Synergies of Observations and Simulations to study Radio Relics

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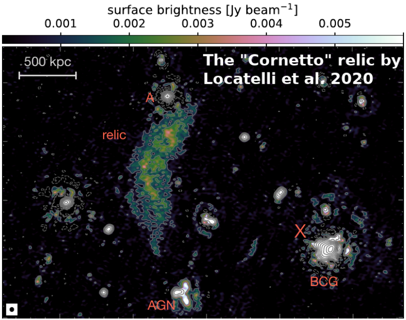
Radio Relics: Sites of large-scale shock acceleration



- elongated $\sim$ Mpc
- at cluster periphery
- synchrotron radiation
  - $P_{\mathrm{radio}} \approx 10^{23} - 10^{25}$ W Hz^{-1}
  - $I_\nu \propto \nu^{-\alpha}$ $(\alpha > 1)$
  - highly polarized $\sim 10 - 50$ %
- located at shocks (X-ray)
  - $\Rightarrow$ shock acceleration
- future observations (e.g. Lofar, SKA) are expected to detect few 100s of relics

- probe acceleration of cosmic-ray electrons and magnetic fields on large scales
- still a lot of open questions

$\Rightarrow$ multi frequency radio observations and simulations are the perfect tool

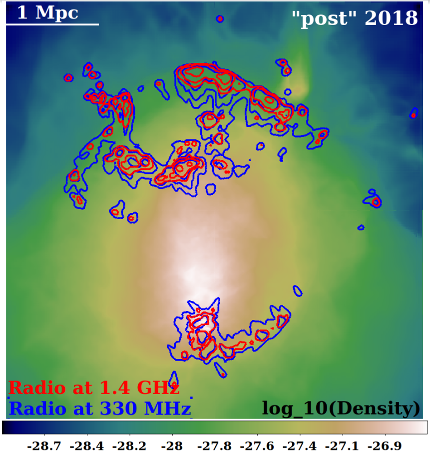
Modelling Relics in Simulations (Wittor et al. 2019)

"pre" $\sim$ 2018: $\Delta x_{\mathrm{sim}} \gtrsim l_{\mathrm{cool}}$

accelerated CR are computed at a single timestep, assuming a (quasi-)stationary balance of acceleration and radiative losses

"post" $\sim$ 2018: $\Delta x_{\mathrm{sim}} \approx l_{\mathrm{cool}}$

resolve aging of CR, compute the aged CR spectrum at distinct grid-points, x, in the post-shock region



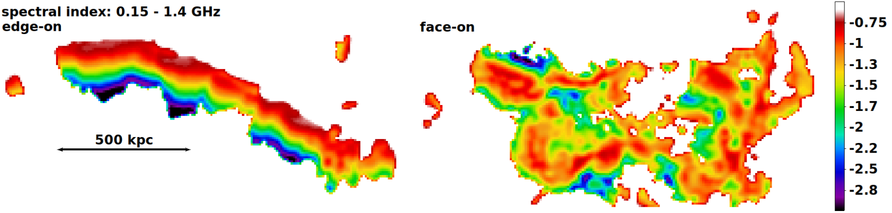
with Hoeft & Brüggen 2007 formalism:

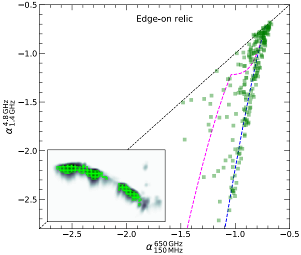
$$\frac{\mathrm{d}P}{\mathrm{d}V\mathrm{d}\nu}(x) = C_{\mathrm{R}} \int_0^{E_{\max}} n_{\mathrm{E}}(\tau, x) F\left(\frac{1}{\tau^2}\right) \mathrm{d}\tau$$

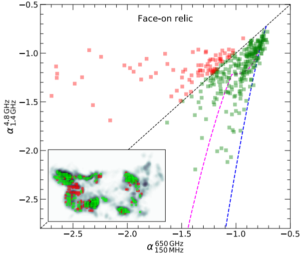
studied

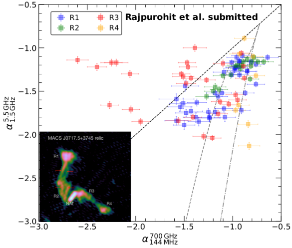
- a $\sim 10^{15}\ \mathrm{M}_\odot$ cluster (Vazza et al 2018 & Dominguez-Fernandez et al. 2019)
- that undergoes a major merger that produces a bright "prototype" radio relic with $P_{1.4\ \mathrm{GHz}} = 10^{30}\ \mathrm{erg/s/Hz}$

Spectral Properties in Simulations



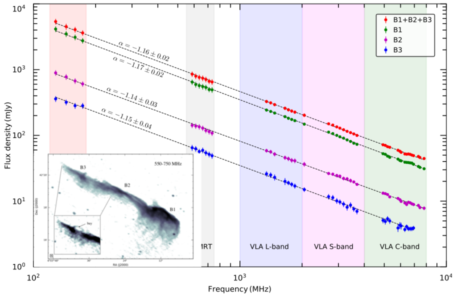


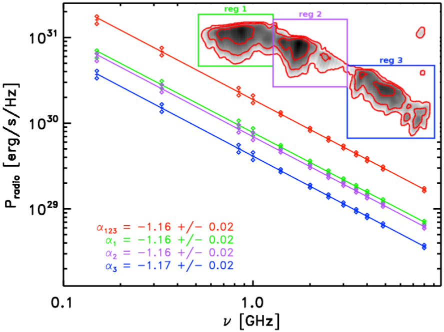




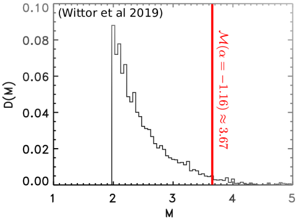
- spectral gradient if seen edge-on ⇒ aging
- patchy spectral index if seen face-on ⇒ Mach distribution of the shock wave
- comparison of color-color diagram with MACSJ0717.5+3745 (Rajpurohit et al. submitted)

Why is the spectrum of 1RXS J0603.3+4212 a "perfect" power-law ? (Rajpurohit et al. 2020)

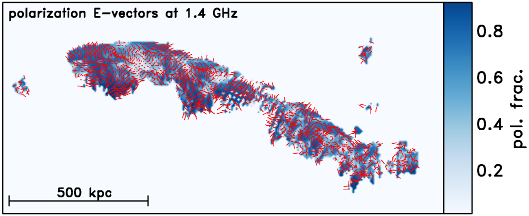


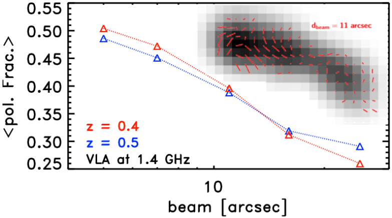


- spectra span a perfect power-law over two decades in frequency
- relic is produced by a distribution of Mach numbers
- spectrum is dominated by the strongest Mach numbers



Polarisation in Simulations (Wittor et al. 2019)

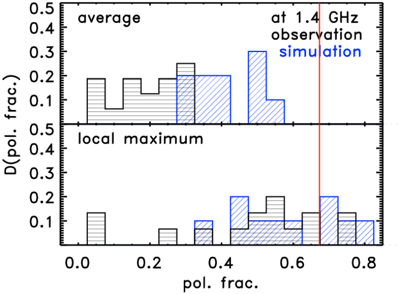




- $\langle\mathrm{pol.\ frac.}\rangle \approx 30 - 65$ %, dominated by a few bright cells along each line-of-sight
- cannot reproduce the large-scale morphology of observed relics, yet shapes can be recovered locally

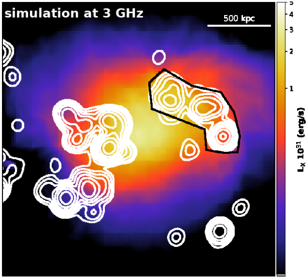
mock observations (plots on right):

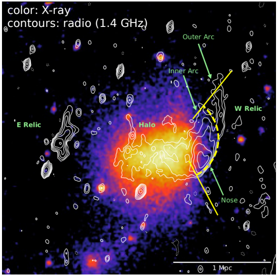
- beam depolarisation
- $\langle\mathrm{pol.\ frac.}\rangle_{\mathrm{sim}} > \langle\mathrm{pol.\ frac.}\rangle_{\mathrm{obs}}$
- max$(\mathrm{pol.\ frac.})_{\mathrm{sim}} \approx$ max$(\mathrm{pol.\ frac.})_{\mathrm{obs}}$

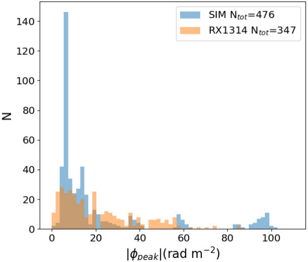


(using the Burn 1966 formalism)

The P_{3GHz} of RXCJ1314.4-2525 (Stuardi et al. 2019)







	P_{3GHz} [10^{23} W/Hz]	L_X [10^{44}erg/s]	n_e [10^{-3} cm^{-3}]	Mach	pol. frac. (3 GHz) [%]
obs.	11.5±0.6	8.91	0.7±0.05	$1.7^{+0.4}_{-0.2}$	31.5
sim.	11.1±0.4	5.65	3.7±0.9	2.2±0.2	32

- $\langle P \rangle \propto B^2 \gamma^2$
- RM Synthesis to both (re-scaling $n_{e,sim}$ by 1/5) $\Rightarrow$ 1 μG of simulation is a good match for the magnetic field in RXC J1314.4-2515
- P_{3GHz} impossible to reach in the simulations from the thermal pool

$\Rightarrow$ a $M \sim 2$ no more than 1 Gyr could explain P_{3GHz}

CONCLUSION

- to study radio relics multi-frequency radio observations and numerical simulations are required

- careful modelling of radio relics in simulations is necessary, i.e. including downstream cooling (Wittor et al. 2019) and re-acceleration (in the future)

simulations ...

... reproduce the observed spectral properties of radio relics

... can reproduce the observed degree of polarisation, if beam depolarisation is included

... only reproduce the polarized morphology of observed relics locally

- synergies of simulations and observations improve our knowledge on radio relics, e.g. for RXC J1314.4-2515 (Stuardi et al. 2019), 1RXS J0603.3+4212 (Rajpurohit et al. 2020) or MACSJ 0717.5+3745 (Rajpurohit et al. submitted)

- link to the video shown at the beginning of the talk: https://vimeo.com/464248944/3fc17a5b8b

Thank you for your attention!

Any questions?