Evolution of cosmic dust in the Milky Way and in the distant Universe

Properties of dust in galactic interstellar clouds

Changes of dust properties in dark clouds

By comparing maps of extinction and infrared emission, we found moderate increase of the far-infrared emissivity in dark clouds. This feature is usually interpreted as the growth of interstellar dust grains by coagulation or by ice-mantle formation. The growth of dust particles should also be observed in the optical wavelength range by the change of extinction properties at different wavelengths; these changes are usually described by one single parameter, the ratio of total over selective extinction, R_V. To test the relationship between the far-infrared emissivity and R_V, we observed six target fields with the Wide Field Camera mounted on the Isaac Newton Telescope (Observatorio del Roque de los Muchachos, La Palma) in B, V and R photometric bands, on May 29-30, 2006. The target fields were previously observed by the ISOPHOT instrument on board the ISO satellite in the far-infrared. The data reduction of the ISO/ISOPHOT measurements has been finished, the data processing of the INT/WFC measurements are still in progress. *(Kiss et al., MNRAS Vol. 373, p. 1213, 2006.)*

Time variable dust emission in young stellar objects

Infrared variability as a new possibility to explore circumstellar disk structure

The infrared emission of young stellar objects is in almost always thermal radiation of dust grains. Careful analysis of ground-based and spaceborne infrared observations revealed variability of a growing number of young stellar objects in the 1-100 umm wavelength range. We developed a new method, in which the lightcurves at different wavelengths can be interpreted via comparison with synthetic time-dependent spectral energy distributions. This technique may place strong constraints on basic assumptions of circumstellar disk models, and serve as an efficient diagnostic tool of the circumstellar structure. *(Ábrahám et al., Proc. of Visions for infrared astronomy, Paris, 2006)*

Long-term infrared variability of the UX Ori-type star SV Cep

We investigated the long-term optical-infrared variability of SV Cep and explained it in the context of an existing UX Ori (UXOR) dust disc model. A 25-month monitoring programme was completed with the Infrared Space Observatory in the 3.3-100 micron wavelength range. Following a careful data reduction, the infrared light curves were correlated with the variations of SV Cep in the V band. A remarkable correlation was found between the optical and the far-infrared light curves. In the mid-infrared regime, the amplitude of variations was smaller, with a hint for a weak anti-correlation with the optical changes. In order to interpret the observations, we modelled the spectral energy distribution of SV Cep assuming a self-shadowed disc with a puffed-up inner rim, using a two-dimensional radiative transfer code. We found that modifying the height of the inner rim, the wavelength dependence of the long-term optical-infrared variations was well reproduced, except the mid-infrared domain. The origin of variation of the rim height might be fluctuation in the accretion rate in the outer disc. The mid-infrared behaviour was tested by adding an optically thin envelope to the system, but this model failed to explain the far-infrared variability. Infrared variability was a powerful tool to discriminate between models of the circumstellar environment. The proposed mechanism of variable rim height may not be restricted to UXOR stars, but might be a general characteristic of intermediate-mass young stars. *(Juhász et al., MNRAS Vol. 374, p. 1242, 2007.)*

Infrared emission and dust properties in eruptive young stellar objects

The outburst of the eruptive young star OO Serpentis between 1995 and 2006

OO Serpentis is a deeply embedded pre-main sequence star in the Serpens NW star-forming region. The star went into outburst in 1995 and gradually faded afterwards. In many respects its eruption resembled the well-known FU Orionis-type (FUor) or EX Lupi-type (EXor) outbursts. Since very few such events have ever been documented at infrared wavelengths, our aim was to study the temporal evolution of OO Ser in the infrared. OO Ser was monitored with the Infrared Space Observatory in the 3.6-100 μm wavelength range, starting 4 months after peak brightness and covering a period of 20 months. Eight years later, in 2004-2006 we again observed OO Ser at 2.2 and 12 μm from the ground and complemented this dataset with archival Spitzer observations also from 2004. We analysed these data with special attention to source confusion and constructed light curves at 10 different wavelengths as well as spectral energy distributions. The outburst caused brightening in the whole infrared regime. According to the infrared light curves, OO Ser started a wavelength-independent fading after the peak brightness. Later the flux decay became slower but stayed practically wavelength-independent. The fading is still ongoing, and current fading rates indicate that OO Ser will not return to quiescent state before 2011. The outburst timescale of OO Ser seems to be shorter than that of FUors, but longer than that of EXors. The outburst timescale and the moderate luminosity suggest that OO Ser is different from both FUors and EXors, and shows some similarities to the recently erupted young star V1647 Ori. Based on its SED and bolometric temperature, OO Ser seems to be an early class I object, with an age of <105 yr. As proposed by outburst models, the object is probably surrounded by an accretion disc and a dense envelope. This picture is also supported by the wavelength-independence of the fading. Due to the shorter outburst timescales, models developed for FUors can only work for OO Ser if the viscosity parameter in the circumstellar disc, α, is set to an order of magnitude higher value than usual for FUors. *(Kóspál et al., Astron. Astrophys., 470, p.211, 2007.)*

High-resolution polarimetry of Parsamian 21: the structure of an edge-on FU Ori disc

We analysed the first high spatial resolution near-infrared direct and polarimetric observations of Parsamian 21, obtained with the VLT/NACO instrument. We complemented these measurements with archival infrared observations, such as HST/WFPC2 imaging, HST/NICMOS polarimetry, Spitzer IRAC and MIPS photometry, Spitzer IRS spectroscopy as well as ISO photometry. Our main conclusions are the following: (1) we argue that Parsamian 21 is probably an FU Orionis-type object; (2) Parsamian 21 is not associated with any rich cluster of young stars; (3) our measurements reveal a circumstellar envelope, a polar cavity and an edge-on disc; the disc seems to be geometrically flat and extends from approximately 48 to 360 AU from the star; (4) the SED can be reproduced with a simple model of a circumstellar disc and an envelope; (5) within the framework of an evolutionary sequence of FUors proposed by Green et al. (2006) and Quanz et al. (2007), Parsamian 21 can be classified as an intermediate-aged object.

The outburst of V1647 Orionis. *In early 2004 a young star, called V1647 Ori, brightened significantly in the Orion constellation. Our group initiated a number of projects in order to characterize and study the eruption via studying the thermal emission of the circumstellar dust.*

The 2004-2006 Outburst and Environment of V1647 Ori

We studied the brightness and spectral evolution of V1647 Ori during its recent outburst in the period 2004 February-2006 September. We performed a photometric follow-up in the bands V, RC, IC, J, H, and Ks, as well as visible and near-IR spectroscopy. The main results derived from combining our data with those published by other authors are as follows: the brightness of V1647 Ori stayed more than 4 mag above the preoutburst level until 2005 October, when it started a rapid fading. In the high state we found a periodic component in the optical light curves with a period of 56 days. The delay between variations of the star and variations in the brightness of clumps of nearby nebulosity corresponds to an angle of 61deg+/-14deg between the axis of the nebula and the line of sight. The overall appearance of the infrared and optical spectra did not change in the period 2004 March-2005 March, although a steady decrease of H I emission-line fluxes could be observed. In 2006 May, in the quiescent phase, the He I 1.083 μm line was observed in emission, contrary to its deep blueshifted absorption observed during the outburst. The J-H and H-Ks color maps of the infrared nebula reveal an envelope around the star whose largest extension is about 18" (0.03 pc). The color distribution of the infrared nebula suggests reddening of the scattered light inside a thick circumstellar disk. Comparison of the Ks and Hα images of McNeil's Nebula, the conical nebulosity illuminated by V1647 Ori, shows that HH 22A, the Spitzer infrared source, and the bright clump C of the nebula may be unrelated objects. We show that the observed properties of V1647 Ori could be interpreted in the framework of the thermal instability models of Bell and coworkers. V1647 Ori might belong to a new class of young eruptive stars, defined by relatively short timescales, recurrent outbursts, a modest increase in bolometric luminosity and accretion rate, and an evolutionary state earlier than that of typical EXors. *(Acosta-Pulido et al, Astronomical Journal, Vol. 133, p. 2020, 2007.)*

First AU-scale observations of V1647 Orionis with VLTI/MIDI

The young eruptive star V1647 Ori was observed with MIDI, the mid-infrared interferometric instrument at the Very Large Telescope Interferometer (VLTI), on March 2, 2005. We presented the first spectrally resolved interferometric visibility points for this object. Our results showed that (1) the mid-infrared emitting region was extended, having a size of approximately 7 AU at 10 micron; (2) no signatures of a close companion could be seen; (3) the 8-13 micron spectrum exhibited no obvious spectral features. Comparison with similar observations of Herbig Ae stars suggested that V1647 Ori probably possessed a disk of moderate flaring. A simple disk model of T~r^(-0.53), surface density of D~r^(-1.5) and M_d=0.05 solar mass was able to fit both the spectral energy distribution and the observed visibility values simultaneously. *(Ábrahám et al., A&A 449, p. L13, 2006.)*

Dynamics during outburst· Multiepoch interferometric observations of V1647 Ori

It is hypothesised that all low-mass young stellar objects undergo eruptive phases during their early evolution. Such phases can last some months – several decades, and are characterised by 2-6 magnitude optical brightening. These eruptions are thought to be due to highly increased mass accretion from the disk. Understanding these eruptive objects might be crucial for the understanding of the evolution of Sun-like stars and their planetary systems. Monitoring the variations of source properties of these outbursting objects is the way to constrain the eruption model. The outburst of V1647 Ori (2003-06) offered a rare opportunity to investigate such accretion event. V1647 Ori was targeted in a large number of observing programs during this recent outburst. By means of our interferometry observing campaign, we aimed at investigating/tracing the temporal evolution of the structure of the inner (few AU) circumstellar environment of V1647 Ori, which plays an important role in the outburst. We observed V1647 Ori with MIDI on the VLTI during this outburst. We used the radiative transfer code MC3D to fit the spectral energy distributions and interferometry data from different epochs. The comparison allows us to trace structural changes in the system on AU-scales. Here we present mid-infrared interferometry data obtained in the second successful observing run in September 2005 and the results of the modeling of four different stages of the outburst. The results show the disk and the envelope are similar to those of non-eruptive young star and the variation of the accretion rate during the outburst. Furthermore we found evidence of significant changes in the structure of the circumstellar matter. Most of our results fit in the canonical picture of young eruptive stars. Although this study could not reveal the trigger and mechanism of the outburst, but provided dynamical information from the regions of the innermost few AUs the system: a surprising episode accompanying the end of the outburst is indicated. *(Mosoni et al., Astron. Astrophys. to be submitted, 2010.)*

The outburst of EX Lupi. *In January 2008 the amateur astronomer Albert Jones reported that EX Lupi, the prototype of the eruptive young star class EXors, went into outburst again, and was brighter than ever before. For us it was a unique opportunity to learn about the outburst mechanism and about the changes of dust grains in the circumstellar disk. The outburst finished in September 2008. We performed a number of observations using ESO instruments and the Spitzer Space Telescope.*

EX Lupi in quiescence

EX Lupi is the prototype of EXors, a subclass of low-mass pre-main sequence stars whose episodic eruptions are attributed to temporarily increased accretion. In quiescence the optical and near-infrared properties of EX Lup cannot be distinguished from those of normal T Tau stars. Here we investigate whether it is the circumstellar disk structure that makes EX Lup an atypical Class II object. During outburst the disk might undergo structural changes. Our characterization of the quiescent disk is intended to serve as a reference for studying the physical changes related to one of EX Lupi's strongest known eruptions in 2008 Jan-Sep. We searched the literature for photometric and spectroscopic observations including ground-based, IRAS, ISO, and Spitzer data. After constructing the optical-infrared spectral energy distribution (SED), we compared it with the typical SEDs of other young stellar objects and modeled it using the Monte Carlo radiative transfer code RADMC. We determined the mineralogical composition of the 10 μm silicate emission feature and also gave a description of the optical and near-infrared spectra. The SED is similar to that of a typical T Tauri star in most aspects, though EX Lup emits higher flux above 7 μm. The quiescent phase data suggest low-level variability in the optical-mid-infrared domain. By integrating the optical and infrared fluxes, we derived a bolometric luminosity of 0.7 Lsun. The 10 μm silicate profile could be fitted by a mixture consisting of amorphous silicates, but no crystalline silicates were found. A modestly flaring disk model with a total mass of 0.025 Msun and an outer radius of 150 AU was able to reproduce the observed SED. The derived inner radius of 0.2 AU is larger than the sublimation radius, and this inner gap sets EX Lup apart from typical T Tauri stars. *(Sipos et al., Astron. Astrophys., Vol. 507, p. 881, 2009.)*

Optical Spectra and Light Curve at early phases of the outburst

In collaboration with the Florida Institute of Technology we used their new spectrograph to obtain optical spectroscopic observations of EX Lupi. In 2008 January-February, at the beginning of the outburst, the star reached the highest peak brightness ever observed. The outburst spectra differ significantly from the quiescent ones, displaying many strong metallic features as well as a variable Hβ line. *(Kóspál et al., IBVS 5819, 1, 2008.)*

Episodic formation of cometary material in the outburst

The Solar System originated in a cloud of interstellar gas and dust. The dust is in the form of amorphous silicate particles and carbonaceous dust. The composition of cometary material, however, shows that a significant fraction of the amorphous silicate dust was transformed into crystalline form during the early evolution of the protosolar nebula. How and when this transformation happened has been a question of debate, with the main options being heating by the young Sun and shock heating. Using observations taken with the Spitzer Space Telescope, we discovered mid-infrared features in the outburst spectrum of EX Lupi that were not present in quiescence. We attributed them to crystalline forsterite, and concluded that the crystals were produced through thermal annealing in the surface layer of the inner disk by heat from the outburst, a process that has hitherto not been considered. The observed lack of cold crystals excludes shock heating at larger radii. *(Ábrahám et al., Nature, Vol. 459, p. 224, 2009.)*

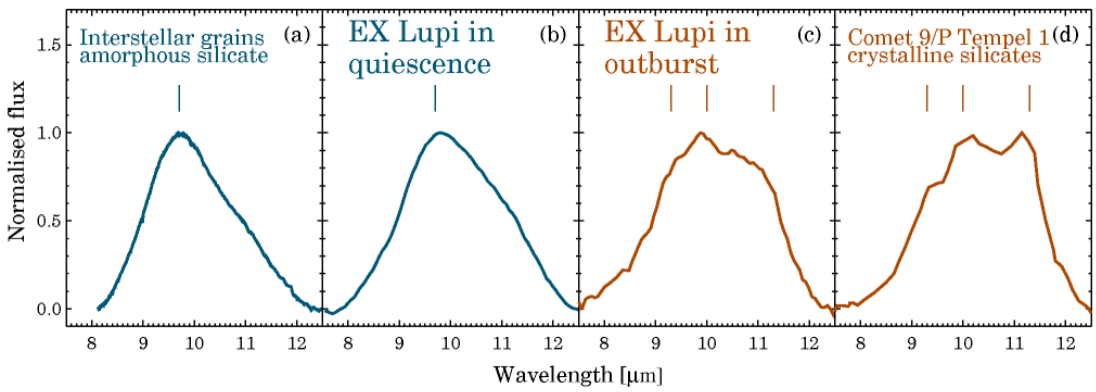

Figure: Silicate emission in the 10 micrometer range. (a) amorphous grains in the interstellar medium; (b) Spitzer spectrum of EX Lup in 2005, in quiescent phase; (c) our Spitzer spectrum of EX Lup in the middle of the present outburst; (d) Spitzer IRS spectrum of the ejecta from comet 9/P Tempel 1 during the Deep Impact experiment. After a linear baseline removal, the spectra were normalized to their peak value. Panels (a) and (b) exhibit the triangular shape silicate profile attributed to amorphous silicate grains; vertical dash marks peak wavelength. In panels (c) and (d) peaks and shoulders due to crystalline silicates (mainly forsterite; red dashes) can be identified. ***The spectrum of EX Lup changed during its outburst, giving for the first time clear signs of on-going crystal formation.***

Fundamental Vibrational Transition of CO during Outburst of EX Lupi in 2008

We obtained monitoring observations of EX Lup in the CO fundamental band of 4.6–5.0 μm during its outburst in 2008. The observations were carried out at the VLT and the Subaru Telescope in 6 epochs from April to August 2008, covering the plateau of the outburst and the return to a quiescent state. The CO spectra consists of 3 components: outburst, quiescent emission lines, and possible disk wind absorption. The outburst spectrum is characterized by broad line emission (FWZI > 200 km s−1) from highly excited vibrational levels (v6). The rotational temperature is Tx =4000–4500 K, while the vibrational temperature is significantly lower (Tv 2000 K). The broad emission lines are short lived, decaying on the same timescale as the optical outburst. The line profiles are double peaked, implying the emitting gas is orbiting around the star at 0.03–0.4 AU. The quiescent component is characterized by narrow emission lines (50 km s−1 in FWHM) near the systemic velocity of EX Lup with a constant equivalent width (1.2–1.7)°—10−4 μm throughout the whole observing epochs. These emission lines appear exclusively in v=1-0 with rotational excitation temperatures 3100–3700 K. The velocity width translates to orbiting radius 0.4 AU, which is directly outside the outburst region. The disk wind appeared toward later epochs as absorption lines at –80 km s−1 on the blue shoulder of the quiescent emission lines. The temporal variation of the CO spectra indicates the presence of definite outer boundary around high accretion region. The outburst contained within small disk radius favors localized disk instability, rejecting the mechanisms that involves global disk instability unlikely, such as unidentified binary companion, or infall of protoplanetary cores. *(Goto et al., Astrophysical Journal, to be submitted, 2010.)*

The 2008 outburst of EXLup - Silicate crystals in motion

EXLup is the prototype of the EXor class of eruptive young stars. These objects show optical outbursts which are thought to be related to runaway accretion onto the star. In our previous study we observed in-situ crystal formation in the disk of EXLup during its recent outburst in 2008, making the object an ideal laboratory to investigate circumstellar crystal formation and transport. This outburst was followed by a campaign of ground-based and Spitzer Space Telescope observations. We modeled the spectral energy distribution of EXLup in the outburst from optical to millimeter wavelengths with a 2D radiative transfer code. Our results show that the shape of the SED at optical wavelengths is rather consistent with a single temperature blackbody than a temperature distribution. We also found that this single temperature component emitted 80–100% of the total accretion luminosity. We concluded that a thermal instability, the currently accepted model of EXor outbursts, was likely not the triggering mechanism of the 2008 outburst of EXLup. Our mid-infrared Spitzer spectra revealed that the strength of all crystalline bands between 8 and 30 μm increased right after the end of the outburst. Six months later, however, the crystallinity in the 10 micron complex decreased. We modeled the midinfrared spectral evolution of EXLup with a 2D radiative transfer code and a 1+1D vertical mixing code. Our results show that, although vertical mixing should be stronger during the outburst than in the quiescent phase, fast radial transport of crystals (e.g., by stellar/disk wind) was required to reproduce the observed mid-infrared spectra. *(Juhász et al., Astrophysical Journal, to be submitted, 2010.)*

Near-infrared spectroscopy of EX Lupi in outburst

We performed medium-resolution near-infrared spectroscopy of the young eruptive star EX Lup, taken during its extreme outburst in 2008. We detected several emission lines (H, He, metals, CO).

By analysing these lines, we draw conclusions about the physical conditions in the emitting gas. *(Kóspál et al., Astrophyis. Journal, in preparation, 2010.)*

Properies of debris dust

Investigation of the Vega-phenomenon among F-type stars

One of the major discoveries of the IRAS mission was that main-sequence stars can be accompanied by circumstellar dust disks (Vega phenomenon). We observed a sample of 78 Vega candidate stars with the IRS and MIPS instruments on-board the Spitzer Space Telescope. All stars were in the spectral range of F0-F9, resulting in a rather homogeneous sample in terms of stellar mass and luminosity. Our investigation focused on the following issues: (i) the temporal evolution of debris disks, concentrating on the evolution of the geometrical structure of the disk; (ii) individual systems with very high fractional luminosity; (iii) old stars with warm debris disks; and (iv) debris disks in young moving groups. Our results can be used to verify model predictions for F stars, and they can also be compared with the outcome of similar programs dedicated to A- and G-type stars. *(Moór et al. Astrophysical Journal, Vol. 644, p. 525, 2006; Moór et al., Astrophysical Journal, in preparation, 2010.)*

The Discovery of New Warm Debris Disks Around F-type Stars

We discovered four rare debris disks with warm excesses around F stars, significantly increasing the number of such systems known in the solar neighborhood. Three of the disks are consistent with the predictions of steady-state planetesimal disk evolution models. The oldest source, HD 169666, displays a dust fractional luminosity too high to be in a steady state and we suggest that this system recently underwent a transient event of dust production. In addition, two spectra of this star separated by approximately three years show silicate emission features, indicative of submicron- to micron-sized grains. We argue that such small grains would be rapidly depleted and their presence in both spectra suggests that the production of small dust is continuous over a timescale of at least a few years. We predict that systems showing variable mid-infrared spectra, if they exist, will provide valuable help in distinguishing the possible scenarios proposed for dust replenishment.

Properies of cosmic dust in high-z galaxies

A Far Infrared Study of SN Ia host galaxies

We observed 50 high-z ($0.1 < z < 1$) SN Ia host galaxies with the MIPS camera on board the Spitzer Space Telescope at the three photometric bands (24, 70 and 160 microns). The galaxies were selected to be detectable up to z~ 1. Their 24, 70 and 160 micron Hubble-diagrams (i.e. redshift vs. brightness) provide information about the dust content of the galaxies, and show whether the visible-light observations should be corrected for an unexpected dust content. Out of the 50 high-z ($0.1 < z < 1$) SN Ia host galaxies 8 were detected at 24 and only 1 at 70 micron. This galaxy is the brightest among those detected in 24 micron. The observed brightness of the detected hosts can be compared with the IRAS galaxies assuming an appropriate SED after K-correction. The low percentage of detected hosts in the whole sample may indicate that most of the hosts do not contain anomalous amount of dust. We are just at the beginning of the detailed analysis of the data and more comprehensive results are expected in the future. *(Balázs et al., Proc. of Visions for Infrared Astronomy, Paris, 2006).*