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Eos, Koronis, and Maria Family Asteroids: Infrared (*JHK*) Photometry

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nfrared photometry at 1,2, 1.6, and 2.2pm (*JHK*) is reported 56 asteroids in the Eos, Koronis and, Maria dynamical fami- s. These data are consistent with a similar surface composition all of the asteroids of each family. The infrared colors within h family cluster in the region observed for the S taxonomic ss, but Eos asteroids may belong to a separable K class. Aster- 243 Ida, which was observed by the Galileo spacecraft, is a ical member of the Koronis family. The average infrared colors the Maria family are slightly redder than those of the Eos and ronis families.

INTRODUCTION

Eos, Koronis, and Maria are three of the first four teroid families recognized by Hirayama (1918). They named after one of the prominent members, namely 1 Eos, 158 Koronis, and 170 Maria. Since then, addi- nal fainter family members have been identified on the sis of the clustering of their derived proper elements. ere is a general consensus on the membership of these pulous families (e.g., Williams 1971, 1979, 1989, Carusi and Massaro 1978, Valsecchi *et al.* 1989, Zappala *et al.* 1990, and additional references in Gradie *et al.* 1979, Chapman *et al.* 1989, Bell 1986, 1989).

Gradie (1978) and Tedesco (1979) observed asteroids in the Eos and Koronis families and found them to have a small range of *UBV* colors. This fact is notable in contrast to the large heterogeneity of colors seen in the main belt (e.g., Gradie and Zellner 1977, Chapman *et al.* 1978). Tedesco (1979) found all asteroids in a small sample of the Maria family had similar, reddish *UBV* colors. Maria asteroids tend to have *UBV* colors in the middle range of the S taxonomic class. The *UBV* colors of the Eos and Koronis assemblages are concentrated toward the lower boundary of the S class adjacent to the more neutral range of the C class. These colors extend into the area between the S and the. C classes. Additional *UBV* and ECAS data have confirmed these trends (Zellner et *al.* 1985, Binzel 1987, Tedesco 1989). At present, more Eos, Koronis, and Maria family members have *UBV* than eight-color ECAS observations. Thus, we use the *UBV* dataset to compare with our new *JHK* results. Accordingly, the TRIAD definition of C and S asteroid classes is an appropriate frame of reference in the following discussion (Chapman *et al.* 1975, Bowell et *al.* 1978, Zellner 1979).

Visual spectra of several Eos asteroids are S-like and are all similar to each other (e.g., 221, 339, 513, 562, 579,

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639, 1075, 1199, and 1364). The visual spectra of a few Koronis (i.e., 158, 167,208,243,462, and 811) and Maria (i.e., 170,472,660,695, and 714) members also appear S-like (McCord and Chapman 1975, Chapman and Gaffey 1979a, b). On the other hand, the extended 52-channel spectrum (0.8 to 2.5 μm) of 221 Eos itself obtained by Bell *et al.* (1987b) is quite unusual. It contains a shallow pyroxene band near 1 μm which is mot seen in C class asteroids but does *not* contain the expected second pyroxene band near 2 μm which is typically seen in S class asteroids. Bell *et al.* (1987a) first proposed a new "K" taxonomic class to include asteroids of this type.

Results from Gradie (1978) show that albedos of 20 Eos asteroids tend to be darker than the S class average. Tedesco *et al.* (1992) present long wavelength data from the Infrared Astronomical Satellite (IRAS) Minor Planet Survey (IMPS) (cf. Matson 1986). These infrared data confirm a strong peak in the albedo distribution near a value of 0.1 for more than 65 Eos members (Veeder *et al.* 1989a, 1991). This is in sharp contrast to the gap in the albedo distribution at the same place which is observed for larger asteroids, Small asteroids may have a relatively flat albedo distribution (cf. Veeder *et al.* 1989b and Tedesco et *al.* 1989a).

The homogeneous spectral character of the Eos family is an important clue to the ongin of densely populated dynamical families. Most likely, a catastrophic collision disrupted the Eos parent body which was itself homogeneous throughout. The dispersion of proper elements among the present family is consistent with plausible impact velocities (Williams *et al.* 1989, Chapman *et al.* 1989). Thus, the asteroids within the Eos family are believed to be physically as well as dynamically related (Williams 1969, 1971, Gradie *et al.* 1979, Tedesco 1979, Carusi and Valsecchi 1982, Chapman 1979, 1985, Bell 1989, Zappala et *al.* 1990).

The presence of the Eos family in the *UBV* color region between and overlapping adjacent parts of the C and S classes has become significant with respect to modern asteroid taxonomy. In the system developed by Bowell *et* al. (1978), small variations-within the Eos family result in individual members being assigned to C, S, or "U" (see atso Chapman *et al.* 1975, Zellner 1979, Bowel] *et al.* 1979, Tholen and Bell 1987). Tholen (1984, 1989) enlarged the S class so as to include all of the observed Eos asteroids by means of a principal components analysis of eight color visual data from ECAS (Zellner *et al.* 1985). Bell *et al.* (1987a) suggested that: "It may be desirable to erect a new spectral class specifically y to contain the Eos famil y" and Bell (1988, 1989) designated "K" for this class. Tholen and Barucci (1989) mention a K class similar to 221 Eos, but Tholen (1989) does not include any K assignments. Tedesco *et al.* (1989a,b, c) have formalized a K-(*i.e., [J-V, u-x,* and albedo). Recently, Granahan *et* al. (1993) and Clark *et* al. (1994) have identified several new K asteroids by means of seven-color (SCAS) infrared spectrophotometry.

Many Eos family members are relatively faint. Thus, for most of them, it is not practical to obtain high-resolution spectra (during the limited amount of available telescope time). Veeder and Owensby (1988) have shown that *JHK* photometry at the IRTF quickly provides adequate signat to noise to characterize the infrared colors of Eos asteroids and enable testing of the uniformity of the Eos family. Our present study compares the Eos, Koronis, and Maria families and explores the context of the K taxonomic class by means of *JHK* photometry.

OBSERVATIONS

JHK (*1.2, 1.6,* and 2.2 μm) observations of asteroids were obtained at the 3-m Infrared Telescope Facility (IRTF) on Mauna Kea. The IRTF cassegrain system utilizes a wobbling secondary mirror and upward-looking dewars. An 8-arcsec-diameter aperture and a chopper throw of 20 arcsec at a frequency of 9 Hz were typically selected. The InSb detector was cooled with liquid helium at ambient atmospheric pressure. The asteroid was found by setting the telescope to its predicted position generated by the PC ephemeris software of D. Tholen. As a further check, the expected rate of motion was confirmed by precise tracking.

Target asteroids were selected from Eos, Koronis, and Maria family members identified by Williams (1979, 1989, and private communication). Priority was given to those with available visual colors and/or radiometric albedos (e.g., Tedesco 1989), but no attempt was made to select for particular values of these parameters. More colors and albedos do tend to be available for brighter rather than fainter members.

Our photometry is presented in Table I. Adopted *J–H* and *H–K* colors for the asteroids are-presented in Table II. A typical asteroid observation run consisted of the filter sequence *JHKJHKJ*. Four to 10 pairs of IO-see integrations were made at each wavelength. All of the measurements had relatively small statistical errors (i. e., SNR >100). In order to compensate for (modest) light-curve variations of some of the asteroids, the *J* magnitude was interpolated to the time of each observation at *H* and *K*. This procedure yields *J-H* and *J–K* colors directly and *H–K* as the difference between them. Our experience with the IRTF suggests that the expected systematic uncertainties are less than approximately ±0.05 mag for color differences.

A separate extinction correction at each filter was derived from the standard stars observed for each night.

TABLE I

Infrared Photometry and Colors of **Eos, Koronis,** and Maria Family Asteroids

Date [UT]	J	J-H	H-K
158 Koronis			
90/ 8/29.333	12.31	.35	.08
90/ W29.337	12.35		
90/ 8/29.348	12.37	.3S	.06
90/ 8/29.353	12.39	.35	.06
90/ 8/29.358	12.42		
90/ 8/30.276	12.63	.39	.07
90/ 8/30.281	12.66	.42	.05
90/ 800.285	12,65	.40	.07
90/ 8/30.290	12.66		
90/ 8/31.299	12.34	.40	.07
90/ 8131.303	12.34		
90/ 8/31.334	12.32	.40	.08
90/ 8/31.339	12.32		
90/ 8/31.345	12.33	.40	.07
90/ 8/31.3S0	12.33		
167 Urda			
91/ 8/13.269	12.62	.39	.01
91/ 8113.274	12.60		
91/ 8/16.257	12.68	.38	.05
91/ 8/16.262	12.68		
170 Maria			
90/ 8/31.577	12.67	.44	.05
90/ 8/31.581	12.67		
90/ 8131.586	12.68	.43	.07
90/ 8/31.590	12,67		
90/ 8/31 .595	12.70	.43	.08
90/ 801.600	12.64		
90/ 8/31.604	12.65	.43	.08
90/ 8/31.609	12.66		
208 Lacrimosa			
91/ 8/12.337	12,19	.40	.06
91/ 8/12.342	12.20		
91/ 8/12.349	12.21	.40	.07
91/ 8/12.353	12.22		
91/ 8/13.302	12,46	.39	.07
91/ 8113.307	12.46		
91/ 8/13.313	12.46	.39	.07
9118113.317	12.45		
221 Eos			
88/ 7/10.324	11.10	.38	.05
88/ 7/10.329	11.10	.38	.06
88/ 7/10.334	11.11		
88/ 7/10.345	11.10	.38	.05
88/ 7/10.349	11.09	.38	.05
88/ 7/10.353	11.08		
88/ 7/11.263	11.04	.37	.04
88/ 7111.267	11.04		
88/ 7111.276	11.04	.38	.04
8817111.281	11.05	.38	.04
88/ 7/11.285	11.05		
88/ 7/12.260	11.07	.39	.05
8817112.264	11.07		
8817112.348	11.08	.40	.05
8817112.351	11.08	.40	.05
88/ 7/12.356	11.08		
8817113.251	11.07	.37	.06
8817113.256	11.07		
243 Ida			
90/ 8/29.403	12.48	.35	.07
90/ 8/29408	12.56	.35	.07
90/ 8*9.413	12.66	.37	.07
90/ 8/29.417	12.78		
90/ 8/30.399	12.64	.38	.08
90/ 8/30.403	12.54		
90/ 8/30.410	12.40	.38	.08
90/ 8/30.415	12.31		
311 Claudia			
90/ 8/29.269	13.81	.33	.08
90/ 8/’29.276	13.85		
90/ 8/29.290	13.80	.37	.06
90/ 8129.296	13,69	.36	,04
90/ 8/29.300	13.60		
90/ 8/30.247	13.69	.38	.07
90/ 8130.251	13.60		
339 Dorothea			
91/ 8/13.555	11.92	.36	.07
91/ 8/13.559	11.92		
91/ 8/13.566	11.91	.36	.06
91/ 8/13.s70	11.91		
9118114.457	11.86	.37	.05
91/ 8114.460	11.86	,37	.05
91/ 8/14.464	11.86		
91/ 8/16.391	12.00	.27	.10
91/ 8/16.395	11.96	.43	.01
91/ S/16.399	11.95		
450 Brigitta			
88/ 7/12.588	14.13	.40	.04
88/ 7/12.594	14.13	.39	.04
88! 7/12.599	14.17		
88/ 7113.576	14.13	.38	.06
88/ 7/13.581	14.16	.39	.06
88/ 7/13.587	14.16		
472 Roma			
90/ 8/30.310	12.31	.40	.06
90/ 8/30.315	12.32	.40	.08
90/ 8/30.319	12.33		
90/ 8/31.269	12,12	.41	.04
90/ 8/31.274	12.20		
529 Preziosa			
90/ 8/2.9.4?2	12.78	.37	.07
90/ 8/29 .476	12.82	.35	.07
90/ 8/29.482	12.76		
90/ 8/30.499	12.83	.41	.06
90/ 8/30.504	12.83		
90/ 8/30.510	12.82	.39	.07
90/ 8/30.515	12.82		
562 Saloma			
89/ 3/1 1.569	14.06	.46	.0
891311 1.574	14.02	.46	.0
8913111.580	13.97		
573 Recha			
88/ 7/10.431	12.24	.38	.0
8817110.436	12.24	.39	.0
88/ 7/104.41	12.21		
88/ 7/12.371	12.29	.39	.0
88/ 7/12.375	12.28	.37	.0
88/ 7/12.379	12.27		
8817113.363	12.35	.36	.0
88/ 7113.367	12.35	.37	.0
88 I 7/13.372	12.38		
575 Renate			
91/ 8/13.594	13.79	.39	.0
91/ 8113.S99	13.72		
91/ 8/13.604	13.62	38	.1
91/ 8/13.608	13.57		
91/ 8/14.542	13.64	.431	.0
91/ 8114.546	13.70	.40	.1
91/ 8/14.550	13.77	.40	.1
91/ 8/14.553	13.84		
91/ 8/14.576	13.63	.40	.1
91/ 8/14.580	13.62	.44	.0
91/ 8114.583	13.64	.43	.0
9118114.587	13.68		
91/ 8/16.620	13.53	.43	.0
91/ 8/16.624	13.51	.43	.0
91/ 8/16.628	13.54		
579 Sidonia			
881 7/12.573	11.94	.39	.0
8817112,576	11.94	.38	.0
88/ 7/12.581	11.95		
8817113.558	11.80	.38	.0

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Date [UT]	J	J-H	H-K
S79 Sidona (continued)			
88/ 7/13.563	11.80	.39	.06
88/17/13 .567	11.80		
616 Elly			
91/ 8/12.440	13.03	.39	.07
91/ 8/12.444	13.03		
91/ 8/12.451	13.00	.38	.09
9118112.453	12.99		
91/ 8/13.423	13.13	.38	.09
91/ 8/13.428	13.11		
91/ 8/13.433	13.06	.40	.08
91/ 8/13.437	13.02		
91/ 8/14.395	12.90	.41	.07
91/ 8/14.398	12.94		
91/ 8/14.400	12.95	.41	.06
91/ 8/14.403	12.99		
639 Latona			
91/ 8/14.471	10.72	.39	.06
91/ 8114.474	10.73		
91/ 8/14.493	10.74	.39	.05
91/ 8114.497	10.76	.40	.02
9118114.499	10.72		
91/ 8/16.357	10.61	,37	.05
91/ 8/16.361	10.58	,37	.07
91/ 8116.366	10.64		
651 Antiklcia			
89/ 3/11 .590	14.31	.39	.09
89/ 3/1 1.599	14.32	.37	,06
89/ 3/11.606	14.36		
653 Berenike			
90/ 8/29,S30	12.86	.3S	.10
90/ 8/29.534	12.88	.40	.11
90/ 8/29.S39	12.96		
90/ 8/31.487	12.86	.40	.07
90/ 8/31.492	12.86		
90/ 8/31.497	12.87	.39	.08
90/ 8/31 .502	12.90		
660 Crescentia			
90/ 8/29.381	11.08	.38	.07
90/ 8/29.385	11.12	.42	.08
90/ 8/29.390	11.25		
90/ 8/31 .283	11 .4?	.43	.08
90/ 8/31.288	11.41	.43	.05
90/ 8/31.292	11.51	.40	.07
90/ 8/31.297	11.50		
661 Coelia			
88/ 7/10.399	1 2.66	.39	.06
88/ 7/10.405	12.67	.38	.06
88/ 7/10,411	12.70		
88/ 7/11.333	12.67	.46	.06
88/ 7/11 .338	12.89	.38	.05
88/ 7/11.342	12.86		
88/ 7/13.382	12.72	.36	.08
8817113.386	12.77		
669 Kypria			
91/ 8/13.321	13.56	.41	.06
91/ 8/13.325	13.58		
91/ 8/13.330	13.56	.41	.02
91/ 8/13.333	13.52		
91/ 8/14.367	13.52	.38	.08
91/ 8/14.372	1350	.38	.05
91/ 8/14.374	1346		
720 Bohlinia			
90/ 8/29.572	1344	.34	.02
90/ 8/29.576	1344	.33	.02
90/ 8/29.581	1343	.34	.04
90/ 8/29.585	13.45		
742 Edisona			
88/ 7/12.329	1280	.31	.02
88/ 7/12.333	12.79	.34	.04
8817112.337	12 ?8		
88/ 7/13.320	1270	.37	.06
88/ 7/13.326	12.74	.36	.07
8817113.330	12.77		
761 Brendelia			
90/ 8/29.369	13.38	.36	.08
90/ 8/29.374	13.38	.36	.0S
90/ 8/29.378	13.40		
90/ 8/30.323	13.64	.41	.07
90/ 8/30.328	13.66	.4]	.07
90/ 8/30.333	13.64		
798 Ruth			
91/ 8/12.368	12.55	.38	.05
91/ 8/12.372	12.55		
9118112.379	12.55	.38	.05
91/ 8/12.383	12.55		
91/ 8/13.356	12.62	.38	.05
91/ 8/13.364	12.62		
91/ 8/13.367	12.65	.39	.06
91/ 8/13.372	12.65		
875 Nymphe			
91/ 8/12.421	12.70	.41	.05
91/ 8/12,425	12,72		
91/ 8/12.431	12.74	.40	.05
91/ 8/12.435	12.77		
91/ 8113.374	12,79	.42	.06
91/ 8/13.378	12.79		
91/ 8/13.383	12.77	.42	.06
91/ 8/13.387	12.75		
879 Ricarda			
901 8/29.619	13.24	.40	.02
90/ 8/29.624	13.22		
90/ 8/29.625	13.24	.38	.05
90/ 8/29.630	13.24		
90/ 8/30.620	13.S0	.42	.08
90/ 8/30.624	13.50	.42	.08
90/ 8/30.629	13.51		
90/ 8/31 .533	13.85	.42	.06
90/ 8/31.538	13.85		
90/ 8/31.542	13.82	.44	.06
90/ 8/31,547	13.84		
890 Waltraut			
88/ 7I1O.512	13.73	.32	.06
88/ 7I1O.S17	13.73	.32	.05
88/ 7I1O.524	13.75		
88/ 7/12.450	14.02	.39	.04
88/ 7/12,456	14.02	.37	.06
88/ 7/12.461	14.02		
88/ 7/12,471	14.00	.36	.07
88/ 7112.476	14.00		
88/ 7/13.425	13.75	.36	.05
88/ 7/13.431	13.76	.35	.08
88/ 7/13.437	13.79		
897 Lysistrata			
91/ 8/12.395	12.13	.4o	.06
91/ 8/12.399	12.14		
91/ 8/12.406	12.16	.40	.06
91/ 8/12.410	12.16		
91/ 8/13.400	12.25	.40	.06
91/ 8/13.04	12,26		
91/ 8113.409	12.27	.41	.06
91/ 8/13,413	12,29		
91/ 8/14.431	12.25	.40	.05
9118114.434	12.25	.39	.06
91/ 8/14.438	12.25		
962 Caia			
90/ 8129.442	13.6S	.35	.09
90/ 8/29.447	13.65	.36	.08
90/ 8/29.451	13.72	.47	-.03
90/ 8/29.456	13.70		

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Date [UT]	J	J-H	H-K
962 Caia (continued)			
90/ 8/30.450	13.?2	.40	.08
90/ 8/30.454	13.69		
90/ 8/30.461	13.67	.41	.08
90/ 8/30.465	13.66		
975 Perseverant			
90/ 8/29.303	13.56	.36	.06
90/ 8/29.308	13.61		
90/ 8/29.322	13.61	.38	.07
90/ 8/29.326	13.58	.36	.05
90/ 8/29.331	13.58		
90! 8/30.265	13.84	.38	.06
90/ 8/30.269	13,87	.39	.05
90/ 8/30.274	13.88		
1075 Helina			
88/ 7/10.444	12.61	.31	.05
88/ 7/10.450	12.62	.28	.06
88/ 7/10.455	12.58		
88/ 7/13.352	12.59	.33	.02
88/ 7113.356	12.59	.33	.03
881 7/13.360	12.62		
88/ 7/13.388	12.58	.32	.03
88/ 7/13.393	12.60	.32	.04
8$/ 7/13.397	12.61		
1087 Arabis			
88/ 7/12.301	14.65	.39	.14
88/ 7/12.307	14.70	.36	.02
88/ 7/12.316	14.86		
88/ 7/13.267	14.75	.31	.11
88/ 7113.274	14.82	.36	.02
88/ 7113.282	14.85		
1105 Fragaria			
90/ 8/29.544	12.95	.33	.06
90/ 8/29.548	12.%	.33	.07
90/ 8/29.553	12.95		
90/ 8/31.505	13.04	.38	.05
90/ 8BI.51O	13.04		
90/ 8/31.515	13.05	.37	.07
90/ 8/31.519	13.07		
J 112 Polonia			
91/ 8/14.484	12.35	.37	.04
91/ 8/14.488	12.34	.36	.05
91/ 8/14.491	12.34		
91/ 8/16.372	12.42	.34	.13
91/ 8/16.377	12.49	.36	-.01
91/ 8/16.381	12.38		
1158 Luda			
91/ 6/12.565	13.78	.43	.07
91/ 8/12.569	13.80		
91/ 8/12.575	13.83	.4S	.07
91/ 8/12,S79	13.85		
91/ 8/13.S78	13.65	.41	.10
9118113.582	13.67		
91/ 8/13.388	13.68	.40	.09
91/8113.592	13.69		
91/ 8114.523	13.64	.42	.07
91/ 8/14.526	13.62	.43	.07
91/ 8/14.529	13.61		
1199 Geldonia			
8817110.467	13.29	.31	.05
88/ 7/10.472	13.30	.33	.06
88/ 7I1O.478	13.34		
881 7/12.400	13.23	.37	.04
88/ 7/12.406	13.25	.38	.02
88/ 7/12.402	13.25		
88/ 7/13.335	13.35	.36	.03
88/ 7/13.339	13.35	.34	.03
8817113.343	13.36		
1210 Morosovia			
88/ 7/11.301	13.85	.38	.06
88/ 7/1 1.307	13.87	.38	.06
88/ 7/11.312	13.89		
88/ 7/12.281	13.85	.39	.07
88/ 7/12.285	13.85	.41	.05
88/ 7/12.087	13.86		
88/ 7/13.291	14.04	.38	.08
88/ 7/13.297	14.08		
1289 Kutaissi			
91/ 8/12.504	12.90	.39	.06
91/ 8/12.S08	12.85		
91/ 8/13.S05	12.87	.37	.06
91/ 8/13.510	12.91		
91/ 8/13.516	12.98	.39	.05
91/ 8/13.520	13,04		
91/ 8/)4.444	12.98	.36	.06
911 8/14.448	12.93	.39	.05
91/ 8/14.451	12.89		
1350 Rosselia			
91/ 8/14.350	13.90	.42	.08
91/ 8/14.354	14.02	.36	.09
91/ 8/14.358	14.04	.38	.08
91/ 8/14.360	14.06		
91/ 8/16.322	13.58	.38	.05
91/ 8/16.327	13.63	.34	.10
91/ 8/16.33S	13,65		
1434 Margot			
90/ 8/29.459	12.85	.34	.05
90/ 8/29,464	12.88	.35	.03
9018129.469	12.83		
90/ 8/30.482	12.90	.37	.04
90/ 8/30.487	12.91		
90/ 8/3(1.492	12.90	.31	.04
90/ 81x.497	12.89		
1533 Saimaa			
88/ 7/10.483	14.24	.33	.08
8817110.492	14.20	.30	.10
88/ 7/10.501	14.23		
8817112.423	14.18	38	.06
88/ 7/12,431	14.18	.37	.06
88/ 7/12.438	14.20		
88/ 7/13.410	14.32	.37	.03
88/ 7/13.416	14.33	.36	.10
88/ 7113,422	14.30		
1604 Tombaugh			
91/ 8/14. 606	14.16	.38	.07
91/ 8/14.610	14.16	.36	.01
91/ 8/14,613	14.16		
91/ 8/16.609	14.11	.37	.05
91/ 8/16.613	14.10	.39	.01
91/ 8/16,617	14.10		
1641 Tana			
88/ 7/10.537	14.58	.38	.0
88/ 7/10.547	14.53	34	.1(
8817110.556	14.47		
88/ 7/12.553	14.68	.37	.0!
8817112.562	14.51		
88/ 7/13.540	14.60	.40	.0
88/ 7113.547	14.56	.34	.0
88/ 7/]3.554	14.53		
1723 Klemola			
89/ 3/11.616	13.76	.47	.0
89/ 3/1 1.623	13.88	.47	.0
89/ 3/11.628	13.85	.42	.0
89/ 3/1 1.634	13.99	.50	.0
89/ 3/11.640	14.01		
1767 Lampland			
88/ 7/12.525	14.81	.41	-.0
88/ 7112,534	14,82	.39	.0
88/ 7112.S42	14.84		

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Date [UT]	J	J-H	H-K
1913 Sekanina	*		
91/8/12.475	13.97	.3S	.05
91/8/12.479	14.00		
91/8/12.48S	13.92	.39	.01
91/S/12.490	13.93		
911 8/13.499	13.94	.38	.04
91/8/13.503	13.93		
91/ 8/14.417	13.86	.40	.01
91/ 8/14.420	13.83	.34	.07
91/8/14.424	13.84		
2051 Chang			
90/ 8/29.421	“14.26	.30	.07
90/ 8/29.426	14.29	.40	.03
90/ 8/29.431	14.36		
SW/8/30.432	14.38	‘.40	.04
90/8/30,437	14.39		
90/8/30,442	14.36	.38	.10
90/ 8/30.447	14.34		
2052 Tamriko			
90/ 8/30.346	13.61	.40	.05
90/ 8/30.350	13.60	.40	.06
90/ S/30.354	13.59		
90/ 8/31.400	13.62	.41	.05
90/ 8/31.405	13.63		
90/ 8/31.410	13.63	.41	.08
90/8/31.415	13.63		
2111 Tselina			
91/8/14.593	14.68	.41	-.02
91/ 8/14.597	14.72	.38	.08
91/8/14.603	14.79		
91/8/14.61S	14.81	.36	.02
91/8/14.618	14.82	,40	.03
9118/14.622	14.83		
91/8/16.593	14.48	.38	.03
91/8/16.597	14.4S	.39	.03
91/8/16.S01	14.43		
2188 Orlenok			
90/801.358	13.72	.36	.05
90/8/31.362	13.74		
90/8/31.368	13.78	.35	-.02
90/8/31.372	13.77		
2345 Fucik			
90/8 /30.528	13.72	.38	.06
90/ 8/30.533	13.72		
90/ 8/30.538	13.74	.37	.08
90/ 8/30,542	13.73		
90/ 8/31.430	13.88	.36	.06
90/ 8/31 .435	13.90		
90/ 8/31 .440	13.89	.36	.05
90/ 8/31,445	13.87		
2928 Epstein			
88/ 7/12,481	15.10	.41	.12
88/ 7/12,491	15.15	.38	.08
88/ 7/12.500	15.18		
881 7/12.510	15.24	.38	.07
88/ 7/12 .519	15.28		
88/ 7/13.514	15.10	.37	.09
88/ 7/13,522	15.09	.36	.06
88/ 7/13.529	15.08		
3066 McFadden			
90/ 8/29.587	13.89	.39	.03
90/ 8/29.592	13.86	.34	.06
90/ 8/29.597	13.87	.38	.02
90/ 8/29.601	13.88		
S0/ 800.598	14.20	.39	.11
90/ 8/30.603	14.23		
90/ 8/30 608	14.20	.39	,06
901800.613	14.19		
3623 Chaplin			
90/ 801.382	14.48	.39	-.04
90/ 8131.387	14.39		
90/ 8131.392	14.34	.38	.01
90/ 8/31.397	14.27		

is similar at *J*, *H*, and *K* and often is less than 0.1 mag per air mass. Almost all observations were made at an air mass of less than two and the derived colors are relatively insensitive to the adopted extinction corrections.

Magnitudes at *JHK* for the standard stars were adopted from Elias et *al.* (1982). These are also a subset of the IRTF list of infrared standard stars. This photometric system defines alpha Lyrae as 0.0 mag for each bandpass. Additional discussion of the infrared calibration, standard star system, and atmospheric extinction may be found in Johnson *et* al. (1975), Veeder et *al.* (1978), Manduca and Bell (1979), McCord and Clark (1979), and Bessel] and Brett (1988). Hahn and Lagerkvist (1988) discuss the conversion between several different infrared photometry systems used for asteroids.

DISCUSSION

Our *J–H* vs *H–K* color data from Table 11 are plotted in Figs. 1 and 2. The ranges for observed C and S class asteroids are indicated (Chapman and Morrison 1976, Leake *et al. 1978*, Veeder et *al.* 1982, 1983, Hahn and Lagerkvist 1988), Note that the C and S TRIAD taxonomic class are defined on the basis of visual albedos, *colors, and other spectral features* (Chapman *et al.* 1975, Bowell *et al.* 1978, Zellner 1979). Tholen (1984, 1989) has

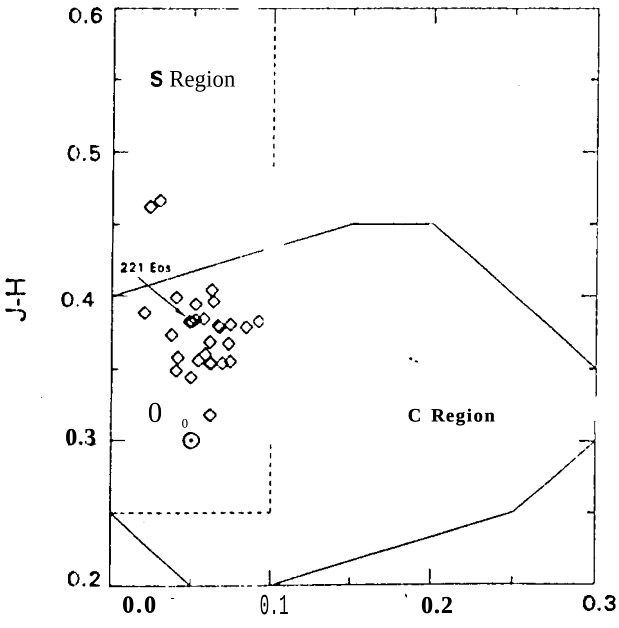

FIG. 1. J-H vs H-K infrared colors for members of the Eos asteroid family. Data are from Table II. Solar colors are approximately 0.3 for J-H and 0.05 for H-K. The two enclosed regions encompass the observed colors for C and S class asteroids (Chapman and Morrison 1976; Leake *et al* 1978; Veeder *et al* 1982, 1983; Hahn and Lagerkvist

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TABLE II
Infrared Colors of Eos, Koronis, and Maria Asteroids -

Asteroid	J-H	H-K	n	Family	Class	Notes
158 Koronis	.38	.07	9	Koronis	S	1-3
167 Urda	.39	.03	2	Koronis	S	3
170 Maria	.43	.07	4	Maria	S	4
	.44	-.0s	2			5
208 Lacrimosa	.39	.07	4	Koronis	S	6
221 Eos	.38	.05	11	Eos	S	7
243 Ida	.37	.07	5	Koronis	S	3
311 Claudia	.36	.06	4	Koronis	S	3
339 Dorothea	.36	.0s	5	Eos	S	8
450 Brigitta	.39	.02	4	Eos	CS	9
4n Roma	.40	.06	3	Maria	S	3
529 Preziosa	.38	.07	4	Eos	S	
562 Saloma	.46	.02	2	Eos	S	3
573 Recha	.38	.07	6	Eos		
575 Renate	.41	.09	10	Maria		
579 Sidona	.38	.06	4	Eos	S	3
616 Elly	.39	.08	6	Maria	S	3
639 Latona	.38	.05	5	Eos	S	3
651 Antikleia	.38	.07	2	Eos	S	3
653 Berenike	.38	.09	4	Eos	S	3
660 c—da	.41	.07	5	Maria	S	3
661 Coelia	.40	.06	5	Eos	S	7
669 Kypria	.39	.05	4	Eos	S	3
720 Bohlinia	.34	.03	3	Koronis	S	3
742 Edisona	.34	.05	4	Eos	S	3
761 Brendelia	.29	.07	4	Koronis	se	
798 Ruth	.38	.05	4	Eos	M	6
87S Nymphe	.41	.05	4	Maria		
879 Ricarda	.42	.06	6	Maria		
890 Waltraut	.35	.06	7	Eos	CTG	9
S97 Lysistrata	.40	.06	6	Maria	S	
962 Aslog	.40	.06	5	Koronis	S	
97s Perseverant	.31	.06	5	Koronis	S	3
1075 Helina	.31	.04	6	Eos	S	
1087 Arabis	.36	.07	4	Eos	S	
1105 Fragaria	.3s	.06	4	Eos	ST	
1112 Polonia	.36	.05	4	Eos	S	
1158 Luda	.42	.08	6	Maria		
1199 Geldonia	.35	.04	6	Eos	CGTP	9
1210 Morosovia	.32	.06	5	Eos	M	6
1289 Kutaissi	.38	.05	5	Koronis	S	6
1350 Rosselia	.38	.08	5	Koronis	S	
1434 Margot	.36	.04	4	Ens	S	3
1533 Saimaa	.35	.07	6	Eos	S	10
1604 Tombaugh	.37	.04	4	Eos	EMPSC	9
1641 Tana	.37	.07	5	Eos		10
1723 Klemola	.47	.03	4	Eos	S	
1767 Lampland	.40	.04	2	Eos	EMPC	3
1913 Sekanina	.37	.04	5	Koronis		
2051 Chang	.37	.06	4	Koronis		
2052 Tamriko	.40	.06	4	Eos	S	
2111 Tselina	.32	.03	6	Eos	S	
2188 Orlenok	.35	.02	2	Koronis		
2345 Fucik	.37	.06	4	Eos	S	
2928 Epstein	.38	.08	5	Eos		
3066 McFadden	.38	.0s	5	Maria		
3623 Chaplin	.38	.01	2	Koronis		

Notes. (1) N is the number of independent values averaged. (2) Class is from Tholen (1989). (3) Bowell *et al.* (1978, 1979). (4) Chapman *et al.* (1975). (5) Veeder *et al.* (1983). (6) S in Gradie (1978). (7) K in Tedesco *et al.* (1989c,d). (8) SK in Tedesco *et al.* (1989c,d). (9) Visual albedo >0.65 (Matson 1986; Tedesco 1989). (10) S in Binzel (1987).

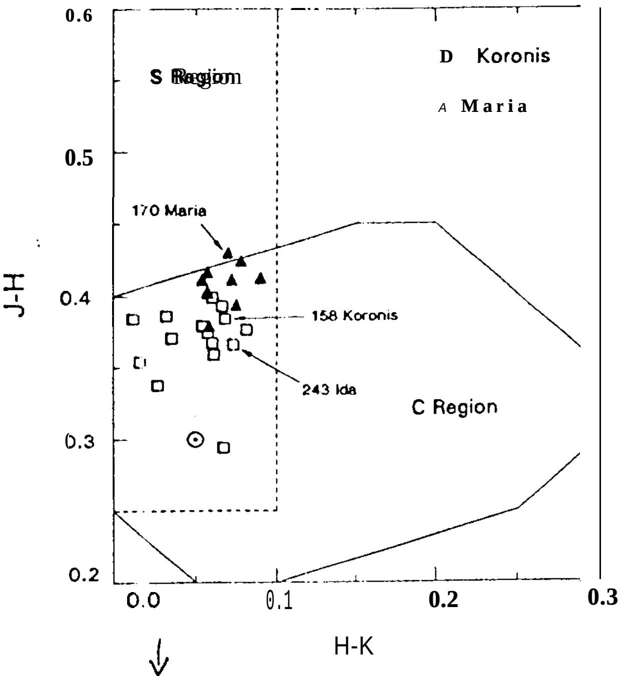

FIG. 2. J-H vs H-K infrared colors for members of the Koronis and Maria asteroid families. This plot is comparable to Fig. 1.

classes by means of a principal components analysis of ECAS data (Zellner *et* al. 1985). Here the observed infrared ranges for the C and S class asteroids form a provisional extension for the definitions of the C and S classes within the *JHK* parameter space.

The observed infrared colors for the Eos, Koronis, and Maria asteroids (Table III) occupy a rather restricted range in Figs. 1 and 2 as discussed by Veeder and Tedesco (1991). Indeed, the scatter for each family is only somewhat larger than might be expected from observational uncertainties alone. However, the *H-K* colors of 170 Maria are somewhat different than previous results from a smaller sample (Veeder *et al.* 1983). All the asteroids here show similar relatively neutral (~0.05) *H-K* colors. The average *J-H* colors of observed Eos, Koronis, and Maria family members are about 0.37,0.37, and 0.41, respectively, That is, Maria members are marginally redder at *J-H* than Eos and Koronis members.

TABLE III
Average Infrared Colors of Asteroids

	J-H	*H-K*	Reference
Eos Family	0.37	0.0s	
Koronis Family	0.37	0.05	
Maria Family	0.41	0.07	
s	0.42	0.07	Hahn and Lagerkvist 1988
s	0,49	0.02	Veeder *et al.* 1982, 1983

The *J–H* colors of these families are somewhat less than the average *J-H* of 0,42 for S asteroids observed more than once by Hahn and Lagerkvist (1988) and an average *J–H* of about 0,49 for the sample of S asteroids (with slightly redder visual colors) observed by Veeder et al. (1982, 1983). The results shown in Fig. 1 confirm that the Eos family is well within the range of the S taxonomic class and that all but two members are in the infrared color region where the C and S classes overlap as noted by Veeder and Owensb y (1988) and Veeder and Tedesco (1991). Figure 2 shows that the Koronis family is entirely within the same region. Maria family members tend to have somewhat redder J-H colors, with 170 Maria itself just outside this overlap region.

Available *U-B* vs. *B–V* colors of Koronis and Maria members are plotted in Fig. 3 (Gradie 1978, Gradie *et al.* *1979,* Bowell *et al.* 1979, Zellner *et al.* *1985,* Binzel 1987, Tedesco 1989). The boxes outline the defined ranges of TRIAD C and S classes. The visual colors of members of the Maria family are similar to those of S class asteroids. Koronis asteroids tend to be somewhat bluer especially in *B–V* such that many of them plot outside the *S* zone. Almost all Koronis asteroids wi(h available ECAS data are classified as S by Tholen (1984, 1989).

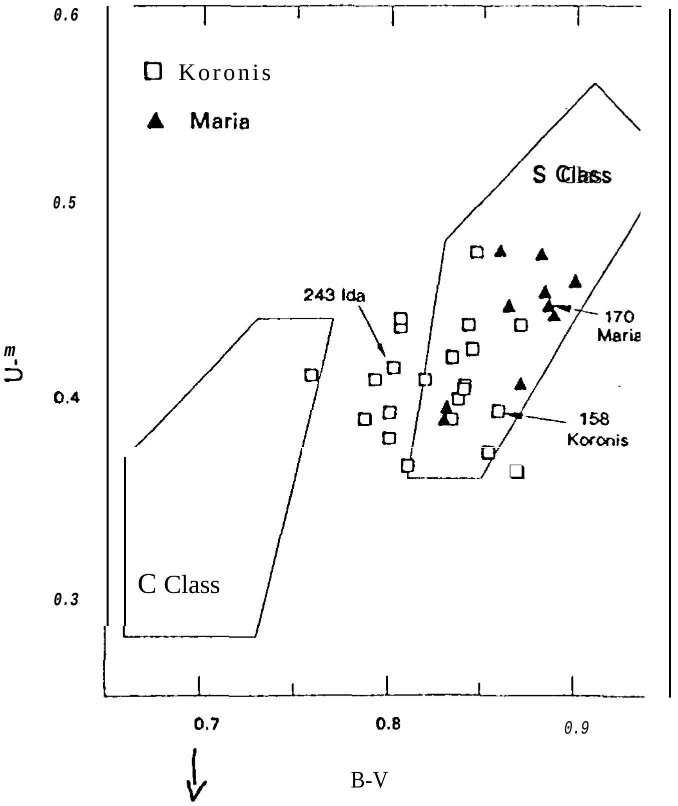

FIG. **3.** U-B vs. **B-V** visual colors for members of the **Koronis** and Maria asteroid families. This figure updates previous presentations (e.g., Gradie and **Zellner 1977; Gradie** 1978; **Tedesco** 1979; **Gradie** *et* al. 1979) **with the** addition of data from **Bowell** *et al.* (1979), **Zellner** *et al.* *(1985),* **Binzel** *(1987)* **and Tedesco** *(1989).* **The solid lines** mark defined boundaries for the TRIAD C and S asteroid taxonomic classes (Chap-

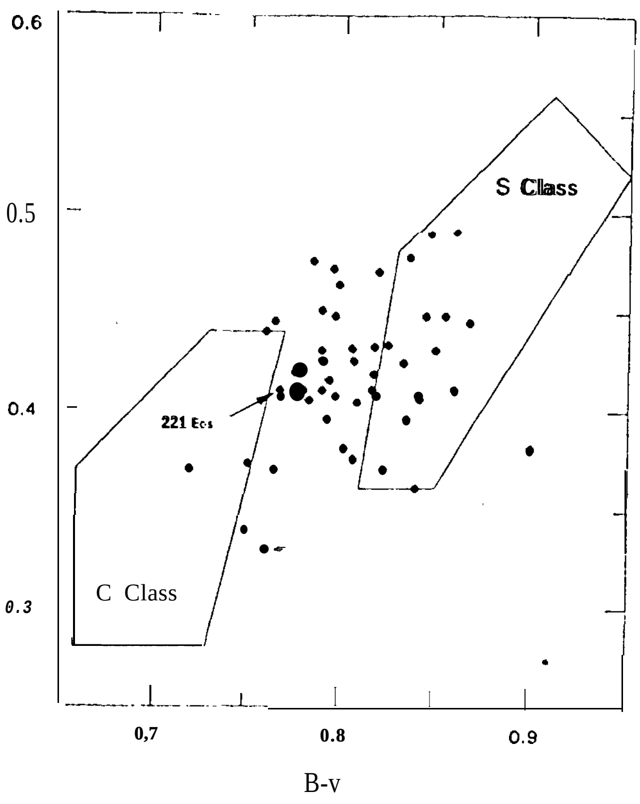

FIG. *4.* U-B vs. B-V visual colors for members of the Eos asteroid family. This figure collates data from **Gradie** and **Zellner** (1977), **Zellner** *et al.* (1977), **Gradie** (1978), **Degewij** *et al. (1978),* **Tedesco** (1979), **Gra**die *et* al. (1979), **Bowell** *et al.* (1979), **Zellner** *et* a/. (1985), **Binzel** (1987) and **Tedesco** (1989). This plot is comparable to Fig. 3.

Available *U–B* vs. *B–V* colors of Eos asteroids are plotted in Fig. *4* (Gradie and Zellner 1977, Zellner *et al.* 1977, Gradie 1978, Degewij et *al.* 1978, Tedesco 1979, Gradie *et* al. 1979, Bowell et *al.* 1979, Zellner et *al.* 1985, Binzel 1987, Tedesco 1989). The *U–B* colors of all three families are similar. However, the *B-V* colors of Eos asteroids tend to be bluer than the S class average to the extent that more than half of them plot outside the TRIAD S zone. Again, many Eos asteroids with available ECAS data are classified as S by Tholen (1984, 1989).

The *UBV* colors of Eos family asteroids cluster tightly (i.e., ± 0.05 mag) on the boundary of the S field and are near to that of the C field (Gradie and Zellner 1977, Gradie 1978, Degewij *et al,* 1978, Tedesco 1979, Gradie et *al.* 1979). Furthermore, their radiometric albedos tend to be in the lower range observed for S class asteroids (Gradie chondrites implies that as near-IR observations are extended to fainter objects some other nonfamily asteroids currently classed as S on the basis of visual spectra alone will turn out to be K. For example, Granahan *et al.* (1993) have identified six new K asteroids. It is possible that the proportion of K asteroids may increase at smaller sizes as suggested by the scenario of Bell *et al.* (1989). Clark *et al.* (1994) suggest that five small main belt asteroids should be reclassified from S to K. Near-infrared observations may also reveal whether some of the Earth-approaching asteroids now classified as S (on the basis of visual spectra only) are actually K.

SUMMARY

All available data show that each of the observed Eos, Koronis, and Maria asteroid subpopulations appear to be homogeneous with respect to surface composition. 243 Ida is a typical member of the Koronis family. Within the Eos family, a unique combination of moderately red visual colors, neutral near infrared colors and intermediate albedos strengthens the justification for the definition of a separate K class which is near the S class in the three-parameter taxonomic system. *JHK* colors of (faint) Eos members are consistent with higher resolution spectra of three bright ones which appear similar to CV or CO carbonaceous chondrites.

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tradictory situation in which the Eos family was thought to be homogeneous in composition, while the individual objects were classed as C, S, or “U” based on small variations in color and albedo (Bowell *et al.* 1978, 1979). Tholen (1984, 1989) and Barucci et *al.* (1987) have expanded their S class to include all members of the Eos family as well as those with similar colors. Asteroid taxonomy continues to evolve. (see also Tholen and Bell 1987, Bell 1989, Bell *et* al. 1989, Chapman *et* al. 1989, Tholen and Barucci 1989).

Geometric visual albedos and diameters for family asteroids from the IMPS are included in Tedesco *et al,* (1992; cf. Matson 1986). The albedos of Eos asteroids are concentrated near a value of 0.1 in a sparsely populated gap in the distribution of large main belt asteroids between the dark (mostly) C and moderately bright (mostly) S taxonomic classes. Koronis and Maria asteroids have albedos similar to other S class asteroids (Veeder *et al.* 1989a, 1991).

Bell et *al.* (1987a,b, 1988) discovered that the asteroid 221 Eos exhibits a flat near infrared reflectance curve with very shallow silicate absorption bands. Fifty-two-channel spectra of the family members 653 Berenike and 661 Cloelia are similar to that of 221 Eos (Bell, unpublished). Fifty-two-channel spectra are not available for any Koronis or Maria asteroids. These three Eos member spectra are unlike those of other S asteroids such that they more closely resemble classical C spectra. Our JHK data suggest that a significant number of Eos family members possess near-infrared spectra that are similar to the three obtained so far. Thus, in the following, we will implicitly assume that the spectrum of Asteroid 221 Eos characterizes typical Eos members as well as the original parent body which was broken up to form the family.

The combined visual and infrared data sets suggest that the parent body of the Eos family was not a typical member of either the C, the S, or any other previously defined taxonomic class. Bell (1988, 1989) proposed that the unique and tightly clustered properties of the Eos family asteroids should be recognized by creating a new asteroid class, “K”, for them. This choice was intended to phonetically suggest their apparent identity with CV or CO carbonaceous chondrites and that their telescopically observed parameters are intermediate to the classical C and S asteroids (cf. Tholen and Bell 1987, Tholen and Barucci 1989). This class was provisionally defined to include objects with albedos near 0.09, S-like spectral curvature at visual wavelengths, weak absorption bands near 1 μm, and flat reflectance from 1,1 to 2.5 μm. A three-parameter taxonomy has been defined by Tedesco *et al.* (1989a,b,c) which includes a K class exhibiting the following ranges: $1.12 < U-V < 1.21$, $0.07 < v-x < 0.18$, and $0.091 < p_v < 0{,}17$.

It is of particular interest to consider what meteorites have similar spectra to that of K class asteroids and might therefore be related to them. The only differentiated meteorites which would be candidates based on spectral constraints alone are the ureilites, which combine dark carbonaceous material with olivine. While they are an approximate spectral match, ureilites are inferred to have differentiated within their parent body. This appears to be inconsistent with the lack of major differences among the colors of the Eos asteroids and the location of the Eos family at the inner edge of the undifferentiated region of the belt. That is, the observed similar colors of its family members suggest that the Eos parent body was relatively homogeneous before its breakup and perhaps remained undifferentiated despite its size. Relatively mild forms of metamorphism, such as hydrothermal activity, may have occurred without producing obvious effects detectable in our current data. In any case, the Eos family would appear to provide an example of (relatively primitive) material that has survived the process of accretion into a planetesimal as well as one or more stages of breakup. In this context, the model for asteroid evolution of Bell *et al.* (1989), implies that many larger K protoasteroids *were* destroyed by an early heating episode.

Comparison of the spectral and albedo data for Eos family asteroids with the available undifferentiated meteorite spectra does reveal a close similarity with CV and CO chondrites while other meteorites with similar intermediate albedos such as “black chondrites” (highly shocked ordinary chondrites) appear to be much less likely candidates (Bell 1988, 1989), It seems possible that the Eos family may provide a source for either CV or CO chondrites.

The identification of CV or CO chondrites with asteroids formerly classed as S may appear inconsistent since “carbonaceous chondrites” have been traditionally associated with the class C asteroids. In fact this association is only strictly true for CI and CM chondrites. The asteroidal affiliations of the anhydrous CV and CO chondrites have been much more obscure. They have moderate albedos and shallow olivine/pyroxene bands, inconsistent with the low albedos and flat near infrared spectra of the traditional C class asteroids. Indeed, over a decade ago CV/CO mineralogies (then lumped together as “C3” chondrites) were specifically associated with certain S class asteroids on the basis of visual-wavelength spectra alone (Gaffey and McCord 1979, Gaffey *et al.* 1989, Lipshutz et *al.* 1989). Thus the current recognition of the K class can be viewed as a return to some “traditional” interpretations which were obscured by rigid and somewhat arbitrary boundaries within the original C-S-M asteroid taxonomy (Bowell *et al.* 1978, 1979, Zellner 1979).

Tedesco et *al.* (1989b,c) *have* identified a few K class asteroids which are not members of the Eos family (e.g., 181, 402, and 519). The existence of both CV and CO

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FIG. 1. Eos family.

FIG. 2. Koronis and Maria families.

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