Tidal Disruption Rates: Promise and Puzzles

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Outline

- General introduction
  - Open questions
- Tidal disruption event rates
  - Two-body relaxation in large galaxy sample
- Implications
  - Optical emission mechanisms
  - SMBH mass function
  - Rate discrepancy

(Wikimedia Commons)

A Brief History of Tidal Disruptions

- First appearance in the literature: Wheeler 71
- Motivation: triggering disintegrational Penrose process

> *The "Squeezed Tube of Toothpaste" Mechanism*
>
> A process that gives directionality but not, he concludes, enough energy to be of interest has been proposed by Physicist X in unpublished work [8]. It starts again with spherical symmetry but this time the symmetry produced by complete

(Wheeler 71)

> [8] Physicist X is the same colleague who has supplied such interesting comments and discussion in THOMAS GOLD, ed., *The Nature of Time*, Cornell University Press, Ithaca, New York (1967).

(Wheeler 71)

- Origin: mysterious…

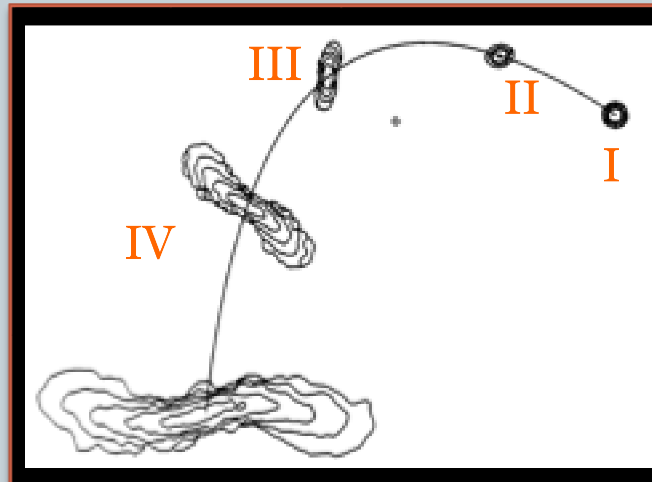
Motivations

- ~~Disintegrational Penrose process~~
- Laboratory for accretion/jet astrophysics
  - Super-Eddington flows
  - Jet launching mechanisms
- Unique probe of quiescent galactic nuclei
  - SMBH mass, spin [?] from *lightcurve, SED*
  - Stellar dynamics from *rate, inferred pericenter*

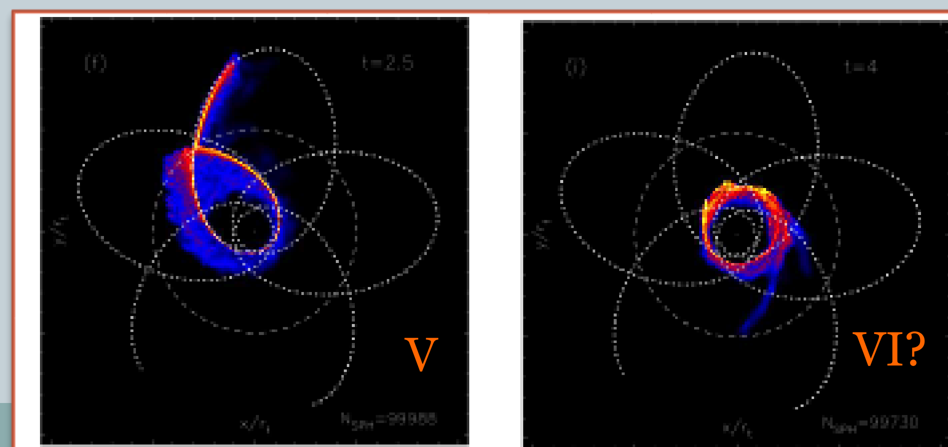
(Wikimedia Commons)

Stages of Tidal Disruption

- I: approximate hydrostatic equilibrium
- II: tidal free fall, vertical collapse
- III: maximum compression, bounce
- IV: rebound/expansion
- V: pericenter return, circularization
- VI: accretion



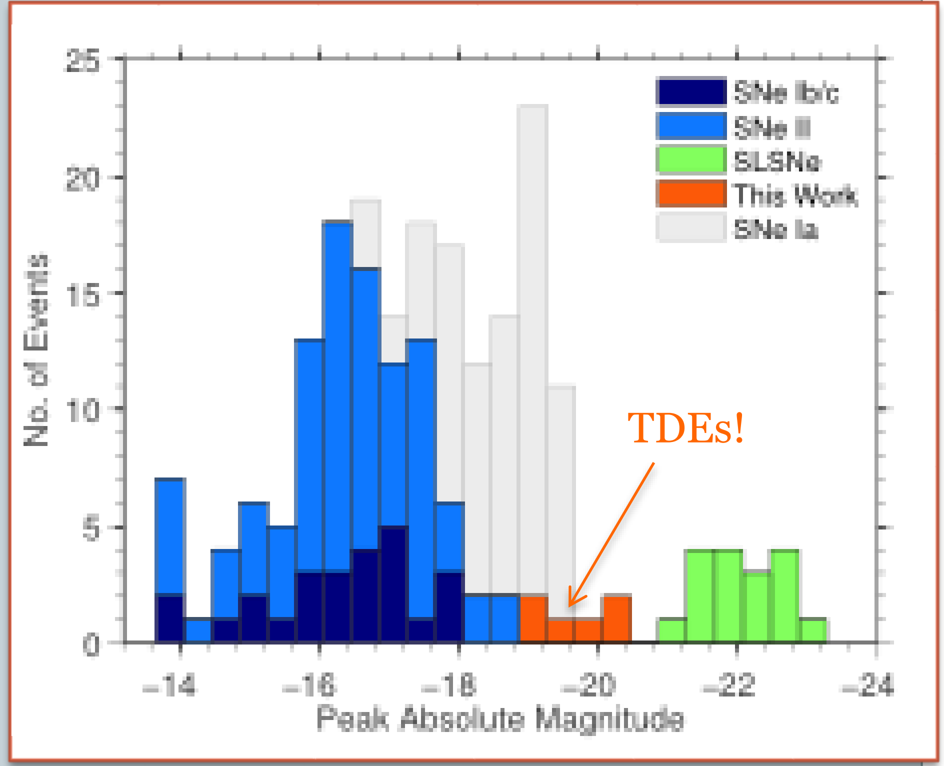
(Evans & Kochanek 89)



(Hayasaki, **Stone** & Loeb 12)

Observational History

- ~10-20 strong candidates
  - Most UV/X-ray
  - Optical (PTF, Pan-STARRS, SDSS) – see van Velzen talk
- Recent surprises:
  - Relativistic jets! (Bloom+11, Zauderer+11)
  - Hydrogen-free spectra! (Gezari+12)
- Upcoming time domain surveys expected to see ~10s-1000s/yr
  - LSST particularly promising (Strubbe & Quataert 09)
  - Radio surveys ~100s/yr? (Rossi/Zauderer talks)



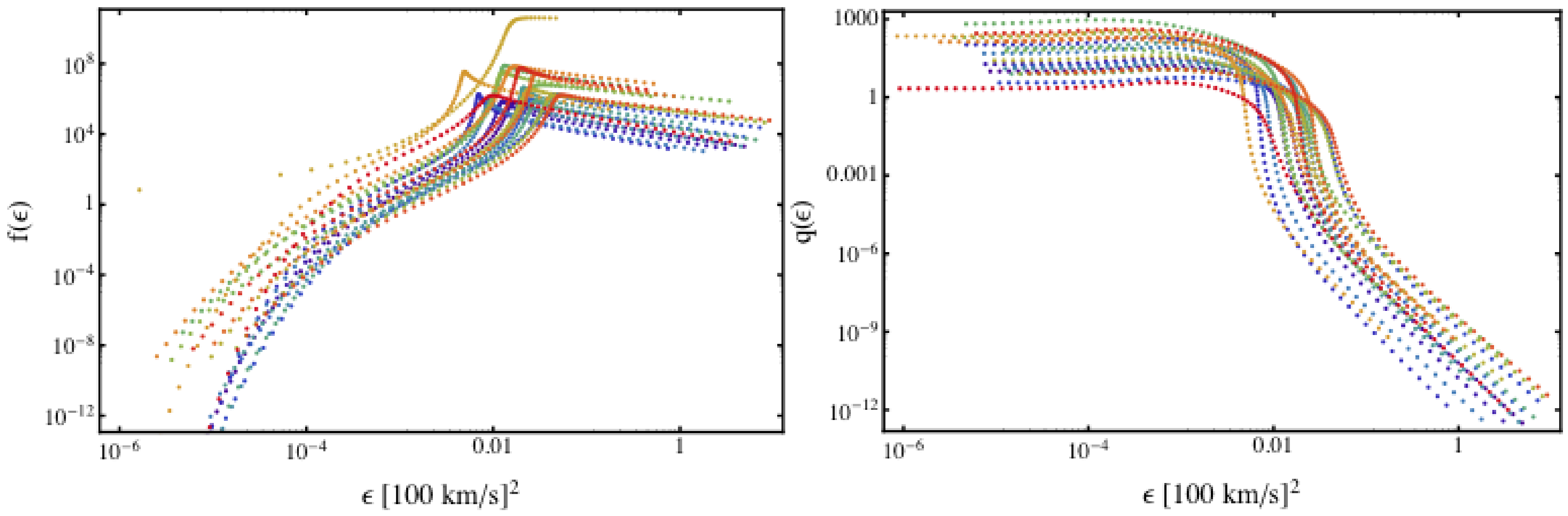
(Arcavi+ 14)

Major Uncertainties

- Event rates
  - Dominant mechanism?
  - Theory vs observation
- Optical emission mechanism?
- Jet launching fraction?
  - See also talks by Rossi, Zauderer
- *Importance of $\beta = R_t/R_p > 1$*
  - *No leading order impact on $\Delta\varepsilon$*
- *Light echoes?*
  - *See poster by Clausen*
- *Circularization of debris*
  - *Hayasaki+13/15, see also talks by Cheng, Rossi, Tejada…*

? ? ?

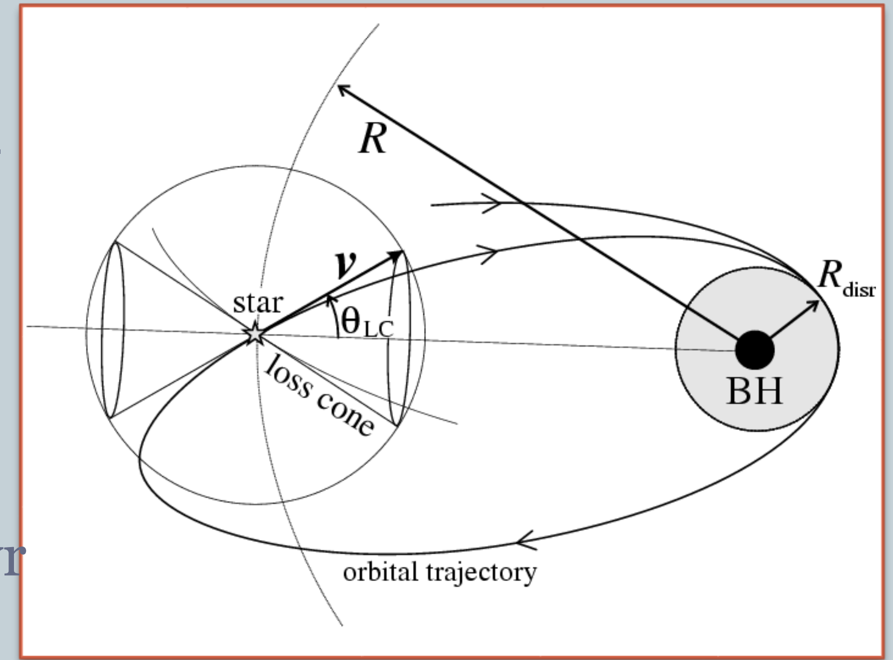
Event Rates



(**Stone** & Metzger 14)

Tidal Disruption Rates

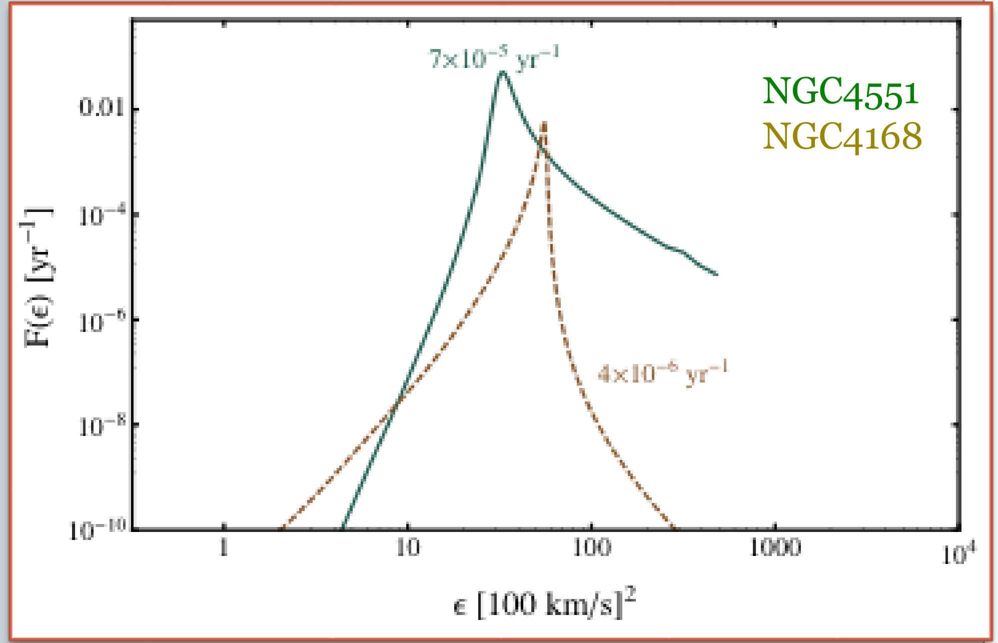
- Loss cone (two body scattering): $J<J_{LC}=(GM_{BH}R_t)^{1/2}$
  - Loss cone replenished via two-body relaxation
- Alternative relaxational mechanisms increase rate
- Motivations
  - Tension between theory (10^{-4} yr^{-1}) and observation (10^{-5} yr^{-1})
  - Probe of low mass SMBH demographics?



(Freitag & Benz 02)

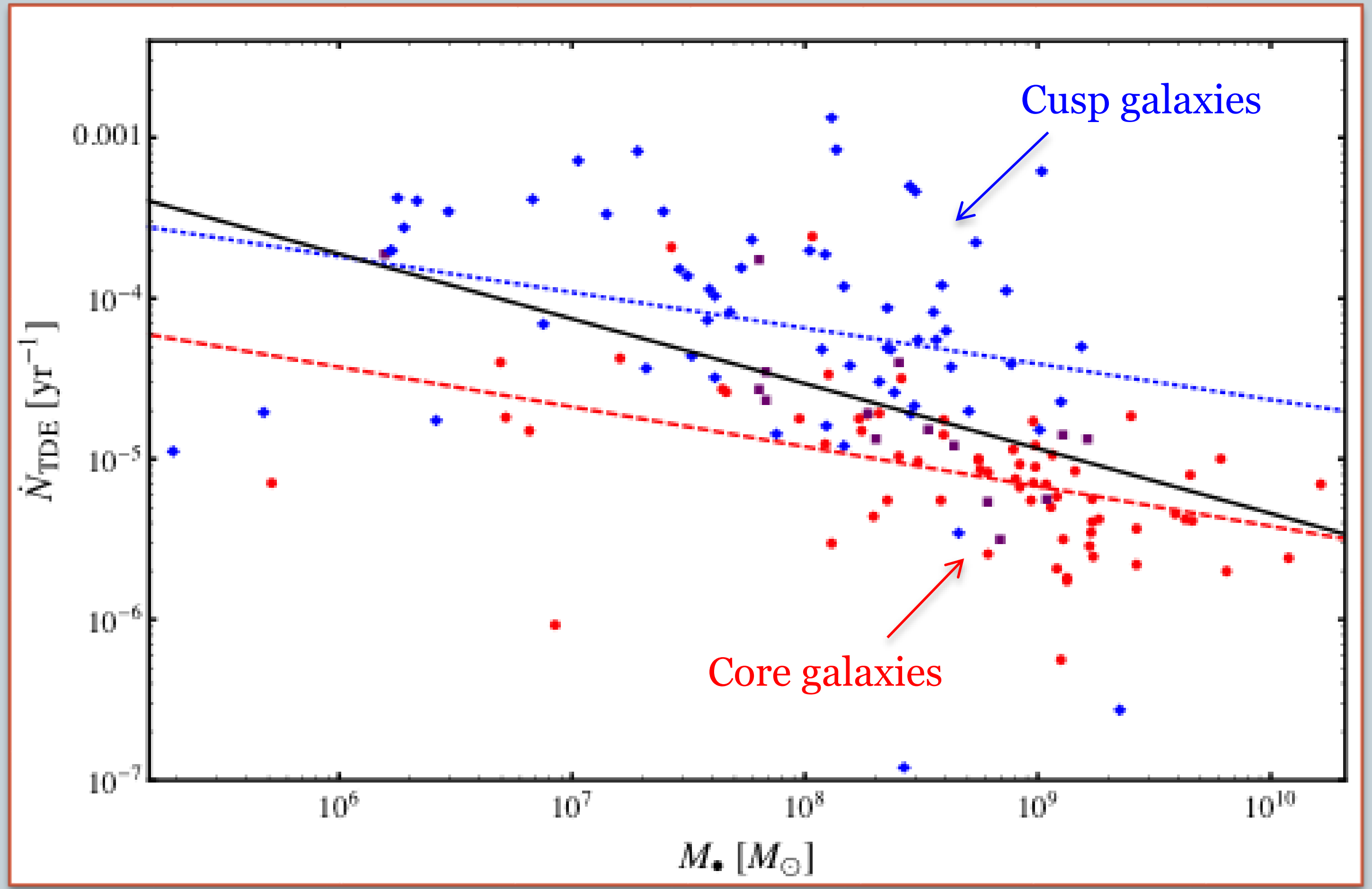
Two Body Scattering Rates

- Our approach: take Nuker (N~150) galaxy sample, use Wang & Merrit 04
- Deproject I(R)
  - Calculate ρ(r), f(ε)
- Orbit-average diffusion coefficients μ(ε)
- Calculate flux, F(ε), into loss cone
- Integrate over stellar PDMF, vary I(R), relax other assumptions…



(**Stone** & Metzger 14)

TDE Rates

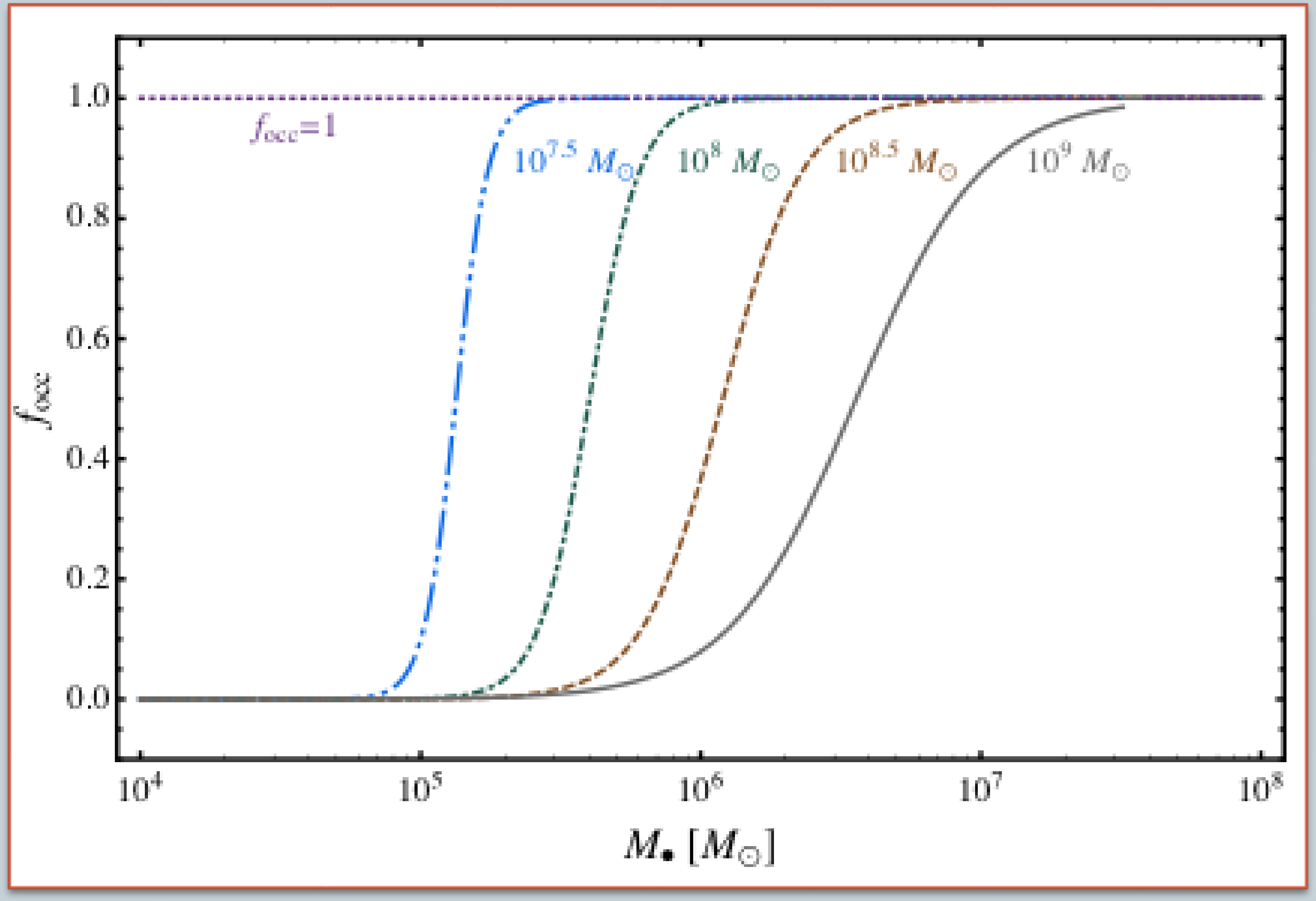


(**Stone** & Metzger 14)

Uncertainties in 2-Body Calculations

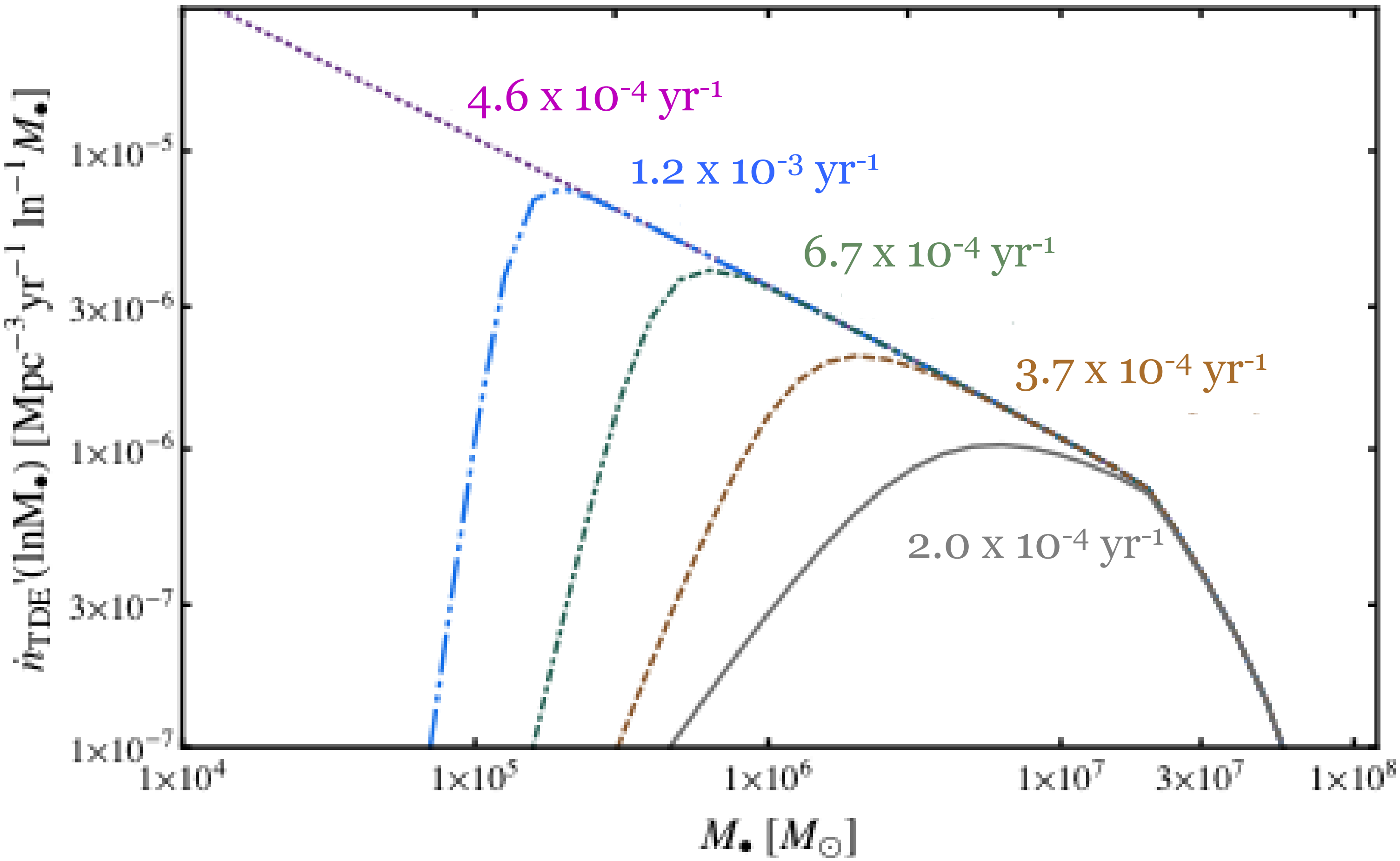
- Choice of I(R) parametrization
  - Nuker, Sersic, core-Sersic all similar in results
- Scaling relations
  - Unimportant
- Symmetry assumptions
  - Sphericity conservative
  - Isotropy mixed – radial bias ups rates, tangential decreases
- Stellar mass function
  - Functional form (Kroupa vs Salpeter) unimportant
  - Smallest stars dominate rate, heaviest diffusion coefficients
  - Stellar remnants *important*

Occupation Fractions



(**Stone** & Metzger 14)

Intrinsic TDE Rates



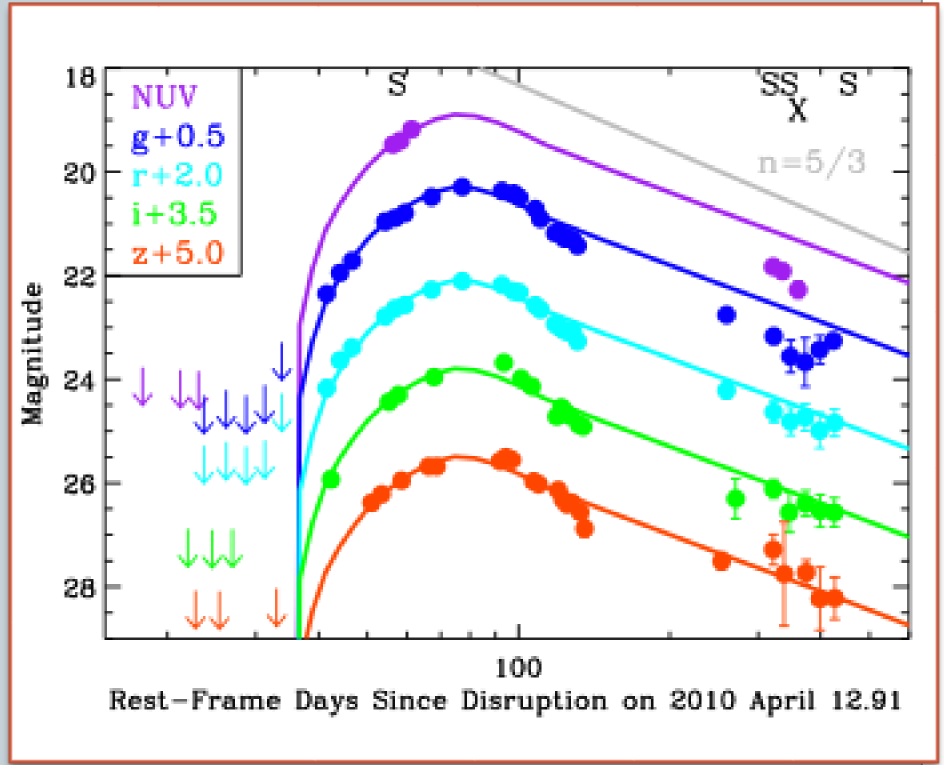
(**Stone** & Metzger 14)

Rates Discrepancy

- Persistent! Our calculation is conservative:
  - 2-body relaxation only
  - Neglect enhanced diffusion from remnants
  - Spherical symmetry
- Possible ways out:
  - *Not* occupation fraction
  - *Probably not* dust obscuration – see talk by van Velzen
  - *Probably not* selection effects – see van Velzen & Farrar 14
  - Bimodality in optical emission?
  - Strong and tangential velocity anisotropies? Aka SMBH binaries?

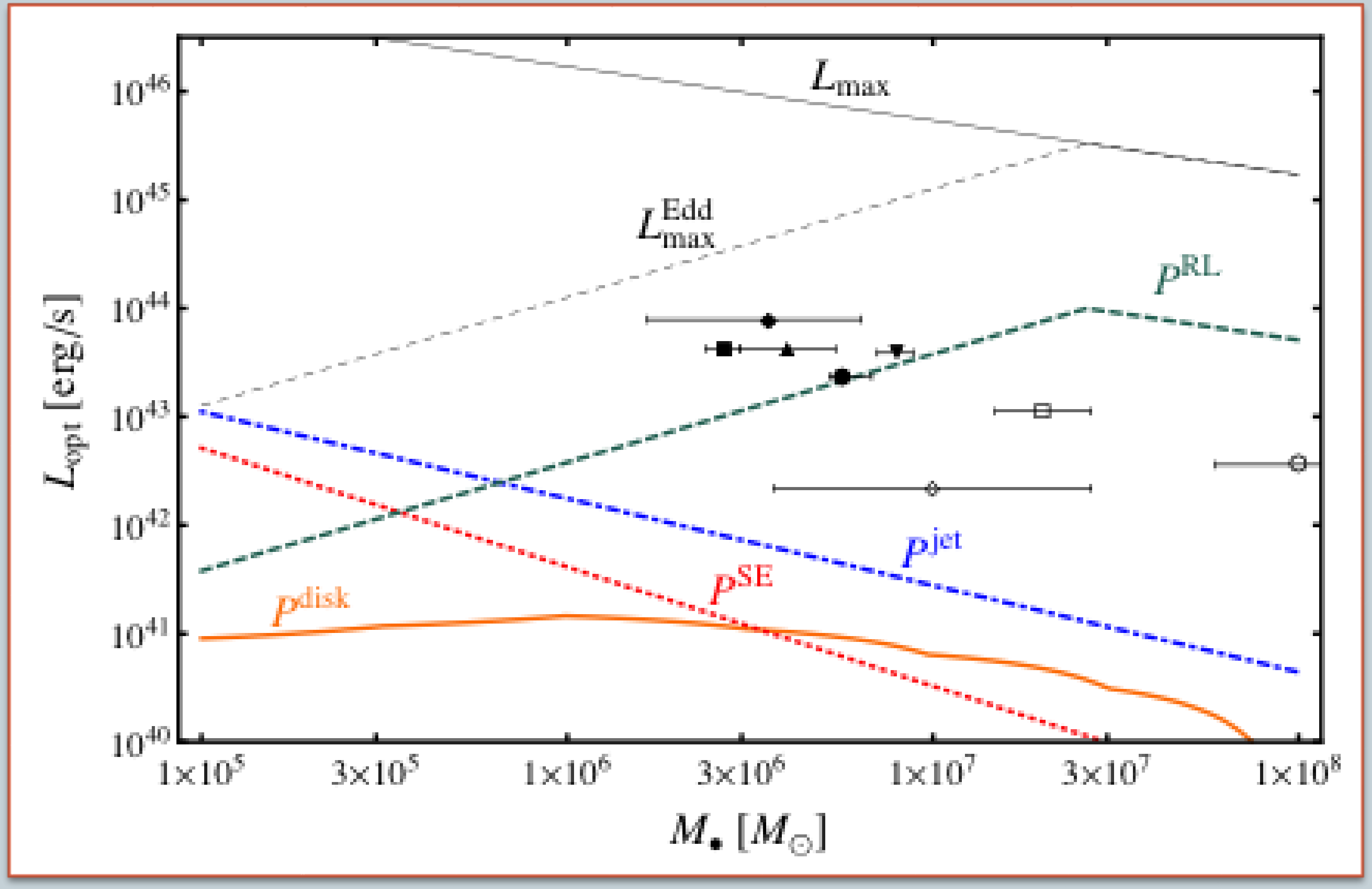
Optical Emission from TDEs

- Highly uncertain, many proposed mechanisms
  - Accretion disk (too dim, fade too slow, $t^{-5/12}$)
    - Strubbe & Quataert 09, Shen & Matzner 14
  - Outflows (fade too fast, $t^{-95/36}$)
    - Strubbe & Quataert 09, Lodato & Rossi 11
  - Relativistic jet (nonthermal spectrum, radio nondetections)
    - **Stone** & Metzger 14
  - Reprocessing layer
    - Guillochon+14, Coughlin & Begelman 14
- Our paper: agnostic



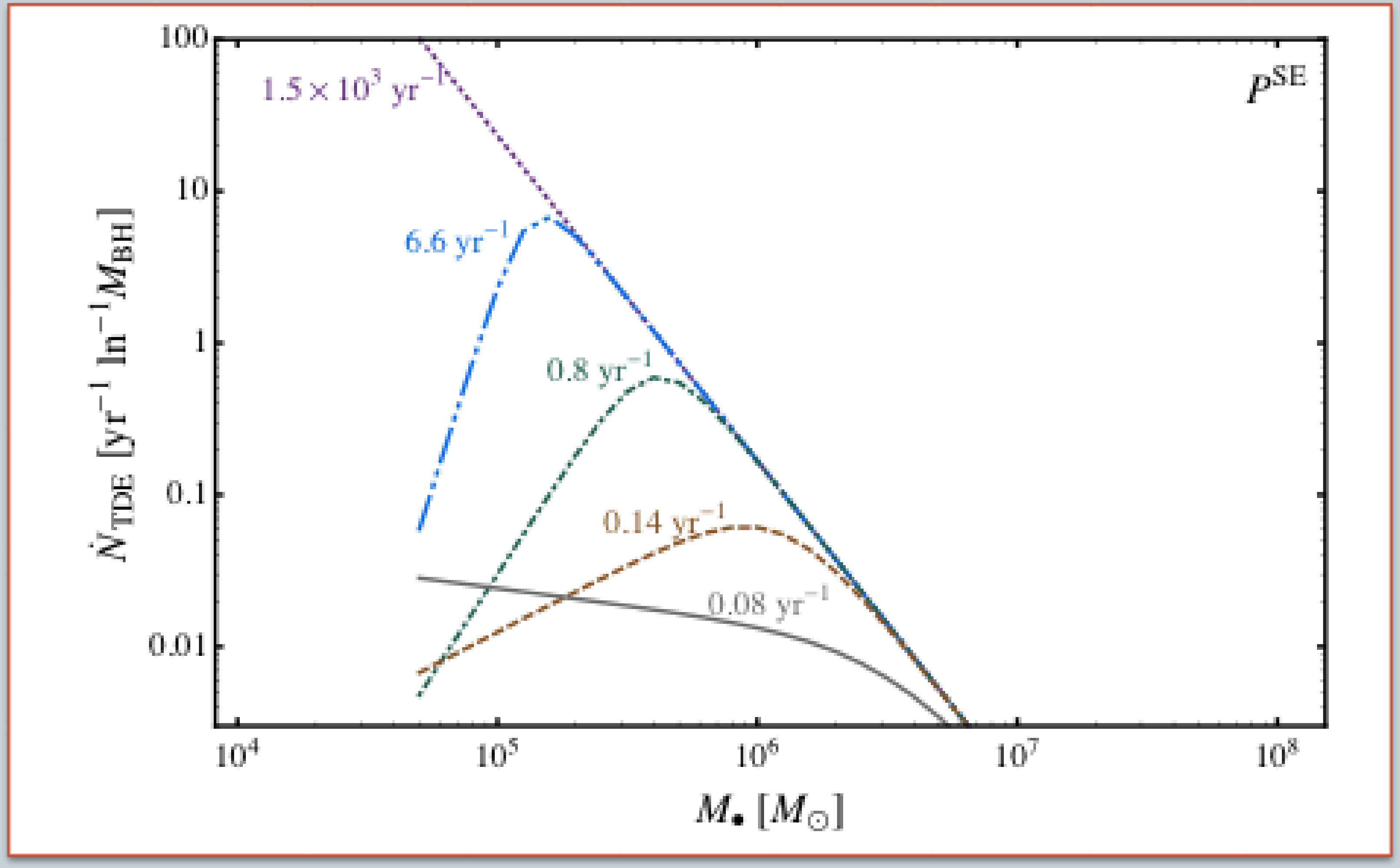
(Gezari+ 12)

Peak Luminosities



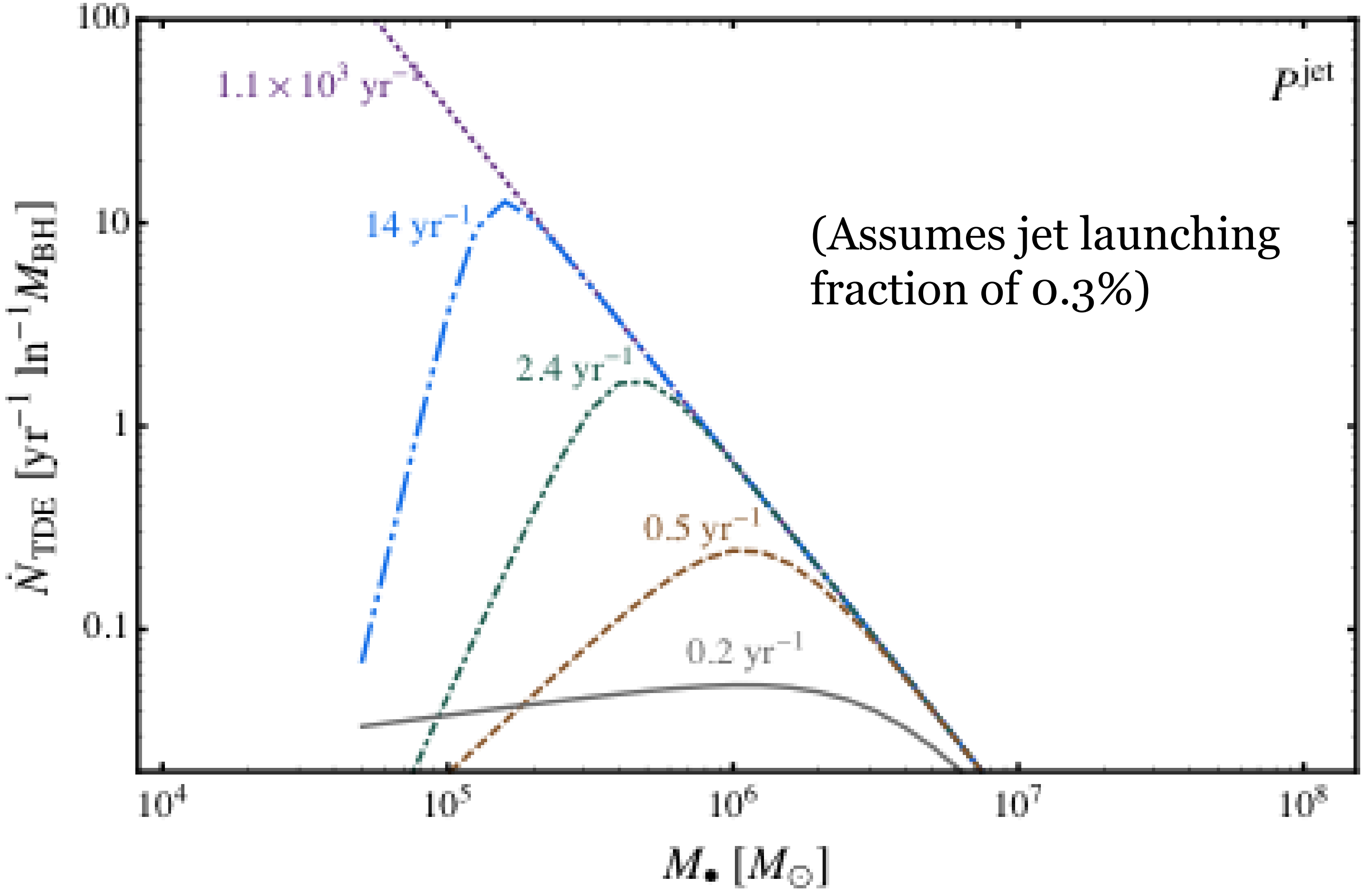
(**Stone** & Metzger 14)

Detectable TDE Rates (Outflow)



(**Stone** & Metzger 14)

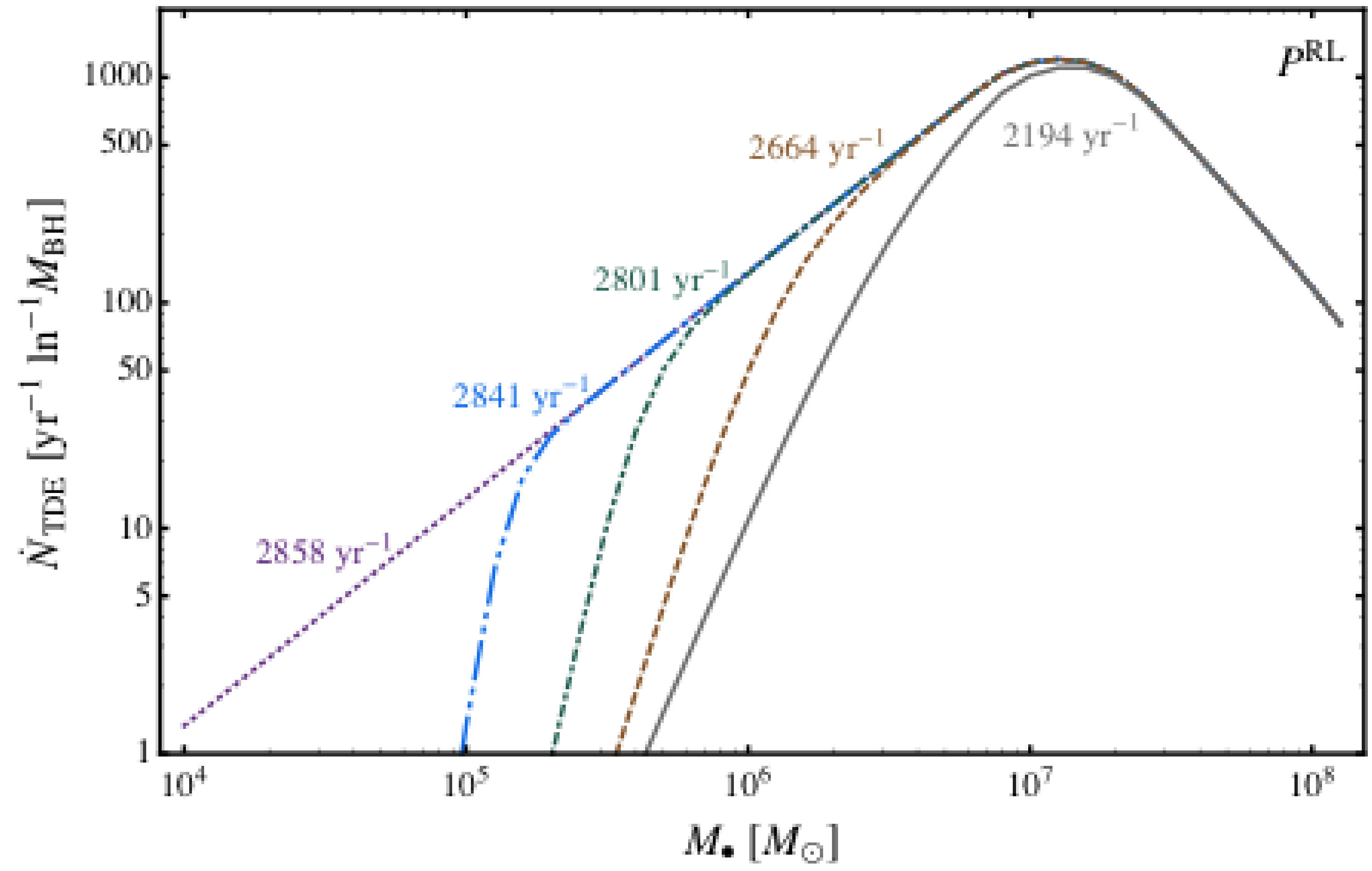
Detectable TDE Rates (Jet)



(Assumes jet launching fraction of 0.3%)

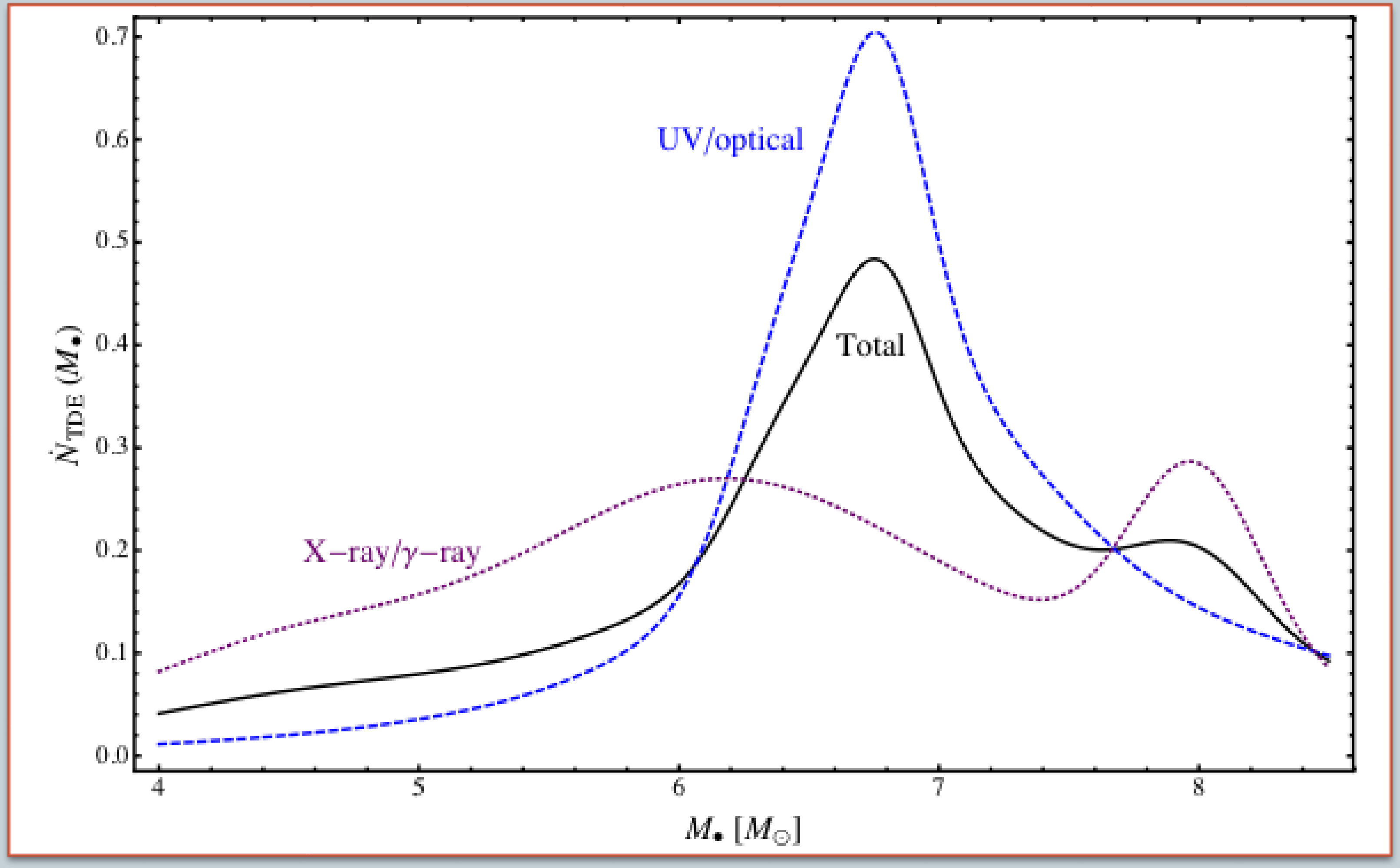
(**Stone** & Metzger 14)

Detectable TDE Rates (Reprocessing Layer)



(**Stone** & Metzger 14)

Observed SMBH Masses



(**Stone** & Metzger 14)

What's Going on in the Optical?

- Spreading disk far too dim to explain observations
- Super-Eddington mechanisms extremely sensitive to f_{Occ}
  - Optical synchrotron constrains jet launching fraction
- Reprocessing layer model ad hoc, closest to observations
  - Detected rate tension unless reprocessing fraction low
  - Circularization efficiency?
- Current MBH sample inhomogeneous, but nonetheless:
  - May rule out super-Eddington optical mechanisms

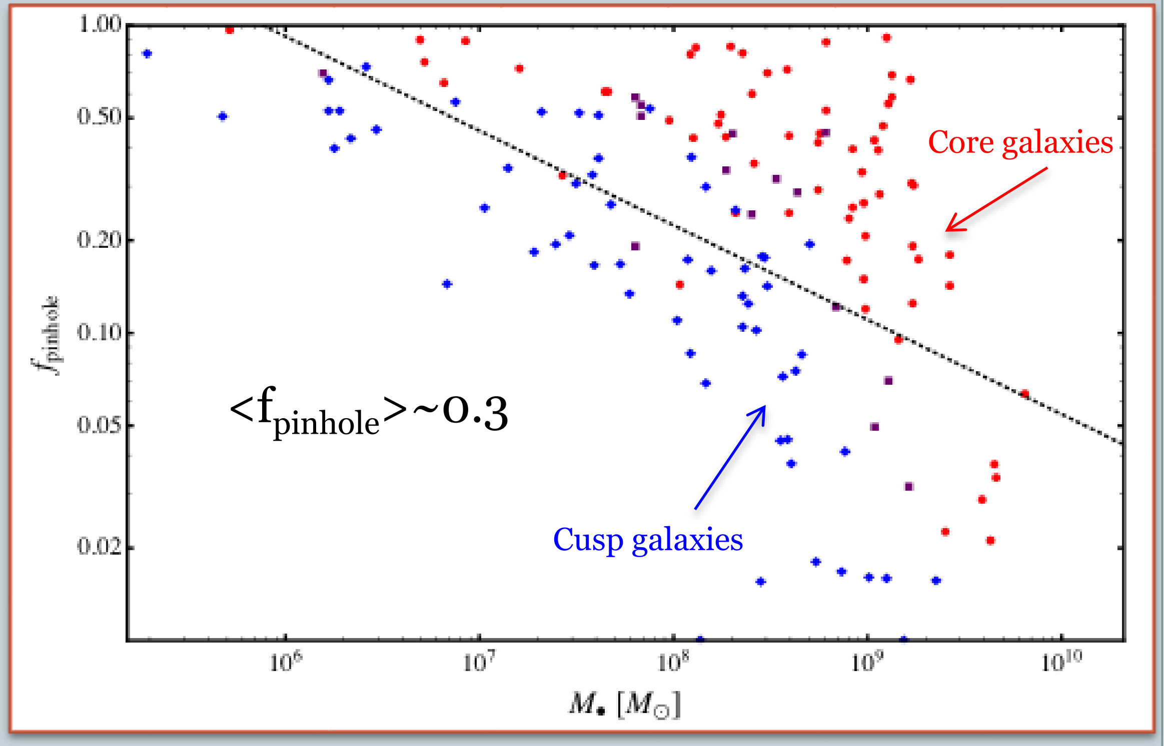
Conclusions

- Discrepancy between theory and observation?
  - Persistent! Even for 2-body scattering
  - Gets worse with realistic IMF, alternate galaxy parametrizations, alternate relaxational mechanisms…
- Sensitive to SMBH occupation fraction?
  - *Very* sensitive, for volume-complete survey OR super-Eddington emission
  - *Weakly* sensitive, for flux-limited survey AND Eddington-limited emission
- Optical emission?
  - Reprocessing layer favored, but possible strong optical bimodality
- High $\beta(=R_t/R_p)$ events?
  - Relatively common! Good news for theorists…

Questions?

Pinhole Fraction

- Two regimes of tidal disruption
- Identified by $q(\varepsilon)=(\Delta J/J_{LC})^2$
  - $J_{LC}=(GM_{BH}R_t)^{1/2}$
- Diffusive regime: $q<1$, $\beta=R_t/R_p=1$
- Pinhole regime: $q>1$, $N(\beta) \propto \beta^{-1}$
  - Only ~15% partial disruptions



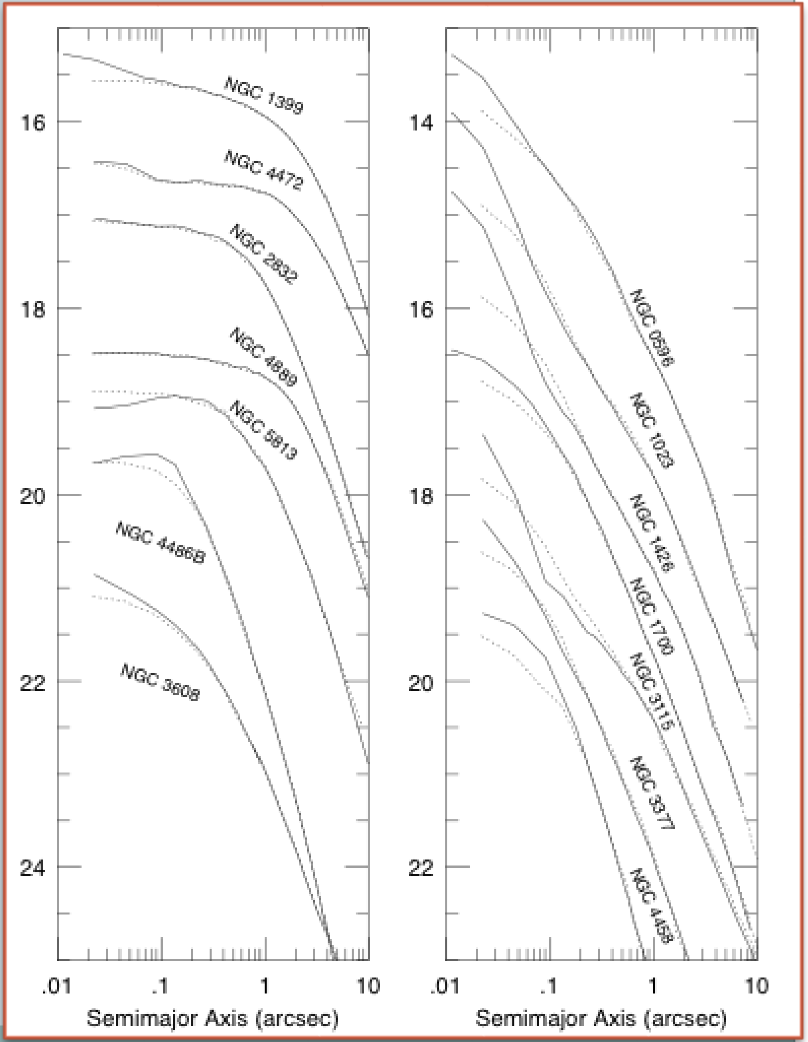
(**Stone** & Metzger 14)

Galaxy Sample

- "Nuker" galaxy sample (Lauer+05, Lauer+07)
- High resolution HST imaging
  - Fit to parametrized profile:

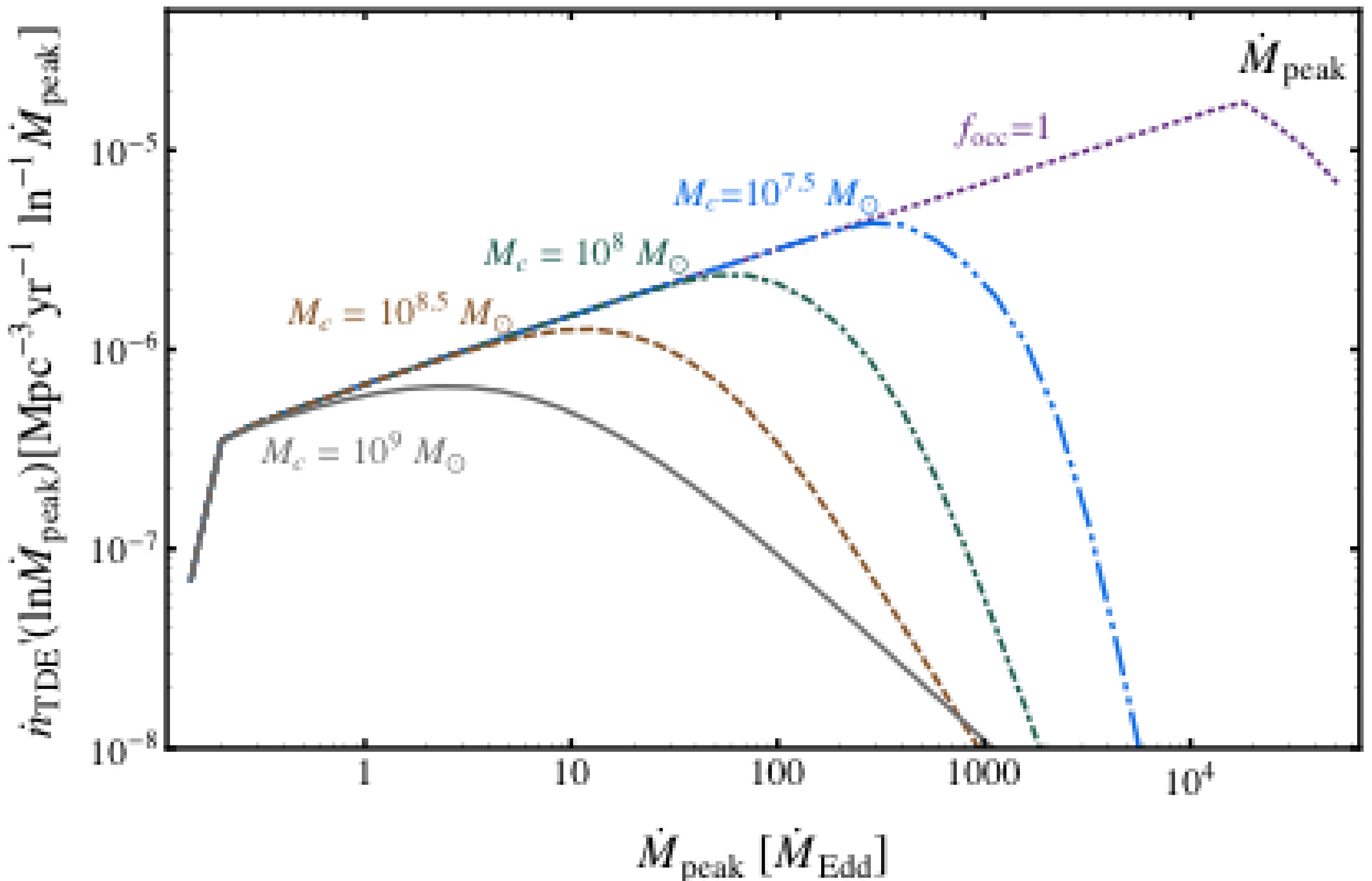
$$I(R) = 2^{(\beta-\gamma)/\alpha} I_b \left(\frac{R_b}{R}\right)^{\gamma} \left(1+\left(\frac{R}{R_b}\right)^{\alpha}\right)^{(\gamma-\beta)/\alpha}$$

- Black hole masses calculated from M_{BH}-σ
- 146 galaxies after rejections (<40 in past works)



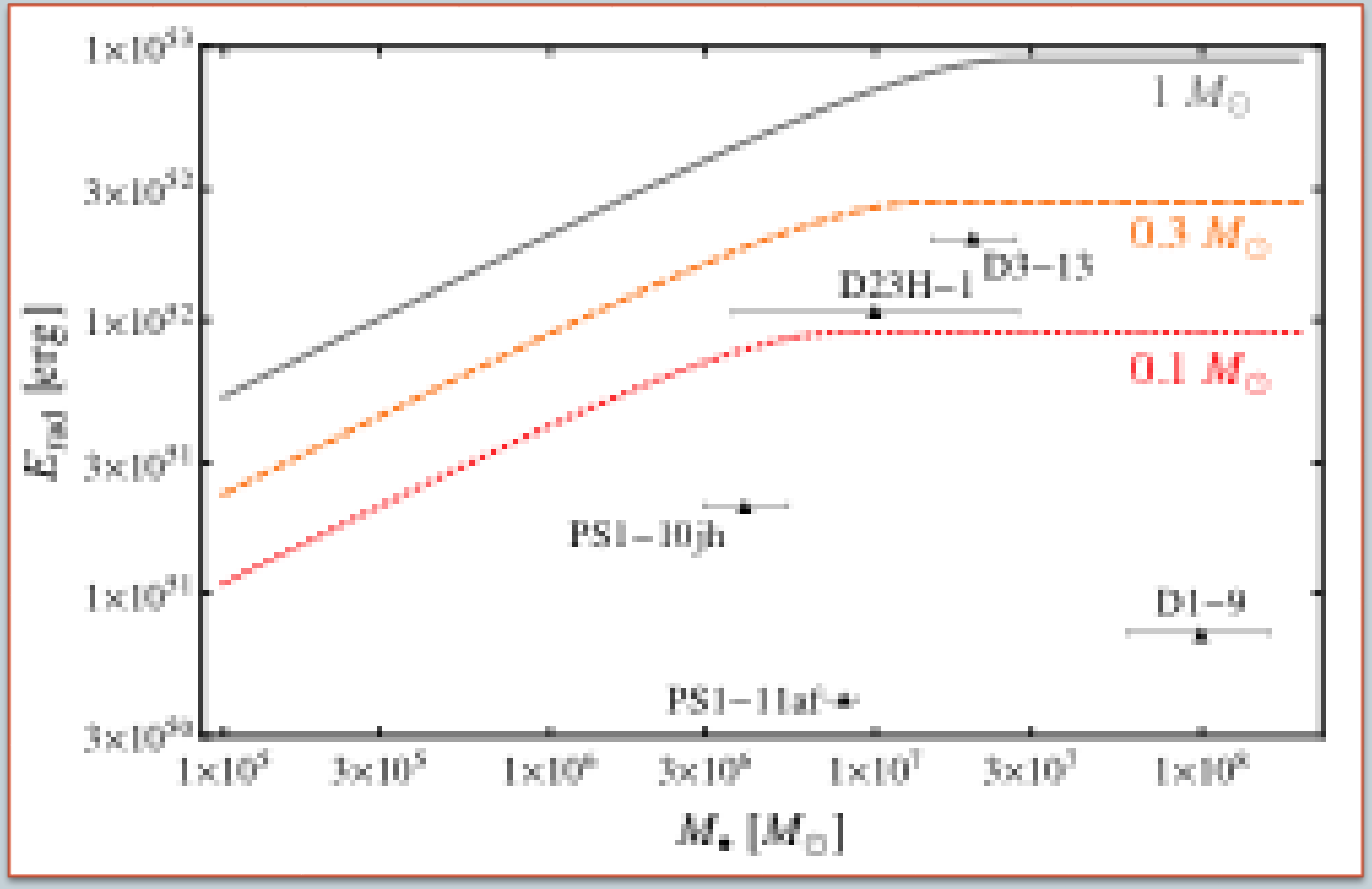
(Lauer+05)

Intrinsic Fallback Rates



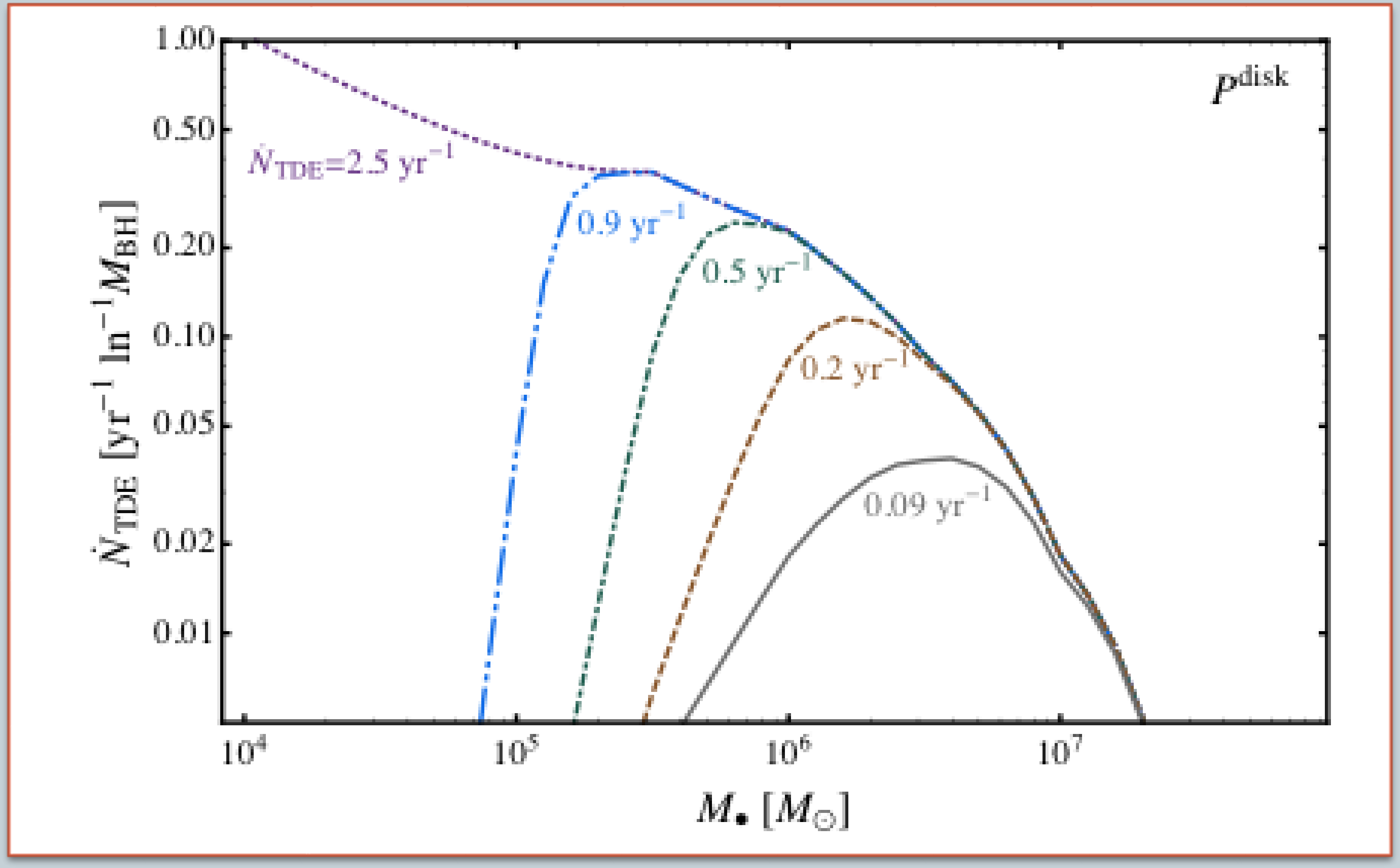
(**Stone** & Metzger 14)

Total Energy Release



(**Stone** & Metzger 14)

Detectable TDE Rates (Disk)



(**Stone** & Metzger 14)