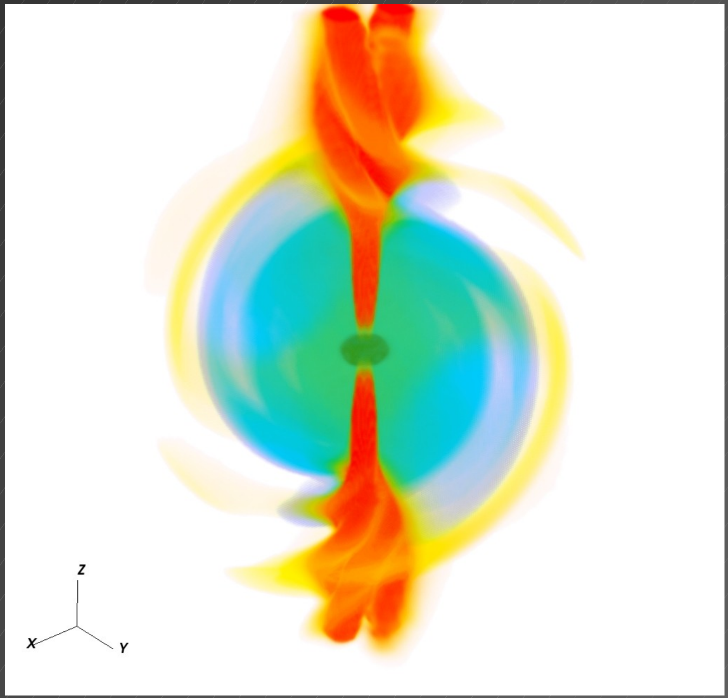
Dual Jets from binary BHs



CITA@25

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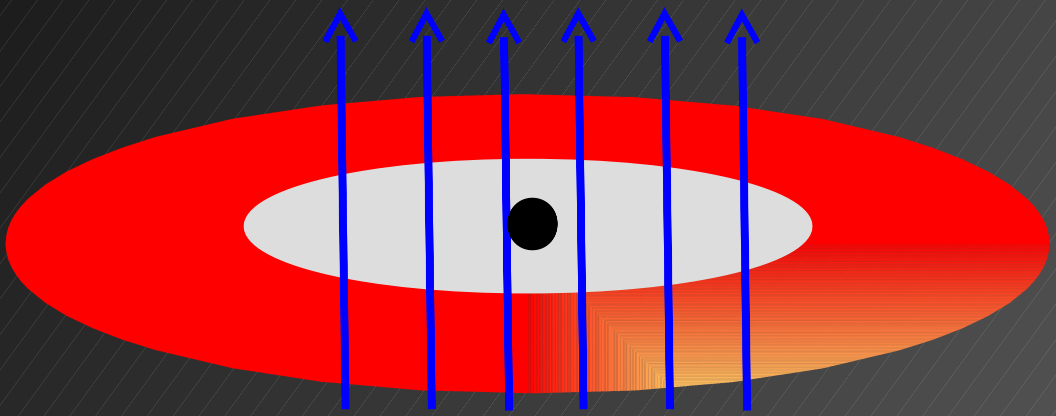
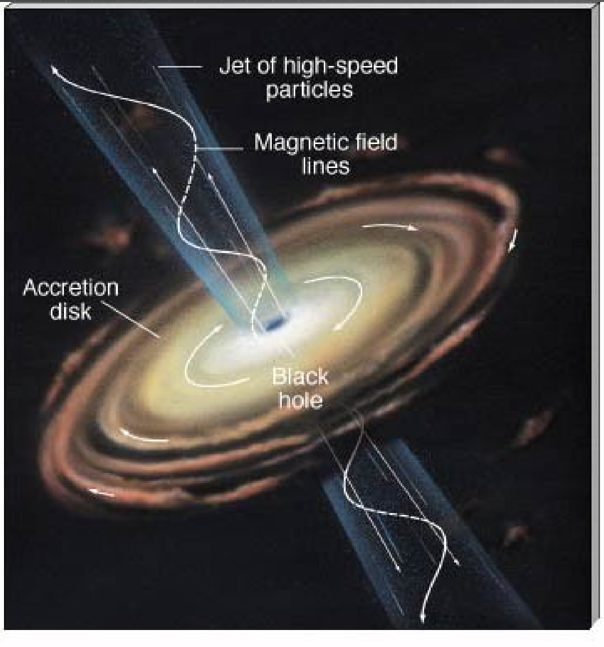
Motivation : merger of galaxies

-observations indicate the presence of supermassive BHs in the center of galaxies, surrounded by gas and an accretion disk

- in the Active Galactic Nuclei (AGN), the BHs are surrounded by a disc of matter likely magnetized. For a $M=10^8 M_\Theta$

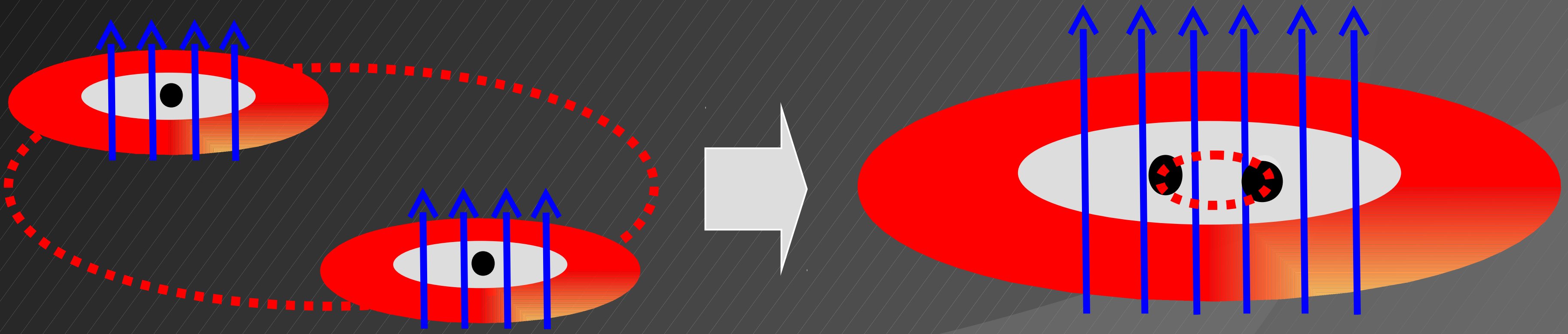
  * bounded by the jets : $B_0 < 10^4$-10^6 G (near the BH)
  * Eddington magnetic field : $B_0 \sim 10^5$ G





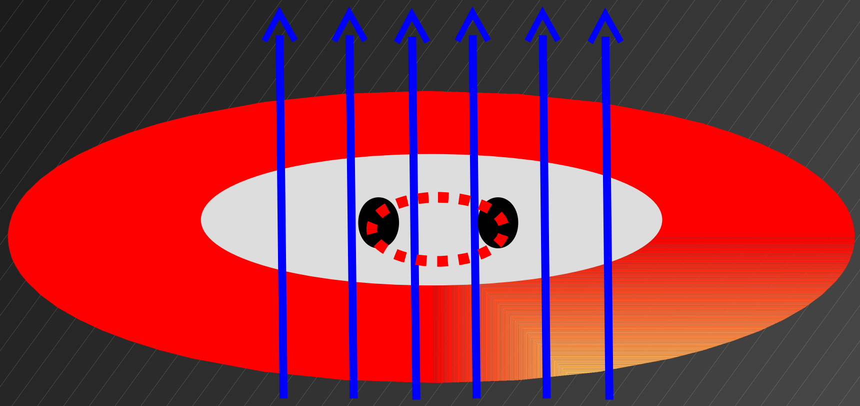
Motivation : merger of galaxies

- the galaxies have undergone some mergers
- during the merger, the binary BH hollows the surrounding gas while their orbit shrinks, forming a circumbinary disk (Milosavljevic & Phinney, Astrophys. J. 622)
- eventually, the dynamics of the binary is dominated by GW



Motivation : merger of galaxies

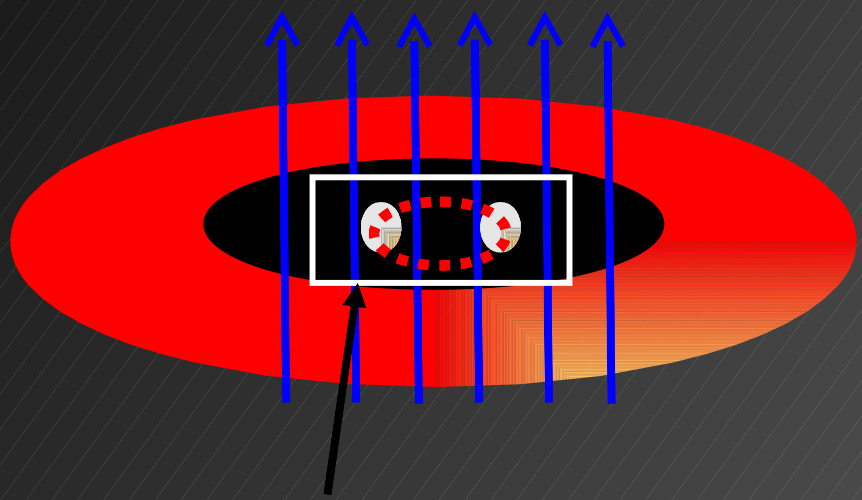
- the luminosity of the disk is modified by the binary BH dynamics
- the merger can enhanced some Blandford-Znajeck mechanism
- study the correlations between GW & EM radiation
- study systems with both bands to extract more information



- General Relativity for the evolution of the spacetime
- Maxwell equations for the evolution of the EM fields
- Hydrodynamics for the evolution of the plasma
- Radiation processes due to the accretion, disk dynamic..

Motivation : pre-merger effects

- before/during the merger (CP et al. , 2010):
 * study the effects of the binary BHs dynamics in the EM fields and the radiation produced at the merger



- sub-domain with the BHs, excluding the disk

- General Relativity for the evolution of the spacetime
- Maxwell equations for the evolution of the EM fields
- Force-free approximation for the plasma
- ~~Radiation processes due to the accretion, disk dynamic…~~

The Einstein-Maxwell system

- Einstein equations (see Abdul's and Harald's talks)

$$R_{ab} - R\, g_{ab}/2 = 0 \qquad\qquad R_{ab} = R_{ab}\,(\partial_{cd}\, g_{ab}, \partial_c\, g_{ab}, g_{ab})$$

- Maxwell equations , with F the Maxwell tensor
  I the current 4-vector

$$\nabla_a F^{ab} = -I^b \qquad\qquad F^{ab} = n^a E^b - n^b E^a + \varepsilon^{abc} B_c$$

$$\nabla_a {}^*F^{ab} = 0 \qquad\qquad \partial_t E - \nabla \mathrm{x} B = -J\,,\ \nabla \cdot E = q$$

$$\partial_t B + \nabla \mathrm{x} E = 0, \quad \nabla \cdot B = 0$$

The force-free approximation

- If B and the black hole spin are large enough ($B \approx 0.2$ T for $M \approx 10^8 M_\Theta$, $a>0.7$), the induced E will accelerate charged particle to high enough energies that will radiate photons decaying into electron-positron pairs.
- The time average of this cascade process will be a magnetosphere full of a tenuous plasma, which can support charges and currents but with negligible inertia

$$\nabla_a T^{ab} = 0 \quad \rightarrow \quad \nabla_a T^{ab}_{(fluid)} = -\nabla_a T^{ab}_{(em)} = -F^{ab} I_a$$

$$\text{if} \quad \rho, P << B^2 \quad \text{then} \quad \nabla_a T^{ab}_{(fluid)} << F^{ab} J_a \approx 0$$

$$\mathbf{E} \cdot \mathbf{J} = 0 \quad , \quad q\,\mathbf{E} + \mathbf{J} \times \mathbf{B} = 0 \;\rightarrow\; E \cdot B = 0$$

The Blandford-Znajek mechanism

- By using these conditions, we can compute the electromagnetic energy flux

$$F_E = 2\,(B^r)^2\,\Omega_F\,r\left(\frac{a}{2\,M\,r} - \Omega_F\right)\,sin^2\theta$$
$$-\;B^r\,B^\phi\,\Omega_F\,\Delta\,sin^2\theta.$$

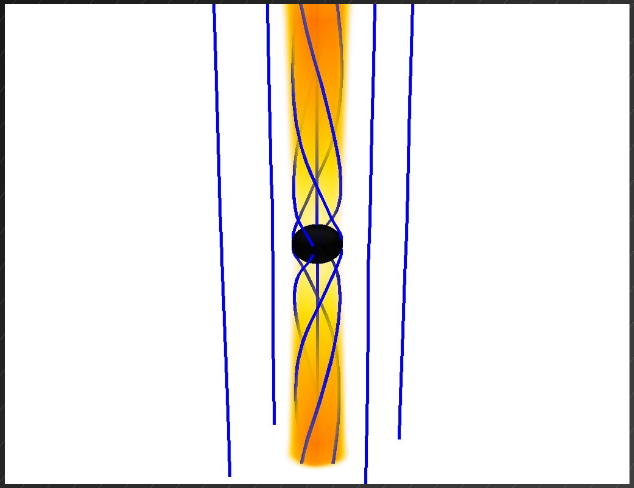
- at the AH, $\Delta=0$ and we define the rotation frequency of the BH like $\Omega_H = a/(2*M*r_H)$

$$F_E\big|_{r=r_H} = 2\,(B^r)^2\,\Omega_F\,r_H\,(\Omega_H - \Omega_F)\,sin^2\theta.$$

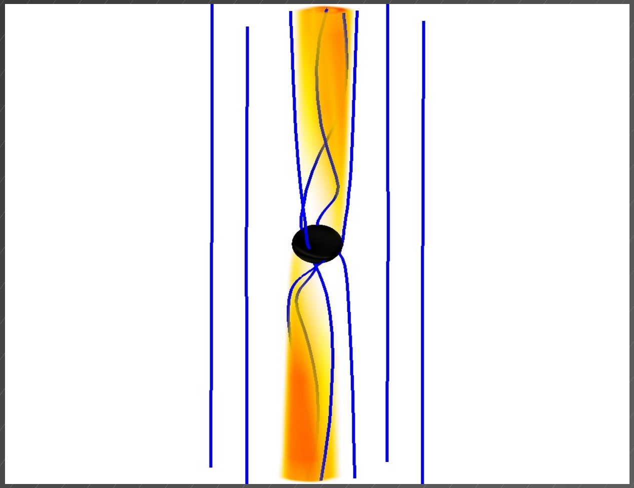
so if $B^r>0$ and $0<\Omega_F<\Omega_H$, there will be an outward energy flux at the AH

Single black holes

- There is a rotation of the EM field lines and an extraction of energy → Blandford-Znajek mechanism



a = 0.99, angle =0



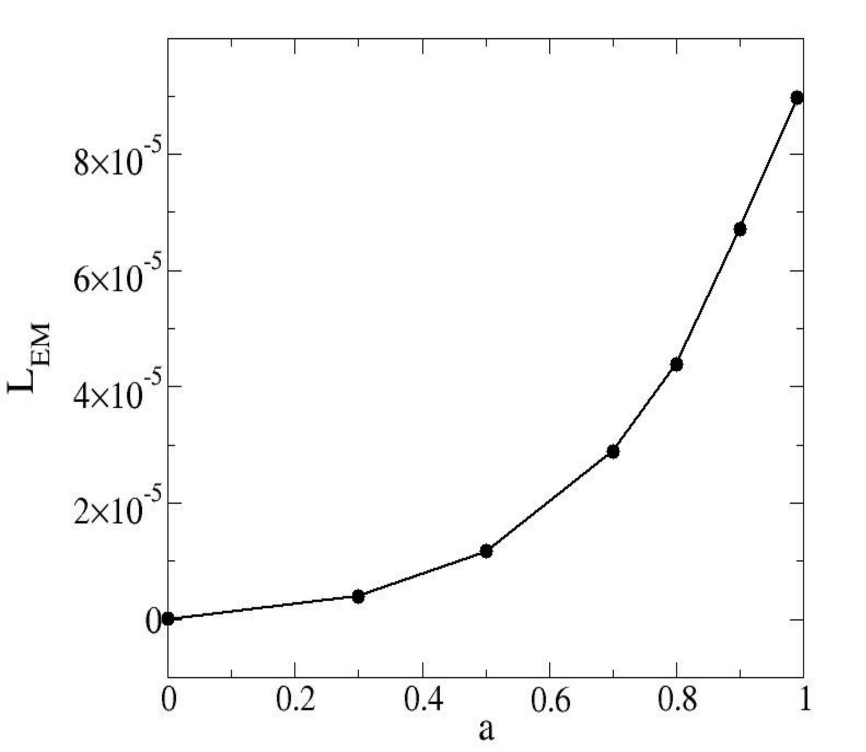
a = 0.99, angle = 45°

$M = 10^8 M_\Theta$, $B = 10^4$ G

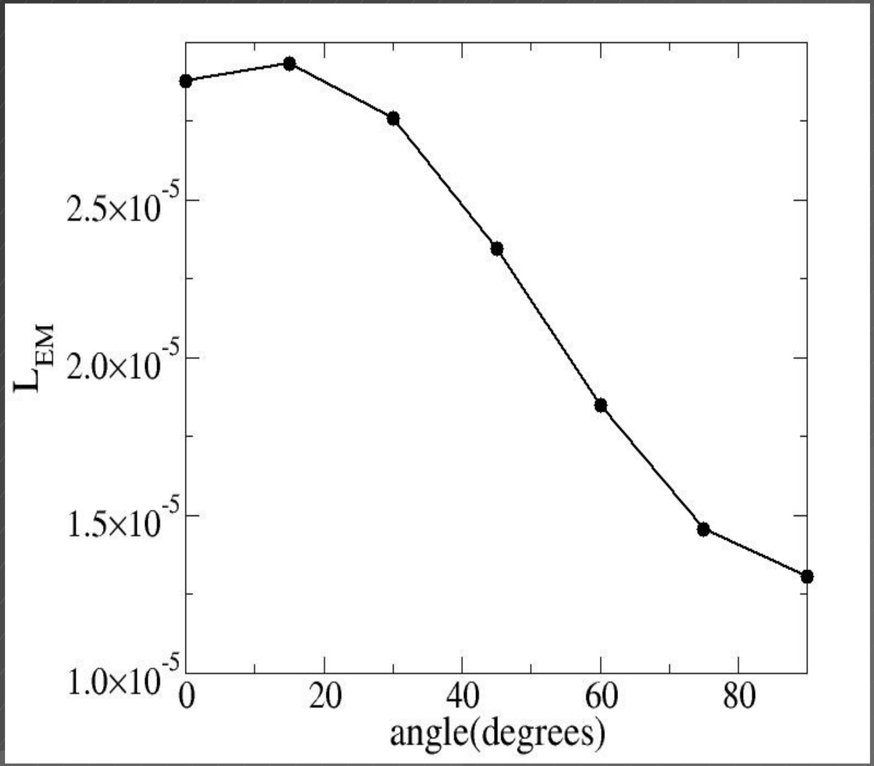
Single black holes

- The radiated power as a function of

the spin

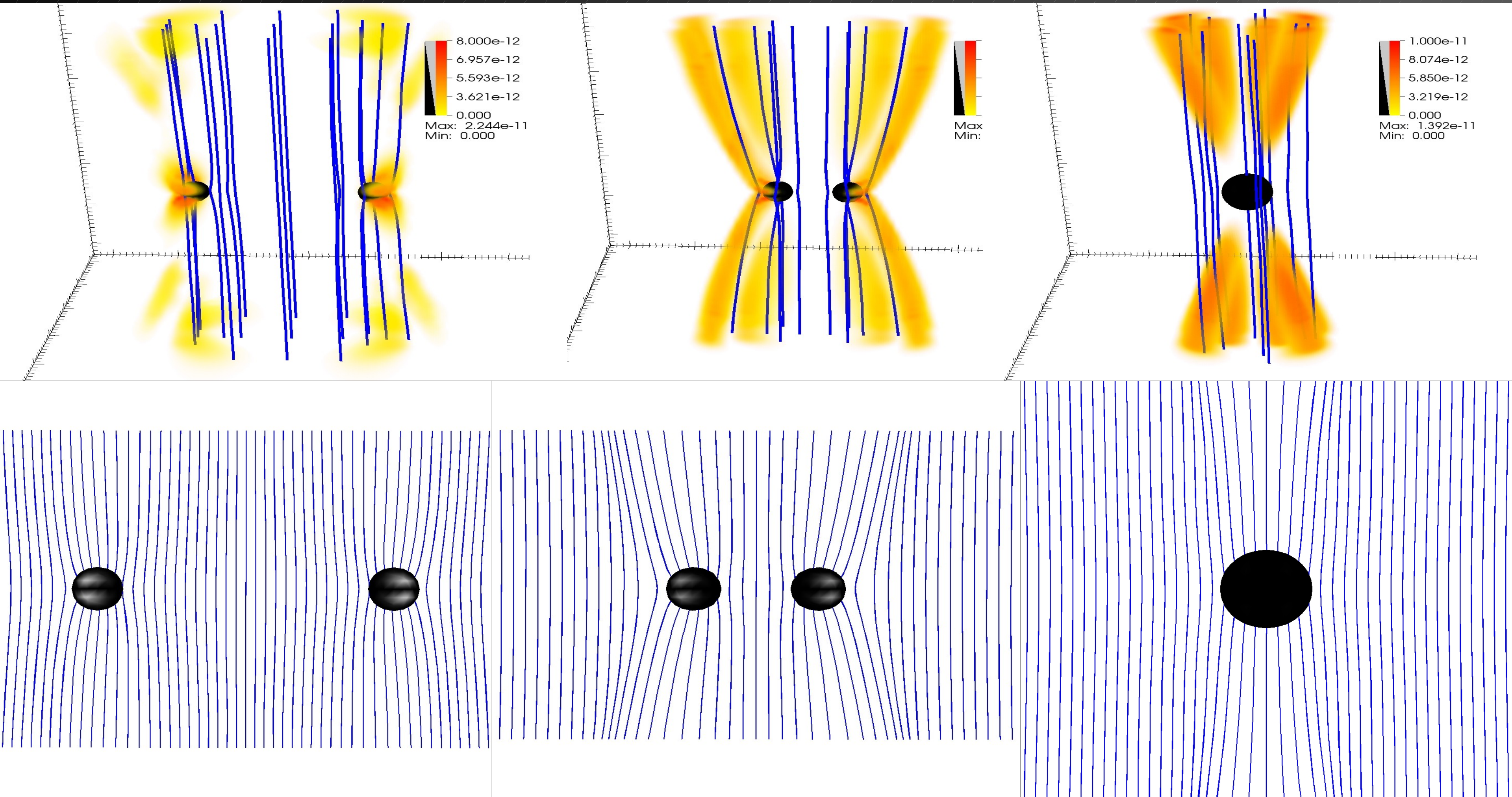


the inclination angle



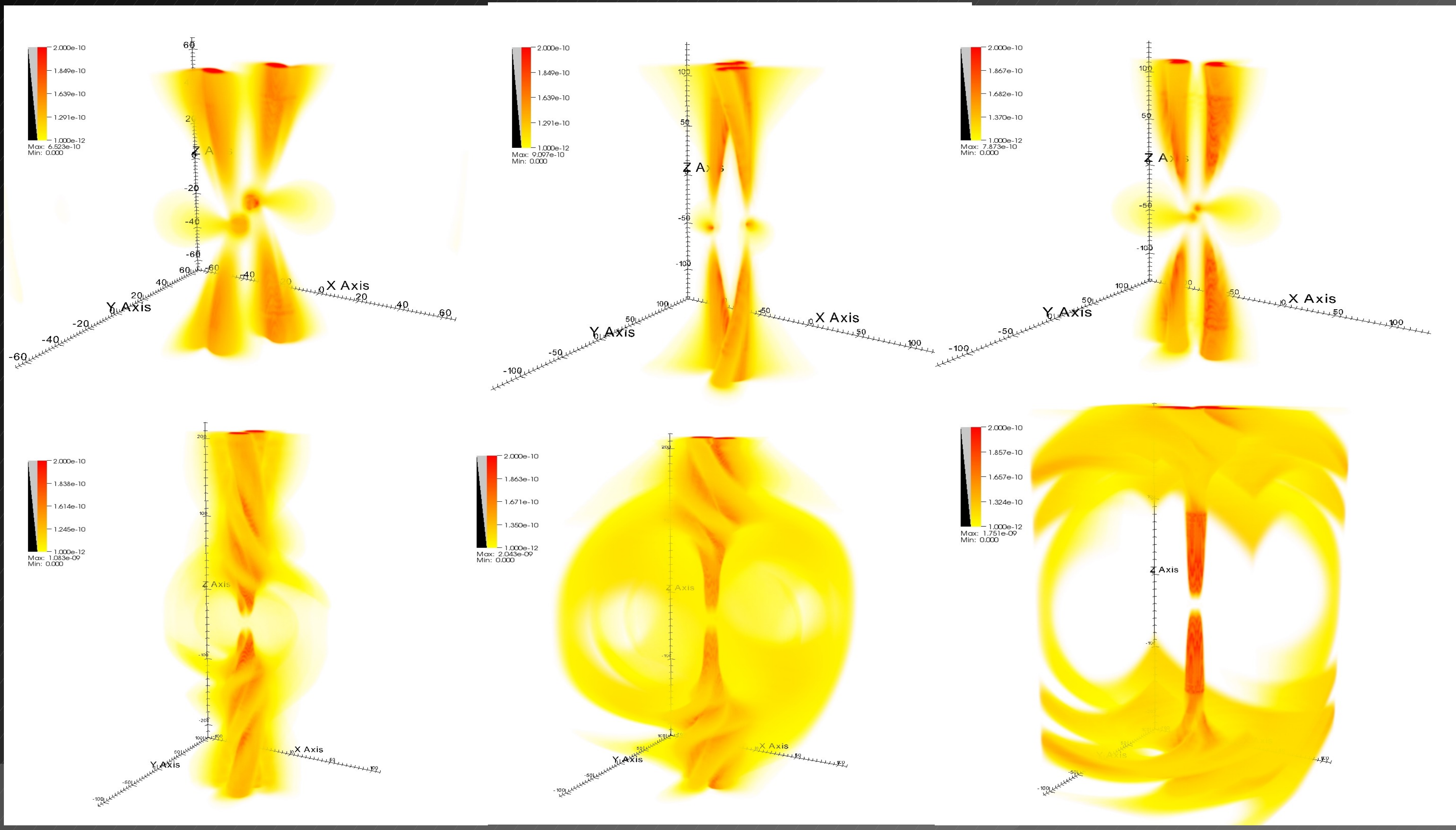
Binary black holes : head on

- The EM radiation propagates along the magnetic field lines



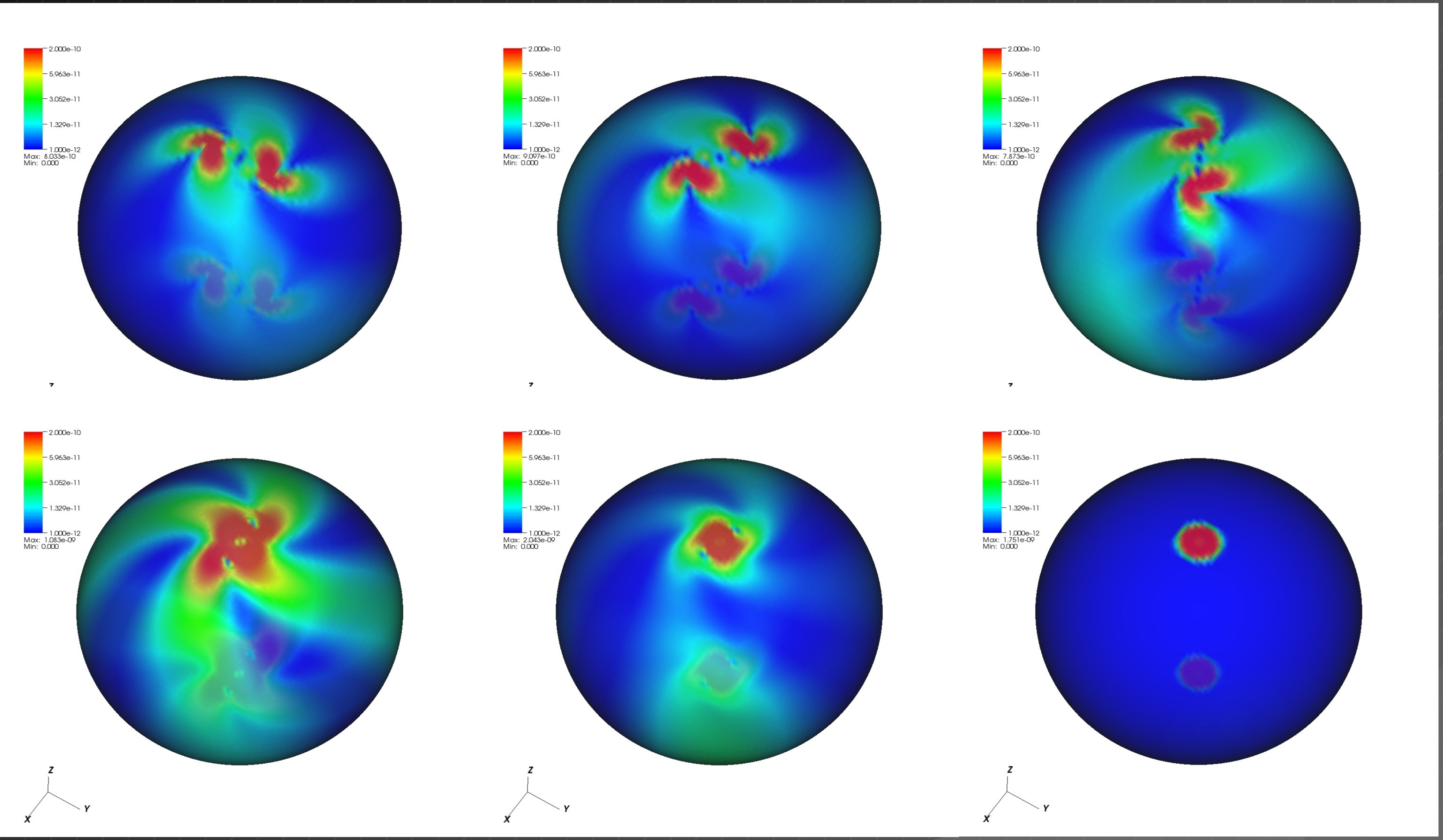
Binary black holes : inspiral-merger

- The EM radiation is collimated !!



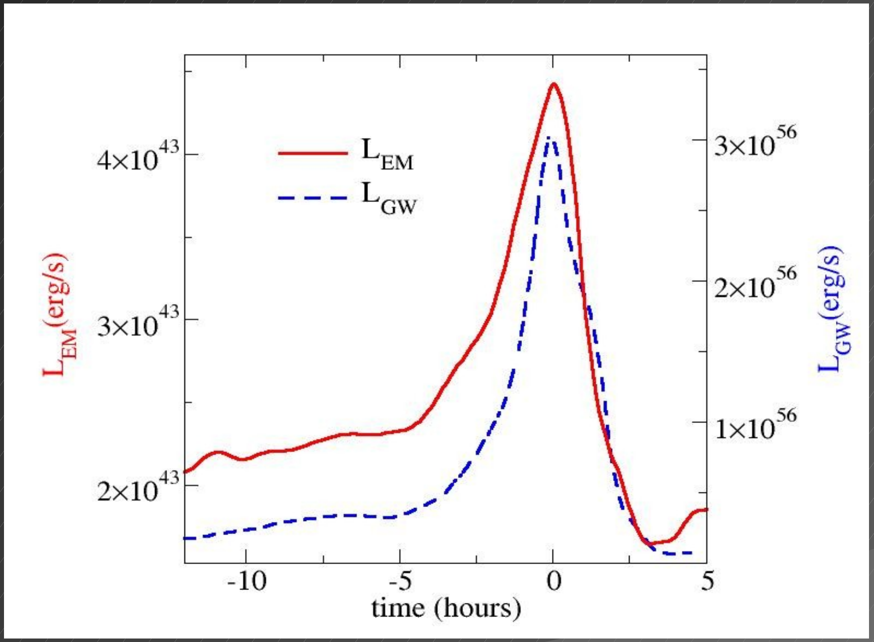
Binary black holes : inspiral-merger

- Transition for m=2 to m=0 (decays to Blandford-Znajek)



Binary black holes : inspiral-merger

• The EM power ~ $(B\Omega\, R)^2$, while the GW power ~ $M^2R^4\Omega^6$.
• A significant amount of EM energy is radiated days/weeks before the merger, while most of the GW is emitted during the last day



Summary

- we have evolved EE + Maxwell + force-free to study the effects of the binary BH dynamics on the EM fields

- EM energy radiation even if the BHs are not spinning.

- Persistent collimated EM radiation, enhanced at the merger

- Future steps :
    * consider spinning cases
    * go beyond the force-free approximation
    * include a realistic disk model
    * include radiation....