THE EIGHTH LUNAR SCIENCE CONFERENCE:

A stock taking of our present knowledge of the solar system and its planets

The solar system formed about 4.6 billion years (b.y.) ago. Although a great deal happened in those early days, at least a few of the important and extensive physical and chemical processes are slowly being understood through the use of modern experimental techniques. Studies of trace elements and extinct radionuclides in meteorites and in lunar soils and rocks have led to the conclusion that several dramatic events, such as condensation and formation of planetary bodies, may have occurred on time scales much shorter than 10 million years (m.y.). Large scale metamorphism and differentiation probably occurred during the subsequent 100-1000 m.y. These ideas are based on a decoding of the chemical and physical evidence present in ancient solar system materials. Some of this early record has been obliterated by later processes, but to me, the single most exciting conclusion derived from these studies is that sufficient information is still preserved to allow one to make a logical story of the early processes. These studies make use of the most sophisticated methods available. Many of these were developed in the early sixties , due to the tremendous incentive provided by the promise of having substantial samples of moon in the laboratory. The six Apollo landings returned more than 2000 separate samples; a total of 382 kg of lunar rocks and soil. Considering the holdings of over 2000 meteorite samples, we certainly have available for direct investigations ample amounts of materials, bearing records of the early history of the solar system.

Shortly after the first acquisition of lunar samples in late 1969, the tradition of holding annual lunar science conferences at Houston, Texas, began. At first, these conferences marked the successful completion of yet another Apollo mission to the Moon and the papers presented dealt mainly with the samples brought back the previous year. As all good things come to an end, so did the manned lunar missions. (The Soviet unmanned missions may still be on-going: we do not know.) However, NASA continued its tradition of holding the annual so-called rock-festival. The emphasis in these meetings has changed steadily since the culmination of the Apollo missions. Extensive studies made it quite clear that lunar samples can not be studied just by themselves; they have to be seen in the perspective of basic information from studies of meteorites and astronomical observations of asteroids and stellar systems.

The conference which was held at Houston during 14-18 March 1977 and hosted jointly by the Johnson Space Centre and the Lunar Science Institute, concentrated on facts relating to studies of the moon. This included direct examination of lunar samples and information gained from a variety of Apollo surface and orbital experiments, as in previous years. However, one significant difference this year was the inclusion of papers dealing with recent explorations of Mars by the Viking Spacecrafts and papers dealing with studies of planets based on data accumulated from NASA and Soviet exploratory missions to Venus, Mercury, Mars and the outer planets.

The seven principal scientific topics considered at the conference were :

A. Constraints on structure and composition of planetary interiors.
B. Characteristics and movements of materials on lunar, planetary and asteroidal surfaces.
C. Characterization and evolution of maria and other volcanic landforms.
D. Characterization and evolution of planetary crusts.
E. Nature and effects of impact processes.
F. Extraterrestrial materials as solar/interplanetary/interstellar probes.
G. Earliest history of the solar system.

A highlight of the conference was the presentation by USSR of five halfgram Luna-24 samples to the American scientists. Luna-24 samples were returned to the earth by an unmanned mission in August 1976 from the eastern-most limb of the visible face of the moon.

Some highlights of the conference :

(a) Planetary Interiors :

A knowledge of planetary interiors is essential to understand the bulk chemistry of the planet. Therefore, intensive efforts are being made to model the evolutionary history of planets. These models depend critically on the time scales for differentiation which have been determined through isotopic studies of moon and meteorite samples. Seismic models for the lunar interior are consistent with a crust, about 60 km thick, on the central nearside, and a radially hetrogeneous mantle. New determinations of seismic velocities have shown substantial geographical variations in the mantle.

Electrical conductivity measurements by M.J. Wiskerchen put an upper limit of 400 km for the radius of the lunar core.

Gary Latham reported that on Mars, at most 2 events were of tectonic origin (possibly small local quakes); the rest were associated with wind activity. Mars appears to be quieter seismically, compared to the Earth and may be even quiter than the Moon.

(B) Planetary Surface Processes :

Extensive data on characteristic spectra of sunlight reflected from asteroids were reported. These can be used to characterize their surface, both chemically and physically. D. Matson and his colleagues believe that both lower impact velocities and weaker gravity on asteroids inhibit formation of impact glasses, which are abundant on the lunar surface. M. Graffey and T. McCord showed that the surfaces of several types of asteroids have identical chemical comoposition with some of the meteorites. Polarimetric measurements by B. Zellner, A. Dollfus and their colleagues indicate that some asteroids may be strongly enriched in carbon. Dollfus showed convincingly that others are covered with metallic dust.

Very detailed studies of lunar soil were reported by a number of workers. Several soil maturity parameters have been studied—for example galactic and solar cosmic ray tracks and spallation products, glassy agglutinates, ferromagnetic resonance parameter I_s, normalized to total FeO content. These studies aim at understanding the evolutionary history of the lunar regolith. Effects due to mixing have to be differentiated from those due to maturation of the soils. Correlation studies between particle tracks and a variety of effects characteristic of near surface exposure appear promising for deducing the variation in the meteoritic flux in the past. This was shown by the Indian group which have analyzed forty-three samples from different stratigraphic units of Apollo 15 deep drill core. The Indian group also showed that it is possible to determine surface exposure ages, the time a soil has spent within a few mm of the lunar surface. This new method is based on a measurement of the solar flare induced changes in the isotopic composition of xenon.

(C) Lunar Maria:

Lunar volcanic and cratering processes, occurring between 4.6 and 3.0 billion years, have been extensively studied. And, at this Conference, a number of exciting developments relating to extraterrestrial basaltic volcanism were discussed. Venera 9 and 10 close-up photographs possibly reveal presence of Venusian basaltic rocks. New results reported for lunar rocks using the Nd/Sm systematics and other methods throw considerable light on the source regions of lunar mare basalts. As our knowledge grows in this area, it becomes possible to make a comparison with other planets.

(D) Lunar Crust:

Crucial to understanding evolution of the lunar crust are data on lunar magnetism, characterization of rocks which crystallized before the final bombardment (about 3.9 billion years ago), and understanding the nature and origin of the low potassium Fra Mauro glass and the potassium—rare earth—phosphorous rich lunar samples (nicknamed as KREEP). These problems were extensively discussed.

There exists no consensus as yet on the nature of ancient lunar magnetism; definitive information would be crucial to our understanding the evolution of lunar surface, mantle and core (?).

(E) Impact Processes:

An important conclusion resulting from the U.S. and Soviet imaging and sampling missions to the Moon is that nearly all the soils and near-surface rocks are impact ejecta. Even pristine rock surfaces are covered with impact craters. New results reported range from data on the dynamic strength of rocks to energy partitioning during impact and crater-stability calculations. Papers discussing the role of volatiles and criteria for the recognition of impact melts were also presented. New constraints on the size and flux rate of impacting objects over the last 3×10^9 years were given.

As recently summarized by T.J. Ahrens, major, readily identified problems include:

Fig. 1: Close-up view of "large" perovskite crystals intergrown with second-generation spinel. Perovskite is partially overlain by submicron spinel which must have formed after the perovskite had grown on the parent spinel. Scale bar 1 micron.

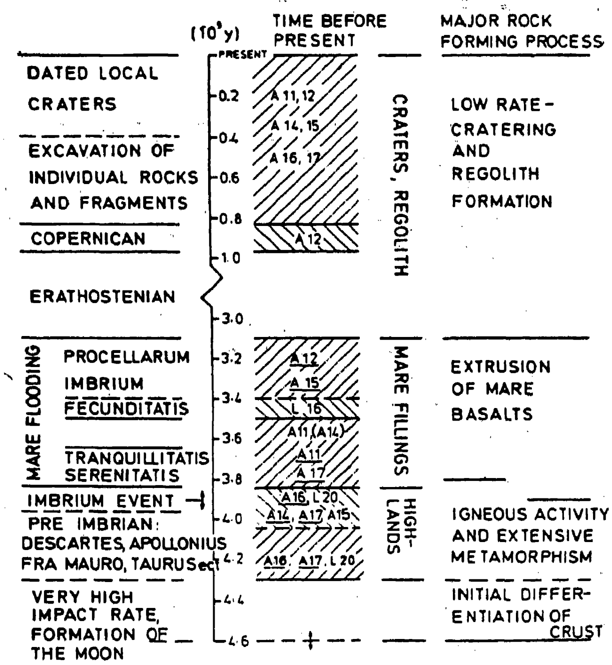

Fig. 2: Chronology of important Lunar events.

(a) the degree to which the larger craters on the terrestrial planets form deep transient cavities (prior to slumping and floor collapse) and hence bring to the surface, by ejecta, samples of the planetary interior;

(b) the degree to which crater size versus frequency data may be relied upon to give surface age, given the incompletely known quantitative effects of regolith thicknesses and dynamic rock strength at large scales; and

(c) the degree to which shock and radiogenic heating has contributed to the thermal evolution of the terrestrial planets during early accretion, and also their effect on later endogenic differentiation processes.

(F) Moon as a probe:

The surface of the Moon, which is devoid of both an

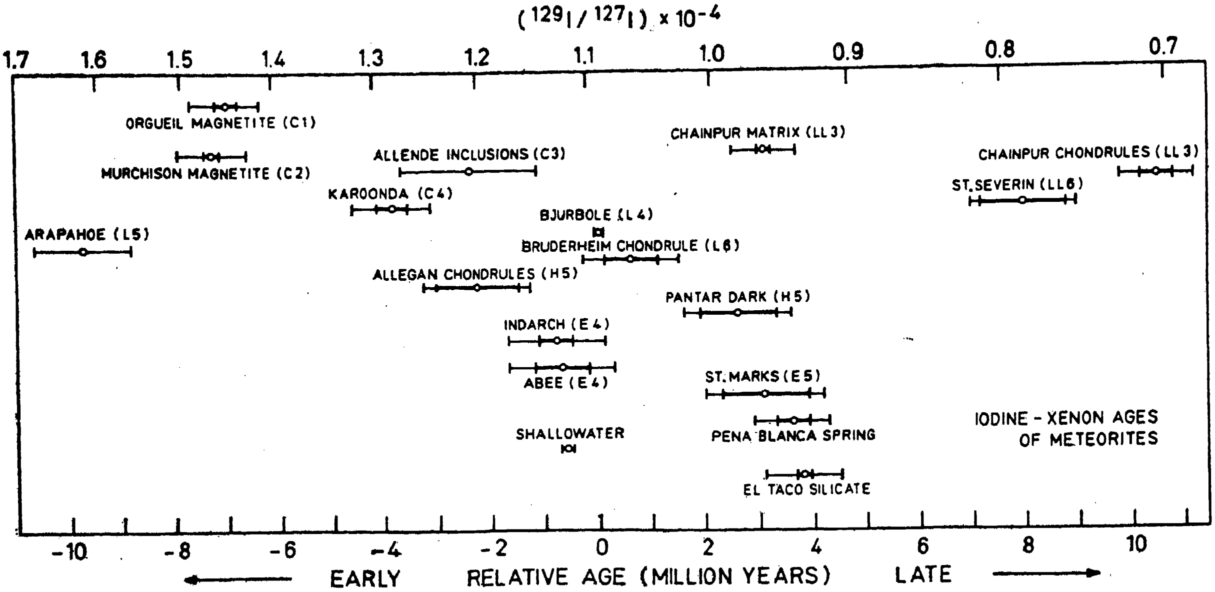

Fig. 3 : Summary of I-Xe ages of meteorites relative to Bjurbole. The respective $^{129}I / ^{127}I$— ratios are indicated on the top scale.

atomosphere and a global magnetic field, is continuously bombarded by solar-wind ions, galactic and solar flare accelerated cosmic rays, and micrometeorites. It can therefore be regarded as a natural space probe recording events and conditions over the last few billions of years. However, since the available samples are generally mixtures of material exposed over a range of time and in different geometries, it is usually very difficult to decipher the record. But indeed the past events can sometimes be fairly well resolved by studying some of the large number of well documented lunar samples of widely different evolutionary histories. Data on effects due to solar and galactic corpuscular bombardment of the Moon are steadily accumulating. Many of these lead to a consistent picture. However, some pose a puzzle, for instance, the nitrogen isotopic data. J.F. Kerridge showed that the $^{15}N / ^{14}N$ ratios for nitrogen implanted in the lunar regolith have increased substantially with time, but all known mechanisms for isotopic evolution fail to explain the observed effect.

(G) **Early solar system:**

Just as at one time all roads led to Rome, it may be said that today all lunar, meteoritic and planetary investigations seem to go back to the important questions relating to the early solar system. Today, speculations about the early processes have become the most fashionable and exciting pastimes of a number of geochemists, nuclear physicists and astrophysicists.

Three sessions of the conference were devoted to early history of the solar system. Extensive discussions were held on the interpretation of isotopic anomalies and on the properties of Ca-Al-rich inclusions in chondritic meteorites. Some isotopic anomalies apparently reflect events and processes that occurred in the Galaxy prior to the formation of the Sun. It seems possible, although there is still no positive proof, that unaltered interstellar grains exist in meteorites. In addition, it is believed that, except for an overprint of planetary metamorphism, the properties of chondrites were produced by nebular condensation. In this picture, the Ca-Al-rich inclusions would relate to the higher temperature part of the condensation and would thus be the earliest-formed solid objects available for study. On the other hand, the differentiated meteorites (achondrites, irons, etc.) provide materials produced in planetary differentiation processes and are useful for comparison with lunar and terrestrial samples.

Astrophysical results were provided by W. Herbst and G.E. Assousa, who reported observational evidence for the formation of a star as a result of a shock wave from a supernova explosion. The evidence was presented for star formation in the young association CMa R1 which contains two classical Herbig emission stars and several extremely young stellar objects of likely ages around $10^5 - 10^6$ yr. The possibility of a chance presence of the star is excluded largely by the argument that the age of the supernova remnant and of the star are the same. The idea, which had been suggested before this observation by Öpik and Chevalier, is based on the hypothesis that the shock results in compressions of clouds in the surrounding interstellar medium. Cameron believes that similar process may have led to formation of our solar system.

Wasserburg and his colleagues presented results on Mg isotopic anomalies in separated phases from the Ca-Al-rich inclusions. The observed lunar $^{26}Mg / ^{24}Mg - ^{27}Al / ^{24}Mg$ correlations argue for an **in-situ** decay of the extinct ^{26}Al activity, which in turn implies that these inclusions formed within a few million years of nucleosynthesis.

The results of R.N. Clayton and T.K. Mayeda on oxygen isotopic composition, however, are in striking contrast to the Mg-Al data. They indicate that the solar

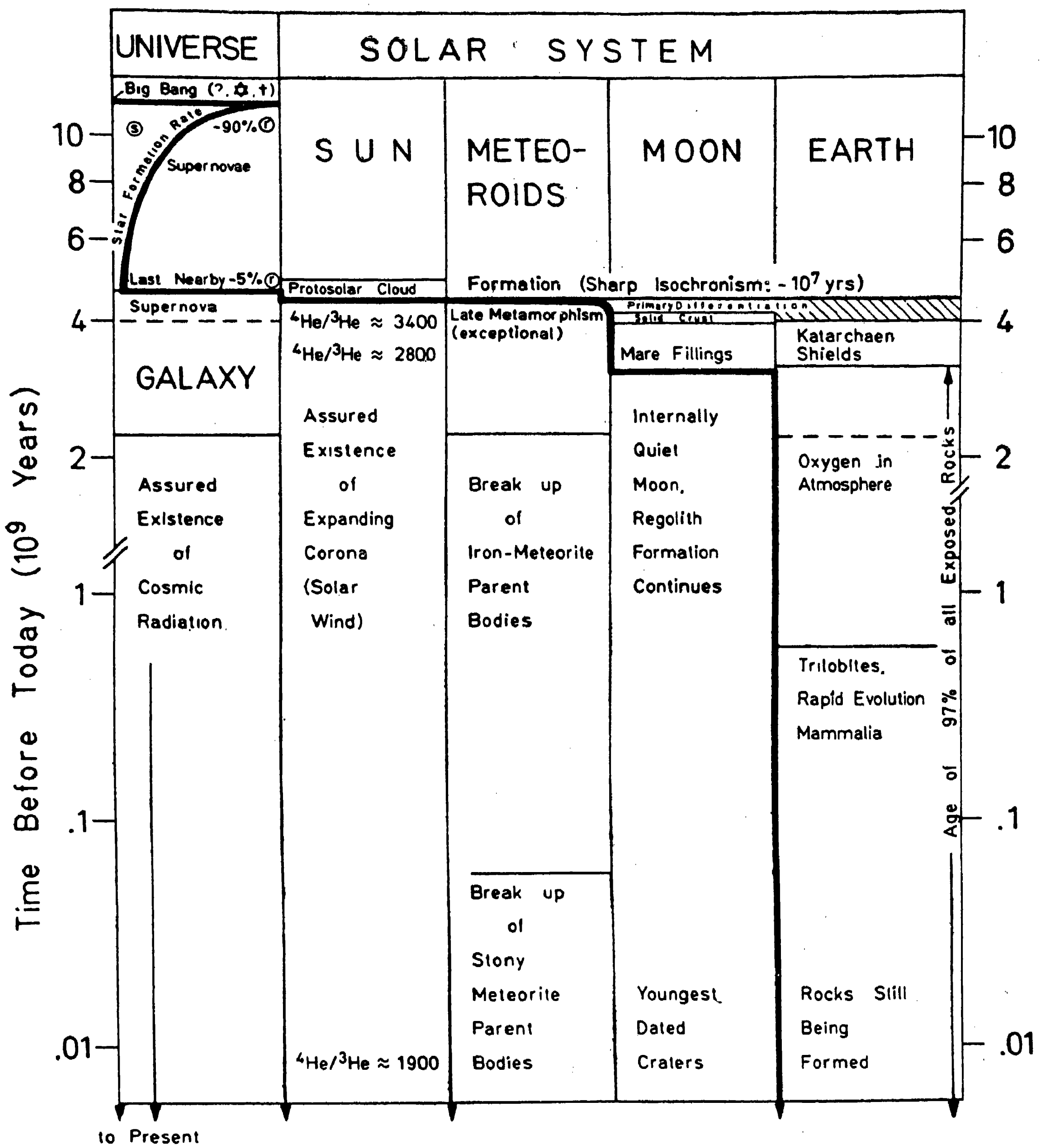

Fig. 4: Schematic summary of a cosmochronological time table; Note the logarithmic scale.

nebula was an inhomogeneous gas cloud containing components rich in ^{16}O - the oxygen isotopes do not appear to be equilibrated in co-existing minerals, unlike Mg and Al.

The cover page photograph shows a S.E.M. photomicrograph of a typical spinel crystal from a coarse grained Allende inclusion. Figure 1 shows a close-up of large perovskite crystals intergrown with second generation spinel. These photographs were made available through the courtesy of I. Hutcheon who, on the basis of such studies, suggested that the formation sequence may be Spinel 1, perovskite, Spinel 2, mellilite. This is in disagreement with the sequence perovskite-mellilite-spinel, based on equilibrium code section theory suggested by L. Grossman. Spinel 1 grains which formed somewhere else may have served as nuclei for condensation of the Allende inclusions and may be the carrier of the ^{16}O anomaly.

The several methods of radiometric age dating have enabled us to delineate the most significant milestones of evolution into an absolute time scale. Particular attention has been given to a clear distinction of planetary age related to solar system formation and rock ages related to the individual planetary evolution. The main task of such studies can be considered to deduce a time frame for the history of the solar system. This must involve delineating the sources of the solar system matter, estimation of the time and duration of the formation of the solar system, determination of the sequence of planetological events in time and unravelling the details of planetary evolution.

Figures 2, 3 and 4 illustrate the type of information we have at hand today on the chronology of various events, based on studies of lunar and meteorite samples. These figures are taken from a recent review "Time and the solar system" by T. Kirsten.

The outrageous simplicity of these figures are merely an indication of the enormous complexity in the early processes. Any models discussed today must be considered merely a reflection of our capability of deciphering the early history. We have yet to understand a great deal, but it is clear that direct studies of lunar samples have greatly speeded up the rate of acquisition of knowledge of early processes. New methods and new concepts in selenology, planetology and meteoritics are leading or trailing the other, and the net result is that our knowledge is quickly expanding, constituting a part of the quickly advancing new frontier.

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REPORT ON THE IAU COLLOQUIM NO. 42

IAU Colloquium No. 42, "The Interaction of Variable Stars with their Environment" was held at Bamberg, F.R.G. during September 6-9, 1977. About one hundred thirty astronomers from several countries participated in the colloquium. Deliberations on over 60 papers inlcuding about a dozen review papers, covering the young stellar objects, cataclysmic variables and evolved stars were carried out during the four days of tight schedule. In the following, we give a brief resume of the proceedings.

Herbig-Haro Objects

In the opening review talk on Herbing-Haro objects, Böhm described the current state of knowledge about these objects. These objects are small condensations ($\simeq$1000 AU) inhabitating the obscured regions near T Tauri stars. In some cases, they are connected with infrared sources and in one case to a H_2O maser. All these objects are variable on a time scale of 10-20 yr. The radial velocities are predominantly negative with respect to the surrounding by as much as 240 km/sec. The spectra show emission lines of Ca II, Cr II, Fe II, Fe III, O I 6300, O I 6364, besides a continuum. Simultaneous presence of H and K lines of Ca and the Ca infrared lines, makes the spectra similar to those of old supernova remnants. They have large ultraviolet excess. They suffer large amount of interstellar reddening, which could be determined with the help of S II lines. H-H1 and H-H2 have $E_{B-V} \backsim 0^m.6$ and $\backsim 0^m.25—0^m.35$ respectively. They have population I abundances.

T Tauri and YY Ori Stars

Contributory papers on T Tau and YY Ori stars then followed. The line profiles in DR Tau were shown to be variable, having a complex structure. The radial velocity variations are 1.5 km/sec. Short period luminosity variations are present.

From the photoelectric photometry of three low mass T Tau stars, Mauder went on to explain the variations in the light and colour of these stars in terms of small planetesimals eclipsing the star periodically. The statement about their low mass, as estimated from the evolutionary tracks in a luminosity-temperature diagram aroused discussions because of the uncertainties in the intrinsic B-V colours and the bolometric corrections of these stars.

Appenzeller pointed out that the frequcncy of YY Ori stars among the T Tau stars should be far greater than hitherto considered. Out of the 161 T Tauri stars known, only 65 have UBV data. Half the T Tau stars, when investigated, would show YY Ori characteristics.

YY Ori stars are T Tau-like stars with strong ultraviolet excess found in the nebulous clusters. They show inverse P Cygni line profiles, i.e., emission lines having red displaced absorption components. Walker has interpreted these objects as very young stars in which the matter is still raining down from the surrounding cloud on to the stellar core.

Bertout described briefly the results of calculations of the line profiles in YY Orionis type atmospheres, employing the photon escape probability method for treatment of the transfer of line radiation in a moving atmosphere.

Appenzellar reported the recent identification of S CrA as a YY Ori star, and suggested the study of BO Ori from this point of view. Mundt showed that the absorption components in the Balmer lines of CoD—35° 10525 are higly variable. Walker showed the profiles of Hβ, Hγ and Hδ lines in the spectrum of YY Ori obtained at a resolution of 0.5Å with the help of Wampler scanner. Swings reported about the image tube spectroscopic search for pecular Be stars having infrared excess in the 800-1100 nm region at a dispersion of 230 A/mm.

Flare Stars

Mirzoyan remarked that the expected number of flares in young cluster stars is larger than the observed number, and that flare stars are also radio stars in general. Swings reported flares in the peculair B_e star HD 45677—a B2 IV star. Thé showed that the variable shell star HR 6000 could be a binary star. He also remarked that the value of A_V increases as the star fades. Swings reported that the P Cygni star CD—52°9243 is a Be star with a shell. The underlying photospheric spectrum is late B or early A, having distance$\backsim$3kpc; k index$\backsim$4.2; h-k=1.2; and V=10. The Fe II lines have variable P Cygani profiles.

Proto-type Envelopes

Yorke dealt with the structure of envelopes around protostars and their subsequent evolution to stars. A condensation develops at the centre of a cloud which is bordered by an accretion shock-front. When the core contracts to stellar densities, thrmonuclear reactions in the core start. The luminous flux now coming out consists of the stellar luminosity and the luminosity of the shock-front. There forms a dust free zone inside the radius of grain melting. Further accretion takes place and luminosity of the star rises. When the intrinsic luminosity