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SOME DEVELOPMENTS IN OPTICAL TELESCOPE INSTRUMENTATION AND DATA REDUCTION SYSTEMS IN JAPAN

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ABSTRACT. In recent times, japanese astronomical instrumentation have been developed in radio and X-ray wavelength ranges, namely the 45-m mm radio telescope and the X-ray satellites, Hakucho, Hinotori, and Tenma, respectively. At optical wavelength, many efforts in developments of telescope instrumentations and data reduction systems are continued. At present, it is very considered the 7.5-m alt-azimuth telescope to be installed on Mauna Kea, Hawaii. In this paper, we will review our efforts on the following topics, although there are many other topics under studying: 1) design work on the 7.5-m telescope, 2) experiments of honeycomb mirror production, 3) development of accurate and high sensitivity detectors, 4) study of analysis system for speckle interferometric observations, and 5) development of two dimensional image processing system.

Key words: OBSERVATORIES — TELESCOPES

I. A SHORT REVIEW OF OBSERVATIONAL DEVELOPMENTS AT NON-OPTICAL WAVELENGTHS

Astronomical observations in Japan are carried out at all the wavelength ranges from radio through optical to gamma-ray. Scientific projects using such space probes as balloons, rockets, and satellites are mainly promoted by the Institute of Space and Astronautical Sciences (ISAS). This institute is organized as a national institution where all the scientists belonging to the other institutes have a right to work jointly and to obtain different kinds of support for their space projects. The ISAS became a national institute from an institution dependent on the University of Tokyo, in April 1982.

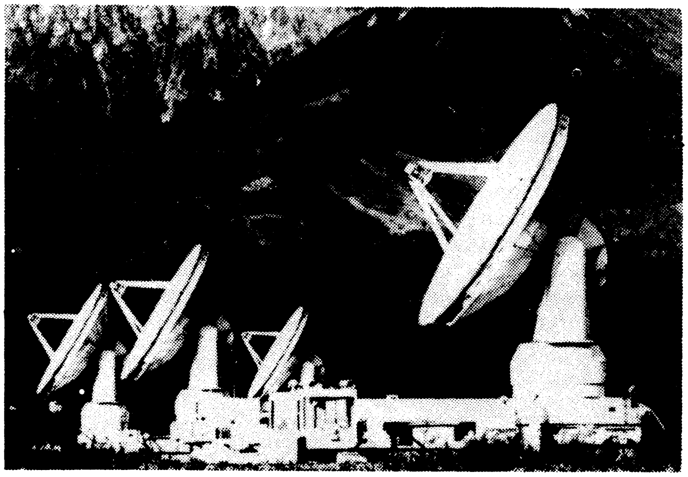
The X-ray satellites launched are Hinotori for solar observations, and Hakucho and Tenma (Kondo *et al.* 1981; Tanaka *et al.* 1984) for cosmic observations; many new data were obtained relating to X-ray bursters and the others (Hayakawa 1981; a special volumen of Publ. Astron. Soc. Japan, Vol. 36, No. 4, 1984, for X-ray astronomy satellite Tenma). The future projects scheduled are ASTRO-C in February 1987, and ASTRO-D about 1993 for cosmic observations and the SOLAR in 1991 during the next phase of the solar maximum for solar observations. Although all the satellites do not weigh more than 500 kg and are very small compared with those by USA and ESA, successive launchings of the satellites without long years of interruption, make the observations effective (Oda 1986).

X-ray observations were started in 1965 using rockets (Hayakawa *et al.* 1966). At present, rockets contribute mostly to ultraviolet and infrared observations for which no satellites have been launched. There is no hope to have a satellite for ultraviolet observations in this century, although efforts to observe ultraviolet objects are continued (Tanaka *et al.* 1984).

At infrared wavelengths, there was an IRTS (infrared telescope in space) project to launch an infrared telescope with a primary mirror 40-cm diameter, by means of the space shuttle, but possibilities to work with the SIRTF at NASA are being pursued (Okuda *et al.* 1986). Infrared observations by rockets are being carried out and one of the recent results is a detection of diffuse infrared light originated probably from the population III stars (Matsumoto *et al.* 1983). Many balloons for infrared observations have been launched by the ISAS in Japan, China, and Australia, and these make long hour flights possible. Many data relating to the galactic center region are obtained (Matsumoto *et al.* 1982; Hiromoro *et al.* 1984).

Ground-based observations are mainly promoted by the Tokyo Astronomical Observatory (TAO), which, at the moment, belongs to the University of Tokyo and is a university observatory. Since recent developments in astronomy require different, very large observational instruments and very large funds to advance these projects, it becomes very difficult for a single university observatories to promote the projects. It is now scheduled that the TAO will move into a national observatory similar system to the ISAS in April, 1988.

The TAO has a 45-m mm radio telescope, which is the best telescope in the world at around the wavelengths of 2-mm (Akabane 1983). An effort to refine a surface of its primary dish gives the total surface accuracy of 200 micron rms (Kaifu 1984). Then, it is now possible to have many fine astronomical results in star forming regions, galactic nucleus, and galaxies (Nobeyama Radio Observatory report No. 94, and in the Proceedings of the IAU Symposium No. 115). Angular resolution of the 45-m telescope at the wavelength of 2-mm is 15". To have a higher angular resolution, an interferometer which is composed of five 10-m dishes and a distorted T shaped configuration with the maximum baseline of 560-m has been developed and is now used for real observations (Figure 1). An example of their observations with an angular resolution of 5" at GHz is shown in Figure 2 (Ishiguro 1986).



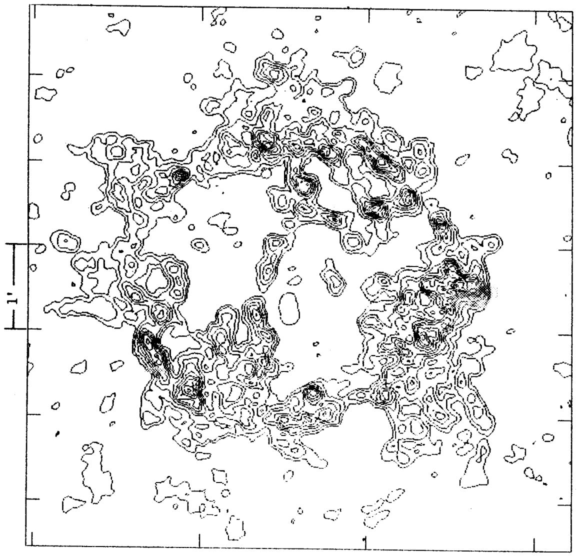


Fig. 1. Interferometer with 5 element 10-m dishes at the Nobeyama Radio Observatory used at mm wavelength.

Fig. 2. Intensity contour map of the supernova remnant Cas-A at 22 GHz. Fifty hours of observations and forty baselines were needed to synthesize the telescopes with a resolution of 5". This map is kindly supplied by M. Ishiguro.

Researches in the TAO, the ISAS, and the Radio Research Laboratory (RRL) in Japan, have been discussing the possibility of Japanese space VLBI programme and the working group has been established for the promotion of the programme. For launching the orbiting station, M3S-III rocket, the projected version of ISAS rocket is assumed (Tsuboi and Hirabayashi 1984; Nishimura *et al.* 1986). The researchers of the aforementioned institutes collaborated with the Jet Propulsion Laboratory (JPL) for the first space VLBI experiment using the TDRSS (Transmission and Data Relay Satellite System). Antennas used were 4.9-m antenna on-board the TDRS satellite, 64-m antenna at Tidbinbilla (NASA, Australia), 64-m antenna at Usuda (ISAS), 26-m antenna at Kashima (RRL) (Figure 3). Fringes were detected for celestial radio sources for the baselines TDRSS-ISAS and TDRSS-Tidbinbilla. The maximum baseline length obtained was about 1.4 times earth diameter and this was by TDRSS-ISAS baseline (Levy *et al.* 1986).

The 64-m radio antenna at the ISAS was built to receive radio signal from the Halley missions, Sakigake and Susei, which made successful observations. This antenna is now used for the space VLBI experiment and also for other astronomical observations. As we show on some examples here, we observe different types of astronomical objects at all wavelengths and have tight collaborative relations between two main astronomical institutes, TAO and ISAS.

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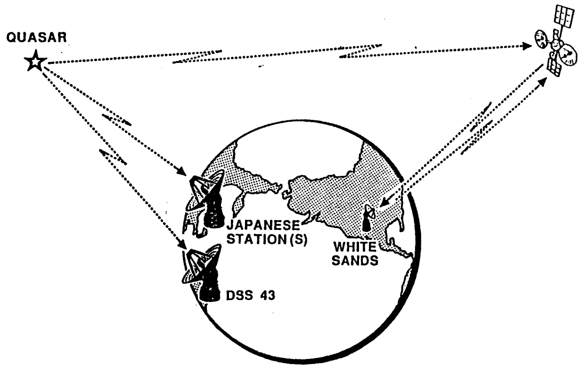


Fig. 3. A schematic drawing of the first space VLBI experiment.

II. A SHORT OVERVIEW IN DEVELOPMENT OF OPTICAL OBSERVATIONS

The largest optical telescope in Japan is a 1.9-m reflector built by the Grubb Parson Ltd. in 1960 at the Okayama Astrophysical Observatory. This telescope, (as well as two 91-cm reflectors built one and two years later), was built by the recommendation of the Japan Science Council and was the first one for real astrophysical observations. It was the 7th largest telescope in the world at the time of its completion. Therefore, the contribution of this telescope to Japanese astronomy was very rewarding both from the scientific and from the engineering points of view. In Figure 4, we will show an increase of number of papers in observational astronomy in the last 25 years (study by the JNLT working group at the TAO).

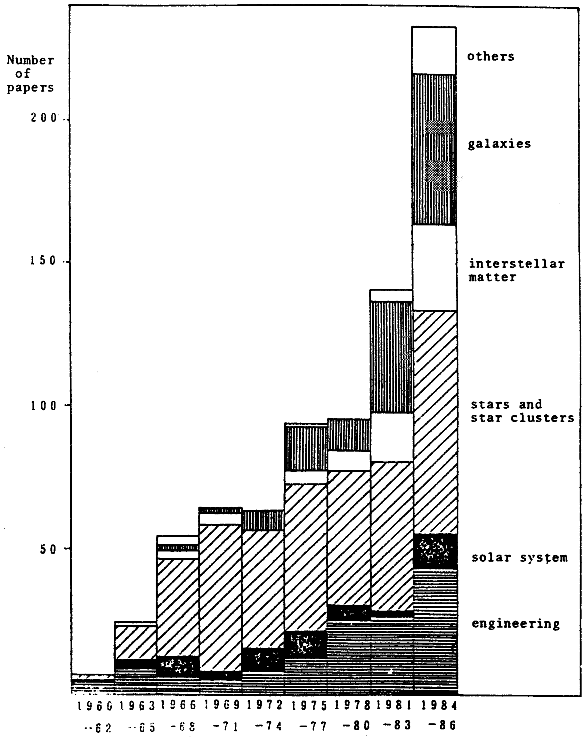


Fig. 4. An increase of number of papers published in each three year period relating to observational astronomy of different fields.

The telescope has the Newtonian, Cassegrain, and coude foci. At its first stage, photographic plates were mostly used as detectors. After 1970, electric devices as the Carnegie Image Intensifier tube, a multi-channel photoelectric photometer, a fourier spectrophotometer, and so on, started to be used.

In 1974, a 105-cm Schmidt telescope at the Kiso Observatory of the TAO was built. Since that, several survey projects are being carried out. For example, 3141 ultraviolet excess galaxies called as KUG have been detected and catalogued (Takase and Miyauchi-Isobe 1984,1985a, 1986a,b). The total number of observed plates until September 1986, is of 5126. To analyse these large number of plates, a system of quick image processing is under development as shown in section VIII.

Besides the TAO, the University of Kyoto has a 1-m telescope for ground-based infrared observations and a domeless solar telescope.

III. THE 7.5-m ALT-AZIMUTH TELESCOPE

After the completion of the 1.9-m telescope in 1960, there were little efforts to consider a future construction of larger optical telescopes by the leading astronomers in the Japanese astronomical community. The effort was started only after the completion of the 105-cm Schmidt telescope. In 1970's, there were rapid developments in electronic and mechanical engineering, and then a feasibility to be built new types of optical telescopes became high. Additionally, a claim for the larger telescopes became also very high because of developments in X-ray and radio observations. However, it was an unhappy situation that the leading astronomers at the time proposed to build a conventional type telescope with an aperture of 3.5-m, because of their lack in realization of two movements at the time shown above. Therefore, about 10 years were lost for us to object against their idea. In 1980, most of the optical and infrared astronomers formed an organization, Group of Optical and Infrared Astronomers, where problems of the future Japanese telescopes have been discussed. Finally, in July 1984, we got into an agreement to have a 7.5-m alt-azimuth telescope for our project. One can follow the discussions during these periods in the papers by Isobe *et al.* (1983); Isobe (1984); Kodaira *et al.* (1984), and Kodaira and Isobe (1986).

This telescope is called as the Japanese National Large Telescope (JNLT), which is given total approval from all the Japanese astronomical community. A systematic conceptual study of the JNLT was started in 1984 at the TAO working group. A report of the technical study in Japanese, which is available on request, was published in February 1986, and its short report in English was published by Kodaira and Isobe (1986). Some kind of preparatory budge of this project for the fiscal year of 1987 will be given to the TAO and the real construction is expected to start in 1989.

Some specifications of this telescope (Figure 5) approved by all the optical and infrared astronomers are:

1) The diameter of the primary mirror is 7.5-m.

2) A light weight primary mirror with single dish and an alt-azimuth mounting, are introduced to reduce its total cost.

3) It will be settled at Mauna Kea to have a good weather and seeing condition.

4) Its angular resolving power should reach to a level of 0.1".

5) Its field should be larger than 0.5° at any one of the foci.

6) A high infrared performance is demanded and infrared background radiation from telescope mechanical parts should be less than 0.08.

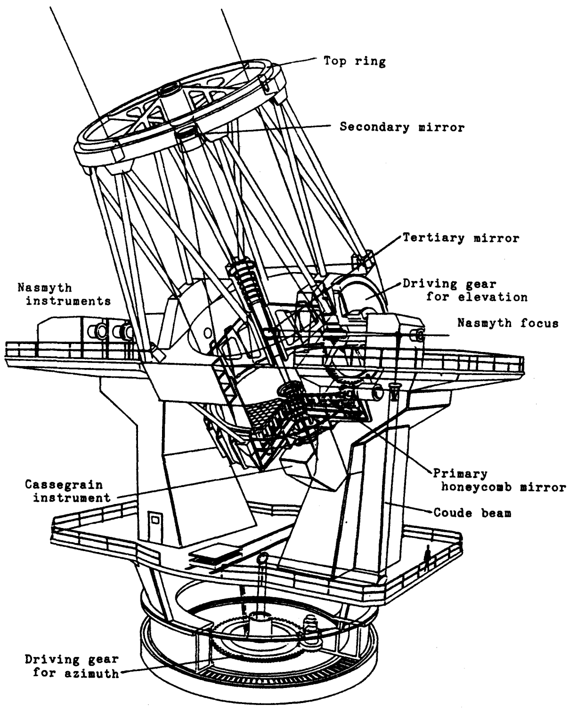
7) There are the primary, Cassegrain, and Nasmyth foci. A coude focus will be prepared to keep future interferometric observations with the neighboring telescope (probably the 10-m telescope built by the University of California at Mauna Kea).

8) A ratio of focal length to aperture of the primary mirror is 2.0.

We are trying to find a telescope system satisfying these specifications. Since Mauna Kea is very far from Japan, we intend to introduce a system of telemeter link in order to operate the telescope from Japan and to have data from the telescope (Figure 6). This telescope will have the best power in the world as shown in Figure 7, if the specifications are satisfied. Additionally to this power, we should also develop efficient detector systems, data reduction systems, and so on. These studies are carried out by the JNLT working group and also by some individual groups in Japan. Here, we will review some topics which our group is working on.

IV. THE 75-cm ALT-AZIMUTH TELESCOPE

The increase of telescope aperture results in the weight of the telescope tube ex-



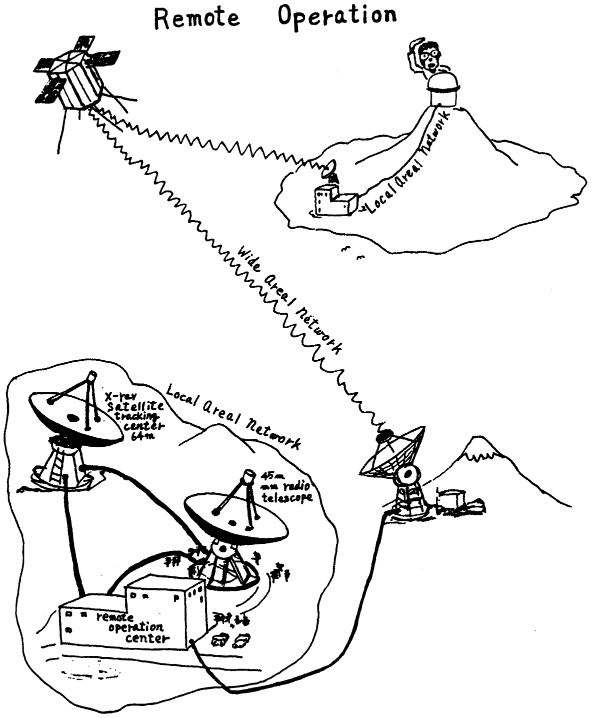


Fig. 5. A conceptual drawing of the 7.5-m telescope.

Fig. 6. A system of telemeter link considered between the JNLT site and the remote operation center in Japan.

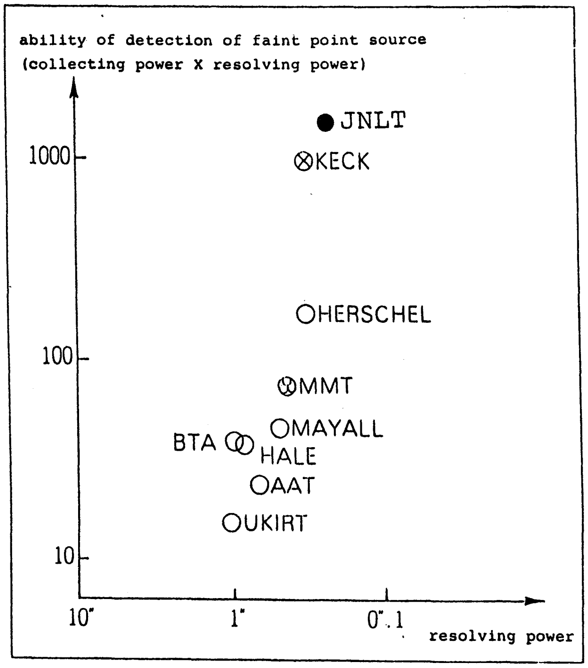


Fig. 7. A comparison of detection ability of faint point source for different telescopes.

ceeding 100 tons and therefore there is a big difficulty to support that weight by an equatorial mounting. Because of recent developments of computer, mechanical system, and electronics sensors, an alt-azimuth mounting becomes accesible to yield a good accuracy for telescope pointing and equatorial motion. The first modern alt-azimuth telescope was a 6-m telescope built in 1976 at Zerenzukskaya (Kopylov *et al.* 1984). The multiple mirror telescope (MMT) built in 1979 at Mt. Hopkins has an alt-azimuth mounting and a quasi-Cassegrain focus, but has not a system for field rotation (Beckers *et al.* 1981). Two 75-cm alt-azimuth telescopes were built in 1976 at the Heidelberg observatory and in 1983 at the Sundai Observatory at Kita-Karuizawa (SOK) (Isobe *et al.* 1984; Isobe *et al.* 1985). There are three other alt-azimuth telescopes, a 2.2-m telescope at the Siding Spring Observatory, a 4.2-m Herschel telescope at La Palma (Pope 1983), and a 2.5-m Nordic telescope. It is certain that most of the future large telescopes under consideration in the world will have an alt-azimuth mounting.

We have built a 75-cm telescope with alt-azimuth mounting (Figure 8) at the SOK to understand the difficulties in adopting this mounting. A computer control system is introduced to point the telescope to an observing field, to track the fixed field, and to rotate the observational instrument for compensation of field rotation during equatorial motion of the celestial object. Dome motion is also controlled by the computer. We have now accuracies of pointing and tracking motion less than 10" and 1"/minute, respectively, which are still being improved.

This telescope has a honeycomb structured mirror made by R. Angel at the University of Arizona, which is his test production and has no back plate. An introduction of this mirror makes its weight half compared to 120 kg for a conventional mirror and therefore the weight of the whole telescope parts are reduced. Additional advantages to the use light weight mirrors is their easy handling.

A knife edge test after its polishing phase gives a surface accuracy of 0.3". The Hartman test on the telescope was made several times during these years, and we got a stellar image of 1" near the zenith but a larger image depending on the zenith distance (Isobe and Agata 1987). This is caused by the supporting system of the primary mirror which has a special rib-structure; a proper supporting system should be developed to have better images.

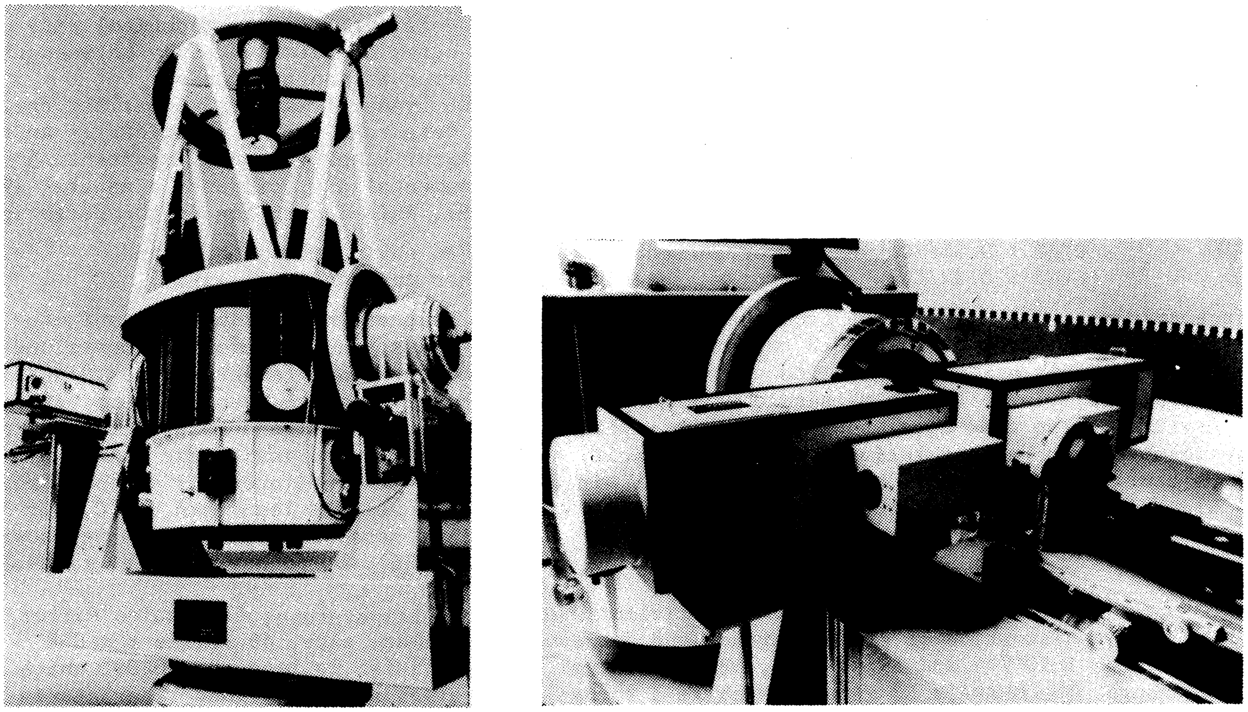


Fig. 8. Photograph of the 75-cm telescope with alt-azimuth mounting at the SOK (left photograph) and photograph showing photometer and spectrometer settled on the Nasmyth platform (right photograph).

There are one primary focus and two Nasmyth foci which are changed each other by turning a flip-flop top ring and by tilting a tertiary mirror by 90°; the time needed to exchange between foci is less than 1 minute and its repeatability is less than 5". The prime focus is used for direct photograph and the first Nasmyth focus is for eye observation. At the second Nasmyth focus, there is a Nasmyth platform which do not change height from ground level during the equatorial motion because of its alt-azimuth mounting. Three instruments are permanently fixed on the platform. A silicon intensifier target (SIT) camera on the line of elevation axis is set on an instrumental rotator to compensate the field rotation. In front of the Nasmyth focal plane, a dichroic mirror is inserted to give stellar light into either a photomultiplier or a spectrometer. The time needed for this change between the two instruments is a few seconds. The photometer contains normal U, B, V filters and space for other three filters. The spectrometer has dispersions of 20 A/mm and 200 A/mm.

This telescope has been used for astronomical observations. One example is an observation of the Comet Halley. Its direct images are stored on video tapes, and time variations of its images is obtained after applying an image processing system as shown in section VIII (Isobe *et al.* 1987).

The performance of this telescope is less accurate than the aimed for the 7.5-m telescope of the JNLT, but we are able to have many experiments in engineering aspects of alt-azimuth mounting, honeycomb mirror, focal exchange system, and electronic devices.

V. A TEST PRODUCTION OF HONEYCOMB MIRROR

There are no mirror blanks with a diameter of 7.5-m. If we would produce a 7.5-m mirror blank with a conventional ratio, 6 to 8 of diameter to thickness, its total weight would be about 120 tons which requires very heavy tube and mounting structures, and therefore it is practically impossible to build a 7.5-m telescope. To reduce the weight of the primary mirror, there are two proposals which we are studying: a honeycomb structured borosilicate mirror such as those developed by the University of Arizona group,and a thin meniscus mirror made of glass materials with very low thermal expansion coefficient such as those investigated by the University of Texas group. A test production of honeycomb mirror is continuously proceeded at the University of Arizona who will make a 3.5-m honeycomb mirror in half year and have the intention of building a 7.5-m one in two years. A feasibility study for production of a 7.5-m thin meniscus mirror has been carried out by the Corning Co. Ltd. who does not find any technical difficulties to produce it. The JNLT working group is carrying out a comparative study between the two types of mirrors, and that the weight of either 7.5-m mirror is about 15 tons.

We have still many problems to be solved for both types of mirrors to satisfy the specifications giving the high quality of image size at the telescope focus. Additionally to the mechanical supporting system, thermal problems inside the mirror blank are very important. A temperature difference ΔT, between mirror surface and environmental air, produces a natural air circulation which causes image degradation of $\Delta\theta$ (Lowne 1979). This is written in the following:

$\Delta\theta/\Delta T \sim 0.5''/^\circ$C when mirror surface is warmer than environmental air, and
$\Delta\theta/\Delta T \sim 0.2''/^\circ$C when mirror surface is cooler than environmental air.

Since thin meniscus mirror made from the ULE glass has high heat capacity, time constant of thermal diffusion to equalize both temperatures is about 10 hours, and therefore, temperature of mirror surface is not able to follow the variation of environmental air temperature of 0.5°/hour (Kodaira 1986). In this case we should have an air conditioning system to keep air temperature at daytime in the dome equal to that at night, which claims very expensive dome structure. Since honeycomb mirror has a relatively low heat capacity and many open cores inside the blank, mirror temperature is able to follow the environmental air temperature if ventilated air is continuously blown into the mirror cores (Angel *et al.* 1983). However, to keep ΔT less than 0.2°C, air mass blown into the cores per hour should be larger than mirror mass of about 15 tons per hour. Although forced cooling system is discussed (Cheng and Angel 1986), we do not find the final solution.

Fluctuations of expansion coefficient, $\delta\alpha$, and of temperature, δT, inside mirror blank make a distortion of mirror surface and degradation of image size, $\delta\theta$. Since the ULE glass has $\alpha = 3\times10^{-9}/^\circ$C and $\delta\alpha/\alpha \sim 0.5$, $\delta\theta$ at a normal site condition is less than 0.02" which is good enough. The OHARA's E6 glass, which is a borosilicate glass and has good characteristics for honeycomb mirror production, has $\alpha \sim 3\times10^{-6}$ and $\delta\alpha/\alpha \sim 0.01$ (Isobe *et al.* 1987). Then, to keep $\delta\theta$ at a normal site condition less than 0.1", temperature fluctuations inside mirror blank should be less than 0.1°C/m, which is quite difficult requirement.

At the moment, we know no glass materials having better characteristics for honeycomb mirror production and higher quality of expansion coefficient than the OHARA's E6 glass.

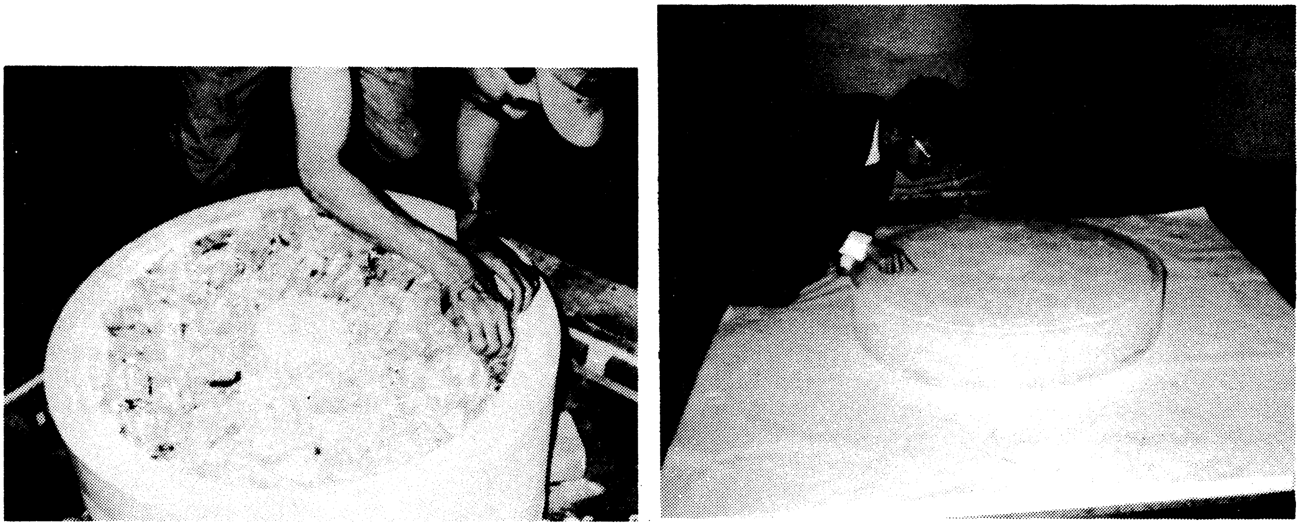


Fig. 9. Photograph of the OHARA's E6 glas materials put on honeycomb core which will be removed (left) and photograph of a completed 94-cm honeycomb mirror blank (right).

Then, we are proceeding the approach of having uniform expansion coefficient inside mirror blank. Even if fluctuations of expansion coefficient for each pieces of glass material is $\delta\alpha \sim 3\times10^{-8}$, one can get much uniform mirror blank if glass material is well mixed during its casting. We are trying to produce several test blanks of a diameter, 30-cm by giving different conditions in maximum casting temperature, its duration, and core materials (Isobe *et al.* 1987). The first 94-cm real honeycomb mirror has been completed but its quality is not satisfactory. The second one will be casted with another combination of parameters, soon.

We believe that future developments in astronomy claims large number of very large telescopes. Therefore, since production cost of a large honeycomb mirror blank is much lower than that of a thin meniscus ULE mirror blank, honeycomb mirror will be a good candidate for the primary mirror blank of future very large telescope.

VI. DEVELOPMENTS OF HIGH SENSITIVE AND ACCURATE DETECTORS

The JNLT will be the best telescope in the world in effective light collecting power for a point source if its specifications are satisfactorily realized (as shown in Figure 7).Additionaly to this power, we should develop effective systems to detect incident light. The JNLT will have a wide field of 0.5° at the prime focus, its focal ratio including the effect of corrector lens is 2.3, and then a linear scale of the field is 155-mm. To observe the whole field, photographic plates are only used as a detector, but several specific objects in the field will be observed with a Medusa-spectrograph for effective observations.

Besides the observations with large field, it is very important to develop high sensitive and accurate detectors which have such two-dimensional picture elements as those of photographic plates. On this line, several new detector systems such as the Wampler scanner and the Boksenberg camera were develope, and are reviewed in some papers (Livingston 1973; Ford Jr. 1979). An SIT TV camera is one of the effective detectors (Isobe *et al.* 1980; Isobe *et al.* 1984). However, this system has a critical limitation on spatial resolution, dynamic intensity range, and especially on integration time. To solve these difficulties, two systems were developed to detect and display individual photons in real time, as well as to carry out follow-up image processing; those are a photon counting image acquisition system (PIAS) (Kinoshita *et al.* 1983; Tsuchiya *et al.* 1983; Isobe *et al.* 1984) and a video intensified microscope (VIM) (Miyaki *et al.* 1985; Isobe *et al.* 1986).

The PIAS consists of a photon counting imager, a position analyser, and an image processor employing a digital video frame memory, a console, and a television monitor. The imager incorporates a photocathode, a three-stage microchannel plate (MCP), and a position sensitive device (PSD). This system is a non-integration type with random read-out. There are packaged in the tube as shown in Figure 10. Incident photons from celestial objects and sky background are converted into photoelectrons at the multiakali photocathode (S-20 type), which has a quantum efficiency of about 10 percent. These photoelectrons are focussed on the input surface of the three-stage MCP, where they are multiplied by a factor of as much as 10^7. Electron clouds forming a beam with a diameter of about 100 micron are injected into the silicon PSD of the read-out section, where they are multiplied by a factor of approximately 100. A total of about 10^9 electronic charges is obtained in this tube for each incident photon. Positional information is given by the PSD. The output signal from each electrode on the PSD is inversely proportional to the resistance between the point of incidence of the electron cloud and the electrode. This resistance is approximately proportional to the distance between two points, since a uniform resistive sheet was laid down on the surface of the PSD. Since the PSD is a charge-division device, the centroid of the electron cloud can be calculated by analysing the charge signals. From four signals obtained from the PSD, the position of the incident photon is calculated. When two or more photons are detected within the response time of the imager (about 6 microseconds), the PSD signal will be two or more times higher than that for a single photon. Consequently, these signals are removed. Since the noise generated in the MCP would have a small pulse hight, this is also eliminated.

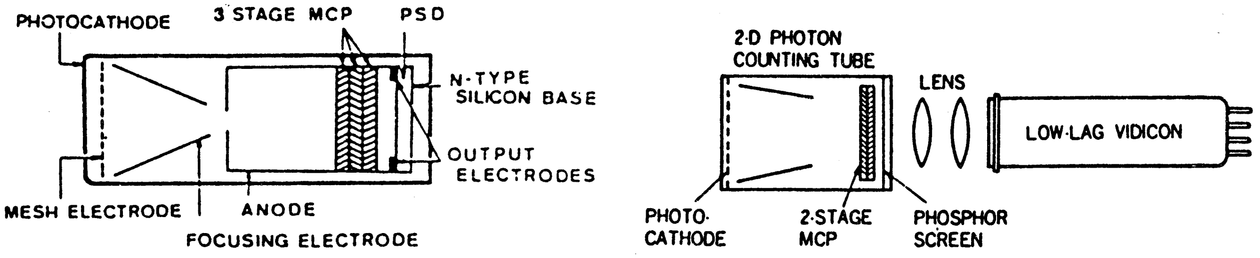


Fig. 10. Schematic drawings of the PIAS (left) and the VIM (right). Both systems have a photocathode and a microchannel plate. The PIAS measures the position of each photon event by the position sensitive device while the VIM obtains all photon events in each 1/30 second frame by a low-lag vidicon camera.

The VIM consists of an ultra-high sensitivity TV camera called as the Hamamatsu C1969-20 VIM (Figure 10) and of an image processor. This combination enables a photon counting imaging additionally to an ordinary low light level imaging. Therefore, the camera has a wide dynamic range (10^0 to 10^9 photons/mm^{2}s). A vidicon TV camera with a low-lag time (5% after 50 ms) is optically coupled by a relay lens with two dimensional photon counting tube as shown in Figure 10. When an optical image is focussed on the photocathode, it emits photoelectrons in accordance with the intensity of the input image. The electron image is focussed on the two stage microchannel plate where it is amplified up to the order of 10^6. Pulse height distribution is good enough. This amplified image produced on the phospher screen is taken by the coupled video camera. When the intensity of input image becomes extremely low, one video frame of the TV scan gives only a dotted image corresponding to input photons and noises produced at the photocathode. By giving a certain discriminative level to reduce an effect of these noises, the dotted images are digitally processed and accumulated in a video frame memory over a desired number of video frames.

Both detectors are used for astronomical tests and are found to be effective detectors. However, there remain some limitations for real observations. Since the read-out frequency of the PSD for the PIAS should be less than 10^5 events per second to make accurate data acquisition, both bright and dark objects in a field cannot be observed simultaneously. The VIM has a large distortion, 7%, of frame originating from the low lag vidicon camera. The main disadvantage of both camera is low quantum efficiency at the photocathode surface. To have the higher quantum efficiency, a CCD camera is now used in the world. Unfortunately, electronic production makers in Japan have at the moment no intentions in developments of CCD used at low light level. Their CCD are not produced to work at liquid nitrogen temperature which is essential to reduce thermal noise of the CCD. We are trying to use the CCD instead of low lag vidicon for the VIM.

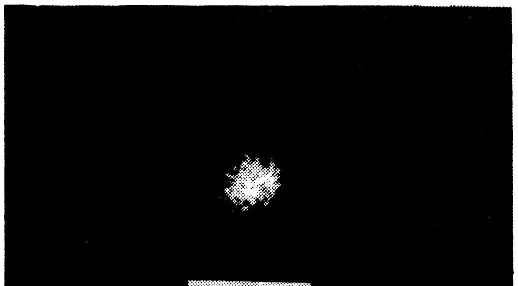
At the Okayama Astrophysical Observatory, a series of test for the CCD produced by RCA and Texas Instrument has been carried out and they detected some stars with V magnitude of 22.7 magnitude in a selected area SA57 (Iye *et al.* 1986). These efforts will be continued.

VII. SPECKLE OBSERVATIONS

The JNLT will be settled at Mauna Kea where the best seeing is 0.2" (Racine 1984). However, its angular resolving power defined by difraction limit of an aperture of 7.5-m is 0.013" which is better than 0.2". There are many astronomical requirements to reach this resolving power. Considering these situations, we are developing a system of speckle interferometry. Since Labeyrie (1970) proposed the stellar speckle interferometry, many observations have been conducted around the world. In Japan, we made the first speckle observation in 1982. There are some methods to process stellar speckle data (Bates 1982). Among them, the sift-and-add (SAA) method proposed by Bates and Cady (1980) is a simple and efficient technique to reconstruct a stellar image (Bagnuolo and McAlister 1983; Baba *et al.* 1985; Christou *et al.* 1986). The SAA method is stated as follows. The brightest point in each speckle image is shifted to the center of image space and the translated image is added to all other speckle images that have been similarly processed. By applying the SAA method to speckle images of binary stars, those angular separation and position angle are determined. Since the SAA method suffers from ghost peak, the estimation of the magnitude difference is more difficult.

We describe here a simple estimation procedure for the magnitude difference of binary star components, based on the SAA (Baba *et al.* 1987). First, we separate a spatial filter, which is determined by the point spread function of the SAA imaging, to each speckle image. The maximum position in each filtered frame is found and the unfiltered image is centered on this position. In general, the SAA image consists of three peaks, namely the primary, the companion, and the ghost peaks. The appearance of the ghost peak mainly due to the mis-shifting of speckle images, and so the value of the primary peak is affected by this mis-shifting. In order to estimate the magnitude difference precisely, we have to evaluate properly the contribution of the ghost peak value to the primary one. If the ghost peak exists, it is considered that a part of the primary peak value results from the ghost peak value times, the intensity ratio between the primary and the companion star. By considering these effects in this way, we can estimate the magnitude difference of the primary and companion stars. Some computer simulations confirm the usefulness of our procedure.

Employing this procedure, we estimate the magnitude difference of o-And. The speckle data were obtained using the 188-cm telescope at the Okayama Astrophysical Observatory in September 1984. The central wavelength and band width for this observation were 420 nm and 15 nm, respectively. 75 speckle images were recorded on photographic film with exposure time of 1/60 seconds. One of these images is shown in Figure 11. These images were scanned with the PDS microdensitometer. Figure 12 shows the iso-intensity contour map of the SAA image. From this figure,



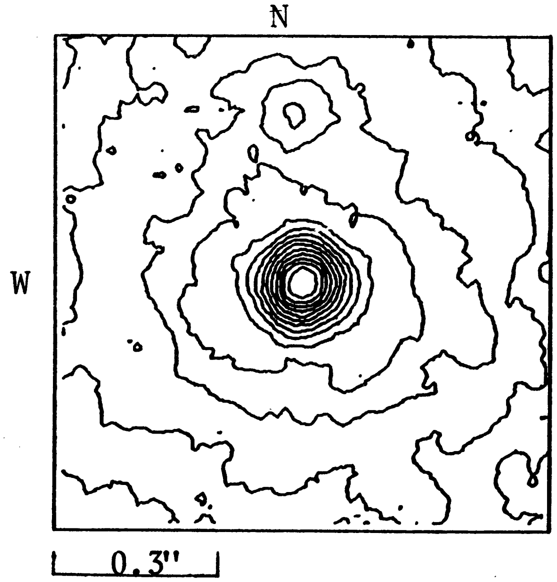


Fig. 11. An example of speckle image of o-And obtained in September, 1984.

Fig. 12. Intensity contour map of binary star of o-And after application of the SAA method. Two stars are separated in angular distance of 0.3".

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the location of the companion star can be specified. The ghost peak is not evident in this figure, because the magnitude difference of o-And is large. By using the procedure described above, we estimate the magnitude difference as 1.55 magnitude at the observed wavelength.

We are currently conducting speckle observations with a high sensitive TV camera by which a star with 12 magnitude is able to be observed. As our future plan, we are studying a system with a photon counting detector. There is the following equation:

$$[S/N]= \frac{[Nph]}{\sqrt{4\ 2}}\sqrt{\frac{Nframe}{[Ns]}}$$

where [Nph] is mean photon number per frame, Nframe is number of frames applied fourier trasformation, [Ns] is mean number of speckle per frame, and [S/N] is signal to noise ratio required. Taking Nframe = 10^5, which is obtained by the exposure time of 3 hours and frame rate of 10 per second, [Ns] = 10^3 , and [S/N] = 5, then [Nph] = 3, when exposure time of each frame is 1/100 second, quantum efficiency of detector is 10%, and light loss on an optical path to the detector is 10%. Then the limiting magnitudes of speckle observations are 14.0 magnitude for an aperture of 1-m telescope, 15.5 magnitude for that of 1.8-m, and 18.0 magnitude for that of 7.5-m. To reduce very large number of data, a development of a new system (Figure 13) is under consideration.

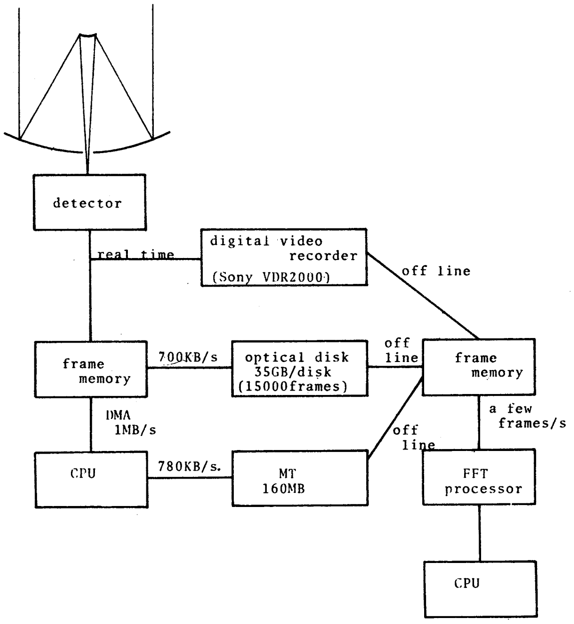

Fig. 13. Schematic drawing of new acquisition system for speckle images. The maximum speed of data acquisition is limited by the speed of FFT processor.

VIII. IMAGE PROCESSING SYSTEM

To reduce data for two dimensional images and spectral images additionally to speckle images, we should develop a good image processing system, which makes observations efficient. This requirement is stronger for the data obtained by the JNLT because the telescope has the highest light collecting power.

We are developing an image processing system to reduce a Schmidt plate with a size of 36-cm x 36-cm. The plate is measured by a pitch of 26 micron and has 10^9 data points. After minimizing the effect of fluctuation of sky background and transferring plate darkness into intensity scale, stellar images are effectively picked up. In our system, we need 10 hours for a measurement of one plate and another 10 hours for its reduction. 80 thousand stars in the Orion region are detected (Maseda *et al.* 1986) and color-magnitude diagrams at some areas in the Orion region are obtained as shown in Figure 14, and then we found that the color-magnitude diagrams are different from one region to another in the Barnard loop. These data give an important information on evolution of the pre-main sequence stars.

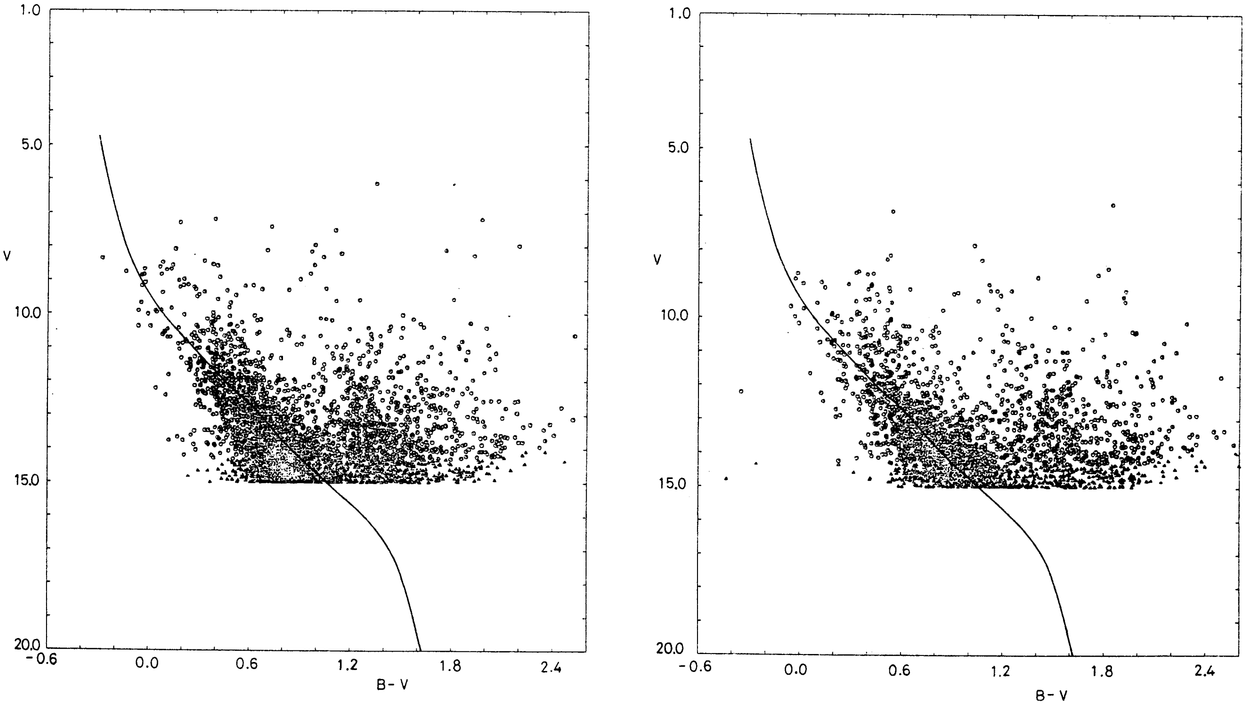

Fig. 14. Color-magnitude diagrams of the stars in the Orion association. Left one are the stars located outside the molecular cloud and right one is the stars located inside the molecular cloud. Right one shows a clear gap of stars between main sequence branch and pre-main sequence branch.

For extended objects, some systems were developed by Okamura (1977), Watanabe (1983) and Yamagata (1986). Recently, at the Kiso Observatory, a new system called SPIRAL (Surface Photometry Interactive Reduction and Analysis Library) (Ichikawa *et al.* 1987) was completed. Although, at the moment, only 3-c x 3-cm areas can be reduced at one time, much larger area will be reduced by introducing additional memory.

IX. CONCLUSION

In this paper, we showed our efforts to develop optical telescope intrumentations and data reduction systems. Additionally, many other developments are carried out by other optical and infrared groups in Japan and cooperative observations with X-ray and radio groups have been proceeded. These kind of efforts should be continued during the construction period of the JNLT, and then we would be able to expect many effective observations by the JNLT after its completion.

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