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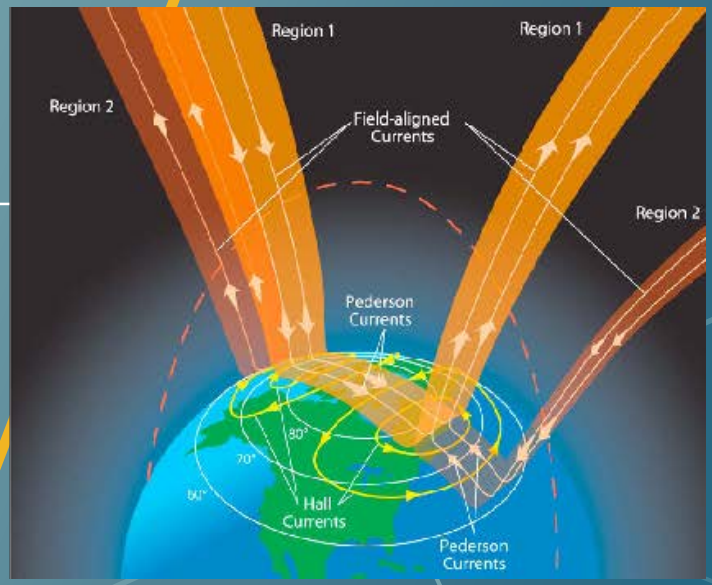
Laser Investigation of the Mesospheric Magnetic Field in the Auroral Zone



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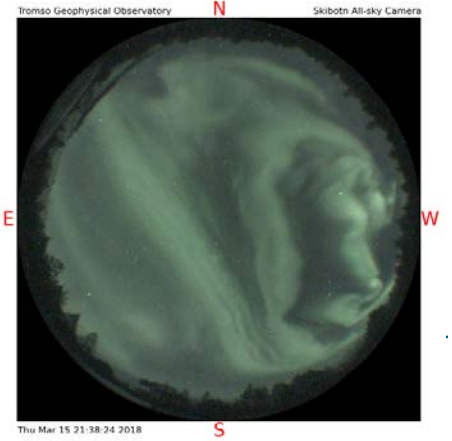
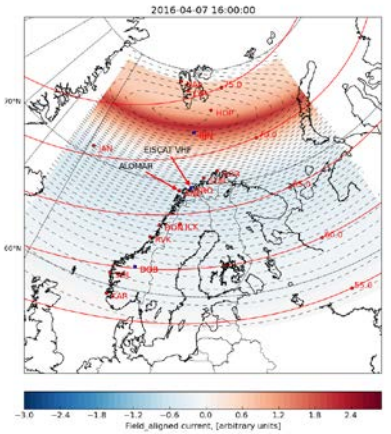
Motivation





The possibility to measure magnetic field in the mesosphere creates an opportunity to make

- long term geomagnetic measurements close to the source of external field variations such as electrojets and Birkeland currents
- long-term, in-situ measurements on the boundary to space at an altitude otherwise only accessible by means of rockets for point measurements.

The project is very much about establishing a proof of concept, and if successful a completely new type of magnetic field measurements is opened for.

The mesospheric sodium layer

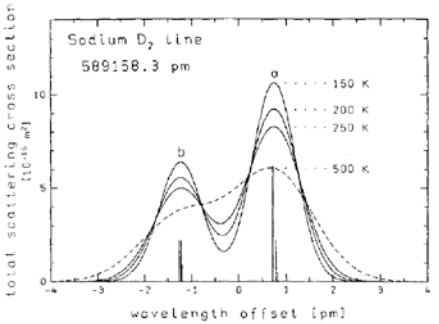
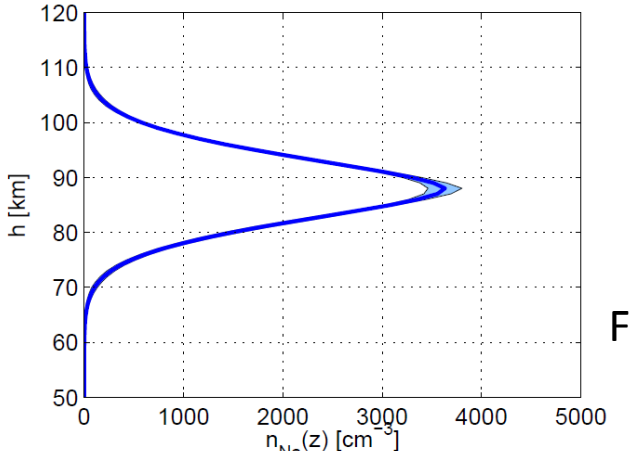


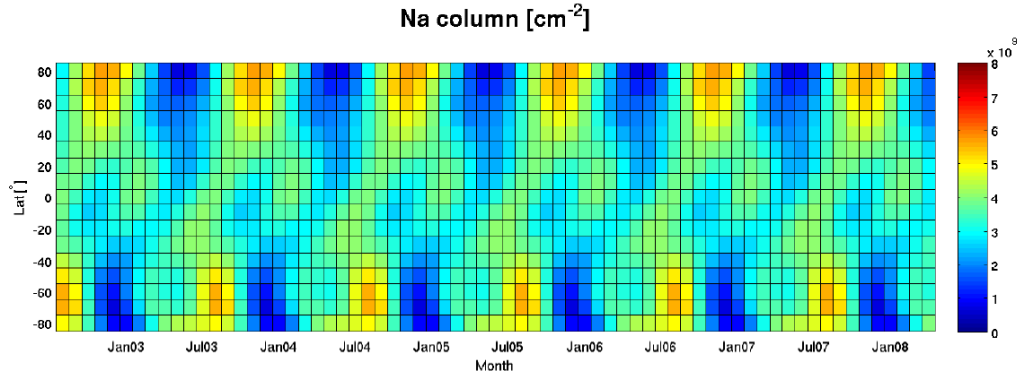
Fig. 2. Variation of the total scattering cross section in the Na hyperfine structure of the D_2 resonance transition with atmospheric temperature.

- Between 80 km and 110 km
- From meteoric ablation (between 98 km and 101 km)
- Lifetime ~ 6 days

Fricke and von Zahn, 1984



From Fussen et. al. 2010



Dunker et. al. 2013

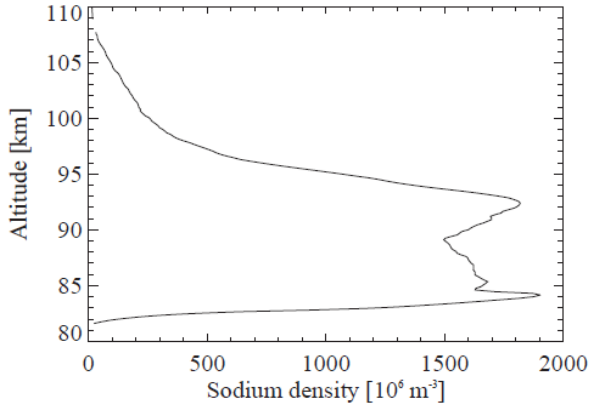
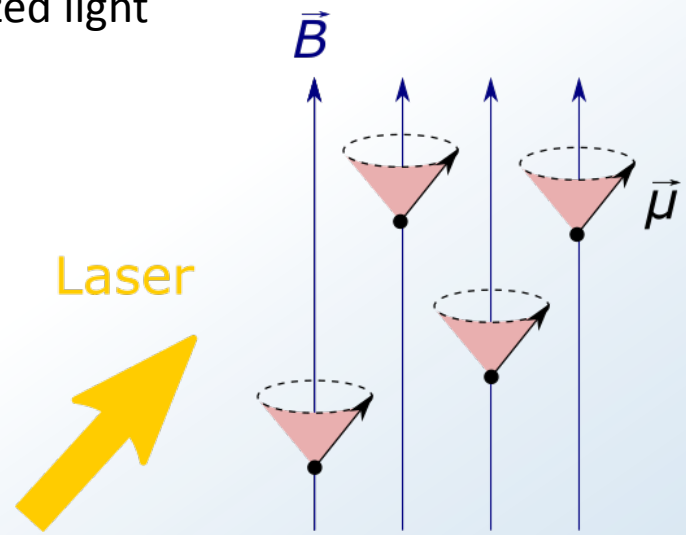


Fig. 2a. Sodium number density on 19 December 2010, 00:38:30 UT. Average of 30 s. Beam pointing: zenith. The sporadic meteor trail at 84 km was observed for less than a minute.

Optical magnetometry

- Precession spin polarization by circular polarized light
- Uses alkaline metals



Torque on the atom

$$\vec{\tau} = \vec{\mu} \times \vec{B}$$

Larmor precession frequency

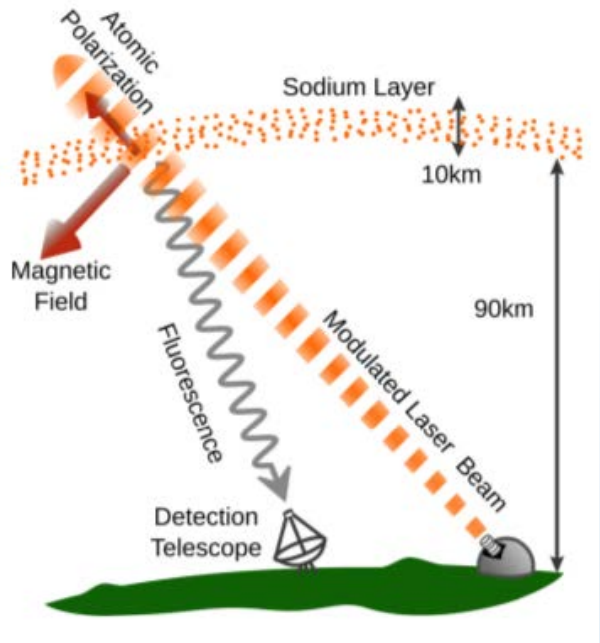
$$f_L = \gamma B$$

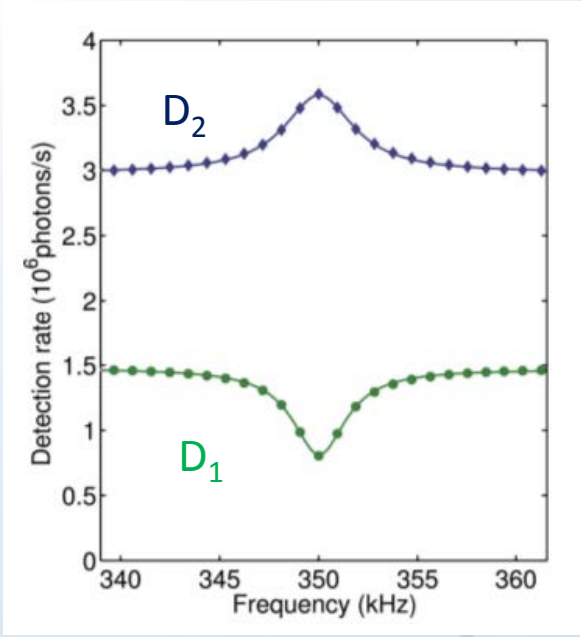
γ – gyromagnetic ratio
6.99812 Hz/nT for sodium

- Pulsing light with Larmor frequency firs suggested by Bell and Bloom (1961)
- Effect is largest perpendicular to the magnetic field.

Optical magnetometry in the sodium layer

- First proposed by Higbie et al. (2011)
- Using laser guide star (LGS) for measuring magnetic field strength in the sodium layer
- Measure spin precession of sodium atoms by spin-polarizing them.
- Sweep laser pulse frequency close to Larmor Frequency (50 000 nT – 350 kHz)
- Resonance manifest itself as a sharp increase in the return fluorescence for the D2 line of sodium.





Source: Higbie et al. 2011

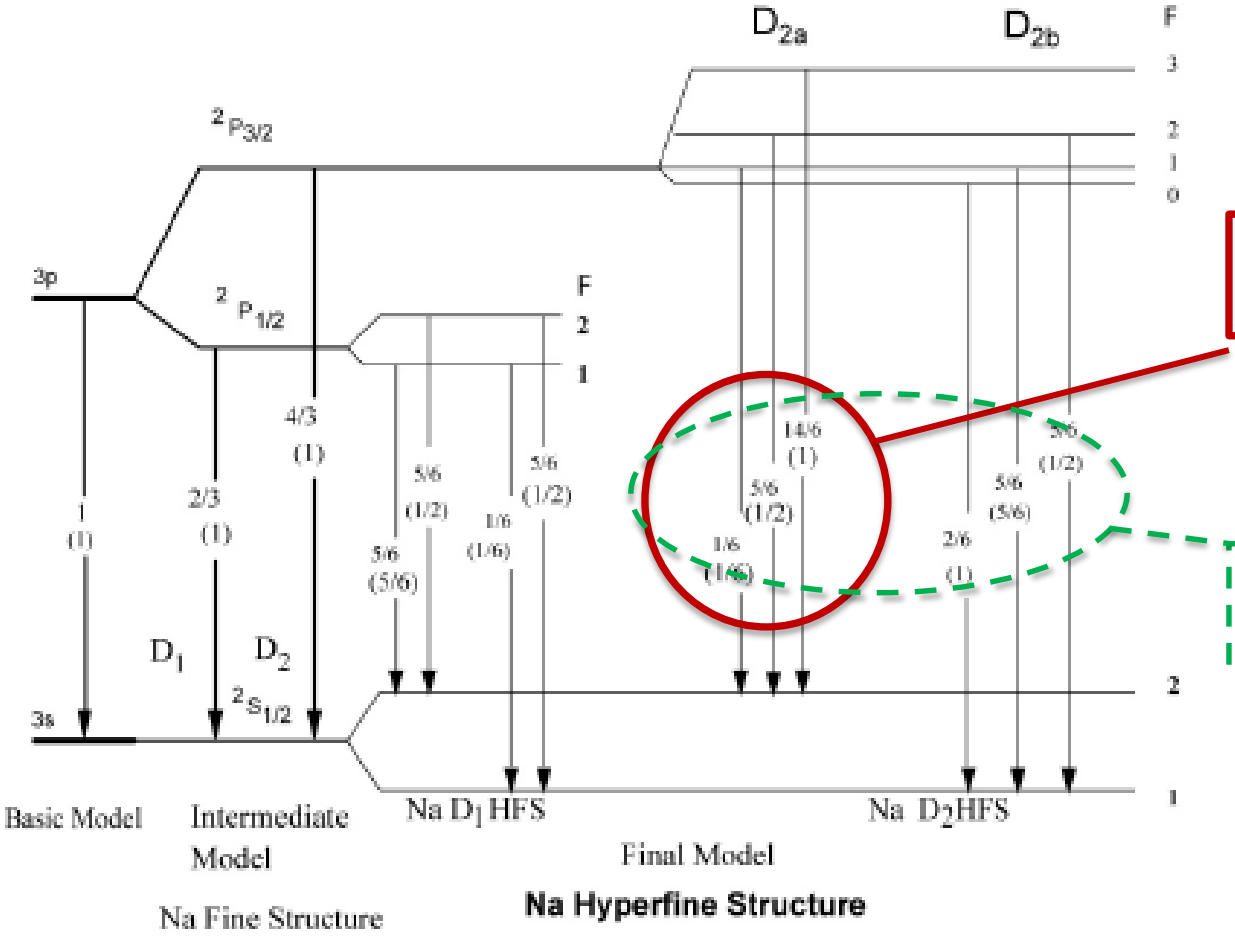


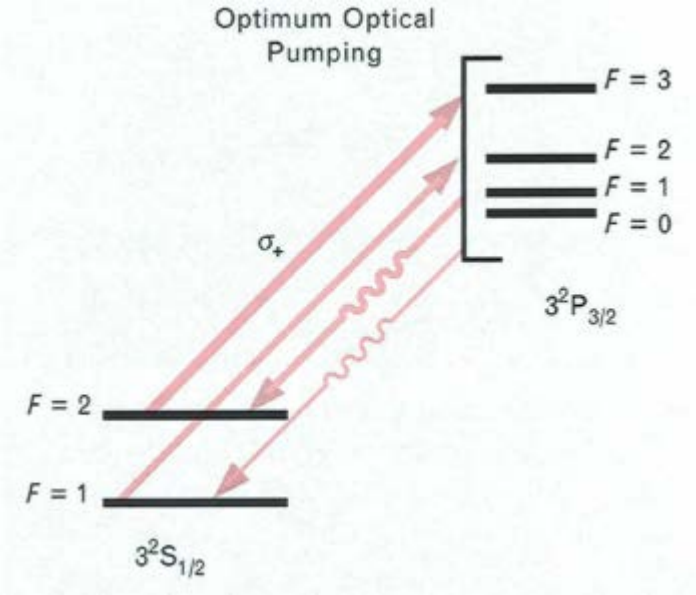
Figure 3.2: The energy level diagram of the sodium atom. The numbers given for each transition are relative line strength and relative Einstein coefficient (bracketed).

Laser pulse frequency = Larmor frequency

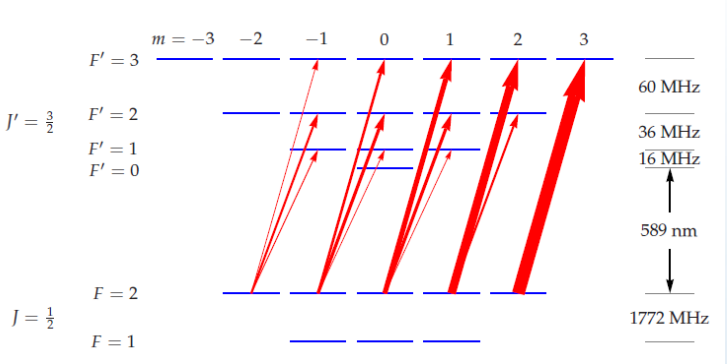
Any other Laser pulse frequency

Heinrich, 2007

Optical pumping of Na with circularly polarized light σ_+



Jays 1991



After several (~20) excitation/decay cycles, most Na atoms will reside in the hyperfine ground state F = 2 (Jeys, 1991), which has a larger cross-section.

Because of the selection rule ΔF = -1, 0, or +1, we then only use the three excited states F = 1, 2, 3, and the ground state F = 2.

However, all Na atoms precess around the geomagnetic field with the Larmor frequency. Which cause forbidden transitions bringing sodium to F=2 to F=1 This can be mended by modulating the signal with the Larmor frequency, achieving resonance and polarizing the atoms.

Rochester 2012

Proven technique: Kane et. al. (Arizona)

Kane et al., 2018 (2016 arXiv)

- Using a 20 W Fasor (Denman et al., 2004) originally built as a Laser Guide Star prototype. (average power used 7 W)
- At Kuiper telescope, Mt. Lemmon, Arizona. (1.55 m)
- 90 min, 162 nT/sqrt(Hz)
- 60 deg angle to B

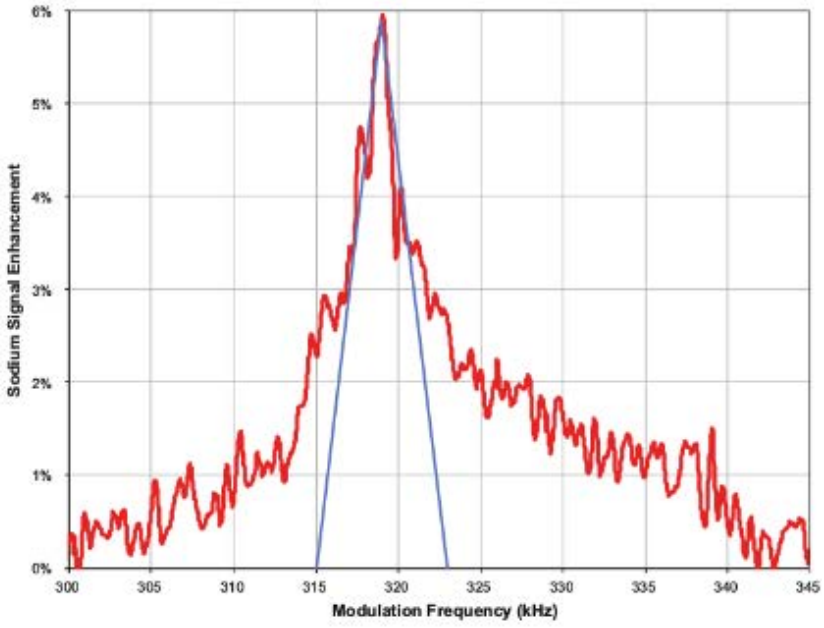


Figure 2. Left, the Kuiper Telescope dome on a moonlit night, with guidestar in operation. Inside the dome, on the right, the Kuiper Telescope used to receive the signal from the sodium layer.

Proven technique: Bustos et. al. (La Palma)

- Recently another group affiliated with ESO has succeeded with measurements at La Palma (Bustos et al. 2018, arXiv)
- 20 W laser
- 40 cm aperture Schmidt-Cassegrain
- 10 min, 28 nT/sqrt(Hz)
- 90 deg angle to B

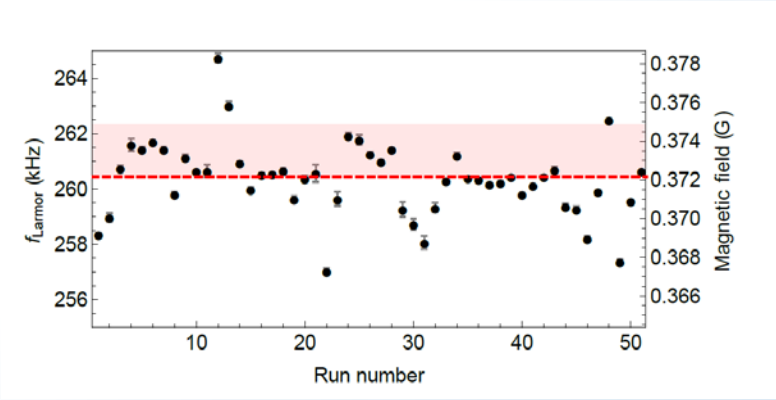
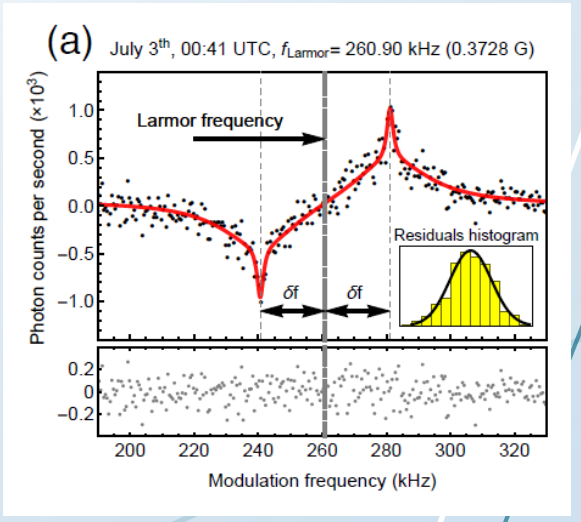
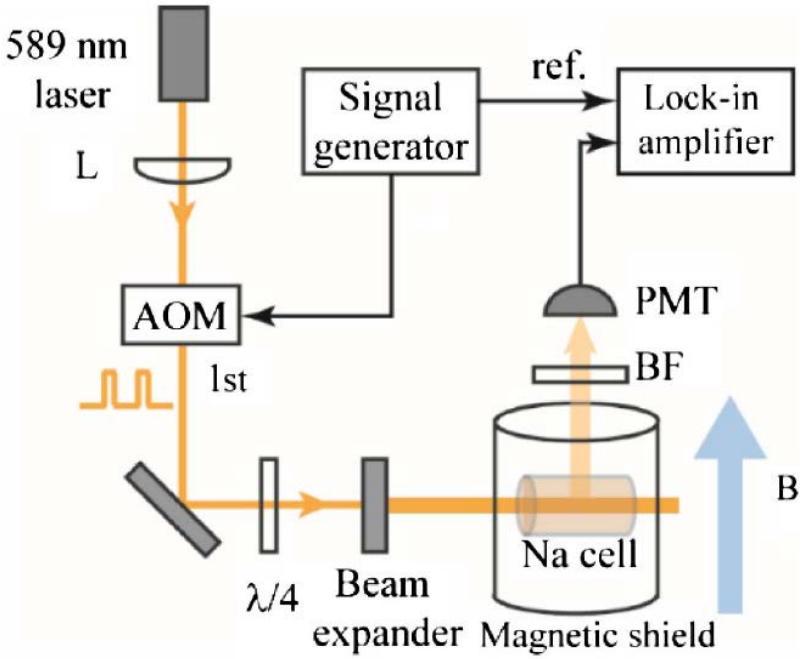


Figure 7: (Left) The 20-Watt laser projector of the European Southern Observatory laser guide star system. (Right) The observing telescope placed next to the laser projector for detection of LGS brightness enhancement.



Laboratory experiment: Fan et.al 2018



- Sensitivity 150 pT / sqrt(Hz)
- Raman fiber amplifier laser

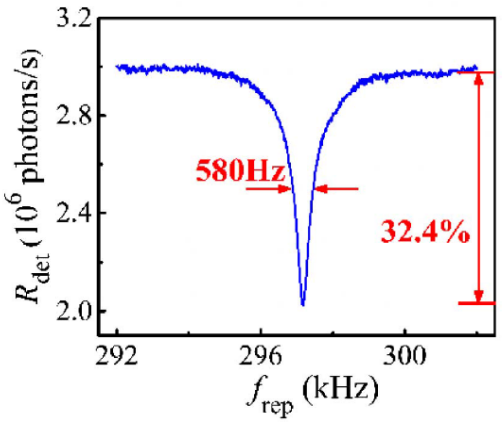
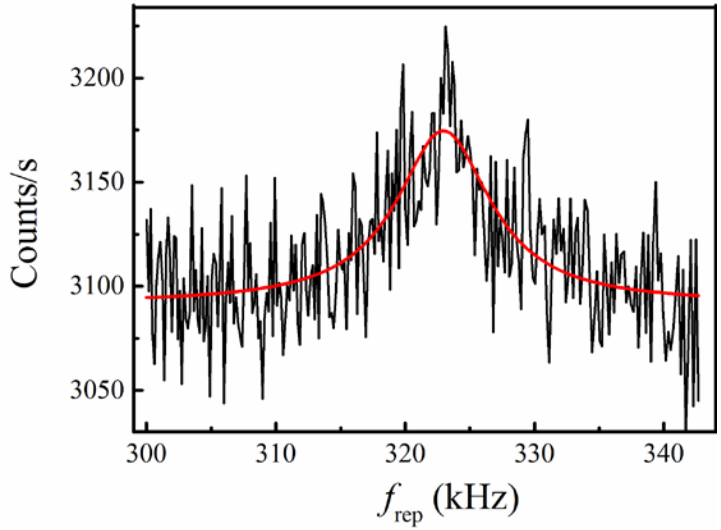
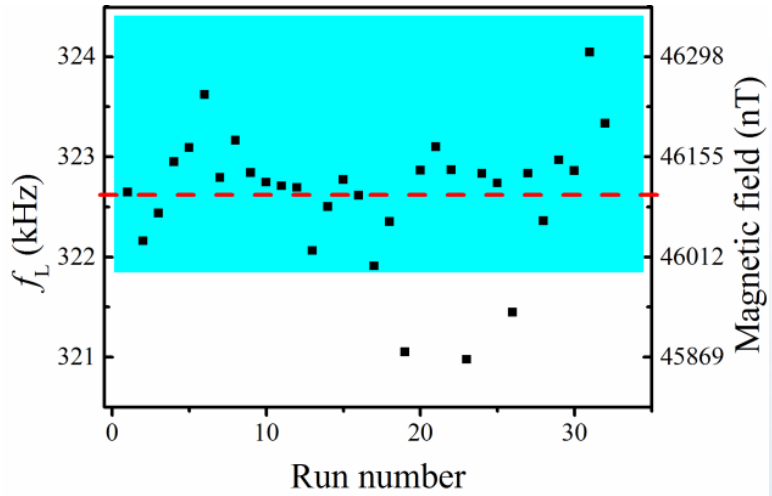
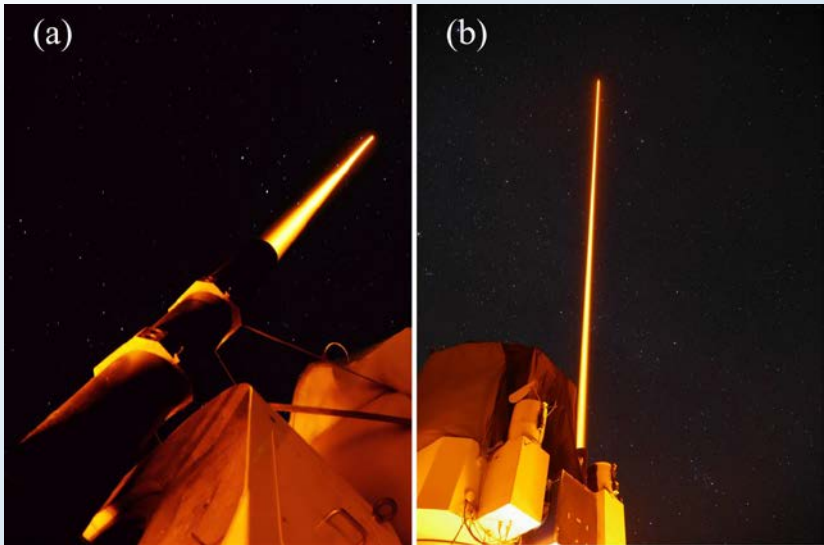


Fig. 2. Typical magnetic resonance signal of Na D_1 line, where the peak laser intensity is 65 W/m^2, pulse duty cycle is 17.5%, and cell temperature is 60°C.

Fan et. al. 2019

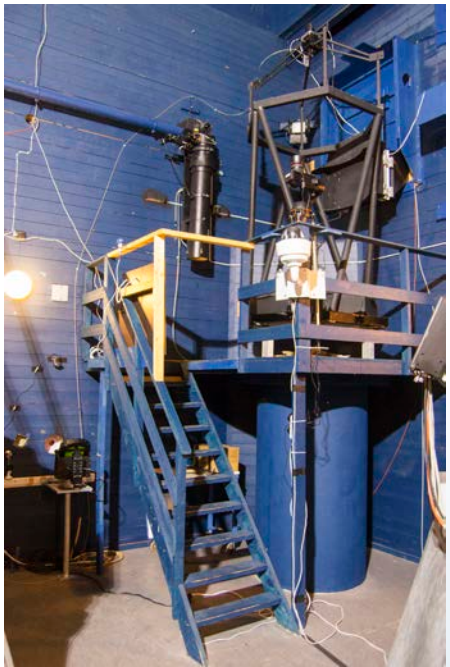






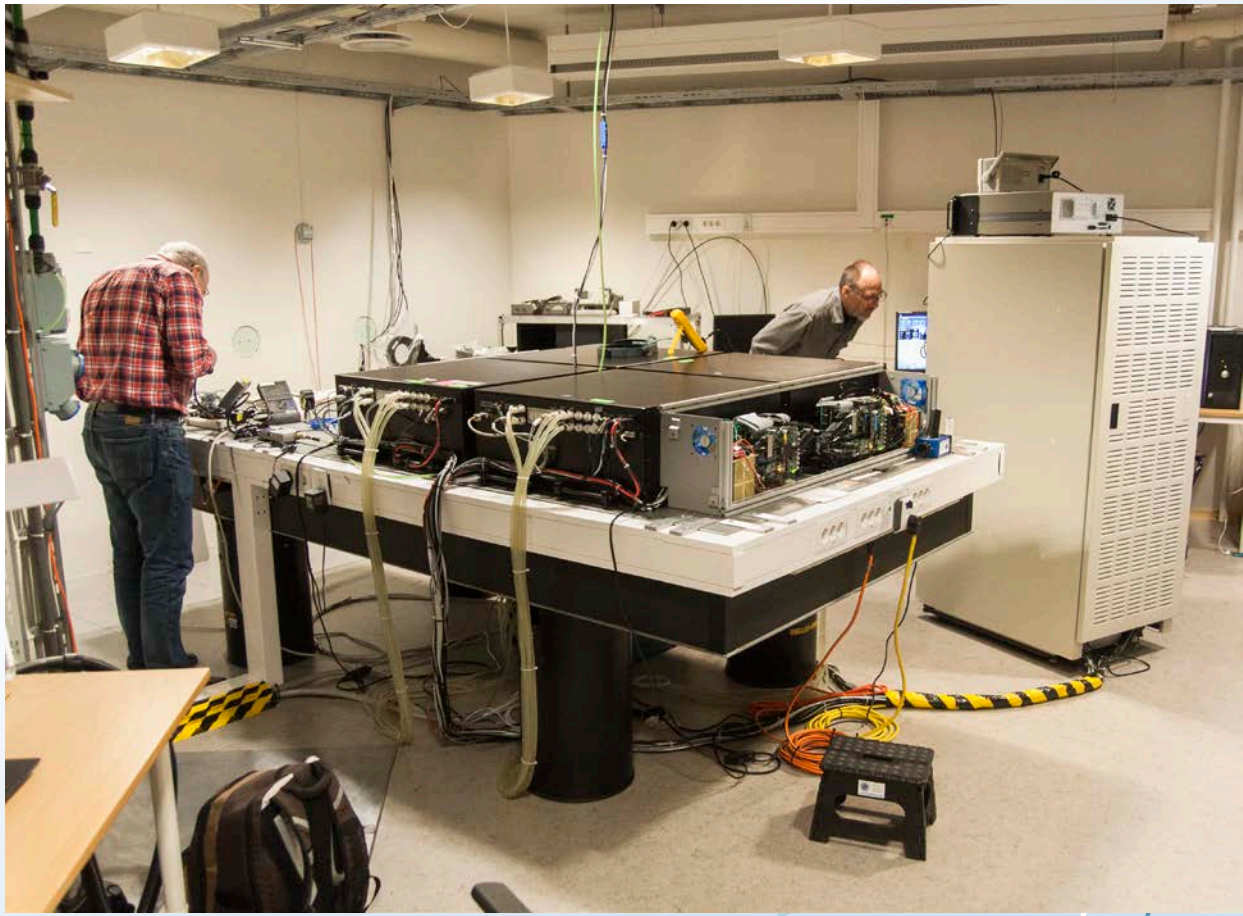
Alomar facility

- Located at Andøya, 69°17’ N 16°01’ E
- RMR Telescope 1.8 m diameter (owned by IAP) *f* = 8.345 m
- Can tilt up to 30° off zenith
- Magnetic Inclination 78°.

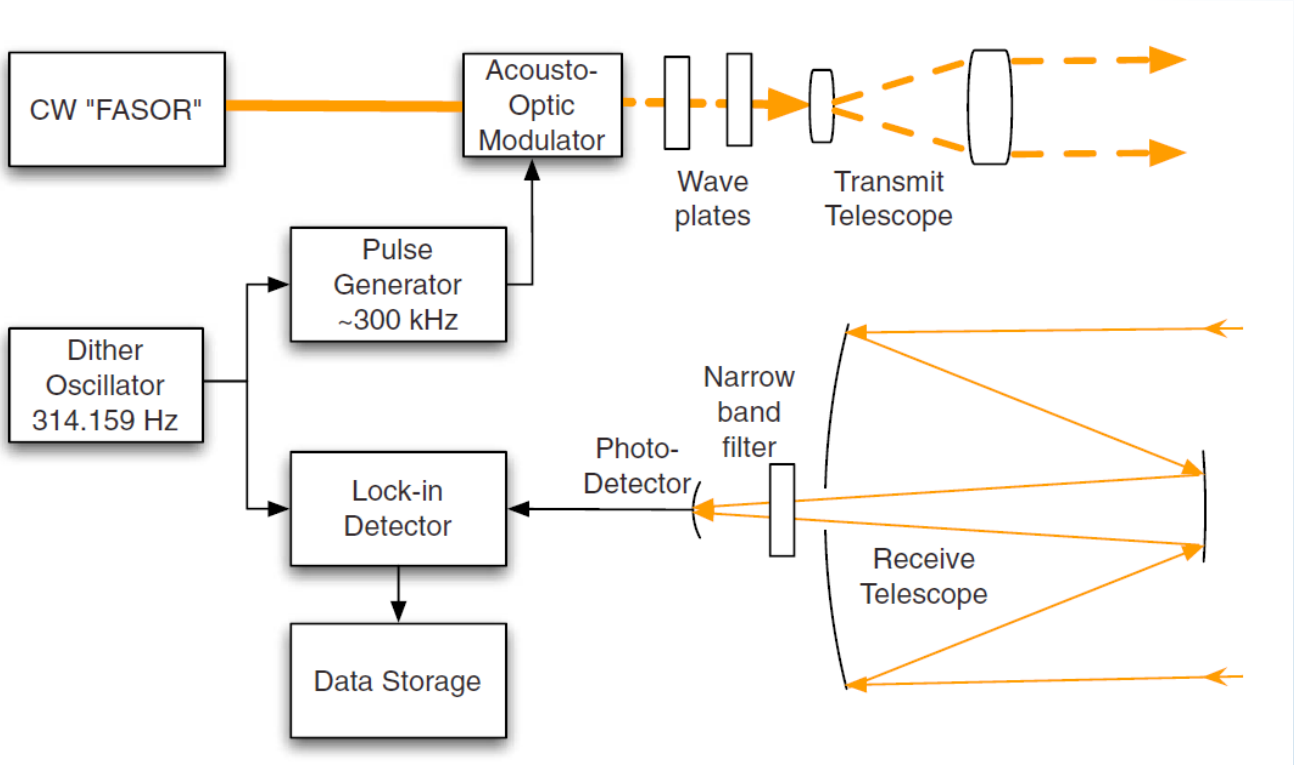


Fasor (Frequency Addition Source of Optical Radiation)

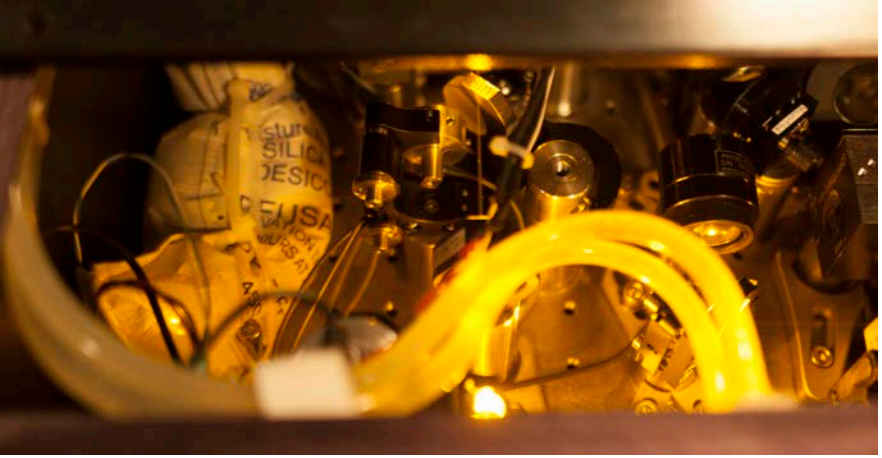
- Theoretical power 20 W
- Wavelength 589.159 nm
- Frequency summing 1319 nm and 1064 nm
- Concept prototype guidestar laser
- We plan 10 W 0.2 – 0.5 duty cycle, with sweeps between 340 and 380 kHz

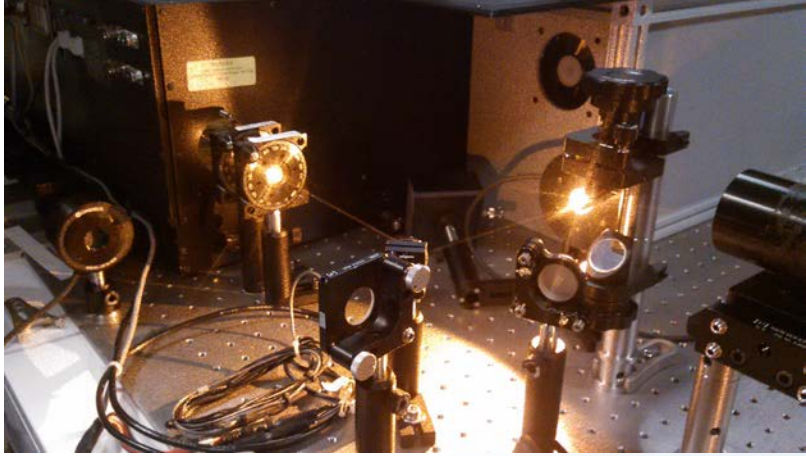


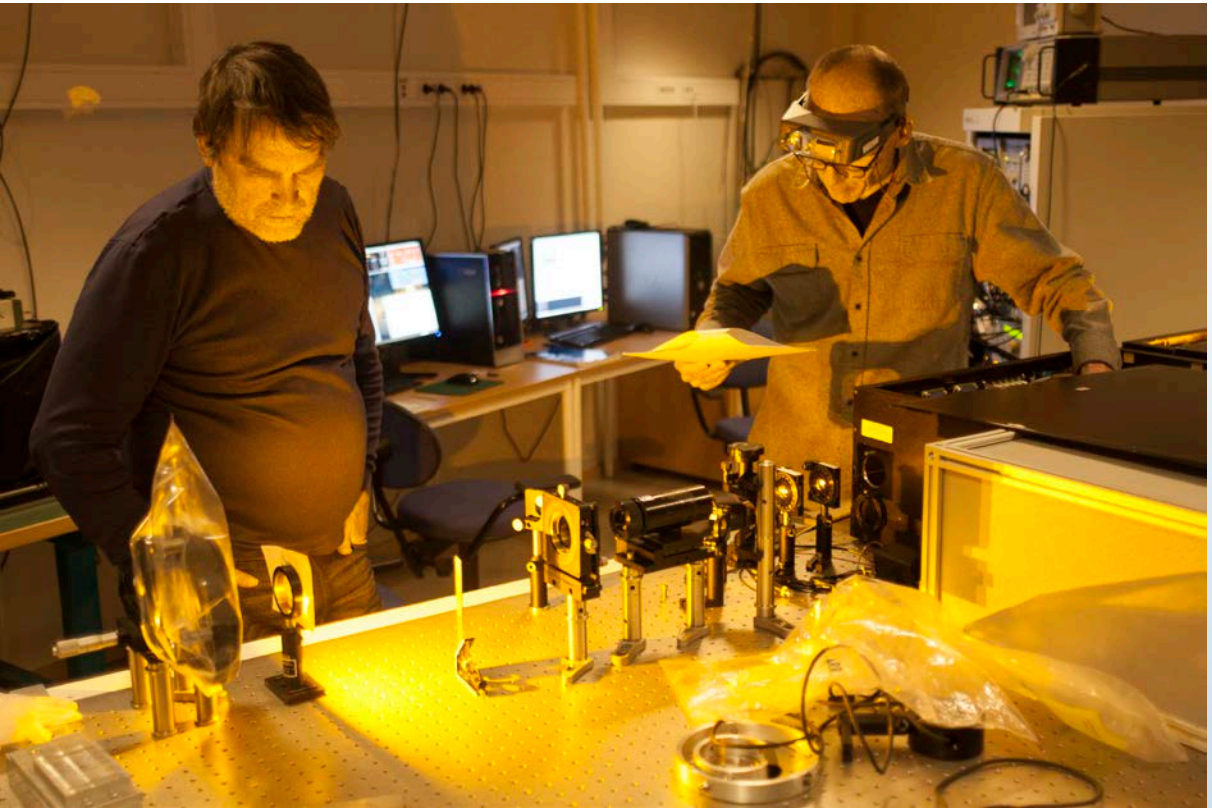
Measurement setup



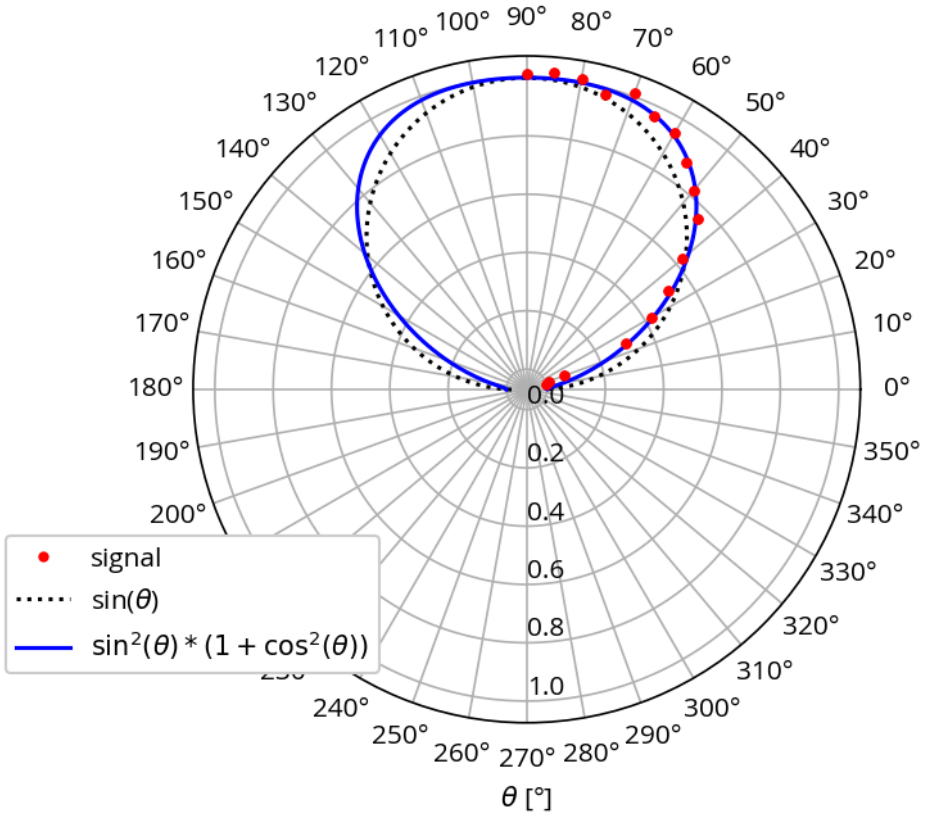
From Kane et al., 2018

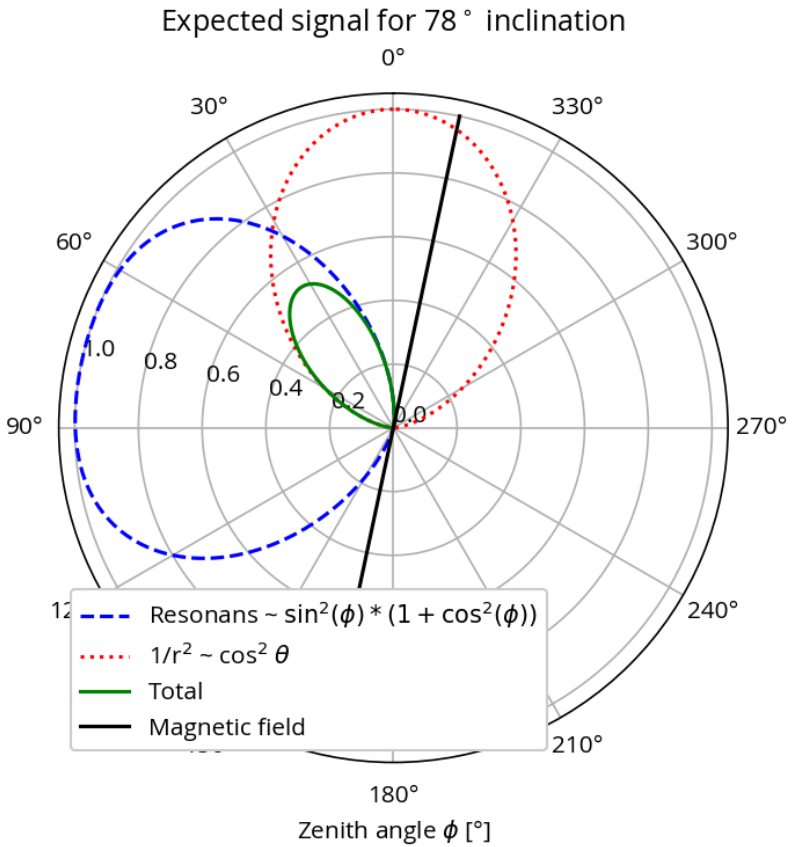






Angular dependence

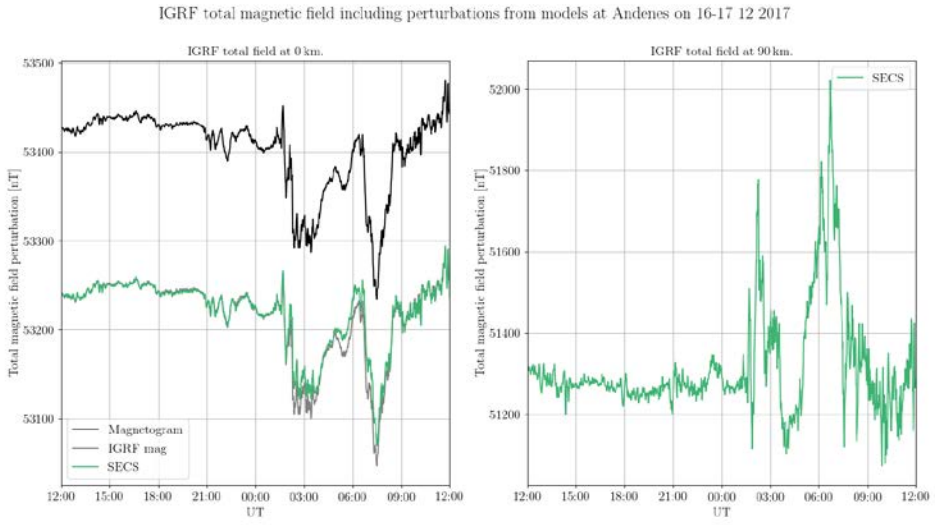


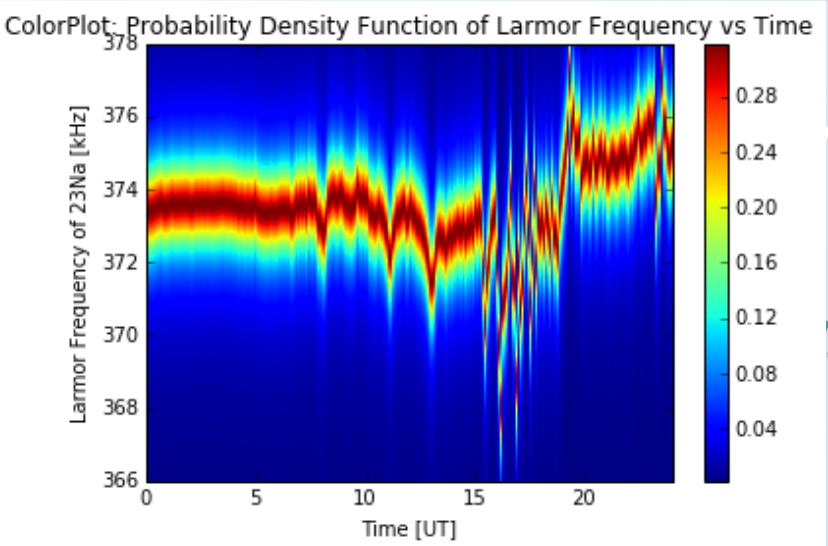


Angualar dependence of absorption in cesium measured in cooperation with Volkmar Schultze, Institute of Photonic Technology (IPHT), Jena. Blue curve: formula taken from Cassimi et. al. J. Phys. II (1991)

Current activety

- The necessary hardware for measurements are in place and operational.
- Tools for modeling the magnetic signature at 90 km altitude are in place.
- We are awaiting dark skies to commence with actual measurements of the magnetic field, which will start in late September/ early October 2019.





Thanks!