MINUTES
THERMAL EMISSION MEETING #2
ISSI, Bern, Oct 26-28, 2011

Björn J. R. Davidsson
Dep. of Physics and Astronomy, Uppsala University, Sweden

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Contents

1 Participants and Background

In alphabetic order and with abbrevations,

1. JB: Bandfield, Joshua (University of Washington, USA)
2. KB: Bauch, Karin (DLR, Berlin, Germany) *via skype*
3. MTC: Capria, Maria Teresa (INAF–IASF, Rome, Italy)
4. BD: Davidsson, Björn (Uppsala University, Sweden)
5. JE: Emery, Joshua (University of Tennessee, USA) *via skype*
6. PG: Gutiérrez, Pedro (Instituto de Astrofísica de Andalucía–CSIC, Granada, Spain)
7. TM: Mueller, Thomas (Max–Planck–Institut für extraterrestrische Physik, Garching, Germany)
8. OG: Groussin, Olivier (Laboratoire d'Astrophysique de Marseille, France)
9. HR: Rickman, Hans (Uppsala University, Sweden / PAN Space Research Center, Warsaw, Poland)
10. AS: Sprague, Ann (University of Arizona, USA) *via skype*
11. MW: Wilska, Magdalena (PAN Space Research Center, Warsaw, Poland)

Following an unsuccessful application to ISSI in 2010, the Team met on November 9–11, 2010, at DLR in Berlin, where it was agreed to improve the proposal and try again. The application made in 2011 was successful and ISSI approved funding of our project, *Deriving Physical Parameters of Atmosphereless Bodies in the Solar System by Modelling their Thermal Emission*. The second meeting was held at ISSI in Bern, Switzerland, organized and chaired by Björn Davidsson and Hans Rickman. The meeting consisted of presentations (day I), general discussions on various research topics (day II), detailed discussions and formulation of action items (day III).

2 Day I

Wednesday, October 26, 2011, 14:00–19:00

Dr. Falanga from ISSI gave a presentation on their activities. After a few welcome words by Rickman and Davidsson, the meeting began. Presentations were given by *Bandfield* on "Lunar thermophysical investigations using LRO Diviner measurements", by *Capria* on "Derivation of thermophysical properties from surface temperature data: Dawn at Vesta and Rosetta at Lutetia. Methods and problems", by *Davidsson, Gutiérrez, and Rickman* on “Thermal inertia and surface roughness of Comet 9P/Tempel 1”.

After a well earned welcome drink from ISSI the presentations continued with *Groussin* discussing “In–situ thermal observations of comets 103P/Hartley 2 and 9P/Tempel 1”, followed by *Mueller* on “Thermophysical modelling of small bodies”. Instead of attempting to summarize the contents of the presentations in these Minutes, we should post the powerpoint files on a website from which they can be downloaded.

3 Day II

Thursday, October 27, 2011, 09:00–18:00

Davidsson gave the presentation “Recalling the Proposal – Purpose of the Meeting” (recallproposal.pdf) to remind us what we have set out to do according to the Proposal. We agreed to stick to the proposed Agenda, where three main topics (*Databases*, *Laboratory work*, *Modeling work*) had been identified. Each topic should first be discussed in general terms for ~ 1 hour, followed by decisions and distribution of action items during another ~ 0.5 hour. After the first presentation, there was a brief discussion:

OG: The weak point is laboratory work, since the most important person in the Team on that topic (Helbert) could not participate.

MTC: We can still make recommendations and formulate “wish lists”.

TM: We need a collection of definitions for the terminology we use (reflectance, albedo, inertia) to minimize misunderstanding.

PG: For example, when people say “temperature” it is often unclear whether they refer to brightness temperature or physical surface temperature, and how the latter is defined (there will never be a single temperature on an unresolved terrain).

BD: We should always use the phrase “effective temperature” or something similar to emphasize that we do not measure real temperatures, but only some equivalent temperature that (when plugged into the Planck function) manages to reproduce observed spectra.

There was some debate whether “effective temperature” was a good option, BD reminded that we basically use it as done in stellar physics.

TM: Regarding intercomparison of models – the goal here should not be to test basic performance or correctness (we take for granted that the models are free of major bugs or numerical problems etc), but to investigate e.g. how different models of surface roughness affect the synthetic spectra.

JB: If the Team has suggestions to spacecraft instrument teams on specific observations that could be made to test ideas or facilitate the retrieval of physical parameters, there is a chance they could do it for us.

MTC: The databases should focus on a limited number of test cases, e.g. standard sets.

BD: One could also attach the results obtained when different models have been used to interpret the data. At least for me it would be interesting to test my own models on a particular dataset and check that I got the same results like everybody else.

3.1 General discussion on Databases

Davidsson showed two slides to provoke a discussion (see discussions.pdf). First a reminder that we have four areas to cover: *remote sensing* (disk–integrated observations from ground or Earth orbit, and auxiliary information such as shape reconstruction extracted from such observations), *in situ* (disk–resolved), *laboratory* (emissivity, reflectance), and *thermophysical models*. We should understand what is already available, what is missing, what we want to do, and if we can pull it off on the time available. Also, two possible approaches were shown to illustrate different levels of ambition (collection of links to pre–existing databases, versus creating our own web–based searchable database).

MTC: Europlanet has infrastructure for these kind of things, e.g. the European Virtual Observatory, that could be utilized.

TM: We need a clear and restricted goal with the Database. For example, the Herschel database has the clear goal of collecting a limited number of data (physical parameters) that facilitates the thermophysical interpretation of the observations.

JB: "Database" is perhaps not the right word for what we want to do. Rather, we should compile lists of available observations etc, oriented towards specific targets, e.g. the Moon.

BD: It would also be good to collect relevant laboratory measurements, for example those covering the 3–5 μm region where several spacecraft instruments operate.

MTC: It would be helpful to extract key information available in papers that we may not have time to read.

OG: We should set up a web page that we can feed with links to pre–existing databases, but having a clear goal with our actions.

TM: We should restrict the database to information needed by thermophysical models, and only consider targets for which we have spatially resolved data. For example, the Moon, a comet, some asteroids.

MTC: Vesta is a good candidate.

BD: What about models? It would be good to have brief descriptions of currently used models (with their major assumption, limitations, capabilities), with references to key papers for each model.

TM: In Asteroids III there was a review paper on models, summarizing the status as of 2000, so it is questionable if we should repeat this.

PG: It is not sufficient to report model parameters, as said previously, we need a document that defines our terminology.

BD: The database should not only be consistent in terms of the meaning of parameters, but we should aim for having the same information format (structure of the website) for all objects in the database to make it easy to navigate.

3.2 Databases – Decisions and Action Items

• We discussed whether a wikipage or a google docs spreadsheet was the best solution for us. We agreed on the former solution. Action Item (Bandfield, Groussin): Set up the wikipage.

• We decided to arrange the database *target by target*, focusing on reporting remote sensing observations (disk–integrated or –resolved), in situ measurements (if any) and relevant laboratory measurements.

• TM gave himself an Action Item: Check if SOFIA can observe the Moon.

• We decided to include the Moon, Mercury, Tempel 1, Itokawa, Vesta, Lutetia, Ceres, Phobos and a Saturnian satellite (TBD) in the database.

Further details on the Database, as well as Action Items for individuals, were discussed on Day III.

3.3 General discussion on Laboratory Work

Davidsson showed two slides to provoke a discussion. The key question is what measurements are requested by observers and modelers to advance the understanding of Solar System bodies. Examples: emissivity versus wavelength (particularly at 3–5, μm but also at TIR and FIR), emissivity versus emergence angle, dependence on grain size, mineralogy (mixtures), temperature (gradients). There is also the issue of suitable analogue materials for asteroids, comets, TNOs, and whether we can reach a better understanding of the effects of surface roughness, shadowing and self heating experimentally. Another key question is of course to understand what is already available, and what can be done at PEL (with a reasonable work load).

Davidsson also exemplified with the MODIS UCSB Emissivity Library [1] and the ASTER Spectral Library[2] (brought to his attention by Gutiérrez) which contains emissivity measurements versus wavelength for water, ice, snow, soils, minerals, vegetation, manmade materials, lunar samples, meteorites. Davidsson perceives a lack of such information for organic materials (relevant for D–type asteroids, comets, TNOs), and questions if measurements for standard minerals (olivines, pyroxenes etc) are applicable due to space weathering effects on real targets. Also, hemispherical emissivities are normally reported, while we may want to have directional emissivities.

[1] http://www.icess.ucsb.edu/modis/EMIS/html/em.html
[2] http://speclib.jpl.nasa.gov/search-1

MTC: Measurements of heat conductivity are important, and more so than thermal inertia that is somewhat "artificial" (only having a clear meaning when conductivities and heat capacities lack temperature dependence, which rarely is the case in Nature).

PG: Measurements of conductivity, emissivity etc are very sensitive to the size distribution of grains, as well as temperature.

OG: We may request many things, but we also have to consider what is feasible to obtain.

MTC: We have to specify which parts of parameter space we wish to map.

BD: I think we should fist make our requests from an observer/modeler point of view, then find out what can actually be carried out.

JB: It is probably more important to systematically study the emission behavior as function of grain size of the medium, rather than considering a large number of minerals with "random" grain properties. Also, large differences in emissivity measurements have been seen when samples are heated from below instead of from above with radiation, indicating that the temperature gradient in the surface layer has a significant influence on the result.

TM: It would be valuable (when interpreting TNO observations) to have measurements performed at very low temperature.

??: We should also investigate if there are other laboratory facilities besides PEL that we could use.

Somebody made a comment about using nightside observations of the Moon to investigate the emergence angle dependence of emissivity. Could that person contact Davidsson to remind him what was said on this topic?

TM: The thermal properties of lunar samples at different temperatures should be included in the database. I recommend Keihm (1984), *Icarus* **60**, 568.

TM, OG: The long–wavelength behavior of minor bodies could/should be explored with ALMA, but might be heavily affected by effects of subsurface emission (lower temperature, different emissivity, grain–size effects *et cetera*).

HR: Back to laboratory work. We should isolate the things that laboratory measurements can tell us. We have to make detailed suggestions, and discuss setups.

Somebody quoted statements of Helbert from the previous meeting (see Minutes): "We can measure emissivity up to 200 μm but none have shown interest so far". However, we are definitively interested, since e.g. Vesta has a anomalous behavior at sub–mm wavelengths (perhaps we can contribute to understanding this).

It was decided to wait with conclusions until the modeling aspect had been discussed. At this point, we attended a seminar by Prof. Ji Wu, Director of the Center for Space Science and Applied Research (CSSAR) in China, addressing "Creation, Application and Contribution – A three–phase roadmap of Chinese Space Activities".

3.4 General discussion on Modeling Work

Davidsson started by showing five slides to provoke a discussion. First, four areas were identified; 1) Intercomparison of models; 2) Models versus ground truth; 3) Models versus disk–resolved observations; 4) Models, disk–integrated and disk–resolved observations. Each of them was then introduced in some detail.

Intercomparison of models: There are many different ways to generate rough surfaces, such as considering craters, trenches, fractal surfaces, stochastic Gaussian surfaces. Even if they have the same formal level of roughness (like the Hapke $\overline{\theta}$), are they really equivalent in terms of observables? How do we disentangle thermal inertia and surface roughness? Is 3D heat conduction important, and if so, when?

Models versus ground truth. Can our models combined with remote sensing data recover the known thermal inertia and degree of surface roughness of the Apollo landing sites? Are there other kinds of ground truth (e.g. laboratory measurements) we could use to test models? Another way to test procedures is to produce synthetic observations with one model, and see if other models can recover the known parameters by applying standard approaches used for interpreting real observations.

Models versus disk–resolved observations: Can models reproduce real surface effects (e.g., spectral properties versus emergence angle)? If the same (resolved) data set is analyzed with different models, are the same fitted parameters (roughness, thermal inertia, emissivity) obtained?

Models, disk–integrated and disk–resolved observations: Again, will different models interpret the same (disk–integrated) observational material in the same manner? Also, it would be interesting to study targets for which there are both spatially resolved and disk–integrated observations (such as Lutetia or Tempel 1). Since these observations often are made at different wavelength regions and observing geometries, it is important to understand if they all converge on the same solution.

Discussion on *Intercomparison of models*:

BD: It would be important to study, for the same rough surface, the effects of applying different levels of refinement when calculating temperatures. For example, one may only consider temperature variations due to slope (i.e., local variation in the cosine of the zenith angle), but ignore shadowing and self heating. Next, one adds shadowing, and as a third step, self heating. How do the resulting temperature distributions or spectra change?

JB: This study should end up with some kind of advice, like "when is it necessary to apply what formalism".

OG, BD: It would be important to study different types of roughness, but a comparison requires that surfaces have some important property in common (so that potential differences in terms of surface temperature distribution or emerging spectrum reveal whether that particular property really should be used to describe the level of roughness). We discussed whether the entire surface slope distribution $D(\theta)$ should be considered, or single parameters such as the Hapke mean slope angle $\overline{\theta}$ or the small–scale surface roughness parameter ξ. OG argued for $\overline{\theta}$ or ξ, while Davidsson argued that $D(\theta)$ may be a better choice. (On day III, Davidsson changed his mind, remembering that different roughness types may have incompatible surface slope distributions. For example, the roughness represented by the Manhattan skyscrapers is basically bimodal – a spike at $\theta = 0$ for streets and roof tops, and a spike at $\theta = 90$ for house walls. A crater model, which always has intermediate slopes and a broader distribution, can never be forced to have the same $D(\theta)$ as Manhattan. It would then be better to force the two models to have e.g. the same $\overline{\theta}$, and investigate how they differ in terms of emerging spectral emission properties. Another complication was mentioned: depending on the fractal dimension, different fractal surfaces may have extremely different ξ–values (a parameter based solely on the surface area), but the same $\overline{\theta}$. It was decided to always compute and provide as many measures of roughness as possible, to fully understand the similarities and differences between different realizations of rough terrain. The minimum set includes $D(\theta)$, $\overline{\theta}$, ξ and the RMS slope angle ρ.

Simulations and observations of nightside conditions were discussed. TM: This is important since most thermophysical models only consider the diurnal heat wave (thermal inertia related to the diurnal temperature changes), but ignore the seasonal heat wave (seasonal thermal inertia), which keeps the nightside (and also parts of the surface which see sun–light only with changing aspect angle) at temperatures which are higher than typical model temperatures. In this context it would also be useful to learn about already existing true nightside temperature measurements (Moon? Lutetia? Steins? Itokawa? comets?) and if our models are capable of reproducing the measurements.

BD: Described a situation where the surface material itself has "simple" emission properties (e.g., Lambertian emission, and lack of wavelength dependence). However, surface roughness (and the surface temperature dispersion that results from it), may yield a resulting emission spectrum, that cannot be reproduced (with a single Planck function evaluated for some best–fit temperature), unless an emissivity is introduced that is a function both of emergence angle and wavelength. One should therefore study the risk that roughness introduces false emissivity properties.

PG: There are many different types of roughness, perhaps resulting in spectral behavior that still show some systematic behavior. It would be important to identify this very basic behavior and try to characterize it with some model or procedure based on very few fitting parameters. This would make it possible for people (that perhaps do not have access to thermophysical models which explicitly consider roughness), to determine those parameters from various empirical data set. It is then a second step to try to interpret those parameters in terms of some real physical property.

??: It's like Hapke analysis. A small number of parameters are used to "summarize" observed behavior, and it is valuable since many people have applied it for many targets.

However, it remains to be seen what these parameters really means, in terms of physics.

OG: Another concern is the considered wavelength interval. The $\beta B_\lambda(T_{\rm eff}) = X' B_\lambda(T_{\rm eff})$ formalism used by OG, BD, PG, HR, only "works" because we consider a very limited wavelength region.

OG, TM: We should select specific ξ or $\overline{\theta}$ values, and generate different types of rough terrain for each. Then calculate the radiance as observed from nadir. Focus on $A = 0$ (to avoid further complications caused by multiple scattering) and zero thermal inertia (since not all models currently take heat conductivity into account – furthermore our focus is on understanding the influence roughness has on spectral properties, and for that any thermal inertia will do (with some exceptions).

Discussion on *Models versus ground truth*

BD: I would like to apply mine and Hans' model to LRO Diviner data to see if I manage to reproduce the known ground truth from the Apollo landing sites, as a sanity check.

Blind tests where discussed (e.g., generating synthetic dataset with the code of PG, have it analyzed in a standard way by TM, OG, and others). More about this on Day III.

TM: As a sanity check, can everybody provide the irradiance ($[\mathrm{W\,m^{-2}\,ster^{-1}\,\mu m^{-1}}]$) for a $1\,\mathrm{m}^2$ surface at 300 K.

TM: Some years ago, I predicted that there should be a thermal opposition effect caused by roughness.

JB: LRO Diviner has observed things that resembles this – should be investigated further.

BD: According to Nicolas Altobelli, a thermal opposition effect has been observed by Cassini for Saturn ring particles.

Discussion on *Models versus disk–resolved observations*:

BD: We need to select at least one data set for a resolved body that can be shared within the time and analyzed with our different codes. What about Tempel 1?

OG: This is possible, but there are certain limitations since Jessica Sunshine and Lori Feaga are working on the retrieval of reflectance and emission properties, which has to be published before we can do something similar.

OG: There is also Deep Impact observations of the Moon. How do they compare with LRO Diviner data?

JB: How do we deal with issues like thermal inertia variation with depth?

TM: In addition to diurnal thermal inertia effects, there are also the seasonal thermal effects. When shadowed areas emerge into sunlight after a prolonged period of darkness, they tend to be warmer than predicted by models.

TM: In order to estimate the thermal inertia of bodies, it is crucial to have access to observations obtained both before and after opposition.

OG: ALMA can observe the nightsides of NEAs, even when the elongation is very small. This should be very important observations for retrieving the thermal inertia of these bodies.

Discussion on *Models, disk–integrated and disk–resolved observations*:

TM: For most objects, standard models work extremely well. However, in the Spitzer and IRAM data sets, there are a few difficult cases.

BD: The TNOs that have strange behavior – are they all behaving strangely in the same manner?

TM: According to wikipedia, there is no naturally occurring material on Earth that has a geometric albedo higher than 0.80. At the same time there are bodies like Enceladus with an extremely high albedo.

OG: It is not good to use geometric albedo when comparing bodies. The opposition effect is often very strong, and differences in geometric albedos between bodies could simply be caused by differences in the particular near–zero phase angle at observations (or less than perfect extrapolations to zero phase).

TM: Spitzer 24 μm observations of Makemake are incompatible with observations at longer wavelengths (according to standard models), unless there are rather extreme dark zones (hot spots) on the surface.

TM: For many objects, the amount of empirical data is so small than "any" model can fit it. Normally one can only estimate size and albedo, nothing more. However, in many cases, data cannot be fitted with models without surface roughness or with an extremely high surface roughness – but *any* "intermediate" value will work.

PG: It is important to investigate which types of observations, e.g. in terms of wavelength range, that are sensitive to roughness (or not).

After a full day of intense discussions, we (I) were not in the right condition to draw some meaningful, concrete conclusions. However, during the night, Davidsson put together a presentation (conclusions.pdf), summarizing the situation to the best of his understanding, including Action Items. This was presented during the following day.

4 Day III

Friday, October 28, 2011, 09:00–13:00

Davidsson summarized the discussions from the previous day, here presented topic by topic, along with further comments.

Action Item (Bauch, Emery, Helbert, Jorda, Sprague): Please let us know if you wish to participate in any of these projects, and if so, in what manner. Also, if you have suggestions for new projects, or ideas on how to modify or improve current ones, please feel free to do so.

4.1 Database

The *goal* of the database is to collect information on those Solar System bodies that are considered to be most suitable for a detailed thermophysical analysis. The *reason* for some bodies being more suitable than others simply relates to the available number of observational constraints, that should be as large as possible. The *criteria* for selection are basically that the body lacks a permanent atmosphere, it has been observed by spacecraft with NIR, TIR or sub–mm instruments, and there is a wealth of ground– or space–based remote sensing observations.

The database should contain an individual page per object, containing the following information (when available):

- Disk–integrated
  - ⋆ Wavelength regions (NIR–FIR), filters (with transmission profiles), phase angle coverage, temporal coverage, heliocentric distance
- Disk–resolved
  - ⋆ As above, plus resolution, coverage
- Ground truth
  - ⋆ Temperature, conductivity, porosity, density, heat capacity (all versus depth), mineralogy, grain size distribution, topographic properties, *when available*.
- Additional information
  - ⋆ Shape model (e.g. from lightcurve inversion techniques, flybys, occultations, adaptive optics, radar, KOALA), spin parameters, geometric albedo, Bond albedo, Hapke parameters, reflectance and emissivity spectra, previous thermal inertia and roughness estimates, H–magnitude, G–slope parameter, opposition surge.

The database should either provide the information directly, or link to specific databases. The entries have to be non–trivial. For example, it is not sufficient to simply state that "NIR observations of target XXX have been performed" – we also need to know exactly where and how to find the observed data in question. It is also not sufficient to provide too generic links, like "see the PDS archive". The whole idea is that information should be *easily* available, through our database.
We decided that each person is responsible for filling the database for one specific target. A substantial fraction of the information ($\sim 80\%$) should be collected by the end of 2011. A mature version should be ready by early May 2012, so that we can use it throughout the course of the Project.

The following objects and responsibilities where agreed on (Action Items here means to fill the Database):

The Moon: Action Item (Bandfield). Bauch: would you like to contribute here?

Mercury: Sprauge: would you like to contribute here?

Itokawa: Action Item (Mueller)

Phobos: Action Item (Rickman, Wilska)

Ceres: Action Item (Davidsson)

Vesta: Action Item (Capria)

Lutetia: Action Item (Gutiérrez)

Tempel 1: Action Item (Groussin)

Saturnian satellite: Emery: would you like to contribute here? First goal could be to suggest one or several specific targets.

As stated previously, Bandfield & Groussin have an Action Item to set up the database infrastructure. According to Bandfield, he needs a couple of weeks to set up the basic version. In addition, Action Item (Davidsson): Write a draft version of the nomenclature document, to be distributed for comments, additions and corrections early next year (February 2012 is realistic). Finally, we consider it important that we include relevant reflectance and emissivity measurements to the database, primarily selected based on *wavelength coverage* (should have a substantial overlap with observations), and *relevance* (in terms of surface analogue material and temperature range). Helbert: would you like to contribute here, together with each person that is responsible for a particular target (as requirements will depend on the body in question)?

Further comments and discussion related to Databases:

TM: It is important that we understand the temperature during which the laboratory measurements have been obtained. Mercury requires high temperature but TNOs requires very low temperature.

BD: We also have to understand what data that is usable for us and how we should use it. For example, the Jena database provides optical parameters $m(\lambda) = n(\lambda) + k(\lambda)i$ for a large number of silicates (pyroxenes and olivines with systematically explored dependence on the Mg/Fe ratio), graphite etc. I have used it together with Mie theory to calculate single–scattering albedo as function of wavelength and grain size, and plugged that into Hapke theory equations to obtain directional and hemispherical emissivities. But how do I know if the derived emissivity spectra correspond well to reality? We should avoid model–dependence as far as possible, and collect *directly measured* emissivities as far as possible.

HR: Meteorites are obvious analogue materials that we should include in the database, for example suitable HED meteorite properties for Vesta. However, we have to be very careful – for example, the Kaidun meteorite has been linked to Phobos by some workers, but I would not trust it too much.

4.2 Laboratory Work

Action Item (Davidsson): Formulate email to be sent to Helbert, with the purpose of understanding better the capabilities and limitations of PEL (both in terms of technology and hardware, as well as available manhours). Some thoughts:

• We are interested in emissivity measurements covering the entire 3–200 μm region, in particular the 3–5 μm micron region where many instruments operate (e.g., HRI–IR on Deep Impact, VIRTIS on Rosetta, VIR on Dawn), and the sub–mm wavelengths where Vesta has an anomalously low emissivity according to remote sensing observations.

• We are interested in understanding the emergence angle dependence of emissivity. Here, we should remember the potential influence of temperature gradients in the surface material (a possible reason why heating from above gives other results than heating from below).

• We are also interested in the reflectance in the 3–5 μm, since we need to subtract scattered solar radiation. This should be possible to measure directly in the laboratory for samples that are so cold that they have negligible emission in this wavelength region.

• We think it is important to understand the influence of grain size on the emissivity (perhaps more so than considering a large number or minerals). Then we need to be able to study samples with very well–characterized size distributions.

• We would like to understand better what is available in the literature and in databases on organic substances that could be analogs for D–type asteroids, comets and TNOs. Also, what we could do to fill potential gaps.

• The same goes for space weathered minerals. MTC mentioned that several research groups in Italy produce "space weathered" minerals by particle bombardment in accelerators. Action Item (Capria): Could you provide a list of institutes, contact names, and perhaps some references to the literature on this?. Also, Action Item (Rickman, Davidsson): Check what possibility we have for producing "space weathered" samples in Uppsala.

4.3 Modeling Work

We have identified seven modeling projects, here described in some detail with action items and further comments / discussion.

4.3.1 Roughness: Level of complexity

The purpose of this project is to investigate to what level of detail it is necessary to model the effect roughness has on the surface temperature distribution (for a rough piece of terrain), and the emergent spectrum (at different wavelengths). A full machinery (including projected shadows, self heating by single– or multiple–scattering) is difficult to implement and is very time consuming to run. It is therefore of great interest to know if simpler and faster approaches may yield similar results at a much lower cost.

In some detail, the project consists of the following steps:

1. BD/HR/MW generates at least three terrains with Low, Medium and High degree of roughness (here taken as $\overline{\theta} = 5^\circ$, 20° and 35°). A reasonable number of surface facets range 800–5000. The surface will be described as z–values for node points above a quadratic planar $\{x, y\}$ grid. Supplementary information (surface normal vectors and surface areas for the facets that can be constructed from the nodes) will be provided.

2. JB will apply his thermophysical code to the surface (assuming a solar constant $S_\odot = 1360\,\mathrm{W\,m^{-2}}$, heliocentric distance $r_\mathrm{h} = 1\,\mathrm{AU}$, Bond albedo $A = 0$, integrated hemispherical emissivity $\overline{\varepsilon}_\mathrm{h} = 1$, zero thermal inertia, a spin pole perpendicular to the orbital plane, an equatorial region, and illumination conditions corresponding to local hours 8 h, 10 h, and 12 h for a 24 h rotation period).

3. As a first step, JB will only consider the effect of facet orientation, i.e, no self heating, no shadowing, only considering local zenith angles (including zero illumination for facets turned away from the Sun). As a second step, JB will switch on his implementation of self heating, where part of the radiation emitted by tilted facets (the "downwelling" fraction) is absorbed by facets with no tilt.

4. For both these cases, histograms showing the distribution of surface temperatures will be made, as well as the resulting thermal emission spectrum (at 1–200 μm with 0.1 μm resolution), for an observer with nadir viewing.

5. In parallel, BD/HR/MW will run their code in two modes; a) considering projected (cast) shadows in addition to tilts, but self heating switched off; b) considering tilts, shadowing and thermal self heating (with no simplifying assumptions, except that the view factor formalism assumes Lambertian emission).

6. BD/HR/MW will then calculate surface temperature distributions and spectra in the same way as JB.

The "products" to be compared are therefore temperature distributions and spectra, for different degrees of roughness, illumination geometries, and wavelengths. The purpose is to understand *if* and *when* (e.g., at what wavelength regions, or for which illumination conditions), simple and rapidly implemented descriptions of roughness produce results similar to those obtained when the full machinery is at work.

Action Item (BD/HR/MW): Generate surfaces and pass them on to JB. Perform their part of the modeling work. Action Item (JB): Once the terrain descriptions have been provided, perform his part of the modeling work.

This project should be completed before the next meeting in ~ 6 months from now, i.e., by April 2012.

4.3.2 Roughness type

The purpose of this project is to investigate how different *types* of roughness implementations affect observables like emission spectra (and the underlying surface temperature distributions). The different types of roughness implementations (and the persons with access to such models) we had in mind are:

- Spherical indentations (craters) on a otherwise planar surface (Emery). Action Item (Emery): Let us know if you are interested in participating in this project
- Parallel trenches or dykes, e.g. with a sinusoidal cross section (Davidsson/Rickman/Wilska).
- Fractal surface (Groussin/Jorda)
- Stochastic Gaussian surface (Gutiérrez)

As some of these codes account for shadowing, self heating, and thermal inertia, while others do not, we need to make sure that we understand what "part" of the potential differences between model results is due to topography type (our main interest here), and what part that is due to e.g. self heating. Everybody should therefore run their codes with zero thermal inertia, and those who consider self heating effects should run their code with this feature switched off (if technically possible), but they should also provide simulations with self heating switched on for comparison.

A comparison between topography types requires that the different terrains have similar *level* of roughness. There are several measures to choose from – the RMS slope angle ρ, the Hapke mean slope angle $\bar{\theta}$, and the small–scale self heating parameter ξ to mention a few. We agreed to try fix two properties – the RMS slope angle ρ and the *number* of surface facets. The latter is particularly important for the fractal surfaces, where a family of surfaces with different fractal dimension (essentially number of facets) may all have the same ρ but very different ξ (that parameter is determined from the integrated surface area). We agreed to use the number of facets $N = 800$ as a baseline, and try to generate our different kinds of rough surfaces so that we get as close as possible to $\rho = 5^\circ$, 20° and 35°. In each case, $\bar{\theta}$ and ξ should be calculated as well, for the records. For comparative reasons, a few fractal surfaces with a much larger N should be considered as well.

The thermophysical models should be run for a solar constant $S_\odot = 1360\,\mathrm{W\,m^{-2}}$, heliocentric distance $r_\mathrm{h} = 1\,\mathrm{AU}$, Bond albedo $A = 0$, integrated hemispherical emissivity $\bar{\varepsilon}_\mathrm{h} = 1$, zero thermal inertia. The incidence angles to be considered are $i = \{0^\circ, 30^\circ, 60^\circ, 80^\circ\}$, for an emergence angle of $e = 0^\circ$ (i.e., nadir observation). In addition, the incidence angle $i = 45^\circ$ should be considered along with an emergence angle of $e = 45^\circ$, for three different values of the azimuth: 0°, 90° and 180°.

The output products will be the distribution of surface (facet) temperatures, but more importantly, the thermal emission spectrum ($1 \leq \lambda \leq 100\,\mu\mathrm{m}$ with $\Delta\lambda = 0.1\,\mu\mathrm{m}$).

In addition, Capria will investigate if constraints can be placed on the suitability of various roughness descriptions, by studying Dawn visual images and NIR spectroscopy at different spatial resolutions. This will eventually lead to code implementations in one way or the other, which may also be part of this project.

As for the near future, we suggest the following steps to be made:

1. As part of the nomenclature document, definitions of $D(\theta)$, ρ, $\overline{\theta}$ and ξ will be distributed, to make sure we all evaluate the degree of roughness in the same manner. Action Item (Davidsson): Distribute definitions of these parameters.

2. As a sanity check, we should make sure everybody calculate the same irradiance from a flat $1\,\mathrm{m}^2$ surface at $T = 300\,\mathrm{K}$ (using the wavelength interval and resolution stated above).

3. Each participant should generate one rough terrain (say, for $N = 800$ and $\rho = 25^\circ$), calculate the corresponding $D(\theta)$, ρ, $\overline{\theta}$ and ξ and compare with result with others (email exchange followed by telecon if necessary).

4. Each participant should calculate the temperature distribution and spectrum for $i = e = 0^\circ$ and compare result with others (email exchange followed by telecon if necessary).

At that point, we should decide how to proceed (and how far), before the next data exchange and telecon.

Action Item (Davidsson): Circulate definitions of roughness parameters before end of November 2011. Action Item (JE(?), BD/HR/MW, OG/LJ, PG): Generate the first surface, calculate roughness parameters, by end of 2011. Action Item (MTC): Distribute information on the resolution (visual and NIR) of Vesta obtained by Dawn, evaluate to what level of accuracy stereoimaging can be used to reconstruct surface topography. If possible, provide examples of Vesta topography, to be compared to our various theoretical models.

We should have the first telecon in early January 2012 (note that Davidsson will be out of office throughout December for personal reasons).

4.3.3 Roughness versus wavelength and phase angle

The effect of surface roughness on the resulting *disk integrated* spectrum is a function of wavelength (strong at NIR, weak at FIR), as well as phase angle. It would be good to perform a systematic study of *if, when, and how* roughness results in measurable effects in disk–integrated data. Such a study may help us formulate recommendations regarding the type of observations needed to estimate the degree of roughness.

Thomas Mueller has volunteered to perform this analysis. Action Item (TM): Before the end of the year, provide a brief outline to the Team on how this investigation will be performed.

4.3.4 Nightside properties

The emission emerging from the nightside of minor bodies is expected to be less sensitive to surface roughness and more sensitive to thermal inertia. Still, it is important to explore how the level of roughness may affect the thermal emission from the nightside. For this, we need codes capable of considering both thermal inertia and surface roughness (e.g., the ones by JE, PG, and BD/HR/MW). We primarily had JE and PG in mind for this project.

For example, similar to previous projects, three different levels of roughness could be considered, perhaps for a few different levels of thermal inertia. The thermal emission spectrum (for a certain thermal inertia but different degrees of roughness) would be compared (e.g. for a nadir observer at different local times), and any difference caused by roughness would be characterized (for two different types of surface roughness – craters and stochastic Gaussian terrain).

Action Item (Emery): Let us know whether you would be interested in participating in a project like this a.s.a.p. Action Item (Gutiérrez, Emery): Before the end of the year, circulate a plan on how you intend to perform this investigation, in some detail.

4.3.5 Roughness disguised as $\varepsilon(e, \lambda)$

Here, we imagine that a surface material has simple emission properties (e.g., Lambertian, with no wavelength dependence). However, the surface has roughness and shadowing (and if accounted for, self heating), which will have its influence on the emitted spectrum. The spectrum could be calculated for a number of emergence angles.

If this synthetic spectrum was observed and interpreted as originating from a flat single–temperature surface, any divergence from a single Planck function (evaluated for the effective temperature that minimizes the χ^2–residual) would be interpreted as a *wavelength–dependent emissivity*, possibly with a certain emergence–angle dependence as well. The risk is that such a "emissivity spectrum" would get interpreted in terms of mineralogy, when in reality, there is no real spectral information (only distortions caused by roughness). The project consist of exploring how severe this effects may be.

Here, we primarily thought of using the code of Davidsson/Rickman/Wilska, but also the code of Groussin/Jorda. One could perhaps recycle calculations performed for the "Roughness Type" project here (but consider a denser grid of emergence angles for some particular illumination conditions).

Action Item (BD/HR/MW, OG/LJ, and other interested): We should perhaps have a telecon to fix the details of this simulation effort, since I have rather little in my notes from the meeting?

4.3.6 Blind test

The general idea here is to use the code of Gutiérrez to calculate the disk–integrated thermal lightcurve and spectrum for a few pre– and post–opposition phase angles, assuming some global convex shape, spin properties, thermal inertia and degree of small–scale surface roughness. These synthetic "observations" will then be passed on to Thomas Mueller and Olivier Groussin (and Josh Emery, if interested), who would apply their models and nominal techniques, in an attempt to recover the known properties of the object (size, shape, spin properties, thermal inertia, surface roughness). The idea was to perhaps introduce properties that may not be considered by default in models (such as presence of sublimating surface ice, which could be particularly relevant for TNOs rich in CO or N_2, or a certain wavelength–dependence of emissivity), and see to what extent this influences estimates of, say, the thermal inertia.

There was a lively debate on this topic – what is the purpose of such an investigation (e.g., what do we think we can learn?); what kind of information will be provided to the "observers" apart from the spectra and thermal light curve?; is it feasible to produce the synthetic data in the first place?

We decided to go for the last point first – if we cannot produce synthetic "observations" in the first place (with a reasonable work load), all the other questions are irrelevant.

Action Item (Gutiérrez, Davidsson): Investigate the feasibility of actually being able to produce synthetic "observations" with our models. We should have some preliminary statements ready by the end of 2011.

4.3.7 Shared data set

We have decided to extract two datasets from the rich LRO Diviner database; 1) a set of spectra that follows the same lunar location for different local hours throughout the day (and night); 2) a set of spectra that considers the same lunar location, for constant illumination conditions, but a variety of emergence angles. The idea is then to apply all available thermophysical models at our disposal (JB, MTC, OG/LJ, PG, TM, JE, BD/HR/MW) to these datasets and see what conclusion we would draw individually, and to what extent they overlap or differ with respect to each other. If this can be made for any of the Apollo landing sites we could benefit from groundtruth.

Action Item (Bandfield): Extract the data from the database and provide the information we will need to process them (e.g., illumination and viewing geometries, visual context images, wavelength regions, filter transmission profiles *et cetera*). Processed products (like brightness temperature) are welcome auxiliary information, but the primary data should be the spectra and/or photometry in physical units.