INTAS Open Call 1999 Grant 652

"Theoretical and experimental investigations of light scattering by heterogeneous non-spherical cosmic dust grains"

Periodic Report (01.06.2000 – 31.05.2001)

1. RESEARCH

1.1. Overview of Research Activities

In accordance with the Work Programme, the P1 team (the Astronomical Institute of the University of Amsterdam) concentrated on space and ground-based observations of different objects (see task T5.2 in the Programme). The team has also contributed to the experimental (T2.1-2) and radiative transfer (T4.1) parts of the project as well as to overall management of the project.

The main field of the P2 team (the Astrophysical Institute of the Friedrich Schiller University, Jena) was the development of a sophisticated code for simulations of polarized radiation transfer (T4.1). The team also took part in research on light scattering theory (T1.3), its applications to astrophysics and observations (T5.1-2).

The P3 team (the Astronomical Institute of the St.Petersburg University) developed several exact and approximate light scattering methods; analytically and numerically investigated them and compared with other approaches (T1.1-5). The team was working nearly in all directions of the project (T3.1-3; T4.1-2; T5.1-3), which provided a basis for tight connection of different team activities.

The P4 team (the Stepanov Institute of Physics, Minsk) created new light scattering methods and algorithms (T1.1-3). Of particular importance was the investigation of fields inside scatterers (T1.2). The collection of references to papers on light scattering produced for the electronic database (T3.3) has no analogues in the world and was extremely useful for all teams involved in the project.

The activity of the P5 team (the Astronomical Observatory of the Kharkov University) was mainly directed at solution of several special problems (T4.3; T5.3-4). Nevertheless the team contributed to other tasks (T1.1; T3.3; T5.2) as well. The developed self-training algorithm of determination of the optical properties of fractal-like clusters based on artificial neutronal network became a very important part of the database (T3.3).

The P6 team (the St.Petersburg State Forest Technical Academy) worked out several light scattering approximations (T1.3) and has compared them with other approaches (T1.5). The WWW design of the database and its graphics library (T3.2-3) have been also elaborated by the team.

Thus, all the teams were undertaking researches in accordance with the Work Programme. Most teams have also contributed to solution of other tasks, which strongly enlarged the area of fruitful discussions and well increased cooperation of all teams.

Practically the only deviation from the Work Programme was the postponed activity within the experimental part of the project (T2.1-2). It was shifted to the second year because of the expected appearance of new powerful equipment at the P1 team. On other hand, a large work planned entirely for the second year has been completed during the first year. It included development of the database (T3.1-3), observations (T5.2-3), etc. Generally, good conformance with the Work Programme can be stated. Future deviations from the Work Programme are not expected.

1.2. Scientific Results

There are many interesting results obtained during the first year activity. However, the lack of space makes it impossible to describe them even briefly. Therefore, we first outline main achievements in each direction and then mention some concrete results for the sake of illustration.

Task 1. *Light scattering theory*

A series of new exact and approximate methods, algorithms and computer codes to calculate the light scattering by particles of different shape and structure were developed and presented in [3,4,7,10,13-15,17-22,32,33,35,37,48,49,60,61][1]. These approaches and numerical tools futher extend the ability of the light scattering theory to treat non-spherical/inhomogeneous scatterers and provide a basis for solution of the theory application tasks planned in the project.

Among the methods suggested we can point out the original exact recursive solution of the light scattering problem for multi-layered axisymmetric particles [15,17] and a powerful version of the S-approximation [10,20] required in various scientific fields.

Detailed consideration of internal fields [1,26-29] made possible further investigation of their effects in different applications, including astronomical ones.

New and old methods of light scattering theory (including new Effective Medium Theories) were compared and the range of their applicability was outlined in [3,4,10,16,17,20-22,34,48,58-62]; a comprehensive review of approximate methods was presented in the book [67]. Such studies are necessary for any further applications of the methods.

One should note here the importance of the analytical and numerical analysis done for the most popular light scattering approaches. It revealed limitations of the T-matrix and Separation of variables methods in the very general case [16].

Task 2. *Light scattering experiments*

The experimental set-up to measure light scattering properties of cosmic dust analogues appeared at the University of Amsterdam (the P1 team). First calibrating experiments are in progress.

Task 3. *Electronic database*

A draft WWW design of the database was worked out and made available for discussions at http://www.astro.spbu.ru/staff/ilin2/DOP/index.html. Three large parts of the database have been realized in the electronic form: *i)* the graphics library of the optical properties of spherical scatterers; *ii)* the section with over 8000 references to papers on light scattering theory; *iii)* the self-training algorithm of determination of the optical properties of clusters based on artificial neutronal network [53]. Their inclusion in the WWW database and presentation will be done later.

Task 4. *Polarized radiation transfer*

A number of computer codes simulating (polarized) radiation transfer were developed. Test calculations were performed and their results along with some useful analytical solutions found were presented in [2,9,11,12,40,41,52,54,67-69]. These tools are required for interpretation of observations of many astronomical objects.

The most universal code created [2,69] can treat polarized radiation transfer in three-dimensional anisotropic media in a self-consistent way in contrast to other similar codes. Another code realized the double-scattering approximation has allowed us to draw important conclusions on the coherent opposition effects [12].

[1] See the List of references attached as the Document #1

Task 5. *Astrophysical applications*

Some planned applications of the light scattering theory and radiation transfer models were done and their results have been presented in [5,23-25,31,42,43,51,65,66,68]. Among them one can note, e.g., the discovered dependence of temperature and infrared (IR) flux of dust grains on their shape [25]. This effect should be taken into account in any modelling of IR spectra of cosmic objects.

A large set of mostly original observations were processed and analyzed. These spectroscopic, photometric and polarimetric data have allowed us to obtain new knowledge on different objects (for more details, see [23,24,30,38,39,44-46,50,55-57,63,64,66]). The data and conclusions will be used in further work on the project.

For instance, the excellent quality data obtained at the JMCT (Hawaii) are used to get constraints on magnetic field strength and structure from submillemeter polarization observed [8].

At last, we should also note extensive observational studies of dusty shells around young and old stars that gave new information on circumstellar dust grains and physical conditions in the shells [30,38,39,55,56,63,64].

The list of references to papers, books, etc. published or submitted during the first year of work on the project is enclosed (see the Attached Document #1).

All together the teams have produced *21 papers, 43 conference contributions, 1 book, 4 theses* with the following distribution:

	ALL PUBLICATIONS			**ONLY: Jointly by INTAS and NIS Project teams**
Scientific Output	**published**	**accepted**	**submitted**	
Paper in an International Journal		4	4	2
Paper in a National Journal *)	3	6	4	
Abstract in proceedings	27	9	7	4
Book, Monograph **)	1			
Internal Report				
Thesis (MSc,PhD,etc.) ***)	3		1	
Patent				

Notes:

*) All the papers are in Russian.

**) The book is in English.

***) A thesis is in German and 3 theses are in Russian.

1.3. Impact and Applications

The methods and computer codes developed have expanded the applicability of light scattering theory to non-spherical (inhomogeneous) scatterers. Therefore, these tools will be widely used in all scientific fields where the optical methods of particle characterization are applied, i.e. in biophysics, colloidal chemistry, radiophysics, meteorology, ecology, and various industrial areas.

The results obtained in studies of internal fields will find applications in different branches of physics where heating and destruction of particles in laser beam are important.

A part of the electronic database appeared in the World Wide Web will be utilized as a place where further information on Internet resources related to the optical characterization of scatterers will be collected. The database will help to solve various light scattering problems and serve as an educational tool in high schools.

The theoretical solutions and computer codes developed in the field of polarized radiation transfer will be applied to solution of problems where effects of the optical thickness of media are essential. Such tasks are encountered in atmosphere and ocean optics, neutron physics, etc. In astronomy the tools created will allow scientists to produce more adequate models of various objects from comets to galaxies.

2. MANAGEMENT

2.1. Meetings and visits

There were 4 co-ordination meetings:

1) a meeting of 9 participants took place in St.Petersburg in July 2000 during the International Radiation Symposium;
2) 6 participants and several interested scientists came together in Amsterdam in October 2000 after the HAEBE workshop;
3) 10 participants specially met in St.Petersburg in February 2001.
4) a meeting of 3 participants occurred in Brighton in April 2001 during the Optical Particle Characterisation Congress.

Some documents and photos from these meetings are available at the site devoted to the project *http://www.astro.spbu.ru/staff/ilin2/INTAS/index.html* This site also contains other information on the project, namely the Work Programme, a description of the teams, full-text papers and posters, codes and databases under construction, etc.

The list of visits is as follows:

Name of person	team	place of travel	date	purpose
Th.Henning	P2	Amsterdam	Oct.27-28, 2000	HAEBE workshop + INTAS meeting *)
B.Posselt **)	P2	St.Petersburg	Oct.,2000 - July,2001	study + sci.work *)
N.Voshchinnikov	P3	Amsterdam	Oct.22-29, 2000	HAEBE workshop + INTAS meeting
N.Voshchinnikov	P3	Brighton	Apr.1-8, 2001	OPC congress
D.Semenov ***)	P3	Jena	Nov.,2000 - Oct.,2003	study + sci.work *)
A.Kokhanovsky	P4	St.Petersburg	July 24-29, 2000	IRS symposium *)
P.Petrov	P4	St.Petersburg	July 24-29, 2000	IRS symposium
L.Astafyeva	P4	Amsterdam	Oct.25-29, 2000	HAEBE workshop + INTAS meeting
L.Astafyeva	P4	St.Petersburg	Jan.31-Feb.2, 2001	INTAS meeting
V.Babenko	P4	St.Petersburg	Jan.31-Feb.2, 2001	INTAS meeting
A.Kokhanovsky	P6	Brighton	Apr.1-8, 2001	OPC congress *)
V.Tishkovets	P5	Amsterdam	Oct.25-28, 2000	HAEBE workshop + INTAS meeting
V.Tishkovets	P5	St.Petersburg	Jan.30-Feb.3, 2001	INTAS meeting
P.Litvinov	P5	St.Petersburg	Jan.30-Feb.3, 2001	INTAS meeting
A.Perelman	P6	Amsterdam	Oct.22-29, 2000	HAEBE workshop + INTAS meeting
A.Perelman	P6	Brighton	Apr.1-8, 2001	OPC congress

Notes:

*) The trips were partly covered by other funds.

**) This student of Prof.Th.Henning (the P2 team contractor) was studying astronomy and making research within the project at the Astronomical Institute of the St.Petersburg University (the P3 team) for about one year due to the student exchange program.

***) This Ph.D. student of Prof.N.Voshchinnikov (the P3 team contractor) became a Ph.D.student of Prof. Th.Henning (the P2 team).

The meetings and visits are summarized in the table

Visits	Number of scientists	Number of person days
West ==> East	1	about 240
East ==> West	5	49 + about 210
West ==> West	1	2
East ==> East	6	28

A visit of 2 participants (including the project head Prof. L.B.F.M. Waters) from Amsterdam to St.Petersburg is planned for summer, 2001. If the visit occurs during the All-Russian Astronomical Conference, there will be a special co-operation meeting.

The next regular co-operation meeting is scheduled for the end of 2001 or the beginning of 2002 in Jena or St.Petersburg.

Individual exchange visits of several scientists are also planned for the second year of the work on the project. A visit of 3 participants (including the P5 contractor Dr. V.P.Tishkovets) from Kharkov to St.Petersburg should occur during the All-Russian Astronomical Conference. The P3 contractor Prof. N.V.Voshchinnikov should attend Jena (the P2 team) for a month in autumn 2001. Details of other visits are not yet clear.

2.2. Collaboration

Collaboration between the teams was highly intensive.

Intensity of Collaboration	**high**	**rather high**	**rather low**	**low**
West <=> East		x		
West <=> West	x			
East <=> East	x			

It should be noted that the cooperation of the INTAS and NIS teams has not yet resulted in a set of joint publications as this cooperation was planned mainly in the field of astronomical applications of the developed tools and according to the Work Programme this part of the project should begin in the second year.

During the first year there was extensive cooperation of the teams with the following additional organizations:
- Dept. Physics, Saratov State University, Russia;
- Dept.Physics & Astronomy, Univ.College London, UK;
- Institut für Werkstofftechnik, Bremen University, Germany;
- Institute of Physics of St.Petersburg University, Russia;
- Instituut voor Sterrenkunde, Katholieke Univ. Leuven, Belgium;
- Kharkov Radiophysics Institute, Ukraina;
- Max-Planck-Institut für Aeronomie, Katlenburg-Lindau, Germany;
- Max-Planck-Institut für Astronomie, Heidelberg, Germany;
- Max-Planck-Institut für Radioastronomie, Bonn, Germany;
- Observatory de Nice, France;
- Saratov Institute of Biochemistry and Physiology of RAS, Russia;
- Space Research Institute, Moscow, Russia;
- Space Research Organization, Groningen, The Netherlands;
- SRON Lab. for Space Research, Utrecht, The Netherlands;
- St.Petersburg University of Aerocosmic Instrumentation, Russia;
- Türinger Landessternwarte, Tautenburg, Germany.

2.3. Time Schedule

The time planning was generally in accordance with the Work Programme (see also the last paragraphs in the Section 1.1). No deviations are foreseen at the moment.

2.4. Problems encountered

Our major problem was connected with the team member replacement procedure. Unfortunately, during the first year several scientists left their NIS institutes (the P3 and P4 teams) for long time or even forever. For successful continuation of work, they should be changed by other scientists useful for the project. The INTAS officer in charge let us know that such introduction of personnel in place of one that has left is rather common problem and this operation is done under certain rules of the INTAS. Although the officer provided us with all required information, it would be much better to know it before the beginning of our project.

A minor problem was encountered by the Belarus (P4) team in money transfer operation. The contractor and some scientists got money (Labour Costs, etc) in another bank (Belarusbank instead of Belvneshekonombank) with a delay of 4-5 weeks and after a long bureaucratic procedure.

Problems encountered	**major**	**minor**	**none**	**not applicable**
Co-operation of team Members			x	
Transfer of funds		x		
Telecommunication			x	
Transfer of goods				x
Other (see text)	x			

2.5. Actions required

It would be fine to find well formulated rules concerning the replacement of team members on the site of the INTAS.

3. FINANCES (in EURO)

The spending was in accordance with the one foreseen in the Work Programme.

There were expenditures on 2 computers and 2 printers (the category Equipment); cartridges, papers, diskettes, etc.(Consumables); books, small devices, conference registration fees, etc.(Other Costs).

For the remaining duration of the project we do not foresee any deviations from the cost table given in the Work Programme.

4. ANNEXES

4.1. List of references from Sect.1.2 (Attached Document #1)

4.2. Summary reports of all teams are attached in the following order:

#2 Summary of Astronomical Institute of University of Amsterdam (P1)
#3 Summary of Astrophysical Institute of Friedrich Schiller University, Jena (P2)
#4 Summary of Astronomical Institute of St.Petersburg University (P3)
#5 Summary of Stepanov Institute of Physics, Minsk (P4)
#6 Summary of Astronomical Observatory of Kharkov University (P5)
#7 Summary of St.Petersburg State Forest Technical Academy (P6)

4.3. Preprints of the following papers with the acknowledgment to the INTAS grant are attached:

#8 Astafyeva L.G., Voshchinnikov N.V., Waters L.B.F.M. *Heating of composite solid aerosol particles by laser radiation.* Applied Optics, 2001, submitted.

#9 Wolf S., Voshchinnikov N.V., Henning Th. *Multiple scattering of polarized radiation by non-spherical grains: first results.* Astronomy & Astrophysics, 2000, submitted.

#10 Perelman A.Y., Voshchinnikov N.V. *Improved S-approximation for dielectric particles.* Journal of Quantitative Spectroscopy & Radiative Transfer, 2001, accepted.

#11 Tishkovets V.P. *Multiple scattering of light by a layer of discrete random medium. Backscattering.* Journal of Quantitative Spectroscopy & Radiative Transfer, 2001, in press.

4.4. Other annexes:

#12 Farafonov V.G., Posselt B., Il'in V.B., Voshchinnikov N.V. *Light scattering by multi-layered ellipsoidal particles in the quasi-static approximation.* A colour copy of the poster at the 6th International Congress on Optical Particle Characterization (Brighton, April 2-5, 2001).

#13 Voshchinnikov N.V., Farafonov V.G. *The light scattering by elongated spheroids.* A colour copy of the poster at the 6th International Congress on Optical Particle Characterization (Brighton, April 2-5, 2001).

#14 Farafonov V.G., Prokopjeva M.S., Il'in V.B., Voshchinnikov N.V. *Recursive solution of light scattering problem for multi-layered axisymmetric particles.* A colour copy of the poster at the 6th International Congress on Optical Particle Characterization (Brighton, April 2-5, 2001).

Attached Document #1

INTAS Open Call 1999 grant 652

LIST OF REFERENCES

♦ Joint Publications of INTAS and NIS project teams

■ International journals

1. Astafyeva L.G., Voshchinnikov N.V., Waters L.B.F.M. Heating of composite solid aerosol particles by laser radiation. *Applied Optics*, 2001, submitted.

2. Wolf S., Voshchinnikov N.V., Henning Th. Multiple scattering of polarized radiation by non-spherical grains: first results. *Astronomy & Astrophysics*, 2000, submitted.

■ Abstracts in proceedings

3. Farafonov V.G., Posselt B., Il'in V.B., Voshchinnikov N.V. Light scattering by multi-layered ellipsoidal particles in the quasi-static approximation. *6th International Congress on Optical Particle Characterization (Brighton, April 2–5, 2001)*, Institute of Physics, 2001, p. 79.

4. Farafonov V.G., Prokopjeva M.S., Il'in V.B., Henning Th. Light scattering by small non-spherical inhomogeneous (layered) particles: the applicability of approximations. In: Smith W.L., Timofeyev Y.M. (eds.) *IRS 2000: Current Problems in Atmospheric Radiation*, A. Deepak Publ., 2001, in press.

5. Prokopjeva M.S., Il'in V.B., Henning Th. Light scattering by interstellar dust: effects of the shape of grains. *All-Russian astronomical conference (St.Petersburg, August 6-12, 2001)*, submitted.

6. Semenov D., Henning Th., Ilgner M. Low temperature Rosseland and Planck mean opacities. *All-Russian astronomical conference (St.Petersburg, August 6-12, 2001)*, submitted.

♦ Publications without INTAS–NIS co-authorship of the project teams

■ International journals

7. Farafonov V.G., Loskutov A.A. The field of vertical dipole in the presence of a perfectly conducting body with the axial symmetry. *IEEE Transactions: Antennas & Propagation*, 2000, submitted.

8. Henning Th., Wolf S., Launhardt R., Waters L.B.F.M. Measurements of the magnetic field geometry and strength in Bok globules. *Astrophysical Journal*, 2001, in press.

9. Kokhanovsky A.A. Polarization characteristics of sunlight reflected and transmitted by water clouds: simple analytical solutions. *Journal of Atmospheric Science*, 2000, submitted.

10. Perelman A.Y., Voshchinnikov N.V. Improved S-approximation for dielectric particles. *Journal of Quantitative Spectroscopy & Radiative Transfer*, 2001, accepted.

11. Tishkovets V.P. Multiple scattering of light by a layer of discrete random medium: backscattering. *Journal of Quantitative Spectroscopy & Radiative Transfer*, 2001, in press.

12. Tishkovets V.P., Litvinov P.V., Lyubchenko M.V. Coherent opposition effects for semi-infinite medium discrete random medium in the double-scattering approximation. *Journal of Quantitative Spectroscopy & Radiative Transfer*, 2001, in press.

■ National journals

13. Farafonov V.G. Light scattering by multi-layered non-confocal ellipsoids in the Rayleigh approximation. *Optics & Spectroscopy*, **90**, 574–579, 2001.

14. Farafonov V.G. New recursive solution of the problem of scattering of electromagnetic radiation by multi-layered spheroidal particles. *Optics & Spectroscopy*, **90**, 743–752, 2001.

15. Farafonov V.G. Light scattering by multi-layered particles with the axial symmetry. *Optics & Spectroscopy*, **91**, N1, 2001, in press.

16. Farafonov V.G. On applicability of T-matrix-like methods. *Optics & Spectroscopy*, 2001, submitted.

17. Farafonov V.G., Il'in V.B. Light scattering by dielectric particles with axial symmetry. II. *Optics & Spectroscopy*, **91**, N10, 2001, in press.

18. Farafonov V.G., Voshchinnikov N.V. Calculations of prolate radial spheroidal wave functions with the aid of Jáffe expansion. *Journal of Computational Mathematics & Mathematical Physics*, 2001, submitted.

19. Farafonov V.G., Il'in V.B., Prokopjeva M.S. Light scattering by homogeneous and multi-layered ellipsoids in the quasistatic approximation. *Optics & Spectroscopy*, submitted.

20. Perelman A.Y., Voshchinnikov N.V. The S-approximation for spherical particles with complex refractive index. *Optics & Spectroscopy*, 2001, accepted.

21. Perelman A.Y., Zinov'eva T.V. Light scattering by sphere with variable optical properties of intermediate layer. *Optics & Spectroscopy*, 2001, accepted.

22. Perelman A.Y., Zinov'eva T.V. Influence of the refractive index variations within the intermediate layer on the scattering characteristics. *Optics of Atmosphere and Ocean*, 2001, submitted.

23. Petrova E.V., Jockers K., Kiselev N.N. The negative branch of the polarization of comets and atmosphereless celestial bodies and scattering light by aggregate particles. *Astronomicheskii Vestnik*, 2001, accepted.

24. Petrova E.V., Jockers K., Kiselev N.N. Scattering light by aggregate particles comparable with the wavelength: An application to the cometary dust. *Astronomicheskii Vestnik*, 2001, in press.

25. Voshchinnikov N.V., Semenov D.A. The temperature of non-spherical circumstellar grains. *Pis'ma v Astronomicheskii Zhurnal*, **26**, 787–800, 2000 (English translation in *Astronomy Letters*, **26**, 679–690, 2000).

■ Abstracts in proceedings

26. Astafyeva L.G., Babenko V.A. Heating of carbon particles by radiation. *6th International Congress on Optical Particle Characterization (Brighton, April 2-5, 2001)*, Institute of Physics, 2001, p. 72–73.

27. Astafyeva L.G., Zheltov G.I. Stimulating laser heating of blood vessels. *6th International Congress on Optical Particle Characterization (Brighton, April 2-5, 2001)*, Institute of Physics, 2001, p. 71–72.

28. Astafyeva L.G., Voshchinnikov N.V. Heating of multilayered aerosol particles by radiation. *European Aerosol Conference (Leipzig, September 3-7, 2001)*, accepted.

29. Astafyeva L.G., Babenko V.A., Ledneva G.P. Heating and destruction of cylindrical particles by laser radiation. In: Videen G. et al. (eds.) *Light Scattering by Nonspherical Particles: Halifax Contributions*, 2000, p. 283–286.

30. Bouwman J., de Koter A., van den Ancker M.E., Waters L.B.F.M. The Spatial Distribution of Dust around the Herbig Ae Stars AB Aur and HD 163296. *Thermal Emission Spectroscopy and Analysis of Dust, Disks, and Regoliths*, eds. Sitko M.L., Sprague A.L., and Lynch D.K., ASP Conf. Ser., 2000, **196**, p. 63–70.

31. Dubkova D.N. Modelling of interstellar extinction taking into account the cosmic abundances of elements. *All-Russian astronomical conference (St.Petersburg, August 6-12, 2001)*, submitted.

32. Farafonov V.G., Il'in V.B. Light scattering by axisymmetric particles: a new approach with the special choice of scalar potentials. In: Smith W.L., Timofeyev Y.M. (eds.) *IRS 2000: Current Problems in Atmospheric Radiation*, A. Deepak Publ., 2001, in press.

33. Farafonov V.G., Loskutov A.A. The field of vertical dipole in the presence of a perfectly conducting body with the axial symmetry. *Annual International Seminar "Day on Diffraction" (St.Petersburg, May 30–June 1, 2000)*, p.59.

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36. Farafonov V.G., Il'in V.B., Voshchinnikov N.V. Reciprocity relation in checking calculations of the optical properties of non-spherical particles. *6th International Congress on Optical Particle Characterization (Brighton, April 2-5, 2001)*, Institute of Physics, 2001, p. 79–80.

37. Farafonov V.G., Prokopjeva M.S., Il'in V.B., Voshchinnikov N.V. Recursive solution of light scattering problem for multi-layered axisymmetric particles. *6th International Congress on Optical Particle Characterization (Brighton, April 2-5, 2001)*, Institute of Physics, 2001, p. 80.

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40. Kokhanovsky A.A. Simple relationships between radiative and microphysical characteristics of cloudy media. In: Smith W.L., Timofeyev Y.M. (eds.) *IRS 2000: Current Problems in Atmospheric Radiation*, A. Deepak Publ., 2001, in press.

41. Kokhanovsky A.A. Optical particle sizing in optically dense media. *6th International Congress on Optical Particle Characterization (Brighton, April 2-5, 2001)*, Institute of Physics, 2001, p. 24 (**invited review**).

42. Krivova N.A., Il'in V.B., Kimura H., Mann I. Scattering and polarization of light by fluffy dust aggregates in the shells of UX Ori-like stars. *Herbig Ae/Be stars: between accretion and debris (Amsterdam, October 25-27, 2000)*, accepted.

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Attached Document #2

Summary report of the P1 team
at Astronomical Institute, University of Amsterdam, NL
(01.06.2000 – 31.05.2001)

Members:
Prof. L.B.F.M. Waters (contractor), Dr. A. de Koter, Dr. F.J. Molster, M.Sc. J. Bouwman, M.Sc. C. Kemper

Activity and results:

Task 2 (Light scattering experiments)

T2.1-2 The experimental set-up to measure light scattering properties of cosmic dust analogues has been moved to a new location in the NWO-funded AMOLF laboratory. The move has triggered some updating of the computer infrastructure and electronics of the equipment. Currently the experiment is being calibrated by using simple materials (e.g. water droplets); the plan is to commence the measurement of several astrophysically relevant materials by late summer or the beginning of autumn.

Task 4 (Polarized radiation transfer)

T4.1 Work also continued on the development of a fast and accurate 2D radiative transfer code for circumstellar dust. The code has been parallelized and now runs on a BEOWULF cluster with 20 nodes. A parallel development has been the improvement of hydrostatic equilibrium models for passive disks around young stars and the application to the Herbig Ae/Be stars.

Task 5 (Astrophysical applications)

T5.2 The past year has seen a continuation of the analysis of infrared spectroscopy of circumstellar and interstellar dust, using mainly data taken from the Infrared Space Observatory (ISO) and also through new ground-based mid-infrared spectroscopy taken at the European Southern Observatory (ESO), Chile.

i) Young stars

The ISO spectra of a sample of isolated Herbig Ae/Be stars sometimes show a conspicuous broad bump near 23 microns. This bump has previously been attributed to small, non-spherical FeO particles. However, primitive materials in our solar system (such as interplanetary dust particles [IDPs] originating from comets) show no large amounts of FeO, but rather FeS. Infrared transmission spectroscopy of FeS taken from IDPs show a broad band near 23 micron that matches that of the ISO spectra of disks around young stars, pointing to substantial amounts of FeS in these disks.

A detailed study of the spectrum of Herbig Ae/Be stars in the 10 micron wavelength region indicates that the amorphous silicates in the inner part of the disk which surrounds these stars, is subject to thermal annealing. This is evidenced by the presence of both forsterite (Mg_2SiO_4) as well as of Silica (SiO_2), that can form from non-stochiometric composition of amorphous silicates. There is no strong evidence for enstatite ($MgSiO_3$) suggesting that the annealing process has only been partially completed.

ii) Old stars

The ISO spectra of carbon-rich post-AGB stars and planetary nebulae show a strong emission band near 30 micron, which has previously been identified with MgS. The ISO data show that the wavelength of the band varies considerably, starting at about 26 microns for C-rich AGB stars with modest mass loss rates, and moving to 30 microns for infrared carbon stars with extreme mass loss rates. The band shifts even to 35 microns in planetary nebulae. This strong evolution of the central wavelength of the band is hard to understand if MgS is the sole carrier of the band.

The ISO spectra of two evolved planetary nebulae show a strong band near 93 microns. Comparison with laboratory data has show that this feature is due to Calcite ($CaCO_3$). This is the first detection of a carbonate outside our solar system, and demonstrates that carbonates can form under primitive conditions: it is commonly assumed that carbonates can only form from aqueous alteration on large parent bodies, i.e. in the vicinity of newly forming planets. The discovery of carbonates in a planetary nebula suggests that other mechanisms to form carbonates must exist that do not require the presence of large parent bodies.

Management

A special workshop of the INTAS teams was held at the University of Amsterdam to coordinate activities of the partners and to initiate new joint projects.

Individual contributions:

- L.B.F.M. Waters: light scattering experiments, space and ground-based observations and their analysis, circumstellar dust, project management;
- A. de Koter: observations of young stars;
- F.J. Molster: astronomical spectroscopy and mineralogy, circumstellar dust;
- J. Bouwman: space and ground-based observations, envelopes of young stars;
- C. Kemper: space and ground-based observations; dust shells around old stars.

Attached Document #3

Summary report of the P2 team
at Astrophysical Institute and University Observatory, Friedrich Schiller University, Jena, DE
(01.06.2000 – 31.05.2001)

Members:
Prof. Th. Henning (contractor), Dr. H. Mutschke, Dr. G. Wurm, M.Sc. S. Wolf

Activity and results:

Task 1 (Light scattering theory)

T1.3 The quasi-static and other approximations for multi-layered non-confocal ellipsoids were developed and the region of their validity was determined.

Task 4 (Polarized radiation transfer)

T4.1 First solution to the radiative transfer problem (including polarization) in dust configurations containing aligned non-spherical (spheroidal) dust grains was developed. The radiative transfer problem is solved on the basis of a Monte-Carlo method for three-dimensional self-consistent simulations. As a first application, the linear and circular polarization from a spherical circumstellar shell containing perfectly aligned prolate or oblate spheroidal grains was investigated.

Task 5 (Astrophysical applications)

T5.1 Basic effects of the shape of cosmic grains in various manifestations of interstellar dust were considered using ellipsoidal model of particles.

The JMCT on Hawaii was used to determine the polarization state of submillimetre radiation. Polarization is produced by dichroic emission from aligned grains. The data have excellent quality and were used to get a constraint on the magnetic field strength and structure.

T5.2 The past year has seen a continuation of the analysis of infrared spectroscopy of circumstellar and interstellar dust, using mainly data taken from the Infrared Space Observatory (ISO) and also through new ground-based mid-infrared spectroscopy taken at the European Southern Observatory (ESO), Chile.

i) Young stars

The ISO spectra of a sample of isolated Herbig Ae/Be stars sometimes show a conspicuous broad bump near 23 microns. This bump has previously been attributed to small, non-spherical FeO particles. However, primitive materials in our solar system (such as interplanetary dust particles [IDPs] originating from comets) show no large amounts of FeO, but rather FeS. Infrared transmission spectroscopy of FeS taken from IDPs show a broad band near 23 micron that matches that of the ISO spectra of disks around young stars, pointing to substantial amounts of FeS in these disks.

ii) Old stars

The ISO spectra of two evolved planetary nebulae show a strong band near 93 microns. Comparison with laboratory data has show that this feature is due to Calcite ($CaCO_3$). This is the first detection of a carbonate outside our solar system, and demonstrates that carbonates can form under primitive conditions: it is commonly assumed that carbonates can only form from aqueous alteration on large parent bodies, i.e. in the vicinity of newly forming planets. The discovery of carbonates in a planetary nebula suggests that other mechanisms to form carbonates must exist that do not require the presence of large parent bodies.

Individual contributions:

- Th. Henning: light scattering theory and its applications, (polarized) radiation transfer, analysis of observations, physics of interstellar and circumstellar dust;
- H. Mutschke: laboratory astrophysics, astronomical spectroscopy and mineralogy;
- G. Wurm: laboratory astrophysics, light scattering experiments;
- S. Wolf: polarized radiation transfer and its applications in astrophysics.

Attached Document #4

Summary report of the P3 team
at Sobolev Astronomical Institute of St. Petersburg University, RU
(01.06.2000 – 31.05.2001)

Members:

Prof. N.V. Voshchinnikov (contractor), Dr. V.B. Il'in, M.Sc. M.S. Prokopjeva, M.Sc. D.A. Semenov/Prof. V.G. Farafonov*, B.Sc. D.N. Dubkova**

Notes:

* Mr. Semenov, the Ph.D. student of Prof. Voshchinnikov, stays permanently since November 2000 at the Astrophysical Institute of the Friedrich Schiller University, Jena, Germany (the P2 team of this INTAS project). His stay is covered by other funds than this grant. Prof. Farafonov from the St. Petersburg University of Aerocosmic Instrumentation, St. Petersburg, Russia was invited for collaboration in the work under the tasks T1.1–1.5. He obtained prominent results (see the list of publications) and by mutual agreement the labour costs of Mr. Semenov since November 2000 till May 2001 were transferred to Prof. Farafonov.

** Mrs. Dubkova is a student of Prof. Voshchinnikov and her M.Sc. thesis is carried out in the frame of the project. She has started working in the project and will continue it the next year.

Activity and results:

Task 1 (Light scattering theory)

T1.1 New algorithm for computation of prolate spheroidal wave functions based on the Jáffe expansion was suggested and realized. It makes possible to beat the world records in simulation of the light scattering by extremely elongated large spheroids.

New solutions to the electromagnetic radiation scattering problem by multi-layered spheroids (in the frame of separation of variables method) and multi-layered axisymmetric particles (using new T-matrix-like method) were developed.

T1.2 Heating of composite spherical aerosol particles by laser radiation was considered. The internal intensity and temperature distributions were calculated.

Expressions for internal radiation field inside spheroids were obtained and the work under the numerical code was begun.

T1.3 The quasi-static and other approximations for multi-layered non-confocal ellipsoids were developed and the region of their validity was determined.

The range of applicability of the soft particles approximation (S-approximation) for spheres was strongly extended. Now the approximation fairly well describes the behaviour of Mie curves and may be used to get the "smoothed" Mie curves (ripple-type fluctuations are averaged) in the analytical form.

T1.4-5 New and old methods (including the Effective Medium Theories) were compared and the range of their applicability was outlined. In particular important here was the analytical and numerical analysis of the T-matrix and Separation of variables methods that revealed their limitations in the very general case.

Task 3 (Electronic database)

T3.1-3 First steps to the creation of Database of Optical Properties (DOP) were undertaken (computations of cross-sections for homogeneous/inhomogeneous spherical particles). A preliminary sketch is available via the Internet: http://www.astro.spbu.ru/staff/ilin2/DOP/.

Task 4 (Polarized radiation transfer)

T4.1 First solution to the radiative transfer problem (including polarization) in dust configurations containing aligned non-spherical (spheroidal) dust grains was developed. The radiative transfer problem is solved on the basis of a Monte-Carlo method for three-dimensional self-consistent simulations. As a first application, the linear and circular polarization from a spherical circumstellar shell containing perfectly aligned prolate or oblate spheroidal grains was investigated.

T4.2 Models based on single light scattering by elementary volume with aligned spheroidal particles were developed. The dependence of the intensity, linear and circular polarization on various parameters (particle size, aspect ratio, orientation, etc.) was analyzed.

Task 5 (Astrophysical applications)

T5.1 New model of multi-layered spherical grains was applied to calculations of the extinction cross sections and modelling the interstellar extinction curve in the direction of the star ζ Ophiuchi using new dust-phase element abundances.

T5.2 The temperatures of prolate and oblate spheroidal dust grains in the envelopes of stars of various spectral types were calculated. It was found that spheroidal grains are generally colder than spherical ones of the same volume and for a fixed dust mass, flux at the wavelength $\lambda \geq 100\ \mu$m is higher provided grains are non-spherical.

T5.3 Observational data for dusty comets were summarized and systemized. The linear and circular polarization observed for the comet Halley was fitted using an ensemble of aligned spheroids having different sizes and chemical compositions.

Individual contributions:

- N.V. Voshchinnikov: spheroidal functions, light scattering by spheroids, heating of particles and internal fields, S-approximation, Monte-Carlo modelling, model of multi-layered spherical grains, temperature of non-spherical circumstellar grains;
- V.B. Il'in: particles with axial symmetry, reciprocity relation, quasi-static approximation, electronic database, model of multi-layered spherical grains;
- M.S. Prokopjeva: axisymmetric and ellipsoidal particles, multi-layered particles, quasi-static approximation, electronic database;
- D.A. Semenov: light scattering by spheroids, internal fields, temperature of non-spherical circumstellar grains, cometary polarization;
- V.G. Farafonov: spheroidal functions, multi-layered spheroids and by multi-layered particles with axial symmetry, reciprocity relation, internal fields, quasi-static approximation;
- D.N. Dubkova: model of multi-layered spherical grains, interstellar extinction.

Attached Document #5

Summary report of the P4 team
at Stepanov Institute of Physics, Minsk, BY
(01.06.2000 – 31.05.2001)

Members:

Dr. V.A. Babenko (contractor), Dr. L.G.Astafyeva, Dr. A.A. Kokhanovsky*, Dr. A.F.Sinyuk**, M.Sc. P.K. Petrov

Notes:

* Mr. Kokhanovsky stays permanently at the Bremen University, Germany since June 2001 and will not take part in the Project from June 2001 till the end of Project.

** Mr. Sinyuk stays permanently at NASA Goddard Space Flight Center (Greenbelt, USA) since May 2000 and did not take part in the Project.

Activity and results:

Task 1 (Light scattering theory)

T1.1 Several stable algorithms and new computer codes are created: for calculation the optical properties (external and internal EM fields) of sphere with arbitrary number of concentric layers, possessing the arbitrary optical constants and size parameters; for calculation of EM fields inside spheroidal particle using General Multipole Technique. At the moment the work is aimed to using these codes for evaluation the temperature fields of dust grains. The work on developing of stable algorithm of integral evaluation in T-matrix approach appears to be unsuccessful due to principal problems. Slight improvement that we achieved with the aid of finite series technique have proved to be incomparable with analytical and computational efforts required.

T1.2 Heating and destruction of cylindrical carbon and quartz particles by lidar radiation was considered. Carbon particles are destroyed under the action of lidar radiation with 1.06 micron, but small quartz particles with radii less than 40 micron are not destroyed. The cylindrical carbon particles heat less rapidly than the spherical ones in the radii region from 0.2 to 20 micron. Heating of three-layered spherical aerosol particles composed of air, quartz and carbon by lidar radiation was considered. The internal intensity and temperature distributions were calculated. The decrease of thickness of strongly absorbed carbon layer on the composite particle surface can result in the reduction of the heating time of such particles.

T1.3 The approximate methods of light scattering calculations were discussed in detail in second revised edition of A.A.Kokhanovsky's book "Light Scattering Media Optics: Problems and Solutions", Springer-Praxis, 2nd edition, 2001.

Task 3 (Electronic database)

T3.3 Our database containing about 8000 references to the papers devoted to the problem of light scattering by small particles and related topics was continually supplemented by new entries. This database was passed to other participants of the Project.

Task 4 (Polarized radiation transfer)

T4.1 Radiative and polarization characteristic of optically thick media with discrete particles were studied in detail. New approximate analytical formulae for the Stokes vector of reflected and transmitted light have been derived for the special case of weakly absorbing media with large optical thickness. In particular, the simple relationship between the spherical albedo of the medium and its degree of polarization was obtained.

Individual contributions:

- V.A. Babenko: light scattering references database, calculation of scattering and internal fields of spheroidal particles by General Multipole Technique and T-matrix approach, multi-layered spherical particles;
- L.G.Astafyeva: cylindrical particles, three-layered spherical particles, internal fields in the particles, heating and destruction of particles, temperature distributions inside the particles;
- A.A. Kokhanovsky: approximate methods of light scattering calculations, polarized radiation transfer;
- P.K. Petrov: calculation of scattering and internal fields of spheroidal particles by General Multipole Technique and T-matrix approach.

Attached Document #6

Summary report of the P5 team
at Astronomical Observatory of Kharkov University, UA
(01.06.2000 – 31.05.2001)

Members:
Dr. V.P. Tishkovets (contractor), Dr. N.N. Kiselev, Dr. P.V. Litvinov, S.A. Beletsky

Activity and results:

Task 1 (Light scattering theory)

T1.1 A new algorithm for presentation of the optical properties of chaotically oriented fractal-like clusters of spherical particles was suggested and realized. It is based on an artificial neuronal network (perceptron). A perceptron training algorithm was developed for this purpose. The neuronal network was trained using the algorithm of Mackowski & Mishchenko (1996, JOSA).

Task 3 (Electronic database)

T3.3 The main part of an electronic database of the optical properties of chaotically oriented fractal-like clusters was created. This database will be used to interpret results of observations of cometary and interplanetary dust. An artificial neuronal network (perceptron) was used to create the database. Now the perceptron is trained for fractal-like clusters with the number of particles up to 50, and for the range of refractive indices such as for silicates in the visual region (the real part of refractive index $1.4 \leq \mathrm{Re}(m) \leq 1.7$ and the imaginary part $0.001 \leq \mathrm{Im}(m) \leq 0.1$). The neuronal network allows one to calculate the expansion coefficients of the scattering matrix elements S_{11}, S_{21} in series of generalized spherical functions in the above-mentioned range of refractive indices. We expect that the fallibility of such calculations will not exceed 5%. The results are prepared for publication.

Task 4 (Polarized radiation transfer)

T4.3 The rigorous equations of multiple light scattering theory for a layer of medium consisting of chaotically oriented arbitrary scatterers were obtained directly from Maxwell's equations. One of new equations describes the scattering matrix of diffuse radiation and corresponds to that of vector radiative transfer theory, whereas another one describes the photometric and polarimetric coherent opposition effect (the collective effects).

Numerical calculations using the equations were carried out in the double-scattering approximation. The results obtained demonstrated a strong dependence of the coherent opposition effect characteristics on the scatterer and medium properties (refractive index, size parameters, and filling factor). That is why the equation for the coherent part of scattering matrix is very important for interpretation of observational data.

Task 5 (Astrophysical applications)

T5.3 Observational data for asteroids and cometary dust were summarized and systemized.

Comparison of the synthetic phase dependence of polarization of comets and asteroids was made. The reasons of their diversity and similarity were investigated.

Analysis of the polarimetric observations of the high-albedo asteroid 64 Angelina at small phase angles was fulfilled. The polarimetric opposition effect for the asteroid was discovered for the first time.

Preliminary interpretation of the observations was carried out. The results of calculations of the light scattering by chaotically oriented clusters of spherical particles was used for this purpose.

Individual contributions:

- V. P. Tishkovets: multiple scattering theory, opposition effects, perceptron, electronic database;
- N.N. Kiselev: observations, astrophysical applications, electronic database;
- P.V. Litvinov: multiple scattering theory, opposition effects, perceptron, electronic database;
- S.A. Beletsky: perceptron, electronic database.

Attached Document #7

Summary report of the P6 team
at St. Petersburg State Forest Technical Academy, RU
(01.06.2000 – 31.05.2001)

Members:
Prof. A.Ya. Perelman (contractor), Dr. T.V. Wielgorskaya, M.Sc. T.V. Zinov'eva

Activity and results:

Task 1 (Light scattering theory)

T1.3 In correspondence with the Work Programme the approximate methods to study various scattering characteristics have been developed. Within the framework of the S-approximation, the expressions for efficiencies are essentially improved. The improved S-approximations (ISA) represents the extinction efficiency to a fairly high degree of accuracy within the wide range of the parameter values. It works well for spheres with refractive indices $m = n - ki$ up to $n = 2.0$ and $k = 0.5$. The ISA is useful to retrieve the microstructure of heterogeneous cosmic dust grains.

The technique based on the ISA allows one to develop the results of the oral representation (A.Y. Perelman, A.D. Yegorov "Lidar monitoring of visibility in polluted air") at the 11th World Clear Air Congress (September 13–18, 1998, Durban, South Africa) on the subject of the urban and industrial aerosol data analysis, and the relationships between the aerosol's particles contribu- tion and the visibility.

In the case of multicomponent particles of composite structure the piecewise continuous hyperbolic approximation (PCHA) has been presented. The PCHA is valid to restore efficiency factors as well as the scattering function for inhomogeneous particles.

The PCHA applied to the spheres with variable refractive indices in the intermediate layer makes it possible to describe the experimental data for fluffy cosmic dust more exactly than the Mie theory does.

Task 3 (Electronic database)

T3.2-3 First steps to the creation of Database of Optical Properties (DOP) were undertaken (computations of cross-sections for homogeneous/inhomogeneous spherical particles). A preliminary sketch is available via the Internet: http://www.astro.spbu.ru/staff/ilin2/DOP/.

Task 5 (Astrophysical applications)

T5.1 Information of infrared bands in spectra of young stars and protostars were collected and systemized. Calculations of the band profiles were carried out and the dependence of the profiles on the shape of dust grains was studied.

Individual contributions:

- A.Ya. Perelman: S-approximation, PCHA approximation;
- T.V. Wielgorskaya: electronic database;
- T.V. Zinov'eva: PCHA approximation, infrared bands.