Astronomy Lab

L) Spectroscopy of Cosmic Silicate Dust

Supervisor: Harald Mutschke
Last Update: April 2026

Practical experiment in astronomy practical course

“Spectroscopy of cosmic silicate dust”

Duration: 3 hours

0. Task:

1. Determine the mineralogical structure of cosmic silicates using infrared spectroscopic measurements on analog materials based on the characteristics of the Si-O stretching vibration band.
2. Calculate the column density of cosmic silicate particles between the Sun and the galactic center from the measured mass absorption coefficient at the maximum of the specified band.

1. Fundamentals:

Cosmic dust accounts for approximately 1% of the mass of the interstellar medium in the galaxy. It consists of solid particles with sizes in the sub-micrometer range. Chemically speaking, a large proportion of this dust consists of silicates, i.e., compounds of silicon, oxygen, and other cosmically abundant elements such as magnesium and iron. Silicates can form both ordered (crystalline) and disordered (amorphous, glassy) solid structures. These can also be transformed into one another by environmental influences (high temperatures, radiation). Therefore, knowledge of the mineralogical structure allows conclusions to be drawn about the environment of the particles, e.g., about the physical conditions in the interstellar medium.

The solid-state structure of silicates consists of SiO_4 tetrahedra, which can be linked together in one or more dimensions via the corners occupied by the O atoms. Crystalline silicates are divided into island silicates (olivines) with isolated tetrahedra, chain silicates (pyroxenes), layer silicates, and SiO_2 modifications with three-dimensional networks (quartz, cristobalite). The incorporation of metal ions (“network modifiers”) reduces the degree of cross-linking. Amorphous silicates exhibit several types of networks simultaneously, but one of them usually dominates.

The mineralogical structure of solids can be elucidated by analyzing their vibrational spectra with infrared spectroscopy. For silicates, these spectra are dominated by the stretching and deformation vibrations of the SiO_4 tetrahedra. Their excitation causes infrared absorption or emission bands at wavelengths of approximately 8-12 and 15-35 micrometers, respectively. Crystalline silicates exhibit many sharp bands in these ranges, while disordered silicates are characterized by broad bands, which can be imagined as resulting from the broadening and merging of the crystalline vibration modes.

2. Experiment procedure:

1. The transmission spectra of six different silicates are to be measured using a Fourier transform infrared spectrometer. To do this, the silicate samples are mixed in a ratio of 1:500 with an IR-transparent material (KBr) and pressed into small pellets weighing 200 mg and measuring 13 mm in diameter. One such pellet is prepared by the students; the others are available at the experiment site, including a comparison pellet made of pure KBr. A precision balance is available for weighing the sample. Approx. 0.4 mg silicate are needed; small losses during preparation should be considered. Mixing is carried out using a mortar and pestle, and pressing is carried out in a pressing tool under vacuum, using a laboratory press at a load of 10 t.

2. The measurement with the FTIR spectrometer (Bruker 113v) is carried out by the students after receiving instructions on how to operate the instrument and the software. The samples, including the reference pellet, are placed in a motorized sample changer. First, the intensity spectrum of the instrument I_{KBr} , together with influences by the KBr matrix material, is measured by placing the reference pellet into the spectrometer beam. The measured spectra of the silicate samples are then normalized to this and yield the respective transmission coefficients $T_{silicate} = I_{sample}/I_{KBr}$. All quantities are functions of the wavenumber, which is defined as the reciprocal wavelength and is given in the unit 1/cm. The instrument settings for these measurements are:

   Source: Globar,
   Aperture: 10
   Beamsplitter: KBr
   Filter: Open
   Detector: DTGS

   They can be loaded from the configuration file „Prakt.XPM“. The accessible wavenumber range with these settings is 5000cm^{-1} – 400cm^{-1}, corresponding to 2µm – 25µm in wavelength.

3. The measured transmission spectra of the silicates are then to be compared with an astronomical spectrum, which was taken by the Infrared Space Observatory (ISO) in the direction towards the galactic center (Lutz et al. 1996, see figure below). For this purpose, the wavelength positions, shape, and width (FWHM) of the silicate absorption bands (Si-O stretching vibration at 8-12µm and longer wavelength bands, if appropriate) should be analyzed in the observed and the laboratory spectra. The laboratory spectrum which reproduces the observed bands best should be identified and conclusions about the structure of the silicates in interstellar space should be drawn and discussed.

4. From the experimental spectrum chosen in 3., the mass-normalized absorption coefficient κ of the corresponding material, in the peak of the Si-O stretching band, must be calculated. This is based on the relationship $T_{Silicate} = \exp(-\kappa * \sigma_{Silicate})$, where the column density $\sigma_{Silicate}$ represents the quotient of the silicate mass in the pellet and its cross-sectional area (at 13mm diameter).

5. The astronomical spectrum can be seen as the result of a similar transmission experiment as the laboratory spectroscopy, with the “light source” Sgr A* and a

"sample" of finely dispersed silicate powder in the "beam" recorded by the ISO telescope instrument. This spectrum has not yet been normalized to the undisturbed spectrum of the "light source". Nevertheless, the transmission coefficient of the "sample" in the minimum of the silicate absorption band can be estimated from the measured flux, ratioed to an estimated reference flux value in the assumed absence of the band (connect spectral points left and right from the band and read in the middle). Taking this ratio as the quantity $T_{silicate}$, we can calculate the column density of the silicate on the line of sight to the galactic center from the formula given in 4., using the κ value derived above for our silicate dust analog material.

6. It is instructive to transform the column density calculated above into a number density N/V of dust particles in space. To do so, we can divide $\sigma_{Silicate}$ by the path length l over which the sample is dispersed, i.e., the distance to the galactic center, and by the mass of a single dust particle ($\sigma_{Silicate} = m / A = N*m_{Particle} / (V/l) = (N/V) *m_{Particle}*l$). For calculating $m_{Particle}$, we may assume a particle diameter of 100 nm and a mass density of the silicate of 3 g/cm^3.

3. Materials and equipment:

1. Silicon dioxide samples (quartz glass and rock crystal)
2. $(Mg,Fe)SiO_3$ samples (magnesium silicate glass and bronzite)
3. $(Mg,Fe)_2SiO_4$ samples (sol-gel silicate and olivine)

4. Potassium bromide embedding material
5. Analytical balance
6. Mortar, pestle
7. Pressing tool
8. Spatula, brush

9. FTIR spectrometer Bruker 113v
10. Infrared spectrum of the galactic center (ISO-SWS, from [1])

4. Literature:

[1] D. Lutz, H. Feuchtgruber, R. Genzel, et al., "SWS observations of the Galactic Center", Astron. Astrophys. 315 (1996), L269
[2] F. Kemper, W.J. Vriend, A.G.G.M. Tielens, „The absence of crystalline silicates in the diffuse interstellar medium", Astrophys. J. 609 (2004), 826

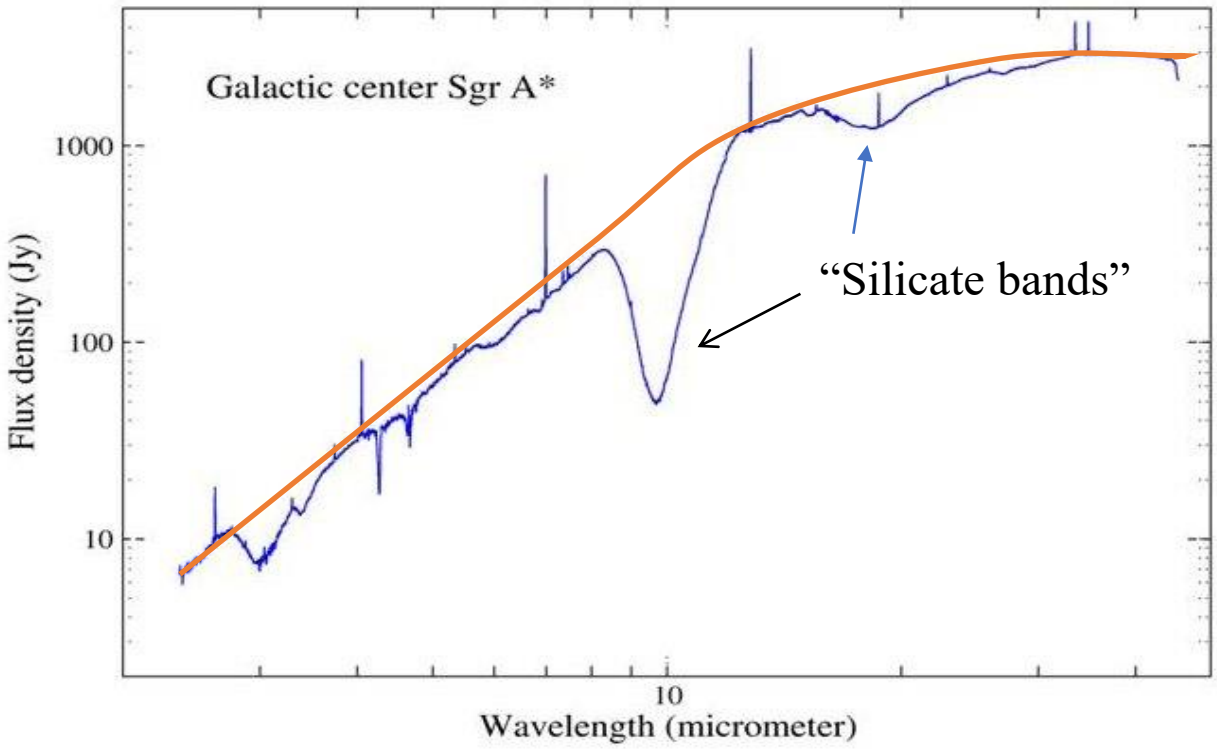

Fig. 1 ISO/SWS spectrum of the galactic center (Lutz et al. 1996, blue curve), the orange line shows an assumed spectrum without the absorption bands of the dust located on the line of sight.