# Revolutions in polarisation:

## Leveraging next-gen telescopes and Faraday rotation to study radio galaxies

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SPARCS, Perth, 20 July 2017

CSIRO ASTRONOMY AND SPACE SCIENCE, PERTH ASTROPHYSICS GROUP
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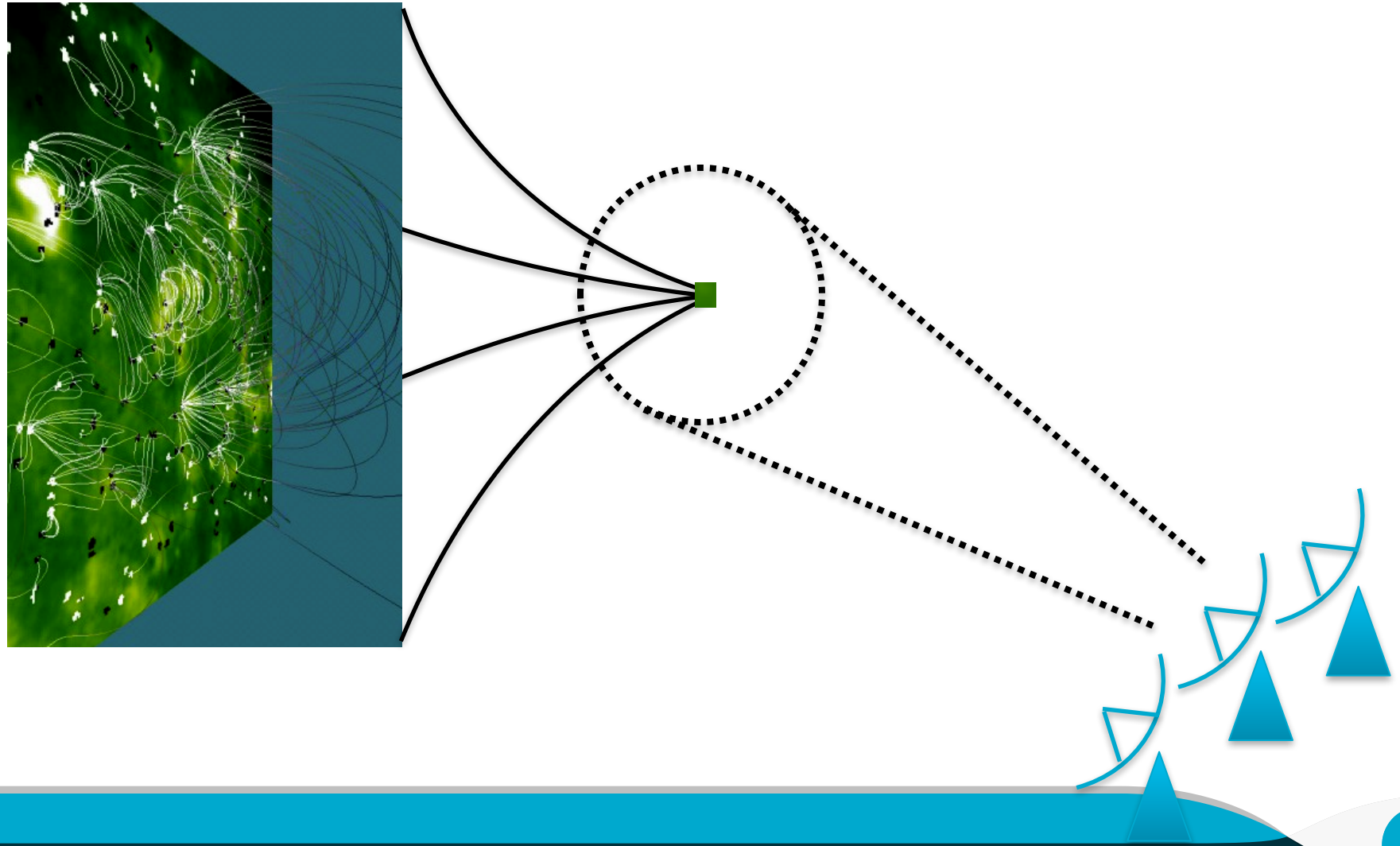
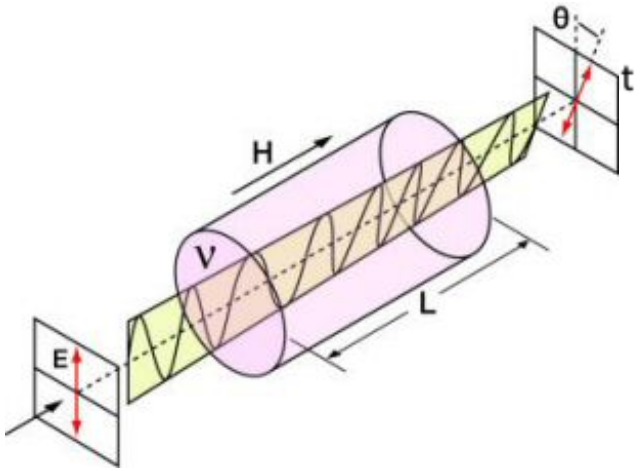
# Motivation – disentangling unresolved magnetoionic structure

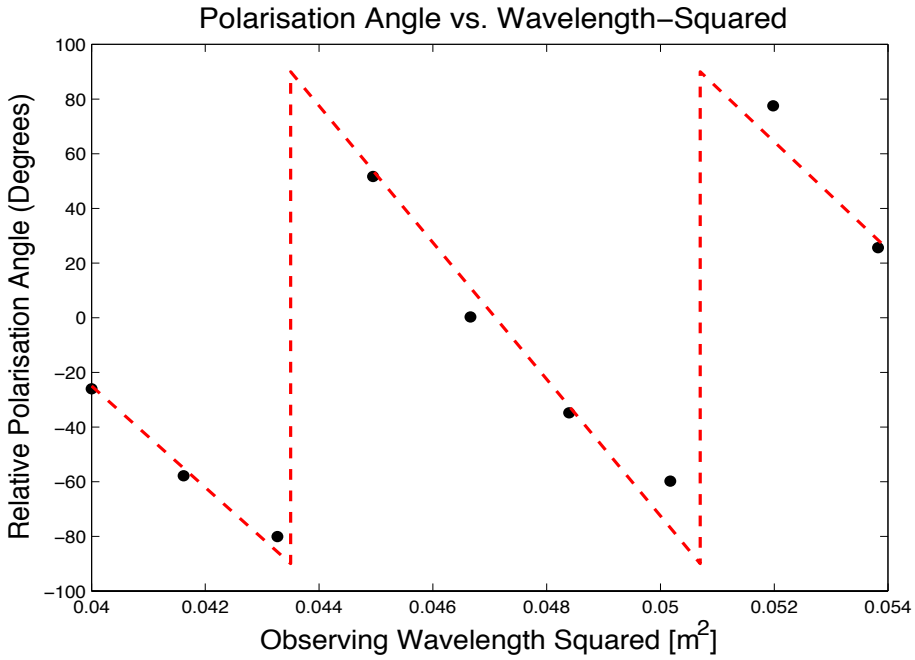


# Refresher: Faraday rotation




$$\theta = \theta_0 + \mathrm{RM}\,\lambda^2$$

$$\mathrm{RM} \propto \int_{source}^{telescope} n_e \boldsymbol{B}.d\boldsymbol{l}$$

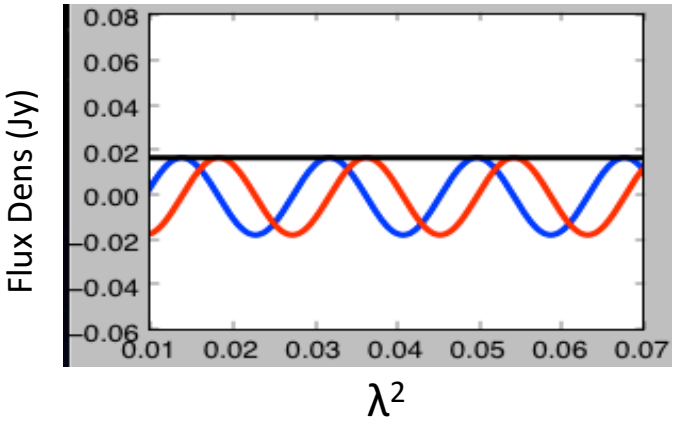


# Faraday rotation

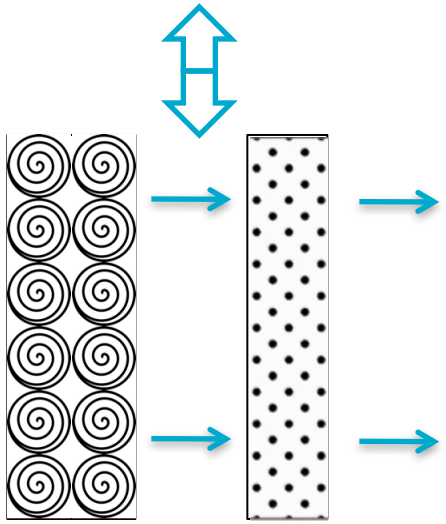
Stokes q

Stokes u

p



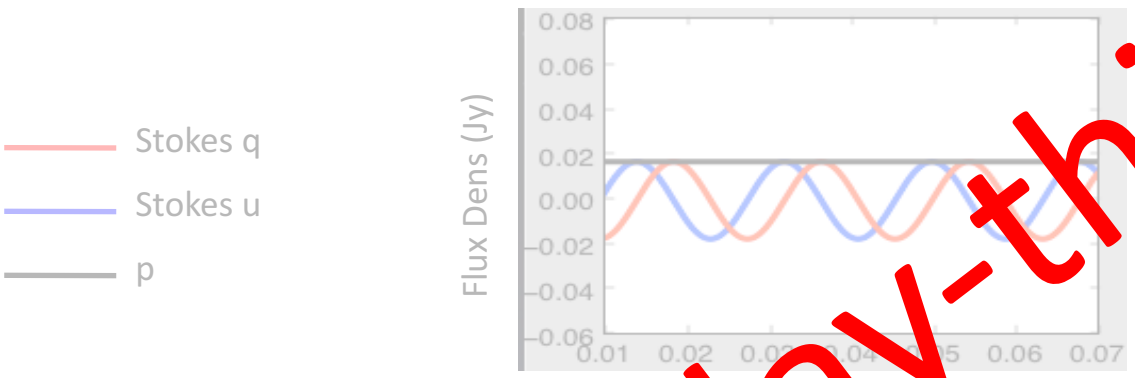

Corresponding physical arrangement:



Synchrotron emitting medium

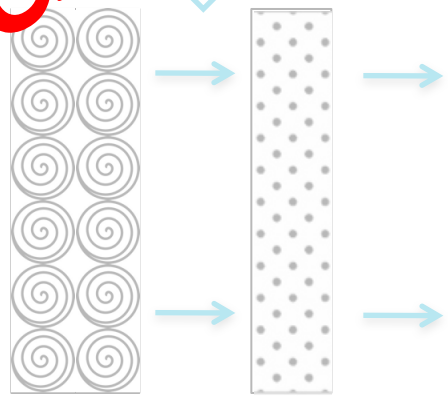
Faraday rotating medium

# Faraday rotation




"Faraday-thin"

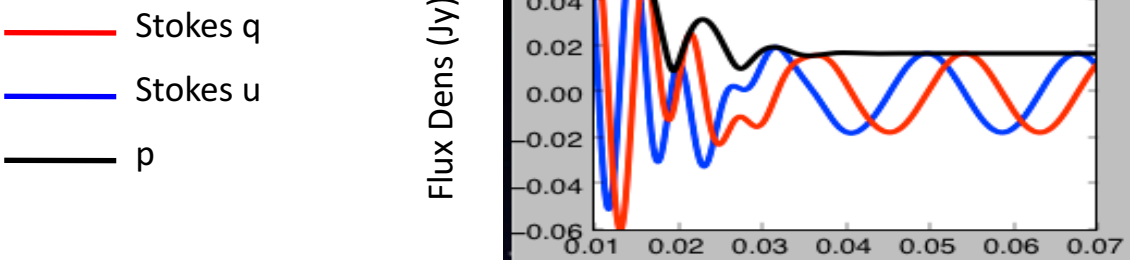
Corresponding physical arrangement:



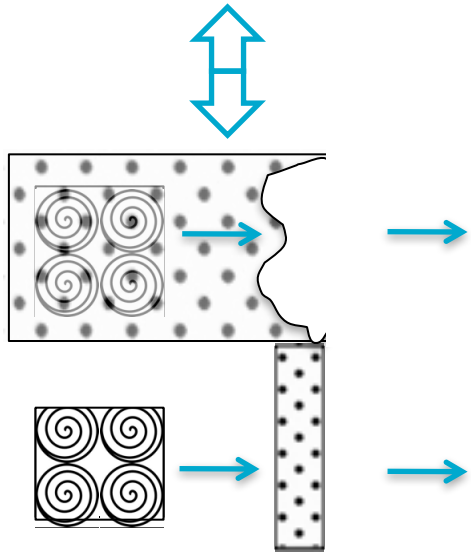
Synchrotron emitting medium

Faraday rotating medium

# Faraday interference effects



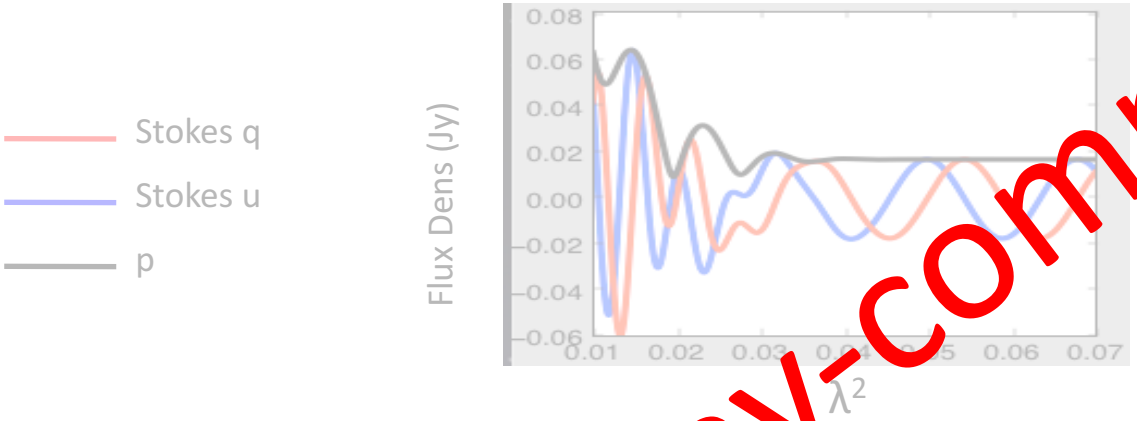

(One possible) corresponding physical arrangement:



Synchrotron emitting medium

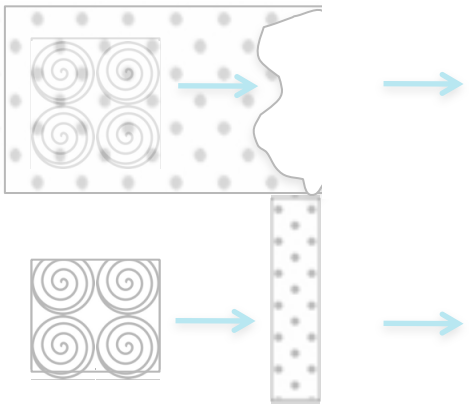
Faraday rotating medium

# Faraday interference effects




"Faraday-complex"

(One possible) corresponding physical arrangement:



Synchrotron emitting medium

Faraday rotating medium

# The $\lambda^2$ coverage issue

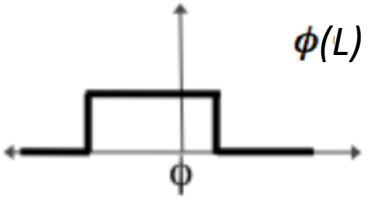
Observational theory of Faraday rotation: (Burn 1966, B.+deB. 2005)

RM synthesis

Aperture synthesis

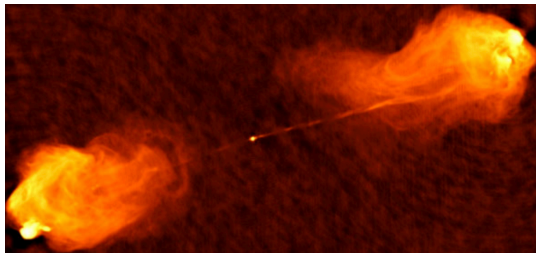
$$\phi(L) \propto \int_L^{telescope} n_e B \, dl$$

FDF




FT

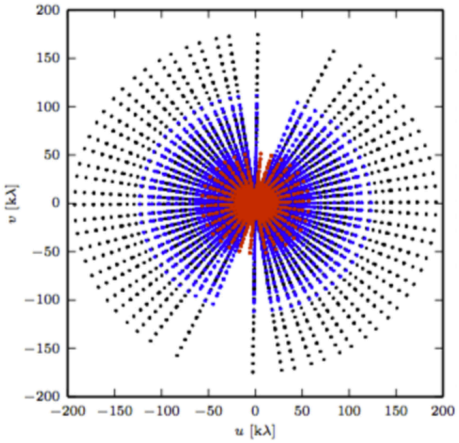
Equivalence! (mostly)



Sky

FT

***P***

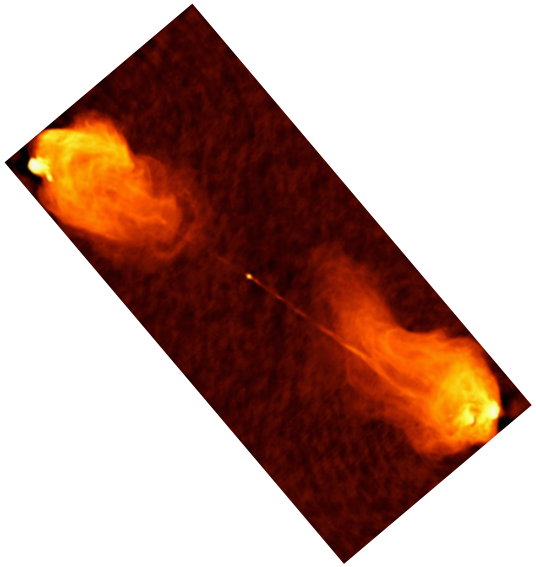

Visbilities

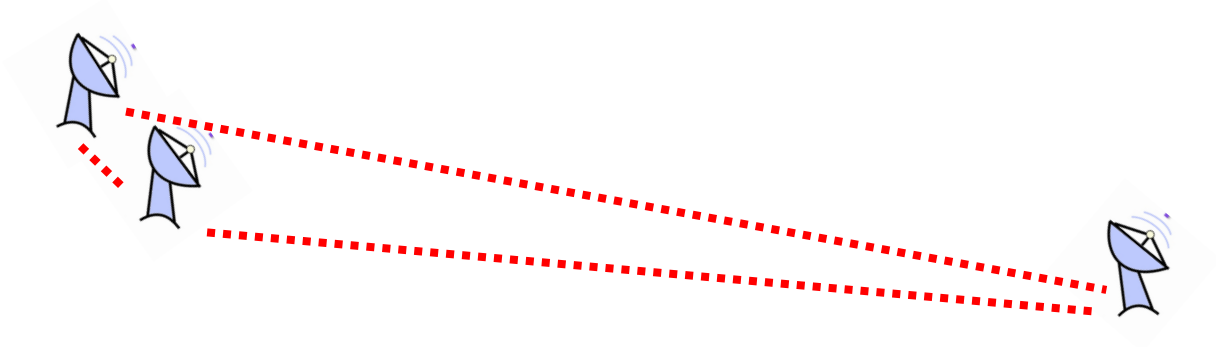
# The $\lambda^2$ coverage issue

RMs / depol. modelling are useful tools, but:

2. Often derived from narrow / sparsely-sampled bands.

> like reconstructing (potentially) complex source morphology using a few baselines!





# Is this important?

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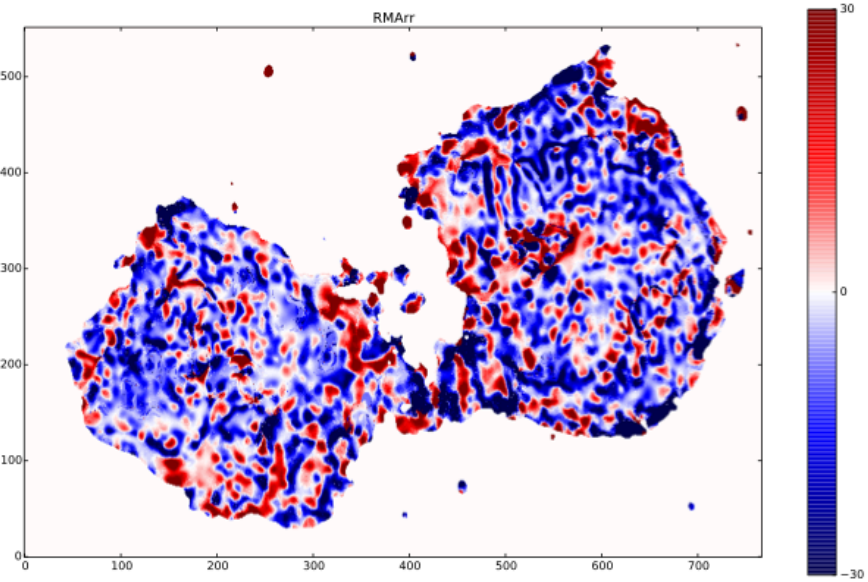
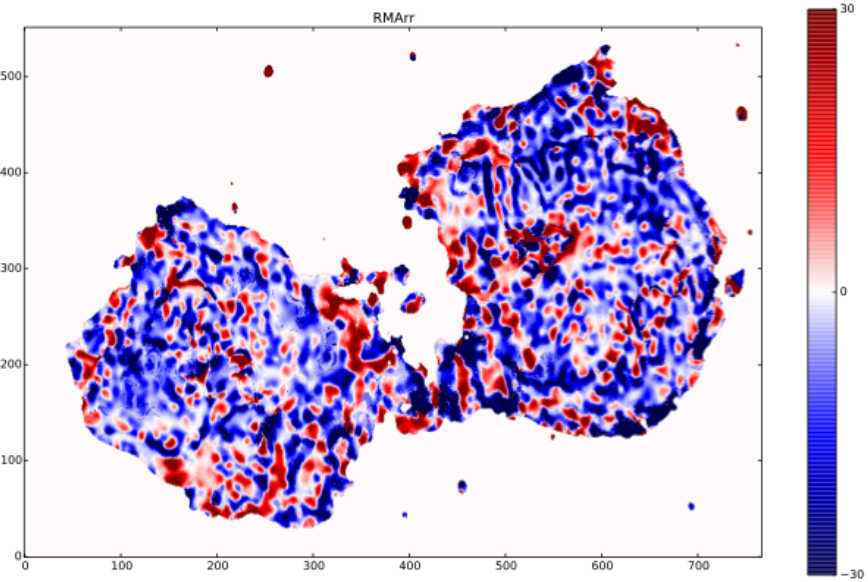
Narrowband RM



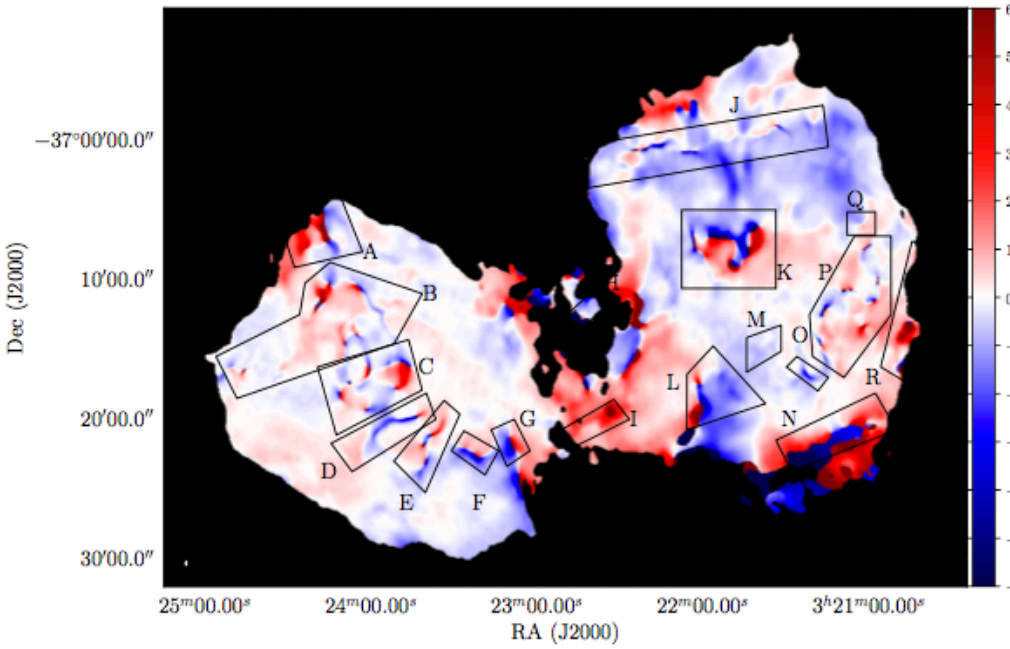

Stokes I / optical

# Is this important?

Narrowband RM

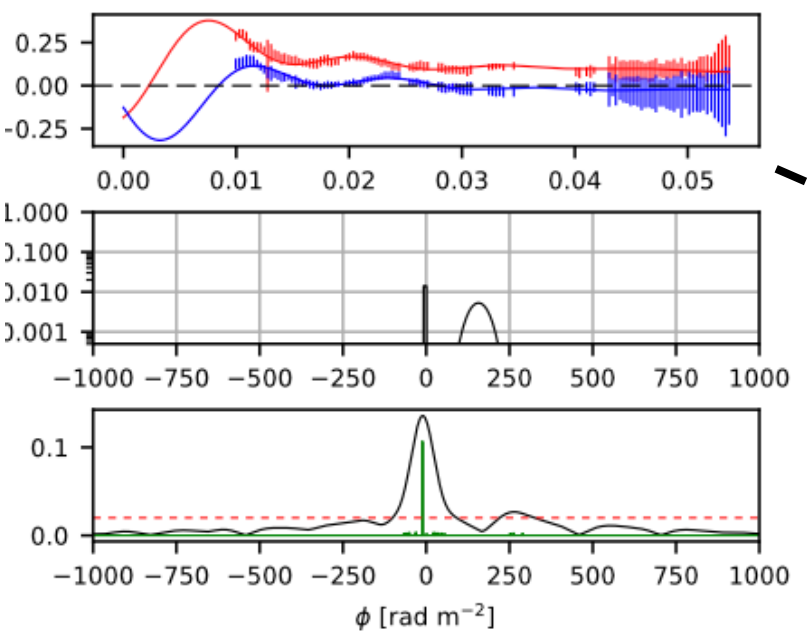


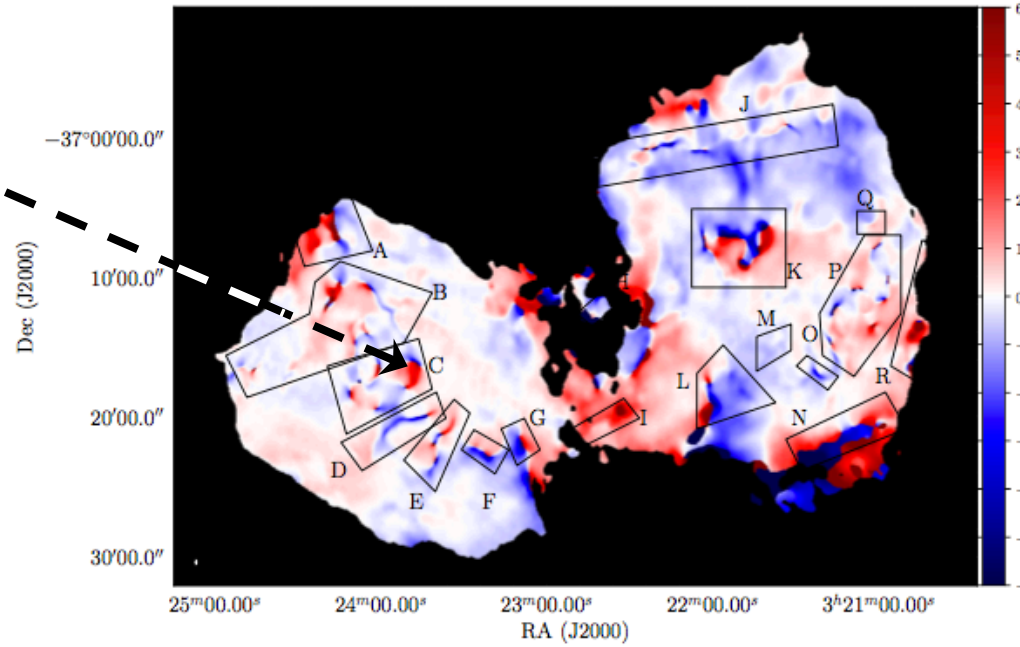

Broadband peak FD




Anderson+ (*submitted*)

# Is this important?

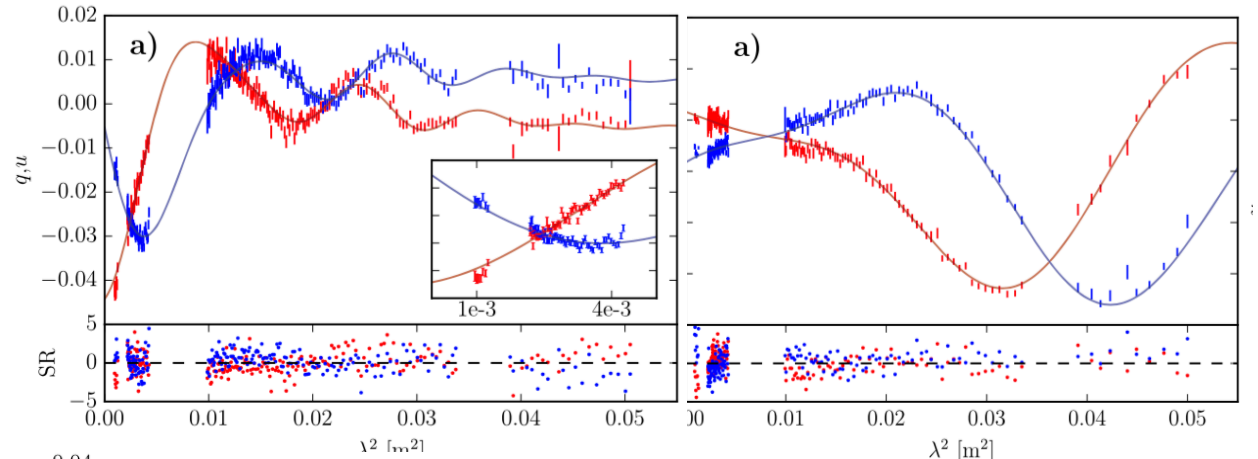


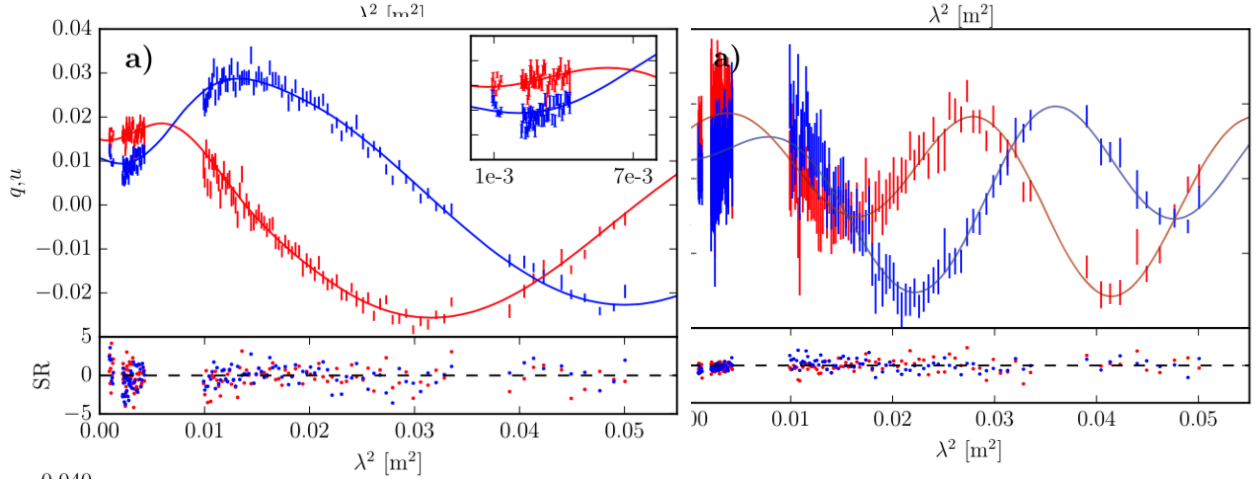

Anderson+ (*submitted*)

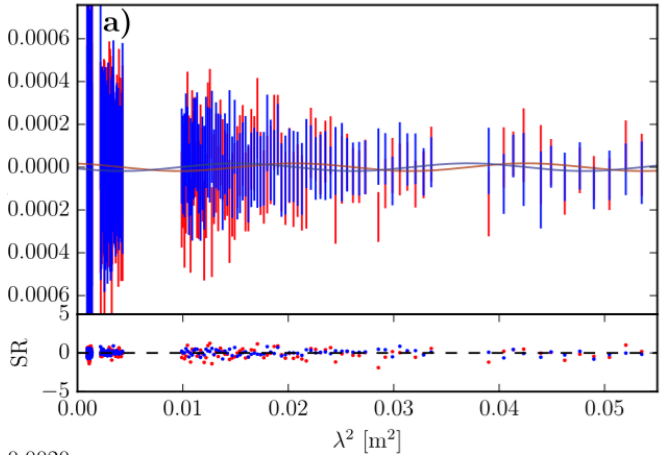
# It this common?

- Rich polarisation behaviours from sub-kpc scale radio jets

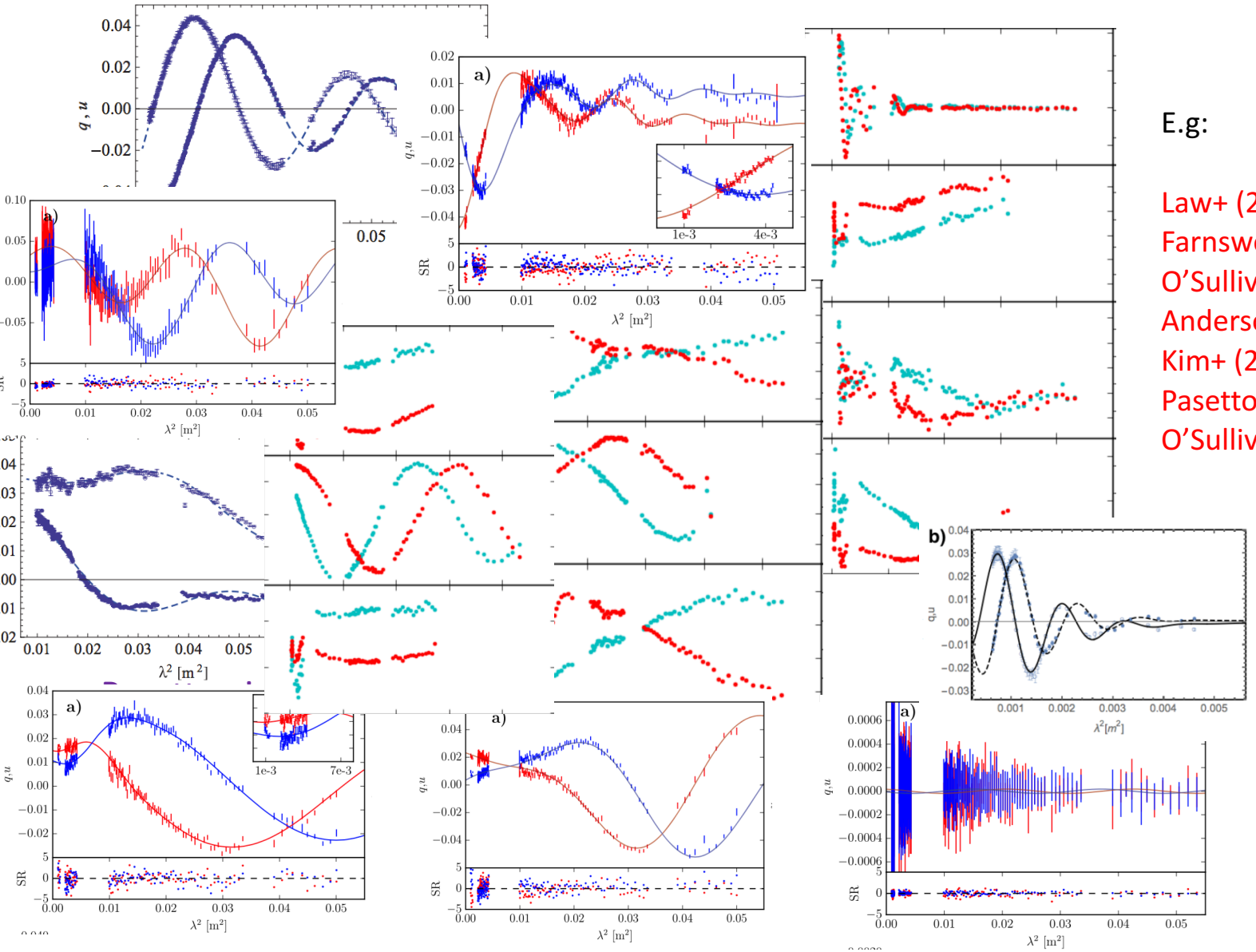



Anderson+ 2016



# Common. (so what is an RM?!)

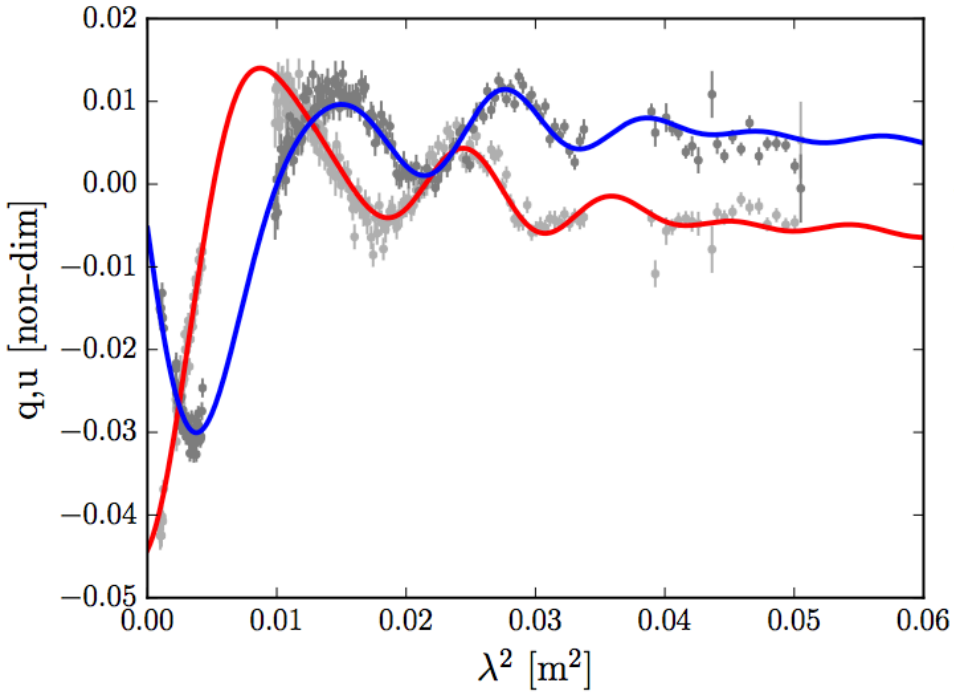


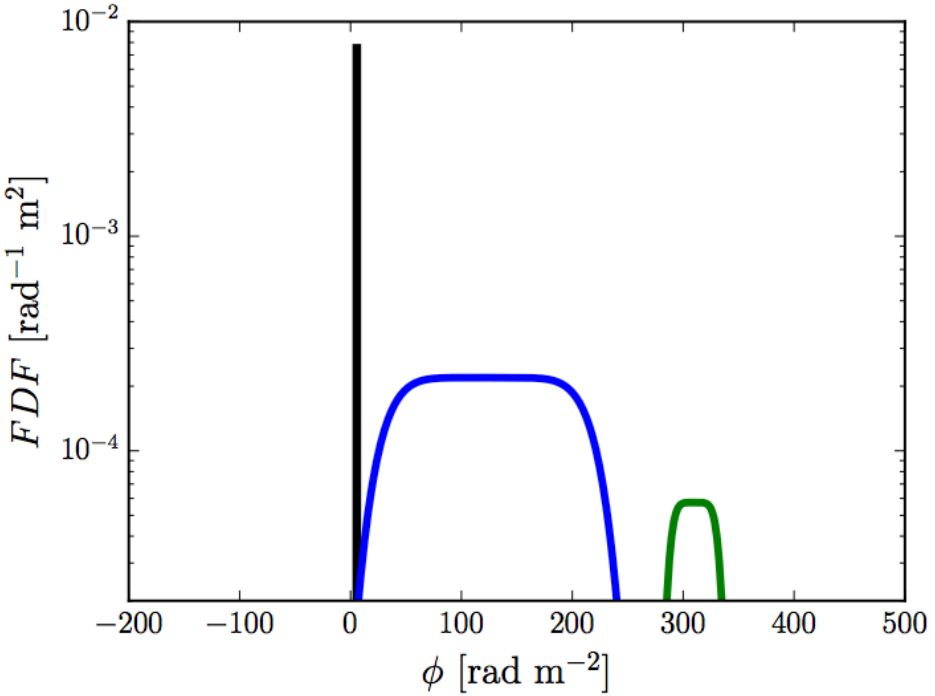

E.g:

Law+ (2011)
Farnsworth+ (2011)
O'Sullivan+ (2012)
Anderson+ (2016)
Kim+ (2016)
Pasetto+ (2016)
O'Sullivan+ (2017)

# Does this convey useful information?

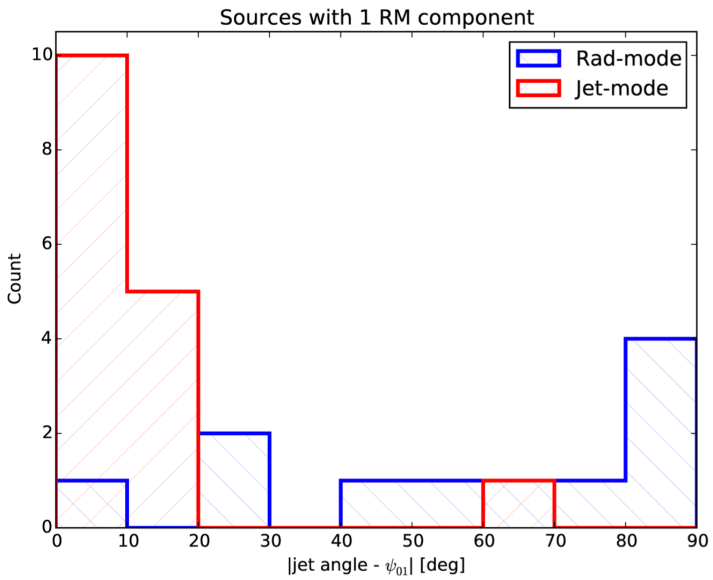
- Constrains global magneto-ionised structure of jets + environments

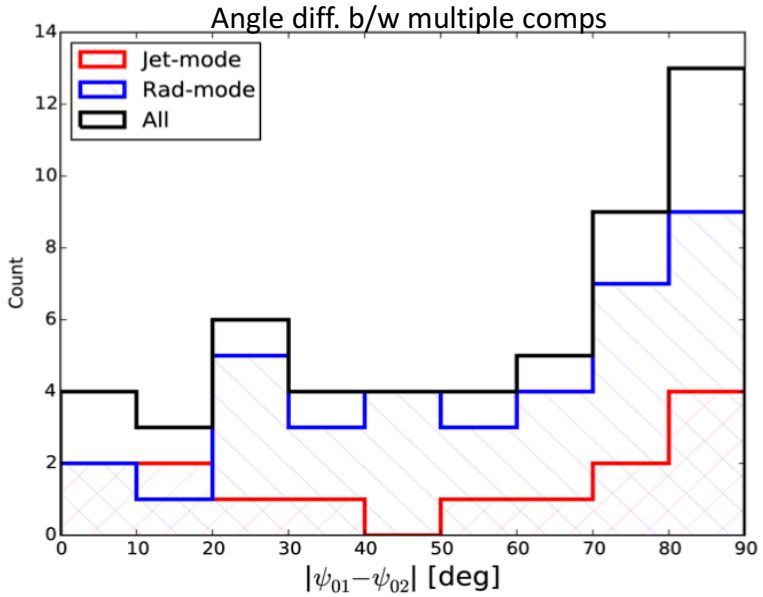



Anderson+ 2016

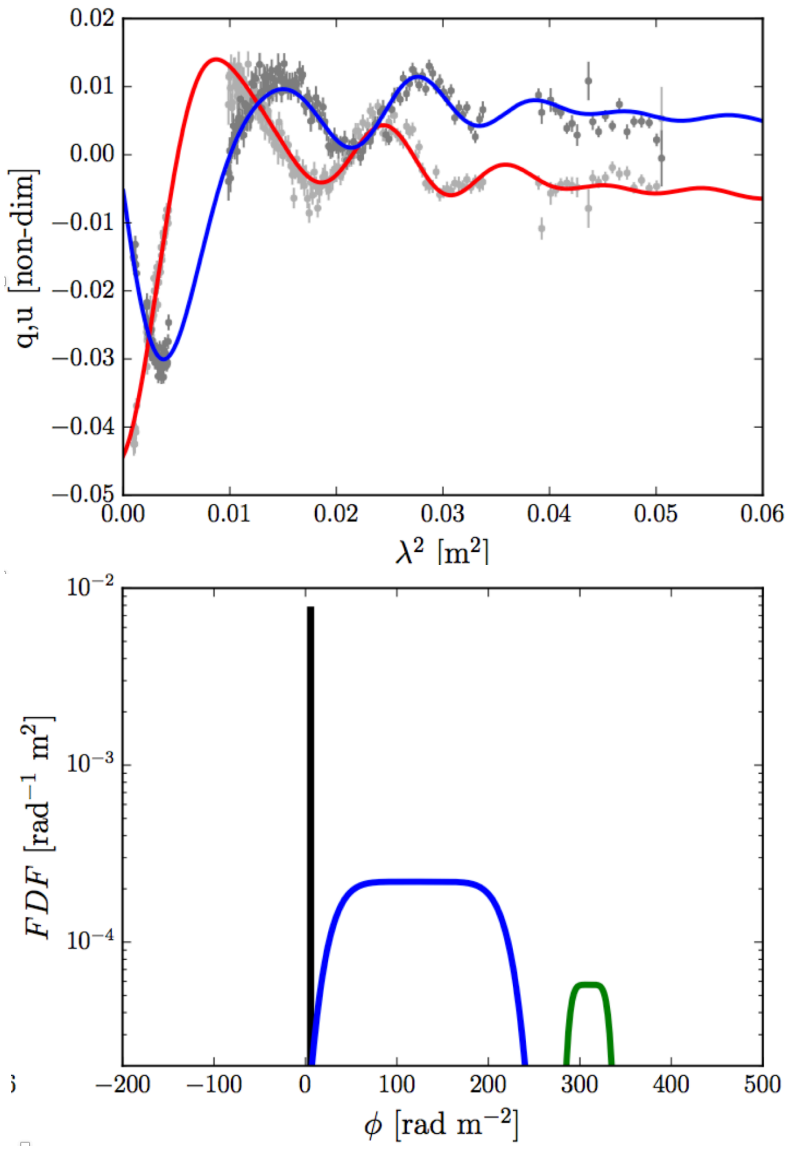
# Does this convey useful information?



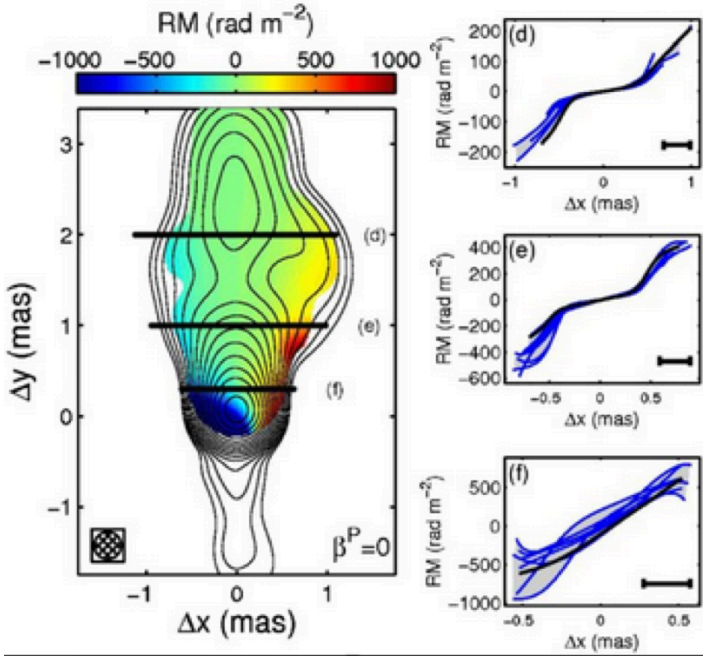




O'Sullivan+ (*2017*)

# What are we seeing?




Broderick & McKinney 2010

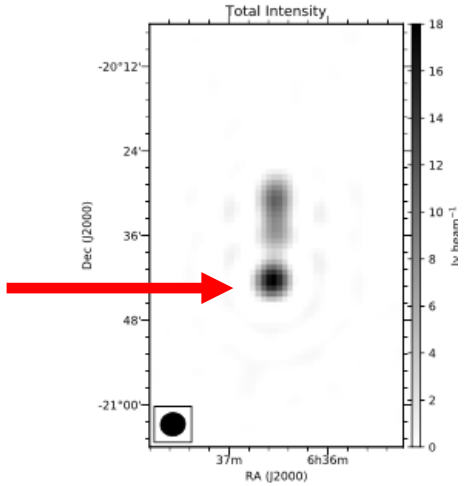


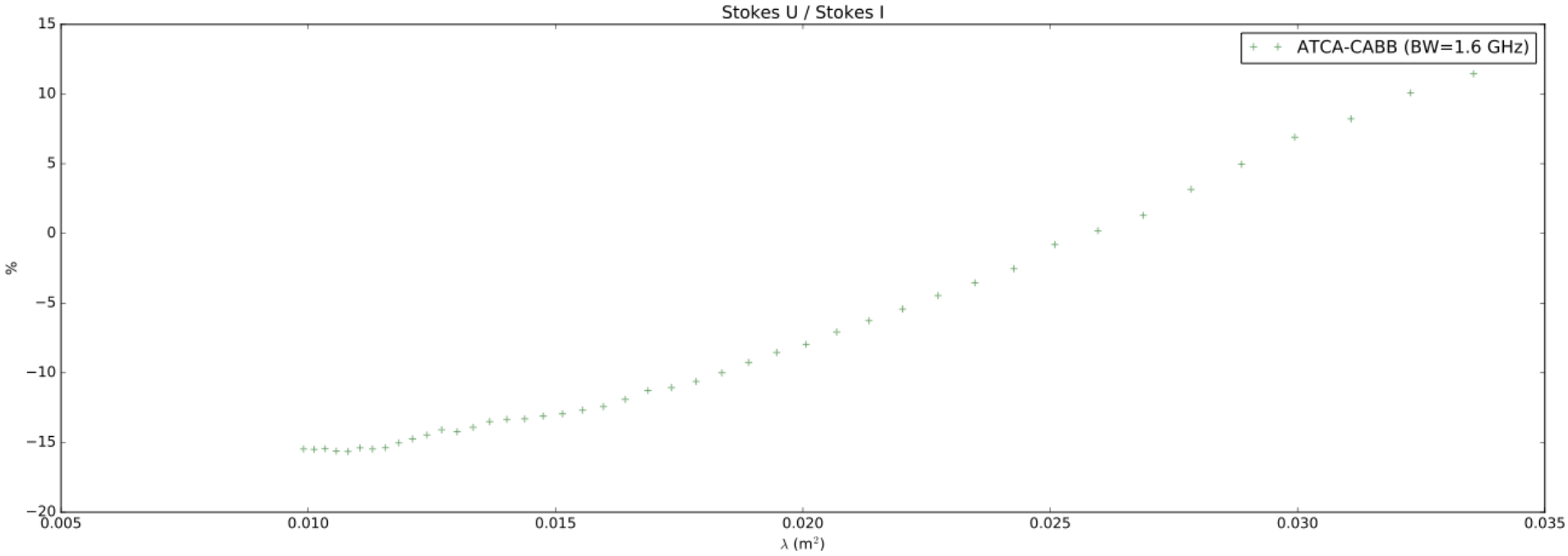

perhaps?

# Oh, so you want $\lambda^2$ coverage?

Observations of PKS J0636-2041

O'Sullivan, Lenc + (submitted)



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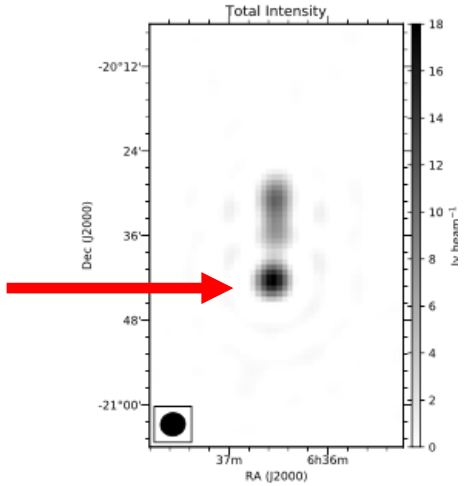
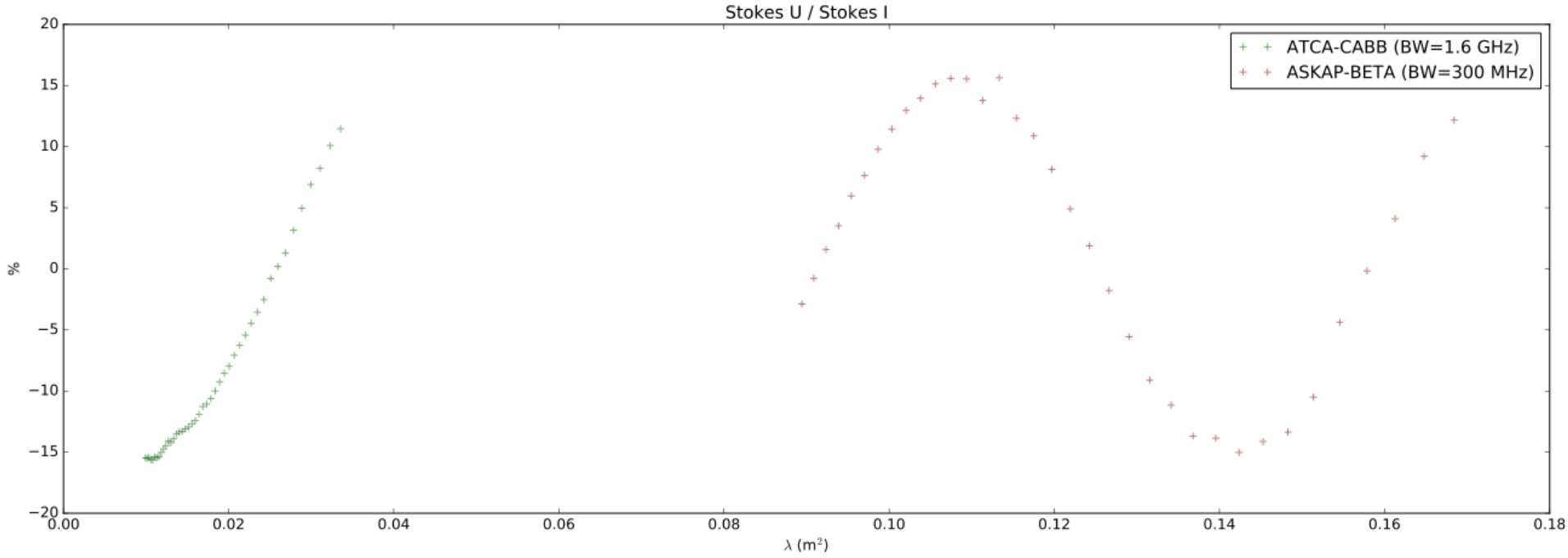
O'Sullivan, Lenc + (submitted)



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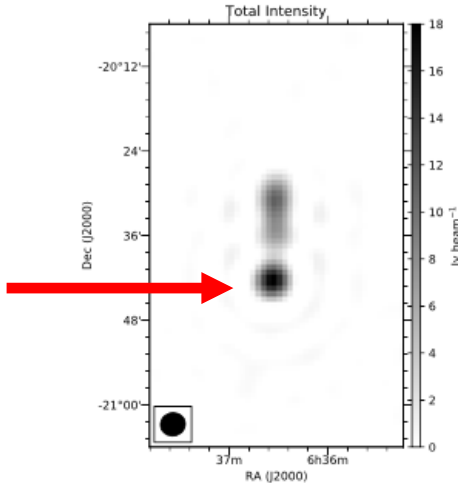


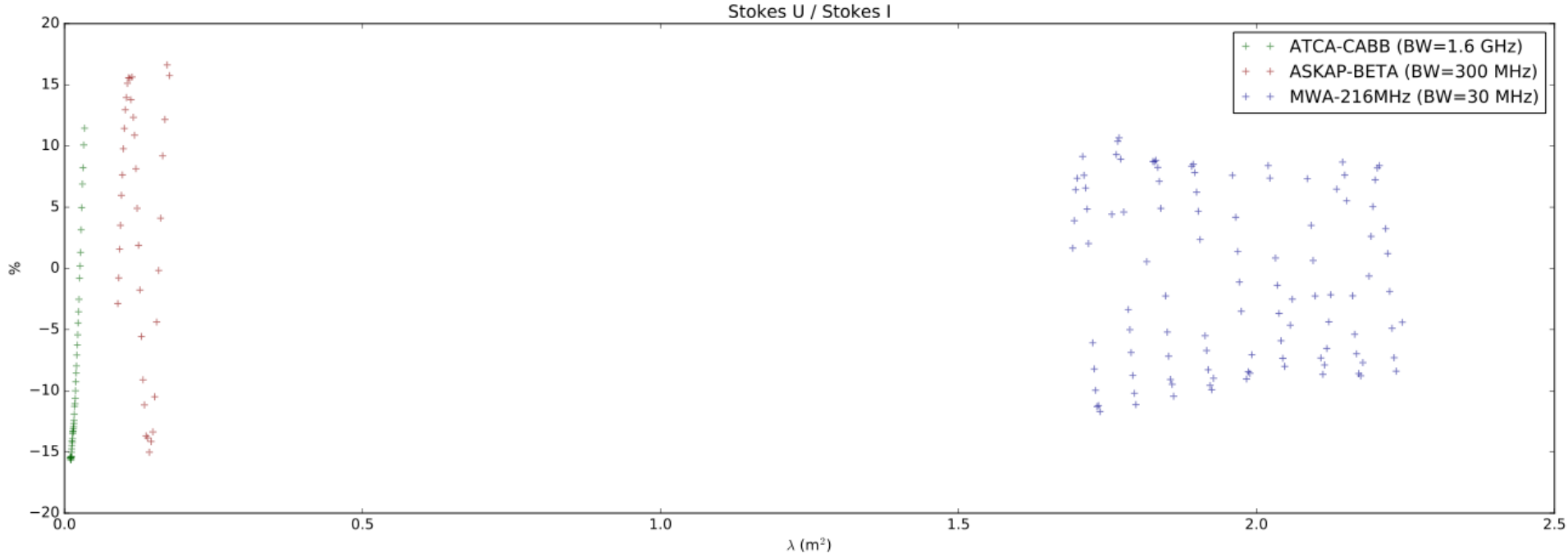

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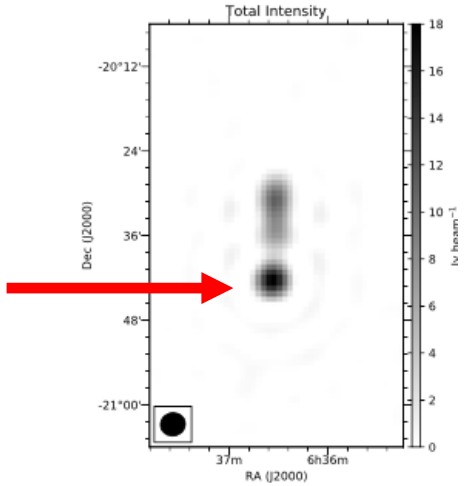


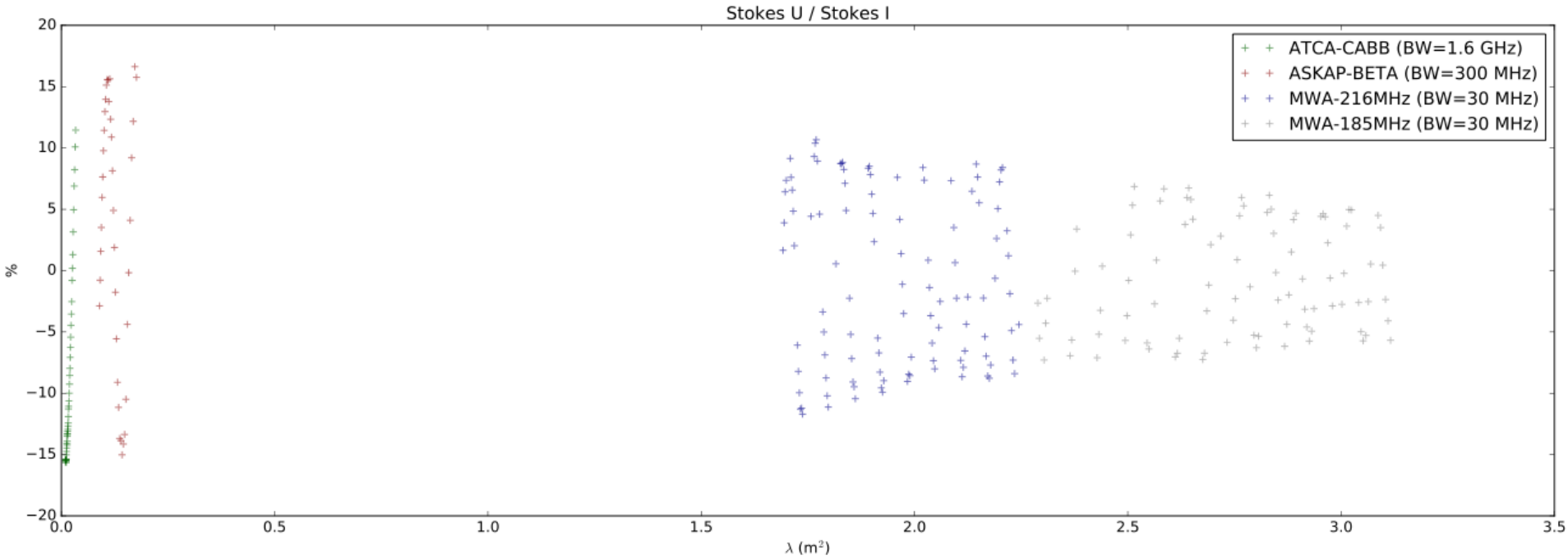

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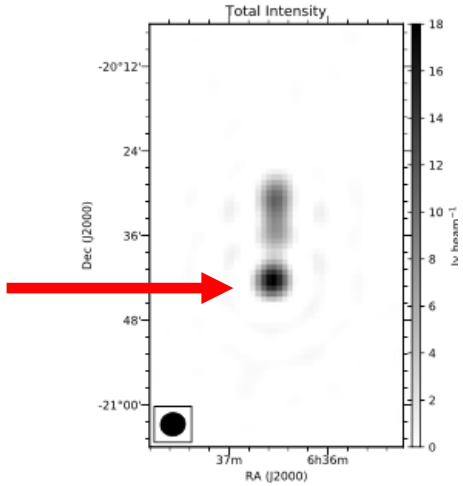
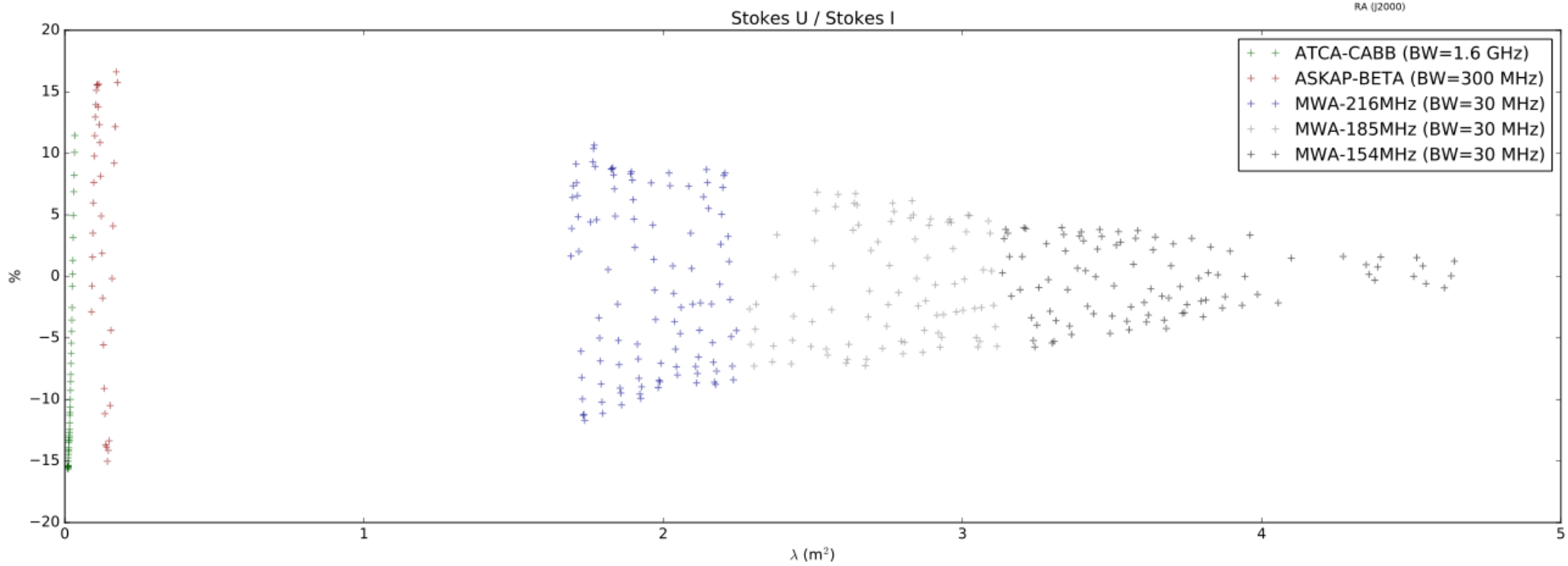
O'Sullivan, Lenc + (submitted)

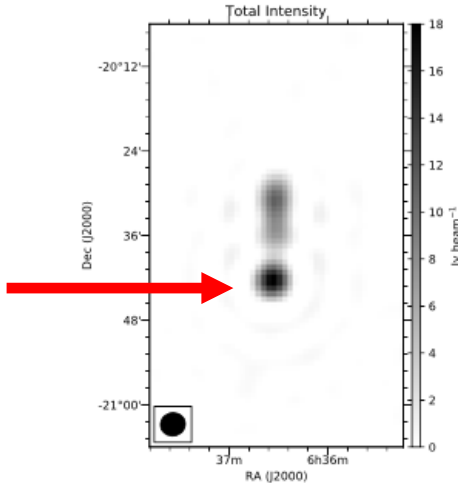


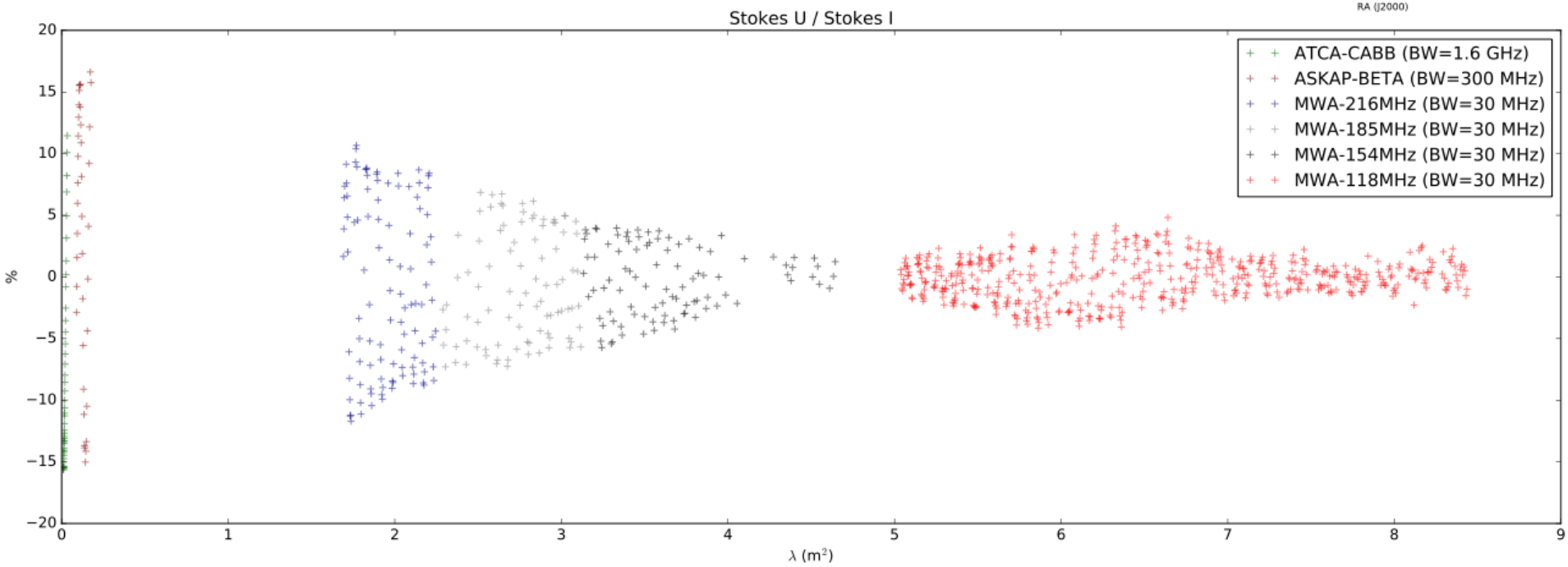



# Oh, so you want $\lambda^2$ coverage?

Observations of PKS J0636-2041

O'Sullivan, Lenc + (submitted)



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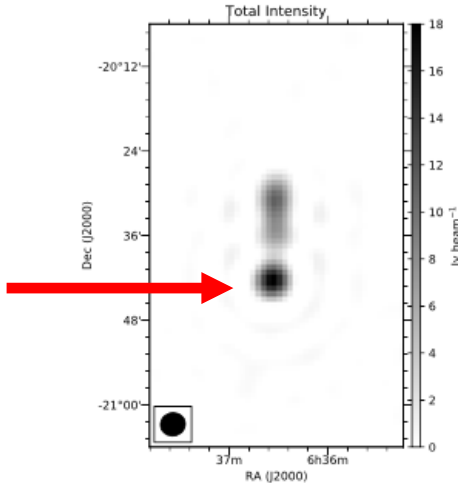
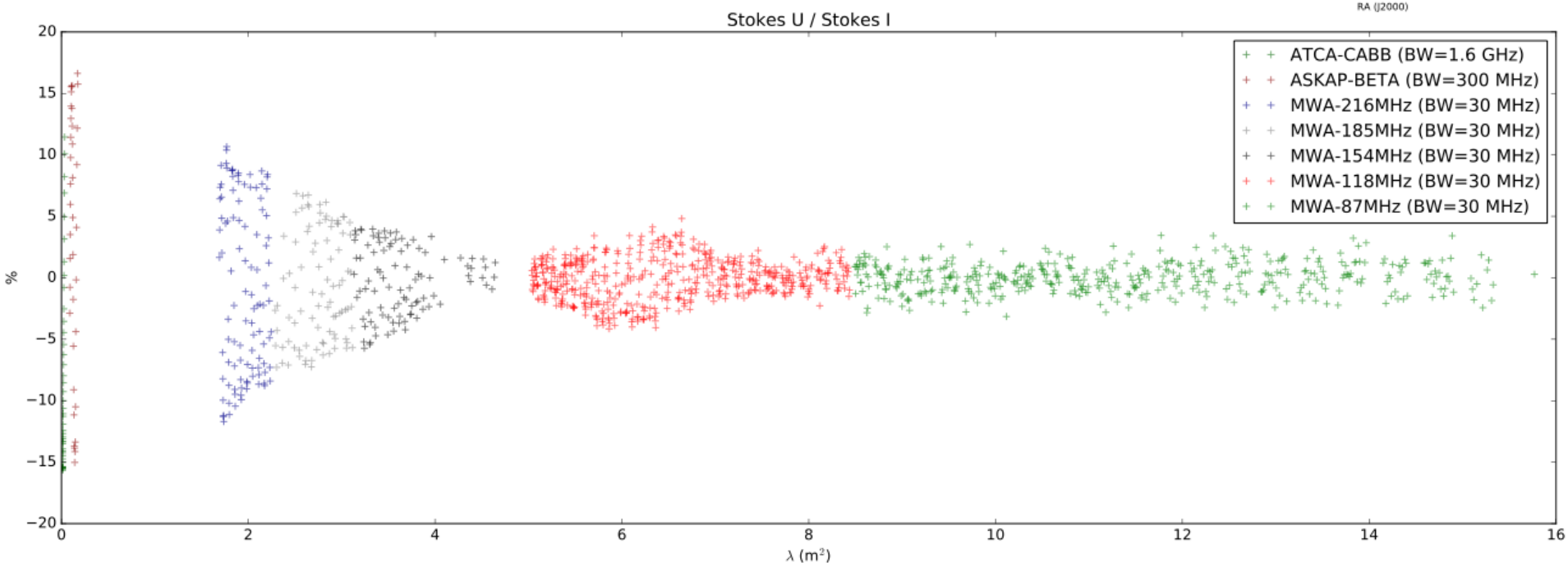
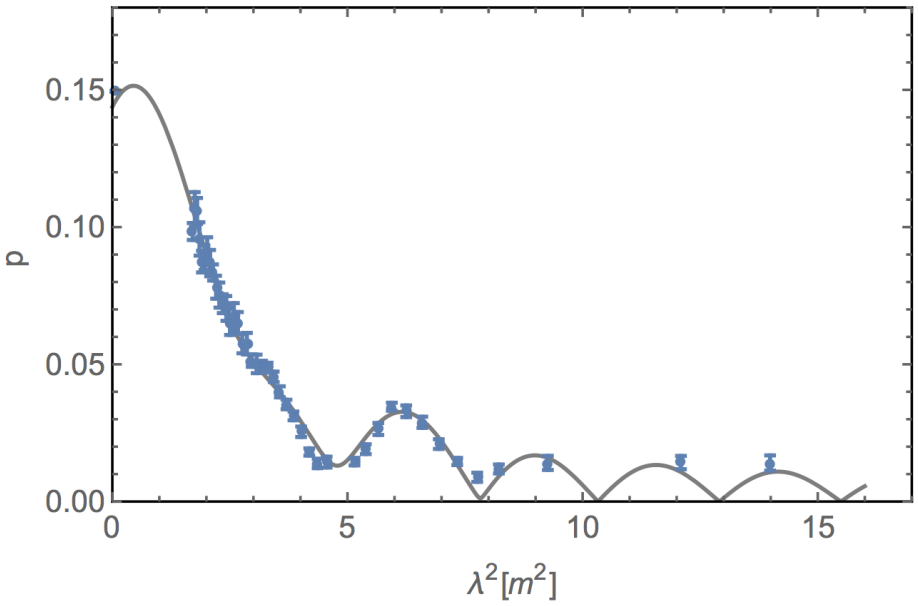


# Oh, so you want $\lambda^2$ coverage?

Uniform foreground | Internal sync./therm. mix | Uniform foreground | Turb. foreground

$$p_{01} e^{2i(\chi_{01}+\mathrm{RM}_1\lambda^2)} \frac{\sin \Delta\mathrm{RM}_1\lambda^2}{\Delta\mathrm{RM}_1\lambda^2} + p_{02} e^{2i(\chi_{02}+\mathrm{RM}_2\lambda^2)} e^{-2\sigma^2_{\mathrm{RM}_2}\lambda^4}$$




- Faraday depth resolution and precision 100x better than any previous study

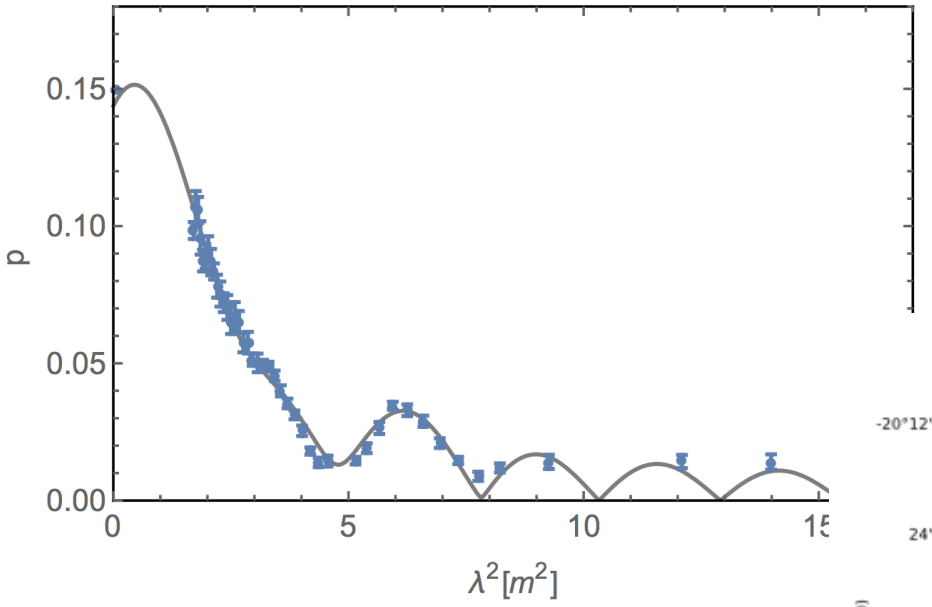
O'Sullivan, Lenc + (submitted)

# Oh, so you want λ² coverage?

Intrinsic angle comp 1.

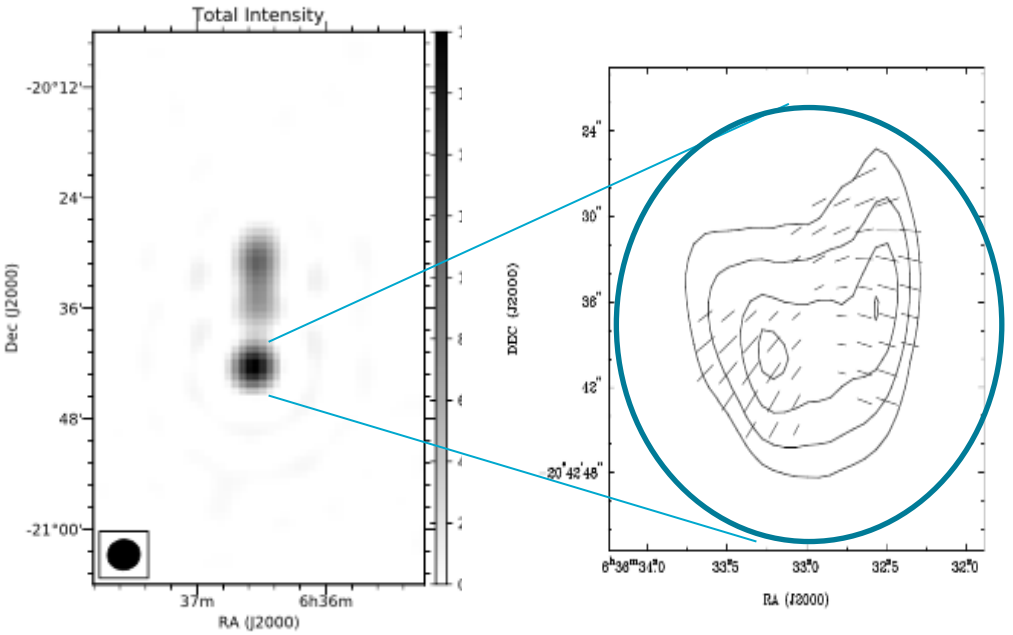
Intrinsic angle comp 2.

$$p_{01}\, e^{2i(\chi_{01}+\mathrm{RM}_1\lambda^2)}\,\frac{\sin \Delta\mathrm{RM}_1\lambda^2}{\Delta\mathrm{RM}_1\lambda^2} + p_{02}\, e^{2i(\chi_{02}+\mathrm{RM}_2\lambda^2)}\, e^{-2\sigma^2_{\mathrm{RM}_2}\lambda^4}$$




- Correctly recovers intrinsic polarisation angles

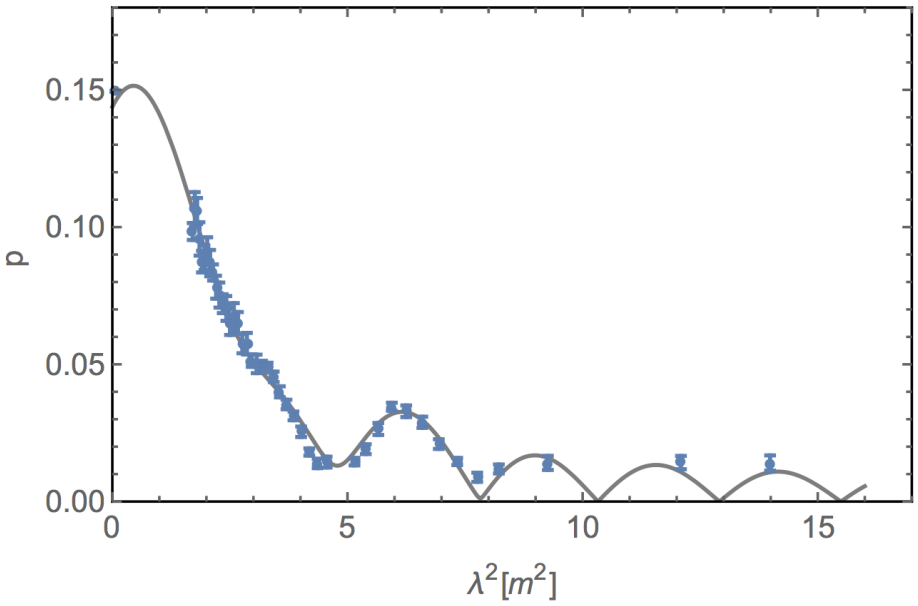
O'Sullivan, Lenc + (submitted)



# Oh, so you want $\lambda^2$ coverage?

Internal sync./therm. mix

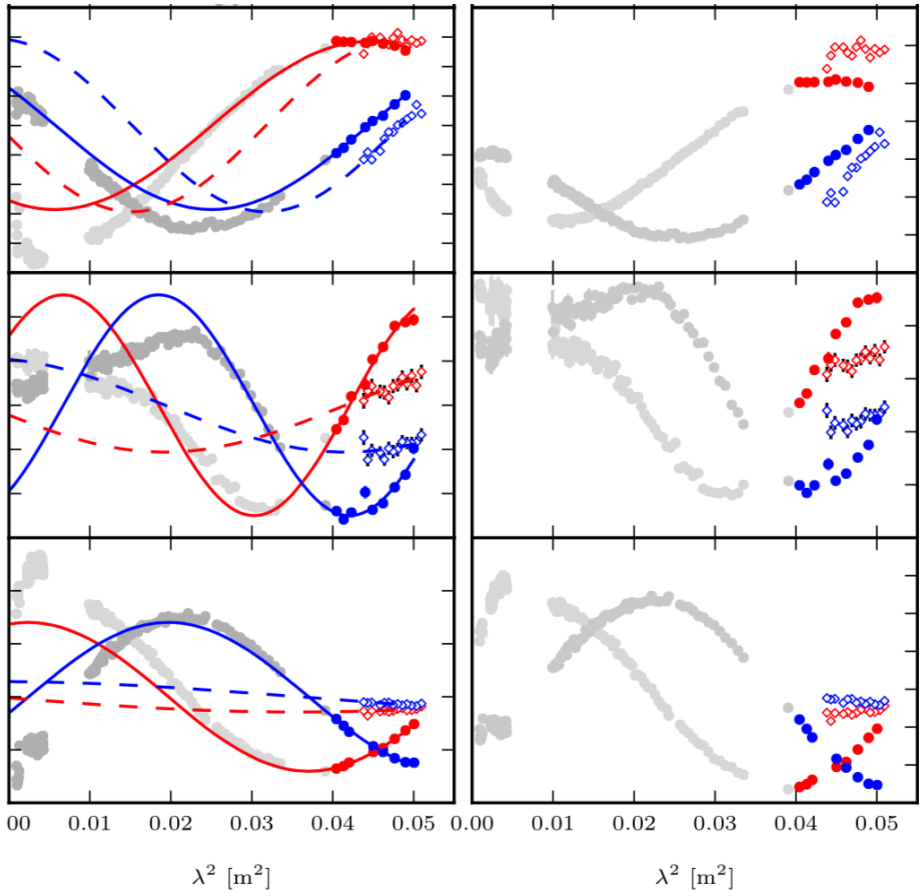
$$p_{01}\, e^{2i(\chi_{01}+\mathrm{RM}_1\lambda^2)}\frac{\sin \Delta\mathrm{RM}_1\lambda^2}{\Delta\mathrm{RM}_1\lambda^2} + p_{02}\, e^{2i(\chi_{02}+\mathrm{RM}_2\lambda^2)} e^{-2\sigma^2_{\mathrm{RM}_2}\lambda^4}$$




- Emission *and* Faraday-rotation from the relativistic plasma in the hotspot

O'Sullivan, Lenc + (submitted)

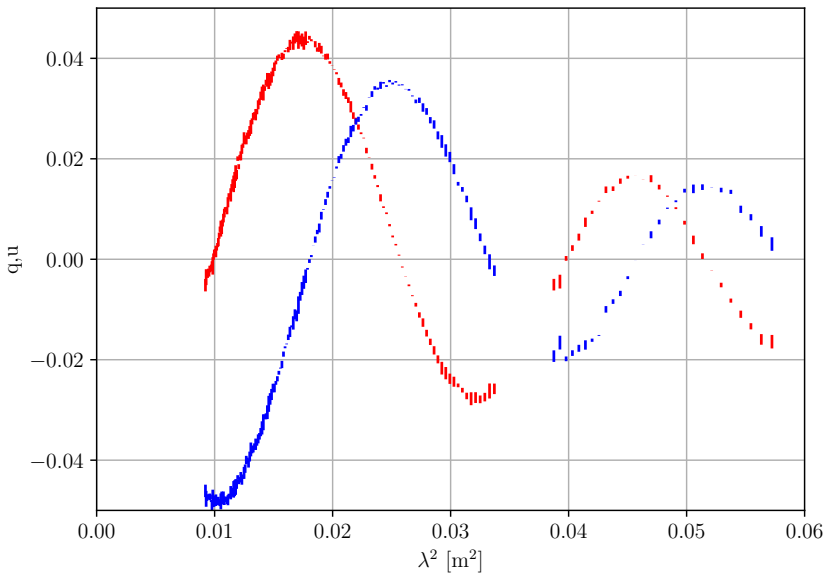
# Taking it to the time domain

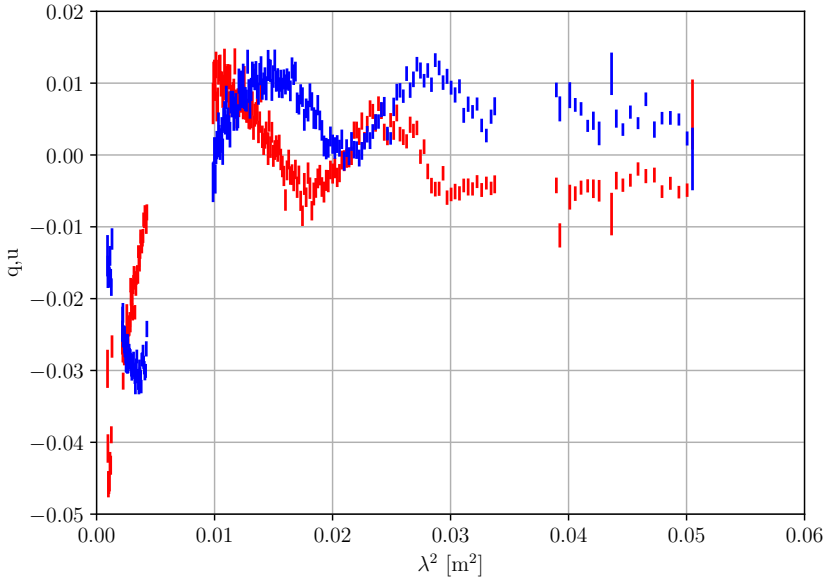



Anderson+ 2016

# Taking it to the time domain

2012

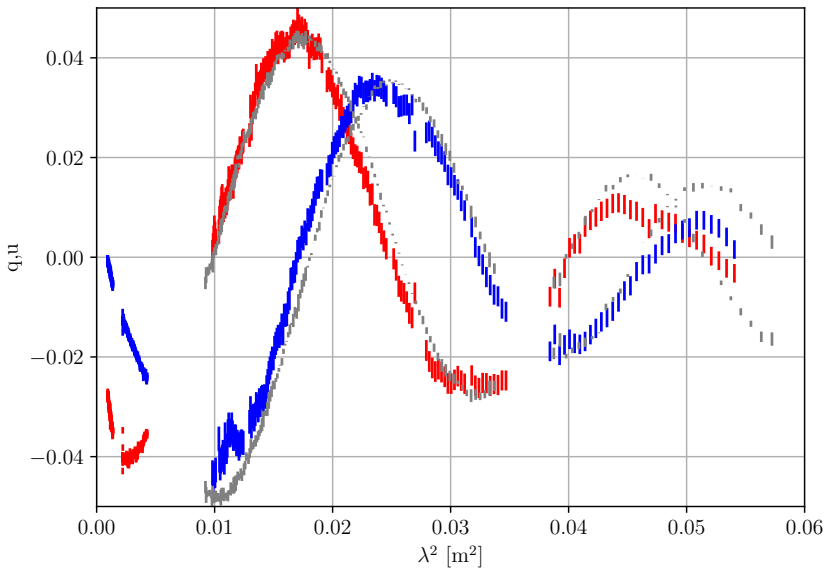


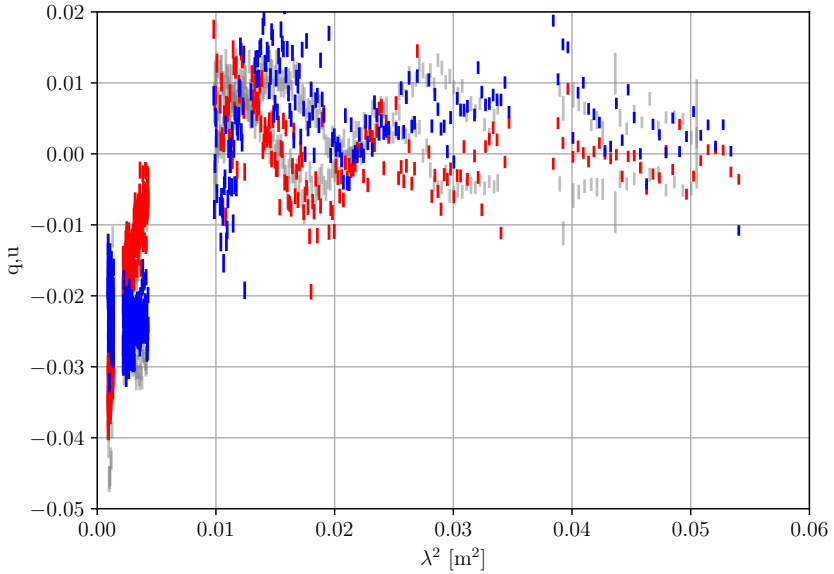




Anderson+ (*in prep.)*

# Taking it to the time domain

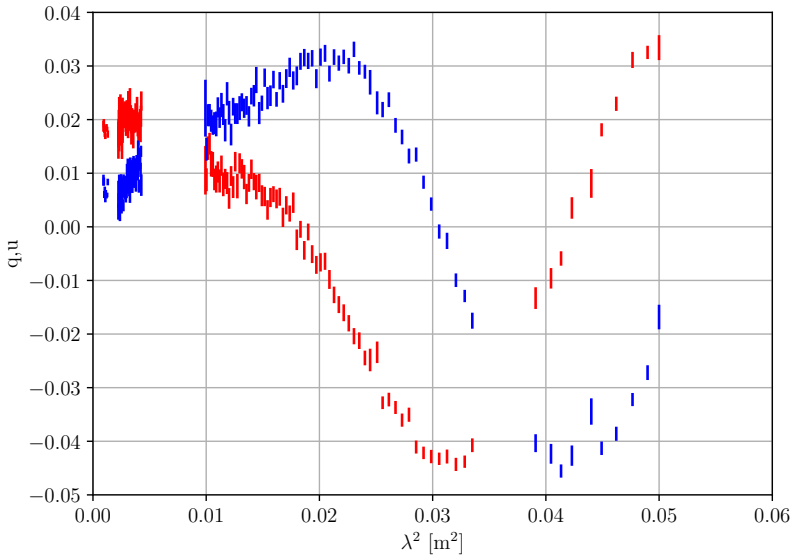
2017



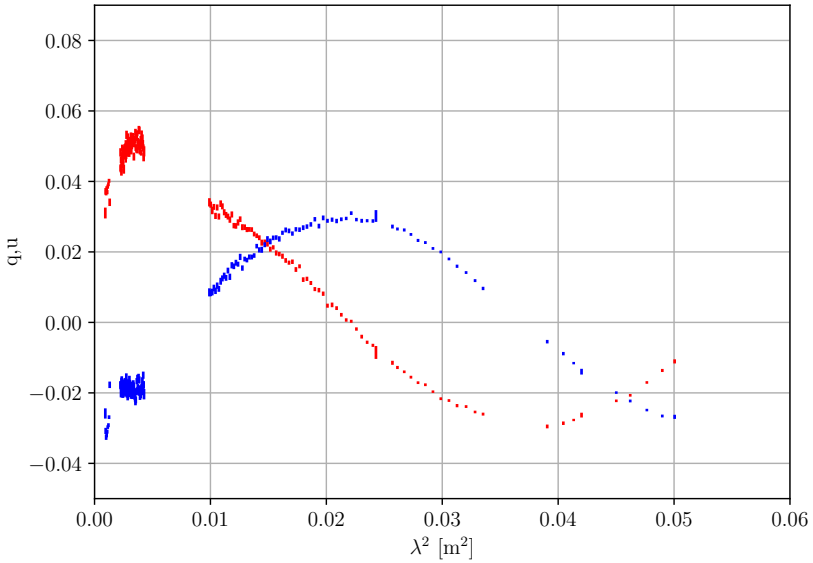



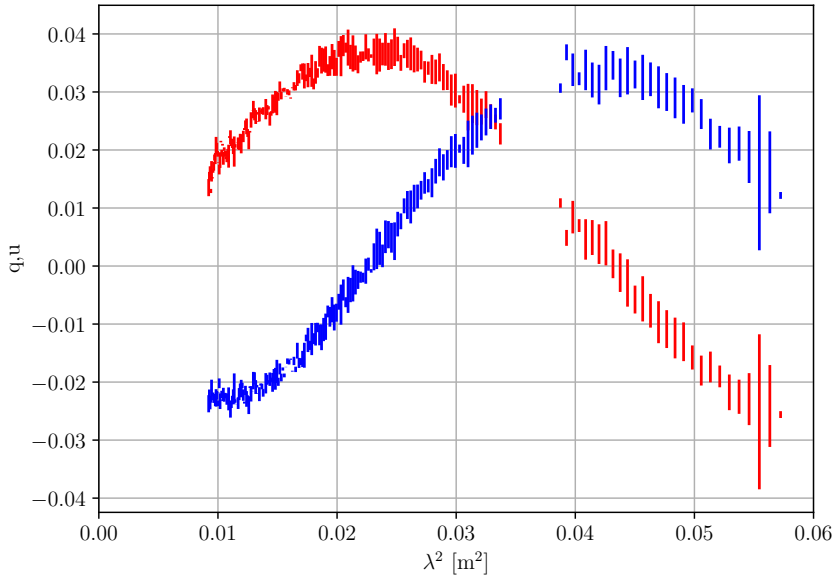

Anderson+ (*in prep.)*

# Taking it to the time domain



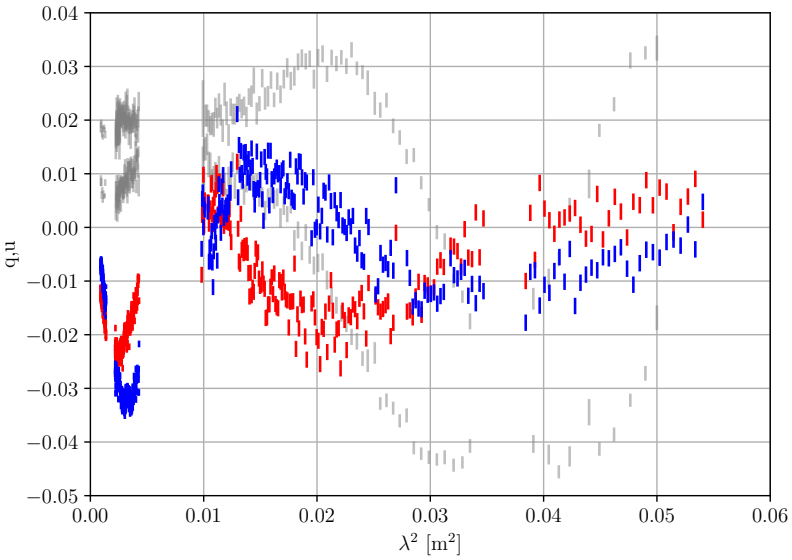

2012



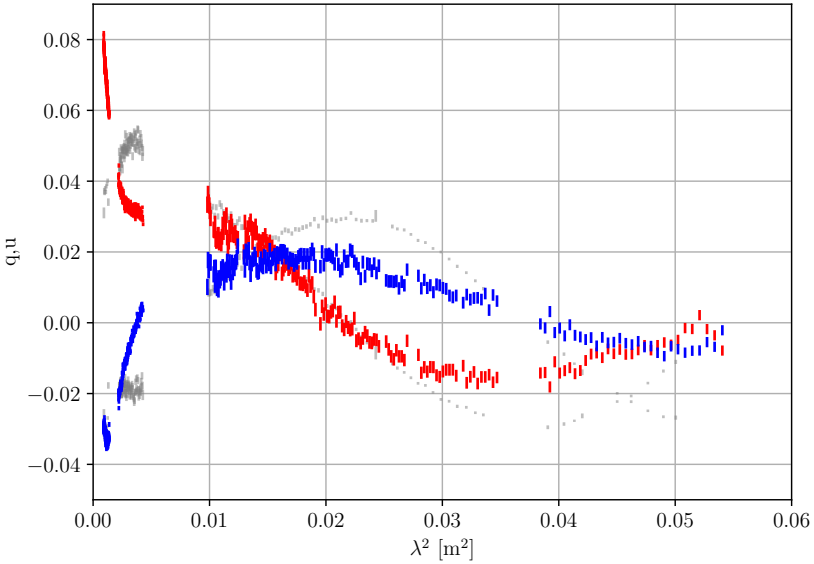



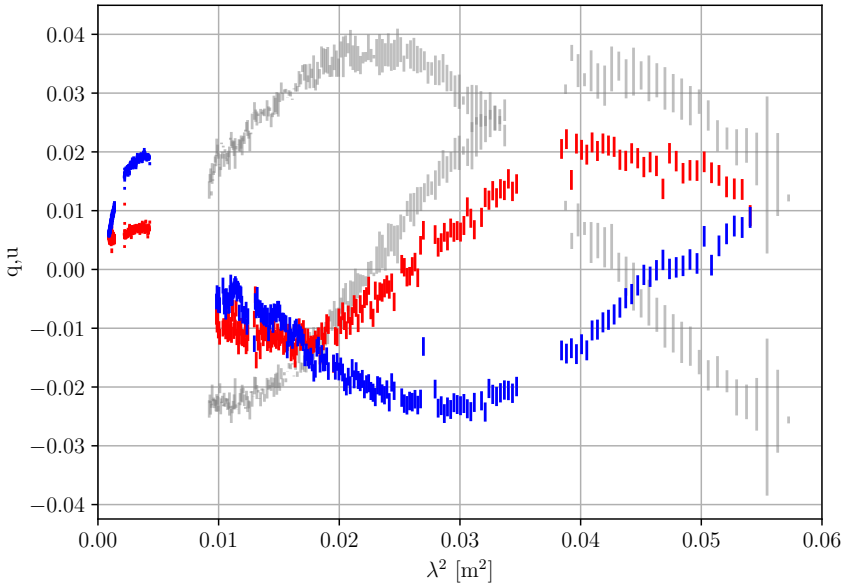

Anderson+ (*in prep.*)

# Taking it to the time domain




2017

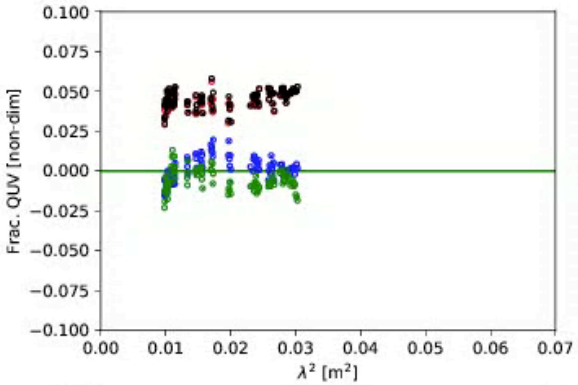


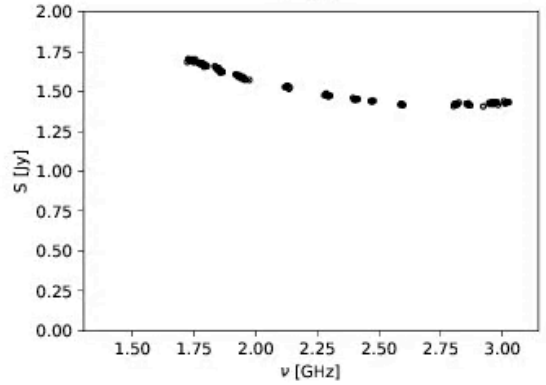

Anderson+ (*in prep.*)

# High resolution time domain

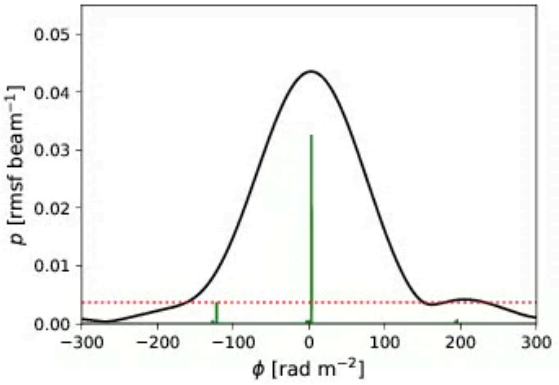
p (black)
q (red)
u (blue)
v (green)




Stokes I

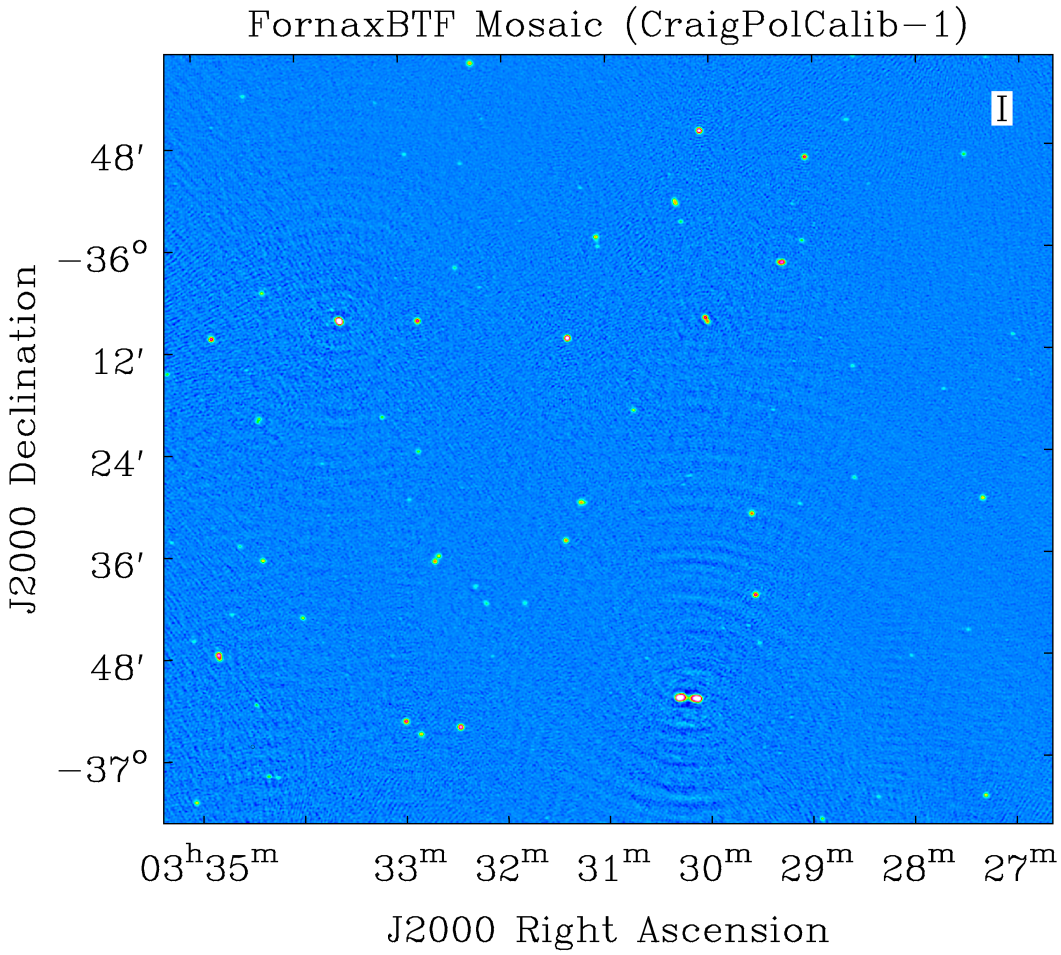



Reconstructed FDF
(RM synthesis + CLEAN)



# Where is it all headed?

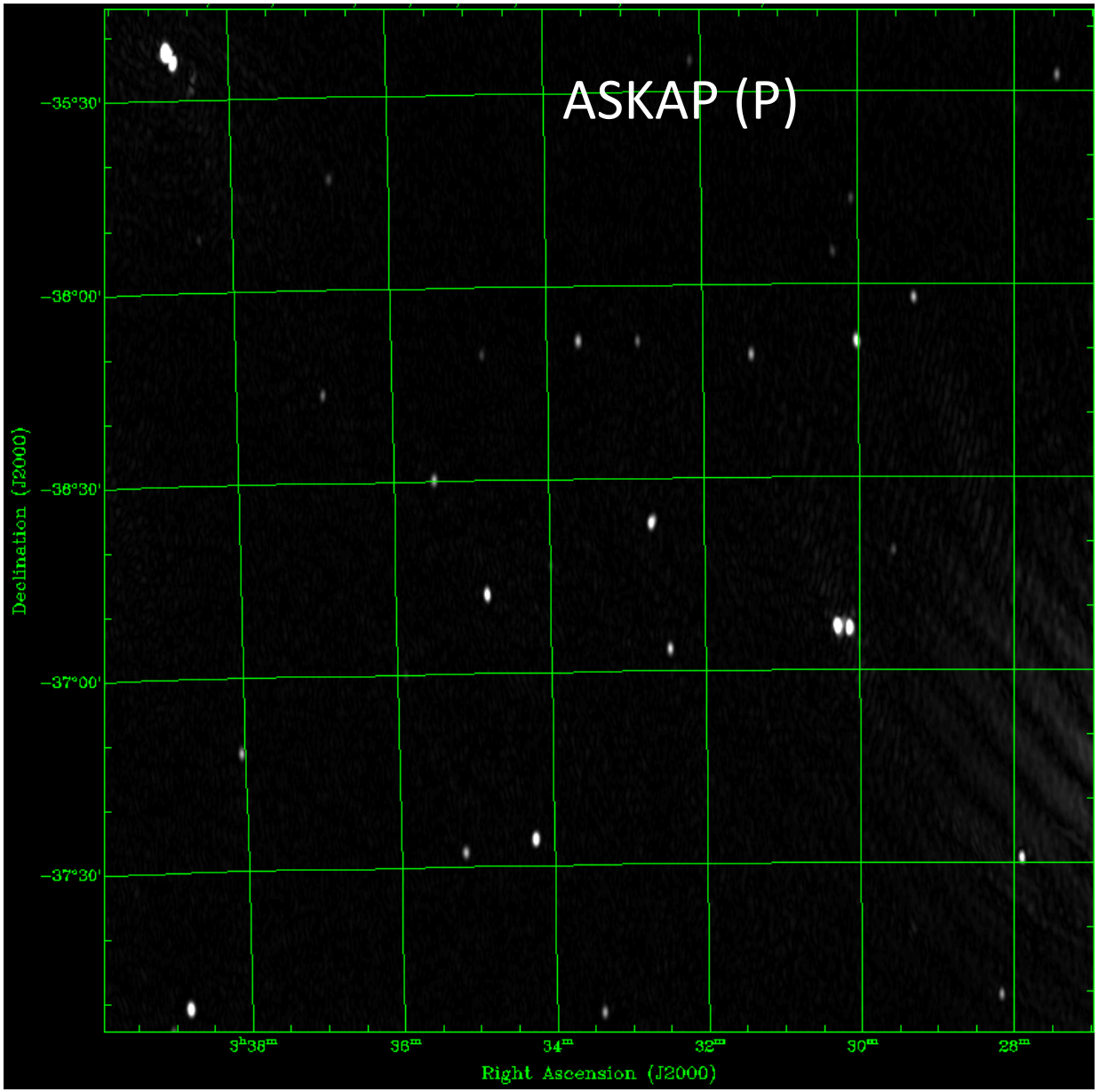
# ASKAP survey science



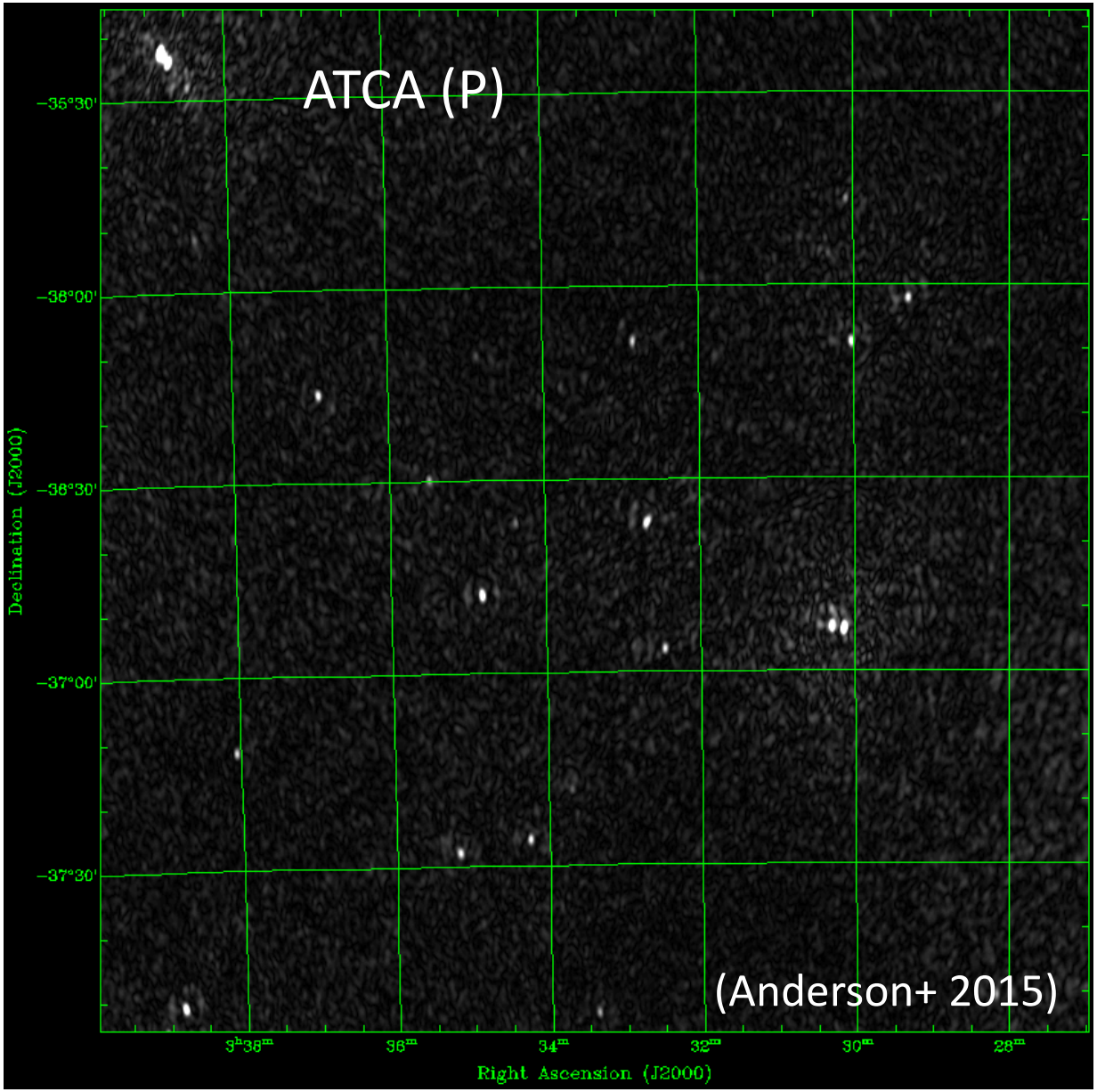

Fornax field sub-region: 8 hours, 30 sq. deg, 48 MHz

Images: Wasim Raja, Craig Anderson

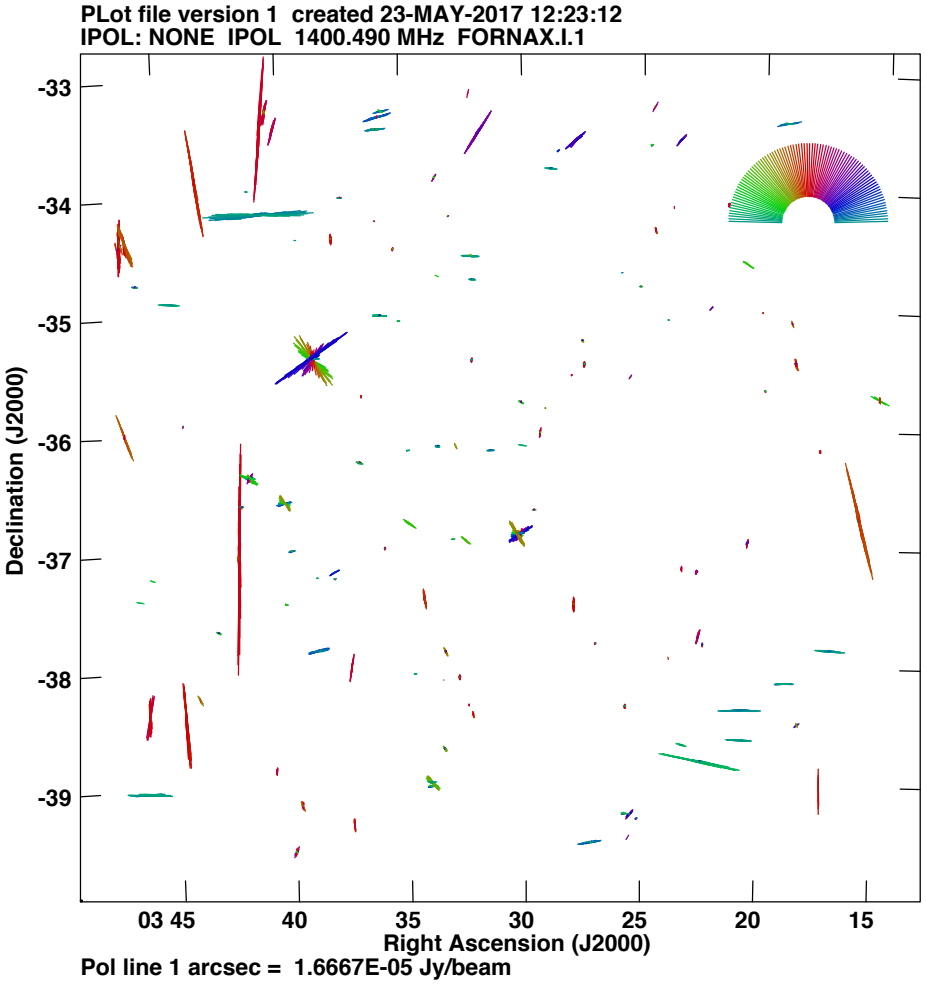
# ASKAP survey science



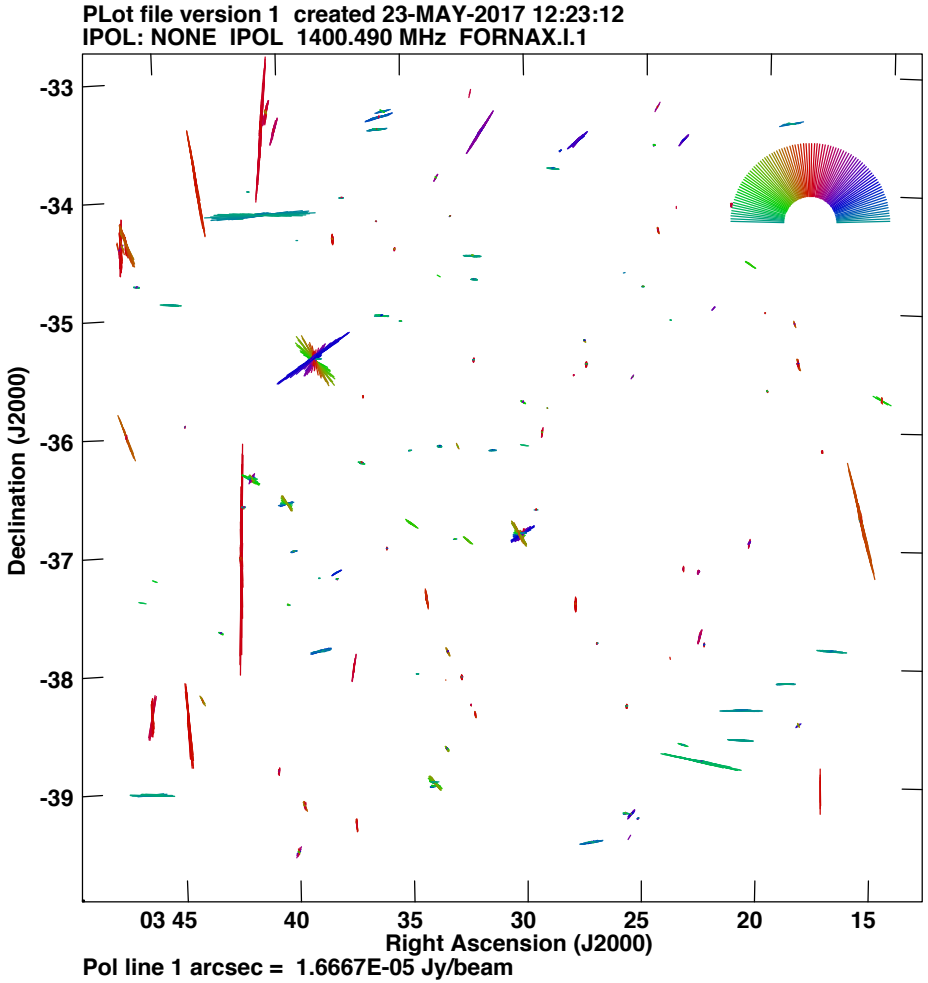
# ASKAP survey science

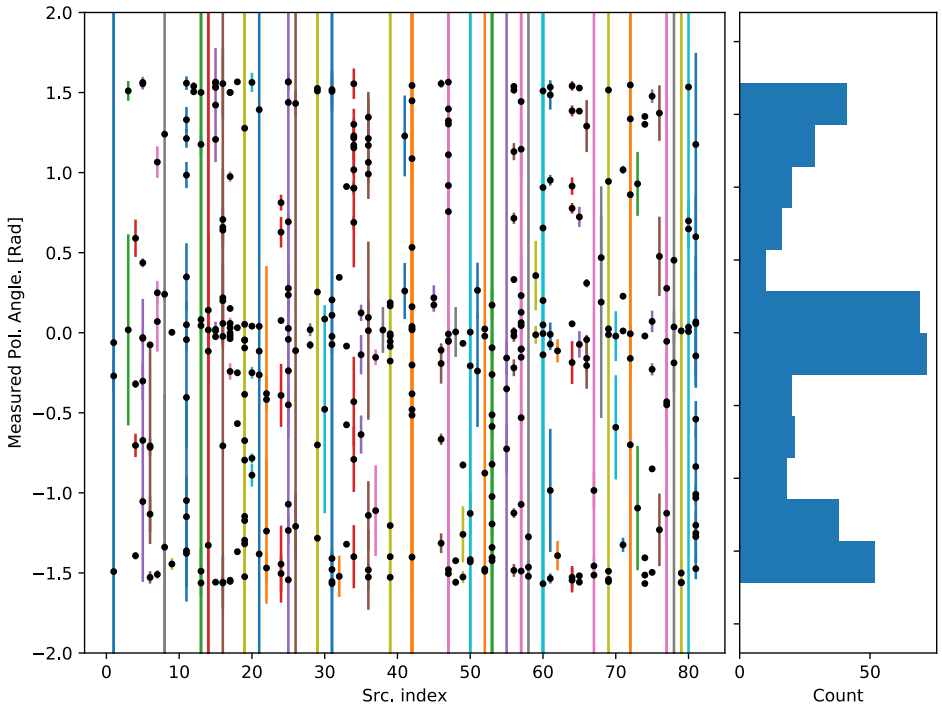


# ASKAP survey science

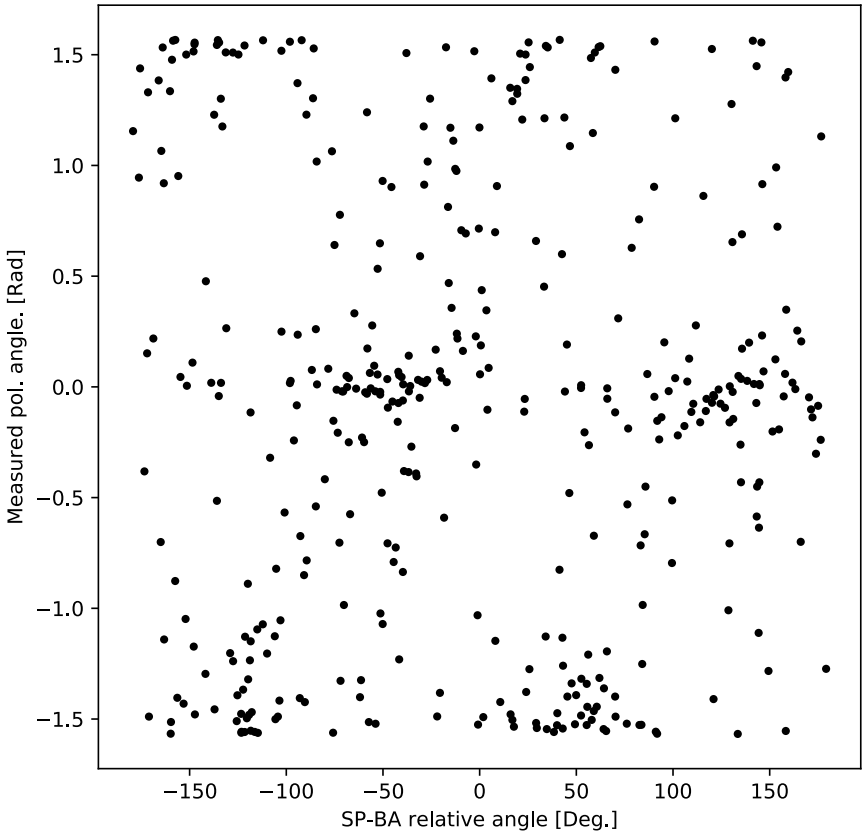


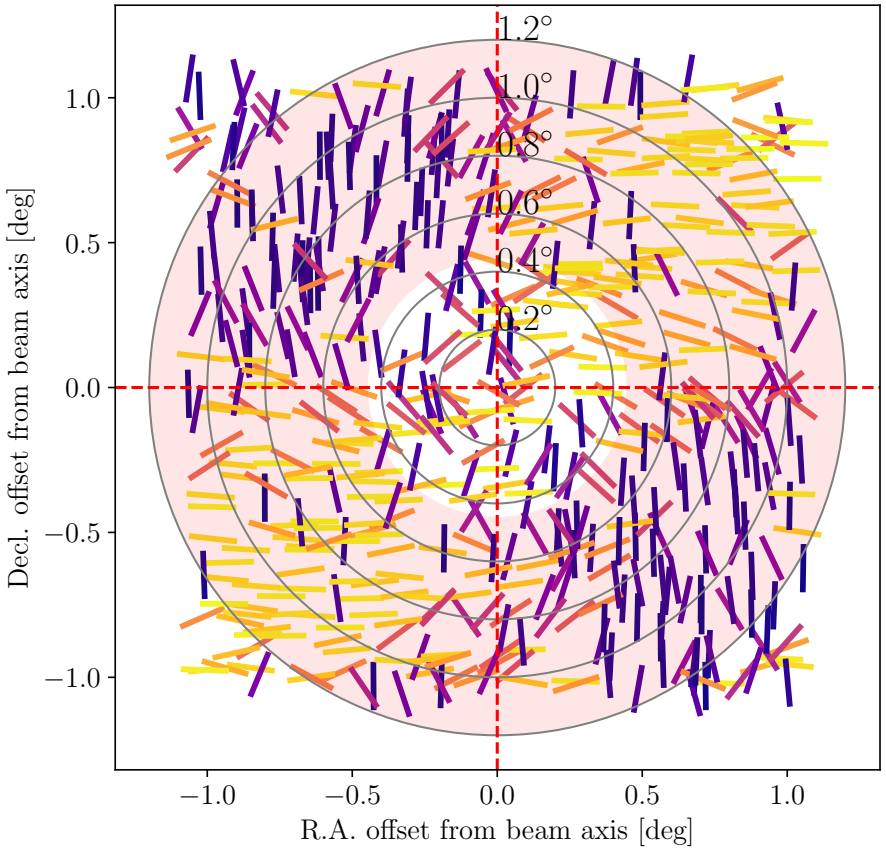
# ASKAP survey science



# ASKAP survey science



# New era of broadband survey science

- POSSUM survey ‘early science’ to begin soon:
  - ~$10^5$ polarised sources (0.7—1.8 GHz)
  - well-studied fields
- Full POSSUM survey:
  - 2 million polarised sources (w/ 300 MHz bw @ ~1.4 GHz)
- + future b.b. pol. surveys by MWA, LOFAR, APERTIF, MeerKAT, JVLA…

# The takeaways

- Broadband polarimetry: A unique and powerful new window on the magnetised universe

- Probes magnetised plasma structure in/around radio sources themselves

- We're entering the era of broadband polarisation survey science:

All-sky, $10^4$—$10^6$ polarised sources > incredible statistical weight, awesome potential for revealing properties of AGN jets/lobes + environment

# Extra slides