Origins of the Expanding Universe: 1912-1932
ASP Conference Series, Vol. 471
Michael J. Way and Deidre Hunter, eds.

Another Unsung Lowell Observatory Achievement: The First Infrared Observation of a Comet

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Abstract. Carl Lampland was the first to observe a comet in the infrared, a feat little known today because he failed to formally publish his data. I have retrieved the radiometry of this comet, C/1927 X1 (Skjellerup-Maristany), taken in broad daylight, from Lampland's logbook in the Lowell Observatory archives, and present a preliminary reduction of it here. There are similarities between Lampland's pioneering achievement and V. M. Slipher's discovery of the redshifts of the spiral nebulae (and thus, arguably, the expansion of the Universe). Each astronomer used state-of-the-art instrumentation, received rave reviews at American Astronomical Society meetings where their novel data were presented, and suffered under-recognition in ensuing decades. A common thread in these poor outcomes was their lackadaisical approach to formal publication – in Slipher's case, publishing in internal or secondary outlets, and in Lampland's case, not publishing at all.

1. Introduction

The first infrared observation of a comet is widely and wrongly attributed (Crovisier et al. 2000; Encrenaz & Knacke 1983; Festou et al. 1993; Gehrz 1997; Hanner & Tokunaga 1991; Hobbs 1981; Ney 1982; Sekanina et al. 2001) to that of C/1965 S1 (Ikeya-Seki) by Becklin & Westphal (1966). But as Hoag (1984) and Yeomans (1991) have pointed out, it is Lowell Observatory staff astronomer Carl O. Lampland (1873-1951) (Figure 1) who must claim that honor. The achievement fell into obscurity because Lampland never converted his abstract report (Lampland 1928) into a formal paper. I have retrieved and examined the original radiometry data on the comet, C/1927 X1 (Skjellerup-Maristany; old style 1927k = 1927 IX), from Lampland's logbook in the Lowell Observatory archives. Here I sketch a method to reduce these data, and present preliminary results to demonstrate that the data are indeed usable. I then draw parallels between Lampland's pioneering observations, and the discovery of the redshifts of the spiral nebulae by V. M. Slipher (1917), including the under-recognition of both astronomers in the astronomical community for their respective achievements.

2. The Comet and the Observations

Several weeks after its discovery, the comet unexpectedly burst into daylight visibility on Dec. 15, taking Lowell Observatory astronomers and the rest of the world by surprise. It reached perihelion on 1927 Dec. 18.18 Universal Time (UT) at q = 0.176 astronomical units (AU), having passed nearly between the earth and the sun on Dec. 15.39 UT at a minimum scattering angle of $\theta = 180° -$ phase angle $= 6.6°$ (the signifi-

Figure 1. Carl Otto Lampland (1873-1951) holds a stellar radiometer used in determining the temperatures of planets at Lowell Observatory. He was one of the permanent "troika" of staff astronomers (with E. C. and V. M. Slipher) remaining at Lowell Observatory in the decades after the death of Percival Lowell. All three observed comet C/1927 X1. Courtesy Lowell Observatory Archives.

cance of which will be discussed). Over Dec. 16-19, in broad daylight, E. C. and V. M. Slipher took spectrograms with the 24-inch Clark refractor (Slipher & Slipher 1928), while Lampland (1928) obtained radiometry measures with the 42-inch reflector in the neighboring dome, assisted by his wife Verna (Giclas 2003). The observing circumstances are provided in the ephemeris in Table 1. The fractional UT dates correspond to the mean times of the observations on each day. Δ and r are the comet's Earth and Sun distances in AU and ϵ is the elongation from the sun. The radiometric quantities φ_{H_2O} and $R_f(\theta)$ will be explained below.

3. The Radiometer

Lampland had been measuring planetary temperatures with the Lowell 42-inch reflector during the 1920s in collaboration with the pioneering infrared physicist W. W. Coblentz

Table 1. Circumstances of Lampland's Radiometric Observations of Comet C/1927 X1

Mean Date (UT)	Δ (AU)	r (AU)	ϵ (°)	θ (°)	φ_{H_2O}	$R_f(\theta)$
Dec. 16.96	0.822	0.183	5.4	30.3	0.636	3.059
Dec. 17.91	0.861	0.177	7.9	49.7	0.374	0.800
Dec. 18.91	0.909	0.179	9.8	70.1	0.261	0.541
Dec. 19.92	0.961	0.190	11.1	88.7	0.177	0.262

(1873-1962), who designed the radiometer (Coblentz & Lampland 1923, Figure 1). The full device, which attached to the telescope, contained tiny thermocouples in an evacuated chamber (see Figures 1 and 2 in Coblentz & Lampland (1923)). Different cutoff transmission filters, or "screens," could be interposed in the light path to parse the radiation and deduce its distribution between light and heat (see Figures 3 and 4 in Coblentz & Lampland (1923)). The screens and their effective cutoff wavelengths – below which radiation was transmitted – were a water cell (1.2 μm), pyrex glass (2.7 μm), quartz (3.8 μm), microscope coverslip glass (6 μm), and fluorite (12.5 μm). The total waveband without any screen was effectively bounded by atmospheric absorption by ozone below 0.3 μm, and the "great wall" of carbon dioxide above 13.8 μm, although a trace of infrared radiation could leak beyond the "wall" between 16.8 μm and the $\sim$18.5 μm cutoff of the radiometer's rock-salt window. The amplified thermoelectric current induced by the comet's radiation was recorded by a Thompson iron-clad galvanometer. Lampland and his wife recorded the needle excursions, to mm precision, with and without the transmission screens, in the logbook. These scale directly to flux and are the basic data.

4. Reduction of Observations

Radiation from comet grains is comprised of scattered sunlight, $f_{scat}(\theta)$, and sunlight absorbed and re-emitted as heat, f_{emit}. $f_{scat}(\theta)$ is a function of the scattering angle, θ (see Section 3). Each flux distribution is approximately blackbody in character. The effective temperature of $f_{scat}(\theta)$ is $T_{scat} = T_{Sun}C$, where $T_{Sun} = 5800°$ K is the color temperature of the Sun, and C is a color index near to or slightly less than 1, depending on the amount of reddening of the sunlight by the dust grains. The effective temperature of f_{emit} is $T_{emit} = T_{BB}S$, where the blackbody temperature $T_{BB} = 278° r^{-1/2}$, and S is the grain "superheat."[1] By Wien's law, peak emissions occur at $\lambda = 0.50$ μm in the visible for $f_{scat}(\theta)$, and, at the comet's heliocentric distance of $r \sim 0.18$ AU (Table 1), between 3.0 μm and 4.5 μm in the near-infrared for f_{emit}, corresponding to grain temperatures in the range $650°\text{K} \le T \le 1000°\text{K}$, which depend on the grain superheats. The $f_{scat}(\theta)$ and f_{emit} spectral distributions overlap in the near-IR over roughly 1.2 μm – 2.3 μm. In this circumstance, the water cell measures essentially $f_{scat}(\theta)$, while the pyrex and quartz screens (and the unfiltered measurements) capture segments of both $f_{scat}(\theta)$ and

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[1] At sizes of the order of the wavelength of sunlight, $\sim 1/2$ μm, coma grains are so small that they do not radiate away their heat efficiently, so $S \ge 1$; see Ney (1982); Gehrz (1997).

f_{emit}. Superimposed on the radiation may be atomic or molecular emission features, mainly from C_2 and Na for $f_{scat}(\theta)$, and silicates for f_{emit}.

The basic data element for analysis is the ratio of the fluxes, as measured in the galvanometer, with (ν') and without (ν) a given transmission screen:

$$\varphi = \frac{\nu'}{\nu} \tag{1}$$

φ is a function of the transmitted fractions, τ, of the $f_{scat}(\theta)$ and f_{emit} fluxes measured with ($'$) and without the given screen:

$$\varphi = \frac{\tau'_{scat} f_{scat}(\theta) + \tau'_{emit} f_{emit}}{\tau_{scat} f_{scat}(\theta) + \tau_{emit} f_{emit}} \tag{2}$$

We seek the diagnostic ratio $R_f(\theta) = f_{scat}(\theta)/f_{emit}$, which relates to the comet grain albedo as $A(\theta) = R_f(\theta)/[1 + R_f(\theta)]$. Substituting in the equation above and solving,

$$R_f(\theta) = \frac{\tau_{emit}\varphi - \tau'_{emit}}{\tau'_{scat} - \tau_{scat}\varphi}. \tag{3}$$

The four transmissivity coefficients are given in general form by,

$$\tau = \frac{\int_0^\infty f(\lambda)\tau(\lambda)d\lambda}{\int_0^\infty f(\lambda)d\lambda} \tag{4}$$

where the generic $f(\lambda)$ is $f_{scat}(\theta)$ or f_{emit} at a given wavelength, λ, and

$$\tau(\lambda) = \tau_{atm}(\lambda)\tau_{opt}(\lambda)\tau_{scr}(\lambda)\tau_{rad}(\lambda) \tag{5}$$

is the wavelength-specific transmissivity of the entire system, a product of the individual wavelength-dependent transmissivities of the earth's atmosphere, $\tau_{atm}(\lambda)$, the telescope optics, $\tau_{opt}(\lambda)$, the given screen filter, $\tau_{scr}(\lambda)$, and the radiometer, $\tau_{rad}(\lambda)$.

To reduce the data, I constructed a comprehensive numerical model, details of which will be given elsewhere. Here it is sketched in broad outline. $\tau_{atm}(\lambda)$ and $\tau_{opt}(\lambda)$ curves and models were obtained from the standard literature or derived. $\tau_{scr}(\lambda)$ curves were obtained from Coblentz & Lampland (1923) and correspondence in the Lowell Observatory archives. $f_{scat}(\theta)$ and f_{emit} were modeled as Planckian black bodies with dust color and grain superheat/silicate emission, respectively, as free parameters. Free parameters for $\tau_{atm}(\lambda)$ were water vapor, ozone and dust concentrations; for $\tau_{opt}(\lambda)$, the effective thickness of tarnish on the silver mirror coatings convolved with silver reflectivity; and for $\tau_{rad}(\lambda)$, the efficiency (effective thickness) of the thermocouple blackener convolved with the transmissivity of the radiometer rock salt window. All transmissivities and fluxes were incorporated in an Excel spreadsheet with a resolution of $\lambda/\Delta\lambda = 200$. In the preliminary analysis presented here, I restricted the computation of $R_f(\theta)$ to the water cell, pyrex, and quartz screen data. In a chi-square-related approach, I minimized summed squared residuals in $R_f(\theta)$, as computed from $\varphi_{\mathrm{H_2O}}$, φ_{pyrex}, and $\varphi_{\mathrm{quartz}}$, to determine optimal values for the free parameters.

5. Preliminary Results, and Further Work

The fractional transmissions, φ, by the filter screens declined over the observing interval, most markedly for the water cell, as seen in the daily mean values in Table 1. The least-squares minimization disclosed that the thermocouple blackener efficiency was less than optimal, and that the grains had a high superheat. Using optimized free parameters, the resulting mean daily $R_f(\theta)$ values are also provided in Table 1. Note the dramatic augmentation in $R_f(\theta)$ with decreasing θ, with an over 10-fold (!) difference between Dec. 16 and 19. This is due to *forward scattering* enhancement of the $f_{scat}(\theta)$ term in $R_f(\theta) = f_{scat}(\theta)/f_{emit}$ (see above) when the comet passed nearly between the Earth and Sun (Marcus 2007). That Lampland and the Sliphers could observe the comet in broad daylight owed substantially to this effect (Marcus 2007).

Figure 2 plots the $R_f(\theta)$ values as large black diamonds, fitted to a phase function, $\Phi(\theta)$, which has been normalized to unity [$\log \Phi(\theta) = 0$] at $\theta = 90°$. As comparisons, the large open symbols are fits for the two other comets, C/1975 V1 (West) and C/1980 Y1 (Bradfield), for which there is photometry of the scattered and thermal radiation in forward-scattering geometry (in these cases by broadband methods). In contrast, the small open symbols plot normalized photometry of solely $f_{scat}(\theta)$ from the LASCO C3 coronograph aboard the SOHO satellite, taken through a clear filter (0.4 μm – 1.0 μm transmission) for comet 96P/Machholz, and a near-IR filter (0.8 μm – 1.0 μm transmission) for C/2004 F4 (Bradfield). The SOHO data are less robust as proxies for $\Phi(\theta)$ than scattered/thermal photometry because of the need to assume the behavior of the baseline (θ-independent) brightness of the comets over the brief observing intervals. For further details and references, see Marcus (2007). From Figure 2 we see that 1) Lampland's radiometric observations of comet C/1927 X1 are concordant with the photometry of the other four comets, and 2) all of the photometry fits the compound Henyey-Greenstein (HG) phase function model curves (for dust-to-gas light ratios of 1 and 10) well (Marcus 2007).

From this preliminary work, I conclude that the Lampland radiometry of comet C/1927 X1 is reducible and usable. The data reduction is ongoing, but I expect that further refinements to the comet's data points in Figure 2 will be small. I have recently uncovered some unpublished transmission screen curves from the Lowell Observatory archives, which will be incorporated into the model so that the flux data for the full set of the filters can then be reduced. Sodium emission by the comet is another issue. SOHO spacecraft photometry of sungrazing comets (Biesecker et al. 2002; Knight et al. 2010) indicates that sodium D line emission dominates the visual brightness of comets very close to the Sun, and my synthesis of the literature on quantitative cometary Na emission (Marcus 2010) suggests that at the heliocentric distance of C/1927 X1 during Lampland's observations, Na brightness should have been comparable to that of the scattered sunlight. Sodium brightness will therefore be incorporated as an additional model free parameter in the final reduction of the data.

6. Parallels Between Lampland's Observations and V. M. Slipher's Discovery of the Expanding Universe

There are striking parallels between the first infrared observation of a comet by Lampland and Slipher's discovery of the recession of spiral nebulae.

- Each achievement was pioneering.

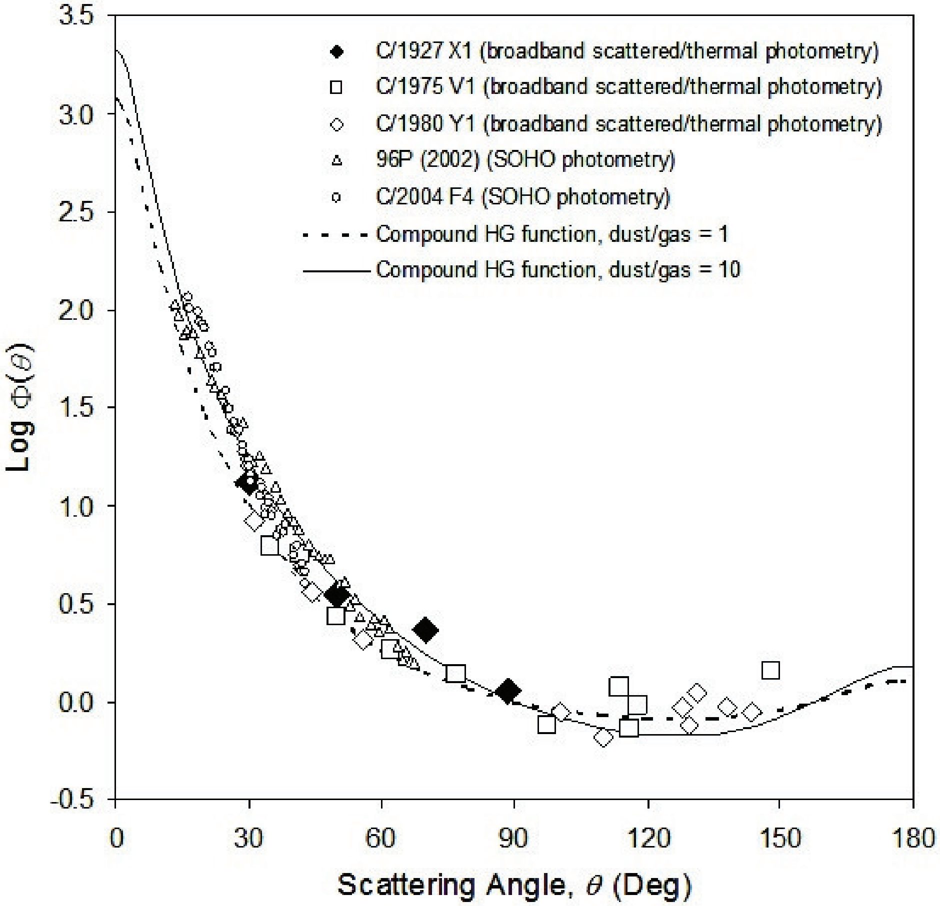

Figure 2. Forward-scattering enhancement of brightness as a function of scattering angle. Lampland's reduced radiometric observations of C/1927 X1 (large black diamonds) are concordant with the photometry for the four other comets, and the data for all five comets fit the model phase function curves well (see text). Note that the scale for the y-axis is logarithmic. Modified from Marcus (2007), with permission of the *International Comet Quarterly* (Cambridge, Massachusetts).

- Each was made possible by pioneering and state-of-the-art instrumentation. In Lampland's case this was the stellar radiometer, a sensitive but difficult instrument designed by his collaborator Coblentz and deployed at Lowell Observatory to measure the temperatures of the planets (Coblentz & Lampland 1923). In Slipher's case, it was the Brashear spectrograph (Slipher 1904), also a difficult and fussy instrument, but fast and capable of great resolution.

- Each achievement was presented to American Astronomical Society (AAS) meetings to rave reviews. The abstract papers on C/1927 X1 (Lampland 1928; Slipher & Slipher 1928) were read on their behalves at the 1927 New Haven meeting by Roger Lowell Putnam (1893-1972), the newly-appointed sole trustee of Lowell Observatory. John C. Duncan, Wellesley College, who was in attendance, wrote Lampland, "These papers were received with enthusiasm and were the sensation of the meeting" (Duncan 1928). Slipher read his paper on the mainly red-shifted velocities of the spiral nebulae at the 1914 meeting in Evanston, Illinois. After he finished, he received an unprecedented standing ovation (Hall 1970).

- Each AAS presentation was published as an extended abstract in the organization's outlet at that time, *Popular Astronomy* (Lampland 1928; Slipher 1915).
- Yet each achievement fell into relative obscurity with priority credit to fall to others. By the end of the 20th century, the infrared astronomy community was mistakenly touting C/1965 S1 (Ikeya-Seki) as the first comet to be observed in the IR (see Introduction). And it is Edwin Hubble, who derived a coefficient (the "Hubble" constant) for the expansion of the Universe (Hubble 1929), who so often gets the credit for the "discovery" of the expansion, which arguably should be shared with Lemaître and Slipher (see contributions by Peacock, Nussbaumer, Belenkiy, O'Raifeartaigh, and Way in this volume for more details).

7. The Problematic Publication Culture at Lowell Observatory in the Early 20th Century

To amplify on the final point, I suggest that a common thread for why each astronomer has received less credit than they deserve for their respective achievements was their attitude toward publication. In Lampland's case with C/1927 X1, the wound was clearly self-inflicted: he failed to follow up his sketchy abstract (Lampland 1928) with a formal paper to exposit his pioneering data. This behavior was by no means isolated for Lampland. His collaborator Coblentz, for example, nagged him to publish their further radiometry on the planets, and his failure to do so resulted in a major falling out between the two in 1926 (Hoyt 1980).

Why did Lampland not publish? The common and sufficient explanation is that he was a perfectionist who was loath to stick his neck out (Putnam 1994; Smith 1987; Tenn 2007). "If 50 observations would do it, he would want 500," his Lowell colleague Henry Giclas (1910-2007) recounted recently (Giclas 2003). In addition, I believe that Lampland's hesitance with the C/1927 X1 data may have been cemented by the wild shift in the flux ratios over the four day observing period, reflected in the φ_{H_2O} values in Table 1. Such behavior would have defied explanation – he and Coblentz had never encountered anything of that sort in their radiometry of the planets (Coblentz & Lampland 1923). Astronomers of the day appeared to be unaware of the forward-scattering property of comet grains (Marcus 2007), which greatly enhances the scattered (visible and near-IR) flux at small scattering angles. This phenomenon would have offered Lampland a framework for explaining the flux ratio changes in his comet data.

In Slipher's case, his seminal redshift data on the spiral nebulae were published in *Popular Astronomy* (Slipher 1915) and the rather peripheral *Proceedings of the American Philosophical Society* (Slipher 1917), rather than in the leading mainline astronomical journals of the day like *Astrophysical Journal*, *Astronomical Journal*, or *Astronomische Nachrichten*. An audit of the Lowell Observatory archives and Astrophysical Data Service (ADS) documents that the publication records of Slipher and Lampland, especially after Percival Lowell's death in 1916, were fairly sparse. Much of what both Slipher and Lampland did publish was confined internally to the *Lowell Observatory Bulletin*, an arguably insular and suboptimal route for obtaining wider recognition for their work, although admittedly observatory bulletins were a common outlet for publication in those days.

Slipher's and Lampland's approaches to publication were not simply lackadaisical; in some respects they were even negative. The young and ambitious Arthur Adel (1908-1994), at Lowell Observatory in the 1930s, relates having to keep his data from Lampland for fear that they would be sequestered and never published (Smith 1987). Adel also relates having to submit his manuscripts to Slipher for clearance, and then battling him to get them sent off to the journals (Smith 1987).

If Slipher was injured by Hubble's failure to cite his spiral nebula redshift work in the seminal paper on the linear dependence of the recession velocities on distance (Hubble 1929) – a theme of this conference – then it is also apparent that Slipher and Lampland did themselves no favors by their approaches to publication. The Lampland comet incident, as presented here, illuminates this point.

Acknowledgments. I thank Donald K. Yeomans, Jet Propulsion Laboratory, for providing his correspondence with the late Arthur Hoag, Antoinette Beiser, Lowell Observatory (LO), for aid in archives research, Henry Giclas (1910-2007), LO, for information on circumstances of the observations, Giclas and Kevin Schindler, LO, for details about the telescope, and two anonymous reviewers and the Editors for their very helpful suggestions.

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