# Thermal/non thermal connection in radio mini-halos


## Alessandro Ignesti

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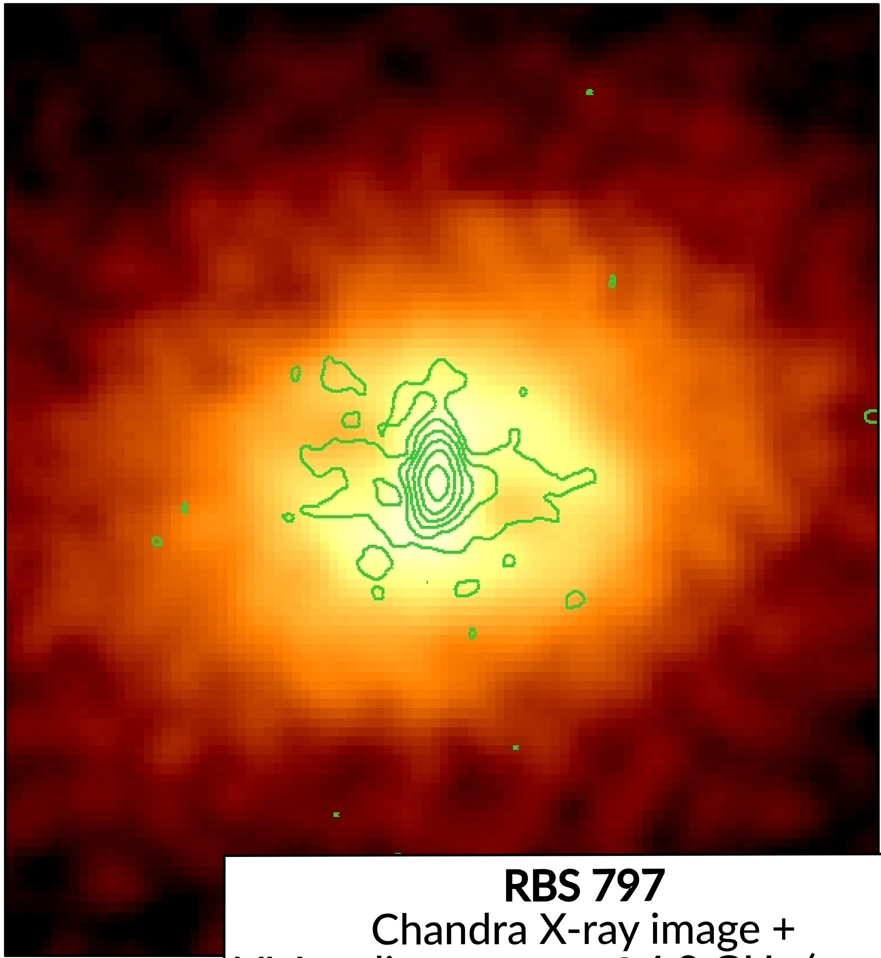
**Project collaborator: S. Giacintucci**



Perseus in Sicily: from black hole to cluster outskirt
Noto 14/05 - 18/05

# Cool core clusters

- Morphologically relaxed clusters;
- Efficient thermal cooling processes (e.g., *Hudson+ '10*);
- Luminous central active galaxies (e.g., *Sanderson+ '09*);
- Magnetic fields of ~10 μG (e.g., *Carilli+ '02*).
- AGN feedback on the ICM *(e.g., McNamara+ '12)*;
- Sloshing of sub-clumps (→ cold fronts) *(e.g.; Markevitch & Vikhlinin '07)*;



**RBS 797**
Chandra X-ray image +
VLA radio contours @4.8 GHz (green)
(*Gitti+ '13*)

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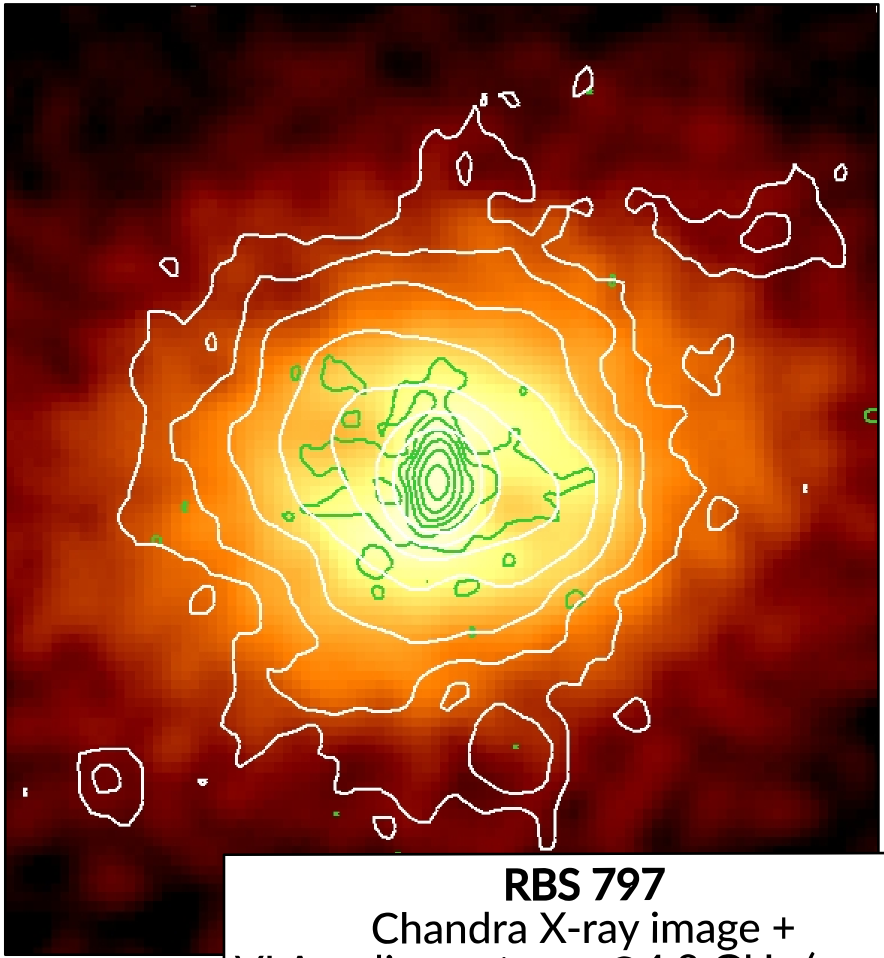

**RBS 797**
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VLA radio contours @4.8 GHz (green)
And @1.4 GHz (*Gitti+ '12,'13*)

# Radio mini halos

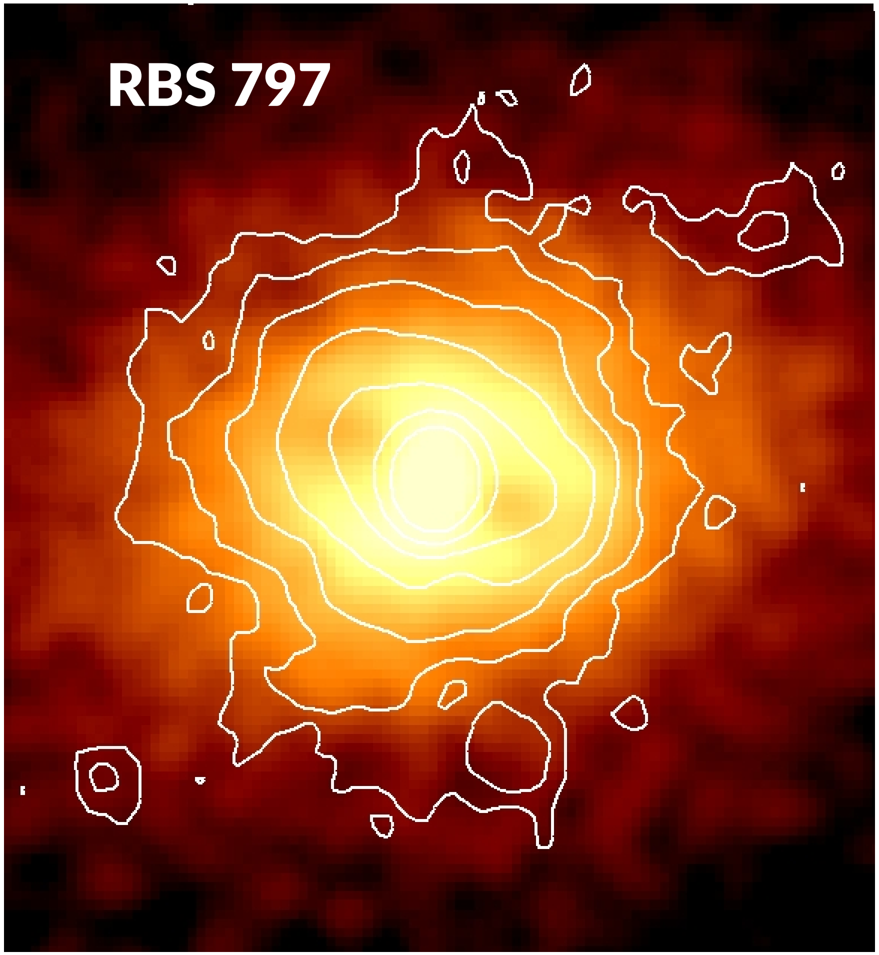
**Main properties:**

- $R_{MH} \sim R_{cool} < 0.2 R_{500}$ (*Giacintucci et al. '17*);
- Steep spectral index α=1-1.5 ($S \sim \nu^{-\alpha}$);
- Surround the BCG; → **Connection still not clear**
- Connections with cold fronts (e.g., *Mazzotta&Giacintucci '08*);
- **Slow diffusion problem**:

**Diffusion time of CRe** >> **Radiative time**
> $10^9$ yr ~$10^8$ yr

two possible solutions:

- **Leptonic models:** CRe injected by the BCG are re-accelerated by ICM turbulence (*e.g., Gitti+ '02, ZuHone '13*);
- **Hadronic models:** CRe are generated during collisions of CRp and thermal protons. Collisions should produce also γ-ray (*e.g., Pfrommer&Enßlin '04, Zandanel '13*).



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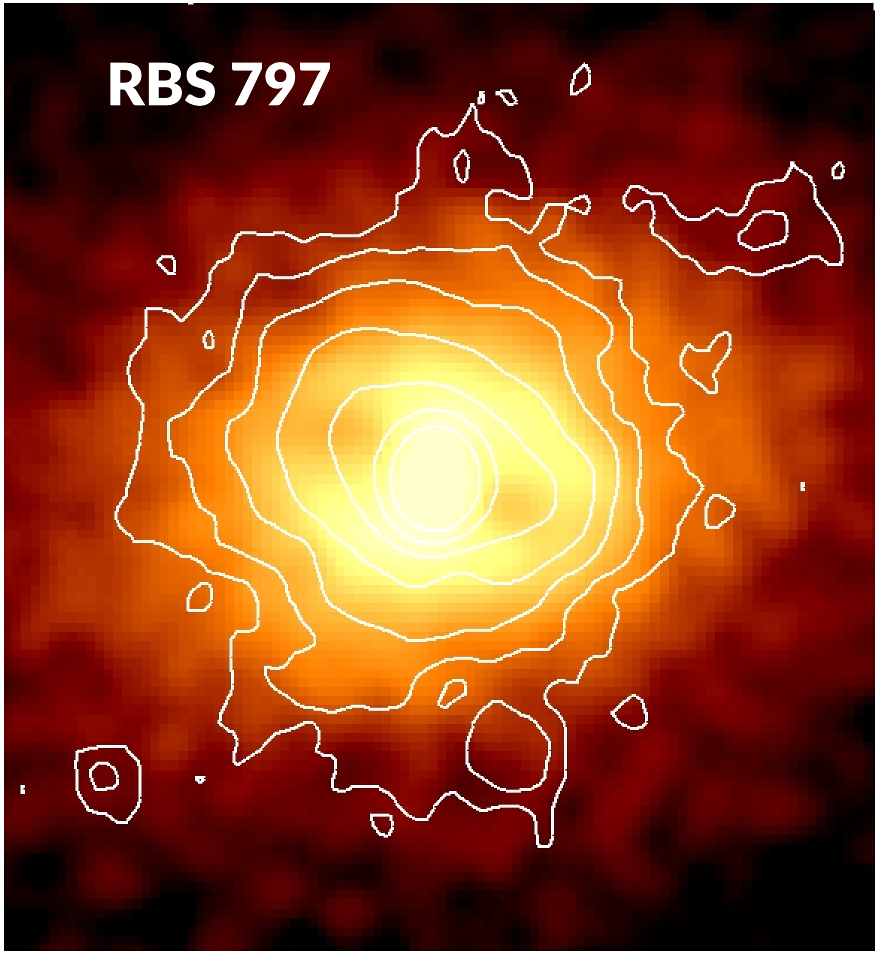

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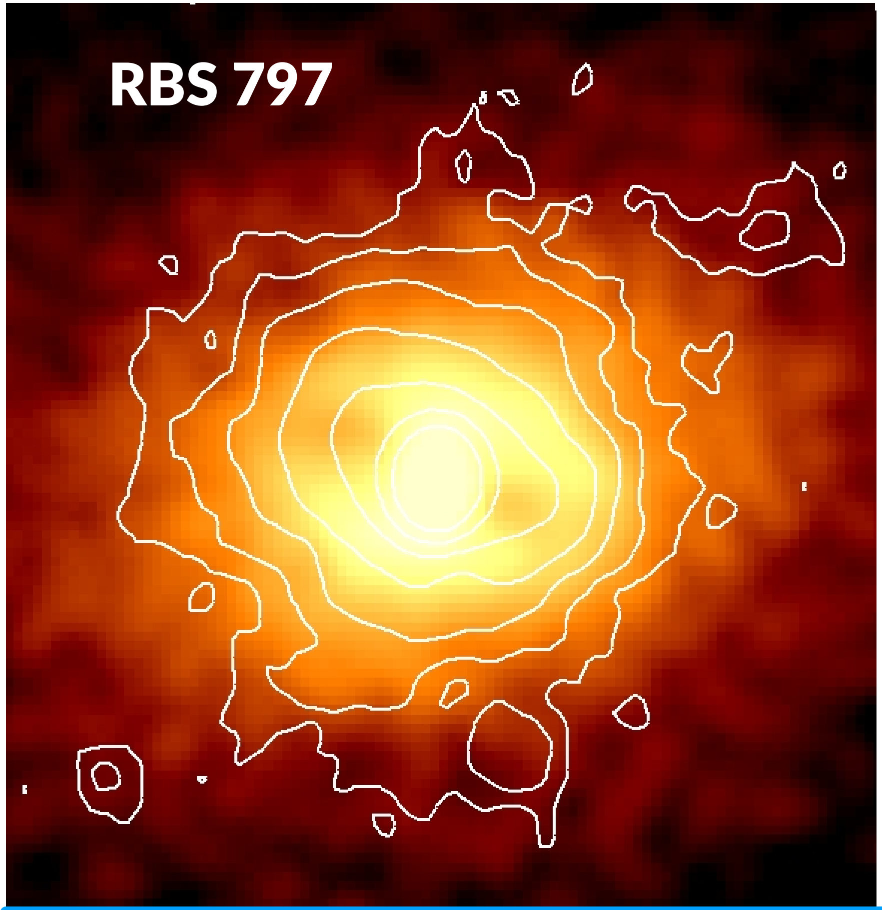


**Valuable probes to study the physics of cool cores**

# Radio/X-ray surface brightness link

**Radio emissivity: synchrotron**

**Single electron emissivity**

$$j_R(r) \propto \int n_{CRe}(r,\epsilon)\omega(\epsilon,B)d\epsilon$$

**CRe distribution function**

**Magnetic field**

**X-rays emissivity: Thermal bremmstrahlung**

$$j_X(r) \propto n_{th}(r)^2\sqrt{T}(r)$$

**ICM density**

**ICM temperature**

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**Leptonic model**

$$\mathbf{F}_{CRe} \propto \rho_{ICM} V_A^3 \frac{M_A^3}{L_0} \eta_{CR}$$

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$$B(r) = B_0\left[\frac{n_{th}(r)}{n_0}\right]^{\eta}$$

$$\epsilon_{CRp}(r) \propto \frac{Q_0}{r}$$

Where $Q_0$ is proportional to CRp luminosity of the AGN

*(Blasi & Colafrancesco '96)*

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**X-rays emissivity: Thermal bremmstrahlung**

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**ICM density (beta model)**

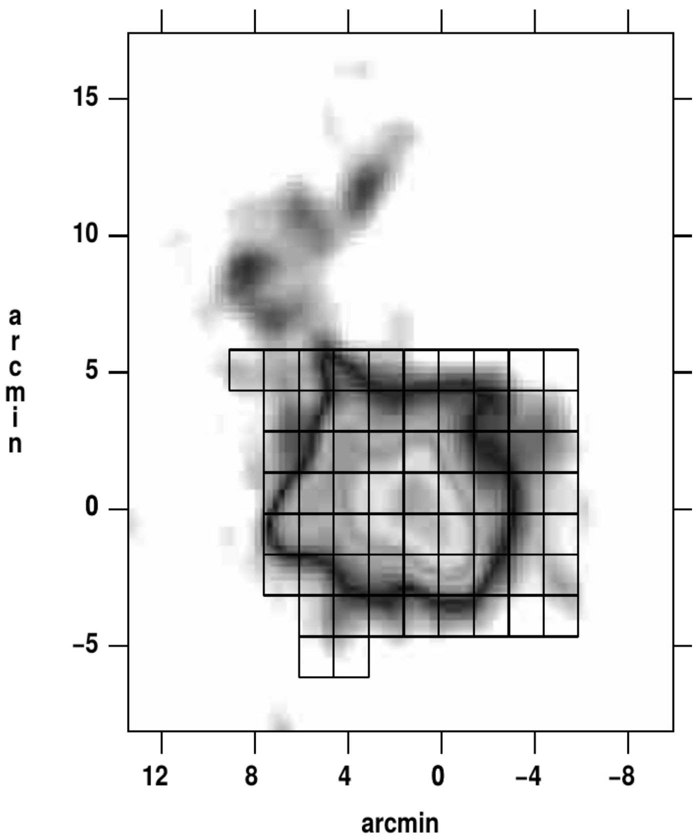
$$I_R \propto I_X^k$$

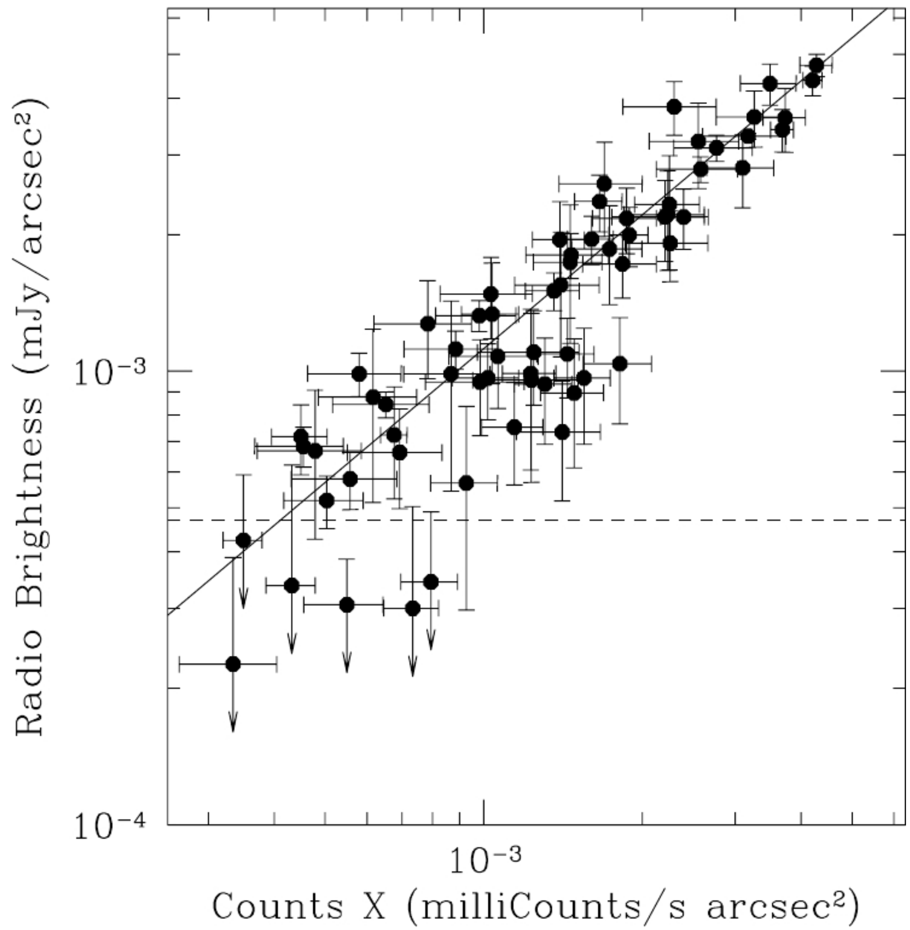
**From *k* we can infer**

- **B(r)**
- **$\epsilon_{CRp}(r,Q_0)$**

# Radio/X-ray surface brightness link

A similar analysis was performed on **giant radio halos** using the **point-to-point analysis** (*Govoni et al.* '01).




$$I_R \propto I_X^k$$

They found

***k*≤1**

Point-to-point analysis performed on Abell 2255 (*Govoni et al.* '01)

# Outline of the project

I. Collect a sample of MHs;

II. Estimate *k* from point-to-point analysis;

III. Model $j_R$ to constrain ICM properties;

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**Work in progress!**

# Our sample (so far)

| 7 mini halos: | Frequency |
|---|---|
| RBS 797 | 1.4 GHz |
| RX J1532.9+3021 | 1.4 GHz |
| RX J1720.1+2637 | 610 MHz |
| MS 1455.0+2232 | 610 MHz |
| RXC J1504.1-0248 | 327 MHz |
| Abell 3444 | 610 MHz<br>1.4 GHz |
| 2A0335+096 | 1.4 GHz<br>5.5 GHz |

**For each cluster we combined:**

**Chandra archival observations**
**+**
**Radio maps from literature**

**Selection criteria**

A "rule of the thumb" for a good point-to-point analysis:

$$\frac{\text{MH angular size}}{\text{Beam size}} > 15$$

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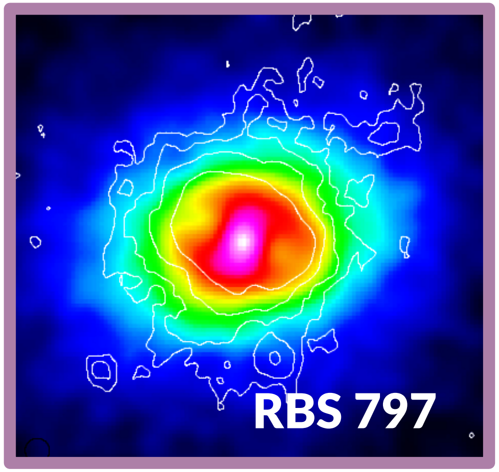
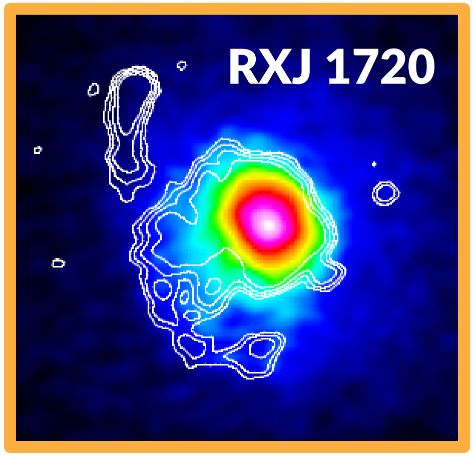
Evidence of strong AGN feedback on the ICM (cavities)



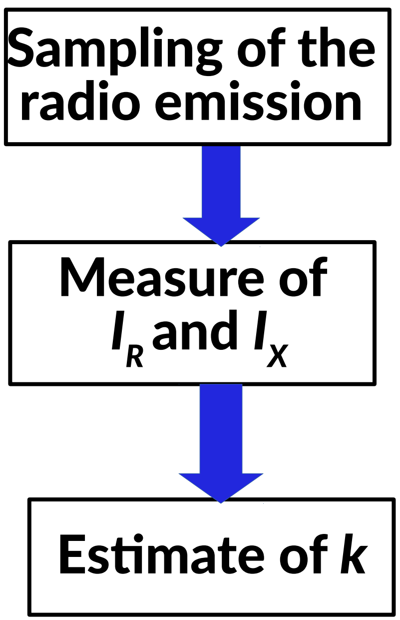

Evidence of connection with cold fronts and sloshing

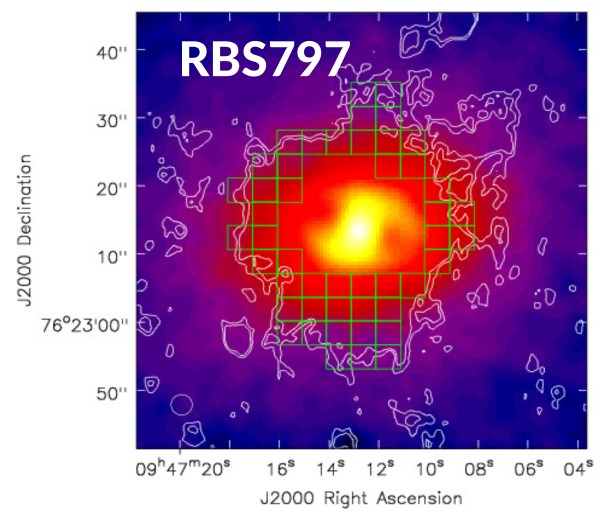


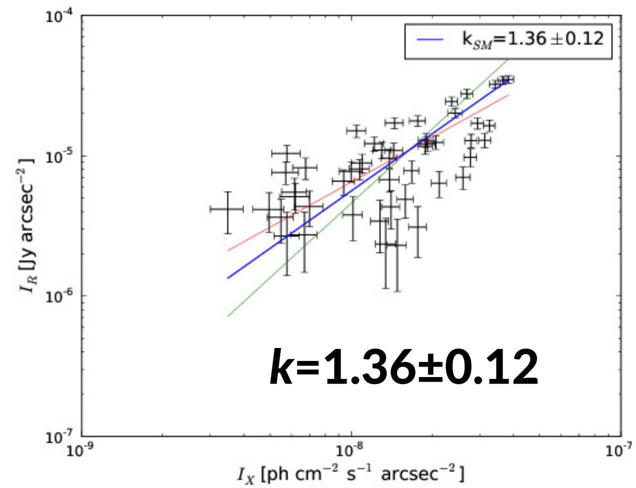

Multi-frequency observations to study the dependence of *k* on the observed frequency

# Point-to-point analysis

$$I_R \propto I_X^k$$




**Single mesh point-to-point analysis**

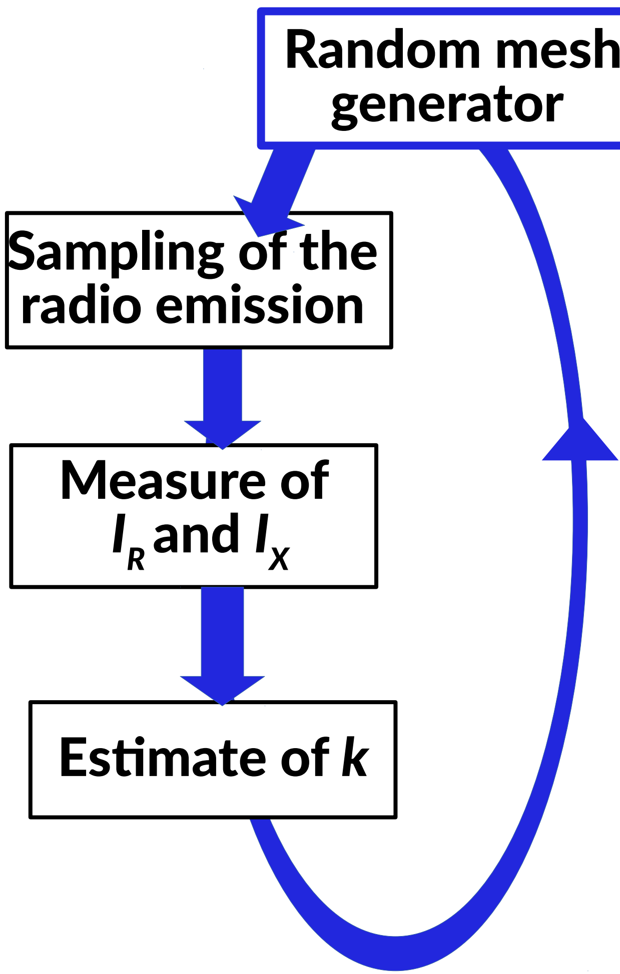
**Pros:**

- Simple;
- Provides a direct estimate of $I_R$-$I_X$ connection;

**Cons:**

- Possible bias related to arbitrary choice of the sampling mesh.

# Point-to-point analysis




- Emission not related to MHs can be excluded (BCG, radio-filled cavities, field sources..);
- Sampling resolution ≥ beam size.

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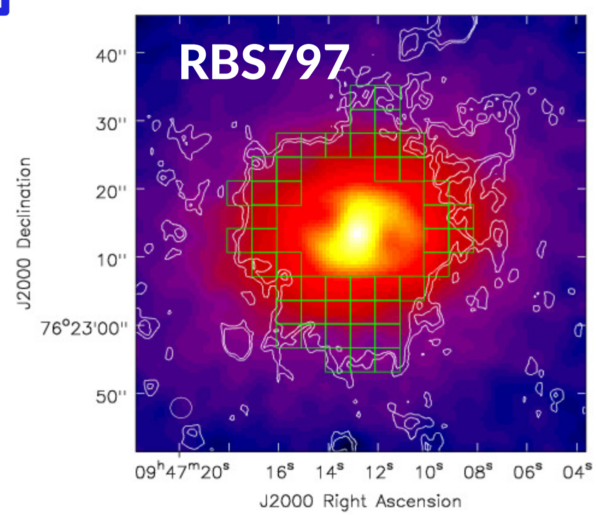
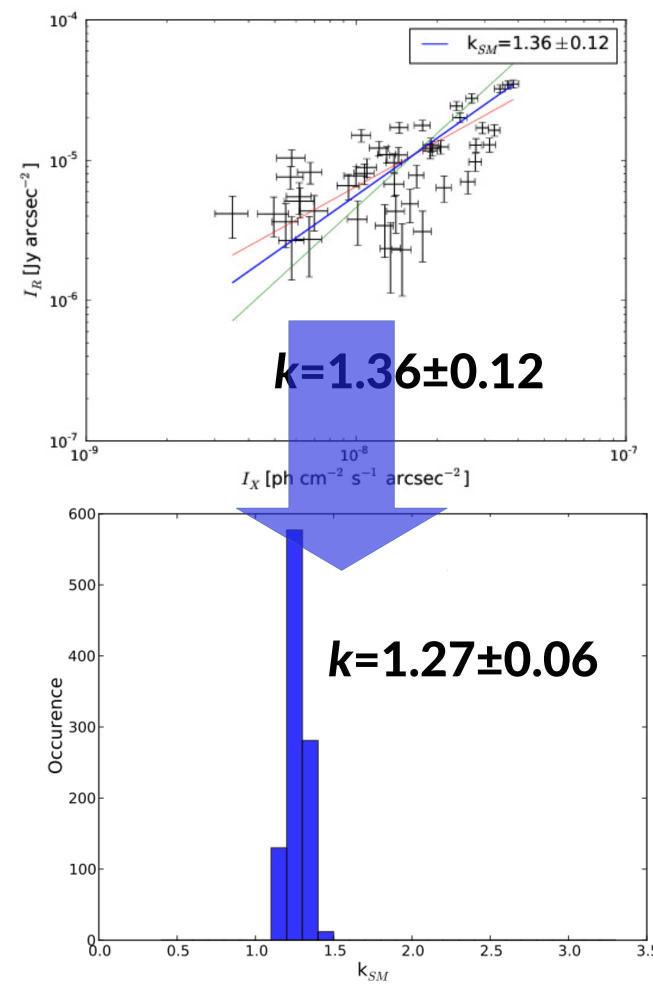



**Single mesh point-to-point analysis**

**Monte Carlo point-to-point analysis**



# Preliminary results

For each cluster:
- **1000** cycles of analysis;
- Several threshold in radio surface brightness.

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*(Ignesti et al. in prep.)*

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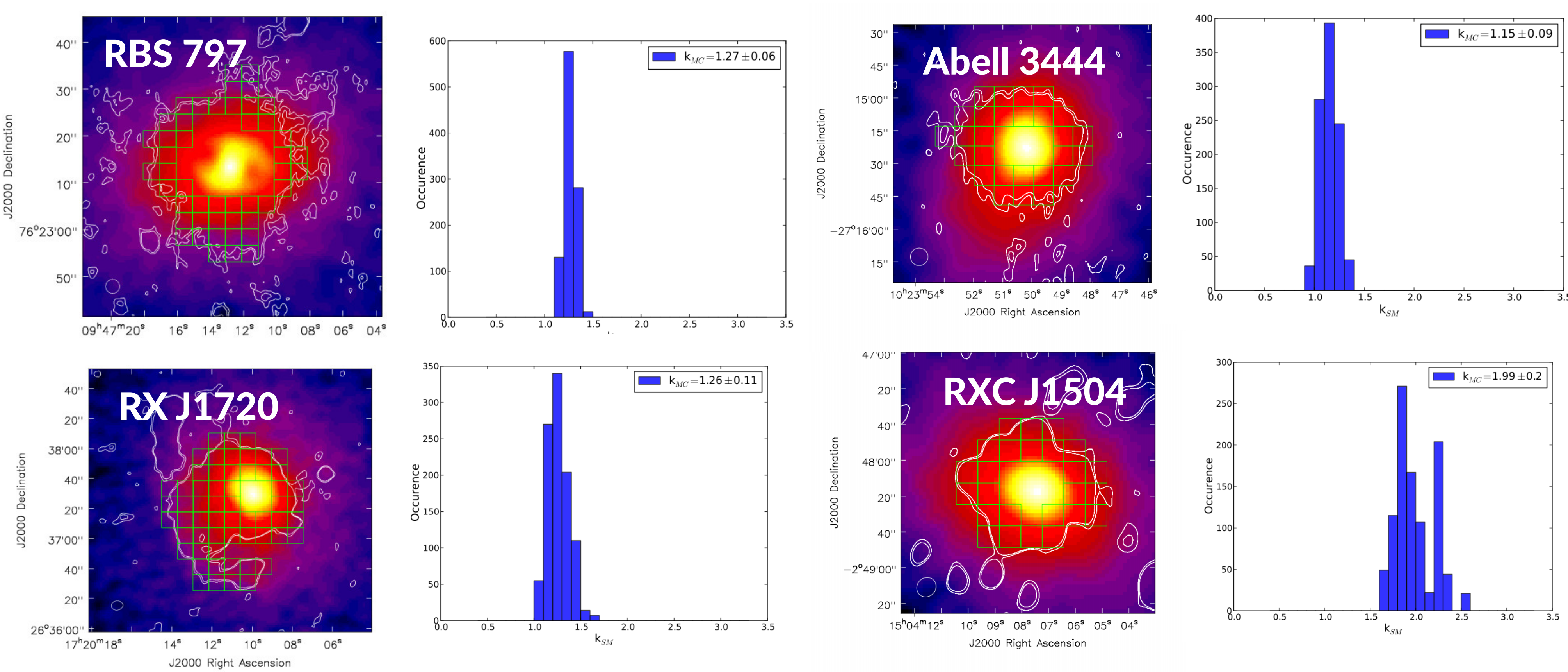


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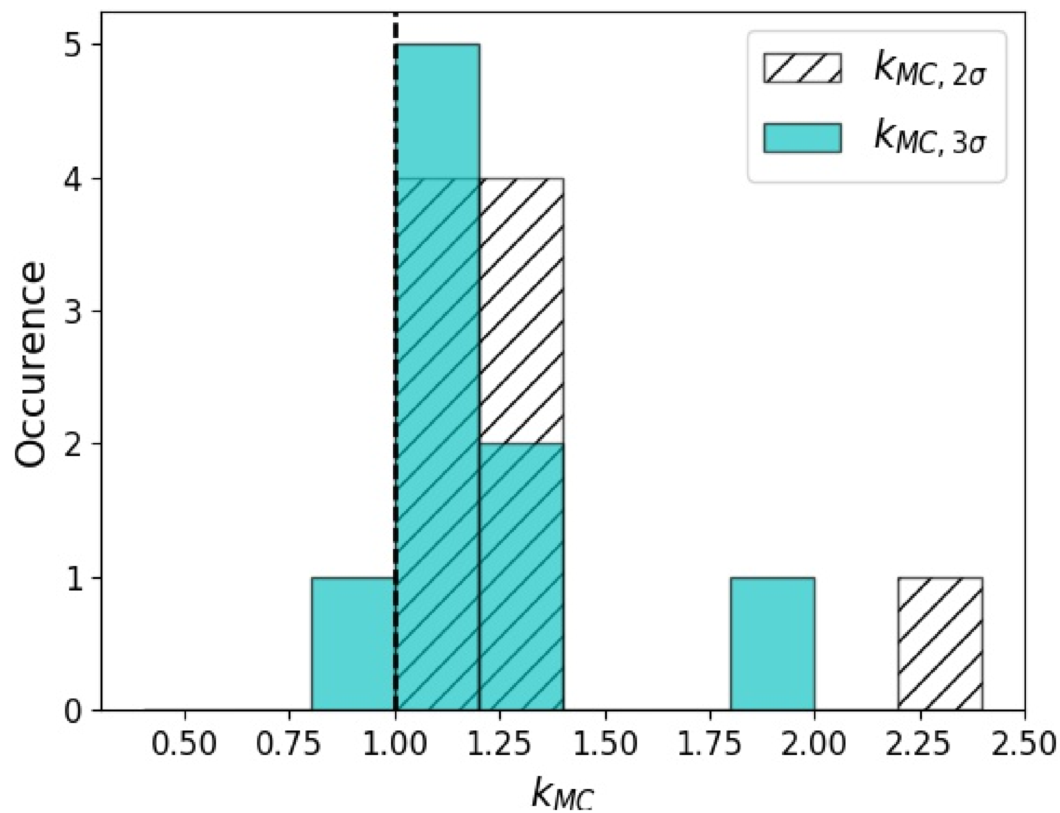


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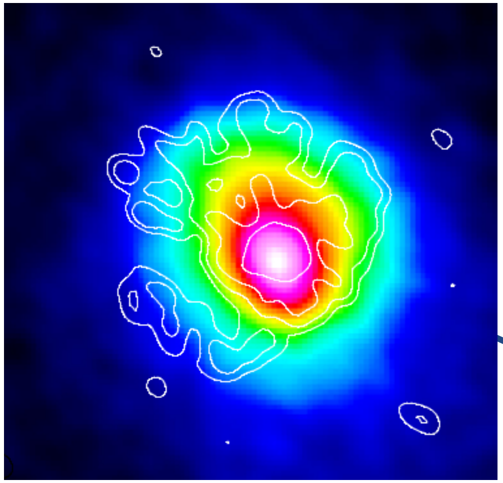
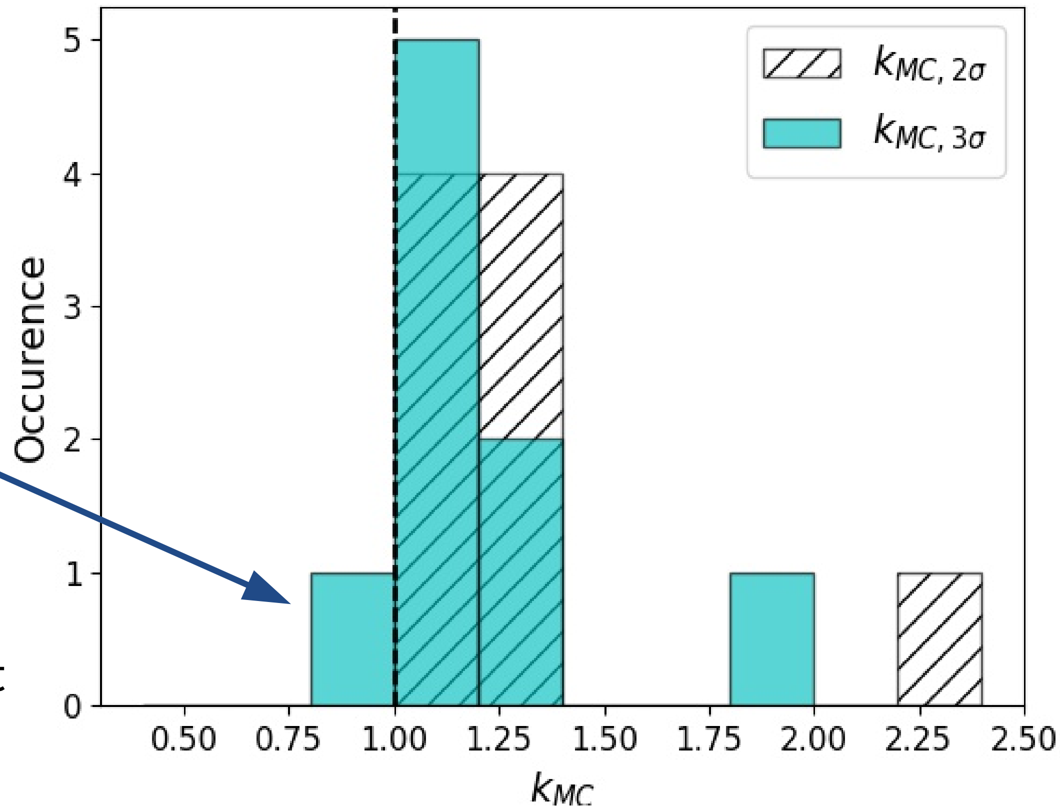


Connection to a cold front
(*Mazzotta & Giacintucci '08* )

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**Giant radio halos:**

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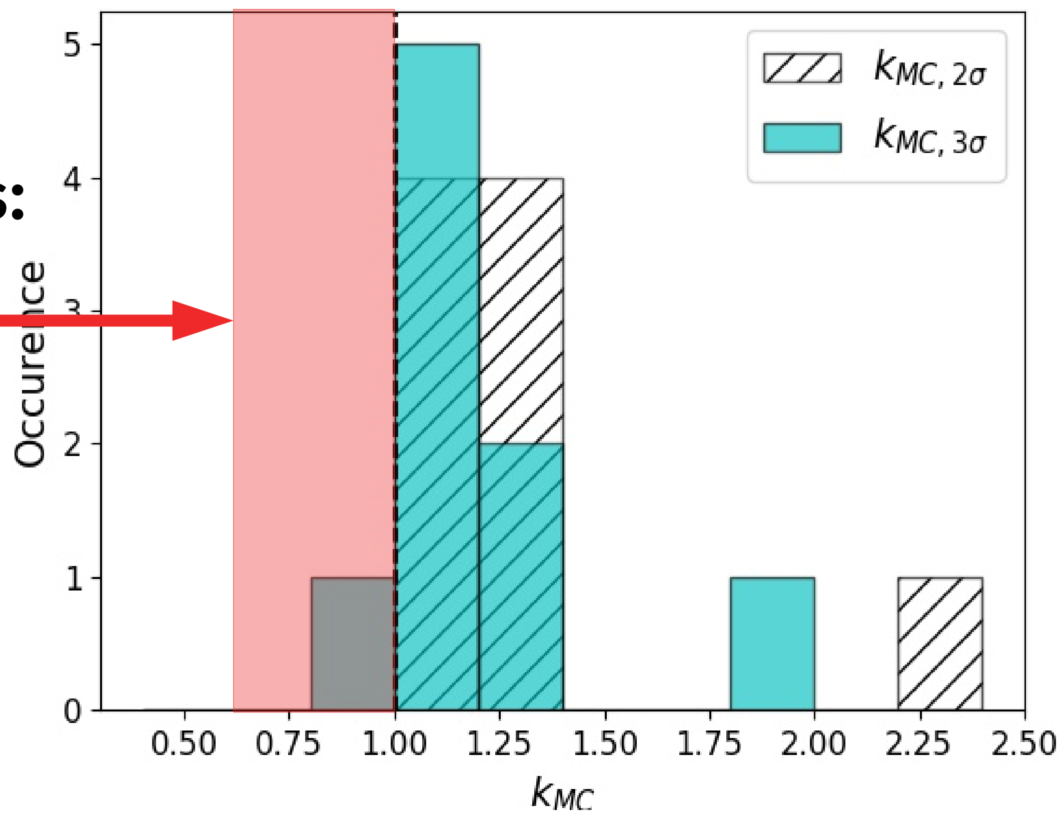
*Govoni et al. '01*




**Mini-halos:**

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# Constraining the magnetic field

**Radio emissivity: synchrotron**

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**Numerical integration of emissivity to obtain radio and X-rays surface brightness radial profiles**

**Compare results with numerical estimates of *k* to constrain $B_0$, η and $Q_0$**

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- η=2/3 **Isotropic compressed field** (Tribble '93)
- η=0 **Uniform magnetic field**

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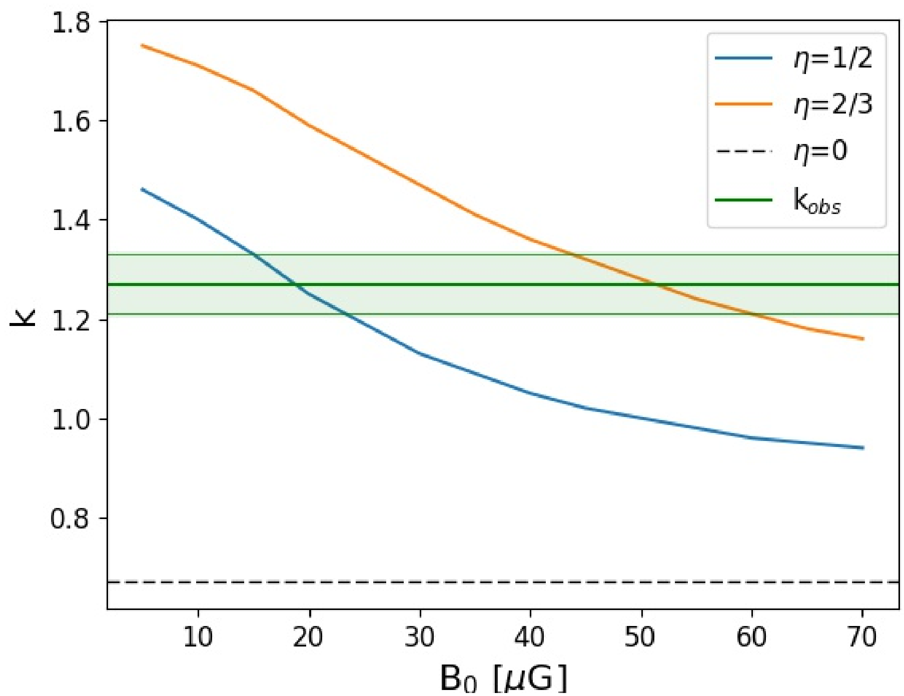


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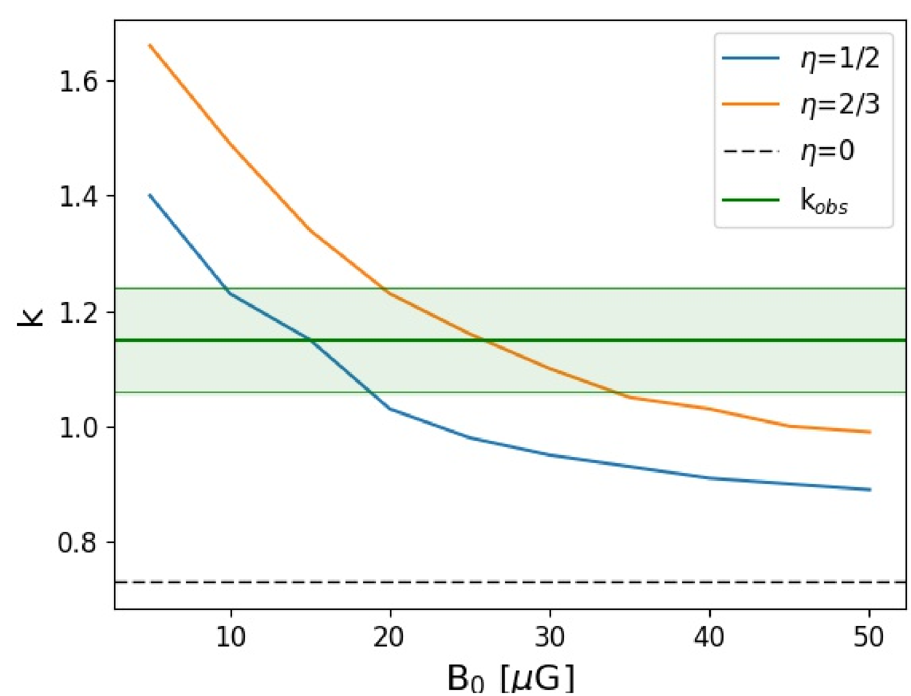


η=1/2 $B_0$≈20 μG
η=2/3 $B_0$≈50 μG

η=1/2 $B_0$≈15 μG
η=2/3 $B_0$≈25 μG

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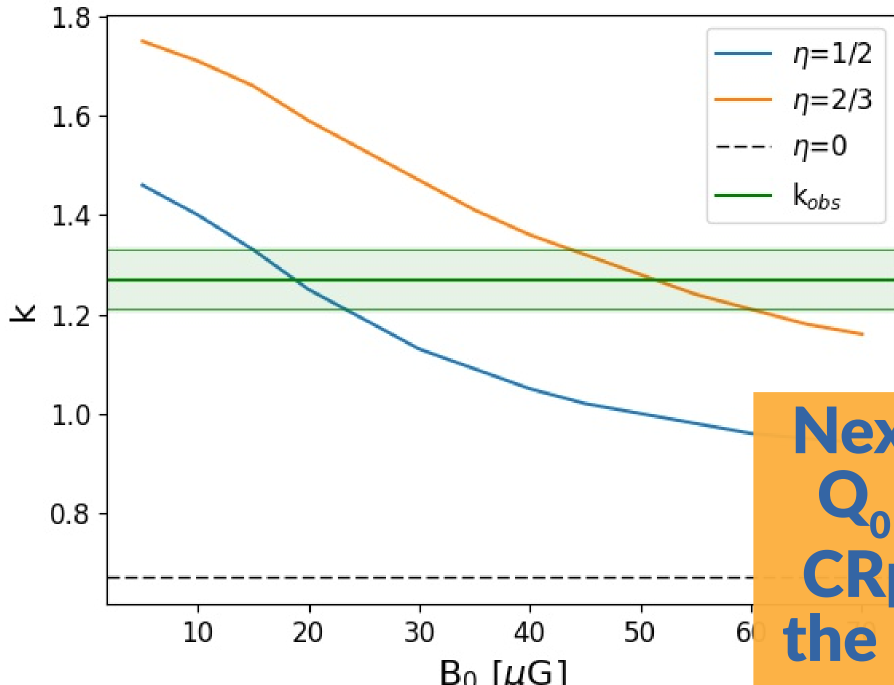


$\eta=1/2$ $B_0 \approx 20$ μG
$\eta=2/3$ $B_0 \approx 50$ μG

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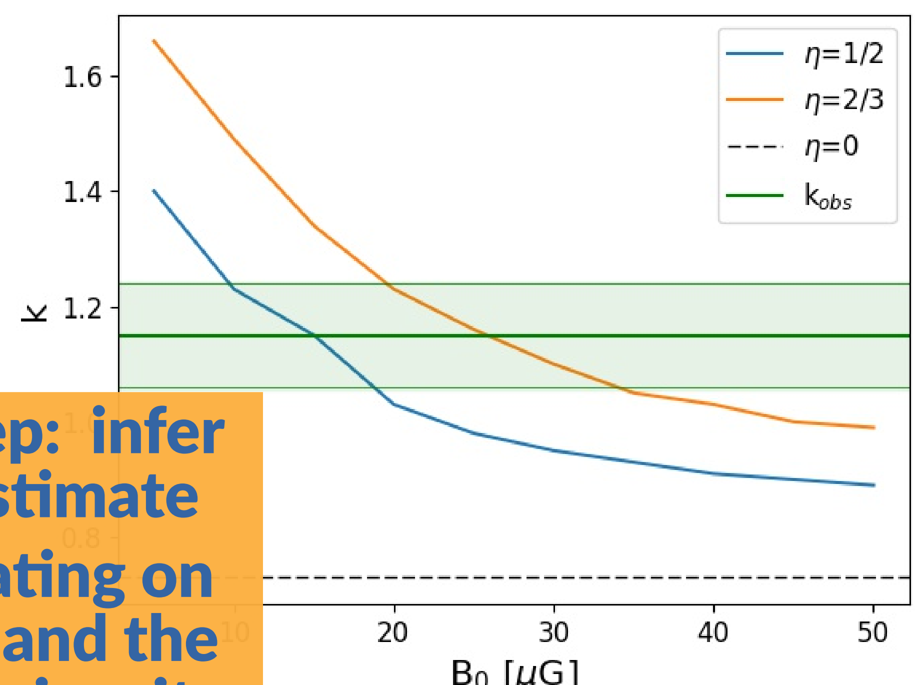


$\eta=1/2$ $B_0 \approx 15$ μG
$\eta=2/3$ $B_0 \approx 25$ μG

**Next step: infer $Q_0$ to estimate CRp heating on the ICM and the γ-ray luminosity of the clusters**

*(Ignesti et al. in prep.)*

# Conclusions and future prospects

- The MHs show a **super-linear** relation between $I_R$ and $I_X$, this is **opposite** to what was observed for giant radio halos.
  -> This may hint to an intrinsic physical difference between these objects;
- The thermal/non-thermal connection allows us to **constrain** the magnetic field of the ICM.

**Future**:

- We will use these results to constrain the **CRp luminosity of the BCGs**, the CRp heating on the ICM and the **γ-ray luminosity** of the clusters;
- We will expand our sample by collecting more MHs to confirm these results + LOFAR observations to study the connection at low-frequency;

# Thank you for your attention