Sub-300 fs, 0.5 mJ pulse at 1kHz from Ho:YLF amplifier and Kagome pulse compression

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Motivation

- Development of driver for mid-IR Optical Parametric Amplifier (OPA)
  - Long wavelength 2 μm pump source
  - High energy CPA scheme (≈ 2mJ, 3.4 ps @ 1kHz)
- Sub-ps pulses for white light seed generation
- Self compression for **3.4 ps, 0.5 mJ** pulse in Kagome fibre
- High Harmonic Generation: $U_p \sim I_L \lambda^2$
- THz generation

Previous Results

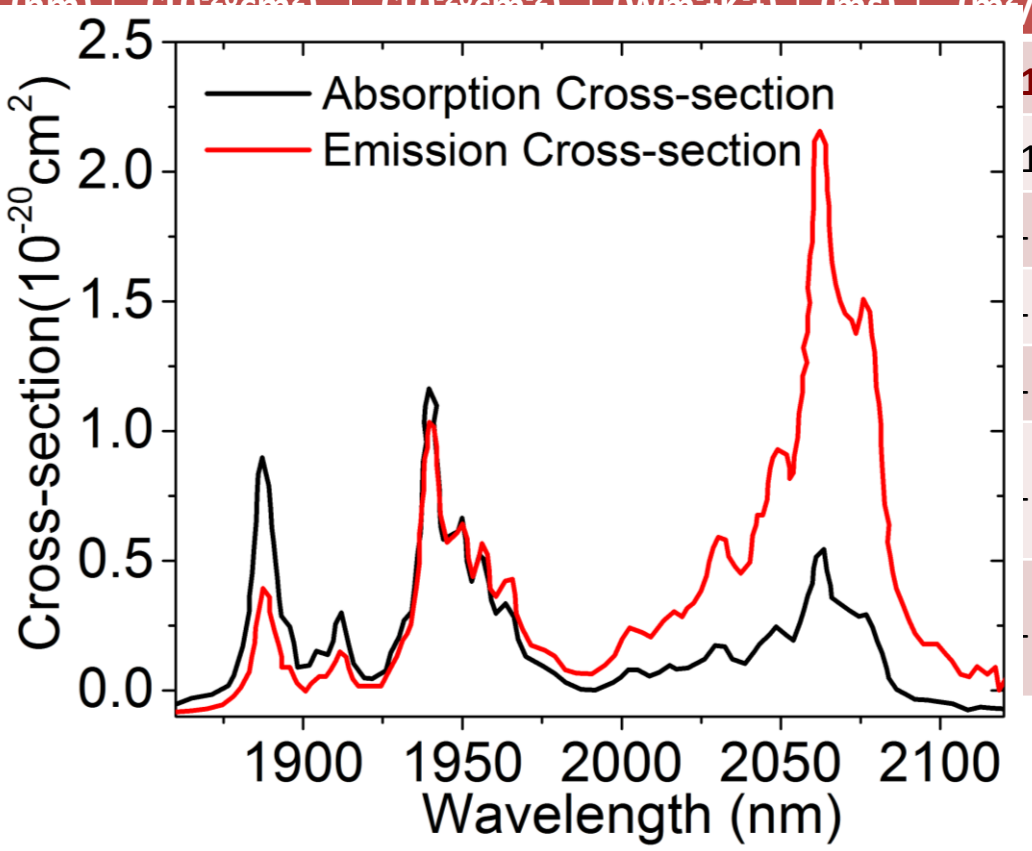
- **A. Dergachev, et al. Proc. SPIE. 8599, 859908 (2013): First Ho:YLF Regenerative Amplifier (RA)**
  - Seed source: Ho:YLF based oscillator $\tau \approx 250$ps
  - RA + SPA: 7.2mJ, 1kHz, **300ps**
- **P. Malevich, et al. Opt Lett. 38, 2746 (2013)**
  - Seed source: 2 stage OPA at 2.1µm. E ≈ 0.7µJ
  - Ho:YAG RA: Anti-gain narrowing filter: 3mJ uncompressed, 5kHz, **530fs**
- **M. Hemmer, et al. Opt. Lett. 40, 451 (2015)**
  - Seed Source: Tm-Ho Amplifier seeded by frequency shifted Er oscillator
  - Ho:YLF RA + cryo cooled Ho:YLF amplifier: 39mJ, 100Hz, 10ps

This Work

- Seeding of Ho:YLF regenerative amplifier with compact home built Ho: fibre oscillator $E_{seed} \approx 60$ pJ and $E_{out} \approx 1.1$ mJ,
  - Amplified gain of 10^7
- Shortest pulse duration achieved with Ho:YLF regen t ≈ 3.4 ps
- Demonstration of pulse self compression of the output using Kagome fibres
- Demonstration of self compression of 3.4 ps long pulses using 2 μm pulses to sub-300 fs

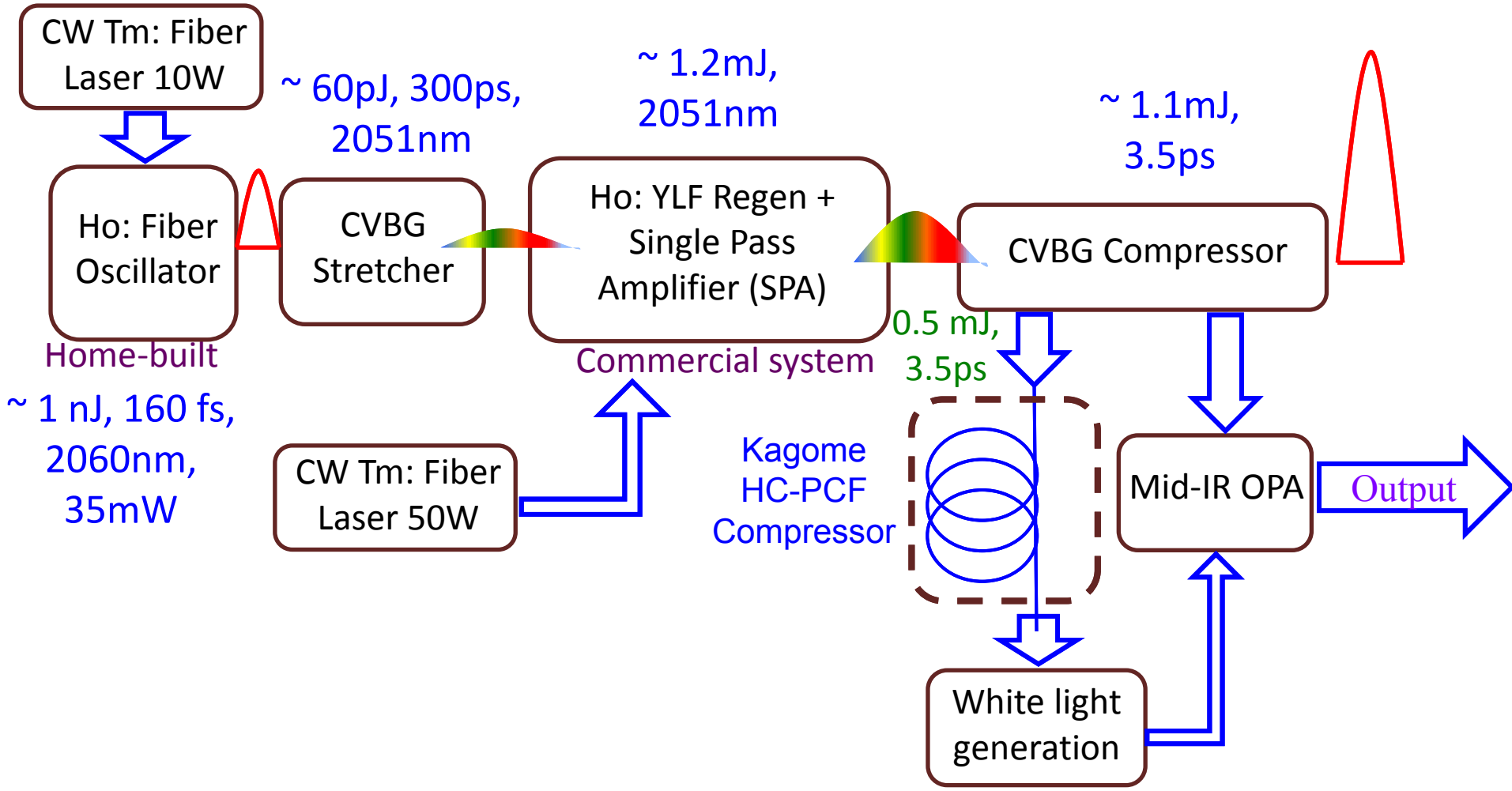
Comparison of 2-μm gain media

Host	λ_{abs} (nm)	λ_{em} (nm)	σ_{abs} (10^{-20}cm^2)	σ_{em} (10^{-20}cm^2)	T_c (Wm^{-1}K^{-1})	τ (ms)	n_2 (m^2/W)	Reference
Ho:YLF	1940						10^{-20}	[1]
Ho: YAG	1907						10^{-20}	[1][2]
Ho:Sc_2O_3	1992						-	[3]
Ho:Lu_2O_3	1945						-	[4][5]
Tm:YAG	-						-	[2]
Tm:Lu_2O_3	796						-	[7]
Tm:YLF	782						-	[8]



1. A. Dergachev, *Proceedings of SP*
2. A. Payne, *IEEE Journal of Quantu*
3. L. Fornasiero, *Conference. Advar*
4. P. Koopmann, *Conference. CLEO EUROPE*, 2009.
5. P. F. Karsten Scholle, *Frontiers in Guided Wave Optics and Optoelectronics*, Intech, 2010.
6. K Scholle, *Laser Physics Letters,* vol. 1, p. 285, 2004.
7. P. Koopmann, Appl Phys B, 102, 19 (2011)
8. B.M. Walsh, N.P. Barnes, B.D. Bartolo, J. Appl. Phys. 83, 2772 (1998)

Experimental Layout



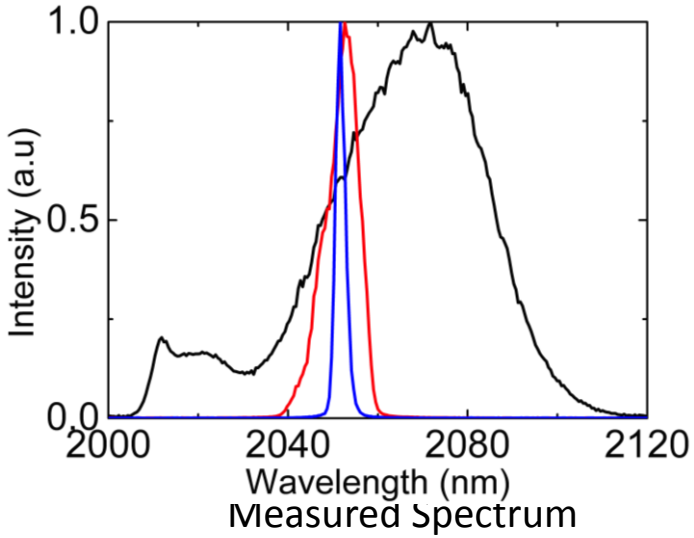
Schematic of self-seeding two stages OPA

Results: Regen + SPA

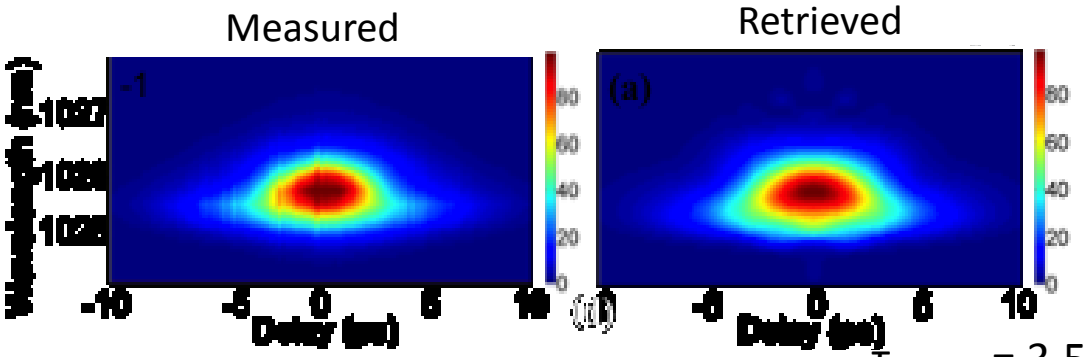
Oscillator Spectrum: FWHM 40.2 nm

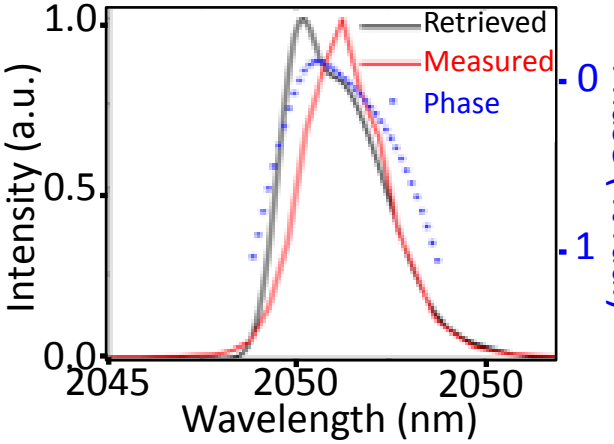
Seed (after stretcher): FWHM 8.2 nm

Amplified (after regen): FWHM 2.5 nm

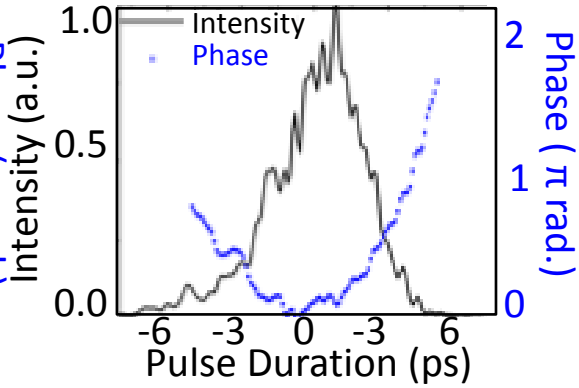


Measured Spectrum





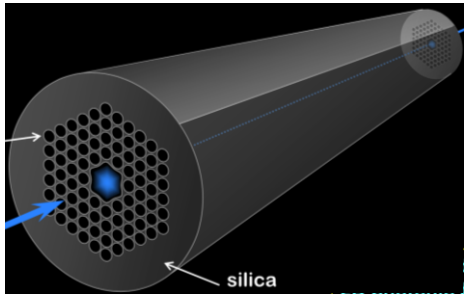
τ_{FWHM} = 3.5 ps



SHG FROG results

Nonlinear Pulse Compression

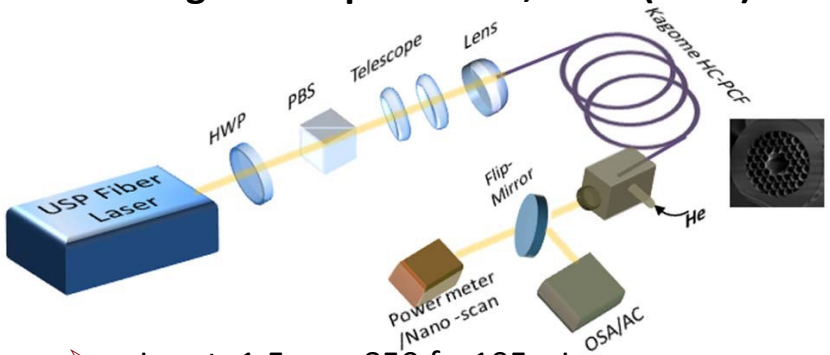
- Spectral broadening in conventional fibres
- Spectral broadening in noble-gas filled hollow capillaries
- Hollow Core Photonic Crystal Fibres (HC-PCFs)
  - Kagome lattice HC-PCFs: Inhibited Coupling
    - Extremely low core-clad power overlap
    - Low transmission loss
    - Dominance of anomalous dispersion over large section of transmission widow



Phillip Russell, MPL

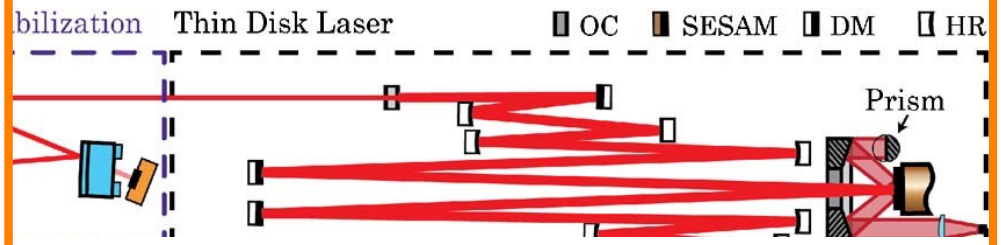
Previous Results

Y.Y.Wang et.al. Opt Lett. 37, 3111 (2012)



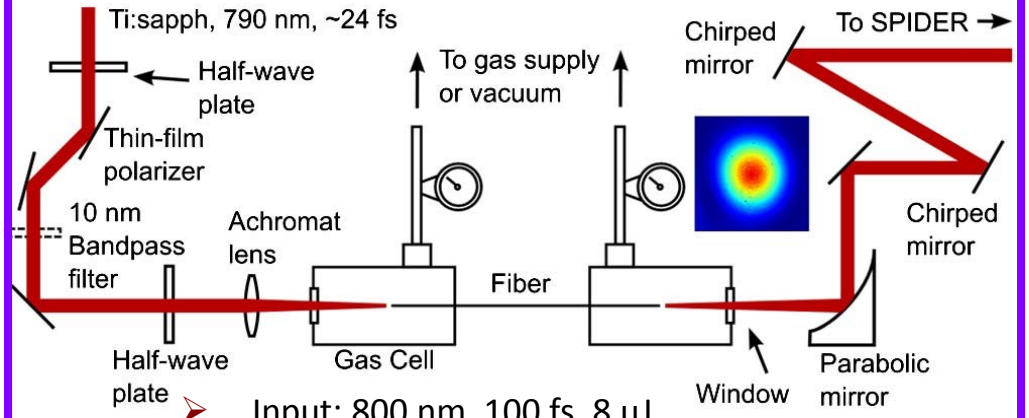
- Input: 1.5 μm, 850 fs, 105 μJ
- 20cm 19-cell Kagome fibre 3.5-bar He-filled
- Compressed to 300 fs

F. Emaury et.al. Opt Lett. 39, 6843 (2014)



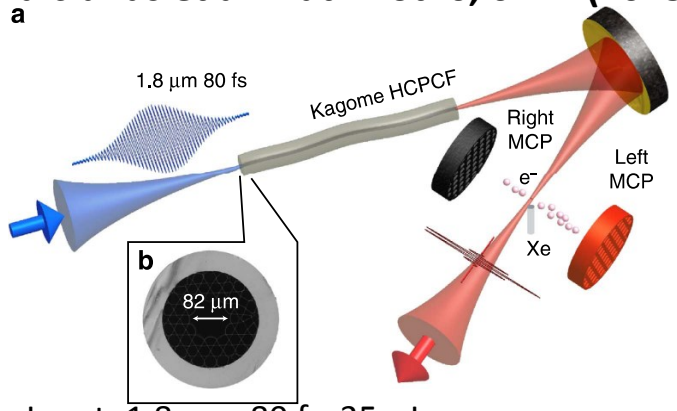
- Input: 1.5 μm, 740 fs, 18 μJ
- 66 cm 19-cell Kagome fibre 13-bar Ar-filled
- Compressed to 88 fs

K. F. Mak et.al. Opt Lett. 38, 3592 (2013)



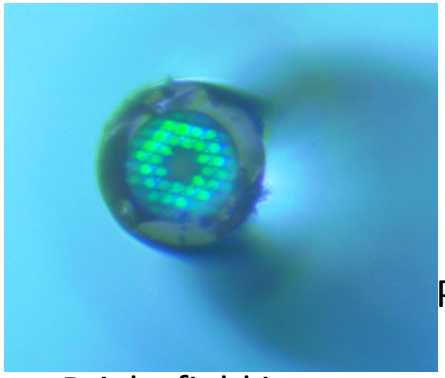
- Input: 800 nm, 100 fs, 8 μJ
- 11 cm 19-cell Kagome fibre 15-bar Kr-filled
- Compressed to 10 fs

T. Balciunas et al. Nat Phot. 6, 6117 (2015)

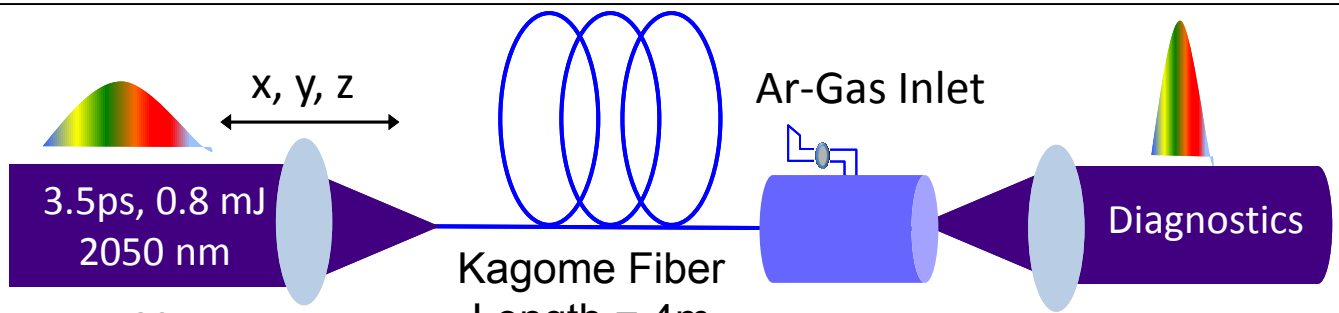


- Input: 1.8 μm, 80 fs, 35 μJ
- 20 cm 19-cell Kagome fibre 4-bar Xe-filled
- Compressed to 4.5 fs

Kagome HC-PCF Compressor

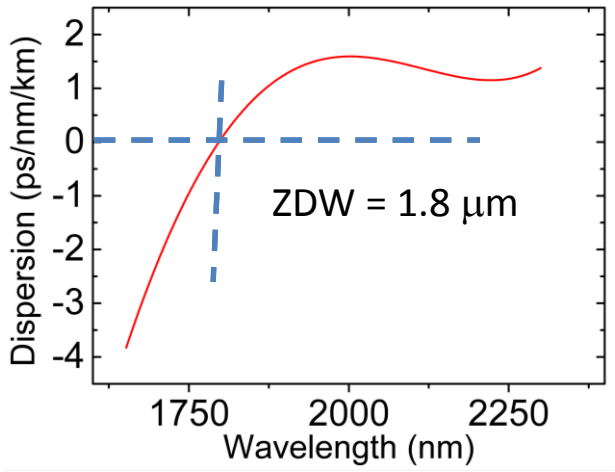


Bright field image

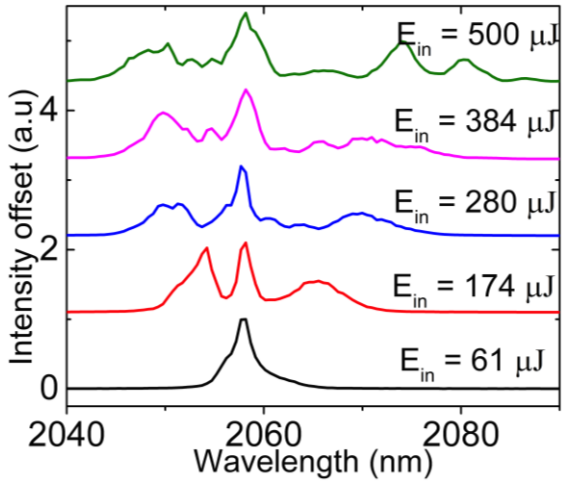


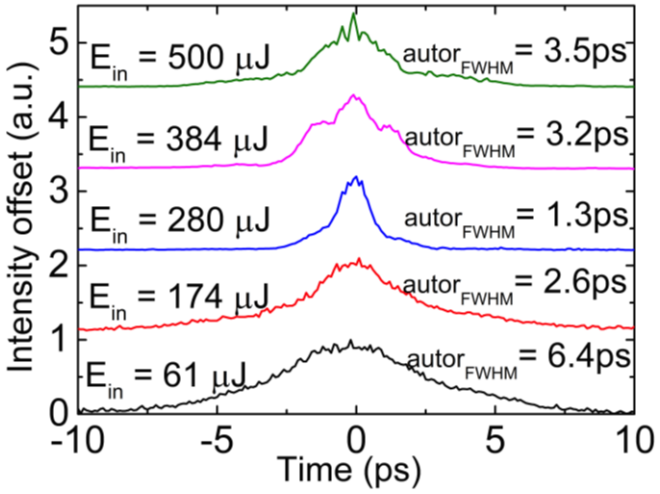
7-cell: D = 50 μm
19-cell: D = 80 μm

- Transmission Efficiency > 90 %



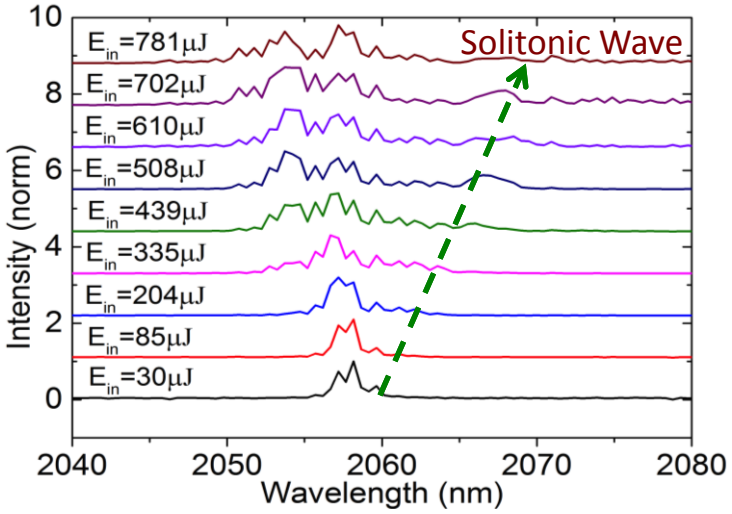
Dispersion curve



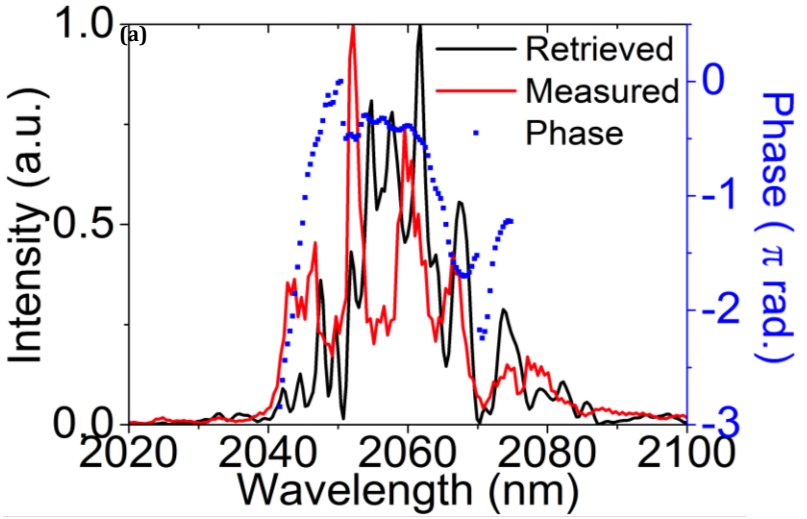


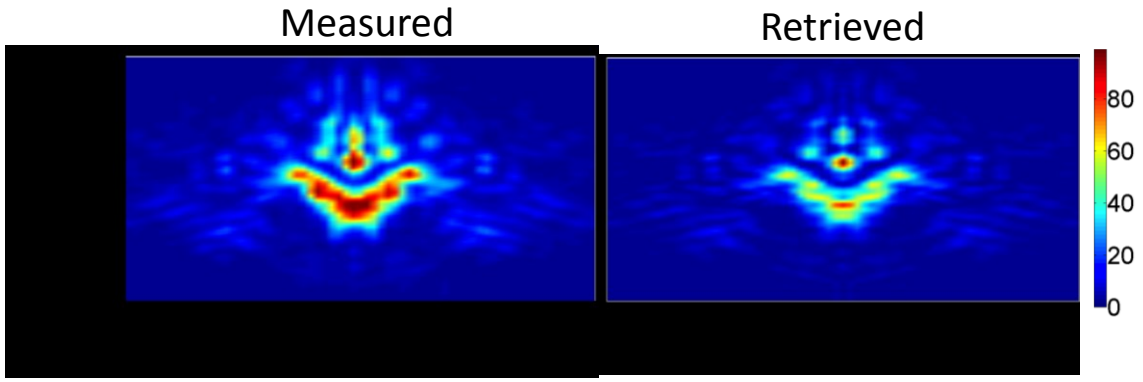
Spectral and temporal evolution for 7-cell fibre 3bar Ar

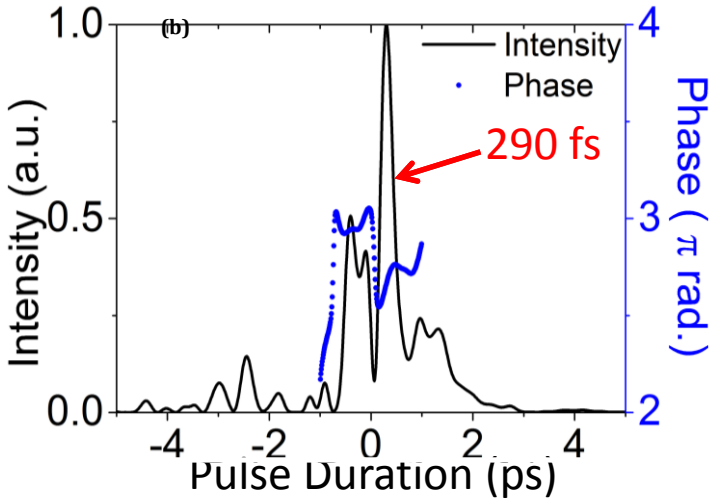
Results: 19-cell



Spectral evolution for 19-cell fibre







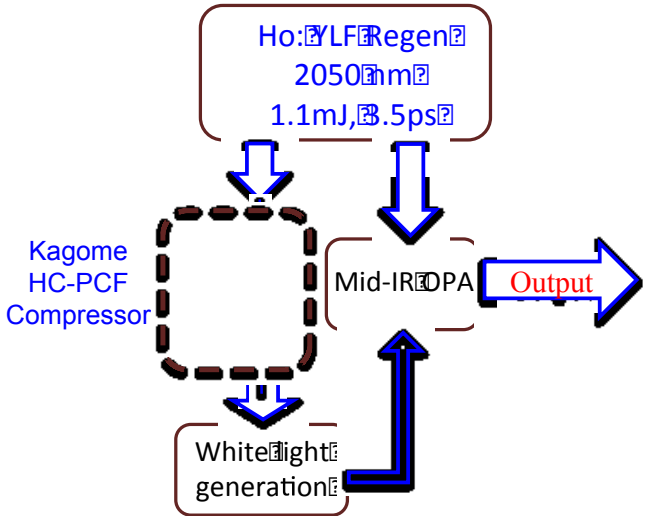
Conclusion

Summary

- Simple and Compact seeding of Ho: YLF regenerative amplifier
- 1.1 mJ output from Ho: YLF amplifier + SPA seeded with Ho:fibre oscillator. Stretched and compressed using CVBG
- Demonstration of self-compression 2 micron pulses using Kagome HC-PCFs
- 3.4 ps long pulses at 2050 nm was compressed to ~300 fs

Outlook

- Further optimization:
  - Gas pressure, fibre length and input pulse duration
- Pumping and seeding MIR-OPCPA



Thanks for your attention