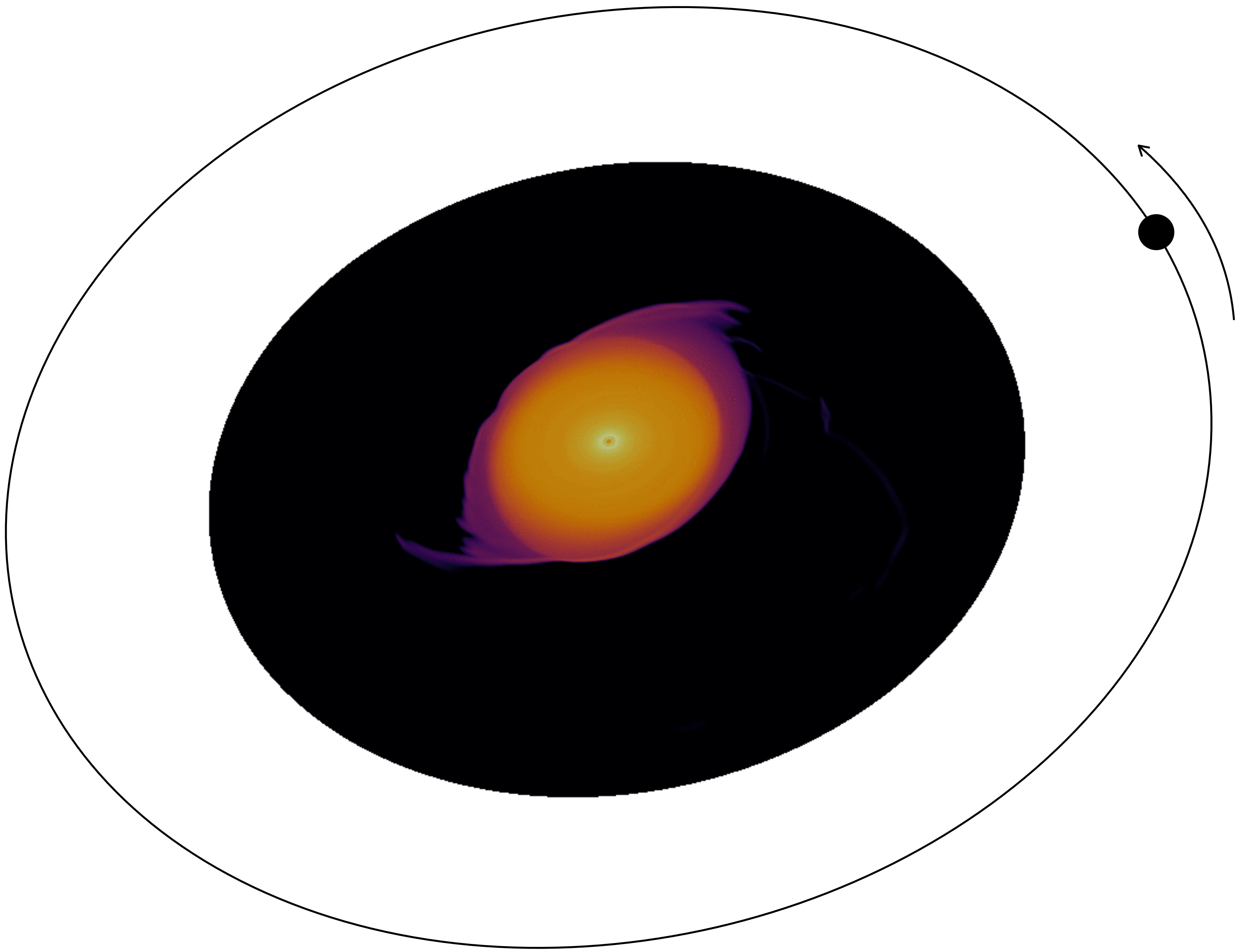
Exploring the detectability of pre-circumbinary disk systems



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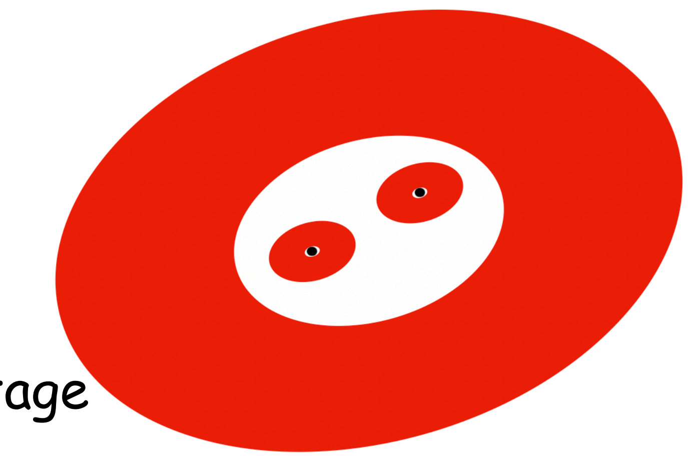
Casse et al., 2025 & Varniere et al., 2025

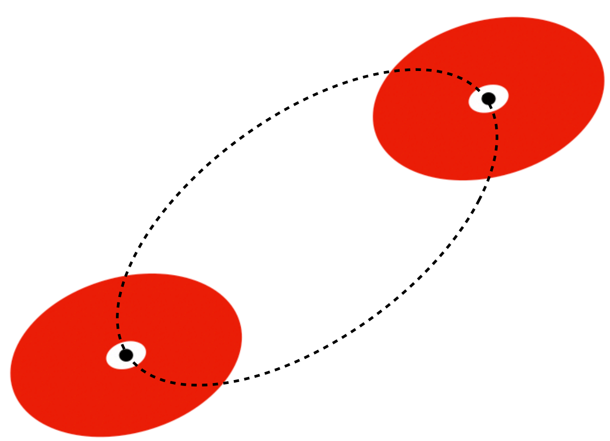
What is a pre-CBD system

when you think pre-merger system often what comes to mind is:

- two black-holes with their individual accretion disk
- a circumbinary disk



➥ but this circumbinary stage represent an already advanced pre-merger stage



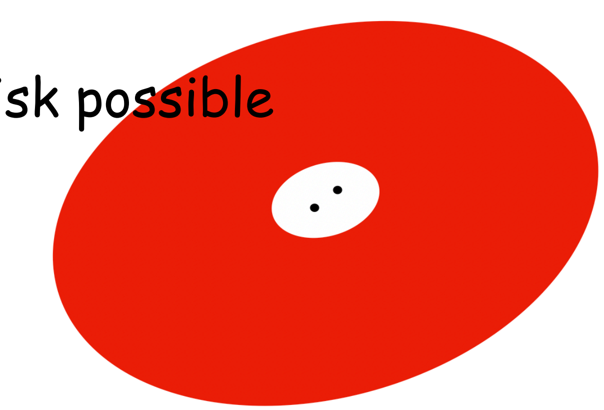
the earliest stage is before any circumbinary structure is formed

- two distant black-holes with their individual accretion disk

➥ the slow inspiral impacts both disks and could help detect them
it is also the "initial condition" to the circumbinary stage.

in the opposite direction, the late pre-merger stage has no individual accretion disk possible

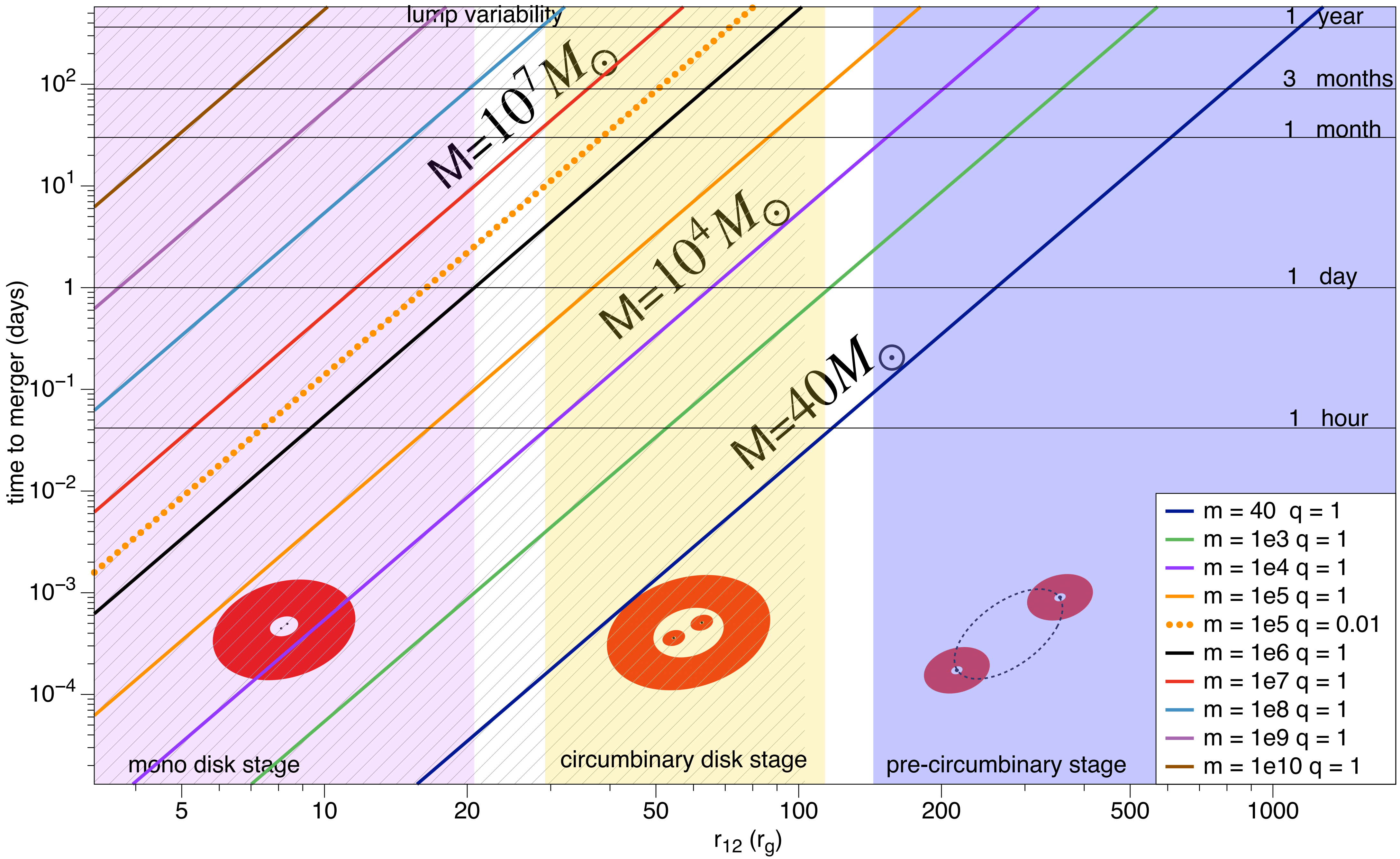
- two close black-holes with a single, circumbinary, disk



➥ this mono-disk stage is typical of separation less than 20 r_g

➥ here we only talked in dynamical timescale, as we want to observed those systems we need to add the human timescale dimension

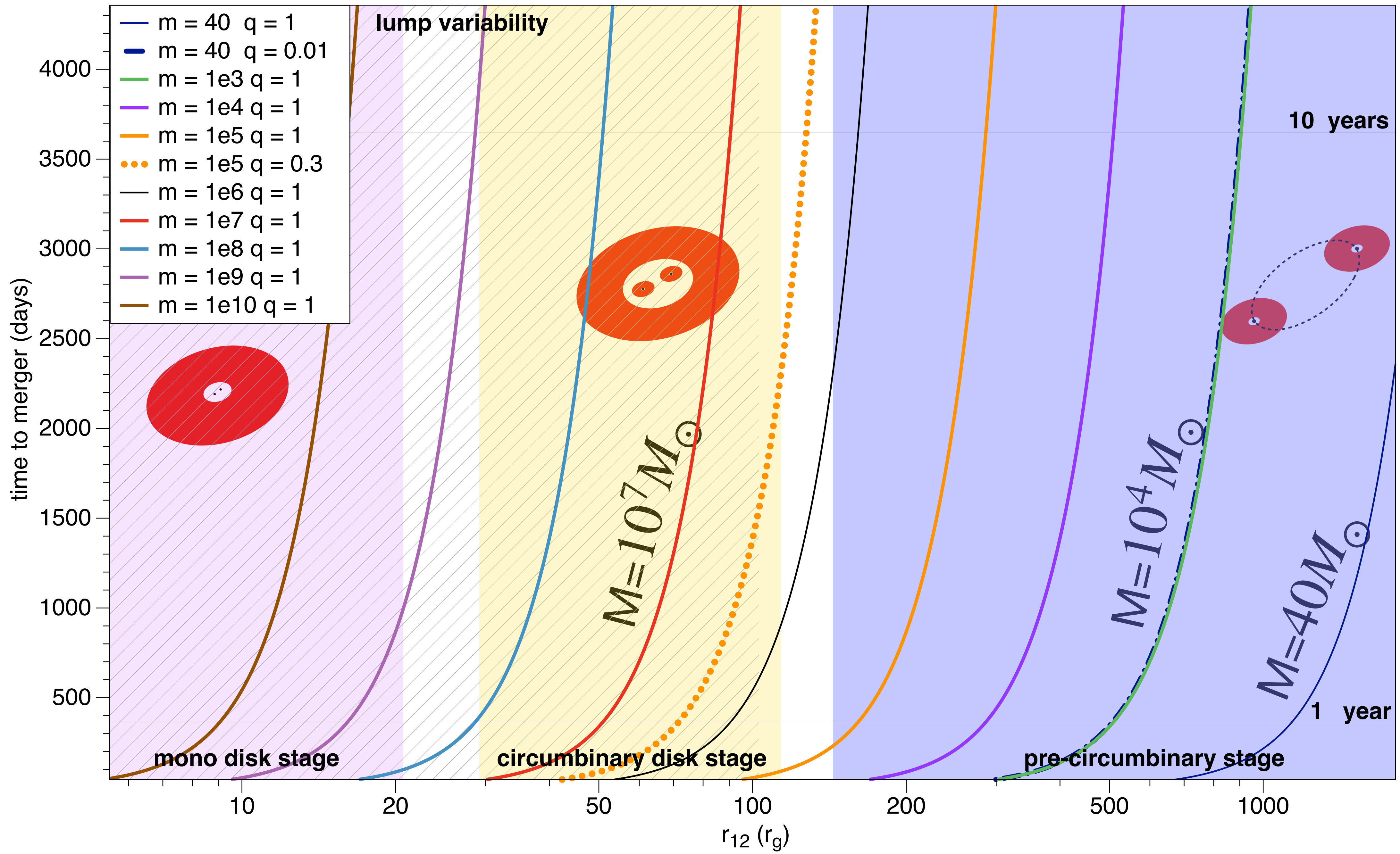
What is a pre-CBD system and why does it matter



➥ the lower mass binary black-holes will start in that stage and intermediate mass system (lower than $10^3M_\odot$) will stay in that regime until a few days before the merger

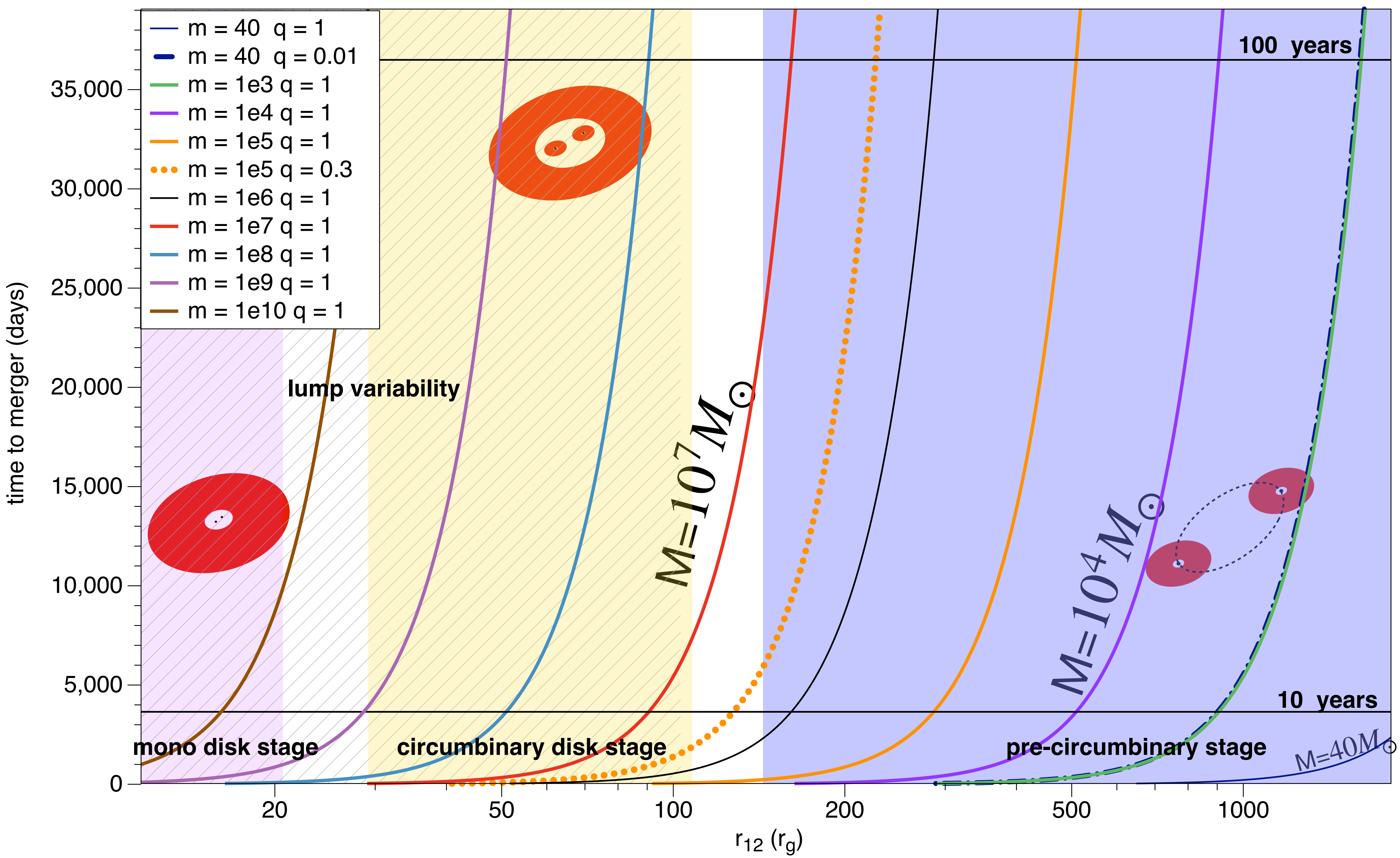
$\Rightarrow$ to identify IM-BBH electromagnetic counterpart we need to characterize pre-CBD systems

What is a pre-CBD system
and why does it matter



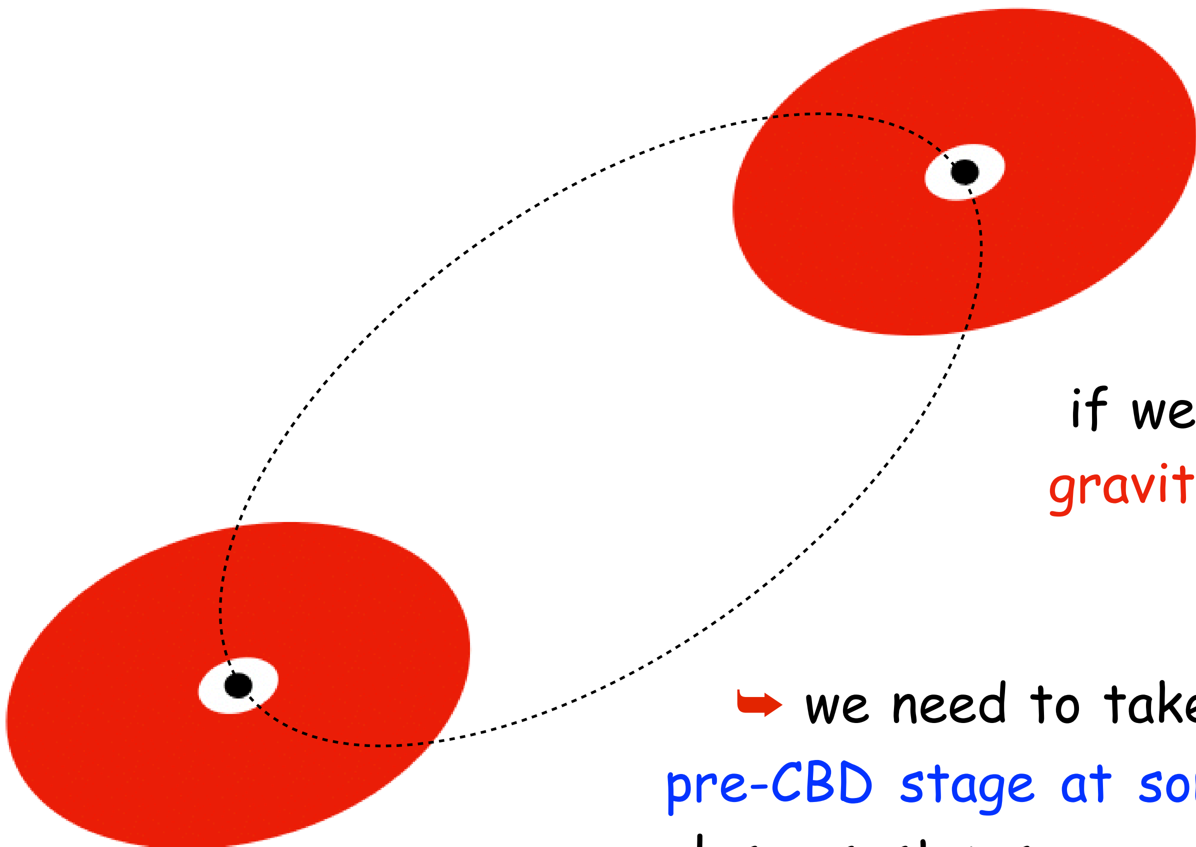
- We can also search NOW for the systems that LISA could detect in ten years and have a complete follow up of the gas behavior in all the stages of merger
   - in that case, systems up to $10^6 M_\odot$ will be in the pre-CBD stage for the next few years

What is a pre-CBD system
and why does it matter



➥ We can also perform archival search ahead of LISA launch and have a complete follow up for an even larger number of systems (systems up to $10^7 M_\odot$ have been in the pre-CBD stage in the last 100 years)

What is a pre-CBD system and why does it matter



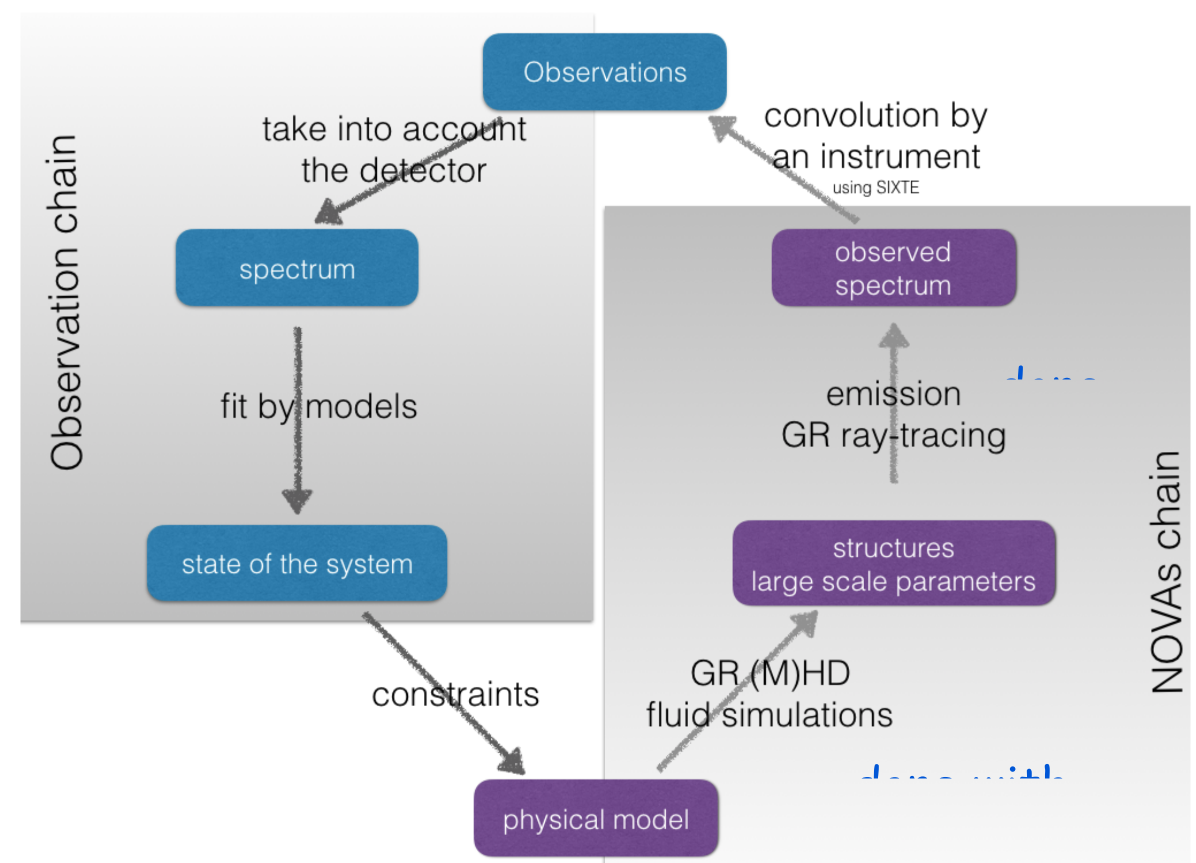
if we want to perform (archival) search for the source of the gravitational wave detected by LISA

➥ we need to take into account that systems up to $10^7 M_\odot$ have been in the pre-CBD stage at some point during the last 100 years and not focus only on closer systems

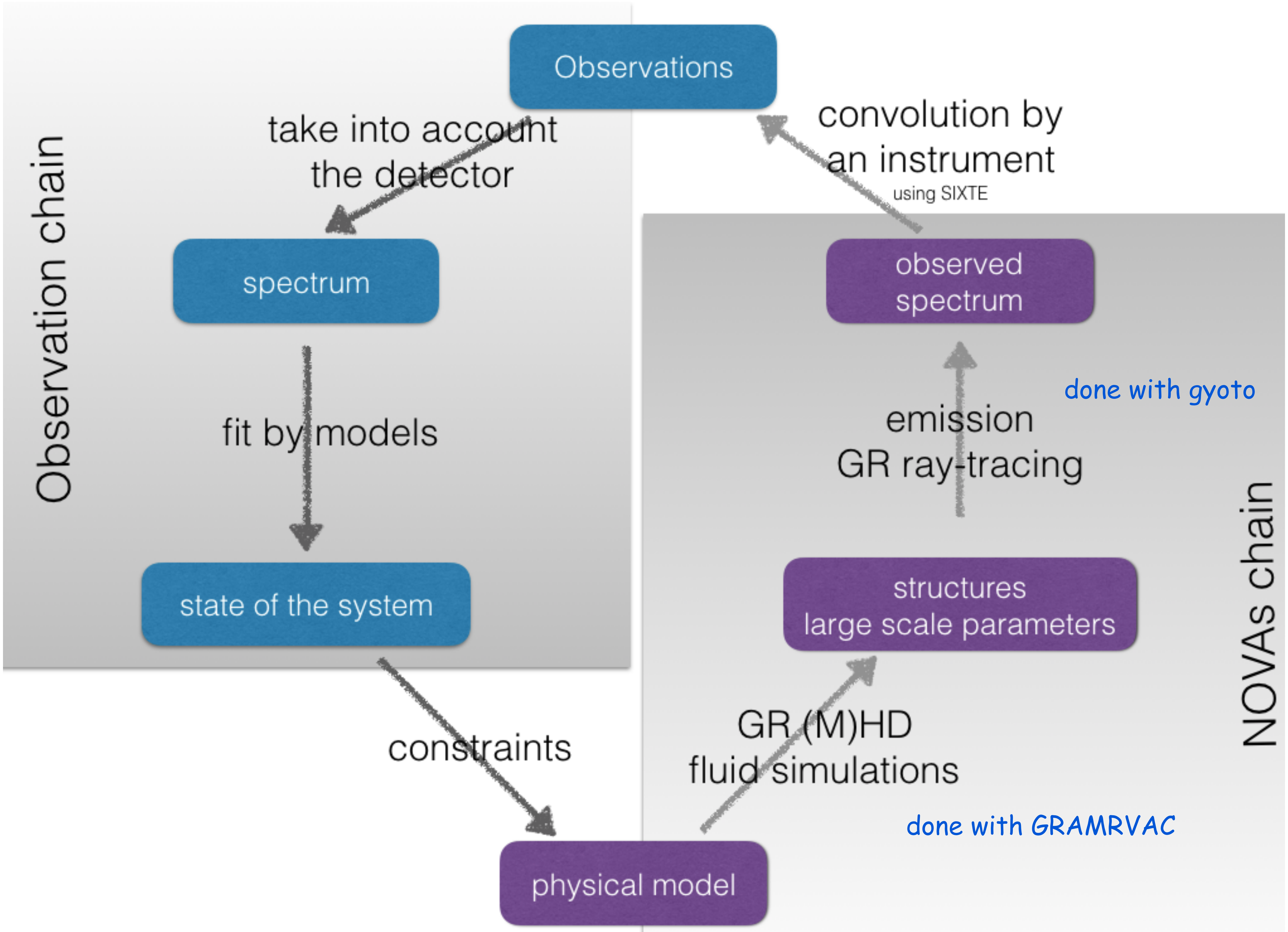
in order to find those pre-CBD system though their electromagnetic emission we need:

- to characterize how the secondary affect the primary's disk

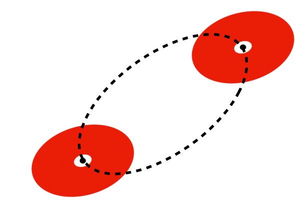
➥ and how does that translate into observables



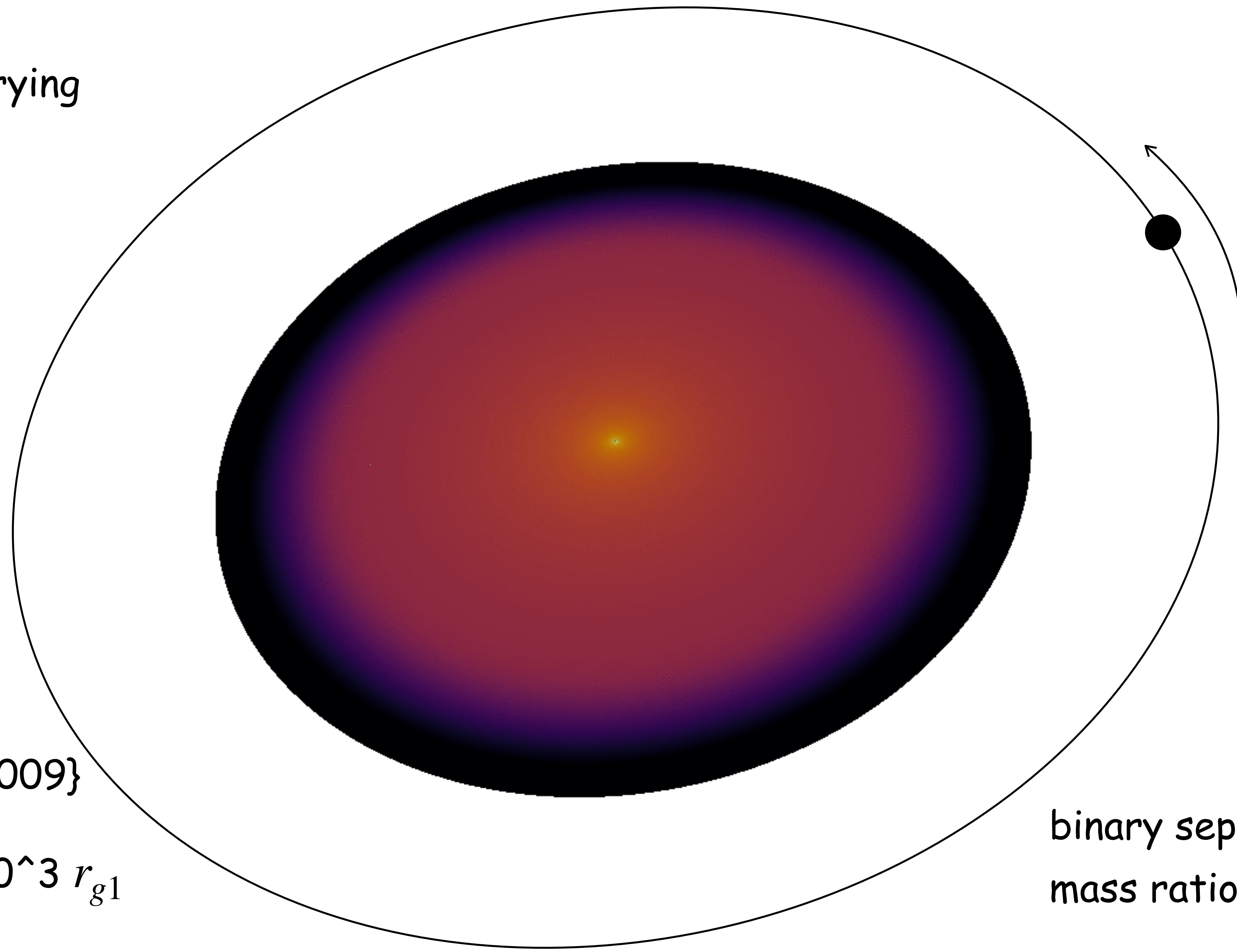
e-NOVAs:
synthetic observation from fluid simulations



Sculpting the outer disk of an AGN with a secondary disruptor



a series of 2D HD simulations for varying binary parameters



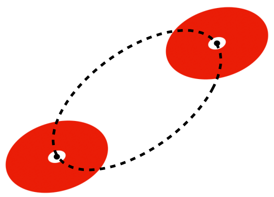
$q \in \{1, 0.3, 0.1, 0.05,$
$0.01, 0.005, 0.0009\}$

$D \in \{1, 1.5, 2, 3, 6\}\ 10^3\ r_{g1}$

binary separation 2000 r_{g1}
mass ratio of 1

those features are typical of the gravitational impacts of a secondary disruptor

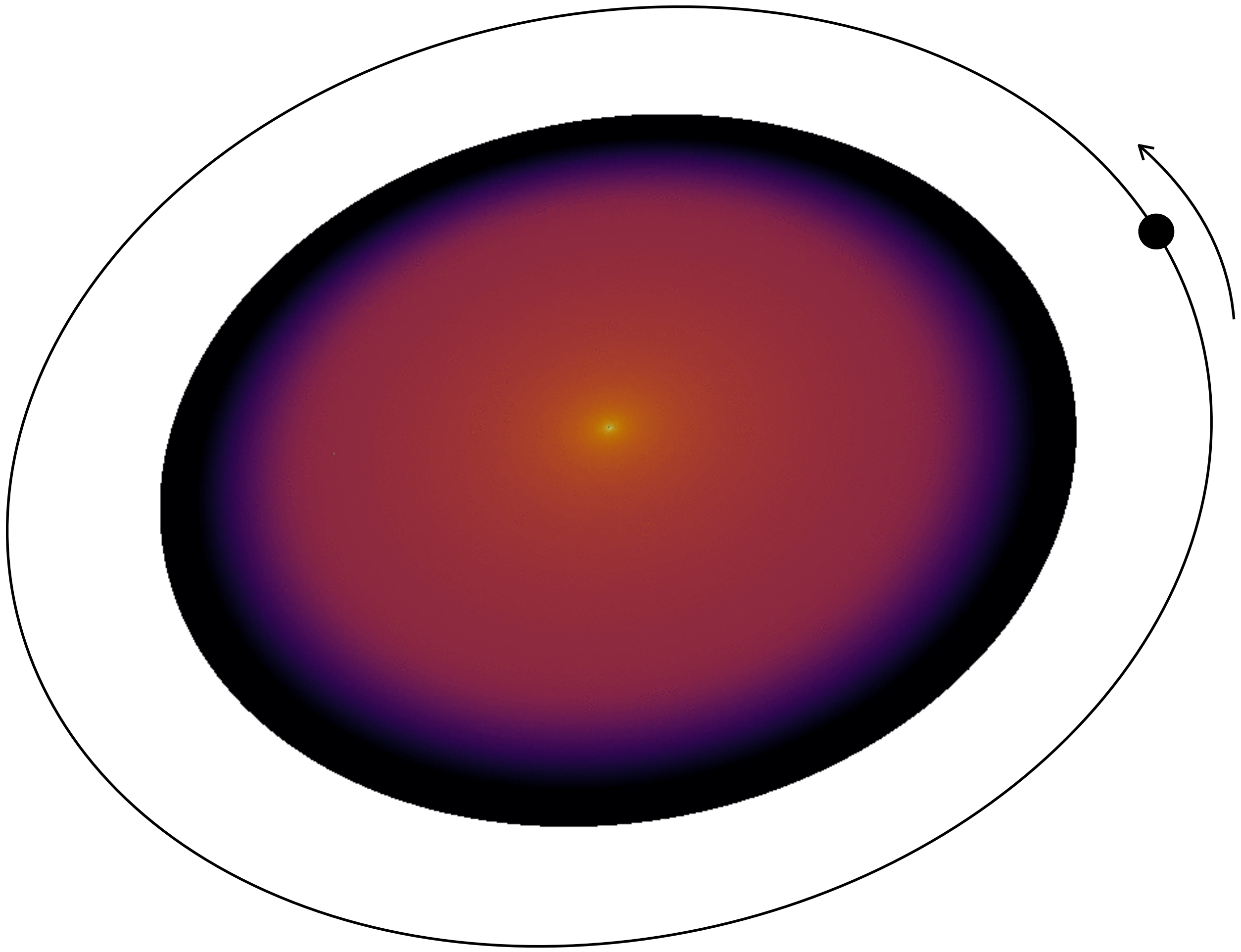
Sculpting the outer disk of an AGN with a secondary disruptor

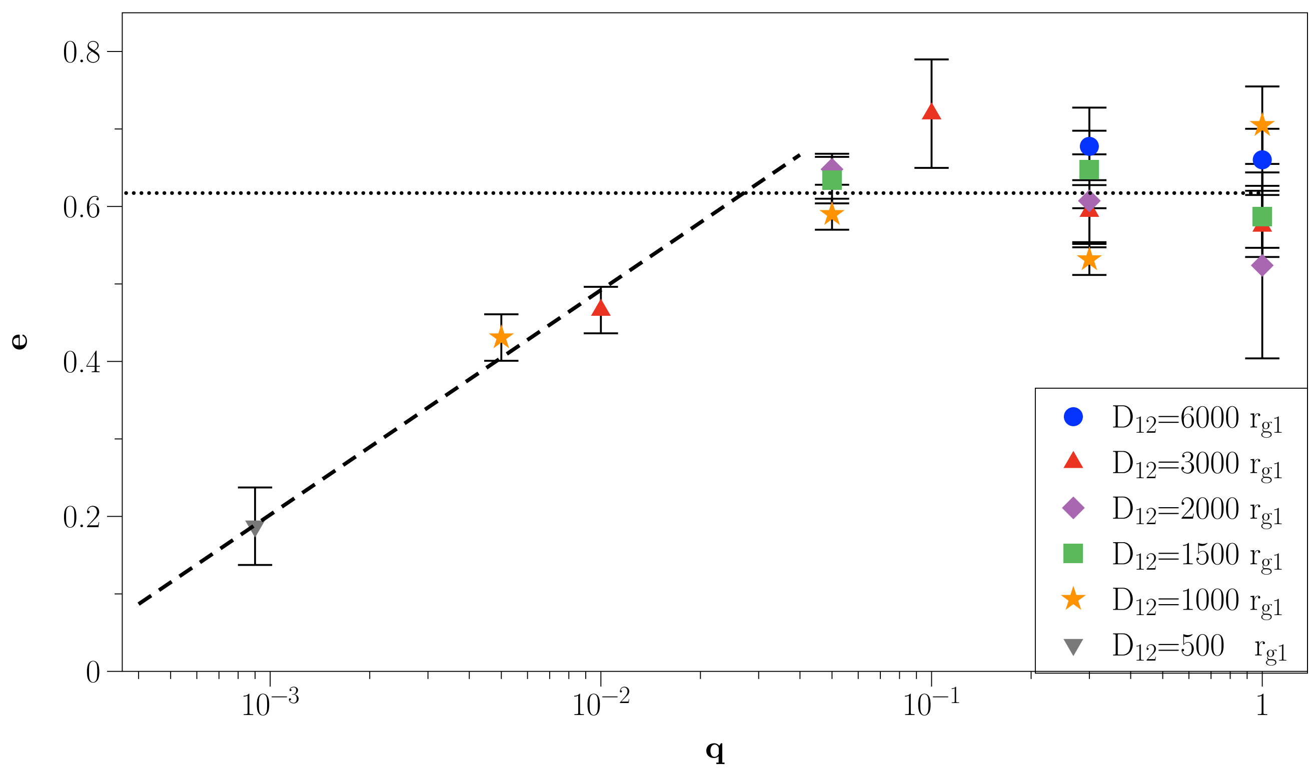


The presence of a secondary black-hole leads to:

⁕ a two-arm spiral in the primary's disk

➥ it could lead to some variability if the the spiral arm are not too faint but spiral wave are too common to help identify BBHs



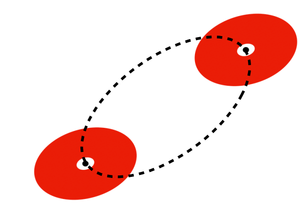


⁕ an elliptical shape for the outer edge of the primary's disk

➥ even for e=0.6 the impact on the observables is small because it is related to a low density region

➥ both signals are at the secondary's orbital frequency

Sculpting the outer disk of an AGN with a secondary disruptor



The presence of a secondary black-hole leads to:

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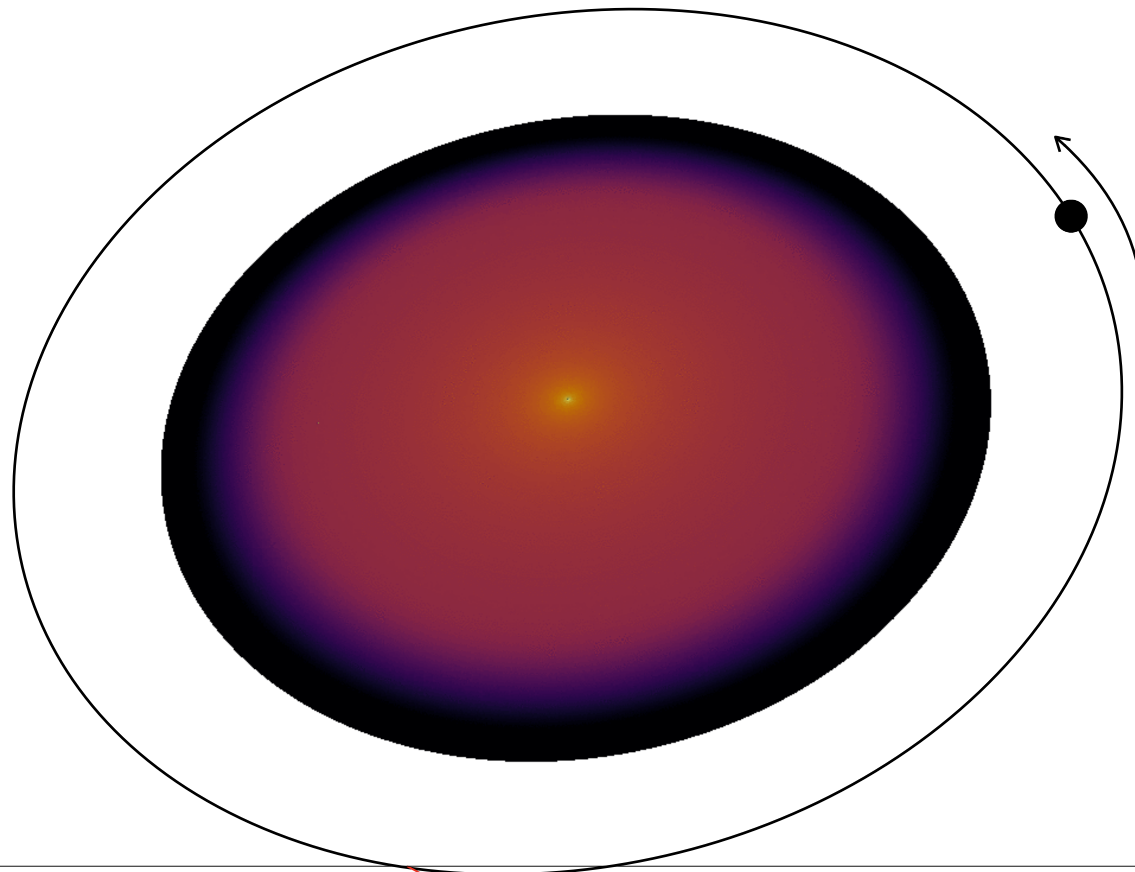
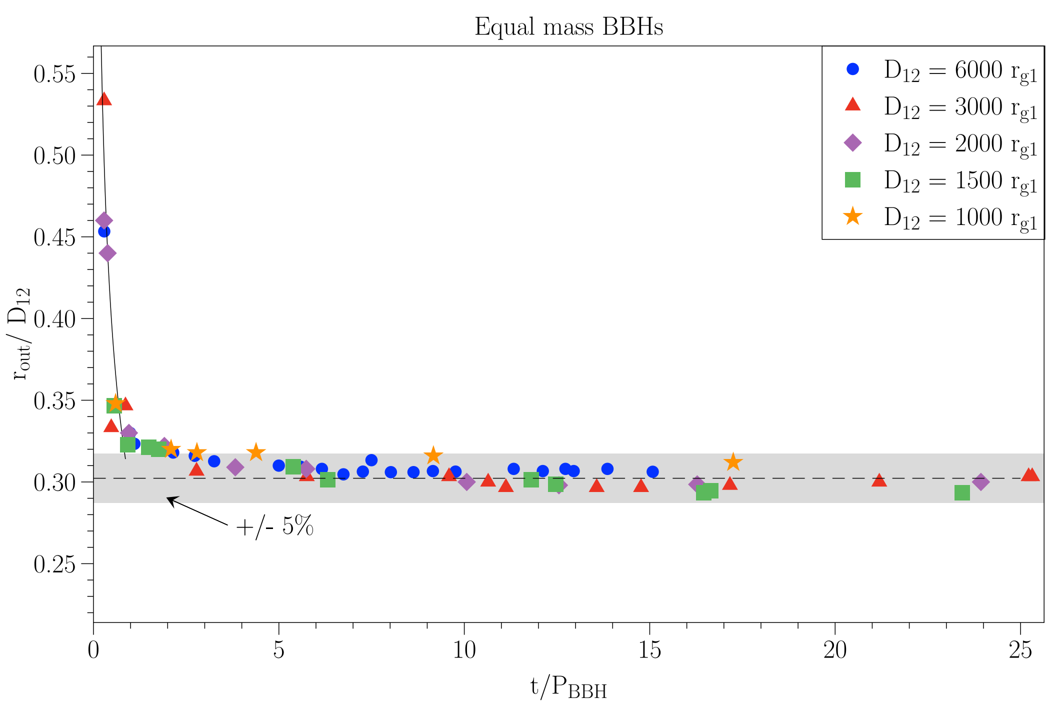
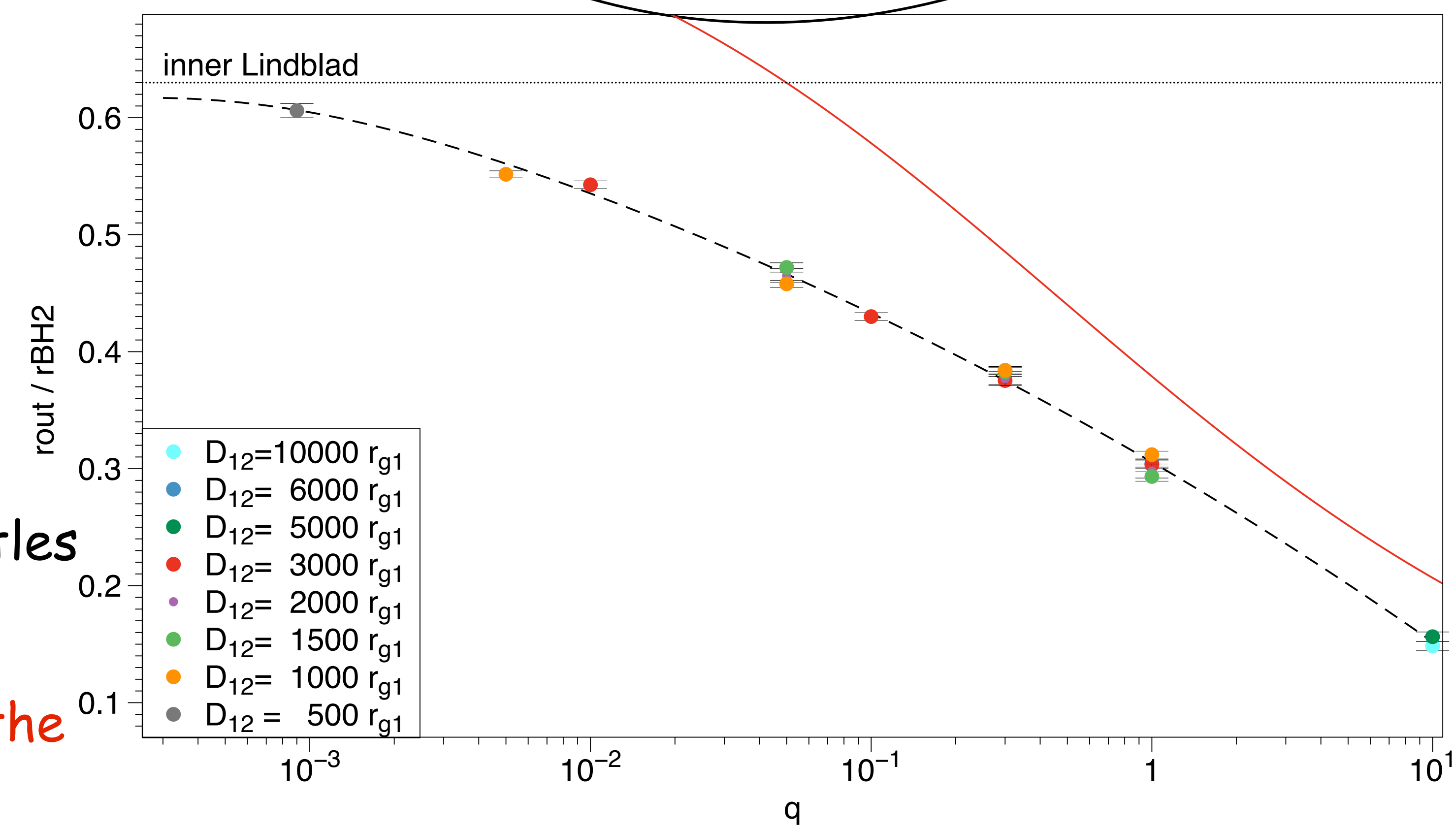


- the shrinking of the primary's disk as the outer gas is being stripped away

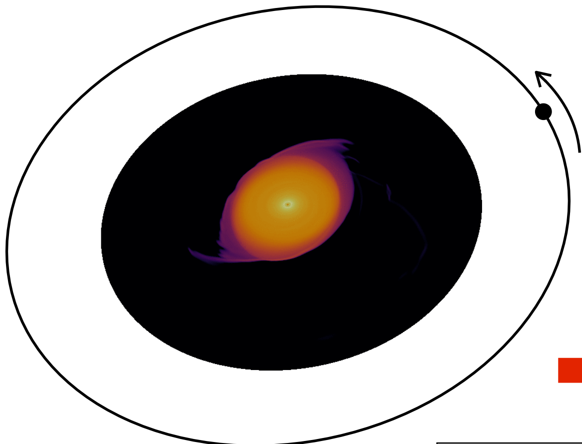


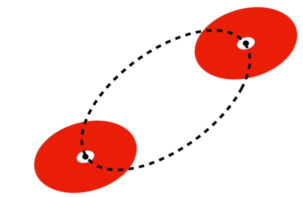
➥ at each binary separation the outer disk settles rapidly at its new position



➥ the shrinking of the outer disk happen on the merger timescale

Sculpting the outer disk of an AGN with a secondary disruptor

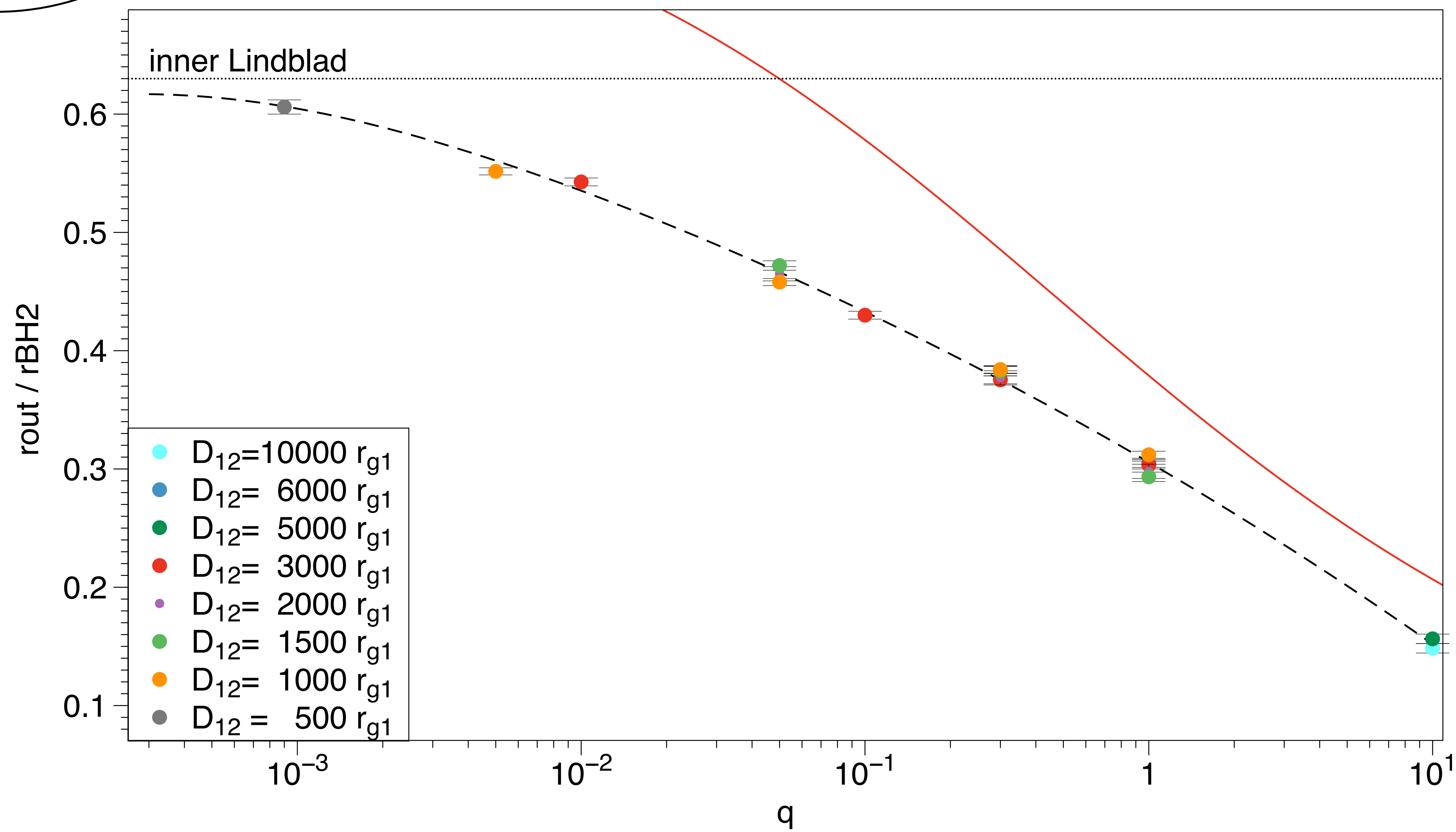




of the three effects of a secondary (spiral, ellipse, shrinking)

the most impactful one is the removal of the primary's outer disk

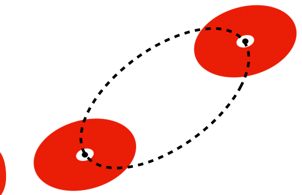
➡ the most prominent features of the primary's disk can be related to the BBH parameters

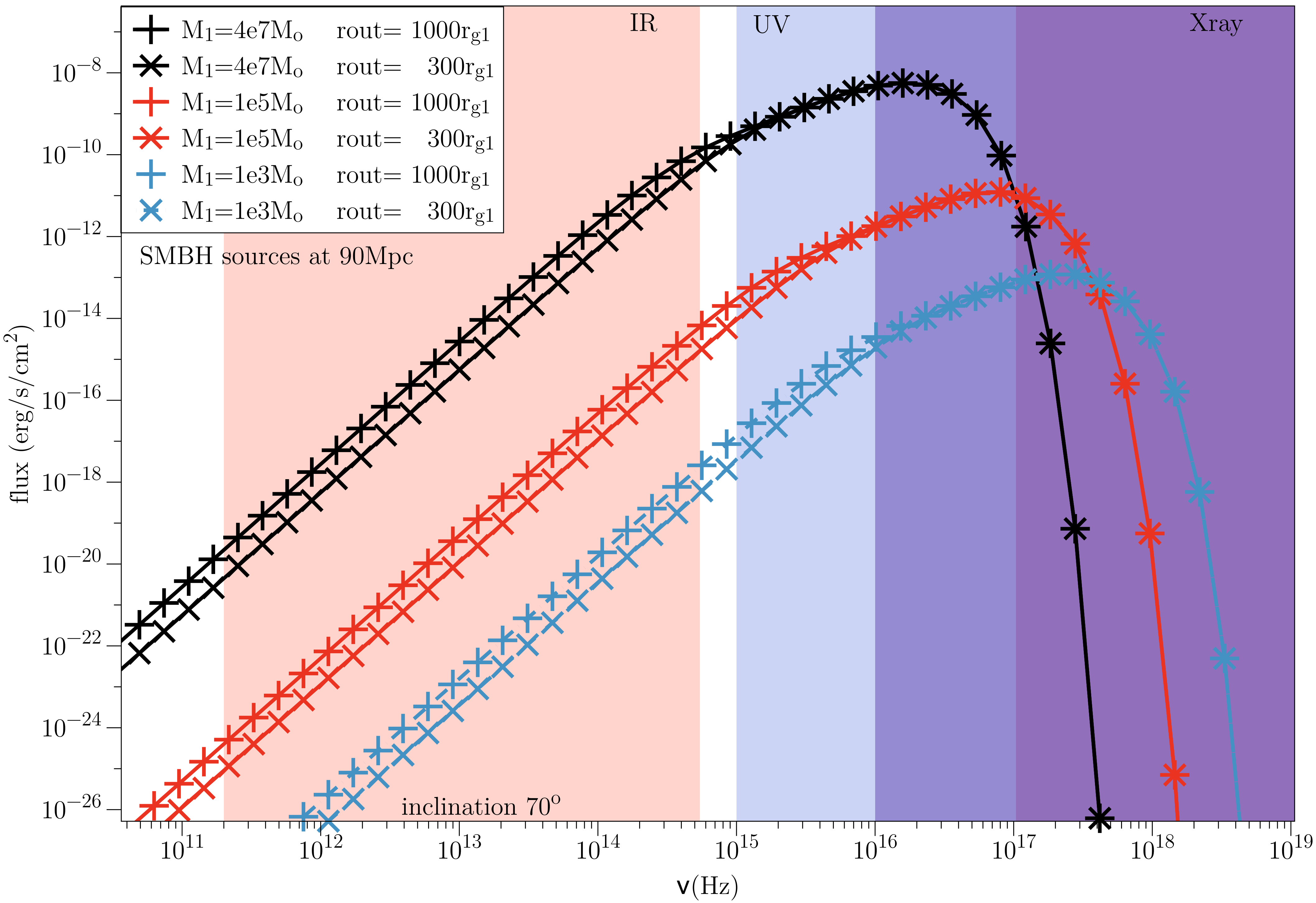


now we need to see how does that missing outer disk impact the SED

to see if we can use it to identify pre-CBD BBH systems

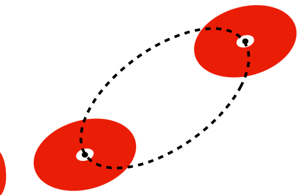
Impact on the SED:
where to look for the rout drop

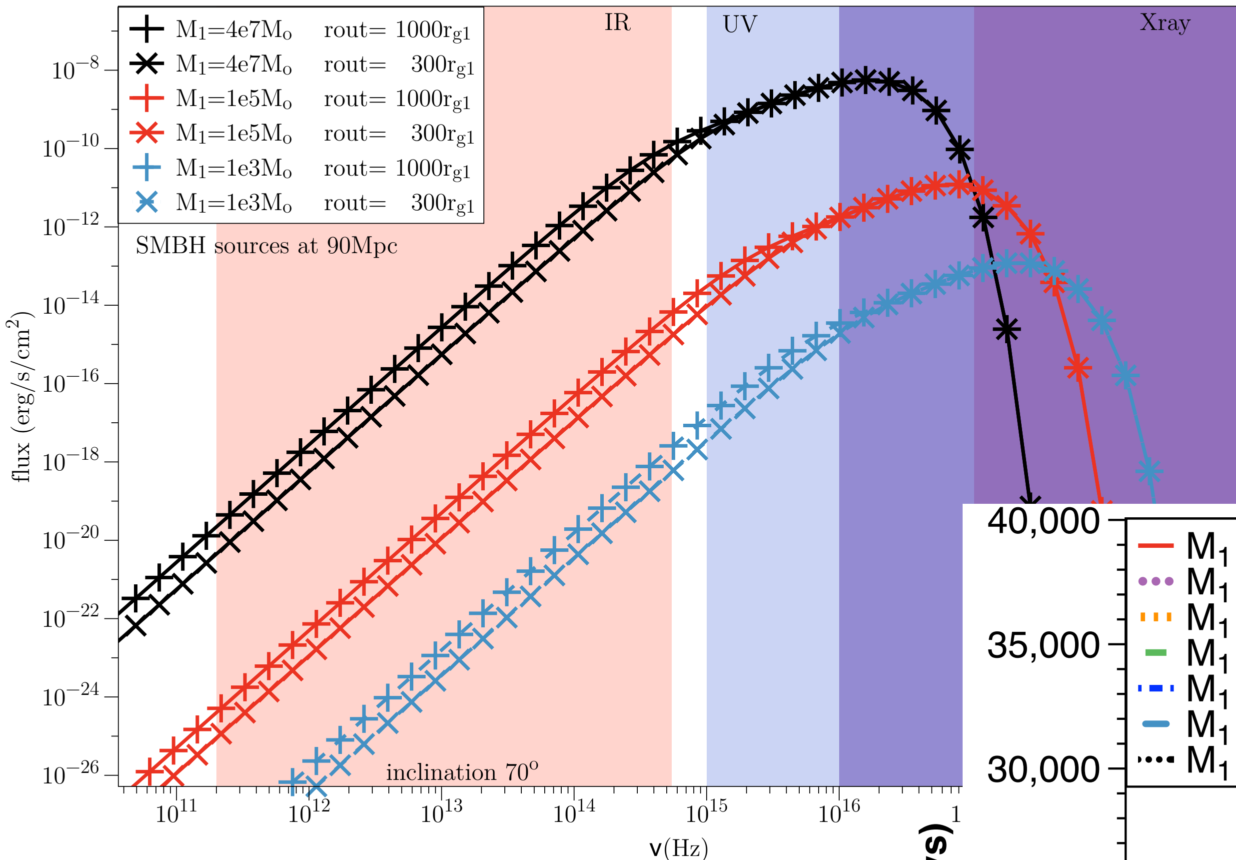




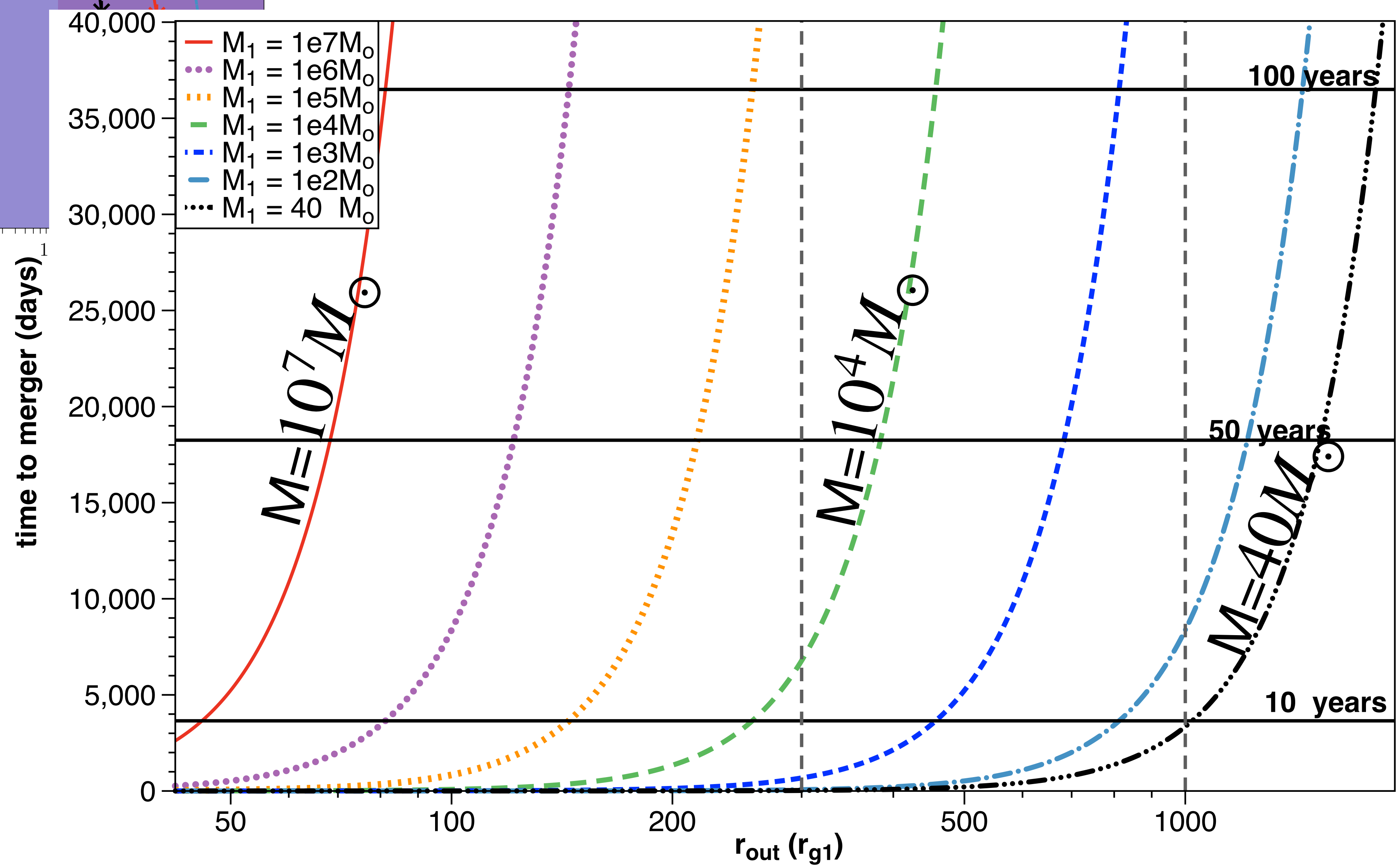
➥ the effect is mostly in the infra-red, with an optical/UV component for the lower masses SMBH

Impact on the SED: where to look for the rout drop



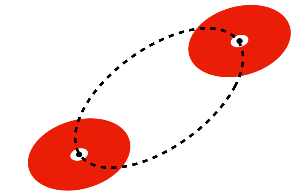


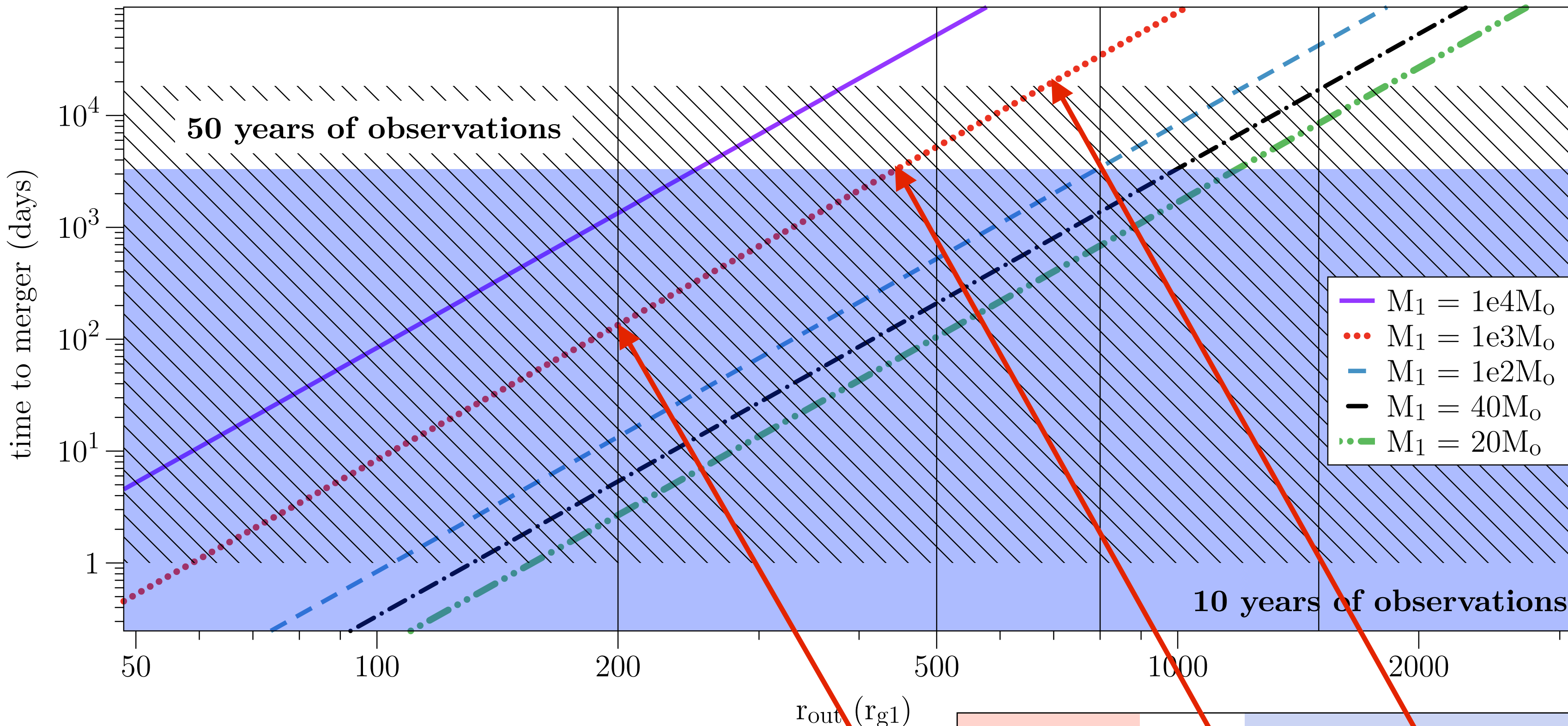
but the shrinking happens on the merger timescale



➥ it will be very hard to see any changes of the rout/lowering of the IR flux for high mass systems

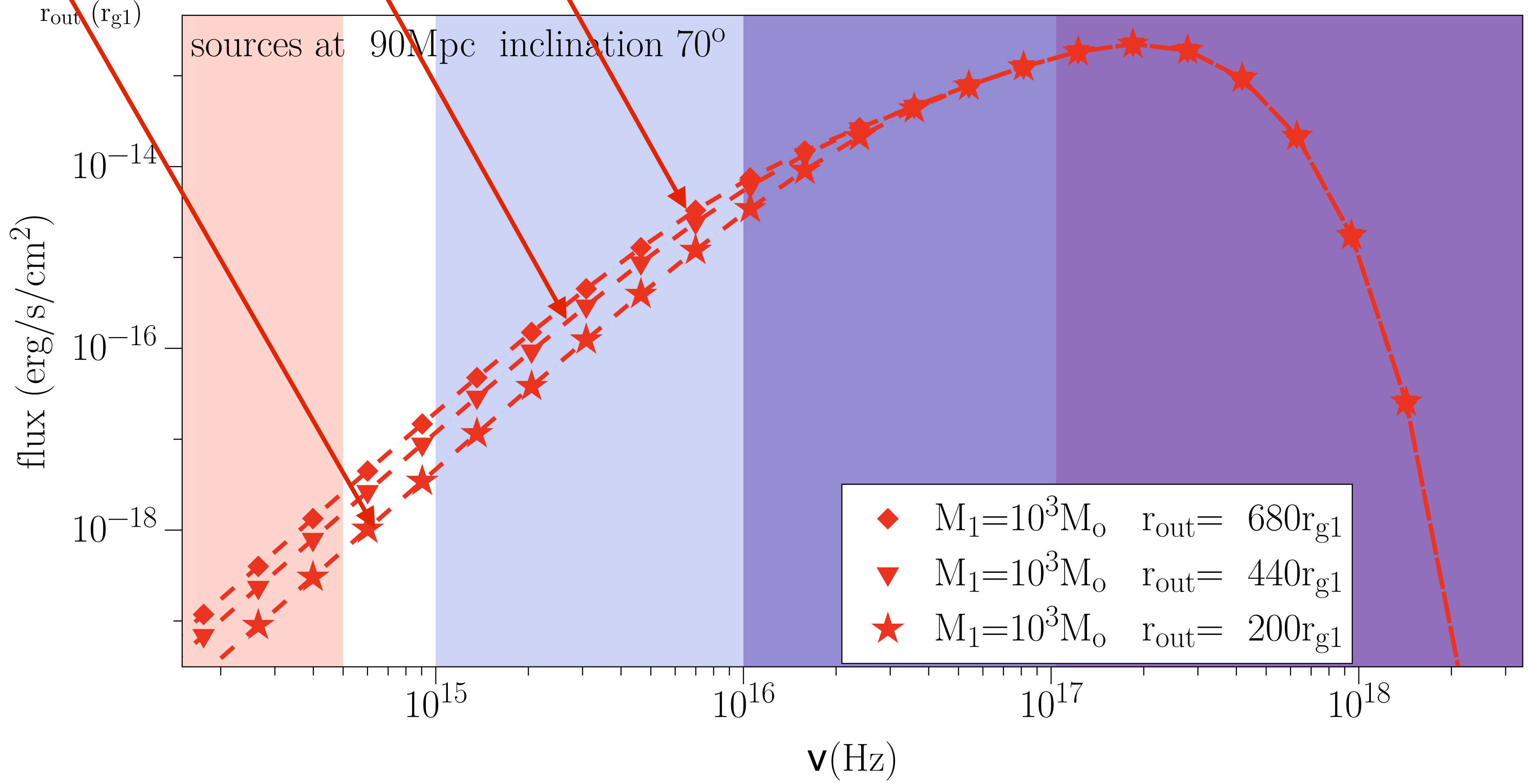
following the outer disk in real time: IM-BBH and lower





for low mass system, we can follow the outer edge of the disk as it shrinks

even a 10 years time span would be able to follow dramatic changes in the accretion structure!



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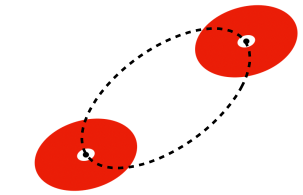

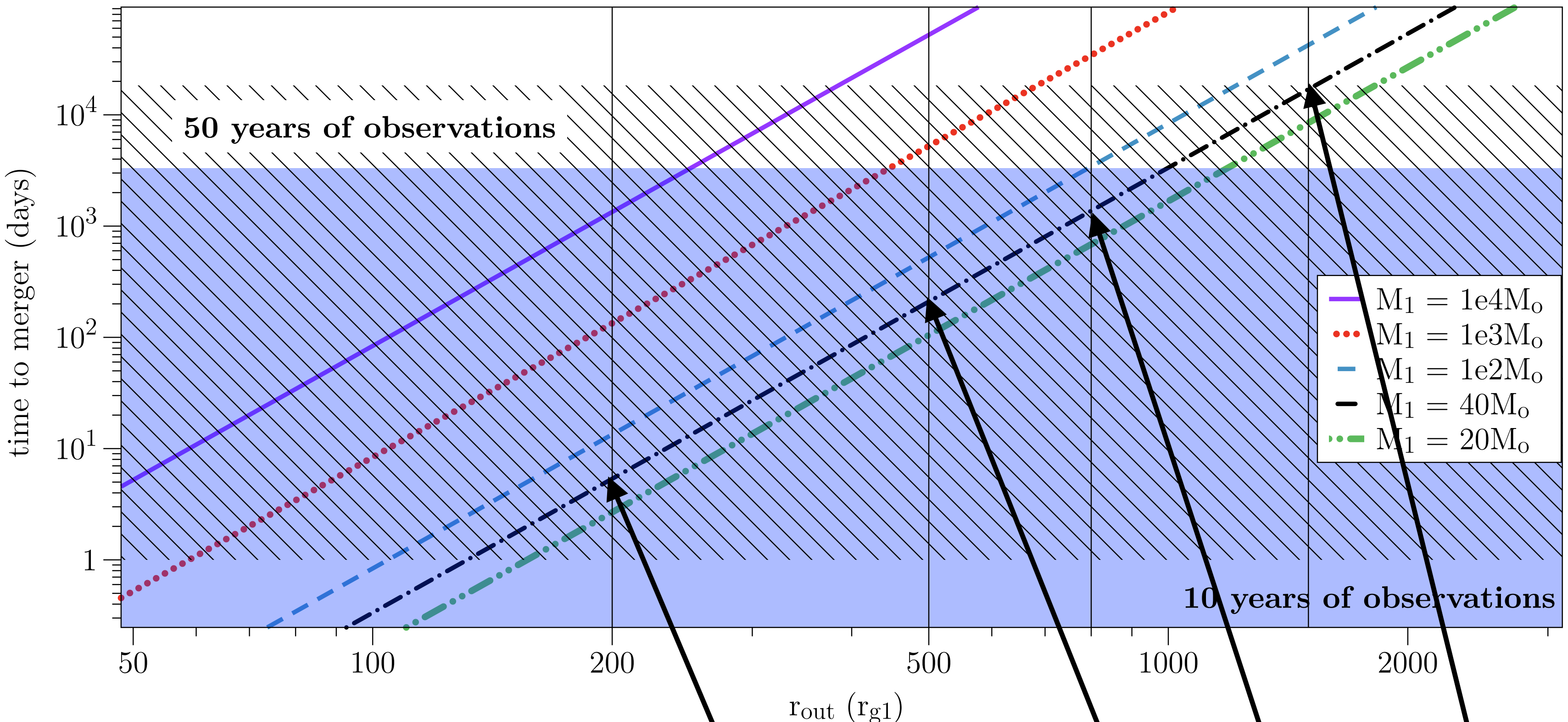

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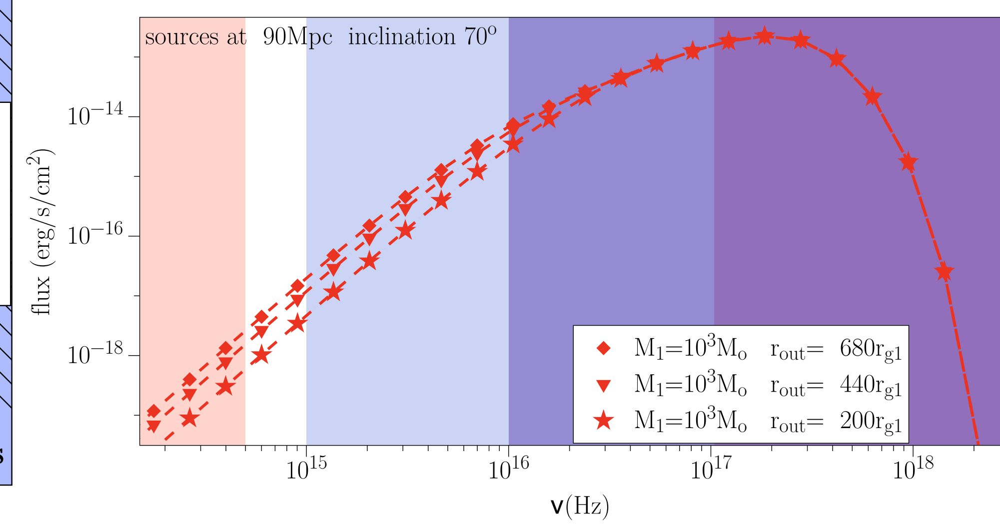

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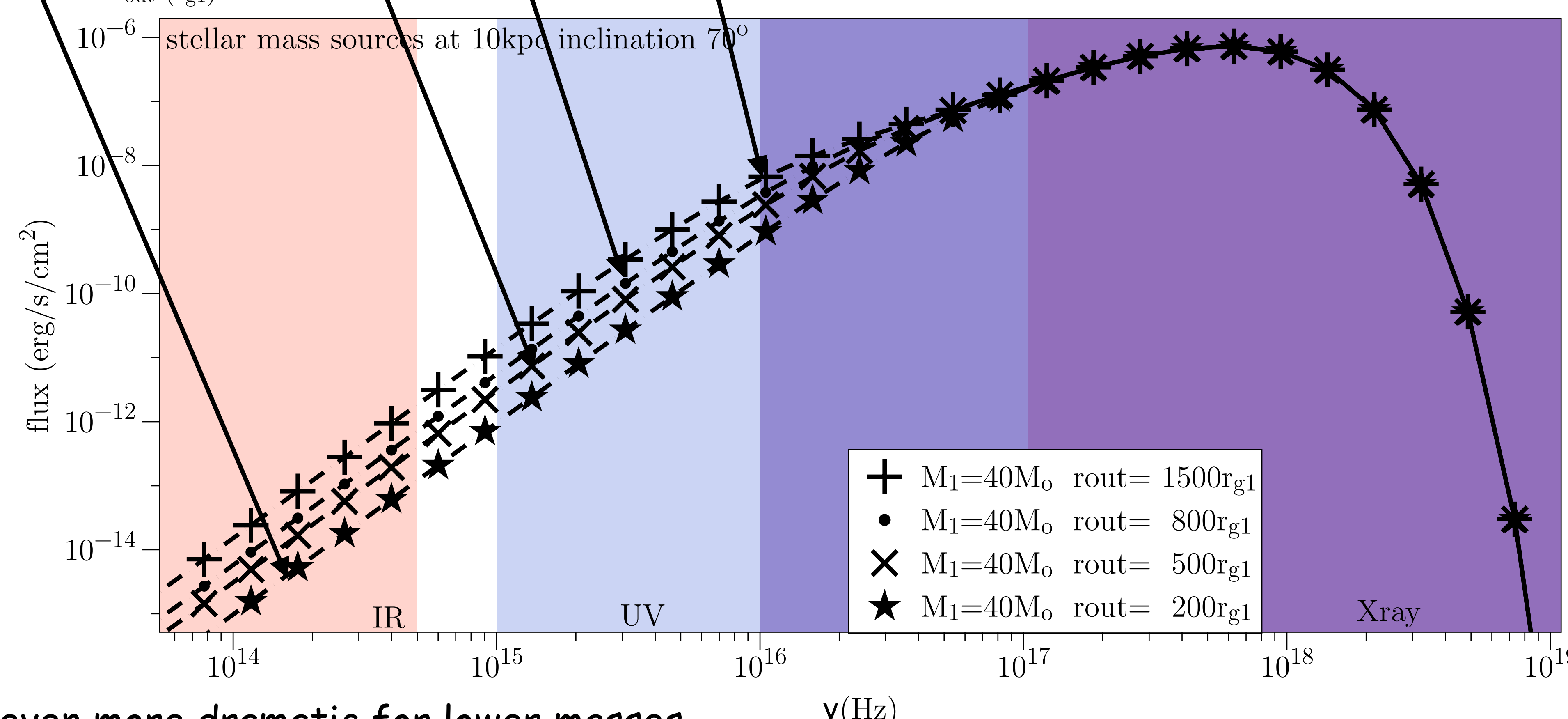
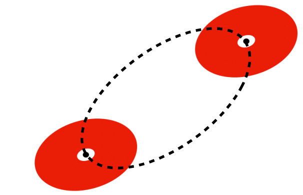


➥ it will get even more dramatic for lower masses

following the outer disk in real time: IM-BBH and lower



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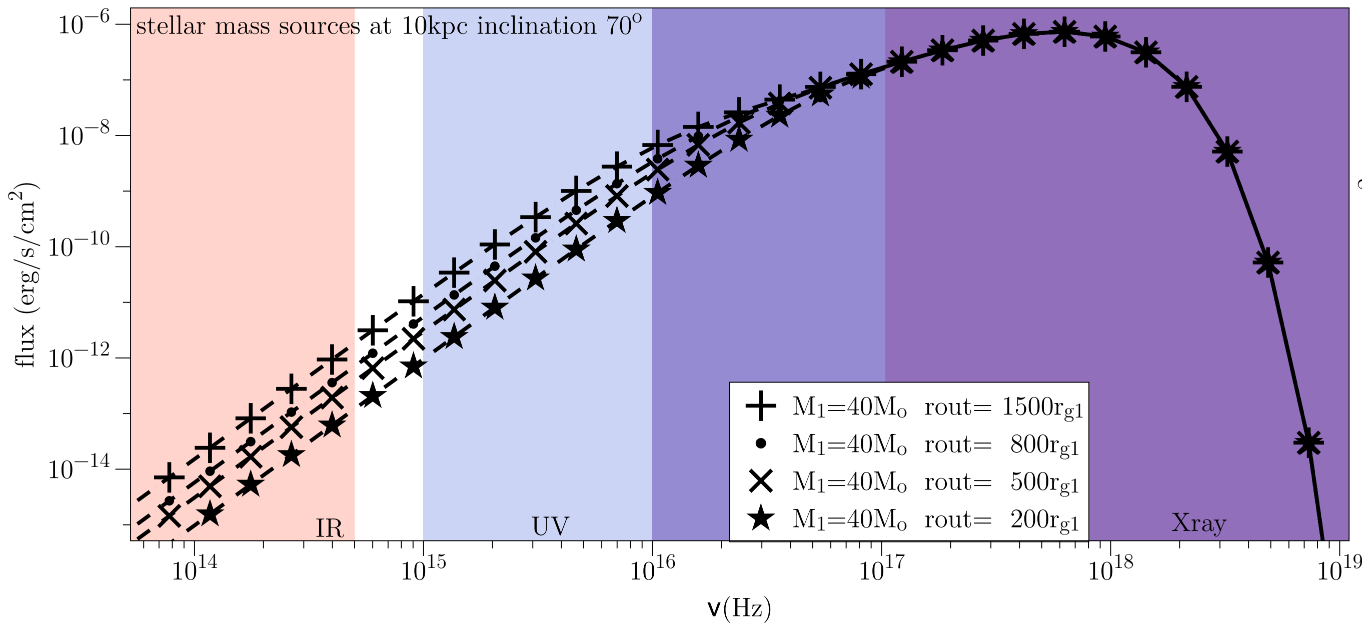
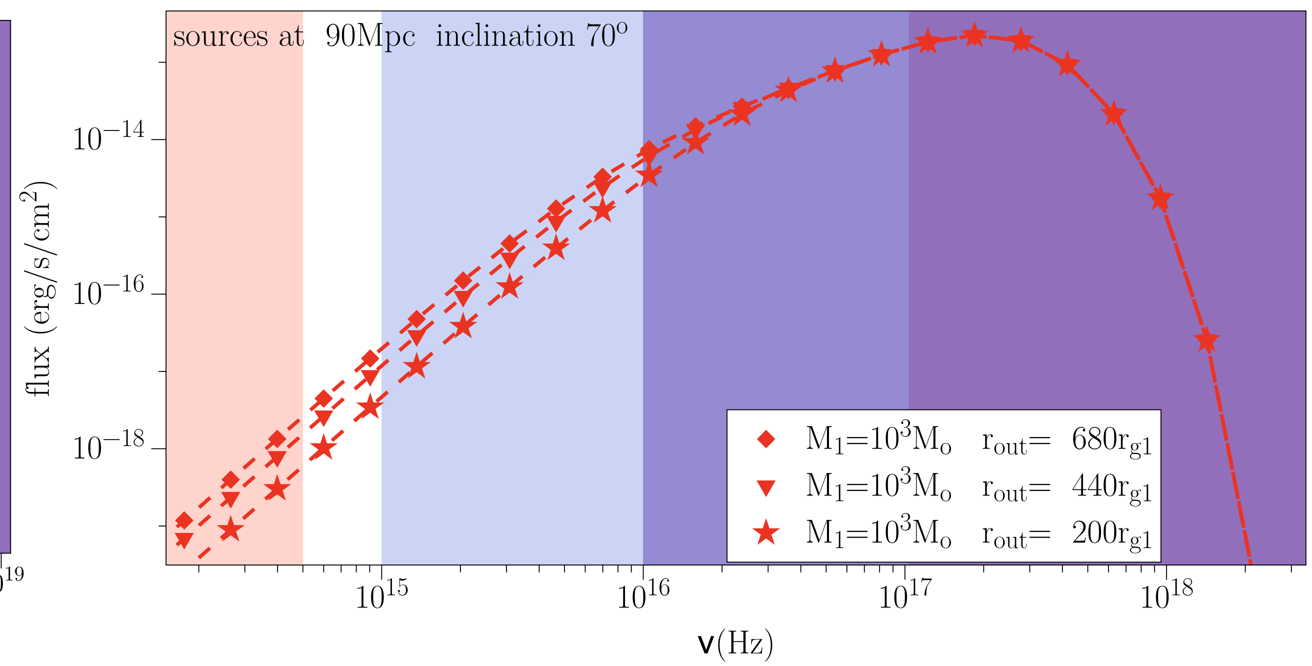
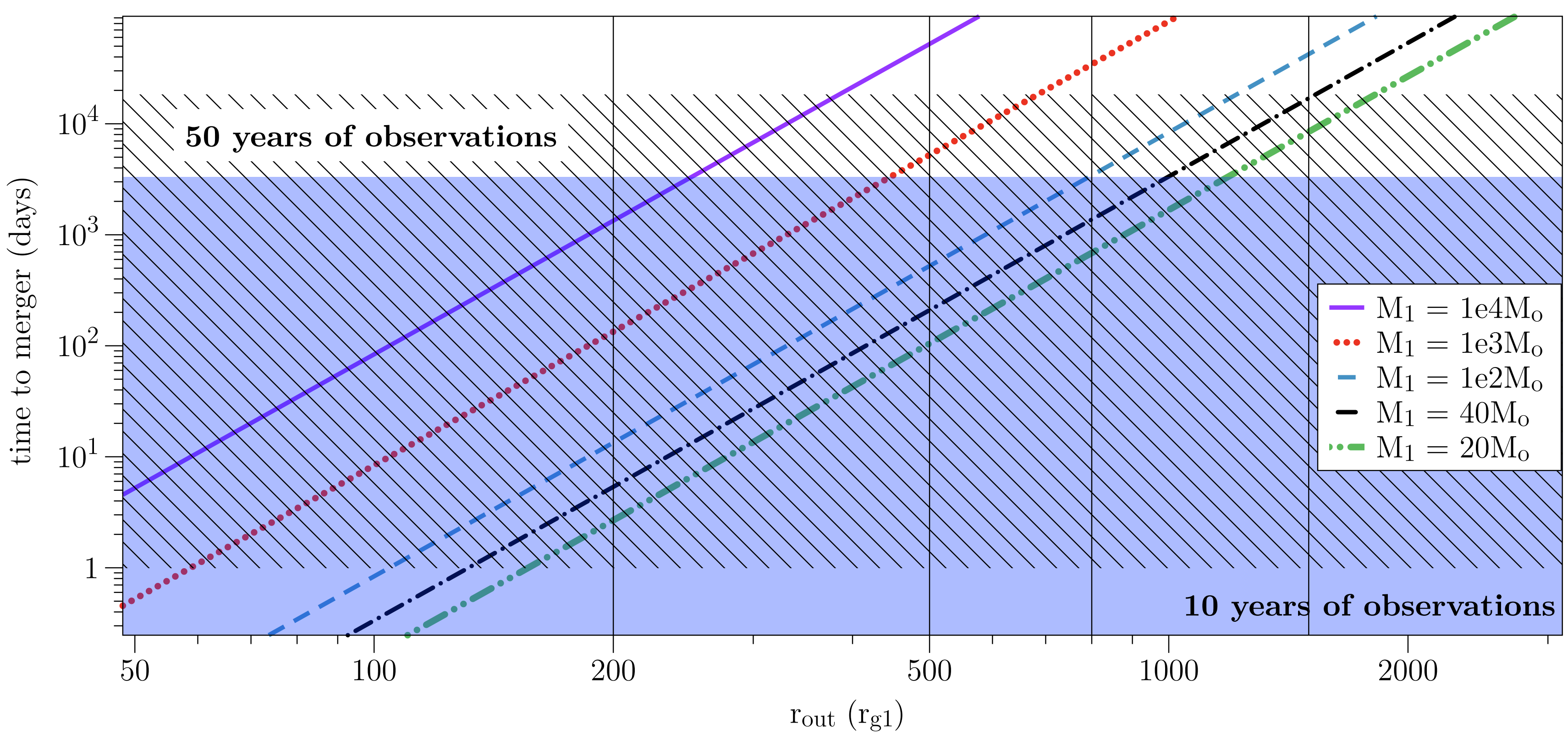


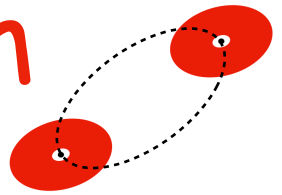


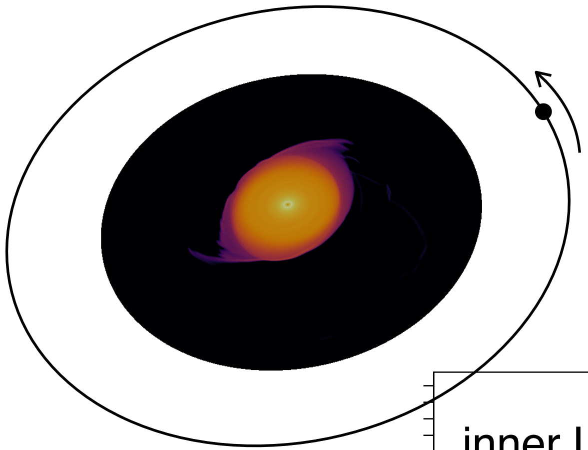


then we can check if the rate at which the outer edge disappear is compatible with the inspiral time to merger

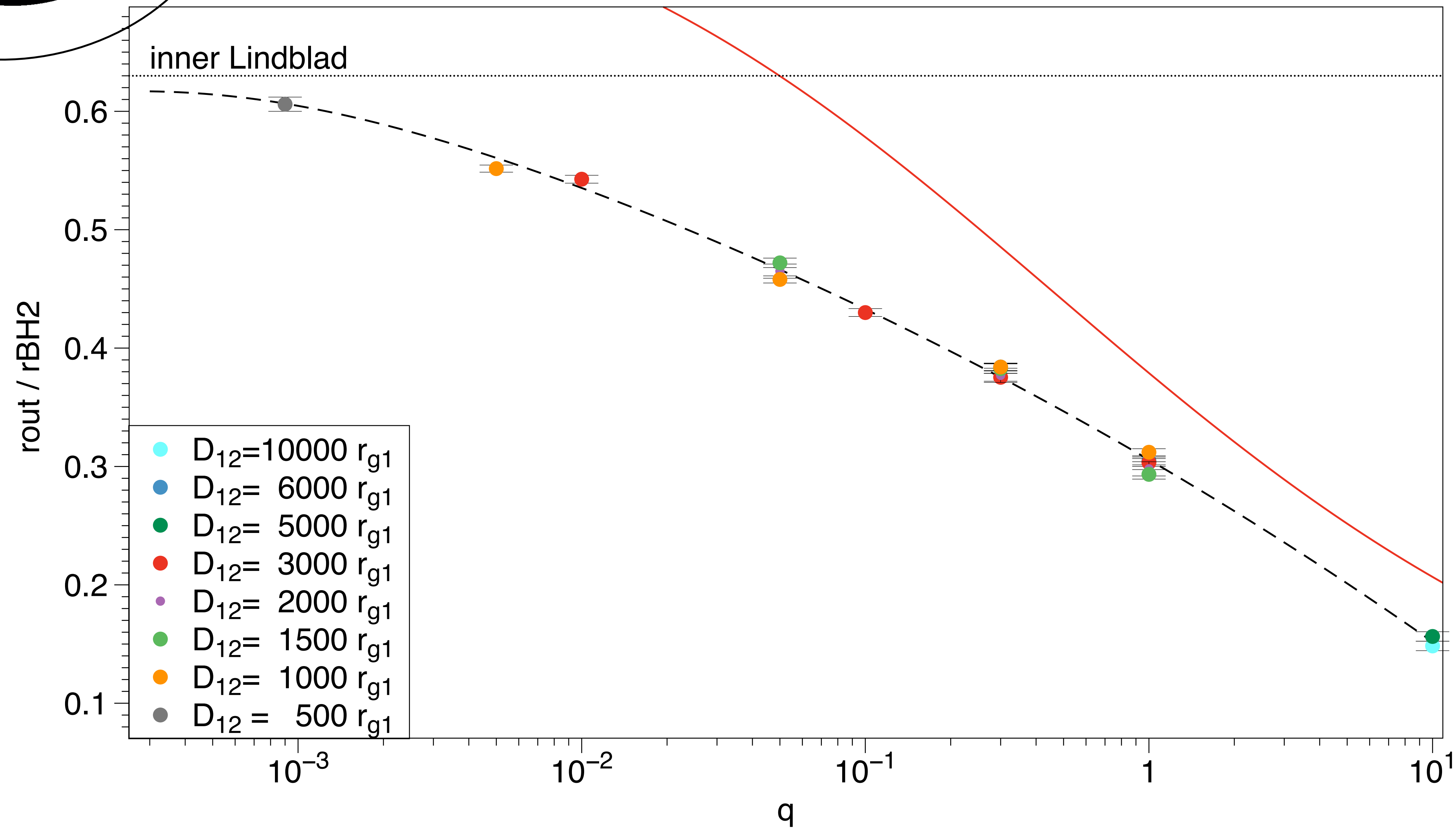
➥ a test for IM (and lower)-BBHs in the pre-CBD stage

the necessary observable of pre-CBD system



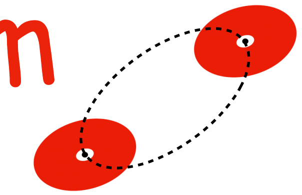


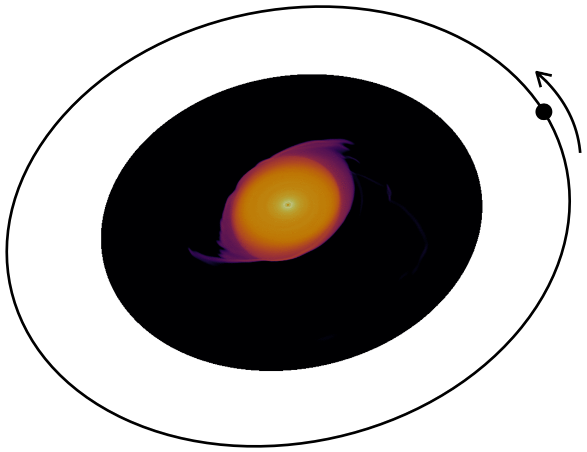
Even if we cannot follow the movement of the shrinking rout along with the reduction of the binary separation for most binary masses



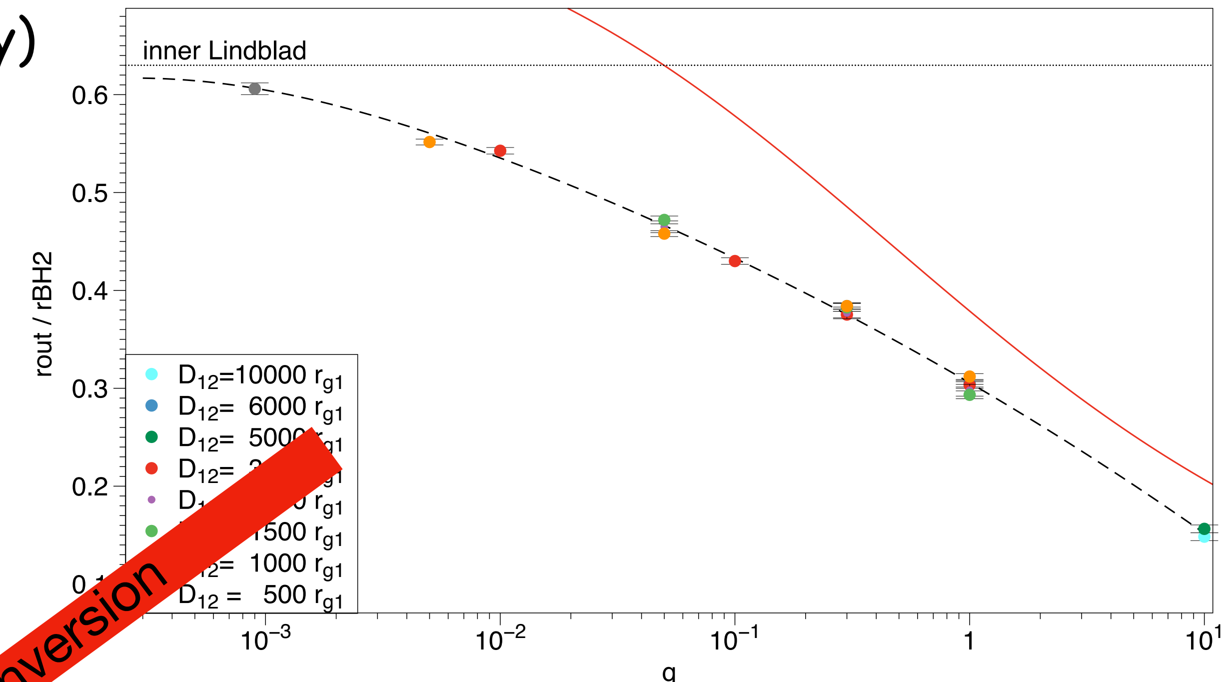
⇒ the "missing outer disk" is a necessary observable for a large portion of binary parameters and should be checked for all BBH candidate compatible with the pre-CBD stage

the necessary observable of pre-CBD system

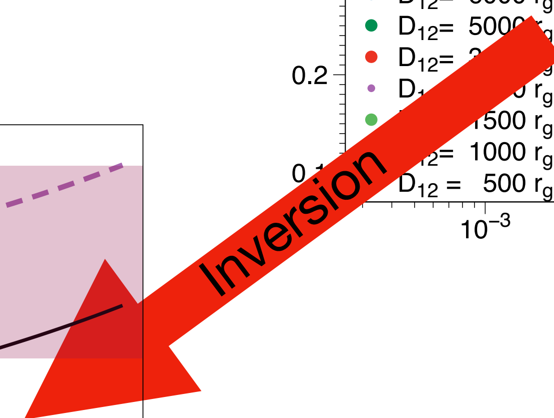


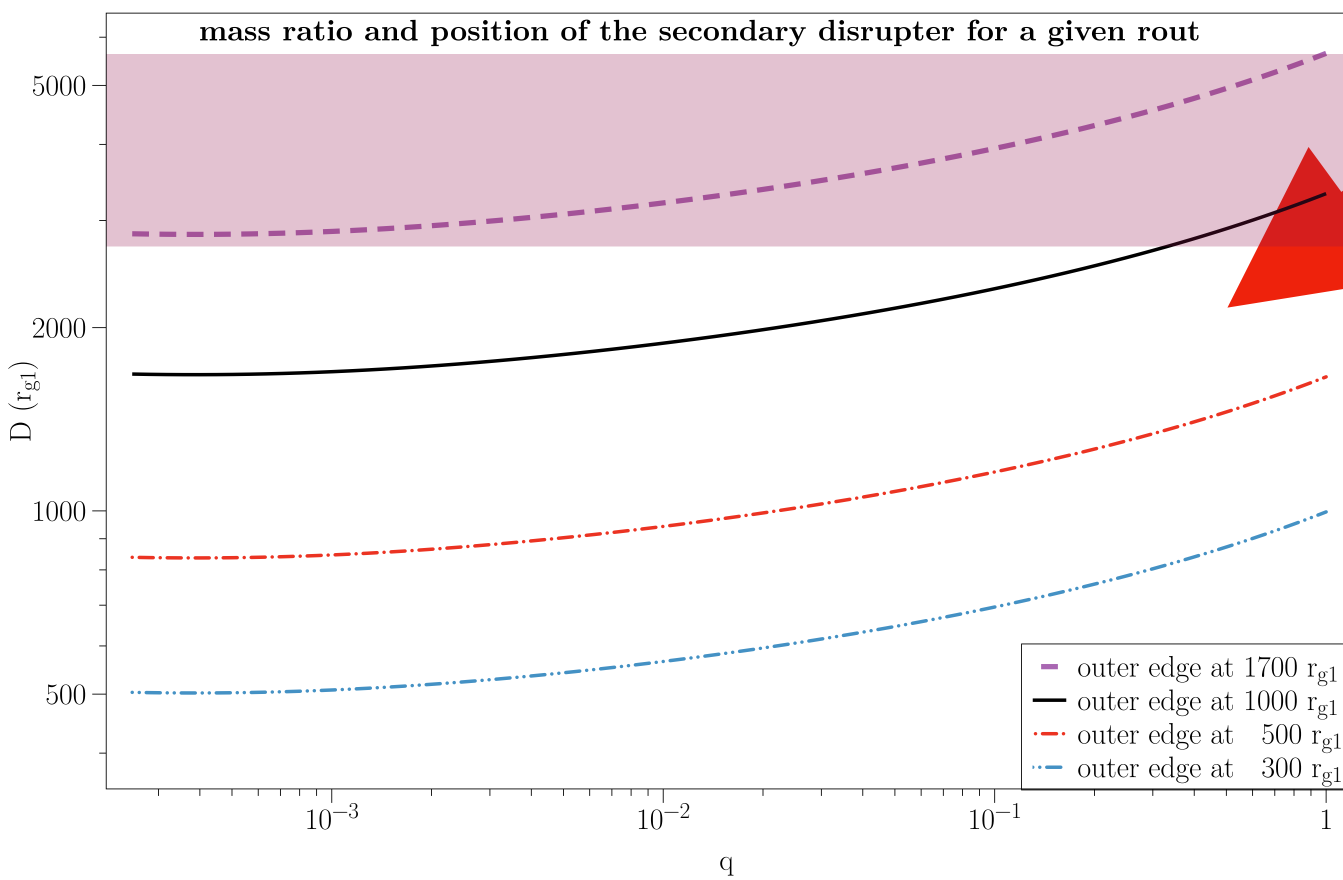


Similarly, any AGN with a "relatively small" outer disk should be check for potential companion (or fly-by)



if you find a disk with a given outer edge then you get a set of BBH of parameters able to cause it





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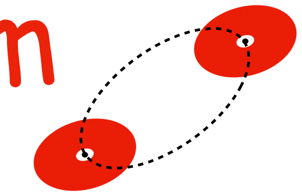

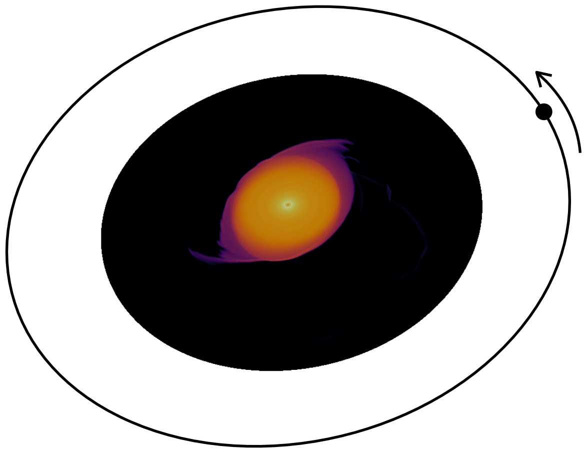

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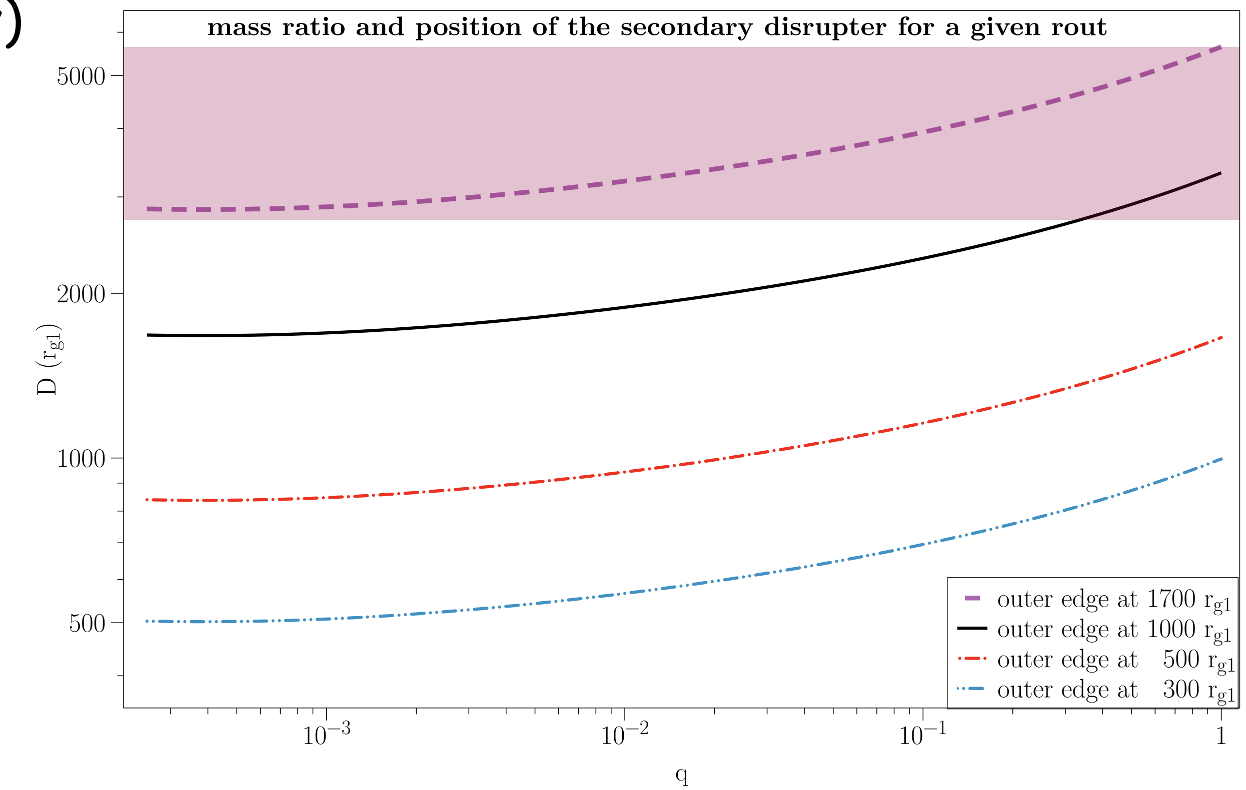

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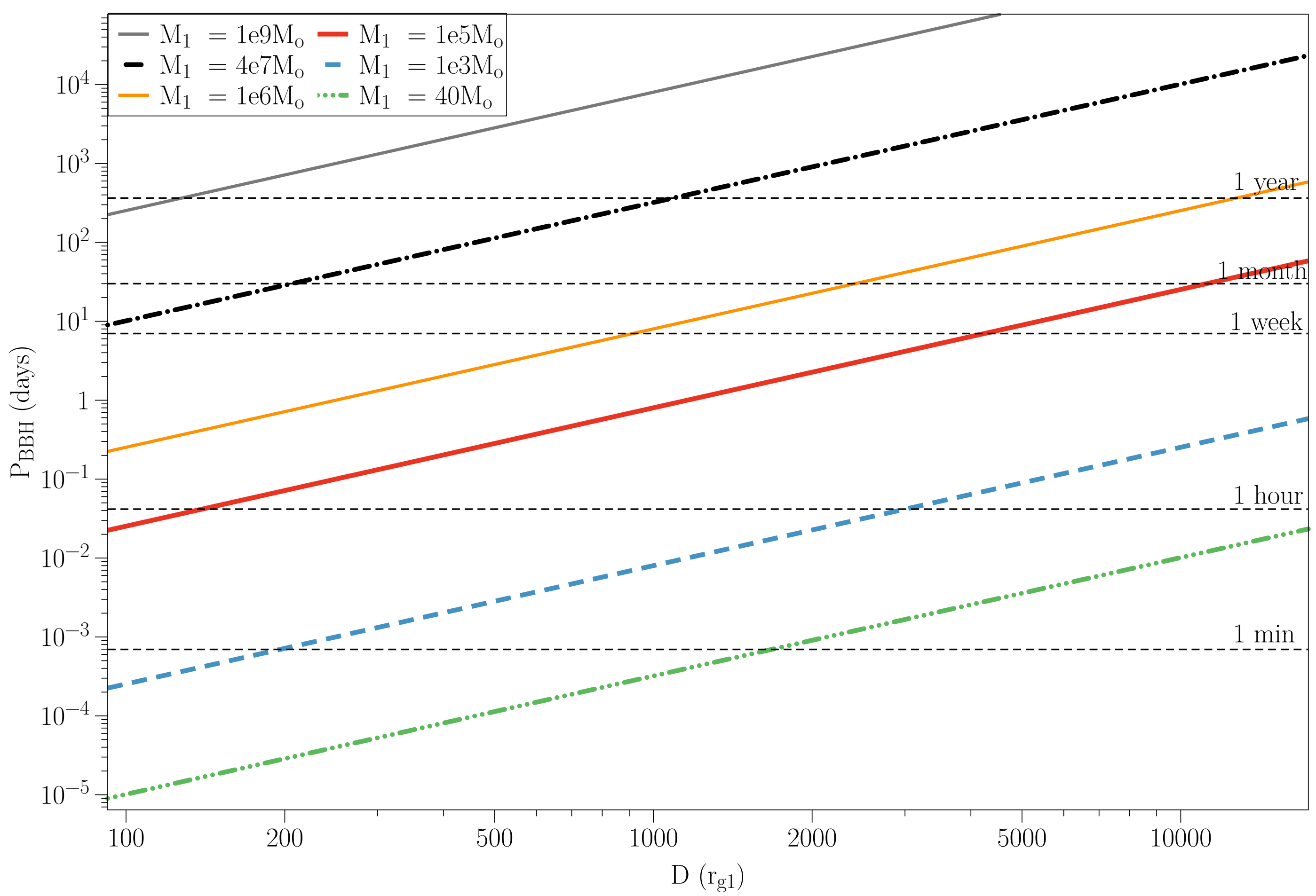
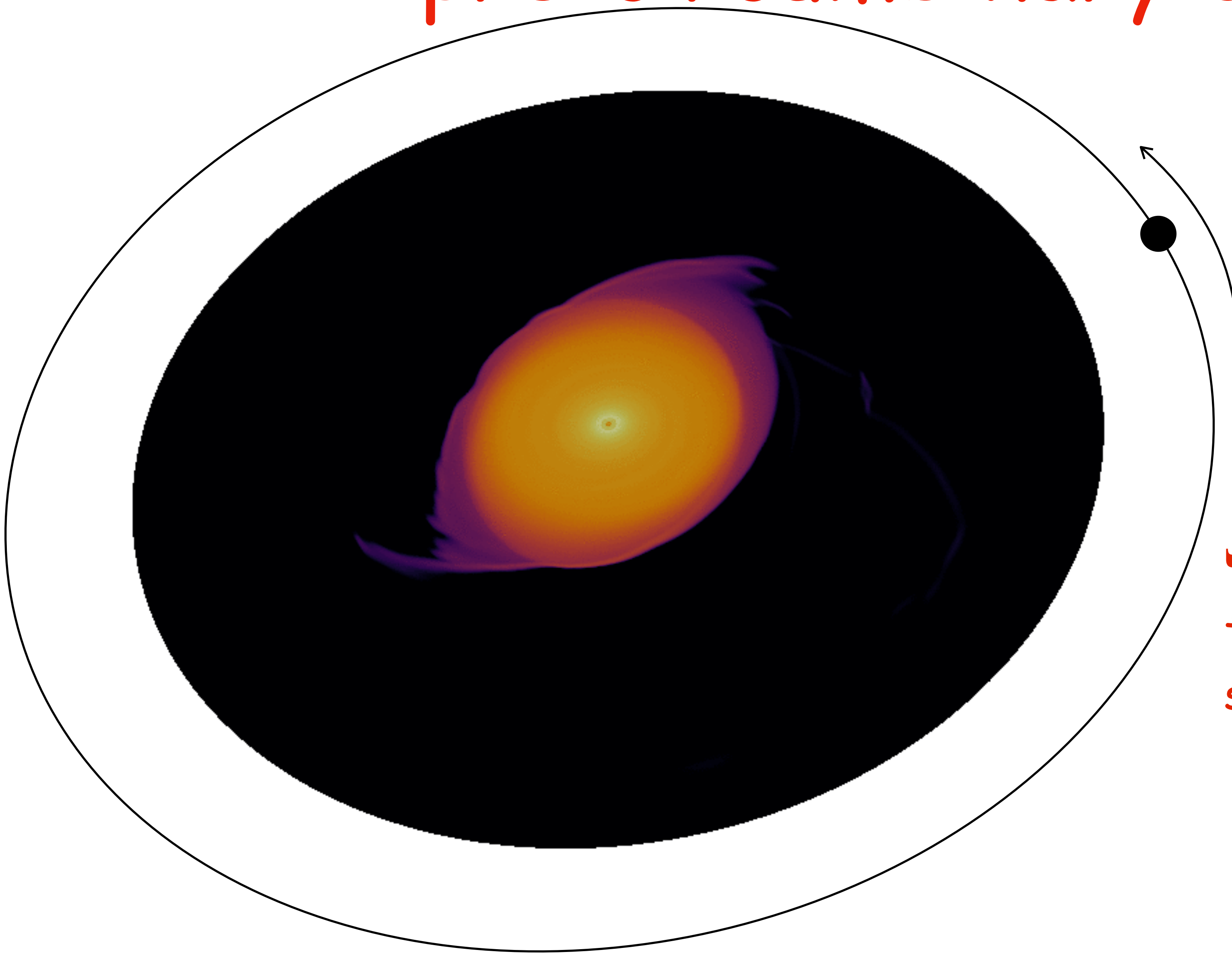


from that we can get the binary period that should modulates the flux (from the spiral and ellipsoid)

➥ this can help the search for a potential companion and identify new BBH candidate

➥ this show the strength of this necessary observable to not only validate BBH candidate but also search for new one

Conclusions: Exploring the detectability of pre-circumbinary disk systems



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of the three effects of a secondary (spiral, ellipse, shrinking) the most impactful one is the removal of the primary's outer disk

$\Rightarrow$ this "missing outer disk" is a necessary observable for a large portion of binary parameters and should be checked for all BBH candidate compatible with the pre-CBD stage