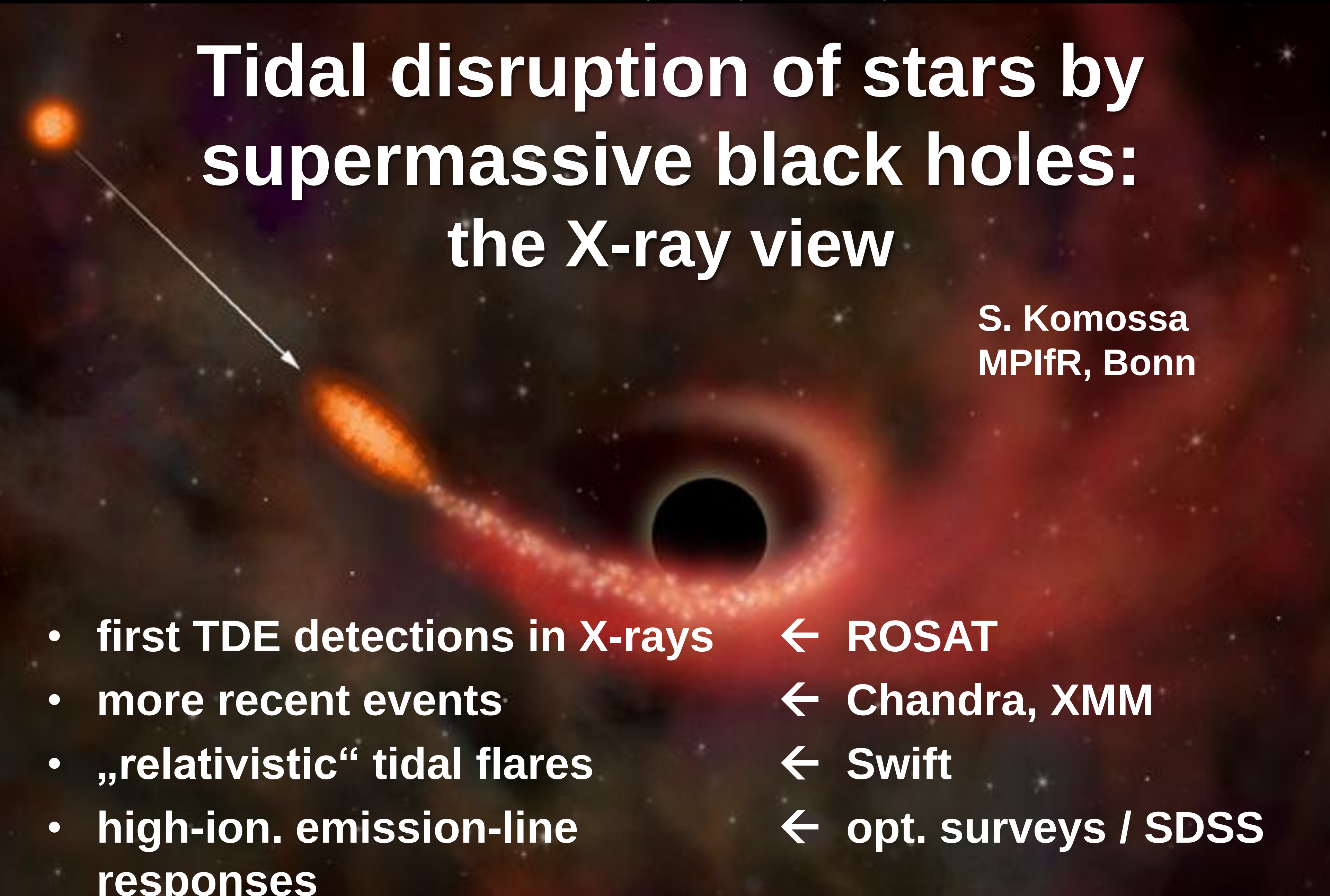


Tidal disruption of stars by supermassive black holes: the X-ray view

S. Komossa
MPIfR, Bonn

- first TDE detections in X-rays ← ROSAT
- more recent events ← Chandra, XMM
- „relativistic“ tidal flares ← Swift
- high-ion. emission-line responses ← opt. surveys / SDSS

tidal capture & disruption of stars by SMBHs

„The best diagnostic for a BH‘s presence would be some inevitable concomitant that cannot be explained in any other way.“ [Rees, *Nature*, 1988]


[NASA/CXC/Weiss/ Komossa+ 04]

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 shov 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

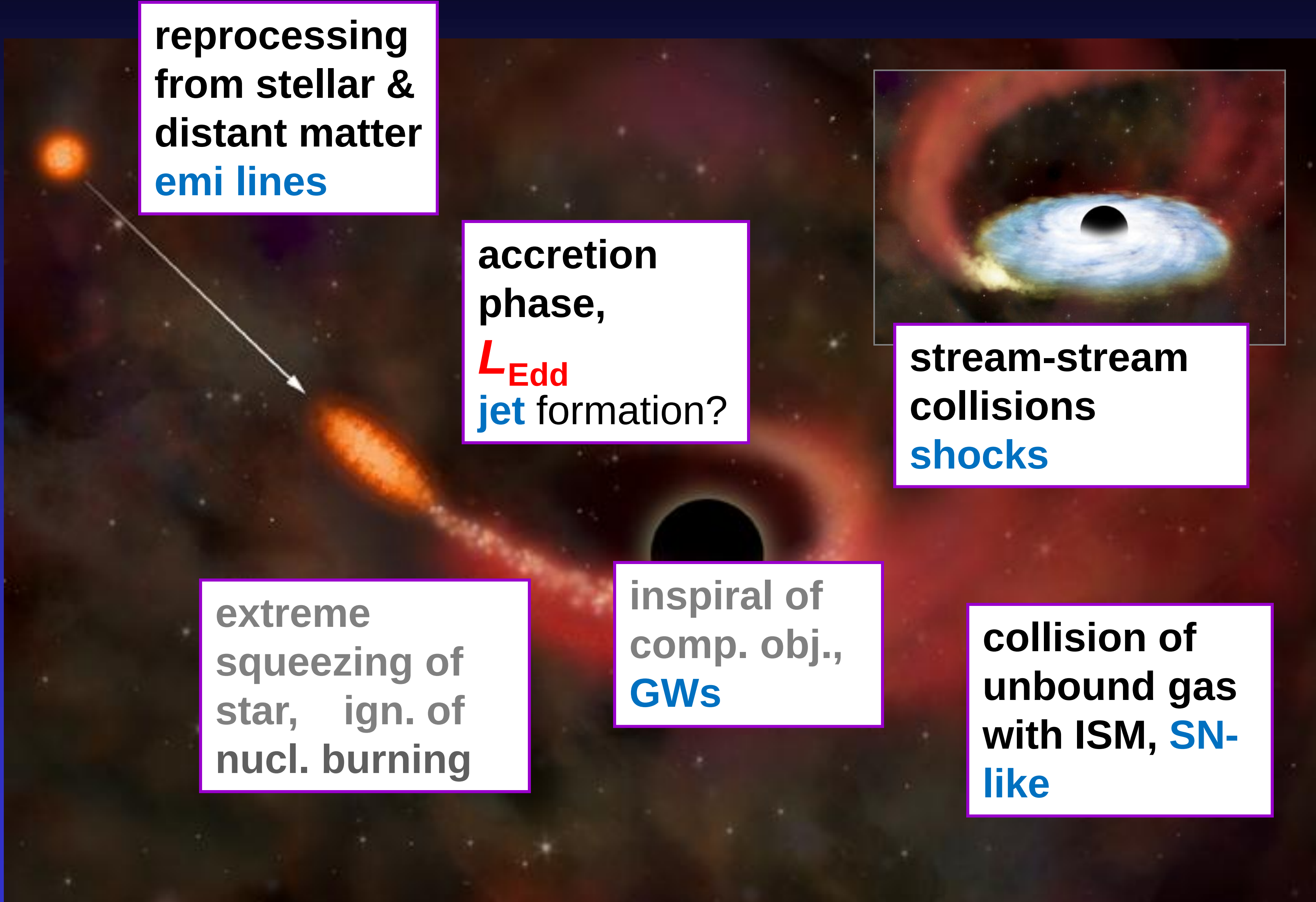
SCIENCE, VOL. 247 — 16 FEBRUARY 1990

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

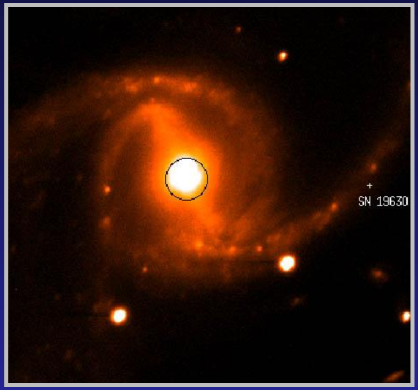
tidal disruption of stars – sources of radiation



see talks on TD theory: Luminet, Lodato, Guillochon, Ivanov et al.

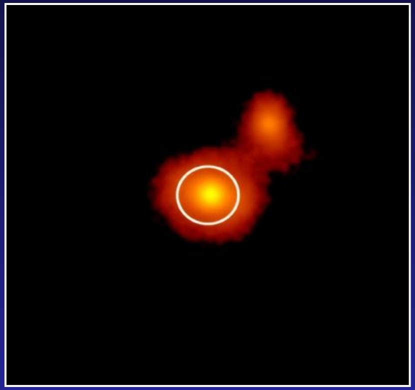
tidal flares – initial X-ray discoveries with ROSAT

NGC 5905



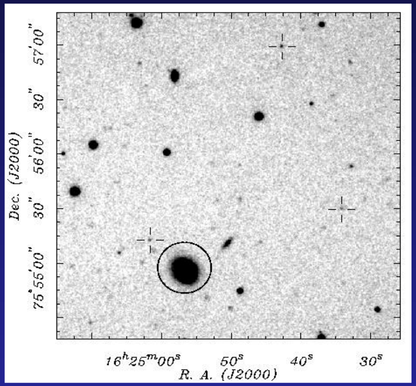
- z = 0.011
- $L_{x,hi}$ = **710**^{42} erg/s

RXJ1242-1119



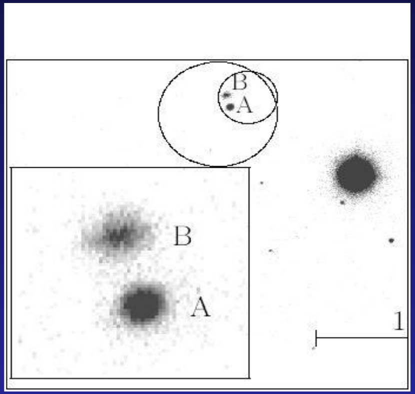
- 0.050
- **9 10**^{43}

RXJ1624+75



- 0.064
- **2 10**^{44}

RXJ1420+53



- 0.147
- **8 10**^{43}

- Γ_x = -4.0 or
  kT_{bb} = 0.06 keV
  @ high-state
- Γ_x = -2.4 later

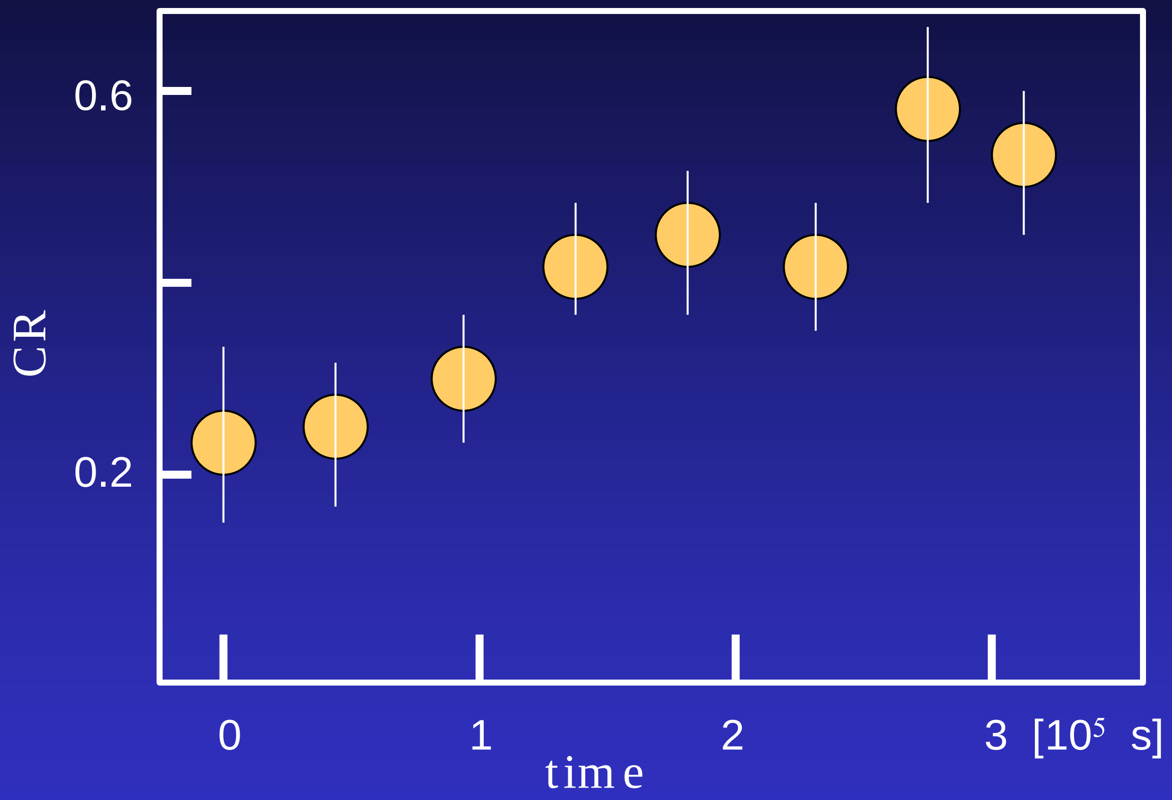
Bade+ 96,
Komossa & Bade 99

Komossa & Greiner 99,

Grupe+ 99,

Greiner+ 00

NGC 5905: X-ray lightcurve

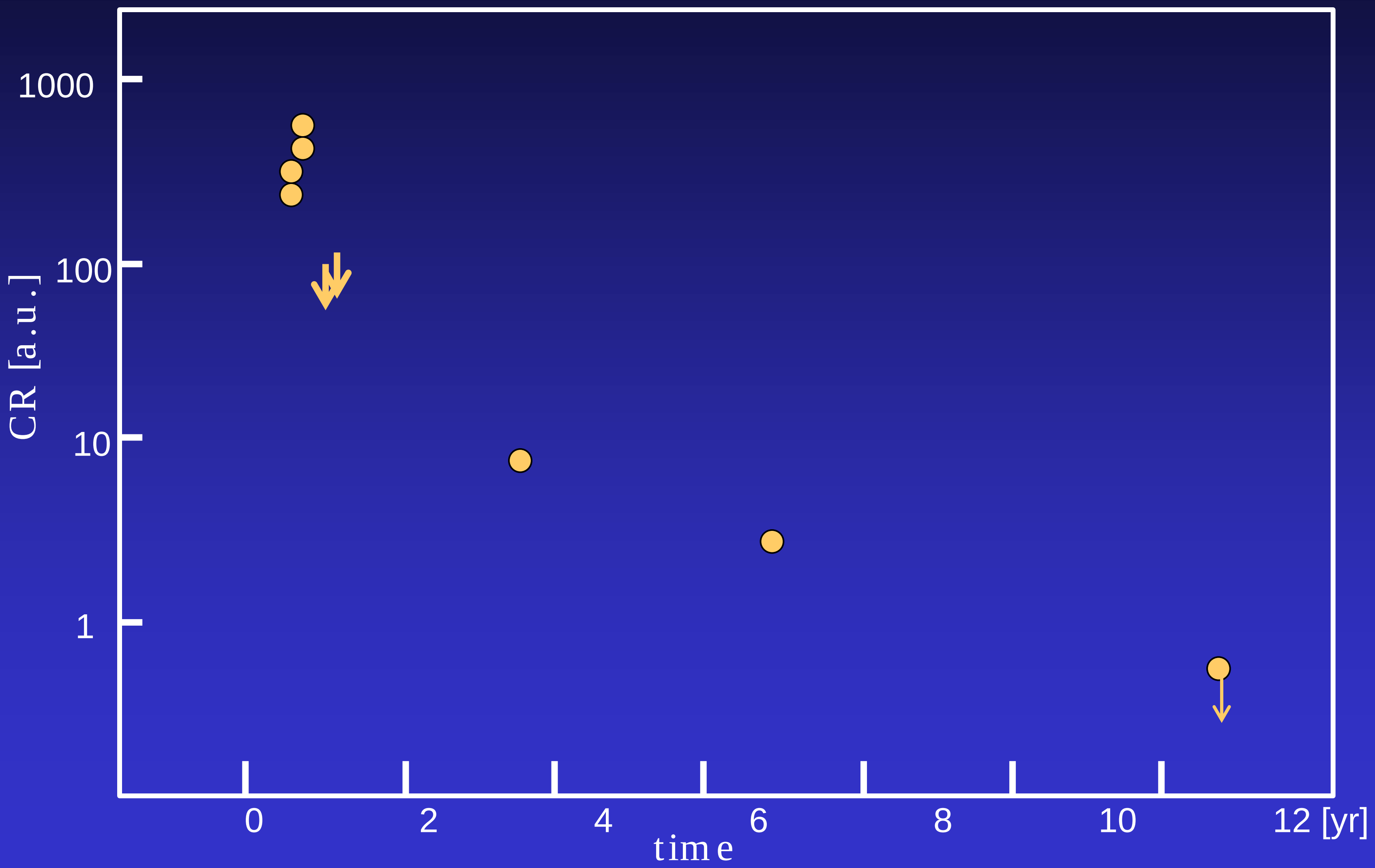


$L_{x,hi}$ = **710**^{42} erg/s

high-state lightcurve during ~5d RASS coverage

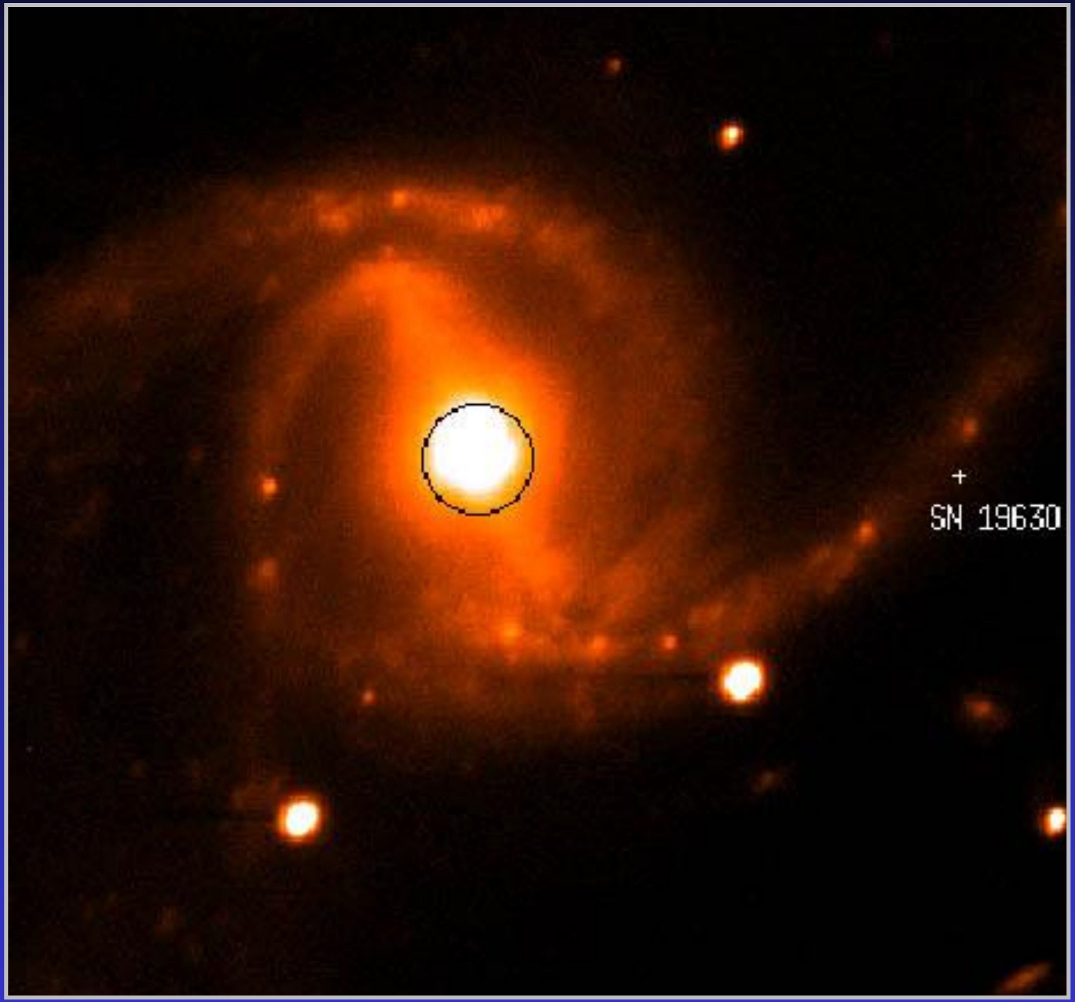
[Bade, Komossa & Dahlem 96, Komossa & Bade 99]

NGC 5905: long-term X-ray lightcurve



[Komossa & Bade 99]

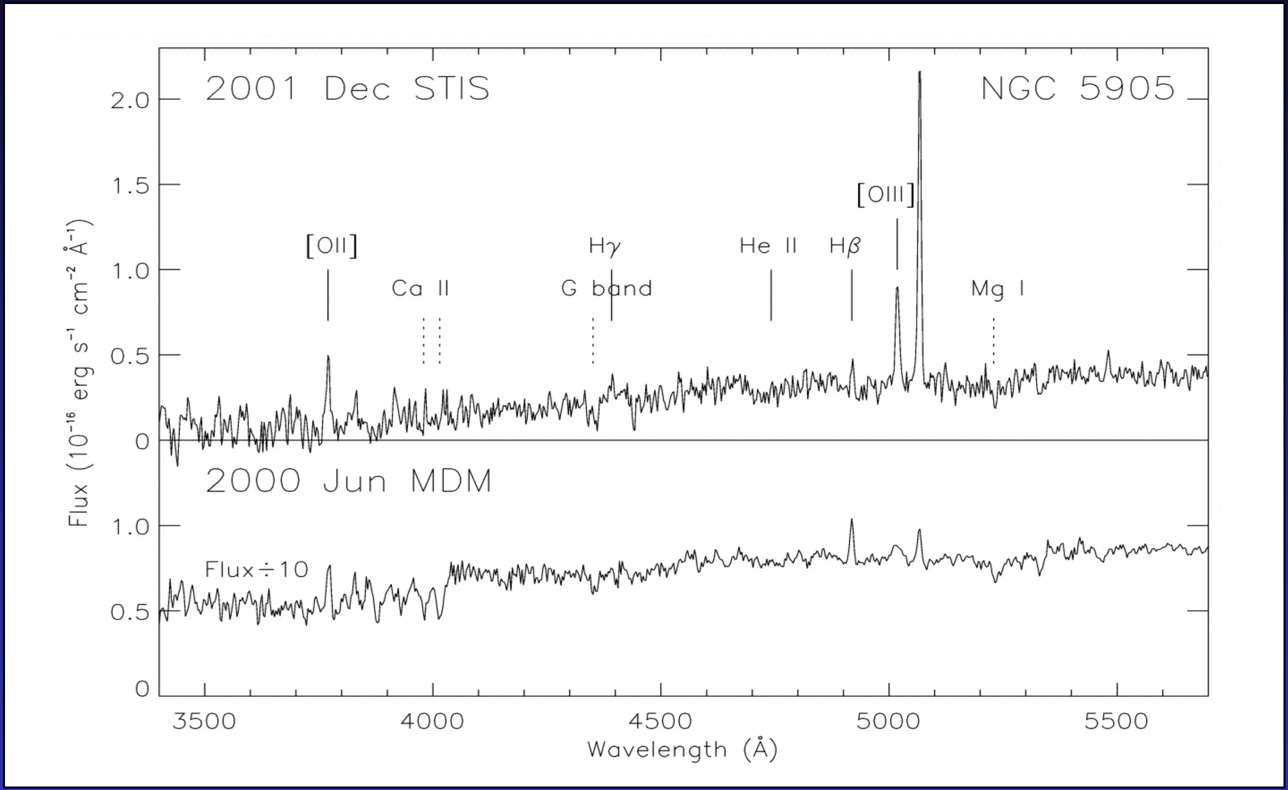
NGC 5905: optical follow-ups



ROSAT error circle on Calar Alto optical image

[Komossa & Bade 99]

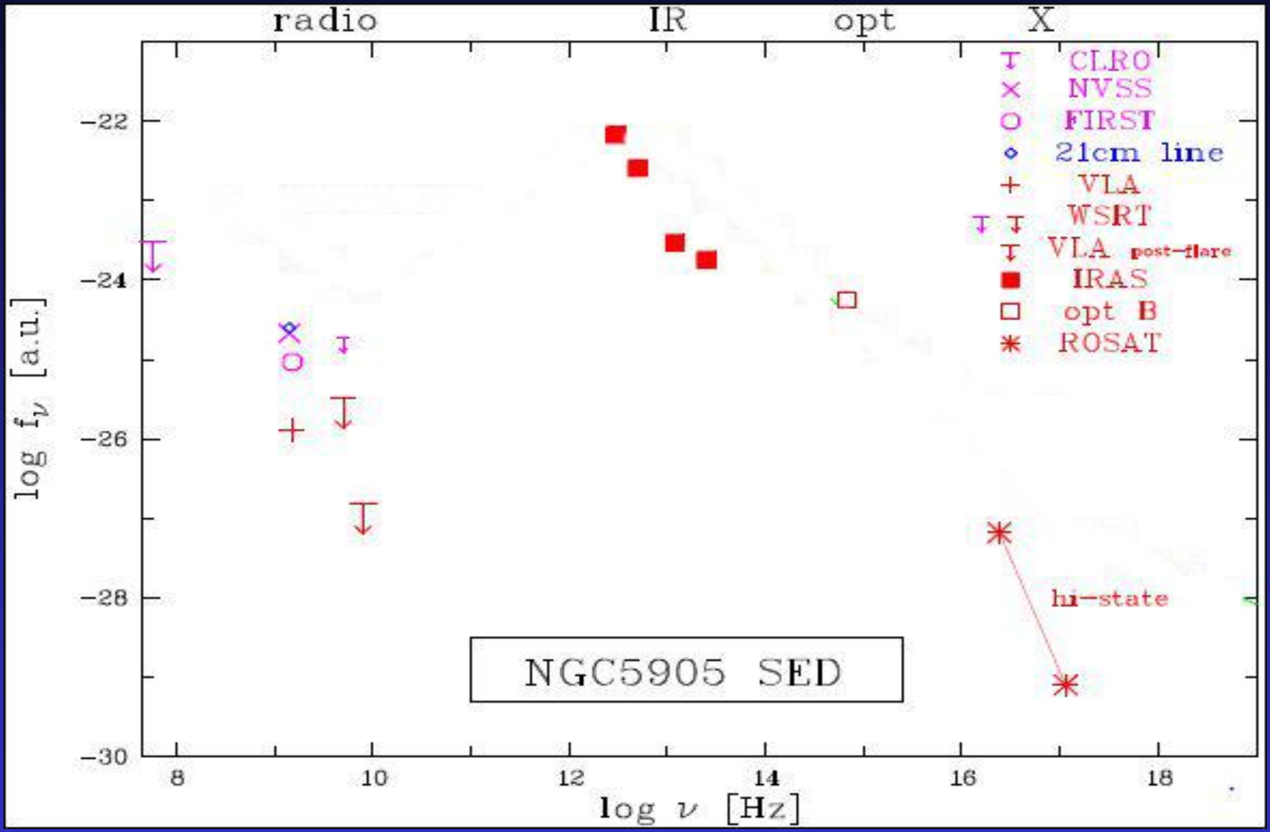
NGC 5905: optical follow-ups



- ground-based optical spectroscopy, pre-flare, and post-flare (6 yrs): HII-type galaxy
- HST post-flare spectroscopy: faint [OIII]/Hbeta > 3 likely excited by the flare (no permanent low-state hard X-ray emission!)

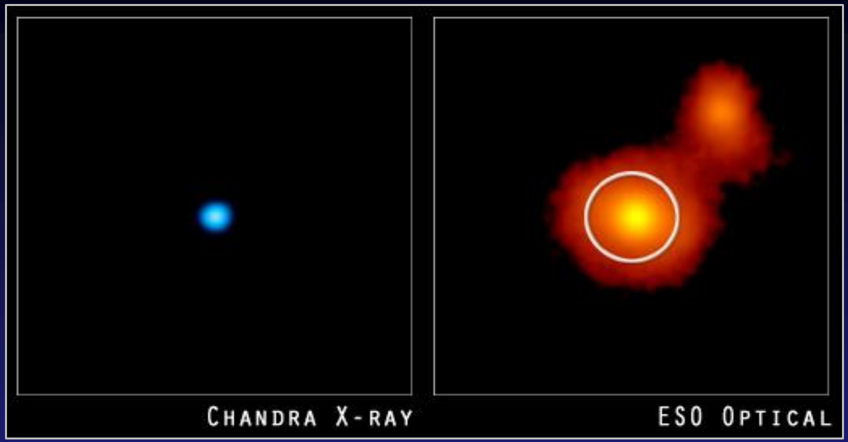
[Komossa & Bade 99, Gezari+ 03]

NGC 5905: radio follow-up



- does tidal disruption power a jet ? ((does N5905 hide a blazar nucleus ?))
- → no detection ~ 6 yrs after X-flare: $f_{8.46\text{GHz, VLA-A}} < 0.15$mJy

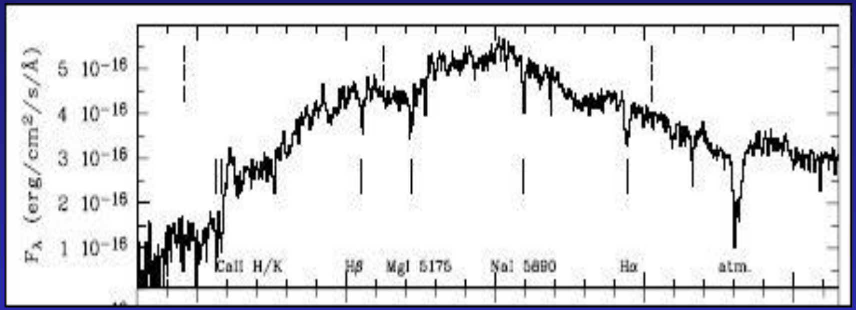
[Komossa 02 -- astro-ph/0209007]



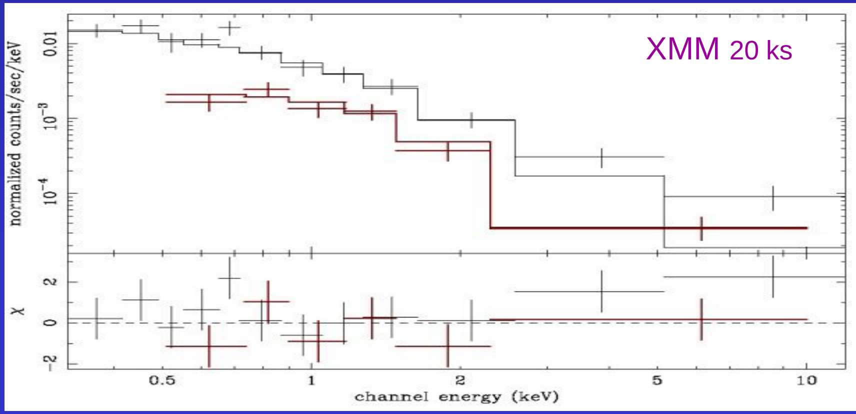
RXJ1242-1119

- $L_{x,hi}$ = 9 10^{43} erg/s
- Γ_x = -5.1

- no optical emission lines at all; no permanent AGN activity



- XMM spectroscopy: spectral hardening Γ_x = -2.4

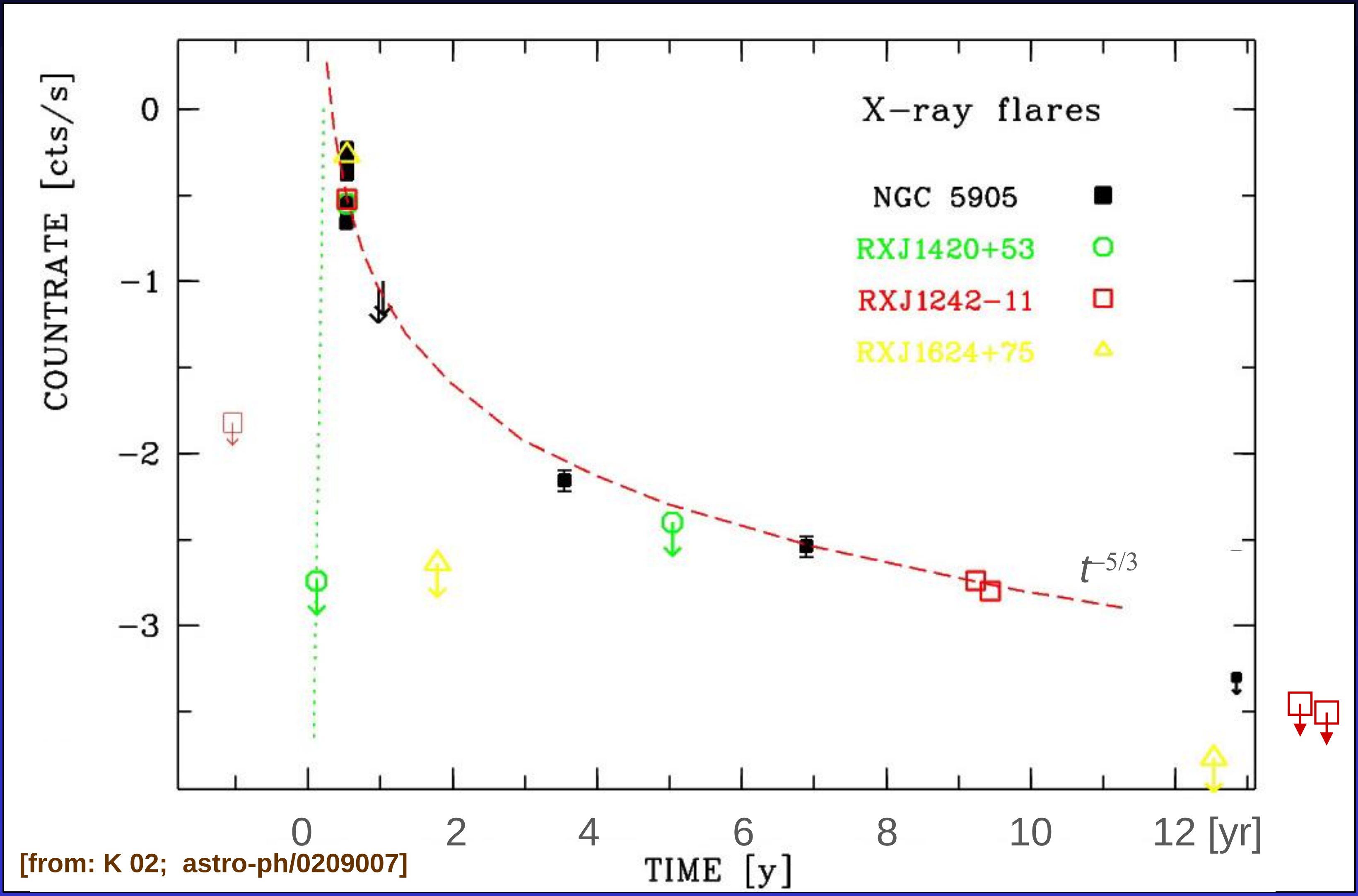


- Chandra follow-up confirms fading; up to factor **1500** (!!)

- amount of accreted stellar mass: $M > 1/100\ M_{sun}$

[Komossa & Greiner 99, Gezari+ 03, Halpern+ 04, Komossa+ 04]

tidal flares – initial X-ray observations



[Komossa & Bade 99, Grupe+ 99, Komossa & Greiner 99, Greiner+ 00, Halpern+ 04, Komossa+ 04, 12-prep]

so, then, _*are*_ these TDEs ?

rejected alternatives:

- lensing ? no (no achromatic var. obs.)
- AGN ? no (no emi lines, no dust, no radio, no low-state X)

  no dusty WAs
  no blazar
  (likely) no disk instab.

- GRBs ? no (none detected simultaneously)
- SN in dense medium ? no (inefficient by orders of mag; hard spectr)
- ULX ? no

[Komossa & Bade 99; see also Komossa 02]

main properties of the ROSAT giant X-ray flares

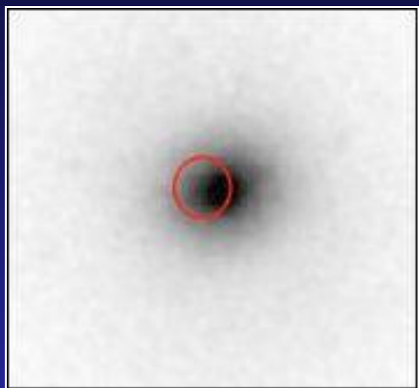
- $L_{x,peak}$ huge: up to sev. 10^{44} erg/s
- very soft X-ray spectra near peak (kT_{BB} ~ 0.04-0.1 keV); then hardening
- amplitudes of decline up to factor 1000-6000, after a ~decade (!!!)
- host galaxies are optically *inactive,* radio *inactive*, and X-ray inactive in low-state
- rapid rise*;* then decline consist. with predicted $t^{-5/3}$ law; plus quicker fading at t>10yr

all of these nicely match the order-of-mag predictions from TD theory, as e.g. given by Rees 1988,90

[Komossa & Bade 99, Grupe+ 99, Komossa & Greiner 99, Greiner+ 00, Gezari+ 03, Halpern+ 04, Komossa+ 04]

tidal flares with Chandra and XMM-Newton

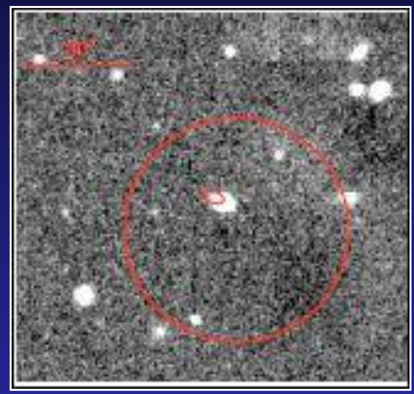
NGC 3599/ SDSSJ1323



- z = 0.0028 !
  0.088
- $L_{x,hi}$ = **1 10^{41}** erg/s
  4 10^{43}
- based on XMM slew-survey search

Esquej+ 07, 08,

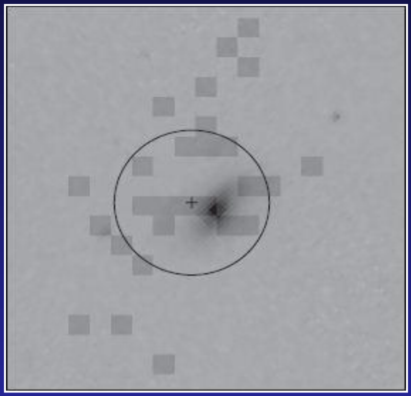
TDXFJ1347-32



- 0.037
- **6 10^{42}**
- in cluster Abell 3571

Cappelluti+ 2009,

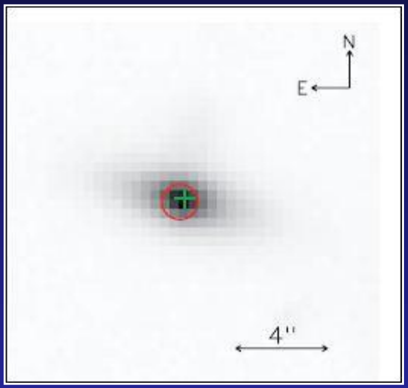
SDSSJ1311-01



- 0.195
- **5 10^{42}**
- in cluster Abell1689

Maksym+ 10,

2XMMiJ1847-63

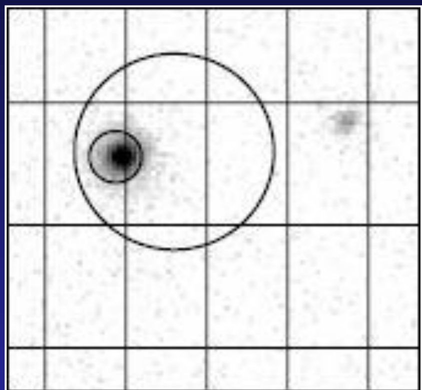


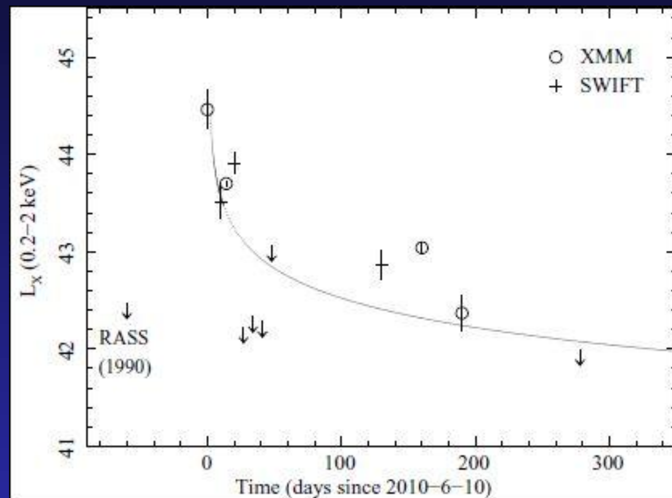
- 0.035
- **3 10^{43}**
- from XMM catalogue

Lin+ 11

tidal flares with Chandra and XMM-Newton

SDSS J1201+30





rates ?

- z = 0.146
- $L_{x,hi}$ = **3 10^{44}** erg/s

- based on XMM slew search
- well-covered 1yr lightcurve
- non-thermal spec

[Saxton+ 12]

- RASS: 10^{-5}/galaxy/yr
- CDF: $<10^{-4}$/galaxy/yr
- XMM slew: 2 10^{-4}/galaxy/yr

[e.g., Donley+ 02, Luo+ 08, Esquej+ 08]

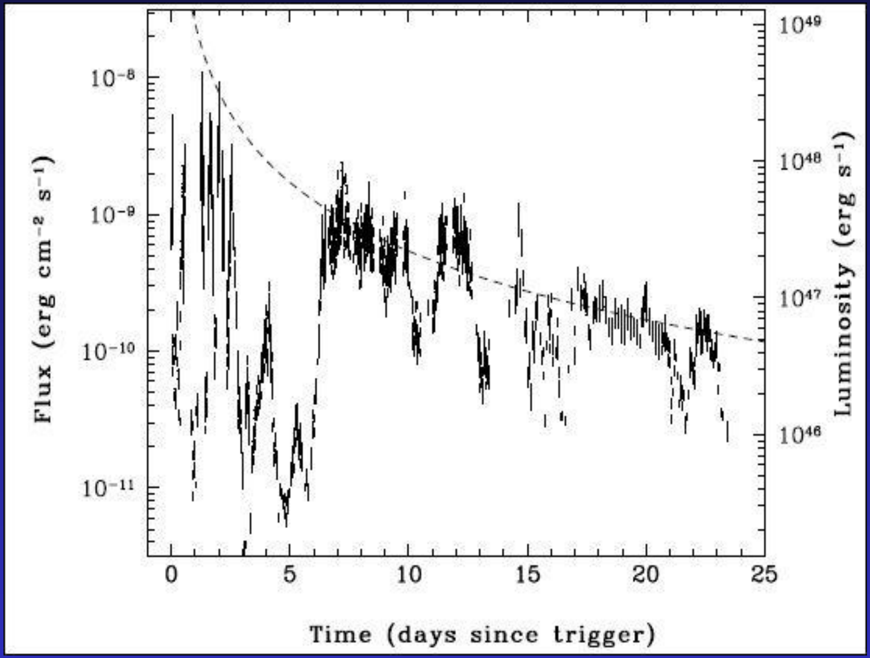
main X-ray properties of the X-ray-sel. TDEs

ROSAT:	XMM/Chandra:
• $L_{x,peak}$ huge: up to sev. 10^{44} erg/s	10^{41} - sev. 10^{44} erg/s
• very soft X-ray spectra near peak (kT_{BB} ~ 0.04-0.1 keV); then hardening with time	√ (one exception; better hard–X spectra now)
• amplitudes of decline up to factor 1000-6000	up to fact. 100-1000
• host galaxies are optically *inactive*	√ (when spectra available)
• decline consist. with predicted $t^{-5/3}$ law	√

then came Swift ....

discovery of „relativistic“ tidal flares with *Swift*

SwiftJ1644+57



[Bloom+ 11, Burrows+ 11, Zauderer+ 11, Levan+ 11, Barres de Almeida & De Angelis 11, Krolik+Piran 11, Cannizzo+ 11, Miller & Gueltekin 11, Metzger+ 11, Lei & Zhang 11, Saxton+ 12, and many more...]

- discovered with Swift BAT March 2011; no detection of „activity“ ever before March 25)1

- $L_{x,isotropic} = 10^{45}$ – **4 10^{48}** erg/s
- peculiar lightcurve
- rapid variability, $\Delta t \sim 100$s

- z_{host} =0.35, optically inactive
- NIR transient

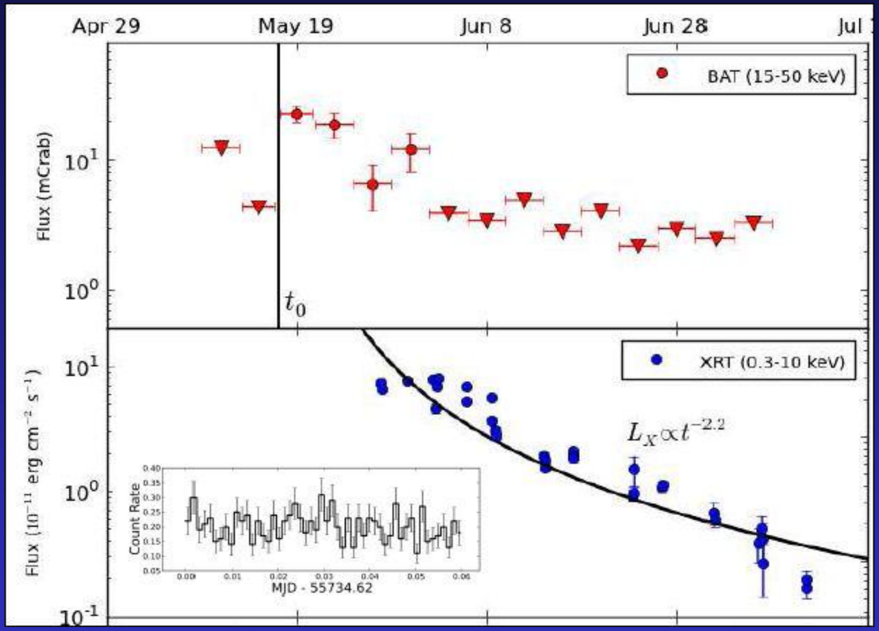
- unresolved, variable, beamed radio emission

➔ rapid onset of a powerful jet, following tidal disruption

)1 but see: talk by J. Grindlay on MAXI

„relativistic“ tidal flares with *Swift*

SwiftJ2058+05



- $L_{x,iso}$ = 3 10^{47} erg/s
- rapid variability, Δt ~ 1000s
- $z_{likely\text{-}host}$ =1.19, optically inactive
- M_{BH} approx 10^{7-8} M_{sun}
- luminous radio emi, likely beamed

→ many similarities with J1644

→ second “relativistic” tidal flare

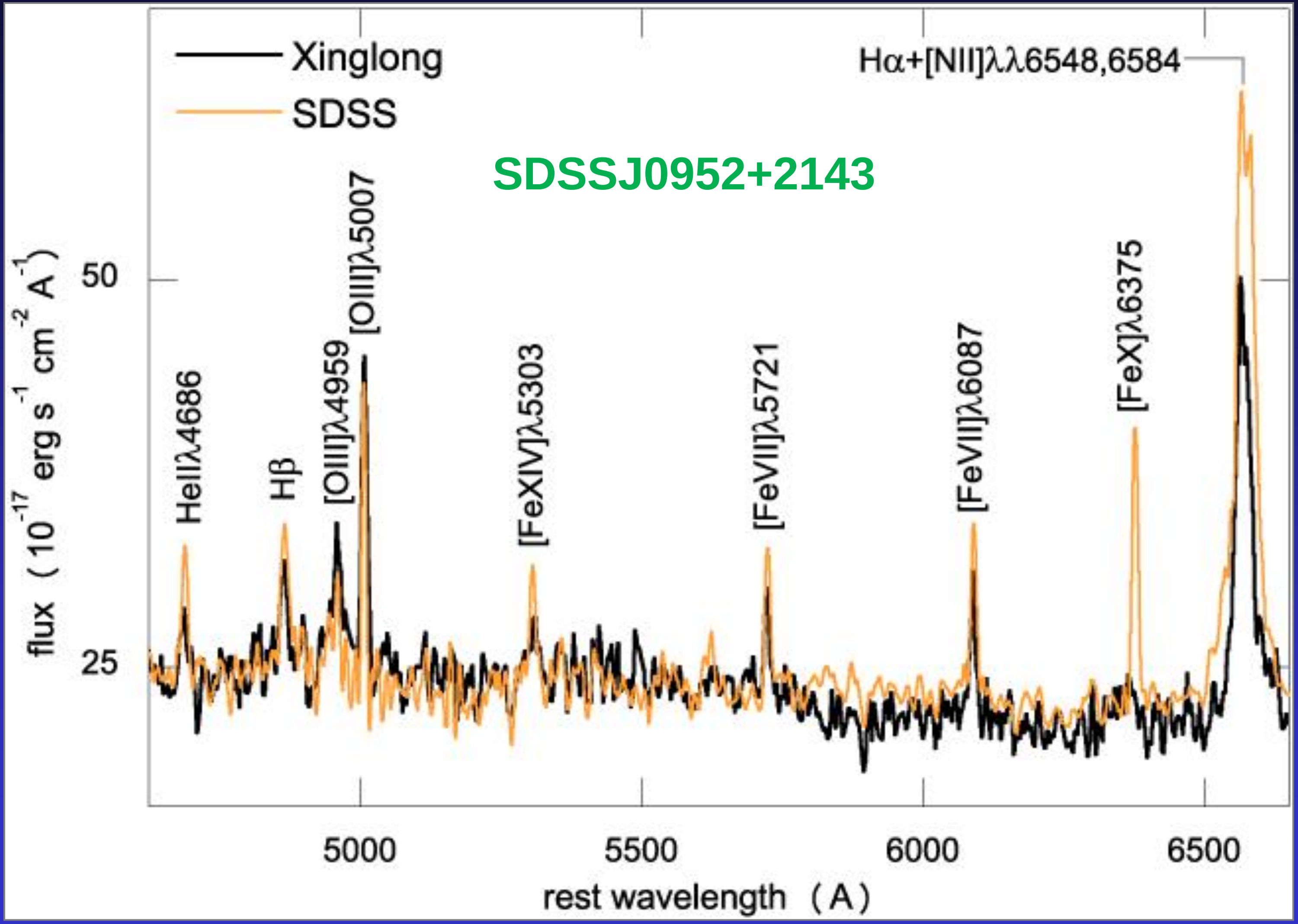
[Cenko+ 11]

tidal flares in gas-rich environments: emission-line „echoes“

imagine, we could map a whole galaxy core, following one giant flare.....

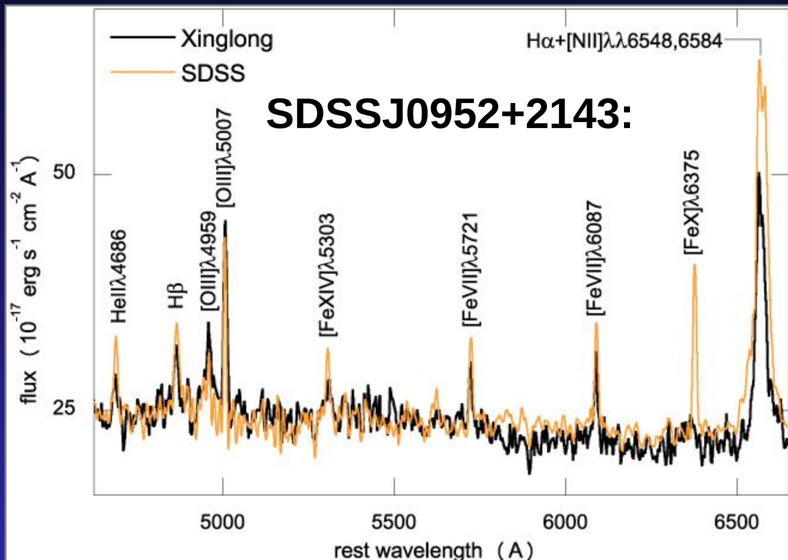
(including, of course, the disrupted star itself)

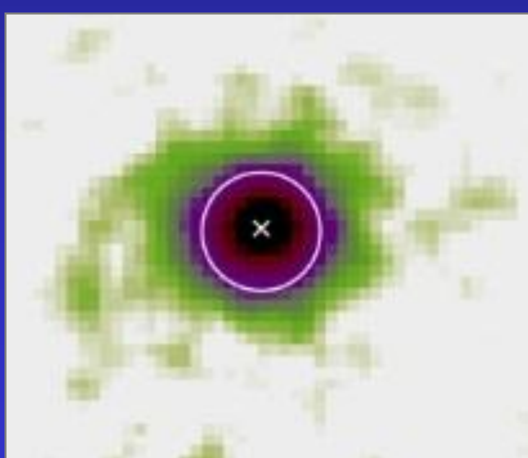
emission-line „light echoes“



[Komossa+ 08, 09]

emission-line „light echoes“



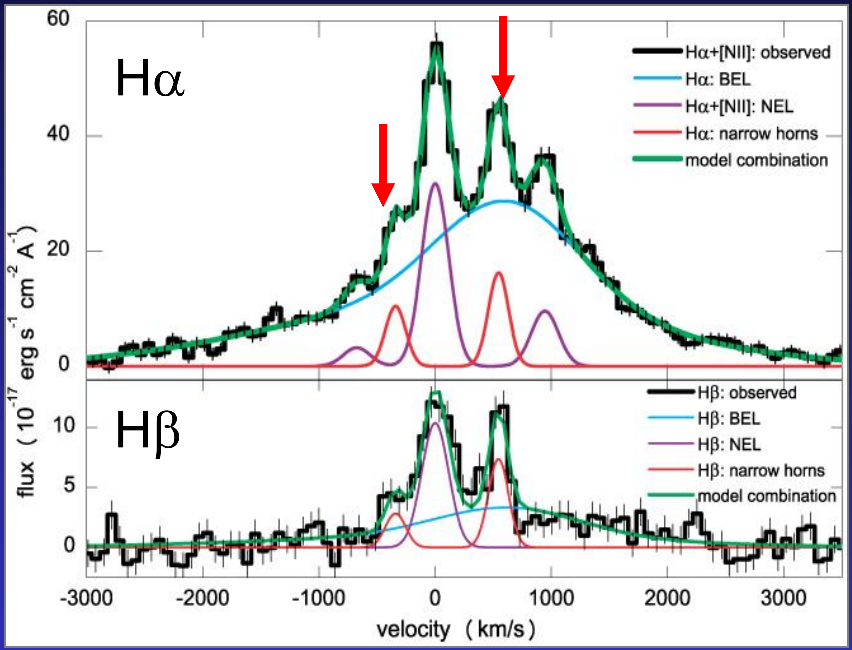


- super-strong Fe lines & HeII
- fade dramatically, x 10, in yrs
- very unusual Balmer profile; incl. redshifted broad comp., fading
- luminous MIR (Spitzer,10-20 μ), ~10^{43} erg/s
- but faint X-rays, ~10^{41} erg/s, few yrs after ‚SDSS‘ high-state
- no clear signs of permanent AGN
- various unusual emission-line properties:

[Komossa+ 08, 09]

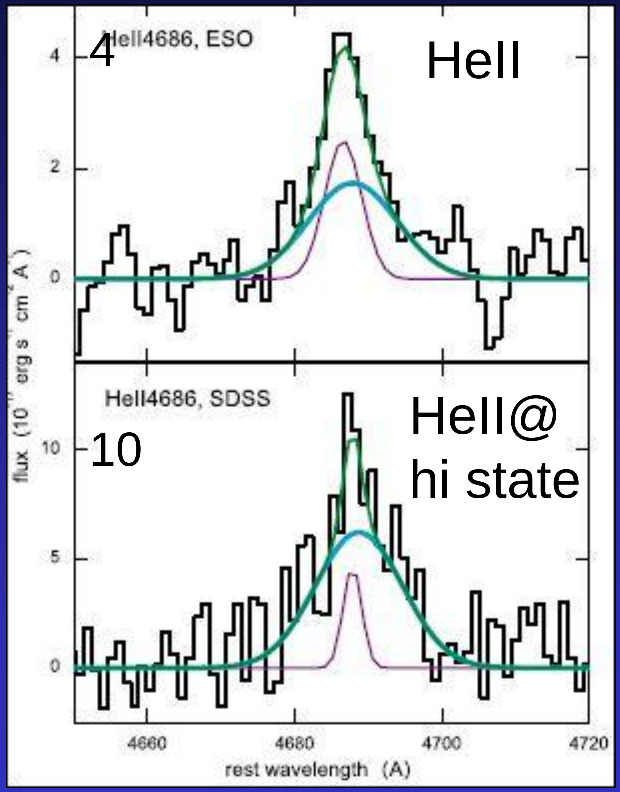
emission-line „light echoes“

very narrow double-peaked “horns” in Balmer lines:



origin unclear. related to stellar debris ??

2-component high-ion. Fe and HeII:



→ **„light echoes“ from tidal flares illuminating surrounding ISM, and perhaps stellar material ?**

→ cannot yet exclude, a previously unknown type of super-luminous (IIn) SNe, only found in galaxy cores ??

[Komossa+ 08, 09]

emission-line „light echoes“

- 2nd case with super-strong Fe lines, up to [FeXIV] and [Ar XIV], but no [FeVII]
- plus unusual broad humps

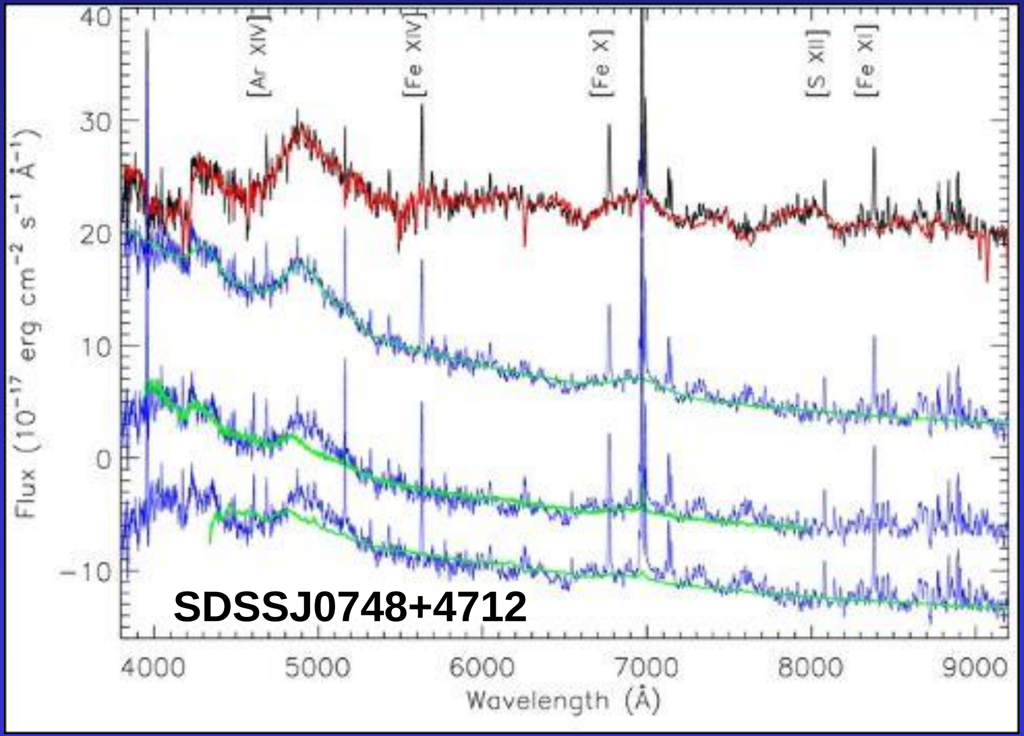
would have been Tinggui’s talk

- highest-ion lines have faded strongly 4-5 years later, while [OIII] increased by factor of 10

favored interpretation: tidal disruption of an evolved star, stripped by its H-envelope → He-rich core produces a strong, shifted HeII bump

SN argued to be unlikely

[T. Wang+ 11; see also Gezari+ 12, **+ her talk**]



emission-line „light echoes“

would have been Tinggui’s talk

- dedicated SDSS search for further extreme coronal line emitters:

  - 5 more found
  - all with very strong [FeX]-[FeXIV]
  - ~50% without [FeVII]

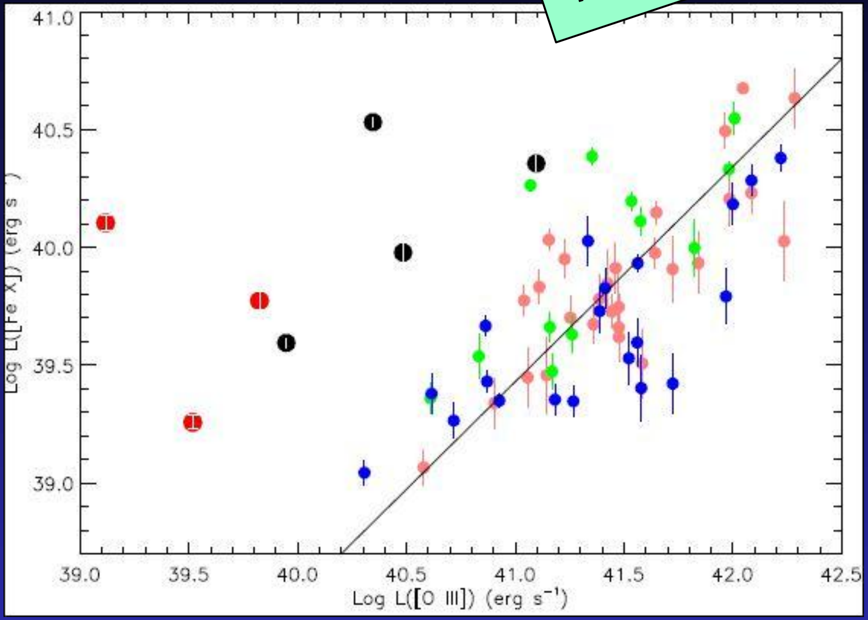
  - in relatively low-mass galaxies

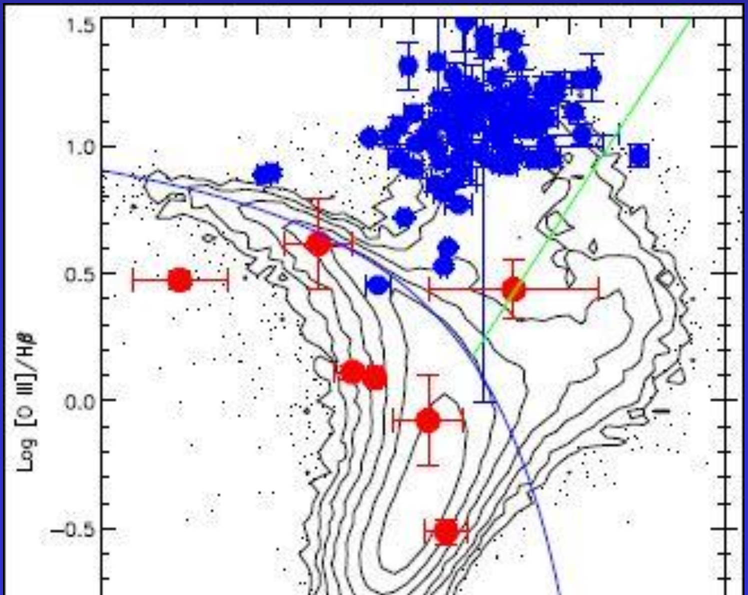
  - 2 appear to be AGN, ~constant Fe
  - 3 have transient (fading) Fe lines; while [OIII] increases

→ same mechanism at work as in SDSSJ0952+2143

- rate: ~10^{-5} /yr /galaxy

[T. Wang+ 12, 13-in prep]



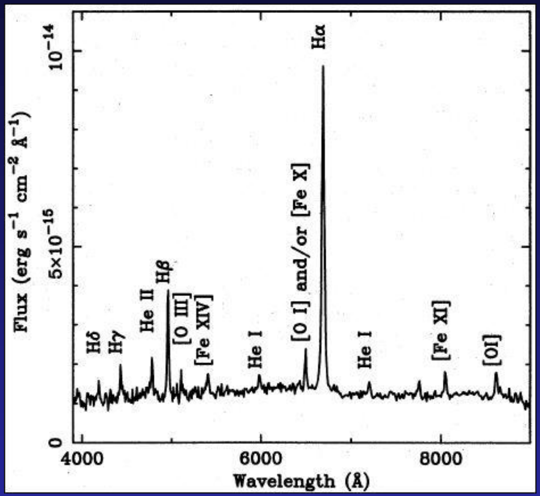


tidal flares in classical AGN ?

are we now ready to search for them, and re-look at (one) previous AGN flares ?

tidal flares in AGN ??

IC 3599



- ‚classical‘ opt AGN before and after
- luminous X-ray outburst (RASS)
- accompanied by transient opt. lines

ph.ion. modelling of the emi-line response to the X-outburst of **IC3599**:

	$I/I_{H\beta_{out}}$	
Line	observed	modeled
HeII 4686	0.36	0.38
Hβ 4861	1.0	1.0
HeI 5876	0.14	0.12
[OIII] 5007	< 0.2	0.02
[FeX] 6375	0.37	0.45
[FeXI] 7892	0.23	0.36
[FeXIV] 5303	0.17	0.11
OI 8446	0.23	0.10

best-fit parameters:

log N ~ 23,

log n ~ 9, r~130 ld;

typical for outer

BLR /CLR

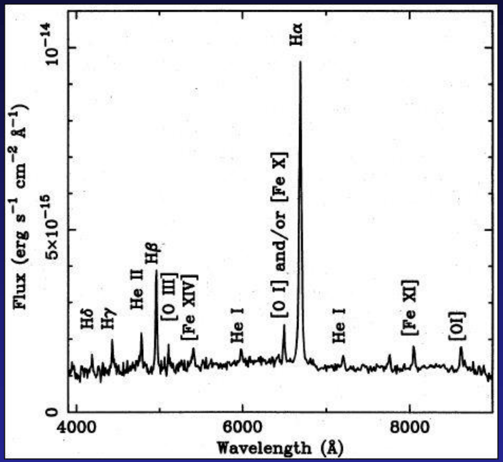
[Komossa & Bade 97]

[Brandt+ 95, Grupe+ 95, Komossa & Bade 99]

see also: transient broad HeII line of NGC 5548, Peterson & Ferland, Nature, 1986 -- SN or TDE ? // transient Balmer-lines of NGC 1097; Storchi-Bergmann+ 97 -- accretion event or TDE ?

tidal flares in AGN ??

IC 3599



- ‚classical‘ opt AGN before and after the luminous X-ray outburst (RASS)
- accompanied by transient opt. lines

suggested possible explanations for IC3599:

→ extreme case of NLS1 variability ?
→ state-change, similar to gal. BHCs ?
→ TDE ?
→ thermal (or other) acc. disk instability ?
→ no SN

[Brandt+ 95, Grupe+ 95, Komossa & Bade 99]

→ we may now start searching for TDEs in classical AGN by looking for properties similar to the flares already seen in the non-active galaxies (esp.: super-softness of the X-ray spectra, decline law)

summary

- stellar tidal disruption flares long predicted by theory. Key probe of SMBHs in non-active galaxies; of accretion & jet physics. ~12 events discovered in X-rays.

- all "non-*Swift*" X-ray tidal flares share ~similiar properties:
  very soft X-ray high-state spectra
  high $L_{x,peak}$ up to > sev. 10^{44} erg/s
  giant amplitude of variability, up to factor 6000
  from the cores of otherwise non-active galaxies
  decline consistent with $t^{-5/3}$, esp. the well-covered lightcurves of NGC5905 & RXJ1242-1119

- the two *Swift* discoveries are markedly different in their giant peak luminosity, hardness, rapid variability, and evidence for beaming
  → "relativistic" tidal flares

- several cases of transient optical emission-lines (H, HeII, hi-ion Fe)
  → ISM, and stellar streams, excited by TD flares (?)

- wealth of future applications, when we find tidal flares in larger numbers & do rapid follow-ups and long-term monitoring