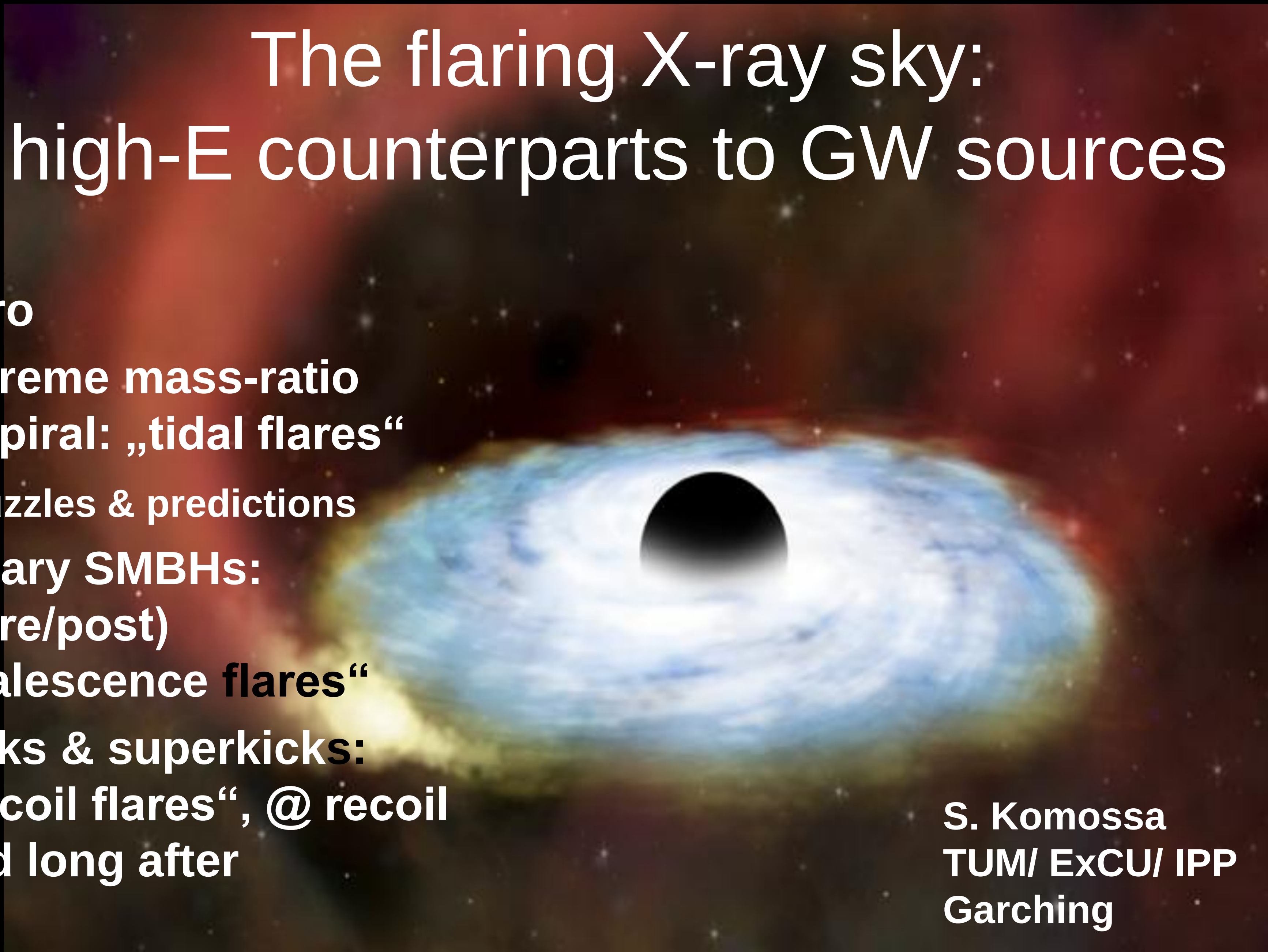
„The X-ray Universe 2011“, Berlin, June 2011

The flaring X-ray sky: high-E counterparts to GW sources



- **intro**
- **extreme mass-ratio inspiral: „tidal flares“**

  puzzles & predictions
- **binary SMBHs: „(pre/post) coalescence flares“**
- **kicks & superkicks: „recoil flares“, @ recoil and long after**

S. Komossa
TUM/ ExCU/ IPP Garching

e.m. counterparts to GW sources

- NS-NS mergers: short GRBs

- extreme mass-ratio inspirals (EMRIs);

  star – MBH pairs] „tidal flares“

  WD – IMBH pairs

  stellar-mass BH – MBH *none ?*

- SMBH – SMBH mergers: „pre/post-coalescence flares“, „recoil flares“

synergies between e.m. and GW astrophysics

• <u>GW</u>	• <u>e.m.</u>	
approx location	precise sky coo →	ctrpart, t_{stalling},...
masses	luminosities →	L/L_{edd}
spins	spectra →	accretion phys
luminosity distances	z →	cosmology
merger rates	merger rates →	merger history
low-M, high z		
high-M, low z (PTAs)		

proof of existence of - GWs,
- SMBHs coalescences

high-precision measurements of BH properties; various tests of strong-field gravity

physics of *matter* under strong gravity; feeding, growth, feedback, cosmic evolution

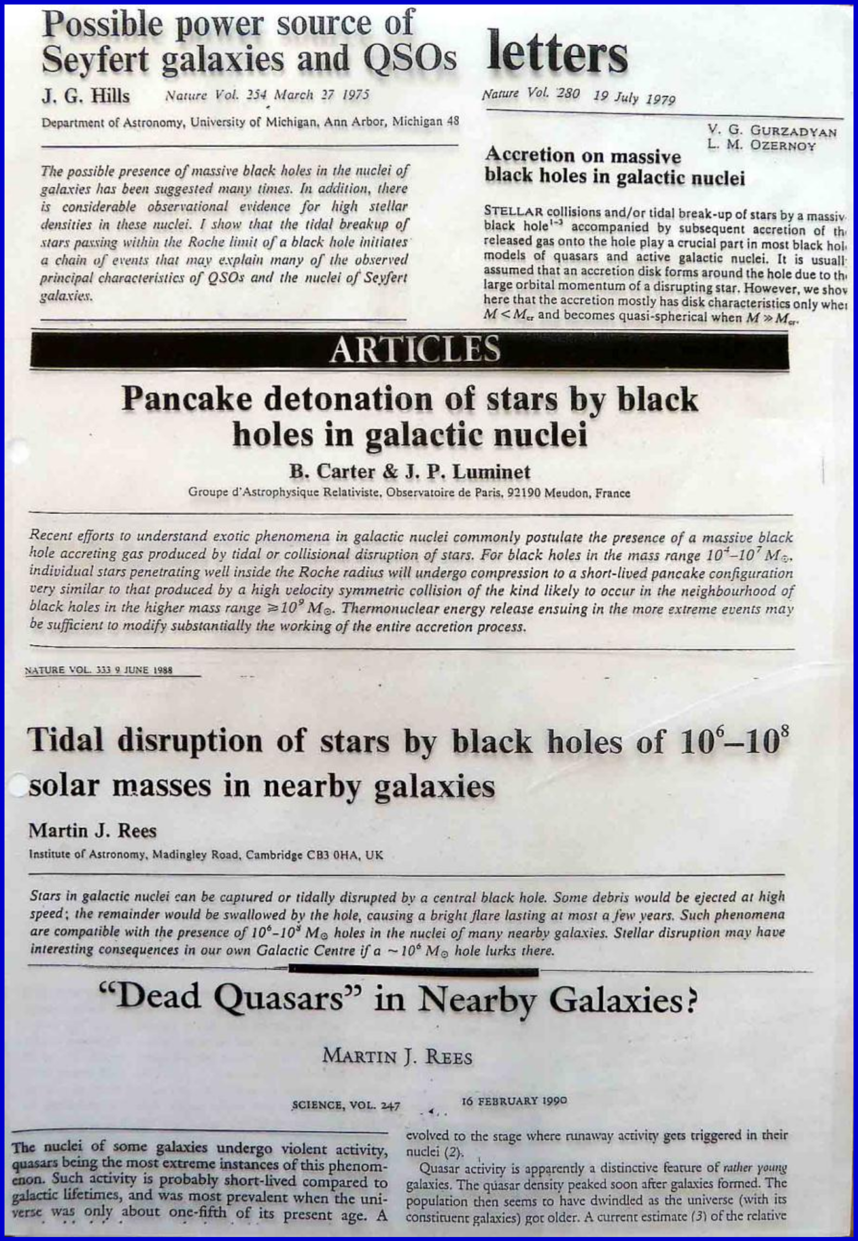
approx. measurements of BH para

extreme mass-ratio „pairs“: tidal capture & disruption of stars by massive BHs

„destructive“ tidal forces on single *stars* in the immediate vicinity of a black hole;

independent way of BH detection, in non-active galaxies; & new probe of strong gravity [e.g., Rees 88, Komossa & Bade 99]


[NASA/CXC/M.Weiss/ Komossa et al. 2004]



Possible power source of Seyfert galaxies and QSOs

J. G. Hills

Nature Vol. 254 March 27 1975

Department of Astronomy, University of Michigan, Ann Arbor, Michigan 48

The possible presence of massive black holes in the nuclei of galaxies has been suggested many times. In addition, there is considerable observational evidence for high stellar densities in these nuclei. I show that the tidal breakup of stars passing within the Roche limit of a black hole initiates a chain of events that may explain many of the observed principal characteristics of QSOs and the nuclei of Seyfert galaxies.

letters

Nature Vol. 280 19 July 1979

V. G. GURZADYAN
L. M. OZERNOY

Accretion on massive black holes in galactic nuclei

STELLAR collisions and/or tidal break-up of stars by a massiv black hole[1-3] accompanied by subsequent accretion of th released gas onto the hole play a crucial part in most black hol models of quasars and active galactic nuclei. It is usuall assumed that an accretion disk forms around the hole due to th large orbital momentum of a disrupting star. However, we show here that the accretion mostly has disk characteristics only whe $M < M_{cr}$ and becomes quasi-spherical when $M \gg M_{cr}$.

ARTICLES

Pancake detonation of stars by black holes in galactic nuclei

B. Carter & J. P. Luminet
Groupe d'Astrophysique Relativiste, Observatoire de Paris, 92190 Meudon, France

Recent efforts to understand exotic phenomena in galactic nuclei commonly postulate the presence of a massive black hole accreting gas produced by tidal or collisional disruption of stars. For black holes in the mass range 10^4–$10^7\,M_\odot$, individual stars penetrating well inside the Roche radius will undergo compression to a short-lived pancake configuration very similar to that produced by a high velocity symmetric collision of the kind likely to occur in the neighbourhood of black holes in the higher mass range $\gtrsim 10^9\,M_\odot$. Thermonuclear energy release ensuing in the more extreme events may be sufficient to modify substantially the working of the entire accretion process.

NATURE VOL. 333 9 JUNE 1988

Tidal disruption of stars by black holes of 10^6–10^8 solar masses in nearby galaxies

Martin J. Rees
Institute of Astronomy, Madingley Road, Cambridge CB3 0HA, UK

Stars in galactic nuclei can be captured or tidally disrupted by a central black hole. Some debris would be ejected at high speed; the remainder would be swallowed by the hole, causing a bright flare lasting at most a few years. Such phenomena are compatible with the presence of 10^6–$10^8\,M_\odot$ holes in the nuclei of many nearby galaxies. Stellar disruption may have interesting consequences in our own Galactic Centre if a $\sim 10^6\,M_\odot$ hole lurks there.

“Dead Quasars” in Nearby Galaxies?

MARTIN J. REES

SCIENCE, VOL. 247 16 FEBRUARY 1990

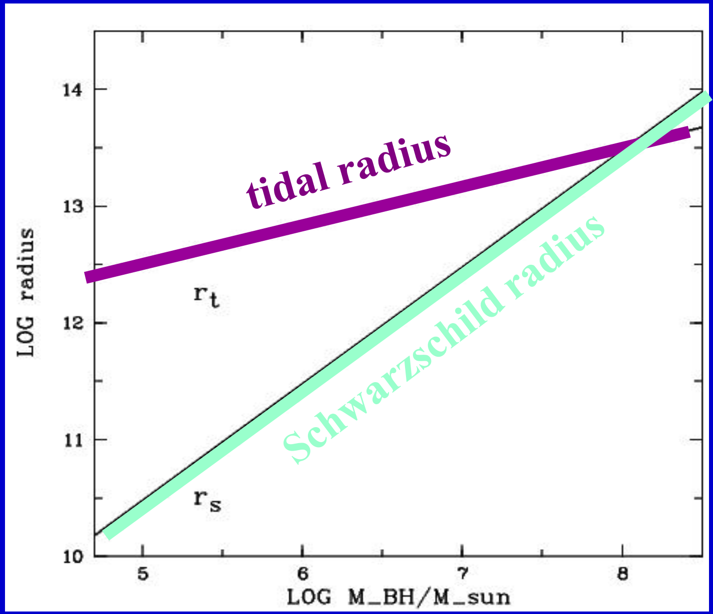
The nuclei of some galaxies undergo violent activity, quasars being the most extreme instances of this phenomenon. Such activity is probably short-lived compared to galactic lifetimes, and was most prevalent when the universe was only about one-fifth of its present age. A

evolved to the stage where runaway activity gets triggered in their nuclei (2).

Quasar activity is apparently a distinctive feature of *rather young* galaxies. The quasar density peaked soon after galaxies formed. The population then seems to have dwindled as the universe (with its constituent galaxies) got older. A current estimate (3) of the relative

tidal disruption of stars by SMBHs

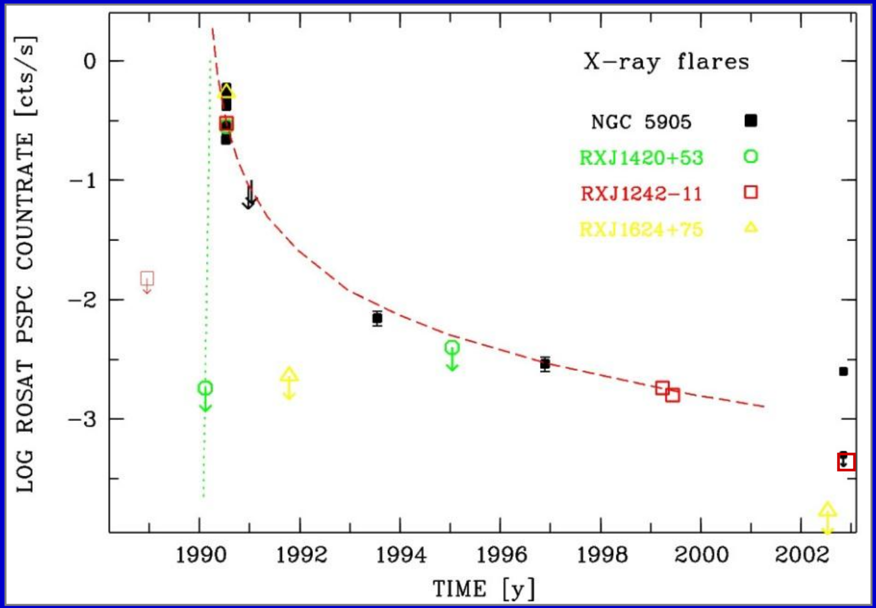
- disruption @ $r = r_{tidal}$, with tidal radius $r_{tidal} = R_*(M_{BH}/m_*)^{1/3} =$ $7\ 10^{12}\ M_{BH,6}^{1/3}\ (R_*/R_{sun})\ (m_*/m_{sun})^{-1/3}$ cm
- high initial gas supply rate $\rightarrow L_{peak} = L_{edd}$
- bbdy temperature at r_t approx 10^{5-6} K
- return rate dm/dt ~ $t^{-5/3}$
- > 90% of the stellar debris is unbound
- event rate $10^{-4..-5}$ /yr /galaxy



[e.g., Hills 75, Carter & Luminet 82, Rees 88 + 90, Evans & Kochanek 89, Cannizzo+ 90, Loeb+Ulmer 97, Wang & Merritt 04, Li+ 00, Ayal+ 00, Lodato+09, Rossi+ 10.....]

tidal flares

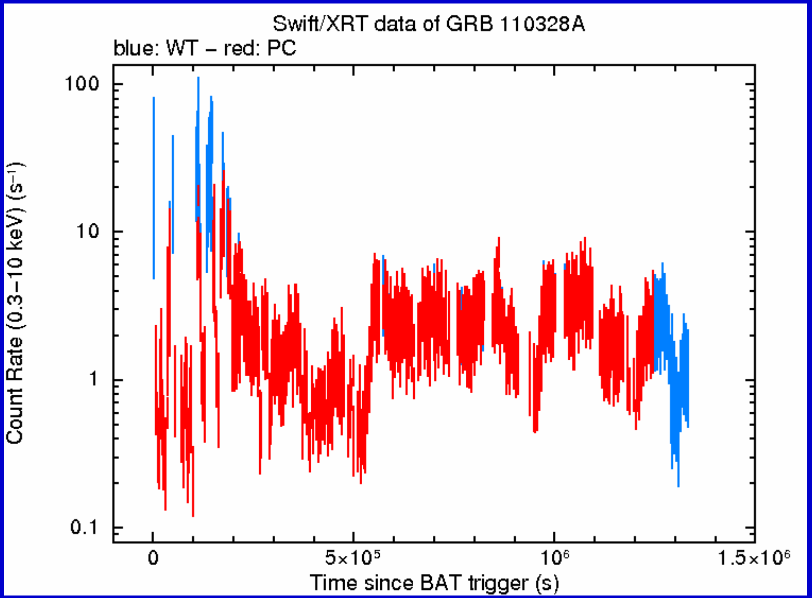
first X-ray events in RASS



- L_x huge: up to sev. 10^{44} erg/s
- very steep X-ray spectra
- from optically *inactive* galaxies
- factor up to 6000 decline
- follow $t^{-5/3}$ decline law

[e.g., Komossa & Bade 99, Komossa & Greiner 99, Grupe+00, Greiner+ 00, Komossa+ 04]

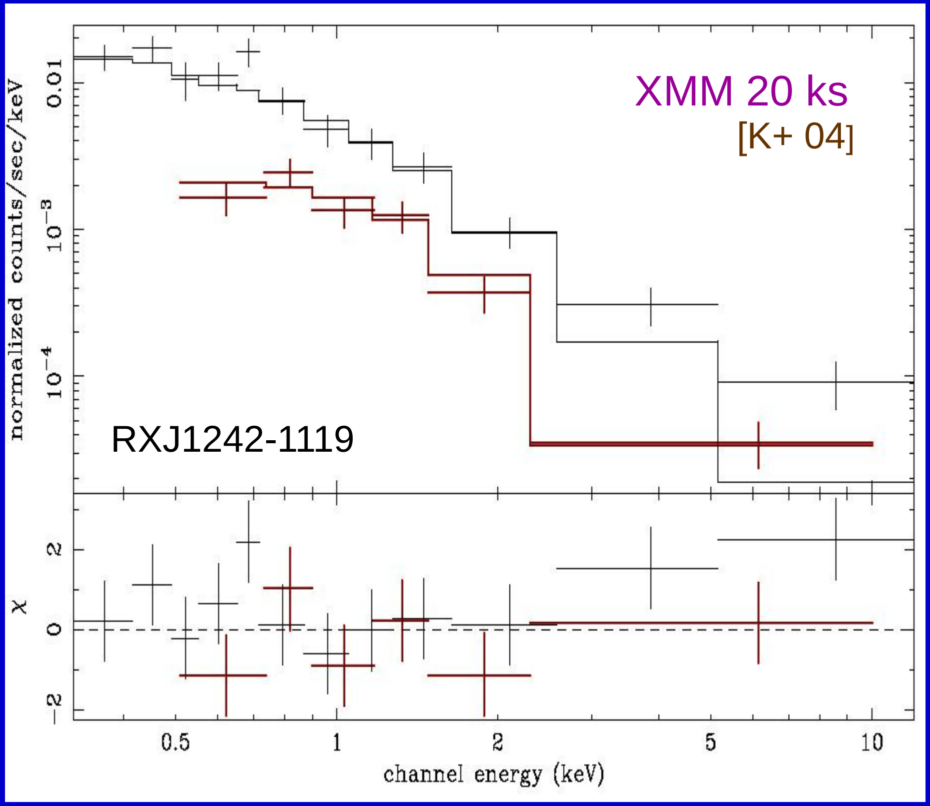
most recent „SWIFT flare“



- peculiar lightcurve, rapid variability (Δt ~ 100s), $L_{x,isotropic}$ = 10^{44} – 4 10^{48} erg/s , z_{host} =0.35
- rapid onset of jet formation, perhaps following tidal disruption ?

[eg., Barres de Almeida & De Angelis 11, Bloom+ 11, Burrows+ 11, Krolik+ 11, Cannizzo+ 11, Zauderer+ 11]

tidal flares

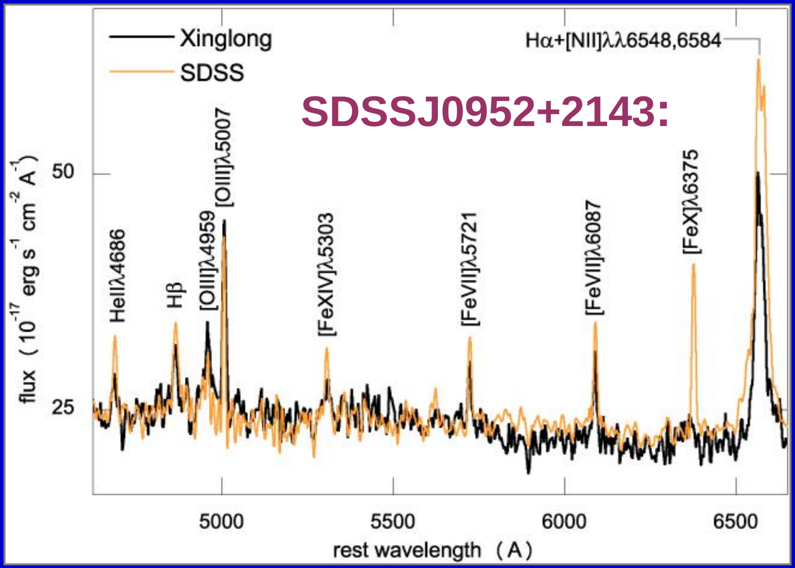


- ultra-soft X-ray spectra, initially
- then spectral hardening, first seen with ROSAT & XMM (NGC 5905, RXJ1242-1119)

tidal flares – results from recent searches

- ongoing X-ray searches:
  ~4 more with *XMM*
  ~2 with *Chandra* in clusters of galaxies
- UV detections:
  ~few with *GALEX,* 1 on phot. plates
- optical continuum variability
  ~2 from SDSS, 1 from PTF
- a few emission-line „light echoes“, based on SDSS spectroscopy

[Komossa+ 08, 09]



- super-strong Fe lines
- fade dramatically, in yrs
- very unusual Balmer profile
- but faint X-rays, ~10^{41} erg/s, few yrs after high-state
- observed rate 10^{-5} /yr /galaxy

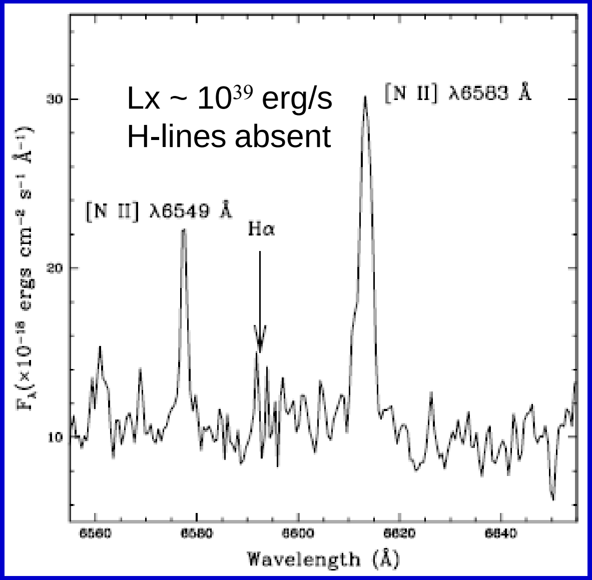
[eg., Esquej+ 07,08, Capellutti+ 09, Gezari+ 07,08, Luo+ 08, Komossa+ 08,09, Maksym+10, Meusinger+ 10, Cenko+ 11, Drake+ 11, van Velden+ 11, Lin+ 11, Saxton+ 11- *this conf.*]

(partial) disruption of WDs by IMBHs

- solar-type stars: GWs only detectable from GC
- stelllar-mass BHs: only GWs (?)
- WDs: (partially) tidally disrupted for $M_{BH} < 10^5\ M_{sun}$ → em & GW signal
- *LISA* rates: approx 0.1 – 100 /yr

WD tidal disruption by an IMBH in a globular cluster in the Fornax-elliptical NGC 1399 ?

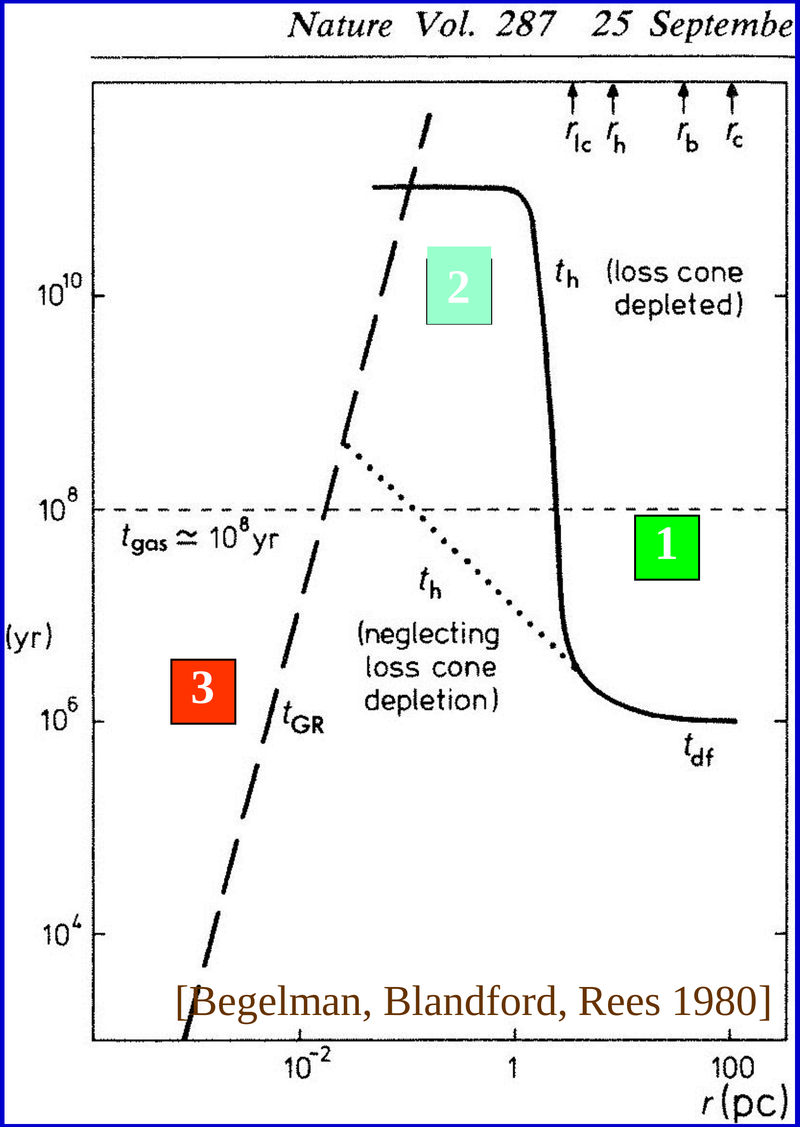
[Irwin +10; see Maccarone & Warner 10 for alternative]



[Amaro-Seoane 07, Rosswog+ 08, Sesana+ 08, Menou+ 08, Amaro-Seoane + Preto 11]

(2) (Super)massive Binary Black Holes

evolution



1 **dynamical friction regime**

2 **binary hardening**

e.g., by stellar slingshot effects (loss-cone refilling), interact. with gas, to prevent stalling @ ~0.1 pc **)***

3 **emission of GWs**

)*[e.g., Saslaw & al. 74, Quinlan & Hernquist 97, Gould & Rix 00, Merritt 01,03, Milosavljevic & Merritt 01,03, Zier & Biermann 01, Ivanov+ 99,04, Yu 02, Blaes et al. 02, Poon & Merritt 02, Haehnelt & Kauffmann 02, Hemsendorf+ 02, Armitage & Natarajan 02,05, Escala+ 03,05, Makino & Funato 04, Berczik+ 05,06, Haardt+. 06, Dotti+ 06, Merritt 06, 07, Matsui & al. 06, Zier 07, Alexander 07, Mayer+ 07, Perets & Alexander 08, Sesana & 08, Berentzen & 08, Mayer+ 09, ...]

supermassive binary BHs

- **galaxy mergers** are the sites of major BH growth

- **coalescing BBHs** are powerful emitters of grav. waves;
  - **GW**s: test GR predictions, precisely measure BH mass & spin, merger rate
  - **e.m.:** identify ctrpart, host galaxy, z

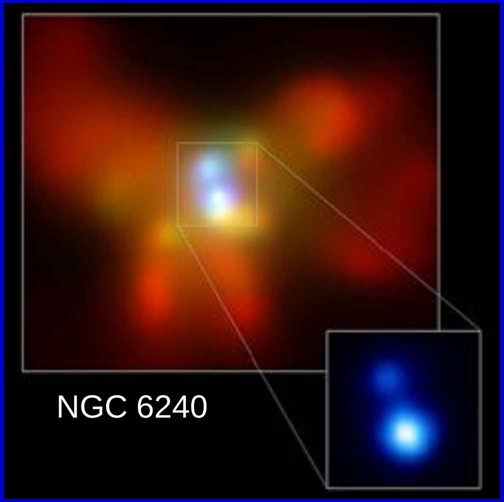
→ structure of host galaxy, t_{stalling}

→ iron lines, accretion physics around BHs with known masses & spins

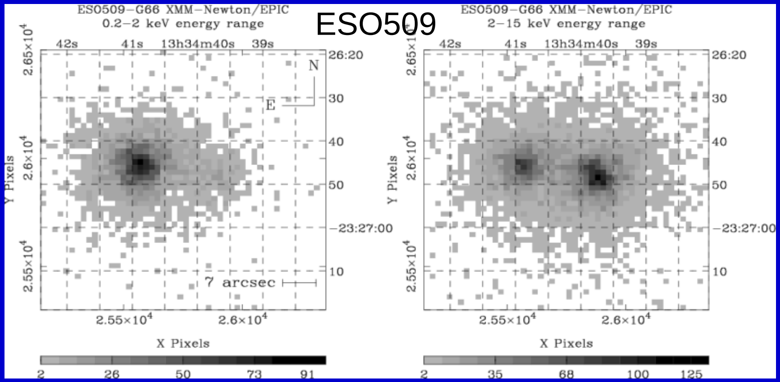
- GW **recoil**: BHs oscillate about gal. cores, or even escape → wealth of potential astrophysical applications

- **central to our understanding of assembly history & demography of BHs, & galaxy-BH (co-)evolution**

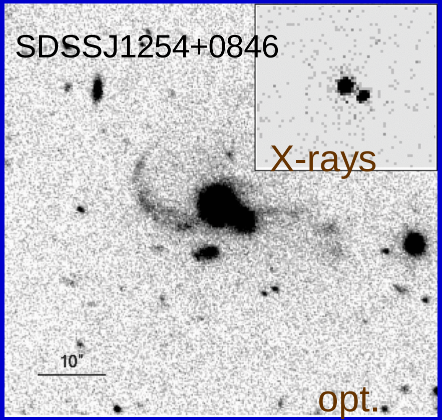
observations of SMBH pairs in single and interacting galaxies, in an early phase of evolution, in X-rays:



r ~ 1 kpc

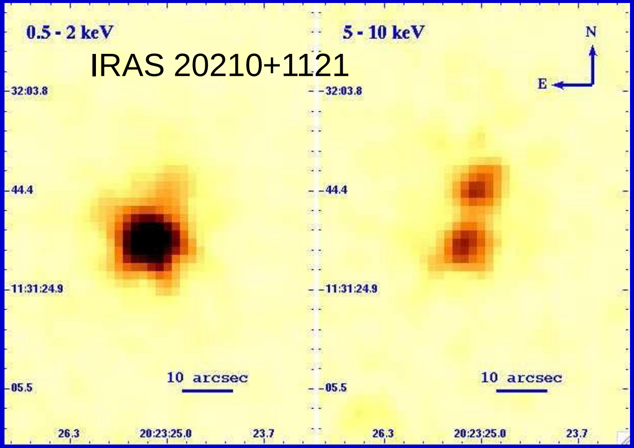


r = 11 kpc



r = 21 kpc

no further one in ~30 LIRGs, observed with Chandra (but could still be there & obscured)



r = 11 kpc

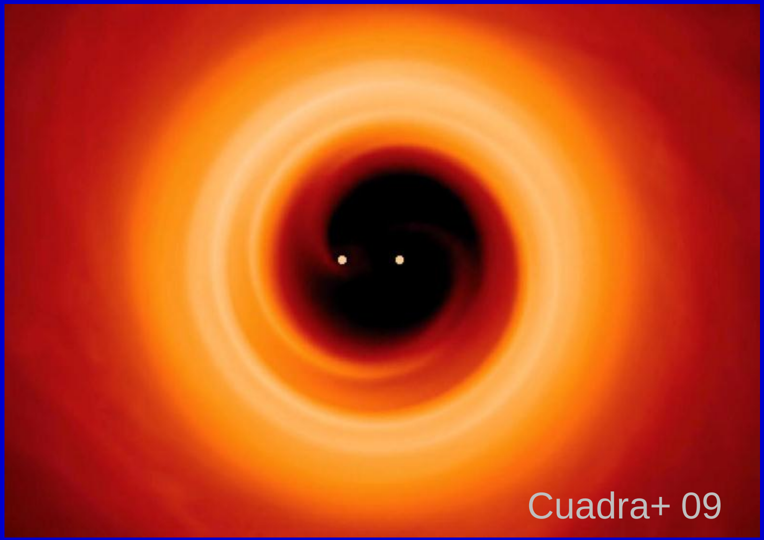
[e.g., Komossa+ 03, Guainazzi+ 05, Piconcelli+ 10, Green+ 10, Iwasawa+ 11]

coalescence flares

pre-coalescence:

- high tidal disruption rate
  (dramatically enhanced temporarily)

- t-dependent accretion signatures (Δt ~ weeks – yr)



Cuadra+ 09

right after coalescence:

- „viscous flares“ when inner disk reforms
- „perturbed-disk flares“, after GW-induced mass loss, or recoil

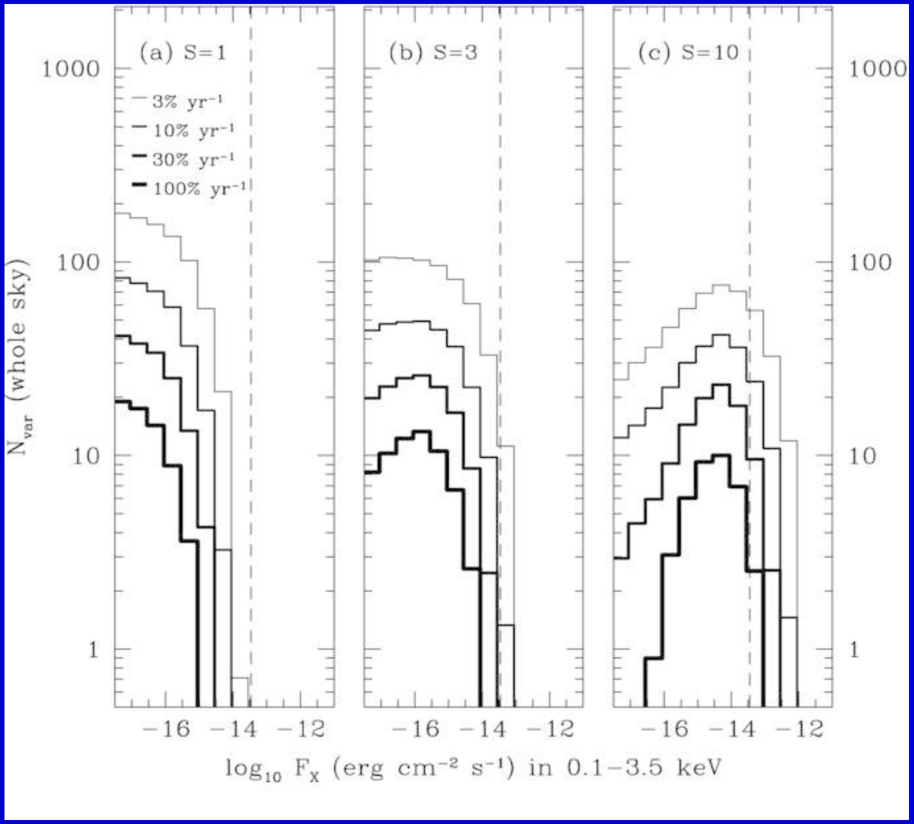
[e.g. Milosavljevic & Phinney 05, Armitage & Natarajan 02, Liu+ 03, Dotti+ 06, Kocsis+ 08, Liu & Chen 07, Tao+ 07, Hayasaki+ 08,11, Shields & Bonning 08, Lippai + 08, Schnittman+ 08, Haiman+ 08, 09, Loeb 09, Cuadra+ 09, Palenzuela+ 09,10, van Meter+ 09, Megevand+ 09, Bogdanovic+ 10, Krolik 10, Chen+ 09, 11, Liu+ 09, Mösta+ 10, Zanotti+ 10, Schnittman 10, Tanaka+ 10, Centrella+ 10, Roedig+ 11, ...]

coalescence flares: viscous flares

after BBH coalescence: evolving, brightening X-ray spectrum, when disk spreads viscously inward

$t_v \sim 10(1+z)\,(M/10^6 M_{sun})^{1.3}$ yr

~ 10 sources with d ln L_x/ dt > 30% / yr for several years, in an all-sky survey with sensitivity $f_x < 3\ 10^{-14}$ (like LWFT), with systematic hardening of X-ray spectrum



Number of afterglow sources as function of their 0.1-3.5 keV flux, 1 < z < 3.

[Milosavljevic+Phinney 05, Tanaka+ 10]

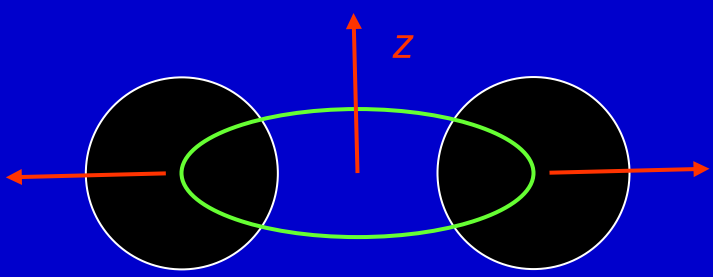
after coalescence: recoiling supermassive black holes, „recoil flares“

recoiling supermassive black holes: kicks & superkicks

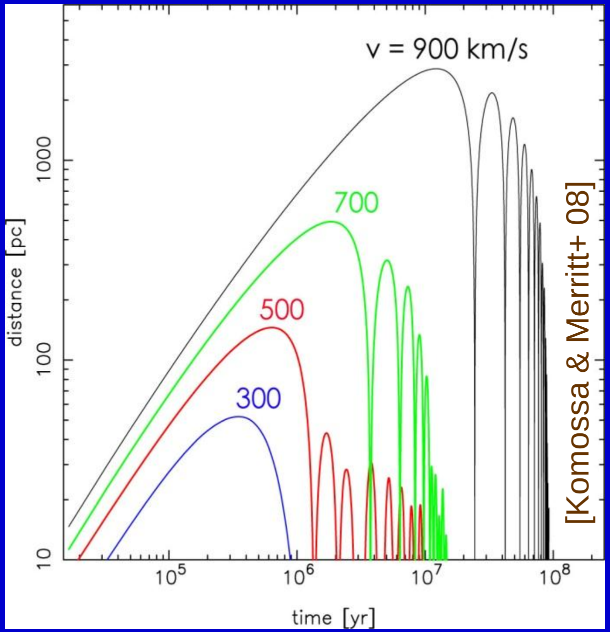
- anisotropic emission of GWs from coalescing BBHs leads to recoil of the newly formed single BH
- NR simulations predict BH „kicks“ with velocities up to **3800 km/s; (10.000 km/s)**

  highest for $m_1=m_2$, $a_1=-a_2=\max$ & in orb. plane

- → recoiling BHs oscillate about host galaxy core, or may even be ejected → various astrophysical implications for galaxy assembly at the epoch of structure formation; BH growth; detection of GW signals; unified AGN models



[e.g., Peres 62, Bekenstein 73, Redmount & Rees 89, ... / Baker+ 06,07,08, Brügmann+ 08, Campanelli+ 06, 07a,b, 08, Dain+08, Gonzales+ 06, 07a,b, Healy+ 09, Herrman+ 07a,b, Koppitz+ 07, Lousto & Zlochower 08, Lousto+ 09, Pretorius 05, 07, Pollney+07, Schnittman+ 07, 08, Sperhake+ 10, Tichy & Marronetti 07, vanMeter+ 10 ... review: Centrella+ 10]

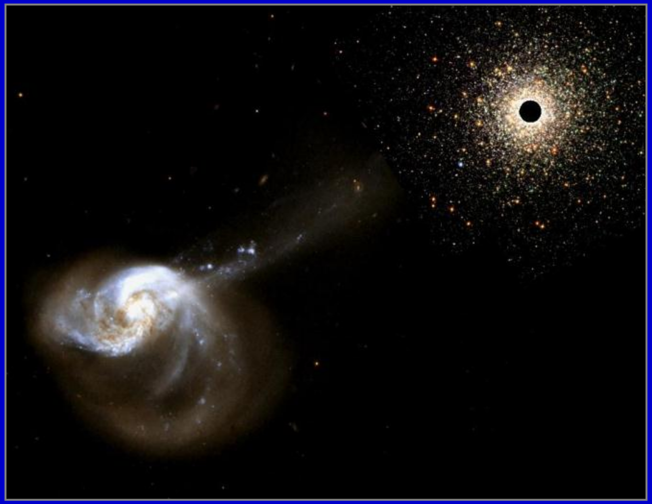


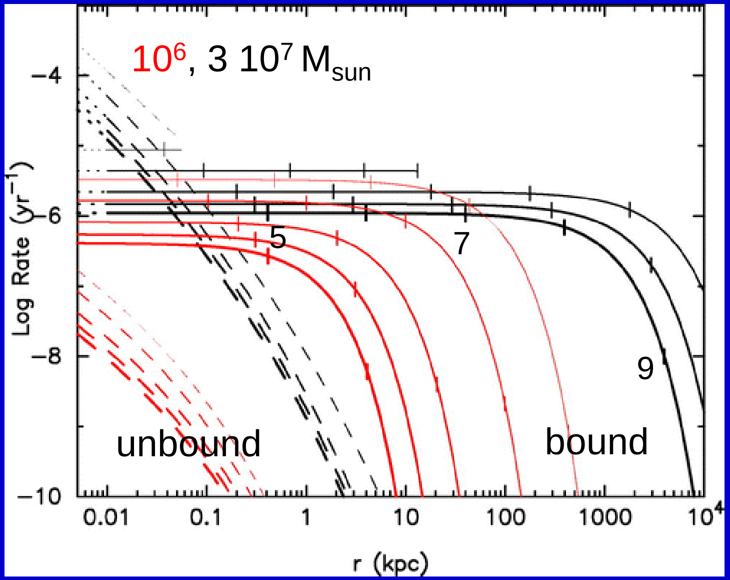
recoiling SMBHs: tidal recoil flares

right after coalescence: disk flares

long after coalescence: **tidal flares**:

- stars will remain bound to the BH within $r_k < GM_{BH}/v_k^2 \sim 0.4\ (M_{BH}/10^8\ M_{sun})\ (v_k/10^3\ \mathrm{km/s})^{-2}$ pc
- → stellar tidal disruption X-ray **flares, of quasar-typical luminosity** – ***off-nuclear*** or even ***intergalactic***
- from bound and unbound stellar pop., at high „early" rate, and „late" rate comparable to „non-recoil rate"
- **+** accretion from stellar mass loss → reservoir of NL gas at v_{kick}
- + intergal. SNe & peculiar WD detonations, no-host GW signals, ...





[Komossa & Merritt 08a]

[Komossa & Merritt 08]

summary

- recent predictions of transient events accompanying mergers/coalescences; motivated in part by breakthroughs in NR
  - tidal flares (esp. from WDs accreting on IMBHs)
  - various types of coalescence flares
  - recoil flares

- → search for these in ongoing & future e.m. surveys

EMRIs		SMBBHs	
* -- MBH	e.m.	early merger	e.m.
WD – IMBH	both	around coalescence	GW / e.m.
BH – MBH	GW	late-phase recoil	e.m.