Radio Phoenix: tracers of ICM turbulence?

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Graduate School Project

Large Scale Structure of Universe

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Radio Phoenix as tracers of cluster mergers

- the precursors of radio phoenices are radio ghosts which form an important unobservable distinct phase of IGM
- Possibly a common origin point of both radio relics and halos?
- Mpc-scale diffuse radio sources cannot trace CR electrons that are accelerated at a single location in the ICM and hence radio phoenices are a potential candidate for USS sources.

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Proposed Mechanisms and problems

- First Order Fermi Acceleration
- Second Order Fermi Acceleration
- Adaibatic Compression Model
- Secondary Models

Problems with each of the model(where DSA does not fit) and natural choice of adiabatic compression forming a part of all shock acceleration mechanism.

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Enslin and Gopal's Mechanism

- The 4 phases of the cocoon

The formalism

- We start with a population of ultra relativistic electrons $\gamma >> 10^3 - 10^4$
- The electron population follows a power law $f_0(p_0) = \tilde{f}_0 p_0^{-\alpha_e}$
- It is assumed that the pitch angle for the population follows a JP model

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The formalism

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

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

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So, there are 3 important components that contribute to variation of this momentum term:

$$-\frac{dp}{dt} = f(\text{Synchrotron, Inverse Compton, Adiabatic variation})$$

Bremsstrahlung losses not considered

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So, there are 3 important components that contribute to variation of this momentum term:

$$-\frac{dp}{dt} = f(\text{Synchrotron, Inverse Compton, Adiabatic variation})$$

$$-\frac{dp}{dt} = a_0(u_B + u_C)p^2 + \frac{1}{3}\frac{1}{V}\frac{dV}{dt}p$$

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The formalism

$$-\frac{dp}{dt} = a_0(u_B + u_C)p^2 + \frac{1}{3}\frac{1}{V}\frac{dV}{dt}p$$

Integrate to get,

$$p(p_0, t) = \frac{p_0}{C(t)^{-1/3} + \frac{p_0}{p_\star(t)}}$$

where,

$$\frac{1}{p_\star(t)} = a_0 \int_{t_0}^{t} dt' \left(u_B(t') + u_C(t')\right) \left(\frac{C(t')}{C(t)}\right)^{1/3}$$

$$f_i(p) = \tilde{f}_0 C_{0i}^{\frac{\alpha_e+2}{3}} p^{-\alpha_e}(1 - p/p_{\star,0i})^{\alpha_e - 2}$$

and finally we have

$$L_{\nu \ i} = c_3 B_i V_i \int_{p_{min \ i}}^{p_{max \ i}} dp f_i(p) \tilde{F}(\nu/\nu_i(p)) \quad (1)$$

The parameters we know and the ones we don't

Summary of the values of each of the phase parameters. The values that are marked with a dash are determined from a fit to the observed cluster properties in each specific application

Phase	Δt_i (Gyr)	τ_i (Gyr)	$C_{i-1\ i}$	b_i
0	0	0.015	1	1.8
1	-	0.010	$(1+\Delta t_1/\tau_1)^{-b_1} < 1$	1.2
2	-	∞	1	0
3	-	-	$(1+\Delta t_3/\tau_3)^{-b_3} > 1$	2
4	-	∞	1	0

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The two systems and what we know and what we don't

- Radio Phoenix in A1914
- Phoenix Candidate in X ray filament in possible cluster merger of A3017 and A3016

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The two systems and what we know and what we don't

- Radio Phoenix in A1914
  Cluster Merger Event in A1914
  - Resdhift z=0.168
  - Buote & Tsai found power ratios $P1/P0$ and $P3/P0$ indicating that the system is disturbed one.
  - Bottean et al. 2018a found surface brightness and temperature jumps in ICM.
  - In Radio Bagchi et al. 2003 found that the cluster hosts steep spectrum and unpolarised radio source
- Phoenix Candidate in X ray filament in possible cluster merger of A3017 and A3016

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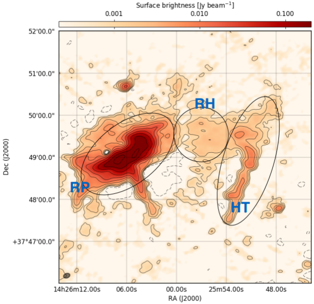
The two systems and what we know and what we don't

- Radio Phoenix in A1914
  Study by Mandal et al. and conclusions:



  - The RP is known to have a steep spectrum $\alpha \sim -2$ and a possible curvature in the spectrum

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The two systems and what we know and what we don't

- Radio Phoenix in A1914

Study by Mandal et al. and conclusions:

ν	S_ν
150 Mhz	$4.68 \pm 0.46 Jy$
325 Mhz	$0.83 \pm 0.08 Jy$
610 Mhz	$0.277 \pm 0.02 Jy$
1.4 Ghz	$34.8 \pm 2.0 mJy$

Table: Flux Density of Radio Phoenix Candidate

The spectral index value ranges from 1.9 to -2.3
[1]

- Extreme steep spectrum
- filamentary morphology
- peripheral location
- misaligned with X-ray
- spectrum curvature rejects the possibility of shock acceleration [Van Weerenn et al. 2017, Bonafede et al. 2014]

detection of shock of RP is crucial to confirm the radio phoenix.[2]

[1] if the Radio galaxy is the source of injection electron, calculate how th electron had to travel in what time given a weak shock that can possibly explain adiabatic comnpression and not fermi acceleration.[Jones at al. 2017]

[2] read last section of discussion

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The two systems and what we know and what we don't

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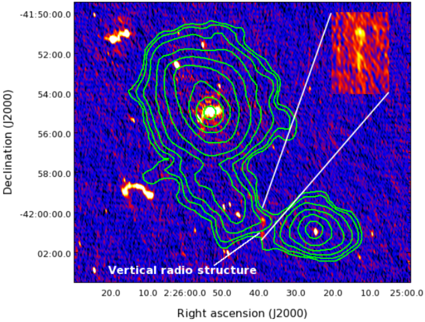
The two systems and what we know and what we don't

- Radio Phoenix in A1914
- Phoenix Candidate in X ray filament in possible cluster merger of A3017 and A3016
  Viral Parekh et al. 2017
  - A3017 (z=0.2195) is a cluster system undergoing cluster merger but is in it's early stage.
  - It shows large scale inter cluster filament ($\sim Mpc$)



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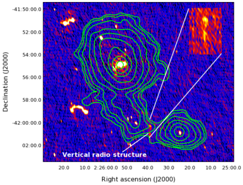
The two systems and what we know and what we don't

- Radio Phoenix in A1914
- Phoenix Candidate in X ray filament in possible cluster merger of A3017 and A3016
  Viral Parekh et al. 2017
  - Presence of a vertical Radio structure

ν	S_ν
235 Mhz	$5.0 \pm 0.9 mJy$
610 Mhz	$3.8 \pm 0.5 mJy$

  - Spectral index of -0.3 $\rightarrow$ significantly flat for a radio galaxy
  - Further X ray studies required to test for presence of weak shocks $M \sim 1.5 - 2.0$ and hence whether the source is actually a Radio Phoenix candidate



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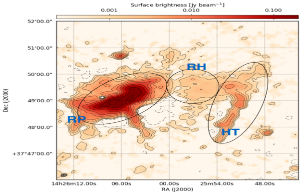
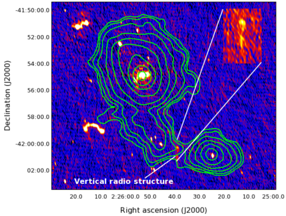
The two systems and Our objectives





- Ultra Steep Spectrum Source
- Curvature of spectrum

$\Longrightarrow$ Adiabatic Compression Scenario is more qualified

Our Objective

- Understand the history of the possible Radio Ghost through adiabatic compression model (2001)
- Complementary study of Shocks through Cluster Merger

- cluster system a candidate for early stage merger
- Radio structure in the filament

$\Longrightarrow$ structure a Possible Phoenix Candidate.

Our Objective

- GMRT Data Reduction and Imaging
  Observation Id: 32_097
- Image Analysis and further test if it qualifies for Adiabatic

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The Results: Cluster Merger Case of A1914

Recap of the set of parameters to be identified:

Phase	Δt_i (Gyr)	τ_i (Gyr)	$C_{i-1\ i}$	b_i
0	0	0.015	1	1.8
1	-	0.010	$(1+\Delta t_1/\tau_1)^{-b_1} < 1$	1.2
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Determination of best fit:
The parameters are identified through the best fit set of parameters determined by:

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

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The Results: Cluster Merger Case of A1914

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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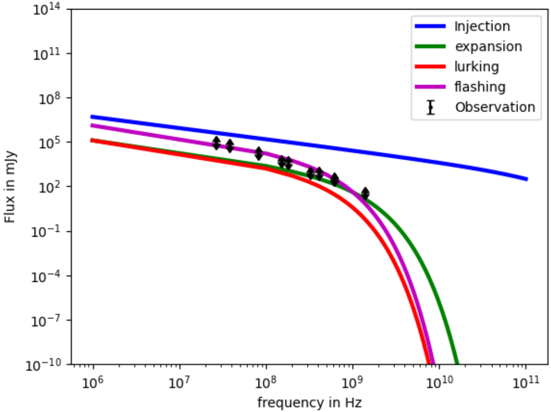
The Results: Cluster Merger Case of A1914

Best fit and possible spectral history of the source:



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The Results: Cluster Merger Case of A1914

Are the parameters real?
What does the parameters correspond to?

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

Pressure jump in thermal gas is related to the Mach number as:

$$\frac{P_3}{P_2} = 11.56 = \frac{2\gamma_B M^2}{\gamma_B + 1} - \frac{\gamma_B - 1}{\gamma_B + 1}$$

γ_B is adaiabatic index of thermal gas=5/3

$$\implies M \approx 3.07$$

where, M is Mach number of the shock.
$M \approx 3.07$ (weak shock) $\implies$ non flat curved spectra against the flat spectra from Fermi Acceleration.
what it tells us about the possible shock and environment?

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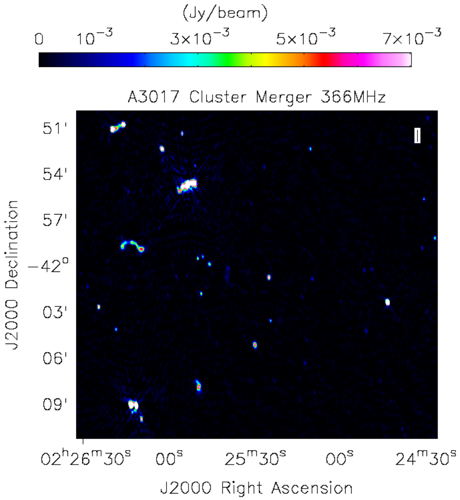
The Results: Cluster Merger Case of A3017



$\nu_0 = 366 Mhz$

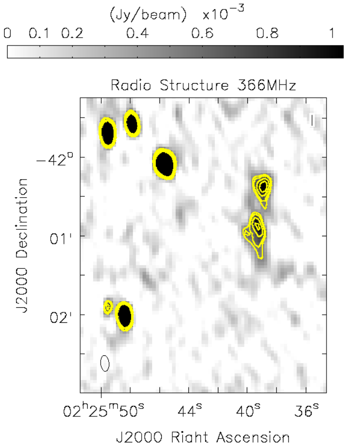
$\sigma_{rms} =$

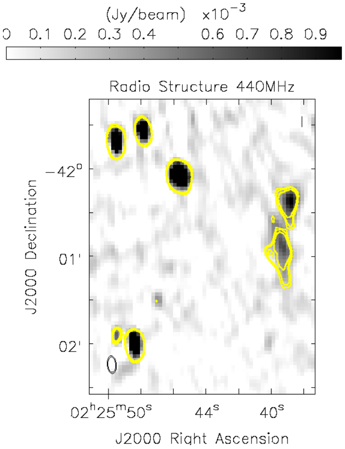
clean beam size=

3

[3]Overlay X ray contours

The Results: Cluster Merger Case of A3017





$S_{360Mhz} = 6.81 \pm 1.05 \;\; mJy$
contours at $5, 7, 9, 10 \times \sigma_{rms}$

$S_{440Mhz} = 6.08 \pm 0.956 \;\; mJy$
contours at $6, 7, 10 \times \sigma_{rms}$

$$\sigma_{rms} = 60\mu Jy$$

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

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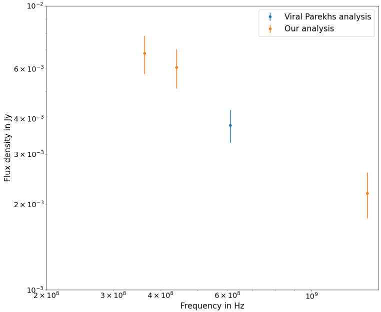
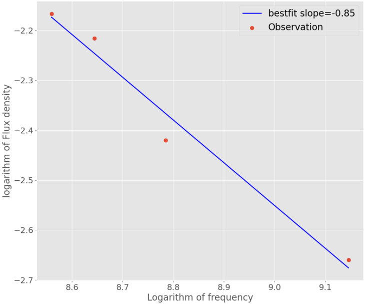
Results: Counterpart of the Radio Source in A3017-A3016 cluster system in other frequencies

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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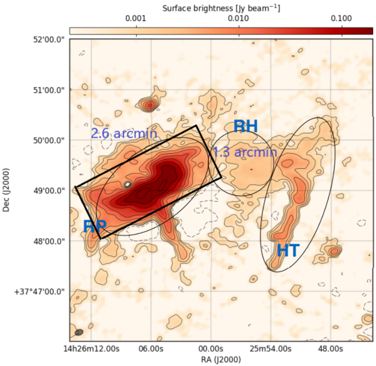
Conclusion: Radio Phoenix tracers of ICM turbulence?

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 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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