Mechanisms of Spontaneous Turbulence-Induced Transition to Detonation

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50th UKELG Anniversary Meeting
Exposion Safety -- Assessment and Challenges
Cardiff, July 2013

How "Unconfined" DDT Might Happen

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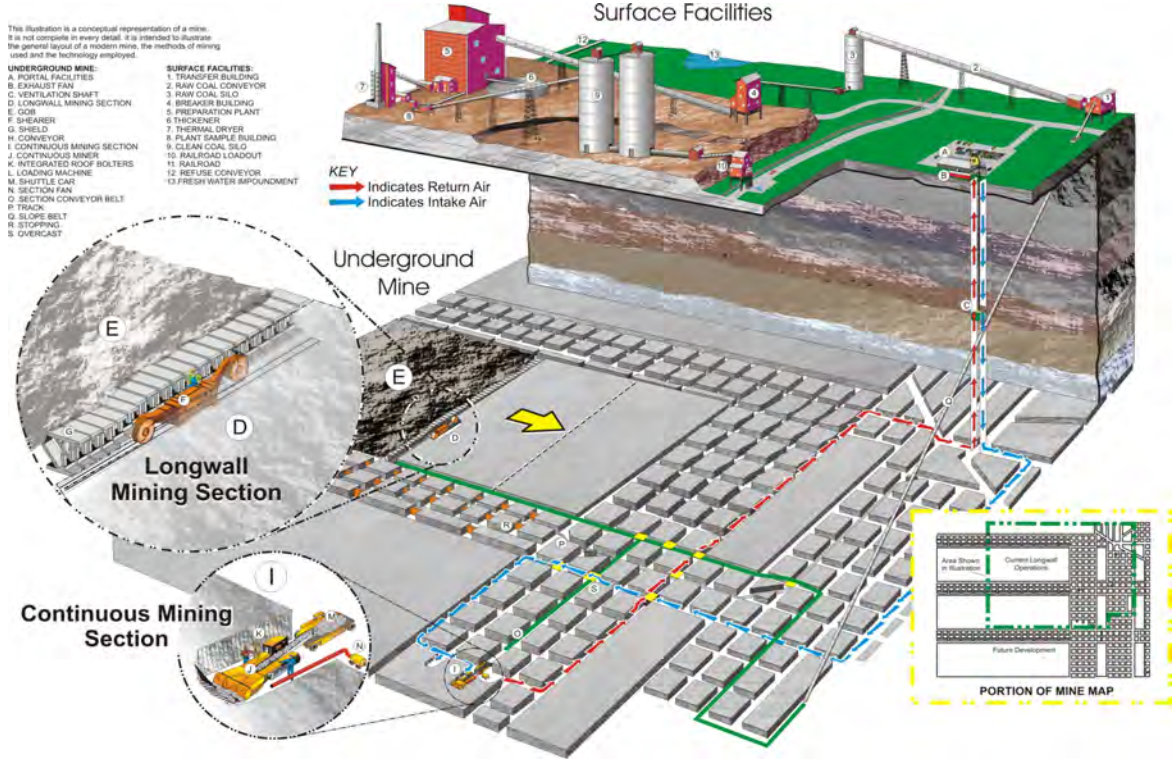
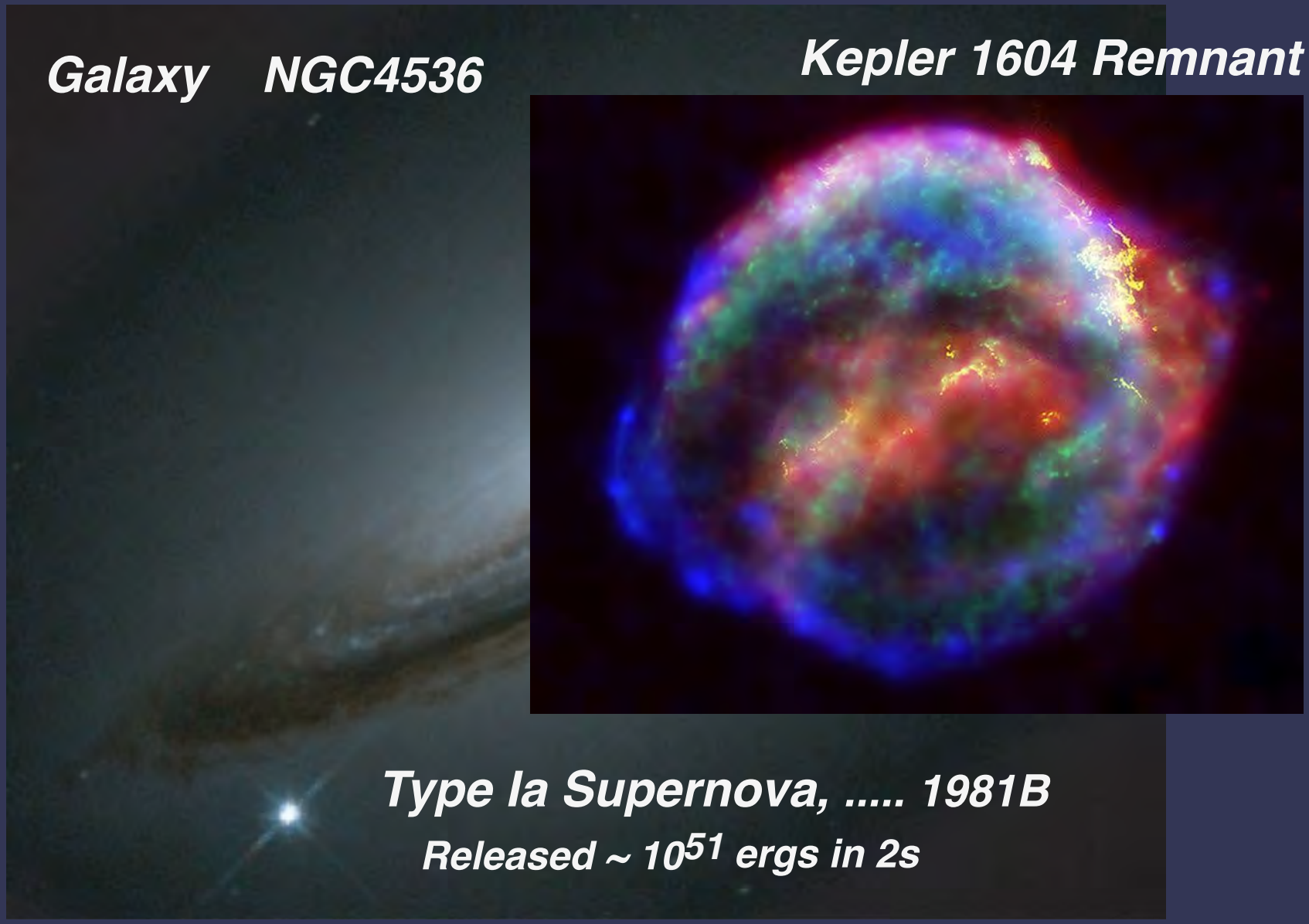
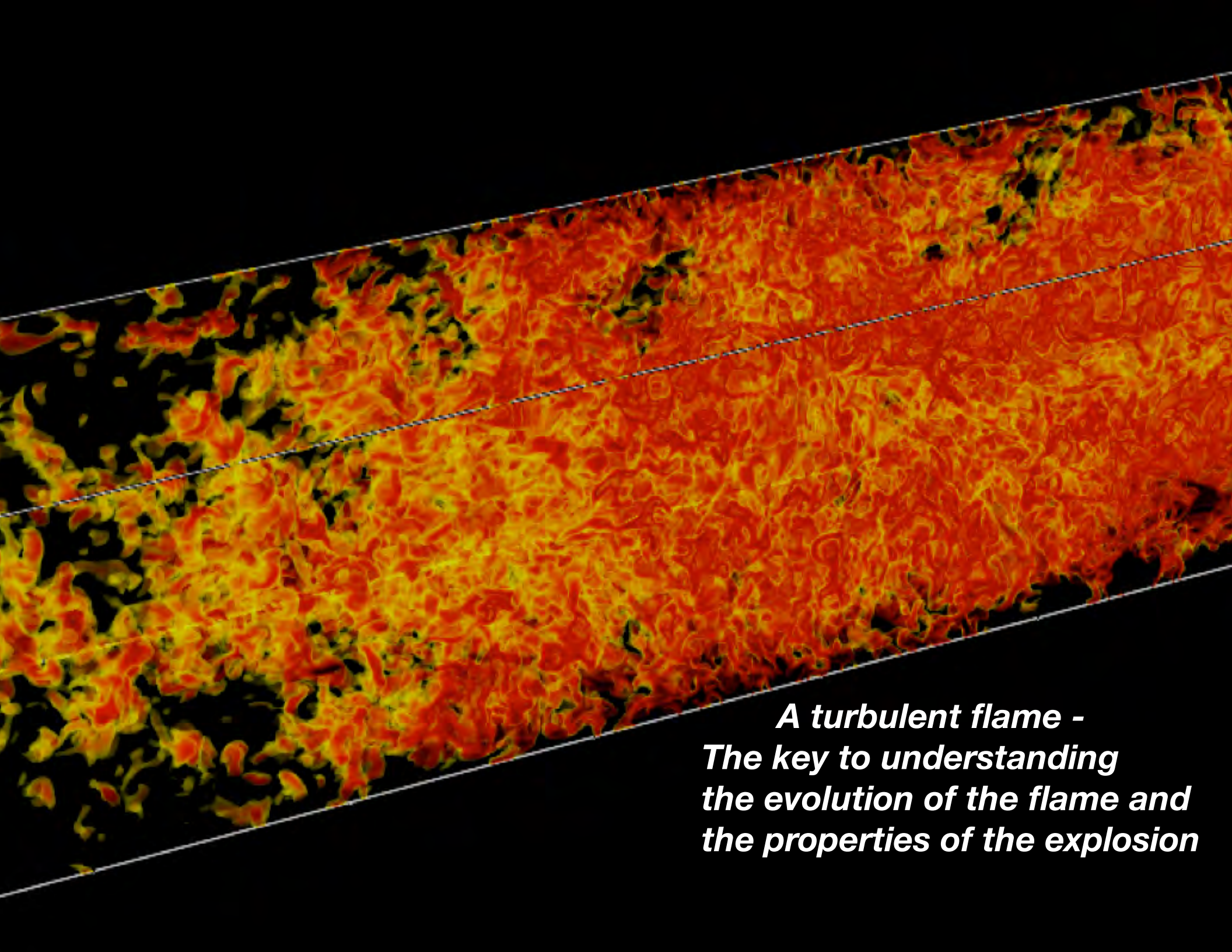
The Mining Environment





Type Ia Supernovae are "perfect combustion laboratories" and the "standard candles" of cosmology.

Buncefield, UK
5 December
2005



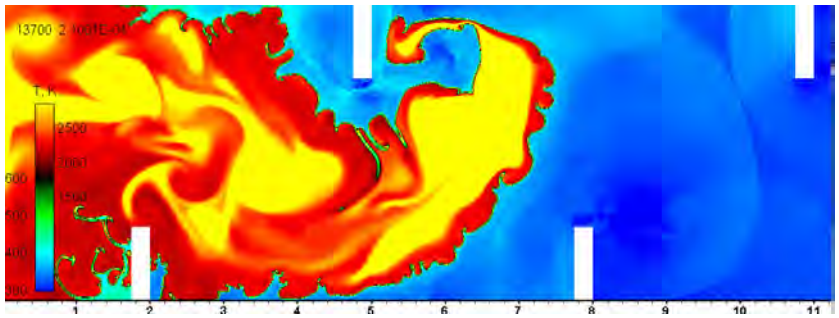
A turbulent flame -
The key to understanding
the evolution of the flame and
the properties of the explosion

Flame Acceleration and Deflagration-to-Detonation Transition (DDT):

Confined or Partially Confined

We know that the formation and development of shocks is critical. Confinement promotes this: Acoustic waves build to shocks, and shocks interact with flames to intensity the turbulence.

Hydrogen-Air (1 atm)



(Ogawa et al.)

What the Movie Showed Us ...

The initially laminar flame moves slowly into unreacted material.

Obstacles perturb the flow. Flow interacts with and distorts the flame. The flame accelerates and becomes turbulent.

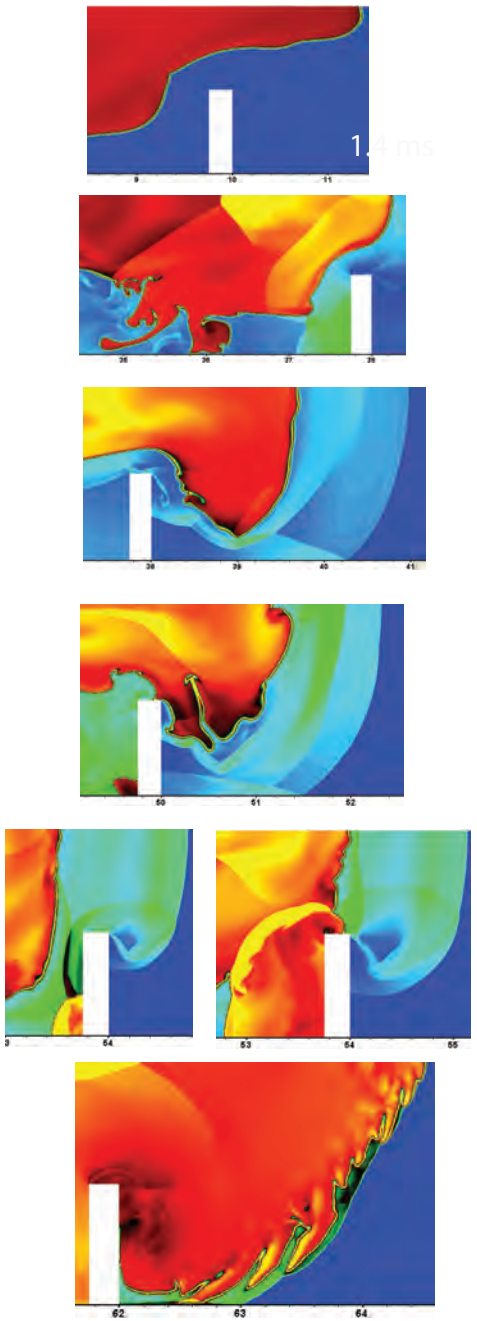
The turbulent flame generates compression waves, which eventually coalesce to form a shock in front of the flame.

The shock is continuously strengthened by compression waves coming from behind.

Shocks reflects from obstacles, create *hot spots,* or *ignition centers,* ignition centers, that may become spontaneous waves.

A resulting combustion wave may result, and may survive, as a detontion or a quasi-detonation..

Temperature Contours



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shocks ⟷ turbulence ⟷ energy release

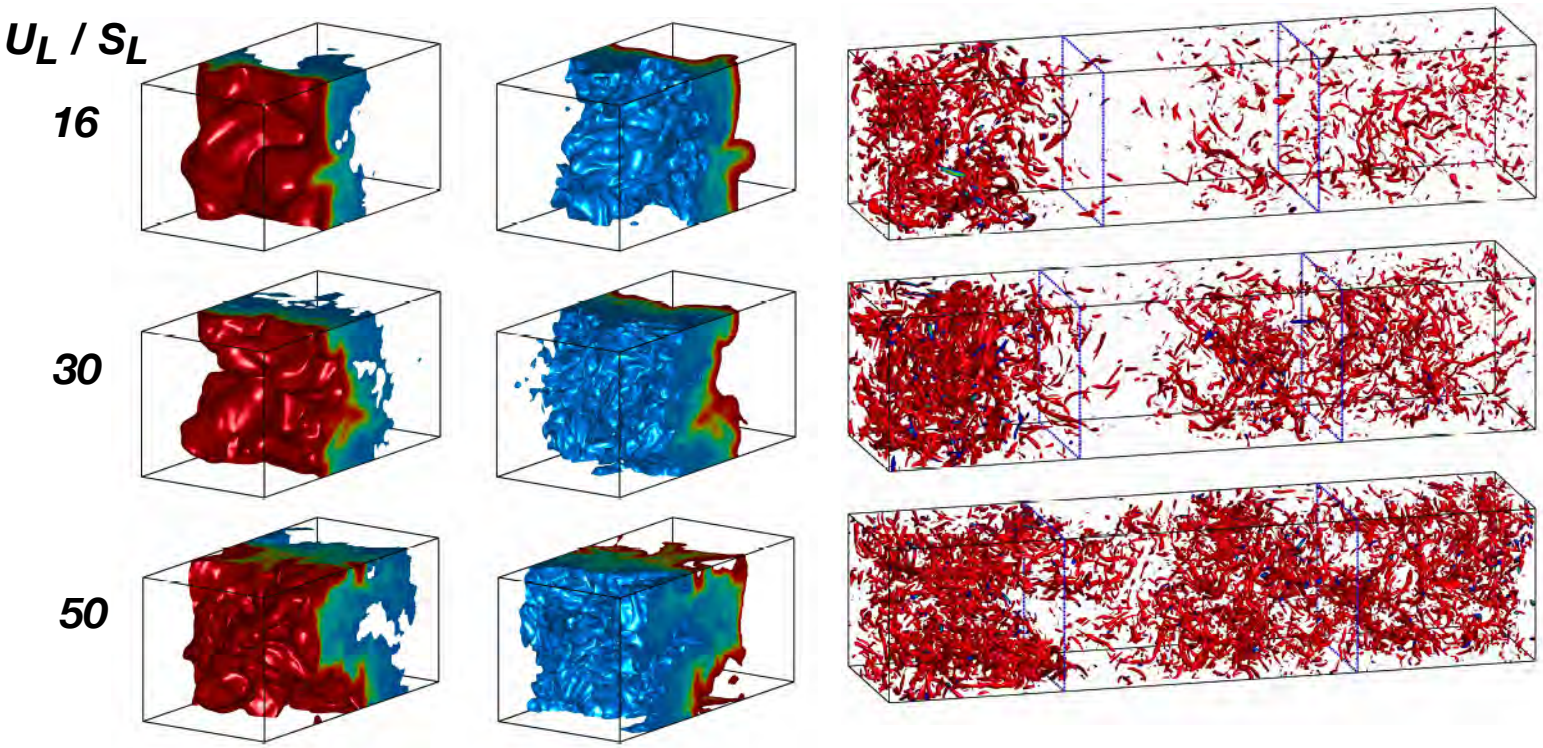
Unconfined or Far Enough from Walls

???

Can DDT occur without a pre-existing shock? How could a shock form?

When the turbulence is relatively weak, its structure is affected strongly by the flame.

Turbulent Flame Structure



Isocontours of concentration (Y)

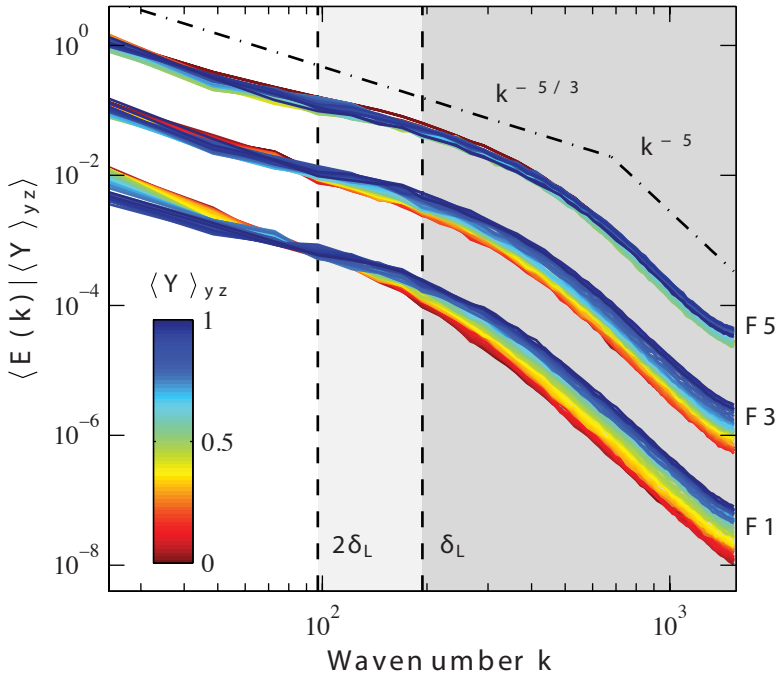
Isocontours of |ω|

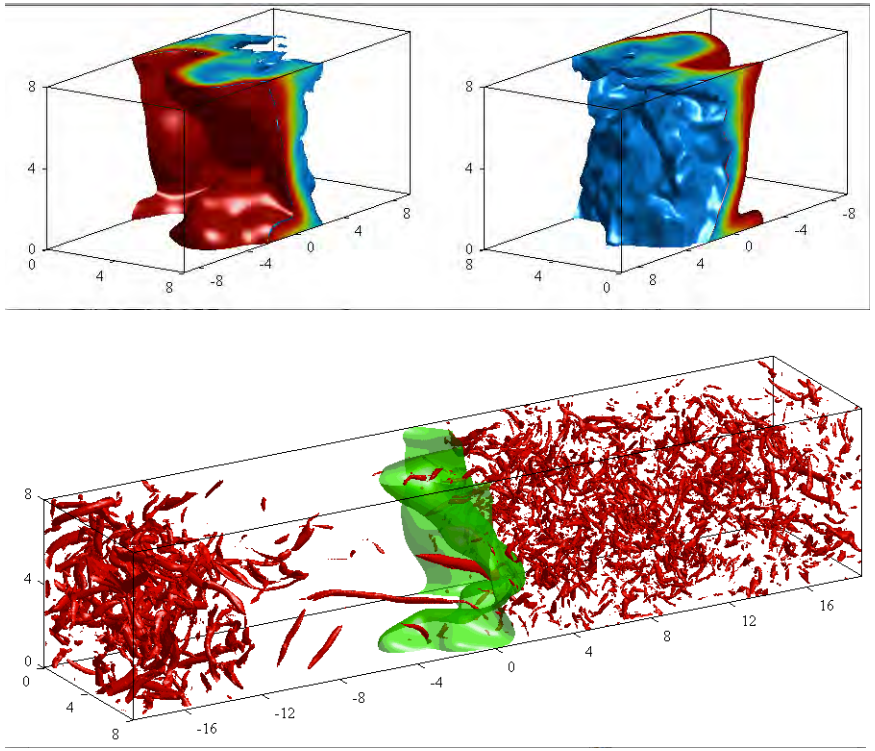
(Hamlington, Poludnenko, & Oran 2010-11)

Flame-Turbulence Interactions

Reactive turbulence itself is never Kolmogorov, even when the large-scale driving is Kolmogorov. Energy is injected on a range of scales in the flame brush.

Turbulence "moves energy around" in the scales of the flame brush. It suppresses small scales, enhances large scales.





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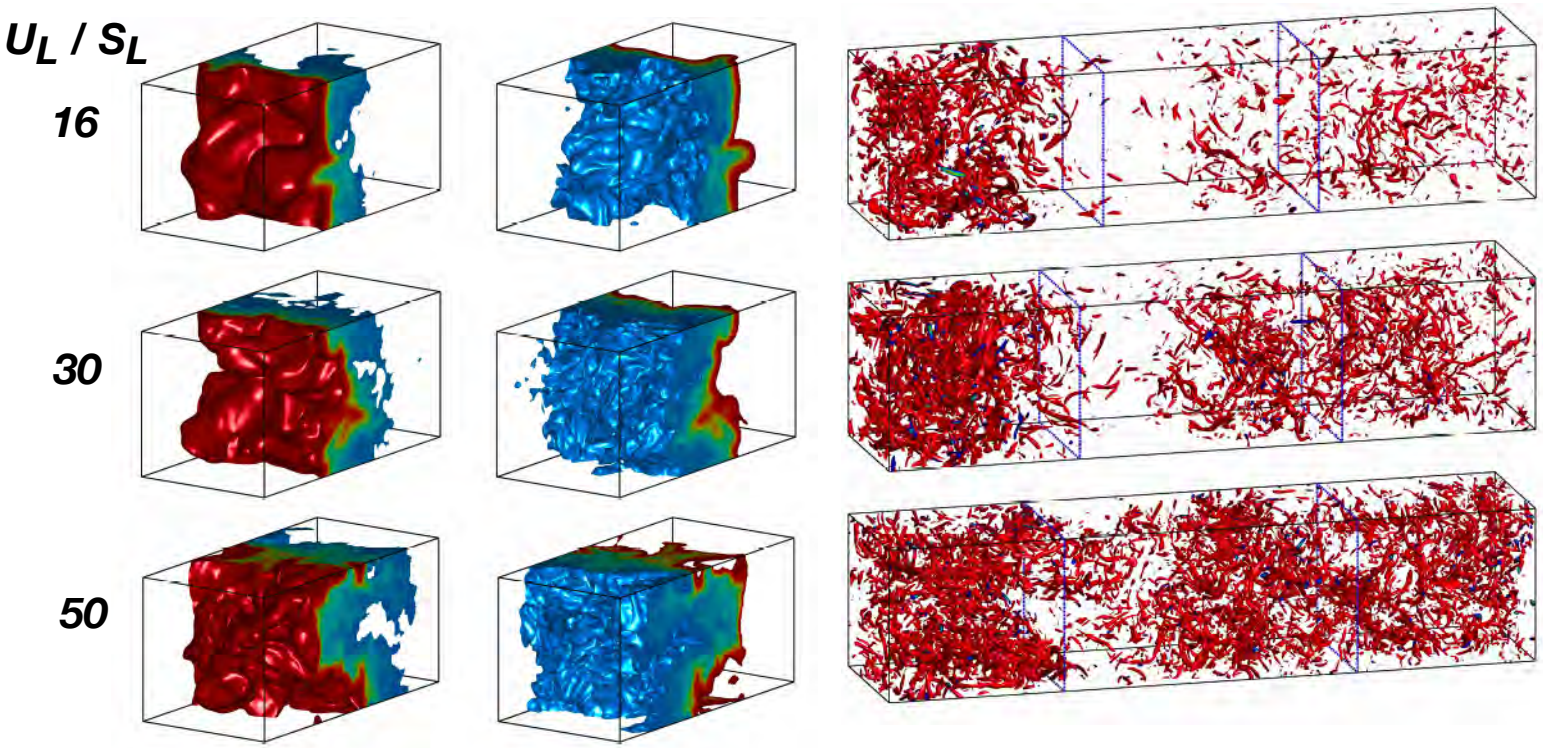


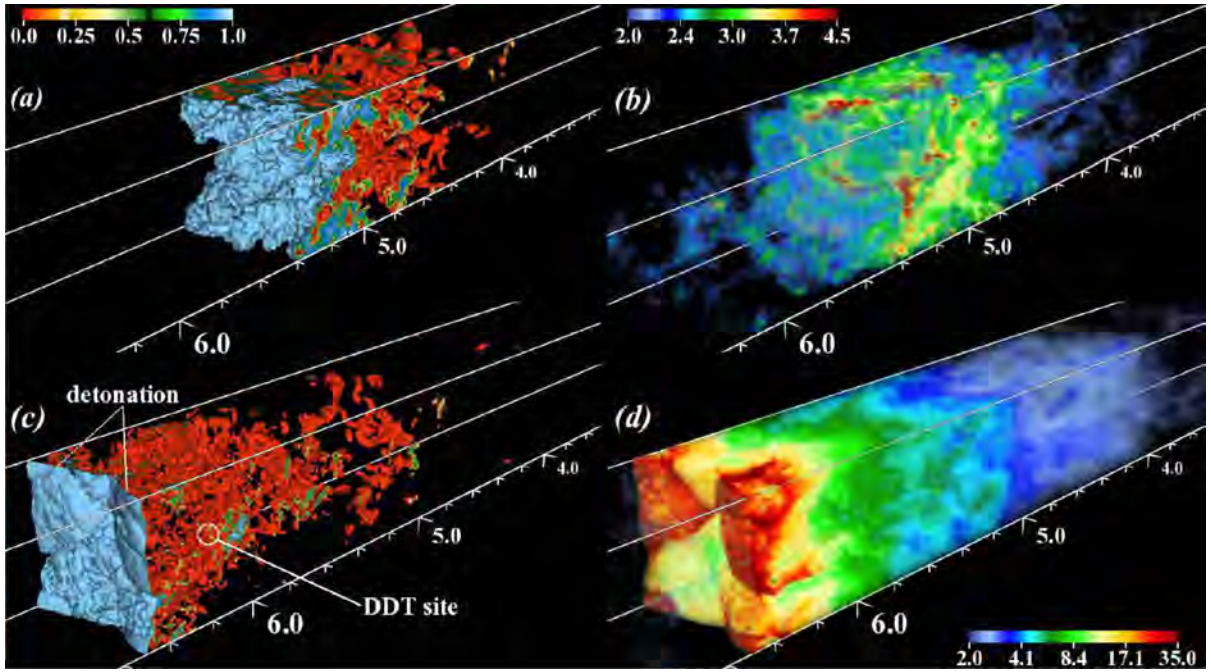
(Hamlington, Poludnenko, & Oran 2010-11)

But when turbulence is strong .... what can it do to the flame?

DDT Can Occur "Spontaneously"

For higher-intensity turbulent-flame interactions, detonations can arise "spontaneously."

A detailed analysis of one H_2-flame simulation showed that the transition was preceded by a large increase in the flame-brush pressure, resulting from intense turbulent-flame interactions. At that point, the entire flame brush accelerated to the CJ flame speed, shocks began to form locally inside the flame brush, and a DDT occurred inside the flame flame brush.

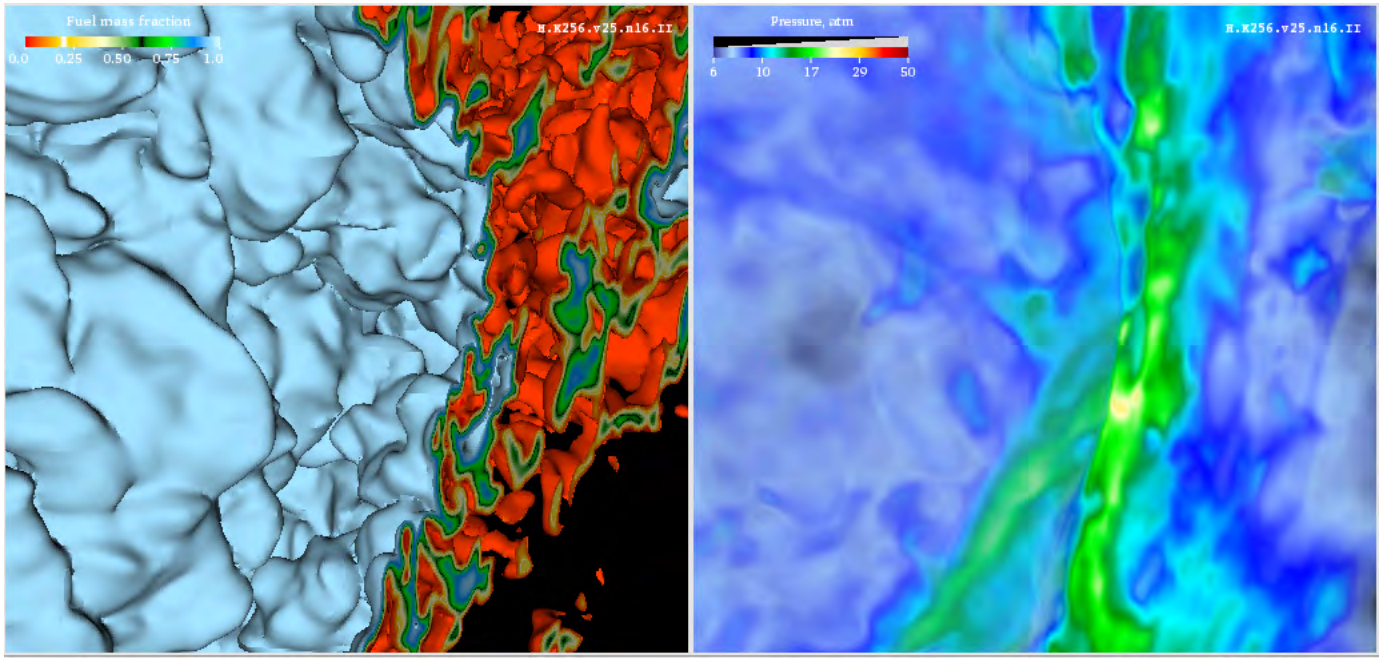


$$S_T = \frac{c_S}{(\rho_f/\rho_p)} = S_{CJ}$$

(Poludnenko, Gardiner, Oran, PRL, 2011, Science (Editor's Choice))

Can we see what is actually happening here?

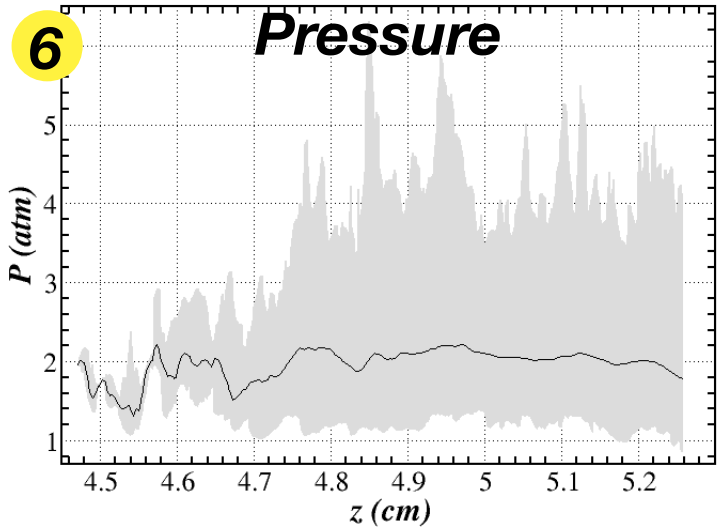
How is the shock formed?
Can we see a “dynamic hot spot” or
is this really something else?

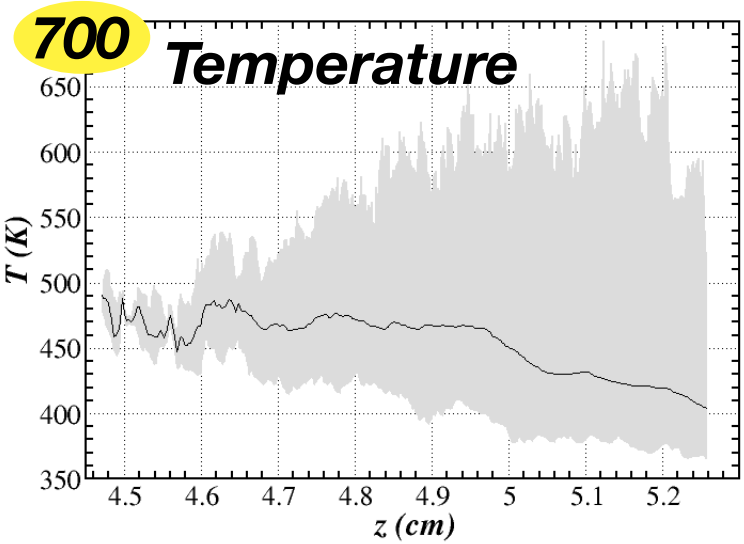


It’s not at all clear ... We do not have the resolution yet.
It looks like a “dynamic hot spot,” caused by a shock generated in the flow, and occurring at very small time and space scales.

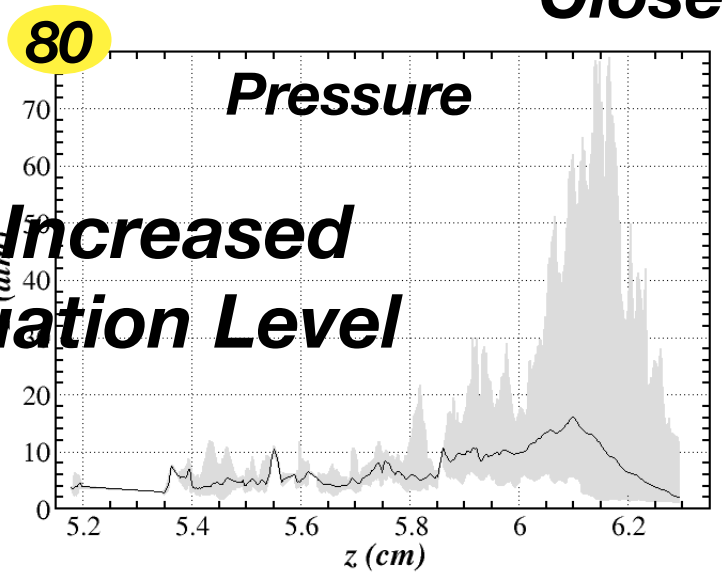
In Flame Brush: Approaching DDT
Local and Mean Temperature and Pressure in z Plane

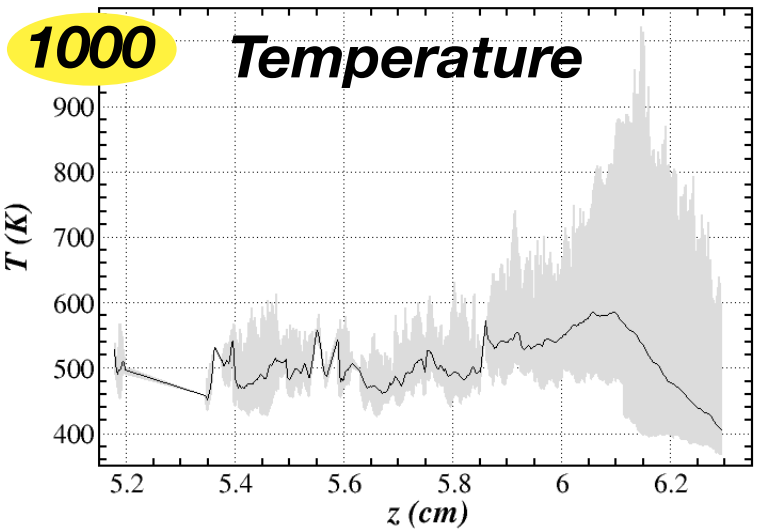
Early





Close to DDT

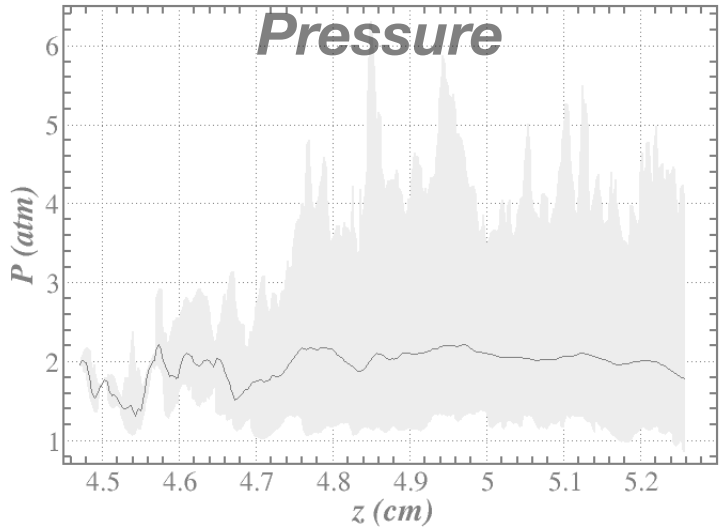


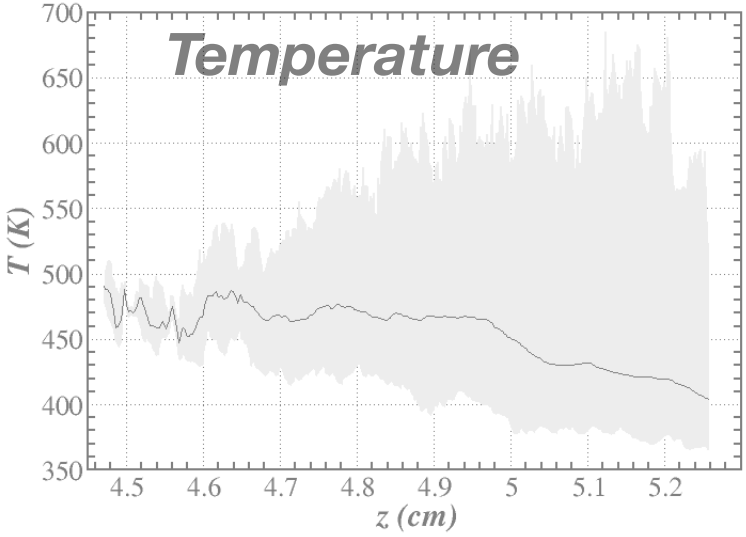


Note: Increased Fluctuation Level

In Flame Brush: Approaching DDT
Local and Mean Temperature and Pressure in z Plane

Early





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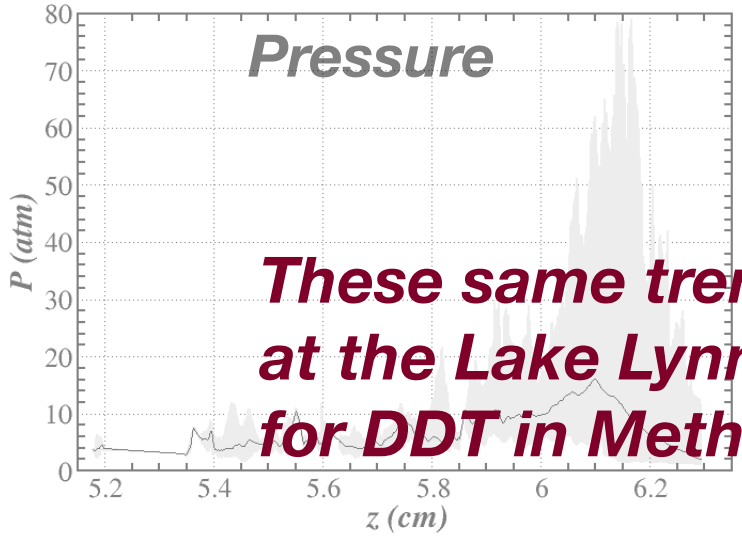
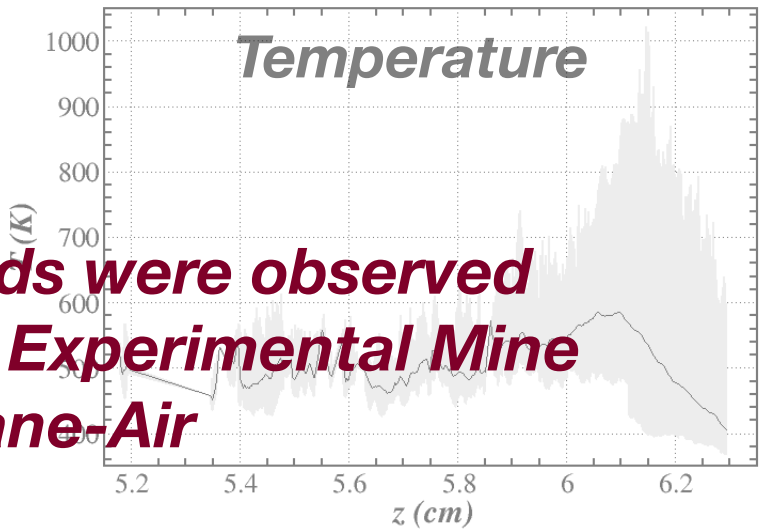


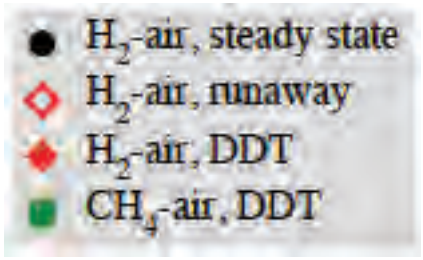


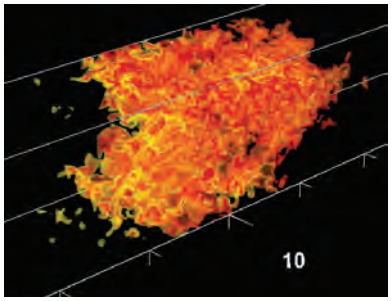
These same trends were observed at the Lake Lynn Experimental Mine for DDT in Methane-Air

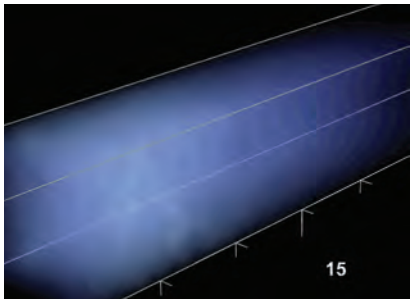
What does intermittency mean for us practically?

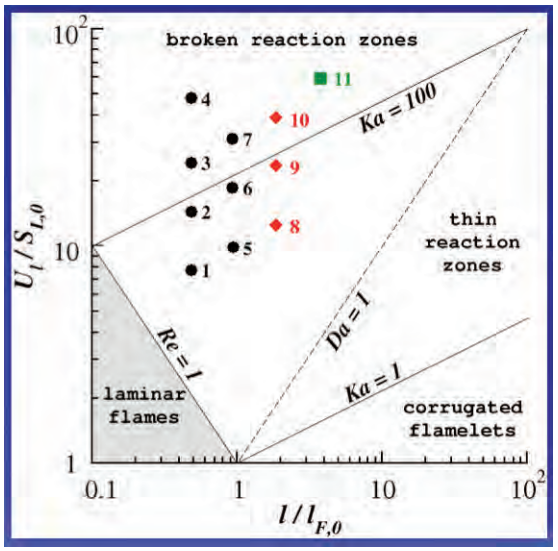
Fluctuatons in physical variables (P, T, v, ...) can have dramatic effects in an exothermic material.

Fuel Mass Fraction **Pressure**

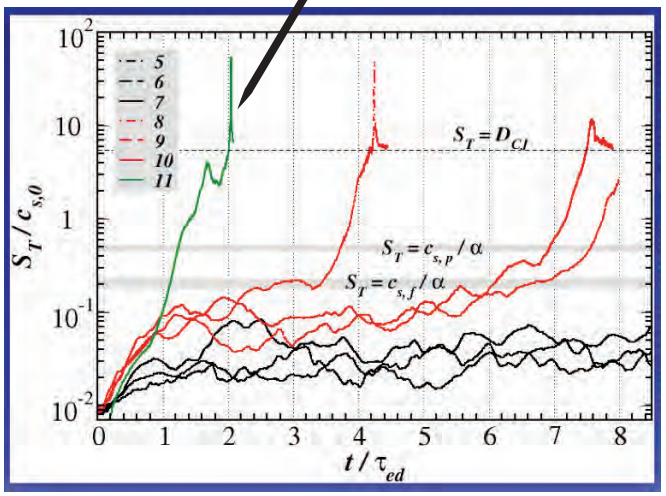








Methane

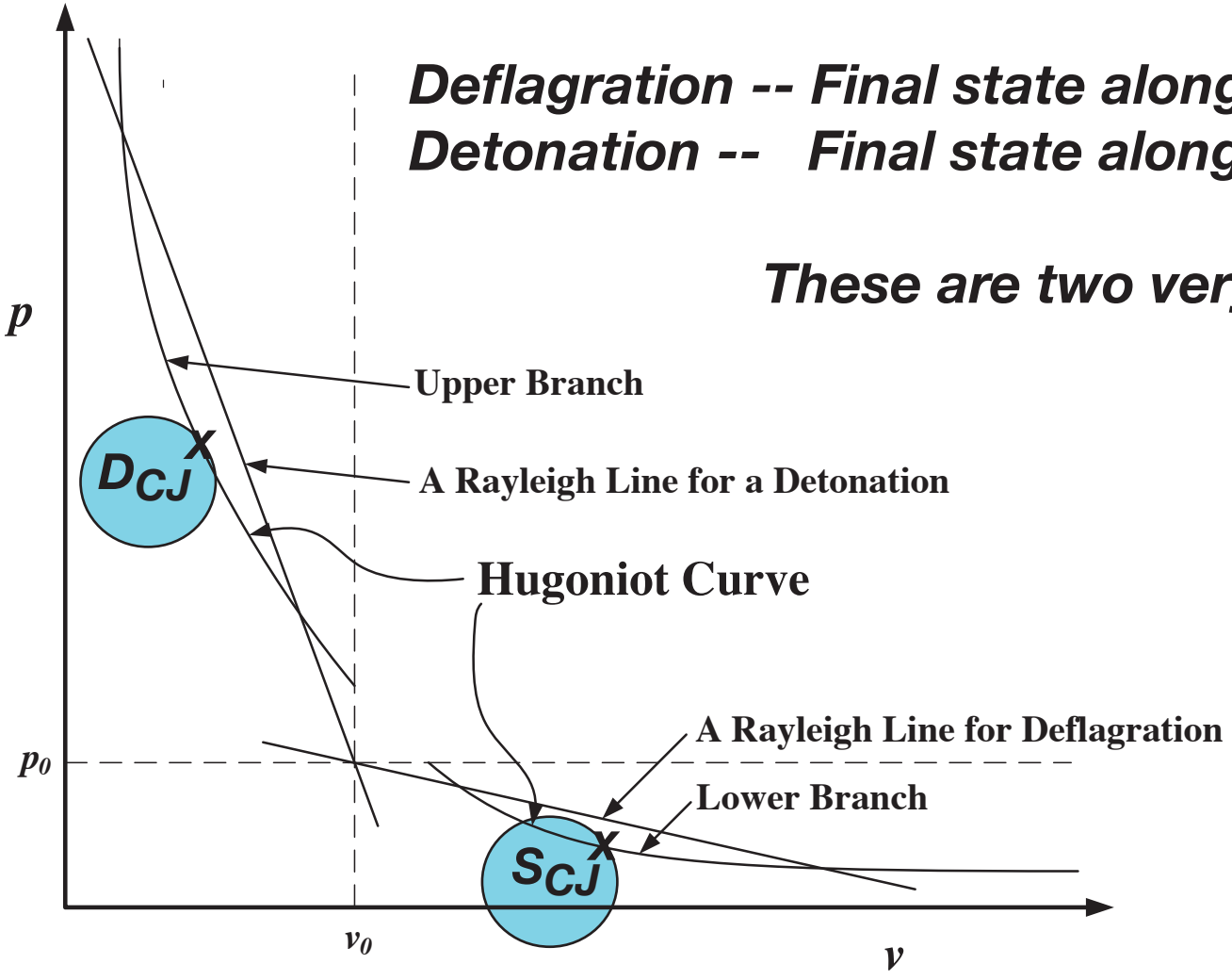


One thing we know: there is more chance of an extreme event, a large and strong effect in the flow, to occur as Re increases.

For exothermic processes, branches must be separated because conservation (mass and momentum) requires that a straight line connecting the initial and final states in diagram (the Rayleigh line) cannot have a positive slope.

Deflagration -- Final state along the lower branch
Detonation -- Final state along the upper branch

These are two very different states!



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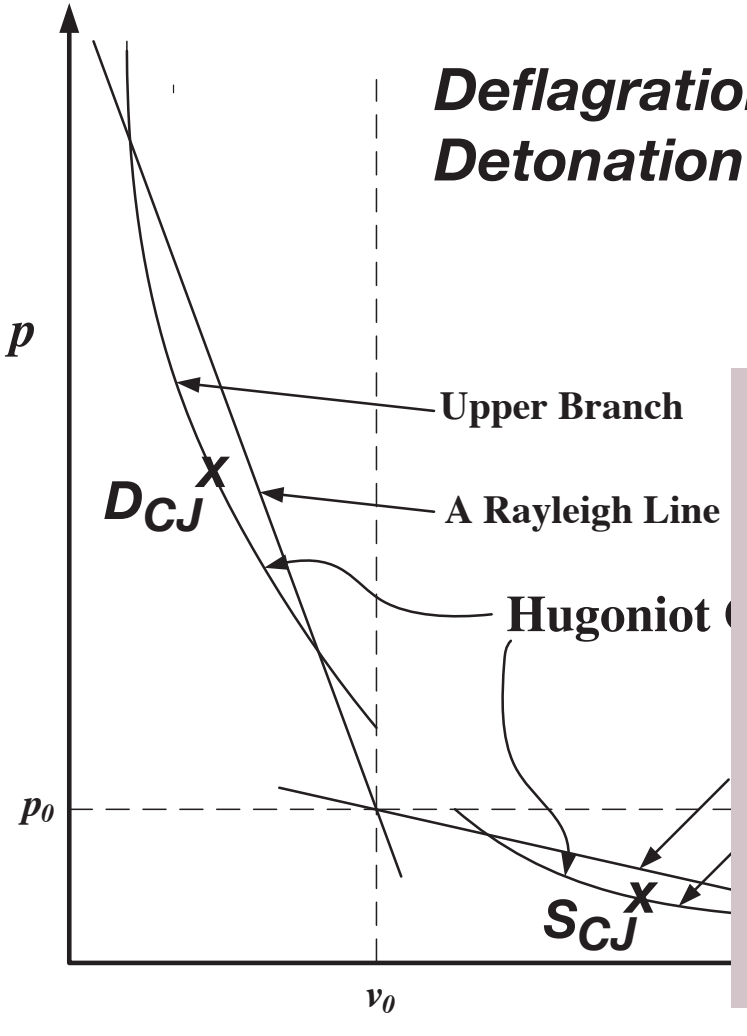

Deflagration -- Final state along the lower branch
Detonation -- Final state along the upper branch

These are two very different states!

This is a steady state picture!

It gives us no idea of the dynamics, or any unsteady intermediate states that could lead to a transition among "steady states."