Cosmic Crystals:
Studies in Astromineralogy

Habilitationskolloquium

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10th October 2011

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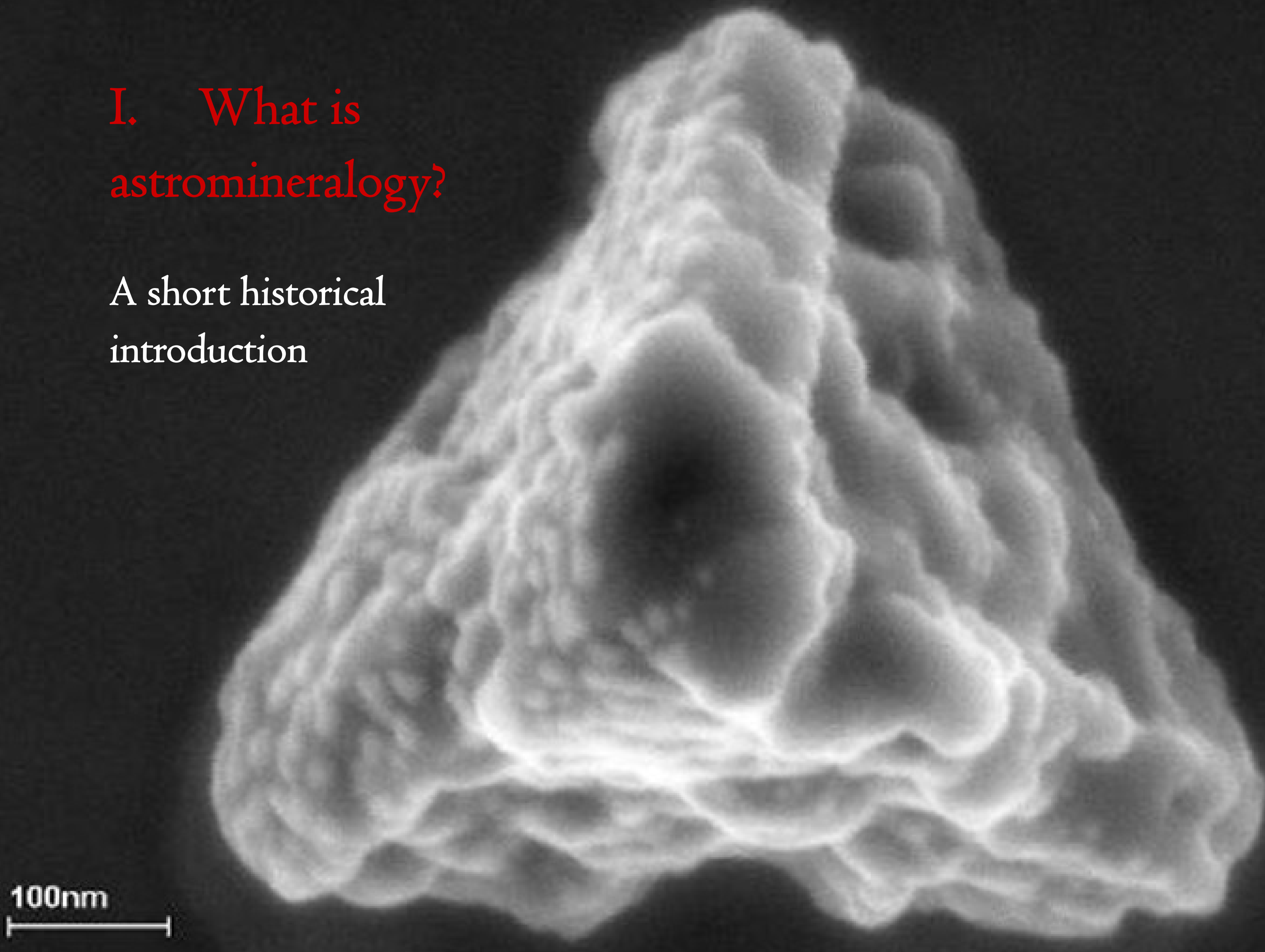
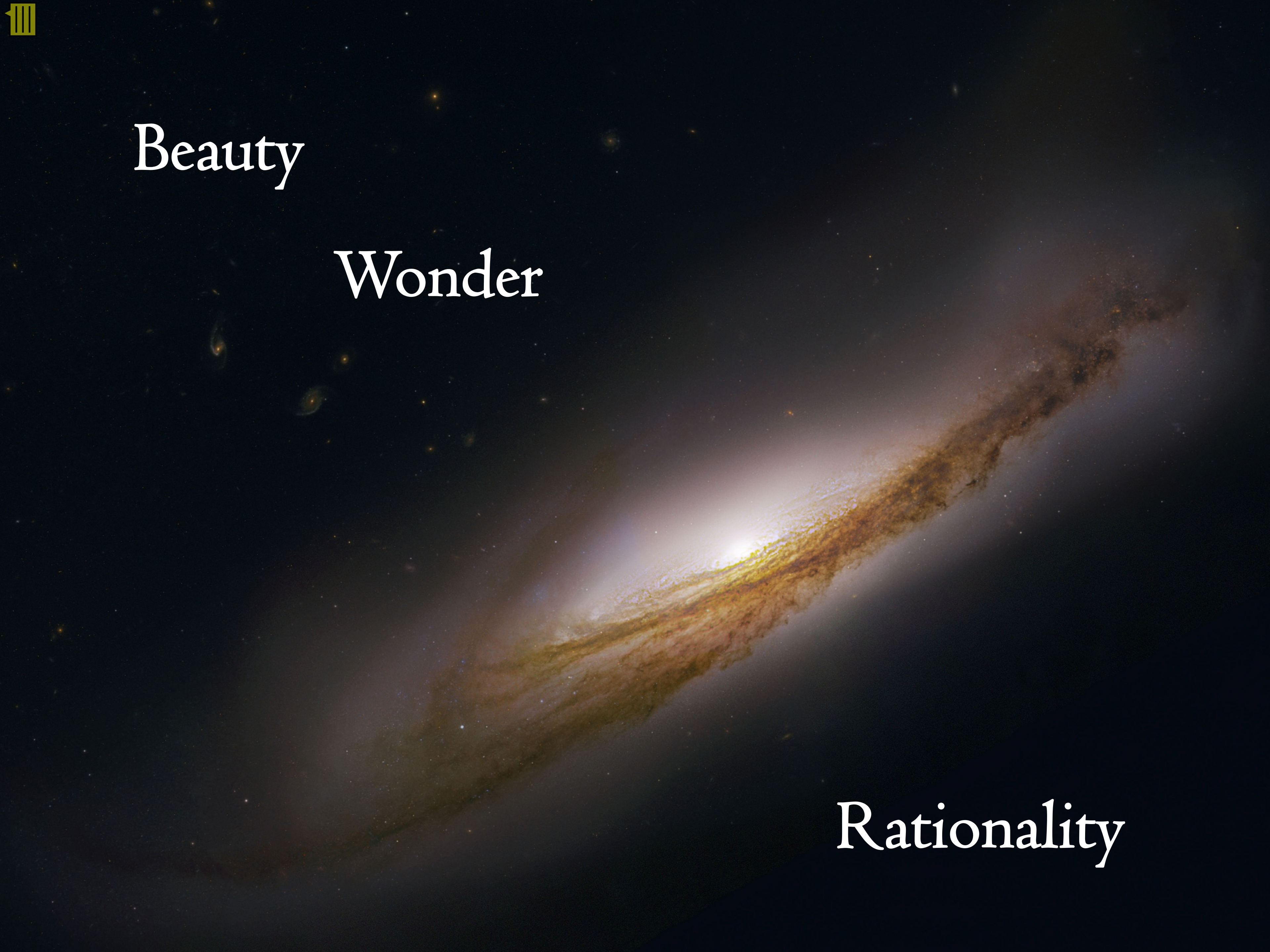
AIU JENA

I. What is astromineralogy?

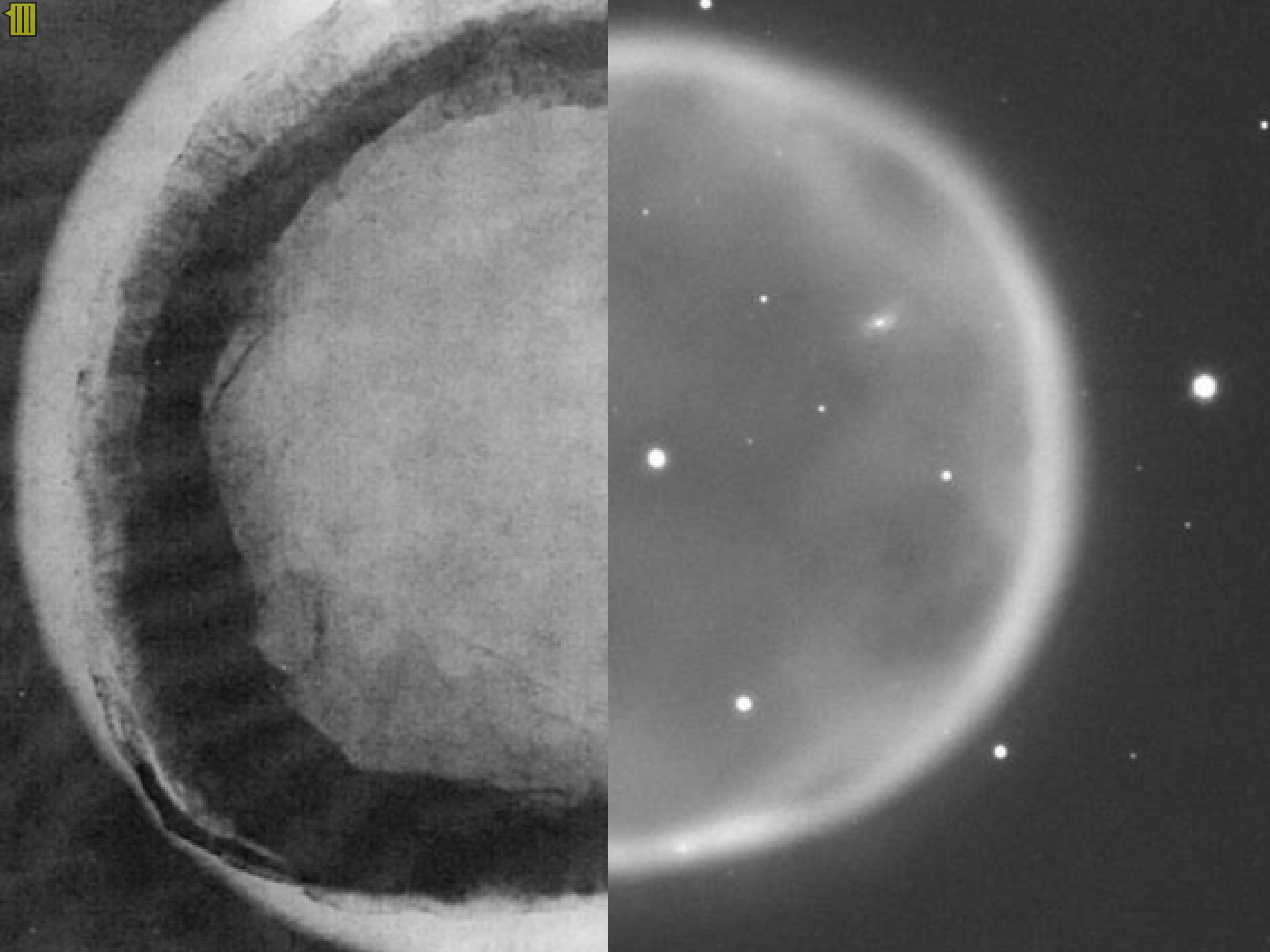
A short historical introduction



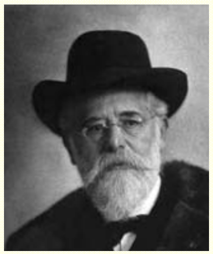
Presolar SiC tetrahedron
from the Murchison meteorite
© P. Hoppe, Max-Planck-Institute for Chemistry, Mainz


Beauty
Wonder
Rationality


Beauty
Wonder
Rationality
© Sandra Yvonne Freregger



What is Astromineralogy? Does it exist?



Gustav Tschermak (1836-1927), a renowned Austrian mineralogist, wrote:

Es werden „…nicht alle anorganischen Körper als Minerale betrachtet, sondern bloß diejenigen, welche ihrer Entstehung nach der Erdrinde zugehören."[1]

A striking consequence of this definition:

„Die Gemengteile, welche die Meteoriten zusammensetzen, sind keine Minerale."[2]

Wolf von Engelhardt similarly stated in 1963:

„…daß die Wortbildung ‚kosmische Mineralogie' der ursprünglichen Bedeutung des Wortes Mineralogie widerspricht.
Mineralogia ist ursprünglich die Wissenschaft von den festen Bestandteilen der Erdrinde …" [3]

⇨ Astromineralogy – a non-existing science?

G. Tschermak, Lehrbuch der Mineralogie, 8th edition, Vienna 1921, [1] p. 1, [2] p. 717.
[3] W.v.Engelhardt, Probleme der kosmischen Mineralogie, Tübingen 1963, p. 5-6.

Astromineralogy does exist – since about 50 years

But: W. von Engelhardt continues:

„Kosmische Mineralogie als allgemein anerkannte Wissenschaft, die sich mit den festen Bestandteilen des ganzen Kosmos beschäftigt, gibt es erst, seitdem die IMA 1962 in Washington eine Kommission für kosmische Mineralogie [...] gegründet hat.“[(4)]

Today, the definition of minerals clearly does include extraterrestrial solids:

„Minerale sind natürliche Festkörper der Erde, des Monds und anderer Himmelskörper.

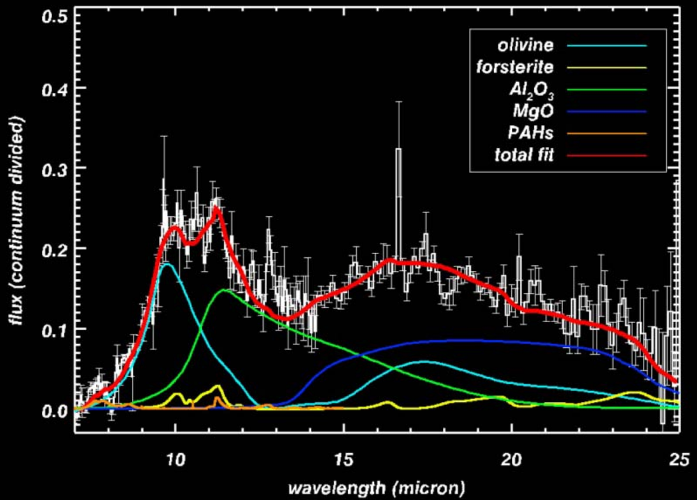
Von wenigen Ausnahmen abgesehen, sind Minerale *anorganisch* und *kristallisiert.*“ [(5)]

⇨ Mineralogy has extended its scope from terrestrial to cosmic minerals.

Astromineralogy is the science of gathering mineralogical information on asteroids, comets and circumstellar/interstellar as well as extragalactic dust .[(6)]

(4) W.v.Engelhardt, Probleme der kosmischen Mineralogie, Tübingen 1963, p.5-6.
(5) S. Matthes, Mineralogie, 6th edition, Berlin-Heidelberg 2000, p. 1.
(6) Th. Henning (ed.), Astromineralogy, 2nd ed., Berlin-Heidelberg 2010, cover text

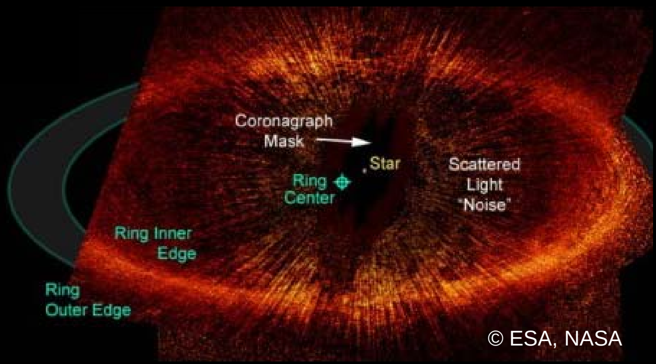
Astromineralogy's receding horizons

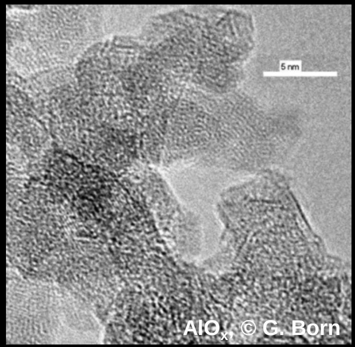


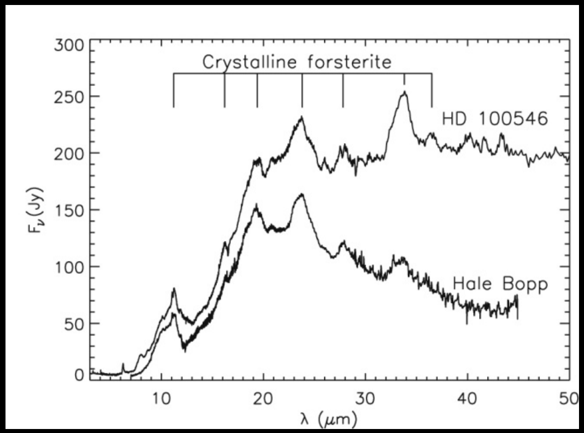
Quasar PG 2112+059
z~0.5
d~5 billion light-years

Marwick-Kemper et al.
2007, ApJ 668, L107

Objects and questions of astromineralogy



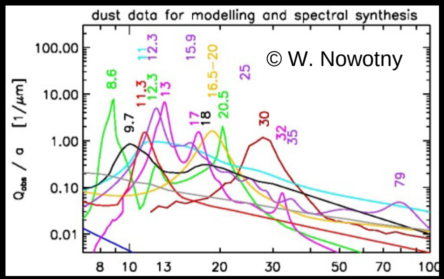


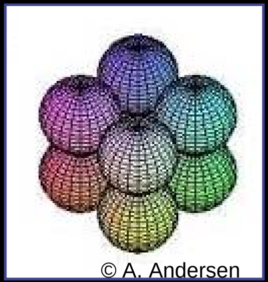


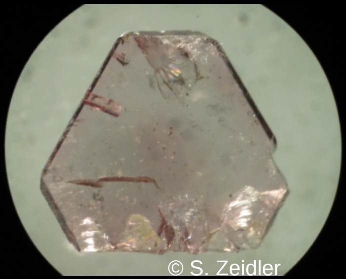
© F. Molster et al. in Th. Henning (ed.), Astromineralogy, 2nd ed., 2010, p. 183

$$Q_{abs} = 4x \, \mathrm{Im} \frac{\varepsilon_1 - \varepsilon_m}{\varepsilon_1 + 2\varepsilon_m},$$

$$Q_{sca} = \frac{8}{3} x^4 \left| \frac{\varepsilon_1 - \varepsilon_m}{\varepsilon_1 + 2\varepsilon_m} \right|^2,$$







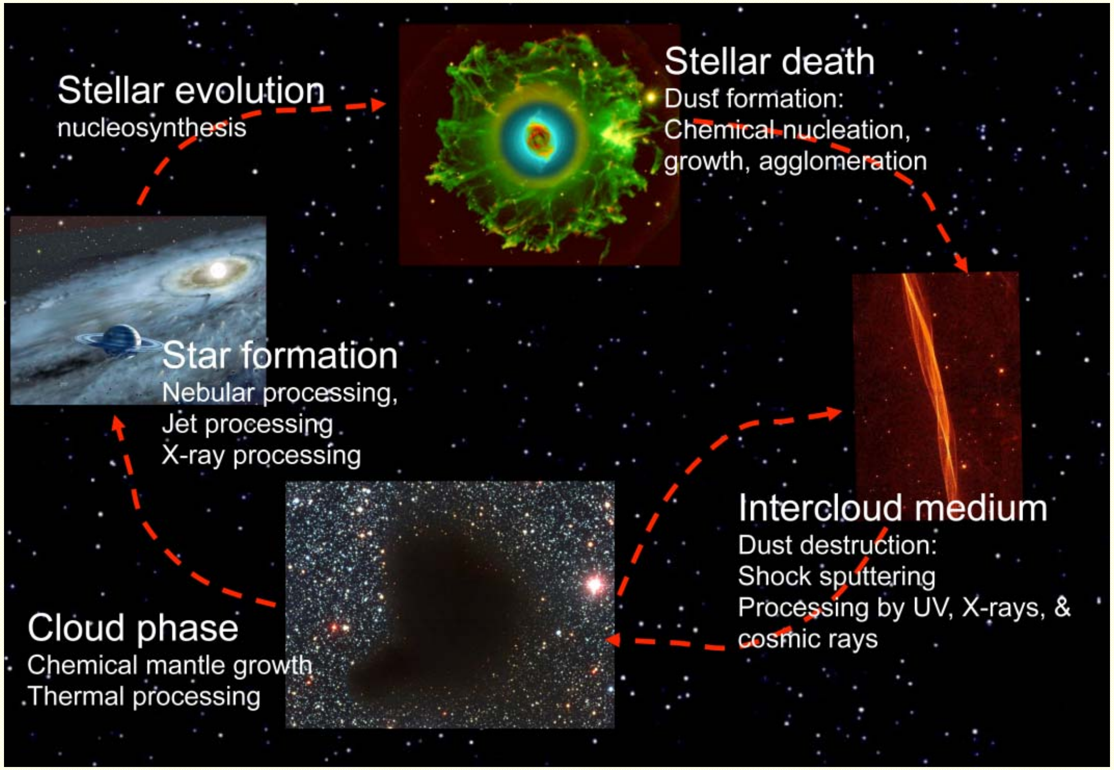
II. Motivation & Context

α Piscis Austrini

Distance: 40 light-years

Picture credit: HARDY

Why to study dust and minerals in space? – (1)



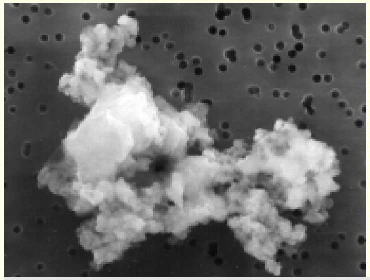
Picture credit: A. Tielens (2011)

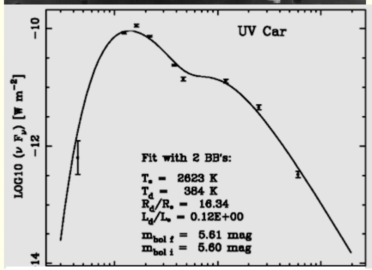
The short answer :
Dust and minerals in space are an essential agent in the cosmic circuit of matter.

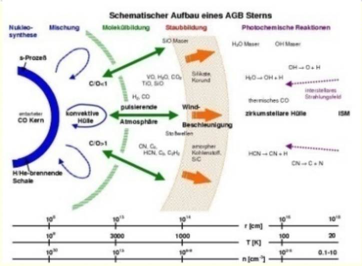
Without dust, no terrestrial planets.

Without astromineralogy, no full understanding of cosmic dust.

Why to study dust and minerals in space? – (2)







Picture credits:
J. Bradley; F. Kerschbaum;
J. Hron

(1) The formation of condensed matter (dust, ices, minerals) creates 2-dimensional surfaces

(2) Dust grains can efficiently redistribute energy (short → long λ) due to their lattice structures, due to their internal degrees of freedom

(3) Dust grains can take up momentum from radiation fields

(4) Dust grains serve as catalysts for chemical reactions

Which “astrominerals” do we know so far?

Table 1 Overview of the presence of the different dust species in astronomical environments

		Young stars				AGB		pAGB		PNe					
	ISM	PS	TT	Her	SS	O	C	O	C	O	C	WD	Mass. stars	SN	EG
O-rich dust															
Amorphous silicates	√	√	√	√	√	√	√	√		√	√	√	√	√	√
Crystalline silicates			√	√	√	√	√	√	√	√	√		√		√
Proto-Mg-silicates														√	
Carbonates		√:			√					√					
Al_2O_3					√	√							√	√:	
$MgAl_2O_4$					√	√									
SiO_2			√	√	√			√:	√:	√:				√	
[Mg,Fe]O		√:		√:	√	√							√:		
C-rich dust															
Carbonaceous dust	√				√		√		√		√				
SiC	√				√		√		√		√				√
TiC					√				√		√				
(nano-)diamonds				√	√				√						
C-glass														√:	
Other dust species															
MgS	√:						√		√		√				√
FeS				√:	√						√			√:	
Si														√:	
Metallic Fe					√	√								√:	

√: indicates an insecure or dubious detection.

ISM = interstellar medium; PS = proto stars; TT = T-Tauri stars; Her = Herbig Ae/Be stars; SS = solar system material, IDPs and meteortites; (p)AGB = (post) asymptotic giant branch star; PNe = planetary nebulae; O = O-rich; C = C-rich; WD = White dwarf; Mass stars = massive stars (e.g. Luminous Blue Variables, Wolf Rayet stars); EG = Extra Galactic detections.

F.J. Moster et al.: The Mineralogy of Interstellar and Circumstellar Dust in Galaxies,
in: Th. Henning (ed.), Astromineralogy, 2nd ed., Berlin-Heidelberg 2010, p. 150

Underlined in green: Minerals studied within the present habilitation thesis

Some of the examined "astrominerals"

Oxides:

Corundum α-Al_2O_3

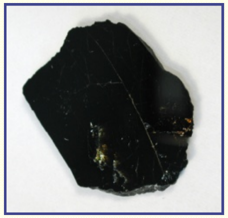
Hibonite $CaAl_{12}O_{19}$

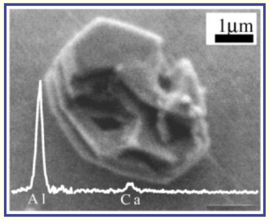
Spinel $MgAl_2O_4$

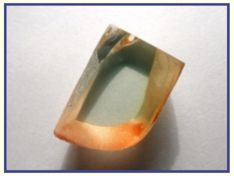
Perovskite $CaTiO_3$

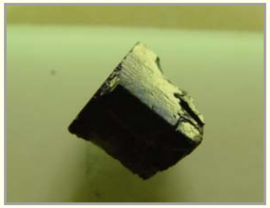
Rutile TiO_2

Anatase TiO_2





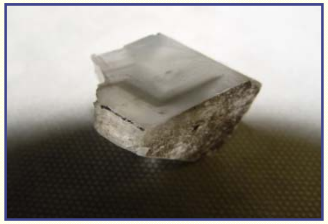




Carbonates:

Dolomite $CaMg[CO_3]_2$

Calcite $Ca[CO_3]$



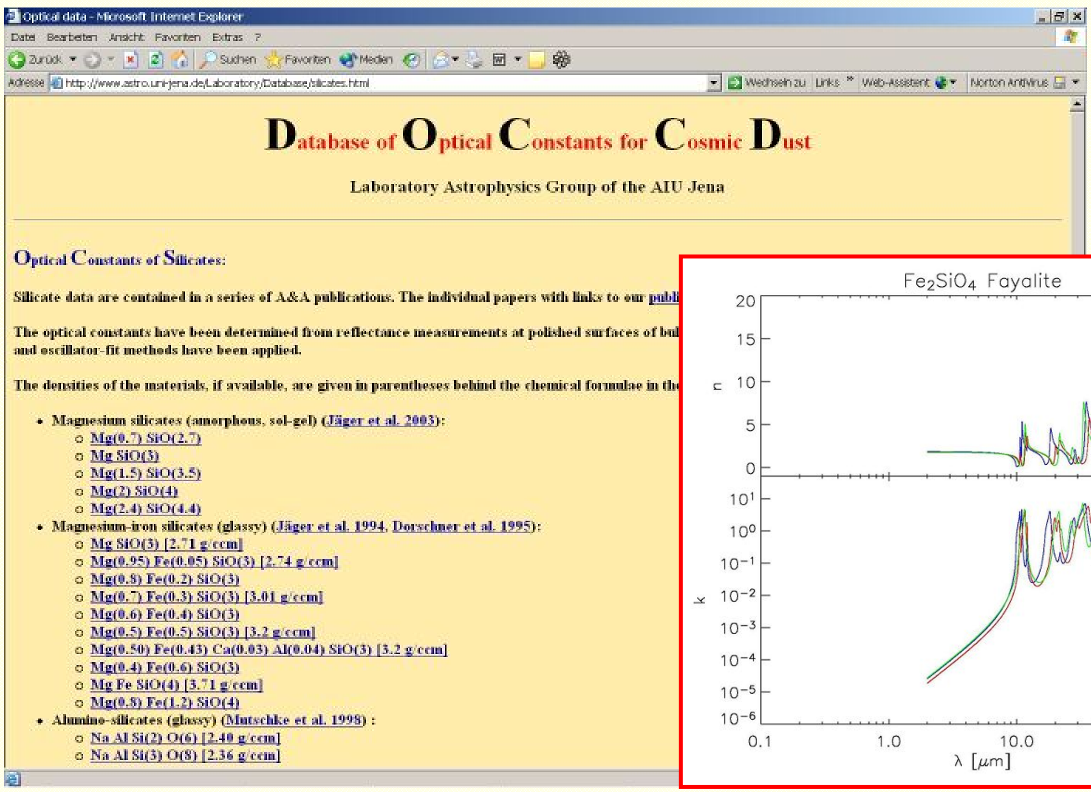
Various Phyllosilicates:

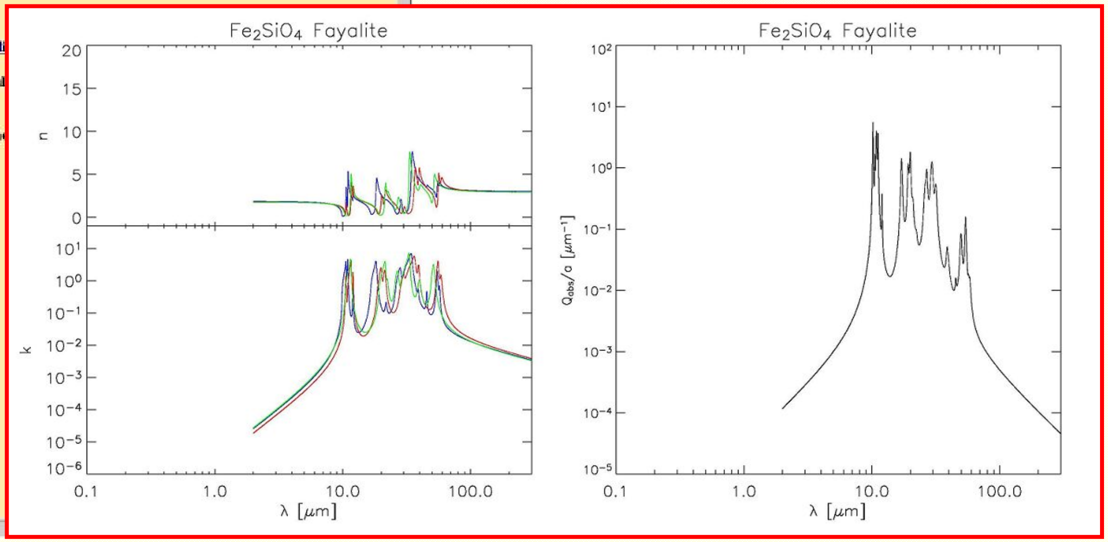
e.g. Talc $Mg[CO_3]_2$

Montmorillonite

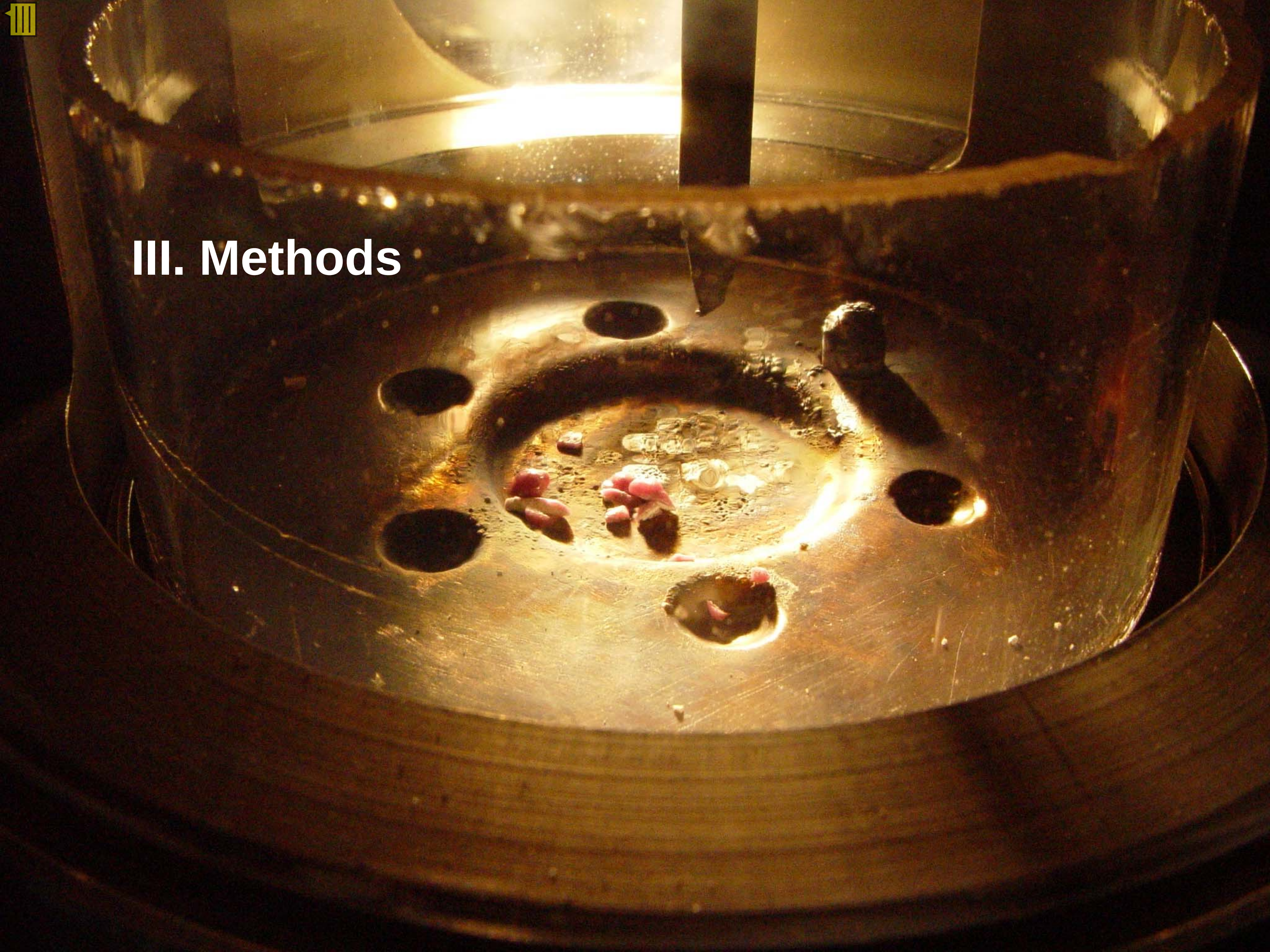
Jena database of optical constants

This is were most of our results went to:
http://www.astro.uni-jena.de/Laboratory/Database/databases.html





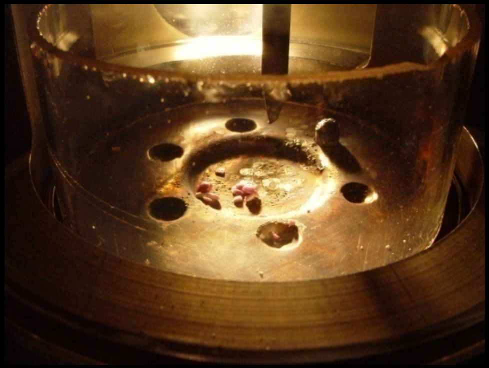
III. Methods



Methods & instruments applied in the course of my habilitation thesis

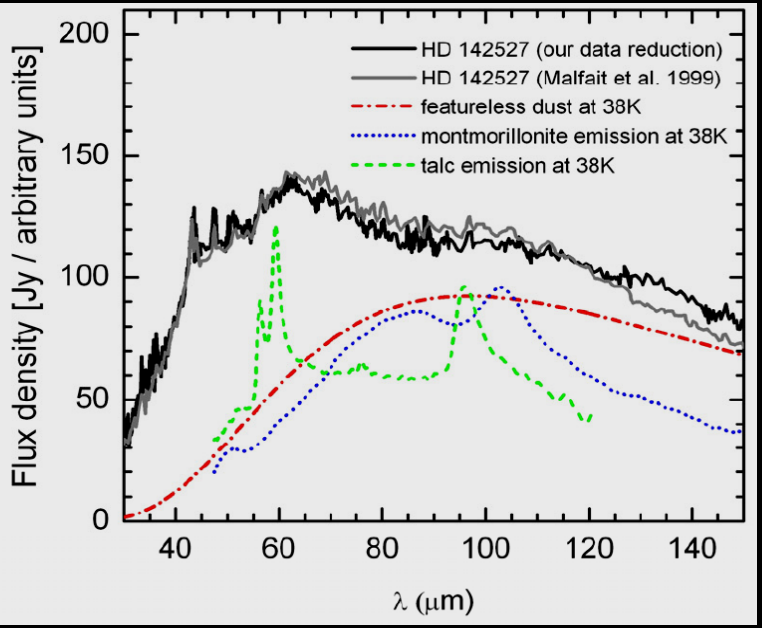
Fourier Transform Spectrometer

Analytical balance / weighing Cr_2O_3



Electric arc furnace producing “spinels”

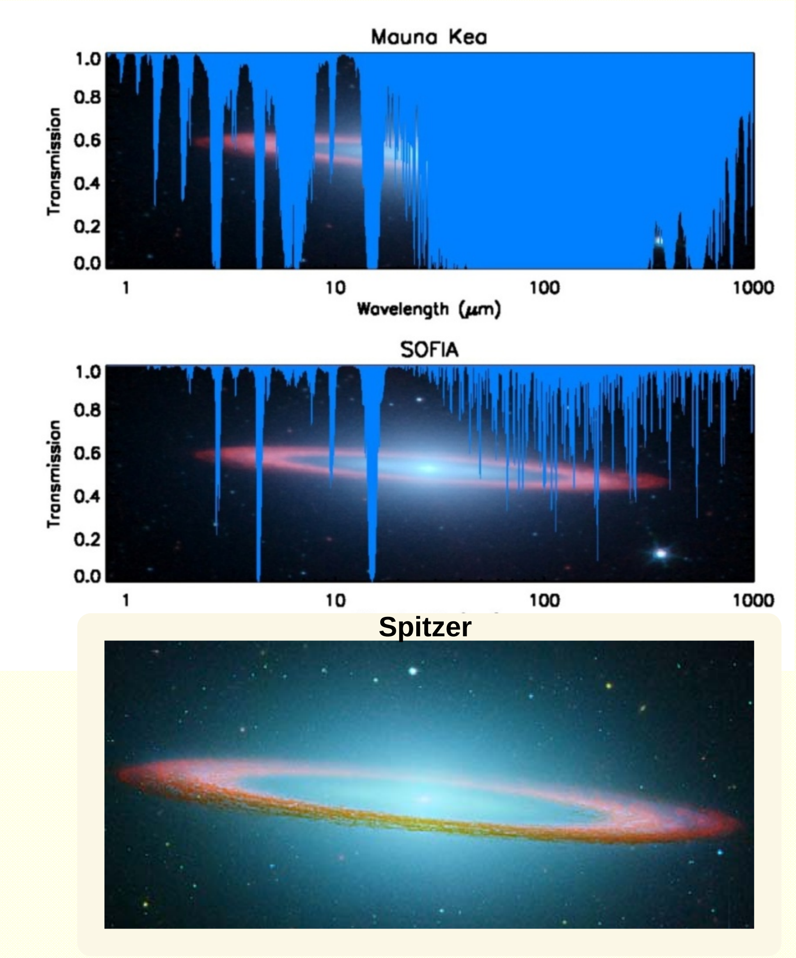
Herschel IR Space Observatory



Mutschke,
Zeidler,
Posch et al.,
A&A 492 (2008),
117

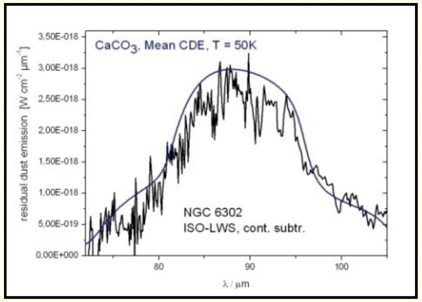
Comparing Lab Spectra
to astronomical IR data

Methods, #1: IR astronomy (mostly from space)



After an idea by E.E.Becklin

IR spectroscopy is crucial for studies of cosmic dust



Example of an IR-spectrum of a Planetary Nebula (Posch et al. 2007)

IR satellites used:

- **ISO, *Spitzer & Herschel***

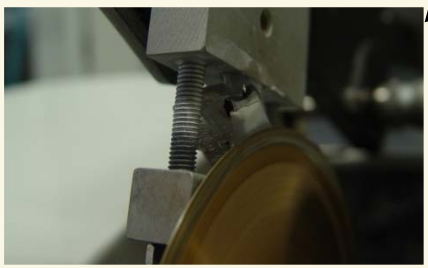
Ground-based:

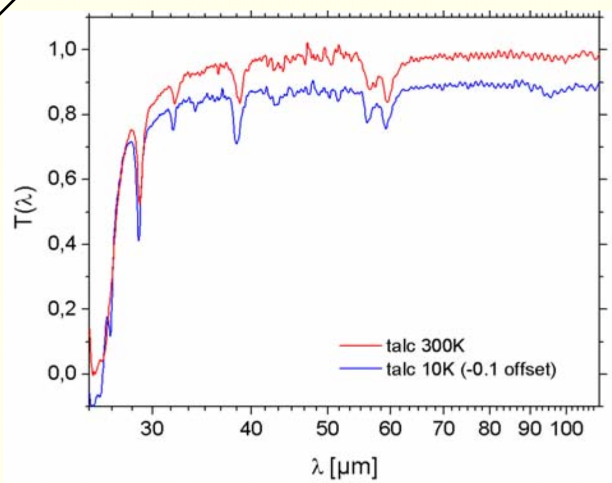
- **ESO's 3.6m telescope**

Methods, #2: Laboratory spectroscopy (mostly MIR)

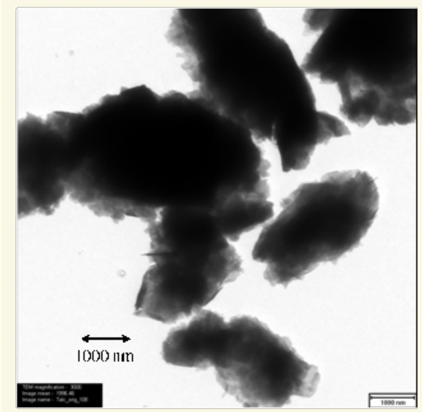
Most extensively used <u>spectrometer</u> (AIU Jena): Bruker FTIR 113v. λ-range: 1.6μm to >200μm

<u>Samples:</u> grains extracted from meteorites, synthetic solids, natural minerals, nanoparticles from the gas phase





Talc ⟺



Zeidler, Mutschke, Posch et al., (2008)

<u>Spectroscopy modes:</u>

- **Powder transmission spectroscopy**
- **Reflectance spectroscopy of polished surfaces**

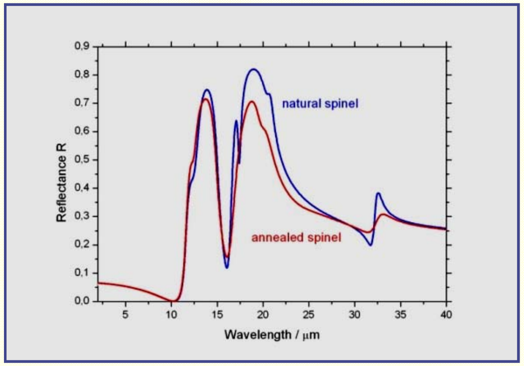
Reflectance spectroscopy is 1st choice!

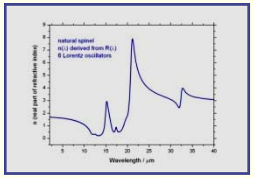
(but not always possible)

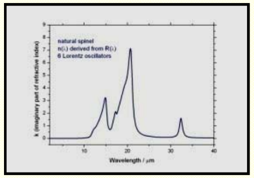
Synthetic Spinel

Methods, #3: Calculations

C1: <u>From</u> R(λ) / T(λ) spectroscopy <u>to</u> optical constants n (λ), k (λ)

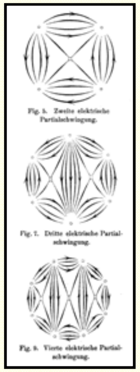




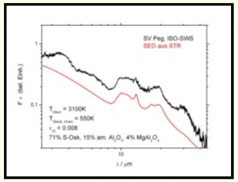


C2: <u>From</u> n (λ) + i k (λ) <u>to</u> C_{abs}(λ), C_{sca} (λ) using Mie theory and its extensions

$$\frac{\langle C_{abs}\rangle}{V} = \frac{2\pi}{\lambda}\,\mathrm{Im}\left(\frac{2\epsilon}{\epsilon-1}\ln\epsilon\right).$$



C3: <u>From</u> C_{abs}(λ), C_{sca} (λ) <u>to</u> SEDs Using radiative transfer calculations



Summary of methods

Theoretical approaches:

Classical theory of optical constants of solids (Lorentz oscillators, KKR)

$\varepsilon = \varepsilon_0 + \Sigma_j \Omega_j^2 / (\omega_j^2 - \omega^2 - i \gamma_j \omega)$

Mie theory

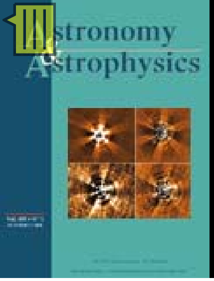
Radiative transfer calculations

Experimental methods:

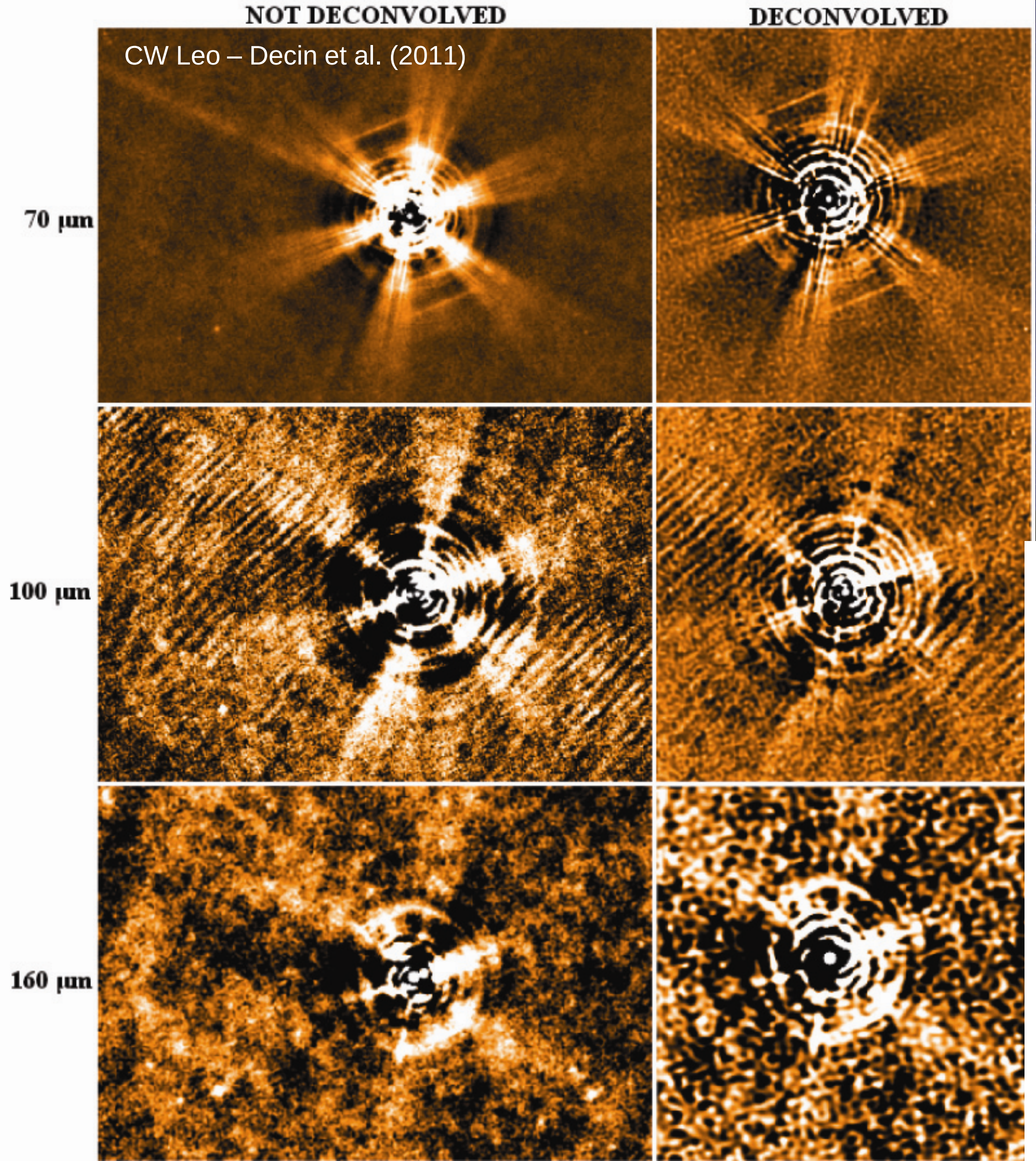
Astronomical IR spectroscopy

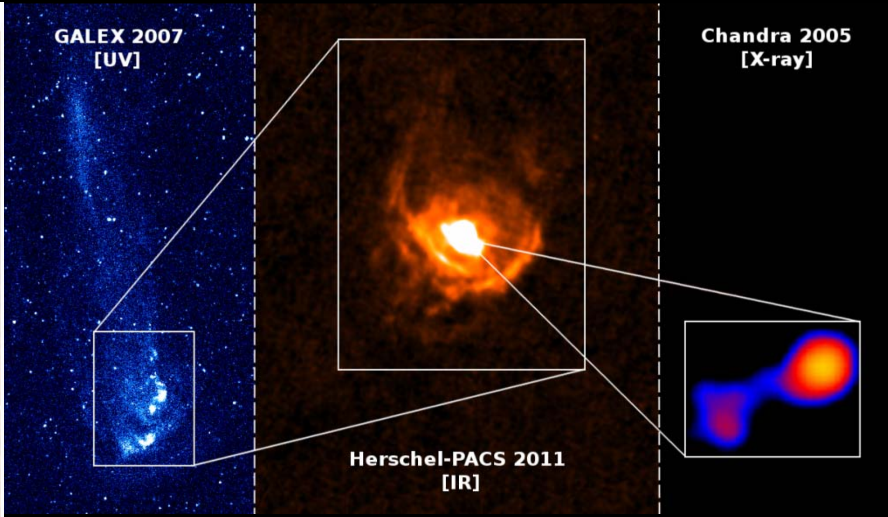
Laboratory (UV to IR) spectroscopy

Common goal:
Insight into the composition
& structural properties of cosmic dust

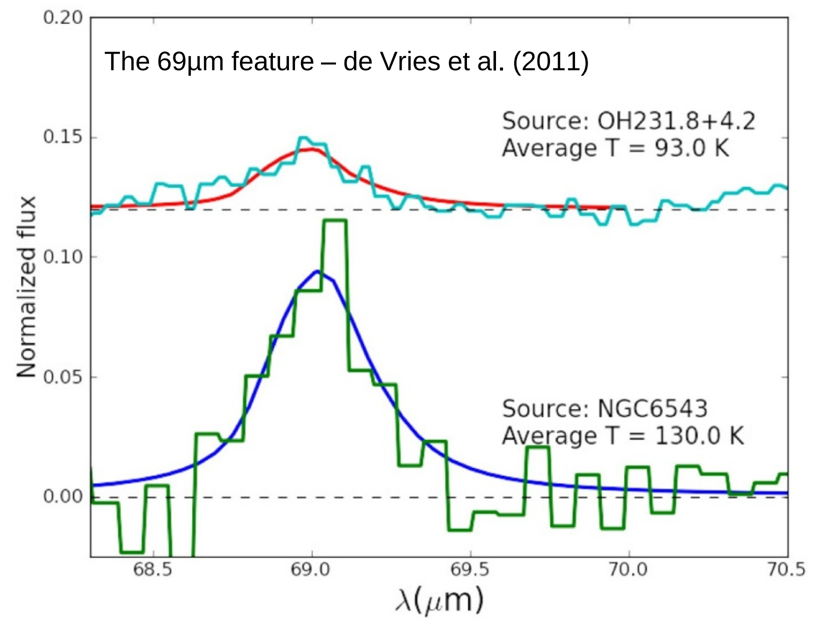


IV. Selected Results





Mira Ceti – Mayer et al. (2011)



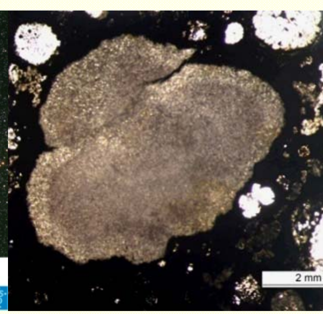
Questions examined

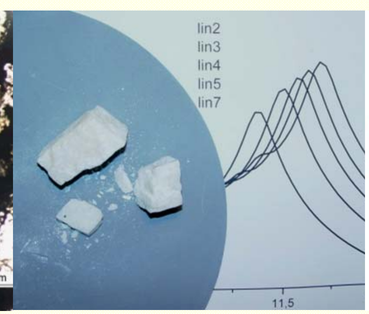
- What is the ‘cosmic’ role of oxide (as opposed to silicate) dust?
- What is the mineralogy of (meteoritic) CAIs?
- Why to care about near-infrared properties of stardust?
- Can we find carbonates in space, and – if so – where?
- What can we learn from the far-infrared spectra of hydrous silicates?

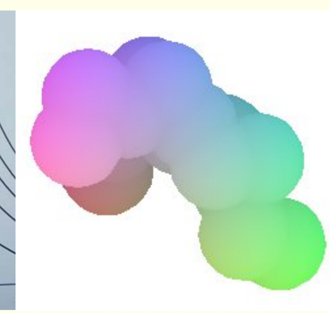
(Lab.)

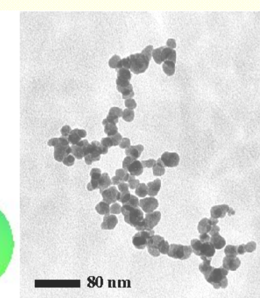
- How to calculate the infrared extinction by stardust grains with complex shapes? (Calc.)
- What can we learn from the stardust formed in 47 Tucanae?
- How did *Herschel* change our views on the mass loss of AGB stars?

(Ast. Obs.)









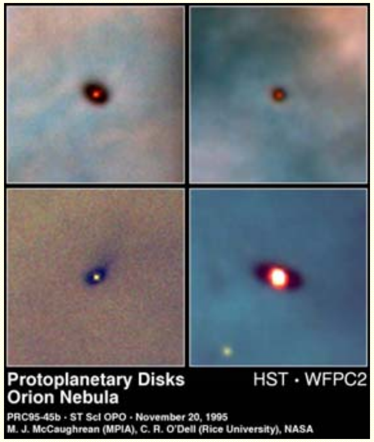
Astromineralogy of CAIs

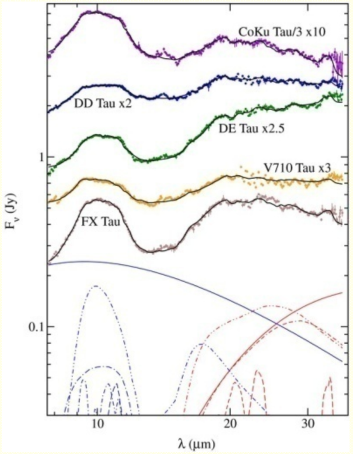
Calcium-Aluminum-rich Inclusions (CAIs) mainly occur in carbonaceous chondrites.

They were formed 4567 million years ago.

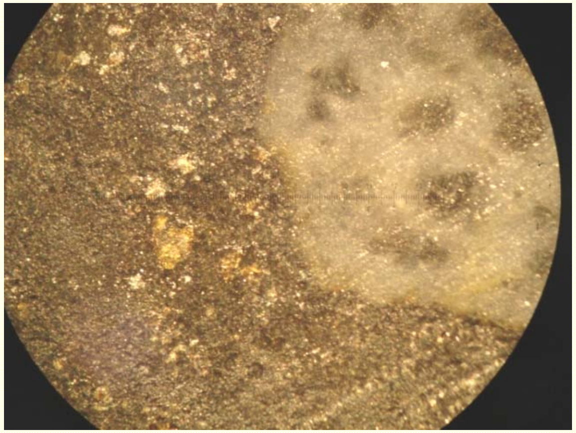
CAIs are supposed to be the oldest known solar system objects.

Studying CAIs yields information on very early stages of planetary systems.

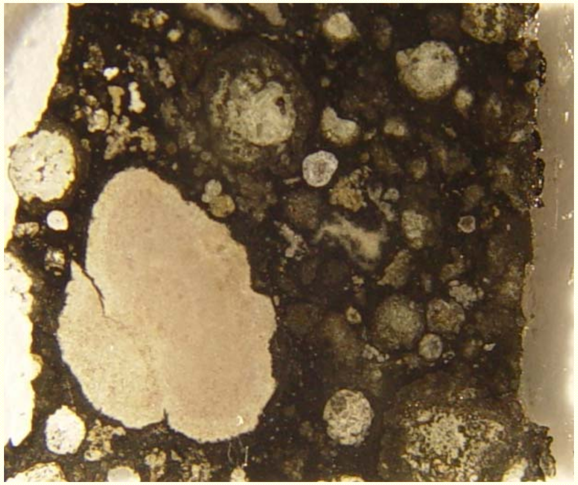




<< *Spitzer* spectra of protoplanetary disks (Sargent et al. 2009)



Type B CAIs (bright inclusions) in the chondrites Leoville and Allende



→ Paper: Posch, Th., Mutschke, H., Trieloff, M., & Henning, Th., 2007, ApJ, 656, 615

Main Minerals of CAIs

Mineralogically, CAIs are divided into three groups:

- **Type A CAIs primarily consist of melilite $Ca_2(Al,Mg)[(Si,Al)_2O_7]$**
- **Type B CAIs additionally contain fassaite $(Ca,Na)(Mg,Fe,Al,Ti)[(Si,Al)_2O_6]$**
- **Type C CAIs are rich in the feldspar plagioclase $(Na,Ca)(Si,Al)_4O_8$**

Melilite

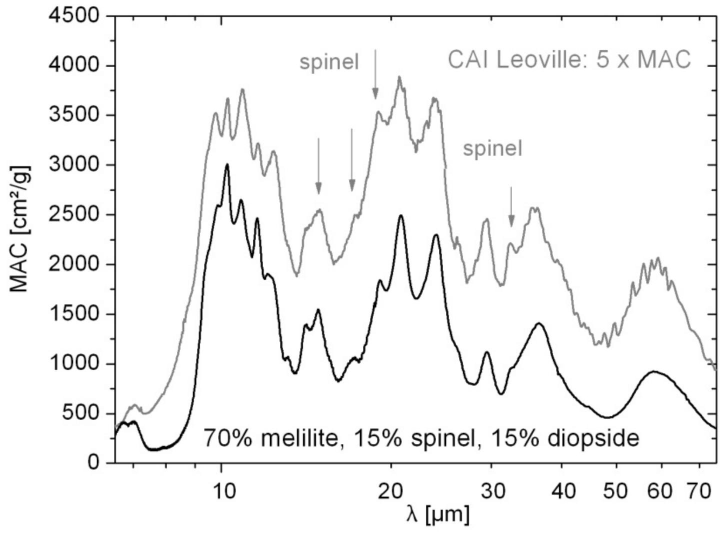
Fassaite (var. of diopside)

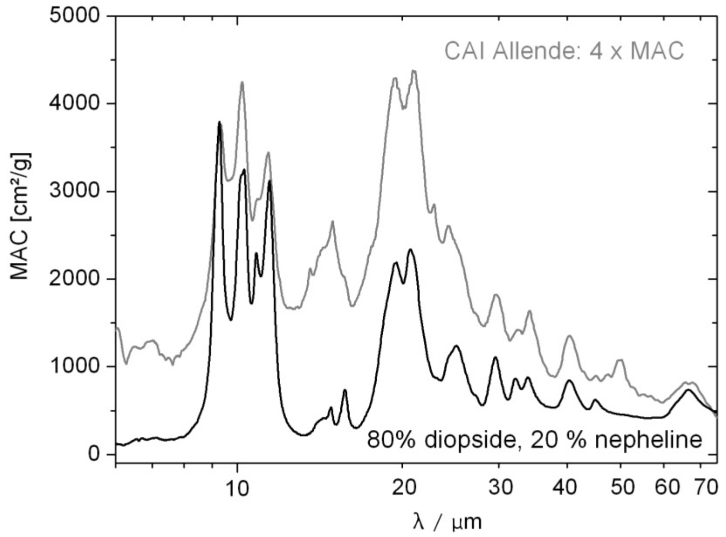
Plagioclase

Mid-IR to Far-IR spectra of type B CAIs

CAI Leoville:
Chemical analysis and IR bands show composition
70% melilite
15% spinel $MgAl_2O_4$
15% diopside $CaMgSi_2O_6$
(→ 60µm band)

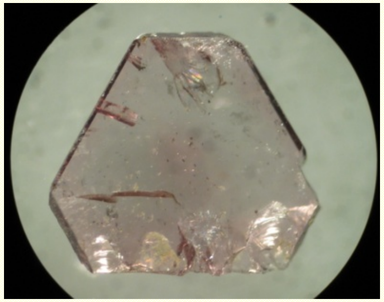
CAI Allende:
Spectroscopy indicates
80% diopside $CaMgSi_2O_6$
20% nepheline $(Na,K)AlSiO_4$
EDX analysis furthermore points to spinel, sodalite, melilite, anorthite





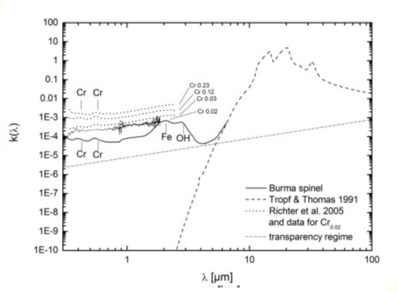
(General) importance of the NIR range

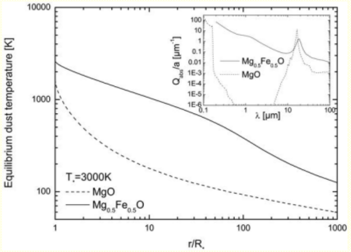
Region around 1µm: k (λ) lacking for many minerals. Strongly dependent on "impurities"
BUT: Without k NIR, no calculation of dust grain energy balance!



$$k(\lambda) = -\frac{\lambda}{4\pi d} \ln\left\{\frac{T}{(1-R)^2}\right\},$$

Section of a spinel from Mogok, Burma
and of a Sri Lanka olivine crystal





Measuring k (λ) using platelets
→"Complete" n+ik datasets
→ Energy balance in radiation field

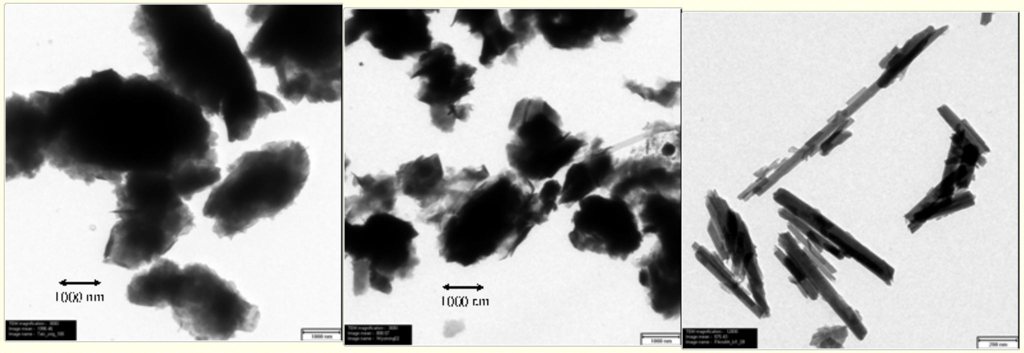
$$I_1 = \int_0^\infty \pi a^2 Q_{\rm abs}(\lambda) \pi B(\lambda, T_*) {\rm d}\lambda,$$

→ Paper: Zeidler, D., Posch, Th., Mutschke, H., et al., 2011, A&A 526, A68

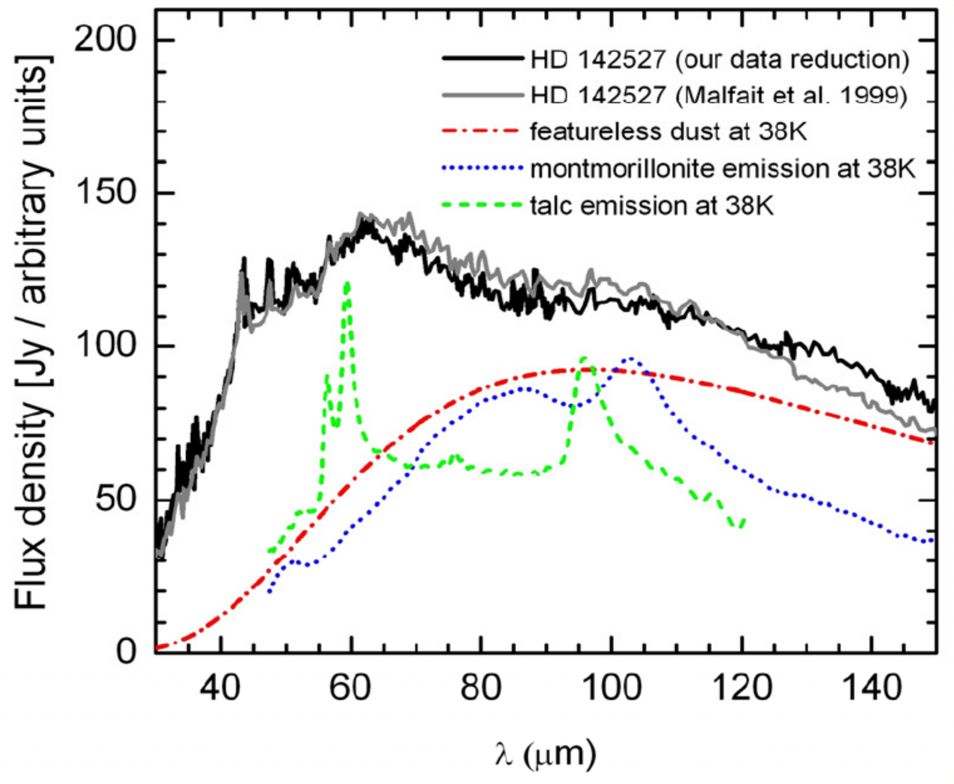
(Low-T) FIR spectra of hydrous silicates

- **Phyllosilicates are of interest due to their <u>OH / H_2O content</u>**
- **We studied several phyllosilicates mentioned in the astronomical literature**

Phyllosilicate	Formula	Group
Chamosite	$Fe_{3,55}Al_{1,88}[(Al,Si_3)O_{10}(OH)_8]$	Chlorite
Talc	$Mg_{3,33}Fe_{0,1}[Si_4O_{10}(OH)_2]$	Talc-Pyrophyllite
Montmorillonite	$Al_{1,5}Mg_{0,25}Fe_{0,17}[Si_4O_{10}(OH)_2](Na,K)\cdot 1,2\ H_2O$	Clay
Picrolite	$Mg_{5,84}Fe_{0,17}[Si_4O_{10}(OH)_8]$	Serpentine



Comparison to astronomical FIR spectra



Paper: Mutschke, Zeidler, Posch et al., A&A 492 (2008), p. 117

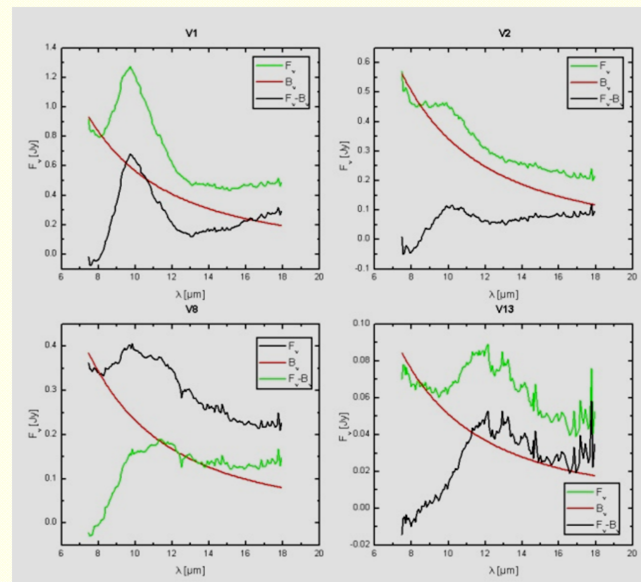
Talc:

- **Formed from enstatite by weathering**
- **Chemical composition $Mg_3[Si_4O_{10}(OH)_2]$**
- **Feature discovered: 98.5μm**
- **Search for "astronomical counterpart" still ongoing**

Dust properties of AGB stars in 47 Tuc

- Imagine studying mineral formation at d = 13.400 light-years – outside our galaxy!
- This became possible due to the high sensitivity (down to milliJanskys) of *Spitzer*
- Lebzelter et al.: > 12 hours of *Spitzer* observing time

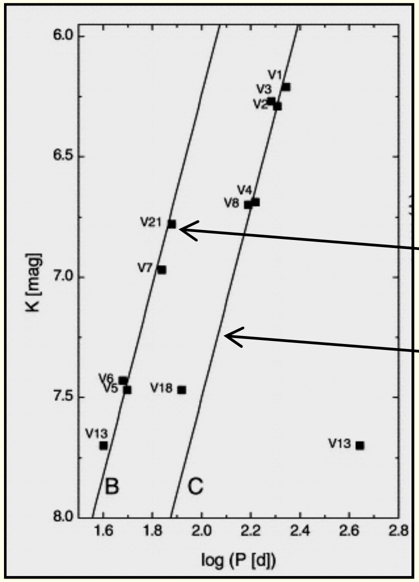
=



AGB stars in the globular cluster 47 Tuc

Why 47 Tuc? Because we have a <u>wealth of information</u> on stellar properties:

- **Metallicity [Fe/H] = -0.7 (only 1/5 solar)**
- **Age: 11.2 (± 1.1) x 10^9 years (only 1/5 less than the age of the universe)**
- **Turnoff mass: 0.9 $M_\odot$**



Q: Is the <u>pulsation mode</u> connected to the <u>dust composition</u>?

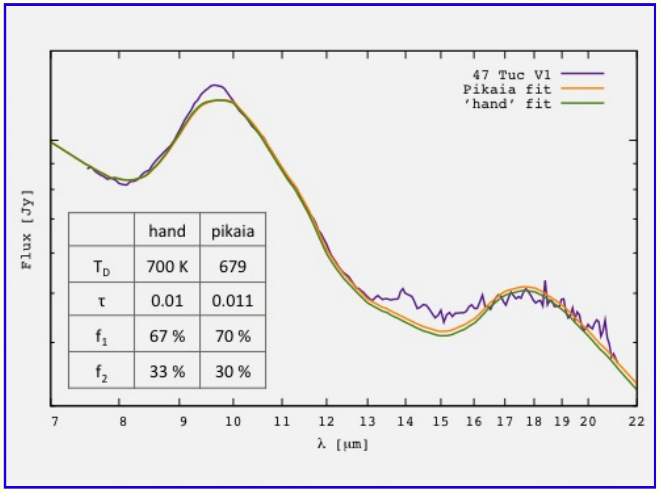
- Overtone pulsators <--> strong oxide bands (esp. broad 11µm amorphous Al_2O_3, 13µm $MgAl_2O_4$ band)

- Fundamental mode pulsators <--> dominant am. silicate bands (esp. broad 10µm band)

Lebzelter, Posch et al. 2005 (ApJ 653, L145)

V1-47Tuc:

Mira-like pulsation – strong silicate emission

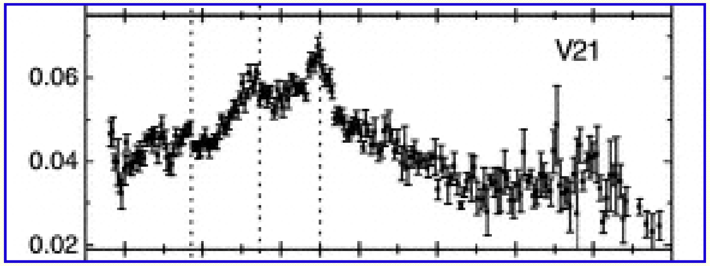


Modeling the MIR spectrum of V1-47 Tuc:

- **Using optical constants from the Jena database**
- **Best results achieved with a combination of amorphous Mg_2SiO_4 and amorphous $MgSiO_3$**
- **Dust Temperature at inner shell boundary: ~700K**
- **Grain sizes from r = 0.005µm to r = 0.25µm**

Baier et al. 2011 (ASPC 445, p. 313)

Lebzelter, Posch et al. 2005 (ApJ 653, L145)



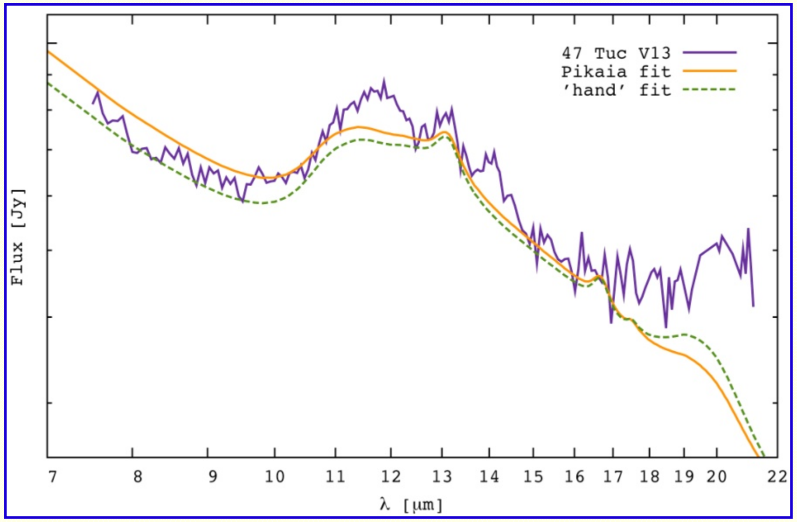
<u>So far confirmed by this study:</u>

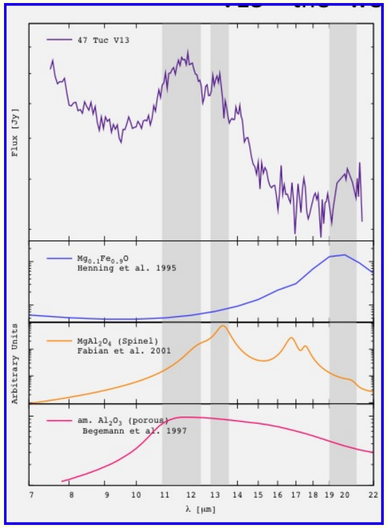
Mira-like pulsators (fund. mode), e.g. V1 dominated by amorphous silicate dust,

Semiregular pulsators (overtone), e.g. V21 additional crystalline oxide bands

V13-47Tuc

Double-period (40d + 2nd) & 'only' oxide dust features?





Lebzelter, Posch et al. 2005 (ApJ 653, L145-L148)

Baier et al. 2011 (ASPC 445, p. 313-314)

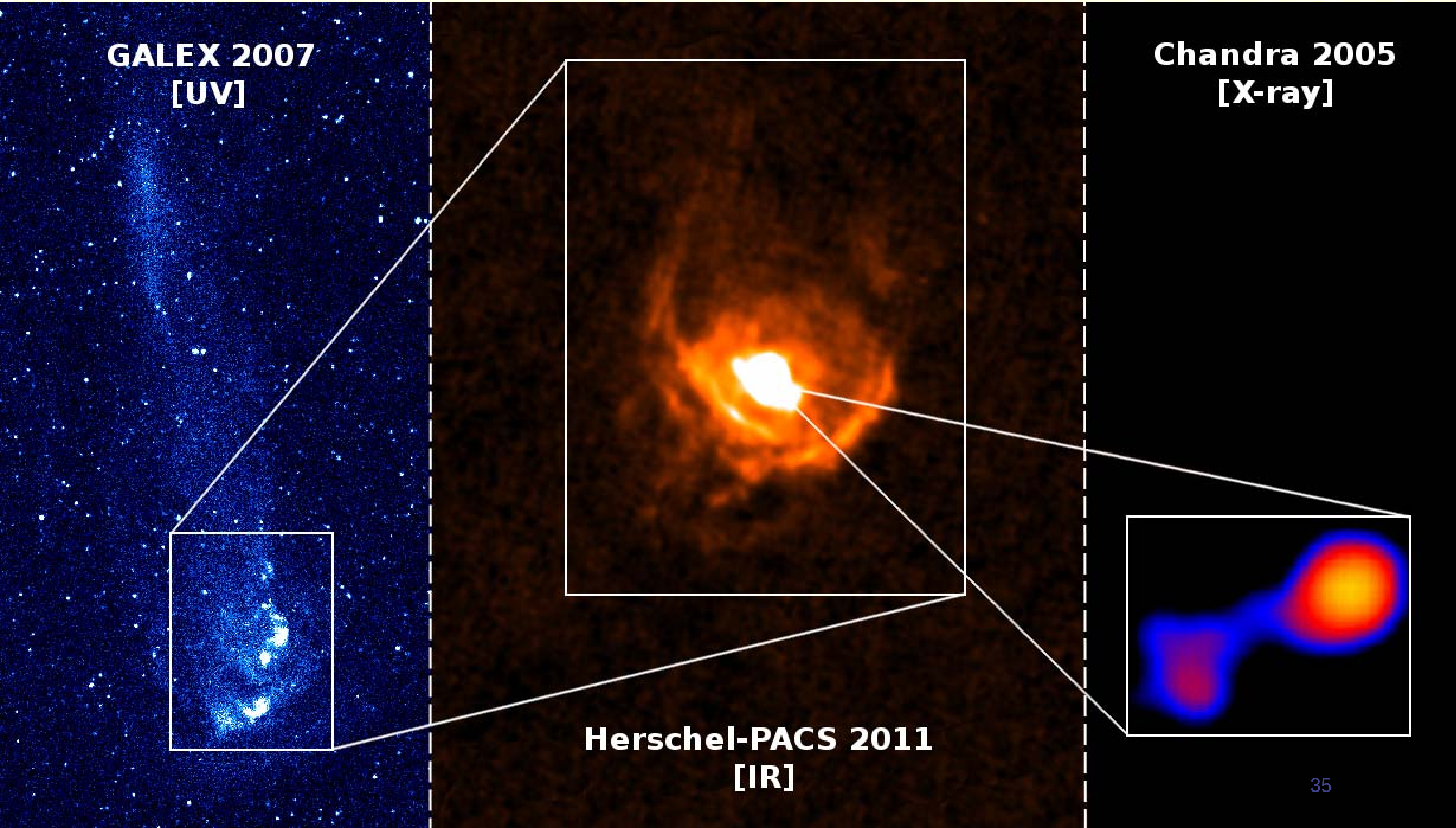
Sloan et al. 2010 (ApJ 719, 1274: >40% of GC AGB stars show 13µm band, only 20% of galactic ones)

	hand	pikaia
T_D	1200K	1210K
τ	0.007	0.007
Al_2O_3	76 %	82 %
$Mg_{0.1}Fe_{0.9}O$	20 %	14 %
$MgAl_2O_4$	4 %	4 %

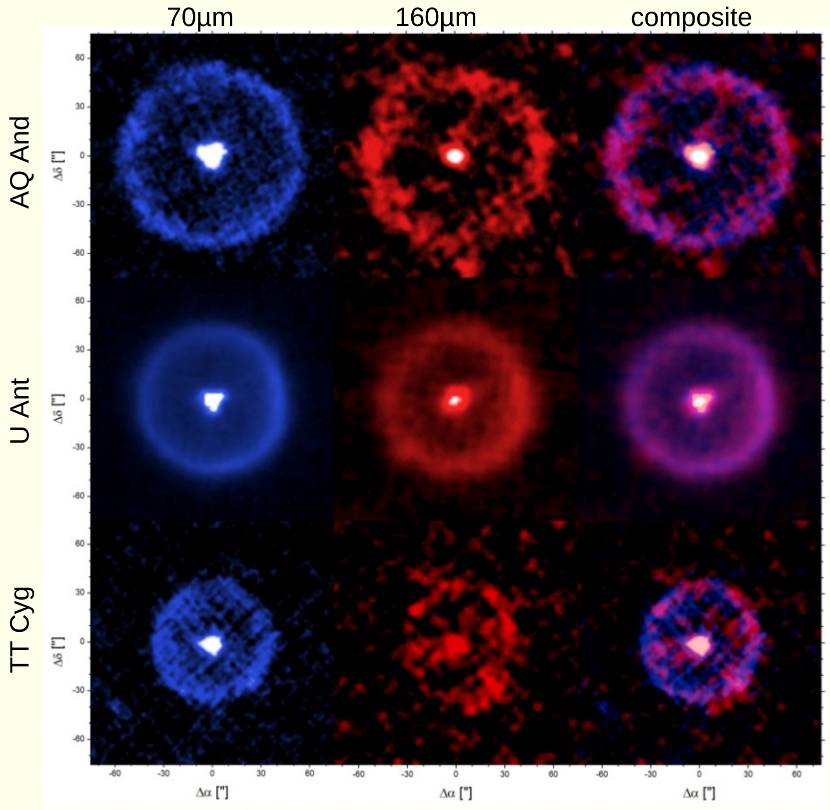
Modeling the MIR spectrum of V13-47 Tuc:

- **Oxide features dominating**
- **Broad 10µm silicate feature missing**
- **Dust components: amorphous alumina, spinel, possibly $Mg_{0.1}Fe_{0.9}O$ (see grey bars above)**
- **Unusual dust composition – related to unusual pulsation behaviour?**

Turning back to our galaxy!



Herschel's new view on stellar mass loss



Kerschbaum , Ladjal, Ottensamer, …, Posch, et al., (2010)

- New detections of **detached shells**
- Probing mass loss history by analysing radial intensity profiles
→ Clear sign of multiple shells
due to times of increased stellar winds
AQ And: every 2000-5000yrs?

- TT Cyg:
Peaks in intensity profiles
at r = 7", 14", 26", 33"
→ enhanced mass loss **every 1500y?**
→ related to thermal pulses?

V. Future Work

Future Work

Laboratory Work (Jena)
High-temperature measurements: corundum, spinel, SiO_2

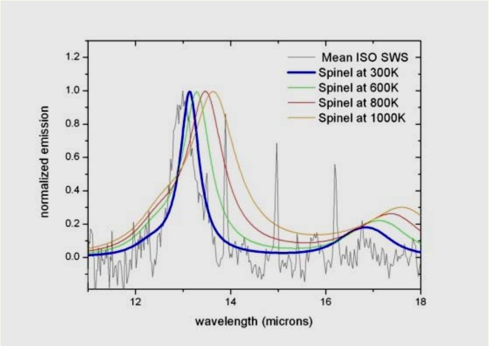
Laboratory Work: Herschel-PACS-observations of 69µm forsterite band → need for more precise data on forsterite's FIR properties

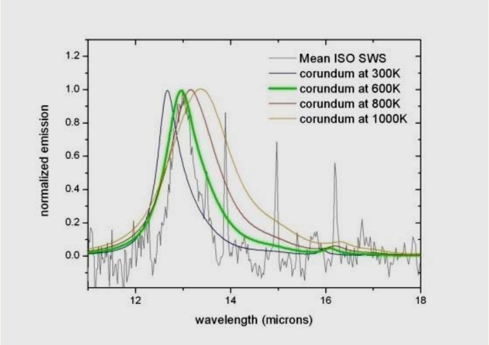
IR spectra of clusters:
Will they lead to identifications of astronomical IR bands?

Analyze astromineralogically relevant existing IR spectra
Rich data sets from MESS and DIGIT projects (Kerschbaum, Güdel)

Future astromineralogical IR spectroscopy / radio imaging with SOFIA, ALMA, E-ELT, JWST
Follow-up studies on identified / unidentified dust bands

Laboratory studies: high temperature measurements





Zeidler, Mutschke, Posch, 2011, in prep.

At high-temperatures, minerals may have distinctly other IR properties than at room temperature:

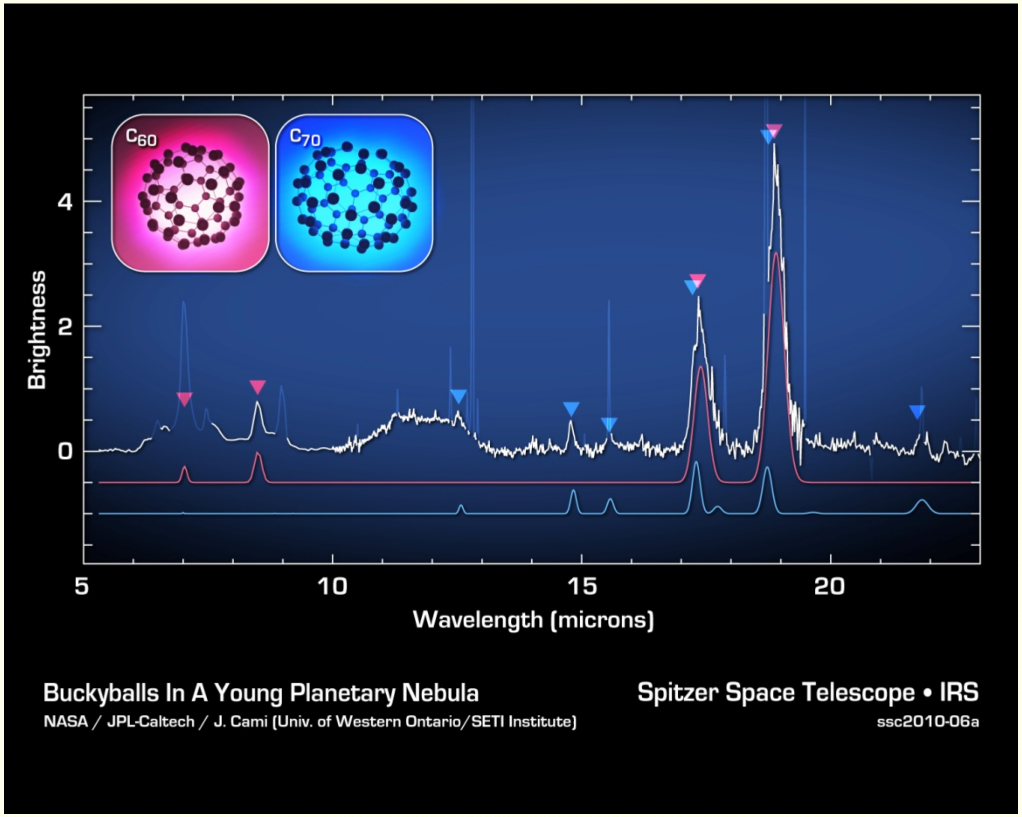
- **band broadening**
- **band peak shifts to larger wavelengths**

Circumstellar dust forms at several 100K

→ n(λ), k(λ), Q_{abs}(λ), Q_{sca}(λ) are needed for T = n x 100K

→High temperature measurements for SiO_2, α-Al_2O_3 and $MgAl_2O_4$

Cluster physics meets astromineralogy



J. Cami et al. 2010:
C_{60} (+C_{70}) fullerenes found in PN Tc1
(Science, Vol. 329, 2010)
Are O-rich clusters detectable as well?

Stratospheric IR astronomy: SOFIA

© E.E. Becklin / NASA

- SOFIA: working at 12-14km altitude since 2011
- “FORCAST” grism (5-8μm, 25-37μm) expected to be operative in 2012


debris disc
size of Saturn's orbit around the Sun
β Pictoris b
β Pictoris
location of the star
North
East
Psst ... R Scl
Ready for new discoveries: ALMA
© Helmut Dannerbauer, Fall 2011

Final slide

Do studies on absorption + scattering by small grains help to understanding the growing city light domes?

© G. Zotti in Posch et al. (2010), „Das Ende der Nacht“

Thanks to

Angela Baier (IfA)
Gabriele Born (AIU Jena)
Johann Dorschner (AIU Jena)
Thomas Henning (MPIA Heidelberg)
Josef Hron (IfA)
Cornelia Jäger (AIU Jena)
Franz Kerschbaum (IfA)
Thomas Lebzelter (IfA)
Isolde Müller (IfA)
Harald Mutschke (AIU Jena)
Walter Nowotny (IfA)
Hannes Richter (IfA)
Mario Trieloff (Uni Heidelberg)
Jürgen Weiprecht (AIU Jena)
Simon Zeidler (AIU Jena)

Motto

"Two things fill the mind with ever-increasing wonder and awe, the more often and the more intensely the mind is drawn to them:

The starry heavens above me and …

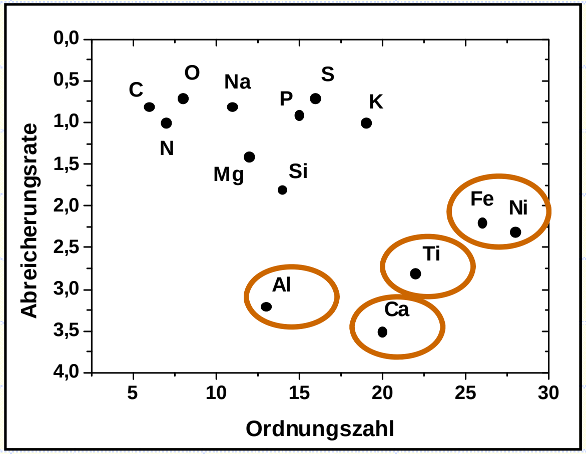
the minerals from the depths of the Earth."

After a dictum by Immanuel Kant (1788)

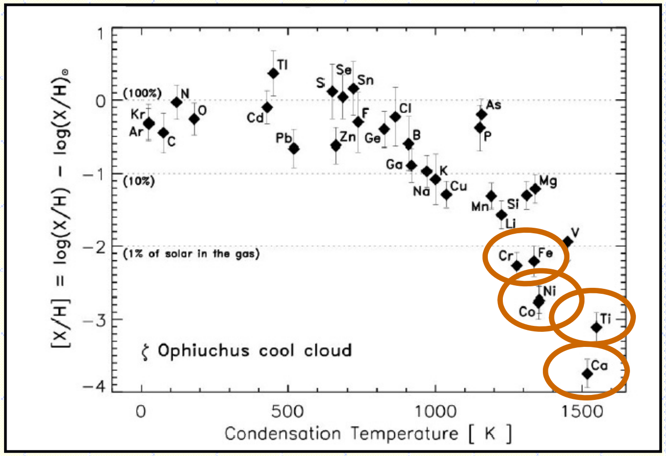
Backup slides

Information aus Element-Abreicherungsraten

Interstellares Gas: Einige Elemente stark unterhäufig (im Verhältnis zu solaren Werten)
Um Faktoren > 100 unterhäufig:
Ca, Ti, Al,
Co, Ni, Cr, Fe



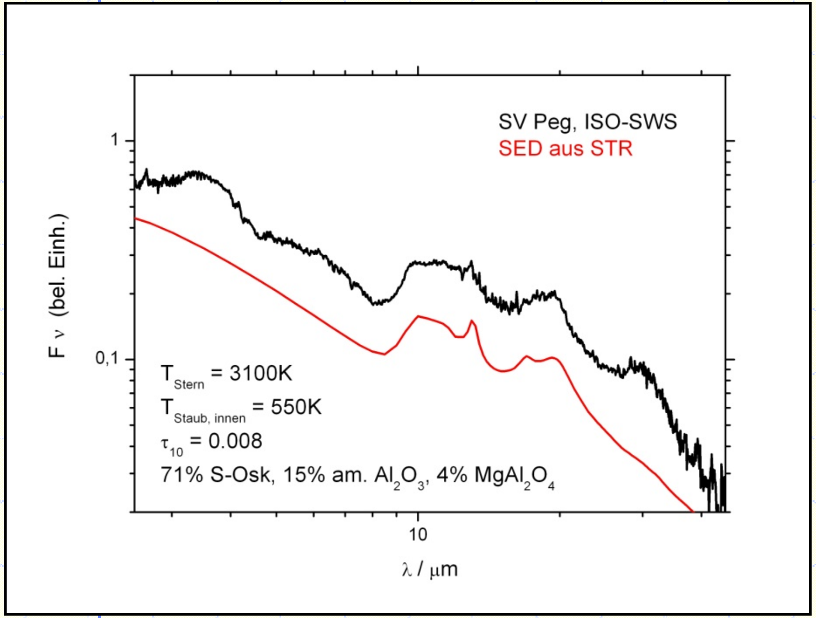
Abreicherungsrate als f(Z) (nach Salpeter 1977)



Warum die Unterhäufigkeit?
Phasenübergang gasförmig → fest
(besonders für Ca, Ti, Al, Fe, ...
⇒ Spektroskopiere deren Verbindungen!)

Abreicherungsrate als Funktion der Kondensationstemperatur (Palme & Jones 2004)

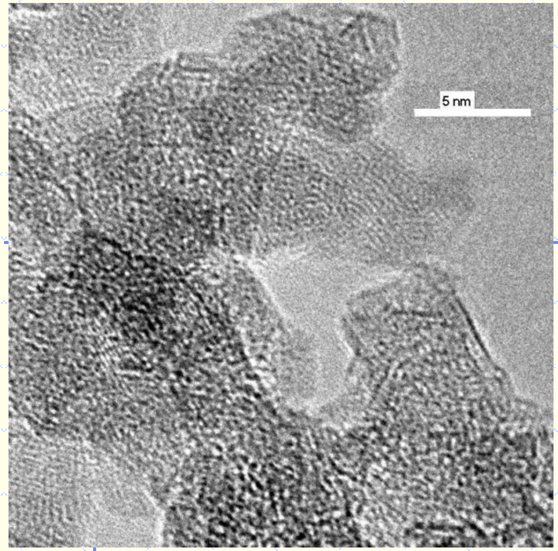
Beobachtungen & Modellrechnungen



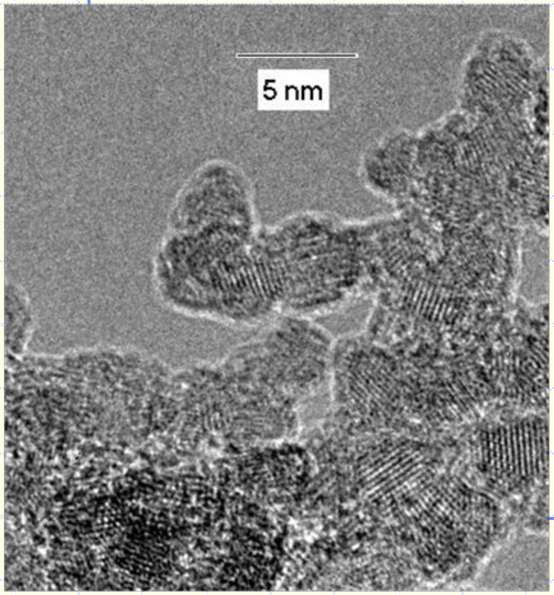
^ SV Peg ISO-SWS-Spektrum
& STR-Modell (DUSTY)

- ISO-Beobachtungen: durchgehende λ-Abdeckung von 2 bis 45 (200) µm
- Beobachtete SED rekonstruierbar mit STR-Rechnungen
- Benötige: Datenbank optischer Konstanten von Staubspezies Modellspektren f. Photosphäre
- Limitationen: Unvollständigkeit der Datenbanken; S/N beobachteter Spektren

Results of condensation experiments

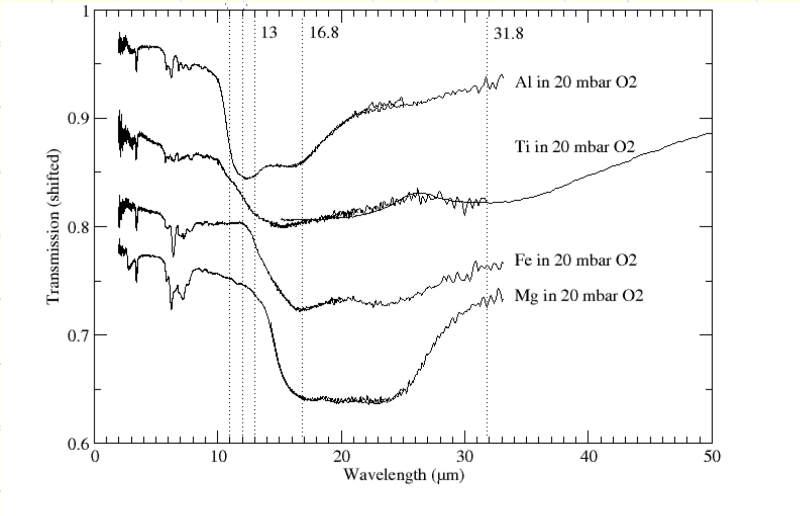


^ AlO_x



< TiO_x

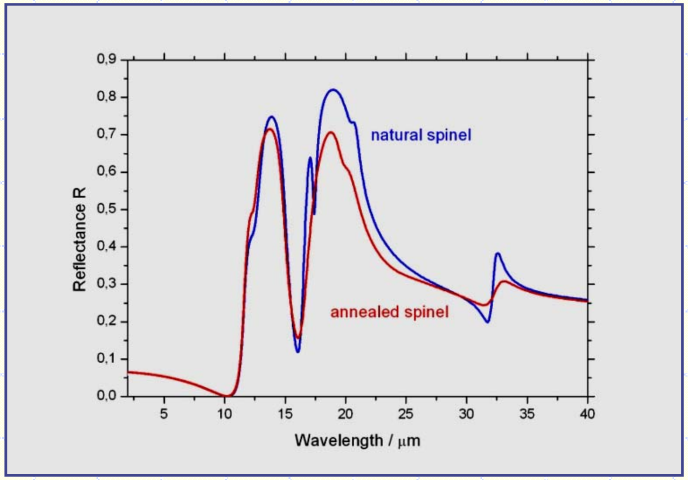
Idee: Statt Berechnung von C_{abs} aus den makrosko-pischen optischen Konstanten: Messung der Absorptivität von frisch kondensierten Partikeln.
Partikelgrößen im Sub-µm-Bereich.



^ IR-Spectra of Al-, Ti-, Fe-, Mg-oxides produced by laser ablation

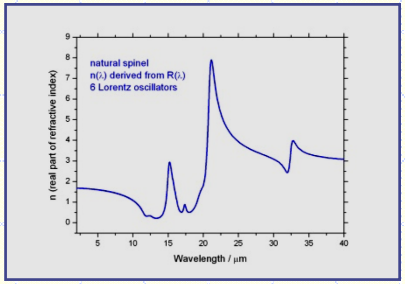
Methods: Lab spectroscopy

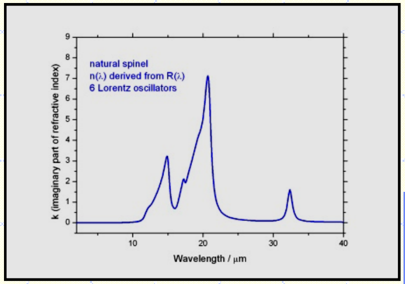
Bsp. eines gemessenen Reflexionsspektrums eines Mg-Al-Spinells:



$R = [(n-1)^2+k^2] / [(n+1)^2+k^2]$

$(n + i\, k)^2 = \varepsilon$





$$\varepsilon = \varepsilon_0 + \Sigma_j\, \Omega_j^2 / (\omega_j^2 - \omega^2 - i\, \gamma_j\, \omega)$$

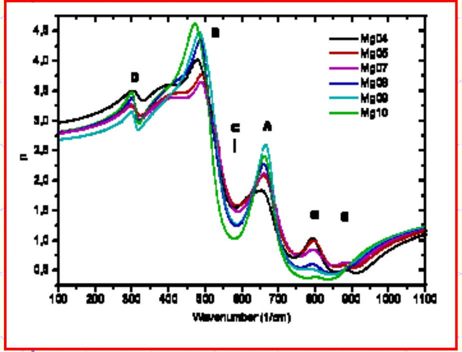
Hitzebehandlung (1h @ 1223K) verändert das Kristallgitter von Spinell (partieller Platztausch Al ↔ Mg)

j	ω_j [1/cm]	Ω_j [1/cm]	γ_j [1/cm]
1	803.6	159.7	82.5
2	666.6	522.9	31.9
3	577.3	132.1	11.5
4	492.4	660.2	30.8
5	478.6	655.5	14.0
6	308.1	151.0	6.9

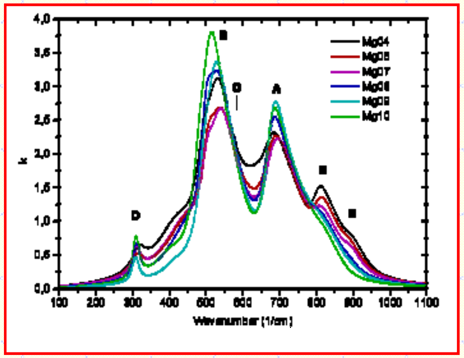
Methods: Mie theory

Maß für WW kleiner Teilchen mit el.-mag. Strahlung $Q_{abs}(\lambda)$, $Q_{streu}(\lambda)$

- **folgen aus <u>Mie-Theorie</u> (unendliche Reihen für $Q_{abs}(\lambda)$ und $Q_{streu}(\lambda)$ für $a \cong \lambda$)**
- **entscheidend abhängig von <u>Partikelform</u> und <u>Partikelgröße</u>**
- **$Q_{abs}(\lambda)/a = 8\,\pi\,/\,\lambda\ *\ 6\,nk\,/\,[(n^2-k^2+2)^2 + 4n^2k^2]$ für <u>sphärische</u> Partikel mit $a << \lambda$**
- **Kugelresonanzen (<u>Fröhlich-Moden</u>) zentriert um $k^2 = 2$ (und $n \rightarrow 0$)**
- **(NB: keine notwendige Bedingung, aber, wenn erfüllt, starke Resonanz)**

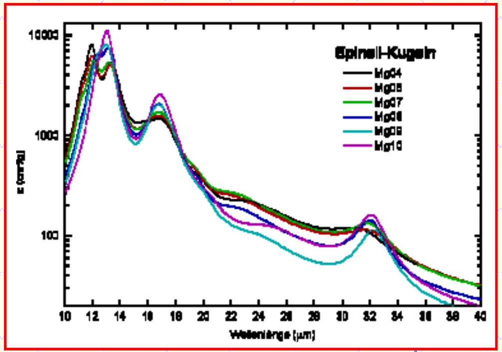


n(ω) für Spinelle
mit versch. Mg:Al-Verh.



k(ω) für synth. Spinelle

⇒



Q_{abs} (λ)

Backup slide on methods

Voraussetzungen:
✓ Laboranaloga präpariert
✓ Analytik durchgeführt

Labor-Messungen und Rechnungen:

1a) Messe Reflektivität $R(n,k,\lambda) \Rightarrow n + i\,k(\lambda)$

1b) Messe Transmission $T(n,k,\lambda,F) \Rightarrow k(\lambda)$

2) Berechne $Q_{abs}(n,k,a,F,\lambda)$

Astronomische Beobachtungen
liefern im einfachsten Falle:
$\Sigma_j\, Q'_{abs,\,j}(n',k',a',F',\lambda) * B_\lambda(<T_d>)$
[genauer: Resultat von STR,
in welche $Q_{abs,\,i}$ eingehen]
$\Rightarrow$ ermittle $Q'_{abs,\,j}\,(n',k',a',F',\lambda)$

a … Teilchenhalbmesser
nstanten
:or
peratur

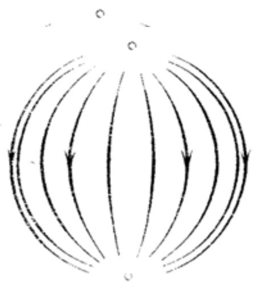


Fig. 3. Erste elektrische Partial-schwingung.

Comparison

Backup slide on methods

272 Thomas Henning

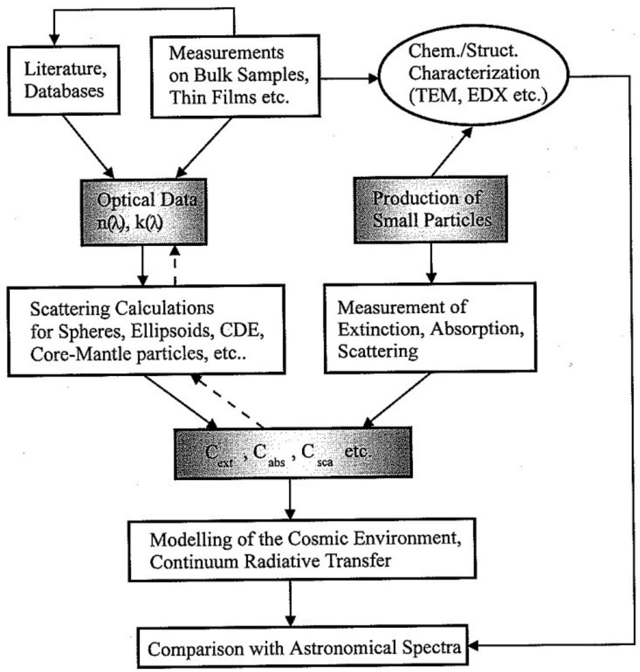
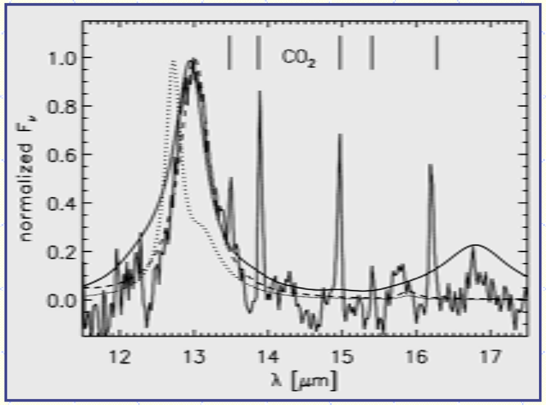
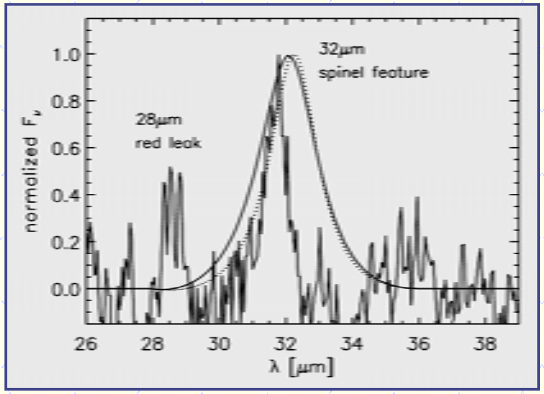


Fig. 3. Different approaches for determining the optical properties of cosmic dust. After [22]

Backup slide on results





<u>Leitfrage:</u> ∃ Korrelation:

Im Labor gemessesene Oxidbanden

↔ Staub-Banden in ISO-Spektren ?

Bsp.1: Emissionbanden bei 13, 17 & 32µm:

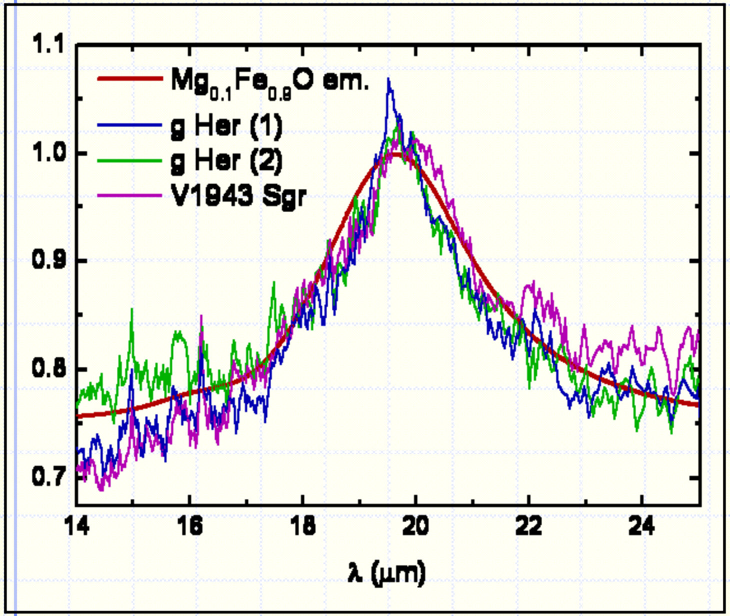
Wahrscheinlichster Urheber:

Spinell ($MgAl_2O_4$)

13µm-Bande: lange Zeit α-Al_2O_3 zugeschrieben (links oben Linie "...")

Sekundärbanden bei 21 und 26µm nicht detektiert

Another backup slide on results

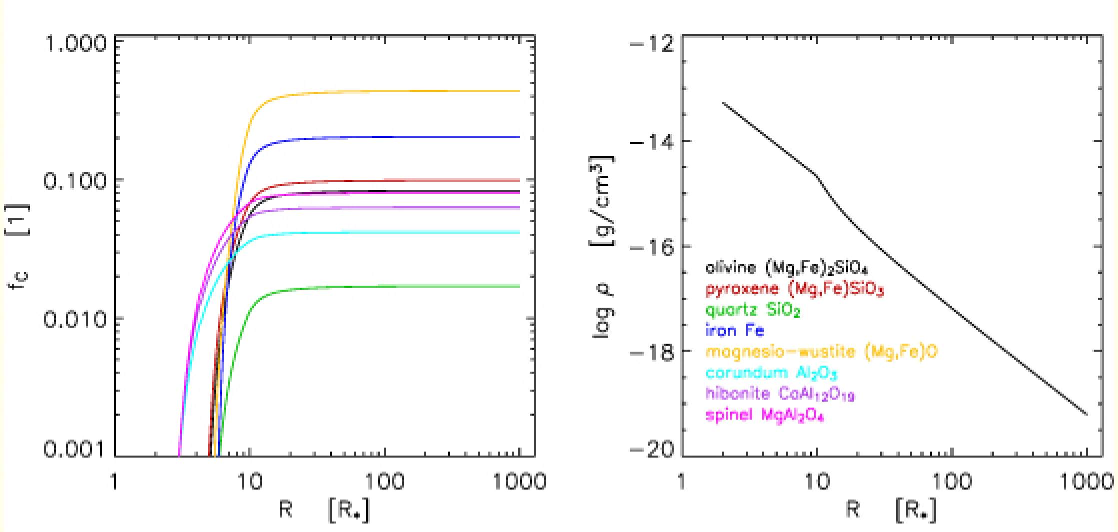


^ ISO-SWS-Staubresiduum von g Her u. V1943 Sgr;
Staubemission von $Mg_{0.1}Fe_{0.9}O$

Die 19.5μm-Emissionsbande:

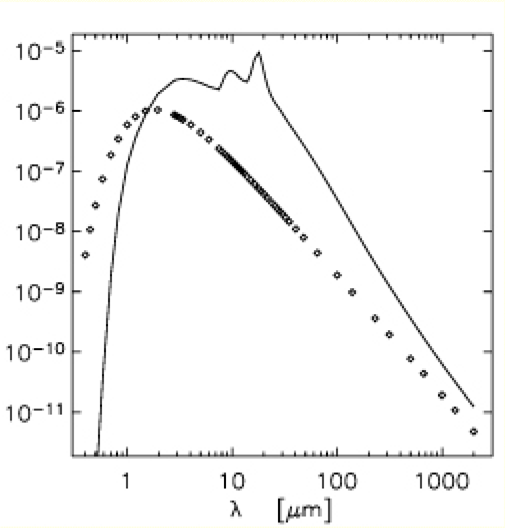
- Erste Hinweise durch IRAS
- Hinreichend aufgelöst erst mit ISO (Posch et al. 2002)
- Beobachtet v.a. in Spektren semiregulärer Veränderlicher
- Kondensationstheorie unterstützt spektroskopische Evidenz für **$Mg_xFe_{1-x}O$** (mit $x \cong 0.1$)

O-rich dust species: results of a stationary wind model



Parameters (II):
T_{eff} = 2800 K
L = 6740 $L_\odot$
M = 1 $M_\odot$
dM/dt = 5 10^{-6} $M_\odot$/yr
v_{init} = 2km/s (v_{end} = 7km/s)
C/O = 0.5

Abundances:
cor, hib, spin:
increasing
mwue:
decreasing (reason: acceleration of sil's dilutes gas before mwue-condensation)



SED strongly dominated by ~20μm band.

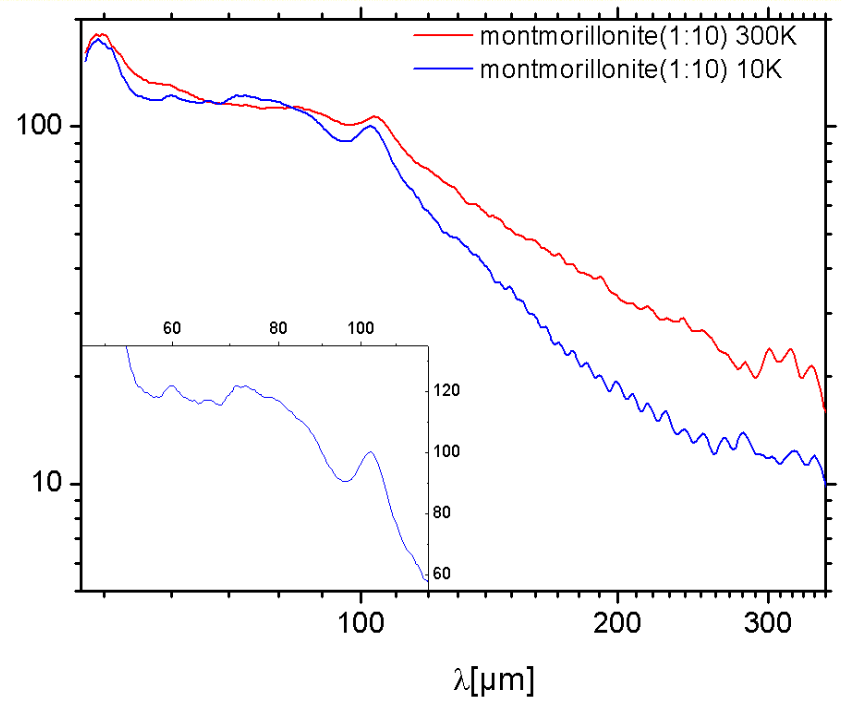
Relative importance of 10μm band (silicates) increased

Future Work

+ NanoSIMS

Philips CM200 electron microscope
at the University of Vienna

Mount? Mont…? what?



Paper: Mutschke, Zeidler, Posch et al., A&A 492 (2008), p. 117

Montmorillonite (MM)

- **„Cold“ (down to 10K) FIR measurements using liquid He:**
- **Weak bands of MM become stronger and sharper**
- **MM does <u>not</u> only show a broad, 85-125µm band**