Magnetic field evolution in interacting galaxies

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26.08.2011, Zakopane, MFU III

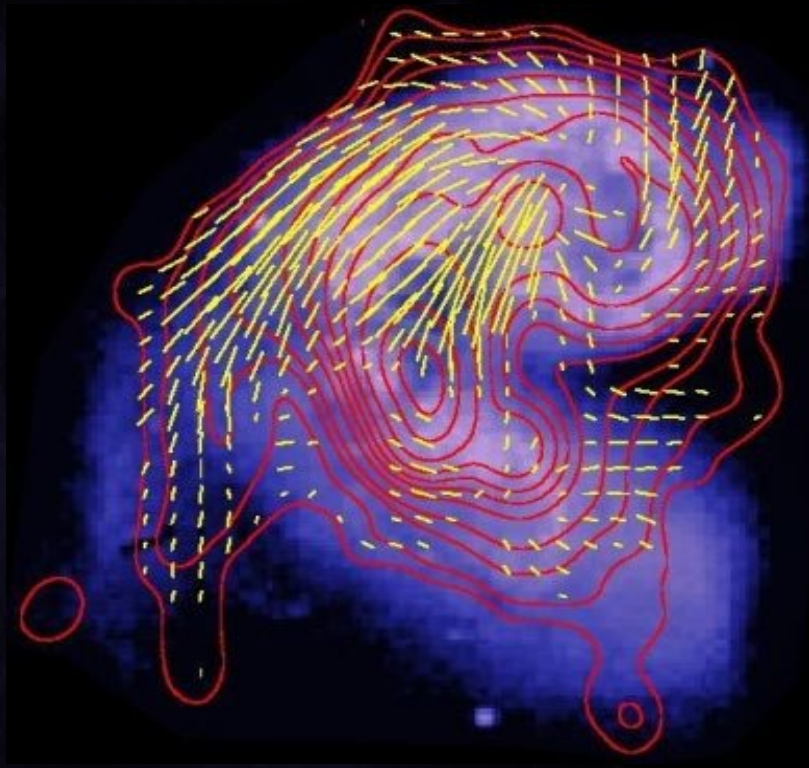
Outlook

- Motivation and new investigations (the sample)
- Results on some individual interacting systems
- Evolution of magnetic fields in interacting galaxies
- Summary

Drzazga et al. (2011) A&A in press

Motivation

- So far magnetic fields were fully studied only in one merging system (the Antennae, Chyży & Beck 2004)
- **Is there any evolution of magnetic fields during galaxy interactions?**
- How gravitational interactions influence the properties of magnetic fields?



From: Chyży & Beck 2004

The Antennae system is before second encounter (Mihos et al. 1993) or 40Myr after it (see, Karl et al. 2010). The morphology and strength of magnetic fields in this system are different from known non-interacting spirals.

The Toomre sequence (Toomre 1977)

- 11 pairs of interacting galaxies arranged from early to late stages of merging
- For each pair a number is assigned from 1 to 11(Interaction Stage, IS)
- Numbers from 1 to 9 describe systems before merging, 10 means a system at the time of nuclear coalescence and 11 is assigned to a merger remnant

The sample

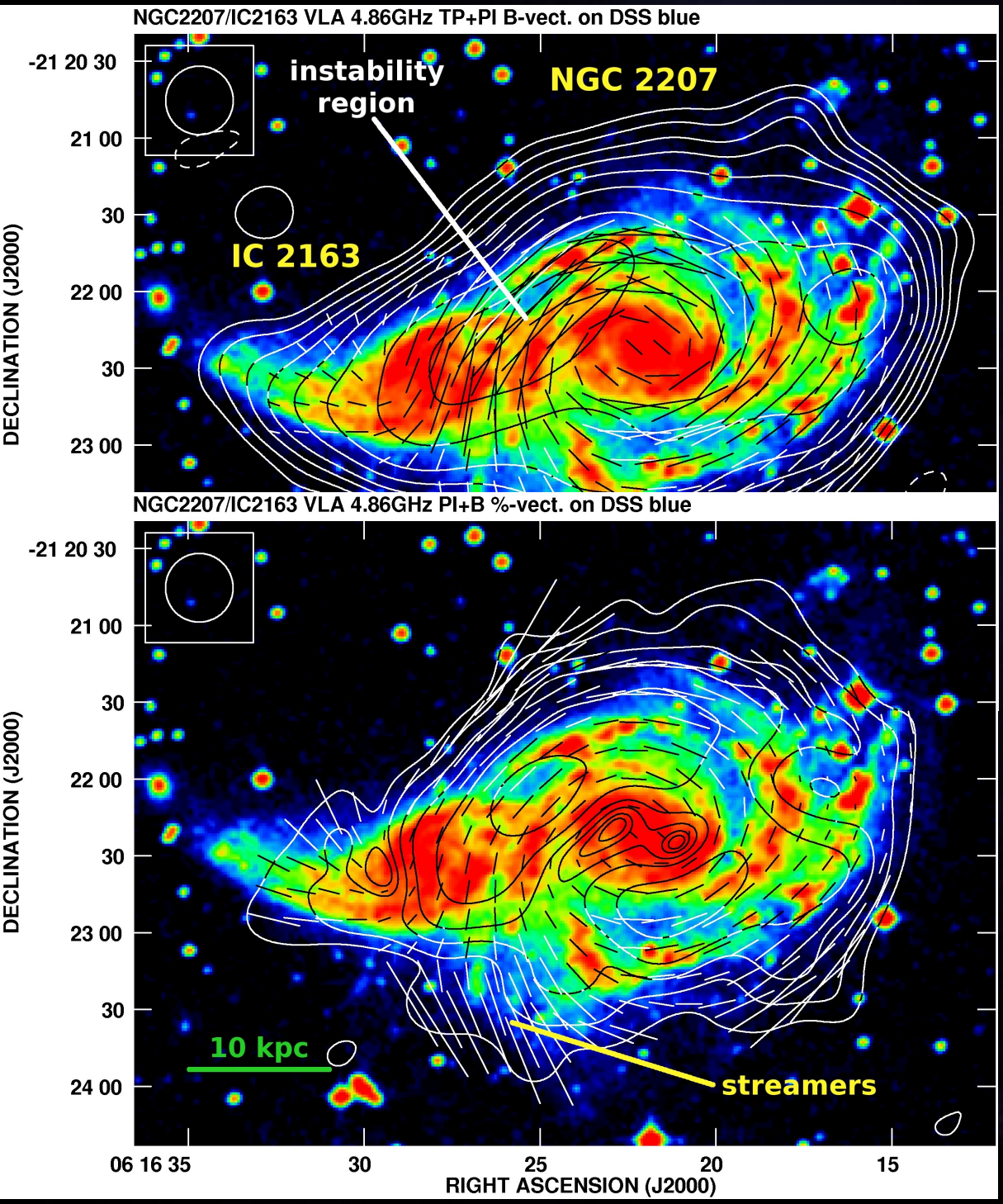
Name	System name or other name	Type	Dist. [Mpc]	Inkl. [deg.]	Pos. angle [deg]	H I extent [kpc]	Interaction Stage
NGC 876^{S}	NGC 876/877	SAc: sp	50.8	77.9	27.3	N/A	−1
NGC 877^{S}	NGC 876/877	SAB(rs)bc LIRG	50.8	35.6	138.0		−1
NGC 4254	The Virgo Cluster	SA(s)c,LINER,HII	17	32.0	60.0	40	−1
NGC 2207^{S}	NGC 2207/IC 2163	SAB(rs)bc pec	35.0	58.2	115.9	56	−1
IC 2163^{S}	NGC 2207/IC 2163	SB(rs)c pec	35.0	78.5	102.6		−1
NGC 5426	Arp 271, NGC 5426/5427	SA(s)c pec	26.7	69.7	0.5	43	−1
NGC 5427^{S}	NGC 5426/5427	SA(s)c pec,Sy2,HII	26.7	25.5	135.0		−1
NGC 6907^{S}	NGC 6907/6908	SB(s)bc	44.5	37.5	66.7	78	0
NGC 6908	NGC 6907/6908	S	44.5	N/A	N/A		0
UGC 12914^{S}	Taffy galaxy	SAB(rs)c,Sbrst,Sy2	59.6	54.1	159.6	52	1
UGC 12915	Taffy galaxy	Sdm	59.6	72.9	135.4		1
UGC 813	Taffy2 galaxy	Sb	67	72.0	110.3	73	1
UGC 816	Taffy2 galaxy	Sc	67	62.0	170.0		1
NGC 660		SB(s)a pec,HII	12.3	78.8	11.9	47	1
NGC 4038^{STX}	Arp 244,The Antennae	SB(s)m pec	26.8	51.9	133.2	133	1
NGC 4039^{STX}	The antennae	SA(s)m,pec,LINER	26.8	71.2	132.0		1
NGC 6621^{T}	Arp 81	Sb pec,LIRG	86.4	70.8	142.5	63	5
NGC 6622^{T}	Arp 81	Sa	86.4	27.3	117.0		5
NGC 520ST	Arp 157	pec	30.2	77.4	130.0	103	7
NGC 3256^{TX}		Sb(s) pec,LIRG	56	48.7	83.2	127	9
Arp 220^{X}		S,Sy,ULIRG	76	57.0	96.5	133	10
NGC 7252^{TX}	Arp 226,The Atoms of Peace	(R)SA(r)	63	25.1	127.0	214	11
Arp 222^{X}		SAB(s)a pec	23	43.4	66.5	N/A	12
NGC 1700^{X}		E4	54	90.0	87.0	N/A	13

Notes. $^{(T)}$ - a member of the Toomre sequence (1977); $^{(X)}$ - a member of the X-ray sample of Brassington et al. (2007); $^{(S)}$ - a member of our compiled sample of angularly-large interacting galaxies

The sample is constructed from: the Toomre sequence + the sample of Brassington et al. + selected objects with available radio data (VLA archive)

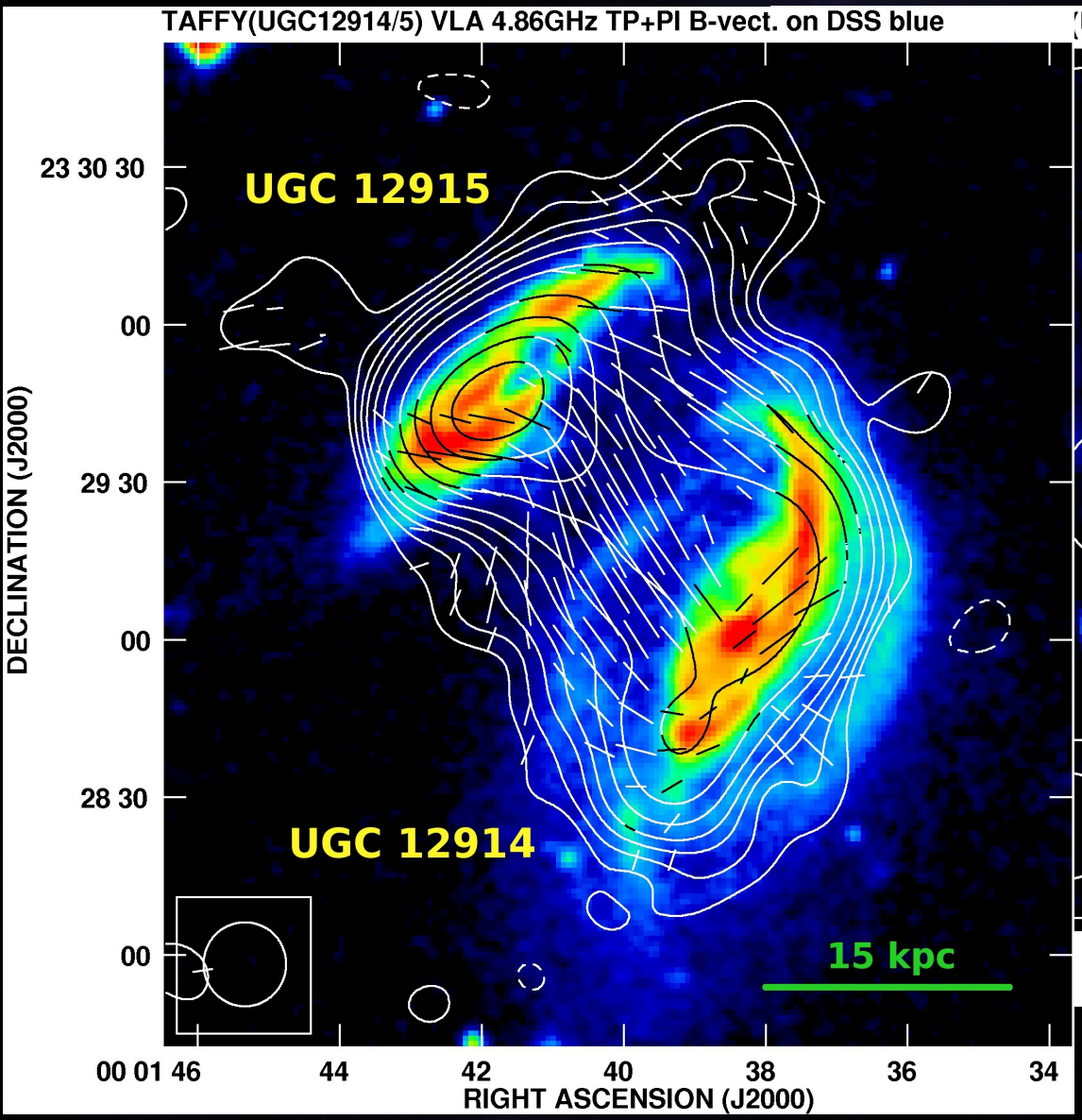
In total we selected 24 galaxies (16 interacting systems)

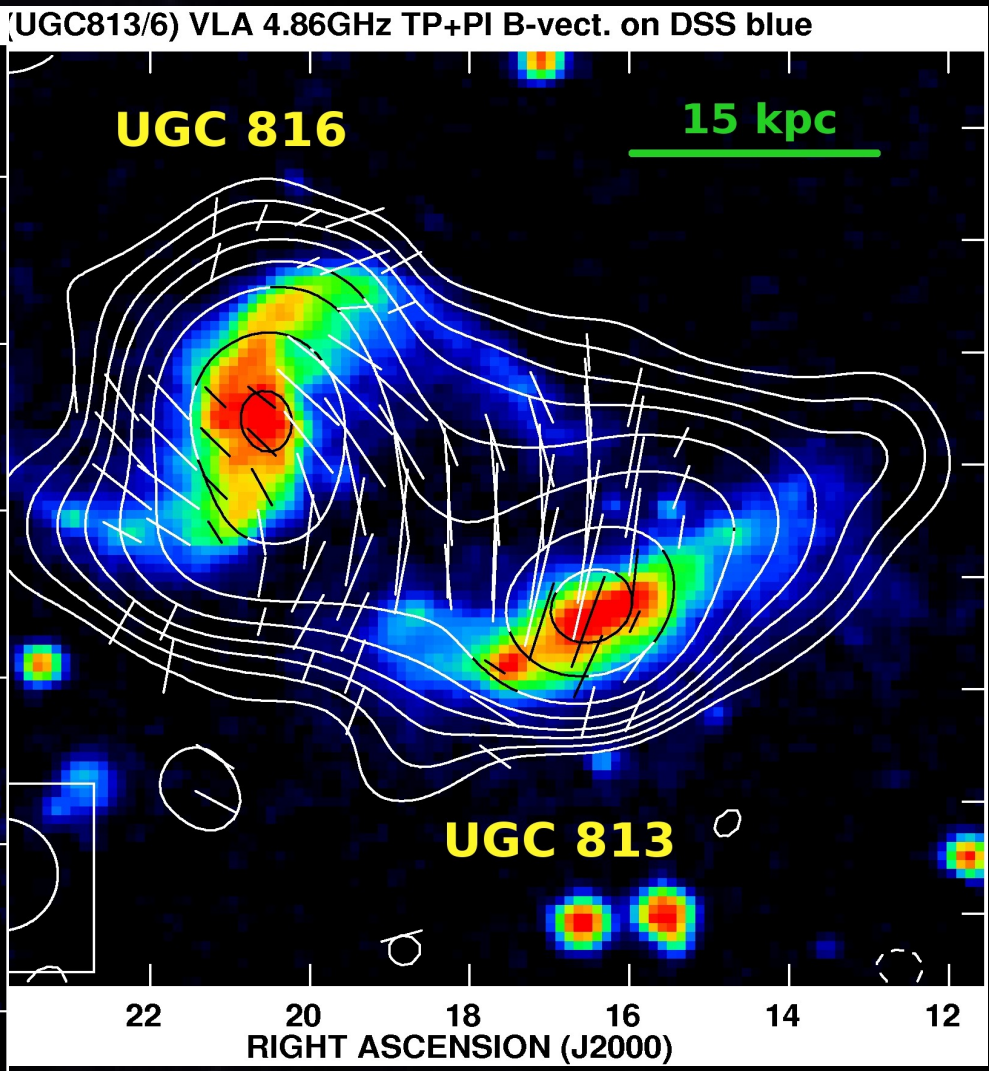
NGC2207/IC2163(IS=-1)



- Magnetic fields in NGC2207 have a spiral structure with small pitch angle
- In the southern part of NGC2207 and in the eastern part of IC 2163 magnetic fields are probably tidally stretched

The Taffy and the Taffy2 (IS=1)





Radio bridges discovered by Condon et al.

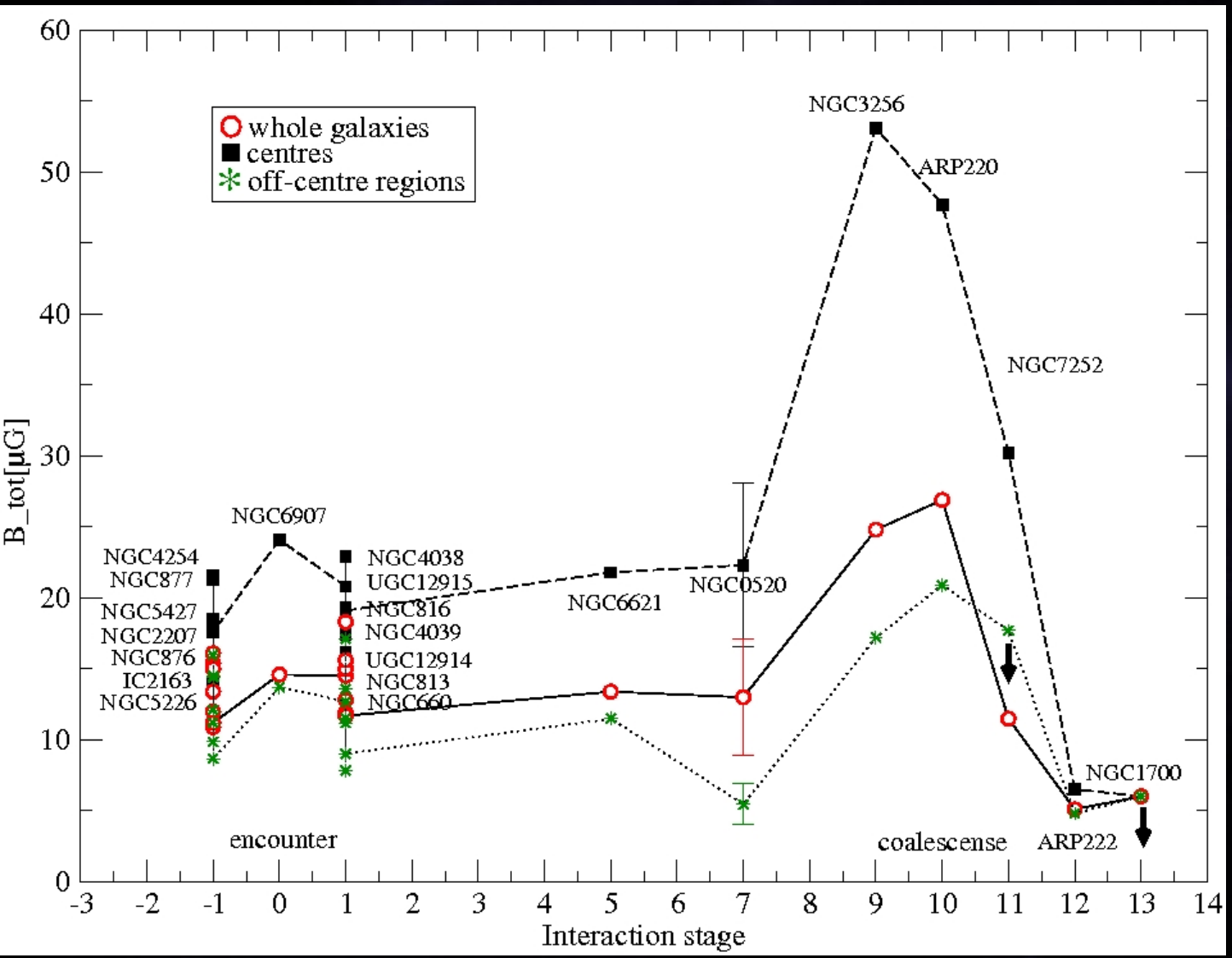
Nearly head-on collision occurred about 10^7 years ago in the Taffy and 5×10^7 years ago in the Taffy2

Magnetic field strengths

Name	B_{tot} [μG]	B_{reg} [μG]	Field Regularity
NGC 4254	15 ± 4	7 ± 2	0.48 ± 0.17
NGC 5426	11 ± 3	3 ± 1	0.32 ± 0.13
NGC 5427	13 ± 4	4 ± 2	0.33 ± 0.13
NGC 876	11 ± 3	2 ± 1	0.21 ± 0.09
NGC 877	15 ± 5	4 ± 2	0.24 ± 0.09
NGC 2207	16 ± 5	6 ± 2	0.39 ± 0.15
IC 2163	12 ± 4	4 ± 2	0.33 ± 0.15
NGC 6907	15 ± 4	3 ± 1	0.23 ± 0.10
UGC 12914	12 ± 4	3 ± 1	0.27 ± 0.11
UGC 12915	15 ± 4	2 ± 1	0.15 ± 0.07
UGC 813	13 ± 4	3 ± 1	0.21 ± 0.09
UGC 816	15 ± 5	3 ± 1	0.19 ± 0.09
NGC 660	16 ± 5	3 ± 1	0.18 ± 0.08
NGC 4038	18 ± 6	4 ± 2	0.24 ± 0.11
NGC 4039	12 ± 4	3 ± 2	0.23 ± 0.12
NGC 6621	13 ± 4	N/A	N/A
NGC 520	13 ± 5	N/A	N/A
NGC 3256	25 ± 8	N/A	N/A
Arp 220	27 ± 7	N/A	N/A
NGC 7252	12 ± 4	N/A	N/A
Arp 222	5 ± 2	N/A	N/A
NGC 1700	<6 ± 2	N/A	N/A

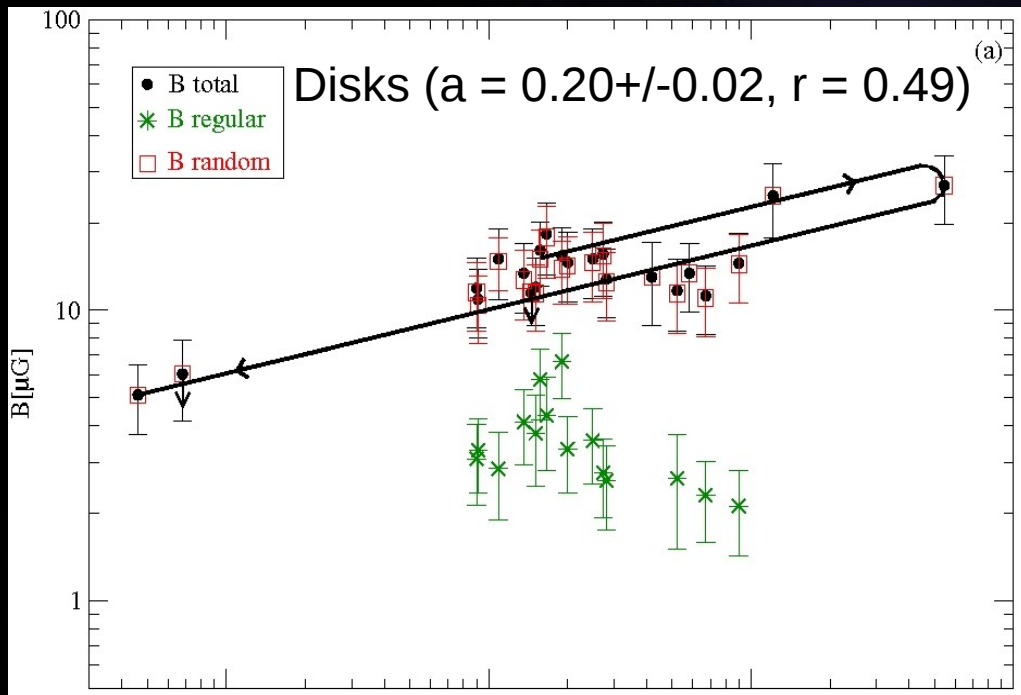
- To estimate magnetic field strengths formulas given by Krause & Beck (2005) are used
- The mean value of magnetic field strength is 14 +/- 5μG (15 +/- 4μG, without Arp222 and NGC1700)
- Niklas et al. (1995) for a sample of 74 galaxies obtained 9μG
- For spiral galaxies a typical strength of the regular component of magnetic field is 2 – 5μG(Beck 2005)
- Typical regularity (Breg/Bran) is about 0.5 (Beck et al. 1996)

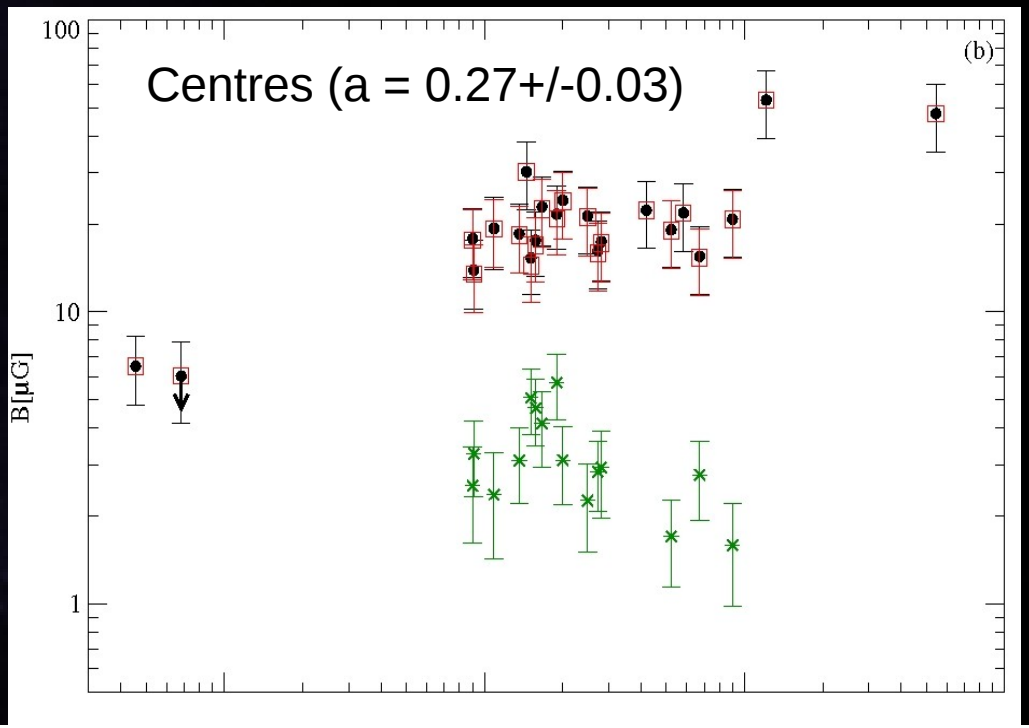
Evolution of magnetic fields in interacting galaxies

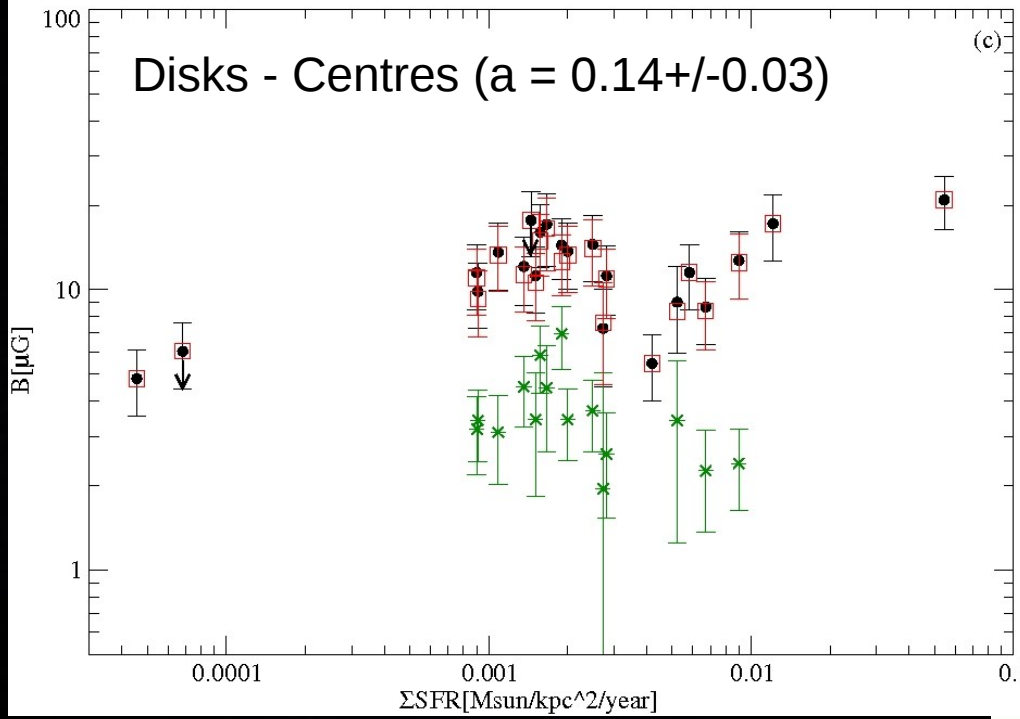


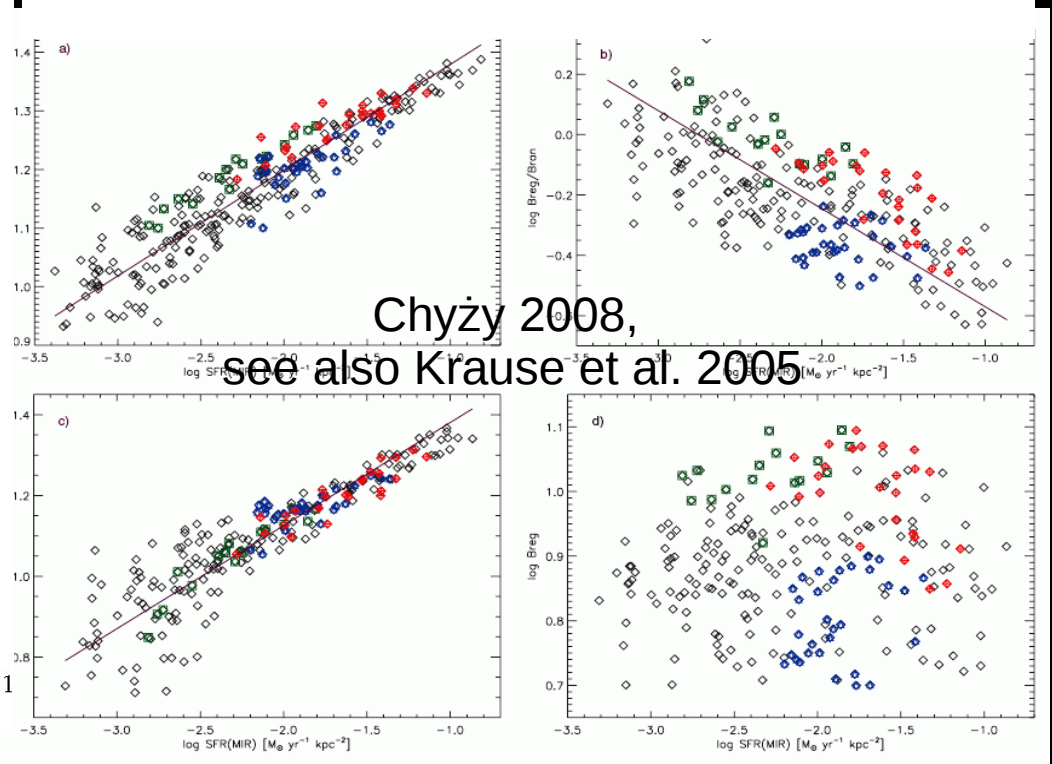
- Major enhancement of magnetic energy occurs at the stage of nuclear coalescence
- After that the process of generation of magnetic fields is terminated
- Agreement with the evolution of the SFE (Georgakakis et al. 2000)
- The strongest evolution is observed for nuclear regions

B vs. ΣSFR



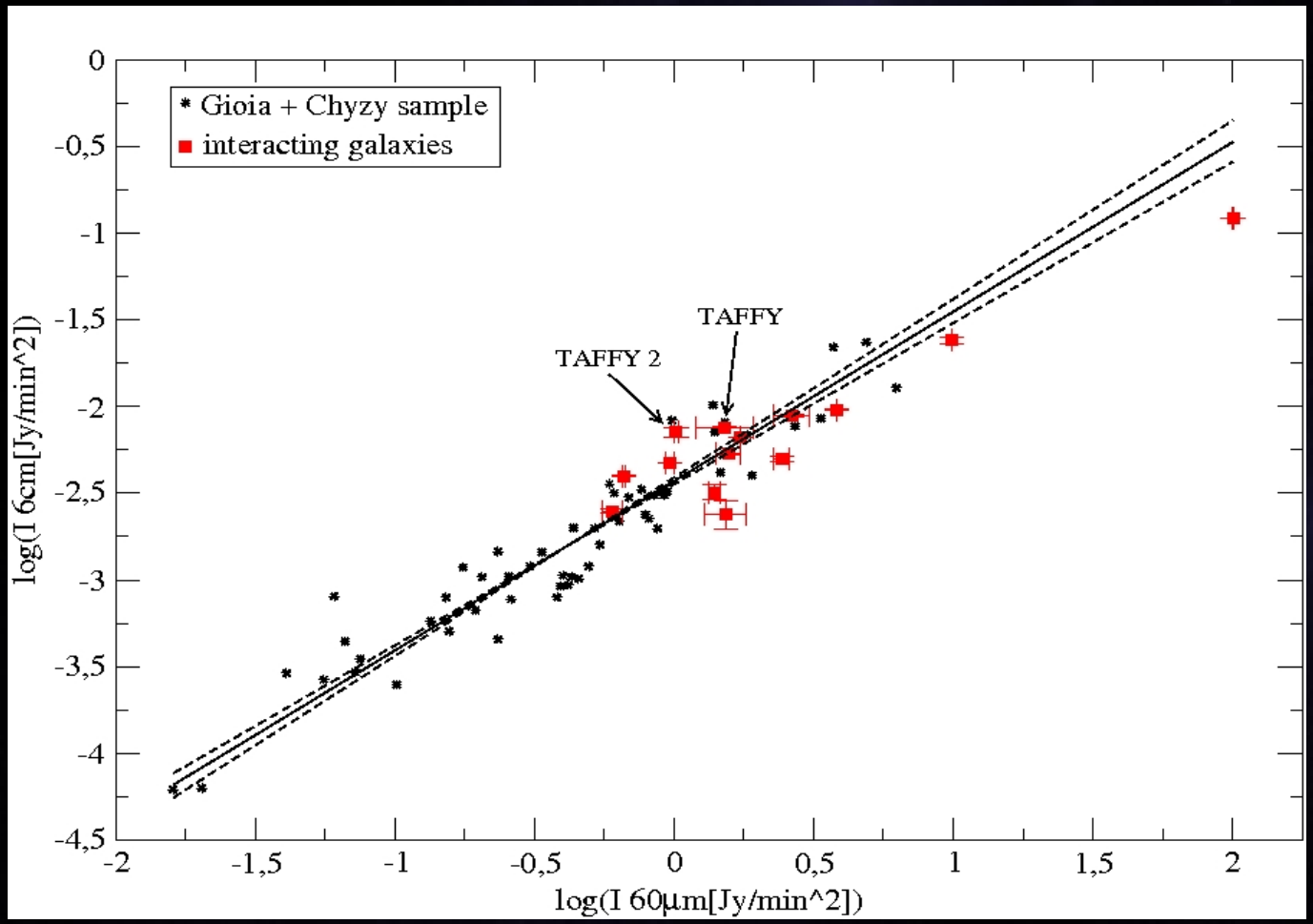






Chyży 2008,
see also Krause et al. 2005

The radio (6cm) – FIR(60μm) correlation

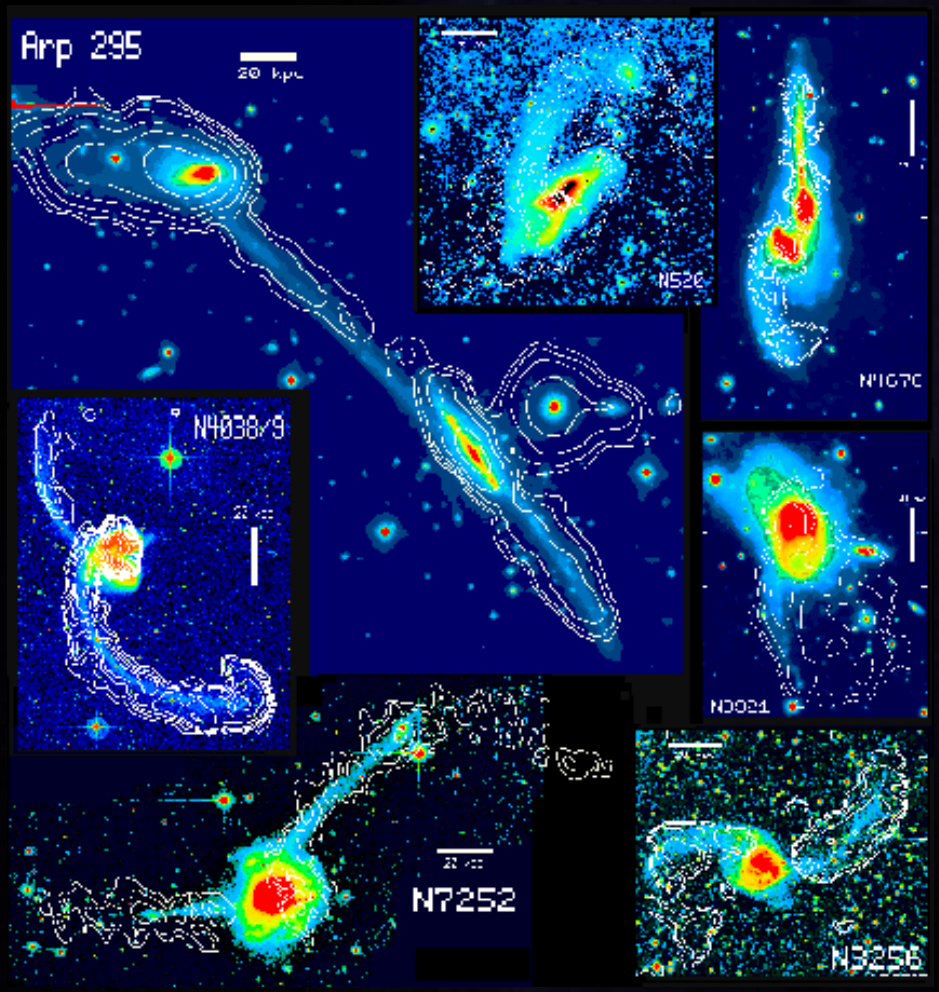


The slope for the normal galaxy sample is 0.98 +/- 0.04

Condon et al. noticed that the Taffy and Taffy2 systems do **NOT** follow the mean radio (21cm) - FIR trend

We do not see this effect for our correlation

The role of interacting galaxies in magnetization of IGM



From: http://www.cv.nrao.edu/~jhibbard/TSeq/TSeq.html

- From observations of TeV and GeV blazars emission it is known that magnetic fields in IGM are stronger than 10^{-15} G and they have a volume filing factor of 0.6 (Tevecchio et al. 2010, Dolag et al. 2010)
- Interacting galaxies were considered as a potential source of IGM field

Our study (based on HI extent) suggests that interacting galaxies are probably sufficient to magnetize only their own surroundings

UHECRs and mergers

B-random			B-regular	
L_{BC} kpc	L_B kpc	B_{ran} μG	L_B kpc	B_{reg} μG
galactic disk				
0.05	10	15	3	10
$\delta = 3.4°$			$\delta = 16°$	
bridge, tidal tail				
0.1	10	15	5	10
$\delta = 4.9°$			$\delta = 23°$	
merger's halo				
2	200	0.1	200	0.01
$\delta = 0.7°$			$\delta = 1.0°$	

- Mergers can be considered as sources of deflecting UHECRs
- The largest deflection angle due to magnetic fields related to interacting objects is ~23 degrees. For these estimations the approach of Neronov & Semikoz (2009) was used

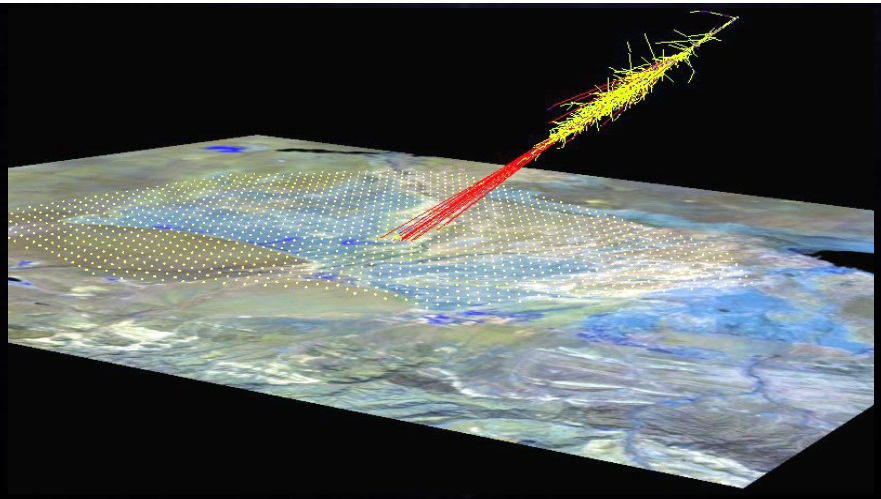


Photo by Cosmus at Univ. of Chicago: R. Landsberg, D. Surendran, and M. SubbaRao

If interacting galaxies generate UHECRs such magnetized outflows can deflect them and make an association of the observed cosmic rays with the sites of their origin very uncertain

Summary & Conclusions

- The estimated mean of total magnetic field strength for our sample of interacting galaxies is 14 ± 5 μG, which is larger than for the non-interacting objects - this seems to be caused by enhanced production of random field component
- For the first time, we show a global evolution of magnetic fields with the advance of interaction process. The main production of magnetic fields terminates somewhere close to the nuclear coalescence. The strengths of magnetic fields in interacting galaxies are controlled by the star formation processes
- The radio – FIR relations constructed for interacting and non-interacting galaxies display similar balance of the generation of cosmic rays and magnetic fields with the production of thermal energy and dust radiation
- Interacting galaxies are probably sufficient to magnetize only their own surroundings. If some UHERCs are generated in merging galaxies the disk or magnetized outflows can deflect them (up to 23^{o}), and make an association of the observed UHECRs with the sites of their origin very uncertain