LIGO-G980155-00-D

# ONE YEAR AT THE 40 METER

## (School of Hard Locks)

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LIGO Science Seminar

Caltech - PasadenaΓCalifornia

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†Work at Caltech supported by LIGO Visitor's Program

## Outline

- Summary of 40 Meter Status

- 40 Meter *vs* LIGO – Comparison
  - Optics Refresher
  - Instrument Comparison

- Why Can't We Align the IFO While Maintaining Lock? (Snapshot of most important investigation underway)

- Wave Front Sensing at the 40 Meter

- Michigan Gravity Wave Group (MGWG)
  - Contributions
  - Plans

# Summary of 40 Meter Status

## Configuration

- LIGO-like topology
  Recycling cavity with Fabry-Perot (FP) arms;
  Schnupp asymmetry

- Three of six masses with LIGO-like core optics suspensions
  - Single-wire loop
  - Permanent Magnet actuation
  - Four-layer isolation stacks

- Low-loss optics (514 nm)

- Single-frequency frontal modulation servo scheme

- LIGO-like PSL system

- Wave Front Sensing (WFS) available for auto alignment
  (Using hardware / software adapted from MIT FMI)

- Wide scale use of digital controls & filtering

- LIGO-like DAQ and data display programs in place

# Summary of 40 Meter Status

## Recycling Operation Accomplishments

- Power Recycled Michelson (PRM) cavity locked (2-servo bootstrap) – 11/97

- Full recycled IFO lock – 12/97

- PRM behavior confirmed to agree with design (GainsΓalignment sensitivityΓdegeneracy)

- Investigation of modal structure via RF sideband resonances

- Full control of PRM alignment via WFS

- Control of single end-mass alignment DOF via WFS

# Summary of 40 Meter Status

## Work in Progress or Immediately Planned

- Investigate lock instability when IFO best aligned
- Confirm previous determination that IFO is under-coupled
  (Due to anomalously high arm losses)
- Determine servo dynamic ranges / gain margin limitations
- Complete WFS control of end-mass alignments
  (Expected to reduce large power fluctuations in arms)
- Identify and fix worst noise sources
- Take one week of data (December 12-18)
  with all DAQ channels recorded

# Summary of 40 Meter Status

## The 40 Meter Crew in 1998[†]:

### Caltech

Mark Coles[1]ΓBill KellsΓJenny Logan[2]Γ
Nergis Mavalvala[3]ΓSteve Vass

### U. Michigan

Dick GustafsonΓKeith RilesΓJamie Rollins[4]

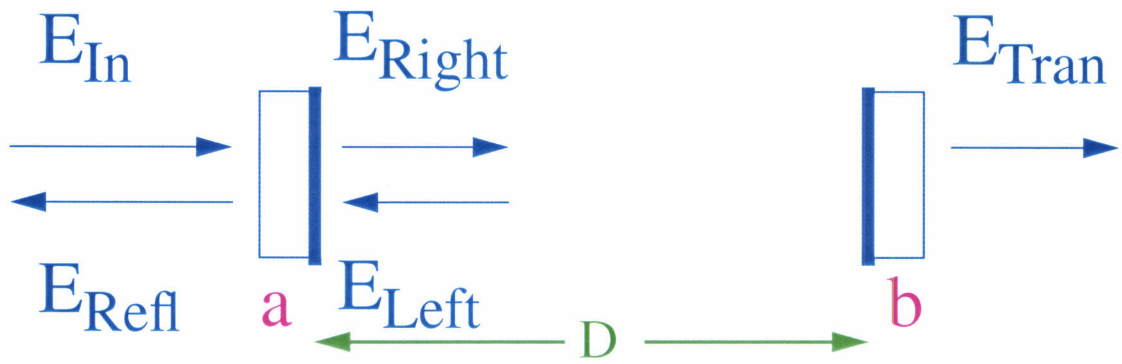
### Short-term Visitors

Raffaele Flaminio (VIRGO)ΓKoji Arai (TAMA)

[1]Departed in June for Livingston
[2]Departed in September for JPL
[3]Began 40M work in September
[4]Began 40M work in May

[†] Many thanks to S. AndersonΓR. BorkΓH. DingΓJ. HeefnerΓA. IvanovΓ W. MajidΓS. TilavΓand L. Wallace

Cavity Optics Refresher:




Conventions used:

$$R_i = r_i^2; \qquad T_i = t_i^2; \qquad L_i = 1 - R_i - T_i$$

$$r_a, r_b > 0; \qquad \phi = 2kD - 2\,\phi_{\mathrm{Guoy}}$$

Steady-state equations†:

$$E_{Right} = t_a E_{In} - r_a E_{Left} \qquad E_{Left} = -r_b e^{i\phi} E_{Right}$$

$$E_{Refl} = r_a E_{In} + t_a E_{Left} \qquad E_{Tran} = t_b e^{i\phi/2} E_{Right}$$

Solutions:

$$\frac{E_{Refl}}{E_{In}} = \frac{r_a - (1 - L_a) r_b e^{i\phi}}{1 - r_a r_b e^{i\phi}}$$

$$\frac{E_{Tran}}{E_{In}} = \frac{t_a t_b e^{i\phi/2}}{1 - r_a r_b e^{i\phi}}$$

Resonance (anti-resonance) when $\phi = 0$ $(\pi)$

†Time dependence discussed later

# 40 Meter *vs* LIGO – Comparison

## Closer Look at Transmission

On resonance:

$$\frac{E_{Tran}}{E_{In}} = \frac{t_a t_b}{1 - r_a r_b}$$

Power away from resonance:

$$\left|\frac{E_{Tran}}{E_{In}}\right|^2 = \frac{t_a^2 t_b^2}{1 + r_a^2 r_b^2 - 2\, r_a r_b \cos\phi}$$

For $r_a, r_b \approx 1\Gamma$

$$\mathrm{FWHM}_\nu \approx \frac{c}{2D}\,\frac{1 - r_a r_b}{\pi\sqrt{r_a r_b}} \equiv \frac{\mathrm{FSR}}{\mathrm{F}}$$

where FSR = Frequency spacing between cavity resonances

and F = Finesse $\equiv \pi\sqrt{\frac{r_a r_b}{1 - r_a r_b}}$

For $(1 - r_b) \ll (1 - r_a) \ll 1\Gamma$

$$\mathrm{F} \approx \frac{\pi}{1 - r_a}$$

High Finesse $\Longrightarrow$ Sharp Resonance

$\Longrightarrow$ Large Power Buildup

# 40 Meter *vs* LIGO – Comparison

40 Meter arms:

$$r_a \approx 0.997$$

$$r_b \approx 0.99994$$

$$\Longrightarrow \mathrm{F} \approx 1100$$

LIGO arms:

$$r_a \approx 0.985$$

$$r_b \approx 0.999960$$

$$\Longrightarrow \mathrm{F} \approx 207$$

# 40 Meter *vs* LIGO – Comparison

## Closer Look at Reflection

On resonance:

$$\frac{E_{Refl}}{E_{In}} = \frac{r_a - (1 - L_a)\, r_b}{1 - r_a r_b}$$

For $(1 - r_a), (1 - r_b) \ll 1\Gamma$

expand $r_i = \sqrt{(1 - T_i - L_i)} \approx 1 - \frac{1}{2}(T_i + L_i)$

$$\frac{E_{Refl}}{E_{In}} \approx -\frac{T_a - (L_a + T_b + L_b)}{T_a + (L_a + T_b + L_b)}$$

$$\approx -\frac{T_a - \Sigma(\text{Losses})}{T_a + \Sigma(\text{Losses})}$$

Some jargon:

"Overcoupled" means $\frac{E_{Refl}}{E_{In}} < 0$

"Undercoupled" means $\frac{E_{Refl}}{E_{In}} > 0$

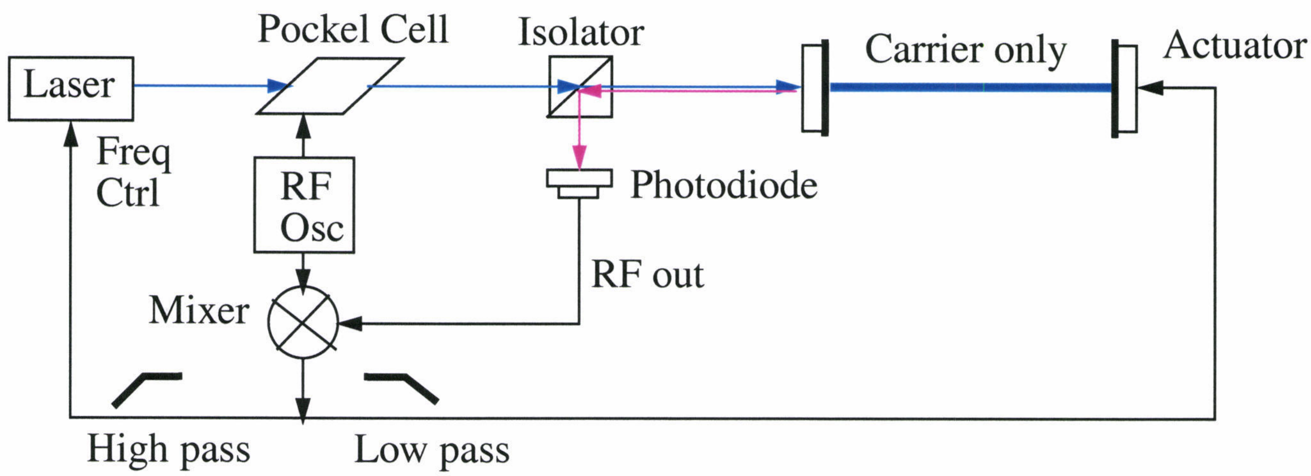
$\Sigma(\text{Losses}) <$ input mirror transmission $\Longrightarrow$ Overcoupled

End mirror absent $\left(\frac{E_{Refl}}{E_{In}} = +r_a\right) \Longrightarrow$ Undercoupled

## 40 Meter *vs* LIGO – Comparison

How does one "lock" to resonance?

Pound-Drever-Hall technique:




Phase-modulate light such that

- Carrier resonates in cavity: $N\lambda_{\rm CR} = 2\,D$
- Sidebands (nearly) anti-resonate: $(N \pm m + \frac{1}{2})\lambda_{\rm SB} = 2\,D$

Requires:

Modulation frequency $f_{mod} = (m + 1/2) \times {\rm FSR}$

(or $D = \frac{1}{2}(m + \frac{1}{2})\lambda_{mod}$)

40 Meter arms: $f_{mod} = 32.7$ MHz $(m \approx 8)$

LIGO arms: $f_{mod} = 24.6$ MHz $(m \approx 650)$