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Observations and analysis of NOAA AR 11429 at KSU-Astronomical Observatory

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ABSTRACT

We study the evolution of the sunspots in the recent super active region NOAA 11429, which spawned a powerful X5.4/3B flare on March 07, 2012 (2^{nd} on record occurred since 2010), associated with a wide and fast Coronal Mass Ejection (CME; Halo/070036) and a large proton flux event (6530 $p.f.u$). The sunspot group consists a rare example of "*Island Delta*" in $\beta\gamma\delta-$ magnetic configuration. This active region dominated the Solar activities on the northern hemisphere during the period March 03–15, 2012, of the present Solar Cycle 24, erupting 2 X-class flares, 13 M-class flares, and about 32 C-class flares.

We analyze white-light images, wavelengths around 540 nm, observed at the Astronomical Observatory of King Saud University (AOKSU). The observations are part of a campaign conducted locally since early 2012, for monitoring Solar activities on a daily basis. The observations and data reduction are presented and discussed. We examine the main properties of AR 11429 (i.e. structure, growth and decay) by computing its daily "area" and "tilt- & trend-" angles, and infer information about its development and dynamics. The area curve is found to show three distinguishable phases, nicely fitted adopting double-Gaussian distribution. A close relation between sunspot group area and tilt-angle with the major March 07 powerful flare can be noticed from the current results, that certainly necessitates deep and careful inspections through studying large sample of events.

The follow-up of the sunspot group the period it inhabits the Solar photosphere, permits exploiting the proper motion of four long-lived individual spots, as well as tracing the local surface differential rotation, found to be consistent with empirical results.

1. Introduction

Understanding the Solar active regions (ARs) and their related phenomena is one of the main quests of nowadays modern Solar physics. Although great achievements have been accomplished in performing Solar observations with both high angular resolutions and very short-time cadence imaging (i.e. ground-based telescopes such as: DOT, DST, STT, VTT, THEMIS, BBSO-NST; and space-based telescopes such as: SDO, SOHO, HINODE, RHESSI, STEREO), much still to be revealed, especially providing an understanding to the observational peculiarities of active regions and their associated phenomena (i.e. triggered physics, structure and dynamics). In particular, the accepted physical theoretical models can be questioned when dealing with special cases of complex sunspot groups such as "$\beta\gamma\delta$", those having a strong effect to the space weather and almost hosting the to-date observed most large solar eruptive events, especially energetic flares and fast-speed CMEs (Sammis et al., 2000). The magnetic fields in such sunspot groups are usually very complicated, structure and evolution (Liu and Y, 2001; Schmieder et al., 1994). Thus, observing and tracing the nature, growth, motion and decay of $\beta\gamma\delta-$ class groups might offer a unique opportunity to exploit and test the present understanding of the related processes that drive these Solar events (i.e. magnetic field-plasma interaction; coronal loops/prominences and reconnection events; magnetic flux tubes structure and emergence; turbulent convection; differential rotation).

In the present paper we report some first results of monitoring Solar activities on a daily basis. Indeed, starting early 2012 we conducted an observational campaign at the Astronomical Observatory of King Saud University[1] (AOKSU). Our project coincides with the rise in activity of the present Solar cycle (i.e. cycle 24). Based on observational data, such as the smoothed SS number and 10.7 cm radio flux values, the minimum of cycle 24 is estimated to have occurred around December 2008 with an expected next

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[1] The Astronomical Observatory at King Saud University was originally established and inaugurated in 1976. Moved to a new location by 1985, the telescopes (domes) have been installed on the roof of the College of Science. More details about the observatory can be found at the IAU Newsletter-issue 74; (Elmhamdi et al., 2011).

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maximum to be reached around May 2013, as reported by NOAA/ Space Weather Prediction Center,[2] though these timing predictions remain indefinite since it is subject to the adopted forecasting methodologies (Bhatt et al., 2009; Wang et al., 2009; Uzal et al., 2012).

We focus on investigating the main properties and development of the $\beta\gamma\delta$-class "NOAA AR 11429" as a special manifestation of the Solar activity during the period March 03–15, 2012.

The paper is organized as follows: In Section 2, we describe the data acquisition and we highlight the processing and data reduction steps. Based on AOKSU daily observations, the history and the main properties of the NOAA AR 11429 are outlined in Section 3.1 together with the magnetogram SDO/HMI images, while in Section 3.2 we analyze the behavior of the group in manifesting its presence the period it inhabits the Sun photosphere. The "area" and the "tilt- & trend-" angles curves are presented and discussed, emphasizing the different stages of the AR 11429 development, growth and decay (invoking also the magnetogram images). In Section 3.3, we evaluate the proper motion of four well recognizable constituent umbrae. The rotation angular velocity using AR 11429, center-of-mass, as a Solar photospheric tracer is also performed. We conclude, in Section 4, with a summary and conclusions of our findings and analysis, as well as briefly discussing future prospectives.

2. Instrument characteristics, data acquisition and reduction

For the purpose of the Solar long-term project and the current investigation, daily Solar full-disk white light images were locally observed, recorded and archived at the AOKSU.

The main instrumentation consist of a Zeiss-Coude'-Refractor equatorial Telescope, equipped with a 150 *mm* AS objective of 2250 *mm* focal length, and a digital Nikon-D3 camera (full-frame 35 *mm* sensor, 12 Mega-pixel resolution and pixel diameter of 8.4 μm) attached to the Telescope through a suitable adapter. A full-aperture Baader Solar Continuum filter is used in conjunction with a primary 2-inch Neutral Density (ND 1.8) Solar filter. The set-up is performed through a special adapter-ring that precisely fits and matches the telescope dimension (i.e. mounted onto the front end of the telescope). The Baader Solar filter permits only a very narrow spectral region, free of emission and absorption, around 540 nm with $\sim$10 nm bandwidth.

Performing observational test-analyses, some crucial parameters are determined. On the one hand, based on the camera main characteristics, an allowed upper limit for the lens-aperture is estimated to be about an f-stop: f/16, before significant diffraction effects take place (i.e. maximum tolerable circle of confusion). A typical value of f-stop of f/10 has been adopted for our whole observation period, respecting hence the diffraction limit of the Camera. on the second hand, we estimated the Telescope diffraction-limited resolution, for the permitted light-wavelength ($\lambda \sim 540$ nm) to be $\theta = 0.906$ arcseconds. The image scale of the Camera/Telescope combination is related primary to two main properties of the used system, namely: the Camera pixel-size and the Telescope focal length. For our set-up a value of ~ 0.77 arcseconds/pixel is found.

Furthermore, the simplest approach to matching a good system resolution is to have the single pixel size on the Camera sensor less or equal the diffraction-limited resolution of the Telescope. This is clearly achieved through our observational scheme, giving us confidence about the quality of our results and the subsequent treatment.

Local circumstances and some instrument characteristics are reported in Table 1.

[2] Avalaible at: <http://www.swpc.noaa.gov/SolarCycle/>.

2.1. Image processing and reduction

The processing of the raw images acquired by our instruments set-up involves the following standard procedure:

Stage 1 – Selection of the best observed images (i.e. where the Solar-disk's limb is sharp and the sunspot features are highly resolved and clear).

Stage 2 – Apply the standard data reduction steps, namely Bias, Dark and Flat-field corrections. A "Master" flat-field frame is calculated from a series of data frames obtained at an average of 10 to 20 different locations near disk center adopting the method based on the algorithm of Kuhn et al. (1991).

Stage 3 – Geometric correction: determining the correct orientation of the Solar images is a crucial issue for an accurate measurements of the heliographic coordinates of objects on the disk of the Sun. The camera is oriented parallel to the horizon and fixed, through a special adapter, while directing the telescope towards the Polaris. The set-up, camera + telescope, is then freely moved towards the Sun location depending on the observation time (usually around noon local time). The tracking system is then switched-on for the follow-up during the observation process. A further check is made by controlling the trajectory of the center of the Solar disk on the image frame with the telescope drive turned-off (known as drift method) such that the resulted motion path is east–west (i.e. the north and west cardinal points are respectively at the top and to the right). The correct direction of Solar north is finally obtained by combining the above described orientation method with the known daily Solar position angle "*P*-angle" of the Solar axis against the north–south in the sky (adopted from Solar Ephemeris Data).

Furthermore, precise estimate of a Solar event location involves the detection of the Solar disk and an evaluation of its center and diameter. This is done in the present investigation by using a binarisation of the Sun image to a given intensity threshold and determine the limb pixels. The best circle passing by contours thus defined is then computed[3].

Finally, and after adequate reduction and "*P*-angle" correction as pointed out above, we proceed by determining the coordinates of the events of interest that appear on the Sun-disk. This is established by fitting heliographic coordinates overlay grids on the treated images. Fig. 1 highlights three principle phases of the treatment analysis, for March 09, 2012 local observations, namely: **a** – original observed image. **b** – processed image (reduced and rotated). **c** – grid superimposed, that enables overlaying of latitude, longitude, central meridian and equator lines map. Moreover, we examine the processed images with respect to "*Limb-darkening*" phenomenon, Pierce and Waddelle, 1961, through analyzing the Solar center-to-limb intensity variation. The adopted method (Neckel and Labs, 1994; Neckel, 2003; Neckel, 2005) approximates the intensity ratio $I(\mu)/I_{center}$ by analytical polynomial functions.[4]

Fig. 2 highlights the limb-darkening correction for our March 09 observations. Here, we focus on the horizontal cropped-section parallel to the equator of the Sun-disk, where the sunspot group NOAA 11429 is located (see Section 3 for the descriptive details about the active region). The top panel, "a", displays the intensity curve variation along an horizontal slice-line crossing AR 11429 (dashed line). The bottom panel "b" reports the same image after an adequate "*limb-darkening*" correction, together with the resulted intensity profile along AR 11429 (same slice-line location as the top panel; dashed line). The expected intensity depression

[3] The routine used is implemented within *IRIS* astronomical image processing software (fully scriptable, allowing for automation to be built-in); http://www.astrosurf.com/buil/us/iris/iris.htm; Version 5.59 by Christian Bull.

[4] The algorithm describes the observed intensities across the Solar disk as a function of the heliocentric distance by fifth-order polynomials for 30 frequencies.