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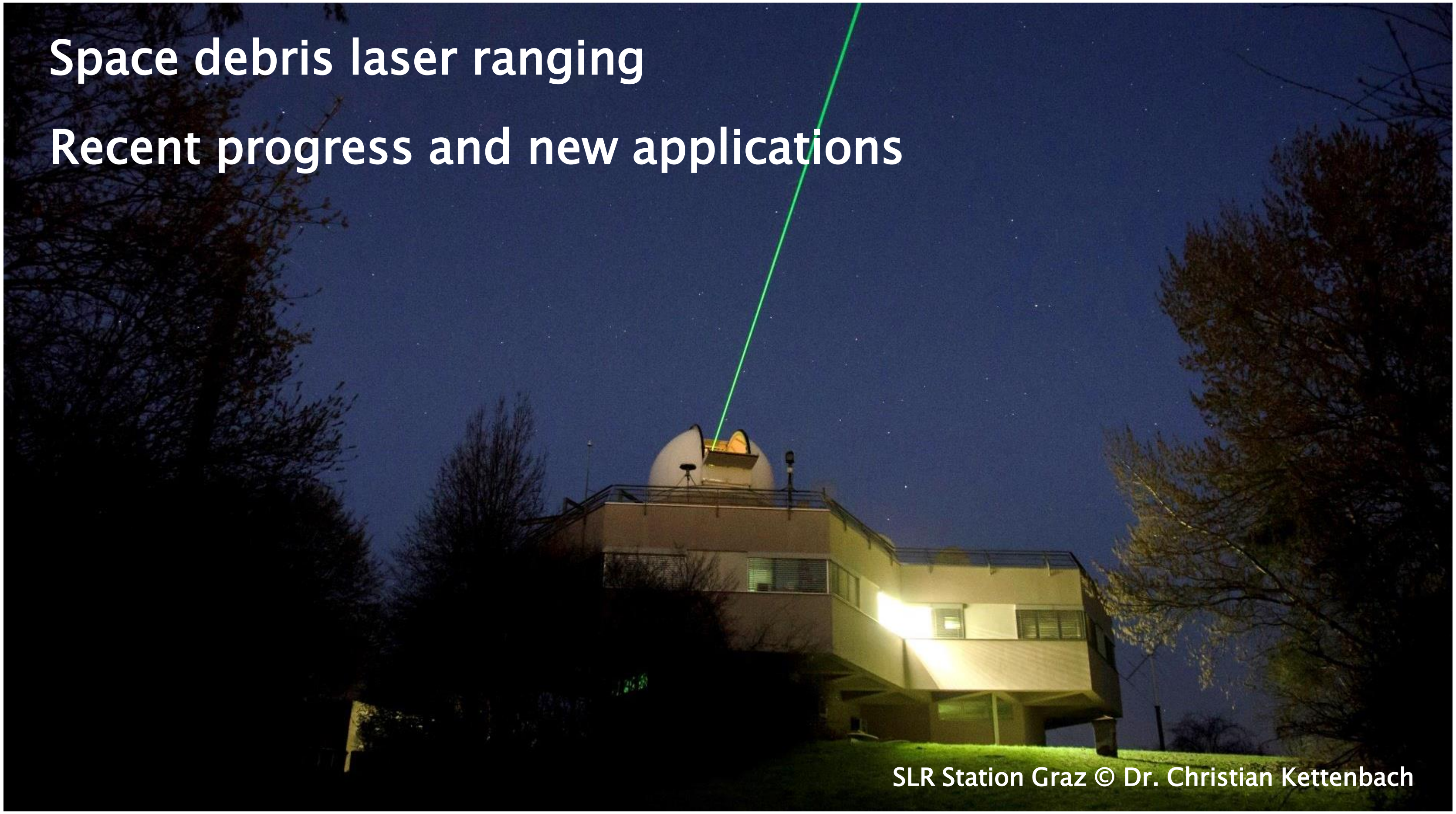
SPACE DEBRIS LASER RANGING

Space debris laser ranging

Recent progress and new applications



SLR Station Graz © Dr. Christian Kettenbach

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1) Space Research Institute, Austrian Academy of Sciences

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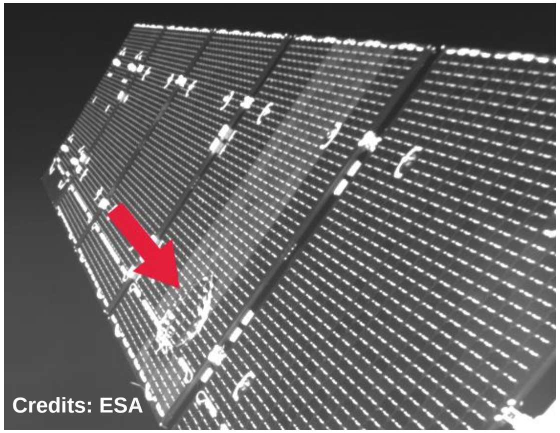
SPACE DEBRIS – AN OVERVIEW

SPACE DEBRIS BY THE NUMBERS (1, ESA, 01/2019)		SOURCES
5450 rocket lauches	since 1957	rocket parts
5000 / 1950 satellites	total / active	payload
34 000 objects	size > 10 cm	break ups, fragmentation
900 000 objects	size > 1 cm	anti-satellite weapons
> 20 000 objects	monitored / Space Surveillance Networks	collisions
Velocity	7 kilometers / second	lost equipment
Impact: mm - particle	> 20 cm craters (Sentinel-1A)	



1) https://www.esa.int/Our_Activities/Space_Safety/Space_Debris/Space_debris_by_the_numbers

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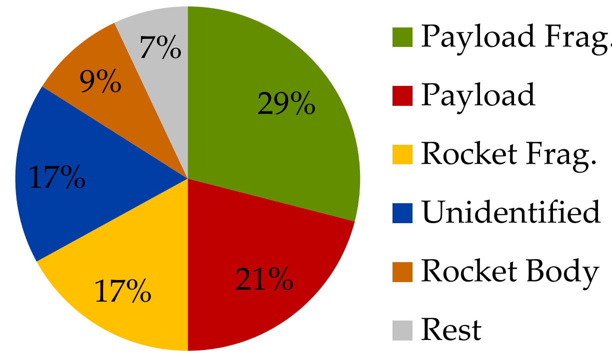
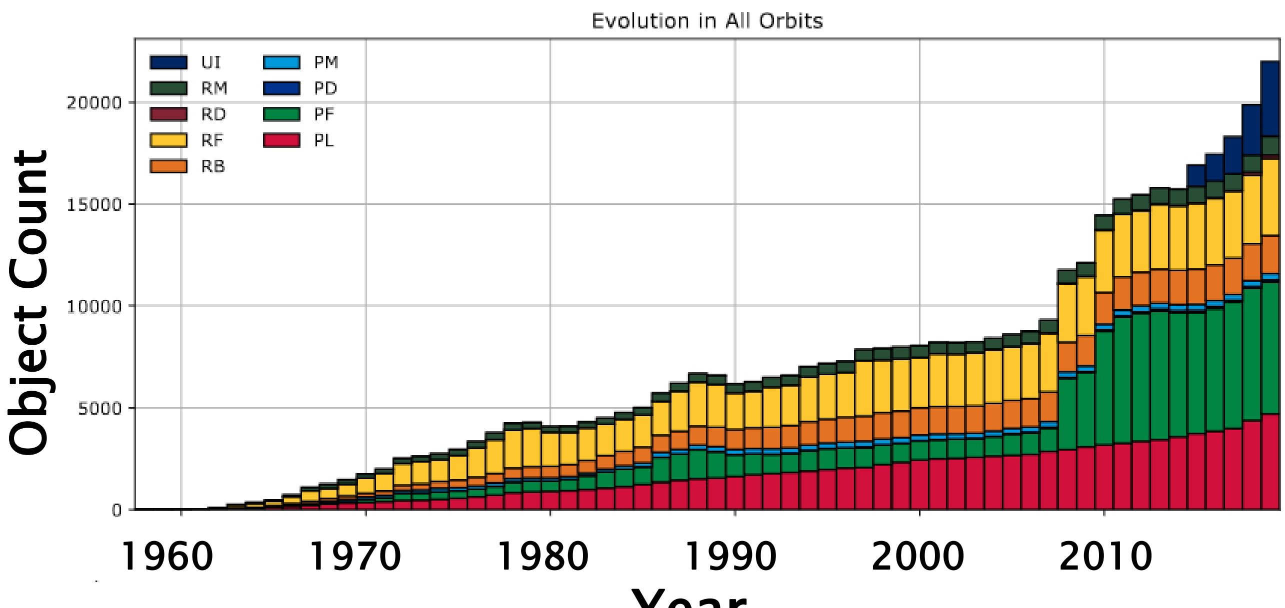
OBJECT NUMBER / TYPE

1) PF … Payload Fragmentation Debris (6469)
2) PL … Payload (4708)
3) RF … Rocket Fragmentation Debris (3778)
4) UI … Unidentified (3681, sensor performance)
5) RB … Rocket body (1883)





Debris Type	
PL	Payload
PF	Payload Fragementation Debris
PD	Payload Debris
PM	Payload Mission Related Object
RB	Rocket Body
RF	Rocket Fragmentation Debris
RD	Rocket Debris
RM	Rocket Mission Related Object
UI	Unidentified

https://www.sdo.esoc.esa.int/environment_report/Space_Environment_Report_latest.pdf

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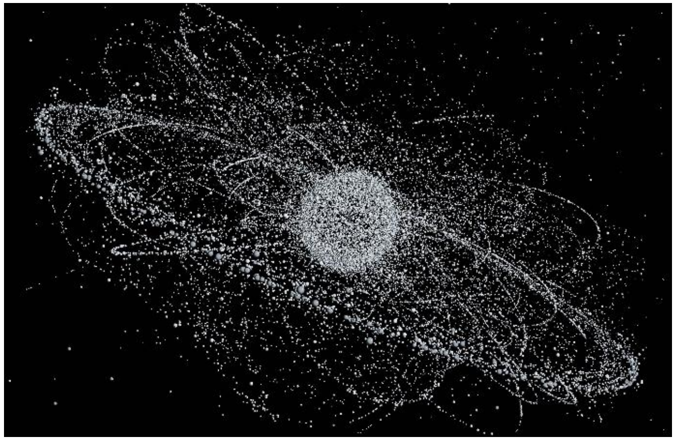
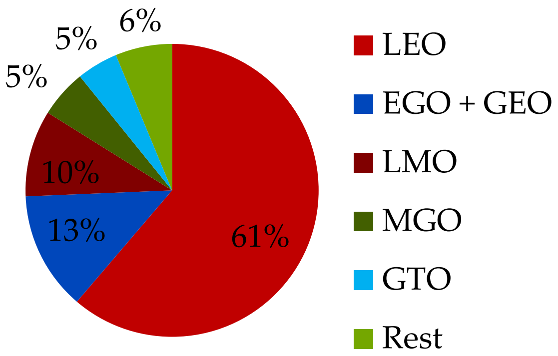
DISTRIBUTION: OBJECT NUMBER / ORBIT

1) 61 %: in Low Earth Orbit (LEO): 0 km - 2000 km
2) 13 %: (2882) in Geostationary Orbit (+ EGO): 35586 km and above
3) 10 %: LEO - MEO Crossing, 5 %: MEO - GEO Crossing, 5 %: GTO
4) 01 %: Navigation Satellite Orbit: 18100 km - 24300 km





Satellite orbits								
LEO	Low Earth Orbit	h_p [0, 2000]	ha [0, 2000]		MEO	Medium Earth Orbit	hp [2000, 31570]	ha [2000, 31570]
GEO	Geostationary Orbit	hp [35586, 35986]	ha [35586, 35986]	i [0, 25]	LMO	LEO-MEO Crossing Orbit	hp [0, 2000]	ha [2000, 31570]
EGO	Extended Geostationary Orbit	a [37948, 46380]	e [0, 0.25]	i [0, 25]	MGO	MEO-GEO Crossing Orbit	hp [2000, 31750]	ha [31750, 40002]
GTO	Geo Transfer Orbit	hp [0, 2000]	ha [31570, 40002]	i [0, 90]	HEO	Highly Eccentric Earth Orbit	hp [0,31570]	ha > 40002
NSO	Navigation Satellite Orbit	hp [18100, 24300]	ha [18100, 24300]	i [50, 70]	Other			

https://www.sdo.esoc.esa.int/environment_report/Space_Environment_Report_latest.pdf

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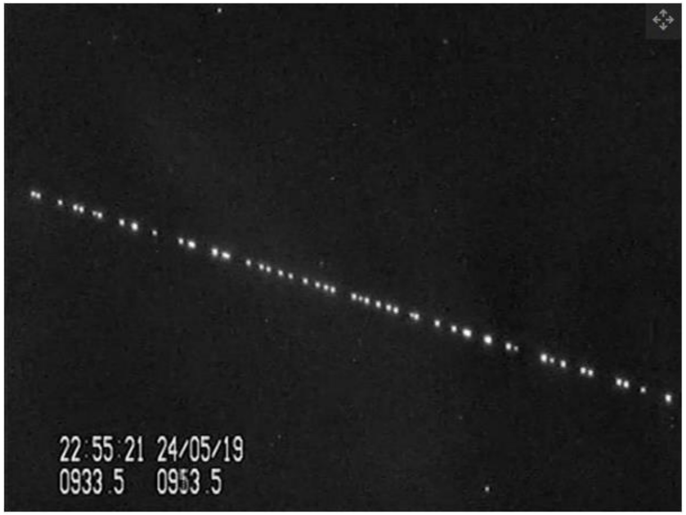
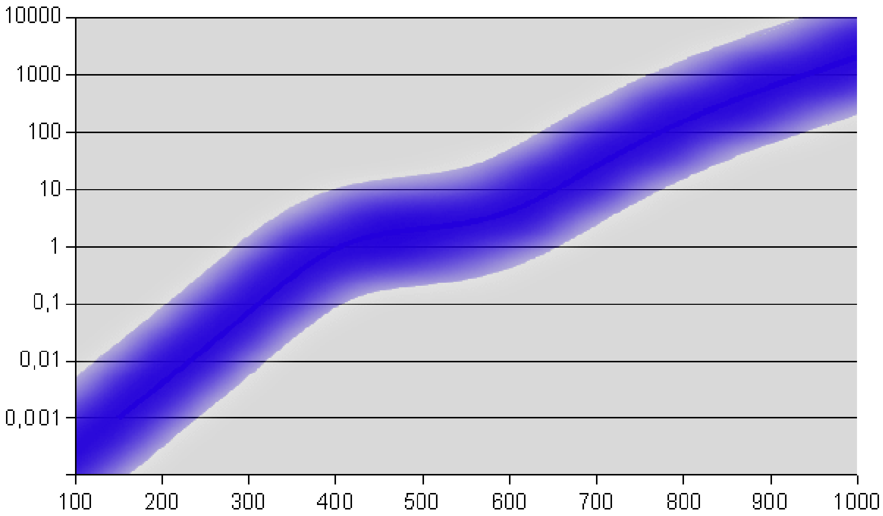
AN OUTLOOK INTO THE FUTURE

- Object lifetime increases drastically the higher the orbit
- Reentry: currently ~ 200 objects per year
- Clearence LEO: limit post-mission presence maximum of 25 years
- Success rate: ~55% payload; ~80% rocket body
- View of the future sky: super constellations (up to 12000 satellites)





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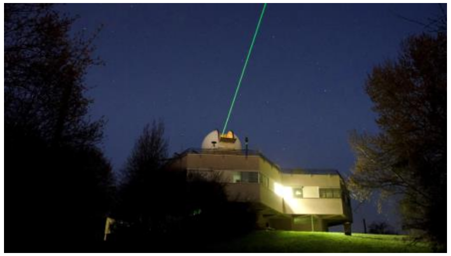


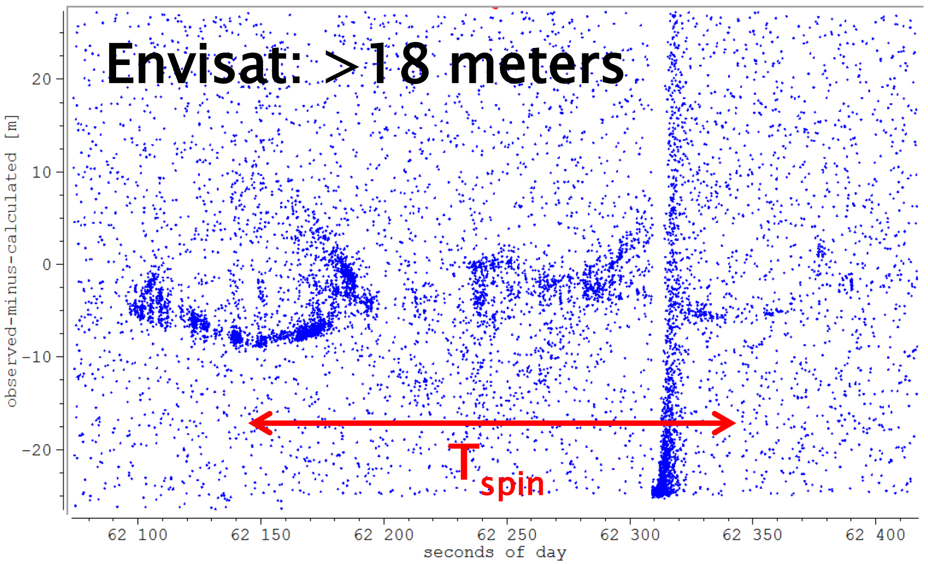
SLR VS. SDLR

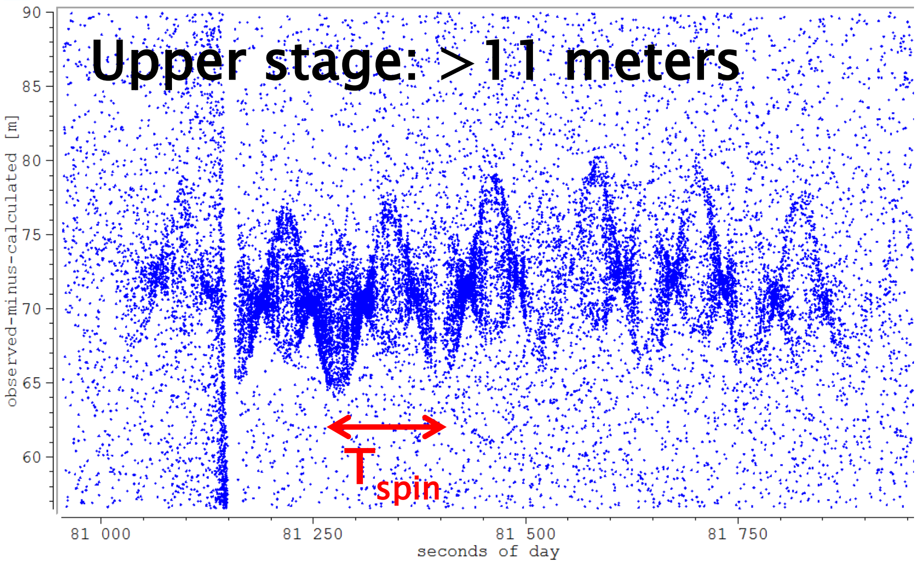
Main differences: Satellite Laser Ranging vs. Space Debris Laser Ranging		
	Satellite Laser Ranging	Space Debris Laser Ranging
Targets	Satellites with retroreflectors	Satellites, rocket bodies
Reflection type	retroreflectors	whole body, diffuse reflection
Naming	cooperative	uncooperative
Laser pulse width	10 picoseconds (10^{-12})	3 nanoseconds (10^{-9})
Laser power	0.8 Watt	16 Watt
Repetition rate	2 kHz	200 Hz
Pulse energy	400 µJ = 0.4 mJ	80 mJ (Factor 200)
Single shot accuracy	a few millimeters	around 1 meter
Range	400-36000 km	< 2000-3000 km
Target size	arbitrary, > 1 CCR	meter sized

SDLR PASSES EXAMPLES

Space debris passes of rotating satellites / rocket bodies

- Observed-Minus-Calculated [m] over time [seconds of day]
- Each point represents photon received by detector
- Denser Areas within noise = Reflections from the body
- Photons can statistically come from front or back of the object
- Object rotating: conclusions on spin period and minimal size of target





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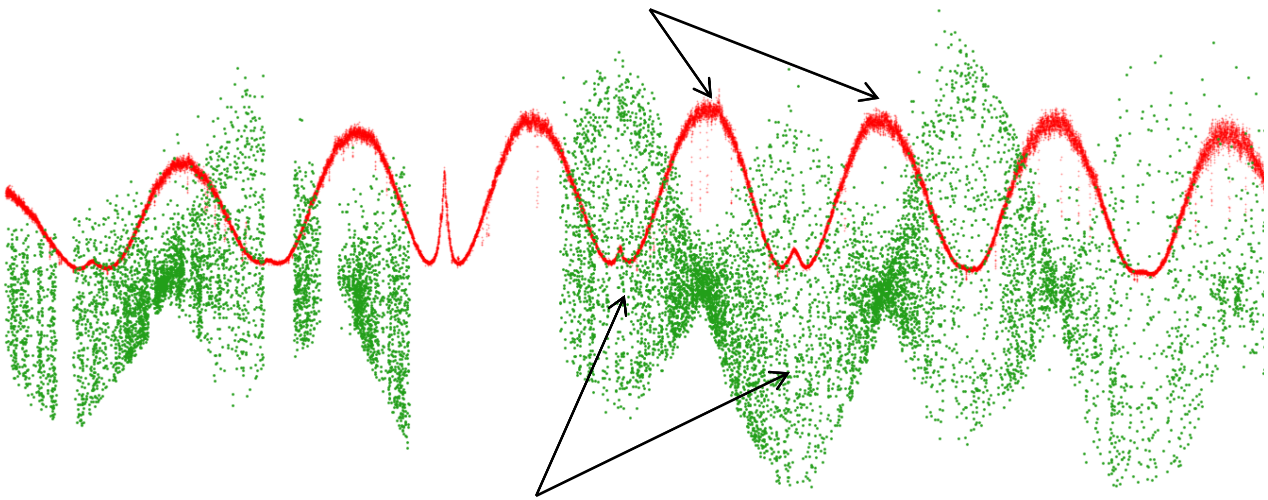
SPACE DEBRIS LASER RANGING / LIGHT CURVES

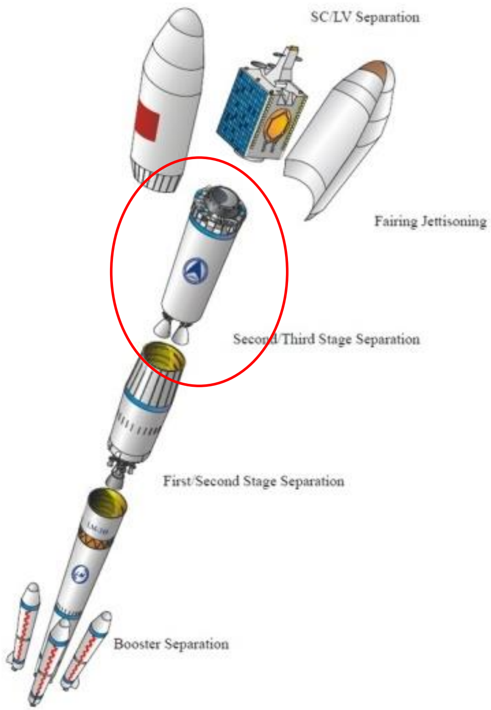
Simultaneously: Single photon light curves (**red**) & space debris laser ranging (**green**)

- Light curve: reflection of sunlight recorded by additional detector
- Rotating upper stage: length: 12 m, diameter: 3 m
- Sunlight: Reflections from cylinder surface and top / bottom surface
- Shifted correlated to distance measurements

cylinder surface (large LC peaks, min SLR)



top / bottom surface (small LC peaks, max SLR)



MULTISTATIC LASER RANGING

- Active station fires laser pulses -> photons diffusely reflected over Europe
- Passive stations detect reflected photons

Example: Experiments with Wettzell // Stuttgart

- Graz sends 532 nm / Wettzell sends 1064 nm
- Graz detects own 532 nm + Wettzell 1064 nm photons
- Wettzell detects own 1064 nm

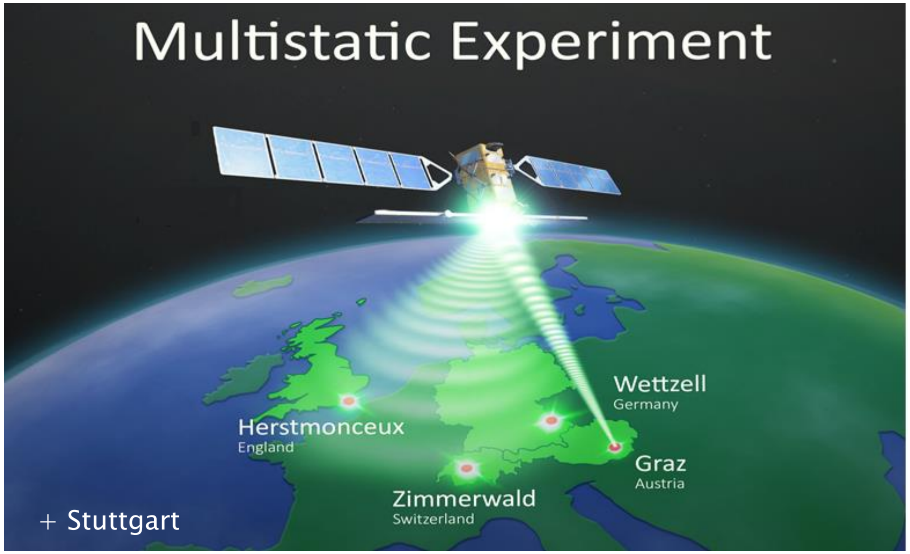


TABLE III. SUMMARY OF DIFFERENT DETECTION SCENARIOS AS PERFORMED DURING THE MULTISTATIC MEASUREMENT CAMPAIGN TOGETHER WITH STUTTGART AND WETTZELL SLR STATIONS.

Conf.	Graz		Wettzell		Stuttgart	
	trans.	*rec.*	*trans.*	*rec.*	*trans.*	*rec.*
C1			X	X		
C2			X	X		X
C3		X	X	X		
C4		X	X	X		X
C5	X	X	X	X		
C6	X	X / X	X	X		

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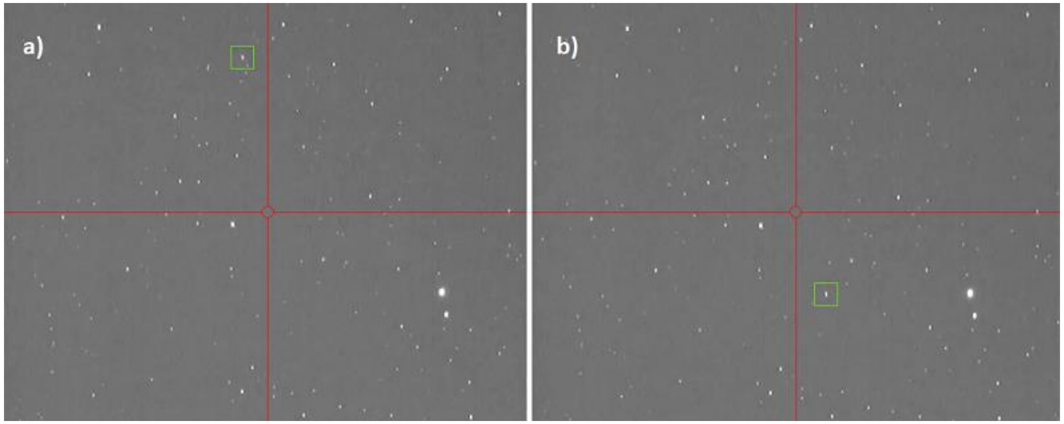
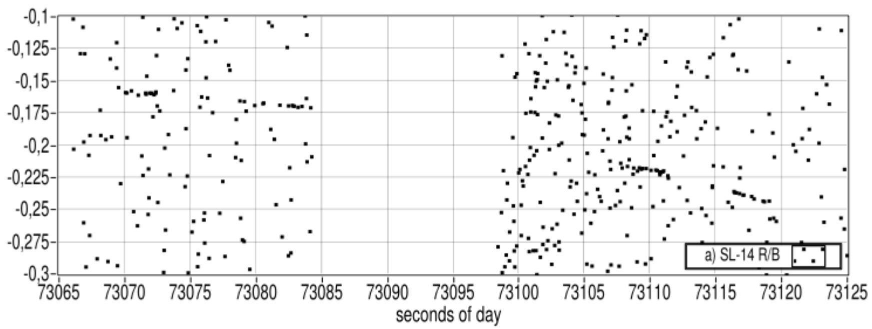
STARE AND CHASE

- Analog CCD camera + COTS photo objective, piggyback mounted, 50 fps, FoV 7x5°
- Space debris targets without a priori orbital information pass through field of view
- Pointing to target detected (equatorial coordinates) --> CPFs calculated
- Within the same pass: Space debris ranging with new CPFs



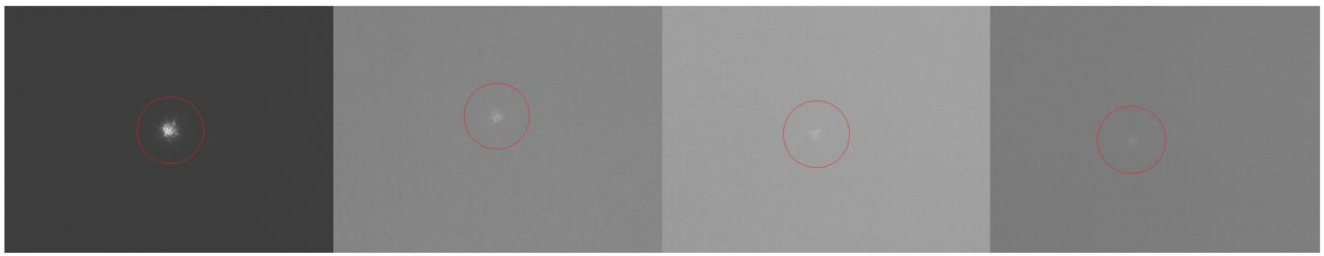
SL14–R/B (NORAD 33505)



STAR & SATALLITE OBSERVATIONS DURING DAYLIGHT

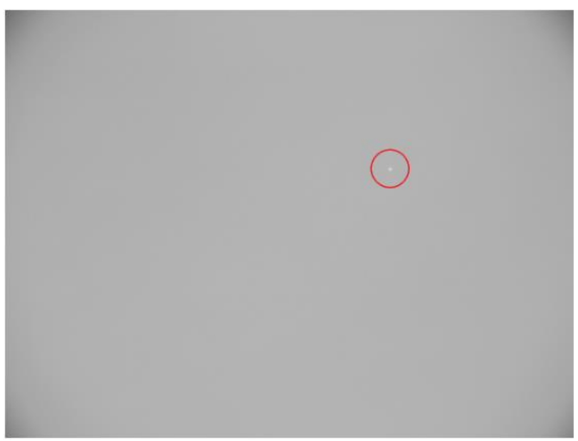
Observations of different stars (up to magnitude 8) at noon (14:00 local time)

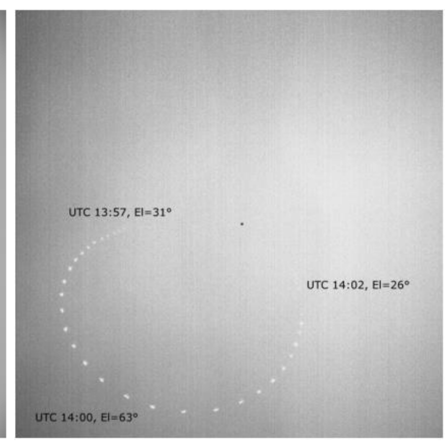
- Magnitude 8: 6x fainter than human eye during night (perfect conditions)



(a) m=0.15 (b) m=3.00 (c) m=6.95 (d) m=8.25

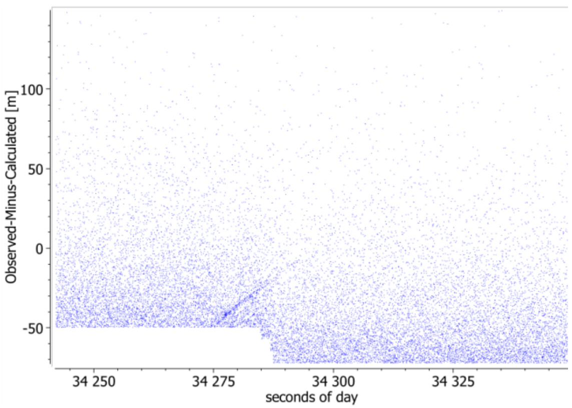
Observations of the sunlight reflection of rocket bodies (SL-12, SL-16, stacked)



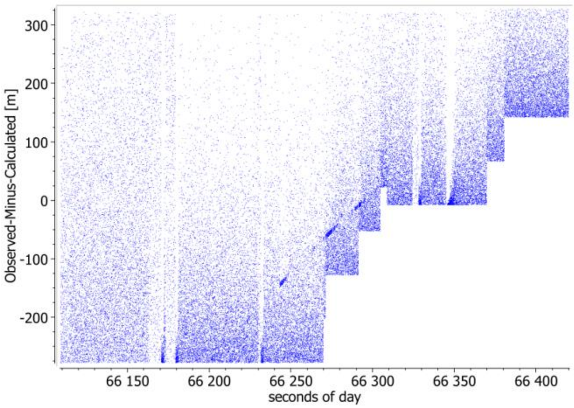


FIRST DAYLIGHT RESULTS

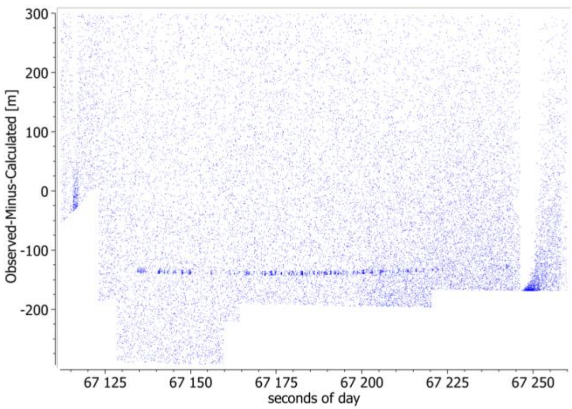
- Orbit predictions of space debris accurate to kilometers
- Offsets need to be corrected (centering target in field of view)
- Target automatically detected and offsets calculated
- First daylight space debris laser ranging results (upper stage rocket bodies)
- Maximum: sun 39° above horizon



(a) SL-16 R/B (#22285), $tb = 9ms$



(b) SL-16 R/B (#23705), $tb = 140ms$



(c) SL-16 R/B (#22803), $tb = -145ms$

!!! THANK YOU !!!


SLR station Graz
© Christian Kettenbach


Alcantara
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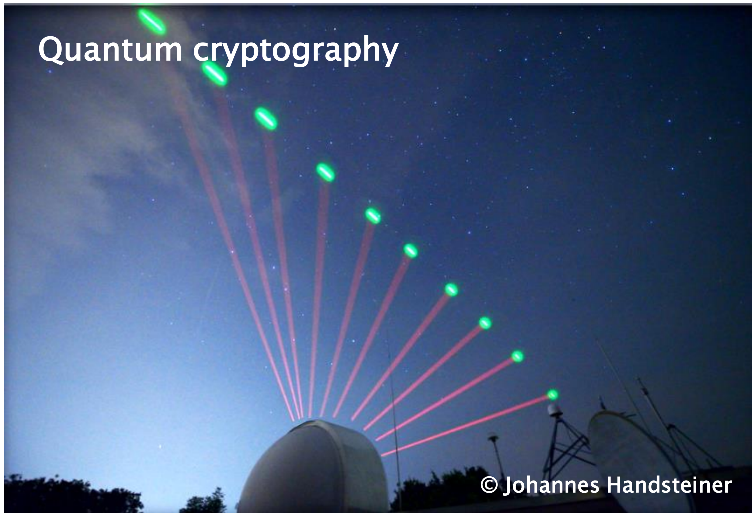
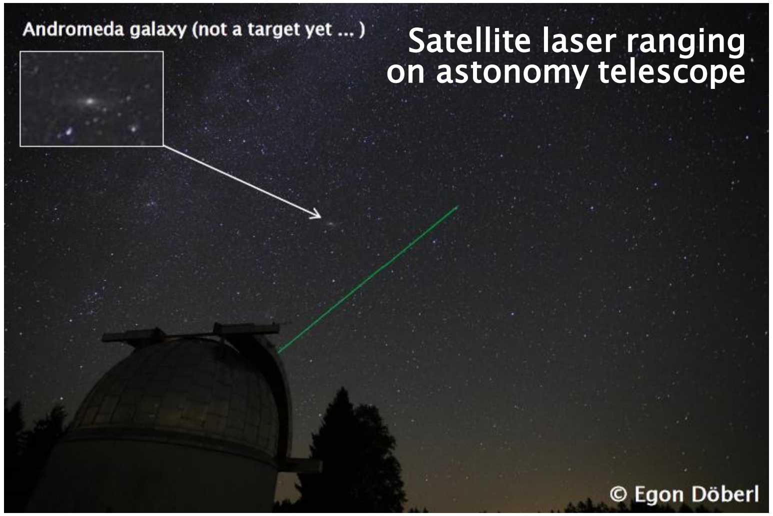

Quantum cryptography
© Johannes Handsteiner


Andromeda galaxy (not a target yet ...)
Satellite laser ranging
on astonomy telescope
© Egon Döberl