A New Chronology for the Inner Solar System from Crater Counts

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Our approach toward a new chronology

Most updated model to estimate the present lunar impactor flux:

NEO population (Bottke etal. 00,02)**;** **MBA population** (Bottke etal. 05)**;**

Impactors-to-craters: different scaling laws have been tested;

Deriving the cumulative crater distribution: the lunar “Model Production Function” (MPF);

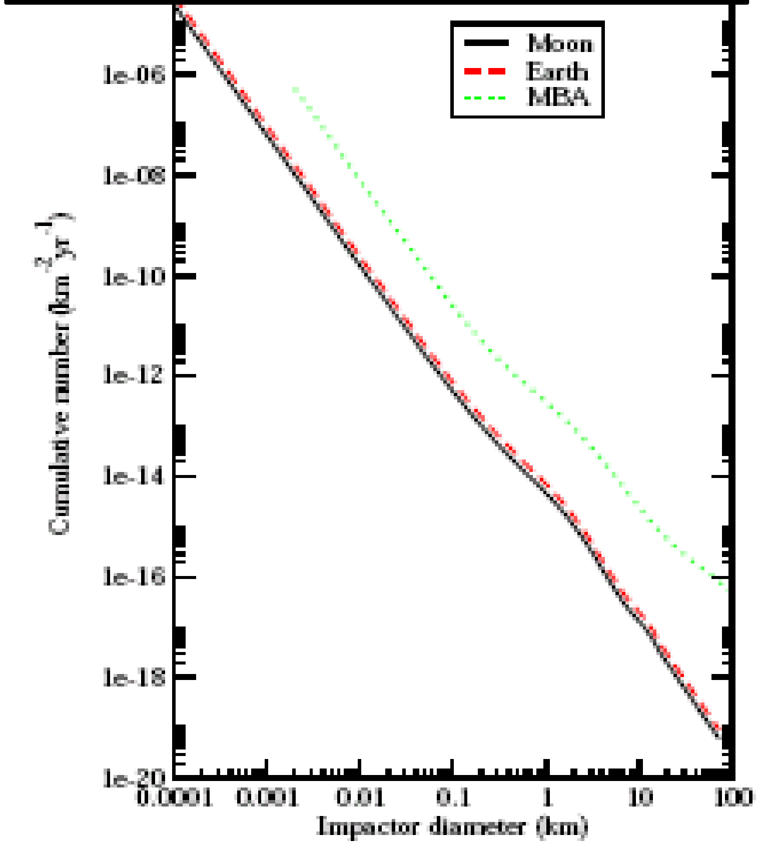
Chronology: The MPF is then fitted to crater counting on lunar calibration regions in order to derive a new lunar chronology.

Additional features: non-constant flux, cratering erasing, regional effects...

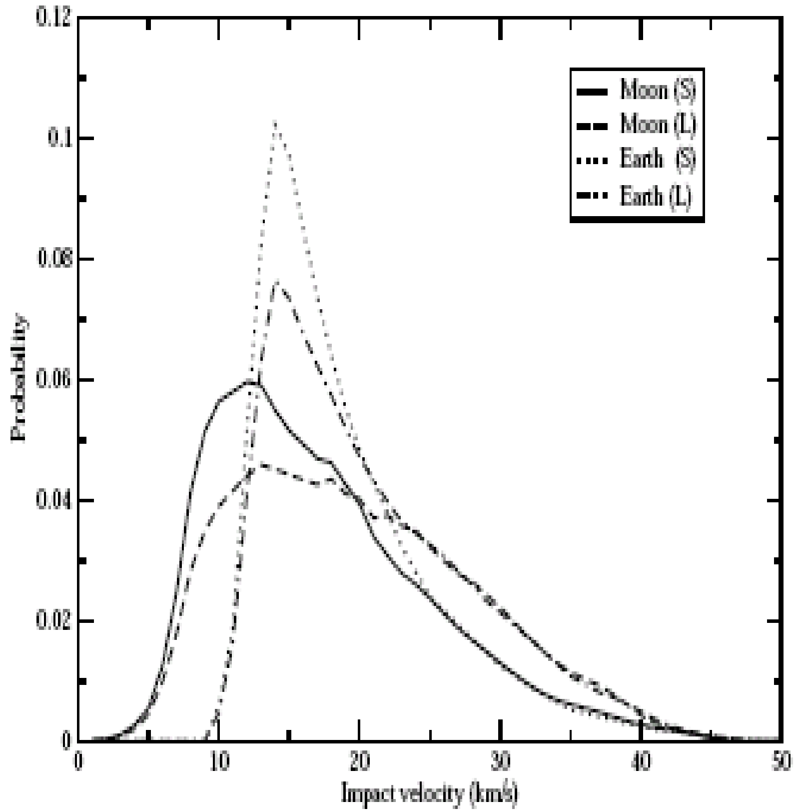
Modelling the present Earth-Moon flux

Differential flux: $\phi(d,v) = h(d)f(d,v)$

Impactor size distribution, h(d):



Impactor velocity distribution, f(d,v):



[After Bottke etal. 00,02,05]

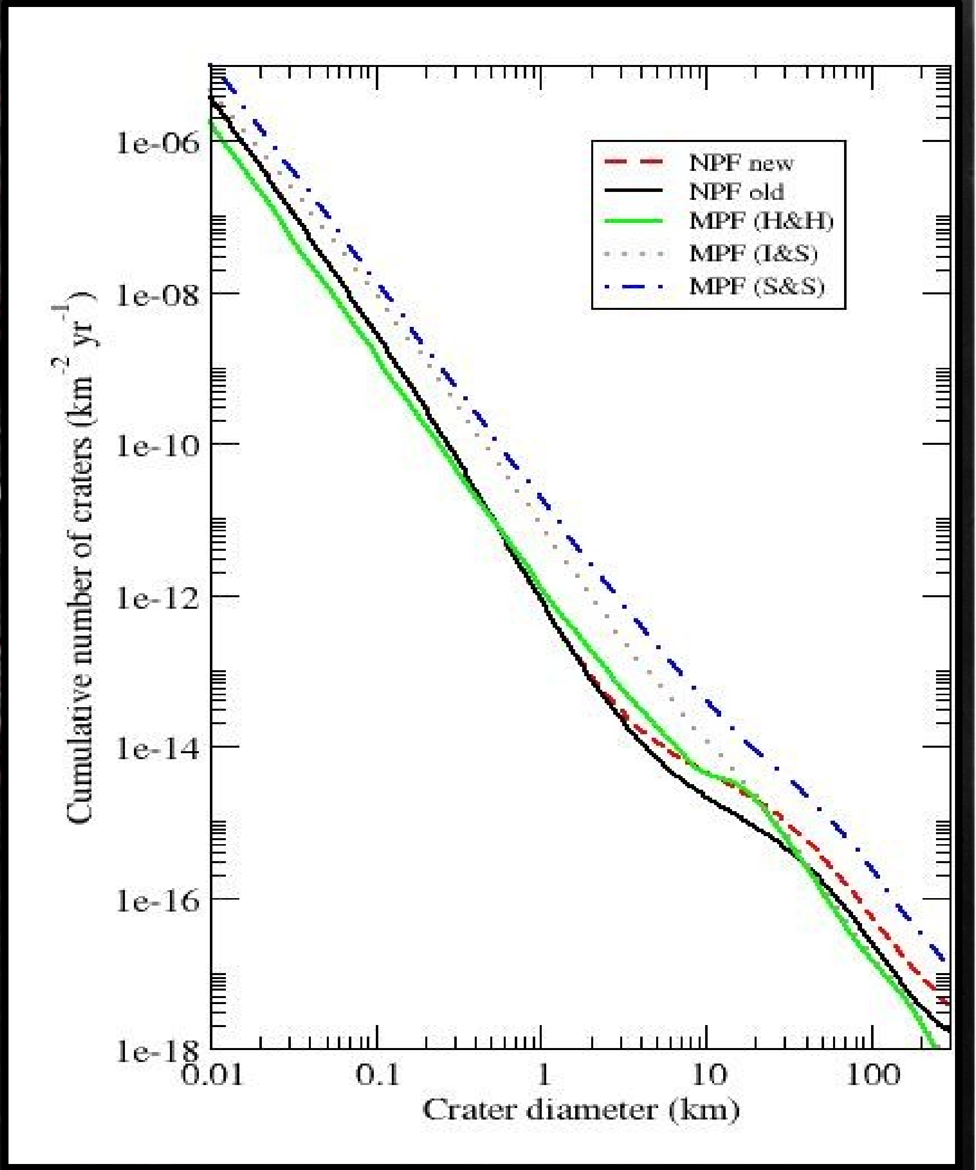
The MPF

A stationary MPF:

$$\mathrm{MPF}(D) = \int_D^\infty \Phi(\tilde{D})d\tilde{D}$$

Good overlap, **within a factor of 2, between MPF (Holsapple and Housen -H&H- scaling law) and the most used NPF-HPF** (Hartmann etal 81, Neukum & Ivanov, 94)**;**

We restrict the following analysis to H&H



Lunar and terrestrial calibration regions

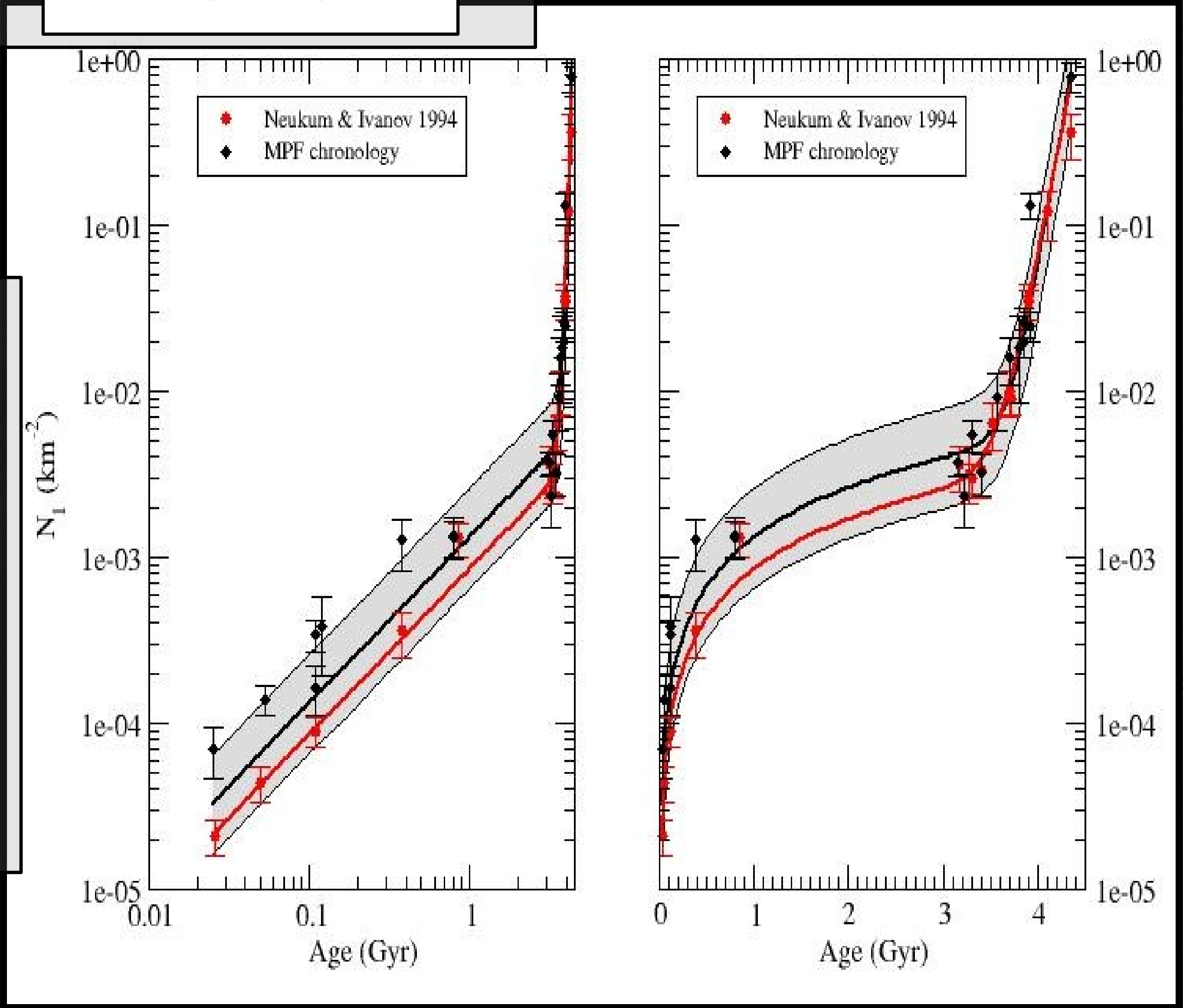
Calibration regions fitted with the MPF to derive the N1 values (cum. numb. of craters @ 1km)**:**

Region	N_1 (NEO)[†] (km^{-2})	N_1 (MBA)[†] (km^{-2})	Age[‡] (Gyr)
Highlands[a]	$7.851 \cdot 10^{-1}$	$2.018 \cdot 10^{-1}$	4.35
Nectaris Basin	$1.327 \cdot 10^{-1}$	$6.648 \cdot 10^{-2}$	3.92
Descartes Formation[b,z]	$2.490 \cdot 10^{-2}$	$2.509 \cdot 10^{-2}$	3.92
Imbrium Apennines[c]	$1.968 \cdot 10^{-2}$	$1.931 \cdot 10^{-2}$	3.85
Fra Mauro Formation	$2.595 \cdot 10^{-2}$	$2.672 \cdot 10^{-2}$	3.85
Mare Tranquillitatis (old)[d,z]	$1.836 \cdot 10^{-2}$	$1.832 \cdot 10^{-2}$	3.80
Taurus Littrow Mare[z]	$1.579 \cdot 10^{-2}$	$1.585 \cdot 10^{-2}$	3.70
Mare Tranquillitatis (young)[d,z]	$9.300 \cdot 10^{-3}$	$9.357 \cdot 10^{-3}$	3.58
Mare Fecunditatis[z]	$3.234 \cdot 10^{-3}$	$3.257 \cdot 10^{-3}$	3.41
Mare Imbrium[z]	$5.468 \cdot 10^{-3}$	$5.526 \cdot 10^{-3}$	3.30
Mare Crisium	$2.335 \cdot 10^{-3}$	$2.377 \cdot 10^{-3}$	3.22
Oceanus Procellarum	$3.683 \cdot 10^{-3}$	$3.695 \cdot 10^{-3}$	3.15
Copernicus Crater (cont. ejecta)[e]	$1.321 \cdot 10^{-3}$	$1.337 \cdot 10^{-3}$	0.80
Copernicus Crater (crater floor)[e]	$1.348 \cdot 10^{-3}$	$1.343 \cdot 10^{-3}$	0.80
Terrestrial Phanerozoic craters[f]	$1.267 \cdot 10^{-3}$	$7.655 \cdot 10^{-4}$	0.375
Terrestrial Phanerozoic craters (young)[g]	$3.835 \cdot 10^{-4}$	$2.195 \cdot 10^{-4}$	0.120
Tycho crater (cont. ejecta)[h]	$3.391 \cdot 10^{-4}$	$3.401 \cdot 10^{-4}$	0.109
Tycho crater (cont. ejecta)[i]	$1.644 \cdot 10^{-4}$	$1.712 \cdot 10^{-4}$	0.109
North Ray crater[l]	$1.389 \cdot 10^{-4}$	$1.421 \cdot 10^{-4}$	0.053
Cone Crater[l]	$6.970 \cdot 10^{-5}$	$7.131 \cdot 10^{-5}$	0.025

Counting from Neukum et al, ages from Stoffler & Ryder 2001

MPF-based lunar chronology

Chronology curve: $$N_1 = a(e^{bt} - 1) + ct$$ (e.g. Neukum & Ivanov 94)



Overall agreement within a factor of 2 between MPF and NPF chronology,

but...

N1 best fit curve not suitable for all ages!

Non-constant flux in recent time?

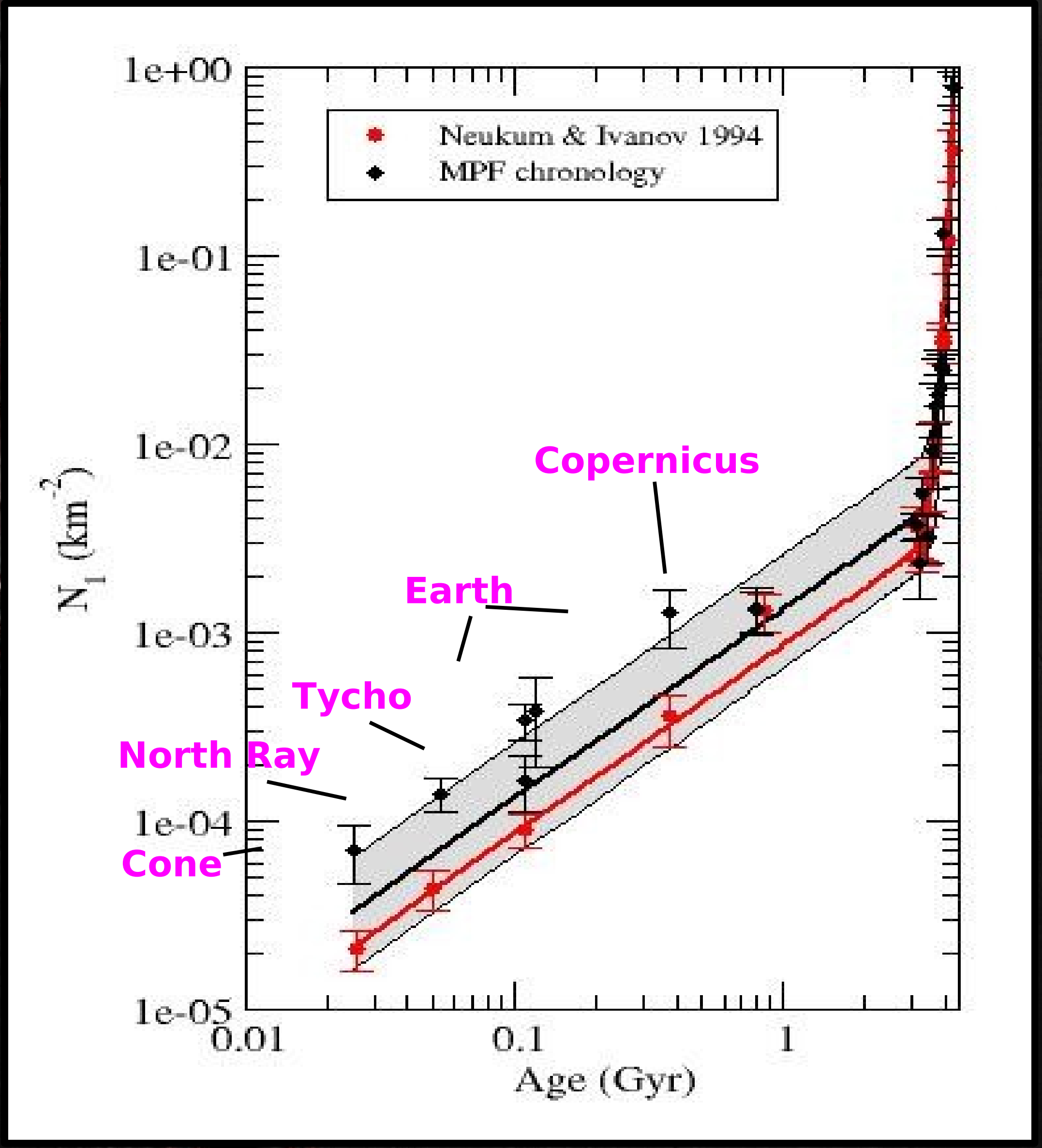
Systematic misfit by a factor of 2 for age<0.5 Gyr;

linear trend for age<0.5 Gyr;

Terrestrial and lunar regions have similar misfit (see discussion in Hartmann etal 07);

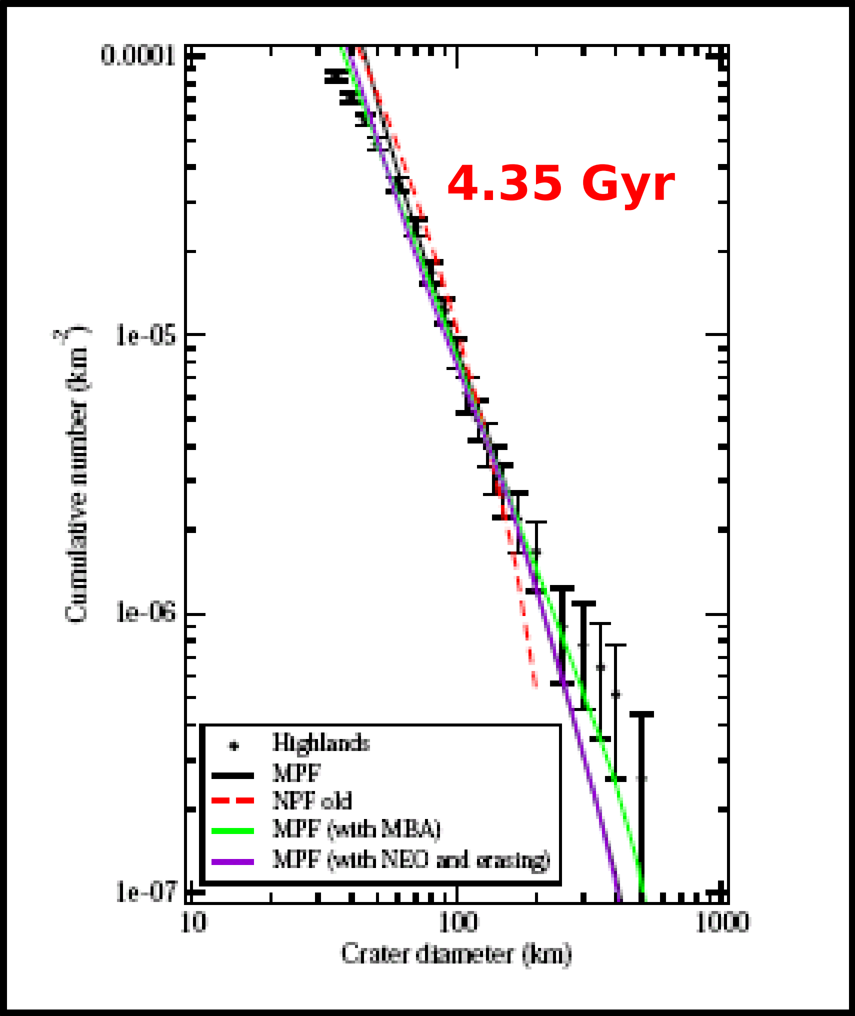
Copernicus (0.8 Gyr) indicates a lower impactor rate;

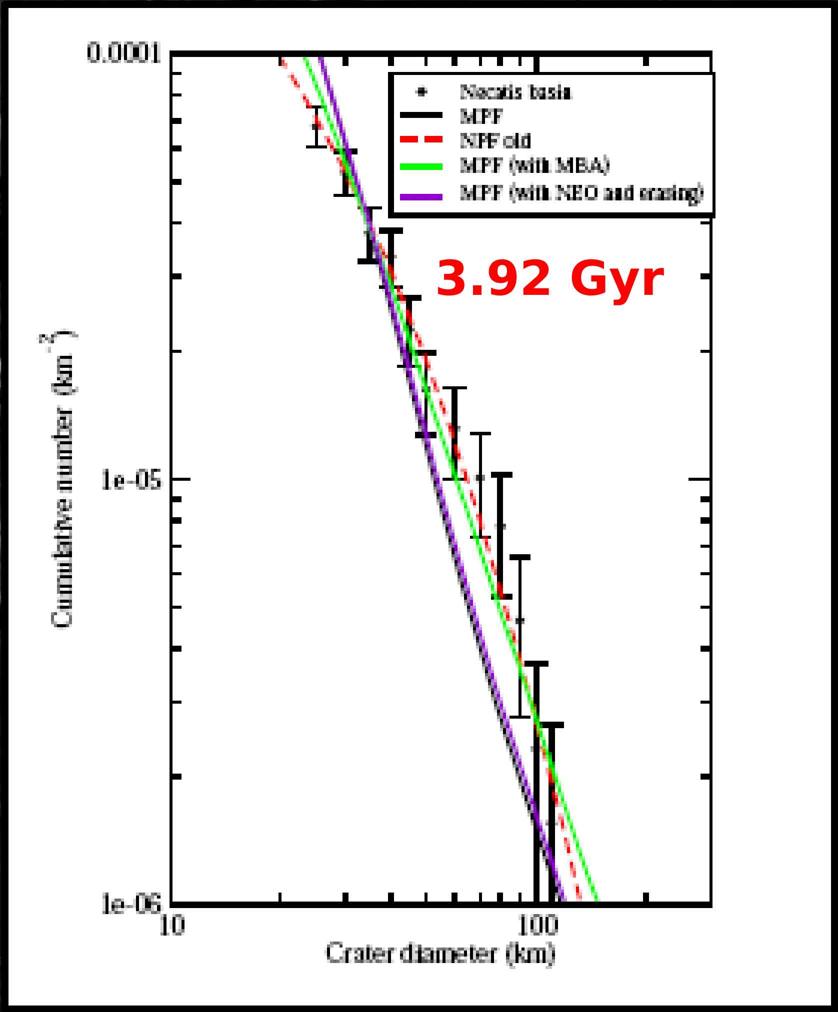
General agreement with the recent enhance in the flux due to Baptistina and Flora families (Nesvorny etal 07, Bottke etal 07).



On the early flux/1

Indications for a different impactor size distribution in the past:
a result in favour of the Late Heavy Bombardment.





A similar result also proposed by Strom etal 05.

On the early flux/2

A time-dependent MPF:

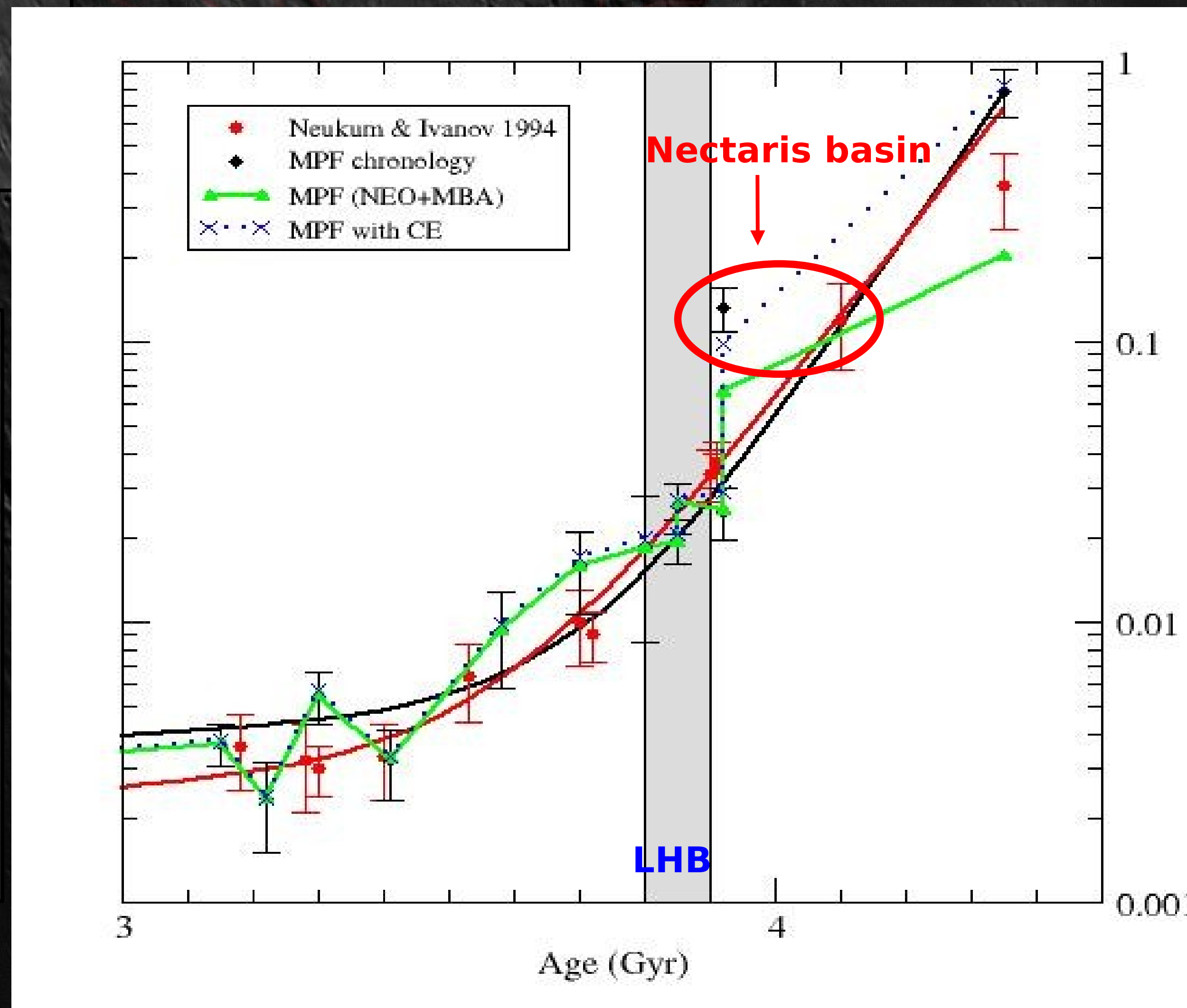
$$\phi(d, v, t) = h(d, t) f(d, v).$$

$$\mathrm{MPF}(D, t) = \int_{D}^{\infty} \Phi(\tilde{D}, t)\mathcal{E}(\tilde{D}, t)\, d\tilde{D}$$

We tested:

- **NEO and MBA size distributions;**

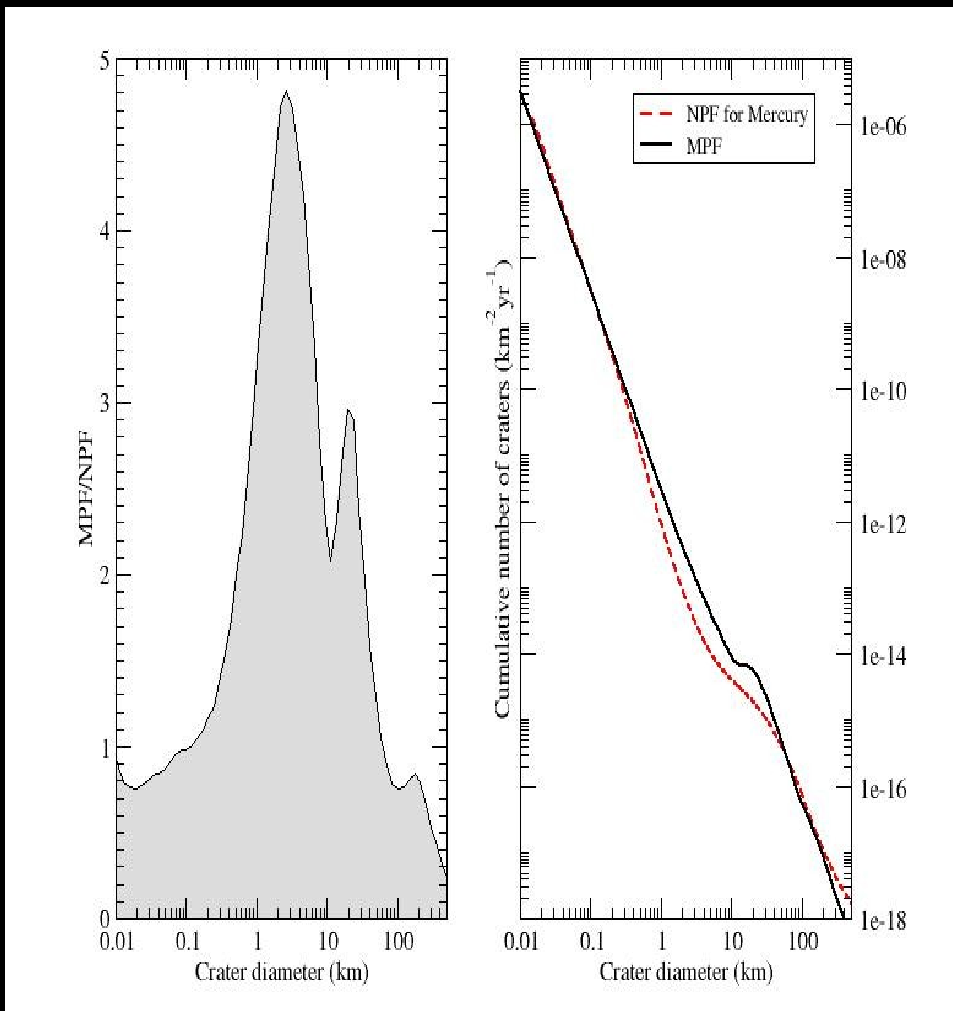
- **cratering erasing (CE) (namely, the saturation effect).**



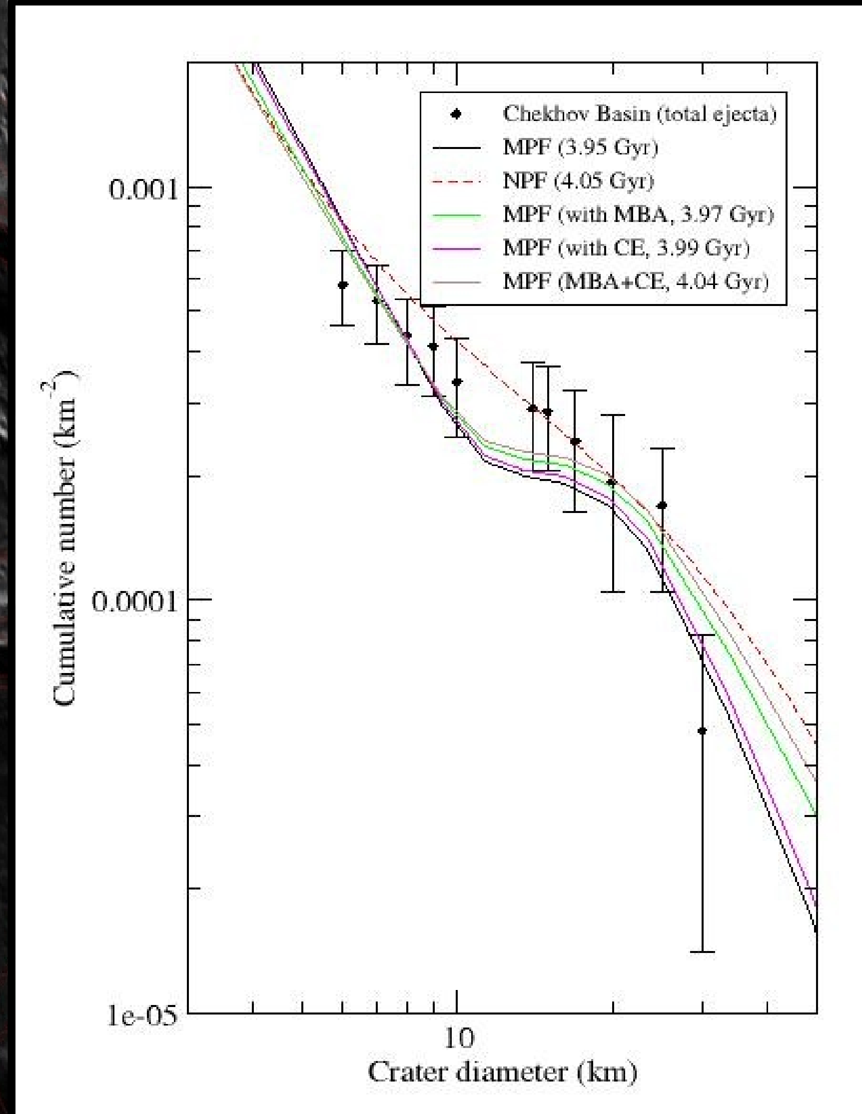
A look at Mercury

Hermean MPF:

MPF/NPF~5 @2km



Chekhov basin:



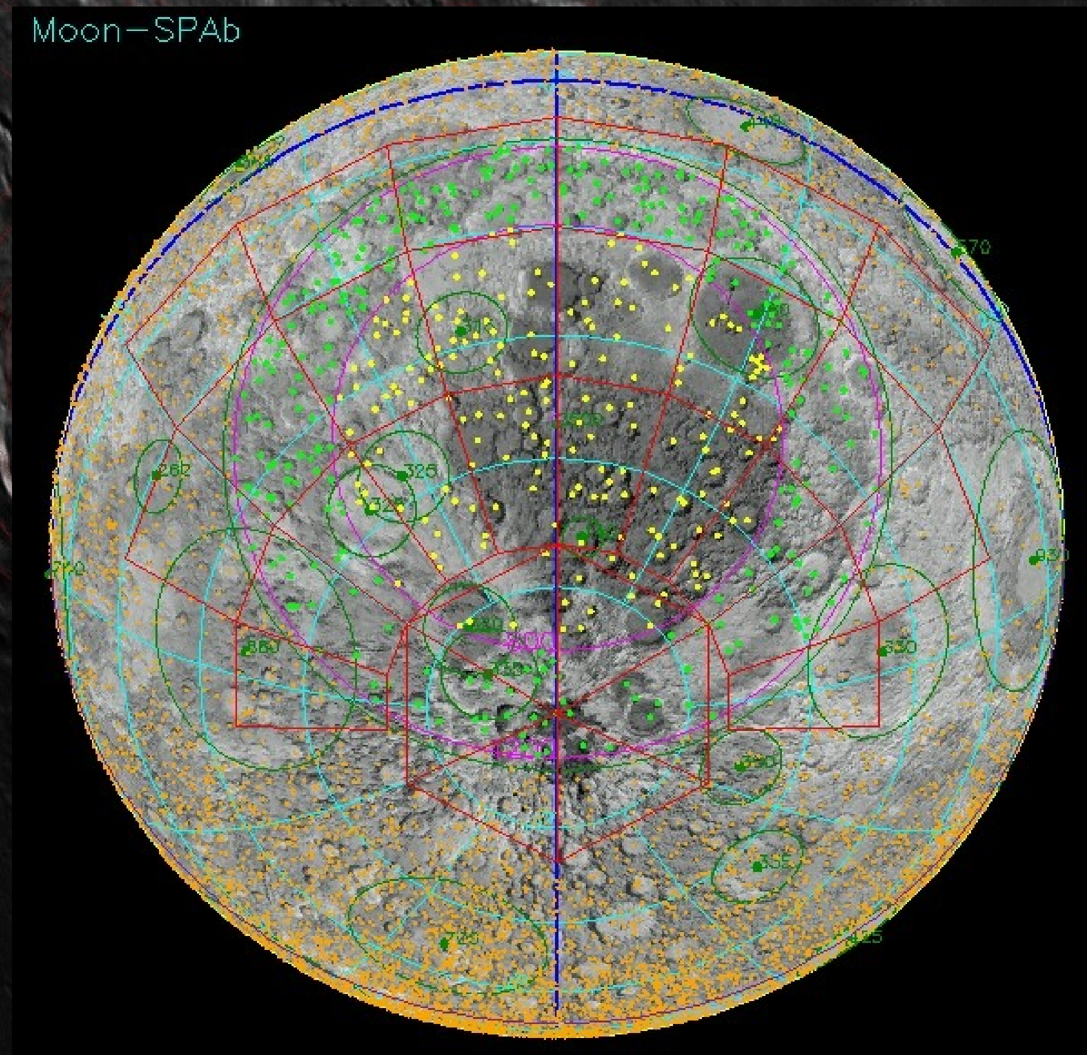
Latest news: the early history of the Moon

New crater counts on very old terrains (SPA, FHT...) using high resolution Clementine data;

First cratering age for SPA;

Importance of cratering erasing processes for FHT and SPA;

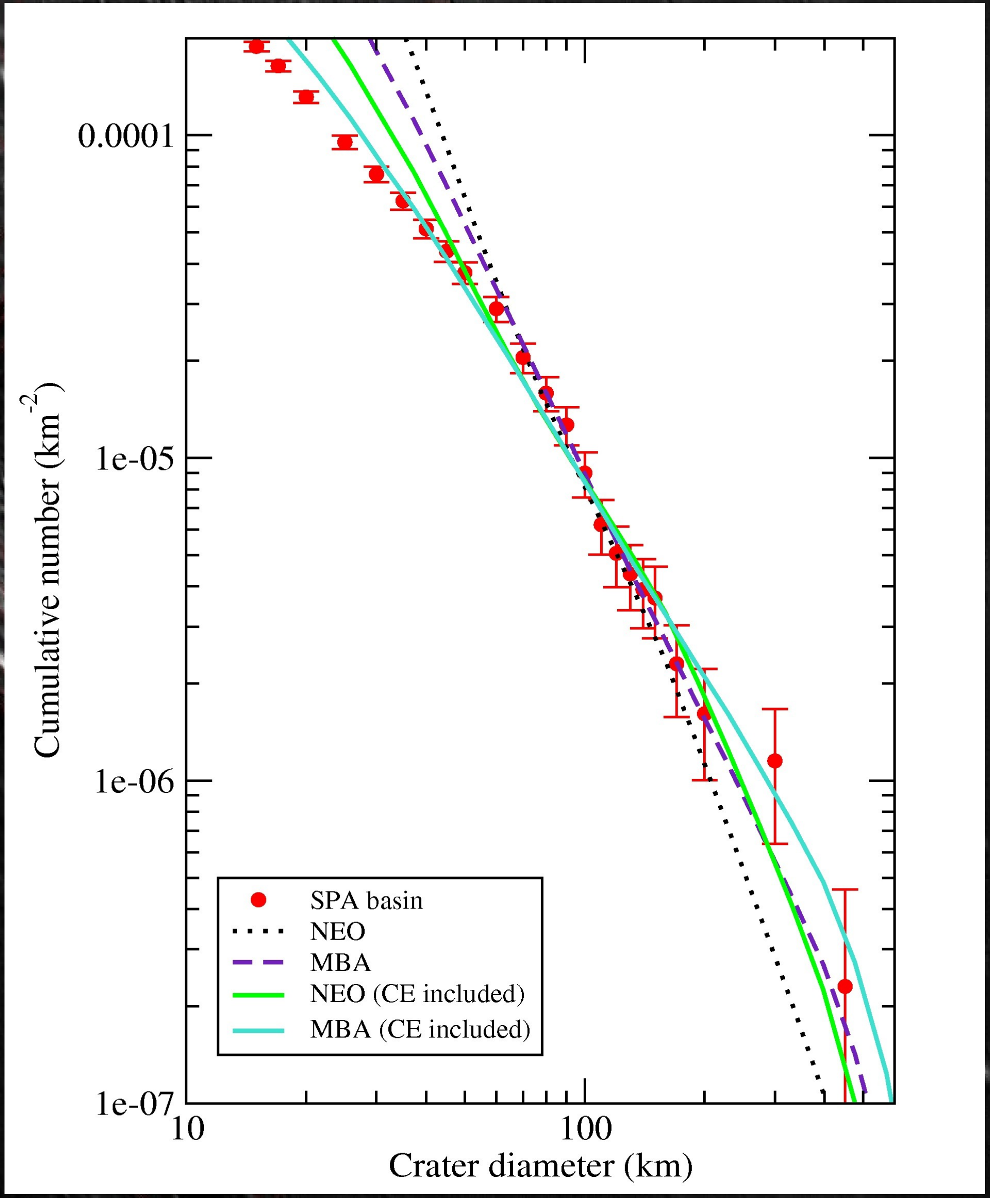
New insights for the Late Heavy Bombardment;



Modeling SPA basin

Crater erasing is important to fit the observed cratering;

According to our model, SPA age estimate is 4.01 Gyr.



Conclusions

- **Published lunar chronology is confirmed within a factor of 2;**
- **Systematic misfit in the assumed linear branch of the chronology, possibly indicating a flux enhancement for age<0.5 Gyr;**
- **Very old lunar regions (Nectaris basin and Highlands) are best fitted by the MBA population;**
- **Using the MBA population, we find a remarkable 'knee' in the chronology curve, possibly a footprint of the LHB;**
- **Age determination for SPA and importance of erasing processes;**
- **For Mercury, our MPF differs up to a factor of 5 (@ 2km) to the NPF, and this may affect age determination of hermean terrains.**

References:

Marchi et al., AJ 137, 2009;

Massironi et al., GRL 36, 2009;

Marchi, 2010, submitted.