Advanced Gravitational Wave Interferometers:
Status and Technology of Second Generation Detectors

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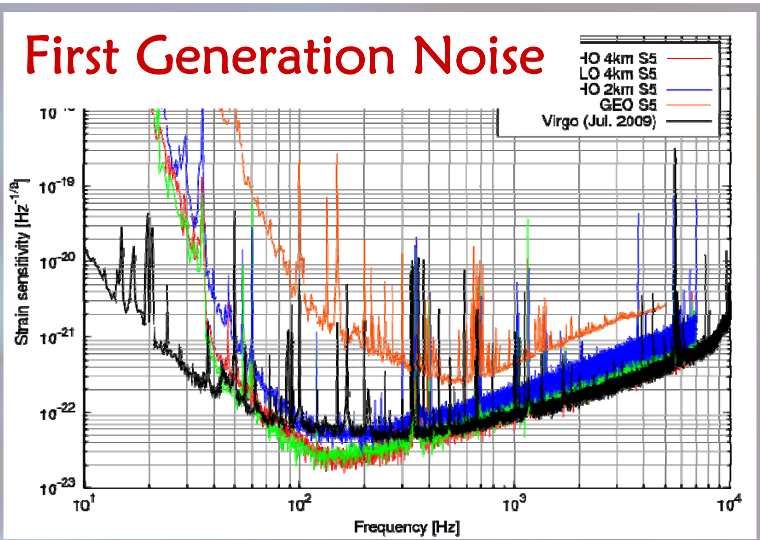
Advanced Detector Overview

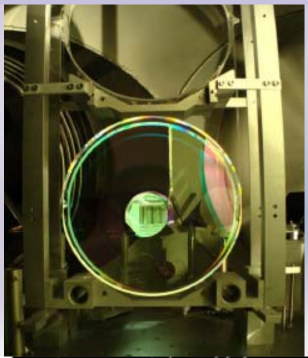
- Advanced LIGO: 4 km interferometers in Washington and Louisiana USA; 3 detectors
- Advanced Virgo: 3 km interferometer near Pisa Italy; low frequency seismic wall
- Large Cryogenic Gravitational Telescope (LCGT): 3 km interferometer in Kamioka Japan; underground, cryogenic
- GEO High Frequency (HF): 600 m interferometer near Hannover Germany; squeezed light, focused on high frequency
- AIGO: proposed 4 km interferometer in Western Australia

First Generation Accomplishments

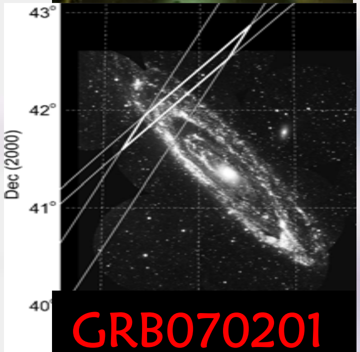
- Reached design sensitivity
  - ~ 10 W laser, shot noise limited
  - Seismic isolation, suspensions
  - (Close to) thermal noise limits



GEO 600 Suspension

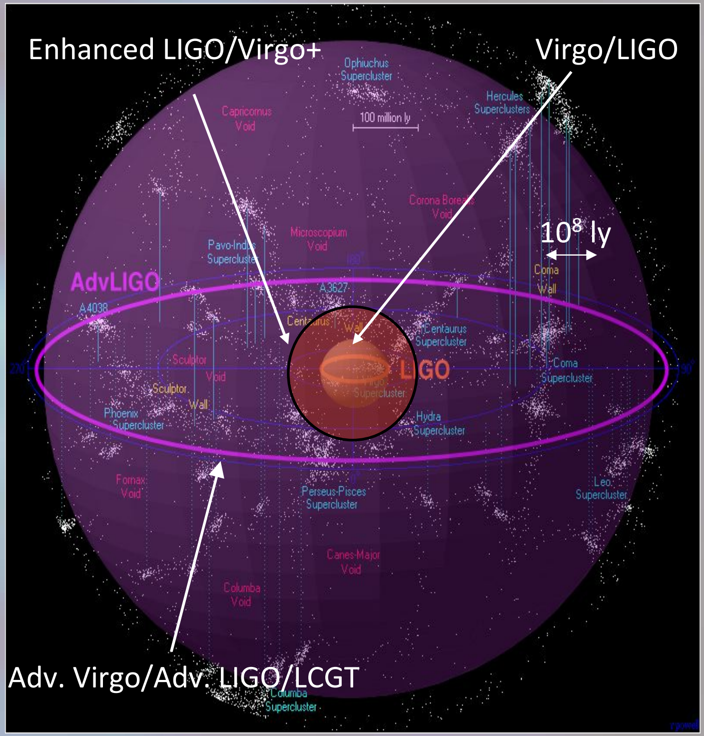


- Demonstrated important technologies
  - Signal recycling, interferometer controls
  - Monolithic suspensions
- Data provided real astrophysics
  - Crab pulsar not spinning down from GW
  - GRB070201 was not neutron star inspiral
  - Stochastic limit beat Big Bang Nucleosynthesis



Goals for Advanced Detectors

- Detections of gravitational waves
  - Gravitational wave astronomy
- Sensitivity and reach
  - ~150-200 Mpc binary neutron stars
  - ~10 better than first generation
- Wider bandwidth than first generation
  - Down to ~10 Hz
  - Tunability at higher frequencies
- Network of comparable detectors
  - Europe and North America
  - High sensitivity Asian plus southern hemisphere detectors



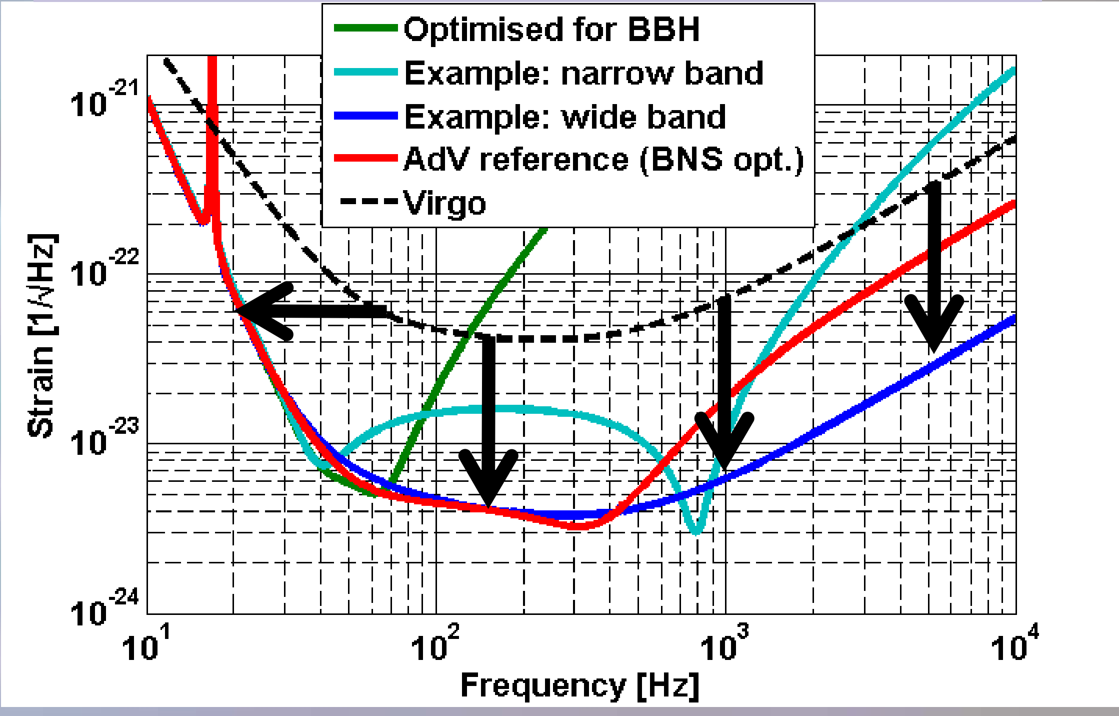
Credit: R.Powell, B.Berger

Astronomical Reach of Second Generation Detectors

Sensitivity Limitations

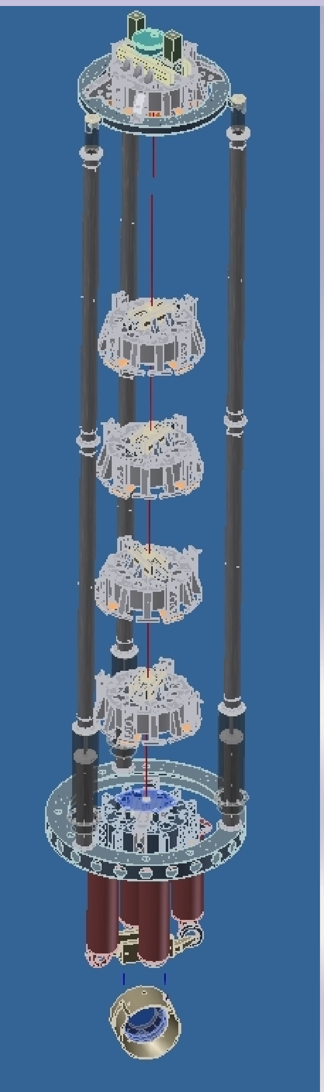
- Seismic noises
  - Seismic noise
  - Gravity gradients
- Thermal noises
  - Suspensions
  - Coatings
  - Substrates
- Quantum noises
  - Shot noise
  - Radiation pressure

Second Generation Improvements in Noise and Bandwidth



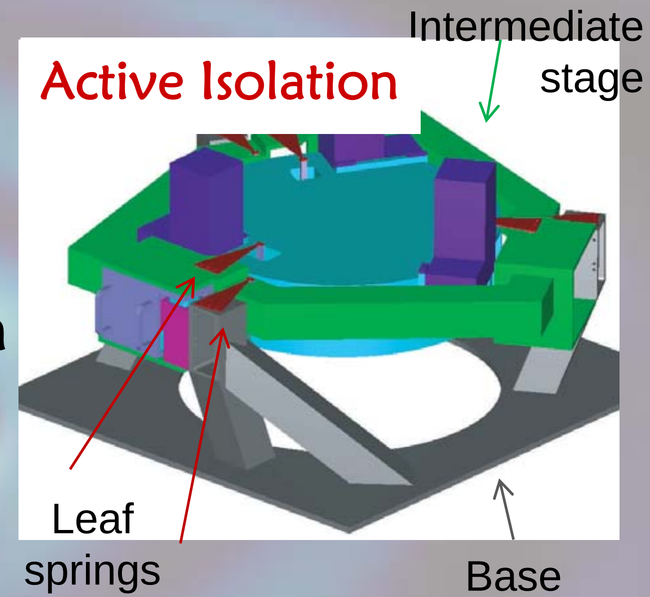
Seismic Noise Solutions

Superattenuator



Superattenuator

- First generation in Virgo
- Advanced Virgo, LCGT
- Multi stage passive isolation
- Geometric anti-spring



Suspension Point Interferometer

- LCGT, possible in others
- Reduce seismic noise at top of suspension

Active Isolation

- Advanced LIGO
- Possibly AIGO
- Feedback controlled

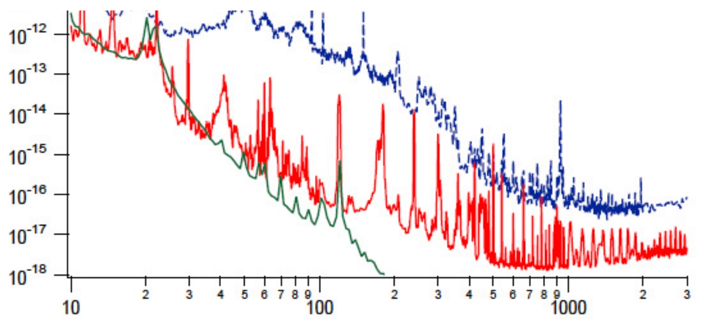
Research: Excess and non-Gaussian noise from environment

Gravity Gradient Solutions

Underground detector

- Symmetry from ground above /below reduces gradients ~ 10
- Seismic noise down by ~10^4
- LCGT to be 100-200 m below ground in Kamioka mine

Underground Noise Reduction



Research: Reduce seismic effects of equipment, finding suitable underground sites

Adaptive Filtering

- Array of seismometers used to fit out noise
- Under consideration for enhancements to other detectors

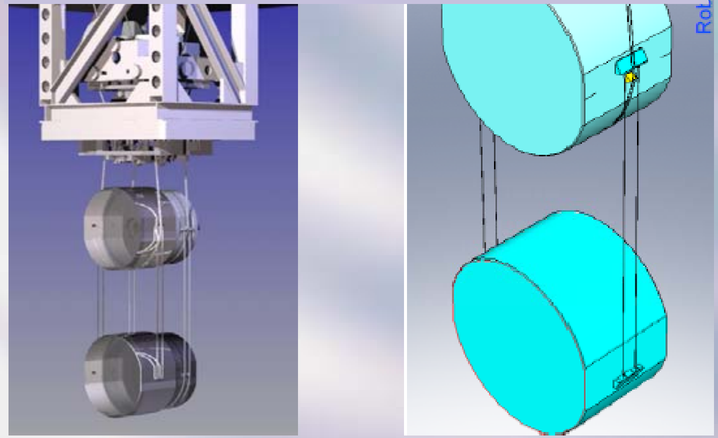
Suspension Thermal Noise Solutions

Cryogenic Sapphire Ribbons

- LCGT, 15-20 K suspensions
- Lower temperature reduces thermal noise directly
- Low thermoelastic noise
- Sapphire-sapphire bond

Cryostat at Kamioka

Monolithic Suspensions



Monolithic Fused Silica Fibers

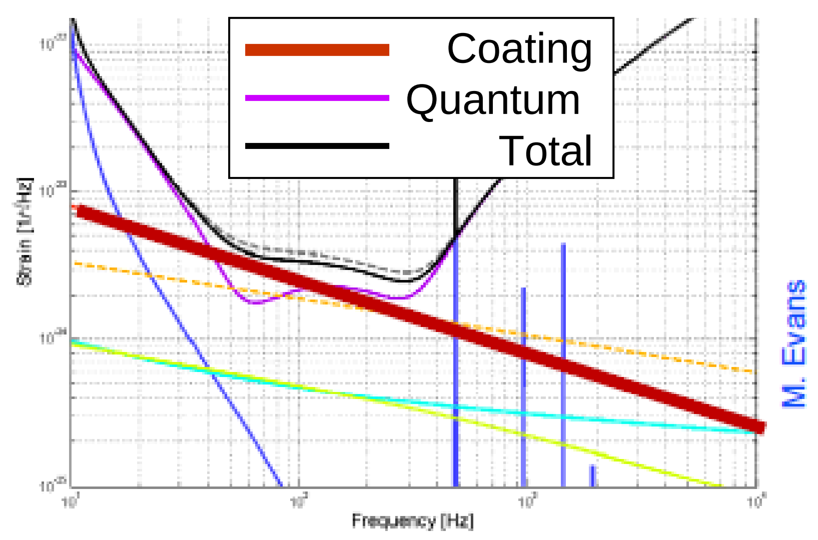
- First generation in GEO 600
- Advanced LIGO, Advanced Virgo, AIGO, GEO HF
- Silicate bond connections
  - Shear: Advanced LIGO, GEO HF
  - Compression: Advanced Virgo?
- See G. Hammond and H. Vocca talk

Research: Excess and non-Gaussian noise from bonds and welds

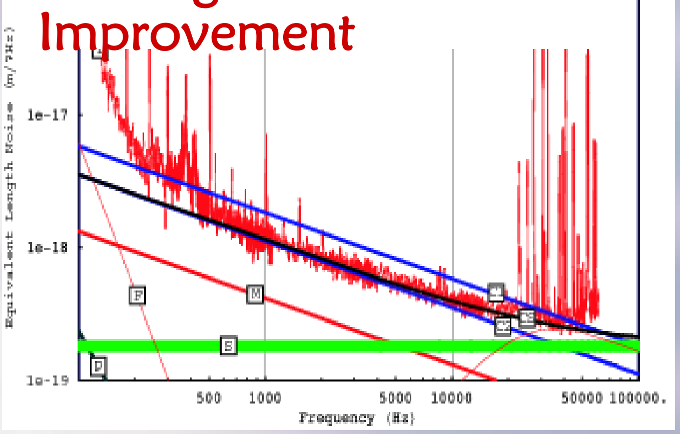
Coating Thermal Noise Solutions

- Larger laser spots ~ 6 cm
- Improved material; titania doped tantala
  - Advanced LIGO, Advanced Virgo, AIGO
- Optimized design, minimizes high mechanical loss material
  - Advanced LIGO, AIGO
- See E. Black's talk Friday

Expected Coating Thermal Noise



Coating Thermal Noise Improvement



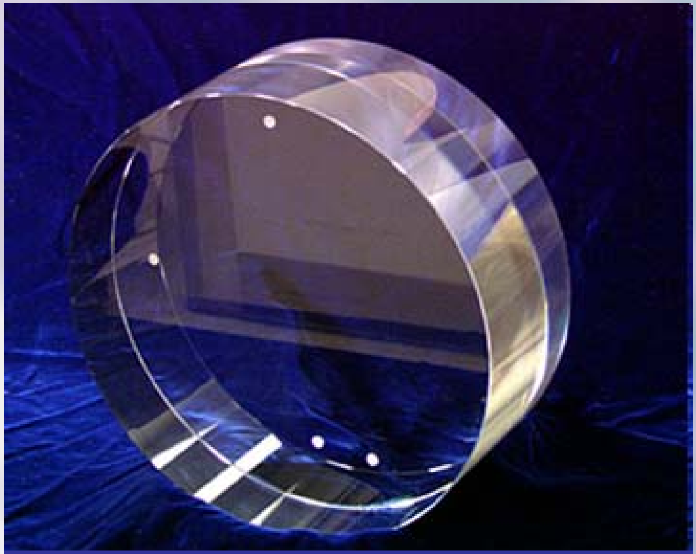
- Tantala/silica coating, 20 K mirrors
  - LCGT

Research: Material properties at cryogenic temperatures, non-Gaussian noise at high optical power, further improvements, scatter – See M. Smith talk

Substrate Thermal Noise Solutions

Sapphire

- AIGO, room temperature
- LCGT, cryogenic, 20 K mirrors
  - Very low thermoelastic noise
  - High thermal conductivity
- Lessened parametric instabilities



Sapphire Mirror

Fused Silica Substrate

Fused Silica

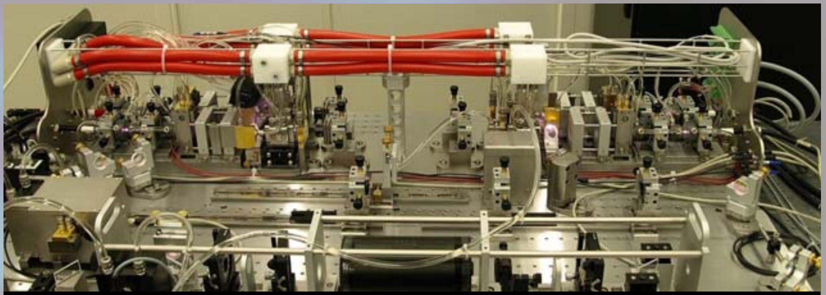
- Continued use from first generation
- Not a limiting noise source
- Advanced LIGO, Advanced Virgo, GEO HF
- See S. Hild talk

Research: Excess and non-Gaussian noise from refrigerators/heat links, charge buildup on dielectric optics

Quantum Noise Solutions I

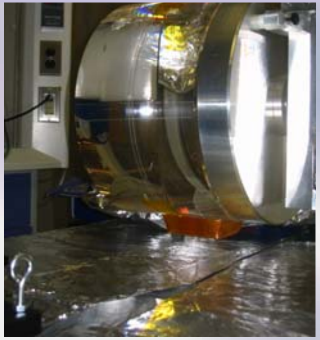
Higher Power Laser

- 150-200 W in all detectors
- Reduces high frequency shot noise
  - Increase radiation pressure
- Can cause thermal lensing



High Power Laser Prototype AEI

Moving a 40 kg optic with LIGO ERGO arm



Larger Test Masses

- ~ 40 kg in Advanced LIGO, Advanced Virgo, AIGO
- 30 kg in LCGT
- Reduces low frequency radiation pressure

Research: Parametric instabilities (reduced risk with sapphire) , thermal compensation (plans to mitigate with ring heaters/projected CO_2 lasers, see M. di Paola Emilo talk)

Quantum Noise Solutions II

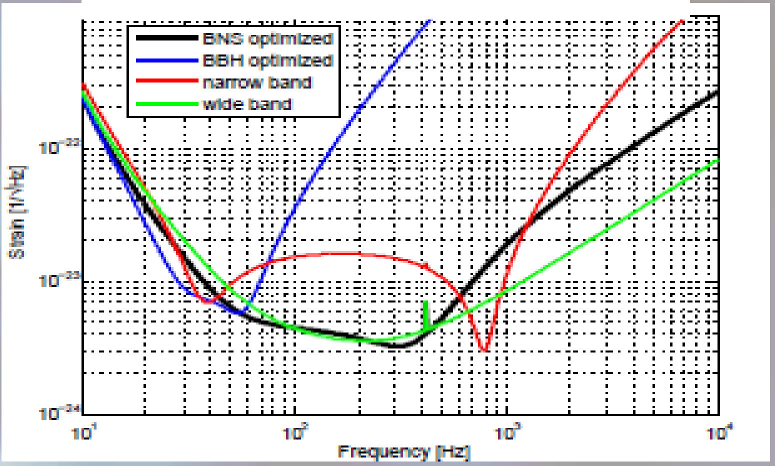
Signal Recycling

- First generation use in GEO 600
  - All detectors second generation
- Additional mirror at output port
  - Allows for some tuning of noise

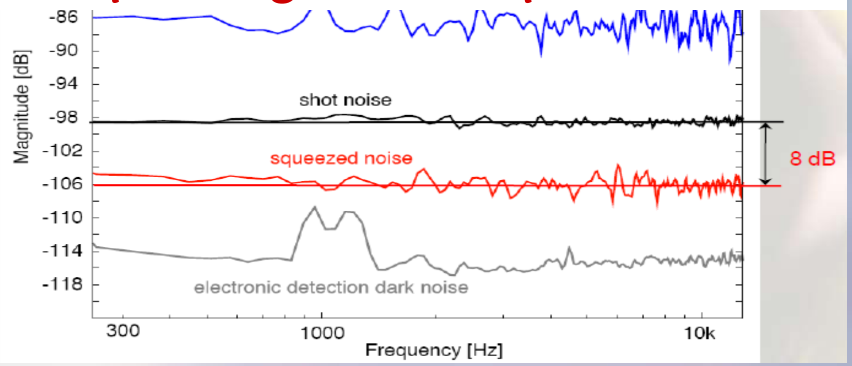
DC Readout

- No shot noise from sidebands
- Eliminates some technical noises

Signal Recycling Tunings



Squeezing Noise Improvement

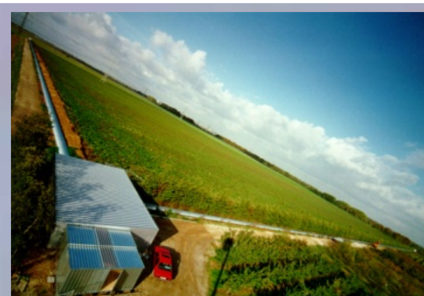


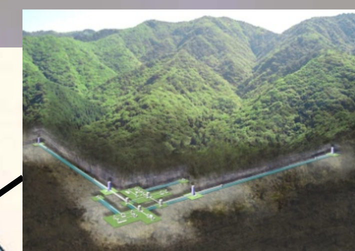
Squeezed Light

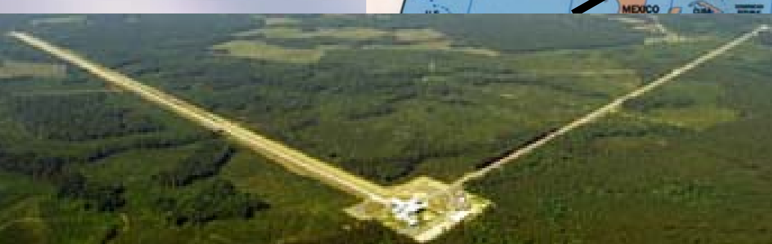
- Reduce both shot noise and radiation pressure
- Planned for GEO HF, possible enhancement in others

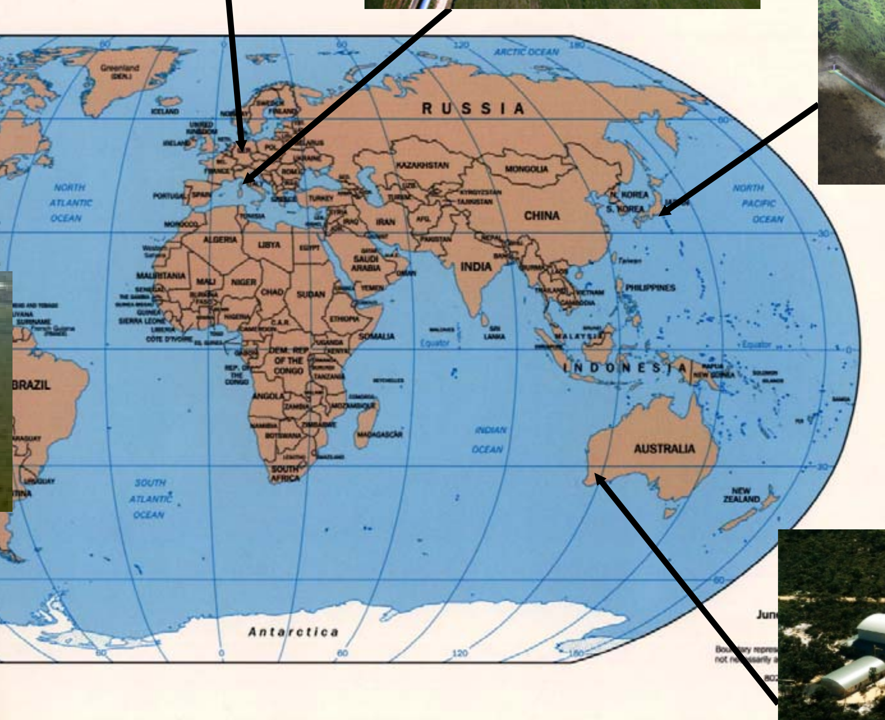
Research: Keeping optical losses low enough for squeezing

Network of Detectors



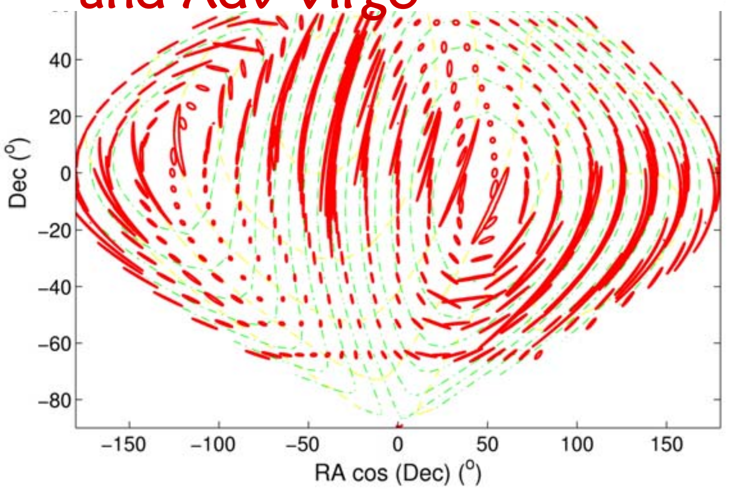






Network Benefits

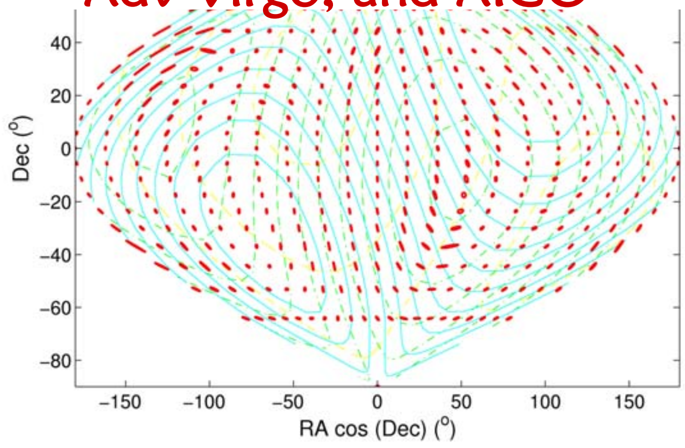
Localization with Adv LIGO and Adv Virgo



- Improved signal-to-noise ratio
- Determination of polarization
  - At least three detectors
- Better localization on sky
  - Identify host galaxies
- Greater uptime

- Greater sky coverage
  - Southern hemisphere important
- Better determination of gravitational waves speed

Localization with Adv LIGO, Adv Virgo, and AIGO



Status of Advanced LIGO

- Funded in April 2008
- In procurement/fabrication
- Installation in 2011-2014

- Prototyping in progress
  - MIT (LASTI)
  - Caltech (40 m, TNI)
  - Hanford/Livingston (enhanced LIGO, possible squeezing tests at Hanford)
- First science data ~2015

Status of Advanced Virgo

- Proposal submitted
- Expect reply soon
- Hope for funding early fall 2009

- Virgo+ prototyping many technologies
- Monolithic suspension upgrade in 2010
- Expect to finish installation 2014
- First science data ~2015
- See P. Puppo talk

Status of LCGT

- Proposal submitted
  - Funding requested for 2010
- Construction to begin 2010
- CLIO, 100 m prototype
  - Underground at Kamioka
  - Plan for cooling soon
  - See M. Ohashi talk

- Expect installation to be complete in 2014
- First science data ~ 2017

Status of GEO HF

- Funded by Max Planck Society with support from STFC in UK
- Plans for 2009
  - Squeezing installation
  - See A. Khalaidovski talk

- Plans for 2010
  - Higher laser power
  - Thermal compensation
  - Higher bandwidth signal recycling
- Science data with other detectors ~ 2015
- See H. Lueck talk

Status of AIGO

- Submit proposal soon
- Advisory panels in place
- Gingin site chosen
  - Already used for 80 m prototype

- Advanced LIGO base
  - Australian technology where appropriate
- International partners
  - GEO : laser
  - LIGO: designs
  - India: possible support
- See D. Blair and C. Zhao talks

Conclusions

- First generation detectors successful
- Many second generation detectors being built, developed, and planned
- Able to do gravitational astronomy
- Range of technologies to improve sensitivity
  - Active and passive isolation, underground
  - Monolithic silica and sapphire suspensions
  - Improved coating and substrate materials, cryogenics
  - Higher laser power, signal recycling, squeezing
- Network of detectors with comparable sensitivity operating ~2015