Transmission in Thin Foils

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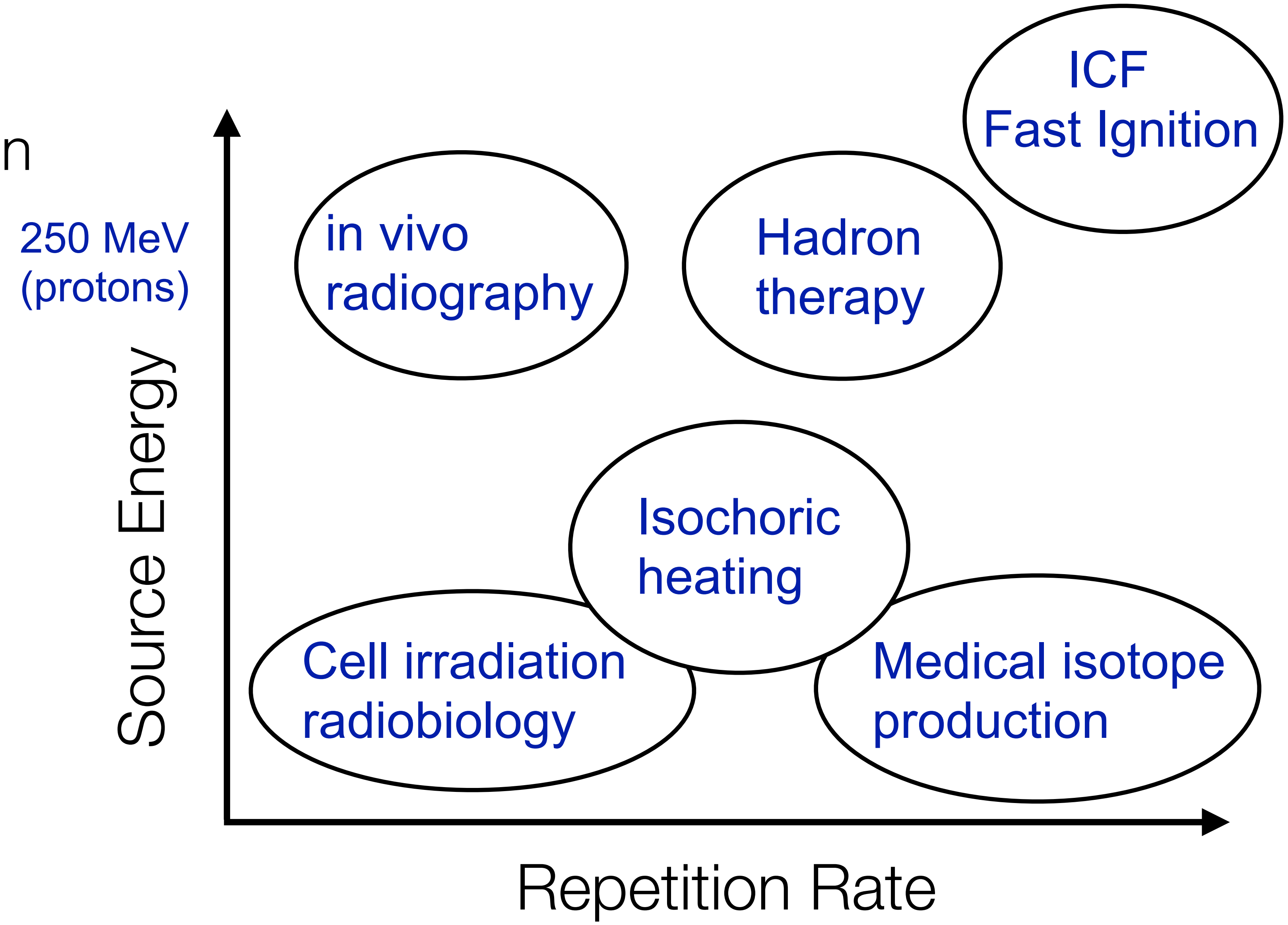
Why plasma based accelerators?

Medium already broken down, can sustain higher accelerating gradients, compact and cheaper, high current, Very high flux, short bunch length, low emittance

- Medium already broken down
- High accelerating gradients
- More compact and cheap

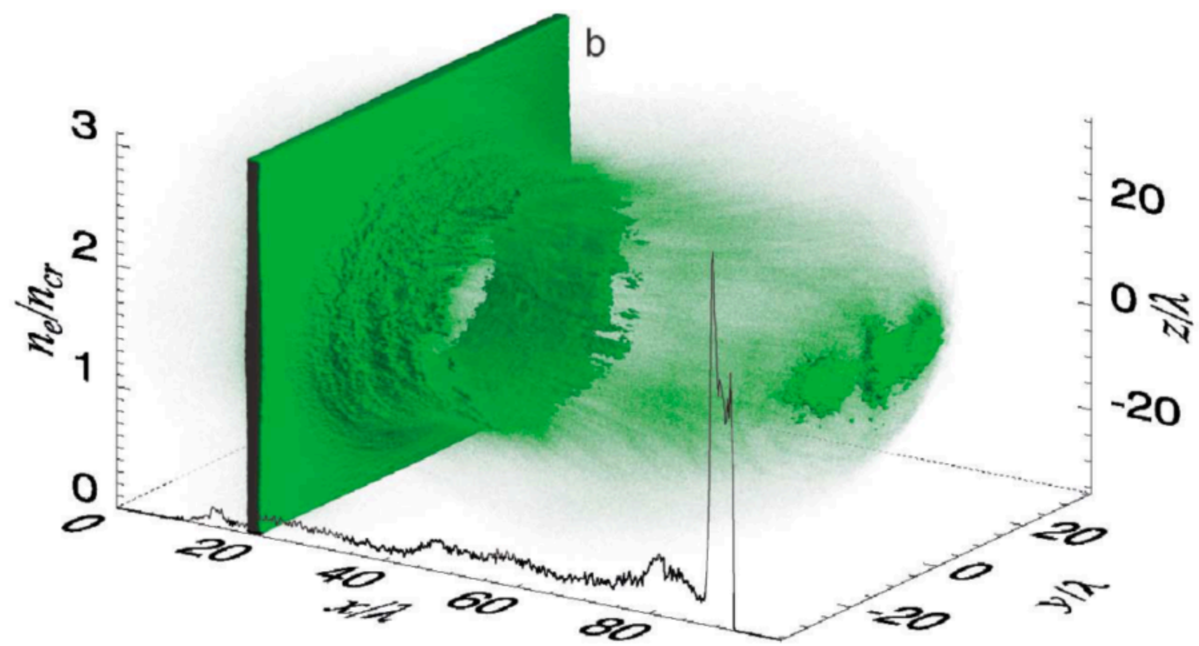


History of Ion Acceleration

- Since CPA interest in ion acceleration peaked
- Sheath acceleration has poor scaling with intensity $E_i \propto I^{1/3}$
- Short pulses introduce new acceleration regimes $E_i \propto I$

Radiation Pressure Acceleration

- Requires very high intensities, sub-micron over-dense targets and good laser contrast
- The radiation pressure of the photons accelerates a slab of material
- Electrons and ions are accelerated together to relativistic velocities



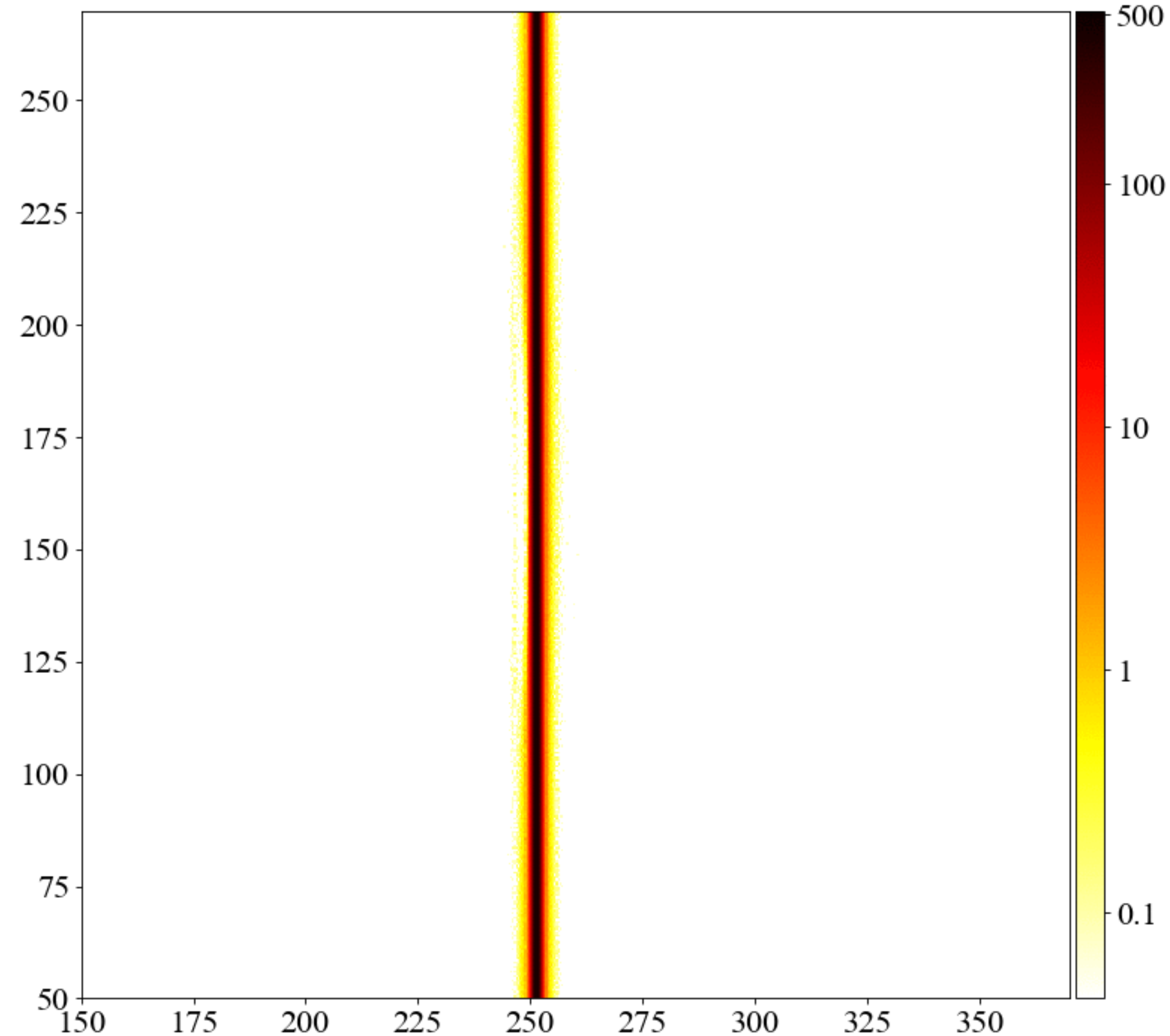
[1] Daido, H., Nishiuchi, M. and Pirozhkov, A. (2012). Review of laser-driven ion sources and their applications. Reports on Progress in Physics, 75(5), p.056401.

Relativistic Transparency Acceleration

- Target expansion -> electron density decreases and plasma frequency decreases

- If $n_e < \gamma n_{crit}$ the laser is able to penetrate the target

- Electrons in focal spot spot go relativistic and transfer energy to the ions



G. Hicks

Motivation

- Ion acceleration from thin foils (nanometer range)
- Explore intersection between RPA and RTA
- Further our understanding of the interaction dynamics
- Compare experimental results with previous plasma dynamics studies

John Adams Institute for Accelerator Science

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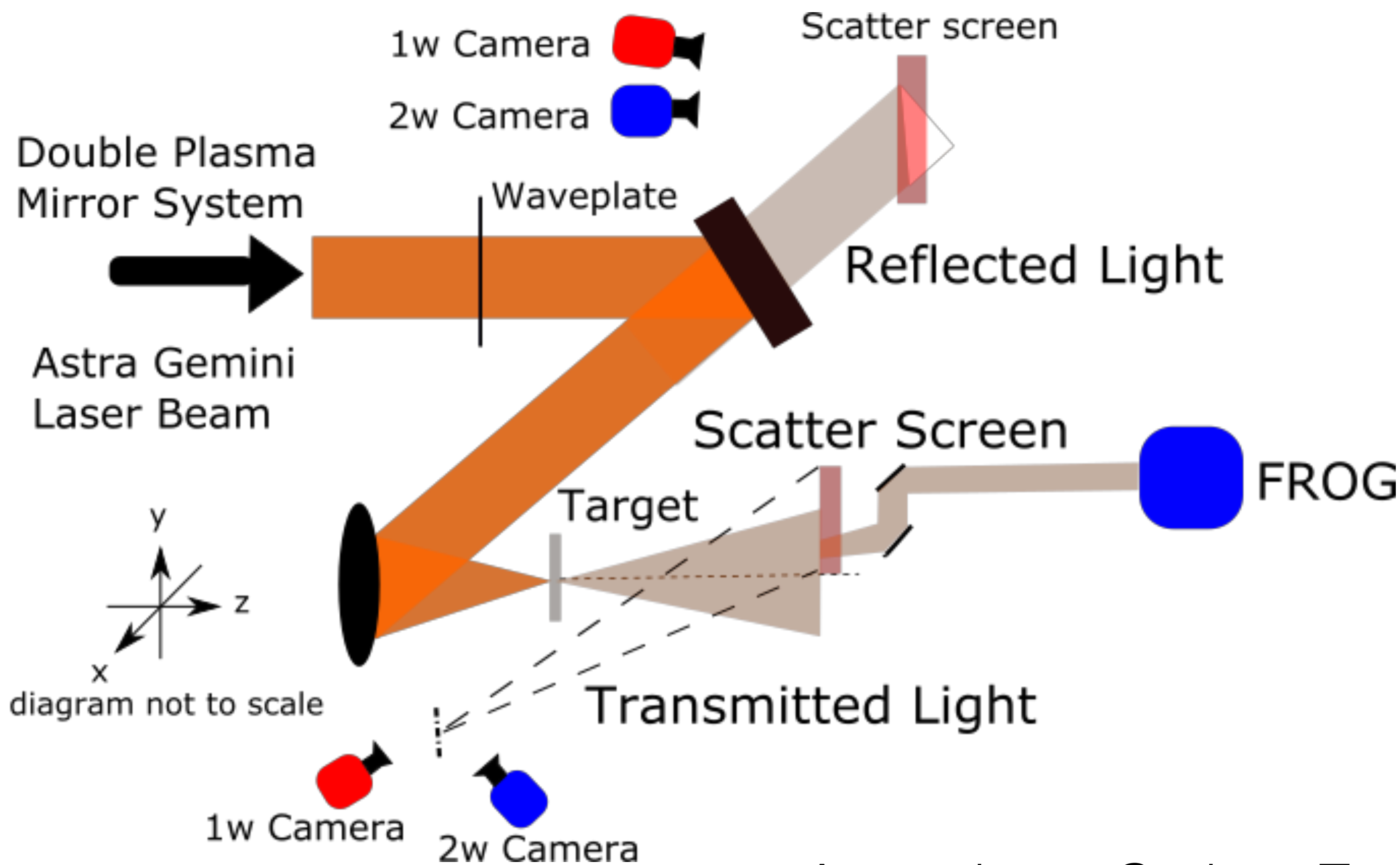
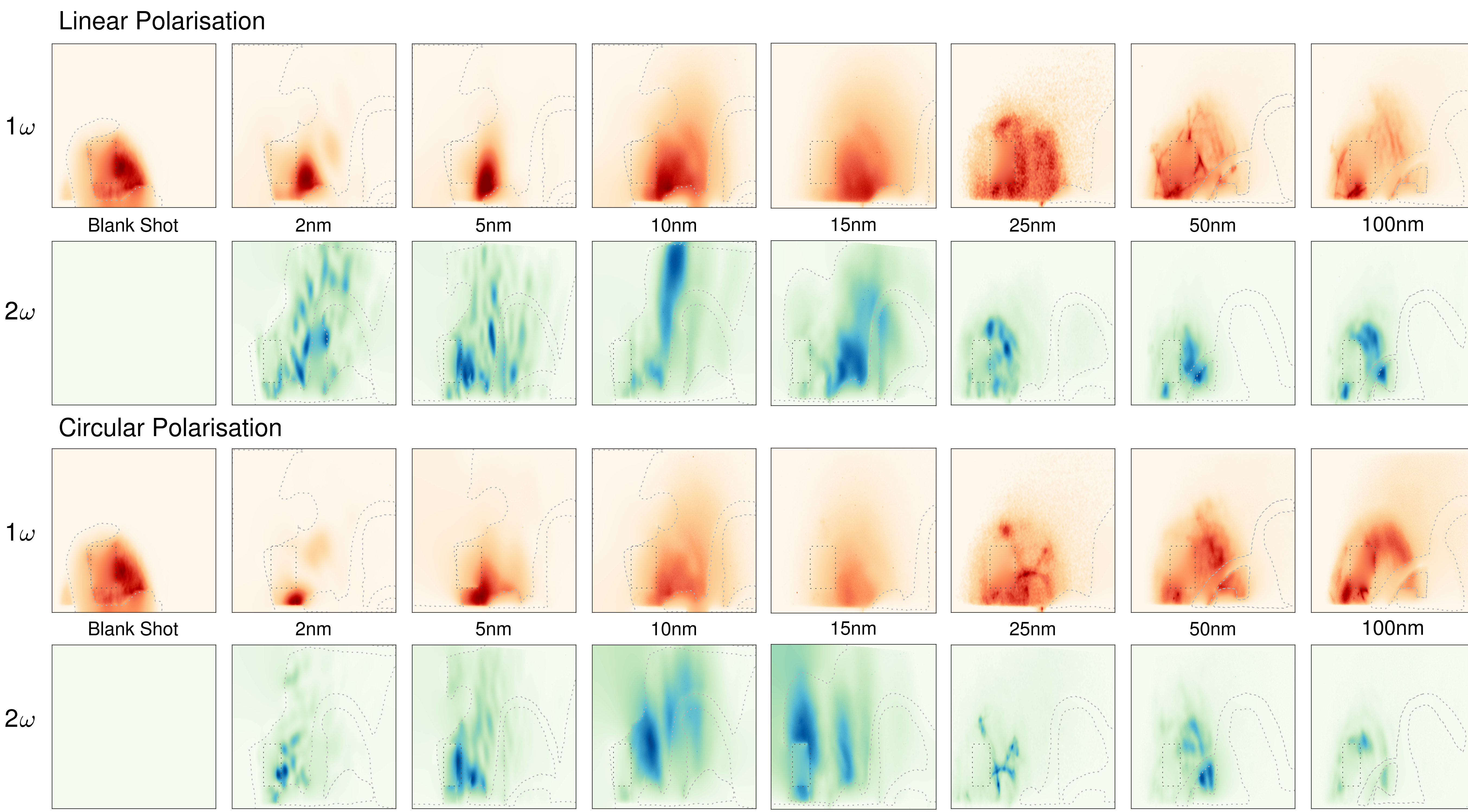
Experimental Set-Up



- Energy: ~5J on target
- Pulse Length: 48fs
- Wavelength: 800nm
- Intensity: 3.5 x 10^{20} Wcm^{-2}
- a_0: ~12

- Amorphous Carbon Targets of density $2gcm^{-3}$
- Contrast of 10^{14} due to double plasma mirrors
- Relativistic critical density: $\sim 13 n_{crit}$

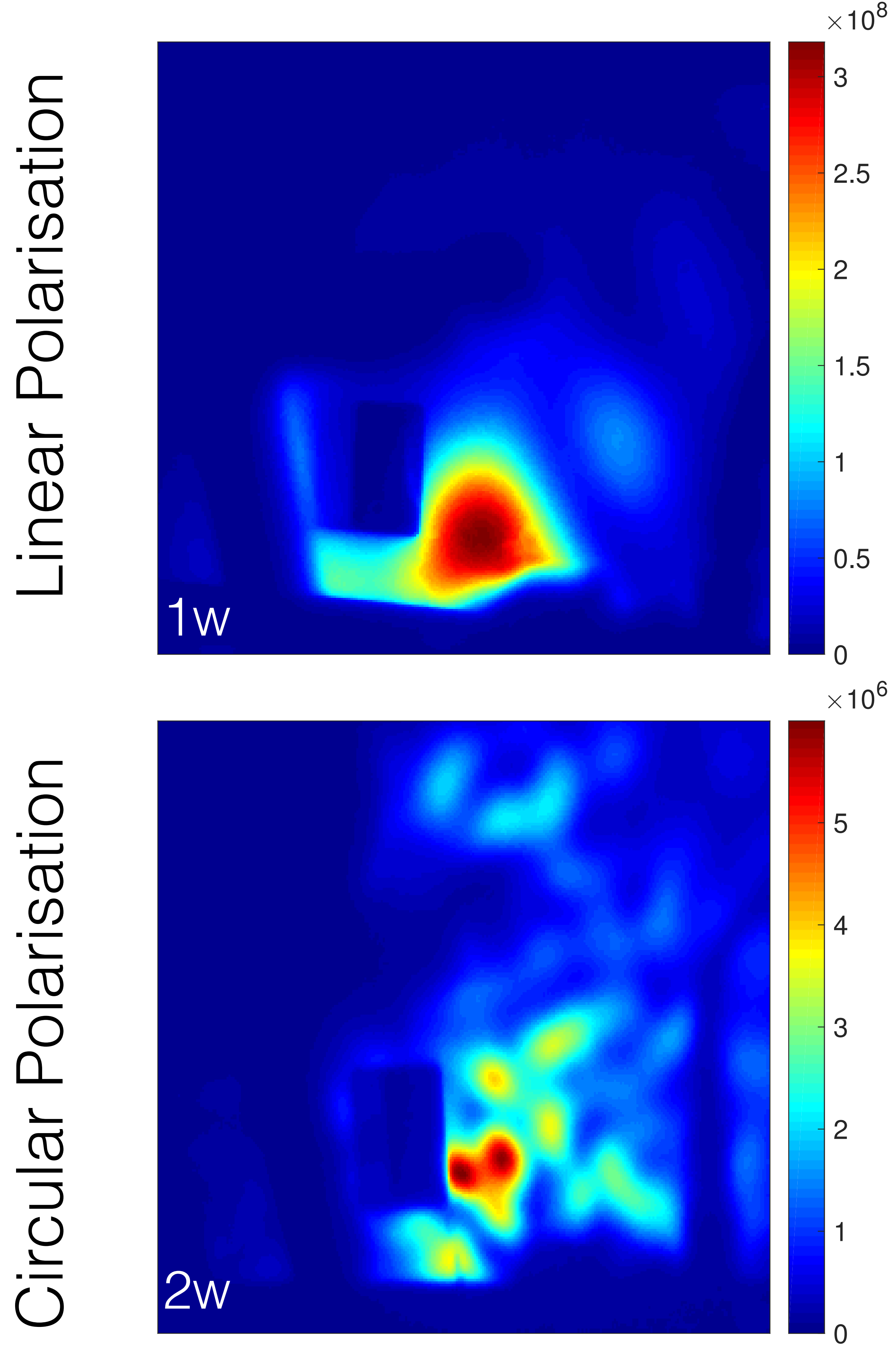
Spatial Profile of Transmitted Beam



smooth profile shows lack of coherence, a lot of light transmitted

2nm

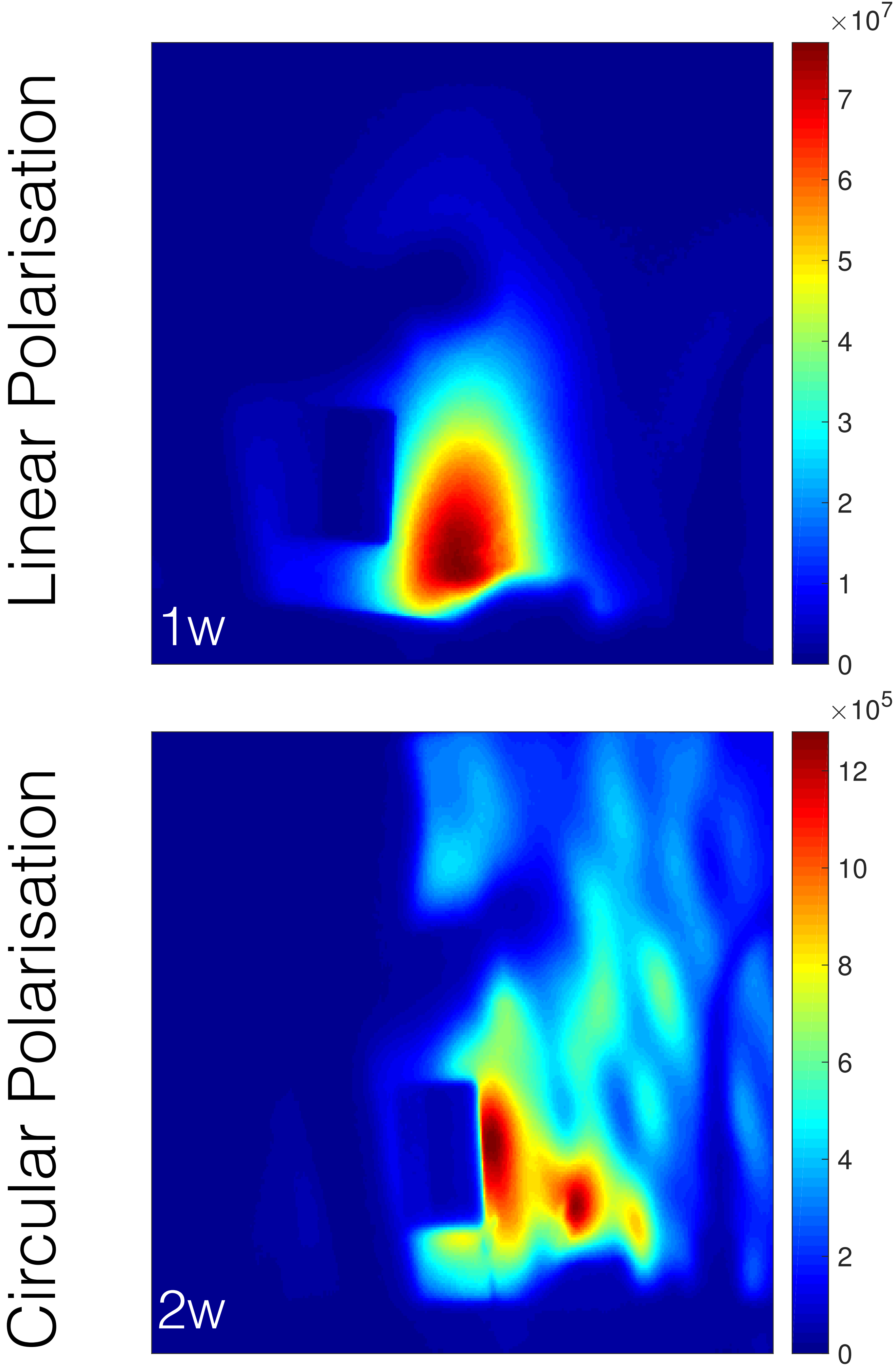
- Ultra-Thin targets
- Smooth 1ω spatial profile
- Strong modulations in the 2ω



Note: Linear colour scale!

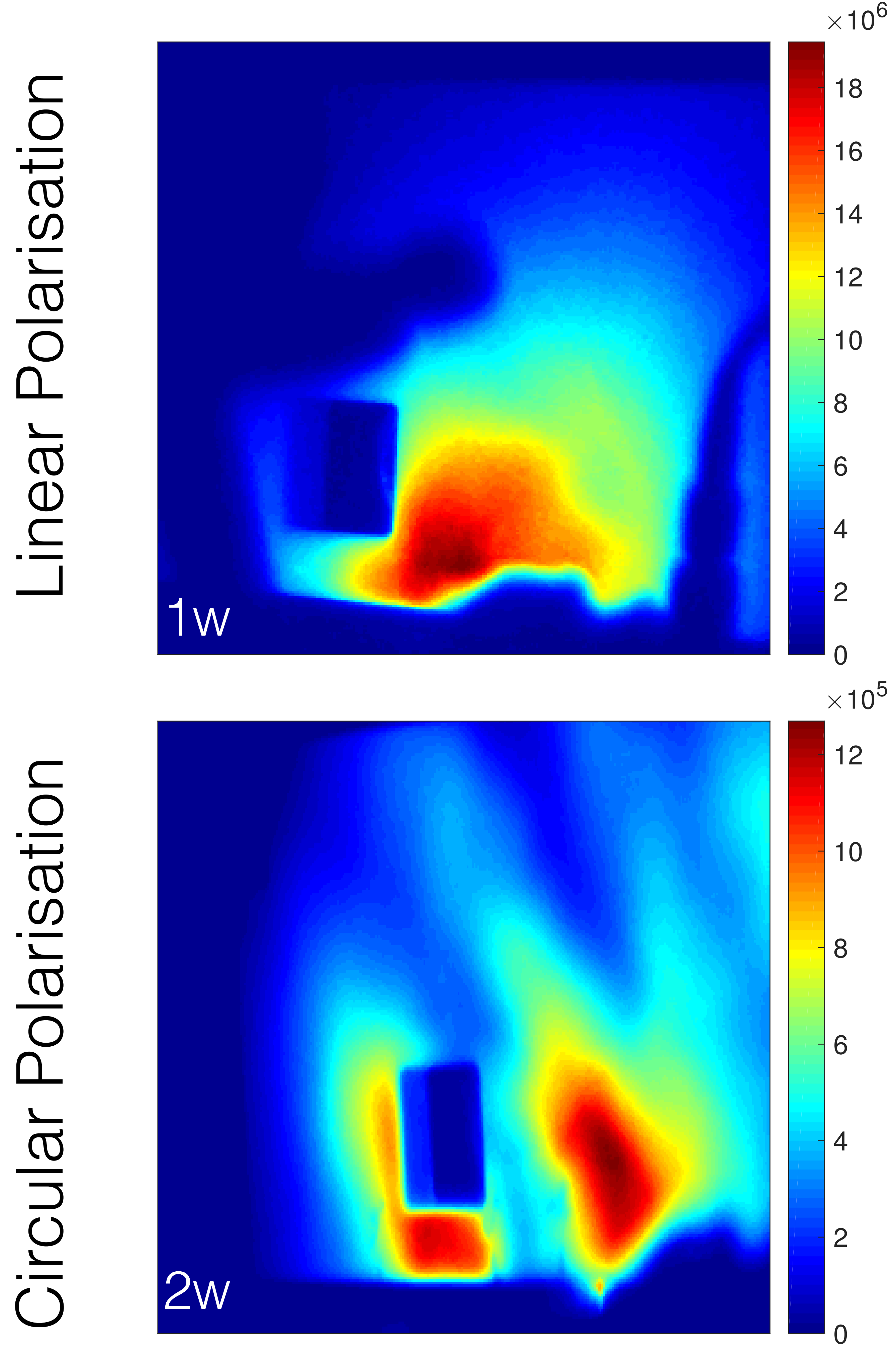
5nm

- Increase in divergence as target thickness increases
- Only most intense part of focal spot goes transparent



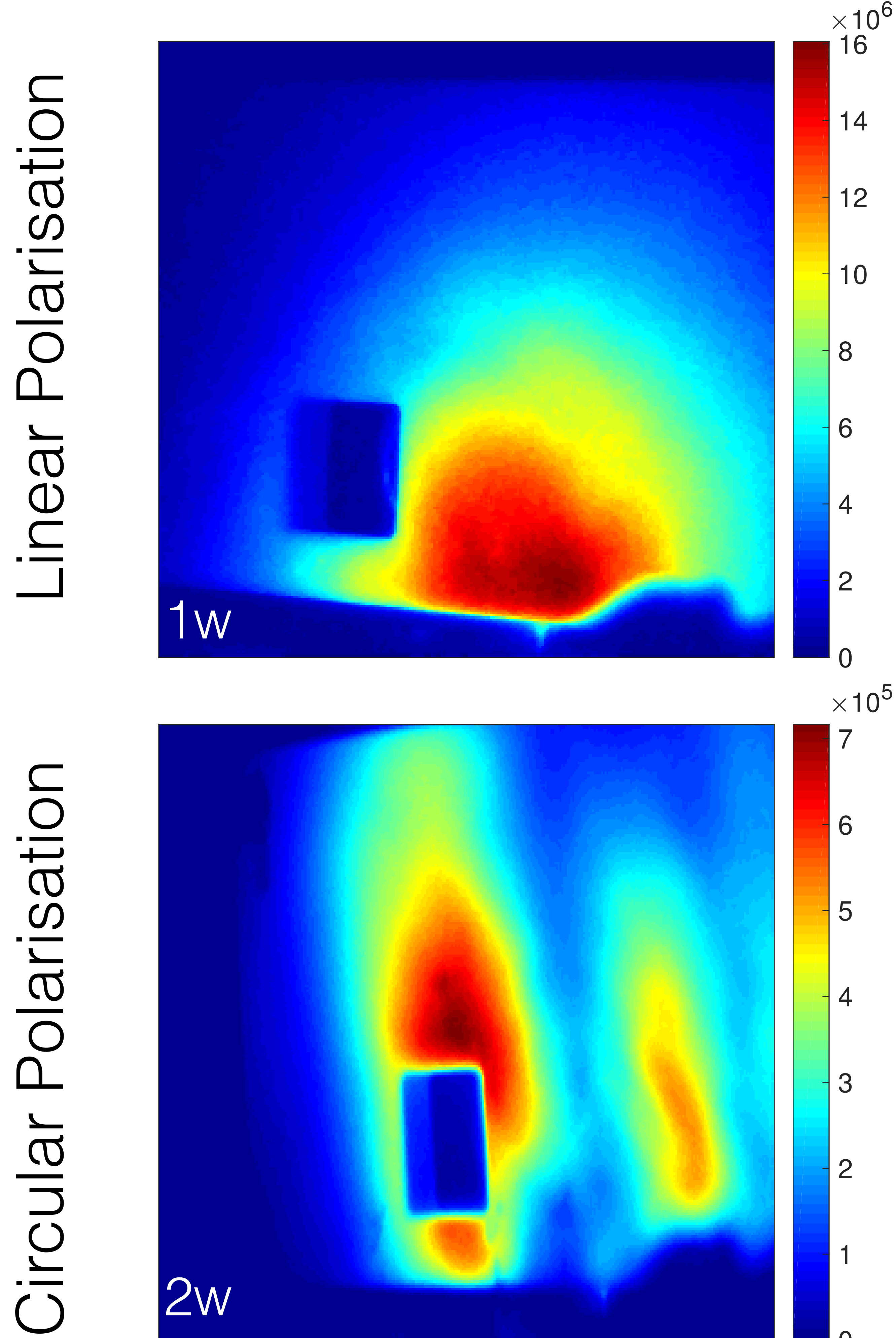
10nm

- Laser effectively sees a "pinhole"
- Laser diffracts strongly upon exit



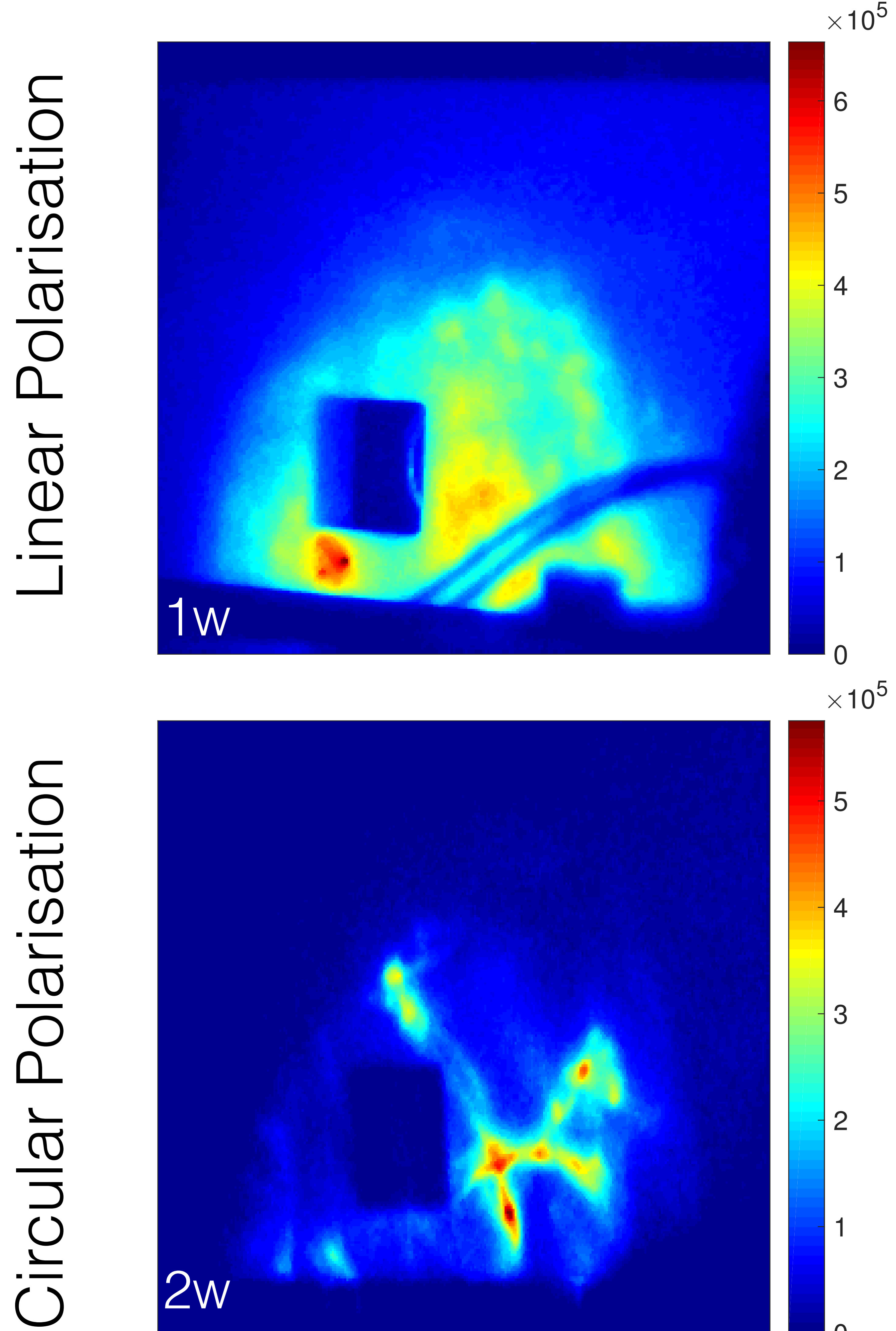
15nm

- As the target thickness increases, the target goes transparent later on in time
- This changed quantity of light transmitted and divergence
- No correlation between 1ω and 2ω



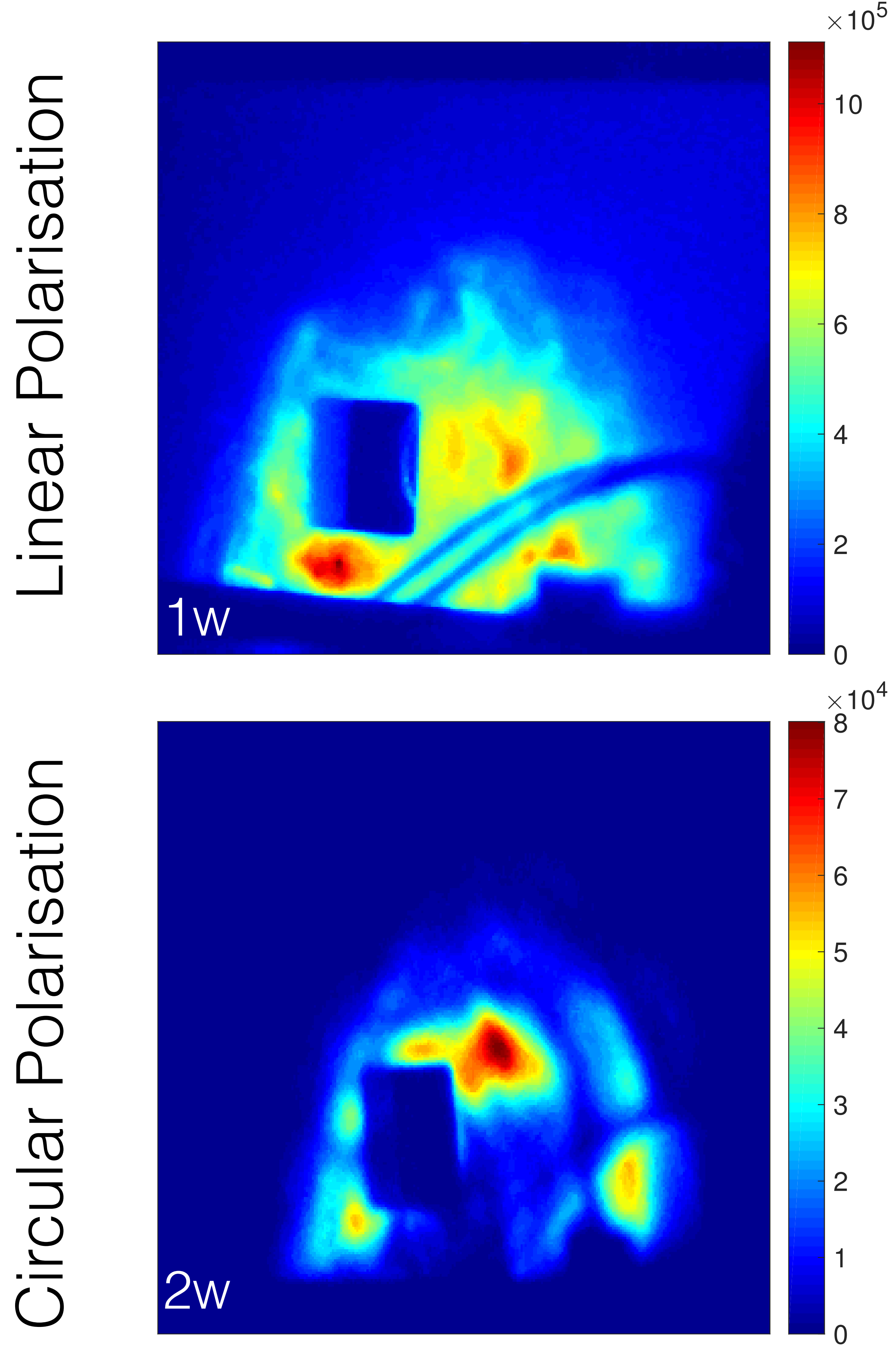
25nm

- Very different beam profile from 15nm target
- Spatial profile shows light in laser cone with strong spatial modulations
- 2ω light also constrained into the laser cone



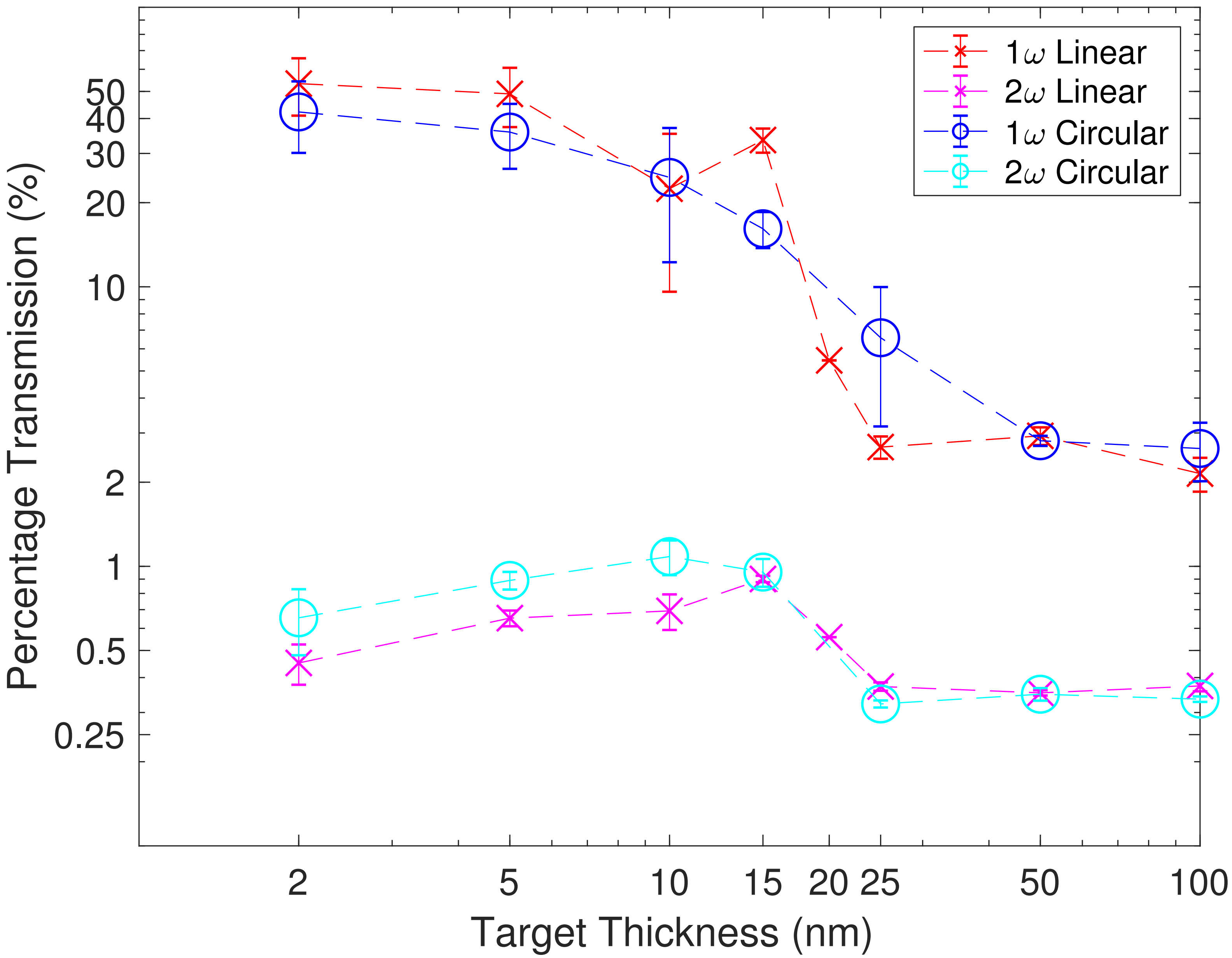
100nm

- Simulations show target remains overdense
- Radiation must come from secondary source: could be Optical Transition Radiation
- No correlation between 1ω and 2ω

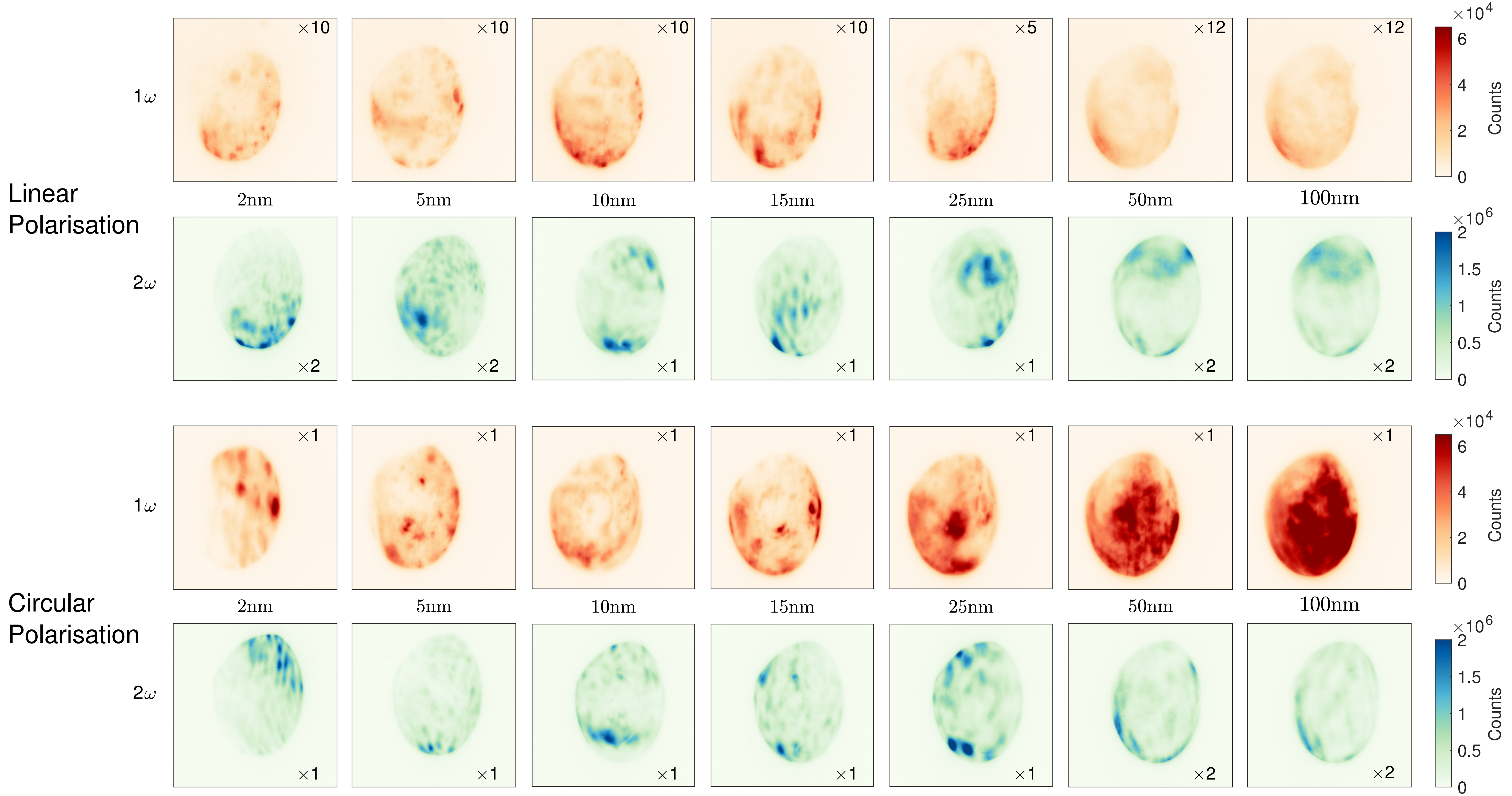


Transmitted Energy

- As target thickness decreases, target become transparent earlier on in the laser pulse
- Linear polarisation transmits more as more target heating
- Peak in 2ω production at 15-25nm due to relativistic transparency regime
- Errors are shot-to-shot variation



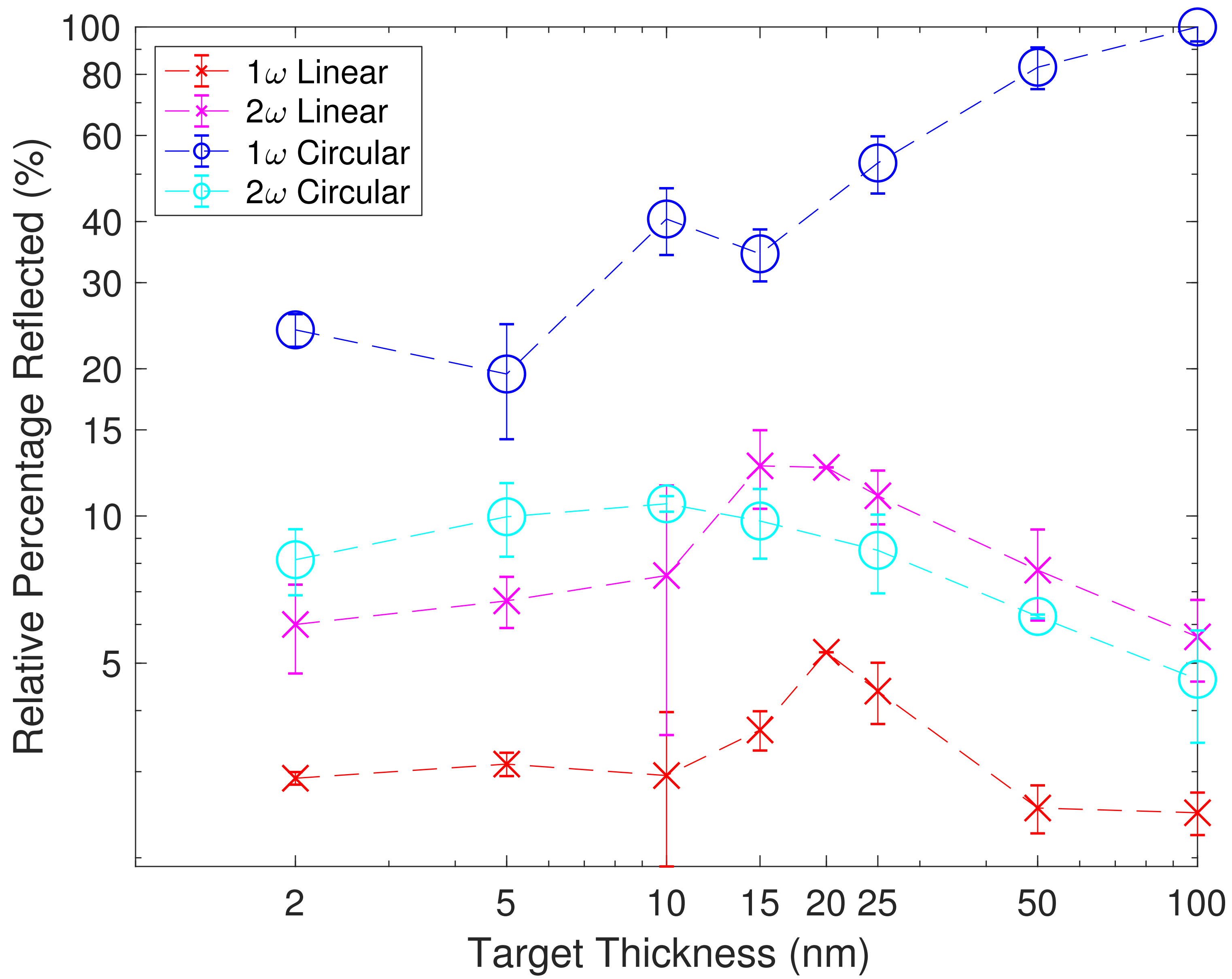
Spatial Profile of Reflected Near Field



target undergoes RTA at 25nm
so a fair amount of 2ω

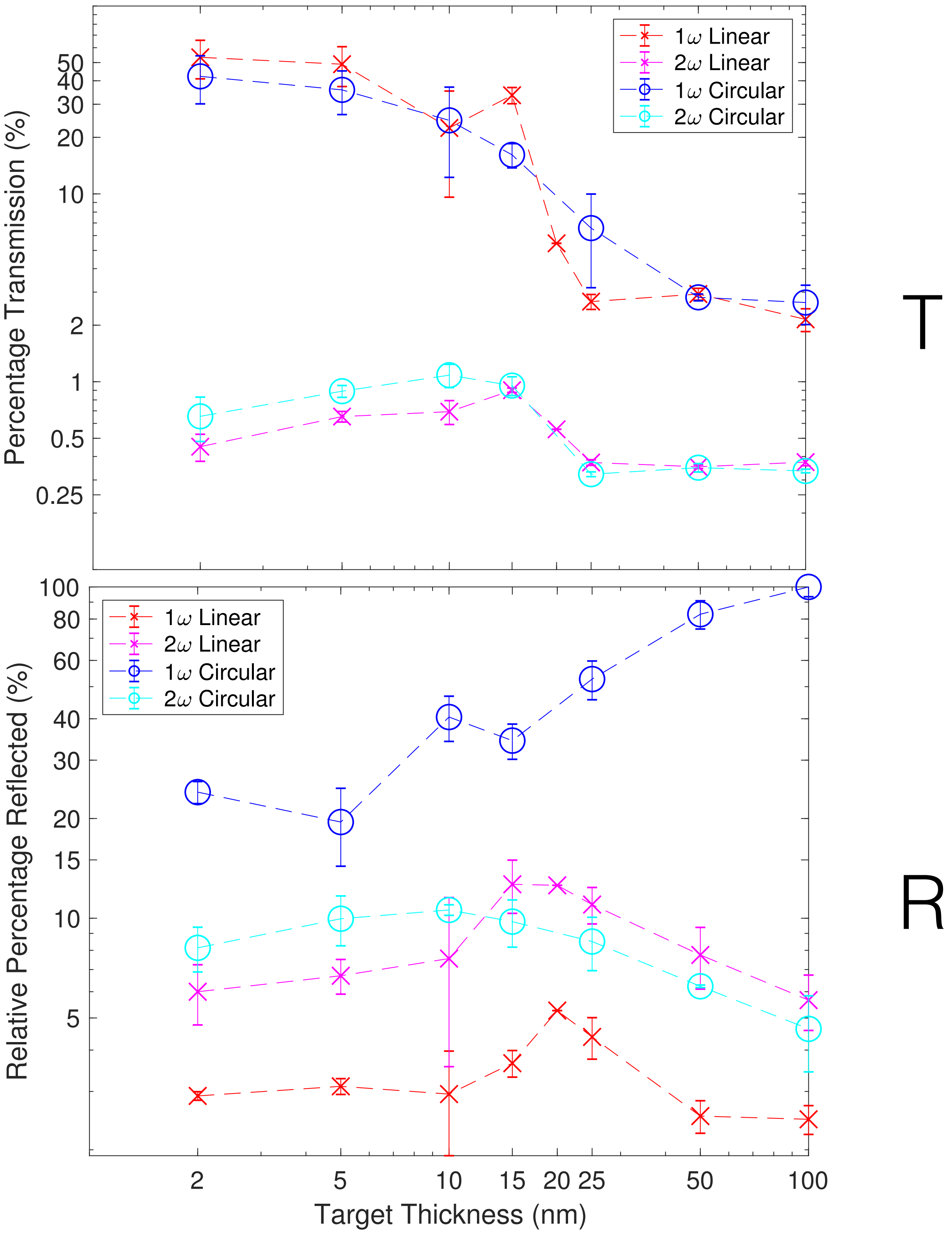
Reflected Energy

- 1ω circular polarisation is significantly more reflected in comparison to linear
- Reflectivity approximatively constant for linear polarisation
- 2ω peak shifted for circular to thinner targets with respect to linear

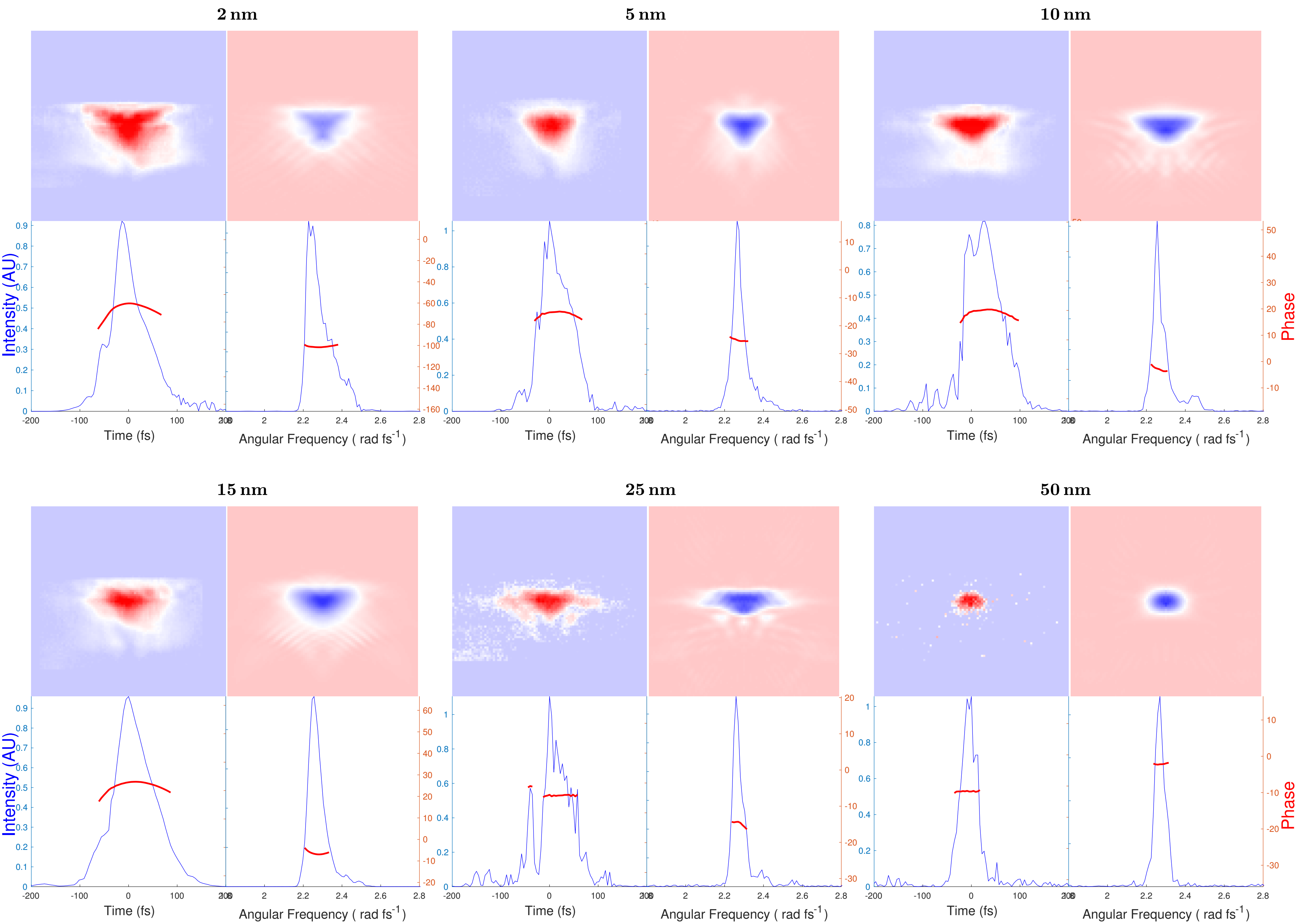


Conclusion so far

- Thick targets absorb more energy with linear polarisation
- Circular polarisation much more reflective -> best for RPA
- Interesting 2ω production - similar trends for transmission and reflection
- 2ω produced in strong intensity and density gradients in underdense channels, or through OTR/oscillating moving mirror for overdense targets



FROG Traces of Transmitted Light

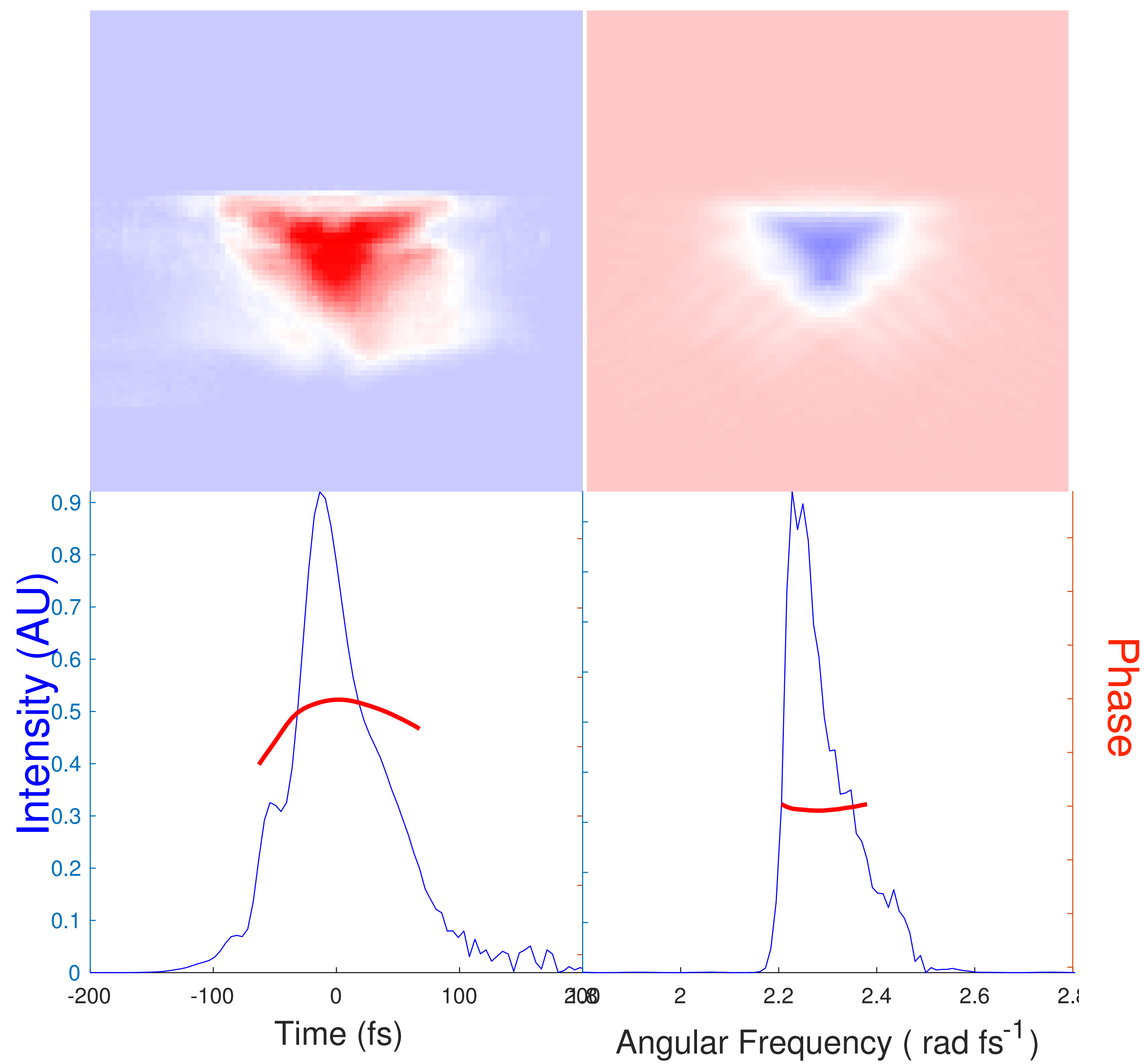


- FROG: Frequency Resolved Autocorrelator
- Measures pulse length, spectral width and phases
- Thin targets show usual laser traces
- Thicker targets show something different

FROG trace of thin target

- Time: $\hat{x}$ Frequency: $\hat{y}$
- FROG trace is typical to that of a laser pulse
- Lower two plots show temporal and spectral intensity and phase
- Sharper rising edge to temporal intensity
- Quadratic phase shows laser pulse is chirped

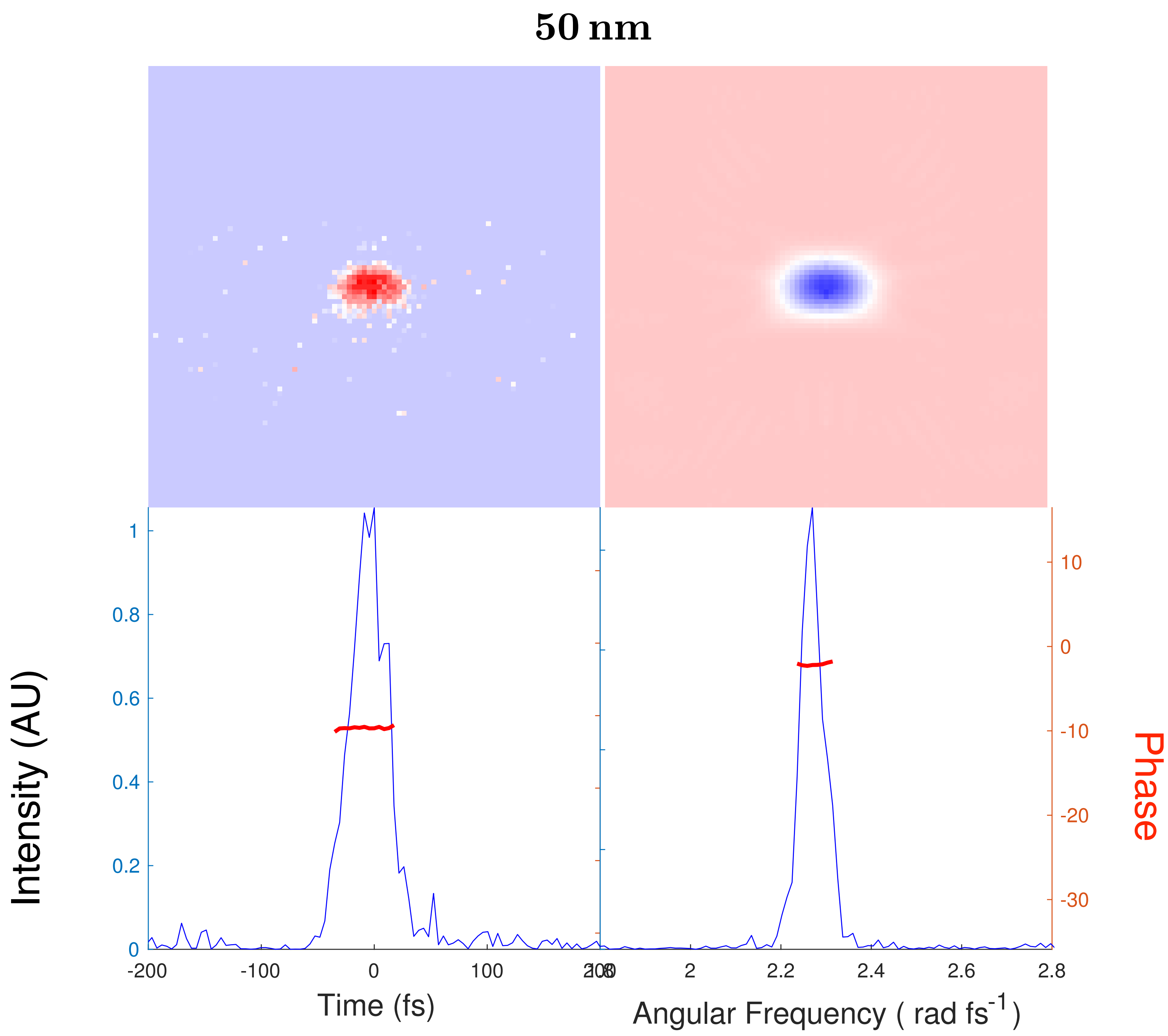
2 nm



FROG trace of thick target

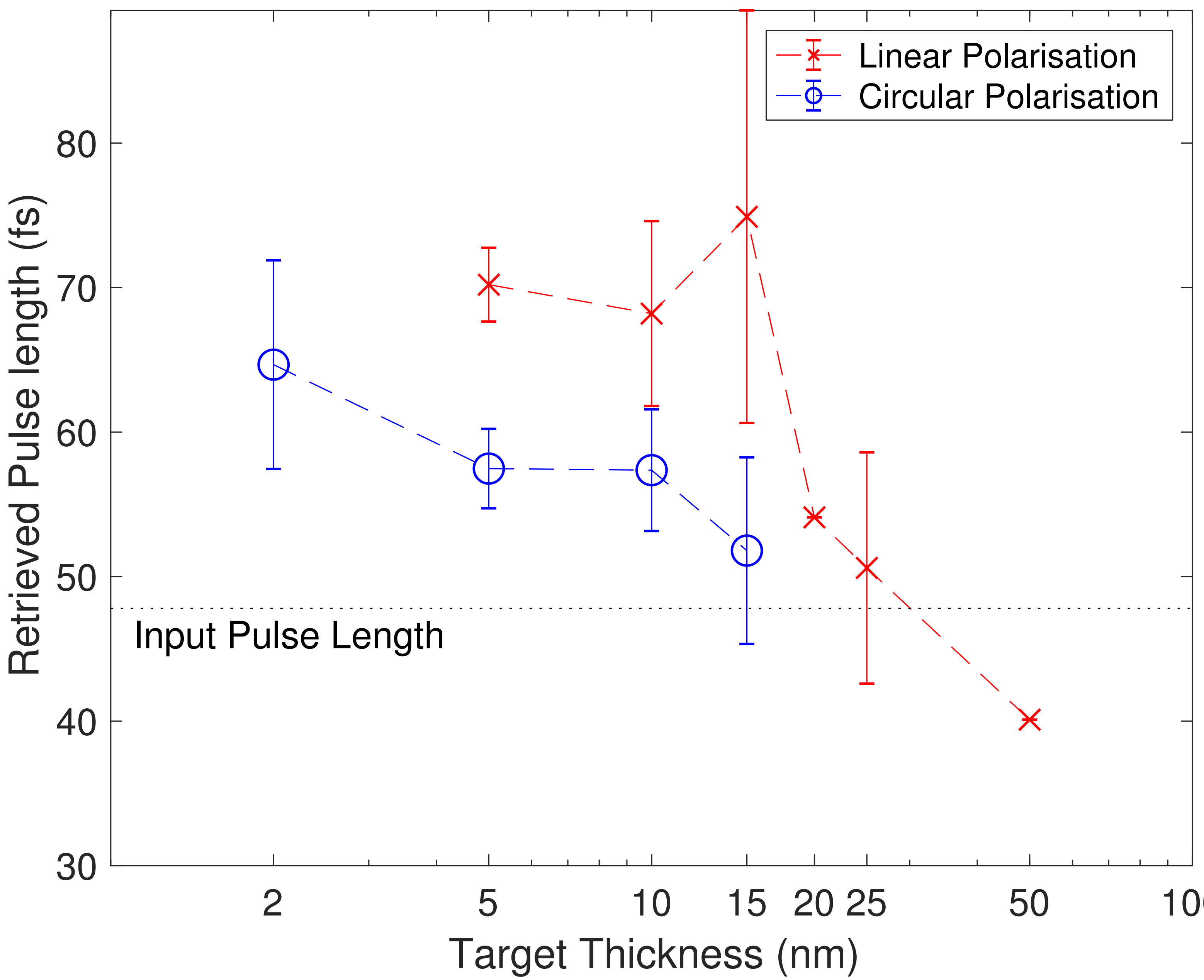
- FROG trace is unlike that of a typical laser pulse

- Flat temporal and spectral phases shows pulse is transform limited



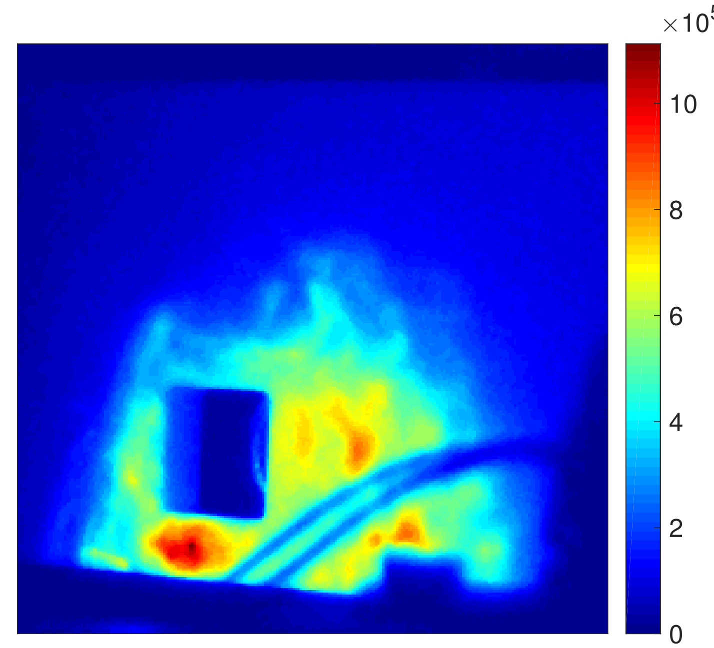
Retrieved Pulse Length

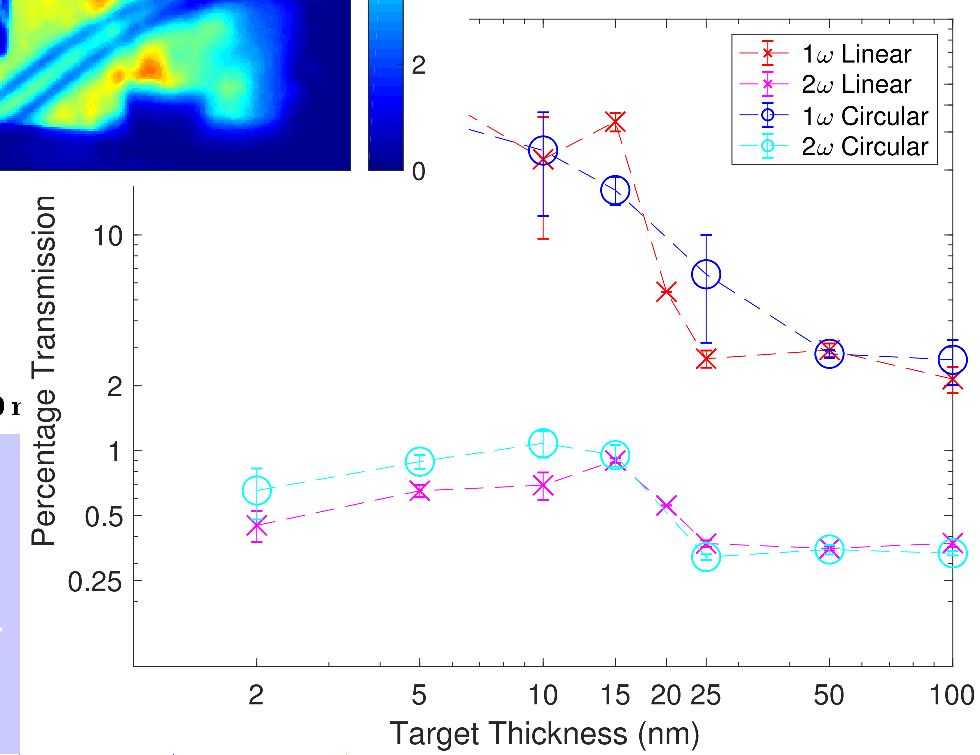
- Pulse length decreases with time, as consistent with the relativistic transparency model
- All pulse lengths are longer than the input pulse length
- Direct of time was chosen during the analysis

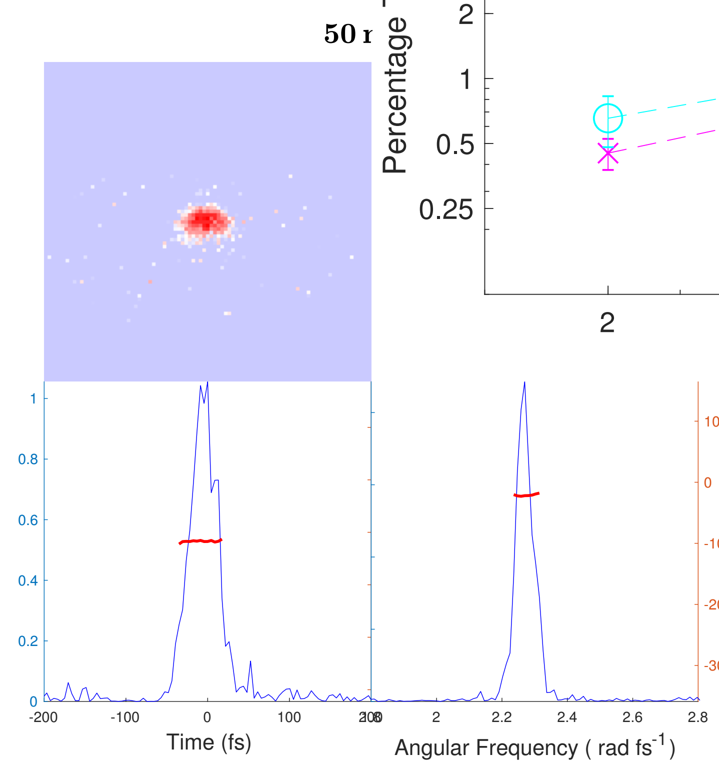


Arguments for OTR

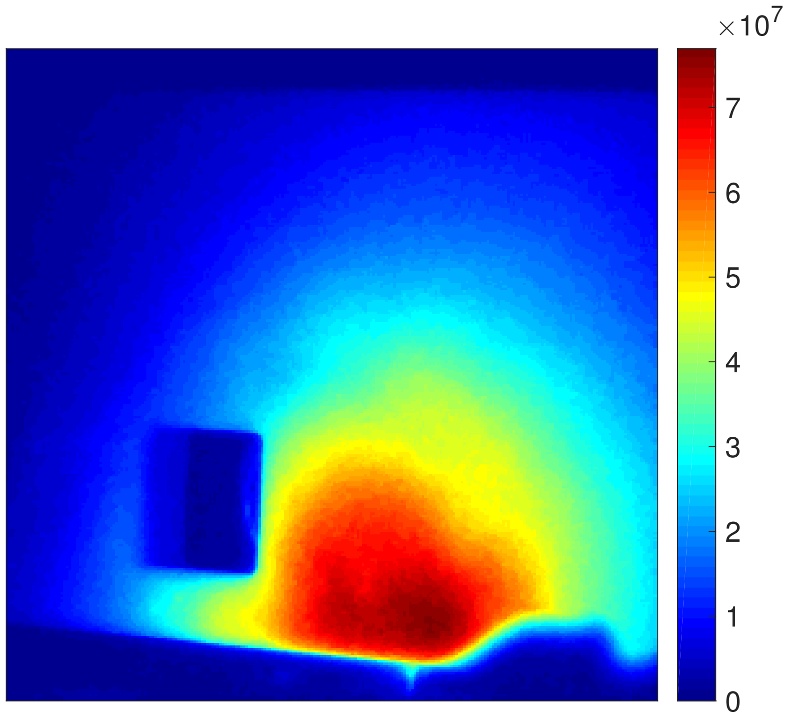
- Spatial profile modulated - comes from electron filaments?
- Constant amount of 1ω radiation produced for thicker targets
- OTR production proportional to target thickness, rear surface density scale length
- Transmitted pulse length very short, transform limited



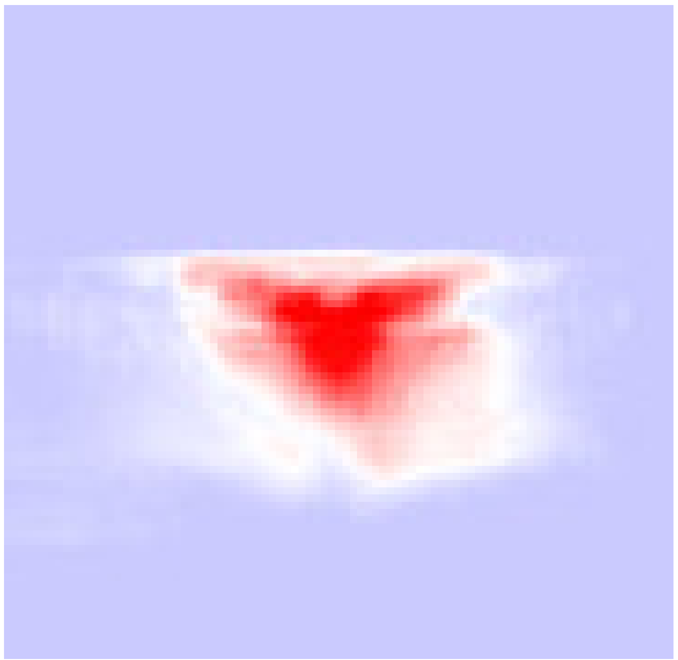




Conclusion



- Significant change in spatial beam profiles across RTA and RPA transition
- Circular polarisation better for Radiation Pressure Acceleration
- Strong emission of 1ω and 2ω likely to be OTR



Highest ion energies measured at 15nm -> corresponds to last transition into transparency

Acknowledgements

ASAIL Collaborators:

G. Hicks[1], O. Ettlinger[1], D. Doria[2], L. Romagnani[3], H. Ahmed[2], P. Martin[2], S. Williamson[4], A. McIlvenny[2], G. Scott[5], N. Booth[5], D. Neely[5], P. McKenna[4], M. Borghesi[2] and Z. Najmudin[1]

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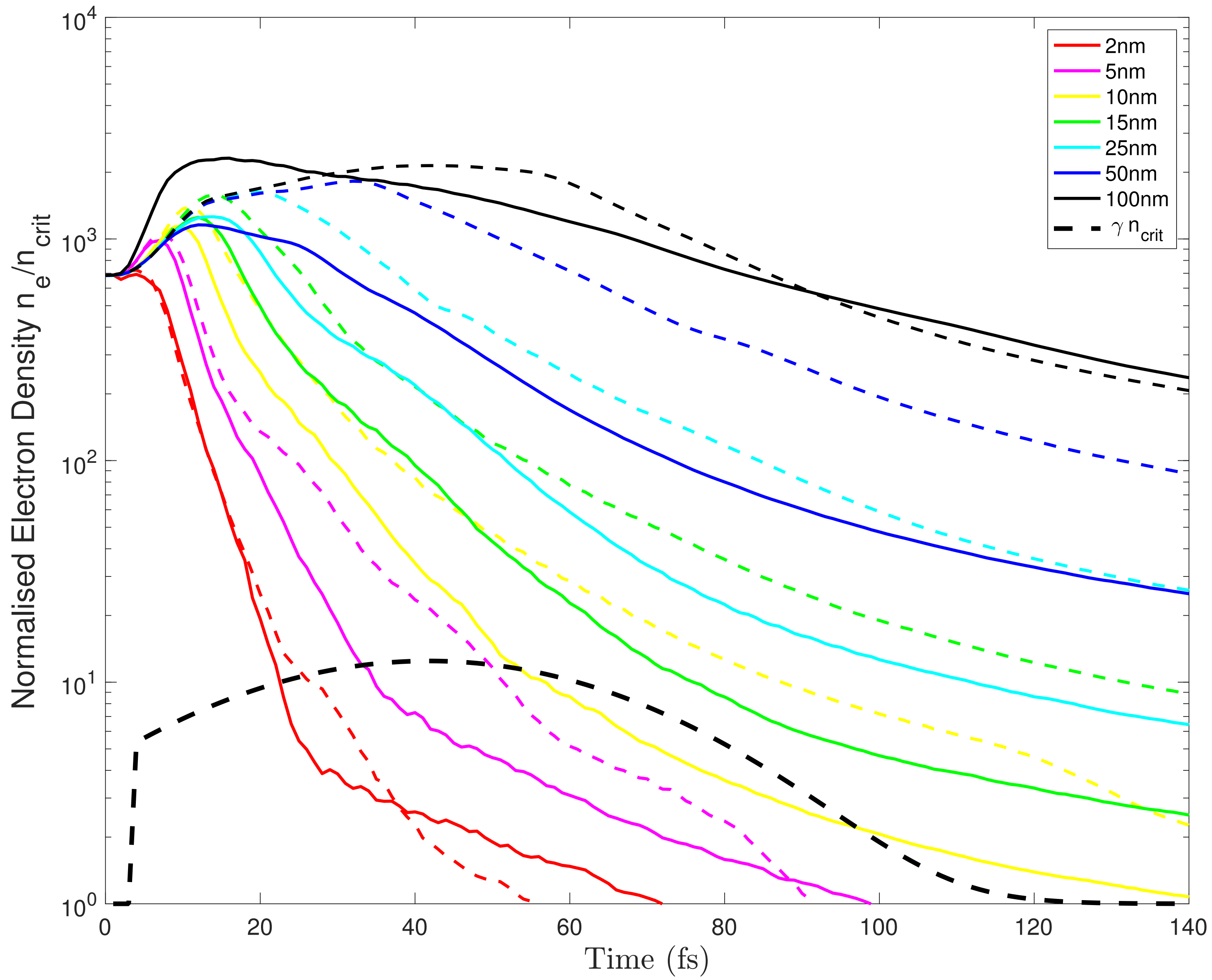
Future Work

- Explore second harmonic production on front and rear surface
-

2D PIC Simulations

- 2D Simulations run using EPOCH
- Peak of the laser pulse at 48fs
- Linear Polarisation ——
- Circular polarisation - - -
- Targets less than 15nm go relativistic transparent
- Initial compression from RPA
- Slower target expansion for thicker targets



Comparing Intensity Traces