Probing Intermediate Mass Black Holes with White Dwarf Tidal Disruptions

Drew Clausen
Mike Eracleous, Alberto Sesana, & Steinn Sigur∂sson

Outline

- Tidal disruption basics
- Tidal disruption of WDs on bound orbits
- Tidal disruption of WDs on unbound orbits
- Conclusions

Tidal Disruption

- Condition for tidal disruption:

$$a_{\rm t} > g_\star$$

- Occurs at a separation:

$$R_{\rm T} = r_\star \left(\eta^2 \frac{M_{\rm BH}}{m_\star} \right)^{1/3}$$

- Strength of encounter:

$$\beta = \frac{R_{\rm T}}{R_{\rm p}}$$

- For a 0.6 $M_\odot$ WD:

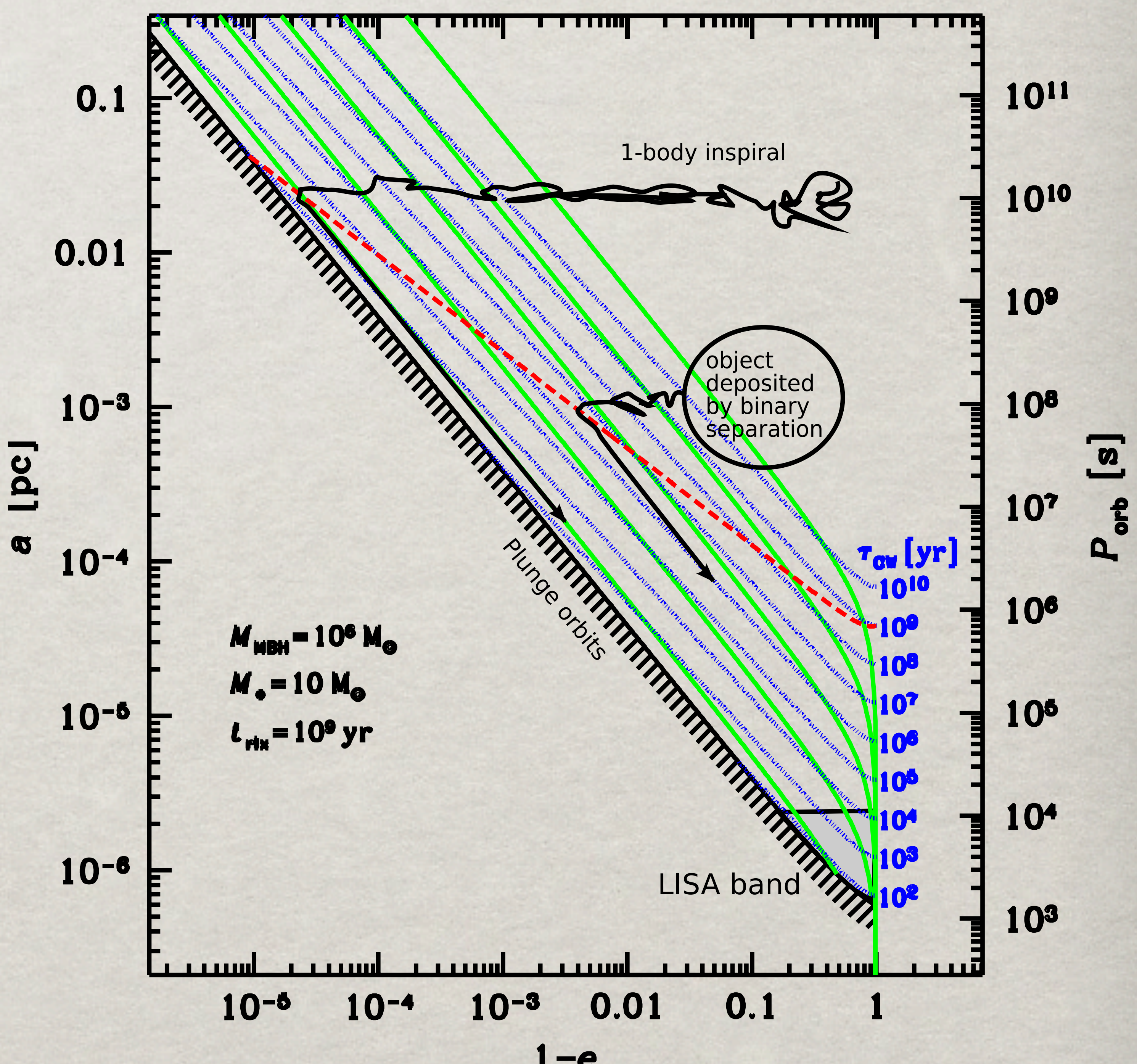
$$R_{\rm T} = R_{\rm S} \quad \text{when} \quad M_{\rm BH} \sim 10^5 M_\odot$$

What can we learn from WD tidal disruptions?

- Probe the low mass end of the massive BH mass function
- Properties of galaxies that host IMBH
  - Dwarf elliptical galaxies? Globular clusters?
  - Dynamical processes and mass segregation in the hosts' cores
- With simultaneous gravitational wave detection:
  - Calibration of the $D_L(z)$ relationship
  - WD equation of state

Capture

- Two body relaxation changes eccentricity until gravitational radiation is significant
- Large number of dissipative encounters drive WD to a pure inspiral
- Rate= 10^{-6} to 10^{-8} yr^{-1}



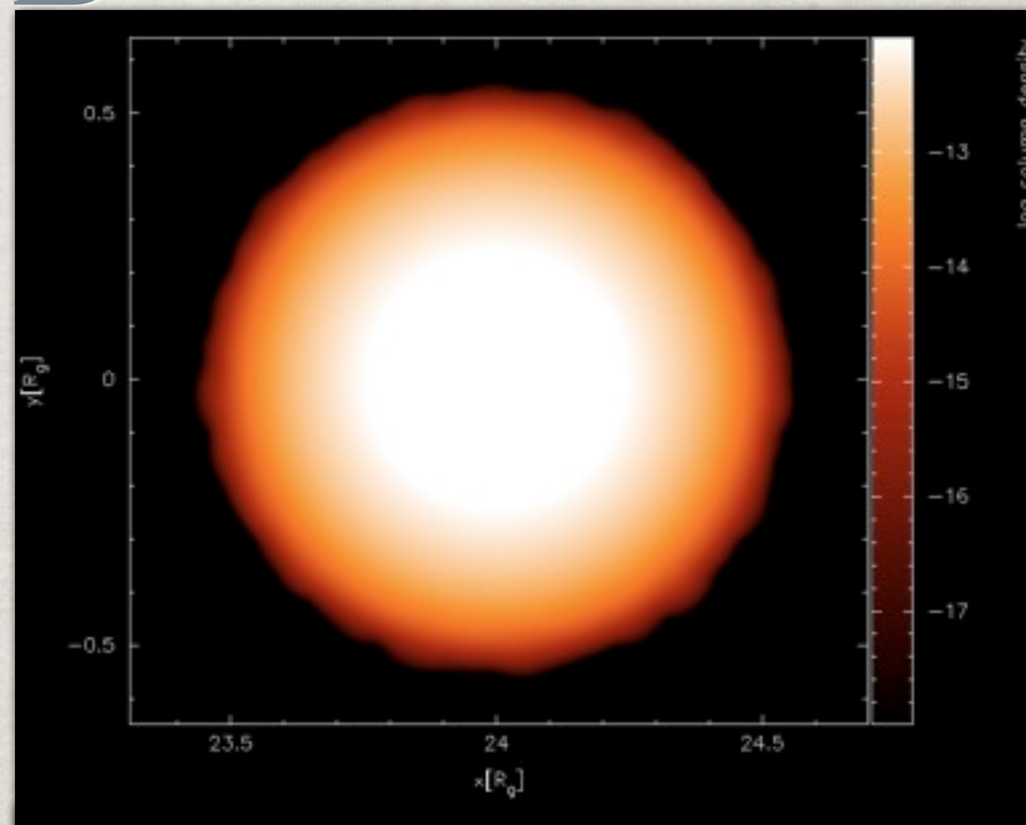
(Amaro-Seoane et al. 2007)

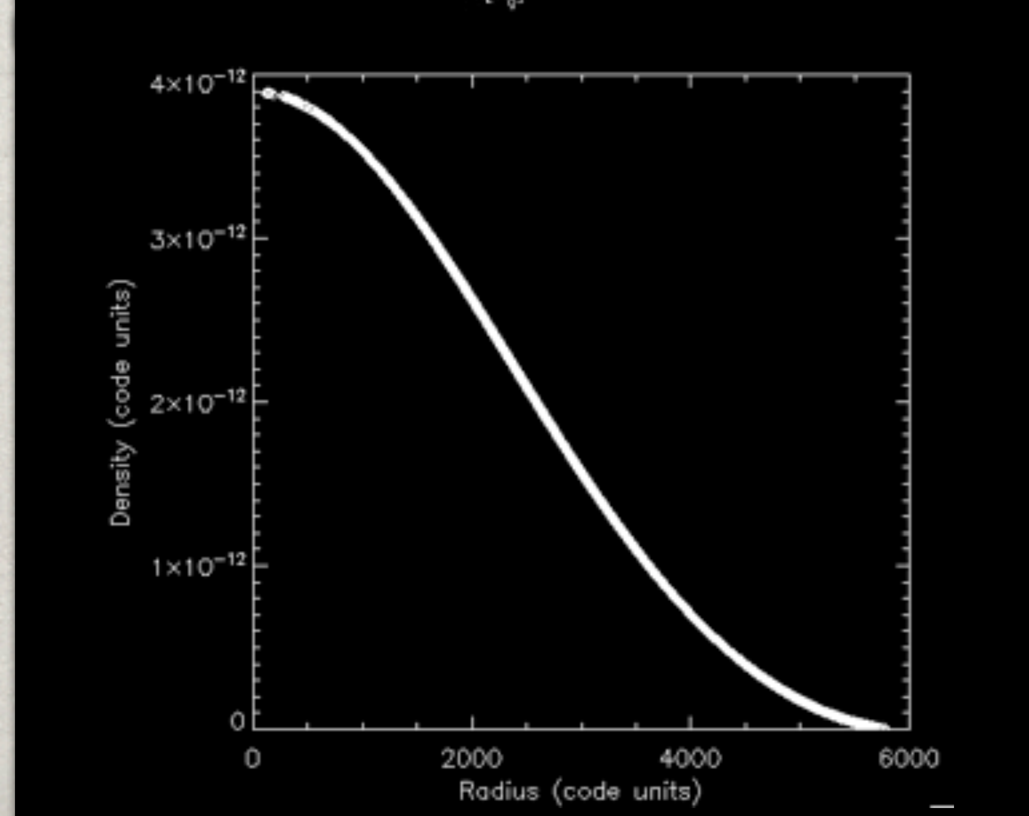
WD Tidal Disruption: Bound

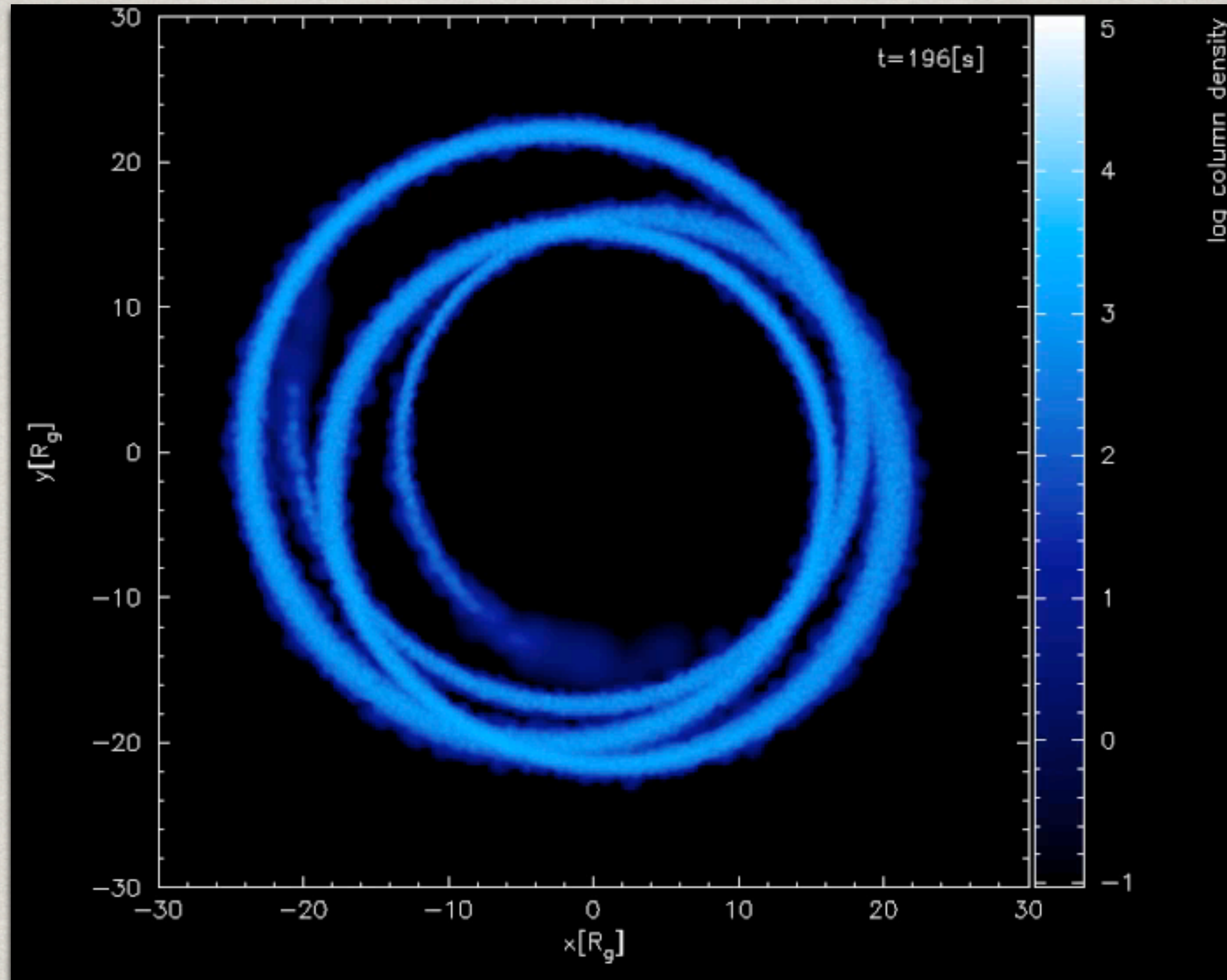
- We simulated the disruption with GADGET-2
  - Added a black hole sink particle with a Paczynski-Wiita potential:

$$\Phi = \frac{GM_{\mathrm{BH}}}{r - R_S}$$

- WD is modeled as a polytrope with $\gamma = 5/3$
- 10^5 particles







$M_{\rm BH} = 10^4\ M_\odot;$ $M_{WD} = 0.55\ M_\odot;$ $e = 0.2$

$a = 19.2\ R_g;$ $R_{\rm T} = 15.4\ R_g$

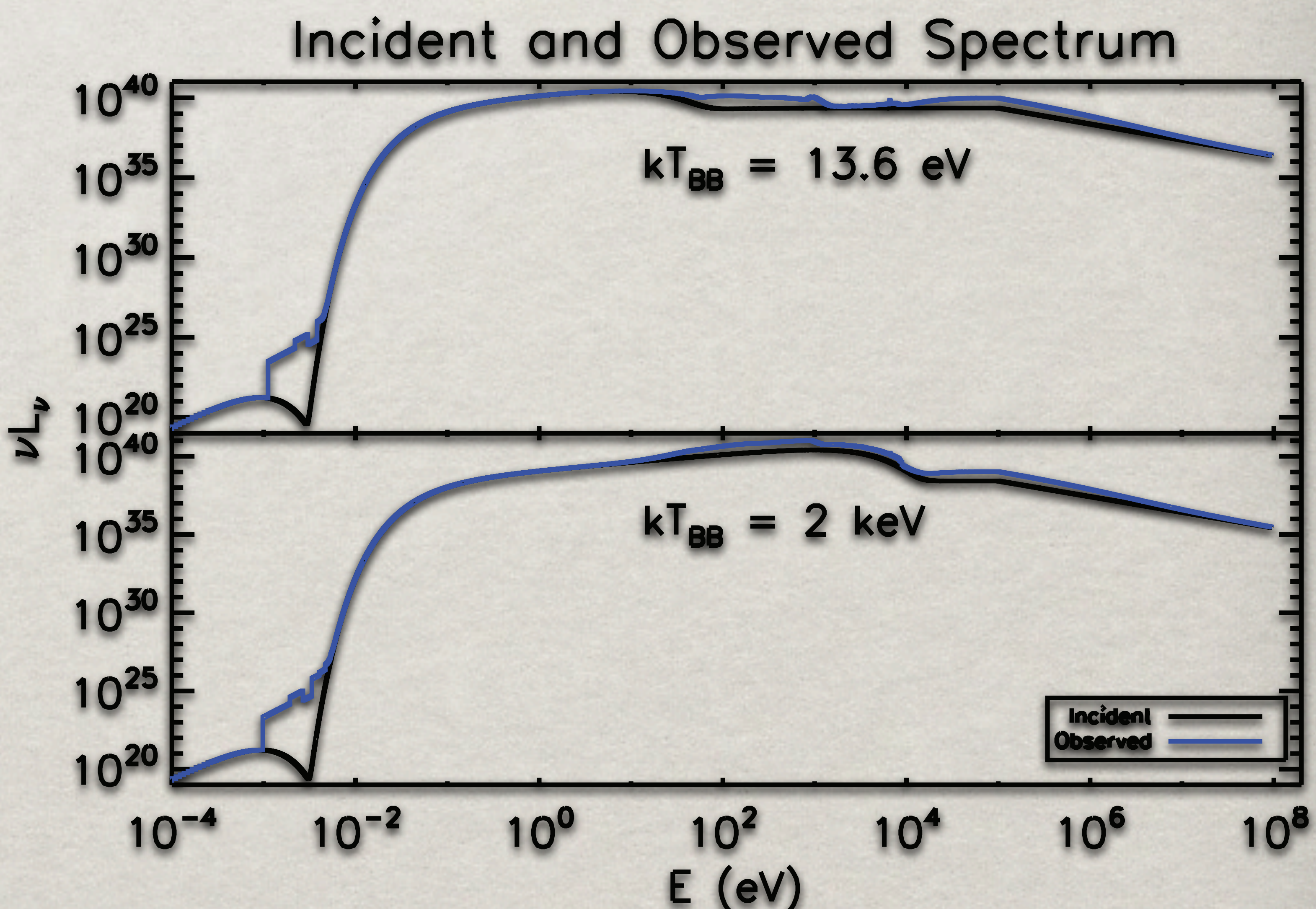
Observable Properties

- An accretion flare with

$$L_{\rm Bol} = 2 \times 10^{43}\ {\rm erg\ s^{-1}}$$

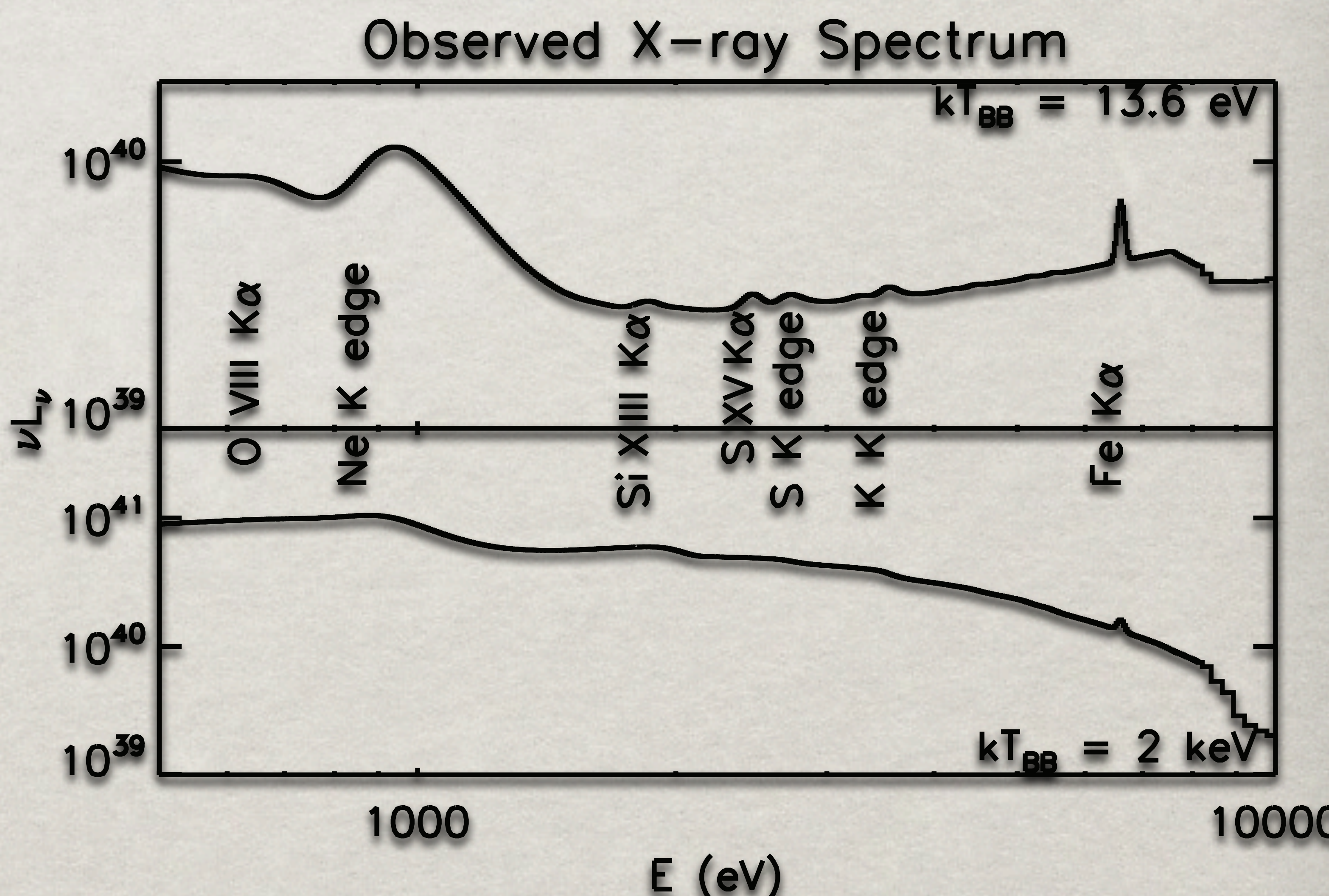
$$L_{\rm X} \sim 10^{41}\ {\rm erg\ s^{-1}}$$

- Beginning ~1 day after tidal disruption.
- The high accretion rate is steady and not impeded by any dynamical processes.



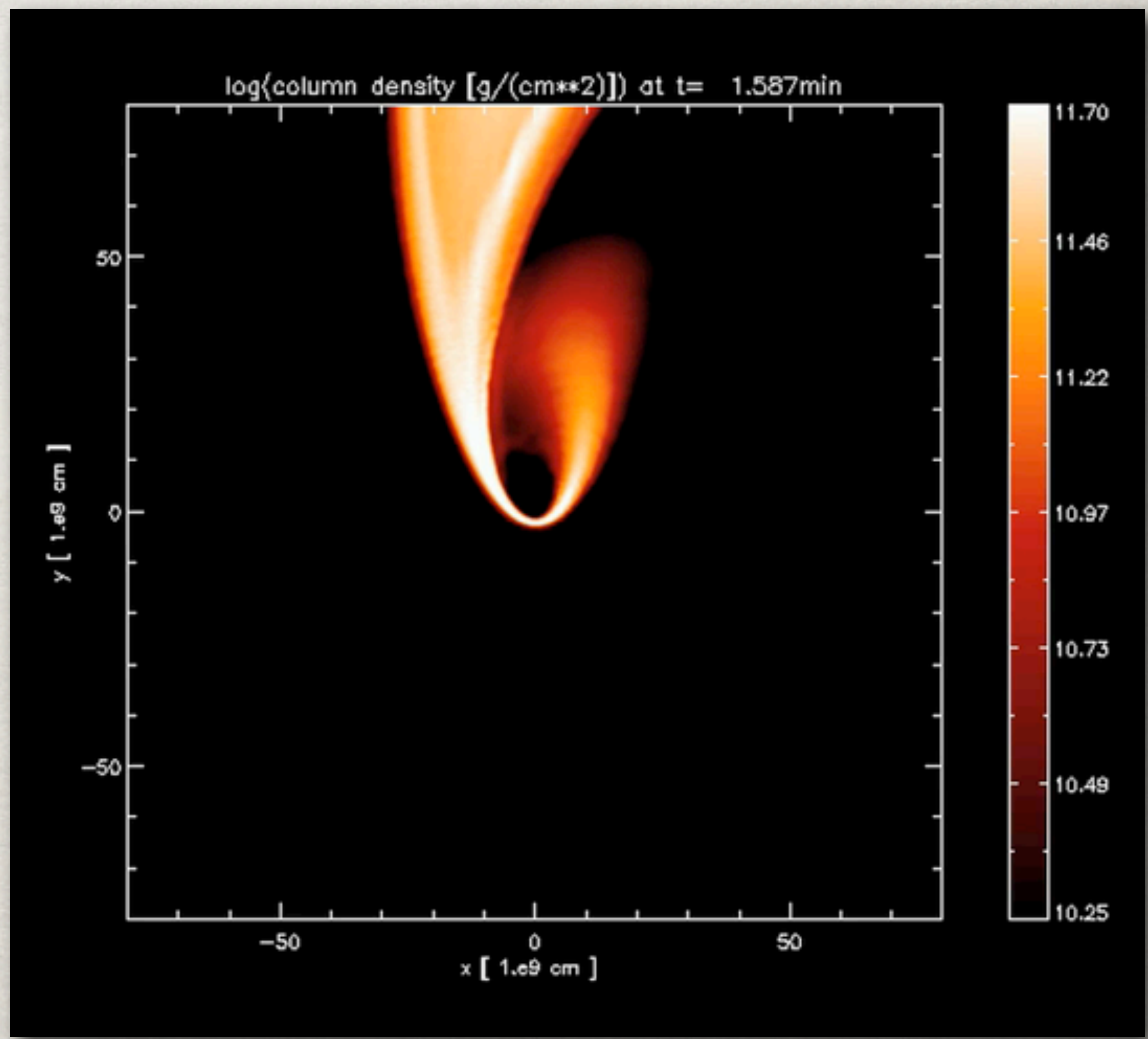
Observable Properties

- The observed spectrum is dominated by continuum emission
- There are some weak X-ray lines



WD Tidal Disruption: Unbound

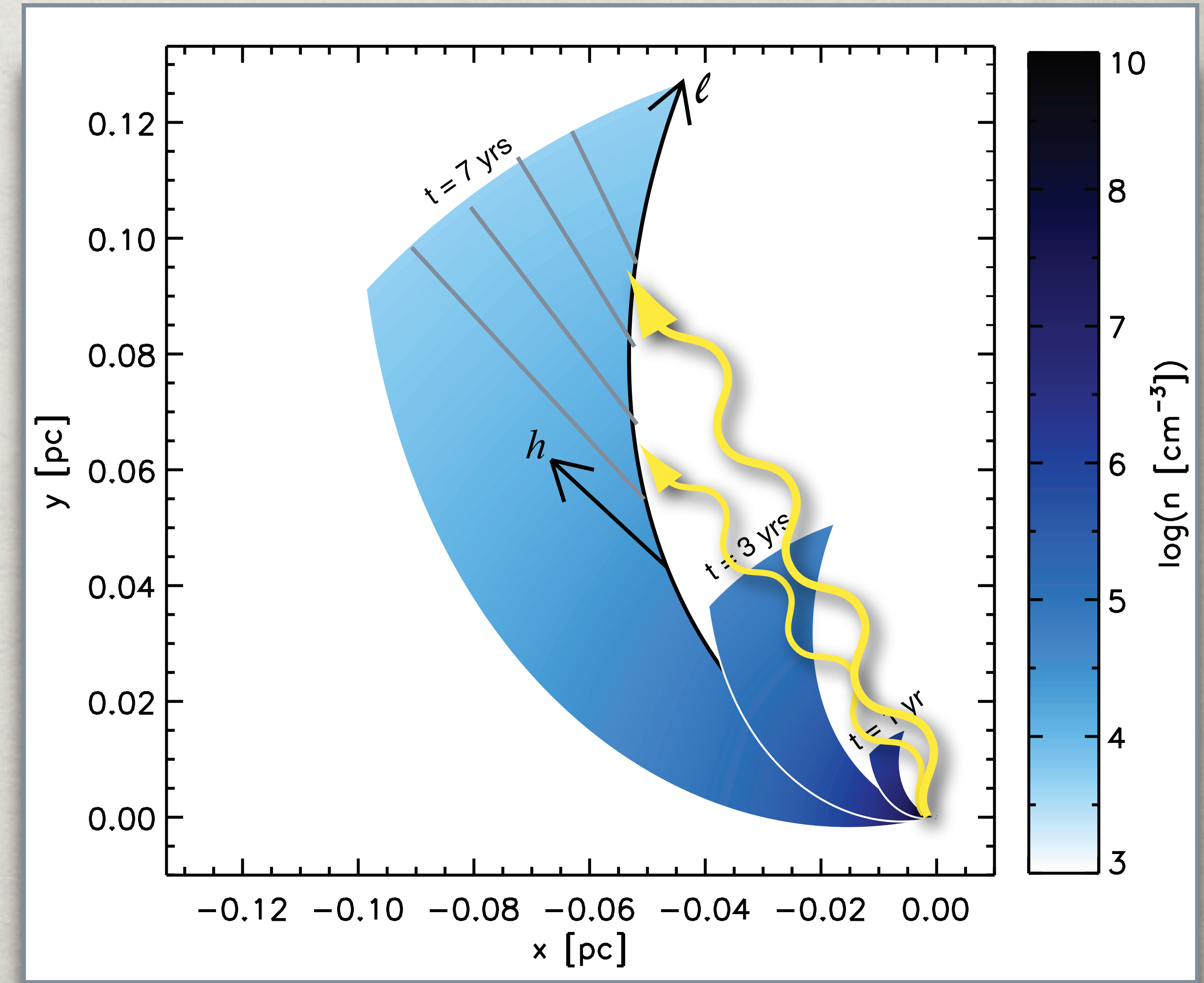
- About half of the material becomes bound to the BH after disruption
- Fallback rate evolves as $t^{-5/3}$
- Half of the material flows away from BH

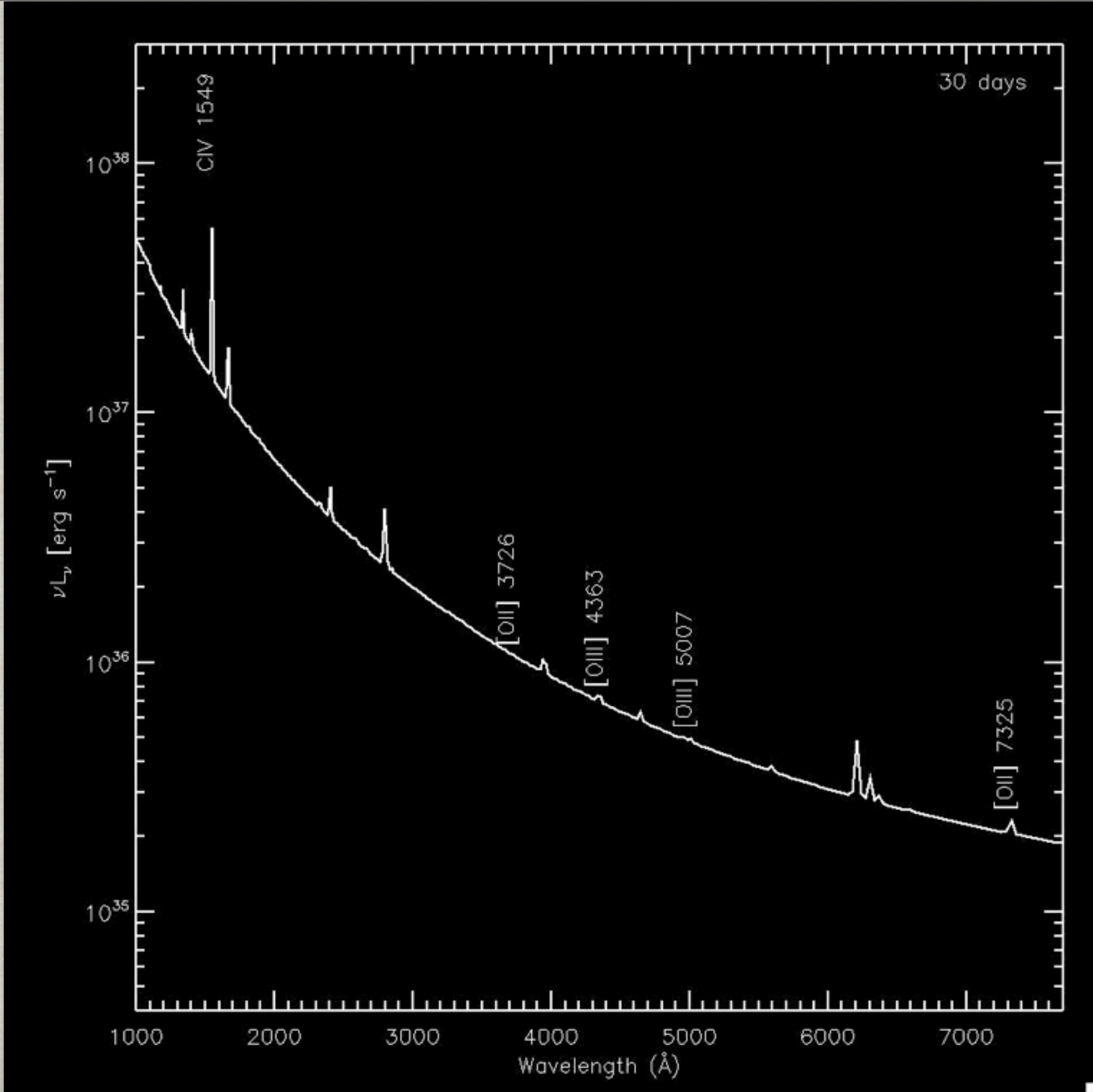


(Rosswog et al. 2009)

WD Tidal Disruption: Unbound

- Accretion flare illuminates the expanding debris tail
- Material is photoionized by soft X-ray and UV photons
- Produces emission lines
- We adapted the Strubbe & Quataert (2009) model for the debris tail

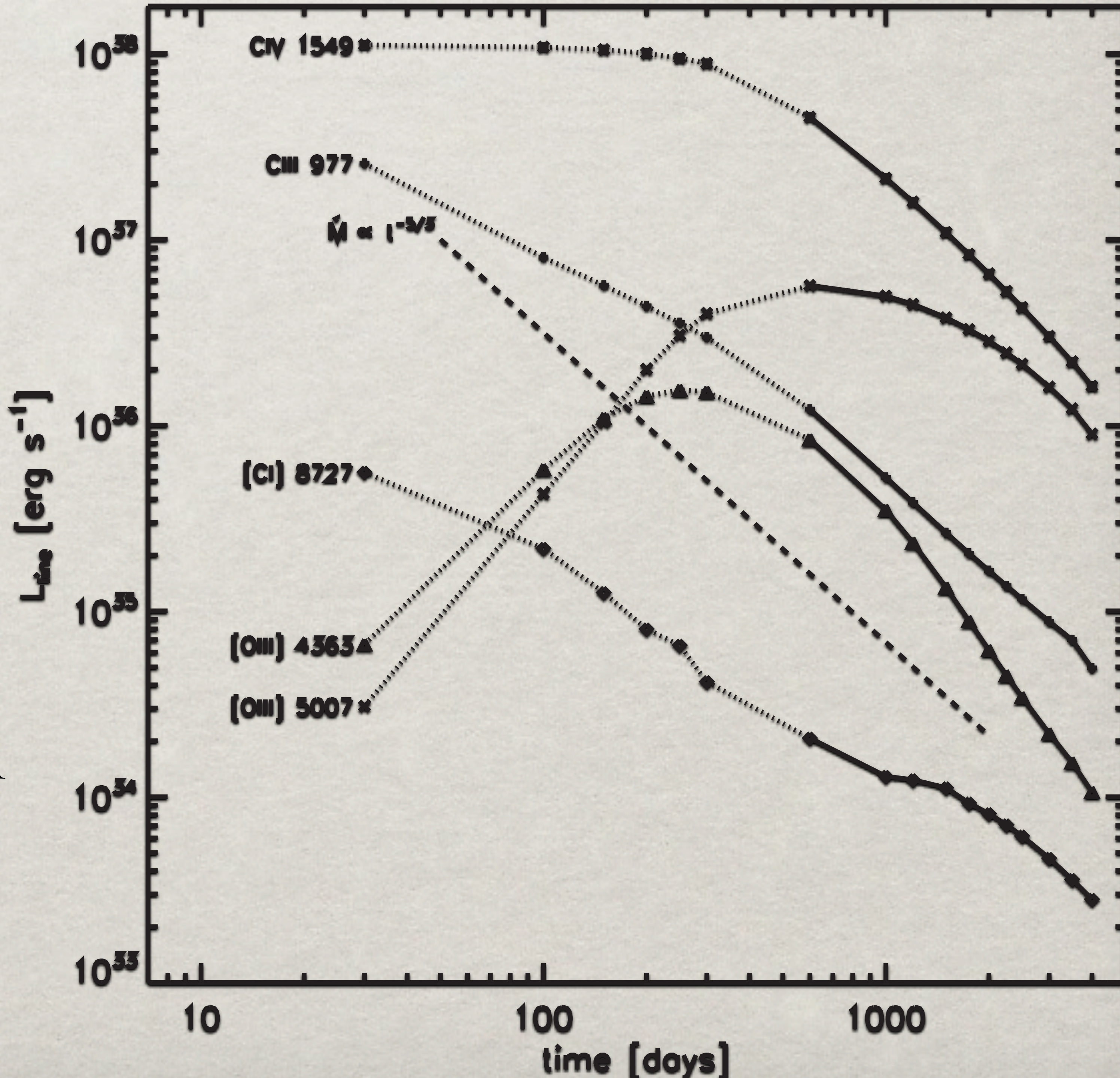




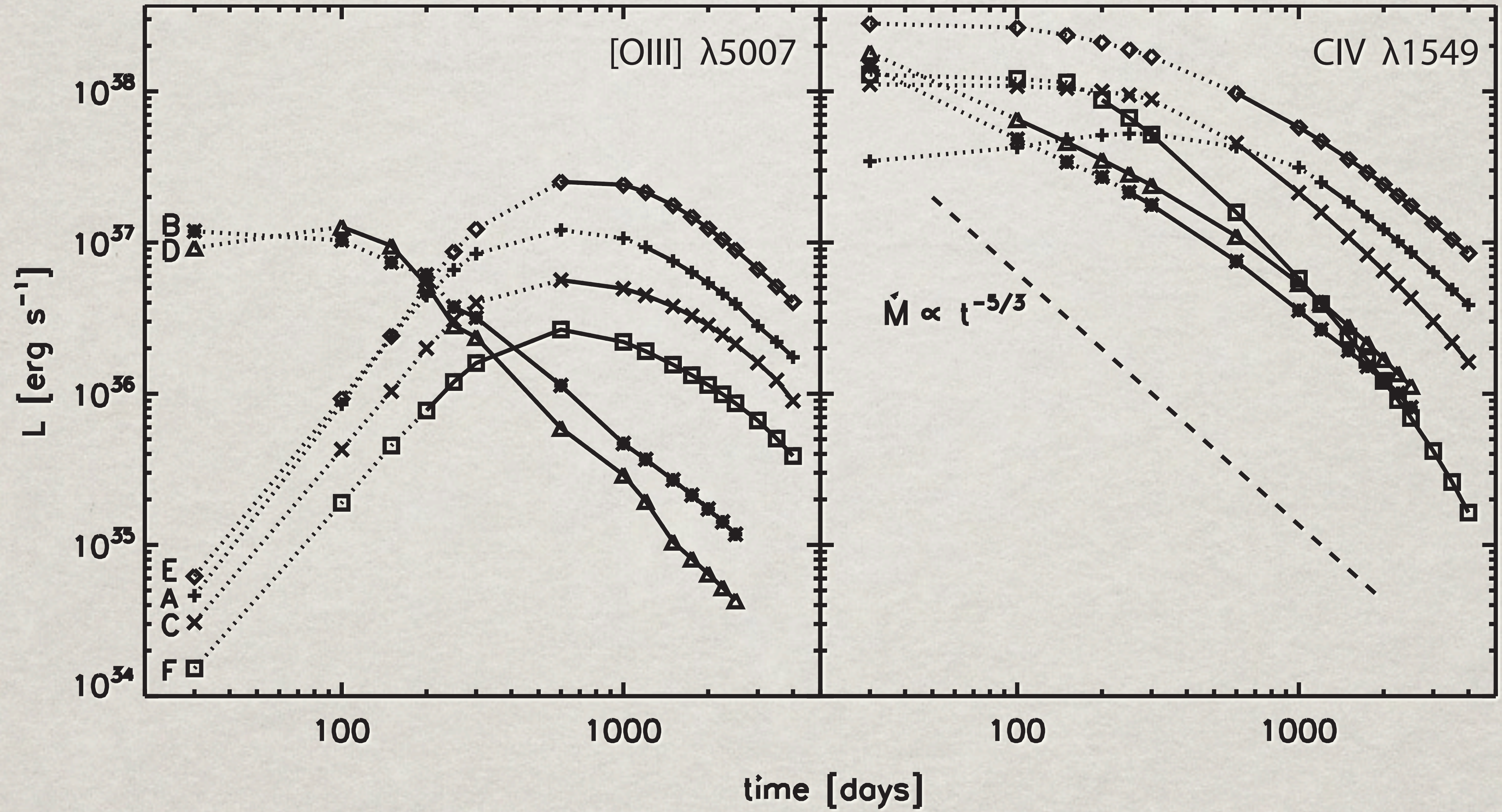
30 days
CIV 1549
[OII] 3726
[OIII] 4363
[OIII] 5007
[OII] 7325
10^{38}
10^{37}
10^{36}
10^{35}
νL_ν [erg s^{-1}]
1000
2000
3000
4000
5000
6000
7000
Wavelength (Å)

Emission Line Light Curves

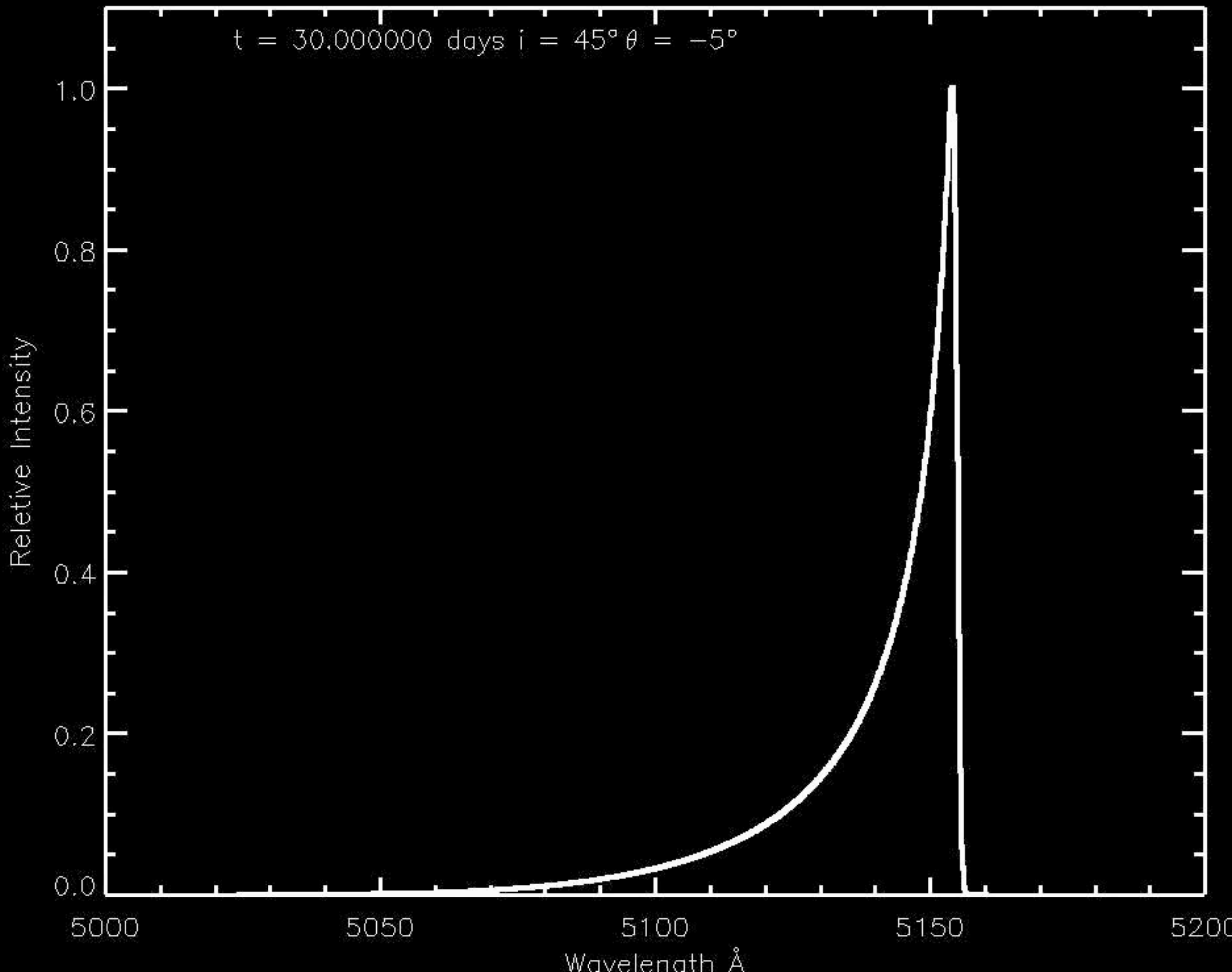
- Permitted emission lines are initially bright and then decay as the density drops
- The luminosity of forbidden lines increases as a larger volume of the cloud drops to the critical density of these transitions



Emission Line Light Curves

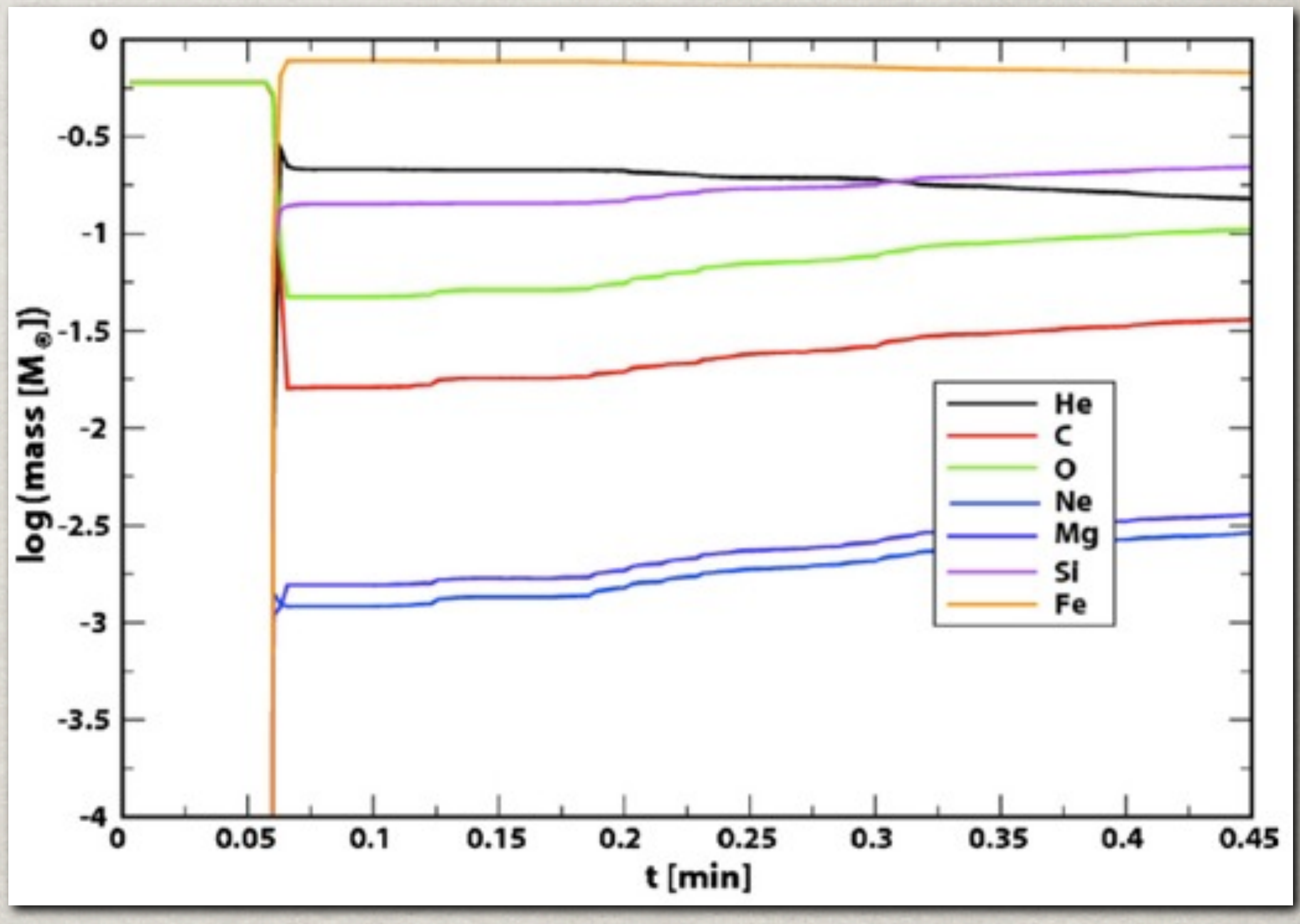


Label	M_{BH}	β	R_{LSO}/R_s
A	100	1	3
B	100	3	3
C	1000	1	3
D	1000	3	3
E	1000	1	0.5
F	10000	1	3

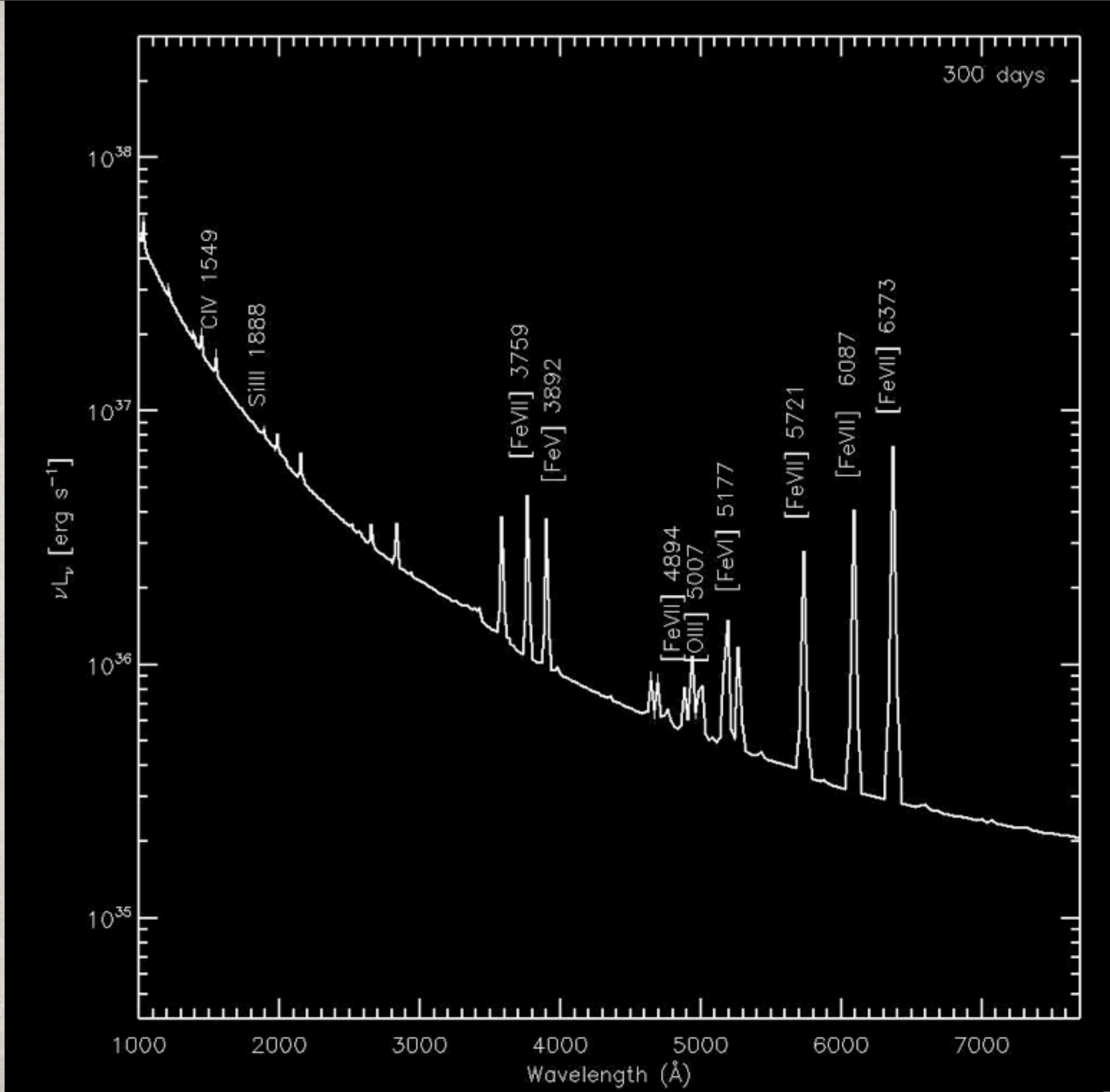

t = 30.000000 days i = 45° θ = −5°
Reletive Intensity
Wavelength Å
1.0
0.8
0.6
0.4
0.2
0.0
5000
5050
5100
5150
5200

Nuclear Burning

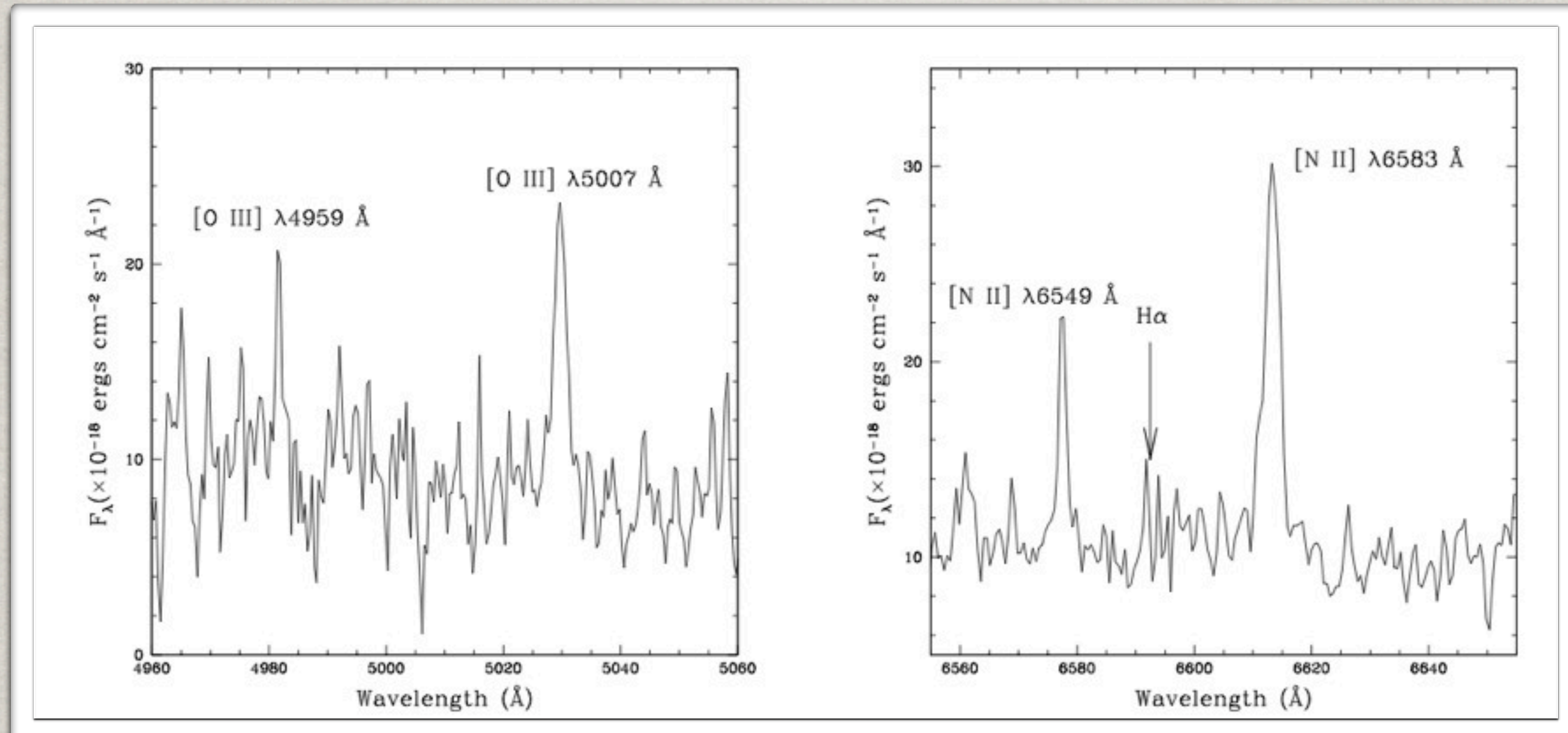
- Rosswog et al. 2009 showed that for large β, C and O would burn into heavier elements
- Modifies composition
- Spectrum dominated by forbidden Fe lines, not O lines



(Rosswog et al. 2009)

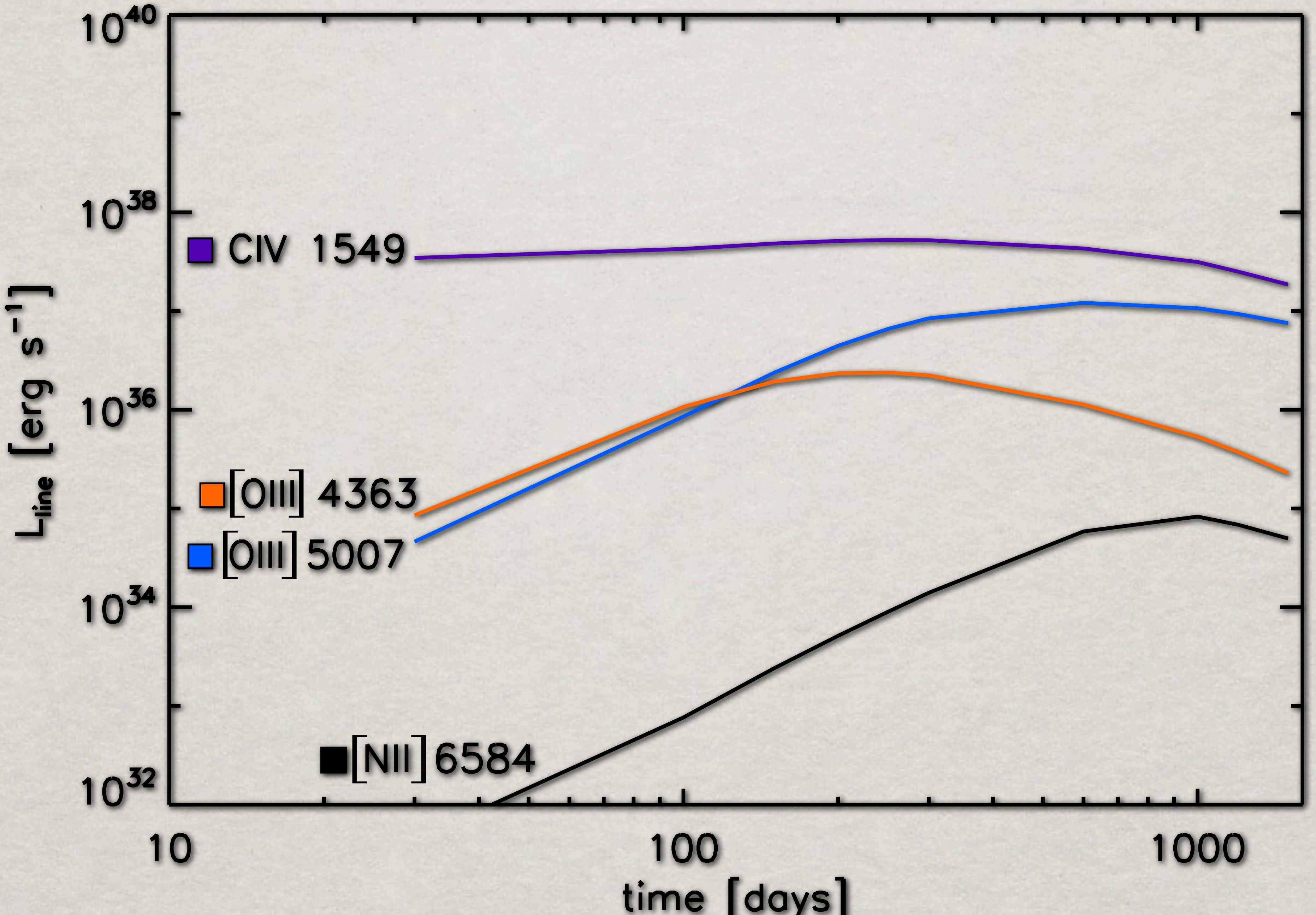

300 days
10^{38}
10^{37}
10^{36}
10^{35}
νL_ν [erg s^{-1}]
CIV 1549
SiIII 1888
[FeVII] 3759
[FeV] 3892
[FeVII] 4894
[OIII] 5007
[FeVI] 5177
[FeVII] 5721
[FeVII] 6087
[FeVII] 6373
1000
2000
3000
4000
5000
6000
7000
Wavelength (Å)

Observations



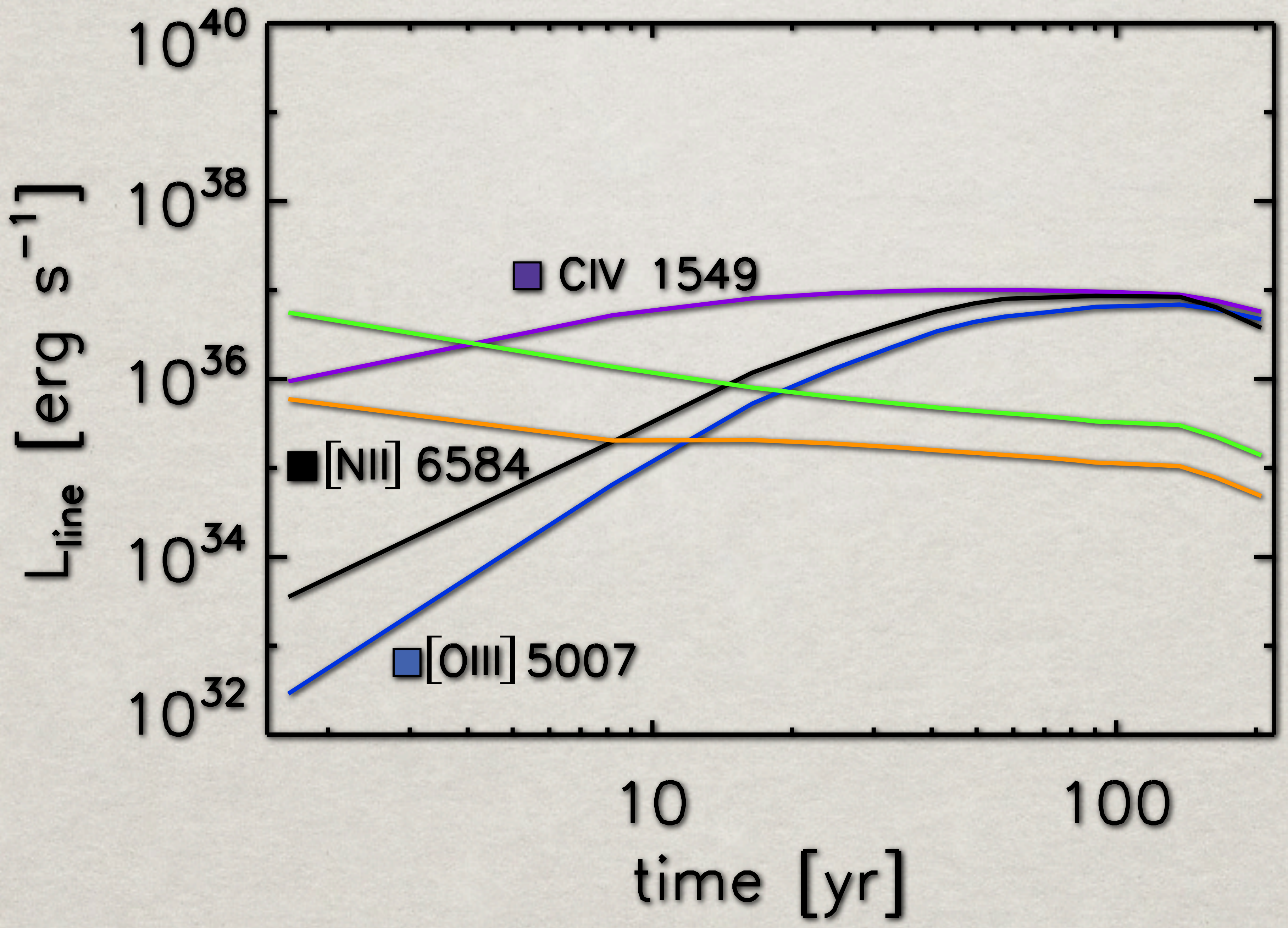
- Irwin et al. (2010) report on the ultraluminous X-ray source CXOJ033831.8-352604.
- X-ray luminosity is consistent with the model

Comparison



- The model predicts that the [NII] luminosity is ~ 2 orders of magnitude lower than [OIII]

Comparison

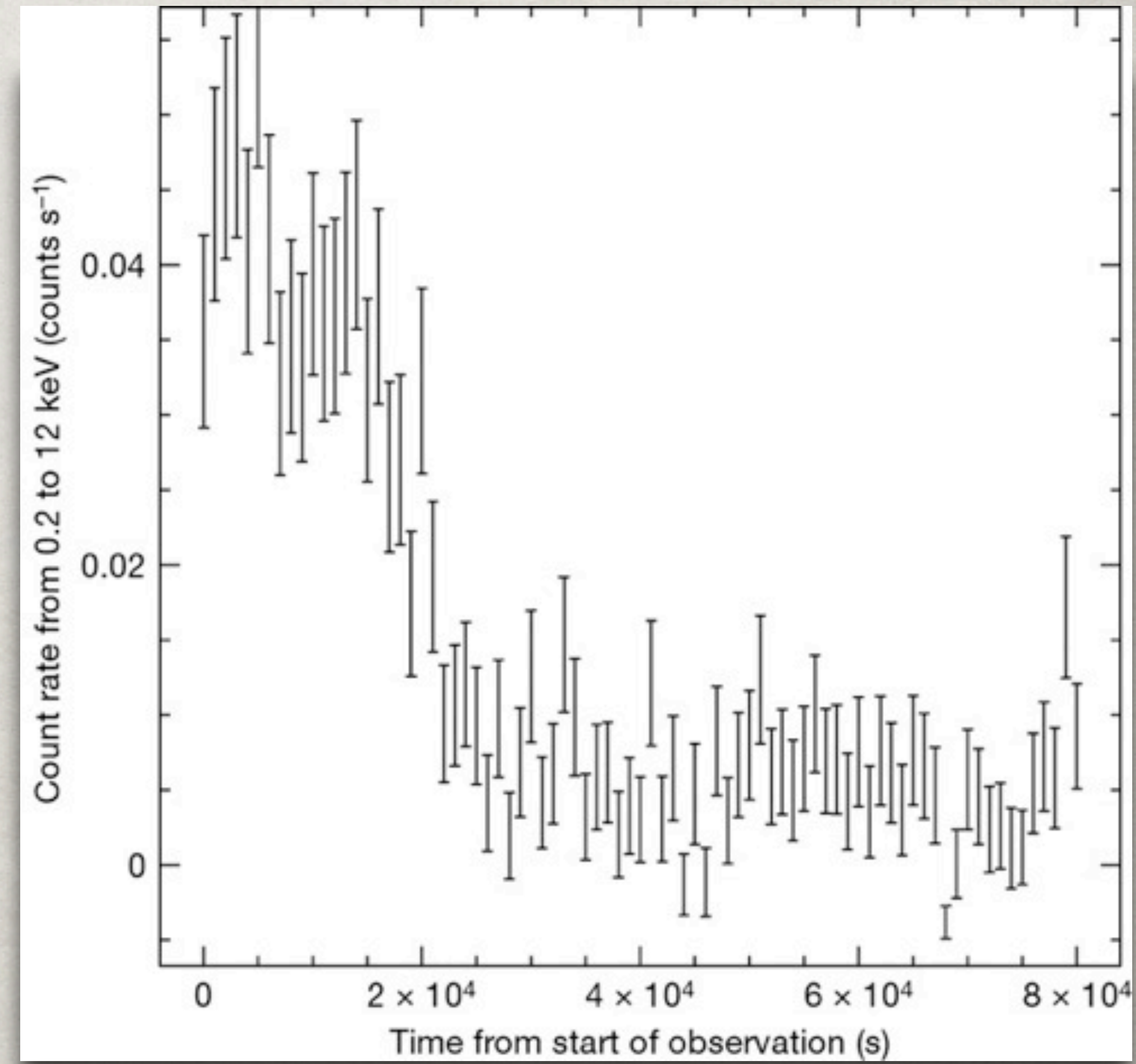


- Tidal disruption of horizontal branch star can account for [NII] luminosity ~ [OIII]

Observations

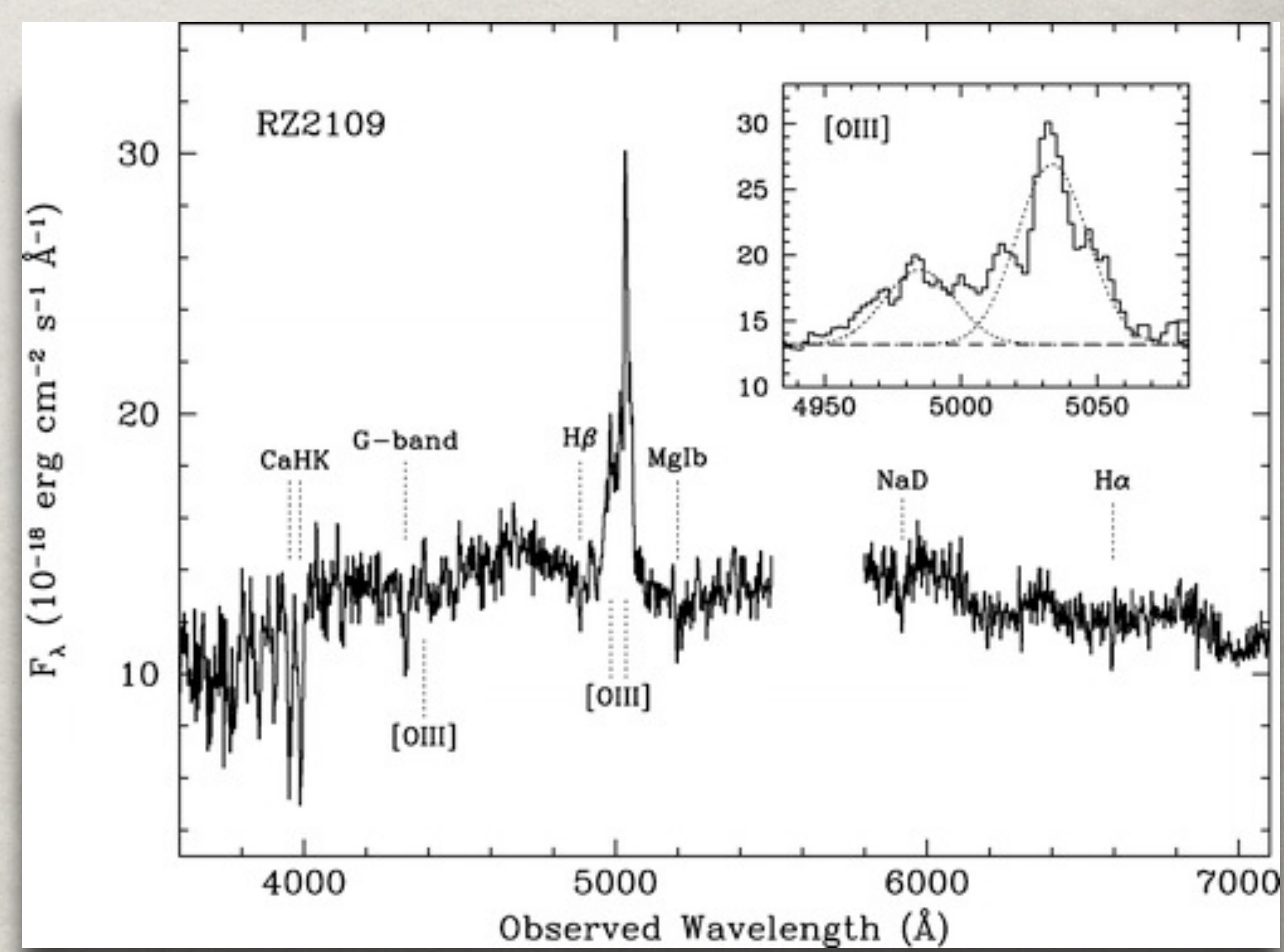
- Maccarone et al. (2007) and Zepf et al. (2008) report observations of an ultraluminous X-ray source in a globular cluster associated with NGC 4472

- The X-ray luminosity is consistent with the model



Observations

- The measured [OIII] 5007 luminosity is consistent with the peak [OIII] luminosity predicted by the model
- L_{5007} = 1.4 x 10^{37} erg/s
- Line has a width of 1500 km/s



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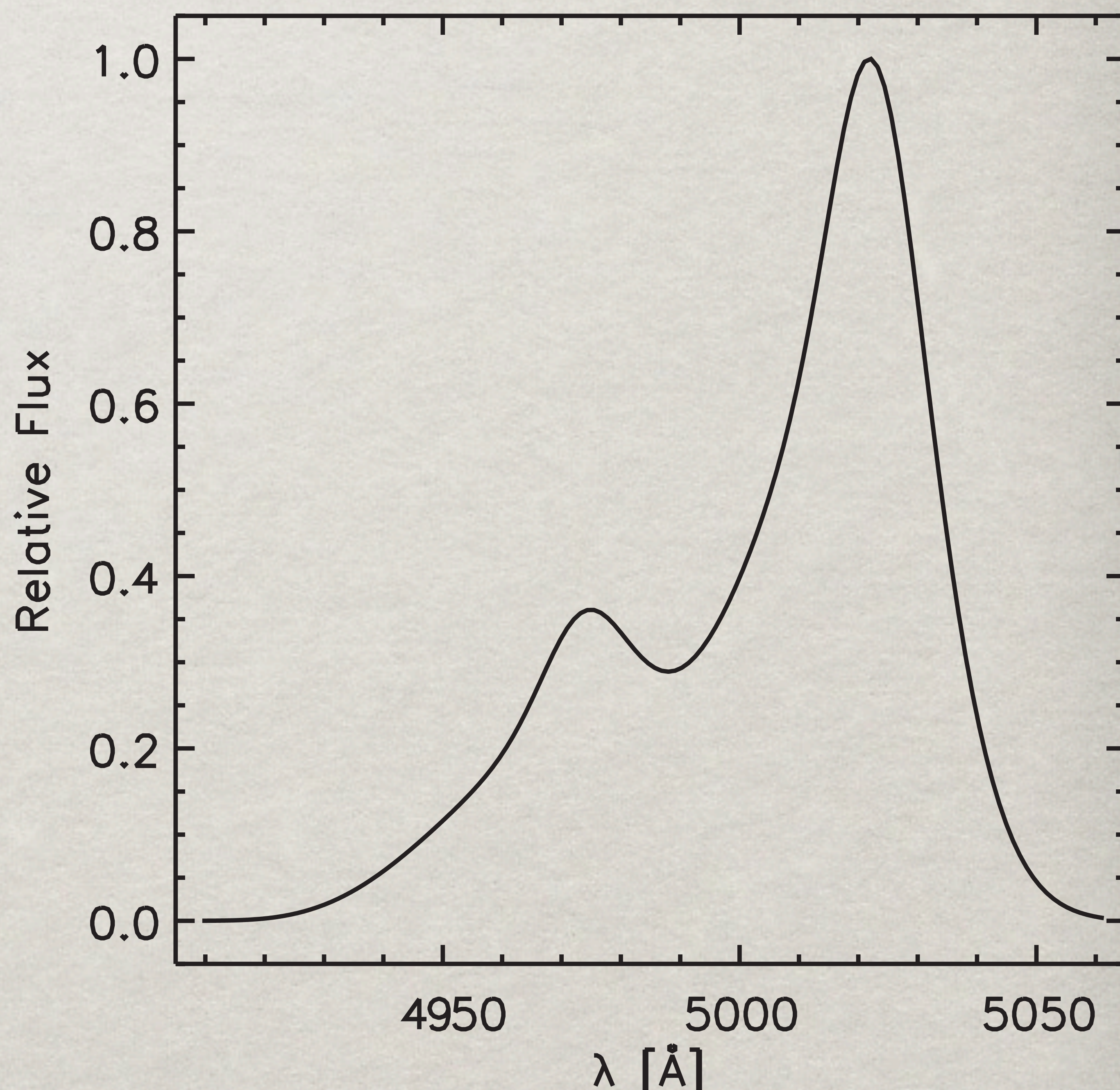

Observations

But...

- ROSAT measured the X-ray luminosity of the source to be 8.5 x 10^{39} erg/s in 1992
- This means that the [OIII] 5007 luminosity measurements by Zepf et al. (2008) were made 14 years after tidal disruption, long after the peak in the [OIII] 5007 light curve at ~ 2 years
- Unlikely that this is a WD tidal disruption

Conclusions

- Bound Disruptions:
  - Produce a bright accretion flare
  - Difficult to distinguish from other bright flares
- Unbound Disruptions:
  - Optical and UV emission lines from the unbound material uniquely identify WD tidal disruptions.
  - Given the uncertainty of the model and the degeneracies in black hole mass and spin and observer orientation, the emission lines cannot be used to determine the parameters of the system.

Discussion Questions

- Have any white dwarf tidal disruption flares been detected in transient surveys?
- What are the prospects for detecting such flares with future transient surveys? All sky X-ray monitor?
- Can we avoid confusion with super novae and trigger follow up spectroscopy?
- Rapid UV follow up?