A Scientific Computing Sampler

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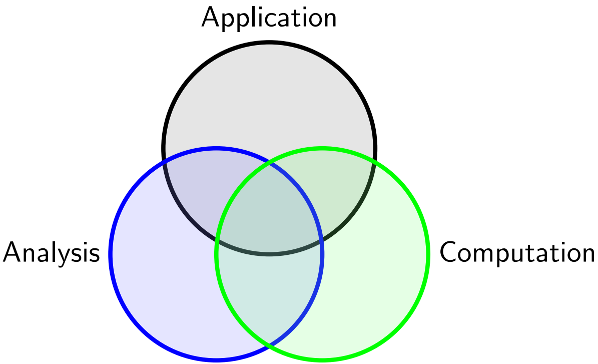
9 Mar 2018

The Computational Science & Engineering Picture

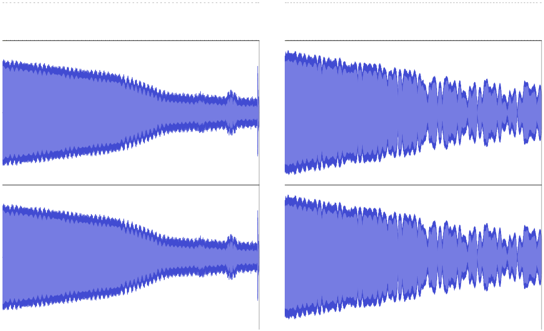


- MEMS
- Smart grids
- Networks
- Systems

- Linear algebra
- Approximation theory
- Symmetry + structure
- Optimization

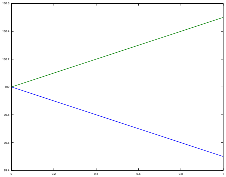
- HPC / cloud
- Simulators
- Solvers
- Frameworks

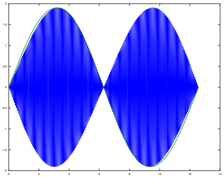
Chapter 1: Musical Microspheres



“On the beats in the vibrations of a revolving cylinder or bell”
by G. H. Bryan, 1890

The Beat Goes On





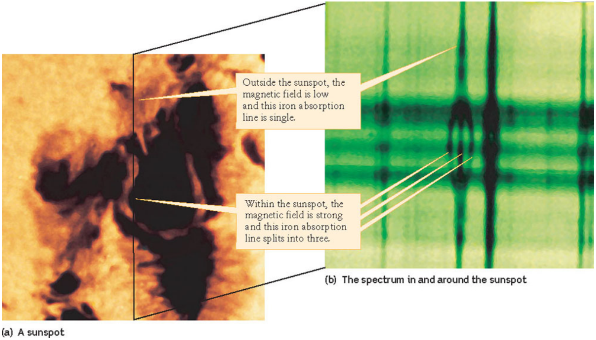
Free vibrations in a rotating frame (simplified):

$$\ddot{\mathbf{q}} + 2\beta\Omega\mathbf{J}\dot{\mathbf{q}} + \omega_0^2\mathbf{q} = 0, \qquad \mathbf{J} \equiv \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix}$$

Eigenvalue problem: $\left(-\omega^2\mathbf{I} + 2i\omega\beta\Omega\mathbf{J} + \omega_0^2\right) q = 0.$

Solutions: $\omega \approx \Omega_0 \pm \beta\Omega. \implies$ beating $\propto \Omega$!

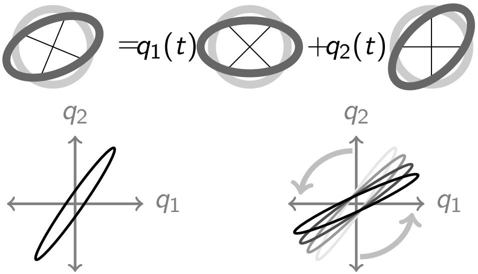
Bryan, Zeeman, Stark, ...



This is a common picture:

- Symmetry leads to degenerate modes
- Perturbations split (some) degeneracies

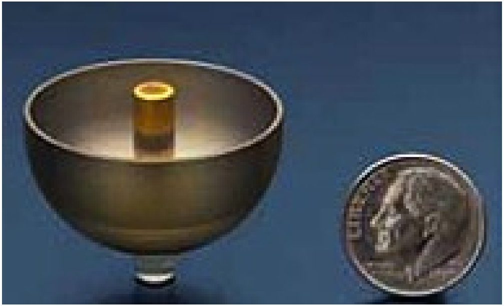
A General Picture



$$\begin{bmatrix} q_1(t) \\ q_2(t) \end{bmatrix} \approx \begin{bmatrix} \cos(-\beta\Omega t) & -\sin(-\beta\Omega t) \\ \sin(-\beta\Omega t) & \cos(-\beta\Omega t) \end{bmatrix} \begin{bmatrix} q_1^0(t) \\ q_2^0(t) \end{bmatrix}.$$

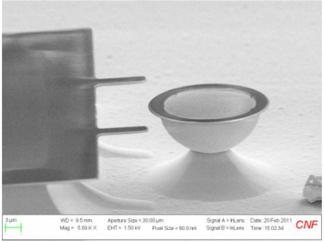
Foucault in Solid State

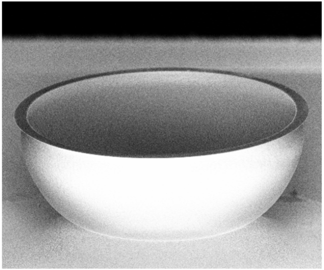
A Small Application

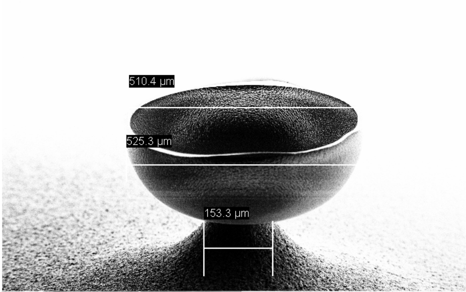


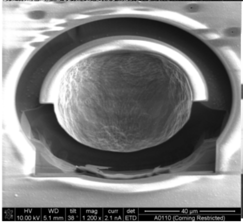
Northrup-Grumman HRG
(developed c. 1965–early 1990s)

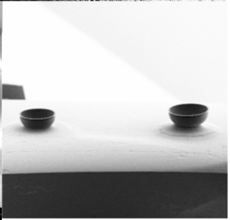
A Smaller Application (Cornell)



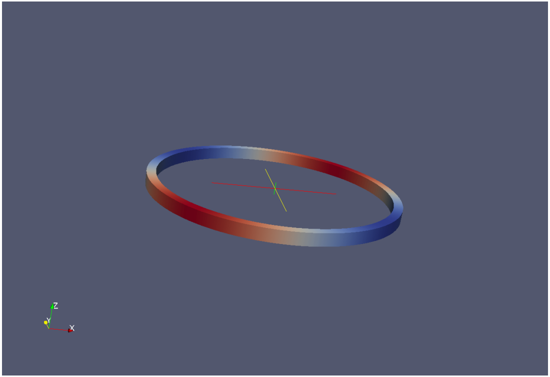








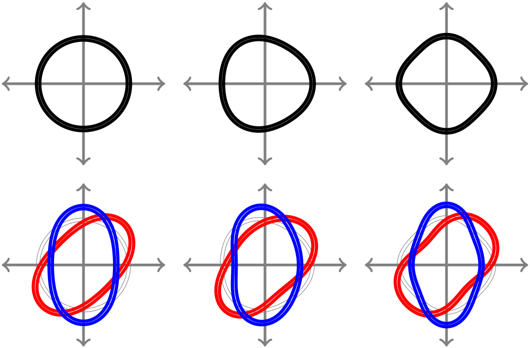
The Perturbation Picture



Perturbations split degenerate modes:

- Coriolis forces (good)
- Imperfect fab (bad, but physical)
- Discretization error (non-physical)

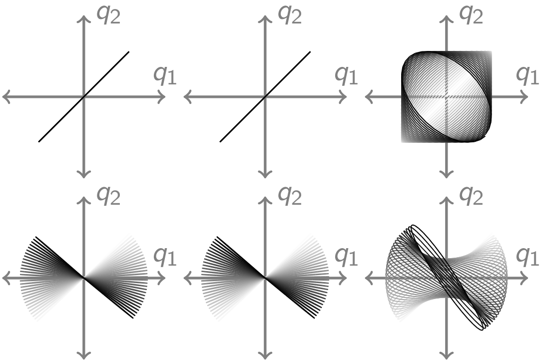
Analyzing Imperfections



Basic framework:

- Represent geometry and imperfections in Fourier series
- Treat imperfections as perturbations

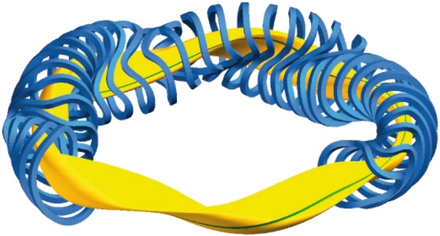
Analyzing Imperfections



Payoff:

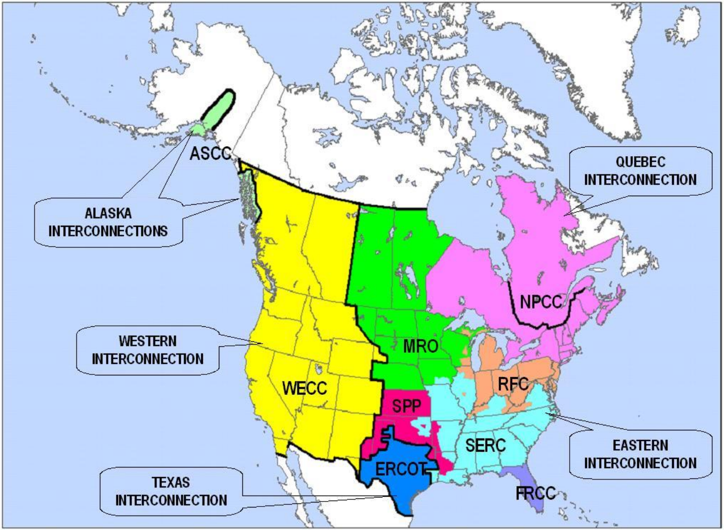
- Quantitative: Fast and accurate "2.5D" simulations
- Qualitative: *Selection rules* identify "dangerous" imperfections

Then and now

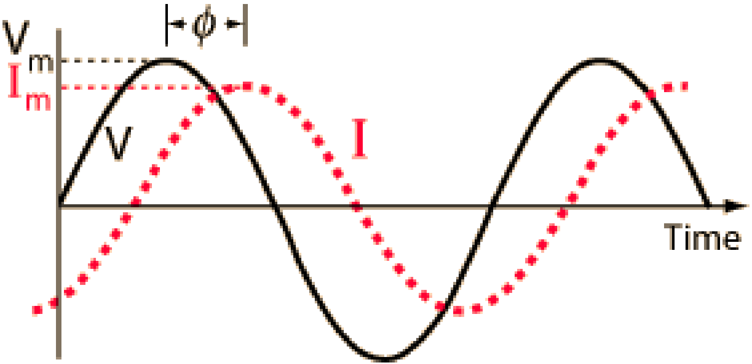


Then: Yilmaz and Bindel
"Effects of Imperfections on Solid-Wave Gyroscope Dynamics"
Proceedings of IEEE Sensors 2013, Nov 3–6.

Now: "Finding Optimimum Magnetic Fields with Hidden Symmetries"
Collaborative proposal submitted to Simons on 2/15/2018.
One piece: Robustness to imperfect fabrication/assembly of coils!

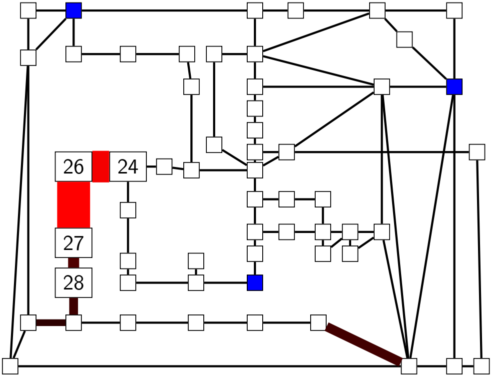

ASCC
ALASKA INTERCONNECTIONS
QUEBEC INTERCONNECTION
NPCC
MRO
WESTERN INTERCONNECTION
WECC
RFC
SPP
SERC
EASTERN INTERCONNECTION
ERCOT
TEXAS INTERCONNECTION
FRCC

Reminder: AC Power



Voltages	$V(t) = \sqrt{2} V_{\text{avg}} \cos(\omega t)$
Currents	$I(t) = \sqrt{2} I_{\text{avg}} \cos(\omega t + \phi)$
Power	$P_{\text{avg}} = V_{\text{avg}} I_{\text{avg}} \cos \phi$

Where's the Problem?

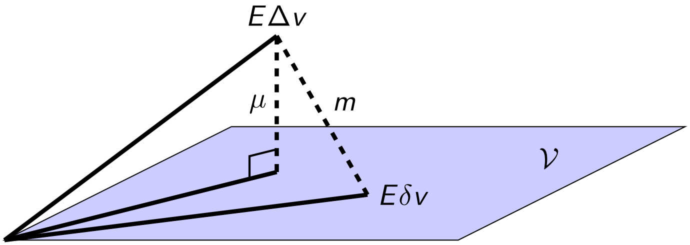


Straw man

- Simulate every possible failure (fast)
- Compare simulated observation to real observation
- Report (mismatch, update) pairs in descending order

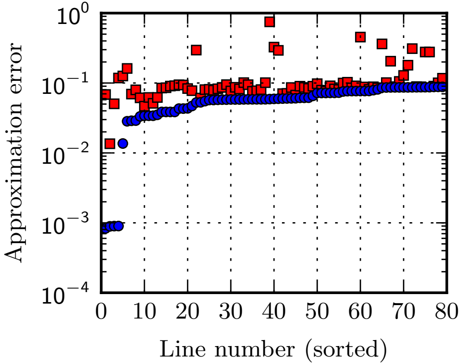
But running all these predictions is too expensive!

Partial Predictions



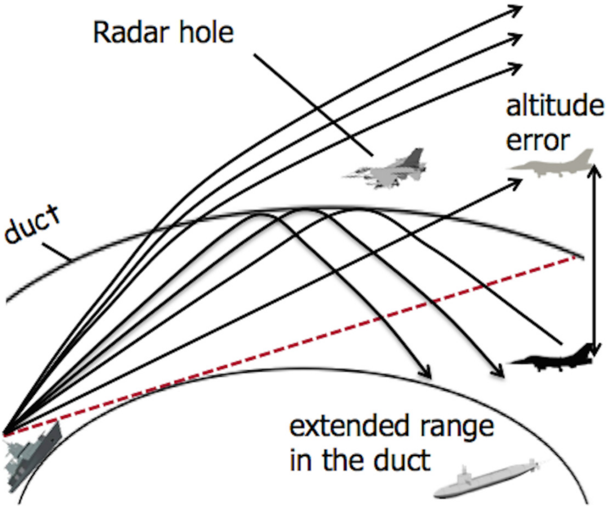
- Find *subspace* $\mathcal{V}_c$ containing predictions $E\delta v_c$
- Bound: subspace distance $\mu(c) \leq$ mismatch $m(c)$
- Sort events by ascending $\mu(c)$
- Check $c_1, \ldots, c_k$ until $\mu(c_{k+1}) \leq \min_{1 \leq j \leq k} m(c_j)$

Filter Effectiveness (IEEE 57-bus, line trips only)

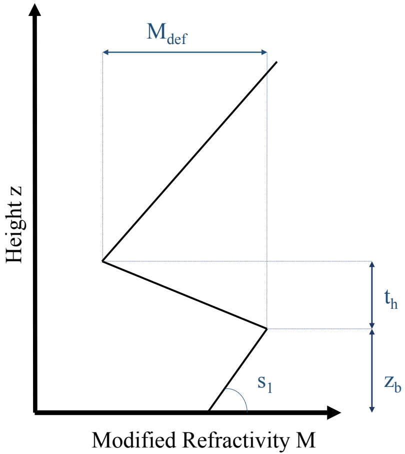


Blue squares are filter scores ($\mu(c)$), red are actual mismatches ($m(c)$).

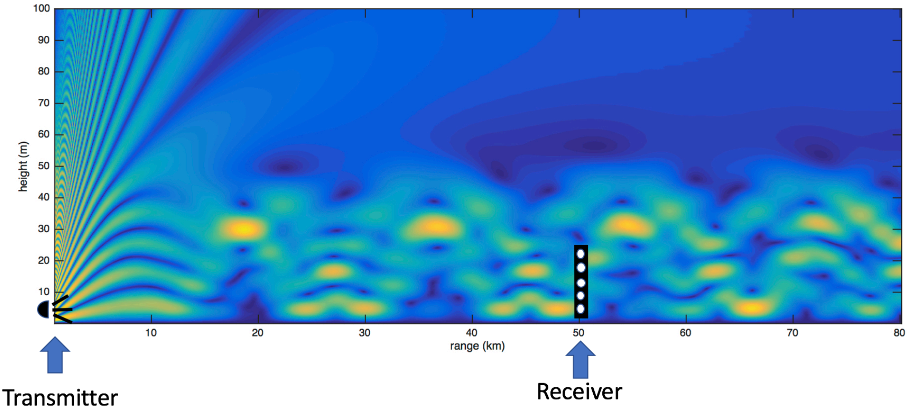
Same Tune, Different Words



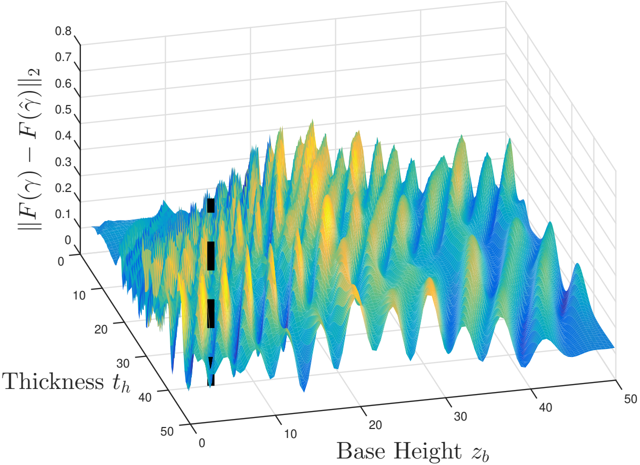
Duct, Duct, Goose



Duct, Duct, Goose

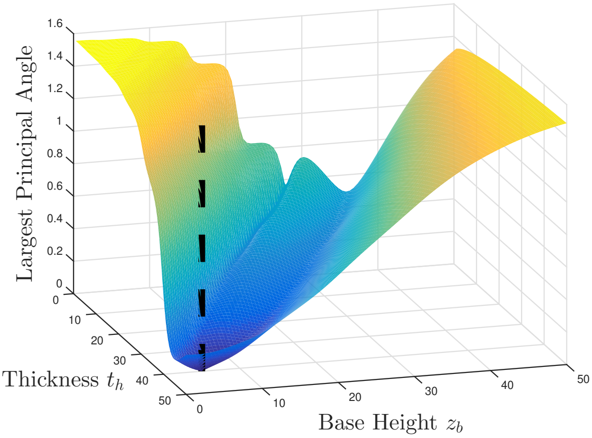


Direct fit?



0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
$\|F(\gamma) - F(\hat{\gamma})\|_2$
0
10
20
30
40
50
Thickness t_h
0
10
20
30
40
50
Base Height z_b

Subspace to the rescue!



Then and now

Then: Ponce and Bindel,
"FLiER: Practical Topology Update Detection Using Sparse PMUs."
IEEE Trans Power Systems, 2017.

Now: Gilles, Earls, and Bindel,
"A subspace pursuit method to invert for refractivity in the Marine Atmospheric Boundary Layer."
In preparation

And many others...