ESO fiber lasers program

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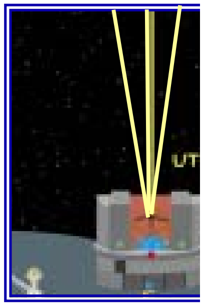
- For MCAO and next generation LGS-AO systems, ESO strategy is to develop 10W CW fiber lasers at 589nm, together with industry.
- This strategy has created an internal effort on fiber Raman lasers and a collaboration agreement with LLNL to develop a sum frequency fiber laser

Two concepts of Solid-State Fiber Laser Development



1. Collaborative effort with LLNL for a Sum-Frequency Fibre Laser (see other presentations)

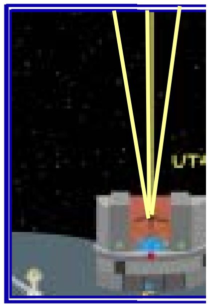
$$\frac{1}{1583\,\text{nm}} + \frac{1}{938\,\text{nm}} = \frac{1}{589\,\text{nm}}$$

2. Frequency-Doubled Fibre Raman Laser (done in house + cooperation with European industry) ESO Patent obtained at EPO, Sept 18th 2002

$$2 \leftrightarrow \frac{1}{1178\,\text{nm}} = \frac{1}{589\,\text{nm}}$$

- *For each path a low-power breadboard demonstrator is developed*
- *The most successful approach will be selected for engineering with industry*

13 Telescopes using or planning LGS

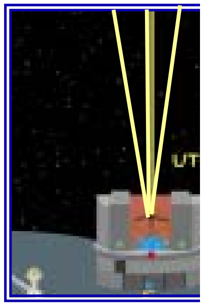


Site	Tel dia	No. actuators	1st light	Laser type
SOR	1.5	241	<`92	10KHz Rayleigh (CuV 513nm), 200W
Lick Obs	3	69	`96	10 KHz Sodium dye, 13W
Calar Alto	3.5	97	`98	CW Sodium dye, 4.2W
Mt.Wilson	2.5	241	`99	300 Hz Excimer Rayleigh,420nm 50W
Keck II	10	349	`01 (`**03**)	30 KHz Sodium dye, 20 (14) W
SOR	3.5	900	`02	25W CW Sodium Solid State Laser
MMT	6.5	300	`02	$\mathrm{CaW0_4}$ Sodium Raman, 10W
ESO-UT4	**8**	**196/60**	**`03**	**CW Sodium dye >10W**
Gemini-N	8	177	`03	Pulsed Sodium 10W Solid State Laser
ARC	3.5	97	`04	840 Hz Sodium Sum Frequency, 8-10 W
LBT	8	900 MCAO	`04	Sodium or Excimer Rayleigh TBD
Gemini-S	8	MCAO	`05	5x10W Sodium Solid State Laser
SUBARU	8	36/90	`04	CW Sodium dye >4W

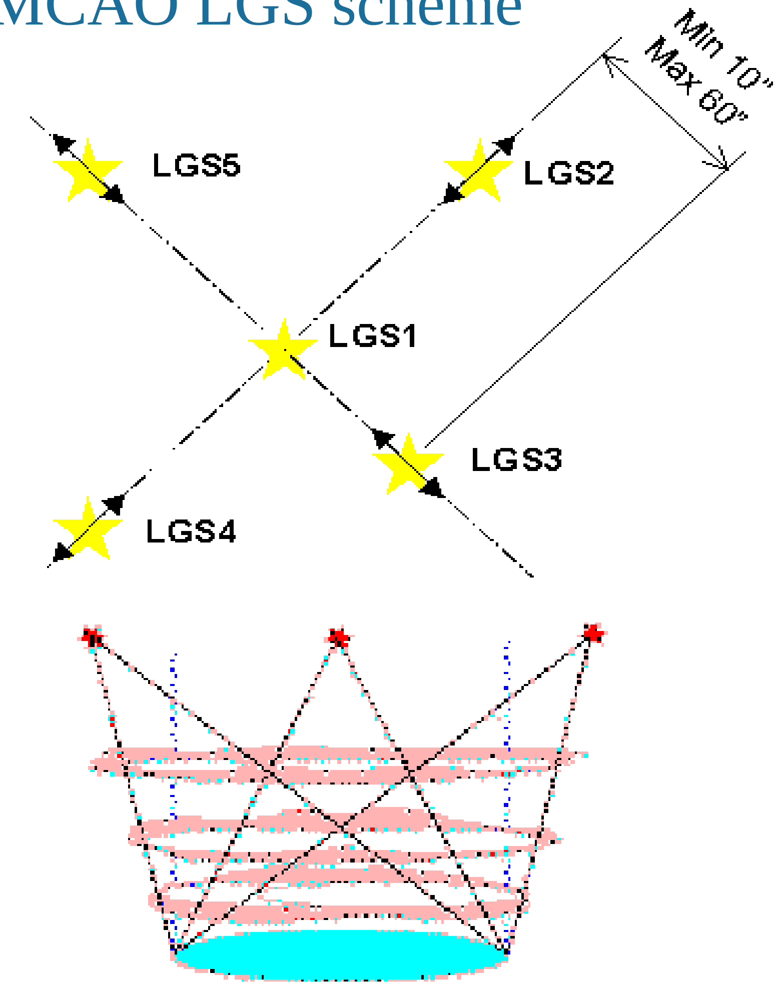
ESO LGS activities

- single laser LGSF in 2003, with provision for an upgrade to 5 LGS
- R&D on fiber lasers and AO-LGS schemes. ESO RFL - LLNL SFFL

LGSF MCAO Provision

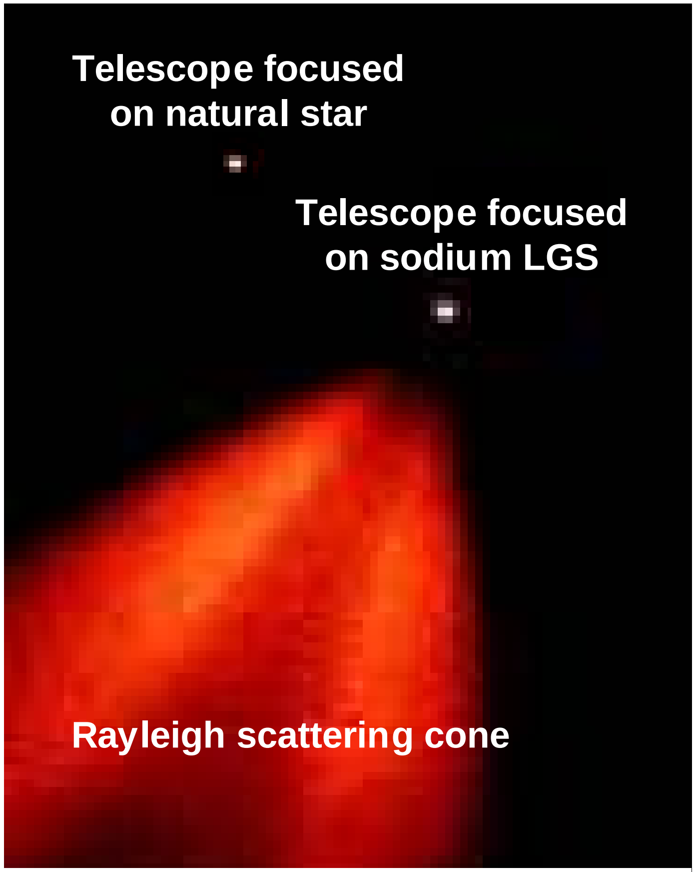


MCAO LGS scheme



- 5 LGS fibers, radial geometry, 60” max offset
- Special piezo-optomechanical mount from PI
- 5 fibers relay implemented
- 5 x 10-W (CW) 1 GHz bandwith fiber lasers (R&D)
- BRS Output diagnostic multiplexed
- LTA specifications compliant for 5x10W CW

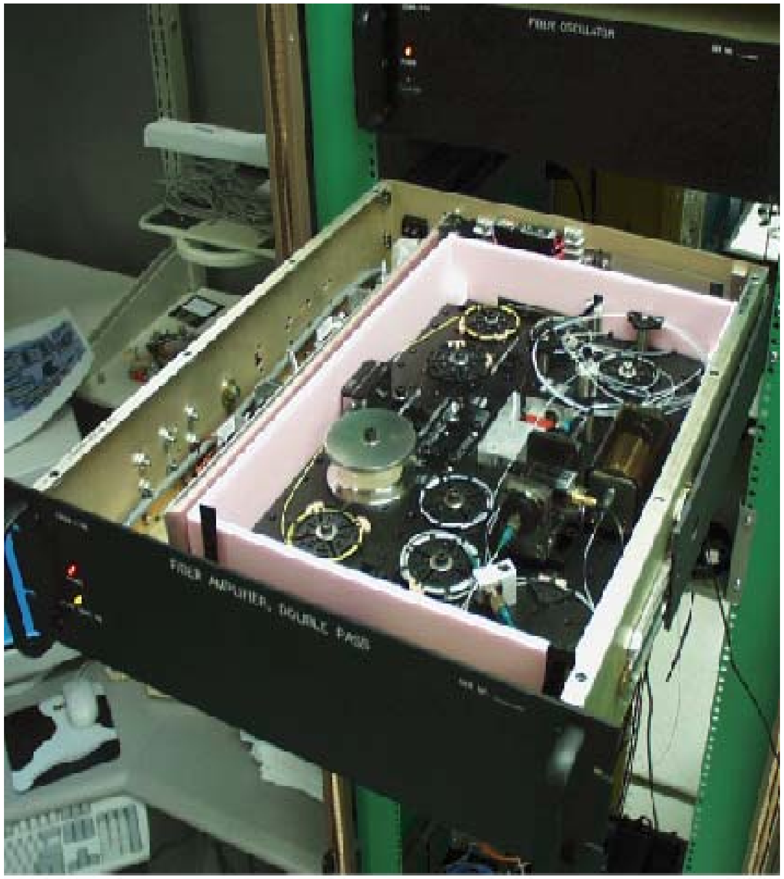
Sodium-guide star laser requirements



MPE/MPIA ALFA LGS-AO

- Compact, efficient, highly reliable & turn-key system
- Output wavelength centred on the sodium D_2-line @ 589.15 nm to generate resonant flourescence from mesospheric sodium atoms at 90 km altitude
- > 10 W continuous-wave output power for each laser guide star (LGS) in MCAO
- Diffraction-limited output beam quality for maximum LGS peak intensity
- Polarised output for optical pumping of sodium atoms in order to enhance the resonant backscatter

Fibre laser provide a robust solution to-next generation guide star lasers



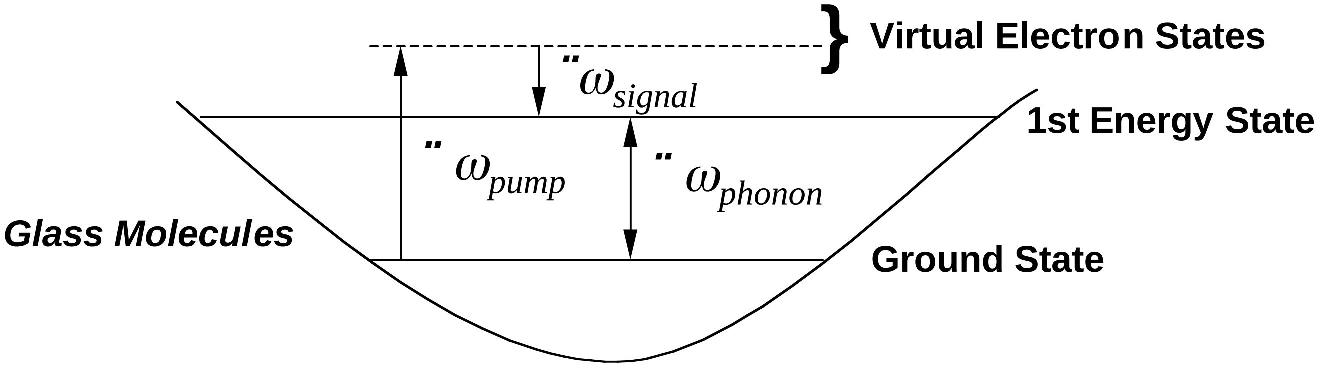
**Example at U.S. National Ignition Facility
Front End Fibre Oscillator & Amplifier**

- Compact (rack-mounted)
- Efficient (diode-pumped)
- Robust & reliable (commercial availability of key components from telecom industry)
- Safe (all-solid state, no chemicals)
- Alignment free (turnkey operation)
- In-built fibre delivery
- Diffraction-limited output
- Power scalable (e.g. by multiplexing)

In our lab we are following the fibre Raman amplifier/laser approach

There are no optical materials directly lasing at 589 nm, therefore nonlinear optical effects have to be used:

We have decided to develop a amplifier/laser system utilising stimulated Raman scattering (SRS) in a silica optical fibre:



SRS is the inelastic scattering of a photon with an optical phonon, which originates from a finite response time of the third-order nonlinear polarisation of the material.

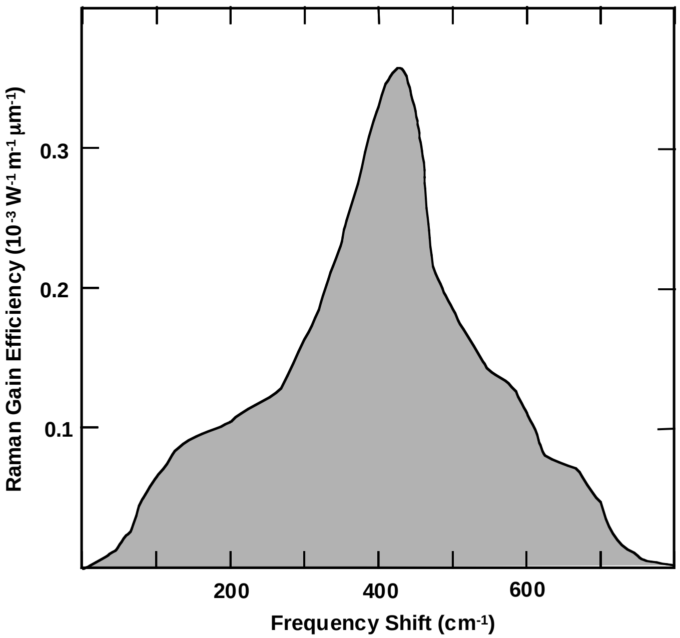
The incident photon loses energy equivalent to that of an optical phonon, downshifting its frequency by what is called the Stokes shift.

In SRS, a coincident photon at the downshifted frequency will receive a gain.

Relevant features of SRS

- by proper selection of the pump frequency, one can realise gain in any signal band (Stokes shift in silica is ~ 13 THz)

- Raman gain in silica extends over a broad and continuous band range (~ 5 THz), which simplifies the finding of a proper pump source



- Since the Raman gain profile is inhomogeneously broadened, all of the broadband pump power within the gain profile can contribute to a narrowband signal

- Raman amplification generates little noise in the absence of pump light, i.e., Raman amplifiers are almost always “fully inverted”, regardless of pump rate. Thus, the noise properties of the Raman amplifier is determined by the pump only

- The nonresonant nature of Raman amplification makes this process insensitive to temperature

- SRS is a polarisation-sensitive process

Second-harmonic generation of 589 nm from the Raman amplifier/laser output

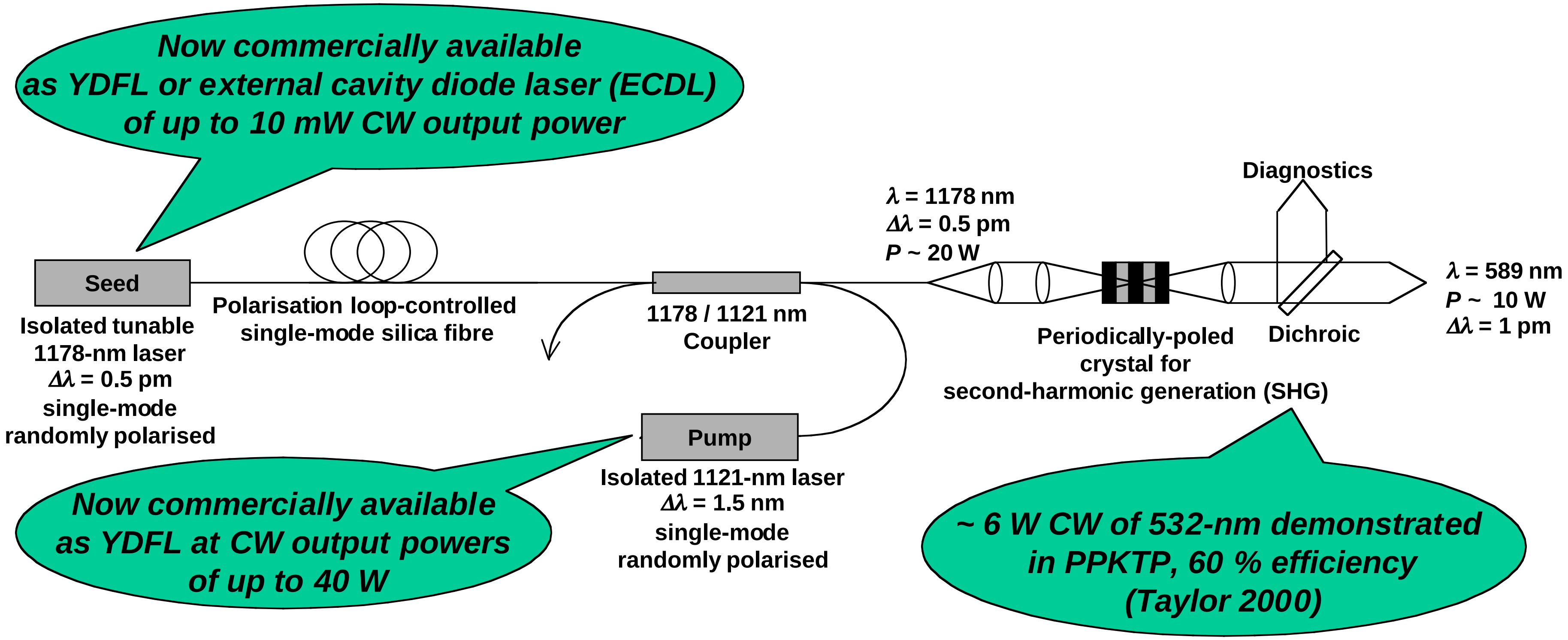
In our sodium guide-star laser approach the Raman fibre is pumped with a high-power 1.1-µm continuous-wave (CW) Ytterbium-doped fibre laser (YDFL) to generate light at 1178 nm.
Afterwards the output of the Raman fibre is frequency-doubled in a single-pass in a periodically-poled crystal to produce light at 589 nm.

For the selection of exactly the wavelength needed for the frequency-doubling process we are following two approaches:

- **in the amplifier approach the Raman fibre is seeded with light from a tunable low-power laser operating at exactly twice the sodium D2-line wavelength. This approach has now become very attractive due to the recent commercial introduction of low-power tunable all-solid state 1178-nm laser**
- **in the laser approach a pair of dedicated fibre Bragg gratings, written into the Raman fibre and tuned to twice the sodium D2-line wavelength are used as the frequency selective elements.**

In this poster we are focusing on the amplifier approach.

Conceptual design of the frequency-doubled single-stage amplifier



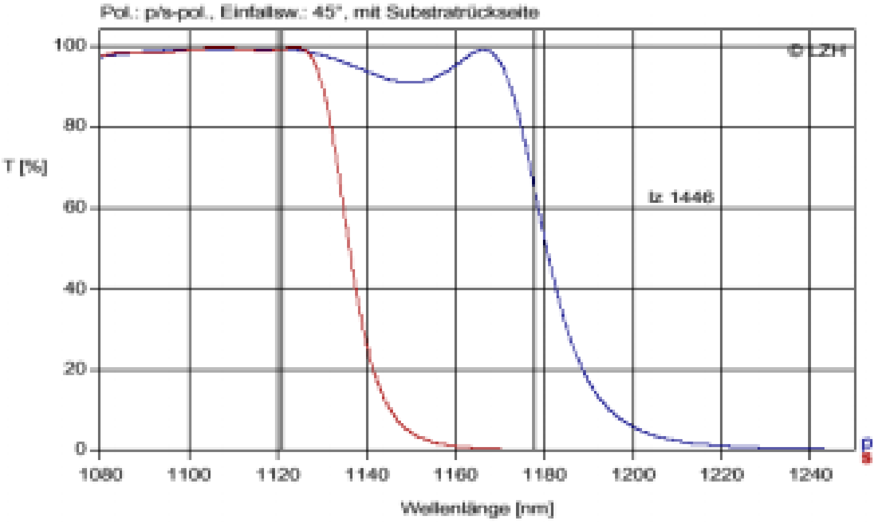
The main technical challenges of this approach are:

- **realising a steep coupler transmission curve**
- **scaling the components (especially the coupler and SHG crystal) to high average power**

In 2002 we are investigating a low-power amplifier demonstrator (goal ~ 1 W @ 589 nm)

For the 1121/1178-nm coupler in the demonstrator setup we initially will use bulk optics, i.e.,

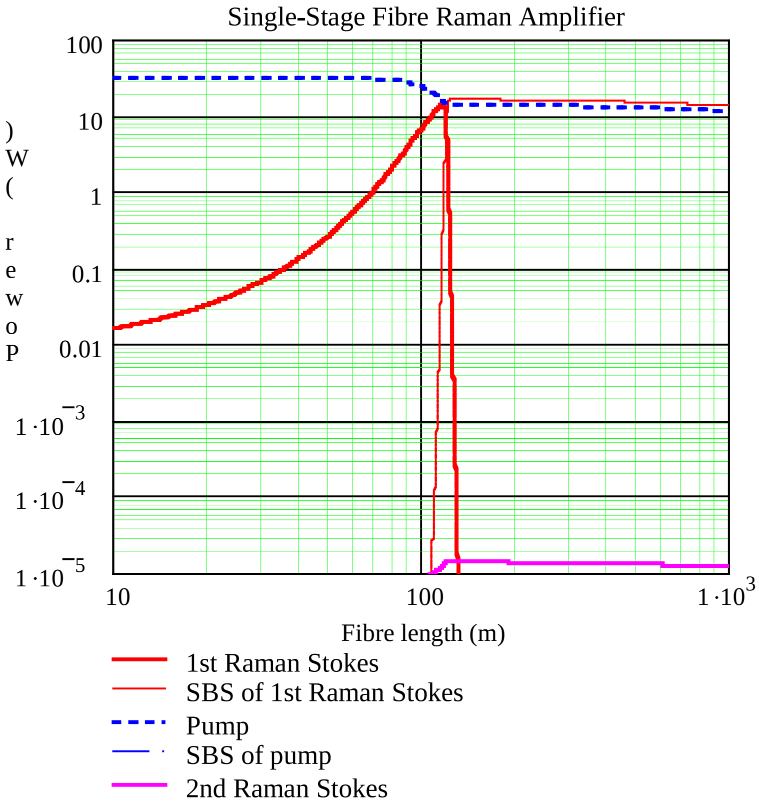
- **a dichroic beamsplitter, fabricated by LZH e.V.**



For the pump, seed and SHG we have purchased:

- **a 40-W 1121-nm YDFL from IPG Laser GmbH**
- **a 10-mW 1178-nm YDFL from Koheras A/S (needs to be externally phase-modulated for discrete linewidth broadening). It will be replaced by an ECDL from Toptica GmbH that allows continuous frequency broadening**
- **a 1×5×30 mm^3 PPKTP crystal from Raicol Ltd.**

We have modelled the performance of the demonstrator

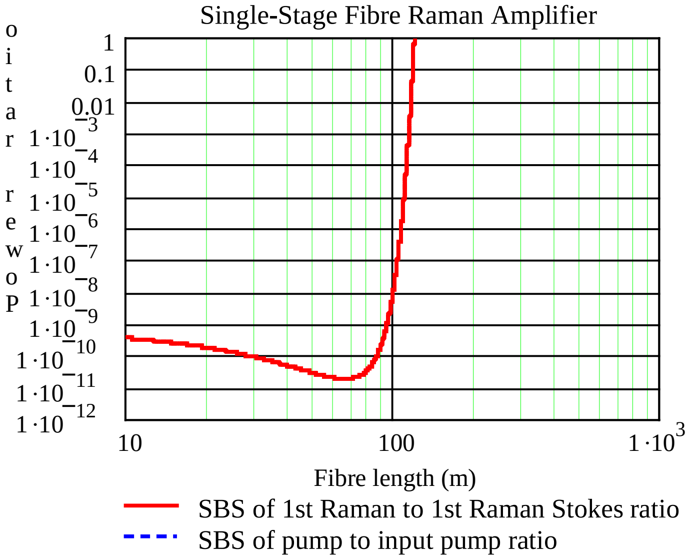


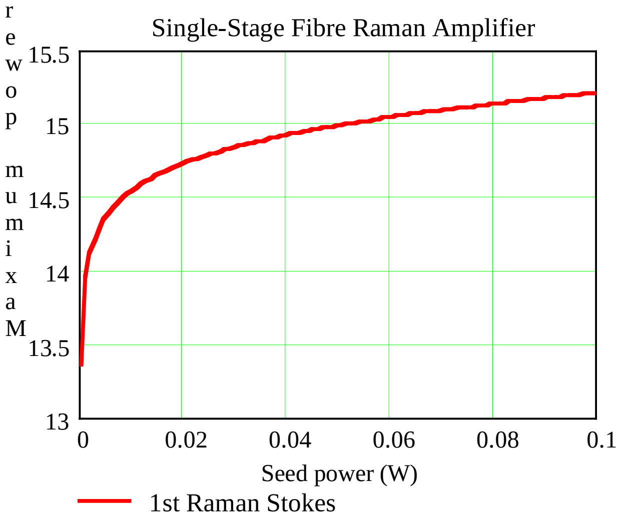
For the simulation we have solved the coupled differential equations describing the pump, 1st and 2nd Raman Stokes signals, as well as parasitic stimulated Brillouin scattering (SBS) of the 1st Stokes (and pump) signal.

The main input parameters are:

- **40 W pump @ 1121 nm, 1 nm bandwidth, 80% coupling efficiency**
- **10 mW seed @ 1178 nm, 500 MHz bandwidth (assuming continuously broadened frequency spectrum), 80 % coupling efficiency**
- **Pure silica fibre, effective area 4 × 10^{-11} μm^2**

Modelling (2)





The calculated amplifier output power for the input parameters given above is about 15 W @ 1178 nm, polarised, 0.5 GHz linewidth.

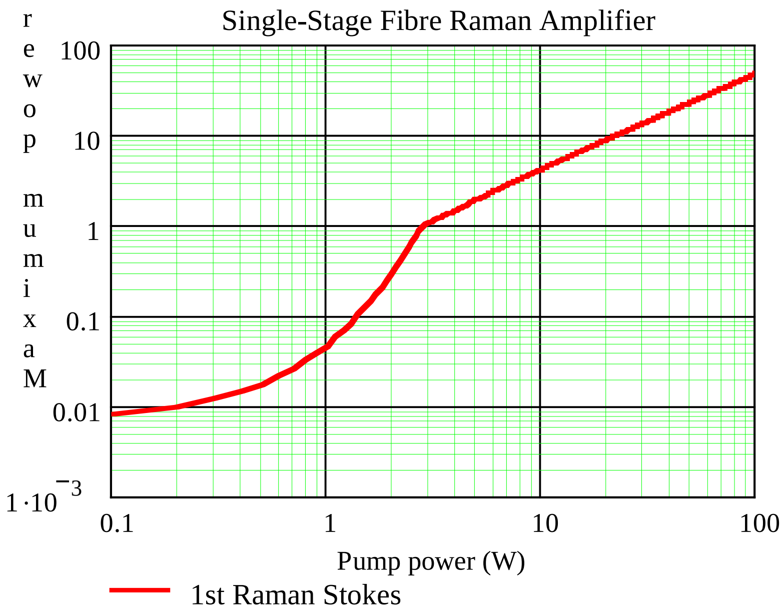
This value is for a SBS to output power ratio of 0.1 %.

The SBS of the pump light is fully negligible due to the large bandwidth of the pump source.

The optimal fibre length for a 40-W pump is about 120 m.

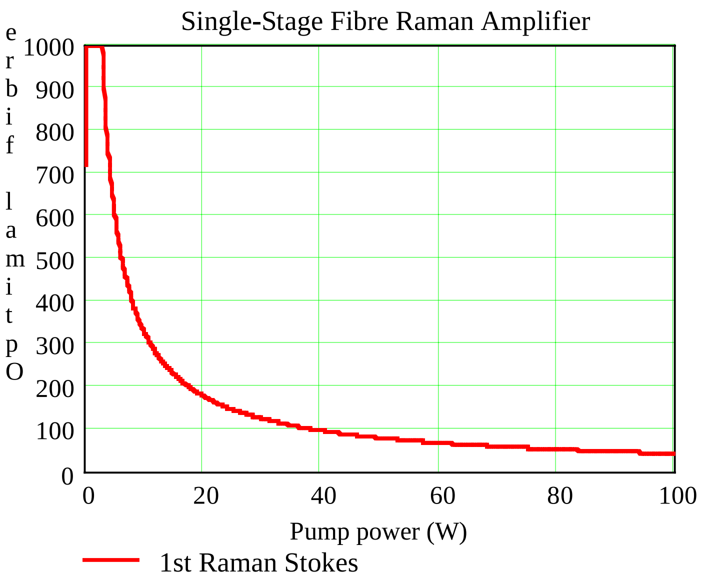
At least ~10 mW of seed power is required to sufficiently suppress amplified spontaneous emission.

Modelling (3)



The 100-W 1121-nm YDFL system recently announced by IPG Laser GmbH should allow a 1st Raman Stokes output power of about 40 W single-pass at 1178 nm, 0.5 GHz linewidth.

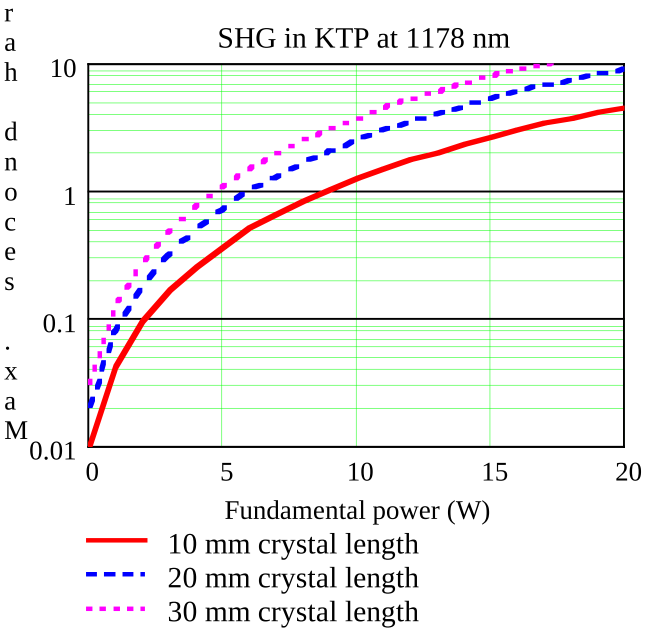
The optimal fibre length for such an amplifier system decreases to about 50 m.



The performance of the system could be further improved by:

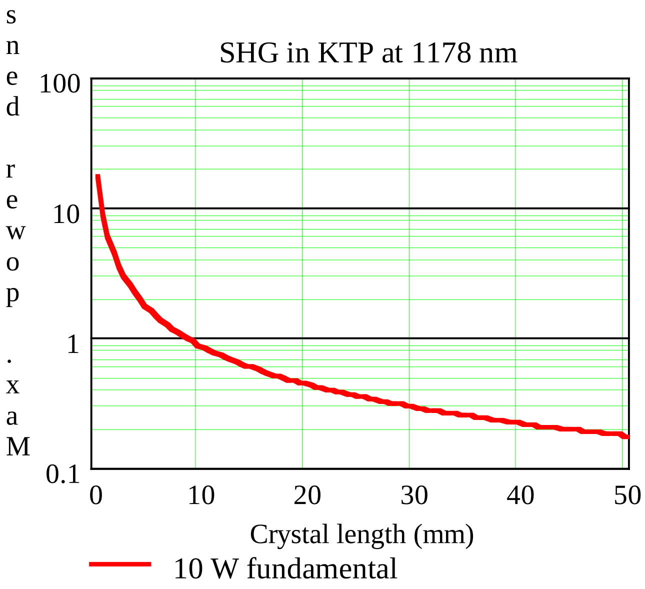
- ***double-stage amplification,***
- ***highly doping the Raman fibre with germanium. We are currently investigating the availability of such fibres.***

Modelling (4)



For the 40-W pumped single-stage fibre Raman amplifier with its maximum 15-W fundamental output power, the maximum possible output power at 589 nm is 8 W for a single-pass through a 30-mm long crystal.

The maximum power density in case of optimal focusing of the 40-W pumped amplifier output into the PPKTP crystal is well below the material's damage threshold of ~ 500 MW/cm².



Summary & Outlook

- We are developing in-house a fibre Raman laser for sodium guide star application in multi-conjugate adaptive optics.

- In this summer we have started to set up a fibre Raman *amplifier* demonstrator system. The goal is to achieve ~ 1 W CW output power at 589 nm at the end of this year. In parallel we are also following the fibre Raman *laser* approach.

- Provided that the lab experiments are successful, next year will be used to assess the power scalability and to prepare a breadboard pre-production unit of the fibre Raman amplifier or laser. The fully engineered units will be produced by industry. It is planned to have the final systems engineered at the beginning of 2005