Explaining the Lx-Lbol Relation for Massive-Star X-rays

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& many more...

X-rays from Massive Star Winds

- Instability-generated Embedded Wind Shocks
  - Soft (< 1keV) X-rays

- Magnetically Confined Wind Shocks (MCWS)
  - Harder (~1-2 keV) thermal X-rays

- Colliding Wind Shocks (CWS) in Binaries
  - Hardest (1-10 keV) thermal X-rays

Outline

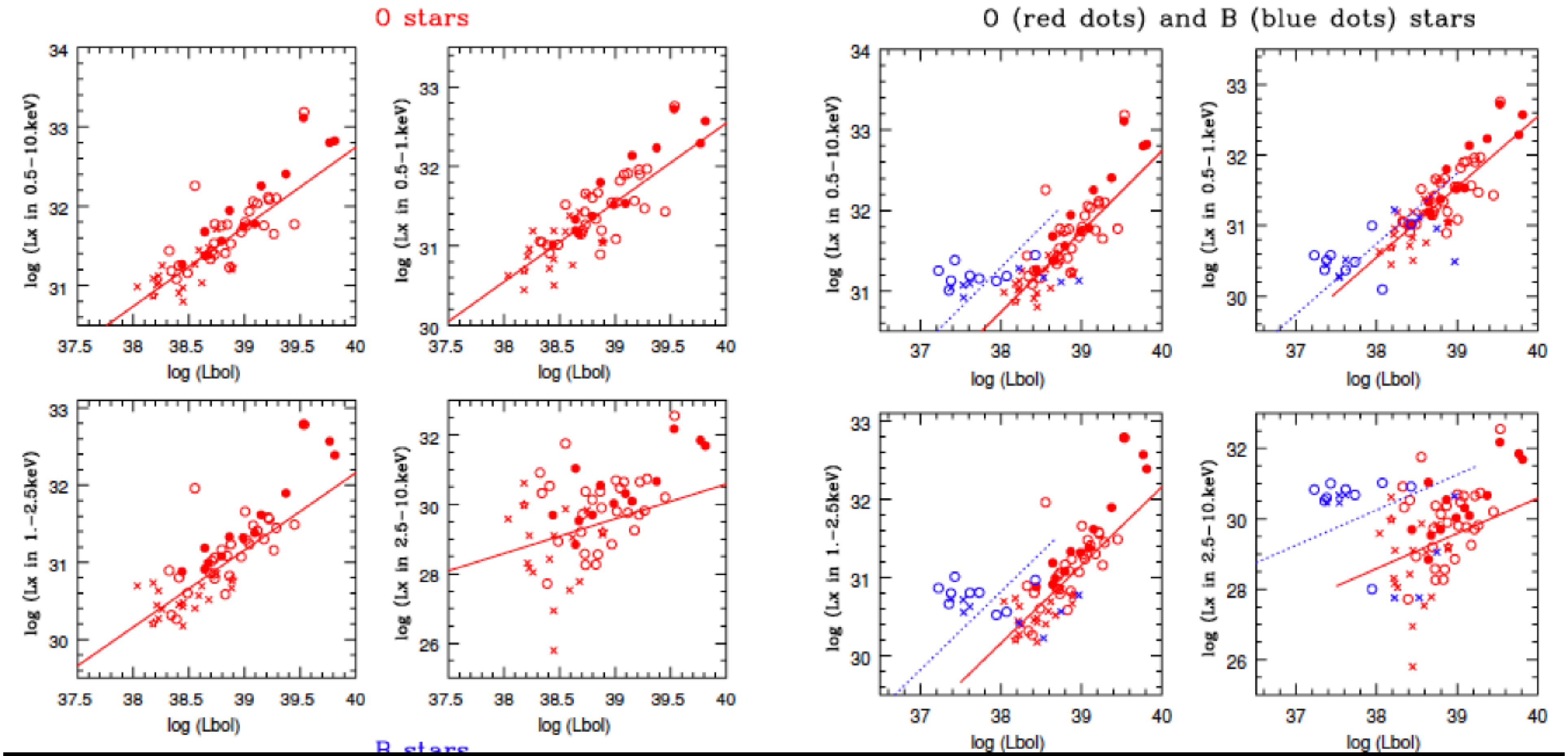
- O-stars observed to emit soft (~0.5 kev) X-rays
- Thought to arise from Embedded Wind Shocks
- EWS arise from intrinsic Instabilty of line-driving

- Observed scaling is $L_x \sim 10^{-7} L_{bol}$
- EWS theory predicts $L_x \sim M_{dot}/V_\infty \sim (L_{bol})^{1.7}$

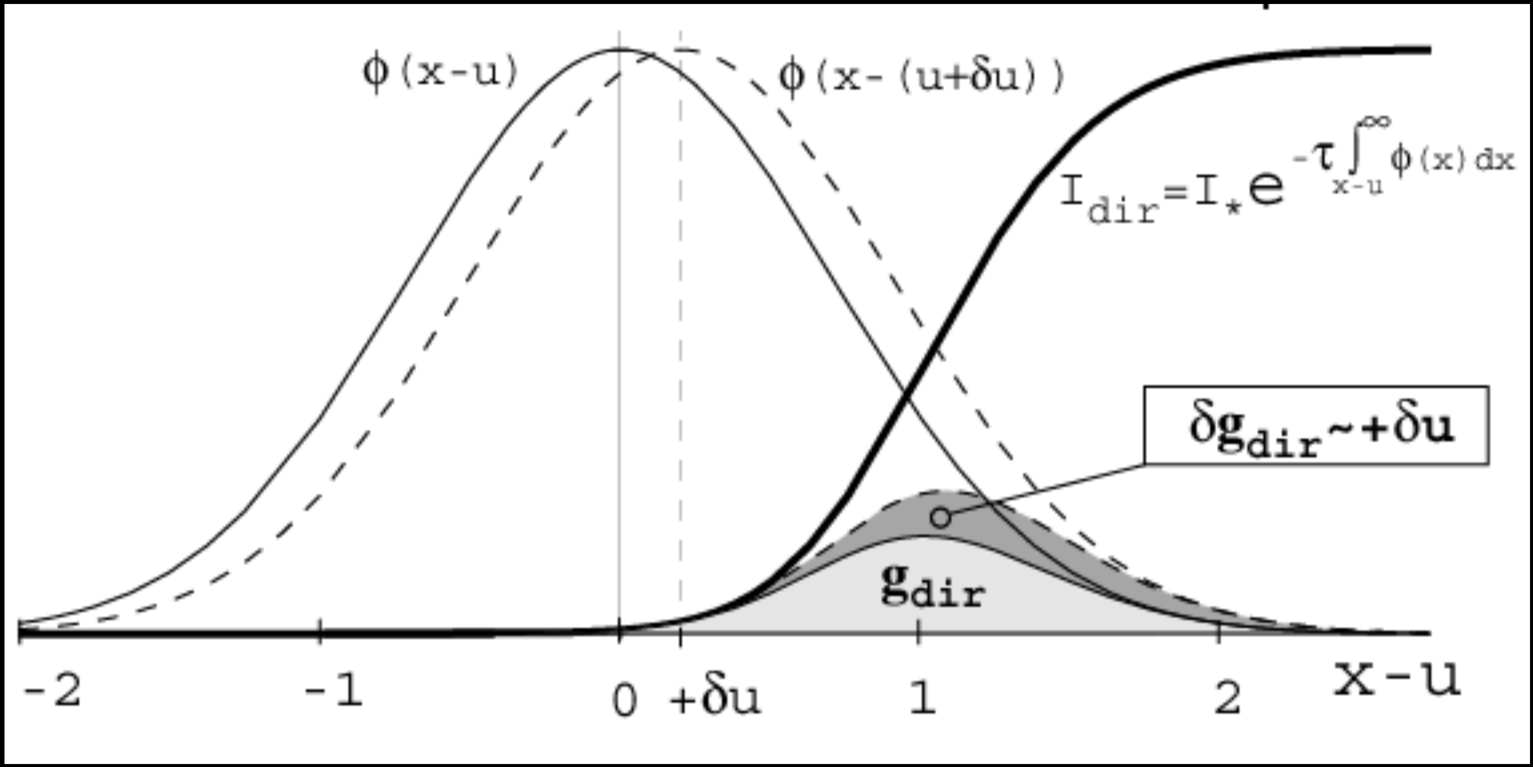
- Reconcile here with “thin shell mixing” of shocks

L_x vs. L_{bol} for Chandra observations of Carina OB stars

Naze et al. 2011



Line-Deshadowing Instability



for $\lambda < L_{sob}$:
$i\omega = \delta g/\delta v$
$= +g_o/v_{th} = \Omega$

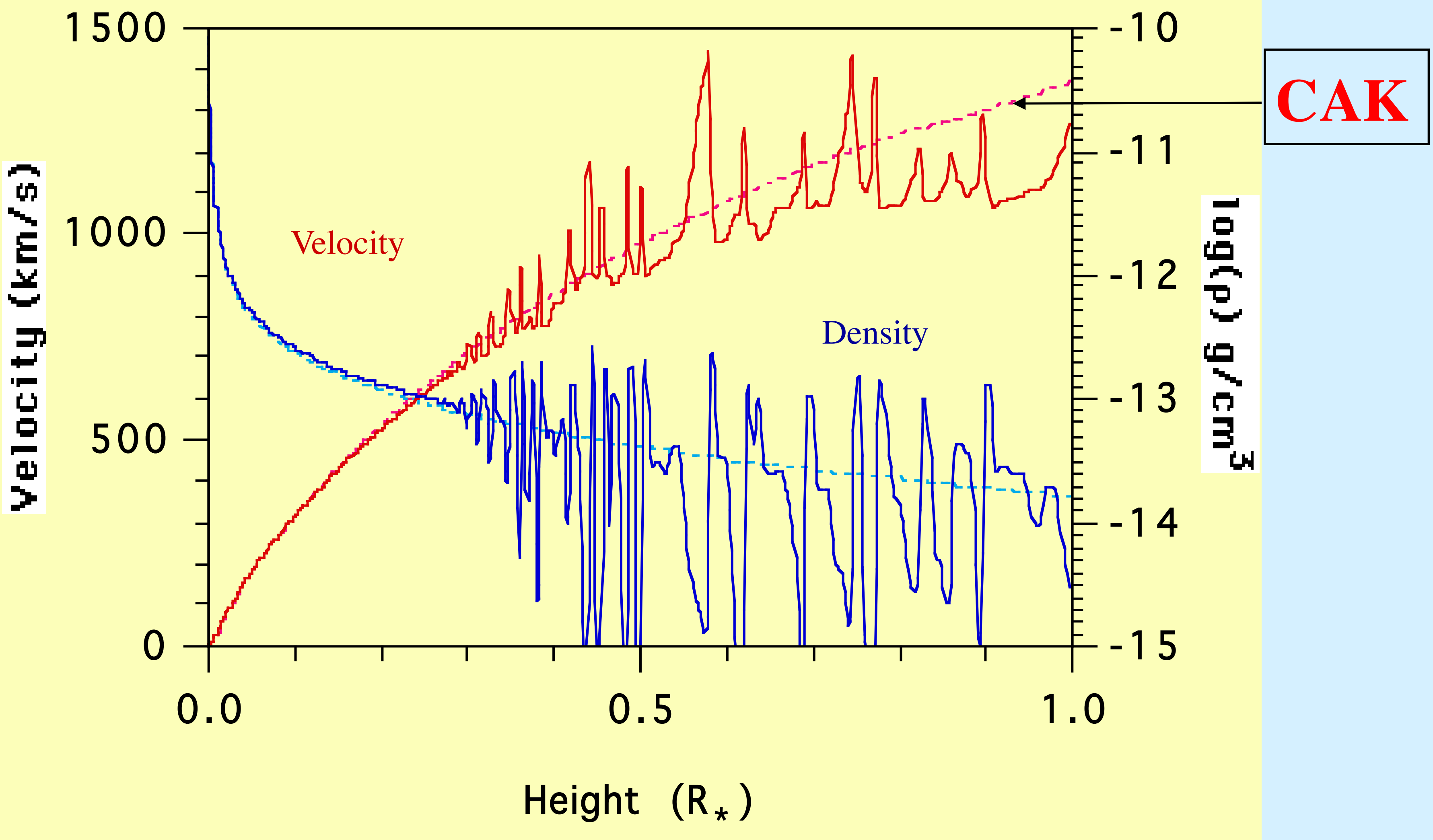
→

Instability with growth rate

$\Omega \sim g_o/v_{th} \sim vv'/v_{th} \sim v/L_{sob} \sim 100\ v/R$

e100 growth!

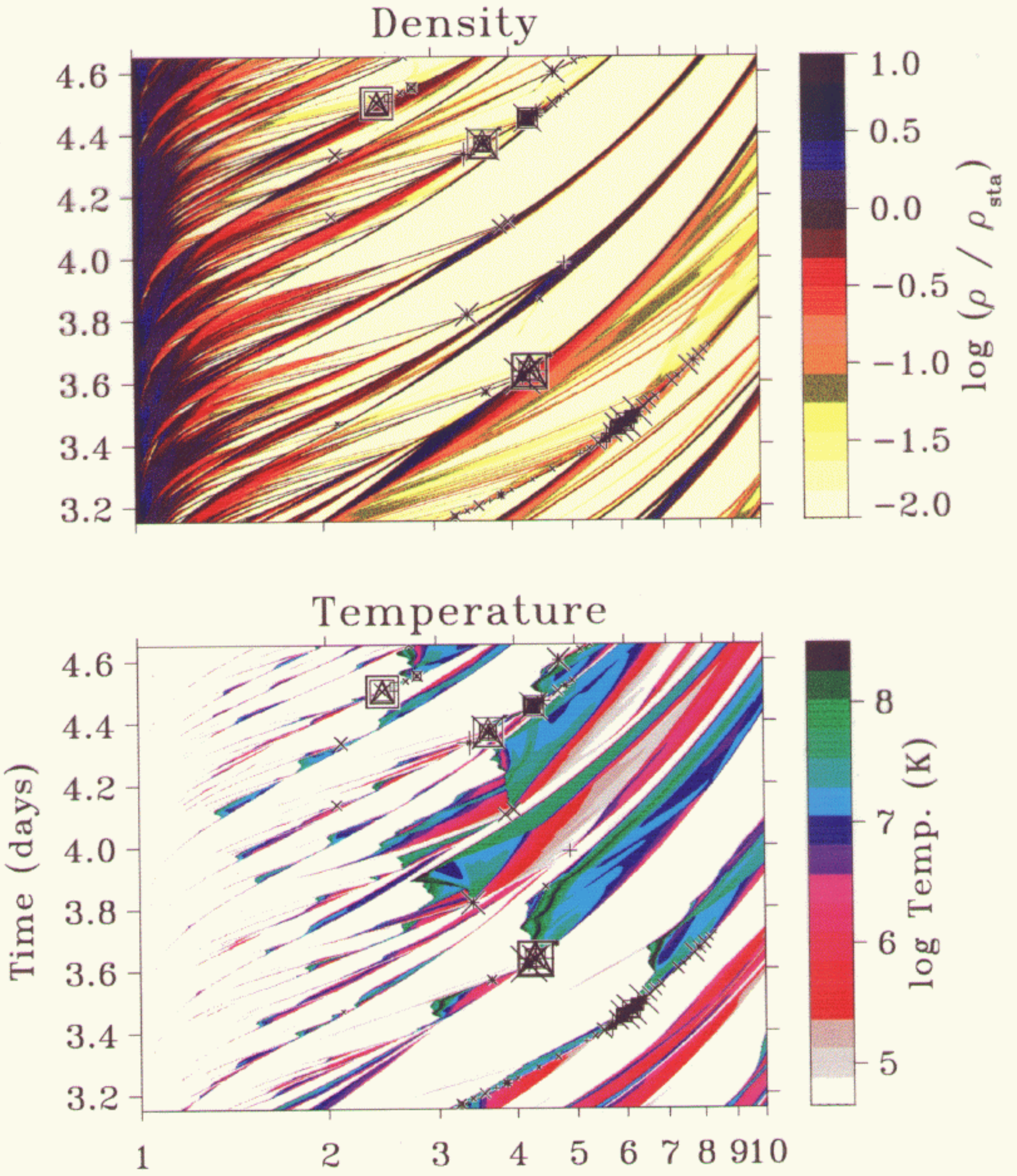
Time snapshot of wind instability simulation



Turbulence-seeded clump collisions

Enhances V_{disp} and thus X-ray emission

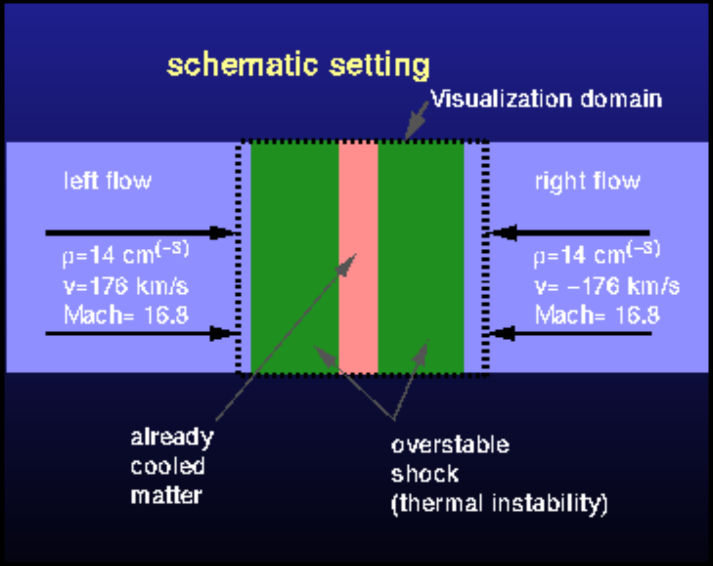
Feldmeier et al. 1997



2D Planar Simulation of Interaction Layer

Walder & Folini

1998,1999

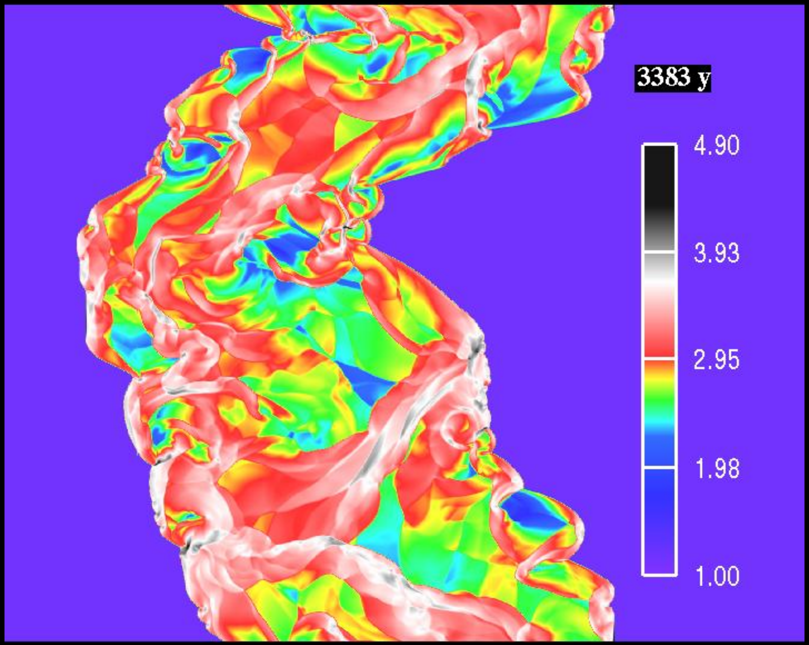


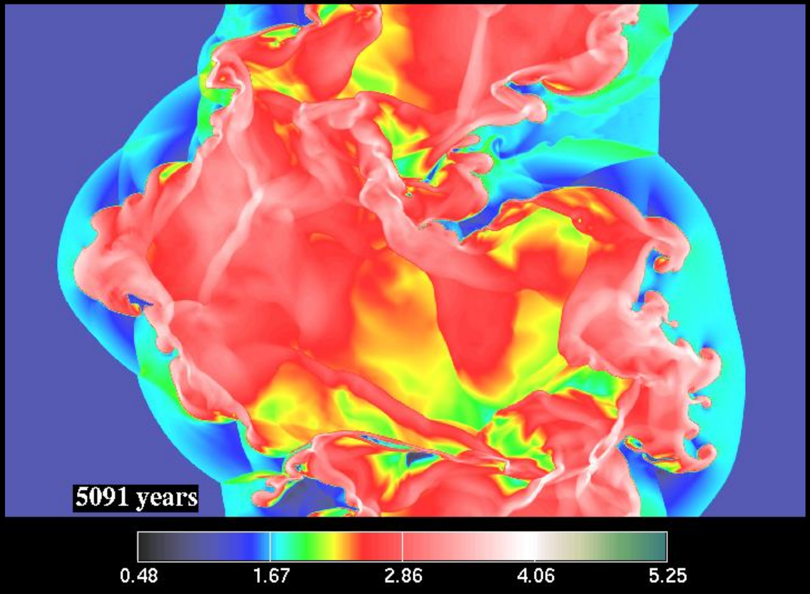
Isothermal case:

Thin-shell instability

Radiative cooling case:

Cooling overstability

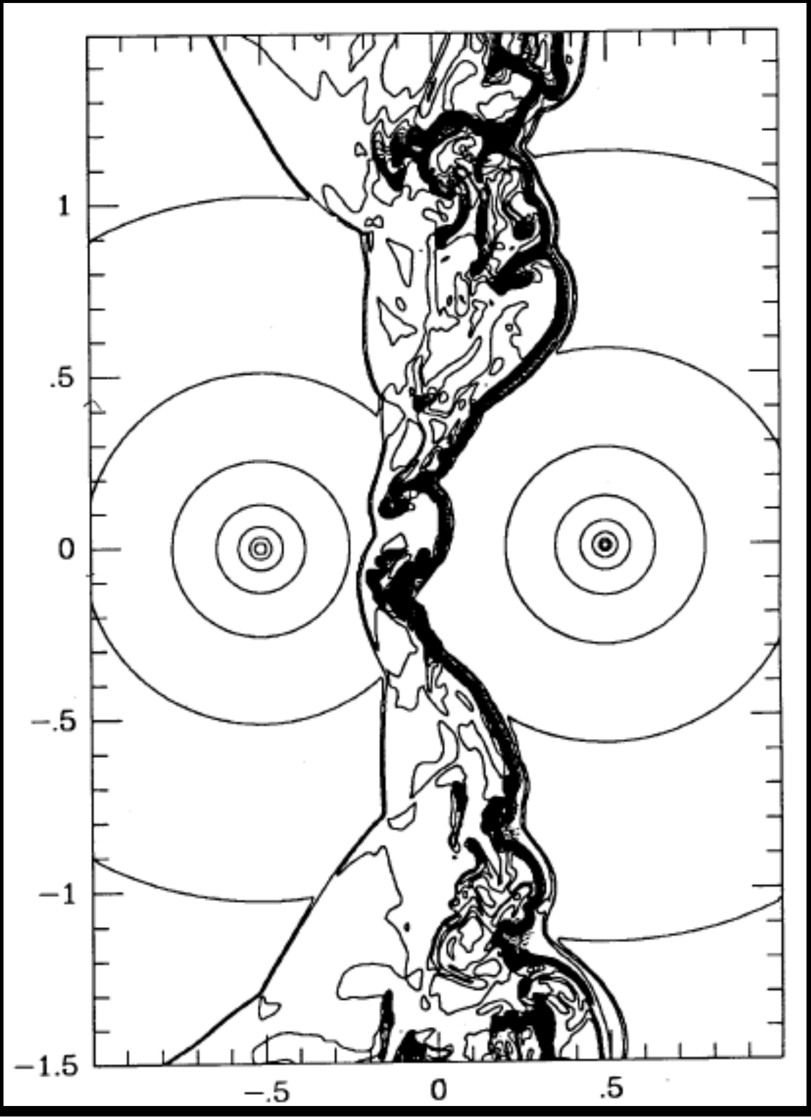




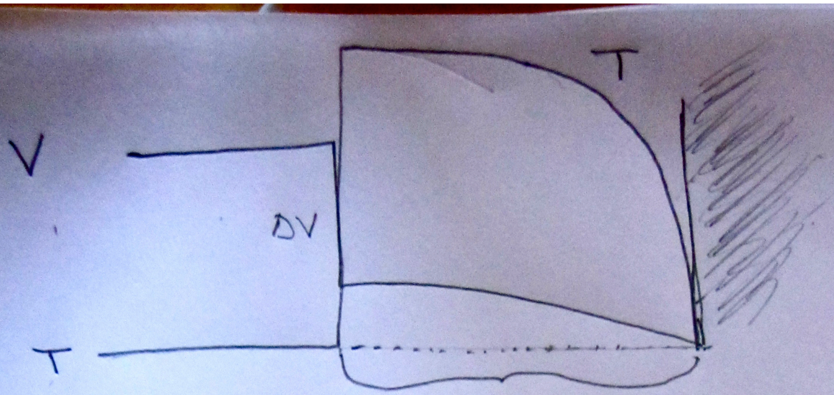
Density

2000

X-rays from Colliding Wind Binaries



Stevens
et al. 1992



$$\ell = \frac{m_c}{\rho} \sim \frac{1}{\dot{M}}$$

$$L_x \sim f_x \, \dot{M} \, \Delta V^2$$

adiabatic: $\ell \gg r$ $\quad f_x \sim \frac{r}{\ell} \Rightarrow L_x \sim \dot{M}^2$

radiative : $\ell \ll r$ $\quad f_x \sim \text{const} \Rightarrow L_x \sim \dot{M}$

\+

thin-shell mixing

$$f_x \sim \left(\frac{\ell}{r}\right)^m \Rightarrow L_x \sim \dot{M}^{1-m}$$

CAK $\quad \dot{M} \sim L_{Bol}^{1/\alpha} \Rightarrow L_x \sim L_{Bol}^{\frac{1-m}{\alpha}}$

if $m \simeq 1-\alpha = 0.6 \Rightarrow \underline{L_x \sim L_{Bol}}$

Embedded Wind Shock X-ray emission

$$L_X \sim \int \frac{\rho^2}{\left(m_c + \rho r\right)^{1+m}}\, dV \sim \dot{M}^{1-m} \sim L_X^{(1-m)/\alpha}$$

Summary

- Winds unstable => clumps, soft X-rays
- Observed $L_x \sim L_{bol}$
- Simple EWS theory $L_x \sim M_{dot} \sim L_{bol}^{1/\alpha} \sim L_{bol}^{1.7}$
- Reconcile by assuming mixing $f_x \sim l_c^m \sim M_{dot}^{-m}$
- $L_x \sim M_{dot}^{1-m} \sim L_{bol}^{(1-m)/\alpha} \sim L_{bol}$ if $m \sim 1-\alpha$