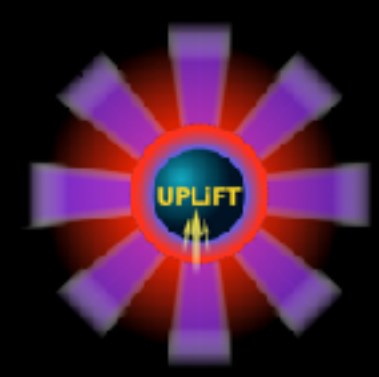
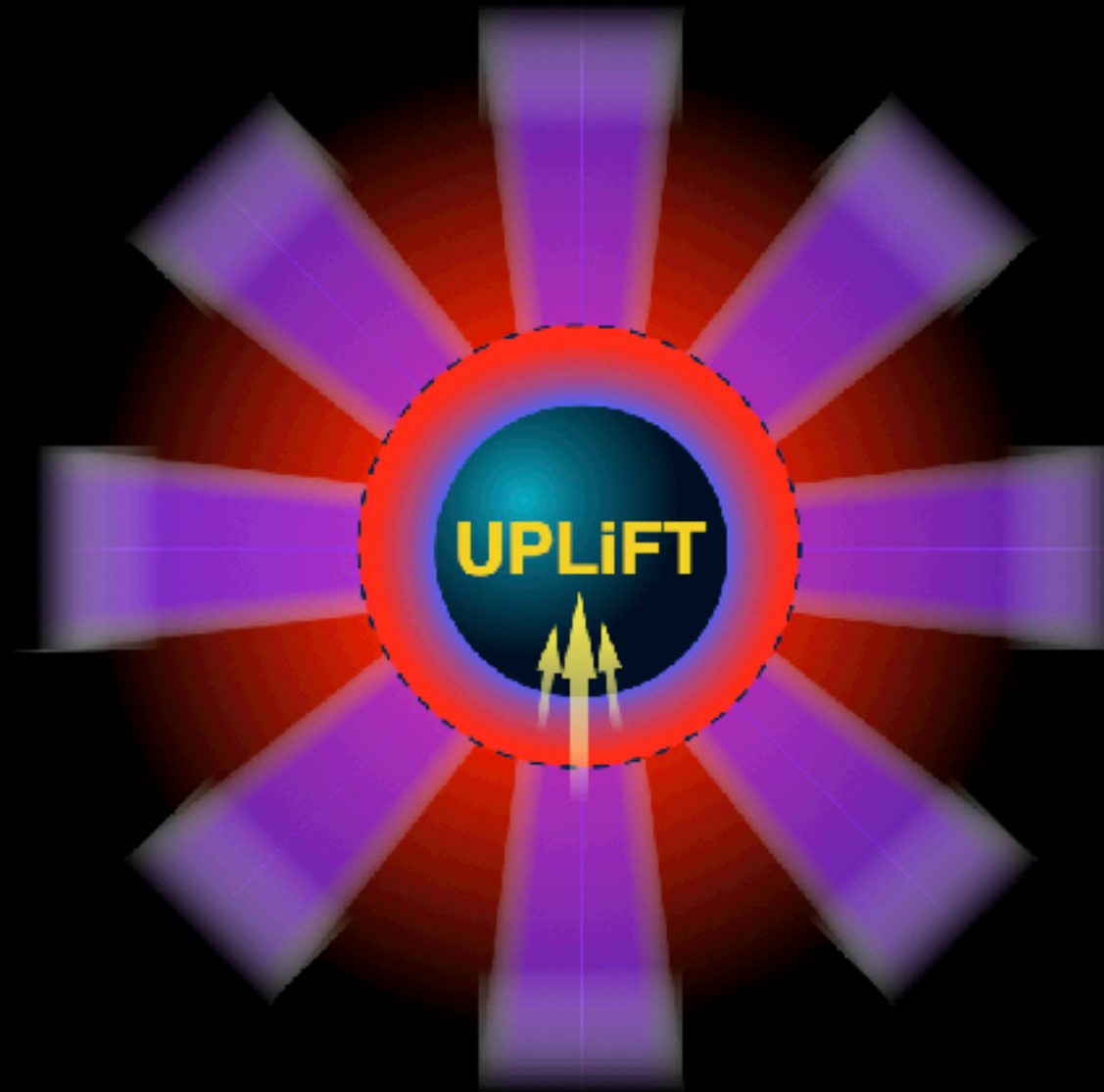


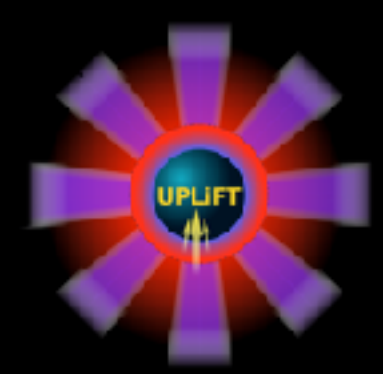


UK Programme of Laser inertial Fusion Technology for Energy

UPLiFT



Dr Robbie Scott, UPLiFT Chief Scientist, on behalf of the UPLiFT team
Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Oxford.



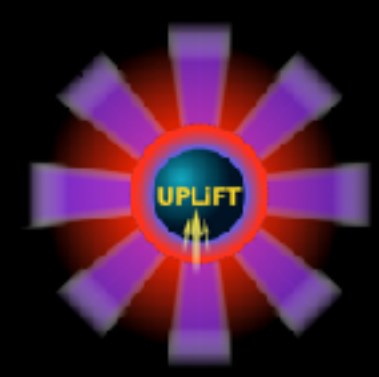
Fusion Energy: Clean, Safe, Limitless, Reliable, & Secure

- **Clean:**
 - No CO₂
 - No long-lived radioactive waste
- **Safe:** No possibility of melt-down
- **Limitless:** Enough fuel to power humankind for millions of years
- **Reliable:** base-load energy complements erratic renewables
- **Secure:** The fuel source is readily available in sea water
- The ultimate energy source *if it can be made economically viable*



Almost* all our energy comes from fusion.
Our goal is to harness this by creating
tiny stars on earth

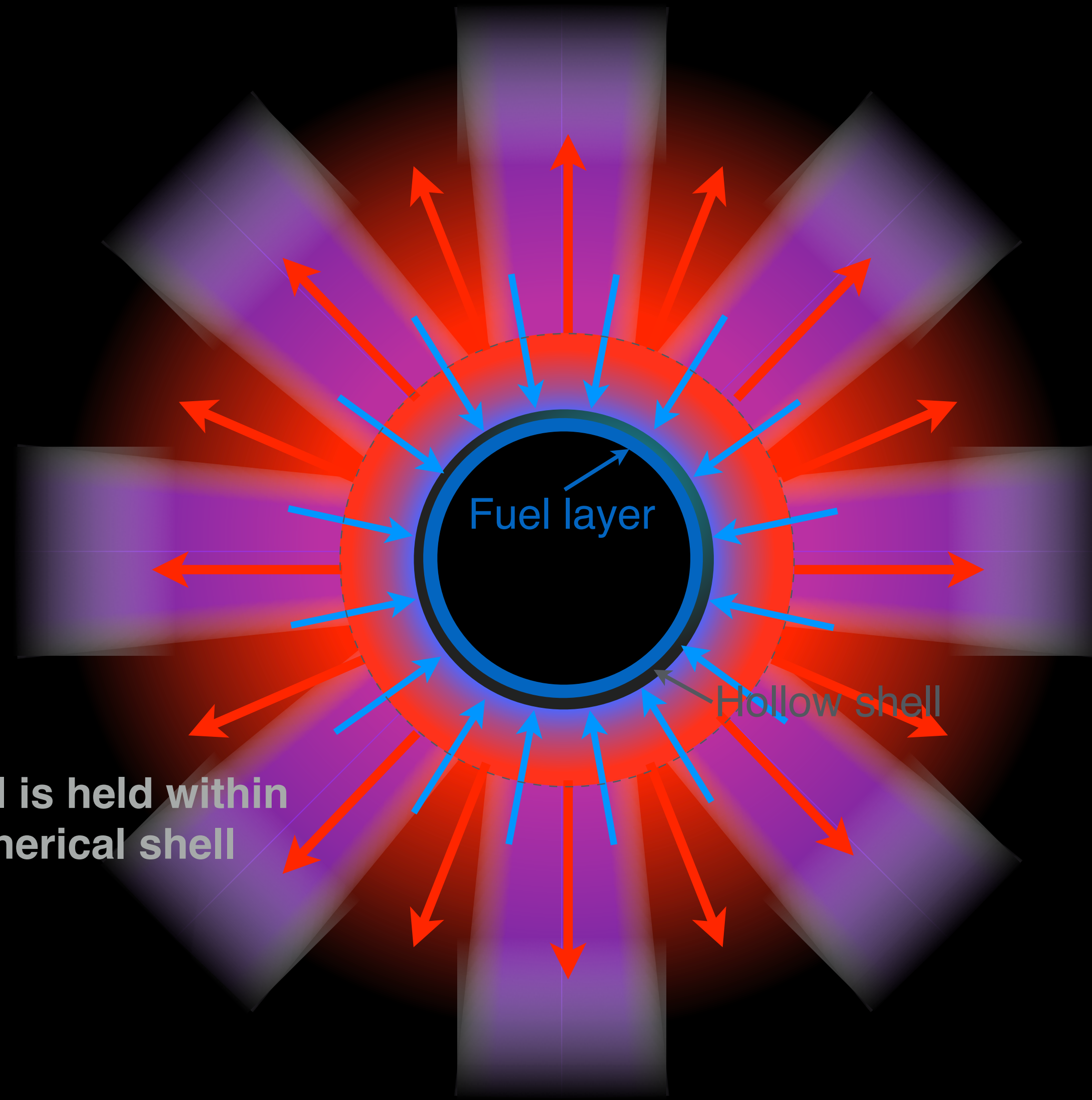
*everything except tidal power!



Laser Inertial Fusion



Huge inward pressure is caused by the ablation

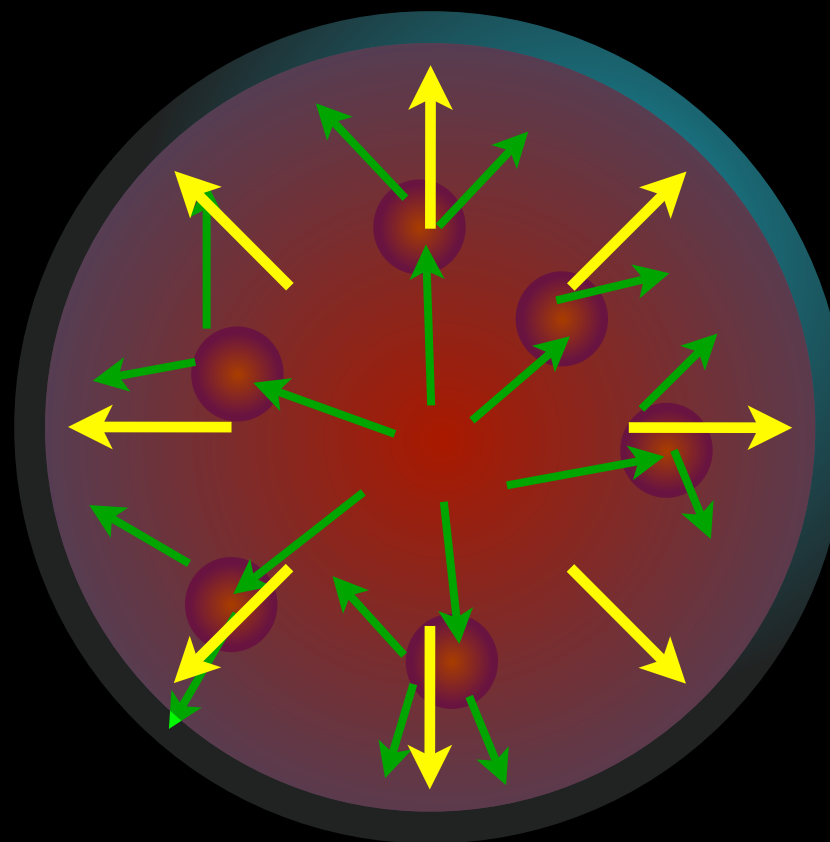


The fusion fuel is held within a hollow spherical shell

The fuel shell is imploded by laser energy, compressing and heating the fusion fuel to conditions very similar to those in the centre of the Sun

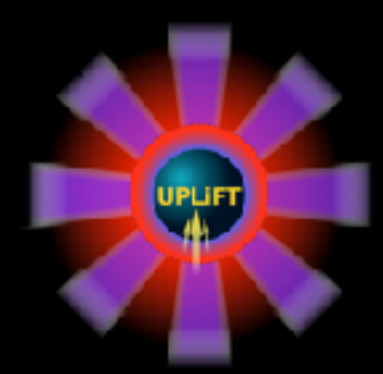


$$c_{\text{DT}} \frac{dT_{\text{th}}}{dt} = f_{\alpha} Q_{\alpha} - f_B Q_{B,\text{DT}} - Q_e - \frac{1}{m} p \frac{dV}{dt}$$



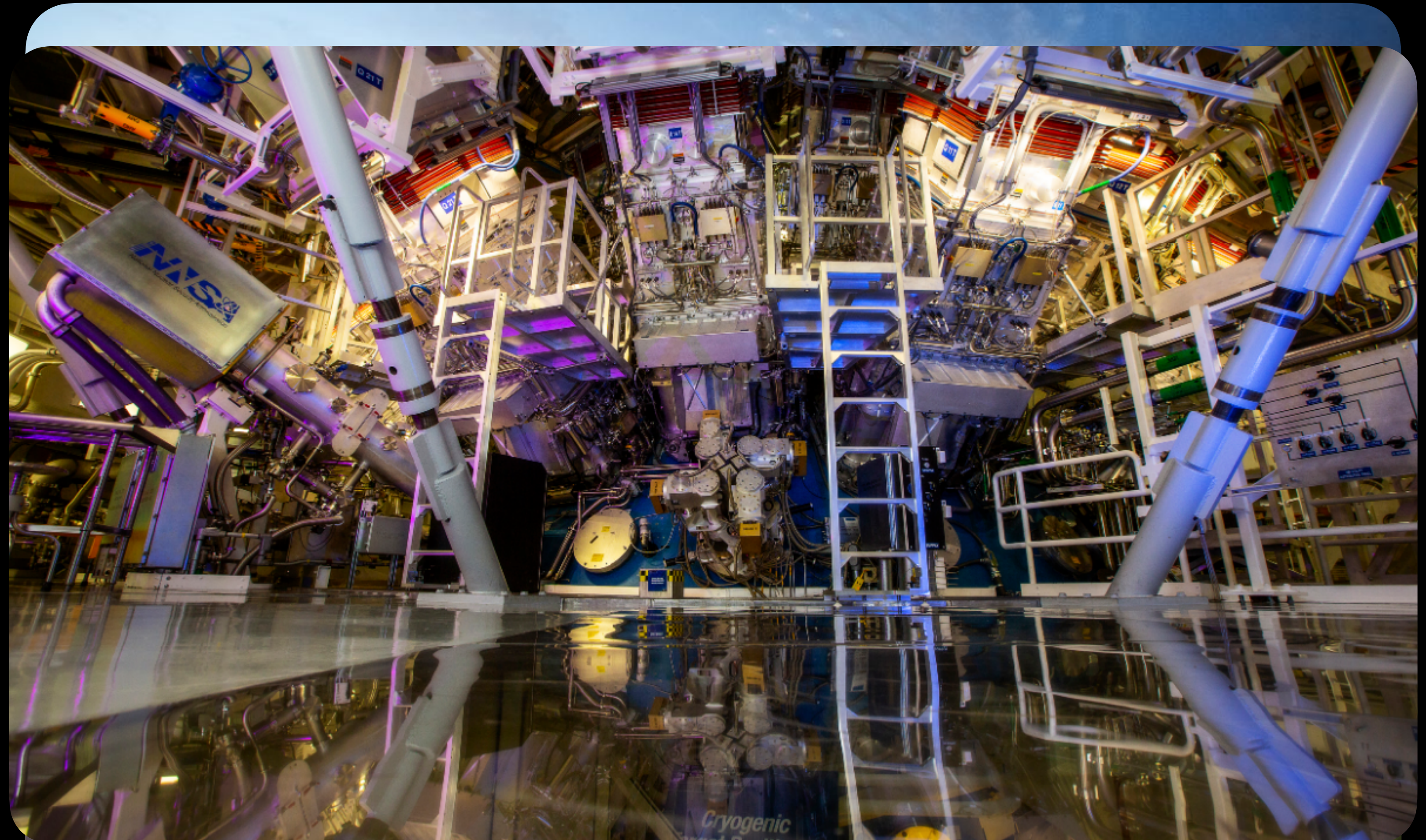
more heating

Fusion reactions convert matter into energy. The alpha particles released in fusion reactions create more alpha particles, which in turn create more alpha particles, and so on. This is a chain reaction.

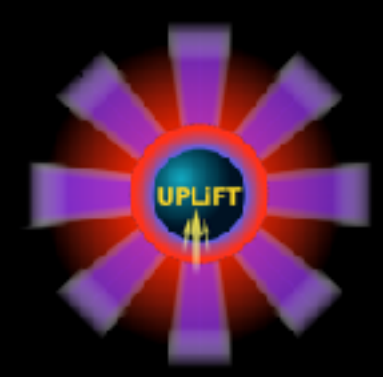


Laser Inertial Fusion on The National Ignition Facility

- Highest energy laser
- Size of Wembley Stadium
- 192 laser beams
- Energy:
 - 2.1 million Joules
 - K.E. of Car @ 200 km/hr
- Pulse Duration:
 - 10 billionths of a second
- Power:
 - 500 Trillion W
(500,000,000,000,000 W)
 - 100x global electricity power usage!

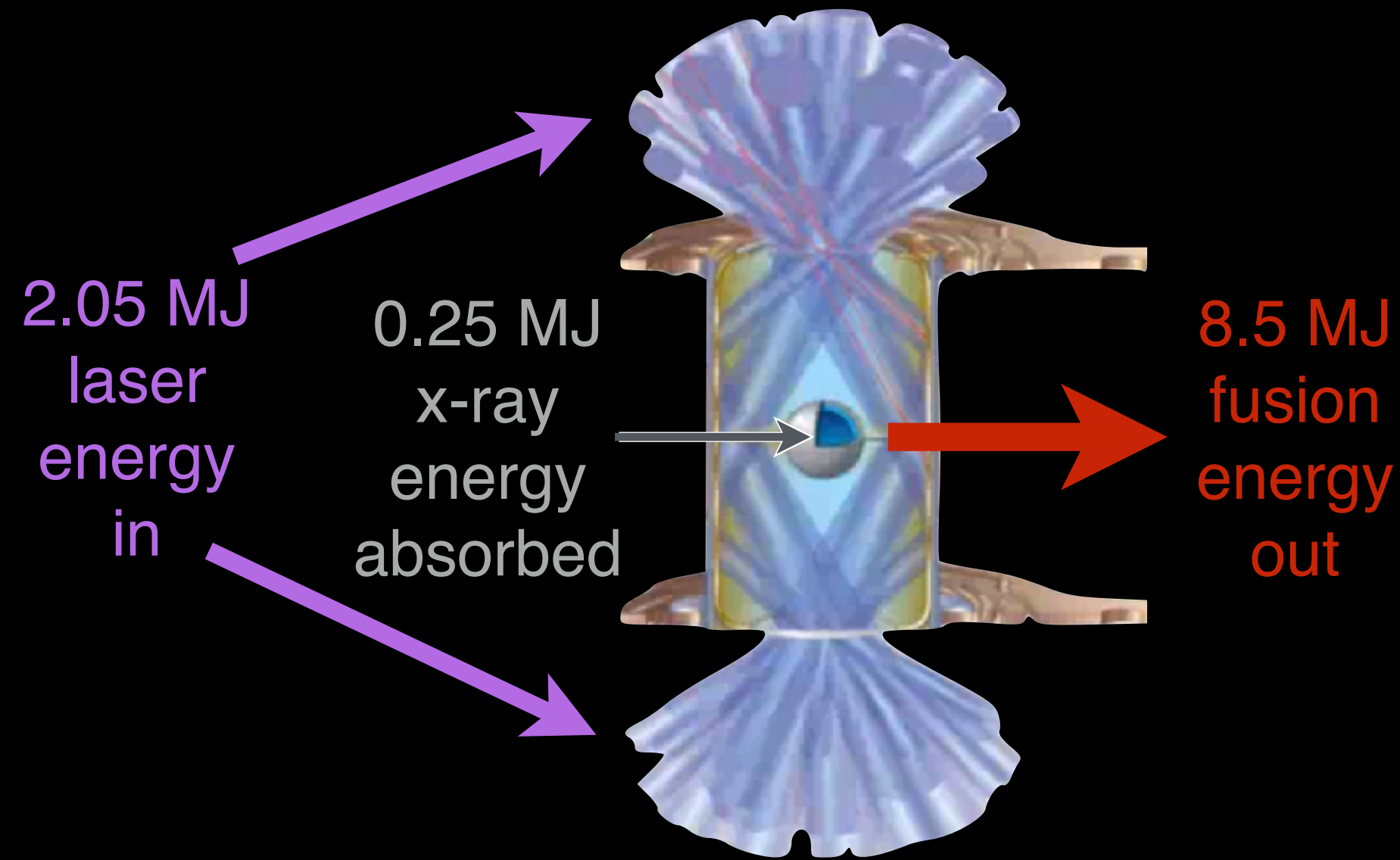


NIF's 10m diameter target chamber
NIF from the outside



UPLiFT builds on NIF's results, and improves efficiency

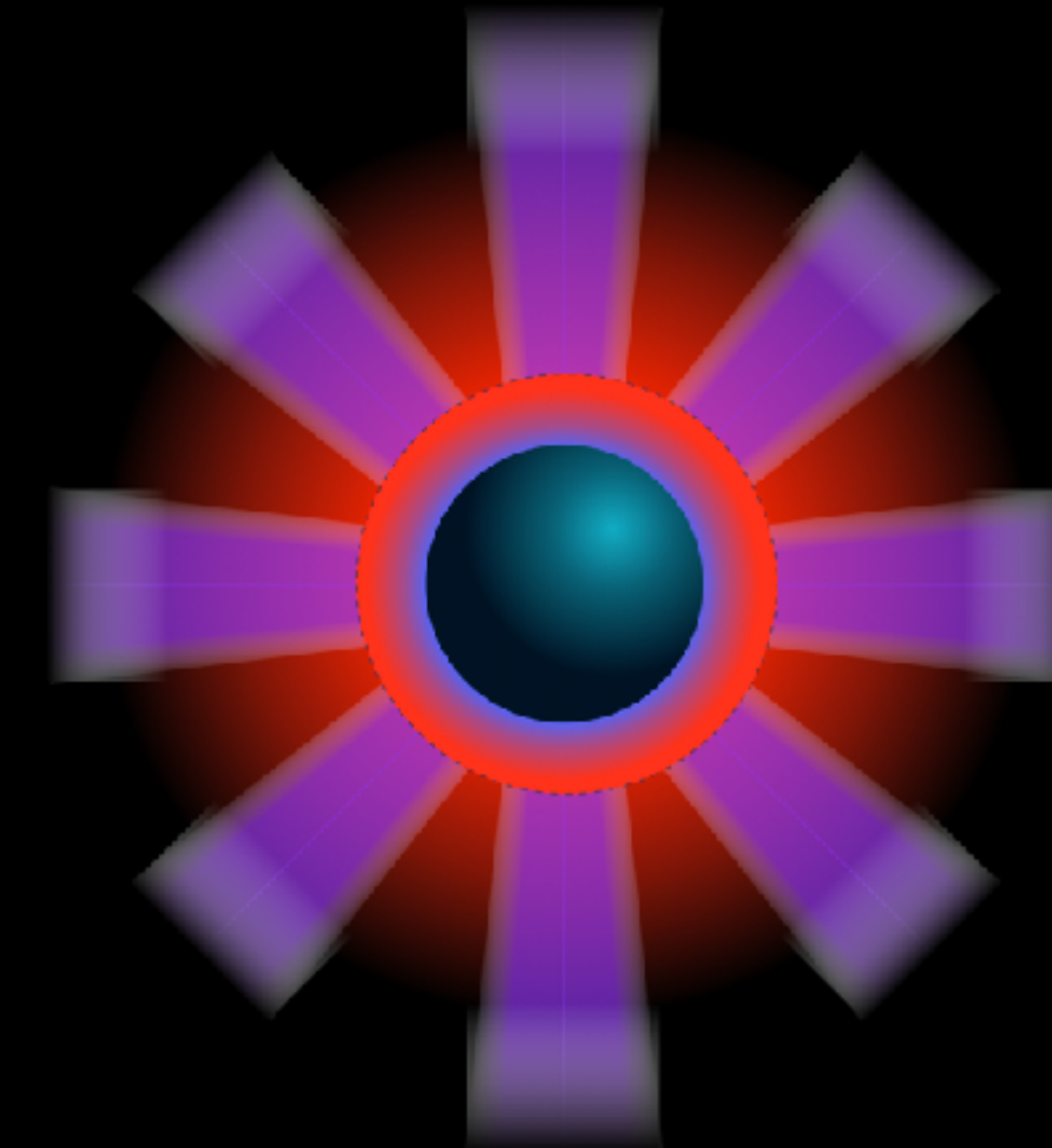
NIF 'indirect' drive



- ✓ 1st demonstration of fusion energy-gain
 - Fusion Gain $(8.5 / 2.05) = 4.15$
 - Inertial fusion ignition physics are proven

- ✗ Inefficient
 - ✗ Complex, expensive targets
 - ✗ Material activation
- } Make fusion energy challenging

Direct Drive



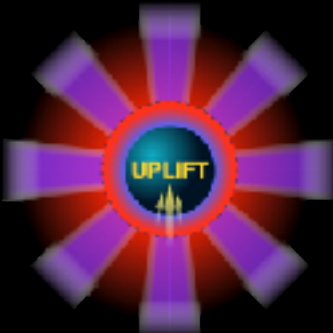
- ✓ Same proven *ignition* physics
- ✓ ~ 5 x higher efficiency
- ✓ Lower energy laser

- ✓ Higher fusion energy-gain
- ✓ Cheaper laser
- ✓ Simpler, cheaper, targets
- ✗ Some physics uncertainties remain

Help with
fusion
energy



Department for
Energy Security
& Net Zero



UK Programme: Laser inertial Fusion Technology for Energy



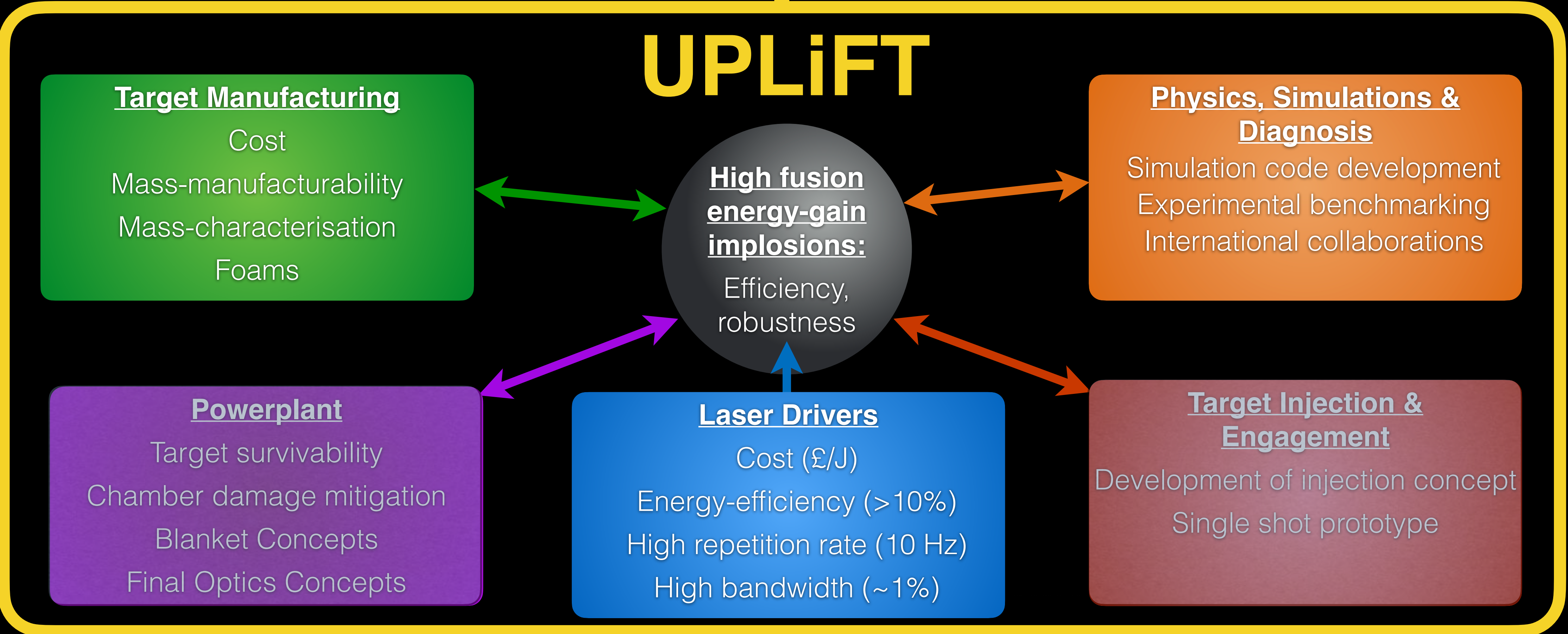
- £10M
- 4 years

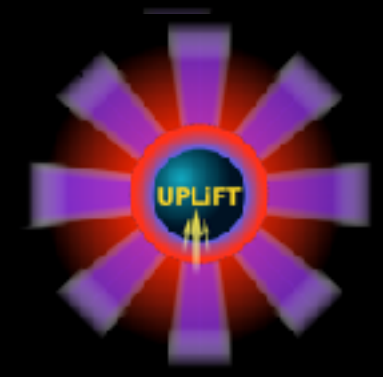
HiGAIN Facility

Next generation laser-implosion facility

Demonstrate sufficient gain for IFE

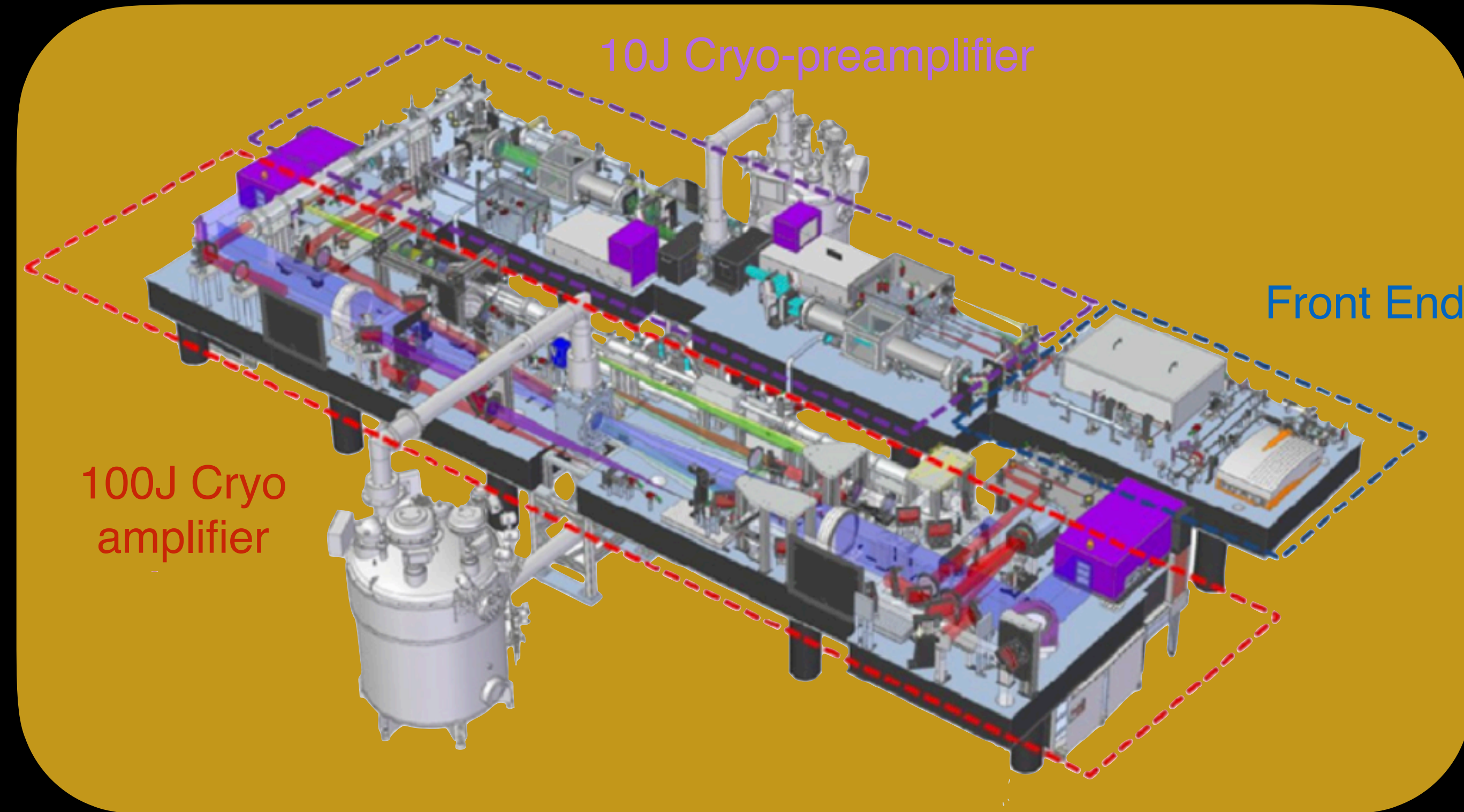
Fulfil UK strategic requirements





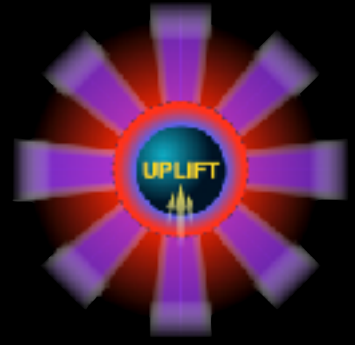
Lasers for Fusion Must Be Efficient & Affordable

- NIF lasers are only **0.6% efficient**
- Electricity input = 166x laser energy output!
- Not feasible for power production
- Central Laser Facility:
 - DiPOLE* laser **10% efficient**
 - **30x** efficiency improvement
 - **World-leading** technology
 - But currently too expensive for IFE



CLF's 100J, 10Hz, Diode-pumped 'DiPOLE' laser

*M. Divoky et al., "150 J DPSSL operating at 1.5 kW level," Opt. Lett., 46, 2021.



IFE laser cost is mostly due to diodes, so can we reduce diode costs making IFE commercially competitive?

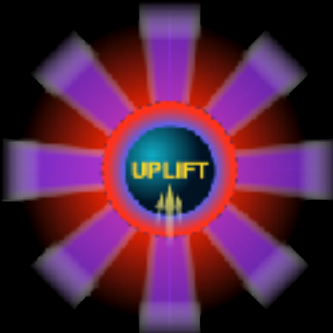


- Laser gain medium stores diode energy
 - Longer storage lifetime => less diodes => reduced cost
- But attractive media require very high fluences for efficiency ($\sim 100 \text{ J/cm}^2$)
 - Optics damage threshold $\sim 10 \text{ J/cm}^2$
 - Is efficient extraction impossible?
- Optics damage threshold proportional to (laser pulse duration) $^{1/2}$
 - Can we stretch the laser pulse?
 - No: laser pulse duration is set by implosion physics



Laser-induced optics damage

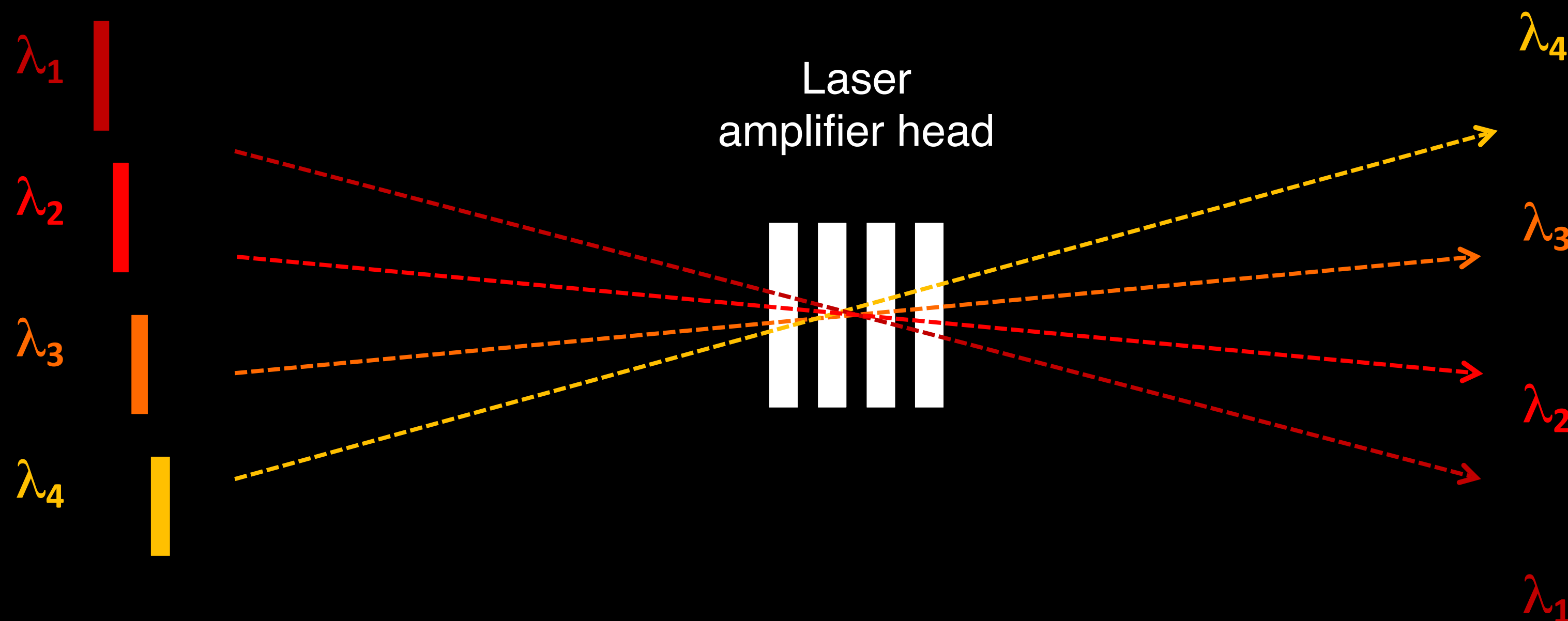
Gain medium	Storage lifetime (ms)	Relative Diode Cost	Fluence required for high efficiency (Jcm^{-2})	Comments
Nd:glass	0.24	1	~ 10	NIF's gain medium
Tm:YLF	15.6	1 / 65	~ 100	Central wavelength



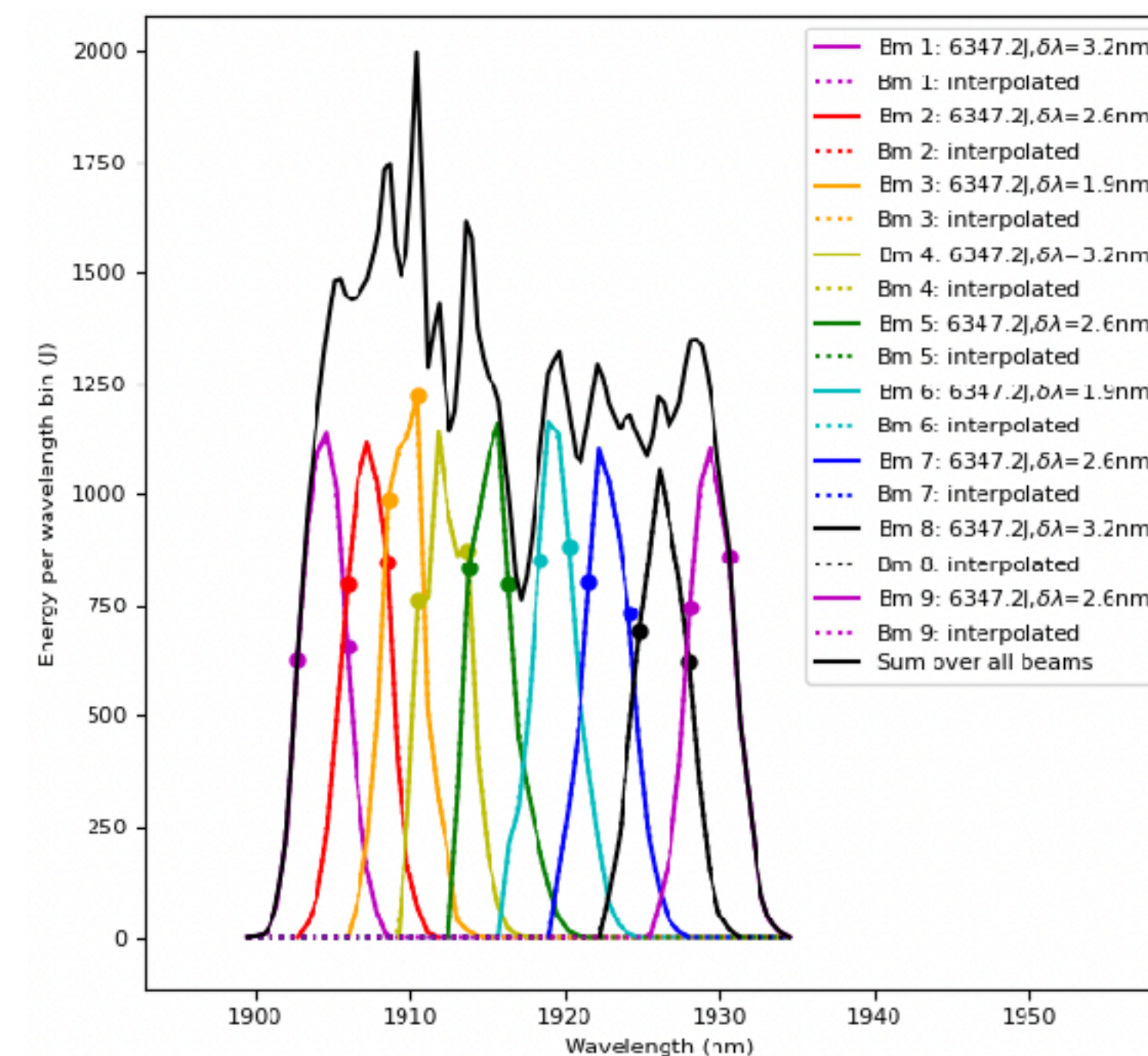
Sequential Pulse Amplification and Recombination (SPARc)

- Our solution: temporally stack multiple beams in the amplifier
- Patent filed: Scott & Mason (2024)

Do conventional multi-pass extraction

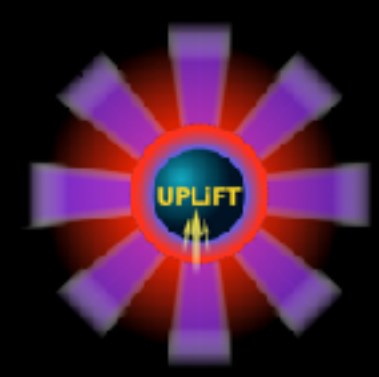


Multiple narrow-band beams:
efficient up conversion &
large bandwidth

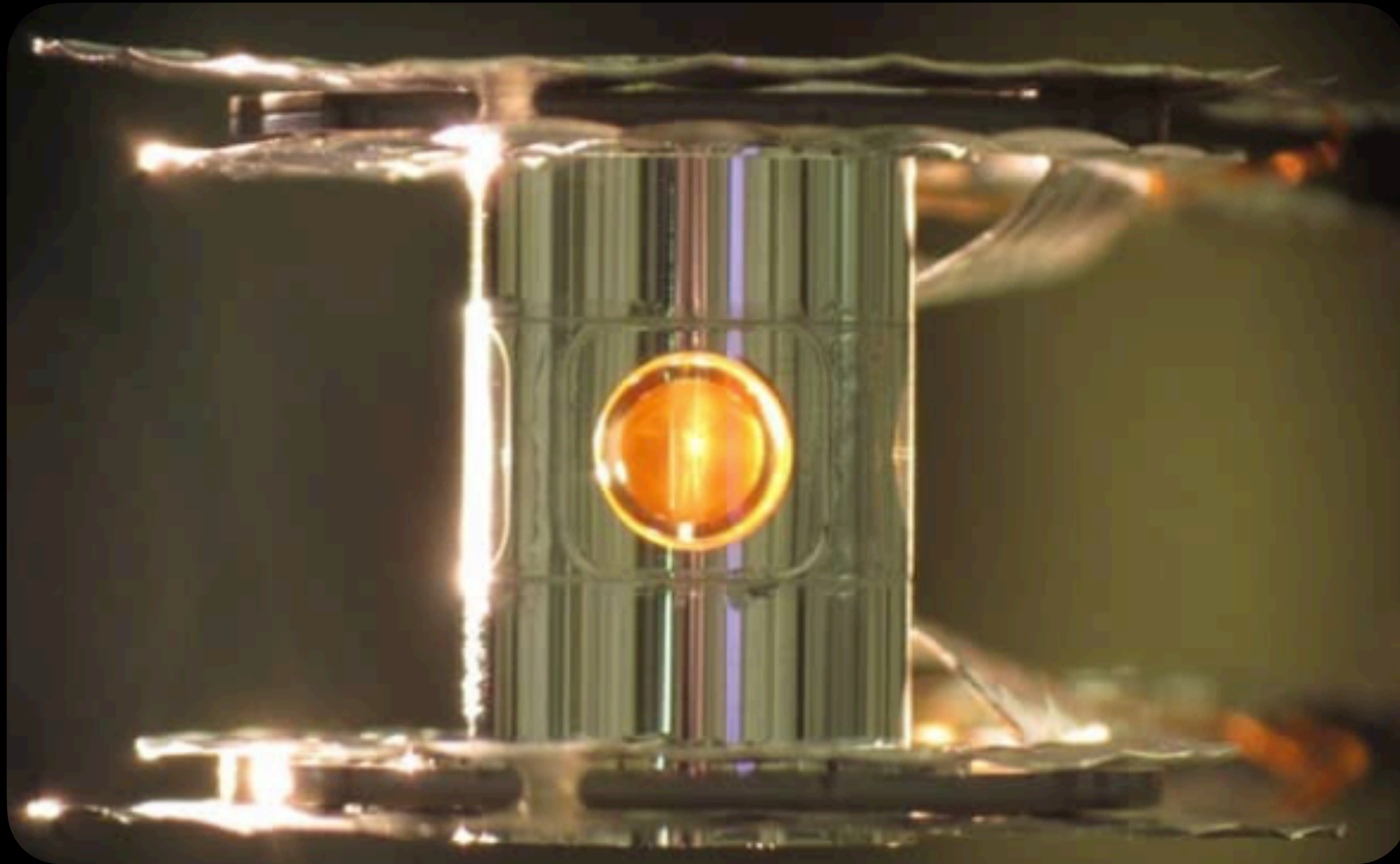


- n IFE-duration pulses
- Low fluence ($1/n$)

- Single 'long-pulse' in amplifier:
- High fluence = efficient extraction
- Increased duration = increased damage threshold ($n^{1/2}$)

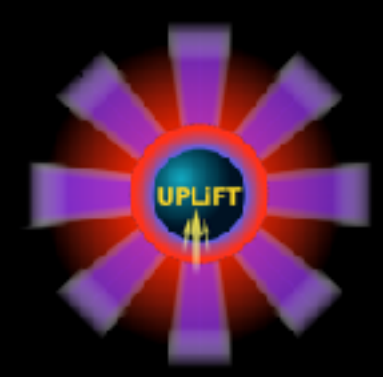


IFE Fuel Capsules: Production & Characterisation



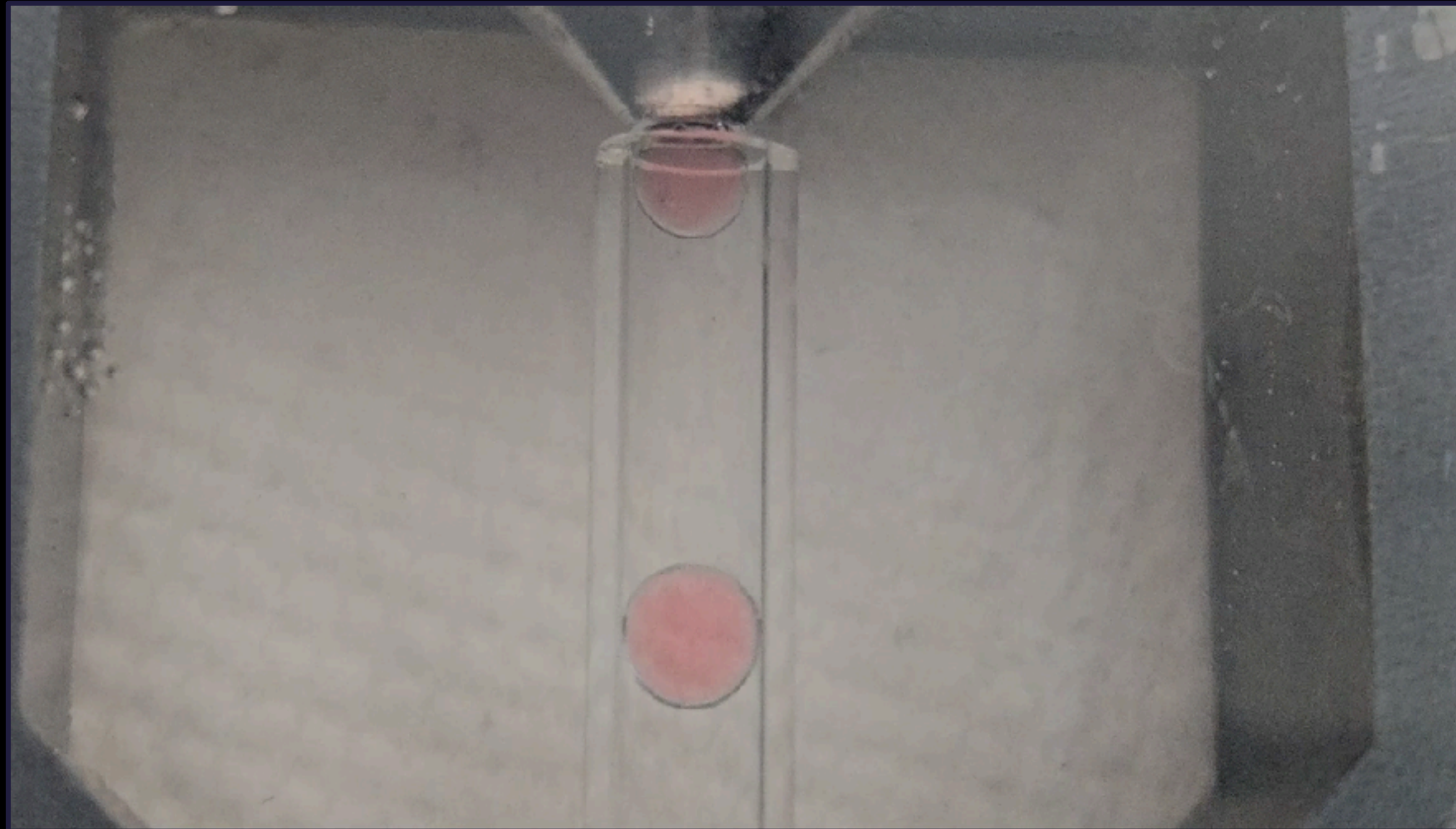
NIF target with surrounding 'hohlraum'

- Target manufacturing to-date:
 - Entirely focussed on quality
 - Unbelievably expensive (~£100k per target)
 - ~1 per day
- Inertial fusion energy requirements:
 - Similar quality
 - ~£1 per target
 - ~1 million per day
- Improvements factor required $\sim 10^{11}$!

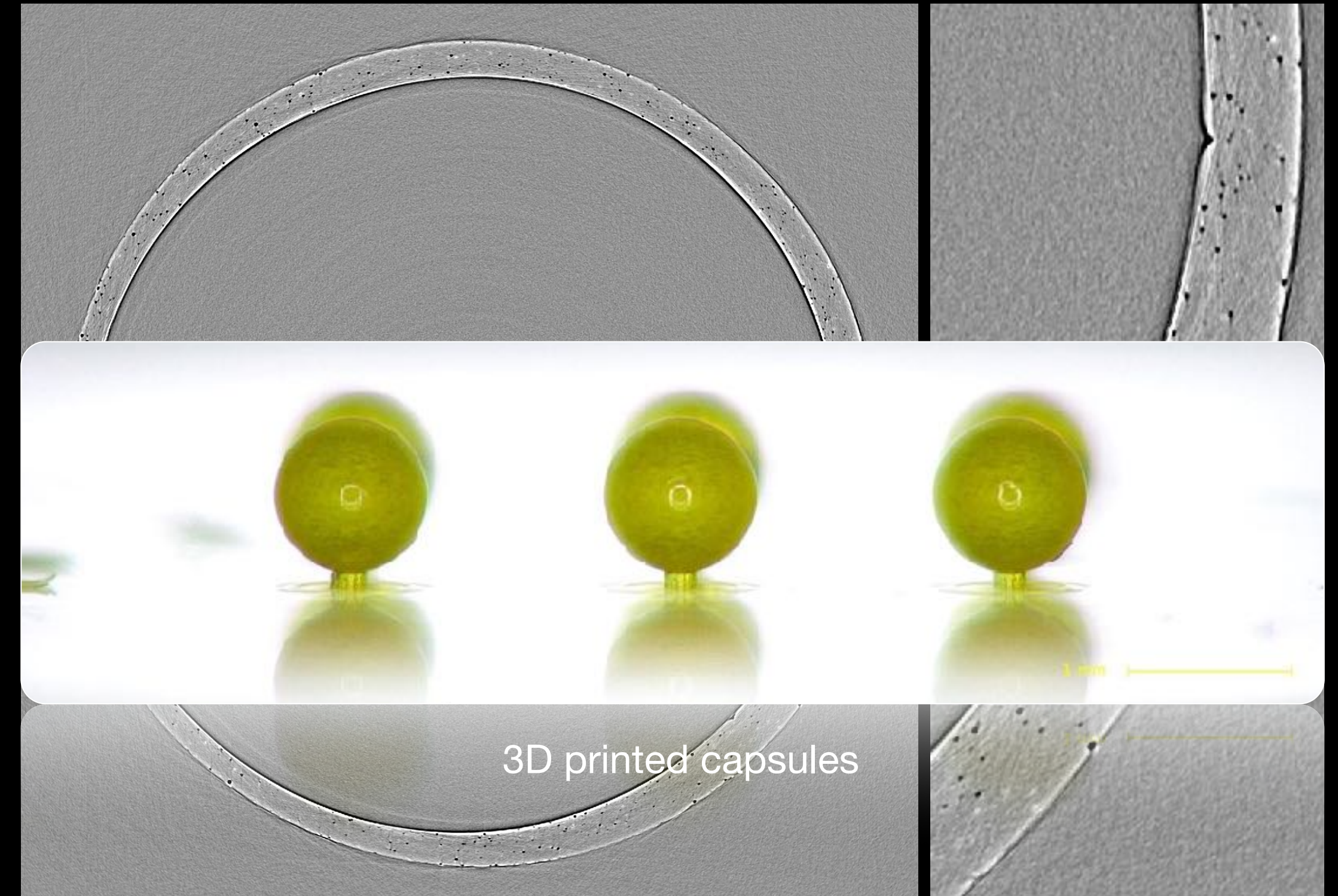


IFE Fuel Capsules: Production & Characterisation

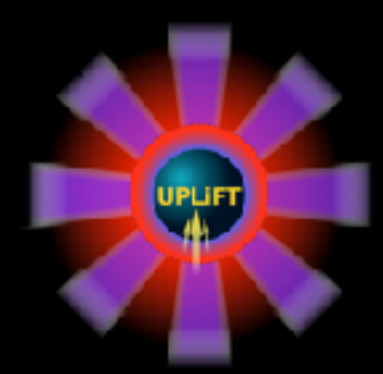
- Chris Spindloe, Sam Irving, Martin Tolley, Emily Reynolds, Ann-Marie Norton, Nelia Viza



IFE capsule production.
Inner phase has red dye added for clarity

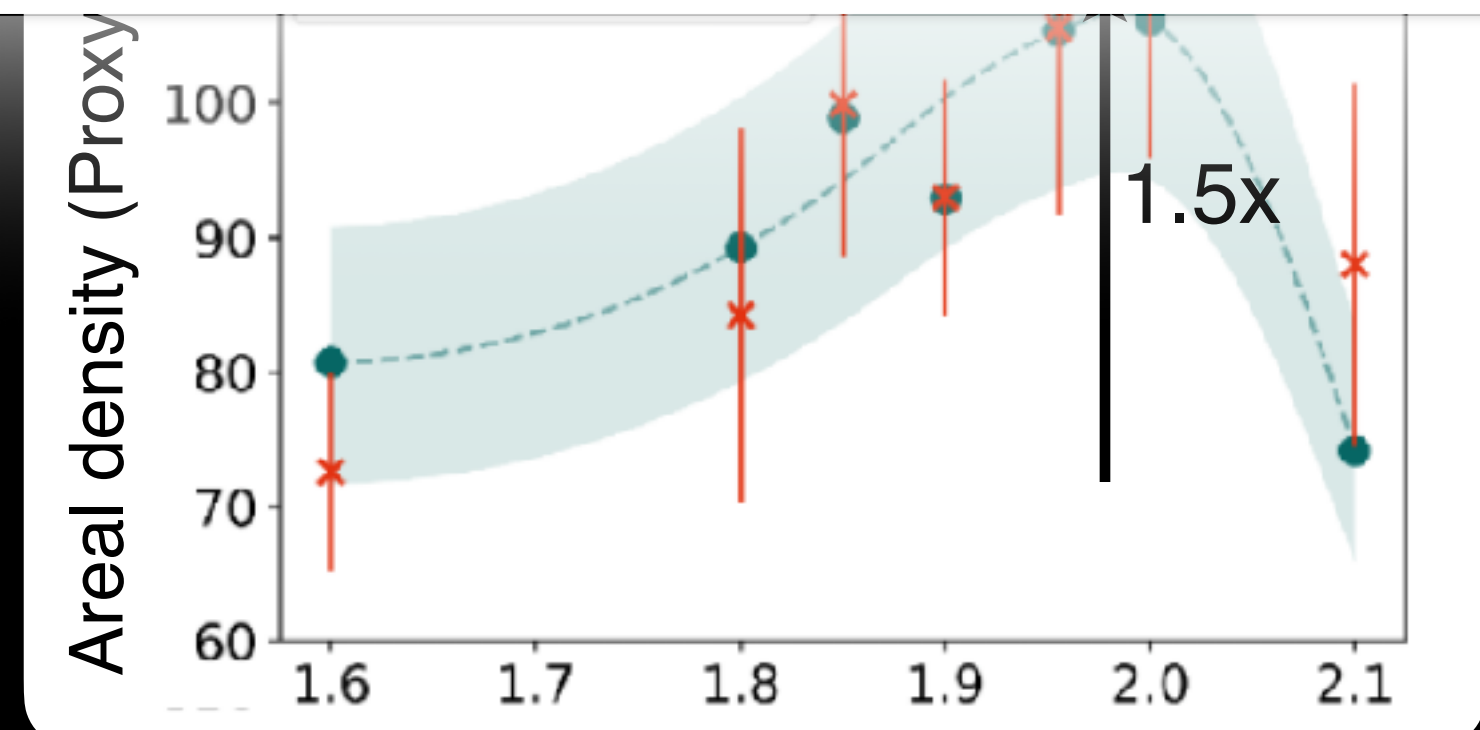
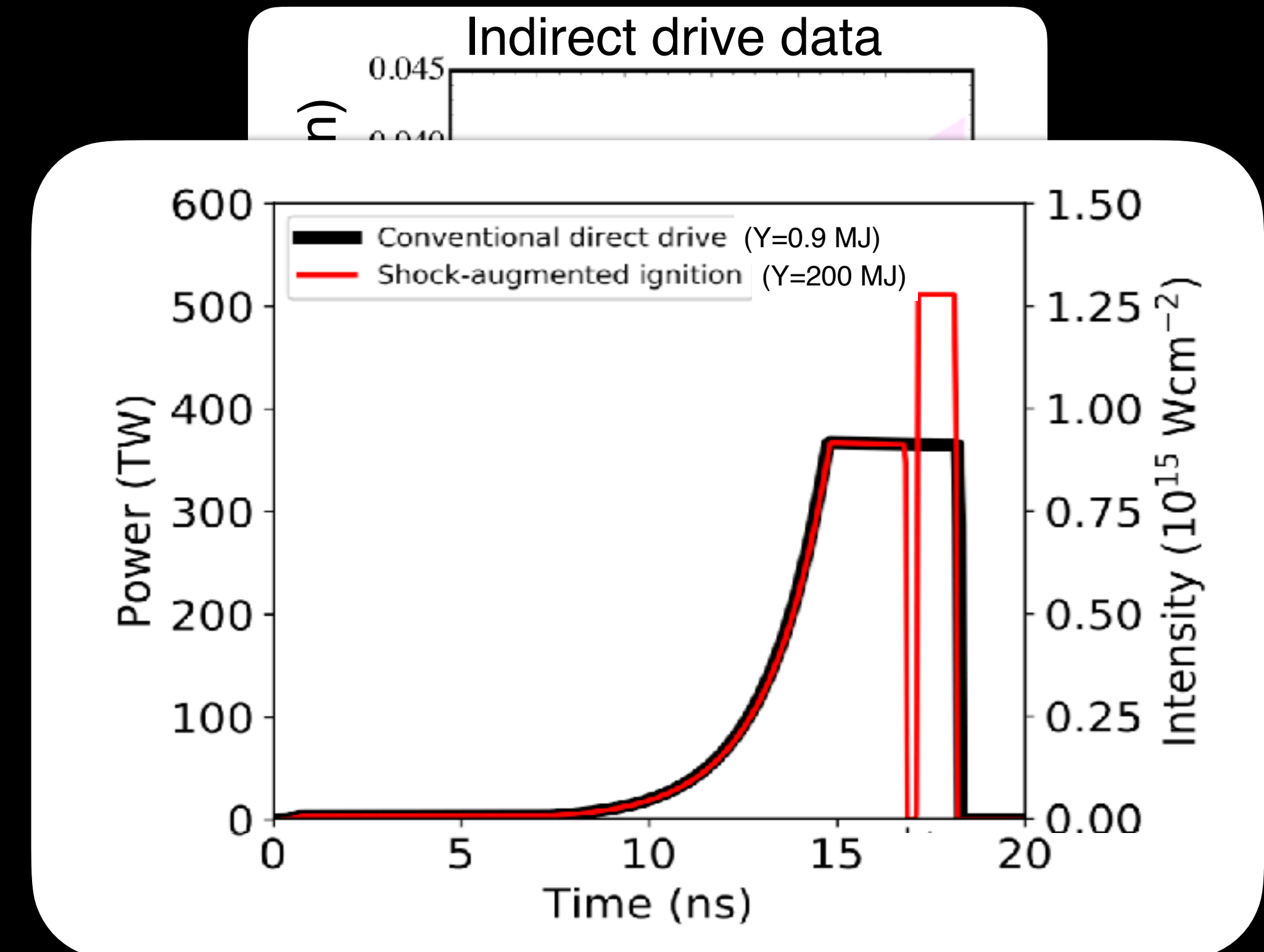


UV cured shell. Characterised on the Diamond Light Source
synchrotron. Not perfect yet: more work to be done!

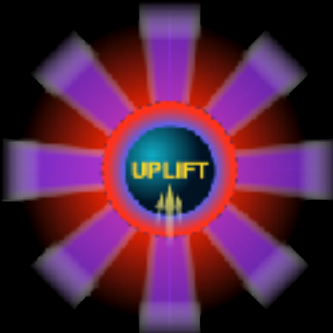


The Shock-Augmented Approach to Laser Fusion*

- Goals:
 - Realise benefits of existing laser fusion concepts
 - Mitigate main challenges
- Method:
 - Introduce power dip in laser pulse
 - Dip in power: pre-conditions ablation plasma
 - Rise in power: launches strong shock
- Potential Advantages:
 - Enhanced implosion stability (hydrodynamic & laser-plasma)
 - ~ 2 x increase in gain (energy out / energy in ~ 100)
 - Encouraging initial experiments on NIF, Omega, & LMJ



*R. Scott et al., *Physical Review Letters* (2022)



Towards Predictive Direct Drive Implosion Simulations

End Goals:

- High-gain direct drive implosion design(s)
 - Realistic
 - Robust
 - Consistent with limitations imposed by a power-plant
 - Provide design basis for HiGAIN implosion facility
- 3D simulation capability(s):
 - Physics models for all key Direct Drive physics
 - Benchmarked against experiments

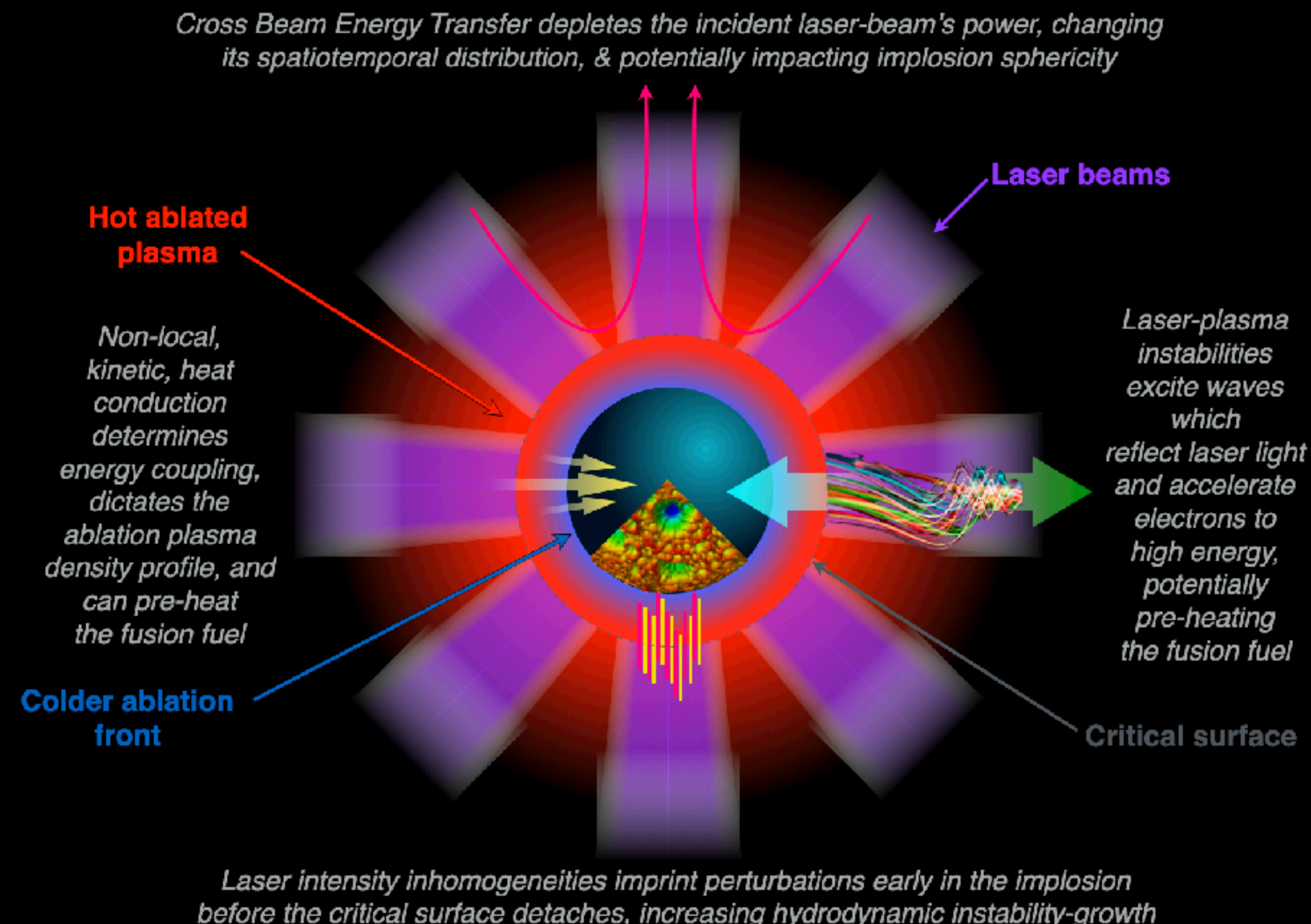
4 Physics Sub-Projects to realise this:

1. Laser-plasma instabilities
2. Laser imprint
3. Non-local transport
4. High-gain implosion design

Each Sub-Project has targeted:

- Simulation code development
- Dedicated Omega experiment(s)
- Code benchmarking

Direct Drive implosion dynamics:
a highly coupled non-linear system





Ambition: Create a rapid, cost-efficient, path to fusion energy

- UPLiFT (modular technologies, simulation capabilities, facility design):

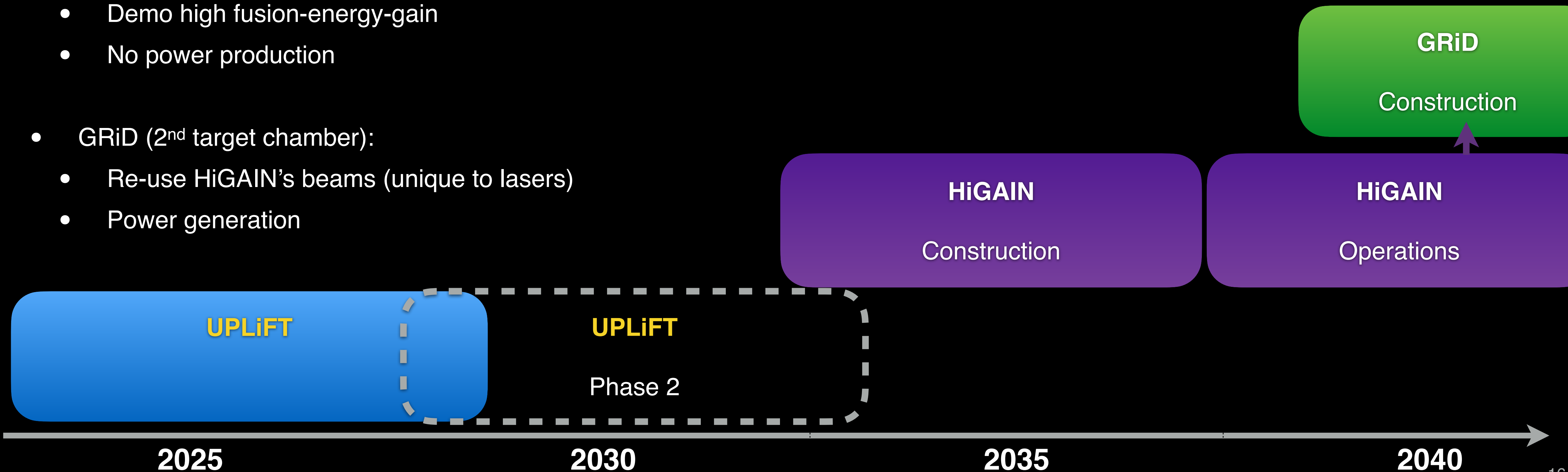
- Phase 1: Lasers, targets, direct drive physics
- Phase 2: += cryo targetry, target injection, facility design

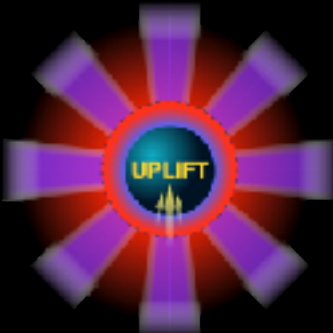
- HiGAIN:

- Rep-rated Laser Fusion implosion facility
- Demo high fusion-energy-gain
- No power production

- GRiD (2nd target chamber):

- Re-use HiGAIN's beams (unique to lasers)
- Power generation



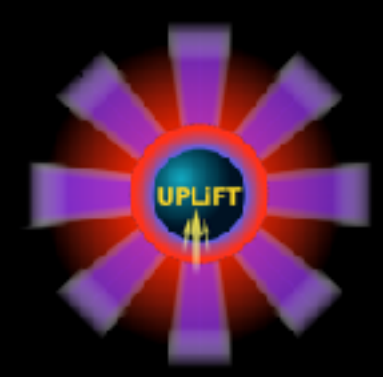


Summary



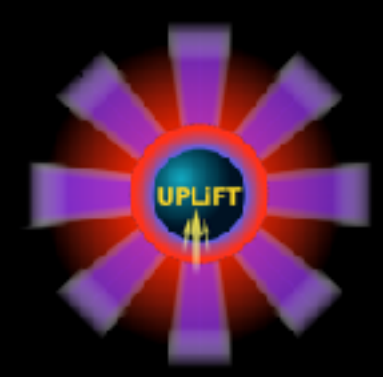
- Laser Fusion works!
- NIF is a fantastic machine, but it was built for **science**, not **energy**
- Known science and technologies can **rapidly advance** Laser Fusion energy:
 - **Laser efficiency** & smoothing methods
 - **Advanced targets**
 - **Direct Drive** Laser Fusion
 - Advanced ignition methods such as **Shock-Augmented Ignition**
- Laser Fusion is a highly credible approach to fusion energy & an exciting field to work in

} **UPLIFT**



UPLiFT Partners & Collaborators





Energy Generation using Laser Fusion

