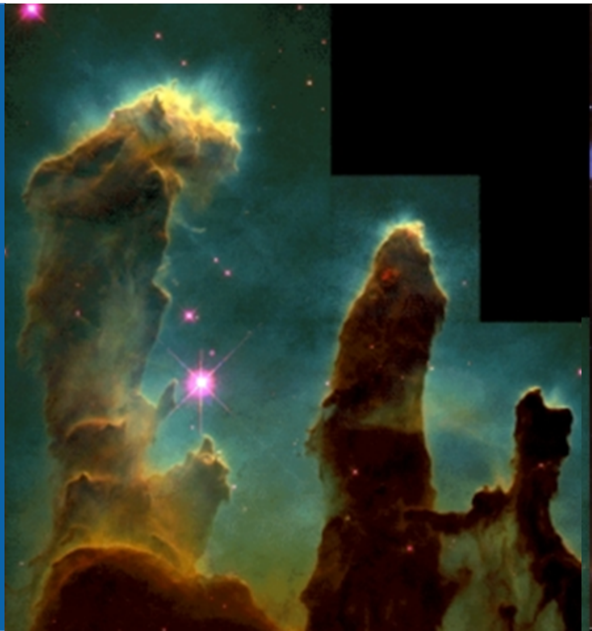
Using multi-hohlraum arrays for studying the "Pillars of Creation"

Omega User Group Meeting

April 28th 2017

David Martinez



Lawrence Livermore
National Laboratory

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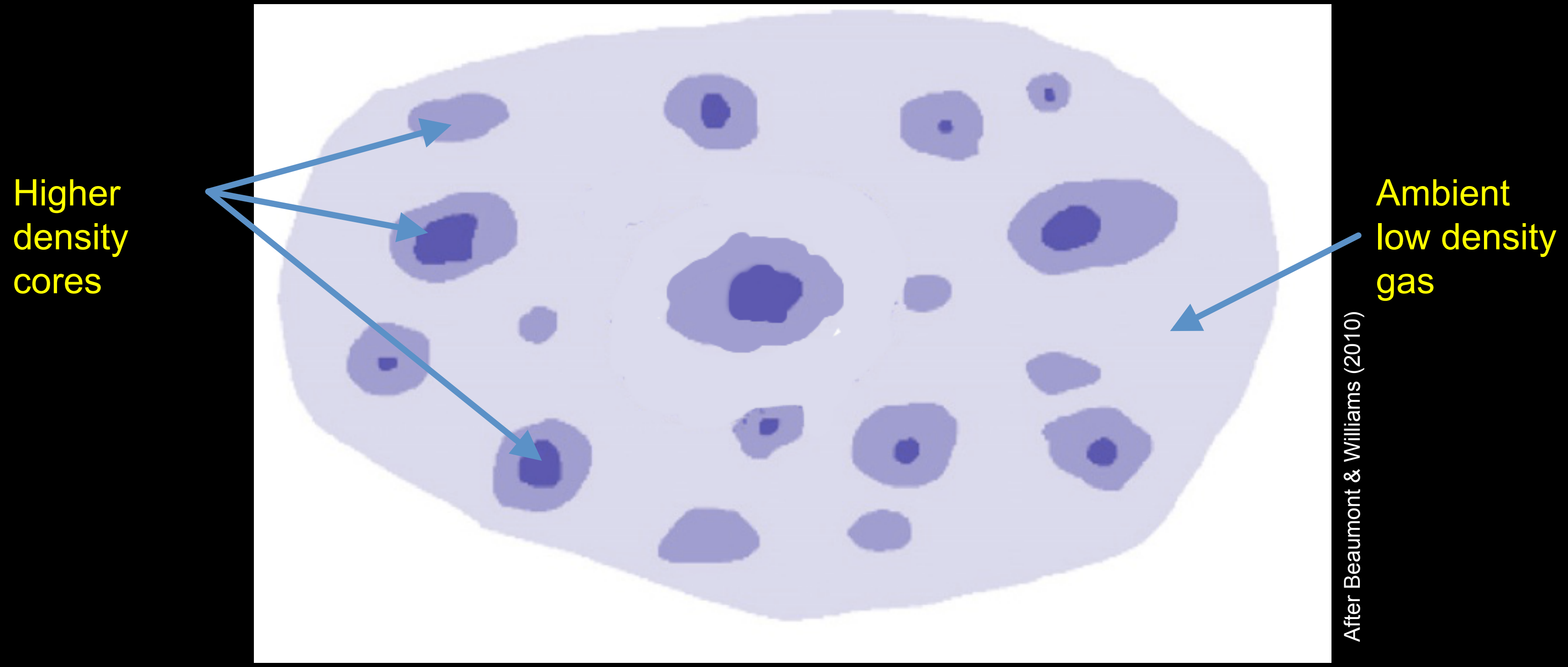
Outline

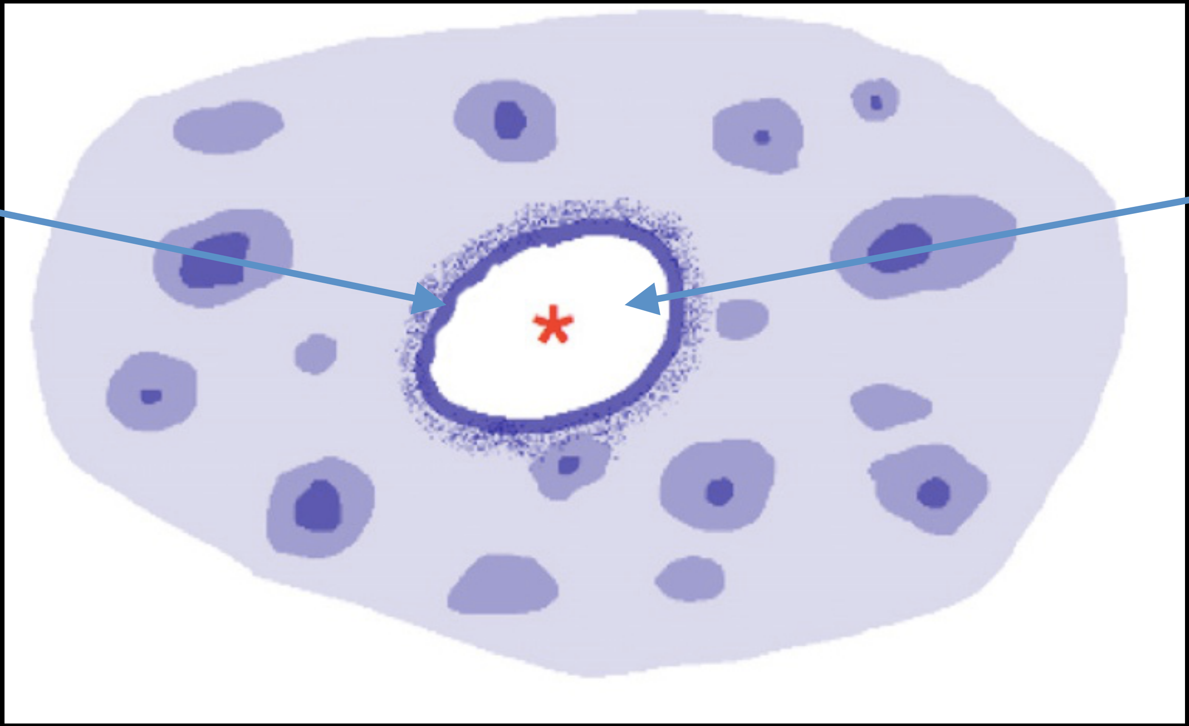
- The Pillars of creation
- Generating a long duration x-ray drive
- Initial Shadow experiments
- Initial Cometary experiment

Where Do Pillars Form?



We start with a molecular cloud, T ~ 10 K, L ~ 10 pc, $n(H_2) \sim 10^2 - 10^4$ /cc , 10^3-10^5 $M_\odot$

Where Do Pillars Form?



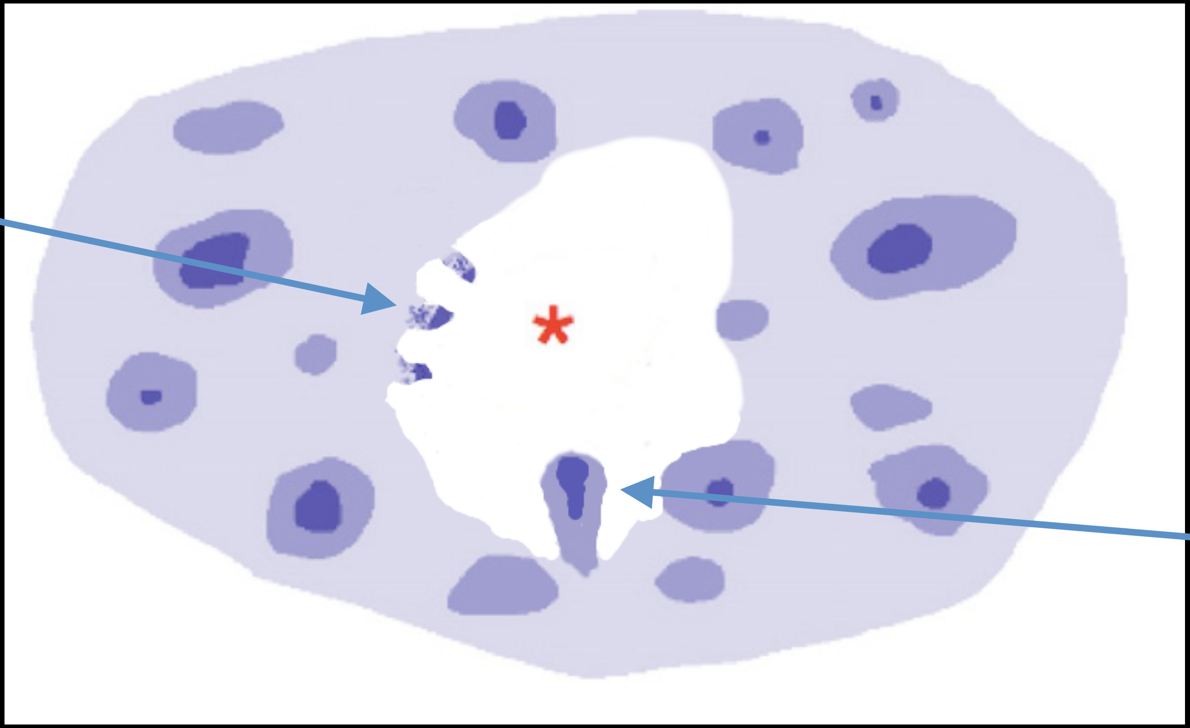
Molecular gas gets compressed and heated.

Fully ionized region
$T \sim 10^4$ K
$n(e) \sim 10^3$ /cc

One or more massive stars (O/B spectral types) form from a dense core. Intense UV radiation creates H II region.

Where Do Pillars Form?

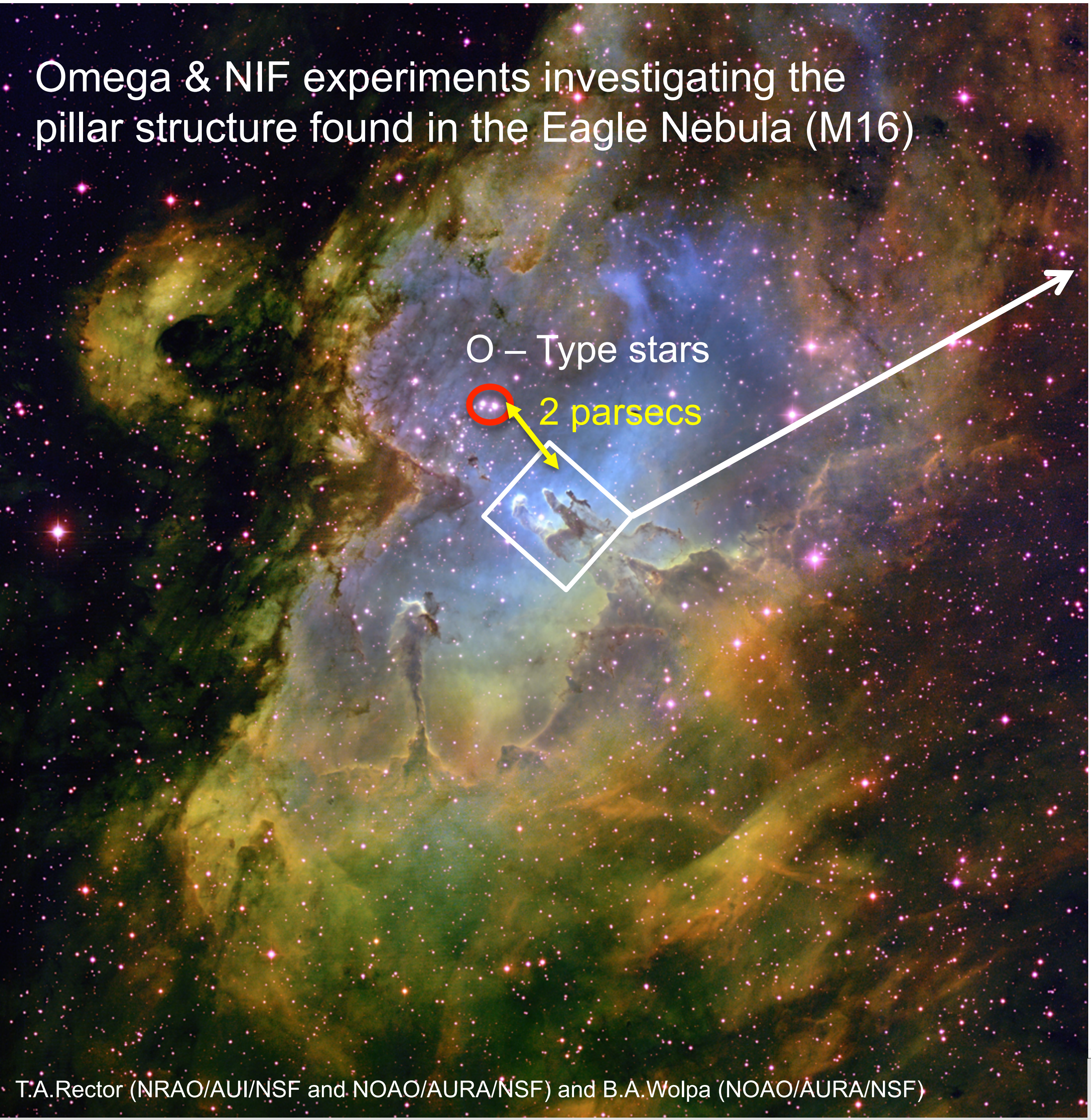
Maybe from a surface perturbation.



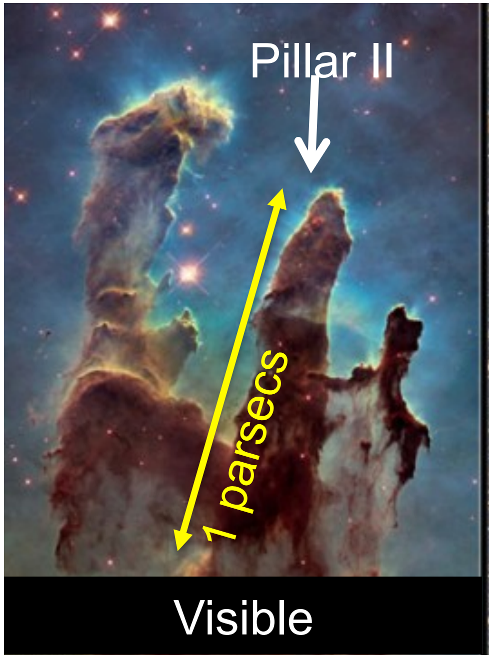
Maybe from a pre-existing dense core

Pillars form from action of ablation, compression, photoevaporation, photodissociation, recombination.

Omega & NIF experiments investigating the pillar structure found in the Eagle Nebula (M16)



T.A.Rector (NRAO/AUI/NSF and NOAO/AURA/NSF) and B.A.Wolpa (NOAO/AURA/NSF)

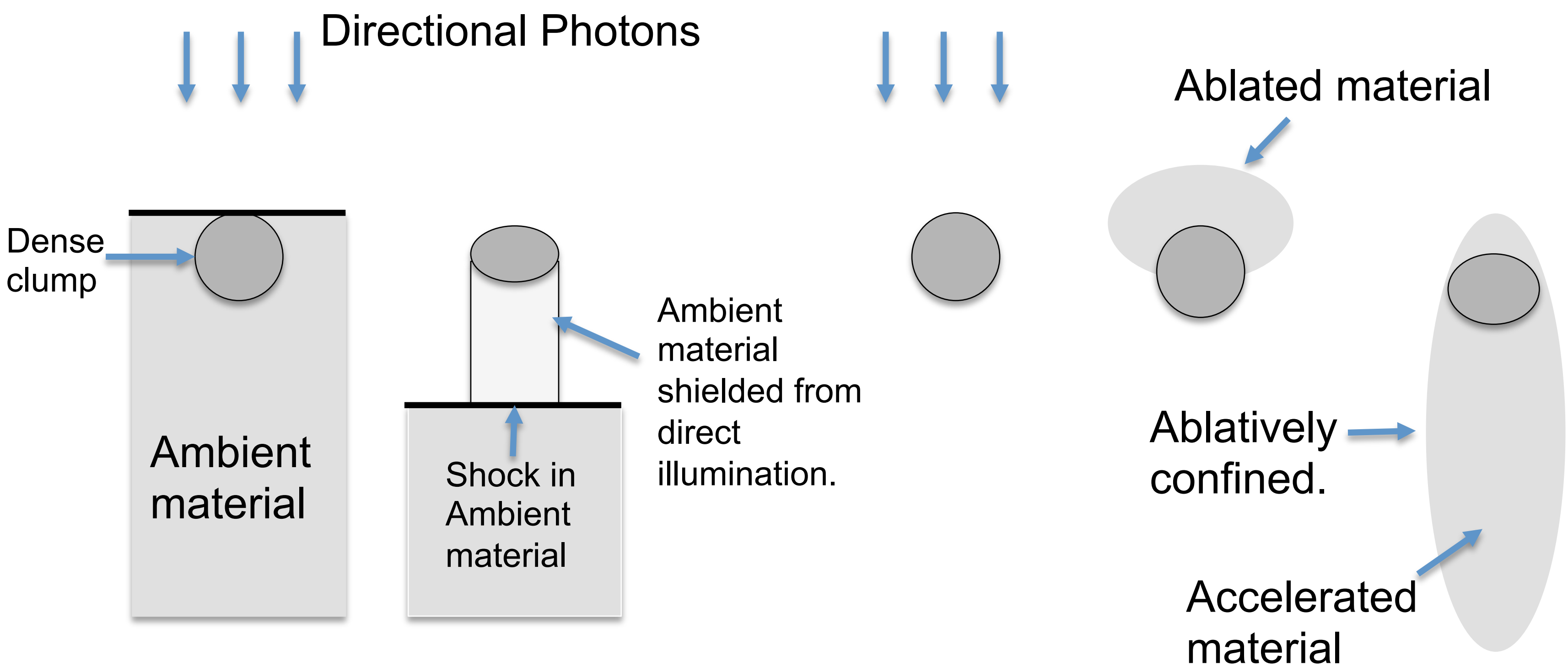


NASA, ESA, and the Hubble Heritage Team (STScI/AURA)

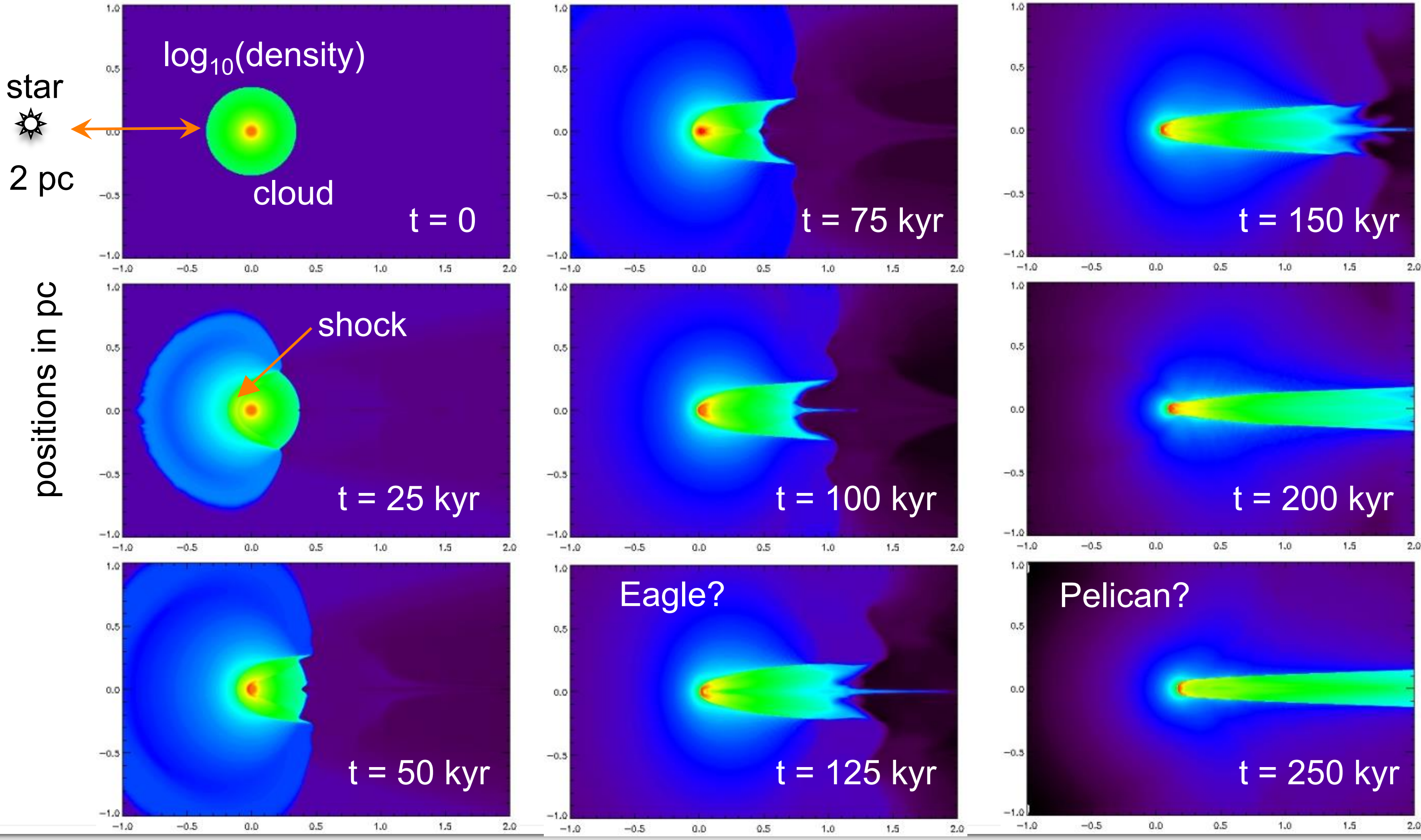
Investigating different models explaining the formation of the Eagle nebula.

Pillar from clump shadow

Cometary model

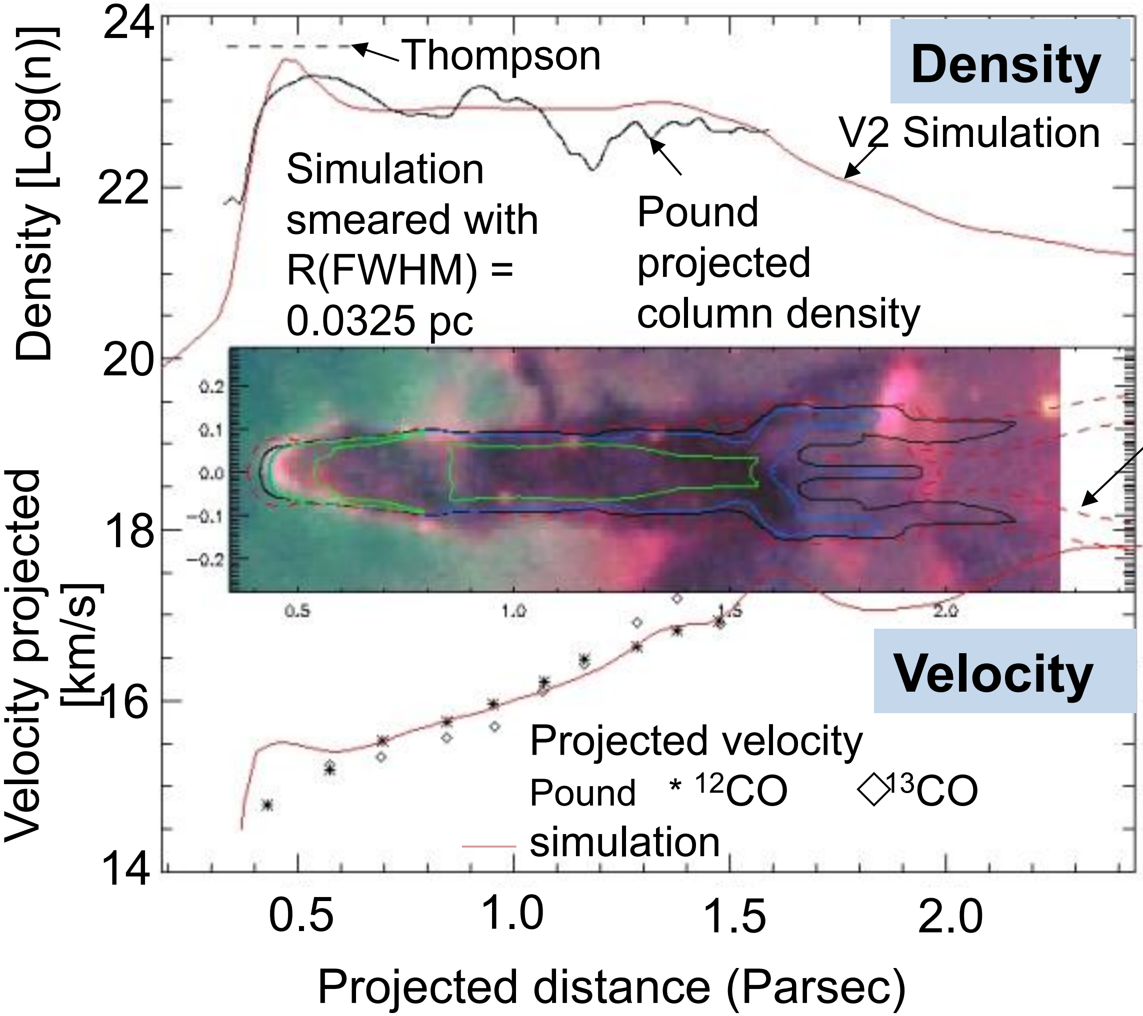


A spherical cloud with a dense core and power law density profile generates a cometary pillar



Kane (2006)

A cometary model can reproduce several aspects of the Pillars



t = 125 kyr
projection angle 26º
Star at *z* = -1.75 pc

Simulated $\log_{10}(n_H)$ contours
3
3.5
4
5

ground-based image

The Hydrodynamics of the pillar was scaled using the Mach number inside the Eagle pillar

- The thickness of the absorbing layer near the surface of the target is small compared to other geometrical dimensions, and details of the absorption become less important.
- The density and structure of the clump drop out since for the cometary model the clump mainly acts to
  - Hold back the head of the comet.
  - Provide a reservoir of material that releases down to a low density determined by the drive flux.

Under such circumstances, the similarity between the two systems requires a similar value of the parameter

$$A = \frac{\tau^*}{L^*}\sqrt{\frac{p^*_{\mathrm{abl}}}{\rho^*}}$$

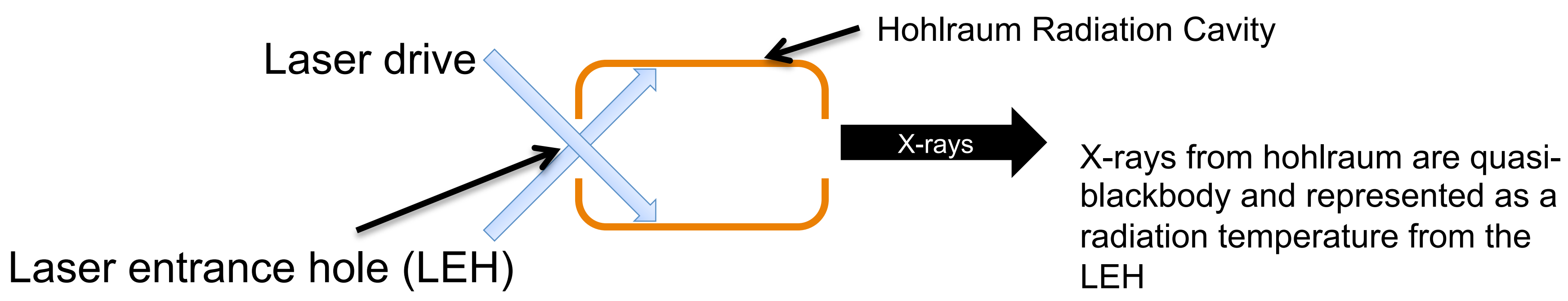
where p_{abl}, ρ^*, L^* and τ^* are the characteristic ablation pressure, density, scale length, and time for evolution. As shown in the following table, the scaling is reasonable.

Parameter	Eagle pillar	Laboratory experiment
L^* (cm)	3E+18	0.1
p_{abl} (dyne cm^{-2})	5E-09	1e+10
ρ^* (g cm^{-3})	5E-21	10e-3
τ^* (s)	4e+12	1.0e-07
A	**1.33**	**1**

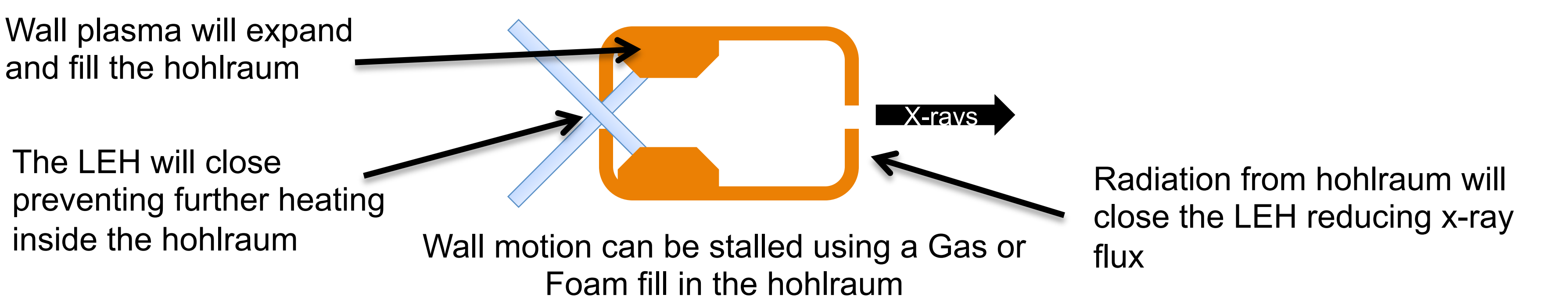
D.D. Ryutov and B.A. Remington, "Scaling astrophysical phenomena to high-energy-density laboratory experiments," Plasma Phys. Control. Fusion 44, B407 (2002). D.D. Ryutov, B.A. Remington, H.F. Robey and R.P Drake, *Phys.Plasmas* 8, 1804 (2001)

Laser driven hohlraums will eventually close due to plasma expansion reducing the x-ray drive.

Initial heating of a hohlraum

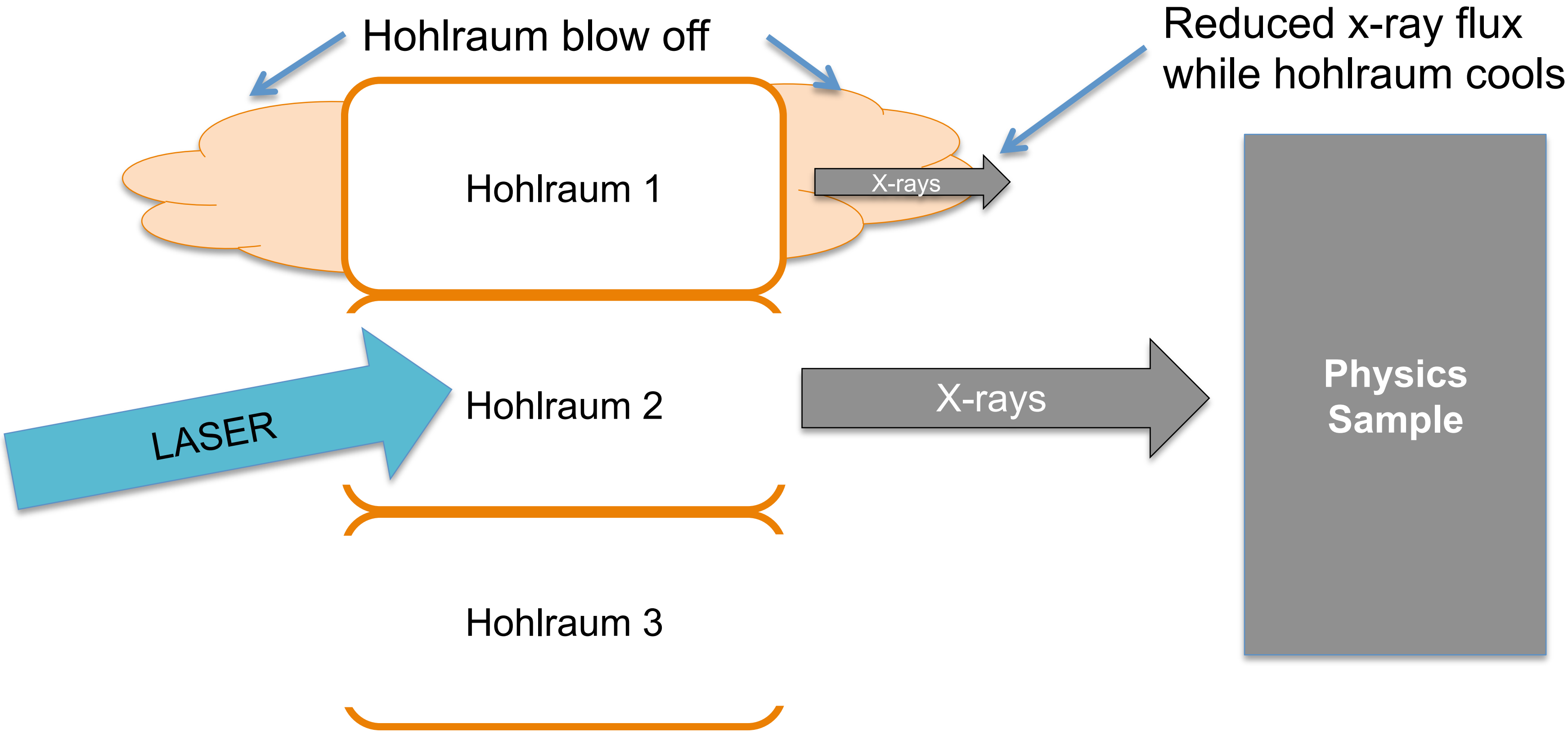


Late time behavior of hohlraum (~10ns)



Dewald et al Phys Rev Lett. (2005)

The multi-hohlraum approach to long duration x-ray sources.

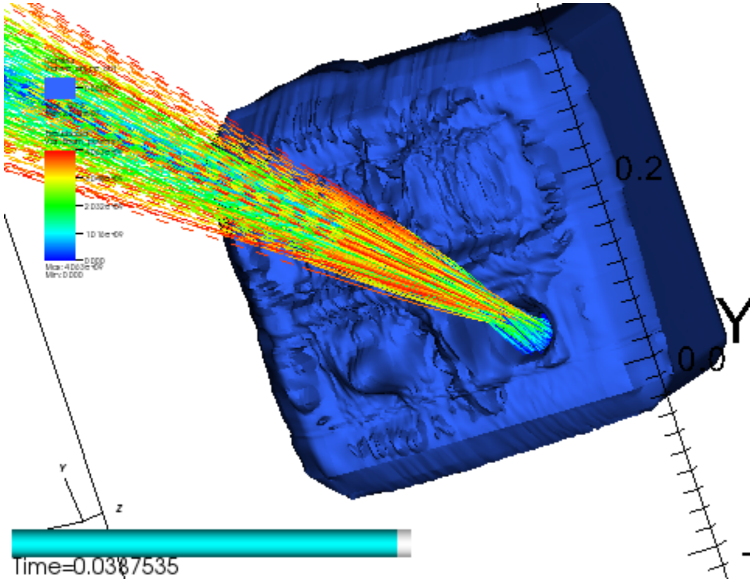


One method to overcome hohlraum closure is to heat multiple hohlraum cavities in succession.

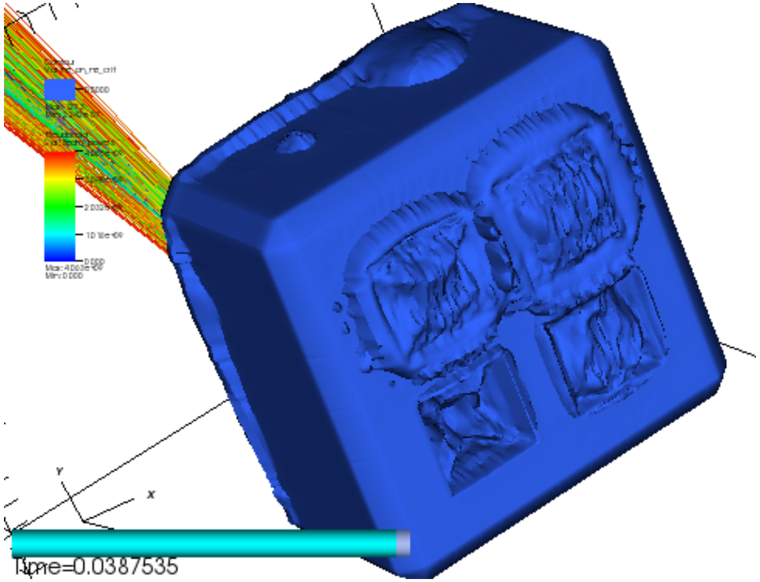
The position of the 50% critical surface suggests the ablative plumes do not interfere with the other hohlraums

t = 39 ns

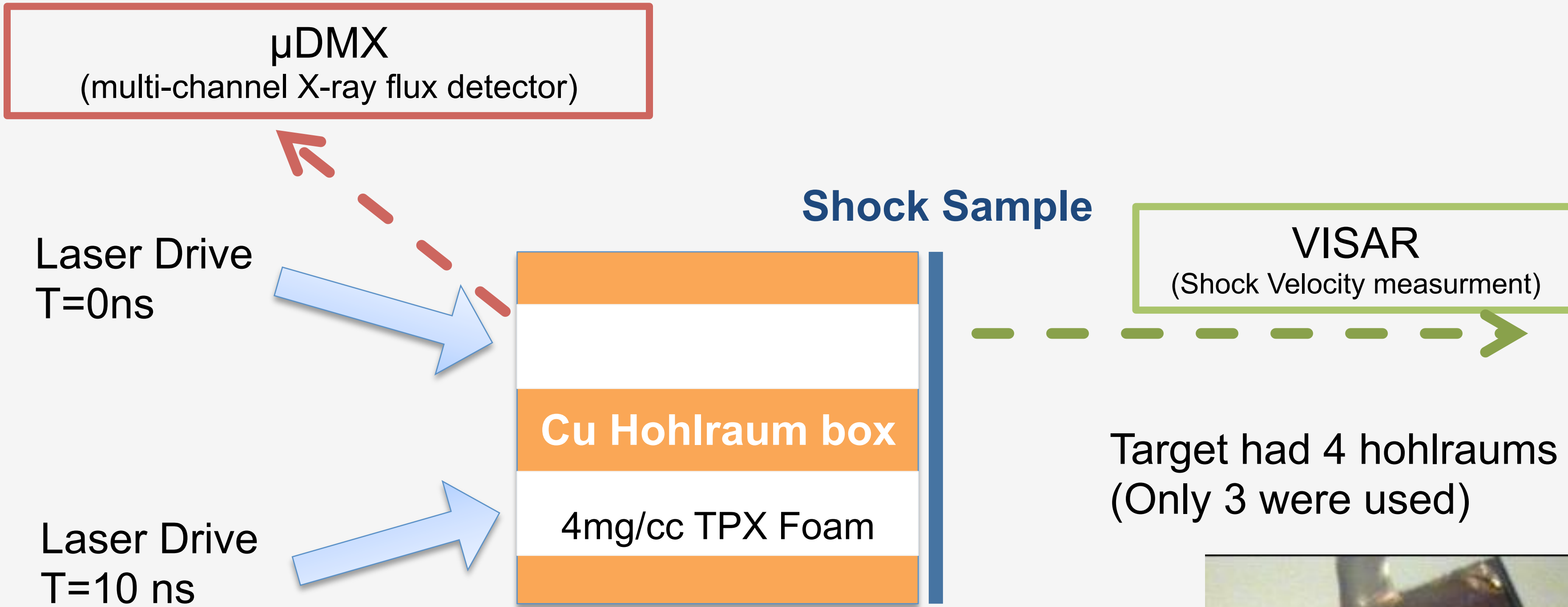
Beam side



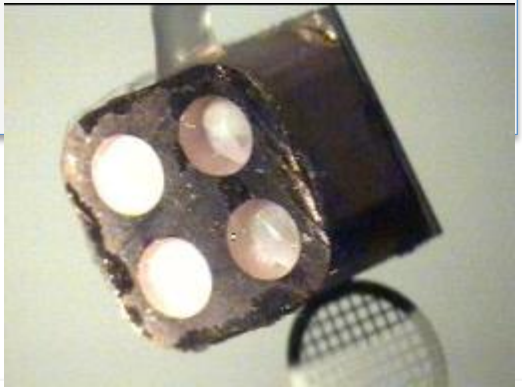
Back side



Hohlraum performance was diagnosed using shock velocity and X-ray flux detectors.



Target had 4 hohlraums
(Only 3 were used)



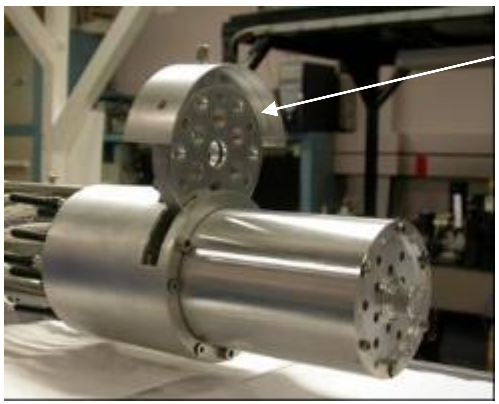
Hohlraum driven with 3 UV Laser beams on Omega EP
Pulse: 10ns for 30 ns drive
Energy per hohlraum : 4kJ

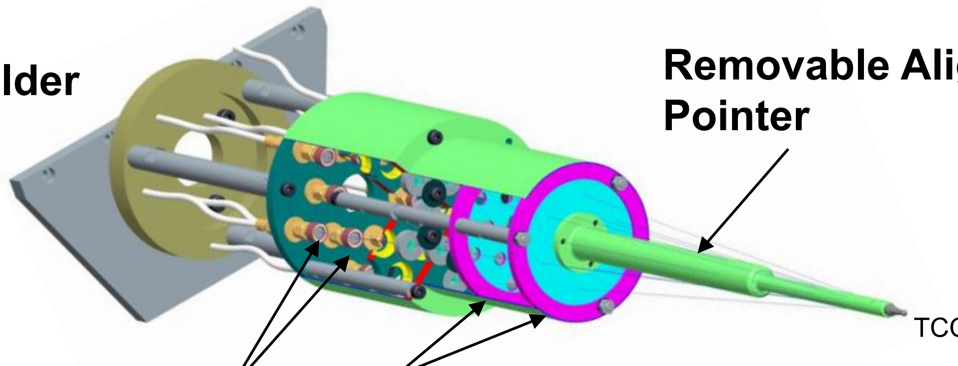
Diameter: 1.4mm
Length: 2.8 mm
Foam Fill: 4mg/cc
TPX (CH2)

µDMX diagnostic

µDMX is a broadband channel spectrometer designed for X-ray power measurement

- Is composed by 12 channels equipped by filters and XRDs
- Distance XRD / TCC : 500 mm with FOV is Ø 5 mm
- The 12 signals are recorded by 3 Digital Signal Oscilloscopes (Agilent 4 Ghz).

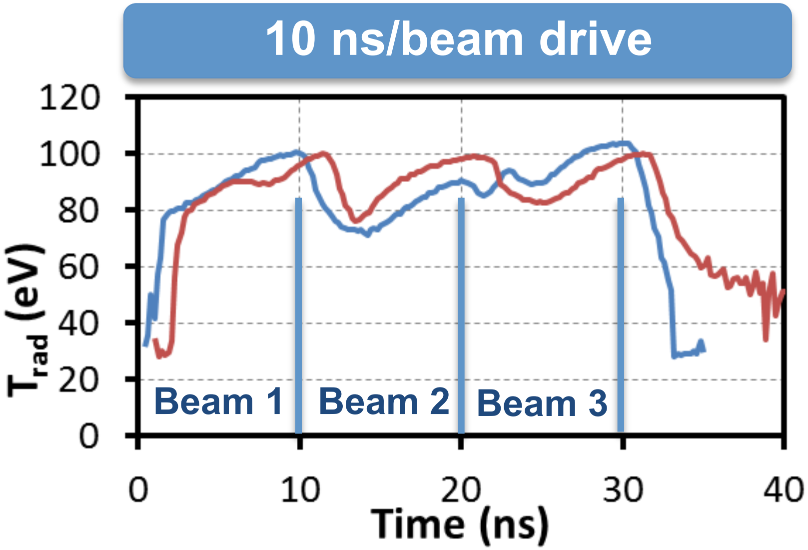


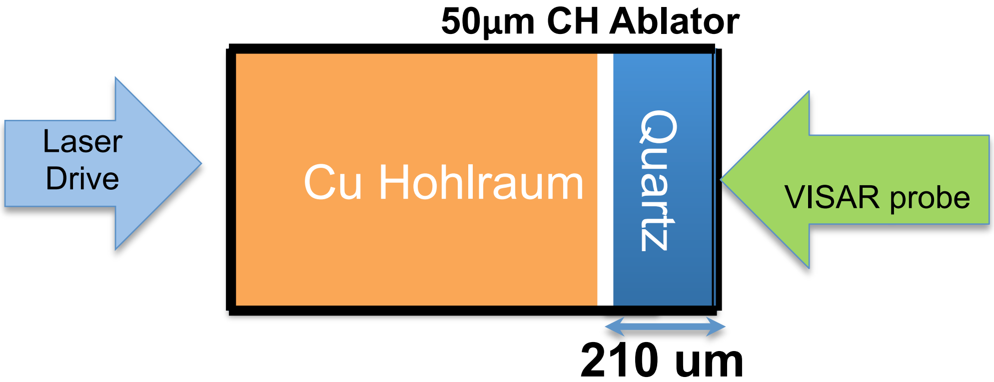


µDMX 8 channel configuration for Gatling gun campaign

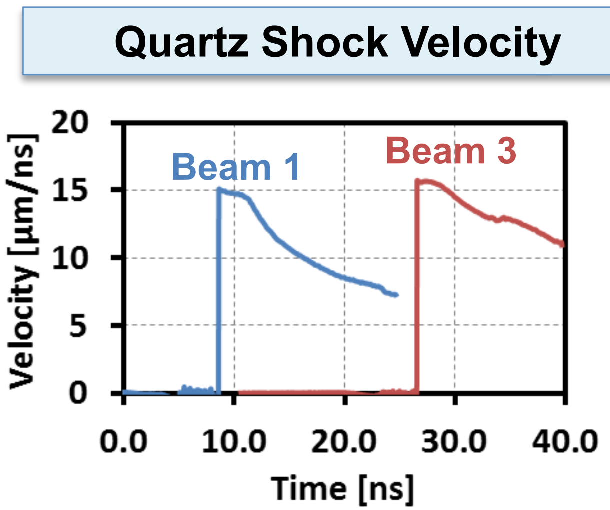
Channel	1	2	3	4	5	6	7	8
Filter Thickness	Al 2 µm	B/Lexan 2 µm / 0.2µm	Mylar 6 µm	Ti 2 µm	V 2 µm	Fe 2 µm	Ni 2 µm	Cu 2 µm
Energy range (eV)	35 – 75	130 - 188	230 - 280	350 - 450	415 - 510	570 - 710	690 - 850	730 - 930

Flux and shock velocity measurements give consistent results for the hohlraum drive





Laser Energy	Laser Pulse	X-ray width	$\langle T_r \rangle$	Peak Tr
4.3 kJ/beam	10 ns	30 ns	90 eV	102 eV



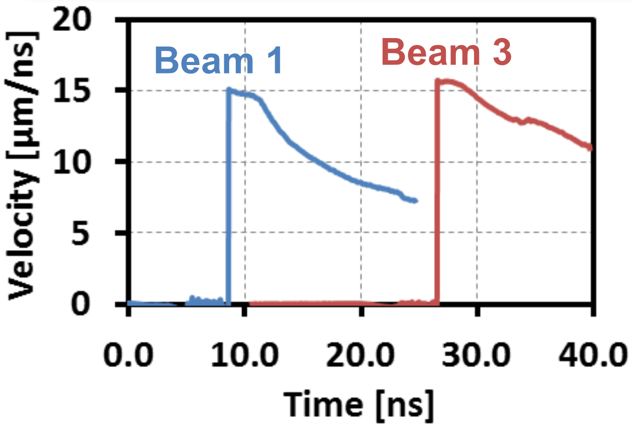
Hohlraum	Peak U_S (µm/ns)	Peak T_R (eV)
10 ns (First)	14.8 $\pm$ 0.1	99
10 ns (Last)	15.6 $\pm$ 0.1	102

Early and late time observations do not show a reduction in x-ray drive due to hohlraum cross talk.

Hohlraum cross talk includes:

1. Plasma plume interference blocking laser light into the next hohlraum
2. Shocks breaking into the adjacent hohlraum, causing early hohlraum closure.

30 ns drive



Hohlraum temperature from shock velocity measurements

For Quartz sample

$$T_r = 21.4 u_s^{0.57}$$

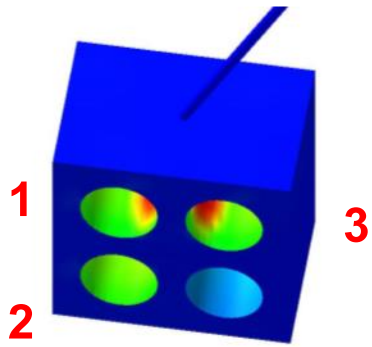
Olson et al. Rev Sci instrum. 2006

Peak shock velocity in quartz corresponds to peak radiation temperature

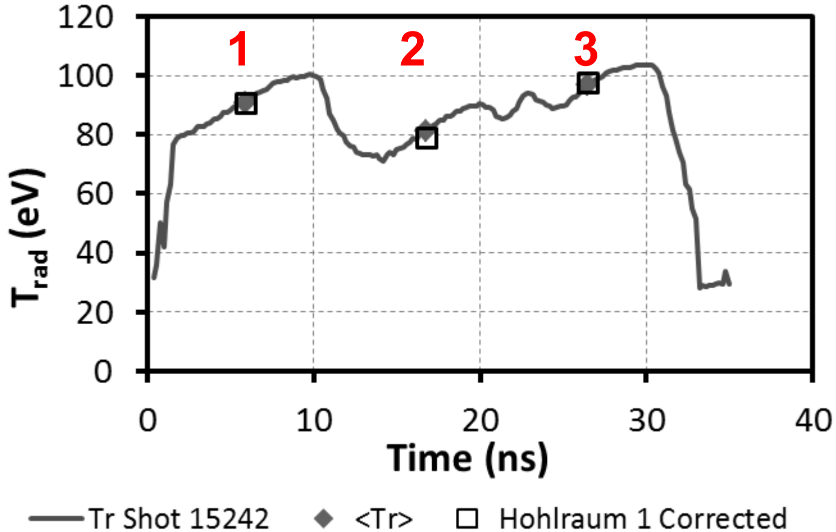
Hohlraum	Peak U_S (µm/ns)	Peak T_R (eV)
10 ns (First)	14.8 $\pm$ 0.1	99
10 ns (Last)	15.6 $\pm$ 0.1	102

The position of the Laser spot relative to μDMX line of sight explains temperature variation

Predicted emission from VisRad*



Hohlraum heated in succession produce different Views for uDMX



Time in terms of start of first beam

The average T_R of first hohlraum matches well with 2nd and 3rd hohlraum when adjusted for the view factor.

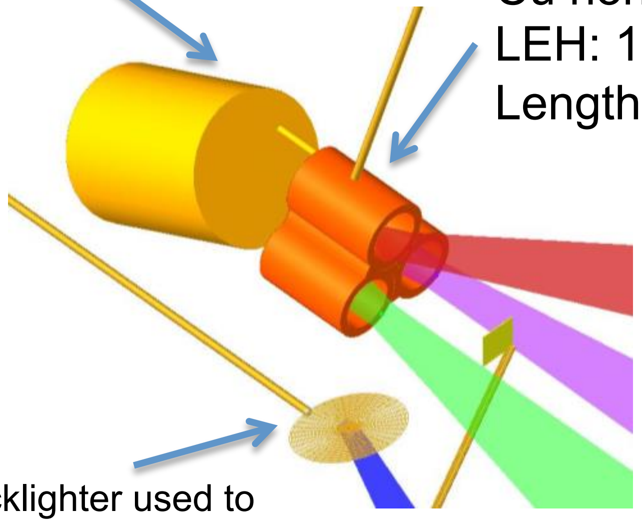
Variation in laser energy between beams also contributes to the different temperatures.

*product of Prism Computational Sciences Inc.

Omega EP is able to test the concept of driving a hydrodynamic flow using the long duration x-ray source

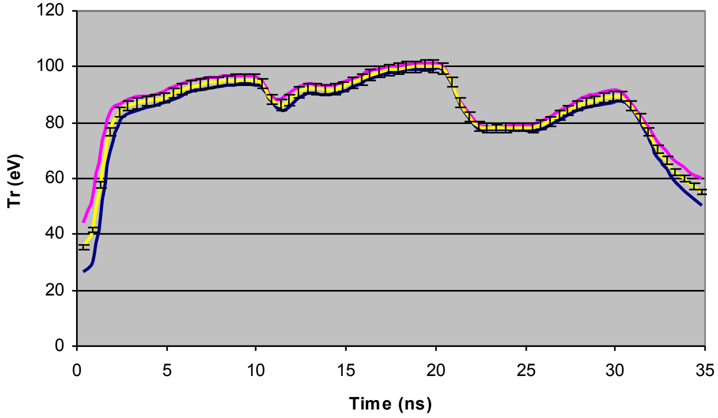
RF Foam with embedded CH "clump"

Cu hohlraum
LEH: 1.4mm
Length: 2.8mm



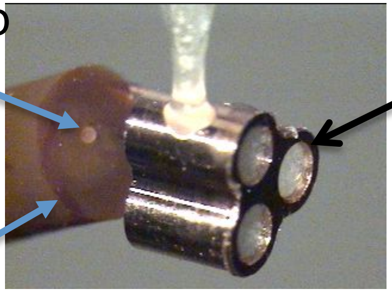
Ti backlighter used to image foam target at 35ns

X-ray measurement from laser side of hohlraum



Actual target

Solid density clump



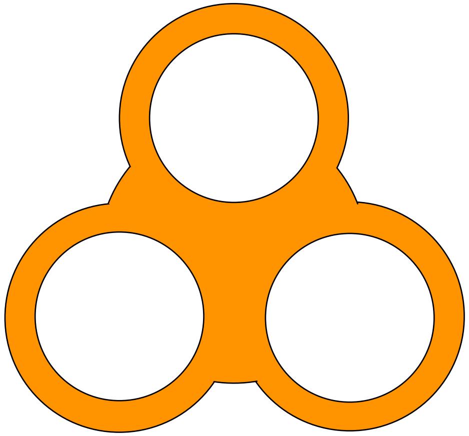
TPX foam fill

Foam angled to accommodate viewing angle for diagnostic.

The debris from the hohlraum array is problematic.

Damage to VSG snout
From previous experiment in TIM 14

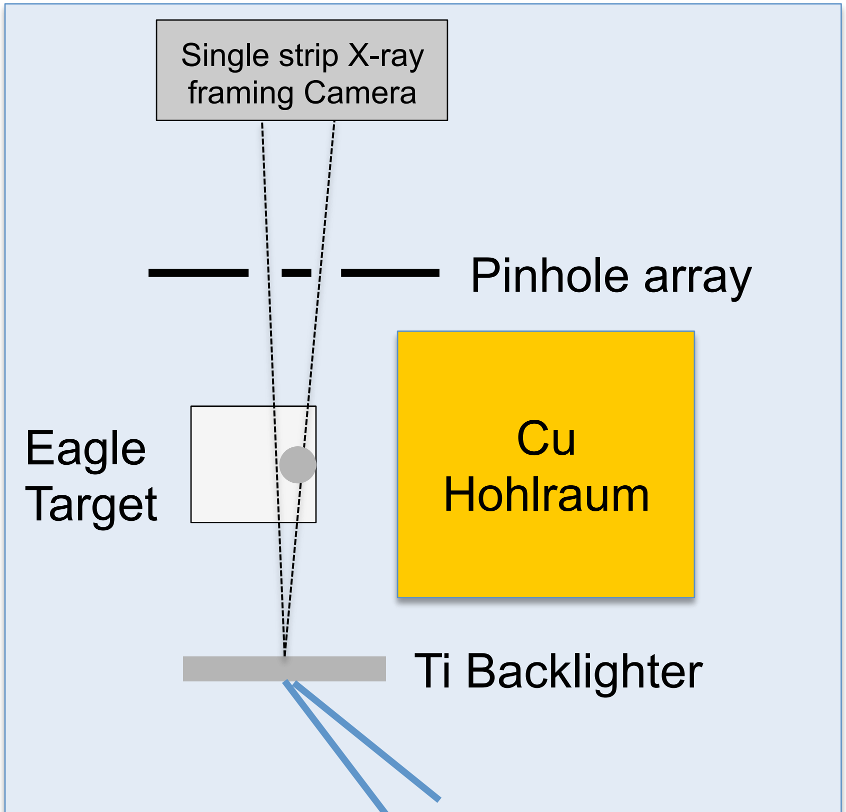
Previous hohlraum Design



Current design

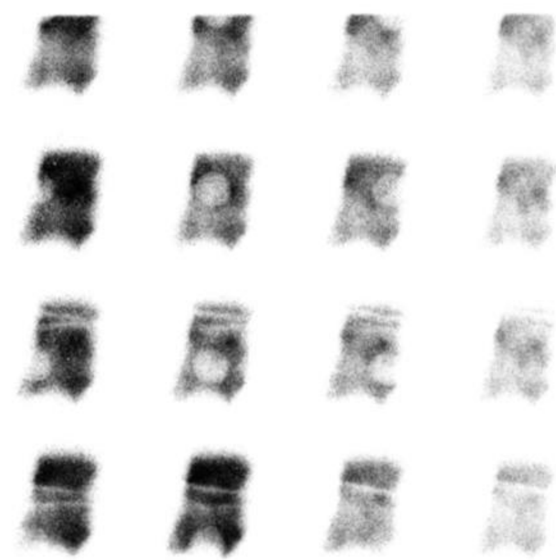
Debris from the hohlraum prevents us from using point projection radiography

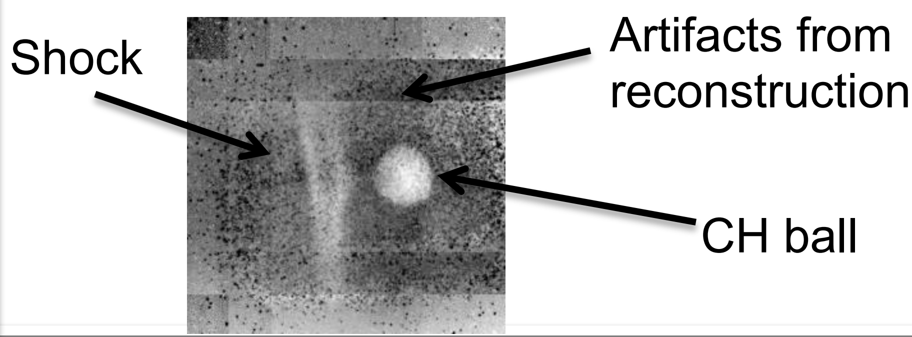
Area backlighter used multiple pinholes to increase FOV.



Backlighter:
1ns UV 500μm spot size
1250kJ

4x4 pinhole images

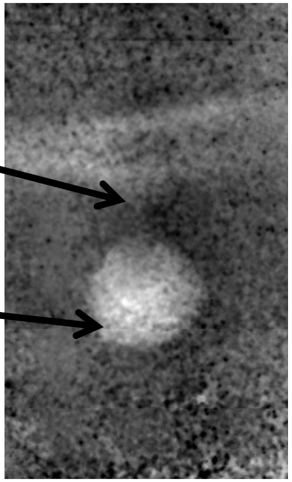


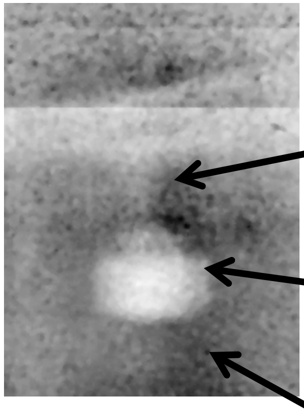


Increased energy and reduced foam density shows more evolution.

Faint evidence of tail

Increased density to front of ball



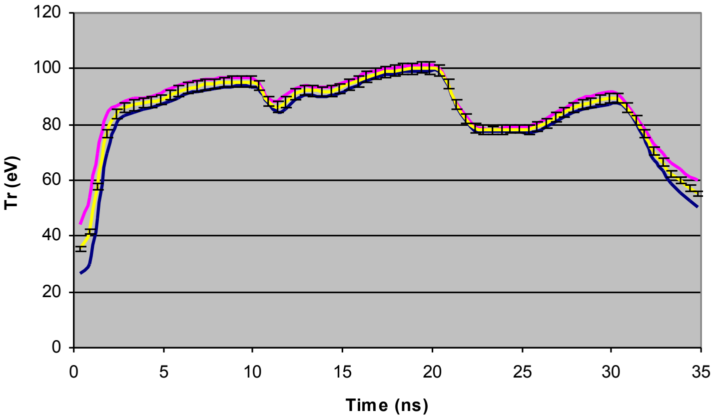


Better formation of tail

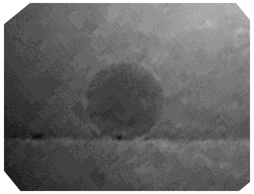
Material from surface is swept behind ball.

increased energy shows ball crushing

Mini DMX extracted source radiation temperature

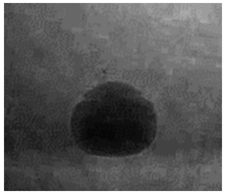


Pre shot Radiographs



$$\rho_{RF} = 52.5\frac{mg}{cc}$$

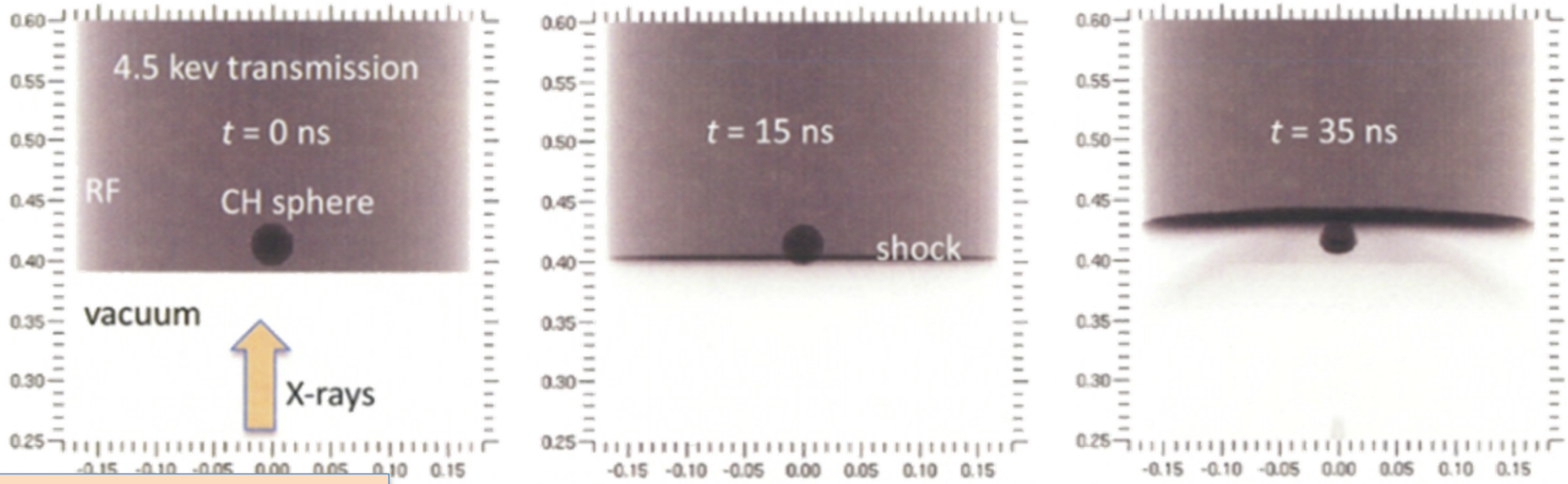
E = 11.1 kJ



$$\rho_{RF} = 48\frac{mg}{cc}$$

E= 12.4kJ

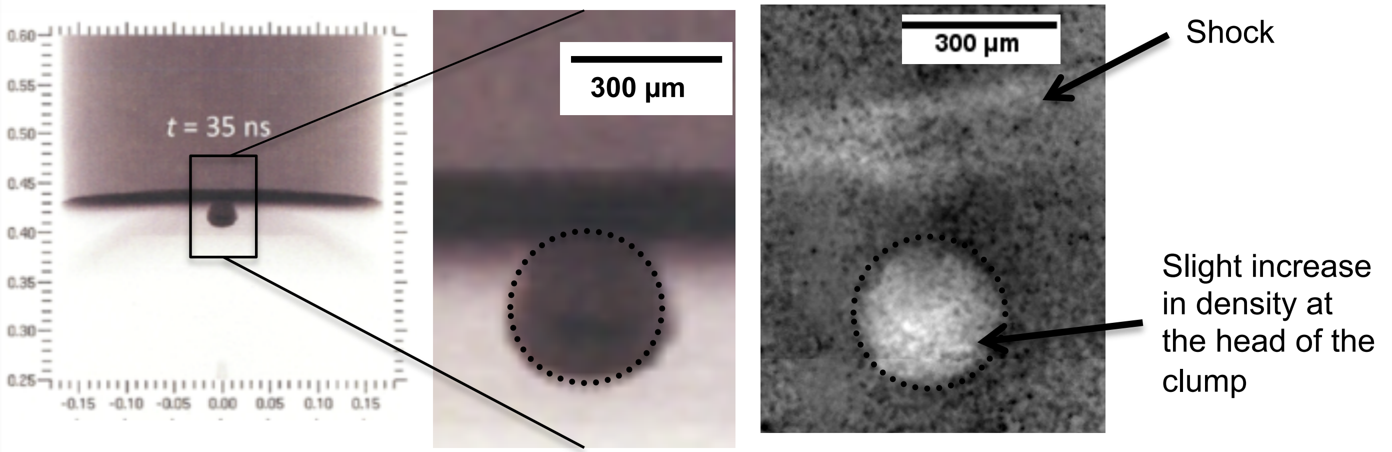
Simulations with a 56mg/cc RF foam with a 370μm diameter ball show the shock just passing the clump.



2D Hydra simulations

Hohlraum Drive
Length: 2.8mm
LEH: 2mm
Energy 12.9kJ
Pulse length: 20ns

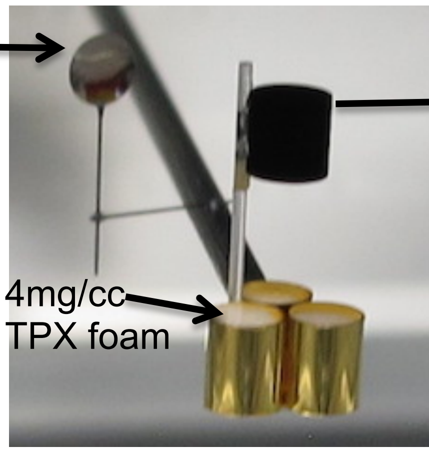
1g/cc CH Clump in
50mg/cc CH foam



Discovery science experiments on NIF used the hohlraum and backlighting designs developed on Omega EP

Ti Backlighter

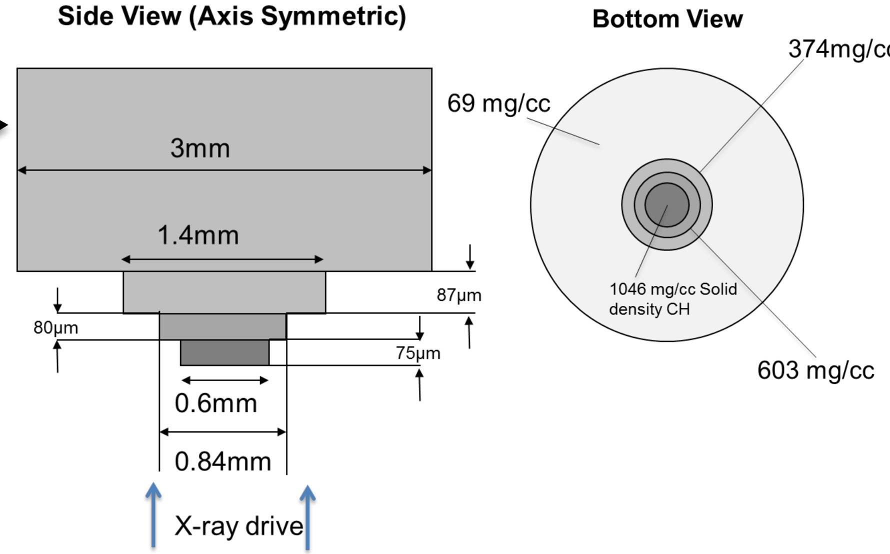
Foam to source distance 5mm-8mm



Laser Drive

3x Hohlraum array "TriStar"
Inner Diameter: 2.7mm
Height: 3.5mm
Material: Au
Fill: 4mg/cc TPX foam

Foam Stack



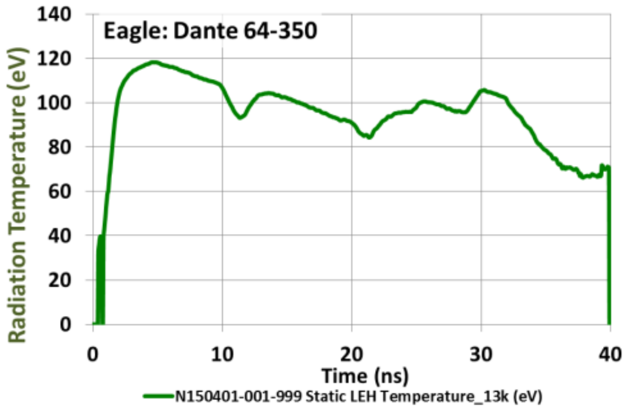
Foams stack acts as a density gradient around a clump.

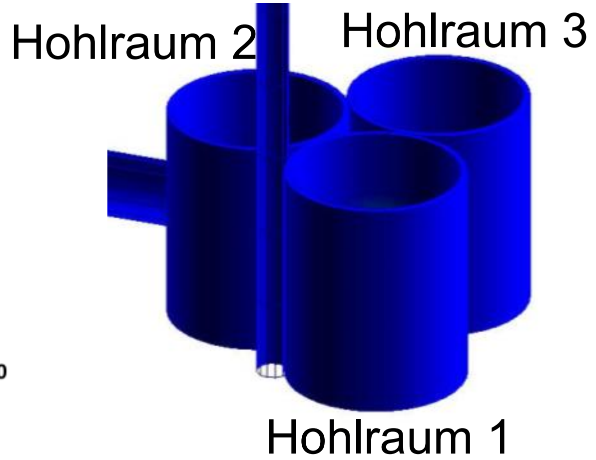
NIF was able to reproduce the results from Omega EP.

Upper Dante (Target side)

100eV radiation temperature over 30ns on the Foam side of the target

Lower Tr is expected since Upper Dante does not see the laser hotspots.

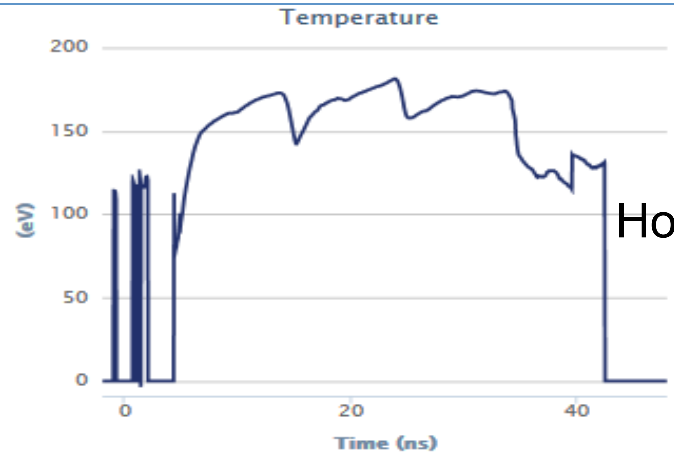


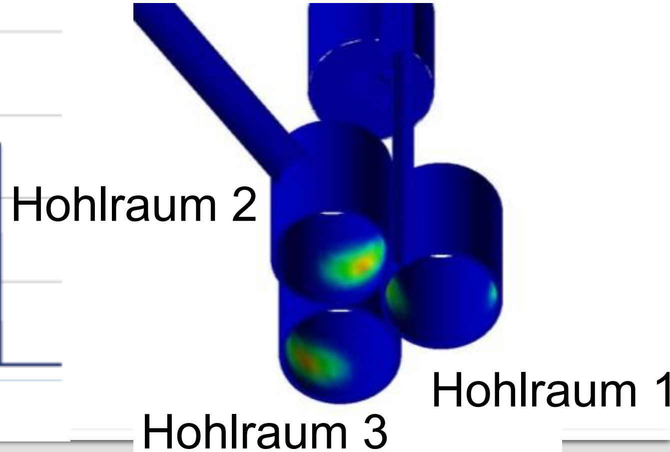


Lower Dante (Laser side)

A Tr > 150eV was observed for lower Dante

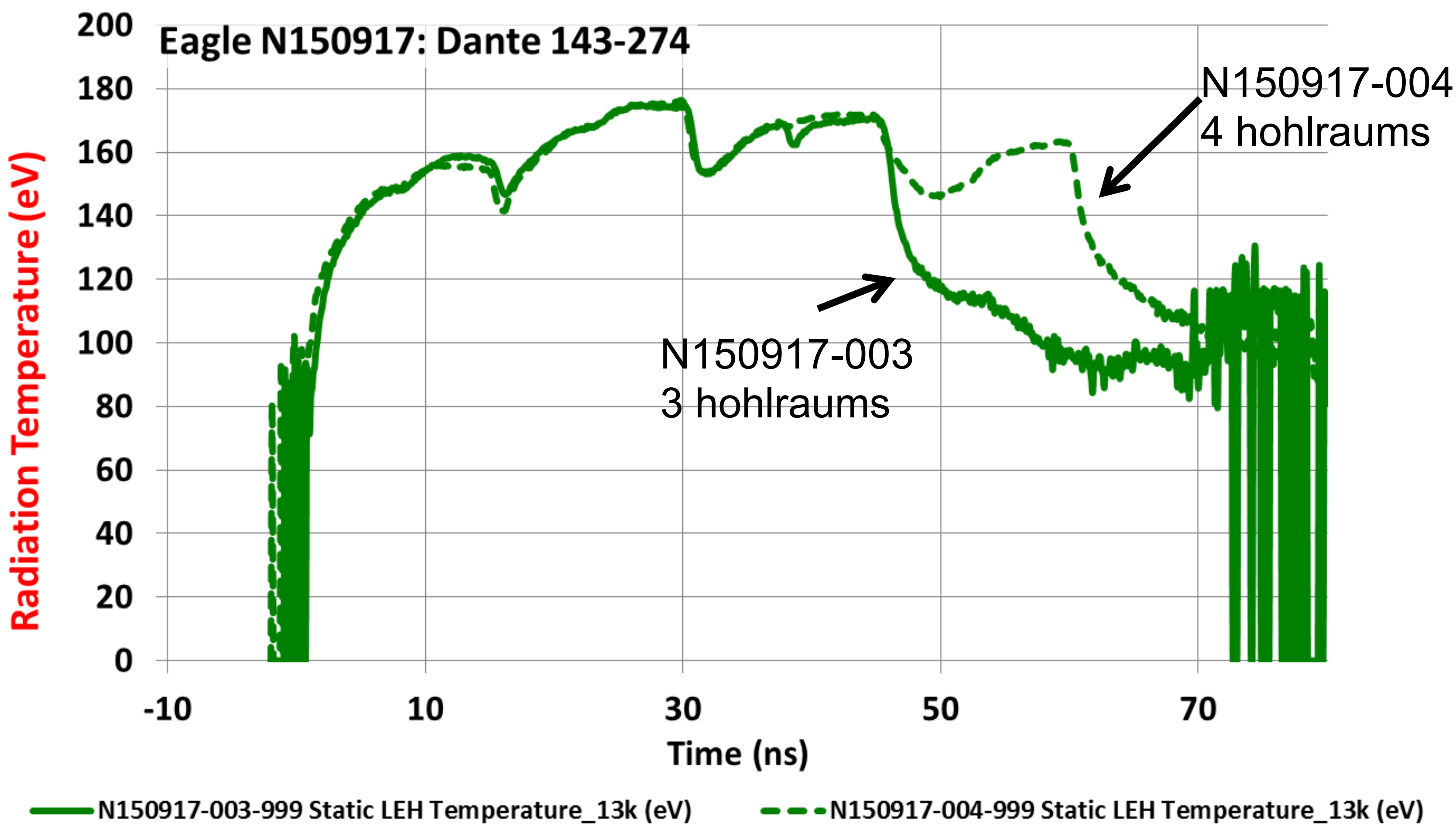
Variation in the peak Tr is expected due to the different hotspot views for each hohlraum.





Dante Analysis by Alastair Moore

Four hohlraum drive was able to create a 60ns ~160eV x-ray source.

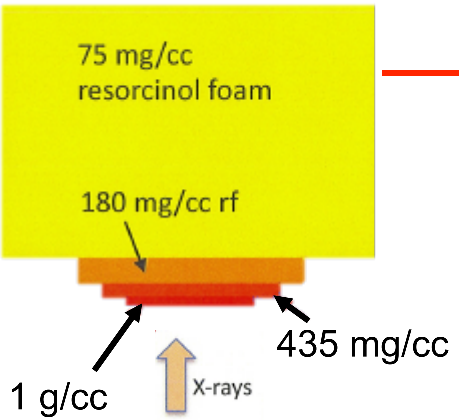


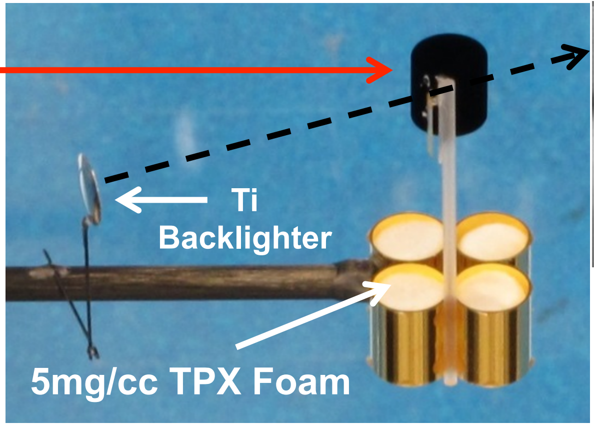
Dante Analysis by Alastair Moore

Special thanks to: Bart Beeman and Bob Chow for setting up the 100ns Dante

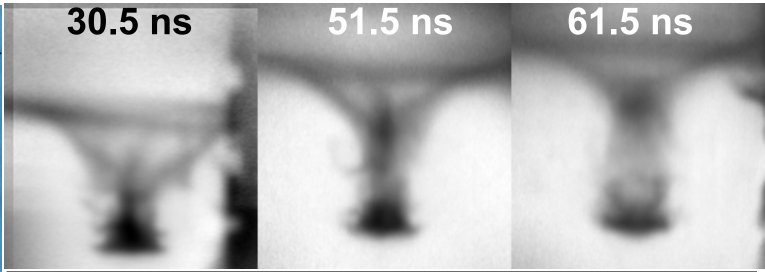
Eagle Nebula experiments are exploring the evolution of the "Pillars of Creation" on the NIF

Target design for creating a pillar



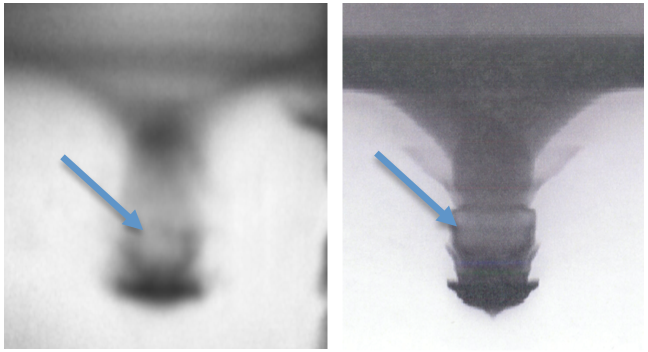


Radiographic data

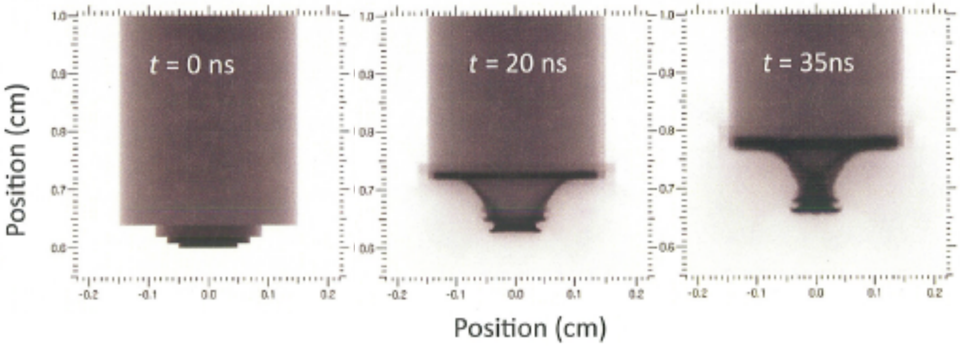


Converging plasma rebounds creating a low density bubble

Data at 61.5ns **HYDRA @ 60 ns**

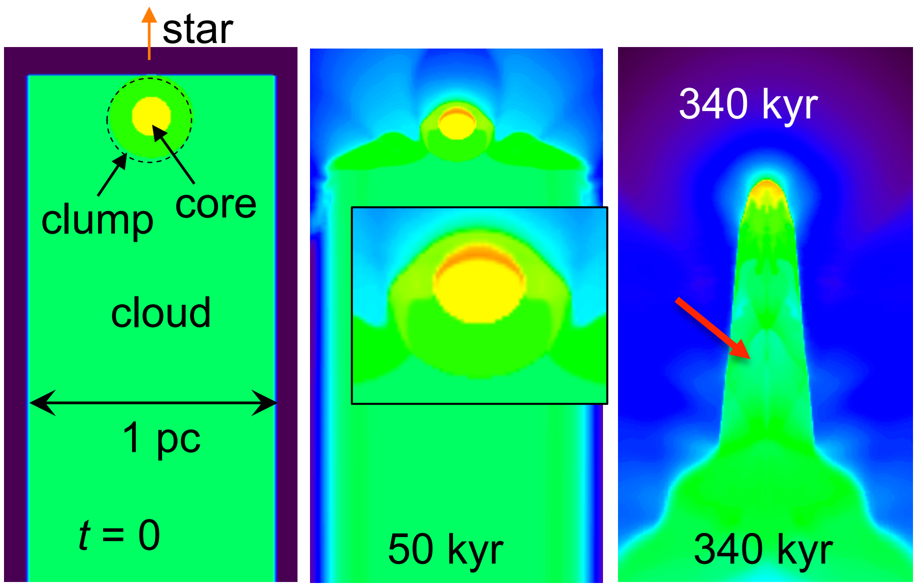


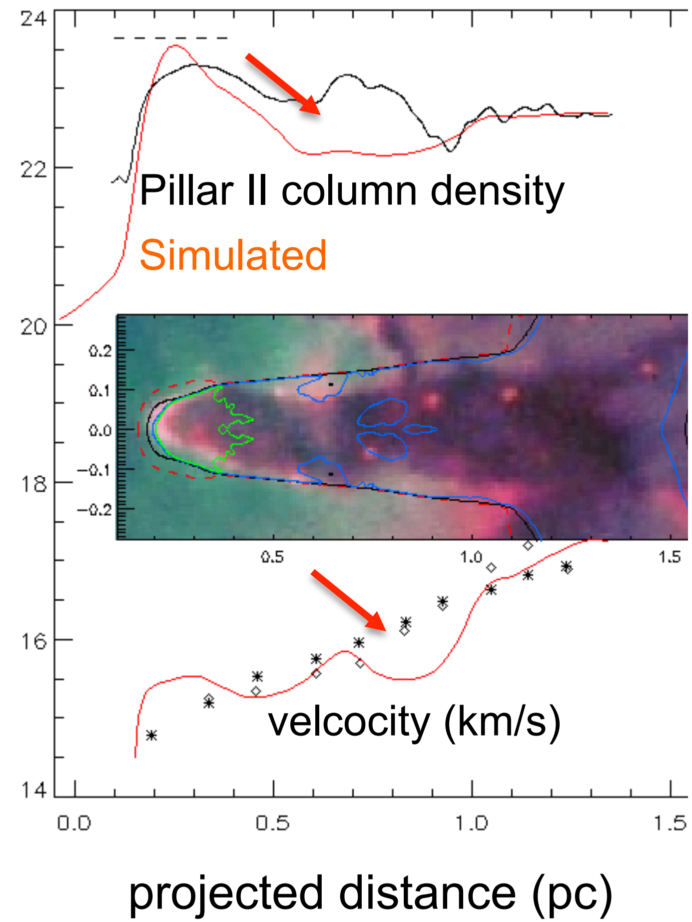
HYDRA 2D simulations



A multi-hohlraum array was used to drive an ablative pillar for 60ns

Astrophysics simulations show that the shadow model tested does not match the measured profiles.

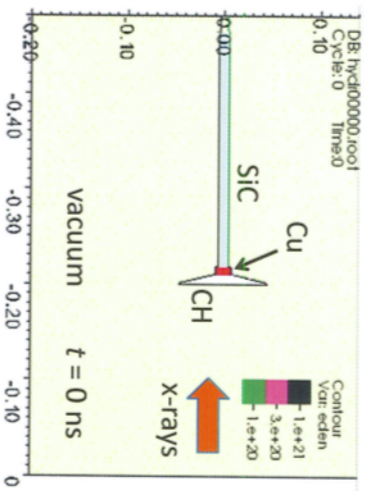




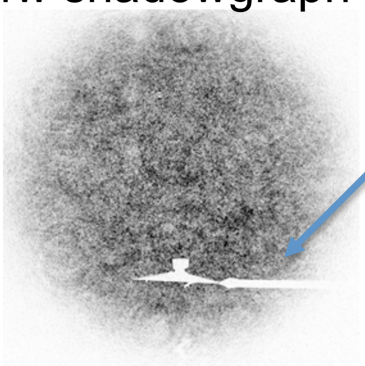
(1) Long background cloud
- shocked clump separates from the shocked background material, leaving a significant deficit of column density in the middle of the pillar.

Investigating the cometary model requires us to probe a lower density plasma.

Eagle Target



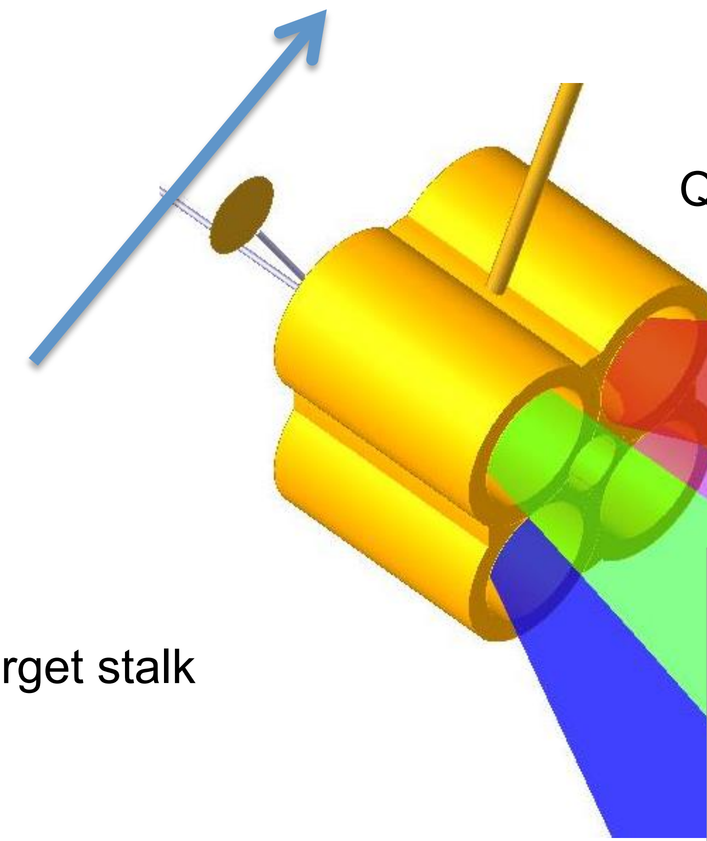
4w shadowgraph



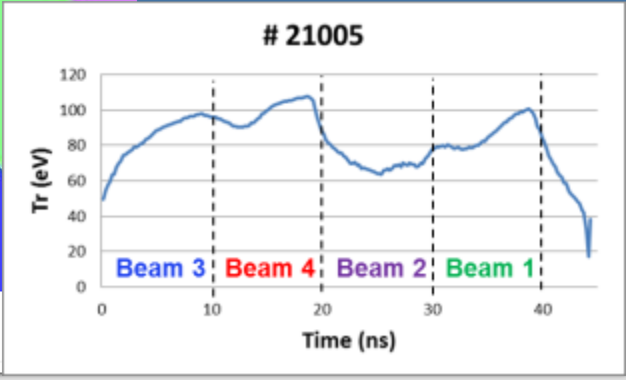
Target stalk

4w Probing direction

QuadStar

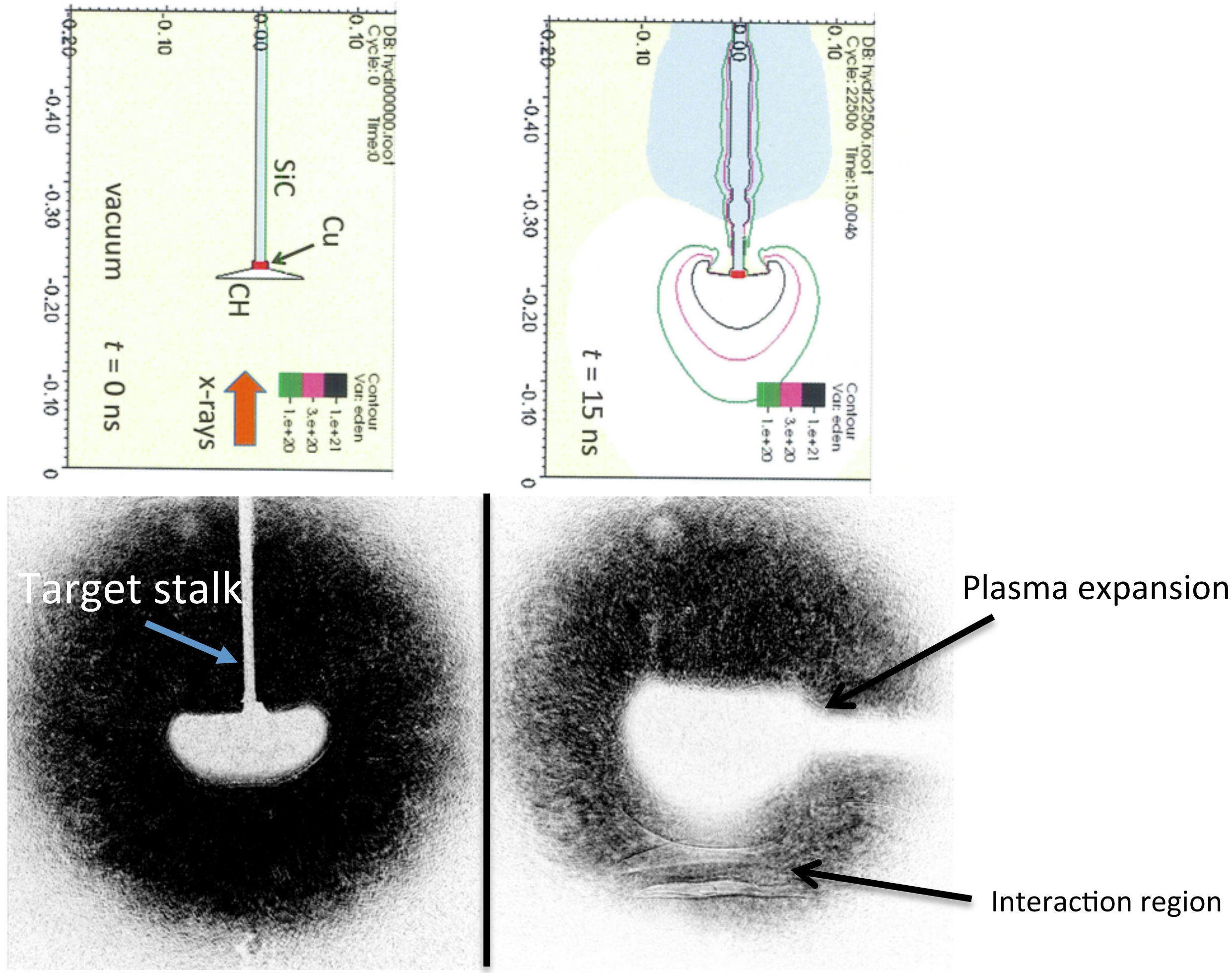


miniDMX



Between 10-20 ns in time we see the pre-pillar evolution

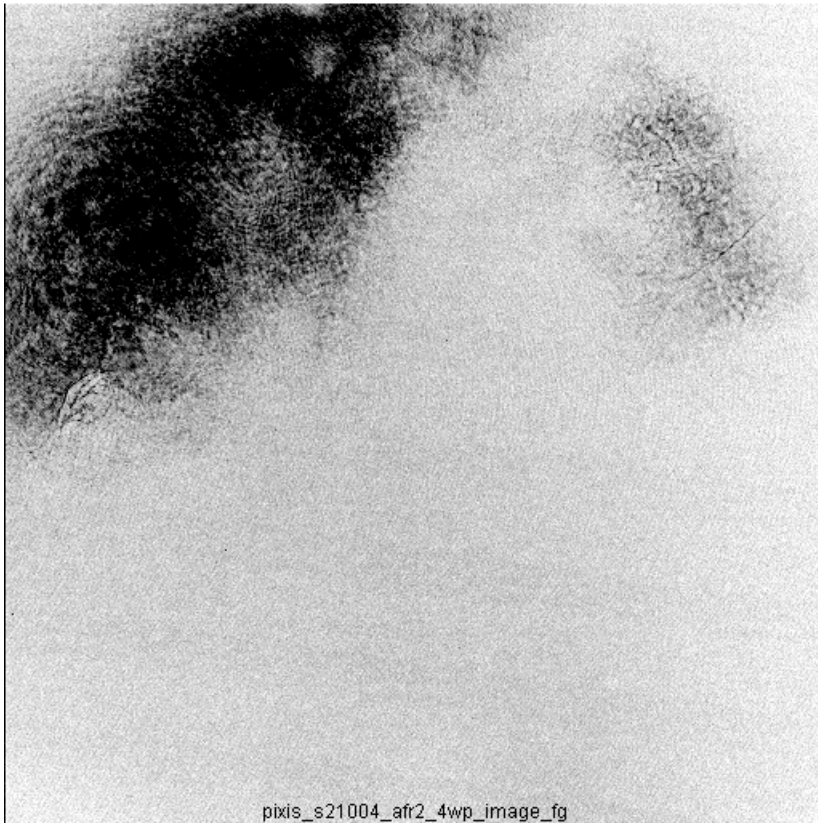
Eagle target was stood off by 3mm from hohlraum source and earlier in time to assess the initial plasma expansion from the Eagle target and the hohlraum



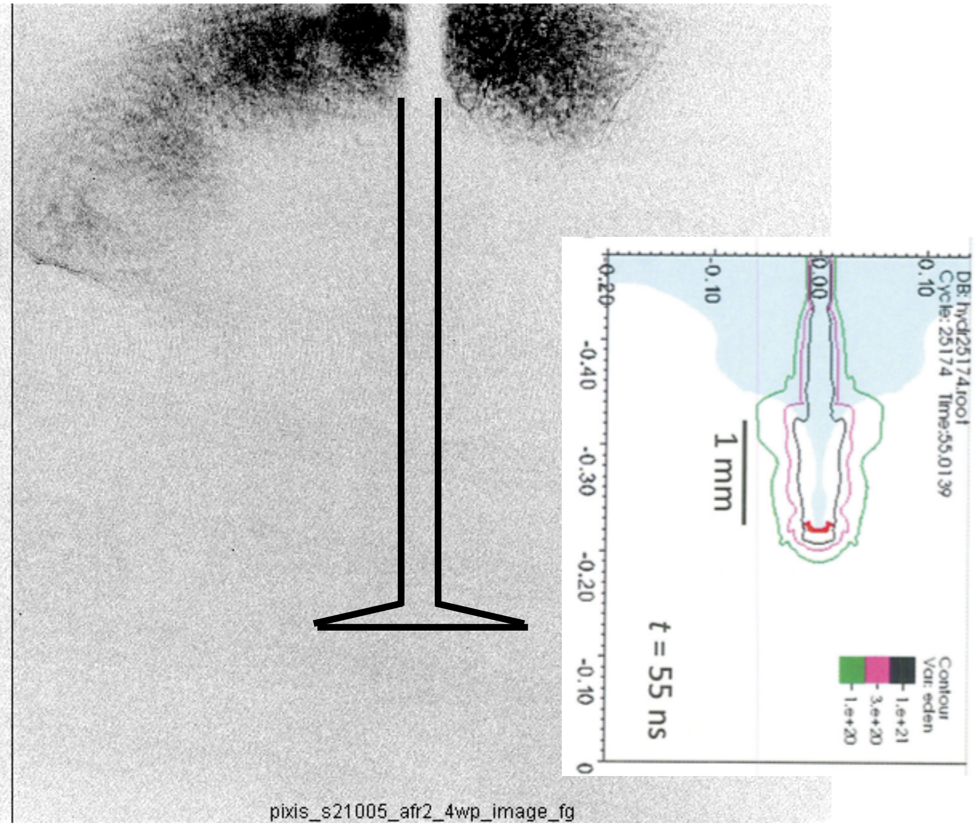
10 ns – Initial expansion of target without wind

20 ns – Wind shocks upon expanding eagle target

At 40ns the blow off plasma from the hohlraum blocks the 4w Field of view

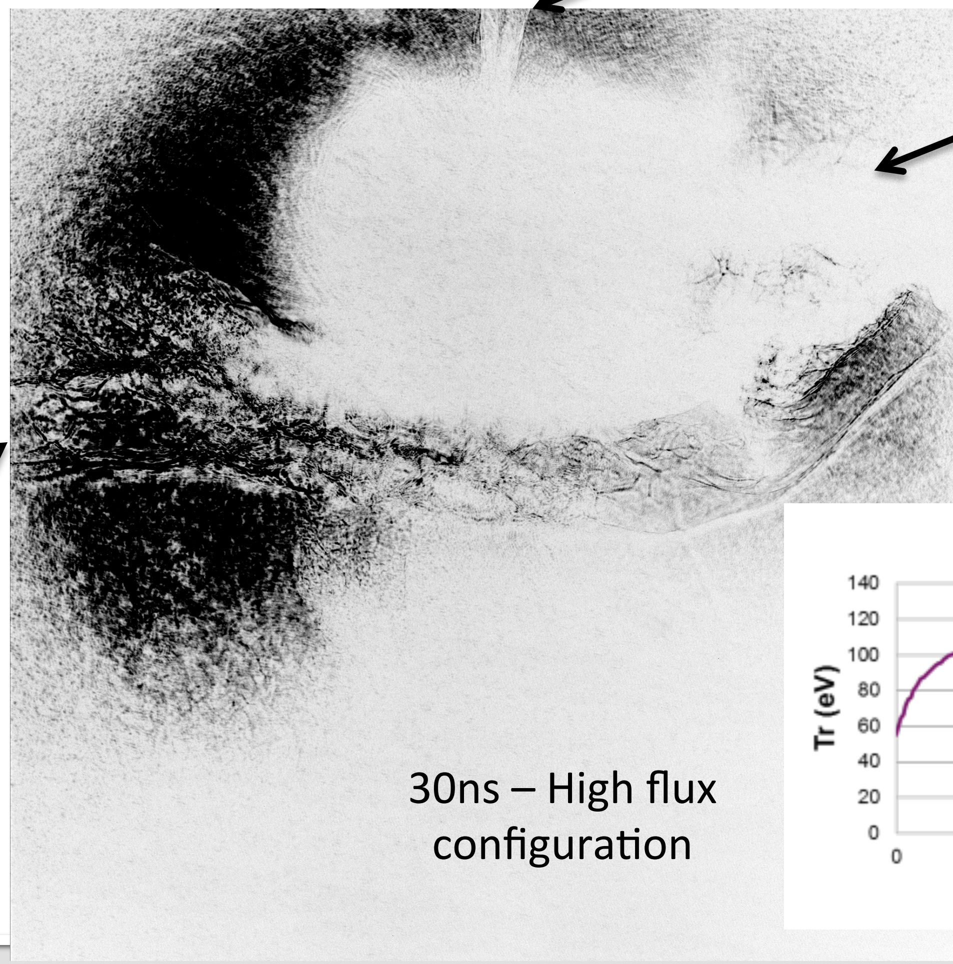


No target

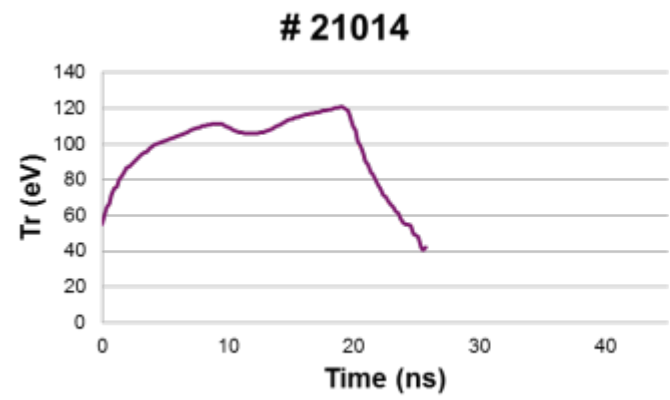


With Target

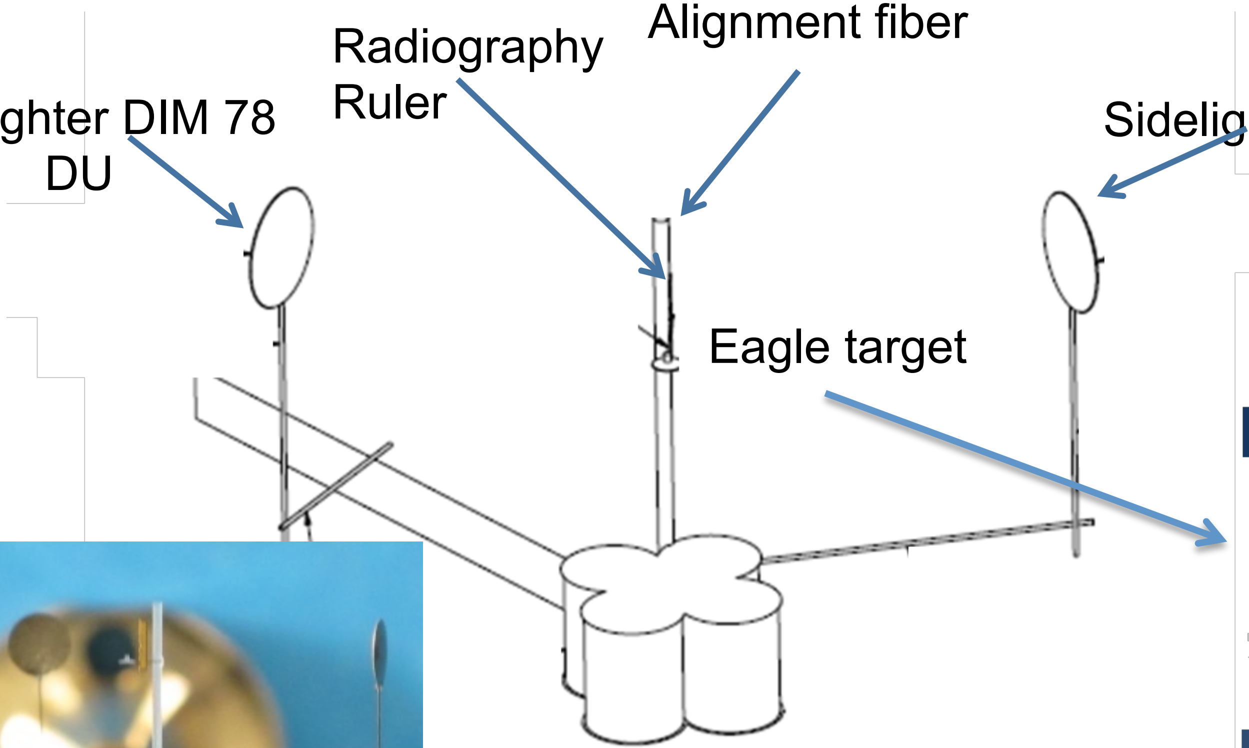
Two hohlraums were co-timed to increase X-ray flux for 20ns with 4mm stand off distance.

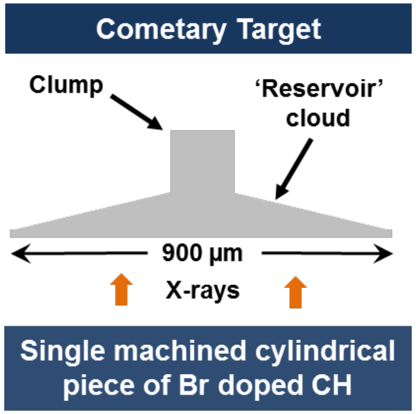


miniDMX

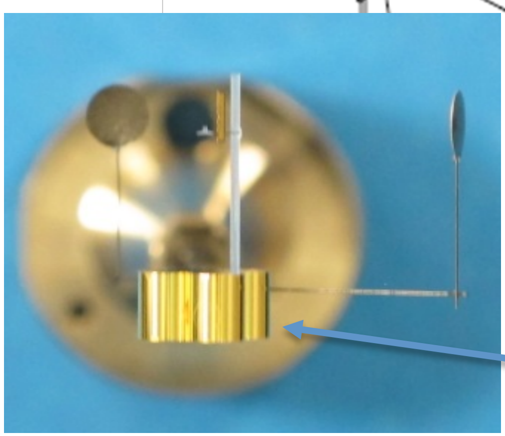


The cometary experiments on Omega were tested on NIF using two backlighters.



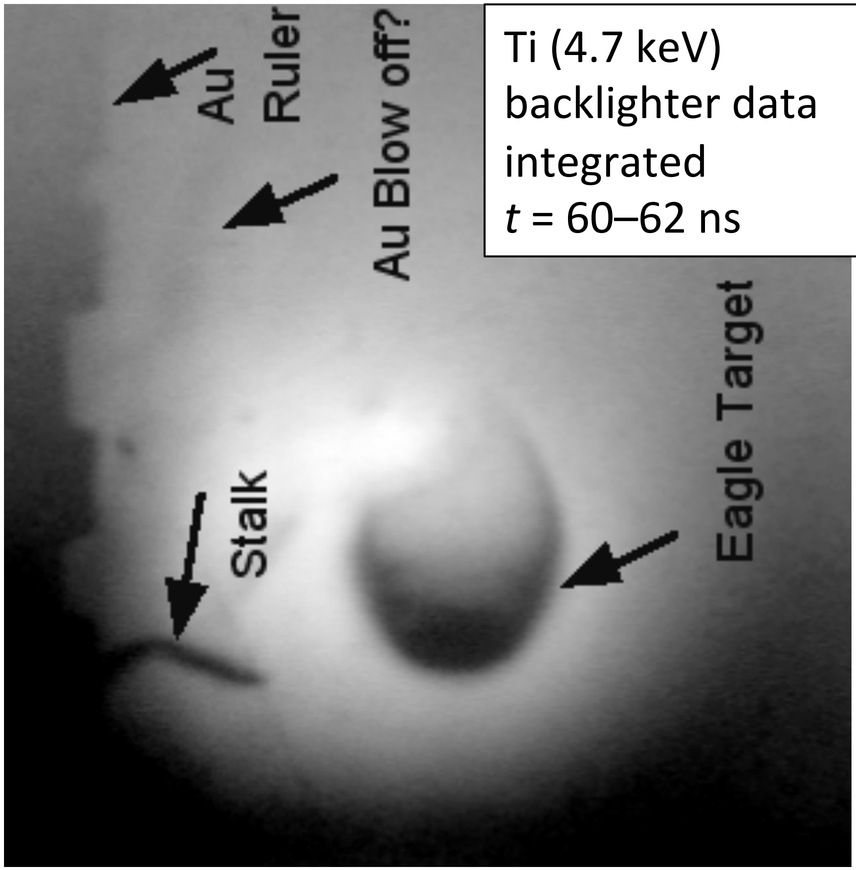


Hohlraum array



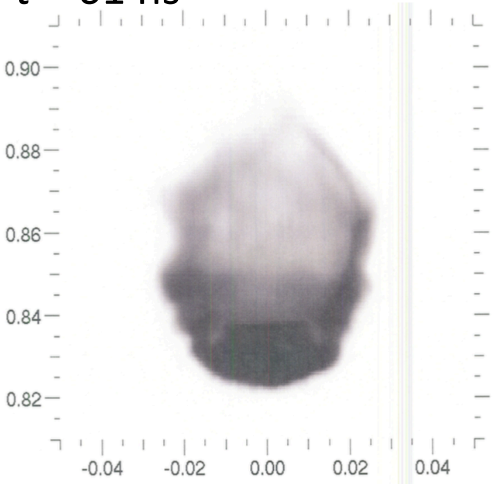
4 Au hohlraums with 4mg/cc TPX foam

3D HYDRA reproduces the evolution and asymmetry with a 120 eV drive



Ti (4.7 keV) backlighter data integrated
t = 60–62 ns

3D HYDRA
Ti Backlighter
t = 61 ns



Position (cm)

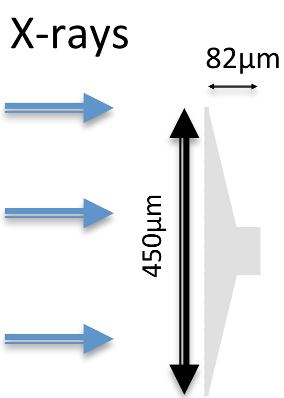
Using a 120eV temperature for the hohlraums

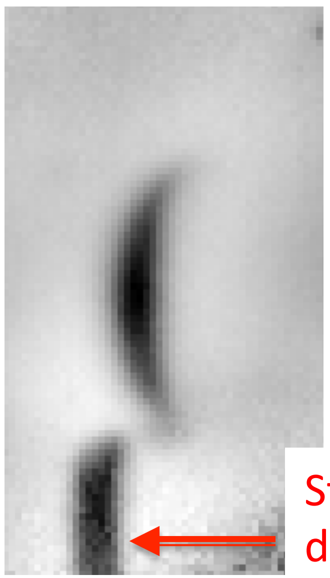
Simulations by Jave Kane

Preliminary data from Omega using x-ray radiography with the cometary target provides useful information on the early time evolution.

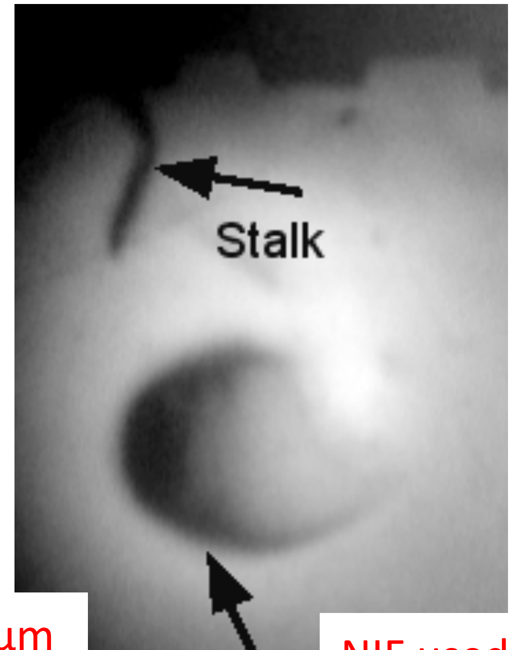
Omega

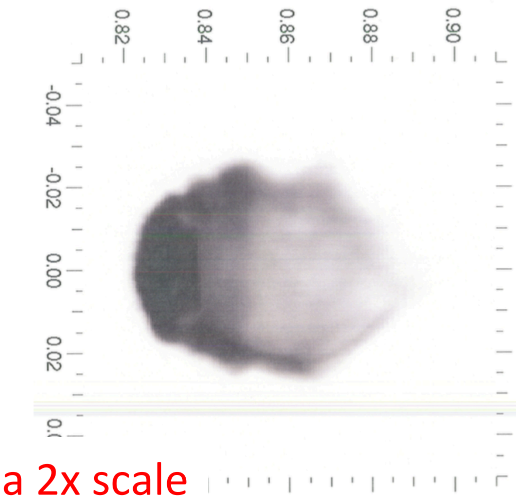
NIF





Stalk 70µm diameter





NIF used a 2x scale Omega target

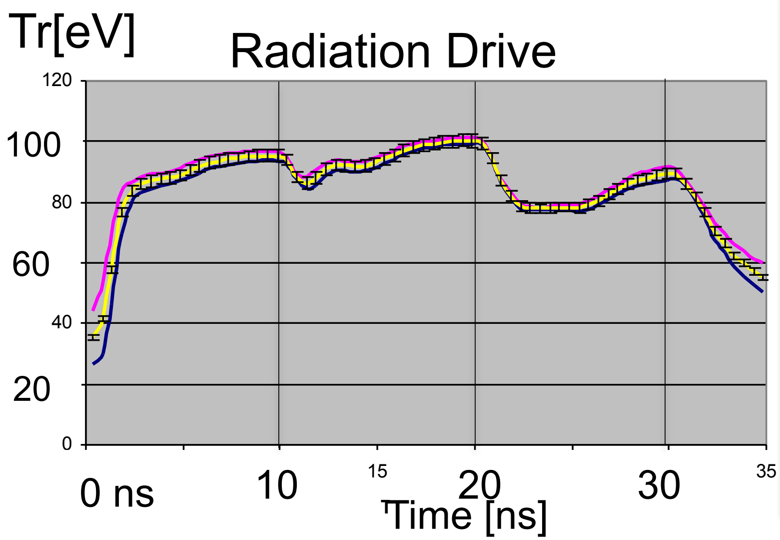
Current Data on Omega EP
Early time image
30ns
Ti Backlighter

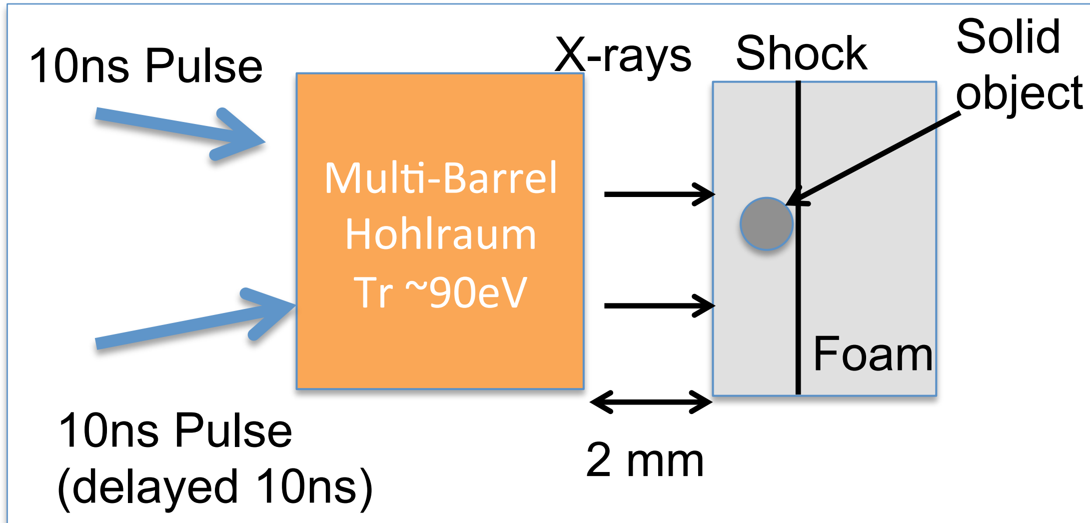
Eagle experiments on NIF
Late time image
60ns
Ti Backlighter

Conclusions

- The hohlraum array is capable of generating a ~90 eV radiation temperature for 30ns On Omega (NIF for 60ns @120eV)
- Experiments show that we can radiograph a foam target and a cometary target
- Staging experiments on Omega refined our designs for NIF.

The multi-source platform can be used to drive a hydrodynamic flow for 30ns

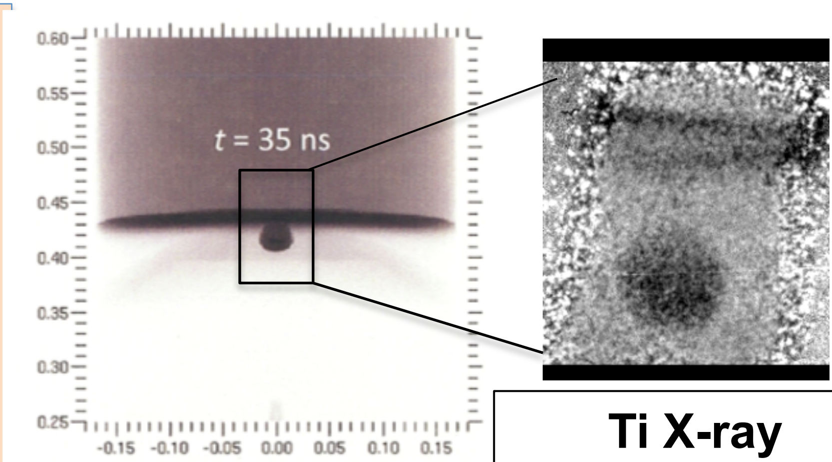




2D Hydra simulations

Hohlraum Drive
Length: 2.8mm
LEH: 2mm
Energy 12.9kJ
Pulse length: 20ns

1g/cc CH Clump in
50mg/cc CH foam

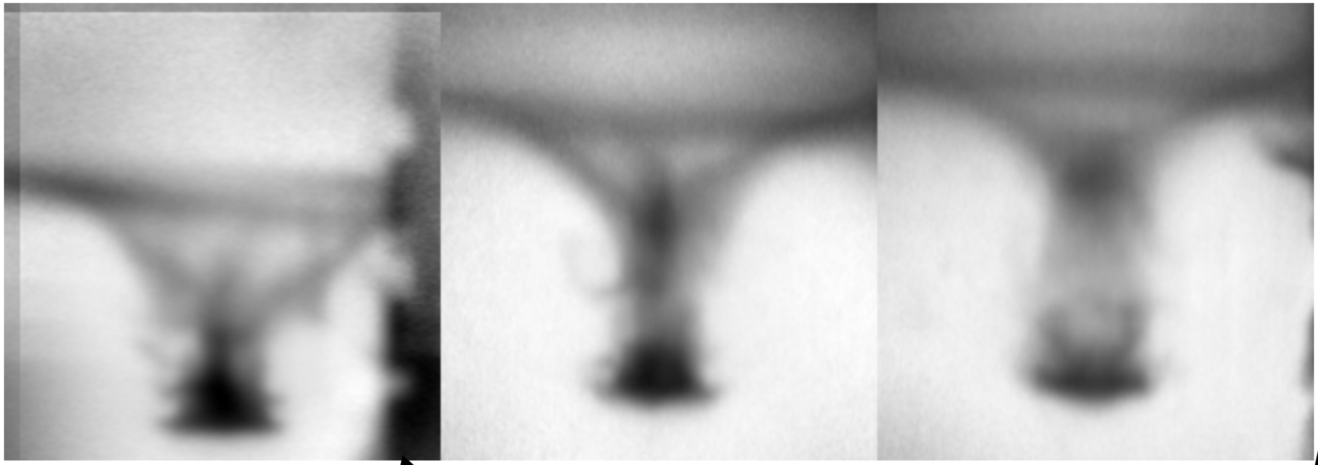


Ti X-ray radiograph On Omega EP

NGC 3603

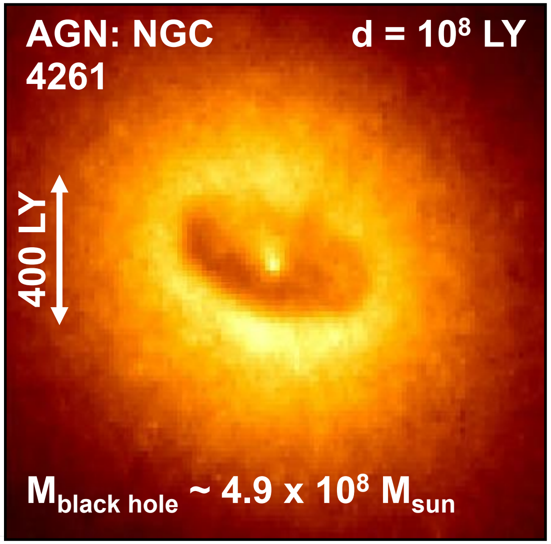
W. Bradner, E. Grebel ,Y.-H. Chu, et al Astron.. J 301, (2000)

30.5 ns (S02)	51.5 ns (S03)	61.5ns (S03)



Au Ruler (Out of focus in reconstruction)

Photoionization experiments need low ρ, high flux & equilibration time



Photoionization Equilibrium

$$\Gamma_{rad}\, n_i\, \sigma_{photo} = n_e\, n_{i+1} \sum \alpha_{\substack{recomb\\rate}}$$

$$\frac{\Gamma_{rad}}{n_e} = \frac{n_{i+1}\,\alpha}{n_i\,\sigma} = \xi$$

$$\bar{Z} = \bar{Z}(\xi),\ T_e = T_e(\xi)$$

$\bar{Z}$ and T_e are determined by ξ in photoionized plasmas

Photoionized plasmas* can be roughly characterized by the ionization scaling parameter $\xi \equiv 4\pi\Gamma / n_e$

*Tarter, et al., ApJ. 156 943 (1969)
Tarter, et al., ApJ. 156 953 (1969)

ξ ~ 1000 is typical of X-ray binaries (accretion disks around black holes consuming stars)

Past and ongoing experiments on Z

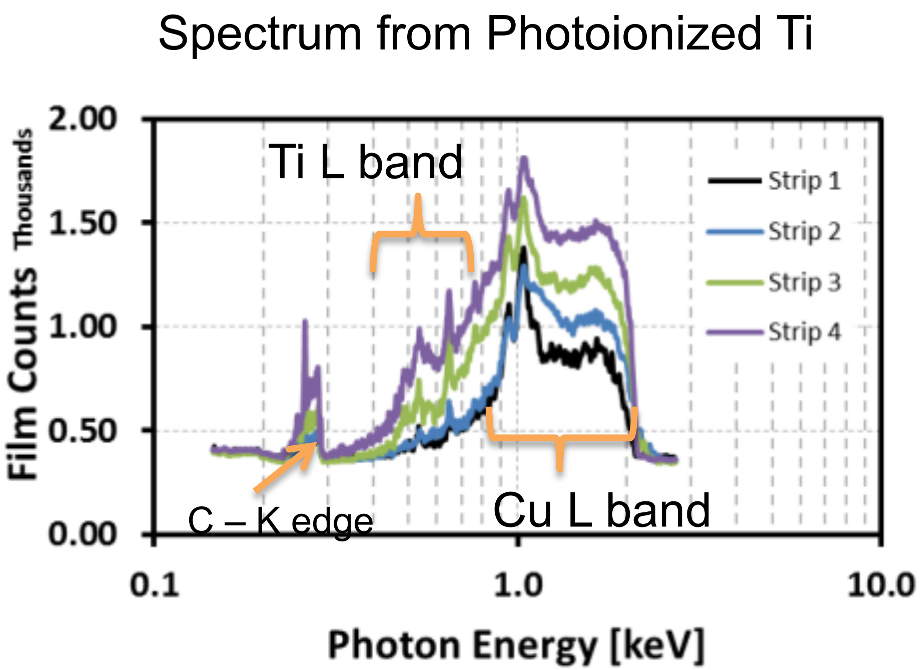
- **1999-2013: ξ=10-100** erg cm/s

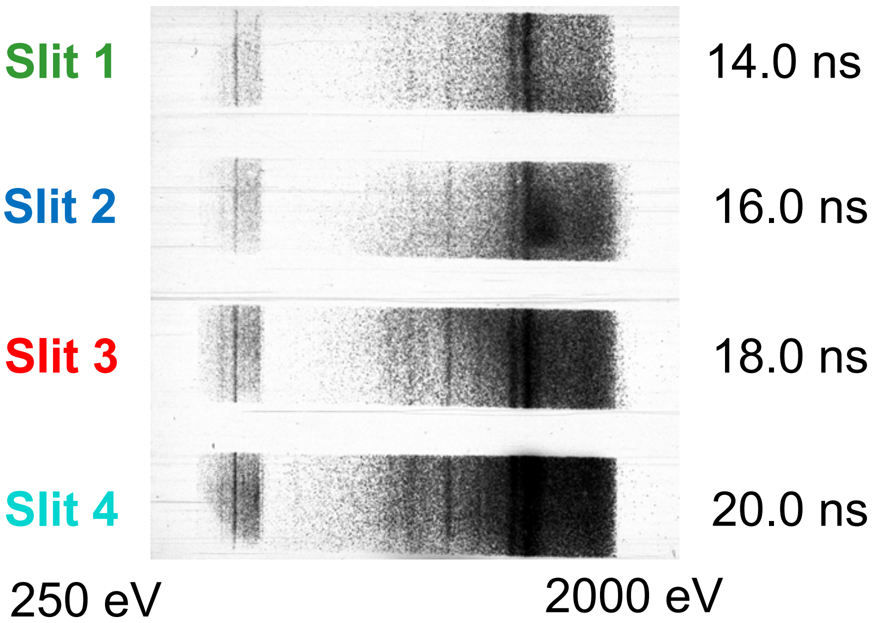
R.F. Heeter et al., RSI 72, 1224 (2001);
M.E. Foord et al., PRL 93, 055002 (2004);
S. Rose, J. Phys. B: At. Mol. Opt. Phys. 37, L337 (2004);
R.C. Mancini et al, PoP 16, 041001 (2009).

Omega EP achieved ξ ≥ 5 for 30 ns:

$n_e = 10^{19}/cm^3$ (CH-tamped exploding foil)
Flux = $\sigma T_r^4 * R^2_{hohlraum} / D^2_{sample}$.
with T_r = 90 eV, R = 0.1 cm, D = 0.4 cm:
$\xi = 4\pi$ Flux / $n_e \approx 5 \times 10^{19} / 10^{19} \approx 5$

Photoionized Ti was observed from 30ns x-ray drive pulse.





Spectrometer observed both Ti emission and Cu emission from hohlraum

Photoionization Sample
1 μm CH / 0.5 μm Ti / 1 μm CH 1000 um square