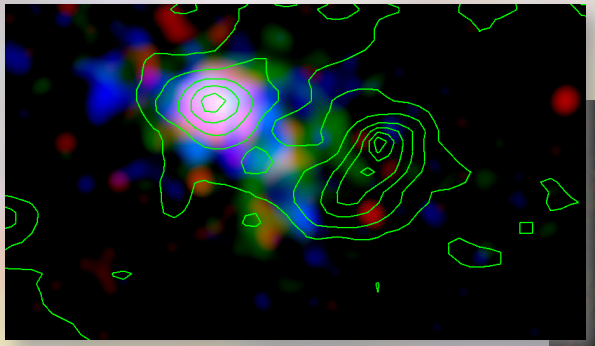
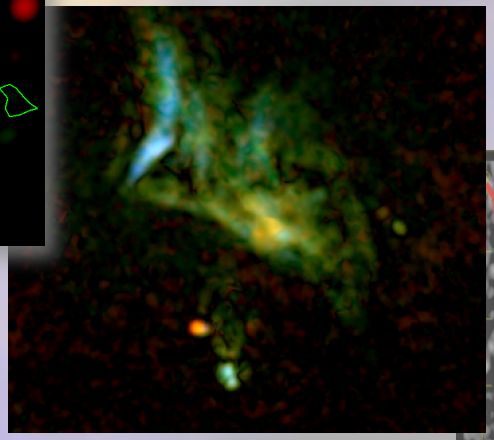
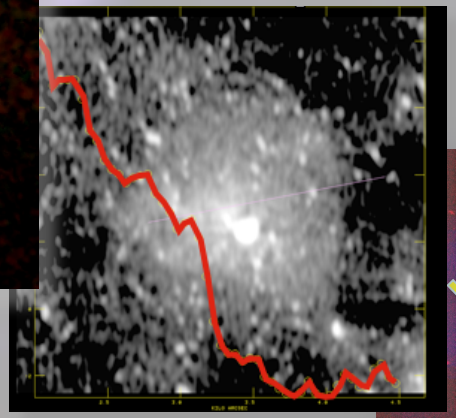
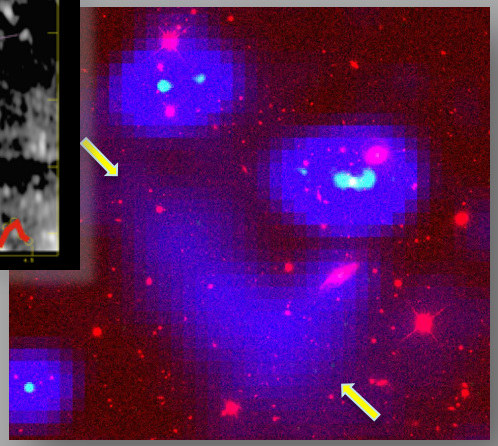
Finding Shocks in All the "Wrong" Places









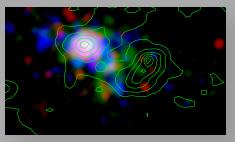
Lawrence Rudnick
University of Minnesota

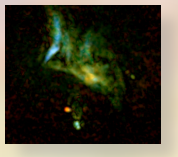
In concert with:
- Shea Brown, CSIRO
- Frazer Owen, NRAO
- Jean Eilek, NMIMT, NRAO
- Urvashi Rao Venkata, NRAO
- Sanjay Bhatnagar, NRAO
- Leonia Kogan, NRAO

Monsters, Inc., KITP. March 2011

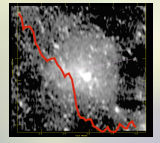
Take home messages

Cluster-scale shocks are showing up in unexpected ways -- we need to fold these into our views of cluster assembly.

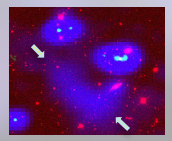




- What is the 3D structure of "peripheral radio relics" from merger shocks? Using RM synthesis, new studies can now probe how the thermal and relativistic plasmas are interspersed. (Abell 2256)

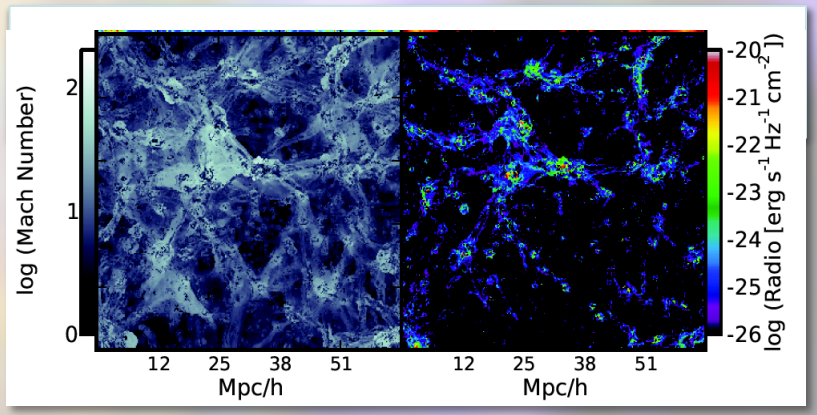


- Do radio halos require current major shocks? Large low Mach number shocks are being found at the edges of radio halos (Coma).



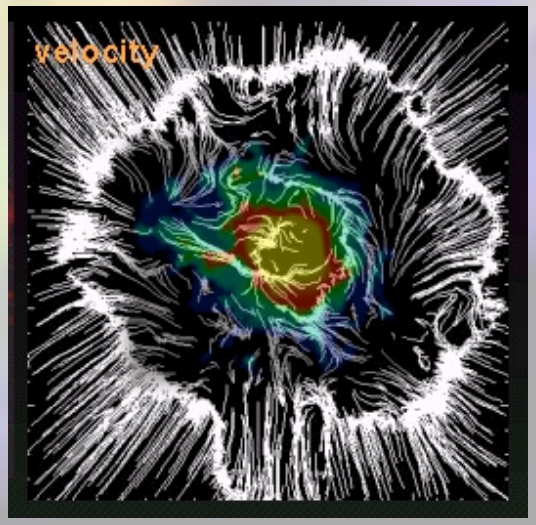
- How can we create substantial relativistic plasmas in low density environments? We find a cluster-like shock in a very poor cluster. (0809+39)

Where should we find shocks?



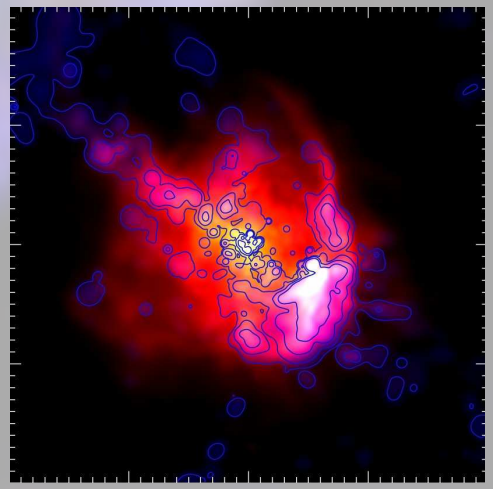
Skillman, S. et al. 2010

ACCRETION



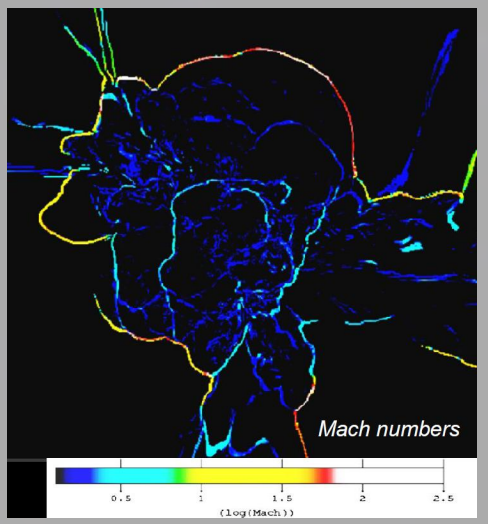
F. Vazza

OUTGOING MERGER



Battaglia et al. 2009

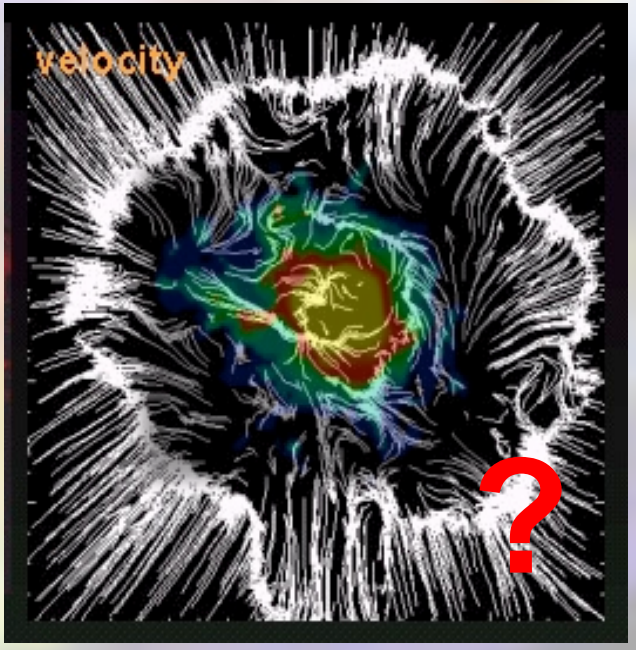
WEAK INTERIOR

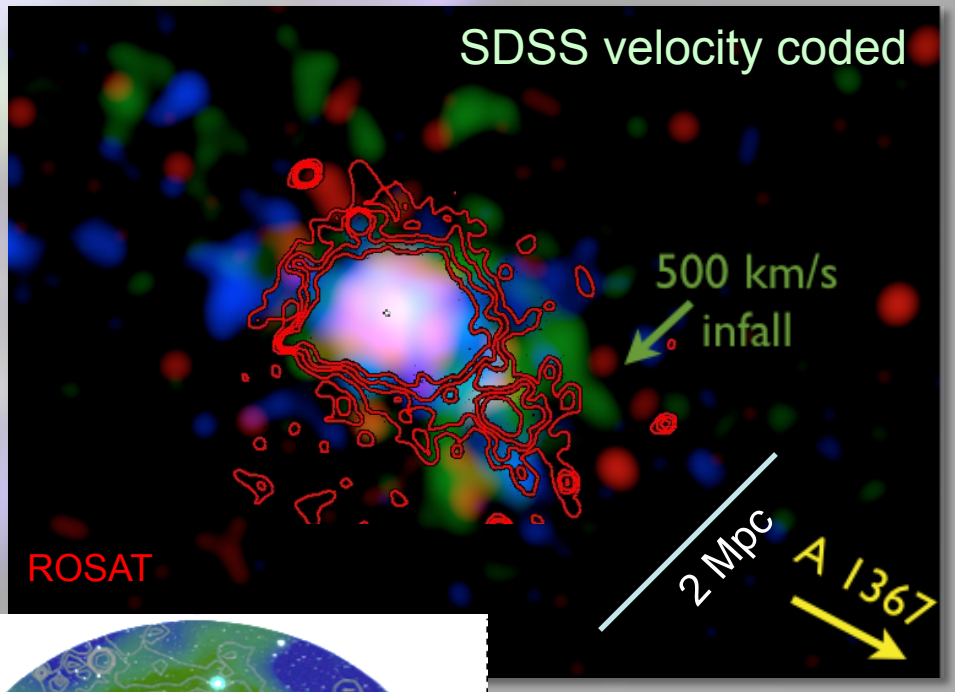


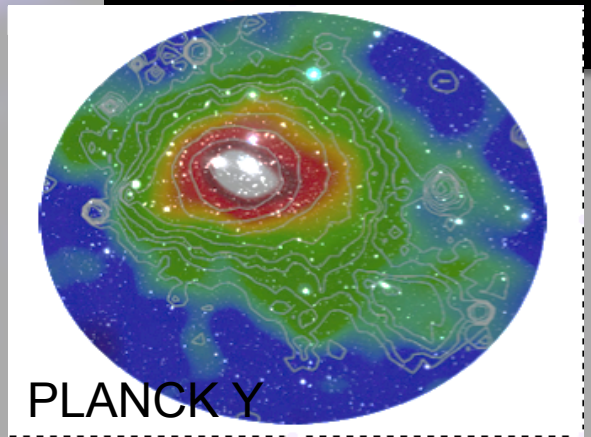
Vazza, Brunetti & Gheller, MNRAS 2009

(Accretion) INFALL

Column of infalling galaxies – 2 Mpc wide

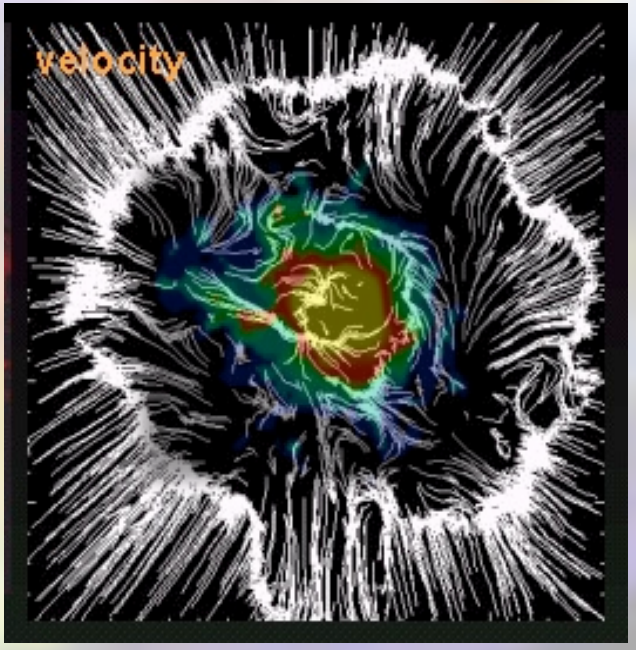


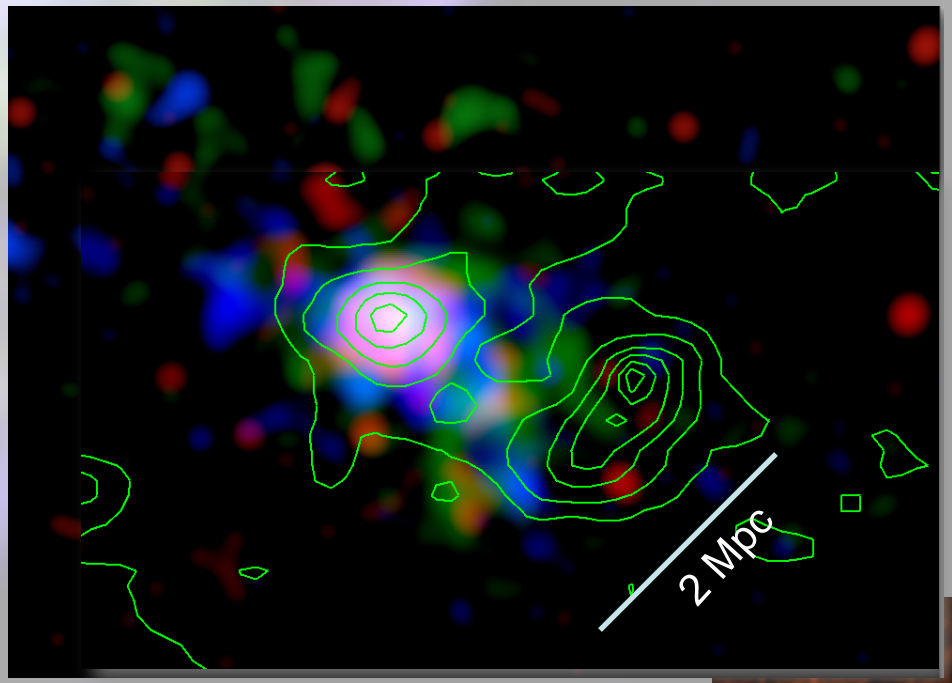




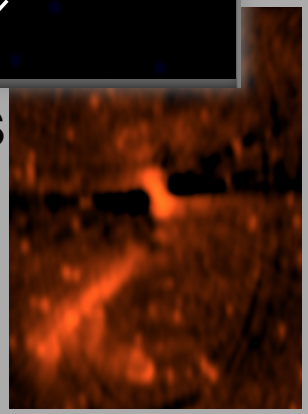
(Accretion) INFALL

Column of infalling galaxies – 2 Mpc wide



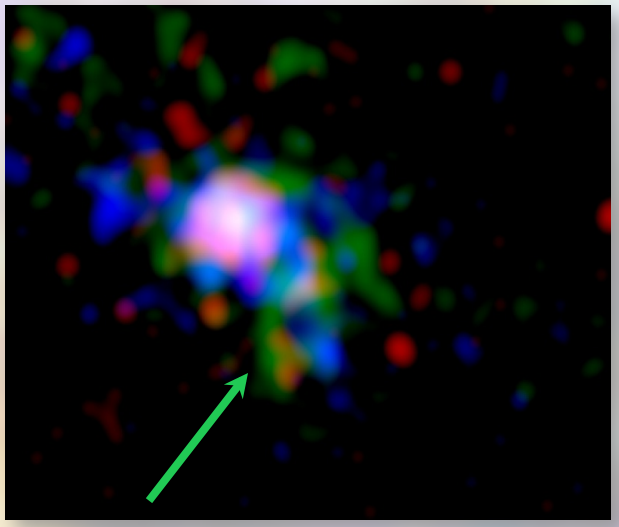


Brown & Rudnick, 2011 MNRAS



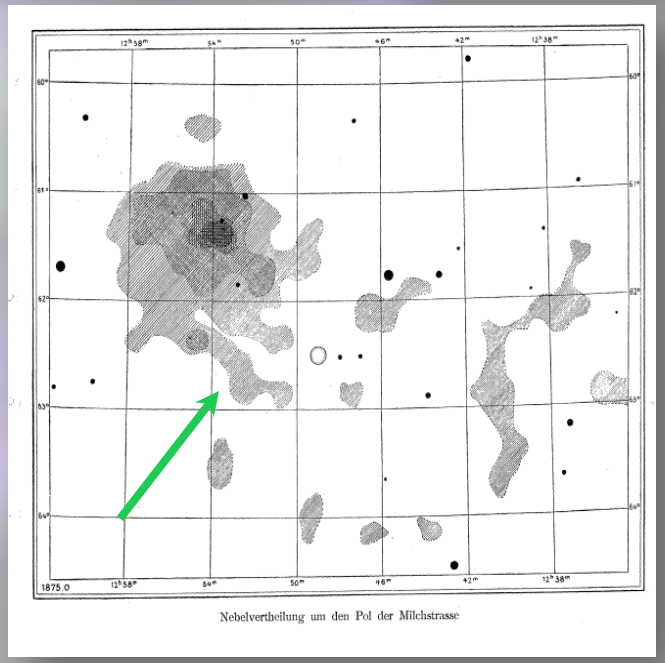
There is nothing new under the sun.

Ecclesiastes 1:9



Die Nebelflecken am Pol der Milchstrasse

Max Wolf, 1902



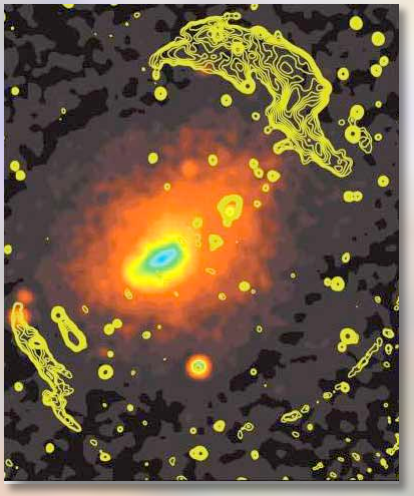
Nebelvertheilung um den Pol der Milchstrasse

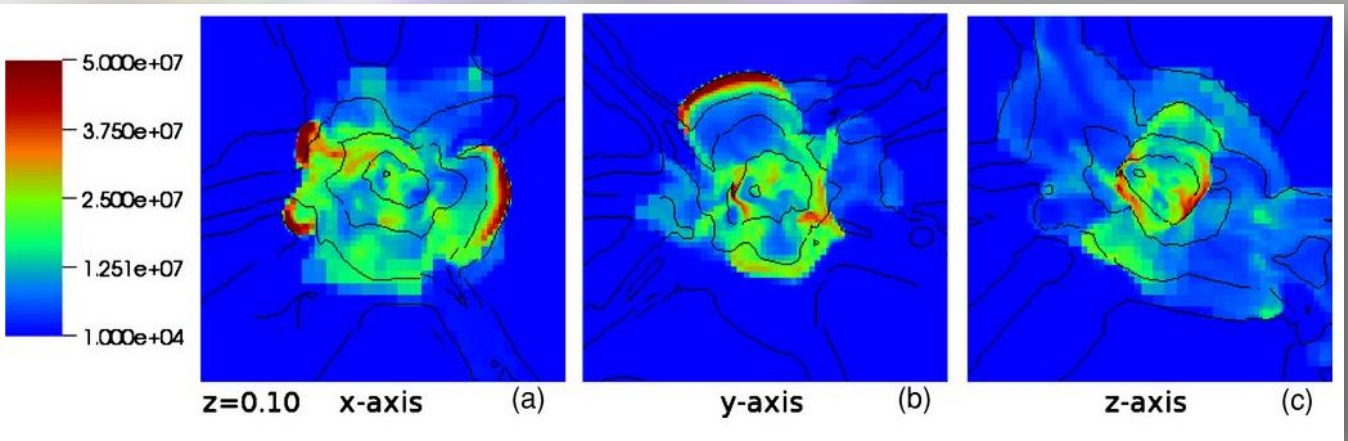
With thanks to Klaus Dolag!

Es wäre verfrüht, irgend welche Speculationen an dieses merkwürdige Resultat zu knüpfen. Immerhin möchte ich nicht versäumen, es der allgemeinen Aufmerksamkeit zu empfehlen.

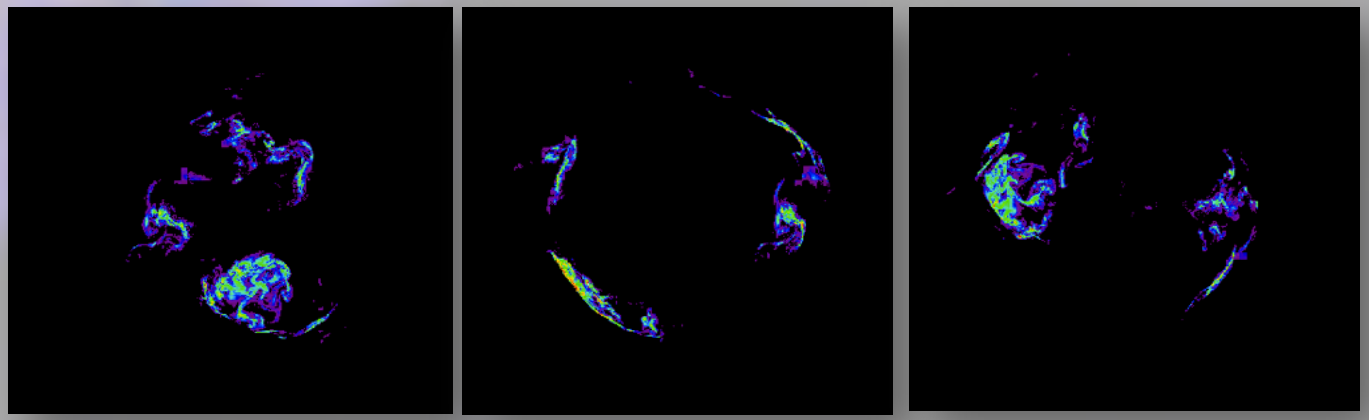
It would be too early to connect any speculations to these strange results. But I do not want to miss mentioning it to the public.

Peripheral shocks – from 2D to 3D



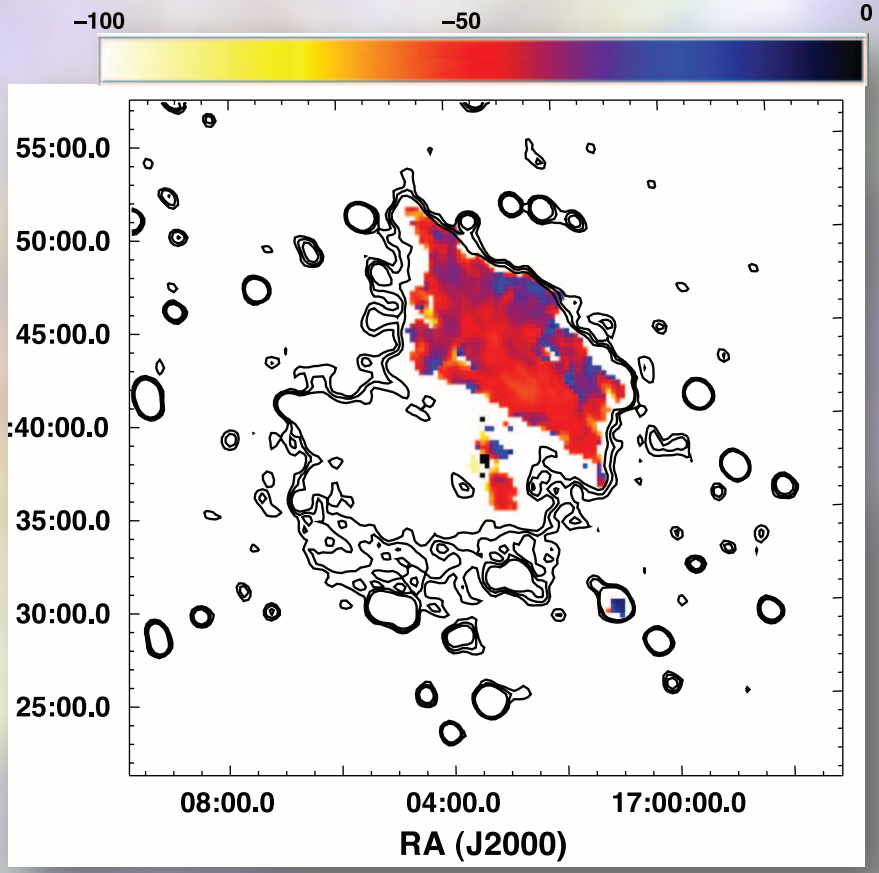


S. Paul et al. 2011, ApJ726, 17

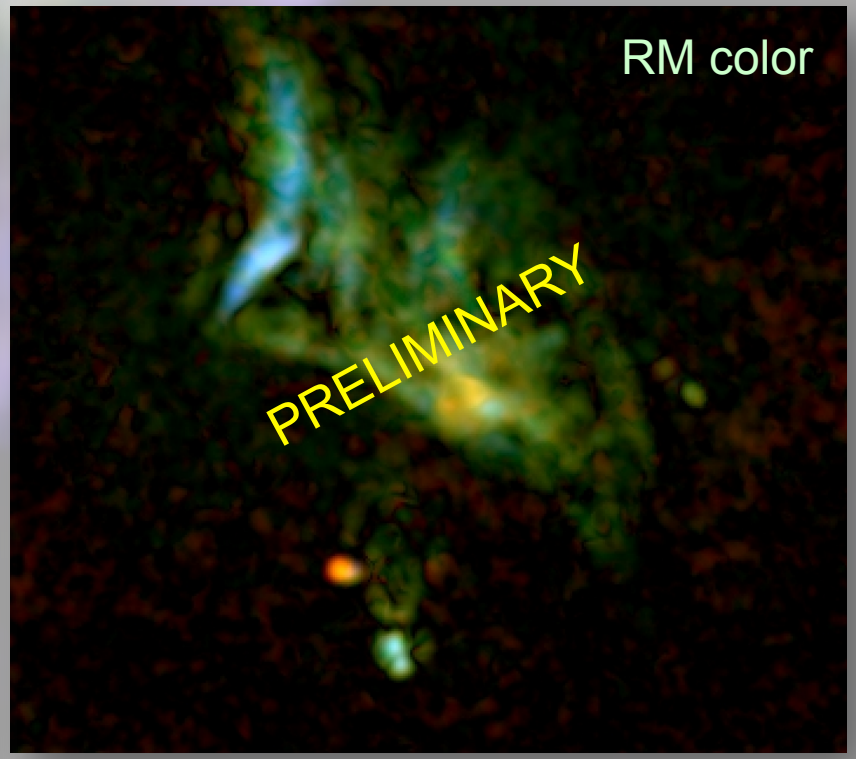


Skillman, Xu, Hallman, Burns et al.

The EVLA and RM synthesis* moving into 3D



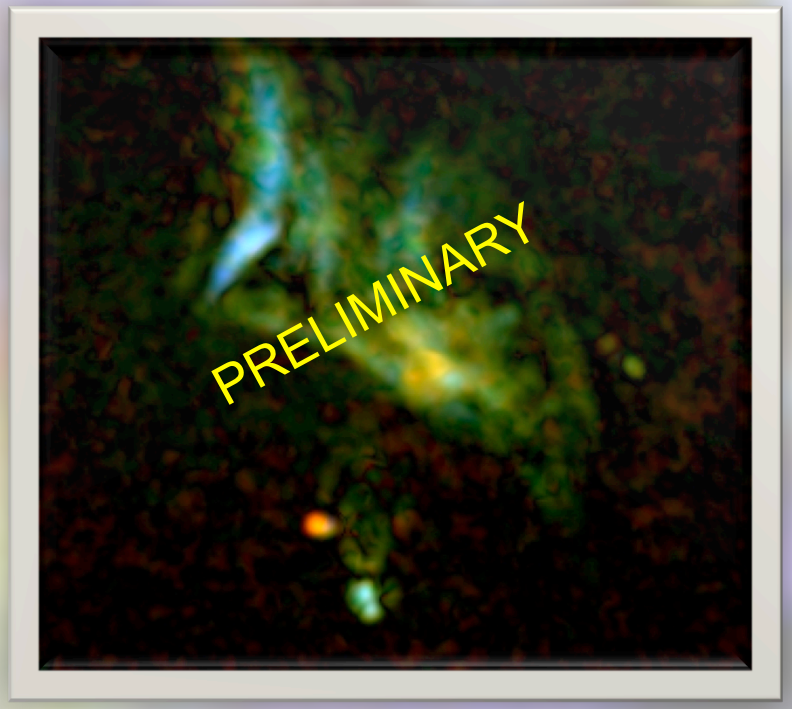
Clarke & Ensslin, 2006



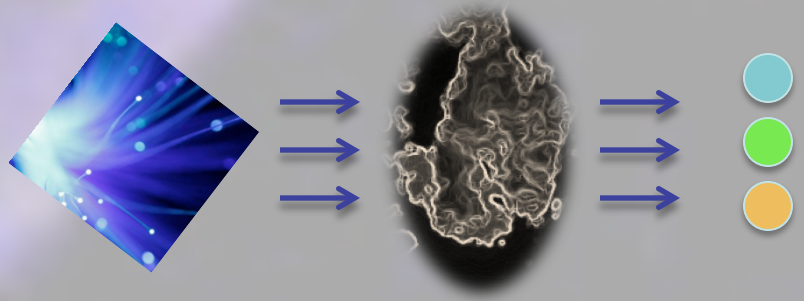
EVLA 1-2 GHz, with
F. Owen, J. Eilek
U. Rao Venkata,
S. Bhatnagar, L. Kogan

* Brentjens & deBruyn, 2005

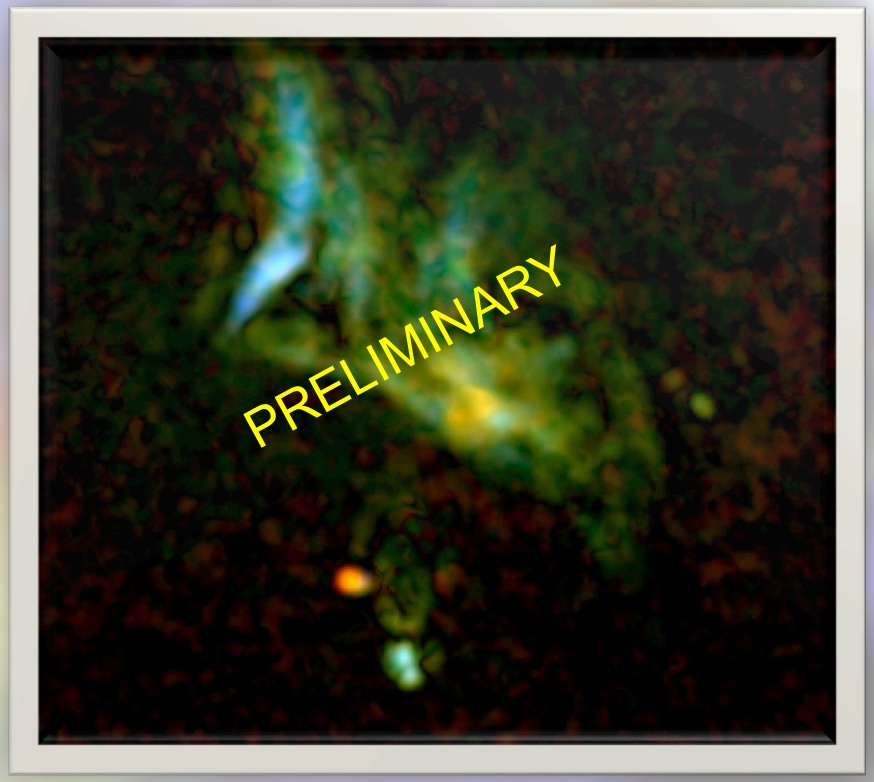
The EVLA and RM synthesis* moving into 3D

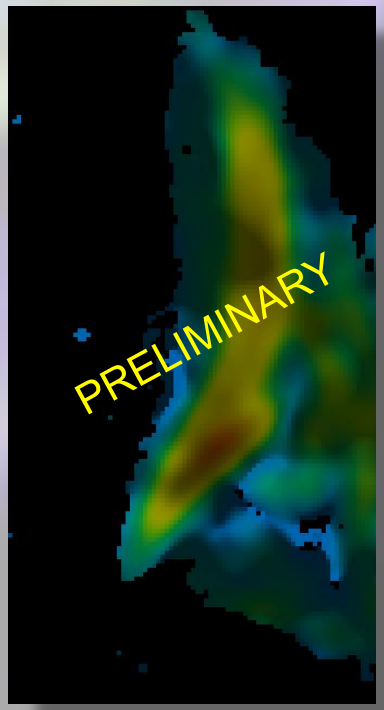


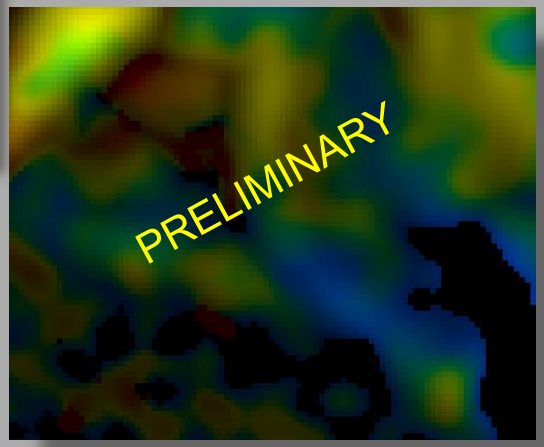
the standard foreground screen

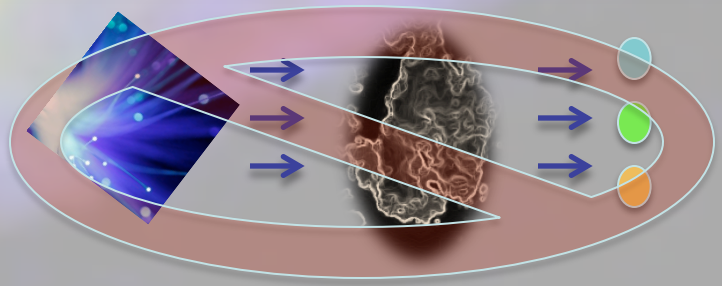


The EVLA and RM synthesis* moving into 3D



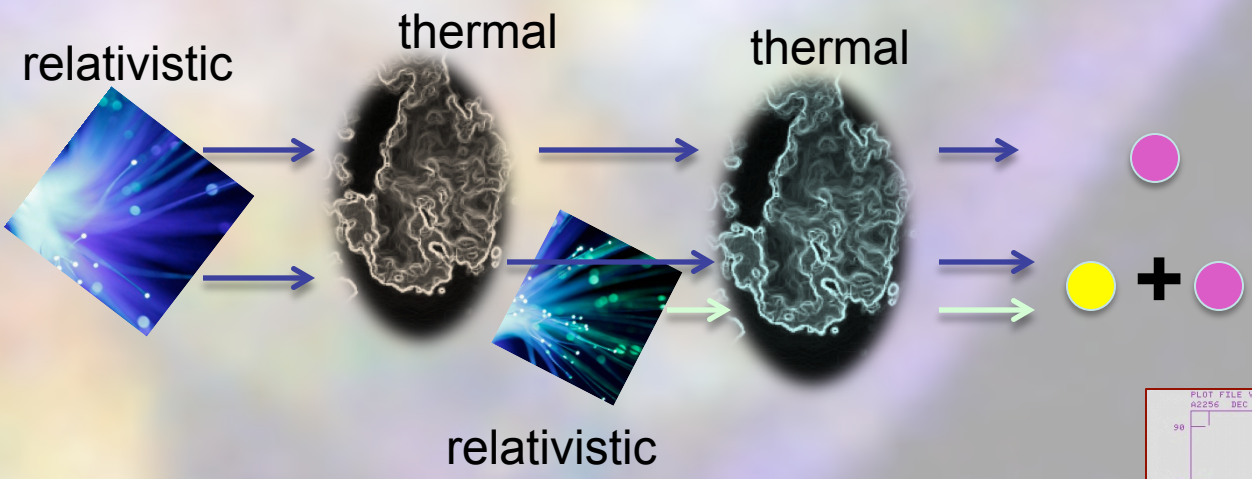




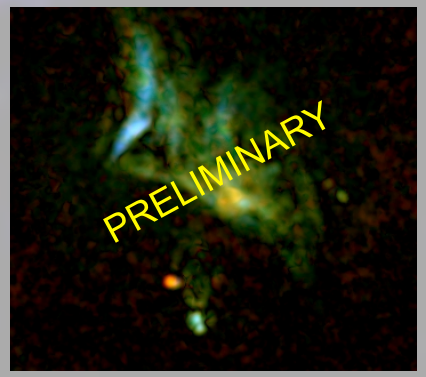


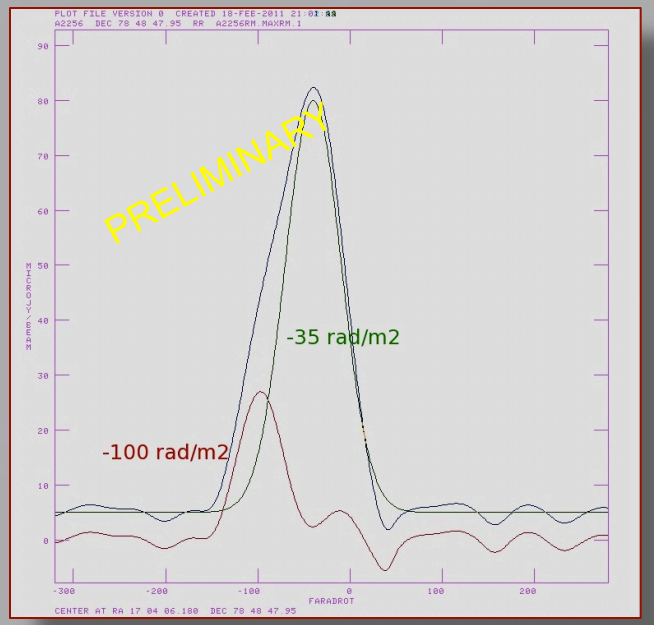
Not foreground screen

The EVLA and RM synthesis* moving into 3D

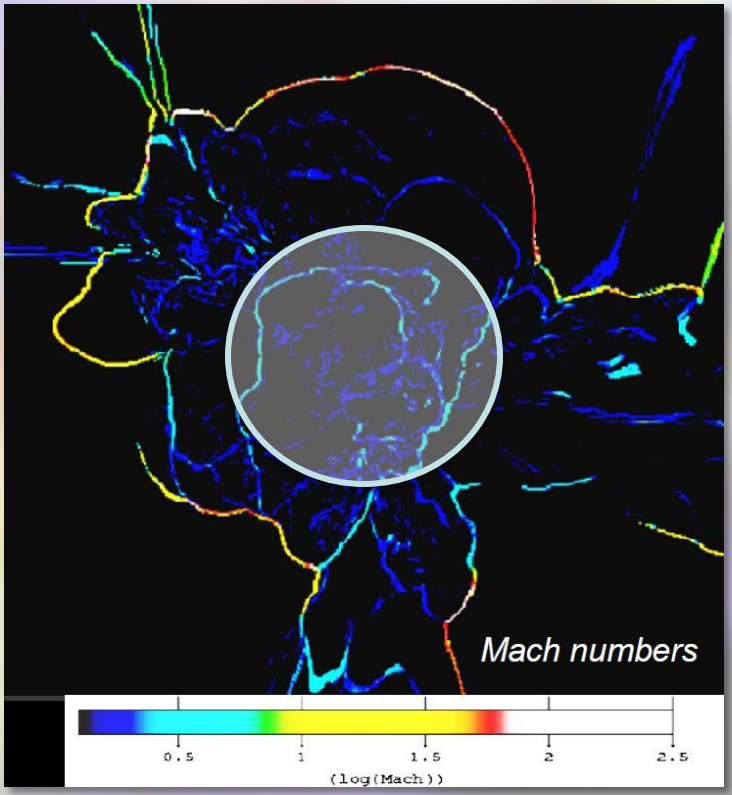


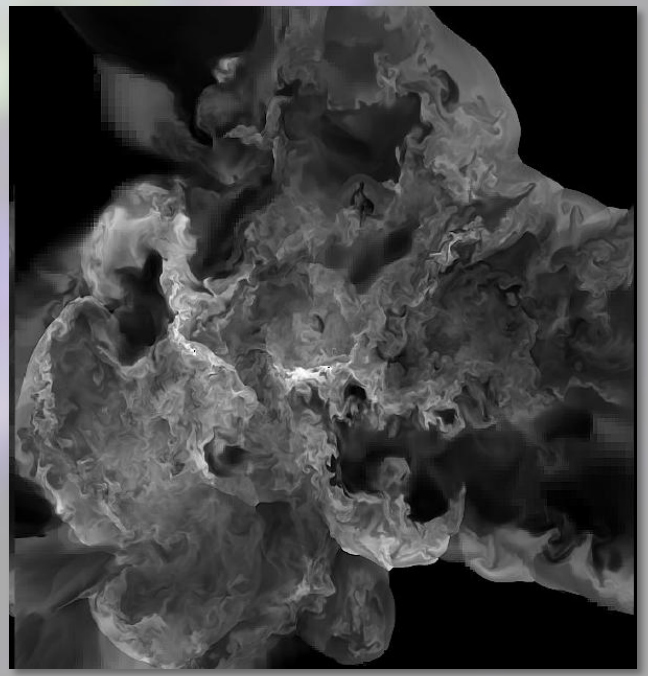
Coherent fields over 100s of kpc
Not only along,
but between filaments





Shocks and Halos what's the connection?



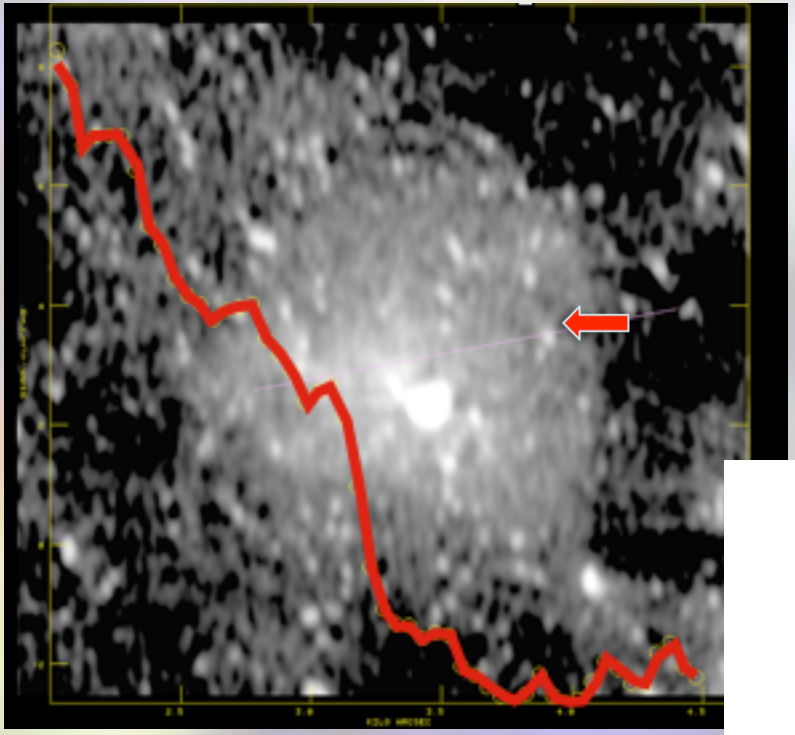


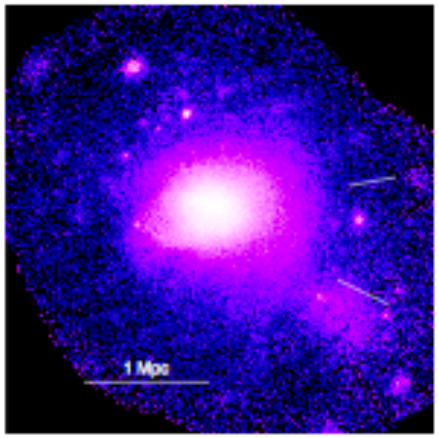
Internal shocks -- too weak for direct relativisitic particle acceleration – Reacceleration OK

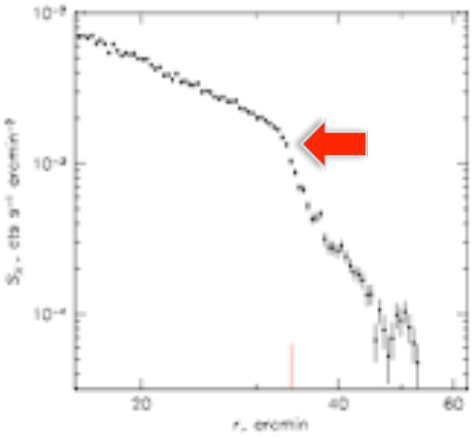
Turbulence – amplifies fields
Accelerates particles (slowly)

Vazza, Brunetti,Gheller, Brunino, Bruggen

Shocks & Halos – the connection?





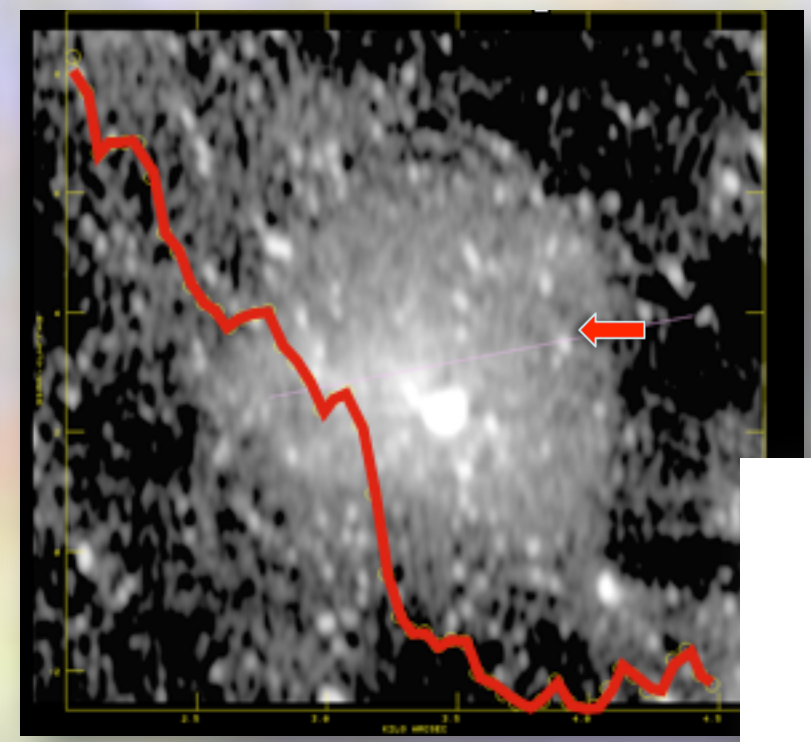


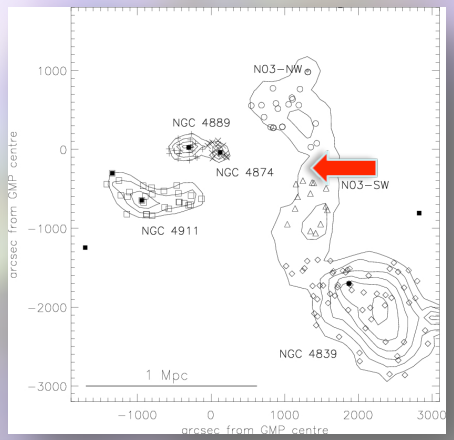
(a) (b)

Fig. 9. (a) *ROSAT* PSPC mosaic of Coma ($1.6^\circ \times 1.6^\circ$), showing a brightness edge in the eastern sector (shown by dashes) that might be a shock front. (b) X-ray brightness profile in that sector, showing this feature at around $r = 33'$ (red dash).

Markevitch 2010arXiv1010.3660M

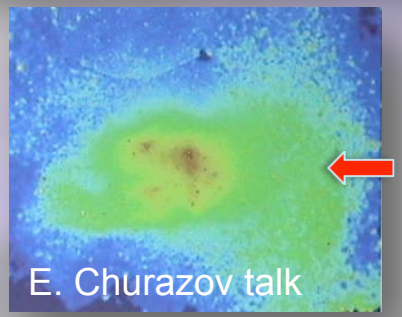
Shocks & Halos – the connection?

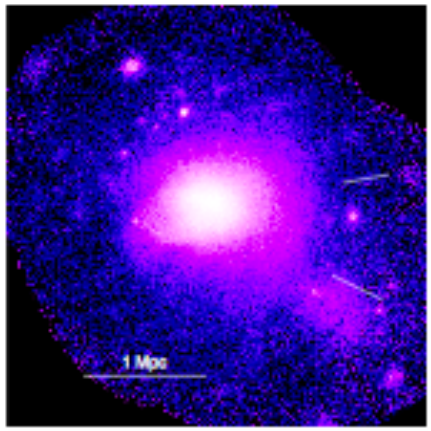


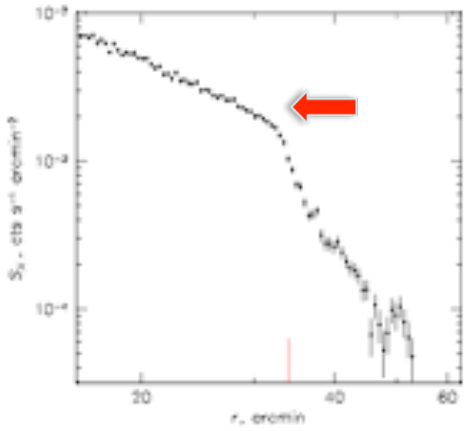


Subclusters on their way out?

Adami et al. 2005





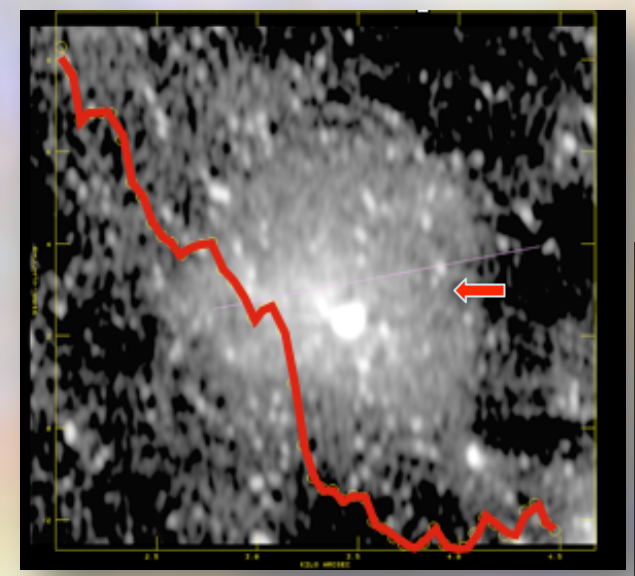


(a) (b)

Fig. 9. (a) *ROSAT* PSPC mosaic of Coma ($1.6° \times 1.6°$), showing a brightness edge in the eastern sector (shown by dashes) that might be a shock front. (b) X-ray brightness profile in that sector, showing this feature at around $r = 33'$ (red dash).

Markevitch 2010arXiv1010.3660M

Shocks & Halos – the connection?

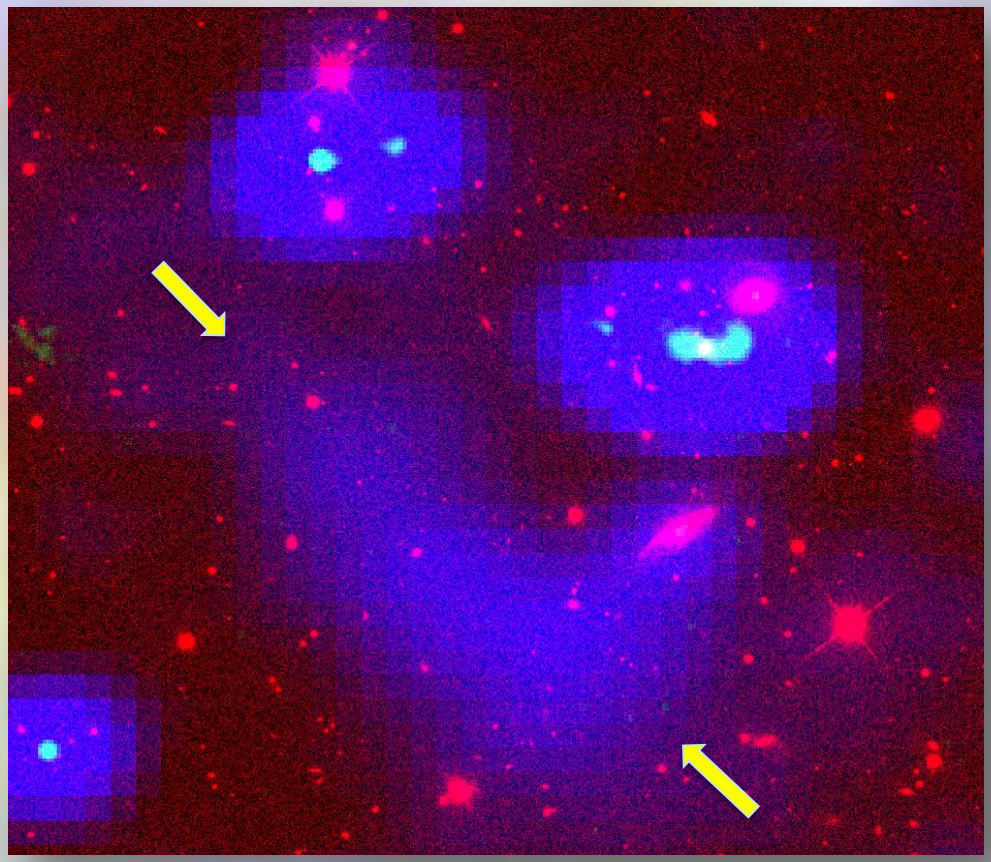


Markevitch 2010arXiv1010.3660M

Table 1. X-ray merger shock fronts and candidates (as of summer 2010)

Cluster	ρ jump	T jump	M	Radio edge?	X-ray refs.
1E 0657–56	yes	yes	3	yes	5,6
A520	yes	yes	2	yes	25
A754	yes	yes	1.6	yes	28–30
A2146 N	yes	yes	2	no data	27
A2146 S	yes	yes	2	no data	27
A521	yes		2	yes	33
RXJ 1314–25	yes		2	yes	36
A3667	yes		2	yes	35
A2744	yes			yes	this work
Coma	yes			yes	this work

Shocks and **poor** clusters



Peripheral Relic - ?
Outgoing merger shock?

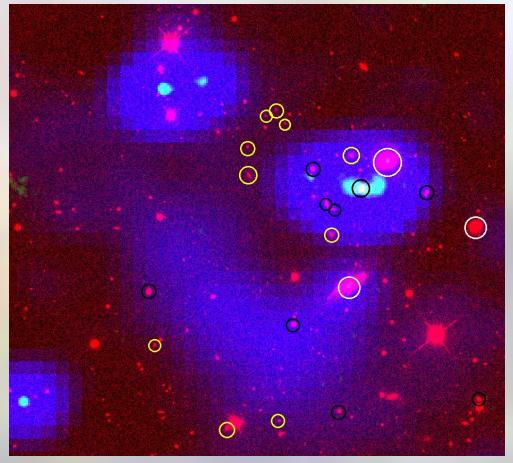
- Size: 2 Mpc
- Luminosity:

  $10^{24.6}$ W/Hz (@1.4GHz)
- Polarization: 19%

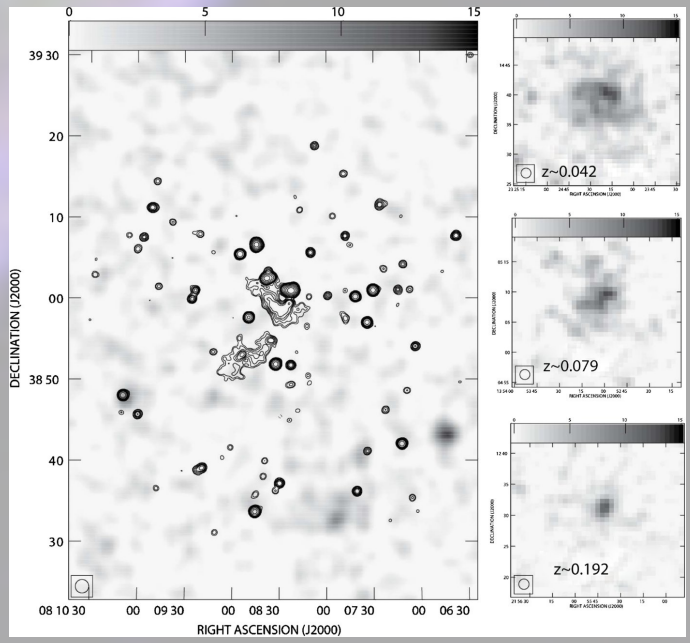
S. Brown & L. Rudnick, 2009 AJ, 137, 3158

Shocks and **poor** clusters

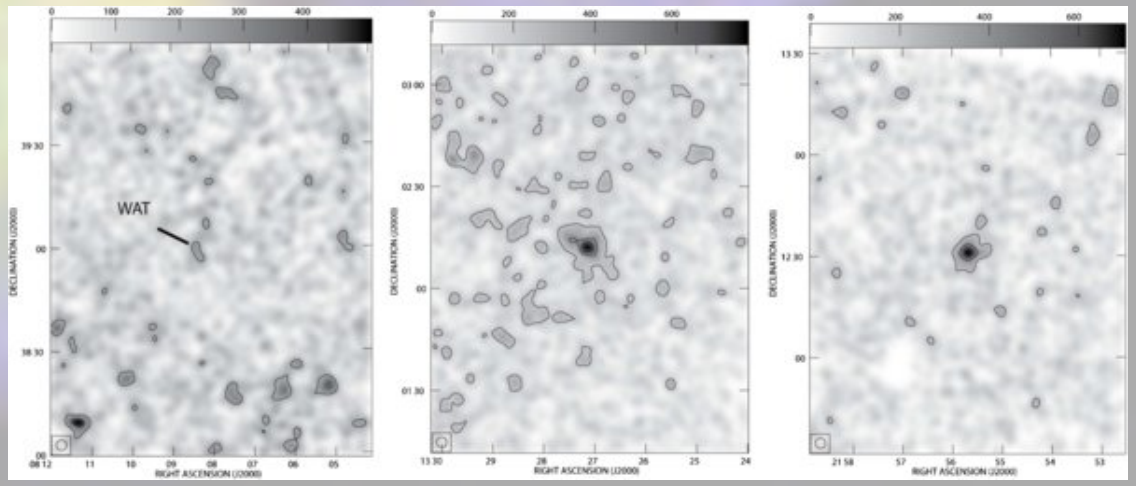
Comparisons with X-ray clusters (z=0.2)



X-rays (ROSAT)

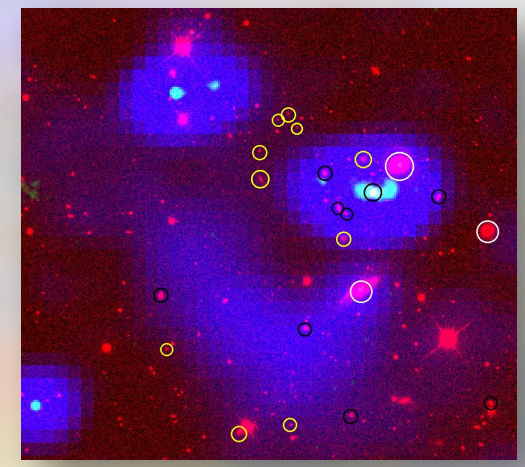


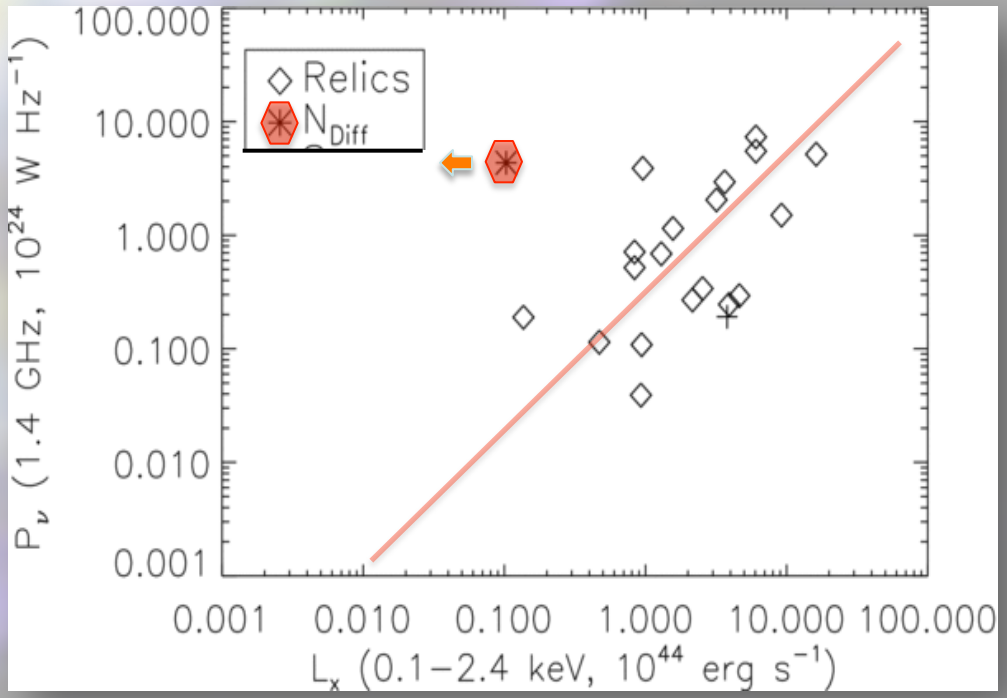
Optical (SDSS)



Shocks and **poor** clusters

Comparisons with X-ray clusters

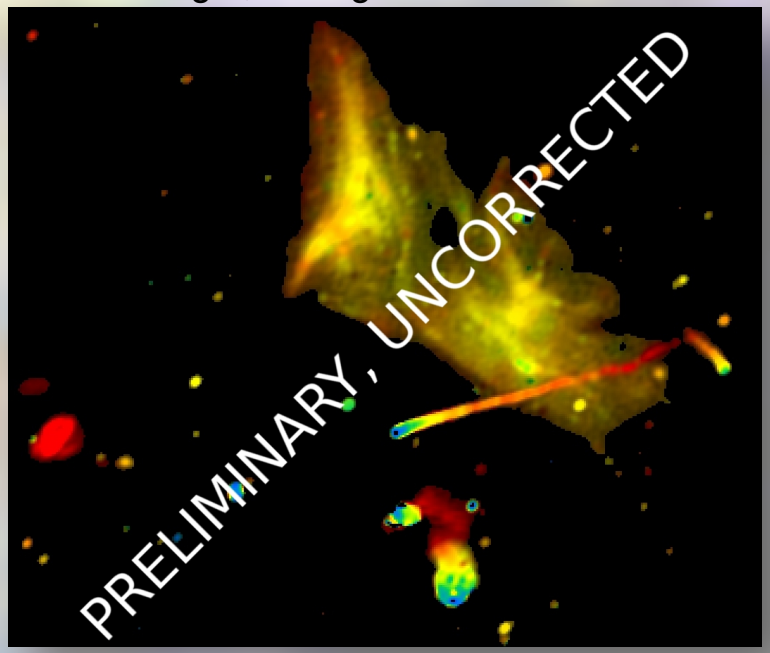




Some unattractive choices:

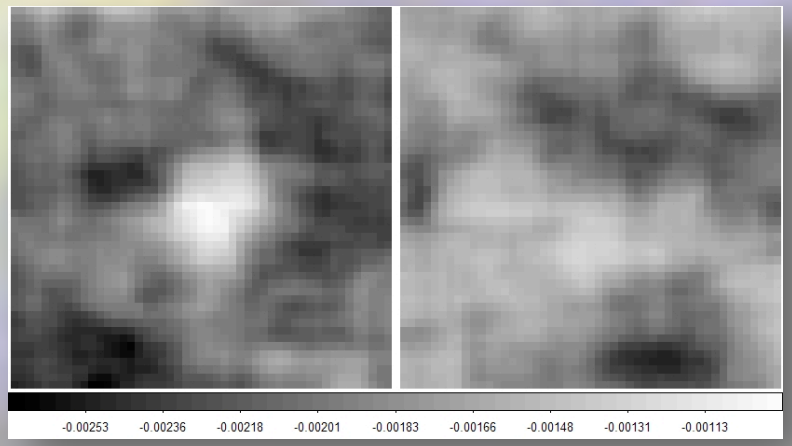
→ artificially high CR acceleration “efficiency”
→ OR, is mass OK, but X-rays underluminous?
→ OR, is mass OK, but little star formation?

EVLA 1-2 GHz, with
F. Owen, J. Eilek
U. Rao Venkata,
S. Bhatnagar, L. Kogan

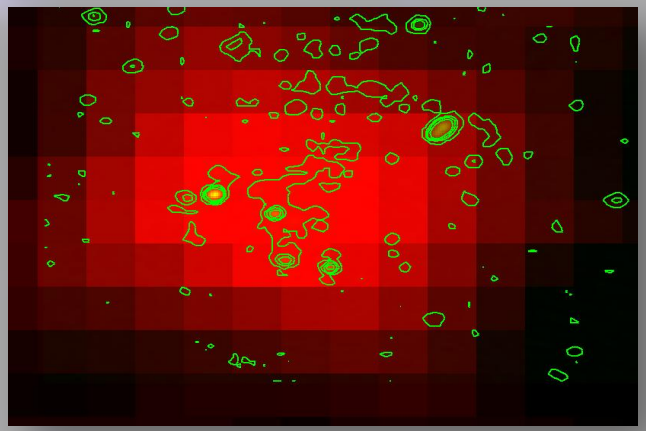


Expanded
Very Large Array

Radio stacked X-ray clusters



Shea Brown, A. Emerick, LR

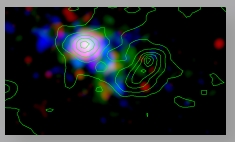


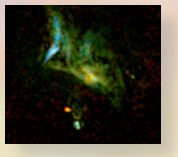
Lot of missing halo flux, as found on GBT

Damon Farnsworth, Shea Brown, LR

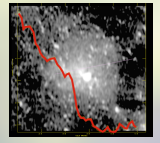
Take home messages

Cluster-scale shocks are showing up in unexpected ways -- we need to fold these into our views of cluster assembly.

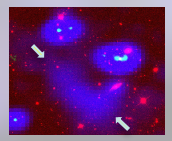




- What is the 3D structure of "peripheral radio relics" from merger shocks? Using RM synthesis, new studies can now probe how the thermal and relativistic plasmas are interspersed. (Abell 2256)



- Do radio halos require current major shocks? Large low Mach number shocks are being found at the edges of radio halos (Coma).



- How can we create substantial relativistic plasmas in low density environments? We find a cluster-like shock in a very poor cluster. (0809+39)