Title: LIGO: Astronomical Observatory and Physics Playground

Date: Apr 11, 2005 02:00 PM

URL: http://pirsa.org/05040050

Abstract:

LIGO: an observatory and physics playground.

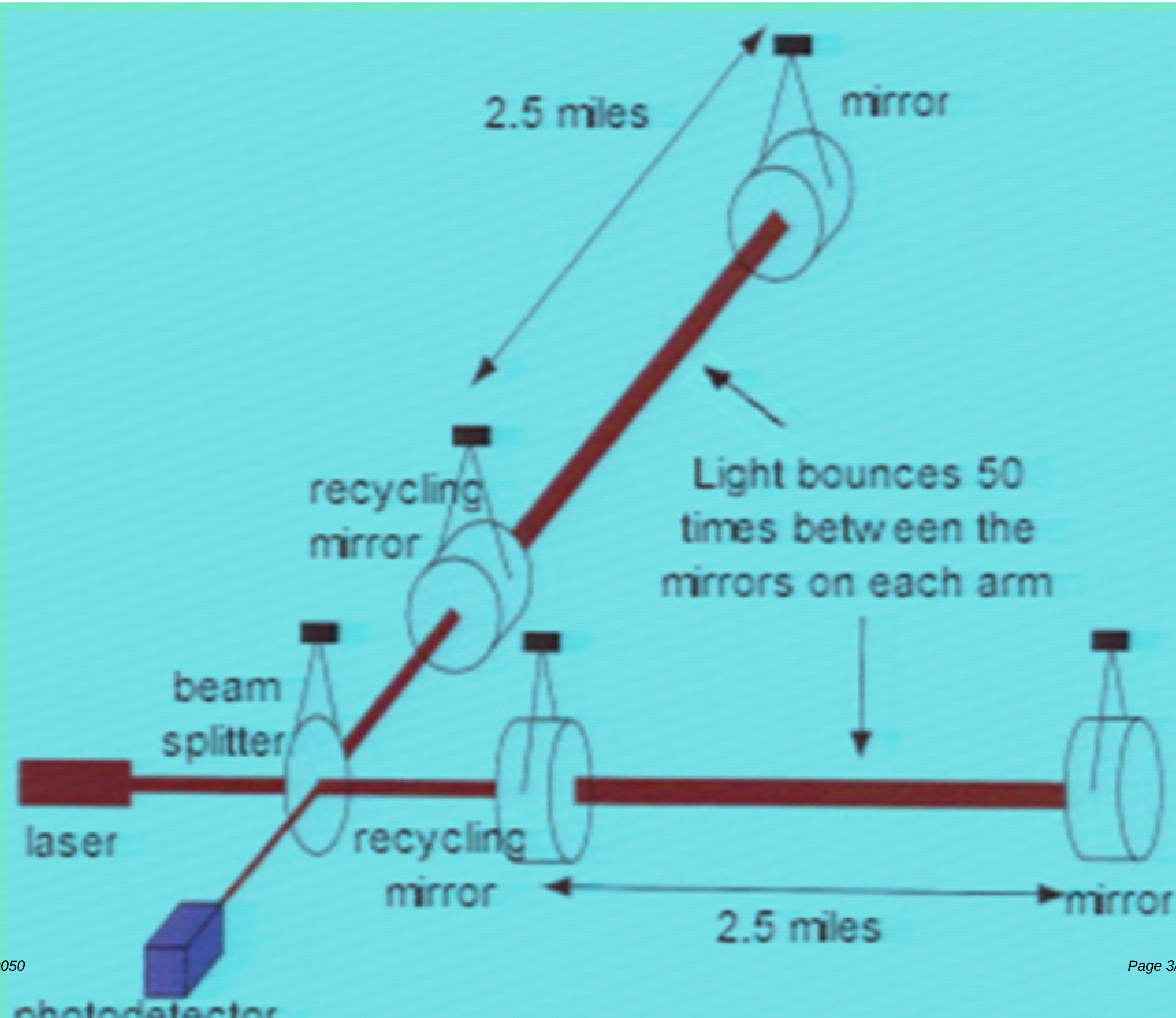
Yuri Levin, CITA

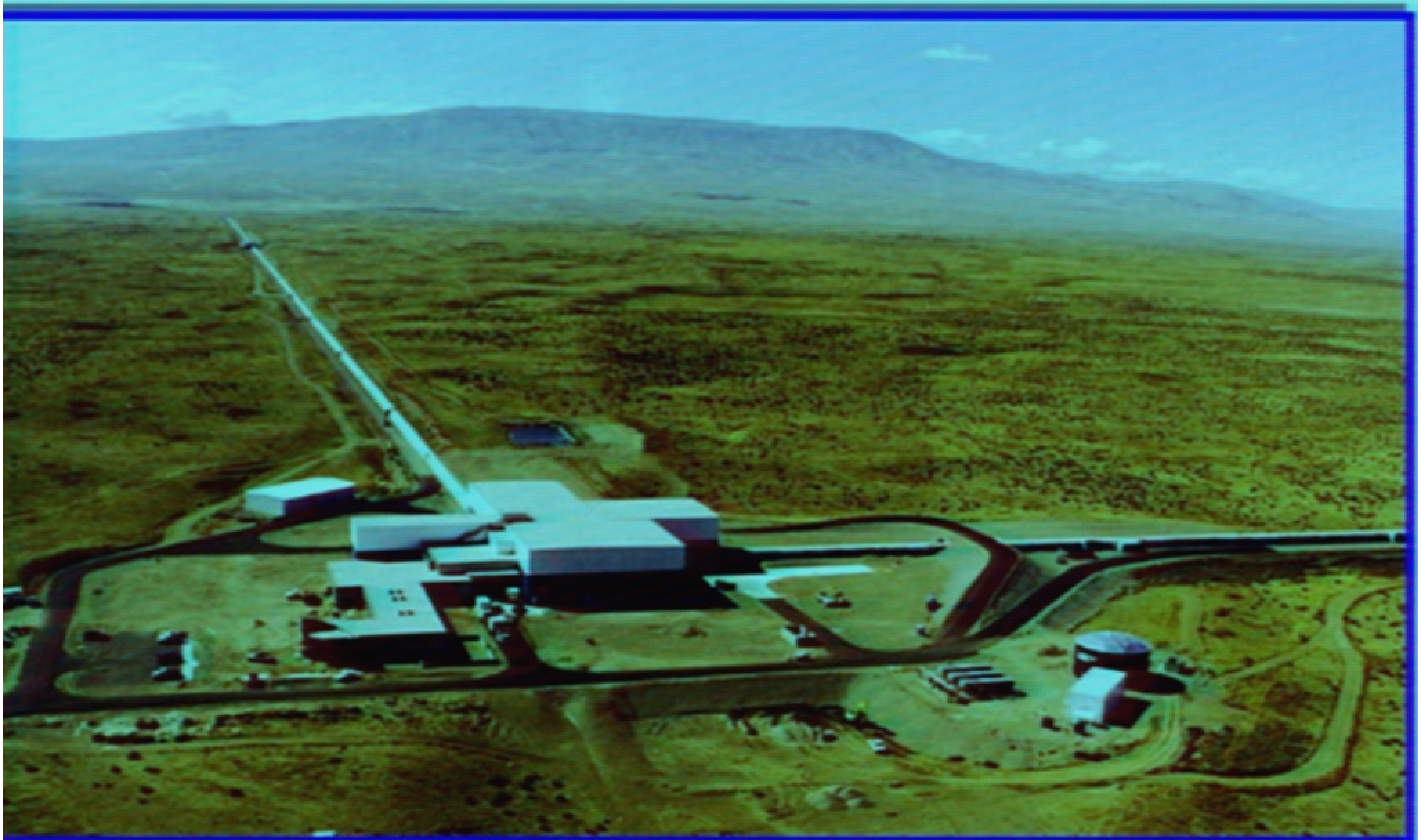
1. LIGO design

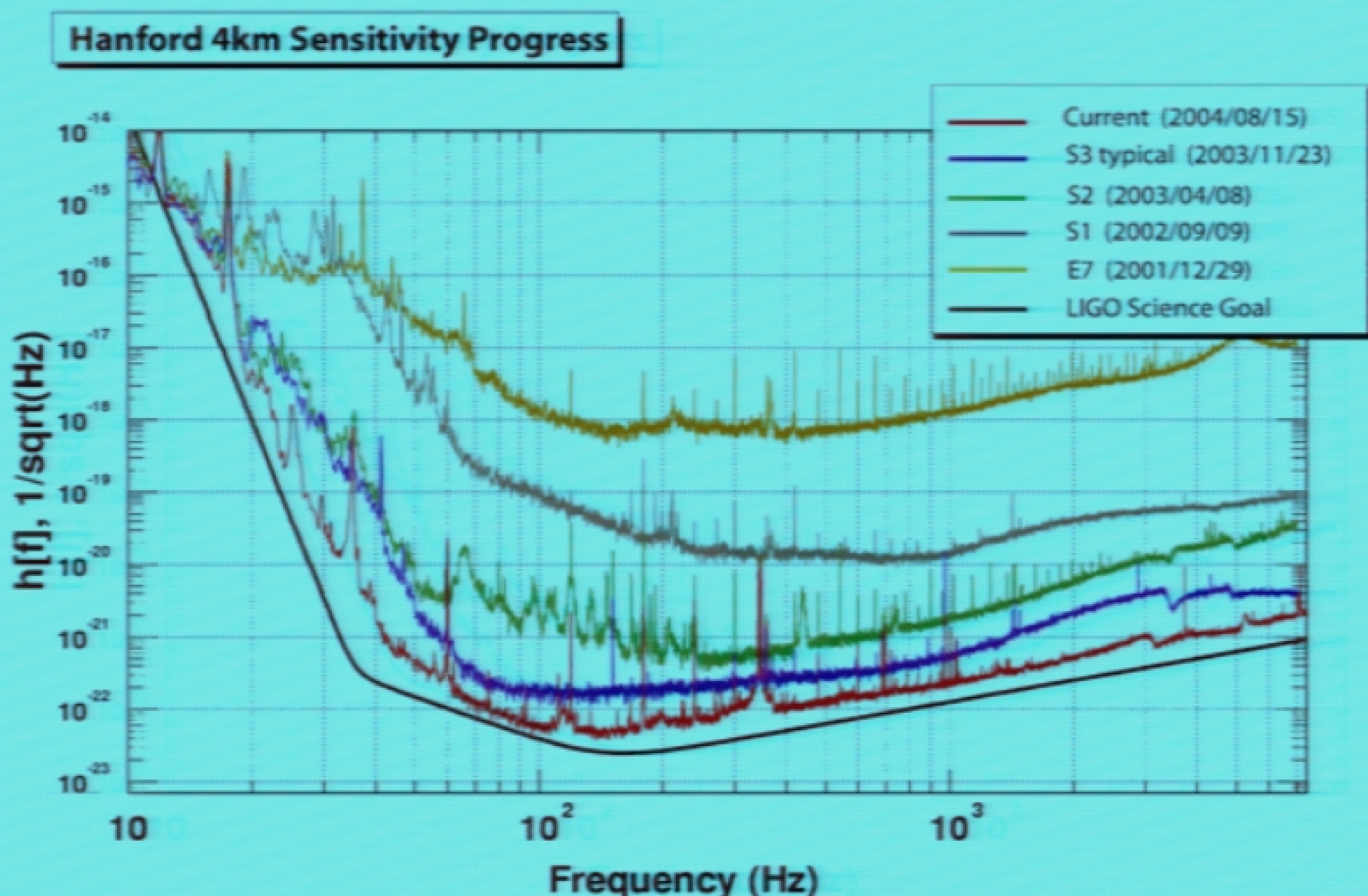
2. Astronomical sources

3. Thermal fluctuations

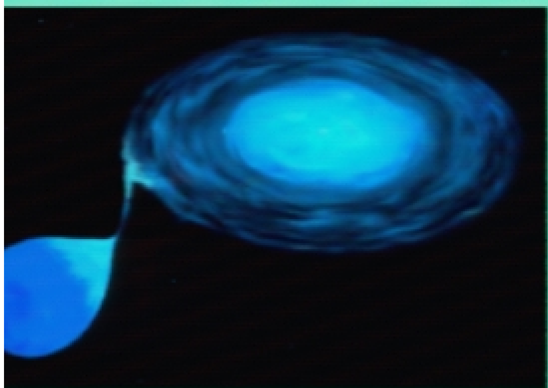
4. Quantum noise ?


2.5 miles
mirror
recycling
mirror
Light bounces 50
times between the
mirrors on each arm
beam
splitter
laser
recycling
mirror
mirror
2.5 miles

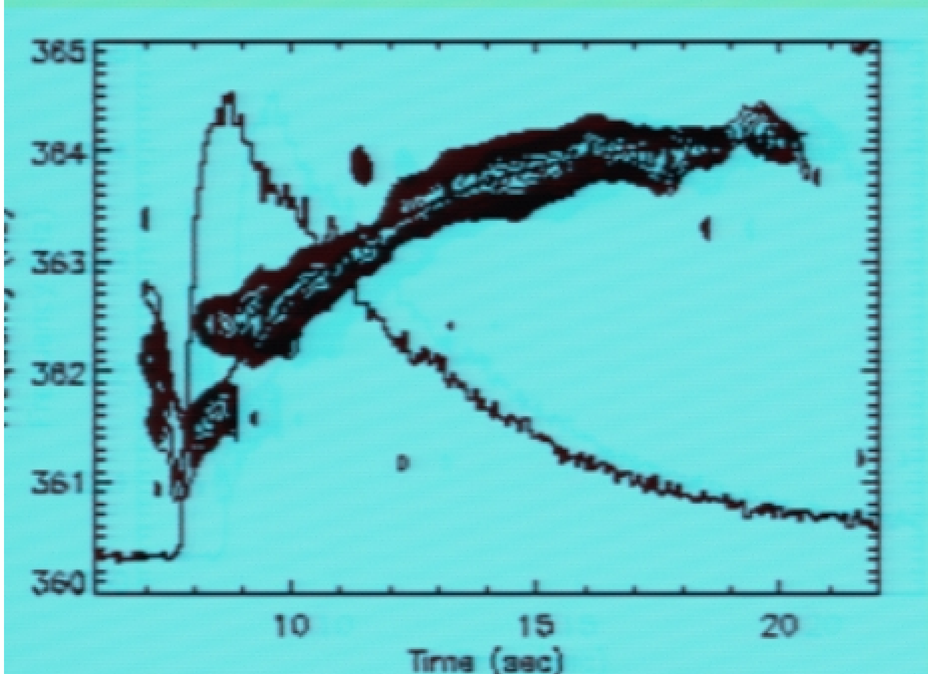



Hanford 4km Sensitivity Progress
Current (2004/08/15)
S3 typical (2003/11/23)
S2 (2003/04/08)
S1 (2002/09/09)
E7 (2001/12/29)
LIGO Science Goal
h[f], 1/sqrt(Hz)
Frequency (Hz)
10
10^2
10^3

Accreting Neutron Stars in LMXBs



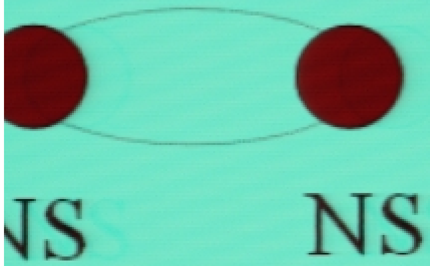
- About 60 in the Galaxy
- 10 bursters with pulsations
- 3 millisecond pulsars



- all spins between 240 and 700 Hz
- NSs non-magnetic or weakly magnetic
- Consistent with radio pulsars

No bias!! What sets the spin?

What we expect from gods for LIGO:



waveform is known, rate 10-10000/yr

Kalogera et. al. 04

Physics:

a. in LIGO band NS are point masses

b. test GR to 5.5 PN order

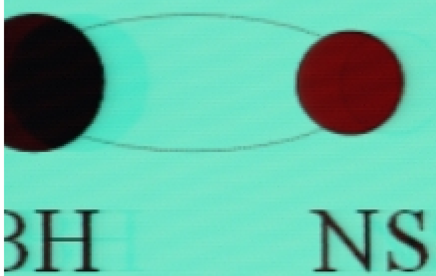
Astronomy:

a. certain to exist

b. tell us about binary evolution

c. cross-correlate with short GRBs.

What we expect from gods for LIGO:



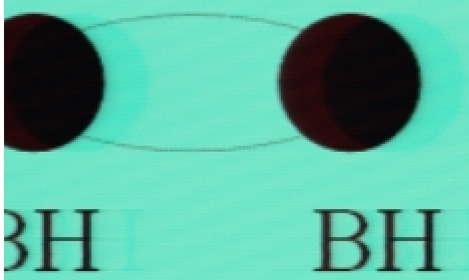
Waveform needs work, rate highly uncertain (pure theory)

Physics: tidal disruption of NS may tell us about equation of state

Astronomy:

a. Unknown whether exist
b. tell us about binary evolution
c. cross-correlate with short GRBs.

What we expect from gods for LIGO:



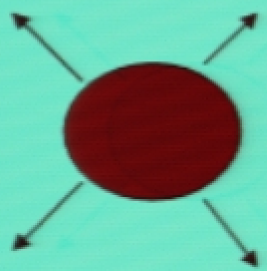
Waveform needs work, rate highly uncertain (pure theory)

Physics: full GR! need simulations.

Astronomy:

a. unknown whether exist
b. tell us about binary evolution
c. tell us about dynamics in .globular clusters

Supernovae: vibration, rapid rotation, bars.

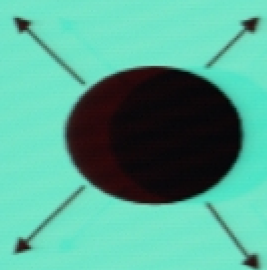


Burrows et. al.,
Centrella et. al.

Everything very uncertain!

Vibrating Intermediate-mass BHs

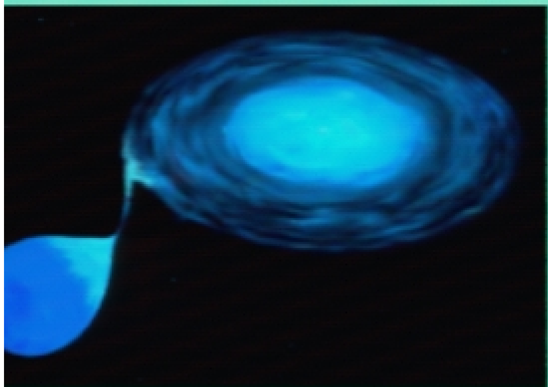
Wyithe and Loeb



Physics: pretty well modeled

Astronomy: high-z mergers;
rate highly uncertain

Accreting Neutron Stars in LMXBs



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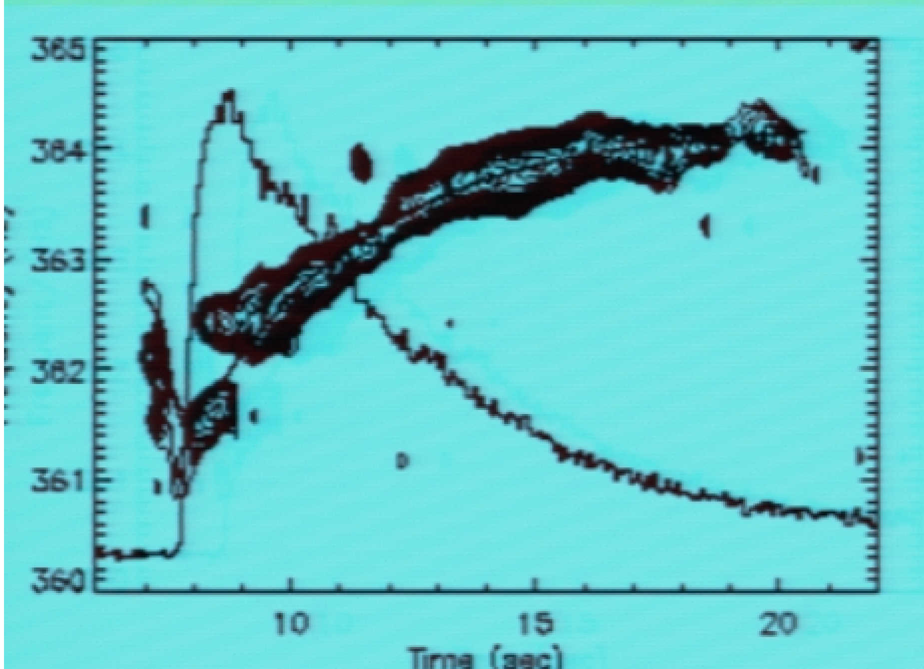

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No bias!! What sets the spin?

Simulations of type-I burst

Spitkovsky, Levin, Ushomirsky 02

Rossby soliton (Boyd)

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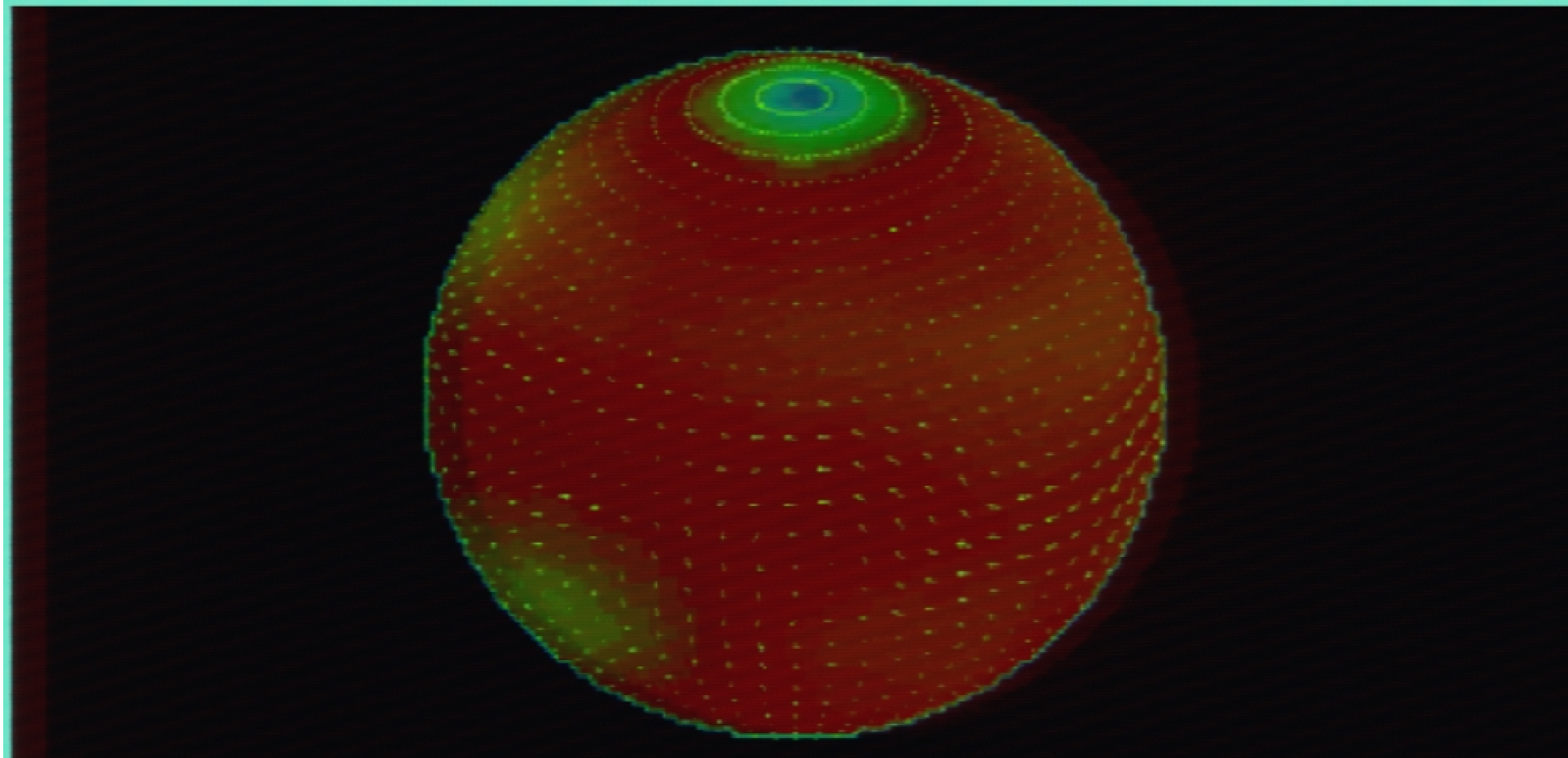

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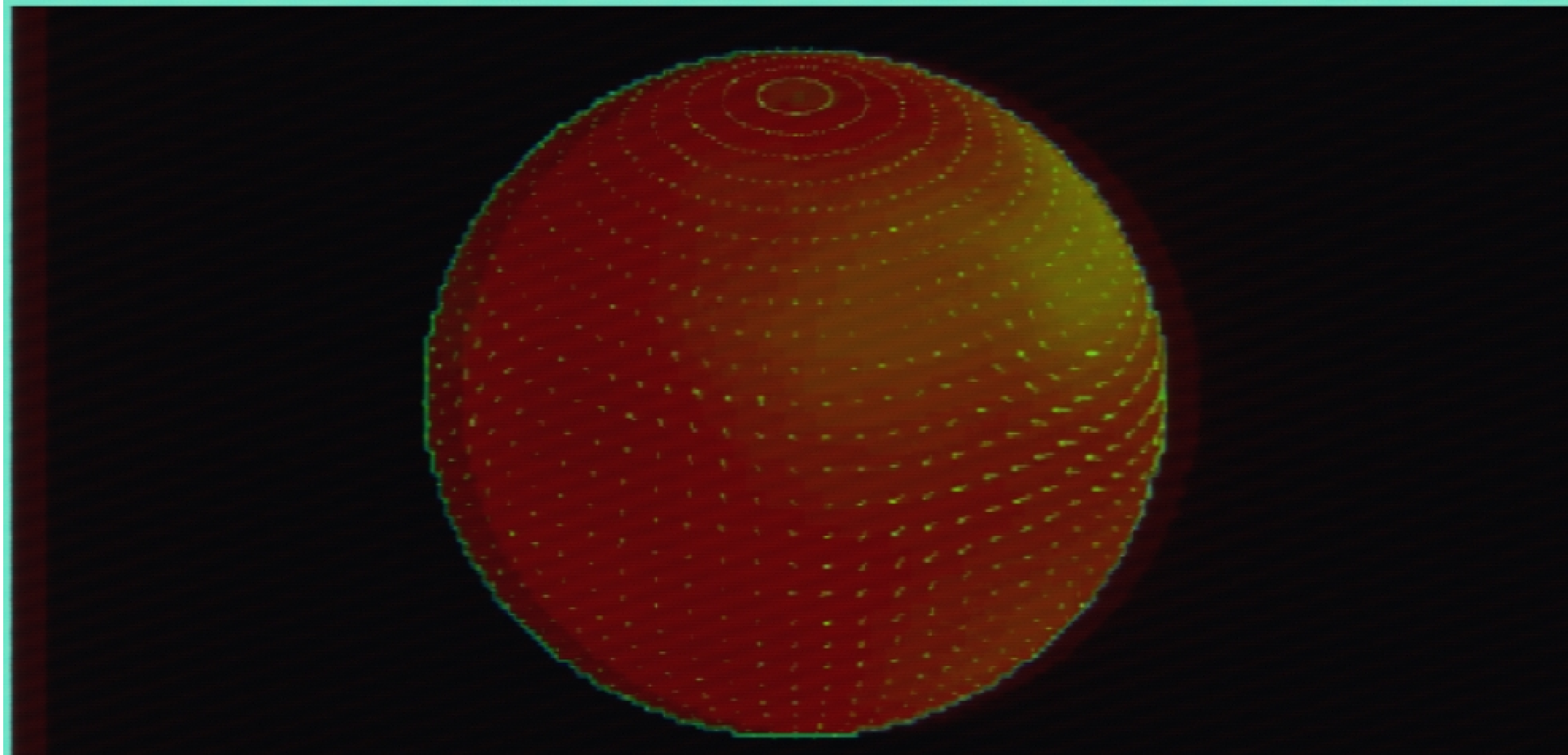

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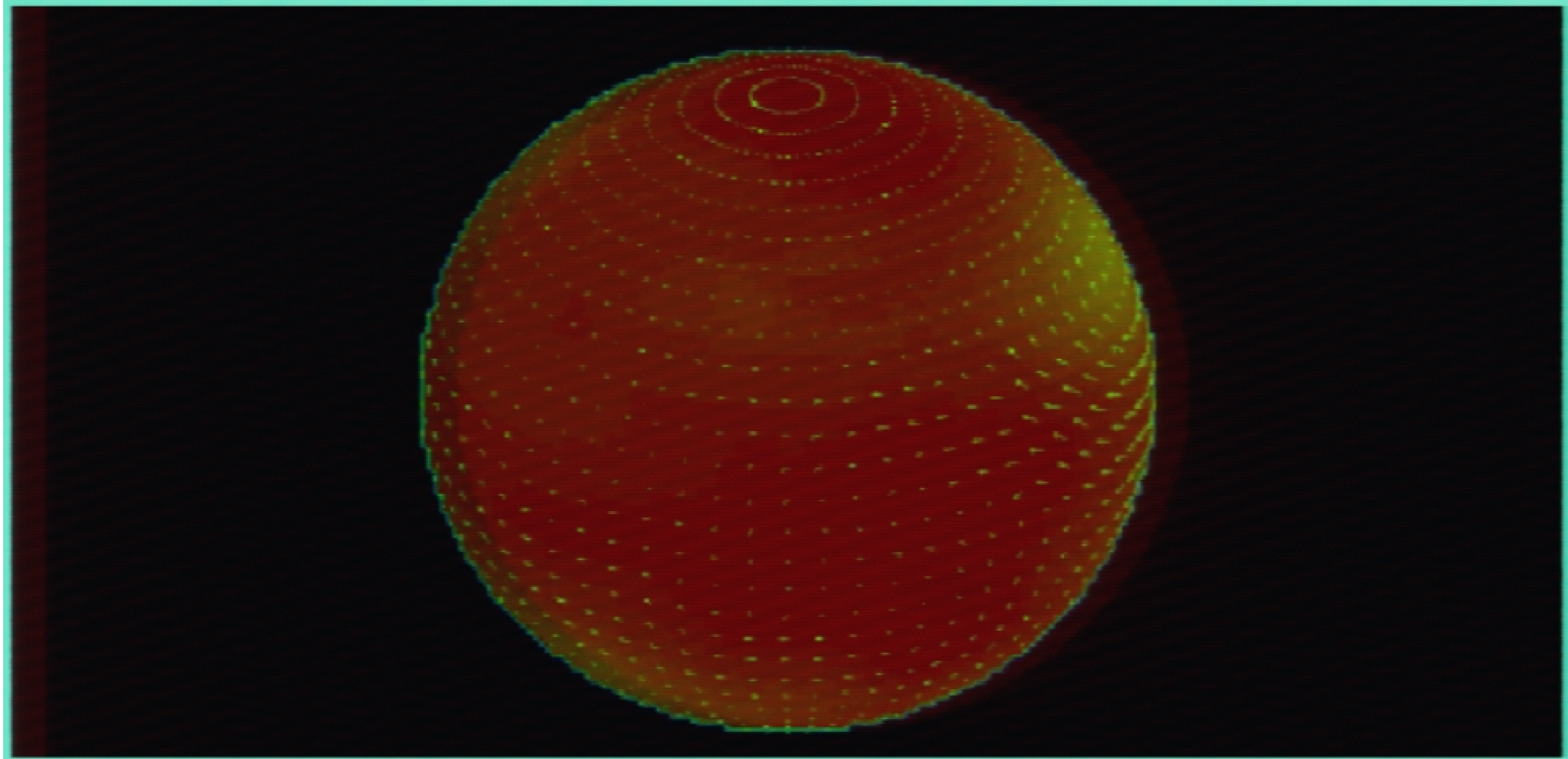

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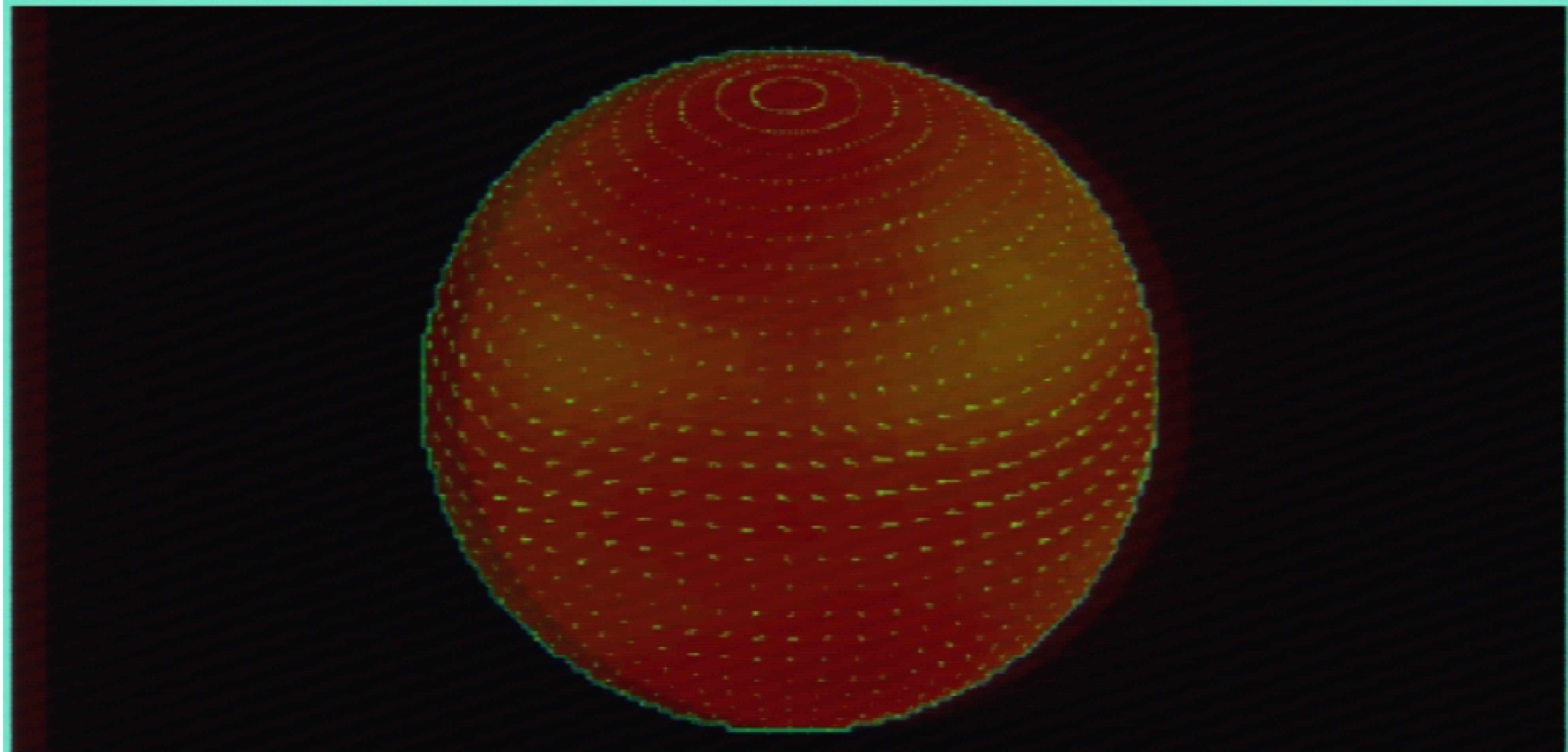

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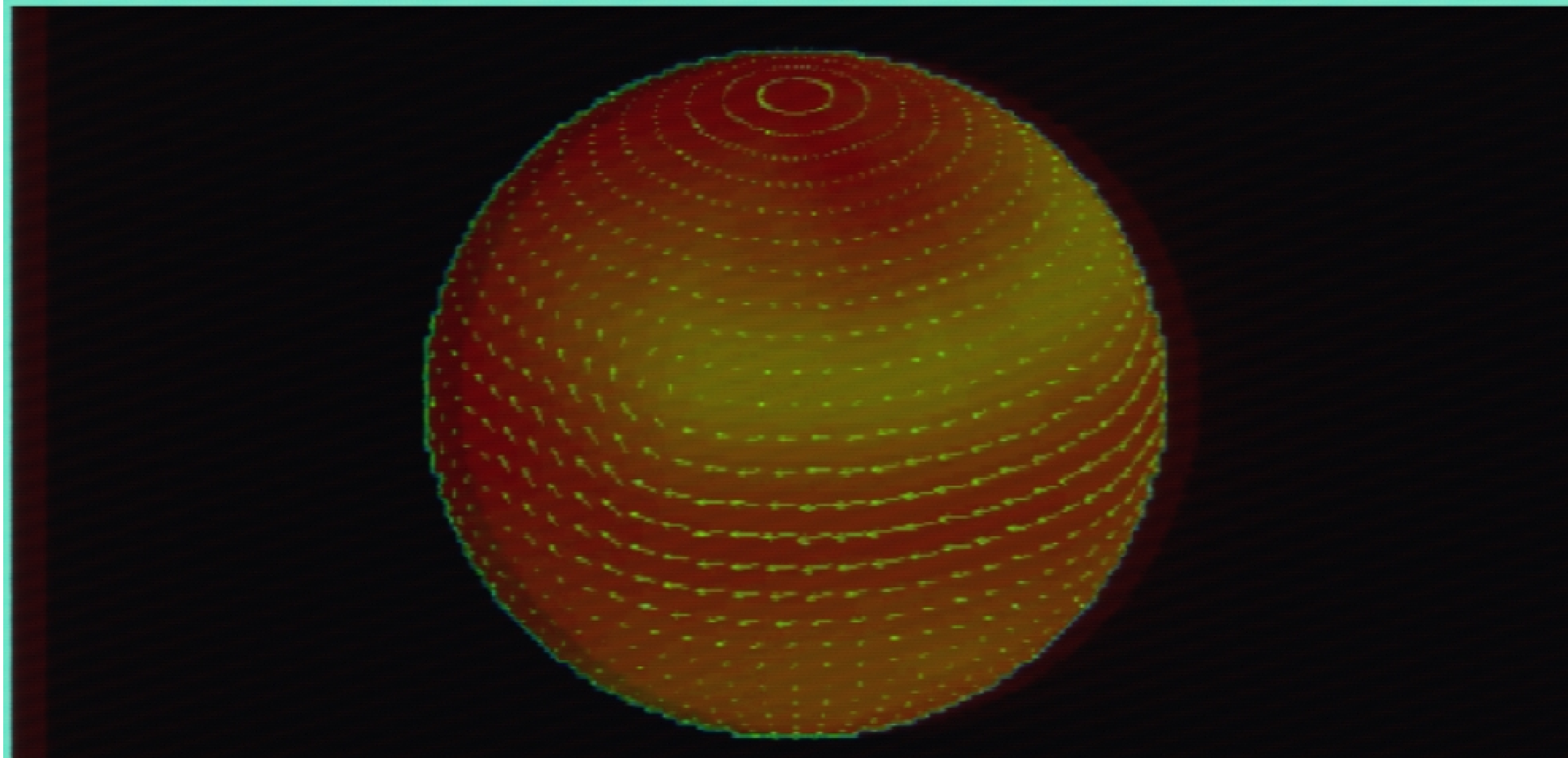

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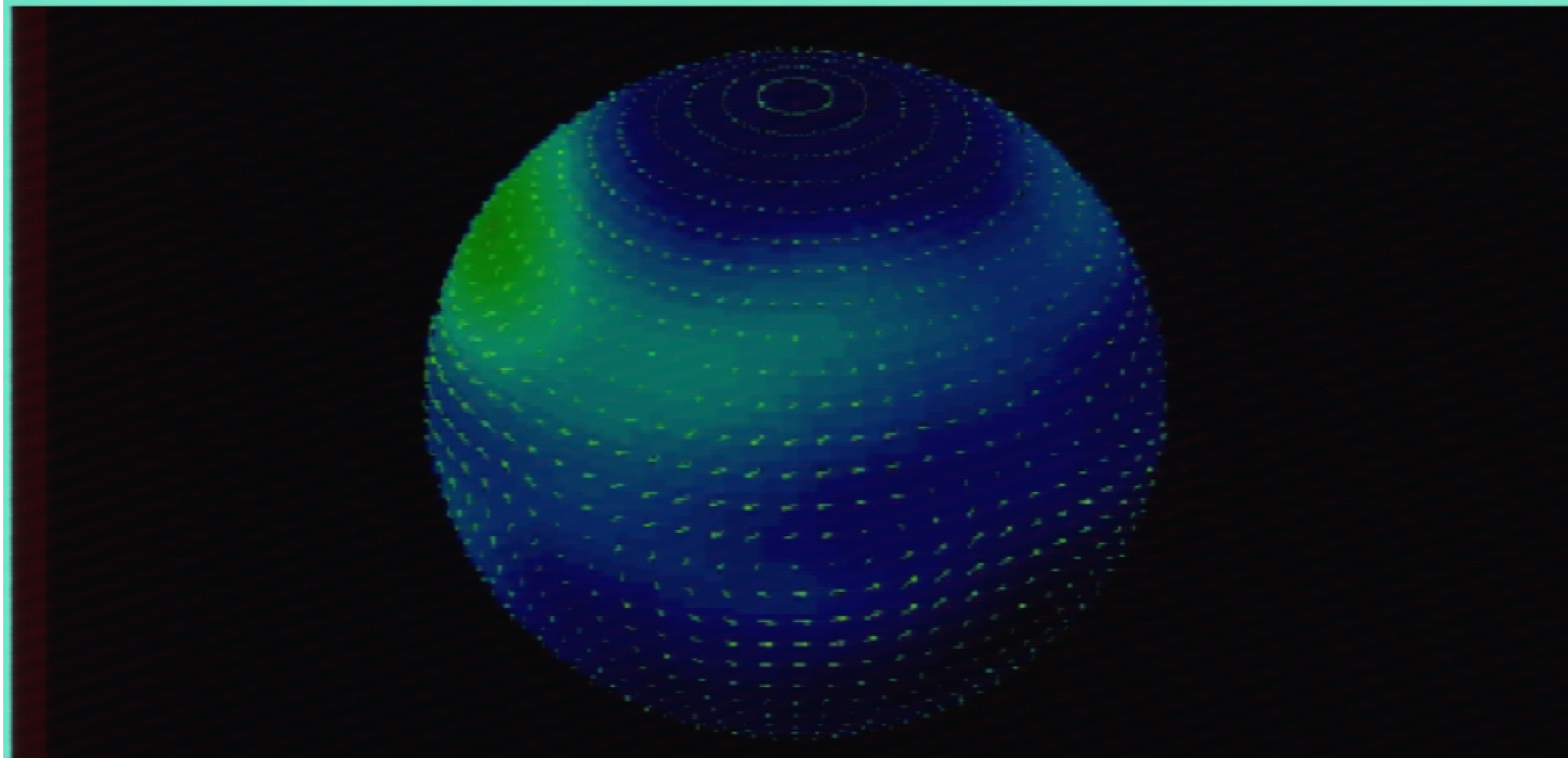

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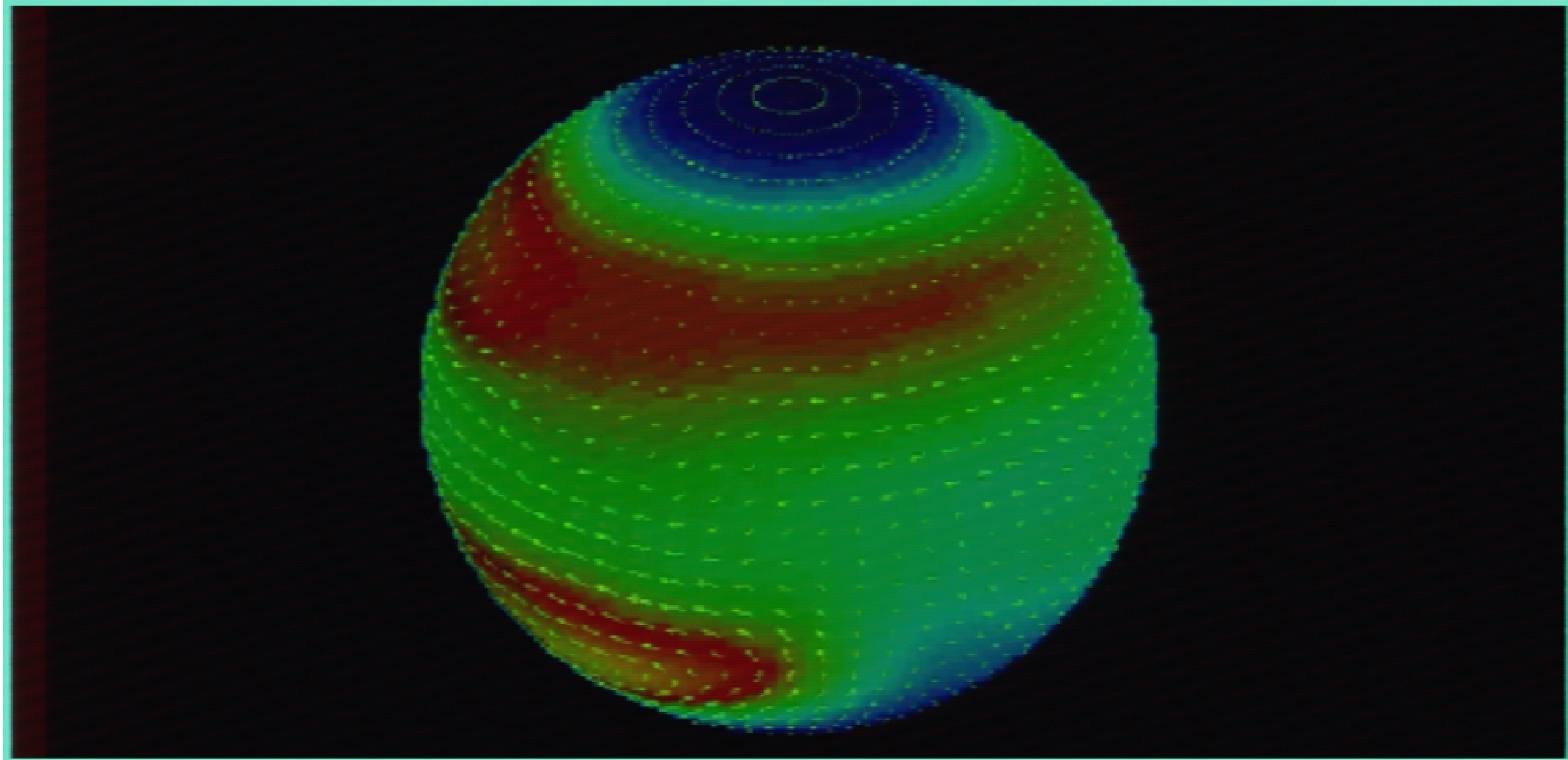

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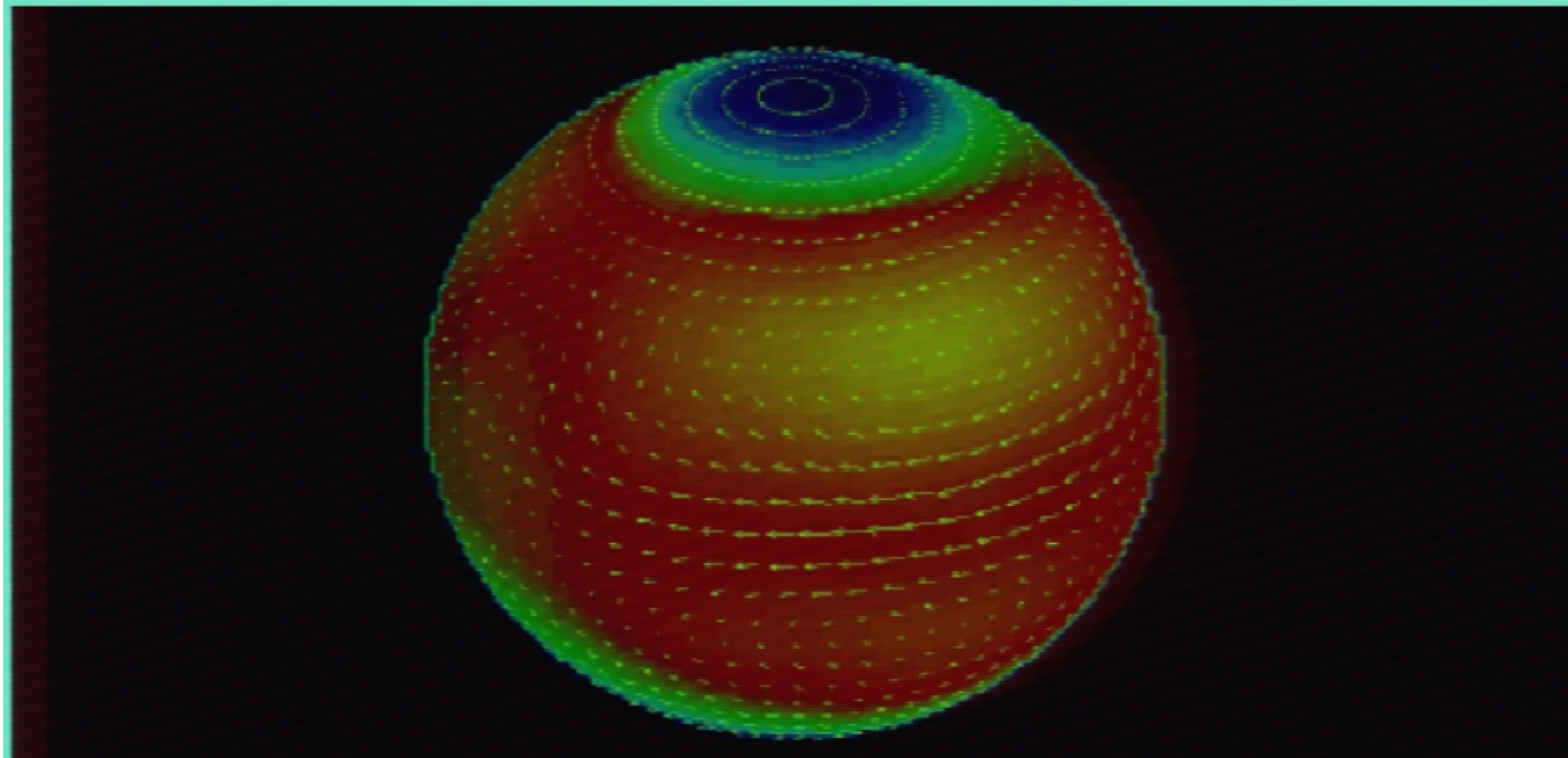

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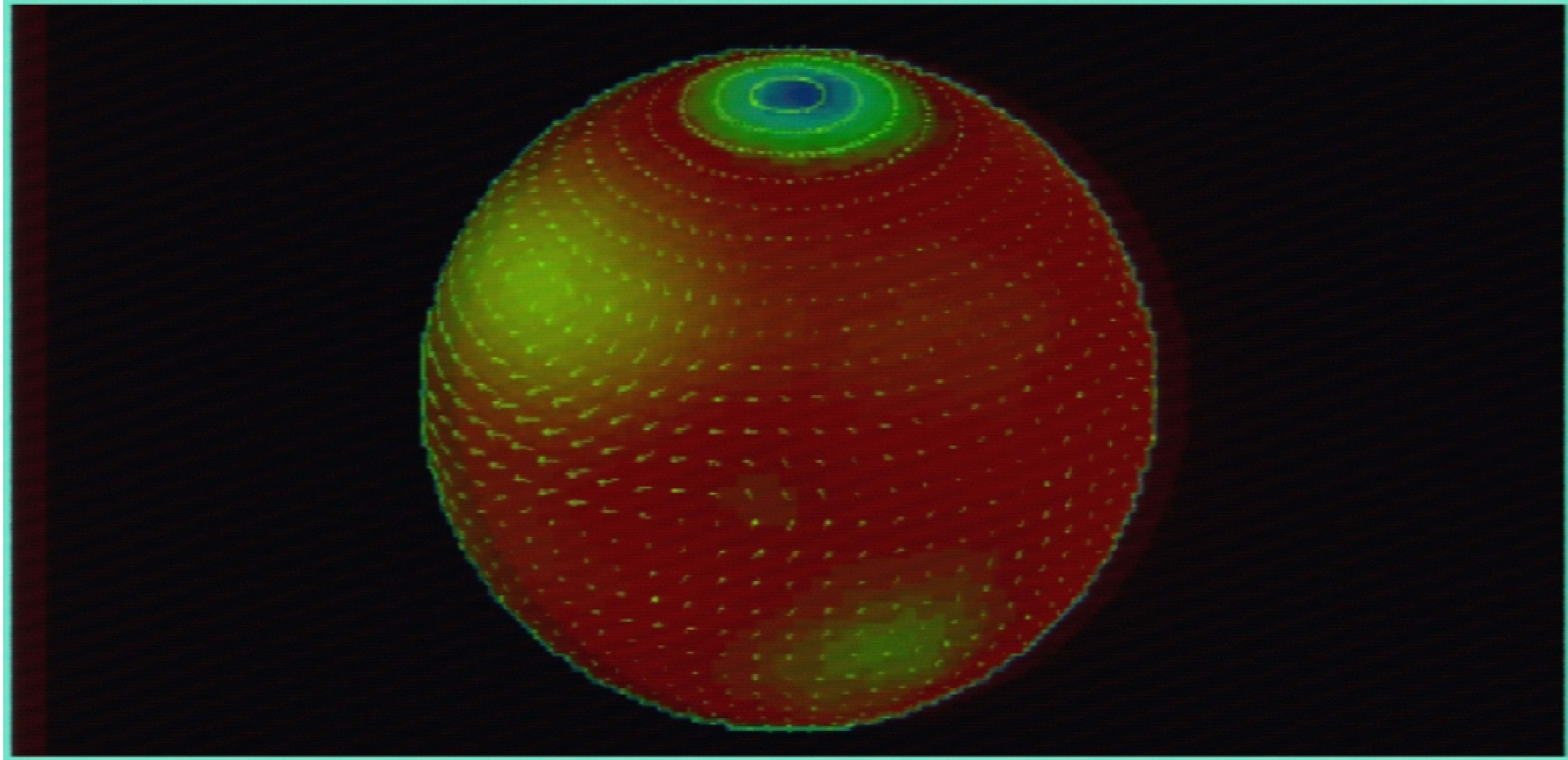

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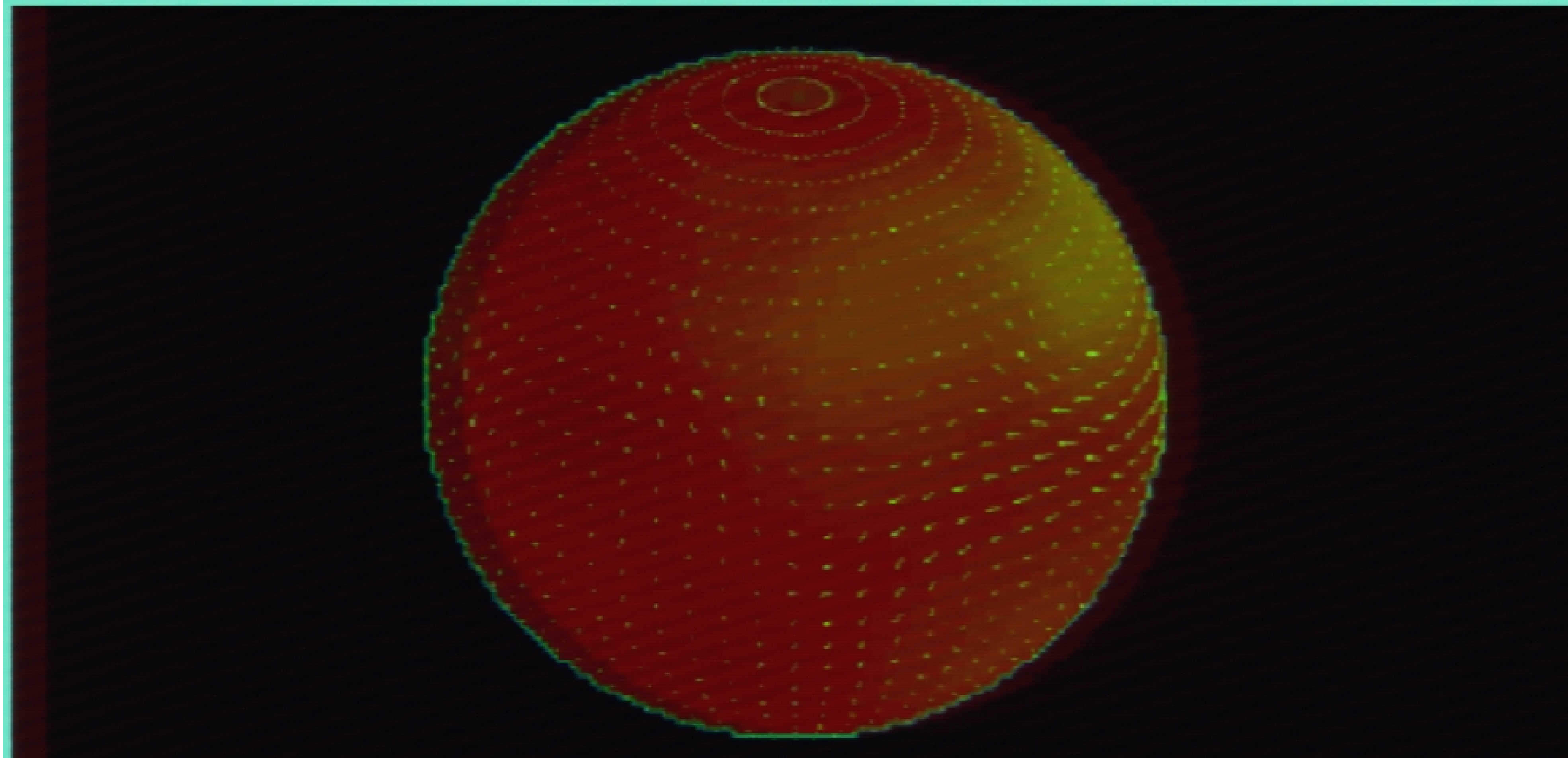

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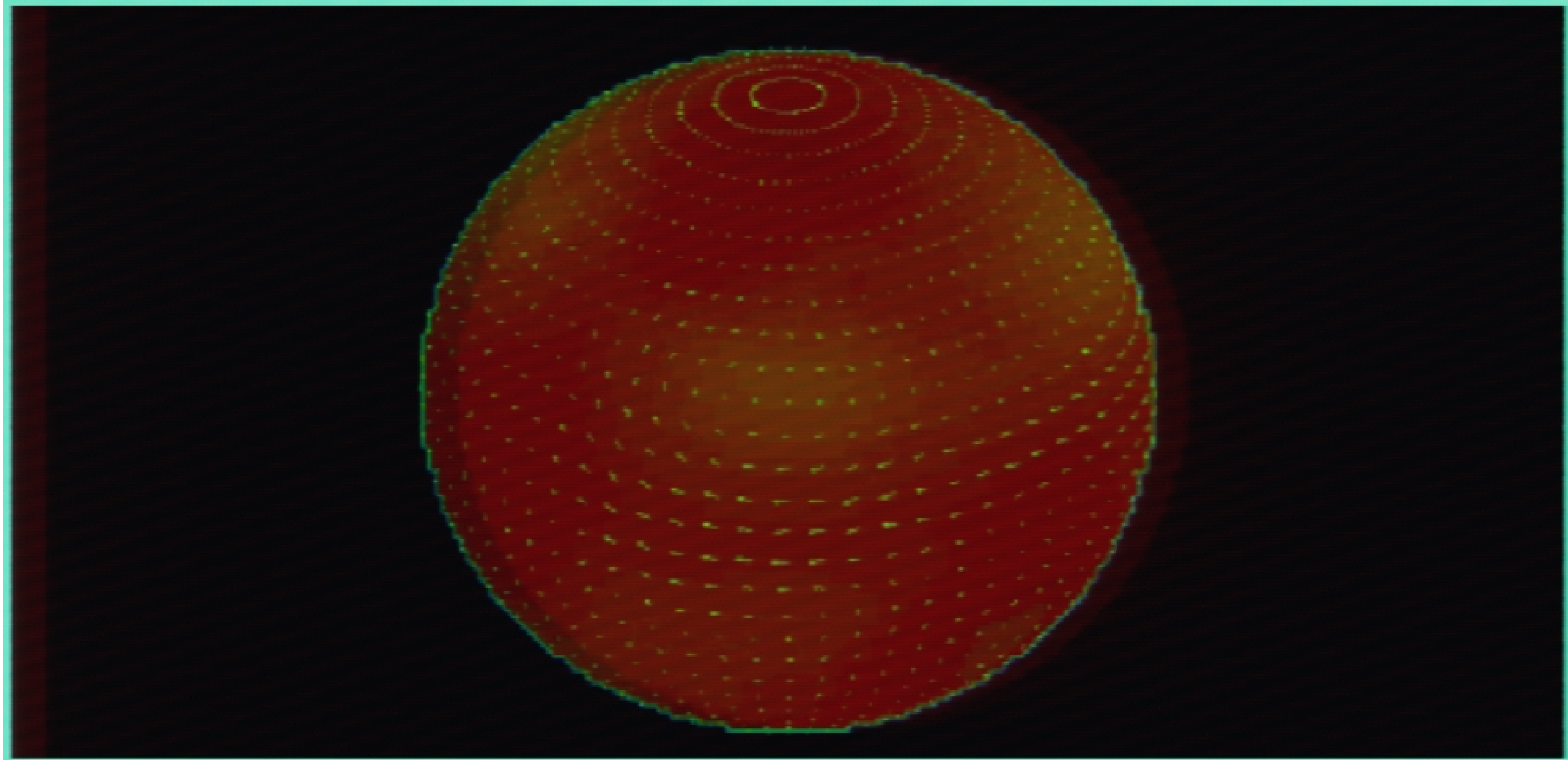

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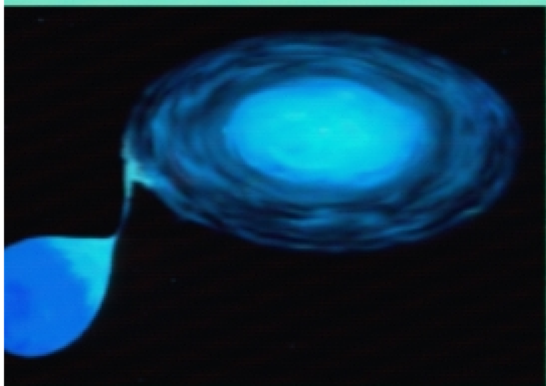

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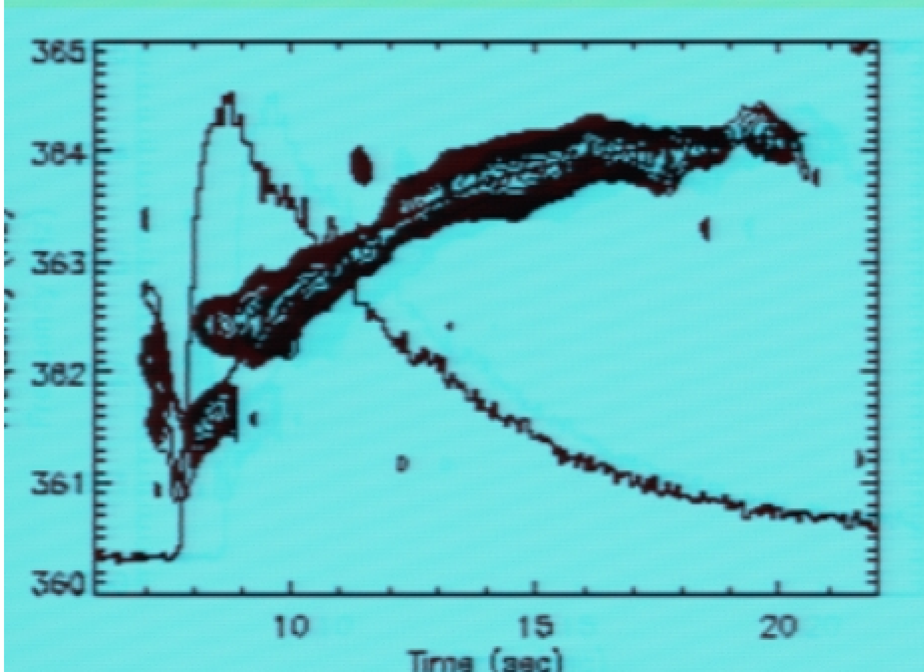

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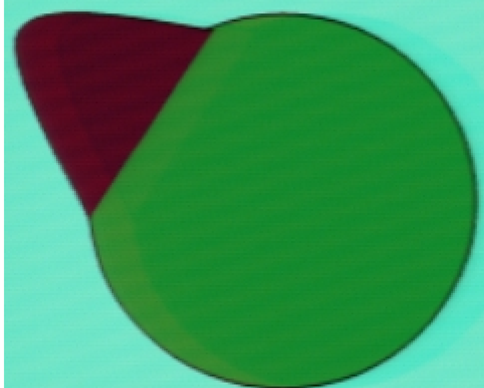
<u>No bias!! What sets the spin?</u>

Gravitational waves!

Bildsten 98

Way 1: build a mountain (magnetic or elastic stresses)

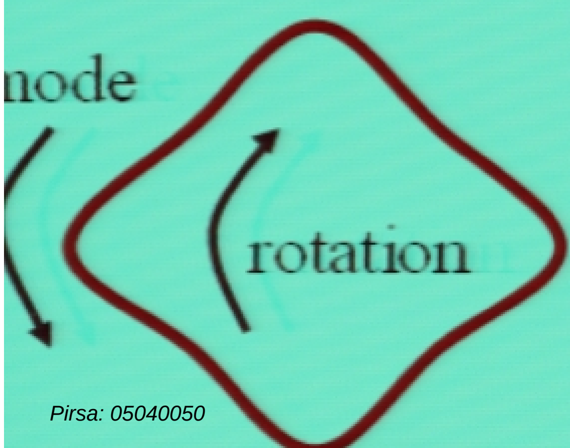


Frequency 2×spin or spin

LIGO would see a few in the Galaxy

Hard to build a mountain on neutron star!

Way 2: unstable mode



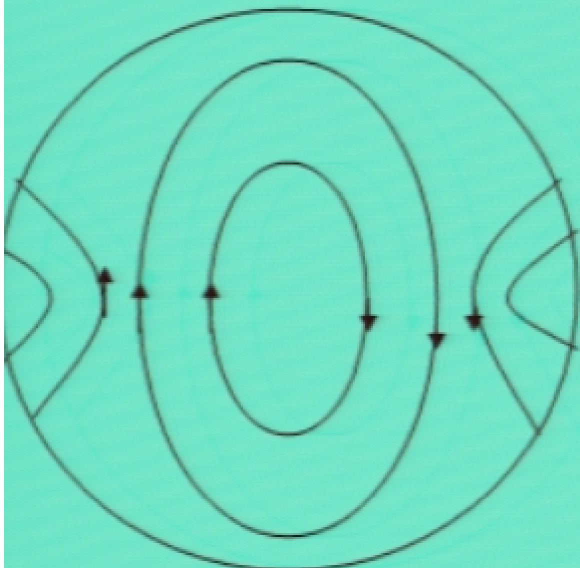
if $V_{mode} < V_{rotation}$

then mode unstable!

Chandrasekhar 70, Friedman & Schutz 78

Way 2: R-mode instability. Andersson 98

Lindblom et. al. 98



•Vorticity wave driven by gravitational radiation - certain.

•damped by viscosity - uncertain!

•GW frequency (4/3)×spin

Nature of GW signal is sensitive to $\nu(T)$: Levin 99

"normal fluid" $d\nu/dT<0$

GWs come in cyclic flashes, last about 5000yr, duty cycle 0.001

Marginal detection in nearby Galaxies.

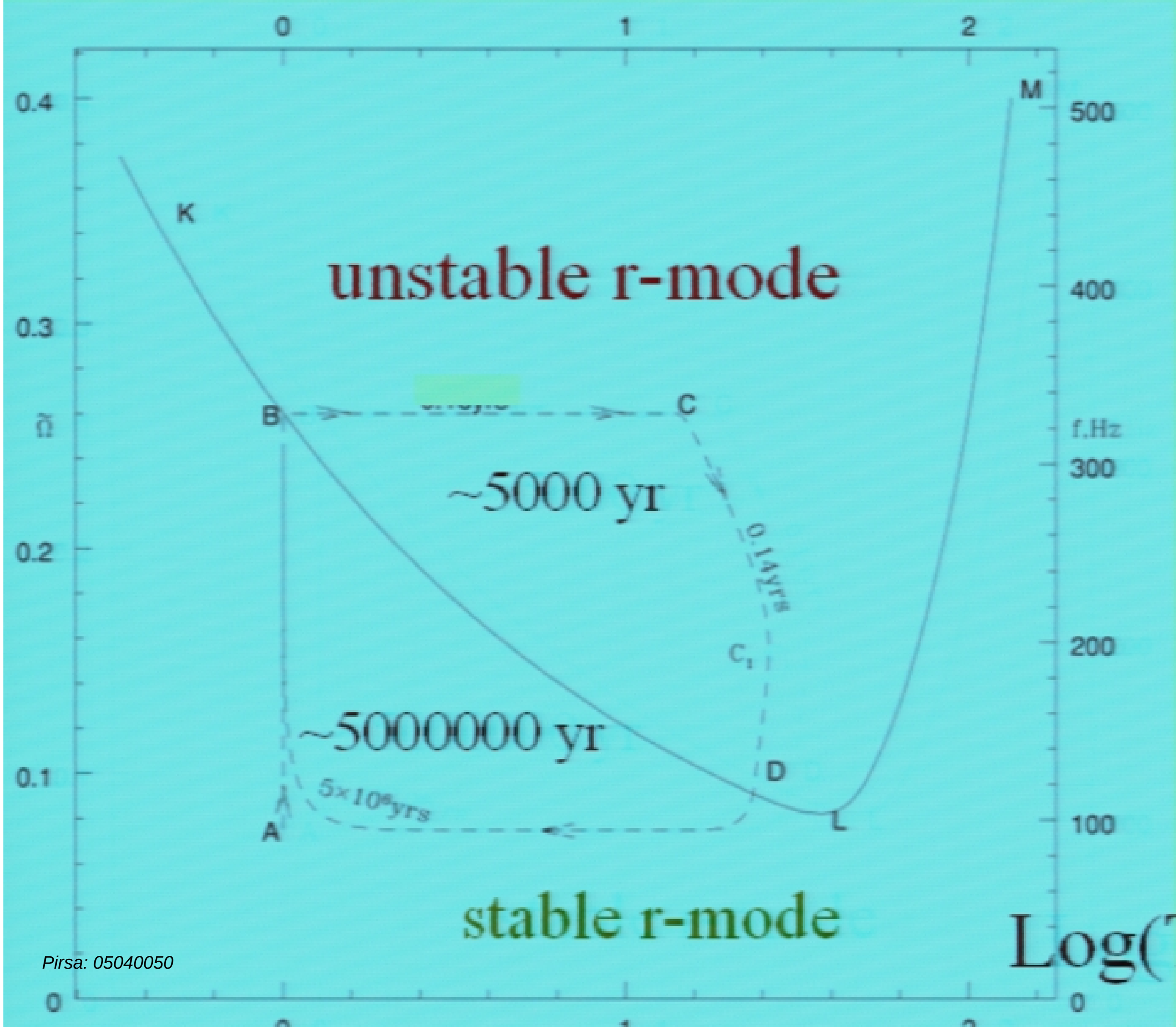
hyperons: $d\nu/dT>0$

Owen 04

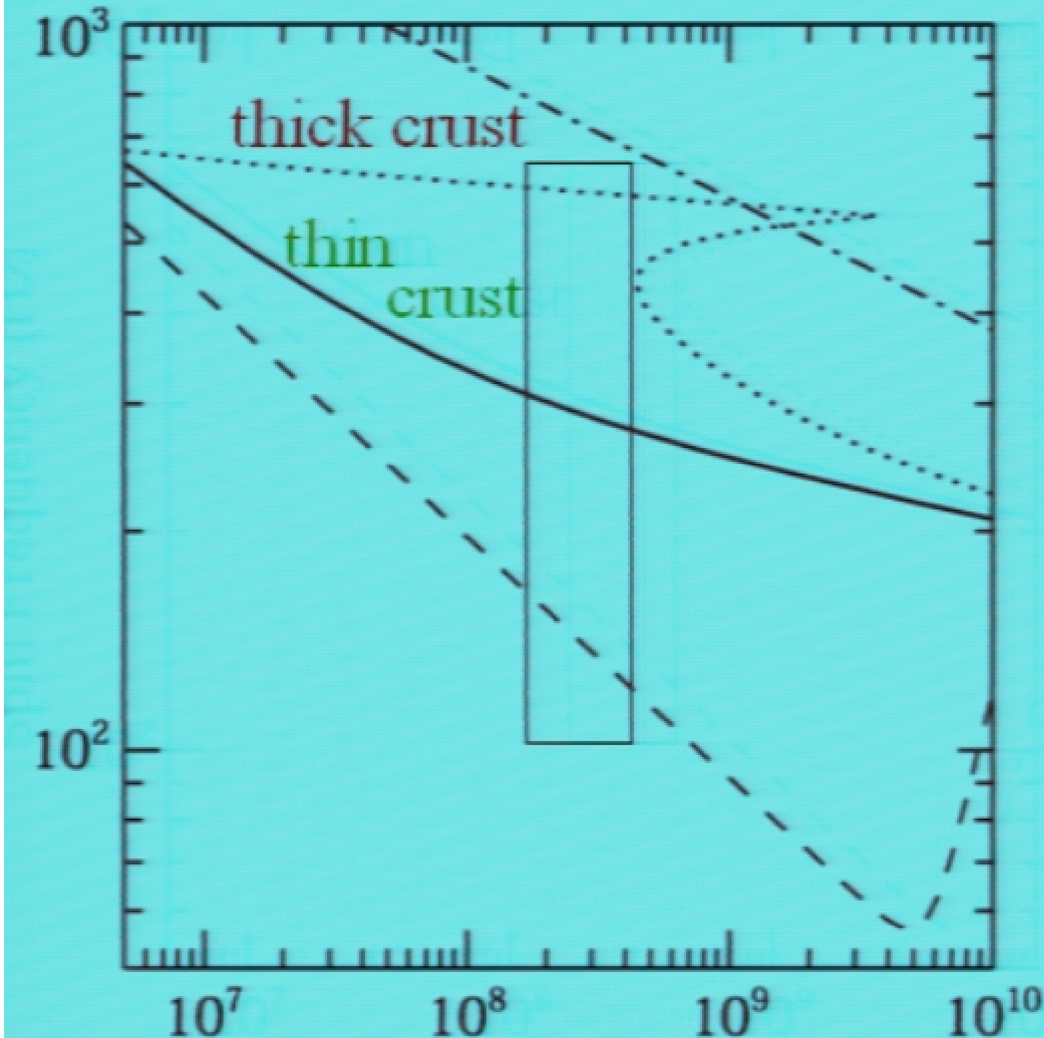
GWs are steady, LIGO will see a few in Our Galaxy

Thermo-gravitational runaway

Levin 99
Spruit 99



- Toy model: more realistic calculations since



Levin and Ushomirsky 02

- damping from crust-core boundary layer
- explains spins of accreting NS' and millisecond pulsars
- details depend on the crust thickness (thick favoured)
- Superfluid effects to be worked out! (in progress).

Thermo-gravitational runaway

Levin 99

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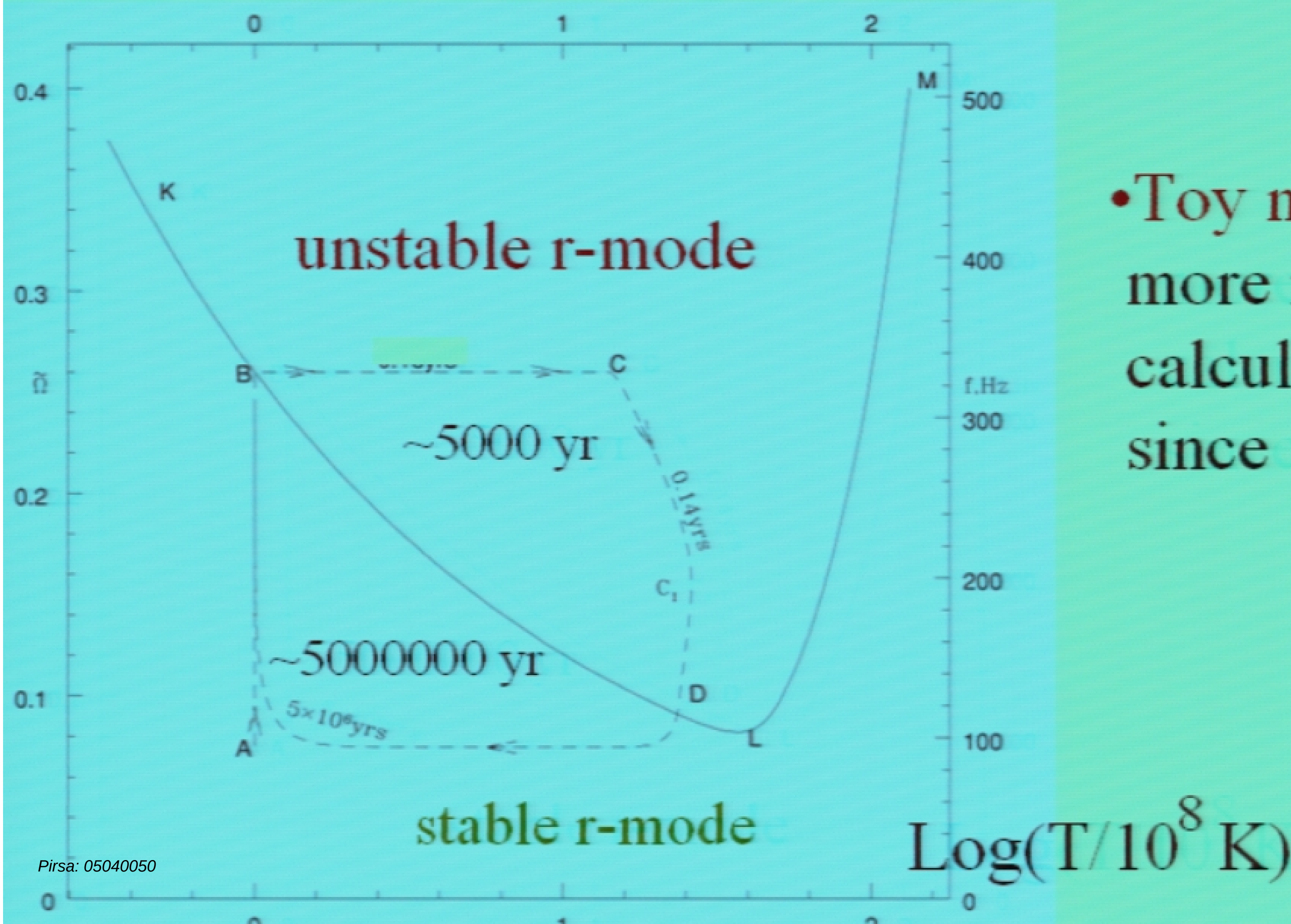

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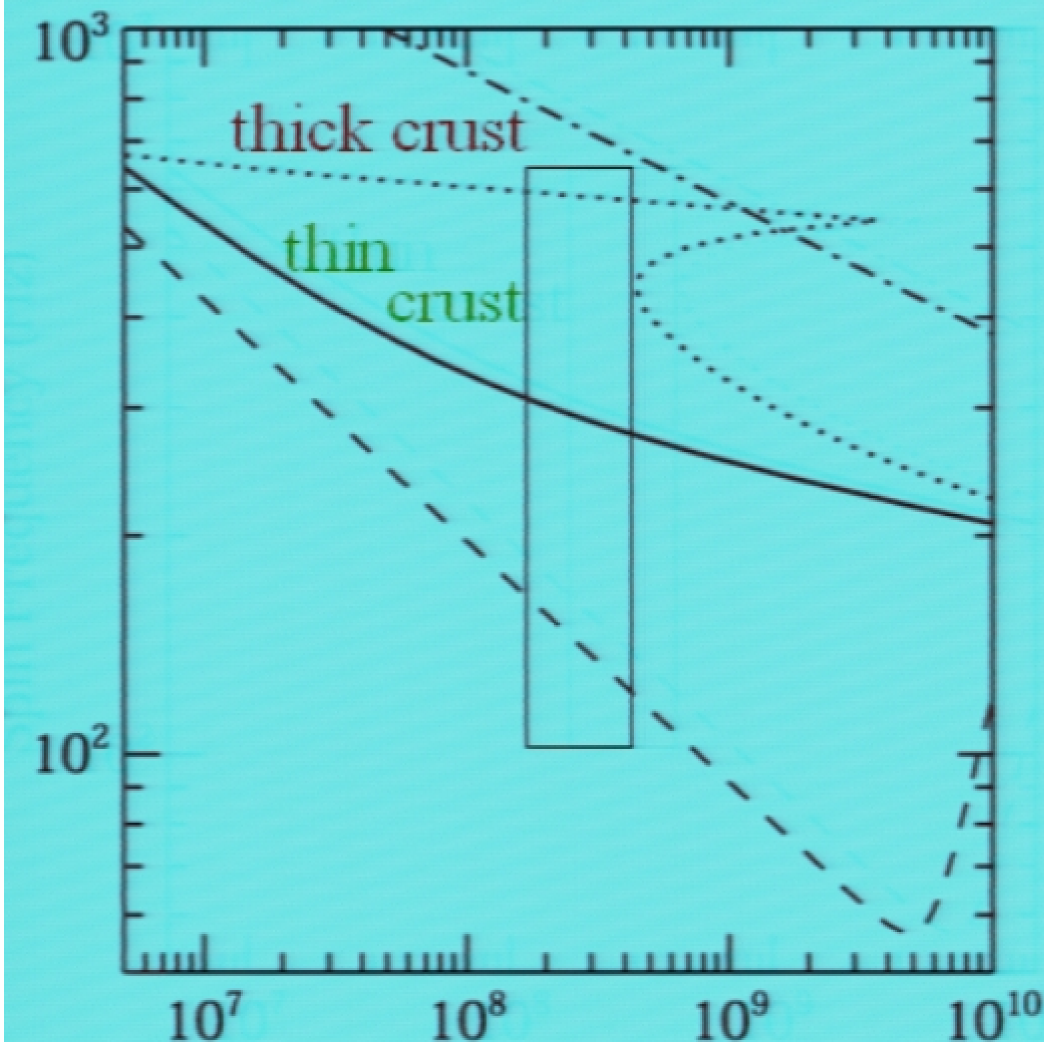

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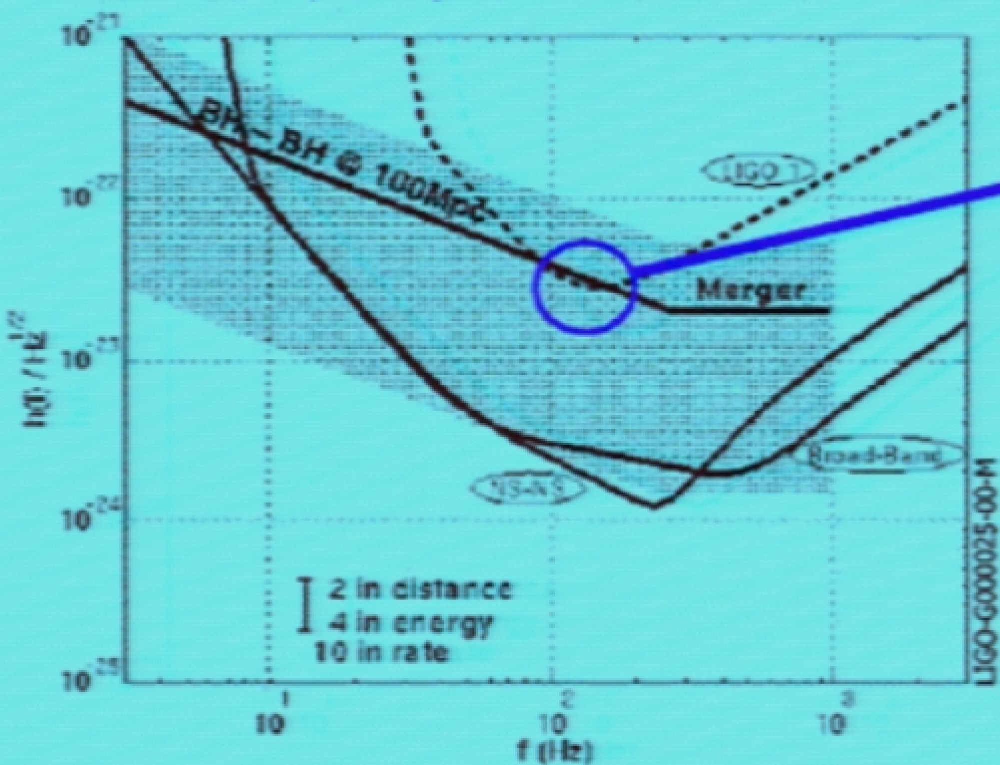
What we expect from the devils:



Thermal Noise

Limits event rate

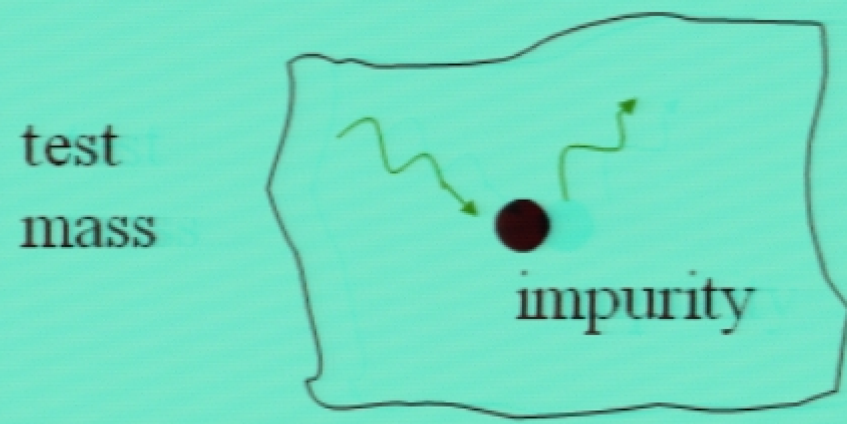
Hard to measure with LIGO

Need to verify models

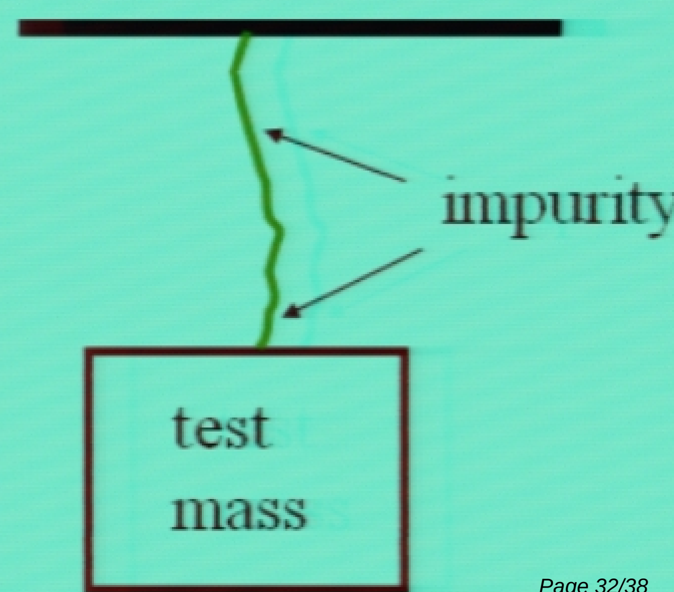
The TNI (Thermal Noise Interferometer) program measures thermal noise for LIGO I and II

Two classes of thermal noise

Internal thermal noise



Suspension thermal noise



re-98 Thermal noise computation (generally incorrect)

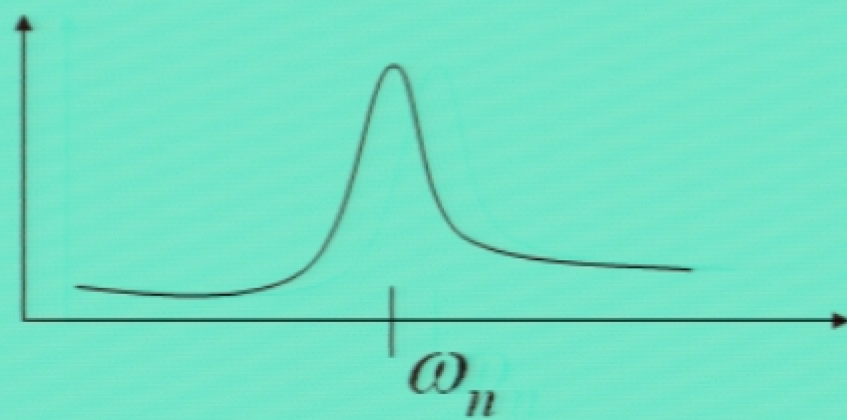
1. Decompose motion into normal modes:

x_n, ω_n, α_n $\qquad\qquad$ Q_n

avefunction $\quad$ frequency $\quad$ coupling $\qquad$ Measured Quality factor

2. Compute

$$S_n(\omega)$$



3. Add!

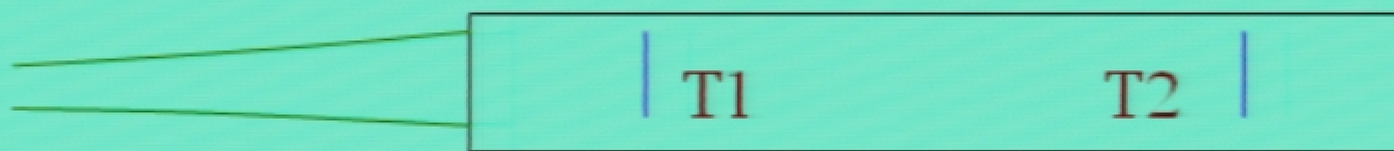
$$S(\omega) = \Sigma \alpha_n^2 S_n(\omega)$$

However: localized defects introduce correlations between modes: $\langle x_i x_j \rangle \neq 0$ Levin 98

Example:

1-D test mass with two defetcs

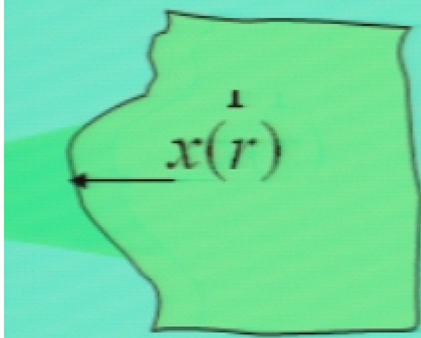
$$Q_{T1} = Q_{T2}$$



But T1 contributes more noise than T2

- Normal modes don't (always) work
- need to know where the defects are
- need a general computational approach

Fluctation-dissipation Theorem



Callen and Welton 51, Levin 98

Readout variable:

$$X = \int x(\vec{r}) \cdot (\text{Gaussian beam}) d^2 r$$

Interaction

$$H_{\text{int}} = -F_0 \cos(2\pi f t) \cdot X$$

1. oscillating pressure

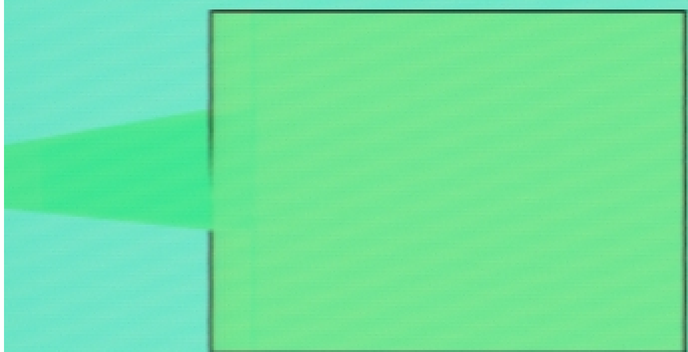
$$P(\vec{r}) = F_0 \cos(2\pi f t) \times (\text{Gaussian beam})$$

2. Compute/measure dissipated power W_{diss}

3.

$$S_x(f) = \frac{8 k_B T}{\omega^2} \frac{W_{diss}}{F_0^2}$$

Structural thermal noise: (Saulson 1990)

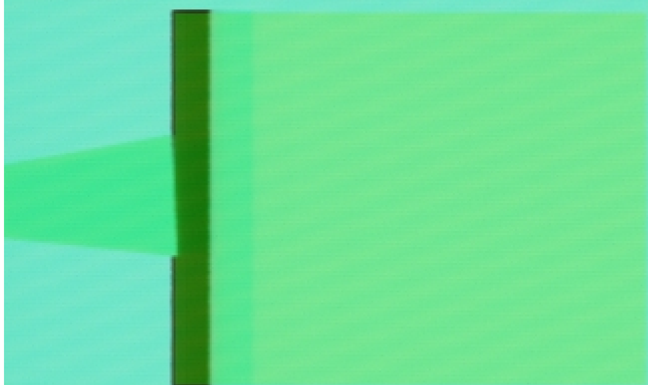


- Homogeneous distribution of defects.
- Weak frequency dependence

$$S_{structural}(f) : 1/r$$

Two other types of thermal noise have been identified:

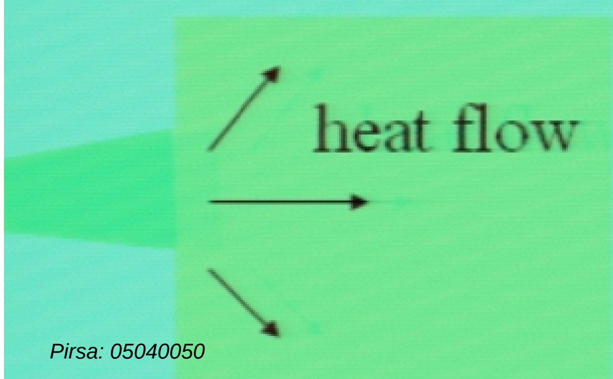
Coating thermal noise!! (Levin 98; Caltech, Stanford, Syracuse, Glasgow, Tokyo, Moscow)



important for LIGO-1 and dominant for LIGO-II (fused silica)

$$S_{coating}(f) : 1/r^2$$

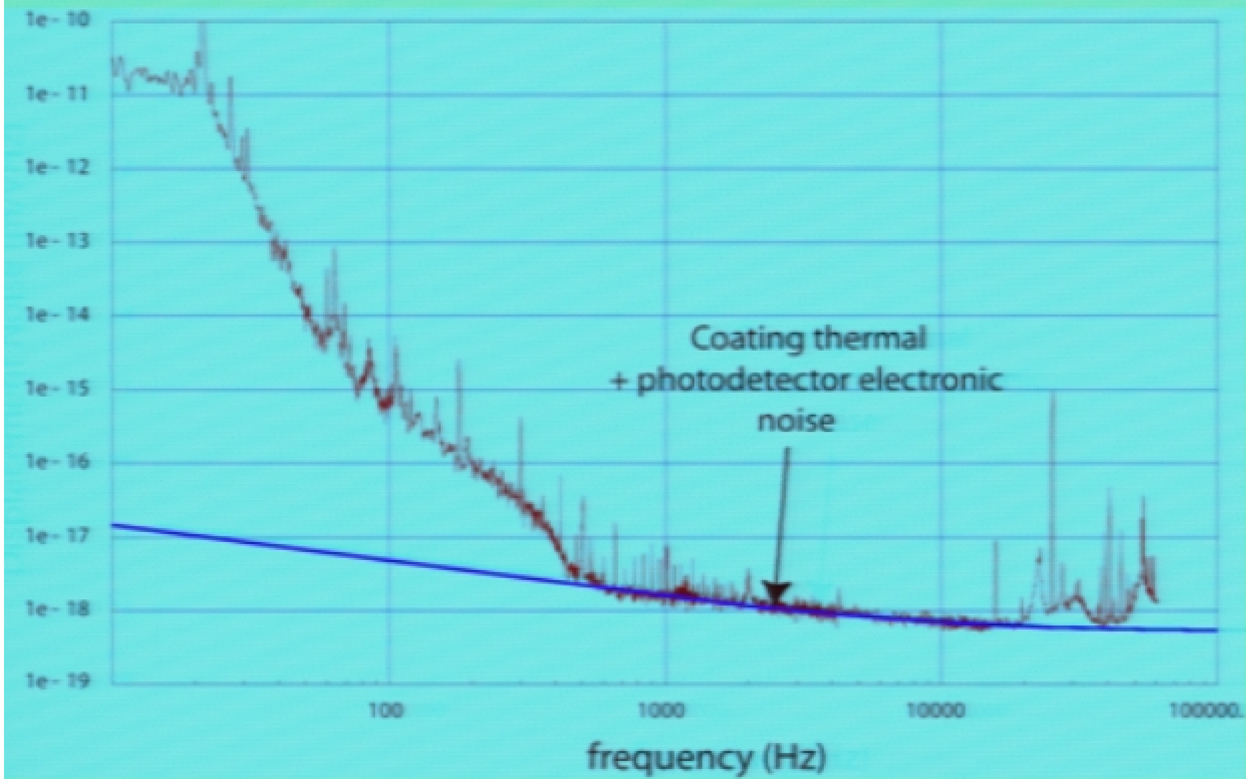
Thermoelastic noise (Braginsky et. al. 00)



Dominant for LIGO-II (saphire)

$$S_{thermoelastic}(f) : 1/r^3$$

Latest Sensitivity Curve: 10/23/03



- Major improvements since August LSC meeting:
  - Increased modulation depth to suppress photodetector electronic noise.
  - Careful calculation of thermal noise to account for multiple mirrors, difference measurement.
- Best sensitivity is now approximately 5e-19 m/√Hz.
- Noise floor appears to be dominated by coating thermal noise from approx. 500 Hz to 20 kHz.