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Title: The Bipolar Behavior of the Richtmyer–Meshkov Instability (U)

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THE BIPOLAR BEHAVIOR OF THE RICHTMYER–MESHKOV INSTABILITY

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A numerical study of the evolution of the multimode planar Richtmyer-Meshkov instability (RMI) in a light-heavy (air-SF6, Atwood number A=0.67) configuration involving a Mach number Ma=1.5 shock is carried out. Our results demonstrate that the initial material interface morphology controls the evolution characteristics of RMI (for fixed A, Ma), and provide a significant basis to develop metrics for transition to turbulence. Depending on initial rms slope of the interface, RMI evolves into linear or nonlinear regimes, with distinctly different flow features and growth rates, turbulence statistics, and material mixing rates. We have called this the bipolar behavior of RMI. Some of our findings are not consistent with heuristic notions of mixing in equilibrium turbulence: more turbulent flow—as measured by spectral bandwidth, can be associated with higher material mixing but, paradoxically, to lower measures of turbulent kinetic energy and integral mixing layer width.

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The Bipolar Behavior of the Richtmyer-Meshkov Instability

F.F. Grinstein, A.A. Gowardhan, and J.R. Ristorcelli

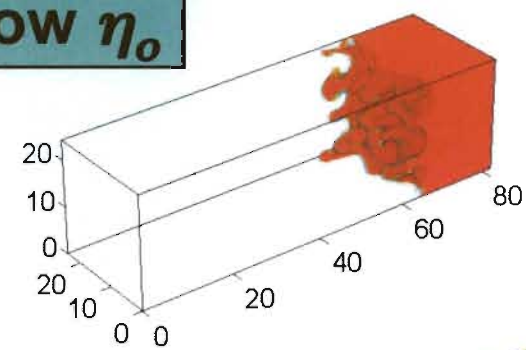
Motivation

- *Characterize Initial condition effects on transition and mixing*
- *Goal: control instability*

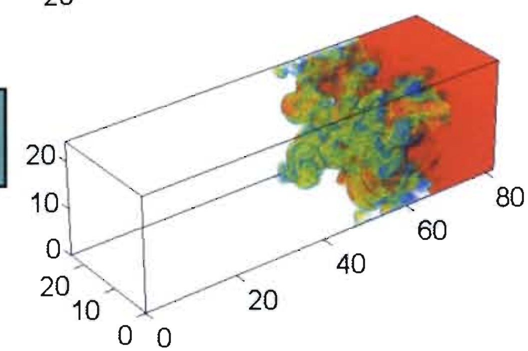
New results

- *Bipolar behavior of the RM instability*
    - *challenges to modeling*
    - *reshock effects on first shock*

low η_o



high η_o



instantaneous material mixing

LANL LDRD-DR Program on "Turbulence by Design"

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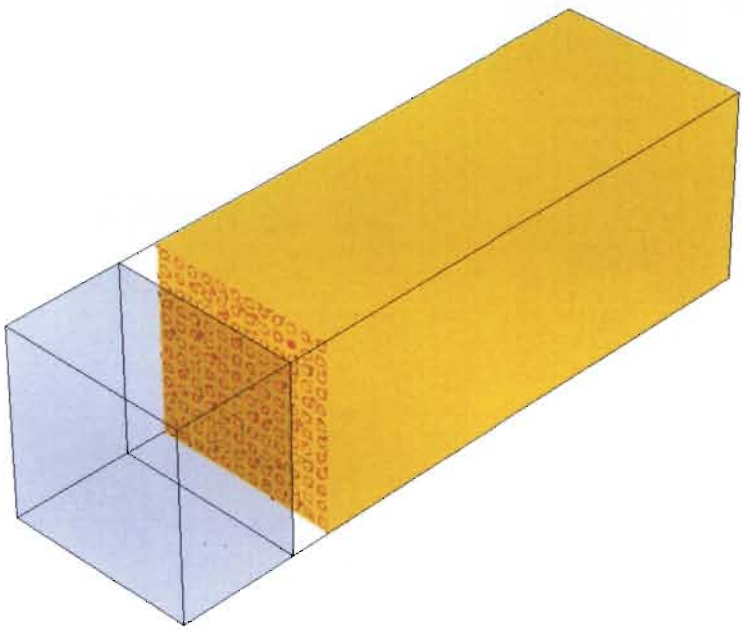
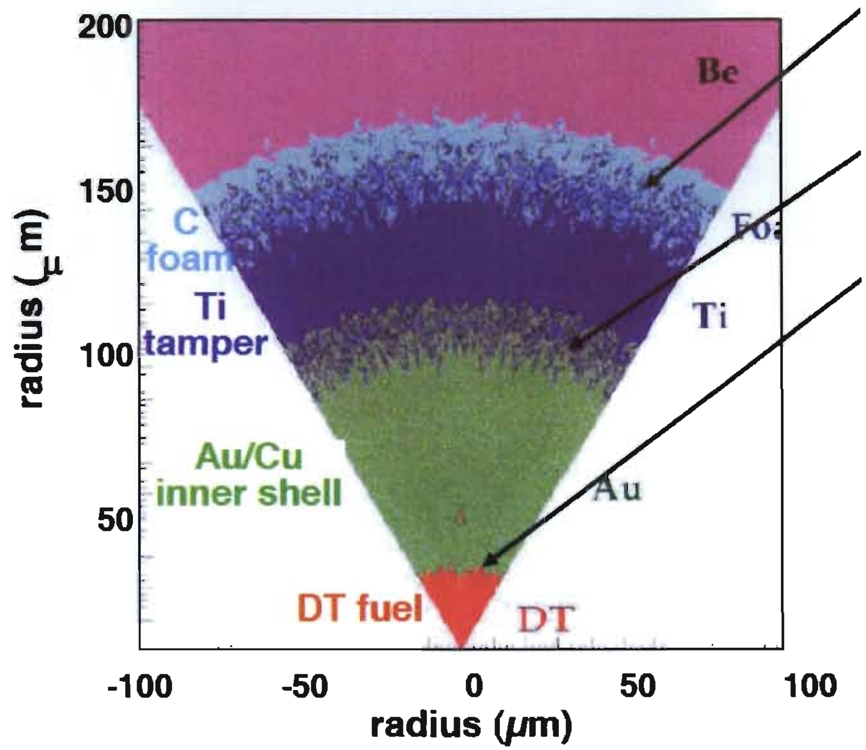
Shock-Driven Turbulent Mixing Experiments
Richtmyer-Meshkov Instability: shocks & turbulence

ILES RAGE simulations
SF_6 mass fraction distributions



planar **single-interface** (V&S 95, Caltech)

2D HYDRA simulation of NIF-scale ignition double shell capsule



- Understand Effects of Initial Material Interface Conditions
- Practical Goal: control (promote or inhibit) RM instability

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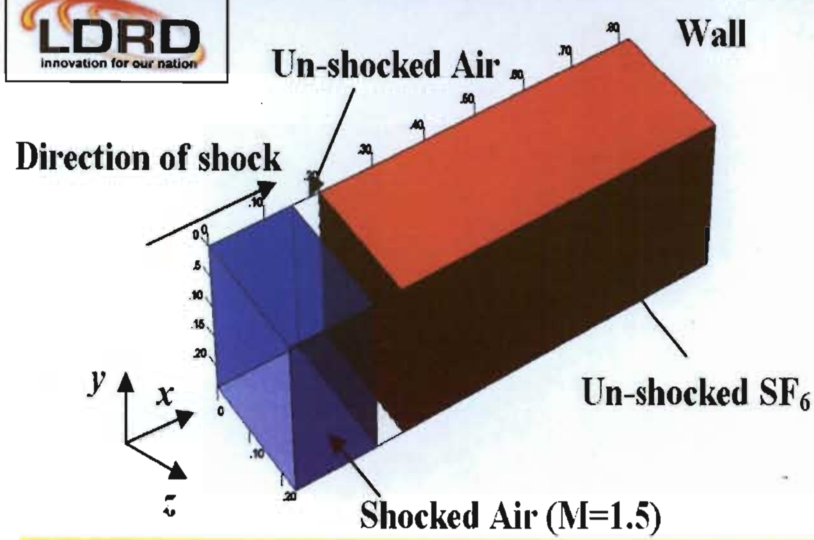
Shock-Driven Turbulence Simulations



- shocks and turbulence, transitional flow
- wide range of length and time scales, non-linear interactions
- Implicit Large Eddy Simulation (ILES), e.g., ILES book, 2nd printing: 2010

- **planar** (Vetter & Sturtevant '95, ….), **gas curtain** (Prestridge et al., LANL P-23)
- **Hybrid WENO / classical LES,** Pullin et al. 2006, …, 2011
- **ILES** , 2002 – 2011: Cohen et al. (FV-PPM), … Schilling et al. (FD-WENO), Youngs, Drikakis et al. (FV-LR, FV-Godunov), Leinov et al. (FV-ALE), …
- **ILES-RAGE**; FV-Godunov, van Leer limiter, no interface treatment, AMR
  - **planar V-S expts.,** ***PoF*** **March 2011**;
  - **planar Bipolar RM,** ***PoF*** **Letters July 2011**; AIAA-Hawaii-2011 / ETC13 → **PoF**
  - **shocked** (double interface) **gas-curtains**, ***J. Turbulence*** **2011**, in press.

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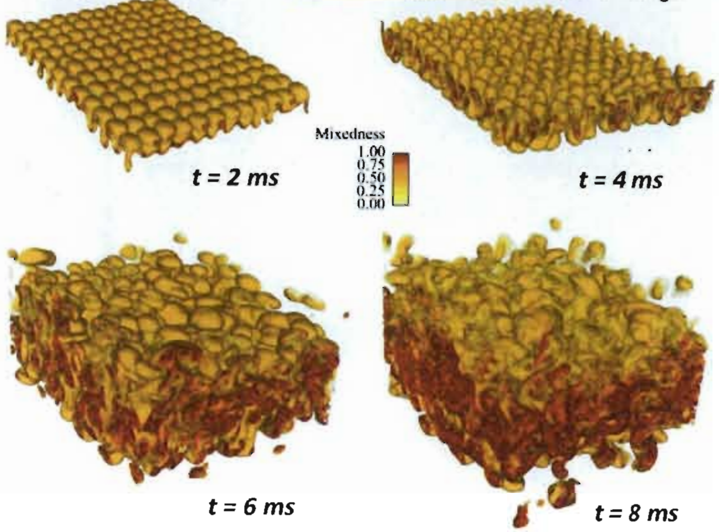
ILES RAGE – Planar RM Expts.

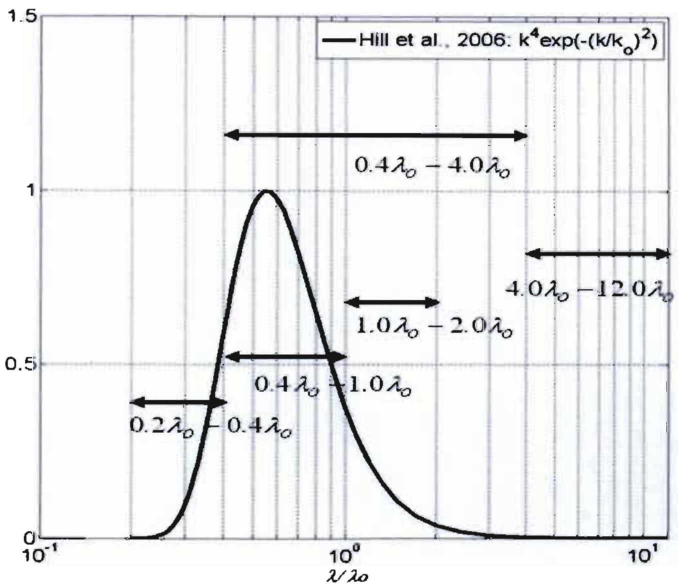
Spectral IC effects on material mixing

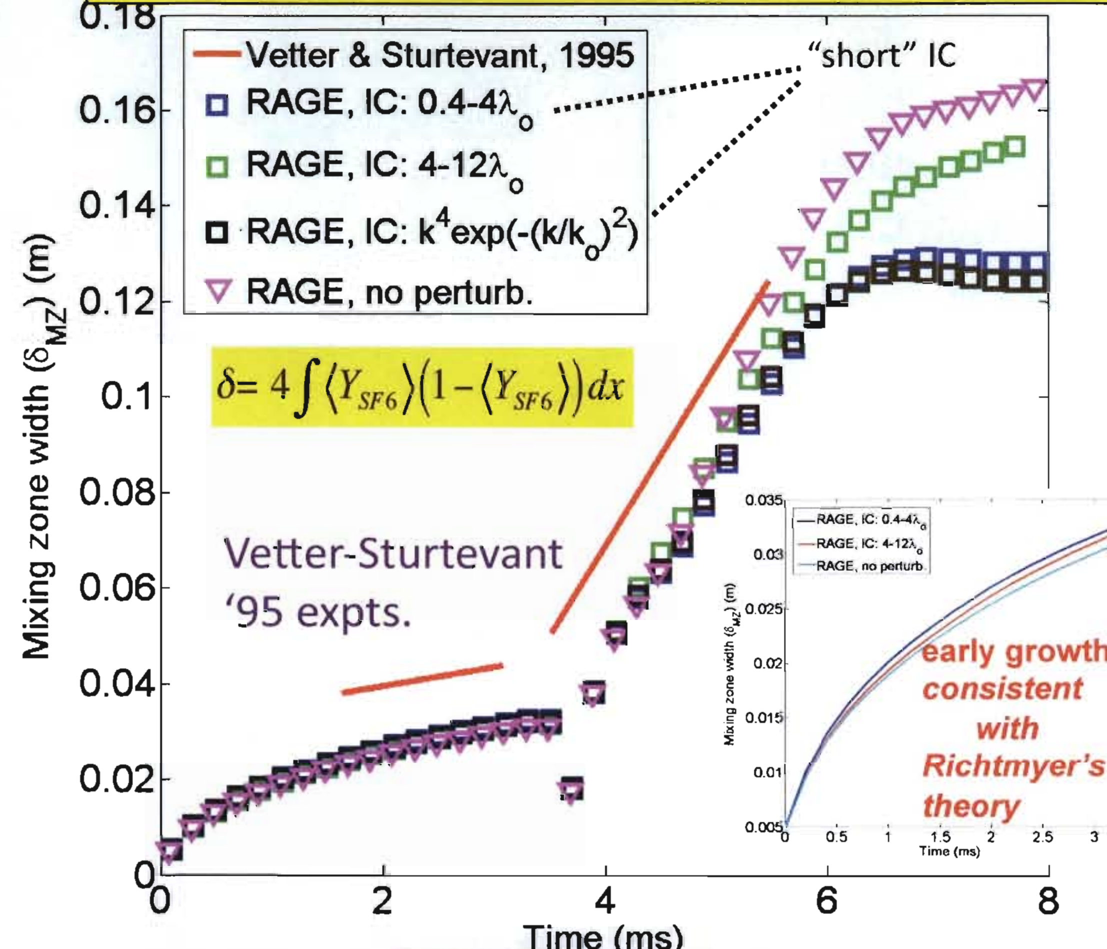
Grinstein, Gowardhan, and Wachtor, *PoF*, March 2011

egg crate (λ_o) $\theta = (1 - Y_{SF6})Y_{SF6}$ + (0.4-4λ_o)



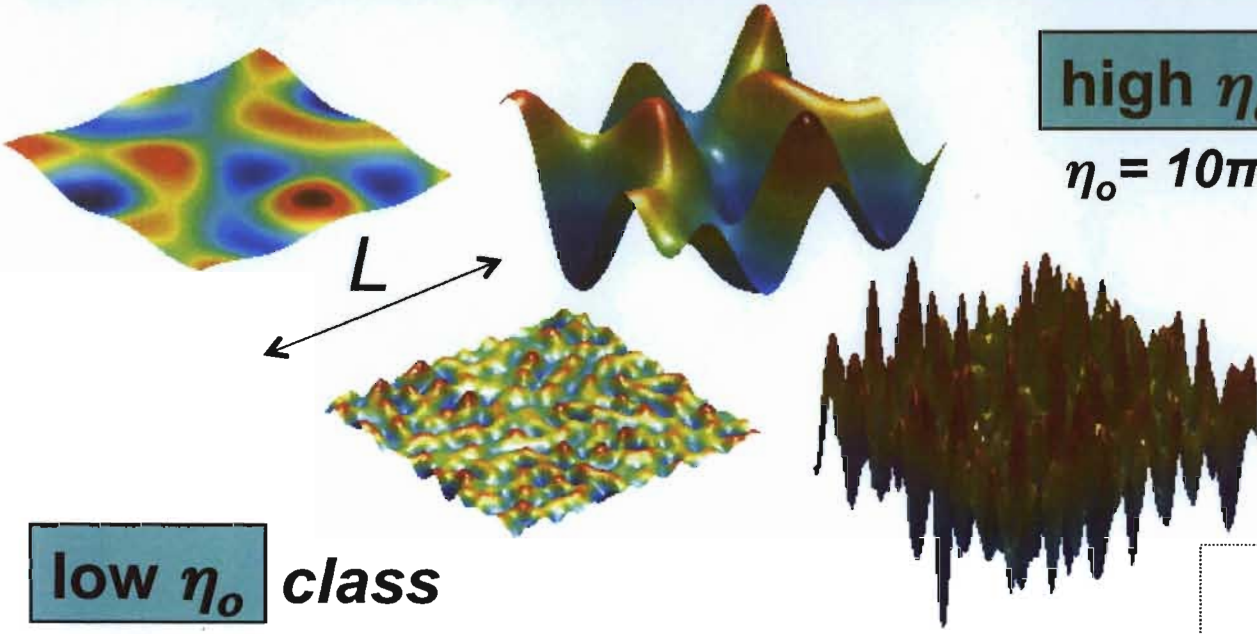
10% IC perturbation added to mode (λ_o)





- results for "thin" **low η_o** initial material interface
- **early-time** (t<~5ms) **growth fairly IC insensitive**
- **late-time sensitive to ICs** (more so for "longer" IC
- **IC resolution issues ... separate discussion req'd ...**

Initial material interface parameterization
(no initial "egg-crate", no reshock…)



high η_o *class* $(\kappa_o\delta_o > \pi)$

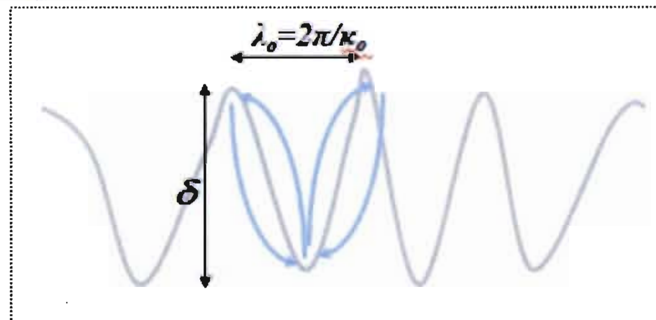
η_o= 10π/12 , 10π/8, 10π/4 , 10π/2

$$\eta_o = \kappa_o\delta_o$$

low η_o *class*

$(\kappa_o\delta_o << \pi)$

η_o= π/12 , π/8 , π/4 , π/2



$(\lambda_{min},\lambda_{max})$	$L(\frac{1}{24},\frac{1}{6})$	$L(\frac{1}{12},\frac{1}{4})$	$L(\frac{1}{6},\frac{1}{3})$	$L(\frac{1}{4},\frac{1}{2})$	$L(\frac{1}{24},\frac{1}{6})$	$L(\frac{1}{12},\frac{1}{4})$	$L(\frac{1}{6},\frac{1}{3})$	$L(\frac{1}{4},\frac{1}{2})$
δ_o (cm)	0.5 (low η_o)				5 (high η_o)			
κ_o (cm^{-1})	π	π/2	π/4	π/6	π	π/2	π/4	π/6

Bipolar Behavior of planar RM

Ma=1.5, air/SF_6 – no egg-crate, no reshock

Gowardhan, Ristorcelli and Grinstein; *PoF* Letters, July 2011

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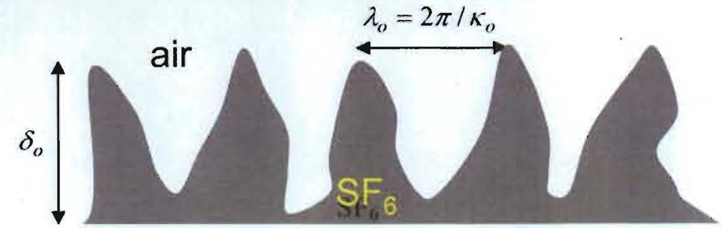
Initial *rms* slope $\eta_o = \kappa_o \delta_o$ of Initial Material Interface

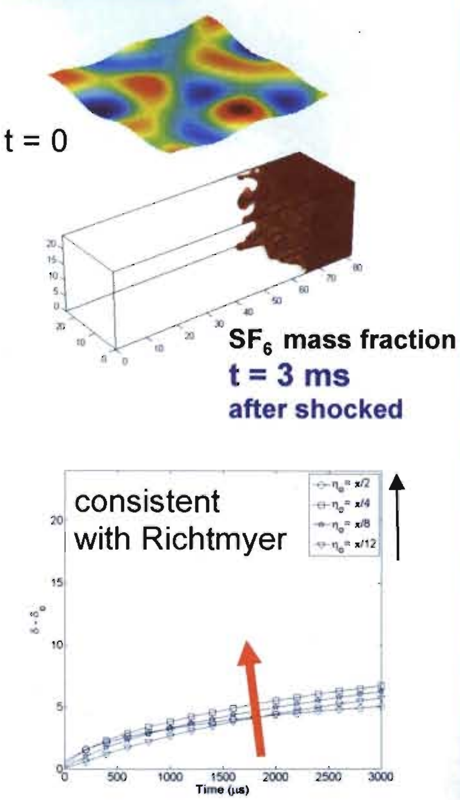


Beyond Richtmyer (*growth = constant × η_o*):

- → ***bipolar RM behavior vs. IC morphology***
- → ***different instability mechanisms & late-time flow***

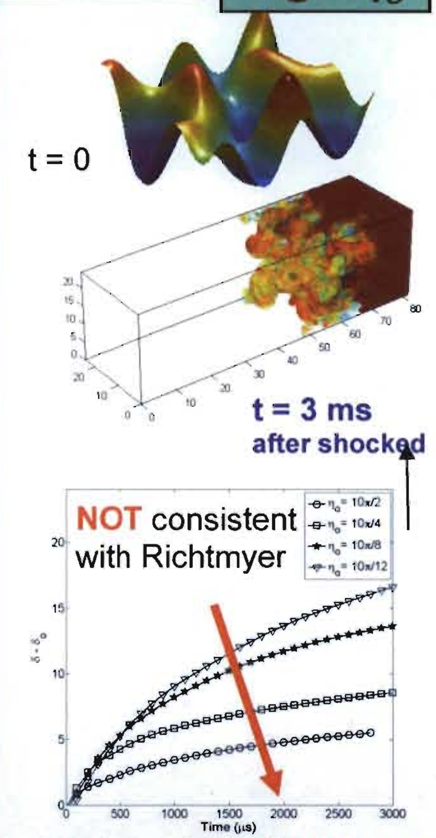
Dimensional **results**

low η_o



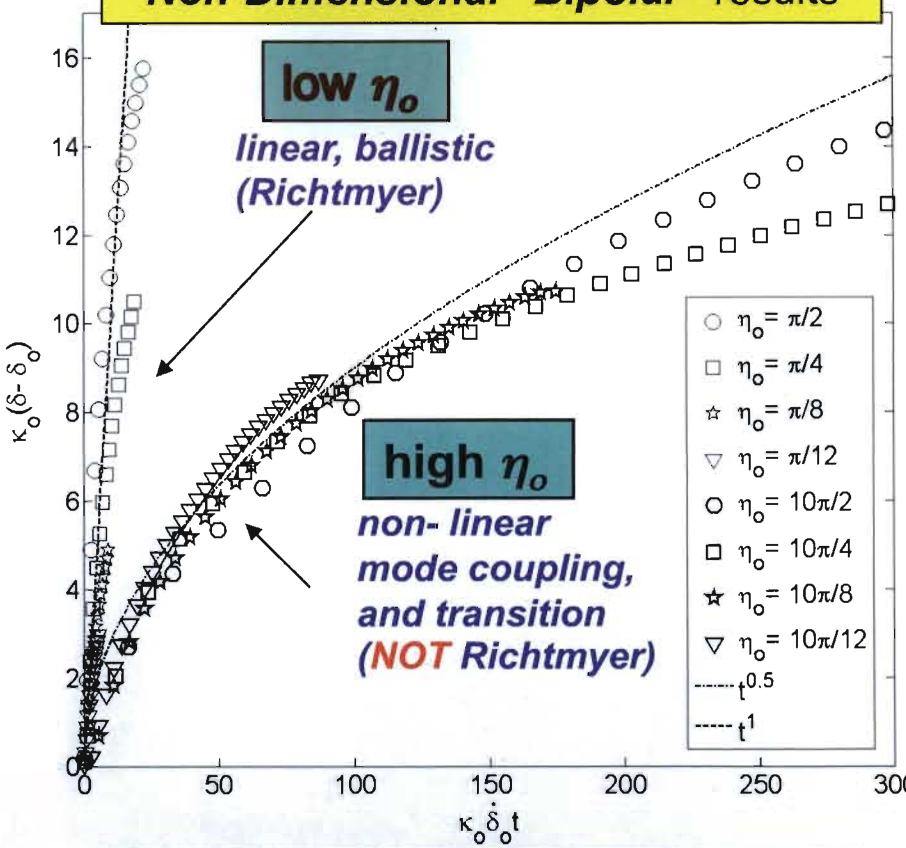
Mixing width **increases** with increasing η_o

high η_o



Mixing width **decreases** with increasing η_o

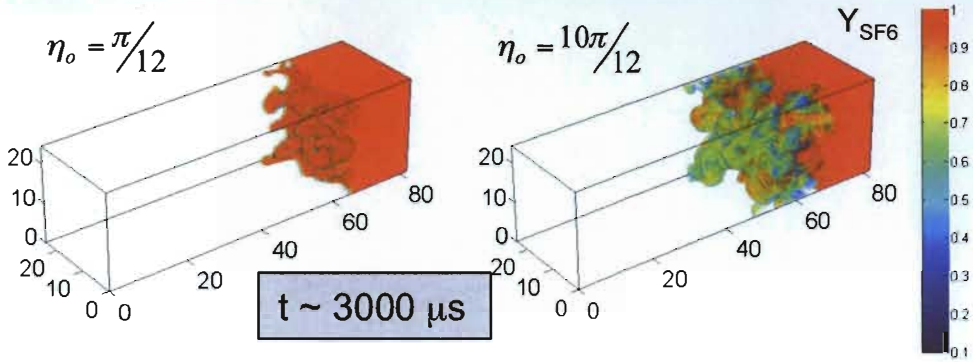
Non-Dimensional "Bipolar" **results**



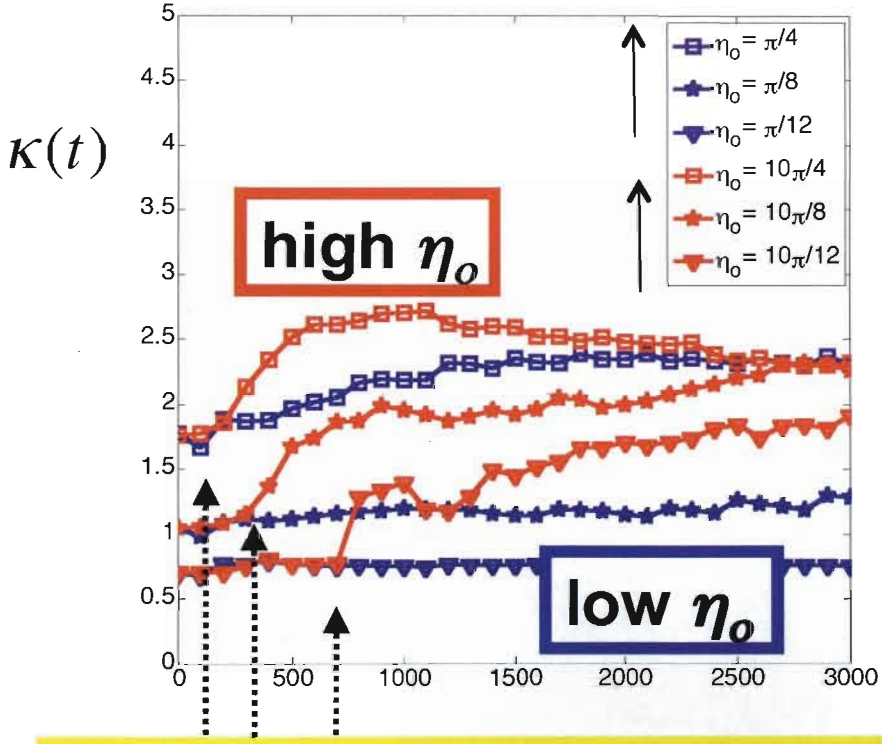
time scaling first proposed by Jacobs et al. '96

Characterizing Small-Scale Production

→ zero-crossing wavenumber κ (e.g., Sreenivasan et al. '83)

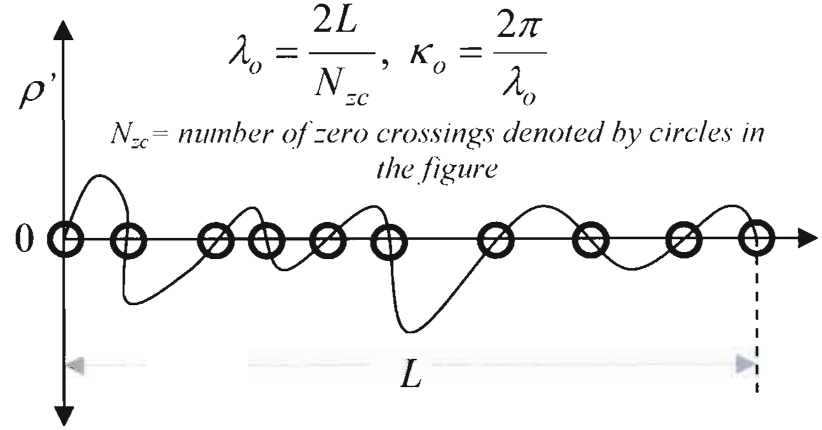


κ is the "zero crossing" wavenumber of the mass density fluctuation



$$\lambda_o = \frac{2L}{N_{zc}}, \quad \kappa_o = \frac{2\pi}{\lambda_o}$$

N_{zc} = *number of zero crossings denoted by circles in the figure*



$$\kappa(t) \sim \frac{1}{\lambda(t)} = \frac{1}{Taylor\ length\ scale}$$

"transition" indicated by rapid increase of κ

Spectral bandwidth of the turbulence

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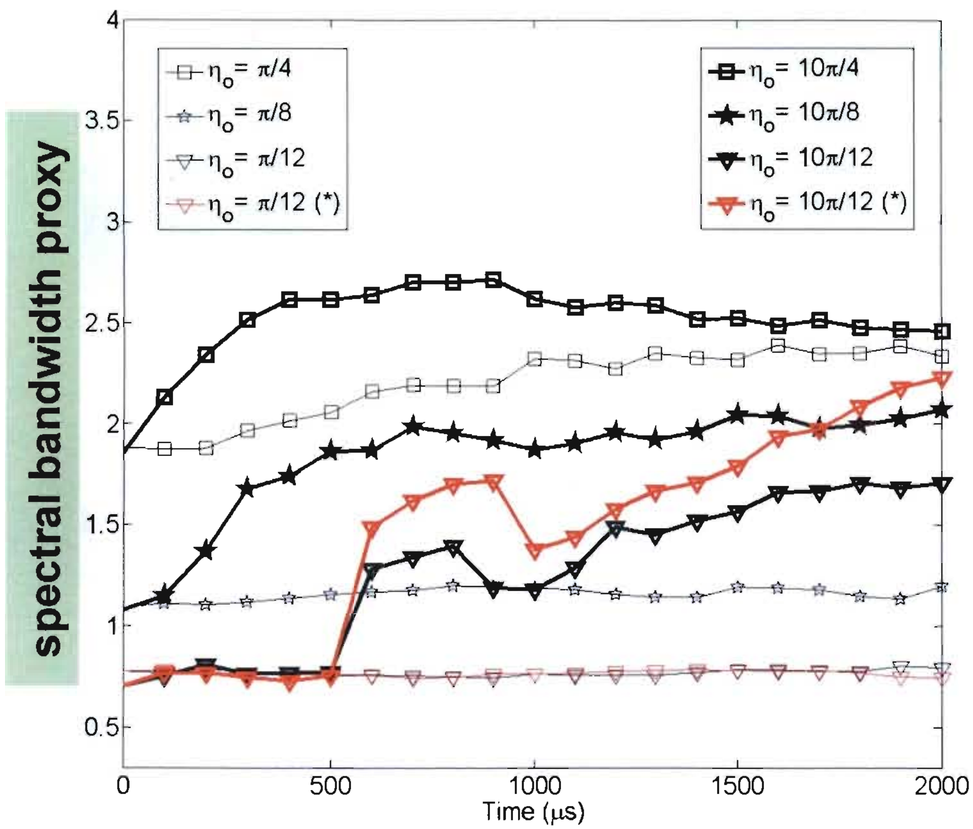
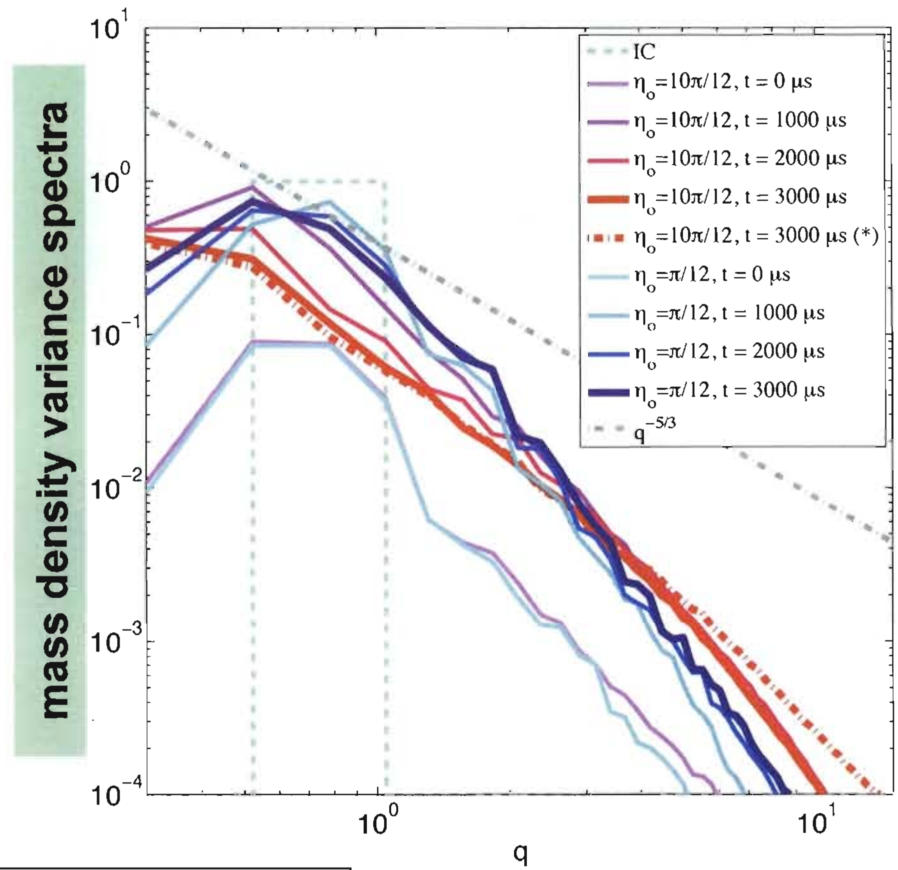
Spectral bandwidth proxy provides a measure of how "turbulent" the flow is

$$\eta(t) = \kappa(t)\delta(t) = \frac{\delta(t)}{\lambda(t)} \sim \frac{Integral\ scale}{Taylor\ length\ scale} \sim \mathrm{Re}_\lambda$$





(*) ***finer*** (doubled) resolution

Higher initial η_o leads to higher $\eta(t)$ at late times

Turbulence metrics

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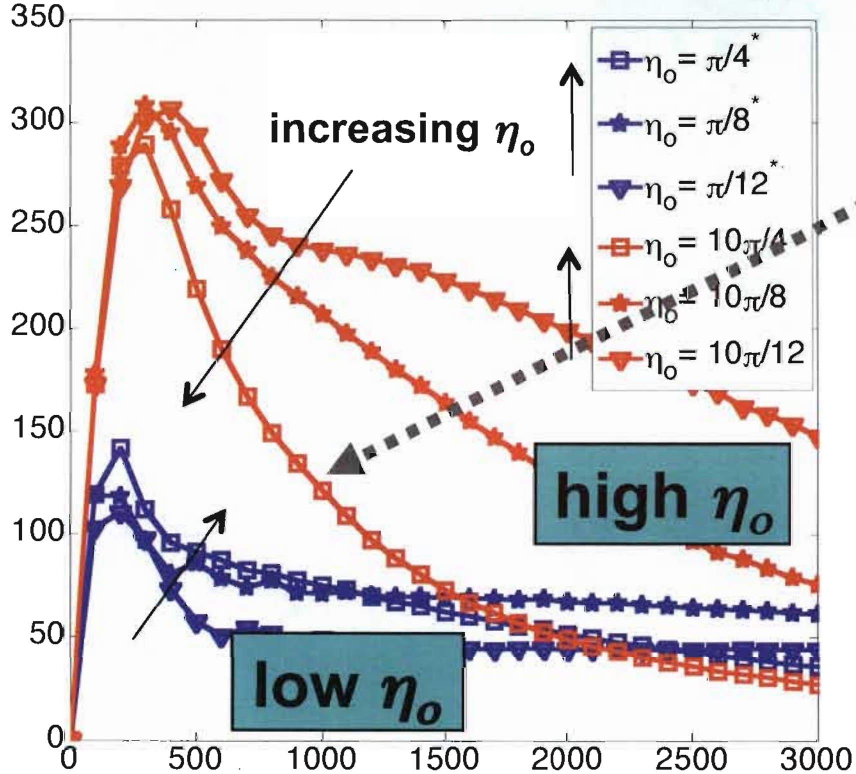
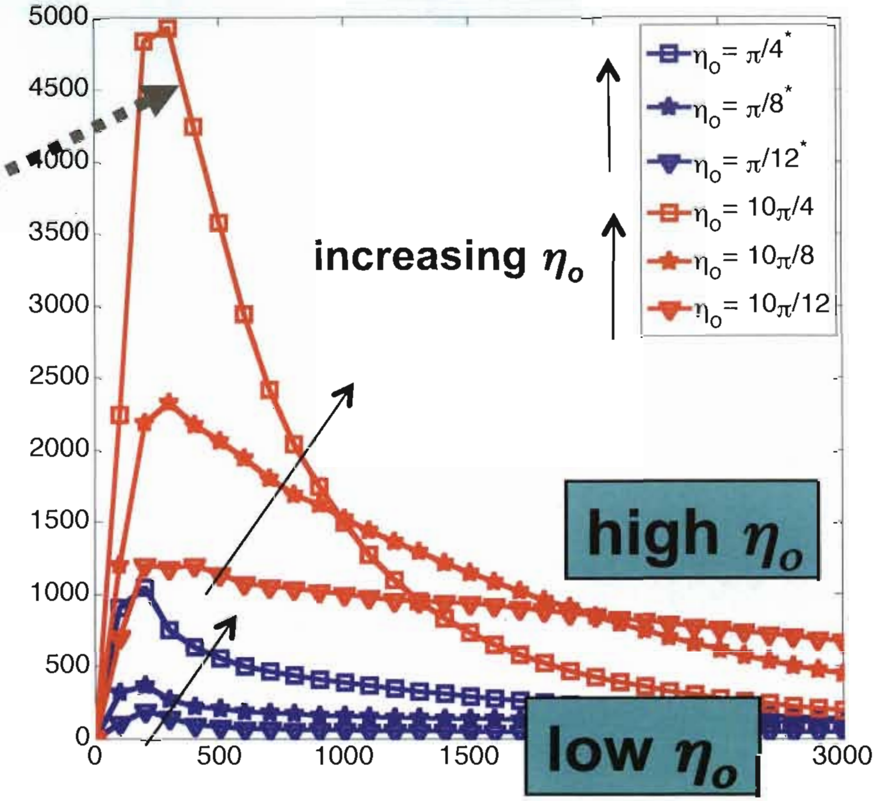
turbulent kinetic energy



enstrophy

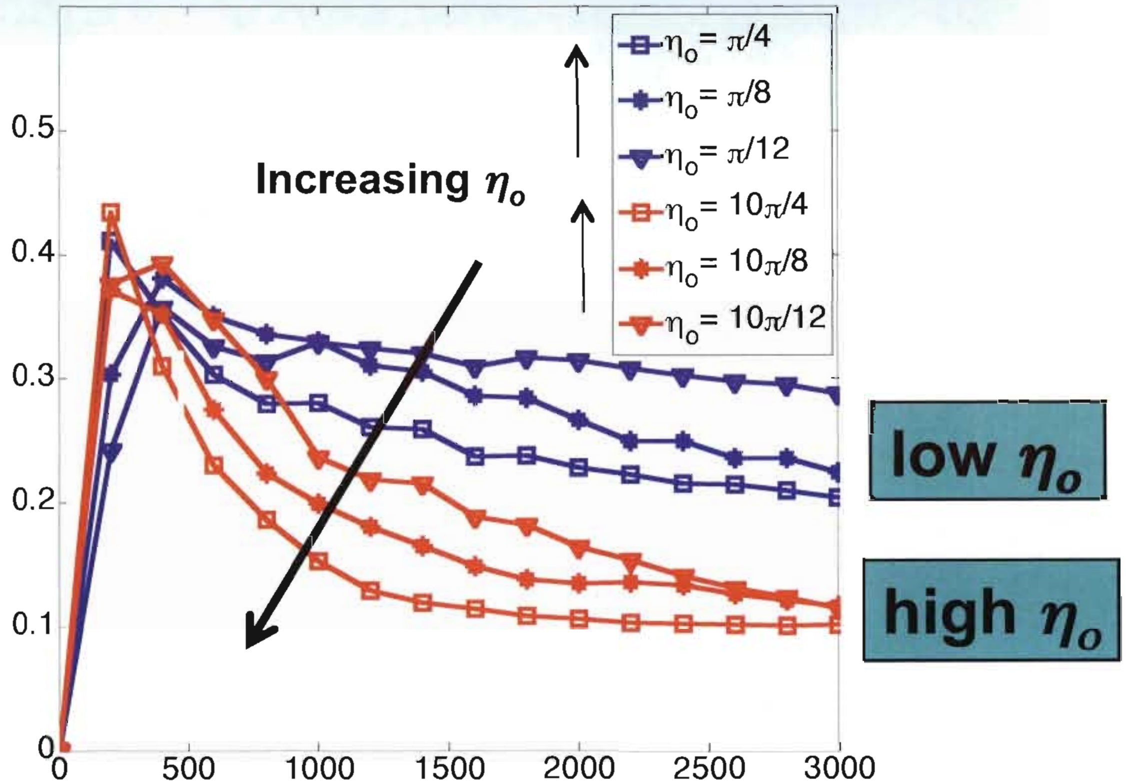


- **MORE enstrophy – LESS turbulent kinetic energy**
- **IC challenge**: enstrophy and energy -- ***different*** deposition mechanisms

Turbulence metrics: isotropy

Lumley's anisotropy tensor analysis

$$b_{11} = \frac{\langle u_1 u_1 \rangle}{2k} - \frac{1}{3}$$

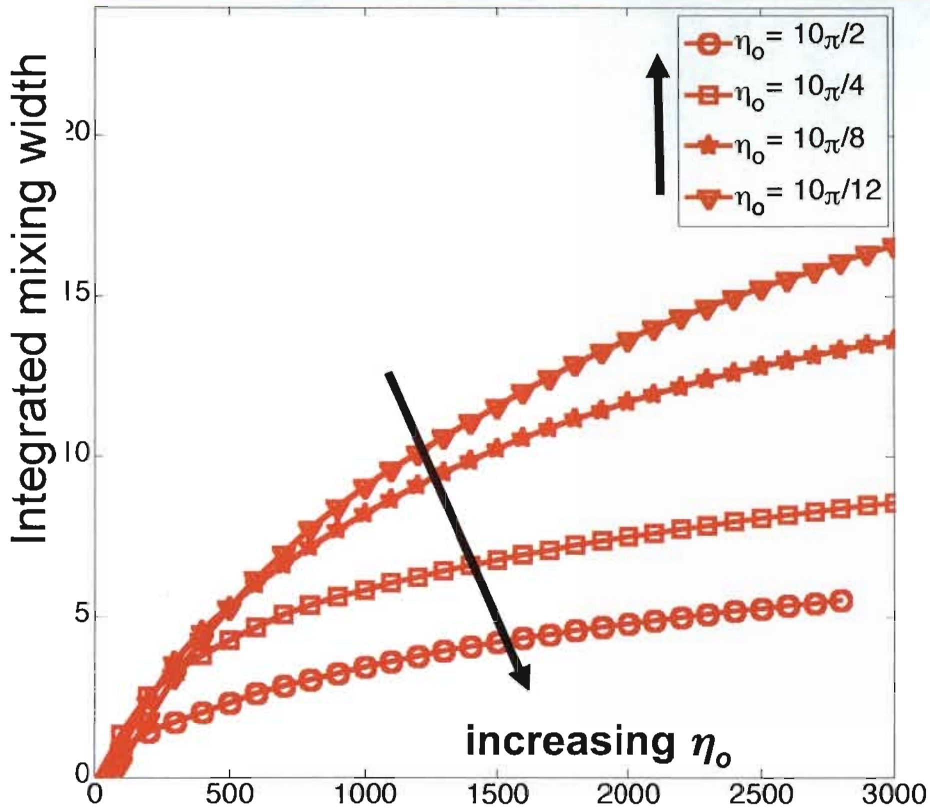


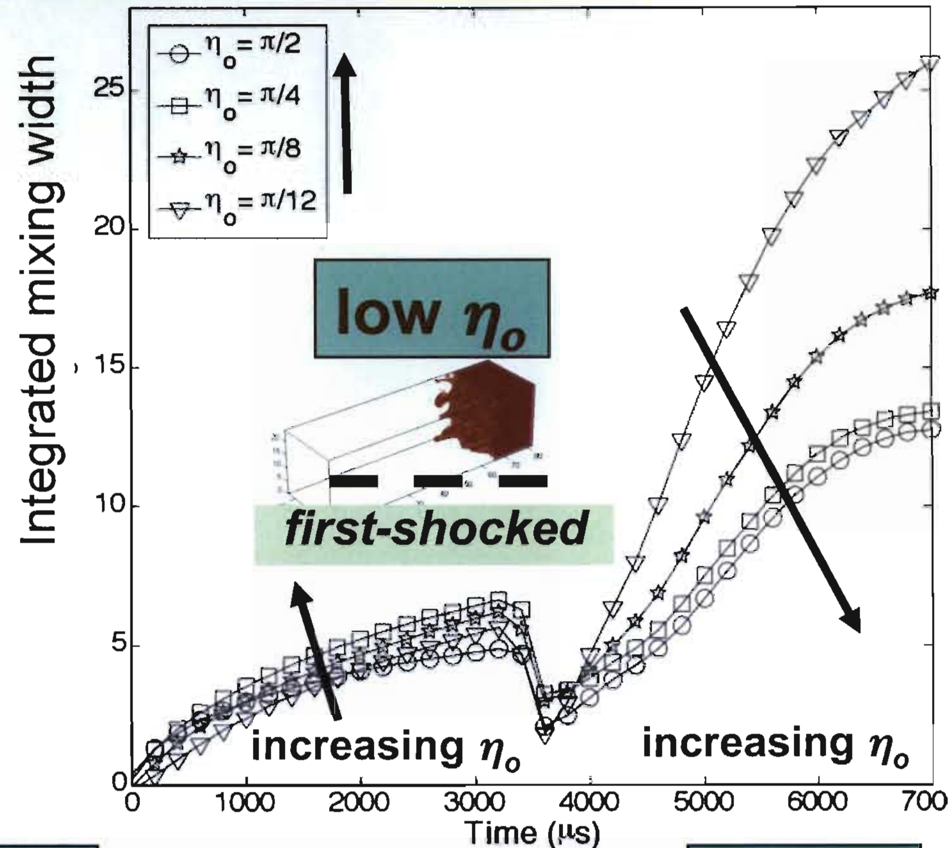
Higher η_o – more mixing, more isotropy

Consequences of Bipolar RM Behavior

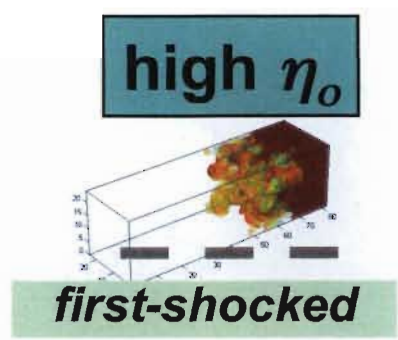
low η_o ***reshock effects*** ~ **high η_o** ***first shock effects***

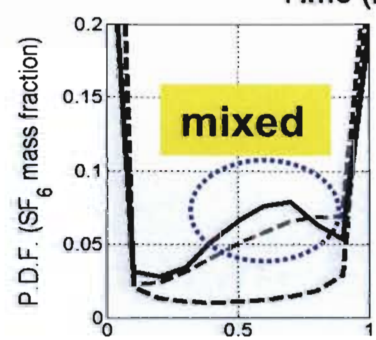
AIAA-Hawaii-2011 / ETC13-Warsaw-2011 → PoF

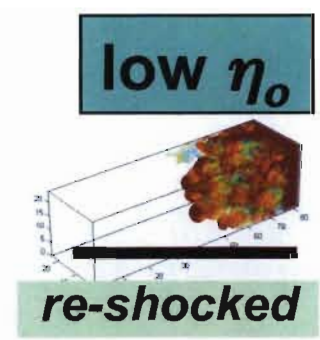




Y_{SF6} visualizations
t ~ 3000 μs
after first-shock
(or after reshock)







Planar Shock-Driven Turbulence

Grinstein, Gowardhan, and Wachtor, *PoF*, 2011; Gowardhan, Ristorcelli and Grinstein; *PoF* Letters, 2011
Shocked (double interface) Gas Curtain → Gowardhan and Grinstein, *J. of Turb.* 2011, in press

LDRD
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- **RM bipolar behavior:** **switch for $\eta_o = \kappa_o \delta_o \sim 1$**

low η_o : *linear, ballistic, mix-width $\delta \sim t$*

high η_o : *non-linear, mode coupling , mix-width $\delta \sim t^{1/2}$*

→ *transition to turbulence suggested*

→ more material mixing & smaller scales

- **Reshock effects on first shock, if $\eta_o > 1$**

- **The modeler's (initial condition) challenge**
  - **two different instabilities & growth trends**

low η_o $\rightarrow$ *as* $\eta_o \uparrow$ *enstrophy* $\uparrow$ *isotropy* $\uparrow$ *TKE* $\uparrow$ $\delta \sim t \uparrow$ ALL GROW with η_o

high η_o $\rightarrow$ *as* $\eta_o \uparrow$ *enstrophy* $\uparrow$ *isotropy* $\uparrow$ GROW with η_o

TKE $\downarrow$ $\delta \sim t^{1/2} \downarrow$ DECREASE with η_o