**Goals of this Study**

- Verification of the TIPC laser performance parameters, against TMT requirements: specifically, power output and power stability, wavelength stability, laser beam quality, and laser beam jitter.
- On-sky testing of the laser to check the LGS photon flux under various laser light formats: circular and linear polarizations, each with and without repumping of the D$_2$ Na line.
- Determination of the laser coupling efficiency ($S_{in}$) to the mesospheric Na atoms for the conditions met during on-sky testing, and estimation of the size for an on-axis-ancestral square size LGS (this last point required use of an available physical model of the laser).

**Location and Setup**

- All tests were conducted at the XingLong Observatory of the National Astronomical Observatories (Chinese Academy of Sciences) near Beijing, China.
- The coordinates of the testing sites are: 40°23'30.6"N, 117°34'52.0"E, 960 m altitude.
- At this location, and as of Jan 2015, the strength of the geomagnetic field, inclination and declination of the geomagnetic field lines, are on the mesospheric Na layer. (Ref #1).
- The equipment includes: 1) The TIPC laser system (Fig. 1), a Lidar system for monitoring the Na atoms column density, and a receiving optical telescope for the imaging of the LGS and reference natural stars (Fig. 2).

**Introduction**

Hereby, we present results from on-sky and laboratory testing of a quasi-continuous-wave (QCW) pulsed laser, based on a Sum-frequency-generation (SFG) approach, designed and built by the Technical Institute of Physics and Chemistry (TIPC) and intended for application in a Laser Guide Star (LGS) system. China is a partner of the TMT International Observatory and has shown strong interest in providing the laser units required to support the TMT’s adaptive optics system. The results shown in here are from a prototype laser built in 2014, tested in Dec 04-Feb 05, and intended to demonstrate the ability to meet the TMT performance requirements in terms of: power output, wavelength stability, laser beam quality, laser beam jitter, as well as laser coupling efficiency to the sodium atoms in the mesosphere relating to the LGS photon flux.

**Laboratory Tests Results**

- **Power Output & Power Stability:** The TIPC laser includes a diagnostics & monitoring stage to help continuously monitor, among other parameters, the laser power its wavelength and beam shape. The power monitor instrument is a ThorLabs model PM100D equipped with a sensor model 5120C. The 5120C sensor has a wavelength range coverage of 400 nm to 1100 nm and accepts a power inputs in the range of 50mW to 130mW (a 3.4 %/µW of the 599m laser beam power is diverted into the power monitor sensor).

- Several long-term tests, 4 hours up to 12 hours, were run to check the magnitude of the 589nm laser beam power and its stability. Fig. 3 shows, a 5% window time series at 3 ms time resolution and statistical histogram, of one of such tests. In the result shown below the power statistics, operating the laser at 800 MHz, $P_{beam}$ = 25.56W, $\nu_L$ = 0.47W, 3σ/$P_{base}$ = 5.5%, range = 2.21W, range (99%/1-mean) = 8.6%. These statistics are similar to those of longer tests. The TMT requirement for the lasers power output is $P > 21.6W$ (using D2b re-pumping), short-term (or pulse-to-pulse) power fluctuations $< 6\%$ (with a goal of $3\%$) and long-term power fluctuations (in 12-hours) better than $15\%$ (with a goal of $6\%$).

**Wavelength Stability:** The TIPC laser wavelength is continuously monitored using a HighFinesse GmbH’s WS-7L wavelength meter. This instrument works in the range 350-1120 nm, with a relative accuracy of 1 part in $10^5$. At the wavelength of the laser (589 nm), this translates into a frequency accuracy of ~ 51 MHz ($\nu_{589}$ = 589.31nm/1.27, with c the speed of light). Fig. 4 shows the time series of the laser stability (in terms of frequency) with respect to the D$_2$ Na line. The TMT specification ask for a frequency stability of +/− 200 MHz (this translates into about 0.231 pm wavelength stability around the D$_2$ Na line). The goal is +/− 100 MHz (0.116 pm).

**On-Sky Tests Results**

Statistics of the absolute photon flux return (in millions of photons/nm/s) for the Test #2 the night of Jan 31st to Feb 1st, 2015. The TIPC pulsed laser was operated at 800 MHz PRR, with circularly polarized laser light and switching between D$_2$ Na re-pumping OFF and ON. The test was run for various levels of laser Power from 5W up to 20W of generated power.

The Na atoms column density was monitored during the test time using a collocated Lidar (optical system TOTOSi), and the atmospheric transmission (Ta) is 0.75 and the atmospheric transmission (Ta) is 0.70, and LGS spot size in the mesosphere is 4 arcsecs FWHM. These information was used to compute the laser coupling efficiency.

**Comparison of Laser Coupling Efficiency between**

A Physical Model of the Laser and Observations

A physical model of the laser (Rochester et al., 2012) using a true pulse shape of the TIPC laser setup, with the known magnitudes for the Na atoms column density, beam transfer optics throughput, atmospheric transmission, laser generated power and LGS spot size, was run to as estimate the photon flux return of the LGS spot. The results (MODELED) agreed within 10% with the median results obtained during the on-sky test observations (OBS).