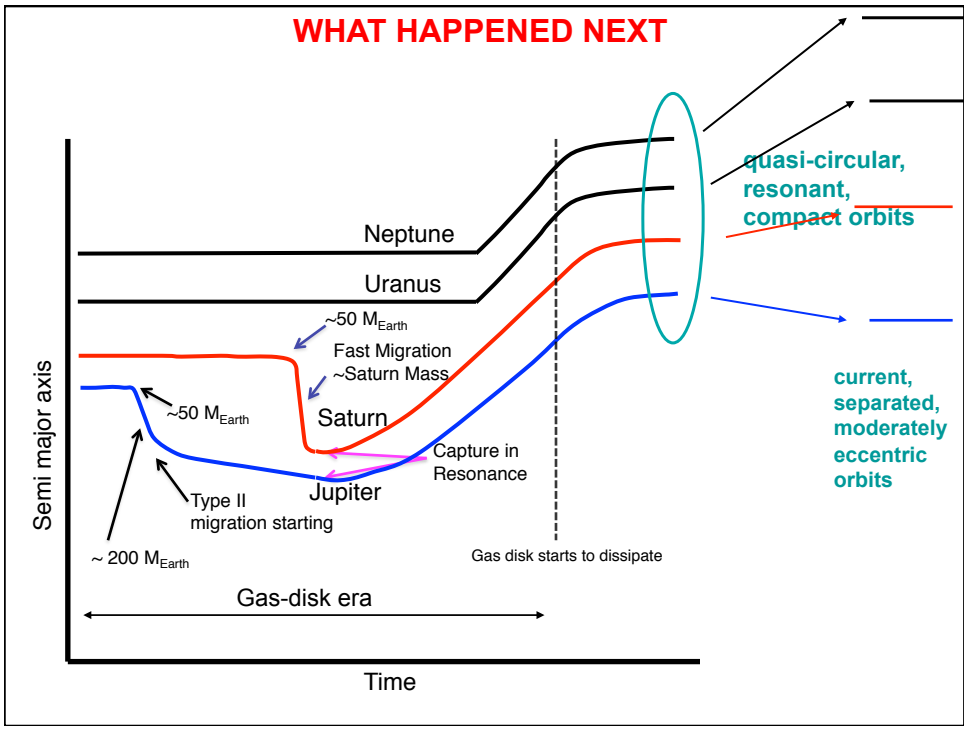
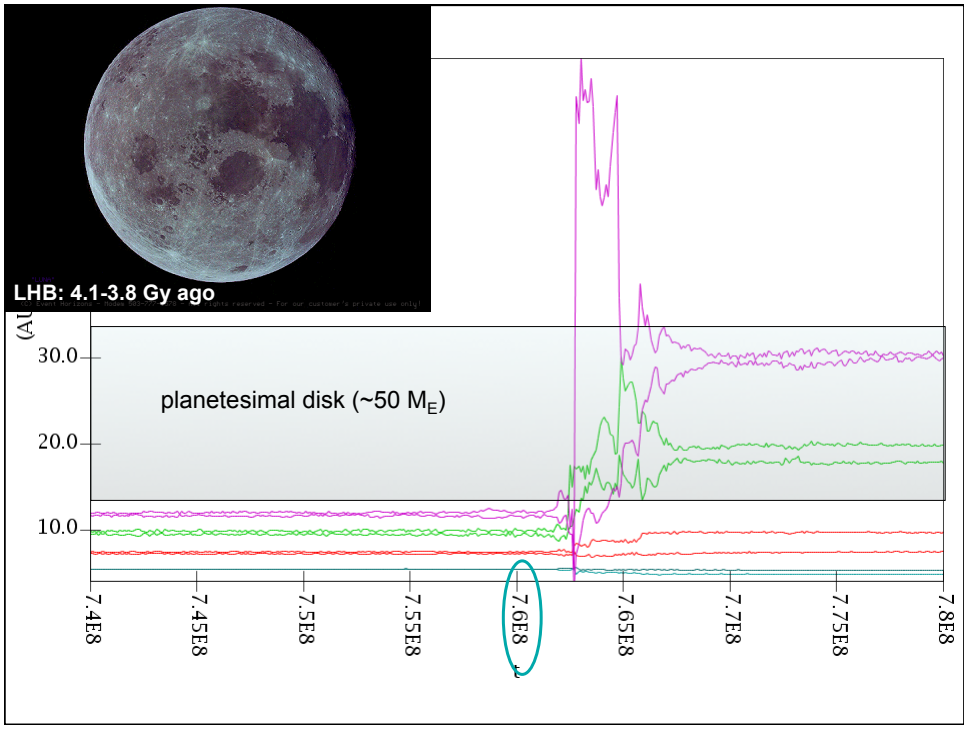
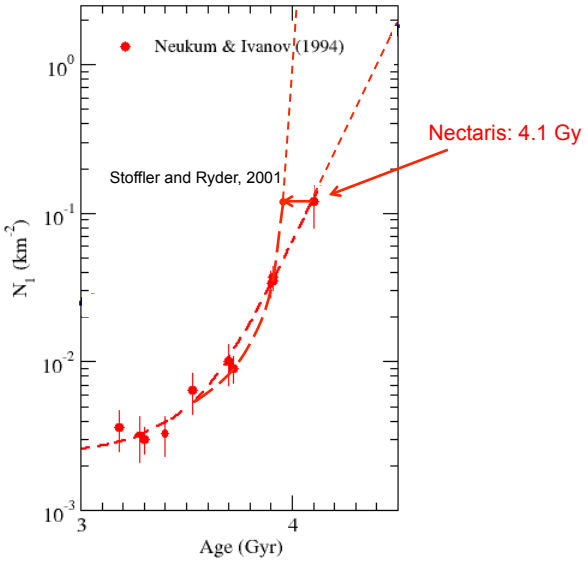
Post accretion Evolution: The Late Heavy Bombardment

WHAT HAPPENED NEXT

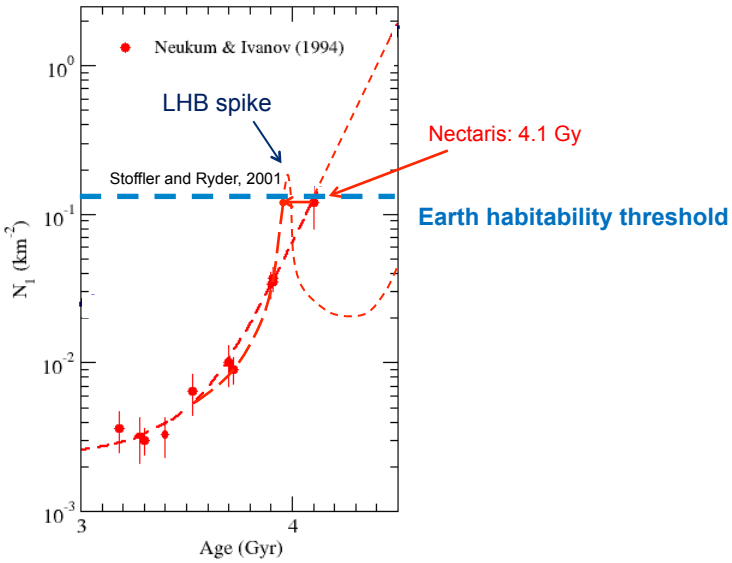


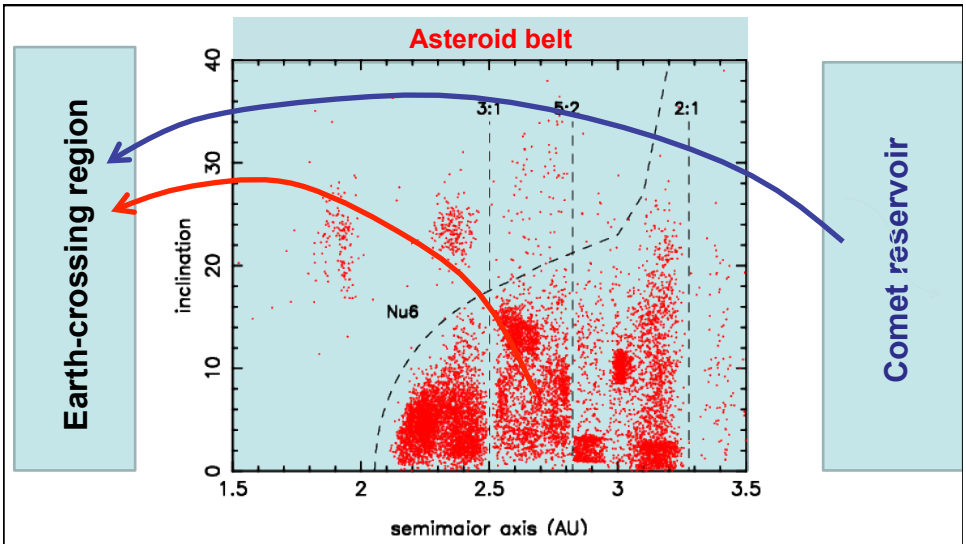


THE CONTROVERSY OF THE LUNAR BOMBARDMENT



THE CONTROVERSY OF THE LUNAR BOMBARDMENT

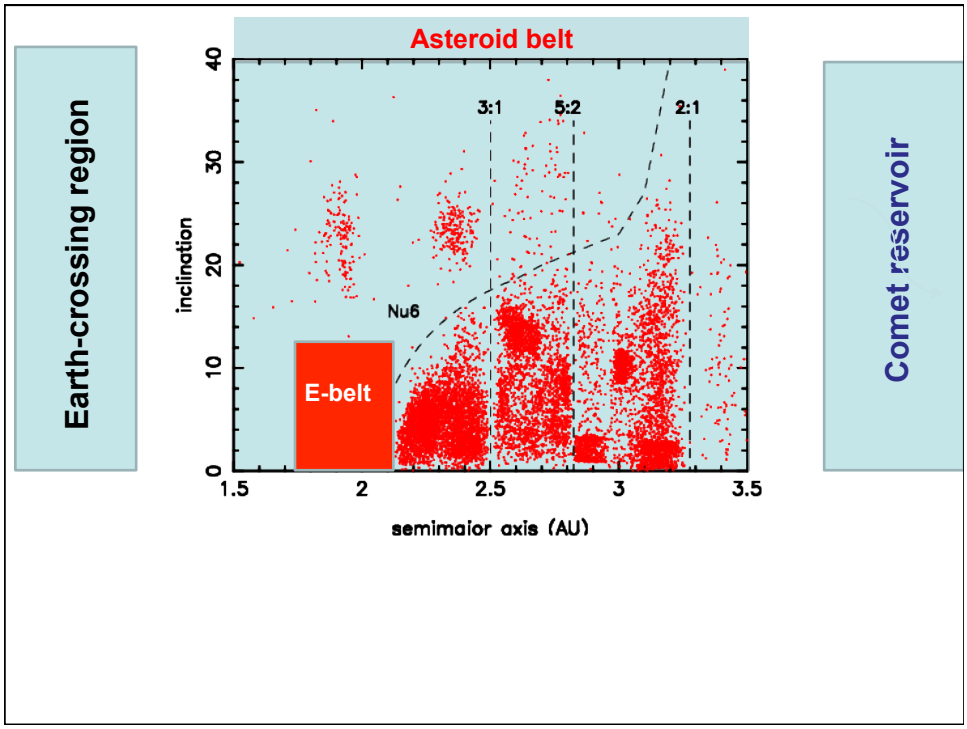


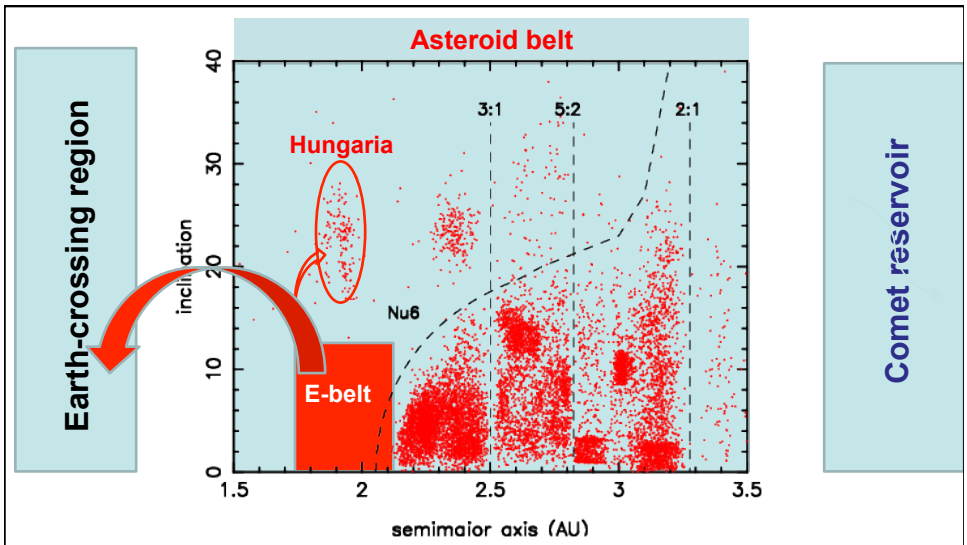


Probably not a dominant population of projectiles, particularly when accounting for physical disintegration when comets penetrate into the inner Solar System

Account only for ~ 2-3 basins on the Moon (Morbidelli et al. (2010))

WHAT ELSE?





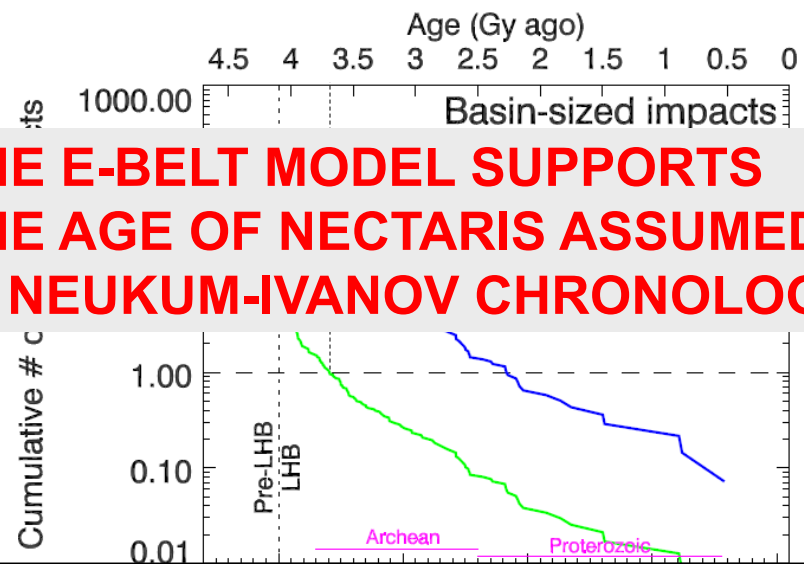
Calibration of the E-belt population using:
(i) Hungaria population
(ii) main belt population density.
Bottke et al., 2012

Give consistent results!

The E-belt could have produced ~10 basins on the Moon

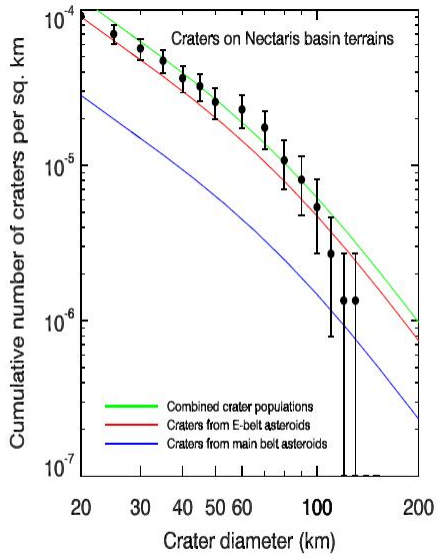
Calibration of the time of the E-belt destabilization using the age of the last basin (Bottke et al., 2012)

The first LHB basin (Nectaris?) occurred 4.1 Gy ago



THE E-BELT MODEL SUPPORTS THE AGE OF NECTARIS ASSUMED IN NEUKUM-IVANOV CHRONOLOGY

The E-belt model predicts a density of craters on the first basin that agrees with crater counts on Nectaris (Marchi et al., 2012)

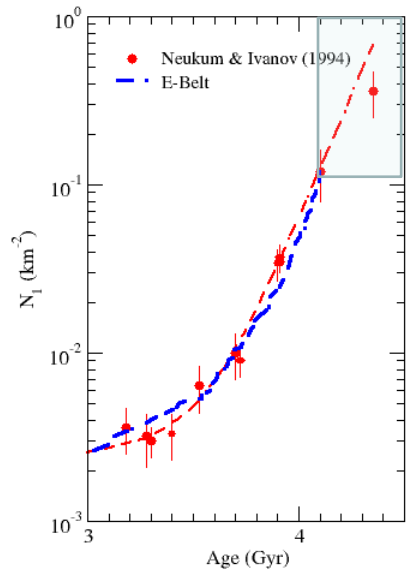


The E-belt model and Neukum-Ivanov curve have to match on Nectaris datapoint at ~4.1Gy

Unexpectedly, the E-belt model predicts a decay of the bombardment rate that matches the Neukum-Ivanov curve all over the 3-4 Gy period

Are Neukum-Ivanov right? No LHB after all?

We think that the extrapolation of the exponential decay for t>4.1 Gy is not correct

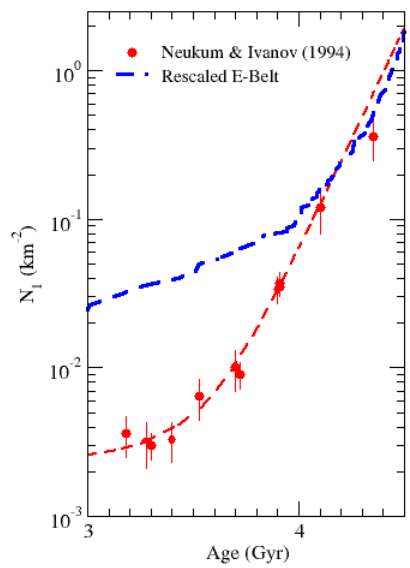


I: We never found a population that matches the exponential decay over ~ 1 Gy. See also Bottke et al. 2007 for a general argument.

II: Siderophile elements argument:

The total amount of HSEs on the moon (mantle + crust) requires that the Moon accreted some 1.7×10^{19} kg of chondritic material (Day et al., 2010)

The extrapolation of the 3.7-4.1 bombardment rate back to 4.5Gy would imply that the Moon accreted ~ 10^{20} kg (~5x too much)

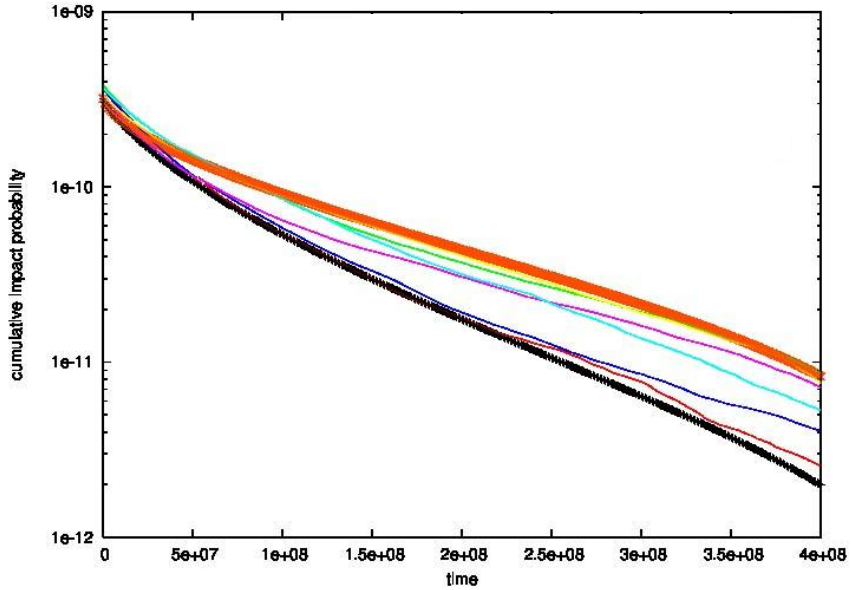


The most likely possibility is that the bombardment rate in the 4.5-4.1Gy and 3.6-4.1 Gy periods are due to two different populations, with different impact rates and temporal decays.

For the 3.6-4.1Gy period it is the E-belt population (with some contribution from the MB)

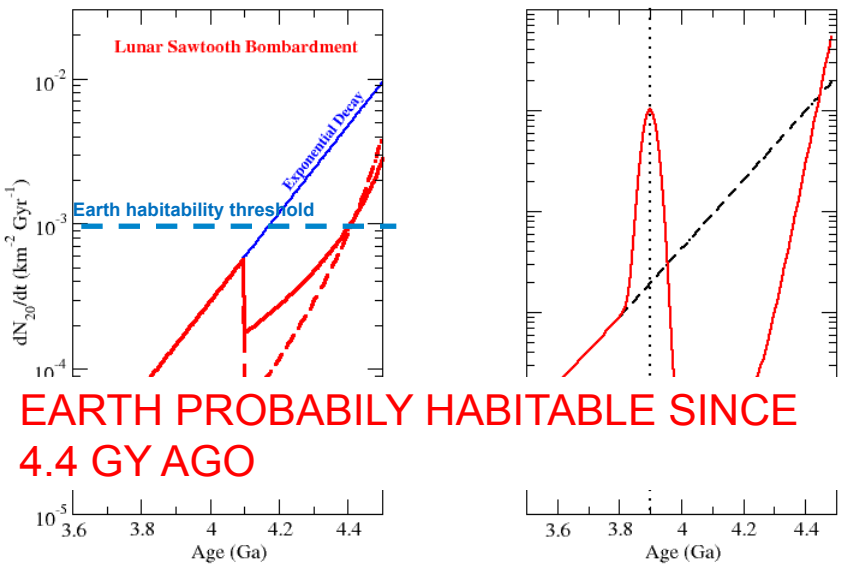
For the 4.1-4.5 Gy period it is the population of planetesimals in the terrestrial planet region, left-over from the planet accretion process.

To characterize the latter we turn to the best-to-date simulations of terrestrial planet accretion (Walsh et al., 2011)

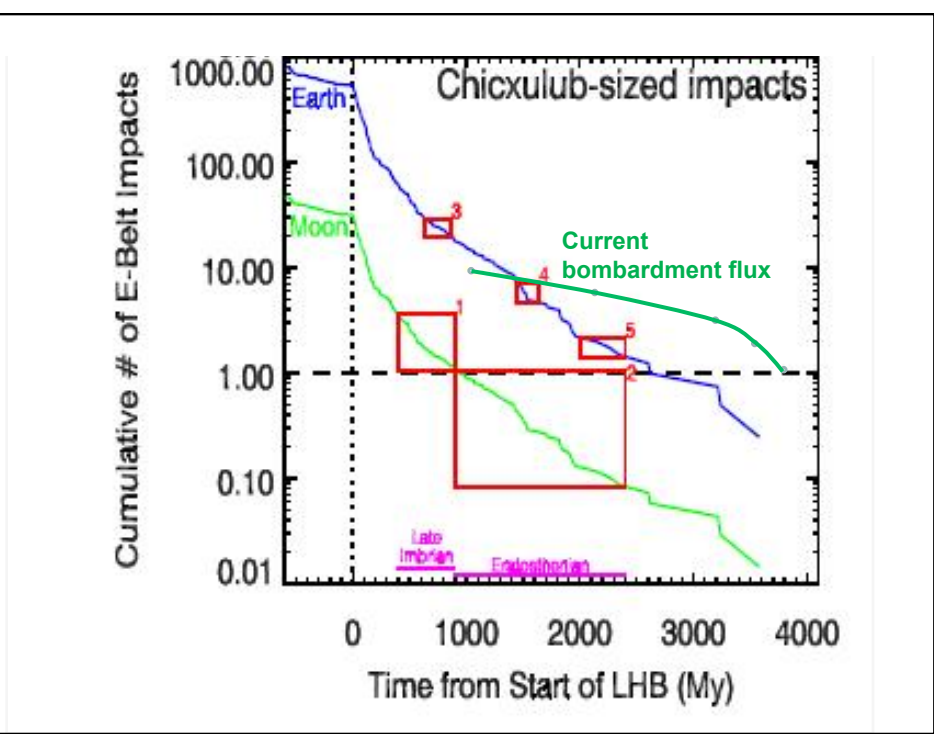


DIFFERENTIAL VIEW

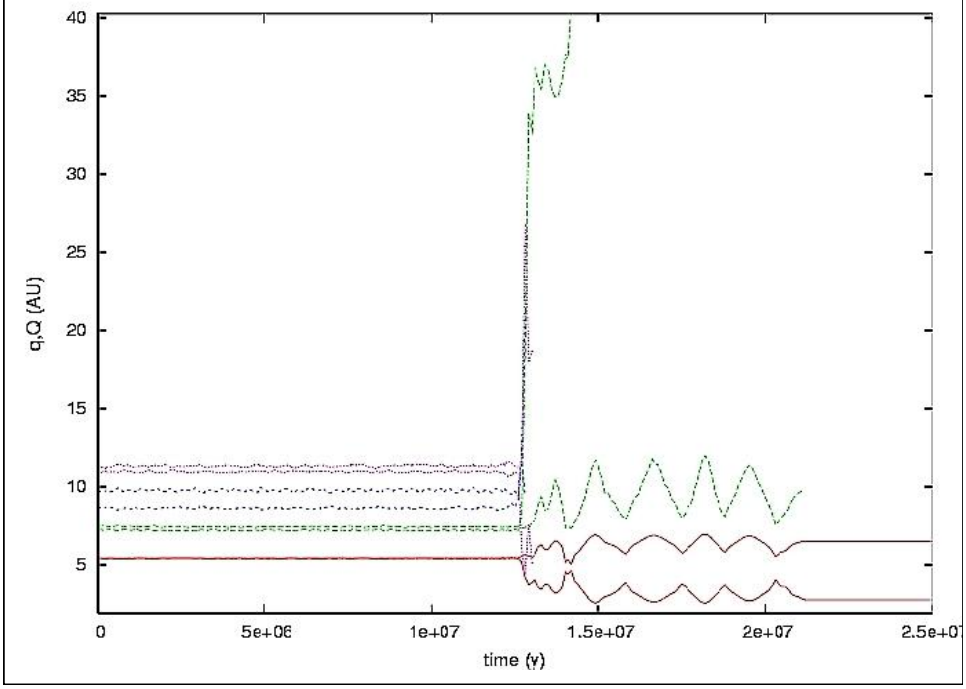
OLD VIEW OF LHB SPIKE



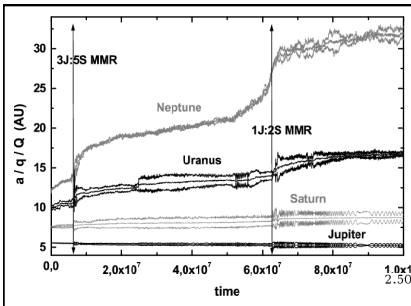
EARTH PROBABILY HABITABLE SINCE 4.4 GY AGO

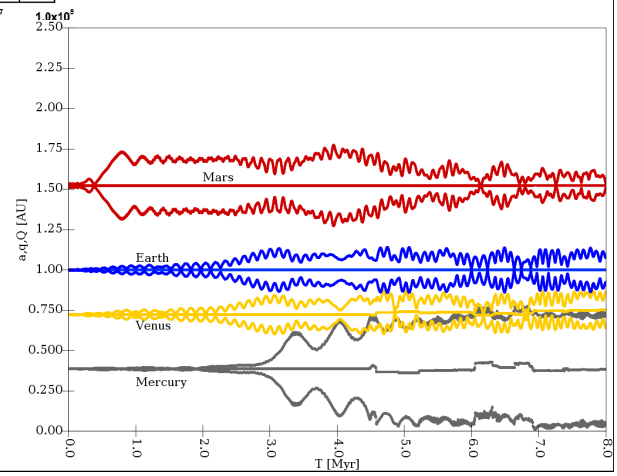


POSSIBLE EVOLUTIONS OF THE GIANT PLANETS AT THE TIME OF THE LHB

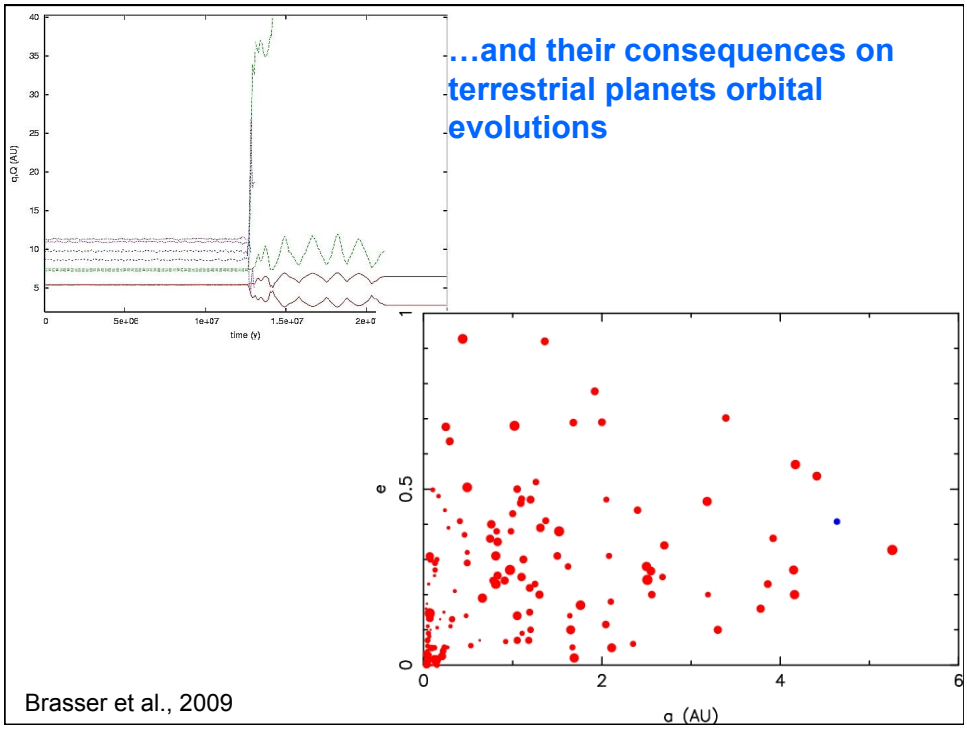


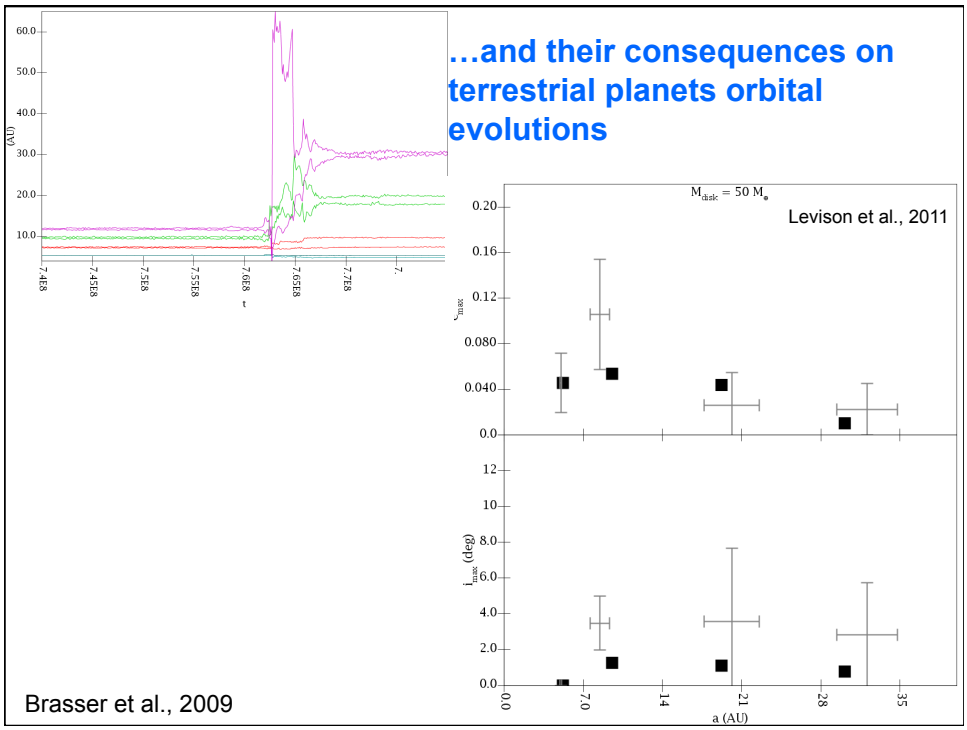
…and their consequences on terrestrial planets orbital evolutions





Brasser et al., 2009


…and their consequences on terrestrial planets orbital evolutions
time (y)
e
a (AU)
Brasser et al., 2009


…and their consequences on terrestrial planets orbital evolutions
$M_{disk} = 50\ M_\oplus$
Levison et al., 2011
a (AU)
Brasser et al., 2009

CONCLUSIONS

If we understand it correctly, the history of the Earth as a habitable planet was full of dangers, as it critically depended on the evolution of the giant planets

- During its formation phase – gas-driven migration of Jupiter/Saturn
- During the LHB – orbital instability of the giant planets

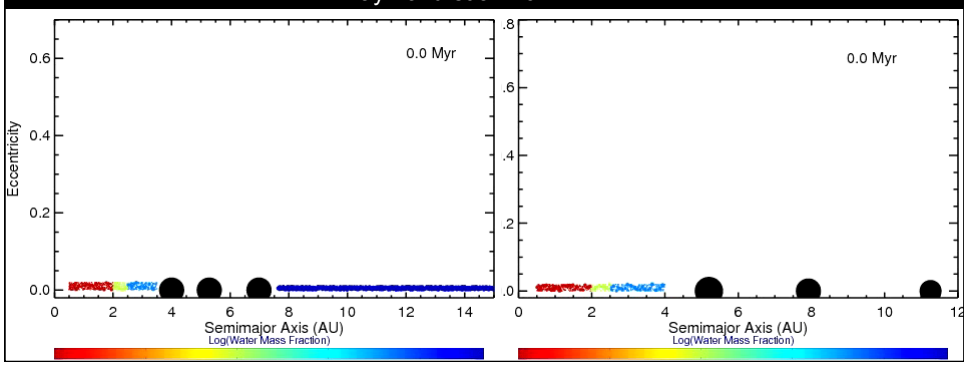
WHAT ABOUT η_{Earth}?

DISCLAIMER: I don't know

Habitable terrestrial planets are very vulnerable if giant planets are around (although we are here….)

Particularly, they don't stand eccentric giant planets (which seem to be the majority in the extra-solar collection)

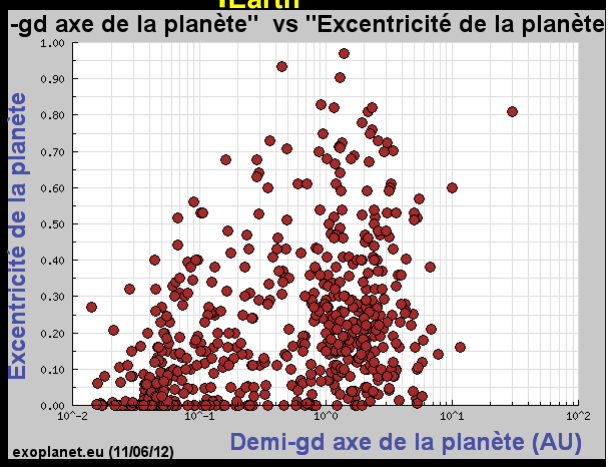
Raymond et al. 2011



WHAT ABOUT η_{Earth}?

Violent instabilities among giant planets are probably the norm…

But only ~20% of the solar-type stars have giant planets, so there is hope that ηEarth is large….



….but remember that in absence of gas-giant planets, Neptune-like planets could migrate into the inner solar system, destabilizing the local « Earths »