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VHE GAMMA-RAY ASTRONOMY IN INDIA: STATUS OF HIGRO AND PARTICIPATION IN CTA

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Abstract. Operating since 2008, HAGAR is the highest altitude gamma-ray experiment using the Cherenkov sampling technique. It is installed in the Himalayas, Nothern India, and constitutes the first phase of the Himalayan Gamma-Ray Observatory (HIGRO). HAGAR is oberving several Galactic and extragalactic sources, and results from Markarian 421 during the flare of February 2010 has been published. Results from Crab nebula are being finalised and upper limits on emission from pulsars have been presented. The second phase of HIGRO is the installation of the 21 m-diameter imaging telescope MACE in the near future, that may be followed by at least one more similar telescope. The Indian gamma-ray collaboration is also part of the Cherenkov Telescope Array (CTA) project, and is involved in site surveys in the Ladakh region (Northern India) for a possible location of CTA-North. Also, it is planned to participate in Monte Carlo simulations and calibration setup for CTA.

Keywords: gamma rays: atmospheric Cherenkov technique, methods: data analysis, R & D, telescopes: HAGAR, MACE, CTA

1 Introduction

Ground-based gamma-ray astronomy experiments in India have started as early as 1969 and these experiments were operationg in various parts of the country. Today, PACT (TIFR, located in Pachmarhi, Madhya-Pradesh) and TACTIC (BARC, located at Mont Abu, Rajasthan) are still in operation (Acharya 2005). These two experiments detect the Cherenkov light caused by relativistic particles of the gamma ray/cosmic ray induced showers, and are sensitive to the TeV domain. Another experiment, called GRAPES (located at Ooty, Tamil Nadu, South India), is a collaboration between TIFR and Osaka City University (Japan) and detect UHE gamma rays and cosmic rays through the relativistic secondary particles of the atmospheric particle/gamma-ray induced showers (Oshima et al. 2010).

2 Observations with HAGAR

Located at 4270 m amsl in the Ladakh region of the Himalayas, in Northern India (Latitude: $32°46'45''$ N, Longitude: $78°58'36''$ E), the HImalayan Gamma Ray Observatory (HIGRO) is the highest altitude ground-based gamma-ray observatory using the atmospheric Cherenkov technique. Phase 1 of HIGRO is the HAGAR experiment, operating fully since 2008. HAGAR is a sampling array of 7 telescopes, each one built with 7

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Table 1. Summary of results obtained from Crab Nebula for event triggers generated by at least six telescopes out of seven.

Data sets	C	no. of selected pairs	duration	Count rate	N_σ	$N_\sigma/\sqrt{h}$
Crab	1	17	10.4 h	5.1 $\pm$ 0.7	7.8	2.4
	2	20	12.6 h	5.7 $\pm$ 0.6	9.5	2.7

para-axially mounted 0.9 m-diameter mirrors, giving a total reflective area of $\sim 31\ m^2$. Relative arrival time of Cherenkov shower front at each mirror is recorded using TDCs and Flash ADCs, in order to obtain a timing precision below 1 ns, to sample the Cherenkov flash. Technical details as well as analysis procedure are given in Britto et al. (2011a).

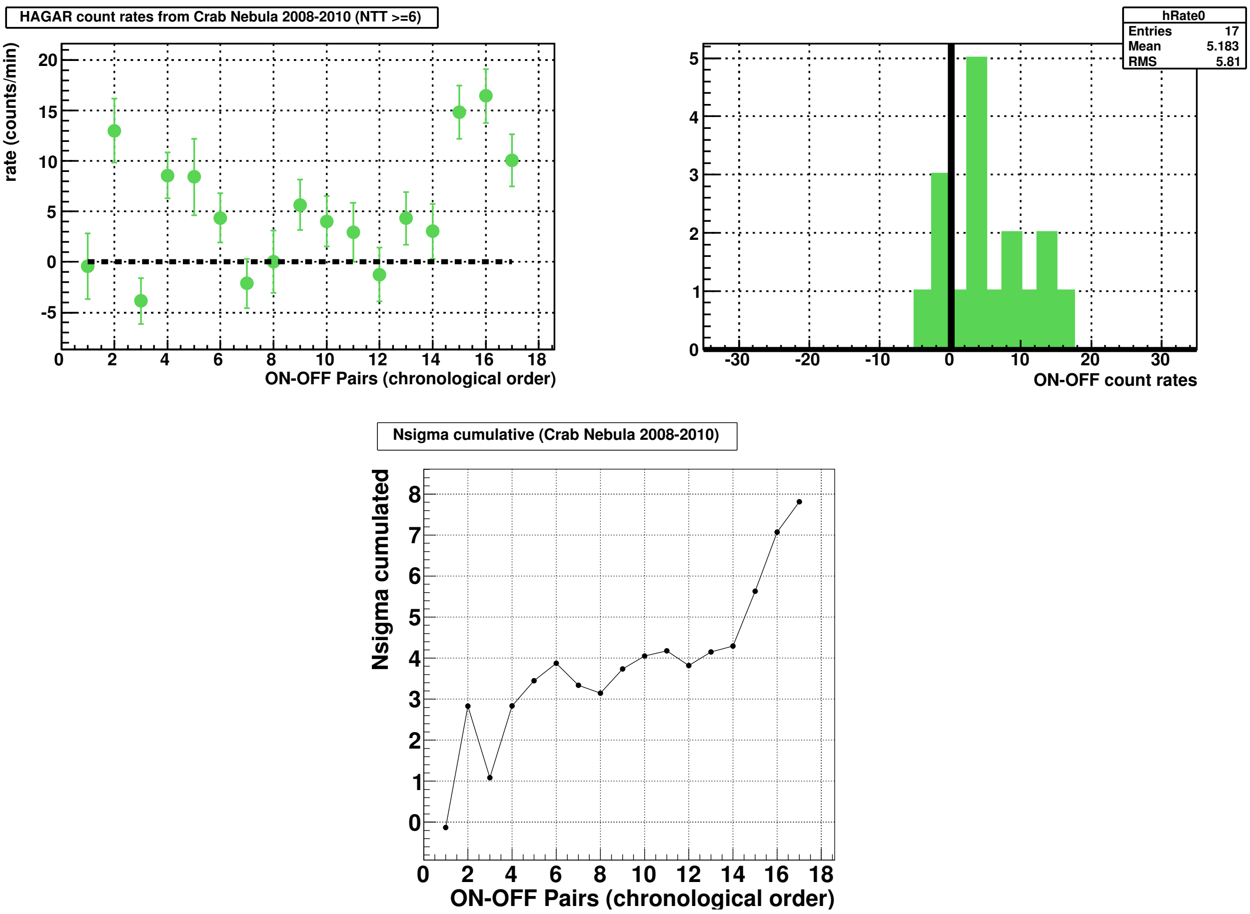

Fig. 1. Count rates of individual data sets (pairs), in chronological order, computed using C1, for the selected data set of Crab Nebula 2008-2011.

In order to remove isotropic emission due to cosmic rays, source observation region (ON) is compared with OFF-source region at same local coordinates. The analysis of data is based on the estimation of the arrival angle of the incident atmospheric shower w.r.t. the source direction. This angle – called space angle – is obtained for each event by measuring relative arrival times of the shower at each telescope. Signal is extracted after rejecting large space angle events, and following the process of normalisation of ON/OFF background events (at large space angle), to balance night sky background differences between both data samples. As the process of computing the normalisation constant 'C' is difficult due to the lack of statistics in the normalisation region, C is computed through two methods, as explained in Britto et al. (2011b). This gives the C1 and C2 values of C respectively, where C1 is the ratio of ON over OFF events in the tail of the space angles, where no gamma-ray s ignal is expected, and C2 is obtained by a more sophisticated method involving a χ^2 minimisation of the distribution of bin-wise ON/OFF ratios of the same normalisation region in the tails of space angles.

2.1 Observations on Crab Nebula

Between September 2008 and February 2011, more than 120 hours of data have been collected from Crab Nebula. Using an event selection procedure, we performed the analysis of 10.4 hours of Crab Nebula data from the period 2008-2011 (Britto et al. 2011b). Because of the light contamination of the bright star ζ Tauri in the field-of-view of Crab nebula, results are reported for events which trigger at least six telescopes out of seven.

An excess at $7.8\,\sigma$ is reported, corresponding to 5.1 ± 0.7 *counts min*$^{-1}$, while computing the excess using C1. An excess of $9.5\,\sigma$, corresponding to $5.7 \pm 0.6\,\mathrm{counts\,min^{-1}}$, is obtained based on 12.6 hours of data and using the normalisation constant C2 (Fig. 1 and Table 1). Monte Carlo simulations predict $2.4\,\mathrm{counts\,min^{-1}}$ for vertical showers for a 1 Crab flux (Saha et al. 2011). However, through our current updates in the analysis method, we are getting now closer to the predicted values. The energy threshold of this analysis is expected to be around 300 GeV.

2.2 Observations on pulsars

Search for pulsed emission at the known period has been carried out for several pulsars, and preliminary analysis have been presented (Singh et al. 2011). Our first target were the Crab and Geminga pulsars. Along with these sources, we now observe J0357+3206, J0633+0632 and J2055+2539, detected by the Fermi Gamma-Ray Space Telescope, since they have high confidence pulsed emission, rotational energy loss rate and flat emission spectrum. Improvements in the analysis are going on for the search of pulsed emission.

2.3 Observations on Markarian 421 during its high activity state

HBL BL Lac AGN Markarian 421 (Mrk421, z=0.031) has been observed during its high activity state, in February-April 2010. Data analysis was performed on data with a zenith angle less than 6 degrees. We reported an excess of 13.4 ± 1.05 *count min*$^{-1}$ at 12.7 σ based on 479 minutes of data during February 2010 (Shukla et al. 2012).

We show on Figure 2 (*Upper panel*) quasi-simultaneous light curves of Mrk 421, during February 2010, as obtained in X-ray and gamma-ray bands, using archived data from other observatories together with the present data. The light curves are plotted with one day binning (daily average) in the above figure. One zone homogeneous SSC model (Krawczynski et al. 2004) is fitted to the X-ray and gamma data to obtain the SED (Figure 2 *Lower panel*). This model assumes a spherical blob of radius R and uniform magnetic field B, moving with respect to the observer with the Lorentz Factor delta which is filled with a homogeneous non-thermal electron population. Best fit SED is obtained for the parameters given in Shukla et al. (2012).

3 Major Atmospheric Cherenkov Experiment (MACE)

Designed by the BARC group to combine the significant advantage of a high altitude and large collection dish (21 m-diameter), Major Atmospheric Cherenkov Experiment (MACE) is being contructed to enable high significance detection of gamma-ray sources above about 20 GeV (Figure 3 and Koul et al. (2005, 2011)). MACE is the second phase of HIGRO, and is expected to be installed at Hanle by 2013, next to the HAGAR array. It will have the following characteristics: a total reflective area of $\sim$330 m^2 from 356 mirror panels; f/1.2 m; FOV of $4^\circ \times 4^\circ$, a 1088 pixel camera. Detailed Monte Carlo simulations (using CORSIKA v6.735) are being carried out to understand the performance of the telescope. Simultaneous observations with HAGAR are expected, in such a way that the same event can be detected by both the experiments. MACE is expected to be operating at Hanle by 2013. We also expect at least a second similar imaging element to be installed later ne xt to the first element to perform stereoscopic observations (MACE II project).

Foundations for the first imaging telescope and building of the control room of MACE at Hanle are well advanced (Figure 3). Installation of MACE is now going on near the city of Hyderabad, South India (Figure 4). This will allow a phase of calibration and observations of Crab Nebula for a few months before the instrument is shifted to Hanle.

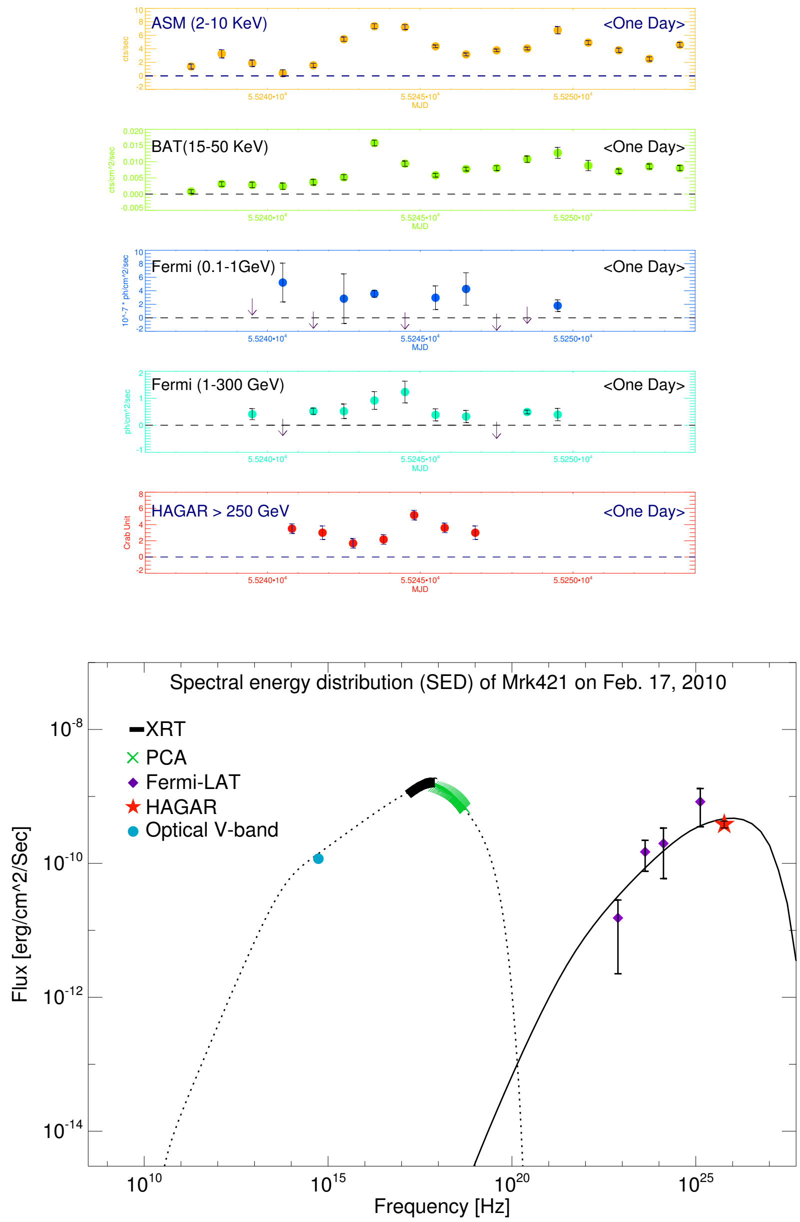

Fig. 2. Upper panel: Daily average light curve of Mrk421 during February 2010 (Shukla et al. 2011). **Lower panel:** Spectral Energy Distribution of Mrk421 of 17 February 2010 (Shukla et al. 2012).

4 Participation in CTA

The Cherenkov Telescope Array (CTA) project is an international collaboration involving 27 countries for the development of a ground-based VHE observatory of new generation imaging Cherenkov telescopes. Two arrays are expected to be installed, one for each Earth hemisphere (CTA 2010).

In 2010, India has joined the CTA collaboration, and has started to contribute with the search for a possible location of CTA-North in the Ladakh region of the Himalayas, in the State of Jammu and Kashmir, North India. We show on Figure 5 a map of the light pollution during the night, centered on North India. The site of Likir and Upshi were previously surveyed, and more recently the site of Thangchung Gari, near the village of Hanle, with better characteristics in term of night quality.

Thangchung Gari is located at 32°48′51″ N, 78°34′41″ E, altitude: 4435 m (Figure 6). Height difference of this area is 33 m for East-West, and 24 m for North-South, related to an area of more than 1.5 × 1.5 km.

Fig. 3. Left: The MACE telescope design. **Right:** Civil work at Hanle: MACE foundation and control room.

Fig. 4. Views of the ongoing installation of MACE near Hyderabad, Andra Pradesh, South India.

Obscuration by hills is within 9°. Himalayan Chandra Telescope (HCT) is operated at Hanle by Indian Institute of Astrophysics, Bangalore since 2001, at the top of a hill located few kilometres away from Thangchung Gari. At HCT, mean night sky brightness ($mag/arcsec^2$) is 22.14 ± 0.32 (U) and 22.42 ± 0.30 (B). The numbers of spectroscopic (photometric) nights are ~ 260 (190) per year.

Beyond the site surveys, we also expect to work on Monte Carlo simulations.

5 Conclusions

We have reported preliminary results from Crab nebula with HAGAR and detection of Markarian 421 during its high state activity. Several other Galactic and extragalactic sources are continuously being observed, and new data are under process. Furthermore, improvement of the method and development of new analysis softwares are still under going. Discrepancies between MC and data are being currently looked into in details and results will be updated in a forthcoming paper. With the coming up of MACE in the near future and then CTA, high quality observations are expected. These further results would significantly constrain theoretical models for various gamma-ray emitting sources.

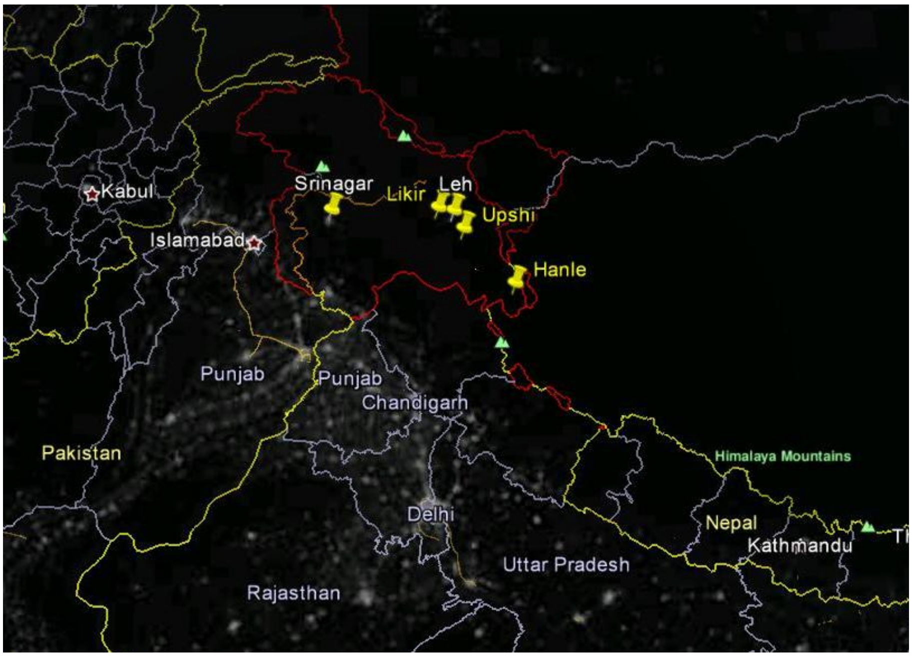

Fig. 5. Light pollution at candidate sites. Data collected by US Air Force Weather Agency, processing and image generation by NOAA's National Geophysical Center.

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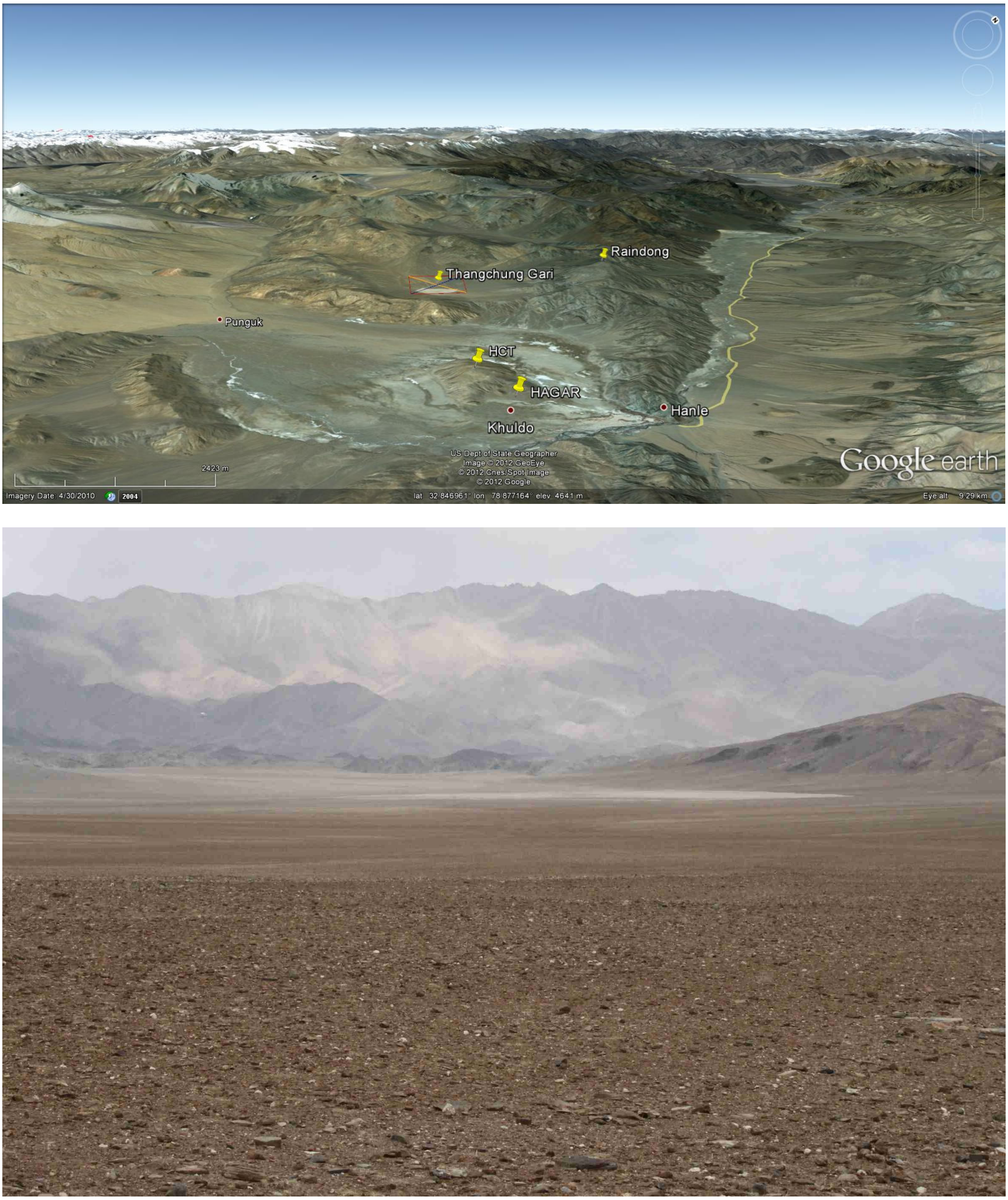

Fig. 6. Upper panel: Google Earth view of the Hanle region. **Lower panel:** photo of the site of Thangchung Gari (B.B. Singh).