The physics of compact objects and experimental improvements on detectors in the gravitational-wave era

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Thesis proposal

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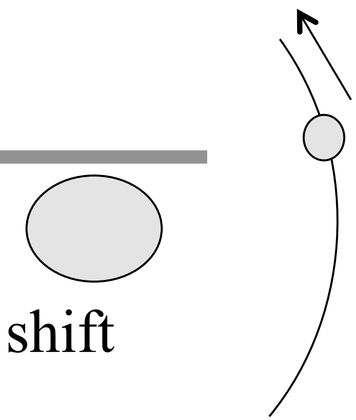
INTRODUCTION

- Adv. LIGO's detection of GW heralds a new age of GW astrophysics.
- It requires both better understanding/modeling of the astrophysical sources,
- and more sensitive and robust GW detector.

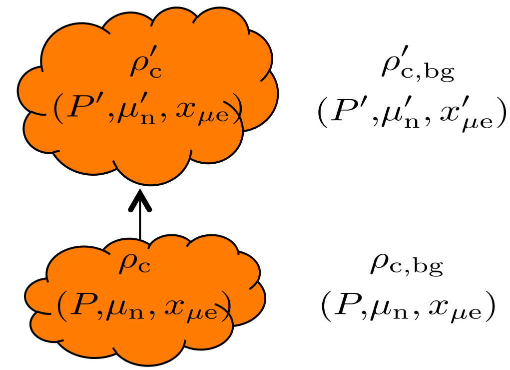
I. OBSERVABLES IN COMPACT OBJECTS (NEUTRON STARS)

- I.1 GW signatures: tidal interactions in coalescing binary NSs
- I.2 Traditional E&M signatures: exposing burning ashes in Type-I X-ray bursts

TIDAL INTERACTIONS IN COALESCING BINARY NS'S



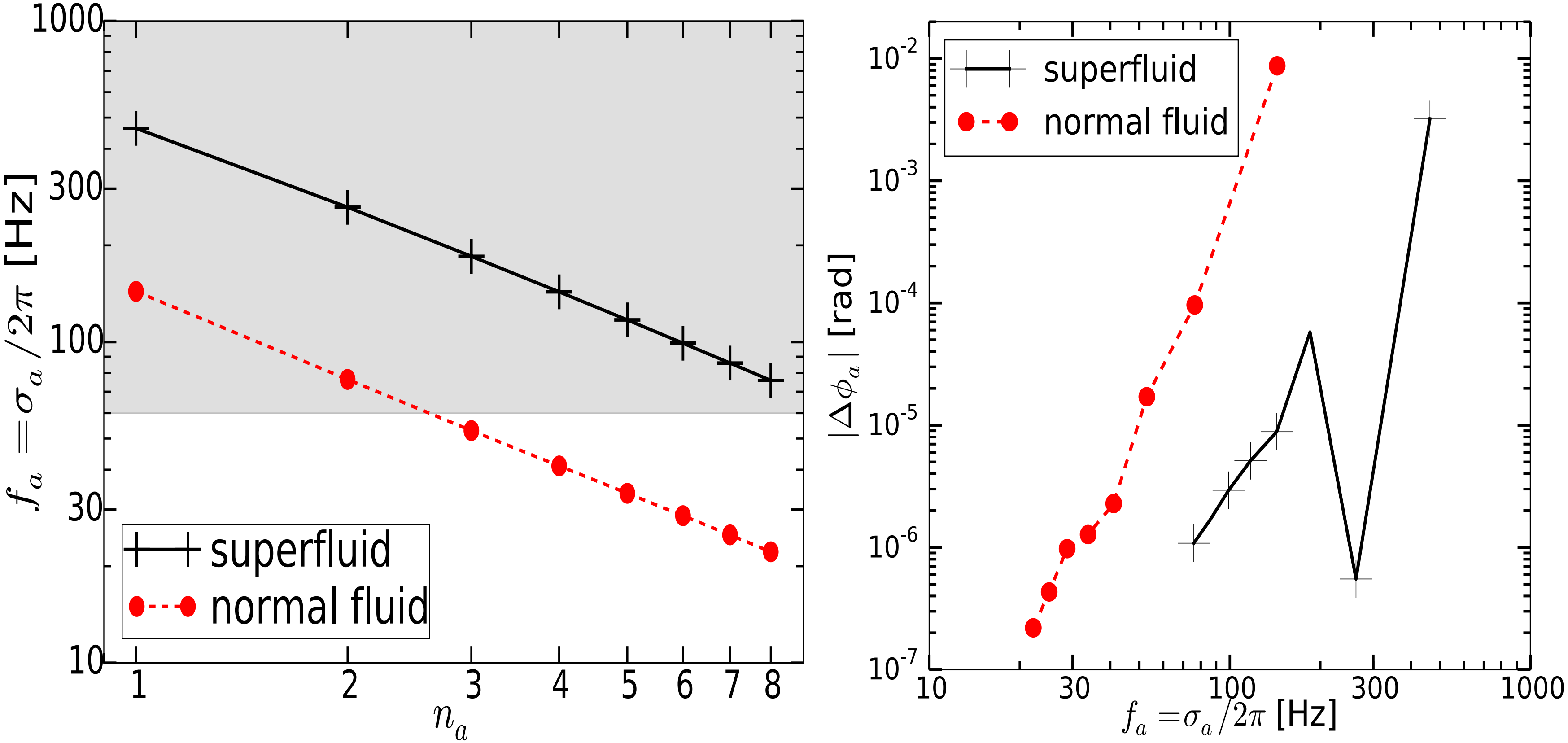
- BNS – Sources for ground-based GW detectors
- Orbital energy to NS internal energy – tidal phase shift
- Linear dynamic tides – driven H.O.
  - NS g mode eigenfreq ~ orbital freq
- Normal fluid vs. superfluid
  - Single fluid vs. two-fluid
  - Different source of bouyancy



- The amplitude and frequency of the resonance probes the stratification, composition, and superfluid state of the core of NS.

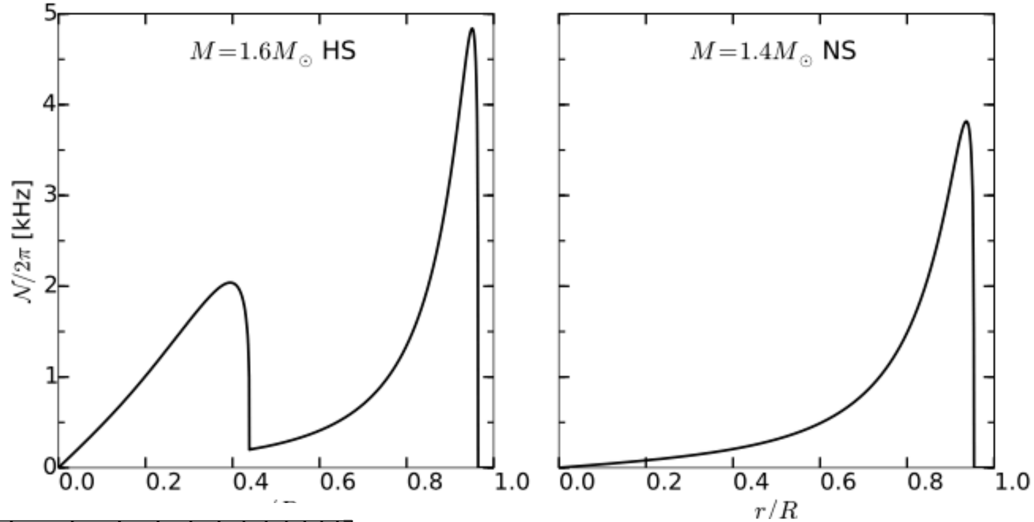
Superfluid npe\mu NS

published: MNRAS, 464, 2622 (2017)



NS with Hyperons in the inner core

(submitted to MNRAS)



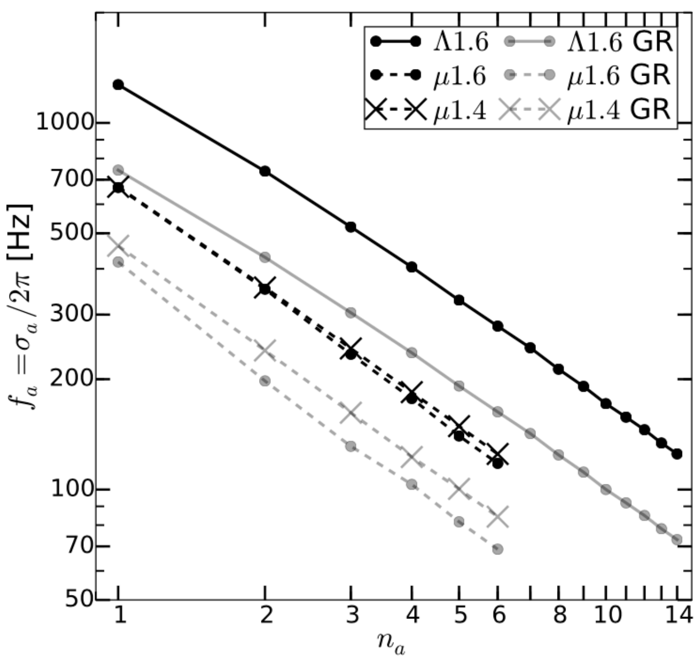


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Table 2. Eigenfrequencies $f_a^{(GR)}$ and gravitational waveform phase shift $\delta\phi_a$ for the three-lowest order $l_a = 2$ g modes for each stellar model. The format is $\{f_a/100\text{ Hz},\ |\delta\phi_a|/\text{rad}\}$.

j	$n_a^{(j)}=1$	$n_a^{(j)}=2$	$n_a^{(j)}=3$
Λ1.6	{7.4, 5.5e-4}	{4.3, 3.4e-4}	{3.0, 3.6e-7}
μ1.6	{4.1, 3.4e-3}	{2.0, 1.6e-5}	{1.3, 1.2e-5}
Λ1.5	{4.1, 1.1e-3}	{2.5, 1.6e-7}	{1.4, 6.6e-7}
μ1.5	{4.5, 5.4e-3}	{2.4, 6.6e-6}	{1.6, 2.1e-5}
μ1.4	{4.6, 9.8e-3}	{2.4, 3.6e-7}	{1.6, 3.0e-5}

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NS with Hyperons in the inner core

(submitted to MNRAS)

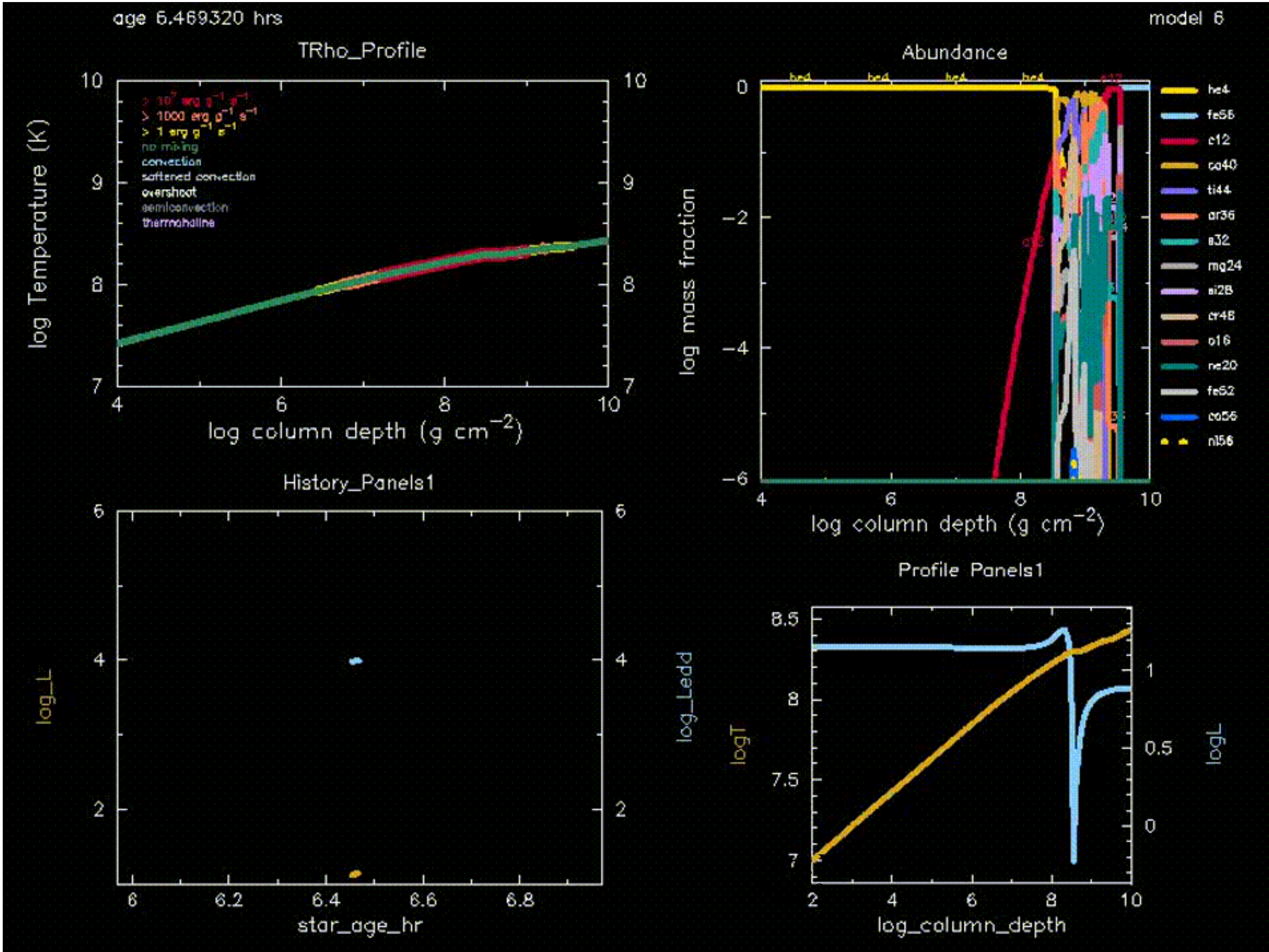
Table 4. Measurement errors found by stacking events for different detectors and values of f_a and $\delta\phi_a$. We assume 5 years of observation, an SNR cutoff of 12, and $\mathcal{R} = 10^3\ \mathrm{Gpc}^{-3}\ \mathrm{yr}^{-1}$, corresponding to expected number of events of 45, 3.3×10^6, and 7.8×10^4, for aLIGO, CE, and ET-D, respectively.

f_a [Hz]	$\lvert\delta\phi_a\rvert$ [rad]	Detector	$\langle\Delta(f_a)\rangle$ [Hz]	$\langle\Delta(\delta\phi_a)\rangle$ [rad]
450	0.01	aLIGO	3.2e+3	1.3e-1
		CE	2.9e+1	1.4e-3
		ET-D	9.1e+1	4.2e-3
450	0.001	aLIGO	3.2e+4	1.3e-1
		CE	2.9e+2	1.4e-3
		ET-D	9.1e+2	4.2e-3
750	0.001	aLIGO	1.0e+5	4.0e-1
		CE	1.1e+3	4.7e-3
		ET-D	3.3e+3	1.4e-2

EXPOSING ASHES IN TYPE I X-RAY BURSTS

(ongoing)

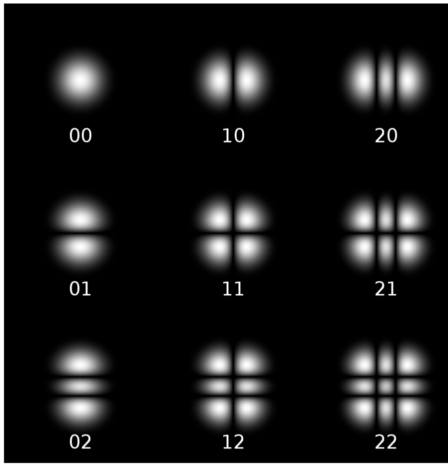
- Type I X-ray bursts: run-away thermonuclear burning of H and/or He on the surface of an NS.
- A small fraction exhibits strong photospheric expansion.
- The freshly synthesized heavy-element ashes can be ejected in radiative wind.
- Ashes -> source of opacity -> absorption edges in spectra.
- Measure surface gravity via redshift of the edge location.
- Constrain EoS.

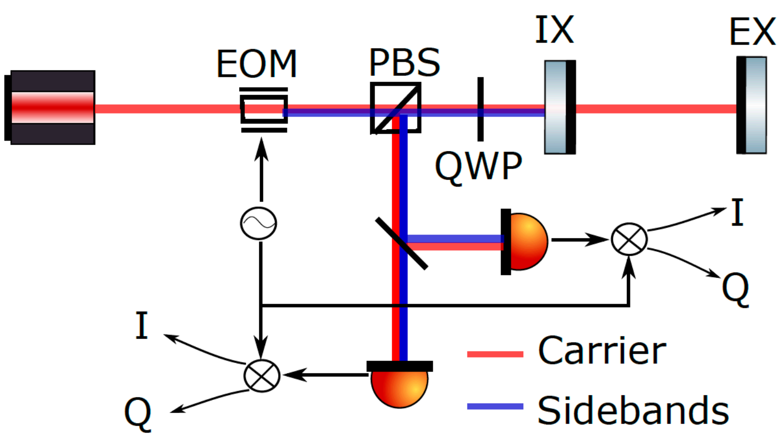

age 6.469320 hrs
model 6
TRho_Profile
log Temperature (K)
log column depth (g cm^{-2})
> 10^7 erg g^{-1} s^{-1}
> 1000 erg g^{-1} s^{-1}
> 1 erg g^{-1} s^{-1}
no mixing
convection
softened convection
overshoot
semiconvection
thermohaline
Abundance
log mass fraction
log column depth (g cm^{-2})
he4
fe56
c12
ca40
ti44
ar36
s32
mg24
si28
cr48
o16
ne20
fe52
co56
ni56
History_Panels1
log_L
log_Ledd
star_age_hr
Profile Panels1
logT
logL
log_column_depth

II. IMPROVING THE PERFORMANCE OF GW DETECTORS

- II.1 LIGO commissioning: alignment sensing and control (ASC)
- II.2 GWcleaning: feed-forward noise cancellation
- II.3 Enhanced chi-sq glitch vetoing
- (II.4 Coating thermal noise)

ALIGO ASC





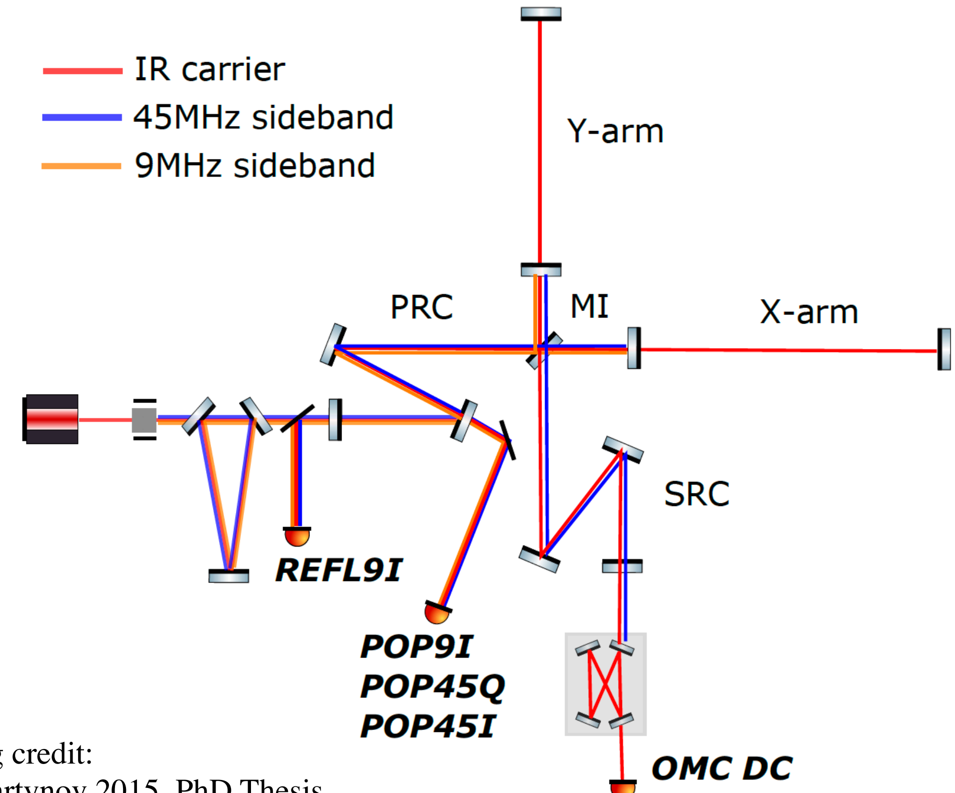


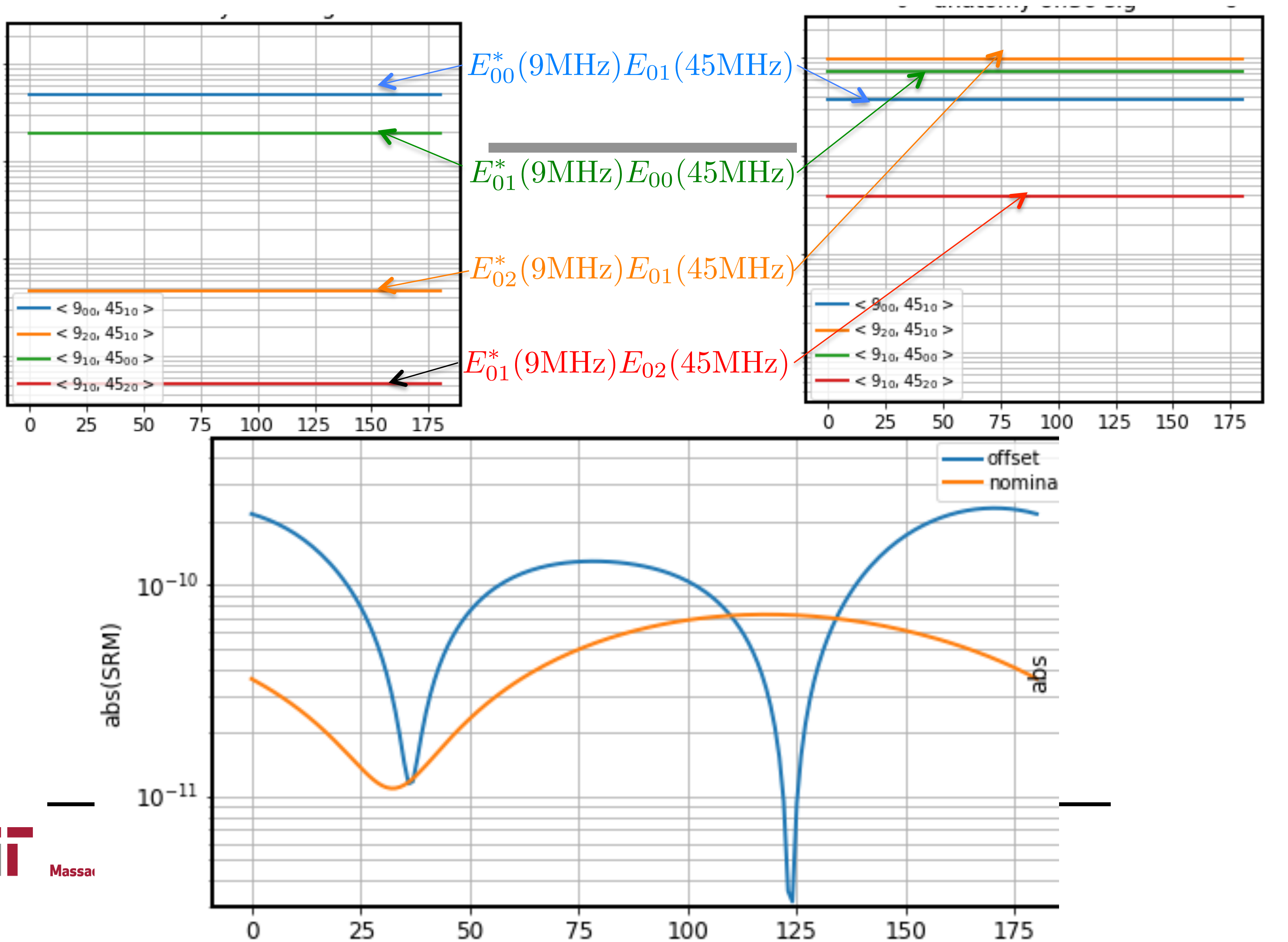
Fig credit:
Martynov 2015, PhD Thesis

Aligning the SRC

- SRC ASC signal problematic at LHO
- Related to IFO thermal state
- Extra absorption at ITMX found -> caused differential thermal lensing
- This can potentially explain why SRC ASC signal being bad.

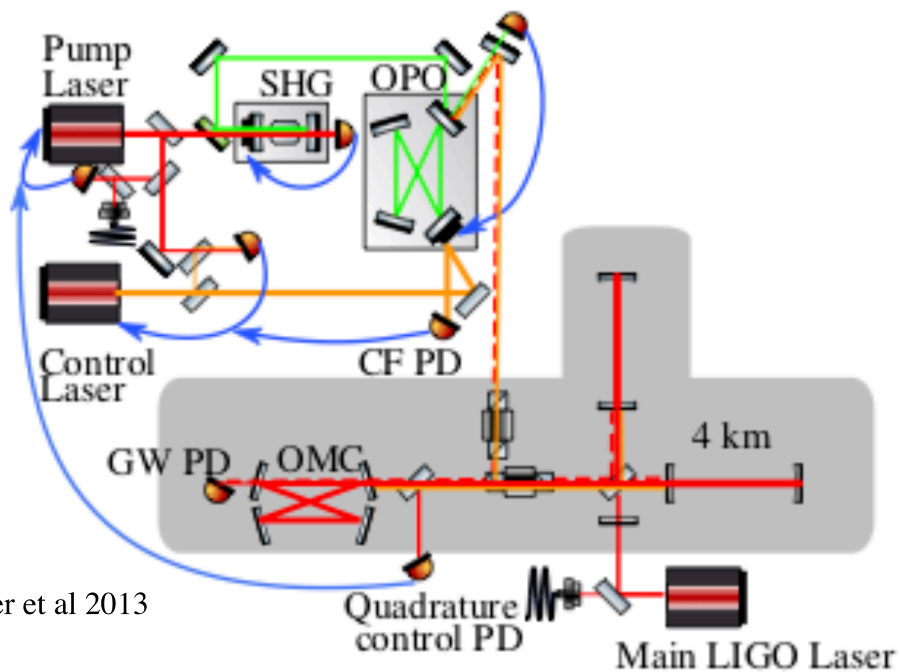
Nominal

Extra 100 km ITMX lens



New ASC Scheme for SRC

- Utilizing the Control Laser used for squeezed vacuum injection.
- Under development.



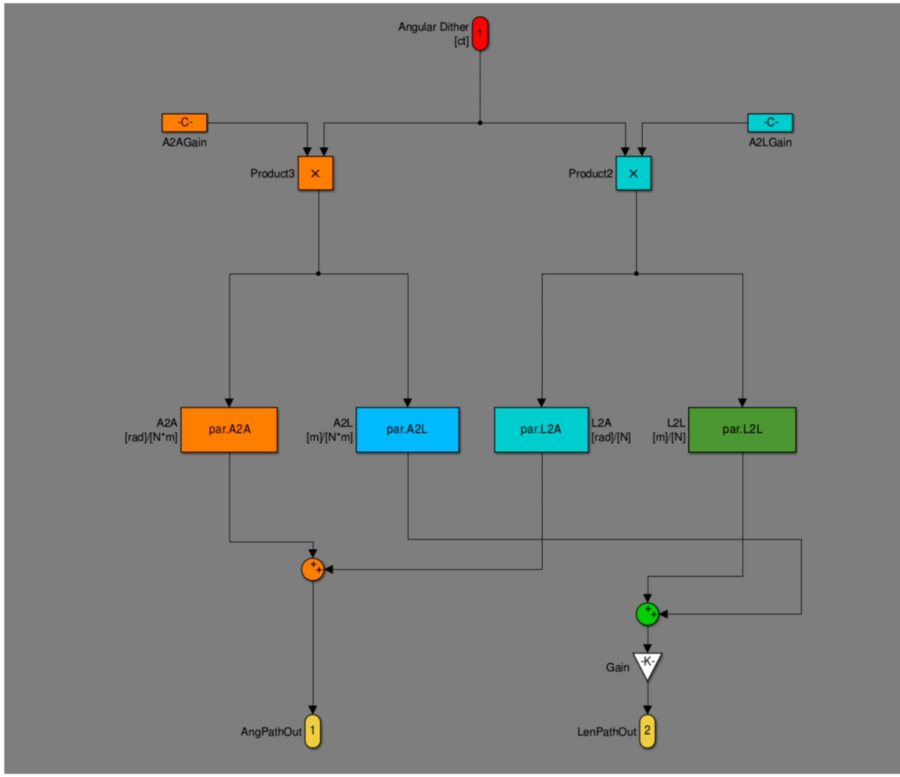
Dwyer et al 2013

GWCLEANING: FEED-FORWARD NOISE CANCELLATION

- Different degrees of freedom are cross-coupled
- Local: angle to length; length to angle
- Global: seismic to length; length to angle
- Suppressing noise via feed-back challenging: high gain to suppress motion, but low bandwidth to avoid sensor noise injection
- Decouple via feed-forward

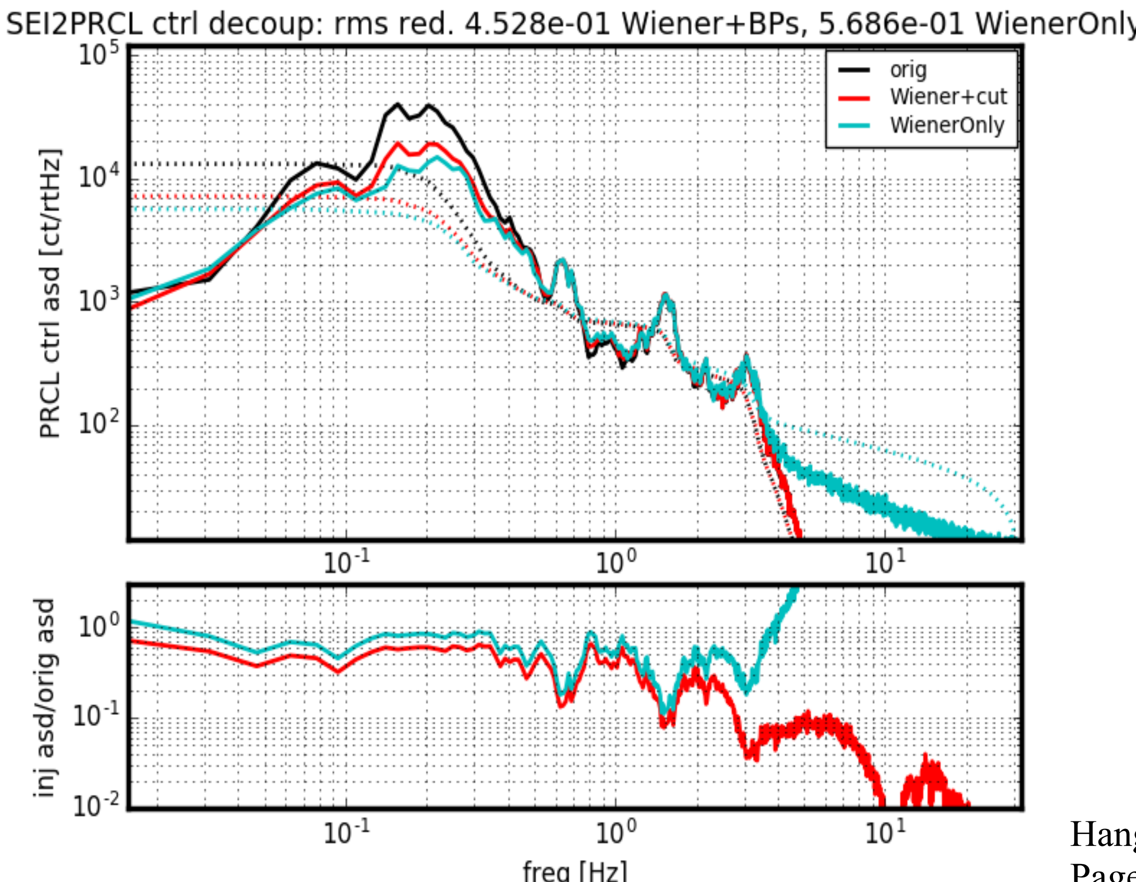
Local Feed-Forward

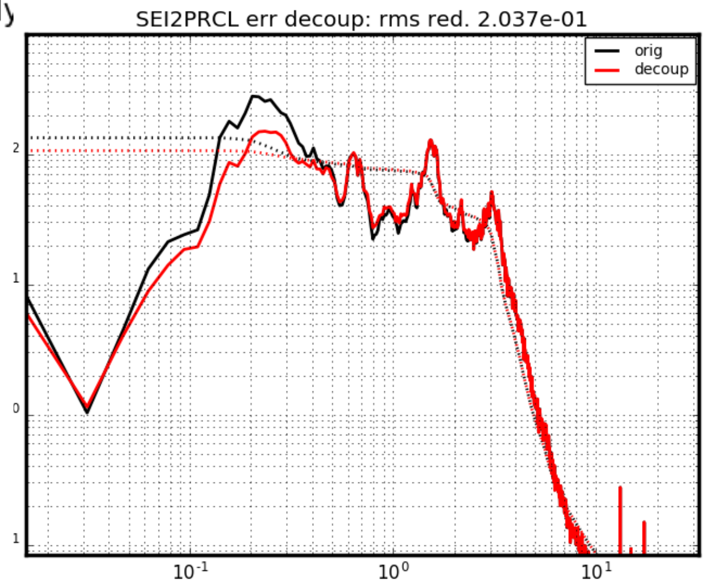
- Local coupling:
  - Spot mis-centering couples angular motion to length
  - Suspension system couples length actuation to angular motion
  - Can be canceled with single-input-single-output system



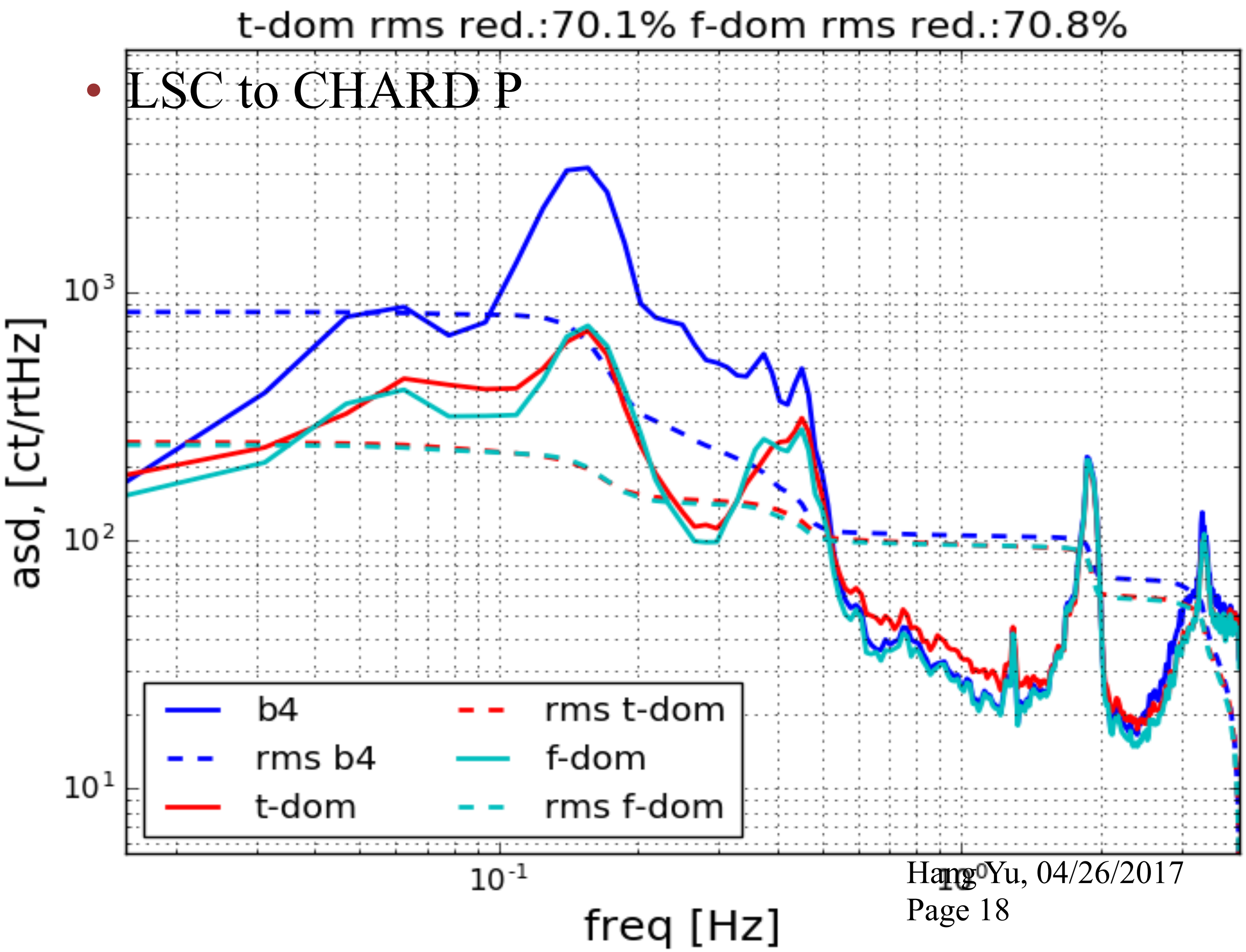
Global Feed-Forward

- SEI to LSC



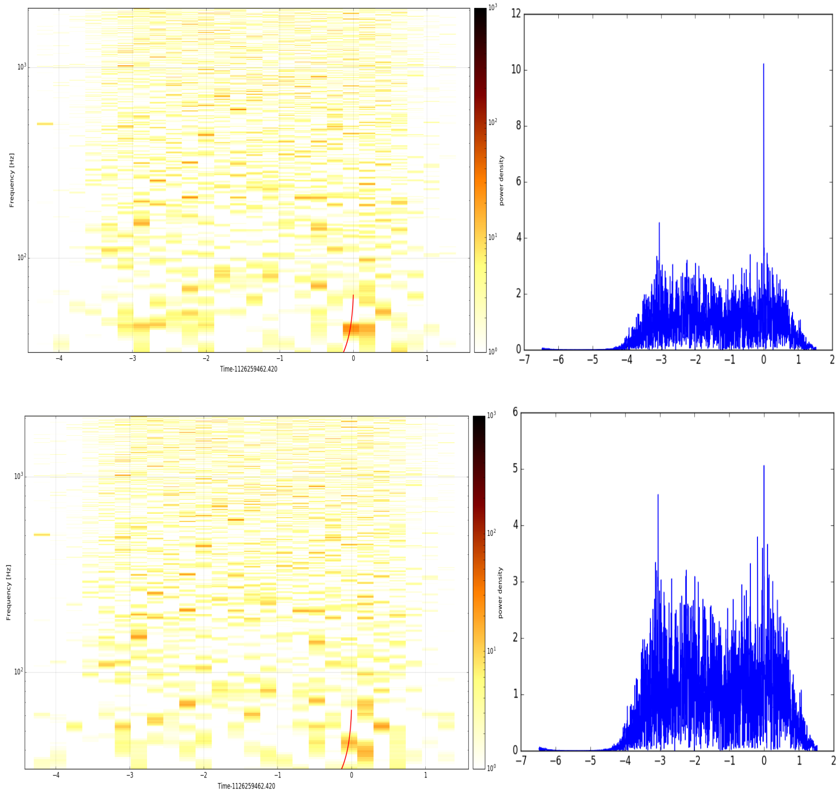


- LSC to CHARD P

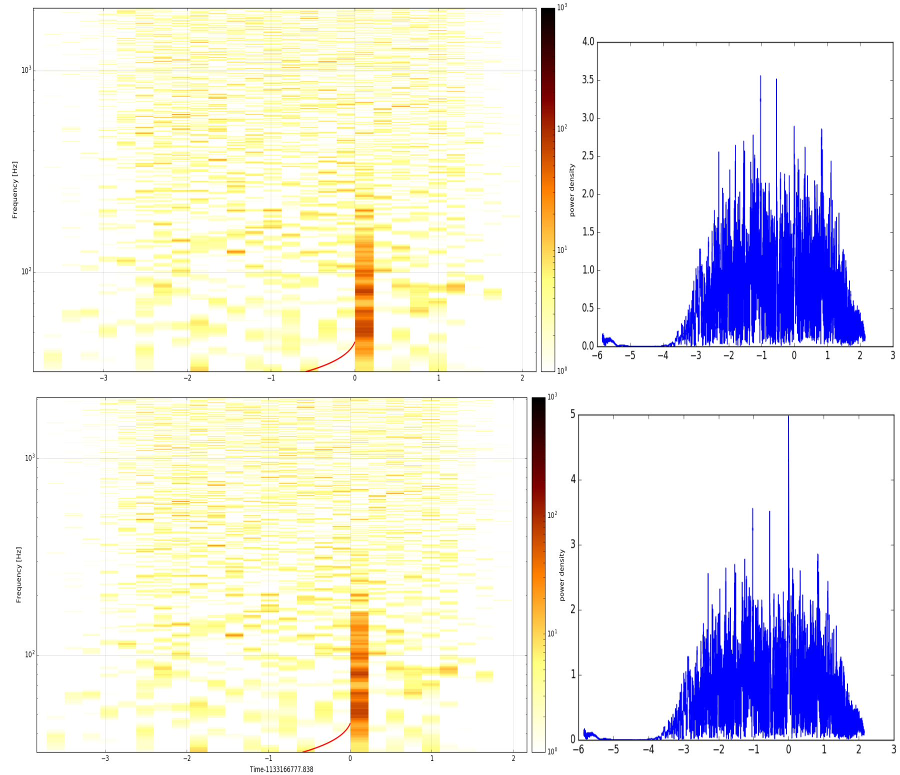


ENHANCED CHI-SQ GLITCH VETOING

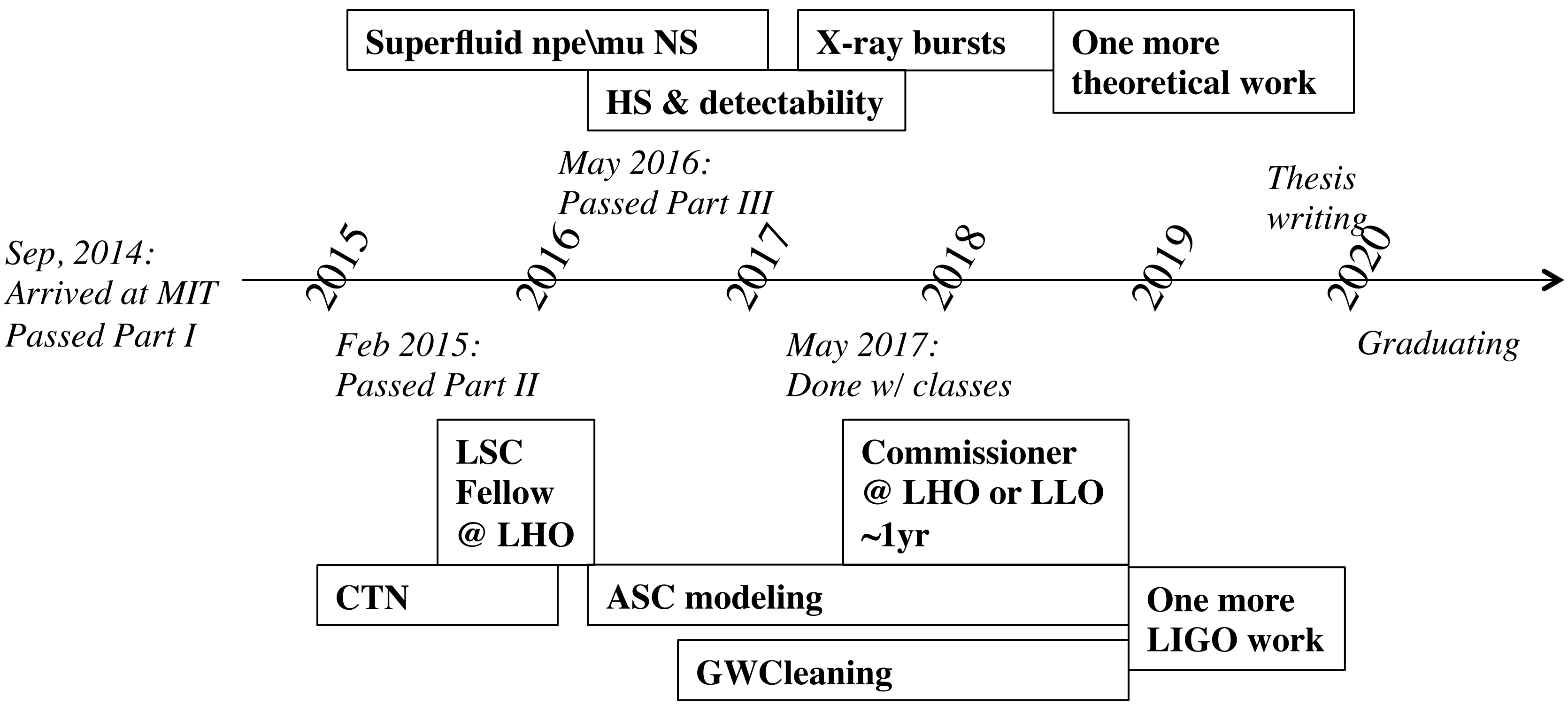
GW150914 in L1



A Glitch



TIMELINE:



Superfluid npe\mu NS
X-ray bursts
One more theoretical work
HS & detectability
May 2016: Passed Part III
Thesis writing
Sep, 2014: Arrived at MIT Passed Part I
2015
2016
2017
2018
2019
2020
Feb 2015: Passed Part II
May 2017: Done w/ classes
Graduating
LSC Fellow @ LHO
Commissioner @ LHO or LLO ~1yr
CTN
ASC modeling
One more LIGO work
GWCleaning