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Data Analysis Research at The Waves Group: Old and New Directions

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The Waves Group

CALTECH, March 9th, 2005.

Plan

- ➡ Past work
- Current work
- More about us
- Conclusions

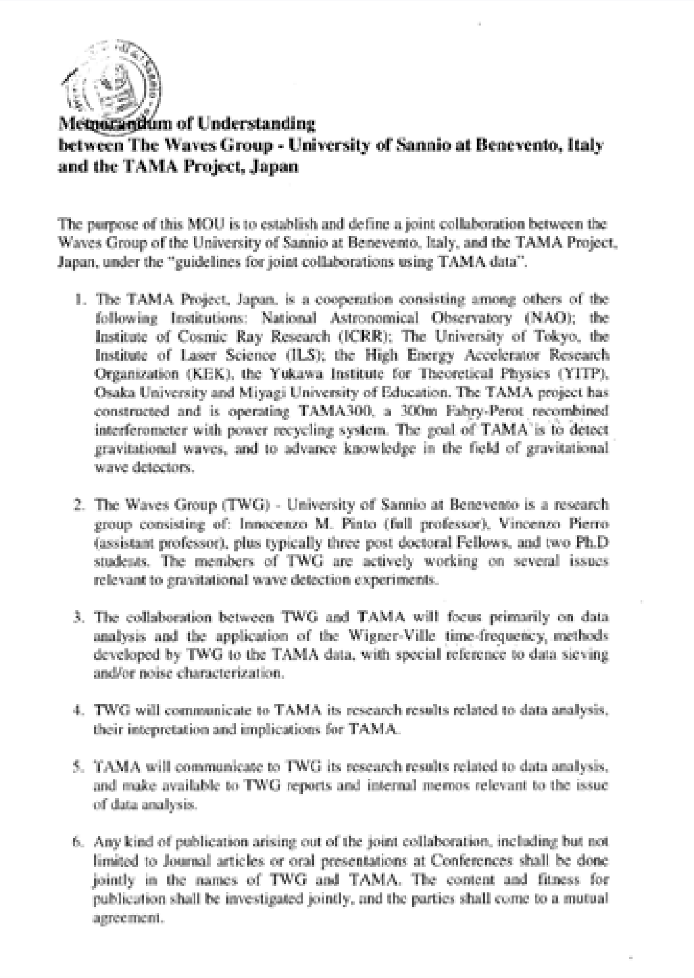
Past work

TAMA

- Time-frequency data analysis;
- Correlator bank economization;
- Tanaka-Tagoshi chirp parameterization;
- Cumulative distribution of bank supremum;
- Binary stars with large eccentricities;
- Radiation-pressure driven chaos in MPFP;
- Symmetry-breaking based detectors;

GW-related, last 10 years

MOU with TAMA (2000-)



Memorandum of Understanding
between The Waves Group - University of Sannio at Benevento, Italy
and the TAMA Project, Japan

The purpose of this MOU is to establish and define a joint collaboration between the Waves Group of the University of Sannio at Benevento, Italy, and the TAMA Project, Japan, under the "guidelines for joint collaborations using TAMA data".

1. The TAMA Project, Japan, is a cooperation consisting among others of the following Institutions: National Astronomical Observatory (NAO); the Institute of Cosmic Ray Research (ICRR); The University of Tokyo, the Institute of Laser Science (ILS); the High Energy Accelerator Research Organization (KEK), the Yukawa Institute for Theoretical Physics (YITP), Osaka University and Miyagi University of Education. The TAMA project has constructed and is operating TAMA300, a 300m Fabry-Perot recombined interferometer with power recycling system. The goal of TAMA is to detect gravitational waves, and to advance knowledge in the field of gravitational wave detectors.

2. The Waves Group (TWG) - University of Sannio at Benevento is a research group consisting of: Innocenzo M. Pinto (full professor), Vincenzo Pierro (assistant professor), plus typically three post doctoral Fellows, and two Ph.D students. The members of TWG are actively working on several issues relevant to gravitational wave detection experiments.

3. The collaboration between TWG and TAMA will focus primarily on data analysis and the application of the Wigner-Ville time-frequency, methods developed by TWG to the TAMA data, with special reference to data sieving and/or noise characterization.

4. TWG will communicate to TAMA its research results related to data analysis, their intepretation and implications for TAMA.

5. TAMA will communicate to TWG its research results related to data analysis, and make available to TWG reports and internal memos relevant to the issue of data analysis.

6. Any kind of publication arising out of the joint collaboration, including but not limited to Journal articles or oral presentations at Conferences shall be done jointly in the names of TWG and TAMA. The content and fitness for publication shall be investigated jointly, and the parties shall come to a mutual agreement.

7. Each party in this agreement continues to be responsible for all support of its own staff, including travel costs associated with the activities under this agreement.

8. This Memorandum of Understanding will remain in force until the parties mutually agree to terminate it. Annual Attachments will define specific activities to be carried out during the following year, and list the members of TWG who will participate in the planned cooperation activities.

Approved:

Yoshihide Kozai
Yoshihide Kozai
TAMA Principal Investigator

Pietro Perlingieri
President, University of Sannio

神田展行
Nobuyuki Kanda
TAMA Data Analysis Group Leader

Innocenzo M. Pinto
The Waves Group Principal Investigator

Date Feb. 9, 2000

Date 10 Feb. 2000

Five Things We Always Wanted to Know About … *Correlator-Bank ML GW-Chirp Detection/Estimation* …but Were Afraid to Ask

Q1 - What is the best (if any) correlator ***interpolation*** scheme [Dhurandhar, Sathyaprakash, Schutz] ?

A1 - Cardinal (Shannon-Kotel'nikov) expansion uses near to absolute minimum number of templates needed for a prescribed minimal-match. Total template number reduction is ≅ 30% at Γ=0.97 (newtonian case). Statistical properties preserved [Phys. Rev., D62, 124020 (2000)].

Q2 - Does cardinal interpolation work with PN templates ? What is the computational gain then ?

A2 - Extension to 1PN order straighforward. Template number reduction is ≅ 75% at Γ=0.97 . [Phys. Rev., D62, R121101 (2000); w. Sathya, also LIGO J3337<033 dqg J33354<033 '1

Q3 - How does this extend to ***post-1PN*** models, where the match does ***not*** depend on the source-template parameter ***differences only*** ?

A3 - Extension to highest available PN order chirp models feasible using globally-flat Tanaka-Tagoshi (spin-free) parametrization. 1PN results confirmed [Phys. Rev., D64, 042005, 2001, ibid., D64, 087101 (2001)].

Q4 - How does cardinal interpolation work at relatively ***low*** minimal match levels ? How to place the templates for this case ?

A4 - Tanaka-Tagoshi parametrization allows to construct optimal (***maximally sparse,regular***) lattices at ***any*** prescribed match level. Cardinal interpolation can work at low match levels too (with slightly lesser gains). [Phys. Rev. D65, 102003 (2002)].

Q5 – R*igorous* characterization of ML detector/estimator including covariance among correlators: how does this affect minimal-match prescription ?

A5 – R*igorous* generalization of Mohanty's formula developed and tested. Votes for hierarchidal.
ŠWrr p dq|õ whp sodwhv p ljkweh xqz ruwk1 ^Sk|v Uhy1G:3/455334 +5337,1`

Past work, contd.

TAMA MOU related (2000)-

Correlator bank economization

Main results: *explicit correlator-interpolation formula getting close-to-theoretical-minimum number of correlators for a prescribed minimal match.*

R. P. Croce, Th. Demma, V. Pierro, I. M. Pinto, D. Churches, B. S. Sathyaprakash, "*Gravitational wave chirp search: Economization of post-Newtonian matched filter bank via cardinal interpolation*", Phys. Rev. **D62**, 121101R (2000).

R. P. Croce, Th. Demma, V. Pierro, and I. M. Pinto, F. Postiglione, "*Nearly Minimum redundant correlator interpolation formula for gravitational wave chirp detection*", Phys. Rev. **D62**, 124020 (2000).

The Match as a QBL Function

$$f_B(x)=\mathcal{F}^{-1}_{y\to x}\left\{W\left(\frac{y}{B}\right)\cdot\mathcal{F}_{x\to y}[f(x)]\right\},$$

$$W(x)=\begin{cases}1, & |x|\leqslant 1,\\ 0, & |x|>1.\end{cases}$$

$f_B(x)$ has the *exact* representation

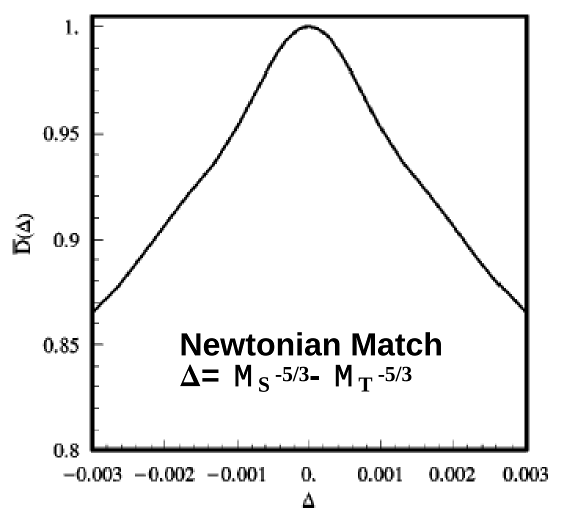
$$f_B(x)=\sum_{n=-\infty}^{\infty} f(x_n)\,\mathrm{sinc}\left[\frac{\pi}{\delta}(x-x_n)\right],$$

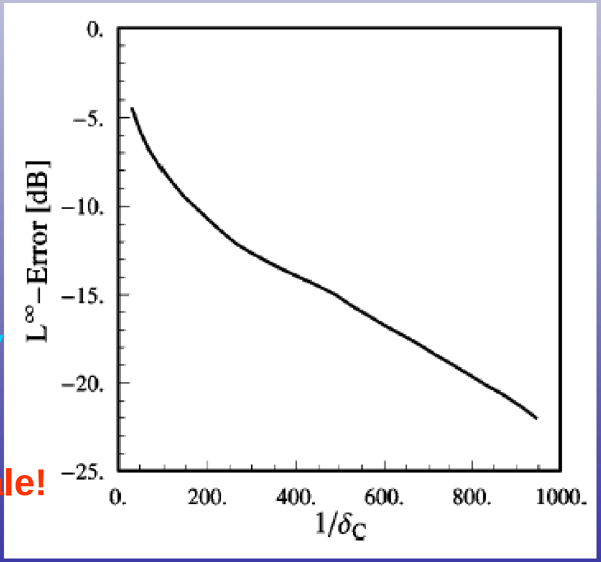
with: $x_{n+1}-x_n=\delta,\quad \delta=\frac{1}{2B}.$

$f(x)$ is QBL iff $\exists\ \gamma, B_c\in\mathcal{R}^+$:

$$\sup_{x\in[a,b]}|f(x)-f_B(x)|=\exp[-\gamma(B-B_c)]$$

$$\Rightarrow\ \forall\epsilon>0,\ \exists\ B:\quad \sup_{x\in[a,b]}|f(x)-f_B(x)|<\epsilon$$





Log scale!

Past work, contd.

Tanaka-Tagoshi chirp parameterization

Main results: *recipe for constructing uniform & maximally sparse PN≥2 order template lattice for any prescribed minimal match.*

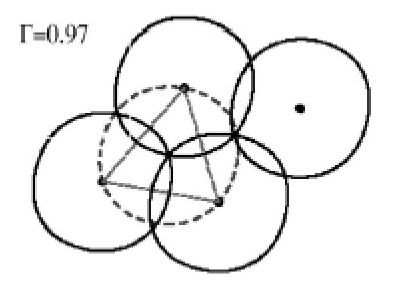
R. P. Croce, Th. Demma, V. Pierro, I. M. Pinto, *"Tanaka-Tagoshi parameterization of post-1PN spin-free gravitational wave chirps: Equispaced and cardinal interpolated lattices for first generation interferometric antennas"*, Phys. Rev. **D64**, 042005 (2001).

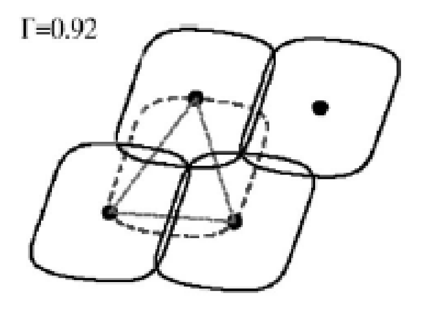
R. P. Croce, Th. Demma, V. Pierro, I. M. Pinto, *"More on the Tanaka-Tagoshi parameterization of post-1PN spin-free gravitational wave chirps: Equispaced and cardinal interpolated lattices"*, Phys. Rev. **D64**, 087101 (2001).

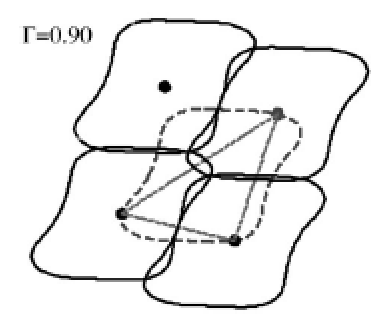
R. P. Croce, Th. Demma, V. Pierro, I. M. Pinto, *"Optimum placement of post-1PN gravitational wave chirp templates made simple at any match level via Tanaka-Tagoshi coordinates"*, Phys. Rev. **D65**, 102003 (2002).

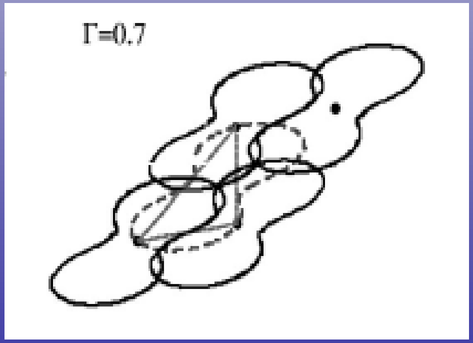
Past work, contd.

Optimum tiling in Tanaka-Tagoshi coordinates









NOTE: Different scalings used!!

Past work, contd.

TAMA MOU related, 2003-

Cumulative distribution of correlator bank supremum (ML detection statistic).

Main results: *accurate approximate representation of whole-bank supremum CDF including covariance among nearby correlators.*

R. P. Croce, Th. Demma, M. Longo, S. Marano, V. Matta, V. Pierro, I.M. Pinto, *"Gravitational wave chirp search: no-signal cumulative distribution of the maximum likelihood detection statistic"*, CQG, **20**, S803 (2003).

R. P. Croce, Th. Demma, M. Longo, S. Marano, V. Matta, V. Pierro, I.M. Pinto, *"How many templates for GW chirp detection? The minimal-match issue revisited"*, CQG, **21**, 4995 (2004).

R. P. Croce, Th. Demma, M. Longo, S. Marano, V. Matta, V. Pierro, and I.M. Pinto, *"Correlator bank detection of gravitational wave chirps: False-alarm probability, tempLate density, and thresholds: Behind and beyond the minimal-match issue"*, Phys. Rev. **D70**, 122001 (2004).

Past work, contd.

Cumulative distribution of ML detection statistic etc.

[Ph.Rev. D70, (2004); CQG 20, S803 (2003); CQG 21, 4955 (2004)]

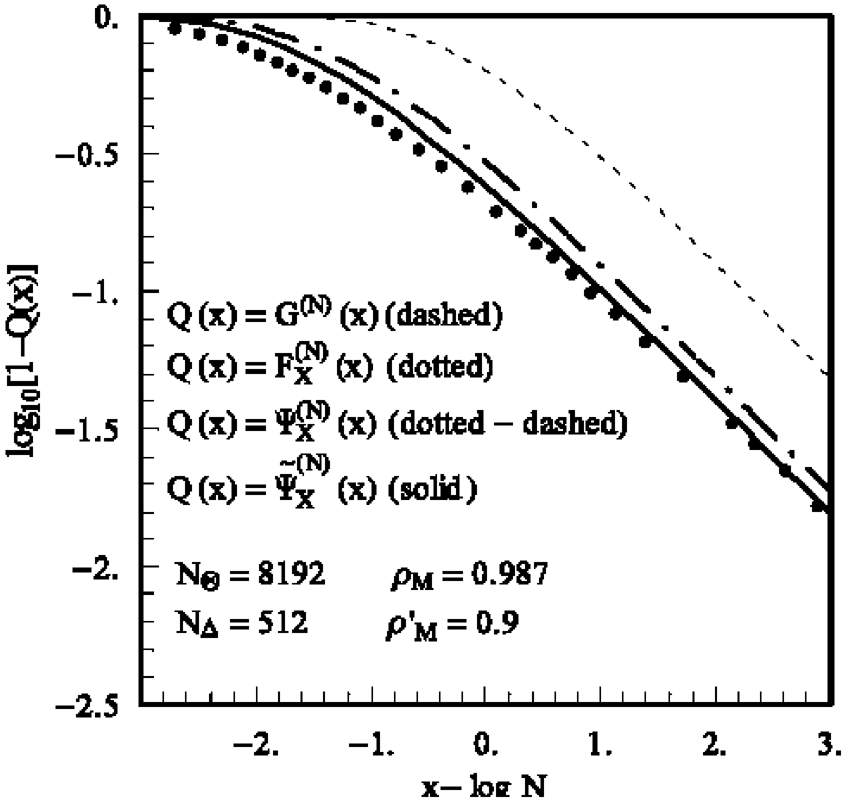


FIG. 5. Comparison among several approximants for the cumulative distribution of the whole-bank supremum vs $x - \log N$. Numerical simulation: 10^4 realizations.

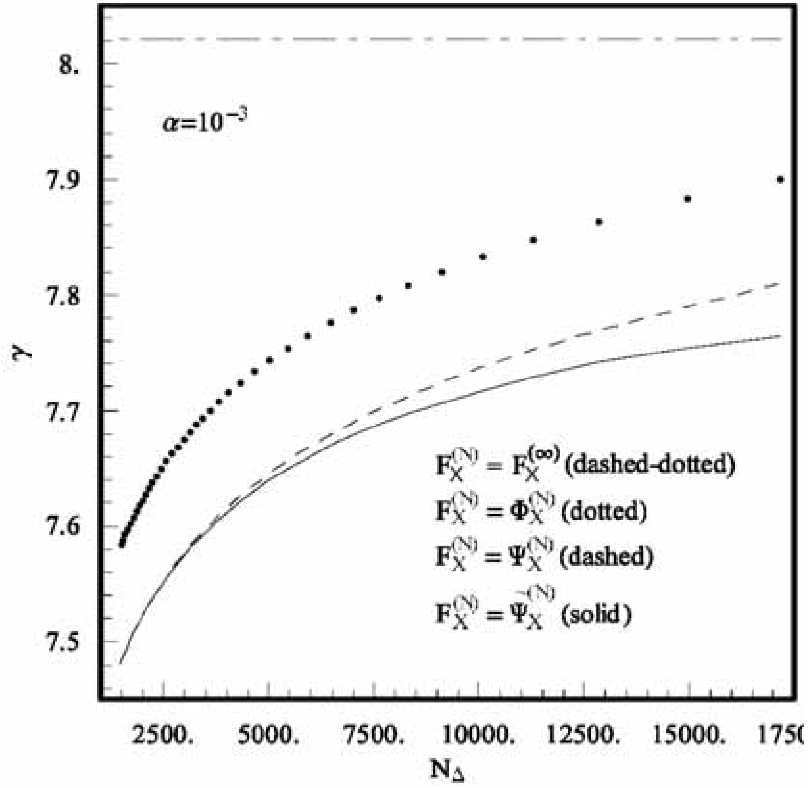


FIG. 6. Detectable fraction η [Eq. (3.8), solid lines] of potentially observable sources at various false-alarm levels, vs the number of reduced templates N_Δ. Dashed line: crudest estimate [Eq. (3.9)]. Inset: close-up of the knee region. Search range $0.2\mathcal{M}_\odot \leq \mathcal{M} \leq 10\mathcal{M}_\odot$, $N_\Theta = 2^{21}$, Newtonian waveforms, Ligo-I noise.

Past work, contd.

Cumulative distribution of ML detection statistic

[Ph.Rev. D70, (2004); CQG 20, S803 (2003); CQG 21, 4955 (2004)]

Fraction of potentially observable sources to go undected due to insufficient minimal match

$$\eta = \frac{N_s}{N_s^{(\max)}} = \left(\frac{\Gamma}{\Gamma_{\max}}\right)^3 \left(\frac{\gamma(\alpha, N_{\max})}{\gamma(\alpha, N)}\right)^3$$

Crudest estimate (ignore dependence of threshold on N, and hence in turn on MM):

$$\eta = \left(\frac{\Gamma}{\Gamma_{\max}}\right)^3$$

Note knee region in curves !

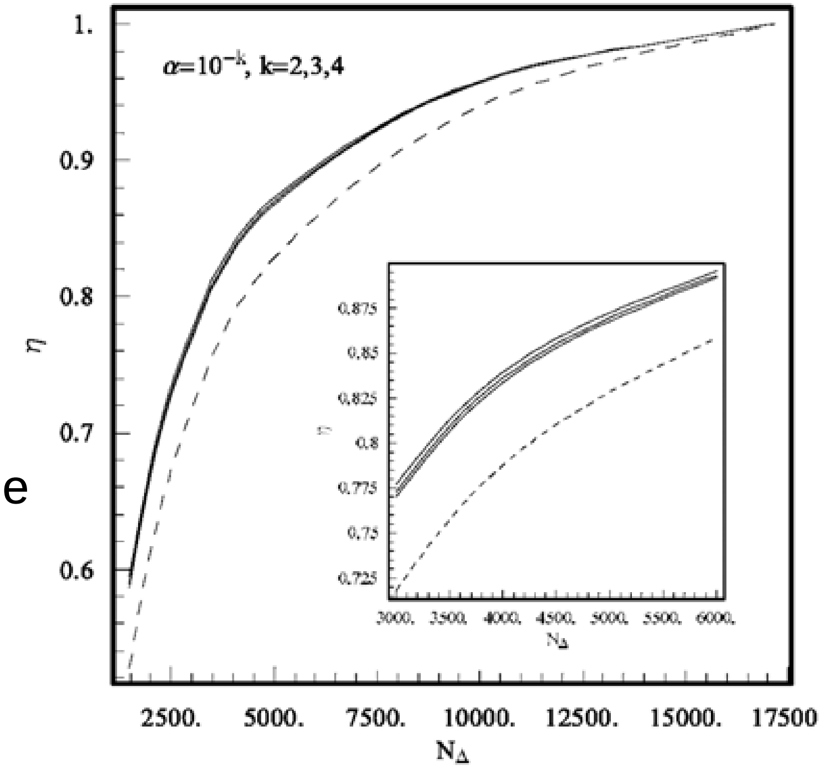


FIG. 7. Detection threshold γ corresponding to $\alpha = 10^{-3}$ obtained from different models of the no-signal cumulative distribution of the whole-bank supremum vs the number of reduced templates N_Δ. Search range $0.2\mathcal{M}_\odot \leq \mathcal{M} \leq 10\mathcal{M}_\odot$, $N_\Theta = 2^{21}$, Newtonian waveforms, Ligo-I noise.

Past work, contd.

TAMA MOU related, 2000-

Time-frequency data analysis

Main results: *parametric (chirps, Hough-Radon estimator) and non-parametric (bursts, 2D Kolmogorov-Smirnov test) fast/robust data sieving, based on Wigner-Ville time-freq. representation.*

M. Feo, V. Pierro, I.M. Pinto, M. Ricciardi, *"Efficient GW chirp detection and estimation via time-frequency analysis and edge detection"*, Proceedings MG- VII, T. Jantzen et al. Eds., World Scientific, 1994, pp. 1986-1090.

M. Feo, V. Pierro, I.M. Pinto, M. Ricciardi, *"Efficient GW chirp estimation via Wigner-Ville representation and generalized Hough transform"*, in Gravitational Waves, F. Fidecaro ed., World Scientific, 1997, pp. 291-294.

\+ *Work done for TAMA (yet unpublished))*

Past work, contd.

TF data analysis – Theoretical Background

PWV surface statistics for (piecewise) stationary Gaussian whitened noise well understood/modeled

→ Key to effective (2D) KS-based Proc.s for identifying unmodeled odds;

PWV transform of GW chirp well understood/modeled (incomplete Airy function) under *extremely broad* assumptions, i. e.

$$\dot{\omega} > 0, \ddot{\omega} \neq 0, \omega_0 T_c >> 1$$

→ Key to effective tayloring of WV transform for identifying chirps;

Past work, contd.

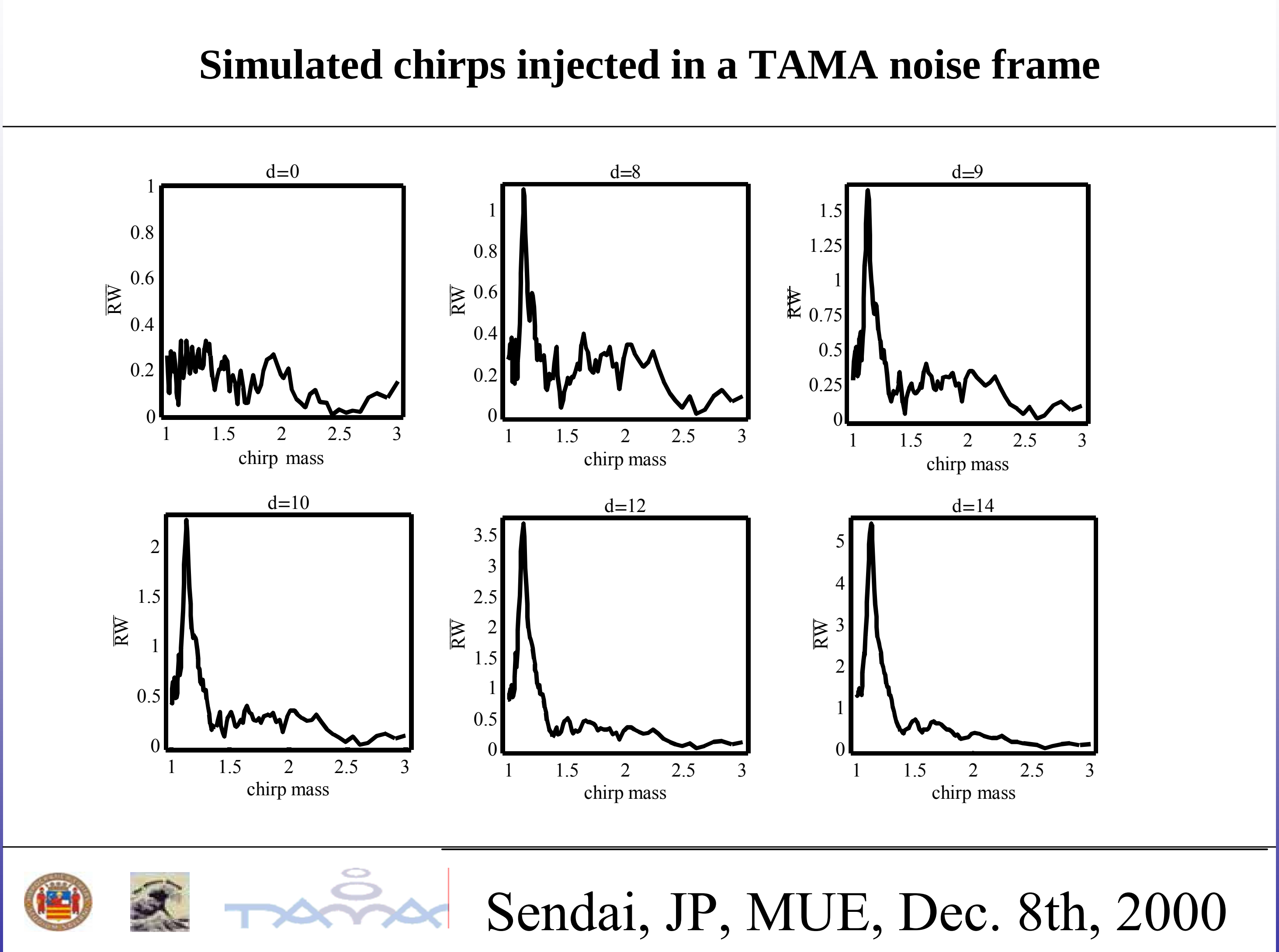
TF data analysis – Background, contd.

0-multiplication algorithm for dispatching WV TF data into (discrete) 0PN parameter space (Radon transform). Approximate implementation of Moyal Formula.

- Trades *power* for *robustness;*
- Trades *faithfulness* for *effecualness;*
- On the fly chirp detection/estimation!

DSP implementation might hold a promise toward real-time data sieving

Past work, *contd.*



Simulated chirps injected in a TAMA noise frame

Sendai, JP, MUE, Dec. 8th, 2000

Past work

Binary stars with large eccentricity

Main results: *fast/accurate GW waveform representations for highly elliptical binaries, including spectral truncation error formulae.*

V. Pierro and I.M. Pinto, *"Exact solution of Peters Mathews equations for any orbital eccentricity",* Nuovo Cimento **B111**, 631, 1996.

V. Pierro and I.M. Pinto, *"Steady state pupulation statistics of compact binary stars",* Astrophys. J., **469**, 272, 1996.

V. Pierro, I. M. Pinto, A. D. Spallicci, E. Laserra and F. Recano, *"Fast and accurate computational tools for gravitational waveforms from binary stars with any orbital eccentricity"*, MNRAS, **325**, 358 (2001).

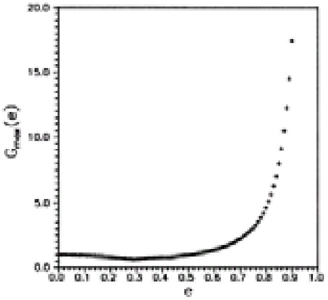
Binary stars with large eccentricity

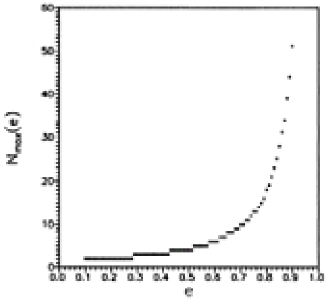
Past work

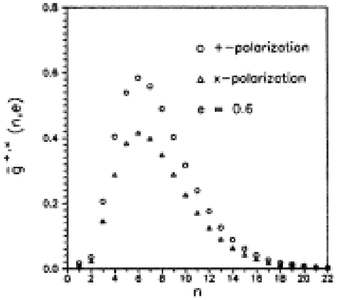
"Universal" Luminosity Spectra

$$\mathcal{L}_n^{+,\times} = \frac{2G}{5c^5}\chi^{-10/3}(1-\Delta^2)^2 G_{\max}(e)\bar{g}^{+,\times}(n,e),$$

$$\chi = (cT/\pi r_g),\ \Delta = |M_1 - M_2|/(M_1+M_2)$$







Waveforms

$$h_{xy} = \sum_{n=1}^{\infty} h_{xy}^{(n)} \sin\left(n\frac{2\pi}{T}t\right),$$

$$h_{x\pm y} = \sum_{n=1}^{\infty} h_{x\pm y}^{(n)} \cos\left(n\frac{2\pi}{T}t\right),$$

$$\begin{cases} h_{xy}^{(n)} = h_0 n(1-e^2)^{1/2}[J_{n-2}(ne) + J_{n+2}(ne) - 2J_n(ne)], \\ h_{x-y}^{(n)} = 2h_0 n\{J_{n-2}(ne) - J_{n+2}(ne) - 2e[J_{n-1}(ne) - J_{n+1}(ne)] + (2/n)J_n(ne), \\ h_{x+y}^{(n)} = -4h_0 J_n(ne), \quad h_0 = \dfrac{cT}{4\pi r}\dfrac{1-\Delta^2}{\chi^{5/3}}. \end{cases}$$

Spectral truncation problem

$$\mathrm{THD} = \left(1 - \frac{\sum_{n=1}^{N_T} |h^{(n)}|^2}{\sum_{n=1}^{\infty} |h^{(n)}|^2}\right)^{1/2}. \quad \mathrm{FF} \sim 1 - \frac{\mathrm{THD}^2}{2}.$$

Closed form (Kapteyn series)

Efficient computation problem

$$J_{n\pm k}(ne),\ 0 \le k \le 2,\ e \le 1$$

Gen.zed Carlini-Meissel Expansion

Past work, contd.

Symmetry-breaking based detectors

[Stochastic Resonance, etc]

Main results: *performance never better than std. MF, but much cheaper and robust; wider class of SBB detectors (Kac poly.s) under investigation.*

R. P. Croce, Th. Demma, V. Galdi, V. Pierro, and I. M. Pinto, F. Postiglione, *"Rejection properties of stochastic-resonance-based detectors of weak harmonic signals",* Phys. Rev. **E69**, 062104 (2004).

V. Galdi, V. Pierro, and I. M. Pinto, *"Evaluation of stochastic-resonance based detectors of weak harmonic signals in additive white Gaussian noise"*, Phys. Rev. **E57**, 6470 (1998).

Past work, contd.

Symmetry-breaking based detectors - SR

Langevin equation w. SWG noise & sinusoidal forcing

$$\dot{x} = -\frac{d}{dx} V(x) + A \sin(\omega_s t + \phi) + \epsilon n(t) \ ,$$

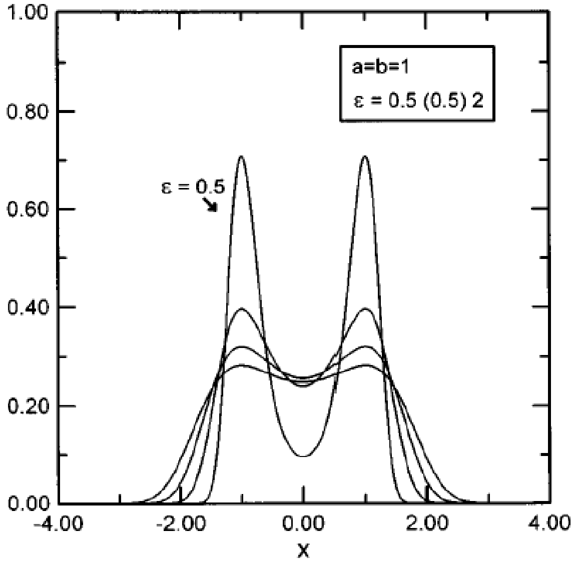
$$x(0) = x_0$$

Double-well quartic potential:

$$V(x) = -a \frac{x^2}{2} + b \frac{x^4}{4}, \quad a, b > 0$$

Average noise-induced hopping time between potential wells (A=0)

$$T_K = \frac{2}{\epsilon^2} \left| \int_0^{x_m^{\pm}} dy \ \exp[2V(y)/\epsilon^2] \int_{-\infty}^{y} \exp\left[-2V(z)/\epsilon^2\right] dz \right|$$



PDF of *x* (*A*=*0*)

Past work, contd.

Symmetry-breaking based detectors

Strobed signum counting: $N_+ = \sum_{k=0}^{2N-1} U(x_k),$

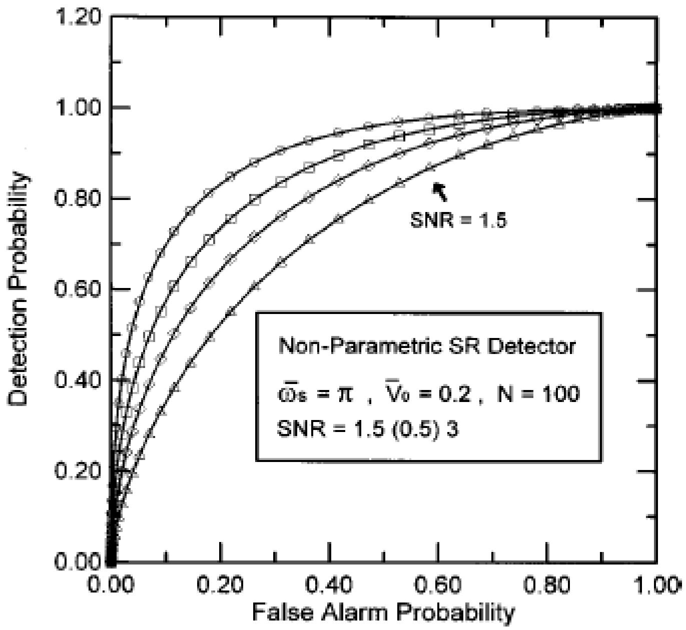


FIG. 11. Receiver operating characteristics of the nonparametric SR detector.

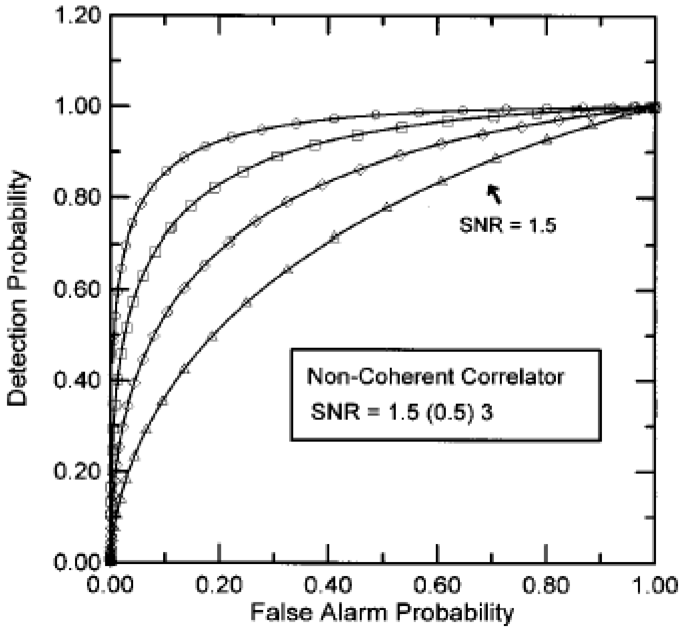


FIG. 12. Receiver operating characteristics of the NCC.

Past work, contd.

Radiation-pressure driven chaos in Multi-Pendular Fabry-Perots

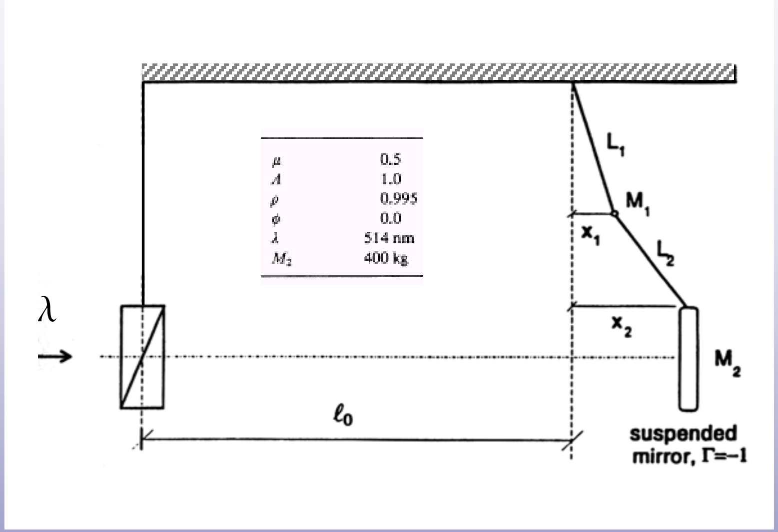
Main results: *Chaotic dynamics and multistability in freely swinging multipendular FP due to radiation pressure nonlinearity w.r.t. mirror position.*

V. Pierro, I.M. Pinto, *"Radiation pressure induced chaos in multipendular Fabry-Perot resonators",* Phys. Lett. **A185**, 14 (1994); ibid. **A193**, 493 (1994).

Past work, contd.

Radiation-pressure Driven Chaos in Multi Pendular Fabry-Perots

[Phys. Lett A185,14 (1994), ibid. A193, 493 (1994).]



Scaled vars. and pars.: $\xi_i = \frac{x_i}{\lambda}, \quad \bar{t} = \left(\frac{g}{L_2}\right)^{1/2} t, \quad \Lambda = \frac{L_2}{L_1}, \quad \mu = \frac{M_2}{M_1+M_2}, \quad \Pi = \frac{2P}{cM_2 g},$

Cavity storage time short w.r.t. pendular per $\Omega \frac{F}{\pi}\frac{l}{c} \ll 1,$

[Opposite a.c.t. Aguirregabiria, Bel, Deruelle & Tourrenc, Ann. Phys. 10, 241 (1985); Phys. Rev. A36, 3768, 1987]

Treat as Hamiltonian over times << pendular damping times:

$$\mathscr{H} = \frac{1}{2}\left(\frac{\mu}{1-\mu}\eta_1^2 + \eta_2^2\right) + \frac{1}{2}\frac{\mu+\Lambda}{\mu}\xi_1^2 - \xi_1\xi_2 + \tfrac{1}{2}\xi_2^2 + \mathscr{U}_{\mathrm{rad}}(\xi_2), \quad \eta_1 = \frac{1-\mu}{\mu}\dot{\xi}_1, \quad \eta_2 = \dot{\xi}_2$$

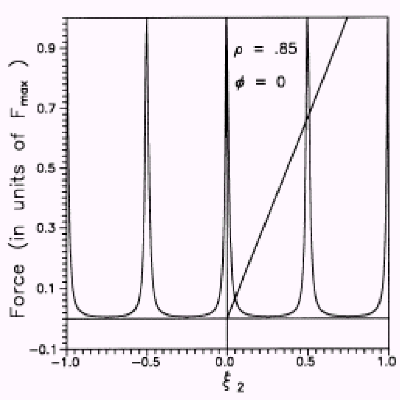
$$\mathscr{U}_{\mathrm{rad}}(\xi_2) = \frac{\Pi}{2\pi}\,\mathrm{atn}\left(\frac{1-\rho}{1+\rho}\cot(2\pi\xi_2 + \tfrac{1}{2}\phi)\right), \quad \phi = \frac{4\pi}{\lambda}(l_0 - l_k) \in [-\pi, \pi],$$

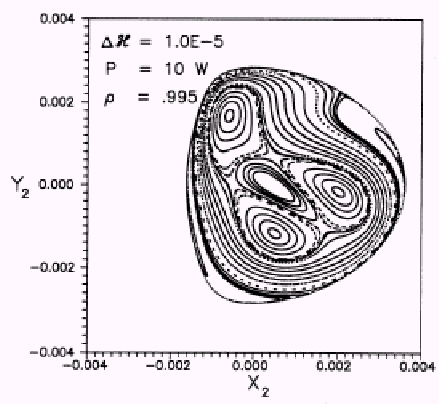
Radiation-force potential; FP detuning parameter

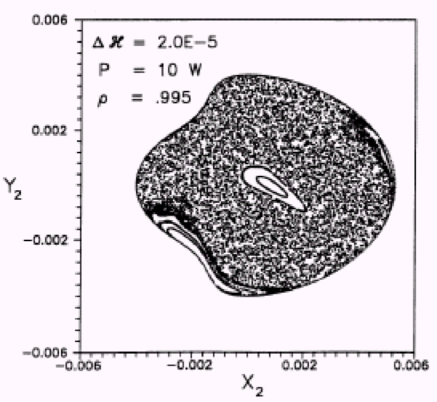
Linearize at (stable) eq. pos. $\begin{pmatrix}\xi_1 - \xi_1^{(\mathrm{eq})} \\ \xi_2 - \xi_2^{(\mathrm{eq})}\end{pmatrix} = \begin{pmatrix}\beta_1(1+\mathscr{U}_{\mathrm{eq}}^{(2)} - \Omega_1^2) & \beta_2(1+\mathscr{U}_{\mathrm{eq}}^{(2)} - \Omega_2^2) \\ \beta_1 & \beta_2\end{pmatrix}\begin{pmatrix}q_1 \\ q_2\end{pmatrix},$

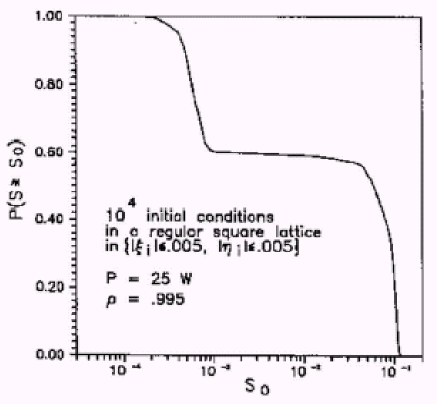
$$\beta_i = \left(\frac{1-\mu}{\mu}(1+\mathscr{U}_{\mathrm{eq}}^{(2)} - \Omega_i^2)^2 + 1\right)^{-1/2} \quad \Omega_{1,2}^2 = \frac{1}{2}\left\{\frac{1+\Lambda}{1-\mu} + \mathscr{U}_{\mathrm{eq}}^{(2)} \pm \left[\left(\frac{1+\Lambda}{1-\mu} + \mathscr{U}_{\mathrm{eq}}^{(2)}\right)^2\right.\right.$$

Use corresponding normal coordinates: $X_i = (\tfrac{1}{2}\Omega_i)^{1/2} q_i, \quad Y_i = (1/2\Omega_i)^{1/2} p_i,$









Plan

Past work

➡ Current work

More about us

Conclusions

Current work

Sequential detection

SIRP modeling of IFO noise

Signum-coded data

Sequential Detection

The Rationale:

Looking for *almost endless* signals (e.g., PSRs) with unknown strength, using *fixed size* data may be *not* the best choice.

A. Wald, *Sequential Analysis*, Dover, NY, 1947.

A.G. Tartakovski, I.A. Ivanova, Prob. Inf. Transm., **28**, 55, 1992

S. Marano, V. Matta, P. Willett, IEEE Trans. **SP-51**, 385, 2003.

Sequential Detection, contd.

-Define *current* log-likelihood ratio,

PDF of n-th sample, signal ON (known)

$$\Lambda_n = \Lambda_{n-1} + \ln\left(\frac{f(x_n|H_1)}{f(x_n|H_0)}\right) \quad , \quad \Lambda_0 = 0,\ n = 0,1,2,\ldots$$

PDF of n-th sample, signal OFF (known)

-Compare *current* log-likelihood ratio to *two* thresholds.

False-alarm prob. (prescribed)

$$\gamma_0 = \ln\frac{\beta}{1-\alpha}, \gamma_1 = \ln\frac{1-\beta}{\alpha}$$

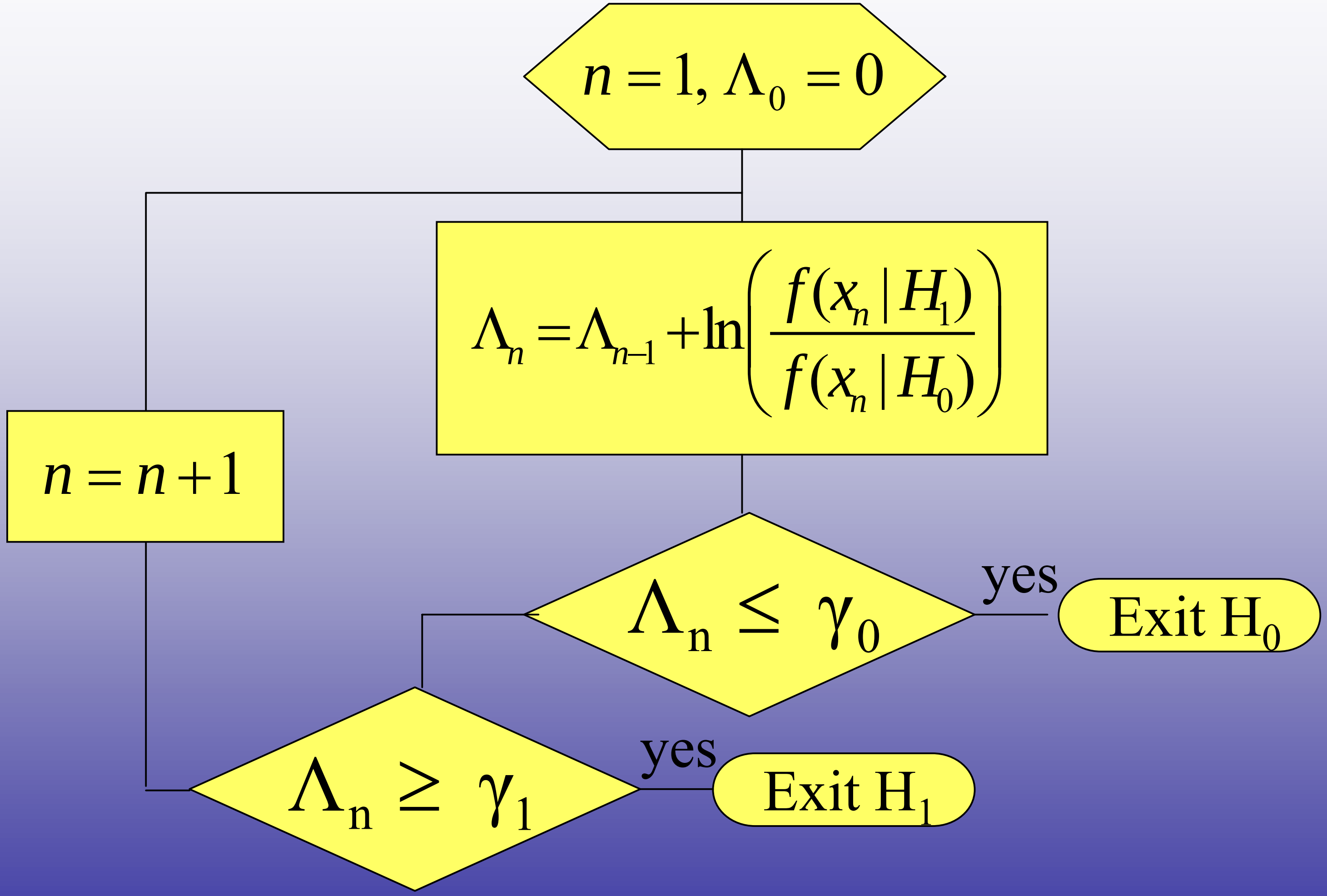
False-dismissal prob. (prescribed)

-Exit *iff* $\Lambda \leq \gamma_0 \ (\Rightarrow H_0)$ or $\Lambda \geq \gamma_1 \ (\Rightarrow H_1)$; otherwise $n \rightarrow n+1$

NO signal detected

signal detected

Sequential Detection, contd.



$n=1,\ \Lambda_0=0$

$$\Lambda_n=\Lambda_{n-1}+\ln\left(\frac{f(x_n\,|\,H_1)}{f(x_n\,|\,H_0)}\right)$$

$n=n+1$

$\Lambda_n \le \gamma_0$

yes

Exit H_0

$\Lambda_n \ge \gamma_1$

yes

Exit H_1

Sequential Detection, contd.

-Test ends at some (*random*) *n=N* (stopping time);

-CDF of *N* *is known* [Tartakovski & Ivanova, 1992];

-*Key* features:

matched filter

$E_{0,1}(N) < N_{MF}$, for *the same* α, β;

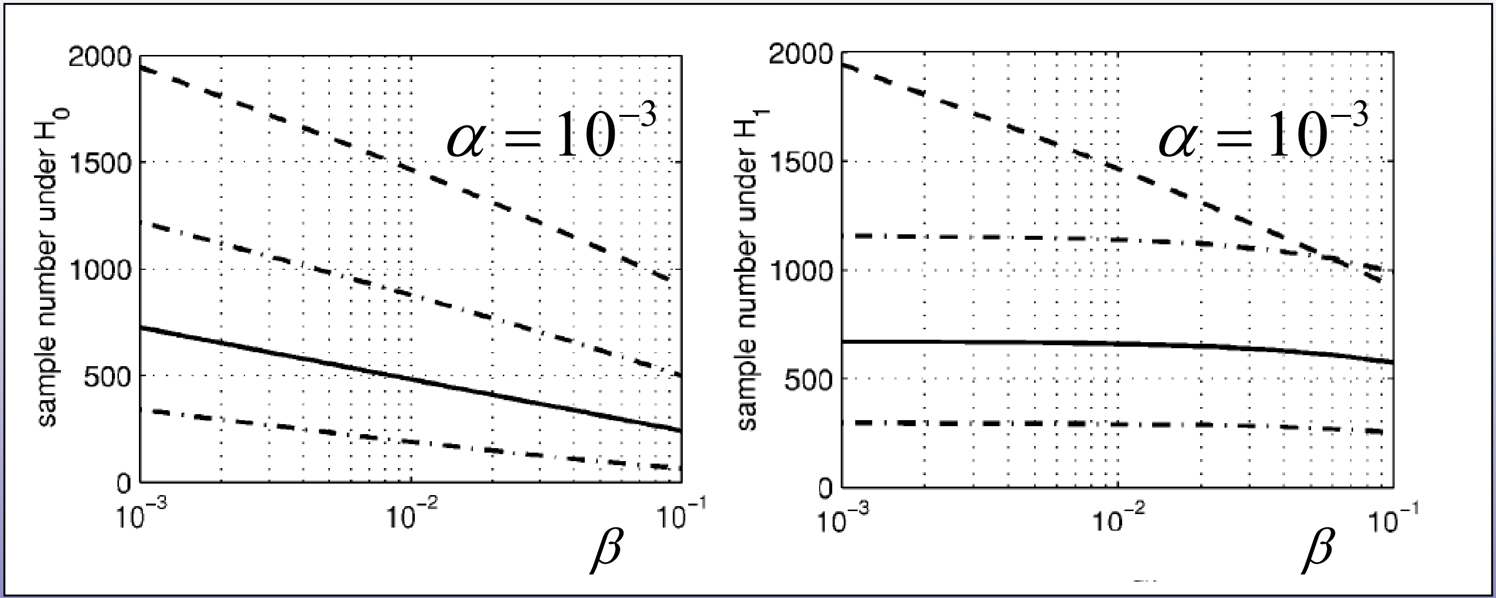
$$VAR_{0,1}(N) \sim \gamma_{0,1} \frac{VAR_{0,1}(\ell)}{E^3_{0,1}(\ell)}, \quad \ell = \ln\left(\frac{f(x|H_1)}{f(x|H_0)}\right)$$

benefits

- -*Shorter ave. time* required for H_0/H_1 decision;
- -*Dynamic re-allocation* of computational resources allowed in template-bank (ML) search;
- -*Straightforward* implementation

Sequential Detection, contd.

Shorter ave. time required for H_0 /H_1 decision



Dashed line: std. MF; solid line: average ST stopping time;
Dashed-dotted line: ST stopping time 10th and 90th percentiles.

S. Marano, V. Matta, P. Willett, IEEE Trans. **SP-51**, 385, 2003.

Sequential Detection, contd.

All-sky, all-frequency PSR search

Extended ML philosophy:

-All correlators implemented *sequentially*;

Decision rule:

- H_1 : *one* correlator exits with H_1
- H_0 : *all* correlators exit with H_0

As test goes on, more correlators exit with H_0

→ **computational resources dynamically re-allocated**

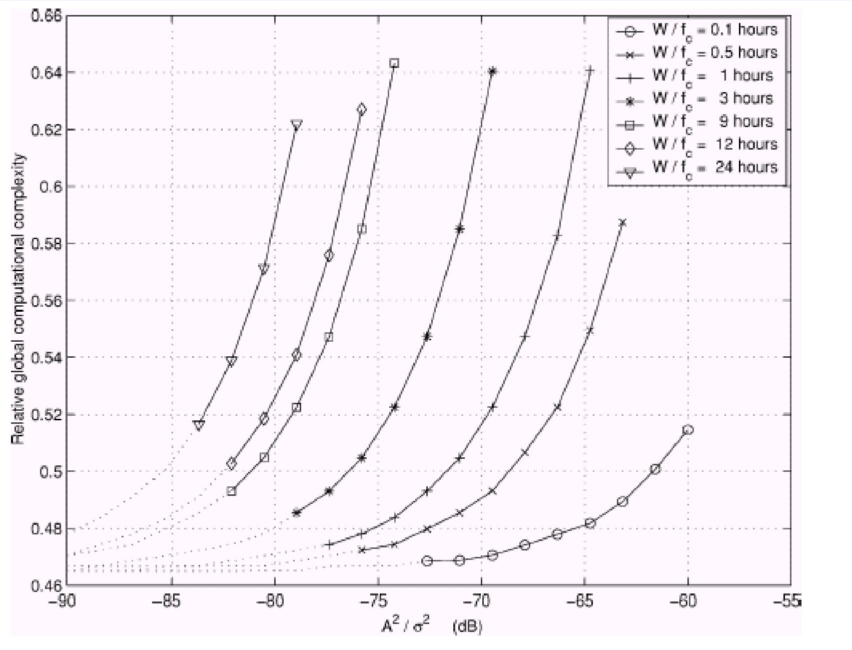
Preliminary formulation

V. Matta, thesis, University of Salerno, 2001;

S. Marano, V. Matta, P. Willett, IEEE Trans. **SP-51**, 385, 2003.

Sequential Detection, contd.

All-sky, all-frequency PSR search, contd.



Detection statistic from incoherently combined STFT (various sizes shown).

Comput. cost reduction sequential vs MF bank as a function of local (single STFT) SNR.

Continuous lines become dashed at T=5 years

V. Matta, thesis, University of Salerno, 2001;

S. Marano, V. Matta, P. Willett, IEEE Trans. **SP-51**, 385, 2003.

SIRP Modeling of IFO noise

Motivation

Real-world IFO noises non-stationary/non-gaussian;

Noise models needed to formulate (locally) optimum detection strategies [B. Allen et al., Phys. Rev. D65 122002 (2002); ibid. D67 122002 (2003)];

SIRP noise models [A..M. Vershik, Th. Prob. And its Appl., 9, 353, 1964 (in russian)] describe a wide class of NS/NG noises [D. Middleton, IEEE Tr. EMC-14, 12, 1972. M. Rangaswamy, et al., IEEE Tr. AES-29, 111, 1993];

Structure of (locally) optimum detector in SIRP is known. [E. Conte et al., IEEE Trans. COM-43, 47, 1995.]

SIRP Modeling of IFO noise, cont.d

Facts

IFO noise (power lines & clicks removed) looks as a (*slowly*) *breathing*-gaussian:

$$\underbrace{n(t)}_{\text{compound gaussian}} = \overbrace{s(t)}^{\text{slowly fluctuating}} \cdot \underbrace{y(t)}_{\text{gaussian}}$$

- *Short* data chunks are still gaussian. *But* variance fluctuates randomly among different chunks (*stationarity lost*).
- *Long* series *not* gaussian (*gaussianity lost*, *but* eventually *stationarity recovered*).

SIRP Modeling of IFO noise, cont.d

SIRP defined

Assume noise variance does *not* fluctuate across a typical time span *T*.

Each and any chunk of data with size *N* (i.e, duration *T*) can be written (*k*=chunk index)

$$s \cdot y^{(N)}_k, \quad k = 1, 2, \ldots$$

random **variable**

gaussian N-vector

SIRP noise: different chunks can be regarded as Different *realizations* corresponding to *different values* of *s* drawn from *the same* distribution.

SIRP Modeling of IFO noise, cont.d

Assume sought signals *shorter* than *T* (fluctuation scale of noise variance)

Possible Strategies

Adopt std. MF, and compute *threshold* from *locally estimated* noise variance (GLRT, heuristic)

Neyman Pearson strategy: *condition* likelihood ratio under H_0 and H_1 w.r.t. to random *s*, and *weight resulting detection statistic* using known (SIRP!) PDF of *s* .

Resulting detector: ***canonical*** and ***CFAR*** *optimum*
[Conte et al., IEEE Trans **CT-43**, 47 (1995)]

SIRP Modeling of IFO noise, cont.d

Testing & characterizing (white) SIRPs

SIRP noise m-tuples $(m \leq N)$ share the following unique properties :

- The related m-tuples $\vec{\xi}_m = \vec{x}_m / \left| \vec{x}_m \right|$ fill *uniformly* the unit-radius m-sphere;

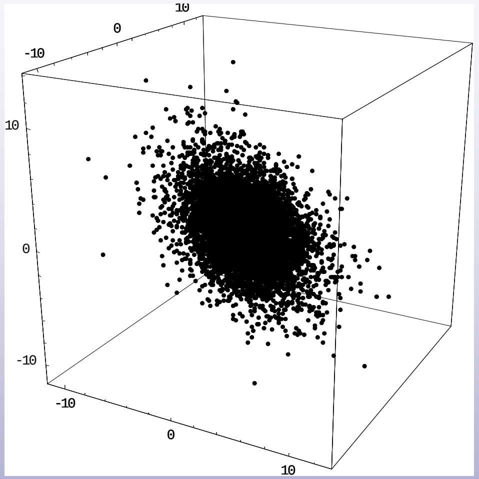
- The related m-tuples $\rho_m = \left| \vec{x}_m \right|$ are distributed according to

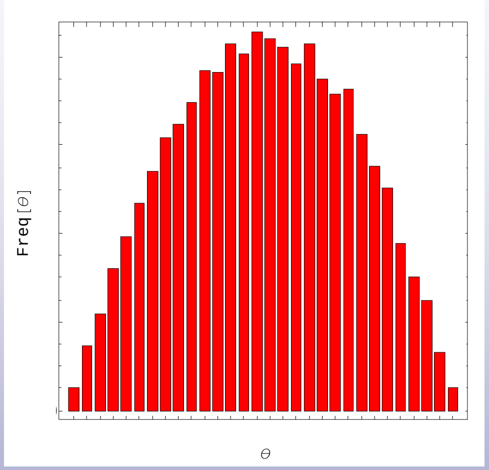
$$f_\rho(\rho) = \frac{2^{1-m/2} \rho^{m-1}}{\Gamma(m/2)} \int_0^\infty s^{-N} \exp\left(-\frac{\rho^2}{2\lambda^2} \right) f_s(s) ds$$

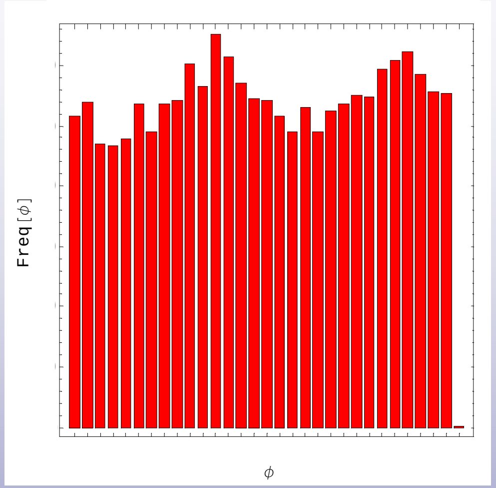
$f_s(s)$ bein the PDF of s (the *breathing factor*).

SIRP Modeling of IFO noise, cont.d

EVIDENCE (TAMA300 DT2-R012)



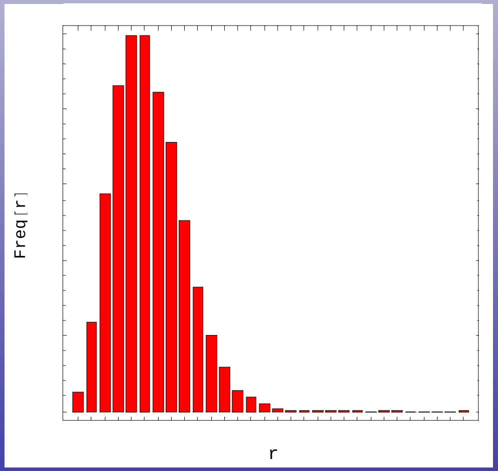




Top left: 3D scatter plot (data triples);

Top mid & right: distribution (histogram) of polar angles θ and ϕ (spherically uniform, SIRP hallmark);

Bottom right: distribution (histogram) of polar radius . Should be Rayleigh if noise were gaussian.



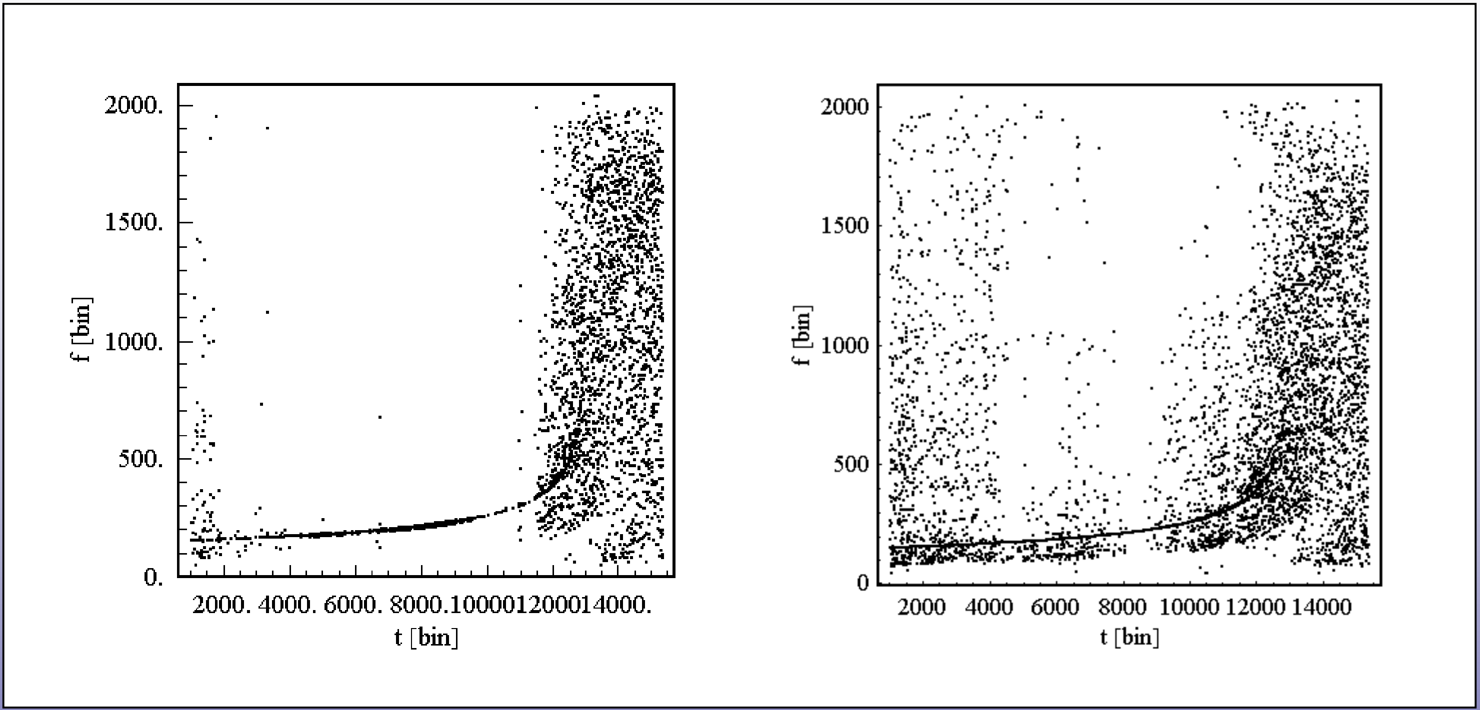
Signum-Coded (1 bit) data

1-bit data coding (signum-coding) entails *huge savings* in storage *and* CPU budget.

Performance degradation predicted and observed [J.H. Miller, J.B. Thomas, IEEE Tr. **COM-25**, 687, 1977.]

Trades off with improved robustness w.r.t. poorly modeled noise features [S.A. Kassam, IEEE Tr. **IT-22**, 22, 1976]

Signum-Coded data, contd.



Thresholded equalized Wigner-Ville t-f image. 2PN (MACHO) chirp in TAMA-DT2 noise, d=24. Left: full data; right: signum-coded (1 bit) data [R.P. Croce, PhD thesis, Univ. of Salerno, *2001*]

Signum-Coded data, contd.

Gaussian noise *mixture*

$$n(t) = \alpha\, n_1(t) + (1-\alpha)\, n_2(t),$$

$$n_i(t) = N(0, \sigma_i^2), \quad 0 \le \alpha \le 1$$

Detection statistics

$$S_{MF} = \sum_k y_k s_k$$

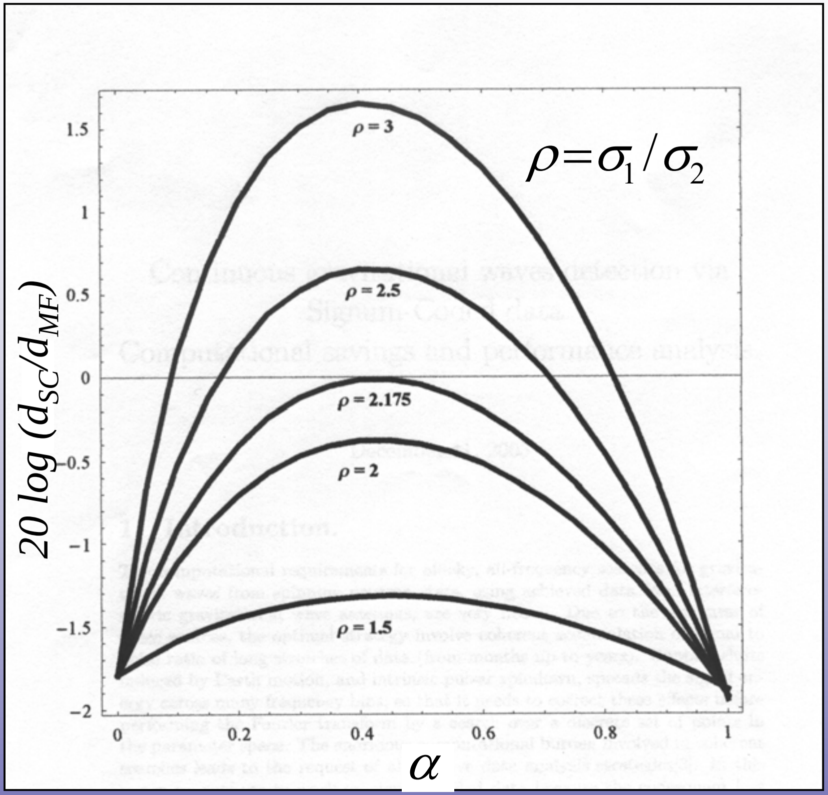
template

data

$$S_{SC} = \sum_k \mathrm{sgn}(y_k)\,\mathrm{sgn}(s_k)$$

Performance-index:

$$d = \frac{\mu_S(H_1) - \mu_S(H_0)}{\sqrt{[\sigma_S^2(H_1) + \sigma_S^2(H_0)]/2}}$$



Signum coded detector vs. standard Matched-Filter in additive gaussian mixture. [R.P. Croce et al., in progress].

Plan

Past work

Current work

➡ More about us

Conclusions

More about us

Faculty:

Innocenzo M. Pinto (professor, Sannio U.)
Maurizio Longo (professor, Salerno U.)
Vincenzo Pierro (associate prof., Sannio U.)
Vincenzo Galdi (associate prof., Sannio U.)
Stefano Marano (associate prof., Salerno U.)
Vincenzo Matta (assistant prof., Salerno U.)

PostDoc:

Rocco P. Croce (Sannio U.)
Theo Demma (Sannio U.)

The Waves Group

www.thewavesgroup.unisannio.it


Pierro


Galdi


Marano


Matta


Croce


Demma

More about us, contd.

More about us, contd.

University of Salerno
www.unisa.it

University of Sannio at Benevento
www.unisannio.it
(a branch of Salerno Univ. until 1998)

40.000 students, 9 Faculties

6.000 students, 4 Faculties

Salerno University Campus

Sannio University Buildings

More about us, contd.

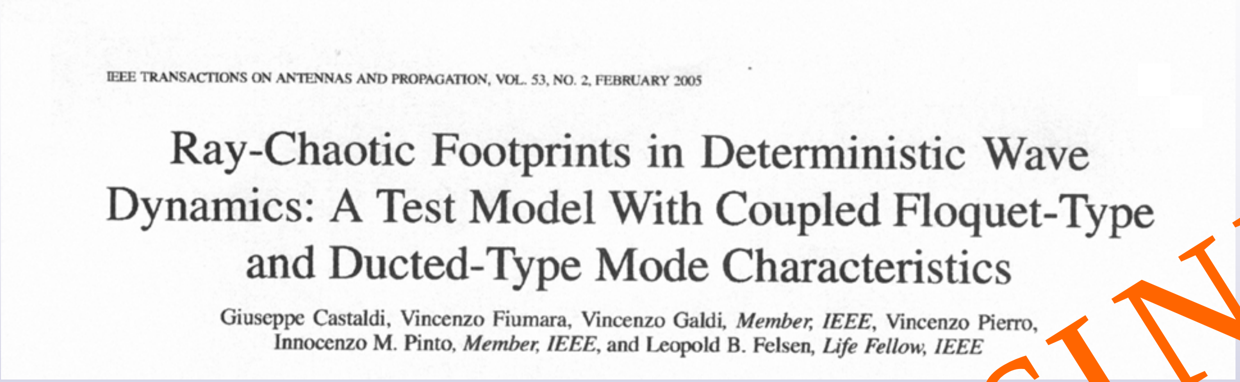
C. BRADASCHIA, R. DEL FABBRO, A. DI VIRGILIO, A. GIAZOTTO, H. KAUTZKY, V. MONTELATICI, D. PASSUELLO, A. BRILLET, O. CREGUT, P. HELLO, C.N. MAN, P.T. MANH, A. MARRAUD, D. SHOEMAKER, J.Y. VINET, F. BARONE, L. DI FIORE, L. MILANO, G. RUSSO, J.M. AGUIRREGABIRIA, H. BEL, J.P. DURUISSEAU, G. LE DENMAT, Ph. TOURRENC, M. CAPOZZI, M. LONGO, M. LOPS, I. PINTO, G. ROTOLI, T. DAMOUR, S. BONAZZOLA, J.A. MARCK, Y. GOURGHOULON, L.E. HOLLOWAY, F. FULIGNI, V. IAFOLLA, G. NATALE;

The Virgo project : a wide band antenna for gravitational wave detection.

Nuclear Instruments and Methods in Physics Research **A289**, pp 518-525, 1990

More about us, contd.

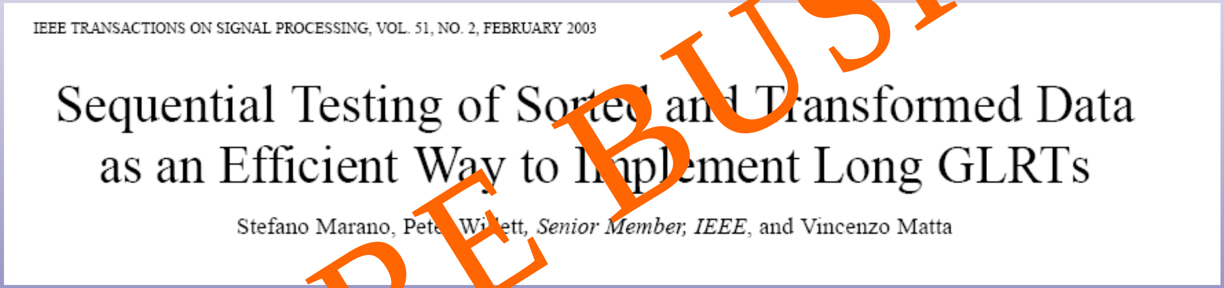
CORE BUSINESS



IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 53, NO. 2, FEBRUARY 2005

Ray-Chaotic Footprints in Deterministic Wave Dynamics: A Test Model With Coupled Floquet-Type and Ducted-Type Mode Characteristics

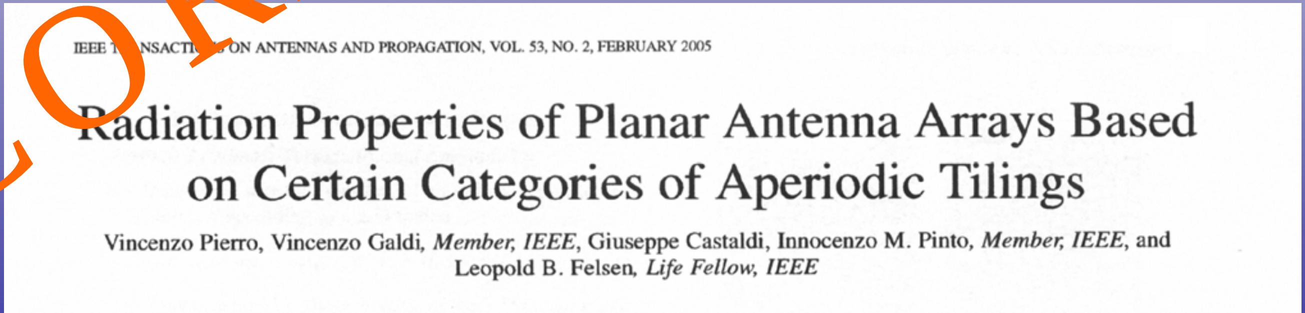
Giuseppe Castaldi, Vincenzo Fiumara, Vincenzo Galdi, *Member, IEEE*, Vincenzo Pierro, Innocenzo M. Pinto, *Member, IEEE*, and Leopold B. Felsen, *Life Fellow, IEEE*



IEEE TRANSACTIONS ON SIGNAL PROCESSING, VOL. 51, NO. 2, FEBRUARY 2003

Sequential Testing of Sorted and Transformed Data as an Efficient Way to Implement Long GLRTs

Stefano Marano, Peter Willett, *Senior Member, IEEE*, and Vincenzo Matta



IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 53, NO. 2, FEBRUARY 2005

Radiation Properties of Planar Antenna Arrays Based on Certain Categories of Aperiodic Tilings

Vincenzo Pierro, Vincenzo Galdi, *Member, IEEE*, Giuseppe Castaldi, Innocenzo M. Pinto, *Member, IEEE*, and Leopold B. Felsen, *Life Fellow, IEEE*

More about us, contd.

Available Simulation Facilities

- 16xCPU PIII/1GHz, (1GBRAM+250GBHD)/node cluster under LINUX/MOSIX;
- QUAD C6701 FP-DSP board+dev.kit;
- TMS XP-30 double-ASIC DSP-board (2005).

Conclusions

Mission

Exploring new data analysis strategies
& sharpening old ones;

Implementation

Merging between Physicists and Engineers
Cultures and Communities;

Motivation

Heard melodies are sweet
but those unheard are sweeter

[John Keats, 1795-1821]

Questions/Comments Welcome