Relativistic tidal disruption events: what do we learn from their rate distribution?

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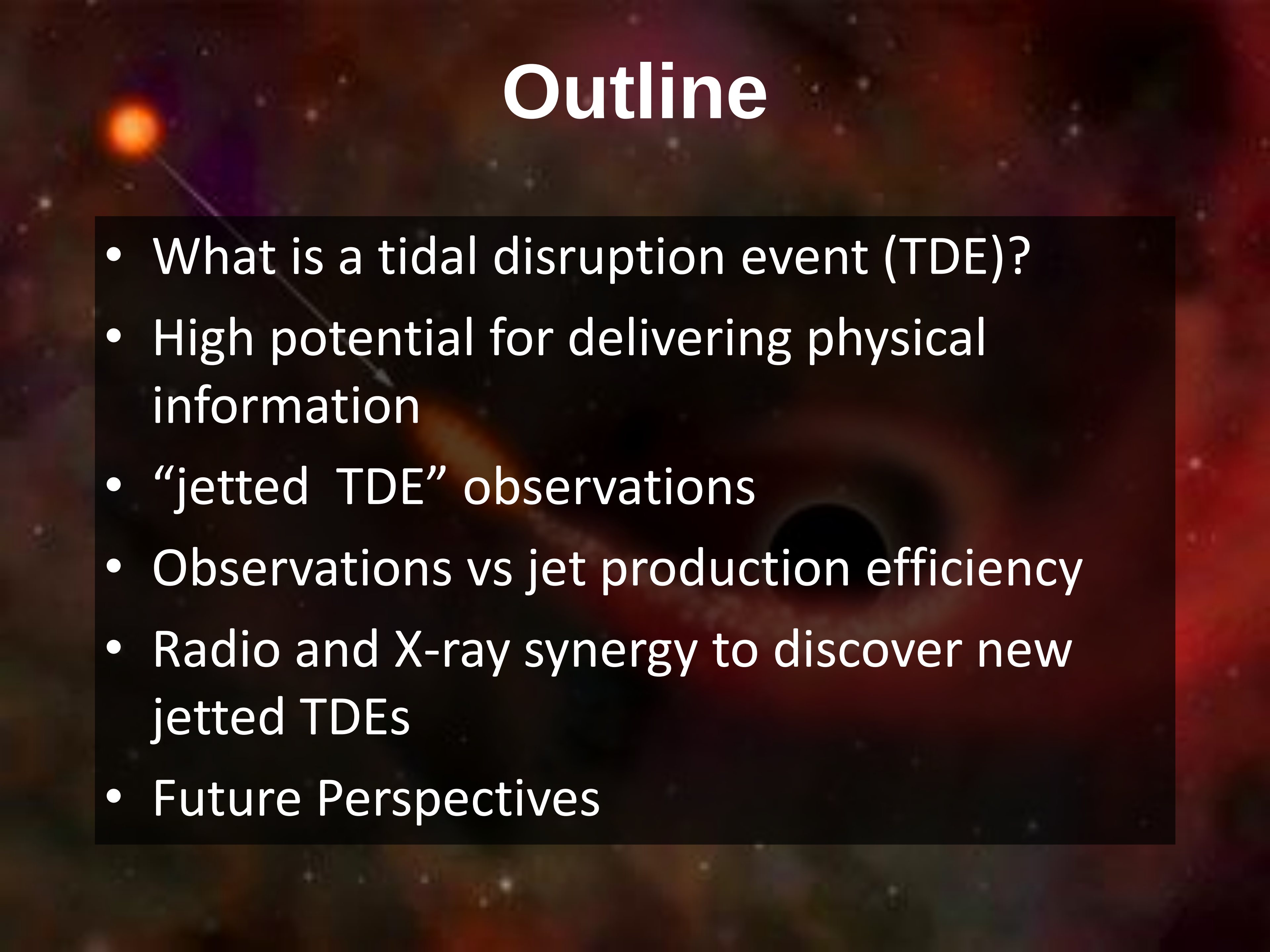
INAF-IAPS

Italy

28th Texas Symposium,
Geneva 2015



Outline

- What is a tidal disruption event (TDE)?
- High potential for delivering physical information
- “jetted TDE” observations
- Observations vs jet production efficiency
- Radio and X-ray synergy to discover new jetted TDEs
- Future Perspectives

Tidal disruption events

When a star orbits close to a massive black hole and its periastron distance reaches $R \sim R_*(M_{BH}/m_*)^{1/3}$*, it will be disrupted and cause what is commonly referred to as a tidal disruption flare.*

MASS FALLS BACK AT A RATE: $\dot{M} \propto t^{-5/3}$

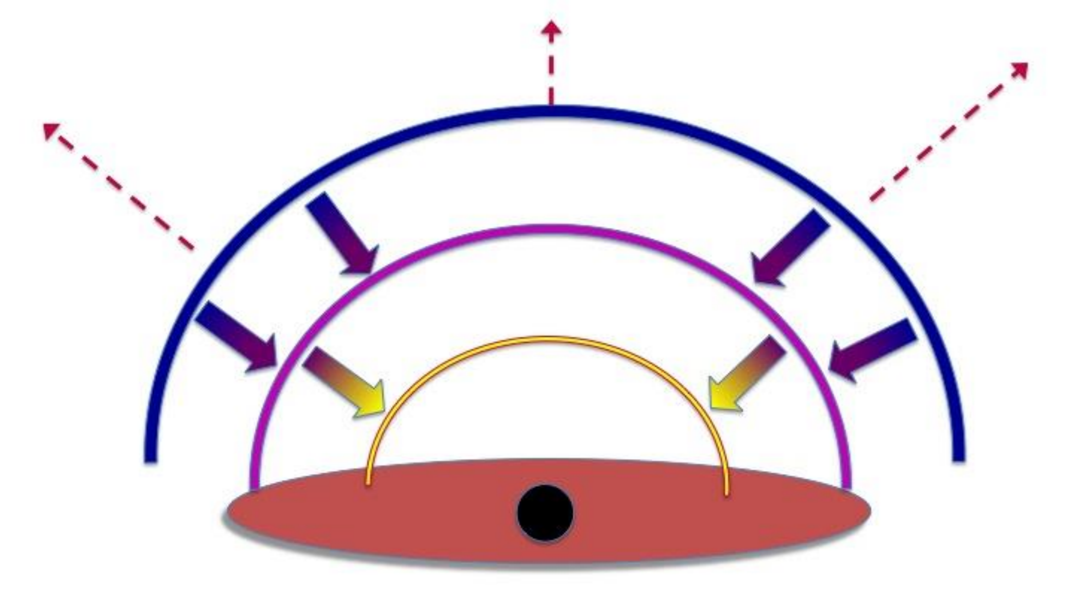
Rees 88
Phinney 89

A TRANSIENT DISC, ACCRETING AT THE FALLBACK RATE

IF SUB-EDDINGTON ONLY THERMAL EMISSION IS FROM DISC

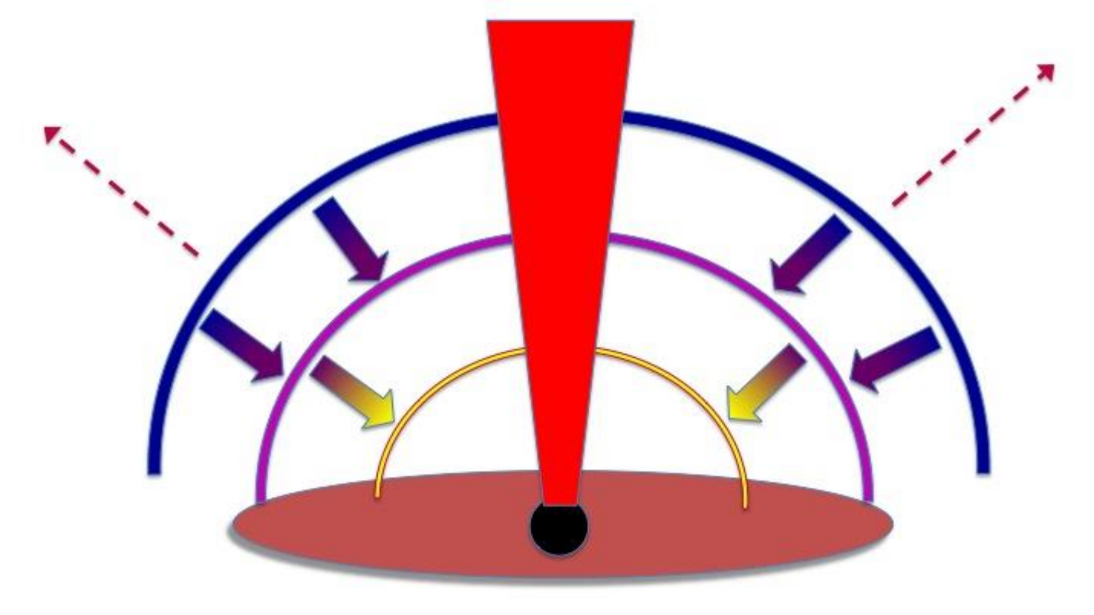
Super Eddington mass loss

Rossi & BEGELMAN ‘08
STRUBBE & QUATAERT ‘09
LODATO & Rossi ‘10

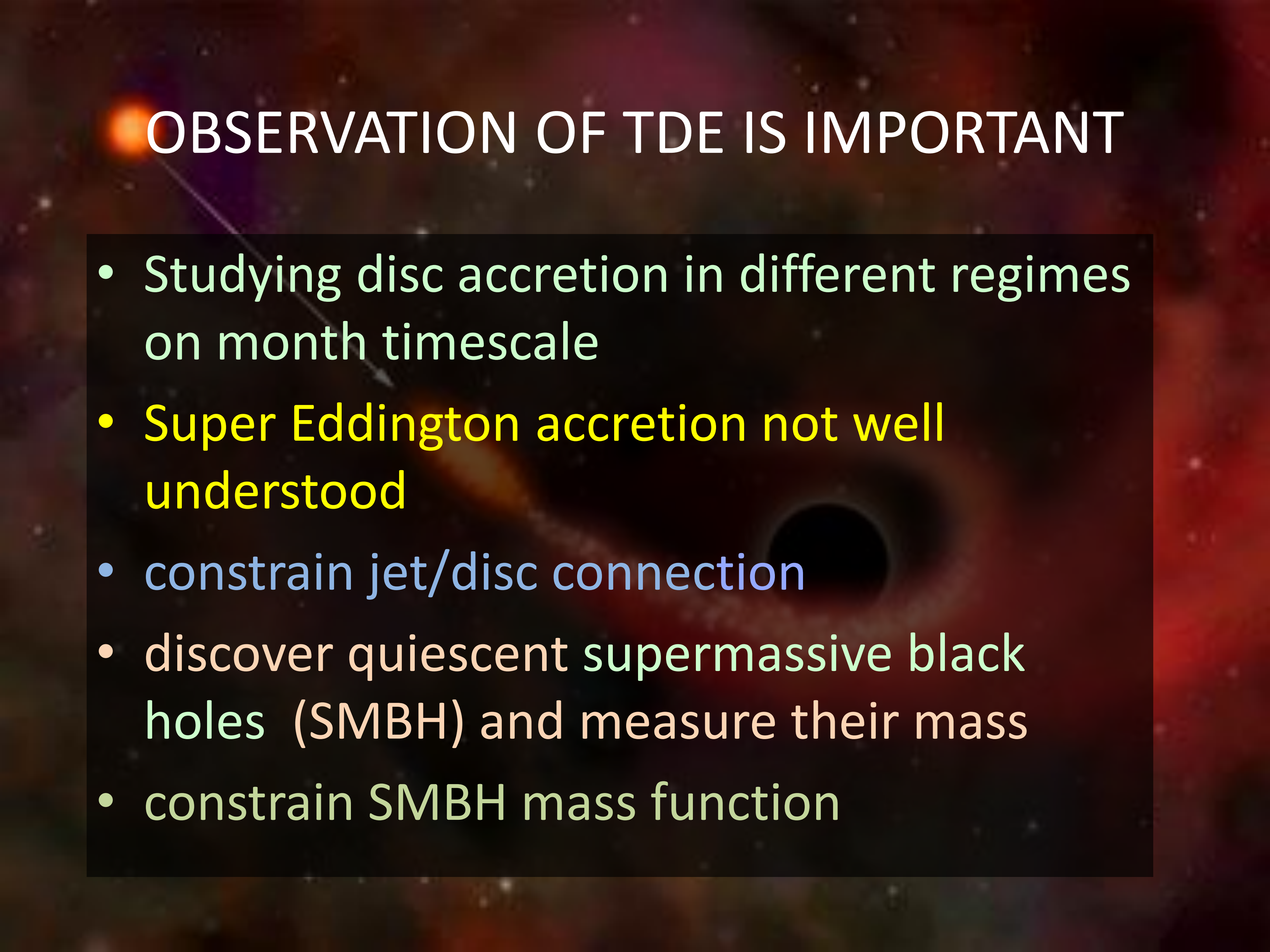


THE PEAK IS FIRST IN optical AND THEN IT MOVES TO higher FREQUENCIES

...and the jet



WHAT WE SEE DEPENDS ON THE VIEWING ANGLE

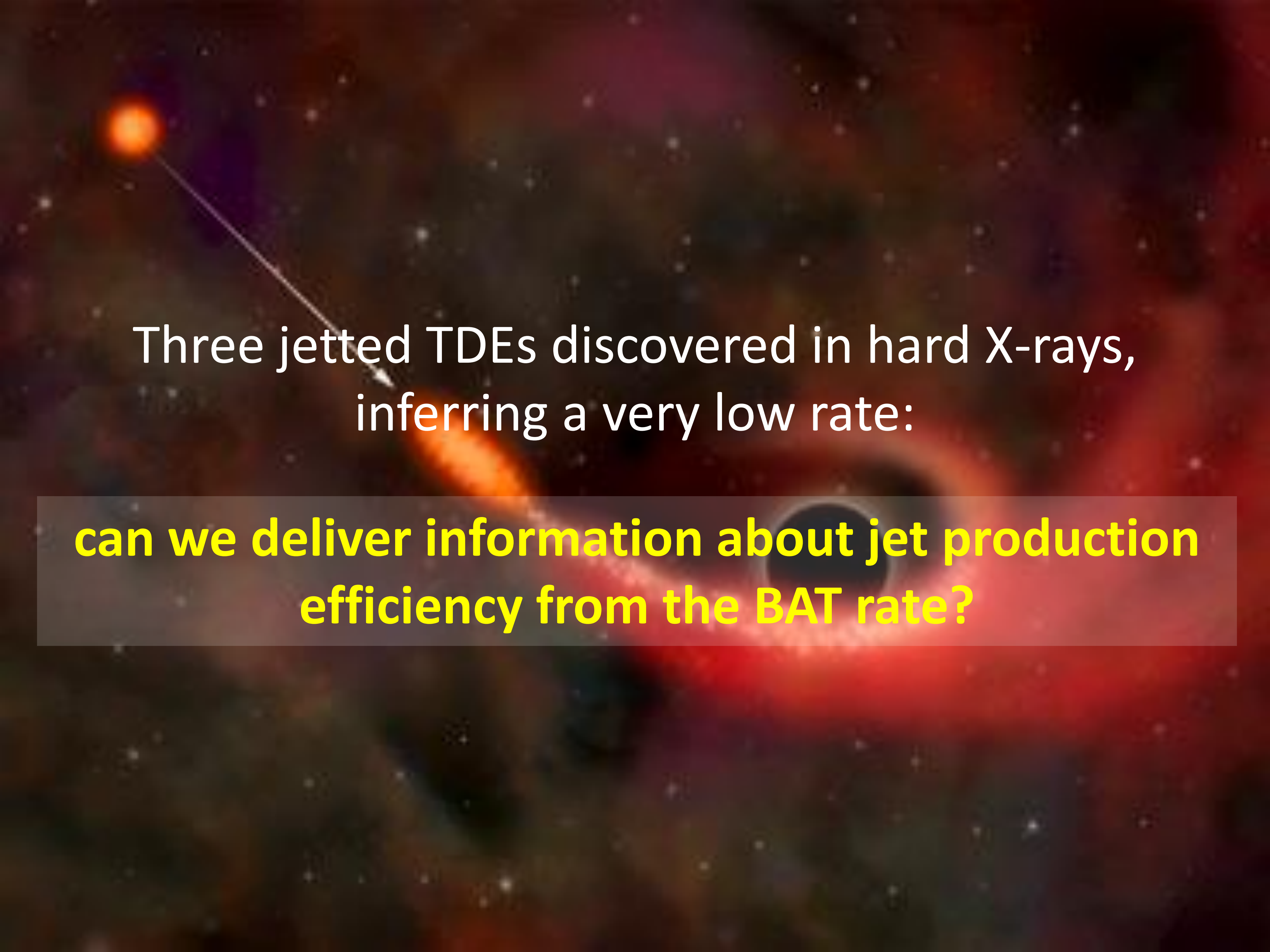


OBSERVATION OF TDE IS IMPORTANT

- Studying disc accretion in different regimes on month timescale
- Super Eddington accretion not well understood
- constrain jet/disc connection
- discover quiescent supermassive black holes (SMBH) and measure their mass
- constrain SMBH mass function

Jetted TDE: 3 SWIFT Events

- **Sw J1644+57** (z=0.35; Burrows et al. 2011), **Sw J2058+05** (z=1.18; Cenko et al. 2011), **Sw J1112.2-8238** (z=0.89; Brown et al. 2015)
- **exploded in quiescent galaxies.**
- **Sw J1644 and Sw J2058 have position within 150 pc and 400 pc of their galactic center, respectively** (Levan et al. 2011, Pasham et al. 2015)
- **Persistent (months), variable and bright X-rays lightcurve ($L \sim 10^{47}$ erg/s after 2 weeks)**
- **bright radio counterparts** (e.g. Zauderer et al. 2011, Cenko et al. 2011)



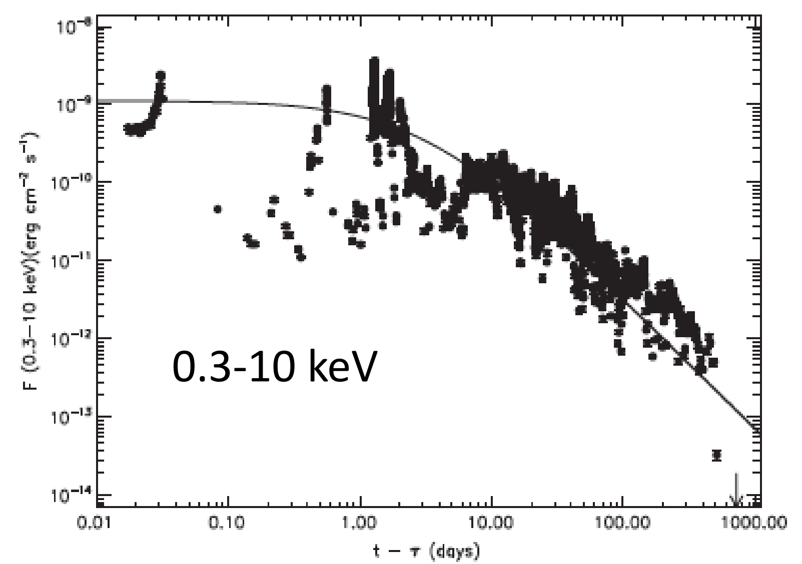
Three jetted TDEs discovered in hard X-rays,
inferring a very low rate:

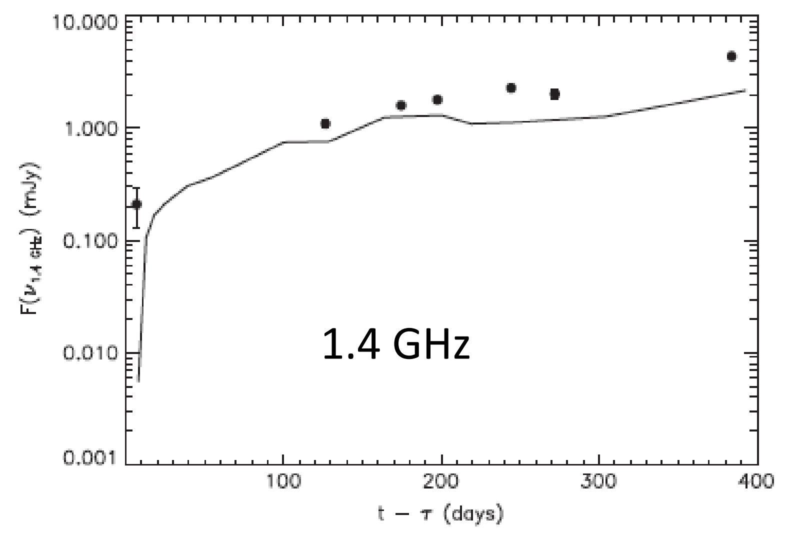
can we deliver information about jet production efficiency from the BAT rate?

Donnarumma & Rossi 2015

How can we derive the rate of jetted TDEs?

Using Sw J1644 as a prototype to make predictions in X-rays and radio energy bands



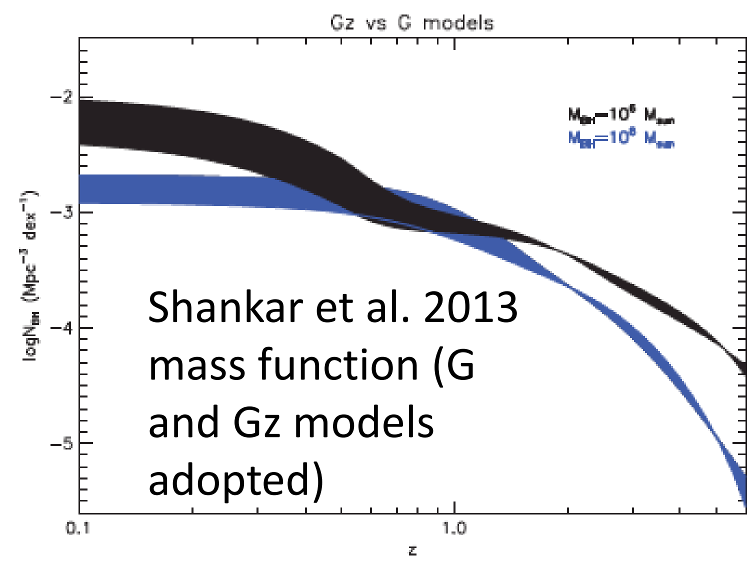


$$L_{\mathrm{x,t}} \approx 1.63 \times 10^{48}\,\mathrm{erg\,s^{-1}} M_6^{-1/2} m_{*,1}^{1/2} \left(\frac{\epsilon_{\mathrm{x}}(z)}{0.2}\right) \times \left(\frac{t_{\min}+\tau}{t_{\min}}\right)^{-5/3},$$

$$F_\nu(\nu_{\mathrm{a}}, \tau) = F_{\nu,\mathrm{sw}}(\nu_{\mathrm{a,sw}}, \tau_{\mathrm{sw}}) \times M_6^{-1/2} m_{*,1}^{1/2} \left(\frac{1+z}{1+z_{\mathrm{sw}}}\right)\left(\frac{D_{\mathrm{sw}}}{D}\right)^2,$$

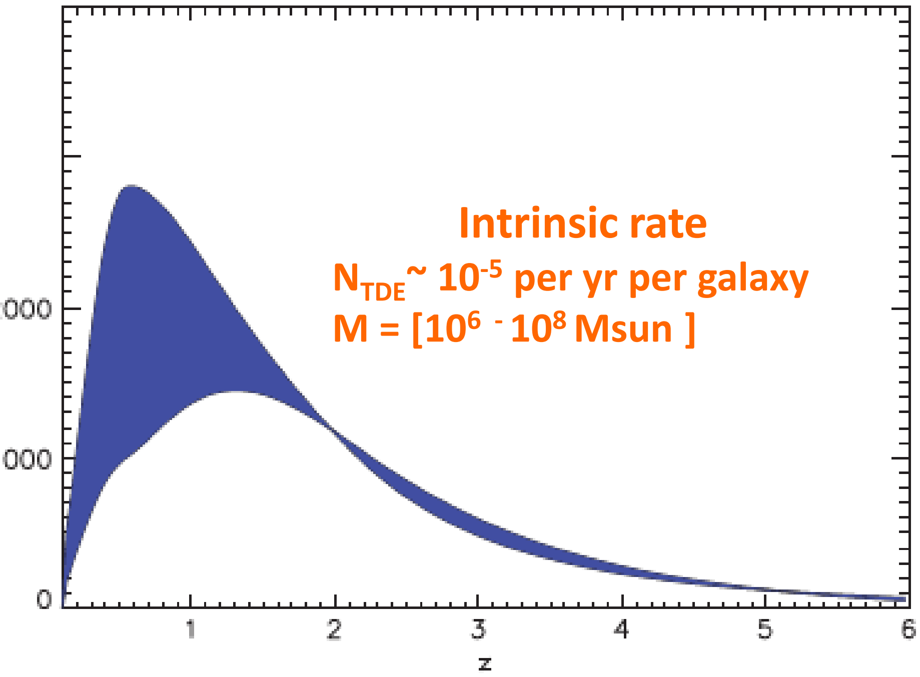
MDL

The intrinsic rate R(z) and the beaming reduction



Shankar et al. 2013 mass function (G and Gz models adopted)

$$R(z) = \int_{M_{\rm min}}^{M_{\rm max}} \phi(M, z) V(z) N_{\rm tde} dM,$$



Intrinsic rate

N_{TDE}~ 10^{-5} per yr per galaxy

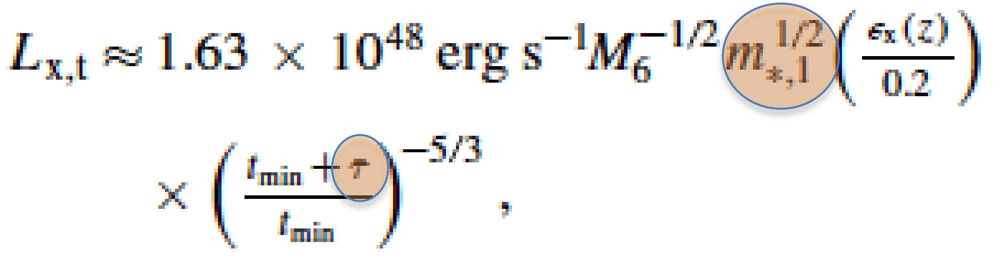
M = [10^6 - 10^8 Msun]

From intrinsic to jetted TDE rate: rescaling R(z) by a factor $(2\Gamma)^{-2}$

Rate predictions: constraints from current observations

A Monte Carlo approach:

main ingredients, τ and m_*



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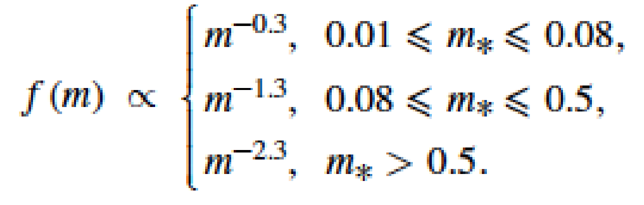
τ = X-ray lag time (the same applies to radio light curve)

m_* = star mass

τ - randomly extracted from a uniform distribution between 0 and 1 yr

m_* -extracted from a Kroupa IMF



$$f(m) \propto \begin{cases} m^{-0.3}, & 0.01 \leqslant m_* \leqslant 0.08, \\ m^{-1.3}, & 0.08 \leqslant m_* \leqslant 0.5, \\ m^{-2.3}, & m_* > 0.5. \end{cases}$$

Looking at the discovery potential for current and future missions

- **The Square Kilometre Array survey:**

large sky coverage (~ 20,000 deg^2) performed with multiple cadence (daily/weekly) at 1.4 GHz with a flux limit of 90 uJy

(Donnarumma et al. 2015, Fender et al. 2015, Donnarumma & Rossi 2015)

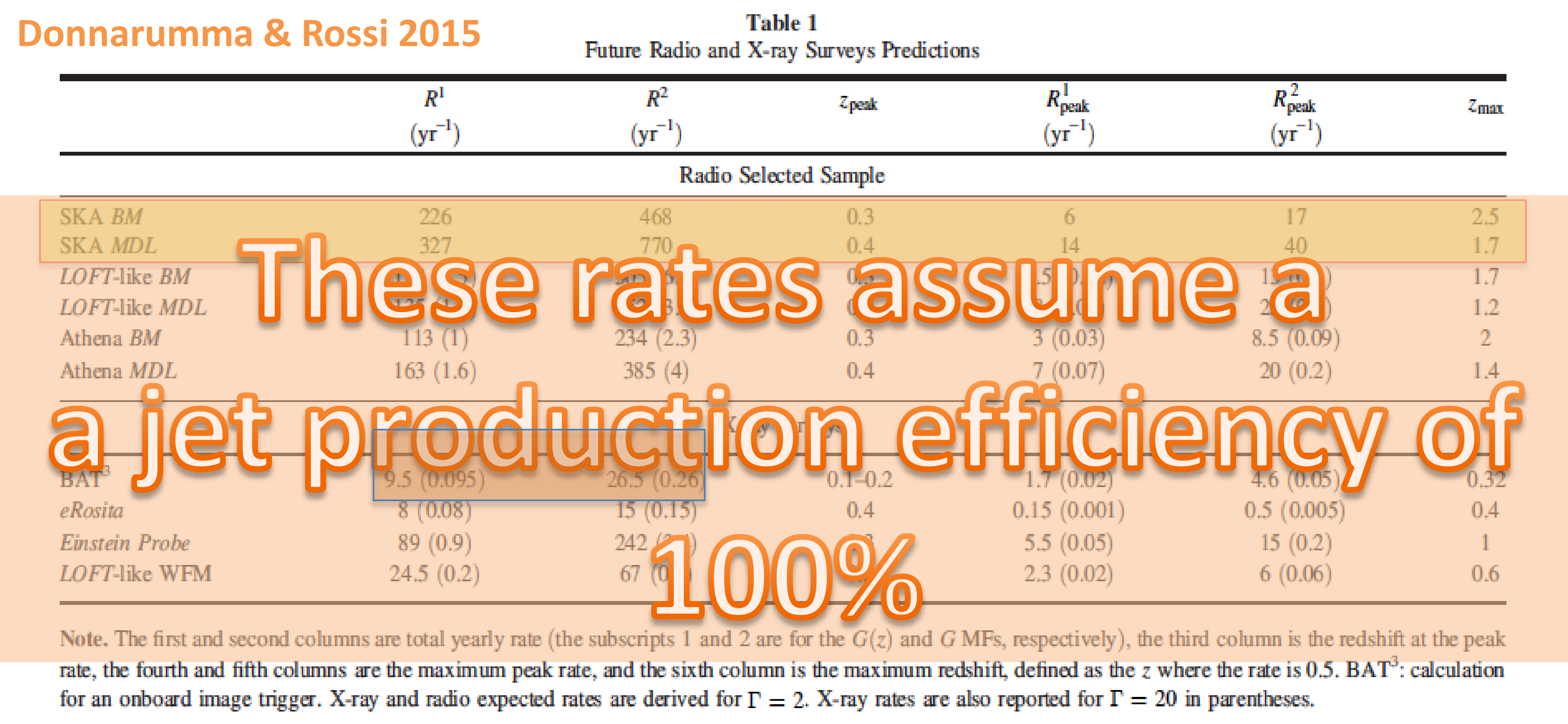
- Current Hard X-ray survey

BAT

- Future X-ray surveys:

eRosita, Einstein-Probe, LOFT-like Wide Field Monitor

Radio and X-ray surveys predictions



Donnarumma & Rossi 2015

Table 1
Future Radio and X-ray Surveys Predictions

	R^1 (yr^{-1})	R^2 (yr^{-1})	$z_{\rm peak}$	$R^1_{\rm peak}$ (yr^{-1})	$R^2_{\rm peak}$ (yr^{-1})	$z_{\rm max}$
Radio Selected Sample						
SKA *BM*	226	468	0.3	6	17	2.5
SKA *MDL*	327	770	0.4	14	40	1.7
LOFT-like *BM*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.7
LOFT-like *MDL*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.2
Athena *BM*	113 (1)	234 (2.3)	0.3	3 (0.03)	8.5 (0.09)	2
Athena *MDL*	163 (1.6)	385 (4)	0.4	7 (0.07)	20 (0.2)	1.4
[illegible]						
BAT^3	9.5 (0.095)	26.5 (0.26)	0.1–0.2	1.7 (0.02)	4.6 (0.05)	0.32
eRosita	8 (0.08)	15 (0.15)	0.4	0.15 (0.001)	0.5 (0.005)	0.4
Einstein Probe	89 (0.9)	[illegible]	[illegible]	5.5 (0.05)	15 (0.2)	1
LOFT-like WFM	24.5 (0.2)	[illegible]	[illegible]	2.3 (0.02)	6 (0.06)	0.6

Note. The first and second columns are total yearly rate (the subscripts 1 and 2 are for the $G(z)$ and G MFs, respectively), the third column is the redshift at the peak rate, the fourth and fifth columns are the maximum peak rate, and the sixth column is the maximum redshift, defined as the z where the rate is 0.5. BAT^3: calculation for an onboard image trigger. X-ray and radio expected rates are derived for $\Gamma = 2$. X-ray rates are also reported for $\Gamma = 20$ in parentheses.

These rates assume a
a jet production efficiency of
100%

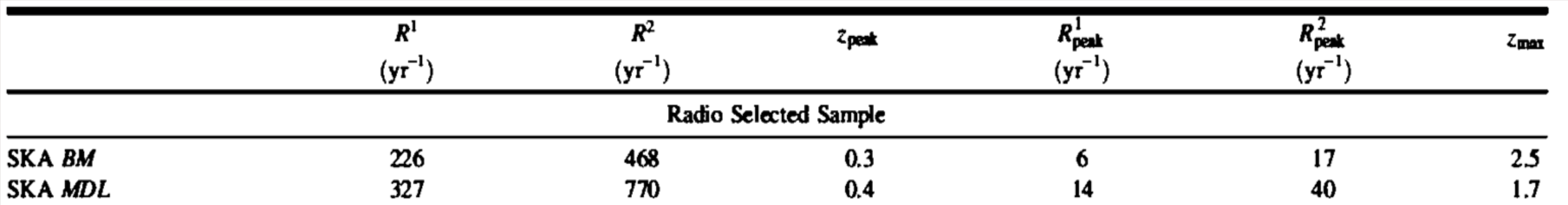
Main findings I

It is not possible to infer jet production efficiency from the BAT rate

this is due to the degeneracy between *observing* efficiency (sky coverage vs flux limit) and the value of the bulk Lorentz factor Γ

Note that even assuming a jet production efficiency of 100%, Γ in the range 10 – 20 can reconcile observations with predictions

TDE rate predictions with SKA



	R^1 (yr^{-1})	R^2 (yr^{-1})	z_{peak}	R^1_{peak} (yr^{-1})	R^2_{peak} (yr^{-1})	z_{max}
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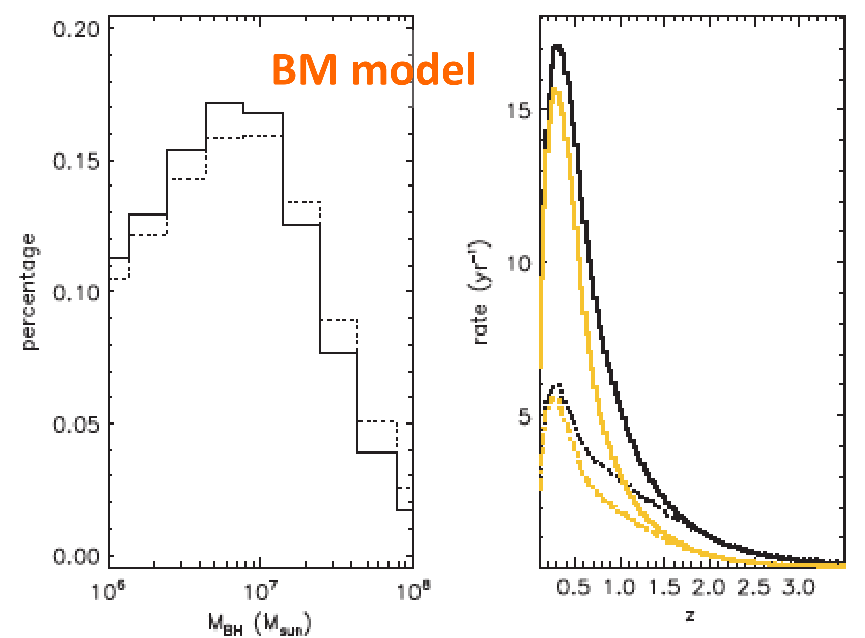
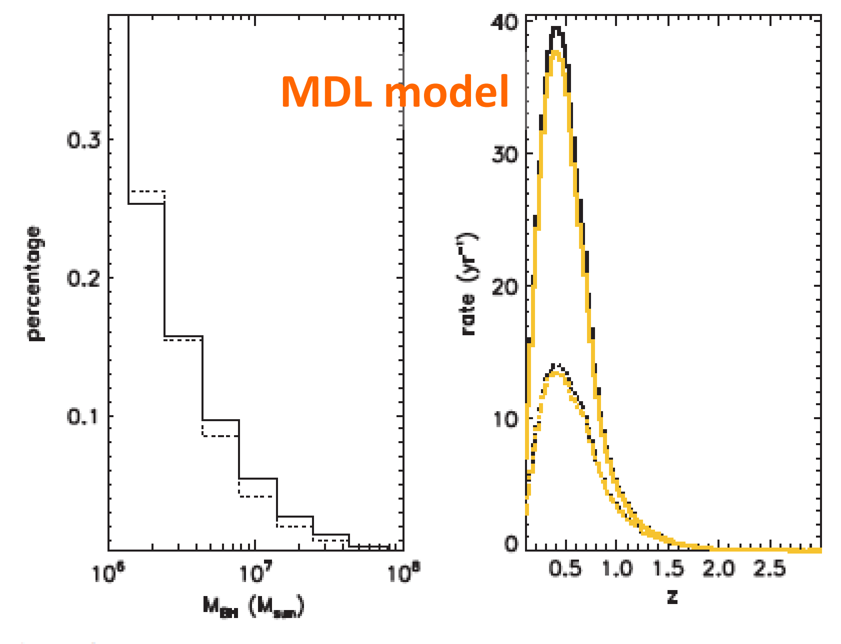
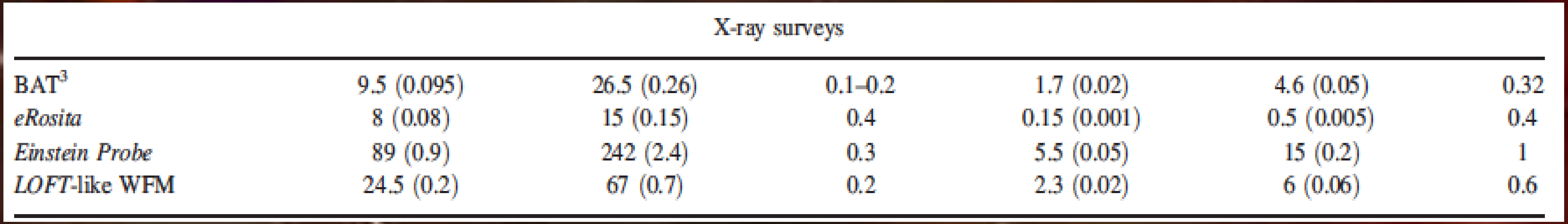




Donnarumma & Rossi 2015; Donnarumma et al. 2015, SKA Science paper

Predictions for future X-ray surveys



X-ray surveys

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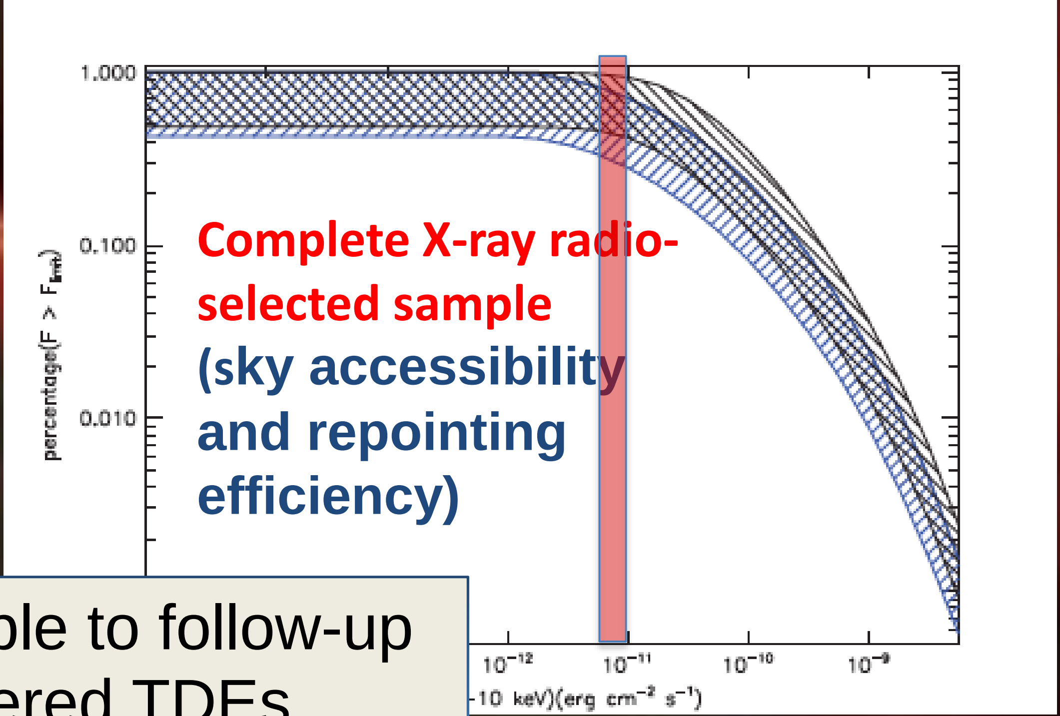
Einstein Probe	89 (0.9)	242 (2.4)	0.3	5.5 (0.05)	15 (0.2)	1
LOFT-like WFM	24.5 (0.2)	67 (0.7)	0.2	2.3 (0.02)	6 (0.06)	0.6

Higher discovery potential with follow-up observations



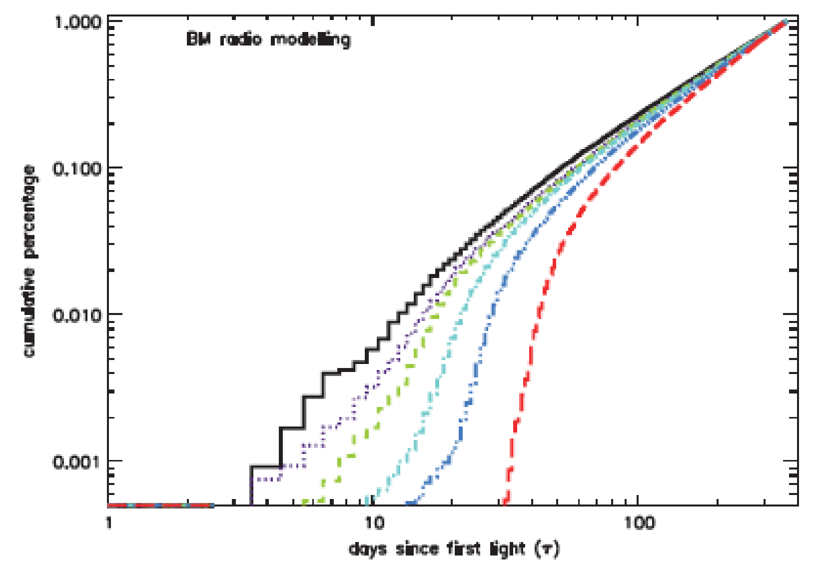
Complete X-ray radio-selected sample

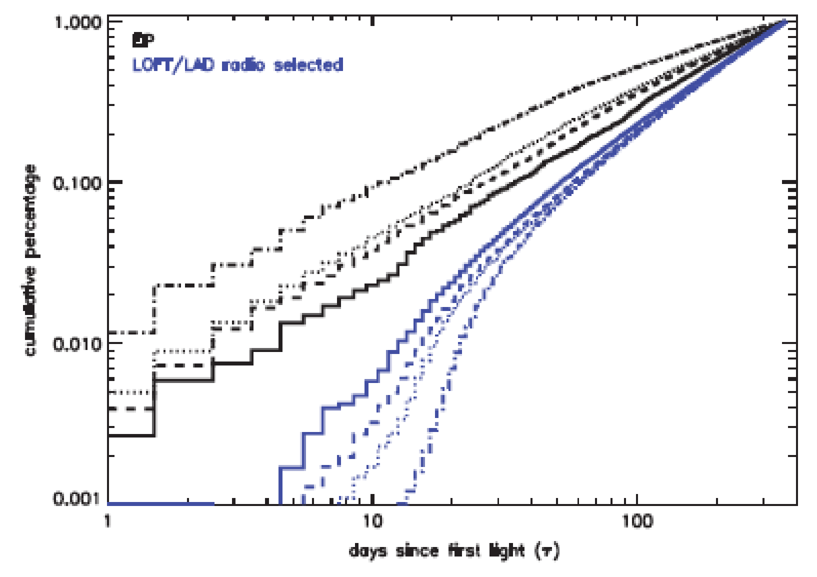
(sky accessibility and repointing efficiency)

ATHENA mission will be able to follow-up "almost" all radio triggered TDEs

(it depends on the sky accessibility, ~50%)

The trigger time: the complementary roles of radio and X-ray surveys





Main findings: II part

- SKA will have a great discovery potential of relativistic TDEs in combination with a prompt follow-up at higher energies (mainly in X-rays, e.g. Athena, XIPE). Several hundreds of TDEs expected to be detected up to z ~ 2.5 (if a jet efficiency of 100% is assumed)
- Future X-ray surveys will be complementary to the SKA detections, because of the chance to detect the TDE earlier than in radio, enabling the studyof the first phases of disc/jet formation

Conclusions

- The rate of TDEs will strongly depend on the observing strategy (20000 deg^2 of the sky covered in daily/even weekly passes looks as an effective strategy)

- A rapid quick look alert system needed for a fast repointing at higher energies

- Great perspectives in the future thanks to the synergy among radio (SKA), optical (LSST) and possibly X-ray surveys

- Jetted TDEs will provide a unique tool to detect quiescent SMBHs in the far Universe z ~2 -3, mainly in the low-mass tail of the SMBH mass function ($L_{TDE} \propto M_{BH}^{-1/2}$)

Future perspectives:
new code for the rate distribution

- Accounting for the spin distributions for different BH seed models (low vs high mass seeds)
- TDE rate dependence on BH m
- SPIN dependenc d in the calculation of th minosity in TDEs

Work in progress with E. Rossi, A. Sesana, E. Barausse