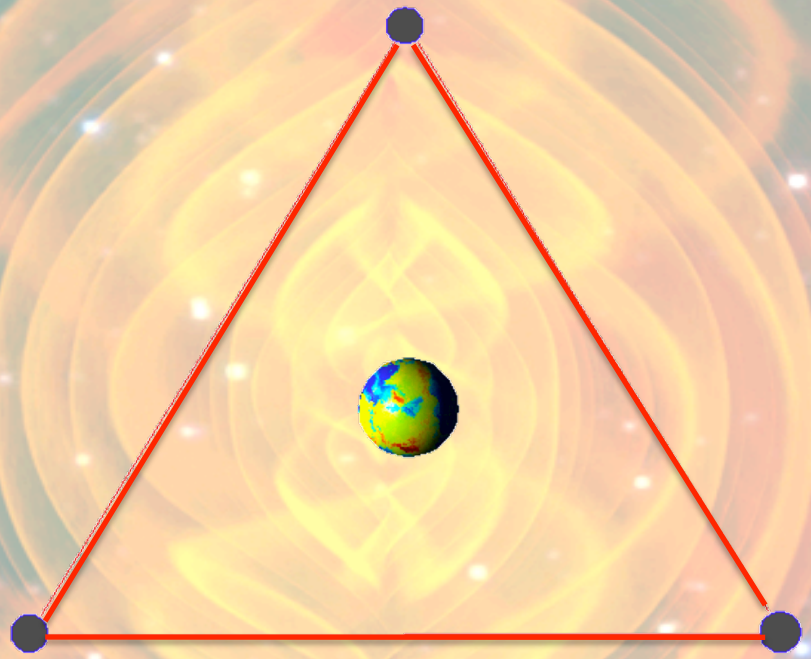
Optimal orbits for eLISA science



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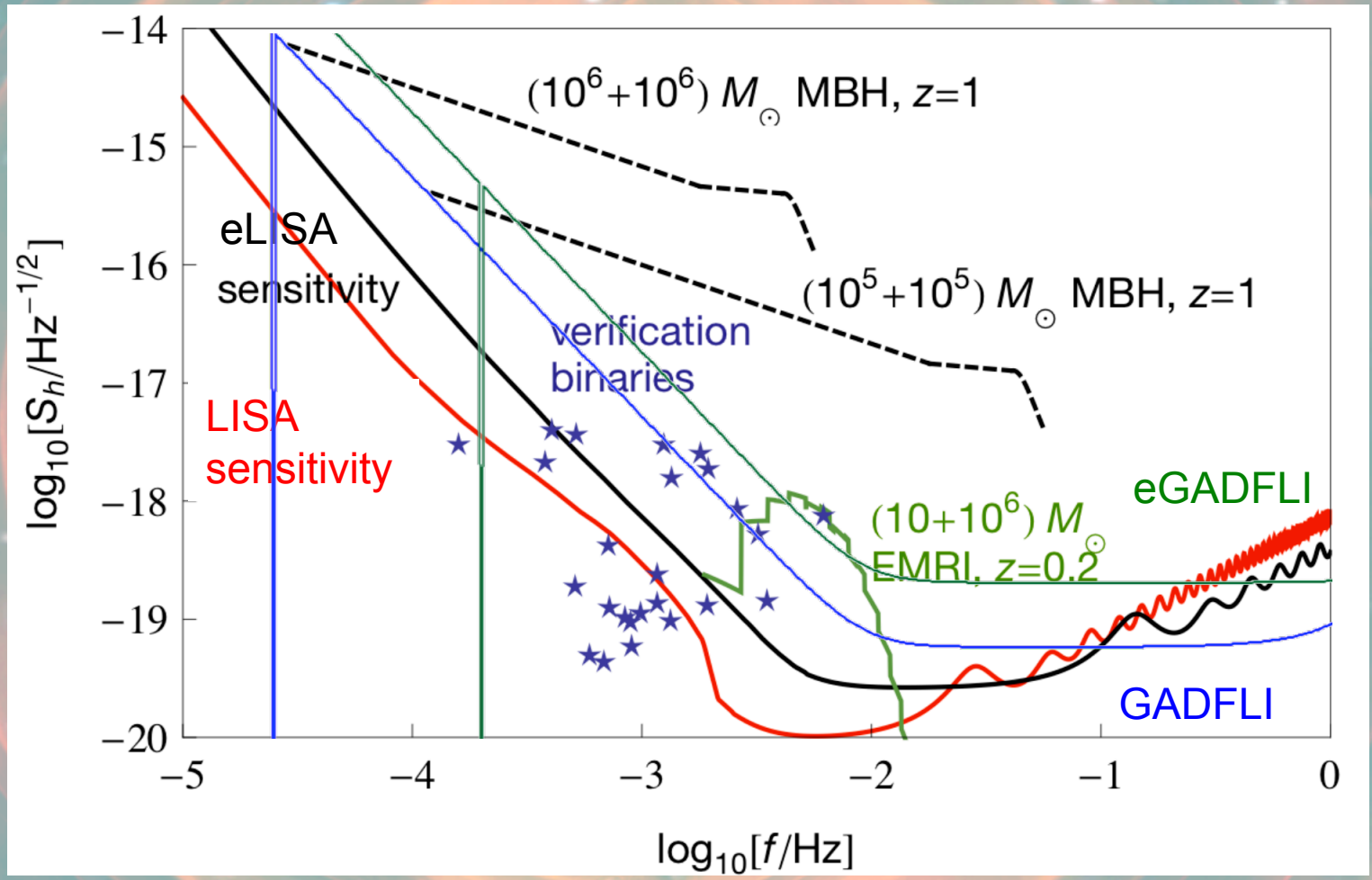
Overview

- Sensitivities and rates of NGO/SGO, Omega, and GADFLI for MBHBs, EMRIs, and GBs
- MBHB parameter estimation, or why you should pay *very* close attention to GADFLI
- Mission details, comparisons of designs
  - NB: very similar concept to GADFLI, GEOGRAWI by Tinto et al
- Cost: speculative comparison
- Conclusions: GADFLI wins on MBHB science (hands down), performs on EMRIs and GBs, uses LPF heritage, and may be the cheapest option. So…

	armlength (Mm)	# links	telescope dia. (cm)	laser (W)	duration (yr)	# modulations
GADFLI	0.073	6	15	0.7	2	730
OMEGA	1.04	6	30	1	3	7
SGO/NGO	1.0	6/4	25	0.7	2	2

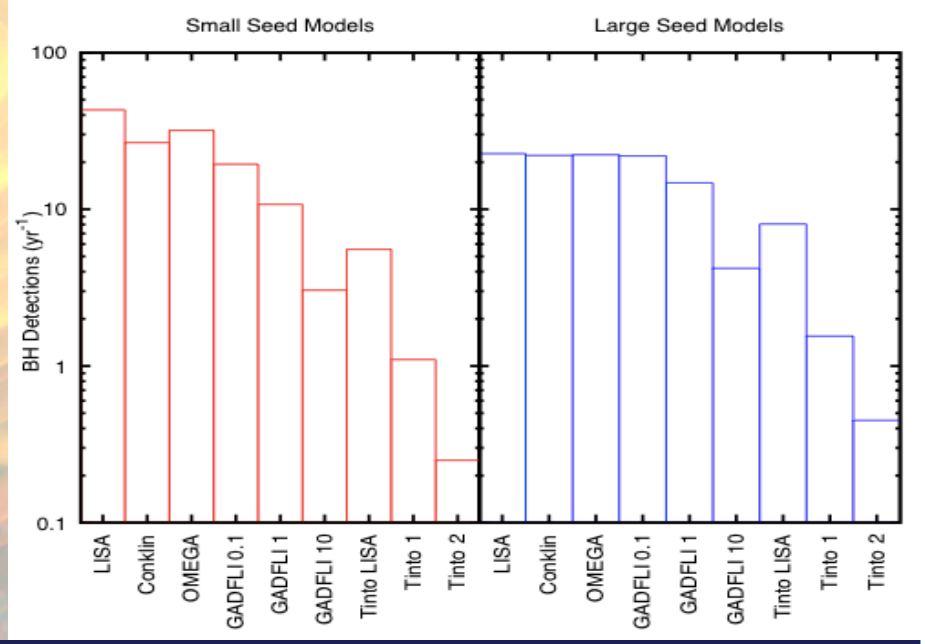
Strain sensitivities for LISA-like concepts



Adapted from Livas *et al*, SGO Mid Concept

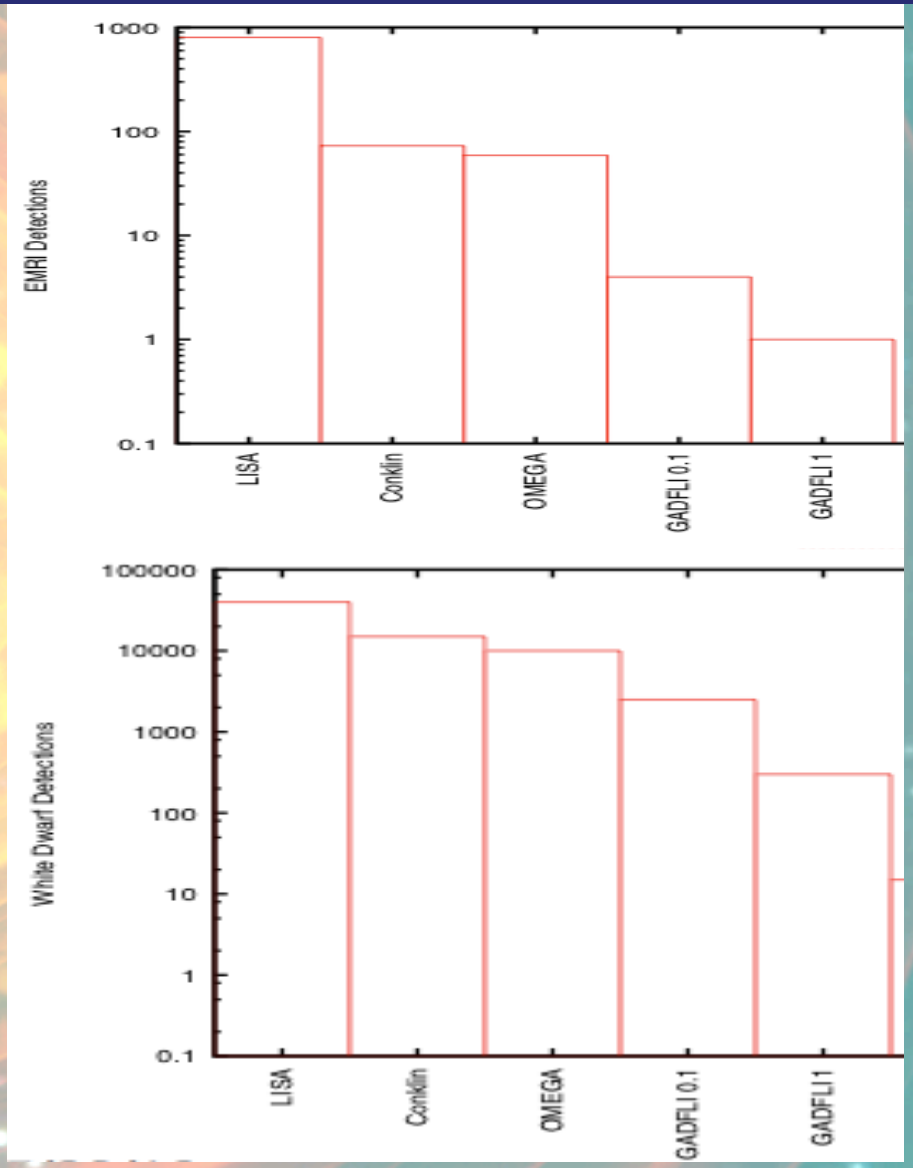
MBHB Sensitivities and Rates

- Total SNR for GADFLI for MBHBs is less than for NGO/ SGO and OMEGA
- HOWEVER, late inspiral SNR for low mass systems is largest for GADFLI
- Detection rate good for all



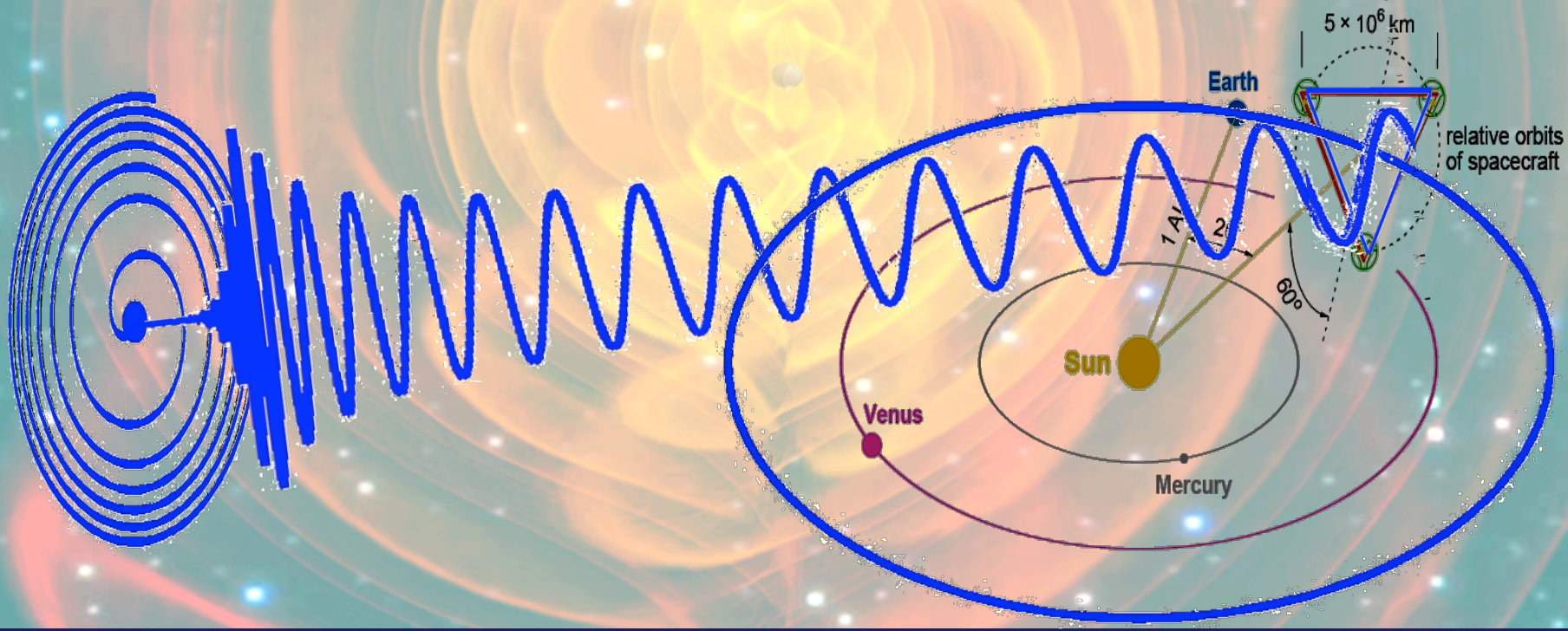
EMRI and GB Rates

- EMRI rate a conservative variant of Gair et al., Class. Quant. Grav. 21 (2004) S1595-S1606
- Extreme uncertainty in EMRI event rates
- All options should see GBs, based on Nelemans catalog
- EMRI and GB parameter estimation generally obey 1/SNR expectations, so GADFLI should worse as $N^{1/3}$, or a factor of ~4 for EMRIs, < 2 for GBs



How does LISA measure MBHB parameters?

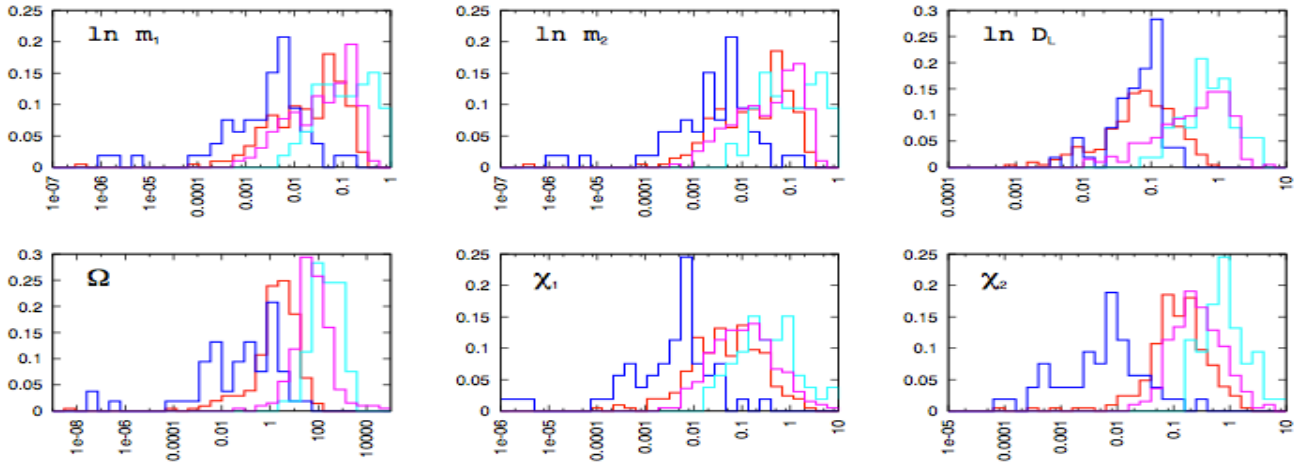
- Intrinsic parameter dependence of waveforms (for MBHBs, q, $\boldsymbol{S}_1$, $\boldsymbol{S}_2$, $\boldsymbol{e}$)
- Independent waveform channels, with different frequency and spatial dependencies (aka TDI observables)
- Doppler modulation: annual (all) and shorter periods (geocentric)
- Frequency dependence of response function



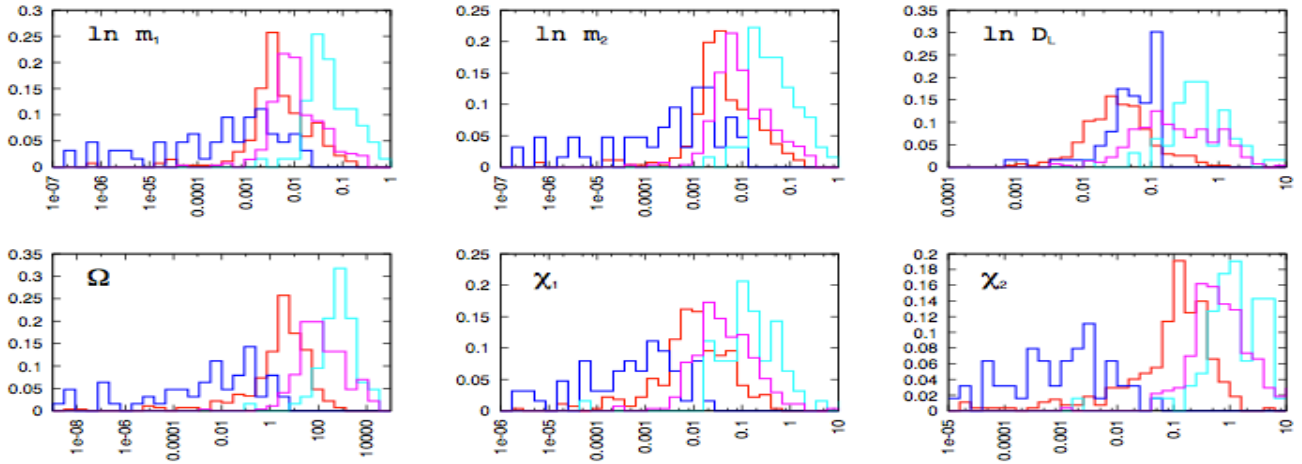
GADFLI: a better instrument for MBHB astrophysics

Large Seeds, SGO lo + mid, GADFLI l

SGO mid
SGO lo
GADFLI 6L
GADFLI 4L



Efficient accretion

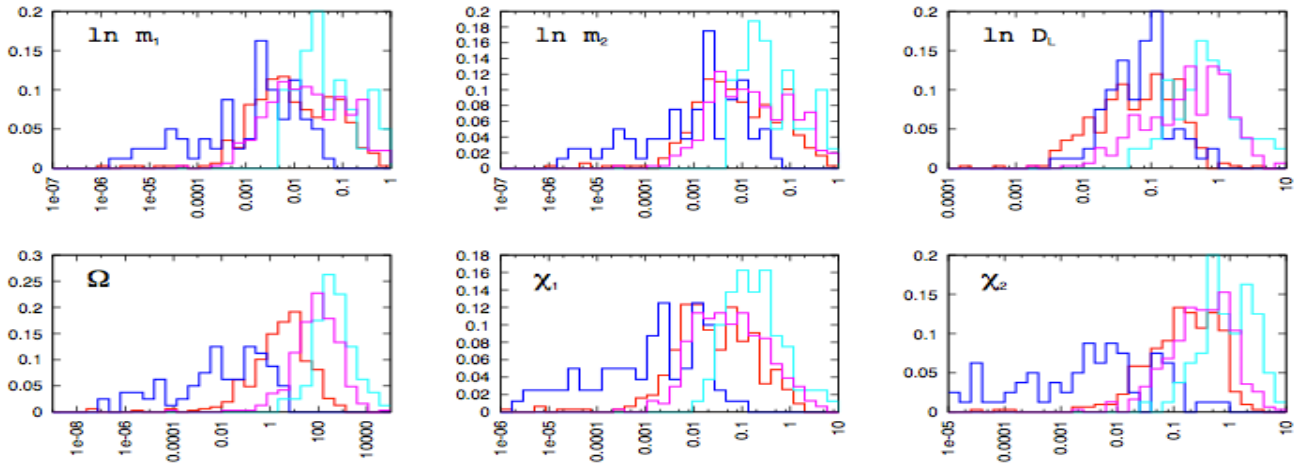


Chaotic accretion

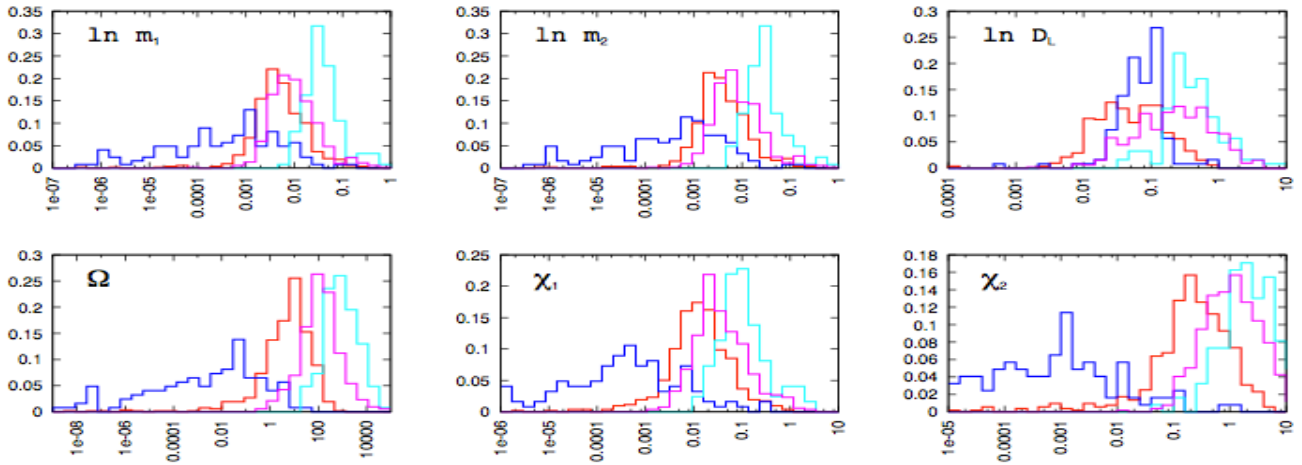
GADFLI: a better instrument for MBHB astrophysics

Small Seeds, SGO lo + mid, GADFLI I

SGO mid
SGO lo
GADFLI 6L
GADFLI 4L



Efficient accretion

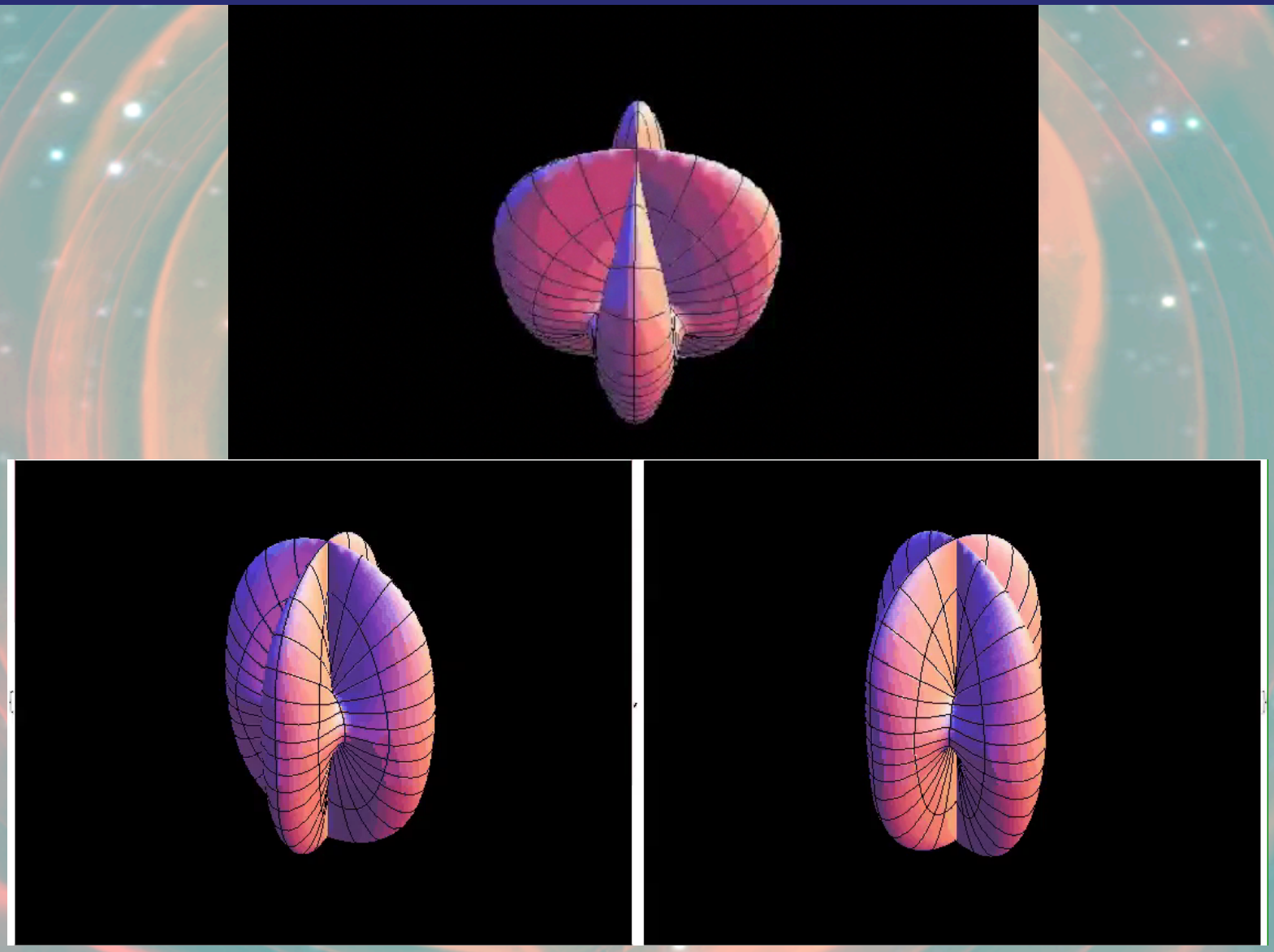


Chaotic accretion

GADFLI: a better instrument for MBHB astrophysics

- In December 2011, GADFLI was proposed as an alternative concept.
- The NASA design assessment, as given in the final PhysPAG report, was very positive.
  - Orbits are sufficiently stable
  - Cost to orbit is cheaper, no propulsion module needed
  - Will detect fewer sources, but should still see many MBHBs and GBs, and some EMRIs
  - Parameter estimation for MBHBs is dramatically improved
- The design was nonetheless not recommended due to lack of thermal stability – geostationary orbits show different surfaces to the Sun, get eclipsed.
- Sun synchronous orbits can fix this problem.
  - Precess due to asphericity of the Earth
  - Stable orbits used in Earth observing
  - Orbits are designed to be stable, equivalent thermal stability to LISA is a bonus

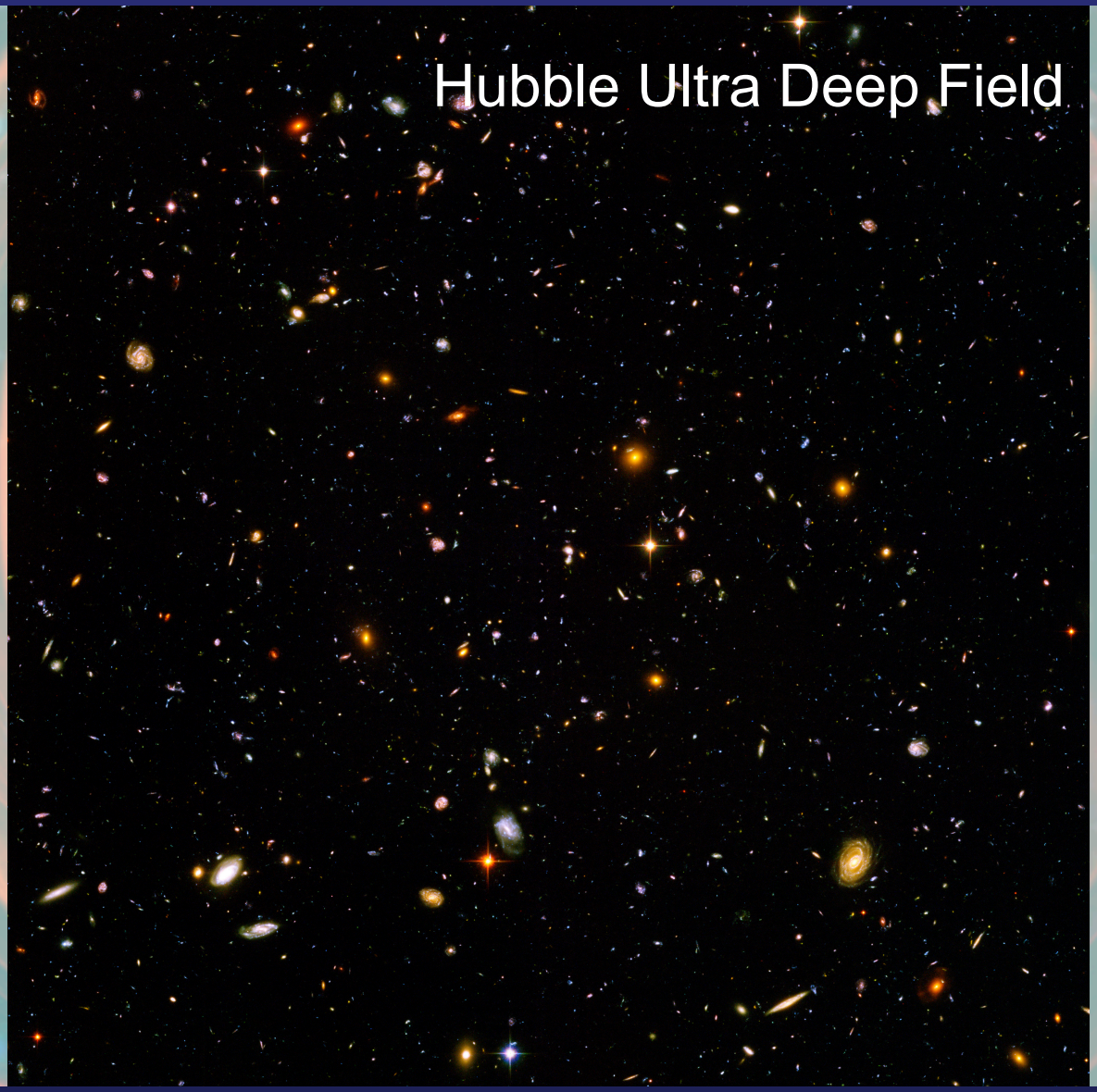
GADFLI: a FAR better instrument for MBHB astrophysics



1 deg^2 resolution (4-link eLISA)

1 arcmin^2 resolution (6-link eLISA)

1 arcsec^2 resolution (GADFLI)



1 arcmin^2
resolution at $z = 1$
(6-link eLISA)
– or –
1 arcsec^2
resolution at $z = 7$
(GADFLI)

1 arcsec^2 resolution at $z = 1$ (GADFLI)

Design comparison

- GADFLI has a far more stable orbit than SGO/NGO or Omega, mission lifetime was limited solely to decrease cost

	Arm variation (%)	Interior angle variation (%)	Range rate (m/s)
GADFLI	0.02	0.02	1
OMEGA	0.1	12	160
LISA	0.01	0.8	13

- GADFLI much less expensive for orbit insertion, does not need a propulsion module

	LV C3 $(km/s)^2$	Δv (m/s)	Cruise duration (months)
GADFLI	-9.0	1	4
OMEGA	-1.6	500	13
LISA	-0.3	1100	14

- GADFLI and Omega must deal with eclipses and sunlight in the telescope. Without mitigation, GADFLI would need to drop out of science mode for ~40 days/yr.

All data provided by Gary Welter for Mission Concept Workshop

GADFLI pros/cons

pros

- seems to outperform even original LISA in MBHB science
- no need for propulsion module
- low launch mass
- uses LPF GRS, space-qualified laser, highest TRL level overall
- lower shot noise requirements
- most stable, cheapest orbit of any conceivable option
- … naively, should be less expensive than other options

cons

- GADFLI less sensitive to EMRIs and GBs by a factor of a few
- For geostationary, thermal issues must be understood
- For sun-synchronous, gravity gradient must be understood