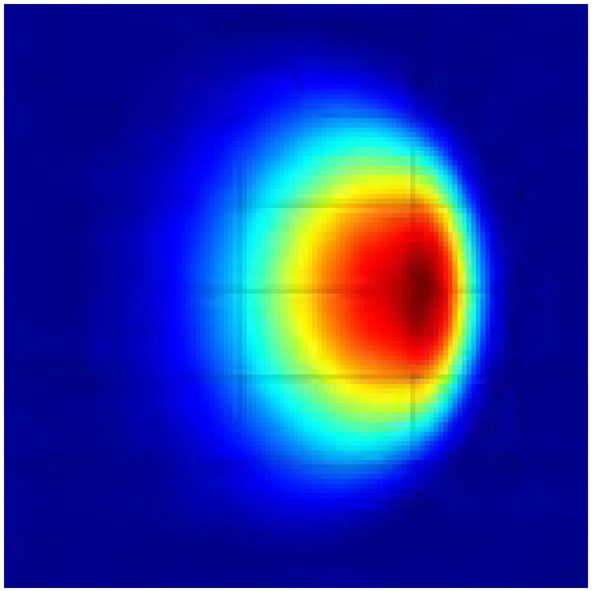
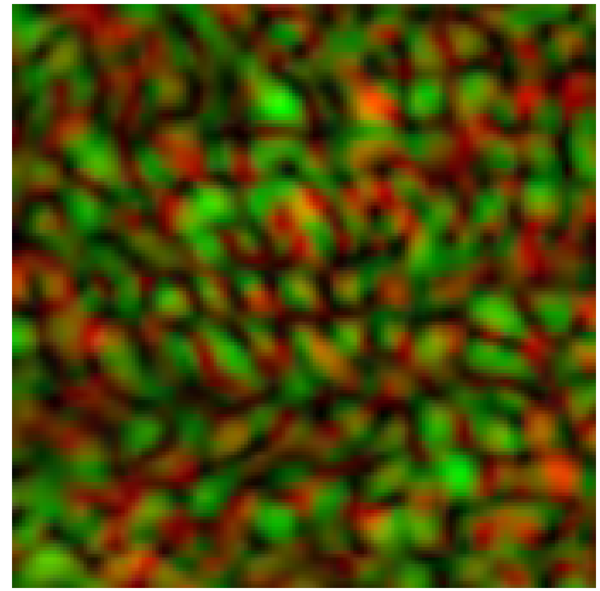
Phase and Polarization Plates for NIF Polar Drive

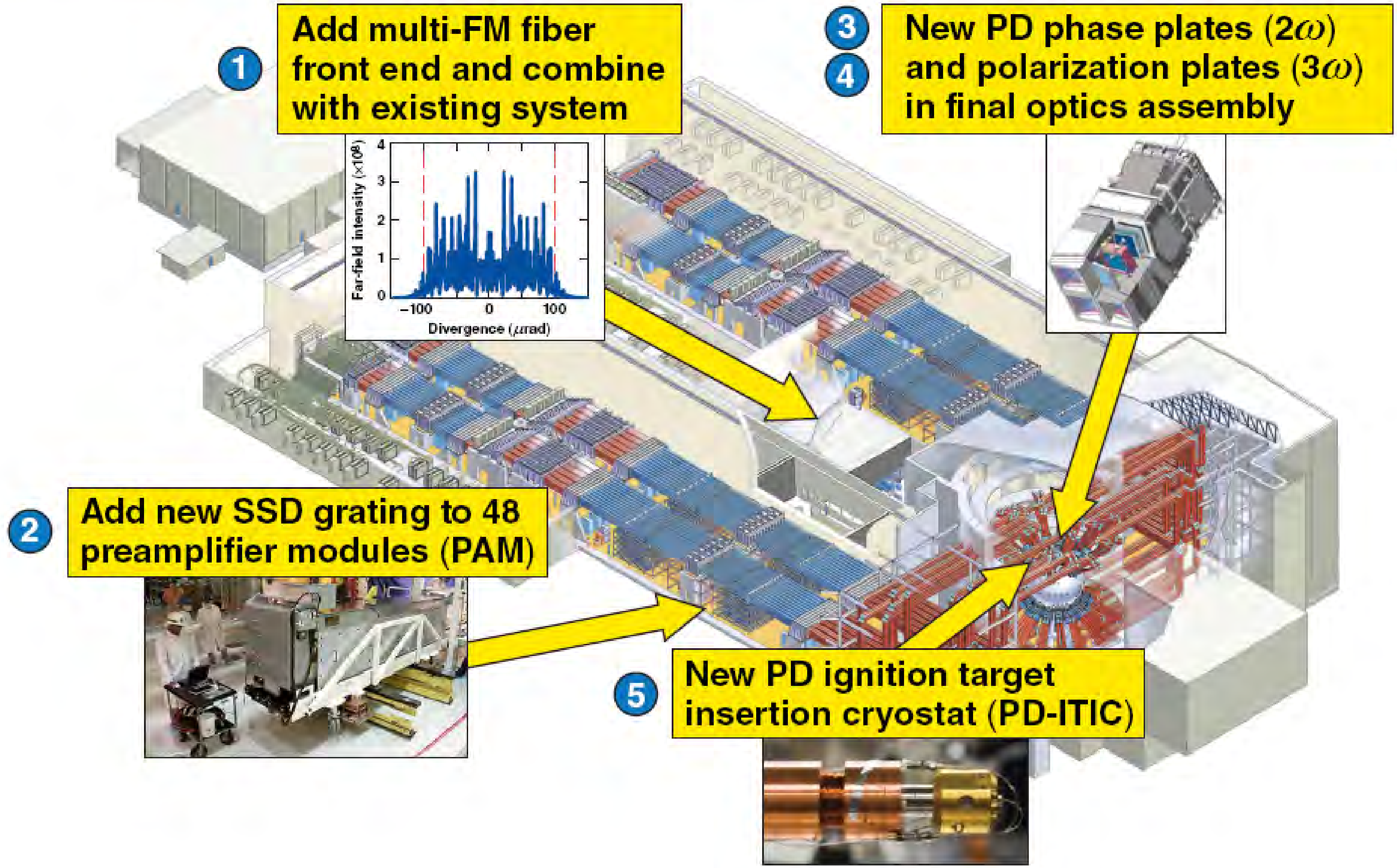




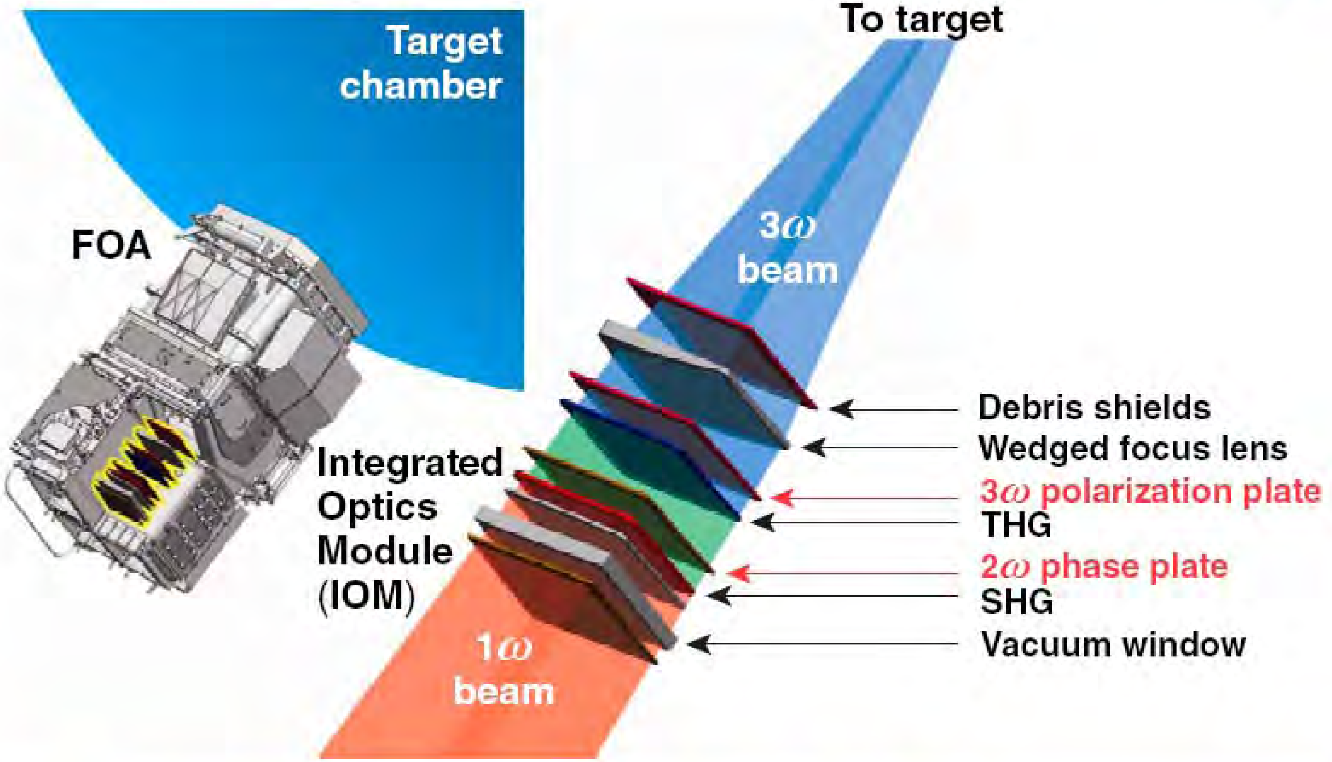
International Workshop
on ICF Shock Ignition
Laboratory for Laser Energetics

Terry Kessler
March 8-10 2011

Implementing polar drive (PD) requires five changes on the NIF for an ignition demonstration



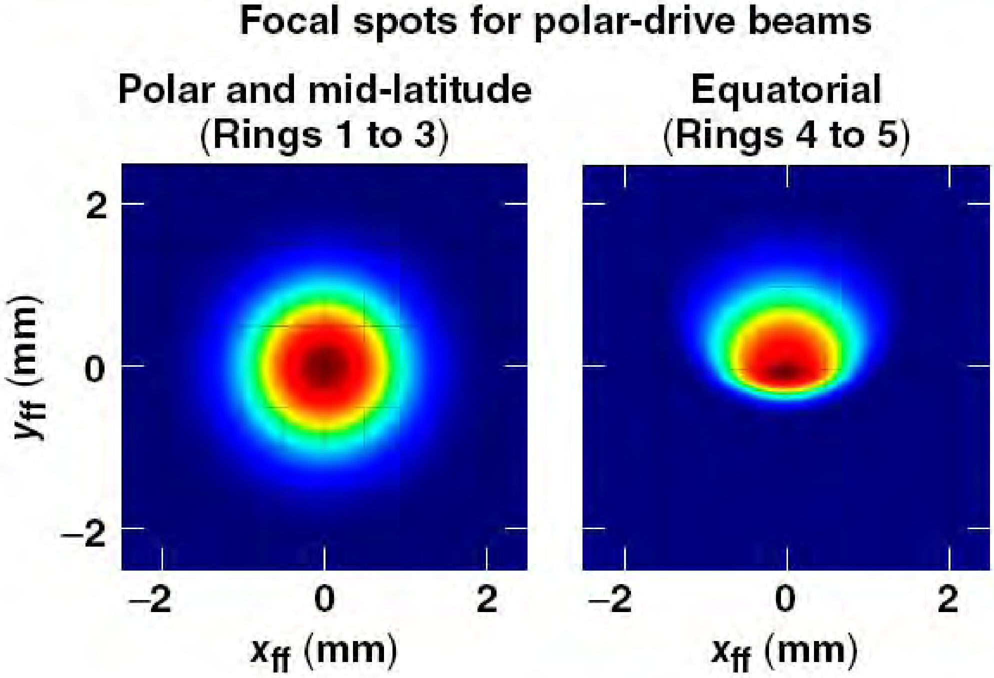
The focal-spot conditioning strategy for polar-drive ignition includes phase and polarization plates

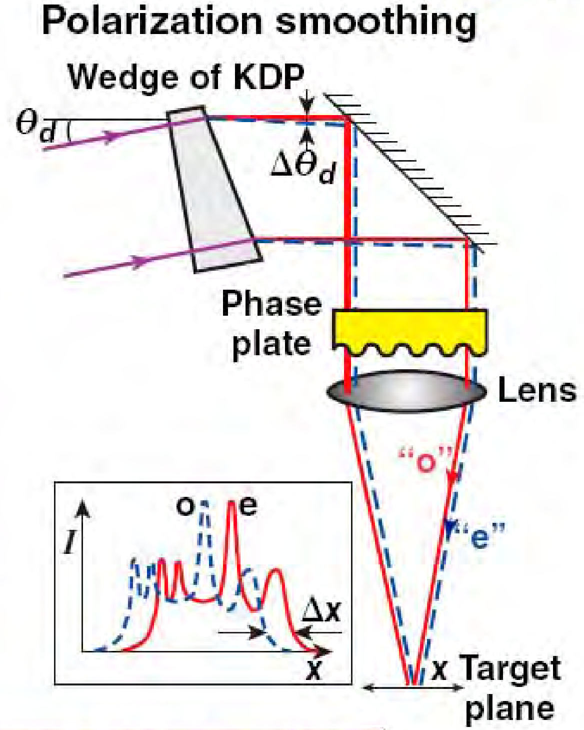


The NIF final optics assembly (FOA) will include:

- **Phase plate between the frequency conversion crystals (2ω)**
- **Polarization plate (3ω)**

Phase plates and polarization smoothing are being designed to efficiently and uniformly couple energy to polar-drive targets



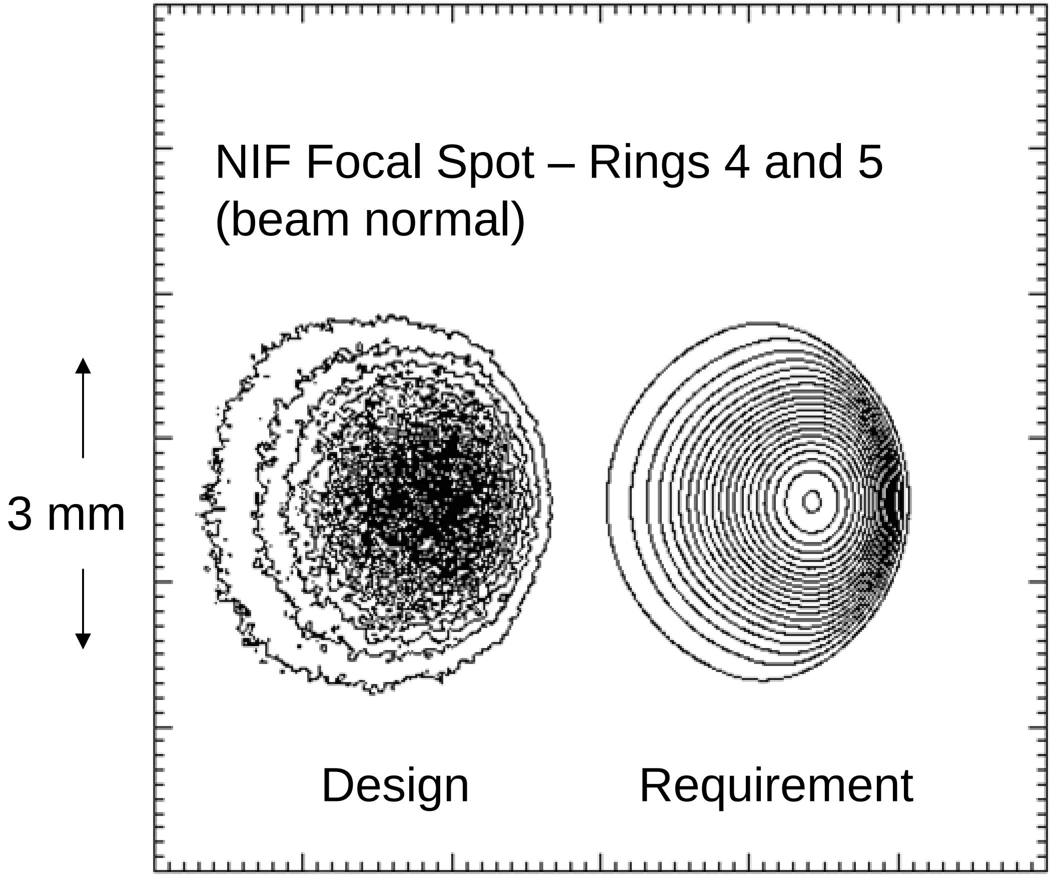


- Phase plates efficiently deliver laser energy with a desired focal pattern to achieve required irradiation uniformity.
- Polarization smoothing instantaneously improves targeted modes of focal-spot irradiance modulation.

NIF PD focal-spot requirements push existing design and fabrication capabilities for phase plates

- Phase plate design iteration includes surface relief design, damage probability calculation, manufacturing (and testing) assessment, low-coherence tripling, and energy coupling to the target
- Phase plate production rate and yield will dictate the manufacturing schedule (Y=192/200 @ N/wk ~ 4/N years)
- A schedule having NIF PD ignition experiments in 2016 allows 1 year of iterative design (N=1)
- Preliminary design for rings 4 and 5 (symmetric and asymmetric elliptical focal spots) awaits LLNL damage assessment

Skewed elliptical phase plate design was completed for design iteration with target, laser system, and fabrication constraints



- Speckle smoothed to show envelope

UV phase plates may be required to obtain optimum laser and target performance

NIF final optics system: frequency conversion and beam conditioning*

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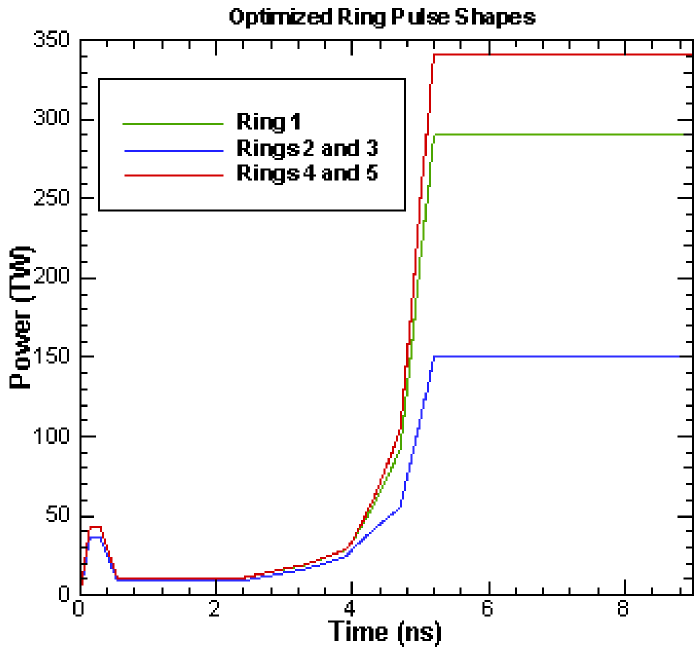
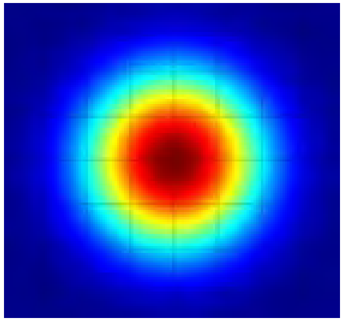
4. BEAM CONDITIONING

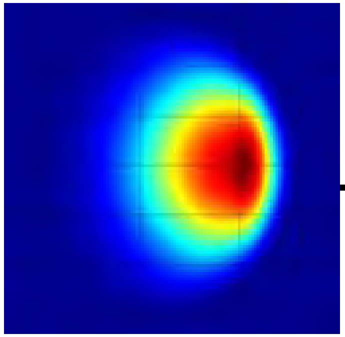
The FOA is designed to accommodate a number of beam conditioning techniques for smoothing the focal spot profile on target, including phase plates, polarization scramblers, and smoothing by spectral dispersion (SSD). Phase plates are an established technology for transforming aberrated laser focal spots into comparatively homogeneous speckle distributions of various shapes and sizes [8]. The phase plates used on NIF are of the continuous (CPP) variety which have smooth profiles to avoid the high levels of near-field intensity modulation associated with the discrete phase jumps of conventional RPPs [9]. Modeling has shown that for spot sizes up to a few mm, CPPs can be installed in the 1ω section of the laser immediately upstream of the FOA vacuum window without significantly impacting the frequency conversion efficiency or the near-field modulation of the 3ω beam. The calculations, shown in Figure 12, were performed for an elliptical spot of 2:1 aspect ratio, oriented with the long axis of the ellipse along the sensitive axis of the tripler. The results show that for 1-mm spots, the reduction in conversion efficiency is less than 0.5% at 3 GW/cm^2 and the increase in 3ω beam contrast is negligible. At 3 mm, the reduction in conversion efficiency has reached 4.5% and the increase in beam contrast is beginning to be noticeable. Experiments requiring spot sizes larger than ~3 mm will require careful evaluation to determine whether the CPP should be deployed in the 1ω or 3ω section of the FOA.

Non-skewed phase plates may be required for rings 4 and 5 to reduce near-field modulation

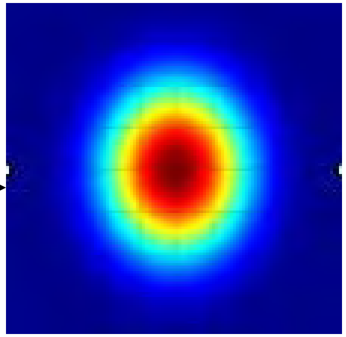




Rings 1, 2, 3



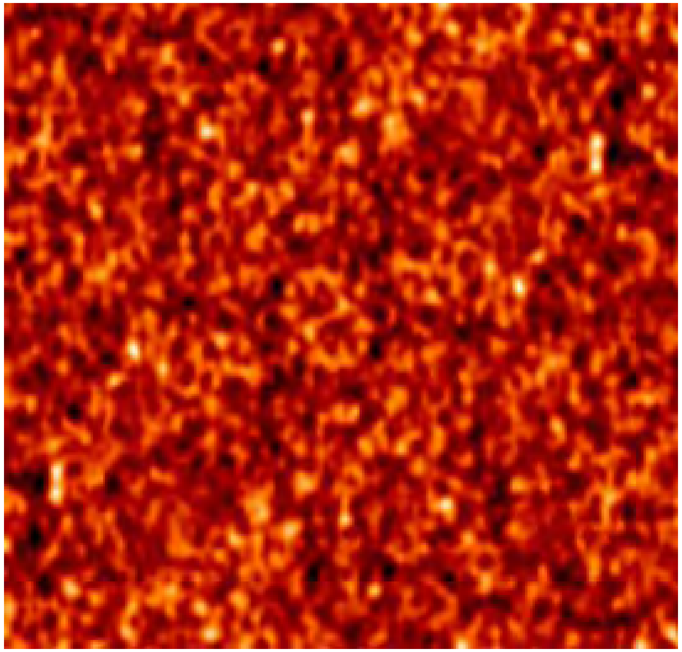
Rings 4, 5



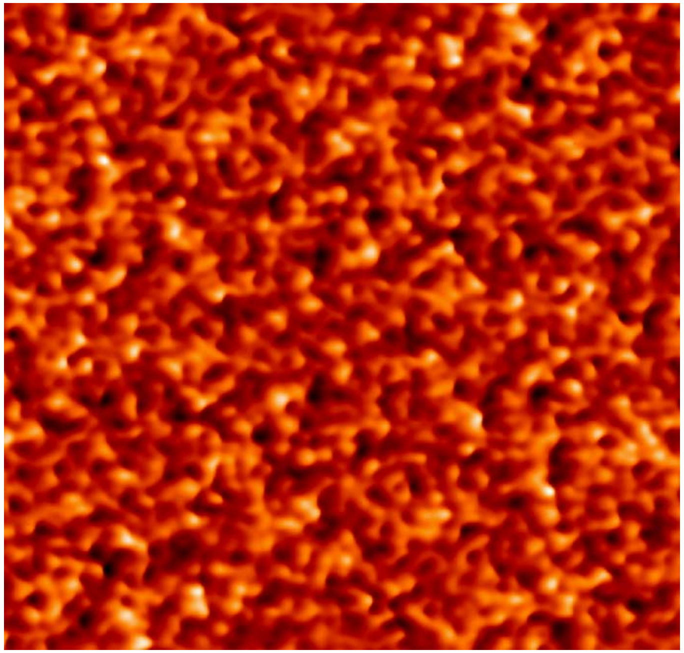
(non-skewed)

Increased energy may be required in rings 4 and 5 using symmetric focal spots

Gradient phase distribution provides focal-spot skew but it also increases irradiance modulation in the near-field



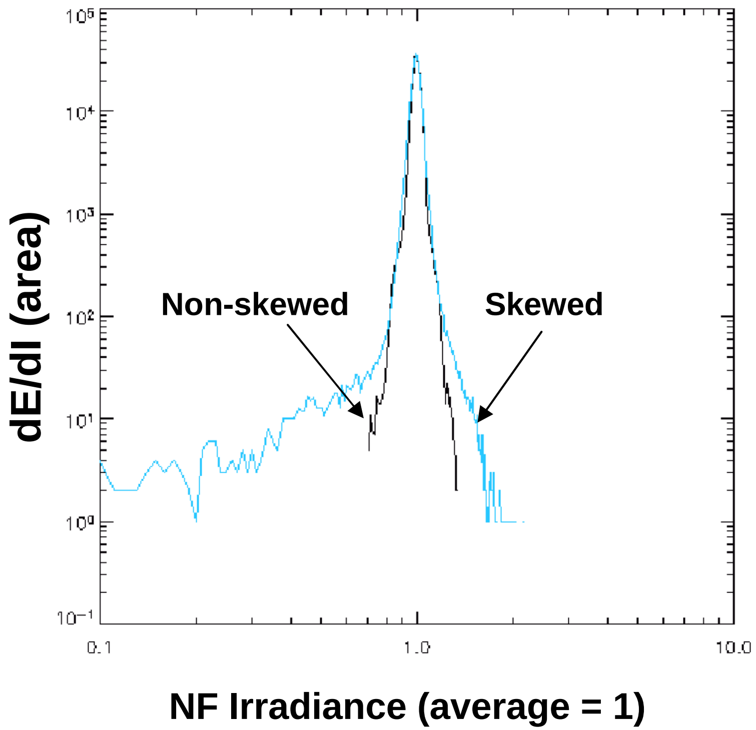
Non-skewed 2D phase



Skewed 2D phase

- 70 radians P-V phase corresponds to 8 μm height

Although RMS phases are similar, near-field irradiance modulation is higher for skewed design due to tilt gradients



- **Phase to intensity for 1 meter propagation (UV)**

Skewed:

Peak to average > 2.0

(smoothed ~ 1.60)

Non-skewed:

Peak to average ~ 1.3

(smoothed < 1.15)

Maximum allowed NIF energy is determined through damage probability assessment

- **LLNL's calculation of damage probability within the FOA is the basis for acceptance of phase plate design and fabrication**
- **Pass requires meeting two criteria at every surface in the FOA: I_p < 12 GW/cm2 (for 3.5 GW/cm^2 1w input), and <N> (expected number of initiation sites) less than 0.03 (1 site every 33 shots)**

Example evaluation suggests a rule of thumb: peak/mean ~ 3

Failed flaws 128

Affected CPPs 57

Statistics	Ave	StDev	Min	Max
<N>	1.02	1.08	0.01	4.36
I peak (GW/cm2)	24.5	26.8	9.0	211.6
Pk/mean	7.0	7.7	2.6	60.5

Passed flaws 2944

Affected CPPs 241

Statistics	Ave	StDev	Min	Max
<N>	0.0002	0.0020	0.0000	0.0290
I peak (GW/cm2)	4.6	1.2	3.2	11.1 ←
Pk/mean	1.3	0.3	0.9	3.2 ←

It may be possible to replicate IR/Green phase plates which possess the required laser damage threshold

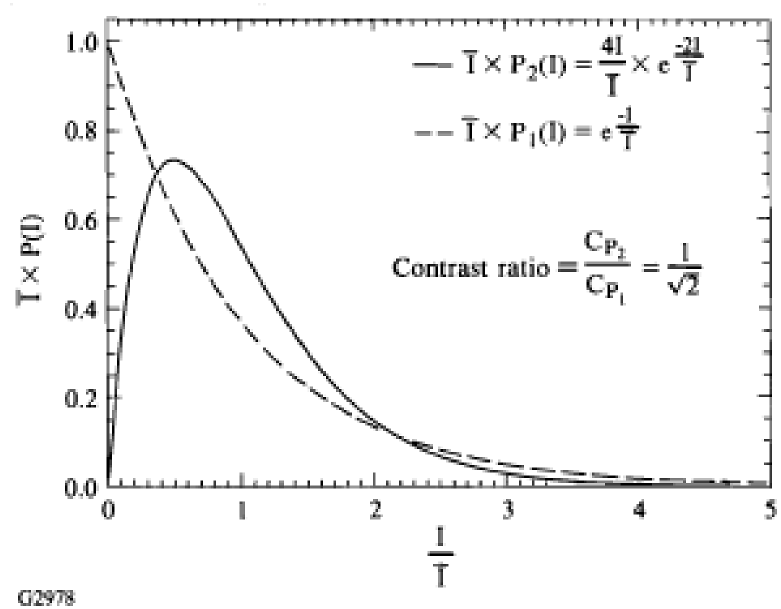
UR LLE

- A small number of master phase plates can be fabricated with high resolution MRF polishing
- Replicas can be fabricated from the masters at a significantly faster rate than polishing 192 plates individually
- Replicas are inherently protected from MRF fluid contamination by a release barrier
- Replicas can be easily erased when alternate phase plates are desired

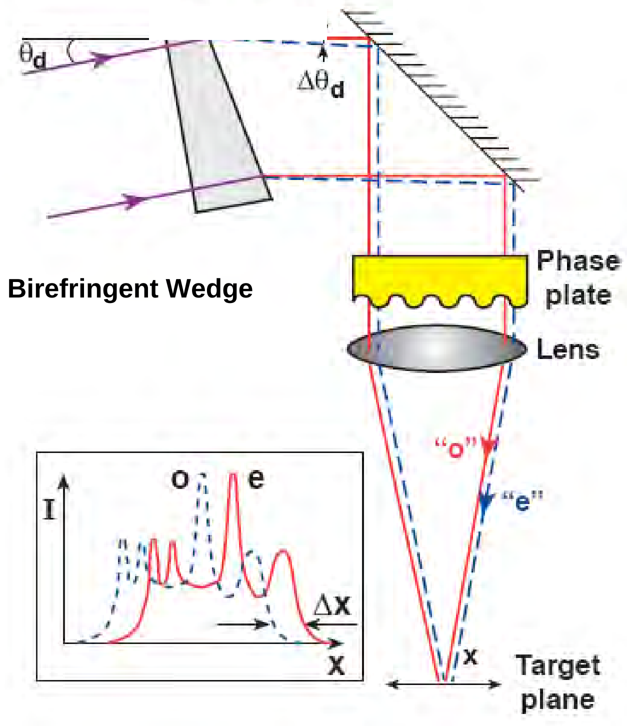
Ultra-clean material processing is required for optical embossing

NIF Polar Drive Ignition requires DPPs, SSD, and DPRs

- **Distributed Polarization Rotators (DPRs) provide time-instantaneous uniformity improvement**
- **DPRs may provide gain quenching for polarization-dependent LPI**
- **Slots exist in the NIF FOA but UV optics are considered undesirable - improved processing is required for DPR survival**

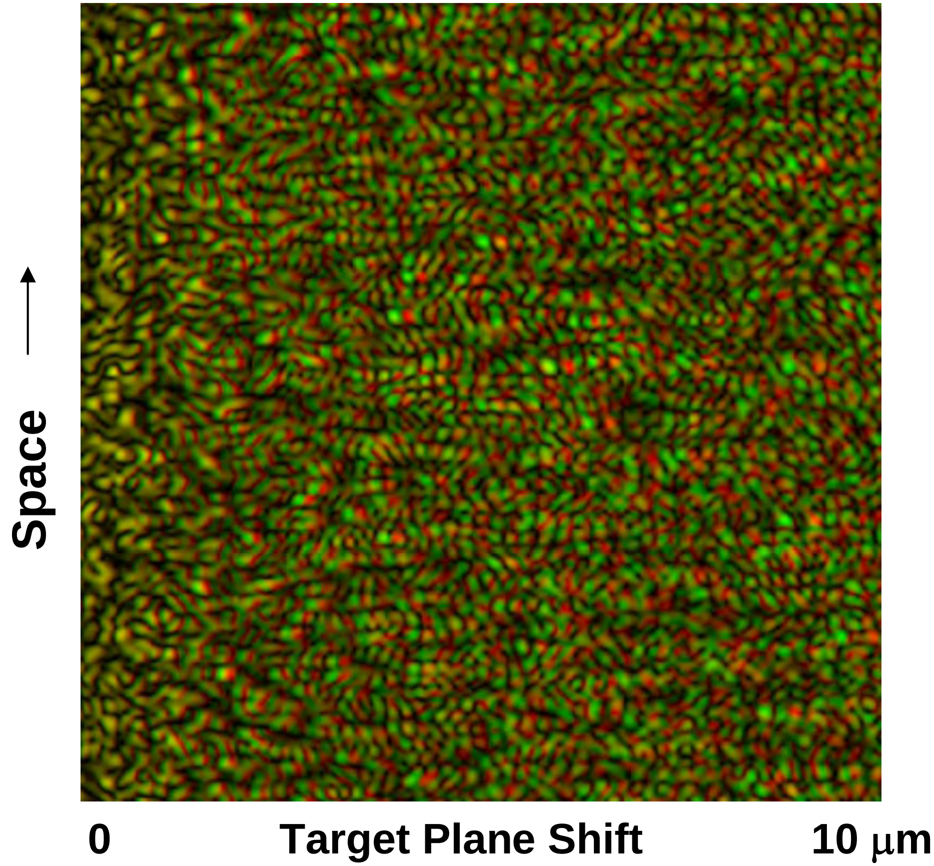


LLE's success with DPRs on OMEGA provides individual-beam smoothing for NIF Polar Drive

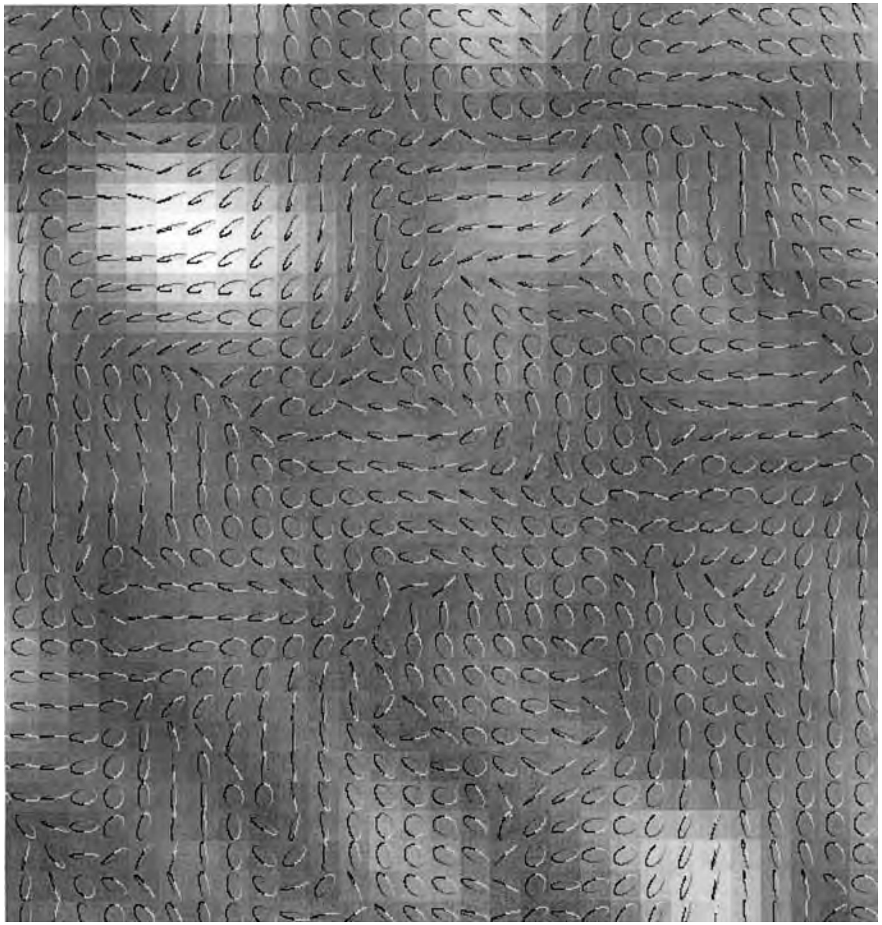


(LLE Review 45, T. Kessler, 1990)

(February 22, 2011 - Hu Huang)



Laser polarization varies over the continuous speckle distribution in the focal plane



- 15 μm x 15 μm focal plane patch
- DPR - Polarization wedge
- S, P differential phase included

LPI modeling should include accurate 2-state speckle

(March 3, 2011 - Hu Huang)

New phase and polarization plates are needed for Polar Drive (shock ignition) on the NIF

- **Preliminary phase plate design for rings 4 and 5 (symmetric and asymmetric elliptical focal spots) awaits LLNL damage assessment**
- **The UV phase plate option should be carried forward since achromatic (refractive) performance breaks down for stronger phase gradients**
- **Phase plate fabrication throughput can be increased by adding MRF machines and developing high damage threshold optical replication**
- **LPI modeling should contain accurate speckle polarization**
- **Improved Distributed Polarization Rotators are required for use in the UV section of the NIF final optics assembly**
- **Close coordination of design, fabrication, and evaluation is required to deploy PD phase and polarization plates on NIF**