LIGO II:

REQUIREMENTS & CONFIGURATIONS

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Working Group Intersections (1)

❑ Thermal lensing in the core optics (all 3)

- ❍ limits optical power in the interferometer, & thus sensing noise
- ❍ new materials: optical properties vs. mechanical (thermal noise) prop.
- ❍ drives the development of configurations more tolerant to thermal distortions (readout techniques, or all-reflective configurations)

❑ Phase modulators (L&O & AIC)

- ❍ location(s) determined by sensing system design
- ❍ sensing noise produced by modulator imperfections

❑ Photodiodes (L&O & AIC)

- ❍ configuration affects: power; uniformity & scattering requirements

❑ Optics fabrication (L&O & AIC)

- ❍ mirror coatings: signal recycling design specifies the transmittance of the input test masses
- ❍ optical quality determines the power & signal recycling gains

❑ Mirror size/mass (all 3)

- ❍ thermal noise
- ❍ radiation pressure noise
- ❍ optical losses
- ❍ impacts suspension design
- ❍ constrained by fabrication capabilities

Working Group Intersections (2)

- Dark fringe lock (all 3)
  - trade-off between laser amplitude noise & tightness of dark fringe lock
  - readout scheme affects the requirement on the above product
  - suspension & isolation design: determines the un-servoed relative motions; affects the control system design via the actuator characteristics
- Thermal noise (AIC & SWG)
  - projected thermal noise contributions are taken as top-level design inputs by the AIC (more later)

AIC Design & Development Ingredients

- **Modeling**
  - Frequency response & sensitivity
  - Sensing schemes
    - gravitational-wave readout
    - other length & alignment degrees-of-freedom
  - Optical noise couplings (laser frequency & amplitude noise, etc)
  - Effects of optical distortions
    - thermal lensing
    - optical polishing/coating imperfections
  - Many useful models exist or are in development
    - End-2-End; FFT; Modal; Melody (opto-thermal)
- **Prototyping**
  - Table-top interferometers
    - 'efficient' way of examining sensing schemes
    - good for concentrating intellectual effort on these problems
  - Suspended interferometers
    - required before installing a new configuration in LIGO
    - 1st prototype to test signal recycling mirror sensing/control schemes
    - followed by a full-up engineering test of final optical configuration

AIC Top level requirements

- Performance should not be significantly limited by sensing noise (shot noise + radiation pressure)
  - thermal noise should be limiting noise source
  - may be difficult to get radiation pressure ‘out of the way’
- Feasibility of meeting this goal is evaluated against observability of potential signals
  - binary inspiral signals
  - pulsar signals (known or unknown), at any frequency within 0 to ~1kHz
  - unknown wideband (pulse) signals
- Clearly, meeting this goal for all source types with a single interferometer type is not possible
  - design should allow some flexibility in the response shape
  - hopefully, we find that some choice of interferometer configuration that covers all cases with a core set of parameters
- Signal recycling of the initial LIGO configuration forms the basis for LIGO IIb upgrade – other candidates are LIGO III
  - Sagnac interferometers
  - Squeezing
  - Quantum non-demolition

Binary Inspiral

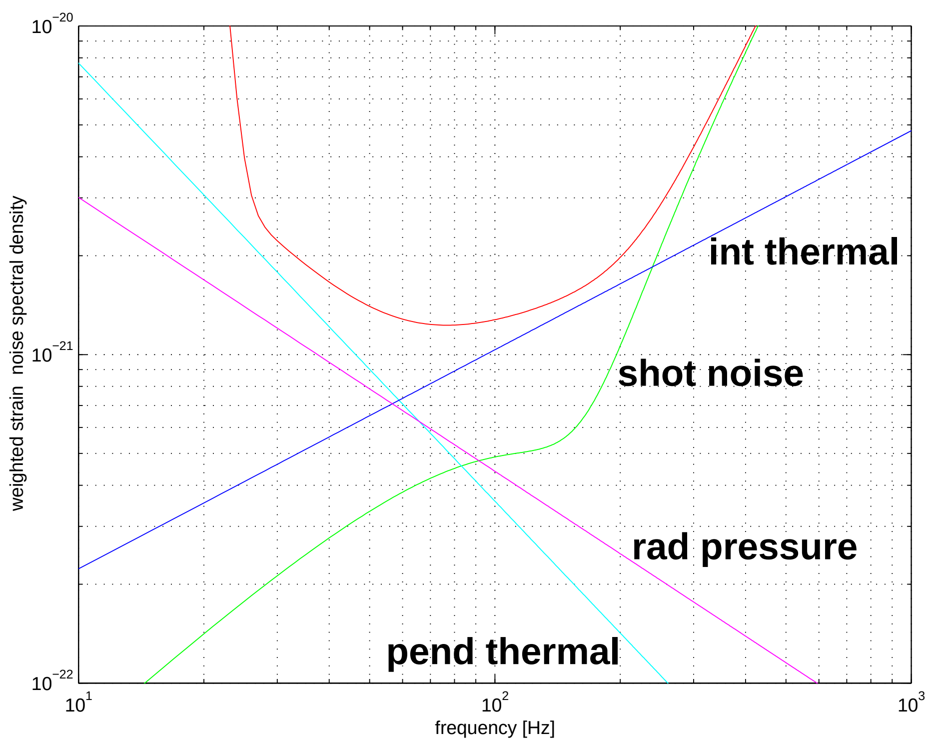
- Calculate normalized (to LIGO I) observation range:

$$R \propto \sqrt{\int_{1}^{1\ \mathrm{kHz}} h^{-2} f^{-7/3} df}$$

(R = 5.9 for WP curve 2)

T_{ITM}	T_{SRM}	ϕ_{SRM}	Input Power	Rel. Range R
10%	40%	2.3 rad	50 W	6.9
3%	45%	0.86 rad	100 W	7.1
1%	20%	0.27 rad	100 W	6.6
0.3%	4.5%	0.07 rad	100 W	5.7

weighted w/ $f^{-7/3}$



Pulsars & Bursts

❑ Again, try to make thermal noise dominant

❍ narrow the bandwidth; tune center frequency to anticipated signal frequency

❍ bandwidth depends on signal recycling mirror reflectivity; choice depends on science goals

T_{ITM}	T_{SRM}	strain/√Hz ($x10^{-24}$) / Hz 250 Hz sens/ BW	500 Hz sens/ BW	1 kHz sens/BW
1%	**1%**	3 / 65	2.3 / 90	2.4 / 200
1%	**3%**	3 / 90	2.7 / 200	4.0 / 500
1%	**10%**	4 150	4.2 / 500	not reached
3%	**1%**	3 / 30	2.2 / 40	2.1 / 80
3%	**3%**	3 / 50	2.4 / 80	3.0 / 190
3%	**30%**	4 / 200	5.5 / 600	not reached

❑ Burst sources

❍ can't really optimize – not enough power to get thermal noise limited performance over whole frequency range

❍ alternative: starting with inspiral-optimized response, improve the wideband performance with only a small degradation of the inspiral sensitivity

❍ given the thermal noise assumptions used in these examples, designs performing like this can be found. E.g., T_{ITM} = 1%, T_{SRM} = 20%, 0.15 rad detuning has improved sensitivity up to 1 kHz.

Signal Recycling Strategy

❑ Early intersection with L&O

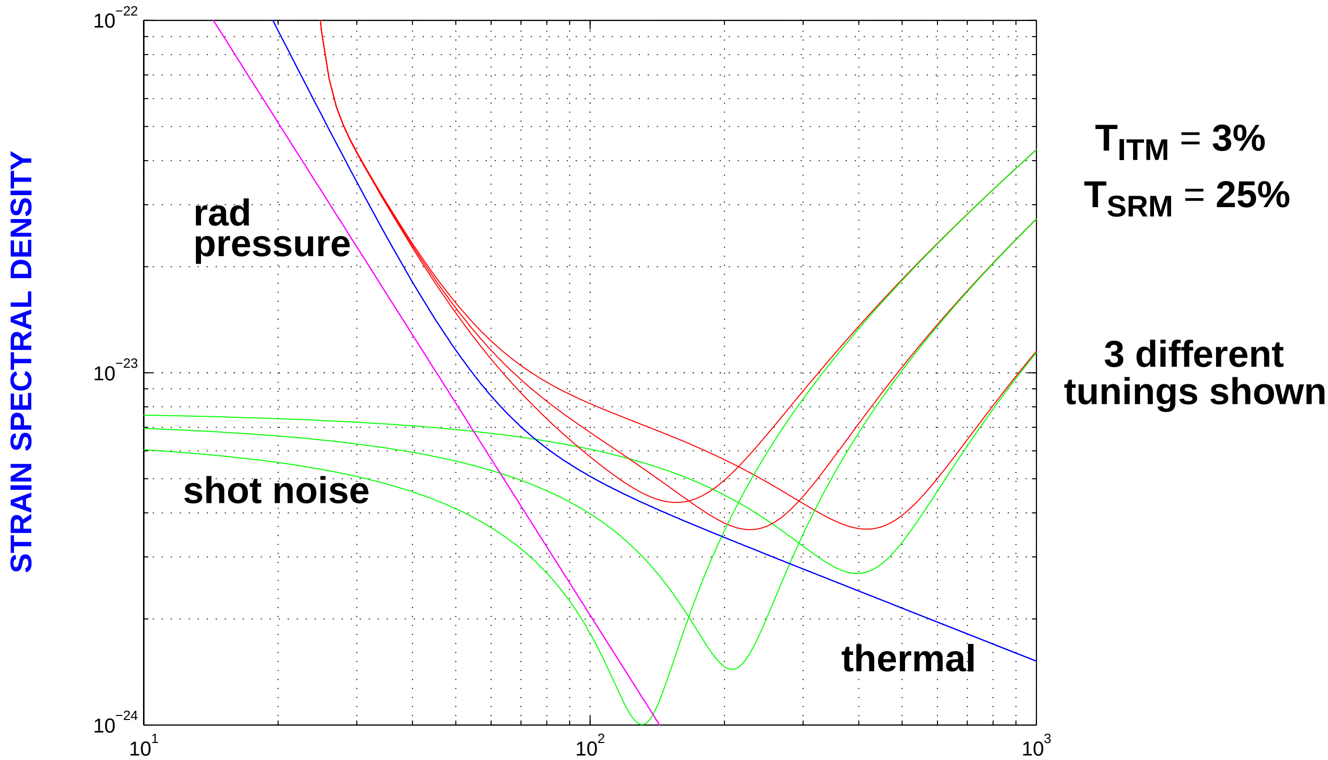
❍ Given the time & expense of new mirrors, the new input mirrors installed in the first upgrade should be compatible with later signal recycling

❍ ITM choice must give good non-signal recycled performance; looks to be possible with a T_{ITM} of 1–3 %

❑ Given that we determine best T_{ITM}, how best to achieve science goals?

❍ One SRM: compromise design, with some weighting given to sensitivity loss for the various source types

❍ Multiple signal recycling mirrors



Technical status

- Table-top experiments underway
  - Caltech, J. Mason et al.
  - University of Florida, T. Delker, et al.
  - Australian National University, D. Shaddock et al.
- Suspended prototype test plan
  - First stage testing at Glasgow 10m prototype; starts with RSE, no power recycling (Glasgow group + U Fla)
  - Engineering test of chosen configuration at Caltech 40m prototype; follows an infrastructure upgrade of the system (A Weinstein et al.)
- Primary remaining technical challenges/work:
  - sensing scheme for the signal recycling mirror position
  - readout scheme for the gravitational-wave
  - evaluation of ‘technical’ sensing noise sources
  - continued evaluation of configurations

AIC Tasks, Coordinators, Groups

Task (Coordinator)	**Active Groups**
Dual Recycling/Resonant Sideband Extraction (K Strain) *exploration of techniques*	ACIGA/ANU: table-top ifo + 18m prototype LIGO/Caltech: table-top + 40m GEO: Glasgow 10m UFl: table-top; Glasgow 10m LIGO/MIT: output mode cleaner
Selection/Optimization (P Fritschel) *propose design for LIGO*	LIGO/MIT LIGO/Caltech UFl GEO (all: readout & control schemes)
Sagnac Interferometers (M Fejer)	Stanford
Squeezing (D McClelland)	ACIGA/ANU
QND (Braginsky)	MSU, CaRT

AIC Timetable

Event	Description	Date
Top level requirements	establish science goals; sensitivity	Q2 1999
Grant applications	UF continued support; Glasgow prototype	Q3 1999
Conceptual design summit	choose configuration; sensing scheme design study; input from table-top tests	Q1 2000
Design review	establish prototype test plans; start of installation in Glasgow; table-top complete	Q3 2000
Performance review	Glasgow signal recycling tests; planning for 40m tests	Q3 2001
Prototype test & preliminary design review	completion of Glasgow tests; set ITM transmission; design of 40m experiment	Q4 2002
Engineering review	review of 40m experiment; design for LIGO II	Q2 2004
Final design review	completion of 40m tests; LIGO sensing/control design complete	Q1 2005