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FeI and NiI in comets

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Metals have been found in cometary dust by in-situ experiments onboard the Giotto and Rosetta spacecrafts[4,10] as well as in dust particles collected by the Stardust spacecraft[11]. They appear in silicate, sulfide and metal grains. Two sungrazing comets, the Great Comet of 1882[2] and C/1965 S1 (Ikeya-Seki)[9], approached the Sun so close that dust grains have vaporized, revealing lines of several metals in the coma spectrum, in particular FeI and NiI. However, it came as a surprise to find numerous FeI and NiI emission lines in high-resolution spectra of comets observed at large heliocentric distances[7], where the equilibrium temperature $T \sim 280 r^{-1/2}$K is far too low to allow sublimation of silicates ($T_{sub} \geq 1200$K) and sulfides ($T_{sub} \geq 600$K). In the present contribution, we summarize this discovery and the challenges it raises.

Dozens of FeI and NiI emission lines were recently found in the spectral region 3000-4000Å for 17 comets at heliocentric distances between 0.68 and 3.25 au[7]. These comets were observed with the high-resolution spectrograph UVES mounted on the ESO VLT. FeI and NiI lines can also be detected in archival data obtained with other telescopes, as shown in Fig.1 for comet Hyakutake. The spatial extension of the lines is very short indicating that the FeI and NiI atoms originate from the inner coma, close to the nucleus. To compute the FeI and NiI production rates we built a fluorescence model that accounts for the complex absorption structure of the solar spectrum (Swings effect). In Fig.2 we show that the FeI+NiI production rate is correlated with the production rate of major constituents of cometary ices, either H_2O or CO.

The NiI/FeI abundance ratios are shown in Fig.3. They cluster around NiI/FeI~1 whatever the comet heliocentric distance. The NiI/FeI ratio does not depend on the comet type but there is evidence (indicated by a F-test) that its variance is higher in the Jupiter-family sample than in the Oort cloud sample. This is reminiscent of the wider range of C_2/CN abundances observed in Jupiter-family comets[5].

The average abundance ratio is log(NiI/FeI)=-0.07 with a standard deviation of 0.29. This value differs from the ratio log(Ni/Fe)=-1.10±0.23 estimated in the dust of P/Halley[4] and log(NiI/FeI)=-1.11±0.09 in the coma of the sungrazing comet Ikeya-Seki[7]. The latter ratios are similar to the ratio measured in the Sun and the meteorites. Interestingly, the NiI/FeI ratio measured in the interstellar comet 2I/Borisov is in agreement with the ratio found in the solar system sample[8].

These observations raise two questions, still open. How can FeI and NiI atoms be released at such low temperatures? Why is the NiI/FeI abundance ratio one order of magnitude higher than the solar value? The release of FeI and NiI atoms from sulfides is appealing since their sublimation temperature is lower than silicates. Moreover FeNi alloys and sulfides formed in the low temperature range are Ni-rich, such as kamacite and pentlandite[6], so that their sublimation could explain the high NiI/FeI ratios we observed. Superheating is nevertheless required to reach T~600K, which might be possible if the grains are very small, like the metallic nanoparticles found in comet 81P/Wild2[11]. Collisions of cometary dust with high-velocity particles could also produce impact vapor with T~1000K[3]. Alternatively, FeI-NiI atoms could be released from organometallic complexes, yet undetected in the cometary material, such as carbonyls that have much lower sublimation temperatures. In particular $Fe(CO)_5$ and $Ni(CO)_4$ are expected to sublimate at T_{sub}~ 100K, intermediate between the sublimation temperature of H_2O and CO_2[7]. The higher sublimation rate of $Ni(CO)_4$ with respect to $Fe(CO)_5$ would naturally explain the overabundance of nickel.

More work is clearly needed to test these hypotheses, both observationnaly and theoretically. The discovery of FeI and NiI atoms in distant comets neverthless indicates that constituents of the nucleus or processes in the coma are still missing.

References

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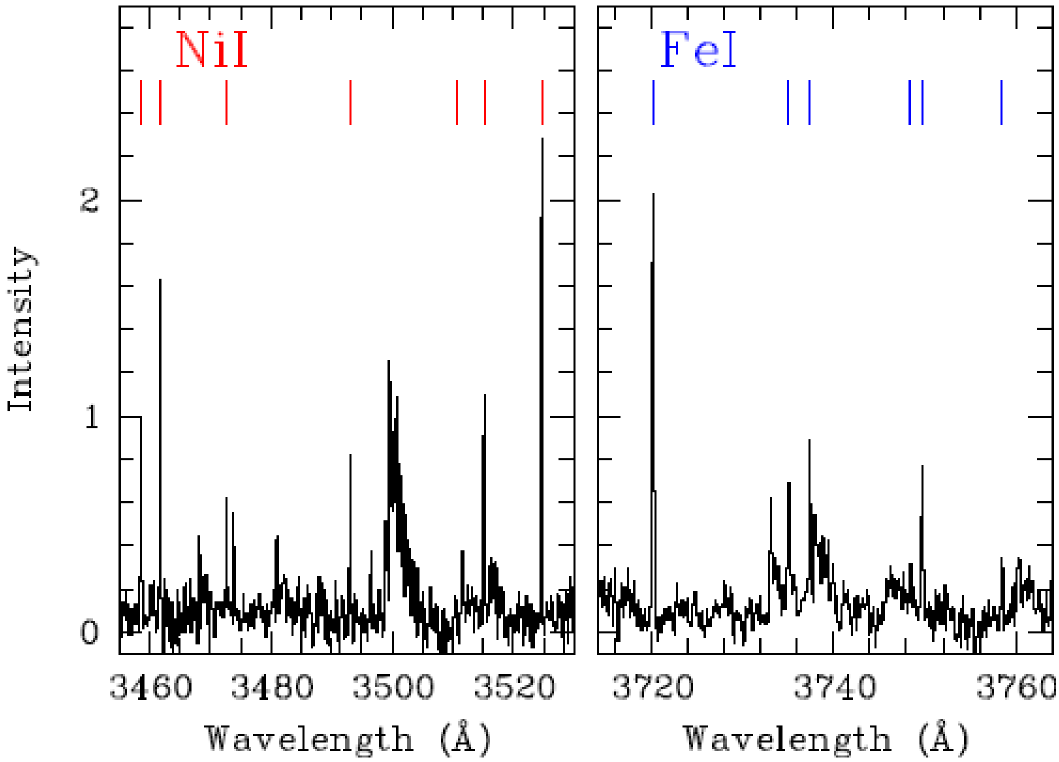

Figure 1: Example of NiI and FeI lines detected in the spectrum of comet C/1996B2 (Hyakutake) obtained on March 26, 1996[1].

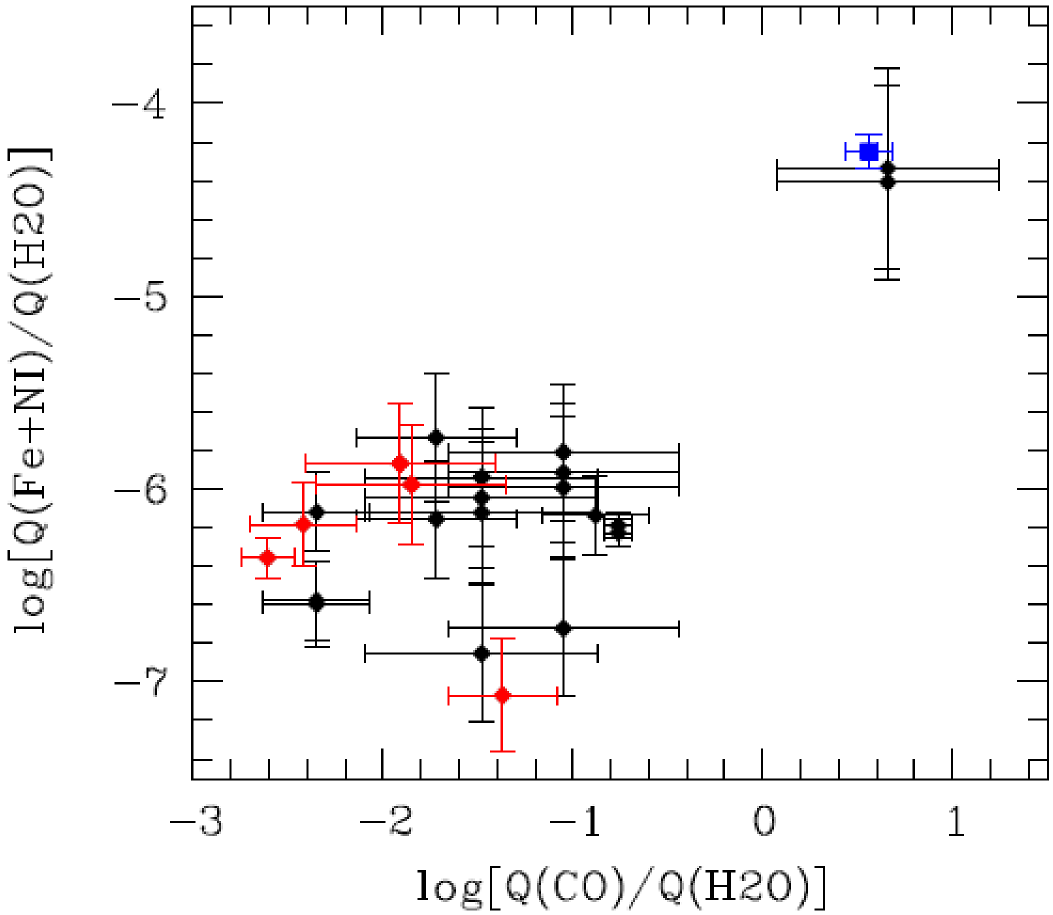

Figure 2: Abundance correlations involving CO, H_2O and FeI+NiI. Jupiter-family comets are in red. The CO-rich interstellar comet 2I (Borisov) (in blue) appears close to C/2016 R2[8].

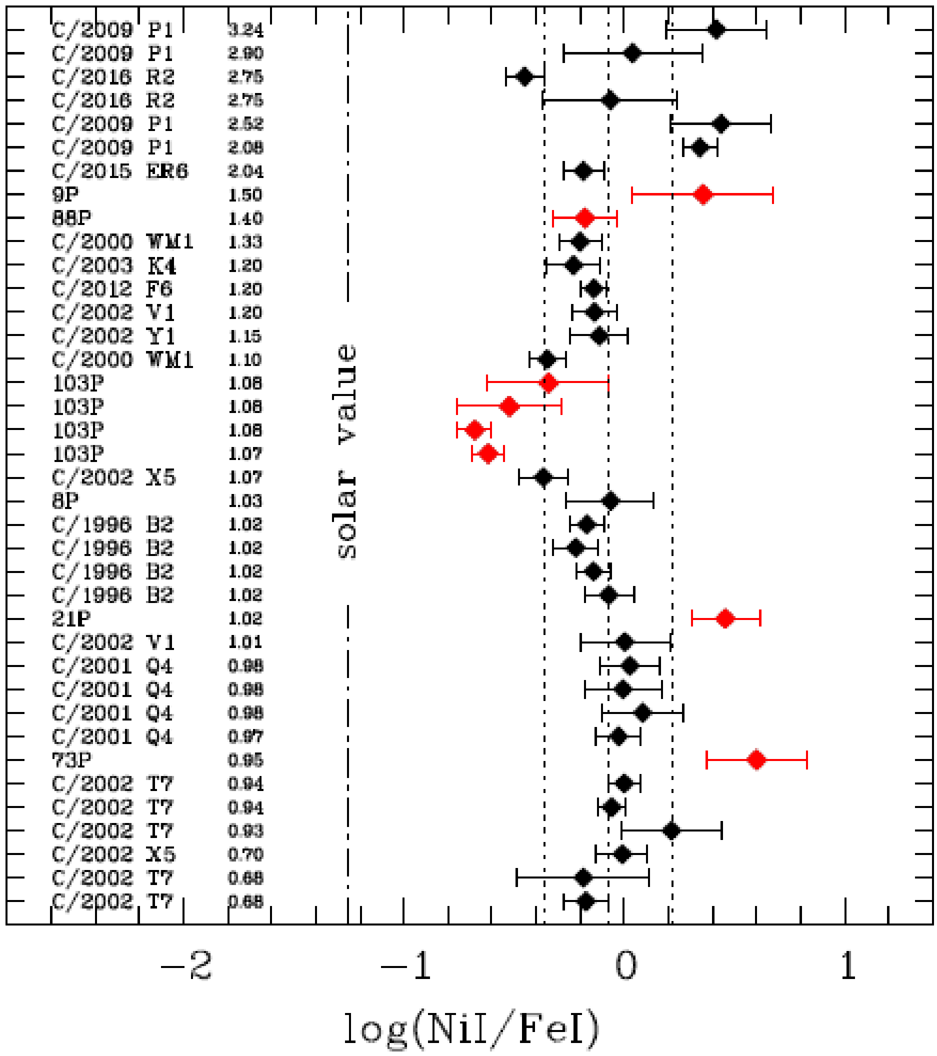

Figure 3: NiI/FeI abundance ratios for 18 solar system comets at various heliocentric distances, including C/1996B2 Hyakutake observed using 4 offset slit positions[1]. The solar Ni/Fe ratio is indicated. Jupiter-family comets are in red.