Gaia and the new comets from the Oort Cloud

Hans Rickman
Marc Fouchard
Christiane Froeschlé
Giovanni Valsecchi

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

[Diagram showing the distribution of comets with a peak at \(1/a\)]

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

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

• Create 3 different initial Oort Clouds \((10^6\) orbits with \(\rho(a_o) \propto a_o^{-1.5}\) between 3000 and \(10^5\) AU, and \(\rho(e_o) \propto e_o\) 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!**

Passing stars: enhancement makers identified with symbol size indicating the stellar mass.
The S and G sets

- **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")

- **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 $S$ or $G$, but some belong to both, and some belong to none…
Injection types

![Diagram of injection types]

G

S

Syn.
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

- 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 $\Delta q$, 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 ⇒ identification of possible culprits

• Get better astrometry for distant, new comets for better orbits (preferably large perihelia to minimize NG effects) ⇒ possible links of comets to stars