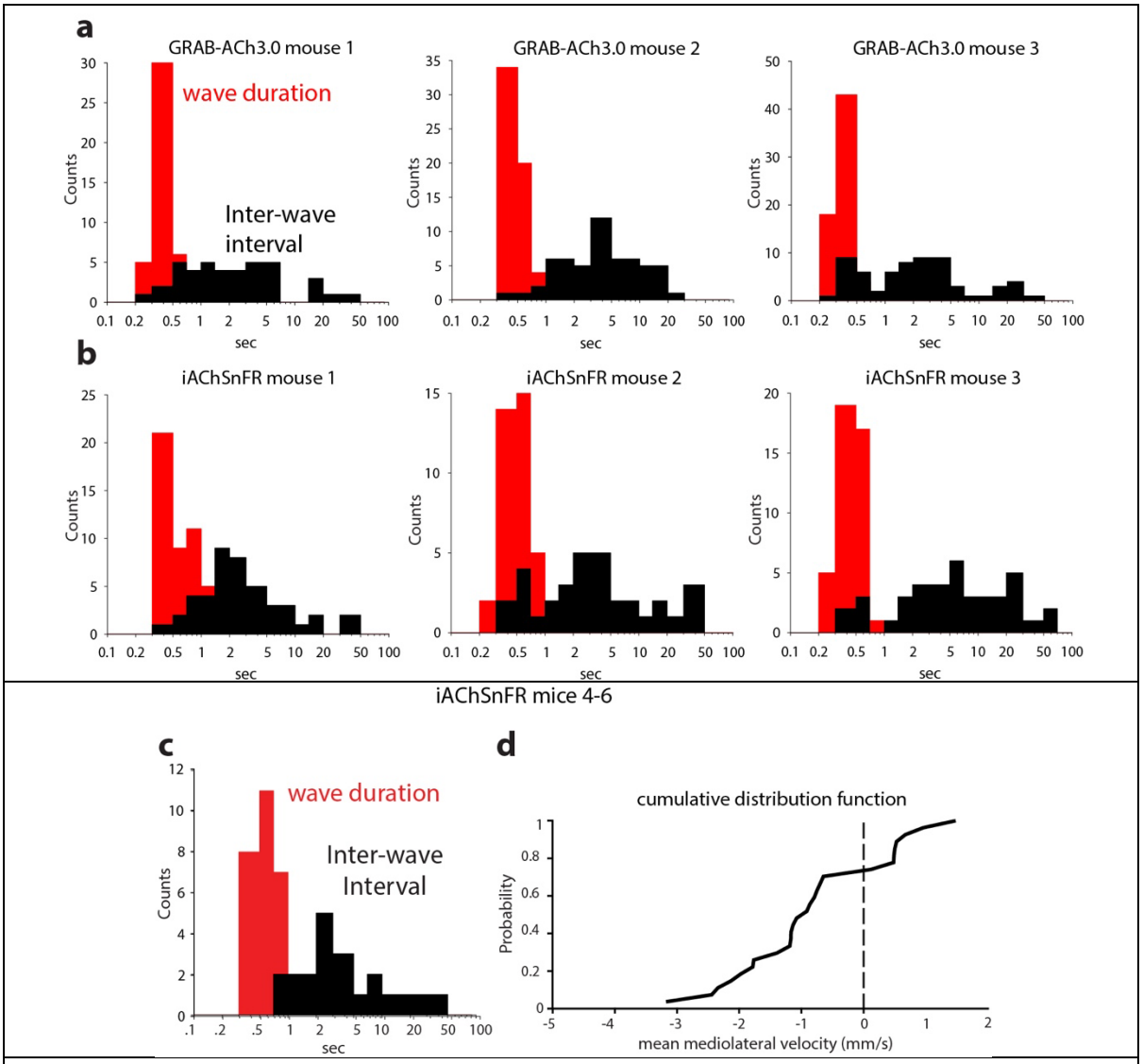
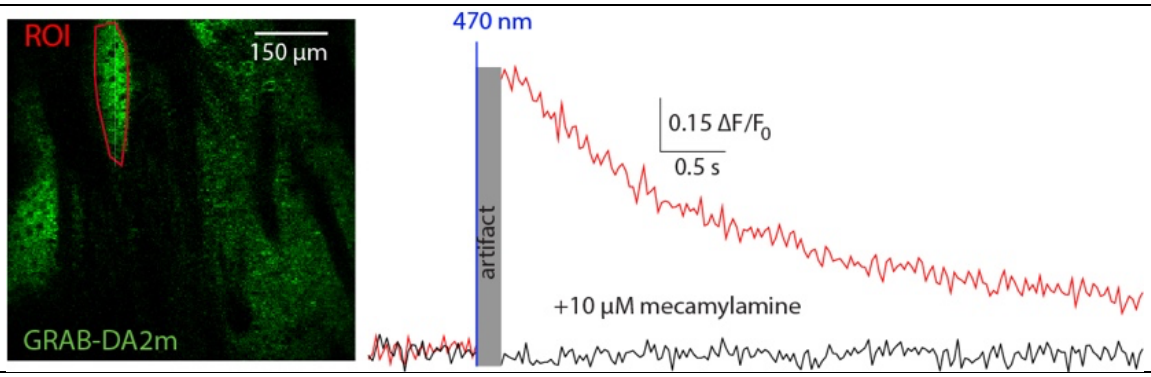
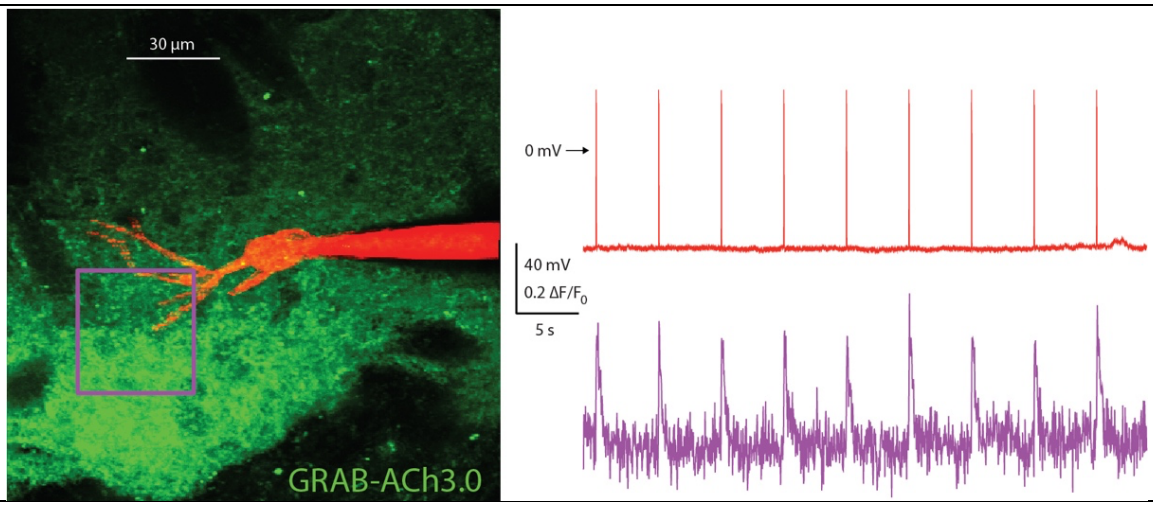


Supplementary Fig. 1: **a**. Distributions of wave durations and inter-wave intervals pooled from individual mice imaged with GRAB-ACh3.0. **b**. Distributions of wave durations and inter-wave intervals pooled from individual mice (1-3) imaged with iAChSnFR. **c**. Distributions of wave durations and inter-wave intervals pooled from mice 4-6 imaged with iAChSnFR. d. Distributions of wave velocities pooled from mice 4-6 imaged with iAChSnFR. Source data are provided as a Source Data file.



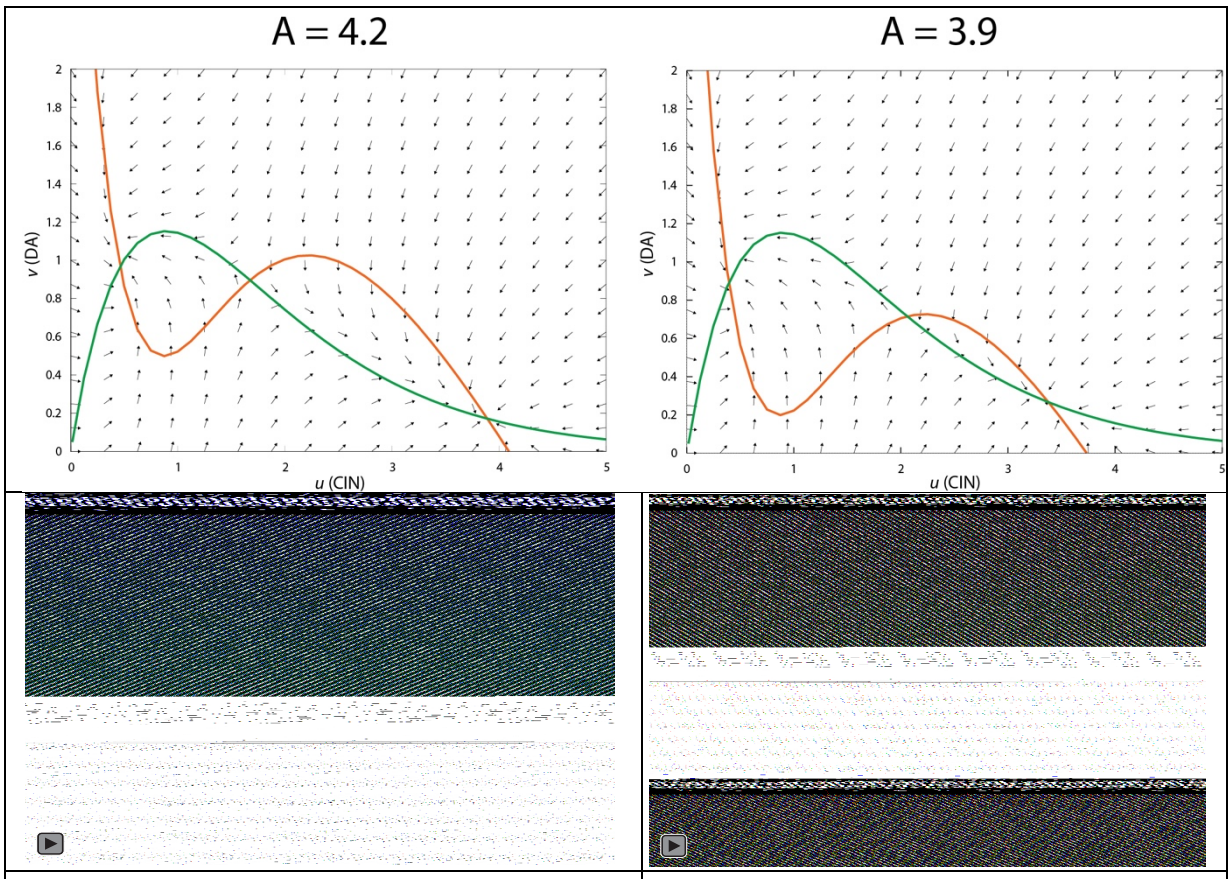
Supplementary Fig. 2a: Synchronous optogenetic activation (with a 1-ms long, 470 nm pulse) of CINs in an acute slice from a ChAT-ChR2 mouse whose dorsal striatum was inoculated with AAVs harboring GRAB-DA2m, causes DA release that is eliminated in the presence of 10 µM mecamylamine, a nAChR antagonist. DA release was evoked in 8 slices from 4 mice, and the mecamylamine block was tested and confirmed in 3 slices from two of these mice. The artifact which is removed is explained in the Methods section.



Supplementary Fig. 2b: Nine action potentials were elicited in an individual CIN hyperpolarized to quiescence (each with a 35 ms-long, 220 pA current pulse). The action potentials triggered ACh release (averaged from the color coded box) as visualized in wild-type mice whose dorsal striatum was inoculated with GRAB-ACh3.0. At this frequency (0.2 Hz) the median decrease of the amplitude of the 2nd to 9th ACh responses was no more than 4% relative to the 1st response (*n* = *4* CINs from *N* = *3* mice).

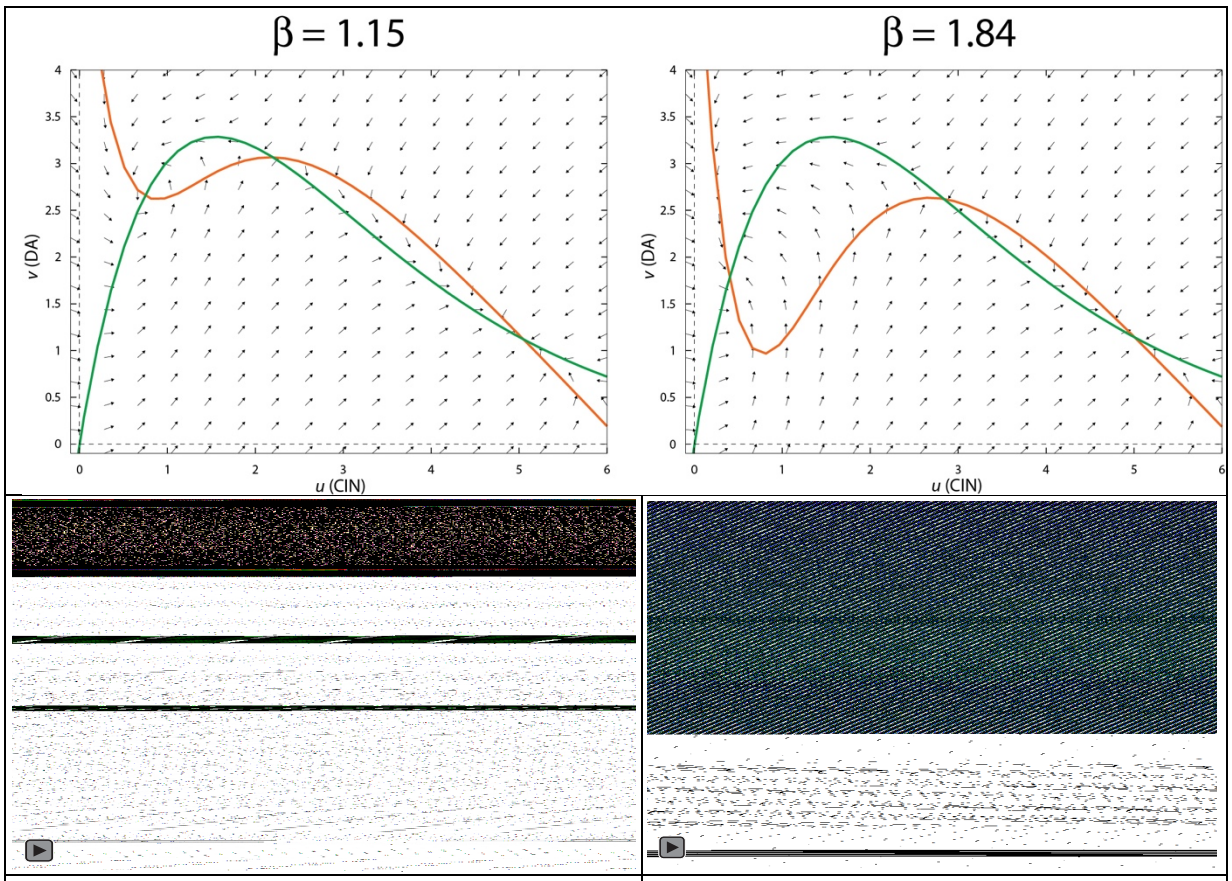
β=1, D_u=0.02 (T=50)	β=1.8, D_u=0.02 (T=50)
β=1, D_u=1 (T=10)	β=1.8, D_u=1 (T=10)

Supplementary Fig. 3a: Full model with $f_1(u)$ and $g_1(u)$. red: $u(x,t)$ (CIN); blue: $v(x,t)$ (DA). Other parameters: $A=4.2$, $\sigma=0.75$, $\kappa=1.5$, $\gamma=0.47$, $\phi = 10$, $D_v=1$. Length of simulation in time units is indicated in parentheses.



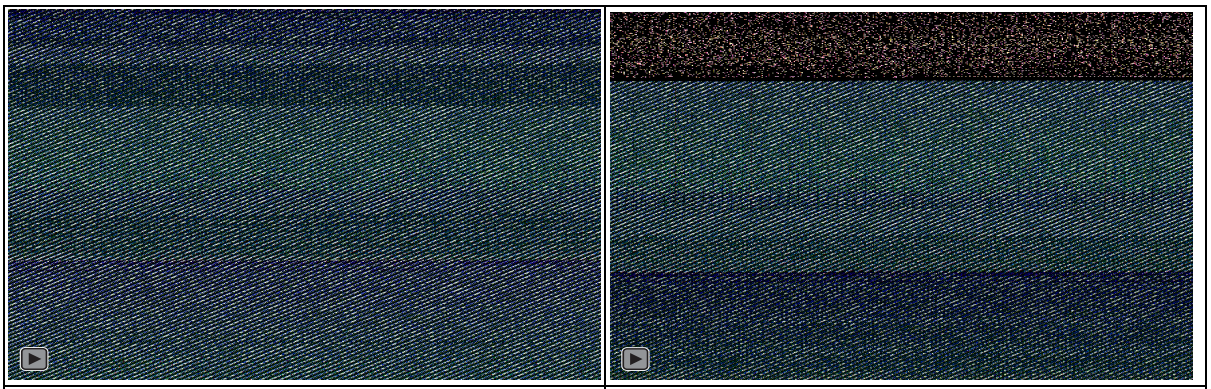
A=4.2 (T=50)	*A=3.9* (T=50)

Supplementary Fig. 3b: Full model with $f_I(u)$ and $g_I(u)$. red: $u(x,t)$ (CIN); blue: $v(x,t)$ (DA). Other parameters: $\beta=1.2$, $\sigma=0.75$, $\kappa=1.5$, $\gamma=0.47$, $\phi = 10$, $D_u=0.02$, $D_v=1$. Length of simulation in time units is indicated in parentheses.



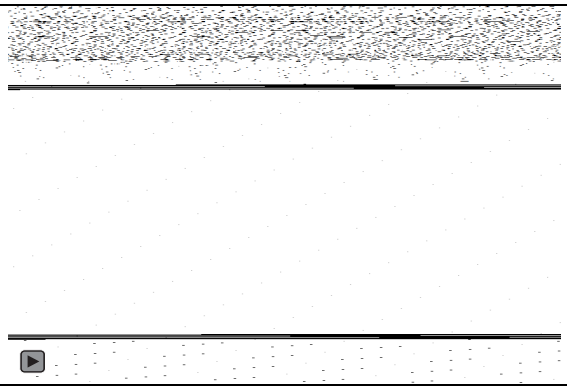
β=1.15, D_v=0 (T=300)	*β=1.84, D_v=0* (T=100)

Supplementary Fig. 3c: Full model with $f_1(u)$ and $g_1(u)$ with $D_v=0$. red: $u(x,t)$ (CIN); blue: $v(x,t)$ (DA). Other parameters: A=*6.2, σ=0.43, κ=1.5, γ=1.34, ϕ = 10,* $D_u=0.1$. Length of simulation in time units is indicated in parentheses.

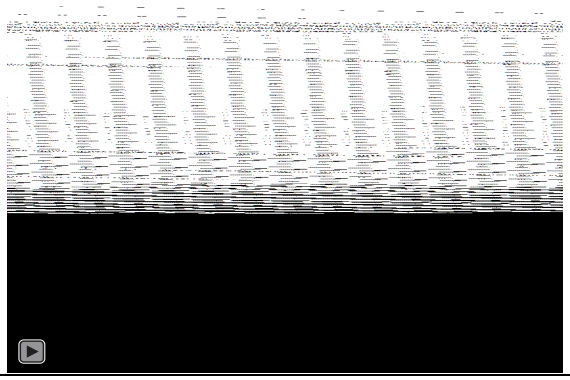


b=0.435	*b=0.7*

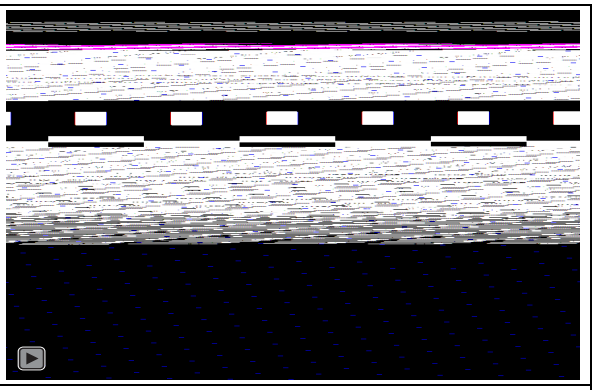
Supplementary Fig. 4: Tractable model with $f_2(u)$ and $g_2(u)$ and $D_v=0$. red: $u(x,t)$ (CIN); blue: $v(x,t)$ (DA). Other parameters: *a=0.3, s=0.2,* $D_u=0.01$.



Supplementary Fig. 5: Turing instability in tractable model with $f_2(u)$ and $g_2(u)$. red: $u(x,t)$ (CIN); blue: $v(x,t)$ (DA). Other parameters: $a=0.3$, $b=0.435$, $s=0.2$, $D_u=0.06$, $D_v=1$.

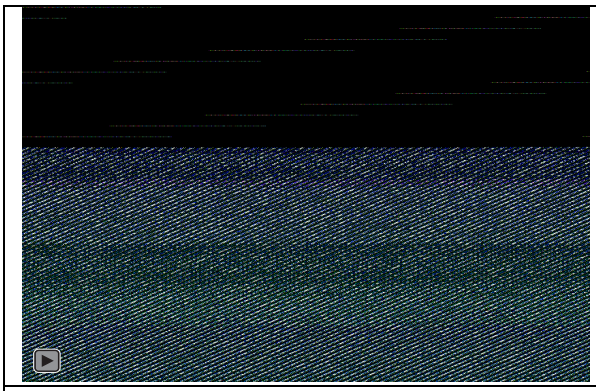


$v(x_o, t=20) = 15$

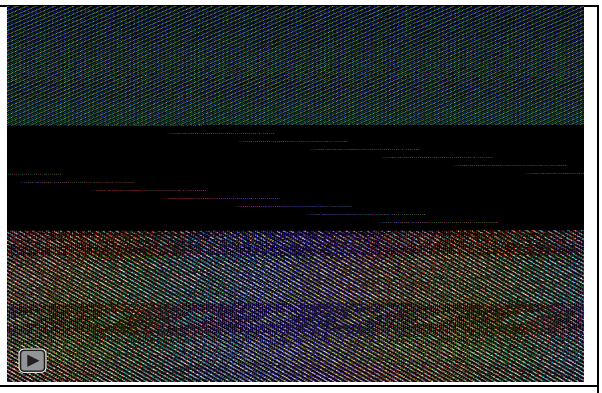


$v(x_o, t=20) = 20$

Supplementary Fig 6a. Response to transient local activation of v (DA) in full model with $f_1(u)$ and $g_1(u)$. red: $u(x,t)$ (CIN); blue: $v(x,t)$ (DA). Other parameters: $A=3.9$, $\beta=1.2$, $\sigma=0.75$, $\kappa=1.5$, $\gamma=0.47$, $\phi = 10$, $D_u=0.01$, $D_v=1$.

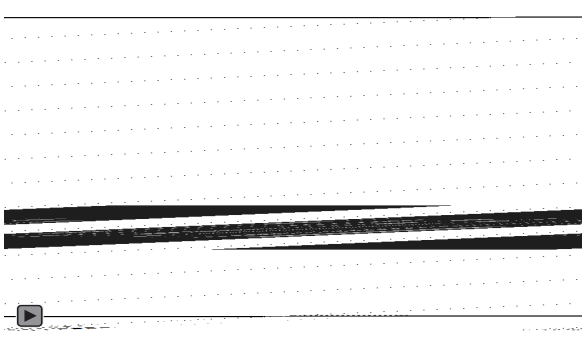
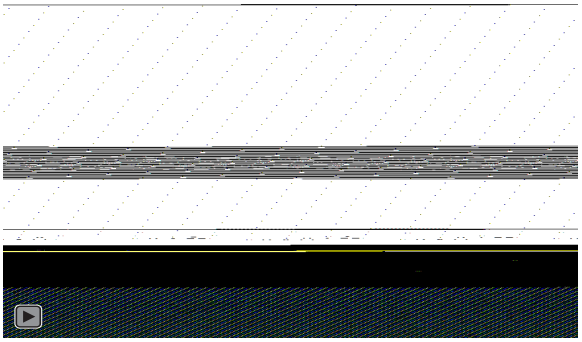


$u(x_o, t=5) = 10$

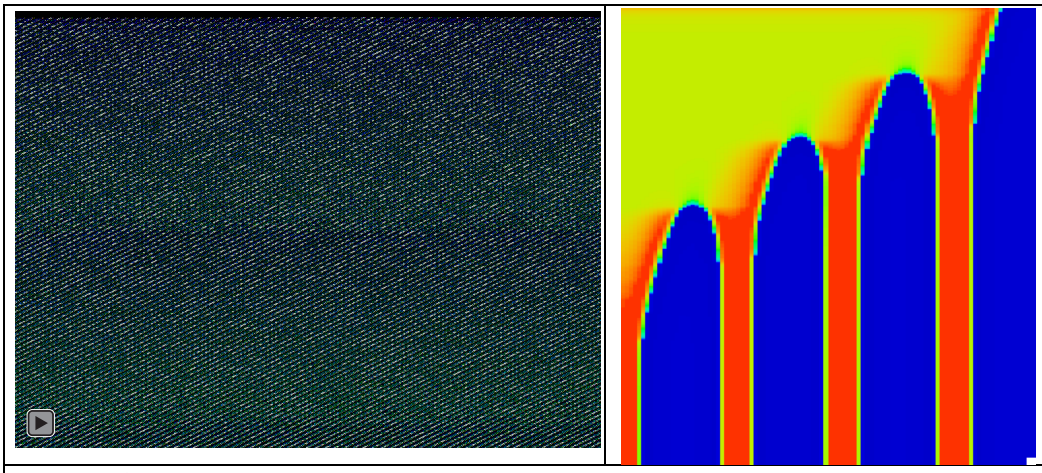


$u(x_o, t=5) = 20$

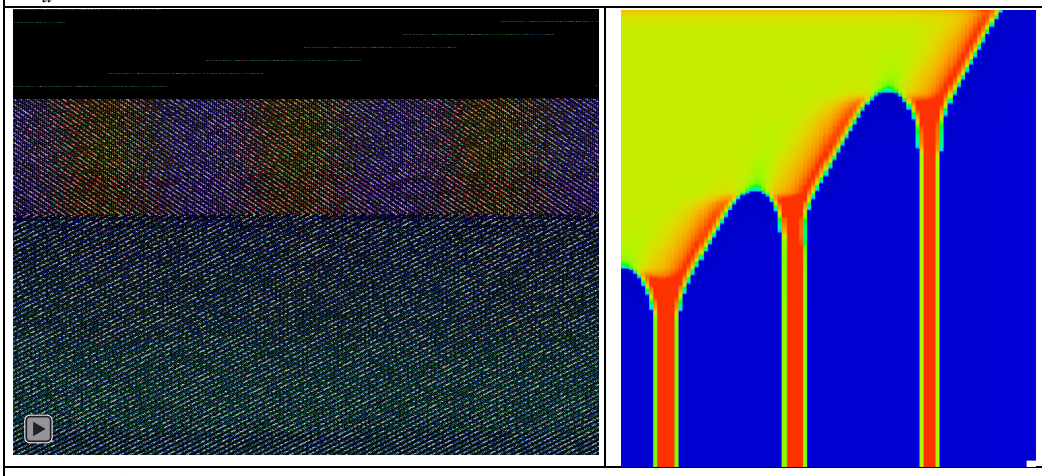
Supplementary Fig 6b. Response to transient local activation of u (CIN) in full model with $f_1(u)$ and $g_1(u)$. red: $u(x,t)$ (CIN); blue: $v(x,t)$ (DA). Other parameters: $A=4.3$, $\beta=1.2$, $\sigma=0.75$, $\kappa=1.5$, $\gamma=0.47$, $\phi = 10$, $D_u=0.01$, $D_v=1$.

	
β=1.35	β=1.55

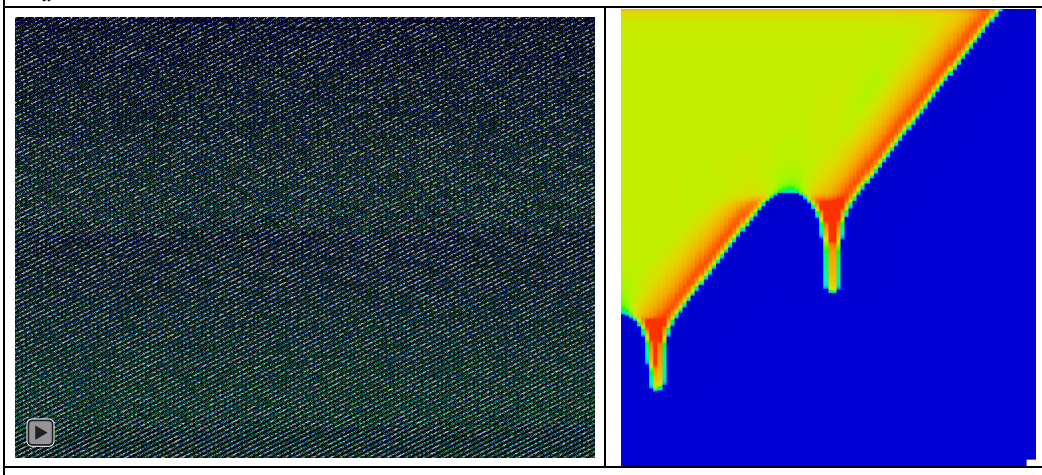
Supplementary Fig 7. Full model with $f_1(u)$ and $g_1(u)$ with $\sigma=0.1$. red: $u(x,t)$ (CIN); blue: $v(x,t)$ (DA). Other parameters: $A=4.3$, $\kappa=1.5$, $\gamma=0.47$, $\phi = 10$, $D_u=0.2$, $D_v=1$.



D_u=0.01

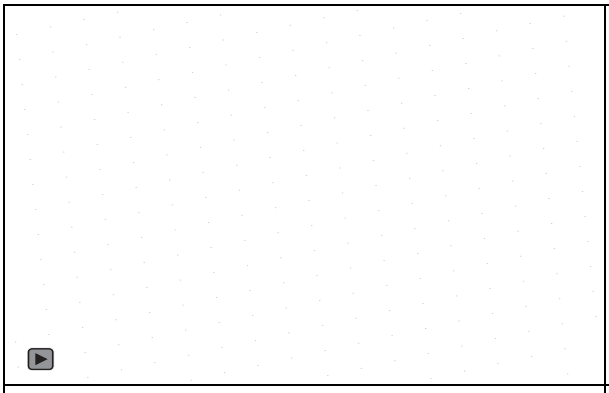
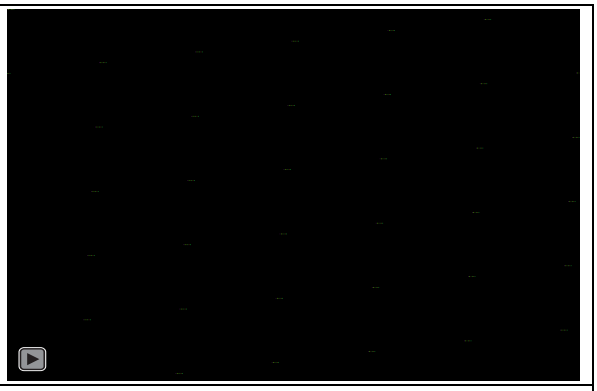


D_u=0.015

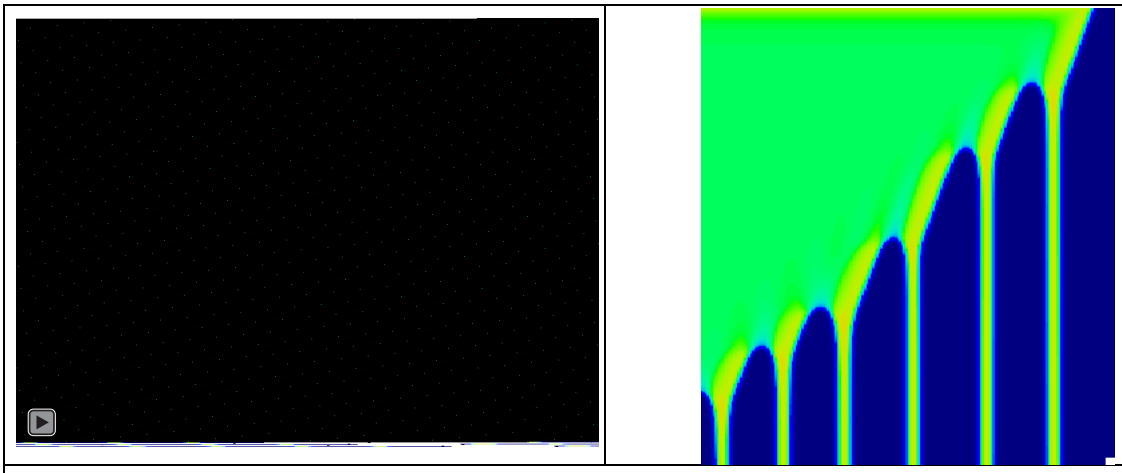


D_u=0.02

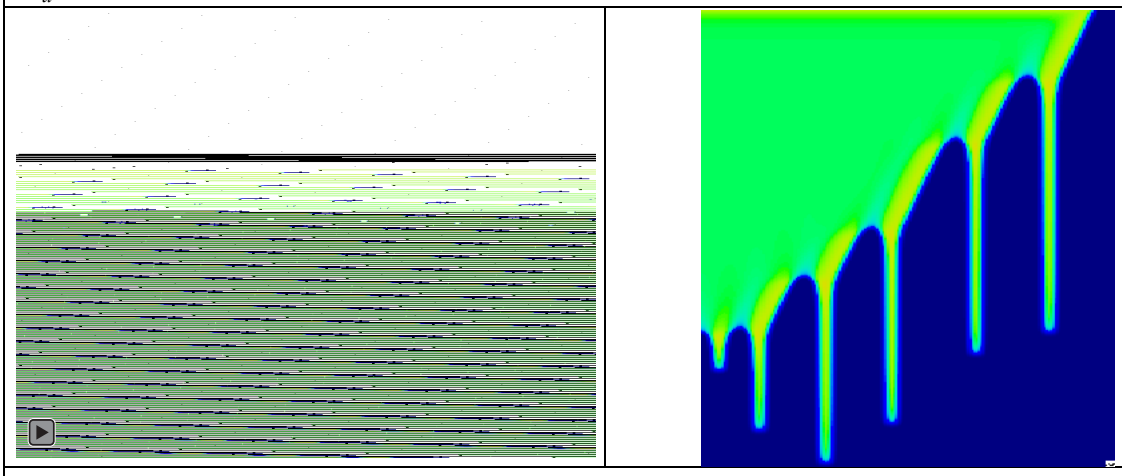
Supplementary Fig. 8: Stable and unstable Turing patterns in full model with $f_1(u)$ and $g_1(u)$. red: $u(x,t)$ (CIN); blue: $v(x,t)$ (DA). Other parameters: $A=4.3$, $\beta=1.62$, $\sigma=0.1$, $\kappa=1.5$, $\gamma=0.5$, $D_v=1$.

	
s=0.1	*s=0.25*

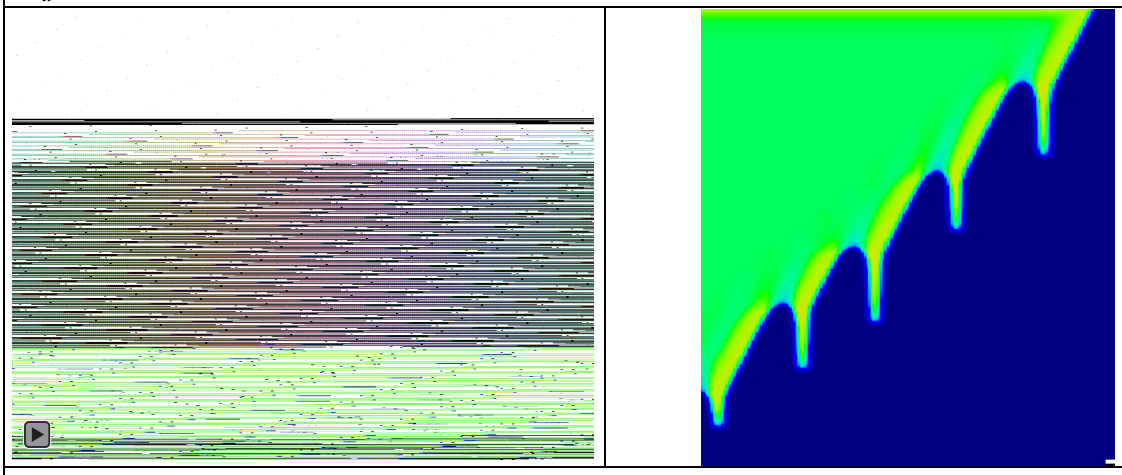
Supplementary Fig 9. Tractable model with $f_3(u)$ and $g_3(u)$. red: $u(x,t)$ (CIN); blue: $v(x,t)$ (DA). Other parameters: $b=0.14$, $D_u=0.1$, $D_v=1$.



D_u=0.02



D_u=0.022



D_u=0.024

Supplementary Fig. 10: Stable and unstable Turing patterns in tractable model with $f_3(u)$ and $g_3(u)$. red: $u(x,t)$ (CIN); blue: $v(x,t)$ (DA). Other parameters: $s=0.25$ $b=0.14$, $D_v=1$.