# X-rays from sporadic jets near the black hole event horizon

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# Outline

- General Relativistic Radiative Transfer (GRRT) code - (brief) outline and tests:

  *Accretion disks and tori, and their subsequent spectra*

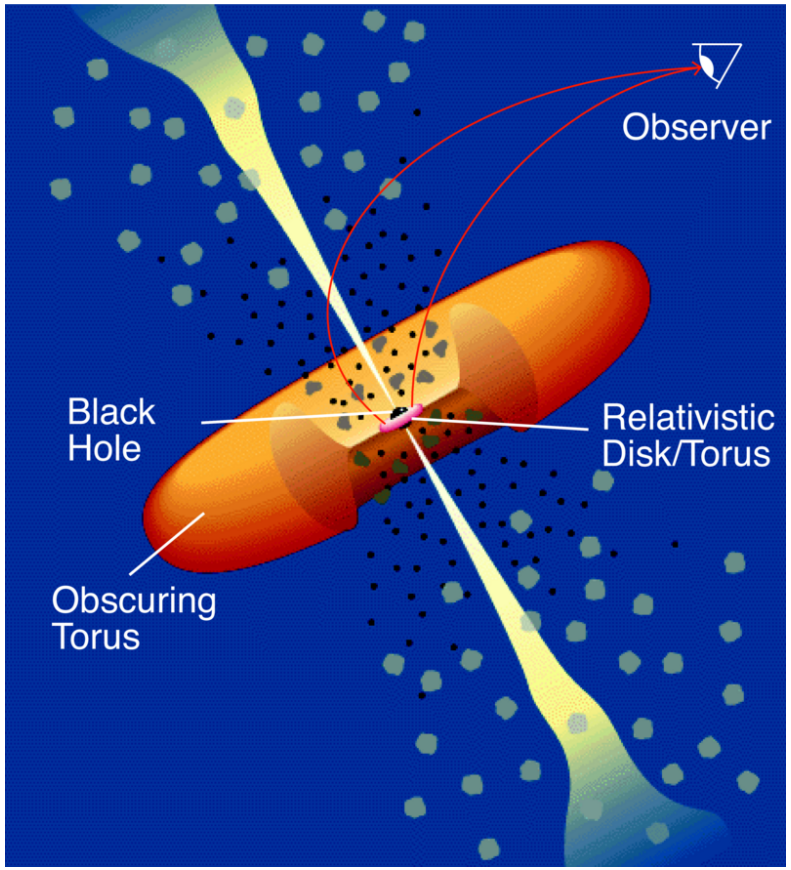
- Preliminary calculations and results of:

  1. *Time-dependent RT – orbiting plasmon*

  2. *Disk MHD model – CME-like plasmon ejection*

- Discussion and Summary

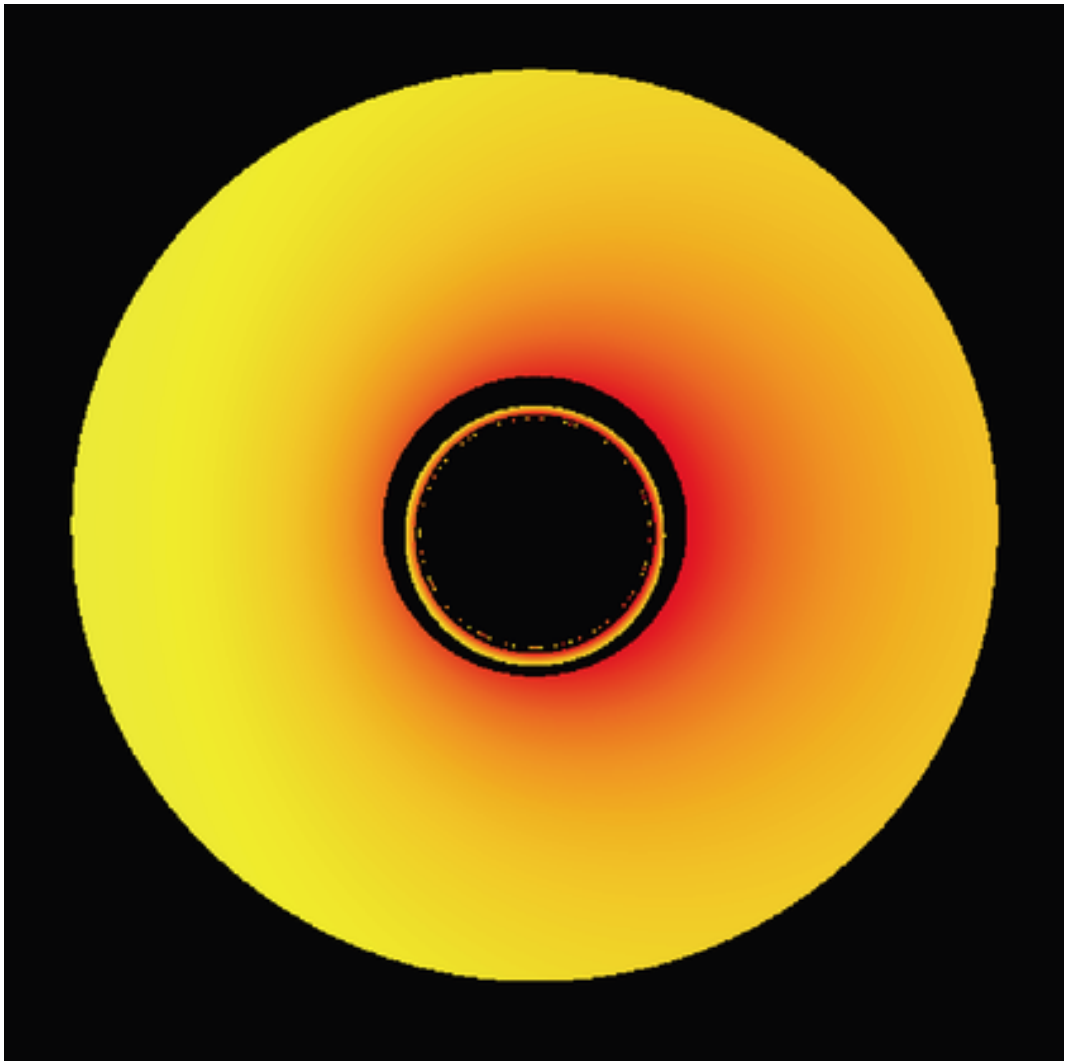
# General Relativistic Radiative Transfer



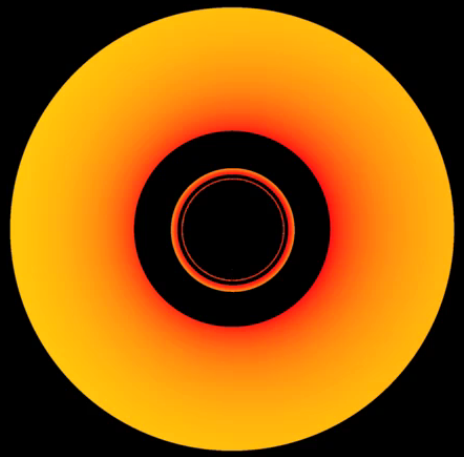

*Adapted from C.M. Urry and P. Padovani*

- Code RTE covariantly
- Specify space time metric
- Solve particle/photon geodesics
- Solve RTE along each geodesic

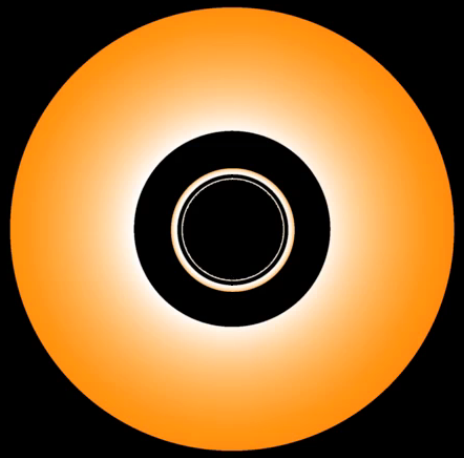
# Accretion Disk



# Optically Thick Accretion Torus

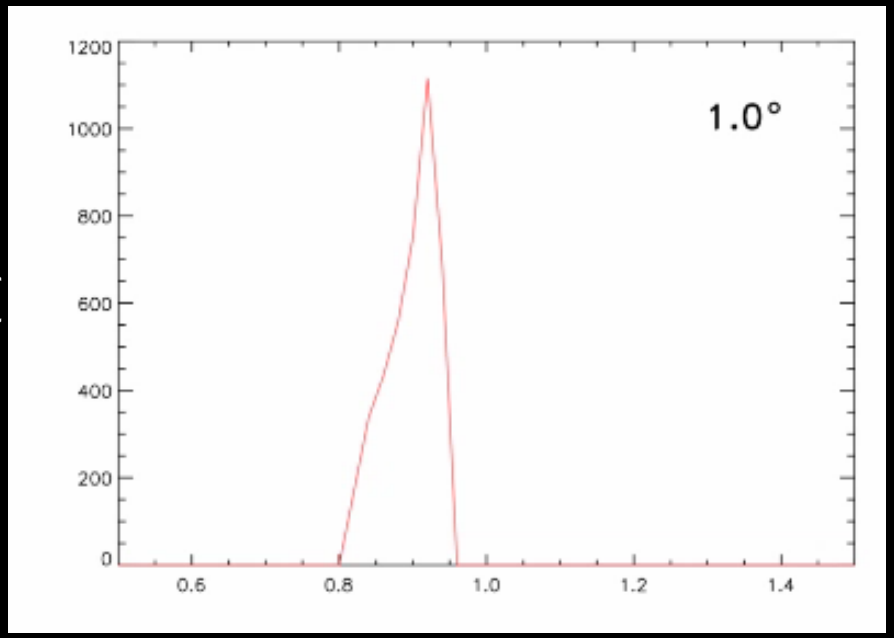


Energy shift

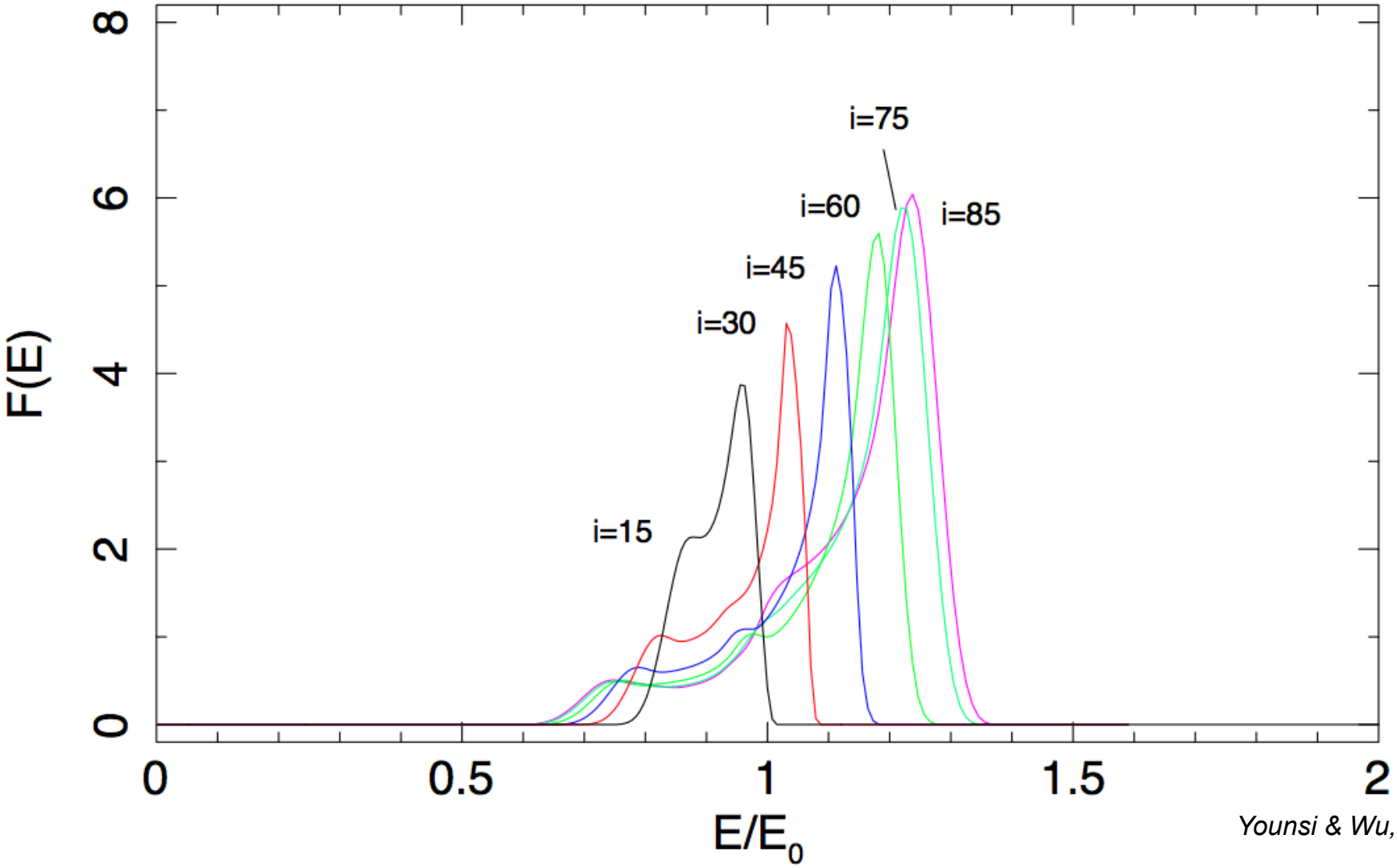


Intensity

Emission line spectrum



# Optically Thin Accretion Torus



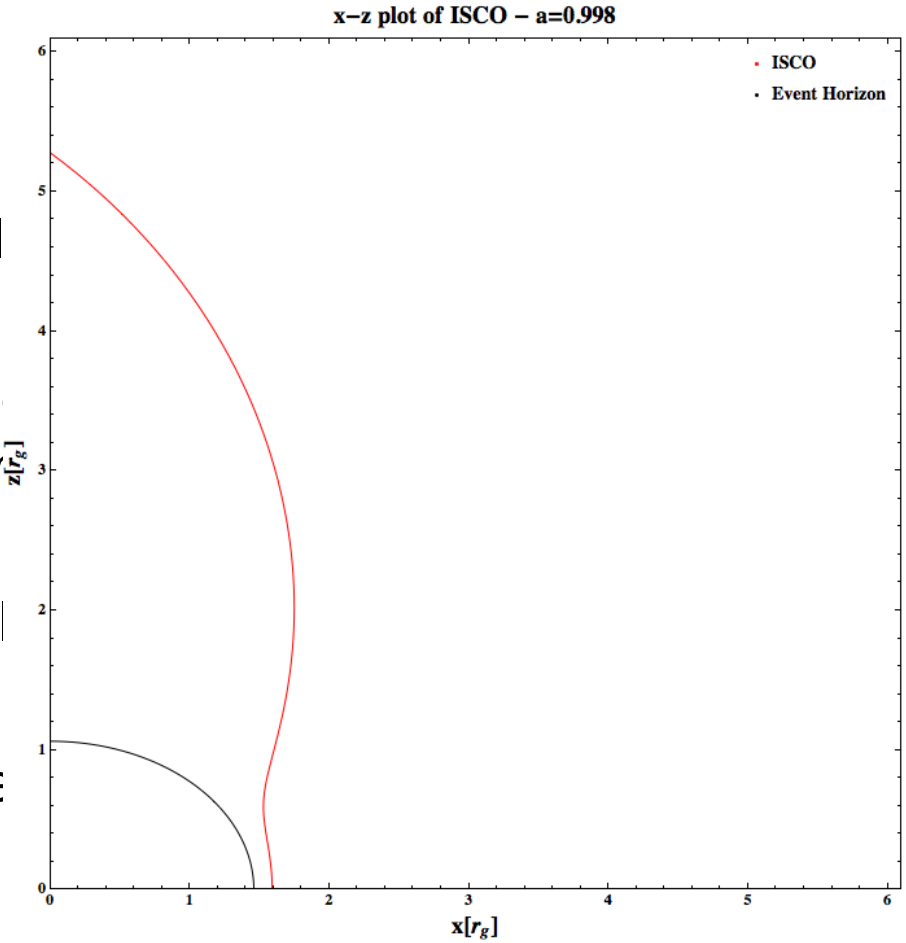

*Younsi & Wu, 2012*

# Plasmon orbiting a supermassive black hole

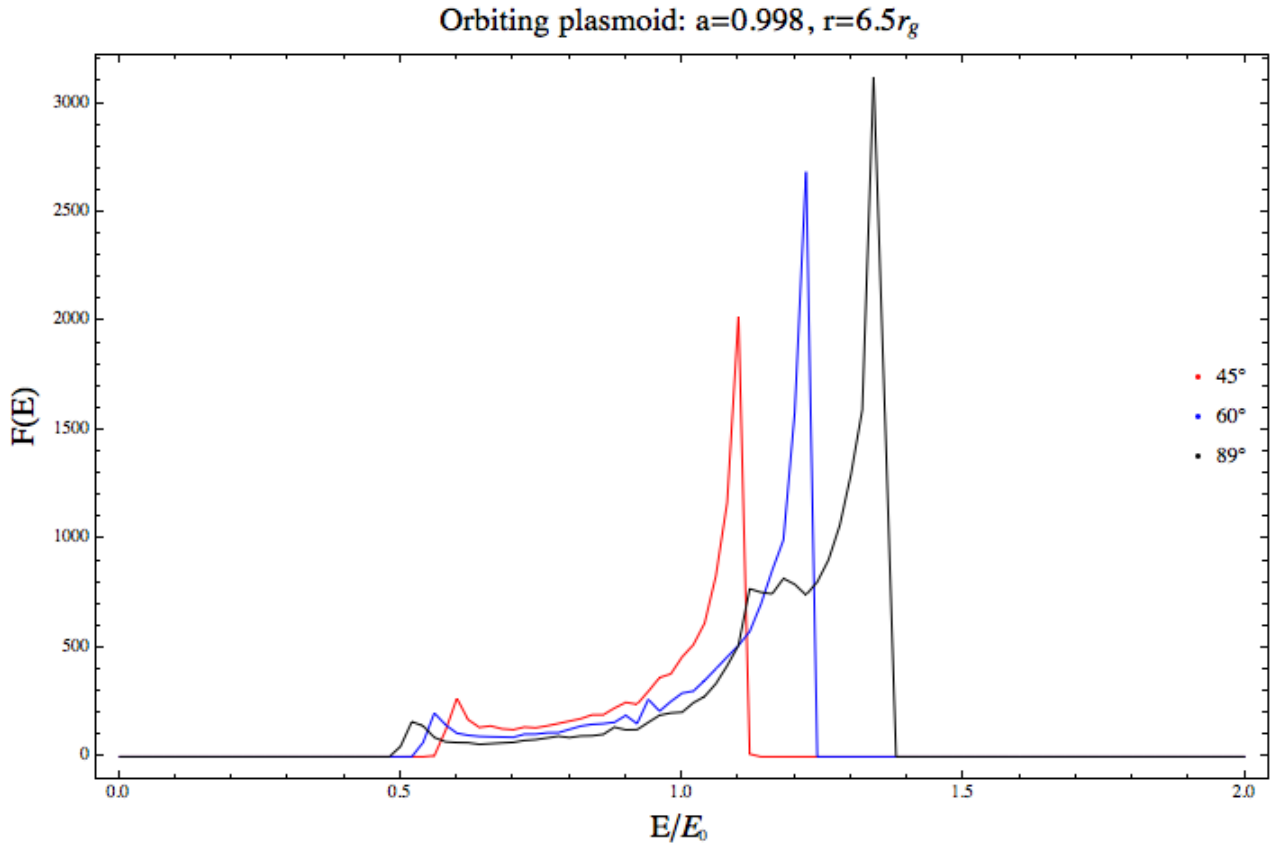
- Timing measurements of black hole systems enable direct measurements of the mass and spin
- LOFT's response to X-rays > 13keV will be crucial to observing emissions from the vicinity of the event horizon
- Can use the ISCO to examine spin and black hole mass
- The simple "hot spot" model explains QPO power spectra well (e.g. Schnitmann & Bertschinger, 2004)

# Plasmon orbiting a supermassive black hole

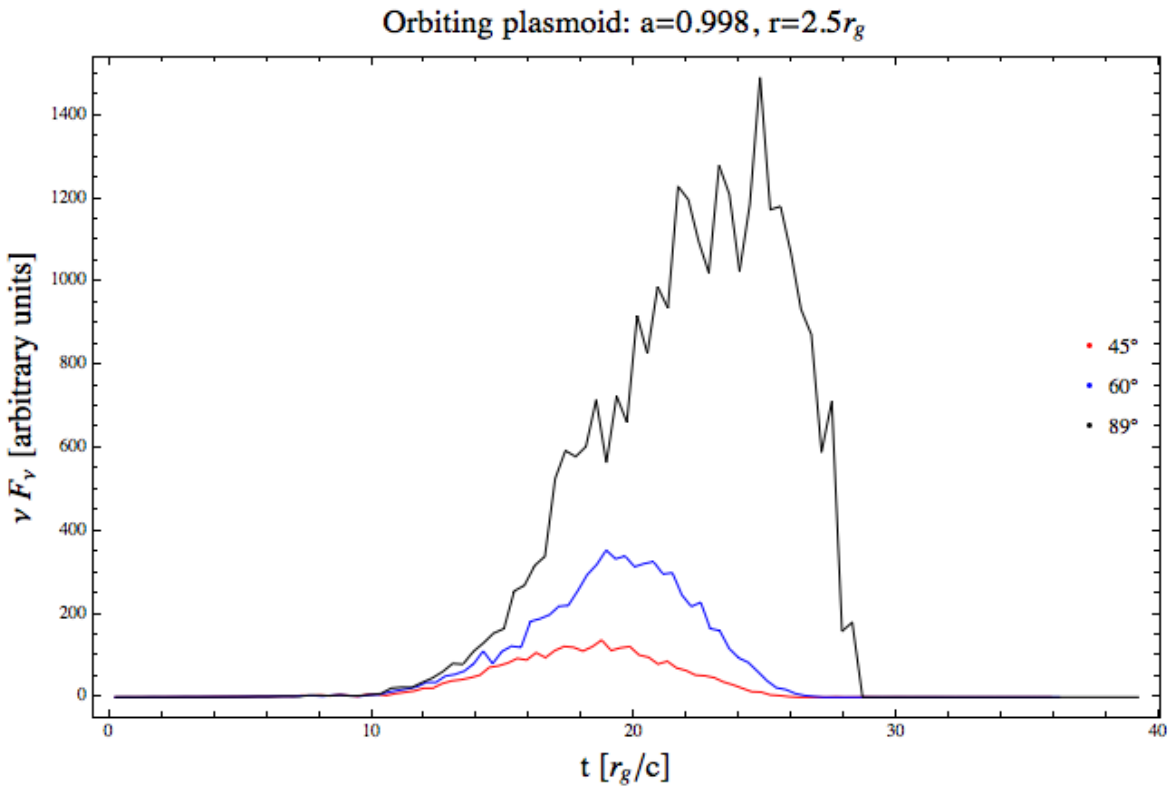
- Assume pl … dius 0.5 $r_g$)
- We investi … r one period of orbital m…
- Blob initiall… with disk
- Investigate…



# Emission from an orbiting plasmon around a SMBH – Time-averaged spectra



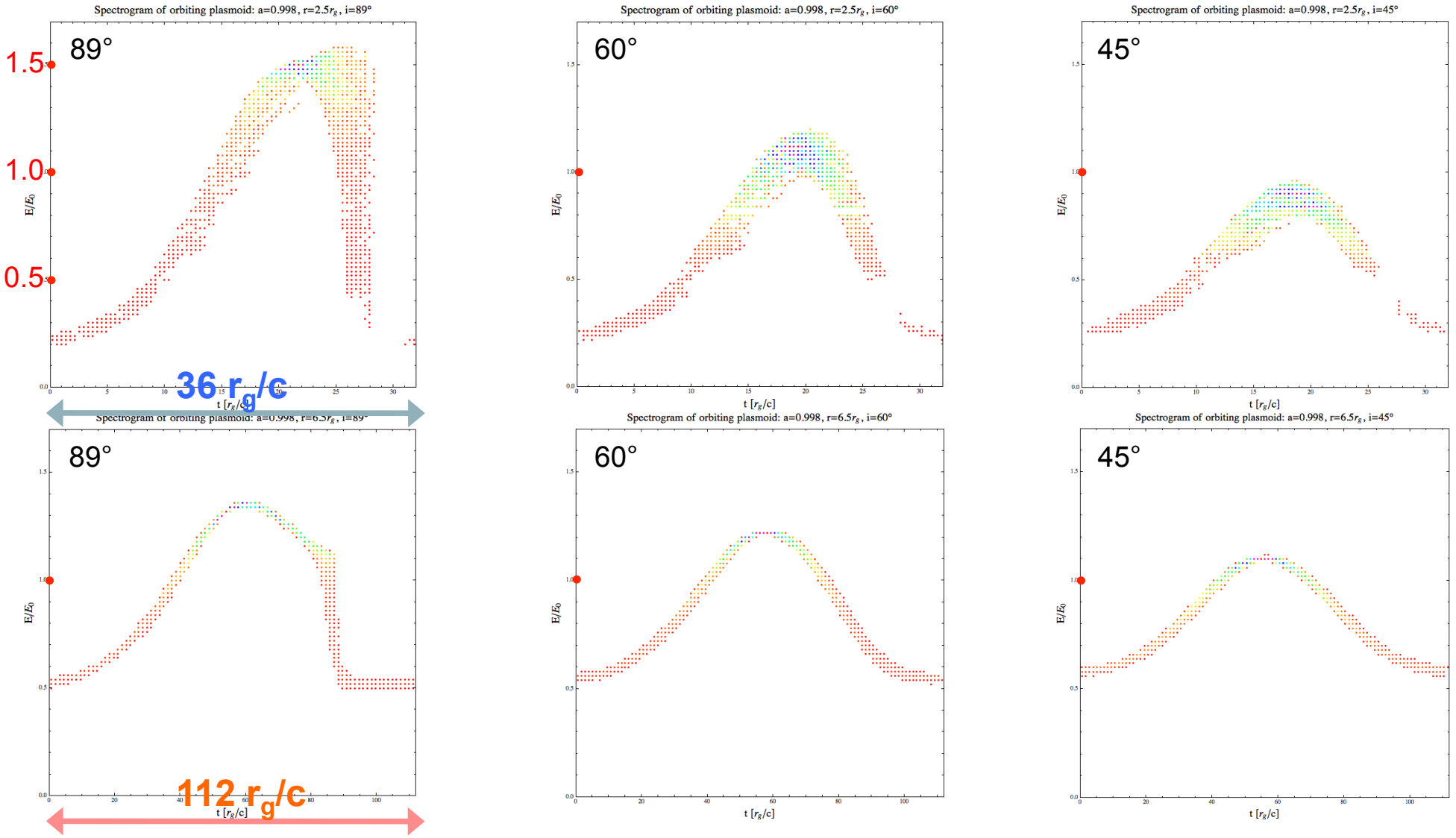
# Emission from an orbiting plasmon around a SMBH – Light curves



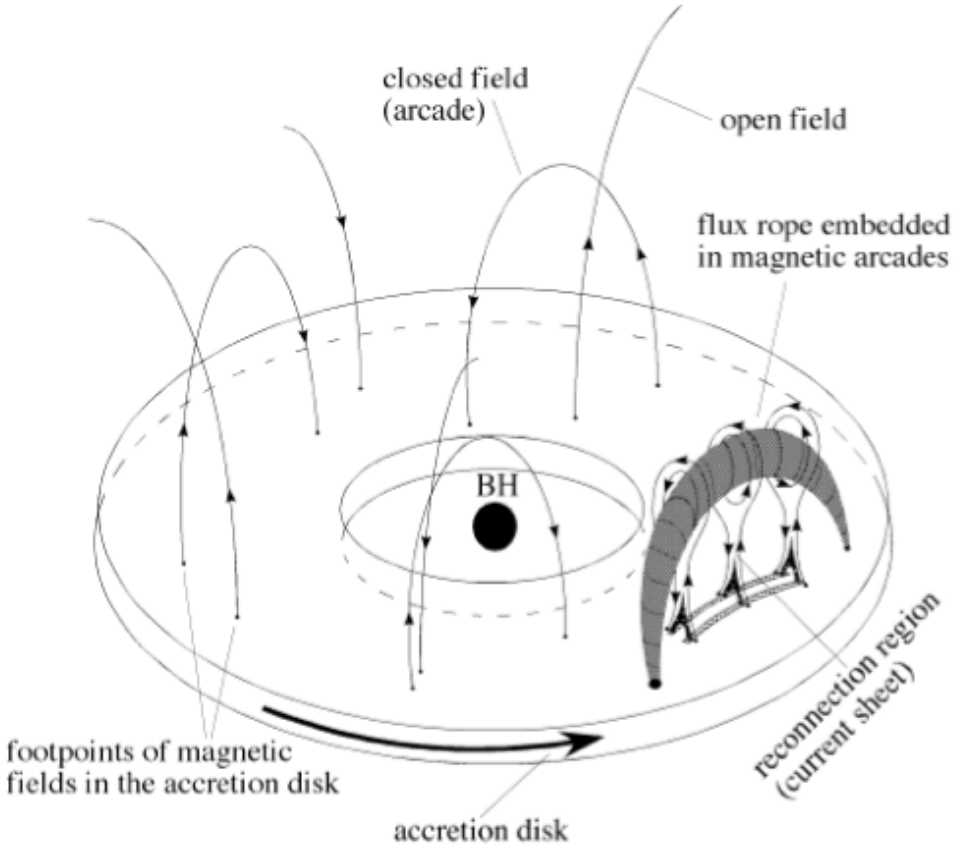

**36 $r_g$/c**

**T~180 ks**

# Emission from an orbiting plasmon around a SMBH – Spectrograms



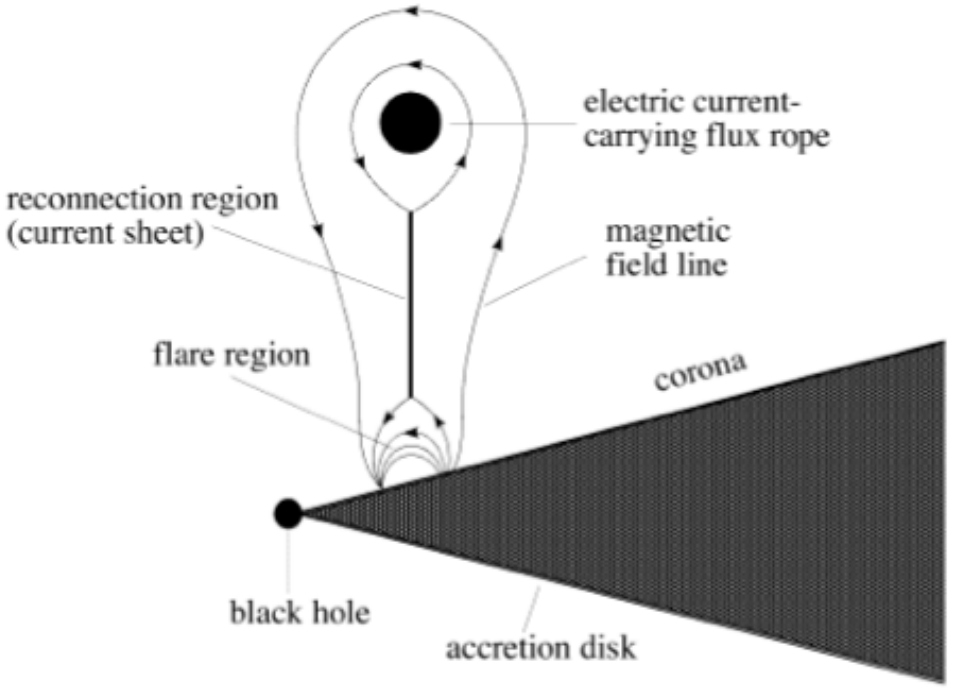
# Accretion Disk CME Formation




*F. Yuan et al. 2009*

- Magnetic arcades emerge from disk into corona
- Convective turbulence motion of their footpoints and subsequent magnetic reconnection form a flux rope (plasmon)
- Plasmon in equilibrium
- Magnetic energy and helicity are continuously transported into the corona and stored in its magnetic field until the energy exceeds a threshold
- The plasmon is then ejected, forming a current sheet

# Accretion Disk CME Ejection




*F. Yuan et al. 2009*

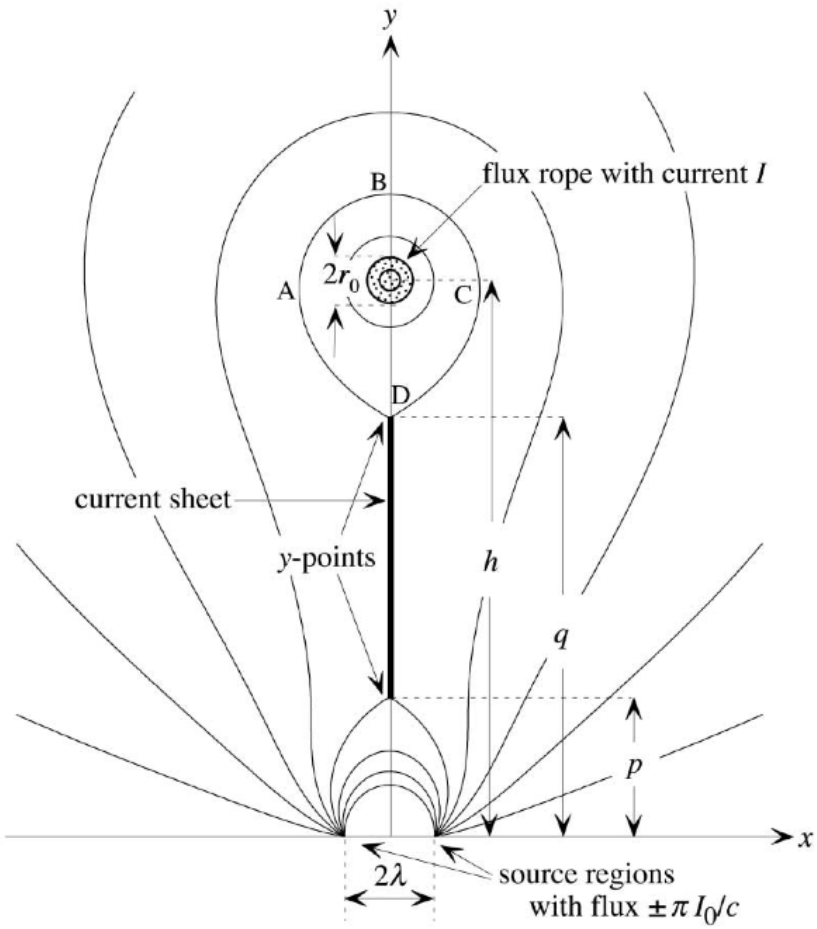
- Magnetic reconnection occurs in the current sheet
- Magnetic tension becomes much weaker than the magnetic compression
- Electromagnetic force exceeds gravity, resulting in the ejection of the flux rope
- The plasma heated in the magnetic reconnection process produces flares

# Accretion Disk CME Setup

- The vertical motion of the plasmon is governed by:

$$m\frac{\mathrm{d}^2 h}{\mathrm{d}t^2} = \frac{1}{c}\,|\boldsymbol{I} \times \boldsymbol{B}_{\mathrm{ext}}|_h - F_{\mathrm{g}}$$

- Obtain 5 ODEs - determine the plasmon height, h, as a function of time
- Plasmon accelerates slowly at first, from 0 to 0.02c in 75 $r_g/c$ ~ 26 mins
- Then a rapid acceleration – peak velocity of 0.82c in 30 $r_g/c$ ~ 10 mins
- From 100 $r_g/c$ to 360 $r_g/c$ the plasmon decelerates to 0.77 (where $h=100r_g$)

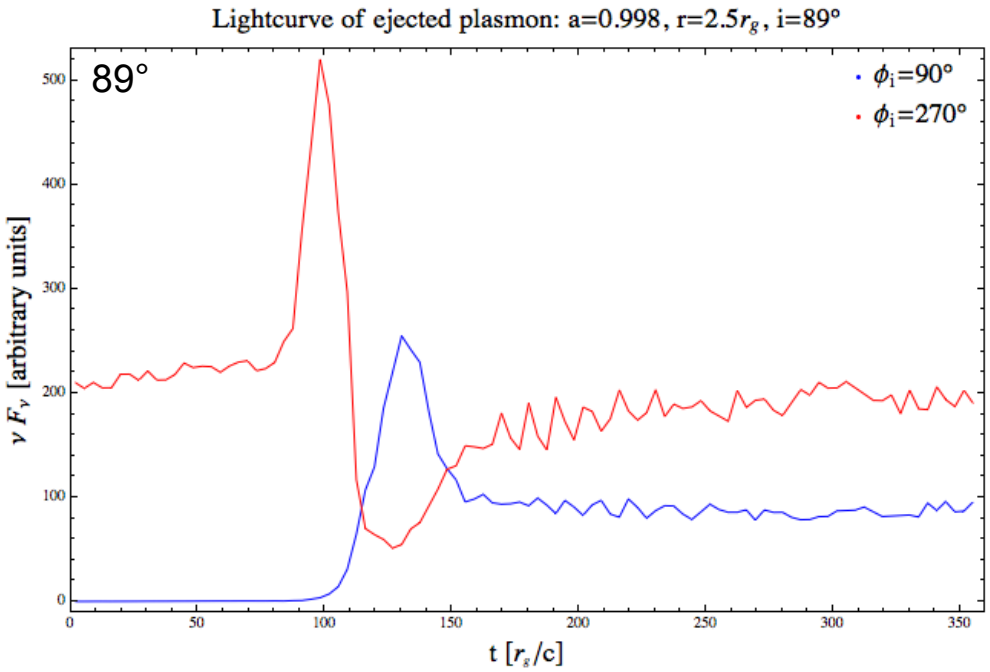


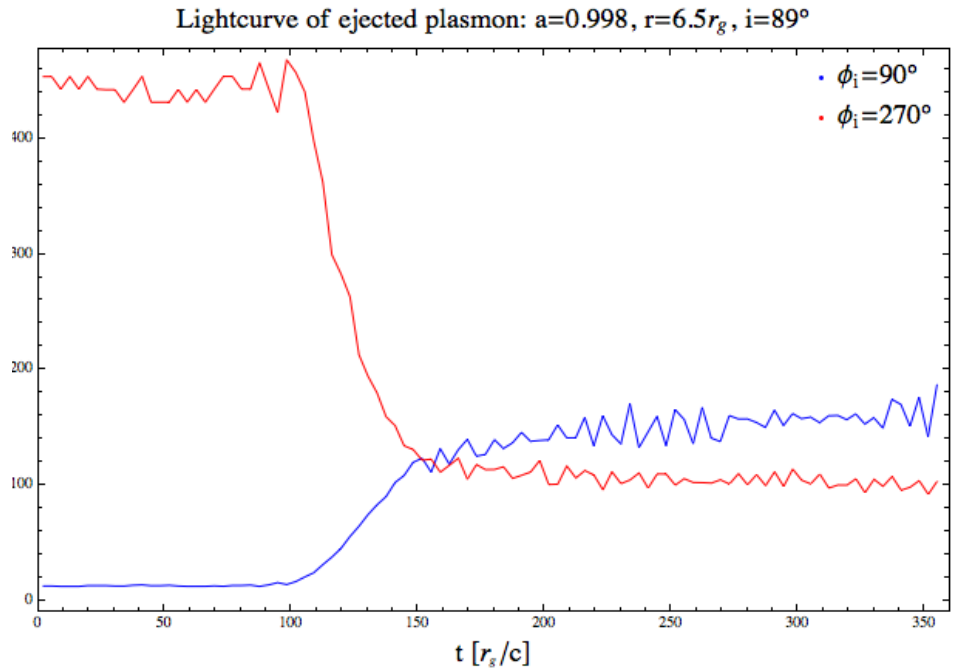
# Accretion Disk CME Setup

- Accretion disk CME model only accounts for vertical motion of the plasmon
- For simplicity, we assume the plasmon remains at a fixed distance from the black hole spin axis (*r sin(θ)* constant)
- However, the plasmon is subject to the black hole's gravity and so will move around the black hole
- This motion can be paramaterised, yielding the change in $\phi$ as a function of plasmon height:

$$\Delta\phi = \frac{1}{r_i}\int_{r_i}^{r_f} dr\, r^2 \left[\sqrt{r}\left(\frac{r^4 + a^2(r^2 - r_i^2)}{\sqrt{r^4 - a^2(r^2 - r_i^2)}}\right) - a\, r_i\right]^{-1}$$

# Ejected plasmon – Lightcurves

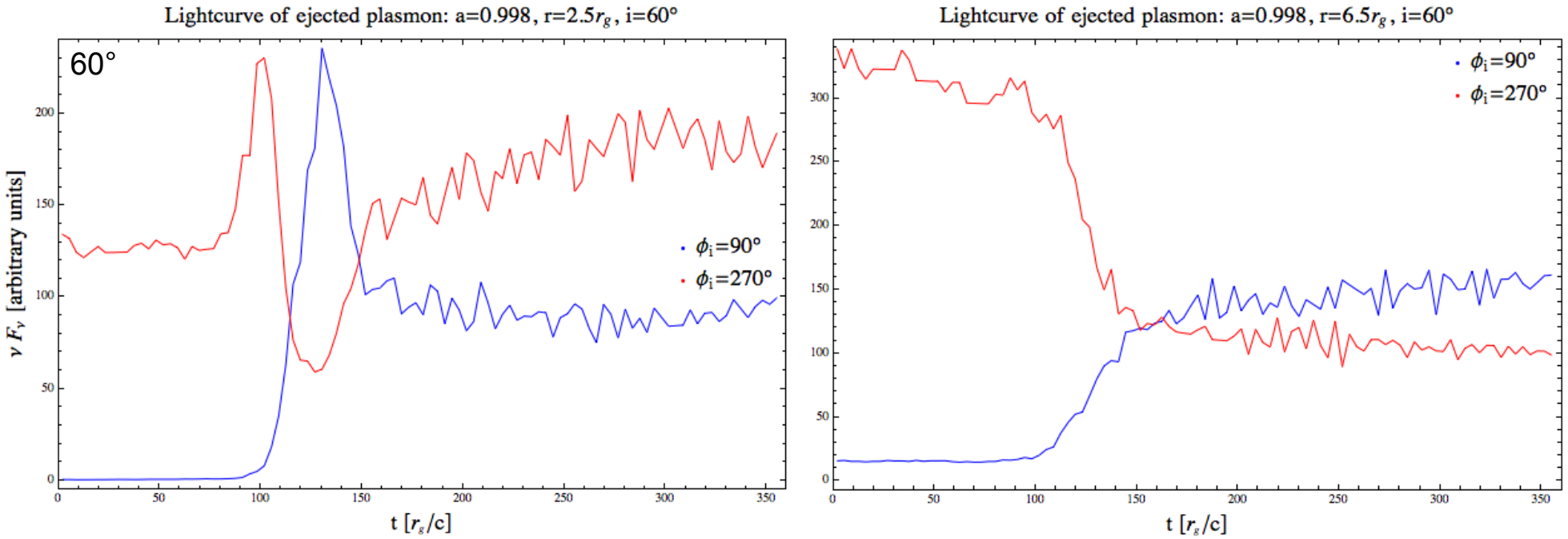



360 $r_g$/c

T~7 ks

# Ejected plasmon – Lightcurves



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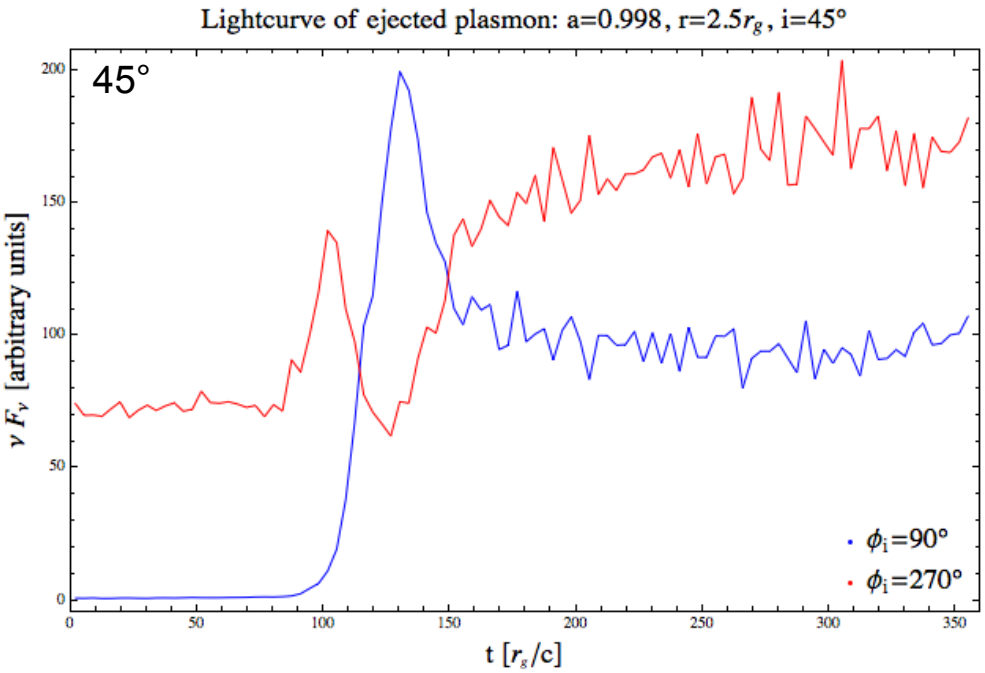
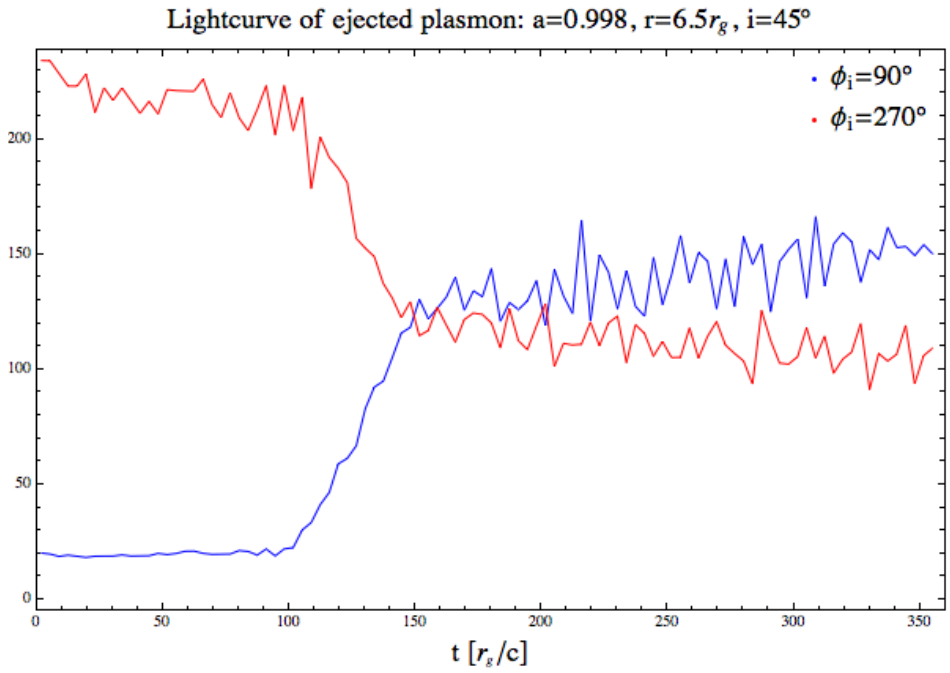
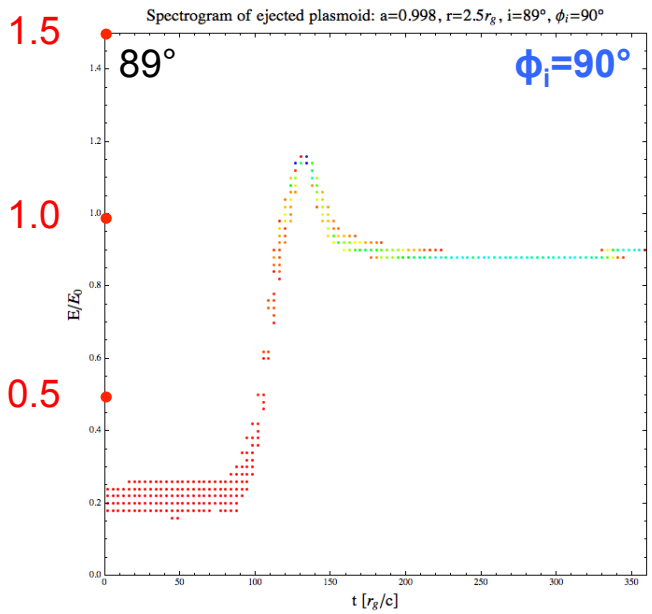
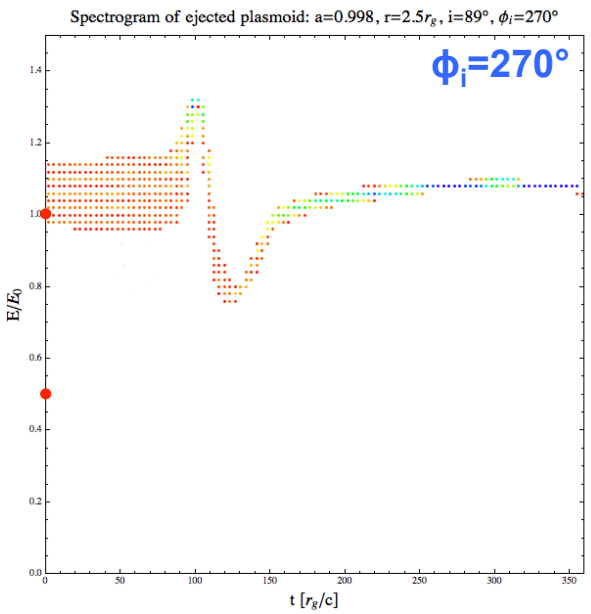
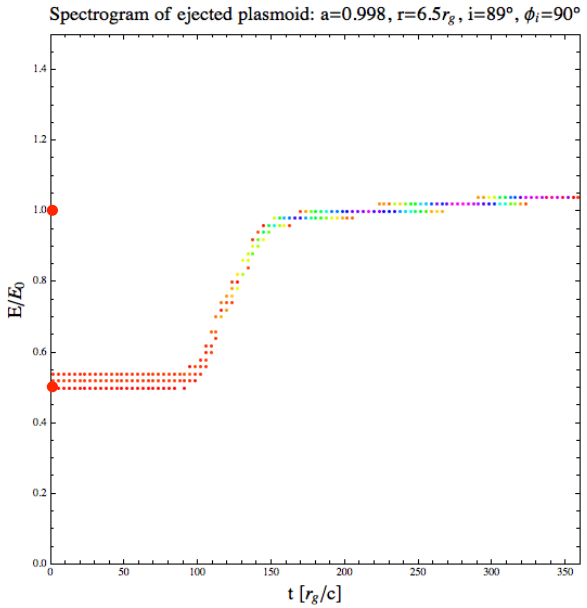


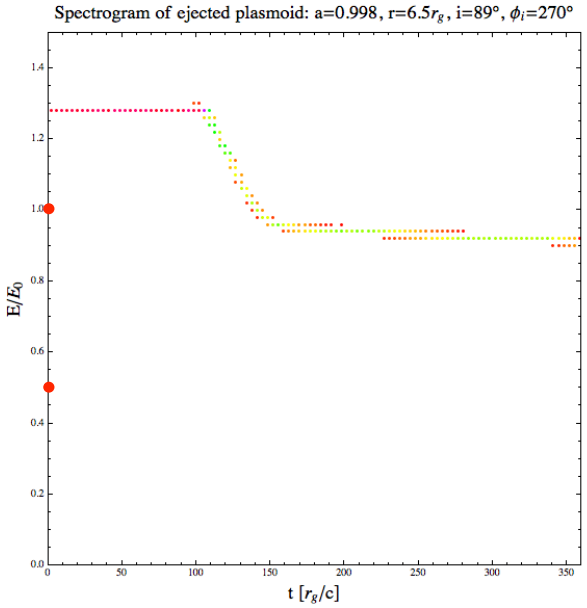



# Ejected plasmon – Spectrograms



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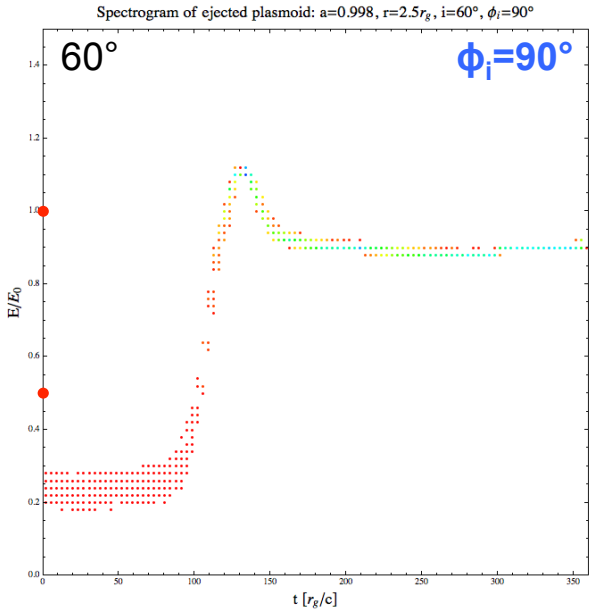


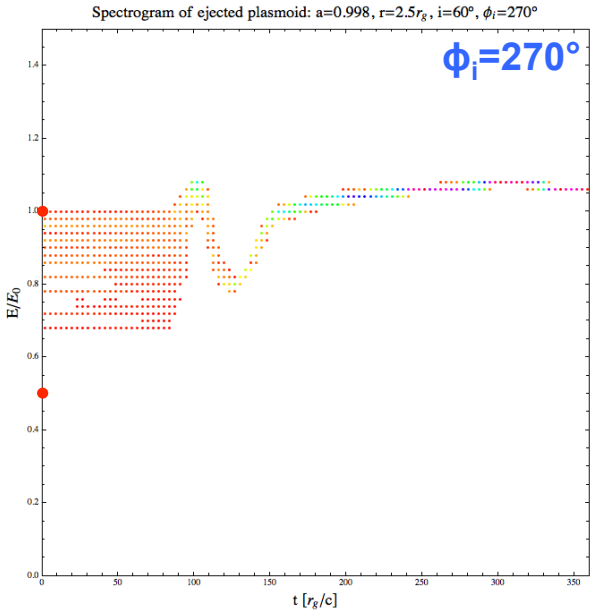


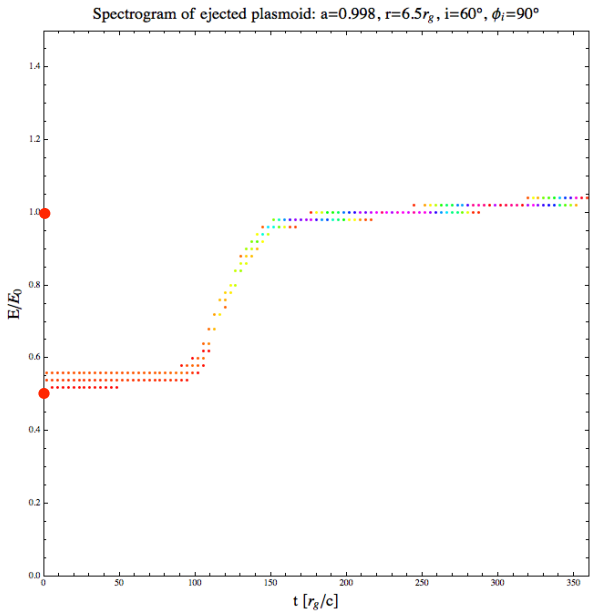


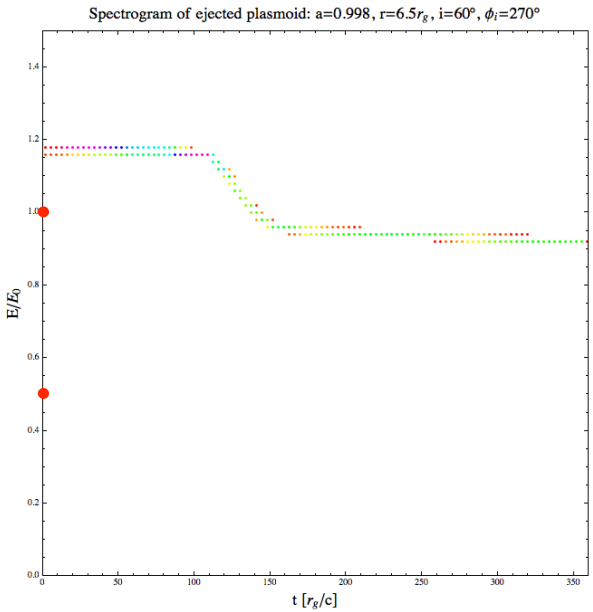

# Plasmon Ejecta - Discussion

- Ejected plasmon light curves are very sensitive both to a and observer inclination angle, as well as initial location of ejection ($\phi$) – characteristic profile shapes
- From spectrograms we can clearly distinguish between black hole spin and $\phi$ values, inclination slightly less so
- Model is very sensitive to initial magnetic field – potential probe of magnetic field within the corona
- Better understanding of the acceleration mechanism offers opportunity to directly determine black hole mass via timing measurements

# Summary

- Timing measurements will allow accurate determination of M and a
- Plasmon light curves and spectrograms very sensitive to black hole mass and spin, as well as inclination
- Plasmon emission from sporadic jets offers insight not just into black hole parameters, but also magnetic activity in the corona
- Better models: full GR in plasmon equations of motion, shock front formation as plasmon moves through ISM, adiabatic expansion of plasmon, Synchrotron radio emission + X-rays (Bremsstrahlung, SSC and Synchrotron)