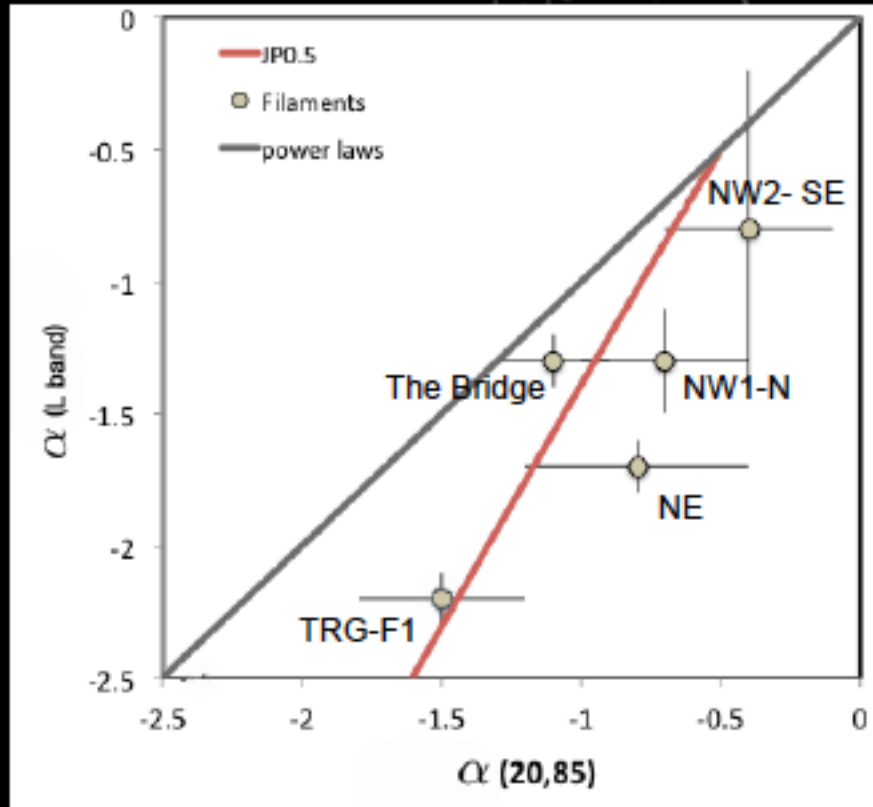


# Original TRG filaments

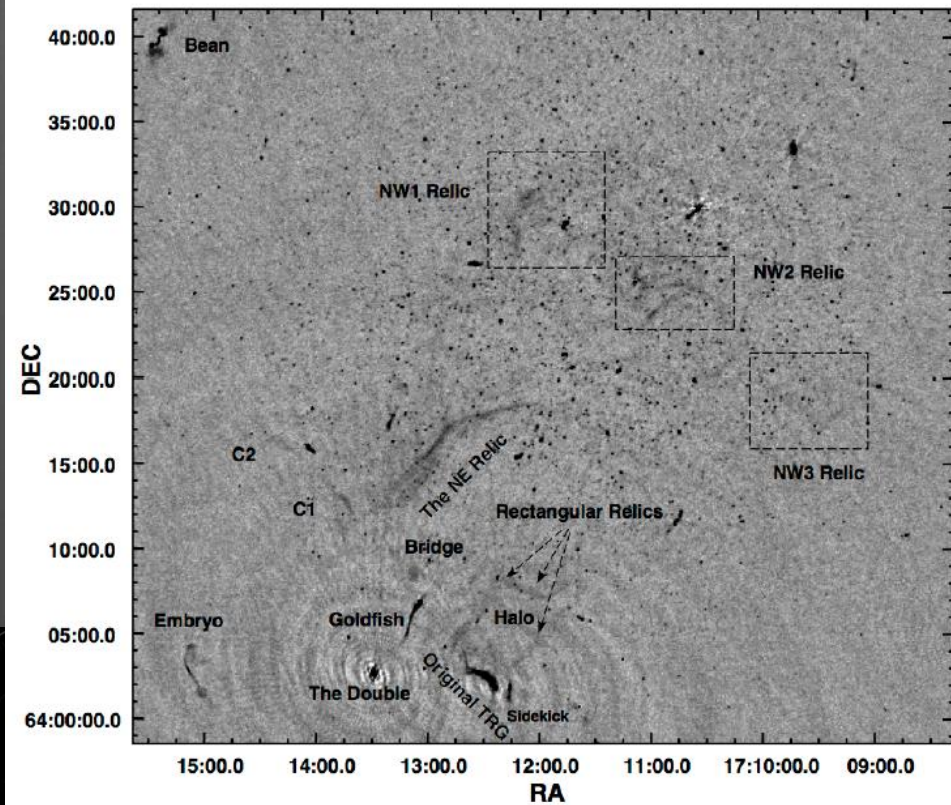
- The L band spectral index of the 200 kpc tail steepens consistent with electron's aging
- TRG-F1 is steep with  $\alpha = -2.2$  but also evidence of slight flattening
- TRG-F2 spectral index is consistent with F1
- The tip of the tail for Sidekick has  $\alpha = -1.4$







A2255 Northern Pointing



A2255 Central Pointing

