ACTIVITY OF 50 LONG-PERIOD COMETS BEYOND 5.2 au

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ABSTRACT

Remote investigations of ancient matter in the solar system have traditionally been carried out through observations of long-period (LP) comets, which are less affected by solar irradiation than their short-period counterparts orbiting much closer to the Sun. Here we summarize the results of our decade-long survey of the distant activity of LP comets. We found that the most important separation in the data set is based on the dynamical nature of the objects. Dynamically new comets are characterized by a higher level of activity on average: the most active new comets in our sample can be characterized by $A_{IF}$ values $>3-4$, higher than those for our most active returning comets. New comets develop more symmetric comae, suggesting a generally isotropic outflow. In contrast to this, the comae of recurrent comets can be less symmetrical, occasionally exhibiting negative slope parameters, which suggest sudden variations in matter production. The morphological appearance of the observed comets is rather diverse. A surprisingly large fraction of the comets have long, tenuous tails, but the presence of impressive tails does not show a clear correlation with the brightness of the comets.

Key words: comets: general – Oort Cloud

1. INTRODUCTION

The origin and behavior of comets are related to the entire solar system—its general history and environment—in several ways. It is widely accepted that in the early solar system a large number of comet-like bodies orbited in the trans-Neptunian region and beyond, through the Oort Cloud. The group of trans-Neptunian objects (TNOs) were recognized as sources of short-period comets and probably various groups of asteroids (e.g., Duncan et al. 2004; Eicher & Levy 2013). The recent exploration of the TNOs by the Herschel Space Observatory revealed the size and albedos of a handful of objects (Lacerda et al. 2014), supporting the idea that comet-like bodies are still present among the TNOs, which include other objects of different nature (e.g., Formasier et al. 2013; Duffard et al. 2014). In recent years, the presence of similar comet clouds was suggested in several extrasolar systems, characterized by a prominent infrared excess due to cold debris (e.g., Beichman et al. 2005; Greaves & Wyatt 2010). These observations show that comets are common by-products of the formation of a solar system, and they preserve the matter from the outskirts of young solar systems for a long time. Even a relationship between comet dust and relics of the interstellar medium was suggested in the case of Hale–Bopp (Wooden et al. 2000).

Observations of cometary activity have been the traditional method of remote investigation. Since long-period (LP) comets suffered the least solar irradiation, they can be ideal targets for studying ancient matter in a fairly intact state. Thanks to automated telescopes (e.g., Spacewatch, LINEAR, LONEOS, CSS/MLS/SSS, Pan-STARRS), relatively bright comets with large perihelion distances are now regularly discovered often several years before their perihelion passage. Hence it has become possible to study distant cometary activity more regularly than before. Observations at heliocentric distances revealed that comets can be significantly active well beyond the snow line. The sublimation of water ice is excluded in this region because it can be efficient only at a few au from the Sun, roughly inside Jupiter’s orbit at 5.2 au (Meech & Svorøe 2004). The main mechanisms that have been proposed to explain the activity of comets at large heliocentric distances are the transition phase between amorphous and crystalline water ice (Prialnik 1992; Capria et al. 2002), the annealing of amorphous water ice (Meech et al. 2009), and the sublimation of more volatile admixtures like CO and/or CO$_2$.

In the past two decades, observational campaigns have been made to reveal the distant activity of comets, mostly with observations of the Jupiter family (Meech 1991, p. 629; O’Ceallaigh et al. 1995; Meech & Hainaut 1997; Lowry et al. 1999; Szabó et al. 2001, 2002, 2008, 2012; KorSun & Chómy 2003; Tozzi et al. 2003; Mazzotta Epifani et al. 2009, 2010, 2014; Meech et al. 2009; KorSun et al. 2010; Shi et al. 2014; Ivanova et al. 2015). However, there is still a shortage of observations of LP comets beyond 5.2 au. Most importantly, there is a natural deficit of LP comets observed on their inward orbit, because distant comets used to be discovered near perihelion (roughly before 2000). For example, at the time of writing this paper, there are only four comets with well documented observations covering at least 1 au on the inward orbit beyond 5.2 au (Fulle et al. 1998), C/2003 WT42 (Korusen et al. 2010), C/2006 S3 (Rousselot et al. 2014), and C/2012 S1 (Krišandová et al. 2014)).
It was recognized by Oort that a dynamically new comet is usually defined as a comet on an orbit with \( a > 10^4 \) au, or \( P > 10^6 \) yr (Eicher & Levy 2013; Mazzotta Epifani et al. 2014). Such comets represent an early stage of the inward migration (this is why they are called “new” comets). They reside very far from the Sun and even spend the vast majority (>99.9%) of their lifetime outside the heliosphere. Therefore, these comets are exposed to marginal solar irradiation, and very little modification by the solar wind. One can expect that the behavior of dynamically new comets differs from that of other comets (known as “returning comets”), and the present paper aims to investigate this.

As a result of our decade-long survey of the distant activity of LP comets, we gained 150 images of 50 comets showing activity beyond the snow line. The observations are still ongoing with the same instruments, but at the present stage, we can already answer some important questions related to the activity of these comets. The observations are presented in the context of the following questions:

1. What is the behavior of LP comets at large heliocentric distances? How does the activity evolve and cease?
2. Are the activity profiles similar to each other during the inward and outward parts of the orbit?
3. What kind of specific correlations can be recognized between the activity parameters (\( A_f \rho \), slope, tail characteristics), and between these parameters and the ephemerides?
4. Can distinct groups be recognized by their activity parameters?
5. What can we deduce from short-timescale variations such as outbursts or rapid evolution of matter production?

The paper is structured as follows. The observations and reduction steps are described in Section 2, while Section 3 deals with the detailed observational results. The discussion of the results is given in Sections 4 and 5.

2. OBSERVATIONS

We carried out CCD observations on 103 nights from 1998 November to 2014 October at the Pizskeletê Station of the Konkoly Observatory, Hungary. Standard Johnson R filtered data were obtained using the 60/90/180 cm Schmidt telescope. The list of observed comets is shown in Table 1, while the full log of observations is given in Table 2. Between 1998 November and 2010 June the telescope was equipped with a Photometrics AT-200 CCD camera (1536 \times 1024 pixel, KAF1600 MCII coated CCD chip). The projected area was \( 29'' \times 18'' \), which corresponded to an angular resolution of 1''01/pixel. Since 2010 August, an Apogee ALTA-U 4096 \times 4096 CCD camera (FOV 70'' \times 70'' arcmin) with the same resolution has been used. The operational temperature of the cameras was \(-40^\circ C\).

The exposure time was limited by the trail of the comets during the exposures. We restricted the maximal tolerable trails to <2'', which is characteristically the FWHM of the stellar profiles on an average night.

During the first ten years, we observed distant comets occasionally, as a complement to the astrometric program of the Konkoly Observatory. Based on the initial results, in 2008 we started a dedicated program to observe distant LP comets at heliocentric distances larger than 5.2 au, i.e., beyond the orbital distance of Jupiter.

The images were corrected in the standard fashion, stacked and evaluated with the Astrometrica software by H. Raab.\(^{10}\) The photometric zero points were determined for the stacked images following our usual method: we first stacked the observed images to non-moving objects (“star” images), measured the zero point of stellar photometry in this image, and then applied the same zero point to the “comet” images, which were stacked taking the apparent motion into account. Stellar magnitudes were taken from the USNO B1 catalog.

Since all comets were observed in activity and all had an apparently extended coma, we could determine the quantity \( A_f \rho \) and its slope (A’Hearn et al. 1984). This quantity measures the relative linear filling factor of dust and allows a comparison of data obtained at different sites, epochs, geometrical circumstances, and/or with different telescopes and photometric apertures. It is the product of Bond albedo \( A \) (Bond 1861; Bell 1917), filling factor \( f \) of the grains within the aperture, and \( \rho \), the radius of the field of view at the comet:

\[
A_f \rho = \frac{(2DR)^2}{\rho} \times \frac{F_{\text{com}}}{F_{\text{sol}}}. \tag{1}
\]

where the Earth–comet distance \( D \) and \( \rho \) are in cm, the Sun–Earth distance \( R \) is in au, \( F_{\text{sol}} \) is the flux of the Sun at 1 au referring to the photometric band used, and \( F_{\text{com}} \) is the observed flux from the comet. \( A_f \rho \) is a function of \( \rho \), usually increasing slightly in the coma and reaching a maximum value of \( A_f \rho_{\text{max}} \) at a distance \( \rho_{\text{max}} \) from the nucleus. Then it starts to decrease with a slope characteristic of the profile of the outer coma. The average profile of the coma brightness is well described by a power law as \( \gamma \rho^\gamma \), where \( \gamma \) is the slope calculated from the log \( \rho \) dependence of log \( A_f \rho \). Denoting the various coefficients simply by \( K \) and \( K' \),

\[
\log A_f \rho = K + \log \left( \frac{1}{\rho} \int \rho \delta \, d\rho \right) = K' + (\gamma + 1) \log \rho, \quad \text{consequently}
\]

\[
\text{slope} = \frac{d \log A_f \rho}{d \log \rho} = \gamma + 1. \tag{2}
\]

Hence, the slope parameter has a value around 0 if the coma is close to a steady state and globular symmetry (and \( \gamma = -1 \) in this case). Deviations from this shape result in a non-zero slope parameter, to either the positive or the negative side. At larger heliocentric distances, comets are known to exhibit negative slope parameters, even down to \(-1\), but there were also indications of temporally positive values of slope parameters (e.g., in the late activity of Hale–Bopp, Szabó et al. 2008).

The \( A_f \rho \) and slope parameters were determined from surface photometry profiles. Multiple aperture photometry (indicatively between 10,000 and 100,000 km) was plotted for all stacked images (in a log–log plot), and we manually selected the linear segment. We fitted a line in the log–log plane, extrapolated the \( A_f \rho \) to an aperture of 50,000 km following the recipe of Milani et al. (2007), and also registered the slope parameter. The peak of the profile (\( \rho_{\text{max}} \)) is often derived and handled as an independent morphological parameter. For the sake of a direct comparison to previous studies we also determined \( \rho_{\text{max}} \) and

\(^{10}\) www.astrometrica.at/
the corresponding $A_{f}/\rho_{\text{max}}$, i.e., $A_{f}/\rho$ at $\rho_{\text{max}}$. Nevertheless we note that we found a strong correlation between the width of the stellar profiles and the $\rho_{\text{max}}$ values, showing that the smearing of the inner coma by the seeing biases the estimate of $\rho_{\text{max}}$, and hence biases $A_{f}/\rho_{\text{max}}$ as well.

3. RESULTS

A summary of the reduced observations ($A_{f}/\rho$ and slope parameters) is given in Table 3. While most targets have no published history in the literature, some comets in the sample have extensive observational records. Here we give a detailed
### Table 2
Summary of Observations

| Object                  | Obs. Time (UT) | R (au) | Δ (au) | α (deg) | PA_{aust} (deg) | Exposure (s) | I/O |
|-------------------------|----------------|--------|--------|---------|----------------|--------------|-----|
| C/1997 BA6 (Spacewatch) | 2003.09.19. 18:49 | 11.267 | 10.563 | 3.8     | 183.2          | 4 × 280      | O   |
| C/1997 J1 (Mueller)     | 1998.11.25. 00:03 | 6.061  | 5.215  | 5.2     | 39.6           | 3 × 240      | O   |
| C/1998 W3 (LINEAR)      | 2000.03.10. 18:35 | 6.304  | 6.474  | 8.8     | 91.0           | 3 × 300      | O   |
| C/1999 J2 (Skiff)       | 1999.09.24. 18:21 | 7.219  | 7.582  | 7.2     | 10.7           | 2 × 300      | I   |
| C/2002 V2 (LINEAR)      | 2003.11.05. 00:18 | 6.909  | 5.940  | 1.9     | 87.0           | 3 × 180      | I   |
| C/2003 A2 (Gleeson)     | 2003.12.27. 02:16 | 11.429 | 10.801 | 3.9     | 281.8          | 4 × 260      | O   |
| C/2003 K4 (LINEAR)      | 2003.07.06. 00:45 | 5.762  | 5.202  | 8.9     | 113.6          | 3 × 120      | I   |
| C/2003 P1 (NEAT)        | 2003.09.09. 19:21 | 5.145  | 4.588  | 9.9     | 93.0           | 5 × 120      | I   |
| C/2003 WT42 (LINEAR)    | 2008.03.31. 00:55 | 7.383  | 6.468  | 3.3     | 321.7          | 9 × 180      | O   |
| C/2004 B1 (LINEAR)      | 2008.07.22. 19:35 | 9.134  | 9.600  | 5.5     | 127.6          | 9 × 200      | O   |
| C/2005 G1 (LINEAR)      | 2005.04.03. 01:52 | 5.566  | 5.432  | 10.3    | 152.5          | 3 × 180      | I   |
| C/2005 L3 (McNaught)    | 2008.03.31. 02:52 | 5.620  | 5.154  | 9.4     | 129.2          | 8 × 180      | O   |
| C/2005 S4 (McNaught)    | 2008.05.28. 23:11 | 5.677  | 4.403  | 7.1     | 125.0          | 9 × 120      | O   |
| C/2006 A2 (Catalina)    | 2006.01.22. 19:14 | 5.625  | 5.192  | 9.4     | 41.1           | 9 × 220      | O   |
| C/2006 K1 (McNaught)    | 2008.10.25. 02:14 | 5.762  | 5.003  | 6.9     | 205.1          | 9 × 180      | O   |
| C/2006 M2 (Spacewatch)  | 2008.11.28. 02:22 | 5.931  | 4.949  | 1.0     | 207.7          | 9 × 180      | O   |
| C/2006 S3 (LINEAR)      | 2008.12.28. 21:03 | 6.088  | 5.219  | 4.7     | 208.8          | 9 × 180      | O   |
| C/2007 B2 (Skiff)       | 2007.03.06. 23:26 | 5.733  | 4.985  | 7.0     | 298.7          | 12 × 120     | I   |
| C/2007 D1 (LINEAR)      | 2008.12.30. 04:19 | 9.369  | 9.233  | 6.0     | 251.7          | 9 × 180      | O   |
| Object          | Obs. Time (UT) | $R$ (au) | $\Delta$ (au) | $\alpha$ (deg) | $PA_{\text{min}}$ (deg) | Exposure (s) | I/O |
|-----------------|----------------|---------|---------------|-----------------|-------------------------|--------------|-----|
| C/2007 D3 (LINEAR) | 2008.03.31. 20:18 | 5.695  | 5.198        | 9.1             | 242.6                   | 8 × 150       | O   |
| C/2007 K1 (Lemmon)  | 2008.05.28. 00:13 | 9.487  | 9.084        | 5.7             | 144.4                   | 8 × 150       | O   |
| C/2007 G1 (LINEAR)   | 2007.05.03. 00:52 | 5.979  | 5.544        | 9.1             | 359.2                   | 12 × 120      | I   |
| C/2007 IA21 (LINEAR)  | 2008.04.01. 01:17 | 6.506  | 6.098        | 8.3             | 15.2                    | 8 × 150       | O   |
| C/2007 U1 (LINEAR)   | 2010.06.13. 00:23 | 6.721  | 6.266        | 8.0             | 80.3                    | 12 × 150      | O   |
| C/2007 VO53 (Spacewatch) | 2008.08.21. 01:02 | 6.707  | 6.819        | 8.5             | 180.2                   | 12 × 150      | I   |
| C/2008 S3 (Boattini)  | 2013.12.27. 19:33 | 13.563 | 12.910       | 3.2             | 194.5                   | 9 × 150       | I   |
| C/2010 D4 (WISE)     | 2010.03.24. 03:24 | 7.469  | 7.242        | 7.6             | 167.5                   | 8 × 150       | O   |
| C/2010 G2 (Hill)     | 2010.05.01. 21:38 | 5.457  | 4.656        | 7.0             | 183.2                   | 9 × 140       | I   |
| C/2010 R1 (LINEAR)   | 2010.12.19. 21:12 | 10.629 | 10.432       | 5.3             | 241.3                   | 8 × 150       | I   |
| C/2010 S1 (LINEAR)   | 2013.07.03. 21:56 | 5.908  | 5.349        | 8.7             | 36.6                    | 3 × 120       | O   |
| C/2010 U3 (Boattini)  | 2013.12.27. 19:33 | 13.563 | 12.910       | 3.2             | 194.5                   | 9 × 150       | I   |
| C/2011 F1 (LINEAR)   | 2011.03.25. 21:13 | 6.926  | 6.510        | 7.7             | 275.9                   | 13 × 150      | I   |
| C/2011 KP36 (Spacewatch) | 2013.08.05. 21:03 | 8.478  | 7.821        | 5.4             | 271.1                   | 2 × 150       | I   |
| C/2012 K1 (PANSTARRS) | 2012.05.20. 01:21 | 8.874  | 8.014        | 4.5             | 125.9                   | 5 × 150       | I   |
| C/2012 K8 (Lemmon)   | 2013.07.14. 22:21 | 5.210  | 4.739        | 10.4            | 112.2                   | 9 × 150       | I   |
| C/2012 LP26 (Palomar) | 2013.08.01. 20:47 | 8.172  | 7.816        | 6.8             | 278.9                   | 12 × 150      | I   |
| C/2012 S1 (ISON)     | 2012.10.21. 03:52 | 5.997  | 5.965        | 9.5             | 296.1                   | 5 × 120       | I   |
|                  |                |        |              |                 |                         |              |     |
C/2012 U1 (PANSTARRS)  
2013.01.05. 18:28 6.609 6.337 8.4 186.0 4 × 150 I  
2013.01.07. 17:43 6.601 6.360 8.4 185.9 3 × 150 I  
2013.07.12. 00:19 5.895 6.369 8.4 206.3 4 × 150 I  
2013.07.20. 01:03 5.869 6.244 9.0 207.2 4 × 120 I  
2014.08.25. 02:24 5.278 5.668 9.8 278.9 3 × 150 O  
C/2013 G9 (Tenagra)  
2013.06.09. 22:47 6.822 5.906 3.9 73.0 7 × 120 I  
2013.07.02. 22:39 6.723 6.019 6.6 73.6 3 × 240 I  
2014.03.14. 03:20 5.799 5.203 8.3 70.7 6 × 150 I  
C/2013 L2 (Catalina)  
2013.06.08. 00:15 5.731 5.078 8.3 155.2 9 × 120 O  
2013.06.12. 22:33 5.750 5.092 8.3 155.0 5 × 150 O  
2013.07.11. 23:27 5.868 5.299 8.7 154.2 5 × 150 I  
2013.08.12. 20:44 6.003 5.714 9.5 154.1 5 × 180 O  
C/2013 P3 (Palomar)  
2013.08.16. 21:36 9.059 8.355 4.8 338.7 15 × 100 I  
2013.09.27. 18:59 8.990 8.100 3.1 338.1 7 × 120 I  
2013.10.31. 19:13 8.938 8.264 4.9 338.0 6 × 150 I  
2013.12.04. 16:56 8.890 8.685 6.3 338.3 5 × 150 I  
2014.07.25. 00:11 8.676 8.162 6.0 340.8 9 × 150 I  
2014.10.25. 19:53 8.648 7.852 4.1 340.4 7 × 150 I  
C/2013 X1 (PANSTARRS)  
2013.12.27. 20:08 8.712 7.746 1.3 113.5 7 × 150 I  
2014.03.14. 20:27 8.119 7.903 6.9 102.2 9 × 120 I  
2014.08.23. 02:08 6.817 7.447 6.4 112.2 3 × 150 I  
2014.08.25. 02:03 6.801 7.404 6.6 112.5 7 × 150 I  
2014.10.28. 03:37 6.255 5.809 8.5 118.1 5 × 120 I  
C/2014 L5 (Lemmon)  
2014.10.27. 19:38 6.207 5.510 6.9 105.1 9 × 150 I  
C/2014 M2 (Christensen)  
2014.09.29. 18:28 6.925 6.829 8.3 239.7 11 × 150 O  
C/2014 R3 (PANSTARRS)  
2014.10.28. 16:54 8.344 8.261 6.8 129.9 9 × 150 I  

**Note.** R—heliocentric distance; Δ—geocentric distance; α—solar phase angle, PA$_{\text{dust}}$—predicted position angle of dust tail. All data were taken from the NASA/ Horizons service (http://ssd.jpl.nasa.gov/horizons.cgi). I/O: inbound/outbound (pre-/post-perihelion) leg of the orbit.

Discussion about those comets that have published independent measurements of Af$_{\text{f}}$, or where our observations cover more than 1 au in heliocentric distance. Morphological parameters were determined following the method we described in Szabó et al. (2001, 2002).

**C/2002 VQ94 (LINEAR):** This LP comet with an orbital period of 2875 yr was discovered as an asteroid by the LINEAR team on 2002 November 11 at a heliocentric distance of 10.0 au. The diameter of the nucleus was estimated to be 80 km (Jewitt 2005) to 96 km (Korsun et al. 2014). Observations from the end of 2003 August, when the heliocentric distance of the comet was 8.9 au, revealed a prominent coma with a fan-like morphology, suggesting that large (>10 μm) grains were not produced (Ivanova et al. 2011). The discovery was made almost three and a half years before the perihelion at 6.78 au, when the initial brightness of 18$^\text{m}$ rose to 16$^\text{m}$.5. The comet was found to be rich in CO$_2$ near perihelion, while the measured N$^+$/CO$^+$ ratio was suggested to be evidence that this comet was formed in a cold environment (Korsun et al. 2006). The late activity was characterized by Af$_{\text{f}}$ values of 2000 cm in 2008, and 800 cm in 2009 and 2011 (Korsun et al. 2014).

We observed this comet at seven epochs, on the inward orbit at $R = 8.58$ au, and on the outward orbit between 8.30 and 11.13 au. Af$_{\text{f}}$ values varied between 1700 and 2100 cm; they showed little dependence on the heliocentric distance and apparently were more influenced by temporary changes. The slope was continuously slightly negative, with values between −0.3 and −0.1. The appearance of the comet was generally similar to the detections reported in the literature, showing a bright photocenter and a fan-like elongated coma. However, in 2003 November and 2010 January, only the photocenter was detected without a coma above the background scatter.

**C/2005 L3 (McNaught):** The comet was discovered about two and a half years prior to perihelion (5.6 au) by Robert McNaught in the Siding Spring Survey project in 2005 June, at 8.7 au heliocentric distance. Further prediscovery images were found from the previous year by McNaught, capturing the comet at 10.4 au. This is a dynamically new comet from the Oort Cloud, according to the classification proposed by Levison & Duncan (1996), because $a > 10^4$ au. The derived absolute brightness is about $H_{10} = 3^\text{m}0$ mag, which is quite bright compared to other similar comets. The perihelion passage occurred at 5.58 au in 2008 January, at a maximum visual brightness of $13^\text{m}5$. Recently, Mazzotta Epifani et al. (2014) derived an Af$_{\text{f}}$ max = 5255 ± 46 cm at $R = 6.64$ au. They detected a large twisted structure in the radial-normalized image, extending mostly to the south, and a well-defined jet-like structure in the Laplace-filtered image. They interpreted these findings as a possible hint of an active area and an effect due to rotation of the nucleus.

We observed this comet on the outward orbit, between 5.62 and 15.15 au. We detected a decreasing trend of Af$_{\text{f}}$ between 8970 and 1450 cm, in accordance with the previous measurements (e.g., we derived 5779 cm on 2009 May 1, on a decreasing trend with the increasing solar distance, while Mazzotta Epifani et al. (2014) published 5255 cm at 2009 May 29). A very prominent coma and tail were observed continuously for this comet during 2008–2010. The length of the tail was measured to be between 4° and 9°. The longest tails were detected in 2009 December (9°) and 2008 December (8°).
### Table 3
Summary of the Results

| Date         | $R$ (au) | $A_p$ (cm) | Slope | I/O |
|--------------|----------|------------|-------|-----|
| C/1997 BA6  | 2003.09.19 | 11.267  | 1047  | 0.16 | O   |
| C/1997 J1   | 1998.11.25 | 6.061  | 83    | 0.14 | O   |
| C/1998 W3   | 2000.03.10 | 6.304  | 246   | −0.01| O   |
| C/1999 J2   | 1999.09.24 | 7.219  | 4931  | −0.69| I   |
| C/2000 V2   | 2001.01.01 | 7.137  | 4090  | −0.28| I   |
| C/2001 A2   | 2003.11.05 | 6.909  | 453   | −0.48| O   |
| C/2002 VQ94 | 2003.12.27 | 11.429 | 2744  | 0.15 | O   |
| C/2003 K4   | 2003.07.06 | 5.762  | 1894  | −0.95| I   |
| C/2003 WT42 | 2008.03.31 | 7.383  | 271   | −0.04| O   |
| C/2004 B1   | 2008.08.22 | 9.134  | 232   | −0.10| O   |
| C/2004 D1   | 2008.12.30 | 10.063 | 149   | −0.13| O   |
| C/2005 EL173| 2005.08.30 | 7.913  | 224   | 0.07 | O   |
| C/2005 G1   | 2005.03.31 | 6.944  | 23    | 0.08 | I   |
| C/2005 L3   | 2008.12.29 | 6.705  | 449   | −0.18| O   |
| C/2005 S4   | 2008.05.26 | 5.677  | 8966  | −0.74| O   |
| C/2006 A2   | 2006.01.22 | 5.625  | 95    | −0.53| O   |
| C/2006 K1   | 2008.10.25 | 5.762  | 332   | −0.18| O   |
| C/2006 K4   | 2006.06.20 | 5.708  | 146   | −0.07| I   |
| C/2006 M2   | 2010.12.20 | 5.708  | 146   | −0.07| I   |

### Table 3 (Continued)

| Date         | $R$ (au) | $A_p$ (cm) | Slope | I/O |
|--------------|----------|------------|-------|-----|
| C/2000 S3   | 2006.06.20 | 5.445  | 36    | −0.88| O   |
| C/2007 B2   | 2007.03.06 | 5.733  | 332   | −0.26| I   |
| C/2007 D1   | 2008.12.30 | 9.369  | 1054  | −0.26| O   |
| C/2007 M1   | 2008.08.24 | 9.611  | 389   | 0.07 | O   |
| C/2007 VOS3 | 2008.10.26 | 6.387  | 161   | 0.03 | I   |
| C/2008 S3   | 2008.12.23 | 6.115  | 193   | −0.25| I   |
| C/2008 K1   | 2008.04.20 | 5.129  | 593   | −0.41| I   |
| C/2010 D4   | 2010.03.24 | 7.469  | 133   | −0.63| O   |
| C/2010 G2   | 2010.05.01 | 5.457  | 147   | −0.18| I   |
| C/2010 R1   | 2012.03.18 | 5.639  | 907   | −0.48| I   |
| C/2011 S1   | 2013.10.02 | 5.977  | 9154  | −0.45| O   |
| C/2013 U3   | 2013.12.27 | 13.563 | 2539  | 0.27 | I   |
| C/2014 T1   | 2014.07.27 | 12.715 | 1353  | 0.15 | I   |
| C/2014 T2   | 2014.10.20 | 12.381 | 1729  | 1.17 | I   |
| C/2015 F1   | 2011.03.25 | 6.926  | 957   | −0.42| I   |
We observed this comet on the outward orbit, between 6.25 and 7.41 au. The appearance was generally similar to that described by Mazzotta Epifani et al. (2014); the diffuse coma with a diameter of a few arcseconds was completed by a faint tail, measured between 30″ (2008 August 22) and 2′ (2009 April 1). On 2009 May 3, the situation changed dramatically: the photocenter and the coma dimmed significantly, while the tail seemed to be relatively brighter, still comparable in brightness to the images from the previous weeks. The overall view suggested that the activity was incessation at the time of our last observation, while the tail was still relatively rich in the matter ejected around the end of the activity.

C/2006 S3 (LINEAR): This dynamically new comet was discovered at a brightness of 19.80 by the Lowell Observatory Near-Earth Object Search (LINEAR) project in 2006 September at a record distance (14.4 au) and a record early time, about five and half years prior to perihelion. Prediscovery images were found on Catalina Sky Survey frames from the previous month. Further orbital calculations provided a perihelion distance of 5.13 au and a perihelion passage in 2012 April. The maximum brightness was around 11.80; the derived absolute brightness is about $H_{10} = 21.80$ mag, which is the second brightest in our sample. Recently, Shi et al. (2014) presented a few photometric data for this target, obtained pre-perihelion at 5.86 au.

Rousselot et al. (2014) performed both spectroscopic and photometric monitoring of the cometary activity for eight years, between 2006 December and 2014 March. They found a lack of emission lines, indicating a dusty comet, and suggested that $A_f$ values were larger in post-perihelion measurements relative to pre-perihelion at similar heliocentric distances. They determined $A_f$ values in the range 700–4000 cm and, considering the long-lasting activity, suggested that this comet represented one of the most dust-productive objects in the solar system. Our measurements nicely complete the data set of Rousselot et al. (2014).

In 2006, we detected an elongated coma toward the northwest, with a dust filling factor of $A_f = 1926$ cm. In 2008–2009, we could detect a faint tail of $\approx30^\prime$–60′ length, leaving the bright coma toward the east, and northeast in 2009. The $A_f$ values followed an increasing trend, and were compatible with those determined by Rousselot et al. (2014). In 2010, the comet kept brightening, while the length of the tail grew to $2^\prime$–3′. In 2014, the appearance changed drastically: on February 24, the coma was unexpectedly bright, and we observed a 10′ long dust tail toward PA $100^\circ \pm 1^\circ$. On that day, we derived an extraordinary $A_f = 7003$ cm, which exceeded all previous determinations and was also a factor of 2 larger than that derived by Rousselot et al. (2014) on 2014 March 2. The environment of the comet was clear of background stars in our image, therefore we expect that the increased $A_f$ value reflects the interesting behavior of this exciting comet, rather than an observational artifact.

### Table 3

(Continued)

| Date            | R (au) | $A_f$ (cm) | Slope | I/O |
|-----------------|-------|------------|-------|-----|
| C/2011 KP36 (Spacewatch) |       |            |       |     |
| 2013.08.05.     | 8.478 | 1435       | −0.19 | I   |
| 2013.09.28.     | 8.212 | 1141       | 0.03  | I   |
| C/2012 K1 (PANSTARRS) |       |            |       |     |
| 2012.05.20.     | 8.784 | 1216       | −0.35 | I   |
| 2013.03.12.     | 6.352 | 2466       | −0.91 | I   |
| 2013.07.14.     | 5.210 | 2738       | −0.65 | I   |
| C/2012 KB (Lemmon) |       |            |       |     |
| 2013.09.27.     | 6.826 | 574        | −0.67 | I   |
| 2014.07.25.     | 6.465 | 769        | −0.38 | I   |
| C/2012 LP26 (Palomar) |       |            |       |     |
| 2013.08.01.     | 8.172 | 340        | −0.78 | I   |
| 2014.06.03.     | 7.162 | 579        | −0.05 | O   |
| 2014.07.26.     | 7.026 | 615        | −0.58 | I   |
| 2014.10.21.     | 6.836 | 568        | −0.42 | I   |
| C/2012 S1 (ISON) |       |            |       |     |
| 2012.10.21.     | 5.997 | 760        | −0.43 | I   |
| 2012.11.14.     | 5.639 | 948        | −0.66 | I   |
| C/2012 U1 (PANSTARRS) |       |            |       |     |
| 2013.01.07.     | 6.601 | 199        | −0.09 | I   |
| 2013.07.12.     | 5.895 | 253        | 0.28  | I   |
| C/2013 G9 (Tenagra) |       |            |       |     |
| 2013.06.09.     | 6.822 | 394        | −0.79 | I   |
| 2013.07.02.     | 6.723 | 467        | 0.29  | O   |
| 2014.03.14.     | 5.799 | 938        | −0.67 | I   |
| C/2013 L2 (Catalina) |       |            |       |     |
| 2013.06.08.     | 5.731 | 173        | −0.54 | O   |
| 2013.06.12.     | 5.750 | 170        | 0.05  | O   |
| 2013.07.11.     | 5.868 | 176        | −0.24 | O   |
| 2013.08.12.     | 6.003 | 173        | −0.51 | O   |
| C/2013 P3 (Palomar) |       |            |       |     |
| 2013.08.16.     | 9.059 | 620        | −0.25 | I   |
| 2013.09.27.     | 8.990 | 905        | −0.43 | I   |
| 2013.10.31.     | 8.938 | 1012       | −0.56 | I   |
| 2013.12.04.     | 8.890 | 1097       | −0.63 | I   |
| 2014.07.25.     | 8.676 | 1071       | −0.79 | I   |
| 2014.10.25.     | 8.648 | 1438       | −0.64 | I   |
| C/2013 X1 (PANSTARRS) |       |            |       |     |
| 2013.12.27.     | 8.712 | 451        | 0.79  | I   |
| 2014.03.14.     | 8.119 | 557        | −0.20 | I   |
| 2014.08.23.     | 8.617 | 1067       | −0.79 | I   |
| 2014.08.25.     | 6.801 | 1153       | −0.81 | I   |
| 2014.10.28.     | 6.255 | 1400       | −0.69 | I   |
| C/2014 L5 (Lemmon) |       |            |       |     |
| 2014.10.27.     | 6.207 | 127        | −0.63 | I   |
| C/2014 M2 (Christensen) |       |            |       |     |
| 2014.09.29.     | 6.925 | 804        | −0.70 | O   |
| C/2014 R3 (PANSTARRS) |       |            |       |     |
| 2014.10.28.     | 8.344 | 459        | −0.47 | I   |

Its appearance changed drastically by 2011, when only a very faint diffuse tail was detectable above the background scatter.

C/2005 S4 (McNaught): Robert McNaught discovered this returning comet ($P \approx 125,000$ yr) in 2005 September at a heliocentric distance of 7.4 au, about two years prior to perihelion passage ($q = 5.9$ au). The initial brightness of $18^m.5$ rose to $16^m.0$, while the absolute brightness was about $H_{10} = 5^m.5$ mag during the inward phase. Mazzotta Epifani et al. (2014) derived an $A_f = 116 \pm 2$ cm at $R = 7.52$ au, when the coma was surrounded by a faint, tail-like feature.
Our observations covered a year. We detected a coma diminishing from $10''$ to $5''$. A dust tail was observed with length $10''$–$80''$ (2008 March 31: 40'', PA 240°, wide shape; 2008 December 31: 80'', PA 250°, narrow shape; 2009 April 18: 10'', PA 225°).

*C/2007 M1 (McNaught):* This returning comet (P $\approx$ 51,000 yr) was discovered again by R. McNaught, who identified the comet in 2007 June at 7.9 au heliocentric distance, about 14 months prior to its perihelion (7.5 au). We observed this comet on the outward orbit, between 7.48 and 8.55 au. Mazzotta Epifani et al. (2014) derived an $A_f$ of 484 $\pm$ 8 cm at $R = 7.69$ au. Due to the low signal-to-noise ratio, they did not describe a detailed morphological analysis; however, their image suggests the detection of an elongated coma without a tail.

Our results are compatible with the findings of Mazzotta Epifani et al. (2014). During 2008–2010, all images showed a diffuse coma without a tail, with $A_f$ values decreasing between 486 and 316 cm on the outward orbit.

*C/2007 VO3 (Spacewatch):* The object was discovered as an asteroid by the Spacewatch project at large heliocentric distance (8.3 au) on 2007 November 1. A faint coma was detected two and half months later with the 1.8 m Spacewatch II Telescope. The orbital calculations suggested that this is a dynamically new comet with perihelion distance of 4.84 au; perihelion passage was in 2010 April. The maximum brightness was around 17 m.

We observed this comet on the inward orbit, between 6.71 and 5.14 au. Interestingly, this was among the faintest comets in our survey, and it exhibited the lowest $A_f$ of 136 cm at 6.71 au heliocentric distance on 2008 August 21. At that time the comet was star-like, suggesting a faint, very compact coma. By 2008 December, however, the view changed dramatically: an expressed coma appeared, and a short, faint tail developed toward PA 170°. On 2009 September 16, the general appearance was similar, but the tail was even expressed and longer, reaching a length of 60'' at least. Evidently, this comet exhibited the most spectacular brightening and morphological evolution on its inward path.

*C/2008 S3 (Boattini):* The dynamically new comet was discovered by Andrea Boattini in the CSS/MLS project in 2008 September at 10.0 au heliocentric distance. Further prescovery images were found on CSS/MLS frames from 2007 December and 2006 December at 10.9 and 12.4 au respectively. The perihelion passage occurred at 8.02 au on 2011 June, with maximum CCD brightness of 17m.5. The derived absolute brightness is about $H_{10}$ = 4.70 mag.

This comet was observed on both the inward (8.87–9.83 au) and outward (9.47–10.74 au) orbits, and provides a prime opportunity to compare the inward/outward behavior of a dynamically new comet. The comet continuously exhibited a compact but not star-like coma, and a faint tail with a length of 20''–30''. The visibility of the tail followed the changes in $A_f$; while its shape underwent some evolution on the orbit. Before perihelion, the tail was narrower, and after perihelion it turned into a more extended, fan-like feature, with its bisector pointing toward the predicted direction of the dust tail.

The general conclusion is that the activity is significantly higher post-perihelion than on the pre-perihelion orbit. This kind of behavior is similar to that observed for C/2006 S3, and strengthens the general conclusion that new comets tend to be more active post-perihelion.

*C/2010 R1 (LINEAR):* The dynamically new comet was discovered by the LINEAR team on 2010 September 4 at 7.2 au heliocentric distance, about 20 months prior to perihelion (5.6 au). We observed this comet on the inward orbit at 5.64 au (2012 March 18) and on the outward orbit at 7.25 au. Mazzotta Epifani et al. (2014) derived an $A_f$ of 703 $\pm$ 56 cm at $R = 6.09$ au on the inward orbit.

On 2012 March 17 an outer coma of 10'' was observed with a 20'' long tail toward PA 105°. By 2014 February 23, the coma reduced to 5'' diameter, while a narrow, very long tail was observed, reaching 130'' in length.

*C/2010 S1 (LINEAR):* The comet is dynamically new and was discovered on 2010 September by the LINEAR team as an asteroid-like object. Follow-up observations revealed a compact coma and faint tail. The comet passed its perihelion on 2013 May 20 at a distance of 5.90 au from the Sun and a visual brightness of 13m. The derived absolute brightness is about $H_{10}$ = 3m0 mag.

Recently, Ivanova et al. (2015) derived an $A_f$ of 3900 cm, at 7.00 au distance, and Shubina et al. (2014) published an $A_f$ of 8400 $\pm$ 600 cm in V and 8200 $\pm$ 1000 cm in the $R$ band, at 6.33 au distance on the inward orbit.

We observed this comet on the outward orbit, between 5.91 and 6.93 au, and detected the decreasing trend of $A_f$ between 9200 and 8700 cm, which is consistent with the pre-perihelion data of Shubina et al. (2014).

Several months after perihelion, the comet showed a large, diffuse coma (1'' in diameter) with a strong central condensation. A prominent, 3''–4'' long tail developed toward PA $\approx$ 40°. In 2014 autumn, the tail had a similar size but the tail generally dimmed. At that time, the most characteristic morphological feature was a fan-shaped, bright outflow extending to 25'' toward PA 220°, where after a complete reversal, its material turned back toward the tail (PA 40°).

*C/2010 U3 (Boattini):* The dynamically new comet was discovered by Andrea Boattini in the CSS/MLS project in 2010 October. Its heliocentric distance (18.4 au) has been the largest discovery distance of a comet ever, and came more than eight years before the perihelion passage. The comet is still far away from perihelion on the inward orbit, because the passage will occur at 8.45 au in 2019 February. The derived absolute magnitude is about $H_{10}$ = 17.0 mag, the brightest in our sample.

In 2013 December the comet showed a slightly diffuse nucleus of 4'' diameter at the southern end of an elliptical coma of 8'' $\times$ 15''. In the second half of 2014 the comet was fainter than the first observation, and the circular coma was diffuse and ill defined. This change in appearance and the decreasing $A_f$ suggested that the comet was undergoing an outburst in 2013 or before.

*C/2012 K1 (PANSTARRS):* This retrograde Oort Cloud comet was discovered by the Pan-STARRS project on 2012 May 19 at 8.8 au heliocentric distance. The object shows a condensed coma with a diameter of several arcseconds, with a total magnitude of about 19.5. The comet came to perihelion on 2014 August 27 at a distance of 1.06 au from the Sun. We observed this comet three times on the inward orbit, at 8.78, 6.35 and 5.21 au.

On 2012 May 20 and 2013 March 12, the coma was compact, while a 10'' long tail has appeared by 2013 March. On 2013 July 14, the coma was quite large (20'') and the tail reached 60'' (PA 120°).
C/2012 LP26 (Palomar): The dynamically new comet was discovered as an asteroidal object by the Palomar Transient Factory program on 2012 June 10 at a heliocentric distance of 9.9 au. A faint coma was detected eight months later with the 0.9 m Spacewatch Telescope, at 8.9 au heliocentric distance. The comet reached perihelion more than three years after the discovery (2015 August 16) at 6.54 au. We observed this comet four times on the inward orbit between 8.17 and 6.84 au.

Both the extent and the brightness of the coma increased during the one year of our observations. The coma was 5″ long on 2013 August 8 and 2014 June 3, while a 10″ PA 265° long tail also appeared by 2014 April. By 2014 July, the coma increased to 8″ and the tail to 15″ (PA 240°).

C/2012 U1 (PANSTARRS): This returning comet (P ≈ 32,000 yr) with large perihelion distance (5.26 au) was discovered by the Pan-STARRS project on 2012 October 18 at a heliocentric distance of 7.0 au, more than 20 months prior to perihelion passage. We observed this comet four times on the inward orbit between 6.61 and 5.87 au; the first and second pairs of observations were separated by only several days. Our fifth observation was made on the outward orbit, 52 days after perihelion at 5.28 au.

This comet was characterized by a diffuse coma (5″) at the time of our observations in 2013. On 2014 August 25, the coma increased to 10″; the tail appeared with 25″ length toward PA 300°.

C/2013 G9 (Tenagra): This apparently asteroidal object was reported by M. Schwartz and P. R. Holvorcem on images obtained with the Tenagra II astrograph on 2013 April 15. A compact coma was detected several days later at 7.1 au. The orbital calculations suggested that this was a dynamically new comet with perihelion distance of 5.34 au; perihelion passage occurred on 2015 January 14. We observed this comet three times on the inward orbit, at 6.83, 6.72 and 5.80 au.

The comet exhibited a similar picture in all images, as a condensed coma completed by a short (5″) tail. By 2014 March 13, the tail increased to 10″.

C/2013 X1 (PANSTARRS): This dynamically new comet was discovered using the 1.8 m Pan-STARRS telescope in 2013 December, when it was still 8.9 au from the Sun with an apparent magnitude of 20. The perihelion passage will be on 2019 April 20 at a heliocentric distance of 1.31 au, when this comet might become a bright, 7–8 mag object. We observed this comet on the inward orbit, between 8.71 and 6.26 au.

The comet showed a stellar appearance at the end of 2013, and became a small fuzzy object with the same brightness in spring 2014. After the conjunction the coma remained fuzzy, but a faint, short tail evolved toward PA 30° (2014 August 25). In autumn 2014 the comet showed a strange, rectangular appearance with a coma+tail of approximate dimension 9″ × 15″. During this time, Afρ increased monotonically between 451 and 1400 cm.

4. DISCUSSION

The program of observations we report here looks back over more than 15 years. There are a few comets that have been observed both before and after perihelion with long coverage (most importantly C/2008 S3, C/2002 VQ94, C/2006 S3). The systematic and comparative study of the activity of LP comets beyond 5 au requires observations covering at least 15–25 years, most importantly because it requires systematic observations of comets that are discovered well before their perihelion. The work we present here can be considered as a basis for such a survey, since it already contains C/2008 S3 with a long inward and outward observation history (and a few comets with a few points both inward and outward, e.g., C/2002 VQ94, C/2006 S3).

About 10 comets in the sample presented here are worth further follow-up lasting for many years, or even decades. These comets are typically around perihelion, or somewhat after it, now, and have a well covered inward history in our data; following their outward activity is highly desirable (C/2006 S3, C/2008 S3, C/2010 S1, C/2012 K8, C/2012 LP26, C/2012 U1, C/2013 G9, C/2013 P3). The most promising objects for further observations are those that are still before perihelion. The brightest targets (C/2005 L3, C/2006 S3, C/2010 S1, C/2010 U3), where the size of the nucleus can be expected to be between those of comets Halley (Hainaut et al. 2004) and Hale–Bopp (Szabó et al. 2012), offer a good detectability of the naked nucleus after the cessation of activity.

A visual inspection suggests that the appearance of the observed comets is rather diverse. With Afρ values spanning over two orders of magnitude (roughly 100–10,000 cm), there are comets that are compact or diffuse—apparently mostly regardless of their brightness or Afρ. A surprisingly large fraction of the comets have tails, which are quite impressive in some cases (see Figure 1 for the best examples), and while these tails are rather tenuous, they have been observed around fainter comets as well and are not necessarily associated with the brightest comets. These visual findings can be analyzed quantitatively by means of Afρ and slope parameters. We will evaluate the results from the three most intriguing aspects in the following.

4.1. The Afρ–R Activity Profiles

The evolution of Afρ with R is plotted in Figure 2. The left panel shows the activity pre-perihelion and the right panel post-perihelion. The heliocentric distance in the left panel increases leftwards, therefore we can imagine that the Sun is at the center, between the two panels. The color coding discriminates the recurrent comets (green) and Oort Cloud comets (red).

The general log Afρ–log R profile is roughly linear for most comets (Figure 2), implying an underlying power law, which we can confirm for a large set of LP comets. Interestingly, the rate of increase of the activity seems to depend on the onset level of the baseline activity. Comets that exhibit high Afρ values far from the Sun tend to follow a shallower activity history, while other comets that are relatively fainter/less active at large solar distances can evolve more spectacularly, following a steeper power index. This observation is also compatible with the remarkable comet disappointments from the previous decades, when impressive comets, discovered at large solar distances with extraordinary activity levels, tended to evolve slowly and significantly underachieved the peak brightness predicted from early data (C/1973 E1 (Kohoutek), C/1989 X1 (Austin), C/2001 Q4 (NEAT)). Our data set suggests that this is the normal pattern of LP comets that exhibit an extraordinary level of distant pre-perihelion activity.

A similar behavior is suggested for the post-perihelion phase, but perhaps with a less expressed difference between more and less active comets, while the more active ones seem to fade more slowly. This slow fading is a well known observation also for periodic comets, and is usually explained by the heat inertia of the nucleus.
Figure 1. Images of comets with dust tails. The top two rows show comets with extended tails, while the bottom two rows show comets with shorter and fainter tails, and these images have been centered on the comet. The fields of view are $6\arcmin 7 \times 6\arcmin 7$ for all comets except C/2005 L3 ($10\arcmin \times 10\arcmin$).
4.2. Comparison of Dynamically New and Recurrent Comets

Based on their database of comet observations (~50 comets over a range of 1 to ~30 au), Meech & Hainaut (1997) have shown that dynamically young comets are intrinsically brighter, exhibiting dust comae and activity at large distances in the region where sublimation of water ice is not possible. The observations to date support this tendency in general, and our results also support this conclusion.

In the two panels of Figures 3 and 4, we plot the dependence of $A_f \rho$ on various orbital and morphological parameters (slope, heliocentric distance, semimajor axis). Note that there are more comets in these figures than in Figure 2, since here we plot those comets that are represented by only one or two observations in the current data set. The cloud of points representing dynamically new comets (Figure 3, right panel, red points) lies convincingly above that of recurrent comets (green points in the same panel), regardless of the solar distance. The difference seems to be most prominent between 5 and 7 au, where the dynamically new comets tend to show a limit in $A_f \rho$ that is up to a factor of $\approx 4$ higher than for recurrent comets. This observation is compatible with the presence of a much larger amount of volatiles on the surface of new comets than on returning comets.

The slope parameter also shows an interesting difference between returning and new comets (Figure 4). Both groups tend to exhibit slightly negative slope, typically between 0 and $-1$, and both groups also have comets that were observed in a non-steady state, with a slightly positive slope value. The difference between the two groups is that the observations of negative slope usually represent the returning comets in the sample. Several features can lead to positive slopes, such as...
fan-like or spinning features in the coma, and the sudden and usually temporary decrease of the activity when the outer coma is richer in dust than the inner coma. The increased occurrence of positive slope in the returning group reflects the fact that such uncommon morphological features and/or puffing activity are more common in the returning group, while activity of the new comets is usually more regular.

It is hard to say whether there were sudden changes in the activity level or morphological parameters during the observed period of the target comets, simply because there is not enough dense coverage for continuous monitoring of such effects. However, several comets have observations separated only by one to three days (see Table 2), and during these observations, the parameters were not observed to change by more than the observational errors. Therefore, we have no evidence of sudden events in the observed data series. In essence, the most important grouping of the data set is related to the recurrent/new nature of the comet. Dynamically new comets are characterized by a higher level of activity on average, with more regular and smoothly evolving matter production. The more symmetrical appearance suggests also a more isotropic outflow.

5. DISCUSSION—WAYS TO FURTHER INTERPRETATION

The observed diverse behavior in our sample is difficult to interpret simply because of the lack of more information. The spacecraft missions have revealed that comets span a wide spectrum of different surface structures and morphology. These missions revealed a very small amount of volatiles on their surfaces. This latter observation is also not too informative for recurrent and dynamically new comets, since they can host a more significant content of surface volatiles on their more intact surfaces. The thermophysical factors are the real bottleneck to modeling the activity: observations by the Herschel Space Observatory have shown that maps of the surface temperature of asteroids are very complex. Due to their general similarity, the same must happen on cometary surfaces, too. Instead of a homogeneous surface—which is an assumption of most models of cometary activity—there are likely steep temperature gradients both laterally and radially. Also similarly to asteroids, the depth of the diurnal layers is likely to vary significantly with position. Extreme temperature inhomogeneities with diurnal and probably seasonal variations were in fact observed by the Rosetta mission on 67P/Churyumov–Gerasimenko (e.g., Gulkis et al. 2015; Hässig et al. 2015). For LP comets, another drawback is that we do not even have a confirmed observation of the naked nucleus of one, and therefore the most important variable in the activity models—the size of the nucleus—is still unknown. Since the local structures are intimately related to the general shape, which is unknown, any modeling effort must be very tentative.

In this respect, the forthcoming sky surveys, most importantly with the Large Synoptic Survey Telescope (LSST), can help significantly. LSST will be able to observe the dormant nuclei of comets at up to 20–50 au (roughly in the size range 10–60 km radius). These samples will consist of several currently active LP comets, which will be dormant by the time of LSST observations, and also pre-perihelion dormant comets that will probably years later be discovered to be active comets when they get closer to the Sun. Another aspect of LSST will be its ability to observe the activity of LP comets during their entire period of visibility with an unprecedentedly dense cadence, allowing the comparison of pre- and post-perihelion activity, and the quest for short-period variations for several objects.

However, this latter task will be difficult to complete even with LSST. Our current survey shows that this 15 yr coverage is still insufficient to cover both the inward and outward activity of the same comet, simply because distant comets move slowly. In the foreseeable future, this task will still mostly be allocated to specific mini-surveys, like the one for which we presented the results from early years in this paper.

6. SUMMARY

Our results can be summarized as follows.

1. We present 152 observations of 50 comets from 103 nights, showing activity at solar distances between 5 and 15 au, $A_f \rho$, $A_f \rho_{\text{max}}$, and slope parameters were determined for all observations.

2. All comets showed a coma and in many cases a tail, which sometimes exceeded 10'.

Figure 4. Left panel: dependence of the slope on the heliocentric radius. Right panel: the same as a function of $A_f \rho$. The color coding is the same as in Figure 3.
3. The $Af_0$ value of the most active recurrent comet was surpassed by that of five new comets. The average value of $Af_0$ of new comets significantly exceeded that of recurrent comets. We explained this observation in terms of an increased amount of volatiles on the surface of the new comets, demonstrating that dynamically new comets are also new in composition.

4. All new comets showed a negative slope parameter and usually a quite symmetric coma. Positive slope parameters, which we interpreted as signs of variations in activity, or jets, arcs, and other internal structures, were observed only in recurrent comets.

5. The evolution of $Af_0$ roughly followed a power law with $R$ for most comets. Those comets that were characterized by larger $Af_0$ values at larger solar distances tended to follow a flatter power law. This suggested that comets that had very significant activity around 10–15 au tended to show a smaller increase in activity with decreasing solar distance, thus representing the “comet disappointment” scenario.

6. The analogous “inverse” comet disappointment behavior was observed post-perihelion, but with a less expressed difference between the most and least active comets.

7. We examined the dependence of the studied activity parameters on orbital elements, the actual ephemerides at the observations, and the visibility of a tail. We did not find significant subgroups; the only significant grouping in the sample was the new or recurrent type of the comet.

8. Since the complete observation of a comet, extending to solar distances beyond 10–15 au on both half-orbits, would last decades, we proposed comet observations covering a very long time of 20–25 years, in order to be able to compare the inward and outward behaviors of the same comets in an extensive sample.

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