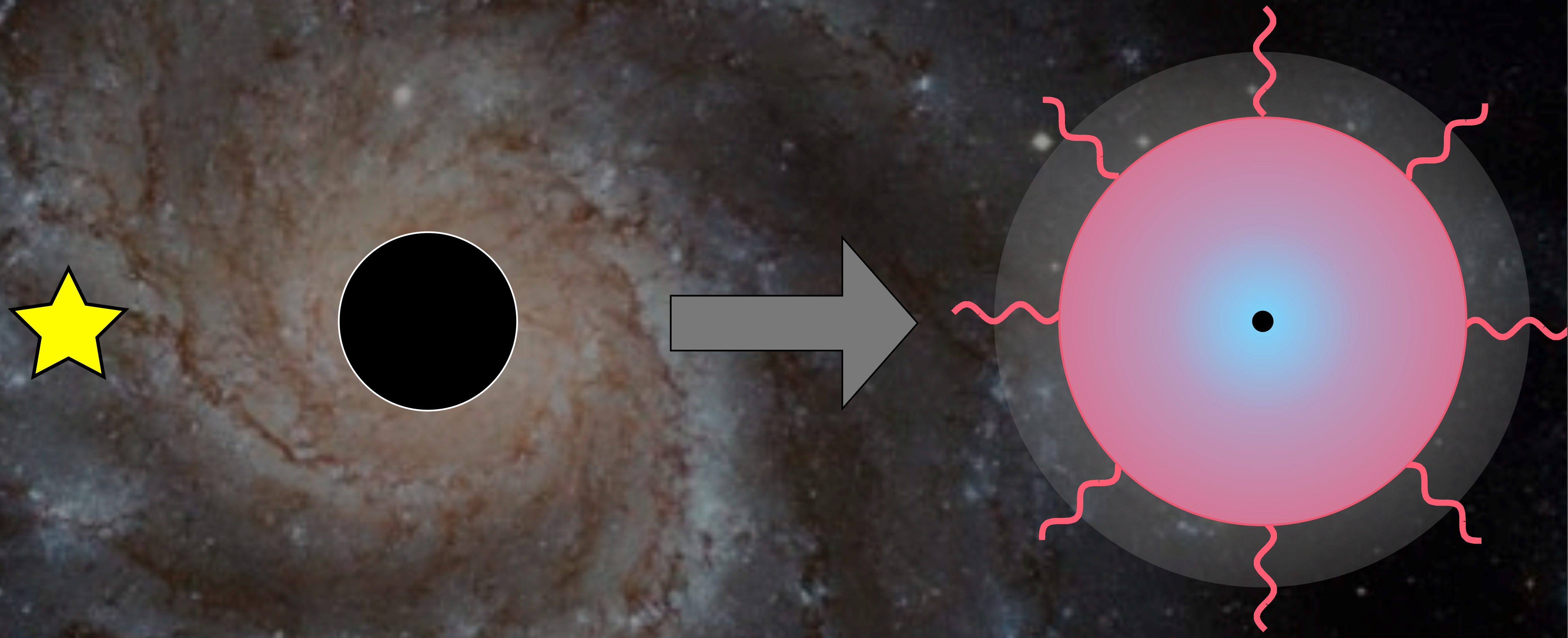
Predictions for the Observational Properties of Tidal Disruption Events:
Super-Eddington Outflow & Accretion Disk



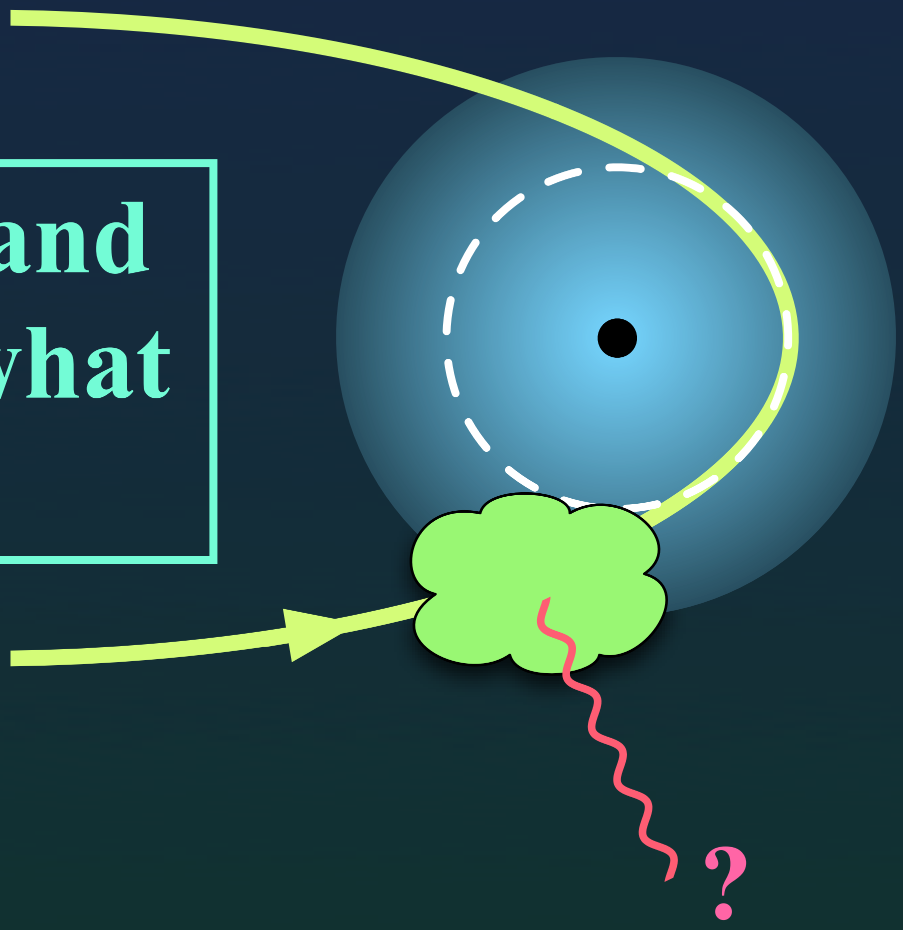
Linda Strubbe

CITA Postdoctoral Fellow (Toronto)

Emission from Tidal Disruption Events

Having an idea about rate of gas falling back to the black hole $\dot{M}_{\rm fallback}$ ...

What are the accretion physics and radiative processes that tell us what we're likely to observe?



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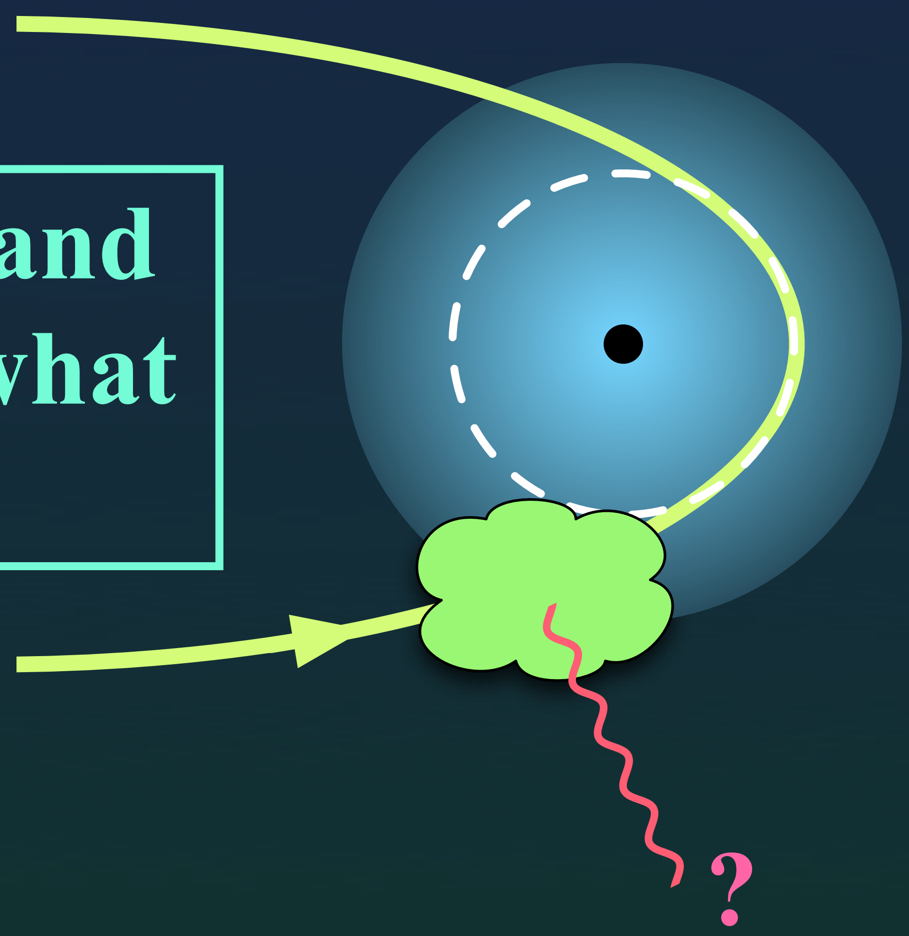


What are the accretion physics and radiative processes that tell us what we're likely to observe?

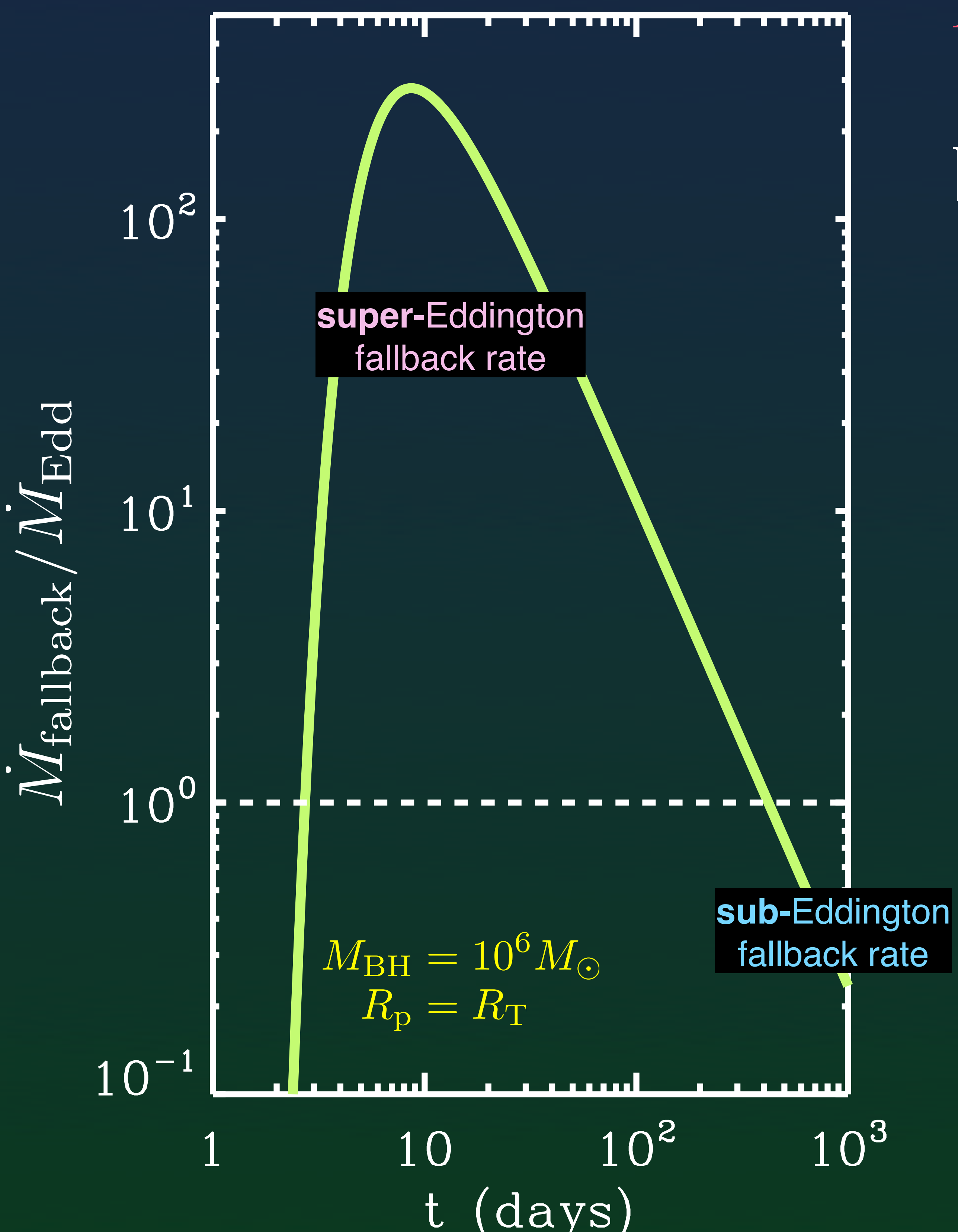
Not as simple as $\nu L_\nu \propto \dot{M}_{\rm fallback}$ ... !

- What observing band?
- What radiative processes? In thermal equilibrium?
- What are temperature and area of emitting region?

Focus on **optical/UV emission**, for recent/upcoming transient surveys **(GALEX, Palomar Transient Factory, Pan-STARRS, LSST)**

The Bound Material: Fallback

$$\dot{M}_{\rm fallback} \sim \frac{M_*}{t_{\rm fallback}} \left(\frac{t}{t_{\rm fallback}} \right)^{-5/3}$$



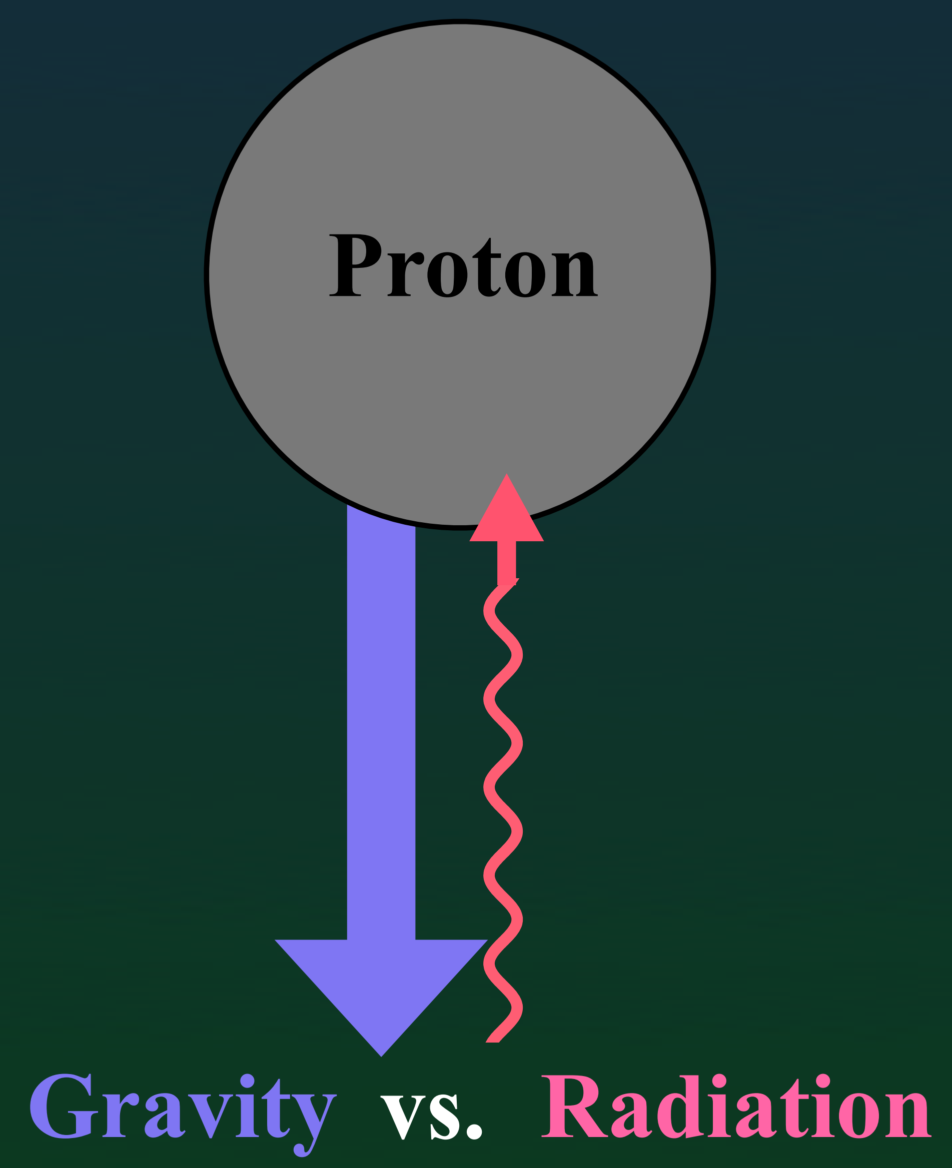
Eddington rate:

Radiation pressure

(produced by accretion)

balances Gravity

(from the black hole)



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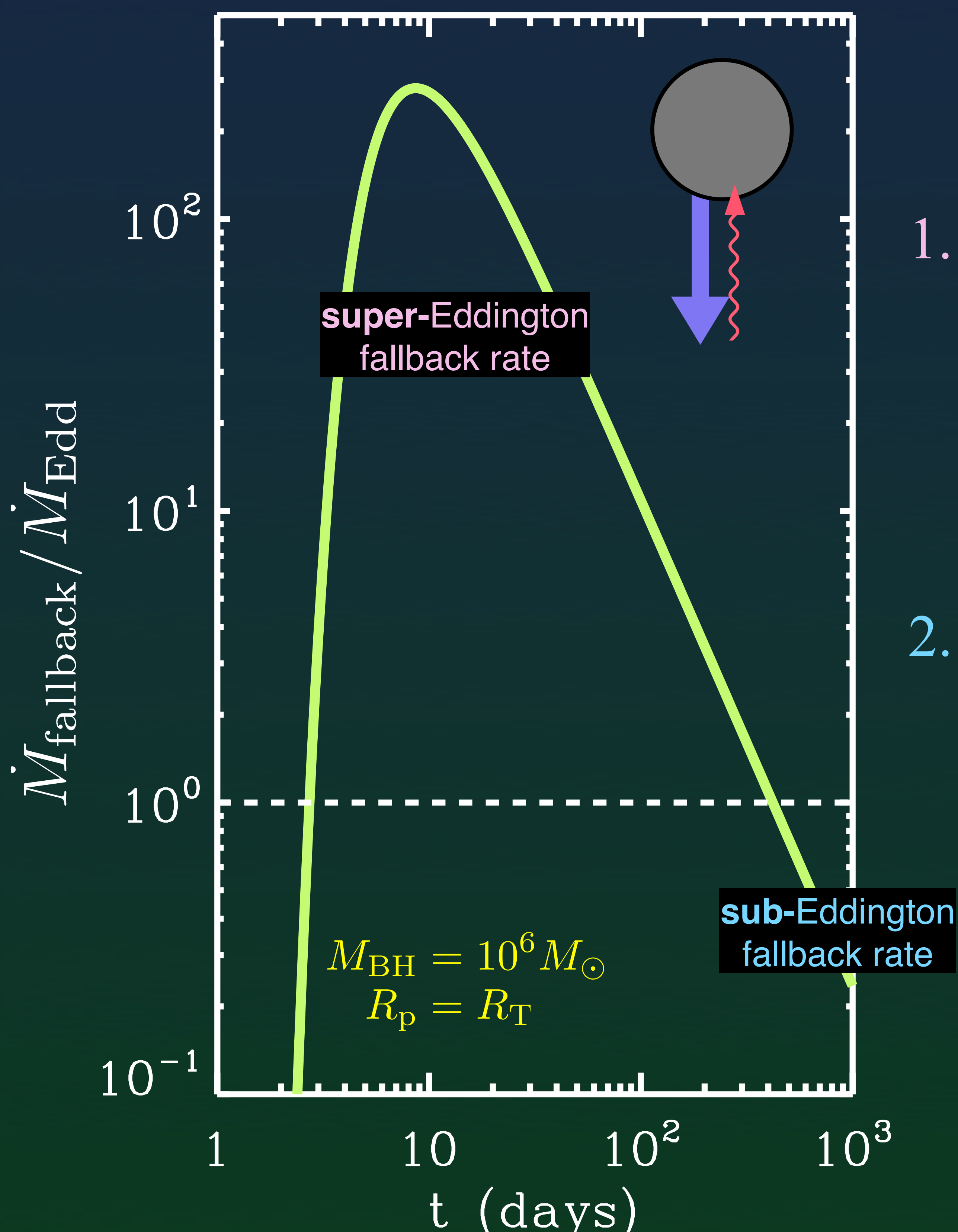

As fallback rate declines with time, 2 Phases of Evolution:

1. **Super-Eddington fallback**: ~weeks - months

   $\dot{M}_{\rm fallback} \gg \dot{M}_{\rm Edd}$

   Physics is uncertain, but likely advective disk + powerful outflows

2. **Sub-Eddington fallback**: ~months - year

   $\dot{M}_{\rm fallback} \lesssim \dot{M}_{\rm Edd}$

   Thin accretion disk

e.g., Evans & Kochanek (1989), Cannizzo et al. (1990), Ramirez-Ruíz & Rosswog (2009), Lodato et al. (2009), Guillochon & Ramirez-Ruíz (2012)

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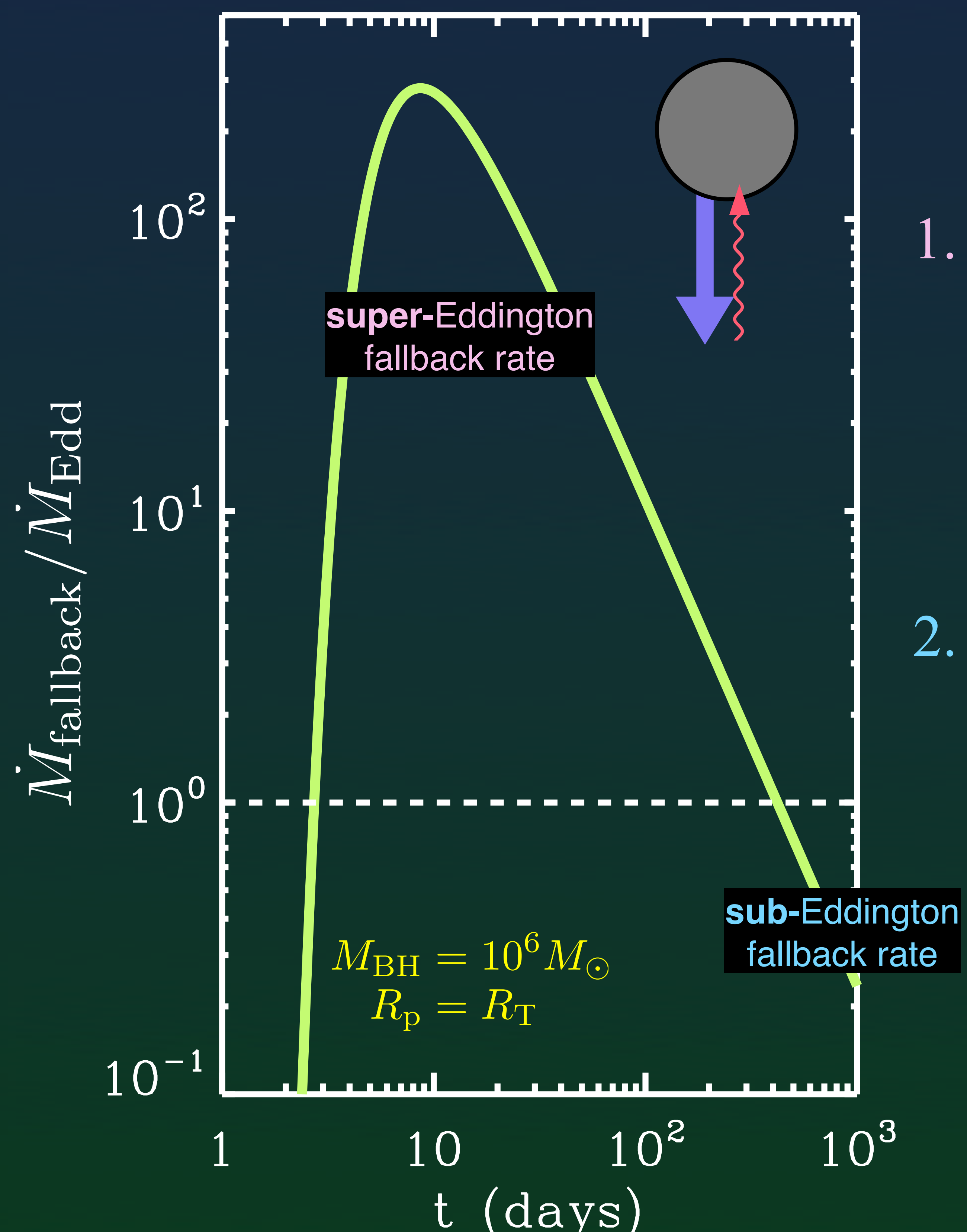

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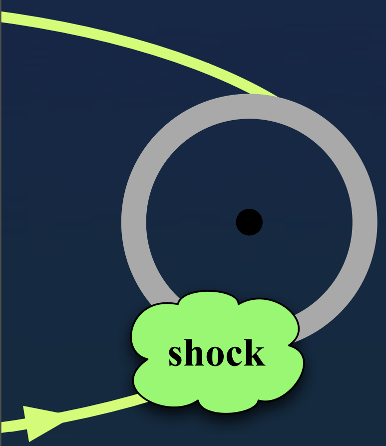


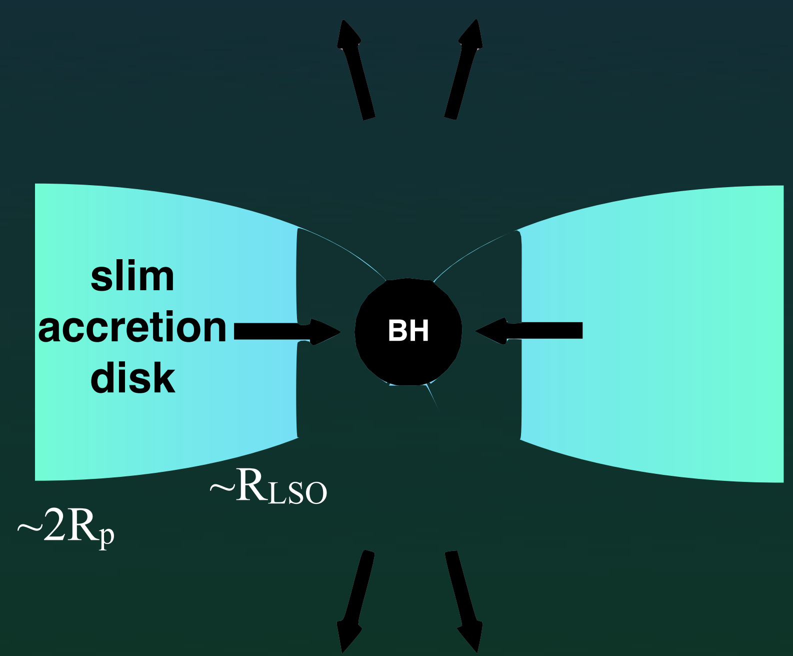
- debris shocks and circularizes
- forms steady accretion disk

in time $t_{\rm visc} \ll t_{\rm fallback}$

- disk is optically thick
- supported by radiation pressure

Solve equations for disk structure:

(discuss outflowing gas shortly)



Super-Eddington fallback rate

$t_{\rm photon\ diff} > t_{\rm advect}$

emission ~capped at $L_{\rm edd}$

Blackbody temperature

Sub-Eddington fallback rate

$t_{\rm photon\ diff} < t_{\rm advect}$

emission declines with time

The Bound Material: Accretion disk

- multicolor blackbody peaks at ~100 eV ~ 100 Å

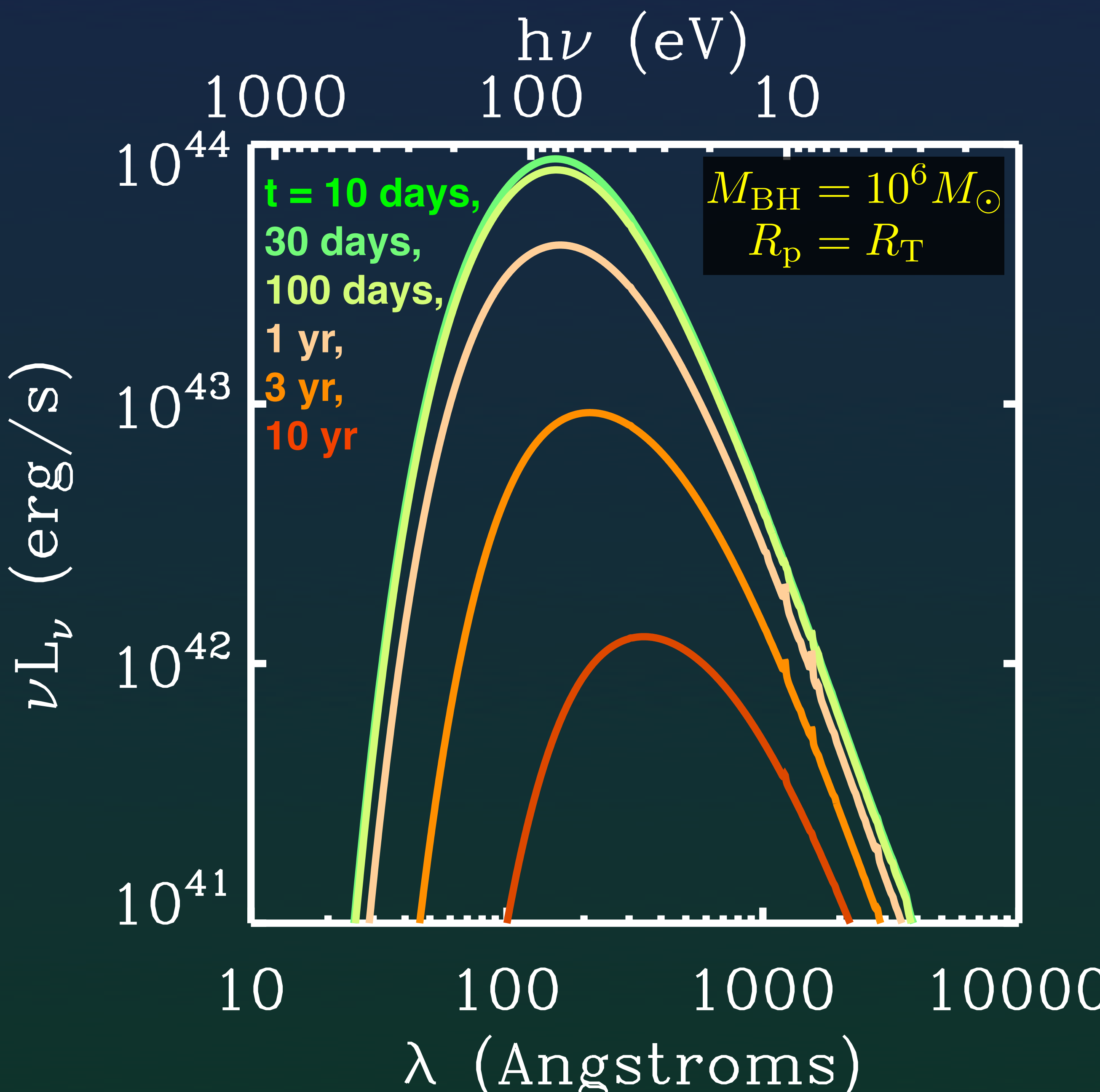
- while $\dot{M}_{\rm fallback} > \dot{M}_{\rm Edd}$, disk luminosity is constant at $L_{\rm Edd}$

- once $\dot{M}_{\rm fallback} < \dot{M}_{\rm Edd}$, disk cools and fades

$$L_{\rm bol} \propto T^4 \propto \dot{M}_{\rm fallback} \underset{\sim}{\propto} t^{-5/3}$$

$$L_{\rm optical} \propto T \propto \dot{M}_{\rm fallback}^{1/4} \underset{\sim}{\propto} t^{-5/12}$$

- faint emission lines from photoionized surface of unbound debris



- fairly modest optical emission

Strubbe & Quataert (2009)

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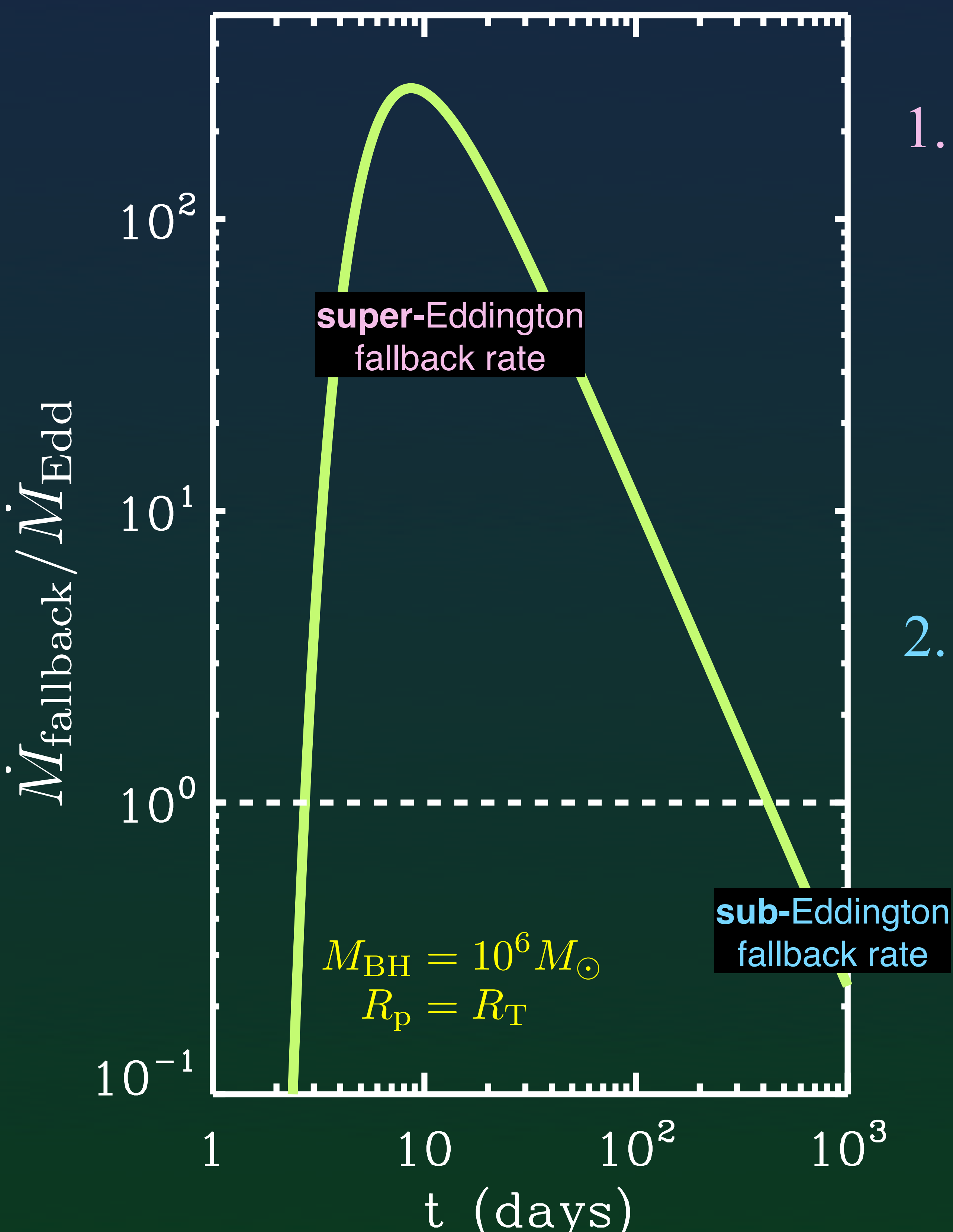

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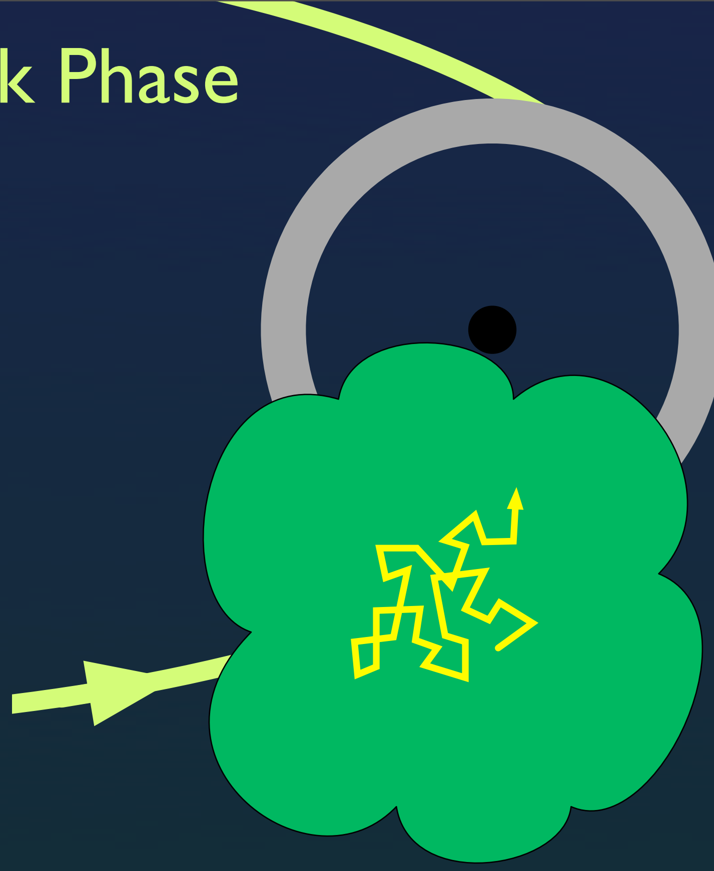
   Thin accretion disk

e.g., Loeb & Ulmer (1997), Ayal et al. (2000)
see also Lodato & Rossi (2011)

The Bound Material: Super-Eddington Fallback Phase

- High fallback rate →
  High density at pericenter

- Electron scattering traps photons.
  Matter is so dense that most photons cannot diffuse out.



Radiation pressure drives gas back outward.

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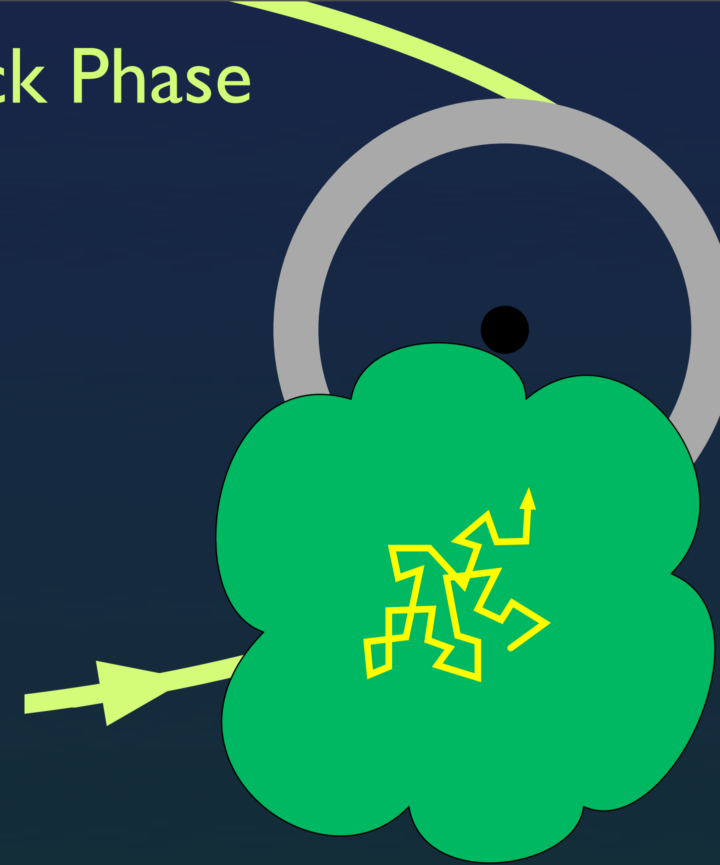
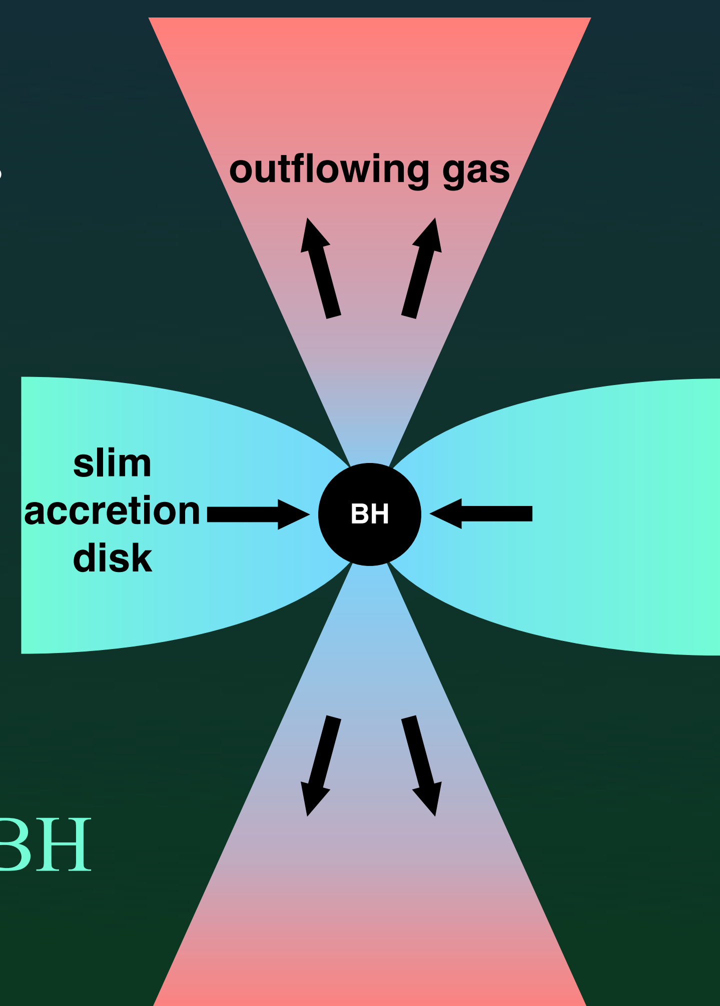


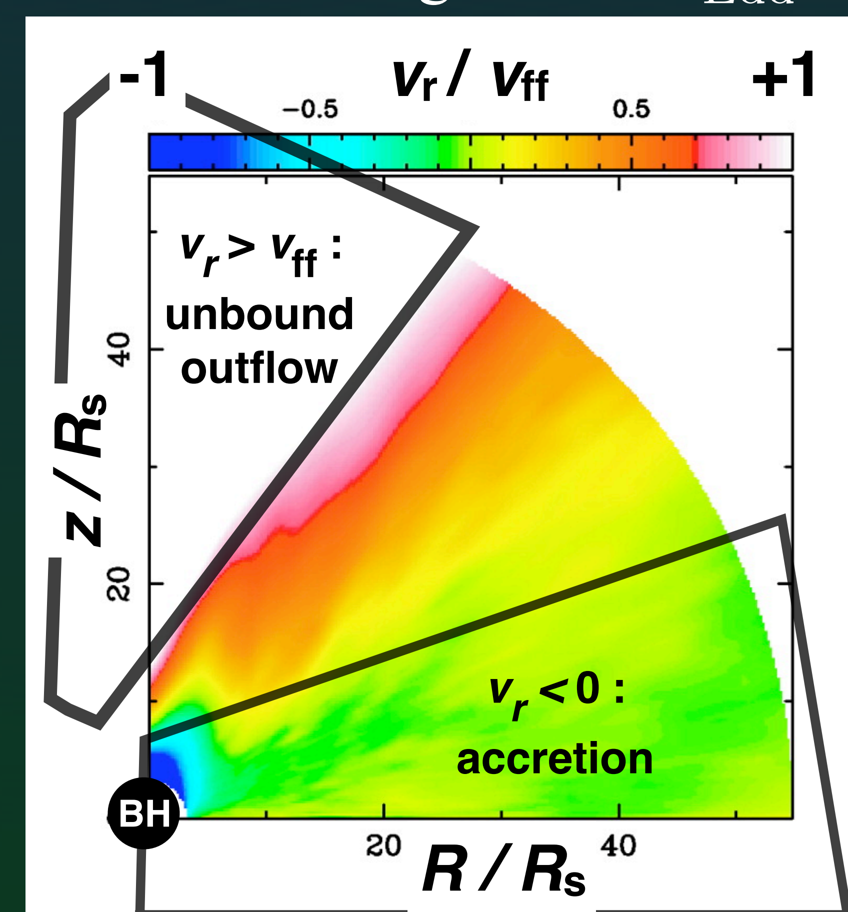
Trapped heat should...

1. unbind gas and drive
outflow

2. be dragged along with gas
accretion disk into the BH



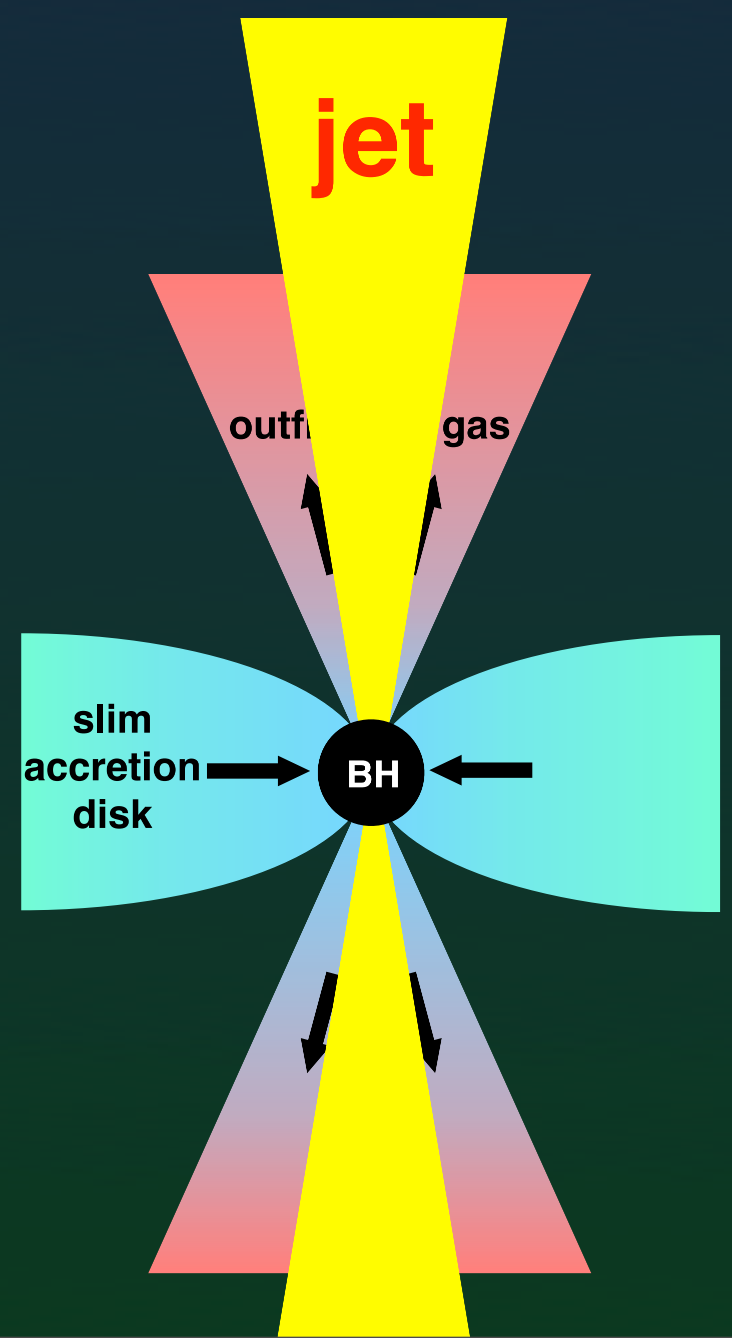
Radiation hydrodynamic sim. of BH feeding at 100 $\dot{M}_{\rm Edd}$



(Ohsuga & Mineshige 2007)

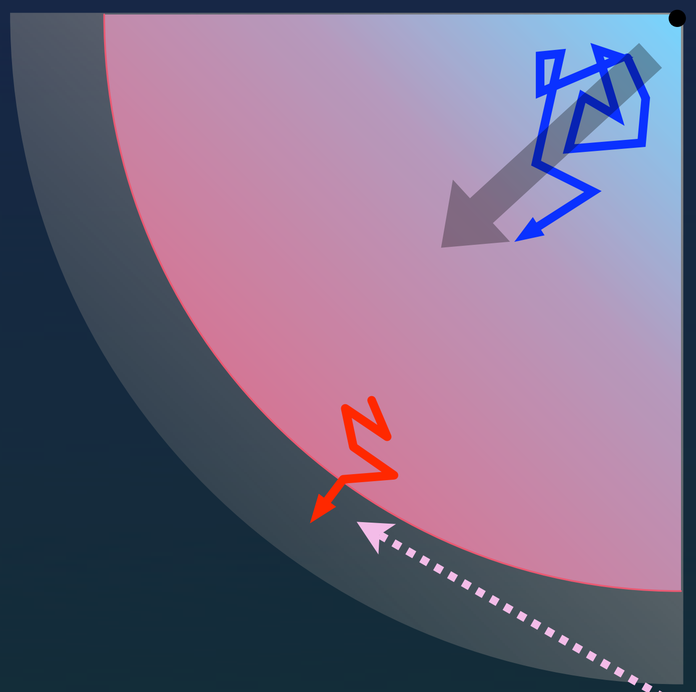
The Bound Material: Super-Eddington Fallback Phase

Maybe also (separate) magnetically-driven relativistic jet



(e.g., Bloom et al. 2011, Metzger & Giannios 2011)

The Bound Material: Super-Eddington Outflows



- assume spherical geometry with density profile

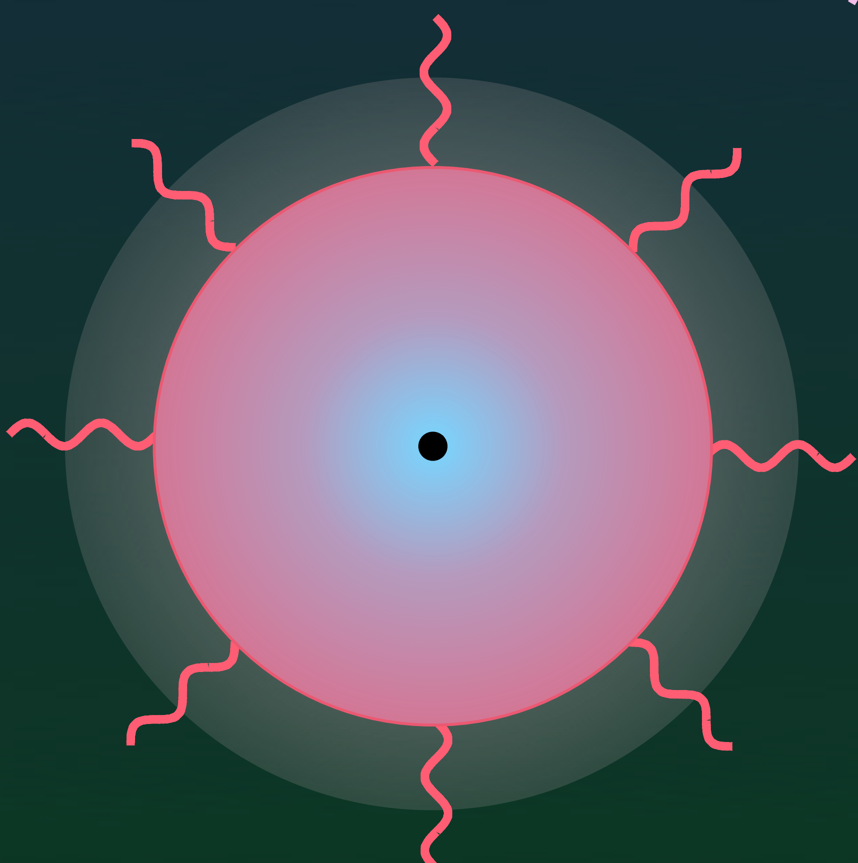
$$\rho(r) \sim \frac{f_{\rm out}\dot{M}_{\rm fallback}}{4\pi r^2 v_{\rm wind}}$$

Deep inside:

- photons are trapped by electron scattering
  $\rightarrow$ adiabatic so $T \propto \rho^{1/3}$

At photosphere:

- lower density, so photons can escape
- photons likely have blackbody spectrum
- if blackbody: large radius, cool temperature
  $\rightarrow$ large optical luminosity



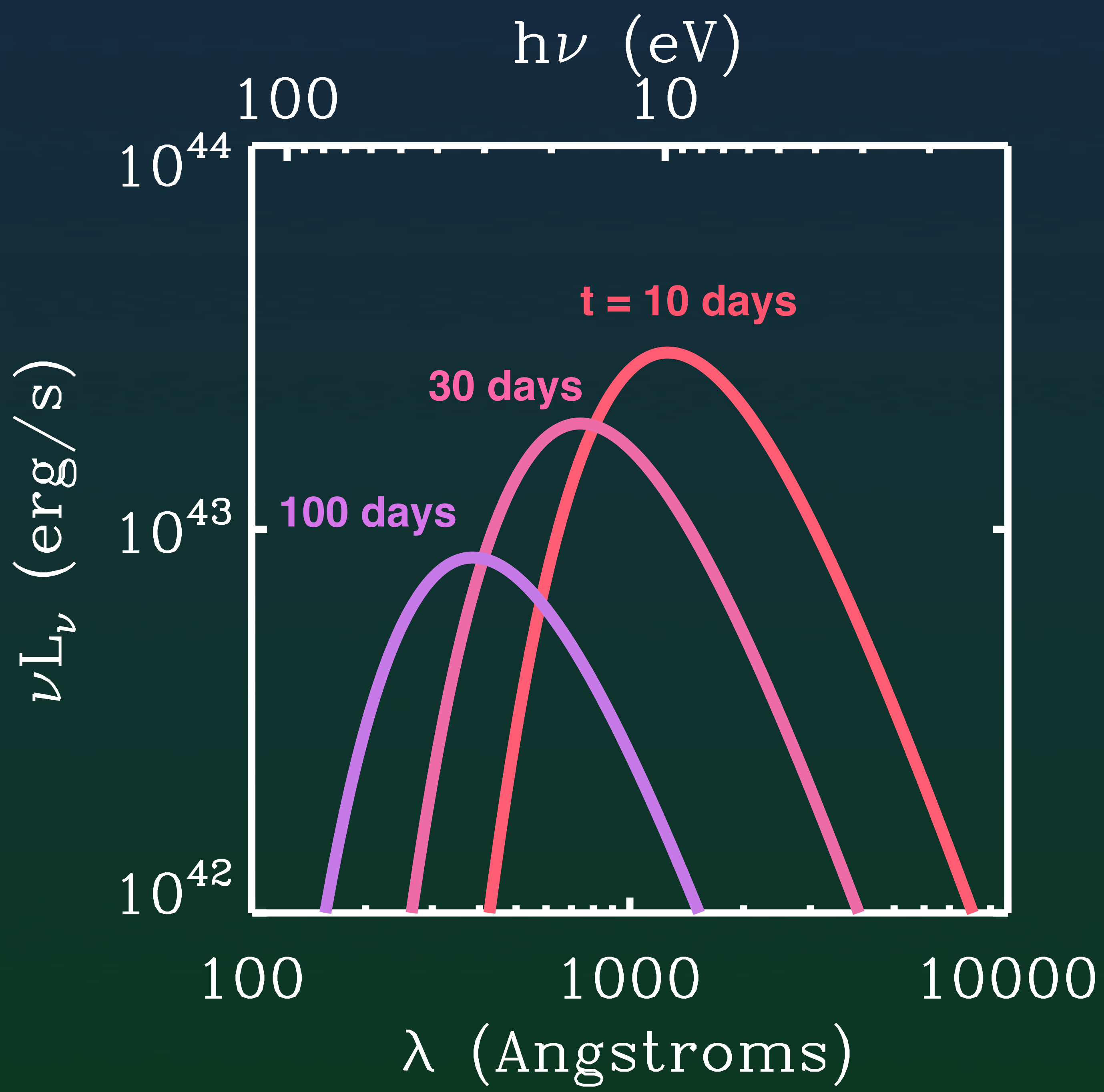
- As $\dot{M}_{\rm fallback}$ and density drop,
  photosphere moves deeper in
  $\rightarrow$ $T_{\rm phot}$ rises while $L_{\rm bol}$ drops

see also Rossi & Begelman (2009)

The Bound Material: Super-Eddington Outflows

Photometric Signature: Blackbody Continuum

e.g., $M_{\rm BH} = 10^6 M_\odot$
$R_{\rm p} = R_{\rm T}$



at 10 days:

$R_{\rm phot} \sim 1000\, R_{\rm S} \sim 20$ AU

$T_{\rm phot} \sim 3 \times 10^4$ K

$L_{\rm optical} \sim 10^{43}$ erg/s !

$M_{\rm AB} \sim -19$

Strubbe & Quataert (2009)

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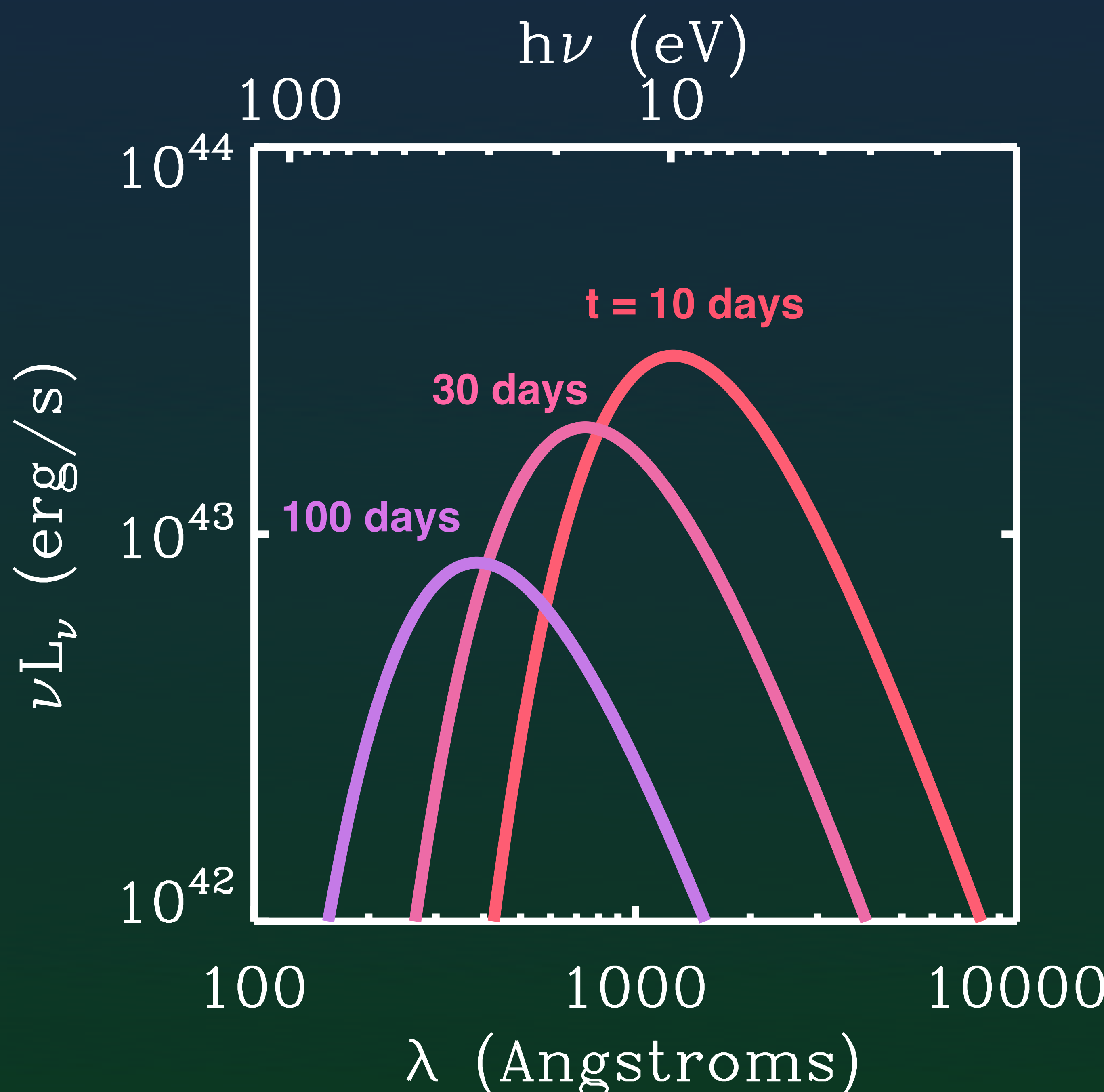

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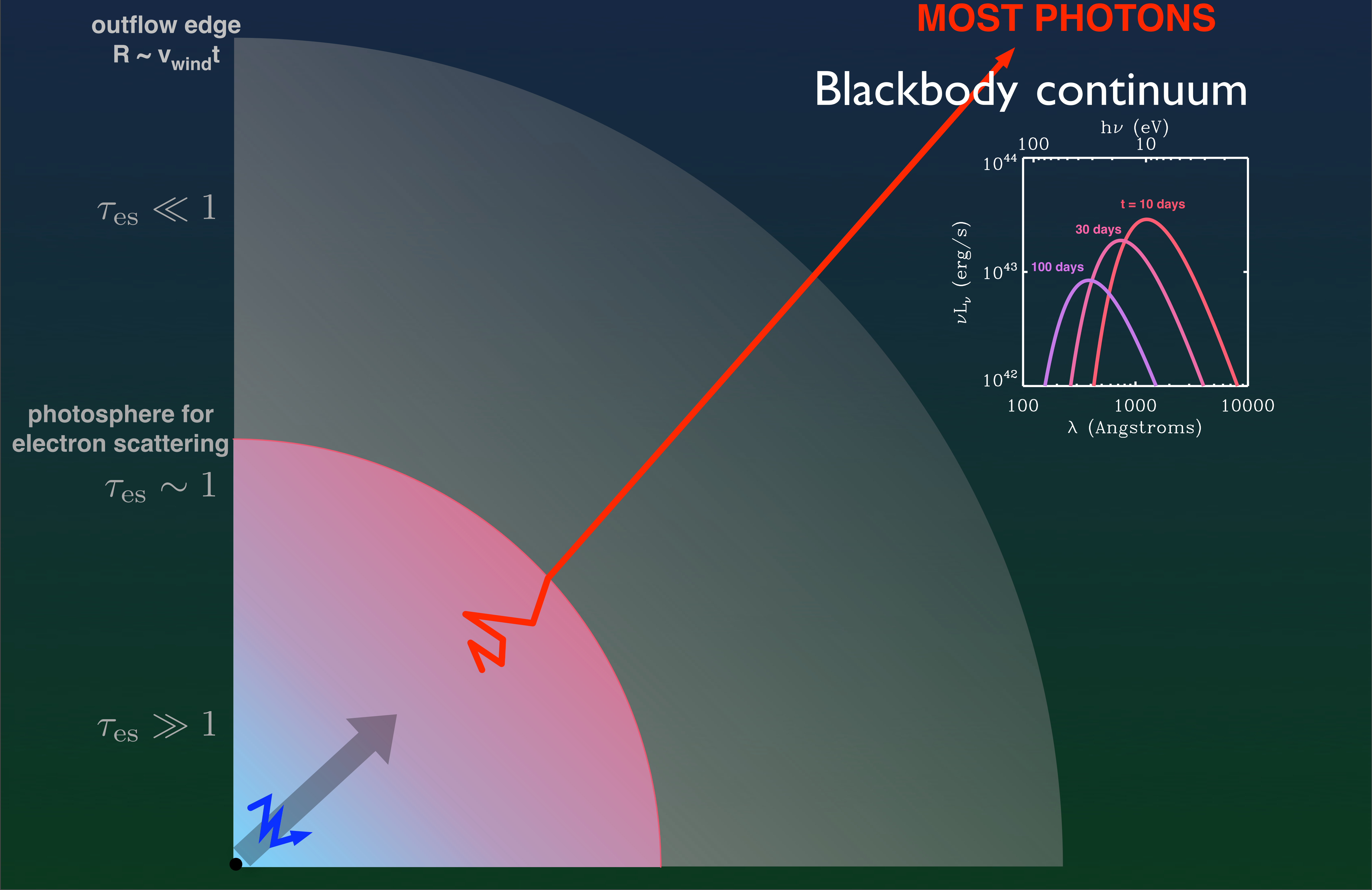
First optical discoveries!

SDSS: van Velzen et al. (2011)
PTF: Cenko et al. (2012)
Pan-STARRS: Gezari et al. (2012)

Strubbe & Quataert (2009)

The Bound Material: Super-Eddington Outflows

Outer gas imprints spectrum on blackbody continuum



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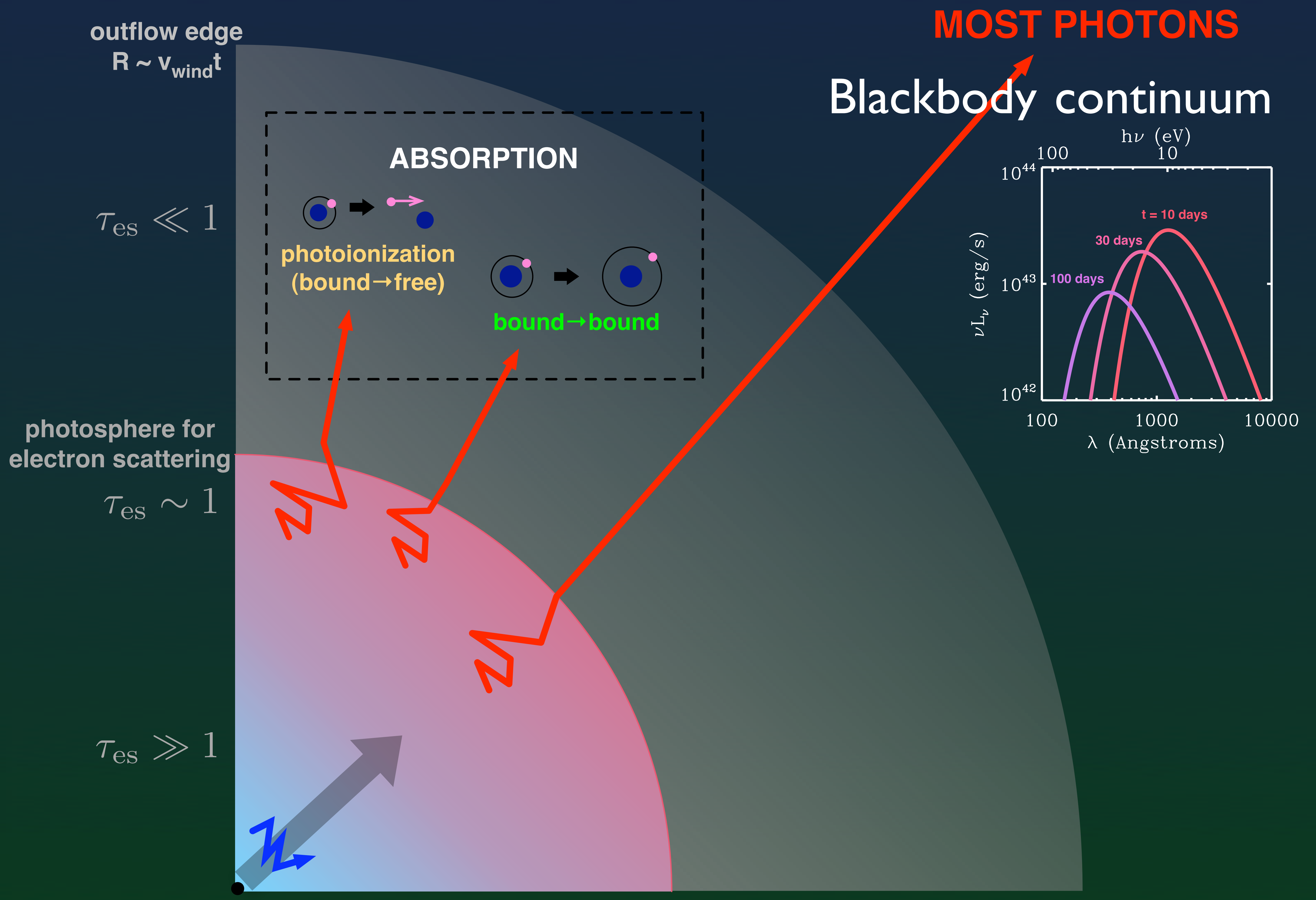

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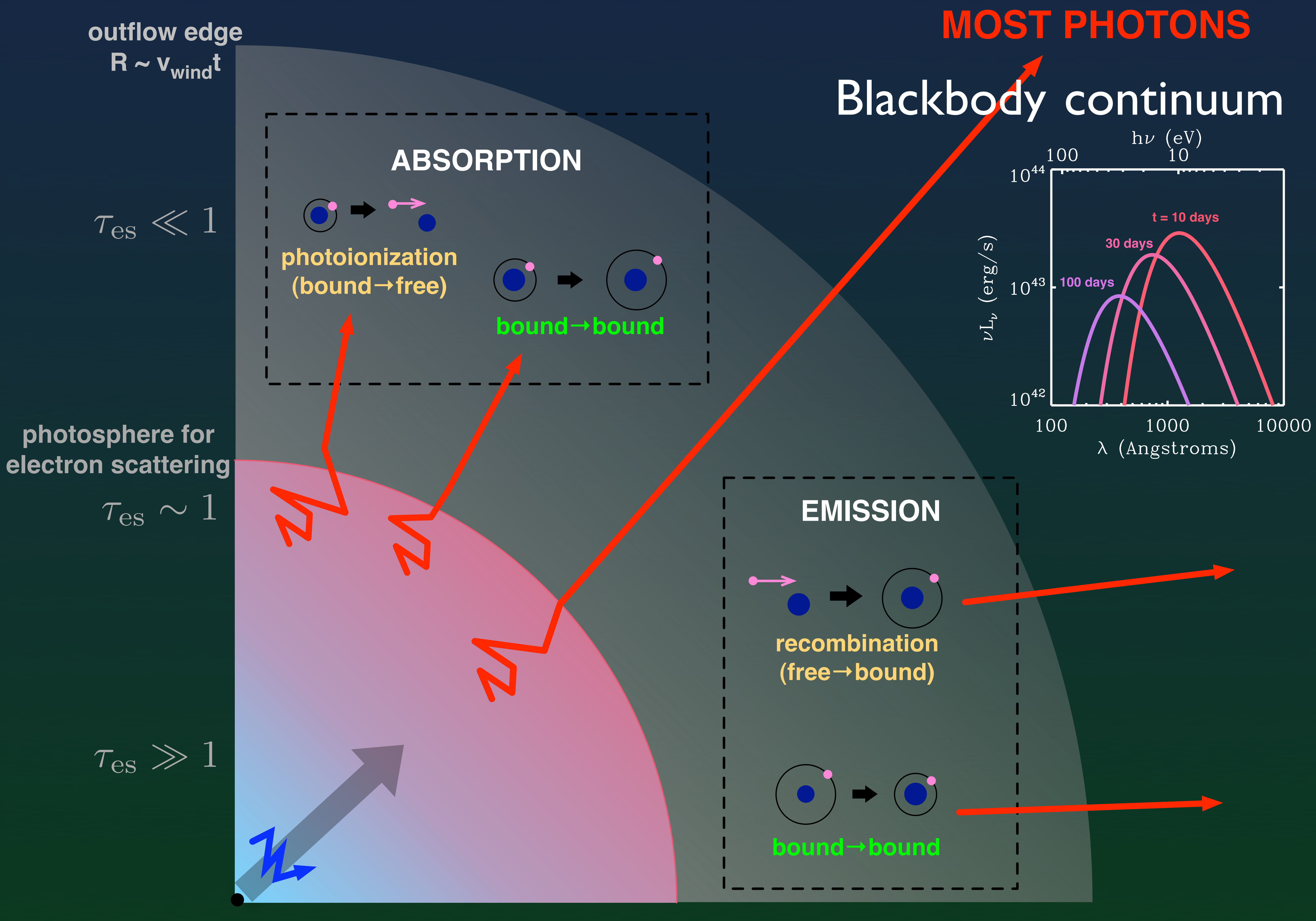
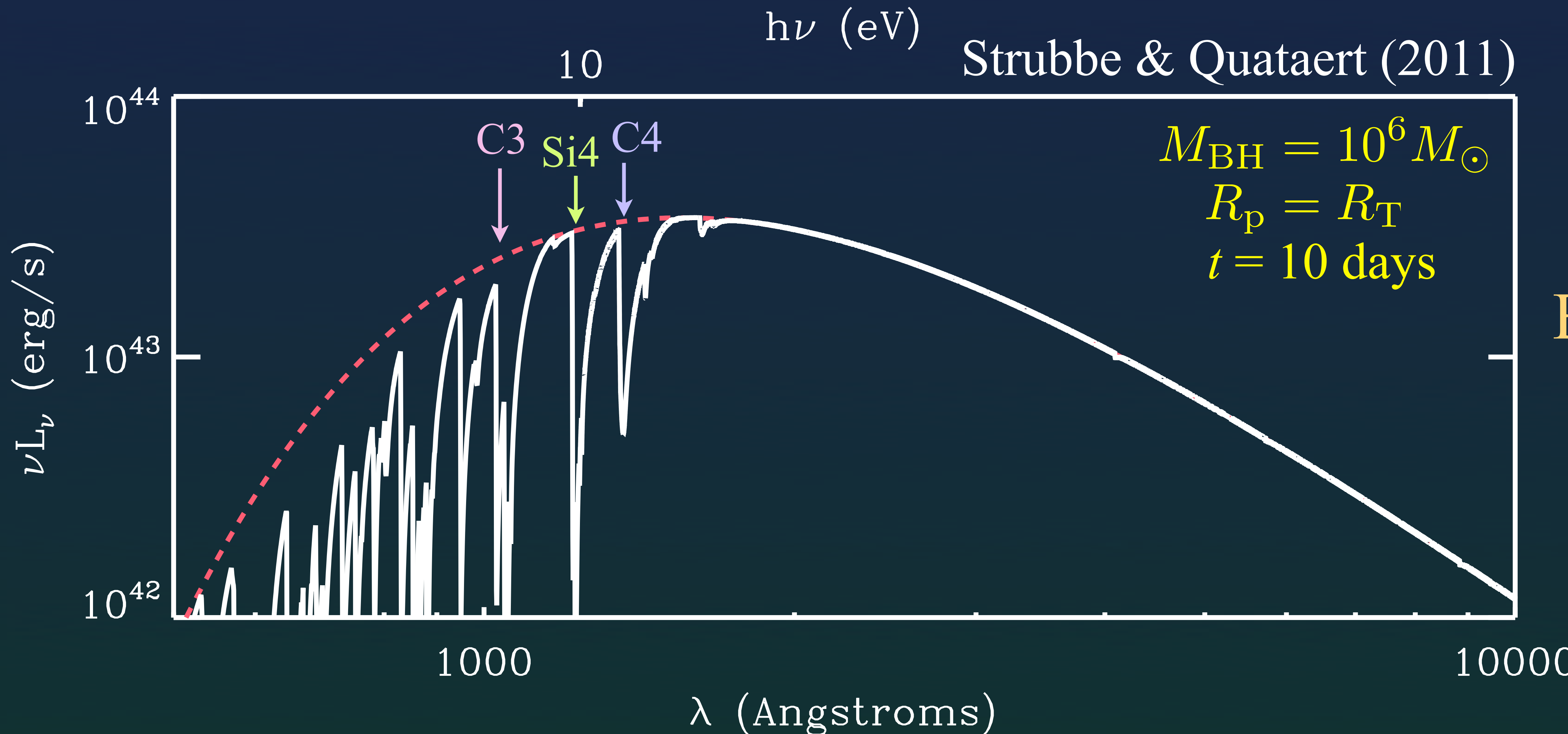
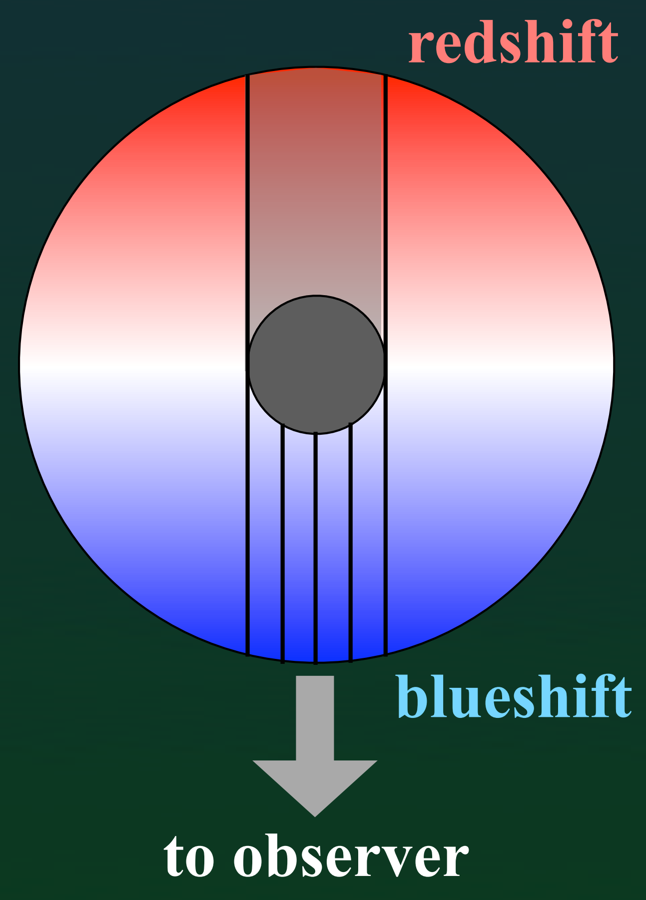


Spectroscopic signature to help identification of event



similar to BAL QSO spectrum



- outer gas is highly ionized:
  - few/no optical lines
  - most lines in FUV - EUV ($\lambda \lesssim 2000$ Å)
- absorption lines:

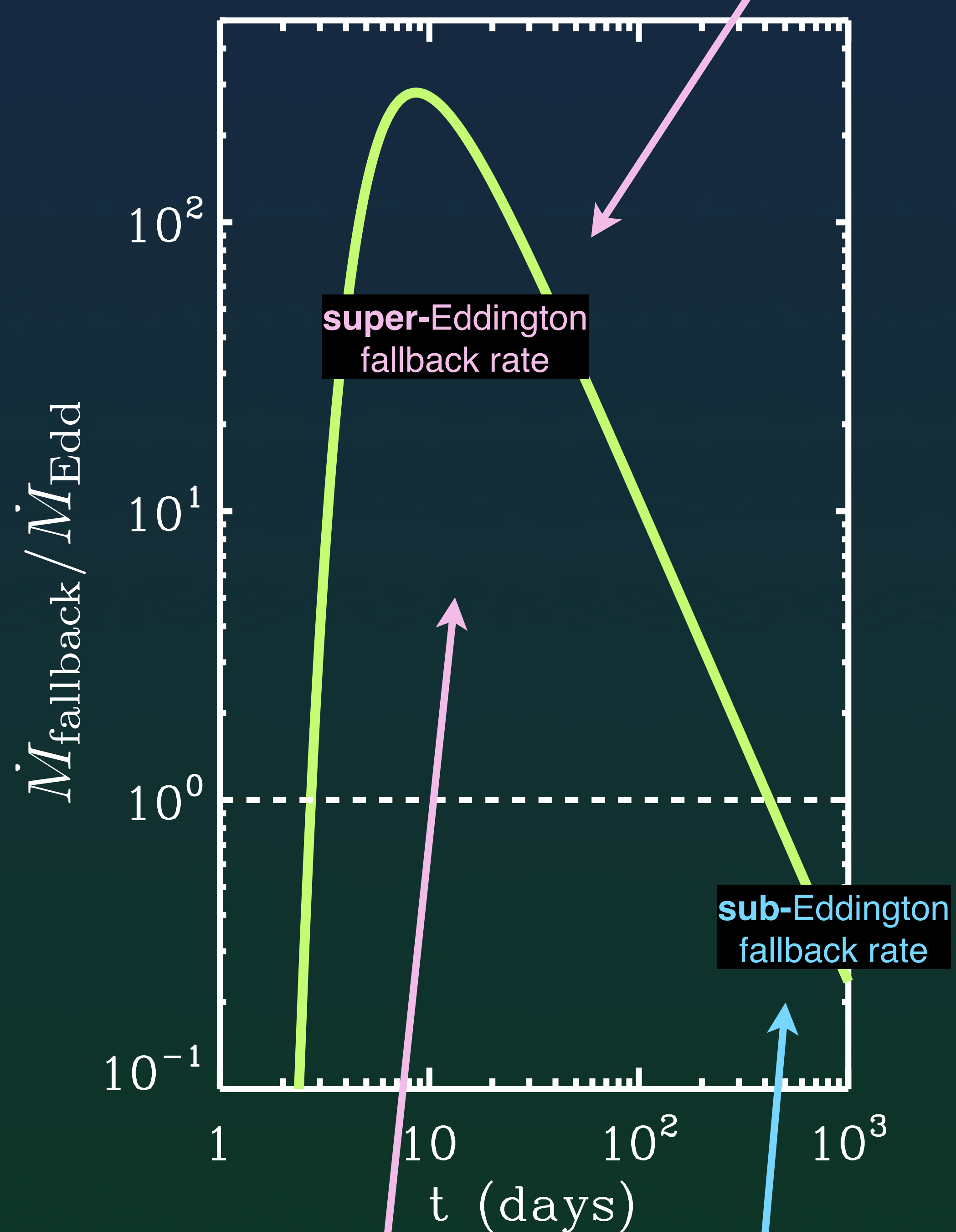
  broad, strong blueshift ($v_{wind}/c \sim 0.1$)

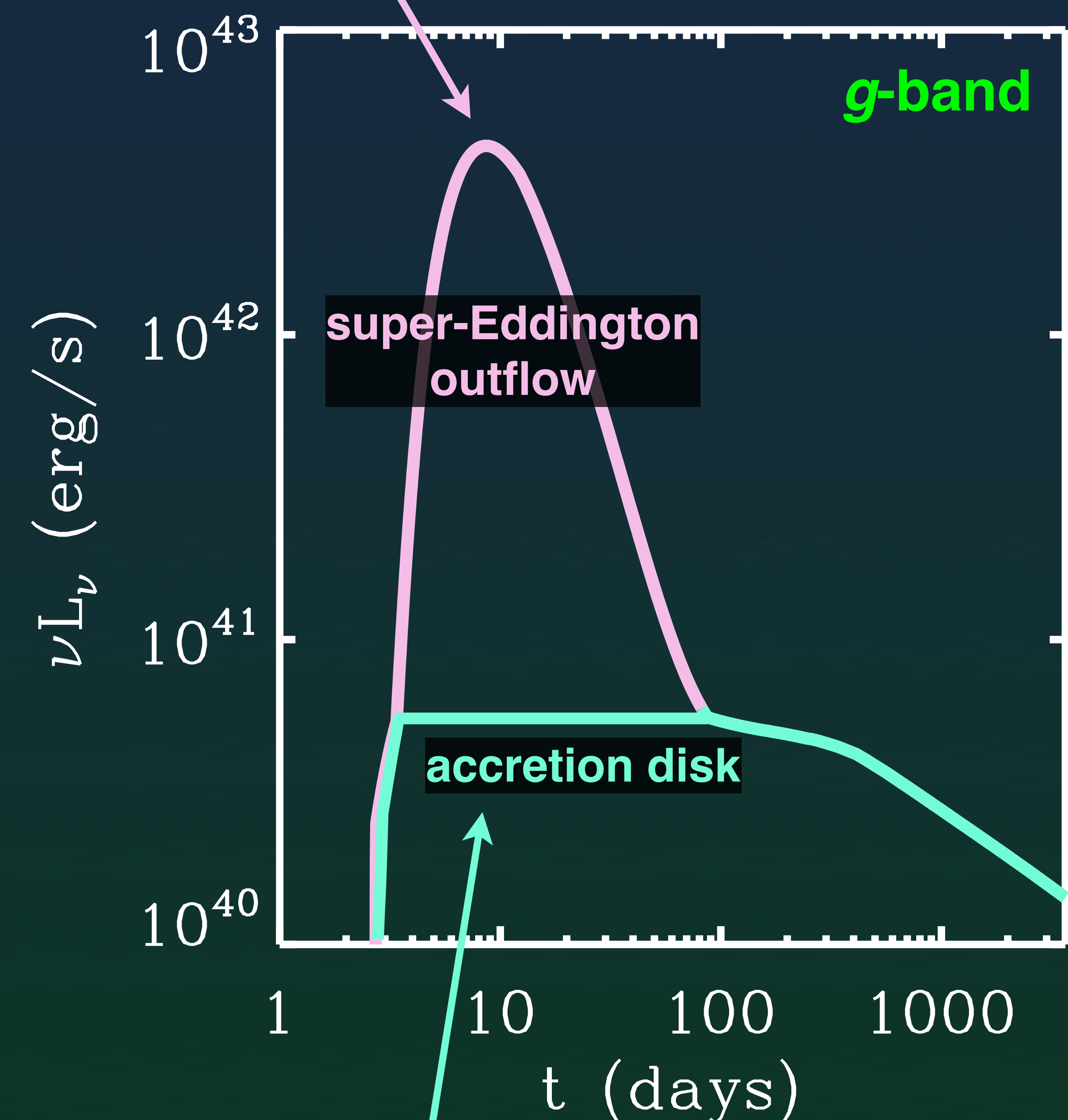
Summary of Predicted Observable Properties

Strubbe & Quataert (2009, 2011)

luminous outflows

(optical/UV emission, blueshifted absorption lines)





accretion disk **(optical -- X-ray emission)**

+ unbound material **(faint offset emission lines)**

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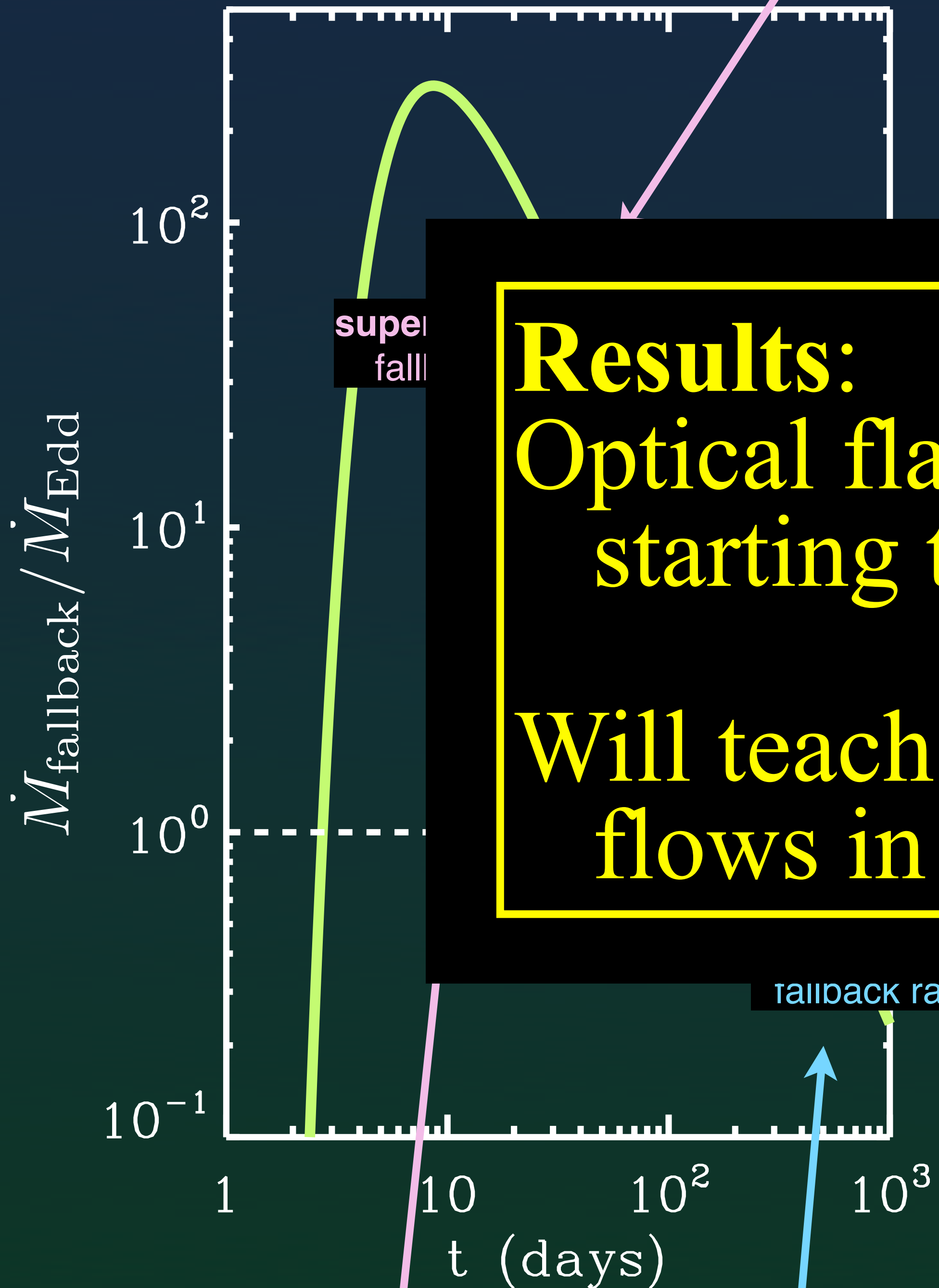

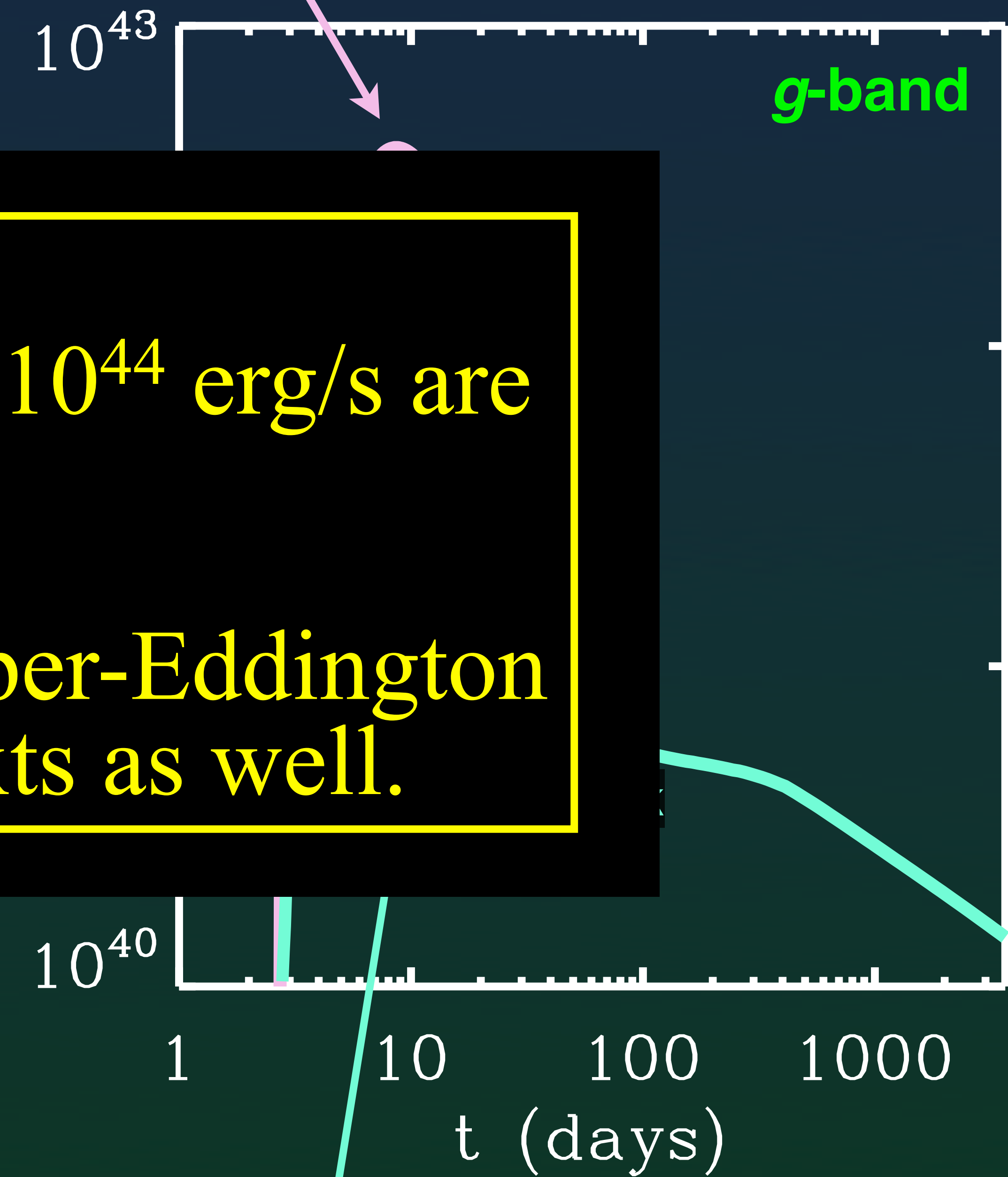

Results:

Optical flares at 10^{43} - 10^{44} erg/s are starting to be found!

Will teach us about super-Eddington flows in other contexts as well.

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+ unbound material **(faint offset emission lines)**