Stellar collisions

GW-, EM radiation and the cosmic ladder argument

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A brief outlook

- Context: **Stellar collisions are important.**
- Collisions are mimickers:

  Different implications on different spectra.
- Multimessenger probes:
  - **In all the electromagnetic spectrum.**
  - **In GWs.**
  - **They produce shocks and accelerate particles.**
  - **And should be a way to produce neutrinos.**
- Potential observations: **One case looks interesting.**

  (No claims made).

What I'm going to show and not show.

- This was a lengthy paper of some

  32 pages, with over 140 equations and 33 plots.
- I'm going to flash some figures **and do a lot of talk.**
- I'm NOT presenting the whole paper today

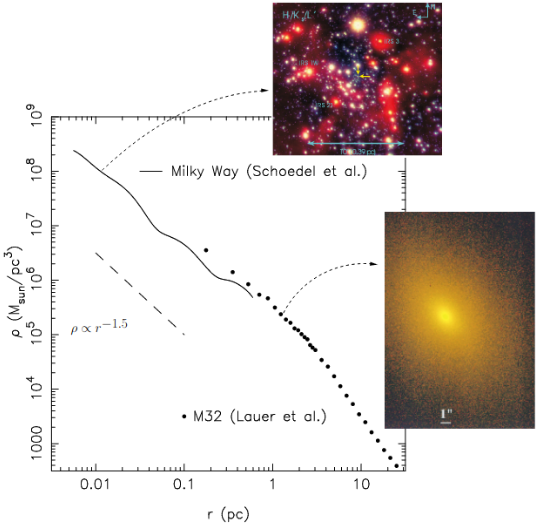
  because that would make me persona non grata.
- I will show no equations **and do a lot of handwaving.**
- This is a completely analytical paper

  but numerical simulations are on-going and agree with the analytical results.

Two regimes and two kind of sources

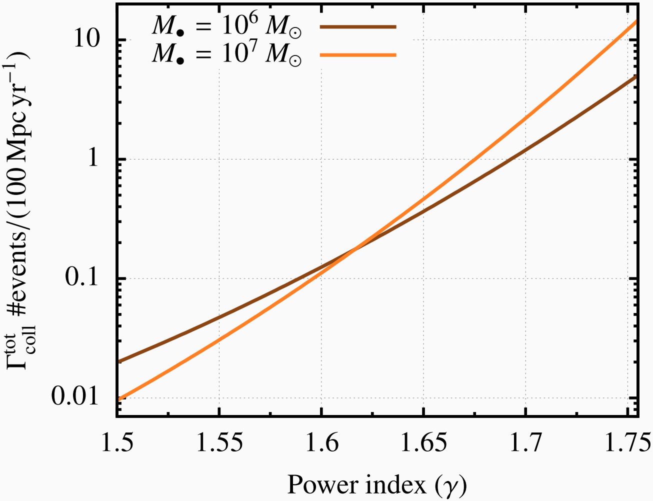
- High-velocity sources, $\sim 10^4$ km/s **are completely destructive.**
  - We "only" have a full electromagnetic signature.
- The electromagnetic description **is valid for both MS and RGs.**
- Lower velocity sources, $\sim 10^3$ km/s **allow cores of MS stars to survive.**
  - This is important, because they form a GW source.
- Red giants **are the most promising source.**
  - Their degenerate cores are a perfect GW source and produce an afterglow.

Stellar densities around supermassive black holes



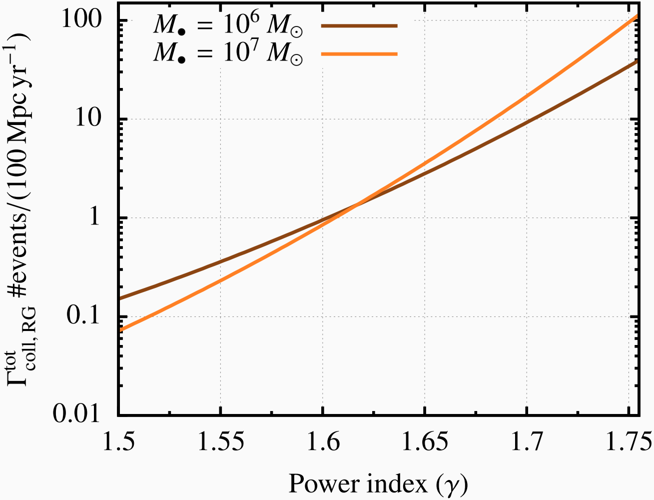
[Amaro Seoane 2018, based on Merritt 2006, Schoedel 2002, Lauer 1998]

Rates MS-MS collisions



[Amaro Seoane, accepted ApJ 2023]

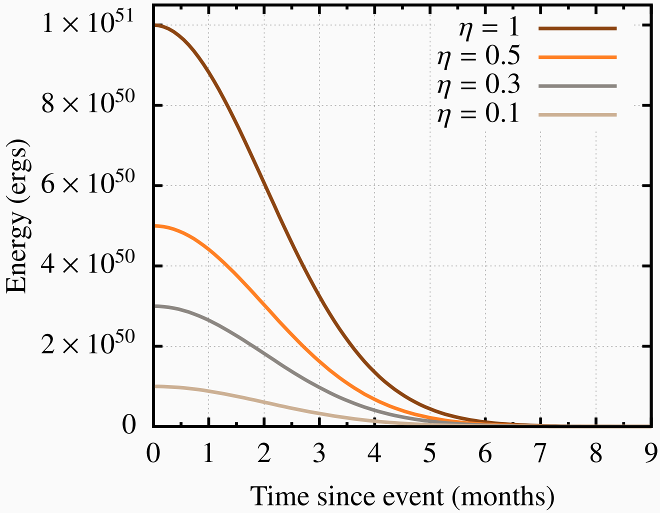
Rates red giants



[Amaro Seoane, accepted ApJ 2023]

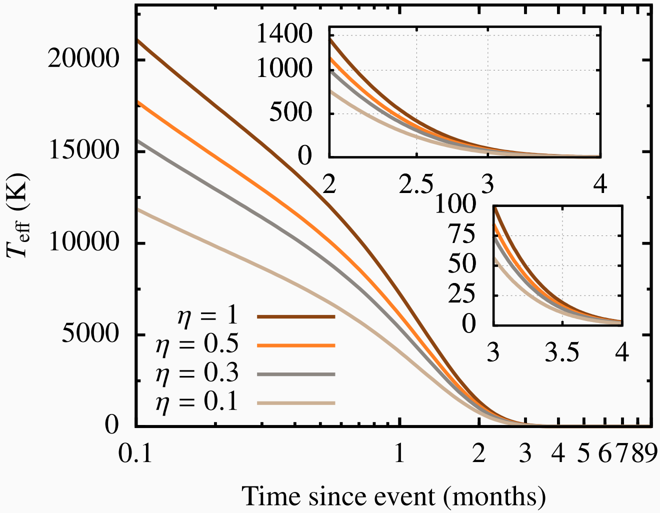
Electromagnetic signatures over all spectra

Evolution of the radiated energy

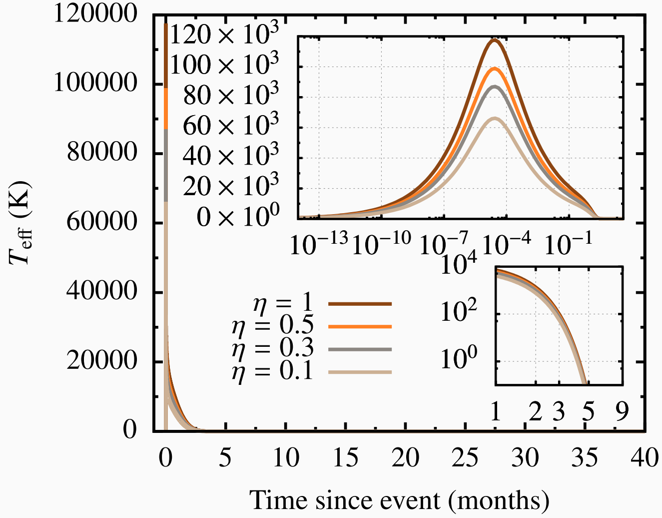


[Amaro Seoane, accepted ApJ 2023]

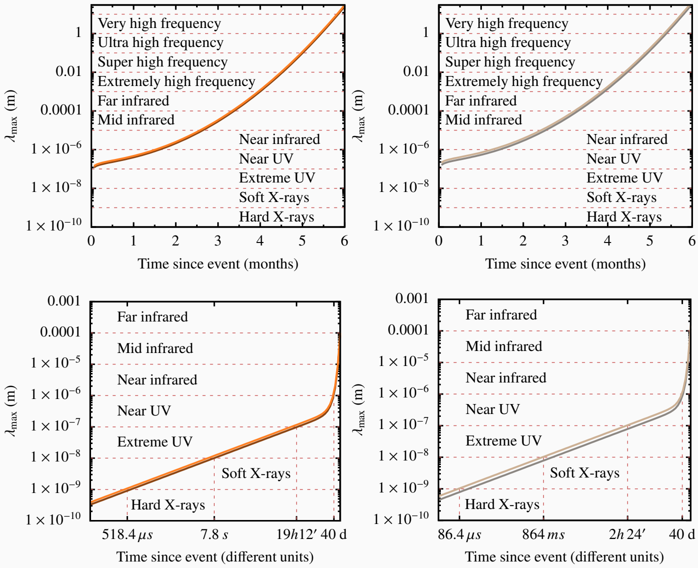
Evolution of the temperature



[Amaro Seoane, accepted ApJ 2023]

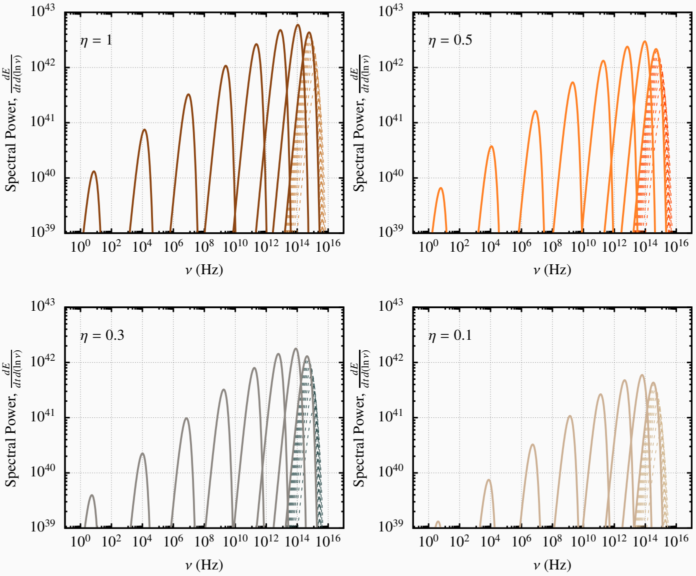

120000
100000
80000
60000
40000
20000
0
$T_{\rm eff}$ (K)
0 5 10 15 20 25 30 35 40
Time since event (months)
120×10^3
100×10^3
80×10^3
60×10^3
40×10^3
20×10^3
0×10^0
10^{-13} 10^{-10} 10^{-7} 10^{-4} 10^{-1}
10^4
10^2
10^0
1 2 3 5 9
η = 1
η = 0.5
η = 0.3
η = 0.1

Wiener's law



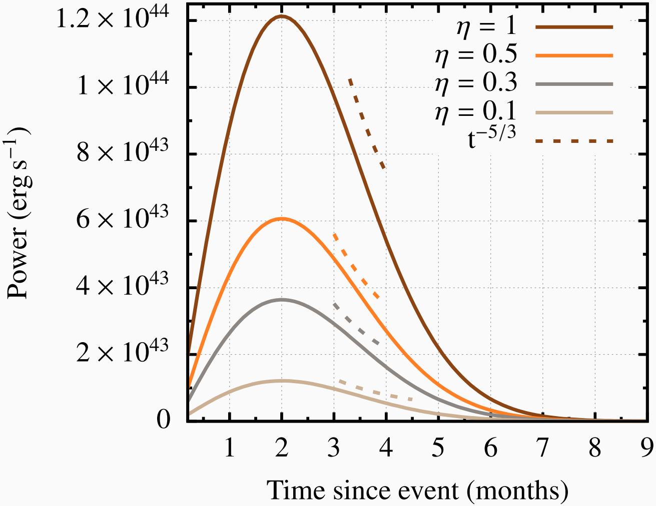
[Amaro Seoane, accepted ApJ 2023]

Spectral power



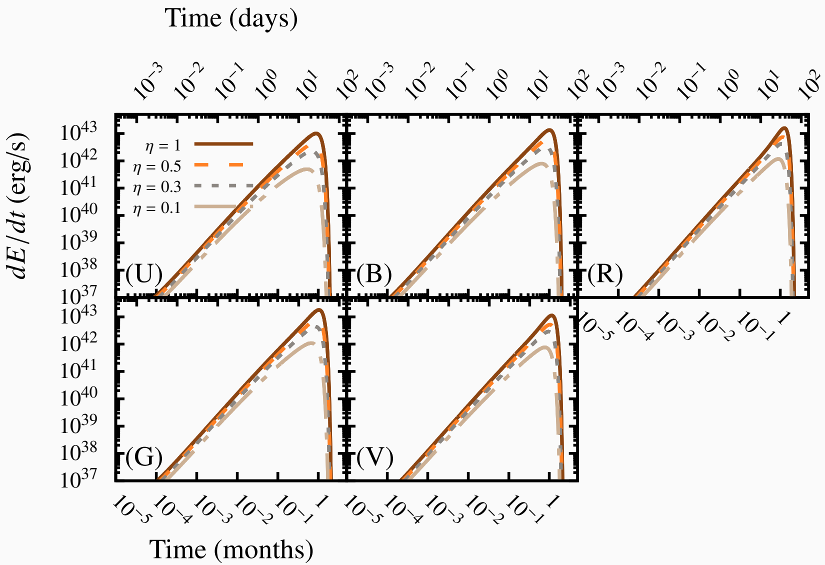
[Amaro Seoane, accepted ApJ 2023]

Power evolution



[Amaro Seoane, accepted ApJ 2023]

Photometry



[Amaro Seoane, accepted ApJ 2023]

Comparison with data

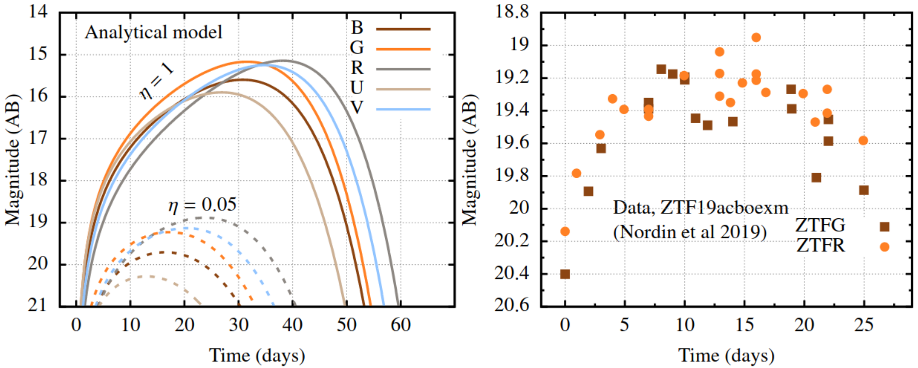


Figure 9. *Left panel:* AB magnitude as calculated from the theoretical model at a distance of 194.4 Mpc. We give the extreme values that we have adopted in this work for the free parameter η, i.e. 1 and also 0.05. *Right panel:* Zwicky Transient Facility (ZTF) report for 2019-10-07 corresponding to the object ZTF19acboexm by Nordin et al. (2019). The data taken with ZTFG are marked with squares and the data taken with ZTFR with circles. If the transient was the result of a stellar collision, it would seem to correspond to a value of $\eta \lesssim 0.05$.

[Amaro Seoane, accepted ApJ 2023]

What to do with that unique free parameter η?

MHD simulations

Arepo

Navigation

- Getting started
- Simulation examples
- Code Configuration
- Parameterfile
- Simulation output
- Diagnostic output
- Related codes
- Code development

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Arepo documentation

Arepo is a massively parallel code for gravitational N-body systems and magnetohydrodynamics, both on Newtonian as well as cosmological backgrounds. It is a flexible code that can be applied to a variety of different types of problems, offering a number of sophisticated simulation algorithms. A description of the numerical algorithms employed by the code is given in the public release code paper. For a more in depth discussion about these algorithms, the original code paper and subsequent publications are the best resource. This documentation only addresses the question how to use the different numerical algorithms.

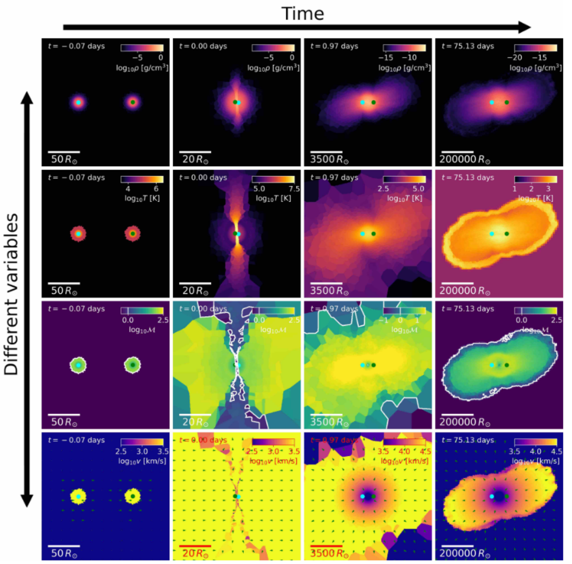
Arepo was written by Volker Springel (vspringel@mpa-garching.mpg.de) with further development by Rüdiger Pakmor (rpakmor@mpa-garching.mpg.de) and contributions by many other authors (www.arepo-code.org/people). The public version of the code was compiled by Rainer Weinberger (rainer.weinberger@cfa.harvard.edu).

Overview

The Arepo code was initially developed to combine the advantages of finite-volume hydrodynamics with the Lagrangian convenience of smoothed particle hydrodynamics (SPH). To this end, Arepo makes use of an unstructured Voronoi-mesh which is, in the standard mode of operating the code, moving with the fluid in a quasi-Lagrangian fashion. The fluxes between cells are computed using a finite-volume approach, and additional spatial adaptivity is provided by the possibility to add and remove cells from the mesh according to user-defined criteria. In addition to gas dynamics, Arepo allows for additional collisionless particle types which interact only gravitationally. Besides self-gravity, forces from external gravitational potentials can also be included.

[From the web page of Arepo, https://arepo-code.org]

Stellar collisions with Arepo



[Ryu, Amaro Seoane & Taylor, in progress.]

Gravitational-wave signature

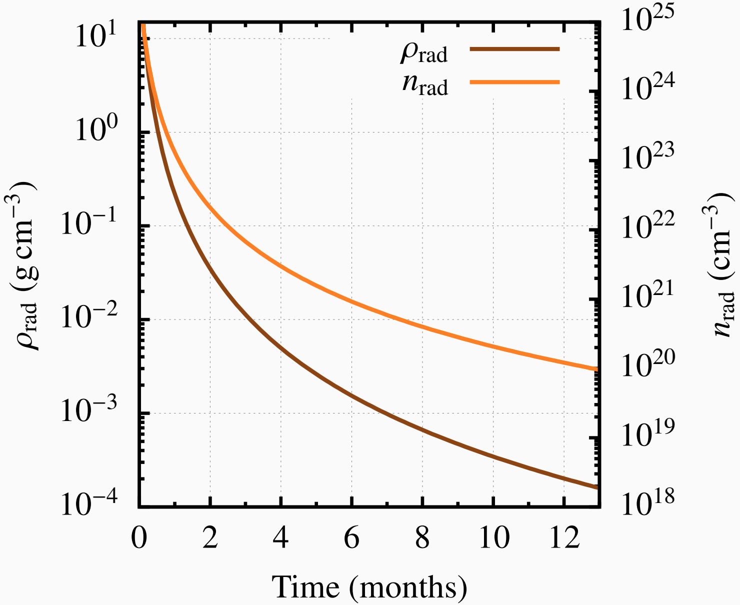
Why is this interesting?

- The GW signature is unique.

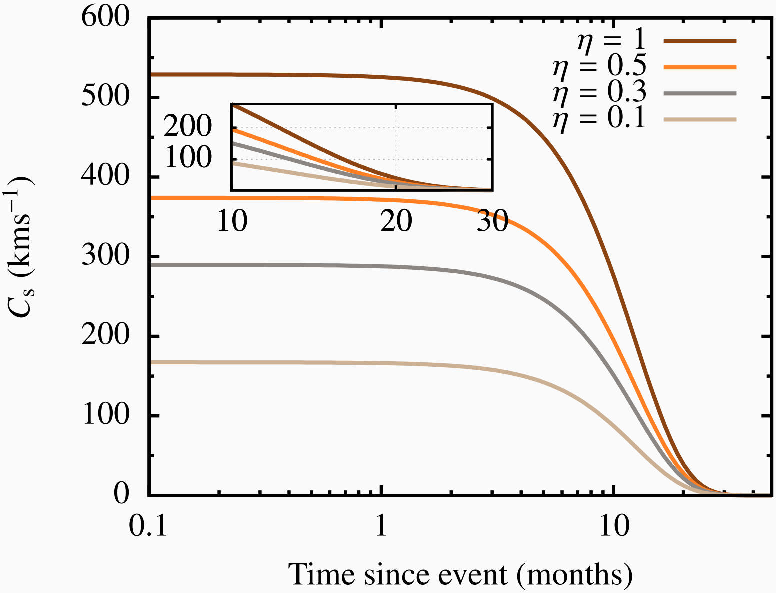
  Fingerprint of a stellar collision and nothing else.
- In the case of the RGs **there will be an EM afterglow.**
- We have hence
  - **An EM signature**
  - **followed by a GW one**
  - **and an additional afterglow.**

  ...Couldn't ask for more.

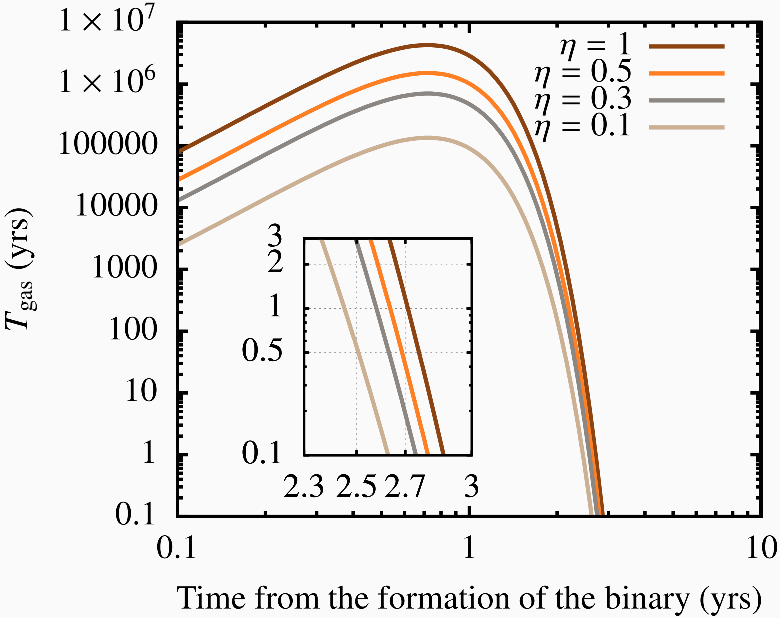
Evolution of the gaseous cloud



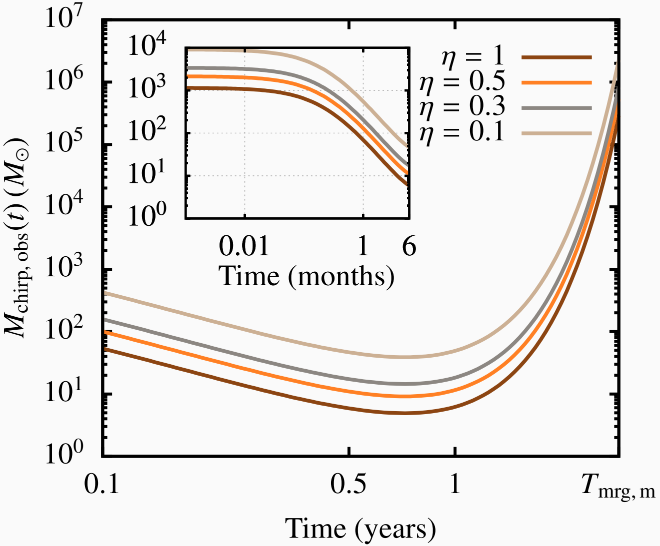
Evolution of the gaseous cloud



Evolution of the gas timescale: Merger after 34.7 months



Impact of gas friction: Chirp mass evolution



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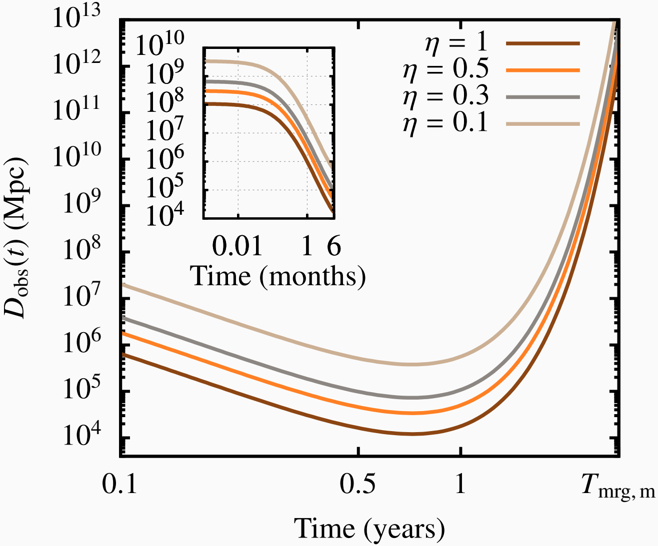
Impact of gas friction: Luminosity distance evolution



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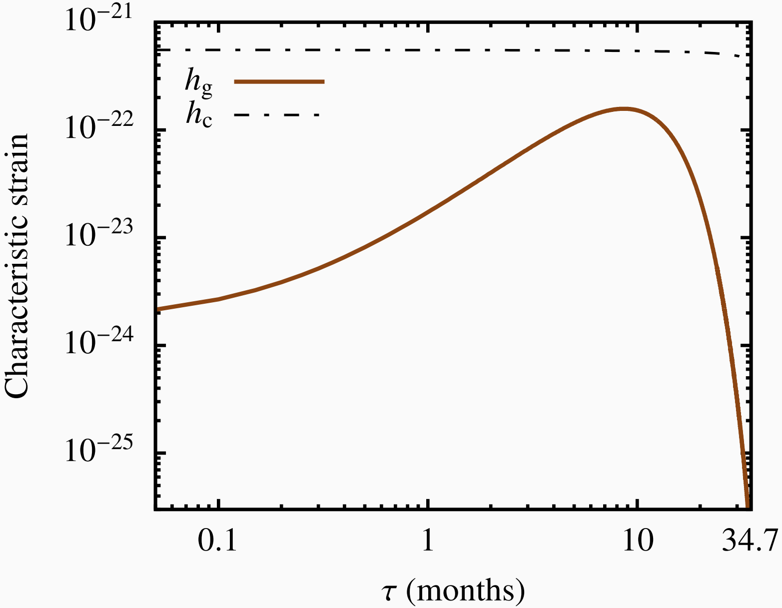
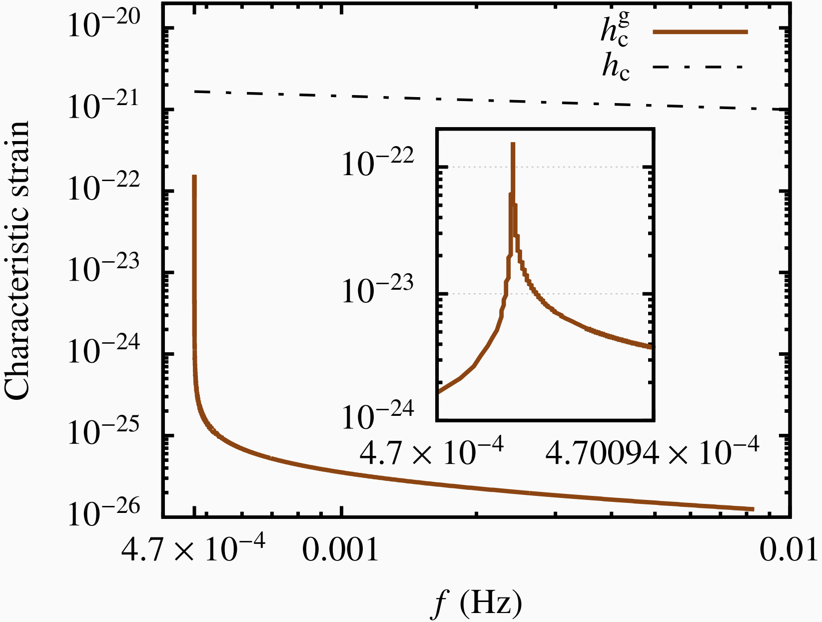

10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{-25}
Characteristic strain
h_g
h_c
0.1
1
10
34.7
τ (months)

Characteristic strains: Frequency domain



Some points to remind

- Collisions seem to have been neglected **but there are a lot of things to look at**
- Rates are important, in particular RGs **because of cross section**
- When they collide **they will mimick Type Ia SN.**
- Cosmic ladder argument **in danger, because the masses and properties of the mergers are very different.**
- Degenerate cores **can be envisaged as white dwarfs.**
- When they merge **they will produce a subsequent afterglow.**
- Grazing collisions in globular clusters **will lead to maintained pulsations until the stars merge.**
- Pulsating stars are another rung in the ladder **but such collisions reproduce their behaviour.**

To summarise

- I have given a detailed analytical description of the process **and found that the GW signature will be unique.**
- Thanks to the GW signal **we can be sure it was a collision.**
- Stellar collisions **are true multimessenger probes.**
- As an on-going work with T. Ryu **I am working out MHD simulations which will help to**
  - Fix the only free parameter of my calculations, η.
  - Allow for systematic searches in the catalogs.
  - Solve the shock properties.
  - Allow us to estimate particle acceleration.
  - Potentially look into neutrino emission.

Spoiler

- Working on the second part **analytically**
- Have derived a few **interesting and unexpected results**
- Again, the results **seem to be confirmed with numerical simulations**

  - High Mach numbers during the collisions: **Particle acceleration.**

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  - The collision is likely to ignite **fusion.**
  - **Afterglow** likelihood very high.
  - Right now struggling with radiative transfer, rotation and magnetic fields.

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Stellar collisions: EM and GW radiation

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