

ITALIAN PHYSICAL SOCIETY

PROCEEDINGS
OF THE
INTERNATIONAL SCHOOL OF PHYSICS
«ENRICO FERMI»

COURSE CXI

edited by E. BUSOLETTI and G. STRAZZULLA

Directors of the Course
VARENNA ON LAKE COMO

VILLA MONASTERO

27 June - 7 July 1989

Solid-State Astrophysics

1991



NORTH-HOLLAND
AMSTERDAM - OXFORD - NEW YORK - TOKYO

INDICE

E. BUSSOLETTI and G. STRAZZULLA – Preface pag. XIII

Gruppo fotografico dei partecipanti al Corso fuori testo

L. J. ALLAMANDOLA – PAHs in space: the evidence and implications.

| | | |
|--|------|----|
| 1. Introduction | pag. | 1 |
| 2. The interstellar emission spectrum | » | 4 |
| 2'1. The $(3200 \div 2700) \text{ cm}^{-1}$ ($(3.125 \div 3.704) \mu\text{m}$) region | » | 8 |
| 2'1.1. The 3050 cm^{-1} ($3.28 \mu\text{m}$) major band | » | 8 |
| 2'1.2. The minor bands in the $(3200 \div 2700) \text{ cm}^{-1}$ ($(3.125 \div 3.704) \mu\text{m}$) region | » | 9 |
| 2'1.3. The broad component in the $(3200 \div 2700) \text{ cm}^{-1}$ ($(3.125 \div 3.704) \mu\text{m}$) region | » | 13 |
| 2'2. The $(2000 \div 1000) \text{ cm}^{-1}$ ($(5 \div 10) \mu\text{m}$) region | » | 14 |
| 2'2.1. The 1610 , « 1350 » and 1150 cm^{-1} (6.2 , « 7.7 », $8.7 \mu\text{m}$) major bands | » | 14 |
| 2'2.2. The minor bands in the $(2000 \div 1000) \text{ cm}^{-1}$ ($(5 \div 10) \mu\text{m}$) region | » | 17 |
| 2'2.3. The broad component in the $(2000 \div 1000) \text{ cm}^{-1}$ ($(5 \div 10) \mu\text{m}$) region | » | 18 |
| 2'3. The $(1000 \div 500) \text{ cm}^{-1}$ ($(10 \div 20) \mu\text{m}$) region | » | 19 |
| 2'3.1. The 890 cm^{-1} ($11.2 \mu\text{m}$) major band | » | 19 |
| 2'3.2. The minor bands in the $(1000 \div 500) \text{ cm}^{-1}$ ($(10 \div 20) \mu\text{m}$) region | » | 19 |
| 2'3.3. The broad component in the $(1000 \div 500) \text{ cm}^{-1}$ ($(10 \div 20) \mu\text{m}$) region | » | 22 |
| 2'4. The far infrared | » | 22 |
| 3. Conclusions | » | 25 |

A. G. G. M. TIELENS, L. J. ALLAMANDOLA and S. A. SANDFORD –
Laboratory, observational and theoretical studies of interstellar
ices.

| | |
|--|---------|
| 1. Introduction | pag. 29 |
| 2. Icy grains mantles in dense molecular clouds | » 31 |
| 2.1. Grain surface chemistry | » 31 |
| 2.2. UV photolysis of icy grain mantles | » 33 |
| 3. Interstellar ice analog production | » 35 |
| 4. Infrared spectroscopy | » 39 |
| 4.1. Vibration-rotation spectroscopy | » 40 |
| 4.2. Solid-state effects | » 41 |
| 4.2.1. Rotational-structure suppression | » 41 |
| 4.2.2. Line broadening | » 43 |
| 4.2.3. Line shifting | » 44 |
| 4.3. The IR spectrum of H ₂ O ice | » 44 |
| 4.4. Column density determination | » 47 |
| 5. The composition of interstellar icy grain mantles | » 47 |
| 5.1. IR spectroscopy of protostars | » 47 |
| 5.1.1. The 3.08 μm (3250 cm ⁻¹) band | » 48 |
| 5.1.2. The 4.62 μm (2160 cm ⁻¹) band | » 49 |
| 5.1.3. The 4.67 μm (2140 cm ⁻¹) band | » 51 |
| 5.1.4. The 6.0 and 6.85 μm (1670 and 1460 cm ⁻¹) bands | » 52 |
| 5.2. Grain mantle abundances | » 53 |
| 5.3. Organic refractory grain mantles | » 55 |
| 6. Summary | » 55 |

W. W. DULEY – Models of interstellar grains.

| | |
|--|------|
| 1. Introduction | » 59 |
| 2. Extinction, polarization and scattering by dust | » 59 |
| 3. Infrared emission and absorption | » 61 |
| 4. Visible and near-infrared emission from dust | » 62 |
| 5. Modelling of interstellar extinction | » 62 |
| 6. Depletion | » 63 |
| 7. IR and visual extinctions | » 65 |
| 8. 3.4 μm absorption and A _V ^C | » 66 |
| 9. A new grain model | » 67 |
| 10. Conclusions | » 69 |

G. FOTI – Ion-solid interaction: the experimental approach.

| | |
|--|------|
| 1. Introduction | » 73 |
| 2. Hydrogen detection | » 75 |
| 3. Ion bombardment of solid hydrocarbons | » 80 |
| 4. Conclusions | » 89 |

L. B. D'HENDENCOURT, A. LÉGER, L. VERSTRAETE and P. EHREN-FREUND – Spectroscopy of PAH molecules.

| | |
|--|---------|
| 1. Introduction | pag. 91 |
| 2. IR emission mechanism from isolated molecules | » 94 |
| 2'1. IR emission of a large molecule at temperature T | » 94 |
| 2'2. IR emission during a thermal spike | » 95 |
| 2'3. IR cooling time | » 96 |
| 2'4. Mean temperature of emitting PAHs | » 96 |
| 2'5. Mean size of emitting molecules | » 97 |
| 3. Laboratory IR spectra of PAHs. Comparison with astronomical data | » 98 |
| 3'1. IR absorption measurements | » 99 |
| 3'2. Calculated emission for compact PAHs | » 99 |
| 4. Abundance: The most abundant known organic molecules in the gas phase | » 100 |
| 5. Conclusion | » 102 |

E. K. JESSBERGER – Asteroids, meteorites, interplanetary and cometary dust.

| | |
|---|-------|
| Introduction | » 107 |
| 1. Asteroids | » 107 |
| 2. Meteorites | » 111 |
| 2'1. Meteorite ages | » 112 |
| 3. Interplanetary dust | » 113 |
| 4. Chemical properties of cometary dust and a note on carbon isotopes | » 115 |
| 4'1. Introduction | » 115 |
| 4'2. Bulk properties of Halley's dust | » 115 |
| 4'3. Properties of individual grains | » 120 |
| 4'4. A note on isotopes | » 121 |
| 4'5. Summary | » 123 |

R. E. JOHNSON – Irradiation of solids: theory

| | |
|--|-------|
| 1. Plasma environment | » 132 |
| 2. Materials | » 138 |
| 3. Interactions | » 139 |
| 4. Material alterations | » 147 |
| 5. Defects and sputtering: elastic collisions | » 147 |
| 6. Electronically induced alterations and sputtering | » 150 |
| 7. Applications | » 159 |
| 8. Summary | » 164 |

J. KISSEL – Mass-spectrometric *in situ* analysis of solid-state extraterrestrial samples.

| | |
|--|----------|
| 1. Why analyse | pag. 169 |
| 2. Why extraterrestrial samples | » 171 |
| 3. Why <i>in situ</i> | » 173 |
| 4. Why mass spectrometry | » 174 |
| 5. What type of mass spectrometry | » 176 |
| 5'1. «Atomization» | » 176 |
| 5'2. Vaporization and sublimation | » 176 |
| 5'3. Laser desorption | » 177 |
| 5'4. «Exploding» | » 177 |
| 5'5. Sputtering | » 177 |
| 5'6. Dust impact | » 178 |
| 5'7. Spectrometer types | » 179 |
| 5'7.1. Quadrupole | » 180 |
| 5'7.2. Magnetic | » 183 |
| 5'7.3. Electrostatic | » 184 |
| 5'7.4. Combination of both methods | » 184 |
| 5'7.5. The time-of-flight mass spectrometer | » 185 |
| 5'7.6. The ion cyclotron resonance mass spectrometer | » 186 |
| 5'8. Detectors | » 187 |
| 5'8.1. Faraday cup | » 187 |
| 5'8.2. Electron multipliers | » 187 |
| 5'8.3. Photomultipliers | » 188 |
| 5'8.4. Channeltrons | » 188 |
| 5'8.5. Channelplates | » 188 |
| 5'8.6. Ion-electron converters | » 189 |
| 5'8.7. Ion-electron-light conversion | » 189 |
| 6. Types of results expected and actually obtained | » 189 |

K. ROESSLER – Suprothermal chemistry in space.

| | |
|---|-------|
| 1. Introduction | » 197 |
| 2. General aspects of suprothermal chemistry | » 198 |
| 3. Kinetics of suprothermal reactions | » 202 |
| 4. Suprothermal species in space | » 208 |
| 4'1. Acceleration processes at stars | » 208 |
| 4'2. Acceleration processes at planets and satellites | » 209 |
| 4'3. Relative notions and turbulences | » 209 |
| 4'4. Photodissociation | » 210 |
| 4'5. Secondary energy transfer by energetic primaries | » 211 |
| 4'6. Dissociative recombination | » 215 |
| 5. Some examples for hot reactions in space | » 217 |
| 5'1. Coma and nucleus of comets | » 217 |
| 5'2. Asteroids | » 220 |
| 5'3. Erosion of spacecraft materials in low Earth orbit (LEO) | » 221 |
| 5'4. Heavy-atom recoils from α -decay processes | » 222 |
| 6. Interaction of radiation chemistry | » 225 |

| | | | |
|------|---|------|-----|
| 7. | Methods for laboratory simulation of suprathermal reactions | pag. | 229 |
| 7'1. | Computer simulation of collision cascades | » | 230 |
| 7'2. | Ion implantation | » | 233 |
| 7'3. | Implantation of radioactive ions | » | 237 |
| 7'4. | Chemical sputtering induced by ion implantation | » | 237 |
| 7'5. | Photon-induced dissociation of molecules | » | 237 |
| 7'6. | Atomic or molecular beams | » | 238 |
| 7'7. | Plasma discharge | » | 238 |
| 7'8. | Nuclear recoil | » | 238 |
| 7'9. | Nuclear-recoil implantation | » | 246 |
| 8. | Hot carbon and nitrogen atoms in icy systems | » | 247 |
| 9. | Conclusion and outlook | » | 261 |

P. HSIUNG and K. ROESSLER – CO₂ profiles in cometary analogs.

| | | | |
|----|--|---|-----|
| 1. | Introduction | » | 267 |
| 2. | Sample preparation | » | 267 |
| 3. | Irradiation experiment and set-up | » | 269 |
| 4. | CO ₂ analysis apparatus and procedure | » | 269 |
| 5. | Results | » | 270 |
| 6. | Conclusion | » | 275 |

T. J. WDOWIAK – Spectroscopy of solid materials simulating cosmic dust.

| | | | |
|------|---|---|-----|
| 1. | Introduction | » | 279 |
| 2. | Conditions in the interstellar, circumstellar and interplanetary medium | » | 280 |
| 3. | Sources of material of astrophysical interest | » | 285 |
| 4. | Sample preparation and modification | » | 288 |
| 5. | Sample containment | » | 295 |
| 6. | Spectroscopic insights into astrophysical phenomena | » | 298 |
| 6'1. | Unidentified infrared bands (UIR) | » | 298 |
| 6'2. | Extended red emission (ERE) | » | 310 |
| 6'3. | Diffuse interstellar bands (DIB) | » | 319 |
| 6'4. | Superparamagnetic material (SPM) and the alignment of interstellar grains | » | 322 |
| 6'5. | Martian dust | » | 328 |
| 7. | Future directions | » | 330 |

J. A. M. McDONNELL – Space exploration of comets and primitive minor bodies.

| | | | |
|----|------------------------------------|---|-----|
| 1. | Introduction | » | 339 |
| 2. | The comet Halley fly-bys | » | 339 |

| | |
|--|----------|
| 3. Laboratory microparticle analysis | pag. 341 |
| 4. Space missions | » 345 |
| 4'1. Galileo and Ulysses | » 345 |
| 4'2. Comet Rendezvous and Asteroids Fly-by Mission (CRAF) | » 345 |
| 4'3. Comet Nucleus Sample Return, Rosetta (previously CNSR) | » 348 |
| D. MOEHLMANN – Physical properties of terrestrial planets and their satellites: an introduction. | |
| Introduction | » 353 |
| 1. What is a «planet»? (or «definition» of a planet) | » 353 |
| 1'1. Equilibrium configurations | » 353 |
| 1'2. Thermal pressure (caused by thermonuclear reactions) | » 354 |
| 1'3. Degenerate-electron gas pressure | » 355 |
| 1'4. Lower planetary mass limit | » 357 |
| 2. Mechanical properties | » 358 |
| 2'1. Orbital elements | » 358 |
| 2'2. Physical parameters of planetary bodies | » 358 |
| 3. Gravitational field and surface figure | » 359 |
| 4. Internal structure and magnetic fields | » 362 |
| 5. Origin | » 367 |
| V. O. NAIDENOV – Modification of solids by cyclotron beams. | |
| 1. Introduction | » 371 |
| 2. Cyclotron | » 371 |
| 3. Radiation damages | » 372 |
| 4. Influence of direct current on the concentration of radiation damages in GaAs | » 373 |
| 5. Increase of radiation stability of solar cells. Optical properties | » 374 |
| 6. The lifetime of nonequilibrium electrons in <i>p</i> -GaAs irradiated by oxygen ions | » 375 |
| 7. Picosecond lasers | » 376 |
| 8. Lifetime reduction of the charge carriers in Si. Optimization of thyristor structures | » 376 |
| 9. Some «simple» applications | » 379 |
| 10. Conclusion | » 379 |
| V. PIRRONELLO – Molecule formation by fast particles in astronomical objects. | |
| 1. Introduction | » 381 |
| 2. Some selected experimental results | » 381 |
| 3. Molecules produced in astronomical environments by the interaction among particles and solids | » 385 |
| 4. Conclusions | » 388 |

| | |
|---|----------|
| J. R. STEPHENS – Experimental data on the nucleation and growth of solid particles from high-temperature gas mixtures | pag. 391 |
| G. STRAZZULLA, G. A. BARATTA and A. MAGAZZÚ – Vibrational spectroscopy of ion-irradiated carbonaceous materials. | |
| 1. Introduction | » 403 |
| 2. IR and Raman vibrational spectroscopy | » 404 |
| 3. <i>In situ</i> IR spectra of ion-irradiated frozen gases | » 408 |
| 4. IR and Raman spectra of refractory organics | » 411 |
| 4'1. The stoichiometric ratio C/H | » 411 |
| 4'2. Structural properties of IPHAC | » 414 |
| 5. Astrophysical applications | » 416 |
| N. N. GOR'KAVYI and T. A. TAJDAKOVA – Determination of Saturn ring particle density: the first result of a new method | |
| » 423 | |