Abell 520

Radio Phoenix: tracer of ICM turbulence?

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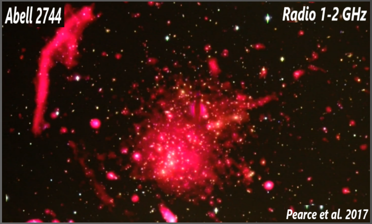
Galaxy Clusters Across Wavelengths

Galaxy Clusters are soup of:

- Dark Matter
- Electron Gas:
  - Thermal Bremsstrahlung : X-ray
  - Non Thermal Synchrotron Emission : Radio
- Galaxies (Optical, Infrared, Radio)



[1]

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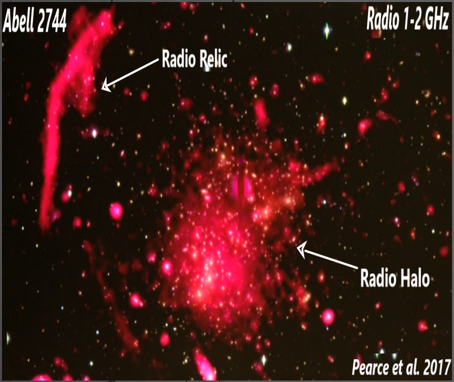
[1] Pearce at al. 2017, ApJ, Vol 845, No. 1

Cluster Sources At Radio Frequencies

Ultra Steep Spectrum(USS) Sources



USS Sources

- Radio Halo
  - MPc sized source which are located at the center of the cluster
  - Smooth Morphology
- Radio Relic
  - MPc sized source which are located peripheral to the cluster
  - Elongated Morphology
- Radio Phoenix
  - Origin from Radio Ghosts
  - Can possibly be a common origin for Radio Halo and Relic.

USS Sources : Radio Phoenix

Radio Phoenix are:

- Ultra Steep Spectrum sources
- formed as a result of re-energisation of self evolving plasma population through cataclysmic activity in ICM.

A possible source for such self evolving plasma is cocoons of radio galaxy which have become invisible to Radio telescopes.

Possible mechanisms which can lead to re-energization of this radio plasma populations:

- Fermi-I and Fermi-II Acceleration
- Adiabatic Compression Model
- Secondary Models

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- Adiabatic Compression Model
- Secondary Models

But:

- **Fermi Acceleration is ineffective in case of weak shocks and explaining spectral curvature of synchrotron.**
- **Secondary Models are ruled out due to current upper limits on gamma ray observation.**

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Objectives of the project

I. GMRT Data Reduction and Imaging of Cluster Abell 3017

Features of Cluster A3017 from the study by Viral Parekh et al. 2017:

- Studied in 235 MHz and 610 MHz from legacy GMRT.
- Cluster system is a candidate for early stage merger.
- A vertical radio structure was observed in the X-ray filament of A3017-A3016 at 235 MHz and 610 MHz with proposed spectral slope of ~ -0.3.
- This radio structure a Possible Phoenix Candidate.

The spectral slope was observed to be flat, this may be due to sparsed frequency observation and hence, requires further analysis at the frequencies in between.

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Our Objective

- GMRT Data Reduction and Imaging for Observation Id: 32_097.
- Obtaining spectral shape of radio emission of the phoenix candidate
- If the candidate qualifies as a USS source apply Adiabatic Compression Model and conclude on the history of the source.

Objectives of the project

II. Understanding the history of Phoenix in Abell 1914 through Adiabatic Compression Model

Features of Cluster A1914 from the study by Mandal et al. 2018:

- Previous to this study the cluster had been identified as a disturbed system (Bottean et al. 2018) and radio observation led to discovery of USS sources (Bagchi et al. 2003)
- Mandal et al. classified these USS sources as a Radio Phoenix and a Radio Halo.
- The Radio Phoenix had a filamentary morphology and steep spectrum ~ 2 with curvature.
- Presence of curvature qualifies this source to have evolved through Adiabatic Compression Model.

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Our Objective

- Understand the history of the possible Radio Ghost through Adiabatic Compression Model (2001)
- Complementary study of Shock properties through parameters derived above.

GMRT Data Reduction and Imaging of Cluster Abell 3017

Observation Details

Observation ID for target source: 32_091.

Date Of Observation: 18 June and 17 September 2017.

Calibrators Selected for the observation:

- Primary Calibrator: 3C48
- Secondary Calibrator: 0155-408

Duration of observation on target source

ν	Observation Time	Channels
Enter band range(Band 3)	$\sim$ 8 hours	2048
Enter band range(Band 5)	$\sim$ 1.5 hours	8192

Predicted Theoretical Sensitivity:

- For Band 3: Enter Sensitivity
- For Band 5: Enter Sensitivity

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A Brief Overview of Radio Data Calibration and Imaging

Visibility File:LTA/FITS file

↓ importgmrt

Visibility File: Multi Source MS

↓ flagdata

Initial Flagging

↓ bandpass,gaincal

Primary and Secondary Calibration

↓ flagdata

Flagging on Calibrated Data

↓ mstransform

Split Calibrated Data

↓ mstransform

Channel average

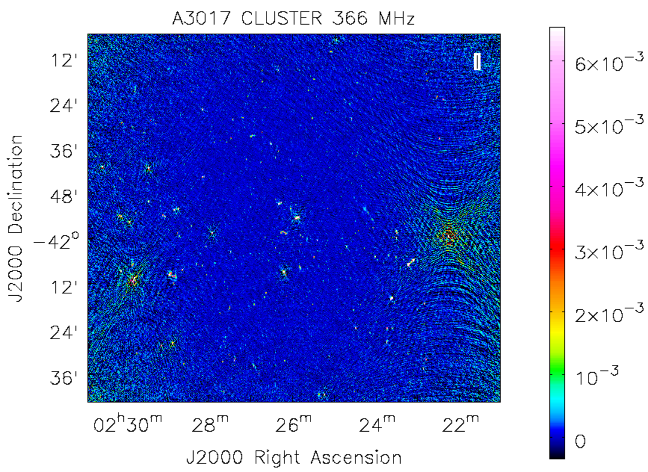
↓ tclean

Imaging the target

↓ gaincal, flagdata, tclean

Self Calibration

Results: Imaging of A3017

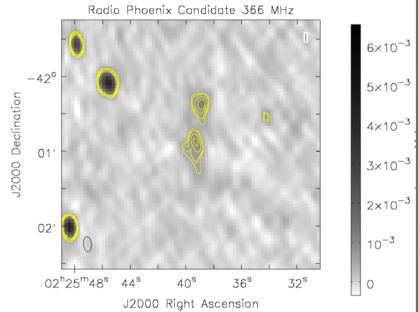


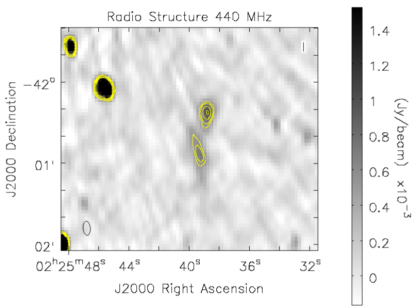
$$\nu = 300 - 400 MHz$$
$$\sigma_{rms} = 50 \mu Jy$$

clean beam size:

- Major axis=12.25 arcsec
- Minor axis= 6.25 arcsec

Results: Radio Phoenix candidate in X-ray filament bridge between A3017- A3016





$S_{360Mhz} = 6.81 \pm 1.05 \;\; mJy$
Band=$300 - 400MHz$

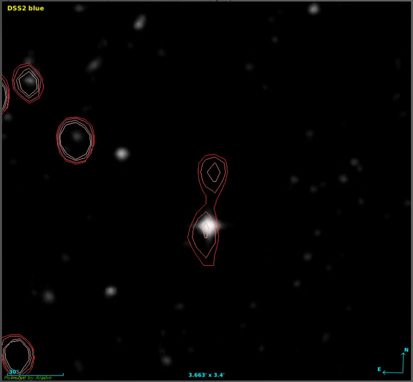
$S_{440Mhz} = 6.08 \pm 0.956 \;\; mJy$
Band=$400 - 500MHz$

contours at $-5, -6, -8, -10, 5, 6, 8, 10 \times \sigma_{rms}$

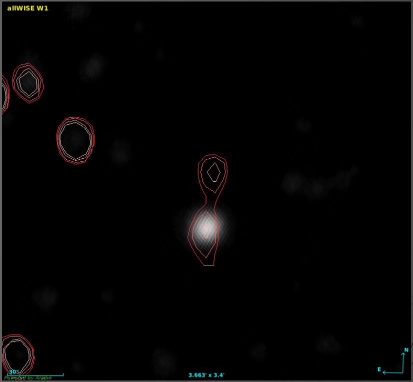
$\sigma_{rms} = 50\mu Jy$

Flux Density calculated for circular beam size of radius 13 arcsec.

Results: Counterpart of the Radio Source in A3017-A3016 cluster system in other frequencies

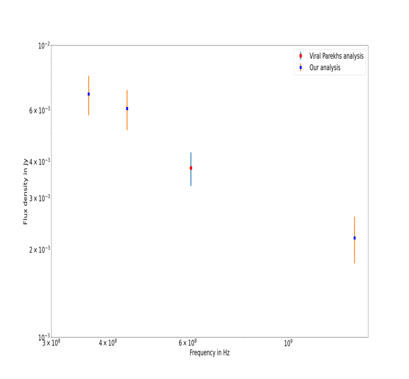


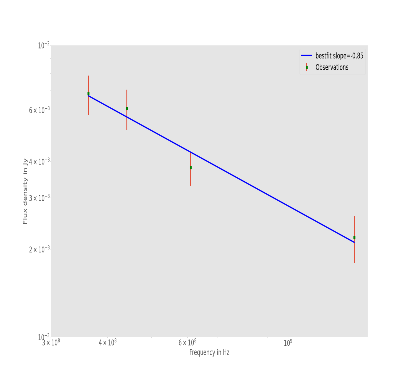
DSS9 counterpart



WISE counterpart

Results: Analysis





The bi-lobed structure and a spectral index of -0.85 is a clear indication of the radio structure to be a radio galaxy with active particle injection though jets in the cocoons.

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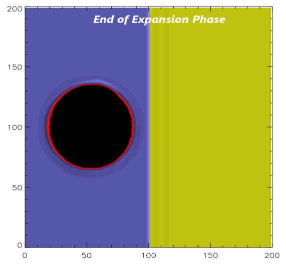
Understanding the history of Phoenix in Abell 1914 through Adiabatic Compression Model

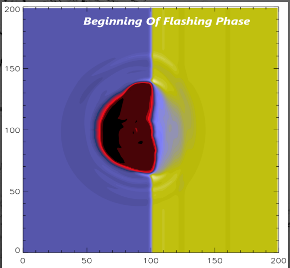
Adiabatic Compression Model

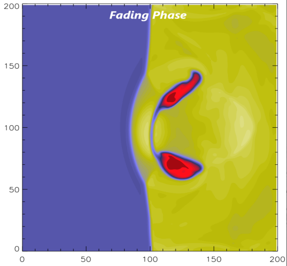
Ensslin and Goplakrishna , 2001

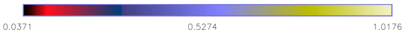
When a radio ghost population comes in the influence of shocks from merger activity:

- It undergoes a series of expansion and compression phases.
- Electrons gain energy adiabatically during this compression phase and become synchrotron visible.









Adiabatic Compression Model: The Formalism

Ensslin and Gopalkrishna , 2001

- The formalism connects temporal variations of momentum in each phase to synchrotron luminosity function.

$$L_{\nu\ i} \propto \int G(p,\nu)_i dp$$

Here G is something that describes emissivity of an electron population i.e. *electron population distribution* $\times$ *emissivity of monoenergetic isotropic electron distribution*

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- The Luminosity function for each phase **i**, is given as:

$$L_{\nu,i} \propto \left(\Pi_{m=1}^{i}\left(1+\frac{\Delta t_i}{\tau_i}\right)^{-b}\right)^{\frac{\alpha_e+2}{3}} p^{-\alpha_e}\left(1-\frac{p}{p_{\star,0i}}\right)^{\alpha_e-2}$$

Applying Adiabatic Compression Model on a radio source

Each phase is described by:

- The duration of the phase Δt_i
- Timescale of expansion or contraction τ_i during that phase.
- b_i is the expansion index
- $C_{i-1,i}$ is the relative compression ratio of the current phase volume with respect to the previous phase volume.

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An overview of the important parameters:

Phase	Δt_i (Gyr)	τ_i (Gyr)	$C_{i-1\ i}$	b_i
Injection	0	0.015	1	1.8
Expansion	-	0.010	$(1+\Delta t_1/\tau_1)^{-b_1} < 1$	1.2
Lurking	-	∞	1	0
Flashing	-	-	$(1+\Delta t_3/\tau_3)^{-b_3} > 1$	2
Fading	-	∞	1	0

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Determination of best fit:

- Depending on the known observational properties, a particular phase is guessed.
- Volume for that phase is determined from the radio morphology
- The magnetic field is assumed to be the equipartition magnetic field.
- The parameters are identified through the best fit set of parameters. The best fit is identified through:

$$\chi^2 = \sum_i \left(\frac{F_{obs} - F_{theory}}{F_{obs\_error}} \right)^2$$

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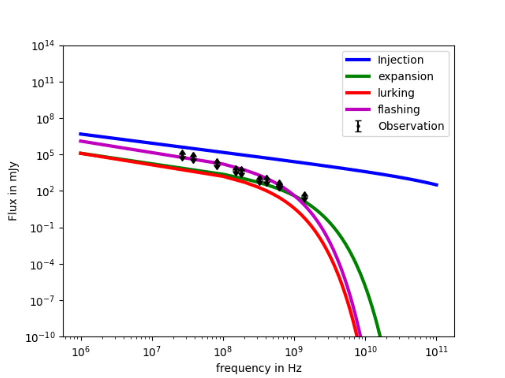
Results from Parameter Fitting:



Set of best fit parameters:

Phase	Δt_i (Gyr)	τ_i (Gyr)	$C_{i-1\ i}$	b_i	B_i (μ *Gauss*)
0	0	0.015	1	1.8	5.678
1	0.045	0.010	0.1287	1.2	1.969
2	0.001	∞	1	0	1.969
3	0.334	-0.556	6.27	2	6.7

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Fit parameters and the Shock connection

From the previous table,

$$C_{23} = \left(\frac{P_3}{P_2}\right)^{3/4} = 6.27$$
$$\implies 11.56 = \frac{P_3}{P_2}$$

Pressure jump $\frac{P_3}{P_2} \implies M \approx 3.07$.
Here, M is Mach number of the shock.

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- Hence, the following derived parameters trace back to a physical scenario in which adiabatic compression model holds up.

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  Time period in injection phase and possible history of the radio cocoon?

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Conclusion

GMRT Dara Reduction and Imaging of Cluster Abell 3017

- GMRT GWB Data was reduced and imaged at Band 2 and Band 5.
- A radio source in the X-ray filament of the cluster A3017 was studied.
- Although the source was thought to be a possible Phoenix candidate, spectral index from this work was found to be around -0.85.
- The bi-lobed structure with -0.85 spectral index suggests that the source is a galaxy with active jets which has both optical and infrared couterpart aligning with the southern lobe.

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Understanding the history of Phoenix in Abell 1914 through Adiabatic Compression Model

- The observed spectrum of Abell 1914 was successfully fitted with the ”Flashing” phase of Adiabatic Compression Model.
- The Mach number for the shock was calculated from the fit parameters to be ~ 3 which is in weak shock regime.
- Weak shock explains us that why Fermi energization process is not a dominant process in this case.
- The above point can also be inferred from curvature of the spectrum which cannot be explained by the Fermi processes.

Radio Phoenix: As tracers of ICM turbulence?

- Merger activity and filamentary accretion leads to production of shock waves in ICM.
- Adiabatic Compression Model helps us explain the USS sources especially in cases where, the Fermi processes do not dominate the re-acceleration of cosmic electrons due to low Mach numbers and spectral curvature.
- Radio Ghosts forms an invisible yet important component of IGM.
- Adiabatic compression of the environment during shock passage leads to re-energization of plasma population and Radio Synchrotron visible.
- The in-situ availability of radio invisible plasma population and the ability of radio ghosts to get revived even after 2 Gyr of turning off of AGN jets, gives long enough period for this plasma population to expand into MPc scale structures.
- The Gyr-timescales and less dependence on strong shocks makes the case of Radio Phoenix as tracers of ICM turbulence strong.

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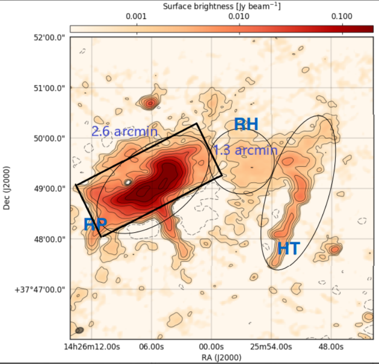
Backup Slides : 1

Volume of The Radio Phoenix

The volume in the above case was calculated by assuming a cylindrical volume with the shortest side of the Radio Phoenix as the diameter of the cylinder.



At the redshift of Abell 1914 ($z = 0.168$) the luminosity distance is 808.5 Mpc and 1 arcsec corresponds to 2.783 kpc.

Hence the volume calculated using the above assumption is = 0.031 Mpc^3

Backup Slides:2

Equipartition Magnetic Field

The reason why we are possibly overestimating magnetic field:

- the lower limit of integration set by $\nu_{min} = 10Mhz$ (Pacholczyk 1970) is determined by the synchrotron self absorption turn over is a issue when we are dealing with higher gas density regions when the spectrum is flatter.
- For regions with $\alpha > 1$, the dominant energy losses arise due to Cosmic Ray Electrons. Thus the energy spectral index between cosmic ray protons and cosmic ray electrons changes, which is assumed to be constant and the same between protons and electrons in the equipartition formula.
- The turbulence the strength of magnetic field and plasma density are not statistically independent. Because of the anisotropy of magnetic field in turbulent medium , the regular magnetic field strength obtained from the equipartition formula may lead to overestimation of the same.

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