



LIGO

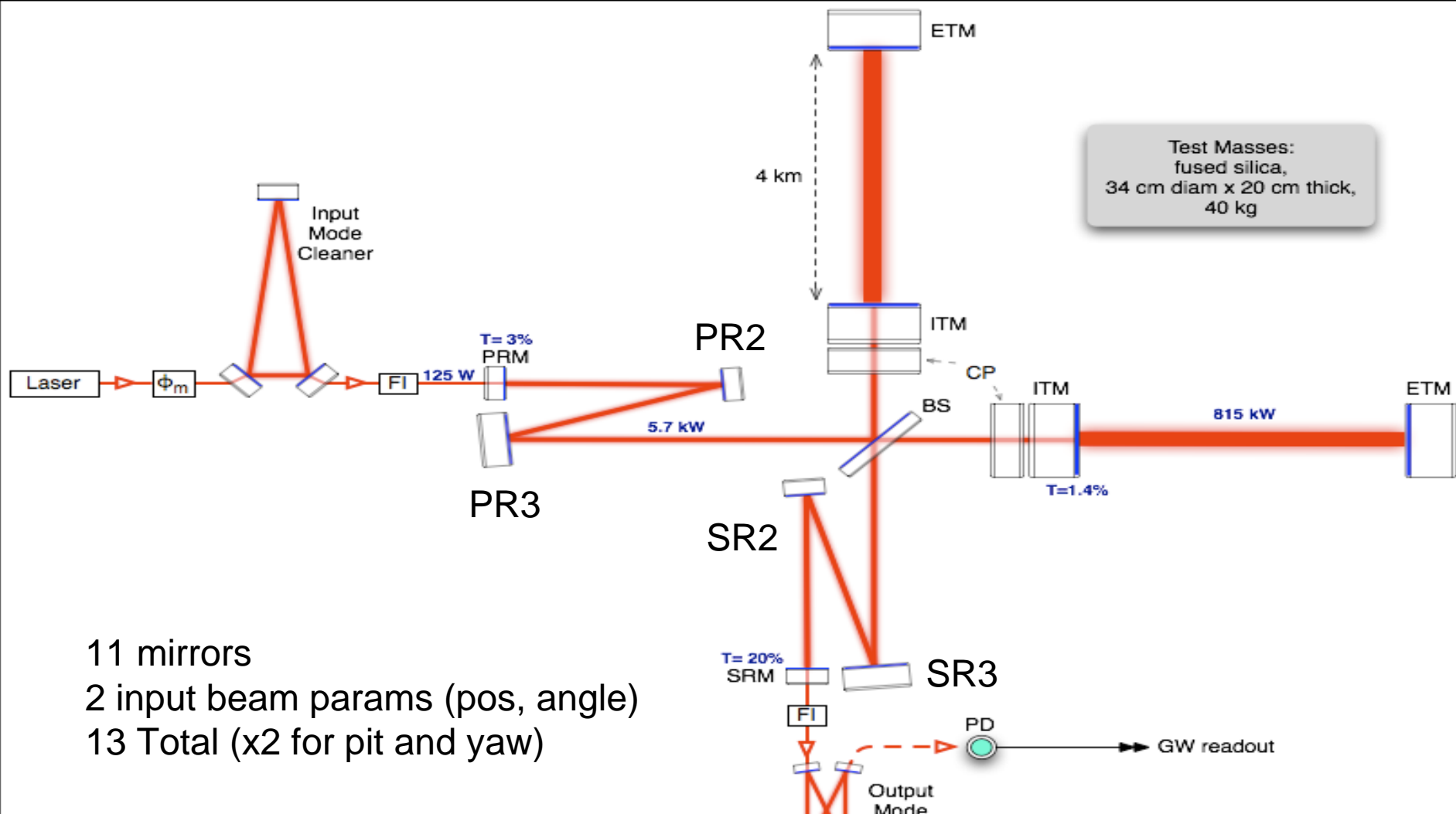
The Advanced LIGO Angular Control System (ASC) (Hanford edition)

Hanford Observatory,
Washington State

July 13, 2015

LIGO-G1500923

Stefan Ballmer



11 mirrors
 2 input beam params (pos, angle)
 13 Total (x2 for pit and yaw)

ASC basics

loop count



- Main Interferometer

- Arm alignment: 4DoF [E/I]TM[X/Y]
- Input beam – IFO: 2DoF IM4 & PR2 (3)
- PRC alignment: 1DoF PRM
- MICH alignment: 1DoF BS
- SRC alignment: 1DoF SRM
- SRC pointing: 1DoF SR2 (3)
 - (3DoF uncontrolled: IMC pointing, PR3, SR3)

- TOTAL: 10DoF controlled

ASC basics aux loops

- Additional loops

- OMC alignment 2DoF OM3, OMC
- WFS centering: 4DoF RM1&2, OM1&2
- IMC: 3DoF IM1-3, PZT
 - (1DoF uncontrolled: IMC output pointing)
 - (no IMC WFS centering)
- ALS arm: 3DoF/arm [E/I]TM, TMS
 - (green beam input position on ETM uncontrolled)
- ALS input beam: 4DoF/arm PZTs

- TOTAL: additional 21DoF (not this talk)

LIGO Rel vs Abs Reference



- 13 loops:

	Rel	Abs
– X-arm:		2
– Y-arm & BS:	2	1
– PRC:	1	2
– SRC:	1	2
– Input:	2	
– Total:	6	7
- Note: We can choose which DoF we want to servo to rel. references, but total (6) is fixed.
- The actual control scheme is more complicated

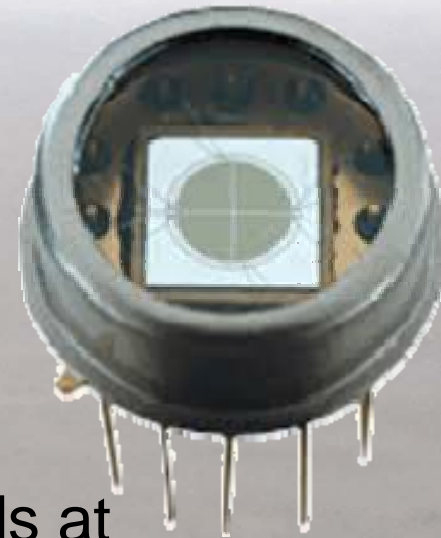
- 2 types of sensors:

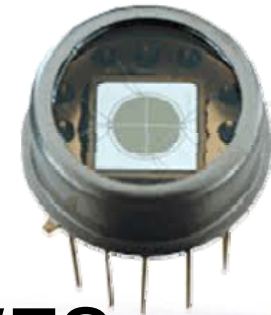
- QPD (quadrant photo diode)

- Gives information about beam position on QPD
 - Signal: e.g. $\text{yaw} = (\text{left} - \text{right}) / \text{sum}$
unit: beam waist on PD

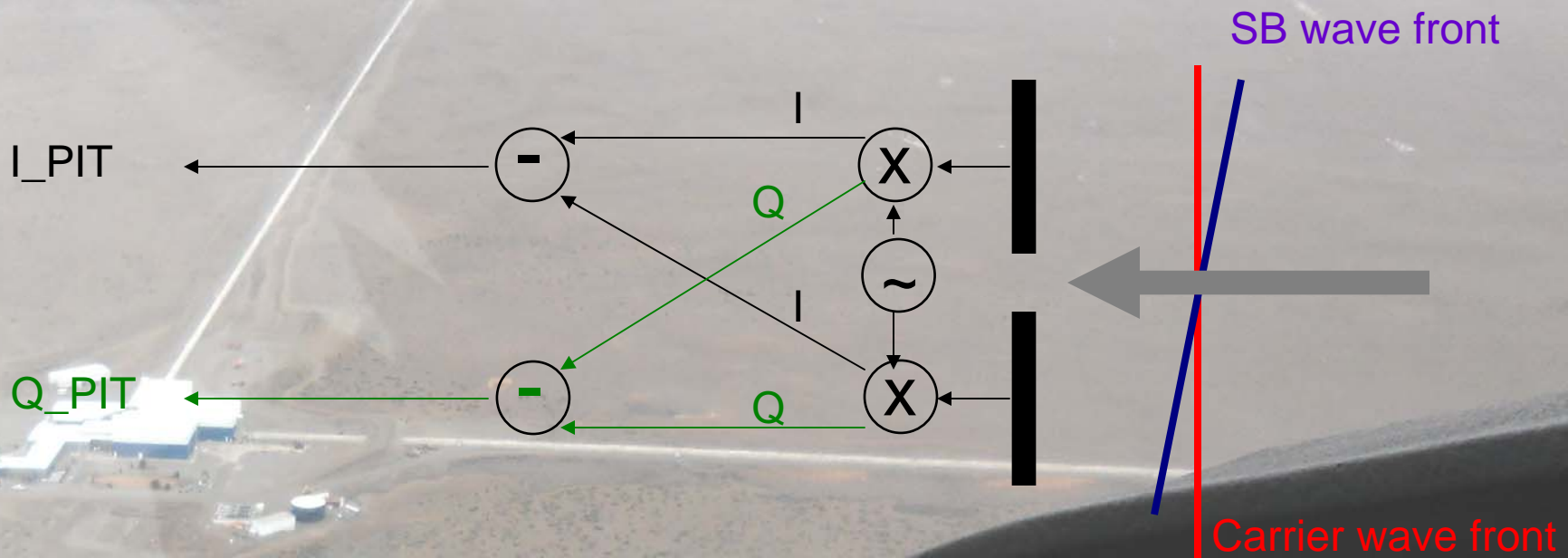
- WFS (wave front sensor)

- Gives relative information two laser fields at different frequencies (e.g. carrier and side band)





- The sensor head is an RF QPD
- Each quadrant gets demodulated with cos and sin (I & Q) → 8 signals/WFS
→ Combined into 4 signals/WFS (I/Q, PIT/YAW)



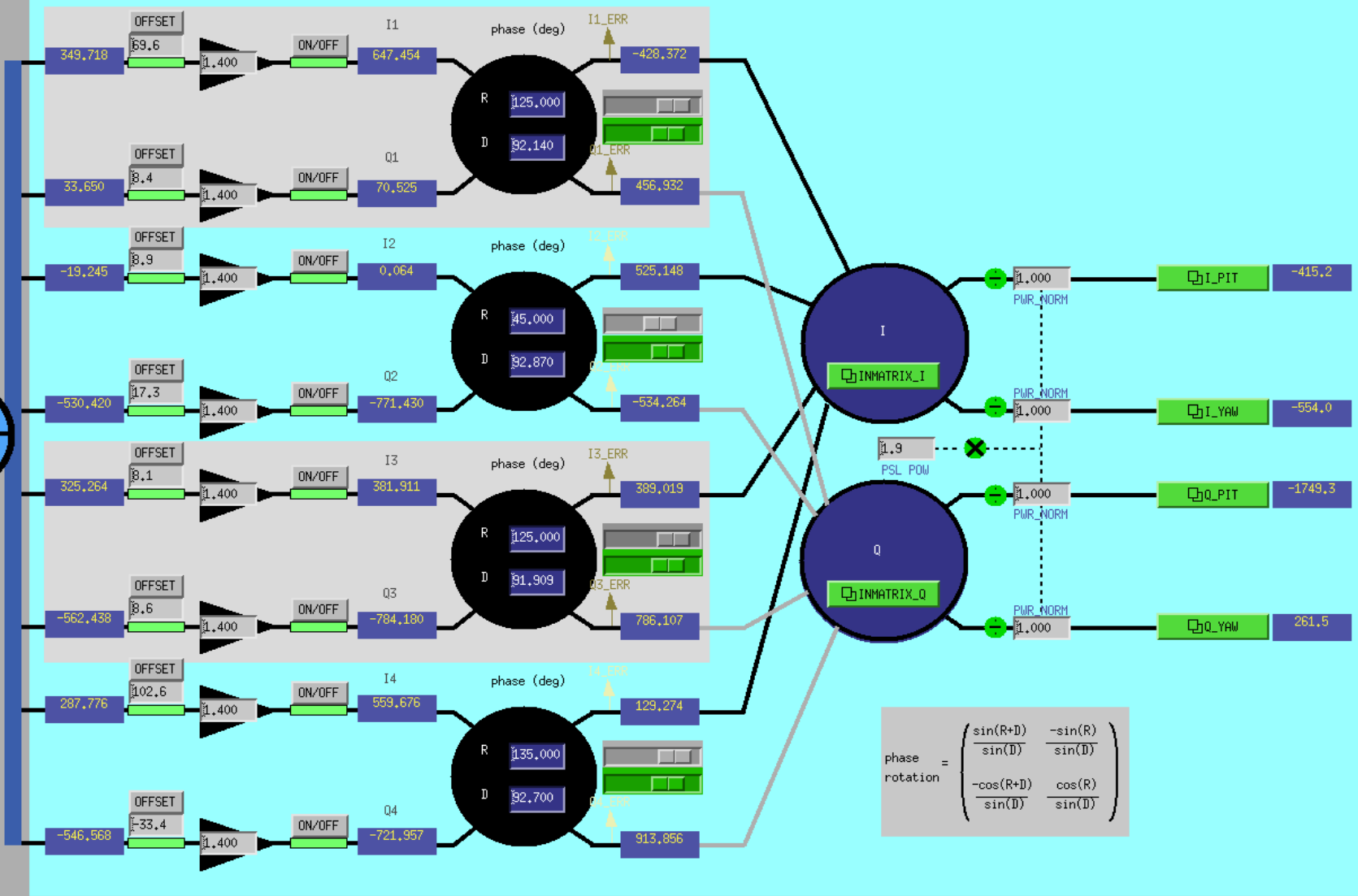
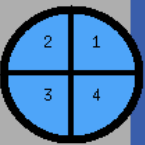
LIGO Example MEDM screen



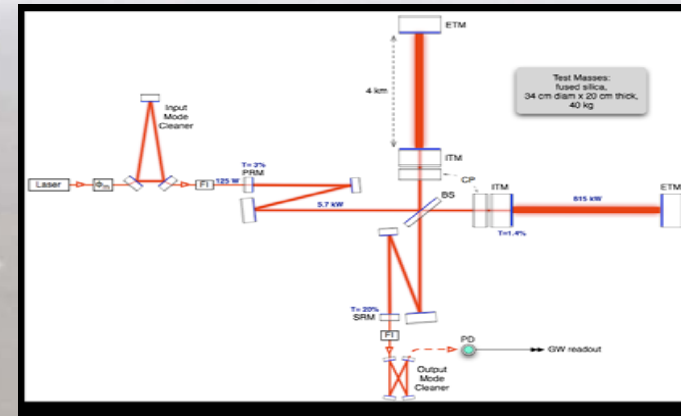
H1ASC_AS_A_RF36_SETTINGS

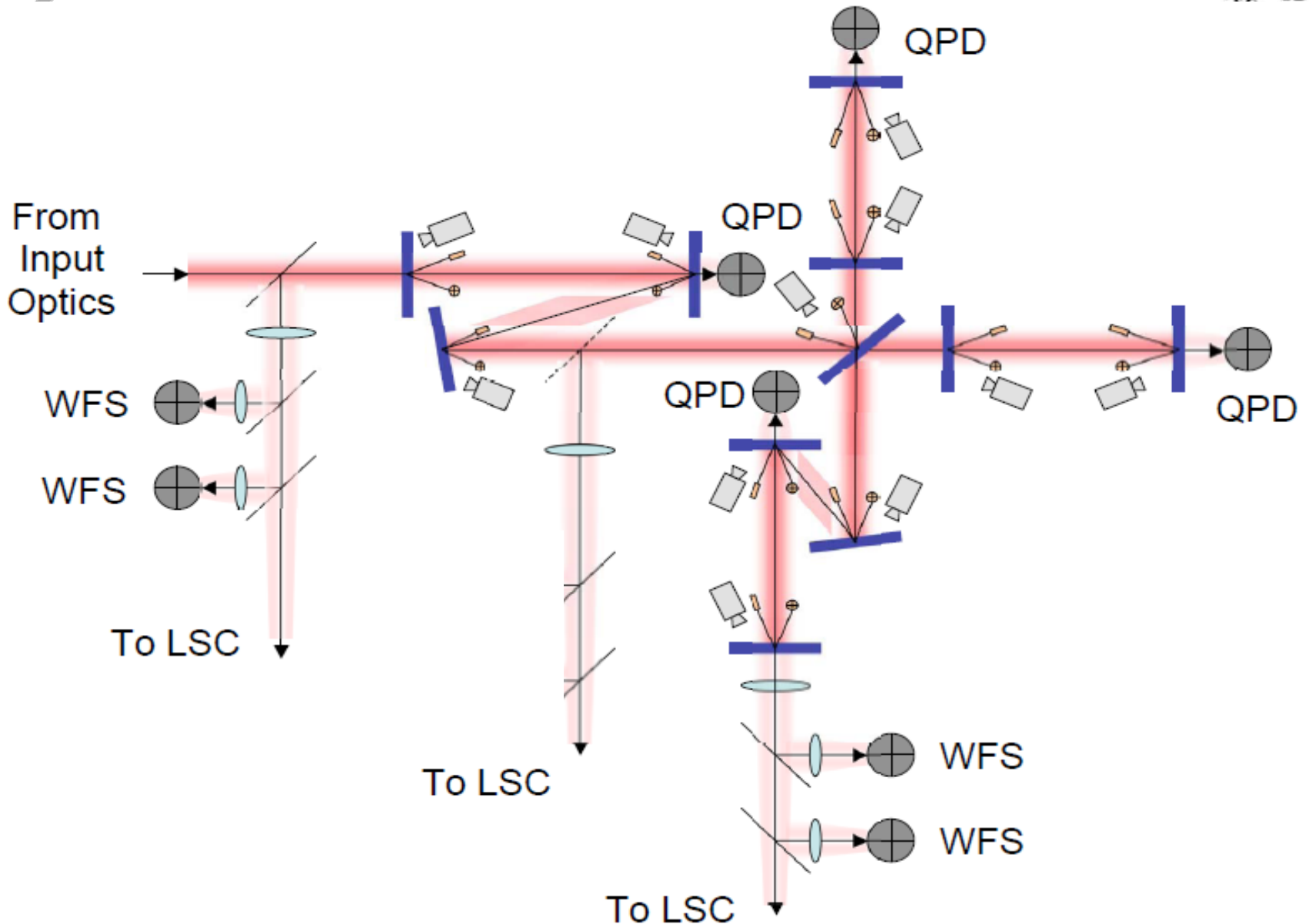
Sat Jul 11 20:48:58 2015

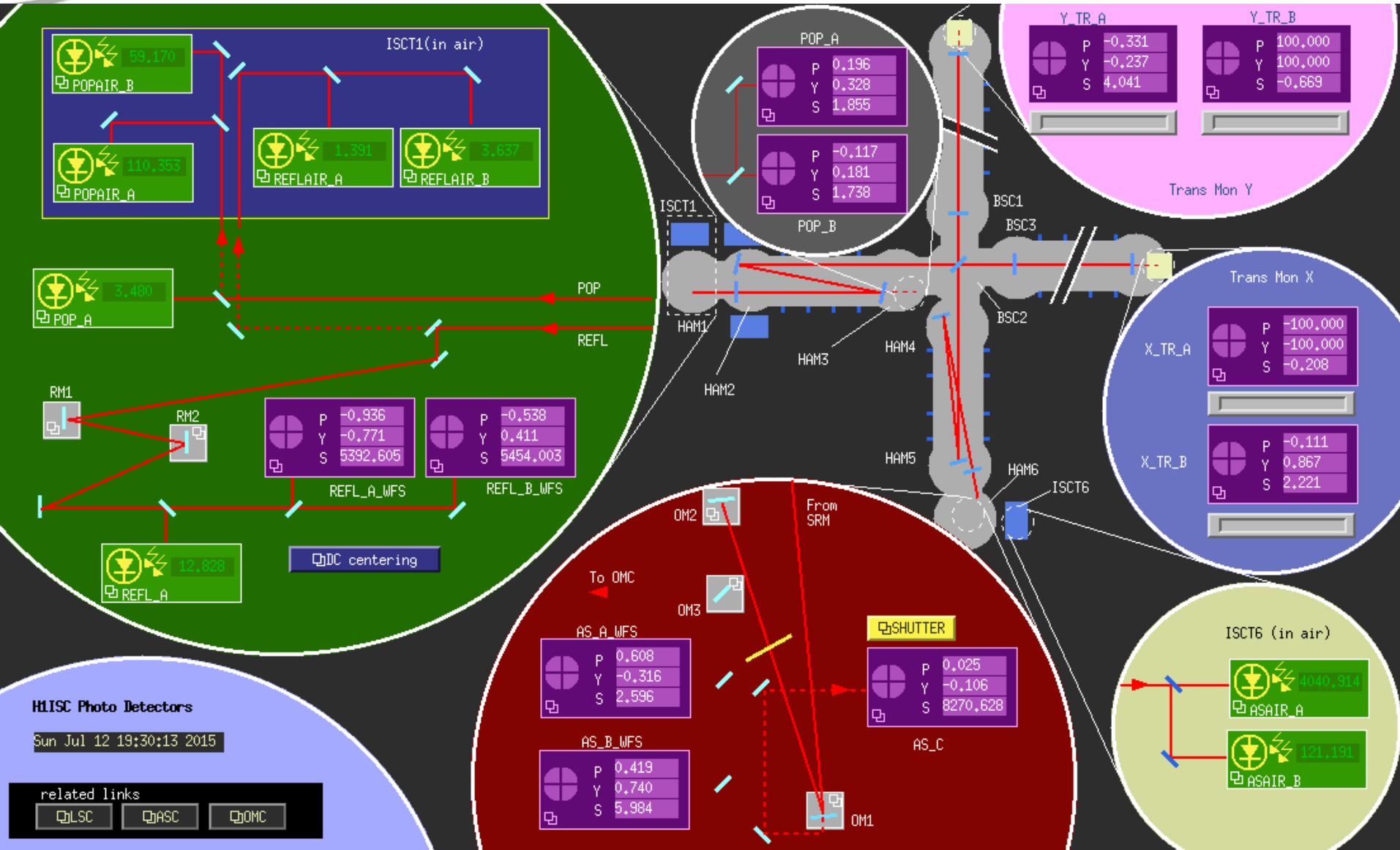
AS_A_RF36



- WFS sensitive to wave front tilt at sensor
 - But 2 such WFS can be placed per beam (different Gouy phase \leftrightarrow near vs far field)
- Two modulation sidebands:
 - 9MHz: mostly sees PRC
 - 45MHz: sees PRC and SRC
- Installed WFS: 4 heads
 - AS: A/B (Gouy phase), RF45 & RF36
 - REFL: A/B (Gouy phase), RF9 & RF45







HLISC Photo Detectors

Sun Jul 12 19:30:13 2015

related links

LSC

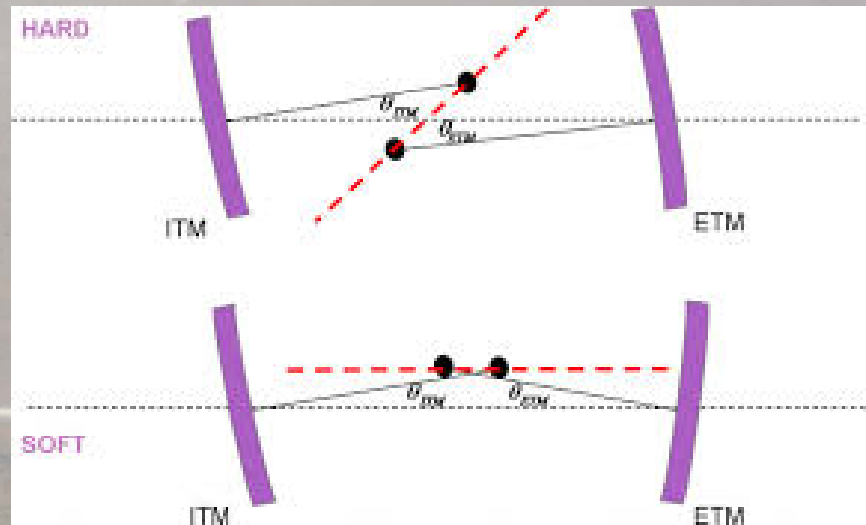
ASC

OMC

LIGO Hard and Soft modes



- At high circulating power the radiation pressure couples the modes of the 4 arms
 - Hard modes have a higher frequency...
 - Soft modes have a lower frequency...
...than individual suspensions (see picture)
- Ideally control arms as comm/diff, hard/soft:
CHARD, DHARD,
CSOFT, DSOFT



LIGO Hard and Soft modes



- In practice:
 - High g-factor cavity means we are mostly sensitive to HARD modes.
 - All test masses thus effectively mostly actuate the HARD mode.
 - We control HARD modes with ETMs only, but at high bandwidth.
 - We control SOFT modes with ITMs only, but at low bandwidth.

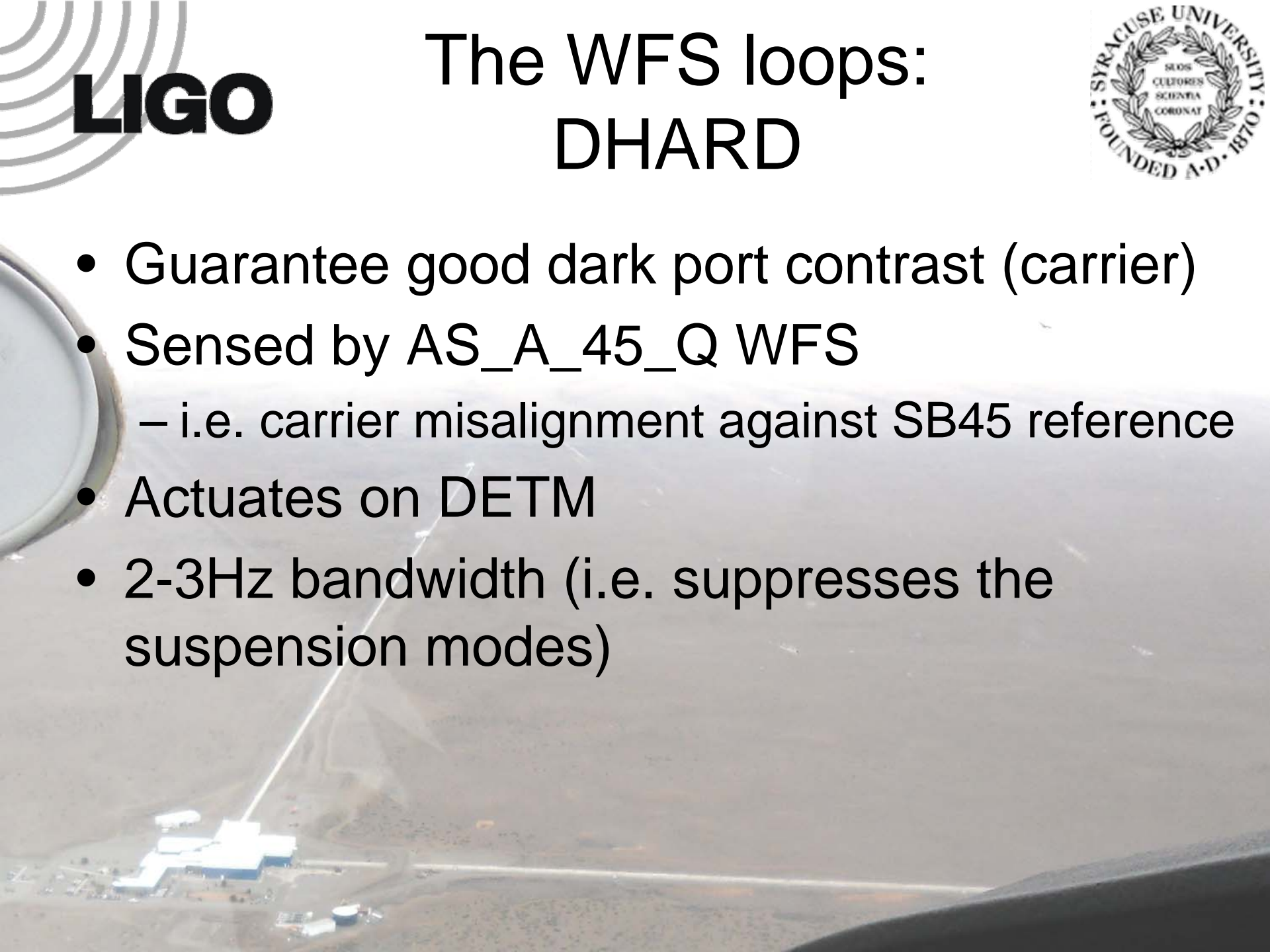
- The following slides refer to the H1 system, as of July 12 2015
- L1 is mostly similar, but some differences exist
- Loops shapes:
 - On most mirrors the ASC actuation is split across several stages
 - Final integrator is in the top SUS stage



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The WFS loops: DHARD



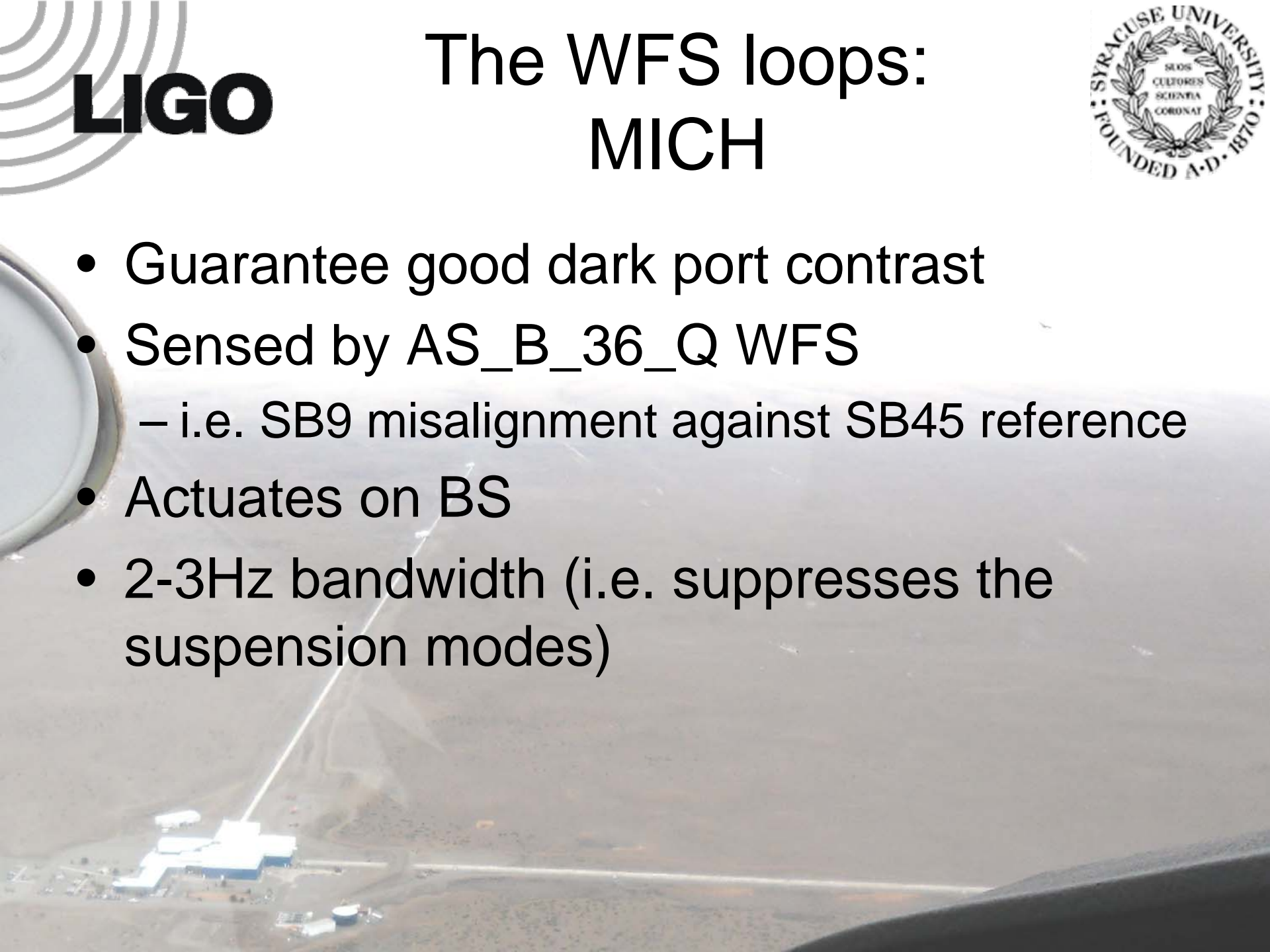
- Guarantee good dark port contrast (carrier)
 - Sensed by AS_A_45_Q WFS
 - i.e. carrier misalignment against SB45 reference
 - Actuates on DETM
 - 2-3Hz bandwidth (i.e. suppresses the suspension modes)
- 



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The WFS loops: MICH



- Guarantee good dark port contrast
 - Sensed by AS_B_36_Q WFS
 - i.e. SB9 misalignment against SB45 reference
 - Actuates on BS
 - 2-3Hz bandwidth (i.e. suppresses the suspension modes)
- 

The WFS loops: INP1 & PRC2

- Guarantee input beam - IFO overlap (2DoF)
- Sensed by a combination of 4 REFL WFS
 - REFL_[A/B]_RF[9/45]_I
- IMP1 actuates on IM4 (last input mirror)
- PRC2 actuates on PR2 (will likely switch to PR3)
- Low bandwidth (so far)

The LIGO logo is displayed in a bold, black, sans-serif font. To its left, there are several concentric, semi-circular lines that resemble ripples or a stylized wave pattern.

The WFS loops: CHARD



- Guarantee PRC – arms (common) overlap
- Sensed by a combination of RELF_A_RF9_I and RELF_B_RF9_I
- Actuates on CETM
- Low bandwidth (so far)

The WFS loops: SRC1

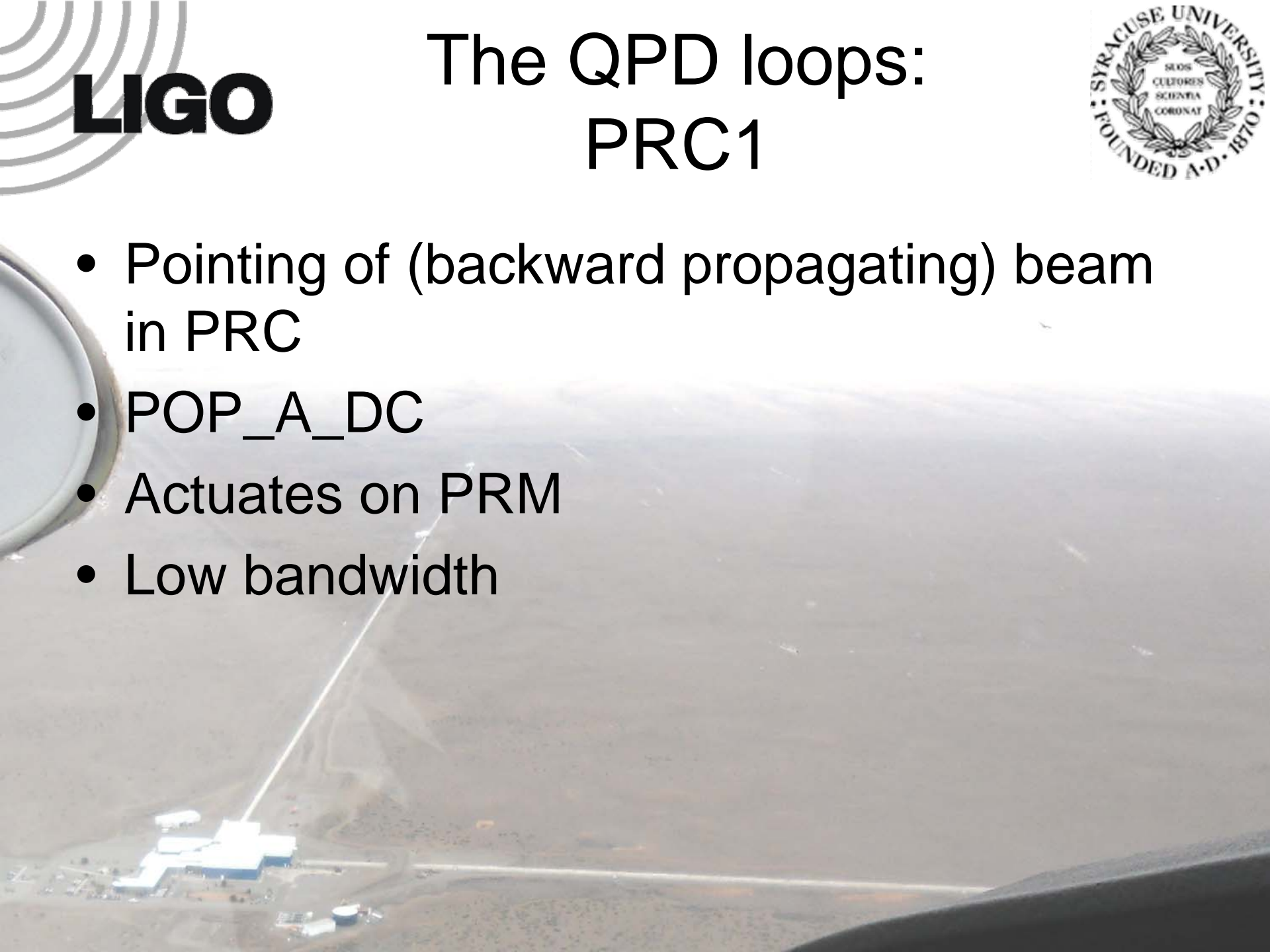


- Guarantee SRC – arms overlap
- Most difficult DoF to sense:
 - For pitch: AS_B_RF36_I WFS
 - For yaw: AS_A_RF36_I WFS
 - (actually currently only lower two quadrants)
- Actuates on SRM
- Low bandwidth (so far)

The LIGO logo is positioned in the top left corner. It features the word "LIGO" in a bold, black, sans-serif font. To the left of the text are several concentric, semi-circular lines that resemble ripples or a stylized wave pattern.

The QPD loops: PRC1



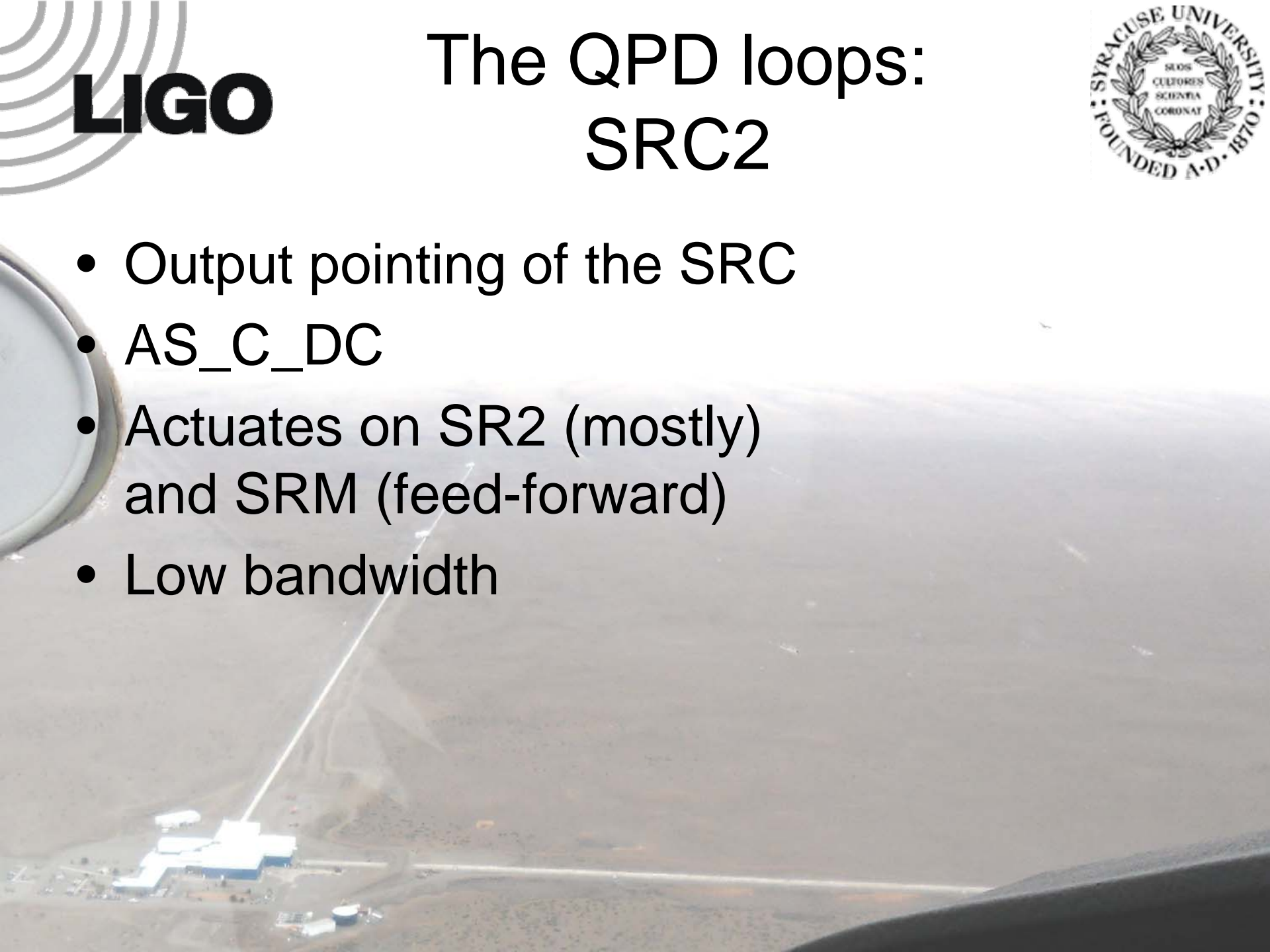
- Pointing of (backward propagating) beam in PRC
 - POP_A_DC
 - Actuates on PRM
 - Low bandwidth
- 
- The background of the slide is an aerial photograph of the LIGO site in a desert landscape. A bright white laser beam is visible, originating from a building complex in the lower-left and extending towards the upper-right. The terrain is arid and hilly.



LIGO

The QPD loops: SRC2



- Output pointing of the SRC
 - AS_C_DC
 - Actuates on SR2 (mostly) and SRM (feed-forward)
 - Low bandwidth
- 
- The background of the slide is an aerial photograph of the LIGO site in a desert landscape. A bright white laser beam is visible, extending from the bottom left towards the center of the image. In the bottom left corner, there is a cluster of white and blue buildings, which are part of the LIGO infrastructure. The overall scene is hazy and shows the vast, flat terrain of the desert.

The QPD loops: DSOFT & CSOFT

- Remaining (soft) arm cavity alignment
- Sensed by transmission QPDs:
 - TR[X/Y]_[A/B]
 - Note: the A and B diodes in transmission are in different Gouy phases
 - The particular combination of signals was picked to make the error signal insensitive to TMS motion.
- Actuates on ITMs, currently:
 - Pitch in DITM/CITM
 - Yaw in ITMX/ITMY (will likely change to DITM/CITM)
- Low bandwidth

- ISC design document
 - T070236
- Modeling of Alignment Sensing and Control for Advanced LIGO
 - T0900511
- L1&H1 ASC configuration for ER7
 - G1500741