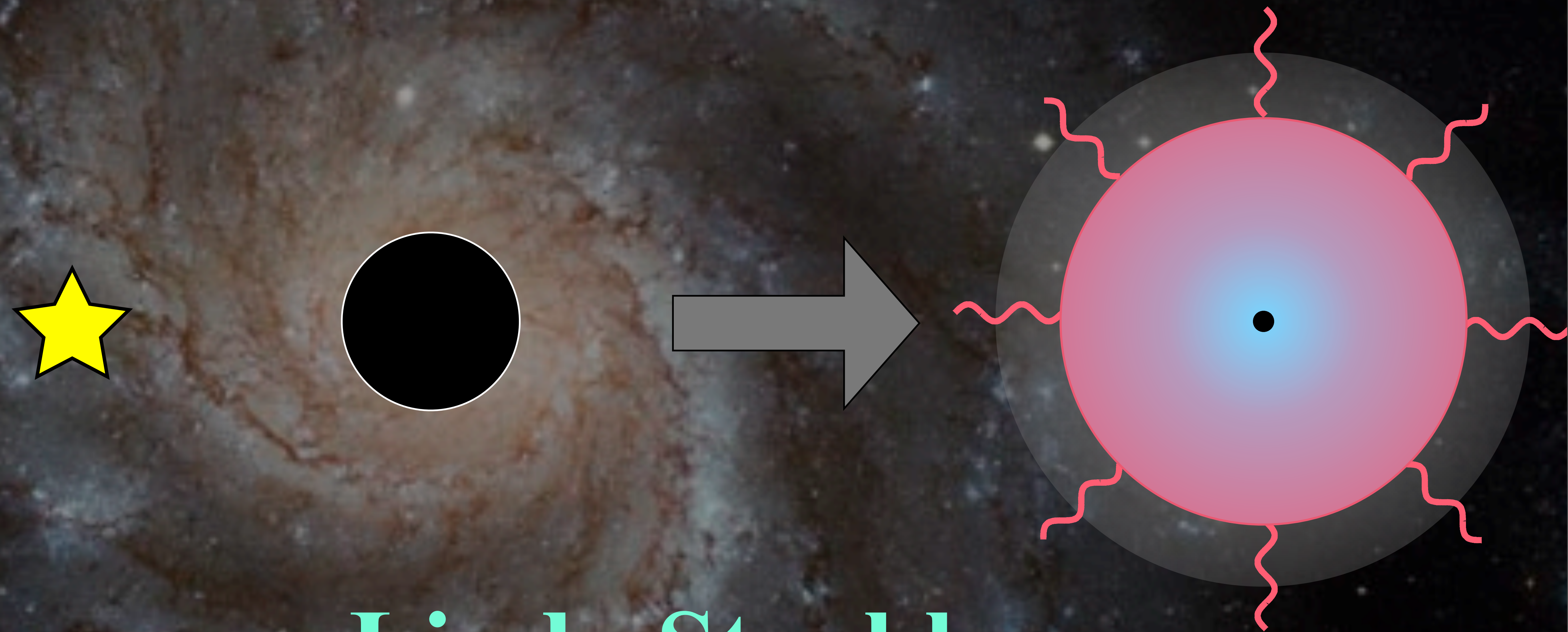
The Tidal Disruption of Stars as a Probe of Galactic Nuclei



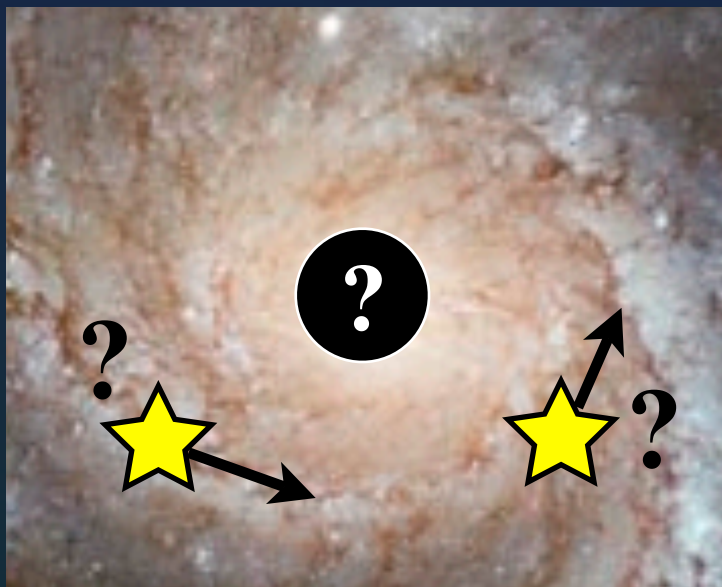
Linda Strubbe

U.C. Berkeley

Strubbe & Quataert 2009, MNRAS, 400, 2070

Strubbe & Quataert 2010, in prep.

Questions about Black Holes in Galactic Nuclei



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2. **What are the dynamical properties of the stars surrounding the BH?**

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One observational tack:

- Study **nearby, moderately massive** galaxies

(e.g., Richstone et al. 1998; Ferrarese & Merritt 2000; Gebhardt et al. 2000)

But ...
- only **~10 nearby galaxies** probed well inside $R_{\rm inf}$
- **lower-mass** galaxies?

Questions about Black Holes in Galactic Nuclei

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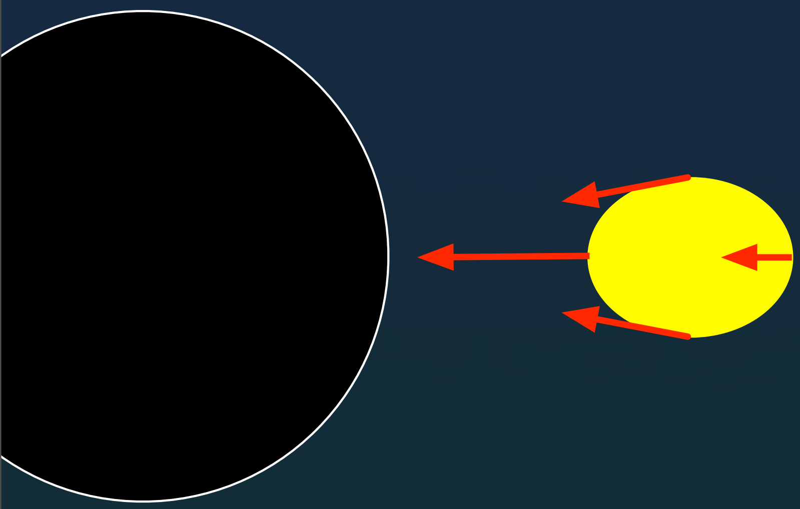
Another tack:

- Study **active** BHs (e.g., Greene et al. 2008)

But ...
- majority of galaxies are **quiescent**
- can't address **dynamics** of stars close to BH

A new tack! Tidal Disruption of Stars by Black Holes

Binding force of star is overcome by BH's tidal gravity if $R_{\rm peri} \leq R_{\rm Tidal}$



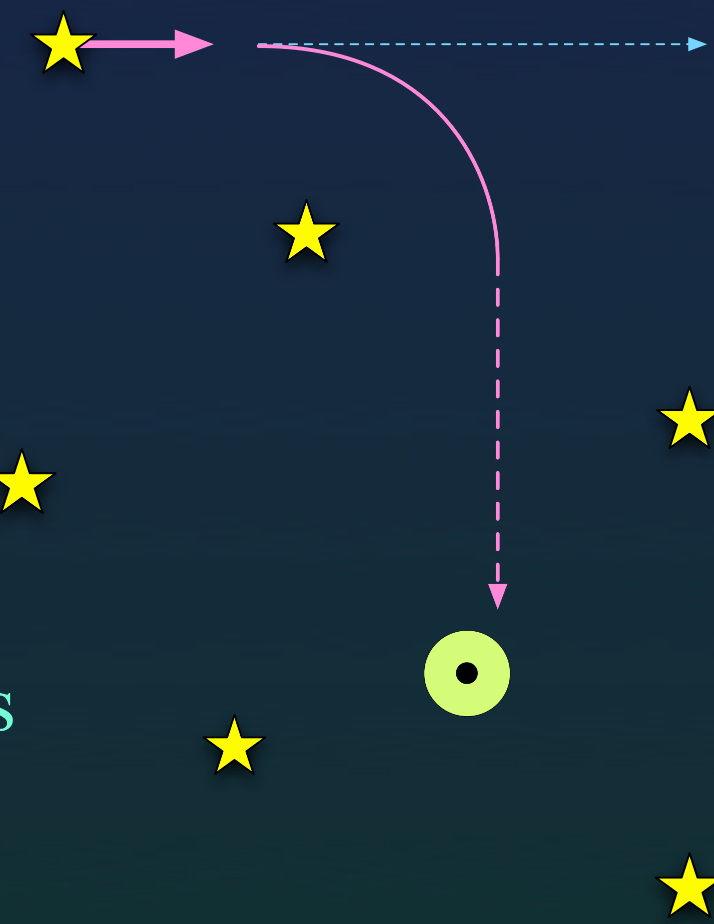
$$\frac{Gm_*}{R_*^2} \sim \frac{GM_{\rm BH}}{R_{\rm Tidal}^2}\left(\frac{R_*}{R_{\rm Tidal}}\right)$$

Solar-type stars: $R_{\rm Tidal} \sim \rm AU$

Must happen in nucleus of *any* stellar system with a BH.

a) detect new BHs (out to $z \sim 1$!) -- particularly lower-mass BHs
b) teach us about dynamics of surrounding stars
c) teach us about BH growth

Tidal Disruption of Stars: Insights for stellar dynamics



Basic Mechanism:

Stars are gravitationally scattered onto new orbits when pass close to other stars.

$$\gamma \sim \frac{N_*(r_{\rm BH})}{t_{\rm relax}(r_{\rm BH})}$$

possible rate enhancers:
- flattened potential
- triaxial potential $\longrightarrow$ chaotic orbits
- giant molecular clouds
- resonant relaxation

$\rightarrow$ theoretical $\gamma_{\rm galaxy} \sim 10^{-5} - 10^{-3}\,{\rm yr}^{-1}$

Tidal disruption rate as fcn of $M_{\rm BH}$, $R_{\rm peri}$, galaxy type is probe of dynamical conditions close to the BH.

e.g., Magorrian & Tremaine (1999), Merritt & Poon (2004), Alexander (2005)

Tidal Disruption of Stars: Insights for BH growth

BHs may grow significantly by consuming stars

- especially IMBHs: if $\gamma_{\rm galaxy} \sim 10^{-5}\,{\rm yr}^{-1}$, then

$$M_\odot \gamma_{\rm galaxy} t_{\rm Hubble} \sim 10^5 M_\odot$$

- ties growth of BH to dynamical conditions in stellar bulge
  - (partial) origin of $M_{\rm BH} - \sigma_*$ relation?

Tidal Disruption of Stars: Observations

Handful of candidate detections by

- ROSAT All-Sky Survey (Komossa 2002)
- XMM Slew Survey (Esquej et al. 2007)
- GALEX Deep Imaging Survey (Gezari et al. 2009)

GALEX Galaxy Evolution Explorer

$$\gamma_{\rm galaxy} \sim 10^{-5}\,{\rm yr}^{-1}$$
(Donley et al. 2002)

Important steps, but: archival, slow cadence, small spatial volume

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New frontier: Rapid-Cadence Wide-Field Surveys

Currently underway :

The Palomar Transient Factory

quarter-sky
$m_{\rm AB} \approx 21$
every few days

Near future :

Pan-STARRS

3π Survey:
$m_{\rm AB} \approx 23$
every few months

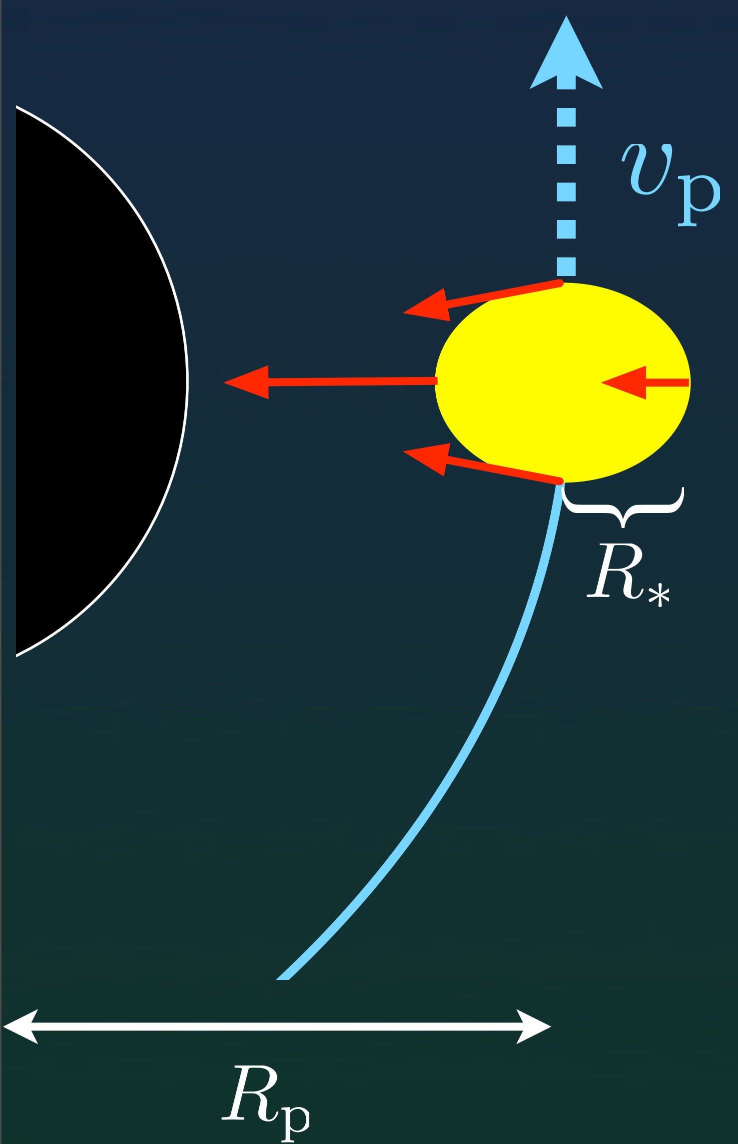
Next decade (?) :

LSST
Large Synoptic Survey Telescope

half-sky
$m_{\rm AB} \approx 24.5$
every few days

The Process of Disruption

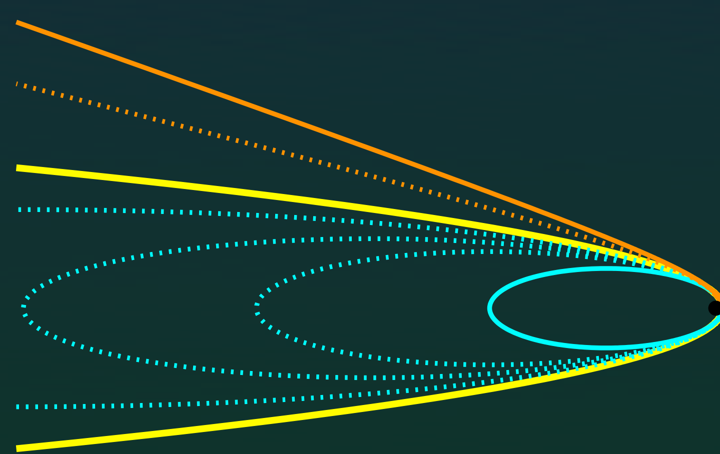
- star approaches from $r \gg R_{\rm Tidal}$ on $E \approx 0$ orbit at $v_{\rm p} \sim v_{\rm esc,BH}$



- slightly different depths in potential well

~half has $\epsilon > 0$ unbound: hyperbolic trajectories

~half has $\epsilon < 0$ bound: elliptical orbits



e.g., Rees (1988)

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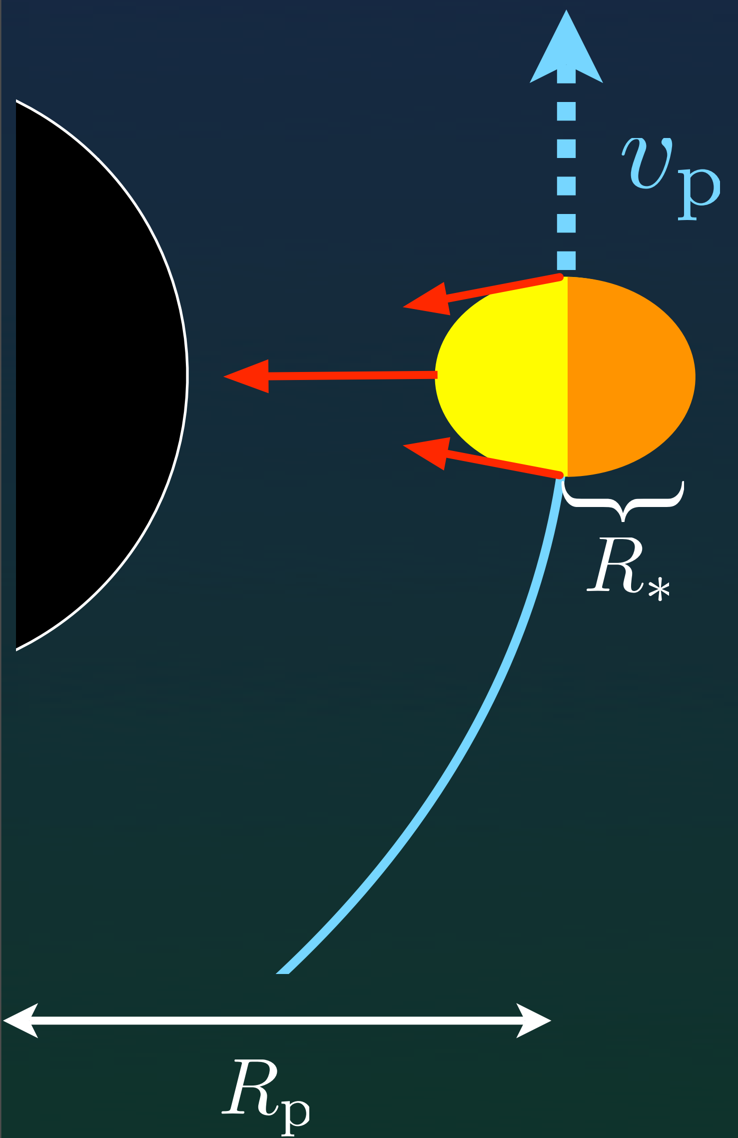

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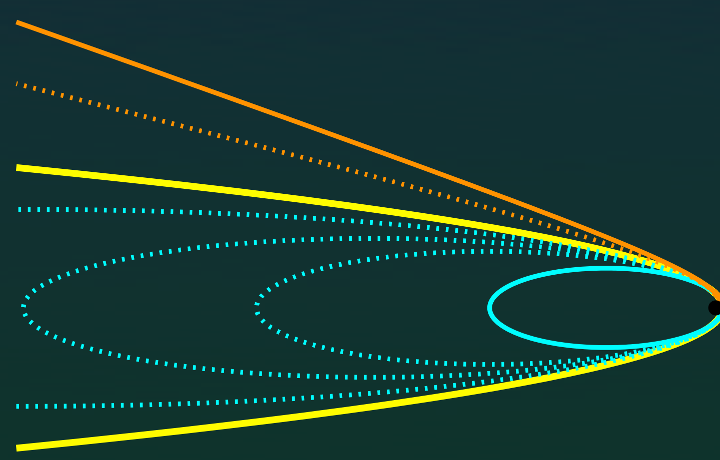

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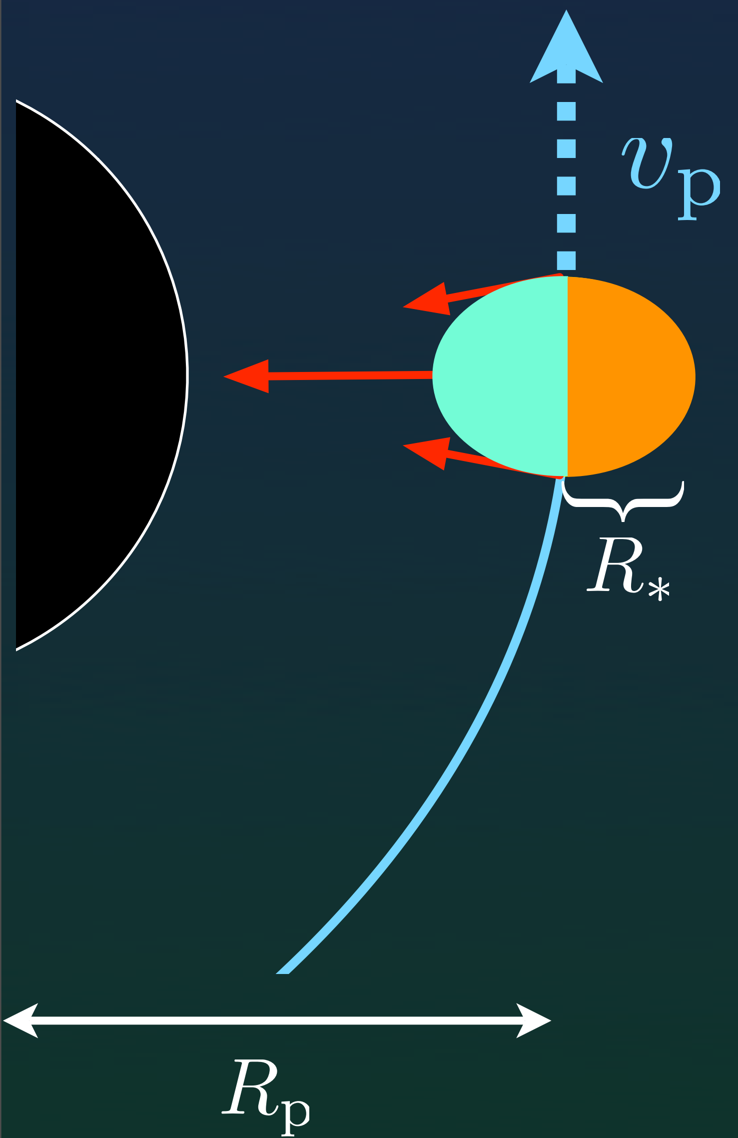

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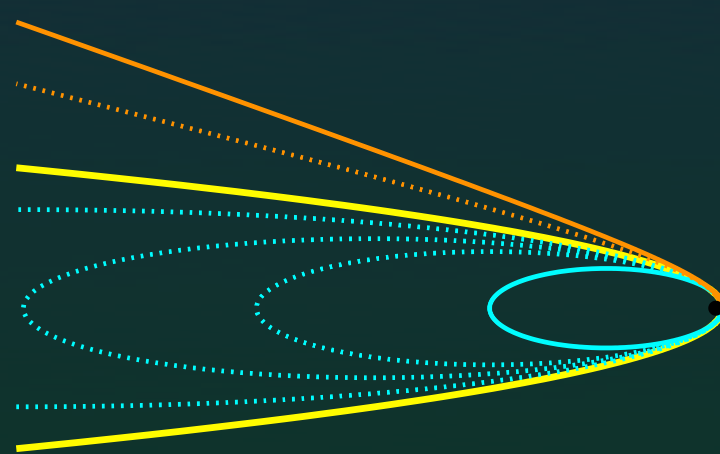

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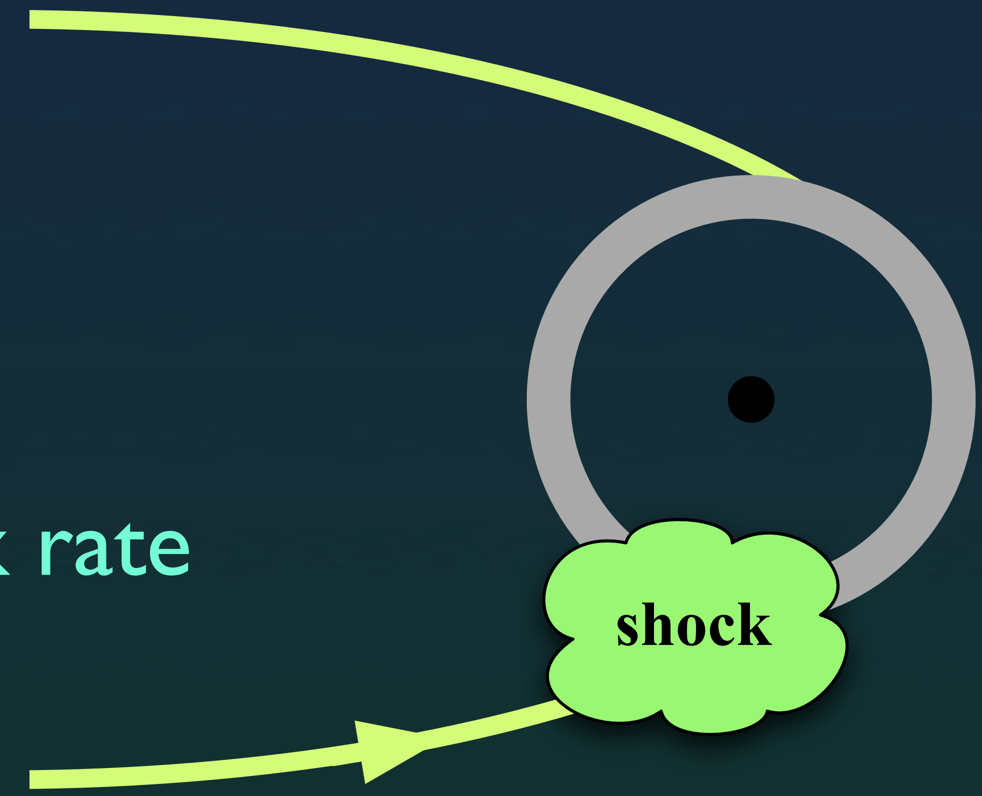
Fallback of the Bound Material

- after $t_{\rm fallback}$ ~ hours - weeks,
debris starts returning to pericenter and shocks, starts to accrete inward



- energy distribution gives mass fallback rate

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

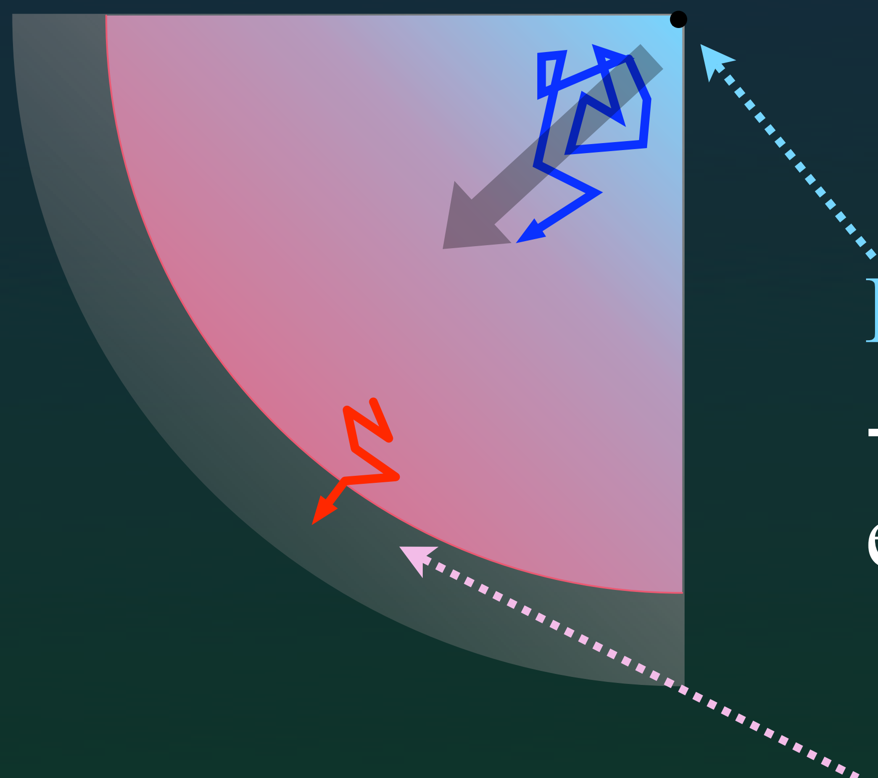
e.g., Rees (1988), Phinney (1989), Evans & Kochanek (1989)

Super-Eddington Fallback → Outflows

- fallback rate can initally be >> Eddington rate

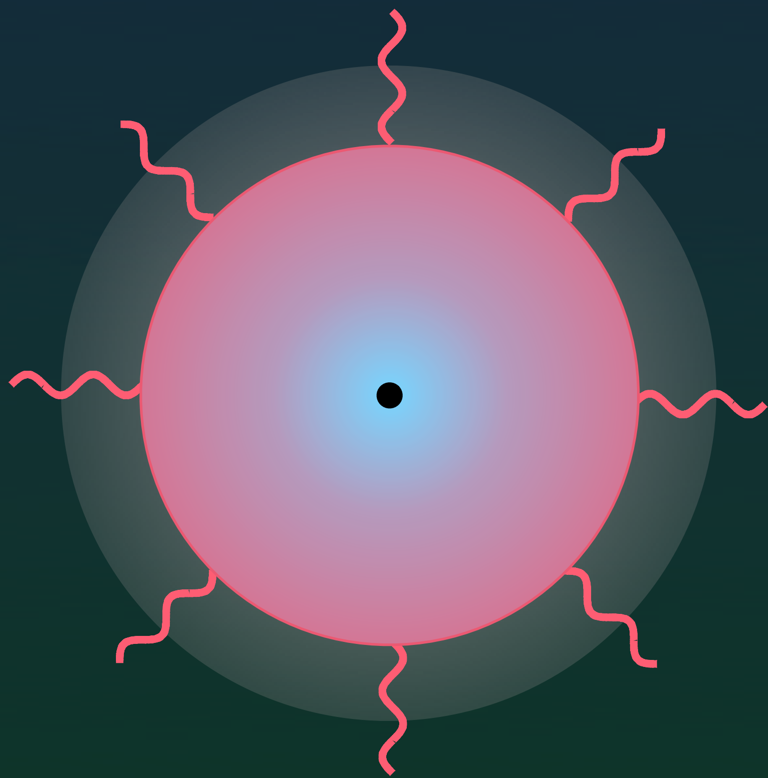
radiation pressure drives gas back outwards

$(v_{\rm wind}/c \sim 0.1)$



Deep inside:

- photons are trapped by electron scattering



At photosphere:

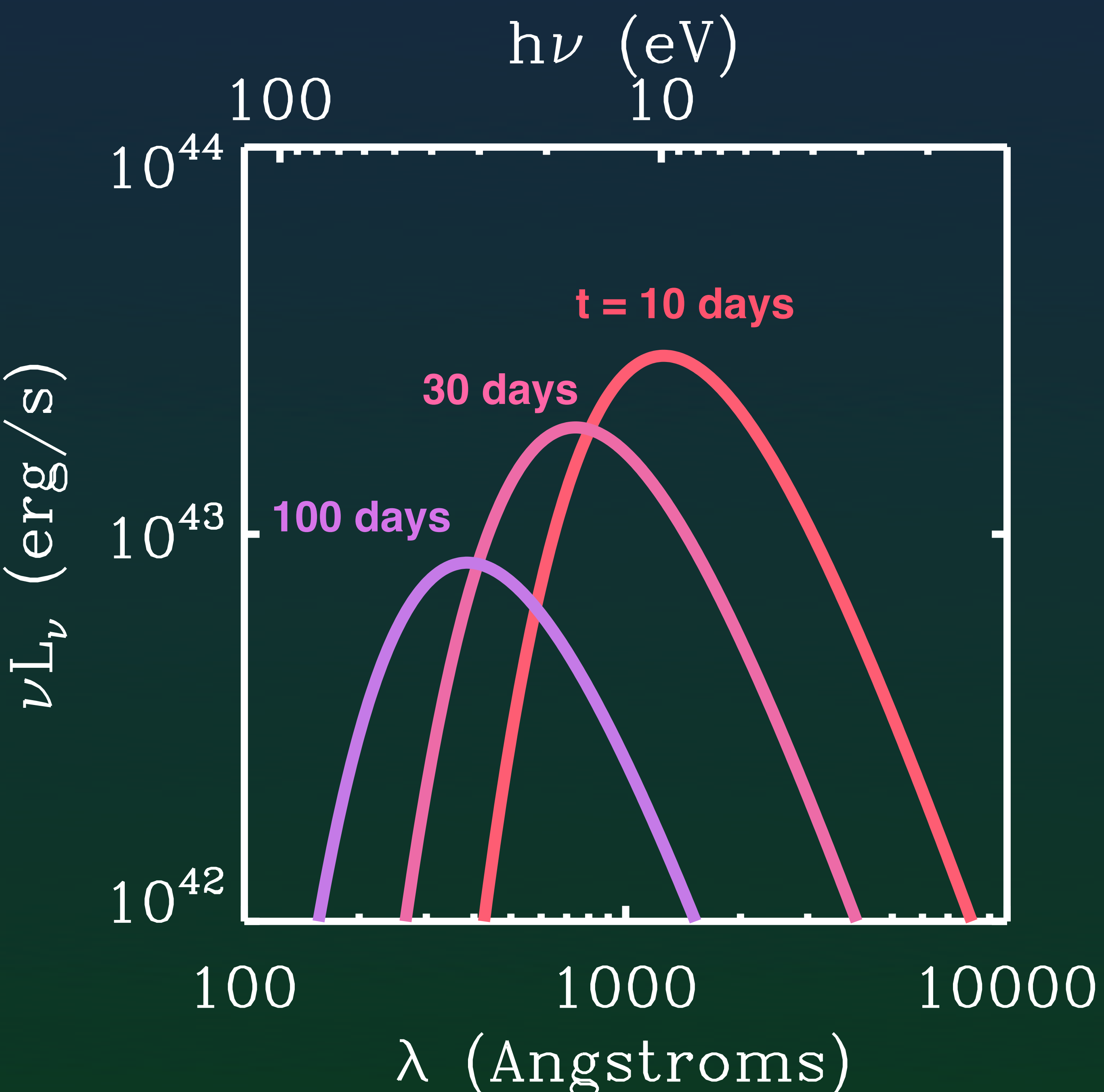
- escaping photons have blackbody spectrum
- cool temperature, large radius

→ large optical luminosity

Super-Eddington Outflows, cont.

Photometric Signature: Blackbody Continuum

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



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)

Predicted Detection Rates: Super-Eddington Outflows

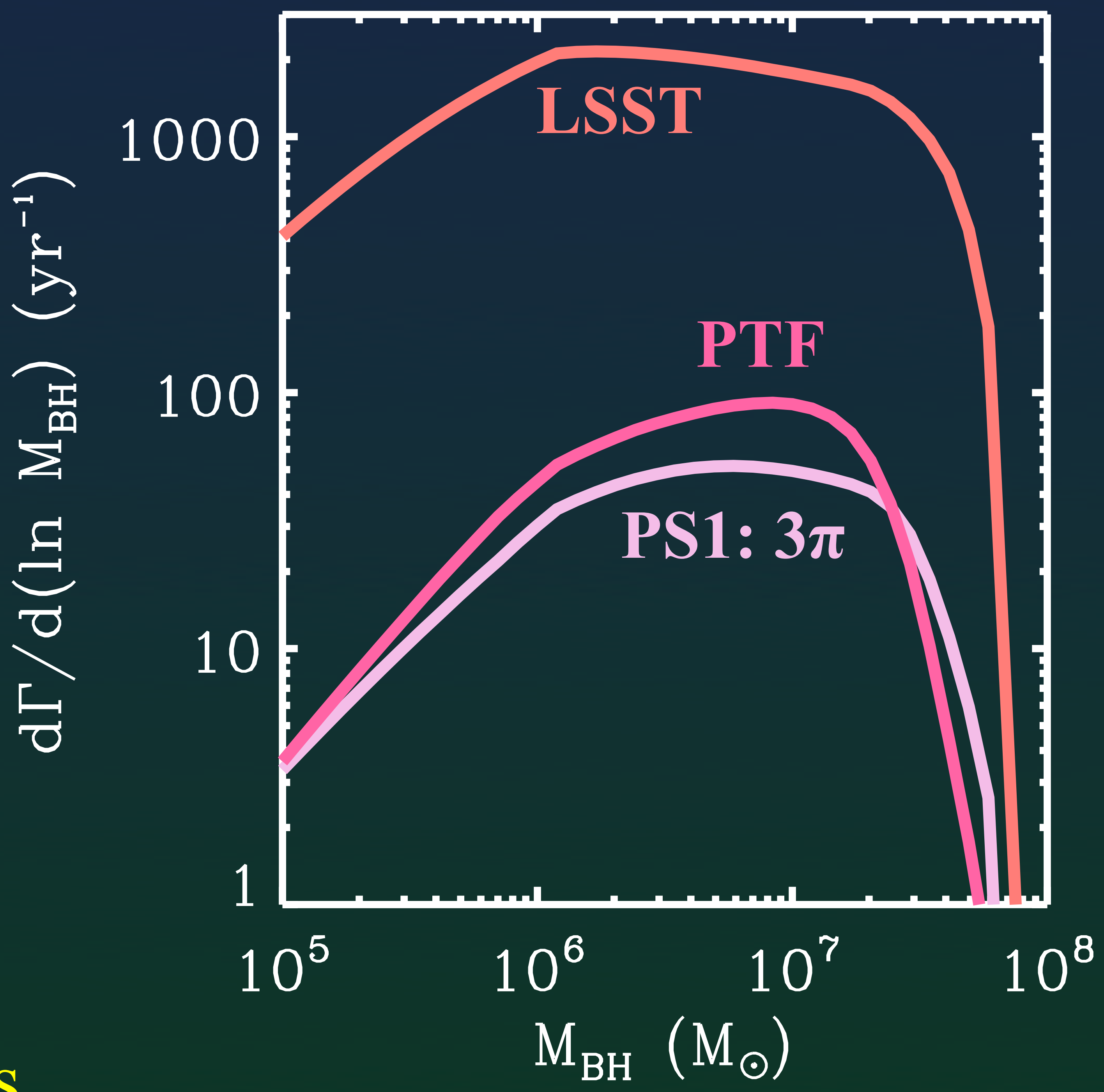
cadence is important

PTF :
100s of events per year

PS 1 :
100s of events per year

LSST :
1000s of events per year

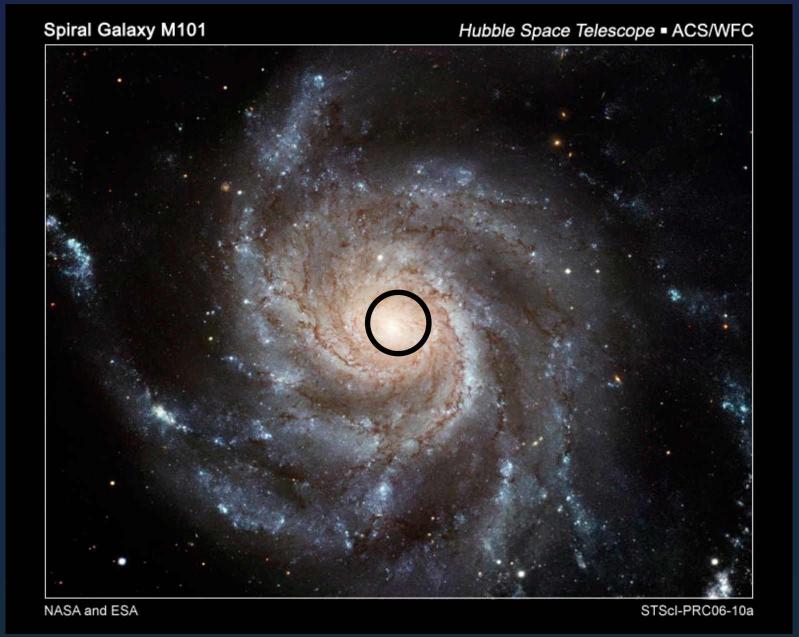
tens - hundreds of IMBHs



May be missed by past surveys
- exclude galactic nuclei
- mistaken for AGN

Strubbe & Quataert (2009)

Predicted Detection Rates: Challenges of Identification



Distinguishing from **supernovae** (close to galactic nucleus) will be tricky:

- most tidal disruption detections likely at $z \sim 1$
  $\rightarrow$ resolution ~ 1" ~ several kpc
- rate of SNe in nucleus ~ 100x tidal disruption rate

Follow-up observations will be crucial: spectroscopy

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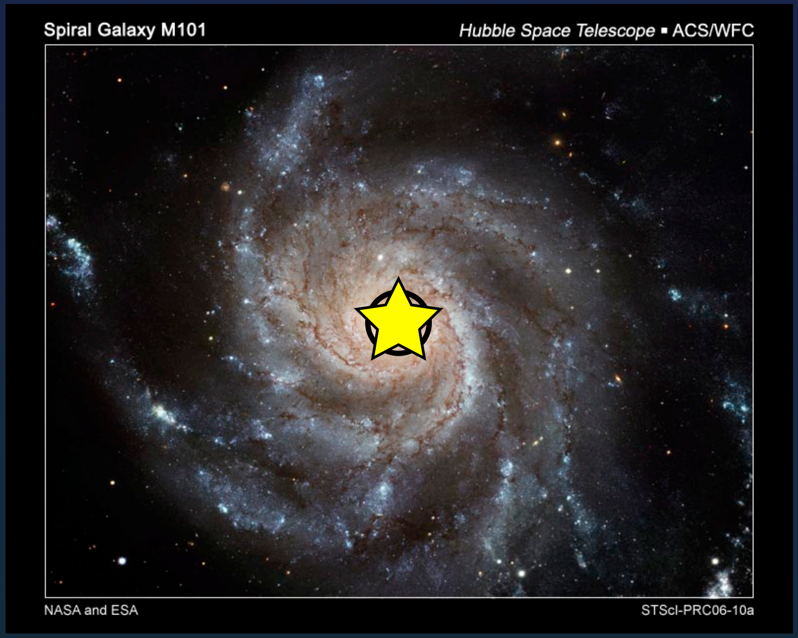

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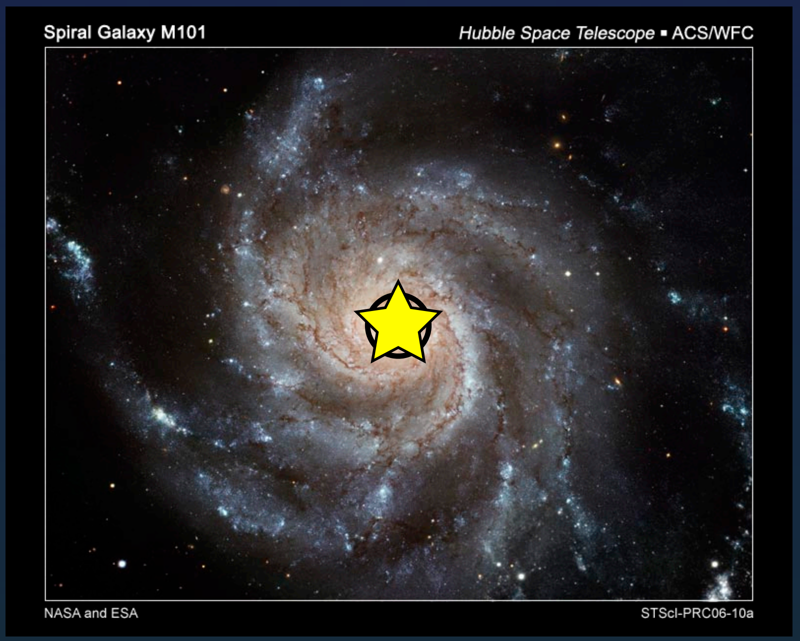

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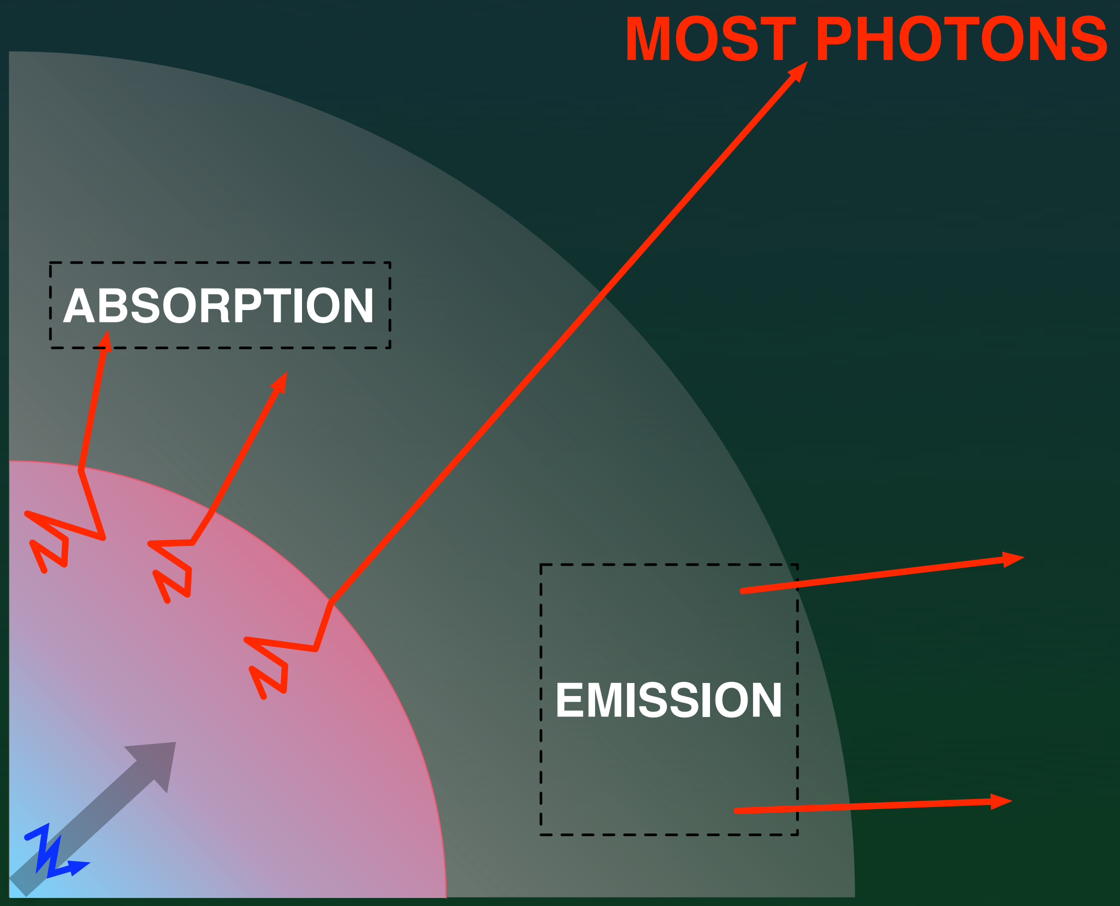
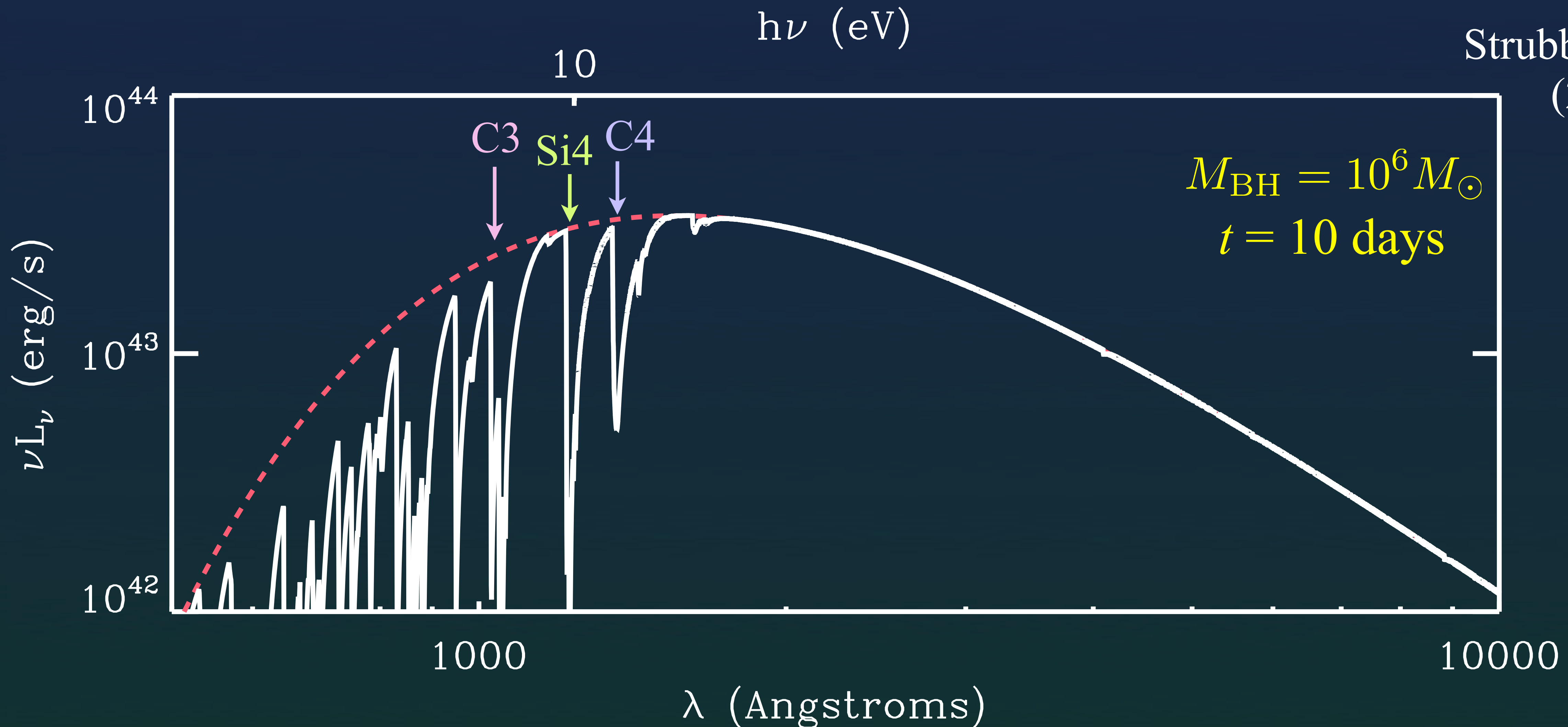
Super-Eddington outflow provides spectroscopic signature.



Spectroscopic signature to help identification of event



Strubbe & Quataert (2010) in prep.

- outer gas is very highly ionized:
  - few/no optical lines
    (but denser/lower-velocity outflow → optical lines)
  - most lines in FUV - EUV $(\lambda \lesssim 2000\ \text{Å})$

- absorption lines:
  broad, strong blueshift $(v_{\rm wind}/c \sim 0.1)$

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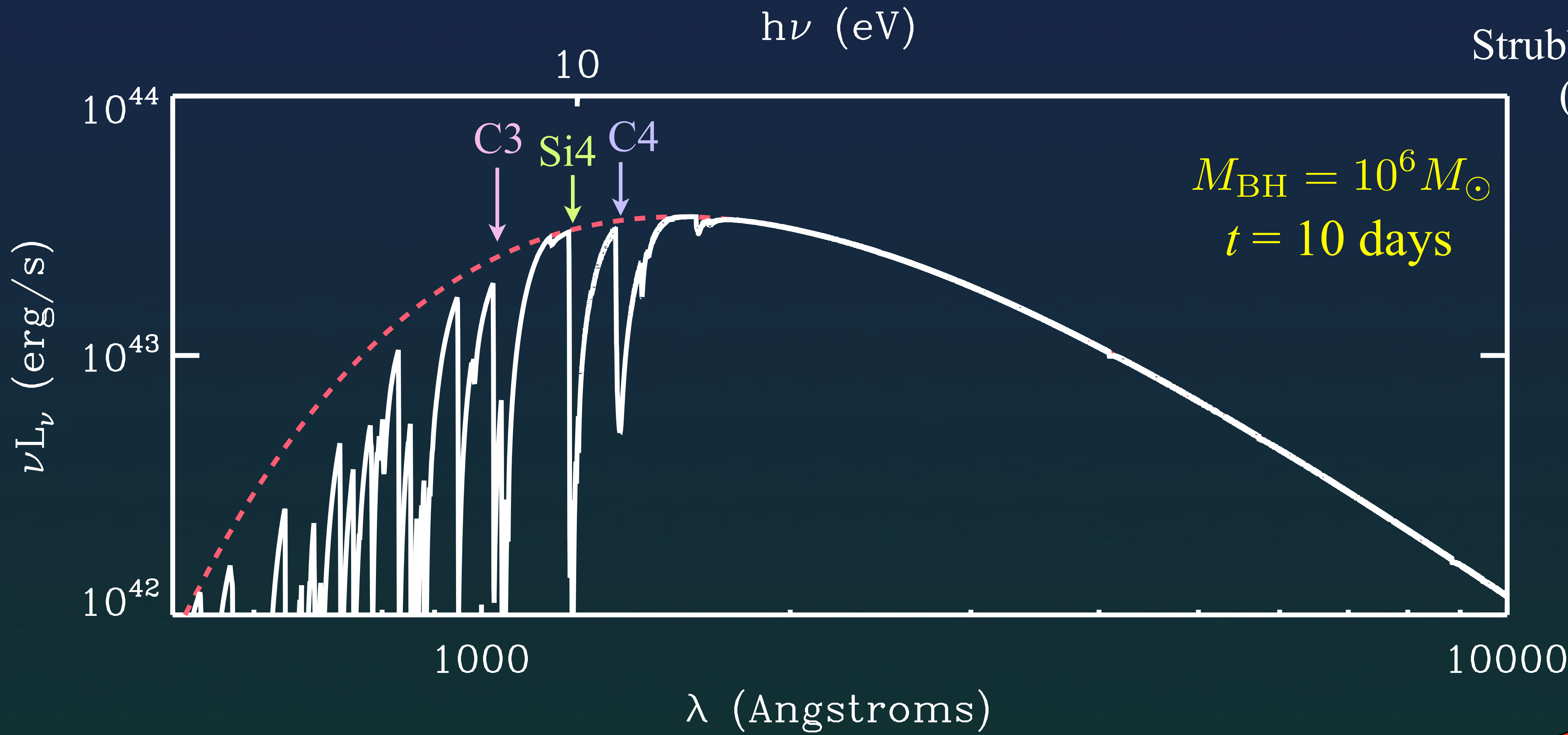

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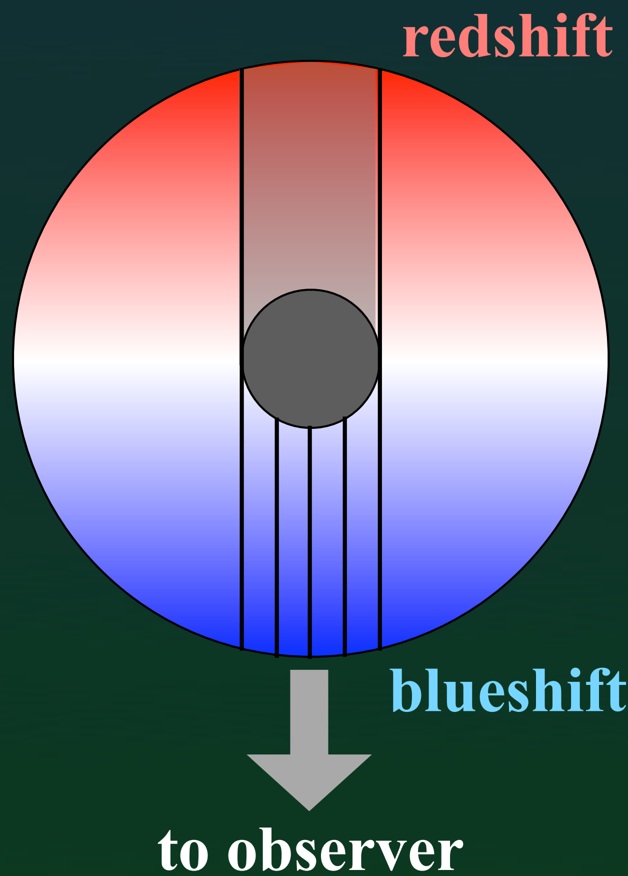

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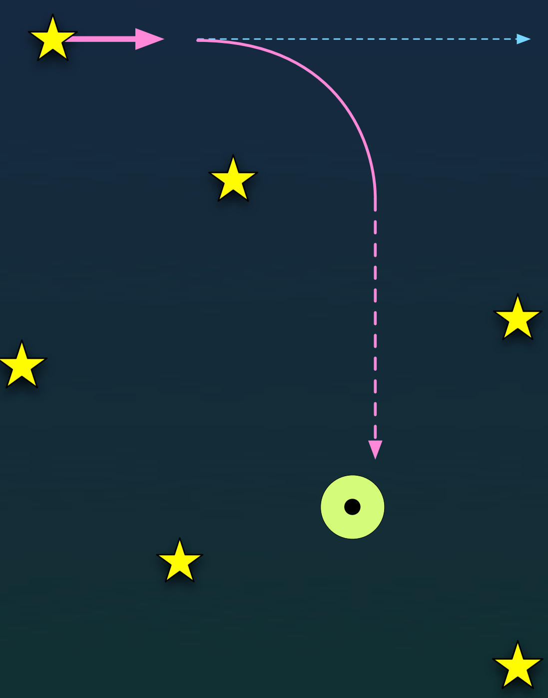
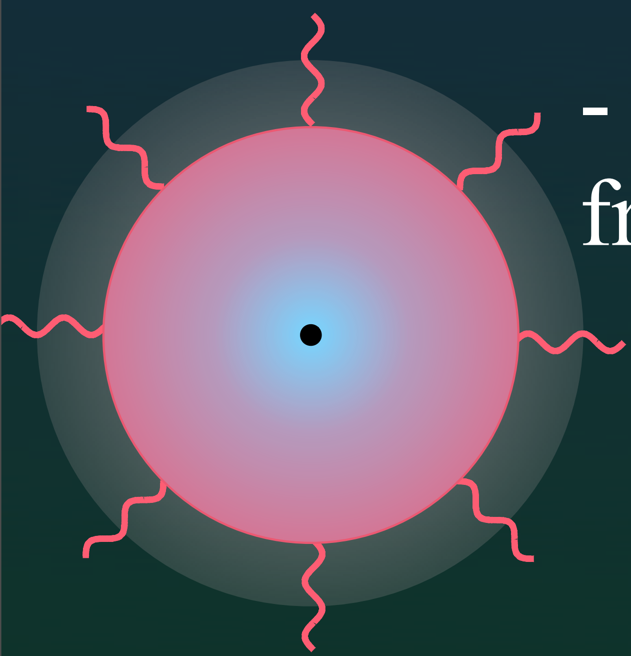
Conclusions

1. New/upcoming transient surveys will detect many tidal disruption events.



- Super-Eddington outflows likely lead to large optical detection rates for PTF, PS1, and LSST.



- Challenging to identify/distinguish from supernovae.

- Outflows produce **spectroscopic signatures**: blueshifted absorption lines in the UV.

2. Studying tidal disruptions will teach us about:

- Demography of BHs in quiescent galaxies, esp. low-mass
- Stellar dynamics in galactic nuclei
- Growth of BHs, connection to growth of stellar bulge