

Intrinsic and Extrinsic Noise Effects on Molecular Distributions in Bacteria

Romain Yvinec

► **To cite this version:**

Romain Yvinec. Intrinsic and Extrinsic Noise Effects on Molecular Distributions in Bacteria. 11th International Conference on Systems Biology, (ICSB 2010), Oct 2010, Edinburgh, United Kingdom. hal-03114885

HAL Id: hal-03114885

<https://hal.archives-ouvertes.fr/hal-03114885>

Submitted on 19 Jan 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Intrinsic and Extrinsic Noise Effects on Molecular Distributions in Bacteria

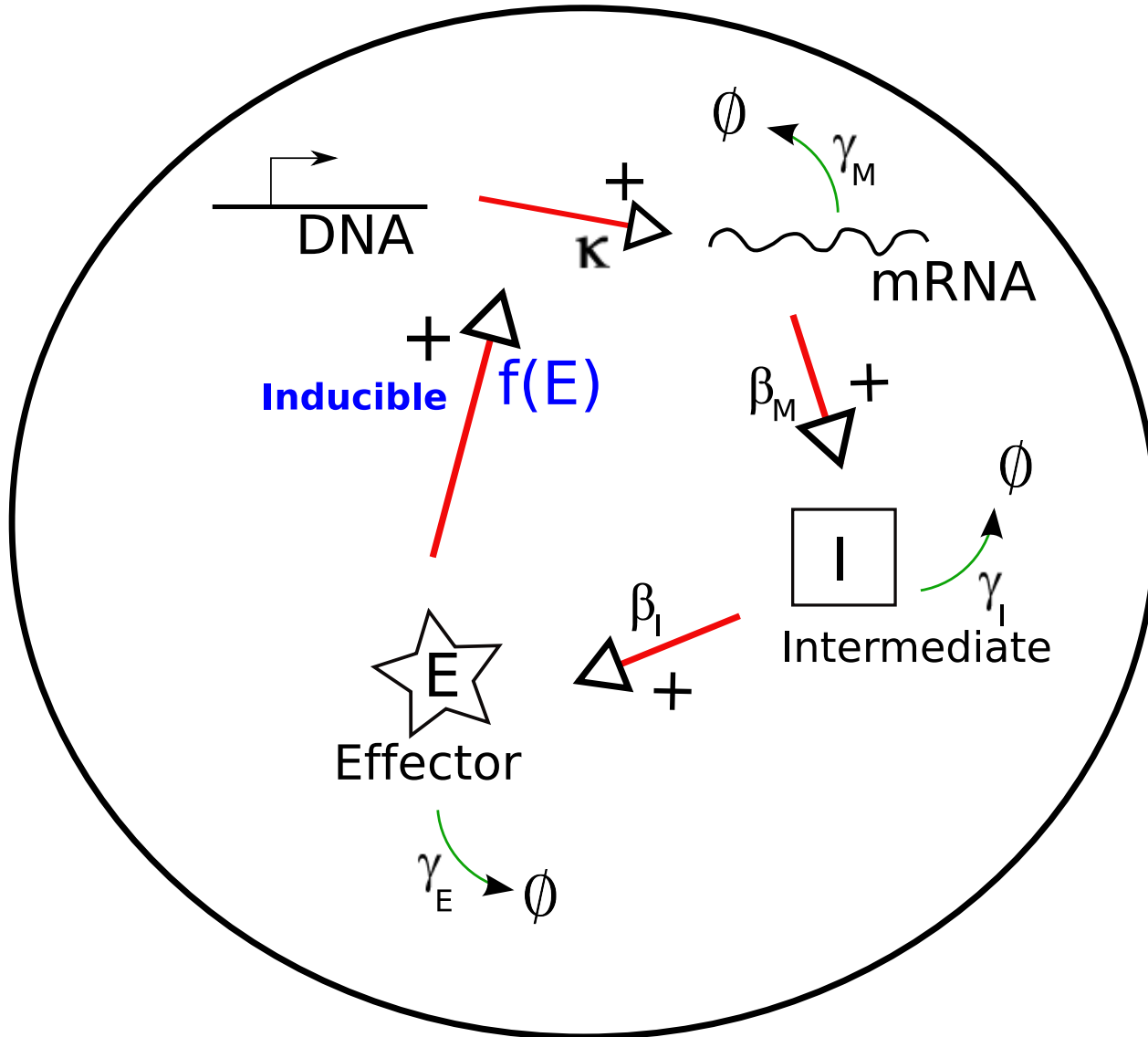
Romain Yvinec (Lyon)

Marta Tyran (Katowice) & Michael C. Mackey (Montreal)

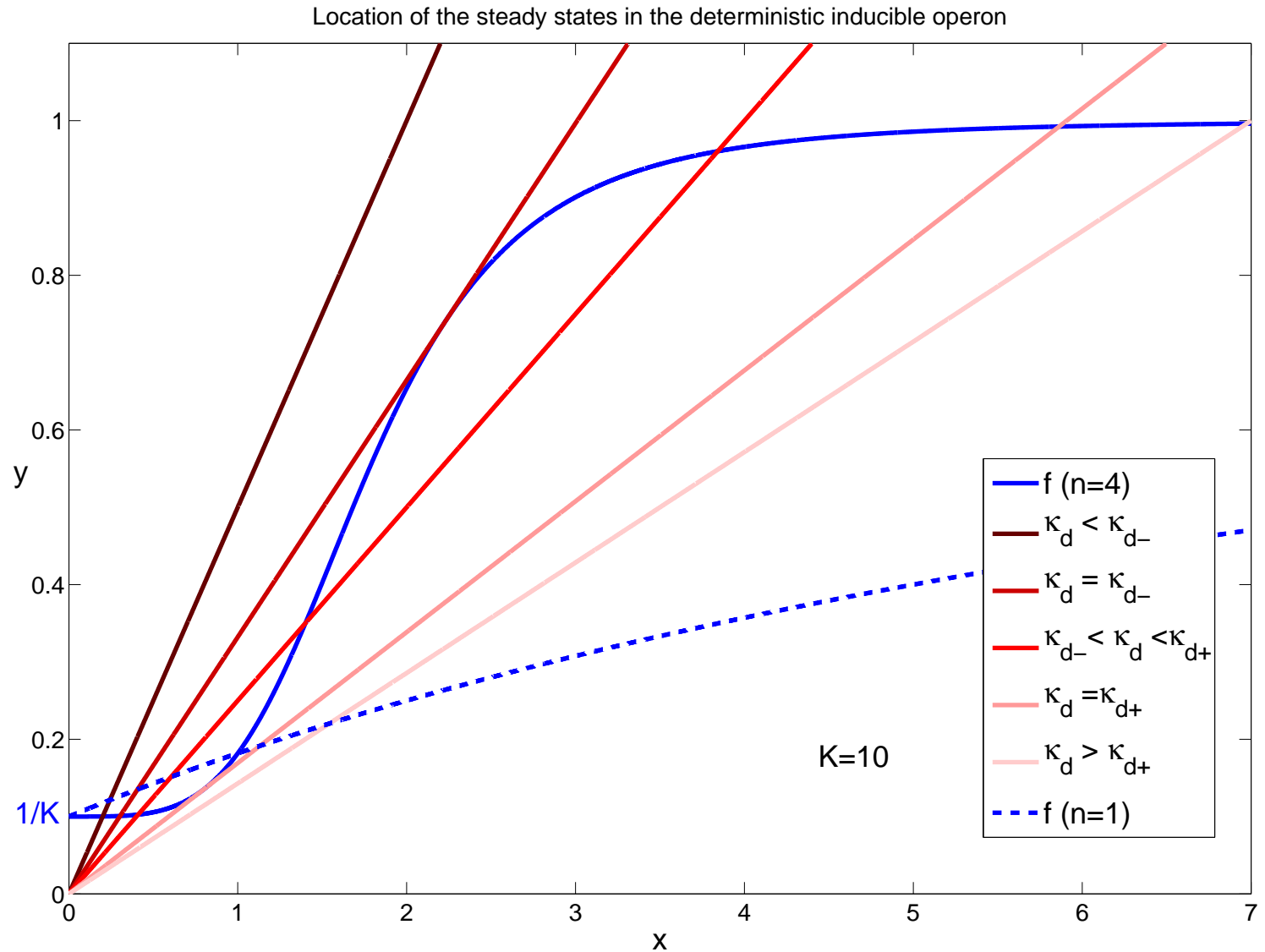
`yvinec@math.univ-lyon1.fr`

Université de Lyon CNRS Université Lyon 1 , Institut Camille Jordan, 43 bd du 11 nov.
1918 F-69622 Villeurbanne Cedex France

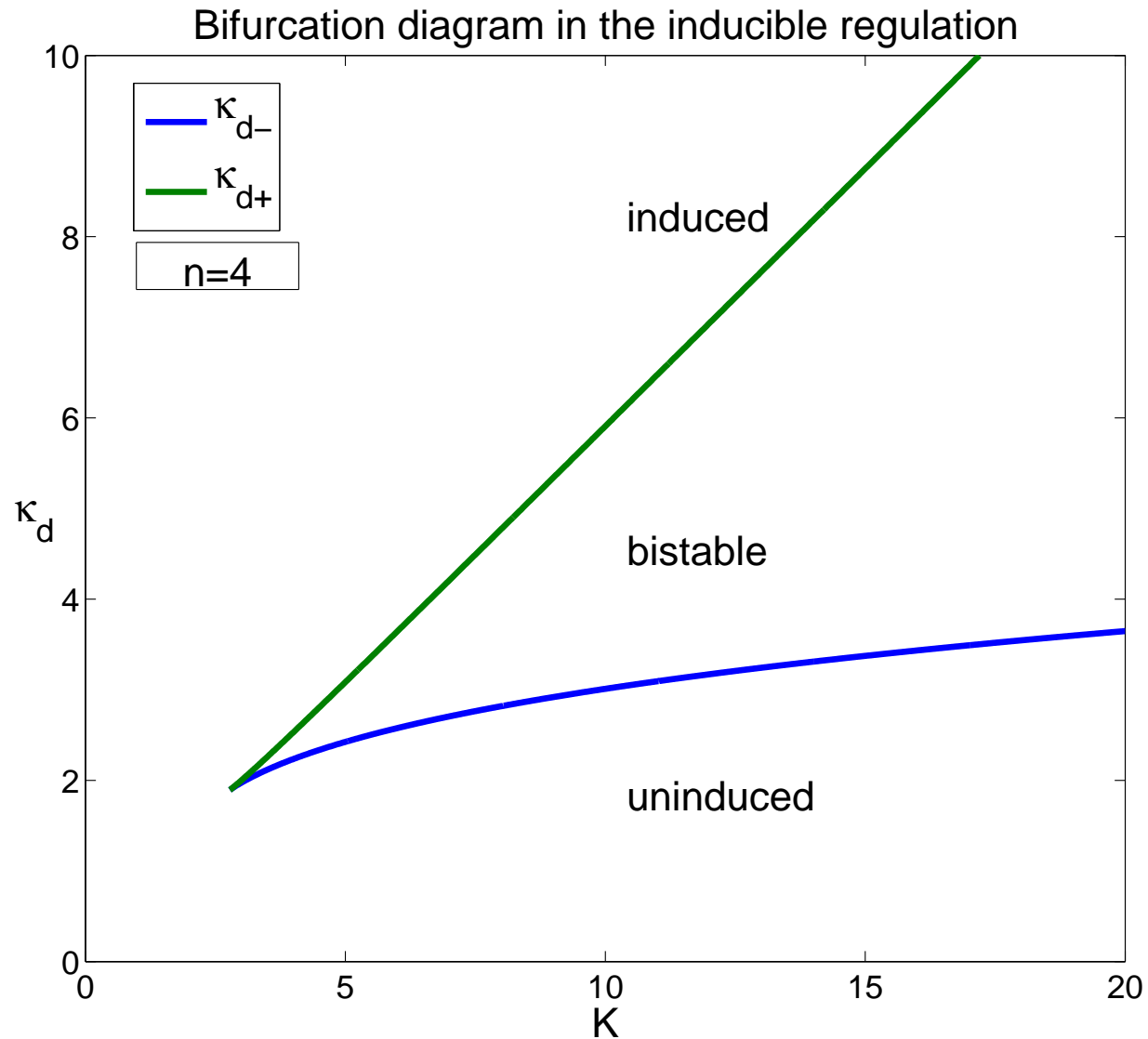
Central dogma



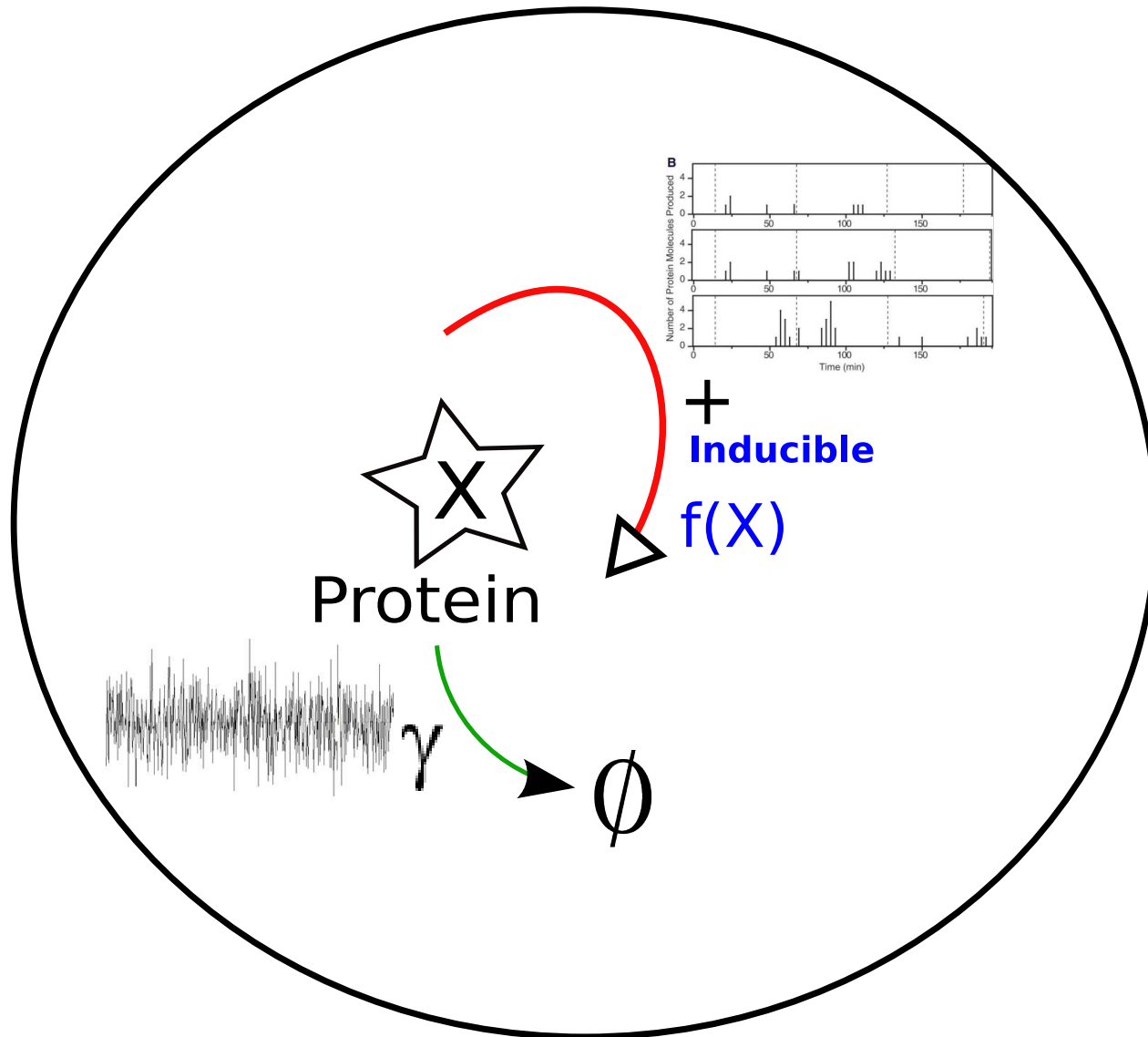
Deterministic inducible regulation



Dependence of bistability on κ_d and K

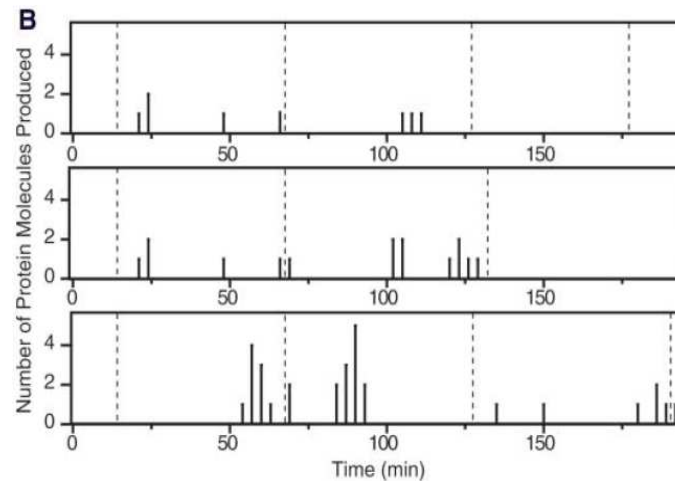


Intrinsic and Extrinsic noise



Bursting (intrinsic noise) in cells

- Experimentally observed that in many organisms the amplitude of protein production through bursting translation of mRNA is exponentially distributed at the single cell level
- Let the density of this distribution be $h(y) = \frac{1}{b}e^{-y/b}$



Yu (2006), Science, **311**

Bursting as a jump Markov process

- Replace the simple deterministic dynamics

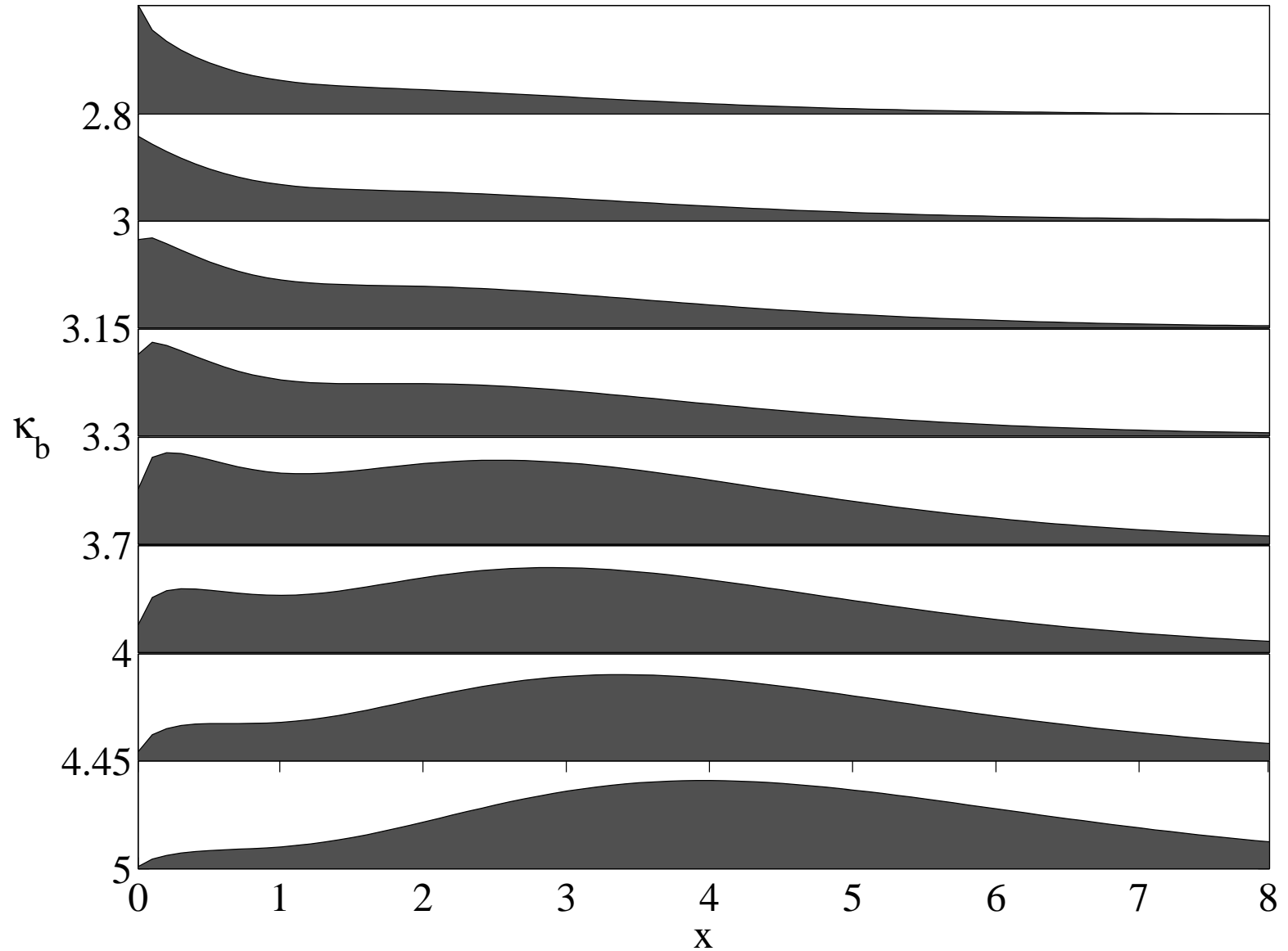
$$\frac{dx}{dt} = -\gamma x + \gamma \kappa_d f(x)$$

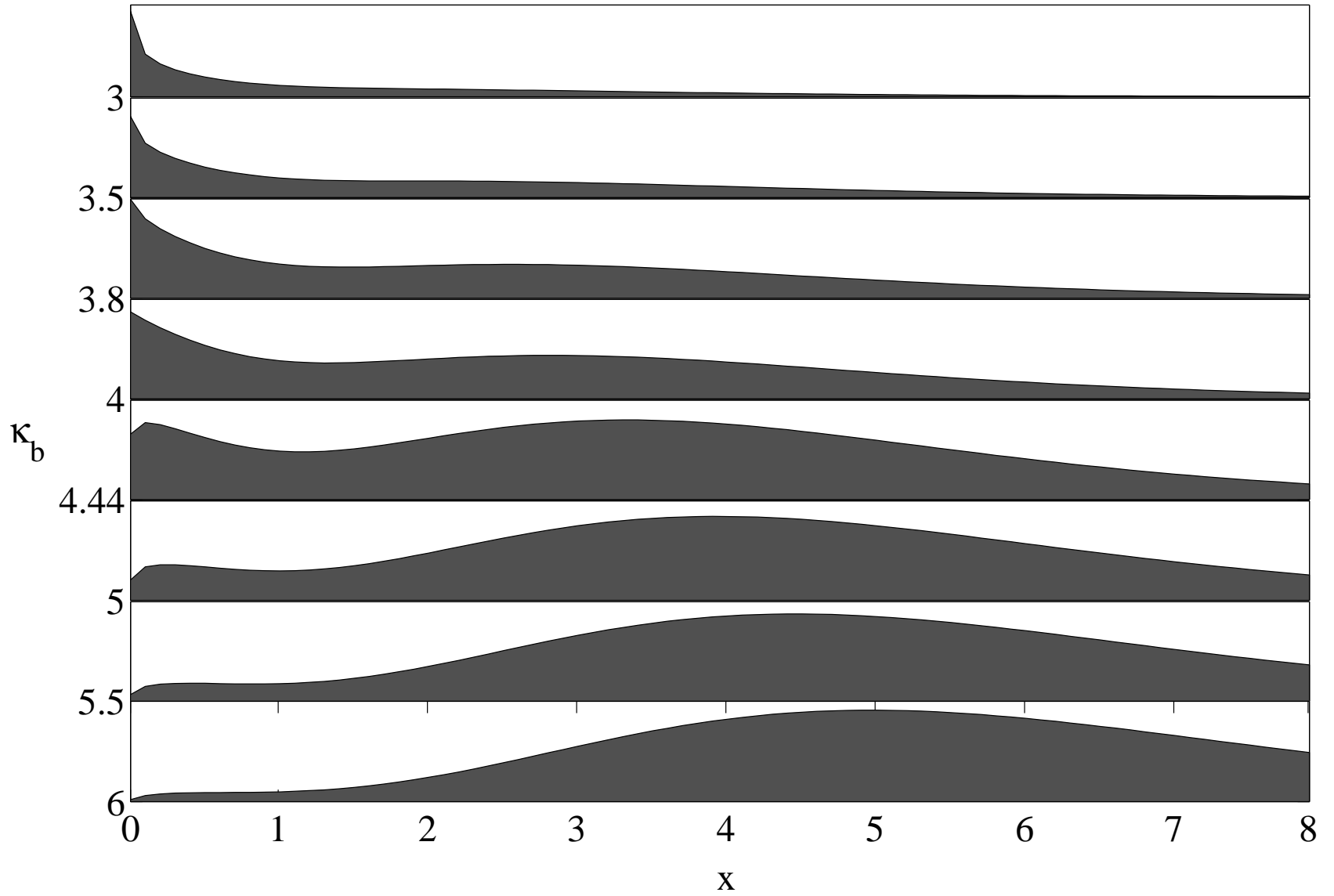
with

$$\frac{dx}{dt} = -\gamma x + \Xi(h, \gamma \kappa_b f(x))$$

where $\Xi(h, \varphi)$ is a jump Markov process occurring at a rate φ and distributed with density h

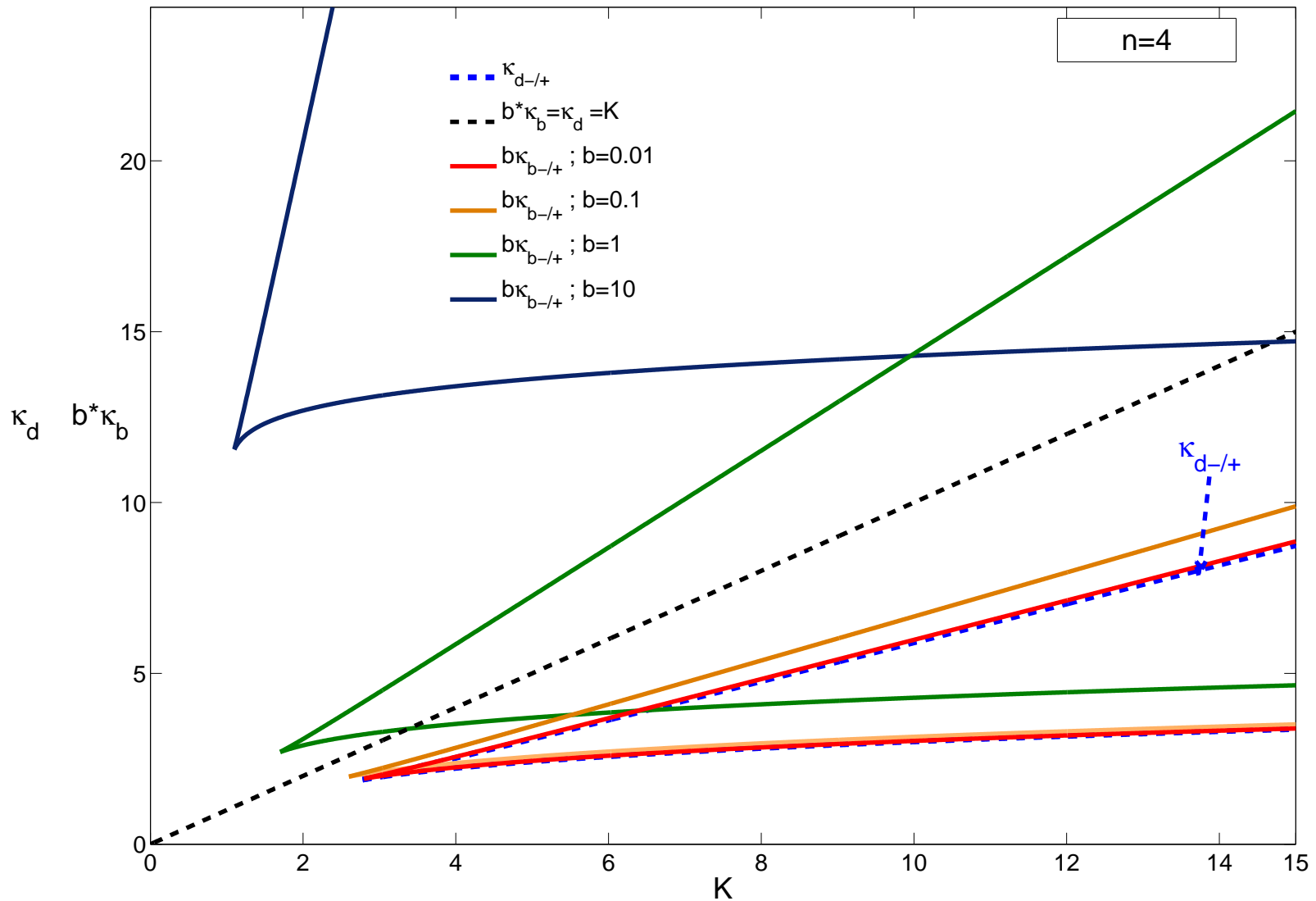
Stationary density as a function of κ_h



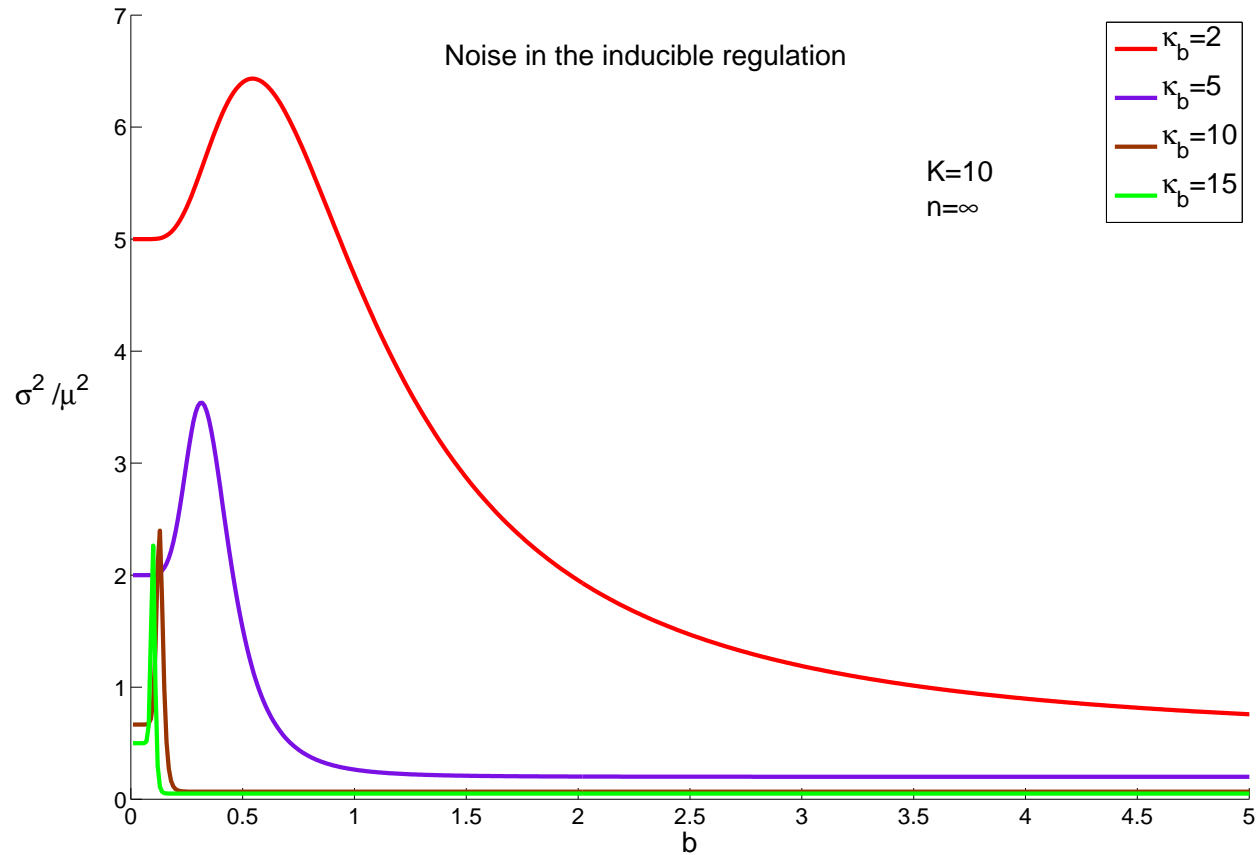


Effects of bursting

The presence of bursting can drastically alter regions of bistability



Noise induced by bursting



Extrinsic noise as a white noise process

- Replace the simple deterministic dynamics

$$\frac{dx}{dt} = -\gamma x + \gamma \kappa_d f(x)$$

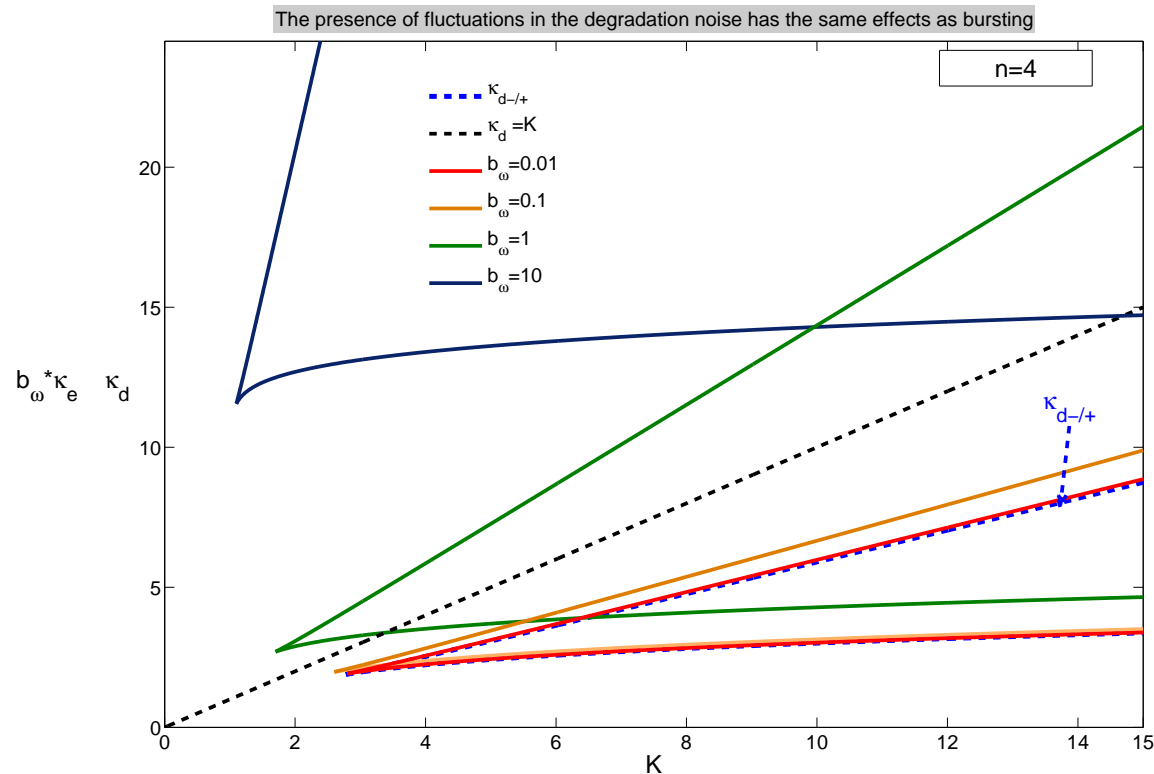
with

$$dx = [\gamma \kappa_d f(x) - \gamma x]dt + \sigma \sqrt{x}dw$$

where dw is a standard white noise process

Extrinsic noise \sim intrinsic noise

- Let replace the average burst amplitude b with $b \rightarrow \sigma^2/2\gamma \equiv b_w$ and $\kappa_b \rightarrow \kappa_e = 2\gamma\kappa_d/\sigma^2 \equiv \kappa_d/b_w$, then the stationary density in the case of extrinsic noise has the **same form** as in the case of intrinsic noise and the **same results** hold.



Conclusion

- Intrinsic noise and extrinsic noise are indistinguishable from the stationary density in this model.
- The stationary densities can be much more wider (and asymmetric) than a poissonian distribution.
- Noise-enhanced bistability.
- And noise-induced bistability when $n = 1$.
- When both noise are present, their effect sum up additively.

Problems and Further Studies

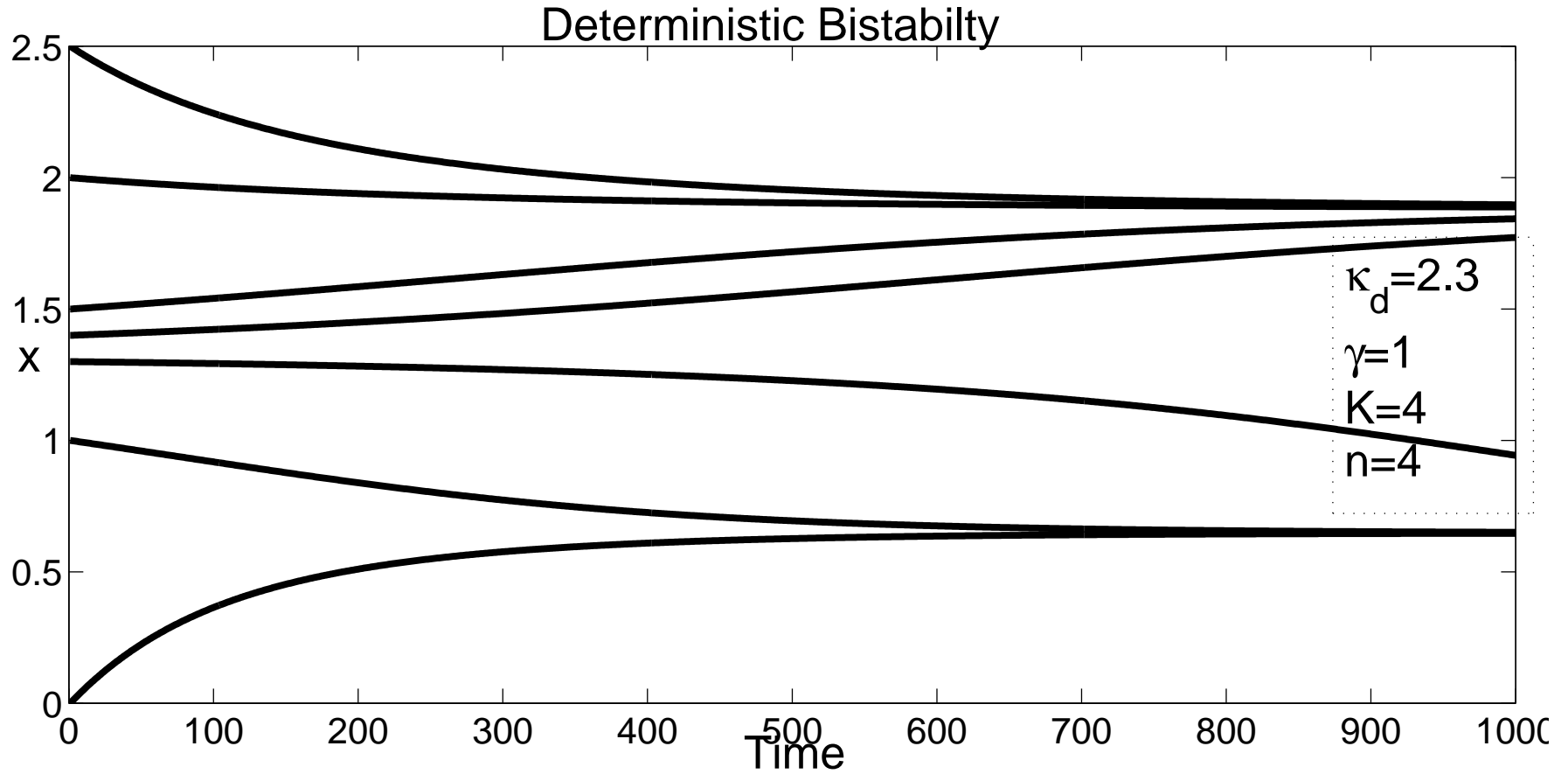
- Intrinsic noise should take into account transcriptional and/or translational delays.
- Extrinsic noise should take into account time correlations.
- Mean exit time and auto-correlation function should be derived to give more information on the dynamics out of equilibrium.
- The full three-stage model should be considered with noise.

Some References (Not exhaustive)

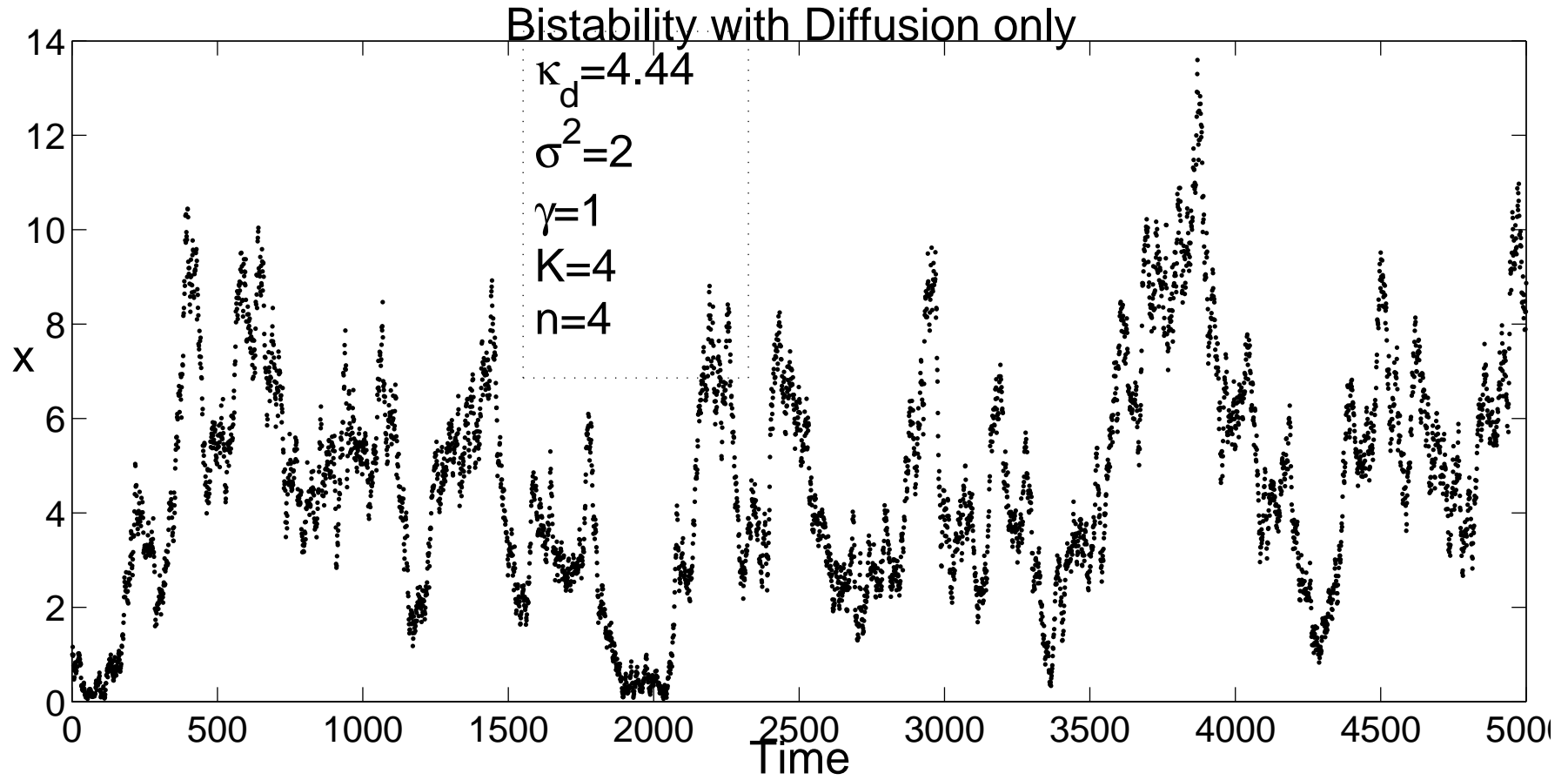
- *Dynamics and density evolution in piecewise deterministic growth processes*, M. C. Mackey and M. Tyran-Kamińska, Ann. Polon. Math., 94 (2008).
- *Linking Stochastic Dynamics to Population Distribution: An Analytical Framework of Gene Expression*, N. Friedman, L. Cai, and X. S. Xie, PRL 97 (2006).
- *Analytical distributions for stochastic gene expression V*. Shahrezaei and P. S. Swain, PNAS vol. 105 no. 45 (2008).
- *Colored extrinsic fluctuations and stochastic gene expression V*. Shahrezaei, J. F. Ollivier and P. S. Swain, Molecular Systems Biology 4:196 (2008)
- *Probing Gene Expression in Live Cells, One Protein Molecule at a Time* J. Yu. et al., SCIENCE 311 (2006).

- *Intrinsic and extrinsic contributions to stochasticity in gene expression* P. S. Swain, M. B. Elowitz, and E. D. Siggia, PNAS vol.99 no.20 (2002).
- *Stochasticity in Transcriptional Regulation: Origins, Consequences, and Mathematical Representations* T. B. Kepler and T. C. Elston, Biophys. J. 81(6) (2001).
- *Nature, Nurture, or Chance: Stochastic Gene Expression and Its Consequences* A. Raj and A. Van Oudenaarden, Cell 135, (2008).
- *Noise in Gene Expression: Origins, Consequences, and Control* J. M. Raser and E. K. O'Shea, Science 309:5743 (2005).
- *Intrinsic noise in gene regulatory networks* M. Thattai and A. Van Oudenaarden PNAS vol. 98 no. 15 (2001).

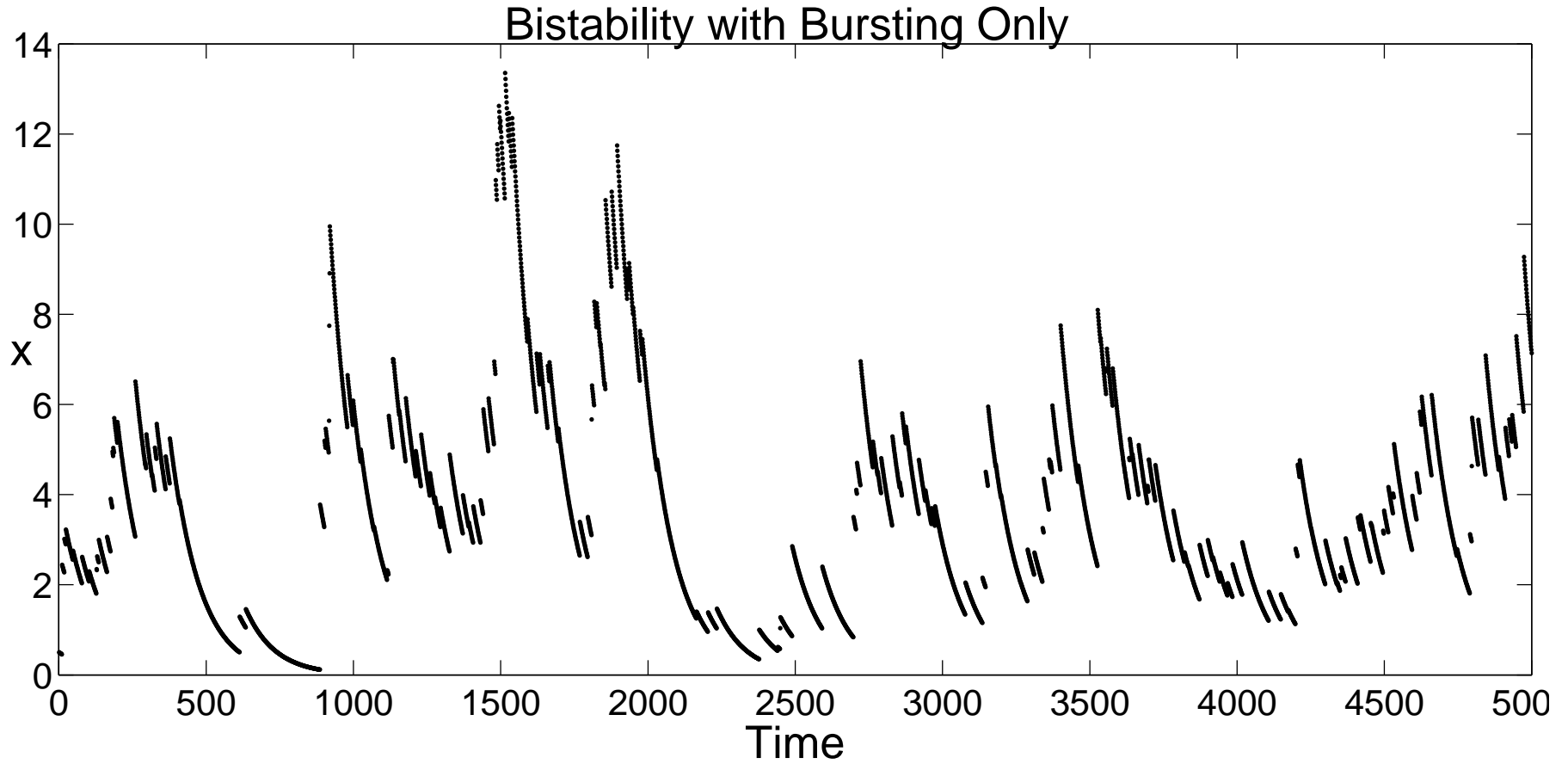
Sample paths



Sample paths



Sample paths



Sample paths

