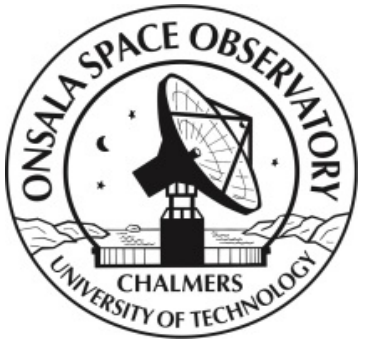


VLBI with GNSS signals

Rüdiger Haas, Andreas Hellerschmied,
Alexander Neidhardt, Vincenza Tornatore,
Grzegorz Klopotek, Thomas Hobiger

Motivation

- VLBI observations of GNSS signals
  - Determination of GNSS orbits in VLBI frame
  - Determination of VLBI station positions in GNSS frame
- Challenges
  - How large networks necessary?
  - How long observation times necessary?
  - Can phase delays be used? Phase connection?
  - Ionospheric correction? Dual frequency observations?
  - Satellite antenna phase centre vs. centre of mass?

Observations

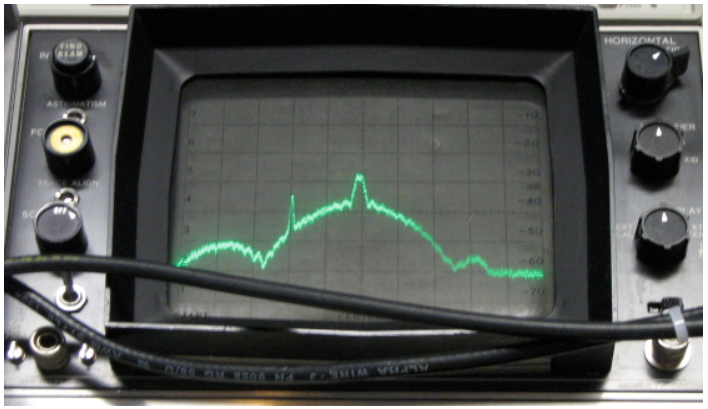
- Several test observations performed during the last years
  - 2010: Onsala – Medicina
  - 2010: Onsala – Medicina – Jodrell Bank
  - 2012: Onsala – Medicina – Noto
  - 2013: Onsala – Wettzell
  - 2014: Onsala – Wettzell
  - 2016: Onsala – Medicina – Sardinia
- Short observational tests (1–4 h) using astronomical radio telescopes with L-band systems, e.g. Onsala 25 m telescope
  - At Wettzell: L-band system via S-band horn
- Often targets GLONASS satellites
- Newest experiment 2016: GPS, GLONASS, Galileo, Beidou

Observations

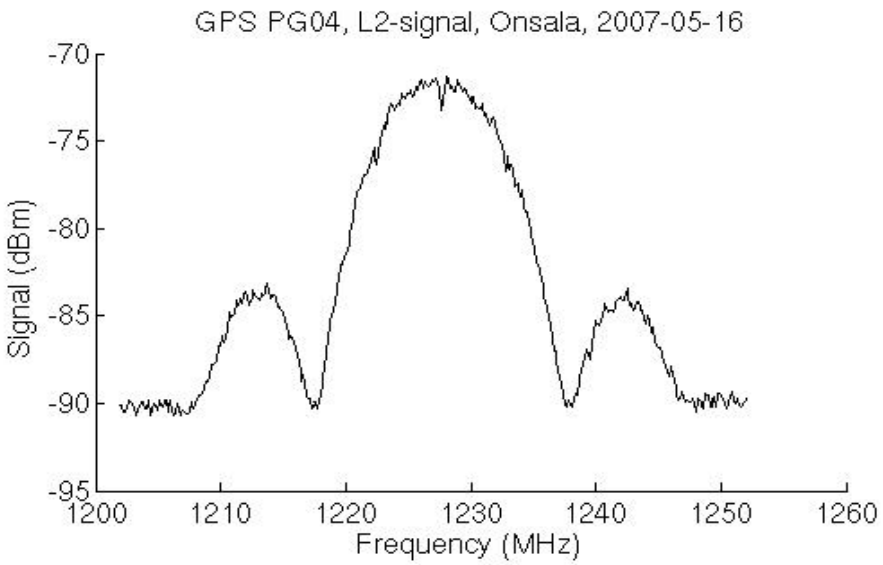
- Challenges:
  - Astronomical L-band telescopes are not “fast slewing”
  - Usually only step-wise tracking possible (e.g. 10 s updates), only modern telescope systems can track continuously
  - Astronomical L-band systems are very sensitive and radio telescopes have high gain => GNSS signals very strong
  - Attenuation of RF-signals necessary
  - Local oscillator settings at several telescopes do not allow simultaneous dual-frequency observations
  - “hand-made” observation schedules
  - Access to telescope time… (Telescope Program Committees do not really regard this as “basic science”…)

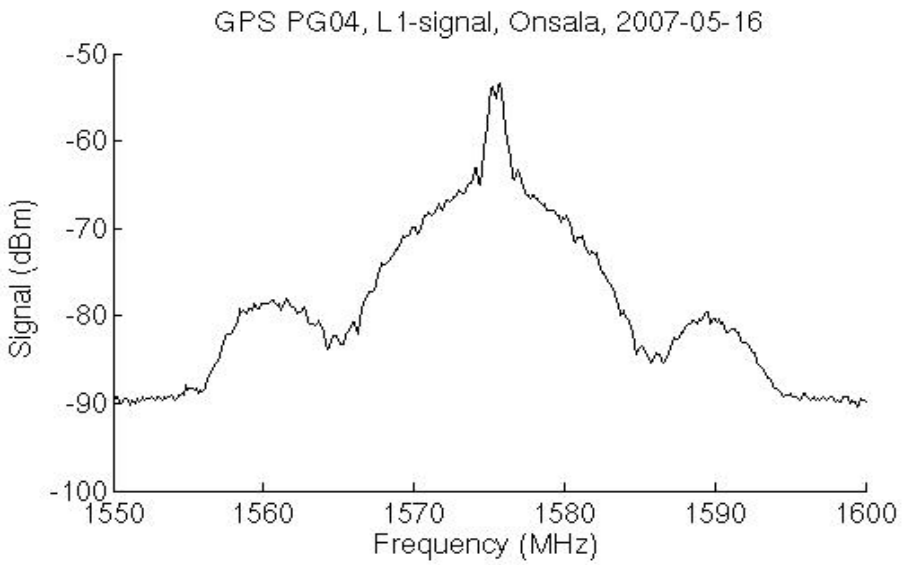
Observations

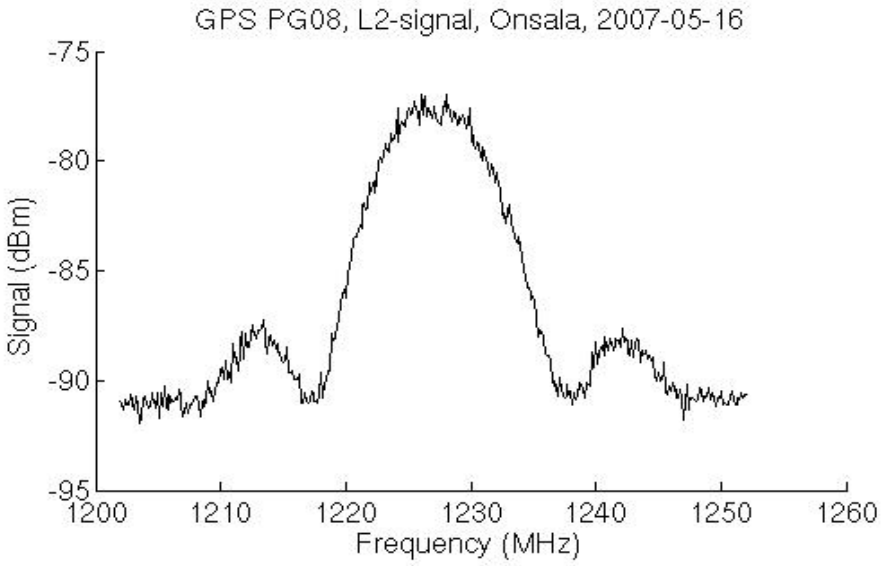
Signal on the spectrum analyser

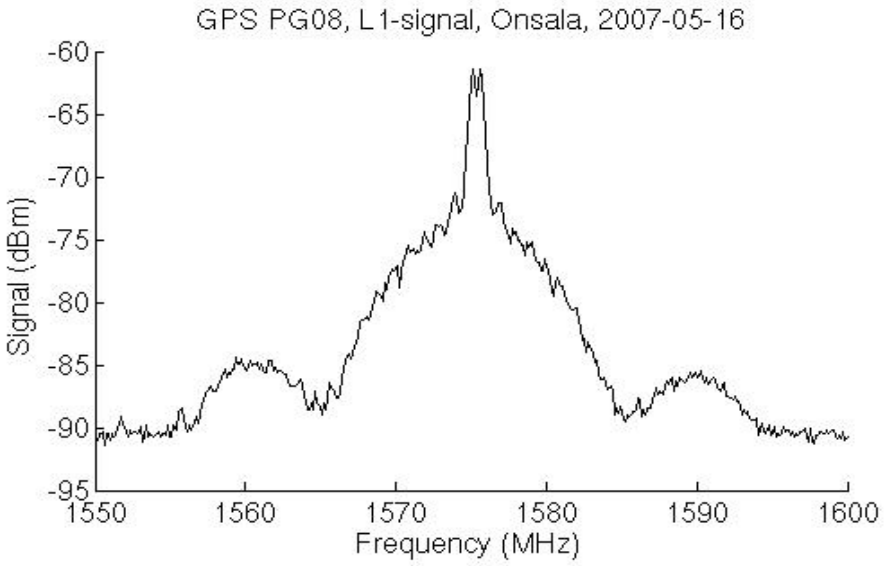


Strong satellite signal:
=> additional RF-attenuation 20–30 dB necessary

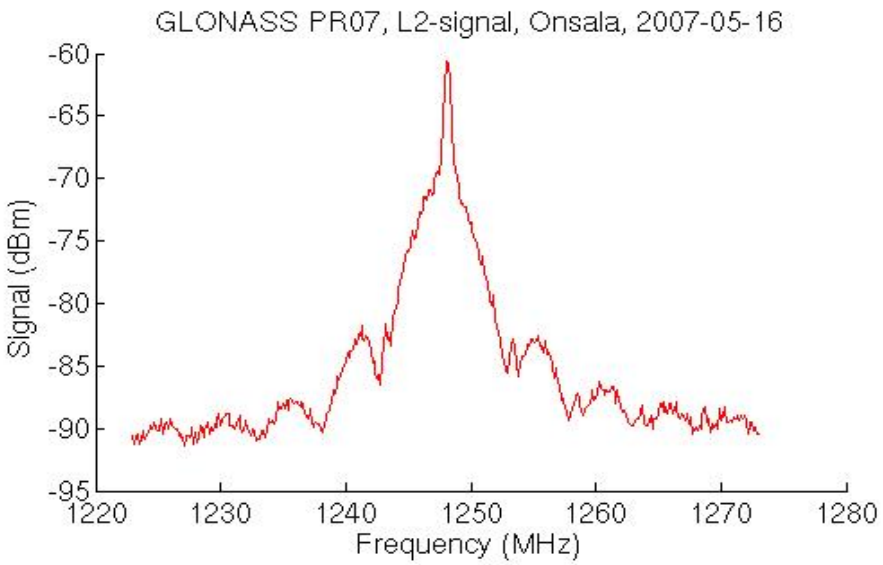


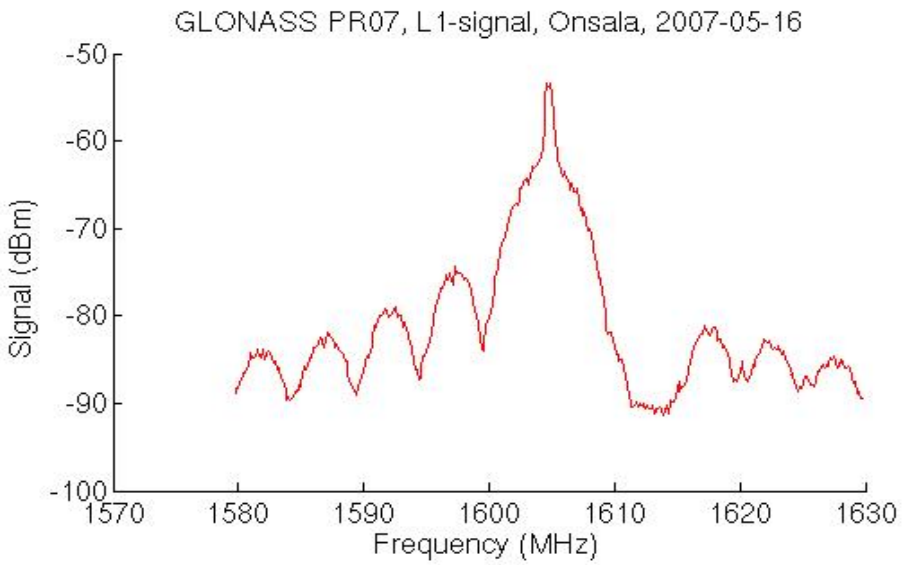


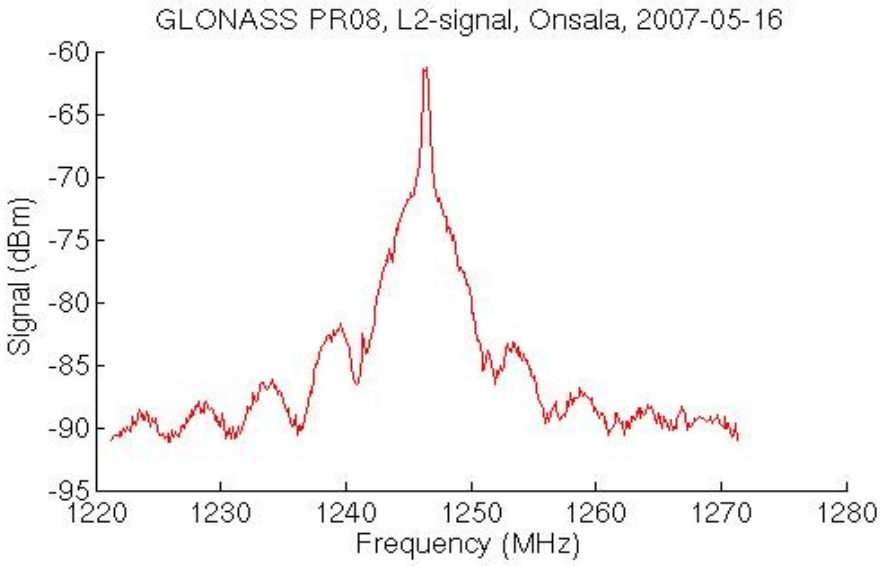


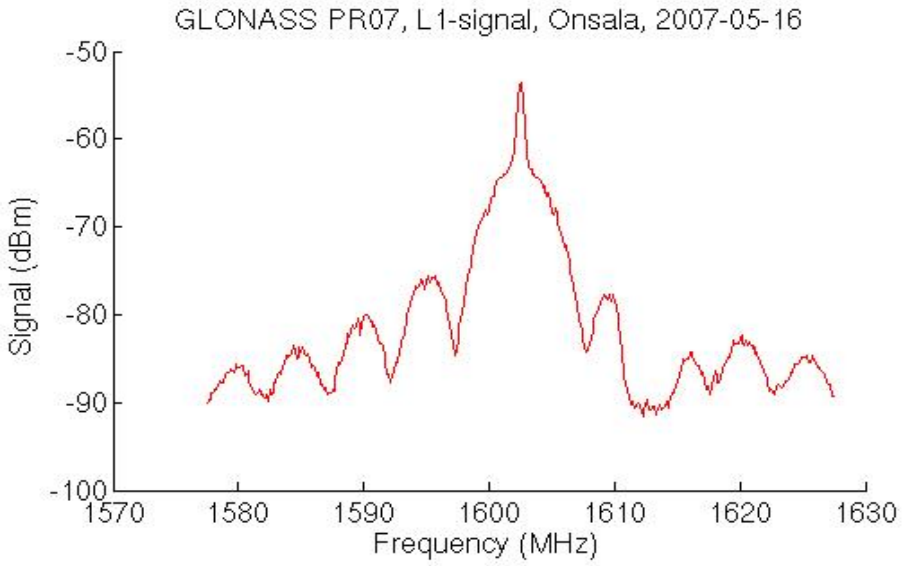


Examples of GPS signals observed at Onsala

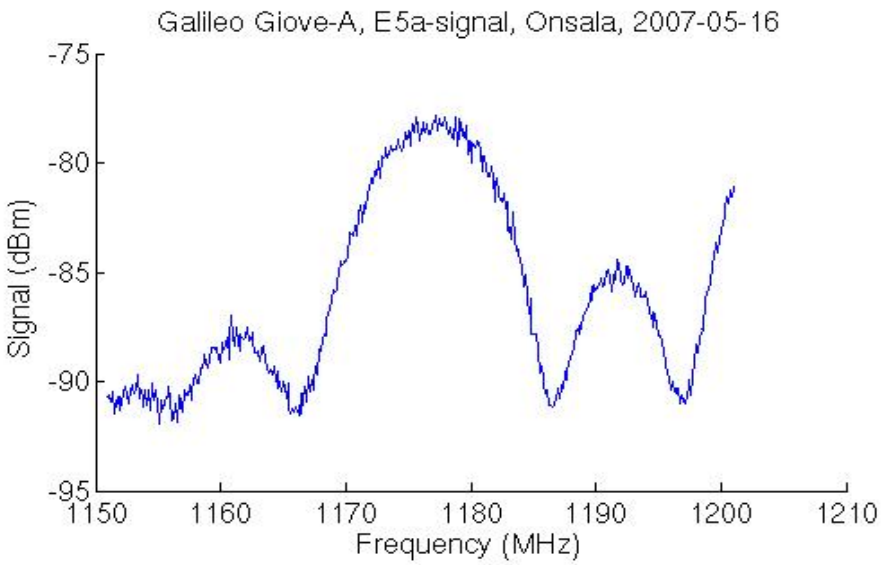


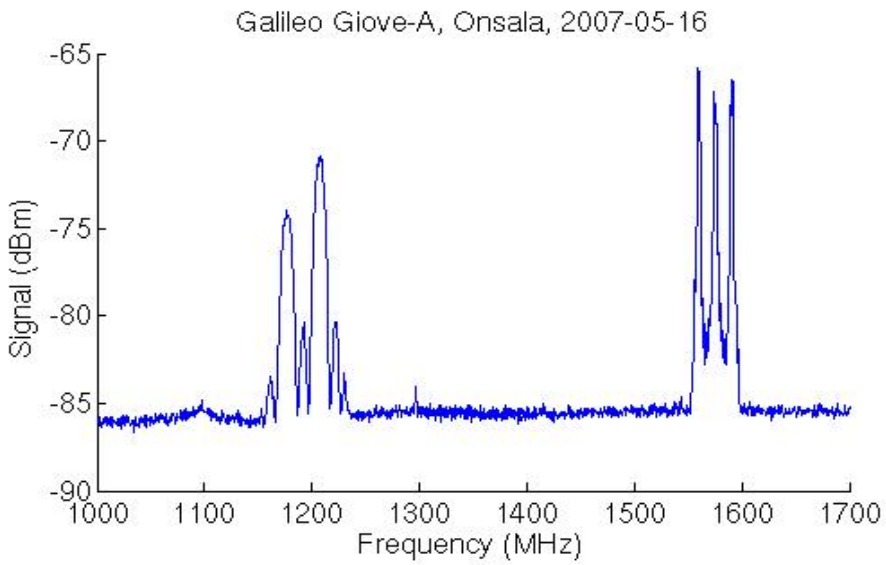


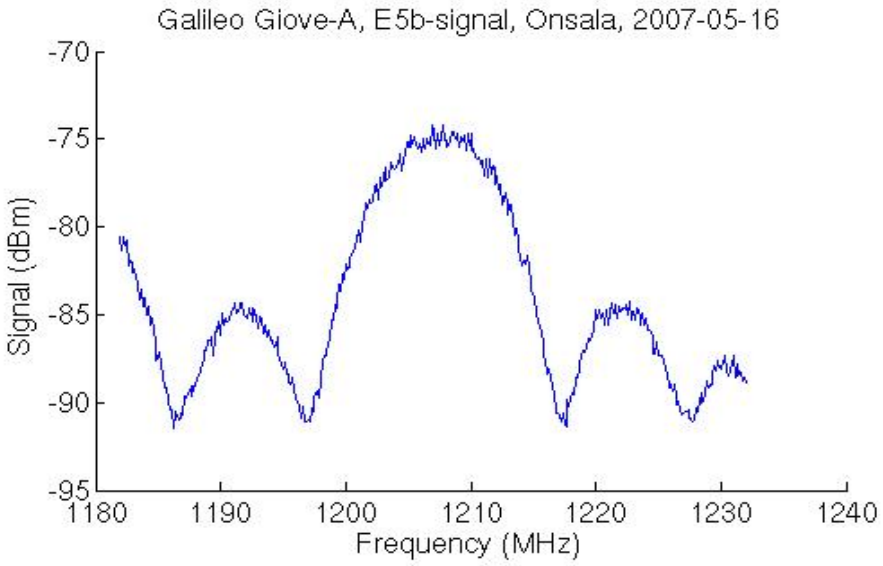


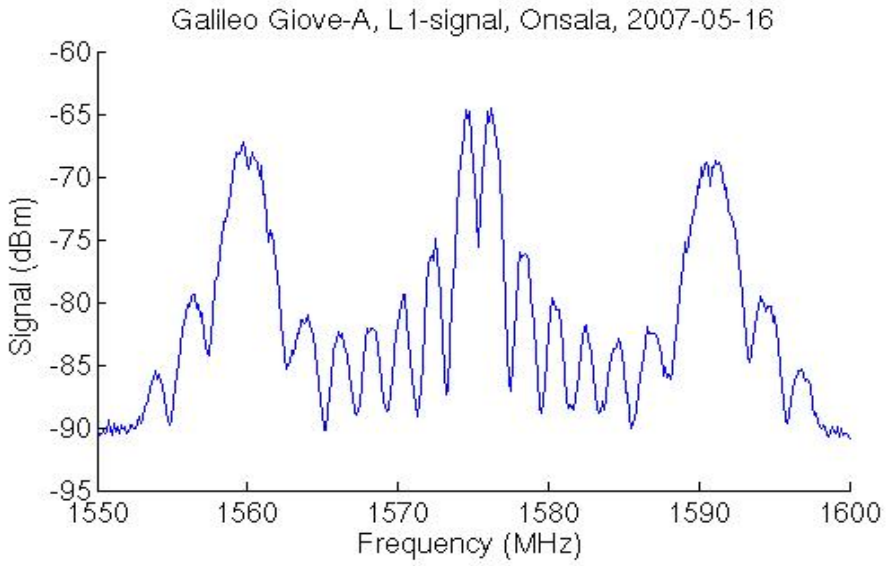


Examples of GLONASS signals observed at Onsala



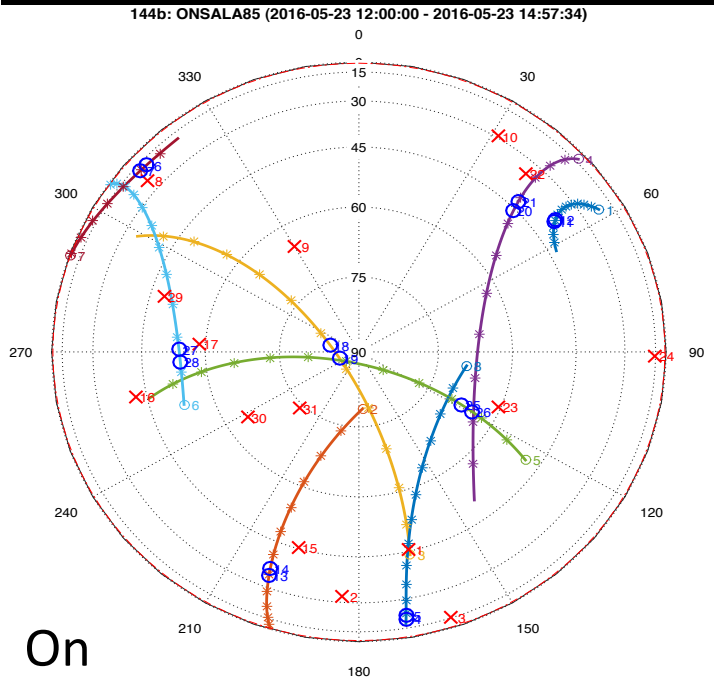




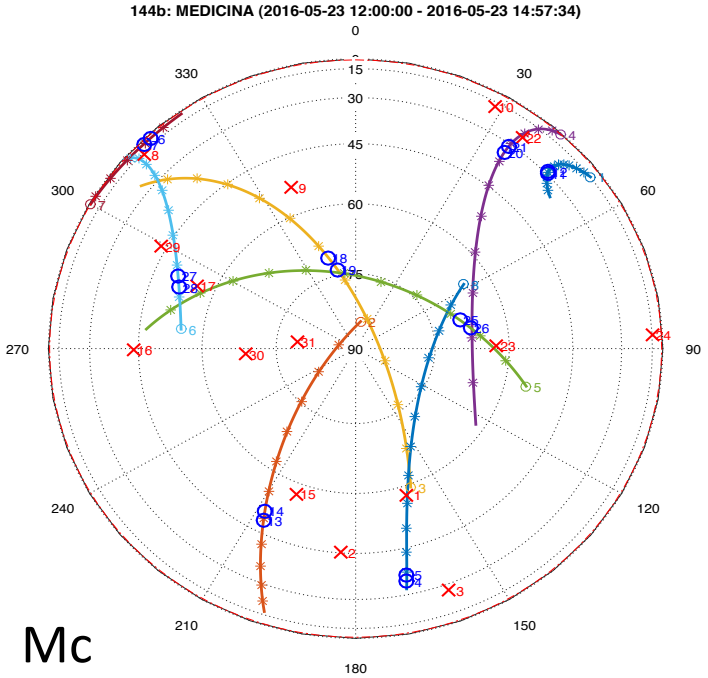


Examples of Galileo signals observed at Onsala

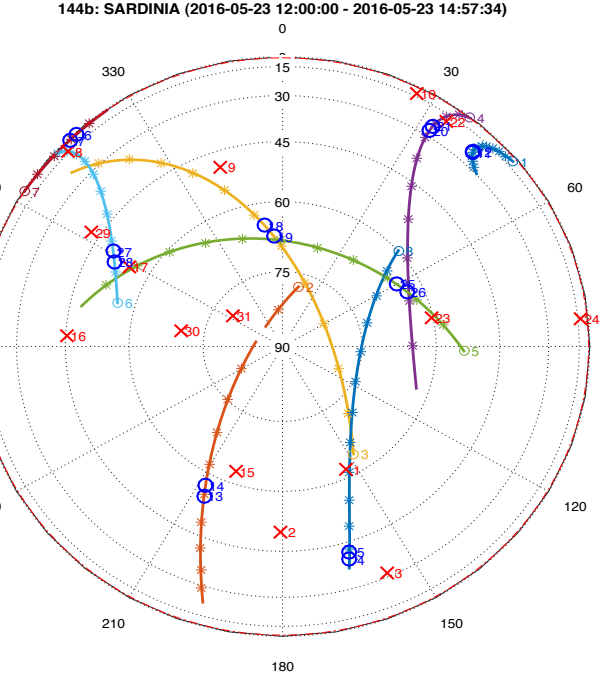
Observations



On



Mc



Sr

1 - BEIDOU IGSO 6
2 - BEIDOU-3 M2
3 - COSMOS 2434 (721)
4 - COSMOS 2459 (731)
5 - GPS BIIF-1 (PRN 25)
6 - GPS BIIRM-2 (PRN 31)
7 - GSAT 0209 (PRN E09)
8 - GSAT0203 (PRN E26)

Example: Experiment 2016-05-23, On–Mc–Sr

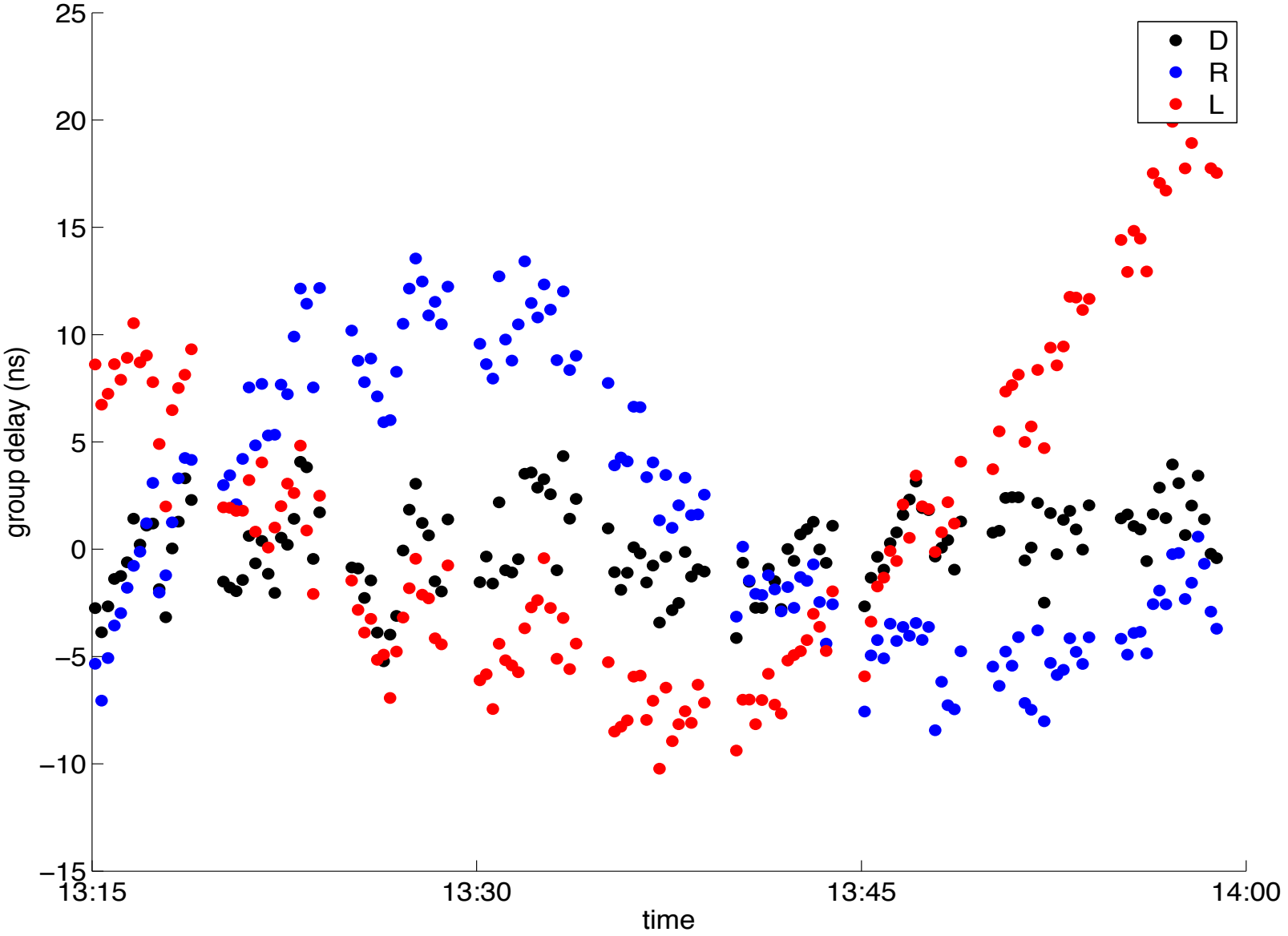
Modelling and correlation

- GNSS satellites are radio sources in the near field…
  - Telescopes do not look parallel as in normal geodetic VLBI
- Near-field model needed, e.g.
  - Sekido & Fukushima (*Journal of Geodesy*, 2006)
  - Duev *et al.* (*Astronomy and Astrophysics*, 2012)
- Software correlator
  - DiFX: Deller *et al.* (*Publications of the Astronomical Society of the Pacific*, 2011)
  - SFXC: Keimpema *et al.* (*Experimental Astronomy*, 2015)

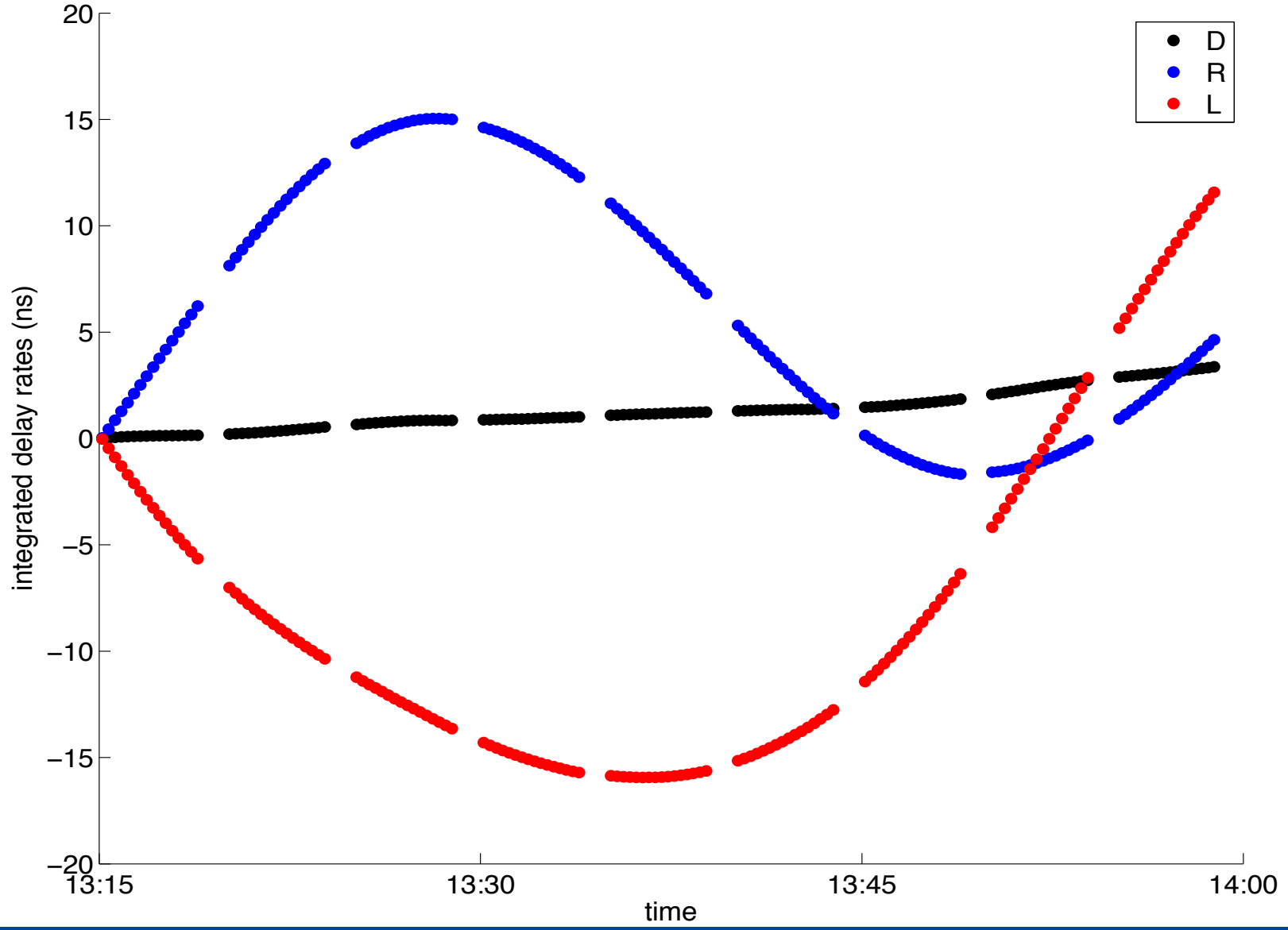
Experiment G130128

- Three different apriori delay models used
  - D-model: Dmitry Duev (Duev *et al.*, A&A, 2012)
  - R-model: Rüdiger Haas (ad hoc 2013)
  - L-model: Lucia Plank (Sekido & Fukushima, 2006)
- Correlation with
  - SFCX (D-model), 0.5 and 1 sec integration
  - DiFX (D-, R- and L-model), 0.25 s integration
- Post-processing
  - with AIPS/Fringe (astronomical VLBI software)

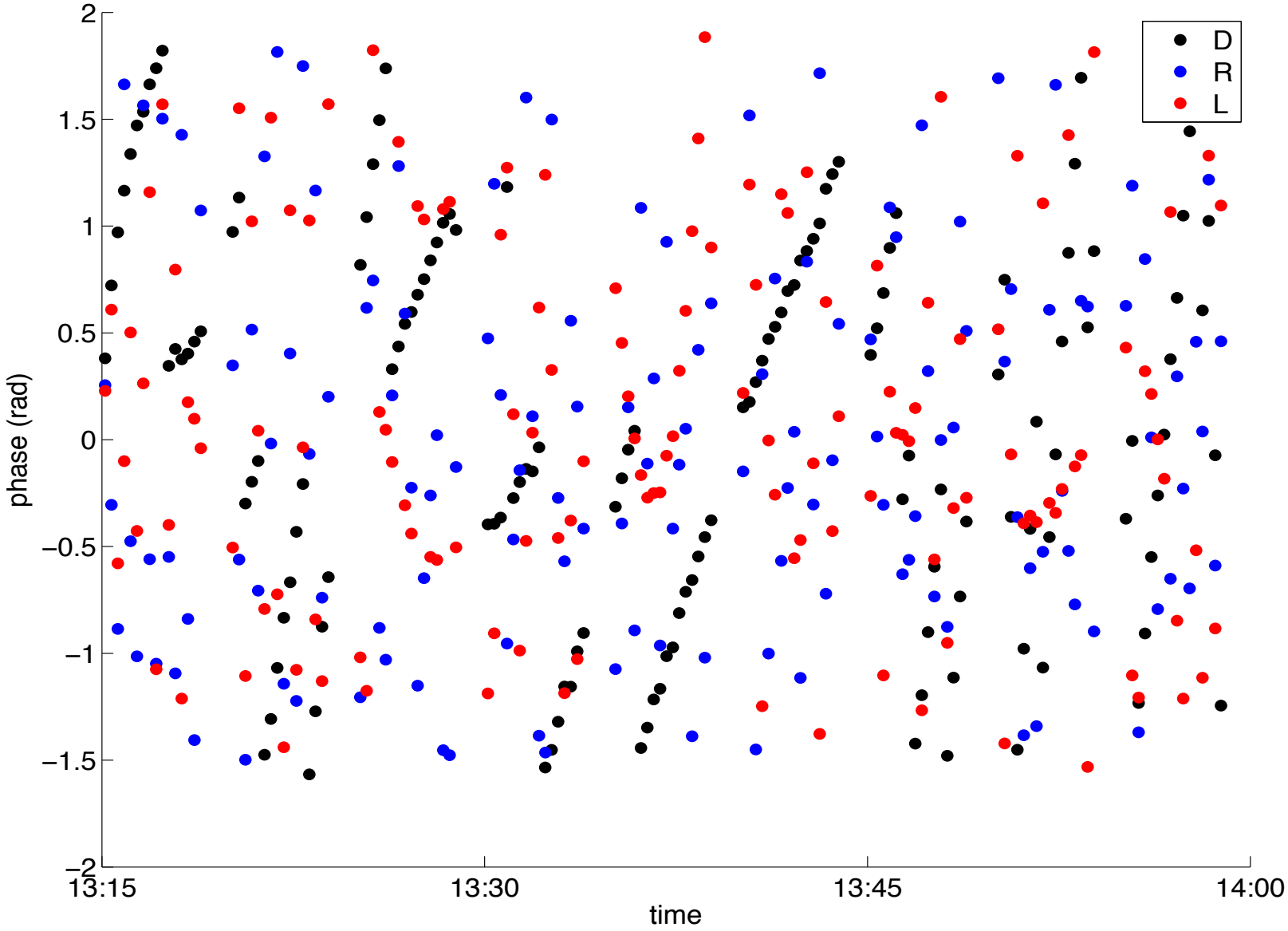
Group delays from AIPS/Fringe



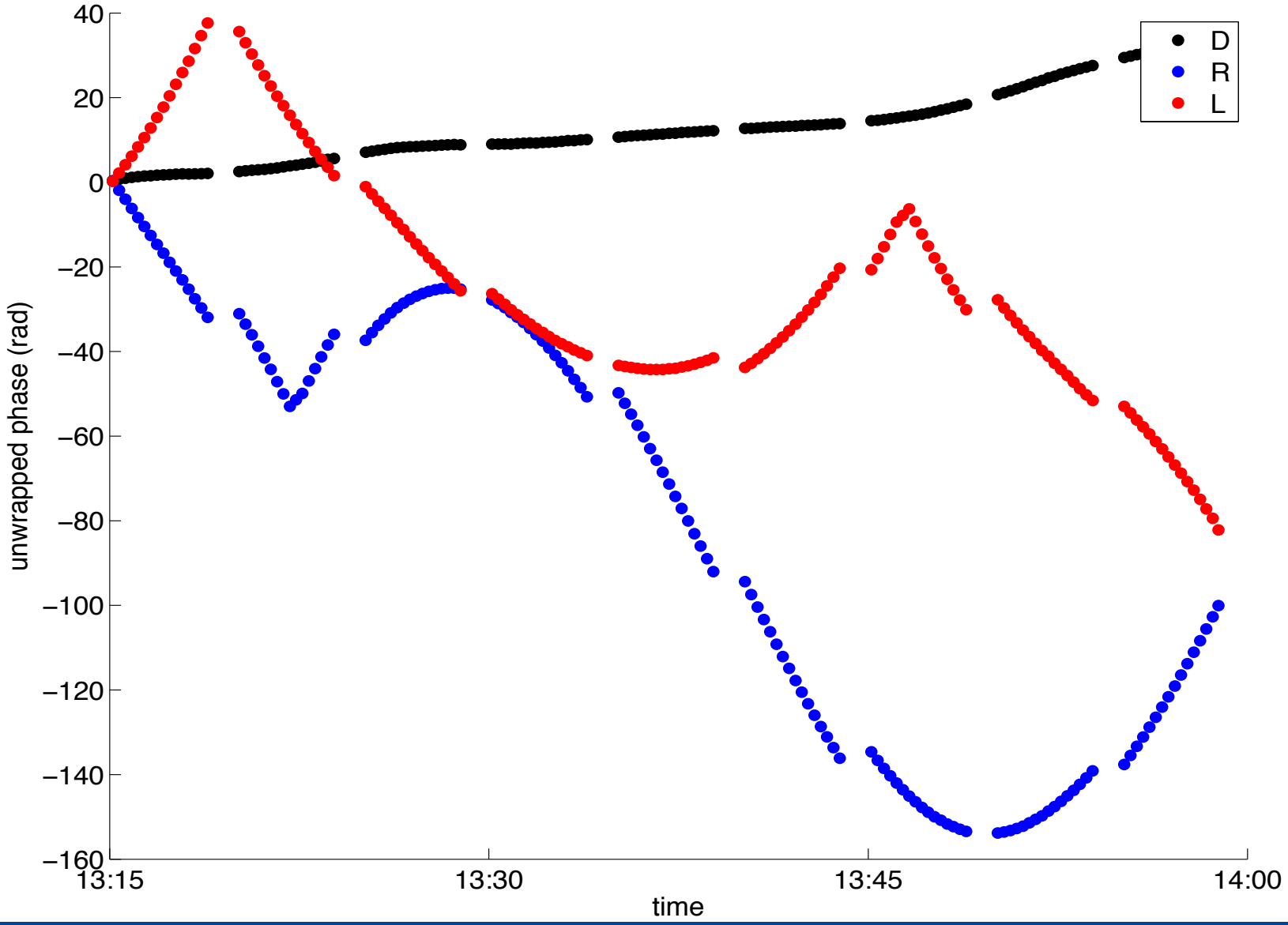
Integrated delay rates from AIPS/fringe



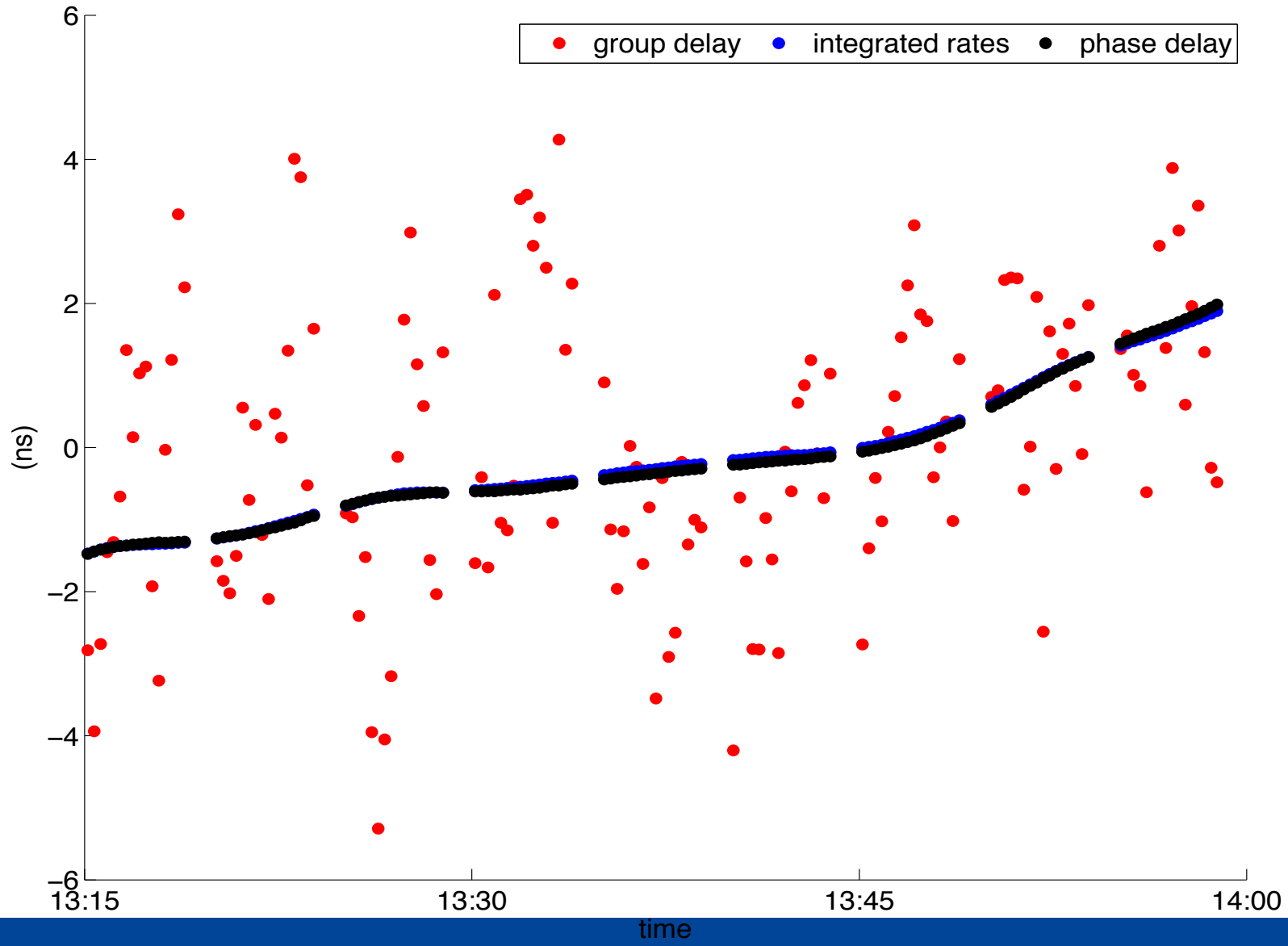
Phases from AIPS/fringe



”Unwrapped” phases



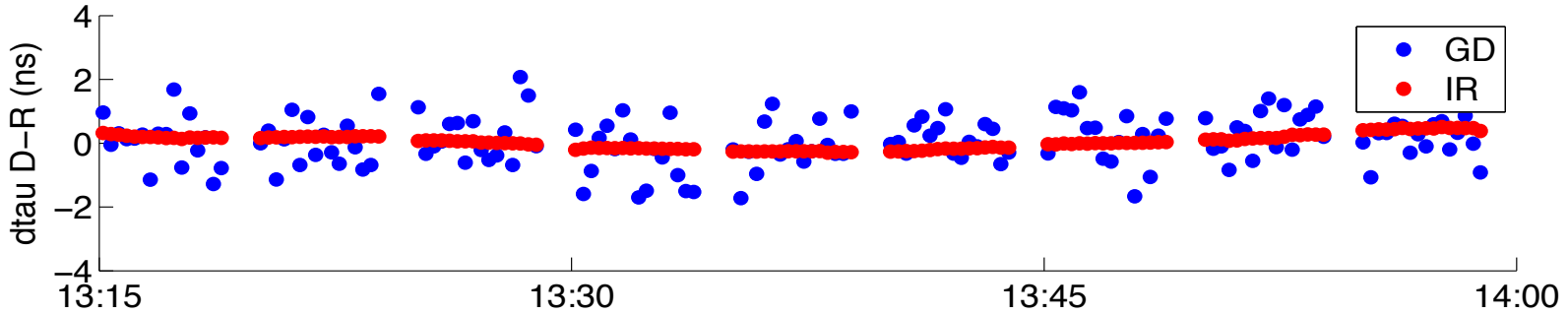
Group delay, integrated delay rate, phase delay



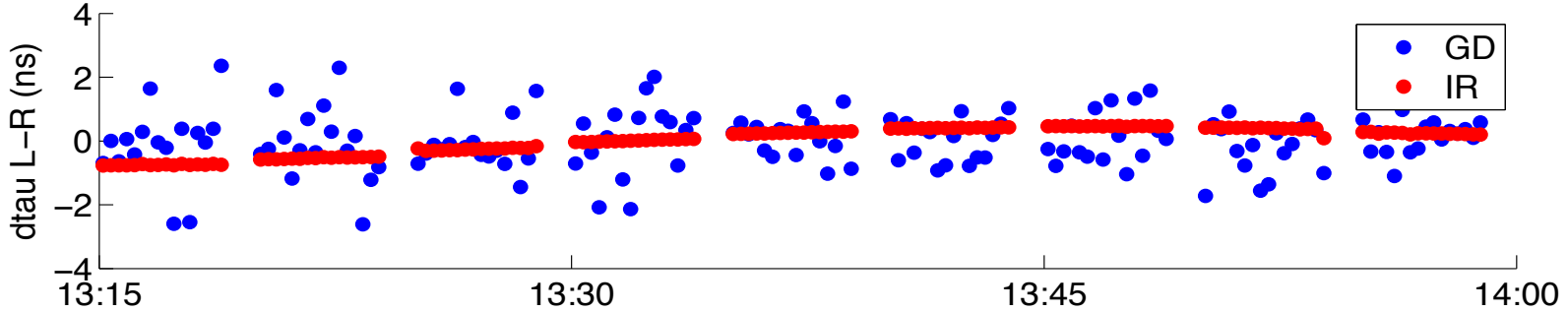
DiFX with D-model aprioris

Total delay differences

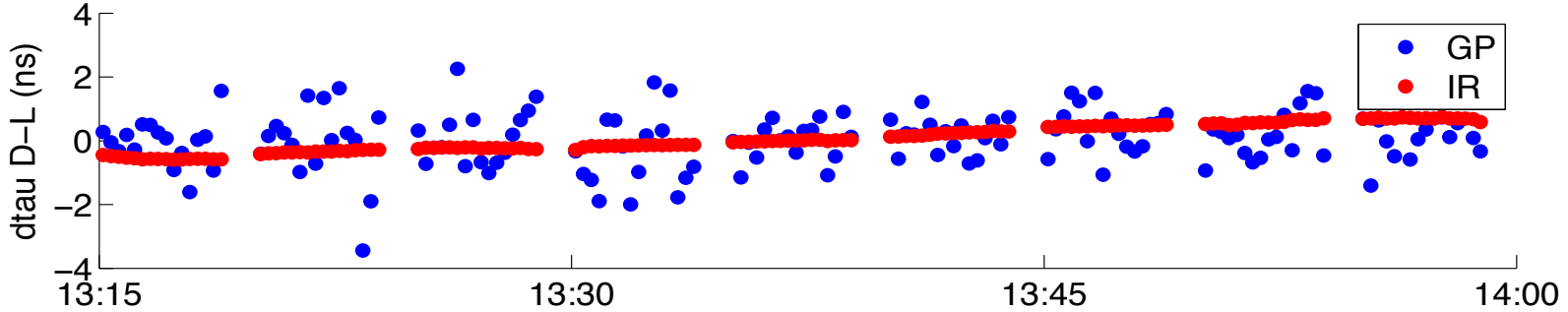
D vs. R



L vs. R



D vs. L



RMS GD:
0.8 – 0.9 ns

RMS IR:
0.2 – 0.4 ns

Experiments G140116 and G140121

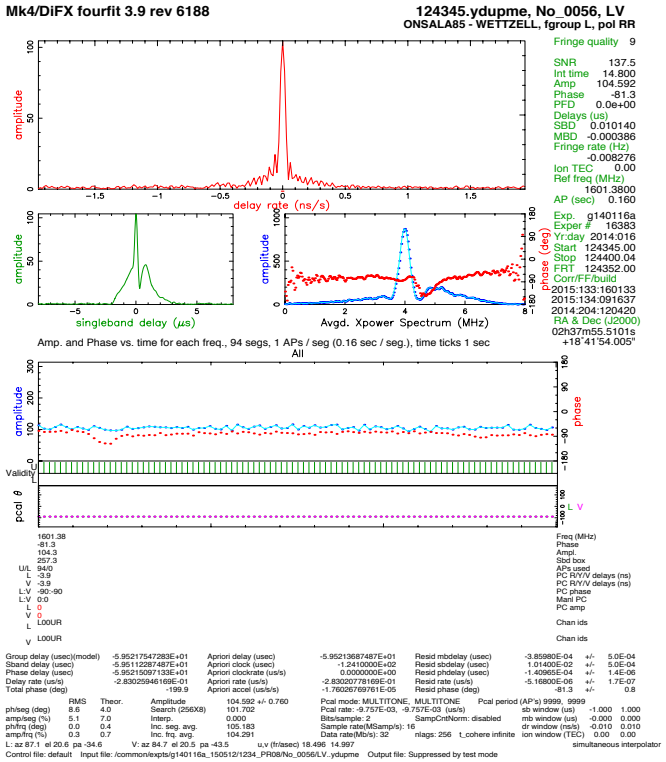
- Modelling
  - R-model
- Correlation with
  - DiFX (R-model), 0.25 s integration
- Post-processing
  - with HOPS/Fourfit (geodetic VLBI software)

G140116 and G140121

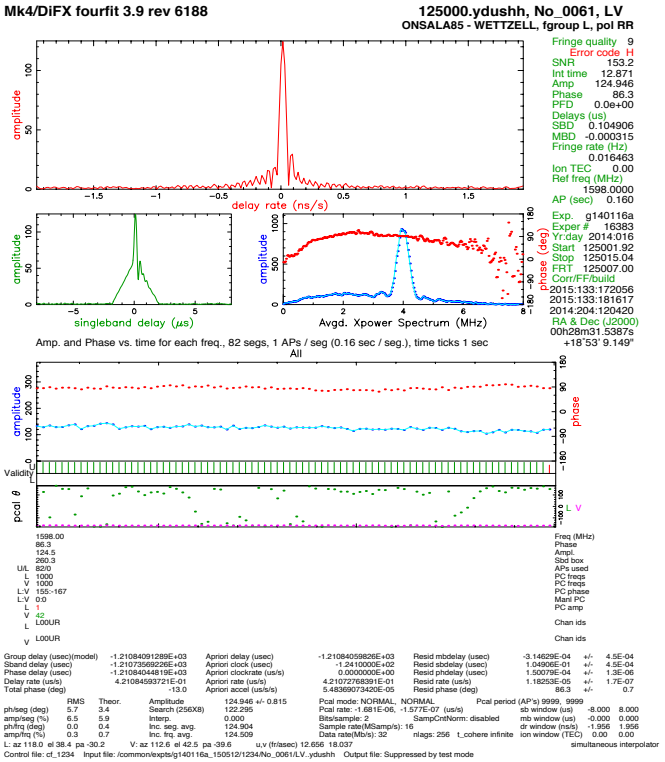
G140116 och G140121

Datum	Tid	GLONASS satellit	NORAD Nr.	PR nr.	MJD start	MJD stop	FRINGES
2014-01-16	12:30-12:45	GLONASS-743	NORAD 37869	PR08	56673.52083333	56673.53125000	YES :-)
(GPS 1775-4)	12:50-13:05	GLONASS-723	NORAD 32395	PR11	56673.53472222	56673.54513889	YES :-)
(MJD 56673)	13:10-13:25	GLONASS-730	NORAD 36111	PR01	56673.54861111	56673.55902778	YES :-)
	14:00-14:15	GLONASS-730	NORAD 36111	PR01	56673.58333333	56673.59375000	YES :-)
	14:20-14:35	GLONASS-737	NORAD 37138	PR12	56673.59722222	56673.60763889	YES :-)
	14:40-15:00	GLONASS-747	NORAD 39155	PR02	56673.61111111	56673.62500000	YES :-)
2014-01-21	13:30-13:35	GLONASS-743	NORAD 37869	PR08	56678.56250000	56678.56597222	YES :-)
(GPS 1776-2)	13:37-13:42	GLONASS-732	NORAD 36402	PR23	56678.56736111	56678.57083333	YES :-)
(MJD 56678)	13:44-13:49	GLONASS-743	NORAD 37869	PR08	56678.57222222	56678.57569444	YES :-)
	13:51-13:56	GLONASS-732	NORAD 36402	PR23	56678.57708333	56678.58055556	YES :-)
	13:59-14:04	GLONASS-743	NORAD 37869	PR08	56678.58263889	56678.58611111	YES :-)
	14:08-14:13	GLONASS-735	NORAD 36401	PR24	56678.58888889	56678.59236111	YES :-)
	14:14-14:19	"	"	"	56678.59305556	56678.59652778	"
	14:25-14:30	GLONASS-732	NORAD 36402	PR23	56678.60069444	56678.60416667	NO (!) =>???
	15:00-15:04	GLONASS-735	NORAD 36401	PR24	56678.62500000	56678.62777778	YES :-)
	15:05-15:09	"	"	"	56678.62847222	56678.63125000	"
	15:10-15:14	"	"	"	56678.63194444	56678.63472222	"
	15:20-15:24	GLONASS-746	NORAD 37938	PR17	56678.63888889	56678.64166667	YES :-)
	15:25-15:29	"	"	"	56678.64236111	56678.64513889	"
	15:30-15:34	"	"	"	56678.64583333	56678.64861111	"
	15:45-15:49	GLONASS-723	NORAD 32395	PR11	56678.65625000	56678.65902778	YES :-)
	15:50-15:54	"	"	"	56678.65972222	56678.66250000	"
	15:55-16:00	"	"	"	56678.66319444	56678.66666667	"

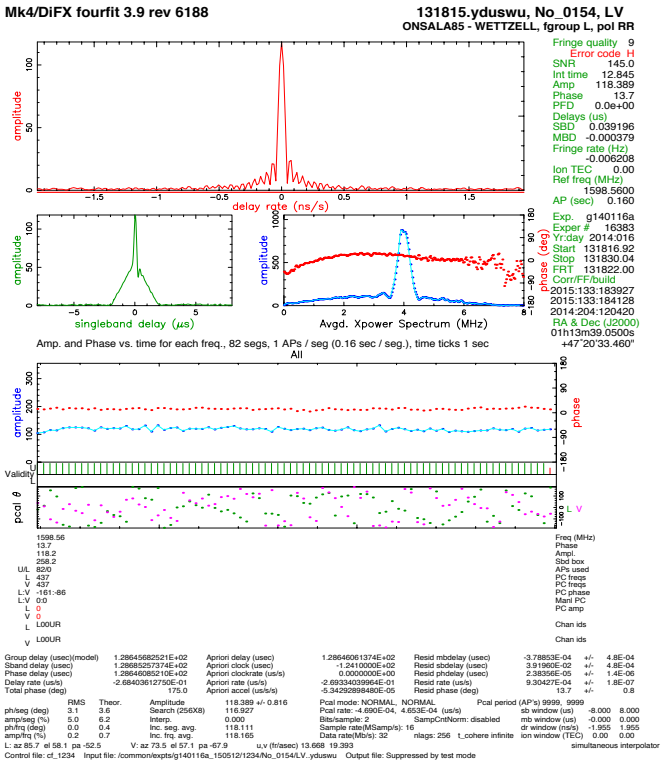
G140116a Fourfit processing



PR08

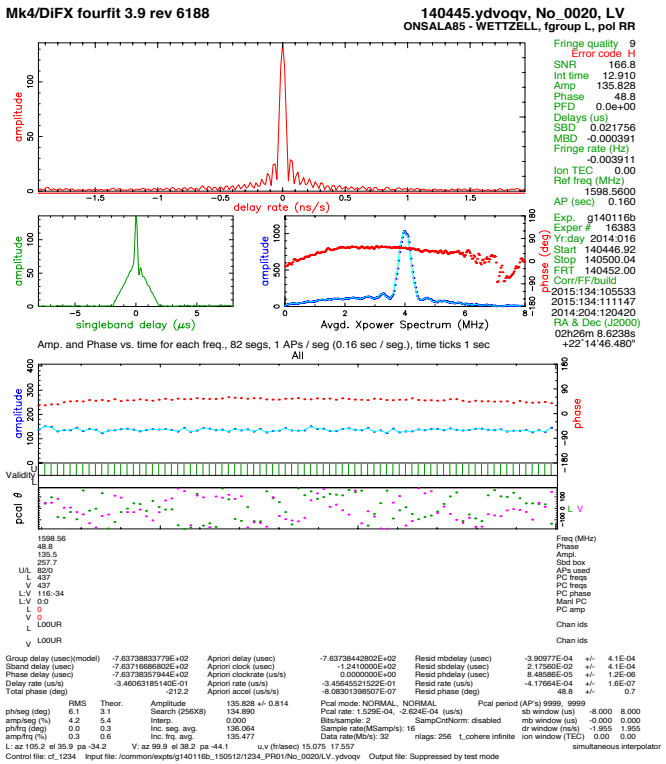


PR11

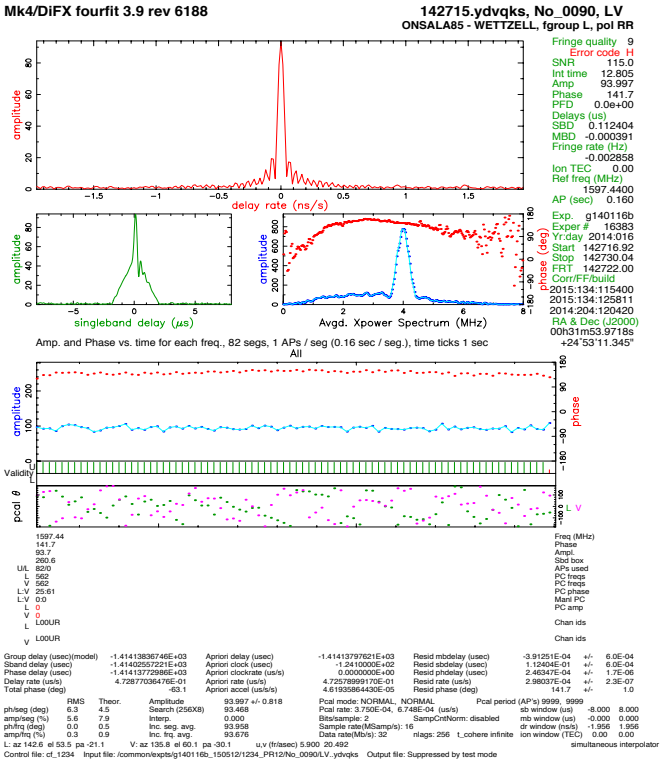


PR01

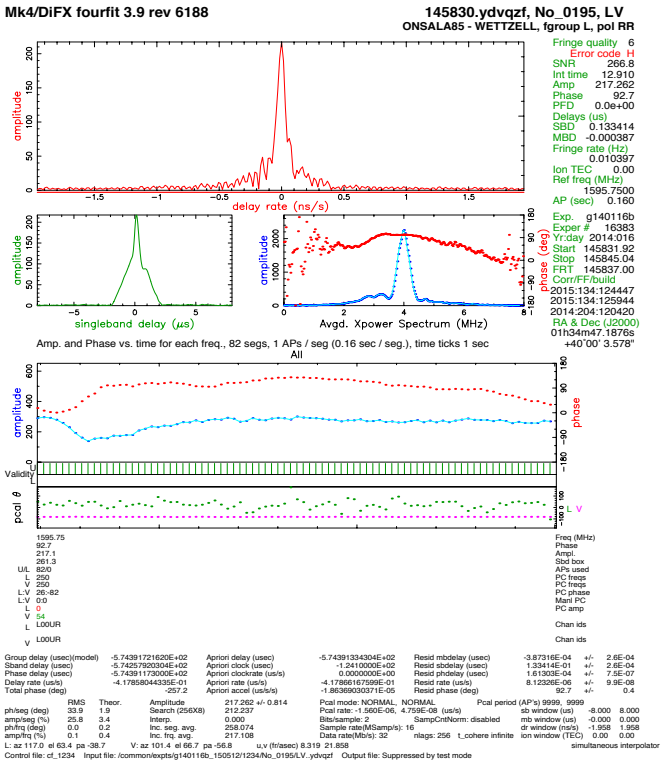
G140116b Fourfit processing



PR01



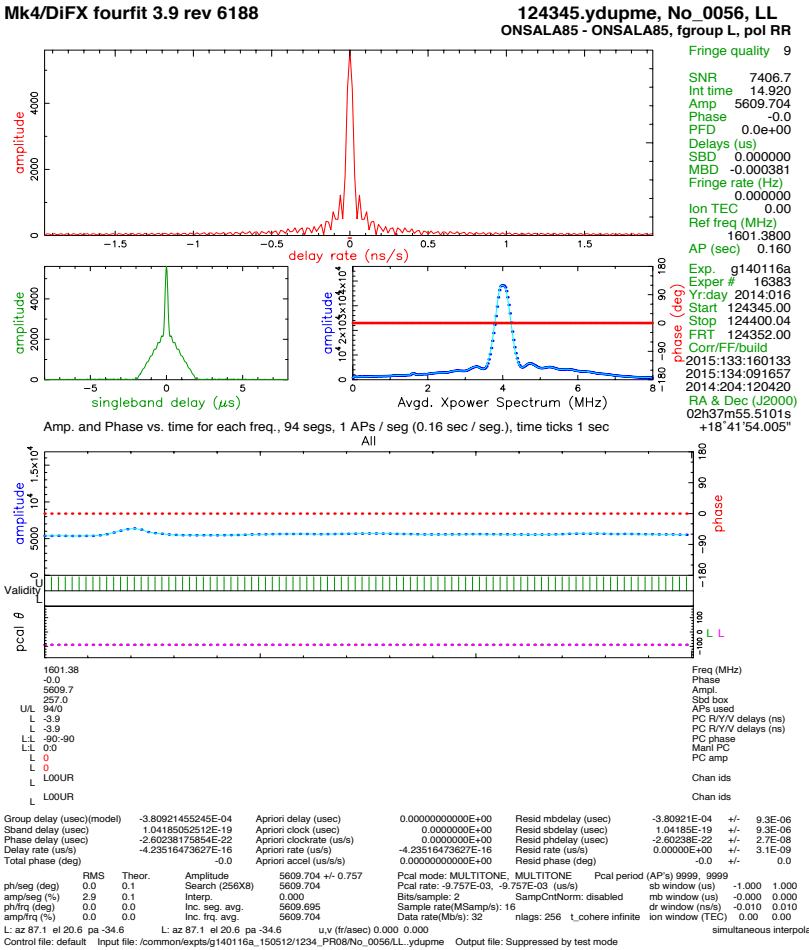
PR12



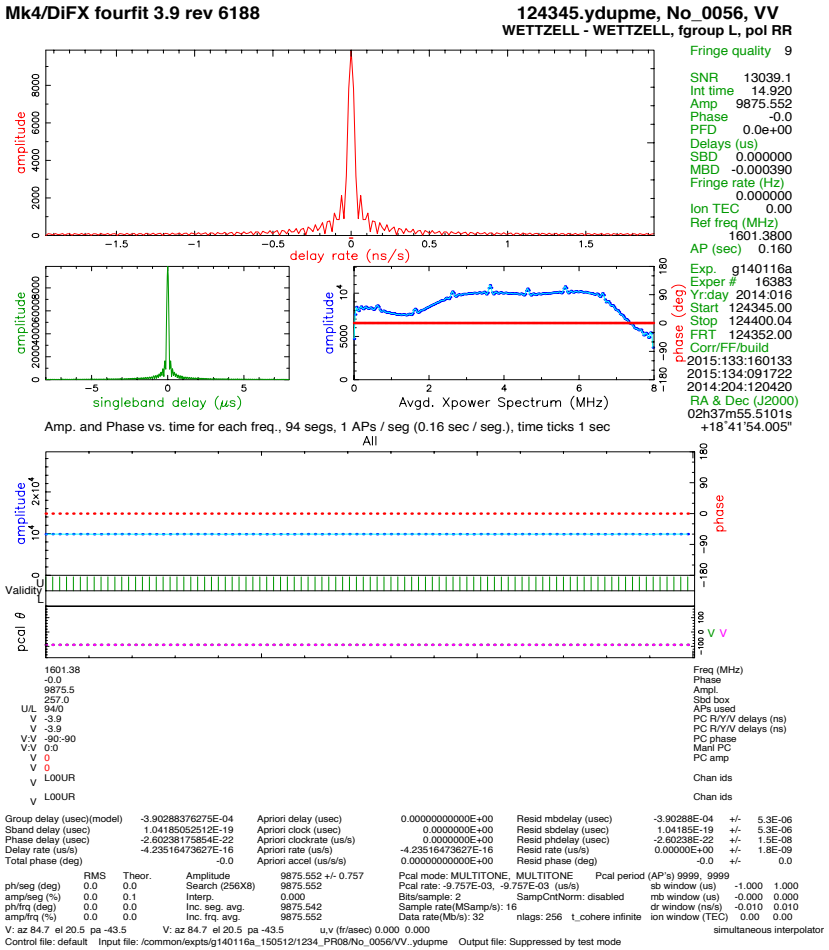
PR02

G140116 autocorrelations

Onsala

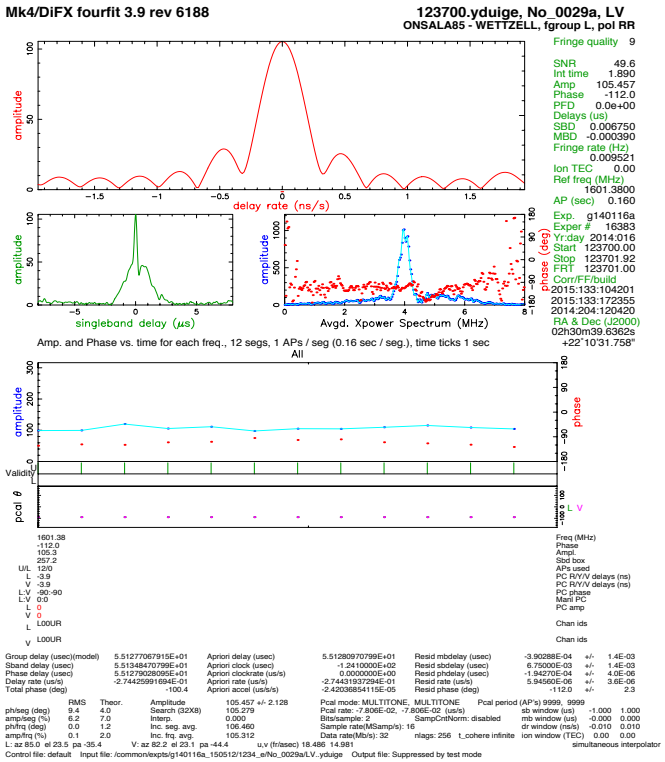


Wettzell

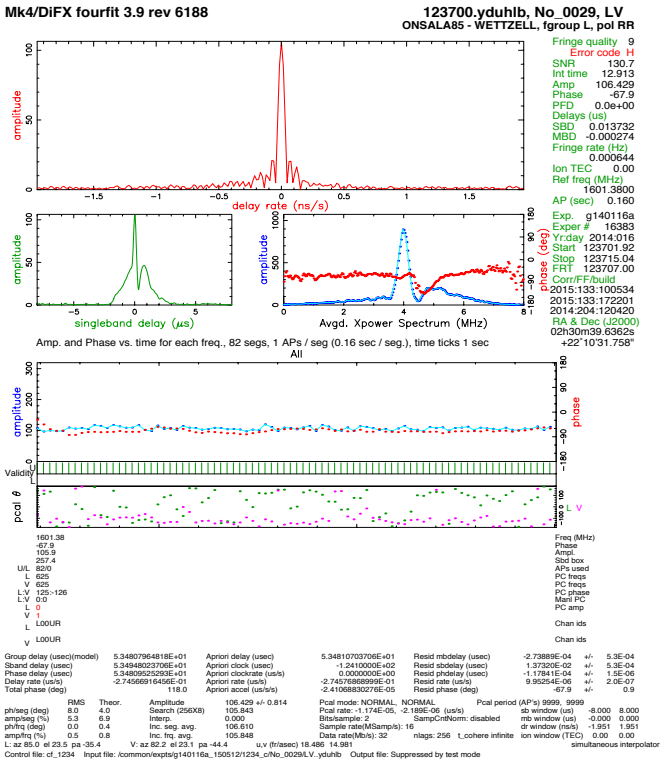


Effect of integration length

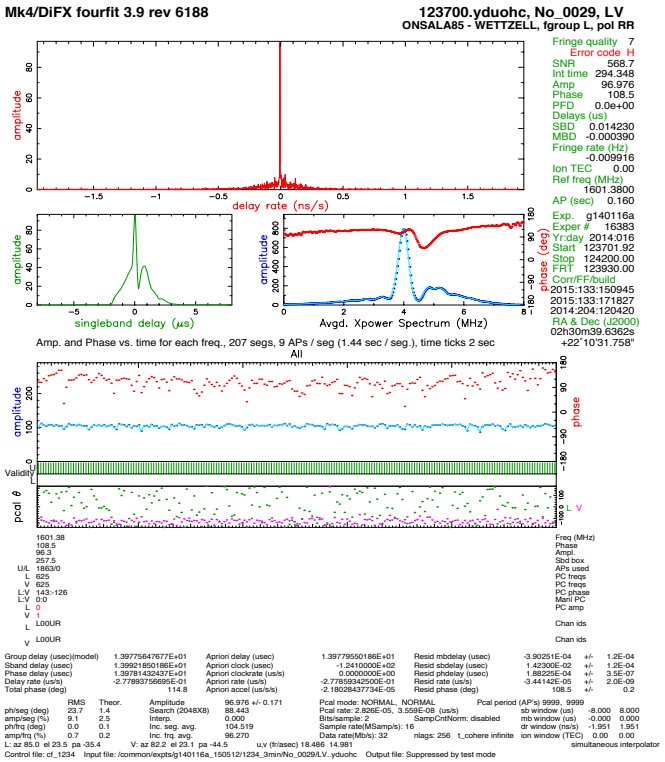
2 s



15 s



300 s



SNR 49.6

SNR 130.7

SNR 568

Conclusions

- Successful experiments with several L-band stations
  - Also L-band via S-band at Wettzell works fine
- Successful correlation with the standard geodetic software correlator DiFX
- Short observation times 10 – 15 s are sufficient
- Successful with three different apriori delay models
- Geodetic post-processing with Fourfit works
- Phase delay determination possible with AIPS and Fourfit
- Total delay values agree with rms 0.8–0.9 ns for group delays and 0.2–0.4 ns for integrated delay rates

Outlook

- Observations:
  - Further test experiments (multi GNSS, dual frequency)
  - Use lager station networks (> 4 stations)
- Correlation:
  - Re-correlation of all observed data 2010–2016
  - Near-field model APP in c5++
- Analysis:
  - Upgrade/extension of the geodetic VLBI data analysis software c5++
  - “Geodetic” data analysis and parameter estimation with c5++
- Further ideas:
  - Perform dedicated L/S/X-experiment: Wettzell (20 m L/S/X), Onsala (25 m L + 20 m S/X), Medicina (32 m L/S/X) + …