ILRS Timing Devices

Specifications, Error Analysis and BEST Practices

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Laser Ranging Error Sources

	Category	Component	Contributes to: Jitter	Contributes to: Range Bias
Ranging Machine	Transmitter	Laser	Yes	Yes
	Reciever	Detector package	Yes	Yes
		Timing	Yes	Yes
		Frequency source	Yes	Yes
	Optics	Mount/Telescope	No	Yes
	Control system		Yes	Yes
	Meteorological system	Met. Sensors	No	Yes
Data Reduction	Data smoothing, outlier rejection, NP creation		Yes	Yes
Local Survey	Calibration range		No	Yes
Satellite	RRA correction		Yes	Yes

Timing Measurements

– The time (epoch) of laser fire

– The **two-way time-of-flight (TOF)** of the optical pulse

- The site removes the calibration constant from the raw satellite TOF and statistically compresses the data into normal points (NP)
- The analysts convert the NP TOF into a **range** measurement

range = **((NP TOF)*c/2)** – **atmosphere** + **satellite CoM** – **relativity**

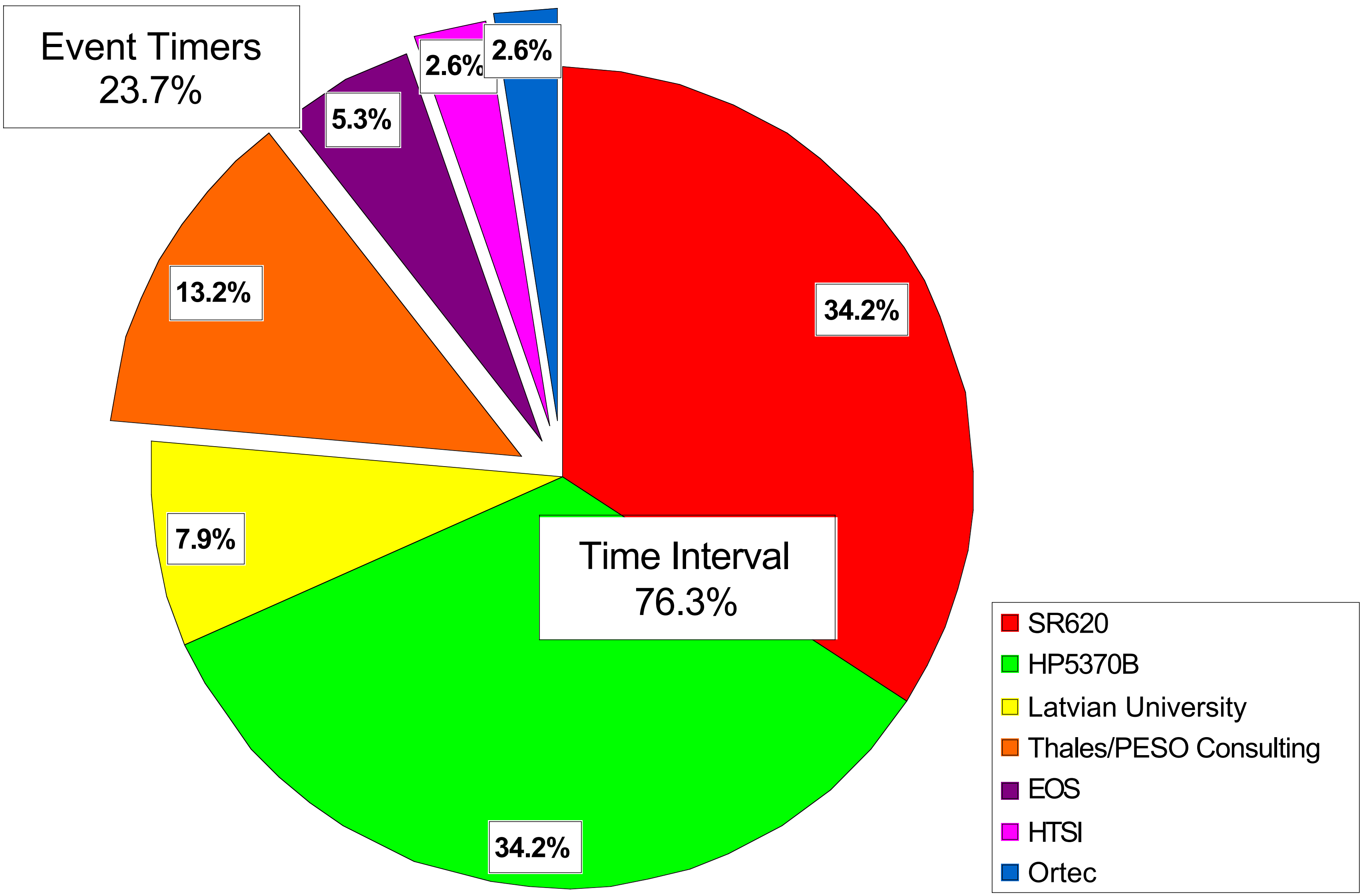
Timing Terminology

- **ACCURACY** – the deviation of a measurement from a standard. *Example: range bias.*
- **PRECISION** – the deviation of a set of measurements about their mean (i.e. does not imply accuracy). *Example: single shot RMS.*
- **RESOLUTION** – the minimum differential measurement which can be made. *Example: granularity of a timing device.*
- **STABILITY** – a measure of change over time. *Example: range bias stability.*
- **JITTER** – the random displacement of a signal from its absolute location. *Example: counter jitter.*
- **LINEARITY** – the relative accuracy between measurements. *Example: counter non-linearity.*
- **ALLAN DEVIATION** - non-classical statistic used to estimate stability. *Example: frequency stability.*

Type of Timers

- **Time Interval**
  - Measures a time interval between a start and stop (i.e. **a single event**)
    - **PROS** – inexpensive (≤10K), can provide sub-cm accuracy with proper care and calibration
    - **CONS** – maximum time-of-flight, limits laser repetition rate, requires special test equipment or multiple counters to remove/minimize non-linearity's, may be a limiting factor in 1 mm accuracy
- **Event**
  - Measures epoch of events, the difference between events will produce a time interval (i.e. **multi-event capability**)
    - **PROS** – supports lunar, interplanetary, and KHz ranging, picosecond event timers are **NOT** a limiting factor in 1mm accuracy.
    - **CONS** – picosecond level event timers are expensive

ILRS Timers (Oct 2002)



ILRS Timers Specifications

Manufacturer	Model	Year	Resolution (ps)	Jitter (ps)	Linearity (ps)	Stability [ps/K]	Stability [ps/H]	Warm-up (hours)	Max. rep. rate (Hz)	Max Tof (secs)
SR	620	1988	4	22	50	5-10	3	1	100	1000
HP	5370B	1982	20	35	20			0.33	10	10
Latvian	A013	2002	10	20	2		0.1	2	80	0.209
EG&G - Ortec	TD811		100			40				N.A.
Peso Consulting	PET 4	1999	1.2	3.5	2.5	0.2	<0.5	4	>100	N.A.
EOS	MRCS V.4	1998	2	10	2	2	1		2000	N.A.
HTSI	MLRO	1998	<2	<4	2		0.5	1	2000	N.A.

Simplified Timer Error Analysis

Accuracy =

measurement resolution ±
timebase error (_f_0/f_0) * time interval ±
trigger errors (start and stop) ±
systematic error

To maximize accuracy:

1. Increase the laser repetition rate (improves **measurement resolution**)
2. Use a stable external frequency source (eliminates **timebase error**)
3. Minimize the noise on the input signal by careful grounding and shielding (reduces **trigger error**)
4. Implement multiple timers or calibrate counter and obey proper warm-up time and environmental conditions (removes or minimizes **systematic error**)

Timebase Error (_f_0/f_0) at SLR Time Intervals

_f_0/f_0

Frequency Stability	LEO (25ms)	LAGEOS (60ms)	High (200ms)	Lunar (2500ms)	Mars (1,000,700ms)
1.E-07	374.741	899.377	3297.717	37474.057	15000000.000
1.E-08	37.474	89.938	329.772	3747.406	1500000.000
1.E-09	3.747	8.994	32.977	374.741	150000.000
1.E-10	0.375	0.899	3.298	37.474	15000.000
1.E-11	0.037	0.090	0.330	3.747	1500.000
1.E-12	0.004	0.009	0.033	0.375	150.000
1.E-13	0.000	0.001	0.003	0.037	15.000
1.E-14	0.000	0.000	0.000	0.004	1.500
1.E-15	0.000	0.000	0.000	0.000	0.150
1.E-16	0.000	0.000	0.000	0.000	0.015

Legend
>10mm
>1mm but <10mm
<1mm
<0.1mm

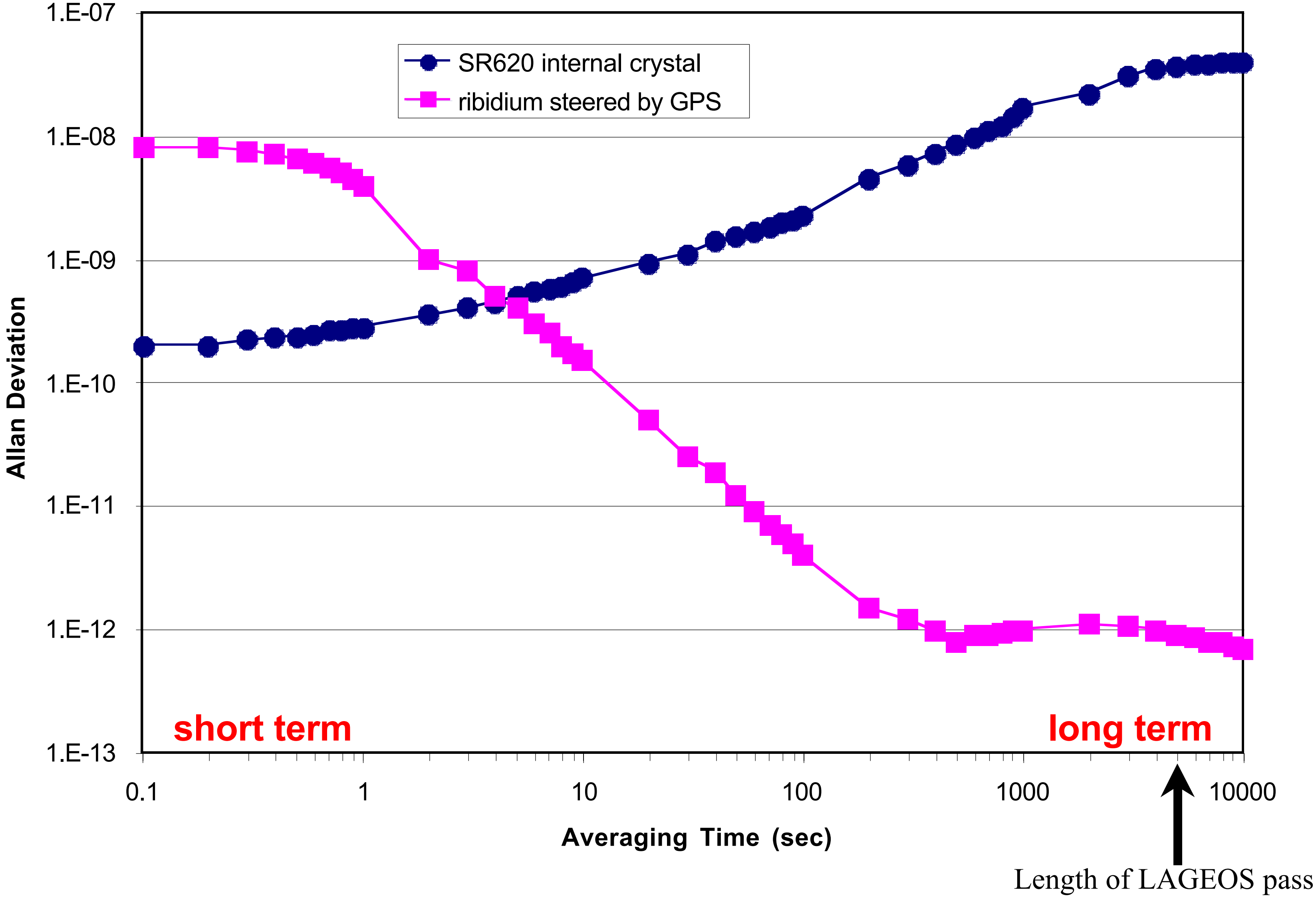
_f_0/f_0 is the stability of the external master oscillator

Oscillator Comparisons

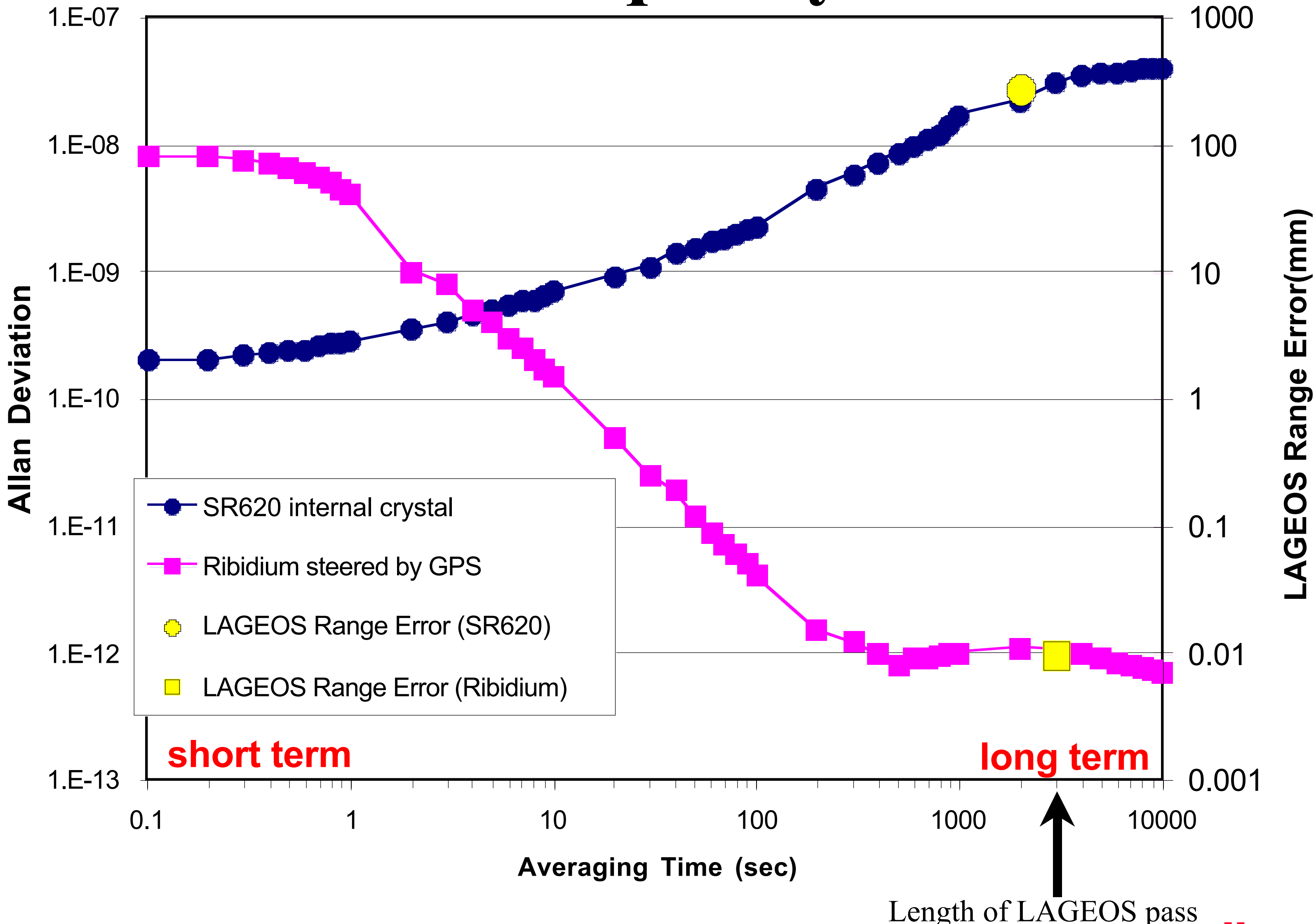
Long Term Frequency Stability	Crystal Performance Range	Rubidium Performance Range	Cesium Performance Range	Hydrogen Maser Performance Range
1.E-07				
1.E-08				
1.E-09				
1.E-10				
1.E-11				
1.E-12				
1.E-13				
1.E-14				
1.E-15				
1.E-16				

Type of Oscillators	Pros	Cons	Comments
Oven Controlled Crystal	cheap, excellent short term stability, durable	generally poor long term stability for SLR, variable performance based on the type and make of crystal	long term stability can be enhanced by GPS steering
Atomic			
Rubidium	cheaper than a cesium, good short term stability	long term stability not as good as cesium, the rubidium will need replacement	
Cesium	good short term and long term stability	not cheap, cesium tubes will eventually need to be replaced and will be costly, environmental controls	
Hydrogen Maser	excellent long term stability	expensive, requires more power and space, strict environmental control	

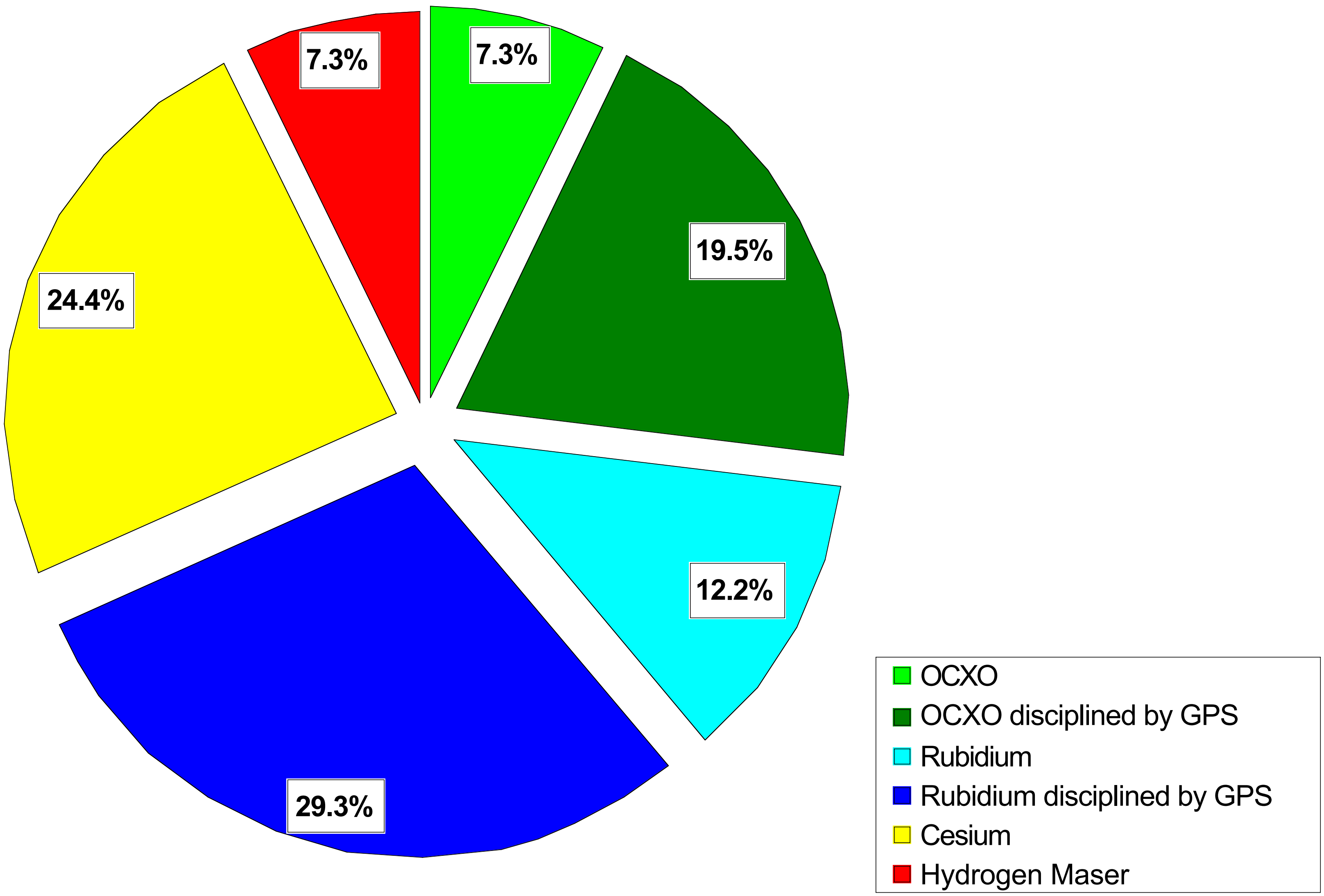
Frequency Stability Comparison



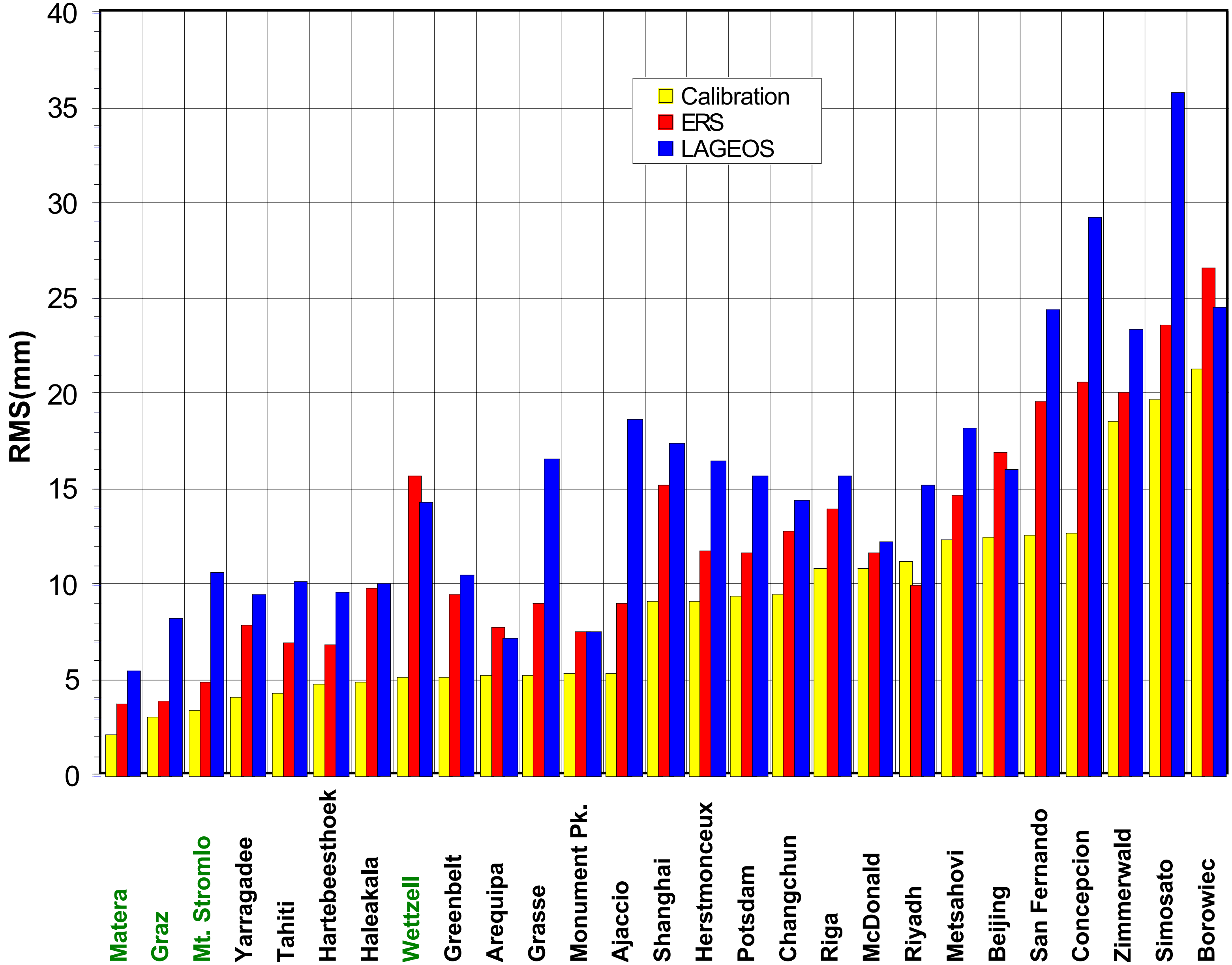
LAGEOS Range Error due to Frequency Error



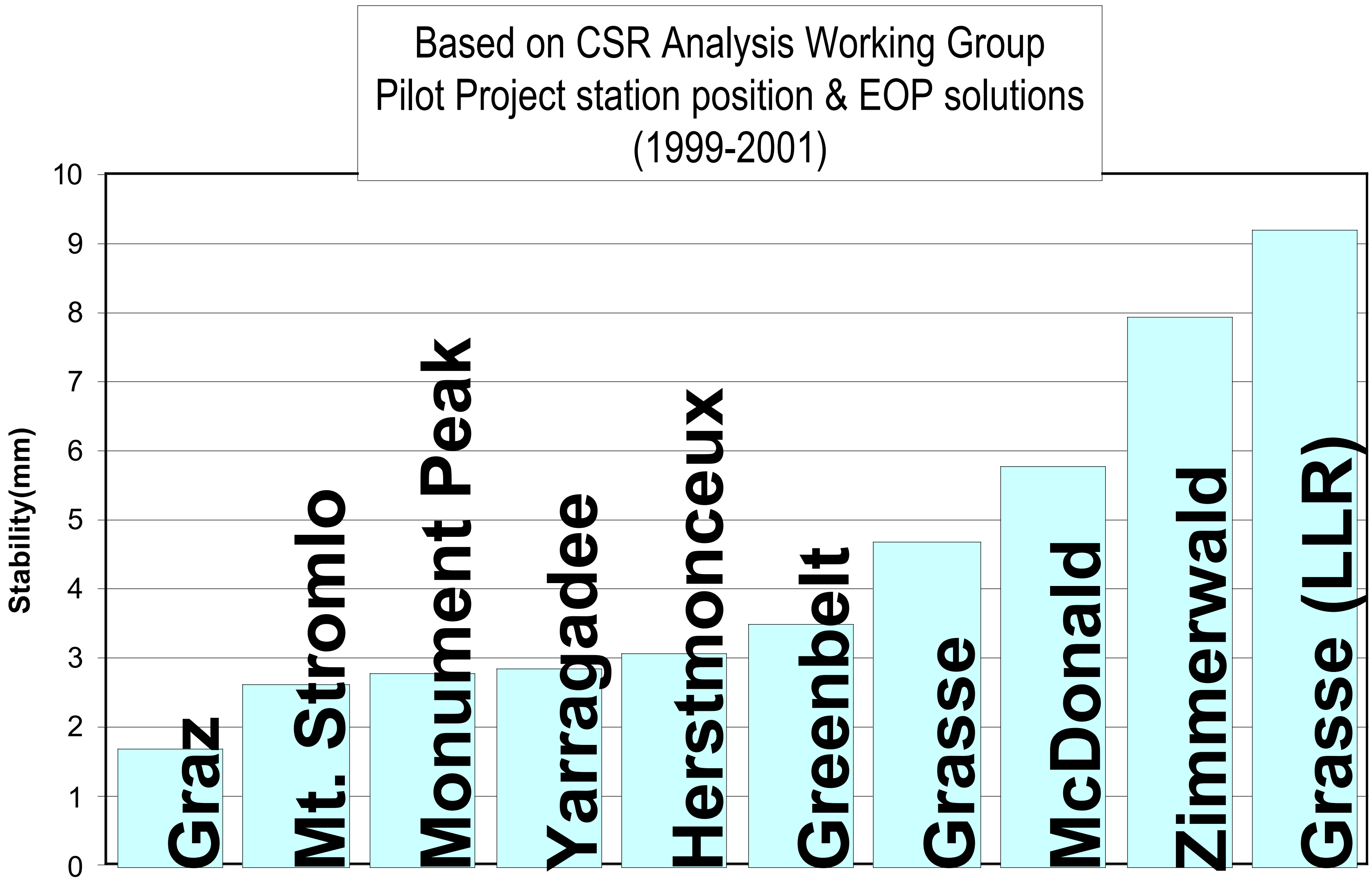
ILRS Frequency Devices (October 2002)



Single Shot RMSs (2002, 2ndQ)



Long Term Range Bias Stability



BEST Practices

- Maintain strict environmental **temperature** control
- Minimize noise on the incoming timing signal with **good grounding and shielding**
- Allow for adequate **equipment warm-up**
- Use an **external oscillator**
- If you use a SR620 or HP5370B have them **calibrated or clustered**

Conclusions

- With proper care and calibration, the current ILRS timers can support sub-cm accuracy
- The picosecond-event timers can support 1mm absolute accuracies and are not a limiting factor in the ranging machine