Electromagnetic counterpart to the coalescence of binary black holes

Raphaël Mignon-Risse[1], Peggy Varniere[2], Fabien Casse[2], Alexis Coleiro[2]

Email : raphael.mignon-risse@apc.in2p3.fr

[1]Université Paris Cité, CNRS, CNES, Astroparticule et Cosmologie, F-75013 Paris, France

[2]Université Paris Cité, CNRS, Astroparticule et Cosmologie, F-75013 Paris, France

WHY OBSERVING BINARY BLACK HOLES?

Black holes are ubiquitous in the Universe: stellar-mass black holes represent the ultimate fate of massive stars, while supermassive black holes are located at the center of most galaxies (including our own, the Milky Way !), with whom they co-evolve. The merger of supermassive binary black holes (SMBBH), like the merger of their host galaxies, is a typical event in the history of the Universe. Because BHs do not emit light, they are only observable via the plasma they accrete (i.e. they attract). Observing the light-emitting plasma around SMBBHs would tell us about:

- **how plasma behaves in strongly curved and dynamical spacetimes and how valid is General Relativity, our theory of Gravitation**
- **how the merger of two black holes can drive extreme events of gas inflow/outflow having an impact on the entire galaxy**
- **how black holes and galaxies evolve and grow.**

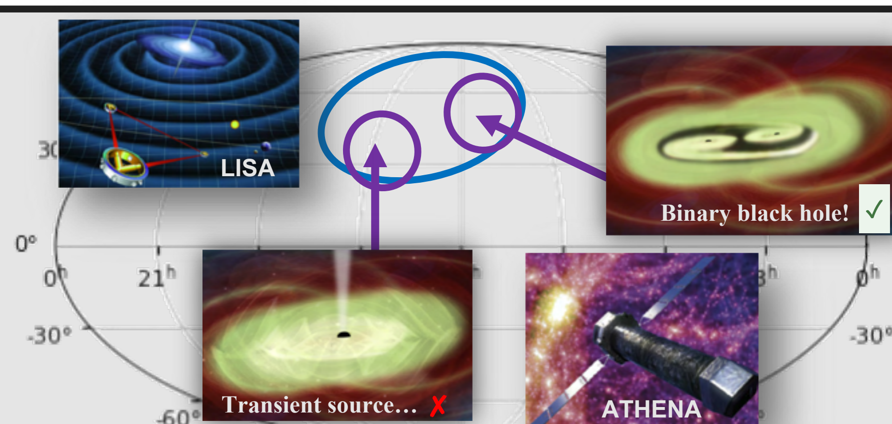
To date, such a detection has never been performed.

THE PROBLEM

Good news first: CNES is involved in the Athena mission (2030+), an X-ray (0.5-12keV) satellite with unprecedented sensitivity and high spectral resolution, and in the space-based interferometer LISA (2030+) that will detect the gravitational waves, i.e. a perturbation of spacetime, due to coalescing SMBBHs. A joint Athena-LISA detection would lead to ground-breaking discoveries (see above). The question is :

How to distinguish binary black holes from other transient sources (e.g. single black holes) in LISA's error box based on their X-ray (for Athena) or more generally their electromagnetic emission ?

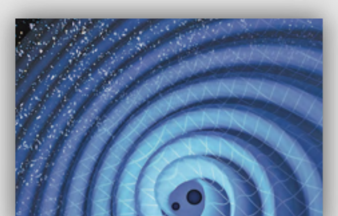
➢ **We need to model the fluid around binary black holes to identify its electromagnetic signatures**



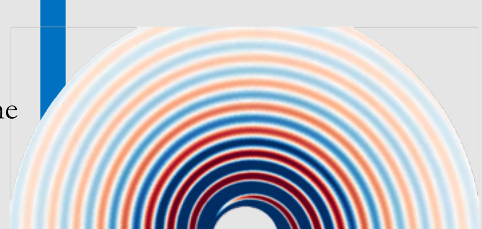
THE TOOL: A NUMERICAL OBSERVATORY

- A fluid simulation code generalized to work in any spacetime (e.g. dynamical spacetimes)
- A ray-tracing code which follows the propagation of photons from the source to a distant observer: us
- The implementation of an approximate binary black hole spacetime in both codes

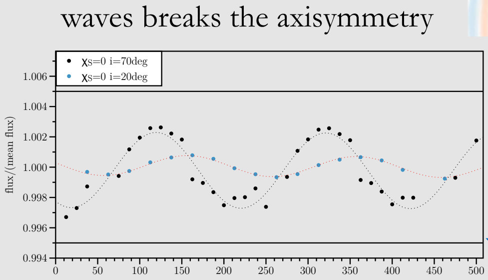
RESULTS #1 : GRAVITATIONAL WAVES LEAVE AN IMPRINT IN THE PLASMA OUTER DISK SURROUNDING THE BINARY



Outgoing gravitational waves accounted for in the binary black hole spacetime



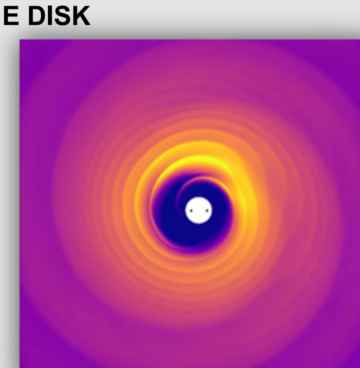
Fluid simulation: the response of the disk (i.e. density variations) to the spacetime curved by gravitational waves breaks the axisymmetry



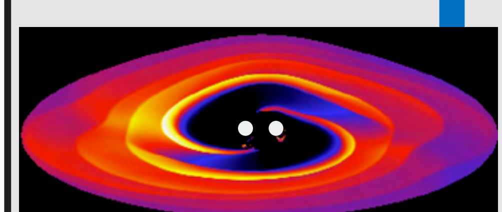
Ray-tracing step: The disk lightcurve (i.e. total flux as a function of time) exhibits a modulation a the semi-orbital period, higher for highly-inclined disks

RESULTS #2 : A STRONG ASYMMETRY FORMS IN THE INNER REGIONS OF THE DISK

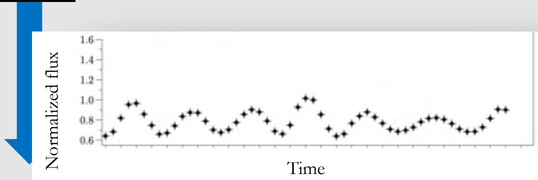
Fluid simulation: formation of structures typical of binary black holes environment: cavity, streams, **overdensity**



Ray-tracing step: i) those structures affect the emission map



ii) the overdensity strongly modulates the electromagnetic emission!



CONCLUSIONS: HOW TO DISTINGUISH BINARIES FROM SINGLE BLACK HOLES?

1. Gravitational waves emitted by binary black holes affect the system's disk, breaking its axisymmetry. As a result, **the outer disk lightcurve is modulated**
2. The inner regions of the disk are strongly impacted by the binary's gravitational field. **An overdensity forms and modulates the lightcurve**

PERSPECTIVES: WHAT WOULD ATHENA SEE?

These lightcurves need to be processed to include the instrumental noise of Athena to see whether those electromagnetic signatures are strong enough to allow one to distinguish a binary from a single black hole.