If we were all born deaf
the discovery of hearing
would be momentous.

We are born deaf
to the sounds of the universe.

Soon we will be able
to listen to the gravitational
sounds of the universe!

AIGO and Gravitational Waves - Science for the Future

David Blair

Australian Consortium for Gravitational Astronomy

University of Western Australia

Australia-Italy Workshop on Gravitational Wave Detection

- Italian Embassy: Dr Nicola Sassanelli
- Gravity Discovery Centre
- UWA
- DEST

AIGO

- **WA Government**
  - 2000: Site, Cornerstation building
  - 2005: Centre of Excellence
- **Federal Government**
  - DEST Systemic Infrastructure Grant
  - ARC Discovery grant

Gravity Discovery Centre

- Numerous industry supporters
- State Regional Infrastructure
- Federal Regional partnerships
- Mr Jim Zadko

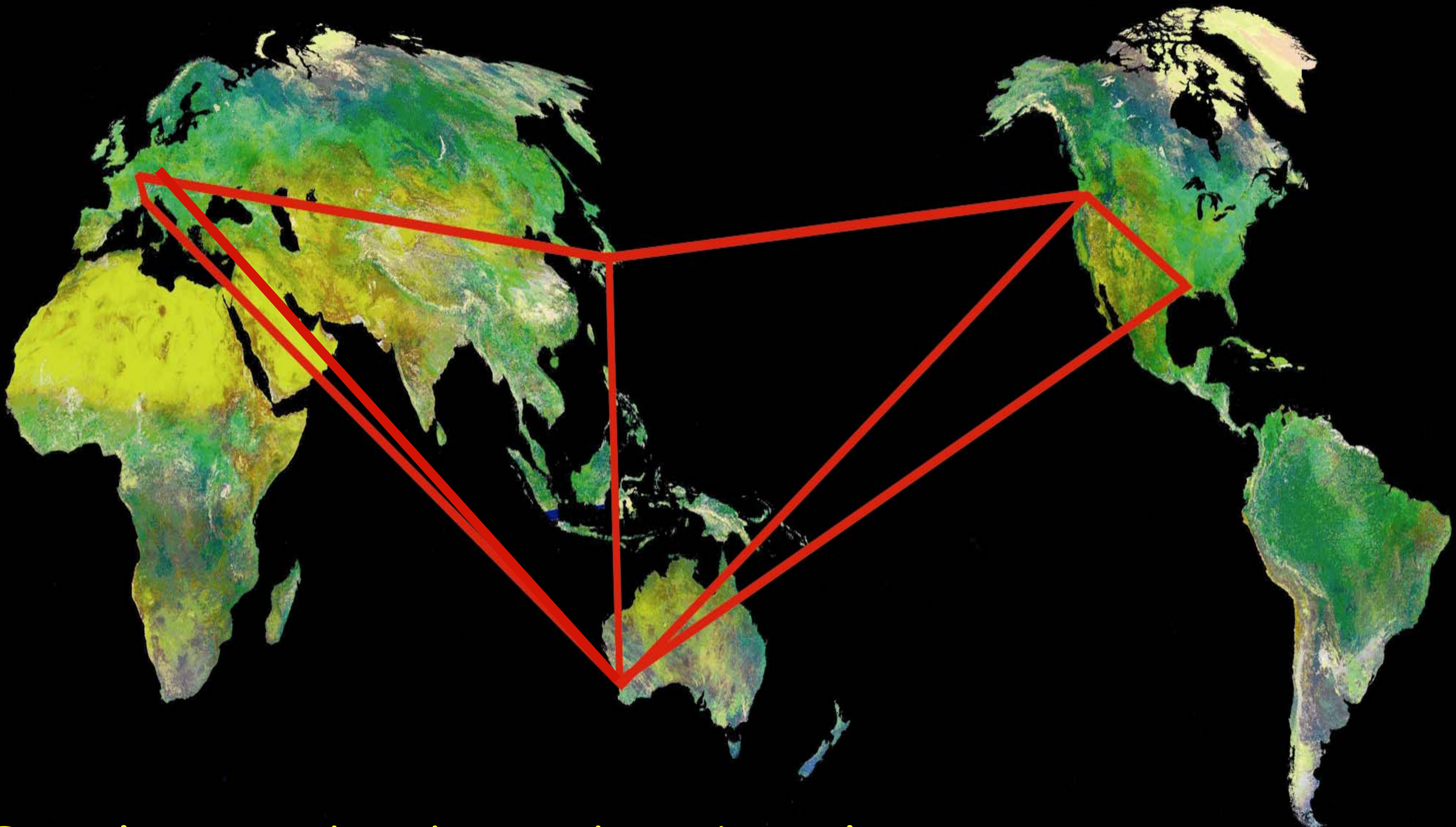
Participants

Thanks to our international and interstate participants

Italy, France, Germany, Japan, China, USA

and

ANU, Melbourne, U of Adelaide, and CSIRO

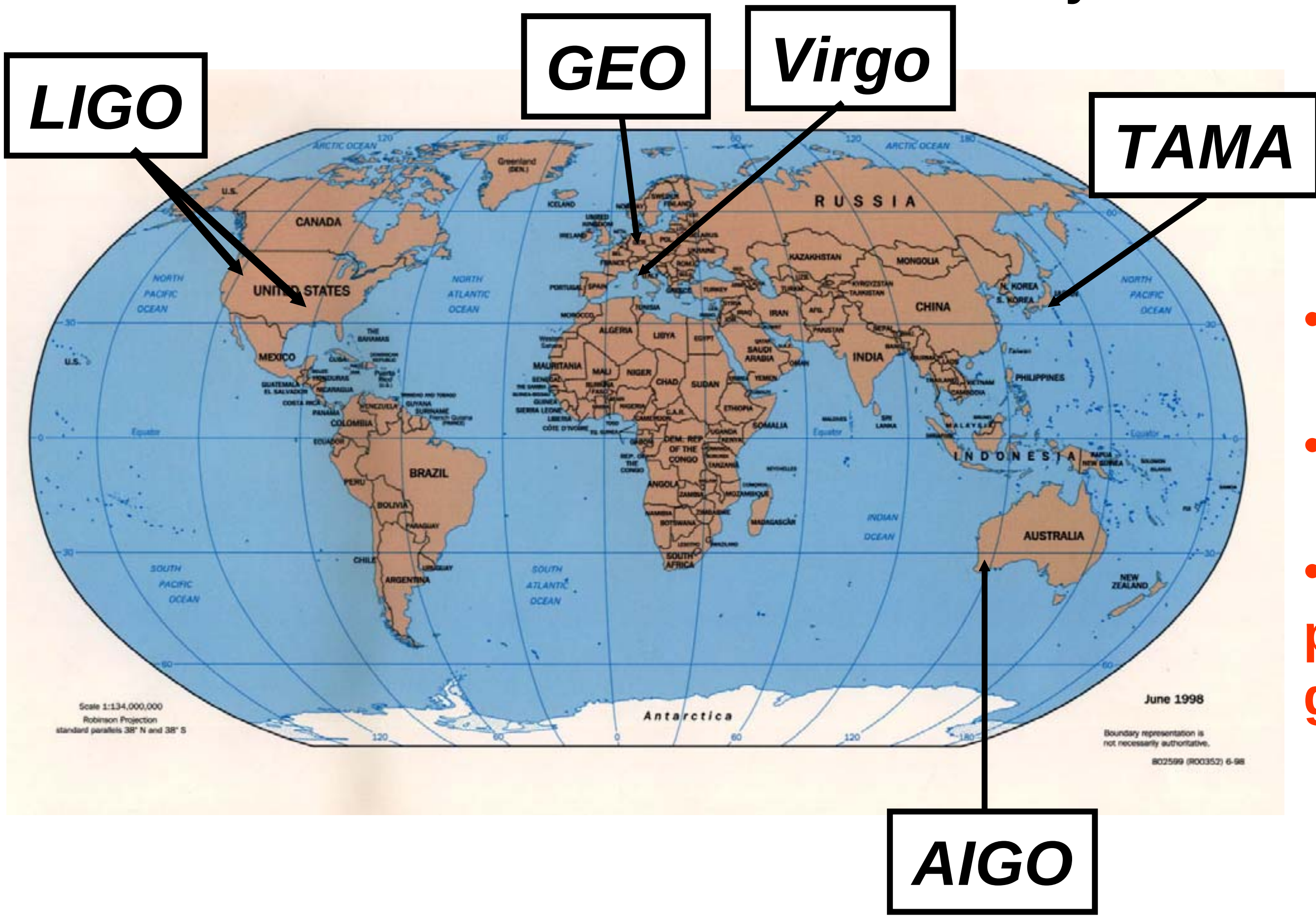


Five long and independent baselines:

Better SNR and much better directional resolution

Toward a Global Network of GW Detectors

Simultaneously detect signal (within msec)



- Detection confidence
- Locate sources
- Decompose the polarization of gravitational waves

LIGO

Einstein's Waves can be detected!

but to do so requires

- enormous ingenuity,
- enormous innovation,
- enormous dedication,
- enormous world wide cooperation.

- This workshop is another demonstration of the international support for our shared vision

Here at the AIGO science precinct we also share your concern for the environment,

- - We are combining our science with education, from the big questions of the universe to renewable energy, preservation of our unique environment and respect for indigenous culture

The next step

- **Take AIGO to an observational instrument**
  - from 80 meters to 2 kilometers
  - bring significant new welding technology to WA
  - Increase local competitiveness
  - Leaverage federal funding
  - Create the southern hemisphere node
  - Boost science education

AIGO: a national project

- Configuration design, photodetection and autoalignment: ANU, UWA
- Lasers, wavefront sensing: U of A
- Isolation, suspension, infrastructure, thermal lensing: UWA with MIT
- Digital controls: LIGO,VIRGO and UWA
- Seismic studies: Monash and UWA
- LIGO: test masses, suspensions and much support and advice.
- Vacuum System: UWA with CSIRO(MIT) and Duraduct
- Sources and data Analysis: Melbourne,UWA, ANU

Why so cheap?

- Large investment so far
- Most elements except vacuum pipe already being developed for 80m interferometer
- Cheap site infrastructure
- Pipe fabrication machine already in Perth
- Competitive Australian resource industry.

What does AIGO Provide?

- Five new independent baselines near to the maximum possible on Earth.
- Improved SNR and greatly improved direction resolution for incoming waves.
- Boost to both physics and steel fabrication industry.(WA Govt goal)
- Symbiotic with SKA as both will be searching for transient and cosmological signals

Thank you for coming!

AIGO: the next stage

- Long baseline AIGO could be constructed ready to operate in partnership with Advanced LIGO soon after AdvLIGO is commissioned.
- It can be created very cheaply!


EXIT

Gravitational lens,

General relativity

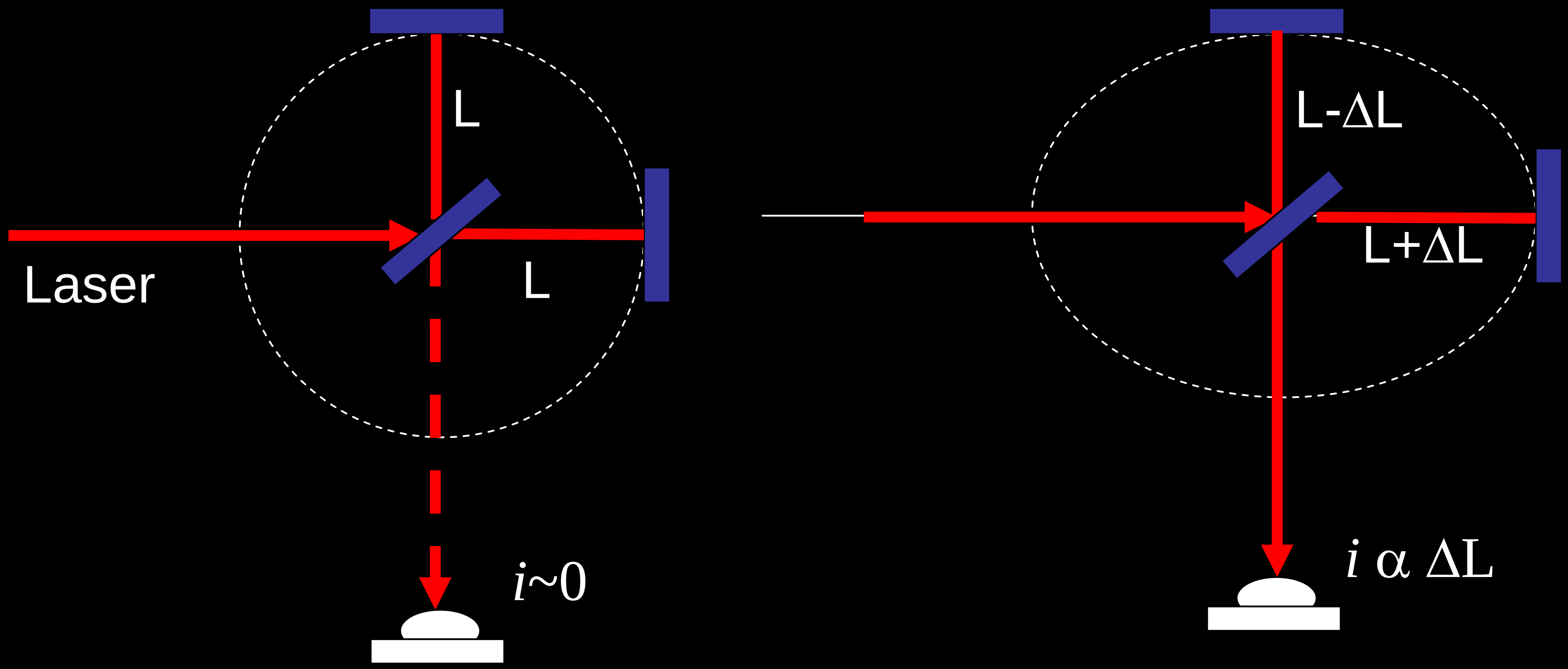
and gorilla pendulum.

Gravity Discovery Centre

Public Education

- Deep public ignorance on General Relativity
- Creation of a centre devoted to General Relativity, Cosmology and the Universe.
- Creation of a mini-campus to increase infrastructure and create public support for large scale gravitational wave detector.
- School education programs closely linked to the school curriculum.

Interferometric Gravitational Waves Detectors:

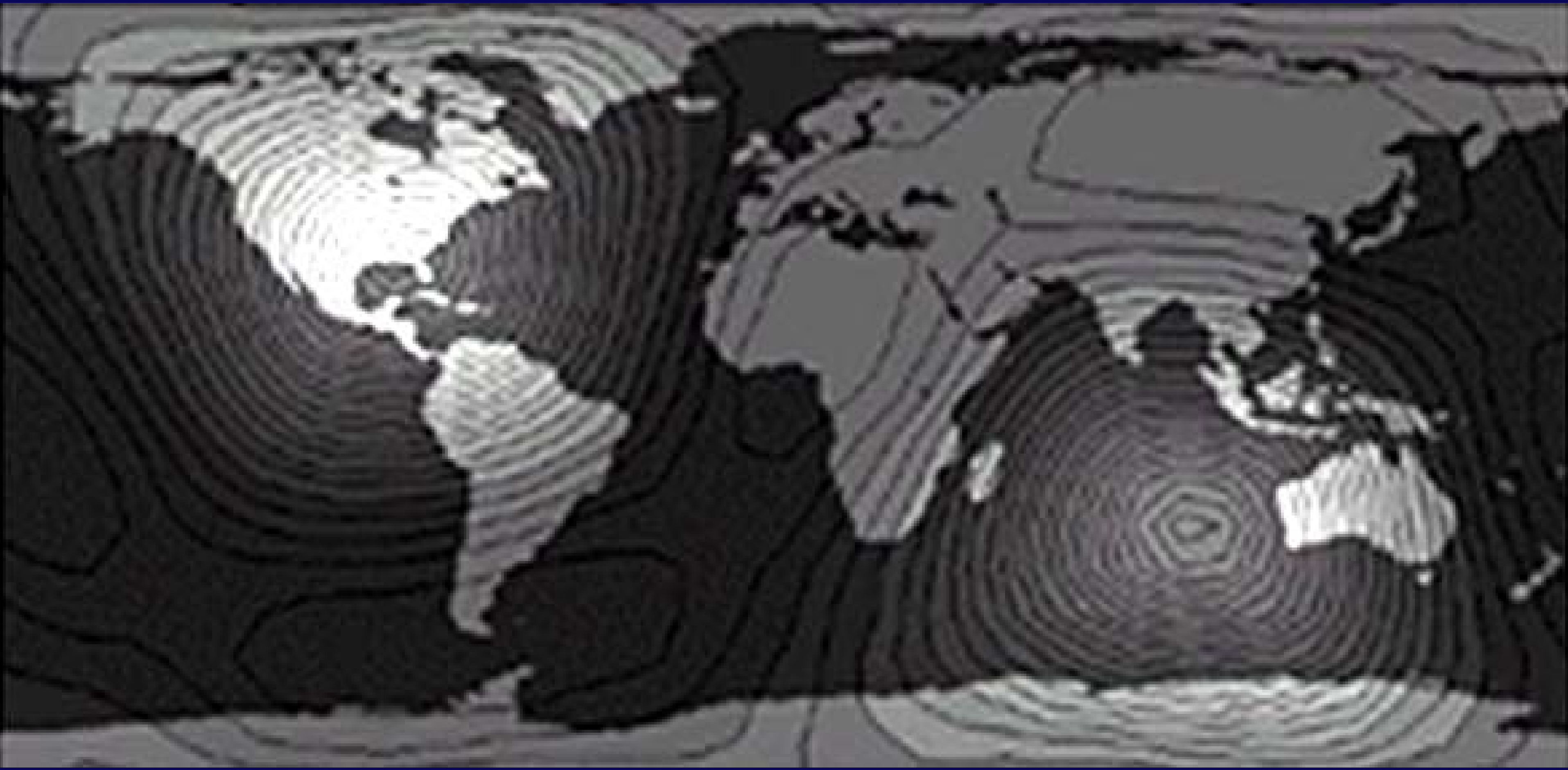


They can detect distances ΔL smaller than ***a proton diameter***!!

They can work at many frequencies: they are “broadband”’

They need to be VERY long : 100 km arms folded into few km

Where is the best location?



- modelling by ACIGA ANU

ACIGA and AIGO

- **Consortium formed 10 years ago**
  - ANU,UWA,Adelaide,Monash,ECU,CSIRO
- **AIGO site given by WA government**
- **AIGO stage 1: laboratory development completed**
- **AIGO stage 2: short baseline advanced detector:**
  - begun 2000, now well underway
- **AIGO stage 3: long baseline advanced detector:**
  - planning, costing underway now

Australian Consortium for Gravitational Astronomy

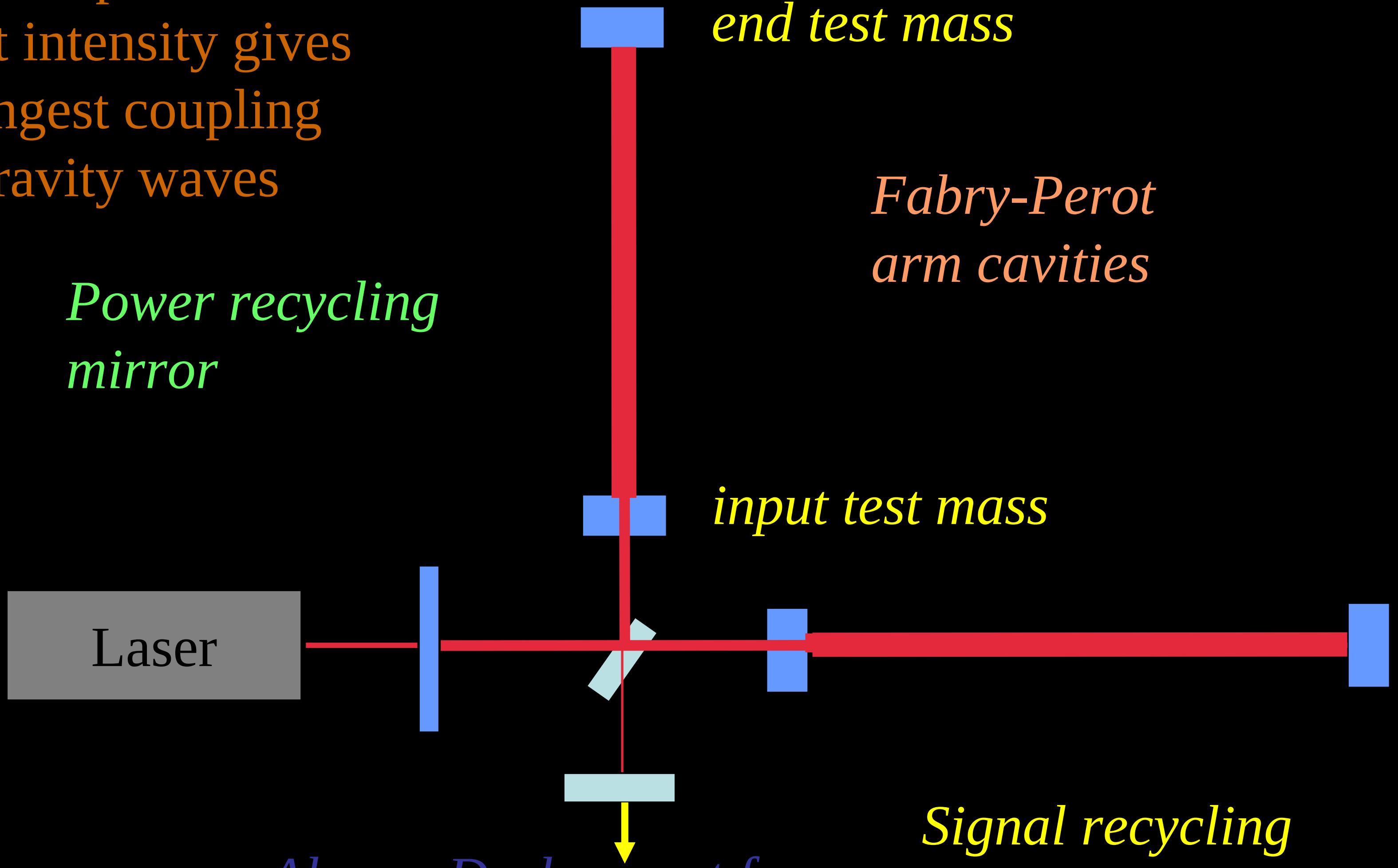
squeezed by a passing gravity wave!

ACIGA and Advanced LIGO

- Advanced LIGO is the second stage of LIGO, designed to achieve astronomy capability.(2009)
- Approved by National Science Board
- Joint US-UK-Germany-Australia project.
- Australia to contribute high optical power R&D plus output optics (total $11M) to be spent in Australia
- $6M already spent (Gingin R&D)
- With final installment we will be full partners in Adv-LIGO

Optical Configuration

Highest possible light intensity gives strongest coupling to gravity waves

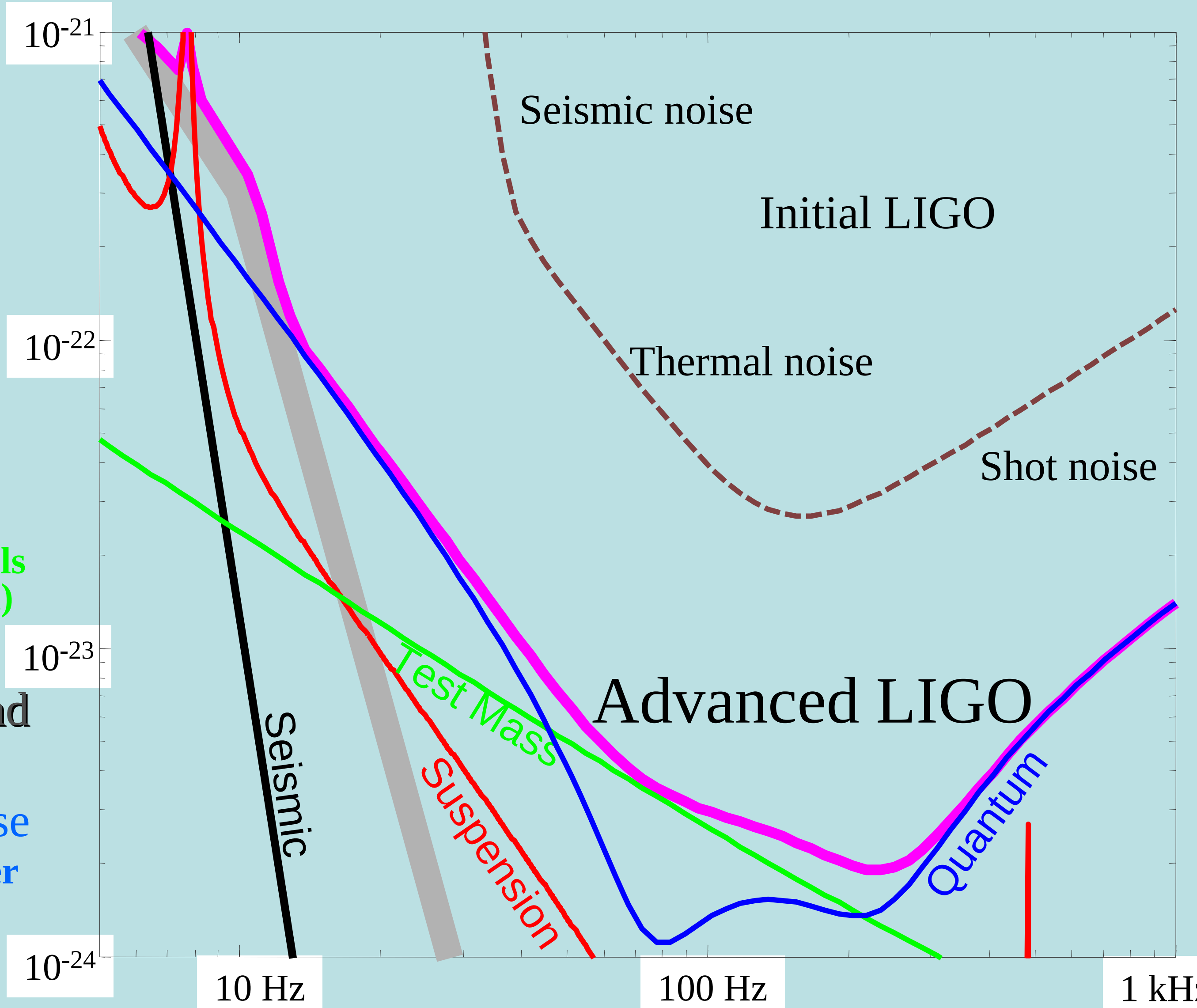


Why High Optical Power?

- **Seismic 'cutoff'**
  High performance vibration isolators
- Suspension thermal noise
  Very low loss suspension scheme
- Test mass thermal noise
  Very low loss materials (sapphire, fused silica)
- Newtonian background
- Unified quantum noise
  Optimized laser power

↓

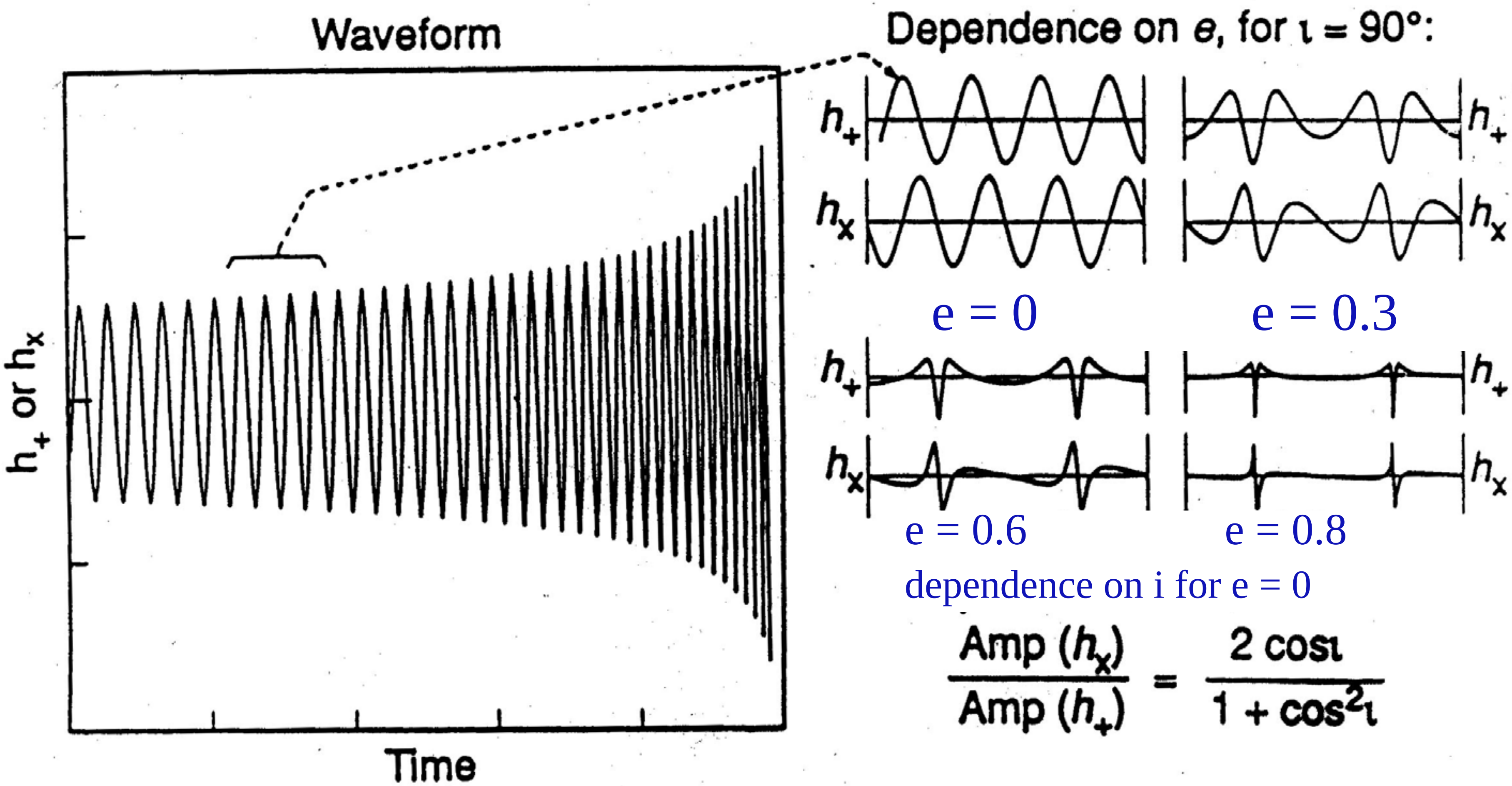
Need factor of 100 increase in Power



Factor of 10 improvement in sensitivity

Binary Inspiral Chirp Signal

Waveform determines: Distance from earth r, Masses M_1 and M_2, Orbital eccentricity e, Orbital inclination *i*

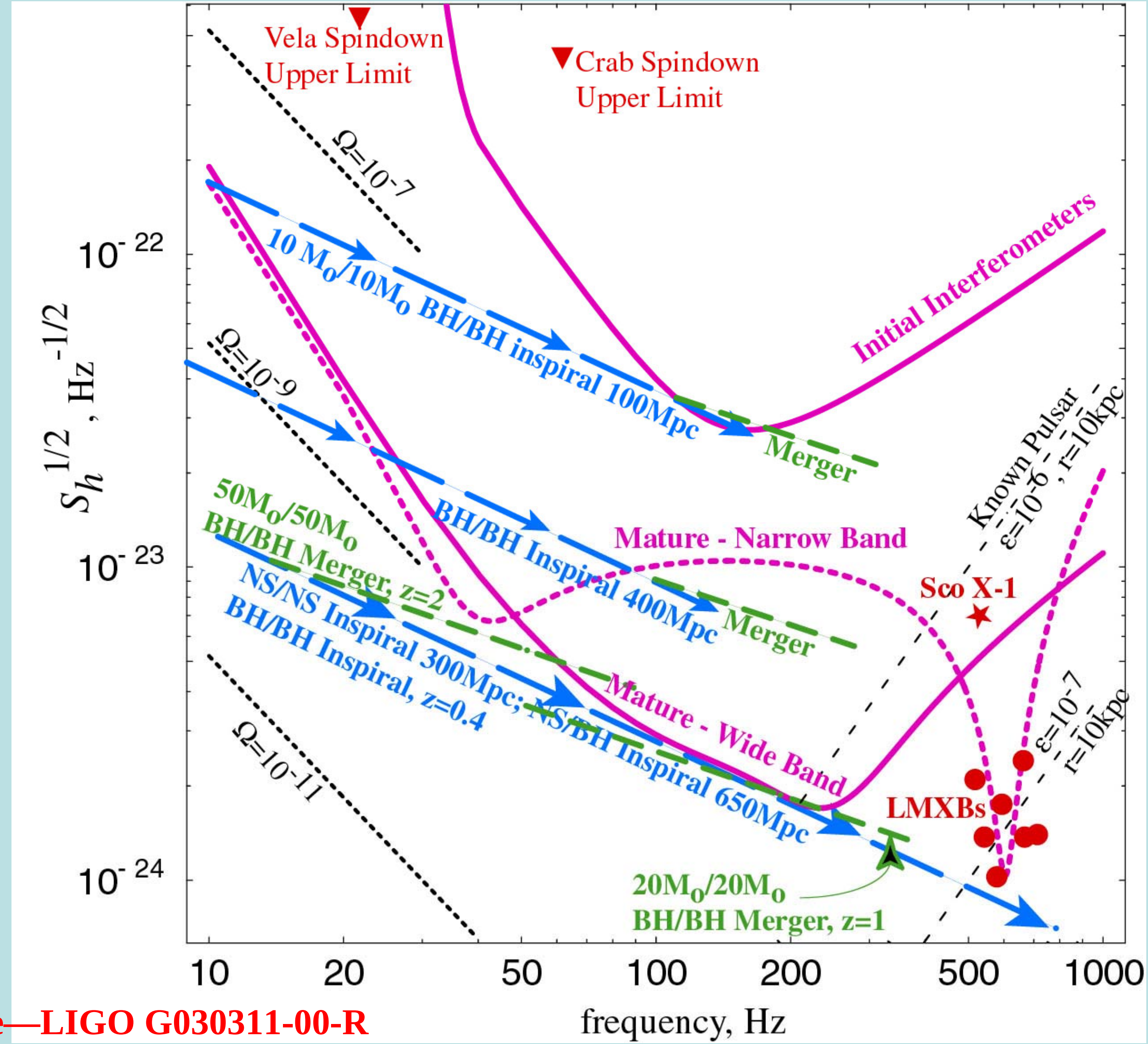


$$\frac{\mathrm{Amp}\,(h_\times)}{\mathrm{Amp}\,(h_+)} = \frac{2\cos\iota}{1+\cos^2\iota}$$

Exciting Discovery of 2003

- **Double Pulsar J0737-3039**
  - Short orbital period…2.5 hours
  - Short lifetime to coalescence…85Myrs
  - Low luminosity
  - Nearby…600pc
- **There should be a big population of such objects.**
- **Hence increased signal rates…10 times more….still large uncertainty**

Overview of Sources



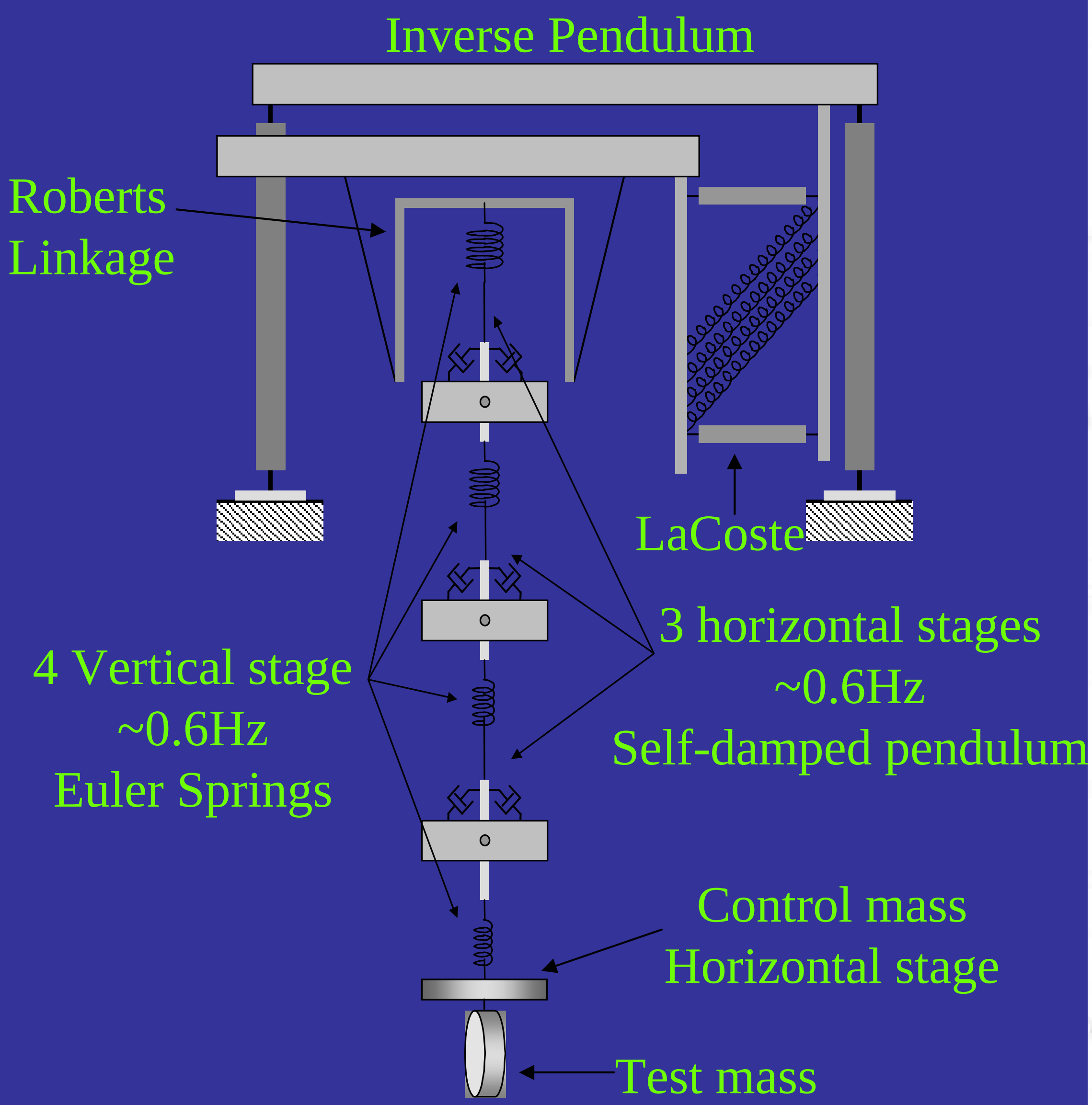
Kip Thorne—LIGO G030311-00-R

Expected Inspiral Detections

	NS-NS	NS-BH	BH-BH
LIGO range Mpc	20	40	100
Adv-LIGO range Mpc	350	700	1500
LIGO events per year	6.10^{-3}-0.7	3.10^{-4}-0.3	4.10^{-3}-3
Adv-LIGO events	5 - 3700	1.5 - 1500	15 -10,000

Central Station

Main Suspension System



Science Progress

- Routine locking and optimisation of optical "LIGO arm" optical cavity (Slagmolen: AOS/Laser)
- How to control thermal lensing …tunable lenses and mirrors (Degallaix AOS poster)
- Acoustic modelling of inhomogeneous losses in test masses.
- Parametric Instabilities: singing interferometers…photons creating phonons (Zhao ASGRG Poster)

Science progress (2)

- How to build a non-astigmatic mode cleaner (Barriga, AOS/Laser)
- Stochastic background modelling and detection: unified model for distant stochastic sources and nearby rare sources.
- Correlation between scattering and absorption in sapphire test masses (Yan AOS poster)

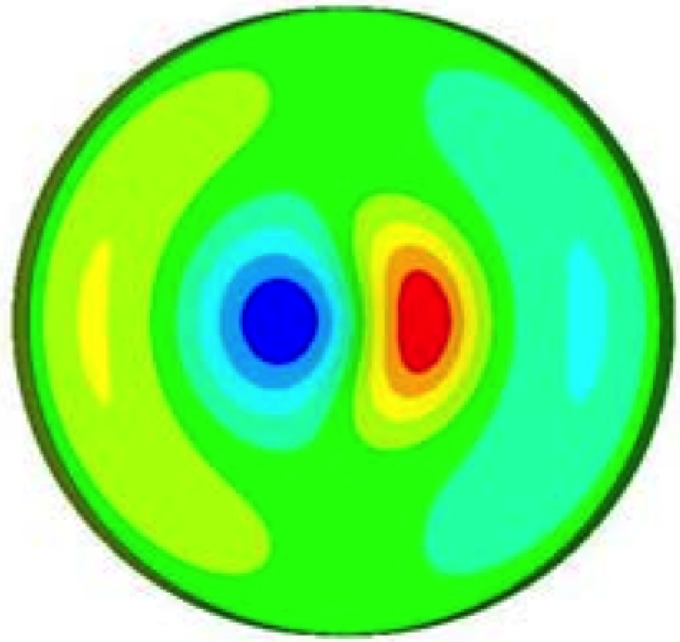
Parametric Instabilities

- Photons scatter to create phonons
- Critical frequencies around 30kHz and 70kHz
- Optical high order mode (HOM) mode shape matches acoustic mode shapes
- Optical HOM difference frequency matches acoustic mode frequency

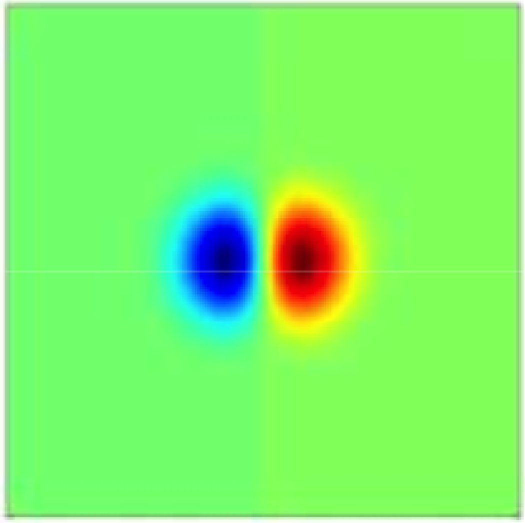
- Acoustic mode shape

- Optical mode shape

- They match!



(b)



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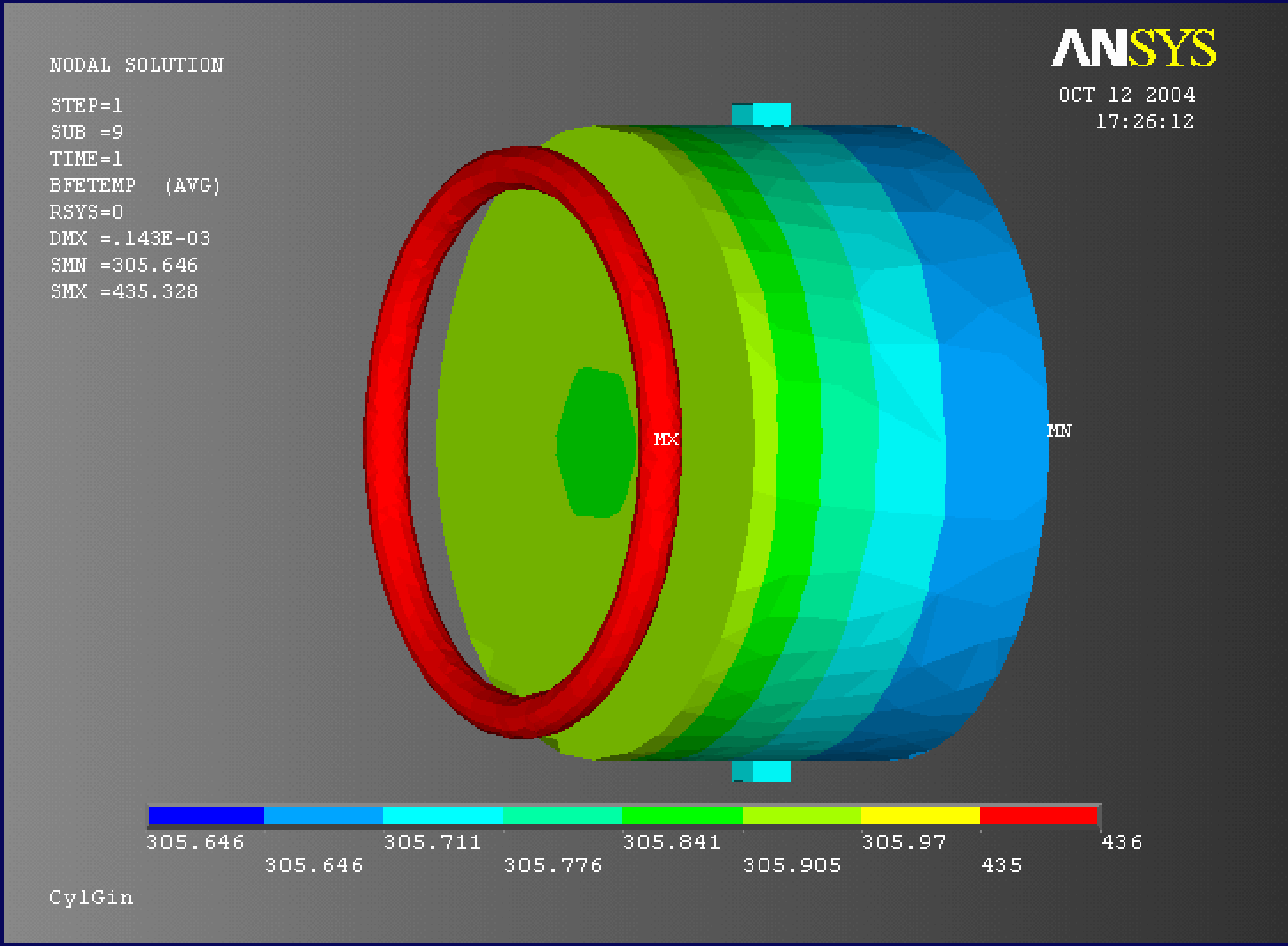
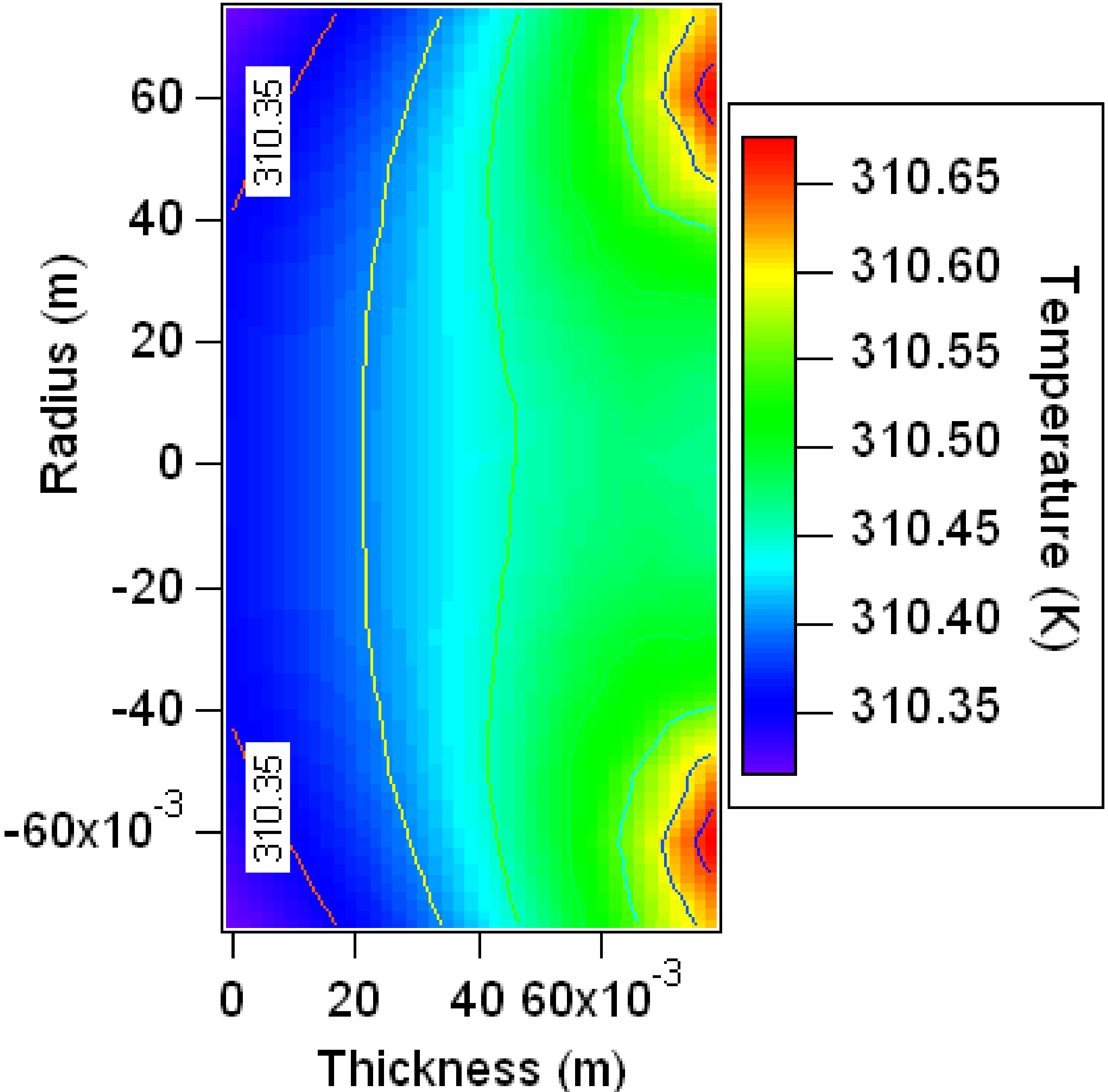
Tuning Parametric Instabilities

- HOM difference frequency is tuned by radius of curvature.
- Thermal tuning of mirrors can allow detuning.
- Parametric gain can be tuned down as long as mode density is not too high.

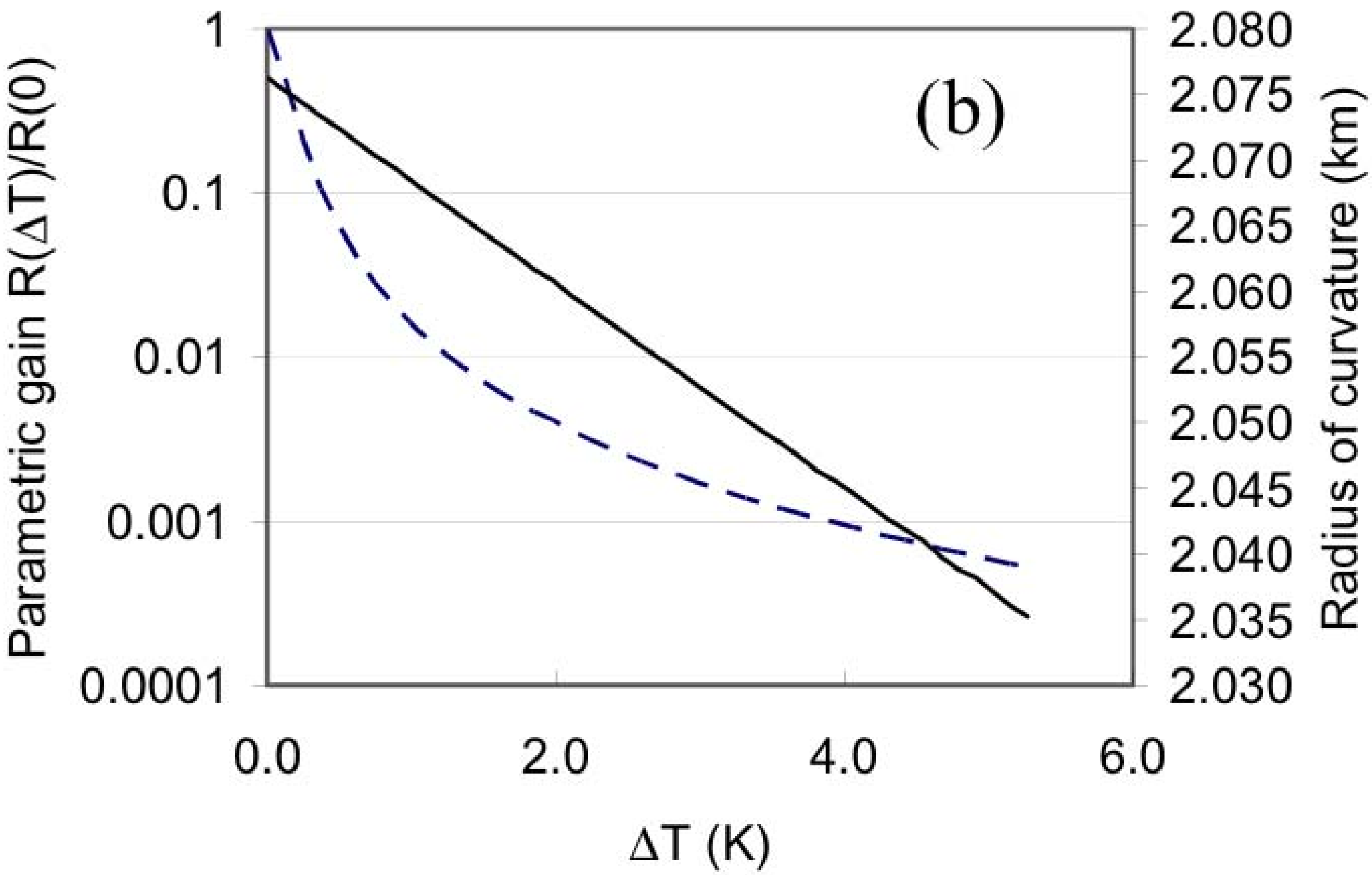


NODAL SOLUTION
STEP=1
SUB =9
TIME=1
BFETEMP (AVG)
RSYS=0
DMX =.143E-03
SMN =305.646
SMX =435.328
ANSYS
OCT 12 2004
17:26:12
MX
MN
305.646
305.646
305.711
305.776
305.841
305.905
305.97
435
436
CylGin



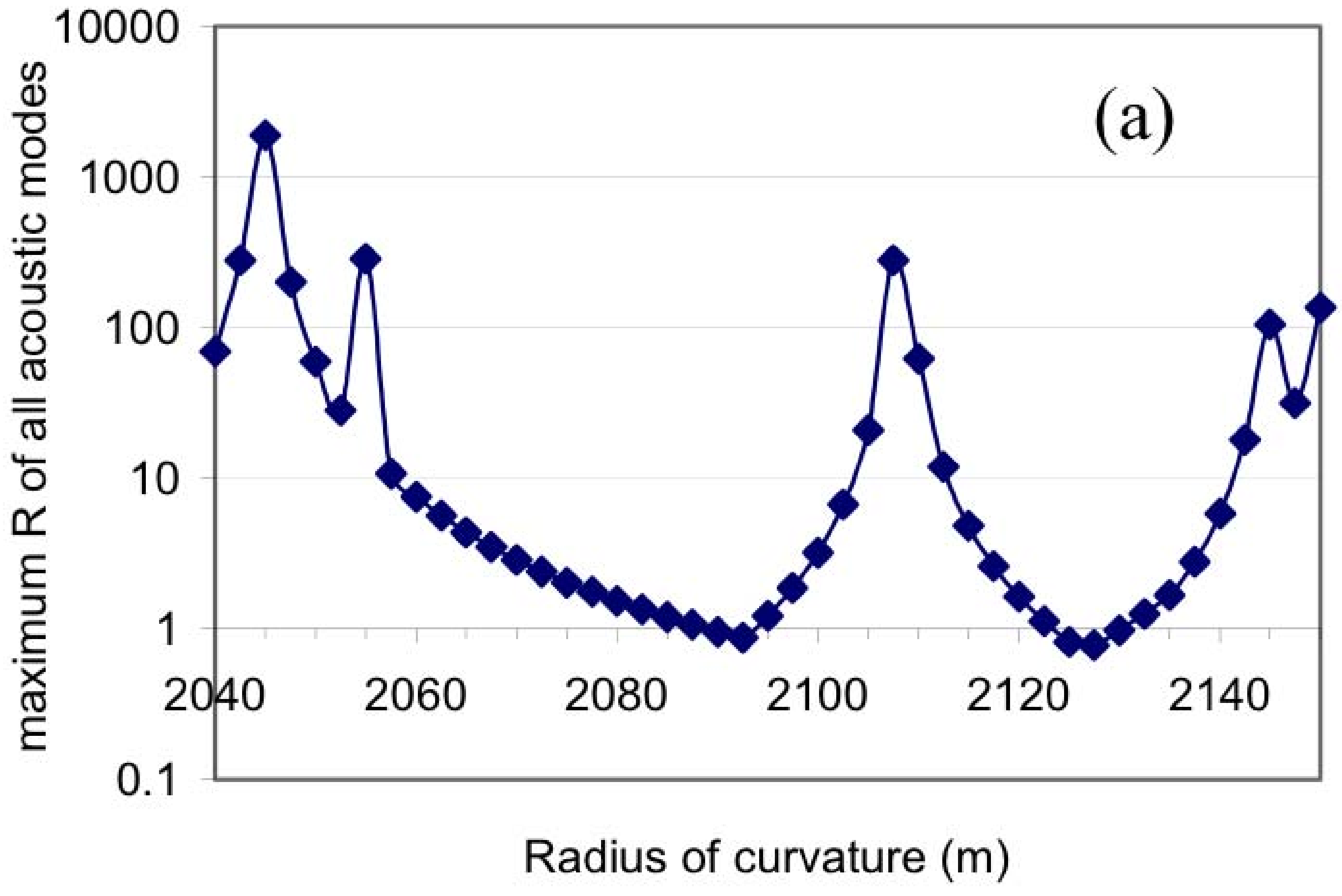
310.35
310.35
60
40
20
0
-20
-40
-60x10-3
Radius (m)
0
20
40 60x10-3
Thickness (m)
310.65
310.60
310.55
310.50
310.45
310.40
310.35
Temperature (K)

Radius of Curvature Tuning



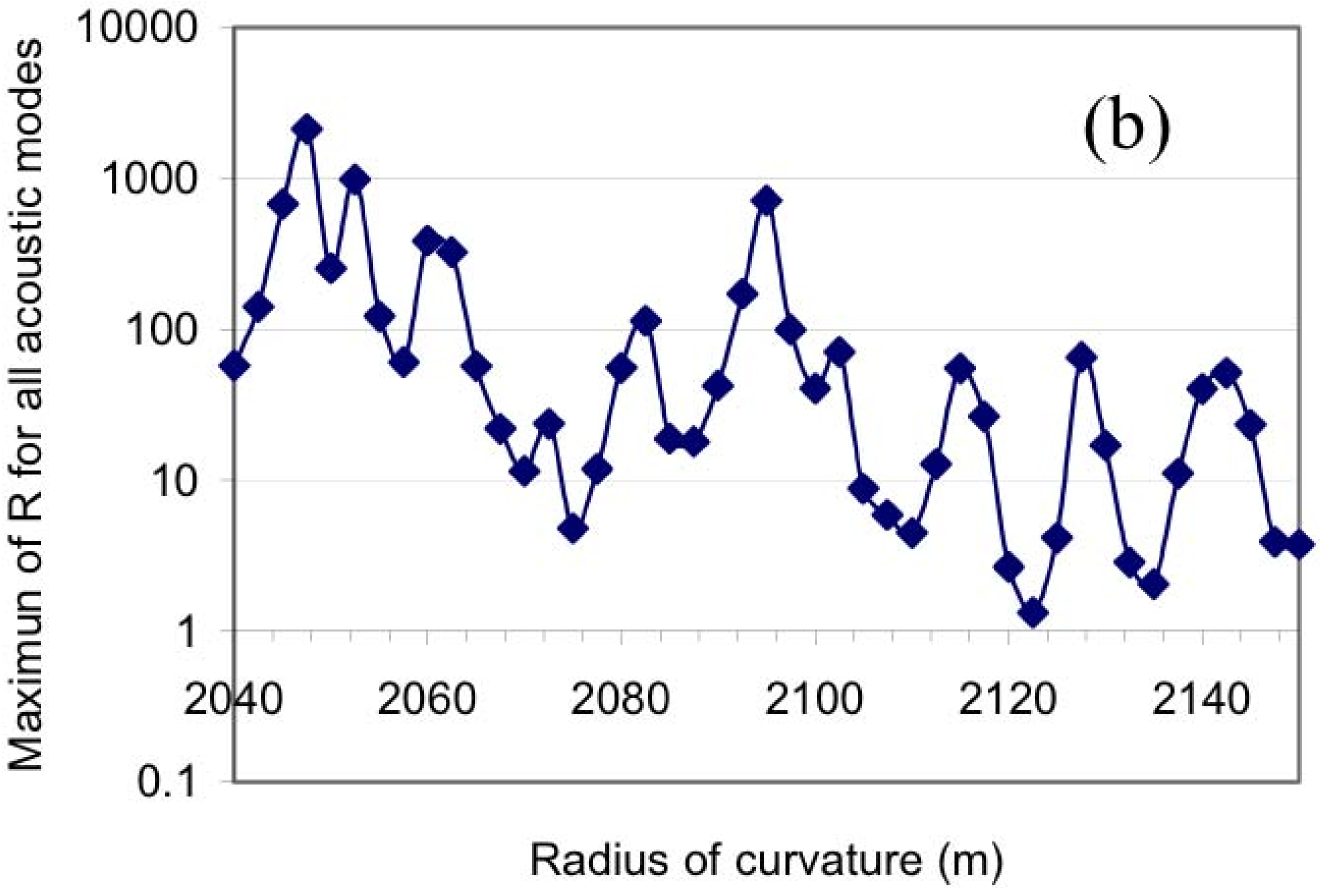
- HOM frequency changes with curvature

Advanced LIGO sapphire



- Two stable points

Advanced LIGO Fused Silica



- No stable points. Best position: two singing modes per test mass.

Problems

- Power outages in the bush: need uninterruptible power
- Usual need to optimise wiring to reduce electrical interference
- High air flow noise from some clean room equipment
- Need optical fibre link instead of satellite (high latency problem)

Conclusion

- Exciting science now and much more to come.
- We are ready to design and build AIGO
- AIGO will allow the world array to localise sources within less than 1 arc minute
- AIGO already helping boost physics through its public outreach

Costing to Upgrade to 2 (4)km

- Roughly $20M ($30M)
- Vacuum pipes $7.5M ($15M)
- ACIGA offered LIGO partnership
- AIGO could be in partnership with LIGO.
- Matching optical configuration, matching data analysis, shared data

International Planning Workshop April 2004

- ACIGA has major R&D role defined for next 3 years
- Gingin best site for southern hemisphere detector
- Minimum length for future AIGO: 1km
- WA Govt vacuum industry study underway
- Vacuum system $4M per km of interferometer (2km of pipe)
- Cost for future AIGO not a major competitor with other astronomy projects

Money

- AIGO investment to date ~ $30M
- By 2007 Gingin facility will have all the elements of a full scale Advanced detector except for half size test masses and short arms.
- Full scale isolators and suspensions,
- high power lasers,
- digital control systems
- vacuum pumping infrastructure
- data processing at ANU and UWA

- Five large scale detectors need one in the southern hemisphere to create a 3D array with long baselines.
- Best location: western edge of Australia

ACIGA

- The Australian Consortium for Gravitational Astronomy has been working towards the goal of a southern hemisphere detector for almost 10 years.

Coincident: LLO