ISS-TAO and TAP

Transient Astronomy / GW Counterpart Missions

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(for the ISS-TAO and TAP teams)

EM counterparts to GWs

- GW localization from LIGO, LISA, or PTA, is obtained from timing and is limited to several to 10s of square degrees
  - In contrast, EM counterparts can be imaged, localizing the host galaxy of the source of GWs

- GW analysis gets masses and possibly spins of compact objects

- Localization provides *astrophysical context* of the event
  - Nature of host galaxy
  - Redshift
  - Gas environment
  - Accretion disk interaction with GW source
    - Evolution in time…
  - Breaks parameter degeneracies

Proposed NASA transient missions to address GW Counterparts

- Transient Astrophysics Observer on the ISS (TAO-ISS)
  - Awarded Phase A study, final decision early 2019
  - Operational in 2022, inexpensive ($70M)
  - Beginning era of GW counterparts

- Transient Astrophysics Probe (TAP)
  - Awarded Concept Study → Decadal Panel
  - Potentially operational in ~ late 2020s
  - Higher cost cap ($1B)
  - Counterpart production era for LIGO sources
    - Possible discovery era for LISA, PTA

- Both missions also emphasize time-domain astrophysics

LIGO observation of NS-NS / NS-BH inspiral and merger

NS-NS merger

short GRB

LIGO Hanford

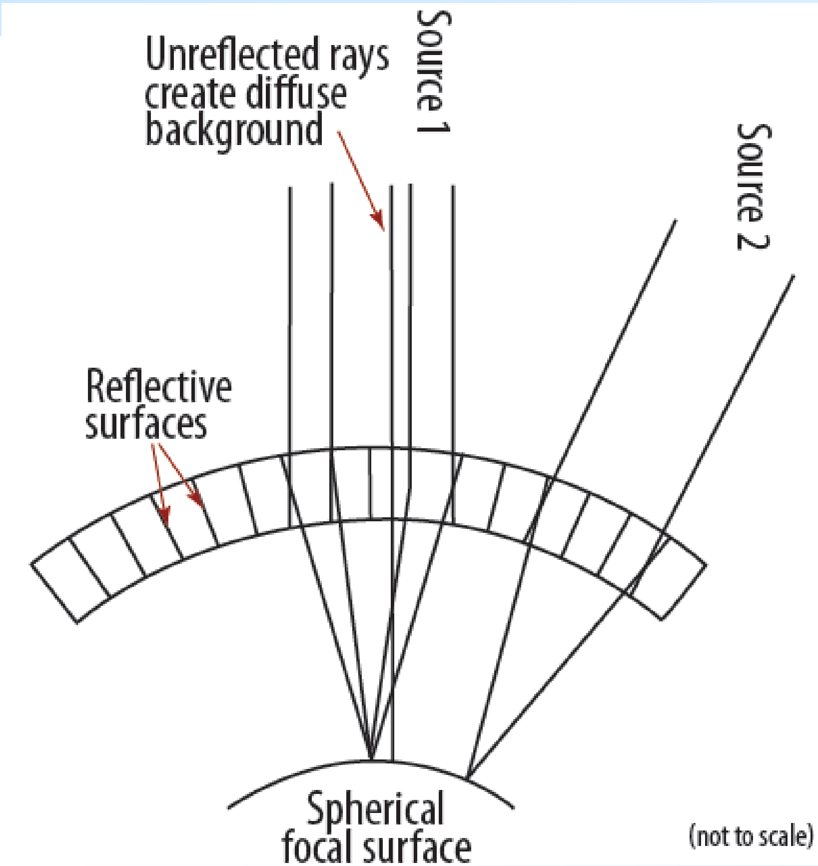
LIGO Livingston

100 deg^2 skymap from 3-detector LIGO-Virgo network in early 2020s

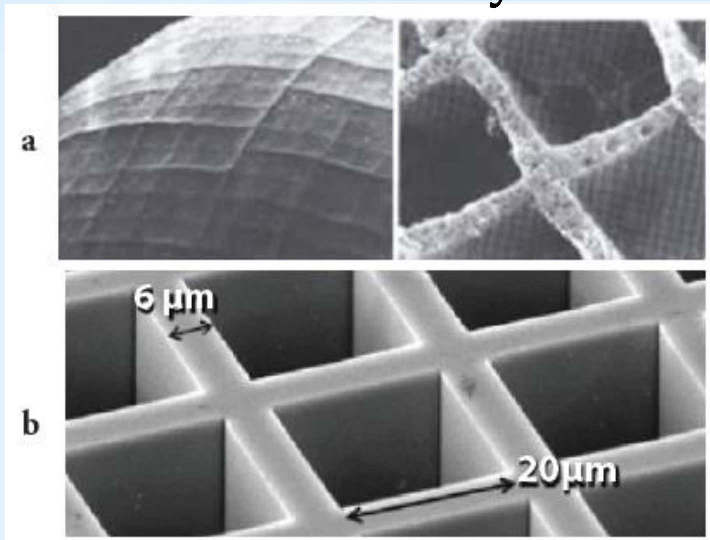
~ 10 deg^2 skymaps from 5-detector LIGO-Virgo-India-Kagra network by late 2020s

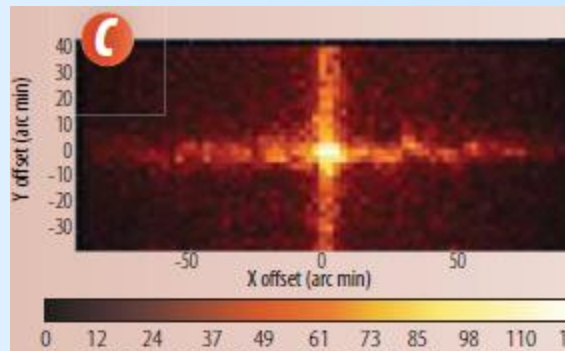
(Kalogera et al, 2016)

Lobster Optics (U Leceister)
New Technology → Breakthrough Science



Lobster Eye





C: PSF for the WFI MCO taken with the GSFC X-ray beam facility. Central core and cross-arms have a FWHM of 8 arcmin.

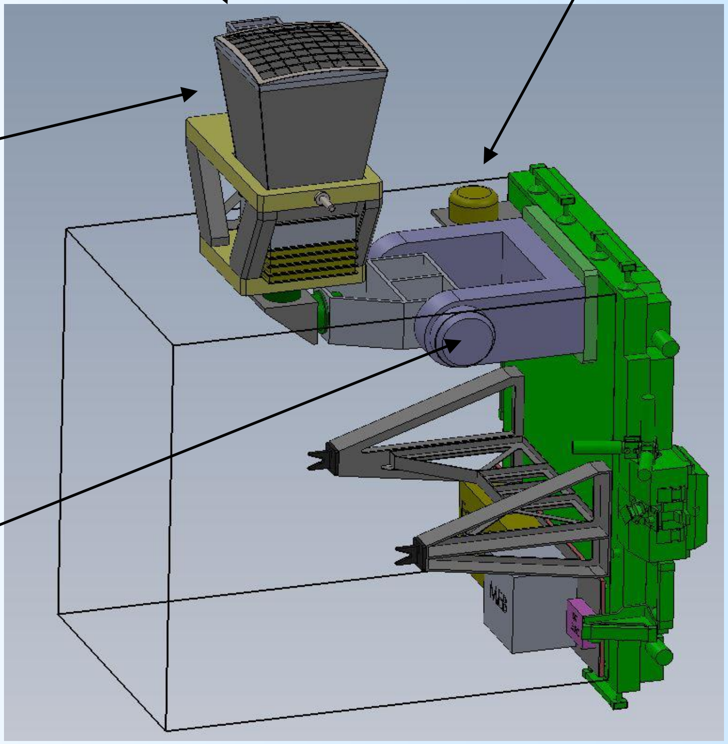
Lobster-Eye geometry provides *simultaneous* large FoV, high position resolution and high sensitivity → Time Domain Astronomy

TAO-ISS Payload and its Instruments

Star Tracker

Gamma-Ray Transient Monitor (GTM)
50 keV to 1 MeV
Technion, Israel

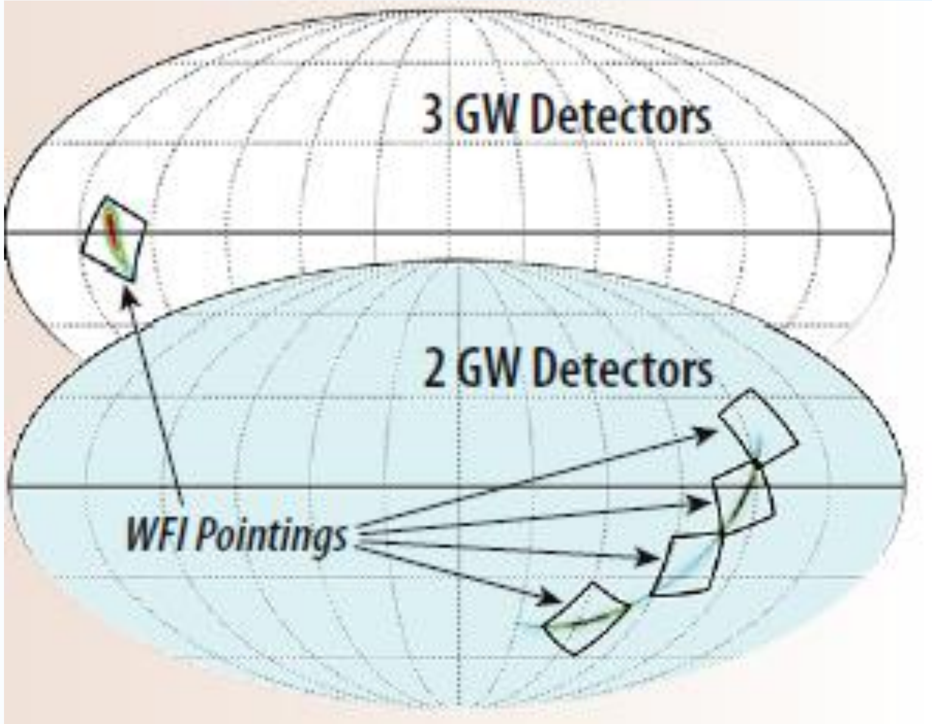
Wide Field Imager (WFI)
FoV: 0.12 sr = 400 sq deg
Resolution = 1 arc min
Energy Range: 0.3 - 6 keV
Detectors: CCDs
Optics: Microchannel plates
10^{-11} erg cm^{-2} s^{-1} (2000 sec)



Pointing System
1 arc min

Proposed in 2016 NASA Explorer

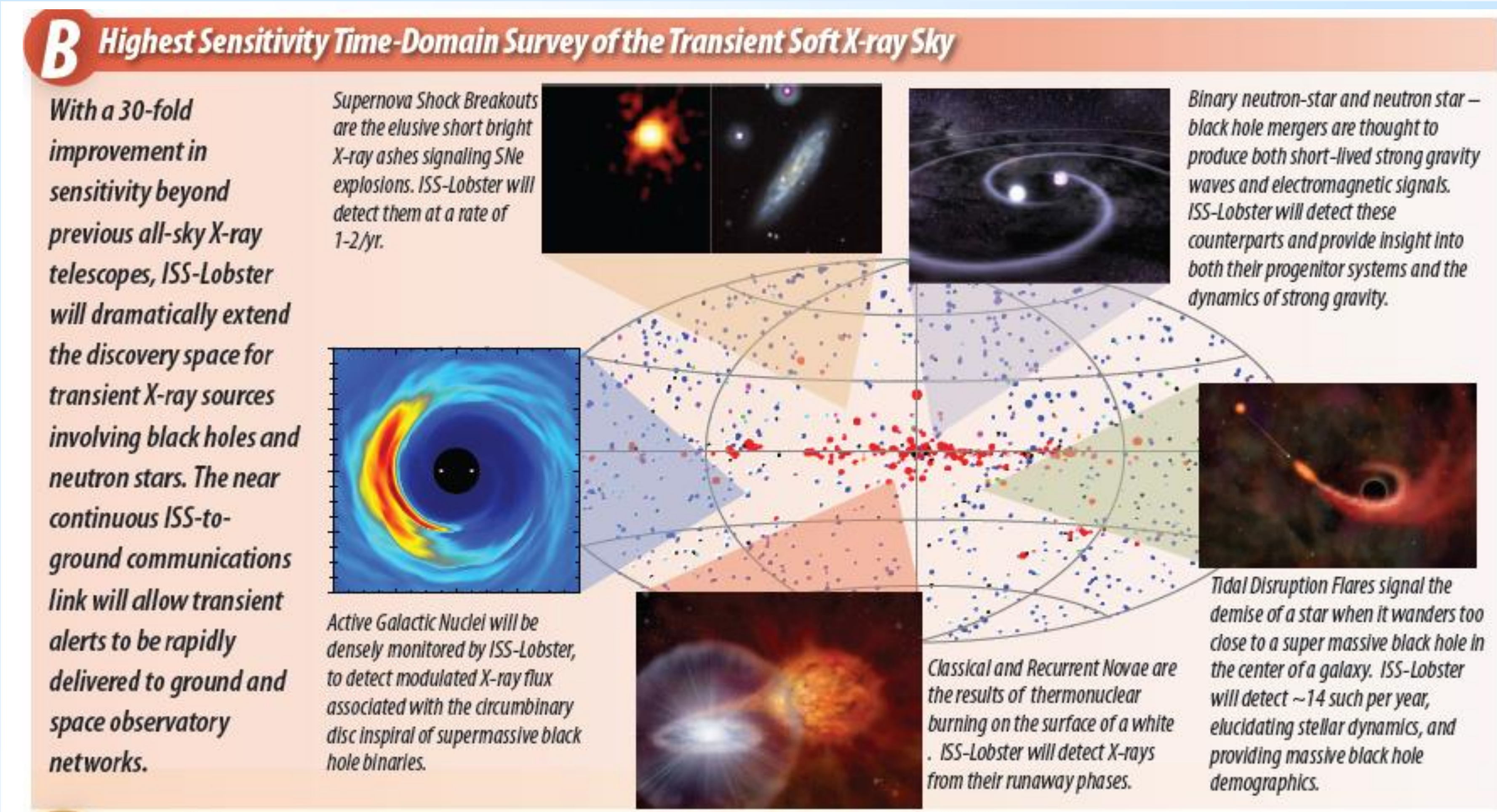
Lobster Wide Field of View (400 deg^2)



LIGO skymaps easily encompassed by TAO FoV

Several events /yr expected for NS-NS / NS-BH mergers

Highest Sensitivity X-Ray Transient Science

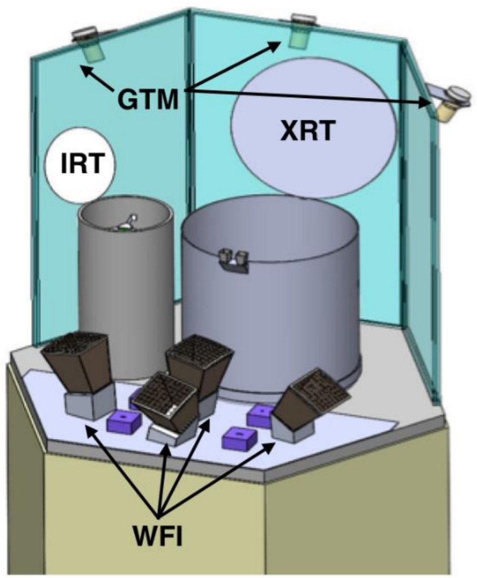


Transient Astrophysics Probe

- **The transient Astrophysics Probe (TAP) comprises *wide-field* X-ray, Gamma-ray, and Infrared telescopes designed to address two major Frontier Discovery Areas of the 2010 Decadal Survey**
  - **EM Counterparts to Gravitational Waves**
  - **Time-Domain Astrophysics**
- **TAP is one of 9 missions funded by NASA for a Probe-Class Concept Study as input to the 2020 Decadal Panel**
  - **Mission design and cost study over 1.5 years**
  - **Decadal Panel could endorse mission, or initiate new Probe opportunity**
- **If chosen, launch in late 2020s**

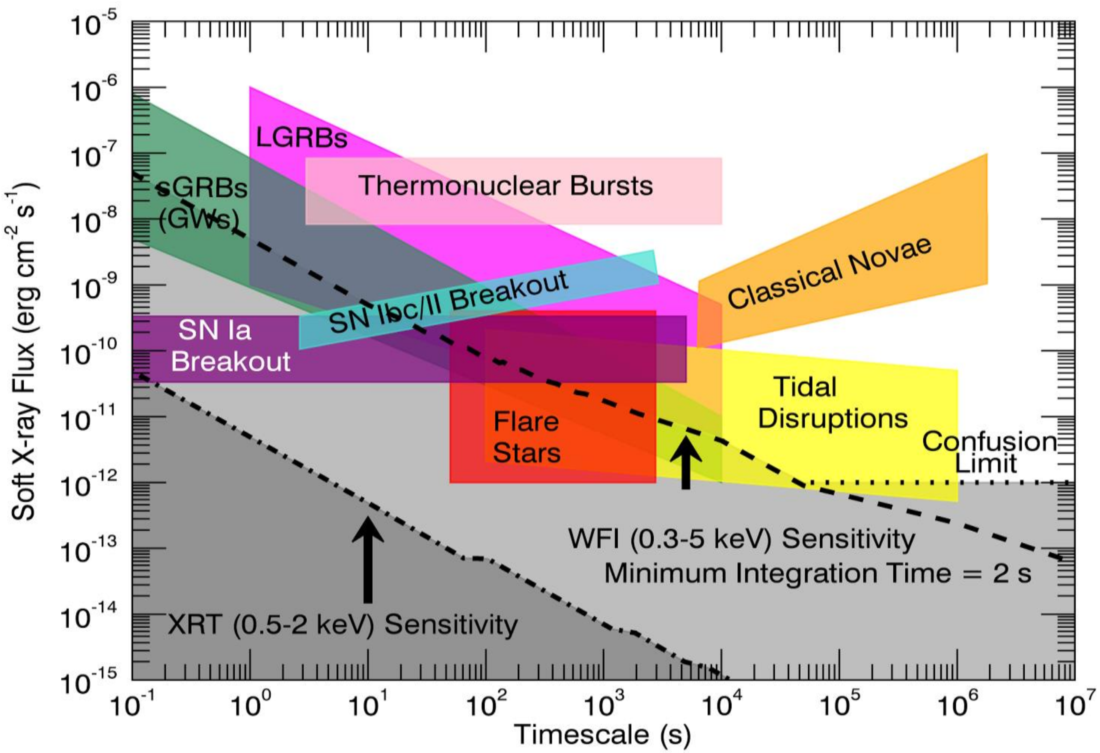
TAP Telescopes: Wide and Deep

- Lobster modules (4-6)
  - 500 deg^2 each
  - 10^{-11} $erg/cm^2/sec$ in 2000 sec
- IR Telescope
  - 1 deg^2
  - 0.6 – 2.5 micron, 80 cm diameter
  - 23-24 Mag across waveband in 500 sec



- X-ray Telescope (single crystal silicon mirror)
  - 1 deg^2
  - 3×10^{-15} $erg/cm^2/sec$ in 3000 sec

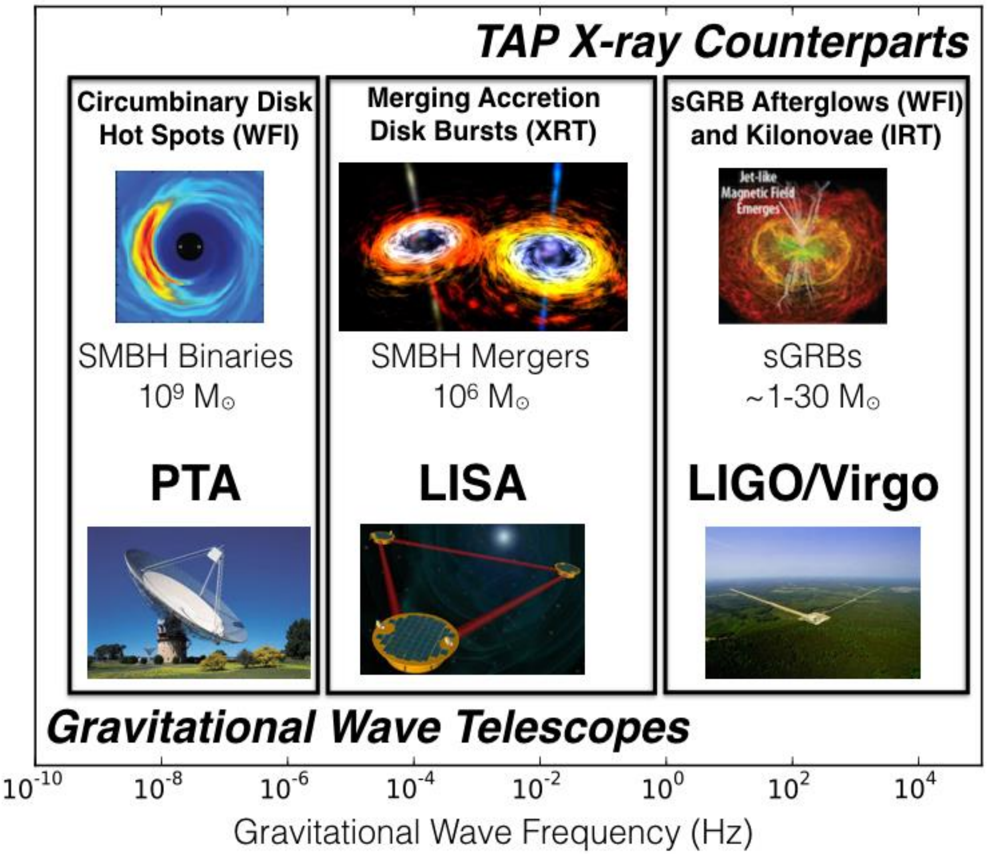
TAP time-domain sources



TAP time-domain science focuses on Tidal Disruptions, Supernovae, and high-Z GRBs

also
TAP followups of LSST and other transient facilities

TAP EM Counterparts (Potential) Rates



$\Delta\theta_{GW}$ 100 deg^2 1 deg^2 20 deg^2

LIGO beamed X-ray counterpart (10s/yr)

LIGO isotropic IR counterpart (100/yr)

LISA X-ray counterpart (1-10/yr) ?

PTA X-ray counterpart (1-10) ??

Summary

- TAO-ISS is a proposed inexpensive discovery mission for the observation of EM Counterparts of Gravitational Waves
  - X-rays from NS and/or BH mergers (LIGO)
  - Approved for Phase A study

- TAP is a proposed Production Facility for the observation of EM counterparts
  - IR and X-rays from NS and BH mergers (LIGO)

and potentially

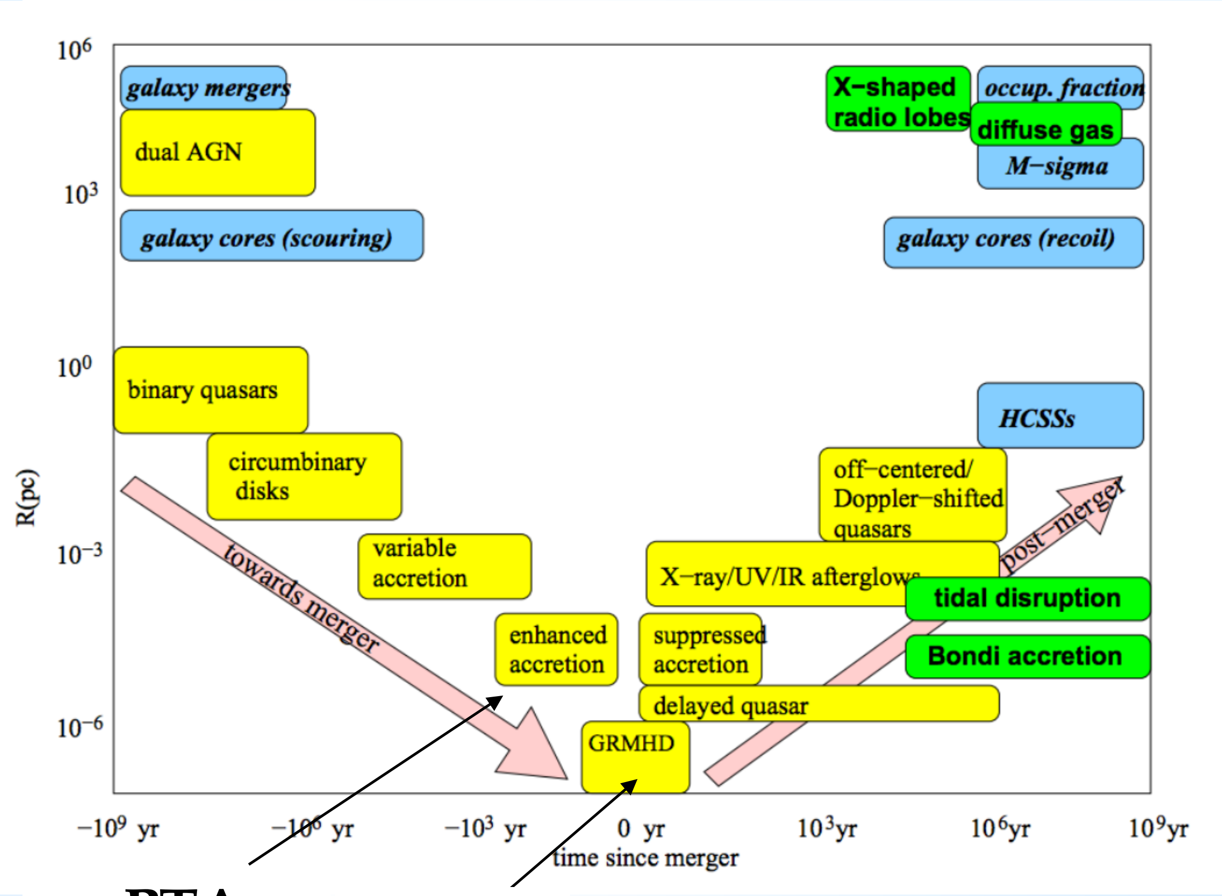
  - X-rays from 10^{6-7} $M_\odot$ SMBH binary mergers (LISA)
  - X-rays from 10^{8-9} $M_\odot$ SMBH binaries (SKA)

- Both missions will investigate time-domain sources
  - Tidal disruptions, Supernovae, High-z GRBs

BACKUP

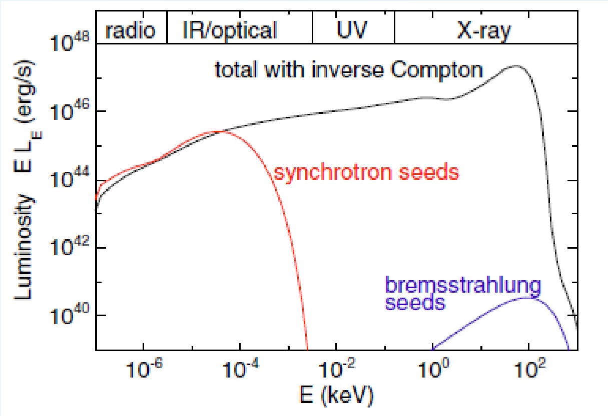
Binary SMBH mergers: A history

direct and indirect evidence of merger



PTA

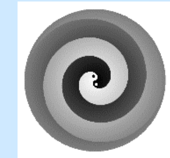
LISA



10^7 M_s binary merger

Schnittman (2014) arXiv:1411.3994

PTA-LISA sources GW and/or Counterpart?

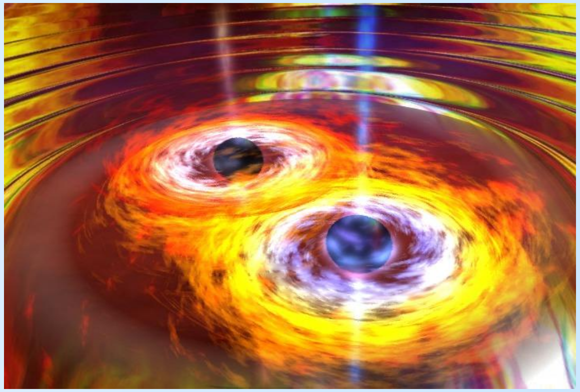


GW source?

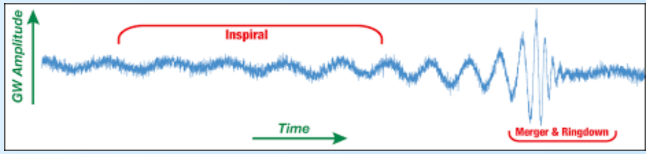
EM source?	Yes	No
Yes	High-mass (>10^9 Msun) PTA source @ 1 Gpc, circumbinary disk with streams, mini-disks: periodic (1-10yr) $F_x \sim 10^{-10}$ mid-mass (~$10^{6\text{-}7}$ Msun) LISA source @ z=1, "snowplow" minidisks with transient jet: burst $F_x \sim 10^{-14}\text{-}10^{-13}$	Mid-mass (~10^8 Msun) PTA confusion @ 100 Mpc, circumbinary disk with streams, mini-disks: periodic (1-10yr) $F_x \sim 10^{-9}$ mid-mass (~$10^{6\text{-}7}$ Msun) pre-LISA source @ 100 Mpc, circumbinary disk with streams, mini-disks: periodic (0.1 yr) $F_x \sim 10^{-11}\text{-}10^{-10}$
No	High-mass (>10^9 Msun) PTA source @ 1 Gpc, no gas "dry merger" low-mass (<10^6 Msun) LISA source @ z>2, too faint to see	Mid-mass (~10^8 Msun) PTA confusion @ z=1, circumbinary disk with streams, mini-disks: periodic (1-10yr) $F_x \sim 10^{-13}$ mid-mass (~$10^{6\text{-}7}$ Msun) pre-LISA source @ z=1, periodic (0.1 yr) $F_x \sim 10^{-14}$

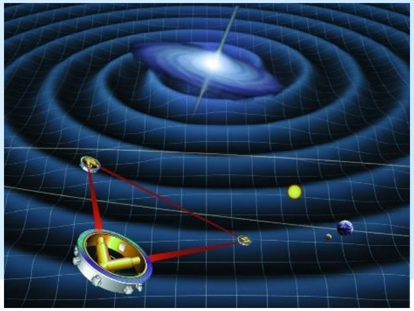
LISA observations of SMBHB inspirals and mergers

- **LISA will observe merging SMBH binaries out to z ~ 20**
- **Several/year mergers expected out to z~1-2**
  - **Can be localized to ~ 1 deg^2 within hours of merger**
- **Possibility of observing Binary inspirals and mergers with sensitive, wide-field XRT**
  - **Could see evolution of accretion disk (pre and post merger)**



10^{6-7} – 10^{6-7} $M_\odot$ BHB



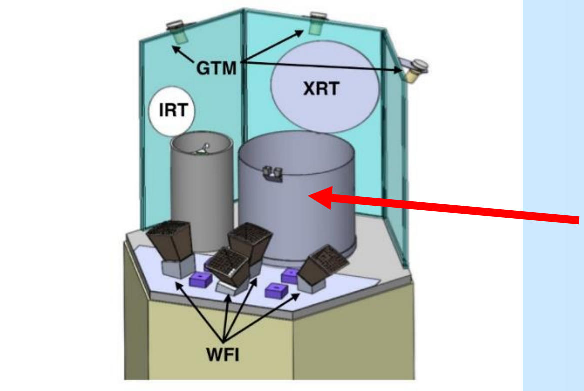


TAP X-ray Counterparts of LISA detections

- Assumptions
  - Simulated SMBHB ($10^{6\text{-}7}\ M_{\odot}$) merger rate out to z=2
  - Mass inflow happens during merger
  - 30 times Eddington accretion rate from gas 'squeezing'
    - TDE events observed up to ~10 times Eddington
  - 10% of luminosity in soft X-rays
  - Both isotropic disk and beamed (5 deg) jet emission

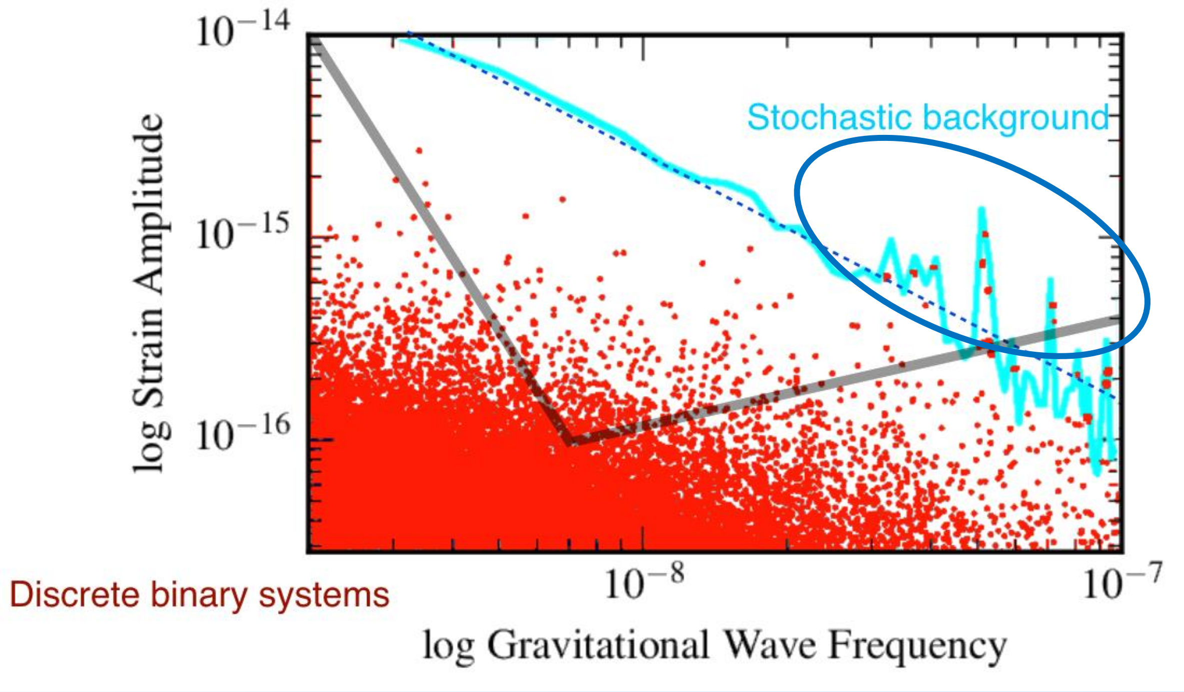
- Counterpart rate
  - 1 - 10 / yr

- MHD simulations ongoing, advancing understanding of source properties



SKA detections of GWs from discrete SMBH binaries

Square kilometer array



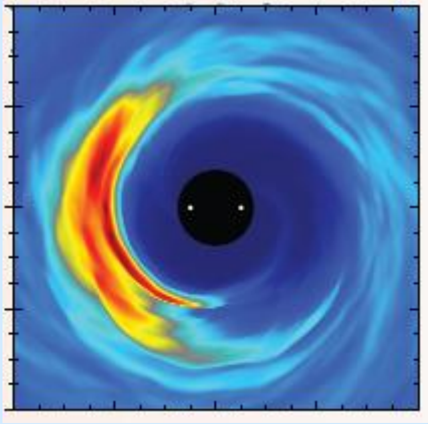
Simulation of discrete SMBHB distribution ($10^{7\text{-}9}$ $M_\odot$) based on 2MASS catalog

Simulation of GW signals from 100 pulsars observed by SKA for 10 years with 200 nsec accuracy (Spolaor, 2017)

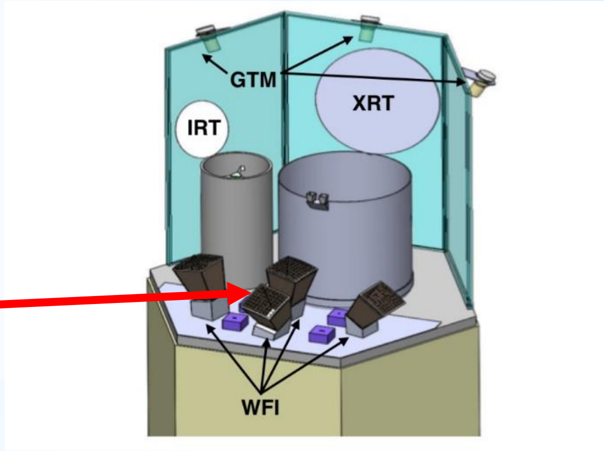
TAP X-ray Counterparts of SKA detections

- Assumptions
  - Hot spot in circumbinary disk and/or streams, existence of minidisks
  - Eddington luminosity
  - 10% of luminosity in soft X-rays
  - Isotropic, periodic emission at ~year period

- Counterparts observed
  - 1 – 10 (?)



Circumbinary disk
“hot spot”
Noble et al, ApJ 755, 51



TAP source rates

Transient Type	WFI Rate (yr^{-1})	XRT Rate (yr^{-1})	IRT Rate (yr^{-1})	GTM (yr^{-1})	Notes
Objective 1 – X-ray and IR Counterparts to Gravitational Wave Sources					
GW NS-NS	6	9	60*	6	LIGO/Virgo
GW NS-BH	45	70	480*	45	LIGO/Virgo
GW SMBH-SMBH	10*	--	--	--	PTA
GW SMBH-SMBH	--	20*	--	--	LISA
Objective 2 - Highest Sensitivity Time-Domain Survey of the Transient Soft X-ray Sky					
ccSN shock breakout	4	20	--	--	
Jetted TDEs	20	0.3	--	--	
Non-jetted TDEs	60	200	--	--	
AGN (daily / weekly)	320 / 2300	1900 / 11000 #	3000 / $3x10^4$ #	--	monitored
Blazars (daily / weekly)	240 / 700	40 / 120 #	300 / 3000 #	--	monitored
Stellar Super Flares	50 - 500	0.03 - 0.3	--	--	
Novae	1.2	--	--	--	
Thermonuclear Bursts	450	--	--	--	
Long GRBs	320	--	320	150	
High-z GRBs (z>5)	27-40	--	27-40	--	
Short GRBs	30	--	15	30	
Off-axis Long GRB Afterglows	--	40	--	--	
High-z Superluminous SNe	--	--	10	--	
Dust-enshrouded transients	--	--	100	--	