Title: Coordinated Science in the Gravitational and Electromagnetic Skies

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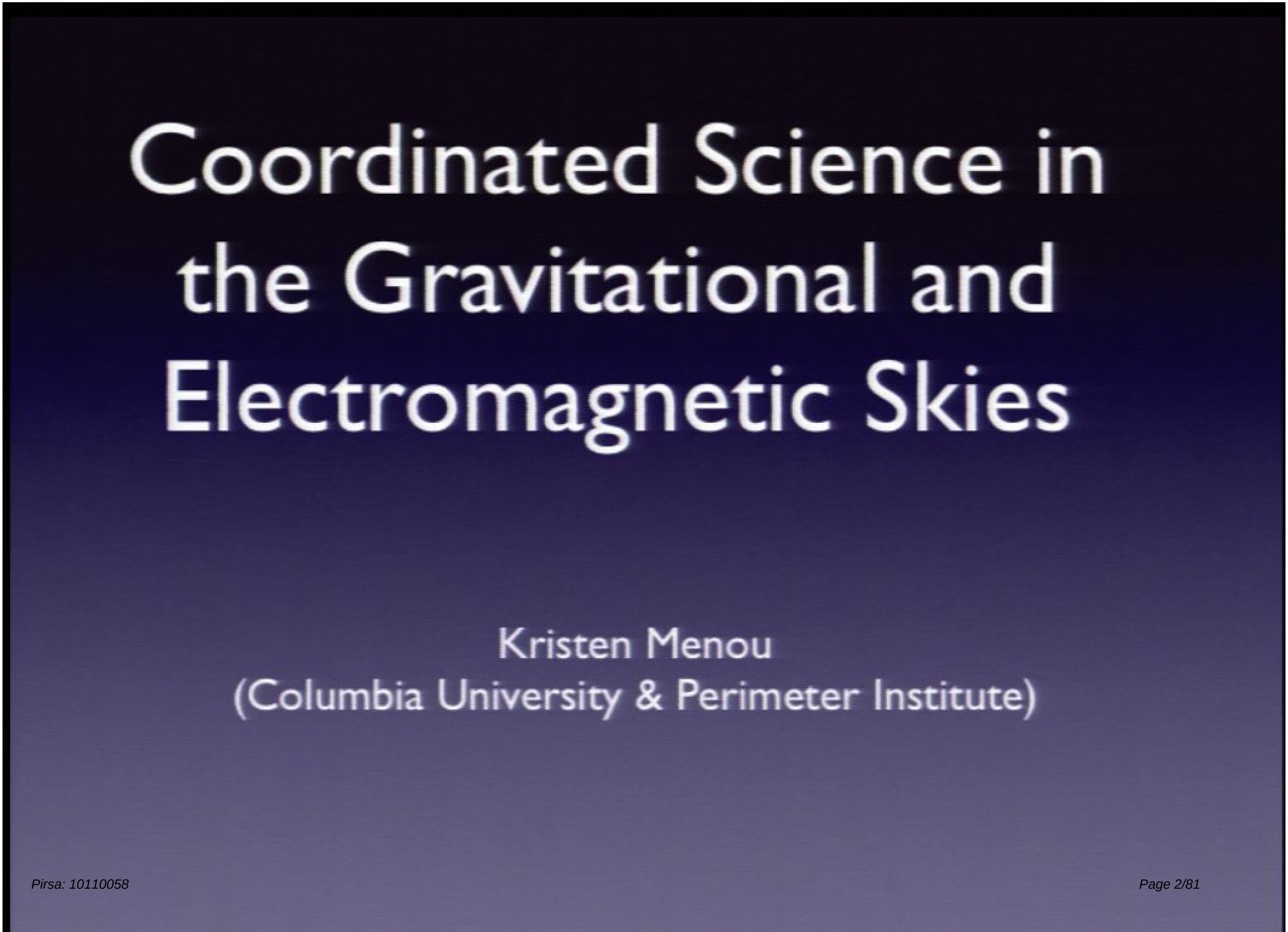
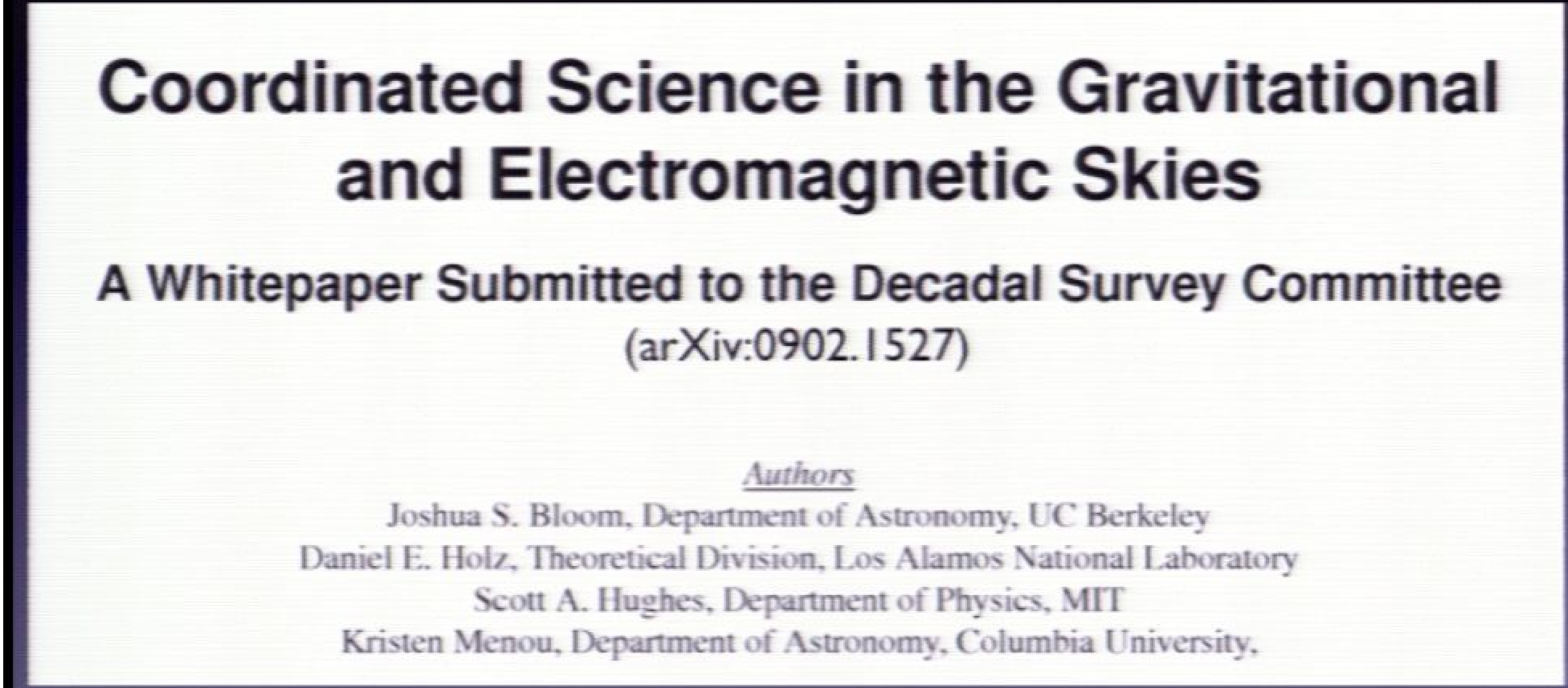
Abstract: The gravitational observatory LISA will detect radiation from massive black hole sources at cosmological distances, accurately measure their luminosity distance and help identify the electromagnetic counterparts that such sources may generate. I will describe various astrophysical scenarios for the generation of electromagnetic counterparts and discuss observational strategies aimed at identifying them. Successful identifications will enable novel studies of black hole astrophysics and cosmological physics.



Coordinated Science in the Gravitational and Electromagnetic Skies

Kristen Menou
(Columbia University & Perimeter Institute)



Coordinated Science in the Gravitational and Electromagnetic Skies

A Whitepaper Submitted to the Decadal Survey Committee

(arXiv:0902.1527)

Authors
Joshua S. Bloom, Department of Astronomy, UC Berkeley
Daniel E. Holz, Theoretical Division, Los Alamos National Laboratory
Scott A. Hughes, Department of Physics, MIT
Kristen Menou, Department of Astronomy, Columbia University,

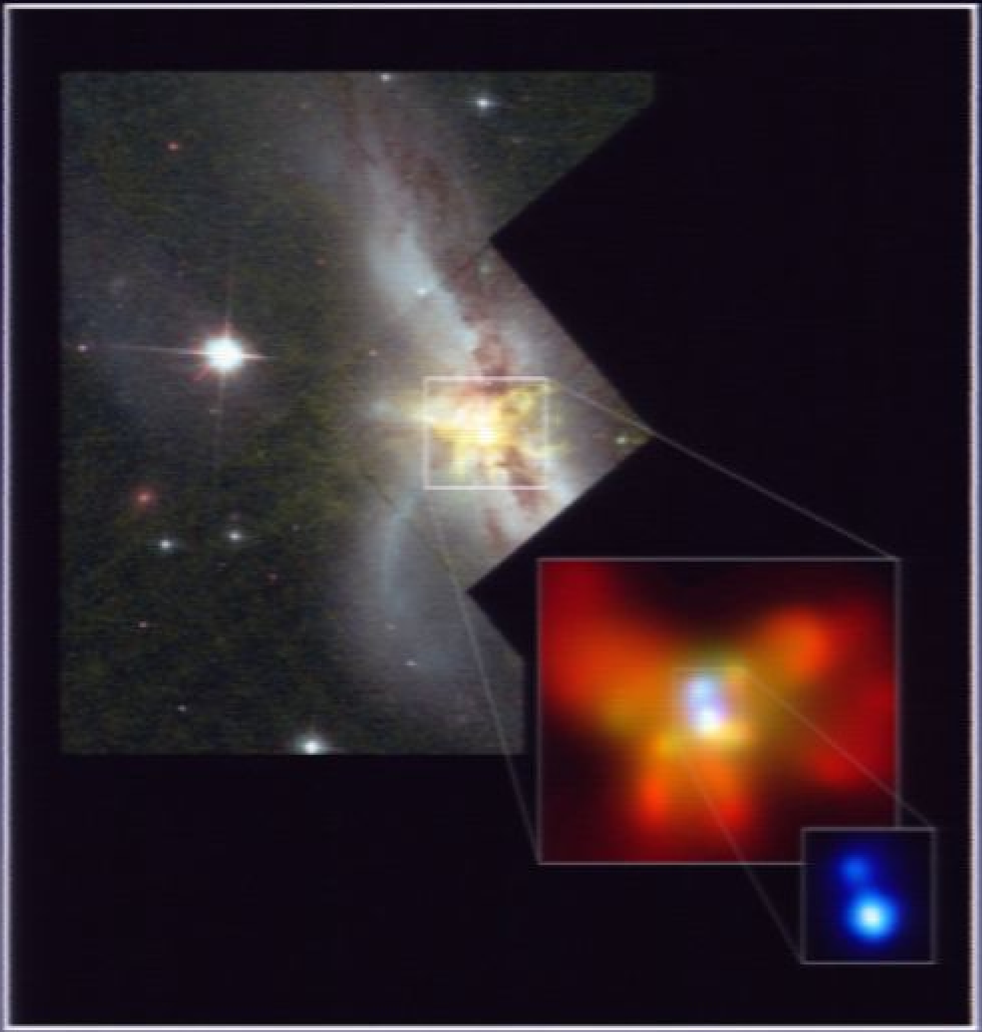
(see also WP by Phinney 2009)

Galaxy mergers...

Colliding Galaxies NGC 4038 and NGC 4039 HST • WFPC2

PRC97-34a • ST ScI OPO • October 21, 1997 • B. Whitmore (ST ScI) and NASA

...lead to BH mergers



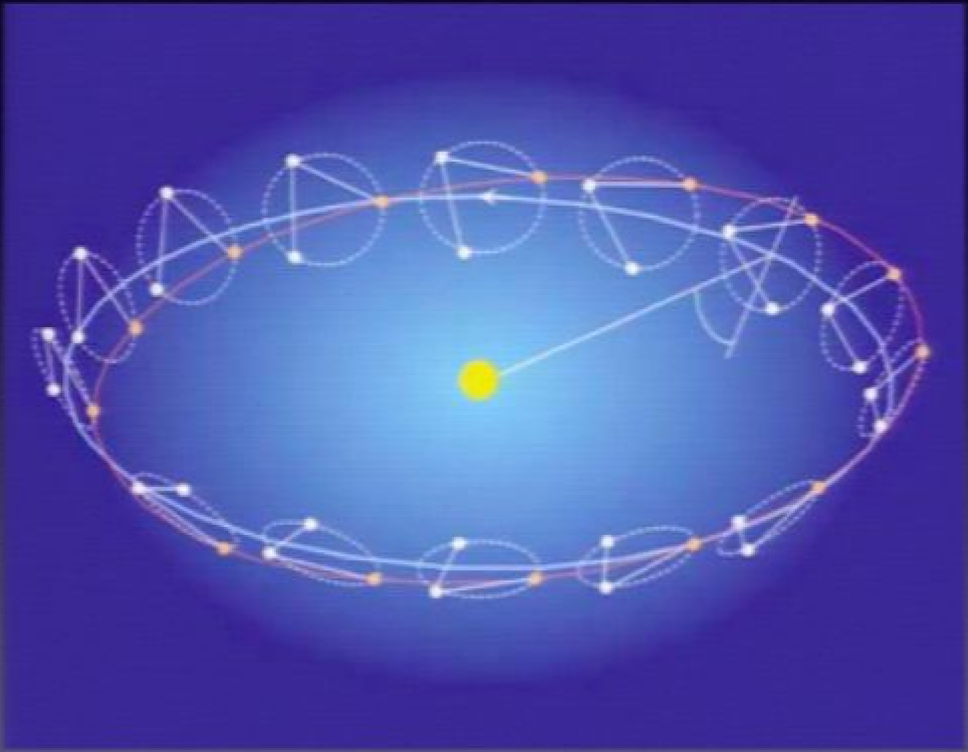
NGC 6240 observed in X-ray

A black hole pair in the process of merging?

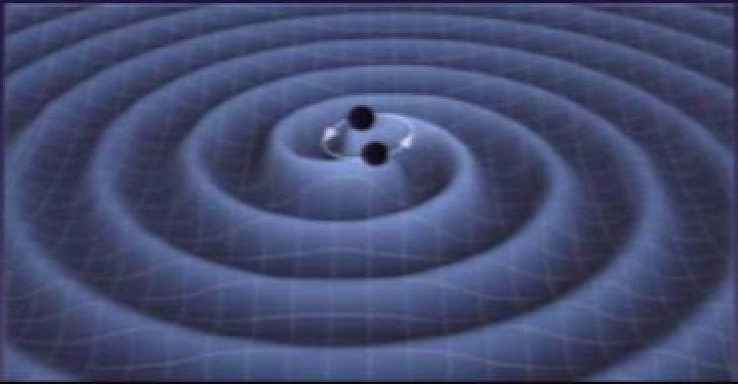
Gas promotes merger.

What about the later phases?

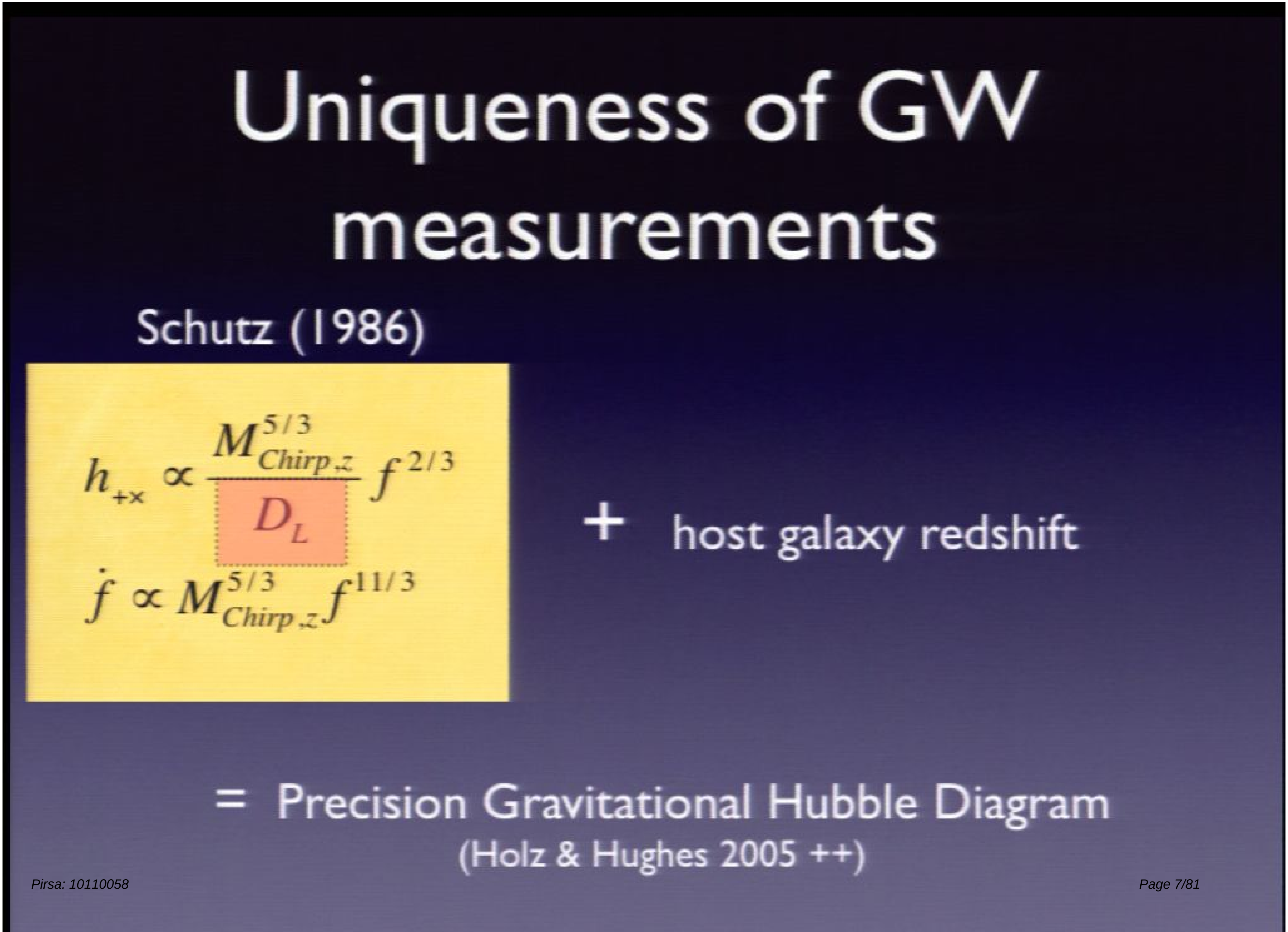
Laser Interferometer Space Antenna (LISA)



MBH coalescences visible for up to 1 yr



A few (?), high SNR, MBH merger events per yr per unit z



Uniqueness of GW measurements

Schutz (1986)

$$h_{+\times} \propto \frac{M_{Chirp,z}^{5/3}}{\boxed{D_L}} f^{2/3}$$

$$\dot{f} \propto M_{Chirp,z}^{5/3} f^{11/3}$$

+ host galaxy redshift

= Precision Gravitational Hubble Diagram

(Holz & Hughes 2005 ++)

Remarkable Accuracy

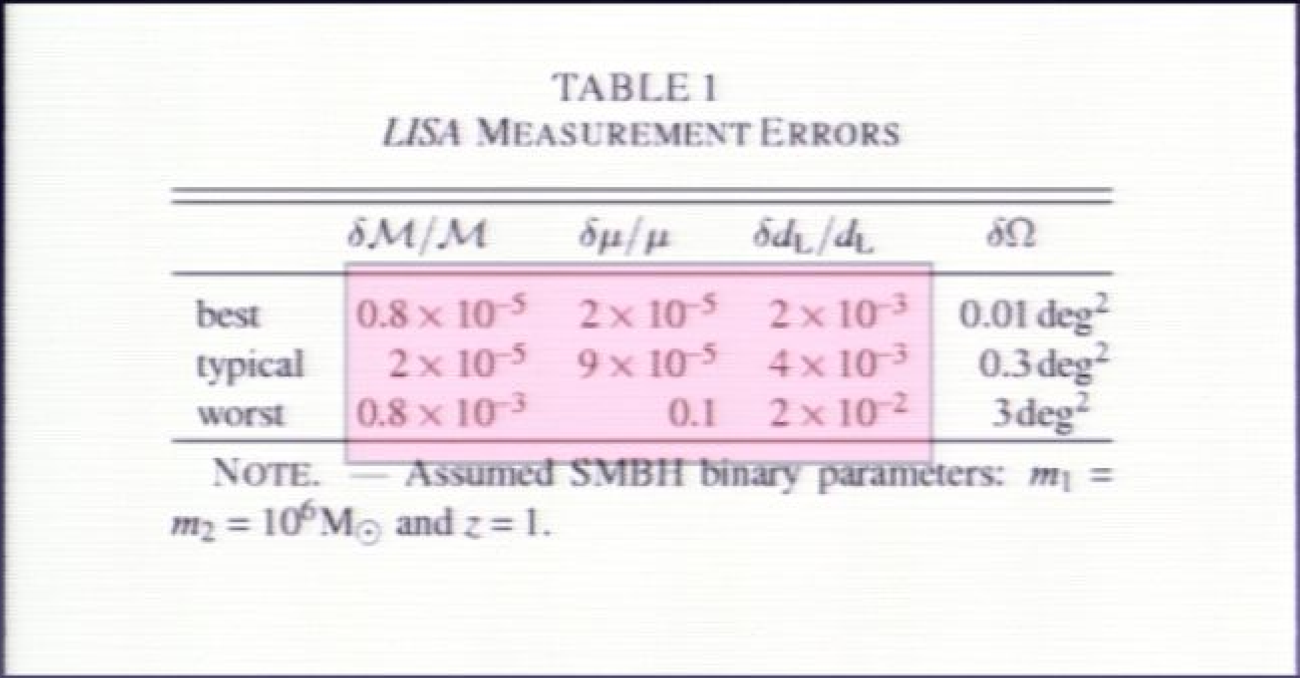


TABLE 1

LISA MEASUREMENT ERRORS

	$\delta\mathcal{M}/\mathcal{M}$	$\delta\mu/\mu$	$\delta d_L/d_L$	$\delta\Omega$
best	0.8×10^{-5}	2×10^{-5}	2×10^{-3}	$0.01\,\mathrm{deg}^2$
typical	2×10^{-5}	9×10^{-5}	4×10^{-3}	$0.3\,\mathrm{deg}^2$
worst	0.8×10^{-3}	0.1	2×10^{-2}	$3\,\mathrm{deg}^2$

NOTE. — Assumed SMBH binary parameters: $m_1 = m_2 = 10^6\mathrm{M}_\odot$ and $z = 1$.

(Kocsis et al. 2006 + many others)

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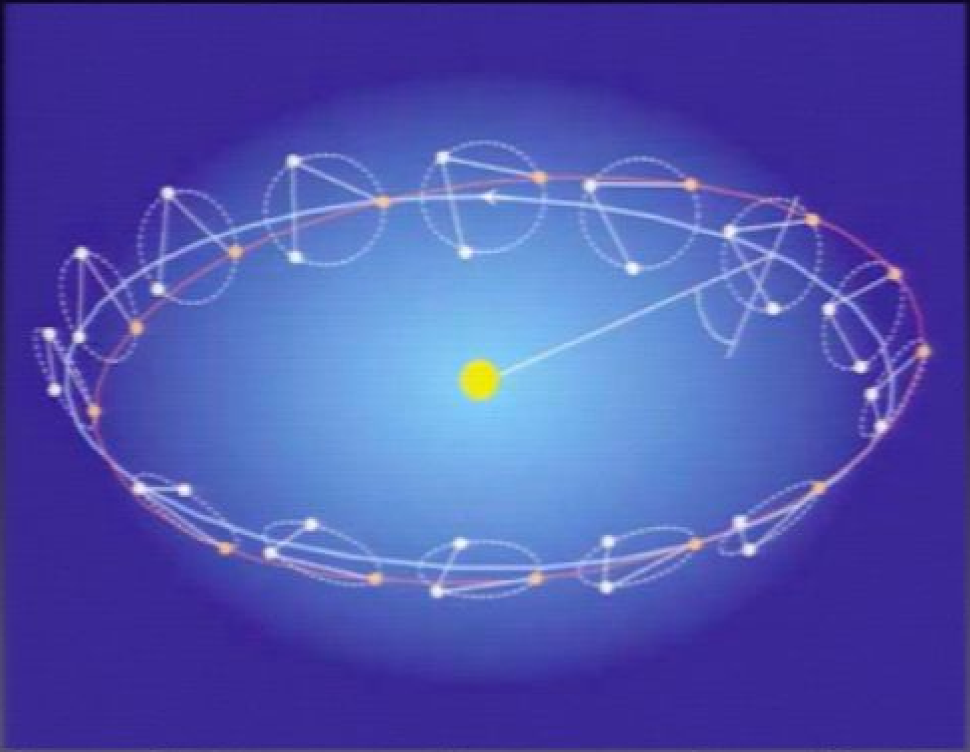

Possibility to “triangulate” the event/host galaxy location on the sky

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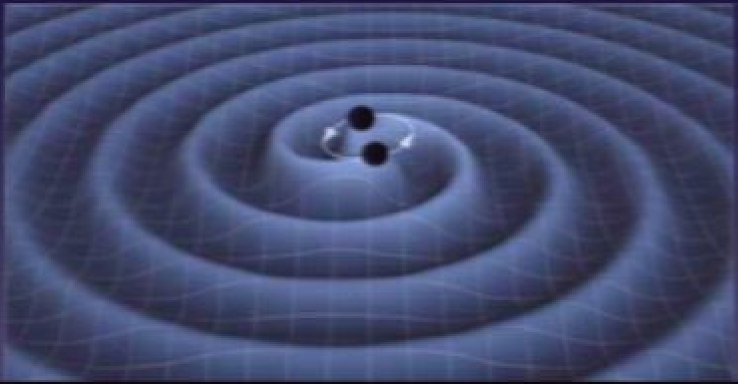
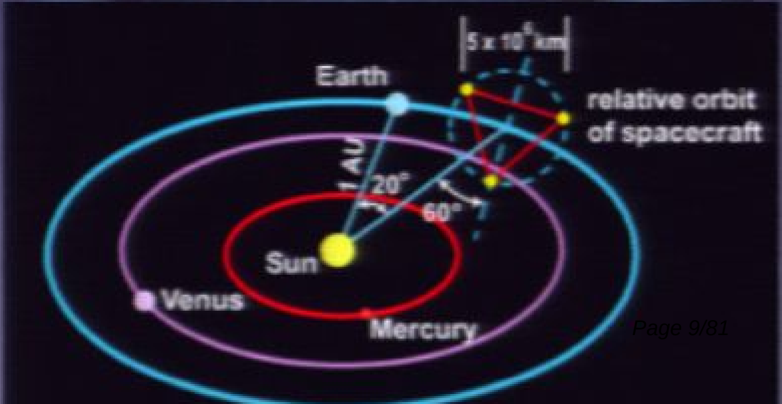
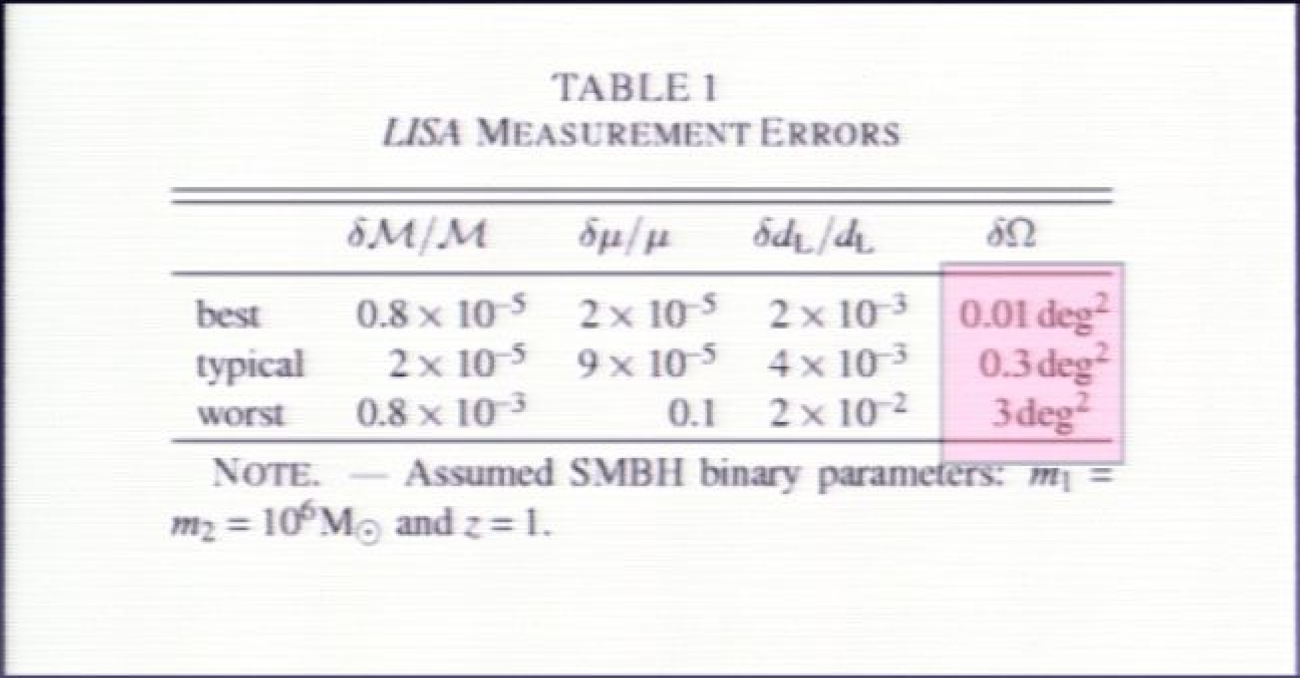




Angular Errors
~ 1-10 deg^2



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following Cutler (1998), Vecchio (2004)
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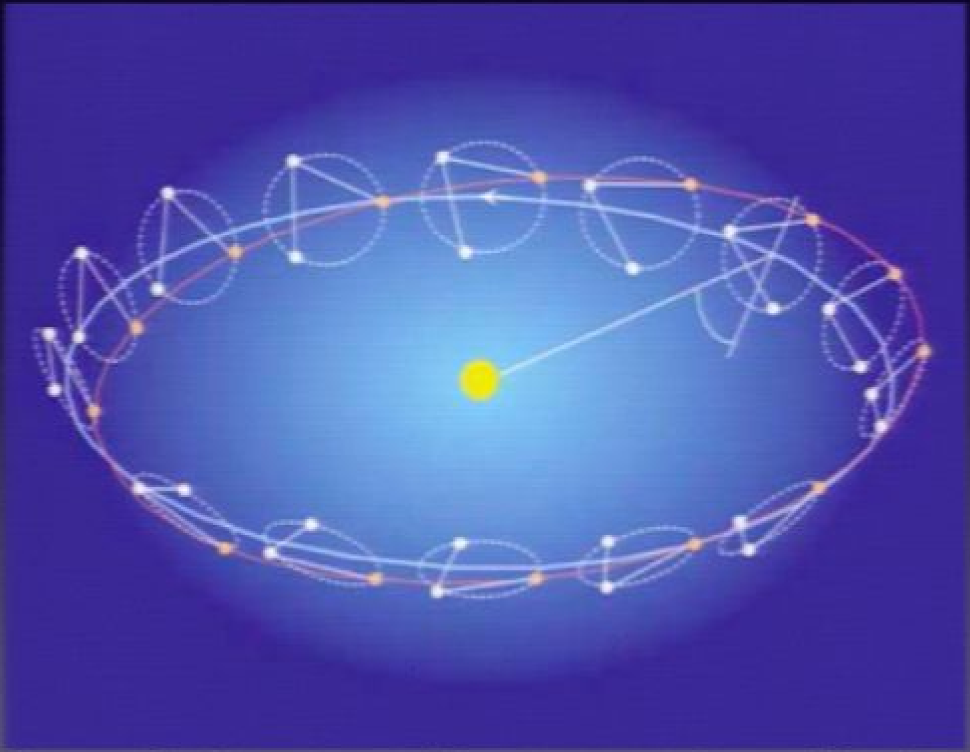

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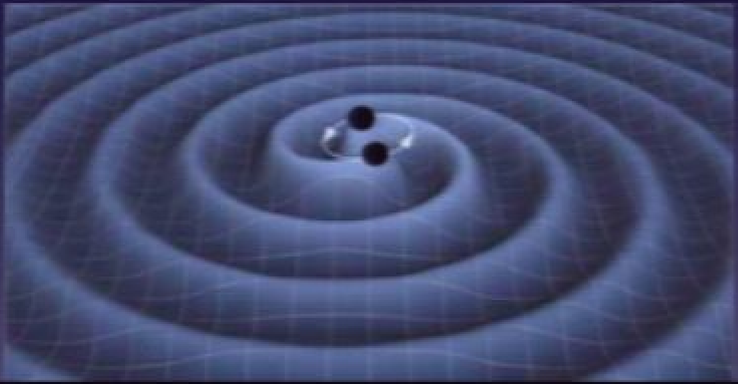

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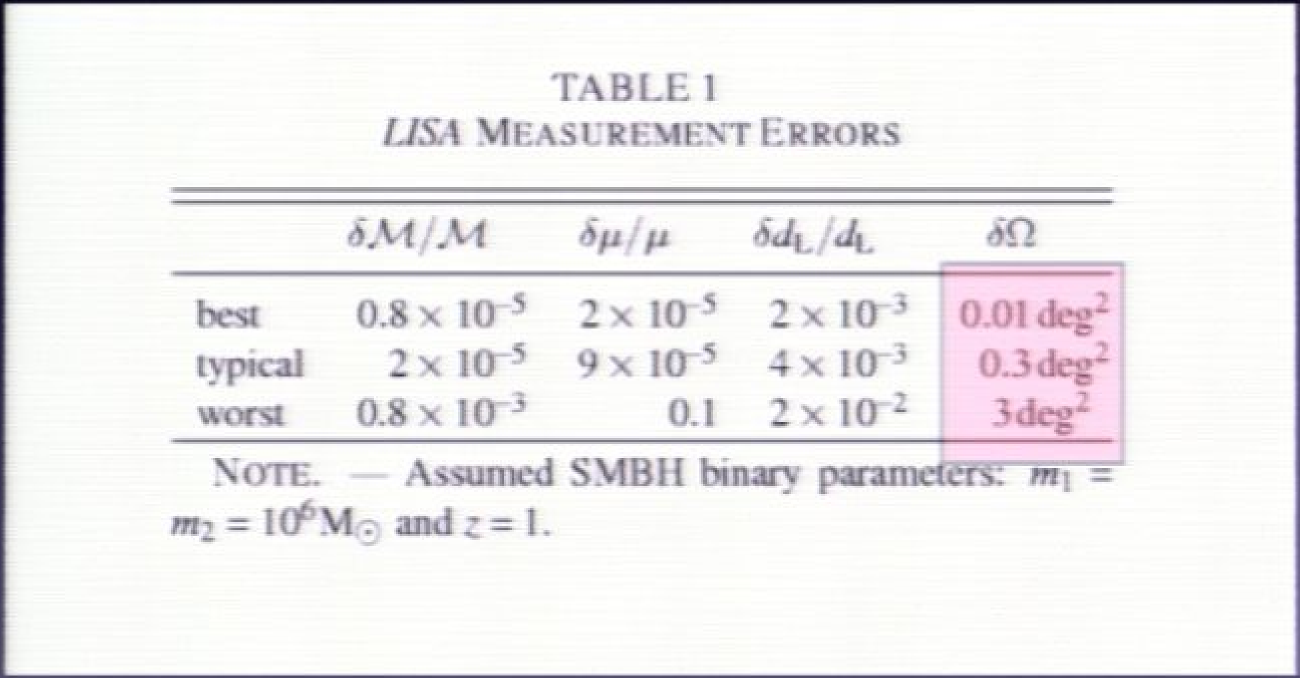

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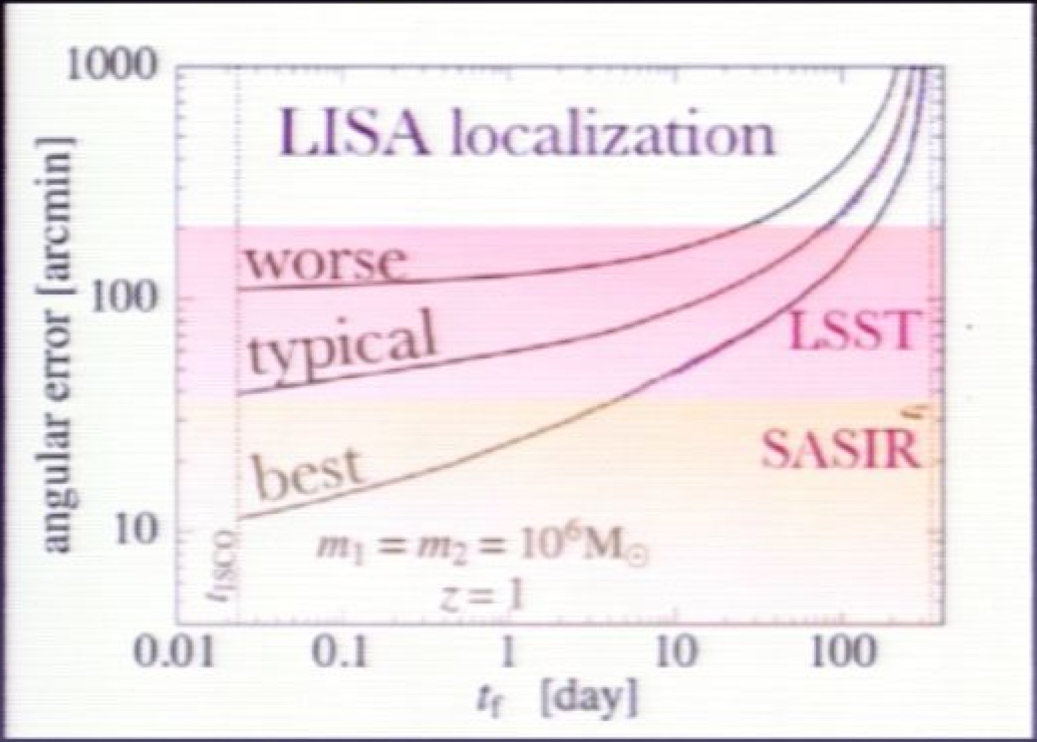
LISA Timed Localization

Linear angular error vs. time



(time prior to merger)

MBH-MBH Case:

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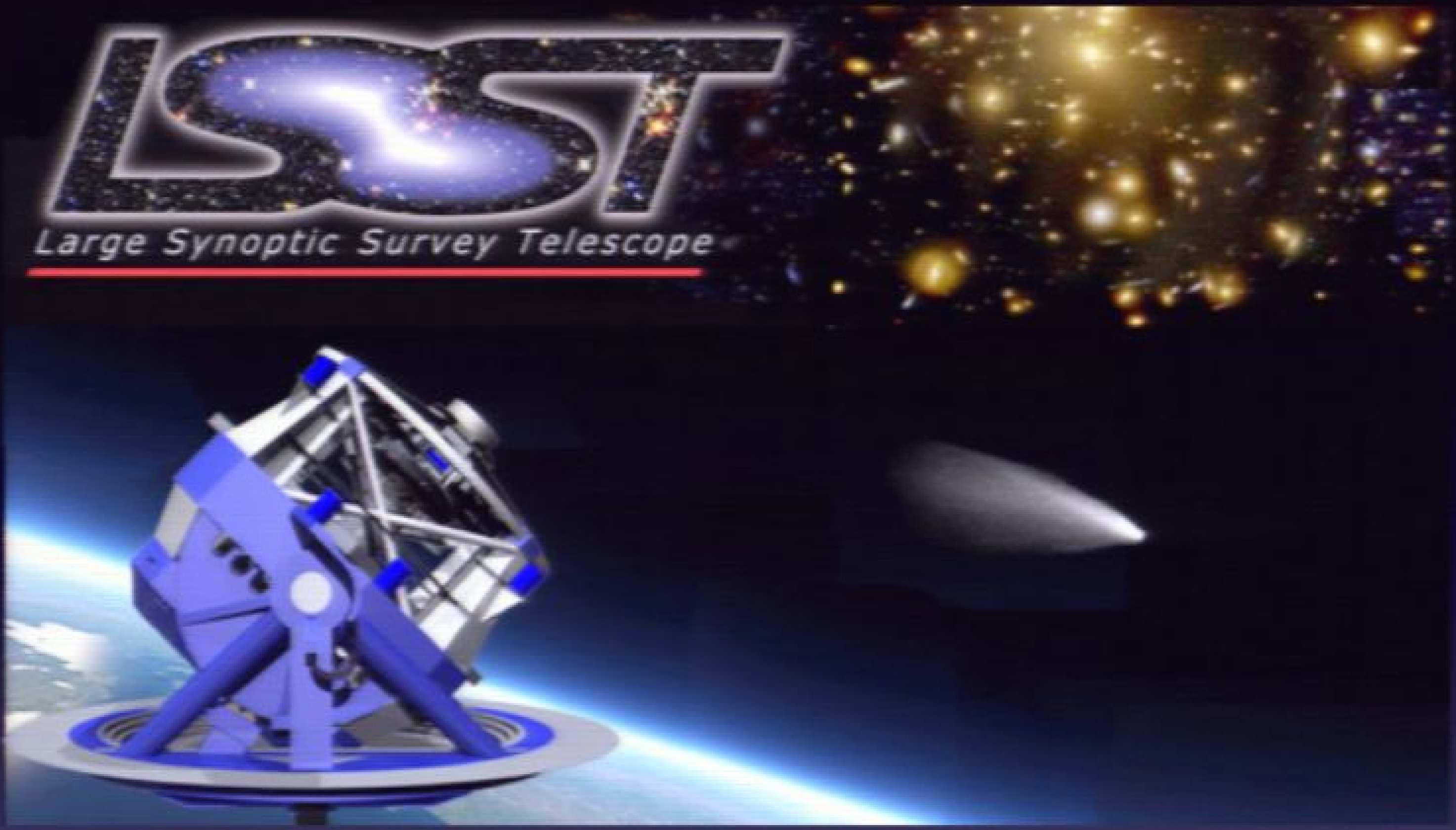
Lang & Hughes 2006, 2008

Matches future IR/Optical wide-field capabilities: LSST, WFIRST, etc...



8.4m, 10 deg^2 F.O.V., 6 bands (V=24 in 15s)
All-sky survey every 3 nights

Now contemplating an option to interrupt the survey mode, to monitor an event based on a LISA trigger

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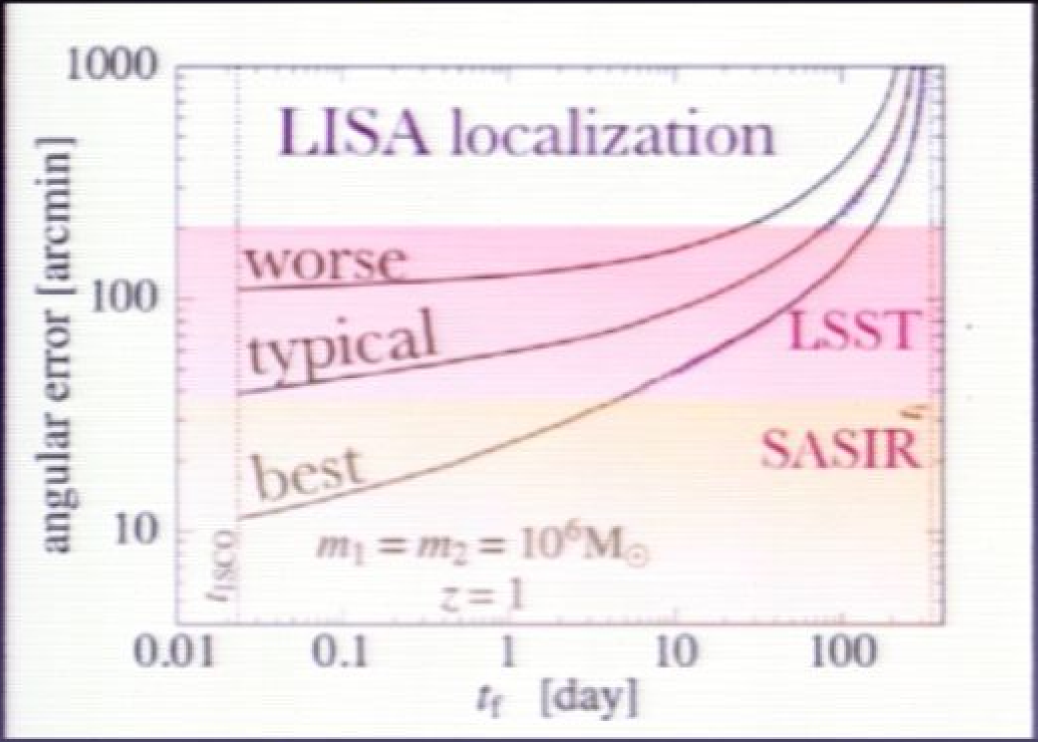

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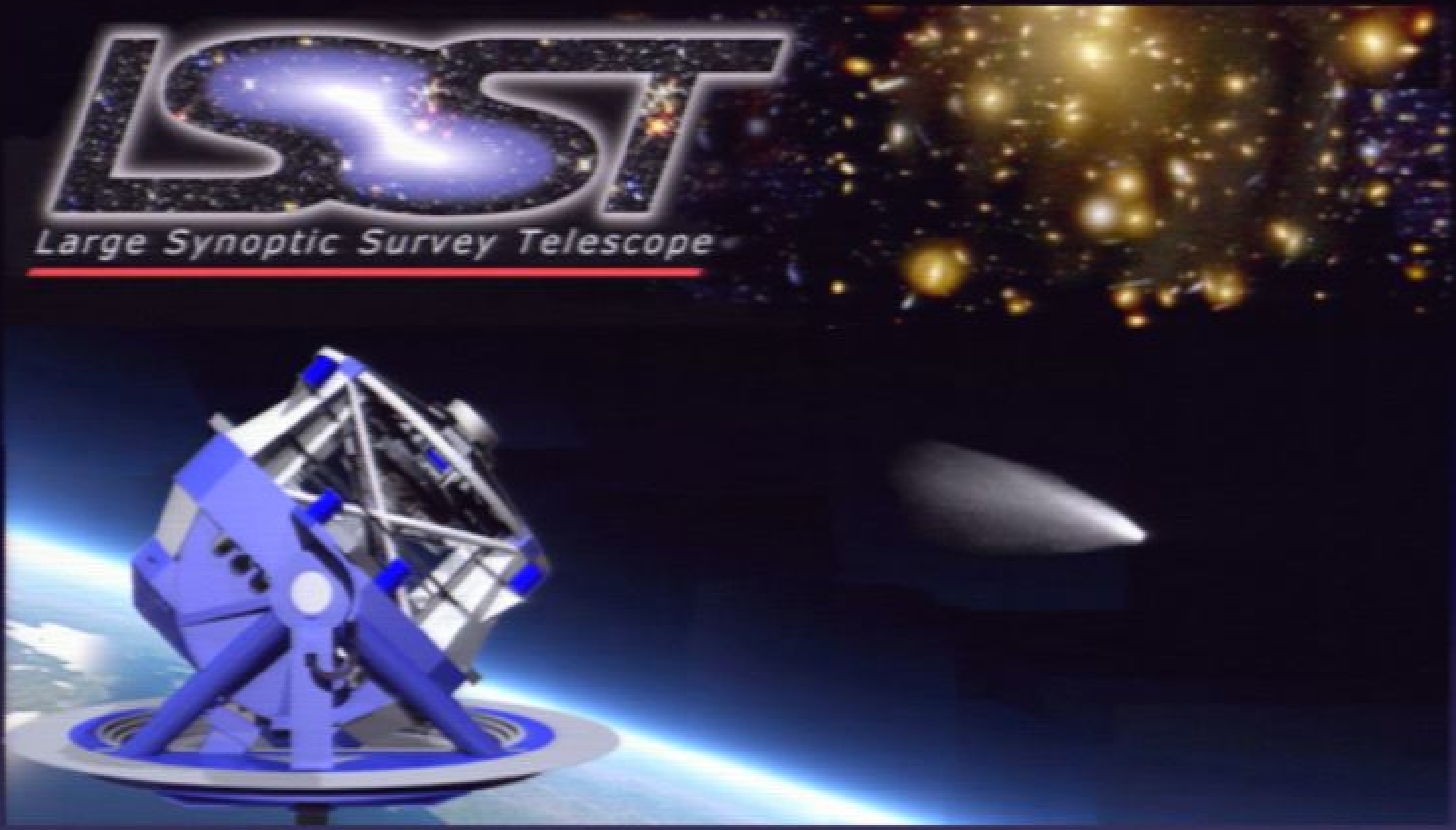

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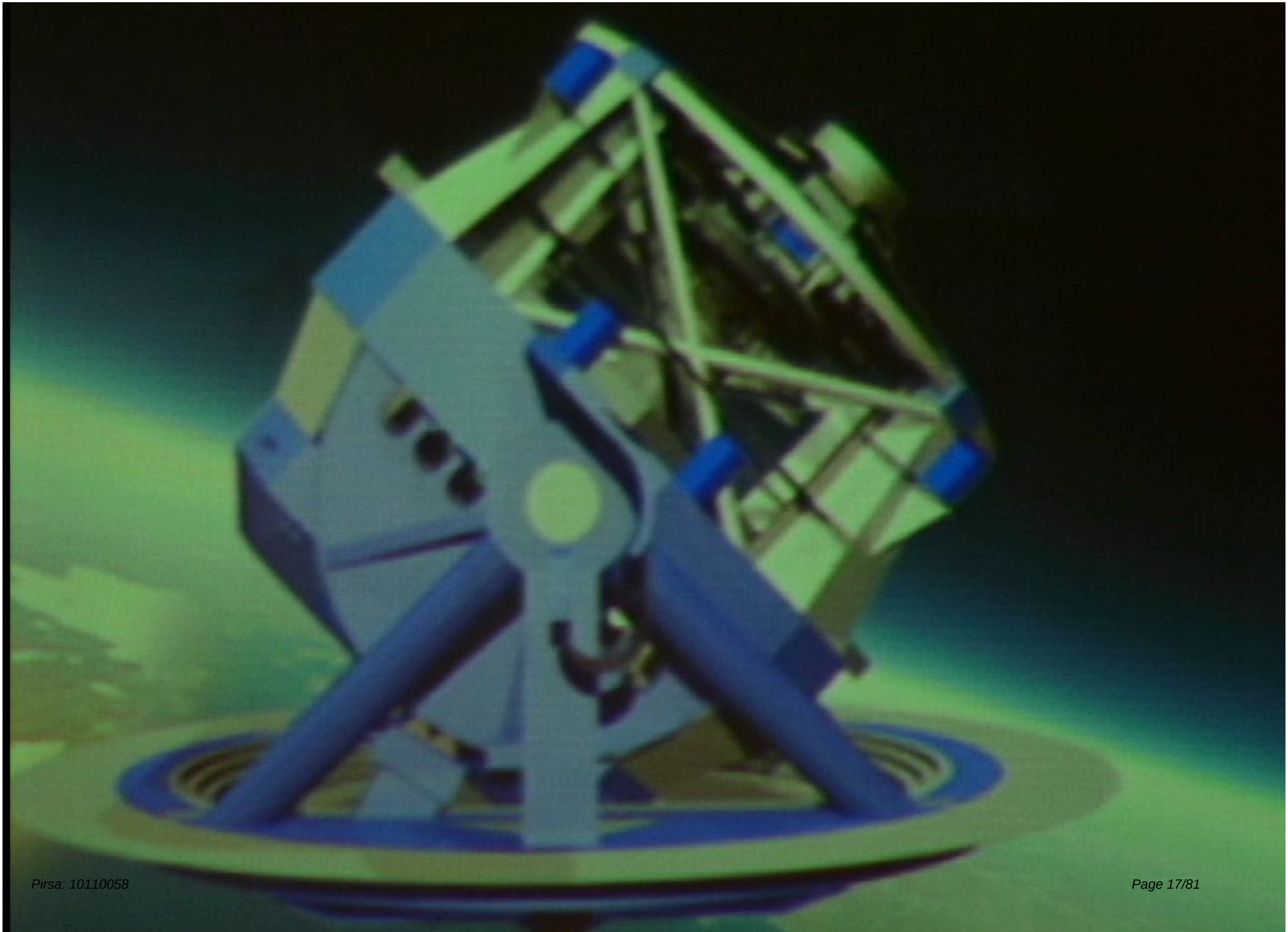

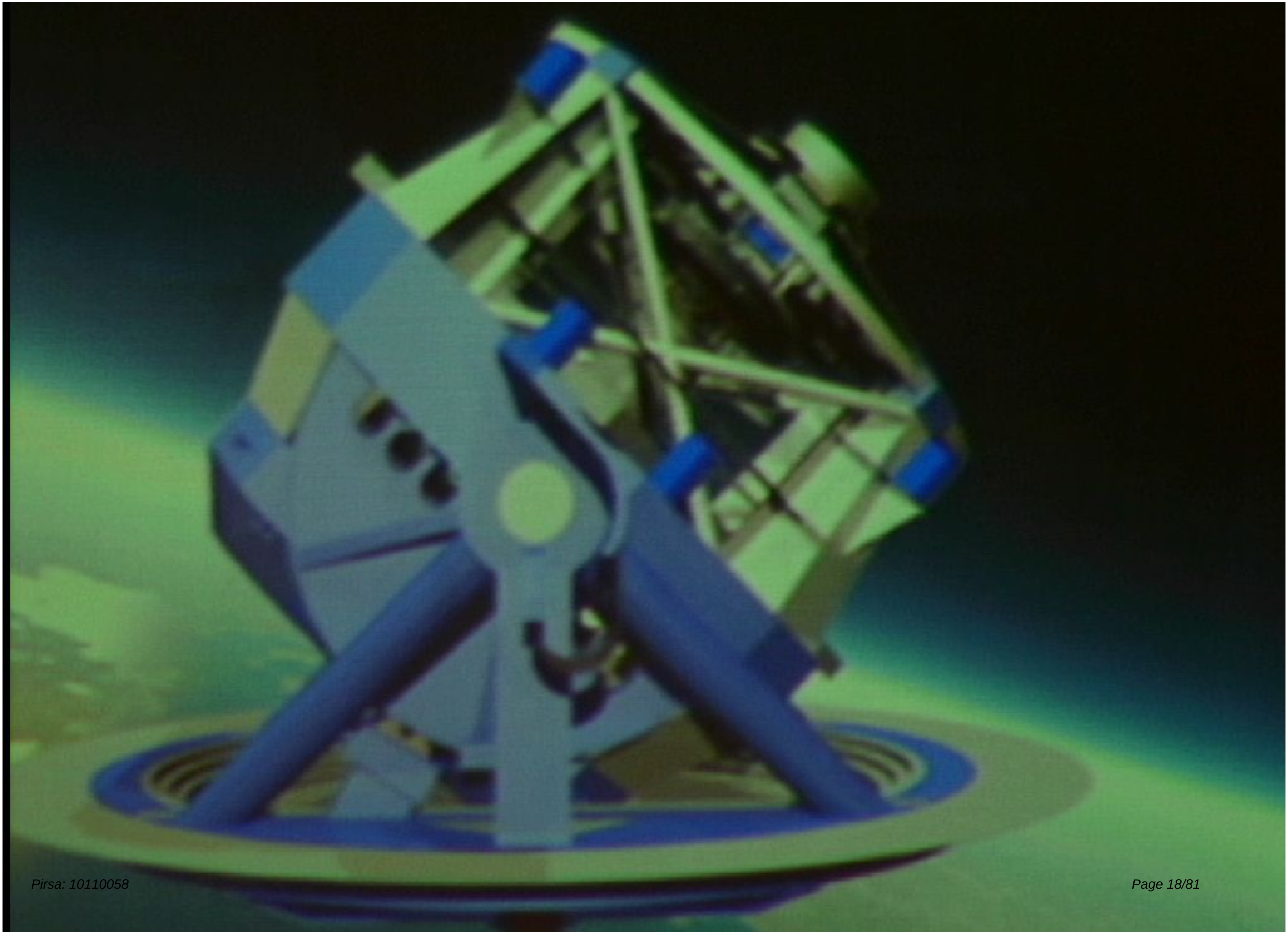

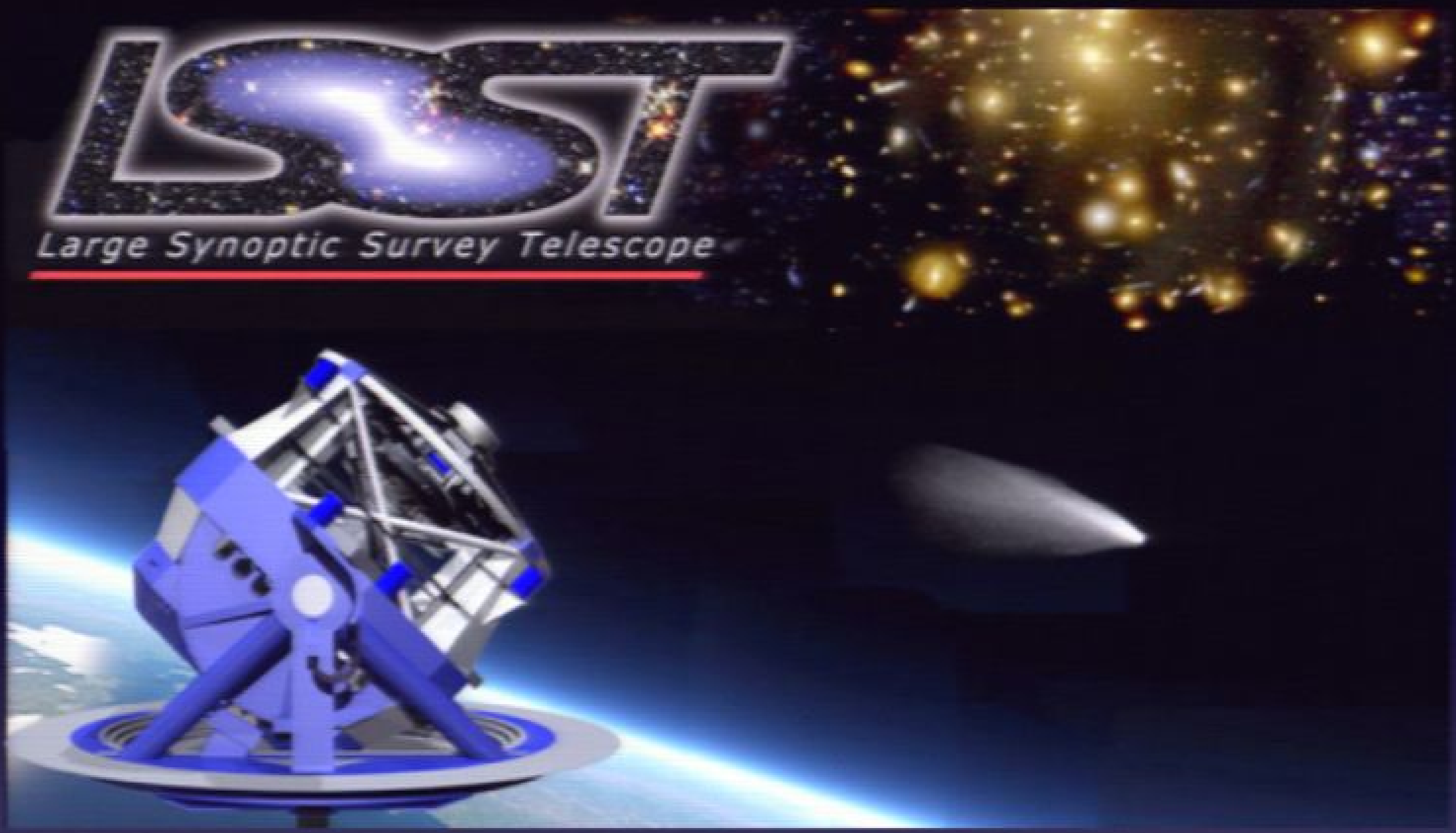

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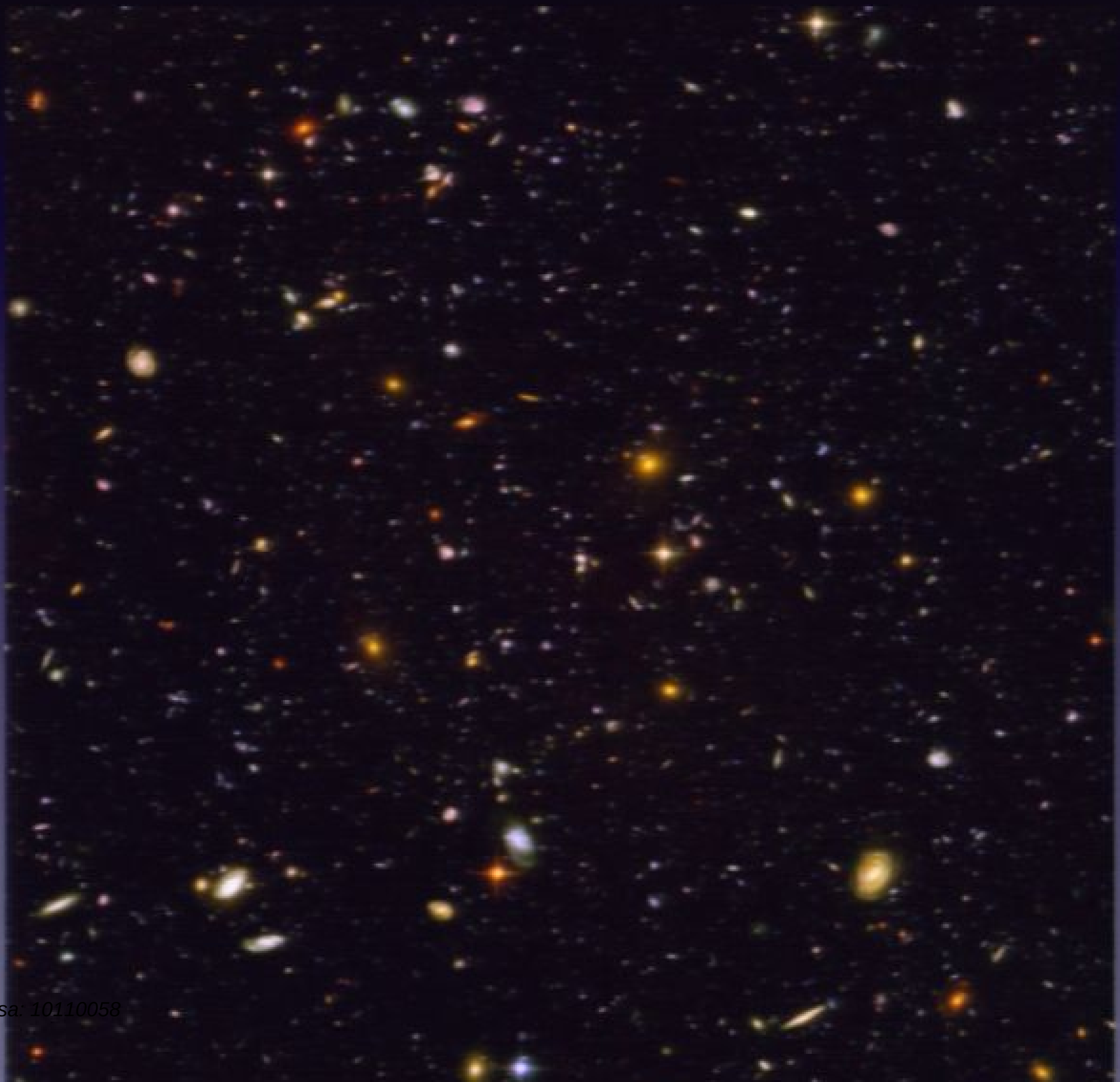
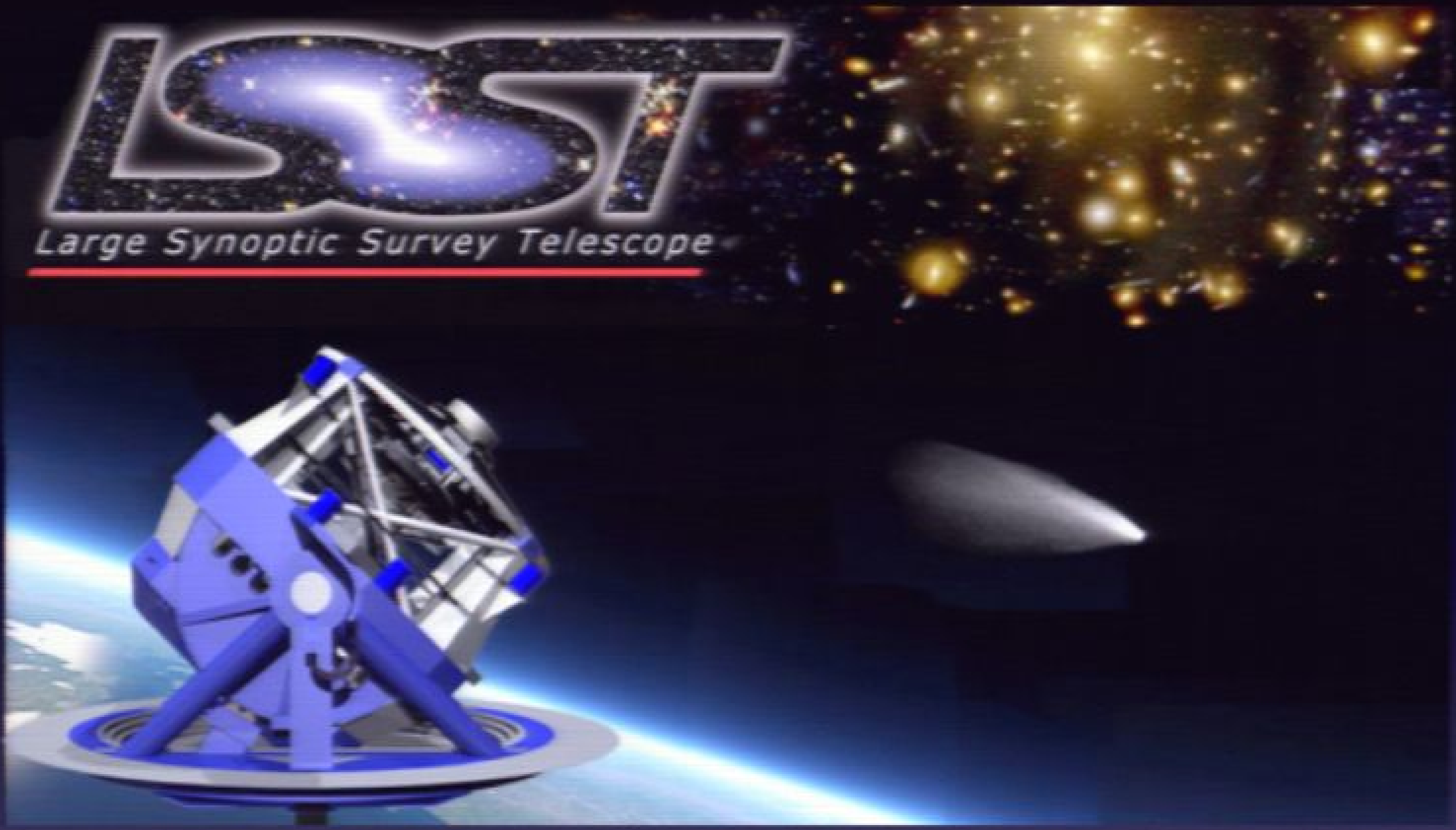
Hubble Deep Field



3 arcmin^2 << 1 deg^2

10,000 galaxies, spread over large z range

=> Need an efficient search strategy



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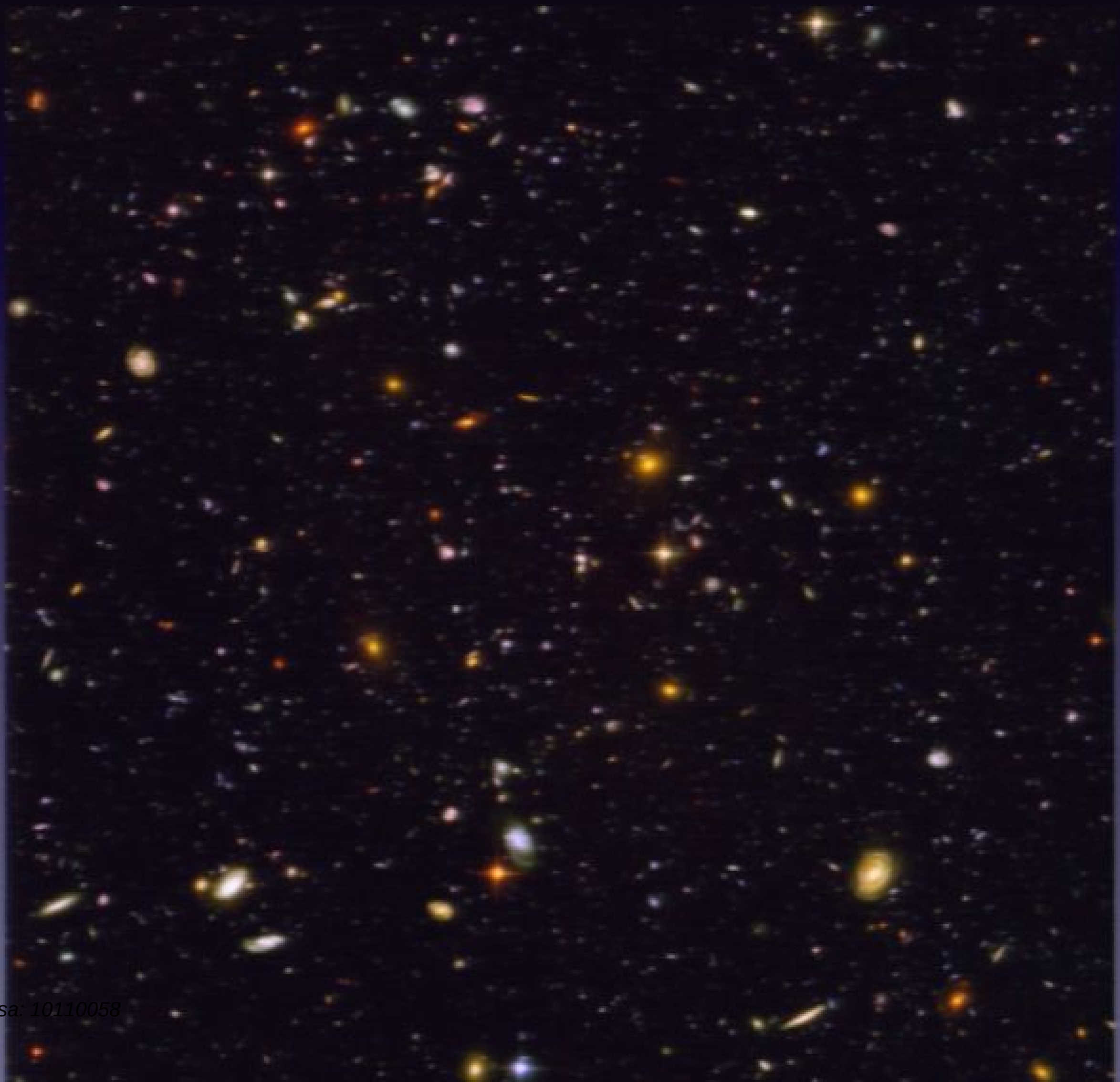

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What is the Nature of the Electromagnetic Counterparts?

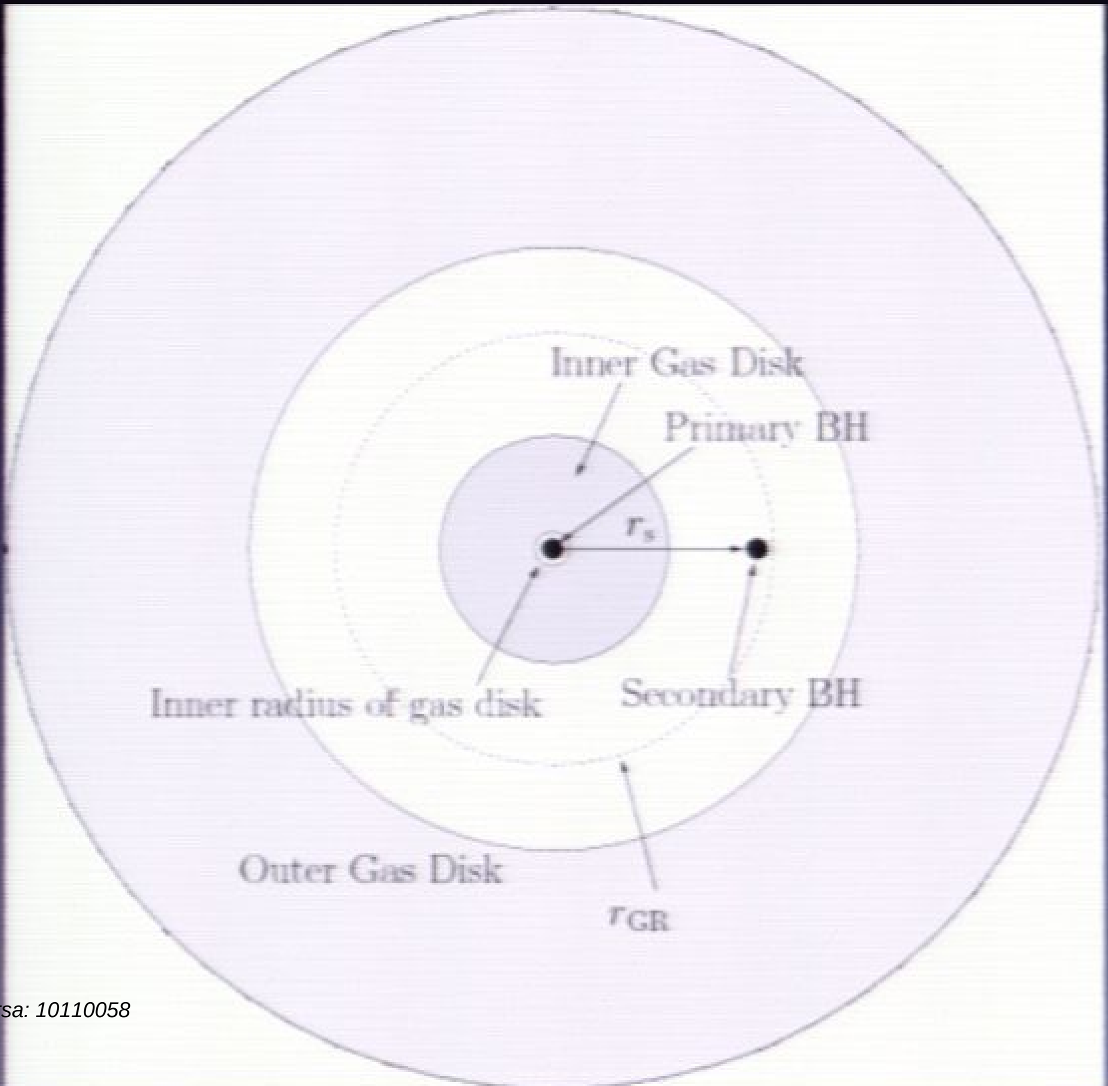
MBH-MBH: precursor + prompt + afterglow signals

EM Counterparts: Basic Considerations

- MBH-MBH mergers are very energetic events
- $E_{gw} \sim 10^{58}$ ergs in ~100s seconds ($\underline{L_{gw} \sim 10^{23} L_{sun}}$)
- Bound gas sees suddenly reduced mass by few %
- Gravitational recoil (>100 km/s) deposits $>10^{53}$ ergs mechanically in the environment (>> SN)
- Rare events, would have been missed so far (transient sky only little explored)

MBH Binary: General Setup

Chang, Strubbe, Menou & Quataert (2010)



Last parsec problem

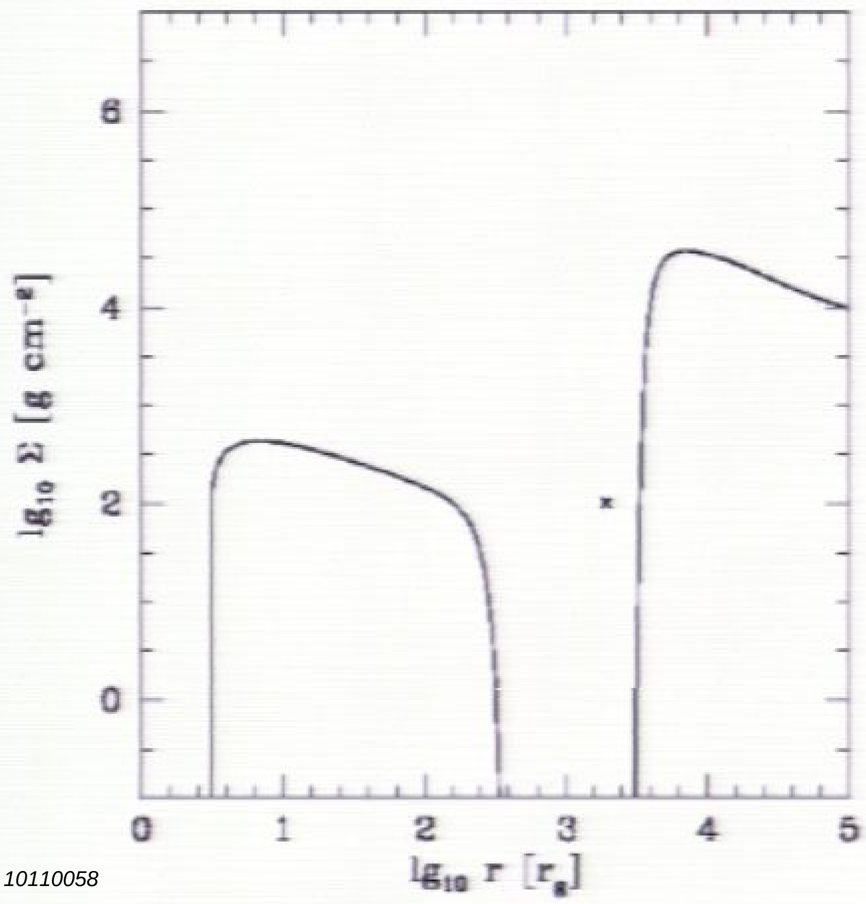
Binary stalls

Gas acts as “orbital sink”

GR losses take over

Precursor signal

Chang, Strubbe, Menou & Quataert (2010)



Inner fossil disk (~10^{-3} M_{sun}) is tidally driven in via GR losses.

Characteristic rise ($t^{-5/4}$) from binding a fixed mass to the central BH, on the GR merger time

Precursor signal

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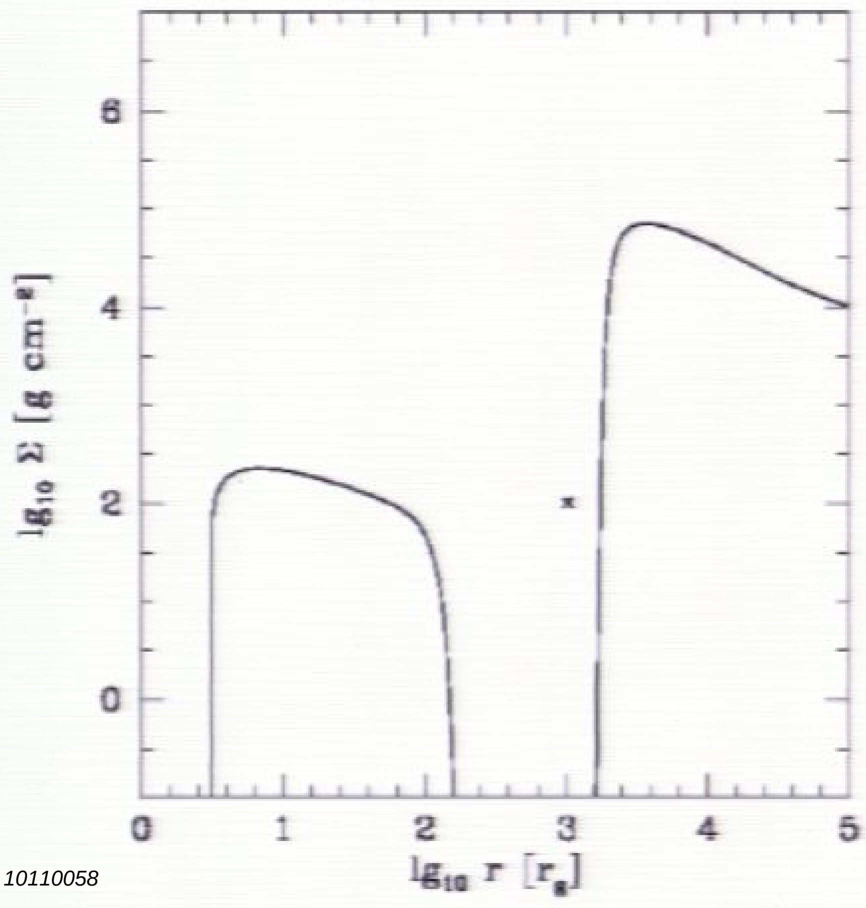

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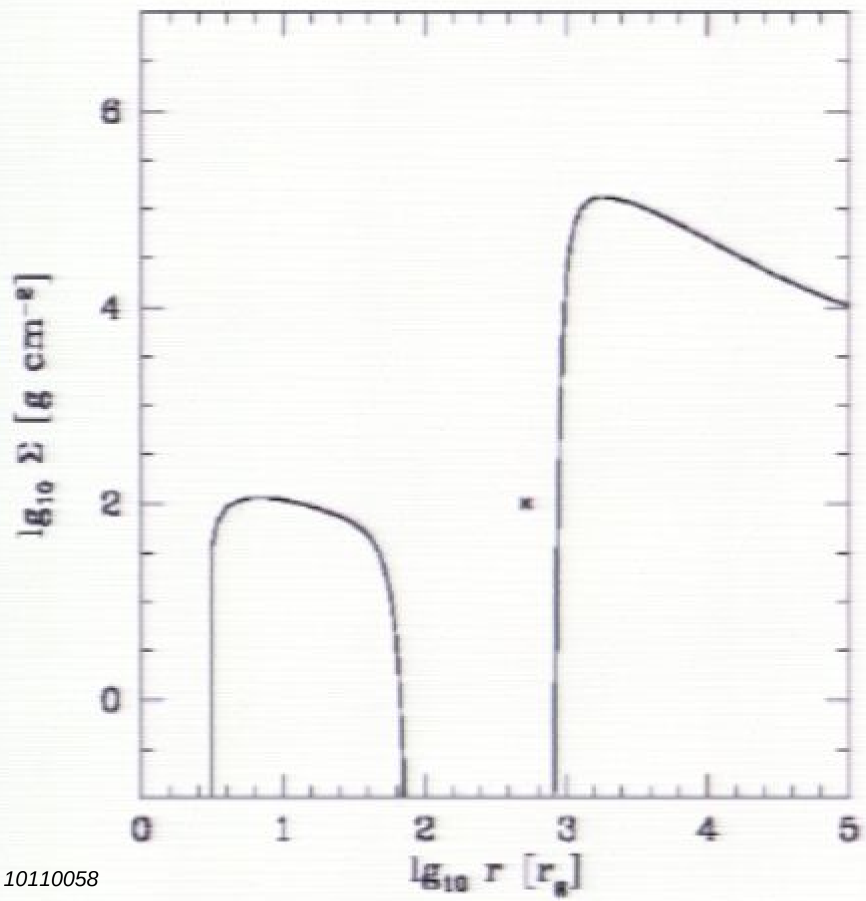

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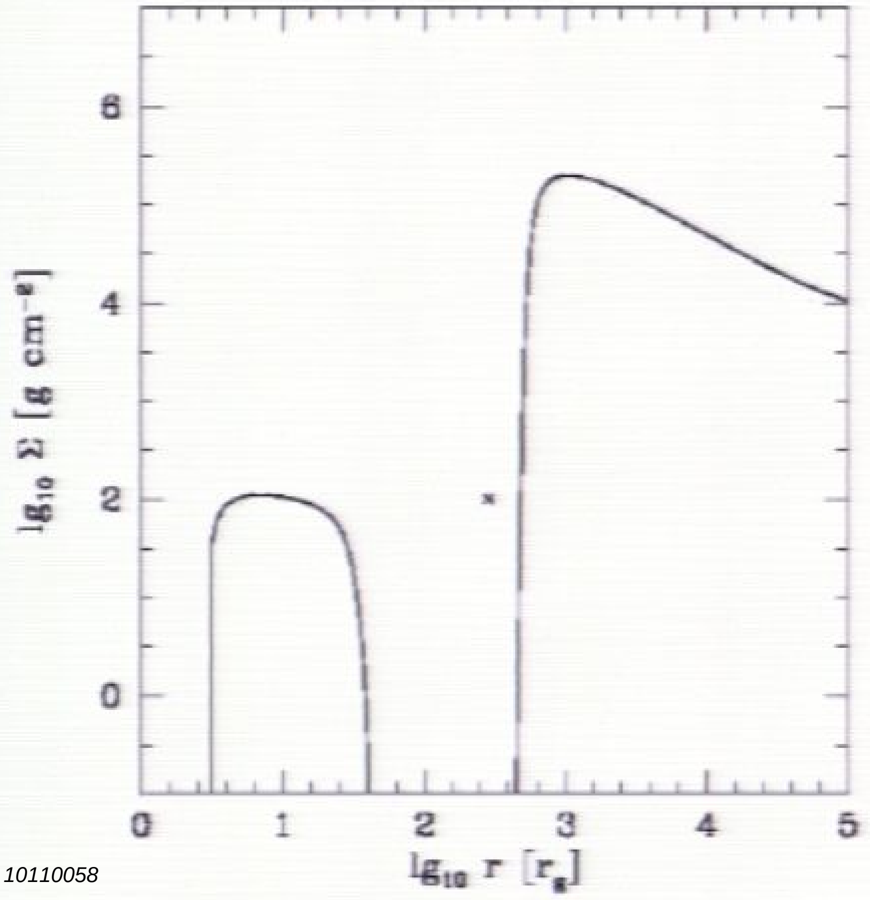

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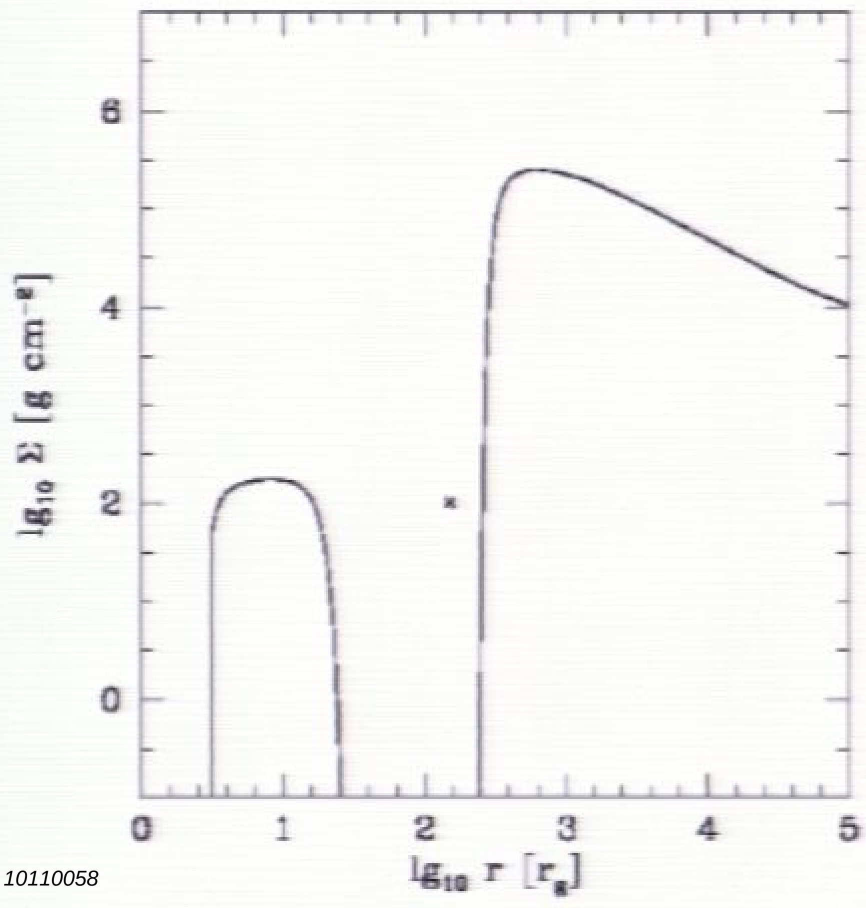

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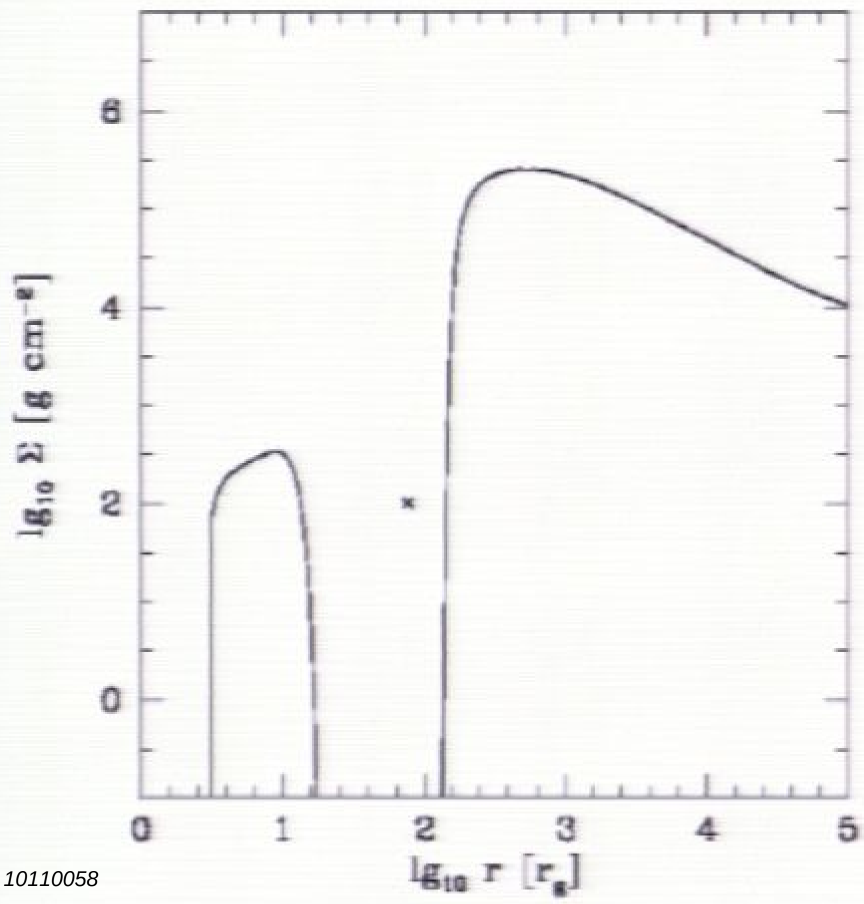

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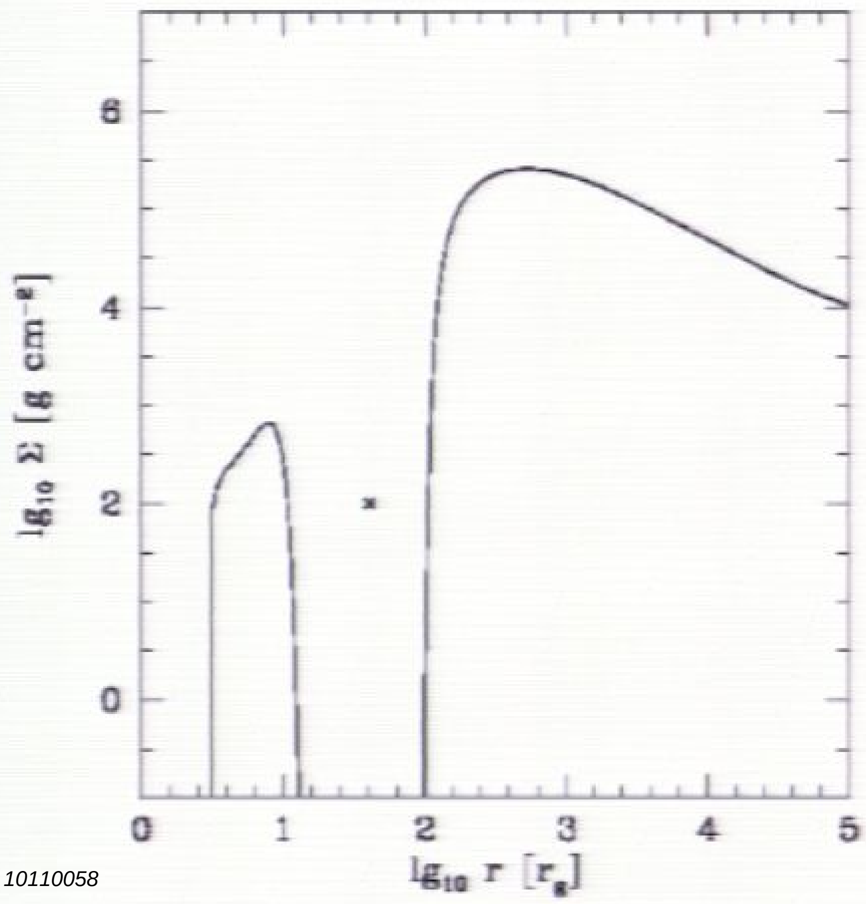

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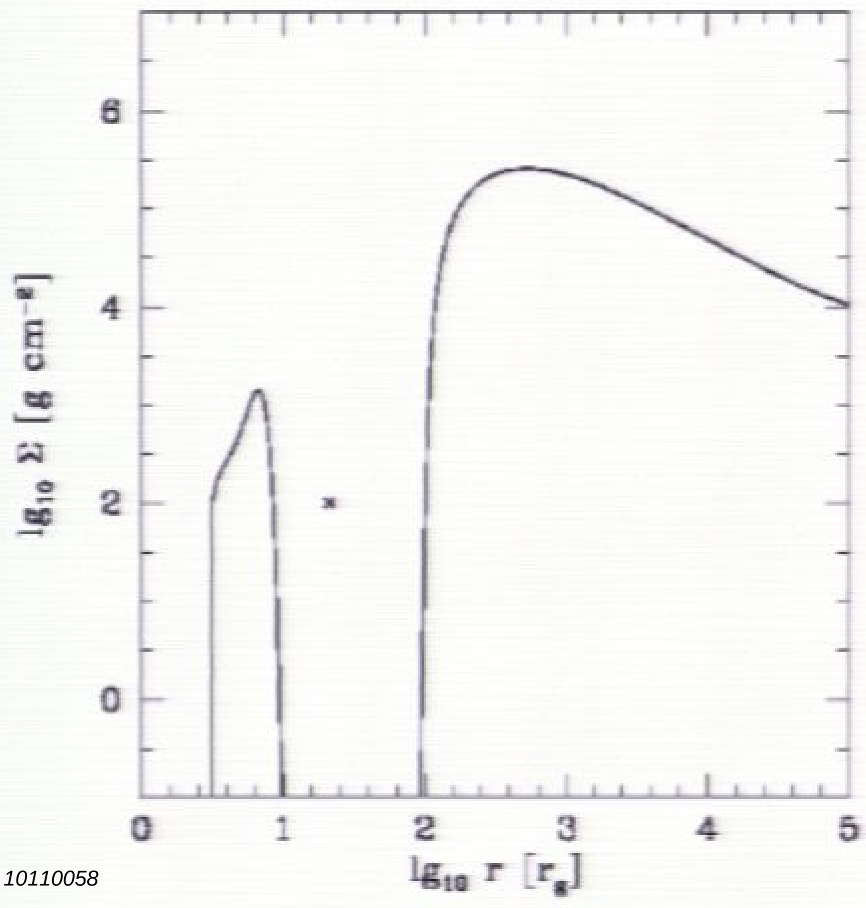

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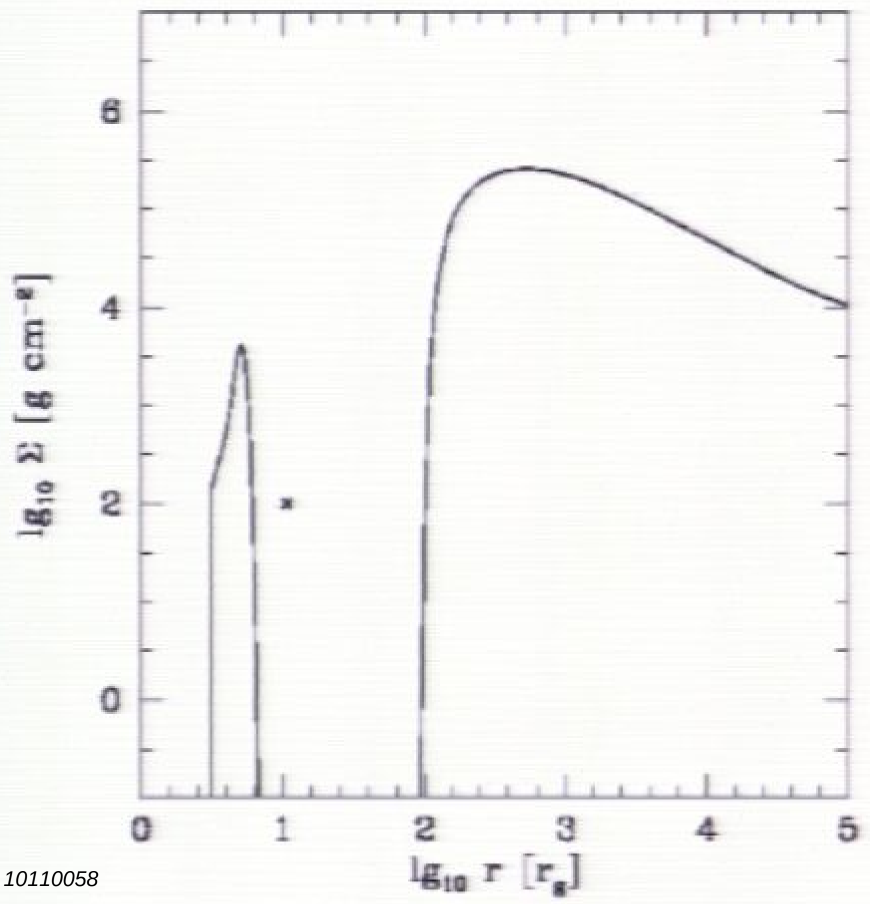

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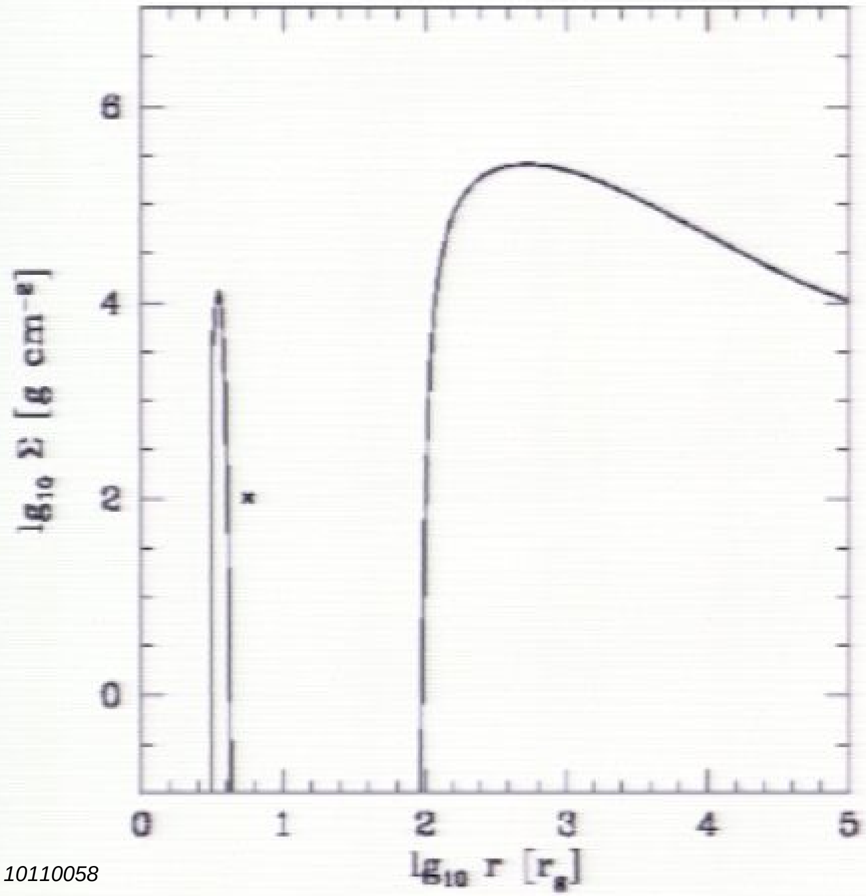

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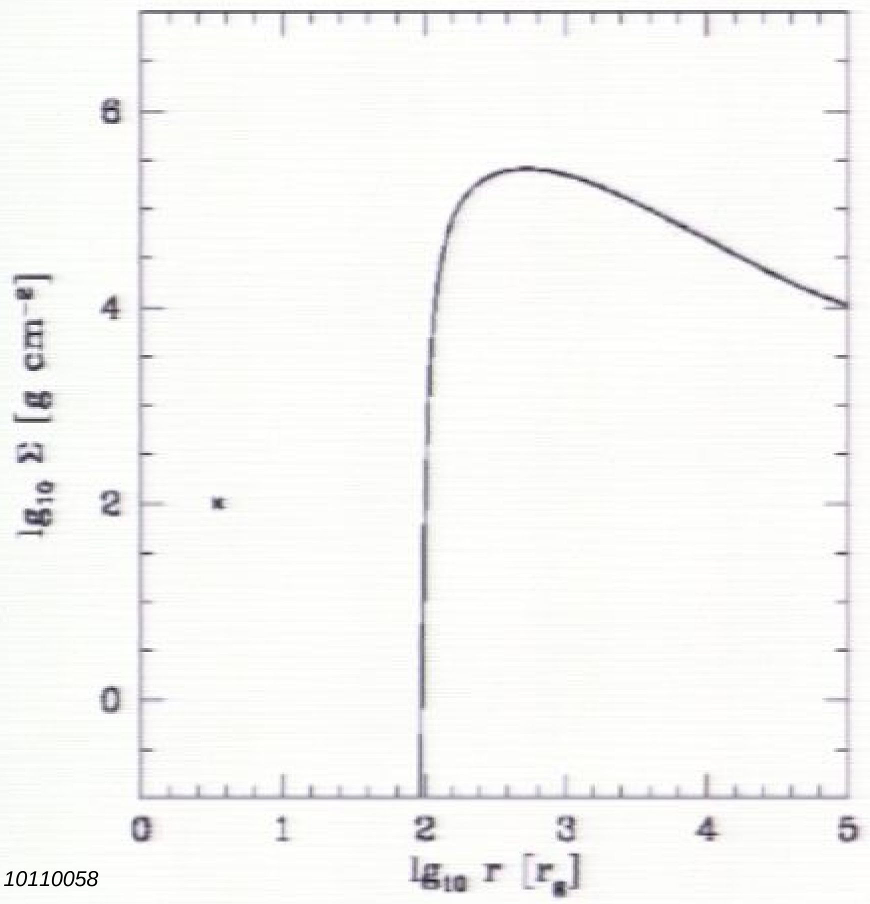

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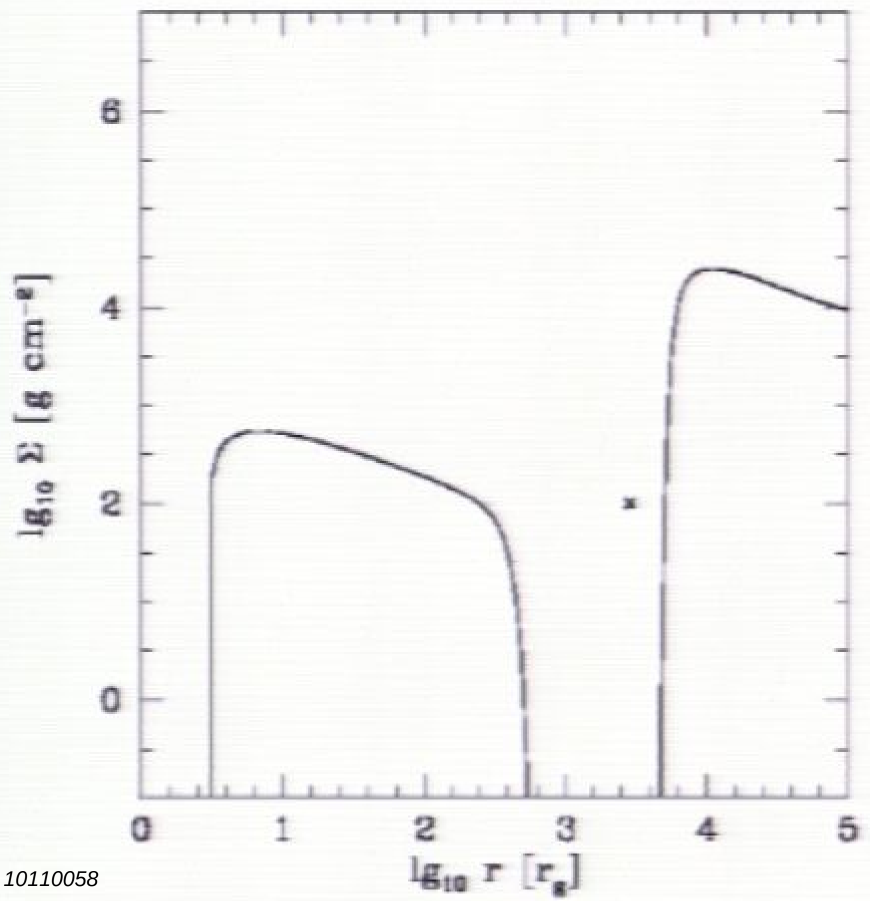

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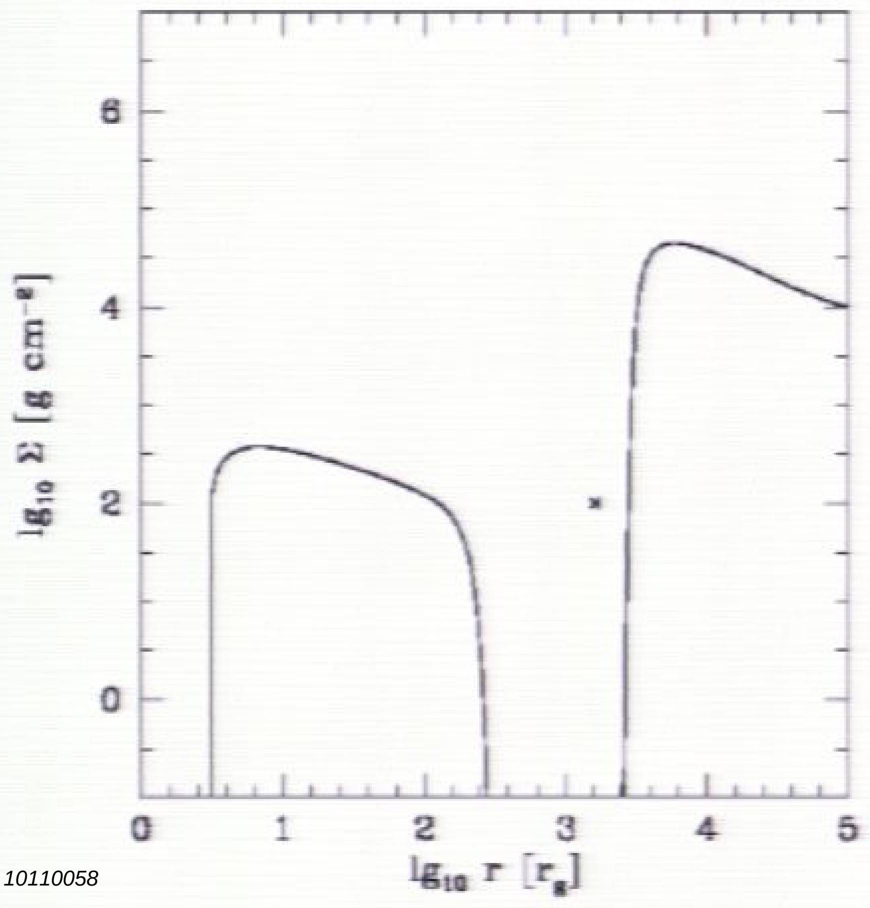

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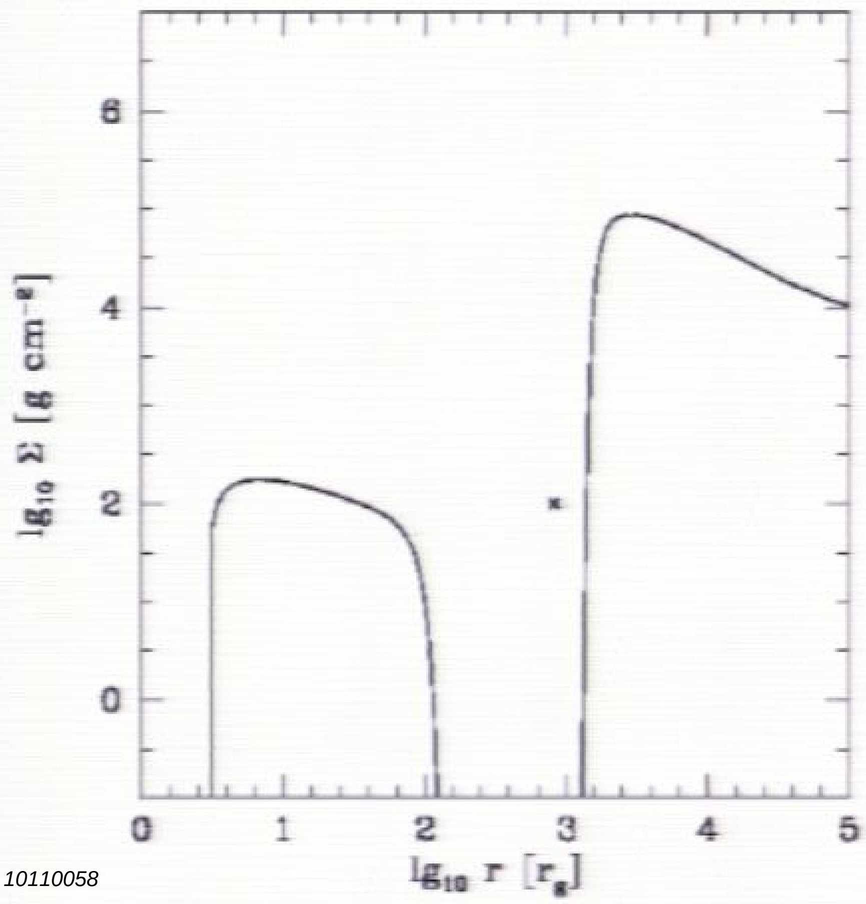

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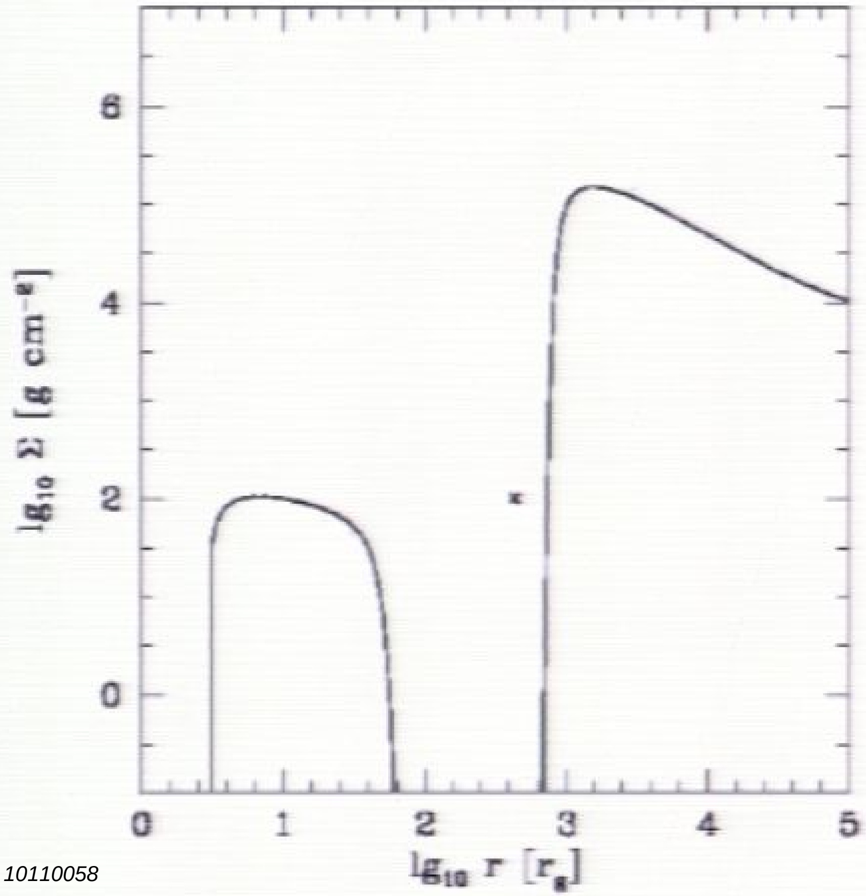

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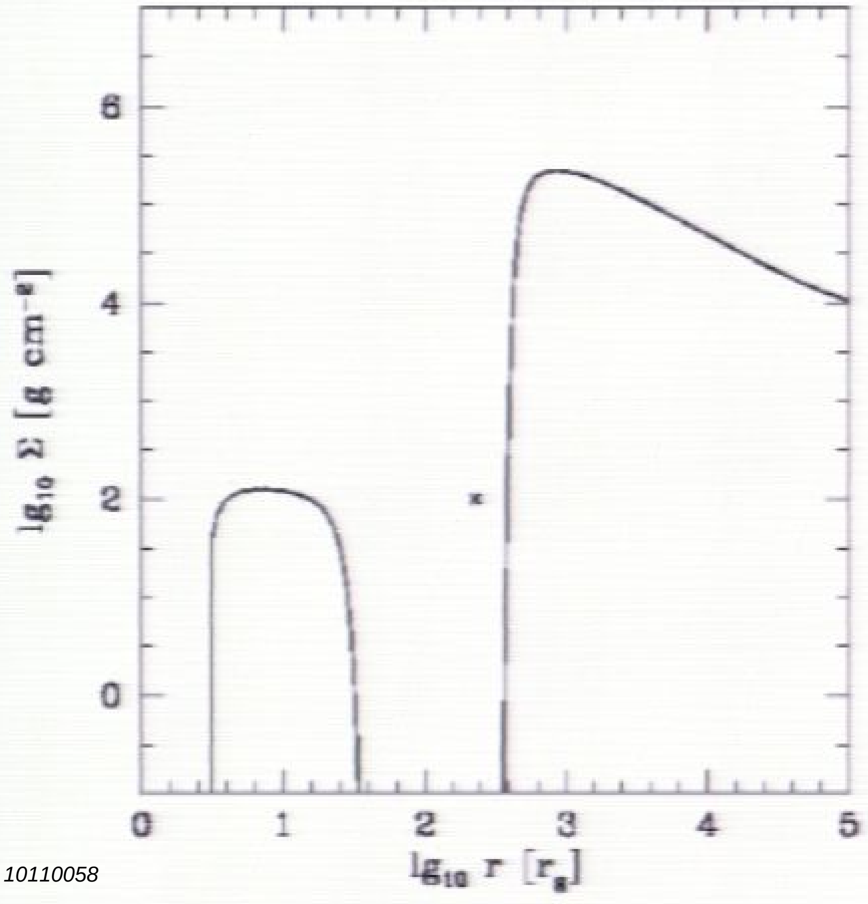

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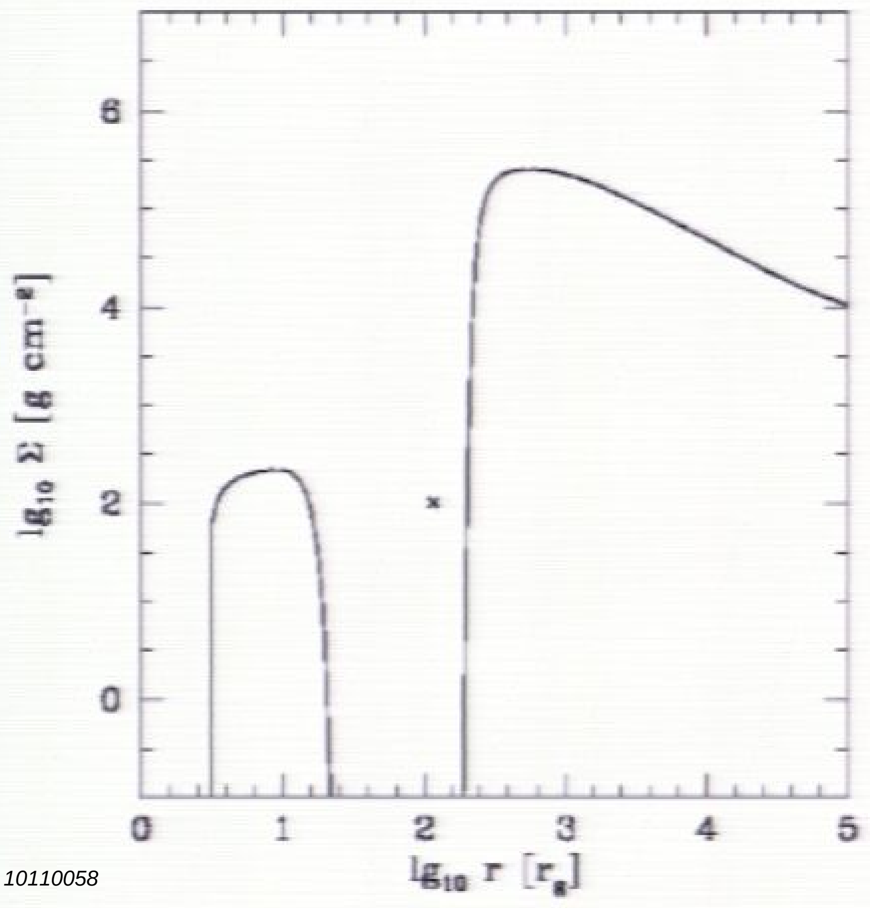

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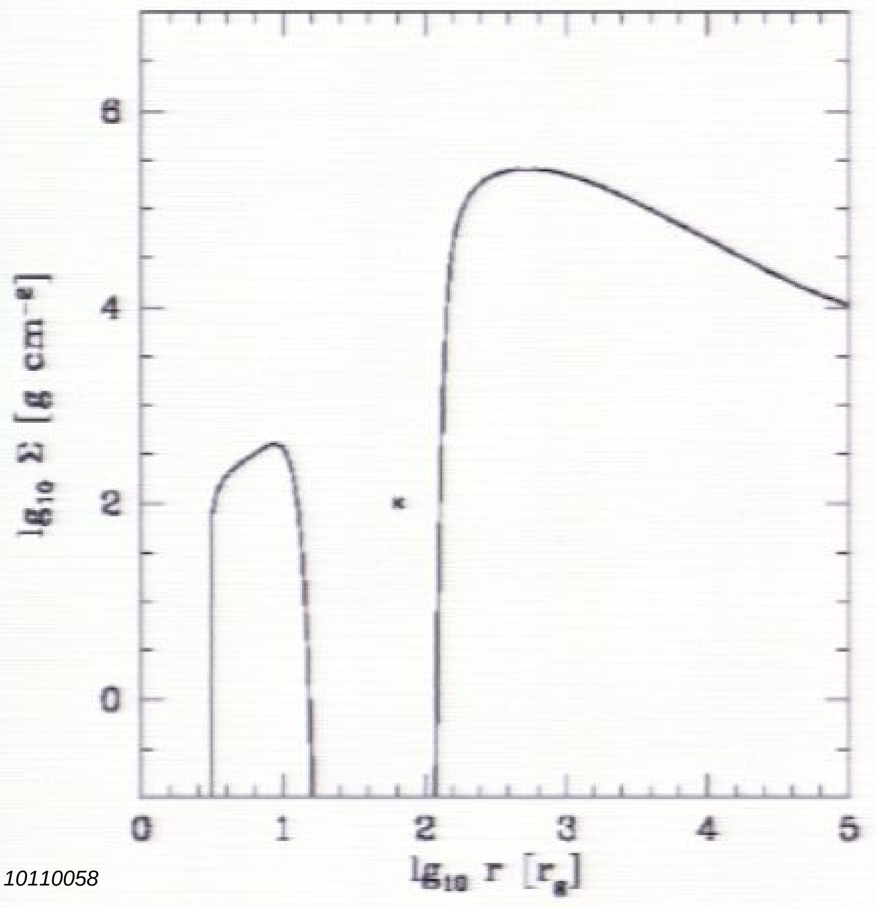

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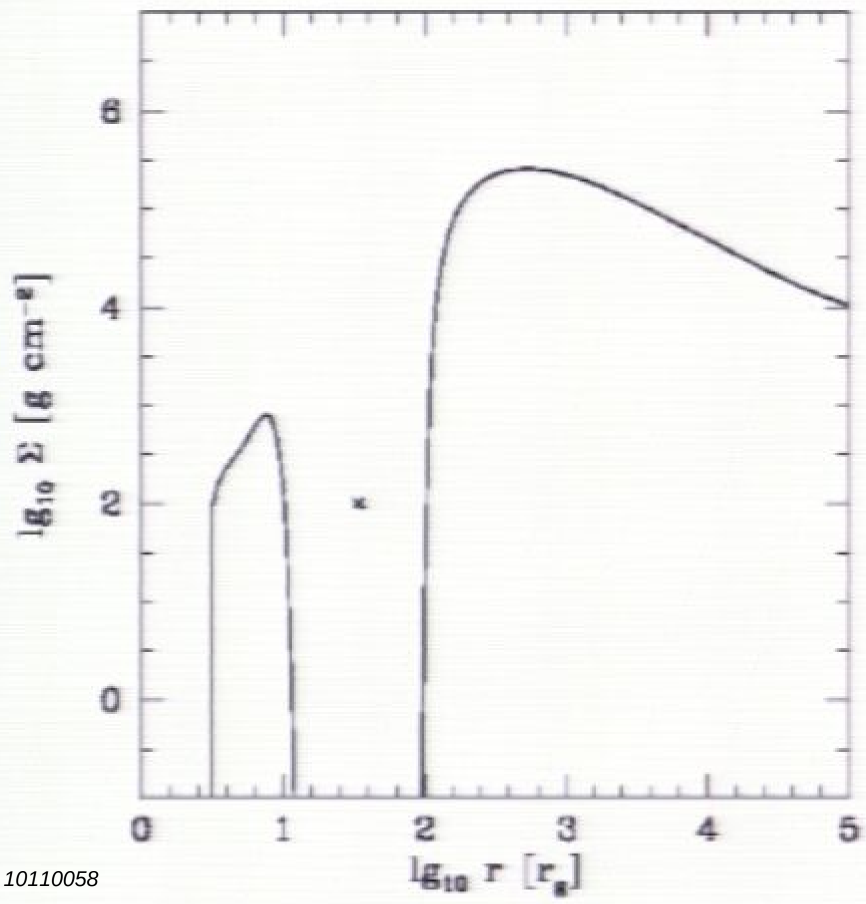

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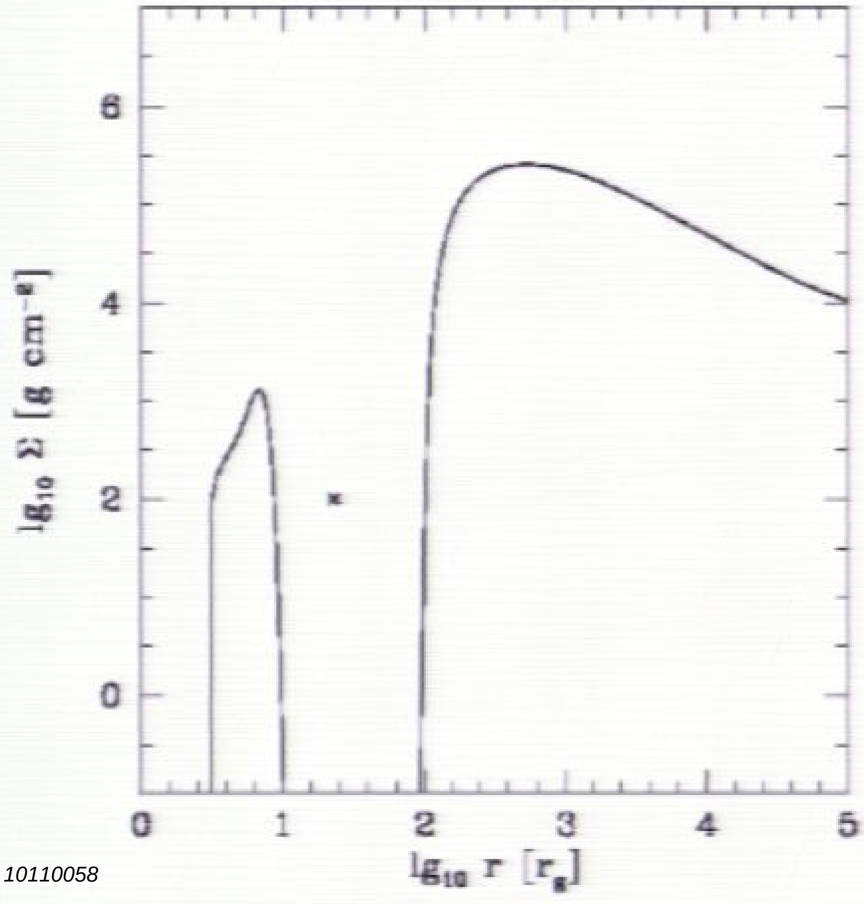

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Characteristic rise ($t^{-5/4}$) from binding a fixed mass to the central BH, on the GR merger time

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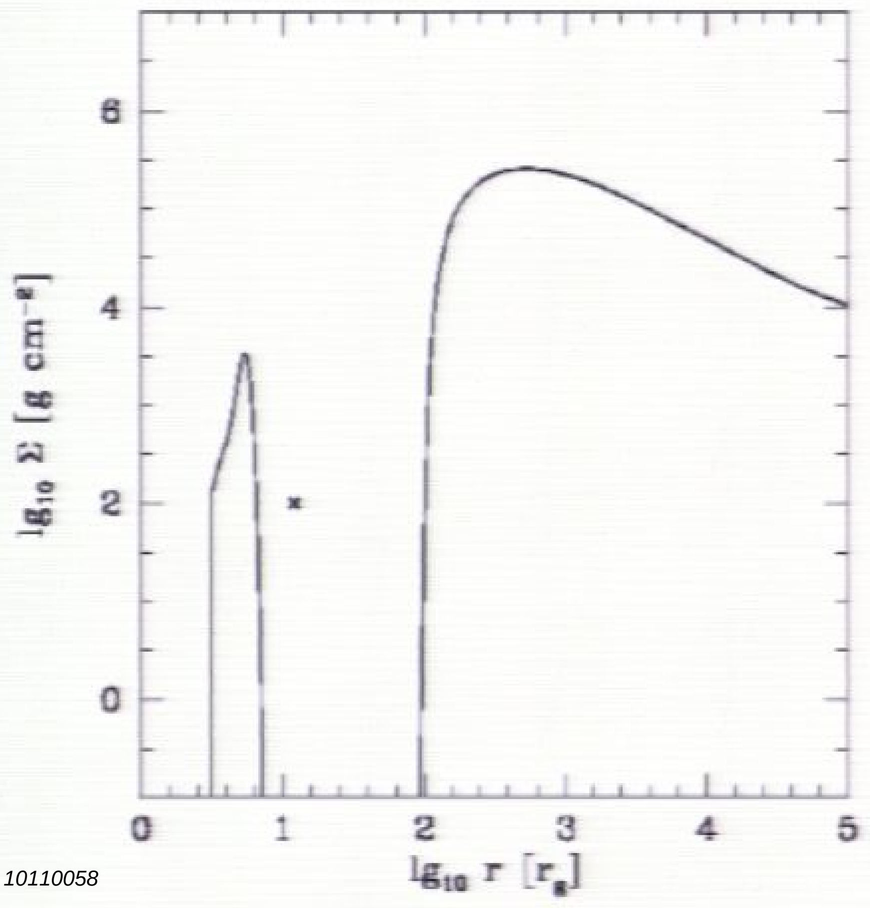

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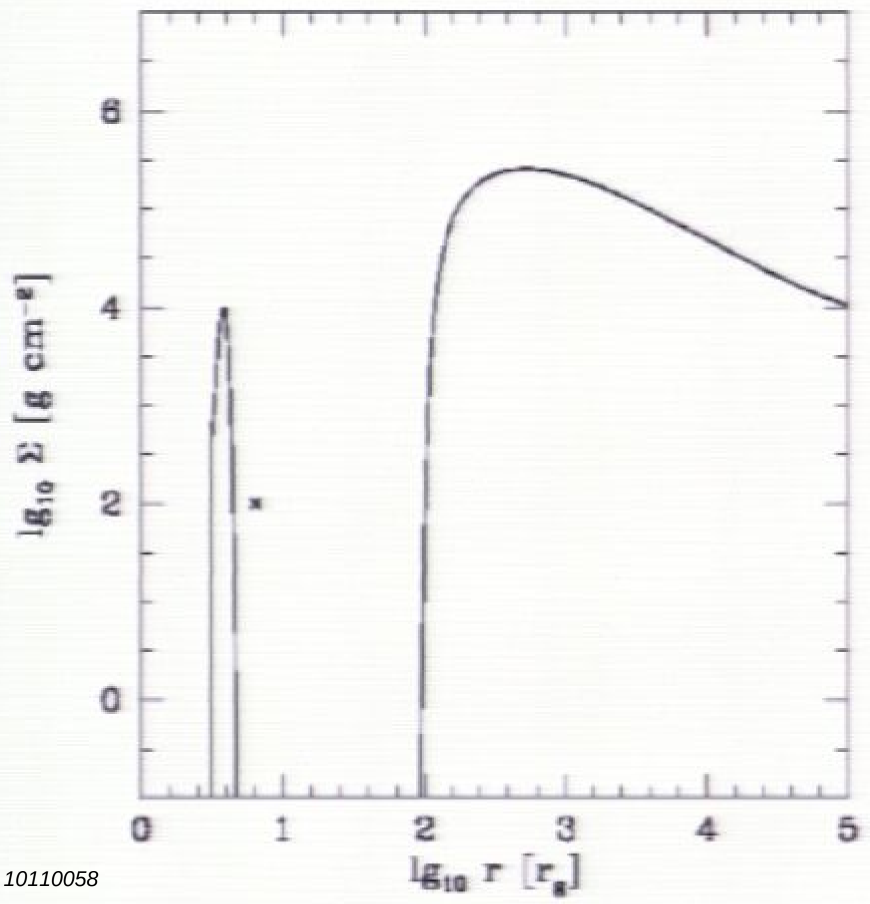

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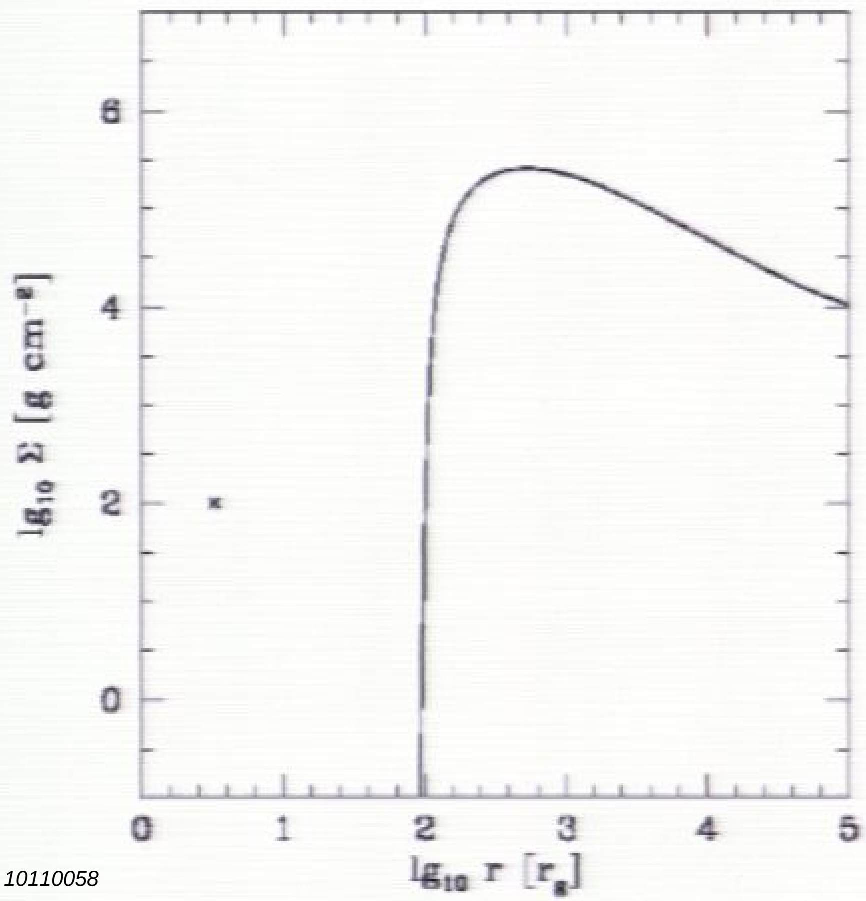

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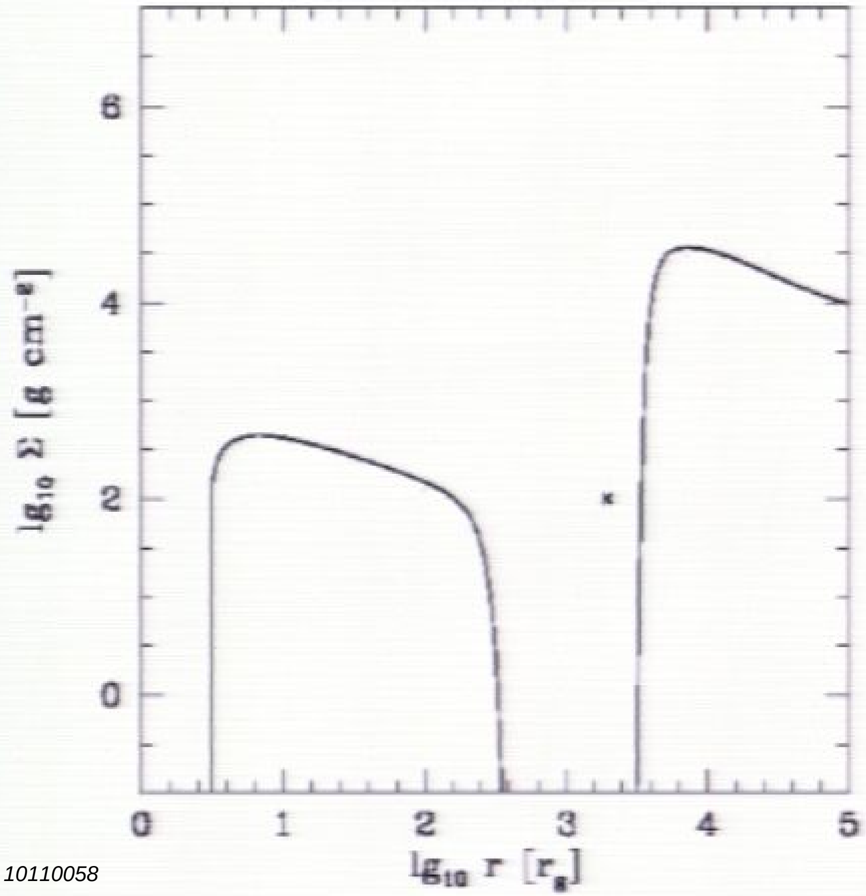

Inner-edge viscous diffusion:
~ 10 years

AGN turns on about a decade after merger:

We might witness the birth of a quasar!

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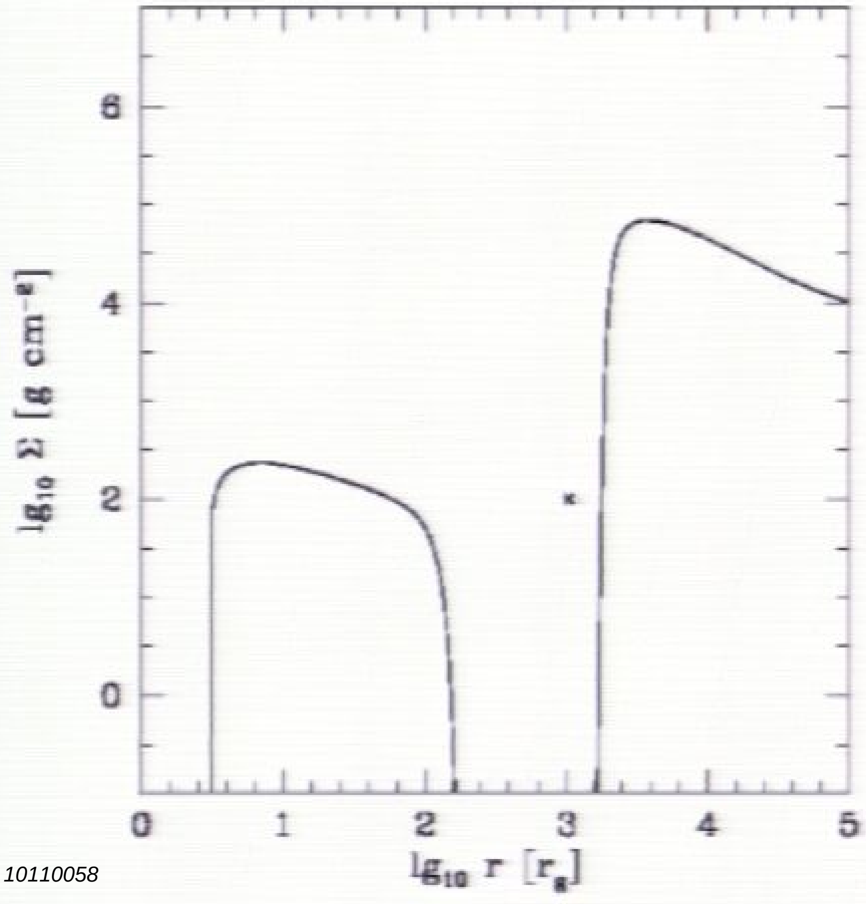

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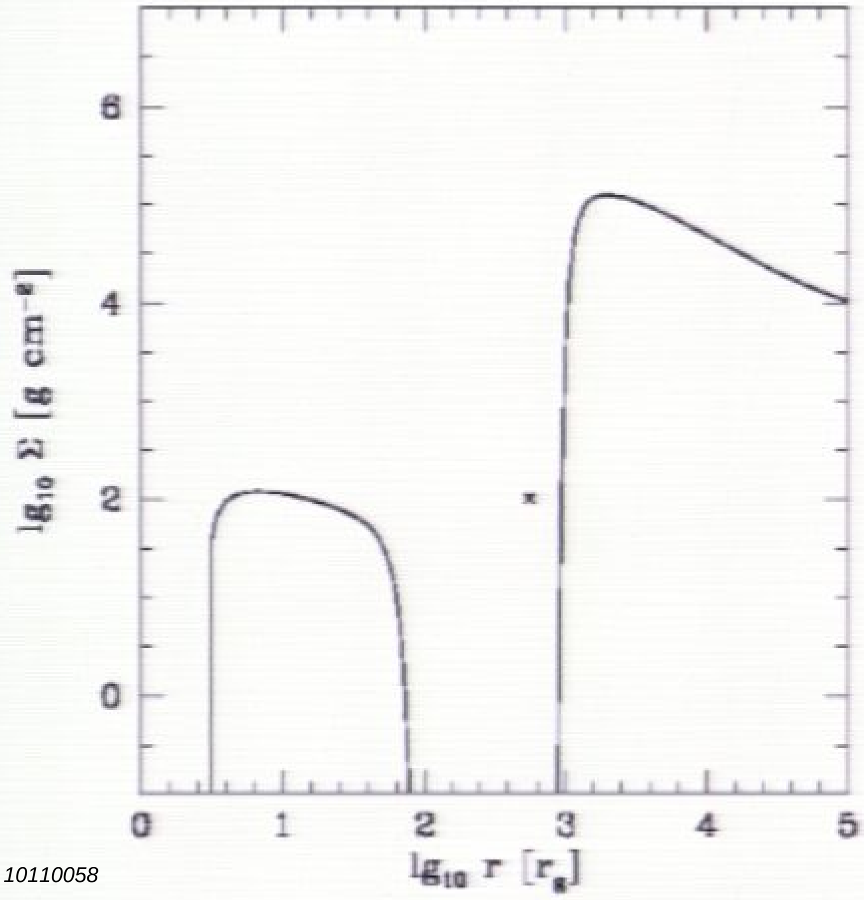

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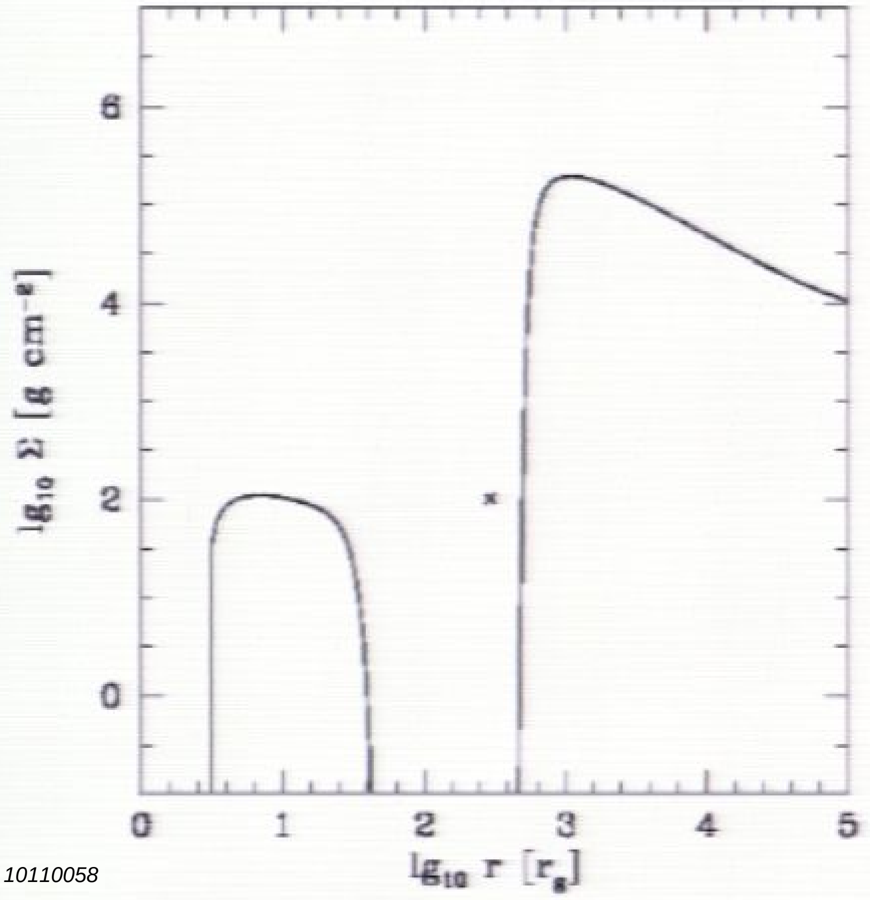

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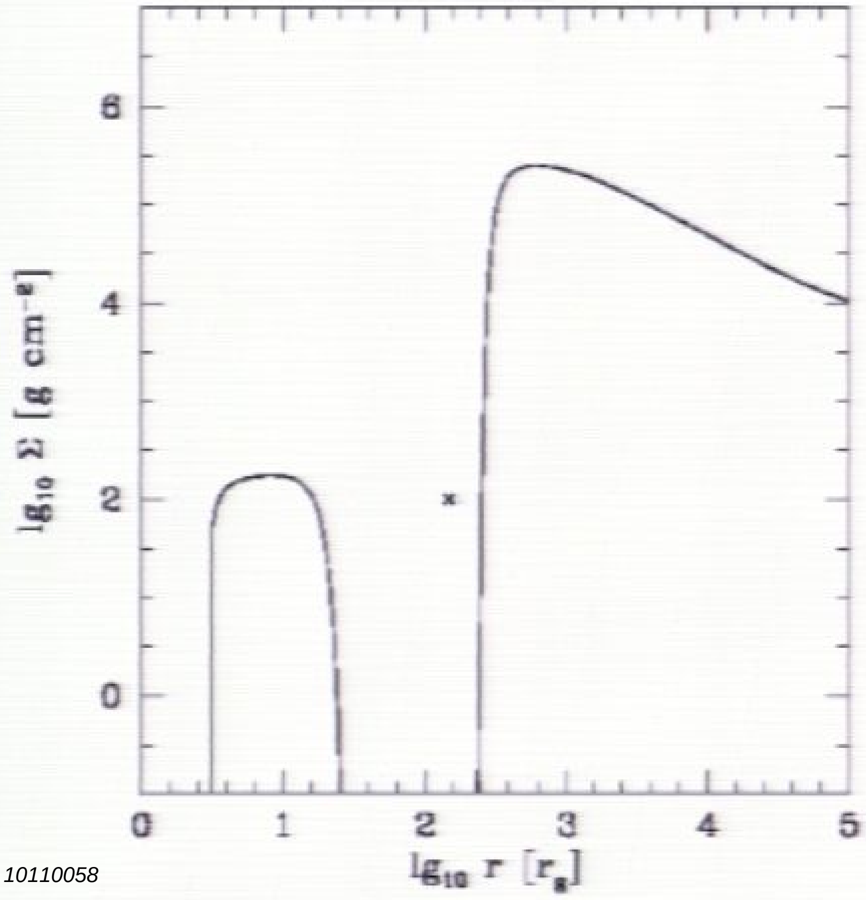

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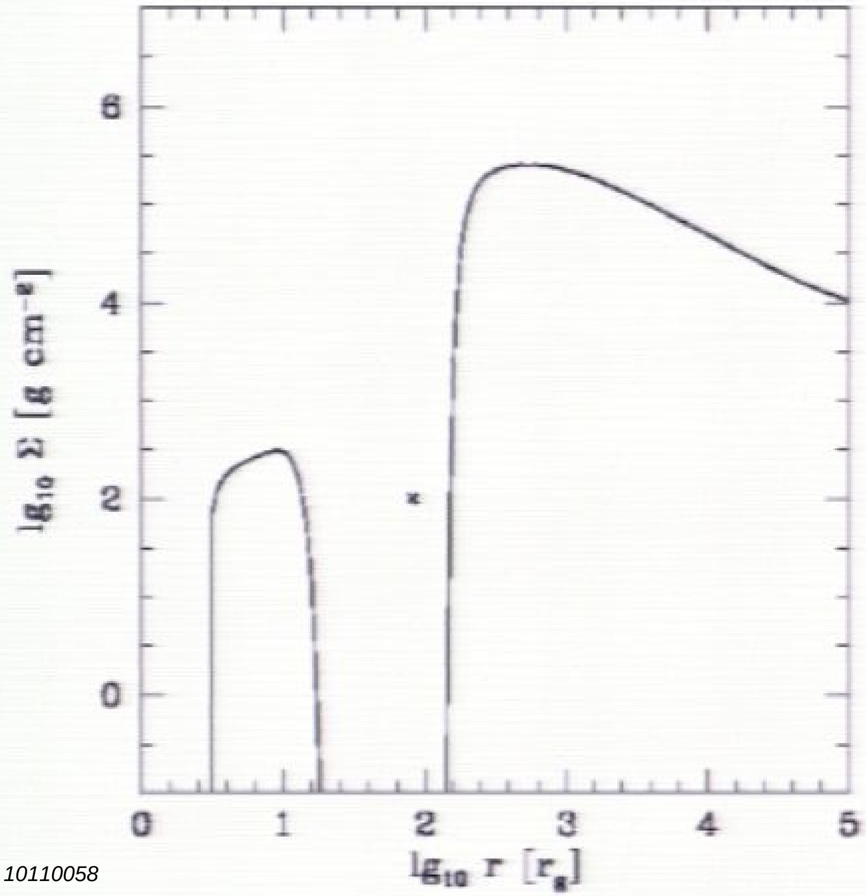

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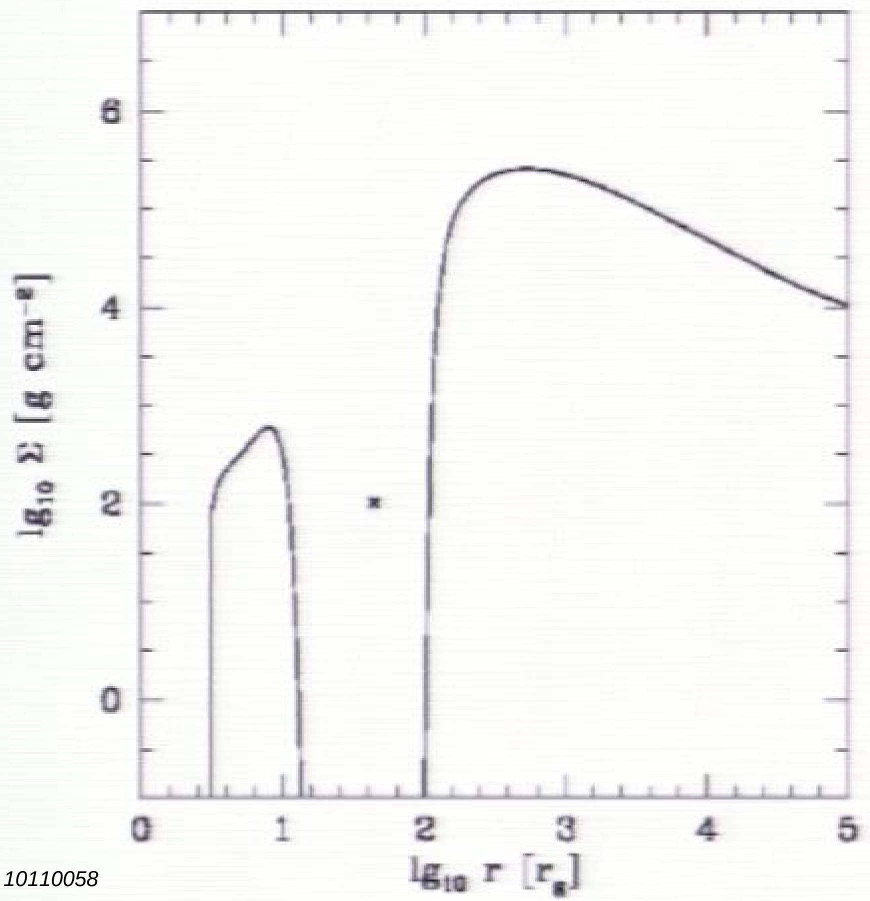

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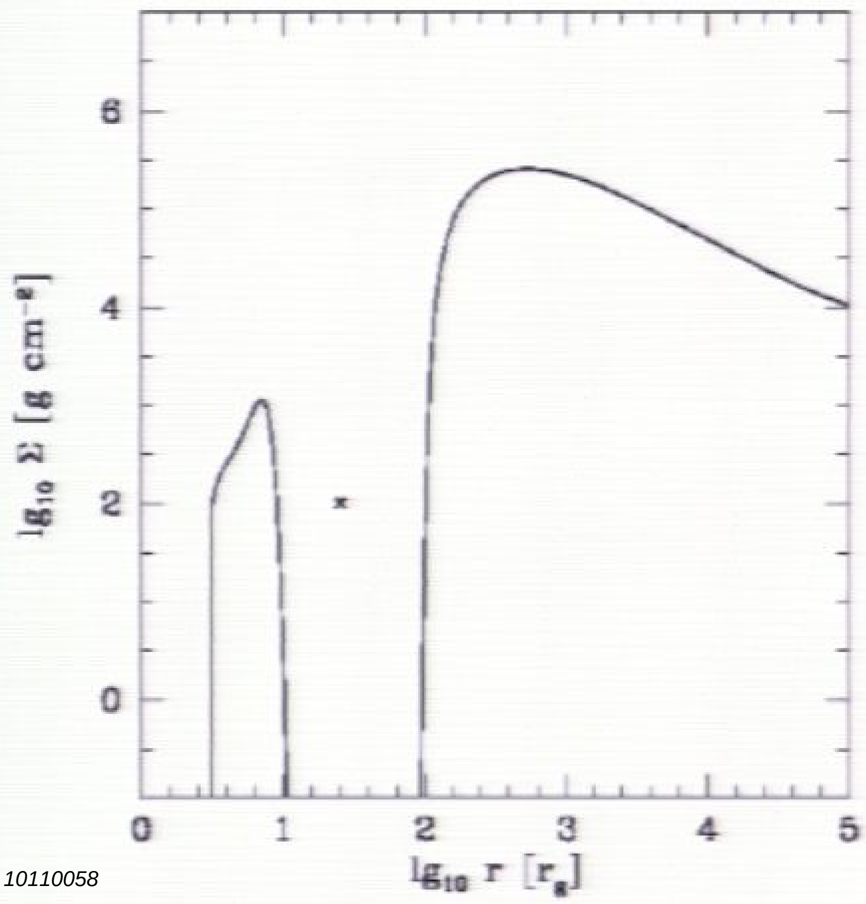

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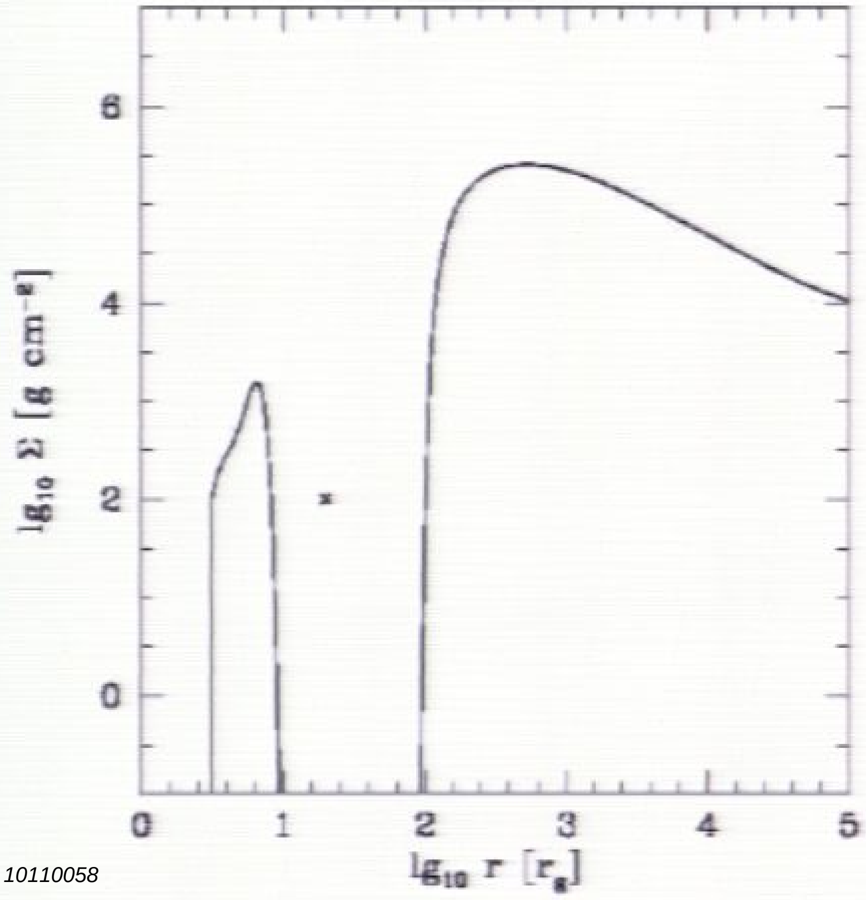

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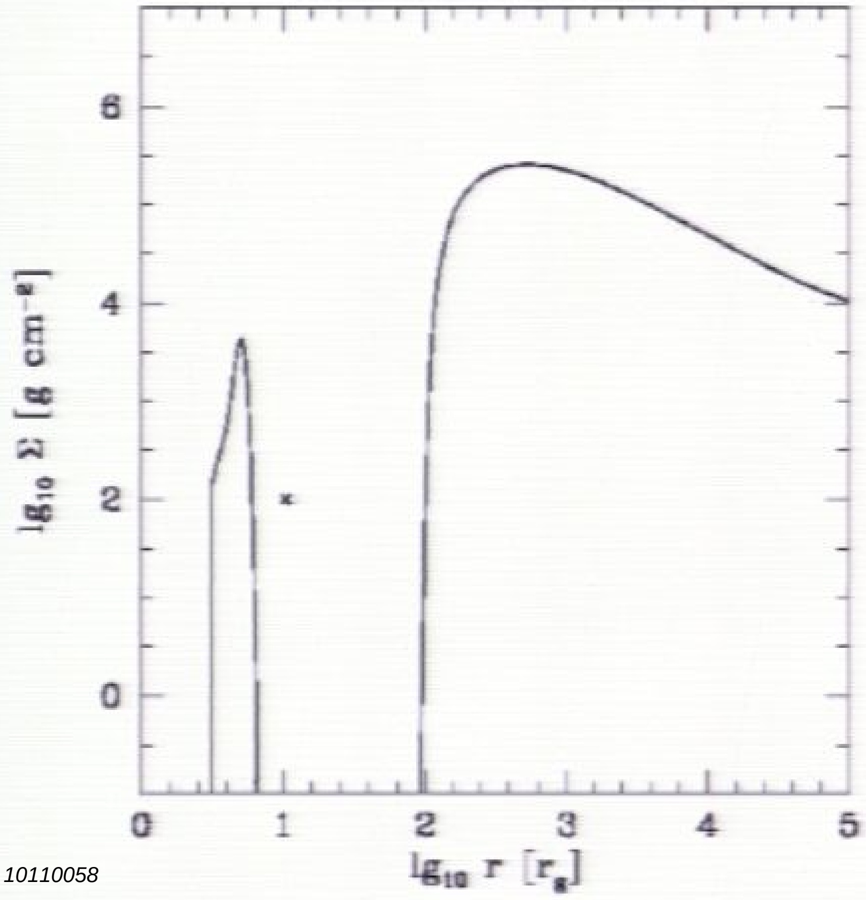

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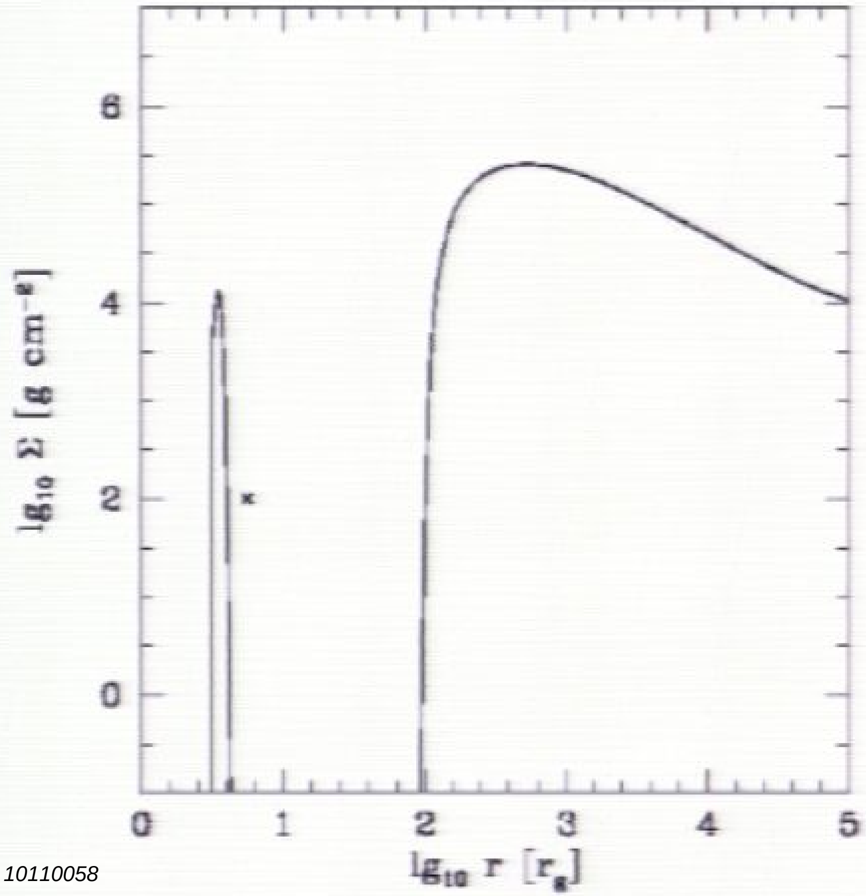

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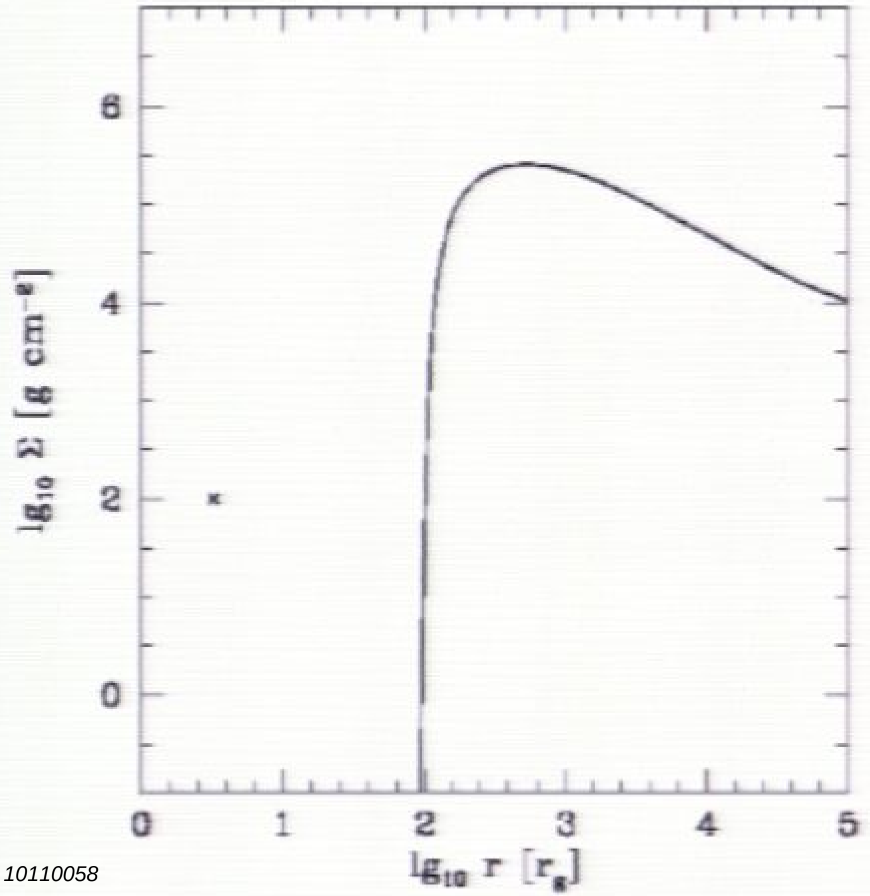

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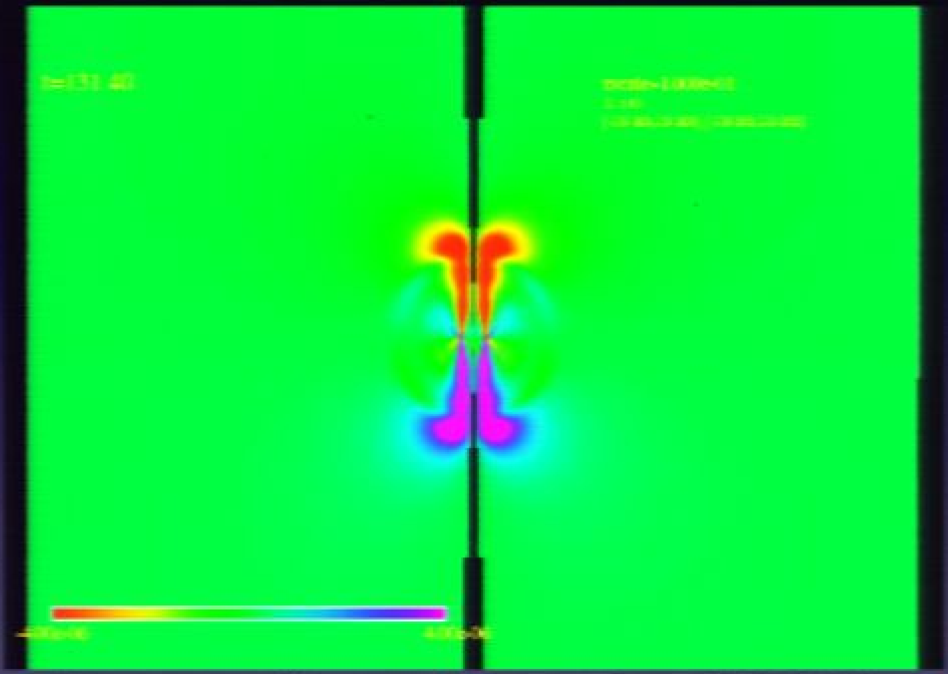

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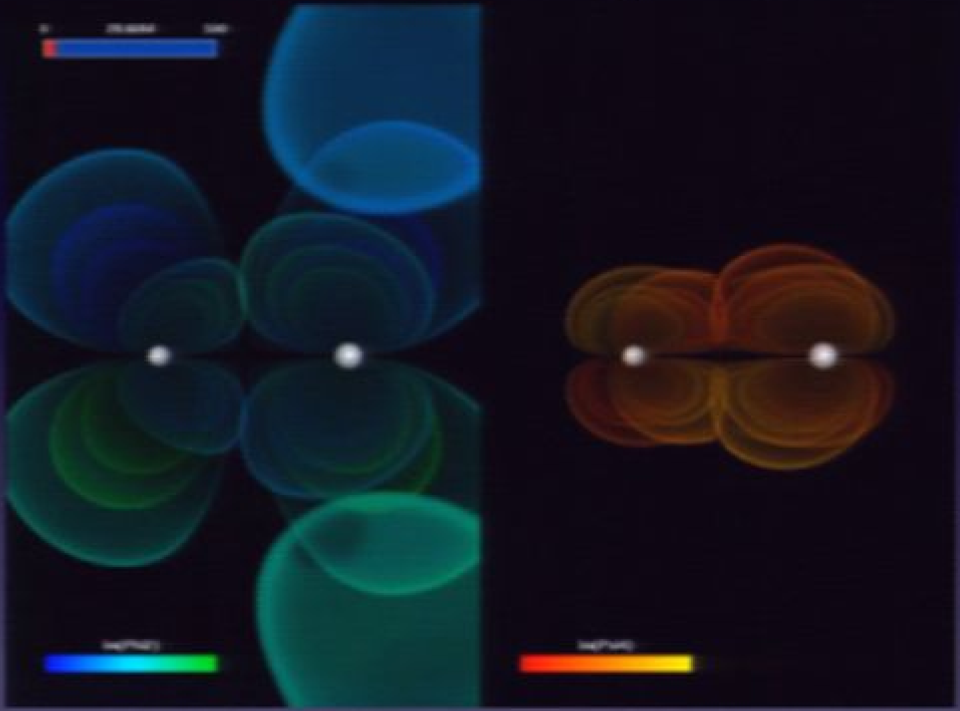
Transient double-jet!

Moesta et al (2010)



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GW field

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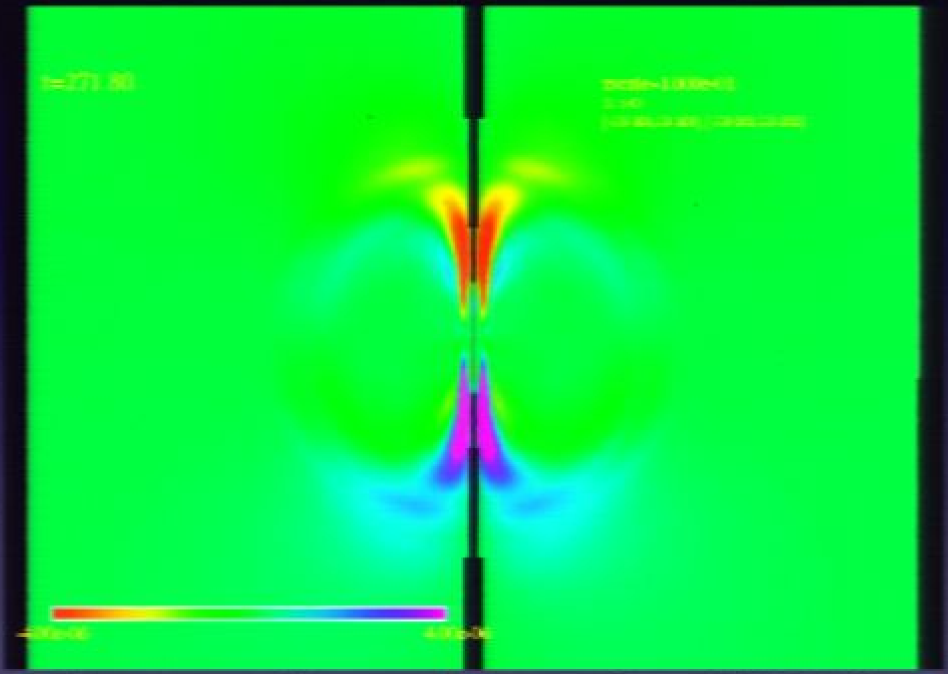

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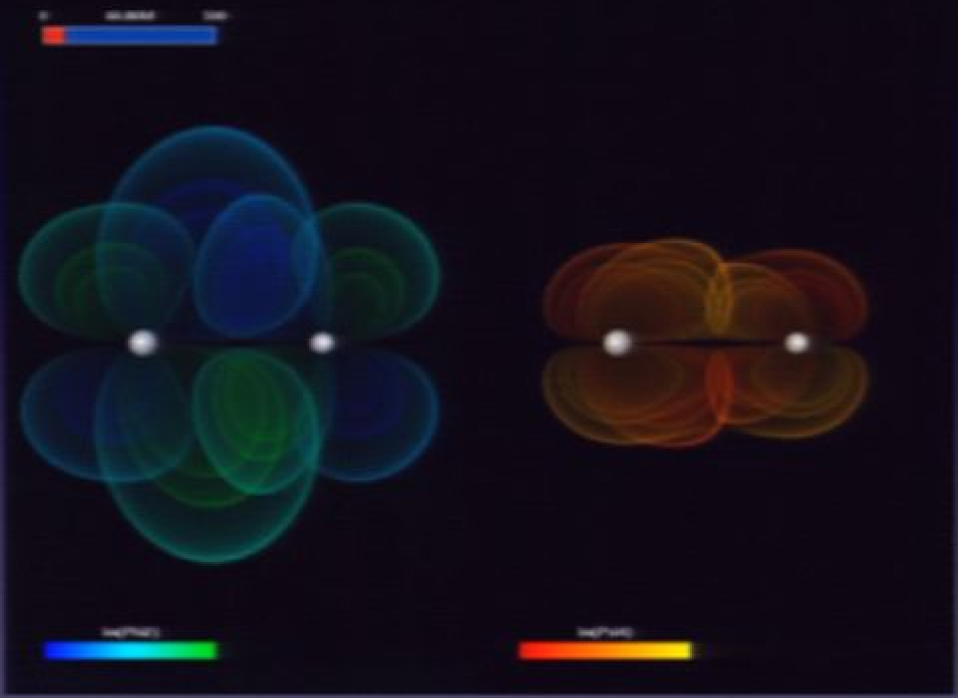

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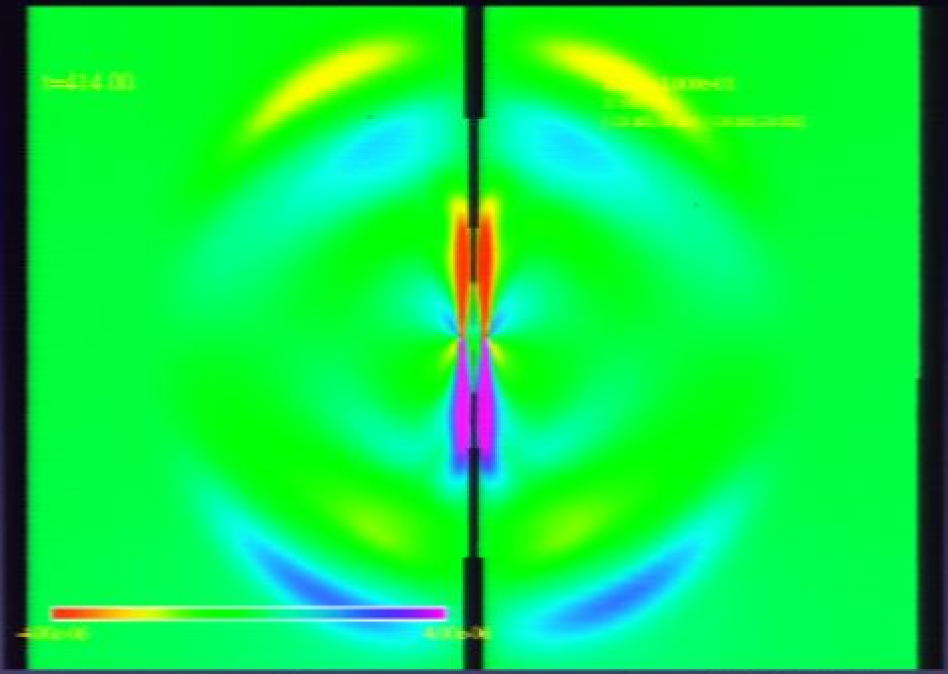

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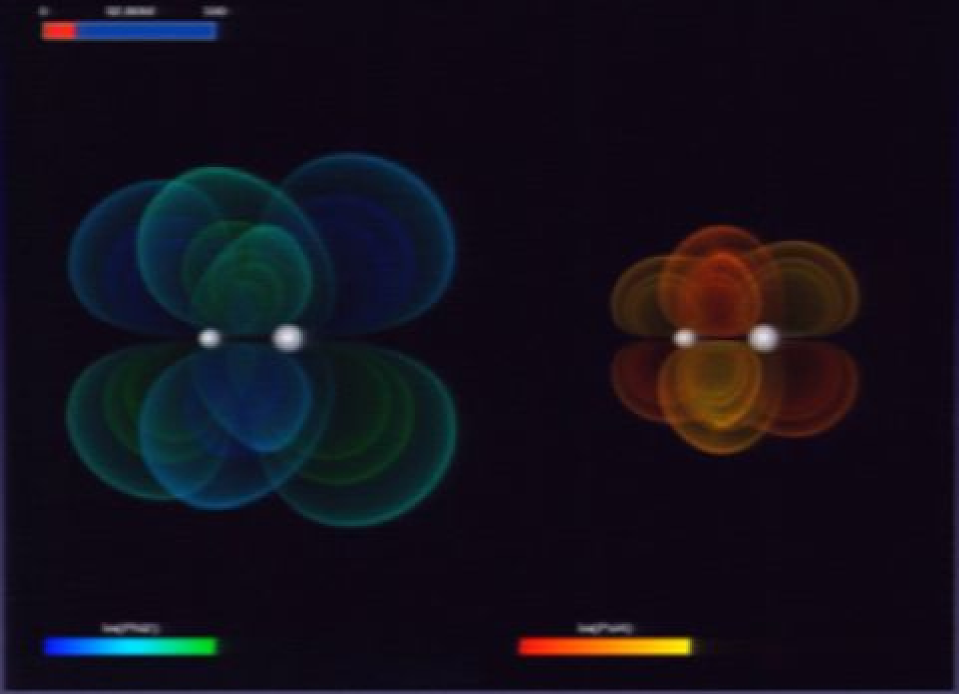

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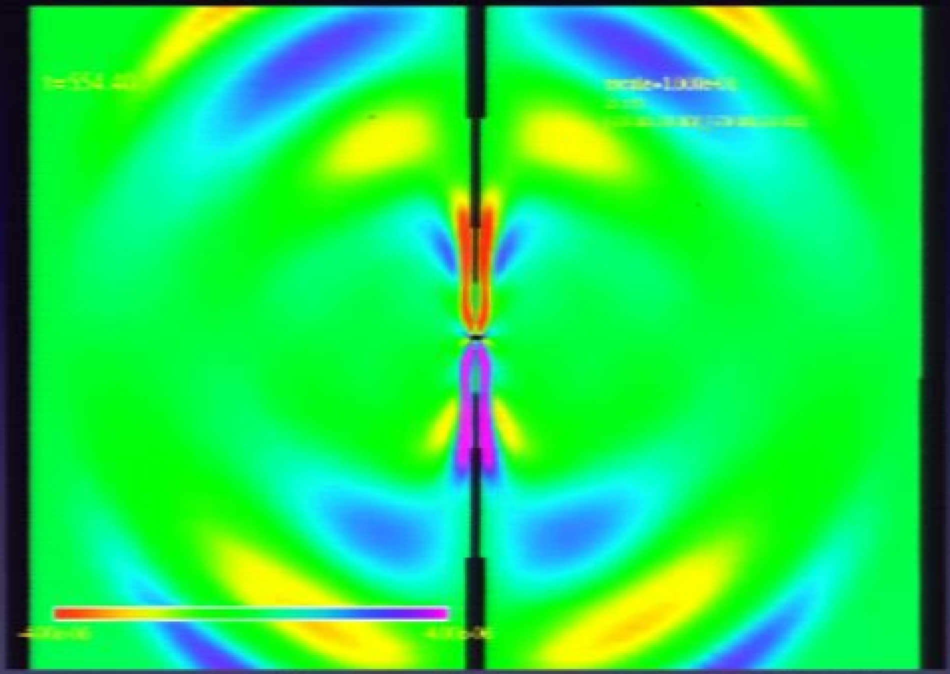

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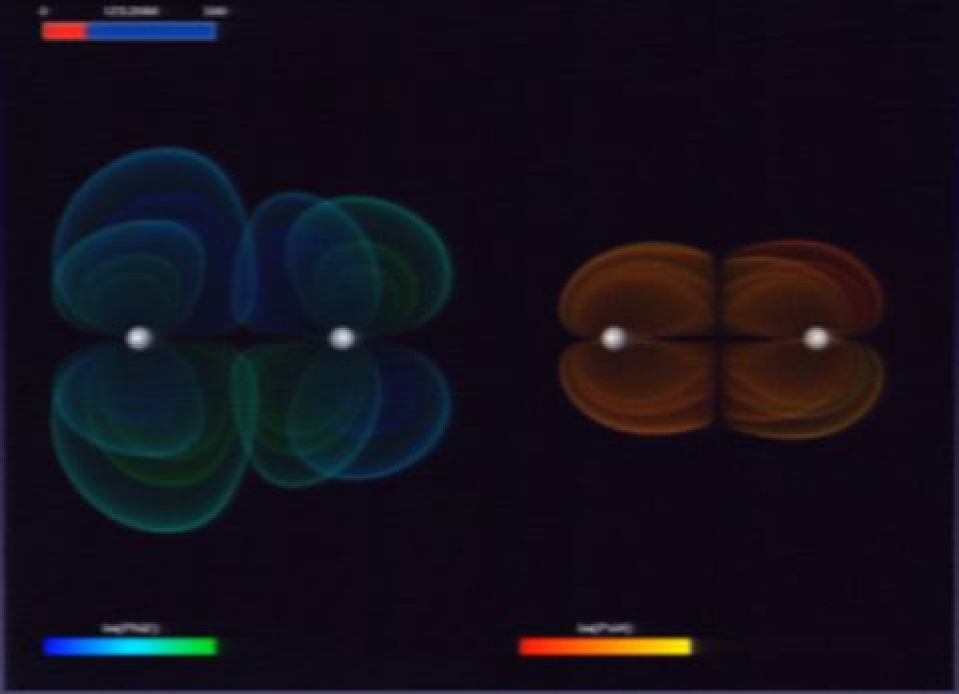

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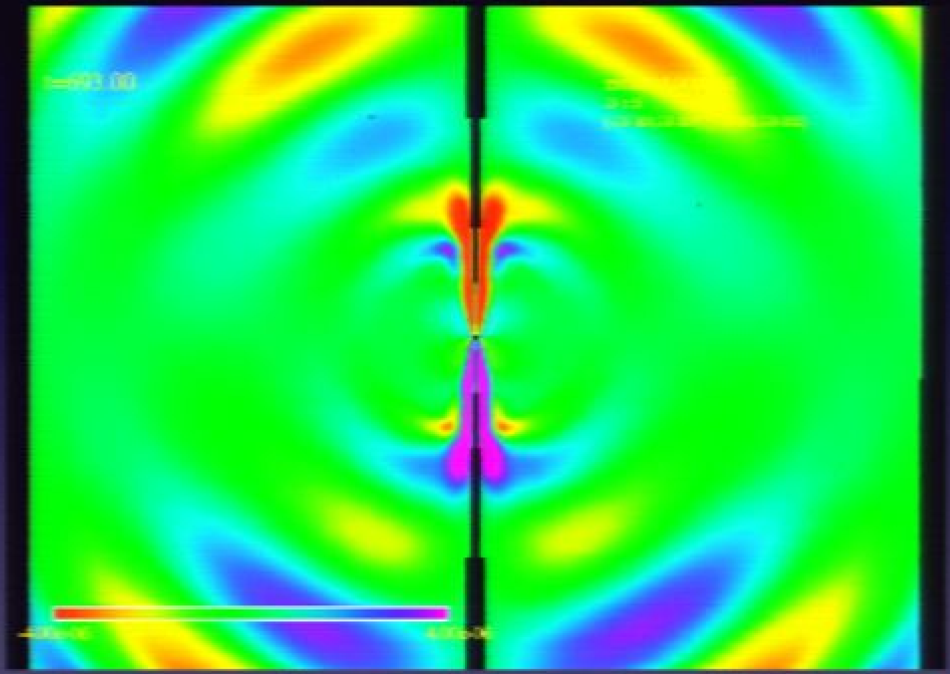

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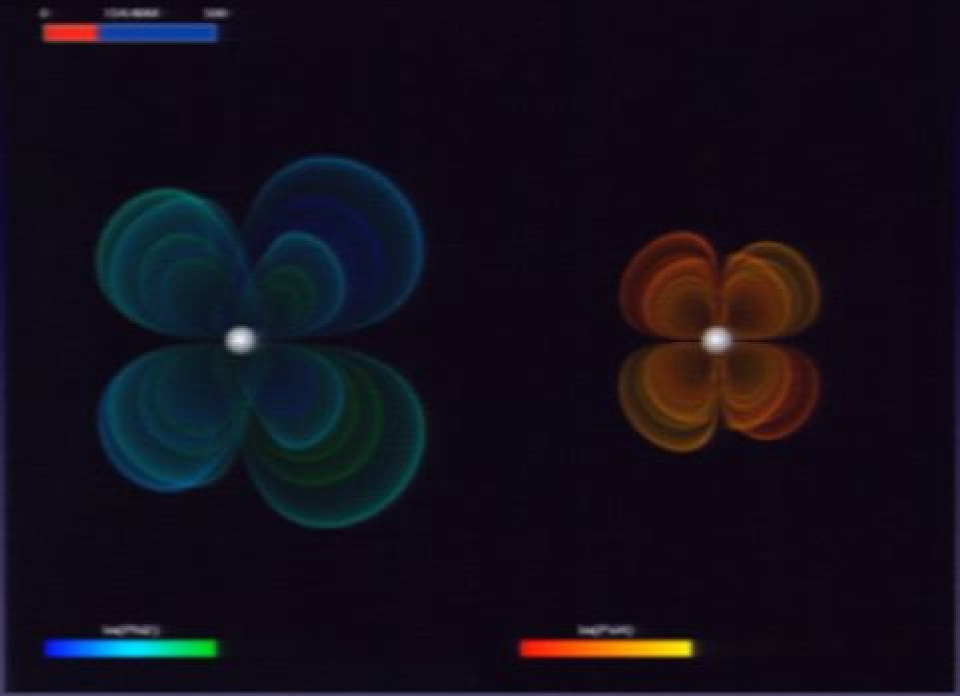

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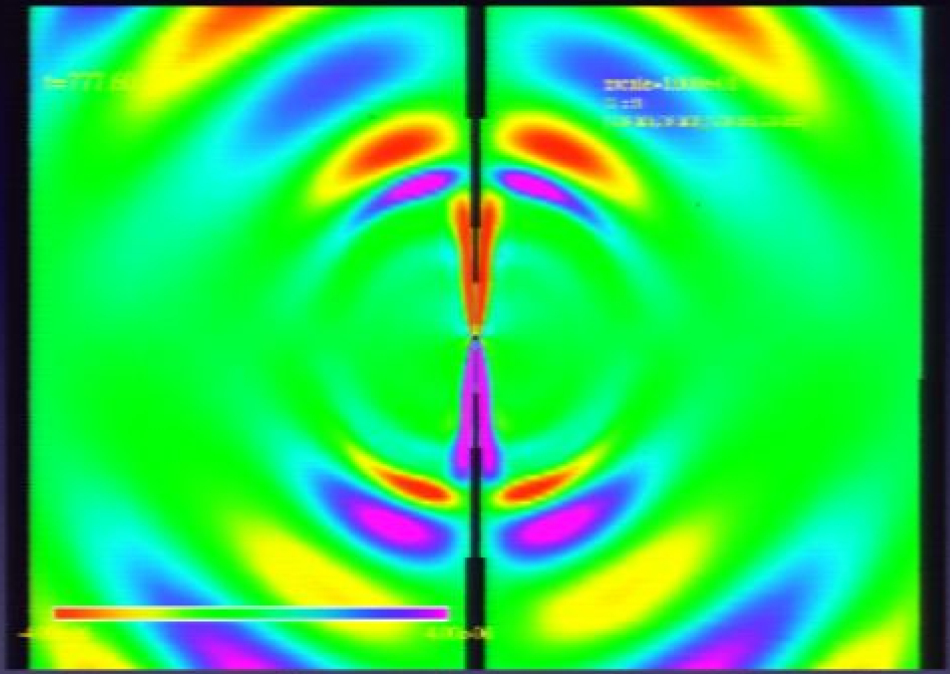

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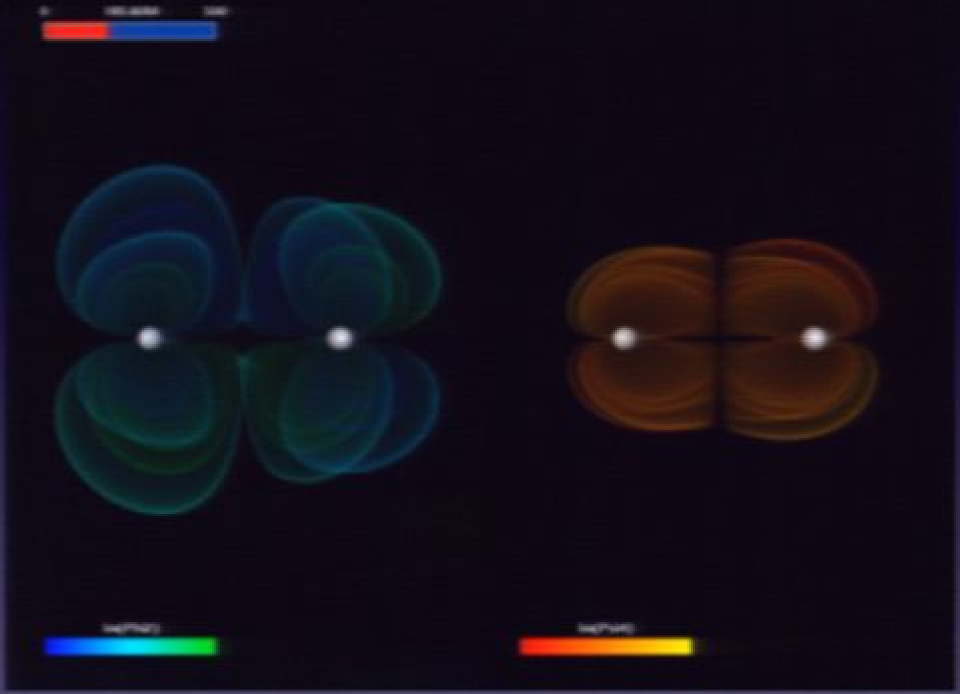

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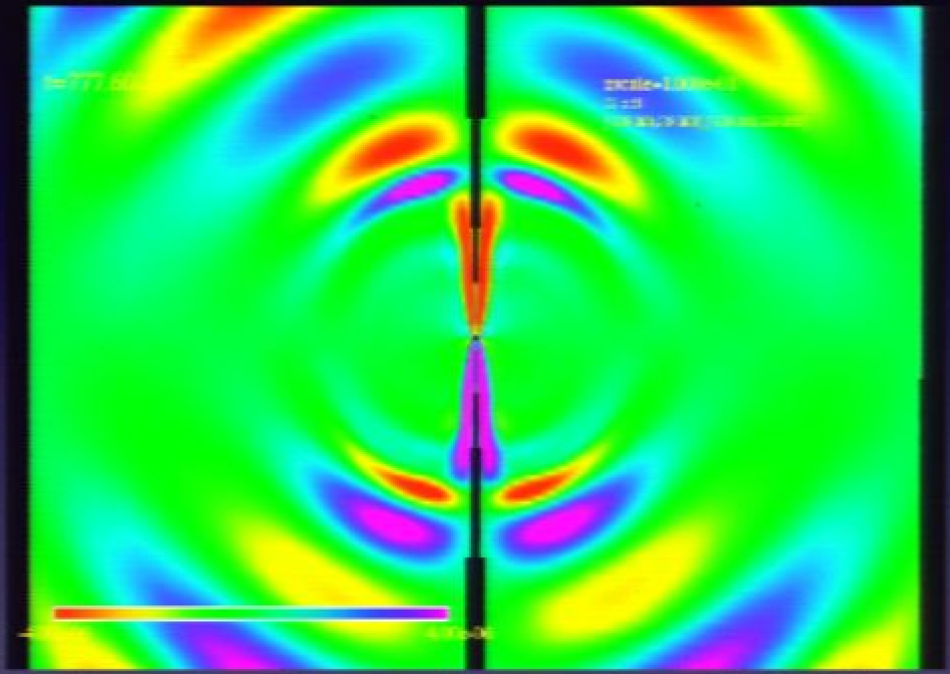

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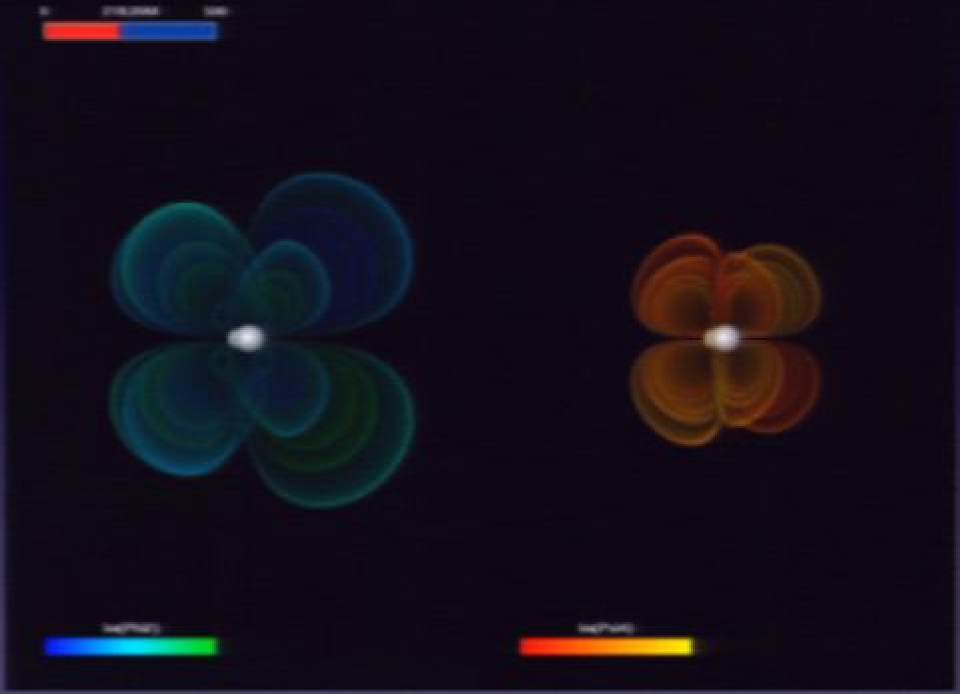

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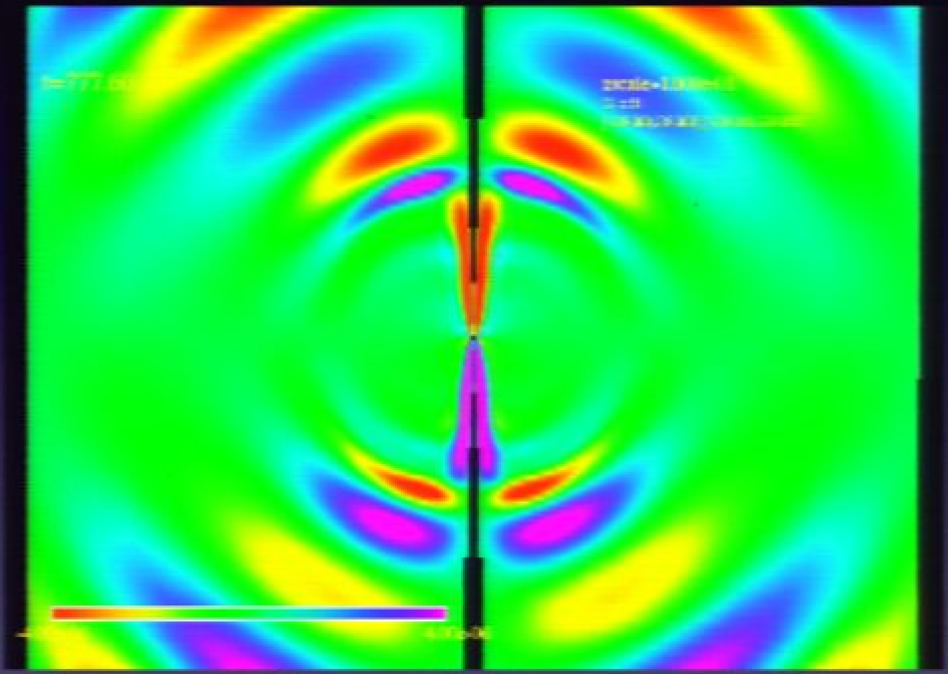

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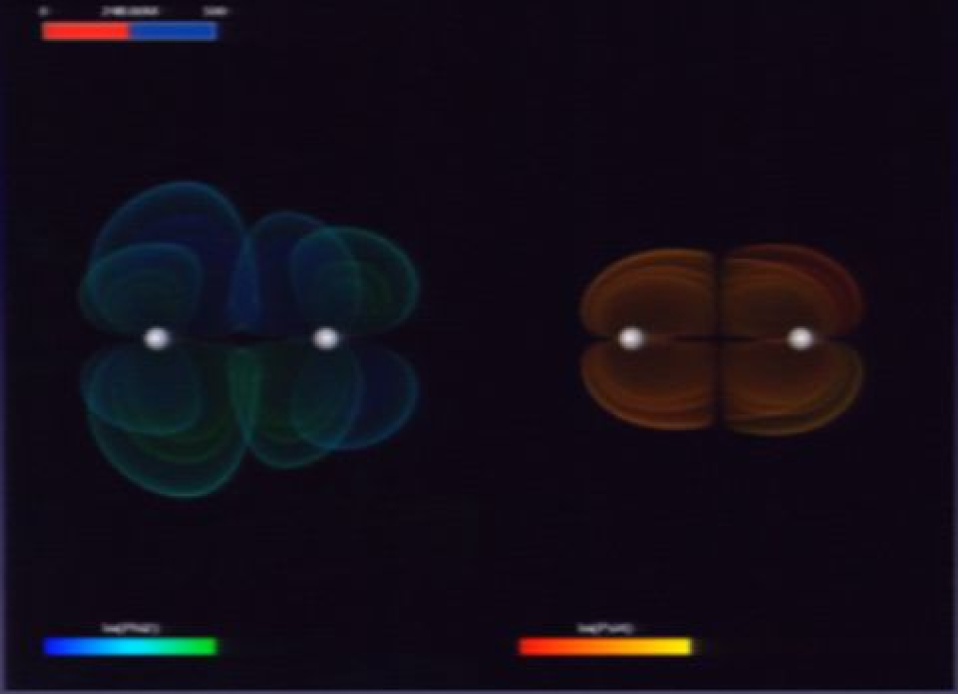

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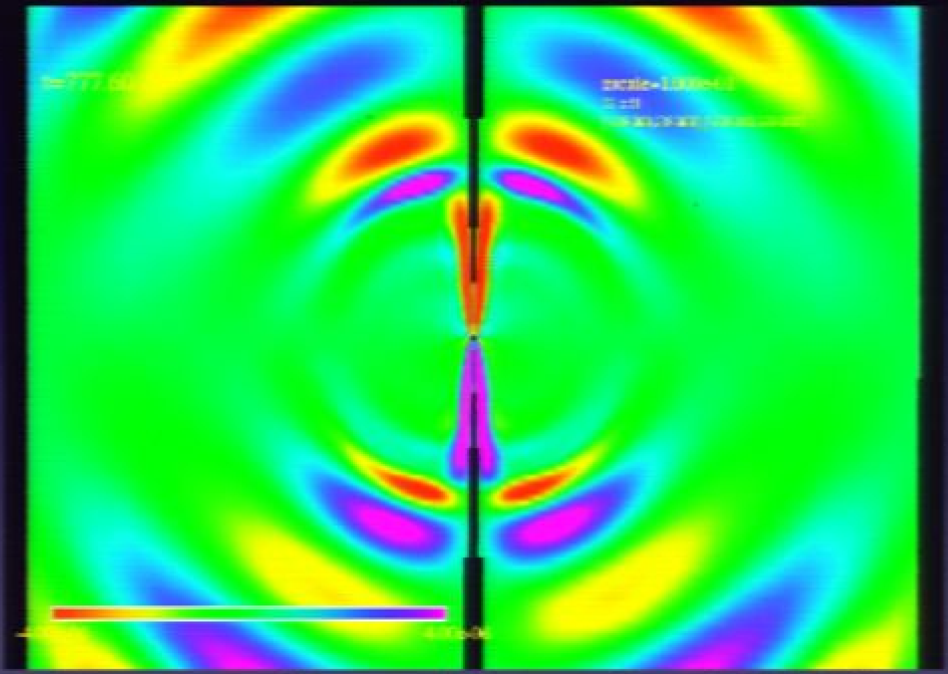

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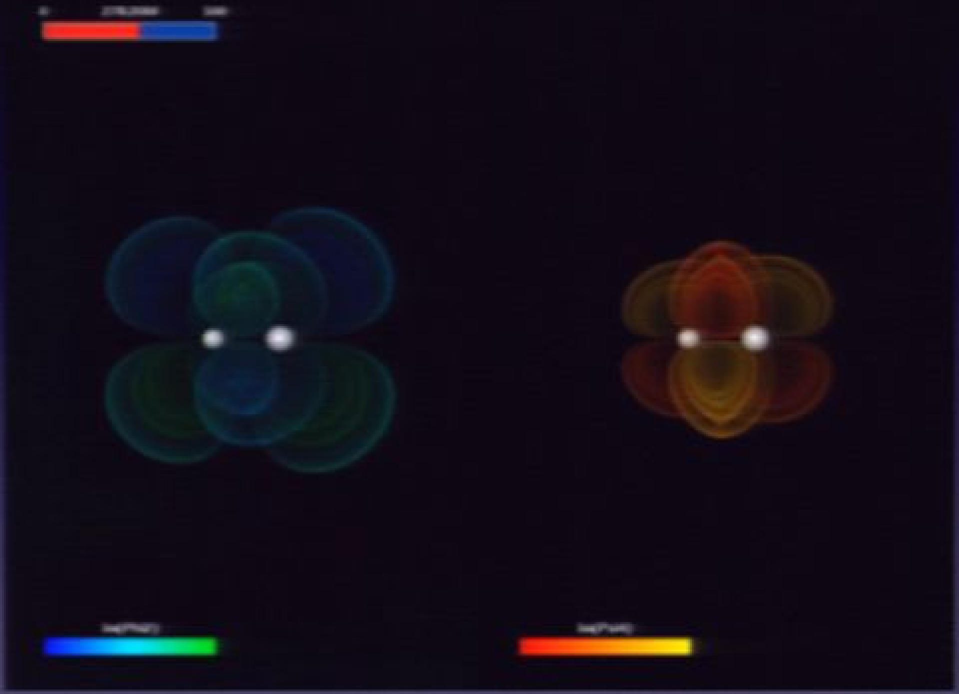

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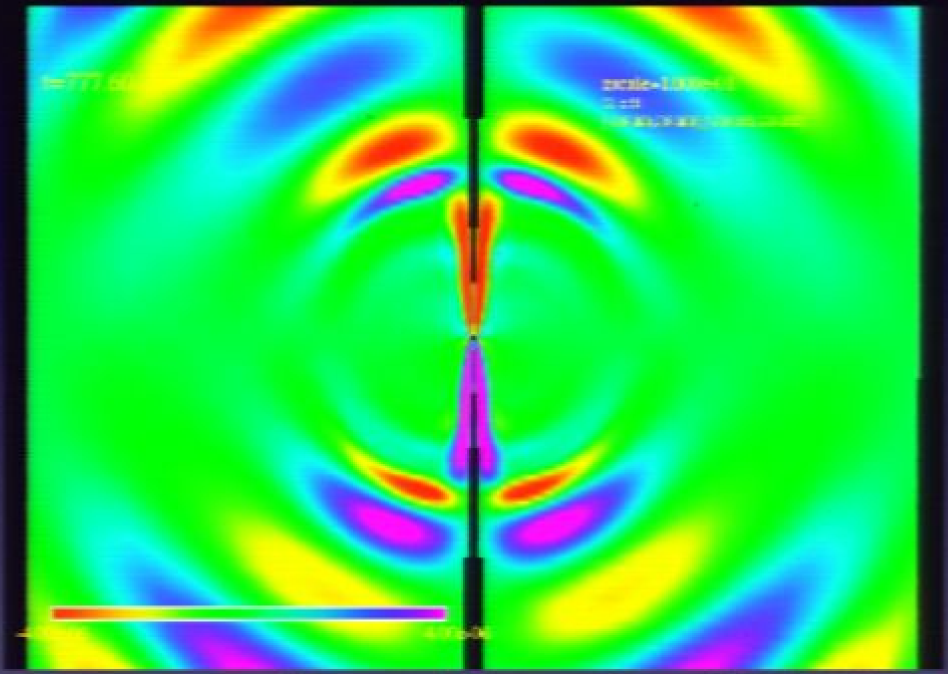

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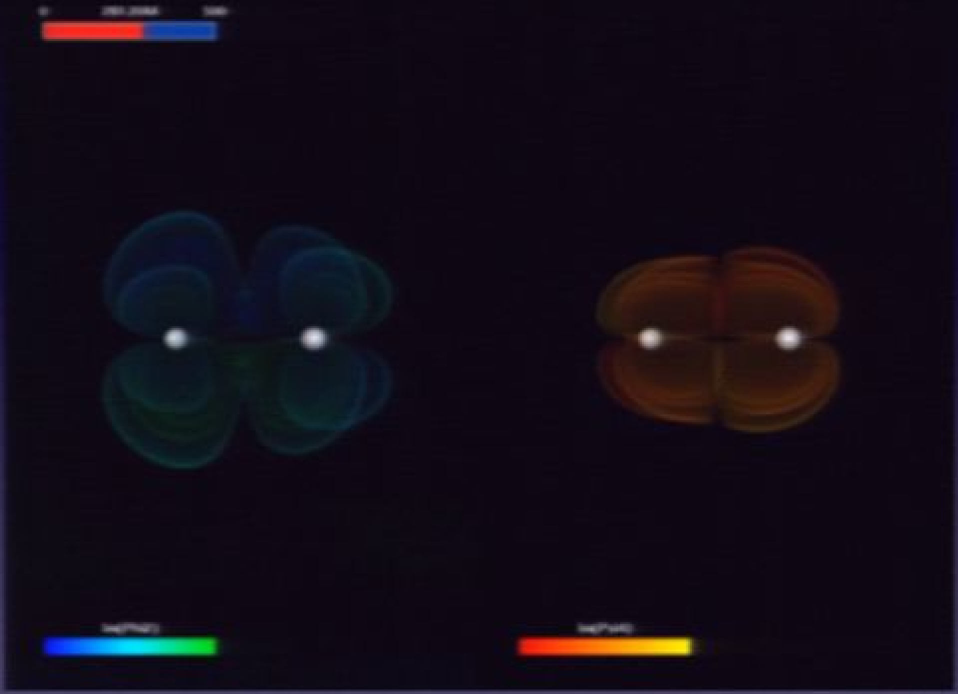

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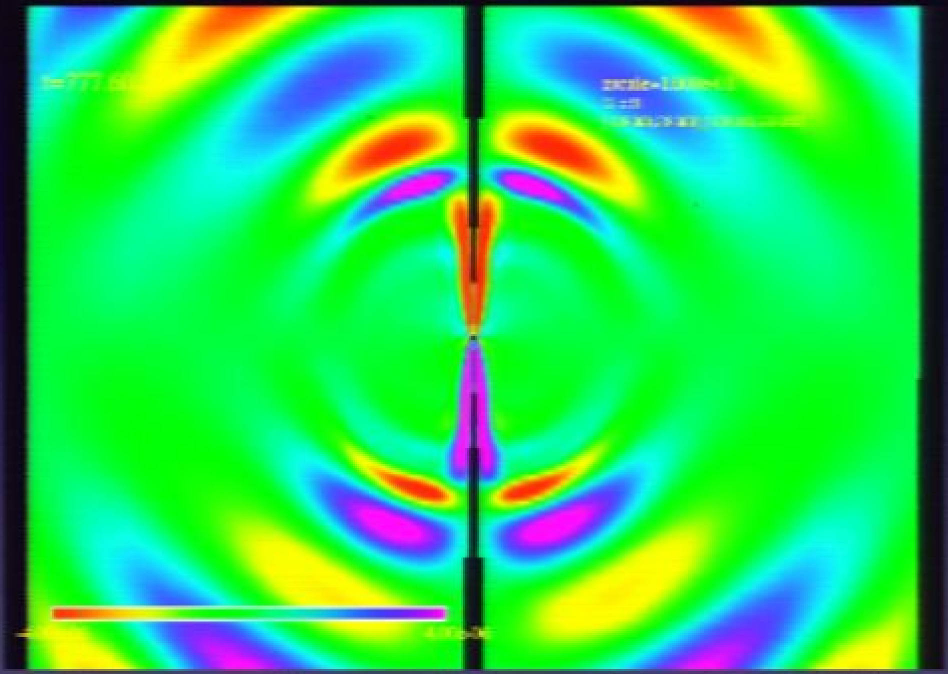

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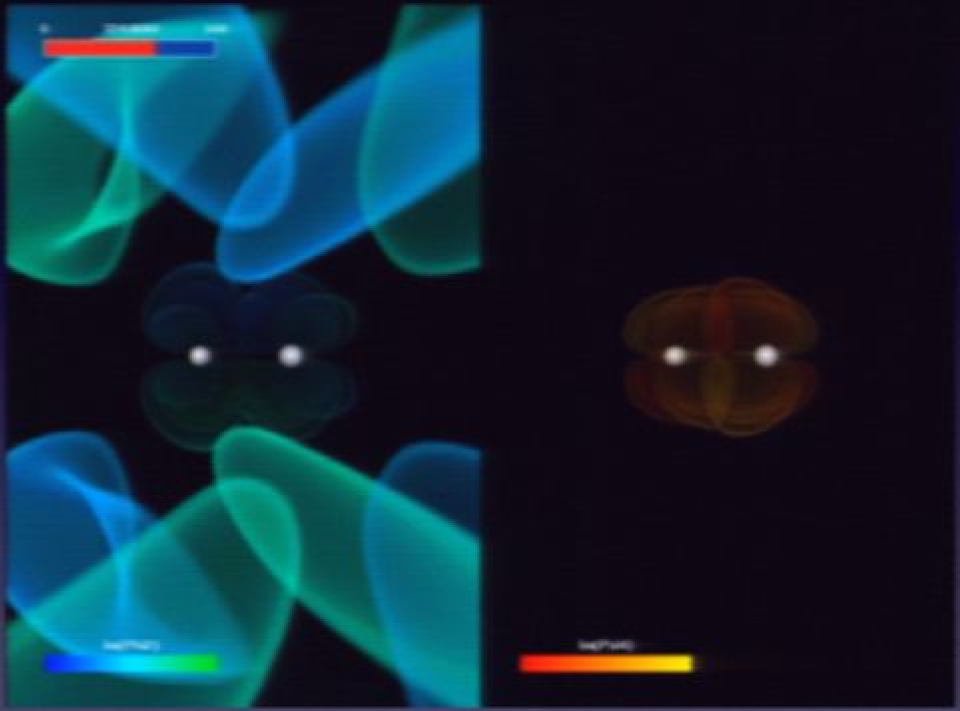

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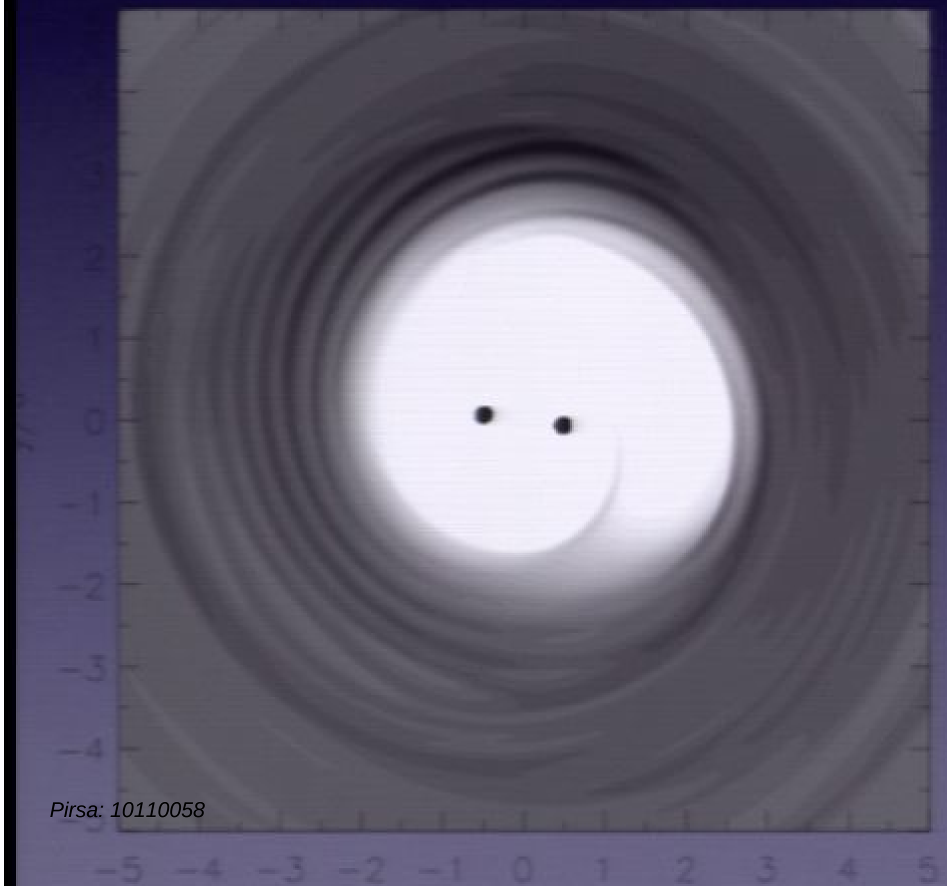
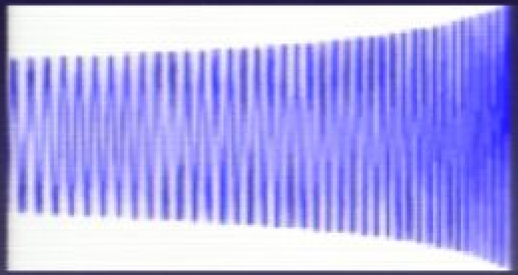
Comparing the GW and EM signal propagations

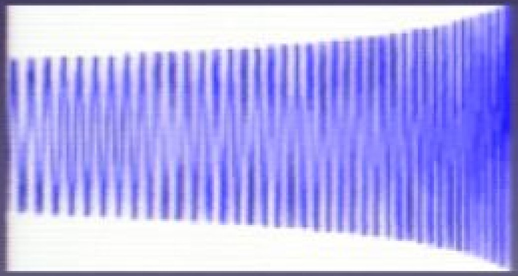
MacFadyen & Miloslavljevic (2008)



<u>Leading-order perturbation:</u>
quadrupolar potential



GW chirp
"trigger"



<u>Later(?)</u>
EM
source

Match the signal frequencies
to compare arrival times?

Conclusion

- LISA could jump-start the field of gravitational wave astronomy by identifying the electromagnetic counterparts and the host galaxies of massive BH binary mergers.
- Time-constrained observations are involved.
- If counterparts are found, new fundamental tests of gravitational physics on cosmological scales may become available.

No Signal

VGA-1

No Signal

VGA-1

No Signal

VGA-1

No Signal

VGA-1

No Signal

VGA-1

No Signal

VGA-1

No Signal

VGA-1

No Signal

VGA-1