

Full-disk synoptic observations of the chromosphere using H α telescope at the Kodaikanal Observatory

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Abstract This paper reports on the installation and observations of a new solar telescope installed on 2014 October 7 at the Kodaikanal Observatory. The telescope is a refractive type equipped with a tunable Lyot H α filter. A CCD camera with size $2k \times 2k$ acquires images of the Sun and has a pixel size of $1.21'' \text{ pixel}^{-1}$ and a full field-of-view of $41'$. The telescope is equipped with a guiding system which keeps the image of the Sun within a few pixels throughout the observations. The FWHM of the Lyot filter is $0.4 \text{ \AA}$ and the filter is motorized, capable of scanning the H α line profile at a smaller step size of $0.01 \text{ \AA}$. Partial-disk imaging covering about $10'$ is also possible with the help of a relay lens kept in front of the CCD camera. In this paper, we report the detailed specifications of the telescope, filter unit, the installation, observations and the procedures we have followed to calibrate and align the data. We also present preliminary results with this new full-disk telescope.

Key words: Sun: chromosphere — instrumentation: miscellaneous — telescopes: solar telescope — object: Sun — observations: H α

1 INTRODUCTION

Apart from white light observations of the Sun, the data recorded in H α wavelength have a long history. The chromosphere was seen to have red and pink color during a total solar eclipse at the beginning of the 18th century. During the beginning of the 19th century, observers reported brilliant, glowing prominences in red color. Later, several others including Jules Jansen observed the spectra of prominences during the total solar eclipse of 1868. In 1889, Hale invented the spectroheliograph to map solar prominences above the solar limb. In addition to Mt. Wilson, several other observatories around the world started observations of the Sun in different wavelengths using this spectroheliograph design. The Kodaikanal Observatory started its Ca-K and H α observations in 1905. These observations were made using the spectroheliograph and siderostat as a light feeding system (Bappu 1967).

In the next few years, several other observatories around the world started observations in H α and Ca-K (Meudon Observatory in France, National Solar Observatory in Sunspot, New Mexico, Nainital and Udaipur Solar Observatories in India, Big Bear Solar Observatory in California, Hida Observatory in Japan and many more). The invention of birefringent filters by Öhman (1938) in Sweden and Lyot (1944) in France

started a new era in observing the Sun using narrow band filters that were able to isolate the spectral line of the desired wavelength. From 1950 to the end of the 20th century, Messers B. Halle company in Germany used to make those filters and at the same time Carl Zeiss also made a few such filters with passbands of 0.25 to $0.5 \text{ \AA}$. The set up could also scan the spectral line profile and made observations of the Sun at different heights in the solar atmosphere. Several observatories around the world utilized these filters and made solar observations in Ca-K and H α . It became possible to take images of the Sun at a faster rate with these filters as compared to taking the images using the exit slit of the spectroheliograph. The introduction of CCD cameras in the 1990s further enhanced the image acquisition rate with high contrast.

During the beginning of the 21st century, observatories around the world started a global H α network with a nearly 24 hour coverage of the Sun. In 2009, the Global Oscillation Network Group (Hill et al. 2009, GONG) added H α to its regular observations along with dopplergrams, magnetograms and pseudo continuum images of the Sun. Apart from these, several other observatories around the world have their own program of H α observations, for e.g., the Improved Solar Optical Observations Network (Neidig et al. 1998, ISOON) which is administered by the US Air Force and the *Chromospheric*

Telescope (Bethge et al. 2011, ChroTel) installed at the Observatorio del Teide, Tenerife makes full-disk observations of the solar chromosphere in Ca II K, H α and He I 10830 Å. The Aryabhata Institute for Observational Sciences (Verma et al. 1997) has set up an H α observational facility. Similarly, the Udaipur Solar Observatory started H α observations in 1970. Thus, ground-based telescopes established at different longitudes around the globe are very useful to monitor solar activity with 24 h coverage.

The Kodaikanal Observatory has a history of solar observations made in white light, Ca-K and H α wavelengths since 1905. The H α observations continued till 2000. Due to the unavailability of the photographic plates, the observations were discontinued, although the same siderostat was used for the Ca-K observations with a CCD camera. Following the installation of the ‘twin telescope’ at the Kodaikanal Observatory (Singh & Ravindra 2012), white light observations were carried out simultaneously with Ca-K. To continue solar chromospheric observations in H α , we have recently installed a new telescope at the Kodaikanal Observatory. In this paper we describe the details of the telescope, control system, the guider unit to stabilize the telescope, the filter unit used to isolate the H α spectral line, scanning of the H α line profile to observe the different layers of the Sun, etc. We also show some of the observational results obtained with this telescope and outline some future plans.

2 SCIENTIFIC OUTLOOK

H α telescopes have been used for more than 100 years for solar observations. Several results from various data sets were published over the years. H α images are used either as supplementary data (Louis et al. 2015; Vemareddy et al. 2012) or as stand-alone data sets (Srivastava et al. 1991; Venkatakrishnan et al. 2008; Wang et al. 1998; Makarov & Sivaraman 1989). Below we illustrate a few scientific goals that can be addressed with the newly installed H α telescope at the Kodaikanal Observatory. These are only representative but not exhaustive.

Solar filaments are chromospheric and coronal features, appearing as large, dark, thread like structures with a certain thickness on the solar disk. Typically, quiet Sun filaments are larger than active region filaments. The largest ones cover more than half the Sun’s diameter (e.g., on 2015 February 11). The observations made in H α provide information on the large scale mass motion inside a filament during its eruption and it is important for modeling solar filament eruption, hence observations made in this wavelength are important for understanding the onset of solar flares and coronal mass ejections.

Solar filaments are complicated yet very important structures that are observed in the corona. Several types of oscillations in filaments are observed in the corona that are excited during a solar flare. Solar flares can excite fast MHD shock waves, such as Moreton waves in the chromosphere (Okamoto et al. 2004; Gilbert et al. 2008) and EIT

waves in the corona (Eto et al. 2002). These waves propagate with velocities in the range 400–1500 km s^{−1} and can excite the oscillations in prominences which dampen over time. The oscillatory properties of solar filaments, associated with flaring active regions, are significant for understanding their stability and the relevant conditions leading to their eruption. To detect these phenomena in the chromosphere, we would require fast cadence full-disk images taken in the H α line core during flares and filament eruptions. This would help us to identify the cause of the large amplitude oscillations of the filaments.

In a 2-D model of a flare, the energy release occurs in the current sheet and the coronal magnetic reconnection rate can be computed by summing the normal component of the photospheric magnetic field at the locations of flare ribbons in the lower solar atmosphere (Priest & Forbes 1986). The flare ribbons are believed to be maps of the footpoints of the magnetic field lines reconnected in the corona. From the assumption of conservation of magnetic flux, one can compute the total magnetic reconnection flux by using the observations of flare ribbons in the lower atmosphere and the corresponding photospheric magnetograms. While this technique is used to compute the magnetic flux involved in the flare, in most cases the TRACE images taken in C IV 1600 Å are used (Longcope et al. 2007) for finding locations of the flare ribbons and newly reconnected regions. The C IV 1600 Å wavelength shows information about both the chromosphere and the photosphere. The line core of H α is formed in the upper chromosphere and the wings are formed closer to the photosphere. One can make a comparison of the total magnetic reconnection flux involved in the flare using the flare ribbons observed in the H α and C IV 1600 Å wavelengths. This will provide important information about the total reconnected magnetic flux involved in the flare which can be compared with the magnetic flux carried away by magnetic clouds (Qiu et al. 2007).

3 THE TELESCOPE

3.1 Optics

The main telescope installed at the Kodaikanal Observatory has a 20.06 cm doublet lens as an objective which makes an f/7.9 beam. This beam is collimated by another doublet having a diameter of 5.2 cm and a focal length of 18.94 cm. The light from the collimator is refocused by a re-imaging lens that has an effective focal length of 25.6 cm.

The final image size is about 2.1 cm for a 32′ field-of-view (FOV) and about 2.7 cm for a 41′ FOV. The H α filter is kept in the collimated beam. A combination of lenses with an effective focal length of 16.52 cm is placed after the re-imaging lens to obtain the magnified view of the Sun. With this set-up, one-quarter of the Sun’s image can be obtained. Both the full-disk and partial-disk mode can be used to study some of the events such as prominence eruptions on the limb, solar flares, filaments, solar

macro-spicules, etc. The final combination of lenses is an optional arrangement and need not be used all the time. The schematic design of the telescope is shown in Figure 1 with the dimensions of the lenses.

There is a guider telescope fitted to the side of the main telescope to correct for any image motion during observations. The guider telescope is made up of a 10 cm objective lens with an effective focal length of 174.3 cm. The lens is cut into four quadrants and each quadrant makes a solar image with partial images overlapping each other. The central portion of the overlapping part of the image is dark. A CCD camera with 795×596 pixels is kept in the dark portion of the overlapped image. Any shift in the Sun's image due to tracking or shaking will produce an error signal which is amplified and fed back to the telescope. The guider telescope helps to keep the image in the CCD camera attached to the main telescope to within a few pixels throughout the observation.

Apart from these, there is one more small telescope which serves as a “finder”. It has a 3 cm diameter small convex lens with a focal length of 252.5 cm. It forms an image with a size of about 2.5 cm on a ground glass prism. A yellow colored filter with a broad passband (5000–6000 Å) is kept in front of the objective lens to get a colored image of the Sun and also to reduce the heat load on the system. This arrangement makes it easy for the initial alignment of the telescope towards the Sun.

The front of the telescope objective is covered with a stepper motor controlled shutter to open and close the lid which prevents dust from entering the telescope system when not in use. Similarly, one more automated shutter is kept in front of the guider telescope as well.

The overall telescope tube length is about 3.2 m. The whole assembly of the telescope including the guiding system is assembled on a German equatorial mount. The mount is installed on a reinforced concrete pier with a steel plate on the top of the foundation. The tracking system is controlled by a motor which in turn receives signals from right ascension (RA) and declination (DEC) encoders. A picture of the telescope is shown in Figure 2. The main and guider telescopes are shown with red arrows in the same Figure.

3.2 The $H\alpha$ Filter Unit

The $H\alpha$ spectral line is isolated by a tunable Lyot filter. The Lyot filter was made using birefringent crystals which split the incoming ray into the ordinary and extraordinary rays. The emergent rays interfere at the polarizer which produces a series of interference patterns. A series of such retarders in combination with polarizers produces a filter. The transmission function of each stage of a polarizer and retarder is different. The thickest retarder decides the final bandwidth of the transmitted peak and the thinnest one determines the distance between successive transmission peaks, which is also called the Free Spectral Range (FSR). The Lyot filter used at the Kodaikanal $H\alpha$ telescope has

seven stages of crystals and the thickest crystal width is about 28 mm.

A stepper motor has been attached to the filter unit and the filter can be tuned to any position on the line profile with an accuracy better than 10 mÅ. The filter unit can scan the line profile about 4 Å away from the line center on both wings which is computer controlled. The shifting of the center of the filter to any desired position on the line can be achieved in about 1 s. The FSR of the filter is 51.2 Å and the filter band width is 0.4 Å as obtained from laboratory measurements.

The birefringent crystals are very sensitive to temperature. The change in the retardation shifts the passband away from the desired wavelength of interest. Hence it is very important to maintain a uniform temperature within the filter unit. Typically, quartz produces a greater shift in wavelength than calcite. The one used in the Kodaikanal $H\alpha$ telescope has two layers of heating units. The entire filter unit is maintained at a temperature of 42°C with a stability of 0.01°C using a heat sensor and feedback unit. The filter works fine even if the ambient temperature varies from –20° to 35°C.

The acceptance angle of the filter is large (about 2°) over which the shift in wavelength is less than 0.1 Å. The overall size of the filter unit is 0.5 m in length, 0.2 m in width, 0.2 m in height and weighs about 35 kg. The clear aperture of the filter unit is about 3.6 cm. The crystal unit along with the polarizers is immersed in silicone oil. Silicone oil has several good properties, which were very useful for optical elements when we used them as one single unit. Some of the properties of silicone oil are: it is insoluble in water; it has a low viscosity; it is colorless; it has a very low freezing point and a very high boiling point; it has good thermal conductivity; it is a poor conductor of electricity; and most importantly the refractive index of the oil is same as the other crystals in the unit thereby reducing the back reflection from each surface.

A pre-filter from the Andover Corporation, having a width of 30 Å and centered on $H\alpha$, is kept in front of the Lyot filter which isolates the spectral line of interest. The overall transmittance of the $H\alpha$ filter is larger than 5%.

3.3 Telescope Mechanical Structure and Drive Units

The equatorial configuration of the telescope mount allows tracking the Sun by rotating about a single axis. The mount is made of cast iron, and it is stable and rigid. It does not require any additional counterweight for balancing. The equatorial fork mount holds the polar axis at an angle of 10°, which corresponds to the latitude of the location. Further fine adjustment in the alignment was made in the telescope pedestal for latitude and azimuth. Finally, the telescope was aligned to the polar axis with an accuracy better than 0.5°.

The telescope is coupled to a direct drive motor system which utilizes permanent magnet DC torque motors. The torque rating of the motors is 50 N m and 25 N m in

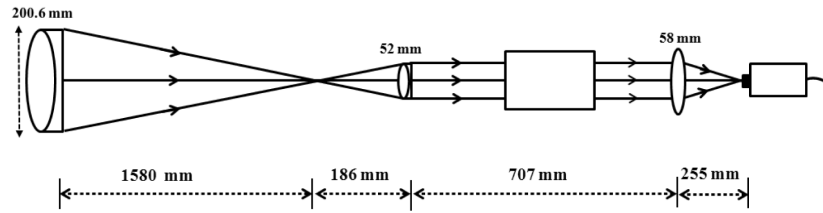


Fig. 1 A schematic layout of the optical configuration of the $H\alpha$ main telescope.

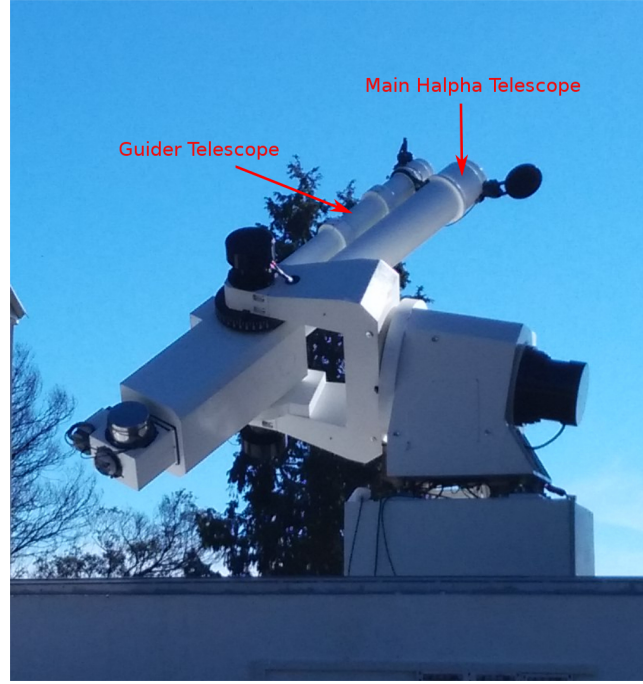


Fig. 2 A picture of the $H\alpha$ telescope installed at the Kodaikanal Observatory.

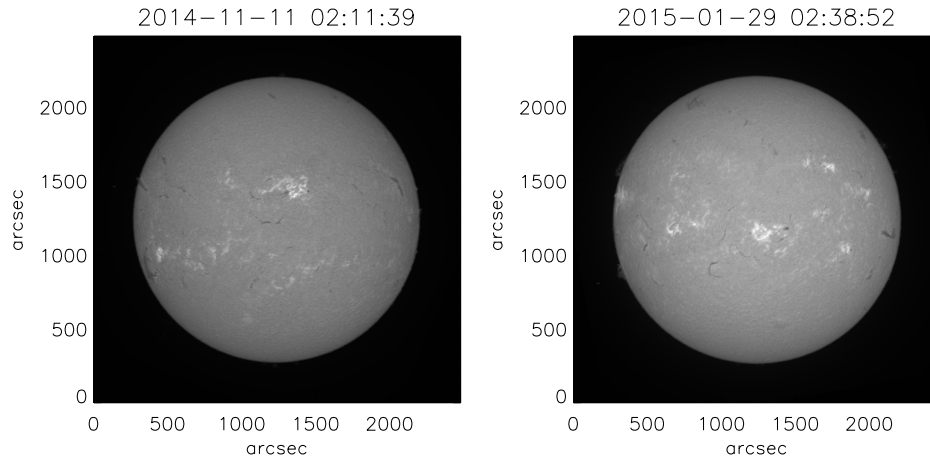


Fig. 3 Images taken with the $H\alpha$ telescope installed at the Kodaikanal Observatory.

the two axes to control the motions in RA and DEC directions, respectively. The RA axis operates at three speeds of 2° s^{-1} , 4° min^{-1} and $5'' \text{ s}^{-1}$. The primary advantage of the direct drive system is that it has a hollow shaft and

it provides a continuous torque with high positional stability and bi-directional repeatability. This property of direct drive motors eliminates mechanical transmission elements

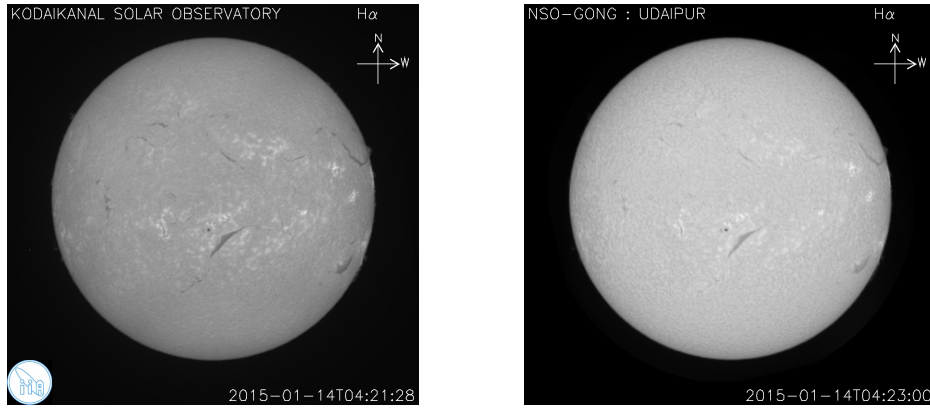


Fig. 4 *Left:* $H\alpha$ image taken with the telescope installed at the Kodaikanal Observatory. The image was taken at 04:21 UT on 2015 January 14. *Right:* image taken with the GONG telescope at the same time.

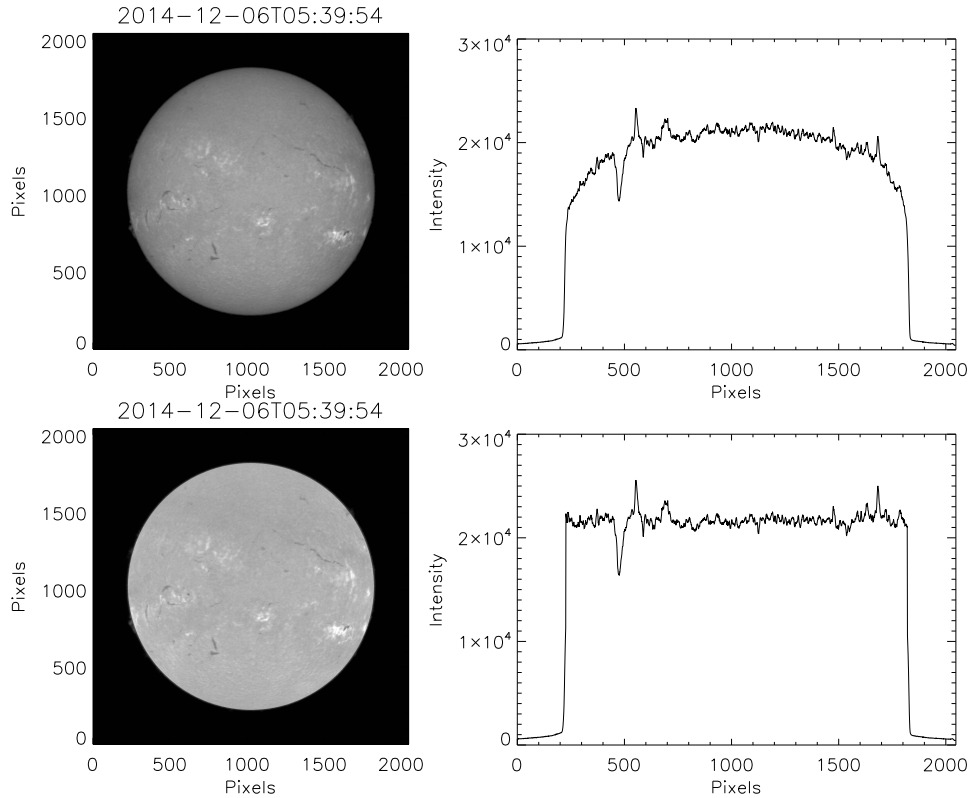


Fig. 5 *Top-left:* $H\alpha$ line center image with center-to-limb variations in intensity. *Top-right:* Limb darkening profile along a row of pixels. *Bottom-left:* Same as top-left side image but after removal of center-to-limb variations in intensity. *Bottom-right:* Profile after correction.

such as gears, belts, friction contact, etc., thereby providing positioning, pointing and tracking with good accuracy.

An internal brake system is installed for both the axes which ensures the safety of the telescope during operation and also takes over in the event of a power failure. A gear and pinion assembly controls the acceleration of the load during power failure and transmits the motion to the motor to engage the brake.

3.4 Encoder Alignment on the RA and DEC Axes

The absolute incremental encoders are used to track the current position of the telescope by getting the information about the rotational motion of the shaft. The advantage is that the absolute encoders store information about the position even when the power is off. The encoder ring was aligned with high accuracy against the encoder head. This

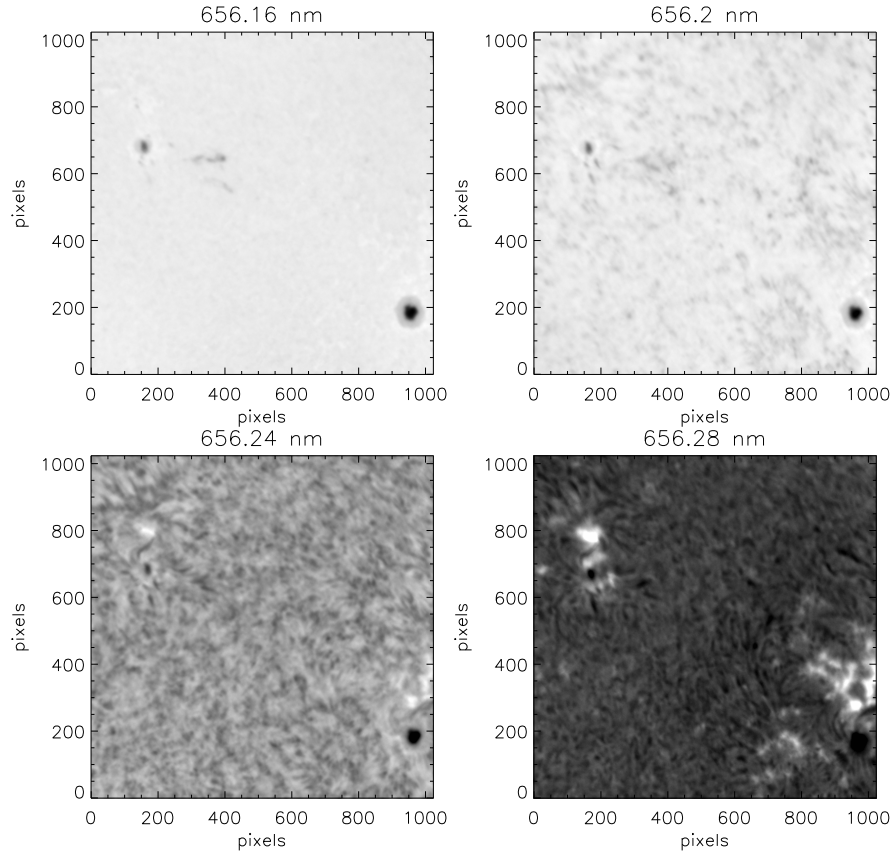


Fig. 6 High resolution $H\alpha$ images taken at different positions on the blue wing. *Top-left*: $H\alpha$ blue wing continuum image (656.28–0.12 nm), *top-right*: $H\alpha$ blue wing image at 656.20 nm (656.28–0.08 nm), *bottom-left*: $H\alpha$ blue wing image at 656.24 nm (656.28–0.04 nm) and *bottom-right*: $H\alpha$ line center image.

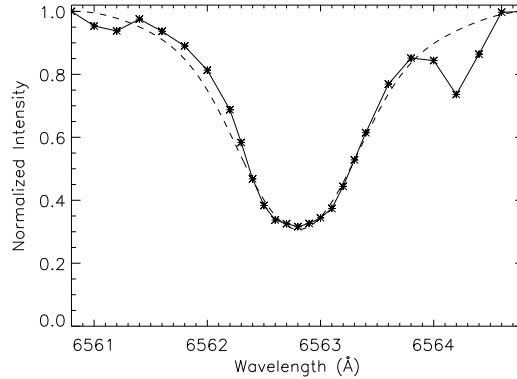


Fig. 7 The reconstructed $H\alpha$ line profile from the set of images taken by tuning the $H\alpha$ filter at various positions along the line profile. The asterisk symbols denote the data points obtained from the observations. The dashed line is obtained from BASS spectra convolved with the Gaussian kernel having a width of 0.32 Å.

provides precise information about the position of the telescope in the RA and DEC axes with an accuracy of $1''$.

3.5 Telescope Operation

The telescope has been operational since October, 2014. Typically the telescope is operated in full-disk mode and

the images are taken in the $H\alpha$ line center. The $H\alpha$ line center images are saved every minute. This is to maintain a data rate on par with other observatories around the world and at the same time manage data storage. The flat fields and dark exposures are taken once a day. During a flare or filament eruption, the images are taken at an interval of 30 s. Occasionally, we scan the $H\alpha$ line profile at six

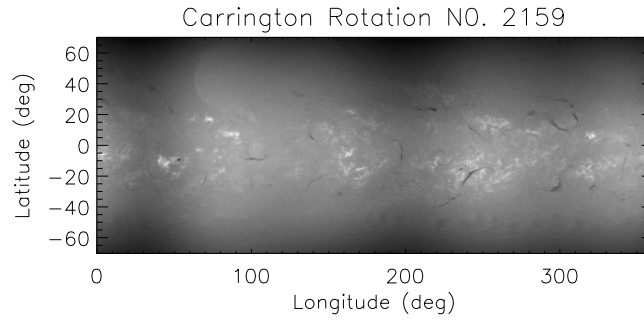


Fig. 8 Chromospheric Carrington map for the Carrington rotation number 2159.

positions – one in the line center, two each on the red and blue wings ($0.4 \text{ \AA}$ and $0.8 \text{ \AA}$ from line center) and finally at $+1.2 \text{ \AA}$ away from the line center, which represents a quasi-continuum point. Each of these images is taken with a cadence of 10 s.

3.6 Detector System

We employ a CCD camera with a grade-I chip supplied by Andor technology, which has 2048×2048 pixels. The pixel size is $13.5 \text{ }\mu\text{m}$ which is about $1.21''$ per pixel for the $H\alpha$ full-disk image and $0.48''$ for partial disk. The full well capacity is 8×10^4 electrons. The CCD is back-illuminated whose quantum efficiency is about 91% at the 656.3 nm $H\alpha$ wavelength band. The CCD camera has 16-bit digitization with a readout rate of 1 MHz. The CCD is cooled to a low temperature by Peltier cooling for low dark current. During observations, the CCD is cooled to -40°C . At this temperature the dark current is about $1 \text{ electron pixel}^{-1} \text{ s}^{-1}$.

The readout noise is less than 0.1%. The normal exposure time used for full-disk images is about 60–70 ms and for partial-disk observations it is about 0.4–0.5 s. It has a mechanical shutter and for an exposure shorter than 20 ms, the shutter pattern appears and the counts are less than 2×10^4 . The software program was written in the Borland C++ language for data acquisition and also to scan the line profile using the Lyot filter.

4 THE DATA CALIBRATION

The data obtained from the telescope have to be calibrated before using them for further scientific analysis. In the following subsections we describe the details of the calibration procedure.

4.1 Flat Fielding

There are several methods given in the literature for the flat-fielding of solar images. One of the widely used methods is the one proposed by Kuhn et al. (1991). In this method, gain tables are generated by using shifted solar images. We obtained nine shifted images and computed the gain table. However, we also used a diffuser for obtaining the flats. The diffuser plate can be inserted into the light

path whenever it is necessary. The diffuser was put in front of the objective and the telescope was pointed towards the Sun. Several flat frames were taken to compute the average. Typically, the flat fields are taken once a day. If the sky is clear from morning to evening then the flats are taken twice a day. The dark exposures are taken as many number of times as the flat fields are taken. An average dark exposure is made from the individual dark frames. Later, the average dark is subtracted from each individual flat field.

Usually, the diffuser produces an intensity pattern which is Gaussian in shape. To remove the gradient in the flat fielded image, a surface fit with a 3rd degree polynomial is used. The resultant fit is subtracted from the flat field. From the residual flat field, the gain table is computed. This is done by dividing the pixel values by the median value of the flat field image. This procedure will rescale the pixel values close to unity. The daily observed solar images are dark subtracted and flat fielded. These flat fielded images are then sent for further processing before providing them to the scientific community.

4.2 Image Alignment and Rotation

Typically, solar images obtained from the telescope would not be in the center of the image window. In addition, for any scientific analysis it is essential to obtain the radius and center of the image. We use the information about the gradient near the solar limb to detect the Sun's limb. Once the solar limb has been detected, we identify the center and radius of the Sun using software available in Interactive Data Language (IDL) from Exelis Visual Information Solutions. This program provides information about the position of the center and radius of the Sun with 1-pixel accuracy, which is used to center the Sun in the image window.

Usually, the heliographic north pole will not be along the $+y$ axis of the image in the CCD. The solar p-angle is calculated for a particular day of the month and time by using the standard solar software. The window centered image is rotated by the corresponding p-angle in such a way that the north pole is aligned along the $+y$ axis of the image. All the image alignment programs are written in IDL. The images are stored in 32-bit Flexible Image Transport System (FITS) format with a standard header. We also save the images in JPEG format for quick look purposes.

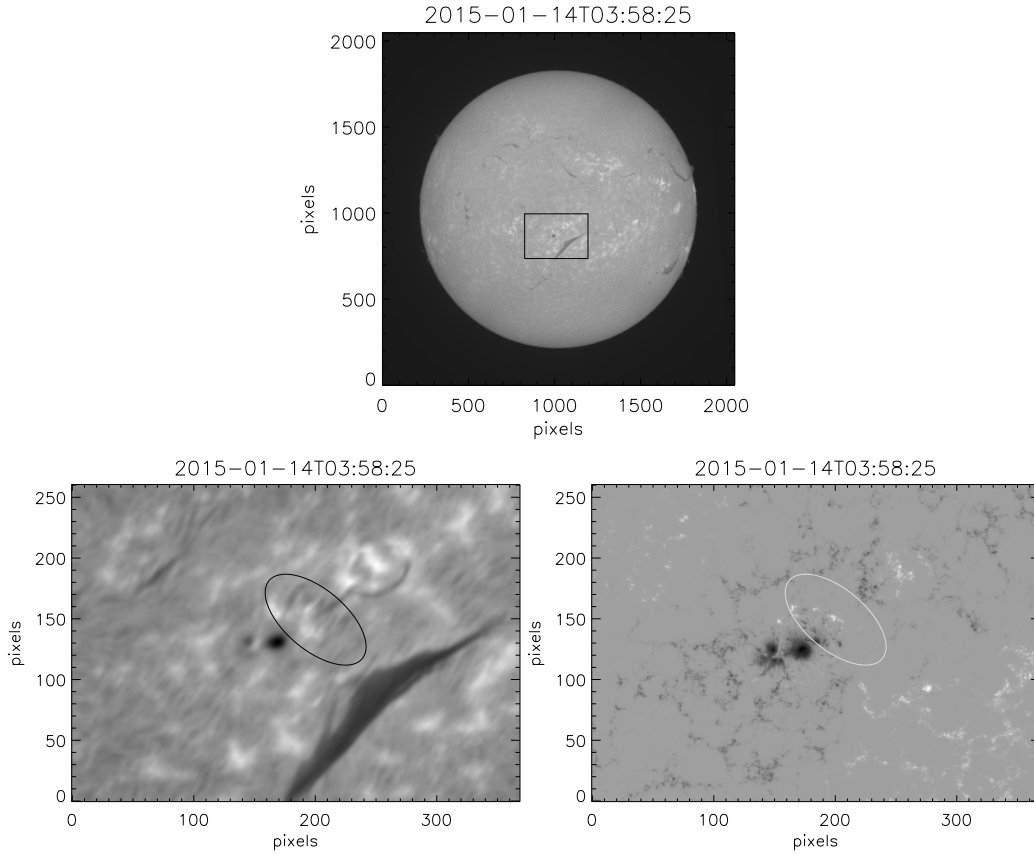


Fig. 9 *Top*: The $H\alpha$ line center image taken on 2015 January 14. The box represents an FOV shown in the *bottom-left* panel. The corresponding HMI line-of-sight magnetogram is shown in the *bottom-right* panel. The ellipse in the image shows the region of interest (see text for details).

5 REPRESENTATIVE RESULTS

The observations began on 2014 October 7. Since then, continuous observations of the chromosphere have been carried out with this telescope whenever the sky is clear. Figure 3 shows a couple of images taken in the line center of $H\alpha$ on different days. Fibrils, filaments and plagues are clearly seen and the image quality is comparable to those from other observatories.

Telescopes that are part of the GONG network started their $H\alpha$ observations in 2010 (Hill et al. 2009). There are six stations around the world making observations of the Sun in this wavelength, providing 24 hour coverage. The GONG station at Udaipur Solar Observatory acquires images which are the closest in time with images taken at the Kodaikanal Observatory. Hence, we can compare the Kodaikanal $H\alpha$ images with those from the GONG Udaipur station. The pixel sizes of both the images are different. The GONG pixel resolution is a little higher than the Kodaikanal images. In order to make a comparison, we rescaled the images to an identical pixel size. This was achieved by taking the ratios of the diameters of the full-disk $H\alpha$ images and then decreasing the size of the GONG solar disk in proportion to the Kodaikanal image.

Figure 4 shows the Kodaikanal and GONG $H\alpha$ images side-by-side. The large scale features such as plagues and filaments are visible in both images. The images obtained at Kodaikanal are another useful contribution for $H\alpha$ data coverage.

The line centered $H\alpha$ images show the limb darkening effect (Figure 5, top-left). In order to remove the limb darkening effect we first transformed the image from Cartesian to polar coordinates. The average radial profile was constructed by taking the median values in the azimuthal direction. The median value was used instead of the mean as plagues and filaments are high contrast features which could increase or decrease the values. The resulting profile was transformed to the Cartesian coordinate system and then interpolated to 2-dimensions to fit the solar image. The limb darkening image was normalized to unity and then the image was divided by the limb darkening image. This procedure removed the limb darkening effect.

In Figure 5 (top-right) we show a plot of the center-to-limb variation of the intensity observed in the $H\alpha$ image, taken from the central portion of the image (top-left). The plot in the bottom-right shows the profile after the limb darkening correction. The limb darkening corrected $H\alpha$ image is shown on the bottom-left in Figure 5. The fi-

nal image is written in FITS format with the appropriate header information.

We have scanned the $H\alpha$ line profile by taking images at each wavelength position at an interval of $0.1 \text{ \AA}$ near the line center and $0.2 \text{ \AA}$ away from the line center. These images are obtained by using the relay lens which magnifies the image so that one-quarter of the image is covered by the CCD. At each wavelength position we have taken the shifted images and using these shifted images we have obtained the flat-field image (Chae 2004).

Figure 6 shows the images taken at different wavelength positions on the line profile. In each of these images we have taken an area of 300×300 pixels in the quiet part of the Sun and then obtained the mean value of the intensity. We normalized the intensity to the maximum value in the data points.

Figure 7 shows the normalized intensity versus wavelength. A spectrum of the $H\alpha$ line profile obtained from BASS (http://bass2000.obspm.fr/solar_spect.php) is convolved with a Gaussian kernel with width ranging from 0.1 to $0.6 \text{ \AA}$ and a comparison of all the convolved spectra with reconstructed spectra from the observations is made, as has been done in Allende Prieto et al. (2004). The comparison shows that the BASS $H\alpha$ line convolved with a Gaussian with width $0.32 \text{ \AA}$ shows better matching with the reconstructed profile. This indicates that the passband of the filter is as large as $0.32 \text{ \AA}$ which is about $0.08 \text{ \AA}$ smaller than the measured value in the laboratory.

In Figure 7 we show the BASS spectra convolved with a Gaussian kernel with width $0.32 \text{ \AA}$ as a dashed line for comparison.

In 1863, Richard Carrington produced synoptic maps for the first time, which provide a 360° view of the Sun in 27 days. The synoptic maps/charts are 27 days of images remapped, put together and plotted in a longitude and latitude coordinate system.

Figure 8 shows the Carrington map for Carrington rotation No. 2159. There were no observations on 2015 January 23 and 24 but we padded the data gaps with data from January 22. While padding the data, we have taken care of the solar rotation. In the map, it is evident that most of the time an intermediate type of filaments exist, and one can see the active region filaments in only two locations. Plages with and without sunspots are also noticeable in the global view. During 2015, the southern hemisphere was predominantly active and plages appeared in the latitude belt 10° – 15° .

Now, we would like to show one of the preliminary results obtained with this telescope using observations in the $H\alpha$ wavelength. Active region NOAA 12259 was a moderate sized sunspot group that appeared on the eastern limb of the Sun on 2015 October 8. On 2015 January 14 there were two large and several small sunspots present in this active region. In the southern half of this active region there was a small sunspot with opposite polarity. This was surrounded by a large area associated with a sunspot group and filaments.

Figure 9 (top) shows the $H\alpha$ image in full-disk with the sunspot group and filaments. A magnified view of the active region in the $H\alpha$ wavelength along with a magnetogram of the same region taken from the Heliospheric Magnetic Imager (Scherrer et al. 2012, HMI) are also shown in the same figure (bottom panel). In the $H\alpha$ images, we observed frequent dark and bright ejecta at regular intervals over a period of 6 hours near the active region (in the location of ellipse). A more detailed study of this phenomenon is required for determining the underlying physical mechanisms.

6 SUMMARY

Since 1905, the Kodaikanal Observatory had a history of observing the Sun in white light, Ca-K and $H\alpha$ wavelengths to monitor solar activity. We have designed and installed an $H\alpha$ telescope for regular observations of the Sun, which has been operational since October, 2014. This telescope is another addition to the existing twin-telescope that provides full-disk images in Ca-K and white light.

The tunable Lyot filter allows observations at different wavelength positions of the $H\alpha$ line. Such a system can be used to construct dopplergrams, which we intend to provide along with full-disk $H\alpha$ images. This telescope is a valuable addition to the existing facilities designed to continuously monitor the Sun. The data are intended for public access and will be made available in a dedicated archive.

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