Highlights of New Astronomies*

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In terms of astronomical reckoning a decade is an extremely short duration of time. However, in the past ten years the pace at which observational astronomy has progressed is phenomenal. Technological thrust has broken open many a guarded window of the electromagnetic spectrum (Fig. 1) and new winds of celestial knowledge are streaming in through these. Stratospheric balloons, sounding rockets, manned and unmanned satellites have ushered in the space age astronomies - ultraviolet astronomy, x-ray astronomy and gamma-ray astronomy. Again technological advances in the field of electronics - maser amplifiers, maser clocks, high speed magnetic storage devices, computers, radiation detectors etc. have led to new developments in ground-based astronomies too. The few windows in the infrared have been exploited and very significant advances have been made already in the field of ground-based infrared astronomy. Evidence for the presence of various types of molecules - ammonia, water vapour and formaldehyde have been obtained in the field of microwave astronomy which, a few years ago, came into the forefront with the discovery of the microwave background radiation. The VLBI (very long baseline interferometer) technique has already yielded new and interesting results. The very high angular resolution achieved with this technique has led to the so-called OH-riddle and probably to the threshold of a new astronomy - the Maser Astronomy. The quasars which, perhaps, are the farthest objects in the universe, have receded into the background and got almost eclipsed by the discovery of the Pulsars - the pulsating radio stars. The developments in this field, both observational and theoretical, have been so rapid that Pulsar Astronomy is already a well

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* Review Talk presented at the Eleventh Symposium on Cosmic Rays, Particle Physics, Astrophysics and Geophysics held at Delhi, October 1969.

established new field.

I shall endeavour in the next 40 minutes to highlight the developments in these new exciting fields.

Microwave Astronomy

In the field of microwave astronomy, apart from the discovery of the microwave background radiation - the so-called 3° radiation which has had its effect felt in diverse fields of physics - cosmic rays, x-rays, cosmology and so on, there have been new developments in the last few years. The Berkeley radio astronomers led by C. Townes discovered the radio emission in the centimeter wavelength range of ammonia and water molecules. The discovery was made with the 20 foot millimeter-wave radio telescope at Hat Creek, California. The observations showed that ammonia molecules are quite abundant in the turbulent gas clouds in the constellation of Sagittarius. From the relative intensity of the two ammonia lines the temperature of the molecule has been deduced to be 23° K. While the estimated density of interstellar ammonia molecules is about 10^{-3}/cc the density in the clouds in which the ammonia molecules have been detected is about 10^{3}/cc. The water molecules have been discovered in regions different from those where ammonia molecules have been discovered.

In April 1969 the radio astronomers at the United States National Radio Astronomy Observatory at Green Banks, West Virginia detected the microwave emission from Formaldehyde ($H_2C^{12}O^{16}$). Efforts to discover sulphydryl radicals (SH) have been unsuccessful so far. This may perhaps suggest some relationship between the distribution of formaldehyde and that of methane (CH_4) which does not have emission lines that can be detected in a similar way. In the latest issue of Astrophysics Journal Letters, the discovery of a rare type of formaldehyde, $H_2C^{13}O^{16}$ has been reported.

What is most surprising however is the unexpectedly large abundance of these molecules. It has been found that the abundances cannot be explained from the rate of formation by collisions of the constituent atoms. The question has been posed whether there are catalytic prodesses which bring together the reacting atoms. Is it possible that interstellar dust on which possibly solid hydrogen has condensed, has a role to play in the formation of these molecules?

The OH-riddle (Maser Astronomy ?)

The OH molecule does not normally exist by itself in terrestrial surroundings except in the upper atmosphere. Each of the rotational levels in the ground electronic state of the OH molecules are split into four sublevels (lambda doubling and hyperfine doubling). The four microwave frequencies corresponding to the ground state transitions are 1612.231, 1665.401, 1667.358 and 1720.527 MHz. These frequencies correspond to a wavelength of about 18 cms. If the populations of different levels are in thermal equilibrium, then the relative strengths of these lines should be 1 : 5 : 9 : 1.

In 1963 the radio astronomers at MIT-Lincoln Observatory first detected OH in absorption at the frequency of 1667 MHz. In 1965 the Berkeley and Harvard radio astronomers almost simultaneously discovered radio emission at the OH frequencies 1665 and 1667 MHz from the radio source W 49. The properties of the signal however were very different from what had been expected. The intensity of 1667 emission was about 100 times greater than the upper limit set while looking at other directions within the galaxy. Even more surprising was that the peak emission at 1665 MHz was three times stronger than at 1667 MHz rather than 5/9th as strong. Also the radial velocities of the material emitting 1665 and 1667 were different. These observations were so perplexing that the possibility of a new element - Mysterium - was even considered at one stage. This possibility, however, was abandoned soon when further observations showed similar traits in radio emissions from other sources too, but not preferentially at 1665 MHz. Another feature that was discovered by the MIT astronomers in the radio source W 3 was the strong linear polarisation by as much as 37%. In 1966 observations at NARO and Jodrell Bank showed that the OH emission from W 3 was 100% circularly polarised which meant that there were two linearly polarised components with 90° phase difference and of equal magnitude. With the VLBI technique it has now been established that the angular size of the smallest OH emission source in the W 3 complex is 0.005 second of arc. This would correspond to an effective radiating temperature of 10^{13} degrees K ! Another feature of OH emissions that has been established is the variability of the intensity of lines more or less randomly in periods of the order of months. Also the lines corresponding to high excitation levels (4765 MHz) have been observed. If the intensities had been normal one could never have hoped to observe the higher order transitions. Attempts to detect OH emission from neighbouring galaxies have not been successful so far.

The conventional astrophysical theories cannot account for the intensity and other properties of the OH emission lines from interstellar space. The intensity observed is so high that some type of amplification of a primary intensity is absolutely essential. The maser type of amplification has been seriously considered in this context. The way in which the maser output may be polarised has also been studied. What is the pump and what is the source that bring about this maser action? Several pump models have been proposed. According to Litvak, OH sources lie near stars which have a large ultraviolet output - the UV photons excite the OH molecules and bring about a population inversion. Shklovsky has suggested that proto stars which are still in the process of formation might be capable of pumping the OH by their infrared radiation. Another models is the formation of OH molecules in excited states which lead to inverted populations. The signal source could be a small continuum radio source or just the general background radiation. It is very significant that recently some of the infrared stars have been found to emit radiation corresponding to OH molecules.

Infrared Astronomy

Ground based infrared astronomy is feasible only at a few narrow wavelengths: 1.65, 2.2, 3.6, 4.8, 8-14 and 17-22 microns; also at 1-3 mms which falls in the realm of microwave astronomy. Some infrared observations have been made using jet aircrafts and stratospheric balloons.

It is the lack of a sensitive infrared detector that has been responsible for the delay in the development of this field. Even now this limitation exists. The sensitivity of an infrared detector is a factor of 1000 less than a detector in the visual region. But for this limitation a 2-inch infrared telescope could do as well as a 62-inch telescope that has been used in recent observations. The infrared detector most commonly used now-a-days is lead sulphide and at 22 liquid helium cooled germanium Bolometers. The two groups that have made outstanding contributions in the field of infrared astronomy are the groups from the University of Arizona and the California Institute of Technology.

Infrared Stars

The existence of infrared stars has been established since Hetzler's photographic work in the 30's. The Caltech group have carried out an exhaustive survey in the last few years with their 62-inch telescope. While 20,000 infrared sources have been picked up there are about 5500 objects which are at least 2.5 times the minimum detectable brightness and therefore are certain to be classified as infrared stars. 30% of these objects emit sufficient light to be picked up with the naked eye. Only about 20% of the bright visible stars are also bright in the infrared (Fig. 2). The reddest infrared stars show an unmistakable concentration along the galactic equator particularly along the general direction of the galactic centre. It is to be pointed out that the interstellar dust in the central regions of our galaxy attenuates visible light by a factor of 10^{10} (25 magnitudes) while the attenuation in the infrared is by a factor of about 10 only.

Of the 5500 stars about 450 are so red that 97% of their energy output is in the infrared showing thereby that their temperature if black body is less than 1700 degrees K. The brightness of many of these stars has been found to vary by a factor of 10 in a period of three years. The most important question regarding the infrared stars is: are they cool stars, or are they ordinary stars reddened by interstellar dust or circumstellar dust? Relevant to this question is the observation on the object known as R. Monocerotis which lies at the head of the comet nebula called Hubble's variable Nebula. For many years R. Monocerotis has been classified as a T. Tauri star on the basis of its optical spectrum. The Mexican astronomer, Eugerio E. Mendoza found that the spectrum of R. Monocerotis had a second very pronounced maximum in the infrared which accounted for most of the energy output from the star (Fig. 3). The peak of infrared component is around 4 microns and the entire energy distribution corresponds to a black body of temperature 750°K except for some excess at 22 microns. It is admitted that it is not possible to explain the infrared observations of this object by extinction alone. It has been shown by Low that the energy distribution observed in R. Monocerotis can be explained by a model in which a proto star heats up a pre-planetary envelope of dust grains which re-radiate at longer wavelengths.

Becklin and Neugebauer discovered an infrared point source in the great Orion Nebula and this object has no optical counterpart detectable even with a 200-inch telescope. The infrared measurements upto 13.5 microns indicated a temperature of 650°K. It was also discovered that this infrared object gives rise to OH emission lines also. If it were a red super-giant it would have to be obscured by a factor of 10^{14} not to be observable in the visual region. Kleinman and Low have discovered that at 22 microns there exists an infrared nebula close to this object.

In the centre of the Galaxy centred around the same position as the radio source Sagittarius-A, an extended source of infrared radiation has been discovered. There is a striking similarity in the profiles of infrared radiation between the nucleus of The Galaxy and that of the Andromeda galaxy M 31 (Fig. 4). From this similarity in profiles it has been deduced that the infrared radiation in our galaxy is produced by millions of stars which are densely packed in a region a few parsecs in diameter. In that case the density of the stars would be a million times more at the central regions of the galaxy compared to the density in the neighbourhood of the sun, and the average distance 200 times smaller.

It has been found that the brightest quasar 3C 273 and quite a few other quasars also have bulk of their energy radiated in the infrared. The Seyfert galaxy NGC 1068 and the Planetary Nebula NGC 7027 are also known to be infrared emitters. In all these cases, the origin of infrared radiation is recognised to be non-thermal but what is the non-thermal mechanism, is the big question.

Ultra-violet astronomy

It has been the convention to define the wavelength region between 3,000 Å and 300 Å as the ultra-violet region of the electromagnetic spectrum. The band between 900 and 2200 Å is absorbed by ozone produced around 50 km in the atmosphere. The radiation between 2200 and 900 Å is absorbed by molecular oxygen which is confined to regions below 100 km. Molecular nitrogen, atomic oxygen and atomic nitrogen absorb ultraviolet radiation of still shorter wavelength and hence observation of this part of the ultra-violet spectrum can be carried out only above altitudes of 240 km. It is clear therefore that ultra-violet astronomy is possible only using rockets and orbiting observatories.

The sun has been investigated extensively in the ultra-violet by means of sounding rockets and more recently by instruments carried on the OSO (Orbiting Solar Observatory) series of satellites launched since March, 1962. The OSO-4 which was launched in October 1967 carried an ultra-violet spectro-heliograph designed and constructed by the Harvard College Observatory. This instrument records the spectrum of radiation in the wavelength range 300 - 1400 Å . A special feature of the spectro-heliograph is the ability to produce monochromatic solar images at all wavelengths in this spectral range. The figure 5 shows details of the ultra-violet spectroheliograph and the figure 6 the solar spectrum in the ultra-violet range 300 - 1400 Å obtained with this instrument. The variety of ionic species that contribute to the ultra-violet emission is clearly seen from the spectrograph. The photosphere of the sun is at a temperature of 6000°K. The temperature drops to about 4500° at the top of the photosphere and remains constant for a few 100 kilometers and then begins to rise in the chromosphere slowly first and then suddenly from 50,000° to 500,000° K in a distance less than a few hundred kilometers, and then it rises more slowly to a temperature of 2 million degrees. The figure 7 shows the temperature at which various emission lines occur and also the height above the solar surface at which these temperatures are encountered.

Considerable knowledge has been obtained in the ultra-violet in the case of the sun with small aperture telescopes not more than an inch in diameter and pointing accuracy of 1 minute of arc. However, in the case of stars, the requirements are much more stringent. Telescopes of at least 10" diameter are required and the pointing accuracy has to be better than a few seconds of arc.

The Russians carried out ultra-violet measurements in Cosmos 51 and Venus 53. Spectra in the ultra-violet regions were obtained by small hand-held telescopes in the wavelength region 2300 to 4000 Å by astronauts in Gemini 10, 11 and 12. The Orbiting Astronomical Observatory (OAO-II) launched in December, 1968 is carrying 11 small telescopes, four of them belonging to the Smithsonian Astronomical Observatory and seven to the University of Wisconsin. The Wisconsin system of 7 telescopes feeding different forms of photometers allows broad-band measurements - 1100 to 3000 Å. The Smithsonian

Celescope consists of 4 telescopes feeding Uvicon image tubes and is designed to map the sky in four wavelengths centred around 1350, 1500, 2250 and 2650 Å.

The Figure 8 shows the importance of the study of the ultra-violet radiation spectrum in the case of high temperature sources. In the case of a star having a temperature of 25,000° much of the spectral information will be in the ultra-violet. If one tries to construct the details of the object from the spectrum in the visible region alone, it will be like constructing the profile of the Himalayas by observing the hill ranges, say somewhere in Assam, having missed Mount Everest!

The important results that have emerged out of the investigations with the UV telescope in the OAO-II may be summarised as follows:

1) About 1% of the sources observed so far have intensities 6-40 times more in the ultra-violet than what had been expected.

2) The stars in the constellation of Pleiades believed to be a collection of young stars and therefore particularly bright in UV are brighter than expected by a factor of 3 to 6.

3) The scan in the wavelength region 1000 - 1400 Å of the star Alpha-Virginis (Spica) is shown in the figure 9. The Lyman alpha-line of hydrogen is seen in absorption due to interstellar hydrogen. Absorption lines due to Carbon III, Silicon III and Carbon II are clearly seen. The average density of hydrogen deduced from the Lyman-alpha absorption comes out to 1 per cc. which is 10 times higher than what has been found in the direction of the constellation of Orion and Puppis, by Morton and Jenkins.

The figure 10 shows the absolute energy radiated by the nucleus of the great spiral galaxy in Andromeda between 2000 and 4000 Å. Observations beyond 3300 Å have been obtained from the ground. The ground based observations in the visible region suggested that the Andromeda galaxy consists of core stars having temperature between 4000 and 5000°K. Ultra-violet observations clearly show the presence of hotter stars in considerable number.

OAO-III and OAO-IV will carry 36" telescopes and an associated spectro-heliograph. This would enable the determination of the line spectra in ultra-violet. The manned satellite, ATM (Apollo Telescope Mount) is expected to carry a visible light coronograph, x-ray telescopes, a vacuum UV spectrograph, EUV photographic and photo-electric imaging systems and H-alpha filter telescopes. The astronaut will guide the telescope which will have a resolution of 5 seconds of arc.

X-ray Astronomy

Two Review Talks are scheduled to be given on this subject in the special session. So I shall confine myself only to the most important results for the benefit of those who will not be attending the special session.

About 40 discrete x-ray sources have been detected so far by rocket experiments and out of these it has been possible to study at balloon altitudes 8 sources. The celestial distribution of these sources is shown in Figure 11. It is clear that the sources are concentrated along the galactic plane. Only one extragalactic source M 87 has been established with reasonable confidence so far. Among the x-ray objects that have been identified with other objects we may mention Sco X-1 which has been identified with a variable blue star having properties similar to an old nova, Tau X-1 which is identified with the Crab nebula and Tycho X-1 which is identified with the Tycho supernova. Variability in intensity and spectral size has been established for three sources Sco X-1, Cyg X-1 and Cen X-2. Variation of Sco X-1 intensity by a factor of 2-3 in time intervals of less than an hour has been reported (Fig. 12) both in balloon and satellite experiments. The birth of a new source in Sagittarius (GX 333+25) between 6th and 9th of July, 1969 was reported by the observations with the Vela satellite (Fig. 13). Subsequently, this source has been picked up in a rocket experiment of the Tokyo group on 9th August. The preliminary results indicate that the intensity of this source which was comparable to that of Sco X-1 with the Vela satellite has come down by a factor of 2 when observed a month later in the rocket experiment.

Measurement on diffuse background spectrum has been extended to lower energies upto 0.25 keV and a pronounced anisotropy has been seen as a function of galactic latitude. However, the latitude variation is much smaller than expected (Fig. 14). An interpretation is given in terms of an isotropic component which is extremely local (terrestrial, solar or galactic) and an extragalactic component.

Gamma-ray Astronomy

Several mechanisms responsible for the production of high energy gamma-ray (greater than 50 MeV) have been recognised for a long time and attempts have been made to estimate the flux of such gamma rays on the basis of known parameters. Decay of neutral pions produced in the cosmic ray particles with interstellar gas, collisions of cosmic ray electrons with optical photons - Inverse Compton effect -, bremsstrahlung of cosmic ray electrons are some of the recognised processes. Also the possibility of discrete gamma ray sources has been suggested, especially the supernova remnants.

All attempts at detecting cosmic gamma rays had failed till recently. Only upper limits were set on the flux of both the background cosmic gamma radiation and on the flux from discrete sources. The Explorer 11 experiment for cosmic gamma rays by Kraushaar, Clark and Garmire set an upper limit of 3×10^{-4} photons/cm^2.sec.st. for gamma rays with energy greater than 100 MeV. While interval evidence favoured the interpretation that the flux is due to cosmic gamma rays, the lack of anisotropy made the interpretation rather inconclusive. Some of the balloon measurements had given a limit almost a factor of 10 higher. The Explorer 11 experiment had not succeeded in detecting any discrete gamma ray sources. Upper limits had been set for various objects of interest.

In 1968 Clark, Garmire and Kraushaar succeeded in detecting high energy gamma rays with a gamma ray detector on board OSO-3 satellite. Convincing evidence that the flux is indeed of cosmic origin came from the observed anisotropy. The experimental results of Clark et al are shown in Fig. 15. The increase of counting rate as the detectors scan the galactic equator is unmistakable. The variation with galactic longitude with intensity having a maximum at the galactic centre is also indicated. Analysis of a larger sample of data from OSO-3 satellite presented at the Rome Symposium on Non-Solar X-ray and Gamma-rays (unpublished) reveal the anisotropy unambiguously. If the excess flux of gamma rays is interpreted as due to a line source coincident with the galactic plane, then the intensity of gamma rays of energy greater than 100 MeV comes out to be 3×10^{-4} photons/cm^2.sec.radian. An apparent isotropic background intensity of $(1.1 \pm 0.2) \times 10^{-4}$/cm^2.sec.st. has been deduced. The identification of this background intensity as due to gamma rays of cosmic origin, however, is not on firm grounds still.

Hutchinson and his collaborators with their gamma ray telescope incorporating a spark chamber on board the space-craft OGO-5 have scanned the sky in the neighbourhood of Cygnus and find quite a pronounced variation of intensity (25 to 100 MeV) with galactic latitude showing a maximum in the galactic plane.

Evidence for a point gamma-ray source ($>$50 MeV) in Sagittarius has been recently reported by the collaboration groups Case Western Reserve University and R.A.A.F. Academy, University of Melbourne based on two balloon flights carried out in Parkes, Australia in February 1969. The detector system was a multiplate spark chamber triggered by scintillators and directional Cerenkov counters. The preliminary coordinates of Sagittarius γ- 1 are $\alpha = 288 \pm 3^\circ$, $\delta = -35 \pm 2^\circ$ and galactic coordinates $l^{II} = 3^\circ$, $b^{II} = 2^\circ$. The intensity of gamma rays $>$ 50 MeV from this source is given as $3 \pm 1 \times 10^{-5}$ photons/cm^2.sec.

In the same flights they looked for the line source along the galactic plane reported by Clark et al. This region passed almost overhead in both their flights. The surprising result is that they see no enhancement in this direction when they analyse the data with the angular resolution of 2.3°. The observed number of events in $\pm 2.3^\circ$ around the galactic plane is 861 and the average over the rest of the area is 833 ± 9.5 yielding an excess of 28 ± 31 events. The corresponding 95% upper limit to the line intensity is 3×10^{-5} photons/cm^2.sec.rad. which is a factor 10 lower than that given by Clark et al. Part of this discrepancy can however be removed if the source is not a line source but is a broad one having a half width of 15°. Even then discrepancy by a factor of 4 remains.

Pulsar Astronomy

The most sensational discovery in astronomy in the last few years is the discovery of the pulsating radio stars which have come to be known as 'Pulsars', the distinctive feature of these objects being the extreme regularity (one part in 10^8) of the pulsations. The discovery of the first pulsar CP 1919 was reported by the Cambridge astronomers in February, 1968. Since then, 41 pulsars have been discovered by astronomers working in different radio observatories in the world. The number of theoretical papers discussing the emission mechanism of the regularly spaced train of pulses and other features of these objects has probably crossed the century mark and still there is no satisfactory theory. In this context, 'the neutron stars' have come into the forefront as will be discussed in the following talk.

The table taken from the paper of J.H. Taylor (Astrophysics Letters, 3, 205, 1969) and also from the recent observations of Large et al (M.I. Large, A.E. Vaughan and R. Wielebinsky, Nature, 220, 1249, 1969) summarises the observational results on the 41 pulsars detected so far. The first column gives the nomenclature of the source, the second and third the celestial coordinates - right ascension and declination, the fourth column gives the periodicity observed, the fifth gives the pulse width and the last column the columnar density along the line of sight from the observer to the pulsar, given in units of cm^{-3} pc, obtained from dispersion measurements.

In Fig. 17 is given a plot of the distribution of the 41 pulsars in celestial coordinates and the figure 18 gives the distribution of the periodicities and the distribution of the dispersion measure.

The Crab Nebula which has been the astronomers' paradise is very much in the news again - it is a Pulsar too. The central star - Minkowski star - has been identified as the pulsating object NP 0531 in the Crab Nebula. This object has the shortest pulsating period of all the pulsars observed so far. The period is 0.033094515 second. Another pulsar, NP 0526, has been discovered very close to the Crab Nebula and probably associated with it in some way, and this pulsar has the longest periodicity, the period being 3.745491 seconds. The Crab pulsar NP 0531 has been observed to be pulsating not only in radio but also in optical and x-ray regions. Simultaneous observations have been made in the x-ray and optical regions (Fig. 19) and it has been established that the times of arrival of x-ray and optical pulsars are in agreement within the accuracy of a millisecond. The Crab Nebula pulsar exhibits also the phenomenon of inter-pulsations. There is a second pulse which is separated from the first one by 14.5 milliseconds. It has been found that the second pulse becomes more and more pronounced at higher energies. In the visible region the relative signal strength of the second to the first pulses is 0.6 : 1, while at keV energies it is 1 : 1 and at energies $>$ 25 keV it is 1.7 : 1. The Crab pulsar has been found to slow down at the rate of one part in 2400 per year. Subsequently many other pulsars have also been found to slow down. From the rate of slowing down it is estimated that NP 0532 is losing rotational energy at 2×10^{38} ergs/sec - which is roughly the amount of energy needed to keep the Crab going.

Finally, a word about theory. It is clear that many new ingredients - proto stars, neutron stars, x-ray stars, pulsars, Ammonia molecules, Formaldehyde molecules, water molecules and 3^{o} background radiation, possibly magnetic fields of 10^{14} gauss, temperatures of hundreds of millions of degrees have been added to the kitchen of the theoretical astrophysicists. Let us hope that they are able to come out with some really good cooking.

The following articles in Scientific American have been very valuable in preparing this Review Talk, especially some of the figures.

(1) 'The Infrared Sky' by G. Neugebauer and R.B. Leighton, Scientific American, August, 1968.

(2) 'Pulsars' by Antony Hewish, Scientific American, October, 1968.

(3) 'Radio Signals from Hydroxyl Radicals' by Allan H. Barret, Scientific American, December, 1968.

(4) 'Ultraviolet Astronomy' by Leo Goldberg, Scientific American, June, 1969.

TABLE

Physical properties of Pulsars

Source		Right Ascension (1950.0)				Declination (1950.0)				Period (sec)		Pulse width (msec)	Dispersion Measure (cm^{-3} pc)	
		h	m	s		o	'	"						
MP	0254-54	02	54	24		-54			±2°	0.448	±0.003	10	10	± 5
MP	0031-07	00	31	37	±1s	-07			±1°	0.940	± 4	25	12	± 5
CP	0329+54	03	29	07	±10	54	23		±6'	0.714518603	± 1 b	6	26.75	± 0.05
MP	0450-18	04	50	22	±2	-18			±1°	0.548	± 5	20	25	± 10
NP	0526+21	05	26	10	±40	21	58		±9'	3.745491	± 1	200	51.1	± 0.5
NP	0531+21	05	31	31.46		21	58	55		0.033094515	± 3	3	56.9	± 0.2
PSR	0628-28	06	28	53	±1	-28	33		±1'	1.244	± 1	50	10	± 5
MP	0736-40	07	36	51	±1	-40			±2°	0.375	± 2	40	100	± 10
CP	0808+74	08	08	58	±6	74	38	10	±25"	1.292241325	± 3 b	45	5.77	± 0.03
AP	0823+26	08	23	52	±10	26	48		±5'	0.53062	± 5	20	19.2	
PSR	0833-45	08	33	39	±1	-45	00	05	±15"	0.089208370	± 4	2	63	
CP	0834+06	08	34	26.6	±0.5	06	19	13	±30"	1.273763151	b	35	12.8	
MP	0835-40	08	35	34	±1	-40			±2°	0.765	± 5	20	120	± 12
PSR	0904+77	09	04		±600	77	40		±50'	1.57905	± 6	80		
MP	0940-56	09	40	40	±3	-56			±2°	0.662	± 3	30	145	± 15
PP	0943+08	09	43			08				1.09			17	

contd...

TABLE (contd.)

Source		Right Ascension (1950.0)				Declination (1950.0)				Period (sec.)		Pulse width (msec)	Dispersion Measure (cm^{-3} pc)	
		h	m	s		°	'	"						
CP	0950+08	09	50	30.76	±0.15	08	09	48	±5"	0.253065037	b	13	2.94	
MP	0959-56	09	59	51	±3	-56			±2°	1.438	± 3	50	90	± 10
CP	1133+16	11	33	26.90	±0.15	16	07	35	±15"	1.187910980	b	38	4.87	
MP	1154-62	11	54	45		-62			±2°	0.400	±0.005		270	± 35
AP	1237+25	12	37	17	±10	25	09	30	±4'	1.3824	± 1	60	8.5	± 0.9
MP	1240-64	12	40	20	±6	-64			±2°	0.388	± 4	60	220	± 20
MP	1426-66	14	26	35	±9	-66			±2°	0.788	± 2	10	60	± 6
MP	1449-65	14	49	22	±3	-65			±1°	0.180	± 2	5	90	± 10
PSR	1451-68	14	51	29	±1	-68	32		±1'	0.264	± 2	25	12	± 5
HP	1507+55	15	07	50	±20	55	41		±6'	0.739677616	± 2 b	13	19.60	± 0.08
MP	1530-53	15	30	23	±2	-53			±1°	1.372	± 2	25	20	± 5
AP	1541+09	15	41	10	±15	09	38		±5'	0.74839	± 5	50	35.0	± 0.5
PSR	1642-03	16	42	25	±2	-03	00		±20'	0.38765	± 3	5	40	± 5
MP	1706-15	17	06	35		-15			±2°	0.65	±0.005	20	10	± 5
MP	1727-50	17	27	50	±4	-50			±2°	0.835	± 3	30	140	± 20
MP	1747-48	17	47	56	±5	-48			±2°	0.742	± 3	20	40	± 10
PSR	1749-28	17	49	48.8	±0.3	-28	05	57	±8"	0.5625533	± 2 b	20	50.88	± 0.14

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TABLE (Contd.)

Source	Right Ascension (1950.0)				Declination (1950.0)				Period (sec.)		Pulse width (msec)	Dispersion Measure (cm^{-3} pc)	
	h	m	s		°	'	"						
MP 1818-05	18	18	14	±2	-05			±2°	0.597	± 5	20	70	± 10
MP 1911-05	19	11	15		- 5			±0.5°	0.825	±0.005	20	75	± 20
CP 1919+21	19	19	37.0	±0.2	21	47	14	±15"	1.337301109	b	32	12.55	± 0.06
PSR 1929+10	19	29	52	±1	10	52	49	±15"	0.226576	± 1	10	8	± 4
JP 1933+16	19	33	10	±20	16	06		±7'	0.358764	± 2	6	143	± 13
AP 2015+28	20	15	58	±10	28	31		±5'	0.557954	± 3	10	14.20	± 0.02
PSR 2045-16	20	45	47.6	±0.4	-16	27	50	±12"	1.9615639	± 7 b	40	11.40	± 0.25
PSR 2218+47	22	18	18	±60	47	30		±30'	0.538461	± 8	30	43.8	± 0.2

Figure Captions

Fig. 1 : Absorption of electromagnetic waves of different wavelength in the atmosphere. The upper boundary of the shaded areas specifies the altitude at which the intensity is reduced to half its original value. From the figure it is clear why ultraviolet x-ray and gamma ray astronomy can only be carried out from high altitudes. The extreme windows in the visible and the infrared region and the broad radio window are also seen in the figure.

Fig. 2 : Distribution of the visible (open circles) and the infrared (black dots) stars in the sky plotted in celestial coordinates (right ascension and declination). From the bottom figure the concentration of bright infrared stars along the galactic plane, especially towards the galactic centre, is clear.

Fig. 3 : The spectrum of the T. Tauri star R. Monocerotis compared with the spectrum of Sun. The spectrum of R. Monocerotis has a peak in the infrared at 4 microns corresponding to a black body temperature of 750°K. On the left can be seen the infrared object which looks like the head of a diving bird.

Fig. 4 : A comparison of the infrared intensity profiles (intensity vs.distance from the centre) of the Andromeda galaxy M 31 and the nucleus of our own galaxy. From the similarity of the profiles it has been deduced that the density of stars in the nucleus of our galaxy is a million times more than the density in the solar neighbourhood.

Fig. 5 : A sketch of the spectro-heliograph aboard OSO-IV. By rotating the grating to various positions any narrow band of ultraviolet between 300 and 1400 Å can be selected for analysis. The instrument scans the sun in a raster fashion as shown in the right.

Fig. 6 : The solar spectrum between 300 and 1400 Å recorded from the centre of the solar disk by the Harvard spectro-heliograph on OSO-IV.

Fig. 7 : Temperature of the sun's atmosphere as a function of height above the solar surface. Temperatures are inferred from the spectral lines of various ions shown in the figure.

Fig. 8 : Comparison of the spectral energy distribution (theoretical) of two stars, one at a temperature of 25,000°K and the other at 6000°K to show the importance of studies in the ultraviolet. The short drop in intensity at about 900 Å is due to the absorption of ultraviolet in the stellar atmosphere, due to atomic hydrogen.

Fig. 9 : Ultraviolet spectrum of Alpha-Virginis made by the University of Wisconsin telescope on OAO-II. Four absorption lines are produced by Carbon and Silicon ions in the star's atmosphere. Hydrogen in the interstellar space produced the Lyman-absorption.

Fig. 10 : The spectrum of the Andromeda galaxy in the visible and ultraviolet. The ultraviolet spectrum has been obtained by the University of Wisconsin telescope on OAO-II. The rise in

: the U.V. flux was unexpected and implies that the nucleus of the Andromeda galaxy probably contains more hot stars than had been deduced from ground observations in the visible.

Fig. 11 : Celestial distribution of x-ray sources plotted in celestial coordinates (right ascension and declination). The concentration of x-ray sources along the galactic plane is evident. Only one extragalactic source M 87 in Virgo has been definitely identified so far.

Fig. 12 : The spectrum of Sco X-1 in the energy range 1-100 keV. The wide spread in the experimental value is indicative of long time variations in the intensity of Sco X-1. Occasional short duration flares have also been recorded (Lewin et al, Ap.J., 152, L49, 1968; Agrawal et al, Nature, 224, 51, 1969).

Fig. 13 : Observed variations in the counting rate of the new X-ray source GX 333+25 in the energy range 3-12 keV between July 9, and July 23, 1969 as recorded with the x-ray telescopes on the Vela satellite which also recorded the birth of this new source to have occurred between 6th and 9th July, 1969.

Fig. 14 : Depicts the absorption features of very soft x-rays obtained from a study of intensity variation as a function of galactic latitude. n_H represents the number of hydrogen atoms along the line of sight corresponding to the galactic latitude as deduced from 21 cm radio observations. The solid line represents the theoretically expected absorption for an isotropic distribution of soft x-rays. The observed flattening has been

: explained in terms of a two component hypothesis - an isotropic component which is extremely local (terrestrial, solar or galactic) and an extragalactic component (M. Oda, paper presented at the IAU Symposium on Non-solar X-ray and Gamma-ray Astronomy, May 1969).

Fig. 15 : Top: Variation of the rate of celestial events with galactic latitude summed over longitude. The dashed line shows the expected response to a line source.

Bottom: Variation with galactic longitude of the rate of celestial events recorded with the detector at a galactic latitude between -15° and $+15^\circ$. Dashed line indicates the average attributable to the isotropic background (G.W. Clark, G.P. Gorenstein and W.L. Kraushaar, Ap.J. 153, L203, 1968).

Fig. 16 : Train of regularly spaced pulses recorded from the Pulsar CP 0808. The spacing between adjacent pulses is 1.29224126 seconds. The duration of each pulse is about 100 milliseconds.

Fig. 17 : Celestial distribution of 41 known pulsars plotted in celestial coordinates (right ascension and declination). A tendency for concentration along the galactic plane is seen. However, there are quite a few pulsars which are off the galactic plane as well.

Fig. 18 : Distribution of the periodicities and the distribution of the dispersion measure (columnar density) of the known 41 pulsars. A preference for pulsars with lower periodicities is discernible. The preference for lower columnar densities may be an observational bias.

Fig. 19 : A comparison of the optical and x-ray pulsations of the Crab pulsar NP 0532. It is seen that the second pulse is more prominent at x-ray energies compared to optical observations (H. Bradt, W. Mayer, R.E. Nather, B. Warner, M. Macferlane, J. Kristian, Nature, 222, 728, 1969.).

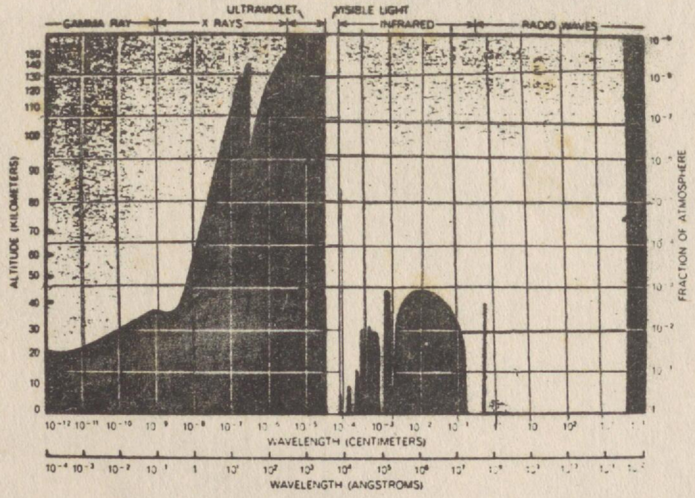


Fig. 1

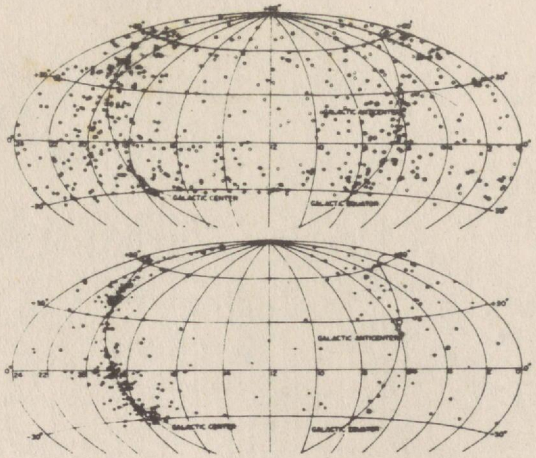


Fig. 2

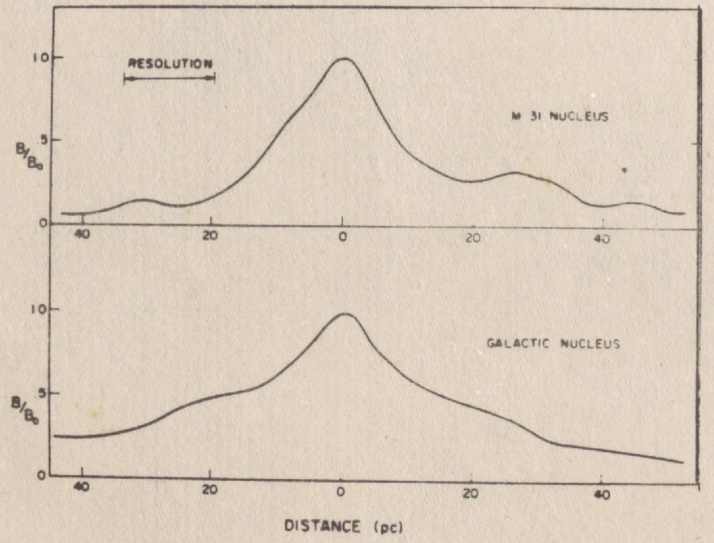


Fig. 4

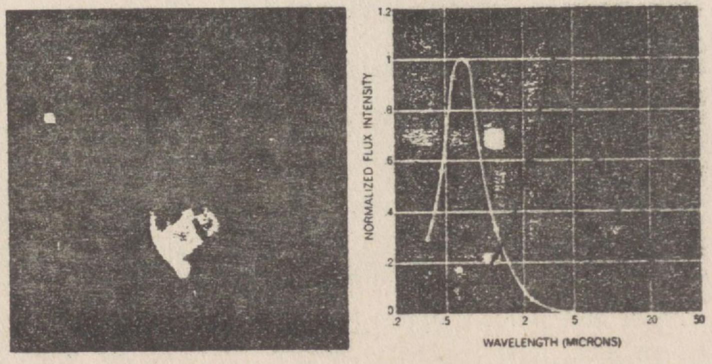
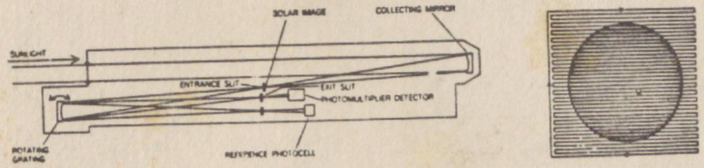


Fig. 3



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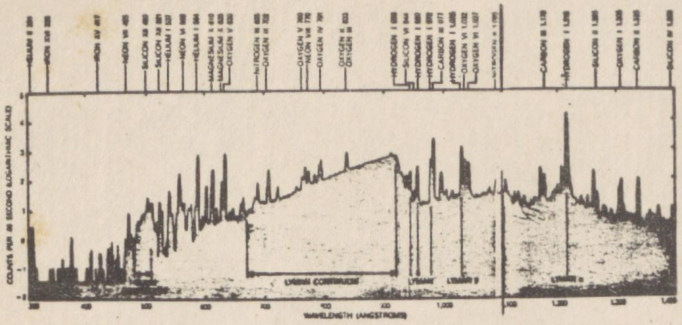
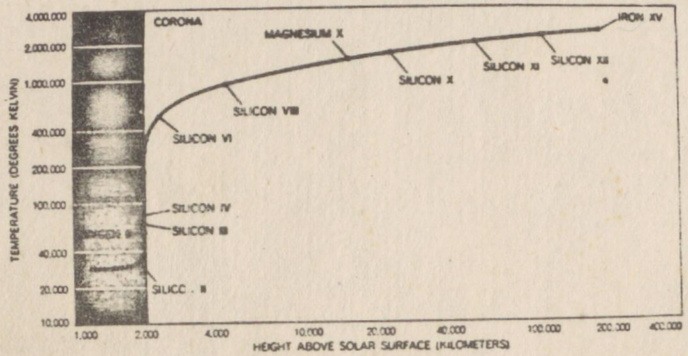


Fig. 6



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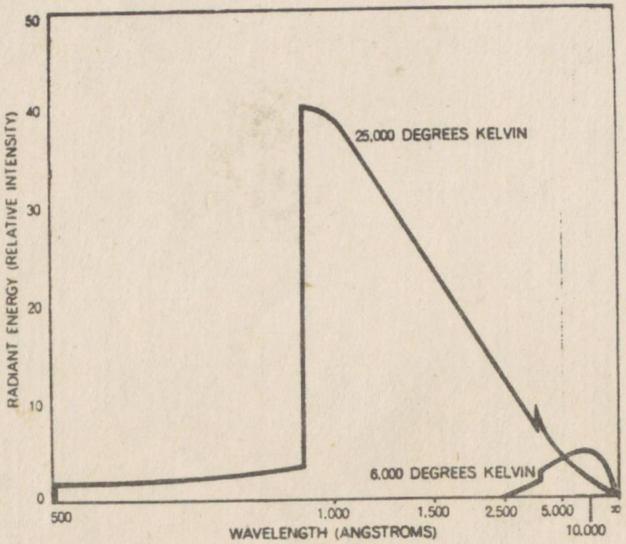


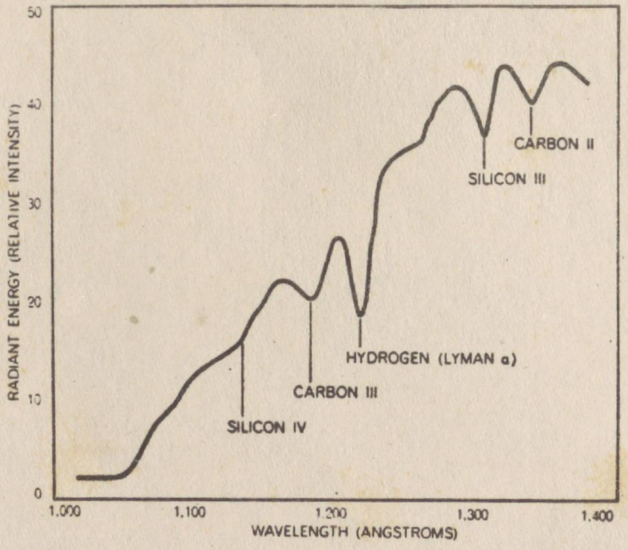


Fig. 9

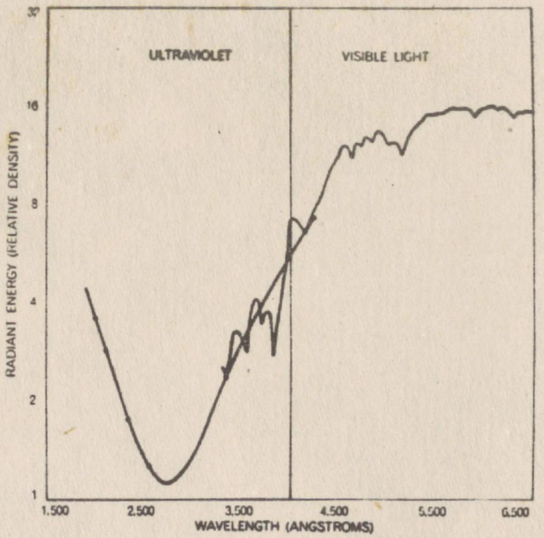


Fig. 10

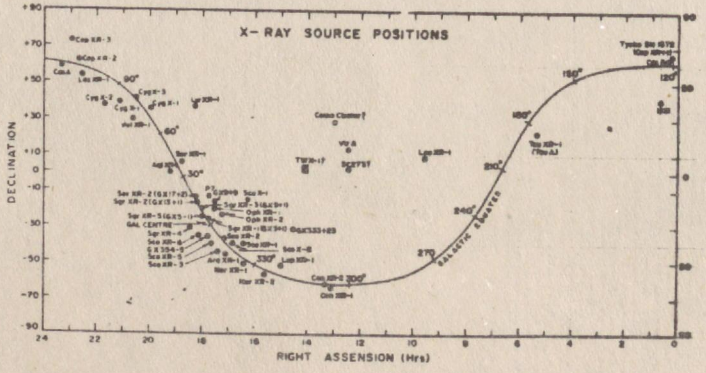
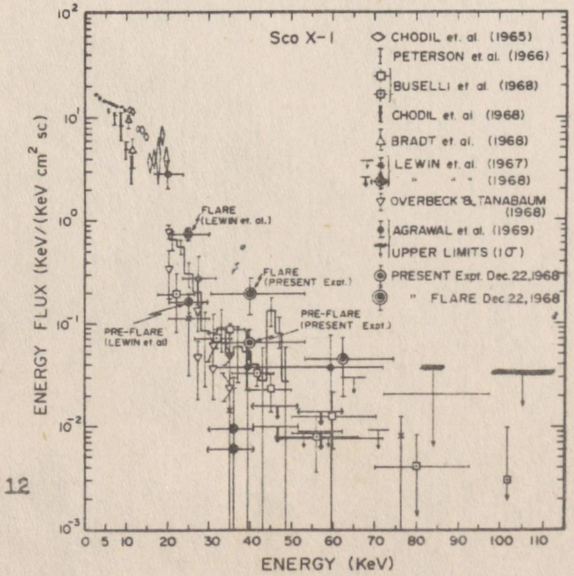


Fig. 11

Fig. 12



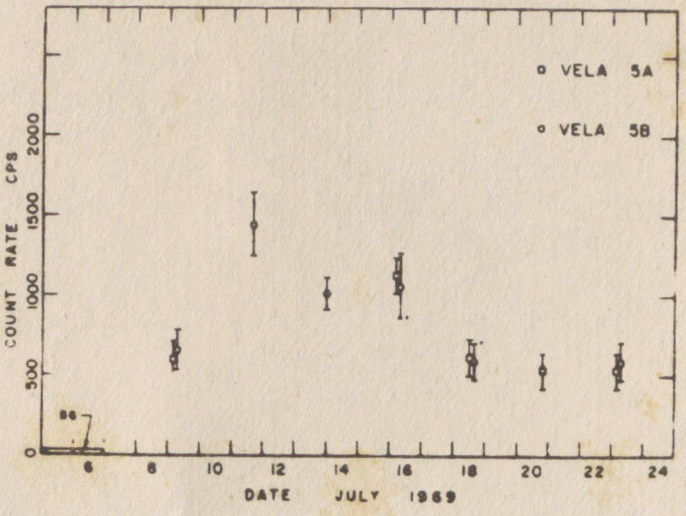


Fig. 13

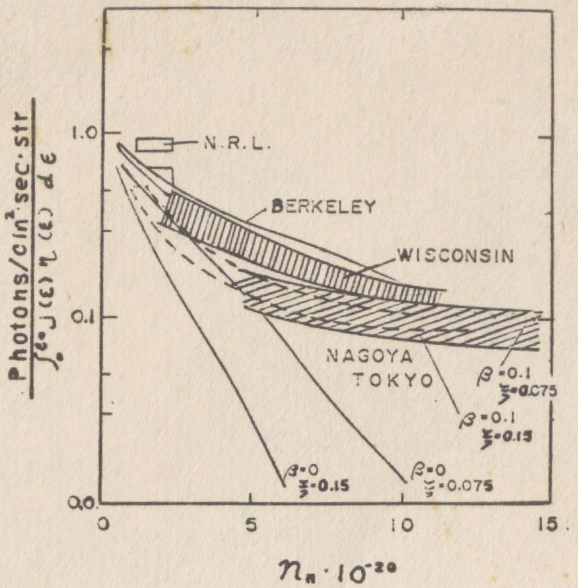


Fig. 14

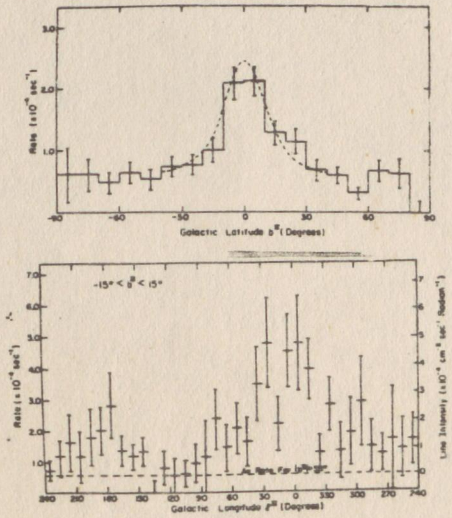


Fig. 15

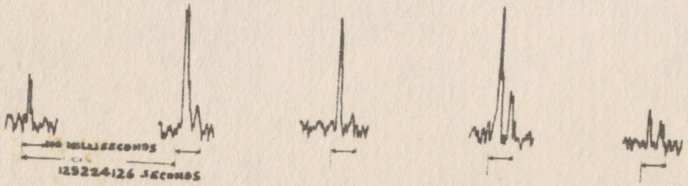
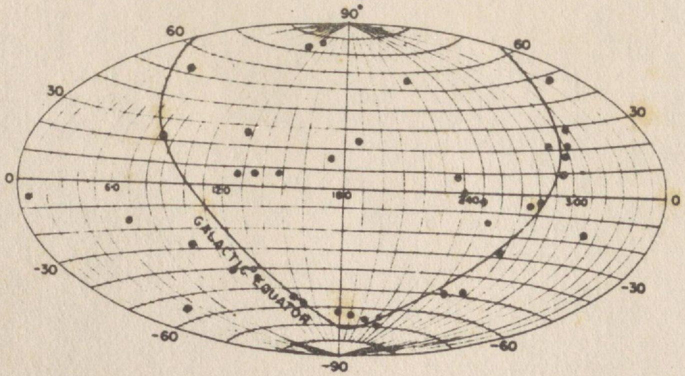


Fig. 16



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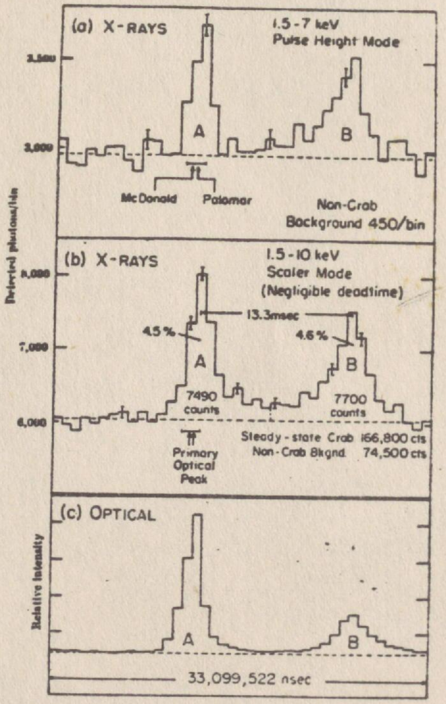

Fig. 19

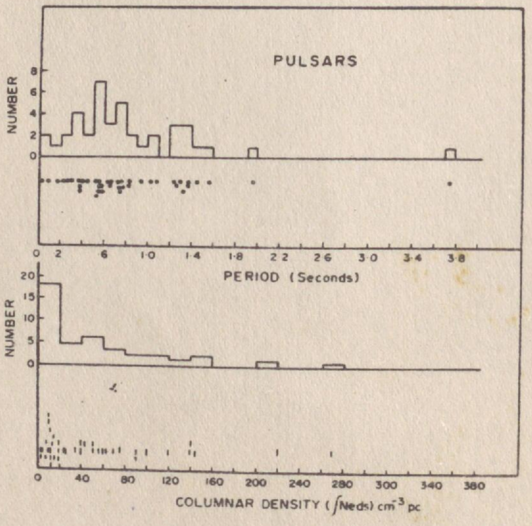

Fig. 18