X-rays & Gamma-rays from Massive Stars

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Massive Star Winds

- High Luminosity drives strong "stellar winds" via line scattering by bound electrons in metals
- M_{dot} ~< 10^{-5} M_{sun}/yr; V_{∞} ~ 3000 km/s
- Collisions => Shocks => X-rays (+γ-rays?)
- HMXRBs => jets => pions => γ-rays

Collisional shock-heated X-ray emission

Rough rule of thumb:

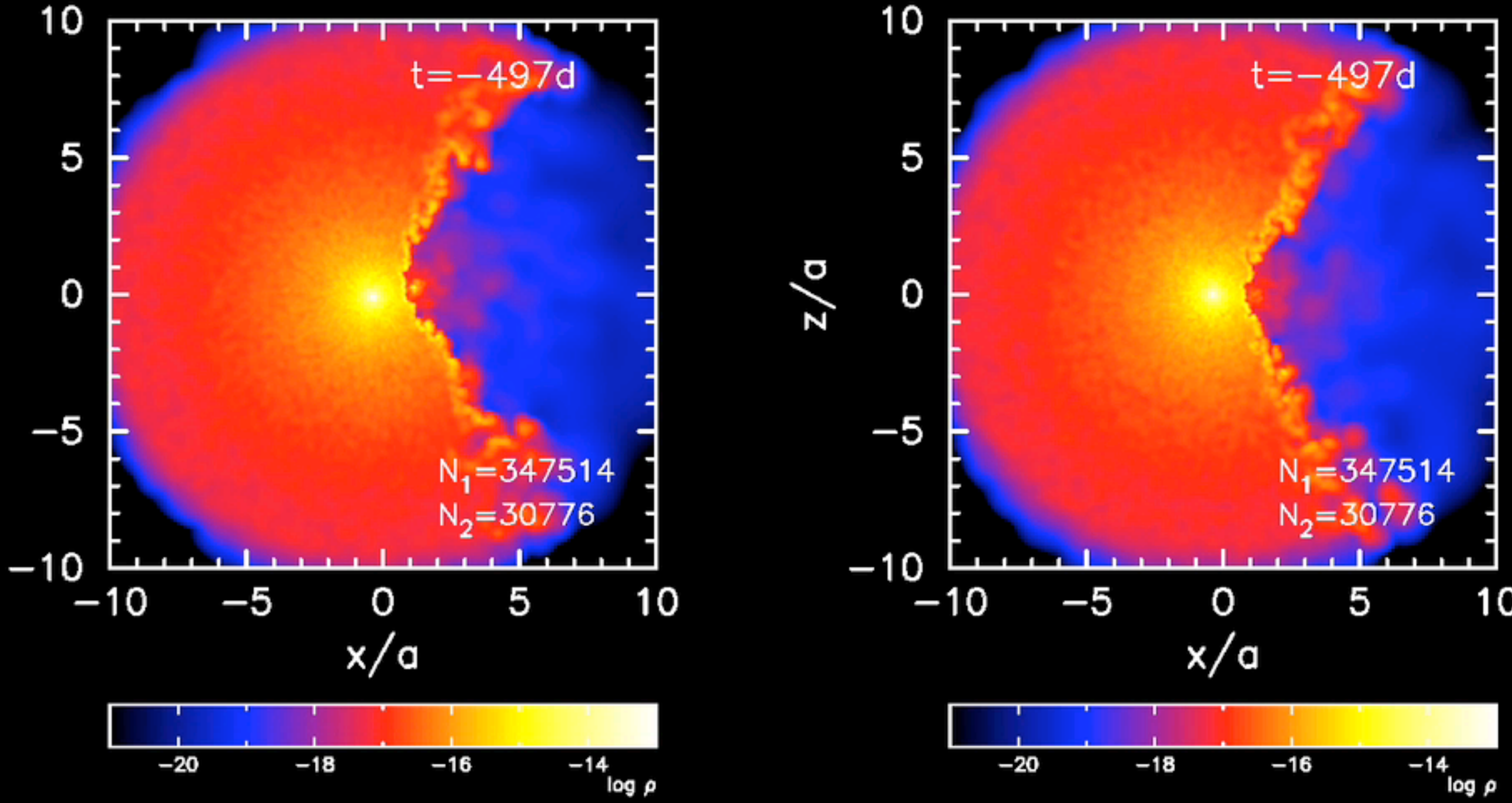
$$\frac{T_x}{10\,MK} \approx \frac{kT_x}{1\,kev} \approx \left(\frac{V}{1000\,\mathrm{km/s}}\right)^2$$

E_x ~ 2-10 kev => V~3000 km/s => Colliding wind binaries

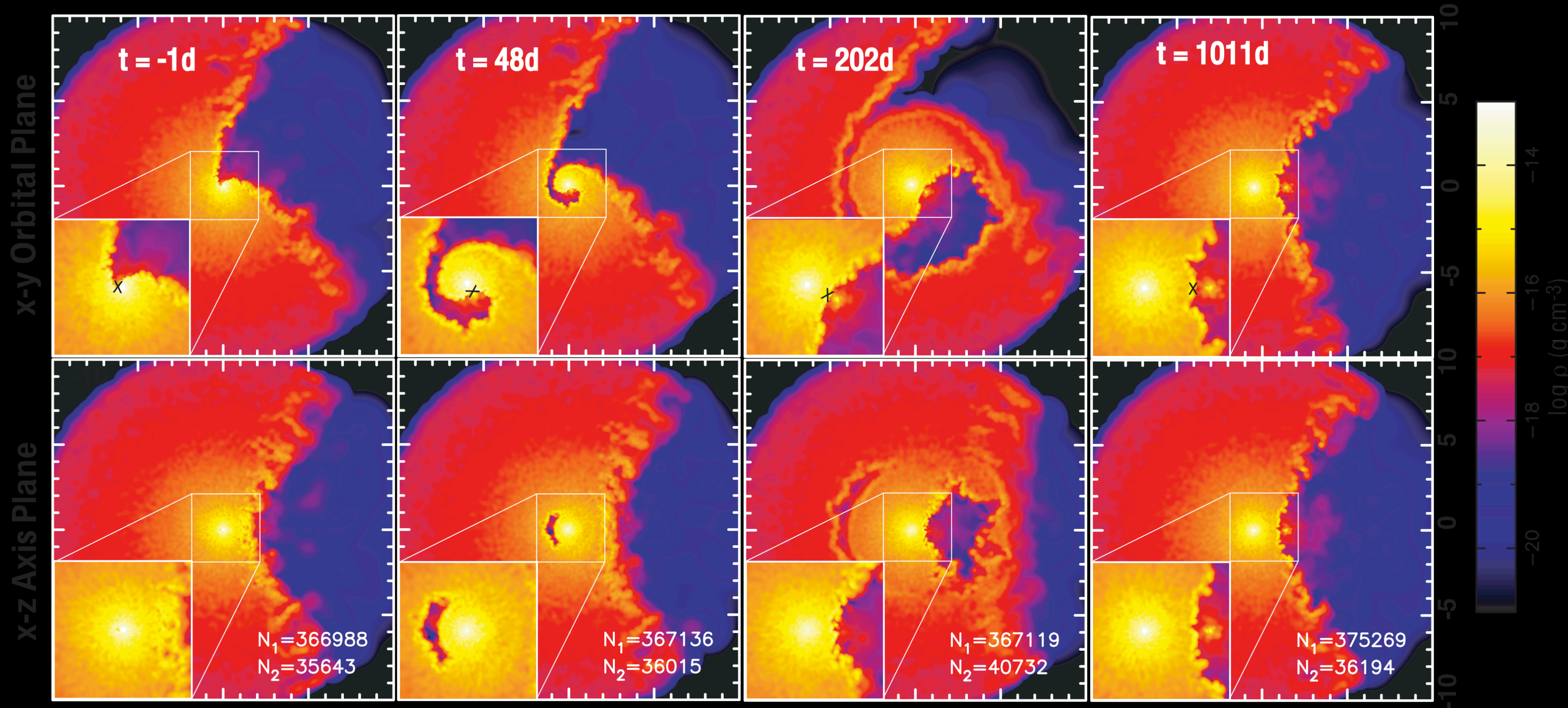
E_x ~ 1-3 kev => V~ 1000 km/s => Magnetic confinement

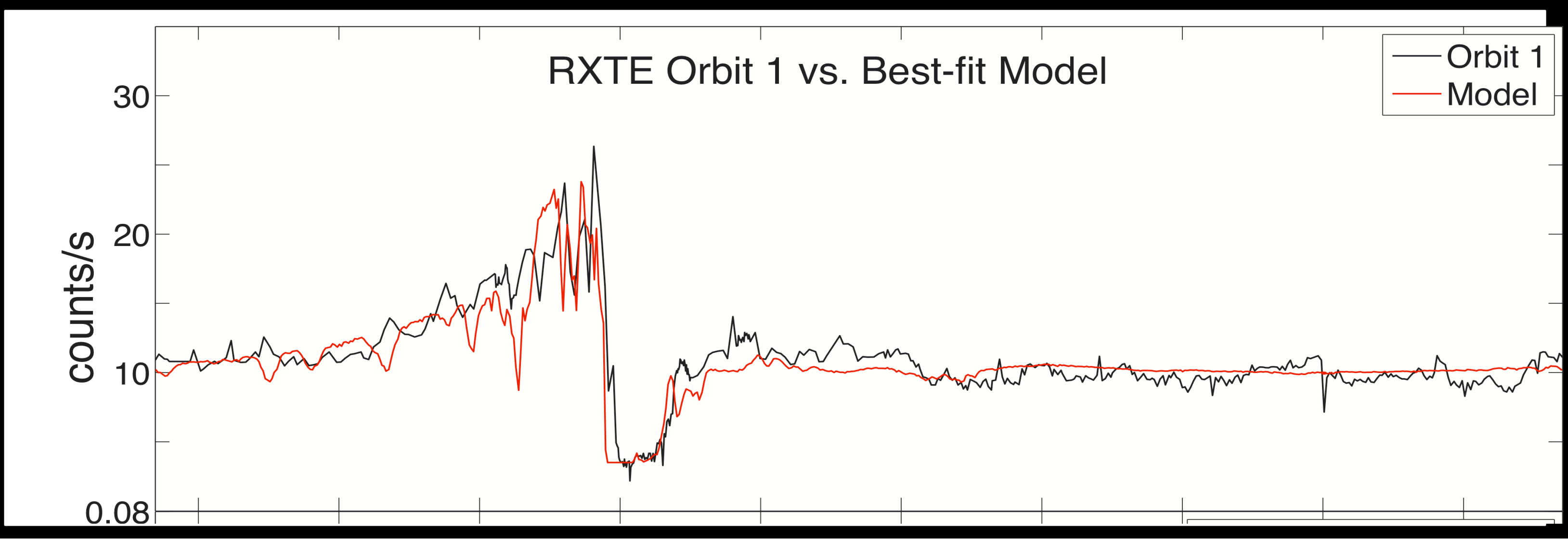
E_x ~ 0.5-1 kev => V ~ 700 km/s => Intrinsic instabilities

3D SPH sim of CWB in eta Car



3D SPH sim of η Car CWB

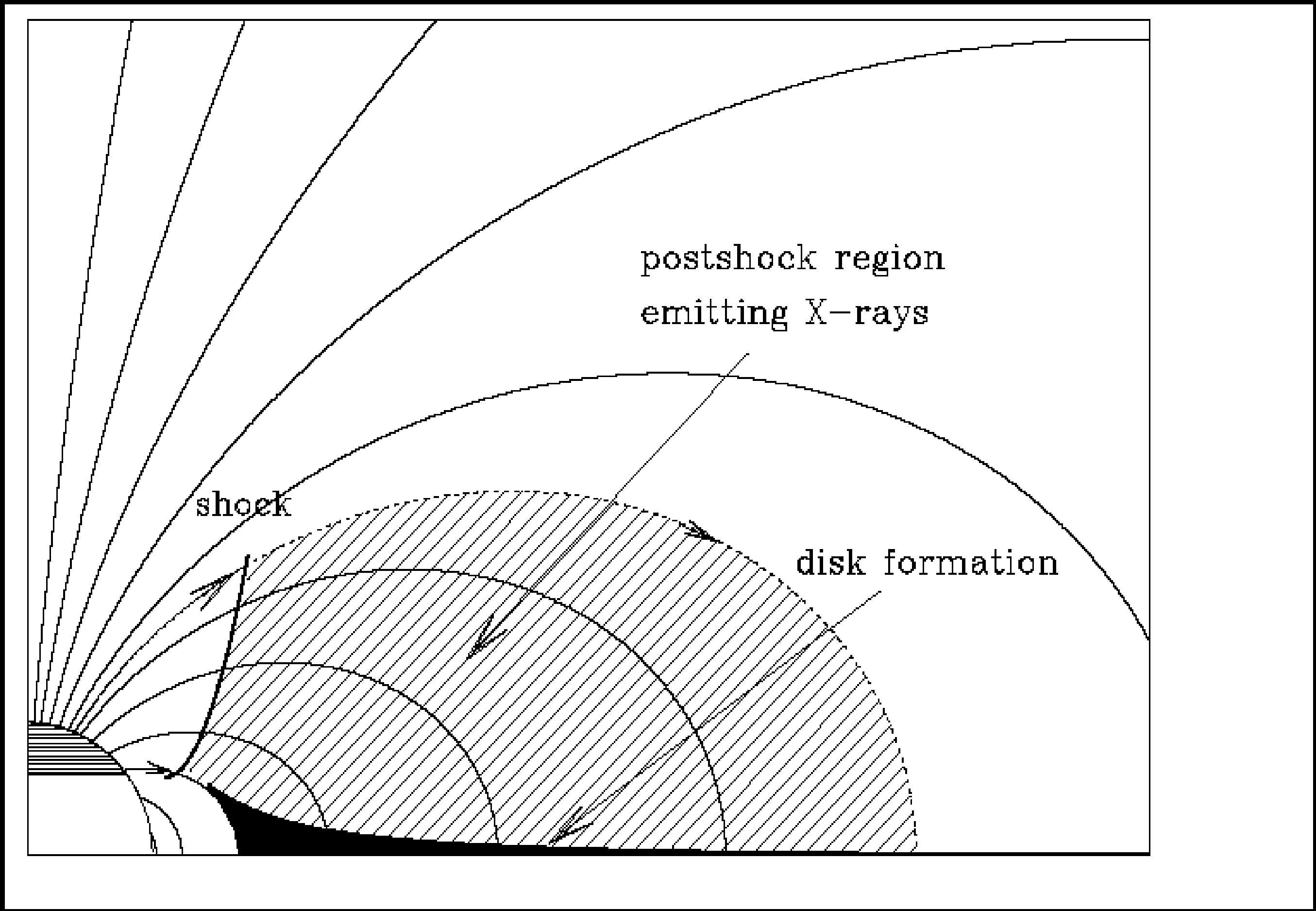




Magnetically Confined Wind-Shocks

Babel & Montmerle 1997

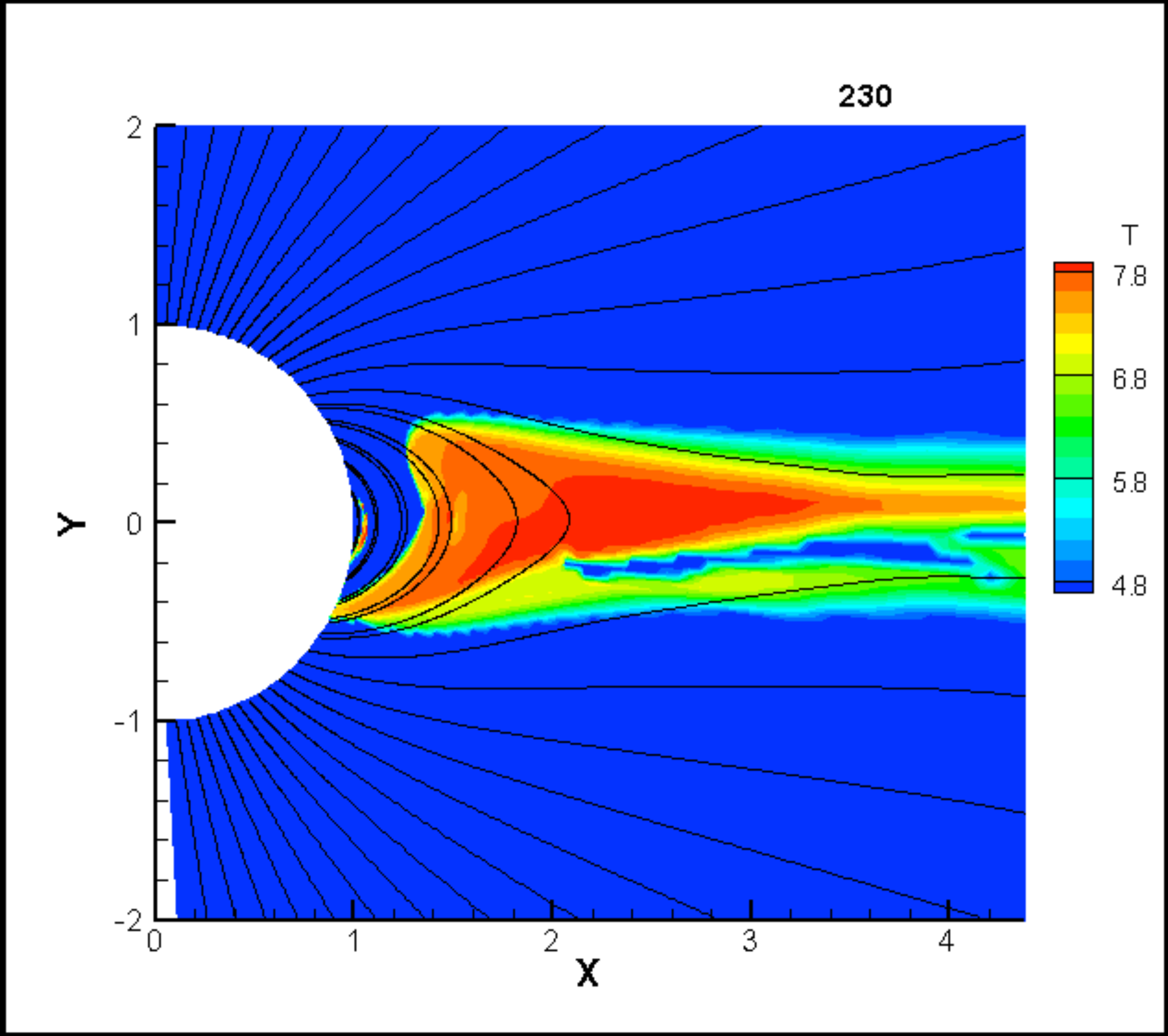
Magnetic Ap-Bp stars



Magnetically Confined Wind Shock

~ 2 kev X-rays
fit Chandra
spectrum

for Θ1 Ori C



Centrifugally Driven Reconnection Flare

log T

$\eta_* = 620$

$v_{rot} = v_{crit}/2$

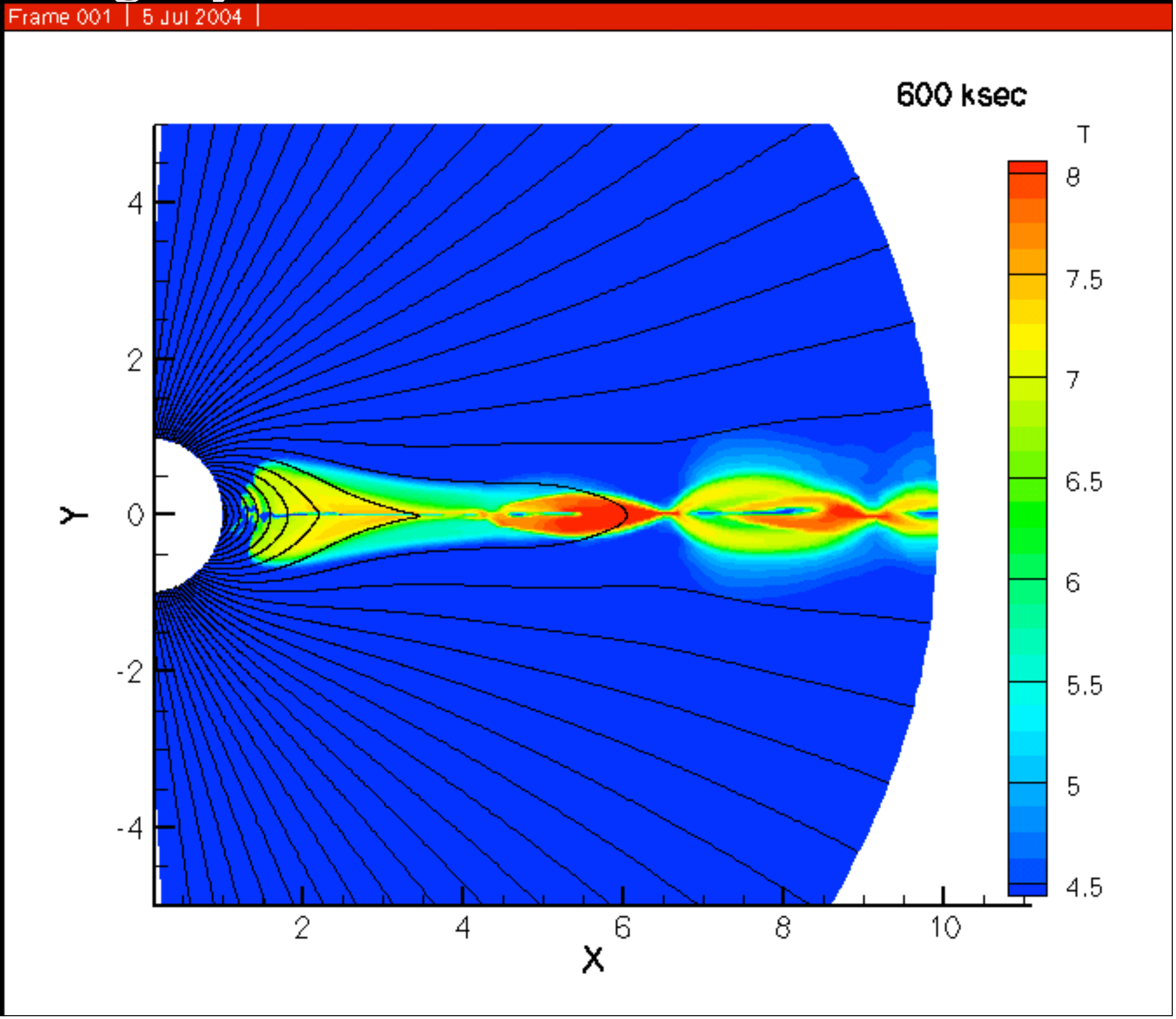
~ 4-5 kev

X-ray

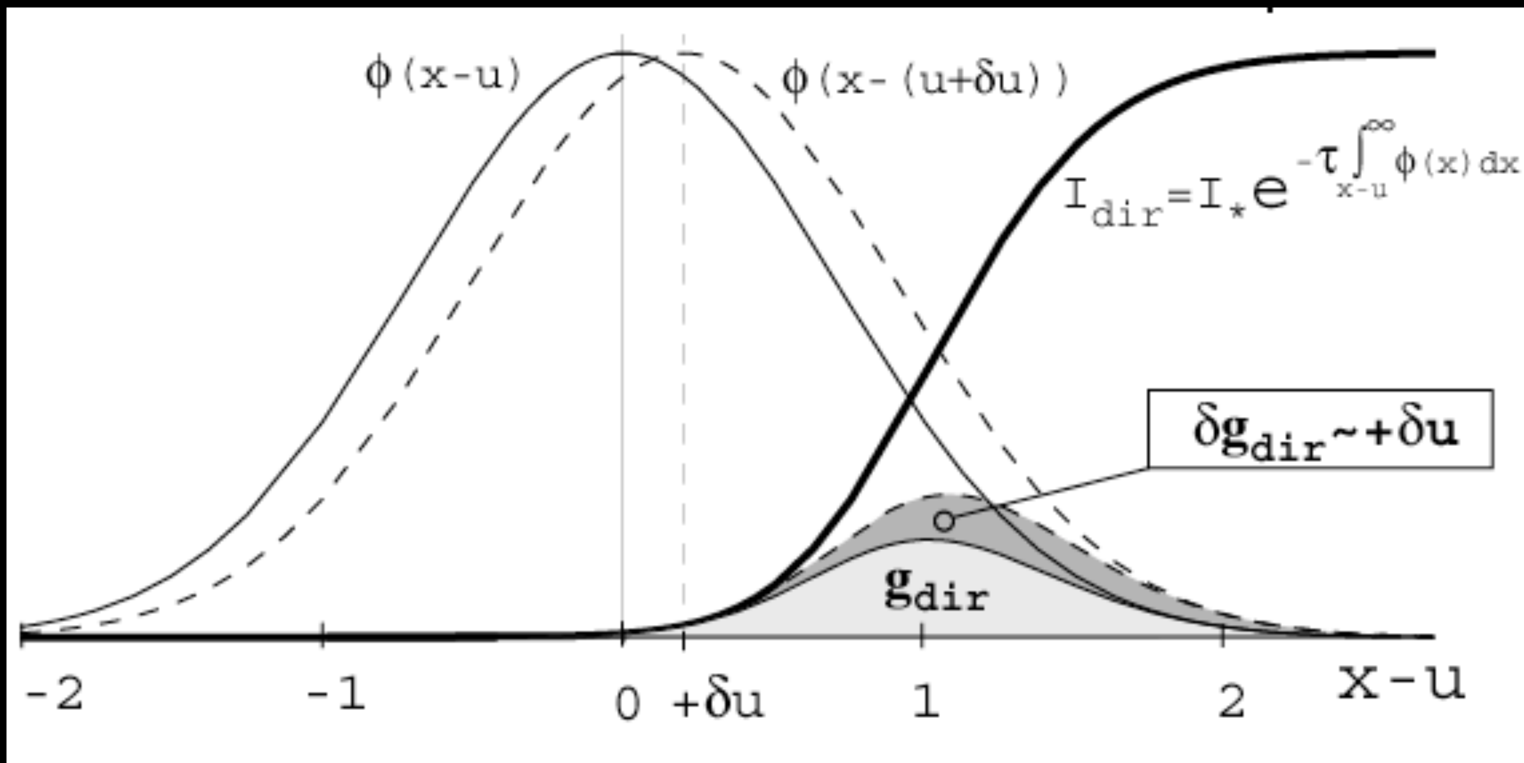
flares,

as seen in

σ Ori E



Line-Deshadowing Instability



for $\lambda < L_{sob}$:

$i\omega = \delta g/\delta v$

$= +g_o/v_{th} = \Omega$

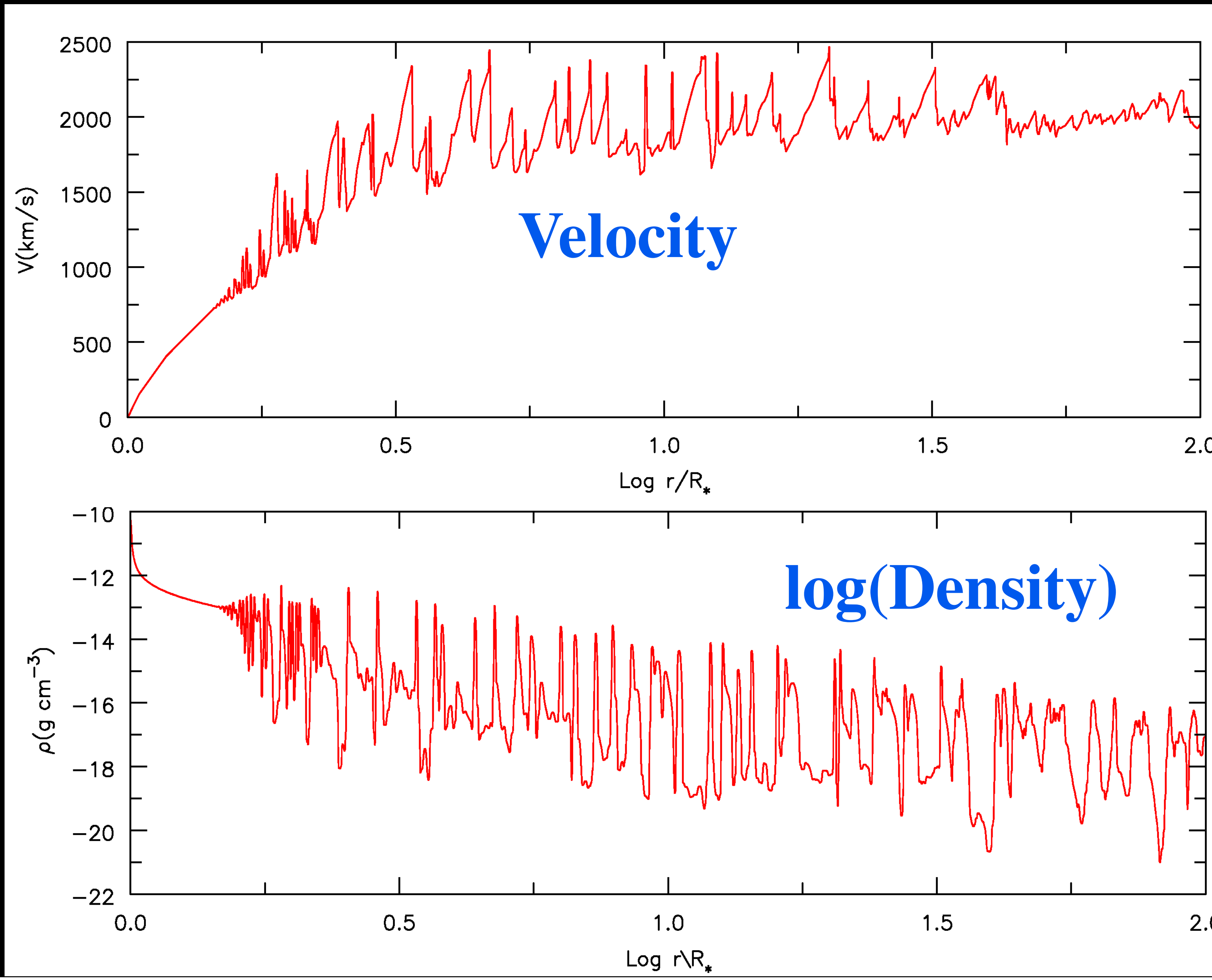
→

Instability with growth rate

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

e^{100} growth!

Time snapshot of wind structure vs. radius



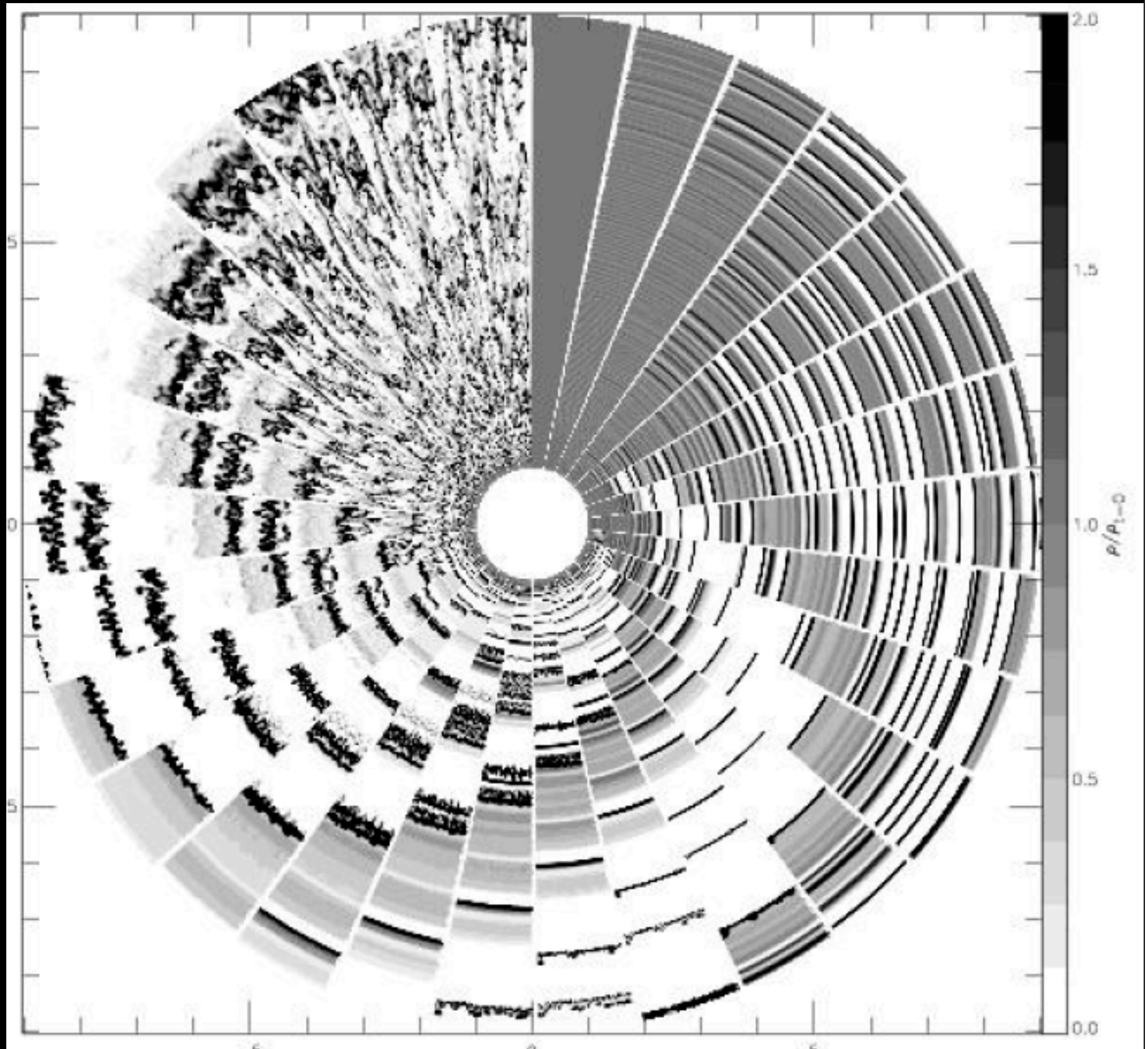
2D-H
+
1D-R

nr=1000

nϕ=60

Δϕ=12deg

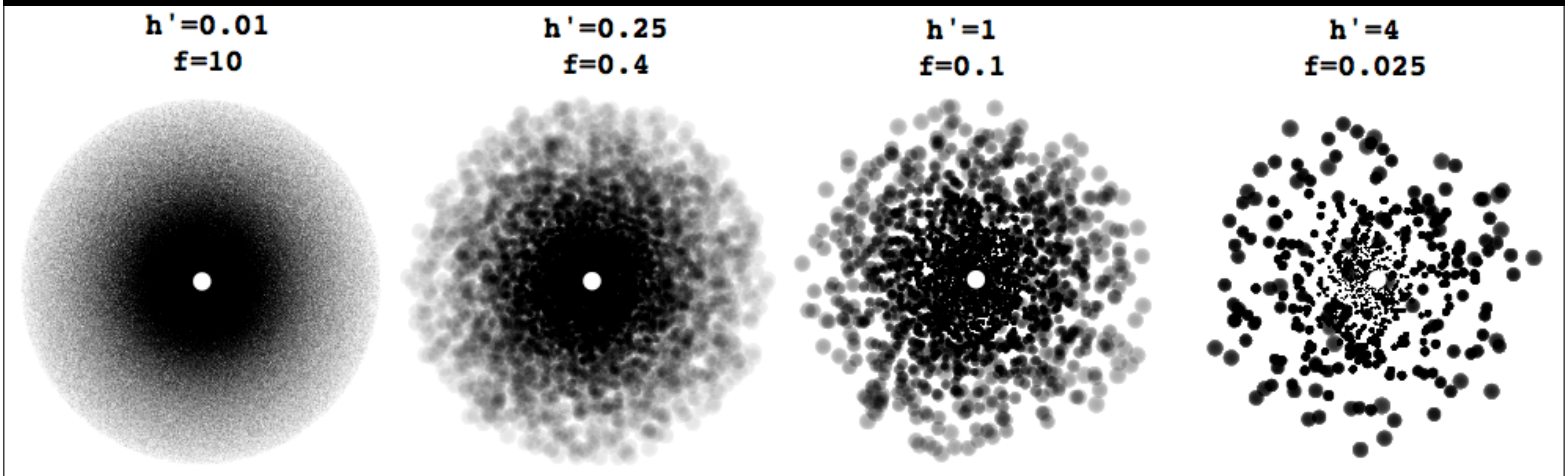
L. Dessart



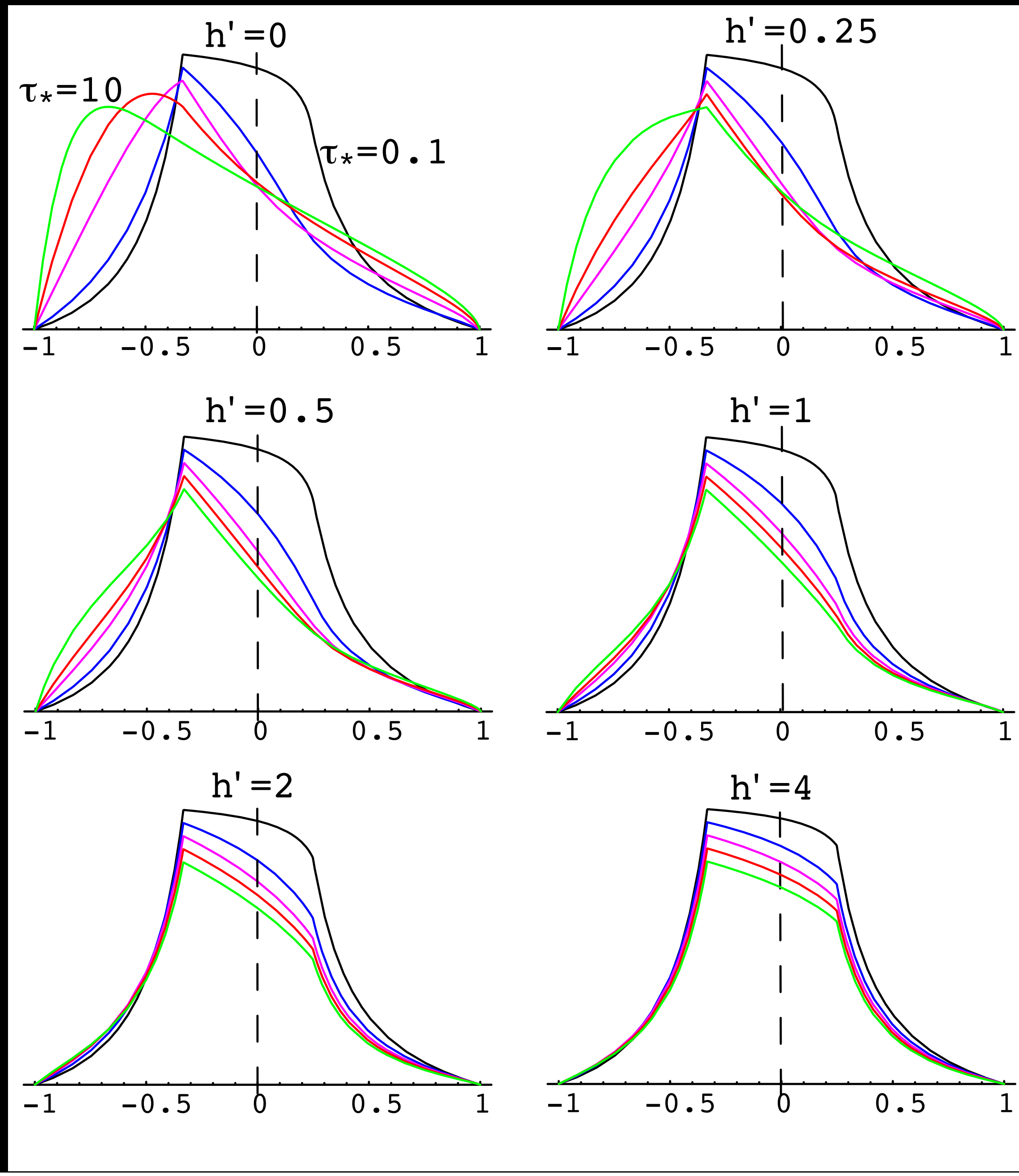
Porous Envelope

Porosity length = size/filling factor

$$h \equiv l/f$$



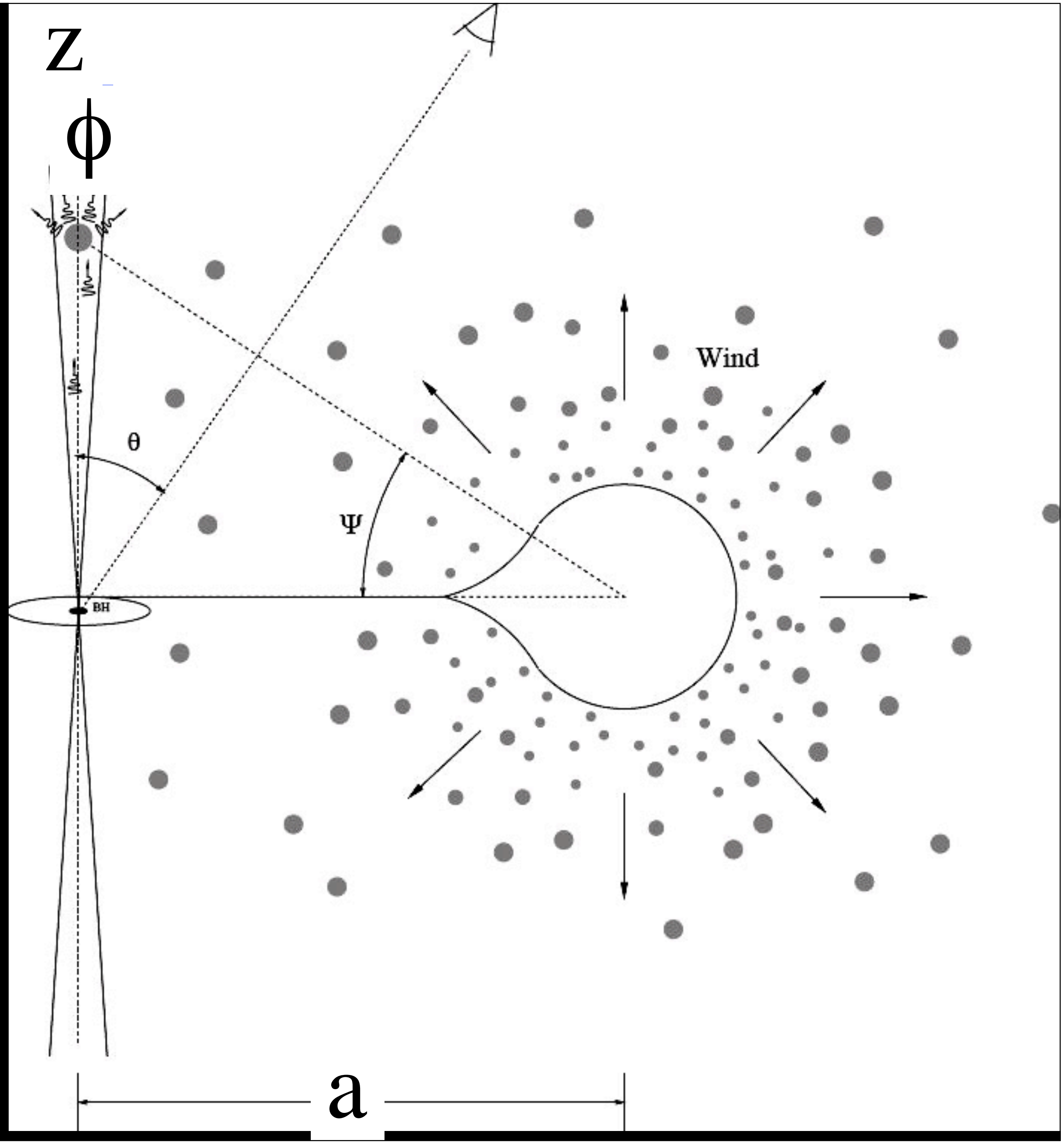
Porosity's effect on X-ray line profiles



Porosity length = mfp

$$mfp = (l^2 n_c)^{-1}$$
$$= L^3/l^2$$
$$= l/f_v$$
$$= h = \text{porosity length}$$

γ-ray emission in HMXRB with clumpy wind



γ-ray fluctuation from wind clumps

$$L_\gamma = L_j \sigma \int_0^\infty n(z)\, dz$$

#
clumps $\Delta N_c = \dfrac{\Delta z}{\boxed{h}}$ **mfp**

$$\Delta L_\gamma = L_j \sigma n \Delta z = L_j \sigma n \Delta N_c h$$

$$\left\langle \Delta L_\gamma^2 \right\rangle - \left\langle \Delta L_\gamma \right\rangle^2 = \frac{L_j^2 \sigma^2 n^2 \Delta z^2}{\Delta N_c} = L_j^2 \sigma^2 n^2 h \Delta z$$

$$\boxed{\frac{\delta L_\gamma}{L_\gamma} = \frac{\sqrt{\int_0^\infty n^2 h\, dz}}{\int_0^\infty n\, dz} = \sqrt{\frac{h}{\pi a}}}$$

Typical example

narrow jet with: l=h/10=0.003a

$$\frac{\delta L_\gamma}{L_\gamma} \approx \sqrt{\frac{h}{\pi a}} \approx 0.1 = 10\%$$

finite-cone jet with: $\phi = 1^o = 0.0017$ rad

$$\frac{\delta L_\gamma}{L_\gamma} \approx \sqrt{\frac{h/\pi a}{1+\phi a/2l}} \approx 0.05 = 5\%$$

Summary

- Massive stars can be prominent sources of high-energy emission
- X-ray from shocks (CWB, MCWS, Instab.)
- γ-rays from CWB, jets
- Emission affected by wind clumping, “porosity”