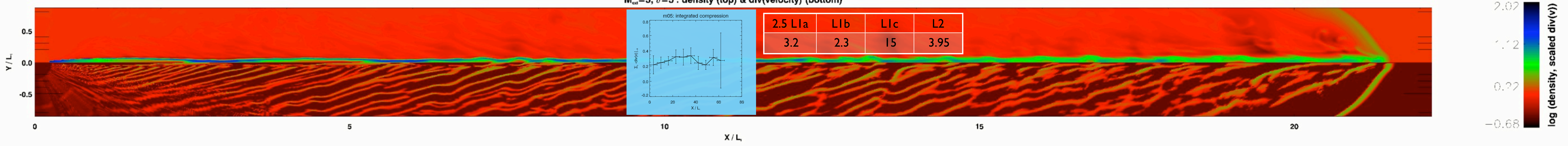
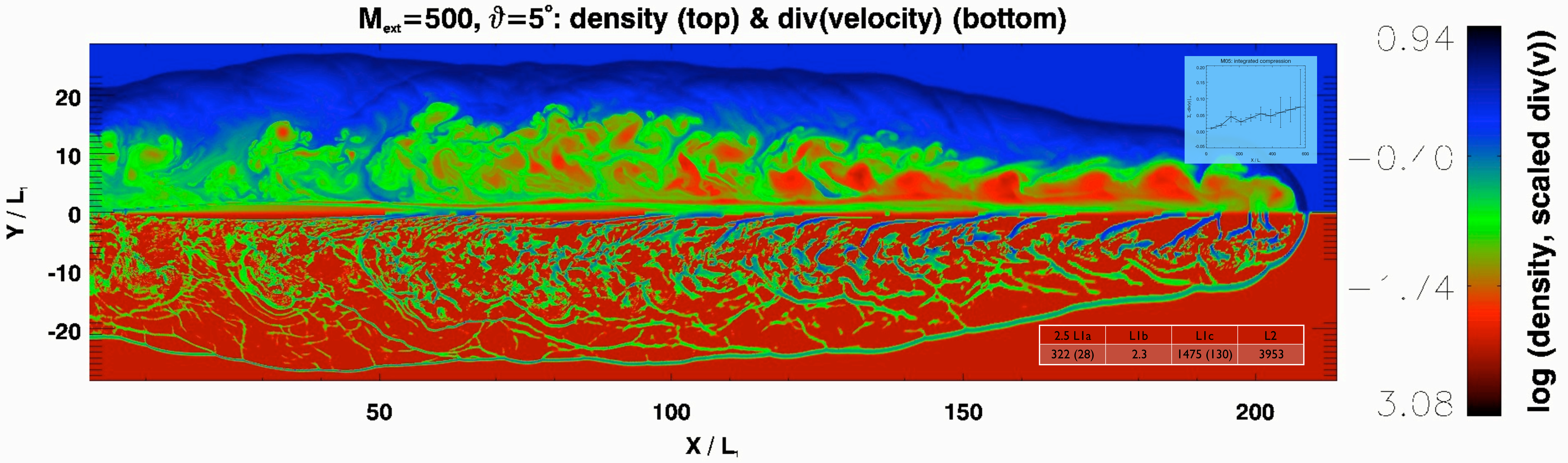
Martin Krause

Universitätssternwarte, Ludwig-Maximilians-Universität München
Max-Planck-Institut für Extraterrestrische Physik

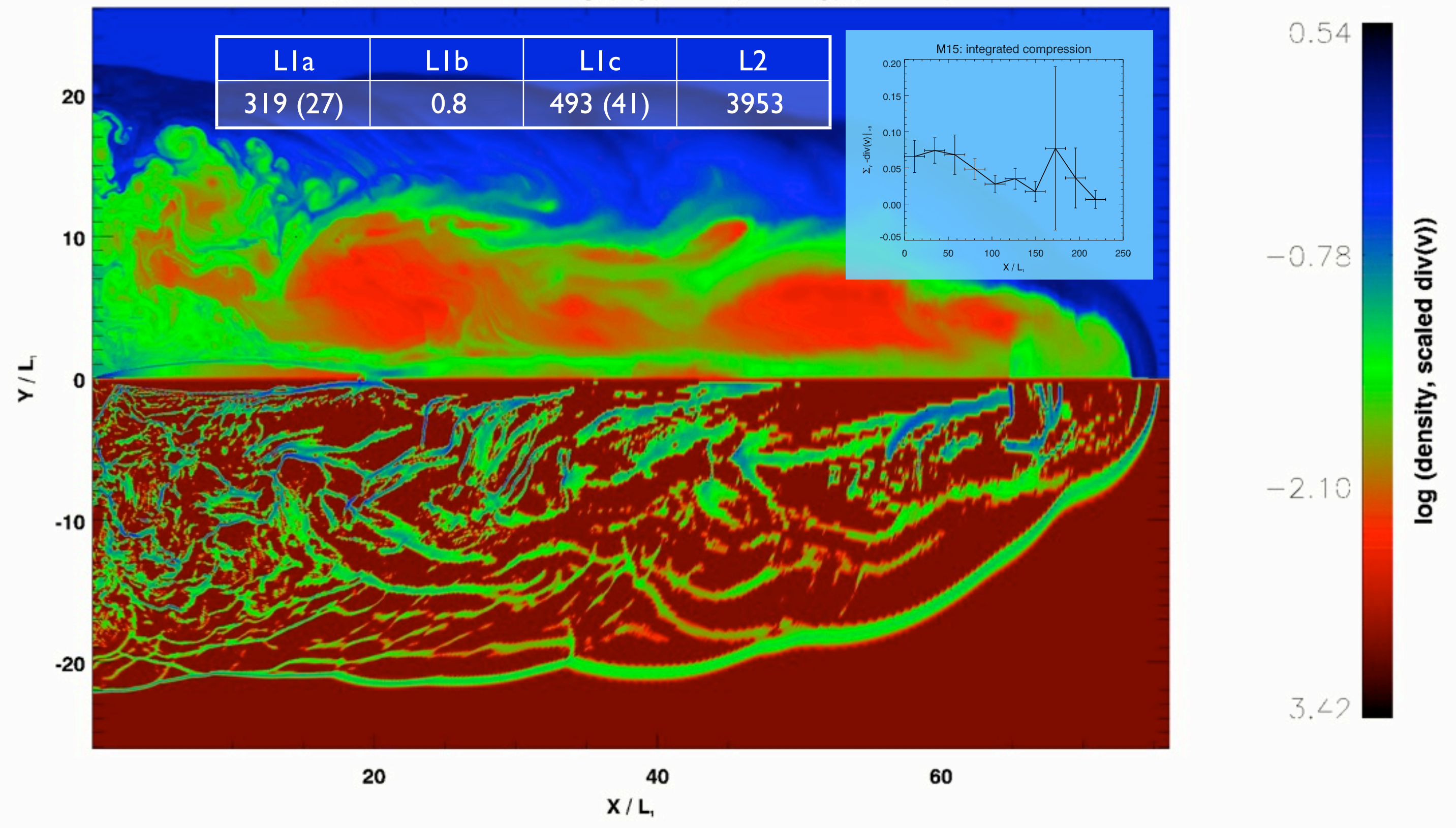

$M_{ext}=5$, $\vartheta=5°$: density (top) & div(velocity) (bottom)

2.5 L1a	L1b	L1c	L2
3.2	2.3	15	3.95

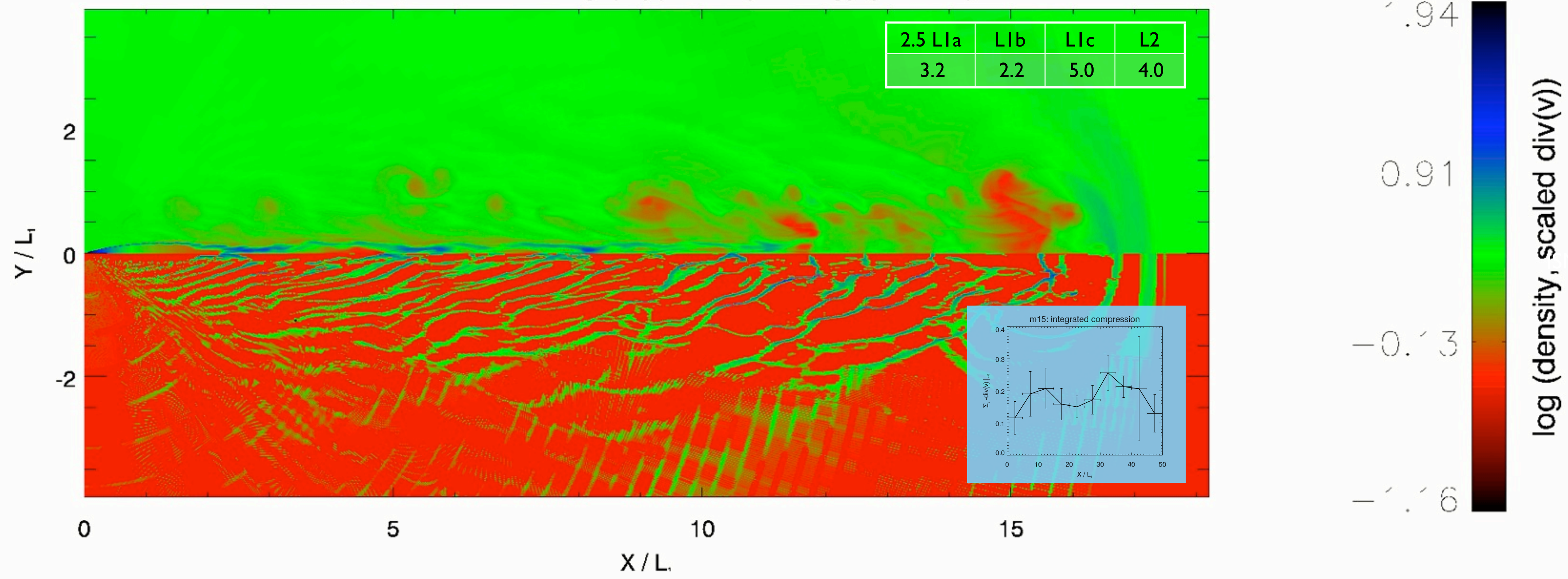
Constraining jet properties by the jet-environment interaction


$M_{ext}=500$, $\vartheta=5°$: density (top) & div(velocity) (bottom)

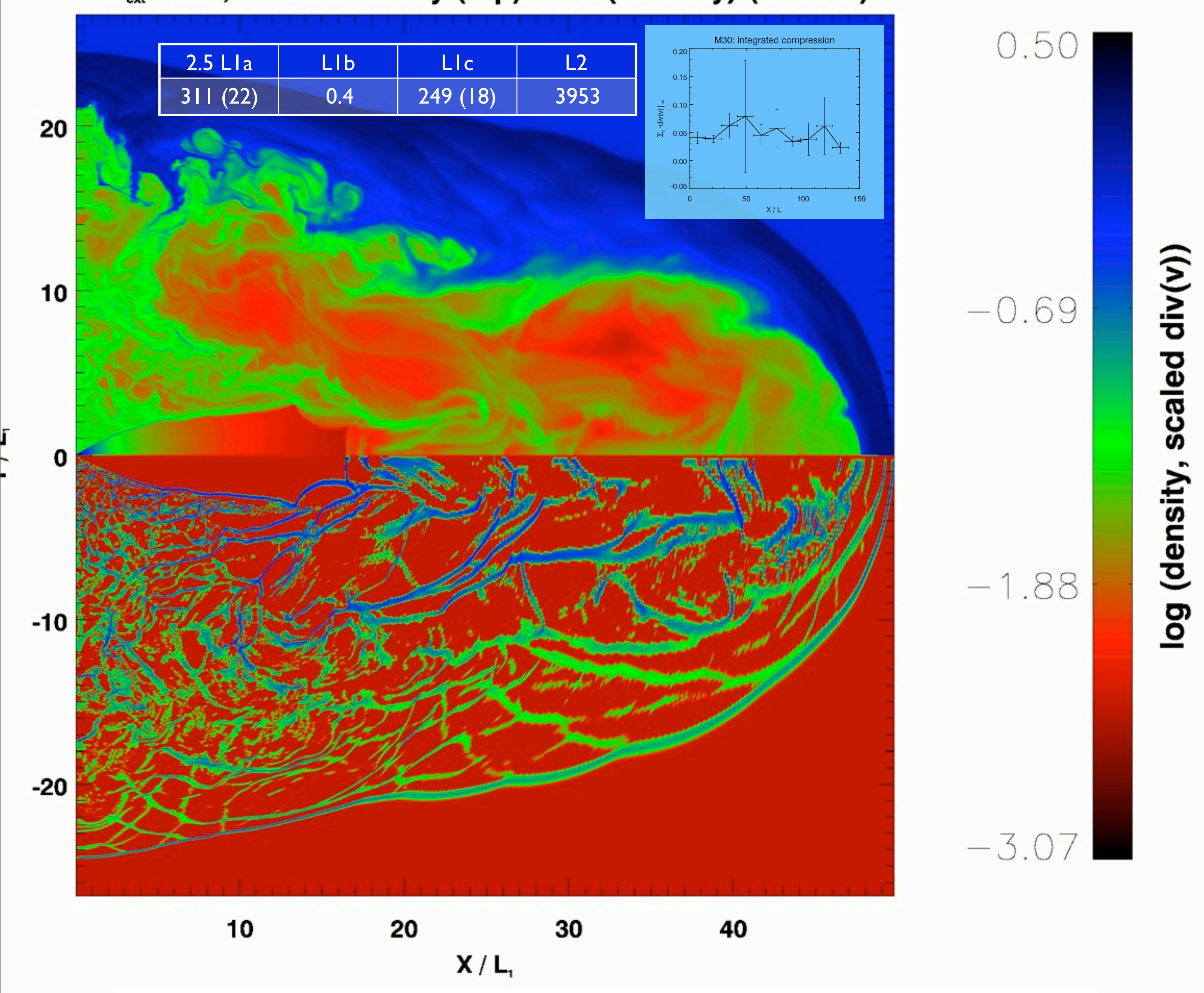
2.5 L1a	L1b	L1c	L2
322 (28)	2.3	1475 (130)	3953


$M_{ext}=500$, $\vartheta=15°$: density (top) & div(velocity) (bottom)

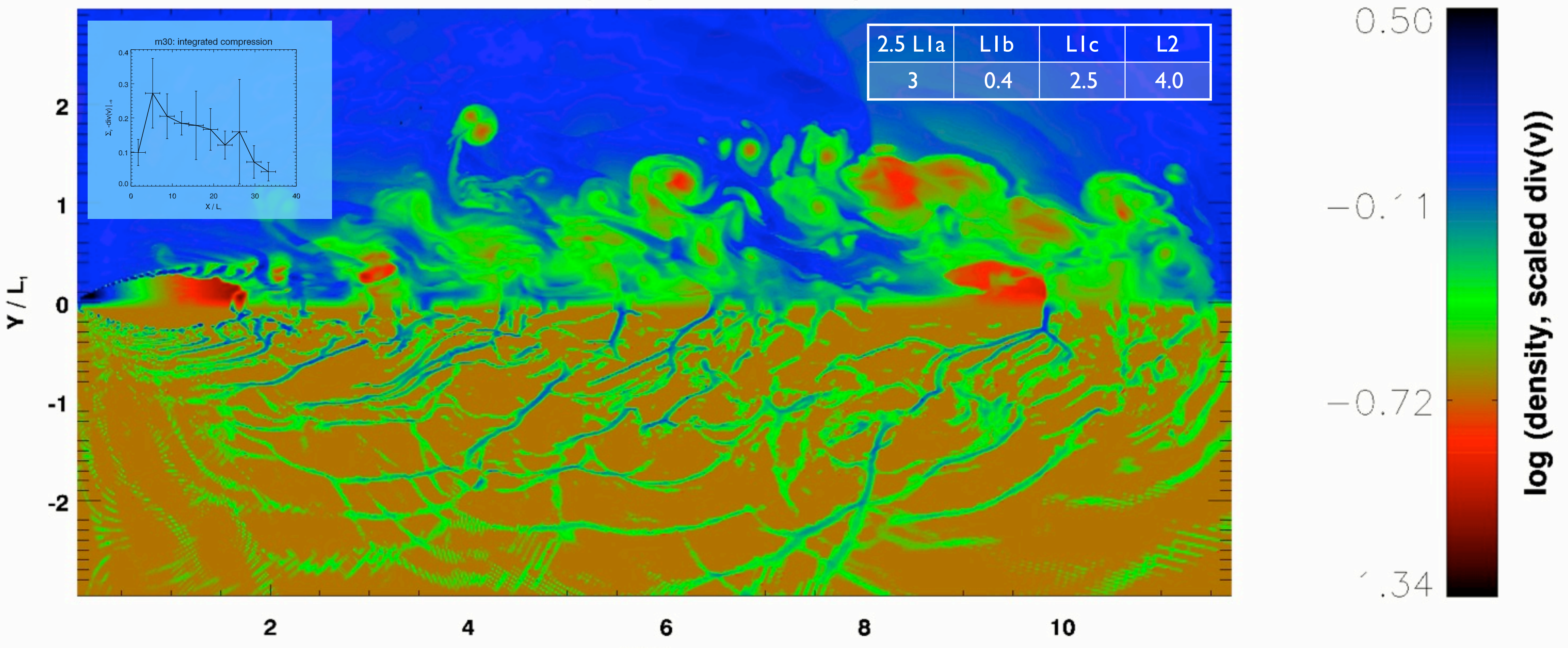
L1a	L1b	L1c	L2
319 (27)	0.8	493 (41)	3953


$M_{ext}=5$, $\vartheta=15°$: density (top) & div(velocity) (bottom)

2.5 L1a	L1b	L1c	L2
3.2	2.2	5.0	4.0


$M_{ext}=500$, $\vartheta=30°$: density (top) & div(velocity) (bottom)

2.5 L1a	L1b	L1c	L2
311 (22)	0.4	249 (18)	3953


$M_{ext}=5$, $\vartheta=30°$: density (top) & div(velocity) (bottom)

2.5 L1a	L1b	L1c	L2
3	0.4	2.5	4.0

Length-scale	formula	symbol
Inner	$\left(\frac{8Q_0}{\rho_x v_j^3}\right)^{1/2}$	L_1
Recollimation	$\gamma^{1/2}M_x \sin\theta L_1/(2\Omega^{1/2})$	L_{1a}
Cocoon formation	$L_1/(2\Omega^{1/2})$	L_{1b}
Terminal shock limit	$\gamma^{1/2}M_x L_1/(2\Omega^{1/2})$	L_{1c}
Outer	$\left(\frac{Q_0}{\rho_x c_x^3}\right)^{1/2}$	L_2

Outline:
Assuming an initially conical jet, the jet environment interaction may be characterized by five important length scales (see Table), which relate fundamentally to the inner opening angle and external Mach number (M_x). Changing the relative size of these scales produces different large scale jet morphologies. We have checked this with 2.5D HD simulations (FLASH 2.4, spherical AMR), some of which are shown here. The figures show density and shock structure (velocity divergence). The ray-traced binned velocity divergence over x is shown as inset, thought to represent radio emissivity. Error bars denote the local variance. Hot spots should have either large average or variance.

How to get fat cocoons: fast jets
Since the density drops in the conical flow and is constant in the collimated jet, we get fat cocoons if the cocoon formation scale (L1b) is larger than the recollimation scale (2.5 L1a), i.e. we need high Mx (left sims in contrast to right ones), and larger opening angle also helps (bottom right). The collimated jet density is given by $\eta=(L_{1a}/L_{1b})^2$.

How to get FR I/II jets: initial opening angle
In the conical flow the ram pressure of the jet drops. The hot spot may therefore only propagate as long as the ram pressure exceeds the ambient (cocoon) pressure. Hence we get an FR I source if the terminal shock limit (L_{1c}) is reached before the jet recollimates (L1a). This results in the sole condition θ > 24° for FR I jets.

Conclusions:
The cocoon width (collimated jet density) is mainly determined by the external Mach number. Therefore, extragalactic jets (fat cocoons) must be at least close to relativistic. The FR I/II dichotomy is related to the initial jet opening angle, i.e. the central engine must be different for FRI and FR II jets, respectively, if this mechanism is indeed responsible for the dichotomy. The literature (e.g. Hardcastle et al. 2007, MNRAS 376, 1849) finds the radiative efficiency of FR I nuclei to be lower, which might be a hint of different accretion/ jet launching mechanisms.