Gaia and the new comets from the Oort Cloud

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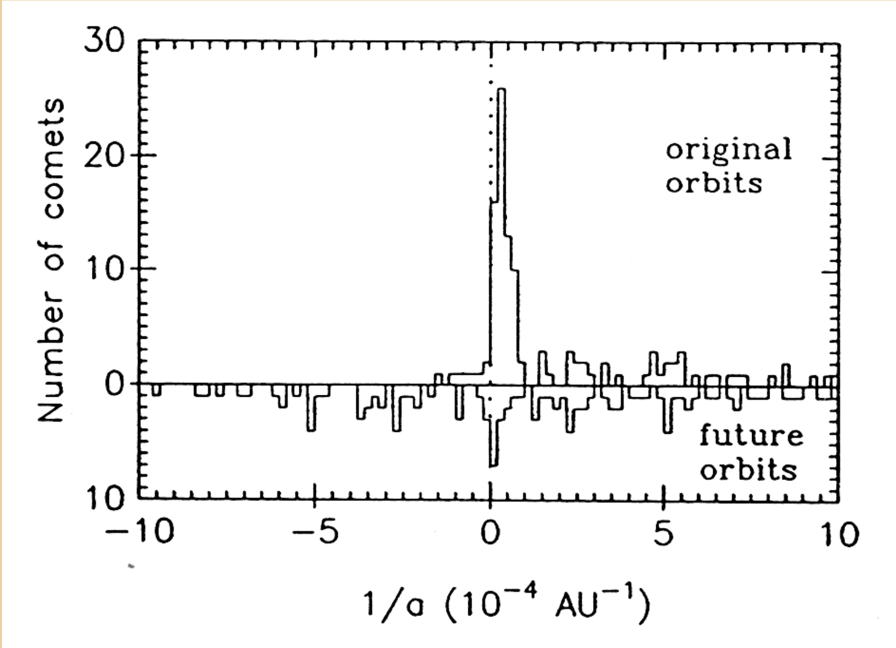
Paper: "***The last revolution of new comets: The role of stars and their detectability***", Fouchard et al. 2011, subm. to *Astron. & Astrophys.*

The Oort Cloud

- Entering into the planetary system, the long-period comets have a strongly peaked distribution of *1/a*
- *But planetary perturbations wipe out the spike*
- The comets of the spike are not returning - they are *newcomers from a very distant reservoir*

 - ***"Old" and "New" comets***



the Oort spike

Comet injectors

- *The tidal force of the Galactic disk (‘**disk tide’**) causes an oscillation of eccentricity and inclination of Oort Cloud comet orbits, which may bring perihelion distances below ~5 AU (thus observable)*
- *Random* ***passing stars*** *of the Galactic field impart heliocentric impulses to the comets, thus changing their perihelion distances*

Our work

- We start 10^6 test comets in thermalized Oort Cloud orbits and integrate them up to 5 Gyr, unless they enter the loss cylinder or diffuse into interstellar space
- We use a full description of the Galactic tide and a random set of stellar encounters using 13 categories with different masses and velocity distributions
- *We take note of all injections into observable orbits* ($q < 5$ AU)

Stellar encounters

Type	Mass ($M_\odot$)	Enc. freq.	$v_\odot$ (km/s)	σ_* (km/s)	$\langle V \rangle$ (km/s)	σ_V (km/s)
B0	9	0.005	18.6	14.7	24.6	6.7
A0	3.2	0.03	17.1	19.7	27.5	9.3
A5	2.1	0.04	13.7	23.7	29.3	10.4
F0	1.7	0.15	17.1	29.1	36.5	12.6
F5	1.3	0.08	17.1	36.2	43.6	15.6
G0	1.1	0.22	26.4	37.4	49.8	17.1
G5	0.93	0.35	23.9	39.2	49.6	17.9
K0	0.78	0.34	19.8	34.1	42.6	15.0
K5	0.69	0.85	25.0	43.4	54.3	19.2
M0	0.47	1.29	17.3	42.7	50.0	18.0
M5	0.21	6.39	23.3	41.8	51.8	18.3
wd	0.9	0.72	38.3	63.4	80.2	28.2
gi	4	0.06	21.0	41.0	49.7	17.5

Method

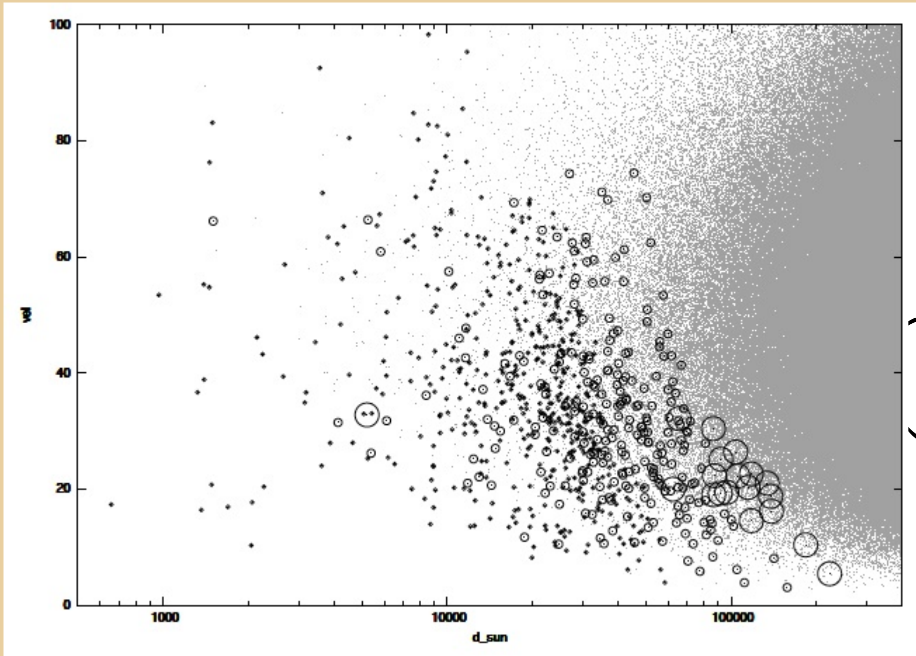
- Create 3 different initial Oort Clouds (10^6 orbits with $p(a_o) \propto a_o^{-1.5}$ between 3000 and 10^5 AU, and $p(e_o) \propto e_o$ with $q_o > 32$ AU
- For each cloud, create a random sequence of ~200,000 stellar encounters during 5 Gyr
- Integrate with tides and stars until comets diffuse out or get injected into $r < 15$ AU
- *For observable comets* ($r < 5$ AU)*, save the elements at the preceding perihelion passage*

Eliminating showers

- *The present flux of new comets is likely not affected by any "comet shower"*
- Thus ***we select the most "quiescent" injected comets*** by excluding all that might have been perturbed by a star causing a significant enhancement
- We are able to statistically identify all such stars using a separate study of comet injection (*Icarus*, in press)

Numbers of stars and comets

- **During the last 3 Gyr:**
- – 355,821 passing stars, whereof 755 enhancement makers
- – 20,446 injected comets, whereof only 30% are quiescent
- Conservative definition!



V (km/s)

$d_{\odot}$ (AU)

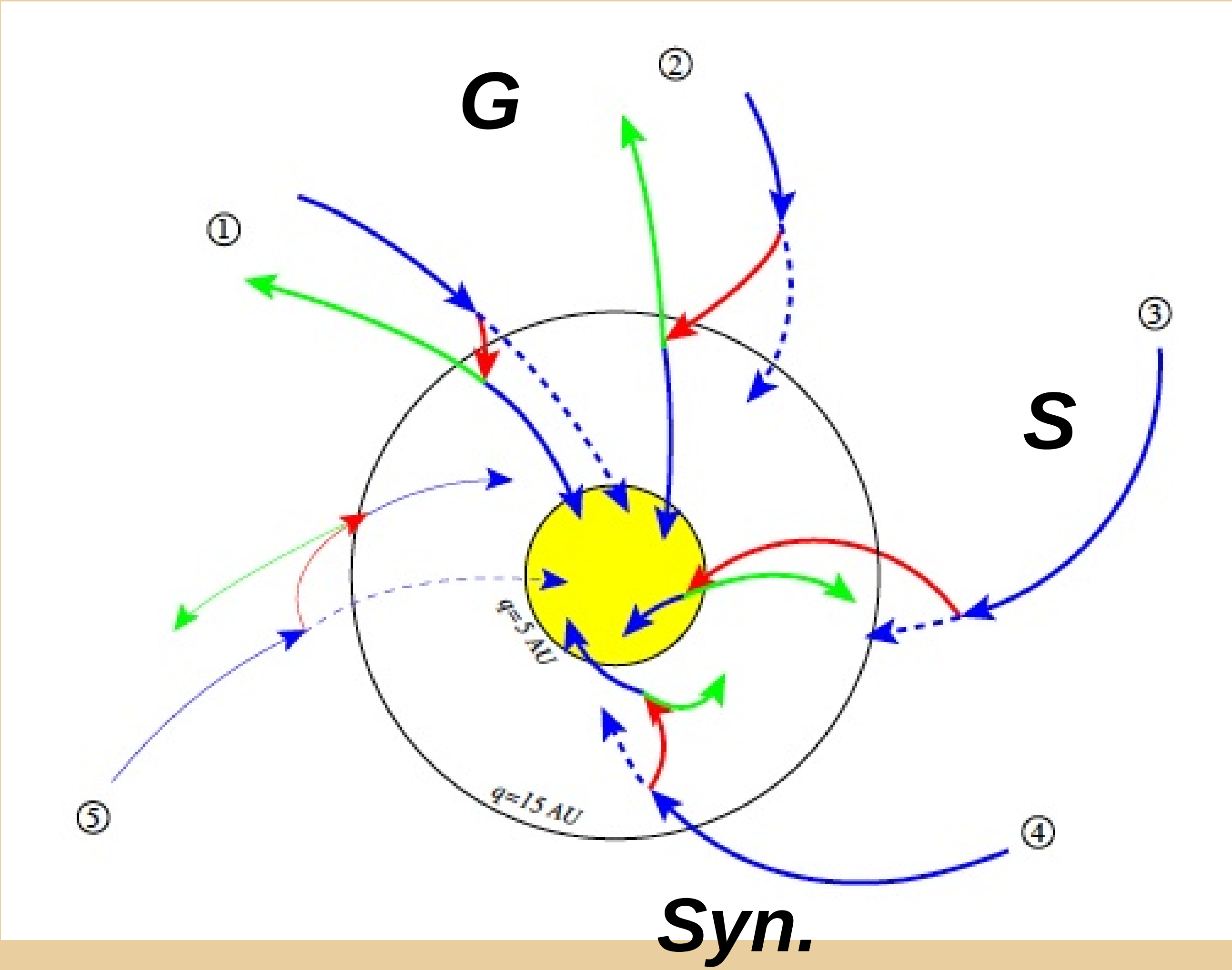
Passing stars: enhancement makers identified with symbol size indicating the stellar mass

The $\mathcal{S}$ and $\mathcal{G}$ sets

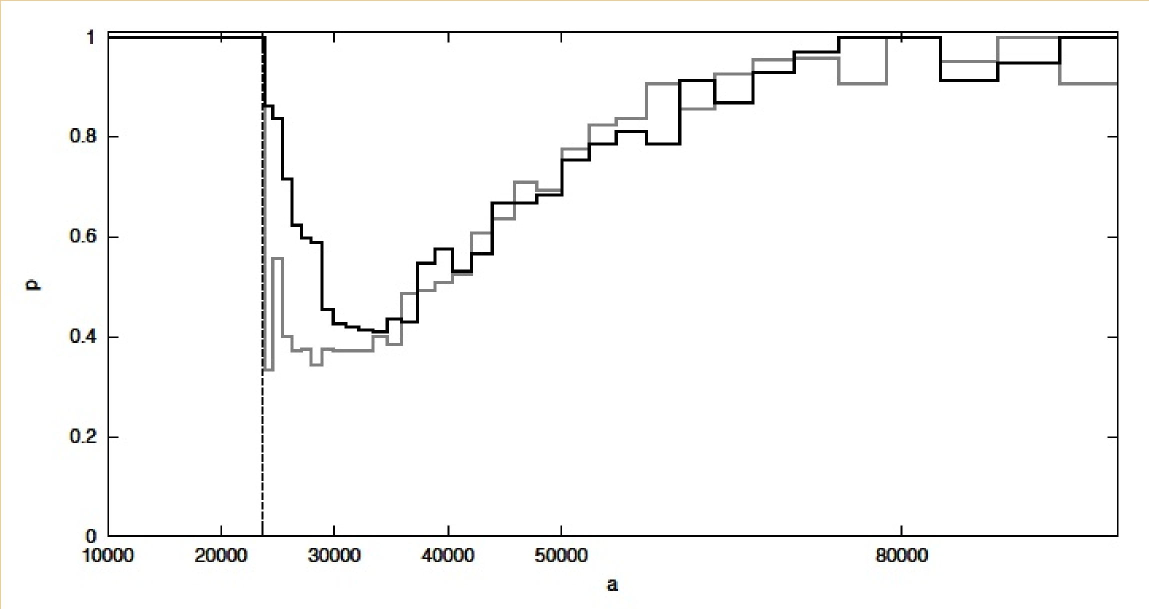
- $\mathcal{S}$ is the set of injected comets, for which one star caused a jump from > 15 AU to < 5 AU in *q* during the last revolution ("*stellar injections*")
- $\mathcal{G}$ is the set of injected comets, for which a tide-only backward integration to the preceding perihelion leads to *q* > 15 AU ("*tidal injections*")

Most comets belong to $\mathcal{S}$ or $\mathcal{G}$, but some belong to both, and some belong to none…

Injection types

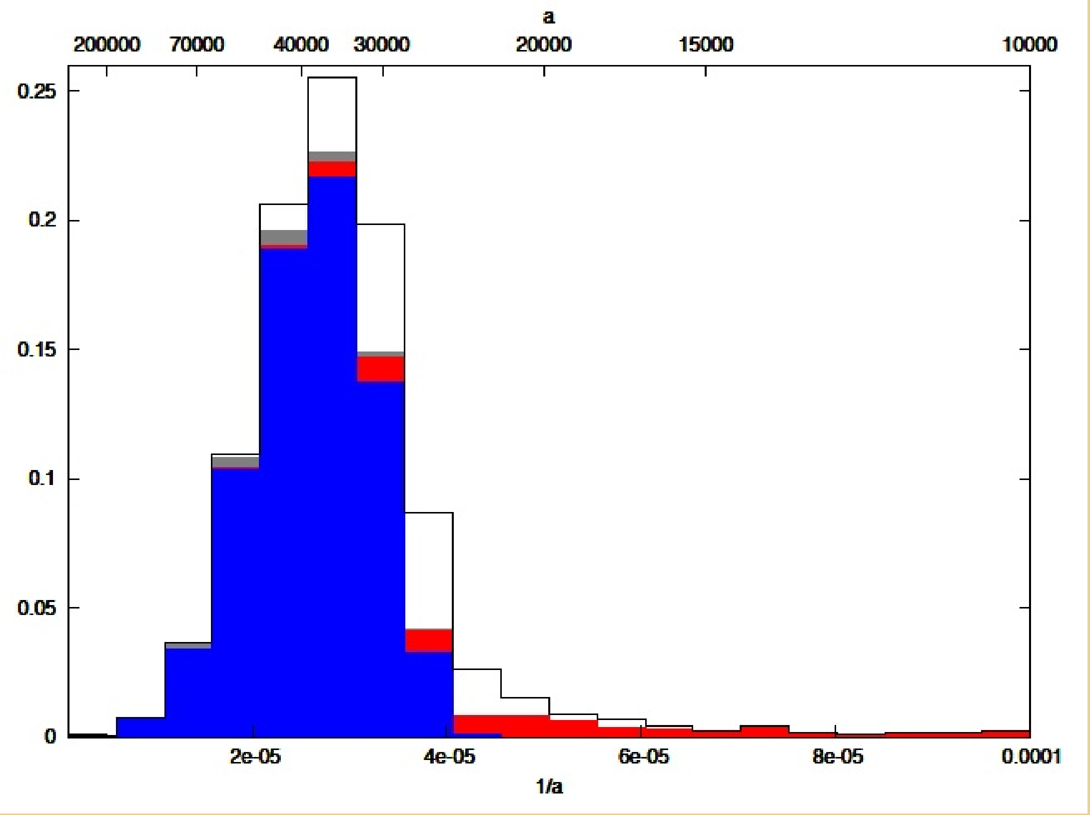


Constructive interference



- Black line: fraction of G-set comets that require a star to be injected
- Grey line: fraction of injections in a tide-only model that disappear when stars are added

Simulated Oort spike



fraction of injected comets

- G-type injections dominate the spike
- But stars are essential in many cases near the maximum and almost always in the outer part

Stars are important!

- *The Galactic tide appears to be the dominant player in the game of comet injection* (the G set dominates the Oort spike)
- ***But most of the injections in general*** (all on the inner side of the spike and almost all on the outer side) ***would not have occurred without the action of a star***

Comet injection: A Team Work

Scoring goals is important, …

… but the backup of the whole team is essential!

The culprit stars

- *For many of the observed new comets, the injection was assisted by a stellar perturbation*
- ***Can we identify the culprit stars using existing catalogues?***
- Dybczyński (2006) made a state-of-the-art search for encounters with Hipparcos stars in the recent past & near future
  - He identified 11 stars to have passed at < 2 pc during the last 3 Myr; *none caused the injection (J-S barrier crossing) of any of the “new comets”*

Detection criteria

- **HIPPARCOS**
- V<8: all detected
- V>13: none detected
- 8<V<13: linear falloff of probability
- p.m.>1 mas/yr: all measured
- p.m.<1 mas/yr: none measured

- **GAIA**
- V<20: all detected
- V>20: none detected
- r<500 pc: all measured
- p.m.>4 μas/yr: measured for V<12
- p.m.>10 μas/yr: measured for 12<V<17
- p.m.>160 μas/yr: measured for V>17

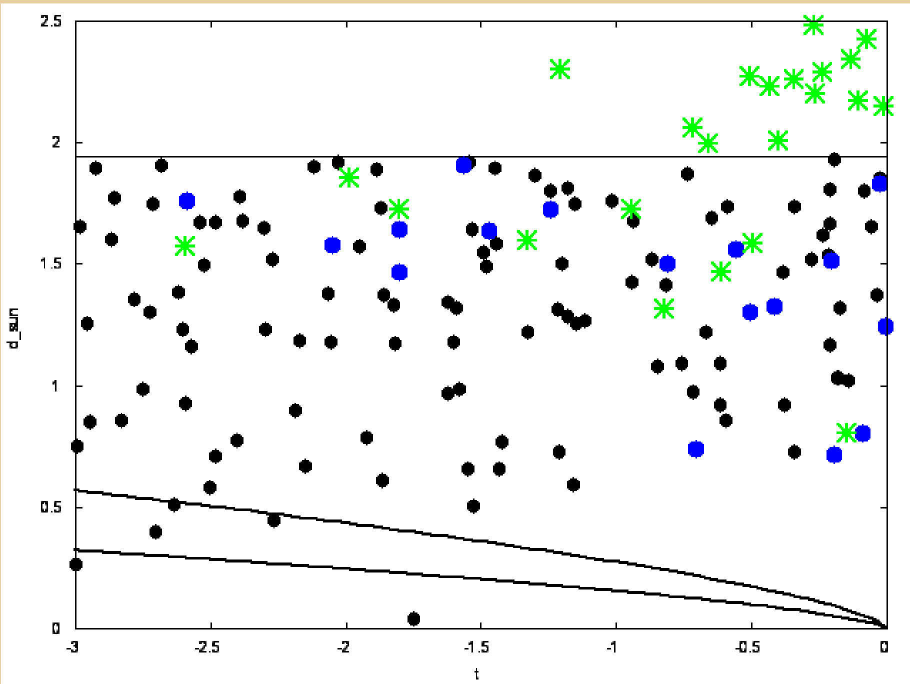
General results

- ***For all injected comets, we compute magnitude & proper motion of all stars that passed during the last orbit at the moment of comet perihelion***

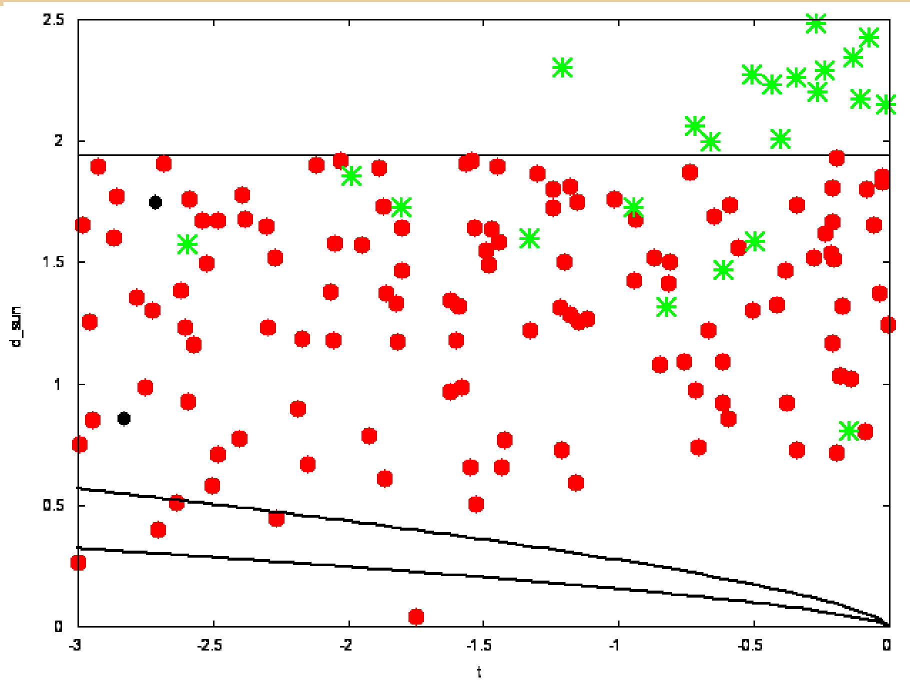
- *For Hipparcos,* ~10% *are detected, and for Gaia,* ~70% *are detected*
- *Taking the star with the largest negative* Δq*, for Hipparcos we get ~30% and for Gaia ~90%*
- *The fraction of p.m. measurements for all detected stars is 73% for Hipparcos and 95% for Gaia; for the most efficient detected stars it is ~20% and >80%, respectively*

Random illustration

Hipparcos detections



Gaia detections



Dybczyński's real stars

The culprit hunt using Gaia

- *Get radial velocities for Gaia stars with very small proper motions, unless Gaia can measure them $\Rightarrow$ identification of possible culprits*
- *Get better astrometry for distant, new comets for better orbits (preferably large perihelia to minimize NG effects) $\Rightarrow$ possible links of comets to stars*