Time Domain Simulation for the Lock Acquisition Study of aLIGO

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Summary (messages)

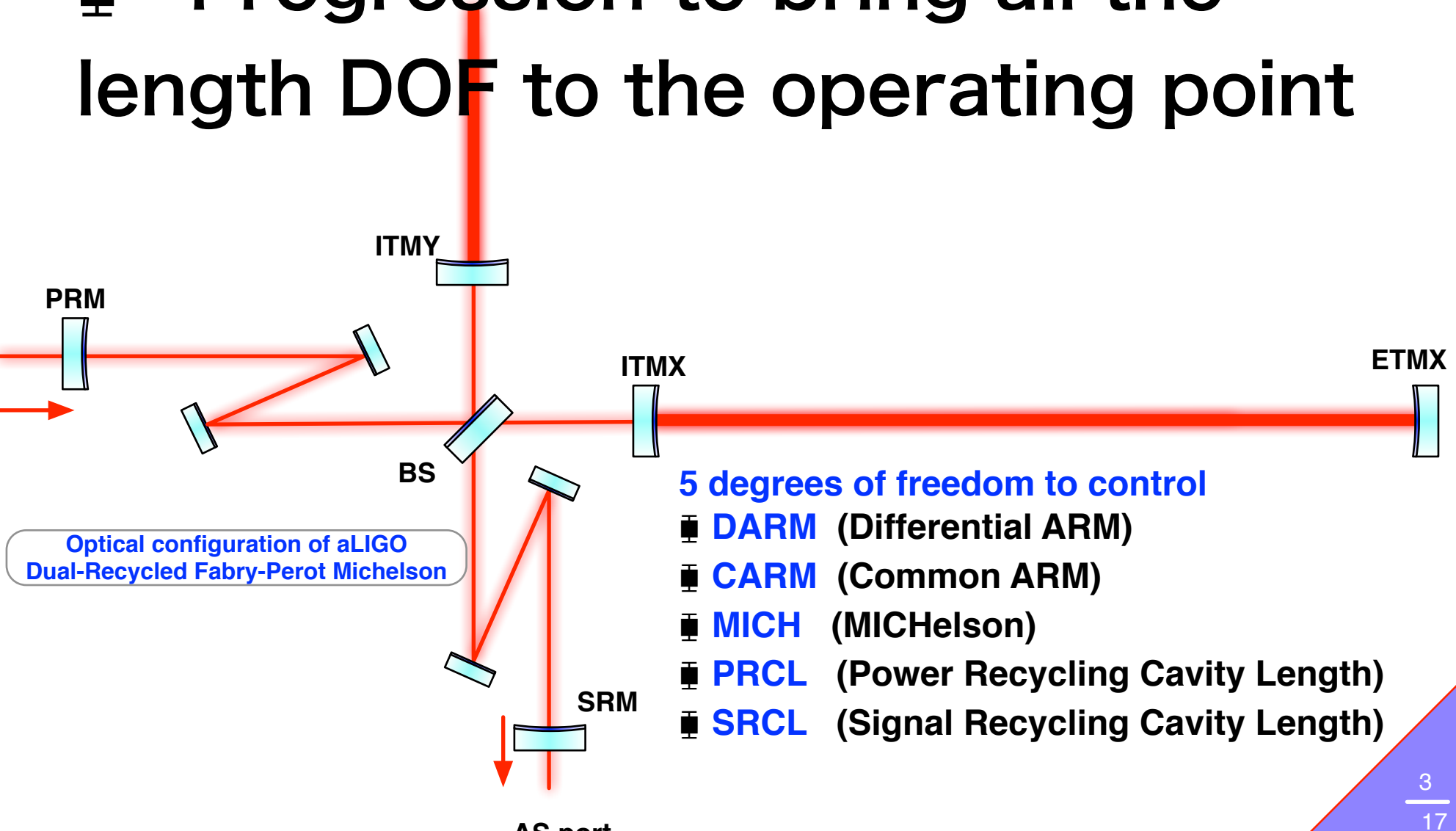
- Time Domain Simulation tells us how exactly to lock aLIGO
  => reduces commissioning down time

- Handing the arm control from Arm Length Stabilisation (ALS) to the infrared sensors is not trivial

- Simulation needs to be done before we waste precious commissioning time

What is lock acquisition ?

- Progression to bring all the length DOF to the operating point



Optical configuration of aLIGO
Dual-Recycled Fabry-Perot Michelson

5 degrees of freedom to control

- DARM (Differential ARM)
- CARM (Common ARM)
- MICH (MICHelson)
- PRCL (Power Recycling Cavity Length)
- SRCL (Signal Recycling Cavity Length)

Difficulty: coupled cavities

The interferometer is a multiple-readout system
And … nonlinear response until you lock all DOFs
Thus complicated.

N x sensor vector [W]	*N x 5 sensing matrix* [W/m]	*DOF vector* [m]

$$\begin{pmatrix} S_1 \\ S_2 \\ \bullet \\ \bullet \\ \bullet \\ S_N \end{pmatrix} = \begin{pmatrix} & & \\ & \hat{M} & \\ & & \end{pmatrix} \begin{pmatrix} \text{DARM} \\ \text{CARM} \\ \text{PRCL} \\ \text{MICH} \\ \text{SRCL} \end{pmatrix}$$

mixture of the length signals

evolves depending on the state

Arm Length Stabilisation

(a.k.a. Green locking)

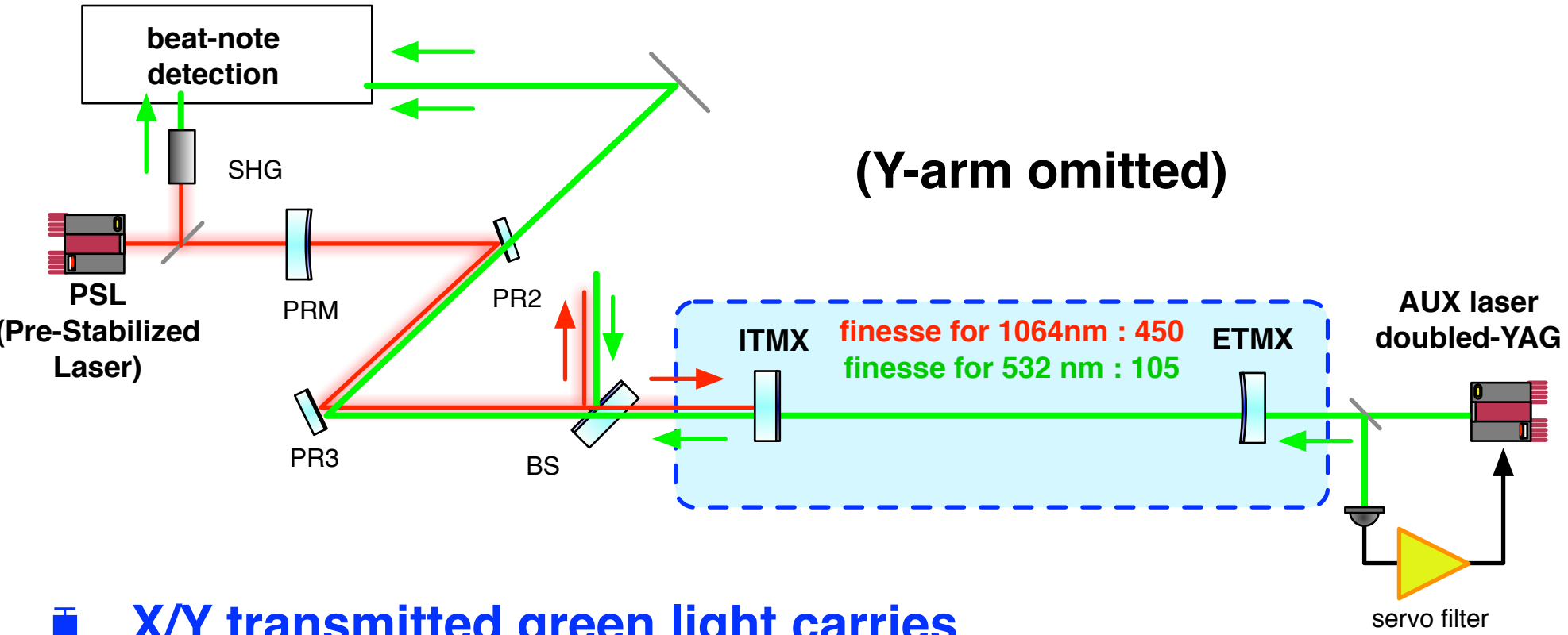
Decouples DARM and CARM

- senses and controls the arms (DARM and CARM) independently of the rest of the interferometer.
- allows to set the arm lengths to a point where they don't interact with the central part.

Makes initial locking easier

- once the ALS is engaged, lock acquisition of the central part should not be difficult.

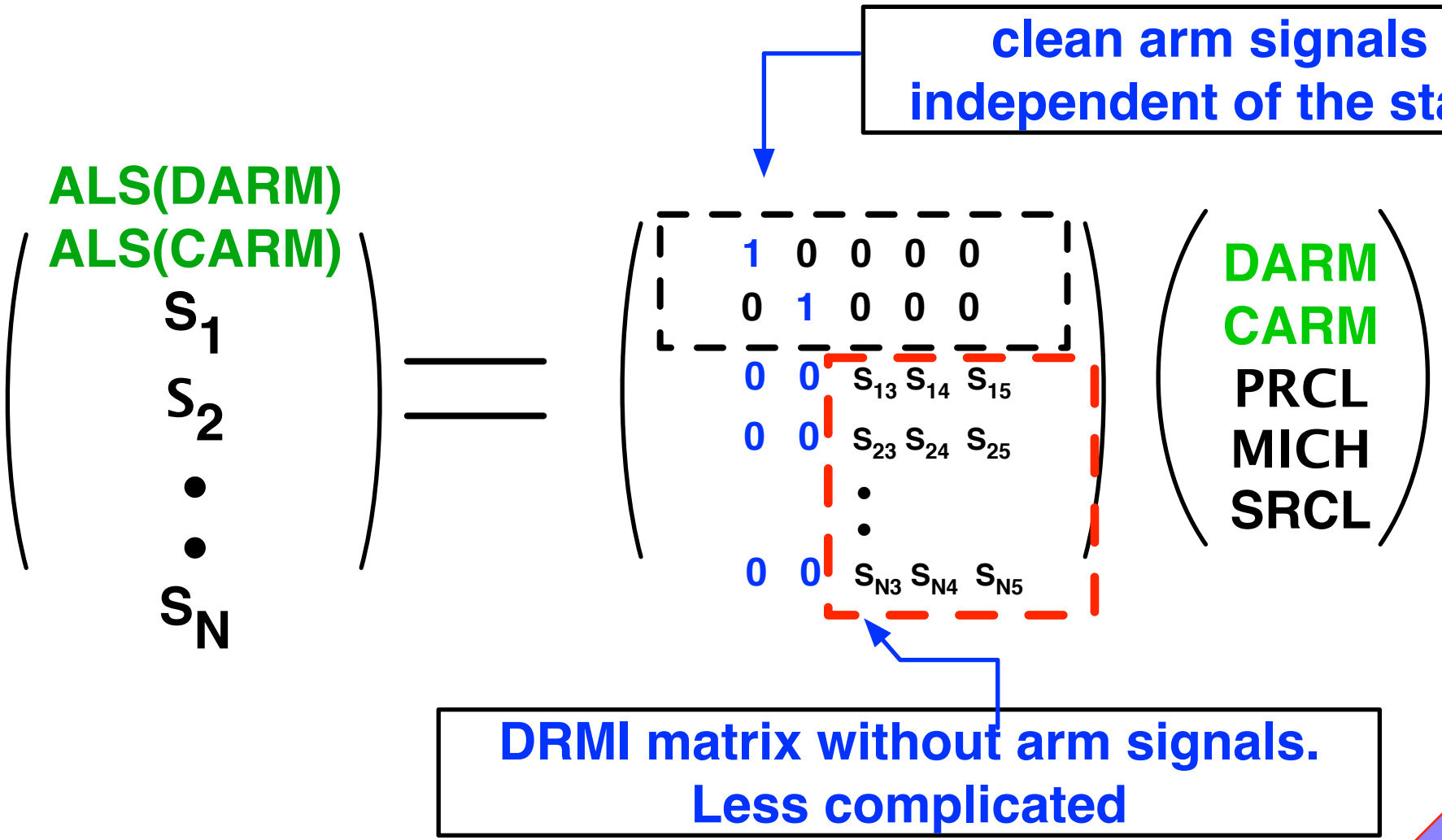
Sensing DARM and CARM



- X/Y transmitted green light carries the information of the arm displacement
- Beatnote of PSL vs Y(X)-arm => CARM sensor
- Beatnote of X vs Y-arm => DARM sensor

Arms are decoupled !

Introducing offset in the arm lengths decouples them



Sounds so easy but...

ALS is excelet !
So the full locking must be easy !

- **Initial acquisition of all the DOF should be easier**

However ...

- **Handing the ALS servo to the infrared sensor is not straightforward**

- **Reduction of the arm offset is not straightforward**

Handing off is the 1st key

The arm control need to be handed to the infrared sensors from ALS

- CARM are initially at off resonance points by ALS
- Reduction of offsets

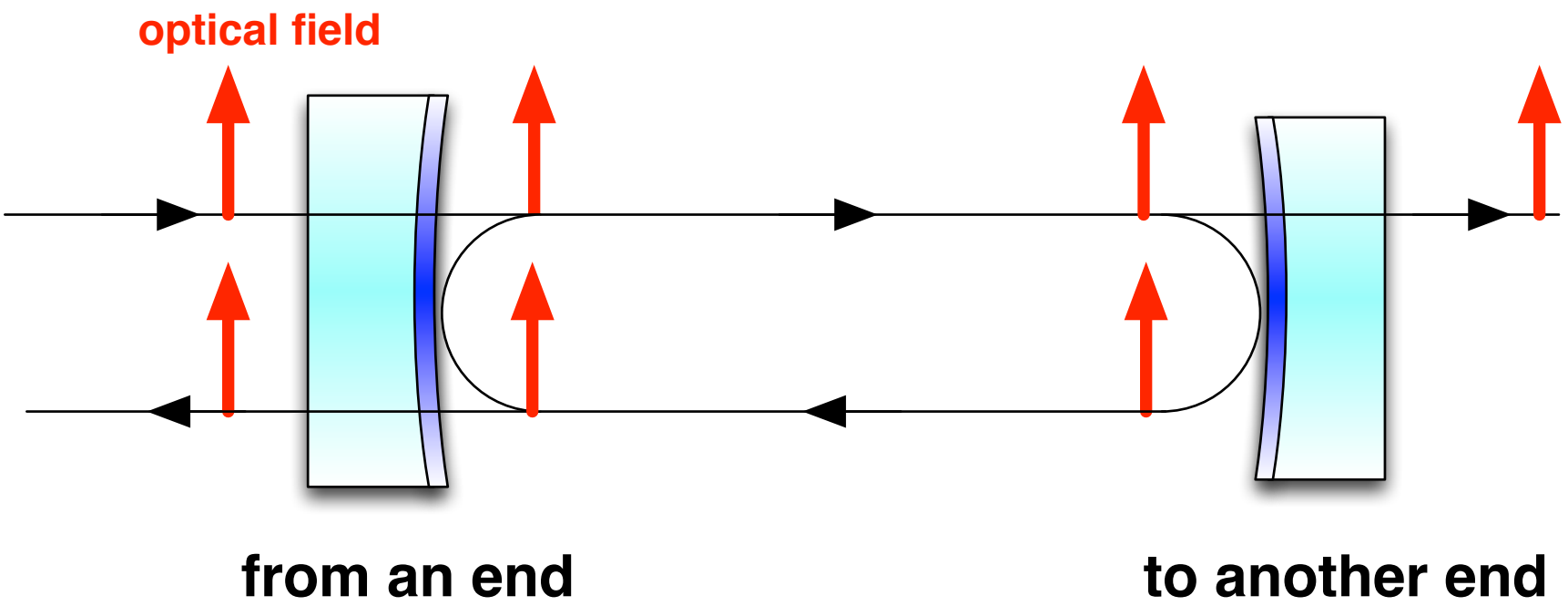
  => infrared signals become available
- ALS stability ~ 100 pm* (arm linewidth ~ 1nm)

  * LIGO-T0900144-v4
- CARM linewidth ~ 10 pm
- Fields dynamically changes

  => Frequency domain simulation is not sufficient

End 2 End

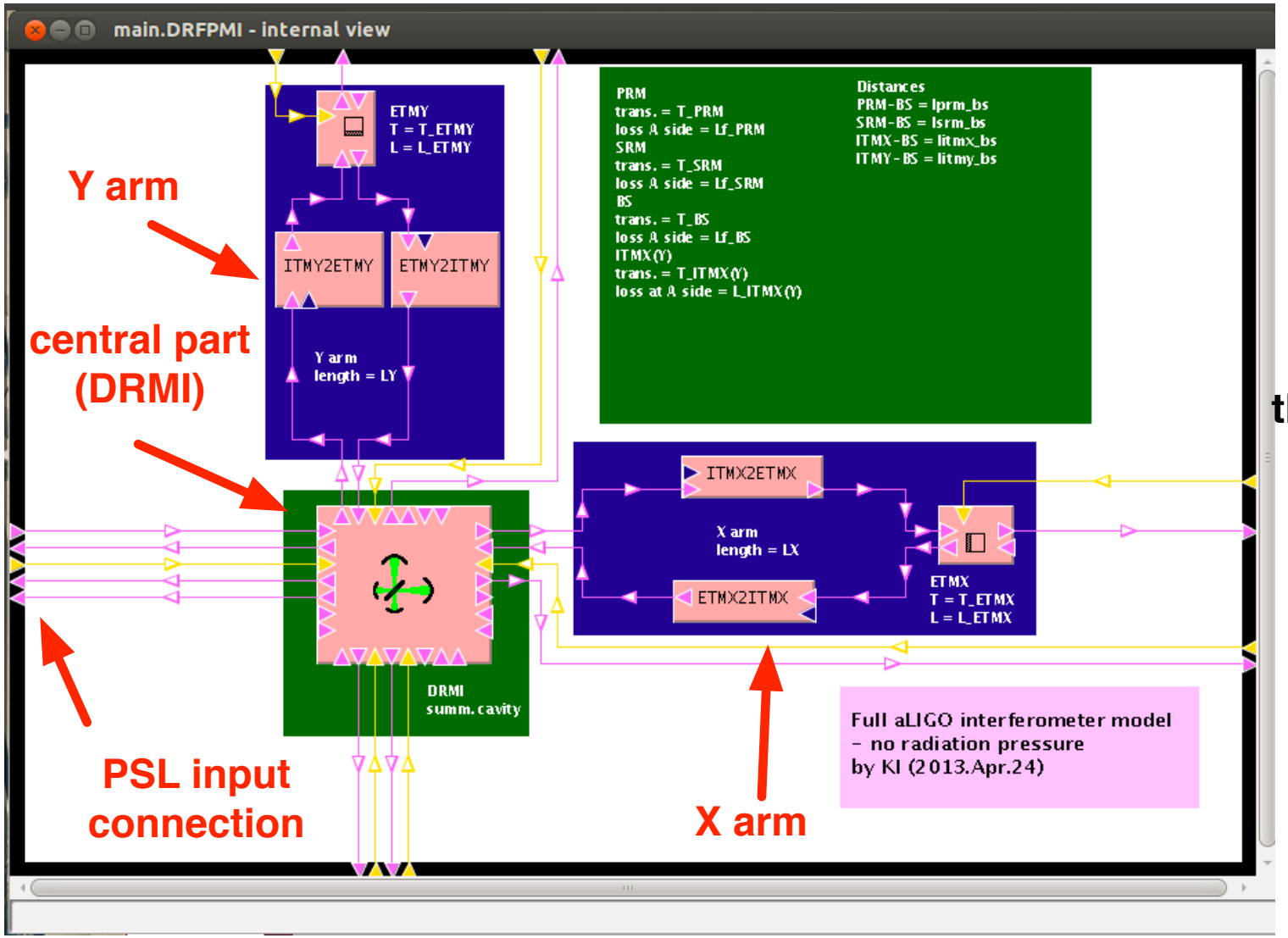
- Time domain simulation kit
- Calculates field at every end



http://e2e.caltech.edu/

Designed to be user friendly

- GUI accelerates your work



JAVA based GUI

GUI Diagram is then interpreted to a file which E2E engine reads

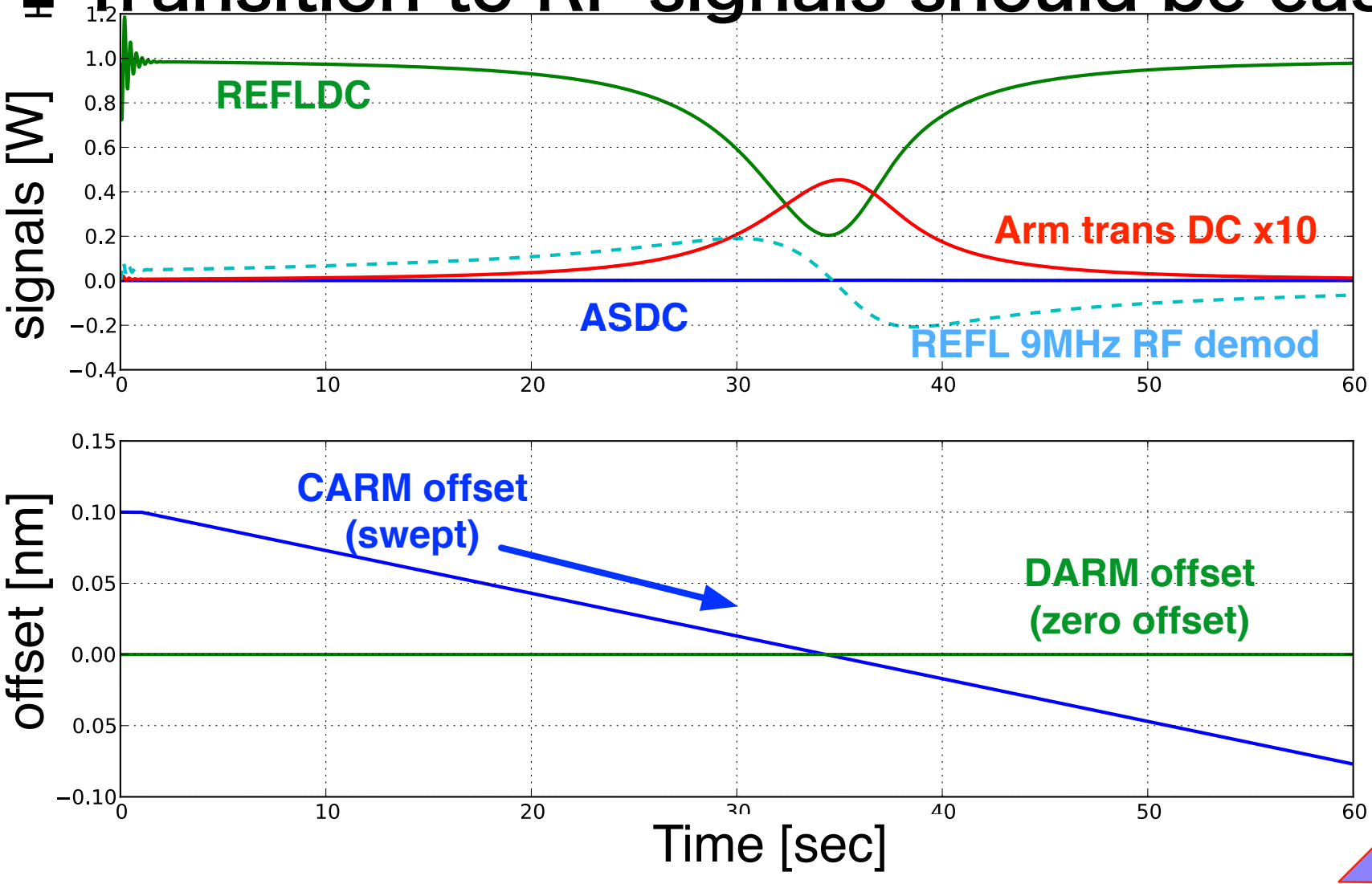
Simulation Setup

- Full aLIGO interferometer
- time step ~ 13 usec
- No radiation pressure
- 1W incident on the interferometer
- T=35% high trans SRM
  (initial low power aLIGO)
- All DOF is magically under control

Let's have a look at signals with CARM sweeping in the following slides

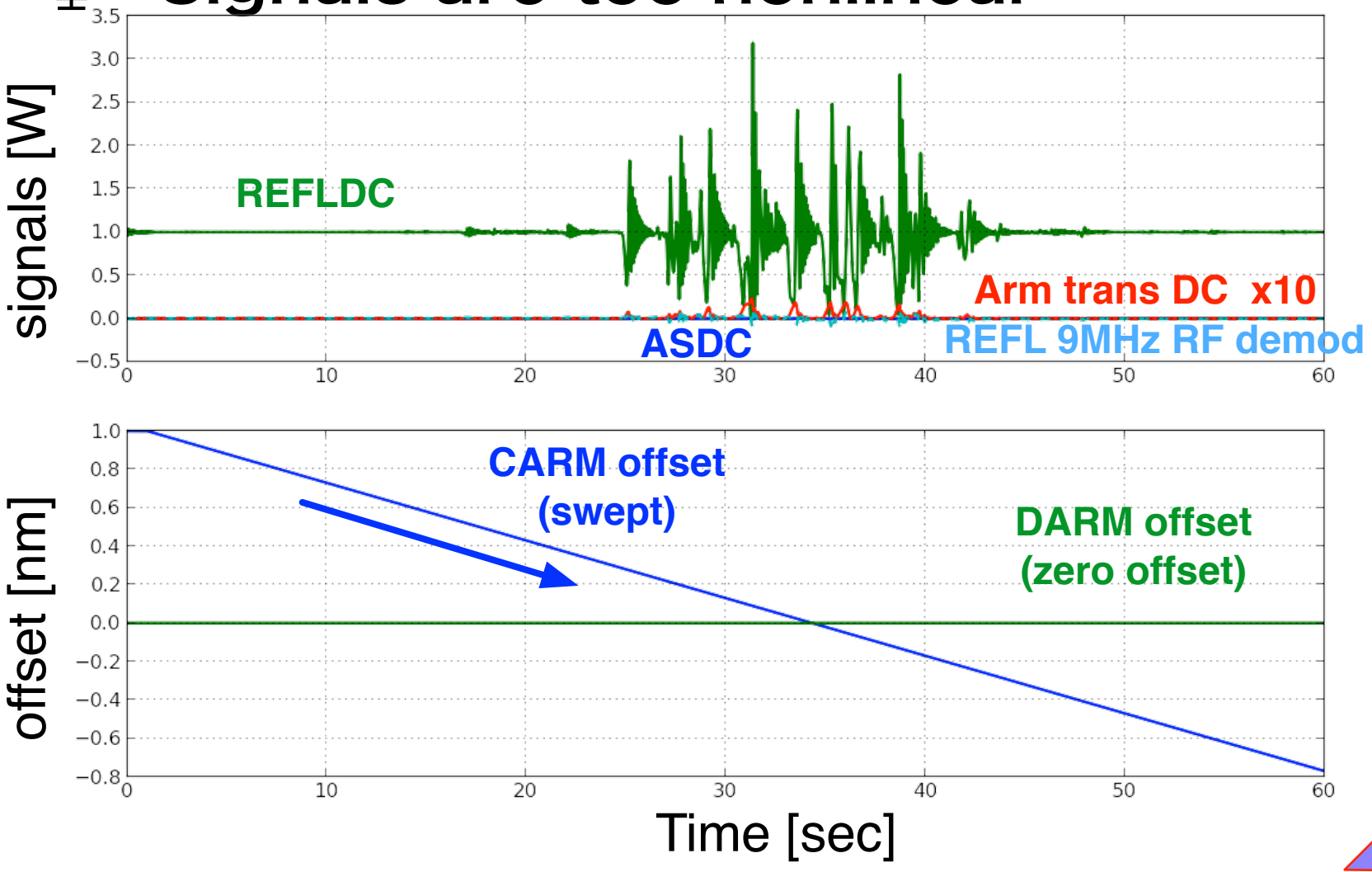
In an ideal world

- Assume ALS well-stabilises the arms
- Transition to RF signals should be easy



Real world is more like this

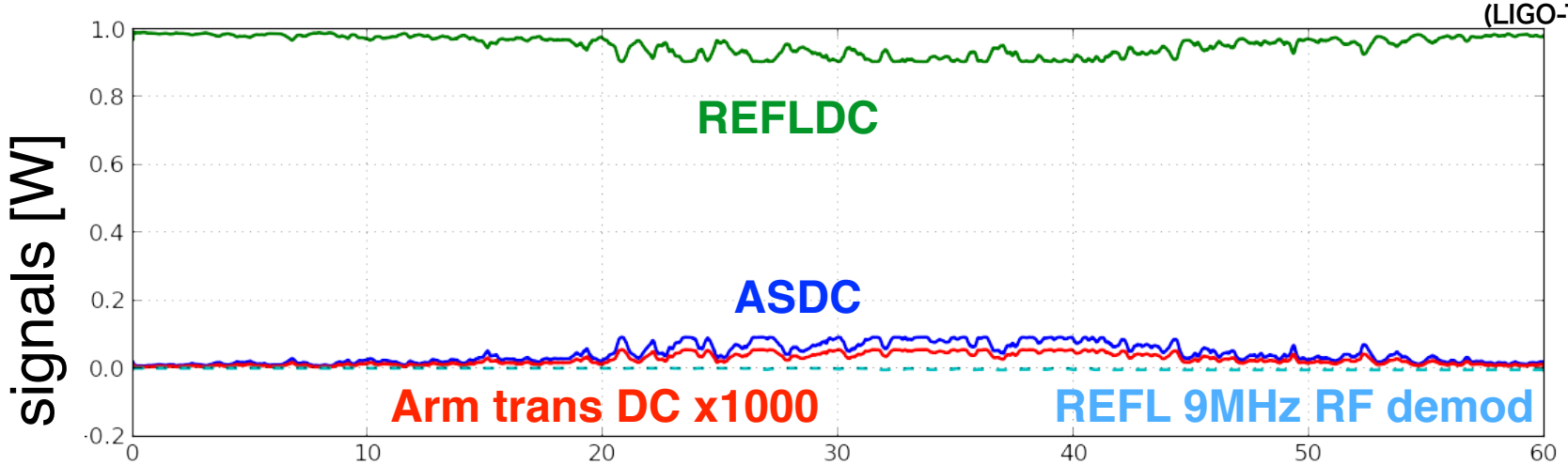
- Arm stability ~ 100 pm in rms
- Signals are too nonlinear

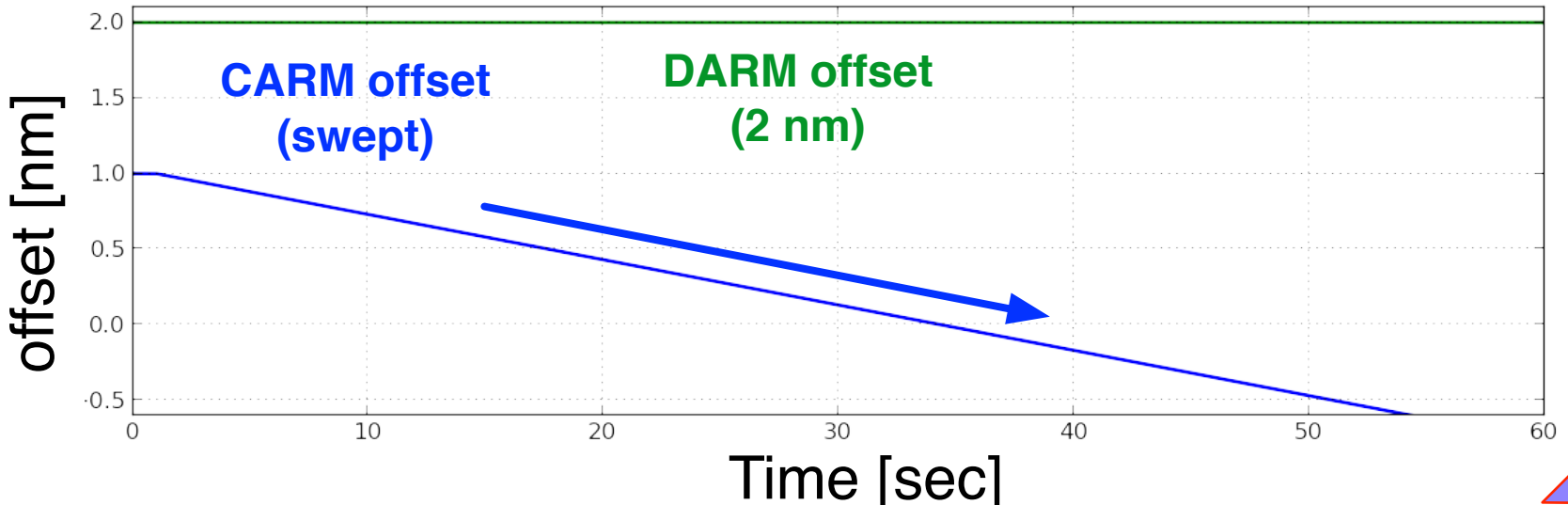


Use of DC signals

- DC signals serve as arm sensors with DARM offseted
- Suggested in early simulation work by L.Barsotti

(LIGO-T1000294)





To make it determinstc

Deterministic = no failure after all the DOF becomes under control

We need to study :

- Handing off of the arm controls
- Further reduction of the offsets
- Dynamic transfer function compensation
- Implementation of locking sequence in the digital control system

Summary

- End 2 End time domain simulation will be telling us how to fully lock aLIGO

- Bringing the arms to the resonance makes the them coupled again

  => ALS is not quiet enough for CARM

- Direct transition to the RF signal is difficult

  => Use DC signals at the beginning

Stay tuned !