Recurrence Quantification Analysis as a technique for SHARK-VIS

(Stangalini et al. 2018 ApJ, 868 6)

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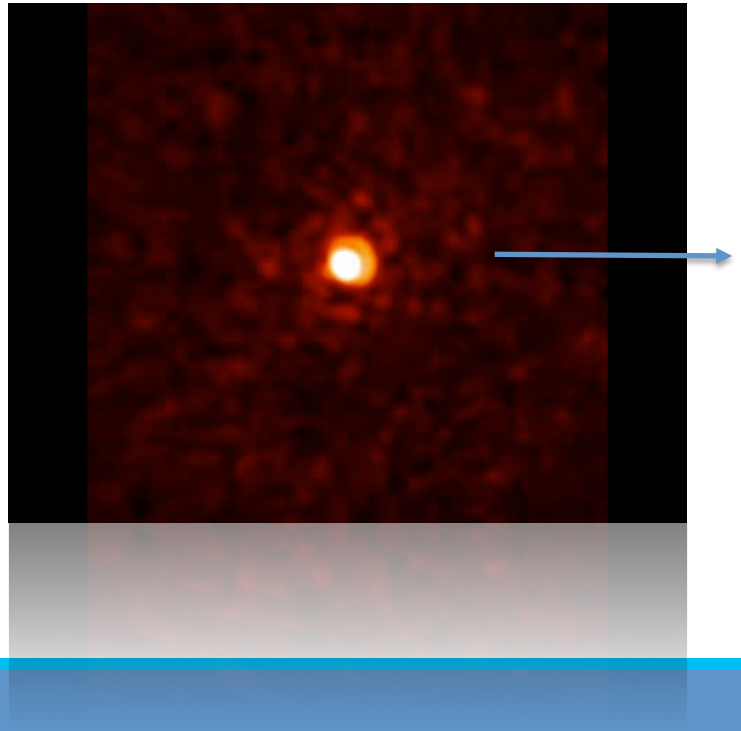
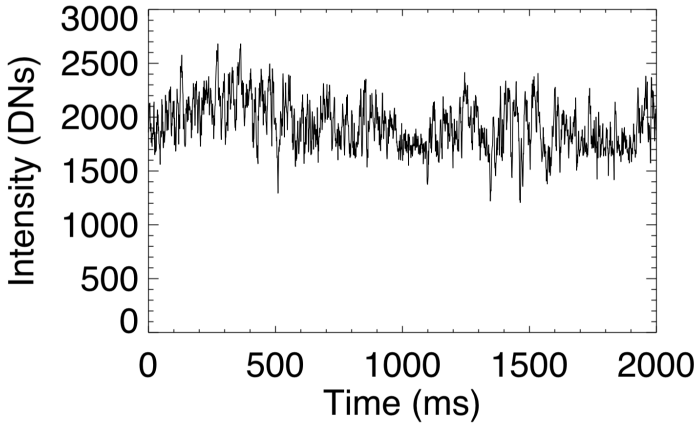
How much information is contained in 2 s of data?





Statistical discrimination of the planet signal

- Planet-Noise discrimination based on probability density functions
  (e.g. Labeyrie 1995, Canales & Caligal 1999, Gladysz et al 2010, Frazin 2016)

- More advanced techniques based on Receiver Operating Characteristics
  (Ruffio et al. 2017, Gomez Gonzalez et al. 2018)

RQA

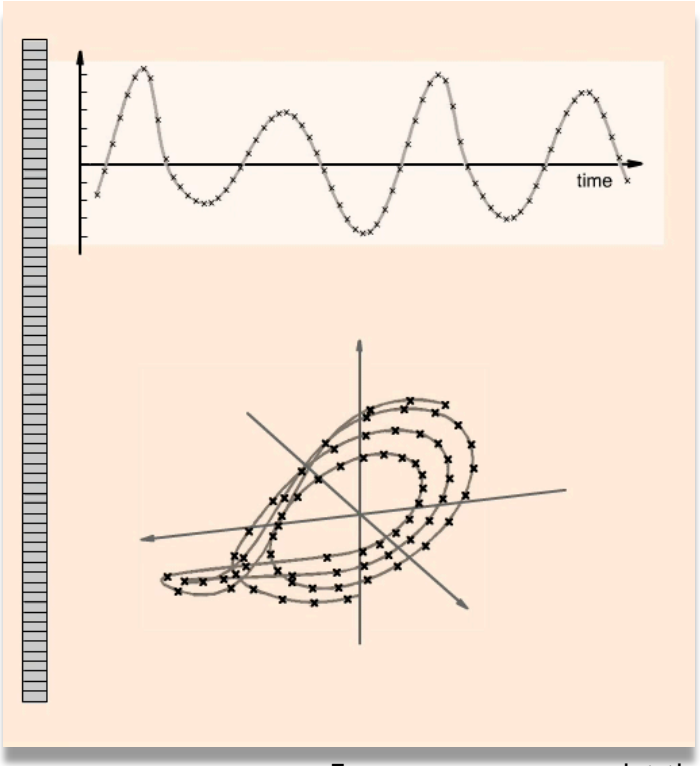
Statistical discrimination in the phase space:
recurrence plots and their quantification

RQA in a nutshell

- Dynamical systems are characterized by recurrent states (Poincaré 1890) —> regions of the phase space visited more than once

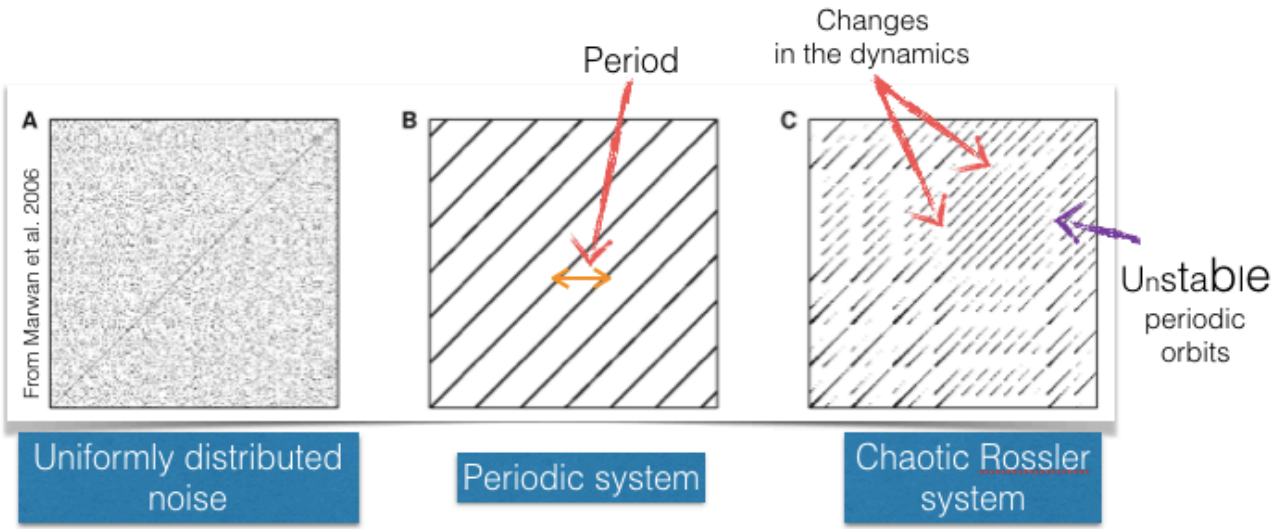
- A recurrence plot is a 2D diagram that visualizes recurrent states

- The phase space can be obtained from embedding the signal (N. Marwan, M. C. Romano, M. Thiel, J. Kurths: Recurrence Plots for the Analysis of Complex Systems, Physics Reports, 438(5-6), 237-329, 2007)



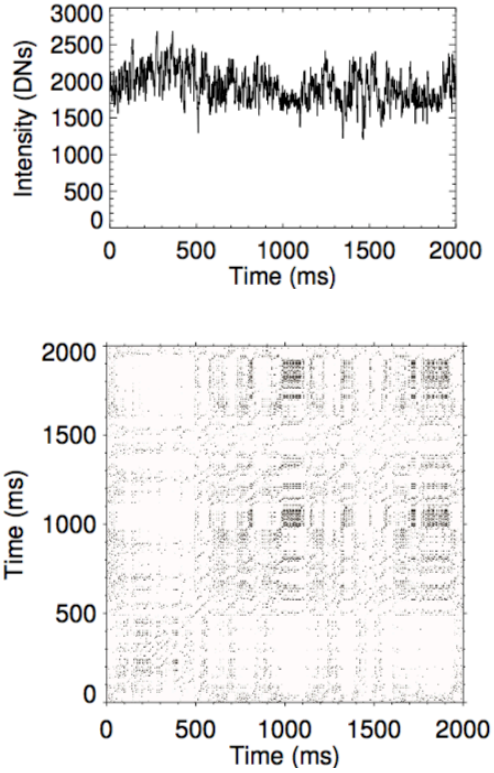
From www.recurrence-plot.tk

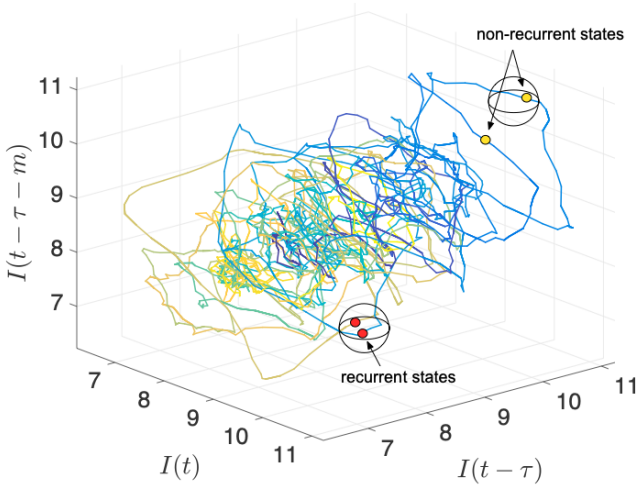
Recurrence plots (Eckmann 1987)



- ✓ Homogeneity —> Stationarity
- ✓ Disruptions —> States are rare, transitions
- ✓ Periodic patterns —> periodicities
- ✓ Diagonal lines —> Evolution of states similar (determinism)
- ✓ Vertical lines —> Some states do not change

Pixel dynamics: a superposition of different processes



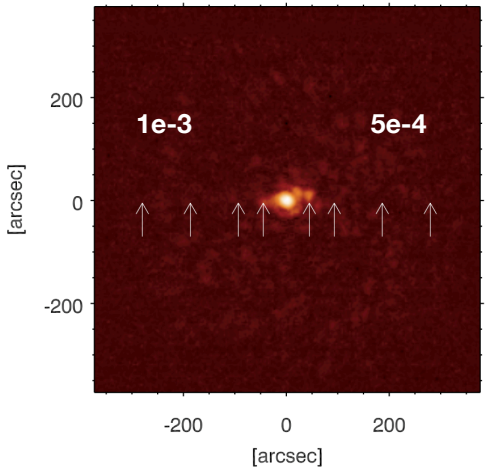


Embedding dimensions are chosen in such a way to maximize the final detection contrast

tau=10 ms

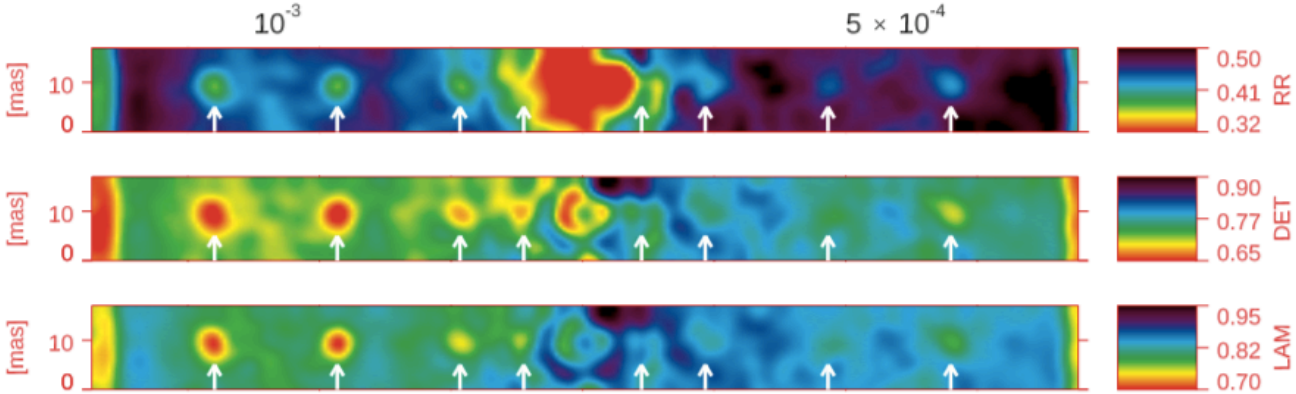
m=1 ms

RQA SHARK on Forerunner data

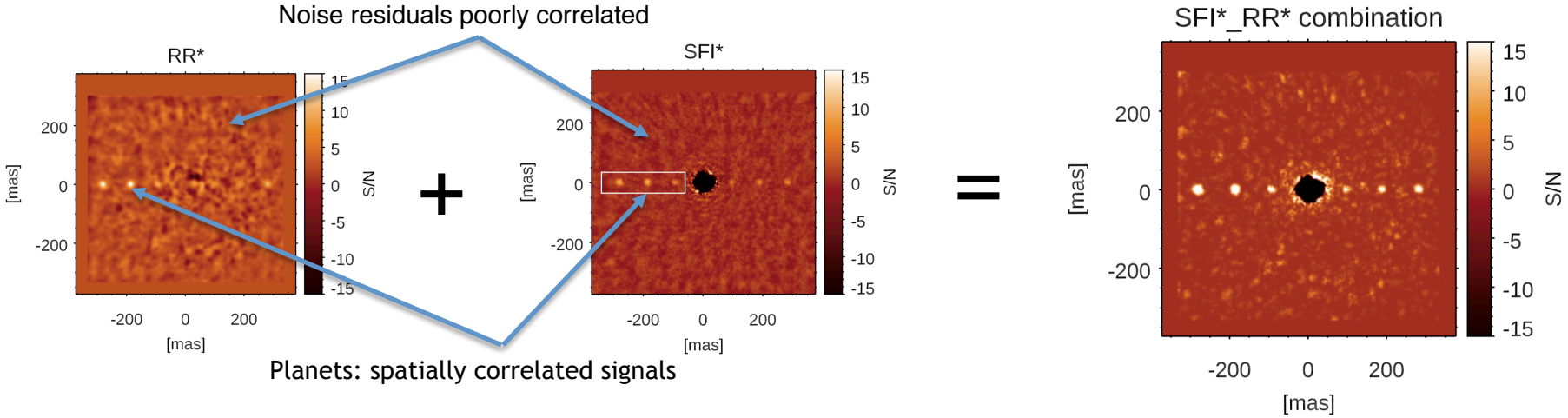


Faint sources are injected by rescaling the central object, thus following seeing evolution

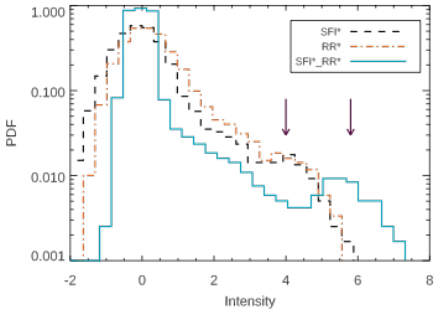
Similar to Pedichini+ (2017) and Li Causi+ (2017)



Combining SFI and RQA



Case	S/N 10^{-3} planets [σ]	S/N 5×10^{-4} planets [σ]
RR*	6.7	3.6
DET*	7.3	2.9
LAM*	8.3	3.4
SFI*	7.6	5.0
DET*-SFI*	64.0	15.6
LAM*-SFI*	72.5	17.5
RR*-SFI*	56.6	18.3



Significant **increase** of S/N up to a factor of **8-9**

- RQA appears to be an interesting method in the detection of small signals buried into noise
- It also works on extremely short data sequences
- Can be used in combination with other independent techniques (on the same data) to improve detection significance
- Ideally suited for photon-counting detectors (e.g. MKID@SCExAO, Mazin et al. 2015, Meeker et al. 2018)