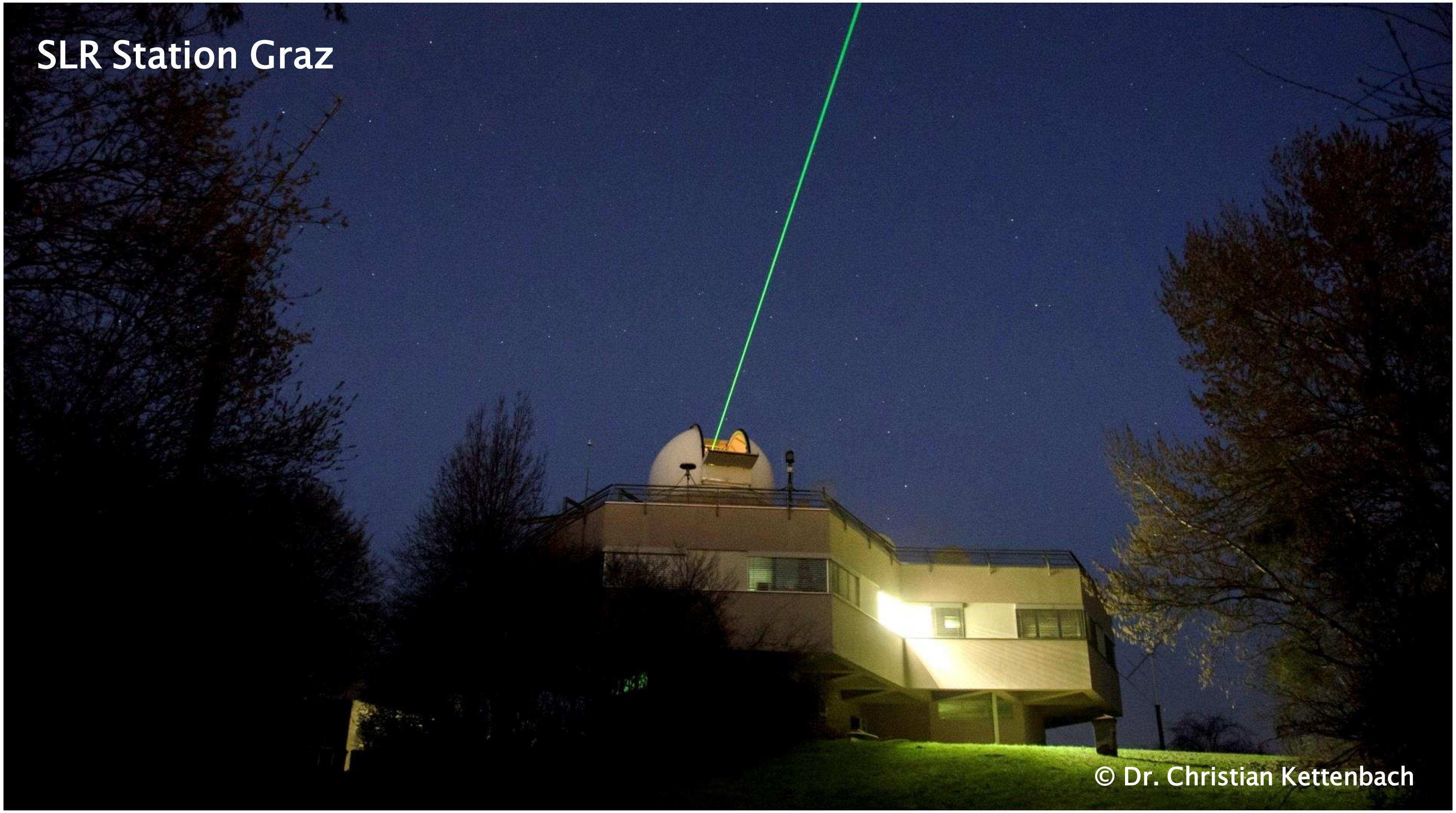
SPACE DEBRIS LASER RANGING TECHNIQUE AND APPLICATIONS



Michael Steindorfer, Georg Kirchner, Franz Koidl, Peiyuan Wang, Harald Wirnsberger
1) Space Research Institute, Austrian Academy of Sciences

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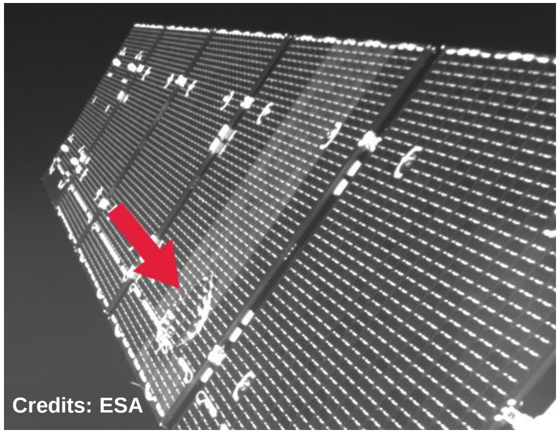
SPACE DEBRIS – AN OVERVIEW

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 by Space Surveillance Networks	collisions
Velocity	7 kilometers / second	lost equipment
Impact: mm - particle	> 20 cm craters (Sentinel-1A)	


Credits: ESA

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

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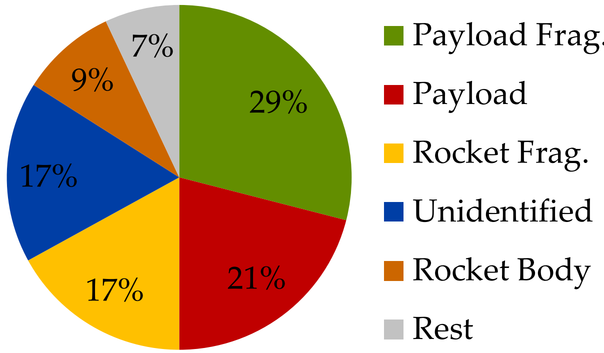
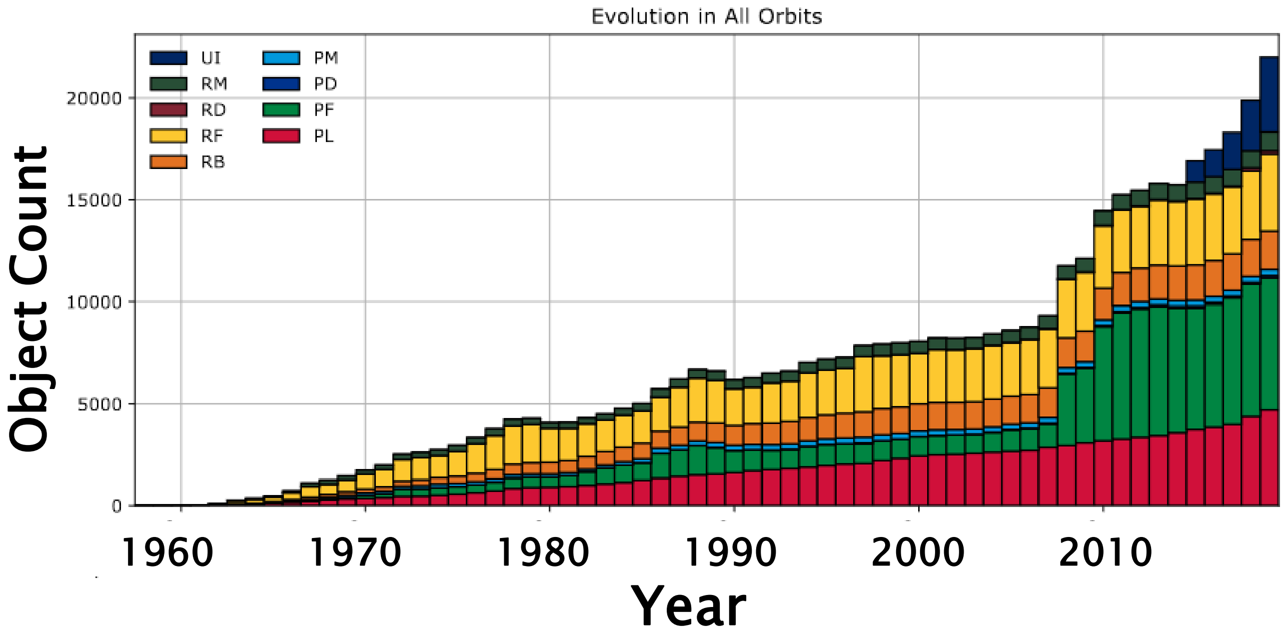
OBJECT NUMBER / TYPE

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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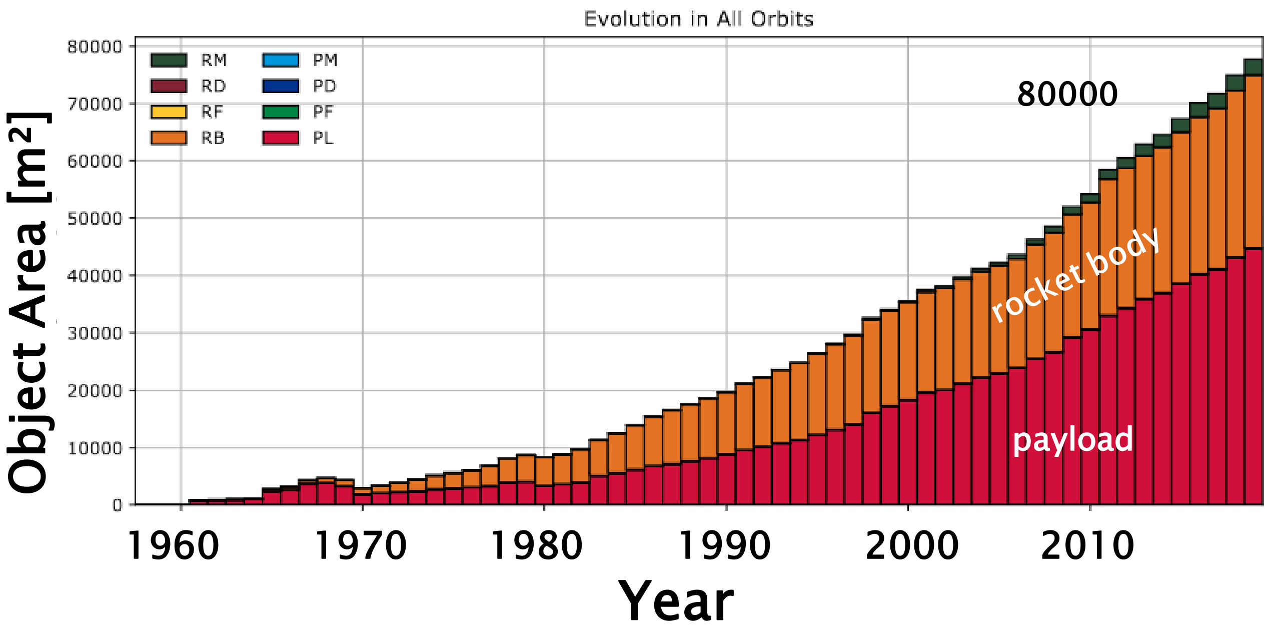
OBJECT AREA / TYPE

1) PL ... Payload (44650 m²)
2) RB ... Rocket Body (30362 m²)
3) RM ... Rocket Mission Related Object (2696 m² , adapters, covers)



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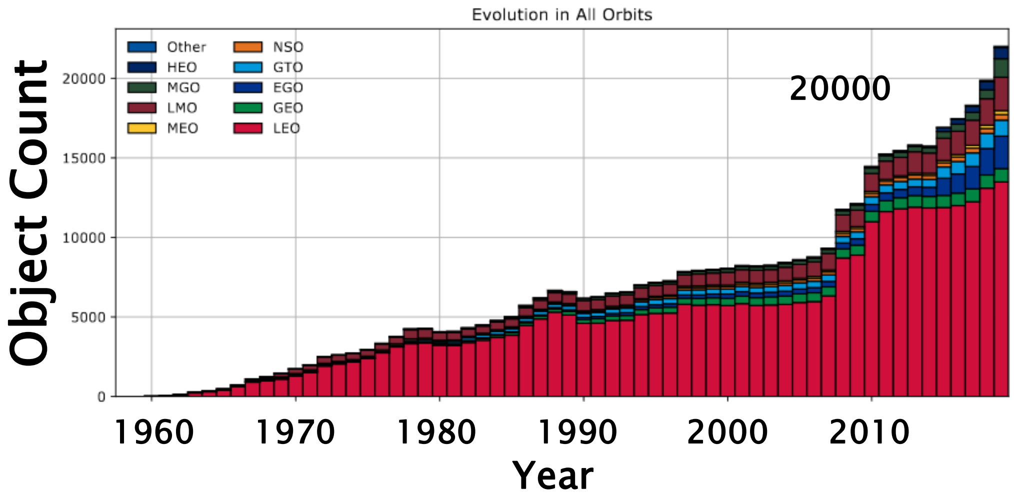
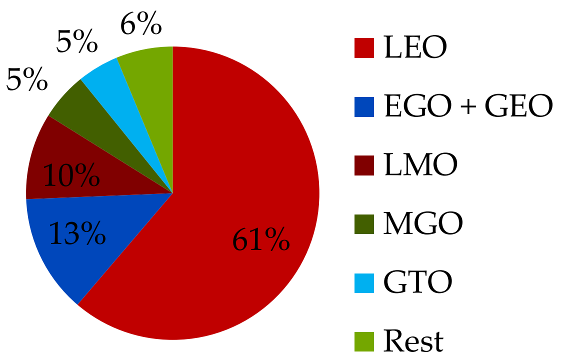
DISTRIBUTION: OBJECT NUMBER / ORBIT

1) LEO ... Low Earth Orbit (61%, 13485)
2) EGO+GEO ... Extended Geost. Orbit + Geost. Orbit (13%, 2040 + 842)
3) LMO ... LEO – MEO Crossing Orbit (10%, 2101)
4) MGO, GTO ... MEO-GEO Crossing Orbit, Geostationary Transfer Orbit (5%, 1100)





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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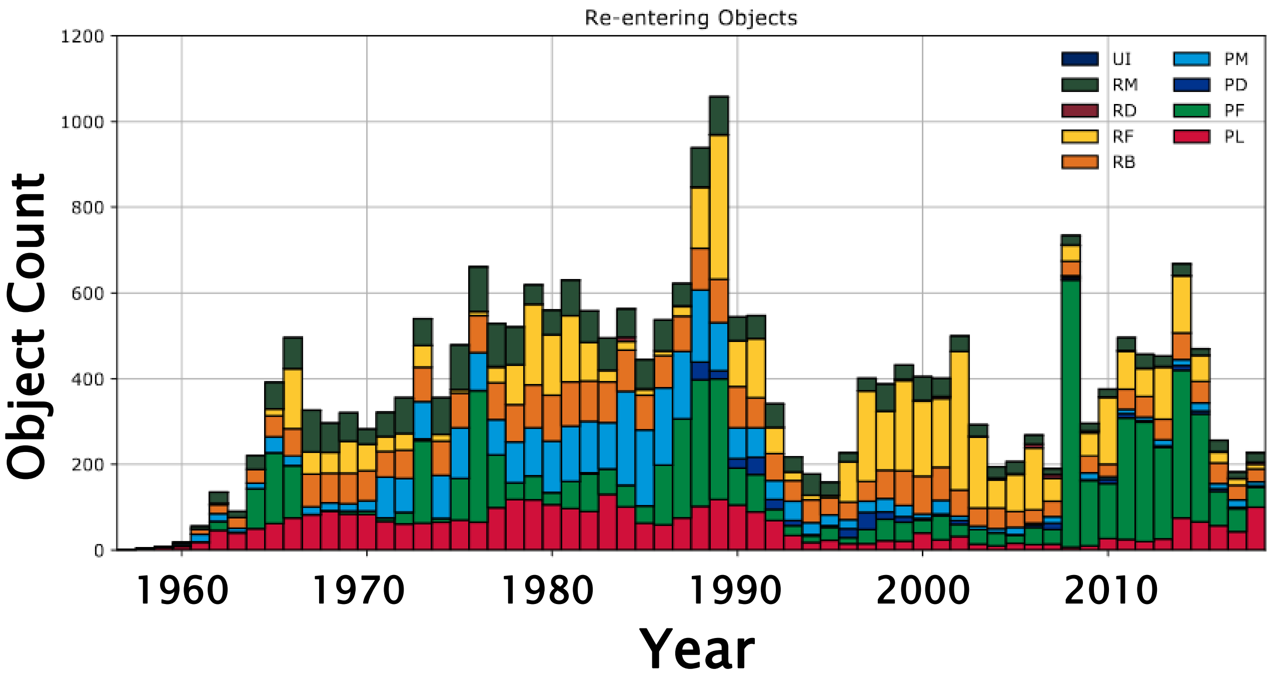
NUMBER OF REENTERED OBJECTS

Reentry: currently 200 objects per year (varying, 2007 + 2009 incidents)

1) PL ... Payload
2) PF ... Payload Fragmentation
3) RB ... Rocket Body



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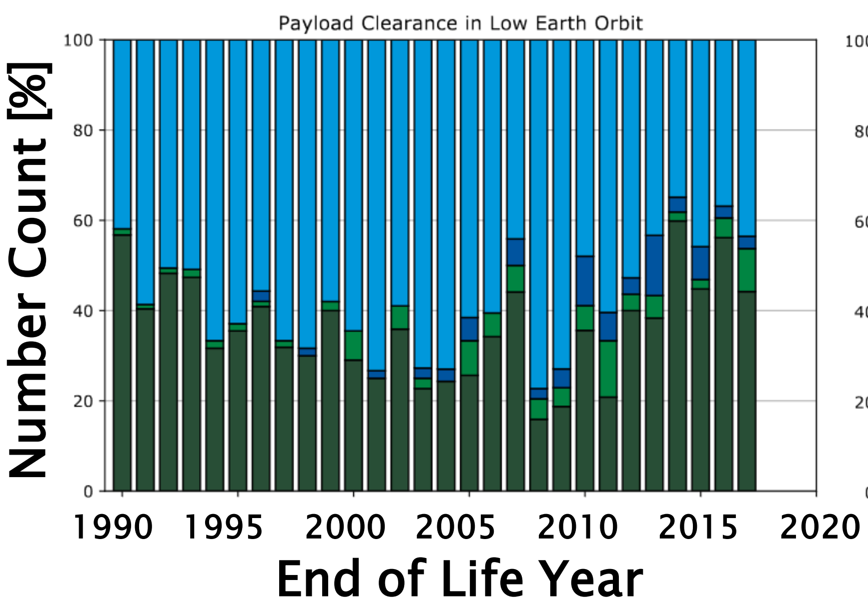
PAYLOAD / ROCKET BODY CLEARANCE

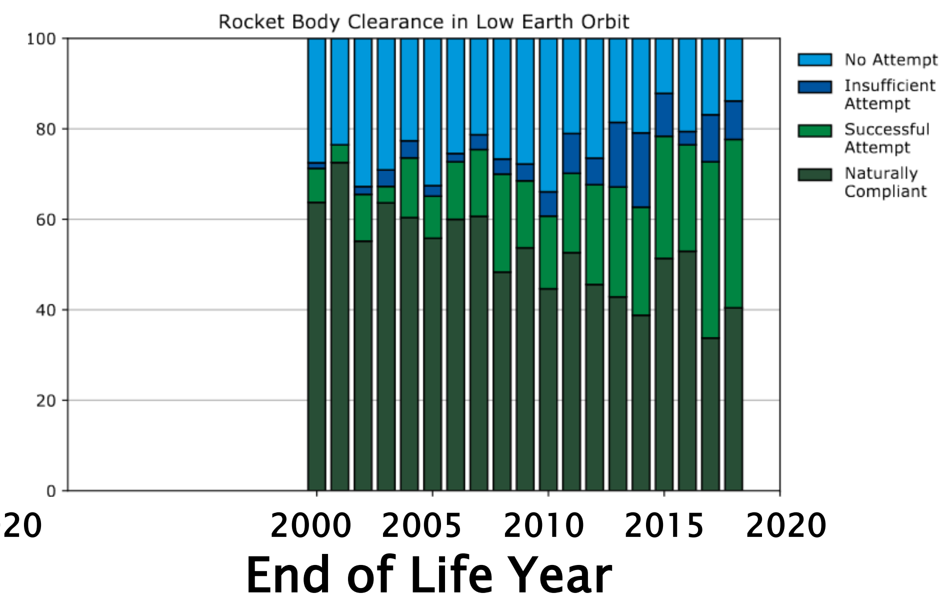
Successful clearance: objects leaving LEO protected region

LEO region: limit of post-mission presence to maximum of 25 years

Number // clearance: ~55% payload; ~80% rocket body

Mass // clearance: ~40% payload; ~ 80% rocket body

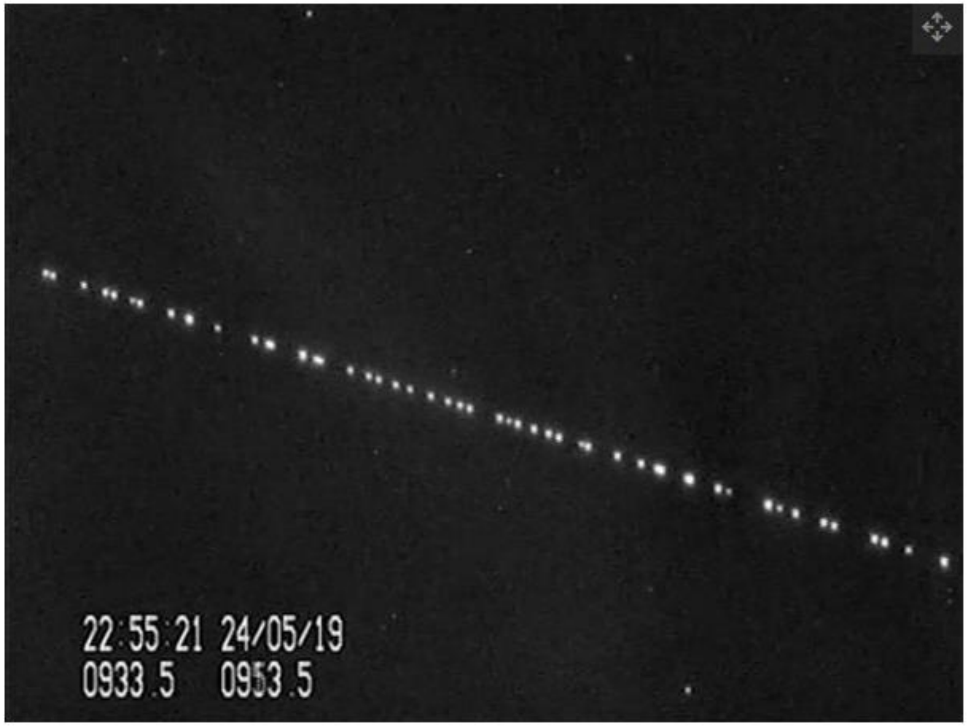




naturally compliant, successful attempt, insufficient attempt, no attempt

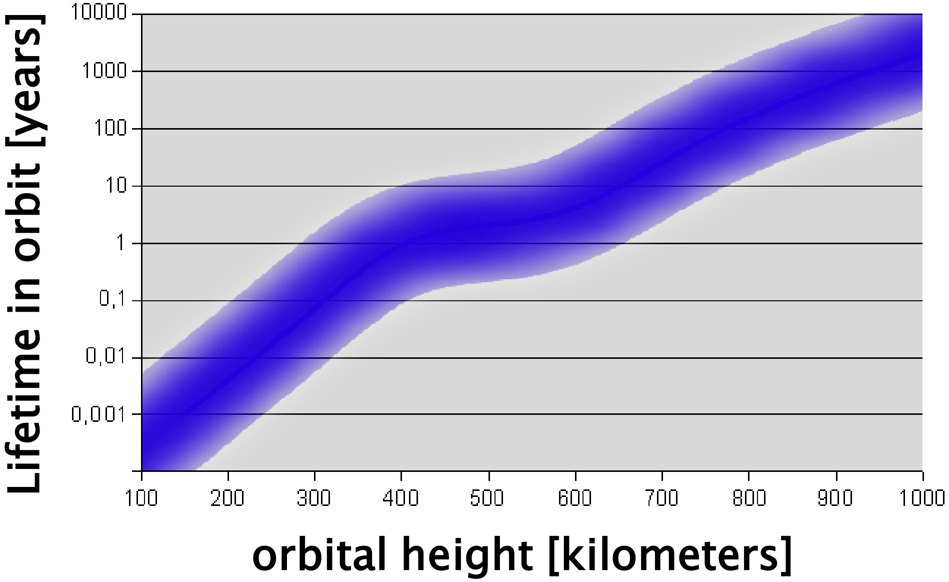
MEGA CONSTELLATIONS

- Number of satellites rapidly increasing --> Mega constellations
- Different companies: Plans to launch constellations with >12000 satellites
- Image by Marco Langbroek, Watec 902H + 50 mm lens -> FOV 8°x 6°



ONCE IN SPACE ...

- Once it orbit, it stays there... for a long time
- Life time in orbit vs. orbital height



- Main reason for re-entry
  - Atmospheric drag -> loss of energy reduces orbital height

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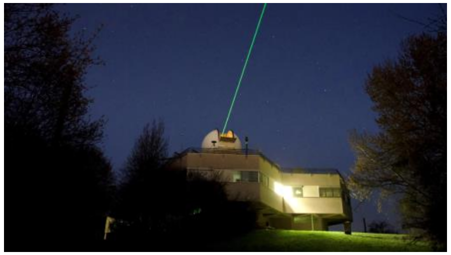

SLR VS. SDLR

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

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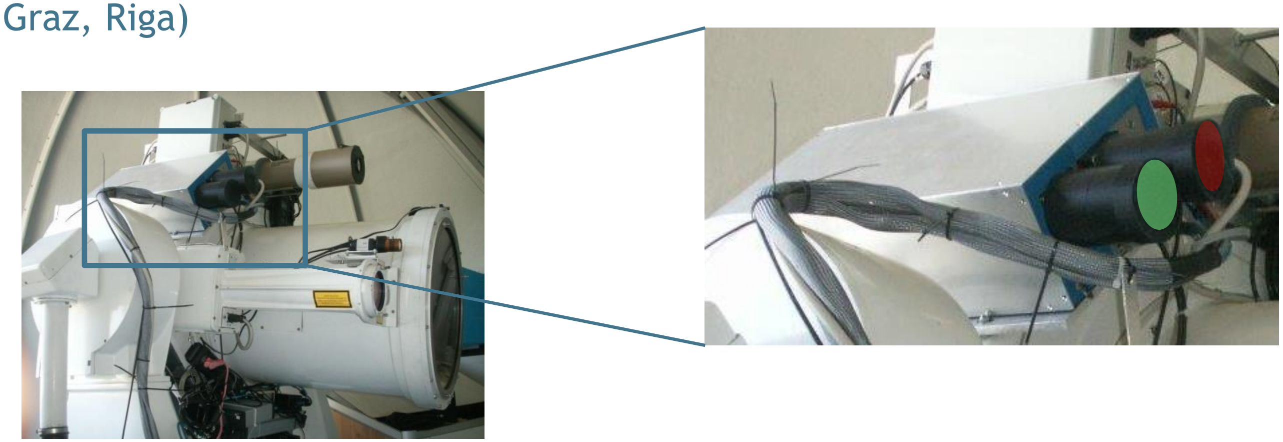
THE FLOAT CONCEPT

Fix Laser On Astronomy Telescope (FLOAT)

- Upgrade astronomy telescope to fully functional SLR station
- Initially designed for tiny 15 µJ @ 2 kHz lasers -->
- Laser + beam expansion optics directly mounted on telescope
- Separate control unit (event timing, GNSS time, met data)
- No Coudé path, lower cost, reduced alignment effort

Same concept used for space debris laser

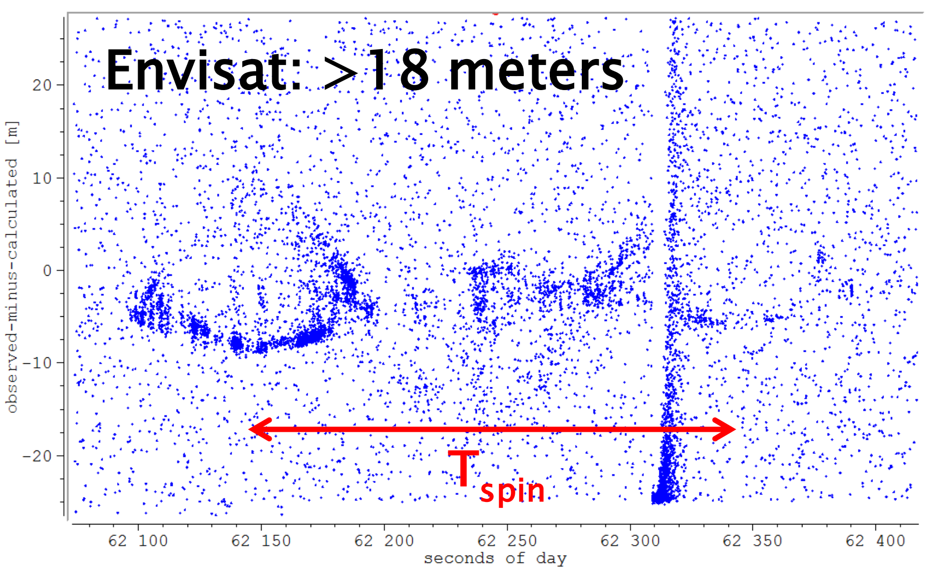
- Space debris: 16 W @ 200 Hz // 532 / 1064 nm
- Laser head directly on mount, Cooling + power through mount
- Also used for ps laser at ESA SLR station Tenerife (ESA, DiGOS, Graz, Riga)

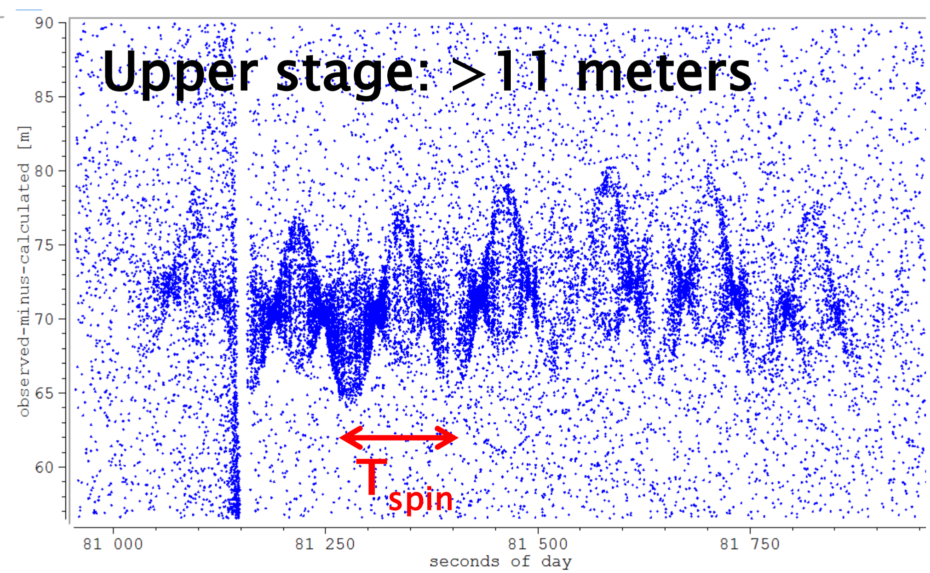


SDLR PASSES EXAMPLES

Space debris passes of rotating satellites / rocket bodies

- Observed-Minus-Calculated [m] over time [seconds of day]
- Reflections from the body
- Photons can come statistically from front or back of the object
- First conclusions on spin period and minimal size of target





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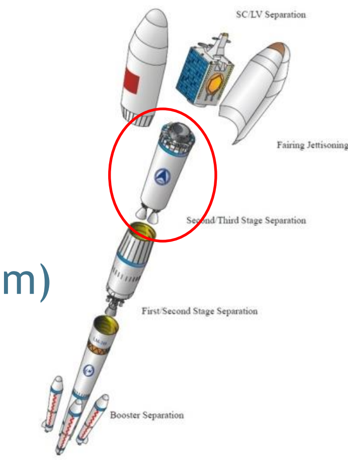
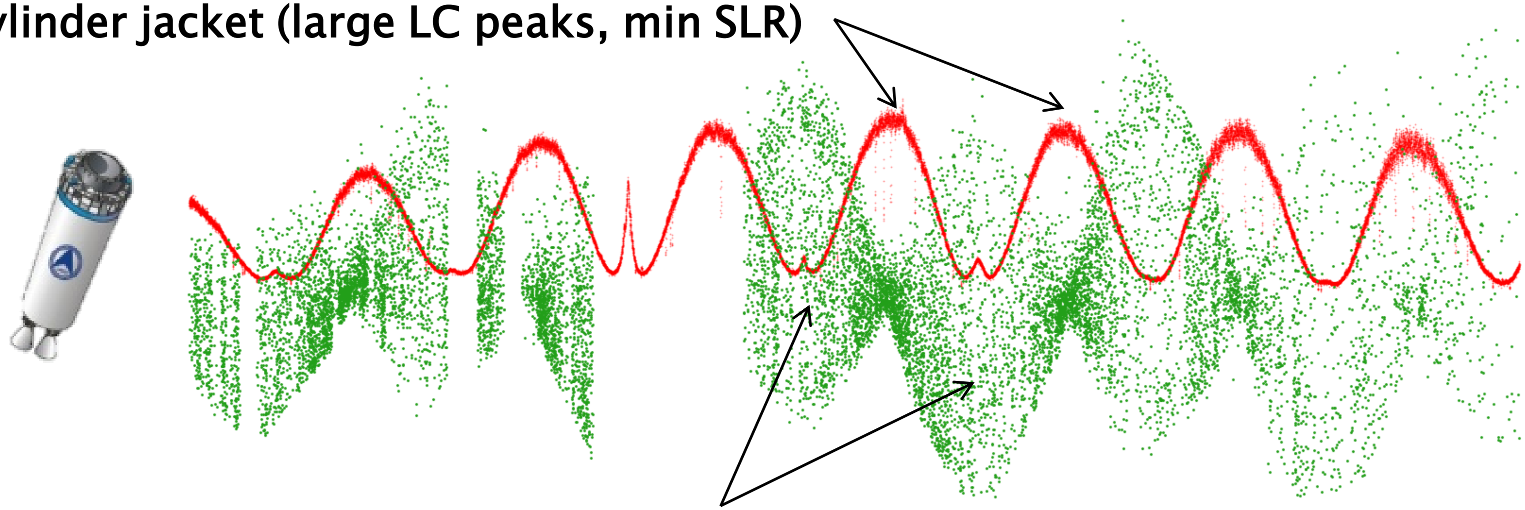
SPACE DEBRIS LASER RANGING / LIGHT CURVES

Simultaneously: Single photon light curves & space debris laser ranging

- Light curve: reflection of sunlight recorded by additional detector
- Max SLR O-C <-> Small LC peaks // Min SLR O-C<-> Large LC peaks
- Large LC peaks: Sunlight reflection from cylinder jacket (SLR Minimum)
- Small LC peaks: Sunlight reflection from top/bottom surface
- Offset of SLR residuals -> center of mass ≠ geometrical center



cylinder jacket (large LC peaks, min SLR)



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

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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

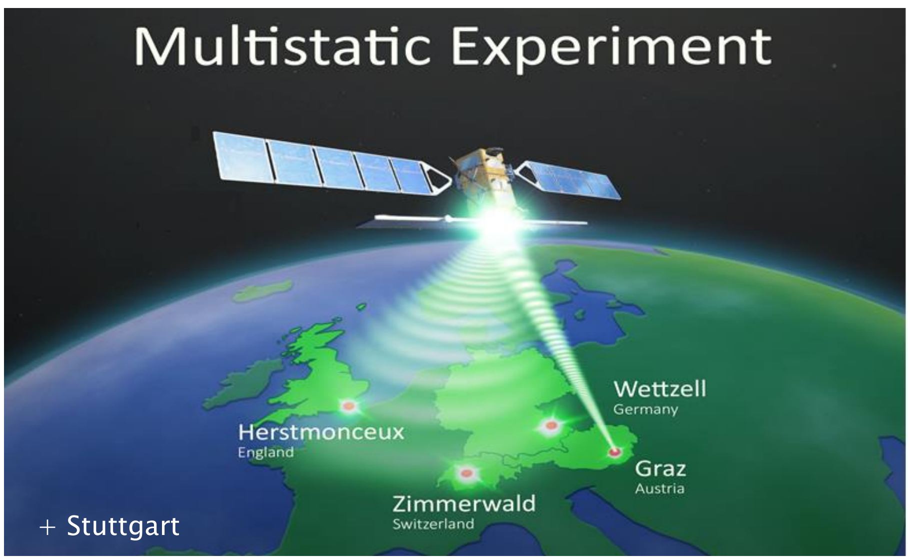
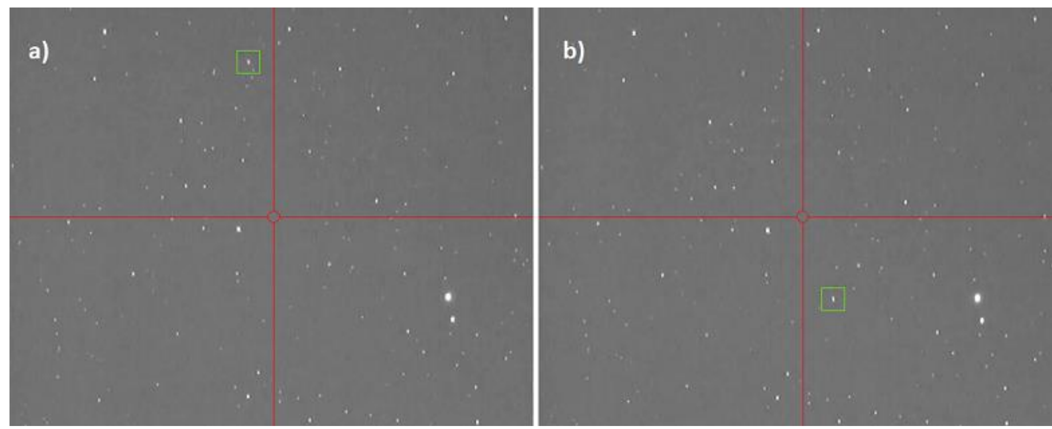


TABLE III. SUMMARY OF DIFFERENT DETECTION SCENARIOS AS PERFORMED DURING THE MULTISTATIC MEASUREMENT CAMPAIGN TOGETHER WITH STUTTGART AND WETTZELL SLR STATIONS.

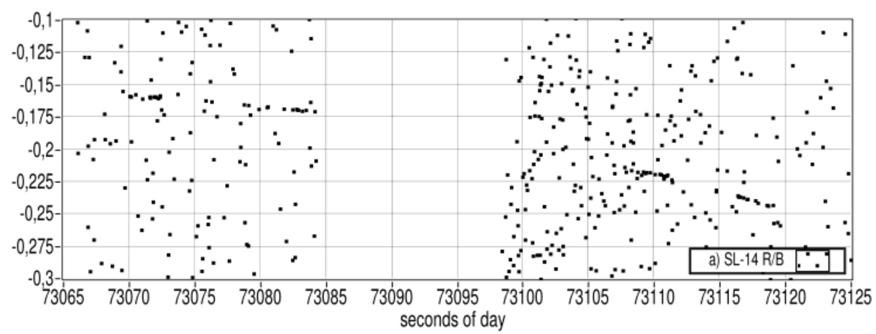
Conf.	**Graz**		**Wettzell**		**Stuttgart**	
	trans.	***rec.***	***trans.***	***rec.***	***trans.***	***rec.***
C1			X	X		
C2			X	X		X
C3		X	X	X		
C4		X	X	X		X
C5	X	X	X	X		
C6	X	X / X	X	X		

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)



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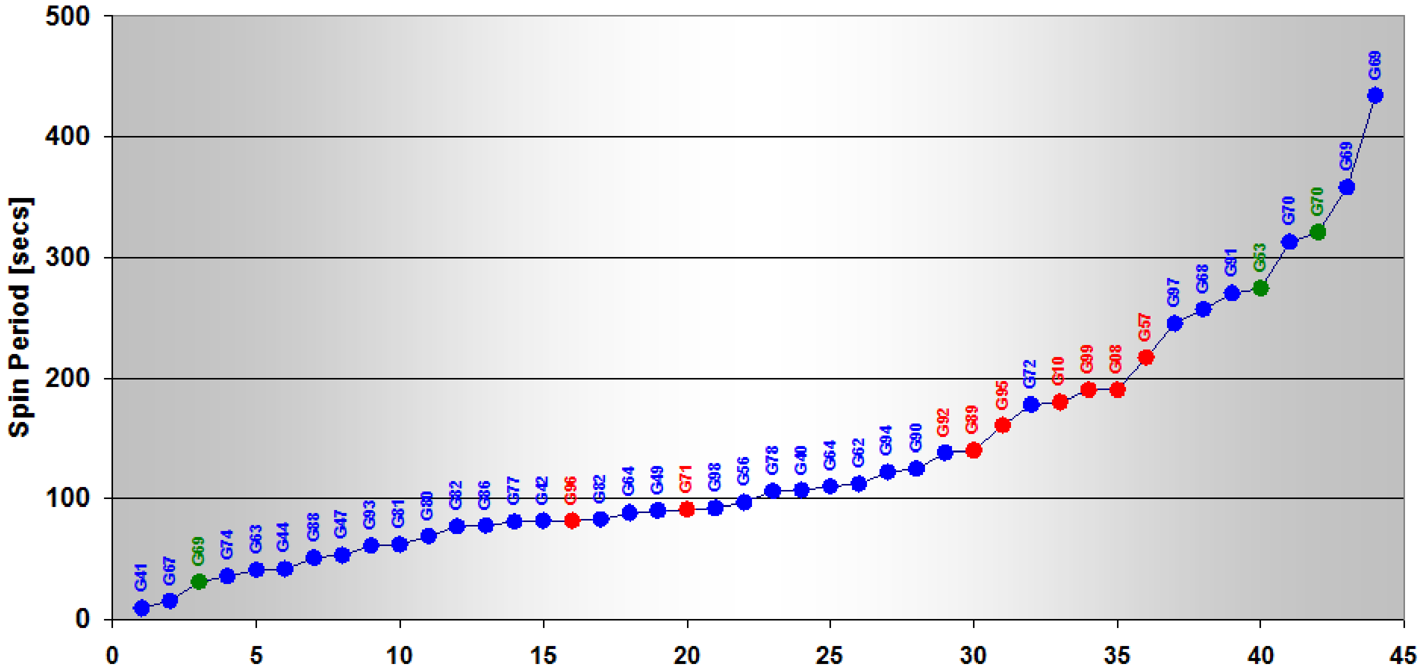
DEFUNCT GLONASS SPIN PERIOD

Glonass spin periods: From < 10 secs to > 400 secs; SLR and Light Curve data

Spin Parameters of 44 Defunct Glonass Satellites;
using SLR (532 nm), Light Curves (> 780 nm), or both

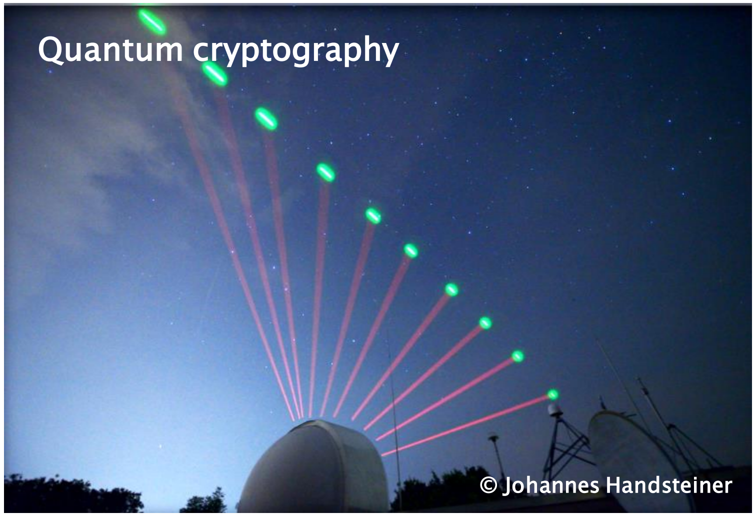


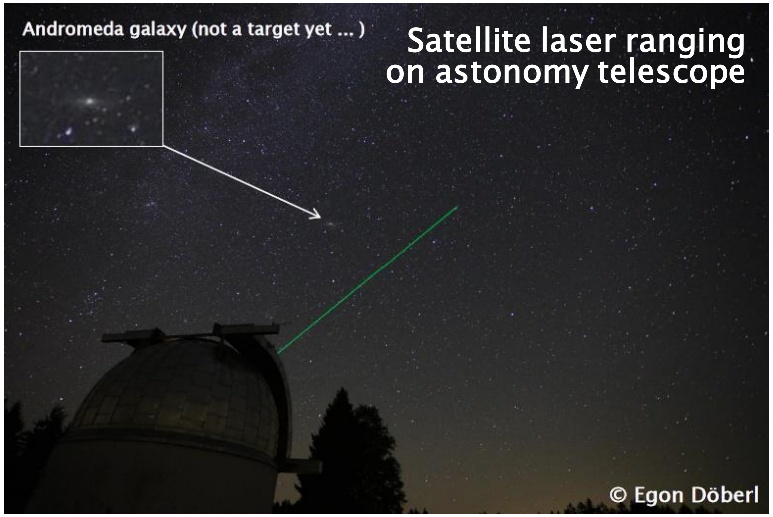
● SLR Data only; ● Light Curve Data only; ● BOTH SLR+Light Curve Data

!!! THANK YOU !!!


SLR station Graz
© Christian Kettenbach


Alcantara
© Michael Steindorfer


Quantum cryptography
© Johannes Handsteiner


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