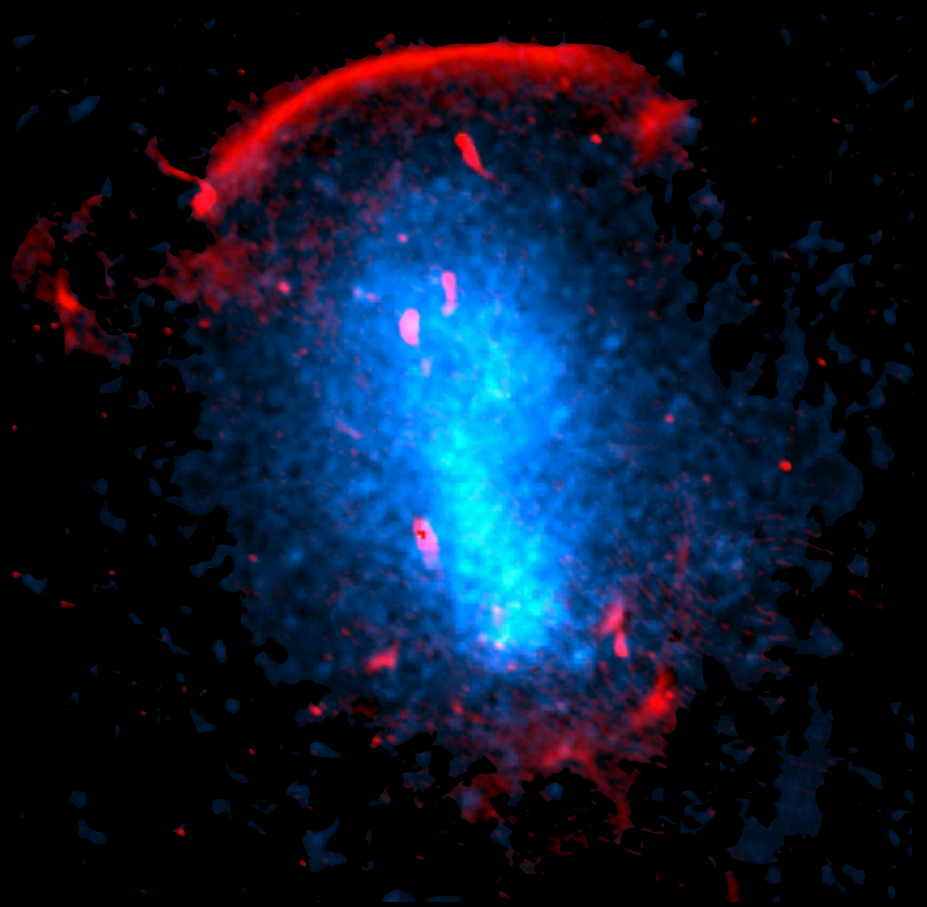
Diffuse Radio Emission in Galaxy Clusters



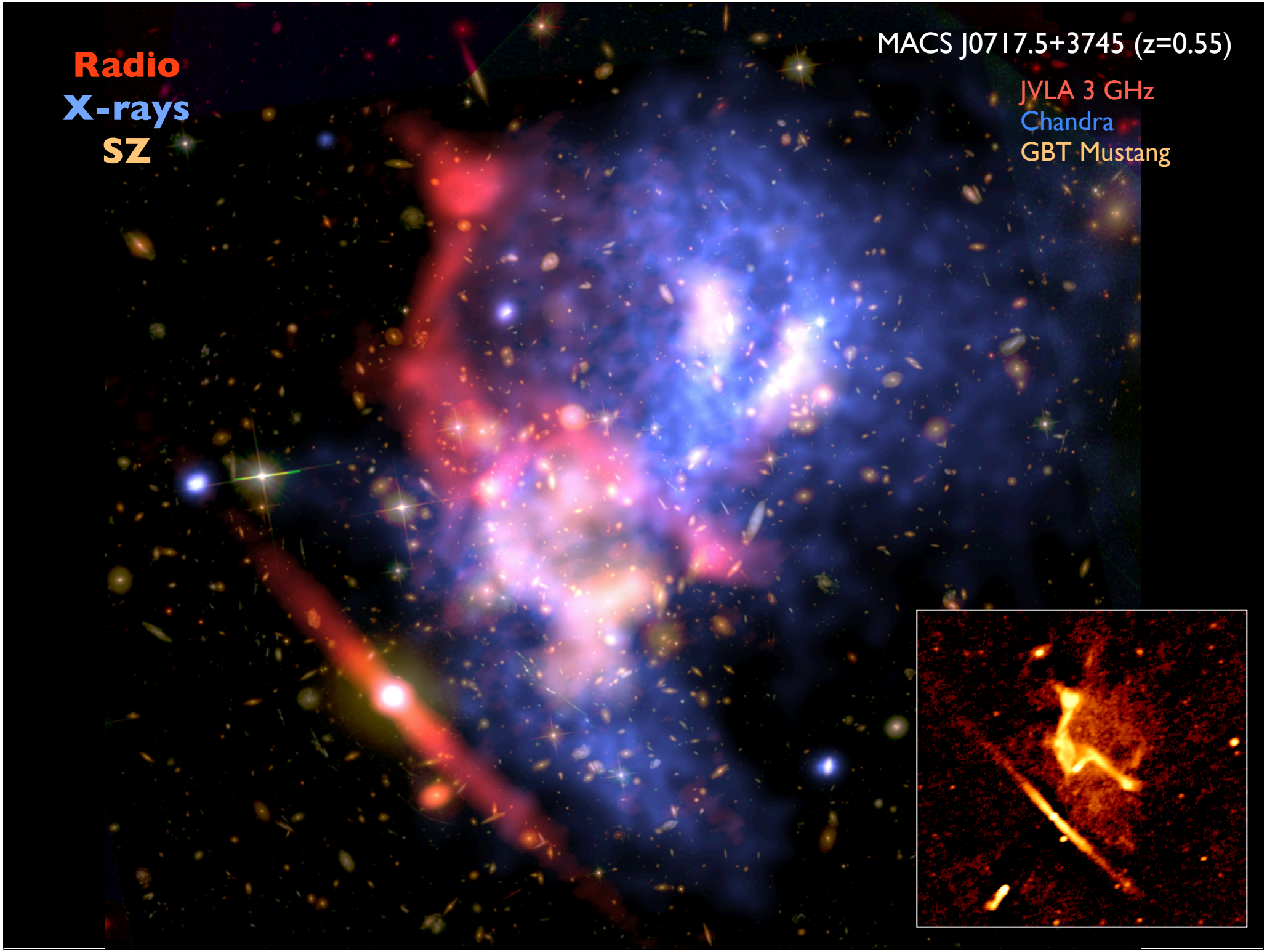
Reinout van Weeren

Harvard-Smithsonian Center for Astrophysics

W. Forman, C. Jones, F. de Gasperin, W. Dawson, H. Intema, G. Ogrean, M. Brüggen, H. Röttgering, A. Bonafede, G. Brunetti, LOFAR Surveys KSP

OUTLINE

- Introduction
- LOFAR HBA calibration
- Toothbrush & Abell 2256
- Summary


Radio
X-rays
SZ
MACS J0717.5+3745 (z=0.55)
JVLA 3 GHz
Chandra
GBT Mustang

- GIANT RELICS
- PHOENICES

- Elongated, filamentary
- Polarized
- Radio emission traces shocks
- Particle acceleration mechanisms :
  - Diffusive shock acceleration (Ensslin+ 1998; ....)
  - Shock re-acceleration (Markevitch+ 2005; ...)
  - Adiabatic compression (Ensslin & Gophal-Krishna 2001; ...)

- GIANT HALOS
- MINI-HALOS

- Smooth, centrally located
- Follow ICM X-ray emission
- Unpolarized
- Particle acceleration mechanisms:
  - Turbulent re-acceleration mechanism (Brunetti+01; Petrosian 2001; ...)
  - Secondary electrons: products of hadronic collisions (Dennison 1980; Blasi & Colafranceso 1999; ...)

Review papers: Brunetti & Jones 2014; Feretti+ 2012

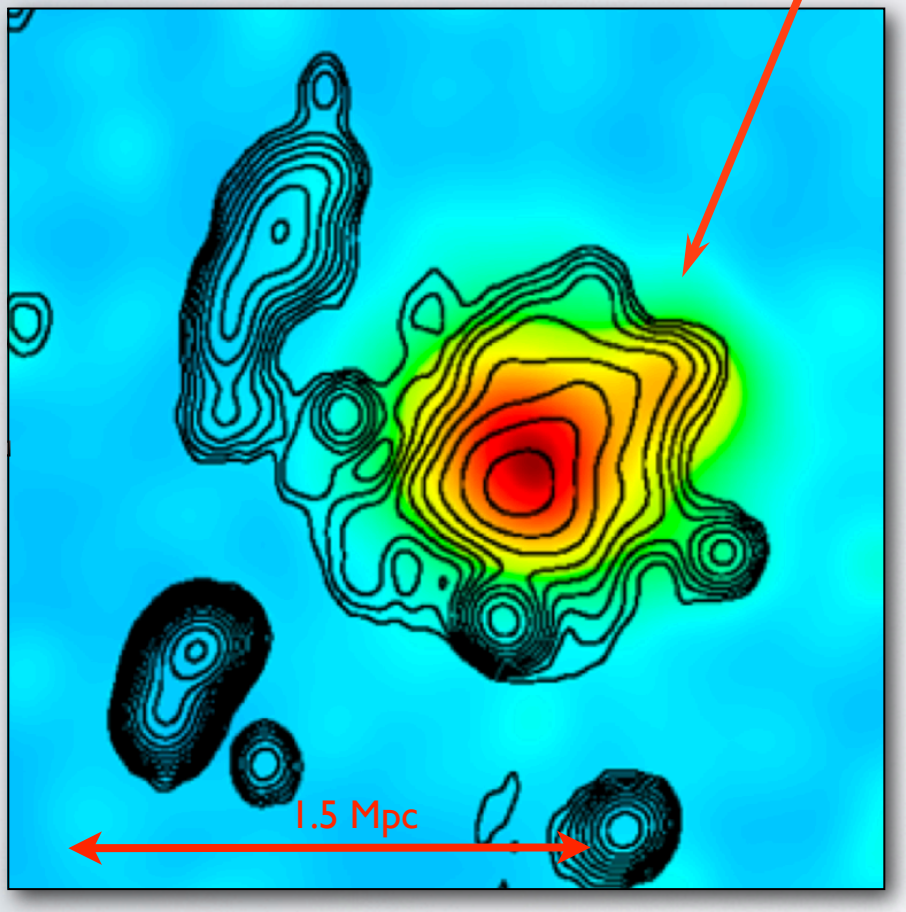
QUESTIONS

- Physics of shocks, turbulence, and particle acceleration in dilute plasmas
- Origin of Cosmic Rays and magnetic fields
- Diffuse Radio emission as a tracer of cluster mergers

RADIO HALOS

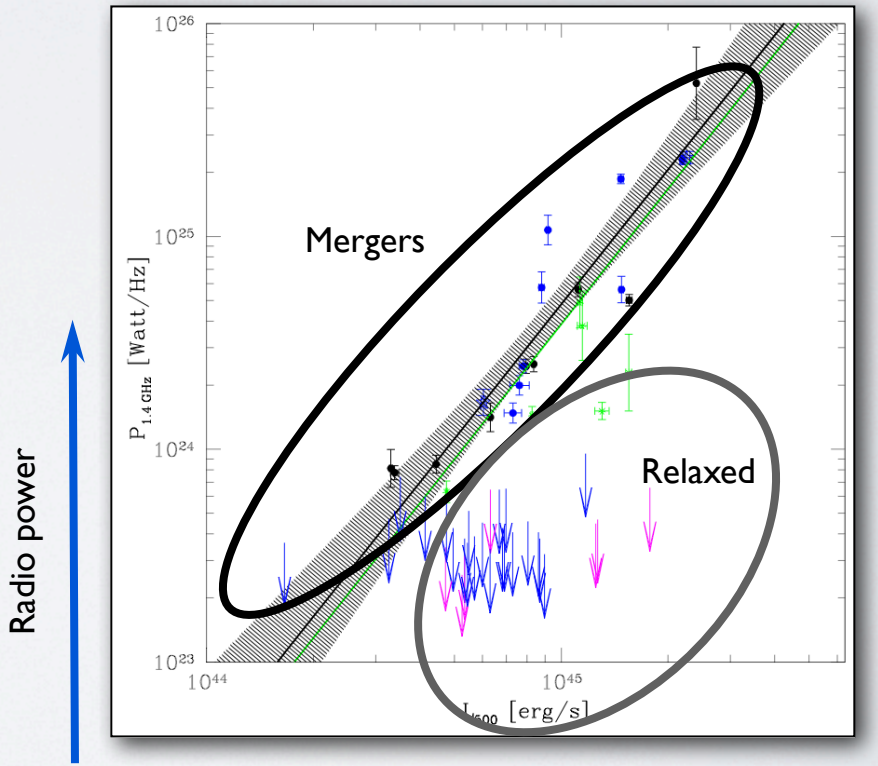
GIANT HALOS

X-ray image + radio contours



Abell 2744: Feretti+ 2012; Govoni+ 2001

- Mpc sizes, centrally located
- unpolarized
- found in disturbed clusters
- radio luminosity scales with cluster mass

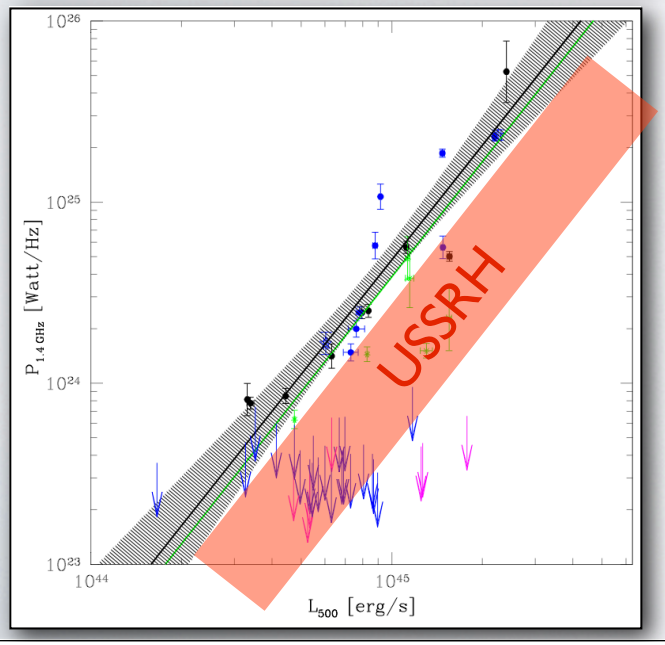


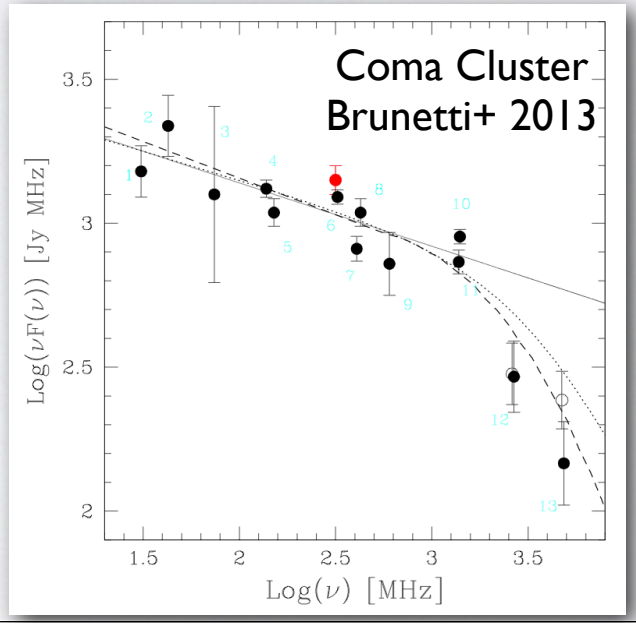
Cassano/Kale+ 2013

HALO SPECTRA

- Typical spectral index -1.1 to -1.3
- USSRH: Should occur in less energetic mergers
- USSRH: Handful discovered (Brunetti+2008; Macario+2010; Bacchi+2003; ...)

- Curved spectra
- Evidence for α- global ICM temperate correlation (Feretti+2004; Giovannini+2009)

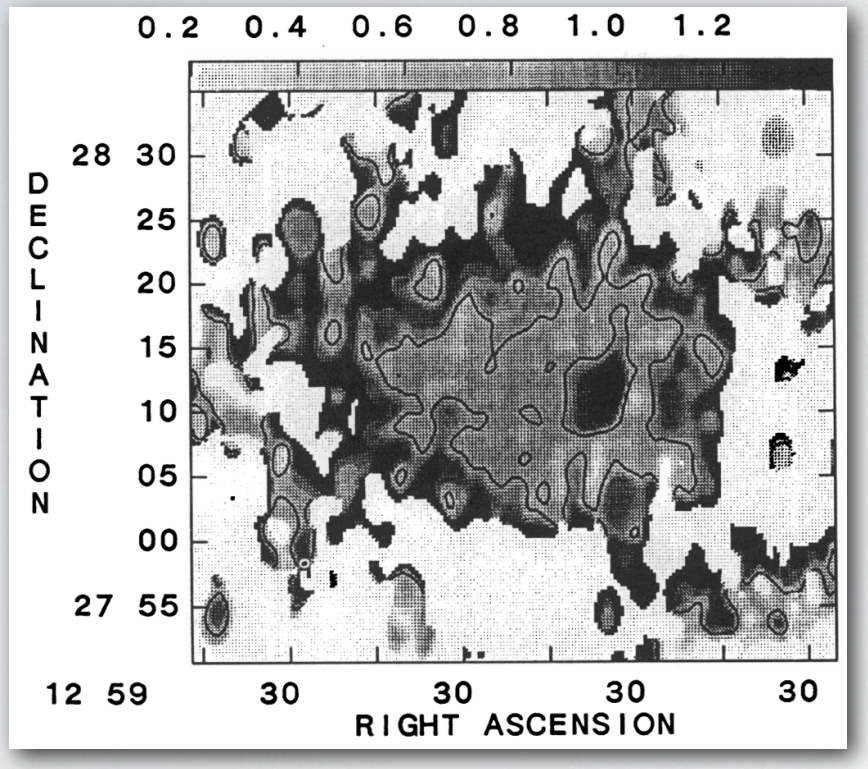




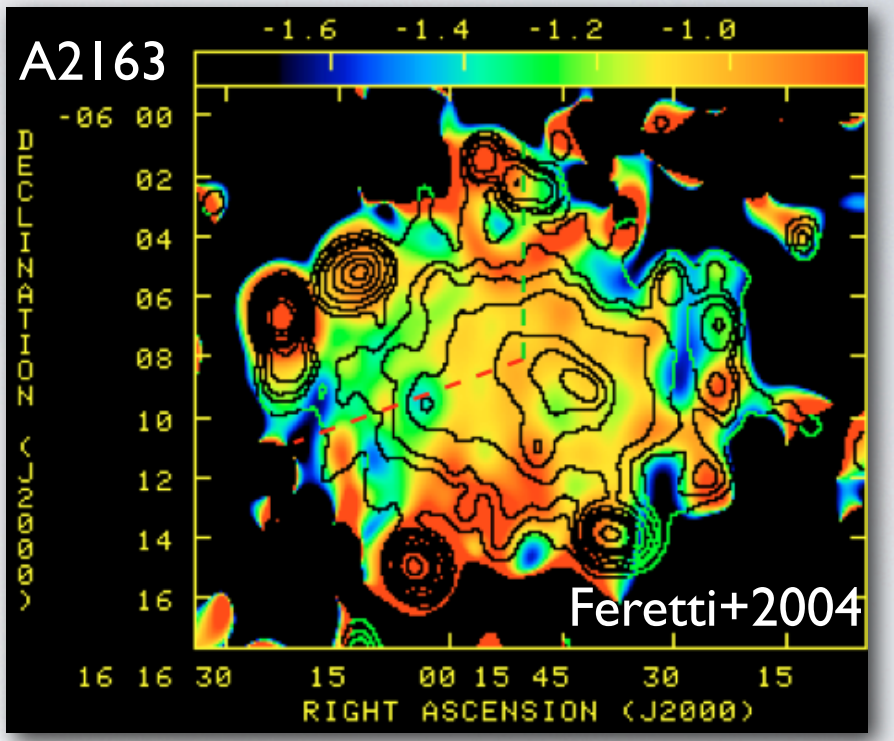
Supports turbulent re-acceleration model

RESOLVED HALO SPECTRA (Challenging !)

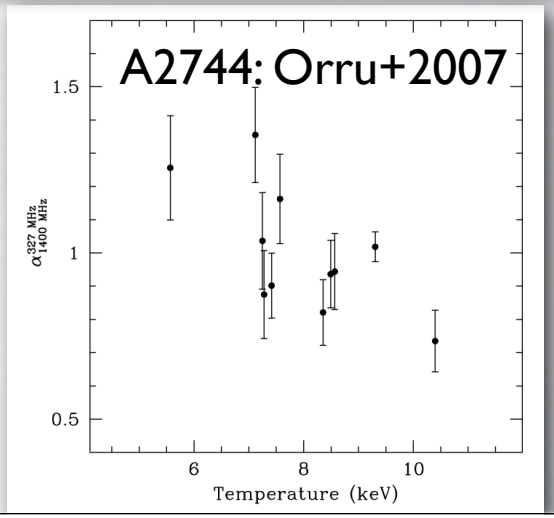
Use spectral index to trace variations in ICM turbulence and/or B-fields ?



Coma Cluster: Giovannini+1993



- Steepening with radial distance
- Correlation with cluster temperature distribution (Orru+2007) (but see Vacca+ 2014, Shimwell+ 2014)



LOW-FREQUENCY CALIBRATION

LOFAR HBA
120-180 MHz

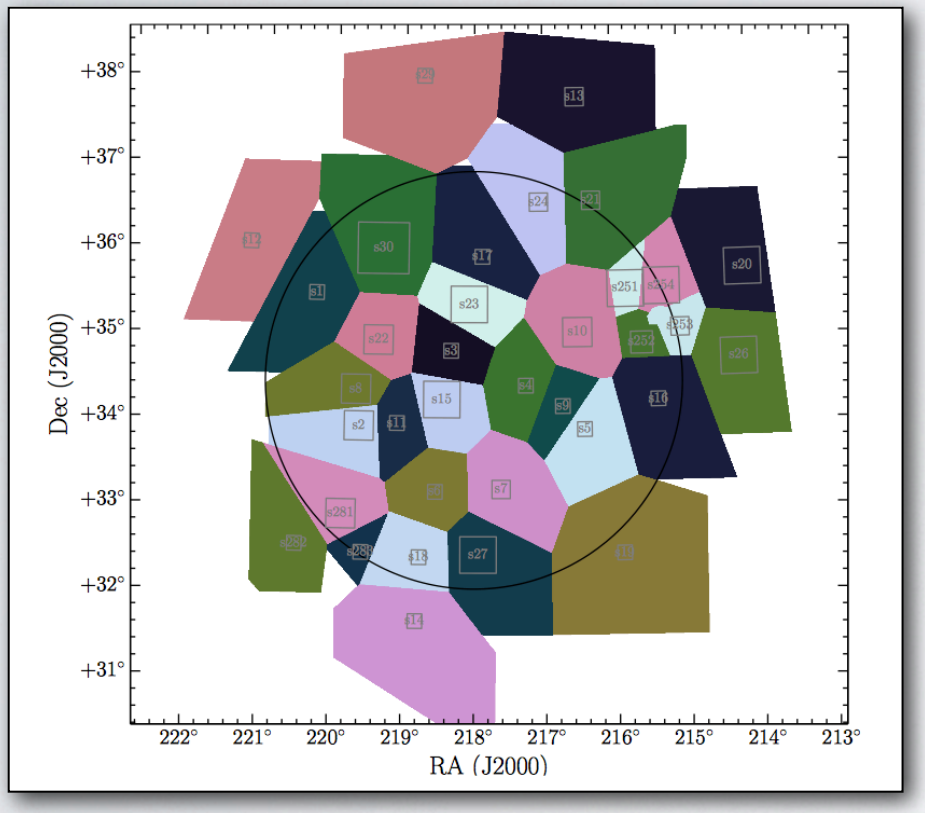
- resolution : ~ 5 arcsec
- depth: ~ 100 □Jy beam^{-1}

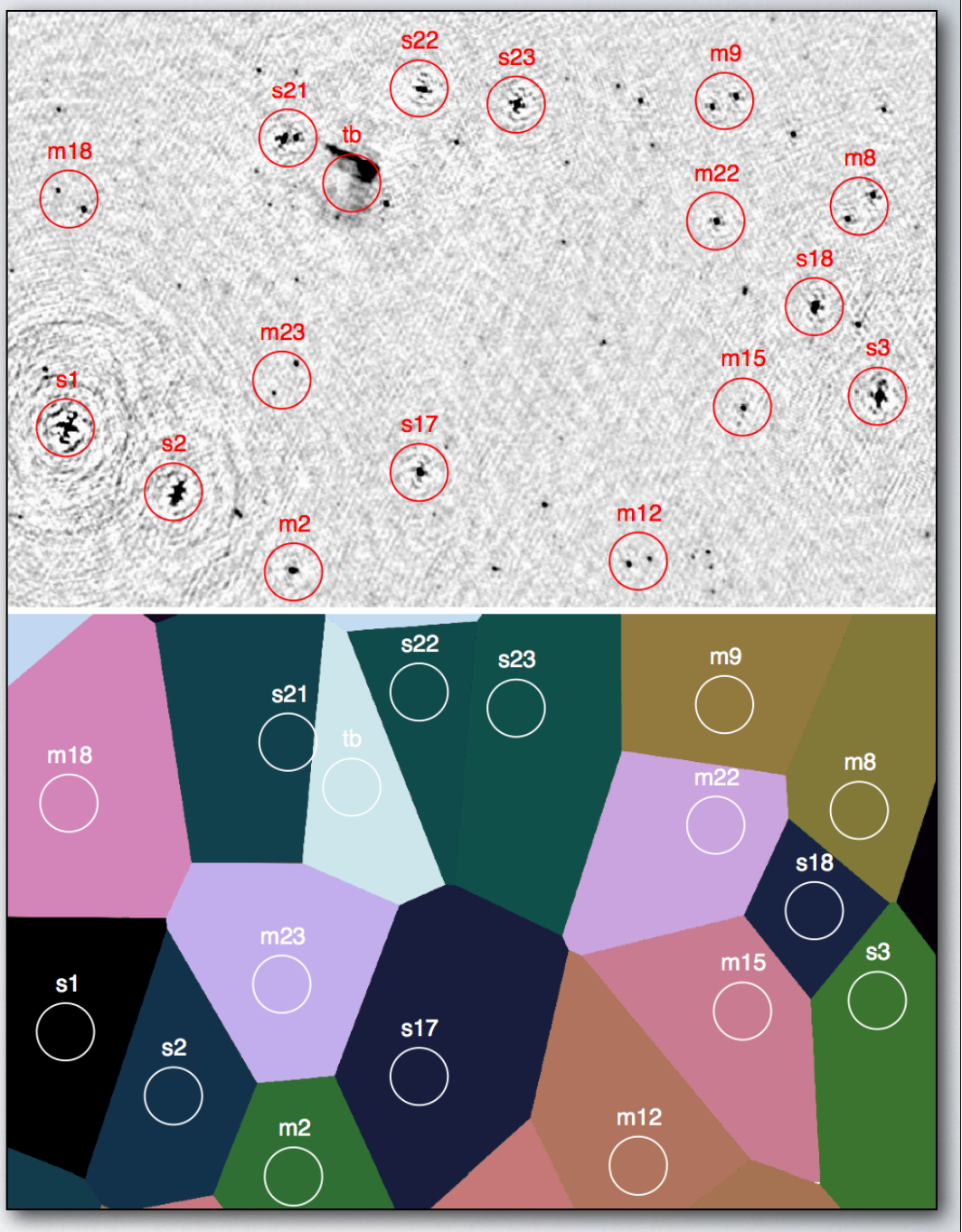
- phased array & beam model not accurately known
- Ionosphere

} → Direction dependent calibration

FACET CALIBRATION

FACET LAYOUT

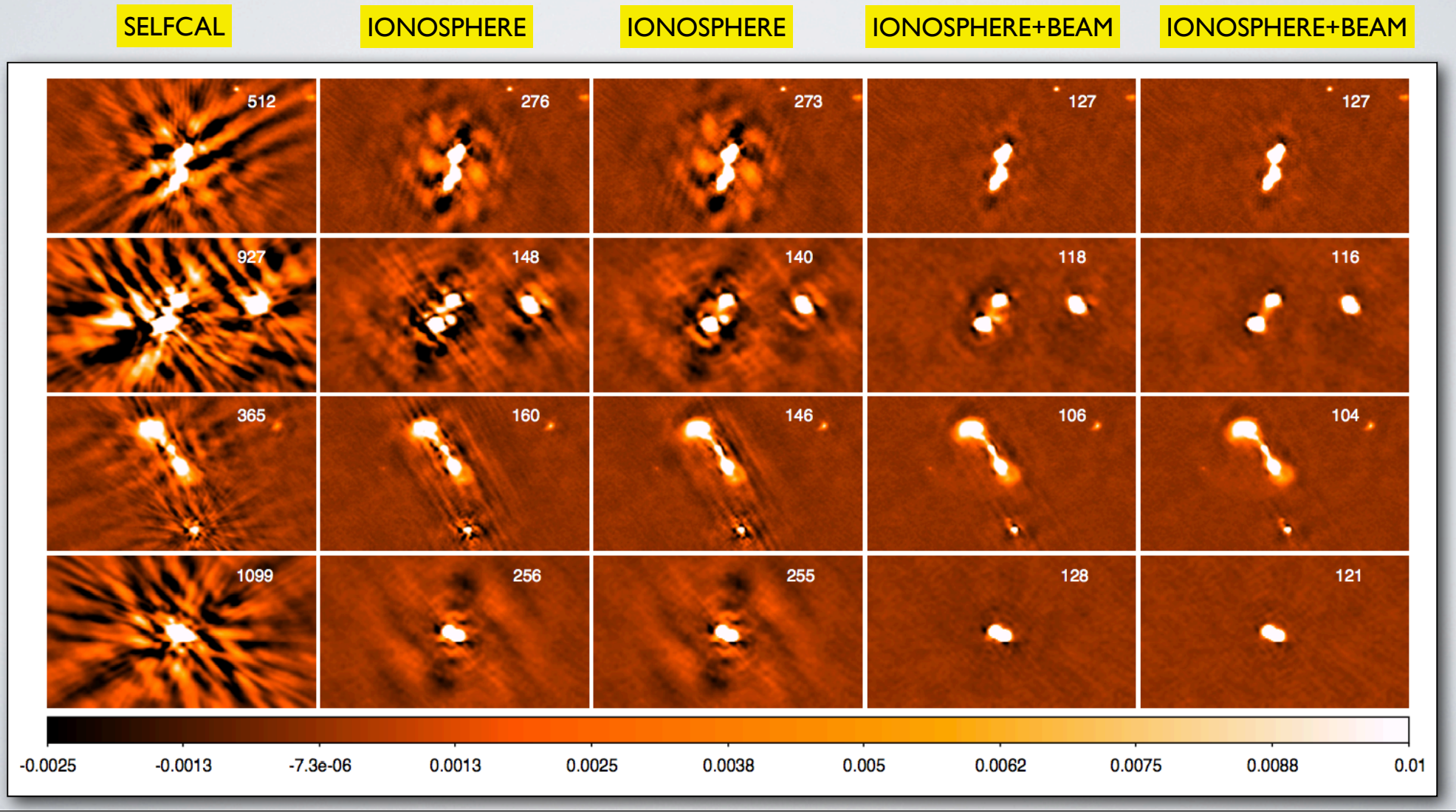




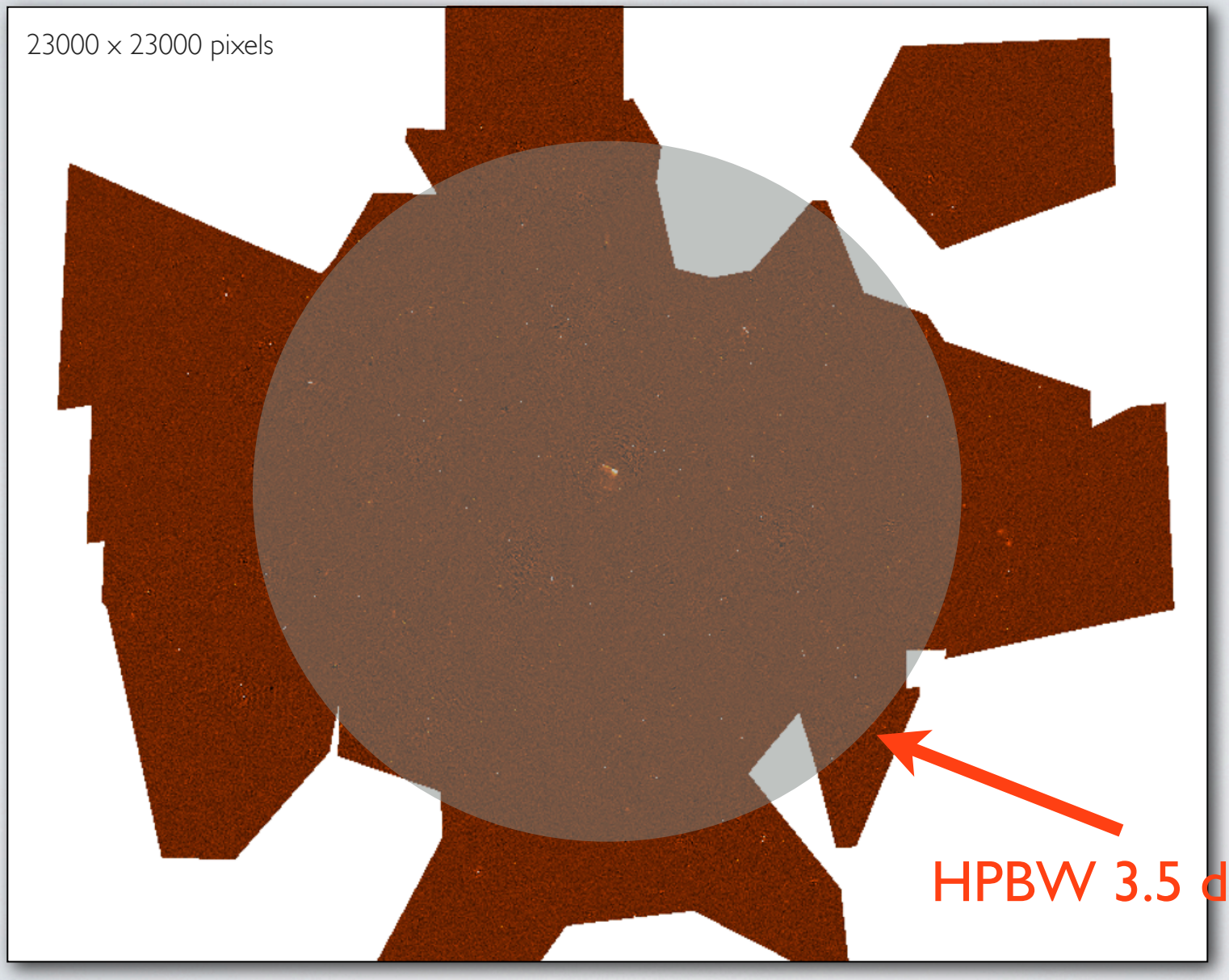
DDE CALIBRATORS

Try to minimize number of fitted parameters

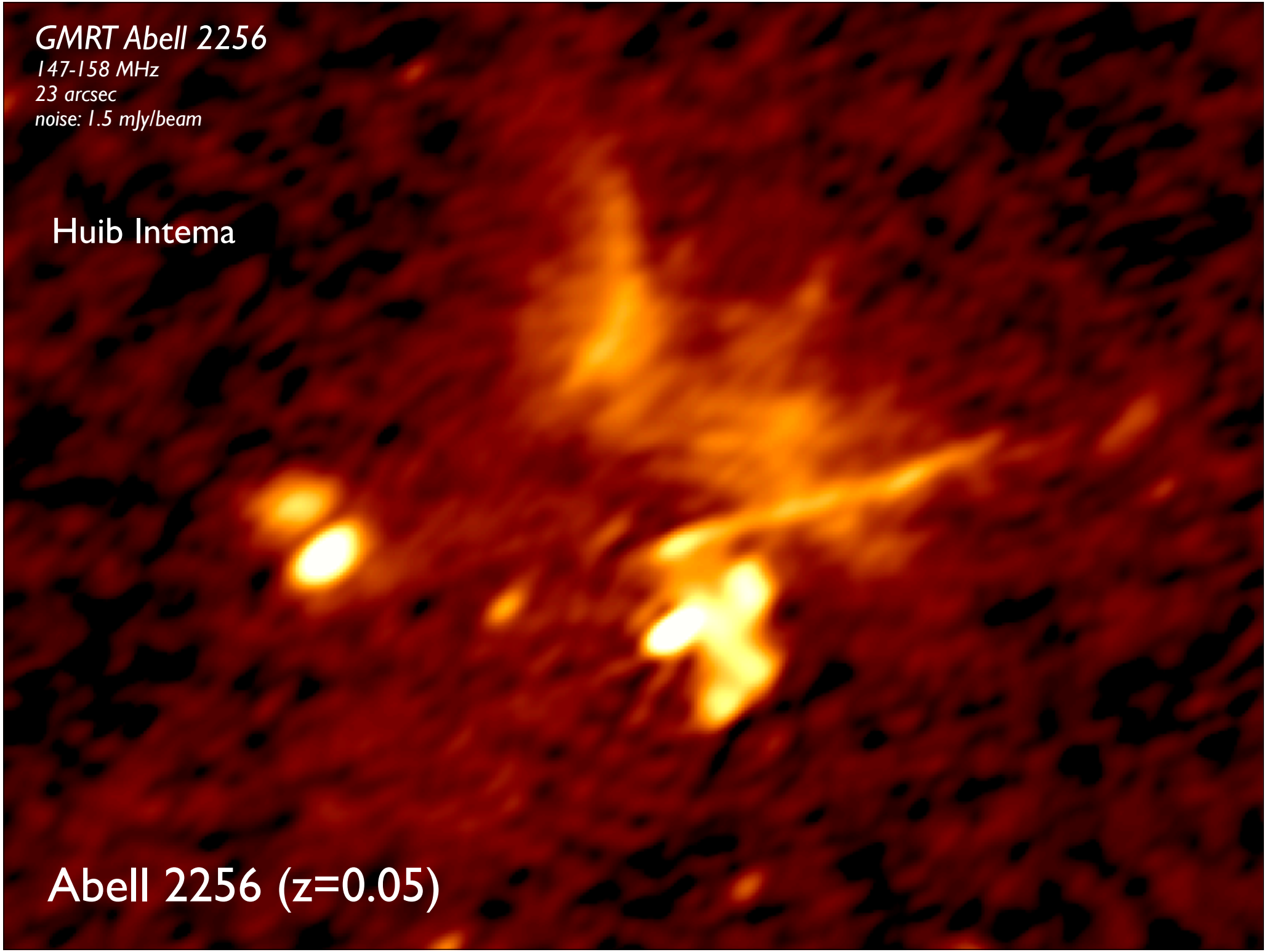
- ionosphere: dTEC (phase $\propto 1/\nu$)
- beam: slow variations, smooth in freq



AFTER ~60 DDE CALIBRATORS

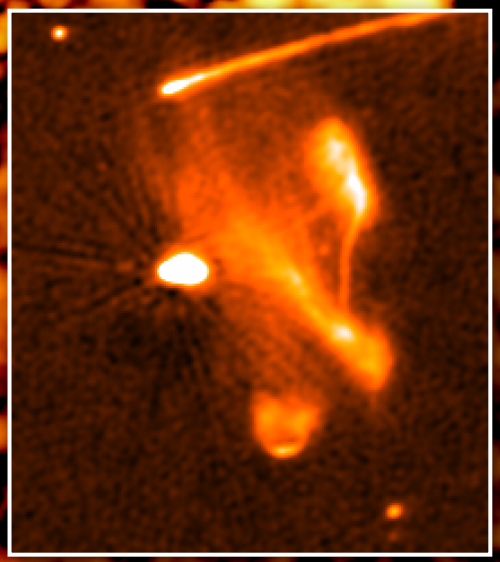


RESULTS


GMRT Abell 2256
147-158 MHz
23 arcsec
noise: 1.5 mJy/beam
Huib Intema
Abell 2256 (z=0.05)

selfcalibration → facet calibration

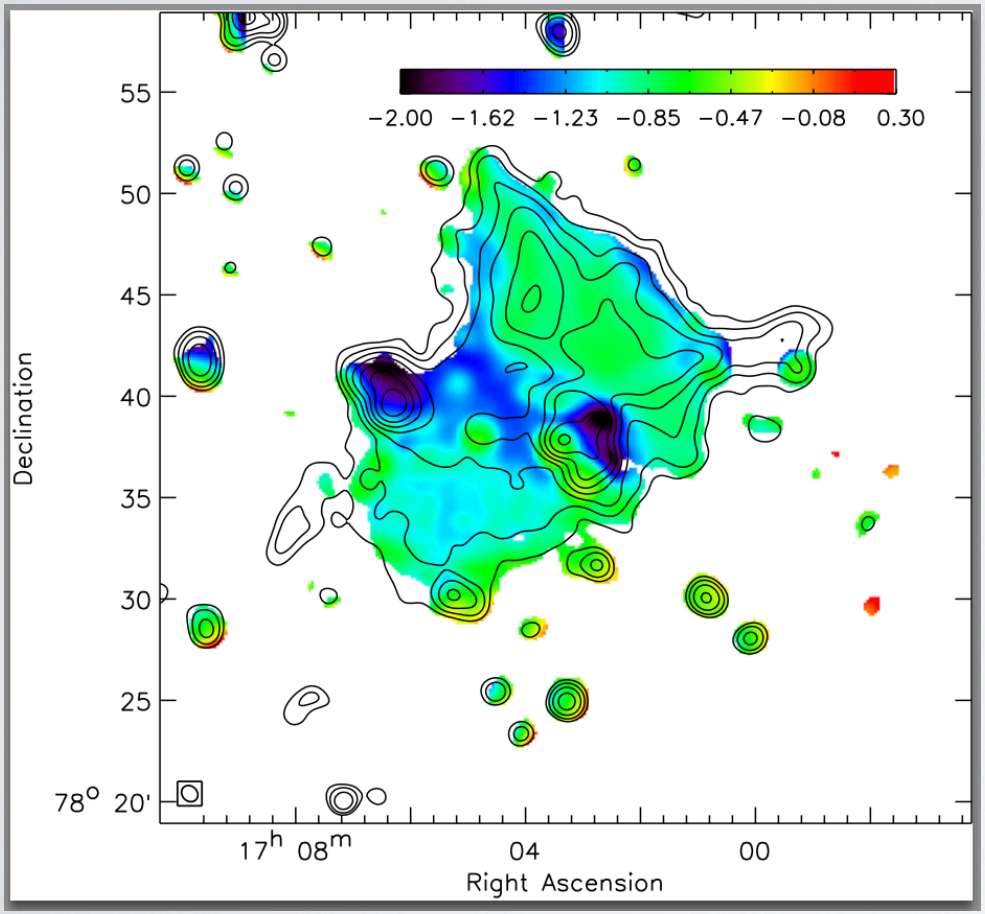
LOFAR Abell 2256
120-180 MHz
5 arcsec
noise: 105 microJy/beam



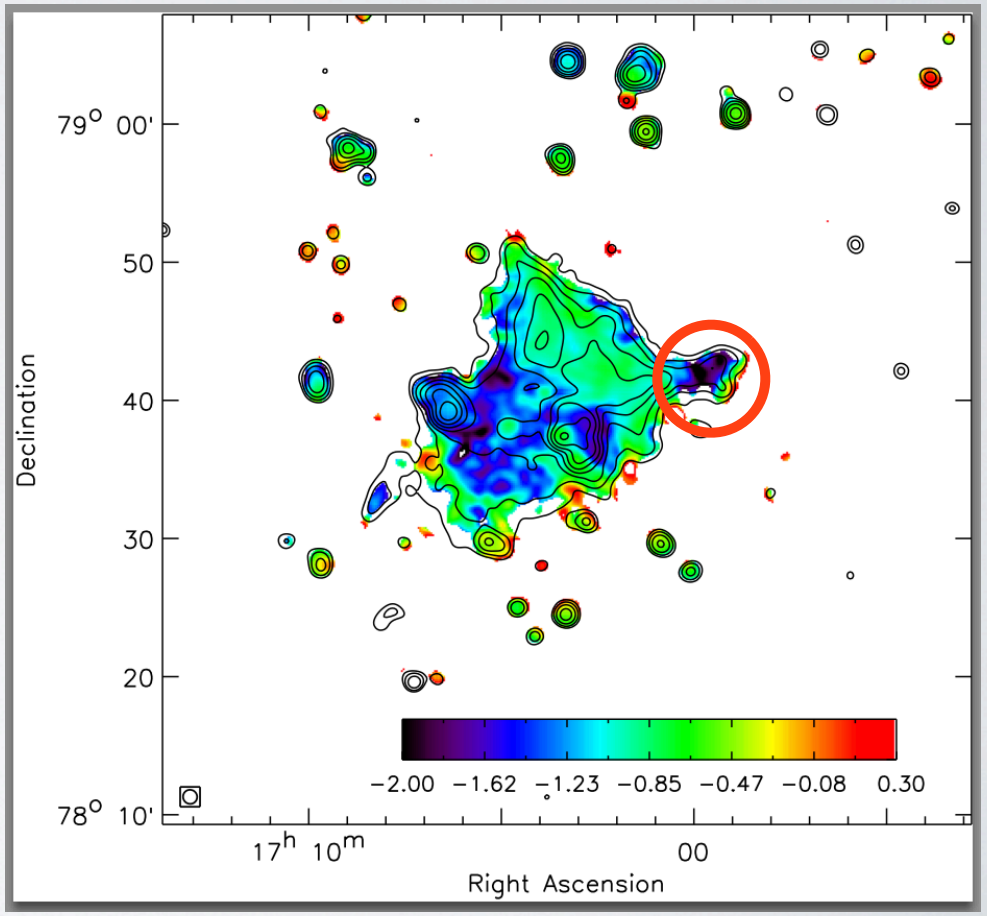
SPECTRA INDEX MAPS

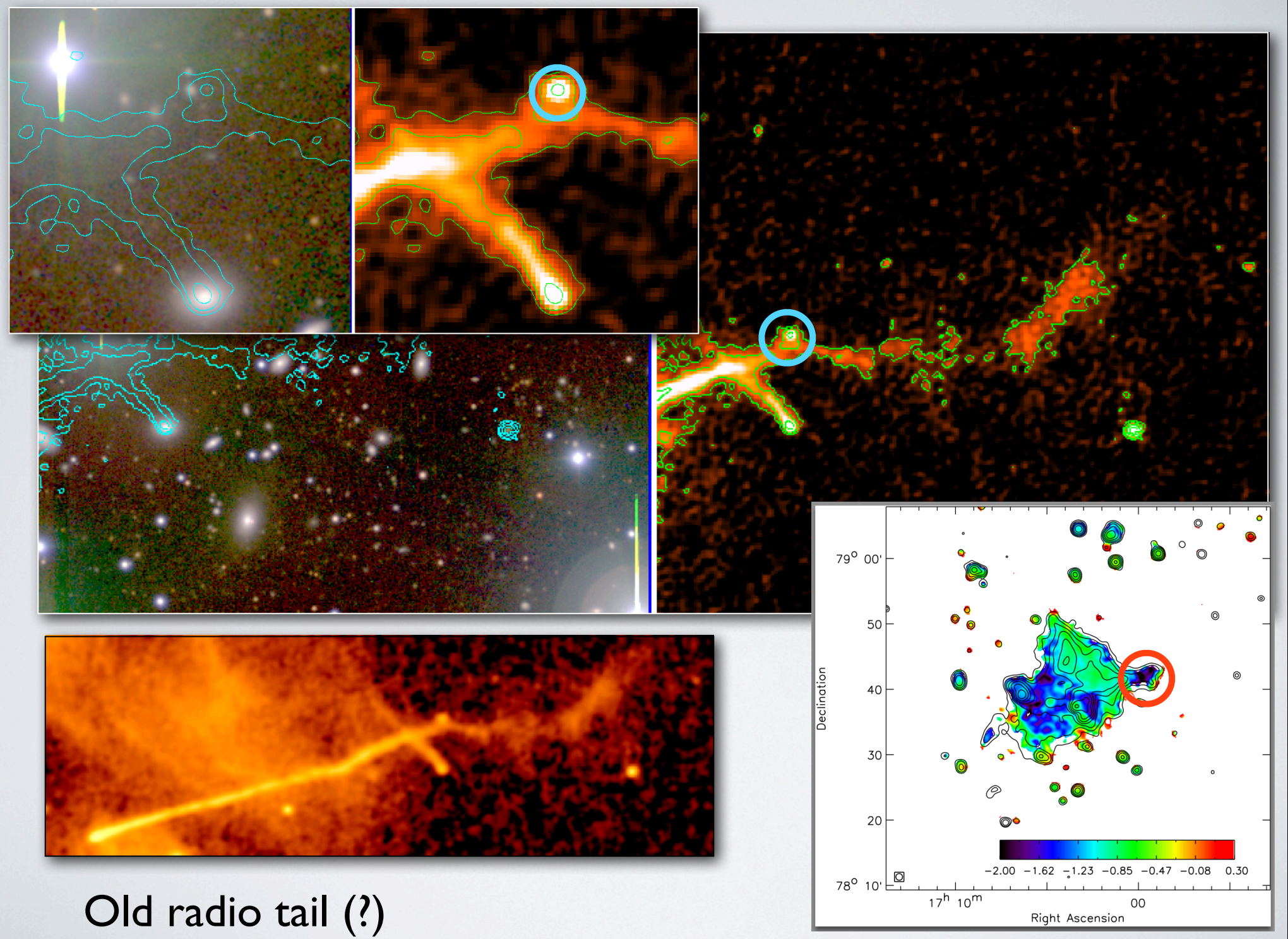
VLA maps: Tracy Clarke

1.5 GHz - 150 MHz
VLA - LOFAR HBA

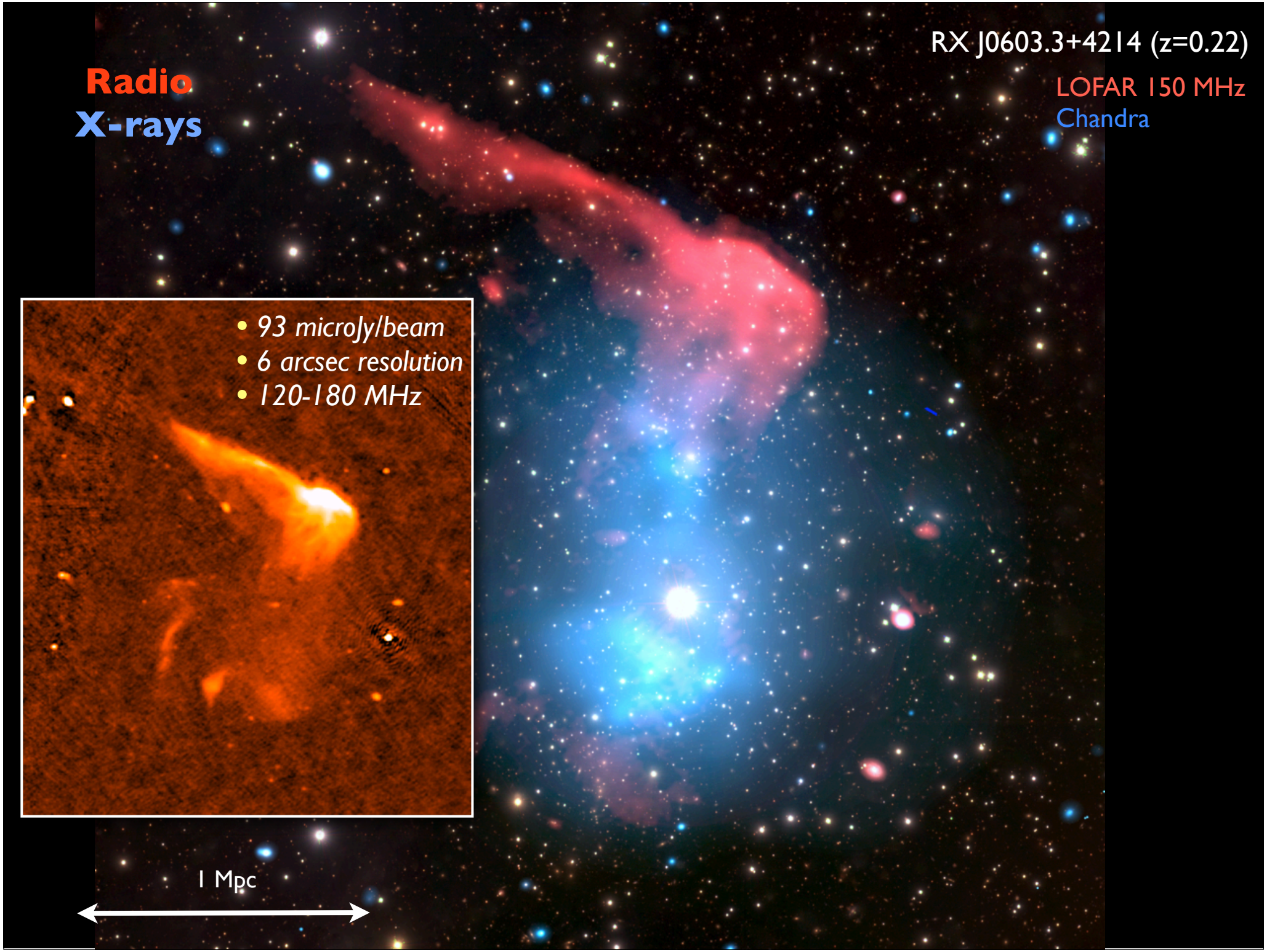


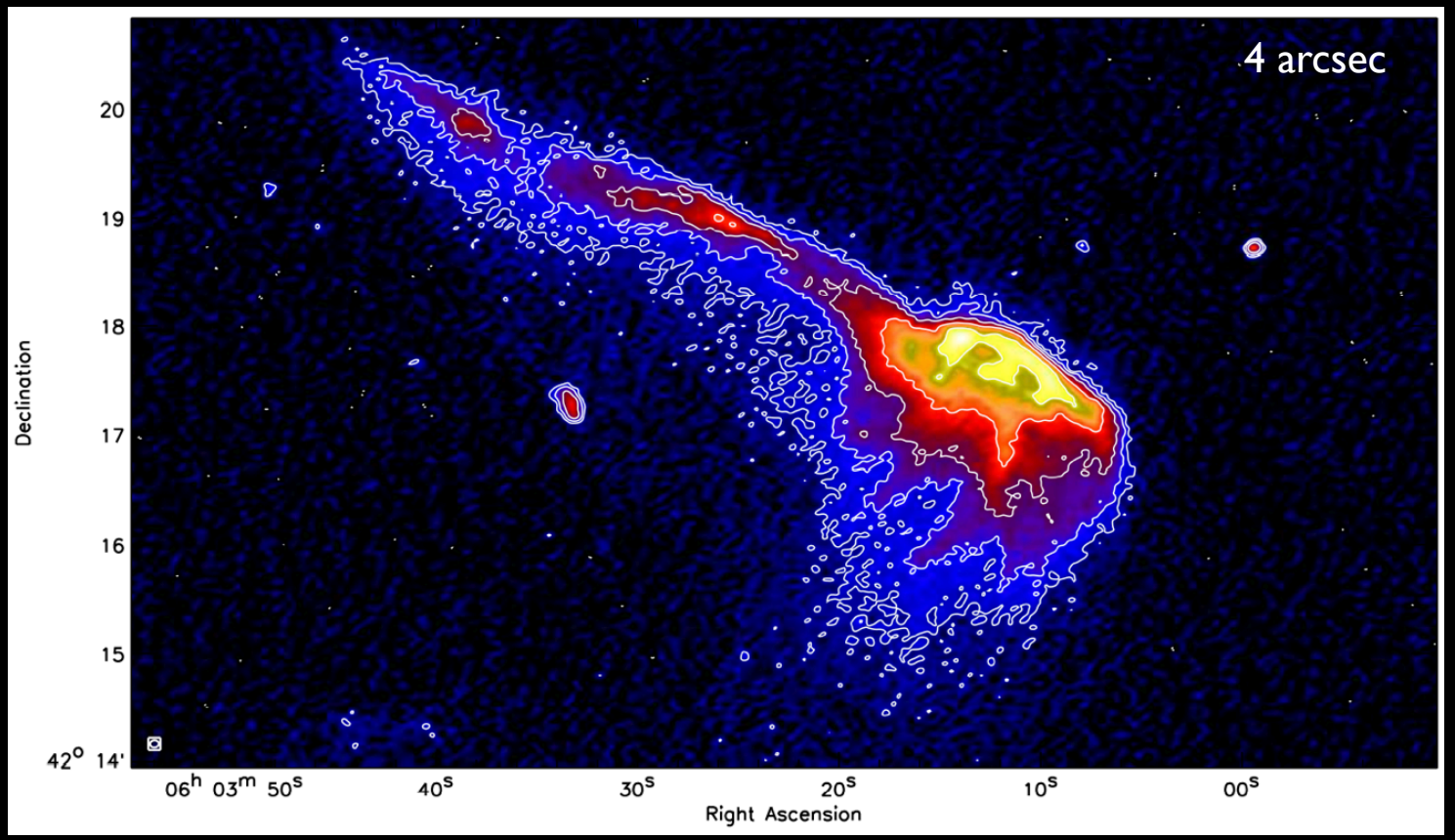
325 MHz - 150 MHz
VLA - LOFAR HBA

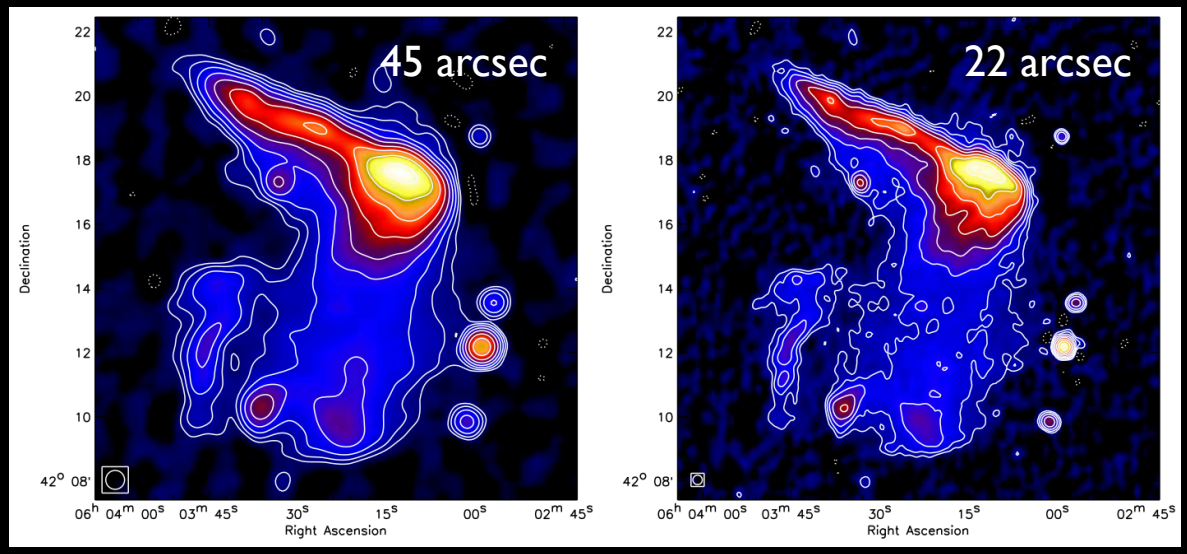




Old radio tail (?)

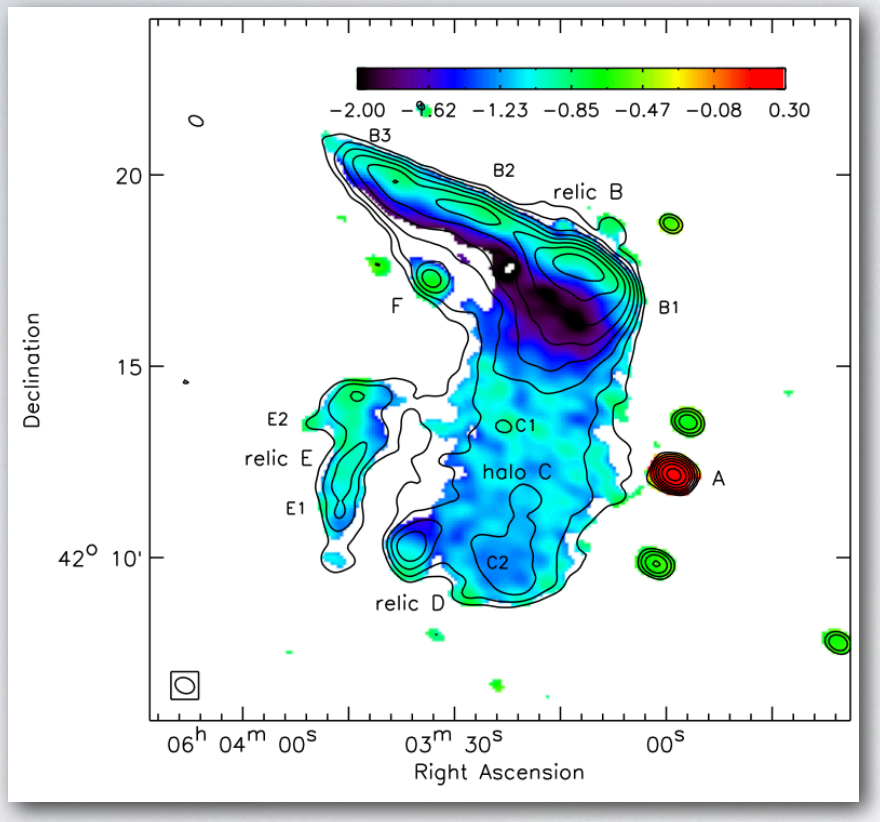

Radio
X-rays
RX J0603.3+4214 (z=0.22)
LOFAR 150 MHz
Chandra
• 93 microJy/beam
• 6 arcsec resolution
• 120-180 MHz
1 Mpc


4 arcsec
Declination
20
19
18
17
16
15
42° 14'
06h 03m 50s
40s
30s
20s
10s
00s
Right Ascension

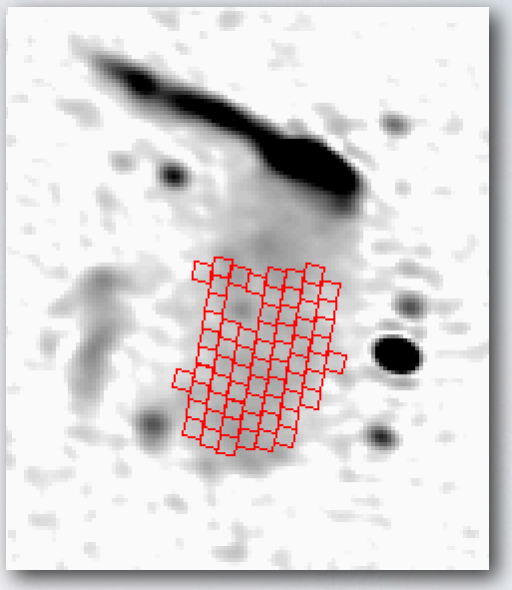

45 arcsec
22 arcsec
Declination
22
20
18
16
14
12
10
42° 08'
06h 04m 00s
03m 45s
30s
15s
00s
02m 45s
Right Ascension

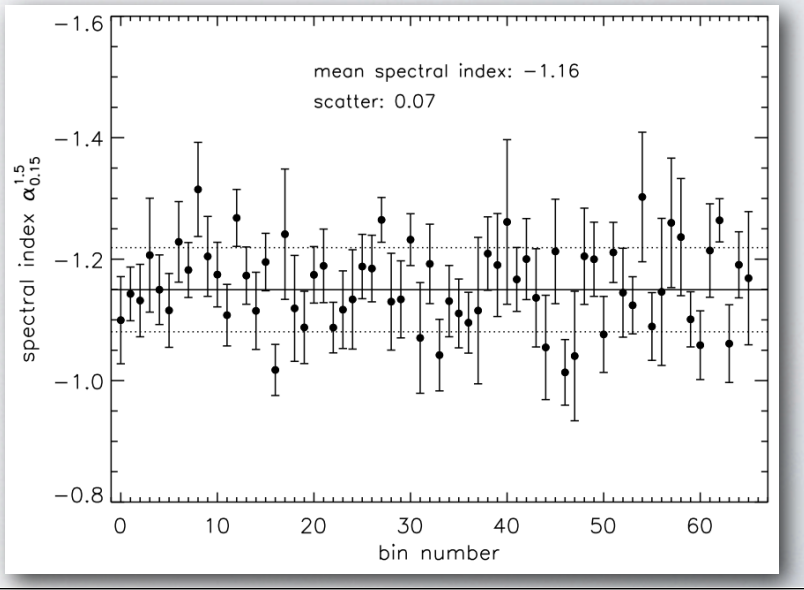
HALO SPECTRAL VARIATIONS

Use spectral index to trace variations in ICM turbulence or B-fields ?



JVLA 1.5 GHz - LOFAR HBA 150 MHz





- Spectral index remarkably(?) uniform
- Intrinsic variations < 0.04

SUMMARY

- Low-frequencies and clusters: enormous amount of progress recently
- Radio halo spectral indices
  - Toothbrush: $\Delta\alpha < 0.04$
  - Need predictions from models
- A2256: work in progress