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Title: COMPARISON OF NEUTRON AND X-RAY IMAGES FROM NIF IMPLOSIONS

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COMPARISON OF NEUTRON AND X-RAY IMAGES FROM NIF IMPLOSIONS

Douglas C. Wilson[1], Robert J. Aragonez[1], Thomas N. Arhculeta[1], Dennis P Atkinson[2], Maria A. Barrios[2], Steven H. Batha[1], Dan E Bower[2], David K. Bradley[2], Robert A Buckles[3], David D. Clark[1], Daniel S. Clark[2], Deborah J. Clark[1], Jerry R Cradick[3], Chris R. Danly[1], Robert D. Day[1], John M. Dzenitis[2], Owen B Drury[2], Valerie E Fatherley[1], Brian Felker[2], Joshua P Finch[1], David N Fittinghoff[2], Matthias Frank[2], Robert A. Gallegos[1], Felix P Garcia[1], Steven M. Glenn[2], Gary. P Grim[1], Nevzat Guler[1], Albert H. Hsu[1], Nobuhiko Izumi[2], Steven A. Jaramillo[1], Ogden S. Jones[2], Morris I. Kaufman[3], Joseph D. Kilkenny[2], George A. Kyrala[1], Sebastien Le Pape[2], Sean N Liddick[2], Eric N. Loomis[1], Steve S Lutz[3], Tammy Ma[2],Andrew J. Mackinnon[2], Robert M Malone[3], Danielle Mares[1], Michael M. Marinak[2], Drew D. Martinson[1], Patrick McKenty[4], Nathan S. Meezan[2], Frank E Merrill[1], Michael J Moran[2], George L Morgan[1], Carter Munson[1], David H. Munro[2], Thomas J Murphy[1], John A Oertel[1], Mehul V. Patel[2], Paul J Polk[1], Sean Regan[4], George P Roberson[2], Derek W Schmidt[1], Scott M. Sepke[2], Brian K. Spears[2], Richard Town[2] ,Riccardo Tommasini[2] , Albert Traille[3], Ian L Tregillis[1], Adelaida Valdez[1], Natalia S Vinyard[1],Petr L Volegov[1],Tai-Sen F Wang[1],Paul Weiss[2], Carl H Wilde[1],Mark D Wilke[1]

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Directly laser driven and X-radiation driven DT filled capsules differ in the relationship between neutron and X-ray images. Shot N110217, a directly driven DT-filled glass micro-balloon provided the first neutron images at the National Ignition Facility. As seen in implosions on the Omega laser, the neutron image can be enclosed inside the contour of the time integrated X-ray images, and the time resolved ones at a time near peak neutron emission rate. HYDRA simulations show the X-ray image is dominated by emission from the glass shell while the neutron image arises from the DT fuel it encloses. In the absence of mix or jetting, X-ray images of a plastic shell, cryogenically layered THD fuel capsule should be dominated by emission from the hydrogen itself rather than the cooler plastic shell which is separated from the hot core by cold DT fuel. This cool, dense DT, invisible in X-ray emission, shows itself by scattering hot core neutrons. Time gated images of neutrons between 10 and 12 MeV show this fuel shell. X-ray emission spectra, and energy resolved images suggest that germanium doped plastic emits from the torus shaped hot spot. This work was performed for the U.S. Department of Energy, National Nuclear Security Administration and by the National Ignition Campaign partners; Lawrence Livermore National Laboratory (LLNL)(contract DE-AC52-07NA27344), University of Rochester -Laboratory for Laser Energetics (LLE), General Atomics (GA), Los Alamos National Laboratory (LANL) (Contract DE-AC52-06NA25396), Sandia National Laboratory (SNL). Other contributors include Lawrence Berkeley National Laboratory (LBNL), Massachusetts Institute of Technology (MIT), Atomic Weapons Establishment (AWE), England, and Commissariat à l'Énergie Atomique (CEA), France.

Comparion of Neutron and X-ray Images from NIF Implosions

7th International Conference on
Inertial Fusion Sciences and Applications
Sept 13, 2011

Douglas C. Wilson
and a *HUGE* NIF team

Los Alamos and Lawrence Livermore National Laboratories – National Ignition Campaign

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A *Huge multi-laboratory* team contributed to this talk.

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[3] *Laboratory for Laser Energetics, U. of Rochester*

[4] *National Security Technologies*

Comparing X-ray and Neutron Images can differentiate regions of high X-ray emission from high DT burn.

- X-ray emission arises from hot plasma with high X-ray emissivity
- Neutron emission from regions with high neutron production rates, i.e. high densities of deuterium and tritium, and high temperatures
- Directly driven glass shells show neutron emission from the hot DT gas, and X-ray emission predominantly from the surrounding glass shell.
- X-ray emission from radiation driven THD or DT capsules calculates to be dominated by dense, high temperature DT fuel, and little from the relatively colder plastic shell.
- Both types of capsules show emission from shell material if it is mixed into the hot central fuel.

Outline

- Directly driven DT filled glass microballoons
  - Calculational technique
    - The need to reduce inner beam cone laser power to match observed oblate X-ray shapes.
  - Observed X-ray (see Ma *et al.*) and Neutron images (Grim *et al.*, Guler *et al.*)
  - X-ray emission surrounds the neutron source

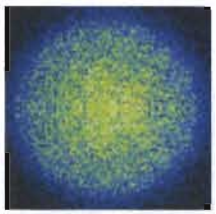
- Cryogenically layered THD and DT capsules
  - Calculational technique (see Jones *et al.*)
    - The need to reduce laser intensity to match shock velocities
  - Observed X-ray and Neutron Images
  - Neutron emission overlays general X-ray emission
  - X-ray bright spots arise in hot, low density regions
    - X-ray bright spots are not apparent in Neutron Images
    - Ross Pair Filtering suggests bright spots include germanium emission (Ma *et al.*)
    - X-ray spectra show Ge emission from the hot spot torus

Directly driven DT gas filled capsules give high yields.

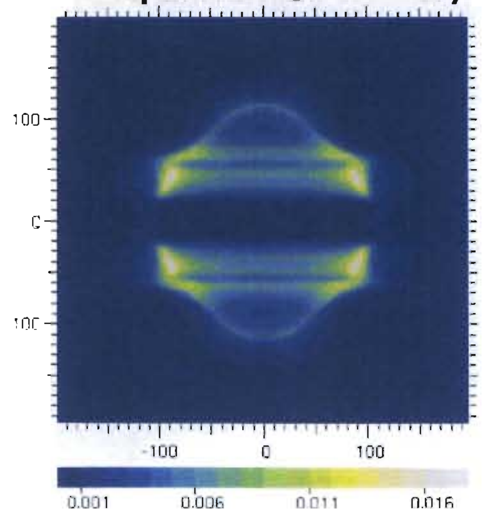
- Capsules:
  - N110217 – 2e+14, 10.1 keV
    - 126 kJ ramp, 1640 OD, 4.3 μm thick SiO_2 shell, 7 atm DT
  - N110603-002 – 2.3e+14, 5.8 keV
    - 353 kJ ramp+flattop, 2100 OD, 10 μm thick SiO_2 shell, 10 atm DT
  - N110618 – 6.8 e+14, 8.0 keV
    - No Neutron images
- Hydra Calculations:
  - 2D implosions with Monte Carlo neutron and charged particle transport
  - 3D laser powers are included (courtesy of S. Finnegan)

For Directly driven gas capsules, X-ray emission is dominated by the hot glass shell, and neutrons by the hot DT fue

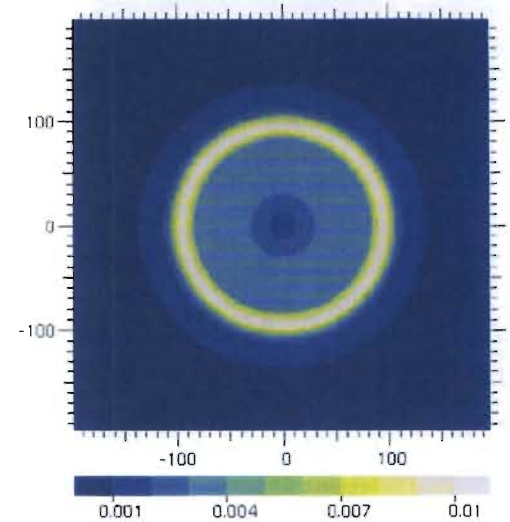
13-15 MeV



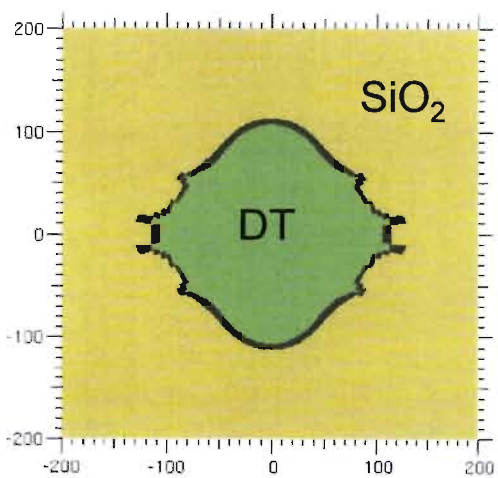
Equatorial X-rays



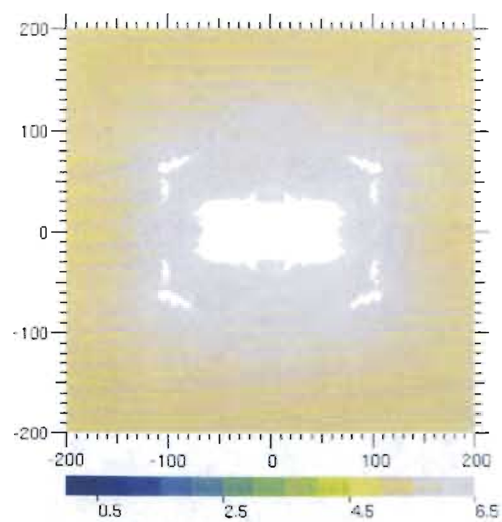
Polar X-rays



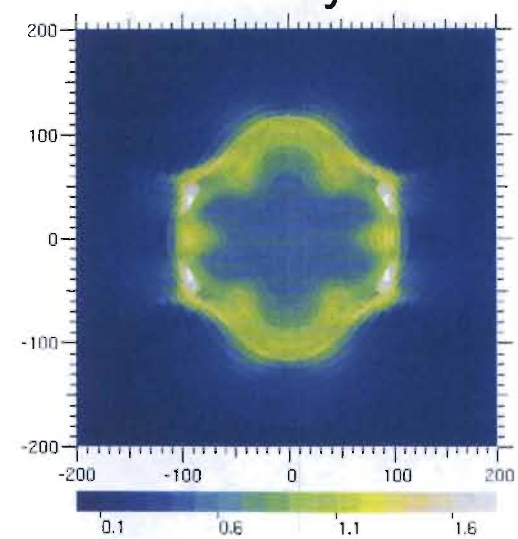
Materials



Electron Temp



Density

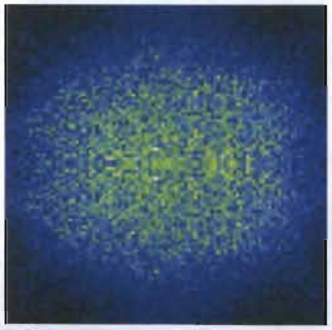


- X-ray is from hot SiO2;neutron emission from a ~sphere of hot, low density DT fuel.

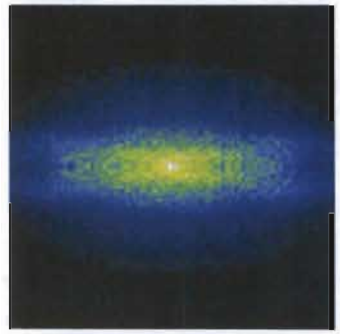
Polar Direct Drive laser powers were adjusted to give a round implosion calculated by Hydra

eutron Images

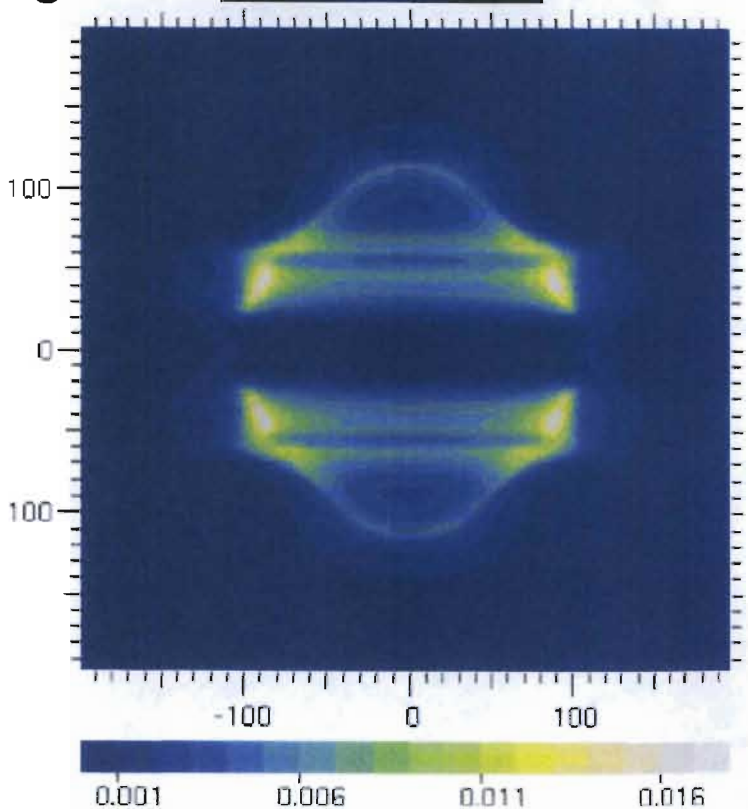
Nominal Calculation

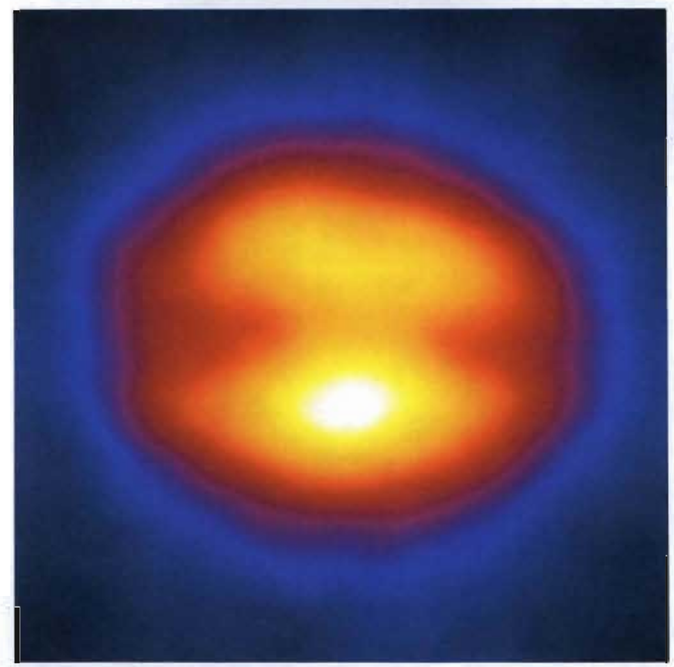


+10% Outers -20% Inners



Observed Image





- **200x200 micron neutron frames**
- **400x400 X-ray frames**

Directly Driven Capsule Neutron and X-ray Images were oblate.

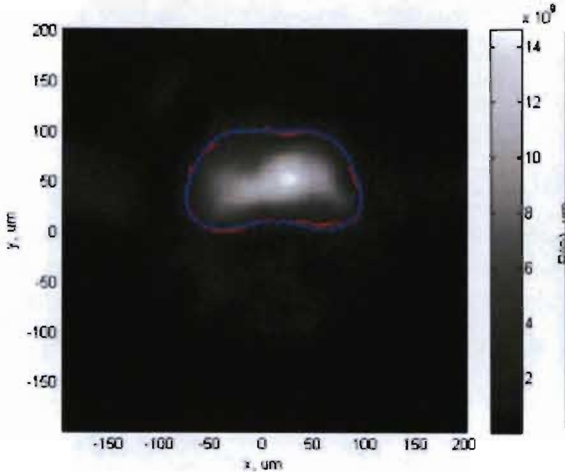
Pinhole neutrons
P0 = 77.8 µm
P2/P0=-63%

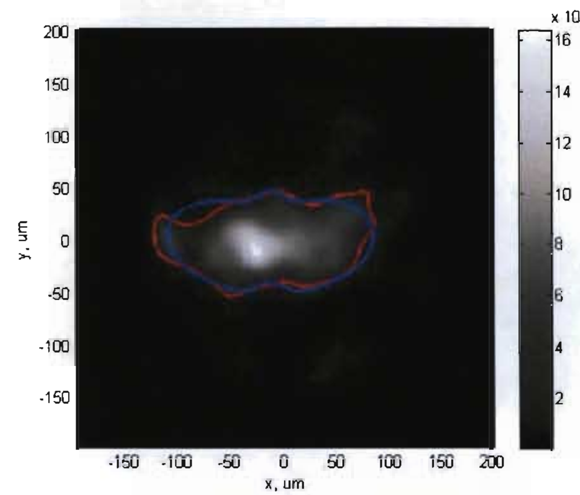
Shot N110217

Penumbral neutrons

Shot N110603-002

Pinhole neutrons
P0 = 72.2 µm
P2/P0=-38%





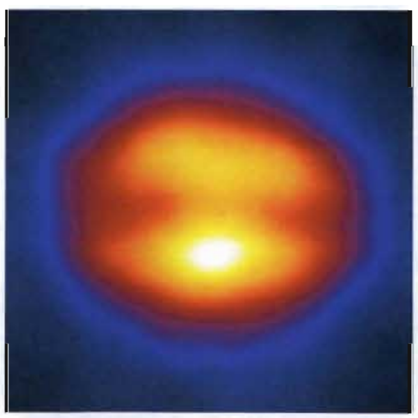
> 6keV X-rays

Equator 90-78

No polar image

Pole 0-0

Equator 90-78



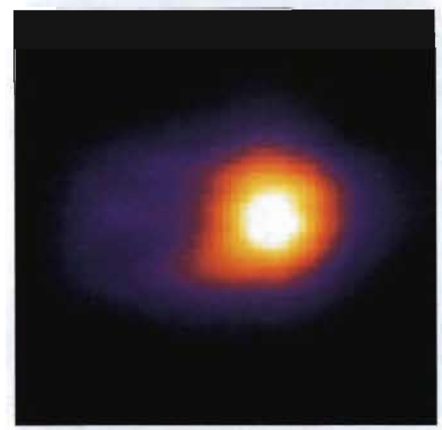


Image frames are 400x400 µm

NIC

The neutron source, reconstructed from either a penumbral or pinhole image fits into the X-ray image near peak yield rate.

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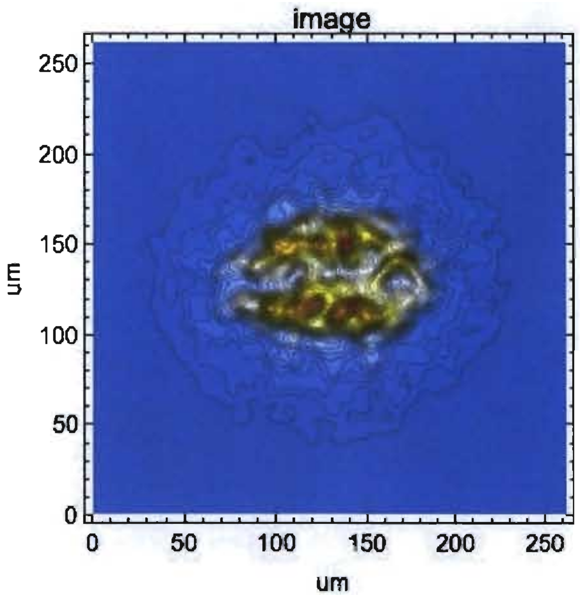
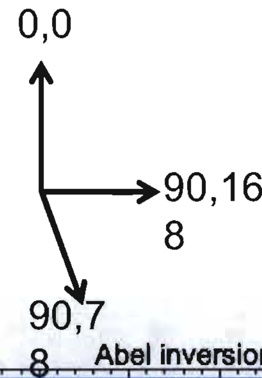
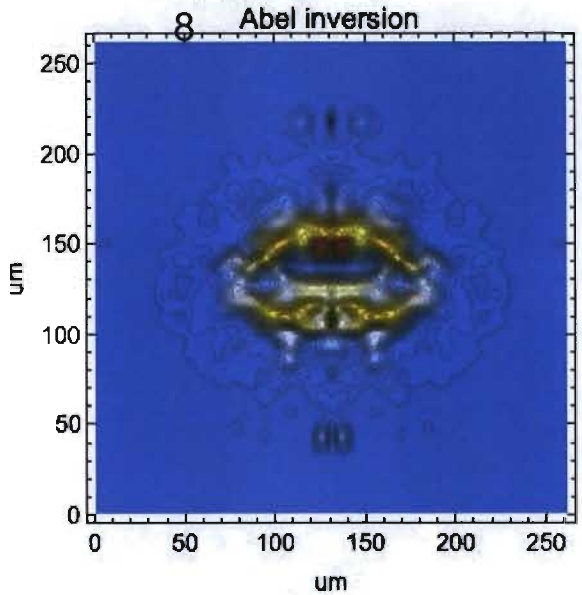
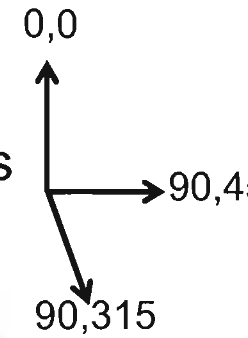
hGXI gated X-ray image near peak neutron yield rate (90-78)







Reconstructed Time integrated Neutron Sources (90-315)

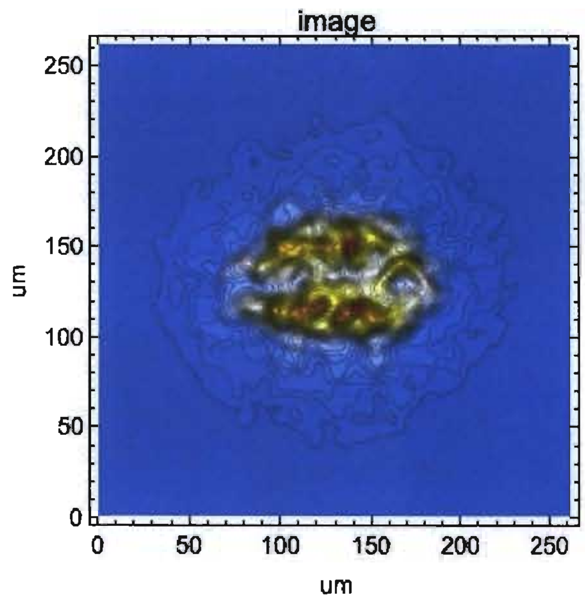


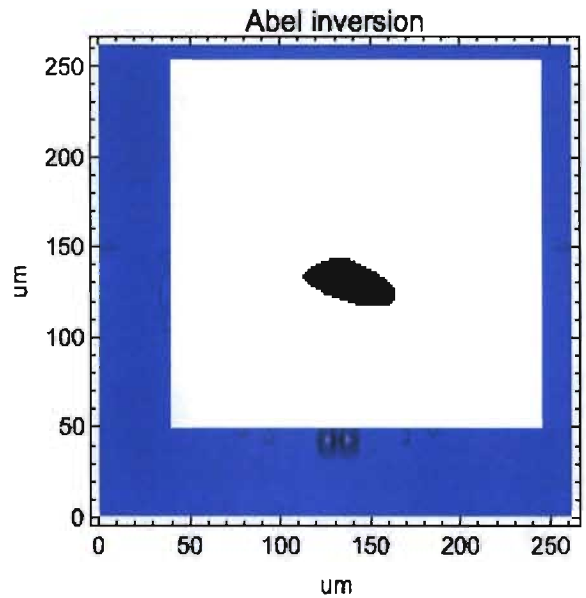
Penumbr

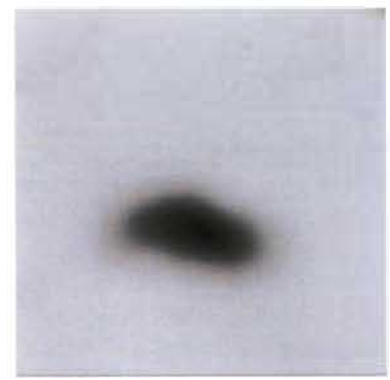
Pinhole

- The hGXI data was analyzed from Riccardo Tommasini (LLNL)
- Neutron sources are in 200x200 μm frames

The neutron image can fit inside the shell of X-ray emission





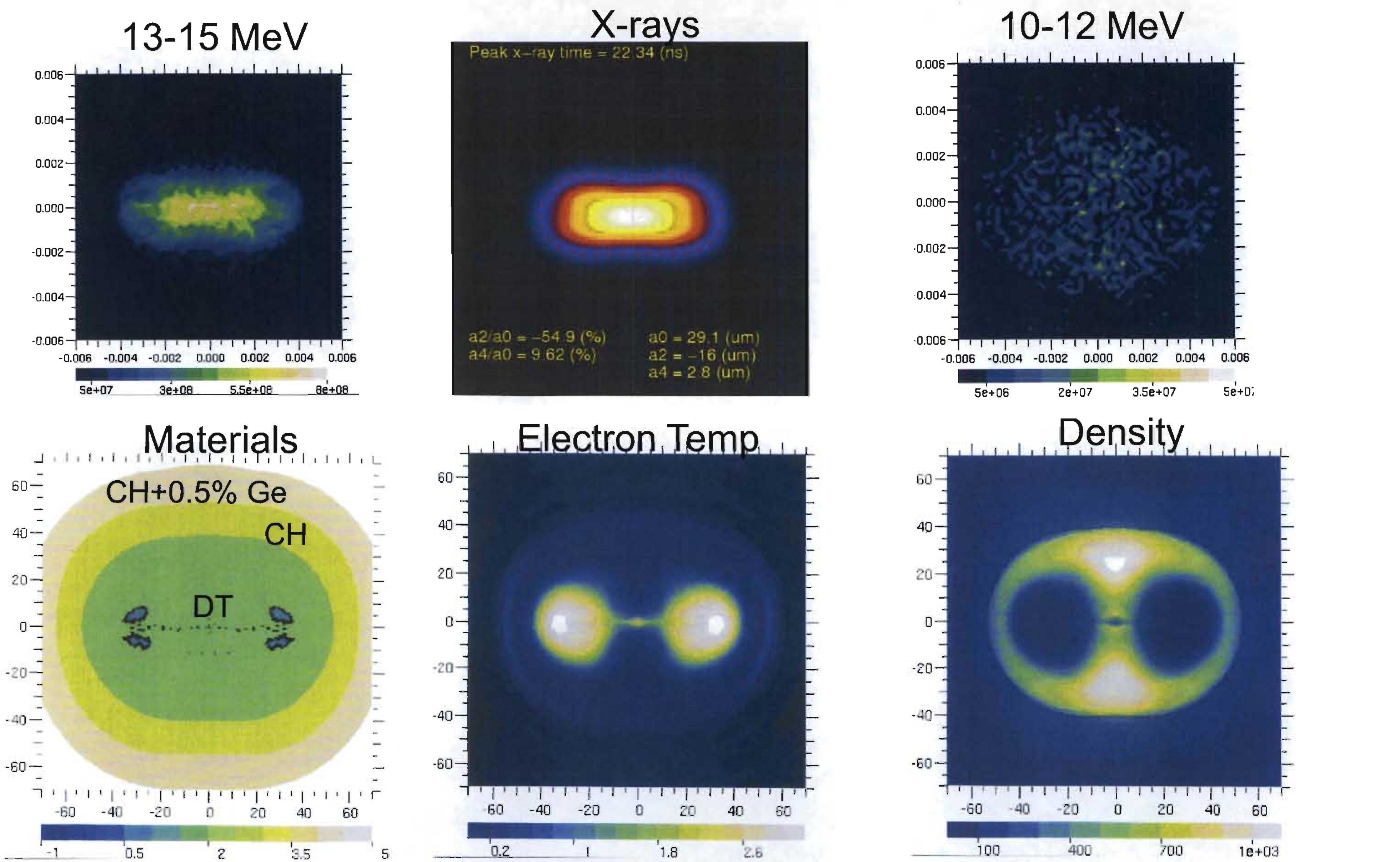


The relative position of the X-ray and neutron images is not measured

HYDRA Simulations of THD and DT capsules

- Calculations were done by O. Jones (see P.Wed_8) with HYDRA and:
  - Laser powers adjusted to give proper shock velocities and timing
  - A beam power transfer script used to get approximately correct X-ray image symmetry.
- Calculations will be done for shots N110608 and N110615 with a different first shock to get the calculated and observed dsr to agree.
- Neutron sources are reconstructed to remove instrument blurring. However high frequency residuals remain in the difference between the observed and calculated images. (see Grim et al.,
- The calculated and observed primary and down-scattered neutron images agree roughly with measured.
- There may be evidence that X-ray bright spots are not bright in the primary neutron image.

In a clean THD or DT ignition capsule X-ray emission arises from hot , low density DT fuel, not CH or Ge doped CH

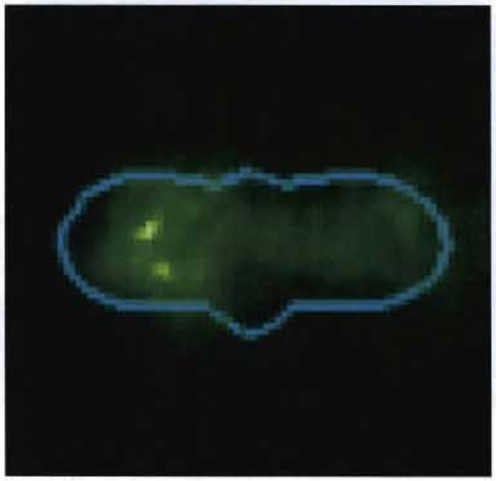


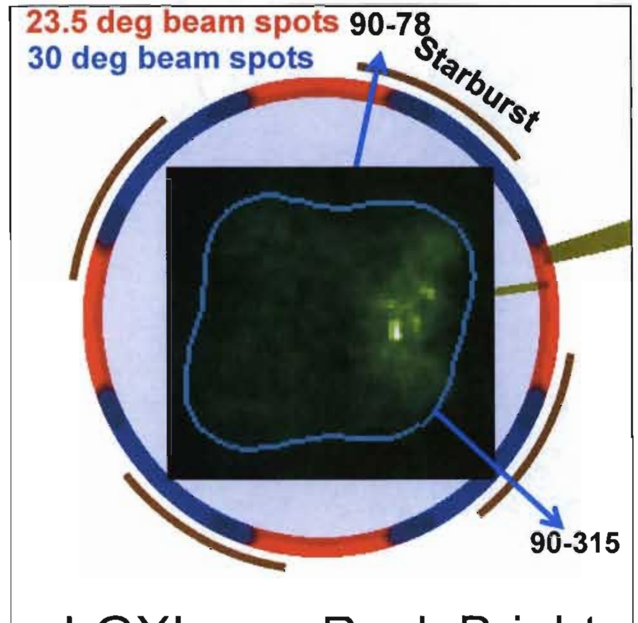
• **Both X-ray and neutron emission is from a torus of hot, low density DT fuel.**

Neutron images and the various X-ray sources are viewed from different directions

hGXI near Peak Brightness
Equatorial (90-78)

All frames are
~ 100x100 μm

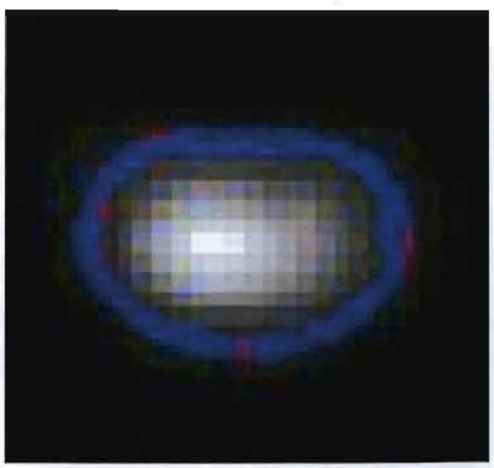




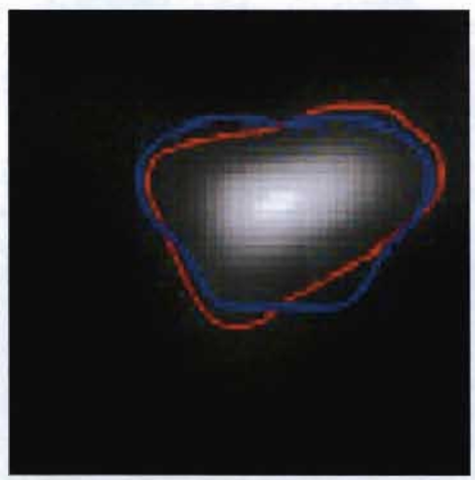
hGXI near Peak Brightness Polar

Neutrons, Equatorial (90-315)

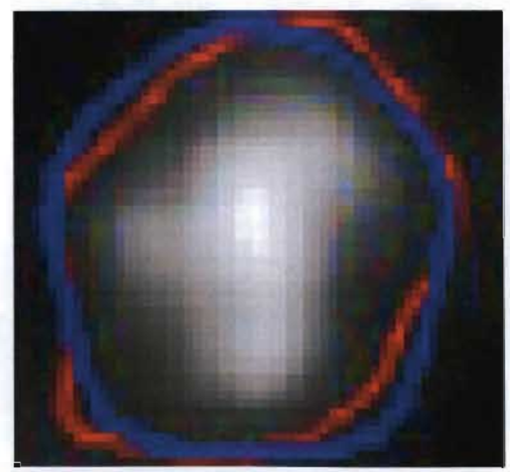
Penumbral 13-17 MeV



Pinhole 13-17 MeV

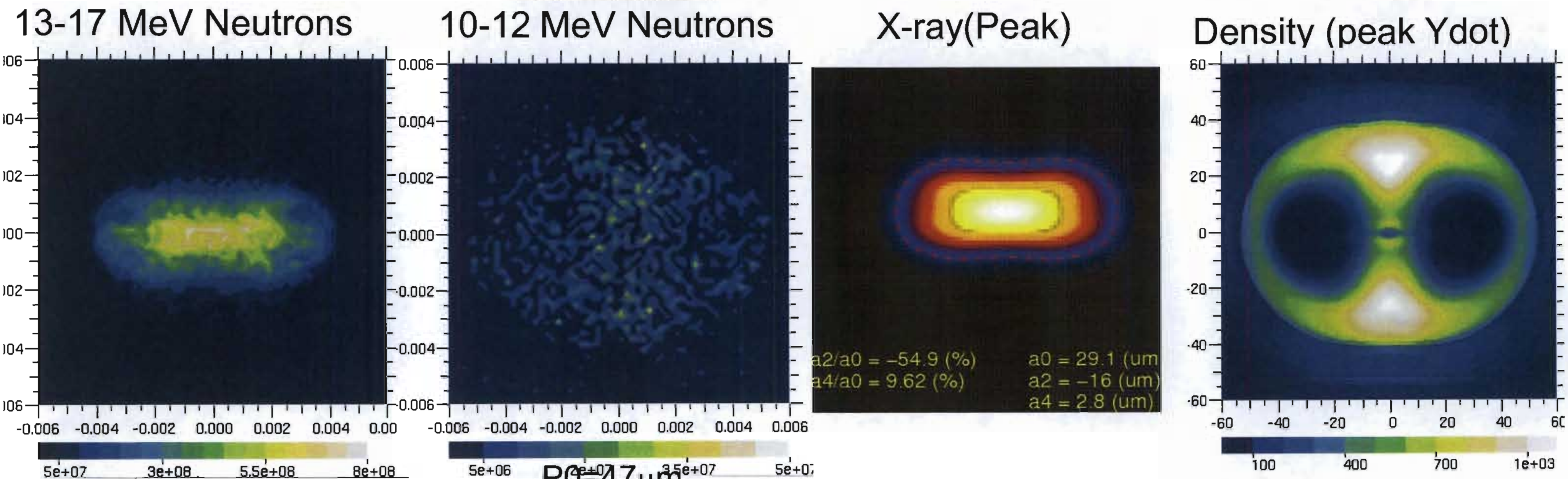


Penumbral 10-12 MeV



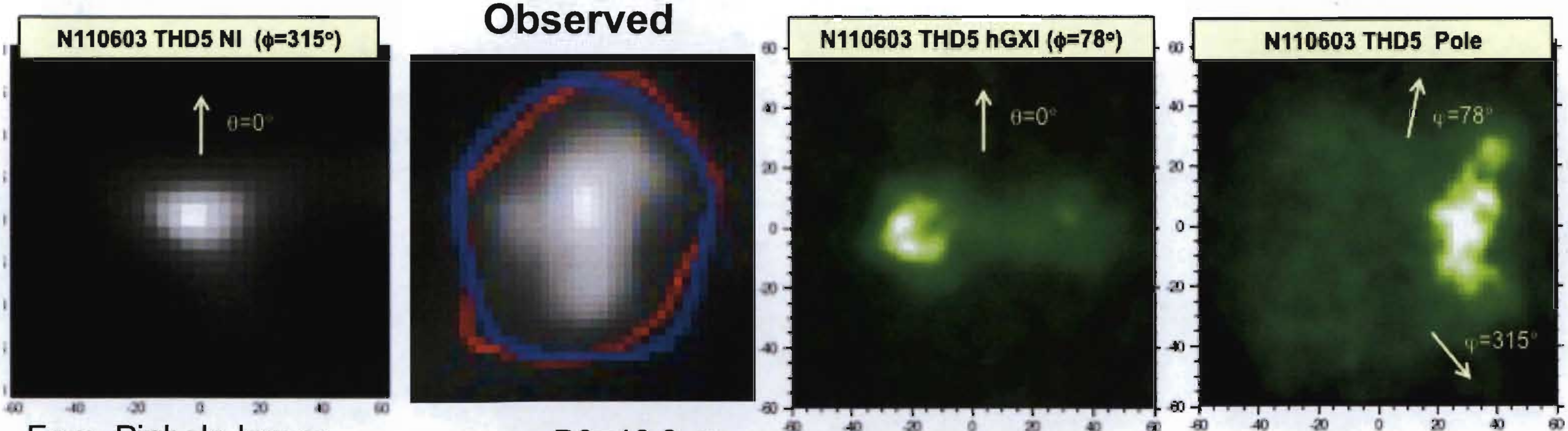
N110603, with TH(20%)D, has bright X-ray spots in a hot low density fuel torus.

Calculated



P0=47μm

Observed



From Pinhole Image

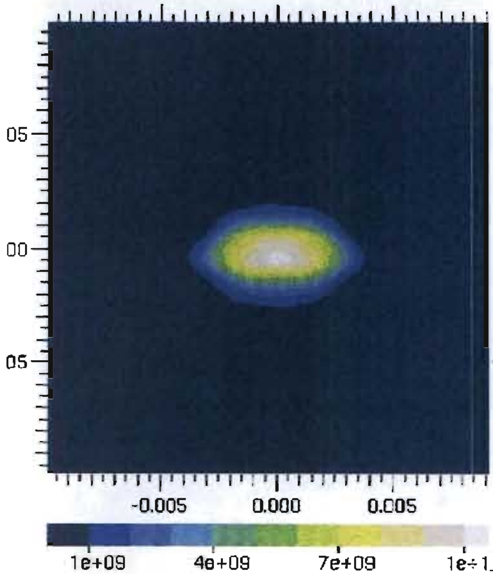
P0=26.8μm, P2/P0=-23%

P0=46.8μm

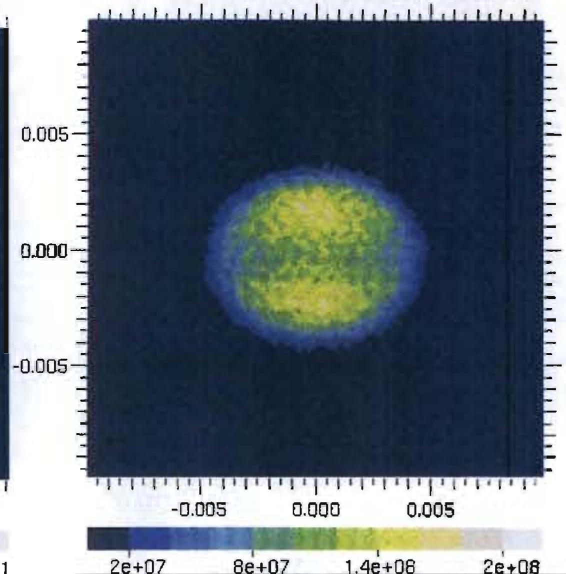
N110608, with T(50%)D , has bright X-ray spots in a hot low density fuel torus.

Calculated

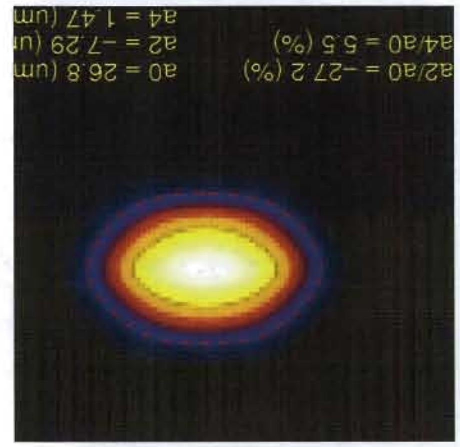
13-17 MeV Neutrons



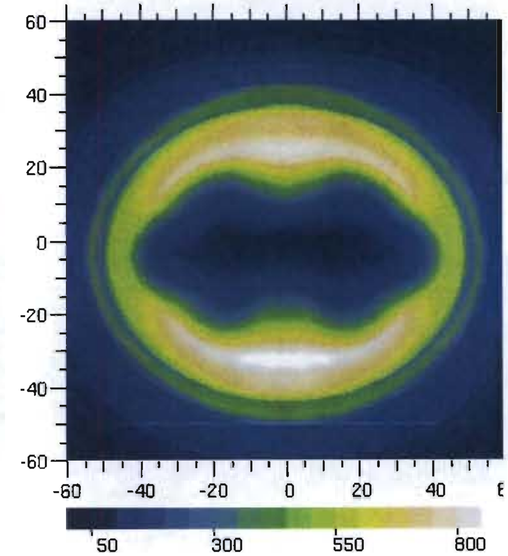
10-12 MeV Neutrons



X-ray(Peak)

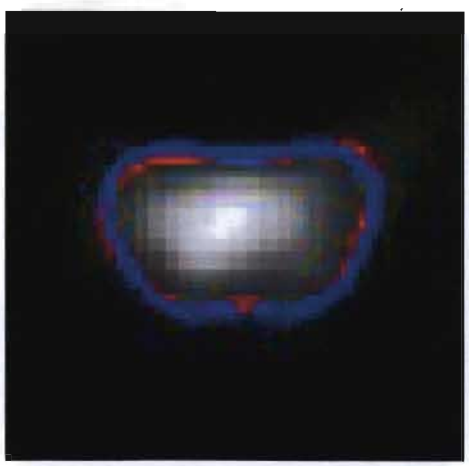


Density (peak Ydot)

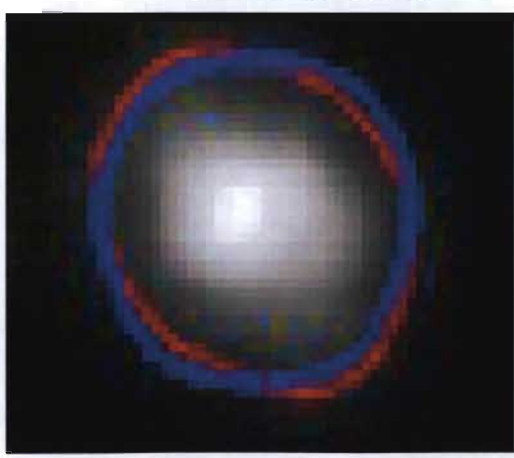


P0=42μm

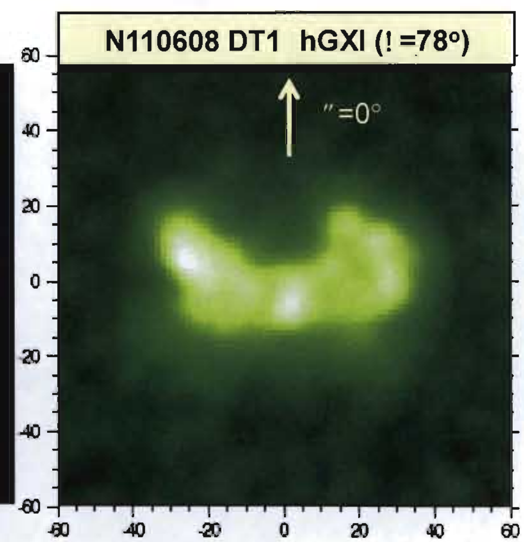
Observed

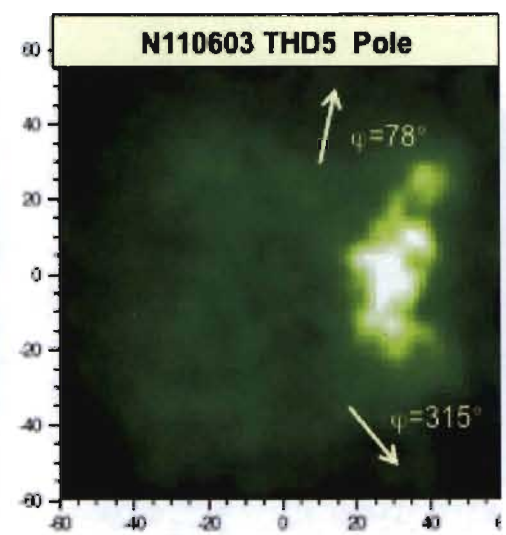


P0=29.1μm, P2/P0=-31%



P0=44.5μm

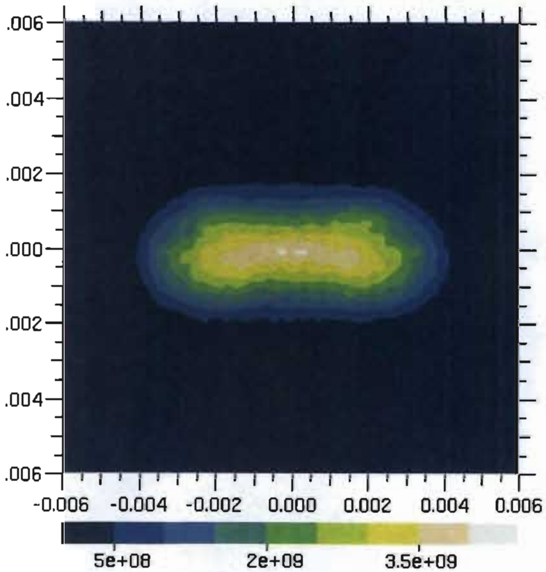




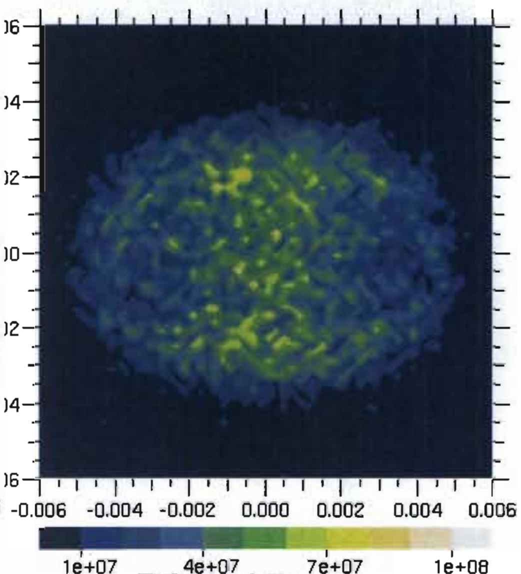
N110615, with T(50%)D, has bright X-ray spots in a hot low density fuel torus.

Calculated

13-17 MeV Neutrons



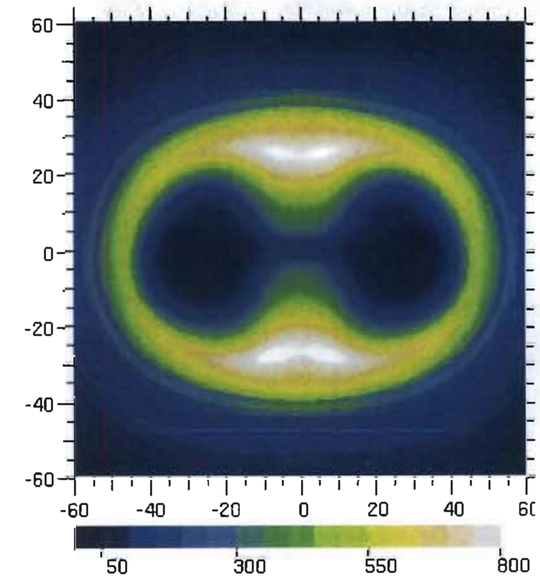
10-12 MeV Neutrons



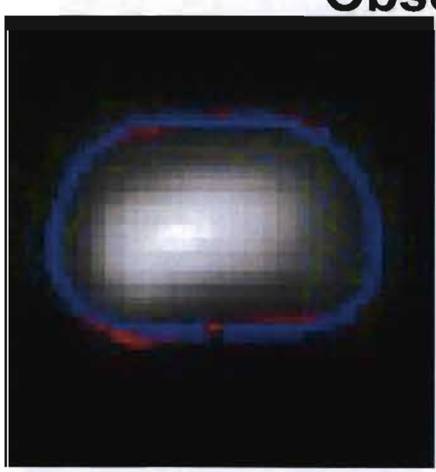
P0=~45 μm

X-ray(Peak)

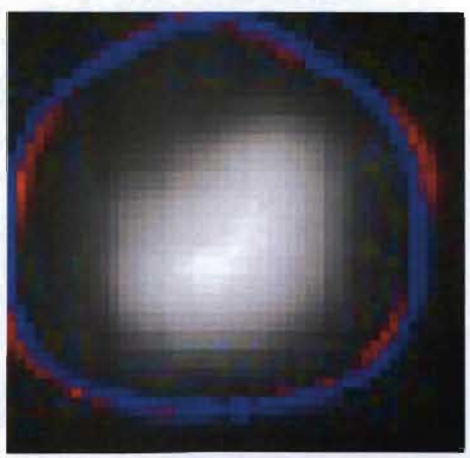
Density (peak Ydot)



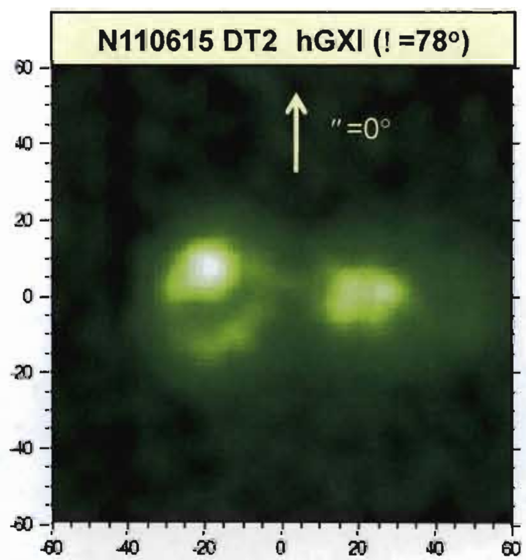
Observed N110615

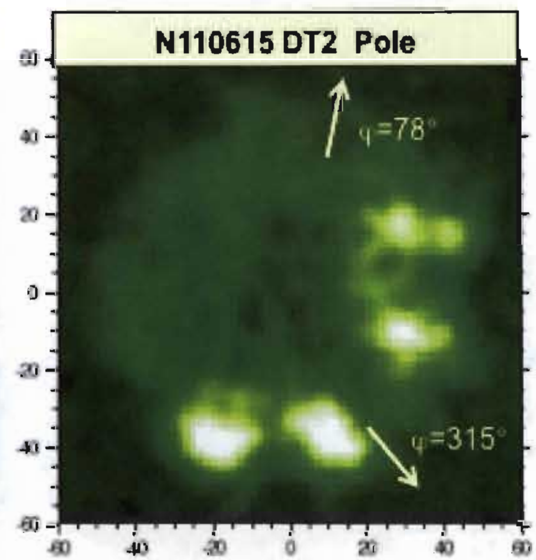


P0=37.7μm, P2/P0=-26%



P0=56.2μm

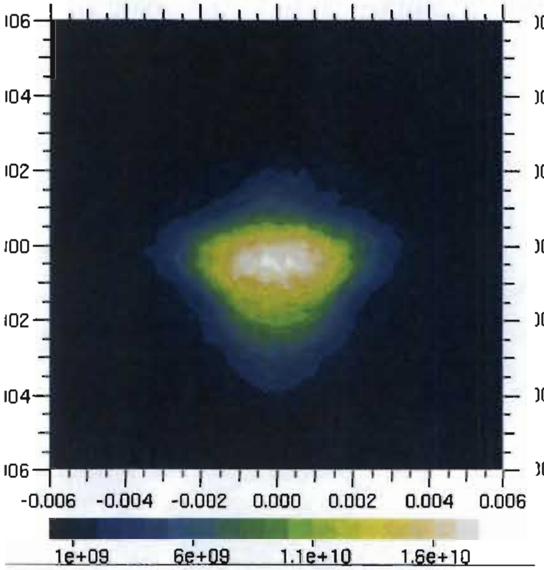




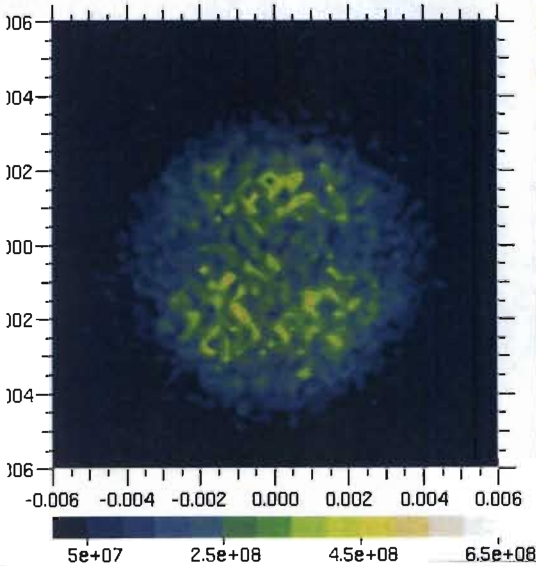
N110620, with T(50%)D, has bright X-ray spots in a hot, low density fuel teardrop.

Calculated

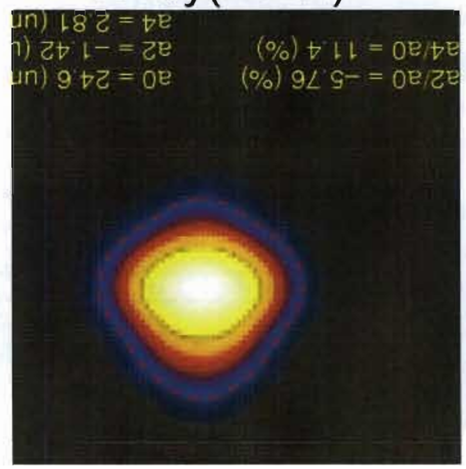
13-17 MeV Neutrons



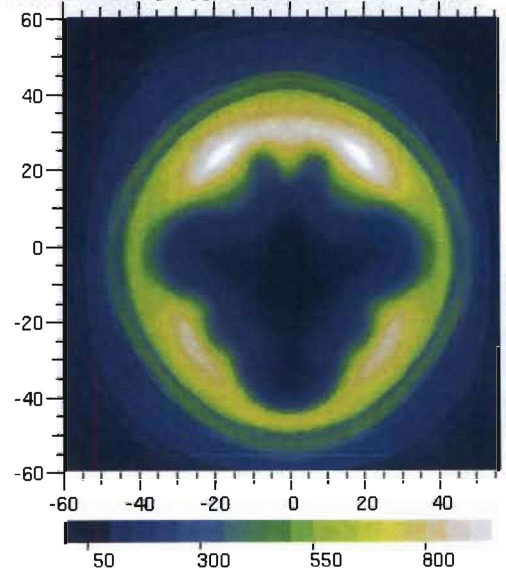
10-12 MeV Neutrons



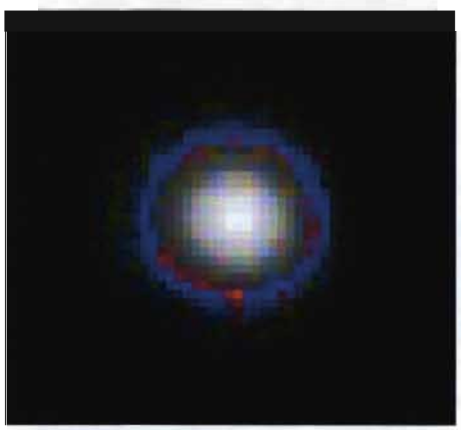
X-ray(Peak)



Density (peak Ydot)

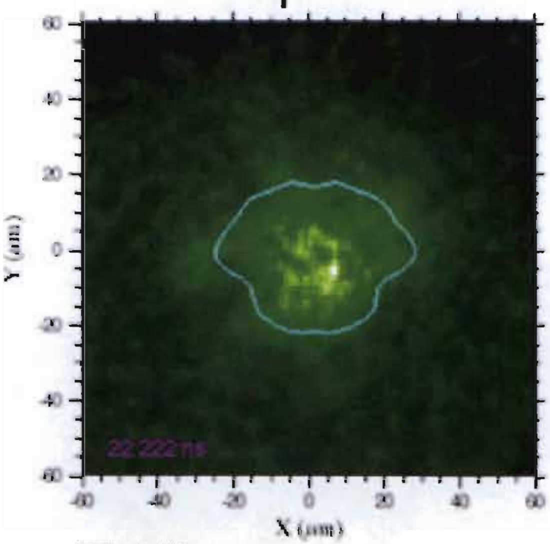


Observed N110620

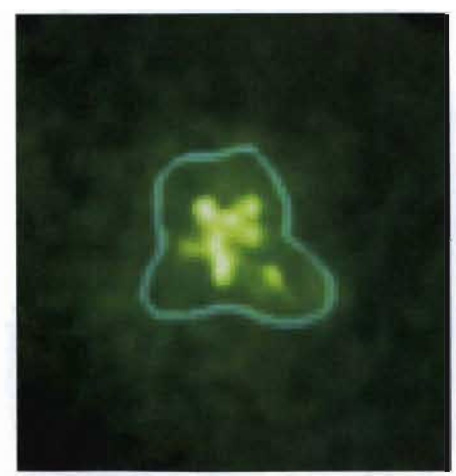


From Penumbral Image
P0=25.1μm, P2/P0=2%

Equator



Pole



Hot spot neutron yield is degraded, possibly by mix.

Even if we calculate the observed dsr, ion temperature, and x-ray and neutron image sizes, there still seems to be a factor of ~5 degradation in the measured yield from observed

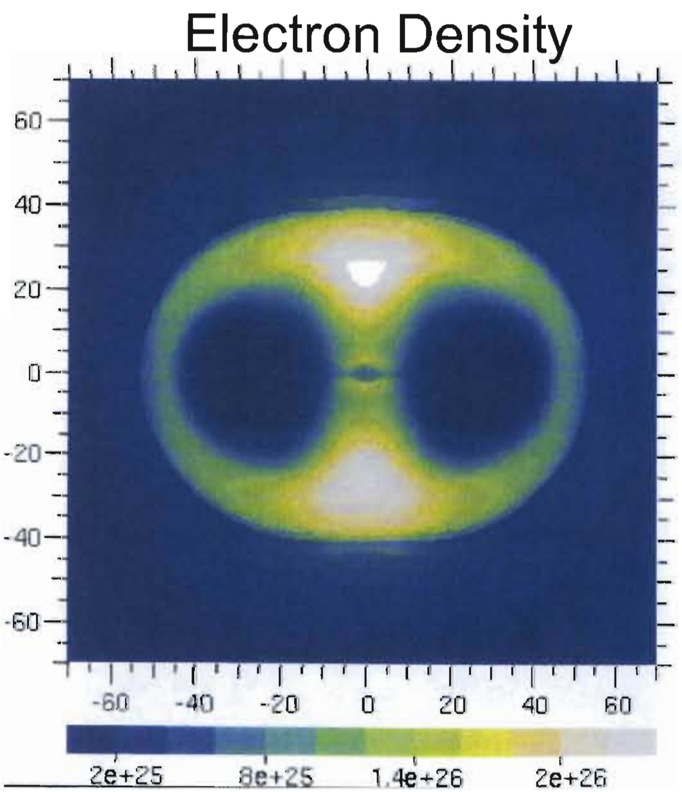
N110603

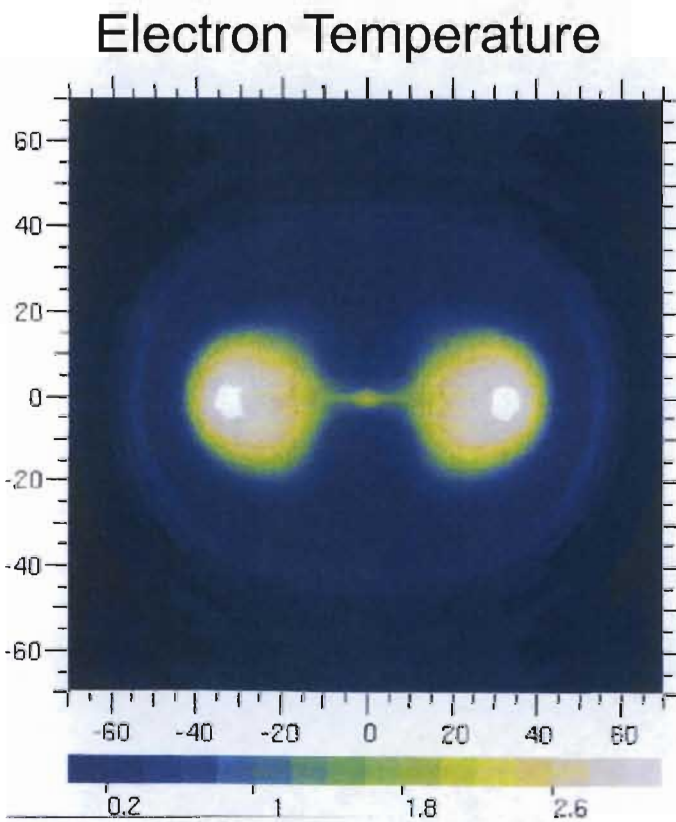
	Obs	Calc	Difference
YBangtime(ns)	22.330	22.369	39ps
Yield(13-15)	6.49e13	~3.2e+14	Factor of 5
Dsr(%)	4.68	4.88	0.2%
Tion(keV)	2.9	3.09	0.19 keV

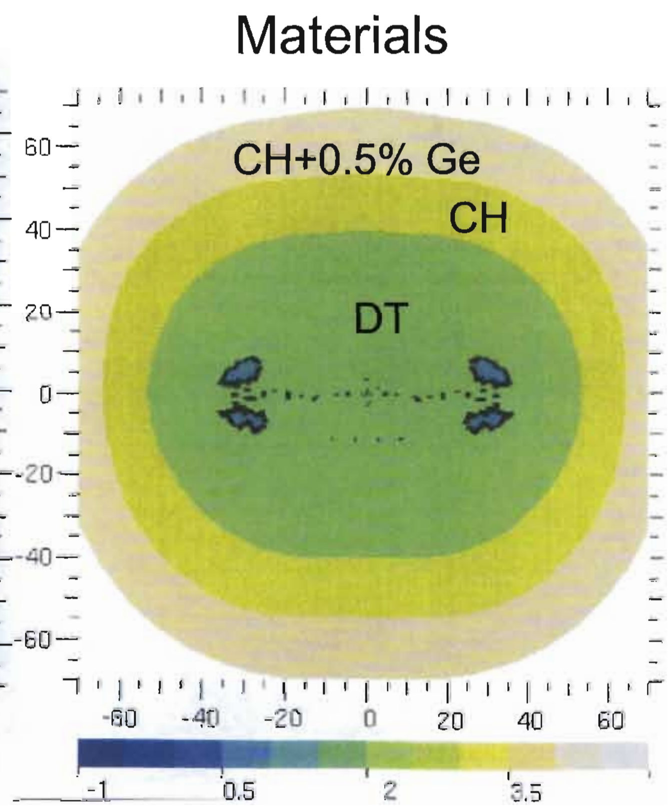
For other THD and DT shots the calculations give too much compression. These will be re-done, setting the fuel on a higher adiabat

Germanium emission must arise from doped plastic mixed into the hot fuel. If Ge is mixed, then so is CH.

- Germanium is observed in emission in N110603 THD and other THD and DT capsules See Regan *et al.* , O.We_A14
  - 2-35 ng of CH /Ge mixed into hot spot
  - Electron Density 0.5-1.0 e+25
  - Electron Temperature 2.2 (-0.6, +0.9) keV
- Ne and Te are consistent with mixing into the hot spot's low density torus.





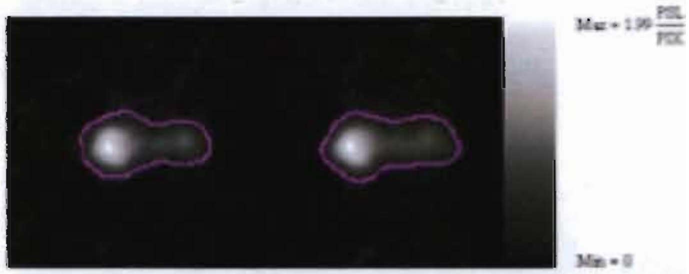


The X-ray bright spot in the THD image is dominated by emission between 9 and 11 keV, probably from germanium

Shot N110603-002

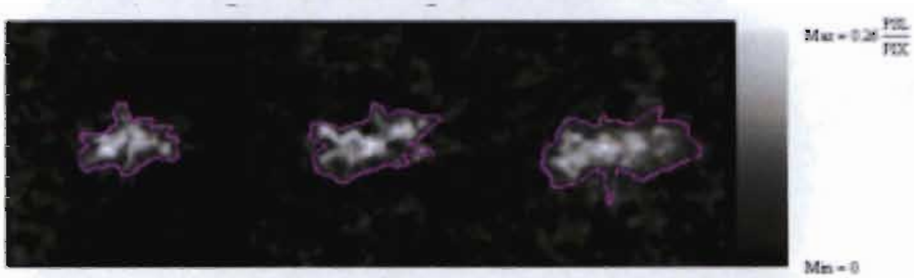
See Ma *et al.* ,P.WE_16

>6 keV



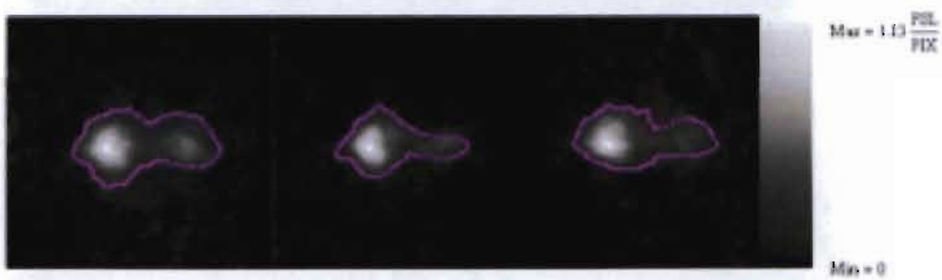
780 ± 50 PSL

6 – 9 keV



110 ± 44 PSL

9 – 11 keV



360 ± 120 PSL

NIC

Summary

- For directly driven gas filled capsules, X-ray emission is dominated by the glass shell, or glass mixed in the central fuel
  - Neutron sources fit inside observed X-ray images.
  - Both neutron and X-ray images show oblate implosions
  - Modeling suggests that more energy is absorbed by the inner cones than the outer cones.
    - Reducing the outer cone power by ~ 20% , or transferring it to the inner cones might alleviate the problem.
- For radiation driven THD and DT capsules, X-ray emission is dominated by material in the hot fuel, either DT or plastic mixed in from the cooler shell
  - Neutron image sizes are large, consistent with the entire X-ray image, not with the X-ray bright spots.
  - Combined with Ross filtered X-ray images and X-ray spectra, this suggests, X-ray bright spots contain plastic.
- Further comparisons may suggest the spatial extent of hot spot yield degradation


NIC