Space-Based Laser Constellation for Active Debris Removal

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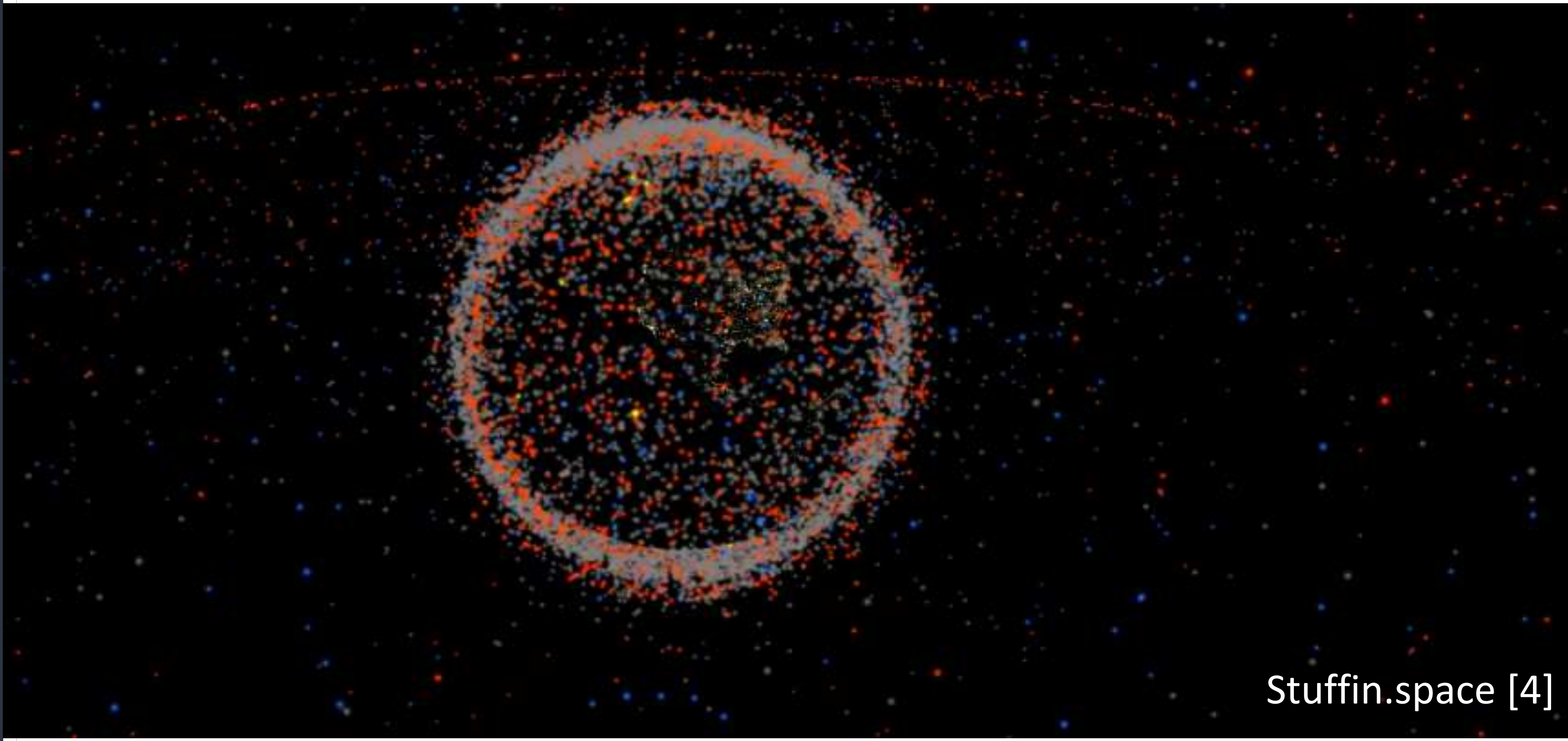
Space Debris Problem

- 15000 trackable debris objects [1]
  - 2200 larger than 1 m [2]
- Kessler Effect predicts almost exponential increase [3]



Stuffin.space [4]

Active vs Passive Debris Removal

Passive Debris Removal

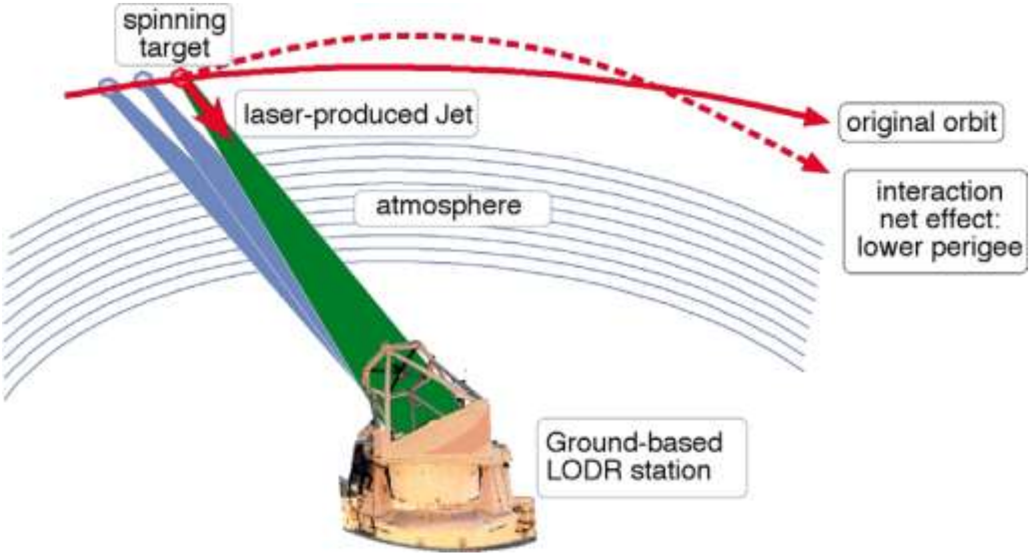
- Post Mission Disposal
- Accommodated before launch
- e.g. Electrodynamic tethers, Drag sails

Active Debris Removal

- Addresses current problem
- Target state unknown
- Similar methods to passive – complicated by rendezvous
- Limited chances and targets
- Non contact method is preferable

Laser Debris Removal

- First Investigated in 1980’s [5]
- Predominately terrestrial [2][6]
  - Long range & atmospheric disturbances
  - Virtually no power, mass & size limitations
- Space based only recently suggested [7][8]
  - Short range
  - Negligible beam disturbance
  - Limited power, mass, size



Phipps [2]

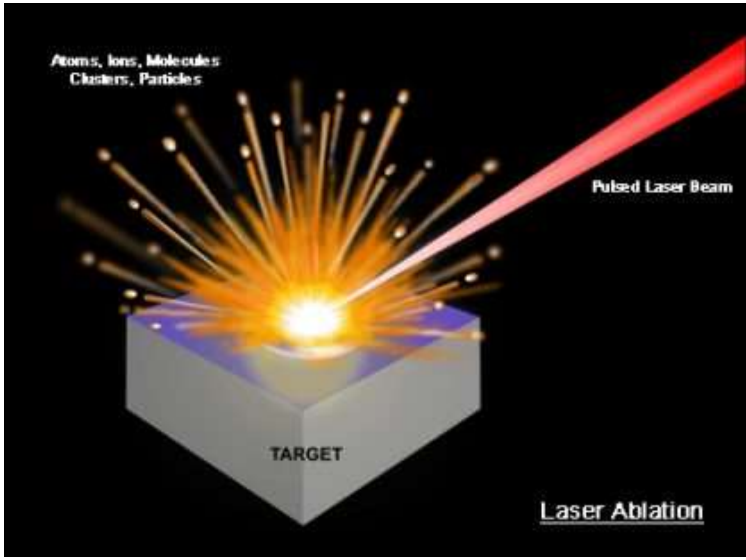
Constellation Approach

- **Reduce requirements of single satellite by using multiple smaller satellites**
  - Increased orbital coverage
  - Increased interaction opportunities
  - Incremental expansion
  - Redundancy and reliability
  - Simultaneous engagement of single or multiple targets

Laser Ablative Propulsion

Operation Modes

- Determined by threshold fluence
- Radiation pressure
- Excessive heating and melt
- Clean ablation



Mechanism

- Target material ablated
- Jet of vapor and plasma expelled
- Force applied in opposite direction

Laser Selection

- Fibre lasers
- Momentum Coupling Coefficient
- $C_m = 150\ \mathrm{N/MW}$
- $\lambda = 1\ \mu\mathrm{m}$
- $\tau = 1\ \mathrm{ns}$
- $d_{spot} = 5\ \mathrm{cm}$
- $E = 31\ \mathrm{J}$
- $f = 200\ \mathrm{Hz}$
- $P = 6.2\ \mathrm{kW}$

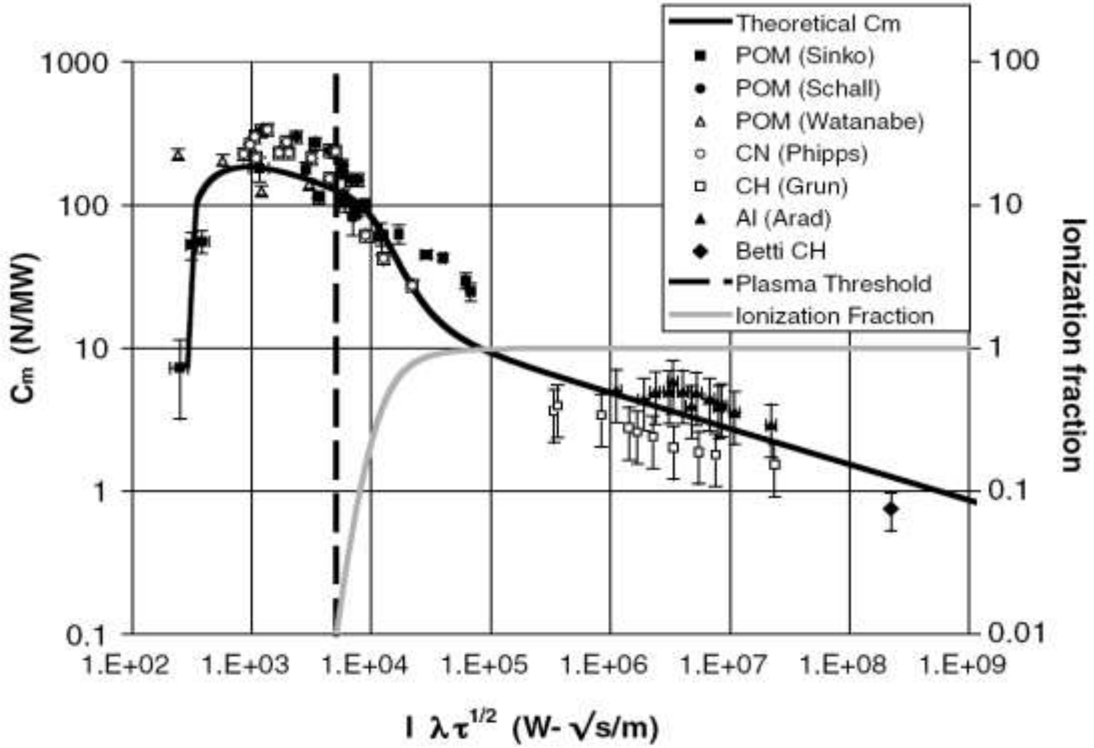


Image courtesy of Phipps et.al. [9]

Laser Selection

Momentum Change

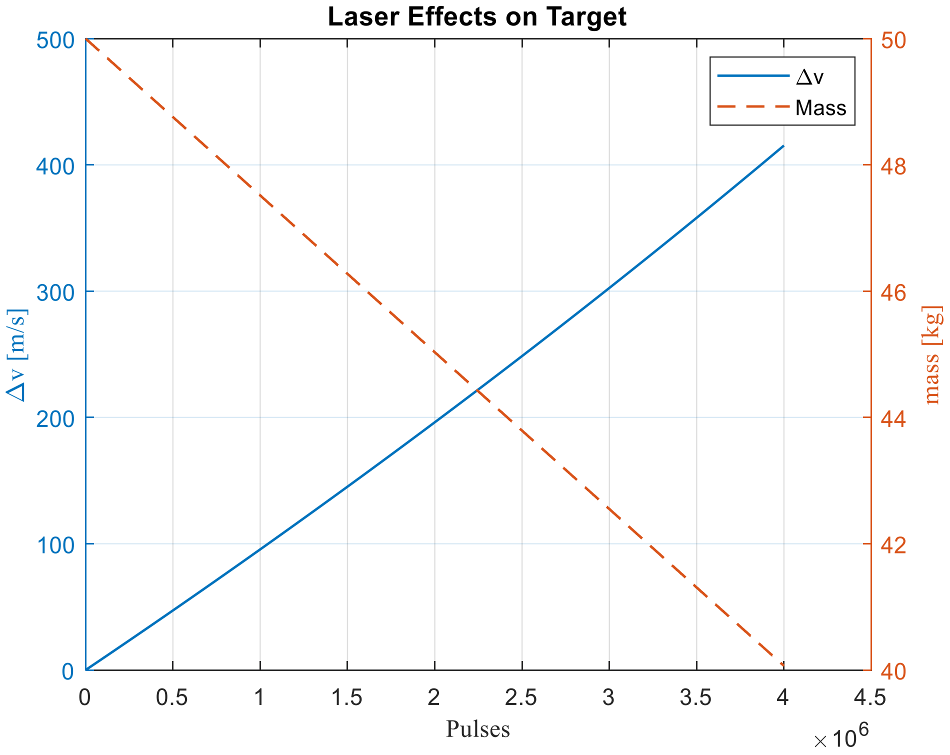
- $m\Delta v = C_m E$
- 0.931 N every second
- 0.652 N effective

Mass Change

- $\Delta m = \mu E$
- μ = 80 µg/J
- 0.5 g/s

Range

- Focusing
- 1.27 m aperture



Technical Feasibility

Power

- 14.3 kW laser system
- 700 W subsystems
- 2.2 kW power generation assuming 10 % laser operation

Size

- Using high power industrial equivalent laser
- Satellite mass < 500 kg

Pointing

- 1 m target at 50 km requires 2.269 arcsec accuracy
- Sensing resolution achievable
- Control resolution is more challenging

Cost

- Design and launch costs split over multiple satellites
- Cost further split between all the individual targets eliminated
- Can launch entire constellation at once
- Constellation supplemented later

Reliability

- No physical contact or rendezvous required
- Primary resource consumed in interaction is electrical power
- Missed interaction does not cost irreplaceable critical resource
- Constellation approach increases overall system’s reliability with increased redundancy

Debris Risk

- Laser satellite becomes defunct
- Miss management of laser energy and its application
  - Excessive heating
  - Melt eject
- Target splits apart
  - Would require very long interaction times
  - Requires very specific conditions i.t.o. target shape, size, etc.

Effectiveness

Target Identification

- Subset of NORAD catalogue
- 120 objects identified
- Primary target within debris field

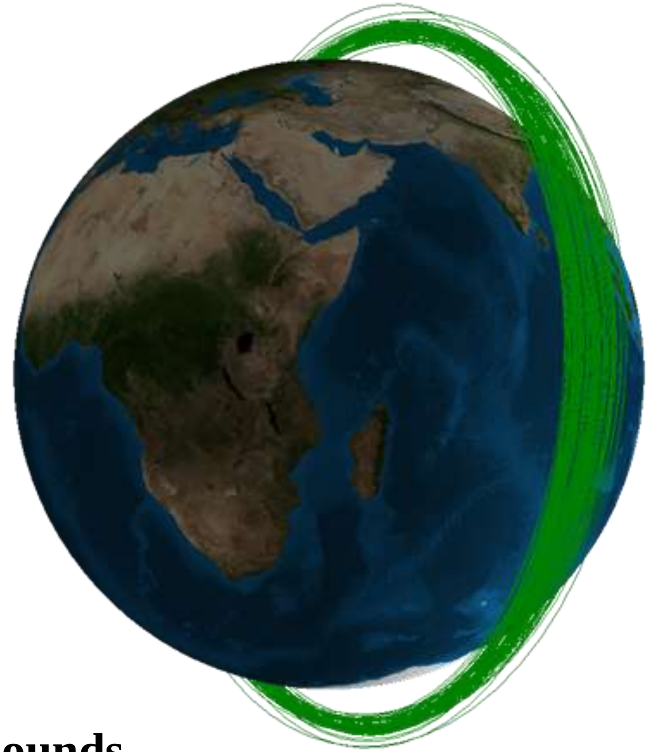


Table 1: Debris field orbital bounds

Orbital Parameter	Eccentricity	RAAN [degree]	Inclination [degree]	Altitude [km]
Minimum	0	25	90	550
Maximum	0.1	35	100	800

Effectiveness

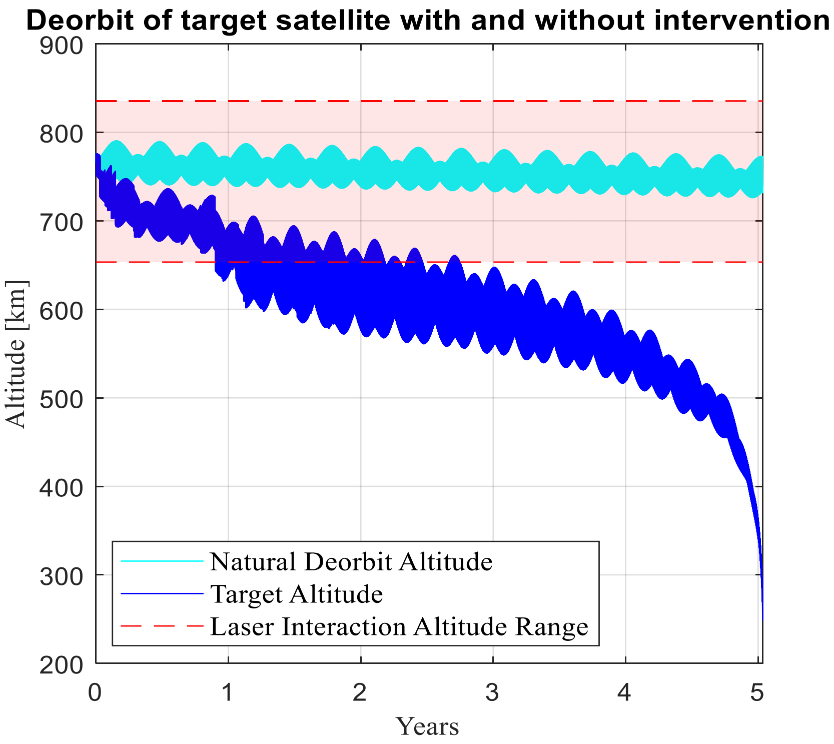
Constellation Selection

- 6 satellites
- 2 altitude tiers
- All 120 objects within range

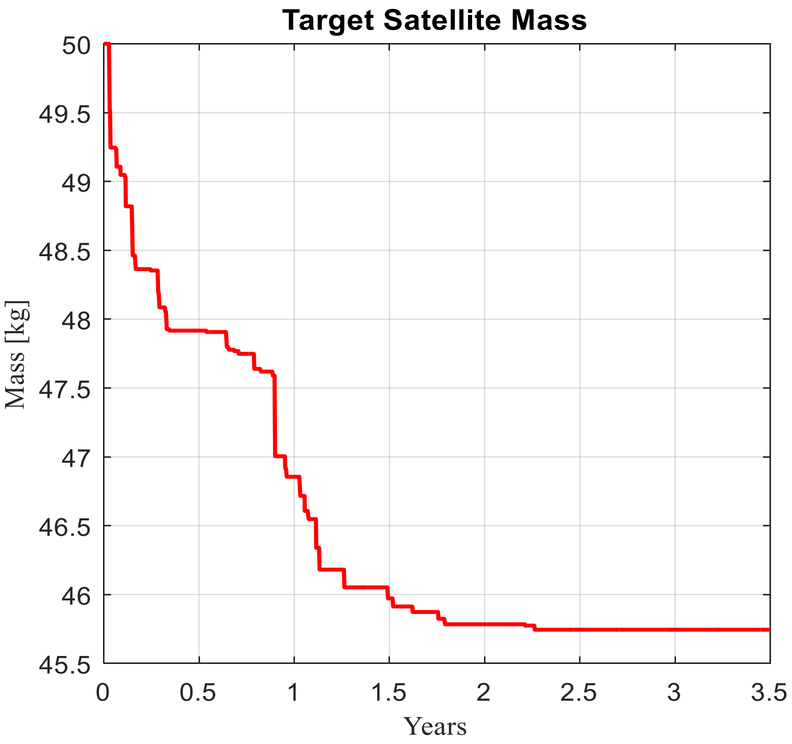
Table 2: Orbital elements

	Primary Target	Satellite 1	Satellite 2	Satellite 3	Satellite 4	Satellite 5	Satellite 6
Semi-major axis [km]	7128	7157	7157	7157	7075	7075	7075
Orbital inclination [degrees]	98.4	98.8	98.5	99.2	98.8	98.5	99.2
Eccentricity	0.001	0.01	0.01	0.01	0.01	0.01	0.01
R.A.A.N [degree]	30.0	29.4	26.5	32.3	29.4	26.5	32.3
Argument of Perigee [degree]	210.0	204.9	119.1	290.7	204.9	119.1	290.7

Main Mission Target



Deorbit of target satellite with and without intervention



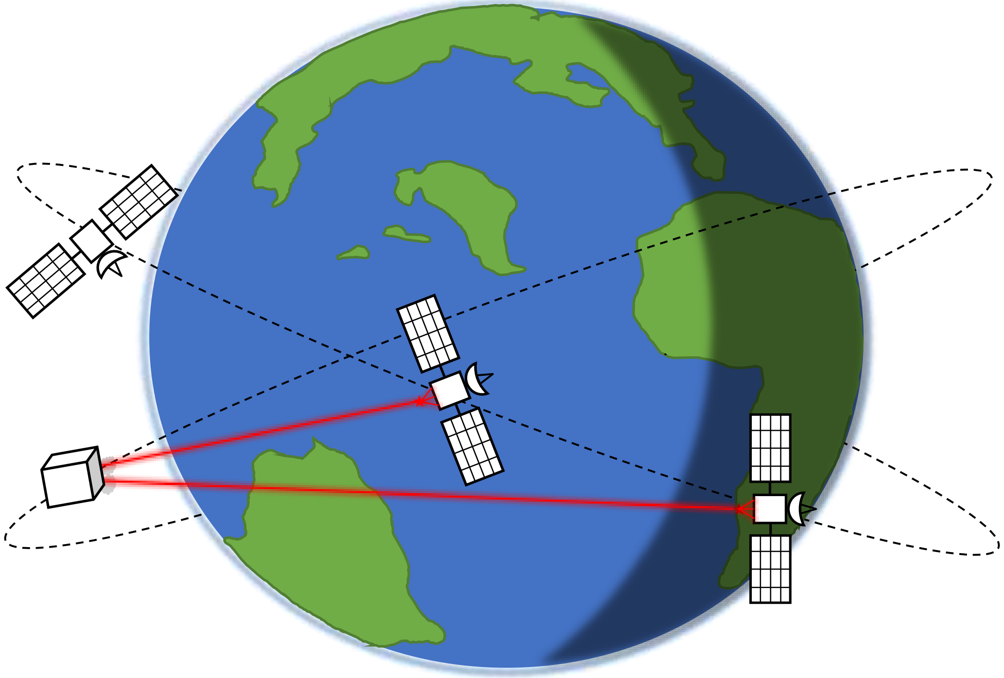
Target Satellite Mass

- Target deorbited to 200 km in 5 years 11 days
- 71.5 minutes interaction time over 45 interactions
- 4.26 kg material removal

Conclusions

- Active debris removal by a constellation of 6 laser satellites
- 6.2 kW fibre laser applying an effective force of 0.652 N
- Main mission target eliminated in < 6 years
- 120 additional targets available
- Constellation allows lower power than previous singe laser solutions
- High level of redundancy
- Low debris risk

Thank You



Questions?

References

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Extra Slide: Fibre Lasers

- Bundled fibres
- Simple beam transmission