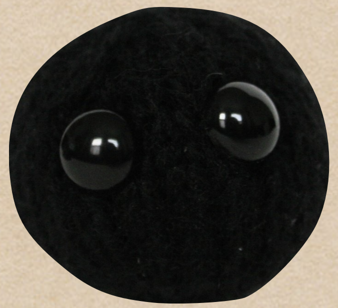
# CAMELIDS IN THE SKY: DROMEDARIES OR CAMELS?

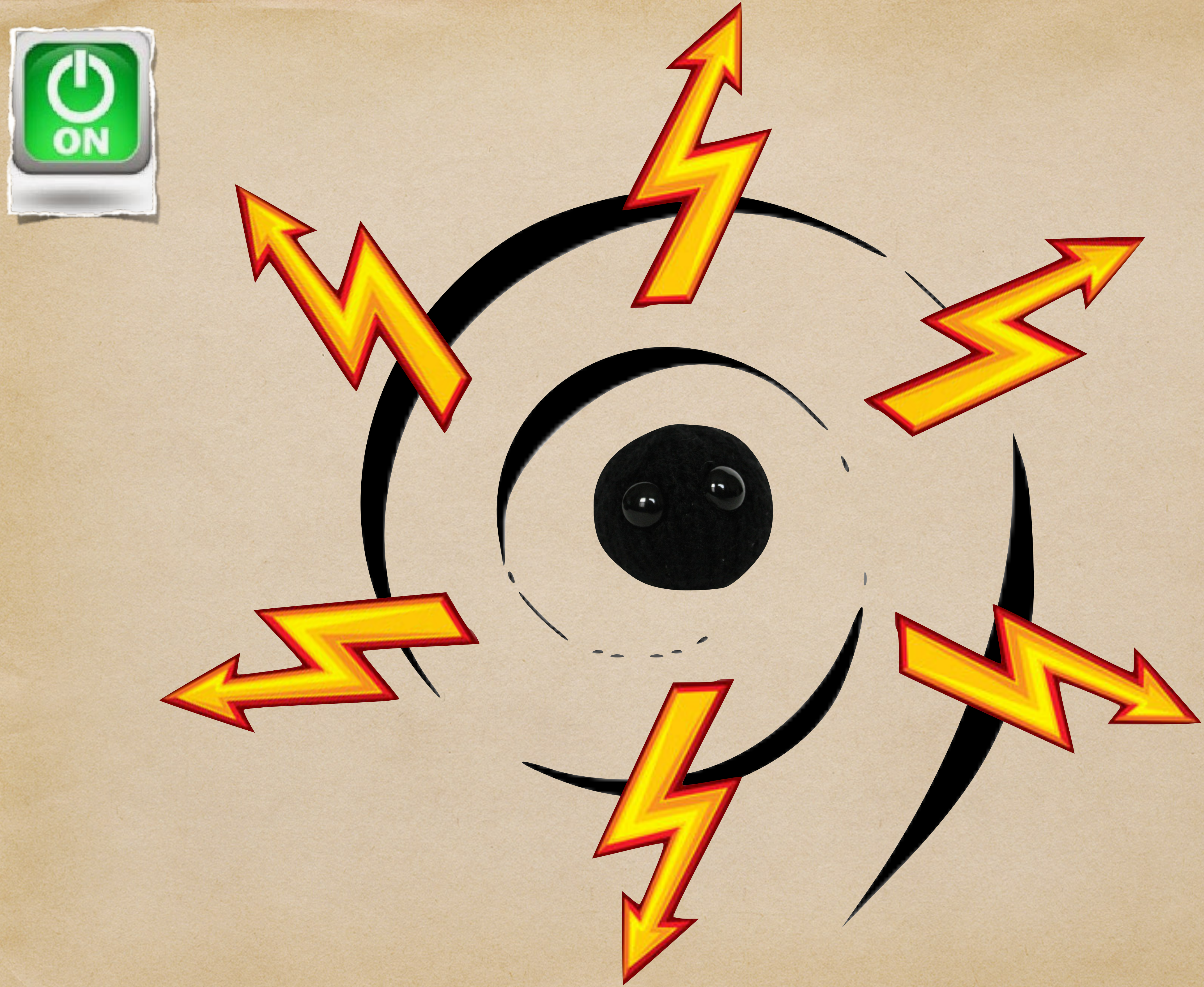
## SINGLE or DOUBLE peaked light curves from double TDEs

DEBORAH MAINETTI

UNIVERSITA' DEGLI STUDI DI MILANO BICOCCA (MILANO) - INAF, OSSERVATORIO ASTRONOMICO DI BRERA (MERATE)

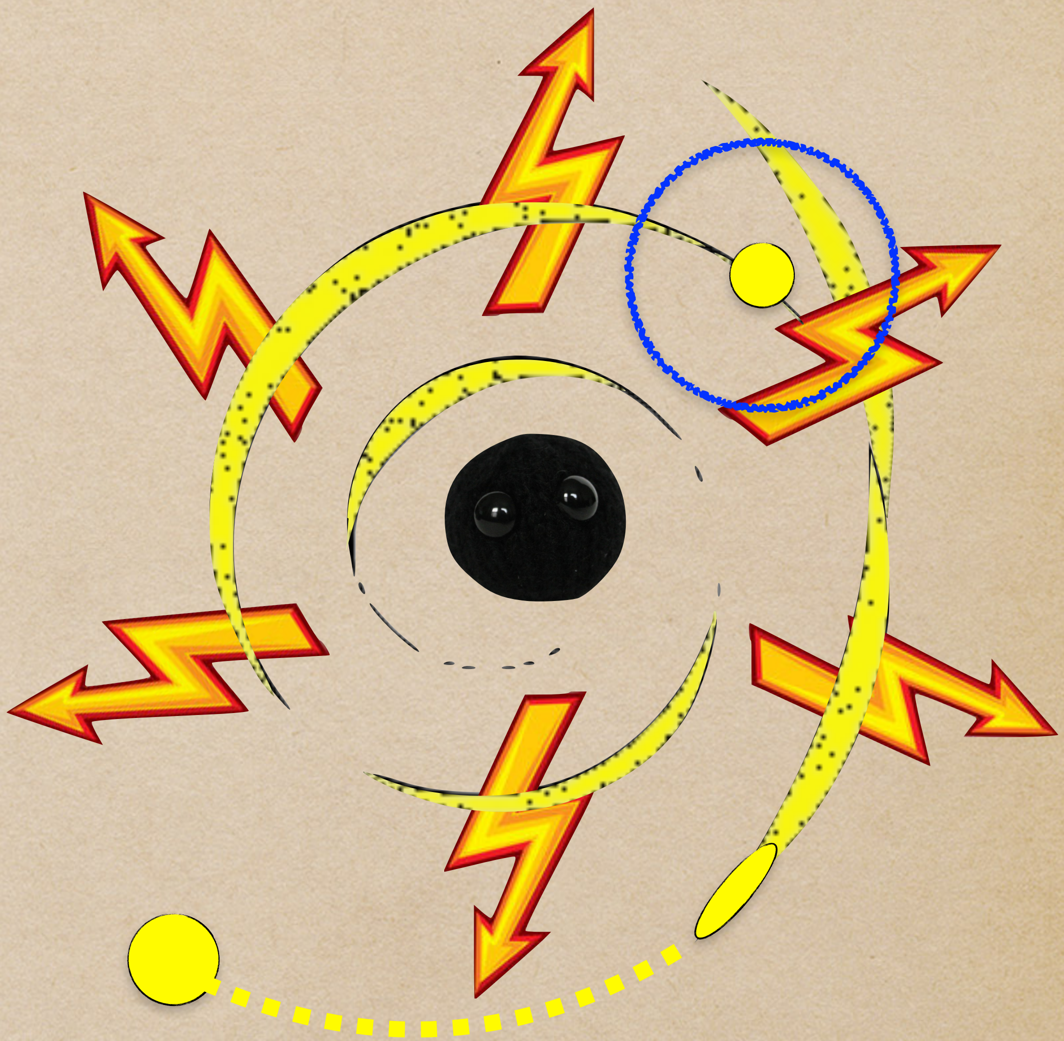

OFF




ON

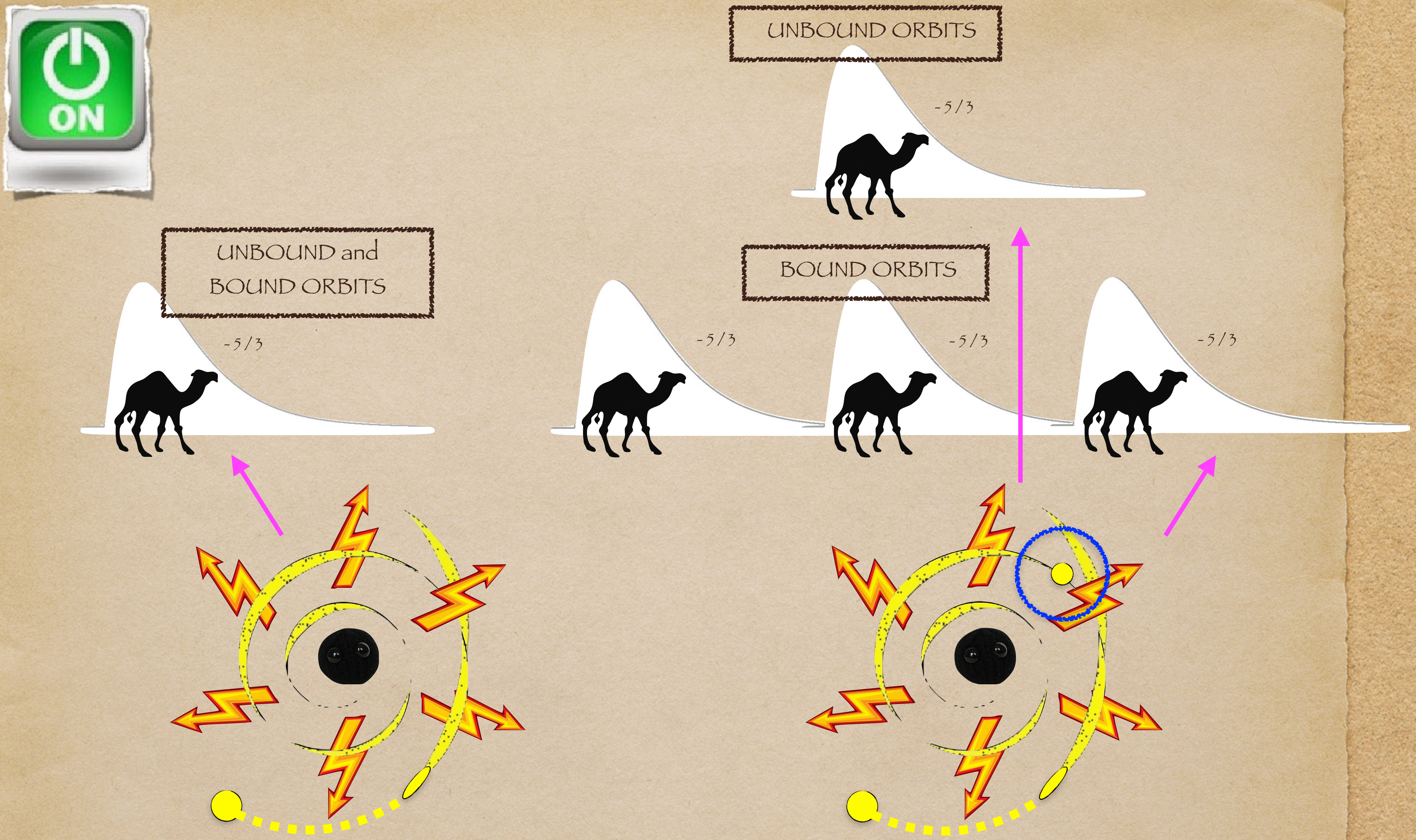
TOTAL disruption

$\beta \simeq {}^{r_{tidal}}/_{r_{pericenter}} \geq 1$



PARTIAL disruption

$\beta \simeq {}^{r_{tidal}}/_{r_{pericenter}} \leq 1$

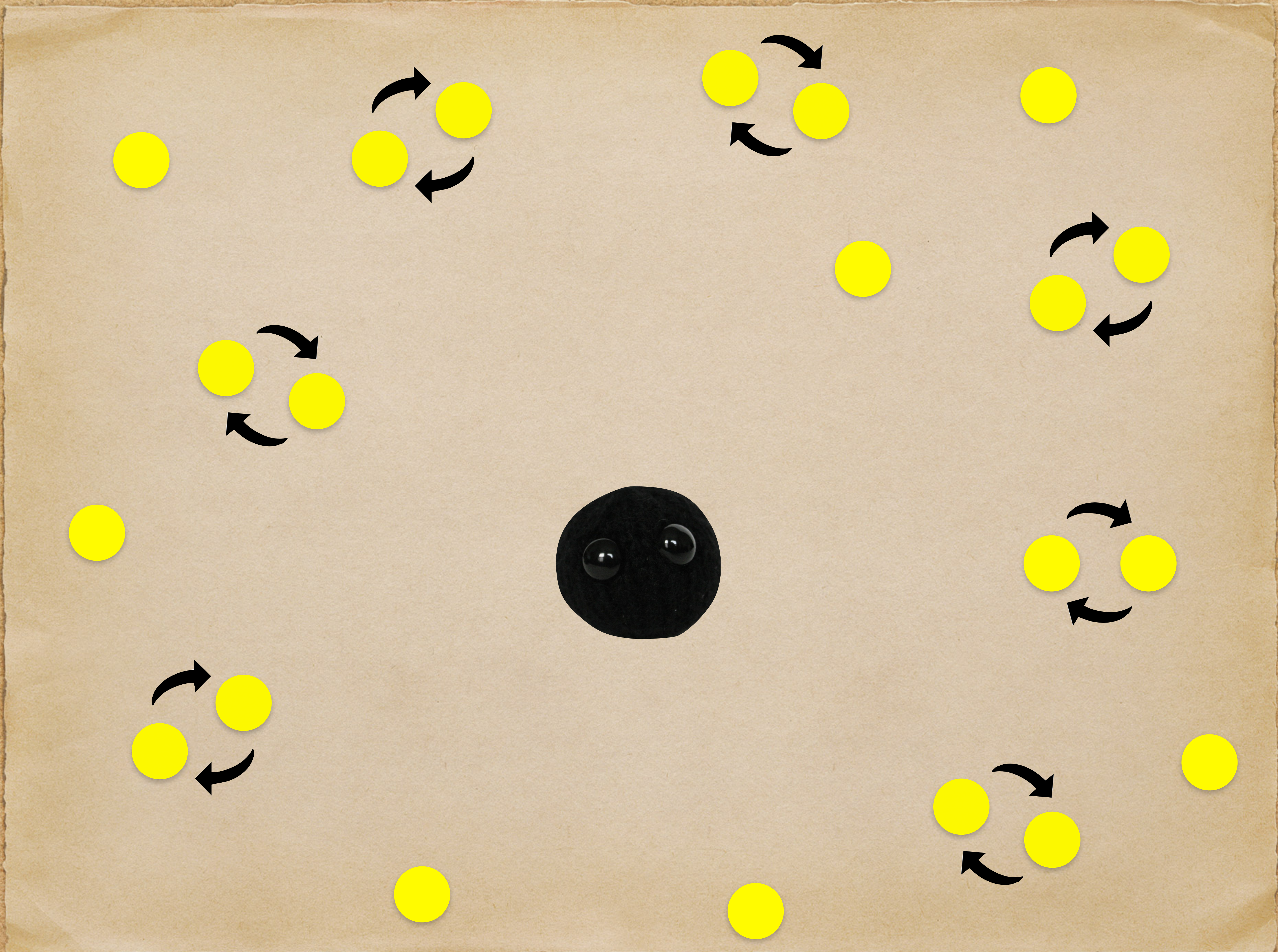


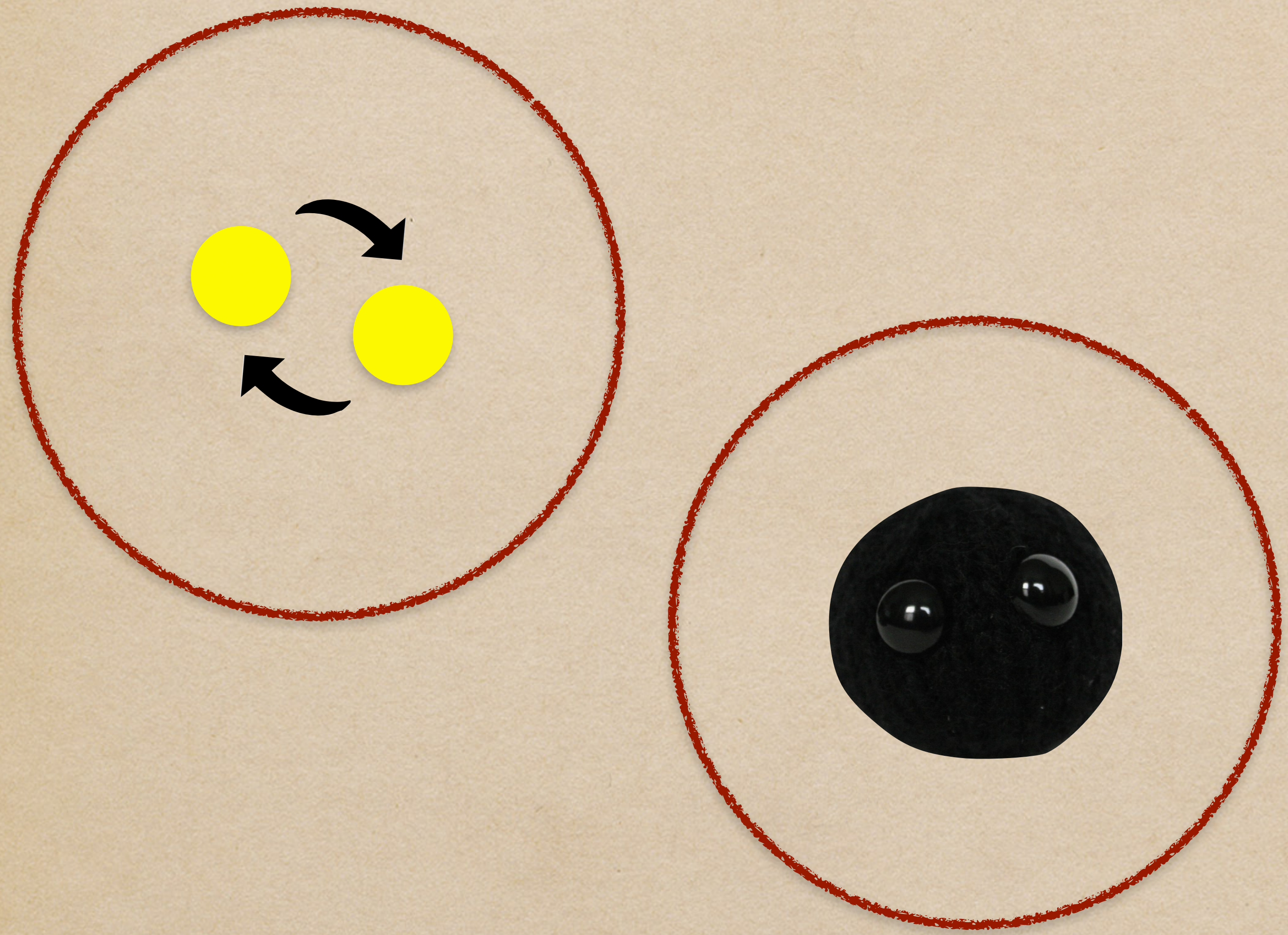

TOTAL disruption

$\beta \simeq r_{tidal}/r_{pericenter} \gtrsim 1$

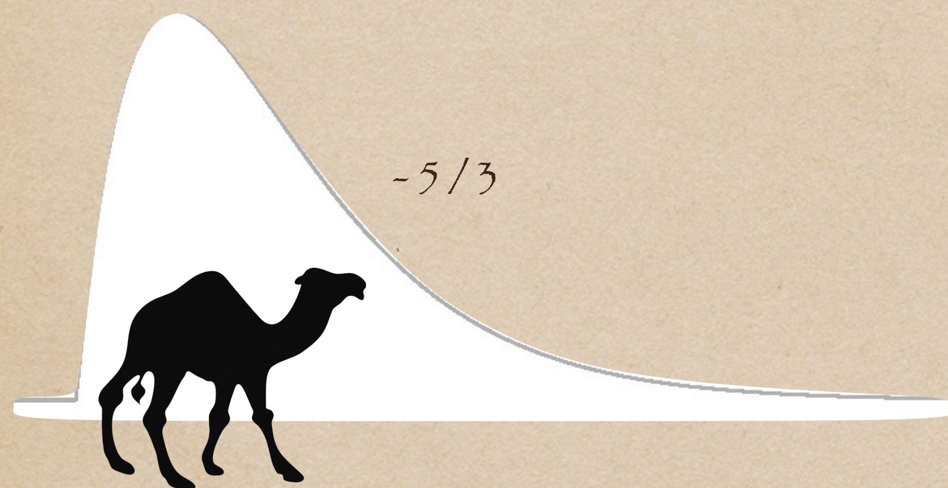
PARTIAL disruption

$\beta \simeq r_{tidal}/r_{pericenter} \lesssim 1$

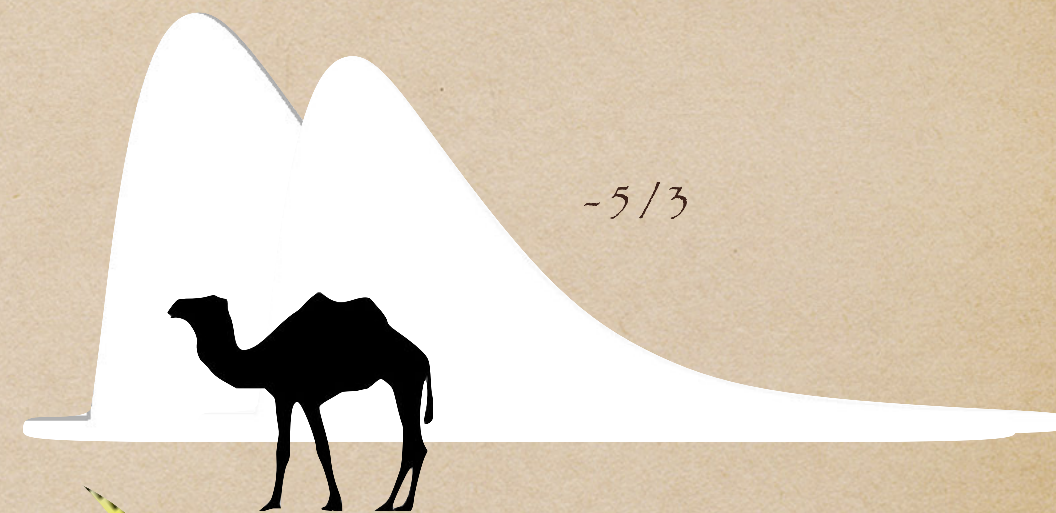




Quite rarely…

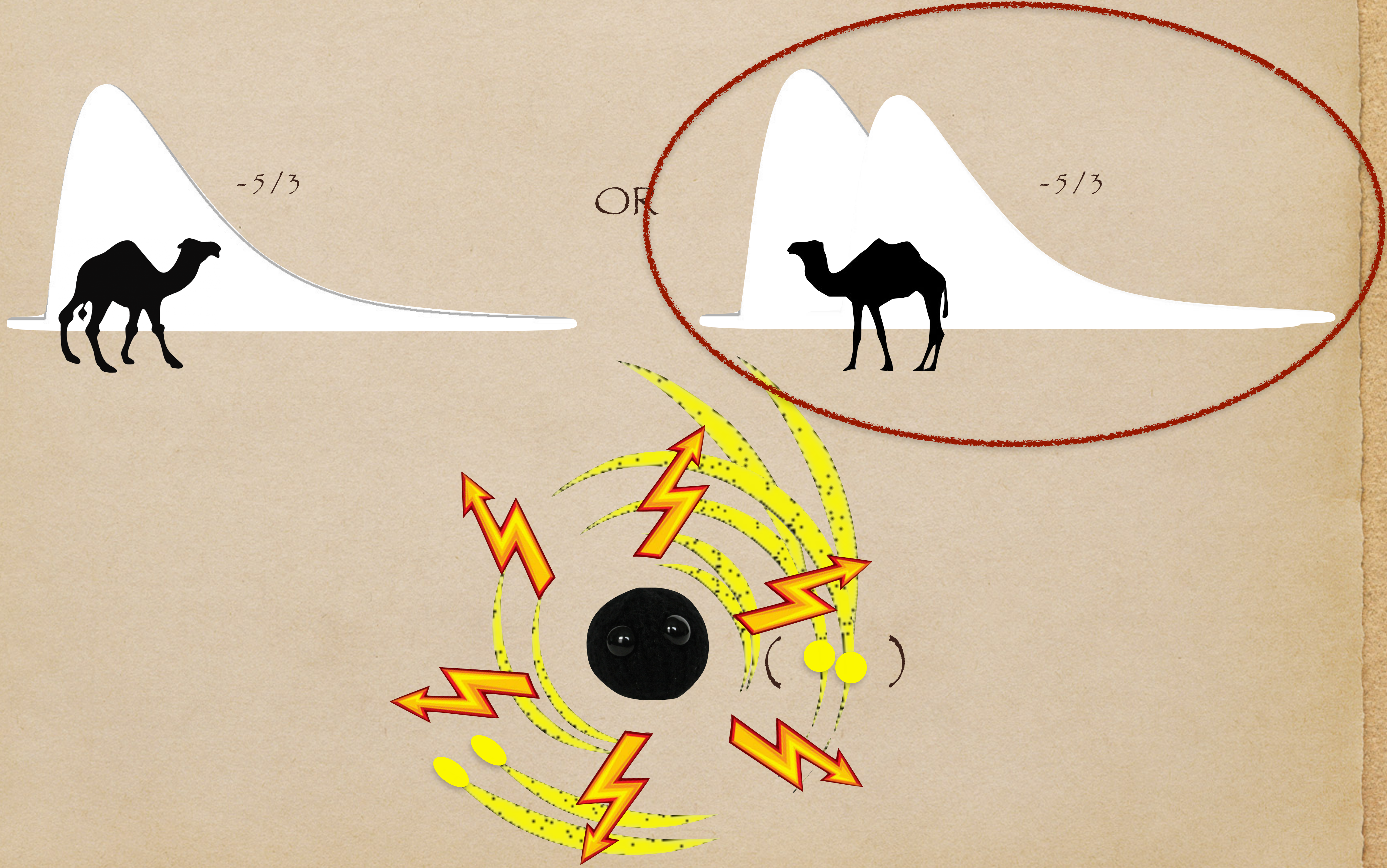



OR




# SPH simulations

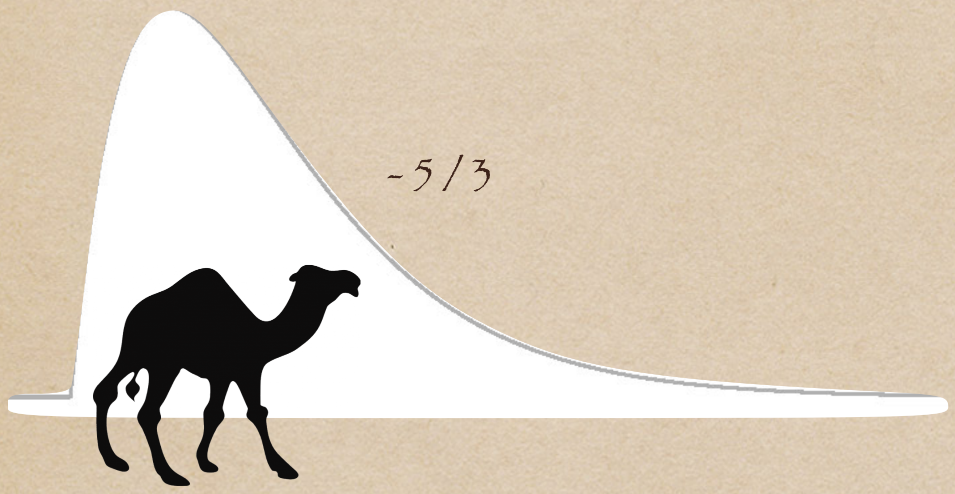
GADGET2 code, Newtonian regime



# SPH simulations

GADGET2 code, Newtonian regime

Fluids divided into a set of discrete elements (particles)
=> unlike n-body codes, SPH codes allow us to follow the evolution of single particle properties in simulations and build light curves directly from them




OR


# BASICS FOR DOUBLE TDEs

Mandel & Levin (2015)

1) each star must have $r_{pericenter}$ similar to the one of the binary CM

=> $a_{bin}$ must be small enough

2) the binary must be still intact when it enters the region of single star tidal disruption

-> this is the only way to have a double TDE immediately after binary break-up

distribution of the parameters of binaries which can potentially experience double TDEs
(useful for the initial conditions of my simulations)

# SPH SIMULATIONS

# LOW-RESOLUTION SPH SIMULATIONS (check the outcomes)

## ASSUMPTIONS:

1) equal-mass binaries ($M_* = 1 M_\odot$, $R_* = 1 R_\odot$), $10^3$ particles per star, $\gamma_{politropic} = 5/3$,

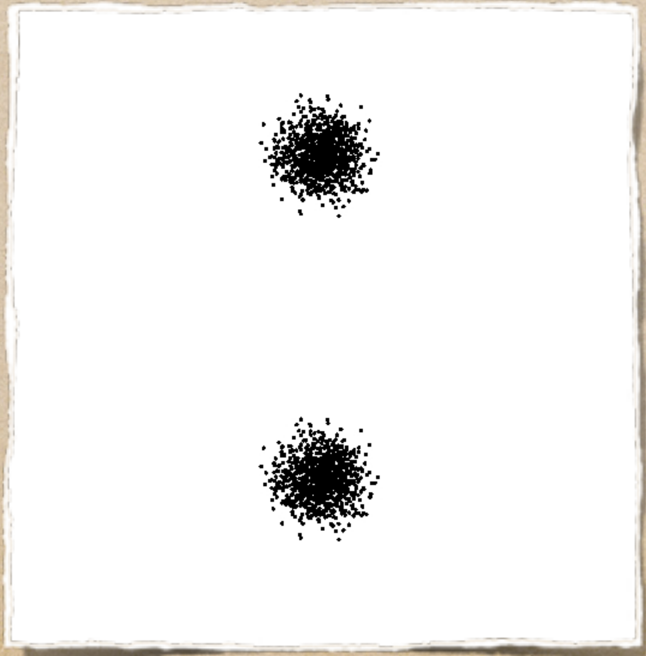
$a_{bin} = 5/10 R_\odot$, $e_{bin} = 0$,

inner binary orbital plane (yz) perpendicular to outer binary orbital plane (xy)

2) $M_{BH} = 10^5$-$10^6 M_\odot$

3) binary cdm on a parabolic orbit around the BH

4) $r_{pericenter}$ free to vary, to test different outcomes



# LOW-RESOLUTION SPH SIMULATIONS (check the outcomes)

## ASSUMPTIONS:

1) equal-mass binaries ($M_* = 1\,M_\odot$, $R_* = 1\,R_\odot$), $10^3$ particles per star, $\gamma_{politropic} = 5/3$,

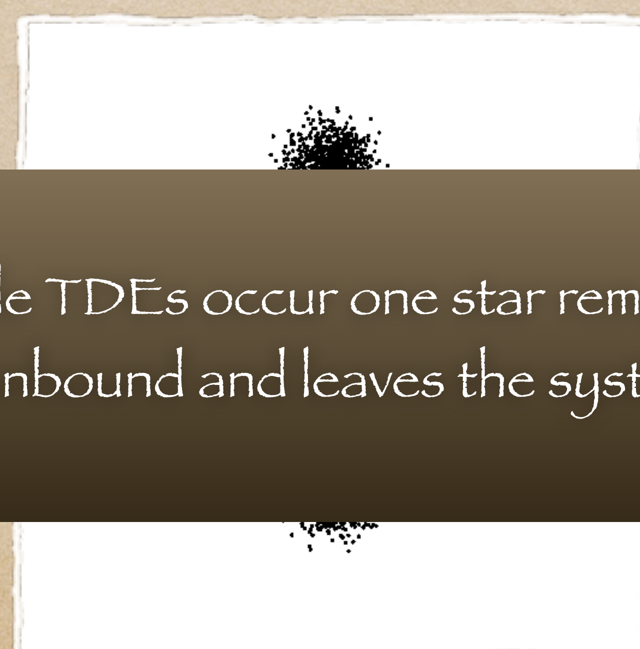
$a_{bin} = 5/10\,R_\odot$, $e_{bin} = 0$,

inner binary orbital plane (yz) perpendicular to outer binary orbital plane (xy)

2) $M_{BH} = 10^5$-$10^6\,M_\odot$

3) binary cdm on a parabolic orbit around the BH

4) $r_{pericenter}$ free to vary, to test different outcomes



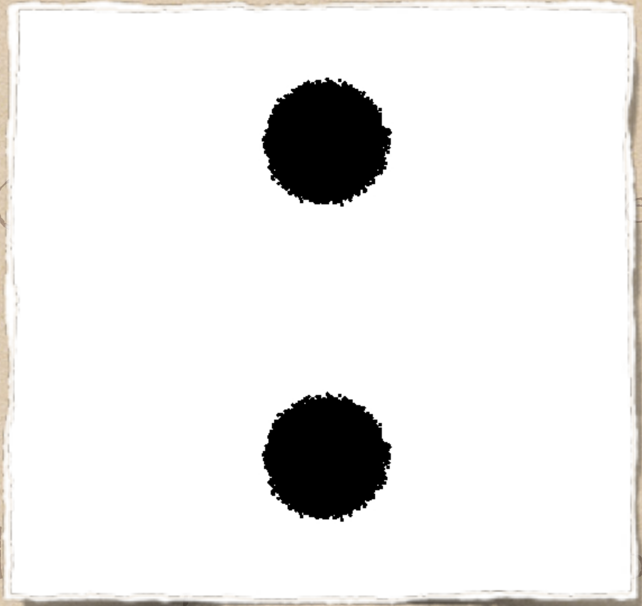
Generally, when double TDEs occur one star remains bound to the BH while the other becomes unbound and leaves the system after binary break-up

# LOW-RESOLUTION SPH SIMULATIONS

ASSUMPTIONS:

1) equal-mass

inner binary orbital plane (



er binary orbital plane (xy)

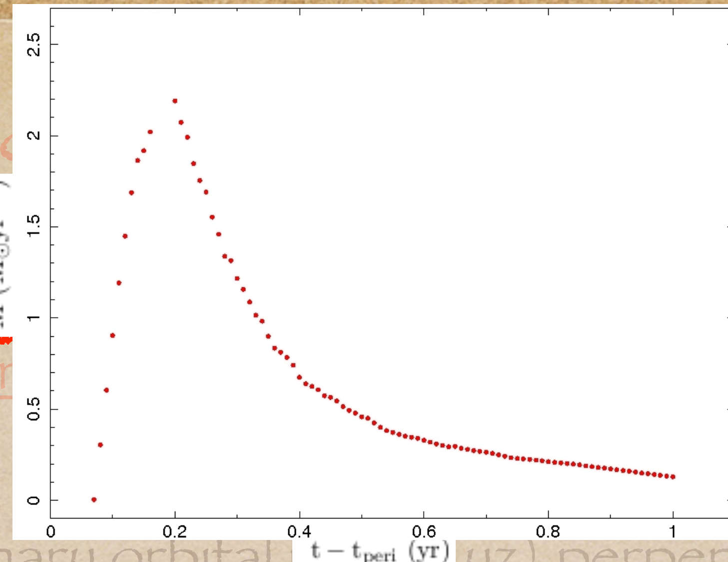
3) binary co

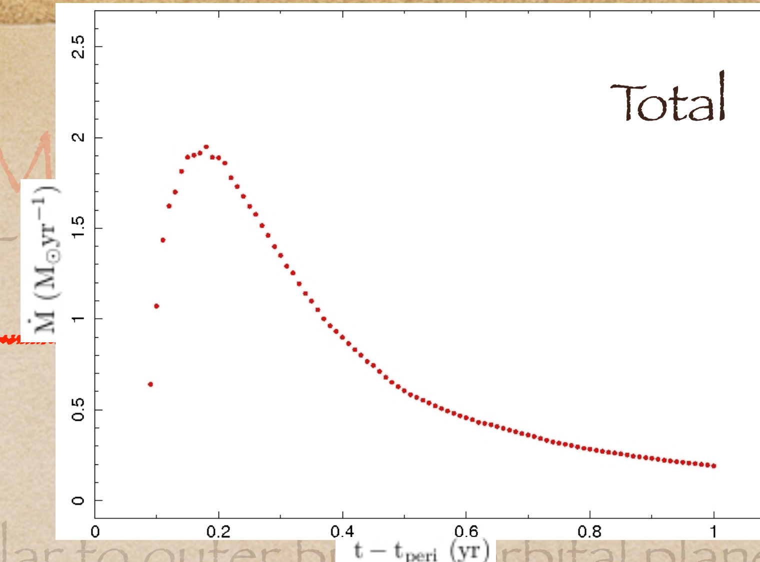
und the BH

4) $r_{pericenter}$

# HIGH-RESOLUTION SPH SIMULATIONS (build the total light curve)

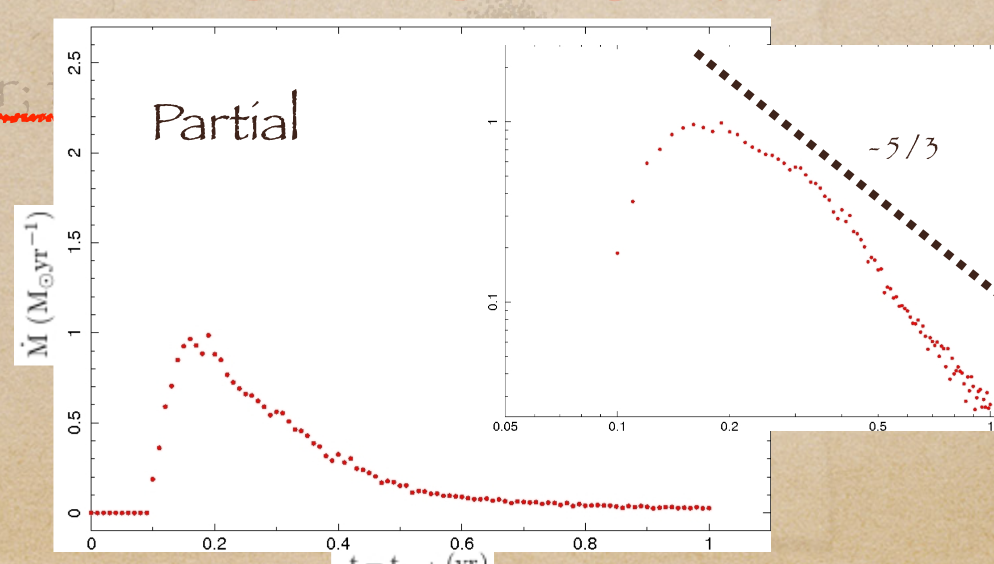
$10^5$ particles per star; total disruption, almost total disruption, partial disruption



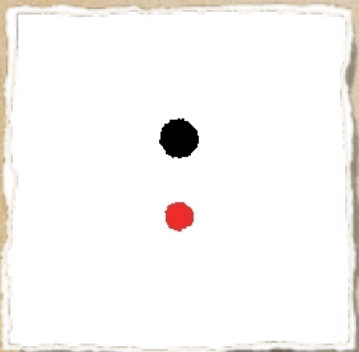

RESULTS: equal mass binary-BH deep encounters do not produce double peaked light curves, equal mass binary-BH grazing encounters can produce double peaked light curves

(see Guillochon & Ramirez-Ruiz (2013, 2015))

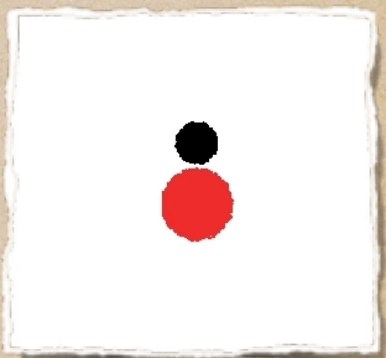


# HIGH-RESOLUTION SPH SIMULATIONS

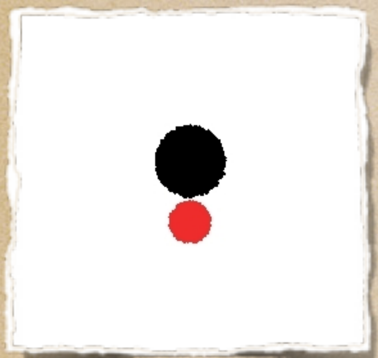
non equal-mass binaries, (almost) total disruptions



SIMULATION 1: $M_{*1} = 0.4\,M_{\odot}$, $R_{*1} = 0.5\,R_{\odot}$ ($4\times10^4$ particles);
$M_{*2} = 0.27\,M_{\odot}$, $R_{*2} = 0.3\,R_{\odot}$ ($2.7\times10^4$ particles) (from Mandel & Levin 2015)



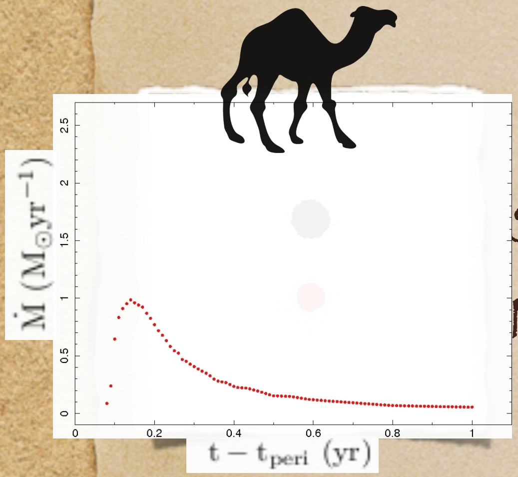
SIMULATION 2: $M_{*1} = 0.5\,M_{\odot}$, $R_{*1} = 0.6\,R_{\odot}$ ($10^5$ particles);
$M_{*2} = 1\,M_{\odot}$, $R_{*2} = 1\,R_{\odot}$ ($2\times10^5$ particles)



SIMULATION 3: $M_{*1} = 1\,M_{\odot}$, $R_{*1} = 1\,R_{\odot}$ ($2\times10^5$ particles);
$M_{*2} = 0.5\,M_{\odot}$, $R_{*2} = 0.6\,R_{\odot}$ ($10^5$ particles)

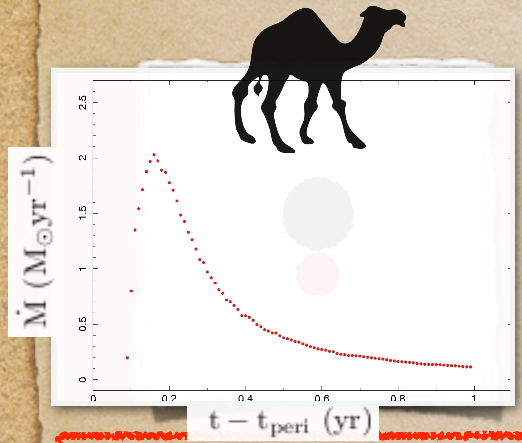
# HIGH-RESOLUTION SPH SIMULATIONS

non equal-mass binaries, (almost) total disruptions

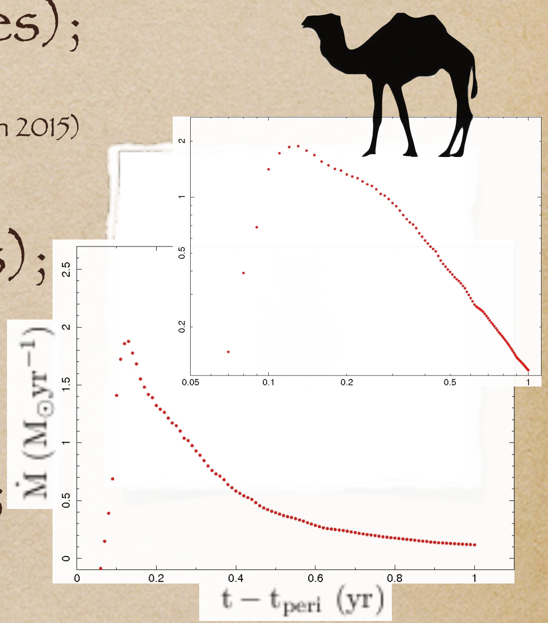



SIMULATION 1: $M_{*1} = 0.4\ M_\odot$, $R_{*1} = 0.5\ R_\odot$ ($4\times10^4$ particles); $M_{*2} = 0.27\ M_\odot$, $R_{*2} = 0.3\ R_\odot$ ($2.7\times10^4$ particles) (from Mandel & Levin 2015)

SIMULATION 2: $M_{*1} = 0.5\ M_\odot$, $R_{*1} = 0.6\ R_\odot$ ($10^5$ particles); $M_{*2} = 1\ M_\odot$, $R_{*2} = 1\ R_\odot$ ($2\times10^5$ particles)




SIMULATION 3: $M_{*1} = 1\ M_\odot$, $R_{*1} = 1\ R_\odot$ ($2\times10^5$ particles); $M_{*2} = 0.5\ M_\odot$, $R_{*2} = 0.6\ R_\odot$ ($10^5$ particles)




RESULTS: the visibility of the double peak increases increasing the difference between the star masses in the binary and if the less massive star remains bound to the BH after binary break-up

# CONCLUSIONS

- high number of stellar binaries => double TDEs to be considered
- under certain conditions, binary components can be disrupted in sequence immediately after binary break-up
- double peaked light curves from double TDEs can be observed in case of grazing encounters and in case of deep encounters but with enough different binary component masses and bond of the less massive star to the BH after binary break-up

- binary break-up -> one star bound to the BH -> possible periodic disruptions (if only partially disrupted), possible periodic single peaked flares after the one of double disruption
  => detecting a double peaked flare allows us to predict the likely presence of periodic flares, which can thus be better modeled due to their possible follow-up
- TDEs allow us the detection of otherwise quiescent BHs

⇩

hope in the advent of new telescopes (LSST)

# THANKS FOR YOUR ATTENTION

# BACKUP SLIDES

# SPH simulations with GADGET2

## SPH (smoothed particle hydrodynamics) codes-GADGET2:

- fluid divided into a set of discrete elements (particles)
- each particle has a characteristic spatial distance (smoothing length) over which its properties are evaluated by summing the properties of particles in the range of the kernel function according to the kernel itself
- smoothing length definition: the correspondent kernel volume must contain a constant mass
- smoothing length allowed to vary with time => adaptation to local conditions
- hierarchical tree algorithm to evaluate gravitational interactions

# SPH (smoothed particle hydrodynamics) codes-GADGET2:

- fluid divided into a set of discrete elements (particles)
- each particle has a characteristic spatial distance (smoothing length) over which its properties are evaluated by summing the properties of particles in the range of the kernel function according to the kernel itself
- smoothing length definition: the correspondent kernel volume must contain a constant mass
- smoothing length allowed to vary with time => adaptation to local conditions
- hierarchical tree algorithm to evaluate gravitational interactions

unlike n-body codes, it allows us to follow the evolution of single particle properties in simulations and build light curves directly from them