ASTROPHYSICS IN ISRAEL

A REPORT FOR
THE ISRAEL ACADEMY
OF SCIENCES AND HUMANITIES

COMMITTEE MEMBERS

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The Israel Academy of Sciences and Humanities

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EXECUTIVE SUMMARY

The Israel Academy of Sciences and Humanities appointed a committee to consider the current situation of astrophysics in Israel and to recommend its course for the future. We found that astrophysics in Israel is facing a difficult time. Even today the astrophysics community, although active and with a good international reputation, is undermanned, under-funded, and under-equipped by comparison with other countries. This will only get worse as the current trend toward big projects and large telescopes continues. We conclude: *if Israel is to maintain its standing in astrophysics it will need a significant increase in level of support and in scope of activity.* The following recommendations for Israeli astrophysics are suggested by the committee:

1. Israel should join an international research body, specifically ESO, and in cooperation with it, should participate in the construction of a major new telescope. This will provide the impetus to keep Israeli astronomy in the forefront of research, and will make effective use of many fine astrophysicists (both new immigrants and native Israelis now overseas). It will also benefit Israeli industry by involving it in the new technologies of modern telescopes and detectors.

If for whatever reason it is not feasible to construct a large telescope with ESO collaboration, Israel should concentrate instead on developing new instrumentation for use on other ESO telescopes. This project would bring many advantages of the first recommendation, although on a smaller scale.

2. There are other large projects to be seriously considered. We should study the possibility of building a large optical telescope in cooperation with Egypt. Israeli participation in space-borne astronomy projects should be encouraged and supported. Israel should consider expanding into the important field of radio astronomy, under the auspices of international projects. The foundations for this step necessitate site character ization and feasibility studies.

3. The projects mentioned must be accompanied by a corresponding increase in professional staff. We recommend that twelve new permanent positions, at least half of which go to experimental and observational astronomers, be created over the next five years. There are excellent candidates among young Israeli and immigrant scientists. We point out that the total number of astrophysicists in Israel (per capita) is well below the average in modern developed countries.

SECTION I: INTRODUCTION

The Israel Academy of Sciences and Humanities appointed a committee to explore the status of astrophysics in Israel and to make recommendations for the field's development in the next decade. We have surveyed all academic research institutions in Israel as to their present and planned astrophysical work (including planetary studies and astroparticle physics). We have also studied trends and developments in the international astrophysical community. Based on this study we have arrived at recommendations for maintaining and strengthening astrophysics in Israel.

In this *Introduction,* we describe the situation in world astrophysics and Israel's place in the global community. In the next section, *Current Activity,* we review ongoing astrophysical research. In the final section, *Plans for the Future,* we explain our major recommendations and add other suggestions to keep Israel in the first category of astrophysics well into the next century.

The last decade has been an eventful one for astrophysics and the next decades promise to be even more remarkable. From the purely scientific perspective we have seen revolutions in almost every area of extraterrestrial physics. Astrophysics is unquestionably a productive and exciting field of research today. Simultaneously with these scientific upheavals, great changes have occurred in the way astrophysicists and the astrophysical community as a whole function. There has been a strong trend toward research facilities so large and expensive that they can be built only with the cooperation of many institutions, or even countries, and which therefore necessitate an extensive collaboration for their use. Such facilities include space observatories and experiments, very large ground-based telescopes, and supercomputers. Astrophysicists are inevitably turning away from working independently or in small groups using primarily the facilities of the home institution, and toward a mode of research closer to that of experimental particle physics.

This worldwide trend has put the Israeli astrophysics community into a critical situation. Israel enjoys a reputation for good theoretical and observational research in a variety of subjects in astrophysics, as well as for excellent students. The Israeli astrophysical community consists of approximately forty senior researchers (roughly the number in the astrophysics department at a large university in the US), working mostly, although not exclusively, with the modest observational and computational facilities available in the country. (This current research will be described in detail in the next section). Neither these facilities, these personnel nor the current organizational structure will be sufficient to maintain

Israel's standing as international astrophysics moves into the new era of radically more sophisticated and expensive methods. We need a major change in both funding and philosophy if we are to persevere. In Section III we describe and justify the steps we recommend to keep Israeli astrophysics vital and productive.

SECTION II: CURRENT ACTIVITY

INSTITUTIONS AND PERSONNEL

The institutions supporting astrophysics research in Israel are the Technion, the Tel Aviv University, the Weizmann Institute of Science, the Hebrew University of Jerusalem, and the Ben-Gurion University of the Negev. Research is conducted at the Technion in the Department of Physics and the Asher Space Research Institute, at Tel Aviv in the School of Physics and Astronomy and the Department of Geophysics and Planetary Sciences, at the Weizmann Institute in the Department of Nuclear Physics, and at Hebrew University of Jerusalem and Ben-Gurion University of the Negev in the Departments of Physics. In addition, individuals working in other departments and institutions are involved in some of these projects and will be mentioned as they arise.

The faculty and research staff of these institutions are:

i. At the Technion: G. Shaviv, A. Dar, M. Livio, O. Regev, A. Harpaz, A. Finzi, B. Rosner, Y. Felsteiner, A. Ori and I. Gertner;

ii. At Tel Aviv University: I. Goldman, Y. Raphaeli, H. Netzer, M. Contini, B. Kozlovsky, S. Cuperman, S. Beck, T. Mazeh, N. Brosch, E. Leibowitz, L. Formiggini, A. Yaniv, and A. Sternberg in the School of Physics and Astronomy and A. Bar-Nun, A. Kovetz, D. Prialnik, A.I. Ershkovich, A. Eviatar, Y. Mekler, and M. Podolak in the Department of Geophysics and Planetary Sciences;

iii. At the Hebrew University of Jerusalem: T. Piran, A. Dekel, Z. Barkay, G. Rakavy, Y. Hoffman, N. Sack, I. Lichtenstadt, Y. Tuchman, A. Glasner, A. Braun, Y. Reiss, A. Wandel, and J. Bekenstein;

iv. At Ben-Gurion University of the Negev: D. Eichler and R. Steinitz;

v. At the Weizmann Institute: M. Milgrom, V. Usov, and I. Kovner.

All these institutions support graduate programs in astronomy and astrophysics. There are about 25 M.Sc and Ph.D students at any given time. The only research astronomical observatory in Israel is the George and Florence Wise Observatory in Mitzpe Ramon, which is administered by Tel Aviv University. This 1-meter telescope is equipped with instrumentation for photometry, imaging and spectroscopy and is regularly used at wavelengths from 0.4 to 2.5 microns.

FIELDS OF RESEARCH — THEORY

Modern theoretical astrophysics is characterized by close attention to observational phenomena and data and by the extensive use of numerical techniques and the resulting need for computing power. Some active research areas in Israel include:

Cosmology and General Relativity

This is a very broad field that includes the early universe, the cosmic background, and many other topics, which often overlaps other fields such as particle physics. It is the largest field of research in Israeli astrophysics. Every university in the country has several projects in this subject and Israeli scientists are involved in many international collaborations as well.

Examples of the main areas of current research are Livio's critical study of the basic tenets of the Anthropic Principle (a collaboration with MPI Munich), Kovner's exploration of theoretical aspects of gravitational lenses, and Dar's relation of gravitational lensing to dark matter. Dar and Nussinov (of the Tel Aviv University Particle Physics Department) are working in many areas of astroparticle physics, including the possible solutions to the solar neutrino problem, the cosmic neutrino background and its possible causes, big bang nucleosynthesis, and dark matter. These projects are characterized by the application of astrophysics to test the standard model of particle physics and look for evidence that the standard model is incomplete. Eichler also works on dark matter, including such possibilities as unstable neutrinos, TeV particles, and charged dark matter, and is concerned for the possible observational signatures of these species. Many researchers are interested in aspects of the relic radiation: Raphaeli studies the spectrum and distribution of the cosmic microwave background, Hoffman studies the microwave background and develops Gaussian field techniques suitable for this problem, and Wandel is calculating the X-ray background. Piran studies the early universe (inflation, strings, and textures), quantum gravity and quantum cosmology, and Bekenstein is considering the basic properties of cosmic strings and the growth of galaxies.

Many groups are interested in formation of galaxies and large scale structures: Hoffman has several projects on the primordial perturbation field and galaxy formation and the large scale velocity field, and Dekel deals with formation and dynamics of galaxies and the effects of dark matter on large scale structure.

General relativity and the law of gravity are basic to cosmology and astrophysics. Several Israeli scientists are interested in testing or finding alternatives to Newtonian gravity. Dar is trying to test general relativity on intergalactic and larger distance scales via gravitational lensing. Goldman looks for astrophysical limits on gravitational theories. Milgrom is exploring the MOND hypothesis of low acceleration departures from Newtonian dynamics; Bekenstein is engaged in a similar search for a physically consistent alternative to general relativity and works on other aspects of relativistic dynamics as well.

Compact Objects

The topic of Compact Objects includes neutron stars, black holes and their accretion disks. In the last year this subject has jumped into the spotlight of astrophysical interest with the discovery that very compact gamma ray burst sources are isotropically distributed. Israel astrophysicists are deeply involved in the ongoing international debate whether this means that gamma ray bursts are cosmological, and if they are — what is the source of their extraordinary energies. Dar, Nussinov and Eichler are looking for mechanisms that can produce gamma ray bursts both locally and at extragalactic distances. Other work in this area includes Goldman's study of neutron stars and his models, with Wandel, of their accretion disks, Wandel's work on plasma processes in accretion, Eichler, Livio, and Piran's work on neutron stars in multiple systems (in collaboration with universities in the United States), and Rakavy, Lichtenstadt and Sack's study of supernova collapse processes.

Research is in progress on the physics of accretion disks in binary systems. Shaviv and Regev are working on the structure of the boundary layer in such accretion disks. Livio is studying envelope evolution of binary systems including white dwarfs and is calculating, with collaborators at Kyoto and MPI Munich, instability in accretion onto compact objects. Livio, Shaviv, Kovetz, Prialnik, and collaborators overseas are working on different aspects of the structure and evolution of novae, and Regev is studying accretion in cataclysmic variables and in T Tauri star systems.

Galaxies and Galaxy Clusters

Theoretical work on galaxies and galaxy clusters ranges from purely mathematical investigations, which have almost no contact with observations, to the construction of models that are motivated and tested by observational data. Current work in Israel includes, on the more mathematical side of the field, Livio's examination of the stability of thick accretion disks, Shaviv's investigation of the interaction of galaxies with the intergalactic medium, and Goldman's work on the implications of turbulence in cluster gas. In more observationally oriented subjects, Felsteiner is modeling the X-ray spectra of extra-galactic sources via Monte Carlo simulations, and Raphaeli is studying the X-ray and nonthermal radio emission of clusters, as well as their magnetic fields and dust processes. In closest collaboration with the observational data are the researchers who are investigating and attempting to model processes in Active Galactic Nuclei (AGN) and Quasi-Stellar Objects (QSOs). Shaviv, Netzer and American and German collaborators are studying the thin disks around massive black holes in galactic nuclei. Netzer is investigating photoionization, cloud dynamics, and radiation processes in the broad line region of AGN, and modeling their central accretion disks. Contini is modeling the narrow line region of AGN with the goal of explaining the emitted spectrum. Wandel is working on new types (composite models) of accretion disks to fit AGN and QSO properties and is studying how evolution of the central energy source can be related to the AGN and QSO luminosity function.

Stars, Stellar Evolution, and Interstellar Matter

The stars may be the best known and most studied astronomical objects, but many fundamental questions on their structure and evolution remain unanswered. This is a subject that relies on sophisticated numerical techniques and needs a great deal of computing power. It is an active field in Israel: Shaviv and Kovetz are studying the effects of element diffusion on stellar evolution, Harpaz and Shaviv are calculating the post-main sequence evolution of low-mass stars, and Harpaz is considering the possible effects of new kinds of elementary particles on stellar evolution. Barkat, Tuchman, and collaborators in Texas are studying different aspects of pre-supernova evolution, and Barkat, Tuchman, and Glasner are working on late stages in the evolution of intermediate mass and pulsating stars. Prialnik is studying evolution of nova outbursts and mass transfer in nova systems, and Regev works on thermal processes in the interstellar medium.

Fundamental Astrophysical Processes

This area includes studies and calculations of radiation processes, plasma physics, and fluid dynamics that are directed toward applicability in many astrophysical situations than toward specific sources. Shaviv works on physical processes in astrophysical fluids and Regev on thermal instability and nonlinear phenomena. Sternberg is concerned with radiation and photon processes in the interstellar medium and in the transition zones between ionized and neutral clouds. Cuperman is studying magnetized astrophysical plasmas and developing new methods of describing stellar magnetic fields. Wandel is researching the effects on supernova shocks on cosmic ray generation.

FIELDS OF RESEARCH — OBSERVATIONS

Modern astrophysics is distinguished among the sciences for how rapidly experimental techniques improve, bringing qualitatively different kinds of observations, and how closely theoreticians work with observers to interpret new results. In the last decade new techniques and observational platforms have lead to near-revolutionary rethinking of astrophysical questions in literally every major subject. If we look back to what was known about star formation before infrared detectors, or galaxies before the IRAS satellite mission, or the outer planets before Voyager, or many other cases, we will hardly recognize the subjects, so much have the new observations changed them. A healthy observational effort is essential if the astrophysics community is to stay up-to-date.

These modern observational methods are inevitably and unfortunately costly. They require more funding, equipment, and technical and engineering staff than do the classic systems now becoming obsolete. *Keeping Israel competitive under these conditions is the single most important challenge this committee sees in the near future.*

The present situation for observational astronomy in Israel is difficult. The only currently working observatory is the Wise Observatory. That one-meter telescope has an admirable history and is still productive, but as new telescopes are built around the world the status of a one-meter keeps dropping. It has already gone from "moderate size" as it was at its construction, to "relatively small", and the situation will only deteriorate. This is reflected in the observational projects described below; they emphasize long-term monitoring or wide-area searches, fields in which a small telescope can do good work, but other types of observations are infrequent. It is also seen in the fact that Israel observers do a great deal of their work at installations abroad.

Besides the Wise Observatory, the only Israeli observatory that exists in concrete (although not yet final) form is the TAUVEX (Tel Aviv University Ultra Violet Explorer) system of telescopes for the extreme ultra-violet. This has been designed and funded and is being built by El-Op for Tel Aviv University. It will be flown in space as part of the Spectrum Roentgen Gamma experiment in 1995, and should provide an ultra-violet observatory for at least three years of operation. The Technion is developing X-ray observing techniques; this project is in its early stages.

Galaxies and Quasars

Netzer is studying AGN and QSOs in Israel, overseas, and from space. There are projects to monitor a sample of AGN spectroscopically and radio quasars photometrically from the Wise Observatory. Monitoring projects, such as these, are a popular use of the Wise Observatory. They often involve the cooperation of many, and sometimes (as in the case of AGN studies) all of the Tel Aviv observers. There are several projects to observe AGN and multiple nucleus galaxies with American and German collaborators overseas. Netzer and American collaborators have been allocated time for two AGN projects on the Hubble Space Telescope and at ground-based telescopes in Chile, Hawaii, and elsewhere. The ground-based and space-based observations are closely related and the ground-based work underlies the space observations. Brosch is studying star formation in galaxies without density waves, using the Wise Observatory and ultra-violet data obtained from space observatories. Beck works on star formation in galaxies using infrared data obtained at Wise, overseas, and from satellites, and radio and millimeter observations made at the VLA and OVRO in the United States.

Stars

Beck uses the Wise Observatory to search for Herbig-Haro objects and to attempt to identify certain IRAS point sources with T Tauri stars. Leibowitz, Netzer and Formiggini study symbiotic and other emission line stars from the Wise Observatory, and Leibowitz does photometry (at Wise) and spectroscopy (in Chile) of all known old novae, with some HII regions and planetary nebulae as well. Mazeh studies spectroscopic binaries and optical counterparts of X-ray sources and, in collaboration with the Center for Astrophysics, searches for low-mass companions to stars. A large part of this work is done overseas.

Gamma Ray Astrophysics

Kozlovsky uses satellite observations to do gamma ray spectroscopy and abundance determinations in the Galaxy and to study solar flares.

Solar System Studies

In this era of spacecraft missions and *in situ* measures of solar system phenomena, data on the solar system are qualitatively different from those in other fields of extra-terrestrial physics. Thus, theory and observations work much more closely together than in other areas. Even the most theoretical work on the solar system is intimately connected with observations, in the expectation that it will soon confront new observations. Therefore, in this report all solar system studies are put into this section on observational work.

Podolak models the formation and the present-day interiors of the giant planets and studies how matter is processed in planetary atmospheres. Eviatar works on the plasma physics of outer planet magnetospheres and Yaniv on rare gases in meteorites and lunar material. The study of comets is very active: Podolak, Prialnik, and Meckler look at the effects of porosity on gas emission from comets, Meckler does spectroscopy of comets, Ershkovich studies how the solar wind interacts with cometary plasma, Bar-Nun does laboratory studies to simulate the behavior of comet nuclei and icy satellites and works on planning the Comet Nucleus Sample Return Mission, Eviatar interprets data from comet encounters, and Prialnik models comet nuclei evolution over orbits. These researchers are closely involved with spacecraft missions.

The sun is also a focus of research. Shaviv and Kovetz are studying how transport processes will affect solar structure and Steinitz has a comprehensive program to observe magnetic structure at the solar surface.

FIELDS OF RESEARCH — INSTRUMENTS AND PLATFORMS

Astrophysicists in Israel are looking for ways to extend and improve their observational capabilities. Work is being done both on developing new detectors and instruments for use on ground-based telescopes and on obtaining observations from space platforms. Infrared equipment has been recently put into use at Wise Observatory by Beck, and other infrared instruments are being developed at the Technion.

Researchers at the Asher Space Research Institute, in collaboration with other researchers at the Technion, are developing a new type of matrix detector for X-ray astronomy. The prototype will be tested on a balloon platform and then the system will be put on a satellite. The Asher Institute is also participating in the MARS-94 mission, in collaboration with the German Space Agency, and has a cooperation agreement with IKI, the Soviet Space Research Institute. The Tel Aviv University Astrophysics group is part of the Spectrum Roentgen Gamma mission, a multi-national and multi-wavelength consortium of experiments to be launched on a Russian platform in 1995. TAUVEX (Tel Aviv University Ultra Violet Explorer) will serve as star tracker for the mission and simultaneously survey the sky in the far ultra violet.

SECTION III: PLANS FOR THE FUTURE

THE PROBLEMS

The astrophysical community in Israel, active in a wide variety of fields, faces today crucial decisions. Astrophysics in Israel has been predominantly involved with relatively cheap theoretical research. Observations have been carried out at the Wise Observatory or in individual collaborations with foreign scientists without major investments in observing facilities. Of the approximately two million US$ Israel spends on astrophysics annually, 1.5 million is salary of tenured researchers supplied by the regular budget of the universities where the researchers teach; the remainder, which includes support for students and non-permanent staff, is supported by research foundations such as the Israel-US Binational Foundation (BSF), the German-Israel Foundation (GIF), and the Israel Science Foundation administered by the Israel Academy of Sciences and Humanities. The only experimental facility that is supported on a regular basis is the Wise Observatory, which has an annual budget of about 100,000 US$ or 5% of the total Israeli investment in astrophysical research. This is much less than the fraction of the total astronomy budget dedicated to the observatory in academic settings elsewhere; American universities that rely on their own observatories typically earmark 25 % of their funds for the facility.

As larger and larger telescopes are built in other countries, the Wise Observatory can compete only in limited areas; this is one reason there has been recently such an emphasis on programs of monitoring and searches at Wise. There are now numerous telescopes in the world with mirror diameters of 3 meters and up, and half a dozen giant telescopes of 8 meter diameter or more are in advanced stages of construction. Since the efficiency of a telescope changes in relation to the square of the diameter, these telescopes are from 9 to 64 times as powerful as the Wise telescope. While the largest telescopes are being built by multi-national collaborations, telescopes in the 4-meter class are now being built by individual universities or small university consortia. Israel is therefore dependent for its national observatory on a telescope about one-tenth as powerful as what is today considered proper for a single large university in the USA or Europe.

In the next few years, astronomical observatories in space will be increasing and expanding. If Israel does not participate in this development, our astrophysicists are in danger of being even further left behind. Finally, the wave of immigration from the former Soviet Union includes many fine space physicists and it is a challenge to the community to absorb and make proper use of them. The current budget and the current organizational structure are not adequate to meet these challenges.

RECOMMENDATIONS

The recommendations are divided into two categories of equal importance: facilities and manpower.

New Facilities

The committee recommends consideration of the following new facilities. The first is of the highest priority and is submitted as a major recommendation to the Academy. The others are alternatives worthy of further study.

Joining ESO

Our first recommendation is that Israel join an international body for cooperation in astrophysics, specifically ESO (the European Southern Observatory). ESO is a scientific world enterprise, and one of its basic goals is to give comparatively small countries access to first-rate astronomical facilities. Moreover, many Israeli researchers have personal experience with the organization.

Israel could benefit from joining in one of two major efforts of ESO — participation in the construction of a modern observatory or participation in the construction of large instruments. Countries much larger and richer than Israel have adopted this approach to support building and operation of large and sophisticated instruments that are out of reach of any single community. (There are an analogy and a precedent in Israel's membership in CERN).

This plan would require ESO membership fees, based on the Gross National Product of the member country. For Israel these would be about 400,000 US$ a year. This sum goes to the operation of the present ESO facilities and opening these facilities to Israeli observers.

i. Building a Major Observatory: Joining ESO and building a new telescope is the best, most economical, and most obvious way to ensure that Israel will stay at the highest level of astrophysics well into the next century.

Other benefits will come from joining ESO and building a new telescope. The money for the telescope would be spent in Israel and Israeli industry would gain experience in the many important technologies and techniques that are involved in modern observatories. This would be an opportunity for Israeli industry to enter the fields of optics (for example adaptive optics), detectors at optical and other wavelengths, signal processing, and many other new subjects. It would also provide places for excellent Israeli astrophysicists now working overseas and equally excellent scientists from the new wave of immigration. Israel has a *low* astrophysicist to population ratio, only about a third that of the USA, and growth of the astrophysics community is overdue.

ii. Building Instruments:
Participation in large instruments calls for participation in instrument development and construction. The importance of the experimental work involved in instrument development is considerable. It will lead to new technologies developed in Israel and to the transfer of new technologies to Israel. The budget increase needed for this activity would be about 600,000 US$ per year.

This arrangement will bring many of the same advantages as the first: access to good research facilities, ability to compete in areas now out of reach, and benefits to Israeli industry. Moreover, when instrumentation is developed as part of a new project, most of the money will be spent in Israel supporting the researchers who will develop the technology and the industry that will manufacture the equipment.

Possibility of Expansion into Radio Astronomy

Observation at wavelengths longer than the infrared is probably the single field in which Israeli astrophysics has the least experience and the weakest representation. Radio and millimeter work is very important in modern astrophysics and the Israeli astrophysical community is troubled by its weakness in this regard. Radio telescopes are comparatively inexpensive to build, and since the trend in that field is toward networks of widely separated antennae it may be possible to put a telescope in Israel as part of an international VLBI network.

We do not yet know if there are feasible sites for radio telescopes in Israel. We therefore recommend site surveys of possible locations for radio telescopes. When possible sites have been characterized, the possibility of expanding into this field can be seriously considered. A current estimate for the cost of a single VLBI dish is approximately five million US$.

Space Astronomy

As astronomy moves into space, it is important for Israel to establish itself in space observations. At present Tel Aviv University and the Technion are working on Israel's first space astronomy efforts. Space projects are expensive, work on long time scales and therefore require long-term commitments. We recommend that local facilities for development, construction and testing of space equipment be supported. A laboratory for satellite testing and integration has been built at the Technion where the first Technion satellite is under construction. Support of these efforts is mainly obtained from donor's contributions.

It is recommended that government agencies support such efforts, since technologies developed in this endeavor are rapidly transferred to industry.

Large Optical Telescope

An alternative to participation in the construction of a large telescope with ESO would be to build a 4-meter class telescope incorporating new technology in collaboration with Egypt, sited in the Sinai. This would be attractive politically as an example of Israel-Arab cooperation, and astronomically because the Sinai is the best site for an observatory close to Israel and a very good site by any standard.

Manpower

The Israeli astrophysics community is now relatively small compared to the size of the country, the university population, and the number of research projects in progress. It will be much too small for the future unless new positions are opened. We recommend that twelve new positions be made available over the next five years. There are many outstanding Israeli students now abroad who would like to return to Israel to work, and many excellent scientists in the new wave of immigration; this is an excellent opportunity to find first class astrophysicists. We urge that at least half these new positions be reserved for experimental and observational astronomers.