Comet Yanaka (1988r): A New Class of Carbon-Poor Comet

Uwe Fink

As part of a program to determine the chemical composition of a sample population of comets, a very unusual comet, Yanaka (1988r), was observed in January 1989. Although the comet showed the usual emissions of O I and NH_2, it did not display any hint of C_2 or CN emission. The comet is depleted in C_2 by at least a factor of 100 and in CN by a factor of 25 relative to typical comets. If comets originate from interstellar clouds, Yanaka (1988r) could be an interloper from a cloud of different composition. If Yanaka (1988r) was formed within our solar system, the solar nebula was less uniform than assumed by most present models of formation.

During the last few years spectra of about 20 comets have been taken in order to search for possible chemical differences among them. When these observations were examined more closely, one comet was found that exhibited a very unusual spectrum. The spectrum of comet Yanaka (1988r) displayed the regular cometary emissions of NH_2 and O I ^1D but showed no trace of CN or C_2 emission (*1*). Charge-coupled device (CCD) images taken simultaneously with the spectra for guiding purposes, on the other hand, showed this comet to be similar to many others that have been observed. The irregular spectral behavior prompted us to analyze this spectrum before continuing a systematic reduction of our complete data set. In this report, I present a quantitative analysis of the production rates for Yanaka (1988r) and compare them to the rates for four other comets: P/Halley, P/Tempel 2, P/Brorsen-Metcalf, and Yanaka (1989a).

The observational circumstances are presented in Table 1. Observational data are also given in Table 1 for a spectrum of P/Halley from our 1985–1986 data set. This spectrum was selected because it matched the heliocentric distance of Yanaka (1988r) closely and can thus be used for comparison. Comet Yanaka (1989a) is also included, despite its much larger heliocentric distance, because it was observed only a few minutes before Yanaka (1988r) and did not show any unusual emission characteristics.

The spectral reductions were carried out with our usual method, detailed elsewhere (*2*). The comet was summed over an object window, while sky was subtracted at both ends of the slit. The integration windows are given in Table 1. For P/Halley the integration window could be extended farther because this comet provided a much higher signal-to-noise ratio. To remove telluric features and the response of the spectrograph, we divided the spectrum by a solar analog comparison star, matched in air mass. For P/Halley we used BS 8931 and for Yanaka BS 2067 (*3*).

The ratio spectra of Yanaka (1988r), P/Halley, and Yanaka (1989a) are shown in Fig. 1, A and B. Comparing the three, one can clearly see the strong $\Delta v = -1$ Swan band sequence of C_2 in the spectrum of P/Halley and, despite its much larger heliocentric distance, also in the spectrum of Yanaka (1989a). Yet this band is totally lacking in the data of Yanaka (1988r). However, Yanaka (1988r) does show strong emissions by NH_2, starting at the 0,12,0 band and progressing to the 0,4,0 band and possibly even the 0,3,0 band. In addition, there is strong emission by the two O I ^1D lines at 6300 and 6364 Å. Because these lines arise from direct dissociation of water (*2, 4*), this indicates that water outgassing is the major mechanism responsible for the activity of this comet.

The absence in the spectrum of Yanaka (1988r) of emissions by the CN red system, particularly the prominent 1-0 and 2-0 bands, can be seen in Fig. 1B. Both Yanaka (1988r) and Yanaka (1989a) were relatively faint comets and their spectra past 9000 Å become perturbed by insufficient subtraction of strong night sky lines as well as incomplete cancellation of the extensive telluric H_2O band at 8900 to 9900 Å. In fact, because of weather constraints, the air mass match of our solar analog comparison star to that of Yanaka (1989a) was not very good; this resulted in an artificial emission feature at the position of the telluric O_2 A band. The dip at 9330 Å and the peak at 9390 Å for Yanaka (1988r) and Yanaka (1989a) are also artifacts of the ratio process. The brighter P/Halley yielded a cleaner looking spectrum with essentially perfect night sky and telluric cancellation; on this spectrum the fainter CN overtone bands 3-1 and 2-1 are readily apparent. Despite the higher noise level of the two Yanakas, the presence of the 2-0 and 1-0 CN bands in Yanaka (1989a) and the absence of these bands in Yanaka (1988r) are quite evident.

Quantitative analysis in terms of production rates and upper limits requires measurement of the emission intensity, absolute calibration, and correction for our finite slit observing aperture via a Haser model. To obtain emission intensities for the various species, we first subtracted the continuum level and then summed the emission features over their spectral extent. Absolute calibration used the flux standard BS 3314 (*5*) and is estimated to be accurate to within 10% for the present observations. Complete details of the reduction procedure are described in papers on the variation of production rates with heliocentric distance for P/Halley (*2, 6*).

The emission fluxes collected by the slit are given in Table 2 for all the measurable bands of the species H_2O (OI), C_2, NH_2, and CN as well as the continuum wavelength at 6250 Å. Bands that were not observed are given upper limits. Because the slit aperture intercepts only a small portion of the coma, we used a Haser model to determine the total luminosity of each band, based on our recent scale lengths (*7*), which for the most part are similar to those adopted by Schleicher *et al.* (*8*). The exact choice of scale lengths as well as fluorescent *g* factors produces only a second-order effect in a comparative study of production rates, because the heliocentric distances of Yanaka (1988r) and our 10 January 1986 P/Halley observations are close. In cases where it was possible to measure a number of bands for a species, an adopted value for

Table 1. Circumstances of observations.

Parameter	Yanaka (1988r)	P/Halley	Yanaka (1989a)
Perihelion passage	1988 Dec. 11.65	1986 Feb. 9.45	1988 Nov. 1.14
Perihelion distance	0.428 AU	0.587 AU	1.90 AU
Observation date	1989 Jan. 15.56	1986 Jan. 10.08	1989 Jan. 15.52
Integration time	3 × 300 s	3 × 60 s	3 × 600 s
Air mass	1.84	~2.50	1.12
Distance from sun (r, AU)	r = 0.932 AU	r = 0.87 AU	r = 2.11 AU
Distance from Earth (Δ, AU)	Δ = 0.367 AU	Δ = 1.32 AU	Δ = 1.88 AU
Integration window	61.5″ by 2.5″ (16,430 by 668 km)	151.5″ by 2.5″ (145,600 by 2,400 km)	61.5″ by 2.5″ (84,200 by 3,420 km)

Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721.

the production rate is listed. This number is not a straight average of all the measured values but takes into account the strengths and signal-to-noise ratios of the various bands as well as an estimate of the reliability of the g factors.

Listed in Table 2 as a measure of dust production is both the quantity $Af\rho$ (8, 9) and the ratio of the continuum flux at 6250 Å to the flux of the 6300 Å OI line, each having been integrated over the same spatial extent. The measurements indicate that comet P/Halley was one of the dustiest comets we have observed so far, whereas P/Brorsen-Metcalf was the gassiest; Yanaka (1988r) falls somewhere in the middle of the range and exhibits no unusual gas-dust characteristics.

The behavior of the emission species and the dust is summarized in Table 3 for the five comets for which we have reasonably complete reductions: Yanaka (1989a), Yanaka (1988r), P/Halley (2, 5, 7), P/Tempel 2 (10), and P/Brorsen-Metcalf (11). If the water production rates are reduced using the $r^{-2.5}$ heliocentric dependence found in our OI paper (2), comet Yanaka (1989a) turns out to be intrinsically most productive, followed by P/Halley and P/Tempel 2, whereas P/Brorsen-Metcalf and Yanaka (1988r) are similar but considerably fainter.

To engage in a meaningful comparative abundance discussion, it is necessary to renormalize the production rates of C_2, NH_2, and CN relative to that of H_2O, to which is assigned a value of 1000. This comparison shows that comets P/Halley, P/Brorsen-Metcalf, and Yanaka (1989a) all have roughly the same relative C_2 and CN production rates, whereas comet P/Tempel 2 is deficient in both of these components by about a factor of 2. On the other hand, P/Tempel 2 exhibits a "typical" NH_2 abundance whereas P/Halley is definitely enhanced in that molecule. As expected, large abundance disparities occur for the species C_2 and CN of Yanaka (1988r). With upper limits to the fluxes, the abundance of C_2 is less than 0.04 relative to water = 1000, and the abundance of CN is less than 0.10. Compared to the other comets, this corresponds to a depletion factor of ~100 for C_2 and ~25 for CN. On the other hand, the NH_2 abundance is essentially "normal."

One other comet exhibits unusual abundance ratios: comet P/Wolf-Harrington. At the recent Asteroids, Comets, and Meteors Meeting in Flagstaff, Arizona, Schleicher *et al.* (12) reported C_2 and C_3 contents less than 1/20 of their nominal abundance ratios, whereas the CN and NH abundances were essentially normal. They note that this is the most severe case of C_2 and C_3 depletion out of a photometry database of ~80 comets (13, 14). Comet P/Wolf-Harrington can be considered the most extreme object of a group (whose most prominent member is P/Giacobini-Zinner) that is deficient in C_2 and C_3 but otherwise exhibits normal abundances.

In the part of the spectrum observed by us, C_2 and CN provide the evidence for the carbon content of a comet. Because the spectral signatures of both are absent, we have tentatively labeled Yanaka (1988r) a "carbon-poor comet." This ignores CO, the major carbon-bearing species observed for comet P/Halley and others. Unfortunately, Yanaka (1988r) was too faint to be observed by the International Ultraviolet Explorer satellite, so that the interesting question of the CO abundance remains unanswered. Emission bands by the carbon-containing species C_3 and CH lie outside our spectral region. Both of these molecules are minor carbon contributors (12, 14) and thus have little effect on the total carbon budget. Nevertheless, the label of "carbon-poor" must be confined to molecular carbon (that is, C_2) and its association with hydrogen or nitrogen (that is, HCN, which is the pre-

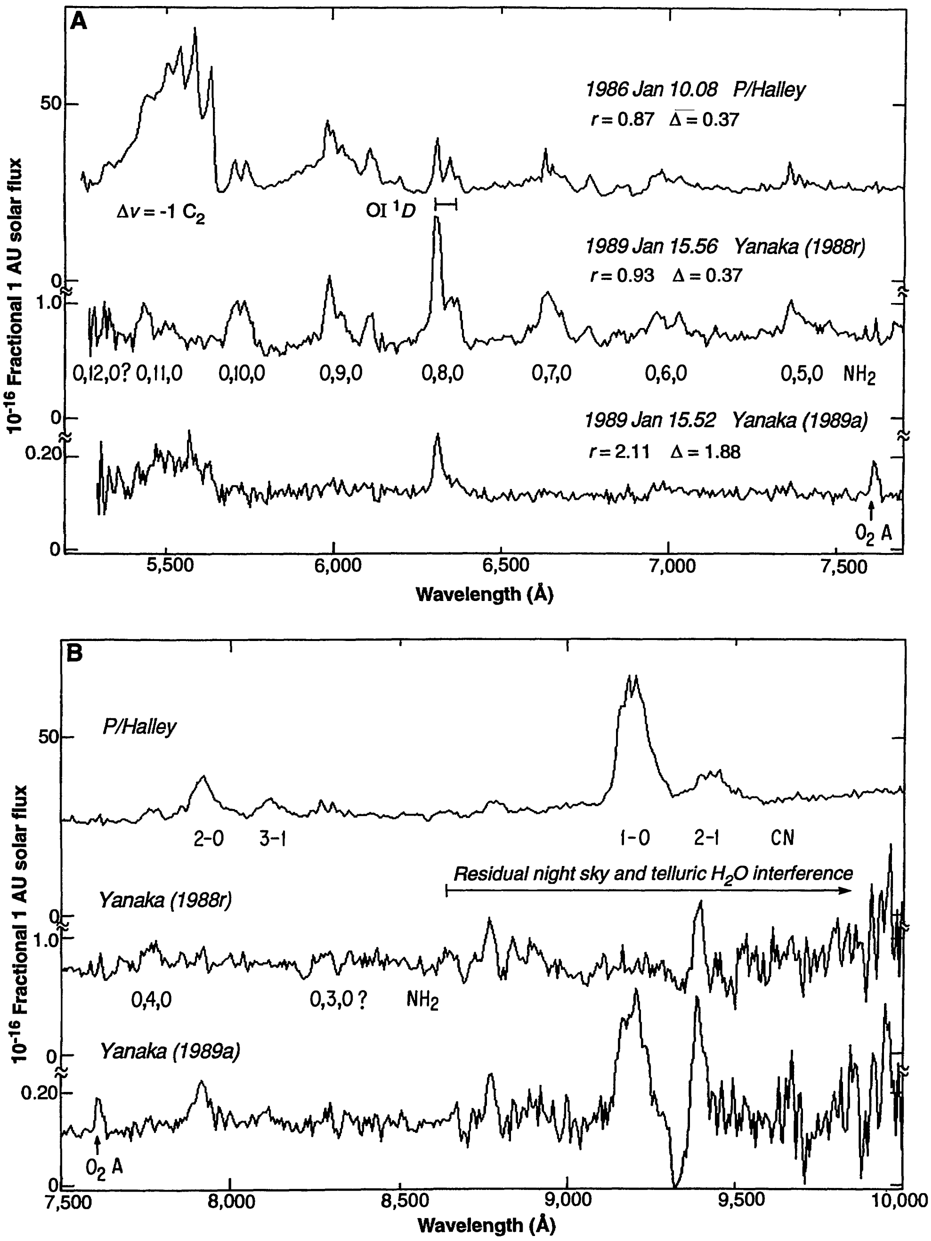

Fig. 1. (**A**) Spectra of the comets P/Halley, Yanaka (1988r), and Yanaka (1989a) from 5200 to 7800 Å. The absence of the strong C_2 emission in the data of Yanaka (1988r) is clearly evident. Instead, the whole sequence of NH_2 emissions can be seen to be relatively free from interference. (**B**) Continuation of the spectra from 7,500 to 10,000 Å. In this spectral region any signs of the usually strong CN emissions are missing. The dip at 9330 Å and the peak at 9390 Å in the Yanaka (1988r) spectrum are not real but are caused by imperfect cancellation of night sky and telluric absorption features.

sumed parent molecule of CN) in a reducing environment.

Trying to explain the different composition of Yanaka (1988r) provides an interesting challenge. There are currently two major theories for the origin of comets: formation within the solar system near the planets Uranus and Neptune followed by perturbation into the Oort cloud, or formation within interstellar molecular clouds and subsequent capture by the solar system as it passes through these clouds (*15*). It is probably easier to account for the deviant composition of Yanaka (1988r) if the molecular cloud genesis is considered.

A recent review on interstellar clouds and protostellar matter (*16*) points out that a reasonably reliable composition inventory is available for only two or three well-studied sources: the Orion and Sgr B2 giant molecular clouds and the cold, dark Taurus molecular cloud TMC-1. In these molecular clouds gaseous CO is more abundant than water vapor by about a factor of 10. Even allowing for the amount of H_2O frozen out on grains brings the two species only to roughly equal abundance levels (*16*). On the other hand, in comets H_2O is by far the major volatile, being more abundant than CO by a factor of ~10. Thus, if one hypothesizes about the formation of comets, using the composition of these clouds, one encounters a major difficulty, and, if comets originate from interstellar clouds, additional options or mechanisms must be considered. Interestingly, the review by Van Dishoeck *et al.* (*16*) also argues that the above well-studied regions are very likely not representative of other molecular clouds and that they are probably chemically different from most other clouds or from other locations in the same cloud. This would point to the existence of molecular clouds with a composition considerably different than presently known, which may help to explain both the formation of "standard" comets and the unusual composition presented by Yanaka (1988r).

There are three possible scenarios for the

Table 2. Production rate determination.

Component	Yanaka (1988r) (r = 0.93, Δ = 0.37) Flux in slit (photon s^{-1} m^{-2})	Yanaka (1988r) Production rate (10^{25} mol s^{-1})	P/Halley (r = 0.87, Δ = 1.32) Flux in slit (photon s^{-1} m^{-2})	P/Halley Production rate (10^{25} mol s^{-1})	Yanaka (1989a) (r = 2.11, Δ = 1.88) Flux in slit (photon s^{-1} m^{-2})	Yanaka (1989a) Production rate (10^{25} mol s^{-1})
H_2O (from O I)	1,090	3,740	6,180	65,800	120	11,000
Adopted value		3,740		65,800		11,000
C_2 ($\Delta v = -1$)	<100 ± 100	<0.17	371,200	286	820	38
Adopted value		<0.17		286		38
NH_2						
0,11,0	1,160	2.9				
0,10,0	1,260	2.5	19,400	46.6	65	3.3
0,9,0	1,990	1.9				
0,8,0	1,530	3.2	24,500	63.2	145	8.0
0,7,0	1,640	3.1	43,300	(100)	44	2.2
0,6,0	1,100	(6.2)	26,400	(183)	22	3.3
0,5,0	1,180	(6.6)				
0,4,0	1,040	(44)				
0,3,0	520?					
Adopted value		2.7		63		4.5
CN						
2-0	<270 ± 200	<1.5	47,600	119	350	51
3-1	<270 ± 200	<3.7	18,200	116	133	50
1-0	<200 ± 200	<0.4	163,000	142	1,080	55
2-1	<50 ± 400	<0.3	38,300	88	500	67
Adopted value		<0.4		120		54
6,250 Å continuum						
Flux (photon s^{-1} m^{-2} $Å^{-1}$)	31		1,334		6.21	
Afρ (cm)*	36.3		1,480		192	
Flux continuum/flux O I ($Å^{-1}$)	0.028		0.24		0.052	

**A* is the albedo of the grain, *f* is the fraction of the aperture filled by the grains, and ρ is the aperture radius.

Table 3. Comparison of absolute production rates (in 10^{25} molecules per second) and relative to H_2O = 1000.

	r (AU)	Δ (AU)	H_2O (O I)	C_2		NH_2		CN		Continuum/O I ($Å^{-1}$)
P/Halley (*5*)										
1985 Dec. 08	1.37	0.70	18,700 = 1,000	70	3.7	26	1.4	43	2.3	0.15
1985 Jan. 10	0.87	1.32	65,800 = 1,000	286	4.3	63	0.96	120	1.8	0.24
P/Tempel 2 (*9*)										
1988 Oct. 09	1.41	1.07	11,200 = 1,000	18	1.61	6.0	0.54	15	1.3	0.027
P/Brorsen-Metcalf (*10*)										
1989 July 13	1.36	0.89	2,570 = 1,000	9.4	3.6	1.5	0.58	6.0	2.3	0.0085
Yanaka (1989a)										
1989 Jan. 15	2.11	1.88	11,000 = 1,000	38	3.5	4.5	0.91	54	4.9	0.052
Yanaka (1988r)										
1989 Jan. 15	0.932	0.367	3,740 = 1,000	<0.17	<0.04	2.7	0.72	<0.4	<0.10	0.028
Depletion factor				~100		"normal"		~25		

odd composition of Yanaka (1988r). The comet could have been formed in the same cloud as the "standard" comets, but in a different region that had undergone a different chemical evolution. Second, Yanaka (1988r) could have formed in a molecular cloud of different composition and, quite by accident, been dispersed in interstellar space, become an interloper, and been captured by our solar system. This process can be expanded by recourse to a theory of Clube and Napier (*17*, *18*), who proposed that encounters of our solar system with giant molecular clouds have repeatedly depleted the Oort cloud, which was then replenished by new encounters with other molecular clouds. In this case, Yanaka (1988r) could be a lone remnant of a previous episode, while the "standard" comets arise from the latest "catch."

If Yanaka (1988r) originated within the solar system, its deviant composition provides evidence that the solar system was not as uniformly mixed as present theories presume. The region between Uranus and Neptune, where comets are believed to have accreted, spans a radial interval of about 10 astronomical units (AU). This interval is large enough to accommodate significant radial gradients in temperature and composition. If local inhomogeneities or compositional "clumpiness" are superimposed on such gradients, considerable deviations from an average composition could result. Compositional studies of comets can thus give us improved clues about the varying conditions during the time of formation of the solar system.

If they originated in molecular clouds, comets such as Yanaka (1988r) could provide us with the opportunity for a spacecraft rendezvous and thus allow direct sampling of the composition of the interstellar medium. Yanaka (1988r) itself, unfortunately, is not periodic and is now well on its way out of the solar system.

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Miocene Fossil Hominids and the Chimp-Human Clade

David R. Begun

Miocene hominoids from Europe are among the earliest members of the great ape and human clade (the Hominidae). One of these forms, represented by well-preserved cranial remains from Rudabánya, Hungary, sheds new light on the question of the evolutionary relations among living hominids. This new evidence supports the view that humans have a specific evolutionary relation with chimpanzees, to the exclusion of all other apes.

Much has been made recently of the discordance between molecular and morphological methods of reconstructing phylogeny and, in particular, hominoid phylogeny (*1–3*). There is an increasing consensus among molecular systematists that the African apes and humans form a clade or lineage distinct from the orang and furthermore that humans and chimps form a clade within the African apes and humans (*4–7*). This is contrasted with the morphological evidence, usually thought to favor a clade uniting the African apes to the exclusion of humans (*8*, *9*). This conclusion derived from the morphological evidence is completely dependent on current character state analyses suggesting that *Pan* and *Gorilla* are united by derived characters of the dentition and postcranium not shared by *Homo* or *Australopithecus*. A small number of derived characters shared among *Pan*, *Australopithecus*, and *Homo* are usually considered to be homoplasies and thus of no phyletic significance. One of the strengths of the cladistic approach is that character state analyses can easily be tested with the use of new outgroups to polarize character states, that is, to test hypotheses presenting particular character states as either primitive or derived. When this is done with the use of newly reconstructed fossil material of the early hominid *Dryopithecus*, the polarity of some of the characters used to reconstruct hominid phylogeny changes. The results suggest that *Gorilla* is primitive in a number of characters and, as a consequence, that features shared among *Homo*, *Australopithecus*, and *Pan* formerly concluded to be primitive are in fact derived and thus indicative of a closer evolutionary relation.

Rudapithecus hungaricus is a nomen attributed to a sample of fossil hominoids from the late Miocene locality of Rudabánya, in north-central Hungary (*10*, *11*). This sample includes large portions of two craniofacial skeletons, two additional palatal specimens, four mandibles, numerous isolated teeth, and a number of postcranial elements (Fig. 1). The gnathic material from Rudabánya shares a number of characters with specimens attributed to the four species of the genus *Dryopithecus*. These include high-crowned, narrow, and thick (labiolingually) upper and lower incisors; upper lateral incisors robust at the cervix and lacking pronounced cingula; tall, buccolingually compressed canines that are relatively small compared to the molars and with thick, rounded distal cingula; reduced lower premolar cusp heteromorphy; broad lower third premolars (P_3) often with well-developed mesio-lingual beaks and small metaconids; elongated lower fourth premolar (P_4) with high talonids; reduced molar cingula; elongated lower molars with tall, peripheralized cusps, broad basins, and relatively early dentine penetrance; and reduction in lower third molar (M_3) size. For these and other reasons, the Rudabánya fossils can be attributed to the genus *Dryopithecus* (*12*, *13*).

Comparisons of the cranial anatomy of *Dryopithecus* to other Miocene and more recent hominoids reveal a pattern of similarities with great apes and humans, to the exclusion of earlier Miocene hominoids. *Dryopithecus* shares with great apes and

Department of Anthropology, University of Toronto, Toronto, Ontario, Canada M5S 1A1.