MAGNETIC FIELDS IN GALAXY MERGERS

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Motivation

In the framework of hierarchical growth of structure in the universe, galaxy interactions are believed to be an essential part of galaxy formation and evolution. Therefore, these events may be expected to provide a non-negligible contribution to the amplification of the galactic and intergalactic magnetic fields on comparatively short timescales.
We present a series of galaxy minor mergers with different initial masses, initial magnetizations and disc orientations. The amplification of a given initial magnetic field within the galaxies and an ambient intergalactic medium (IGM) is investigated focusing on the dependence of the mass ratios, the initial magnetization and the disc orientation of the progenitor galaxies. Also, the evolution of the temperature and the X-ray emission within the merging system is investigated with respect to the initial magnetizations of the progenitor galaxies and the ambient IGM.

Methods

The simulations were performed using the N-body/SPH code GADGET [1]. This code models dark matter and stars as a self-gravitating, collisionless fluid, which is treated by the traditional N-body approach. The intergalactic (IGM) and interstellar (ISM) medium gas is described as a conductive, ideal fluid, whereby hydrodynamics is treated with the SPH method. An additional MHD implementation [2] allows foe the evolution of magnetic fields. The simulations include the effects of radiative cooling, star formation and supernova feedback.

Initial Conditions

Galaxy models

The galaxies are set up using the method described by [3]. This method allows for a galaxy model consisting of a cold dark matter halo, an exponential stellar disc, a stellar bulge (all of these components being collisionless N-body particles) and an exponential gaseous disc (SPH particles).

Orbit

- Merger of largest galaxy M1 with different smaller galaxies
- R_{sep} = sum of virial radii, $R_p = 5$ kpc/h
- Discs collide on a parabolic, prograde encounter

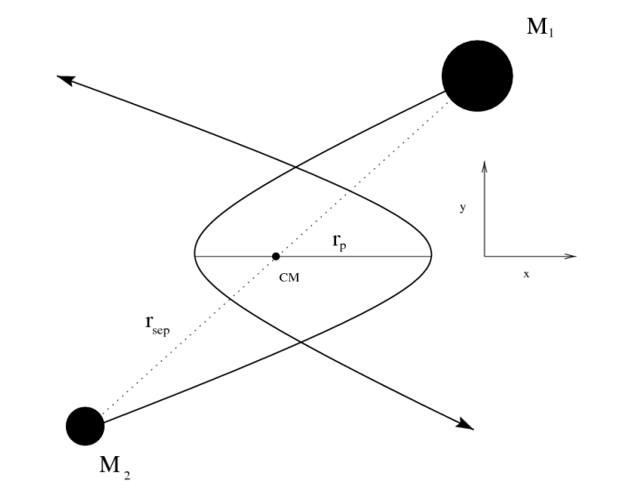

Fig. 1: Parabolic orbit [4]

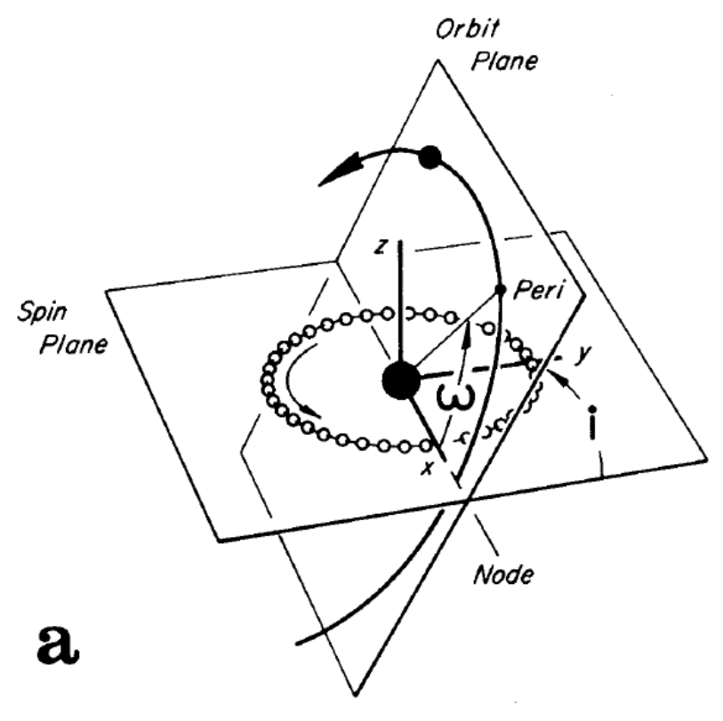

Fig. 2: Disc orientation [5].

- Disc orientation M1: $\omega = 60°$, $\iota = 60°$
- Disc orientation companion: $\omega = -60°$, $\iota = 60°$
- Ambient IGM: gas particles on hcp lattice

Morphological evolution of density and magnetic field

The first encounter takes place at $t \approx 1.3$ Gyr. This encounter is followed by a series of subsequent encounters until the final merger occurs at $t \approx 4$ Gyr.

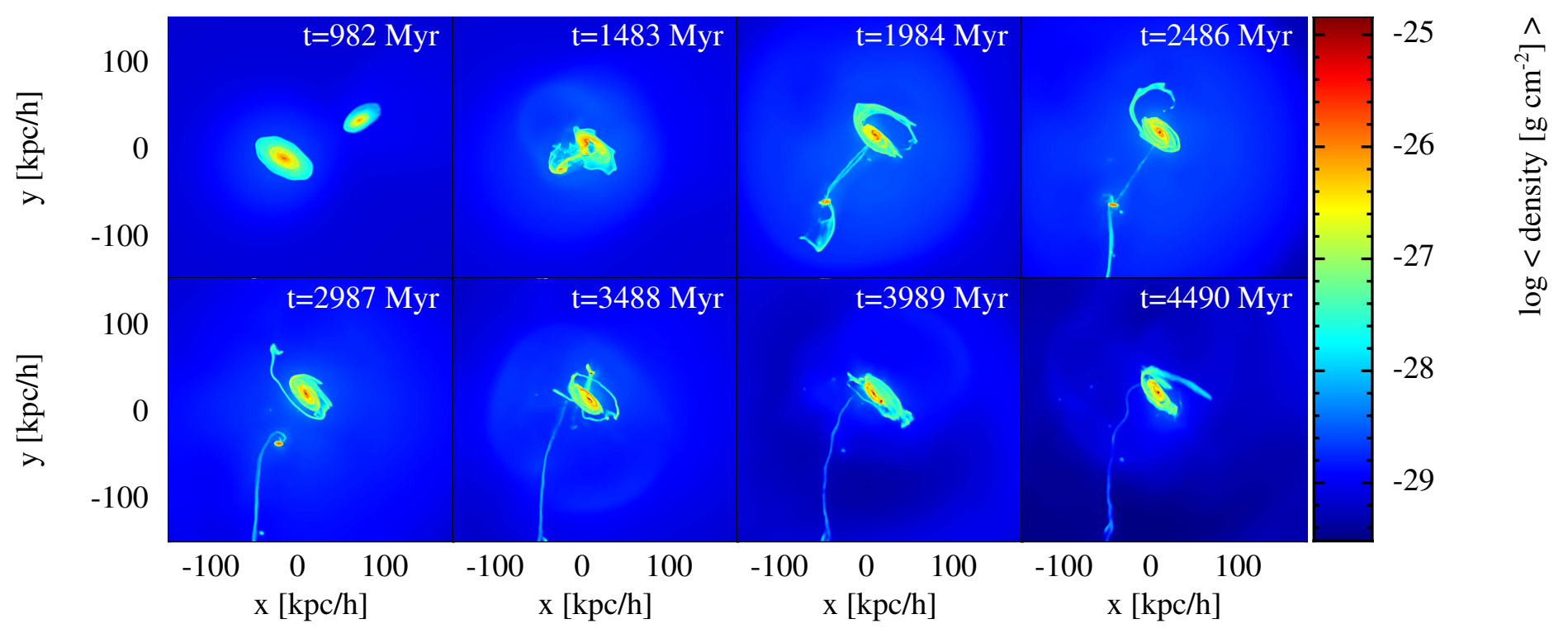

Fig. 3: Mean line-of-sight density for the M1M4_G6I9 scenario [6].

Shocks and interaction-driven outflows caused by the encounters are propagating into the IGM, whereby the IGM magnetic field is strengthened within the shocked regions [cf. 7,8].

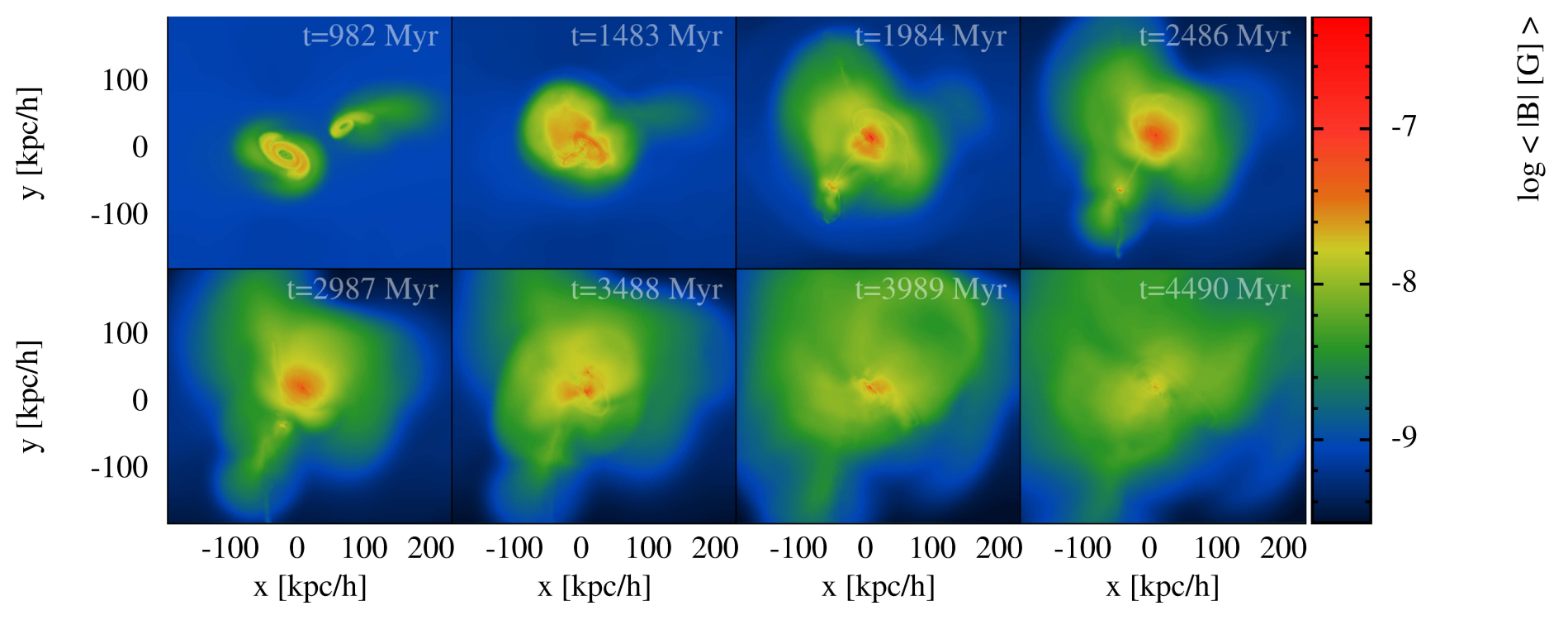

Fig. 4: Mean line-of-sight total magnetic field for the M1M4_G6I9 scenario [6].

Magnetic field evolution

Dependence on mass ratio

- The smaller the companion galaxy, the lower the maximum galactic magnetic field and the flatter the slope of the amplification.
- The magnetic field strength for mass ratios up to 10:1 saturate at values of order μG, whereas scenarios with smaller companion galaxies saturate at values lower than order μG, suggesting that the impact energies for mass ratios higher than 10:1 are not high enough to provide enough energy for conversion into magnetic energy.

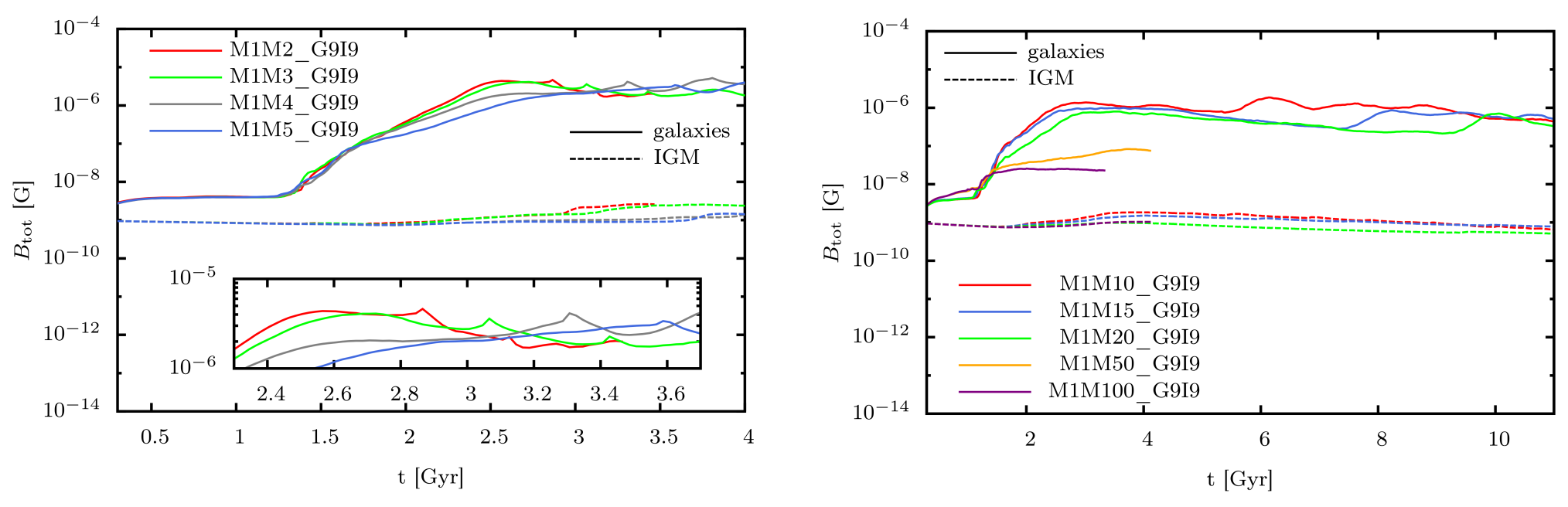

Fig. 5: Total magnetic field as a function of time for the four scenarios with the largest companion galaxies (*left*) and the four scenarios with the smallest companion galaxies (*right*)[6].

Dependence on initial magnetization

- The initial galactic magnetic field of $B_{\text{gal}} = 10^{-6}$ G almost corresponds to the saturation value and thus shows only a slight amplification during the first encounter, whereas the scenarios with $B_{\text{gal}} = 10^{-9}$ G are clearly amplified up to the saturation value, which is in good agreement with previous studies [7,8].
- The IGM magnetic field with an initial IGM magnetic field of $B_{\text{IGM}} = 10^{-12}$ G gets amplified to the IGM saturation value of several 10^{-9} G.

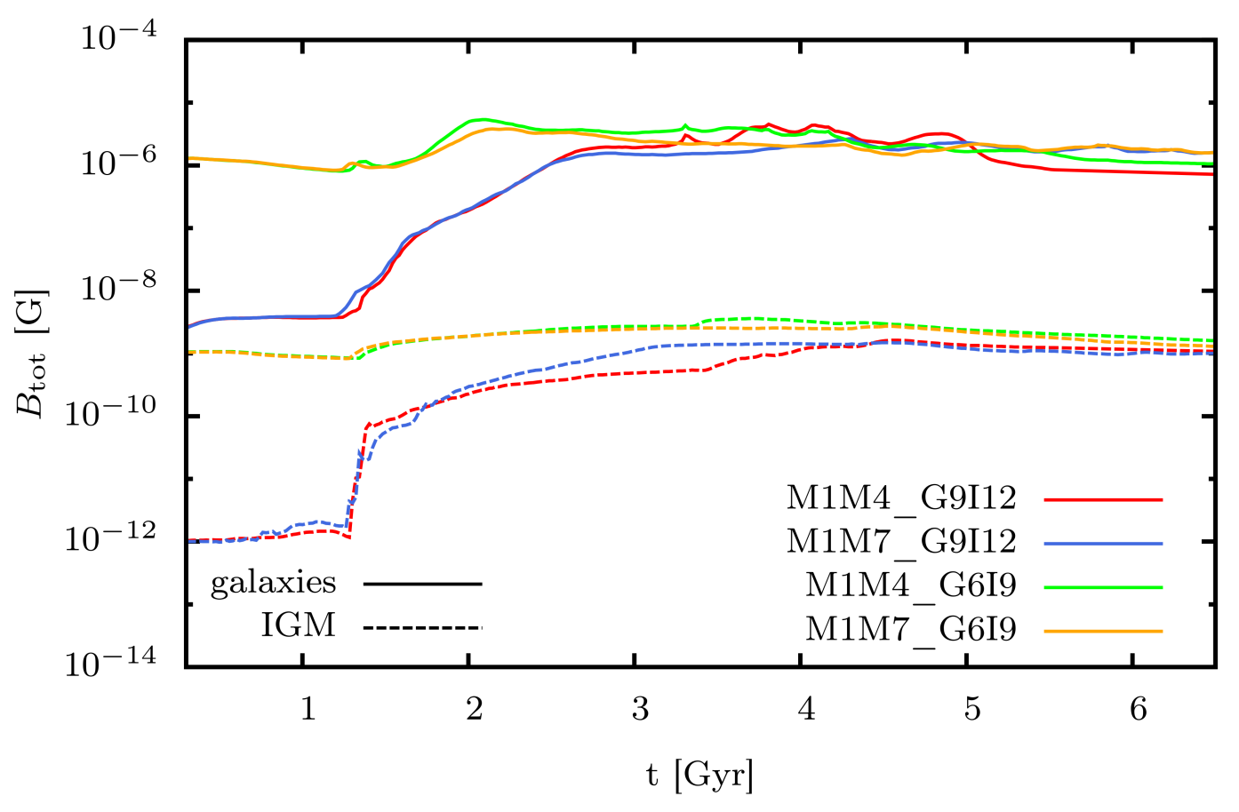

Fig. 6: Total magnetic field as a function of time for scenarios with different initial magnetizations [6].

Dependence on disc orientation

- The evolution of the galactic magnetic field slightly changes for different (prograde or retrograde) disc orientations. The amplification of the galactic magnetic field is slightly more efficient for retrograde scenarios.
- The disc orientation shows only a minor effect on the saturation values of the magnetic field.

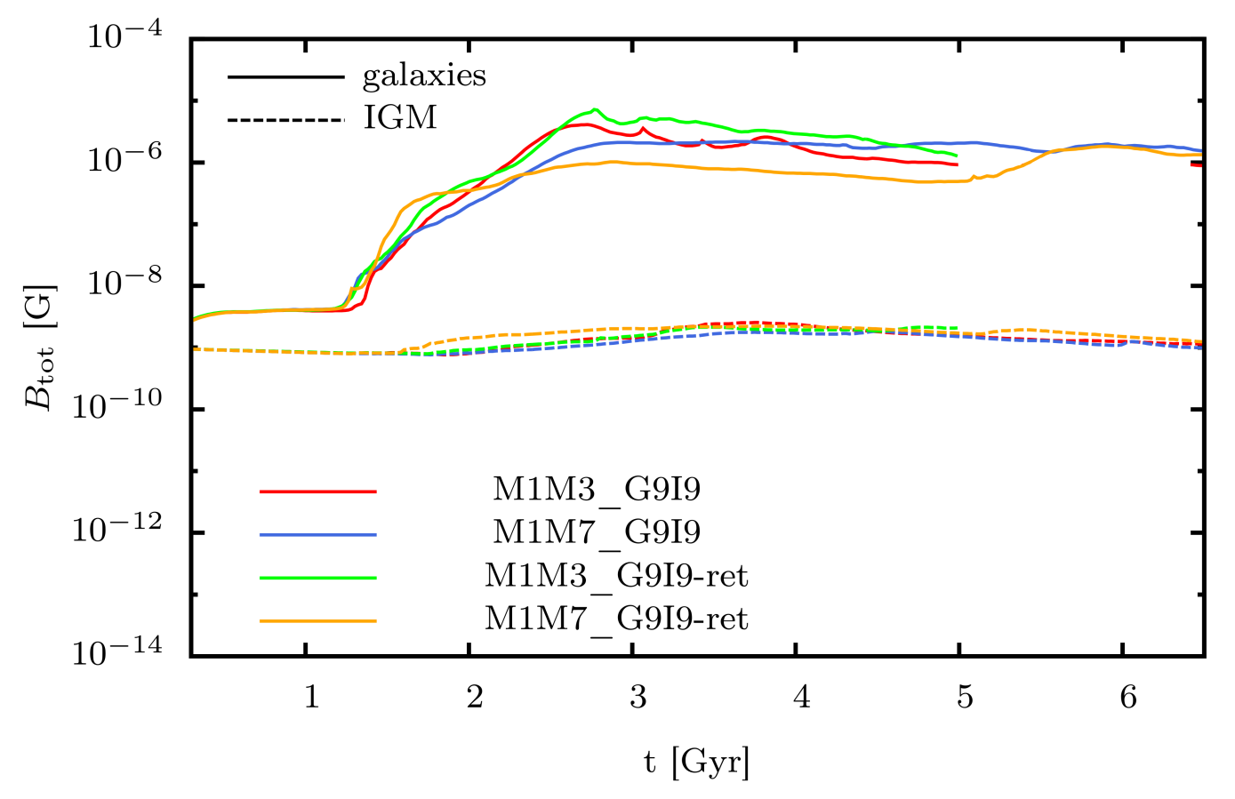

Fig. 7: Total magnetic field as a function of time for scenarios with different disc orientations [6].

Morphological evolution of T and $L_{\text{x, bolo}}$

The shocks and outflows due to the encounters cause a shock-heating of the IGM. After the final merger ($t \approx 1.3$ Gyr), the IGM gas slowly cools down again.

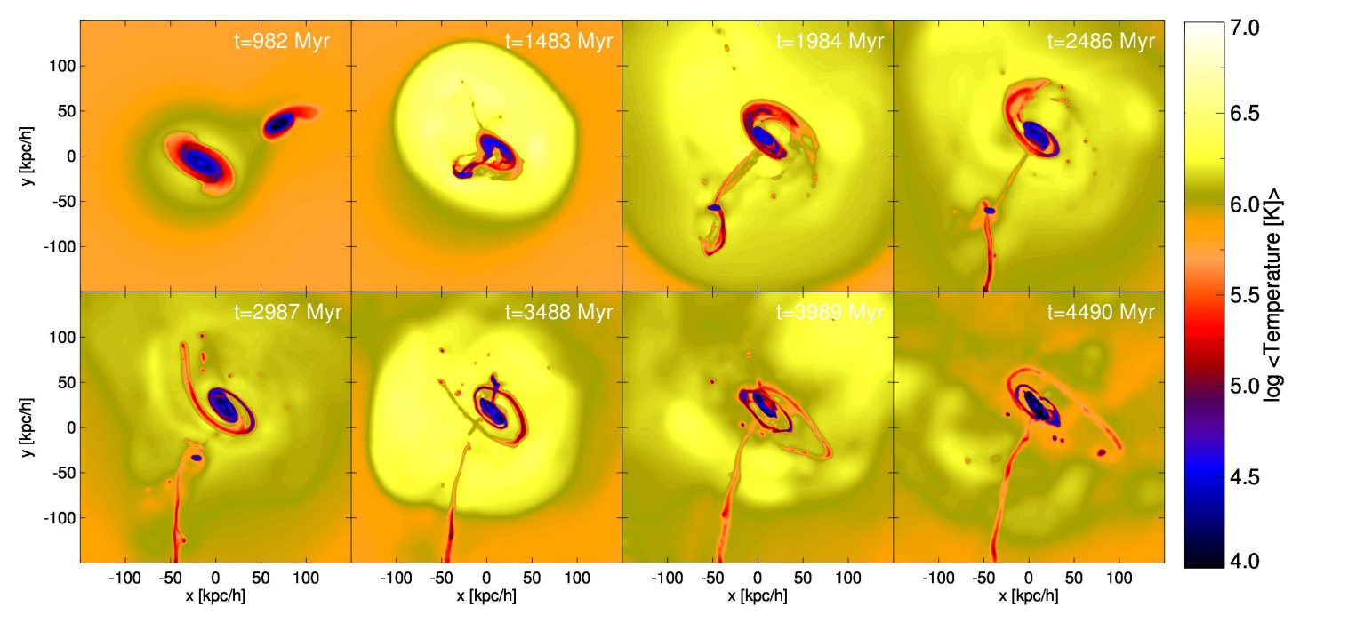

Fig. 8: Evolution of mean line-of-sight temperature [6].

The X-ray emission evolves simular to the temperature and is calculated according to [9]:

$$L_{\text{x, bolo}} = 1.2 \cdot 10^{-24} \frac{1}{(\mu m_{\text{p}})^2} \sum_{i=1}^{N_{\text{gas}}} m_{\text{gas},i}\, \rho_i \left(\frac{k_{\text{B}} T_i}{\text{keV}}\right)^{1/2}.$$

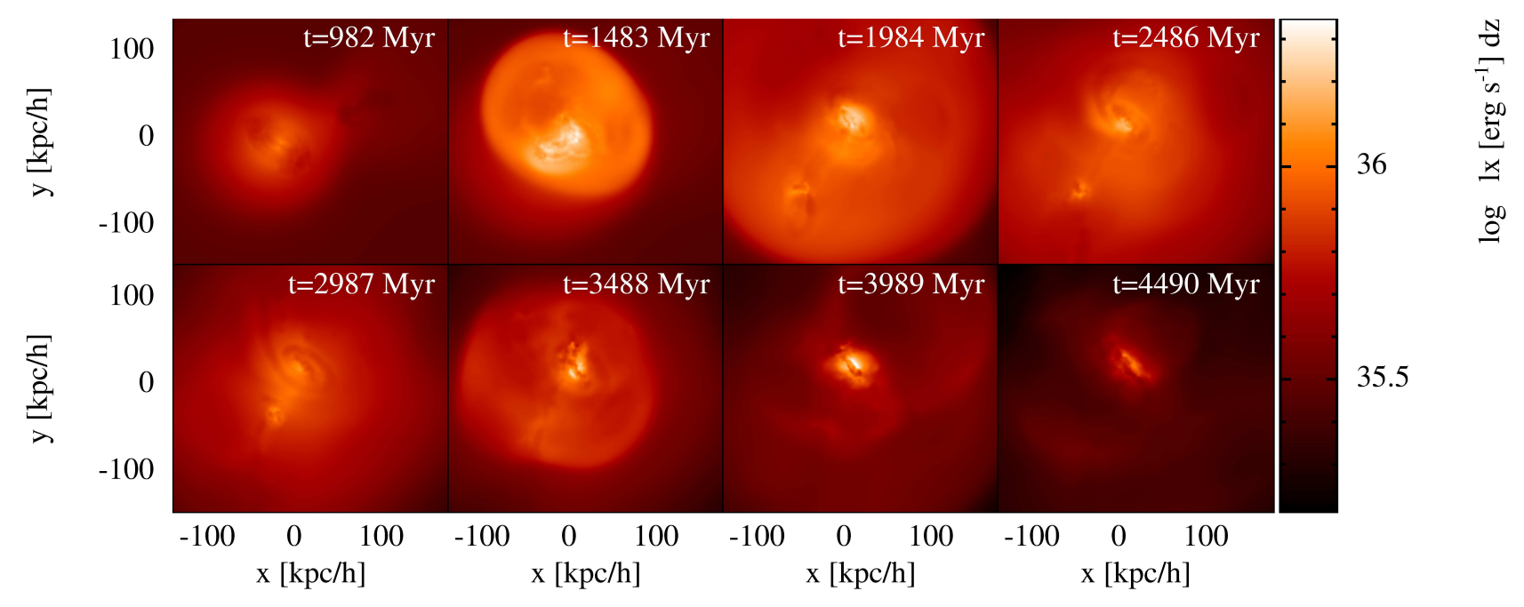

Fig. 9: Evolution of line-of-sight X-ray emission [6].

Temperature evolution and X-ray emission

A magnetic fields seems to have both a positive and a negative feedback on the X-ray luminosity:

- A higher magnetic field results in a more efficient shock-heating of the IGM [cf. 7]. Consequently, the X-ray luminosity is higher within recently shock-heated regions.
- A higher magnetic pressure leads to a more efficient dilution of the shock-heated regions, resulting in lower gas densities and thus lower X-ray luminosities.

Given the different dependence of $L_{\text{x, bolo}}$ on T and ρ, the negative feedback is more important in the long run. Consequently, we find lower final X-ray luminosities for higher initial magnetizations.

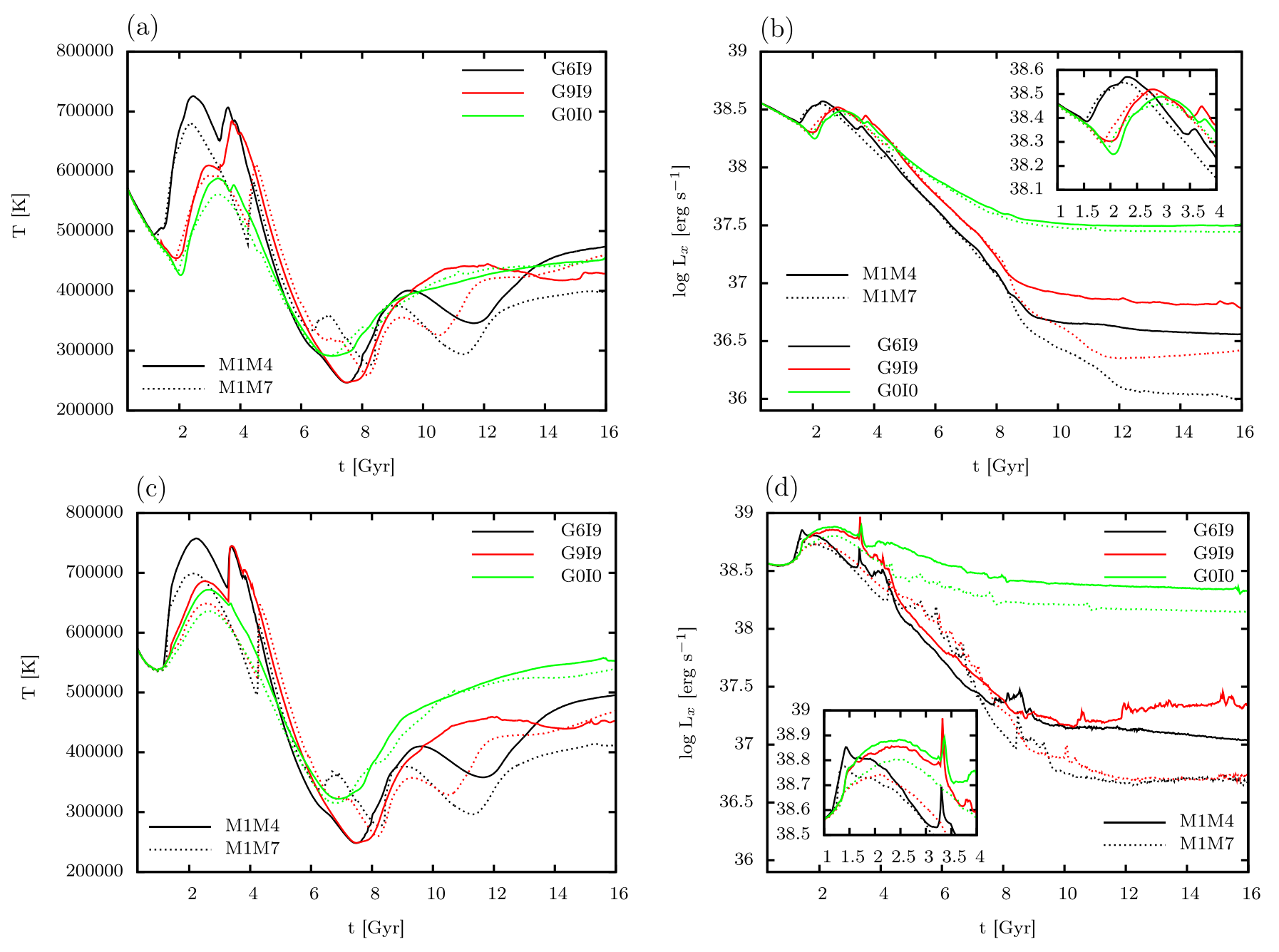

Fig. 10: Mean temperature (a&c) and bolometric X-ray luminosity (b&d) [6].

Outlook

In order to gain a more complete picture of the evolution of magnetic fields within galaxy mergers, it would be interesting to focus on mergers of more complex interacting galactic systems and also on mergers of dwarf galaxies. These studies would be worthwhile for a better understanding of the overall processes of the magnetic field amplification caused by galaxy formation and interaction events today and in the history of the universe.

References

[1] V. Springel, MNRAS, 364, 1105 (2005)
[2] K. Dolag, F. Stasyszyn, MNRAS, 398, 1678 (2009)
[3] V. Springel, T. Di Matteo, L. Hernquist, ApJ, 620, 79 (2005)
[4] T. Naab, PhD thesis, University of Heidelberg (2000)
[5] A. Toomre, J. Toomre, ApJ, 178, 623 (1972)
[6] A. Geng, H. Kotarba, F. Bürzle, K. Dolag, F. Stasyszyn, A. Beck, P. Nielaba, MNRAS, submitted
[7] H. Kotarba, H. Lesch, K. Dolag, T. Naab, P. Johansson, J. Donnert, F. Stasyszyn, MNRAS, tmp, 921 (2011)
[8] H. Kotarba, S. Karl, T. Naab, P. Johansson, K. Dolag, H. Lesch, F. Stasyszyn, ApJ, 716, 1438 (2010)
[9] J.F. Navarro, C.S. Frenk, S.D. White, MNRAS, 275, 720 (1995)