

X-625-72-402

PREPRINT

NASA TM X-66084

# COMET ENCKE: METEOR METALLIC ION IDENTIFICATION BY MASS SPECTROMETER

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(NASA-TM-X-66084) COMET ENCKE: METEOR  
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SPECTROMETER R.A. Goldberg, et al (NASA)  
Oct. 1972 15 p

N73-11855

CSSL 11F

Unclas

G3/30 46435

OCTOBER 1972



— GODDARD SPACE FLIGHT CENTER —  
GREENBELT, MARYLAND

COMET ENCKE: METEOR METALLIC ION IDENTIFICATION  
BY MASS SPECTROMETER

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ABSTRACT

Metal ions including  $23^+(\text{Na}^+)$ ,  $24^+(\text{Mg}^+)$ ,  $28^+(\text{Si}^+)$ ,  $39^+(\text{K}^+)$ ,  $40^+(\text{Ca}^+)$ ,  $45^+(\text{Sc}^+)$ ,  $52^+(\text{Cr}^+)$ ,  $56^+(\text{Fe}^+)$  and  $58^+(\text{Ni}^+)$  have been detected in the upper atmosphere during the  $\beta$  Taurids meteor shower. Abundances of these ions relative to  $\text{Si}^+$  show agreement in most instances with chondrites. A notable exception is  $45^+$ , which if  $\text{Sc}^+$ , is 100 times more abundant than neutral scandium found in chondrites.

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Positive metallic ions have been measured in the Earth's atmosphere between 85 and 120 km, during the period of the  $\beta$  Taurids meteor shower, which is associated with Comet Encke. The ions originate during and immediately following ablation when cometary debris enters the Earth's atmosphere. Their abundances are then most closely representative of the relative neutral composition for the same elements in the debris.

The existence of metallic ions in the upper atmosphere has been known for some time. Many elements have been discovered with the aid of rocket-borne ion mass spectrometers. In most cases the major components are  $Mg^+$  and  $Fe^+$  with lesser quantities of  $Na^+$ ,  $Al^+$ ,  $K^+$ ,  $Ca^+$ ,  $Cr^+$ ,  $Si^+$  and other metals (1,2,3,4). Normally a layer of these constituents is observed near 95 km with a 3-5 km half width. Since metallic ions are atomic, they have long lifetimes and can be acted on by external forces such as those generated by wind shears in the presence of the terrestrial magnetic field (5). At midlatitudes this can result in additional layers of enhanced metal ions having extremely narrow half width ( $1/2$  to 2 km) and located between 105 and 130 km at the wind shear levels. When these layers are observed by ground based ionosondes, they are termed sporadic E ( $E_s$ ).

The enhancement of metal ion density during meteor showers is primary evidence for their extraterrestrial origin (1). In addition, Junge et al (6) have argued that constituents such as sodium could not diffuse from the

Earth's lower atmosphere to 100 km in a reasonable time. Comparisons of metal ion relative abundances with neutral species in Earth crust samples and chondrites have shown closer agreement with chondritic relative abundances even though such comparisons disregarded ion and neutral transport processes and ion-neutral chemistry in the atmosphere (7).

The present results were obtained from a rocket-borne ion mass spectrometer, similar to that discussed previously (4,8). The instrument was flown on July 3, 1972 at 7:43 LMT (solar zenith angle =  $57.1^{\circ}$ ) from El Arenosillo, Spain ( $37.1^{\circ}\text{N}$ ,  $6.7^{\circ}\text{W}$ ) and reached an apogee of 122.8 km. The launch occurred during a growing enhancement of  $E_s$ , observed just prior and during the rocket flight by a ground based ionosonde.

Figure 1 illustrates the measured currents for the observed metallic ion distribution (major isotope for each constituent) from 85 to 120 km. Metal ions ( $24^+$ ,  $\text{Mg}^+$ ;  $40^+$ ,  $\text{Ca}^+$ ;  $56^+$ ,  $\text{Fe}^+$ ;  $58^+$ ,  $\text{Ni}^+$ ) were first detected at 85 km. Near 90 km the ions  $23^+$  ( $\text{Na}^+$ ) and  $28^+$  ( $\text{Si}^+$ ) also appeared. The density of ions continued to increase to 100 km where other constituents emerged. Above 100 km the distribution remained nearly constant to 112 km. At this height, the density increased approximately 30 times to form a well defined metallic ion peak which terminated abruptly at 115 km. The vertical arrows indicate the maximum observed value for each constituent within the peak.

Normally, the region between 100 km and the  $E_s$  layer exhibits minimal concentrations of metallic ions. The strong enhancement between 100 and 114 km on this flight is highly suggestive of a strong abnormal production source just prior and during the rocket flight. Meteor shower predictions (9) suggest July 3 to be within the period expected for contributions from  $\beta$  Taurids, a daytime shower associated with Comet Encke. Enhanced periods for such a shower are expected in the morning hours in the north latitude temperature zone (10). Comparison of local ionograms for the time period of the rocket flight on days prior and during the day of the flight show an abnormal enhancement of  $foE_s$  to 10 MHz from the more nominal 5 MHz values observed on preceding days. Furthermore, this enhancement occurred within the 10 minute period prior to launch and disappeared 45 minutes after launch. All of the above information suggest the presence of a meteor shower immediately preceding and/or during the period of data acquisition.

Observations during or just following a meteor shower are significant, for at this time, ablation processes are most likely to cause species to appear in proportion to their neutral abundances. Immediate observations minimize the influence of very complex ion-atmosphere reactions which convert the atomic ions to molecular form to cause increased ion-electron recombination. The sequence

of reactions varies among ion species so that ionic proportions can be different after extended time periods.

Figure 2 illustrates four upleg spectra obtained during transit through the  $E_s$  layer. The altitude scale is shown on the abscissa. The spectra ordinate in volts is approximately logarithmic in current. The region between each spectrum reflects the period during which the spectrometer operated in a high pass filter mode, the data of which are not pertinent to this discussion.

Assuming the ions to be singly ionized, metallic constituents with their principal isotopes in the layer are identified as  $23^+(\text{Na}^+)$ ;  $24^+$ ,  $25^+$ ,  $26^+$  ( $\text{Mg}^+$ );  $28^+(\text{Si}^+)$ ;  $39^+(\text{K}^+)$ ;  $40^+(\text{Ca}^+)$ ;  $45^+(\text{Sc}^+)$ ;  $52^+(\text{Cr}^+)$ ;  $54^+$ ,  $56^+$  ( $\text{Fe}^+$ );  $58^+$  and  $60^+$  ( $\text{Ni}^+$ ). Other isotopes and constituents, e.g.  $27^+(\text{Al}^+)$  and  $55^+(\text{Mn}^+)$ , may have been present, but instrument resolution did not permit accurate identification of such constituents during the flight. The ions  $16^+(\text{O}^+)$ ;  $30^+(\text{NO}^+)$ ;  $32^+$ ,  $34^+$  ( $\text{O}_2^+$ ) as well as a certain fraction of  $28^+(\text{N}_2^+)$  are gaseous ions normally present at these altitudes. They result from ionization of the different neutral constituents in the Earth's atmosphere together with ion-neutral chemistry.

Table I provides the observed relative abundance of each metallic ion species normalized to  $\text{Si}^+$ , near 101 km and 114 km. Values of major constituents are believed accurate to  $\pm 20\%$ ; of minor constituents, to  $\pm 100\%$ . Each

result contains contributions from all isotopes using the measured value for the principal isotope and the known isotopic abundance ratios to more accurately evaluate minor isotopic concentrations. Since the height resolution near 114 km is 0.8 km, the narrowness of the ledge required comparison of the observed rather than exact maximum value for each constituent within the ledge. Between 101 and 114 km, most constituents maintained a constant relative abundance, with the exception of  $28^+$ , which became dominant between 102 and 112 km. This effect was caused in part by a contribution from  $N_2^+$ , estimated to be not greater than 10% at 114 km and unknown at 101 km. The ratios are therefore lower limits and subject to a uniform increase due to  $N_2^+$ . However, the similarity of the abundances at both heights would tend to suggest a negligible or equivalent contribution of  $N_2^+$  to  $28^+$  at either height. For comparison, the chondritic and Earth crustal abundances of the neutral metals (11) are also included. Due to low  $Si^+$  concentrations below 100 km, ratios based on  $Si^+$  are usually not possible except within the  $E_s$  structure. This may reflect a low proportion of Si in the normal daily meteor influx, a higher altitude for  $Si^+$  ablation, or a unique atmospheric behavior of  $Si^+$  for sufficient periods of time to permit ion-neutral reactions to oxidize  $Si^+$  and enhance recombination, at least below 100 km.

The table demonstrates the similarity of the relative atmospheric ion abundances to neutral metal abundances in chondrites. In particular, the species Mg, Cr, Fe, and Ni most clearly illustrate the extraterrestrial origin of the ion composition. We also note the apparent overabundance of  $\text{Na}^+$ , an enhancement that has also been observed during other metal ion samplings (7). The origin of the large sodium ion densities is not understood.

One intriguing aspect of this data is the relatively high abundance of  $45^+$ , identified as  $\text{Sc}^+$ . This is the first reported observation of  $m/e = 45$  at metallic ion heights.  $\text{Sc}^+$  is not a comfortable identification because of the apparent difficulty in producing a source so rich in this constituent. The suggestion that it might be the molecule  $\text{NH}_2\text{HCO}$ , which is believed to be a stable precursor in cometary material, appears unlikely, as ablation processes would probably dissociate this molecule prior to ionization. Doubly ionized constituents seem to be ruled out because of the rapid recombination rates required for such ions and because there are no observed ions at  $m/e = 90$ . This constituent also exhibits peak concentration in the  $E_s$  layer (Figure 1) implying a high probability that it is atomic in structure. Instrumental contaminants and irregularities do not appear likely since  $45^+$  reappears at the same altitude in the downleg data. The above indicate



an ion enhancement of order  $10^2$  times the normal relative abundance of Sc seen either in chondrites or in the Earth's crust. This may be a property of the cometary debris.

Ion composition measurements during atmospheric entry of cometary debris offer a unique opportunity to study such material. The results of this work dictate further measurements to explore the suggestions made here.

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12. This research occurred through a cooperative scientific program between members of the Spanish Comision de Investigations del Espania and the National Aeronautics and Space Administration. We thank them as well as members of our own scientific and technical team for making this program successful.

## TABLE AND FIGURE CAPTIONS

Table 1 - Relative abundances of ions (rocket data) and neutral elements (chondritic and crustal) normalized to  $\text{Si}^+$ ,  $\text{Si} = 100$ .

Figure 1 - Vertical height profile of positive metallic ion composition observed during the upleg flight of 14.483. Arrows mark the observed peak value for each metallic constituent within the  $E_s$  layer.

Figure 2 - Raw spectra depicting ion composition during transit through the  $E_s$  layer on upleg of 14.483. The voltage display is approximately logarithmic in current and thereby, in relative composition among species.

TABLE 1

ELEMENT	ION ABUNDANCES		NEUTRAL ABUNDANCES	
	NASA	14.483	(Ahrens, 1965)	
	101 km	114 km	CHONDRITES	CRUST
Na	12	9.1	3.8	8.5
Mg	49	57	80.9	6.9
Si	100	100	100	100
K	0.81	0.38	0.51	7.4
Ca	3.6	1.2	7.9	14.9
Sc	1.0	0.35	0.005	0.008
Cr	3.4	1.77	1.7	0.0035
Fe	149	158	141	19.9
Ni	4.2	4.7	7.6	0.027

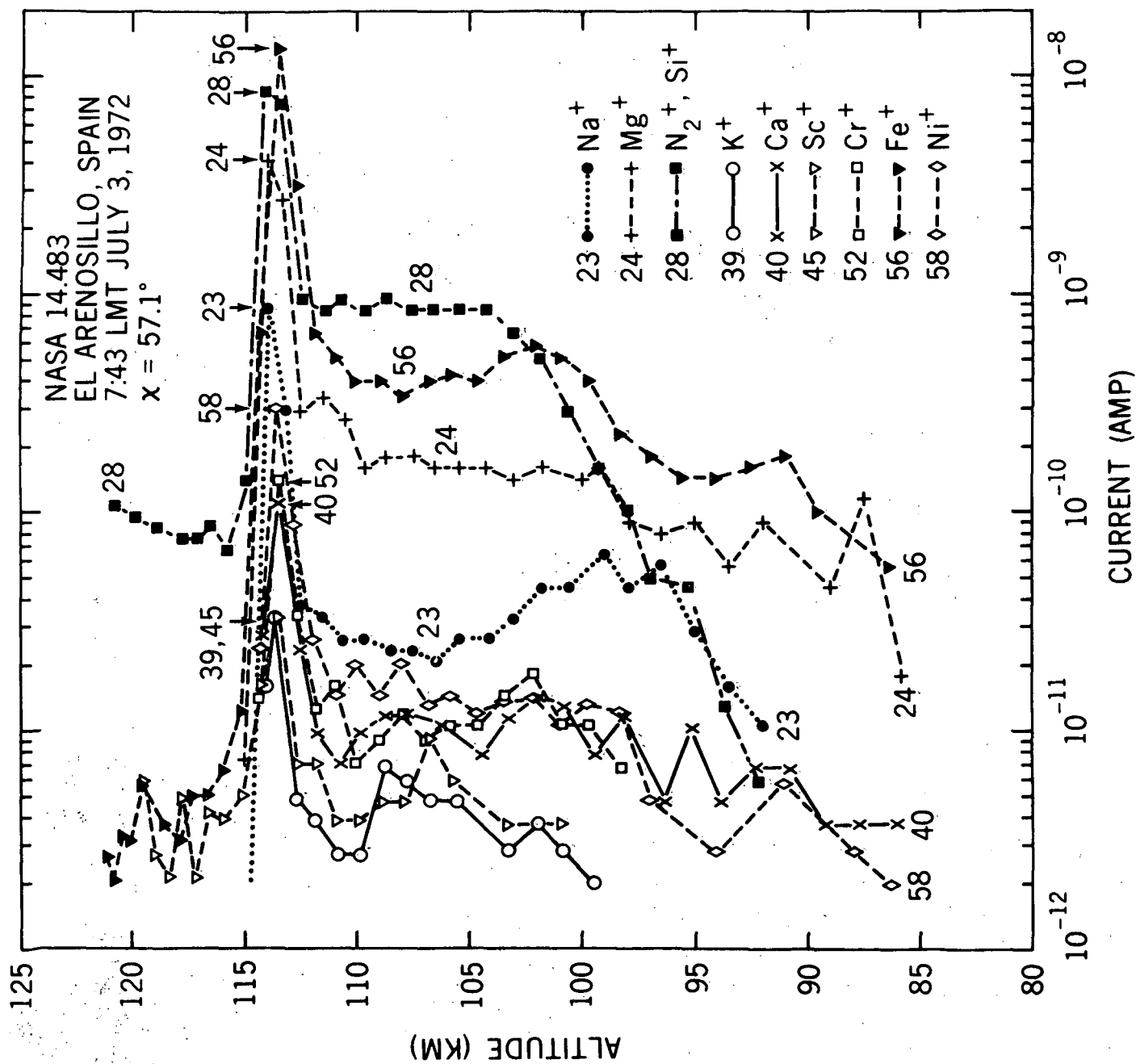
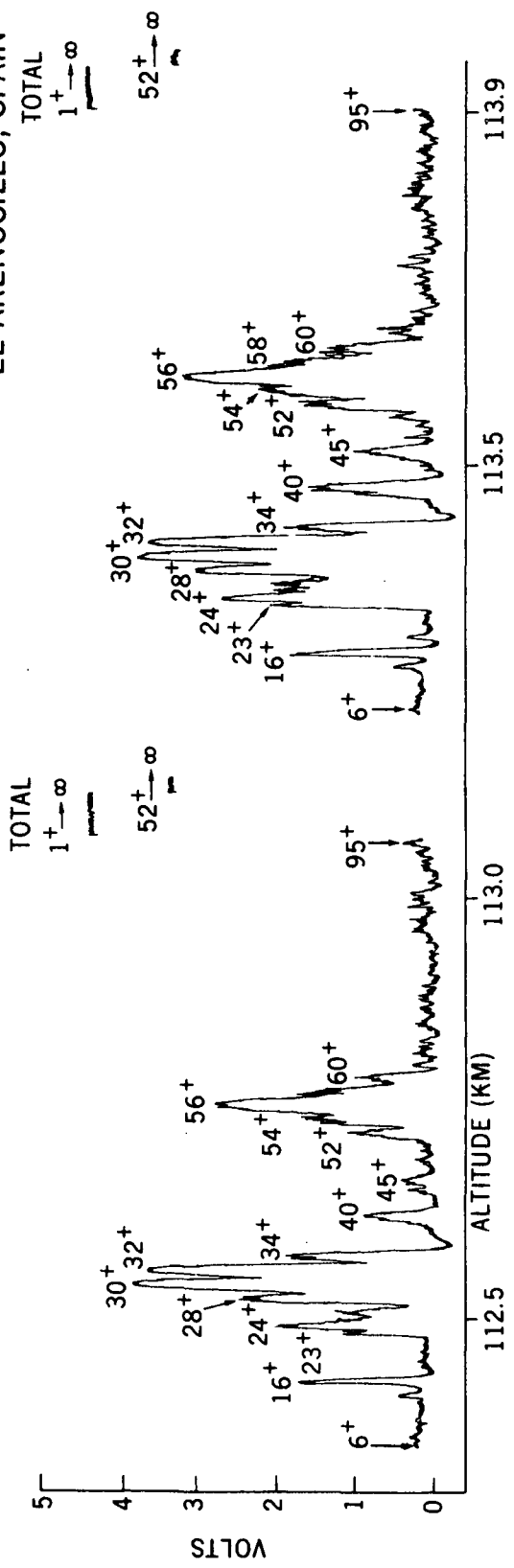


Figure 1

NASA 14.483  
 JULY 3, 1972,  $\chi=57.1^\circ$   
 EL ARENOSILLO, SPAIN



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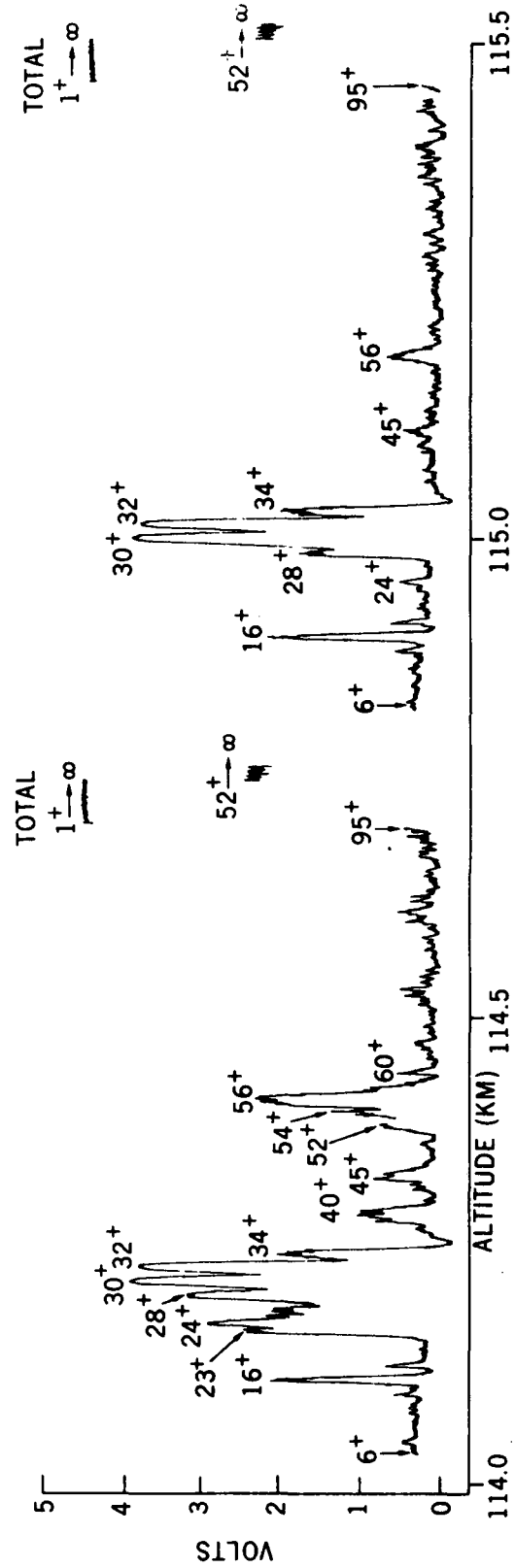


Figure 2