
Tidal destruction of exoplanets
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The main goal of this project is to understand how stars respond to tides. This is usually parameterized by Q which is poorly constrained. Close-in exoplanets provide new observations to refine this value.

Using the times that planets have to live, we can possibly exclude some Q values. Previous estimates of Q range from 10^5 to 10^9.

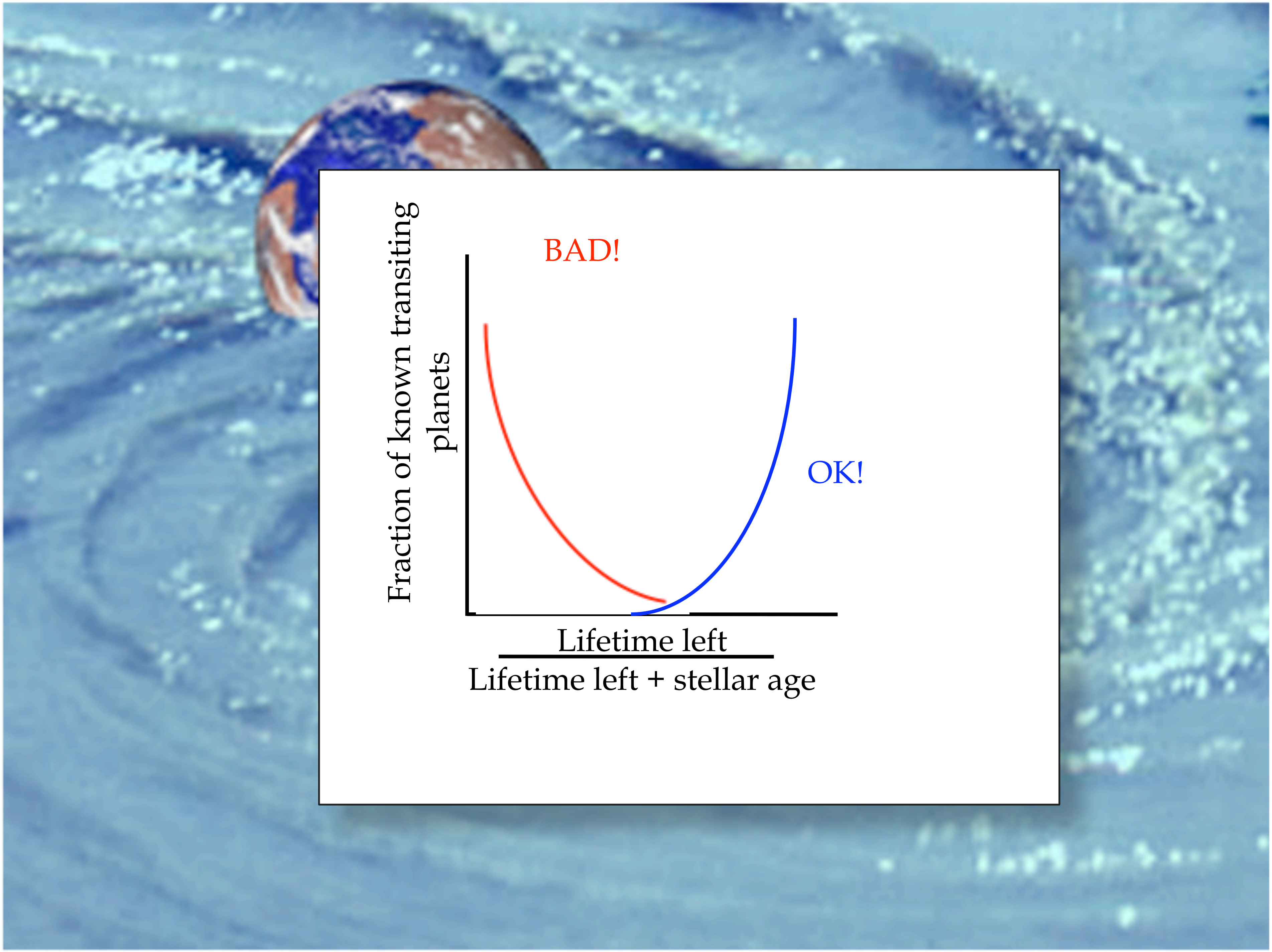
Background and motivation

The distribution of values of the semimajor axis for transiting planets shows a peak around 0.05 AU. This can be taken as strong evidence for the tidal interaction between planet and star leading to the destruction of the planet.

Solving two coupled non-linear differential equations we found values for the remaining lifetime of the 89 known transiting planets before they fall into the host star. We then compared this time to the age of the system.

This analysis will allow us to infer the number of planets that are currently at the end of their lives.

We should not find most planets at the end of their lives.



Fraction of known transiting planets
BAD!
OK!
Lifetime left
Lifetime left + stellar age

Equations of tidal evolution

Q'_p – tidal dissipation parameter of the planet

Q'_* - tidal dissipation parameter of the star

a – semimajor axis
e – eccentricity

M_* - mass of the star
R_* - radius of the star

M_p – mass of the planet
R_p – radius of the planet

$$\frac{1}{a}\frac{\mathrm{d}a}{\mathrm{d}t} = -\left(\frac{63}{2}(GM_*^3)^{1/2}\frac{R_p^5}{Q'_p M_p}e^2 + \frac{9}{2}(G/M_*)^{1/2}\frac{R_*^5 M_p}{Q'_*} \times \left(1+\frac{57}{4}e^2\right)\right)a^{-13/2}$$

$$\frac{1}{e}\frac{\mathrm{d}e}{\mathrm{d}t} = -\left(\frac{63}{4}(GM_*^3)^{1/2}\frac{R_p^5}{Q'_p M_p} + \frac{225}{16}(G/M_*)^{1/2}\frac{R_*^5 M_p}{Q'_*}\right)a^{-13/2}$$

(cf. Goldreich 1963; Goldreich & Soter 1966; Jackson et al. 2008a; Ferraz-Mello et al. 2008)

Model assumptions

• We assumed the nominal age is the actual age of the star.

•We assumed the sample size is sufficient.

•We assumed no other planets in the system perturbed the transiting planet.

•We assumed no evaporative mass loss by the planet.

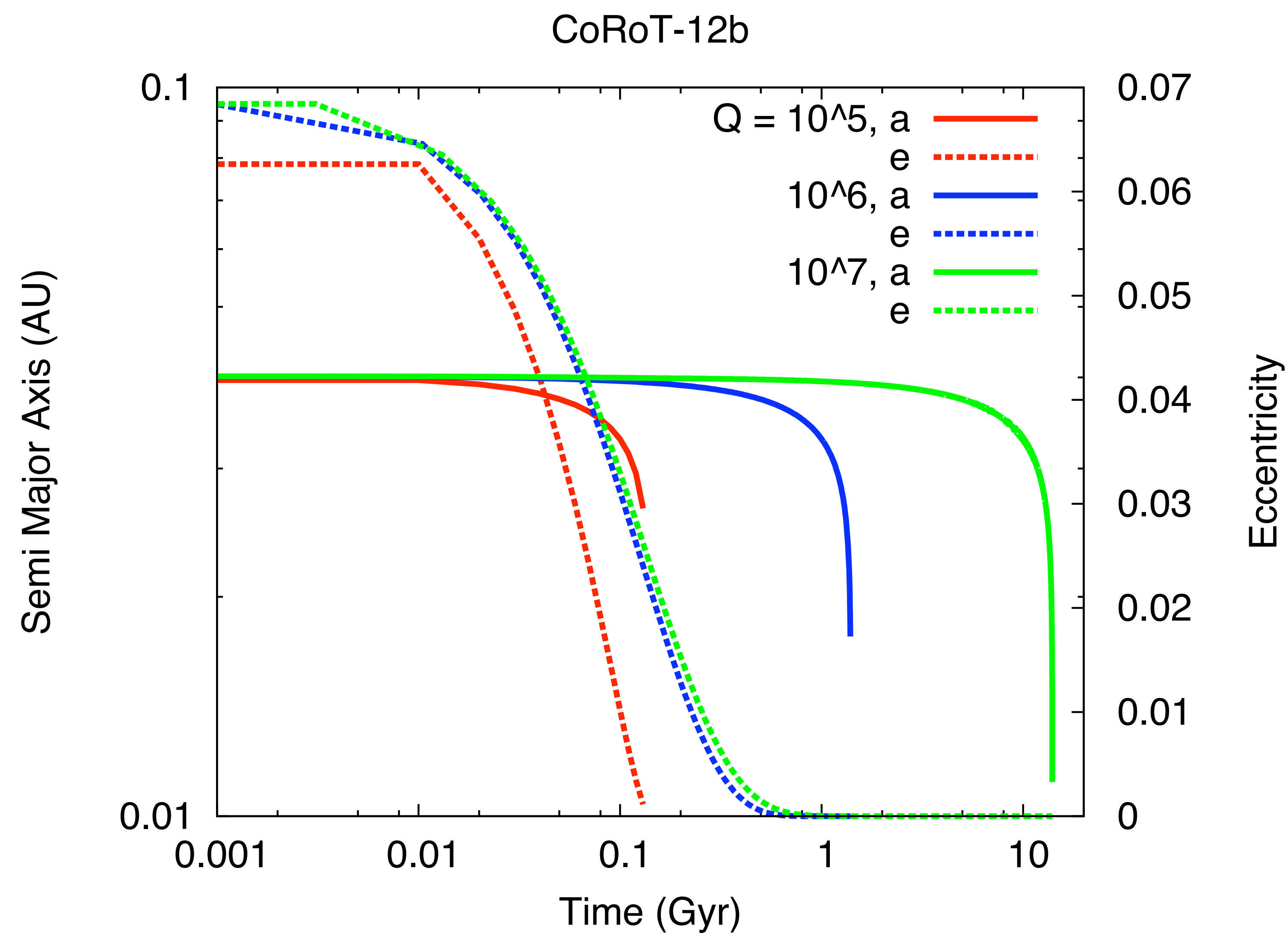
•We assumed that the planet makes it all the way to the photosphere of the star.

•We assumed the stars stay constant with time.

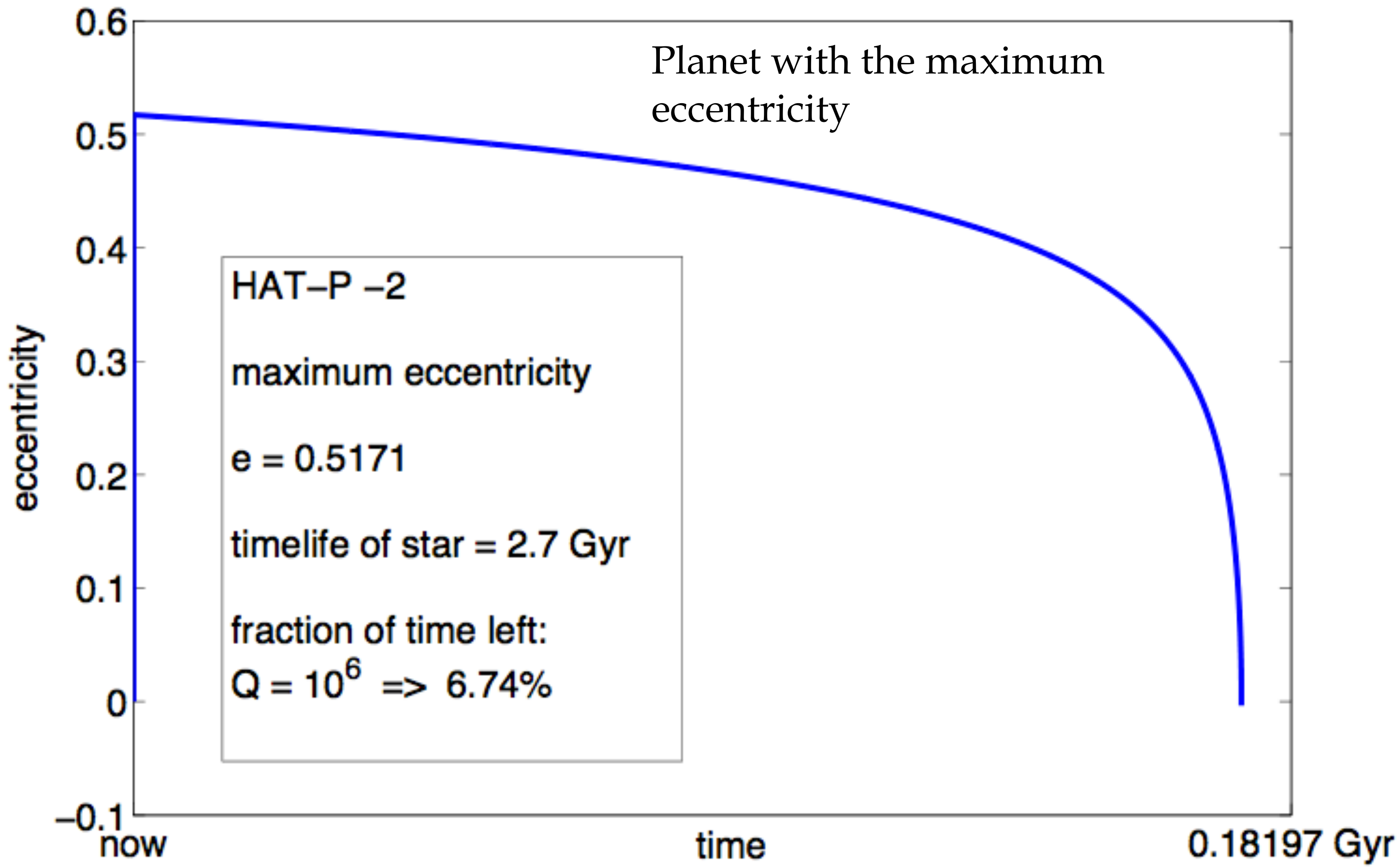
•We do not allow inflation of the radius due to tidal heating.

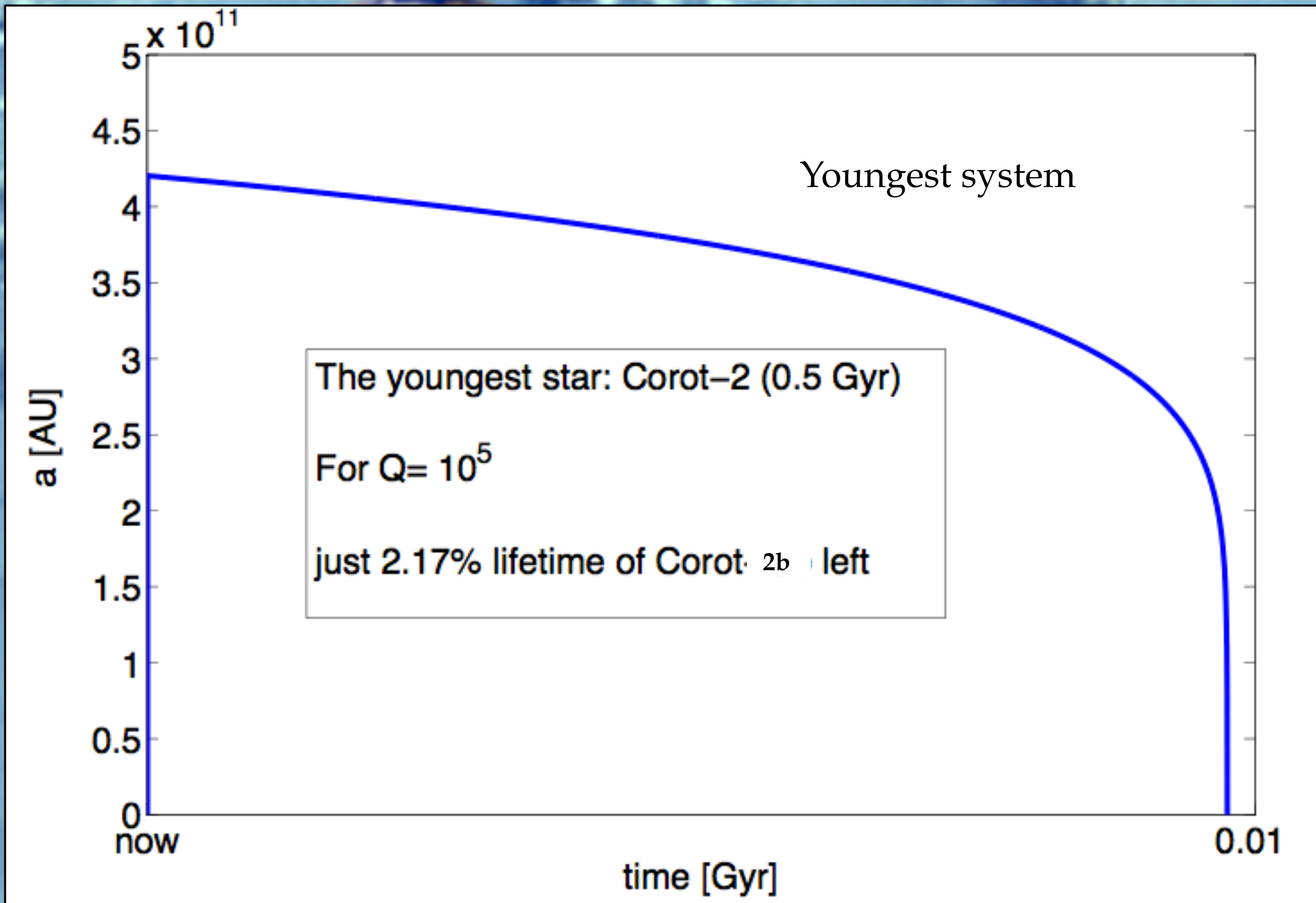
•We assume that Q_* is the same for all the stars.

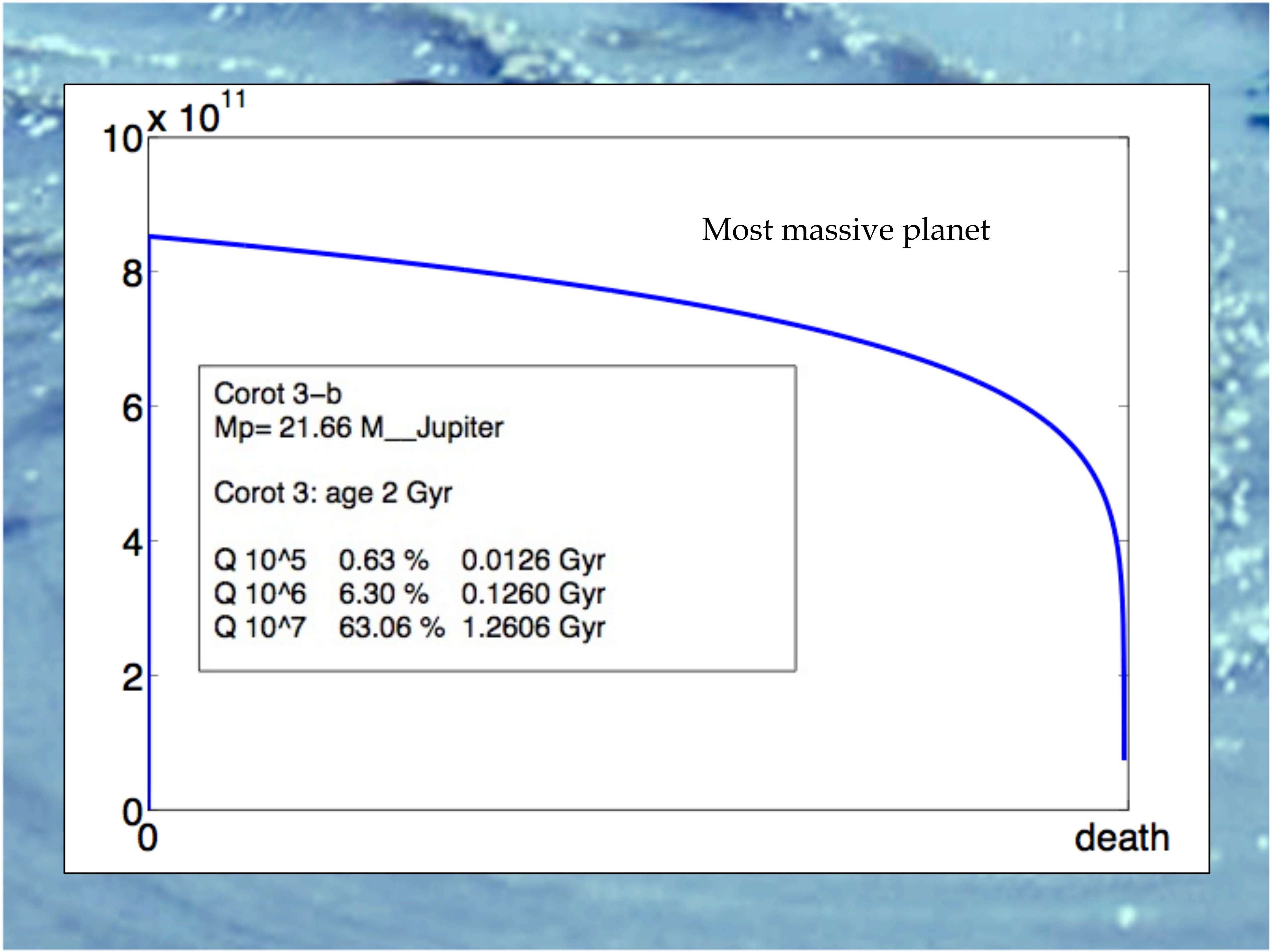
For the planet we used $Q'_p = 10^{6.5}$ and for the star three different values were used: 10^5, 10^6 and 10^7.

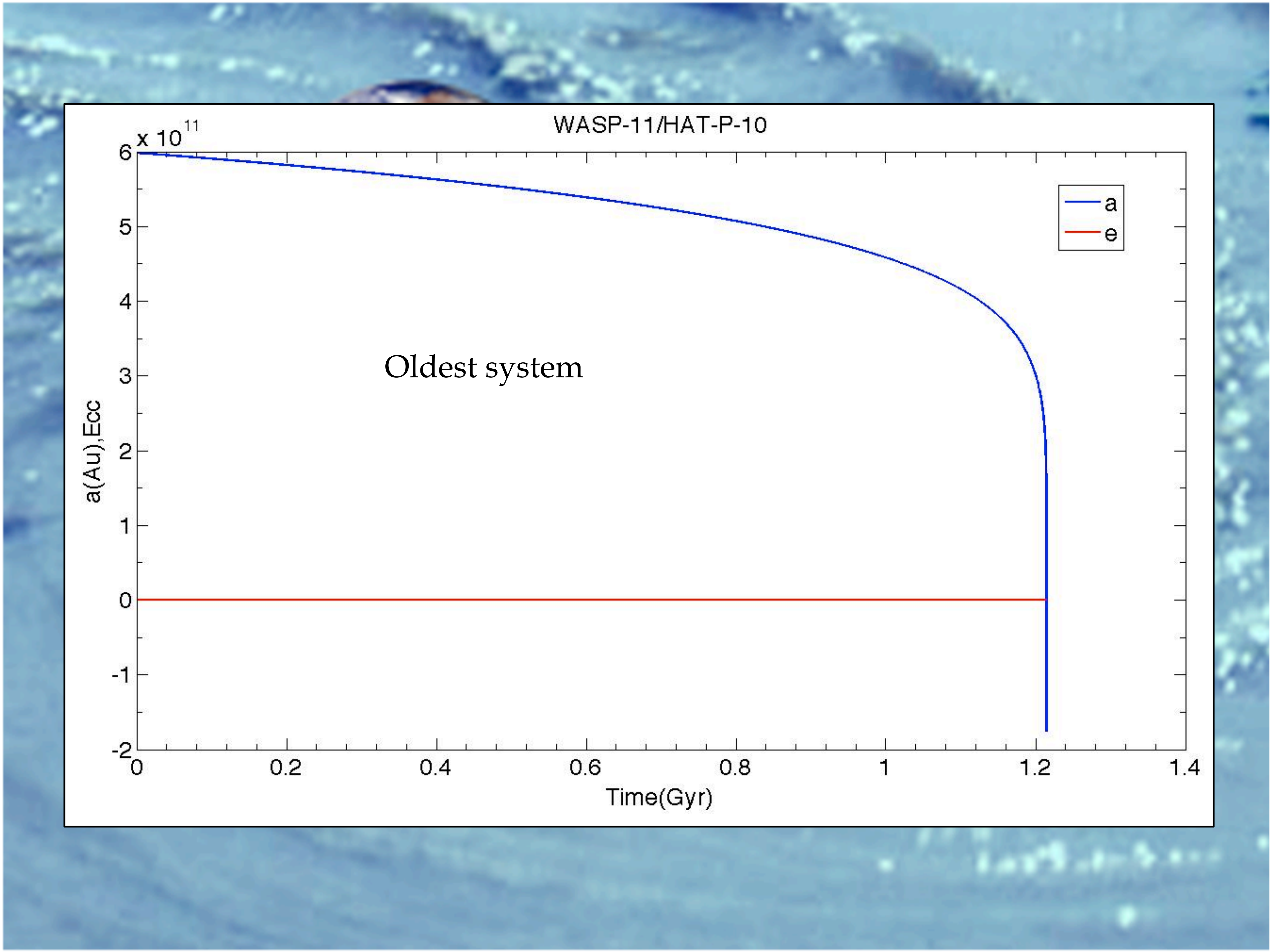


Planet with the maximum eccentricity

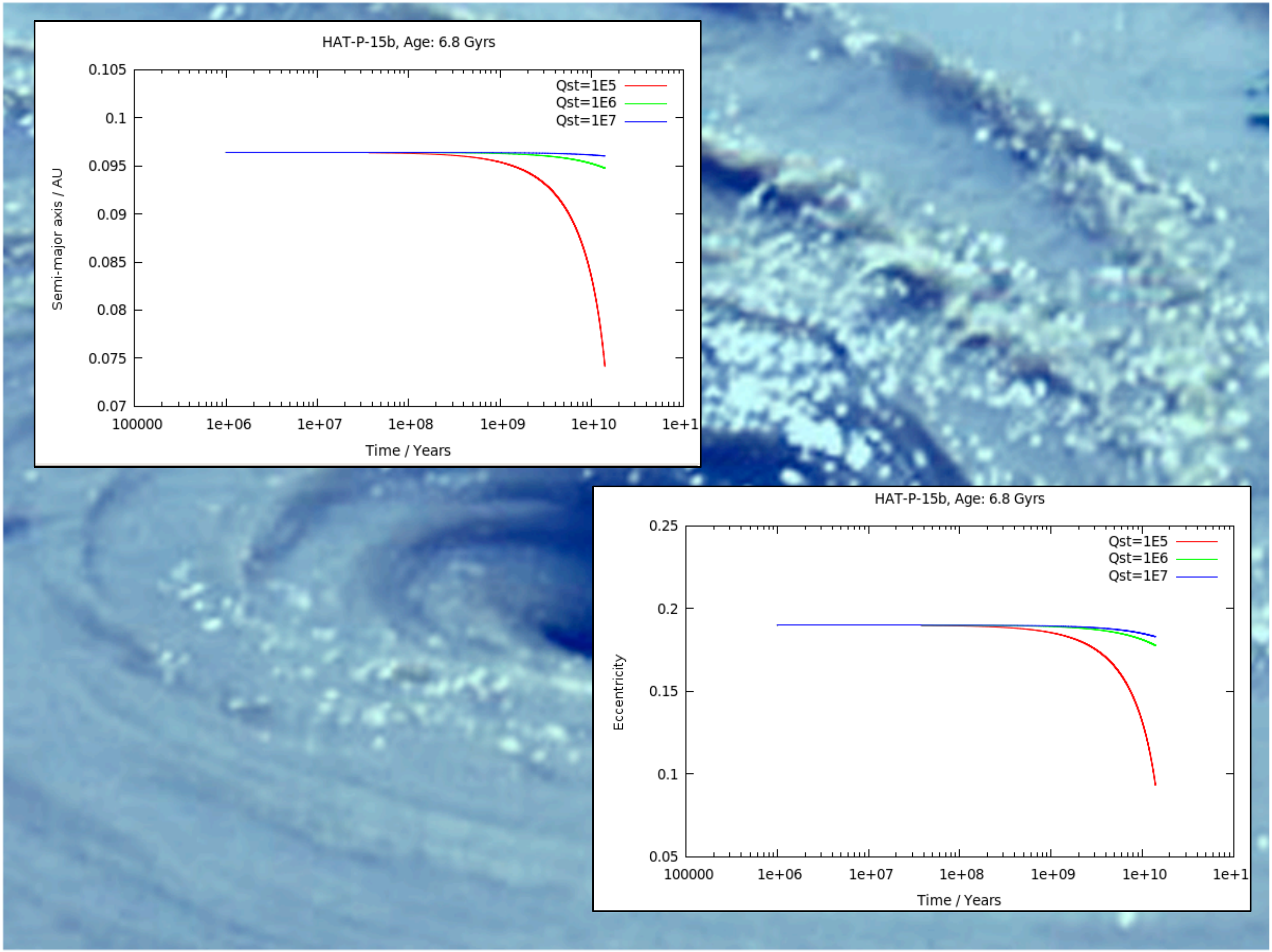


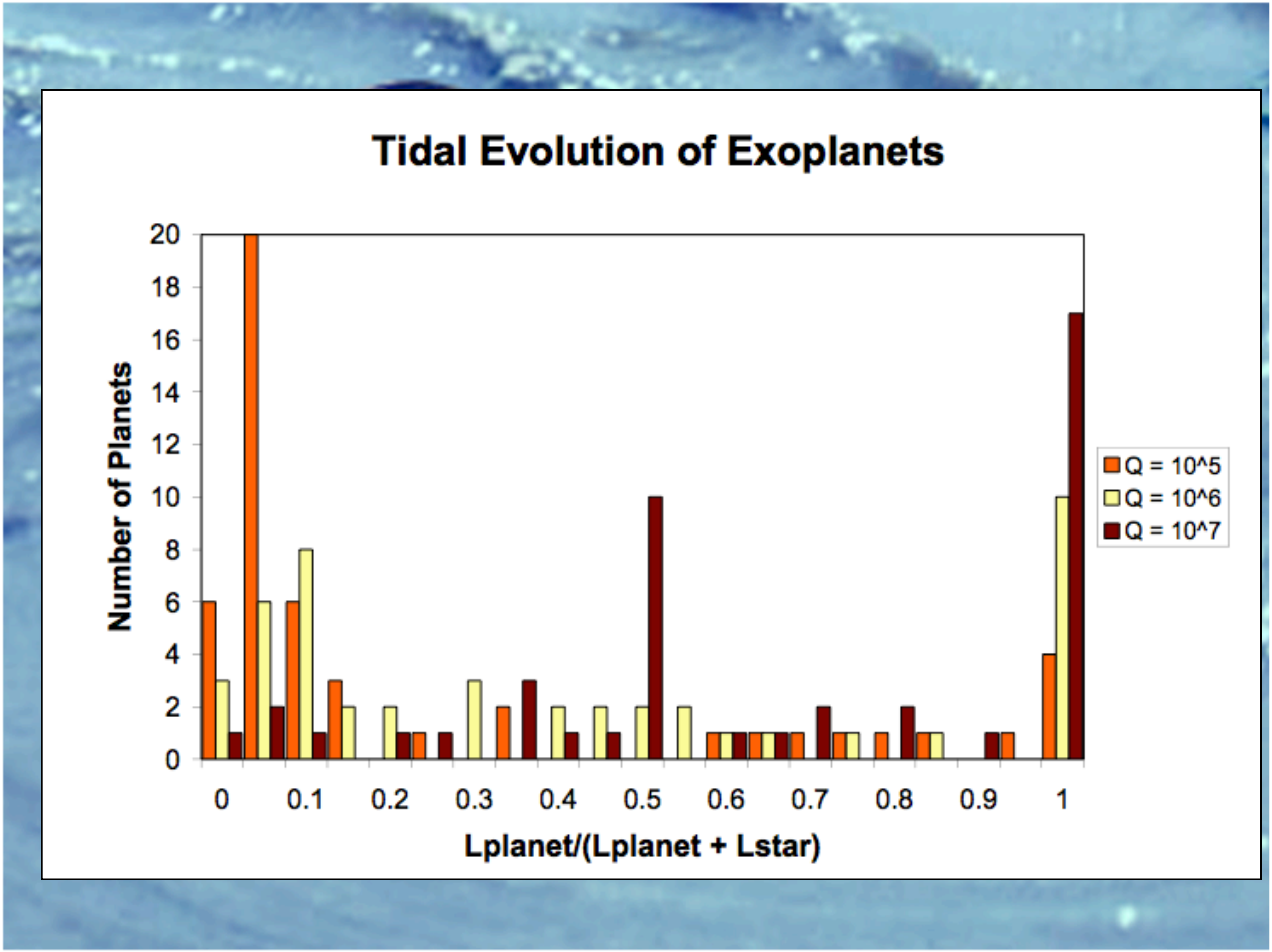

Youngest system
The youngest star: Corot–2 (0.5 Gyr)
For Q= 10^5
just 2.17% lifetime of Corot-2b left
x 10^{11}
a [AU]
time [Gyr]
now
0.01
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5


x 10^11
10
8
6
4
2
0
0
death
Most massive planet
Corot 3–b
Mp= 21.66 M__Jupiter
Corot 3: age 2 Gyr
Q 10^5 0.63 % 0.0126 Gyr
Q 10^6 6.30 % 0.1260 Gyr
Q 10^7 63.06 % 1.2606 Gyr



WASP-11/HAT-P-10
x 10^11
a(Au),Ecc
Time(Gyr)
a
e
Oldest system
6
5
4
3
2
1
0
-1
-2
0
0.2
0.4
0.6
0.8
1
1.2
1.4


HAT-P-15b, Age: 6.8 Gyrs
Semi-major axis / AU
0.105
0.1
0.095
0.09
0.085
0.08
0.075
0.07
100000
1e+06
1e+07
1e+08
1e+09
1e+10
1e+11
Time / Years
Qst=1E5
Qst=1E6
Qst=1E7
HAT-P-15b, Age: 6.8 Gyrs
Eccentricity
0.25
0.2
0.15
0.1
0.05
100000
1e+06
1e+07
1e+08
1e+09
1e+10
1e+11
Time / Years
Qst=1E5
Qst=1E6
Qst=1E7


Tidal Evolution of Exoplanets
Number of Planets
0
2
4
6
8
10
12
14
16
18
20
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Lplanet/(Lplanet + Lstar)
Q = 10^5
Q = 10^6
Q = 10^7

Conclusions

•We calculated the lifetimes of all known transiting exoplanets for three different Q values.

• We find that for low Q_* values, like $Q_* = 10^5$, too many planets would be in their final 10% of their lifetime, which is not expected.

•Therefore we suspect that the value of Q_* must be greater than 10^5.

• Note: observational bias – the closest planets are more likely to be detected.

•Most planets have a significant portion of their lifetime left.