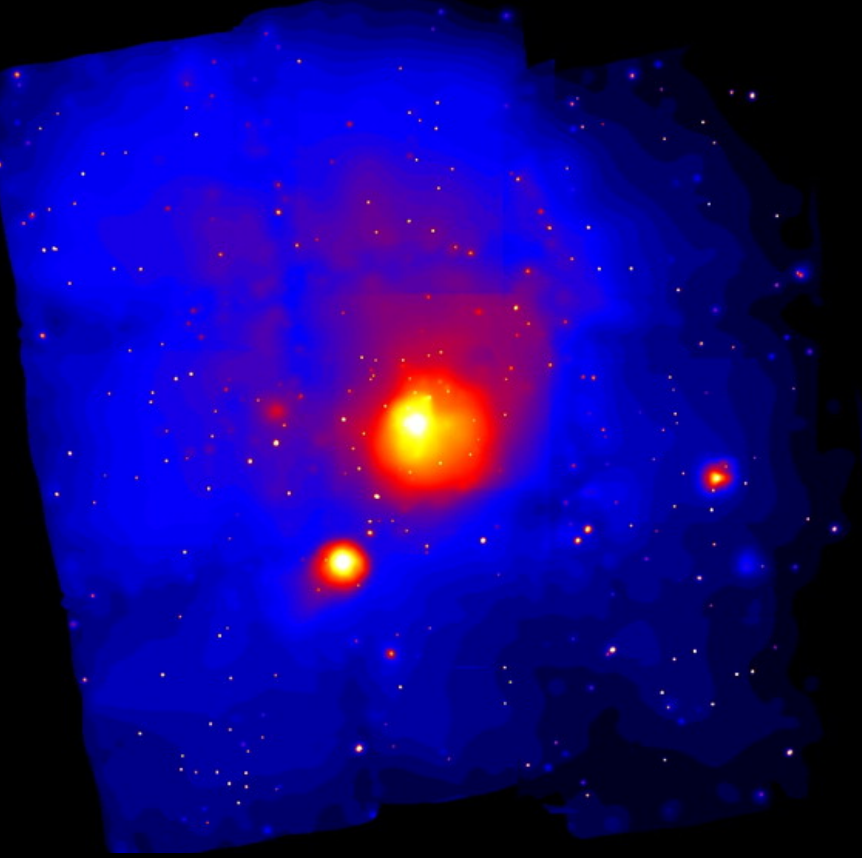


POSSUM early science:

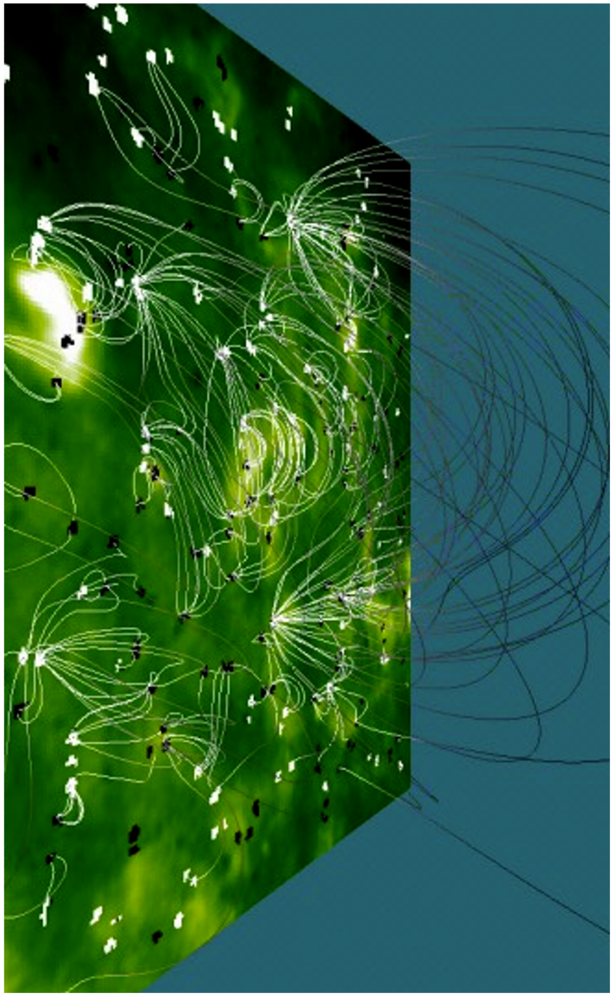
Shocks, turbulence, and 'missing' baryons in the Fornax cluster

Craig Anderson

NRAO Jansky Fellow

NM Symposium, Socorro, 21 Feb 20

Background



Most baryons reside in pools of **magnetized plasma** \`outside’ galaxies.

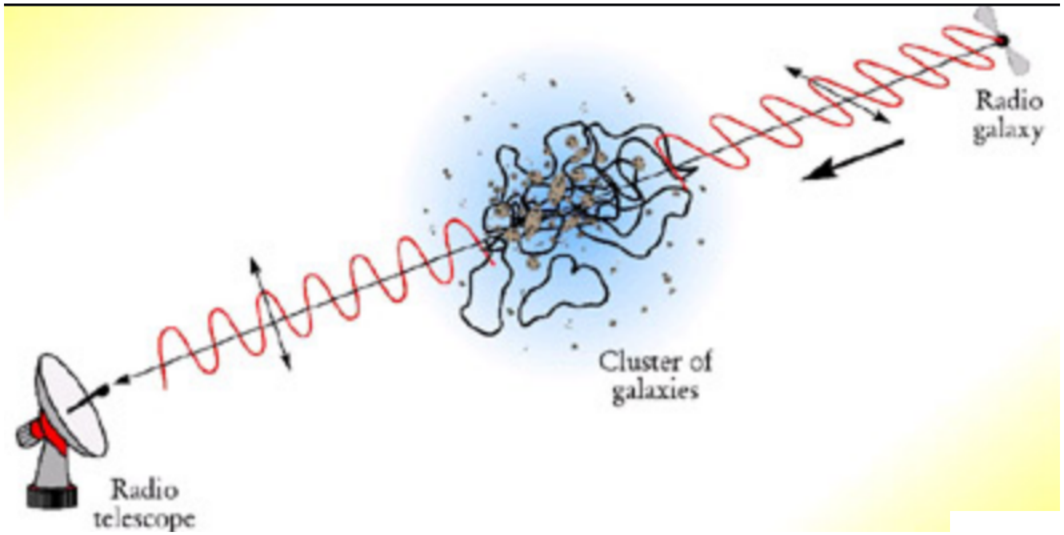
- B fields **affect *and* illuminate** astrophysical processes in these settings

-> break isotropy of viscosity, pressure support, and thermal conductivity

-> trace plasma flows and interactions w/ in-falling gas, embedded galaxies, AGN jets

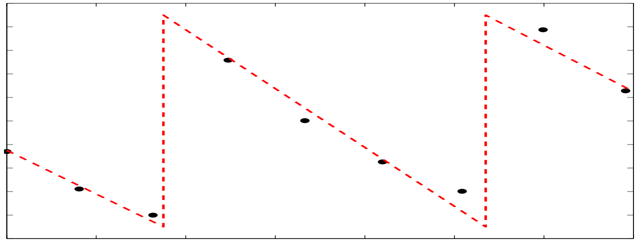
- **Faraday rotation** an effective probe of this material

Faraday rotation

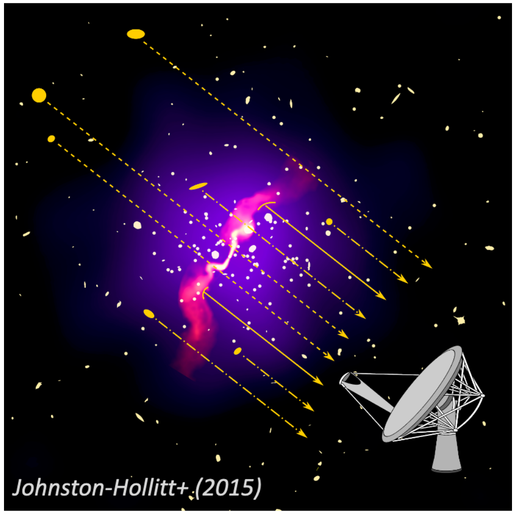


$$\theta = \theta_0 + \phi\lambda^2,$$

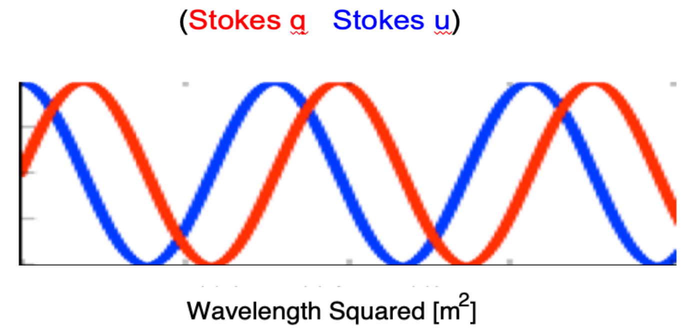
$$\phi \propto \int_{source}^{telescope} n_e B.dl$$



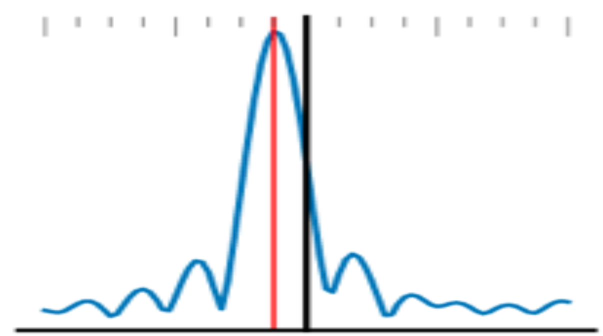
Faraday rotation – RM grids



Extract pol. spectrum



Fourier transform – measure RM

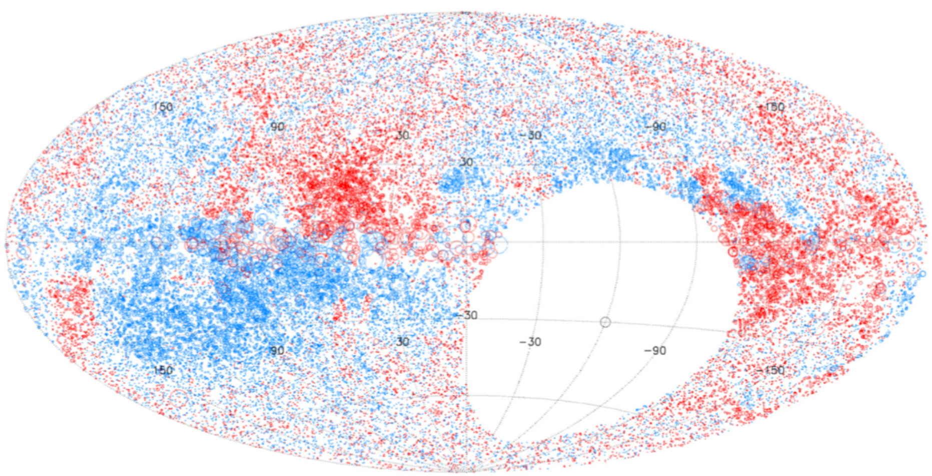


Faraday depth [rad/m/m]

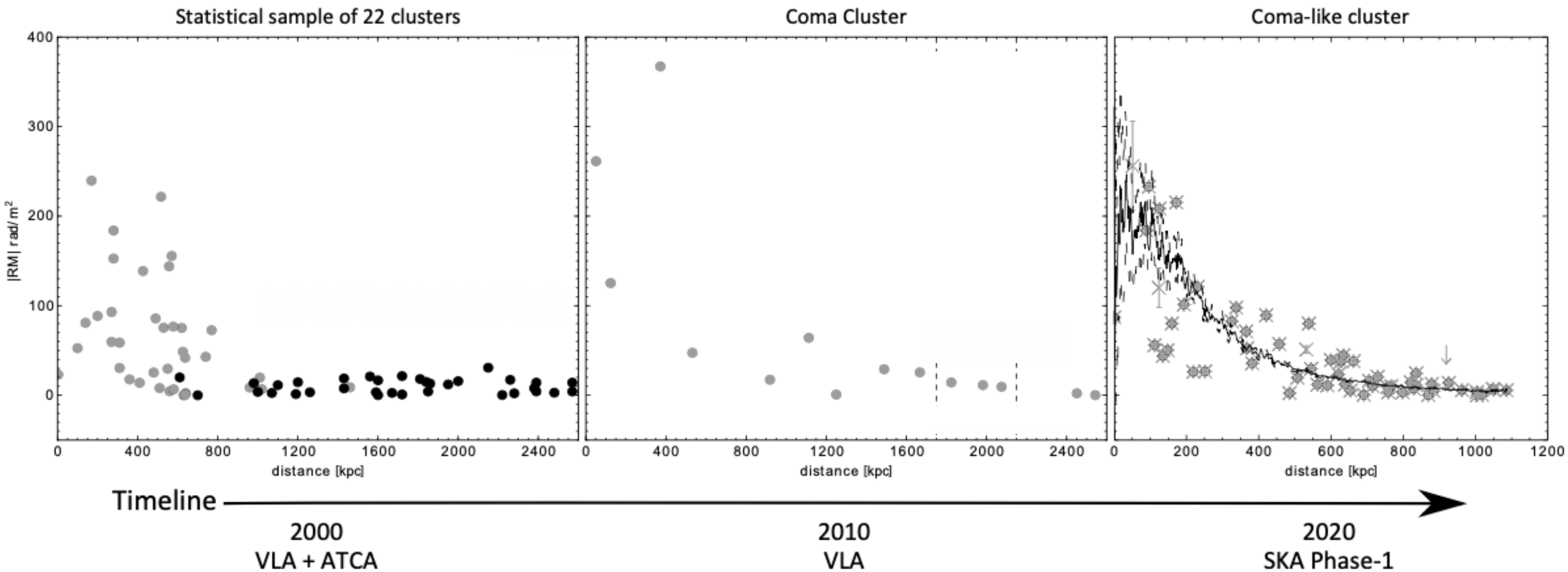
Recall:

$$\phi \propto \int_{source}^{telescope} n_e B.dl$$

All-sky NVSS RM grid (Taylor+ 2009)

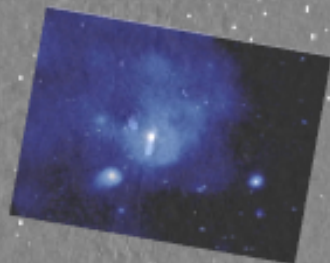


Probing galaxy clusters with RM grids



Adapted from Johnston-Hollitt+ (2015)

The Fornax cluster as a target



Scharf+ 2005

Anderson+ 2015

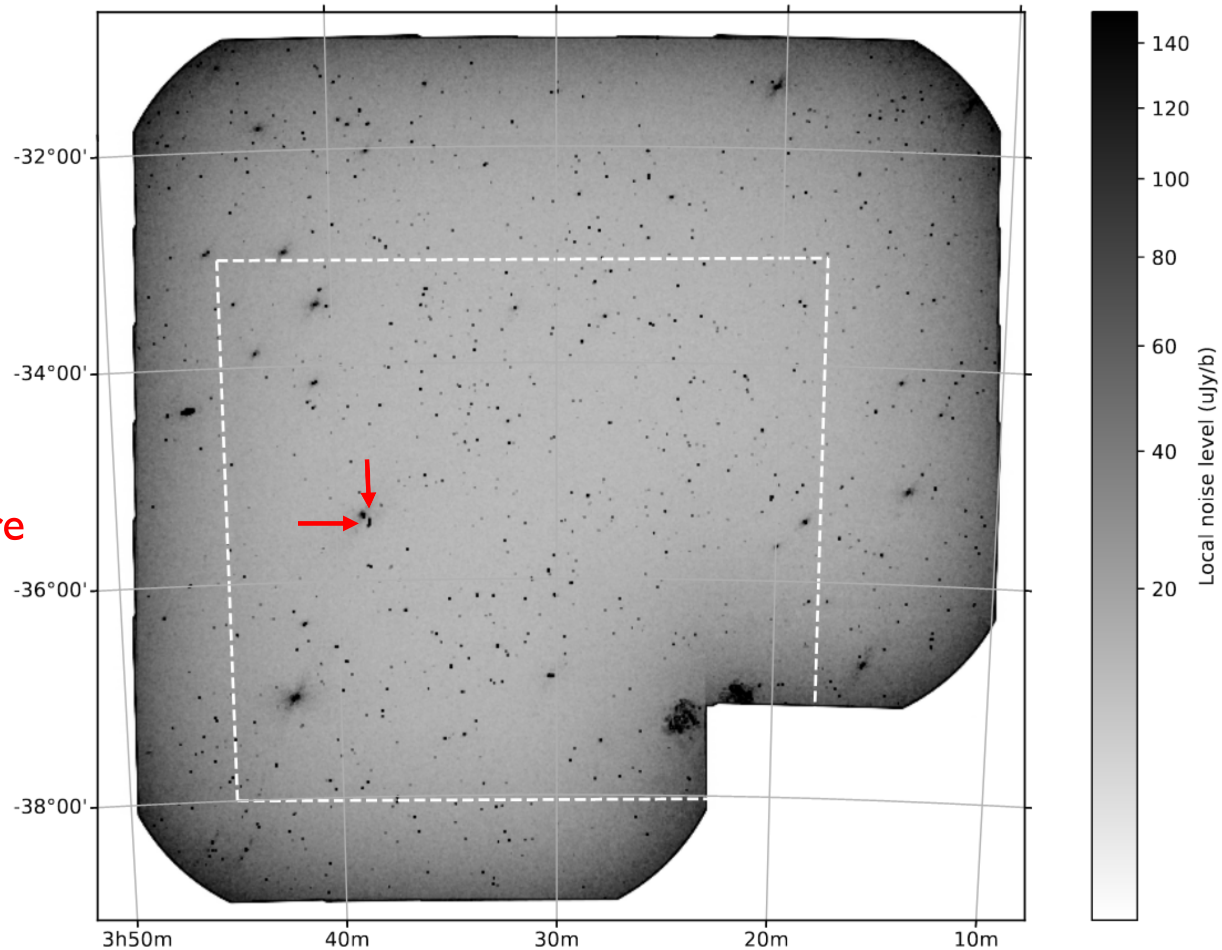
ASKAP POSSUM test obs.

Local RMS in P

Vitals:

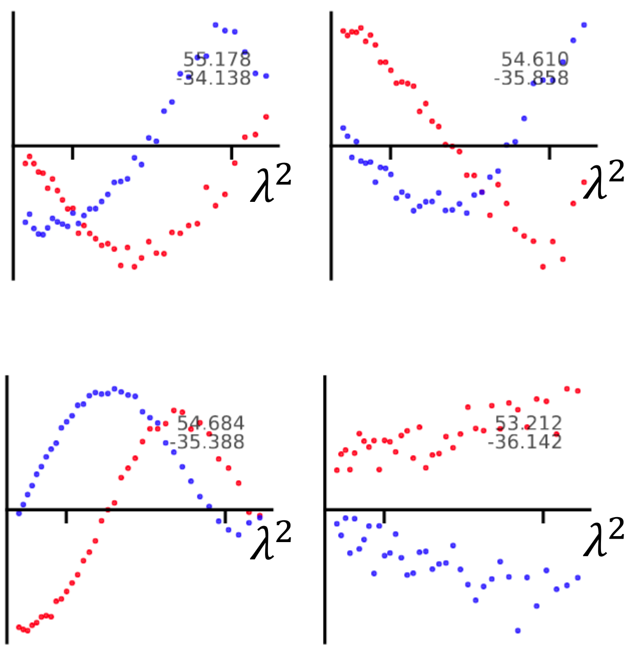
Single pointing
36 beams (4 bad)
36 ants
288 MHz @ 915 MHz
40 sq. deg.
30 uJy/b RMS

Cluster centre

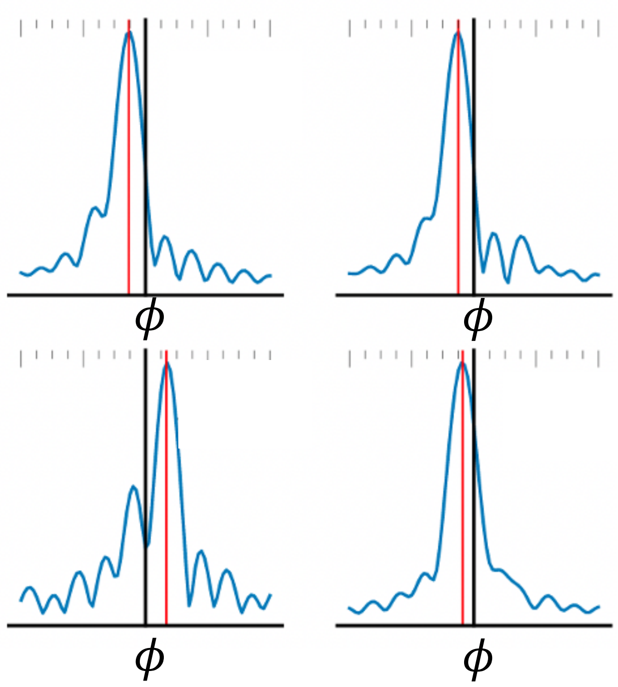


ASKAP observations

Example Stokes Q and U spectra



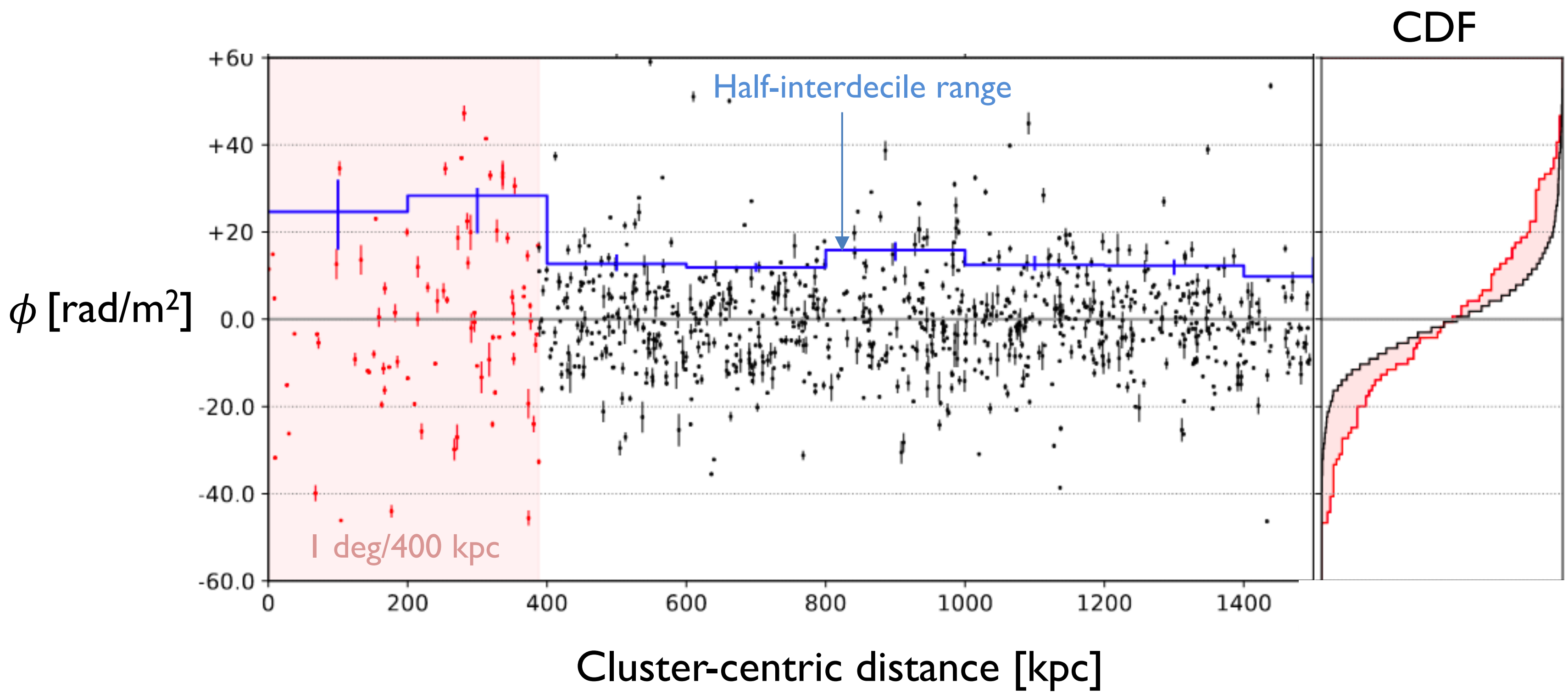
RM synthesis spectra



Anderson+ *in prep.*

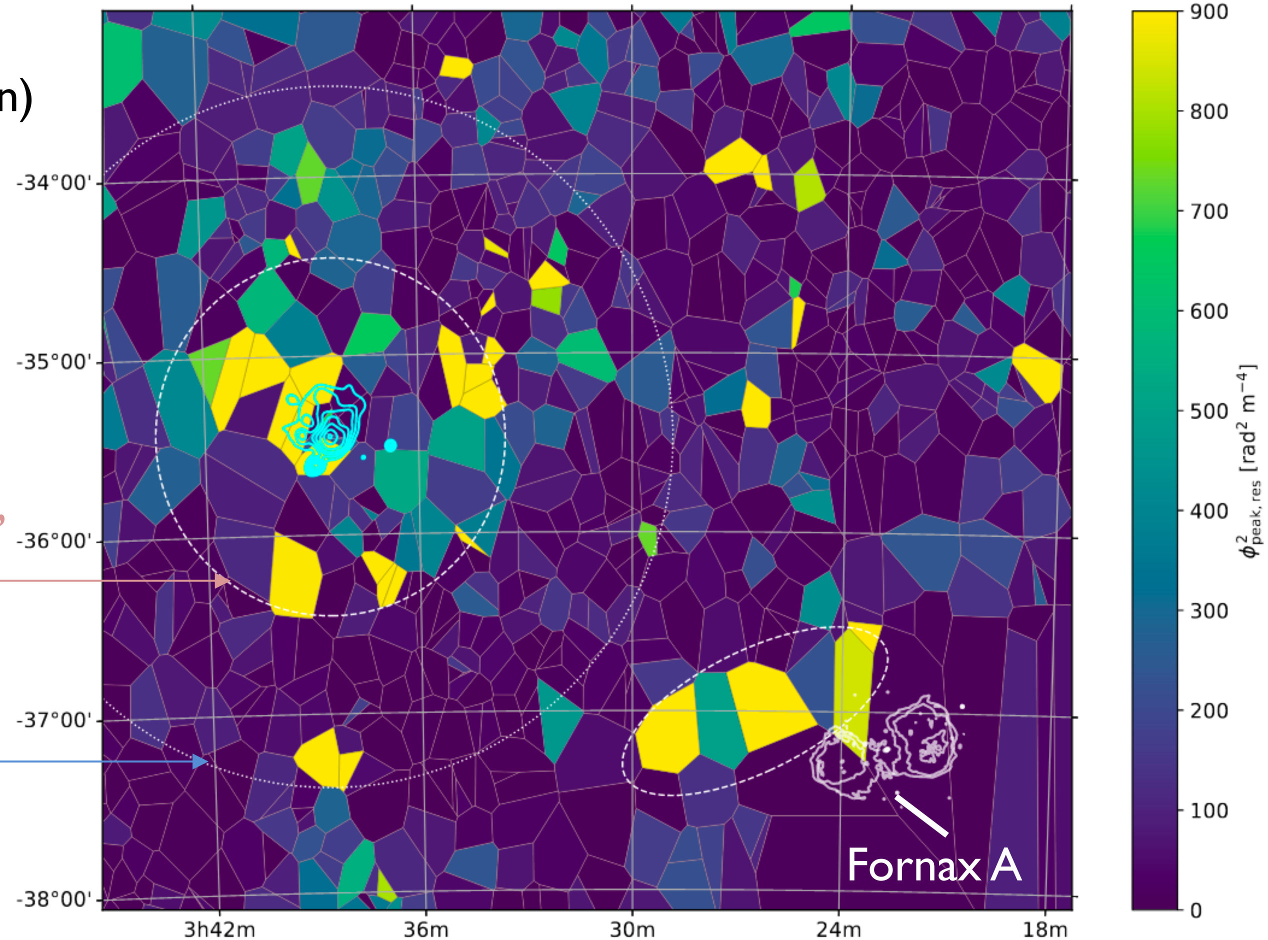
Result I…

RMs are enhanced near the cluster



RMs are enhanced near the cluster

ϕ variance map (NN interpolation)



1 deg/400 kpc 'enhancement radius' from last slide

Virial radius

Massive reservoir of warm baryons

- RM enhancement extends 9x further than X-rays
- Using RMs, estimate:

M_{plasma} = 1.4 x 10^{11} M_{sol}

so

$\overline{n_e}$ = 2.7 x 10^{-5} cm^{-3}

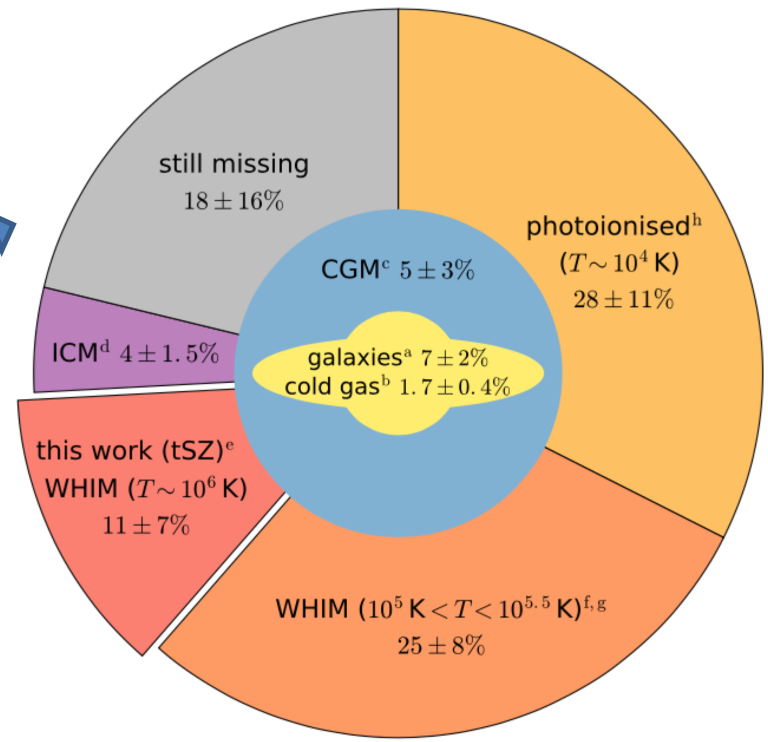
and

δ ~ 15 (over-density; cf. δ > 200 for hot ICM)

➢ Moderately dense regime of the WHIM

➢ Faraday RMs superior to Bremsstrahlung as tracer, because RMs are sensitive to diffuse large-scale envelopes --- i.e. ∝ $n_e BL$ >> n_e^2 (Carl Heiles has argued this for years)

?

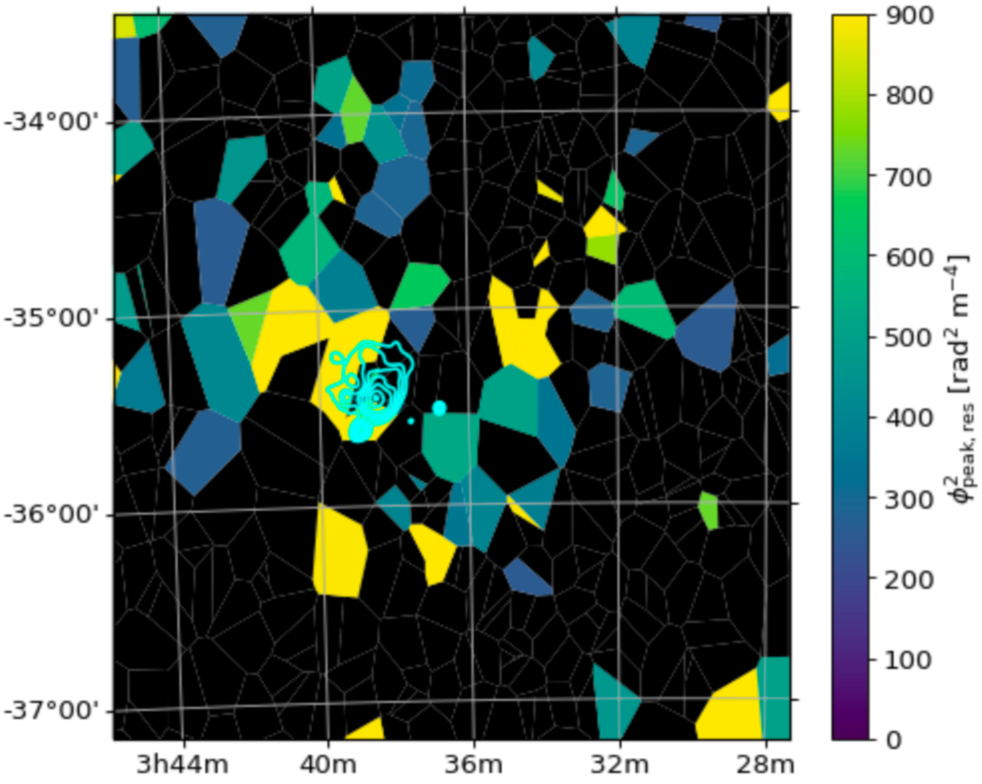


deGraaff+ (2019)

Result II…

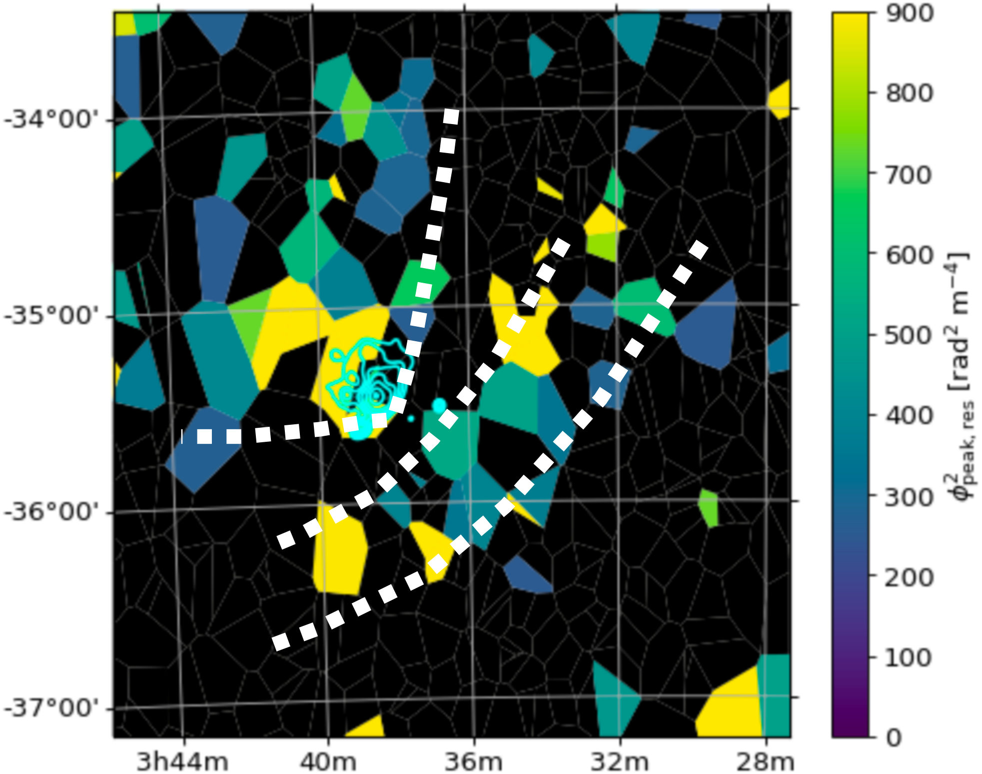
Morphology of FD enhancement

Variance map (masked)

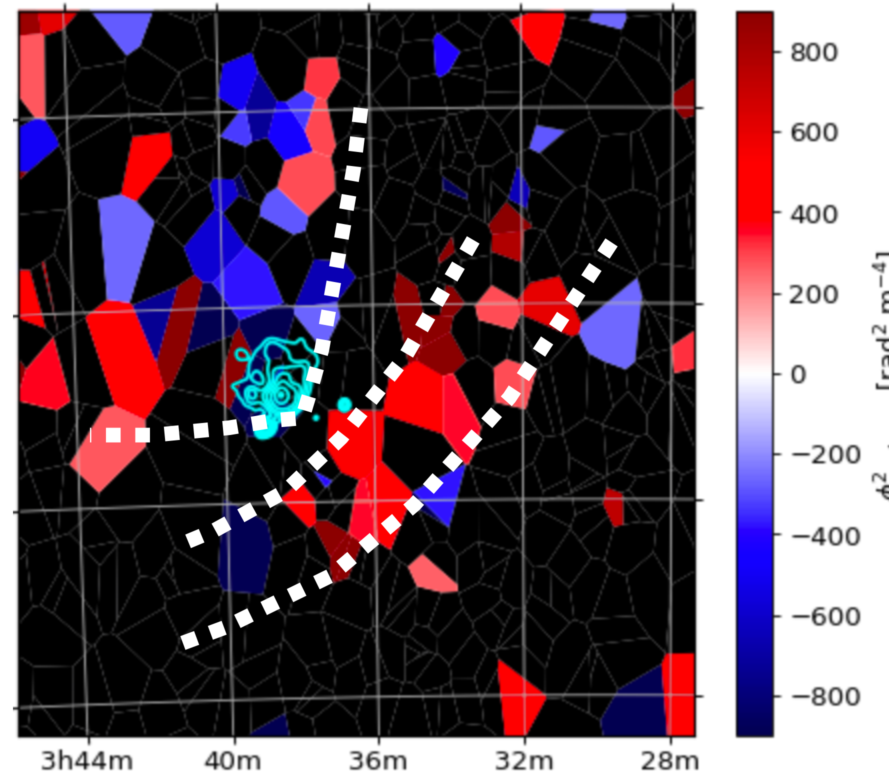


Morphology of FD enhancement

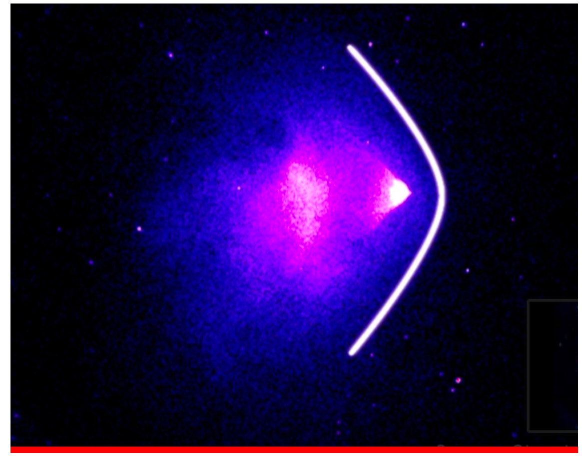
Variance map (masked)

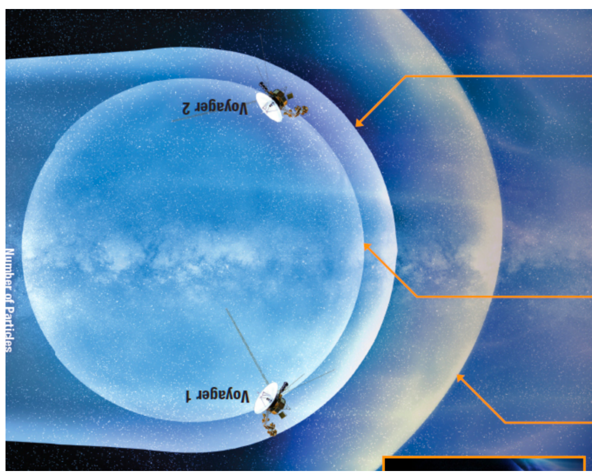


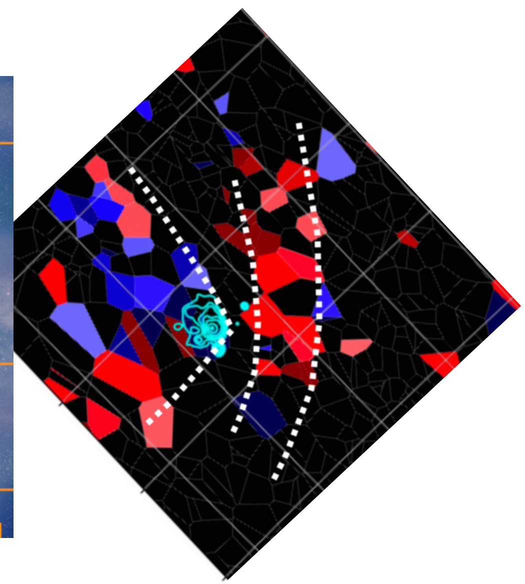
Signed version



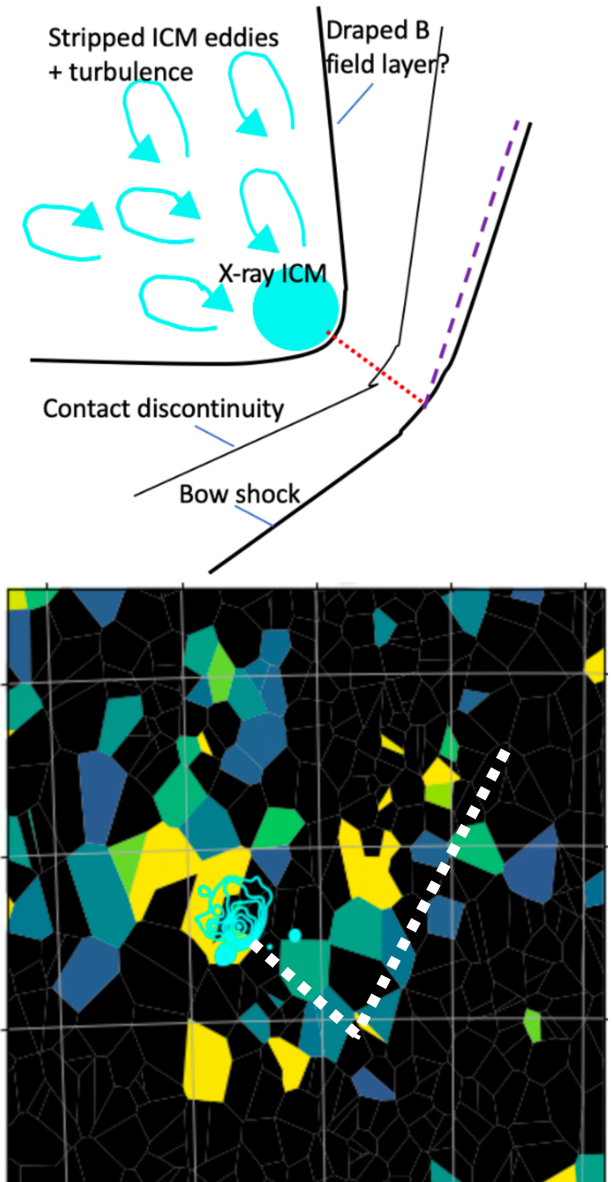
Morphology of astrophysical shocks







The Fornax cluster shock system



Mach angle est. ~70 deg; implies sonic Mach = 1.06. Consistent with speeds proposed in the NE-SW merger model; independent evidence for this model.

For Mach 1.06, predicted shock standoff distance is 50 arcmins --- consistent with proposed shock location.

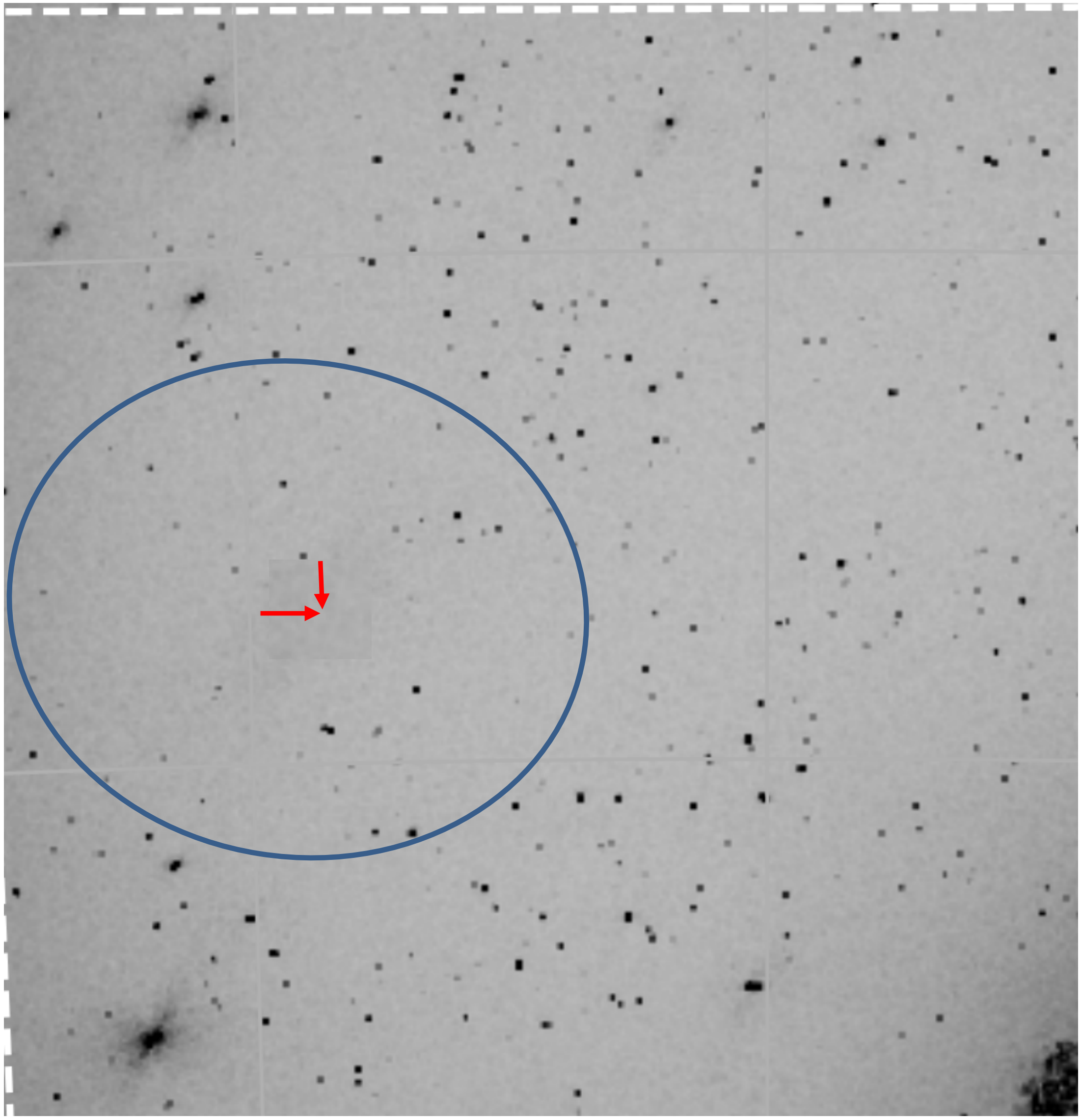
Predictions for deep obs:

- coherent B field vortices in wake w/ scales 15—70 arcmins (vortex shedding).
- magnetic draping layer attached to hot ICM

Bonus teaser result!

The missing flux question

Local RMS in polarised intensity; central source blanked



Conclusions, more questions

- The Fornax cluster is surrounded by an extended halo of warm baryons
- Probably a phase of the WHIM
- Faraday RMs an effective (best?) tracer of such
- The RMs illuminate a shock system in the plasma → ongoing transonic NE-SW subcluster merger.
- A dearth of radio emission near the cluster → scattering by cold dense gas along the line of sight?
- Sensitive, wide-area, full-Stokes polarimetry will reveal dynamical interactions in a slew of individual clusters in the coming years.

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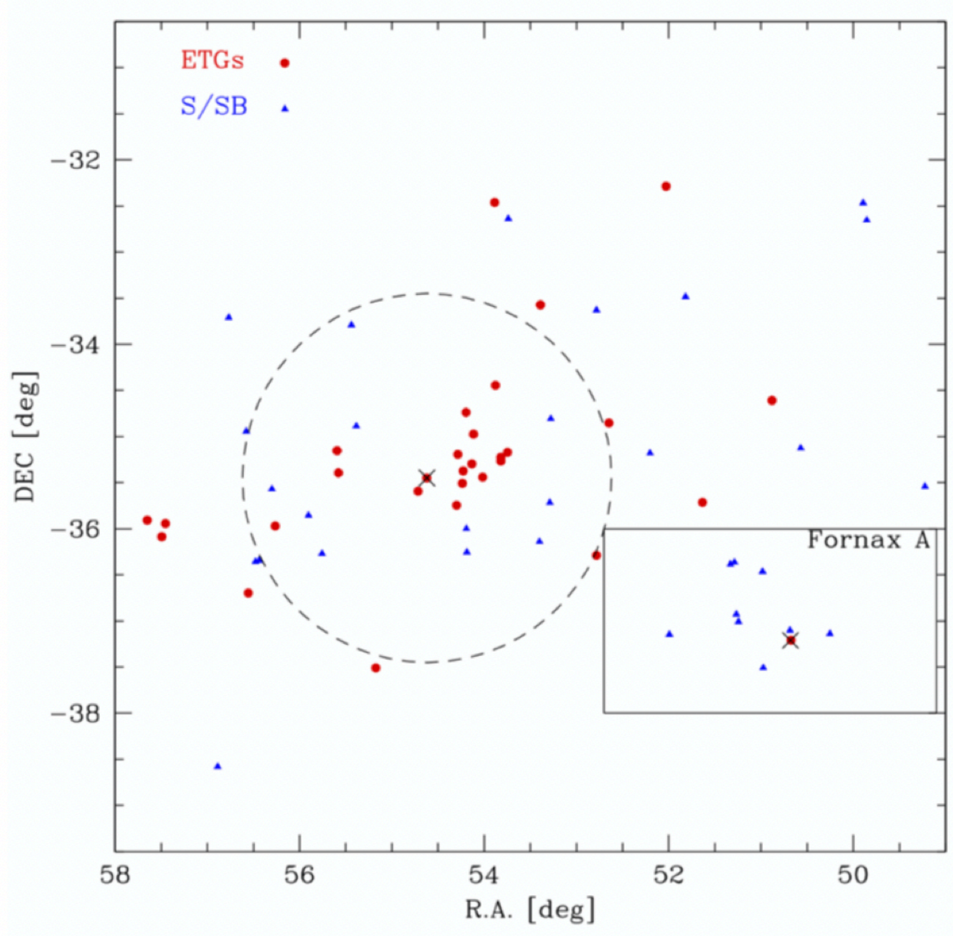
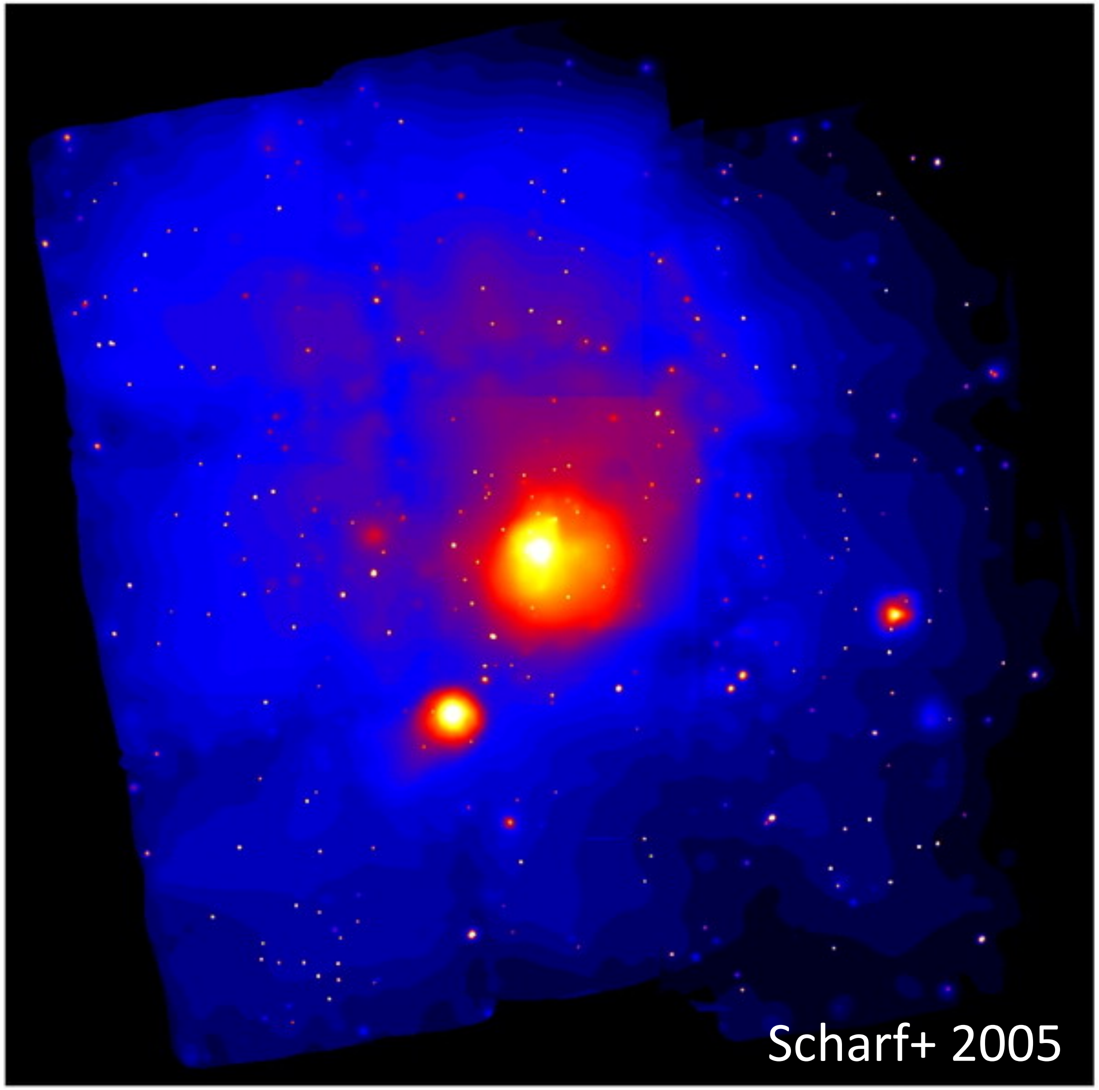
The Fornax cluster as a target

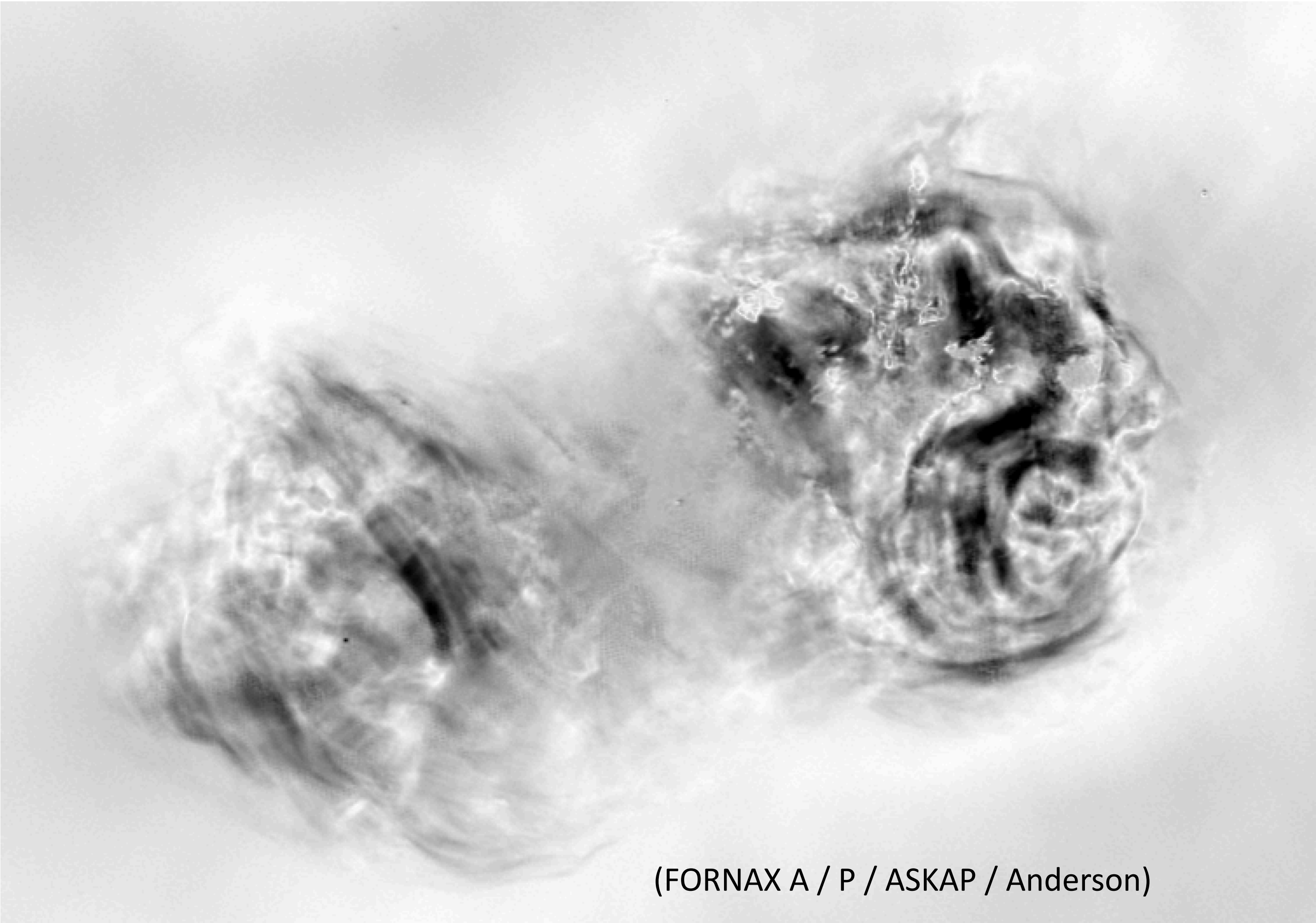


Iodice+ 2017

The Fornax cluster --- northeast



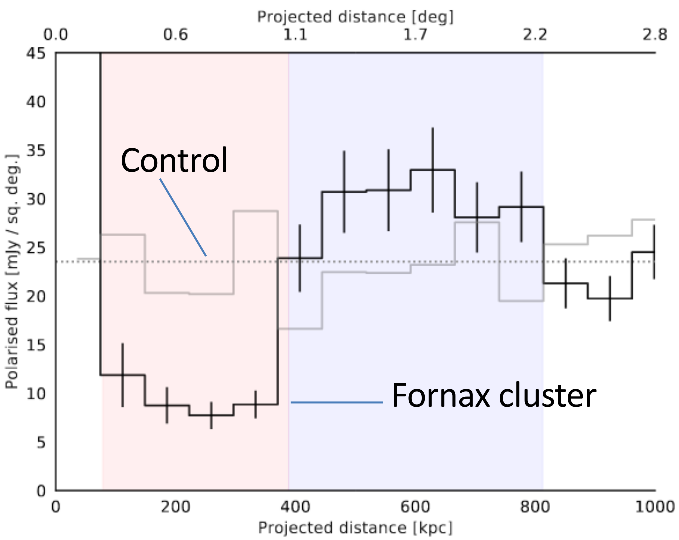
The Fornax cluster --- southwest



(FORNAX A / P / ASKAP / Anderson)

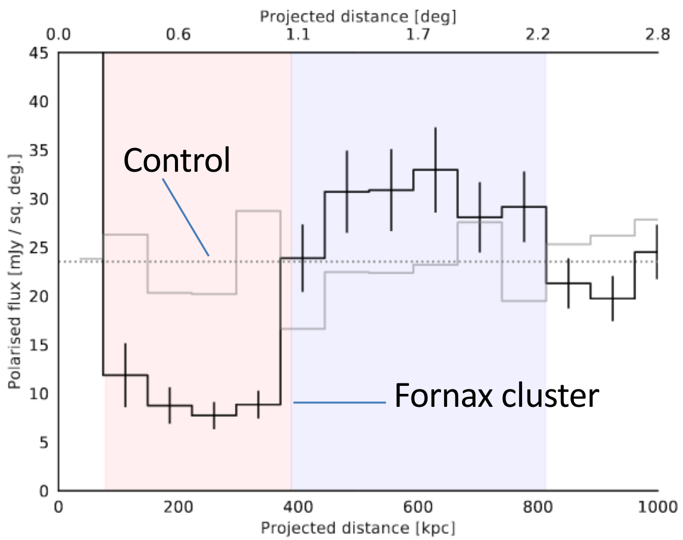
The missing flux question

Pol. emission density

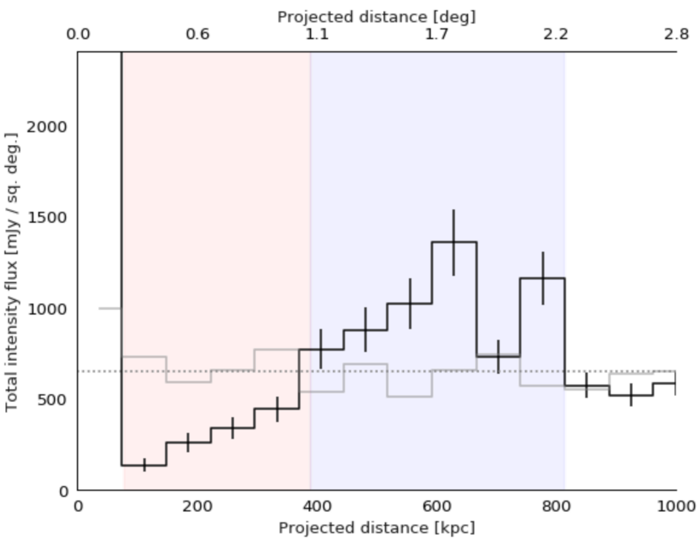


The missing flux question

Pol. emission density

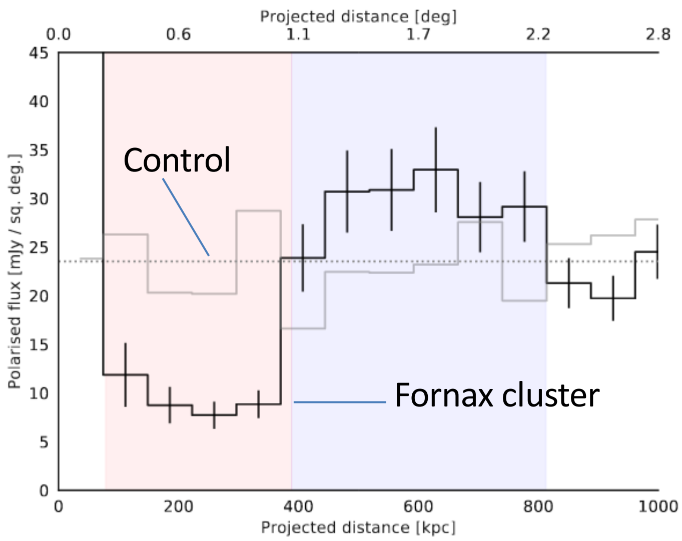


Stokes I

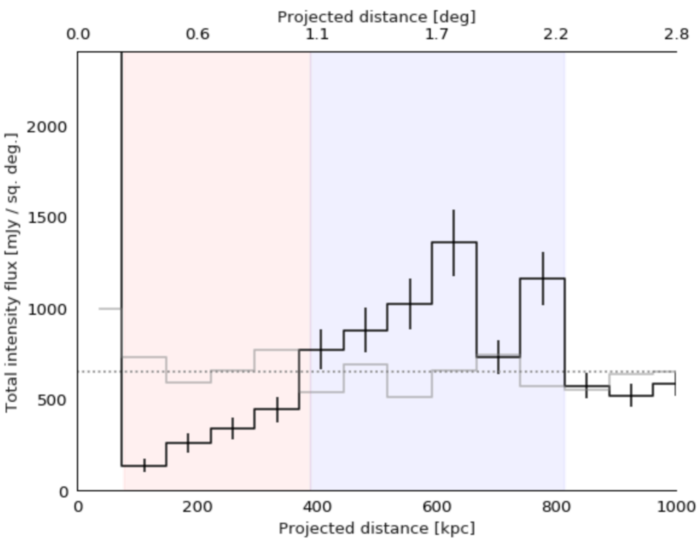


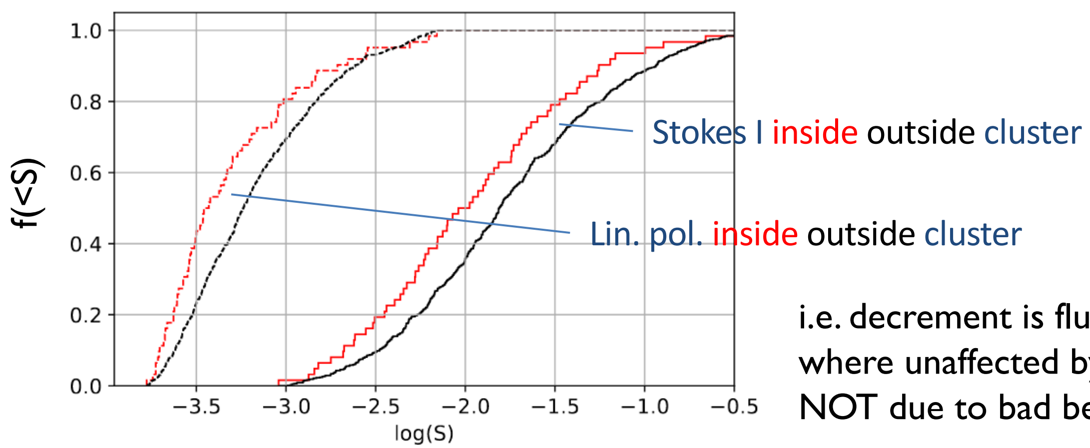
The missing flux question

Pol. emission density



Stokes I





i.e. decrement is flux-independent where unaffected by sample cuts -> NOT due to bad beams

Interpretation is tricky...

Depolarisation? No --- also seen in Stokes I (and NVSS!).

Cosmic variance? <0.1% chance given size of flux decrement, sky area.

Free-free scattering by cold, photoionized CGM?

$$\tau_{ff} \approx 3.27 \times 10^{-7} \boxed{\left(\frac{T_e}{10^4\ \mathrm{K}}\right)^{-1.35}} \left(\frac{\nu}{\mathrm{GHz}}\right)^{-2.1} \left(\frac{\mathrm{EM}}{\mathrm{pc\ cm^{-6}}}\right)$$

- Plausible, but need cold, dense, inhomogenously-distributed cloudlets of gas.
- Pro: required gas properties are similar to those seen in MgII absorption systems, LLSs, DLAs etc.
- Con: requires fine tuning?

Regardless, ultimately very testable!