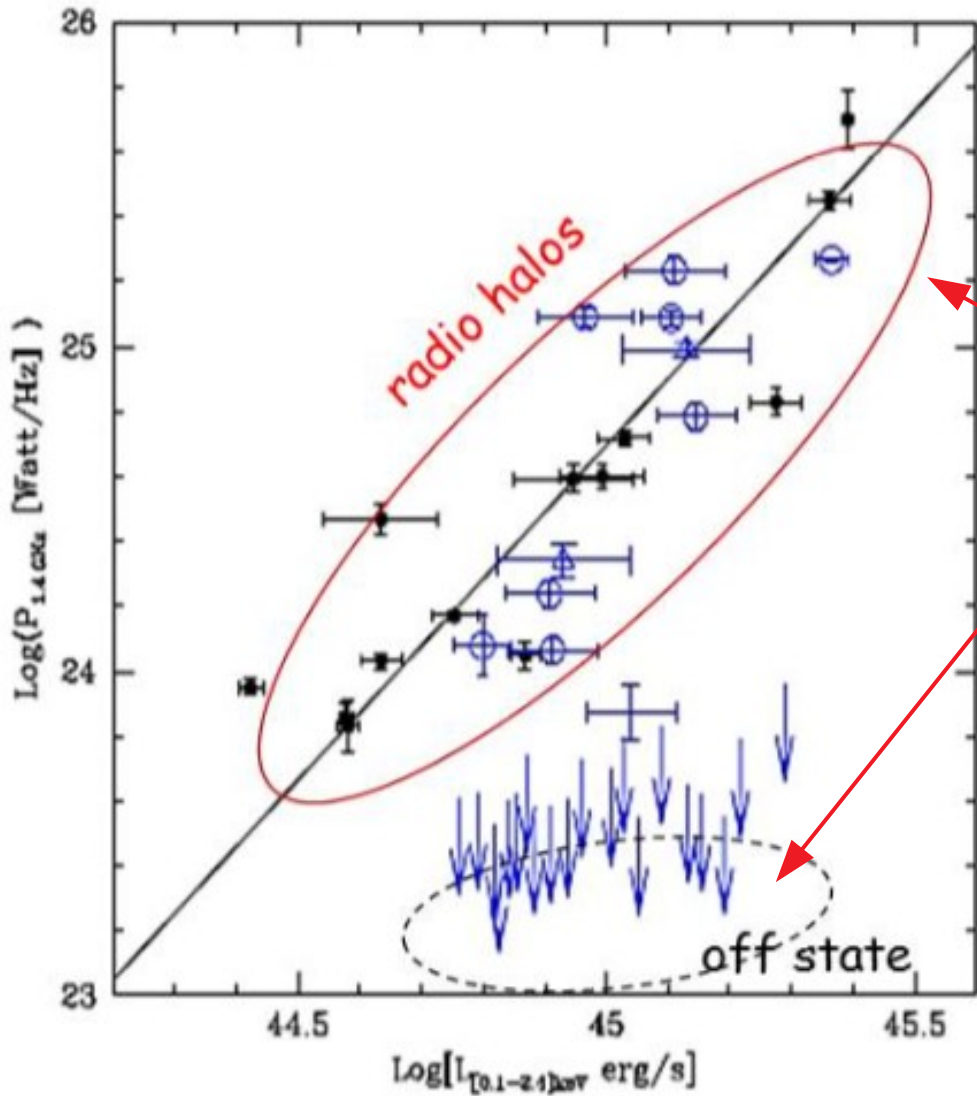




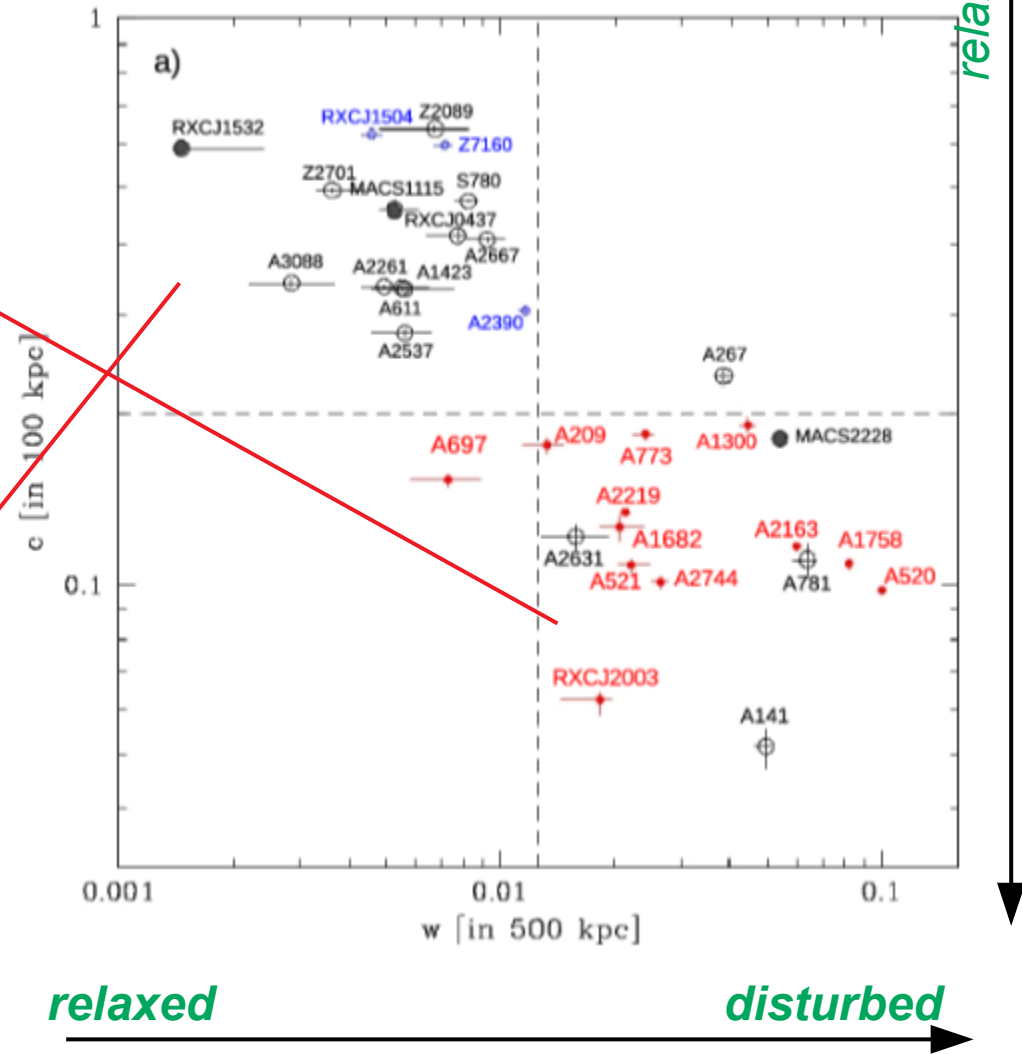
***Diffuse Radio Emission in 'off-state' Galaxy Clusters***

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***MWSKY – II Conference at NCRA, Pune : March 18-22, 2019***



*Radio Power vs X-ray Luminosity  
(VLA, WSRT and GMRT 610 (limits), ROSAT)  
(Brunetti et al 2009, Venturi 2008)*



*Concentration parameter vs Centroid Shift  
Chandra images  
(Cassano et al 2010)*

*The presence, or absence of major mergers appears responsible for the on-state / off-state clusters.*

*However, there are reasons to believe that Mpc-scale diffuse radio emission might exist even in off-state clusters*

*(a) weak mergers could create halos with very steep spectra which are bright and visible only at low frequencies*

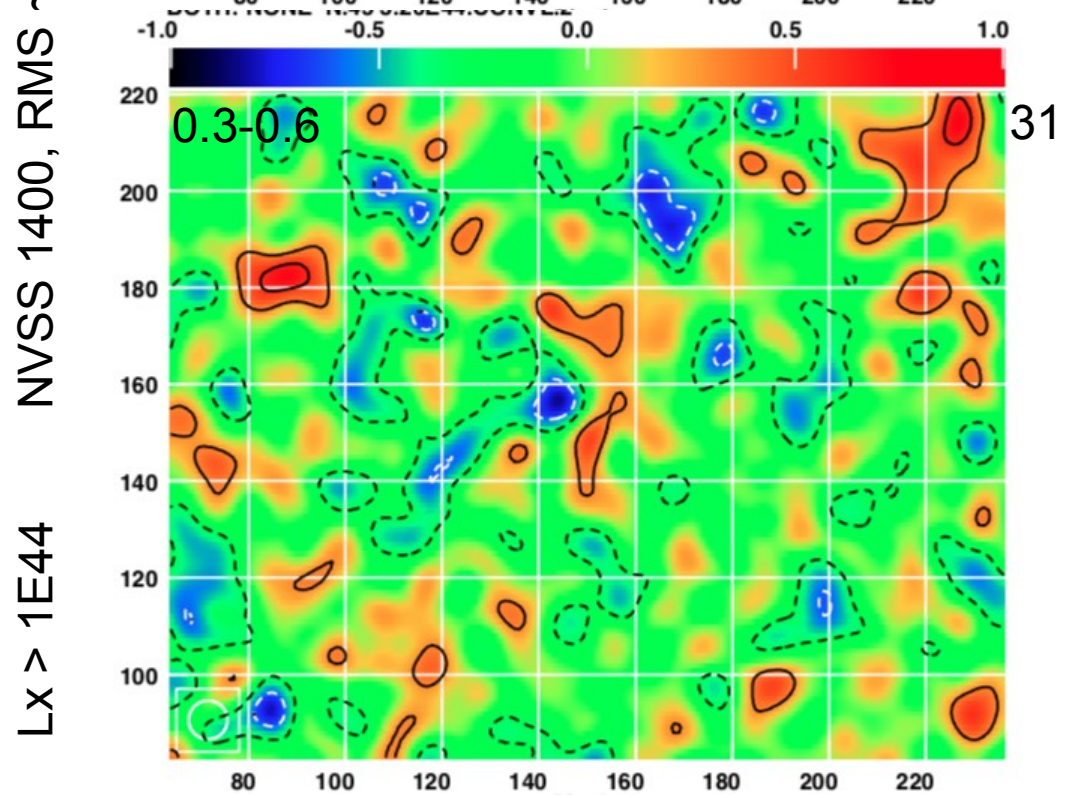
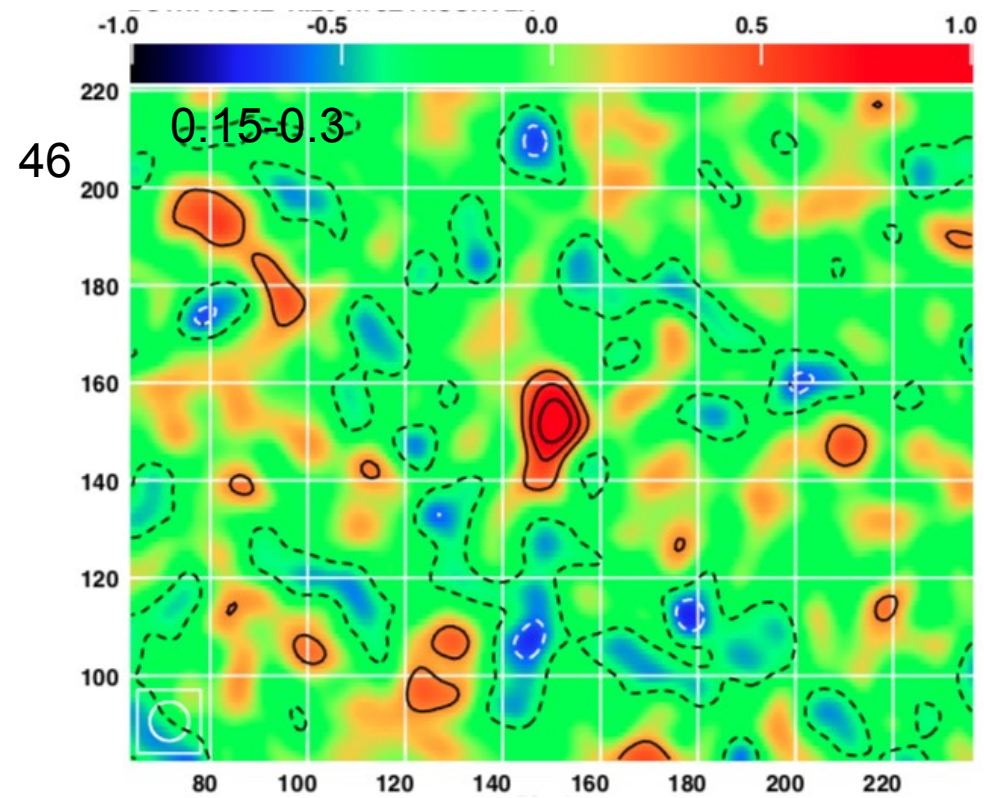
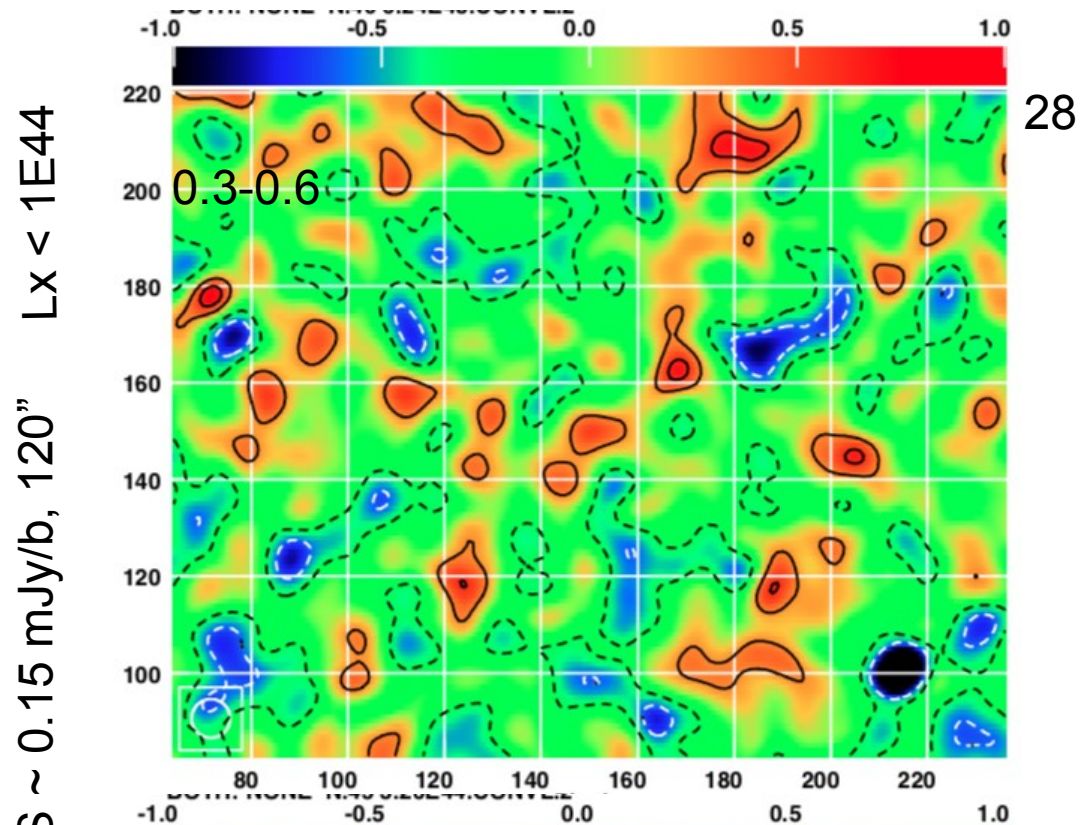
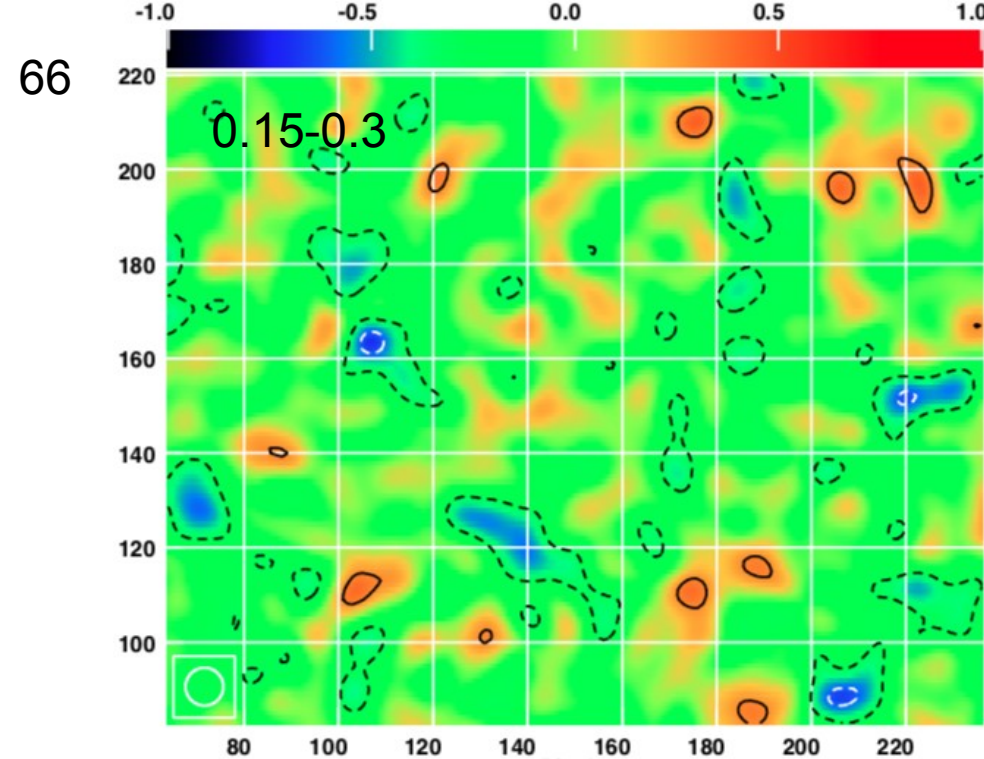
*(b) emission due to secondary CR electrons / positrons in  $\mu\text{G}$  cluster fields*

*Such emission is expected to be  $\sim 10$  times fainter, and is below the current sensitivity limits*

*Estimate average properties of off-state clusters through Stacking of Continuum Images of cluster fields.*

## *Stacking Radio Continuum Images*

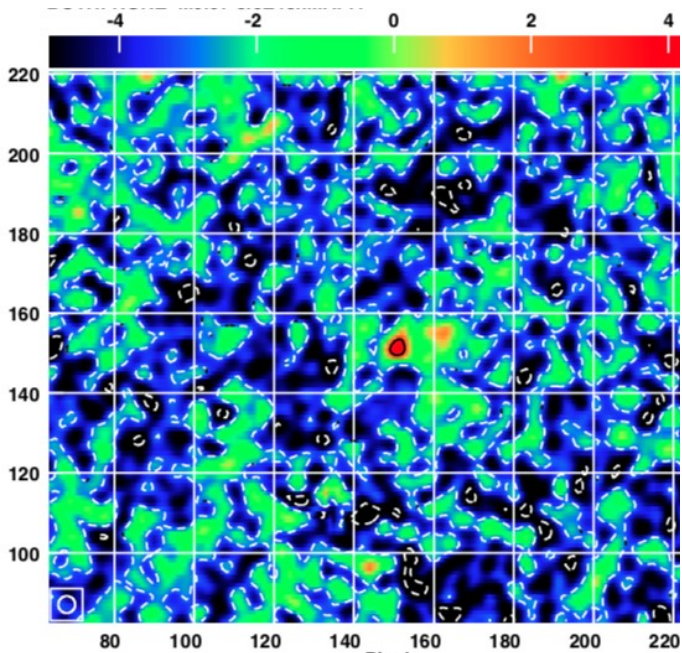
- Meta Catalog of X-ray detected Clusters of galaxies (MCXC)
- 3 redshift bins : 0.07-0.15, 0.15-0.3, 0.3-0.6
- 2  $L_{x\_500}$  (0.1 – 2.4 keV) bins : below and above  $1E44$  erg / s
  
- extract radio images from the NVSS and GLEAM surveys at the cluster positions
- exclude images that have source(s) within 0.5 Mpc from the cluster center in the respective radio catalogs
  
- NVSS – The NRAO VLA Sky Survey, 1400 MHz, 45" (FWHM), 0.45 mJy/b (RMS)  
Dec > -- 40 deg (Condon et al 1998)
  
- GLEAM – The GaLactic and Extra-galactic All-sky MWA survey, 200 MHz, 120" (FWHM) (Hurley-Walker et al 2017)  
7 +/- 2 mJy/b (RMS), -- 72 deg < Dec < +20 deg
  
- TGSS ADR2 (Prelim) – The TIFR GMRT Sky Survey (Intema et al 2019)  
150 MHz, 25" (FWHM), 5 +/- 2 mJy/b (RMS)  
--53 deg < Dec < +90 deg
  
- find sources above 3sigma, subtract them and produce residual images  
Examine each image, discard images with high RMS, obvious artefacts, and / or visible diffuse sources in the center.



LX < 1E44

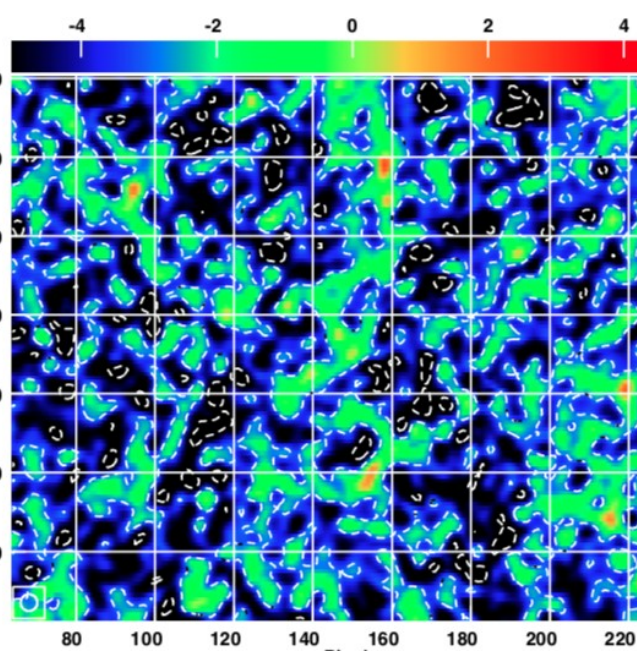
NVSS 1400, RMS ~ 0.15 mJy/b, 120"

LX > 1E44



40

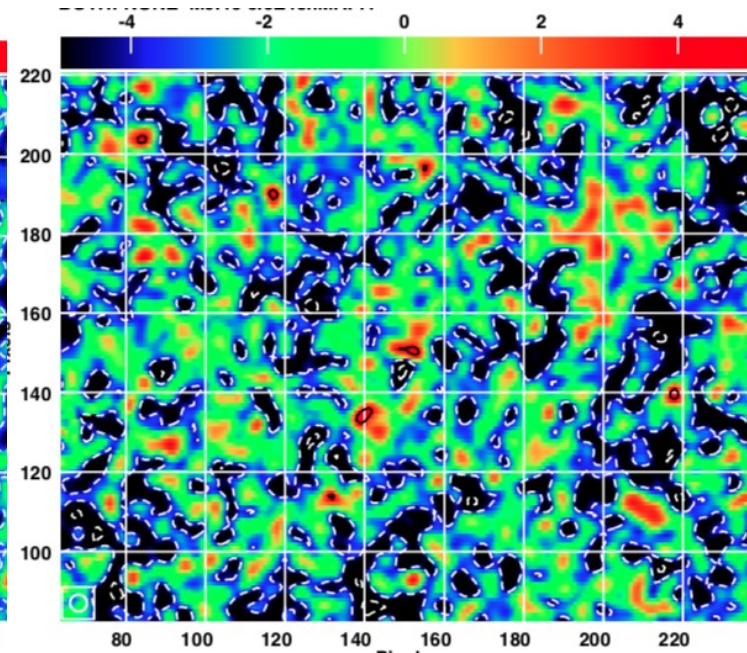
z ranges : 0.07- 0.15



34

$L_x < 1E44$

0.15-0.3

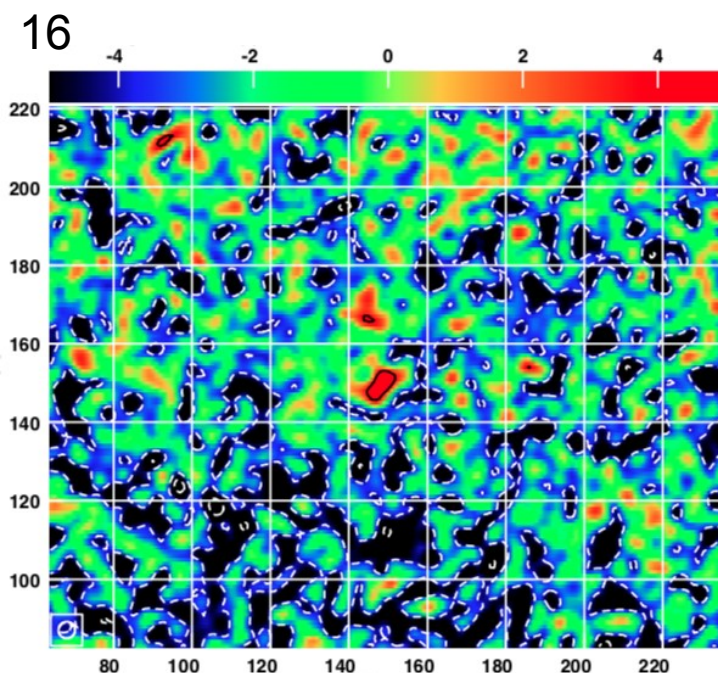


15

GLEAM 200 MHz  
RMS  $\sim 1.75$  mJy/b

0.3-0.6

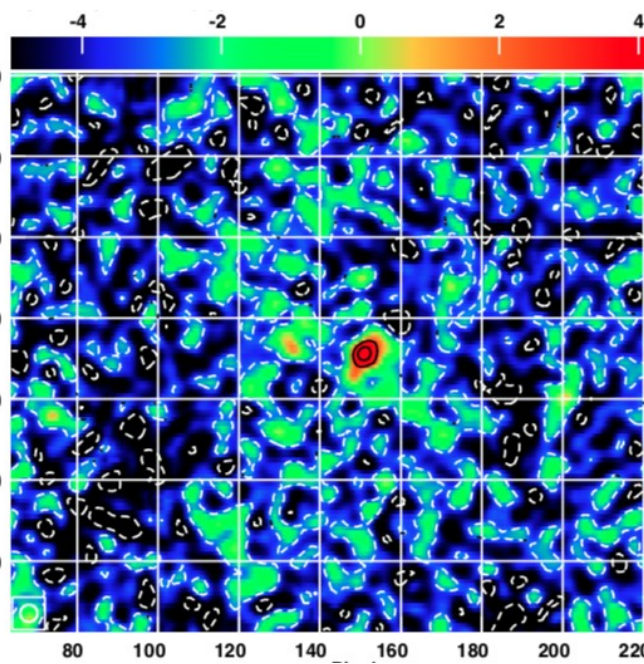
120 "



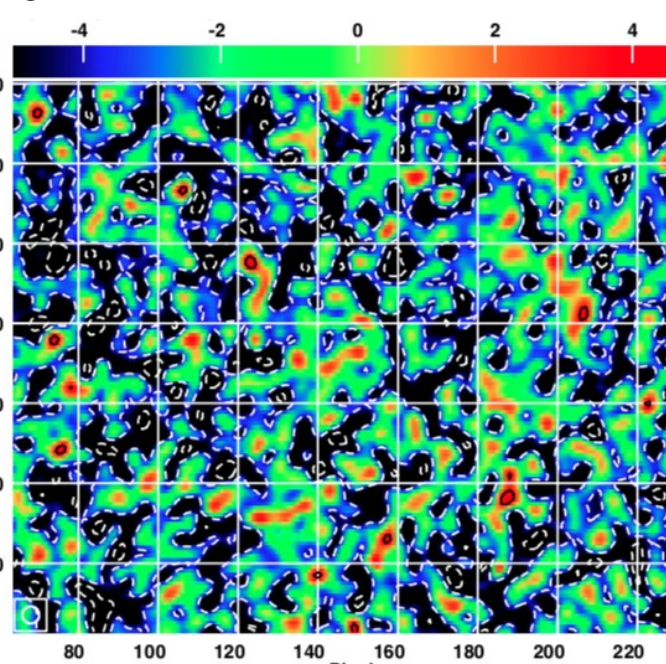
16

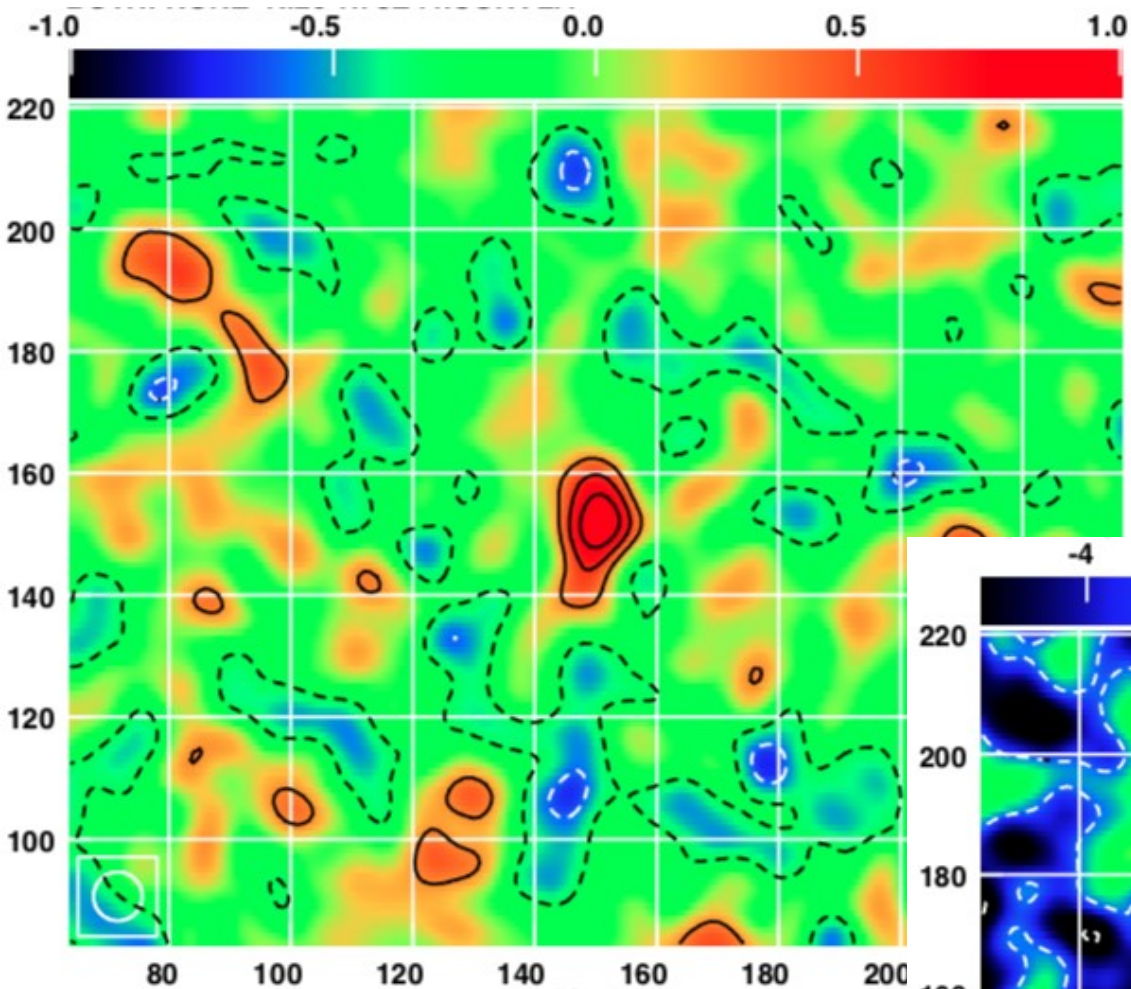
44

$L_x > 1E44$



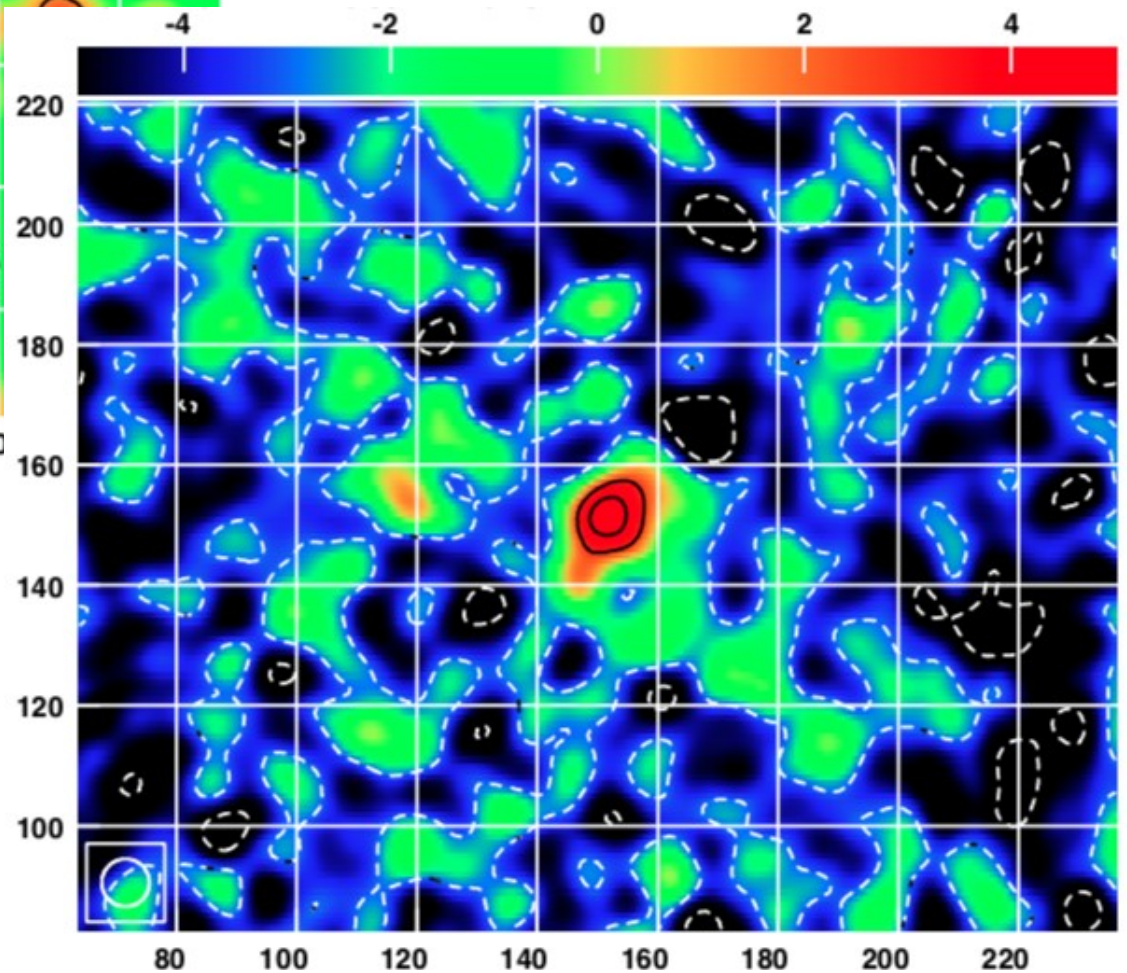
9





NVSS (46), 1400 MHz

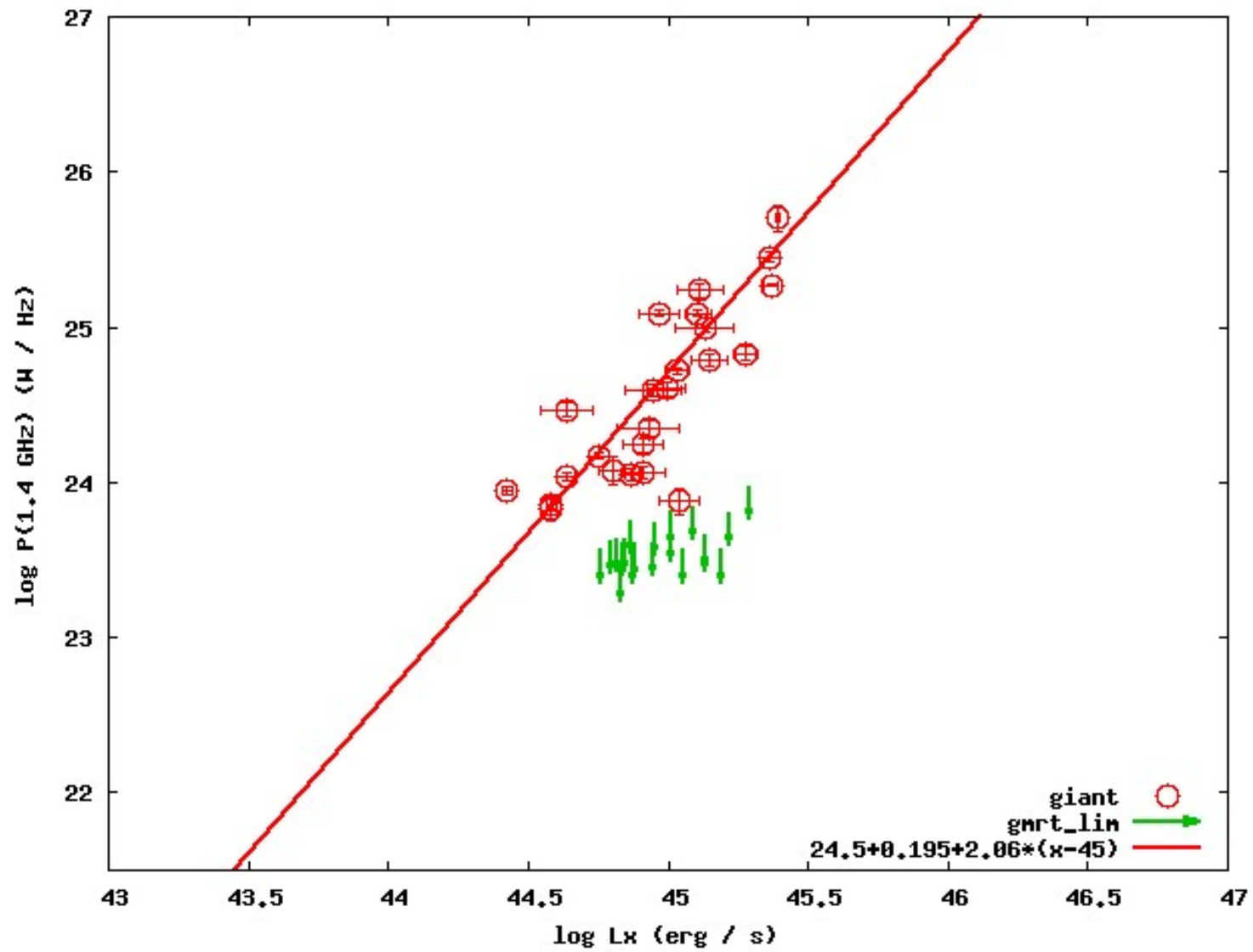
$2.87 \pm 0.5$  ( $1.17 \pm 0.6$ ) mJy  
 900 X 500 kpc



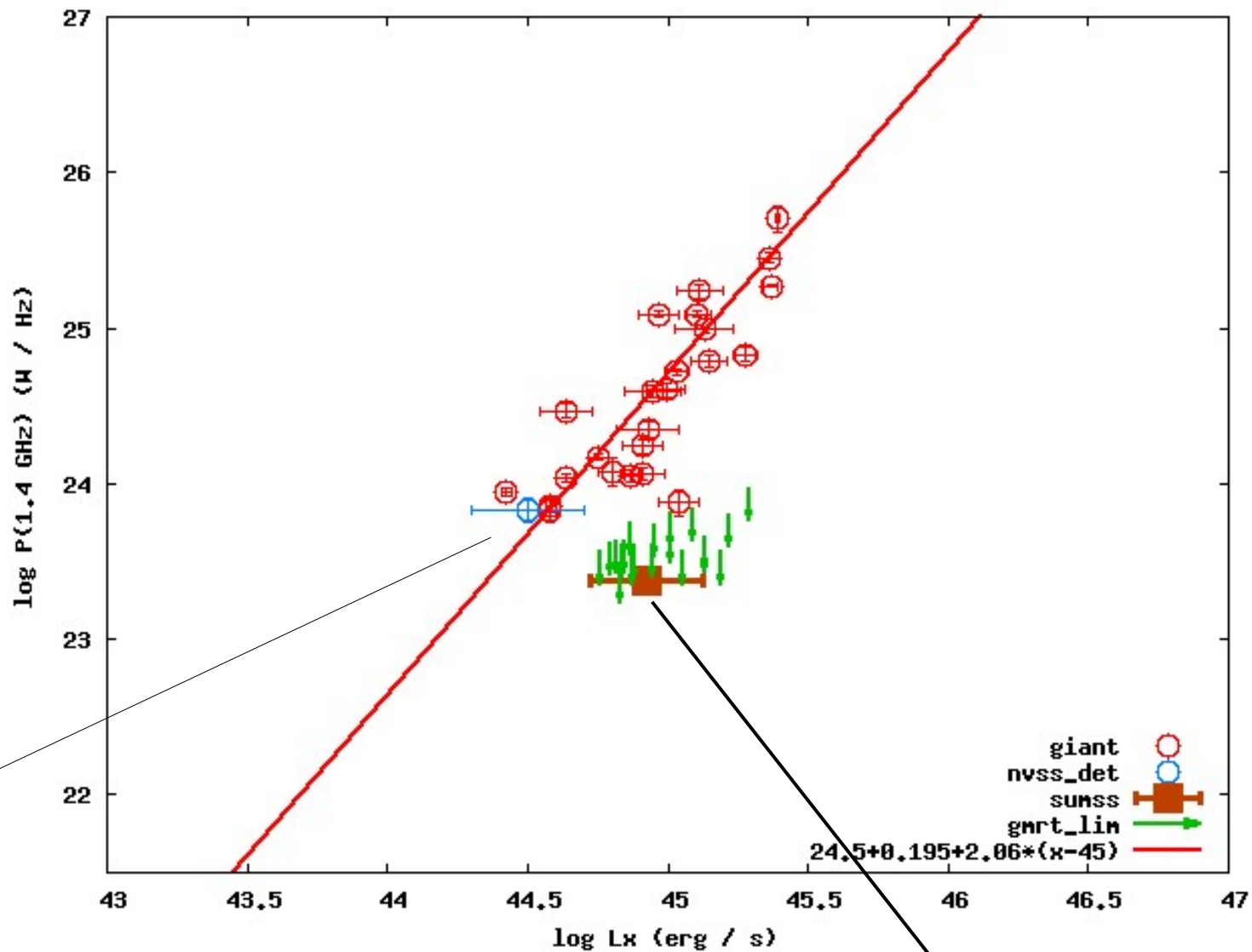
GLEAM (44), 200 MHz

$12.5 \pm 2.8$  ( $7.0 \pm 1.1$ ) mJy

Spectral Index  $\approx -0.75$  !

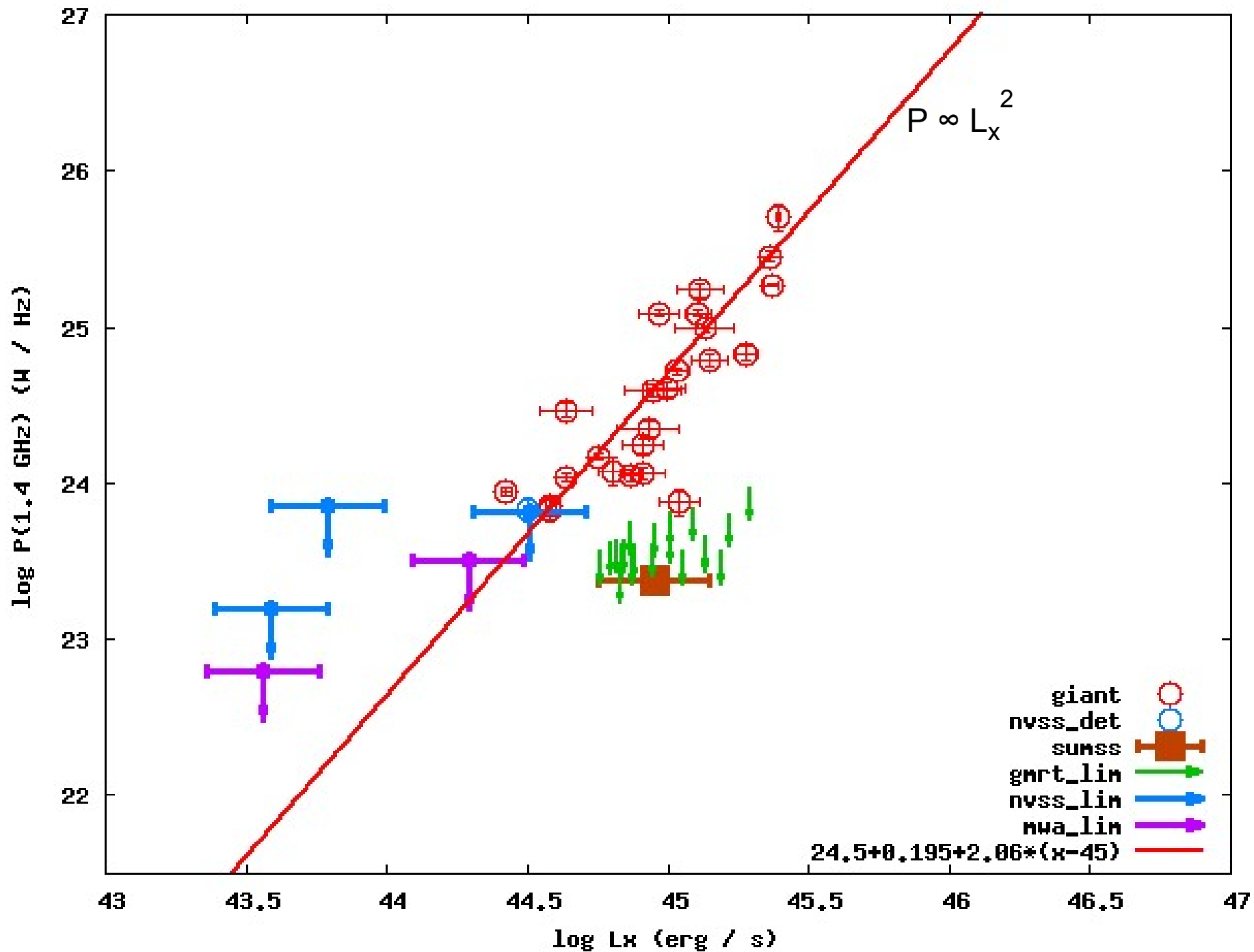






*current  
detection*

*Brown et al 2011 (SUMSS Survey Images)*



## **Implications ...**

*Mpc-scale diffuse radio emission is detected in most of the so-called 'off state', high X-ray luminosity clusters.*

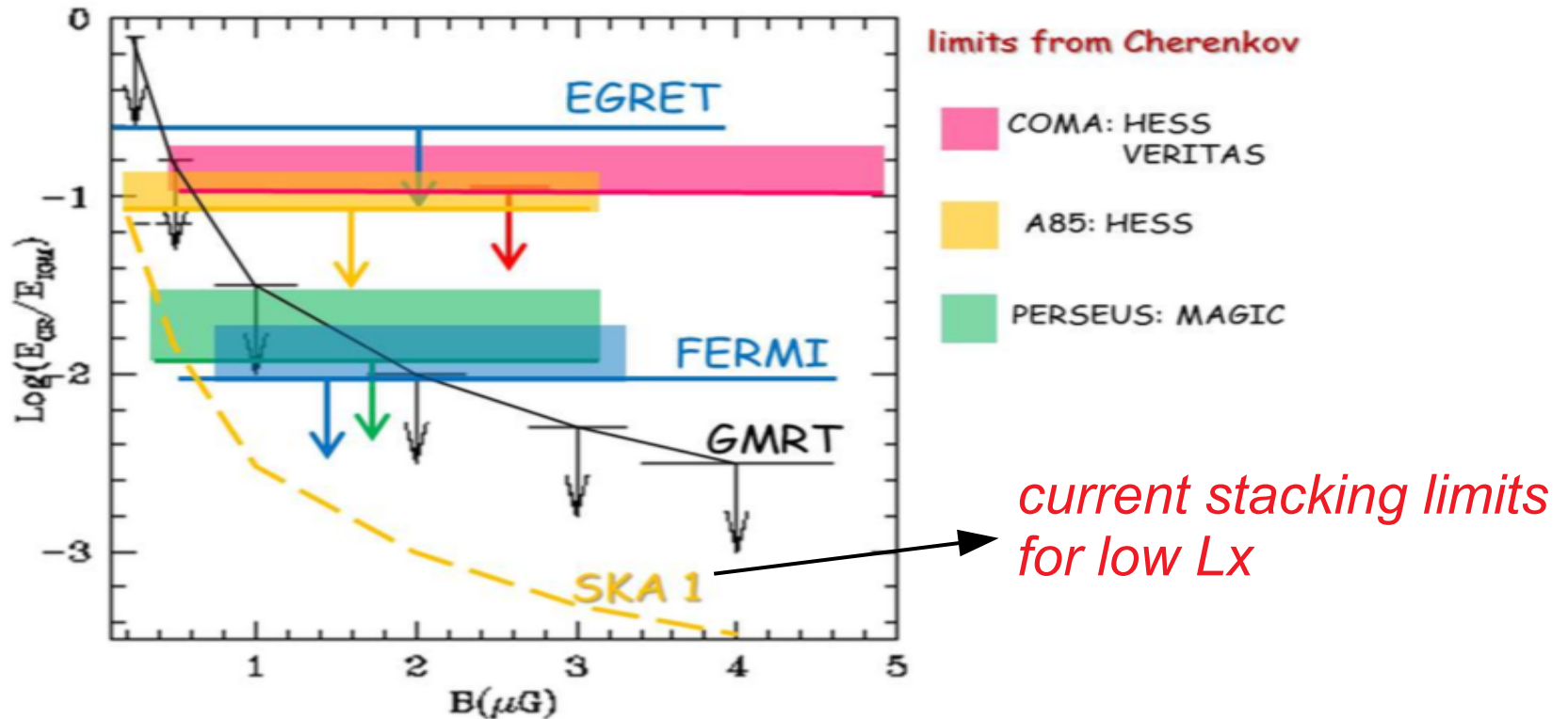
*The average surface brightness at 1.4 GHz of this emission is  $\sim 0.3 \text{ mJy} / \text{arcmin}^2$*

*A cluster-wide magnetic field is implied even in the radio off-state clusters with an equipartition value of  $\sim 0.5 \mu\text{G}$*

*There appears to be no evidence for steep spectrum diffuse radio emission in the off-state clusters expected to be predominantly found at low frequencies as proposed in the 'weak turbulence' models.*

*Implication to the energy content of CR protons.....*

## Upper limits to $E_{CRP}/E_{ICM}$ from $\gamma$ -ray and radio observations



EGRET : Energetic Gamma Ray Experiment Telescope, NASA's CGRO, 0.030 – 30 GeV, 1991 -- 2000  
 FERMI : NASA, 8 keV – 300 GeV, 2008 --  
 MAGIC : Major Atmospheric Gamma Imaging Cherenkov, La Palma, MPP, 30 GeV – 100 TeV, 2009 --