Optical Fibres and e-MERLIN

Ralph Spencer, Roshene McCool,
Simon Garrington, Chris Shenton
and Mike Bentley

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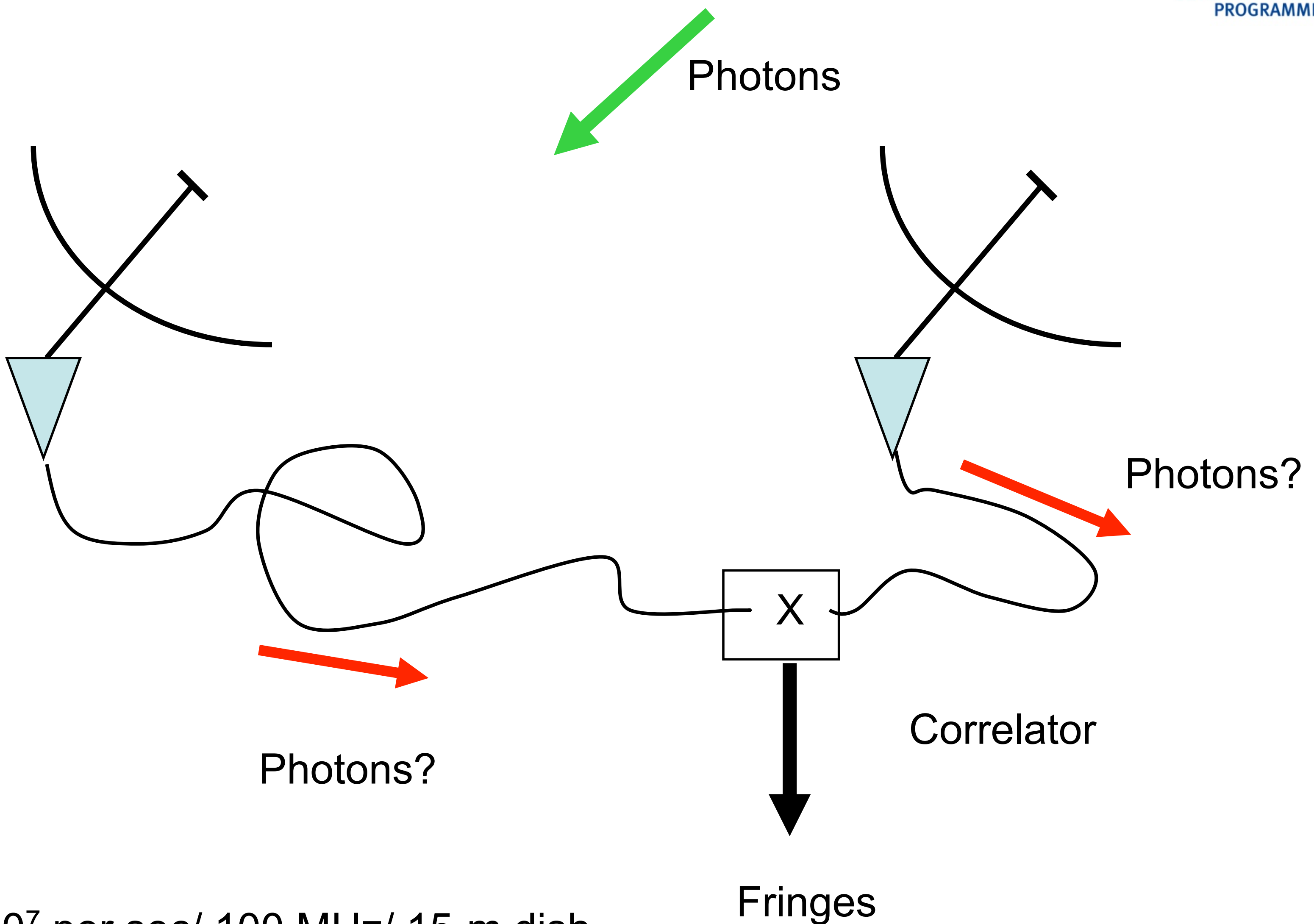
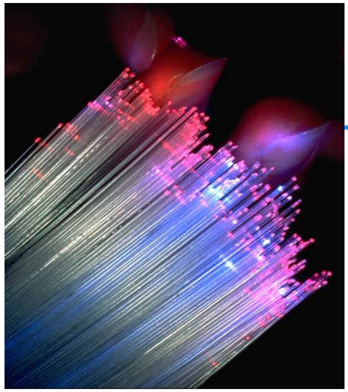
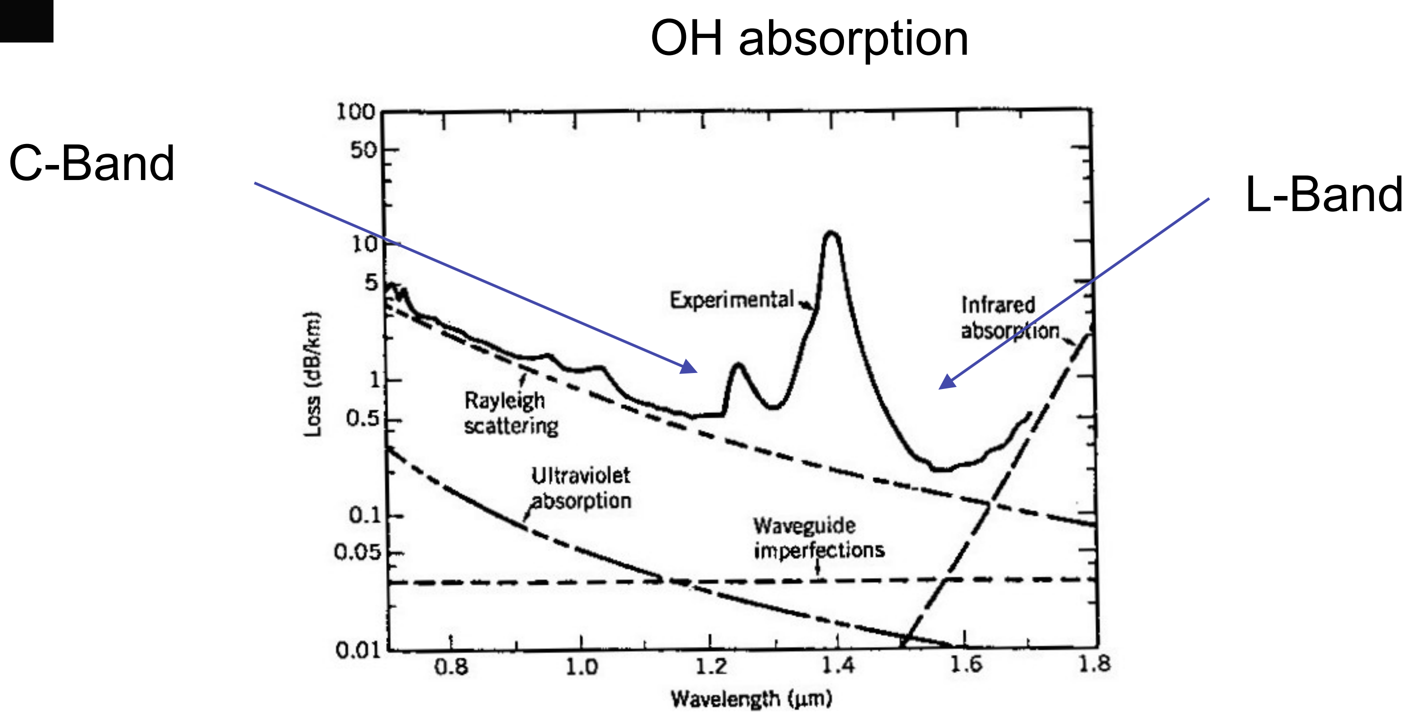
Radio Interferometers



~10^7 per sec/ 100 MHz/ 15-m dish



Why Optical Fibres?



- Very low loss: <0.5 dB per km
- High bandwidth ~12 THz available in L -band

Fibre-optic development work at JBO:

1. 1997 –1999 200km analogue fibre links - A collaboration with BT Laboratories (PIPSS)
2. 1999-2000 Feasibility study on fibre links for EVN (EU TMR programme).
3. 2000-2006 ALMA 120 Gbps prototype data links
4. 2002-2009 e-VLBI development in Europe -- 1Gbps over academic networks
5. 2003-2008 30 Gbps e-MERLIN Links
6. 2006-2010 SKADS study of 16 Tbps data links and phase transfer for SKA.
7. 2002-2009 Data Transfer over commercial links: e-VLBI (ESLEA, EXPReS)
8. 2008-2010 Phase transfer system over 200 km for e-MERLIN (~1 ps)
9. 2010-2012 PREPSKA – data link and time transfer design for SKA
10. 2010-2012 NEXPRES : bandwidth on demand and cloud storage for e-VLBI

The e-MERLIN Fibre Network

e-MERLIN - implementation

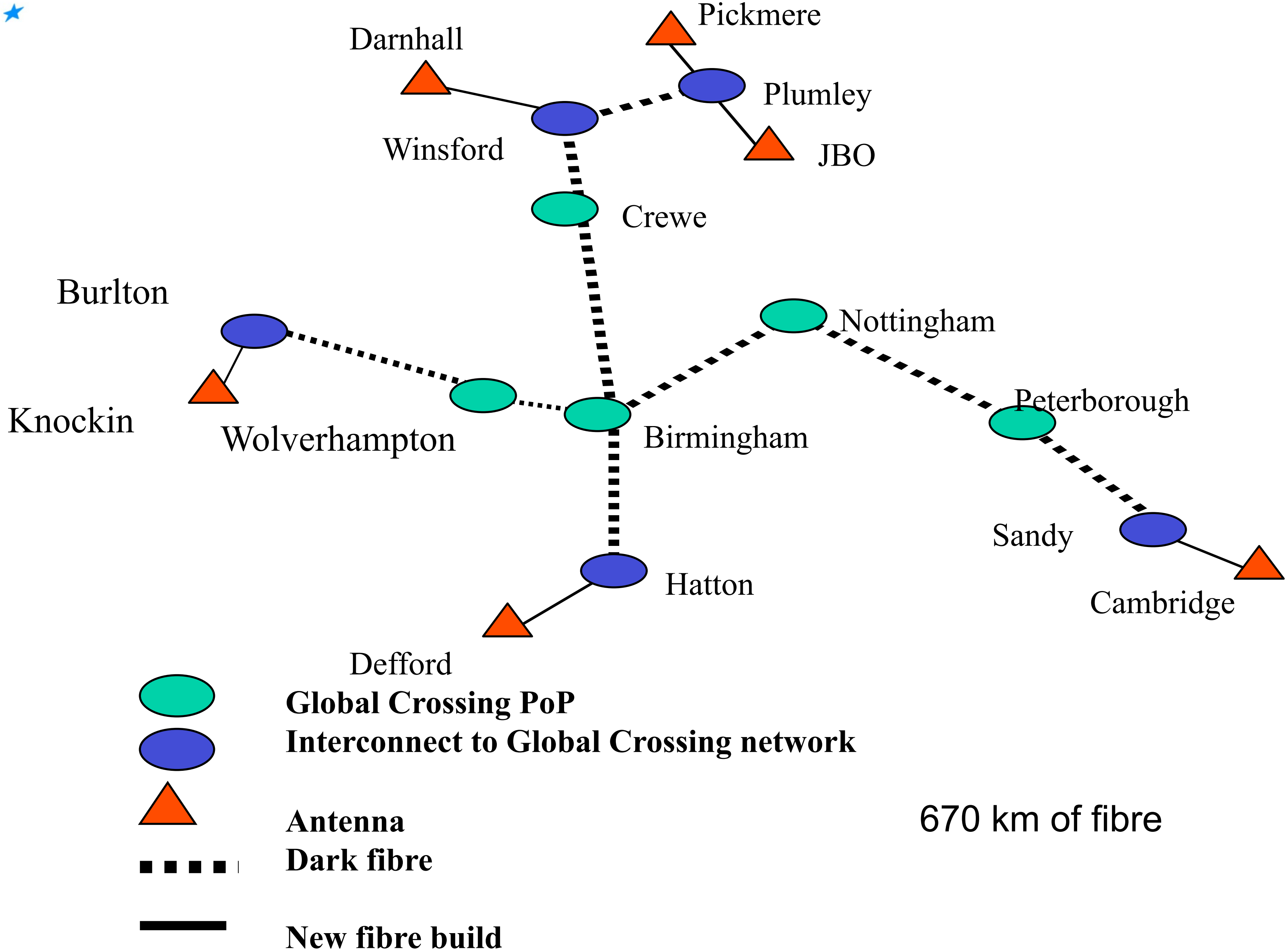
- 2GHz bandwidth in 2 polarisations is digitised to 3 bit precision + encoding = 30 Gbps
- 3 x 10 Gbps channels transmitted *in parallel* for each antenna
- 670 km of dark fibre network, purchased in 2004
  - Dark Fibre network owned by Global Crossing
  - 100km of which is new build, installed by Fujitsu
  - PoPs in Birmingham, Peterborough, Nottingham & Crewe

Installation techniques

Combinati

- Tren
- Mole
- Horiz
  drillin

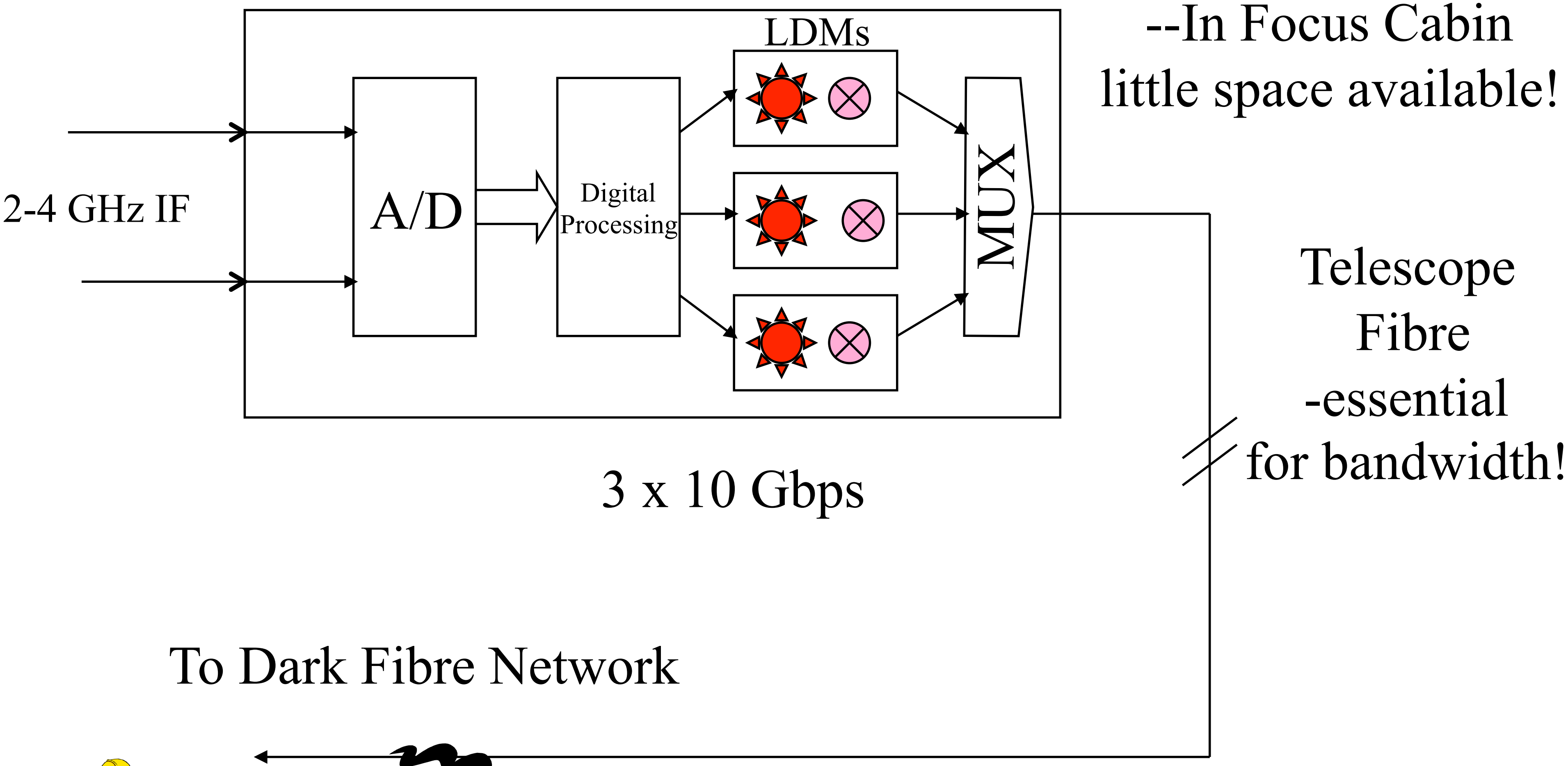
Schematic diagram of the e-MERLIN fibre network

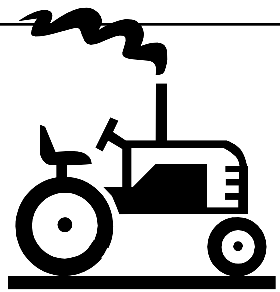


Data Transmission System

DTS

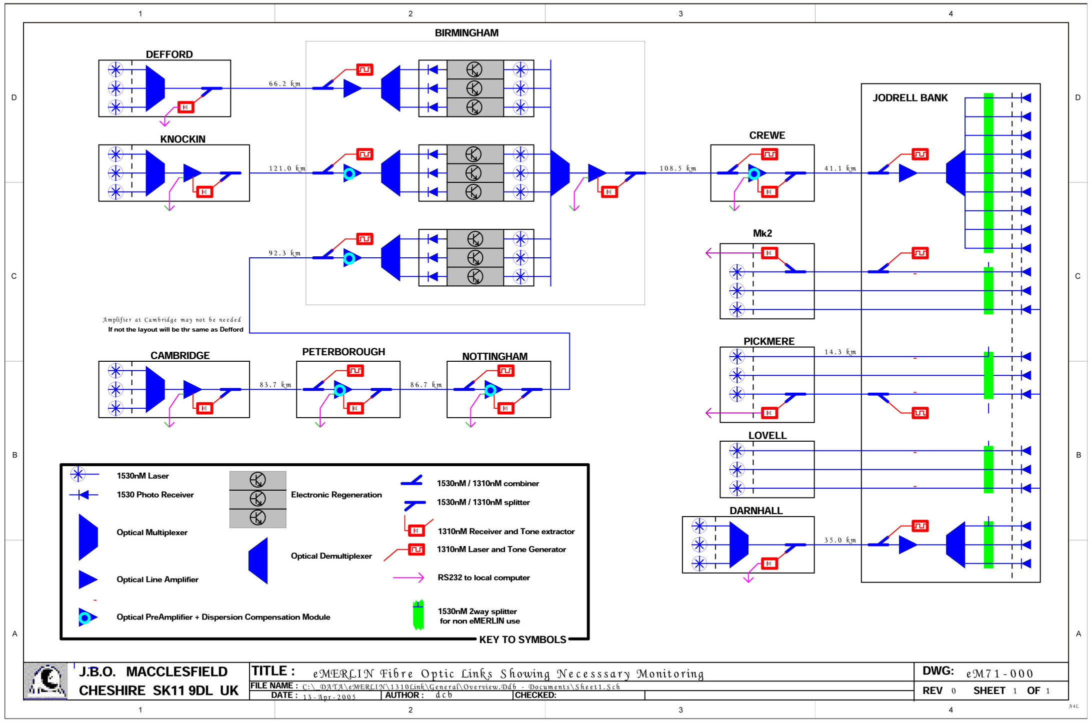
Data Transmission





WP3: safety link

- Automatic shutdown of amplifiers if fibre break suspected
- Only marginally exceed 10dBm limit
- ‘Dead man’s handle’
- Uses 1310nm narrow band signal in reverse direction
- For tests can do manual shutdown



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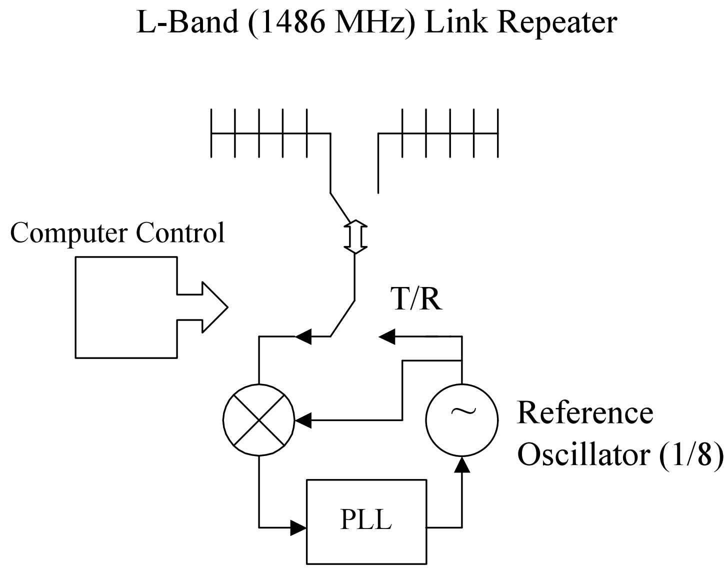
Current State

- All telescopes connected
- Fringes from 5 telescopes
- 4 telescope maps made
- Latest (last week) connected to Cambridge
  - 412 km with no regeneration
  - de-dispersion and EDFA amplifiers every ~90 km

e-MERLIN Phase Transfer using Fibre

Phase Transfer

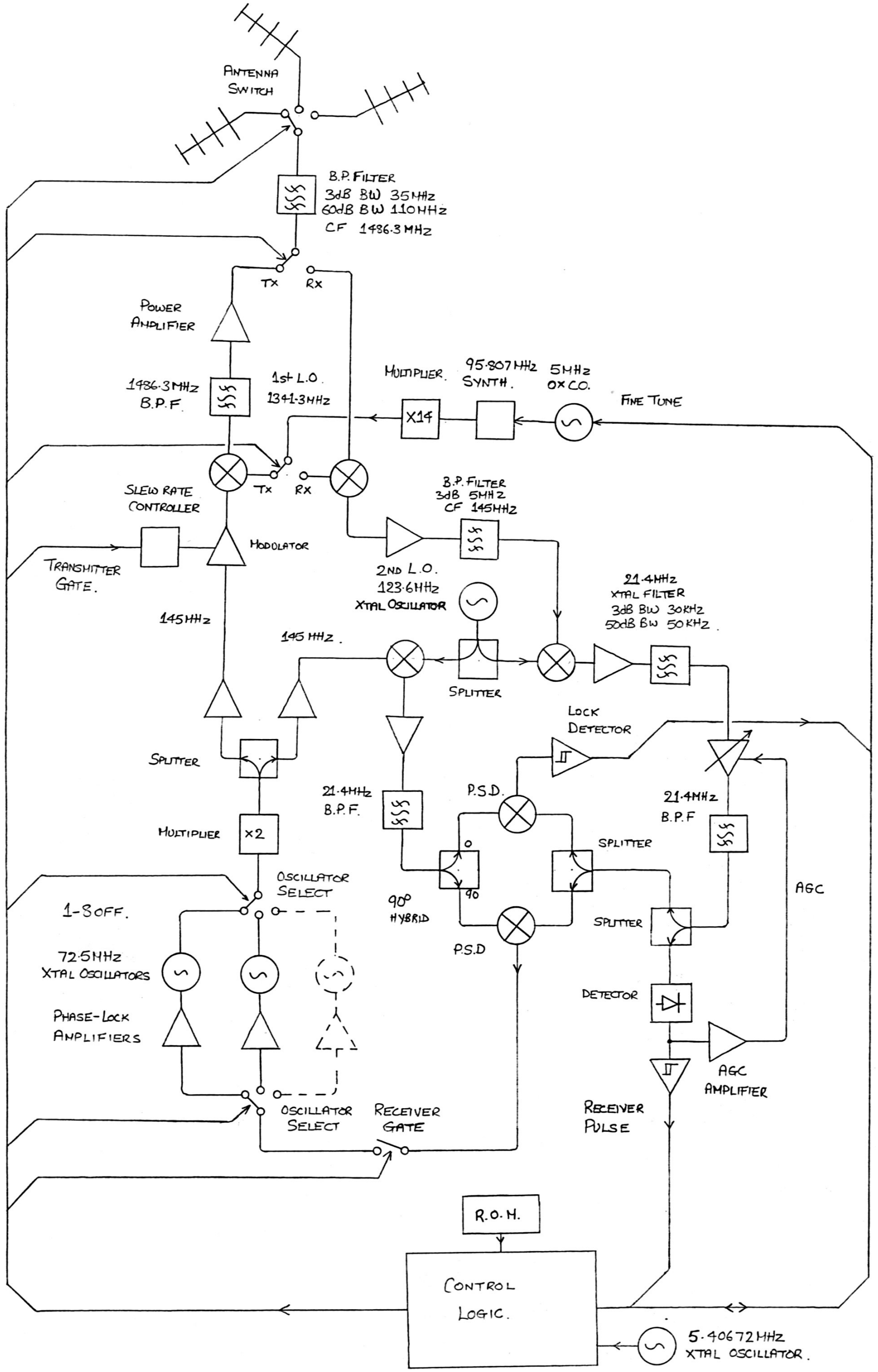
- Requires ~ 1 ps rms stability over ~250 km to maintain coherence at 22 GHz
- Existing L-band link works very well, producing stable fringes for 25 years!



L-band link (c. 1977 !)

- Uses a pulsed system at 1486.3 Mhz, measure go and return delay
- Typical pulse switching cycle:
  - Pulse 1 transmitted from Jodrell, received by repeater A.
  - Pulse 2 transmitted from repeater A, received by repeater B.
  - Pulse 3 transmitted from repeater B, received by outstation.
  - Pulse 4 transmitted from outstation, received by repeater B.
  - Pulse 5 transmitted from repeater B, received by repeater A.
  - Pulse 6 transmitted from repeater A, received by Jodrell.
- Logical timing synchronised via pulse width. Pulse cycle repeats at 88 Hz
- Received 1486.3 Mhz signal phase locks oscillators at 75.3 MHz at repeaters and remote telescopes
- Received signal at the remote telescope used to lock a quality 5 Mhz reference oscillator with 10-sec loop constant. Freq. synthesiser generate LO's etc.

Schematic:



Antenna Switch
B.P. Filter
3dB BW 35MHz
60dB BW 110MHz
CF 1486.3MHz
Tx
Rx
Power Amplifier
1486.3MHz B.P.F.
1st L.O. 1341.3MHz
Multiplier
X14
95.807MHz Synth.
5MHz OXCO.
Fine Tune
Tx
Rx
Slew Rate Controller
B.P. Filter 3dB 5MHz CF 145MHz
Modulator
Transmitter Gate.
2nd L.O. 123.6MHz Xtal Oscillator
21.4MHz Xtal Filter 3dB BW 30KHz 50dB BW 50KHz.
145MHz
145MHz.
Splitter
Lock Detector
Splitter
21.4MHz B.P.F.
P.S.D.
21.4MHz B.P.F
Multiplier
x2
Splitter
0
90
Oscillator Select
90° Hybrid
Splitter
AGC
1-8 off.
P.S.D
72.5MHz Xtal Oscillators
Phase-Lock Amplifiers
Detector
AGC Amplifier
Oscillator Select
Receiver Gate
Receiver Pulse
R.O.H.
Control Logic.
5.40672MHz Xtal Oscillator.

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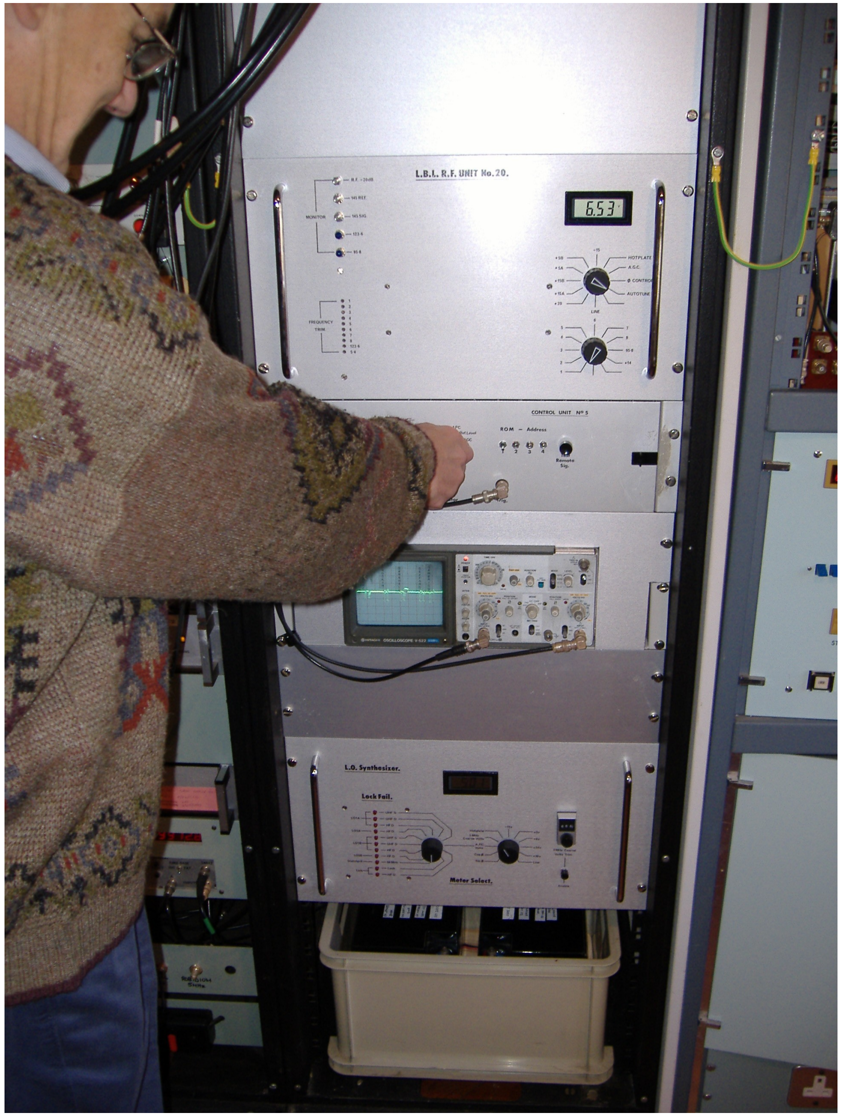
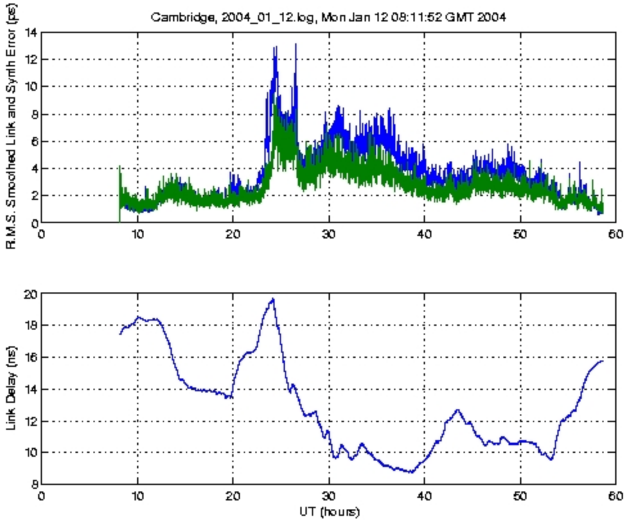
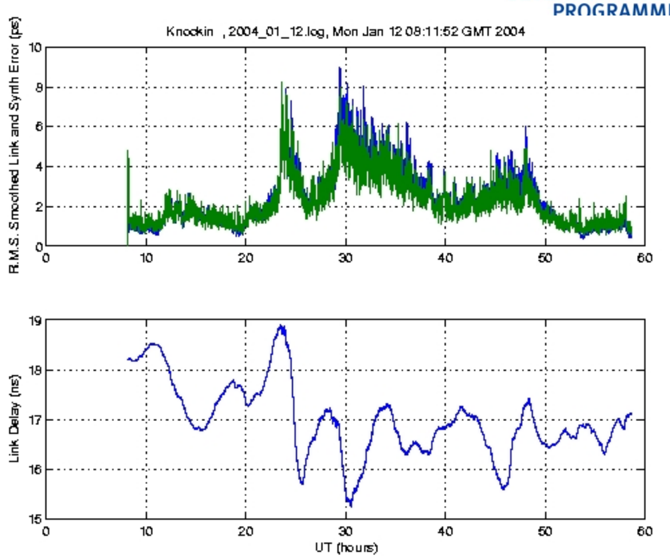


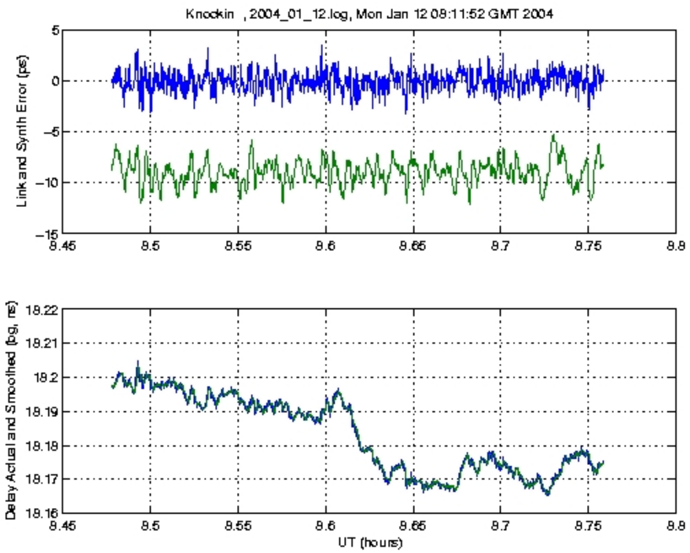
L-band link performance

Long term





Short term



Disadvantages of L-band link:

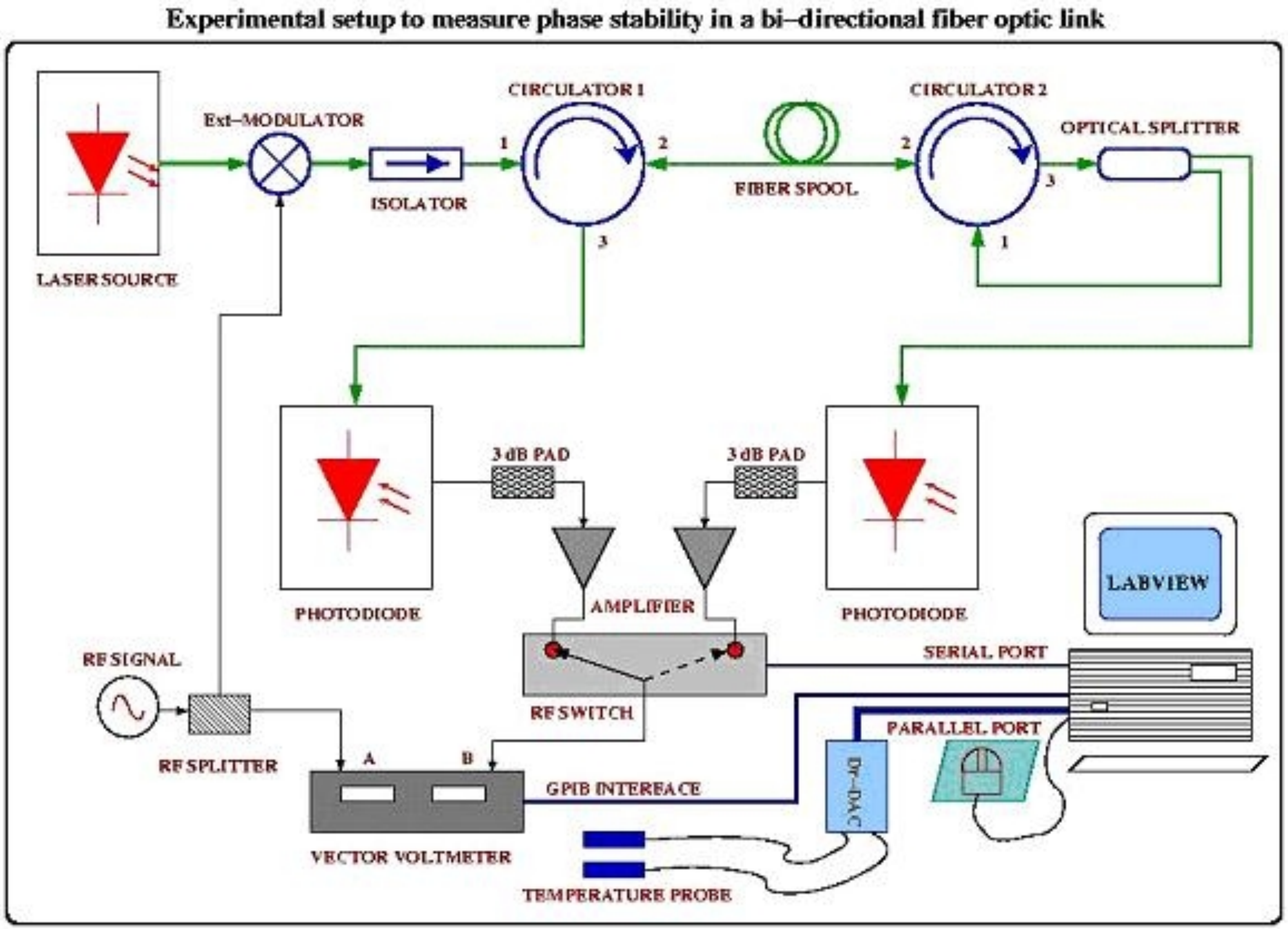
- Cost of rental for link towers is ~£100k per year
- Licence costs £18k per year

Can we use the optical fibre system and save rental costs?

Can we use the fibre?

- Already plan to use fibres to transmit data between telescopes and correlator
- Transfer phase information using fibre optics in a Phase Transfer System
- Inherent problem: fibres do not conserve phase – e.g PMD is non-reciprocal
- Need to develop a system to monitor and correct for phase variations
- Laboratory tests on fibre:

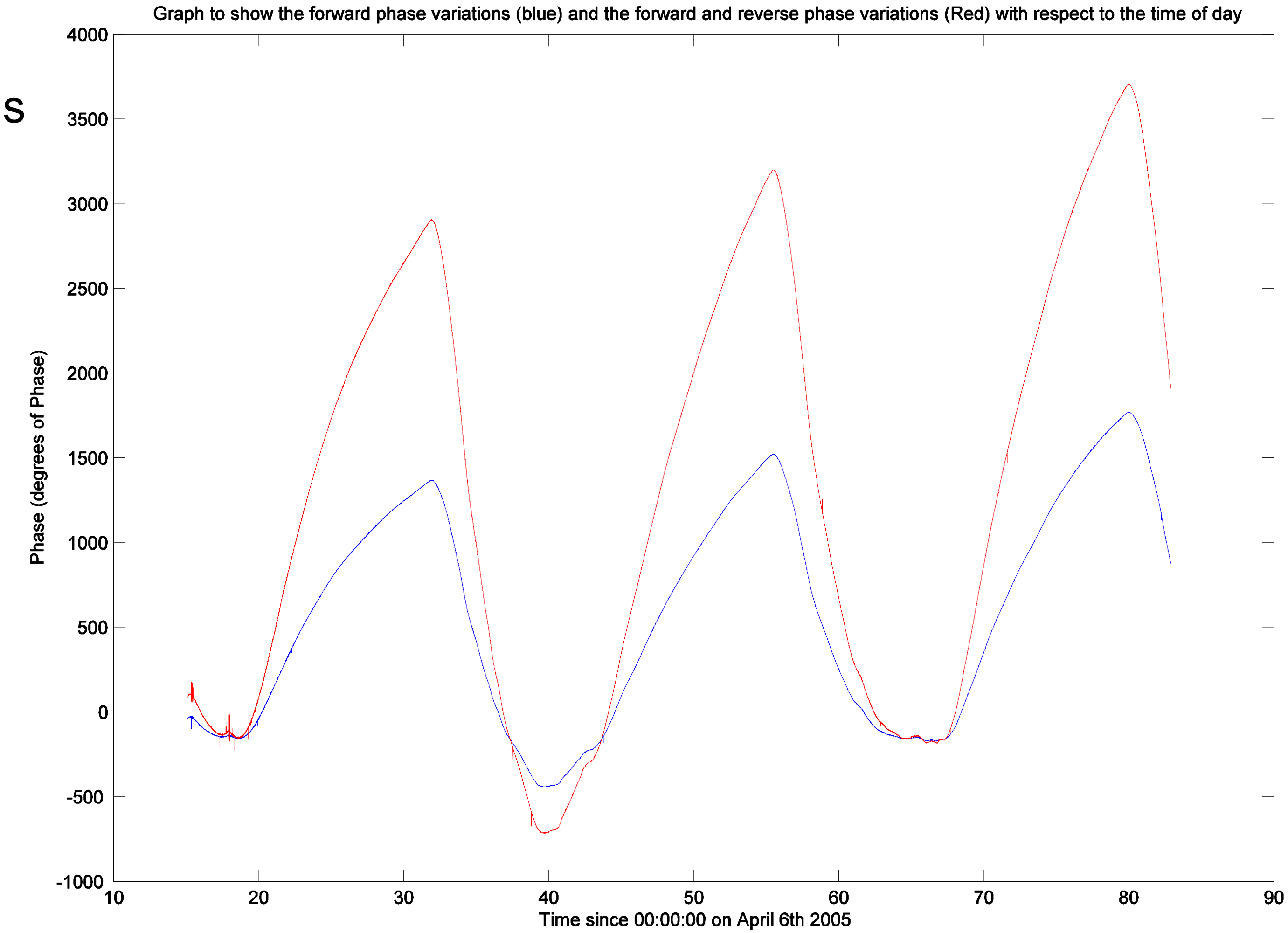
Lab set up



1 GHz modulation, 1550nm laser, 20 km of fibre (M Strong PhD thesis 2005)

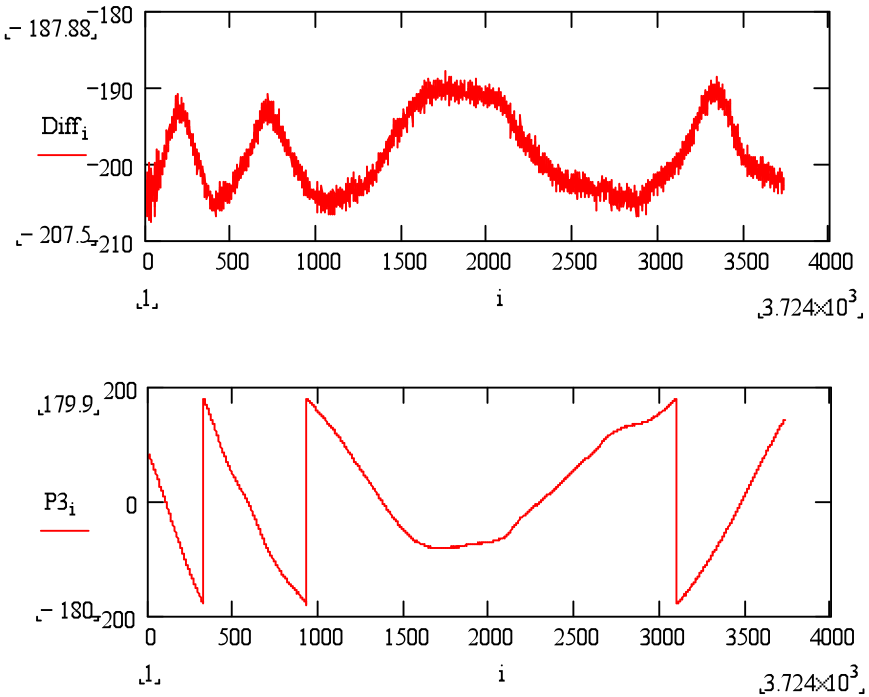
Phase

360 deg=1 ns



Suresh Kumar and Matt Strong

Go and Return path – 2 x one way phase



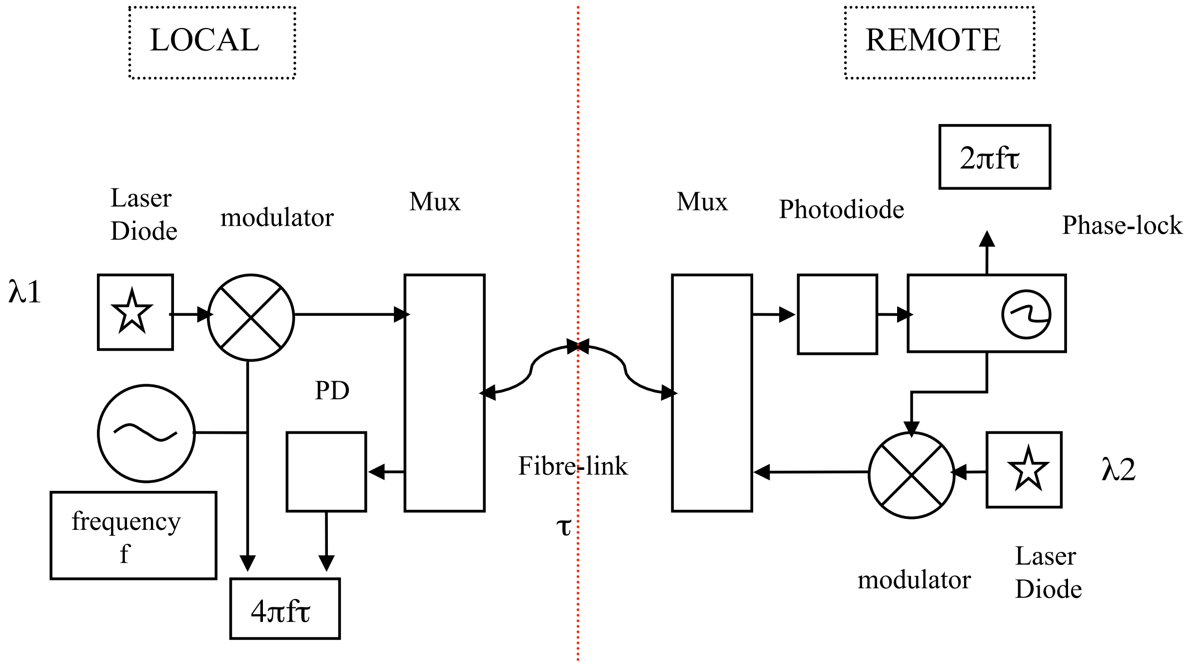
2 deg= 5.5 ps

Beats due to leakage in circulators

Next steps :

- measurements on installed fibre
- L-band link on fibre – RF modulate lasers

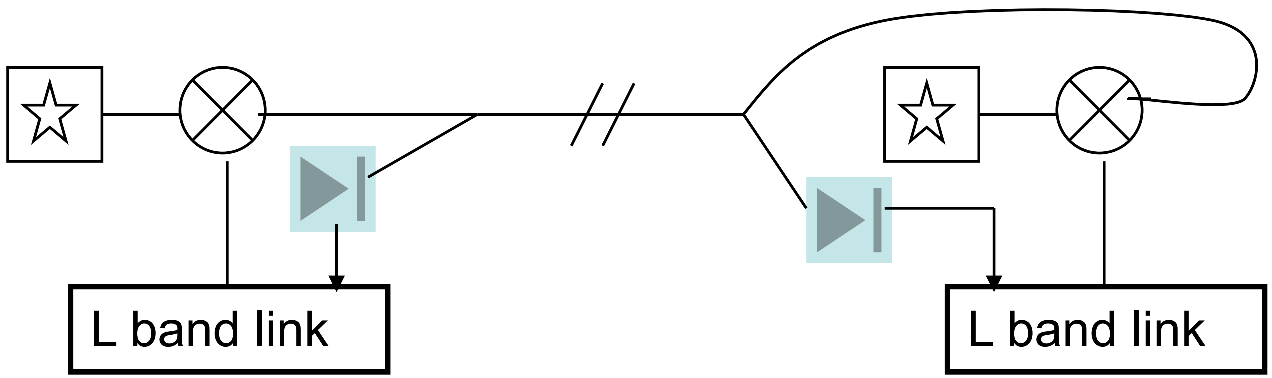
Suggested optical fibre system: (July 2004)



- Multiple lasers, repeaters difficult, needs new electronics

Use the L-band link…

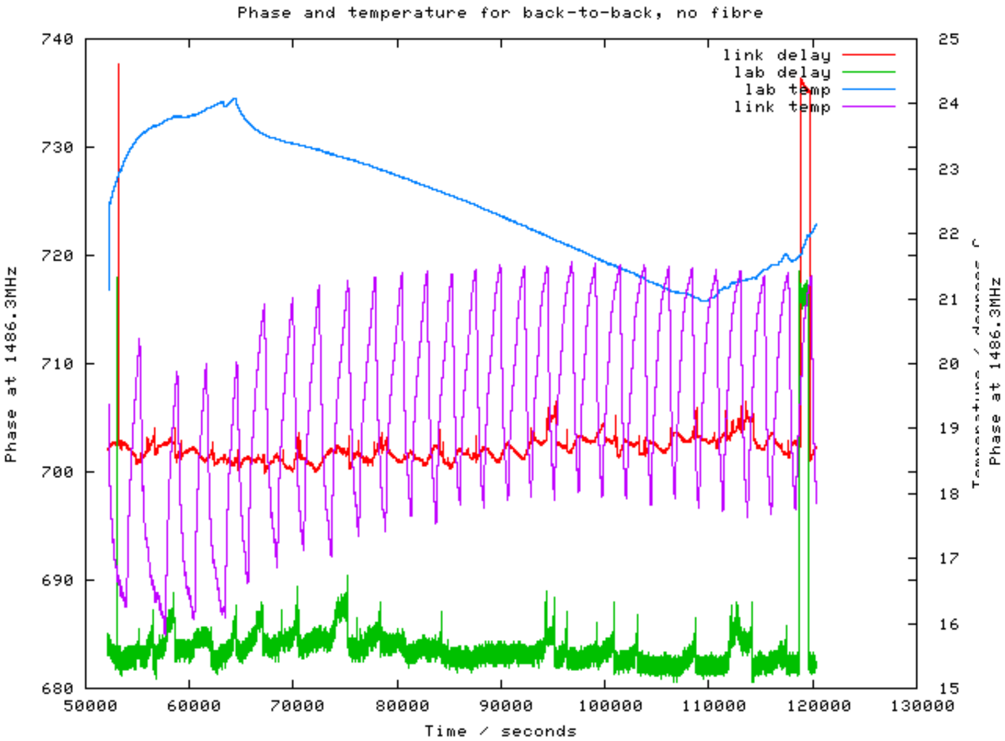
- Modulate lasers instead of driving antennas

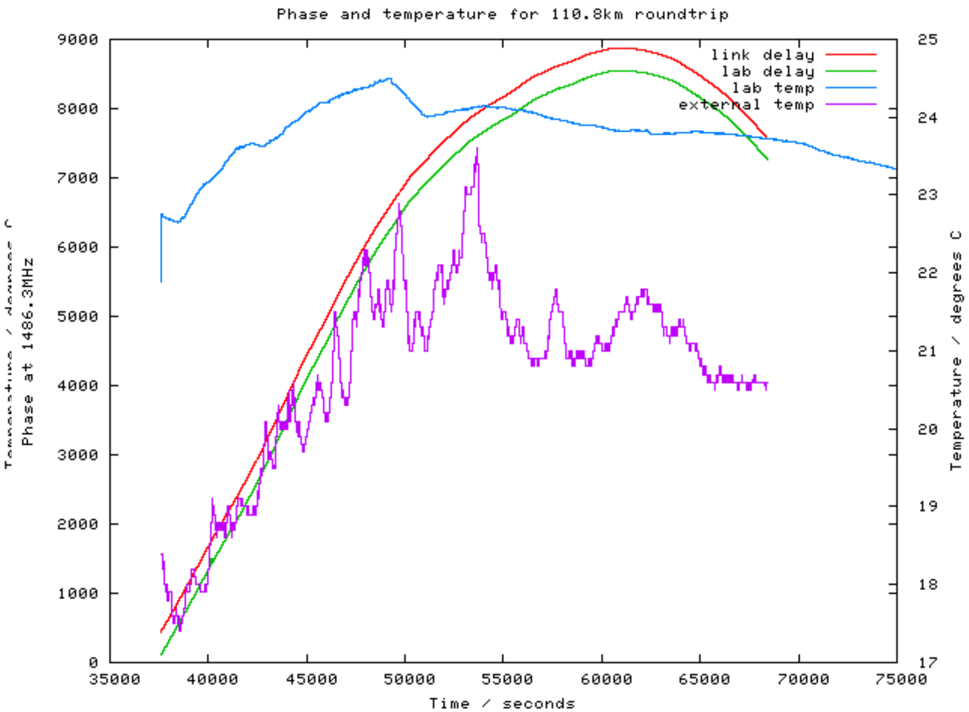


- Pulsed data – separates go and return- avoids problem with circulators
- Test in lab and on installed fibre….

Results

$\Phi_{\text{one way}}$ & $\Phi_{\text{round trip}}/2$





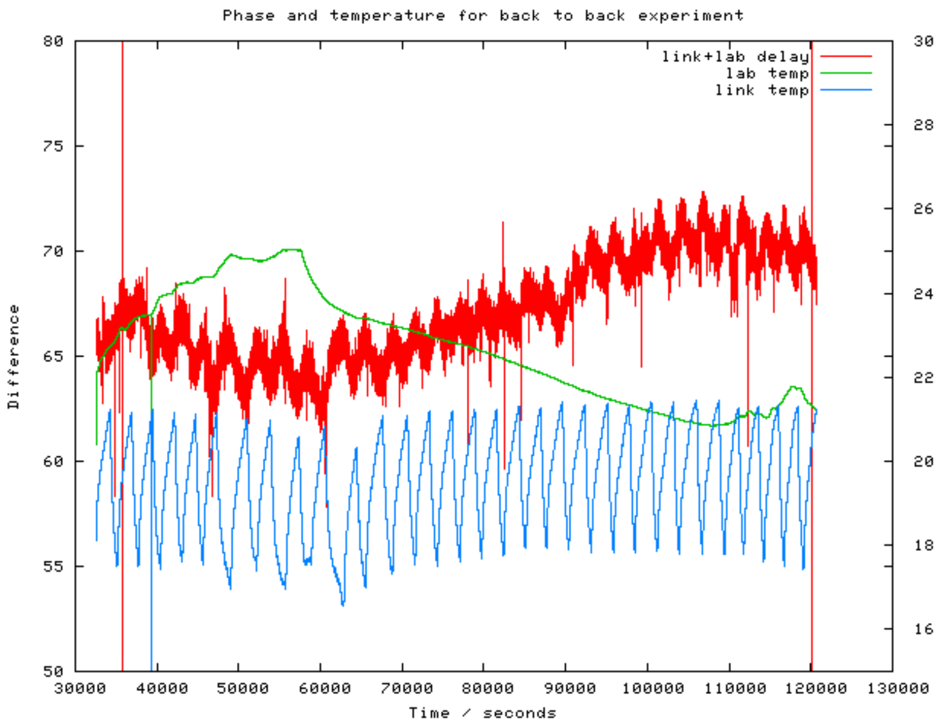
B2B link

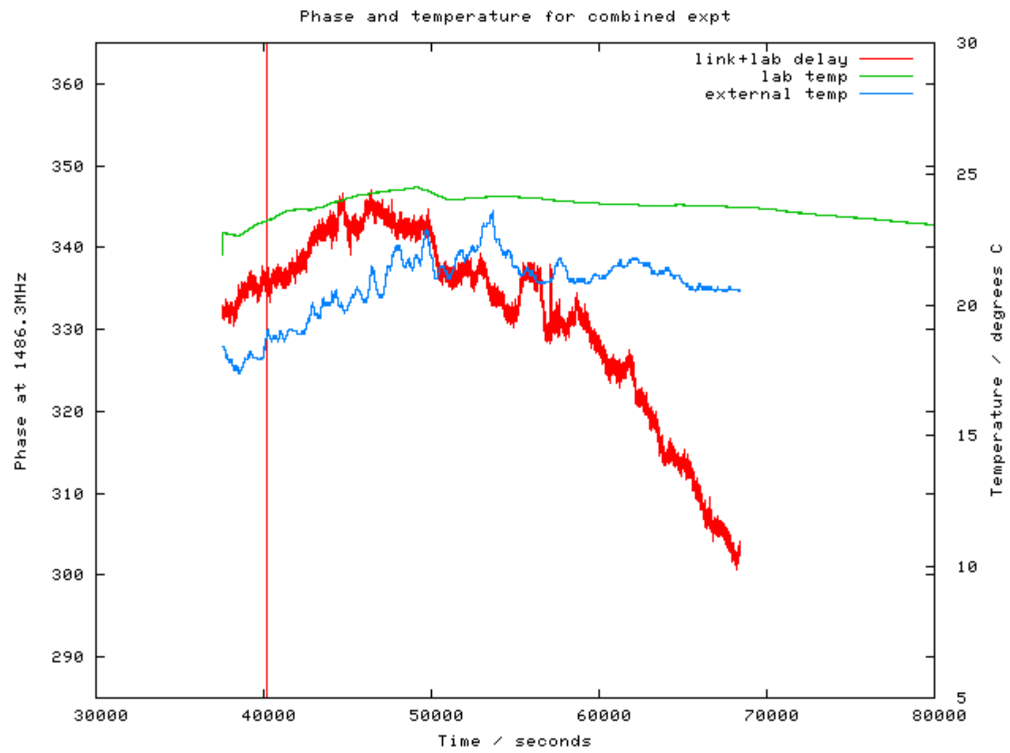
110 km

In the Lab: strong correlation with temperature

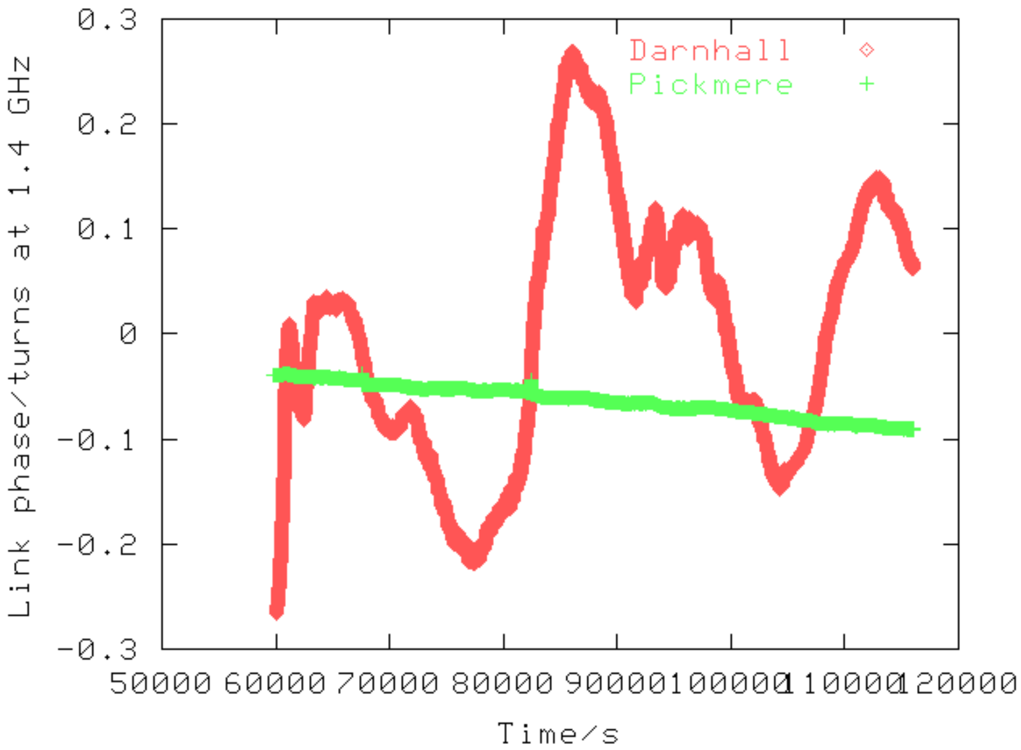
Difference plot

$(\Phi_{one\ way} - \Phi_{round\ trip}/2)$





Installed fibre

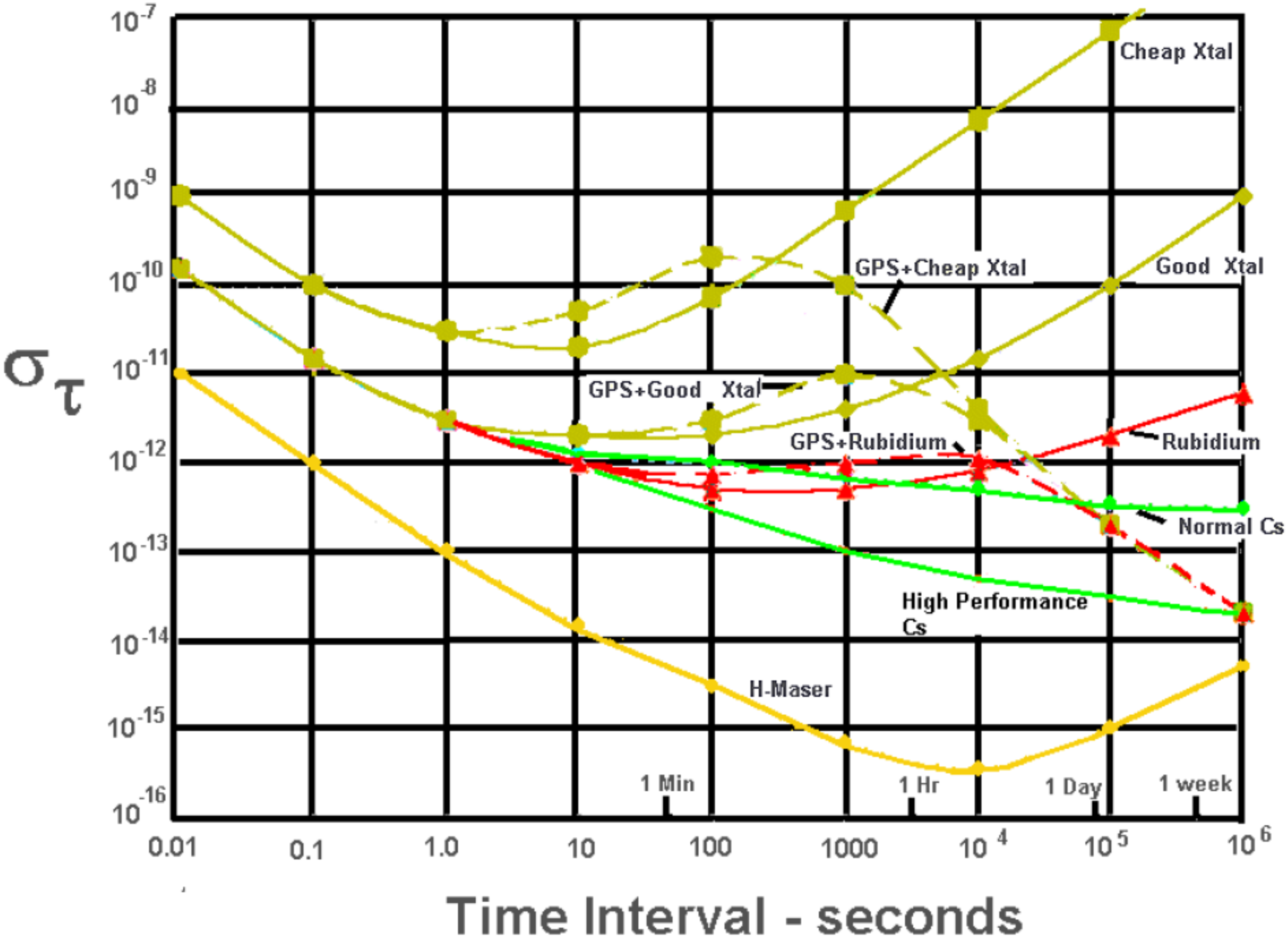


JBO-Darnhall 35 km

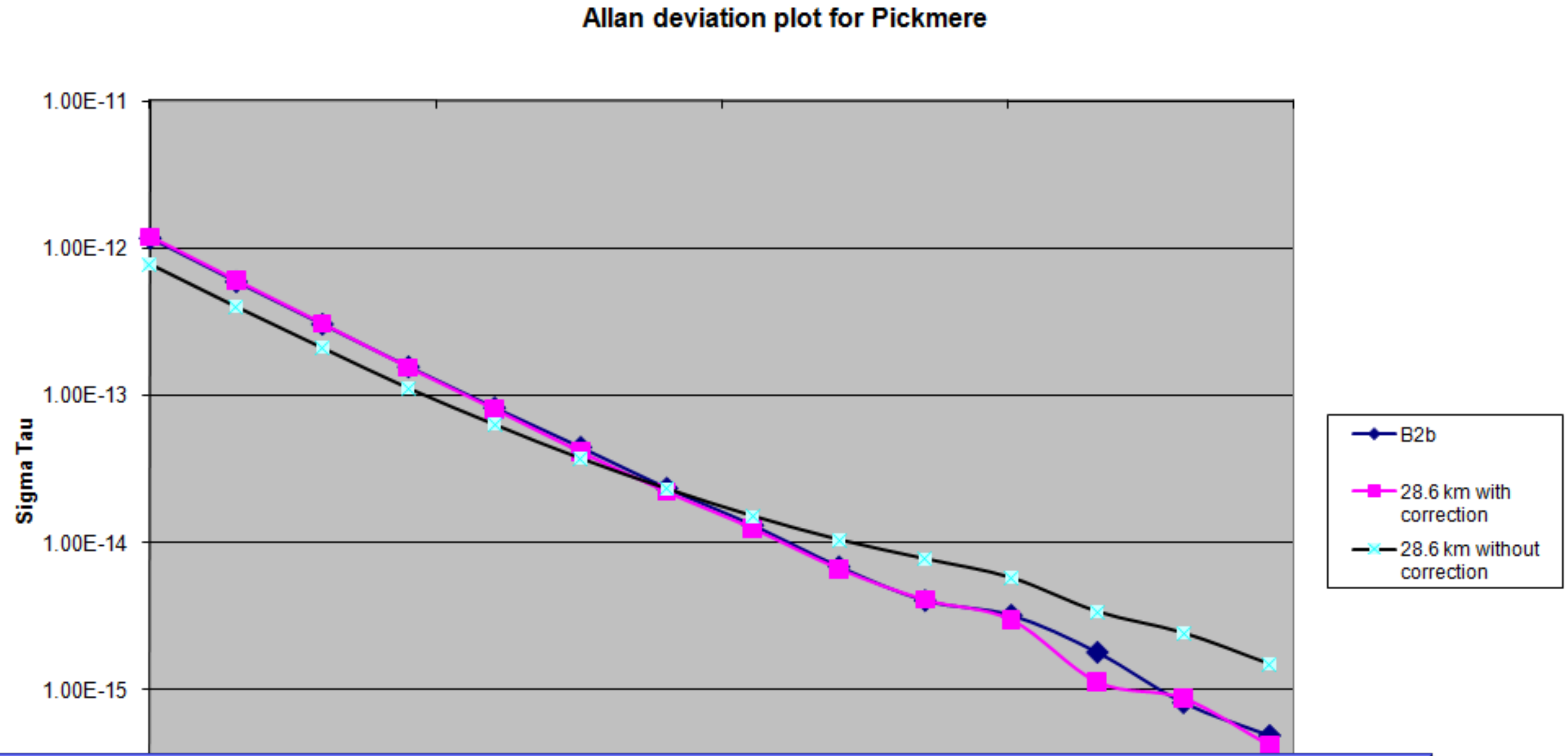
JBO-Pickmere11 km

Much more stable than in lab – underground for much of the run

√Allen Variance

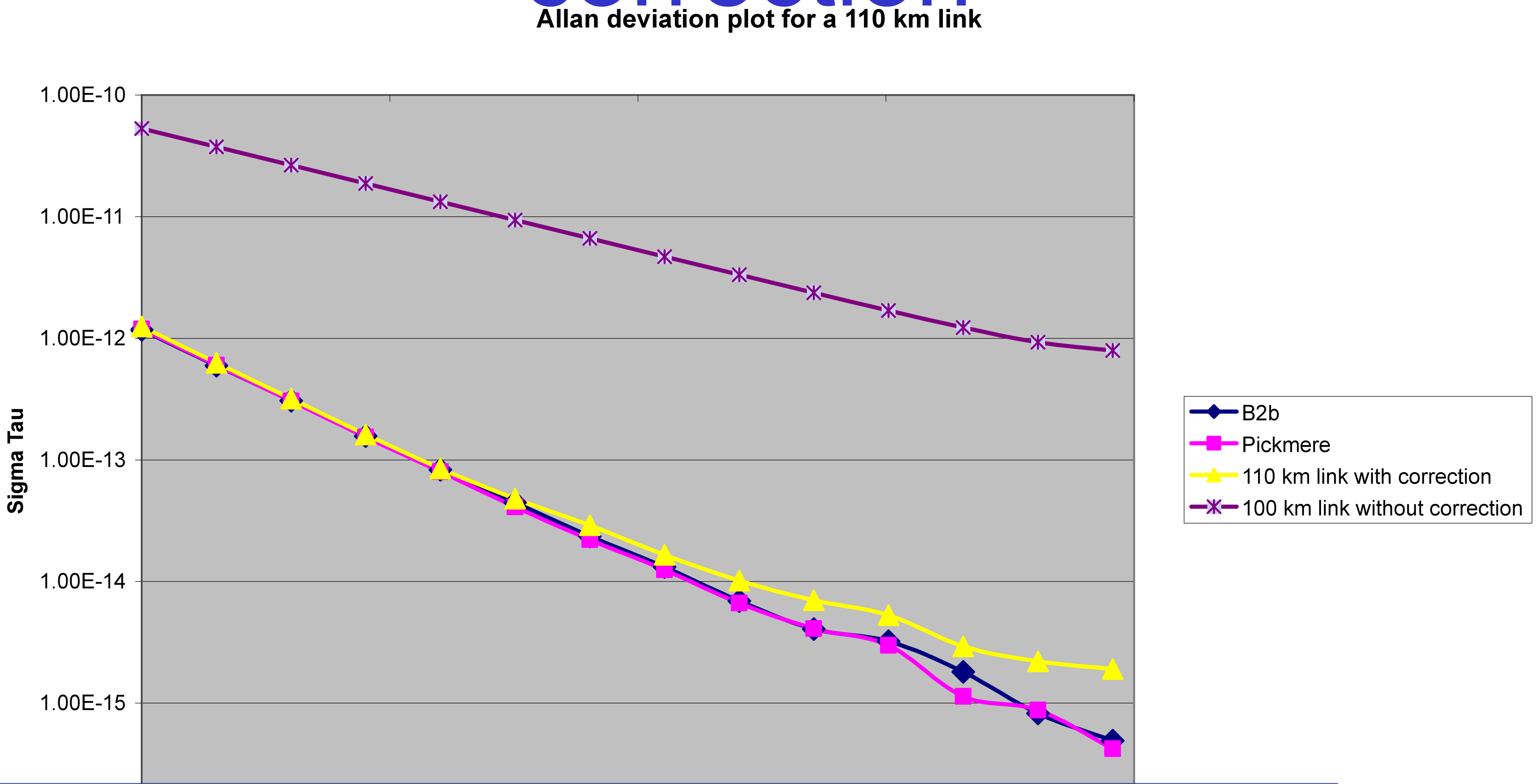


Stability with & without correction



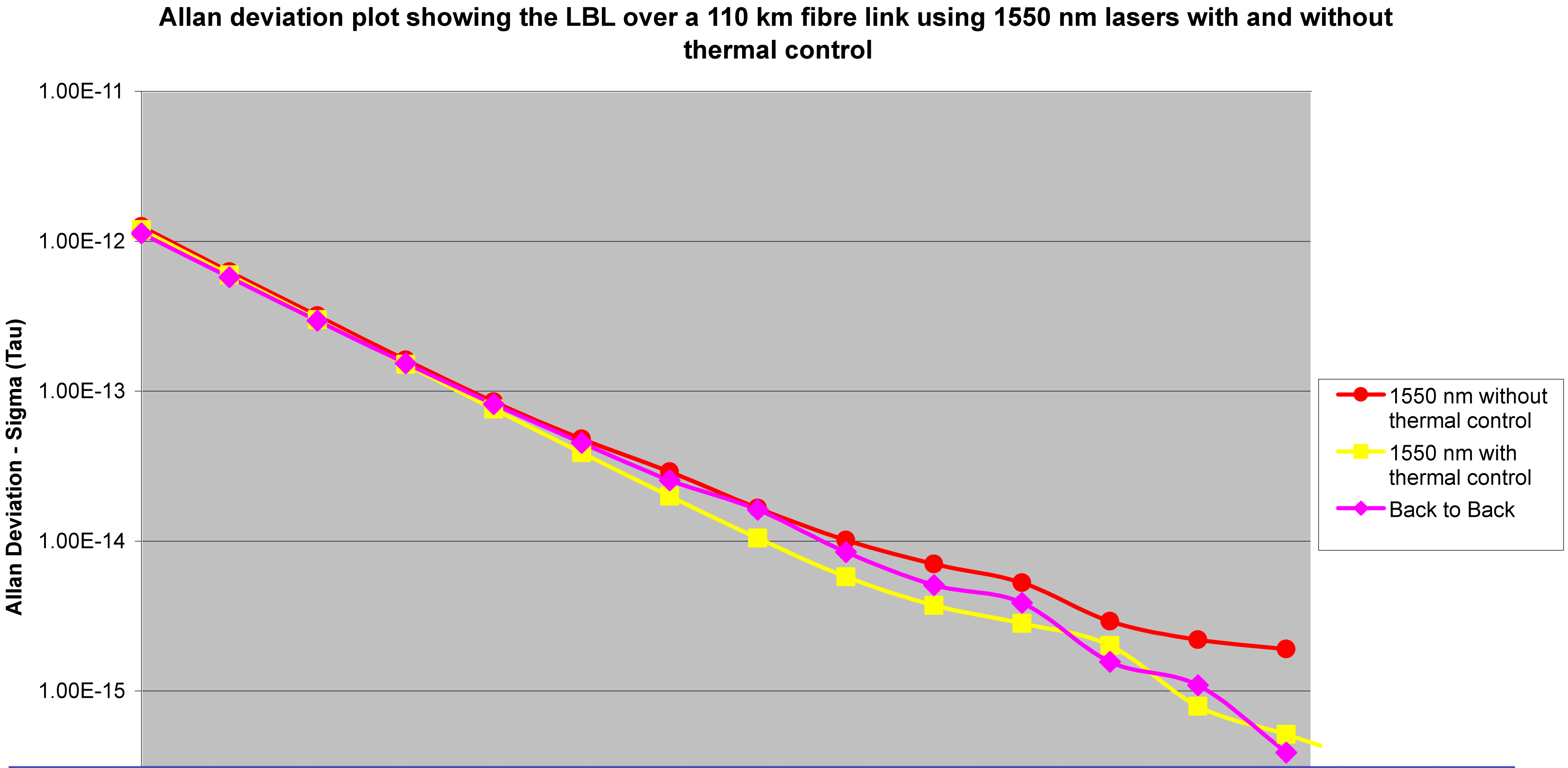
Correction may not be required on short links, but diurnal temperature effects will be visible.

Stability with & without correction



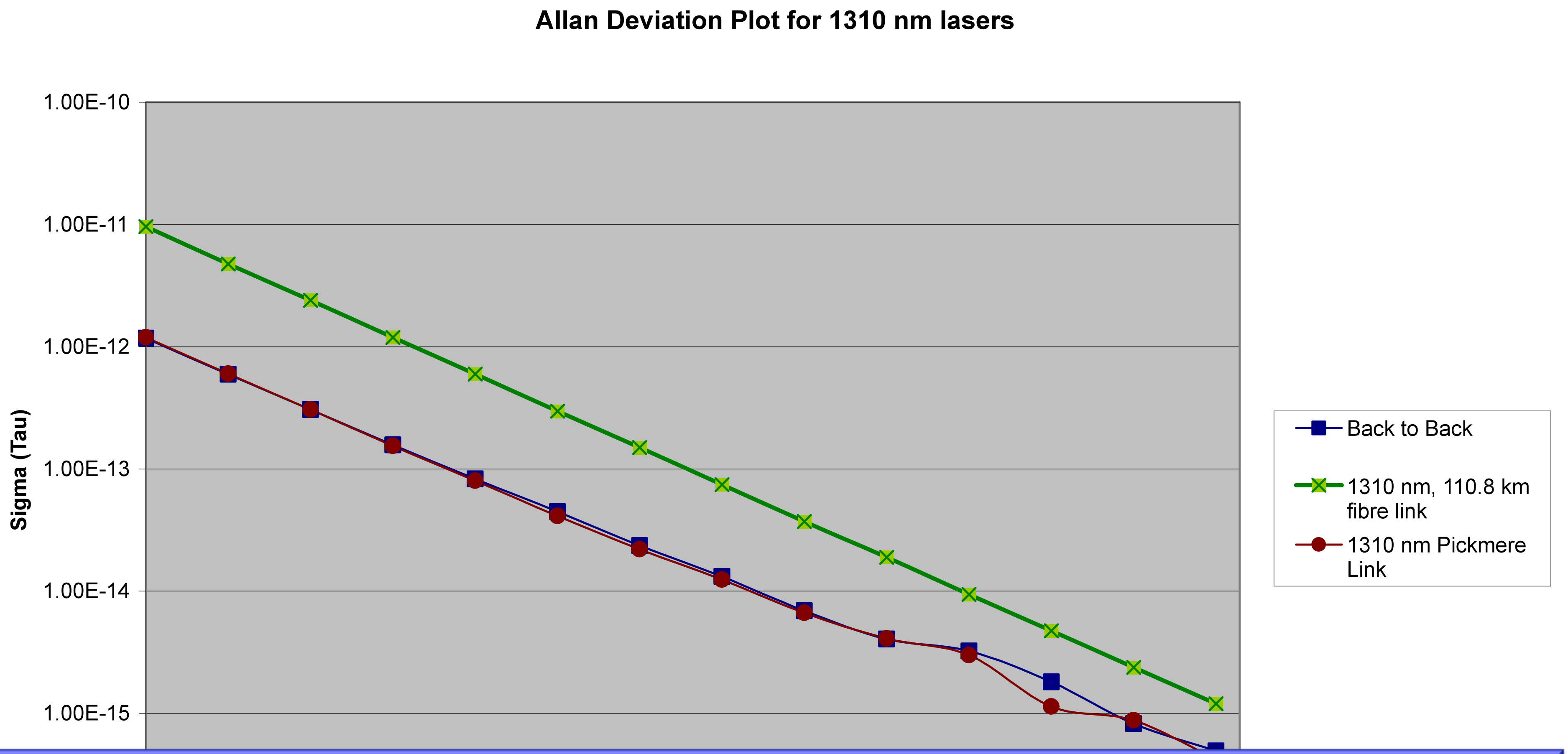
Correction is required on long links to maintain stability

Lasers with and without thermal control



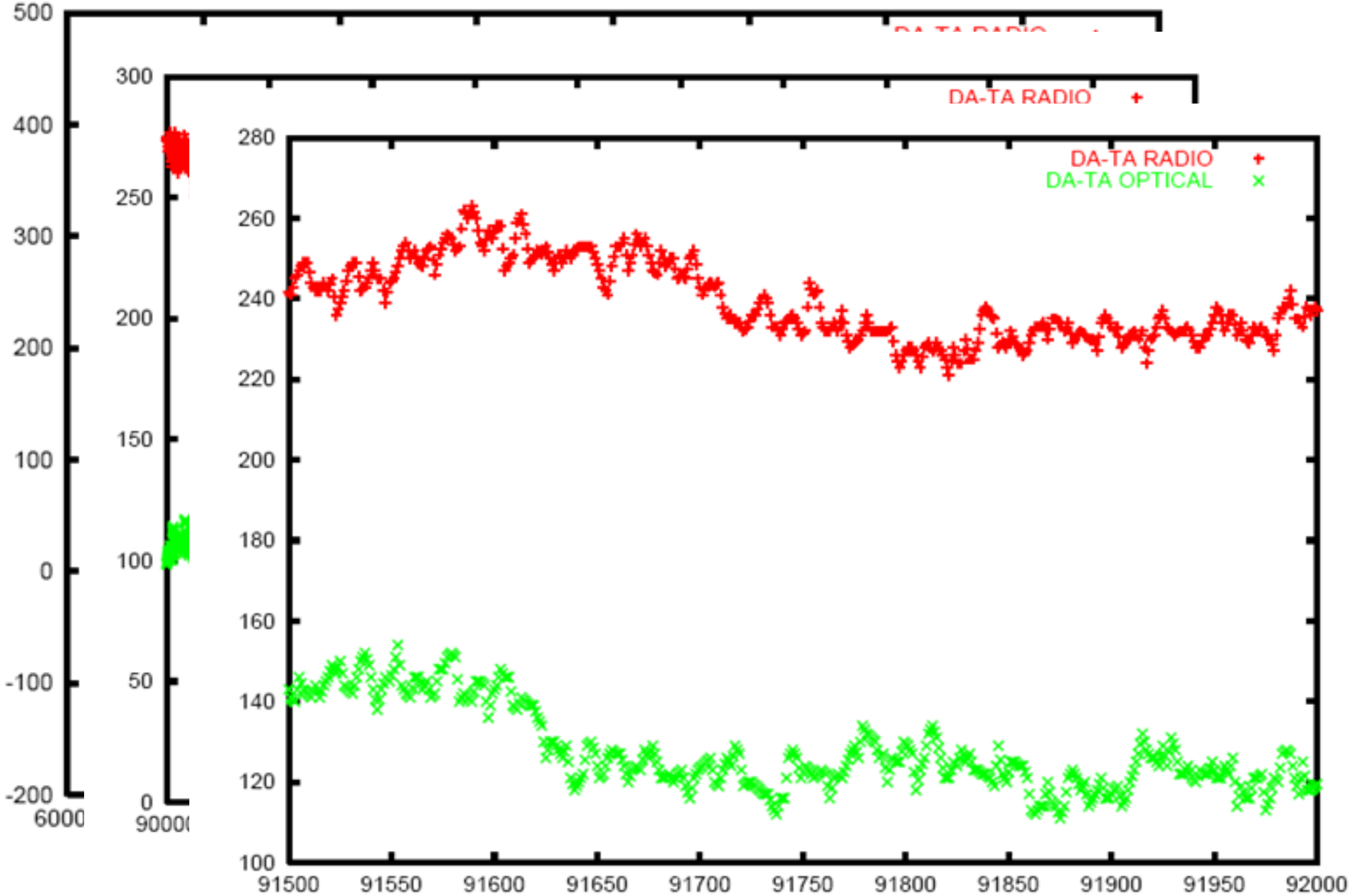
Thermally controlled lasers provide more stability than those without. Lasers with no thermal control may still be used in a fibre lo to good effect

1310 nm or 1550 nm lasers ?

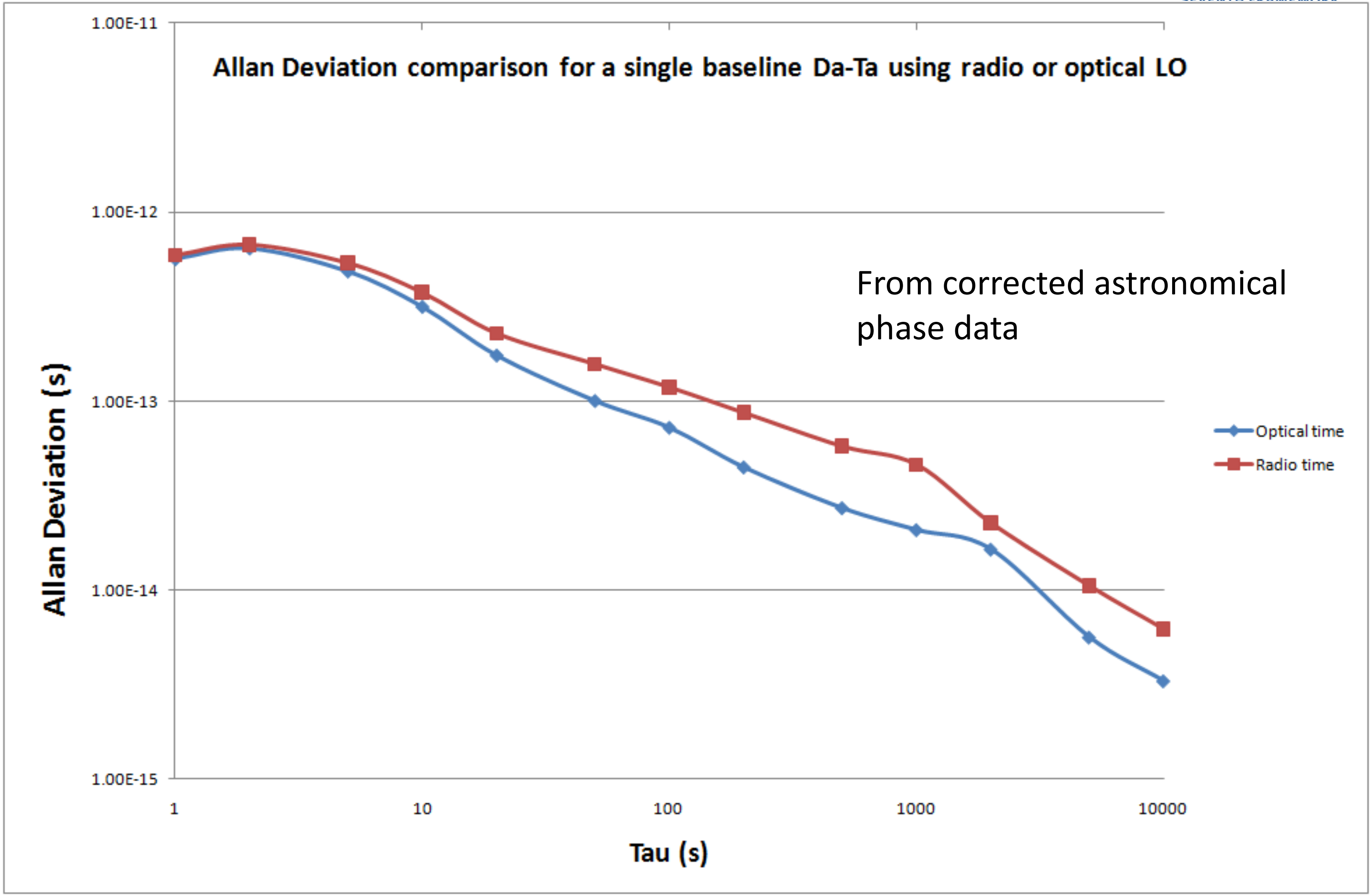


1310 nm lasers are attenuation limited over long links

Comparison of an optical & microwave LO for the same baseline



Comparison of an optical & microwave LO for the same baseline *(different days)*



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Comparison of an optical & microwave link for the same observation

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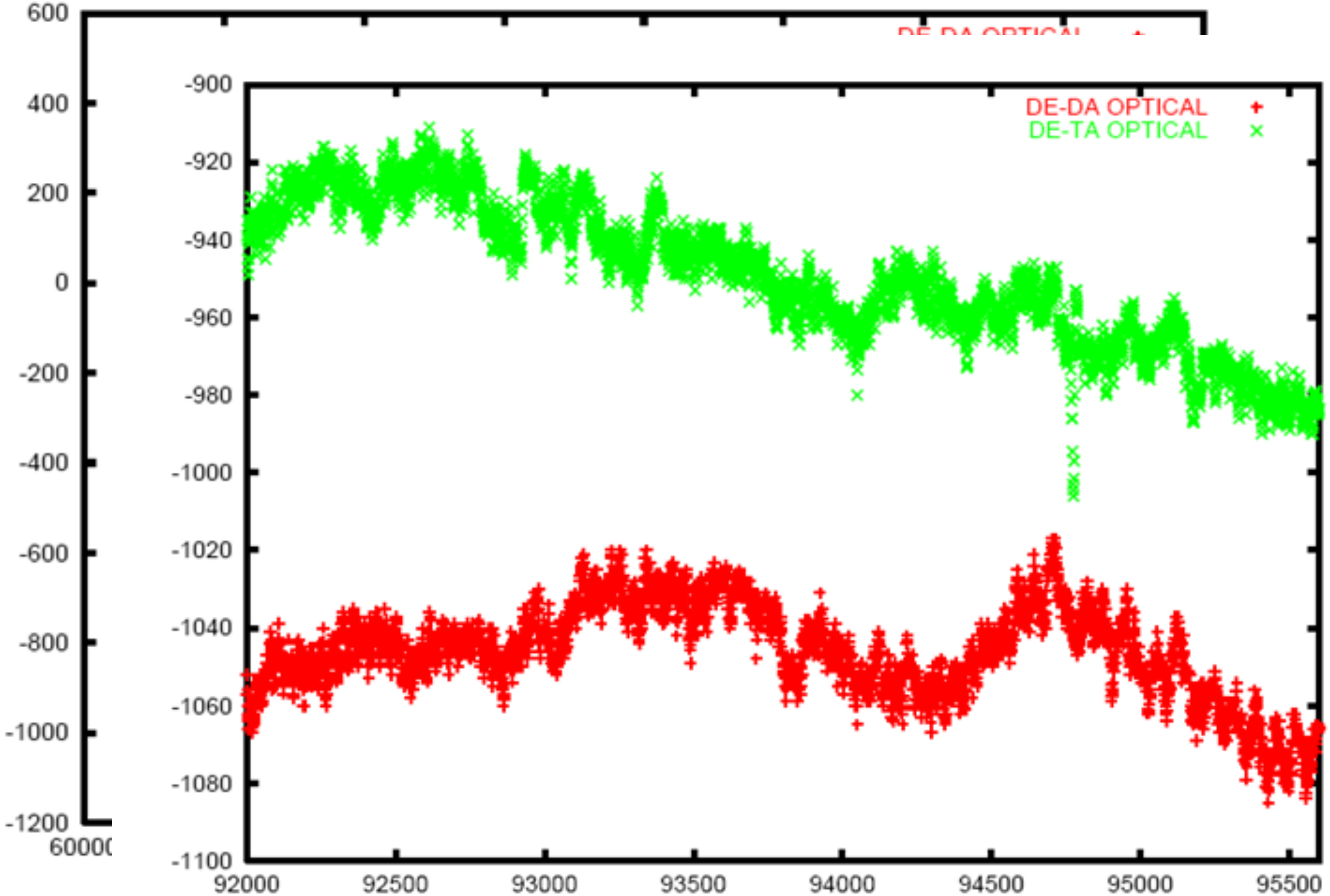
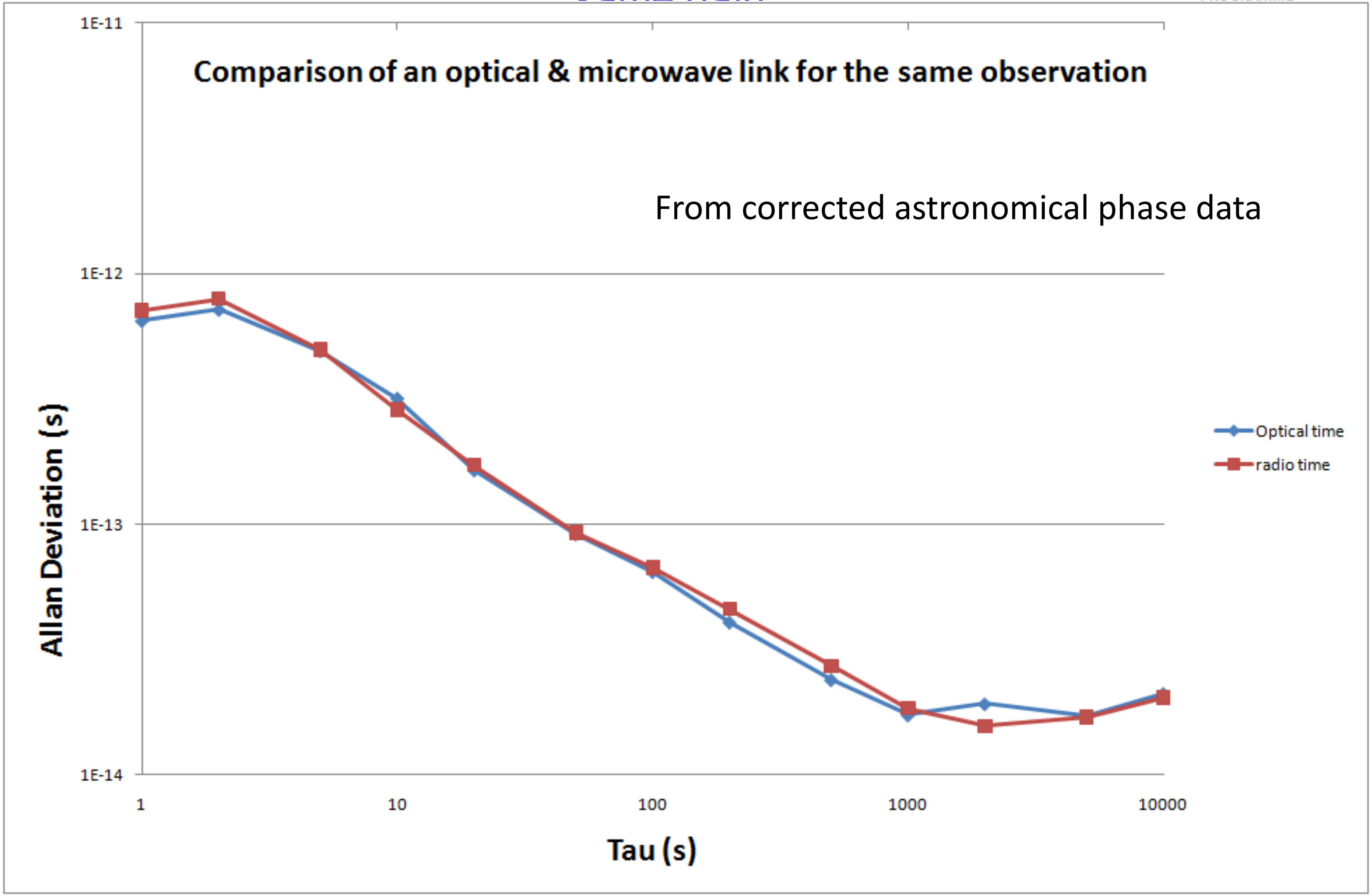


Comparison of an optical & microwave link for the same observation *(different baselines, same day)*



Summary of Results & Conclusions

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The reciprocity assumption applies for a round trip correction system over long fibre links (110 km). We did meet the specs

Stability with and without correction

- Correction may not be required on short links - (27 km) , but diurnal temperature effects will be visible.
- Correction is required on long links to maintain stability

Different Lasers

- Thermally controlled lasers provide more stability than those without.
- Lasers with no thermal control may still be used in a fibre lo to good effect
- 1310 nm lasers can be used on short links, but are attenuation limited over long links

Headline r.m.s stability

	Initial specs	Back to Back stability, no optics	Stability of a 1310 nm laser, over 28.6 km of fibre	Stability of a 1550 nm laser with thermal control over 110 km of fibre ps r.m.s
1 s	1 *ps r.m.s*	1 *ps r.m.s*	1 *ps r.m.s*	1 *ps r.m.s*
1 min	2 *ps r.m.s*	2 *ps r.m.s*	1 *ps r.m.s*	1 *ps r.m.s*
10 min	*10 ps r.m.s*	3 *ps r.m.s*	2 *ps r.m.s*	2 *ps r.m.s*
2 hours	-	3 *ps r.m.s*	3 *ps r.m.s*	4 *ps r.m.s*

Design Issues

- Link power budget – need sufficient signal to noise ratio to get stability required – need L-band link type repeaters at each optical repeater site.
- Reciprocity:
  - chromatic dispersion requires lasers locked to within 50 MHz – is this possible?
  - Polarisation mode dispersion – averaging process in the L-band link helps in this (cf. tower vibration)
  - Wavelength multiplexing with DTS – separate fibre?

Chromatic Dispersion Issue

- Dispersion *D* (typically 17 ps/km/nm) means that delay will change if the laser drifts.
- Separate lasers over link of length *L* will drift in frequency by *Δf* with respect to each other.
- Frequency drift of 49 MHz will give *Δt* = 1 ps over a 100 km link
- This is a higher spec than that for a standard telecomms laser – do we need laser wavelength lockers?

$$\Delta t = D L \Delta\lambda = D L \Delta f \frac{n\lambda^2}{c}$$

$$\Delta f = \frac{c\,\Delta t}{D L n \lambda^2}$$

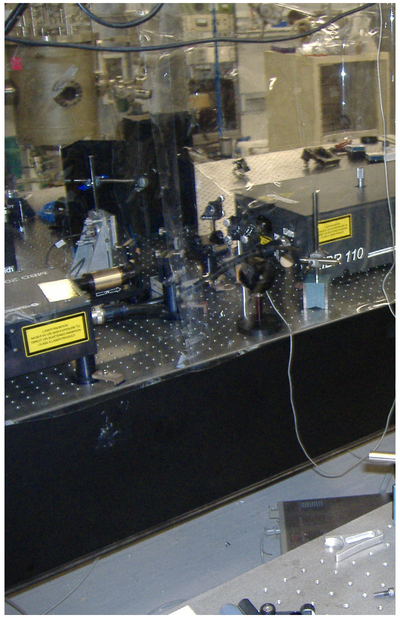
Let's find out:

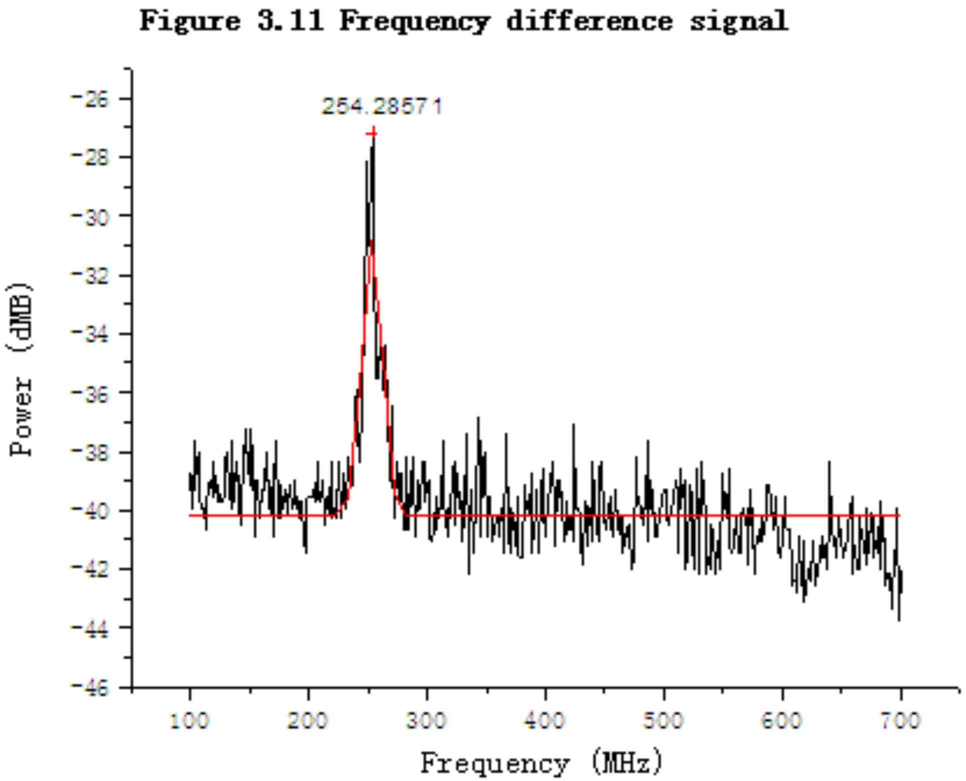
1) In Free space: using TEC controlled 780 nm IR laser, beat with tunable Ti Sapphire (Thanks to Prof. Andy Murray).

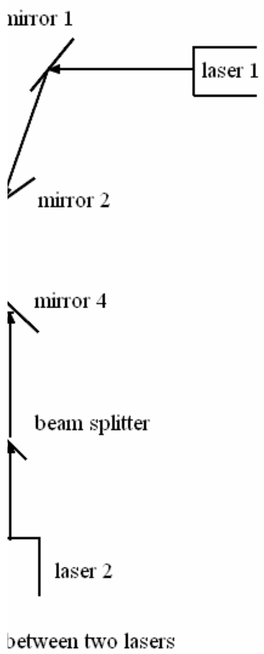
2) In Fibre: using TEC controlled 1550nm communications lasers, beat with Santec DFB tunable laser.

3) Thanks to MSc students Shengwei Cao, Sam Cooke, Ho Ting Fung, Helen Snodgrass

Laser Stability – Free Space Lasers

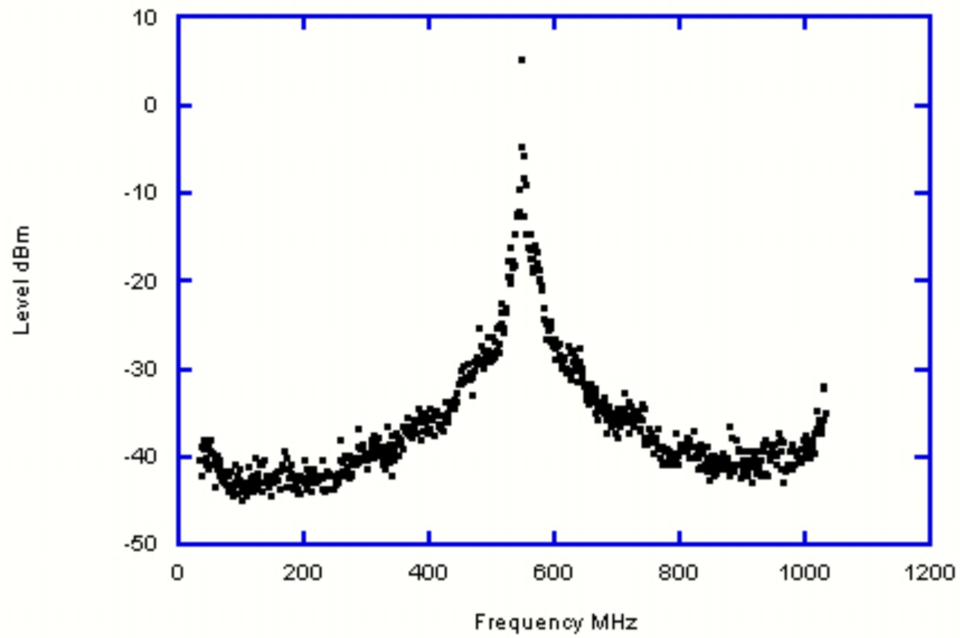






Stability: ~ 50 MHz in 1 min.

Laser Stability – DFB comms. laser



Stability: ~2 MHz in 1 min.

- Good enough! Lockers not required

- Tested for nearest telescopes
- Next:
  - Build up optical equipment including add/drop for link phase light
  - Roll out through the link system
  - Swap over the L-band link
  - Release the link towers!

Conclusion

- Fibre network installed and tested
- All telescopes connected with digital systems
- Phase transfer over fibre works and is being rolled out
- Expect new science real soon now!

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