Quantifying the diffuse continuum contribution from BLR gas:

a modeling approach

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Our approach:

- Build a model BLR

  match the ***intensities*** (*variability timescale/amplitude*)
  of ***strongest*** UV/optical emission lines in NGC 5548

  (***For objects of interest, no such thing as a steady-state model***)

- Compute wavelength-dependent (UV-optical-IR) flux and variability timescale of DC arising from the same gas

- Scale delays according to the fractional flux contribution

  DC/(INCIDENT + DC)

- Drive with model continuum light-curves

  estimate statistically likely delays (CCF/JAVELIN)
  + dependence on *characteristic* timescale & *variability amplitude* of driving continuum (MC approach)

Types of model:

- **Pressure law model** : Rees, Netzer and Ferland 1989,
  Goad, O'Brien, Gondhalekar 1993
  Kaspi and Netzer 1999
  Netzer 2000

- **Local Optimally emitting Clouds** : Baldwin, Ferland, Korista, Verner 1995, Korista and Goad 2000, 2001, 2004.

(1) Pressure Law models :

Lawther, Goad, Korista, Ulrich, Vestergaard 2017, in prep

Run of physical conditions with radius specified by simple radial pressure law

$$P(r) \propto r^{-s} \xrightarrow{\text{const Temp}} n_{\rm H}(r) \propto r^{-s} \qquad U(r) \propto r^{s-2}$$

Assume mass conservation
+ spherical clouds

$$A_c(r) \propto R_c^2 \propto r^{2s/3}$$

$$N_{col}(r) \propto R_c n_H \propto r^{-2s/3}$$

Line luminosity

$$L = 4\pi \int_{r_{in}}^{r_{out}} \epsilon(r) A_c(r) n_c(r) r^2 dr$$

Differential covering fraction

$$dC(r) \propto A_c(r) n_c(r) dr \propto r^{2s/3-3/2} dr$$

Normalization condition : specify

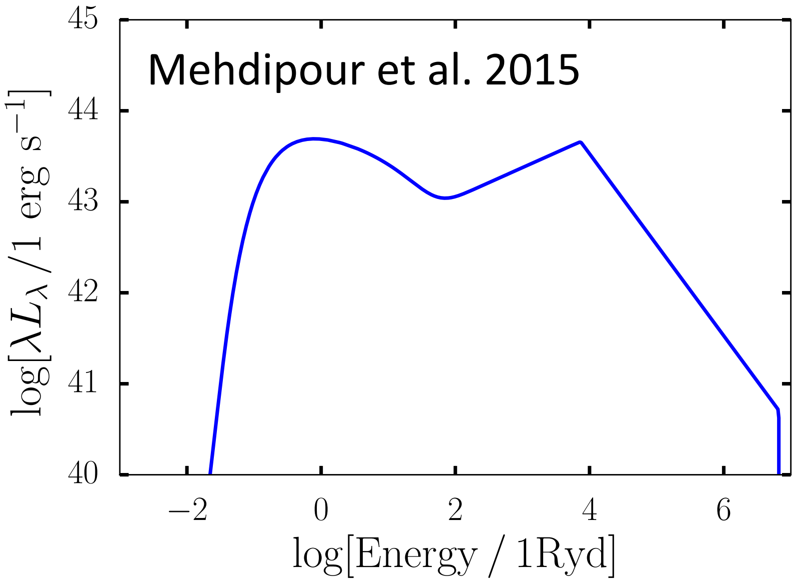
$$\Phi_{\rm H}, n_{\rm H}, N_{\rm col} \quad \text{at} \quad \text{some} \quad r$$

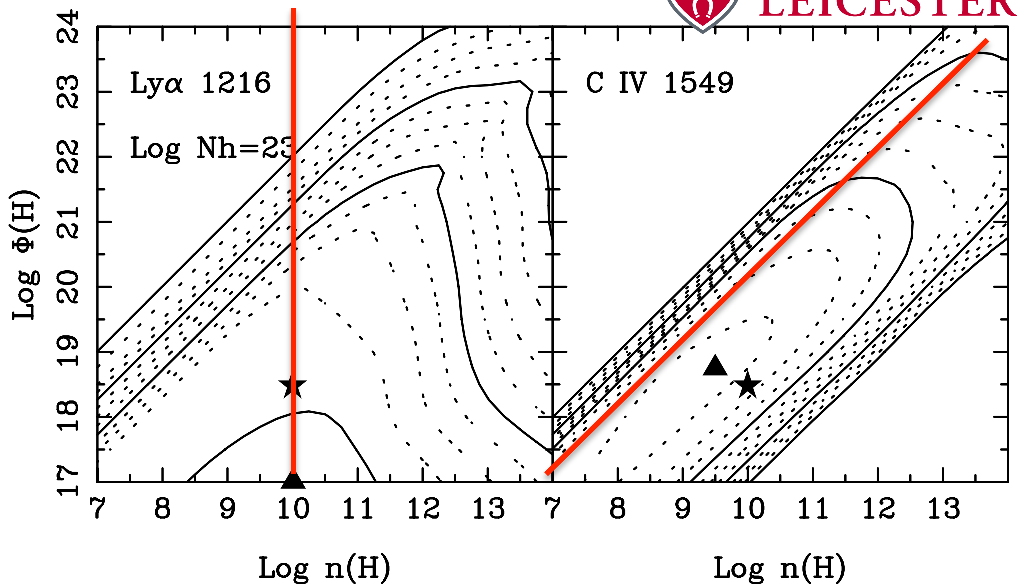
+ inner and outer radius, and total covering fraction Ctot

Choose line radiation pattern – we assume clouds are spherical

$$\epsilon(r,\theta) = \epsilon_{totl}[1 - (2F(r) - 1)\cos\theta]$$

$$F(r) = \epsilon_{inwd}/\epsilon_{totl}$$





Two cases:

s=0 , constant density nh, constant column density Nh

+ s=2 , constant ionization parameter U

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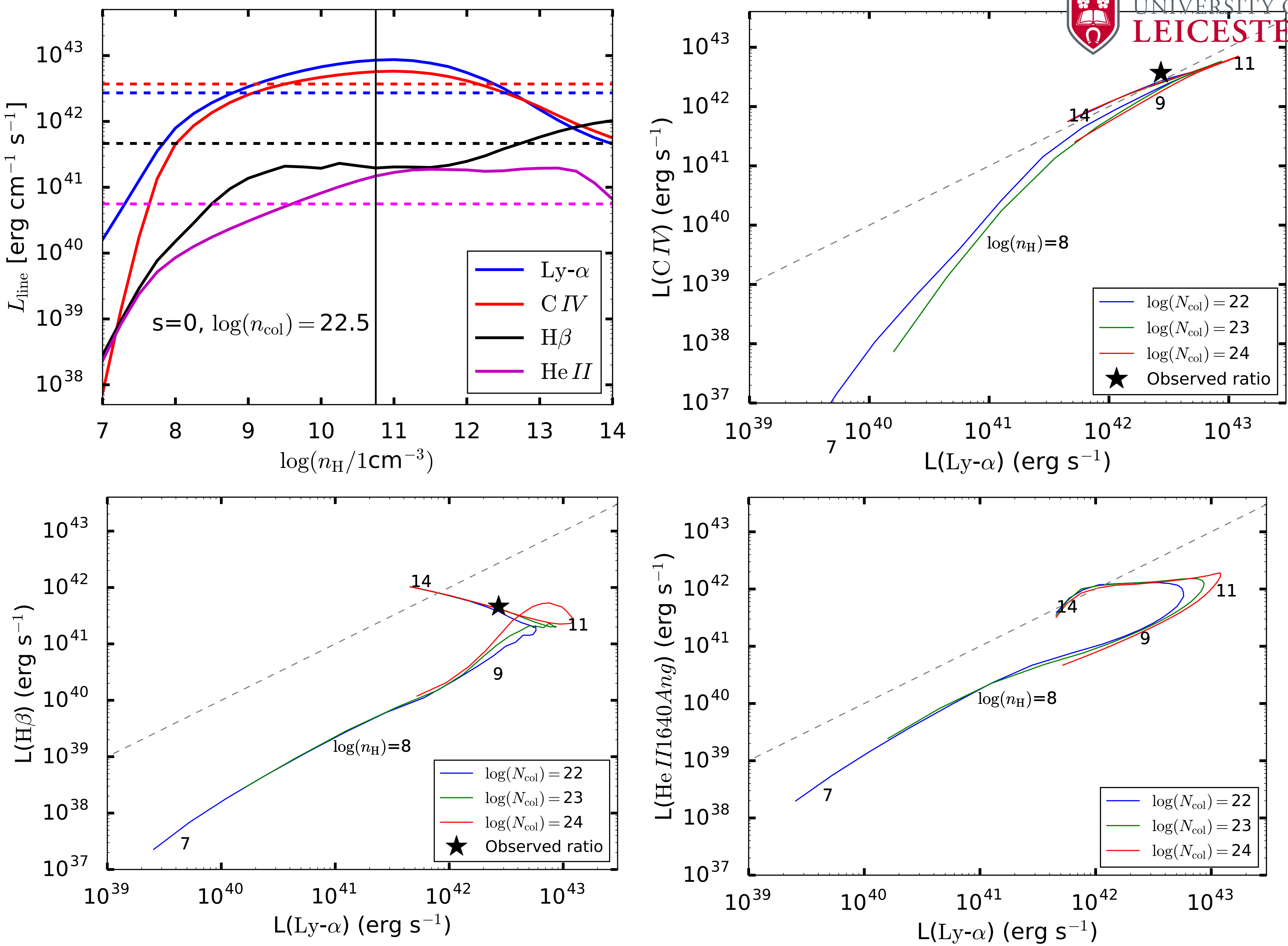
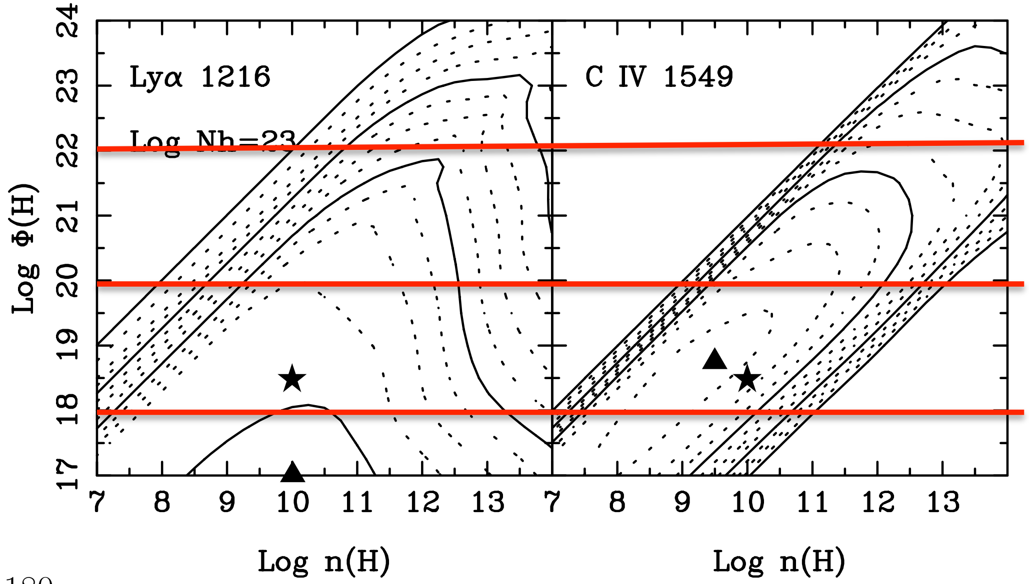
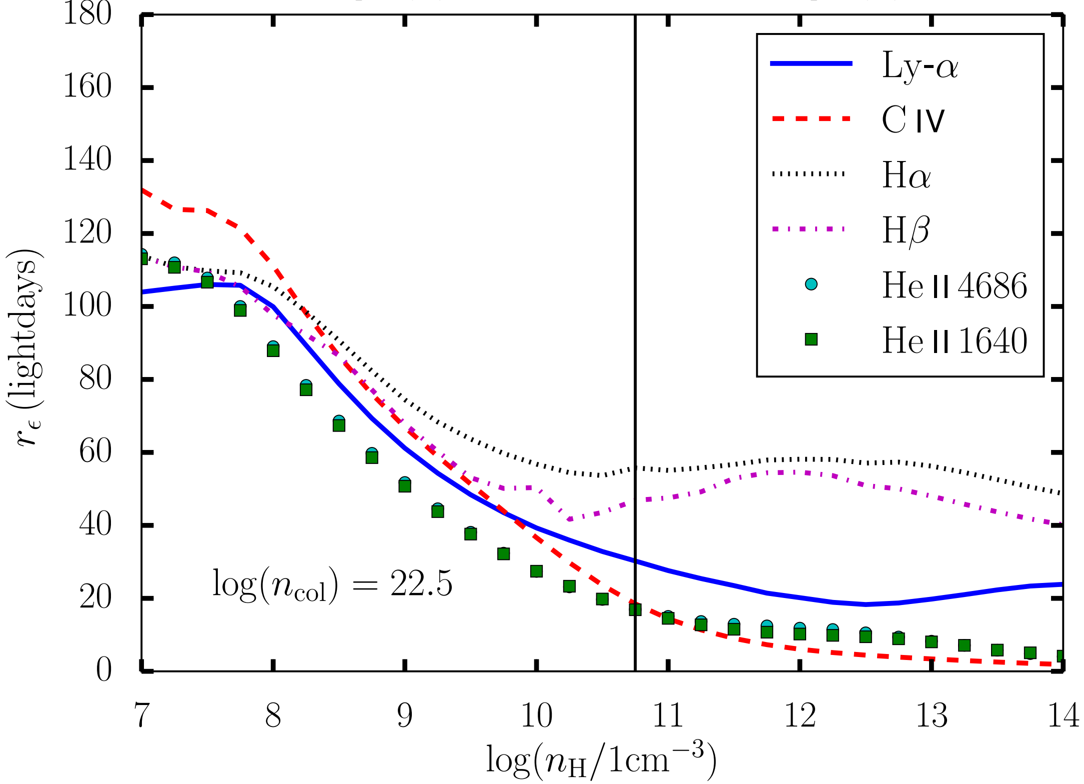




R=1.48 lt-days

R=14.8 lt-days

R=148 lt-days

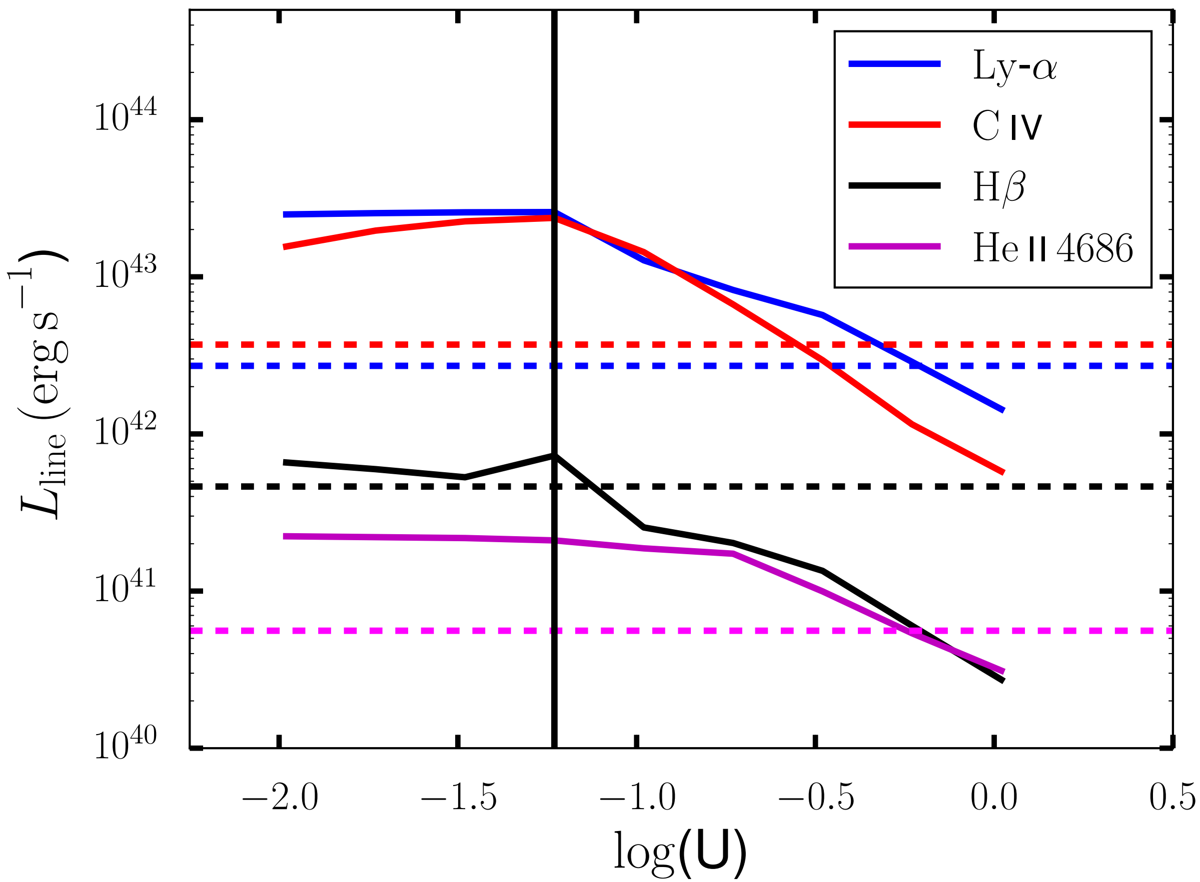


emissivity-weighted radii

can include effects of anisotropy/responsivity

tends to increase delays further

Similarly – ***constant U models***



Broad range in ionization for which we can exceed the measured line luminosities

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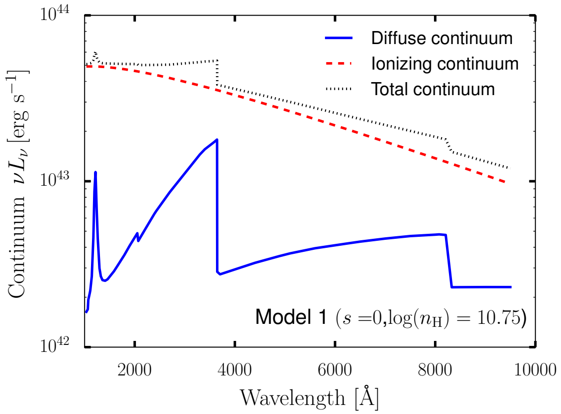

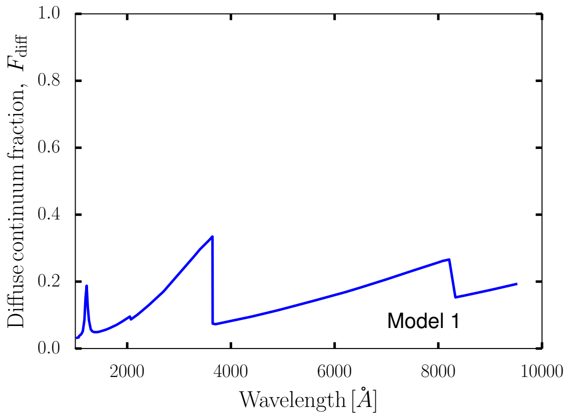

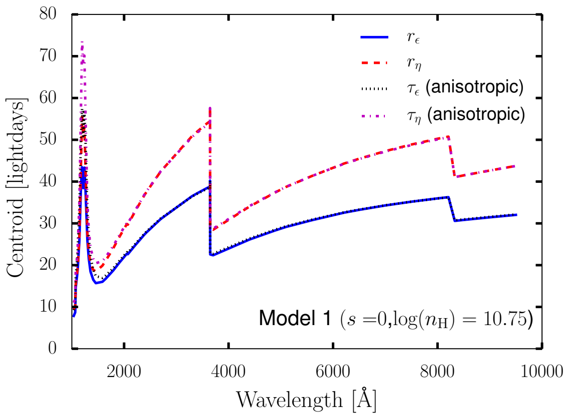

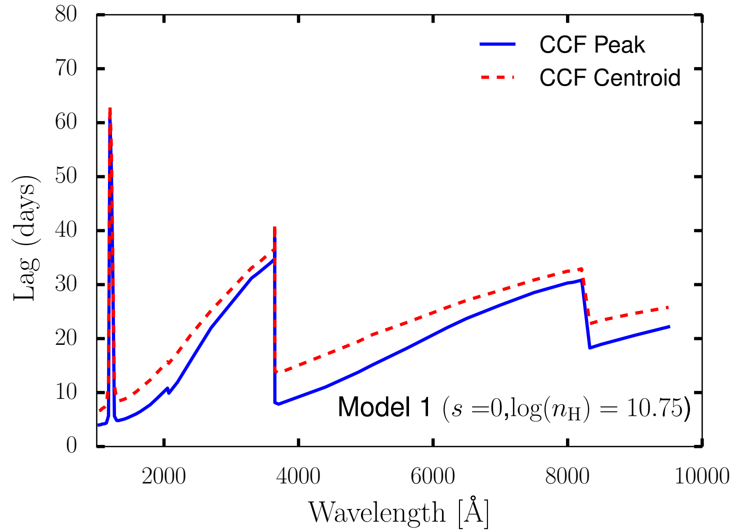

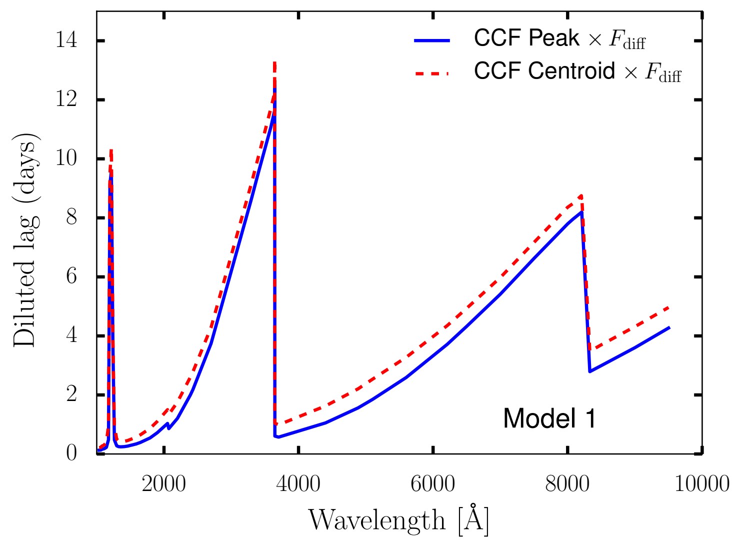

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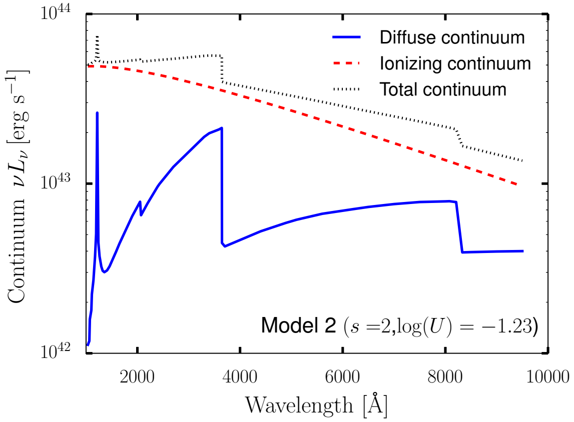
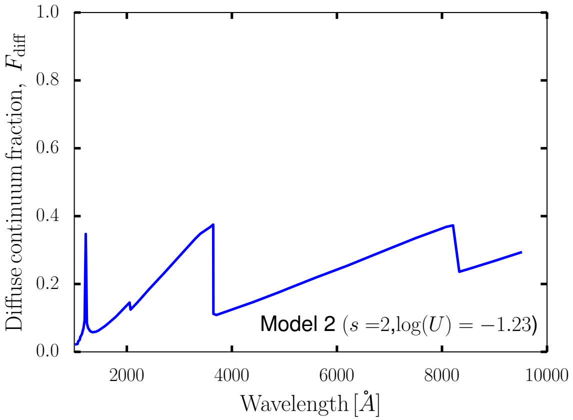
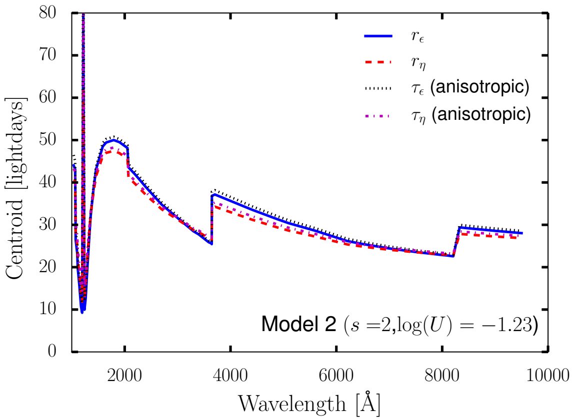
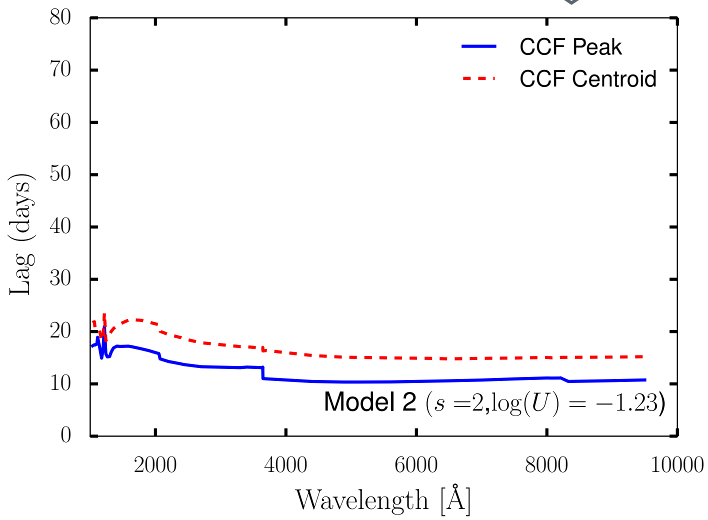
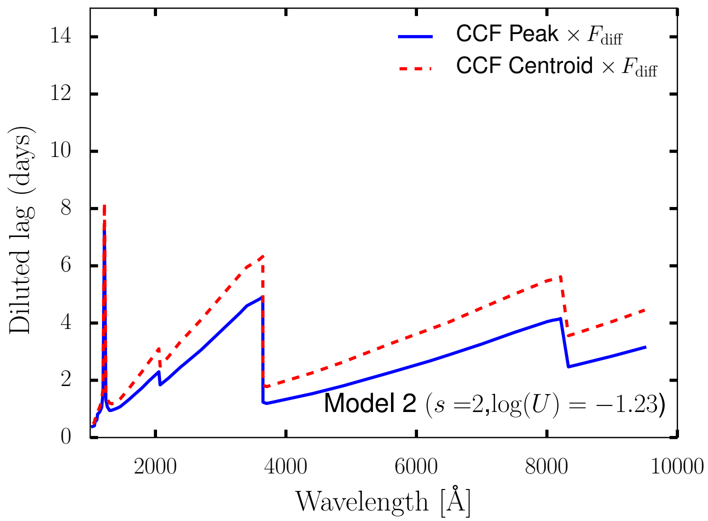

Diffuse continuum
Ionizing continuum
Total continuum
Model 2 (s =2,log(U) = −1.23)
Continuum νL_ν [erg s^{-1}]
Wavelength [Å]
10^{44}
10^{43}
10^{42}
2000
4000
6000
8000
10000

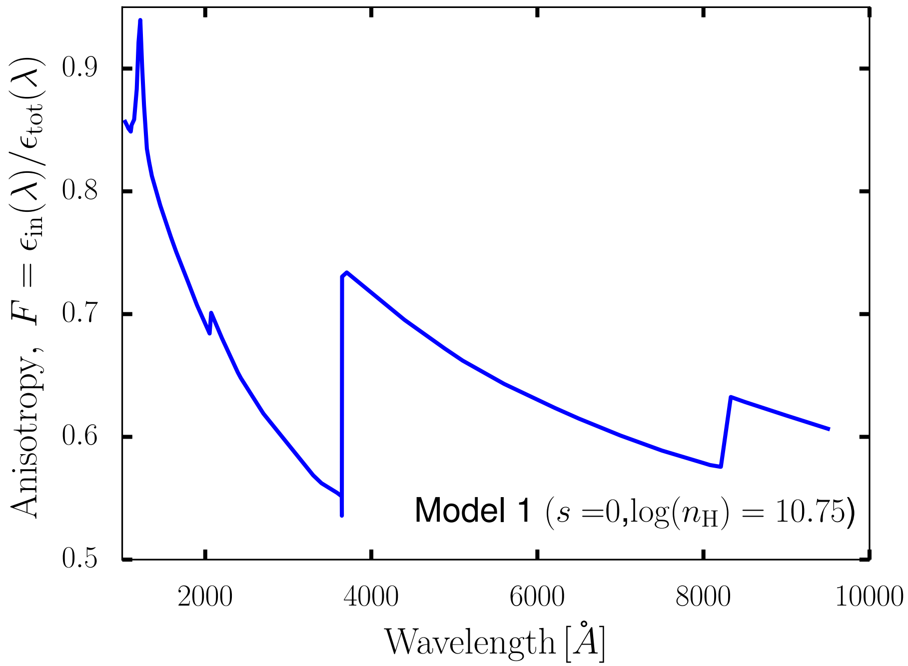

Model 2 (s =2,log(U) = −1.23)
Diffuse continuum fraction, $F_{\rm diff}$
Wavelength [Å]
0.0
0.2
0.4
0.6
0.8
1.0
2000
4000
6000
8000
10000

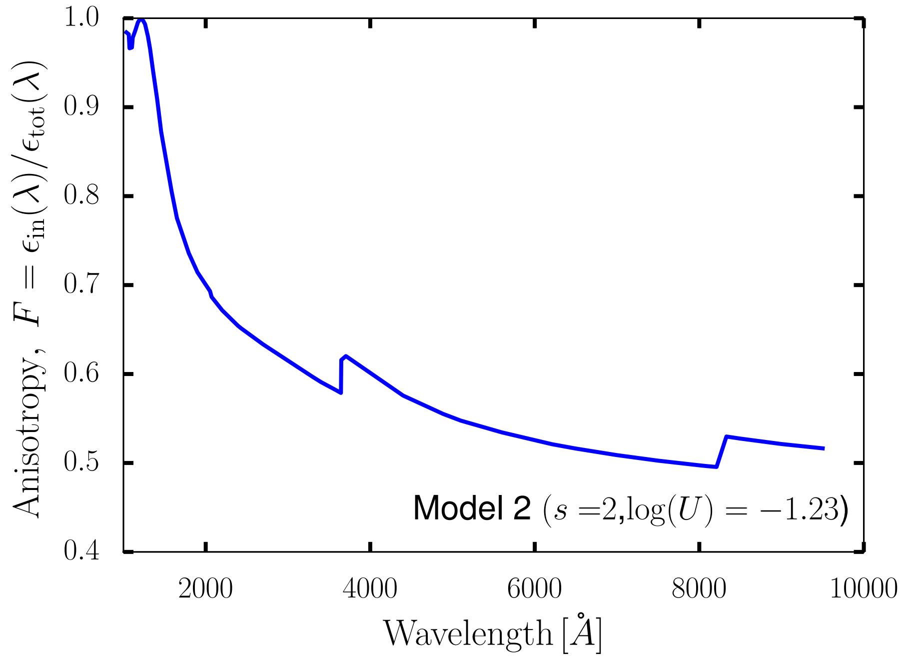

r_ϵ
r_η
τ_ϵ (anisotropic)
τ_η (anisotropic)
Model 2 (s =2,log(U) = −1.23)
Centroid [lightdays]
Wavelength [Å]
0
10
20
30
40
50
60
70
80
2000
4000
6000
8000
10000


CCF Peak
CCF Centroid
Model 2 (s =2,log(U) = −1.23)
Lag (days)
Wavelength [Å]
0
10
20
30
40
50
60
70
80
2000
4000
6000
8000
10000

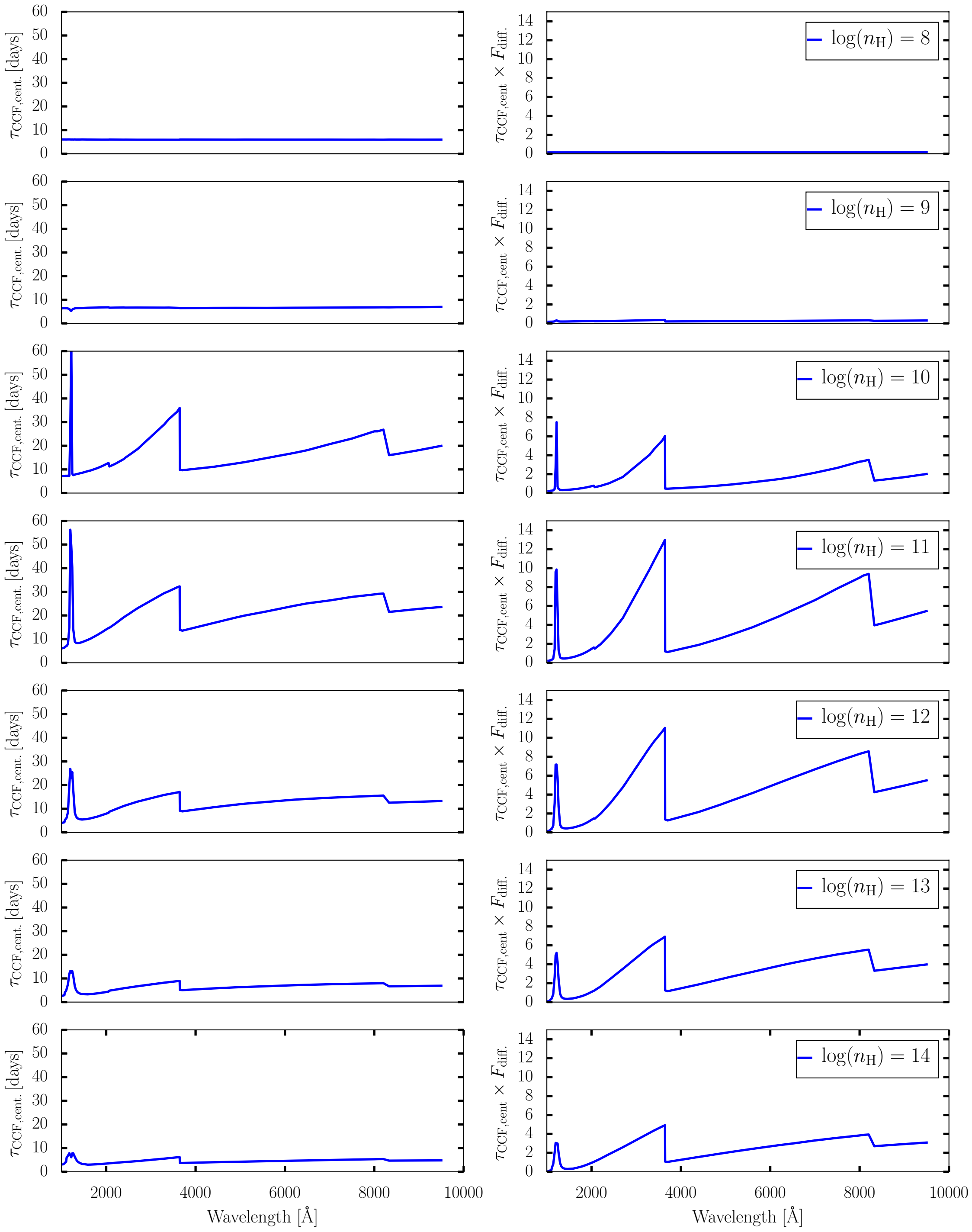

CCF Peak × $F_{\rm diff}$
CCF Centroid × $F_{\rm diff}$
Model 2 (s =2,log(U) = −1.23)
Diluted lag (days)
Wavelength [Å]
0
2
4
6
8
10
12
14
2000
4000
6000
8000
10000

Inward fractions





Density dependence - constant density models



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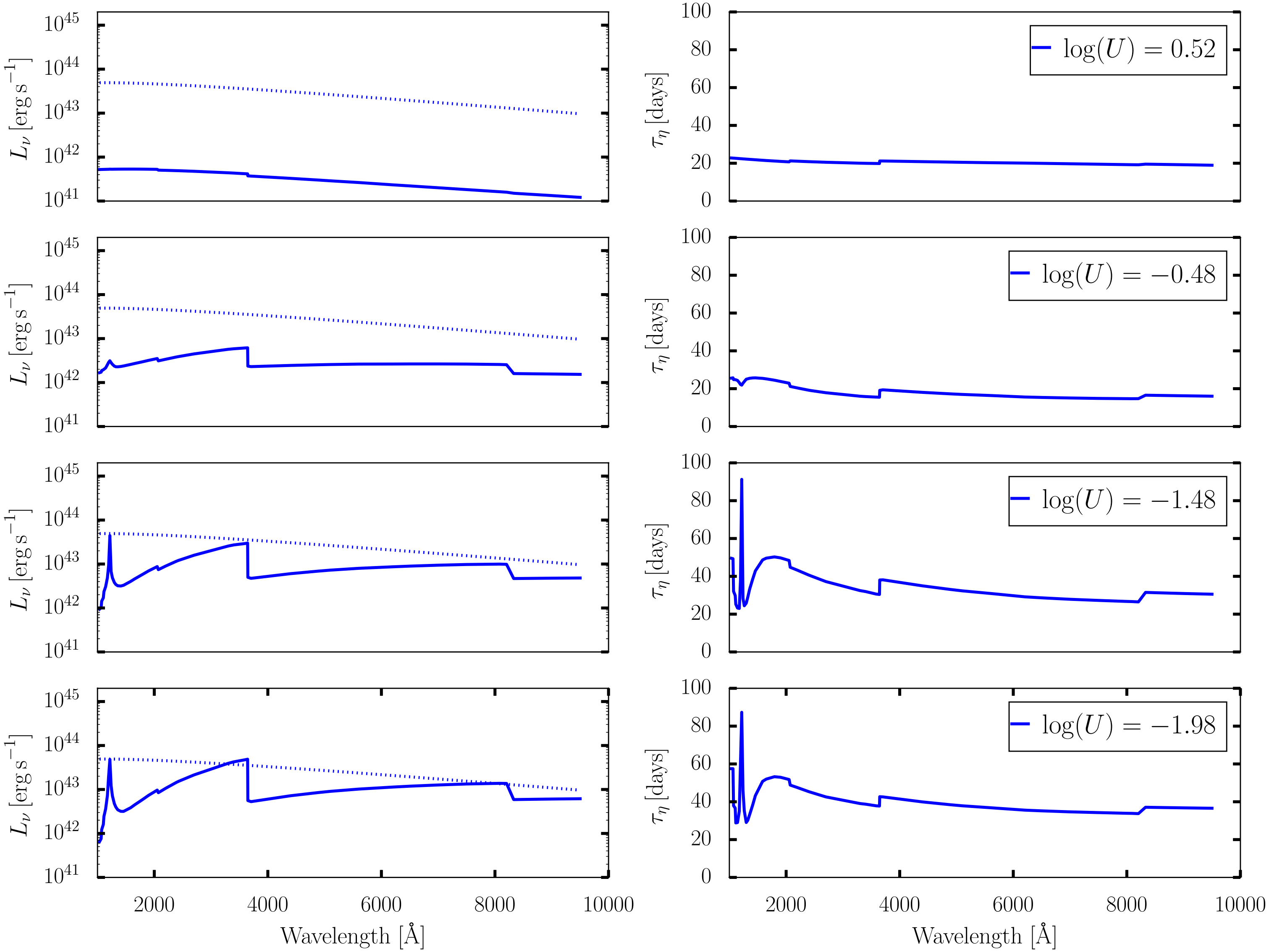
Constant ionization models



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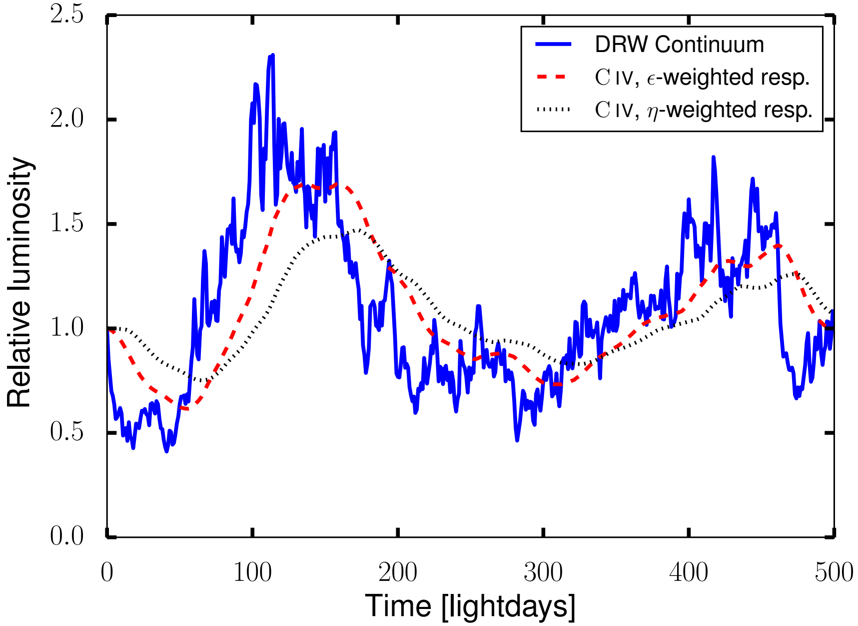
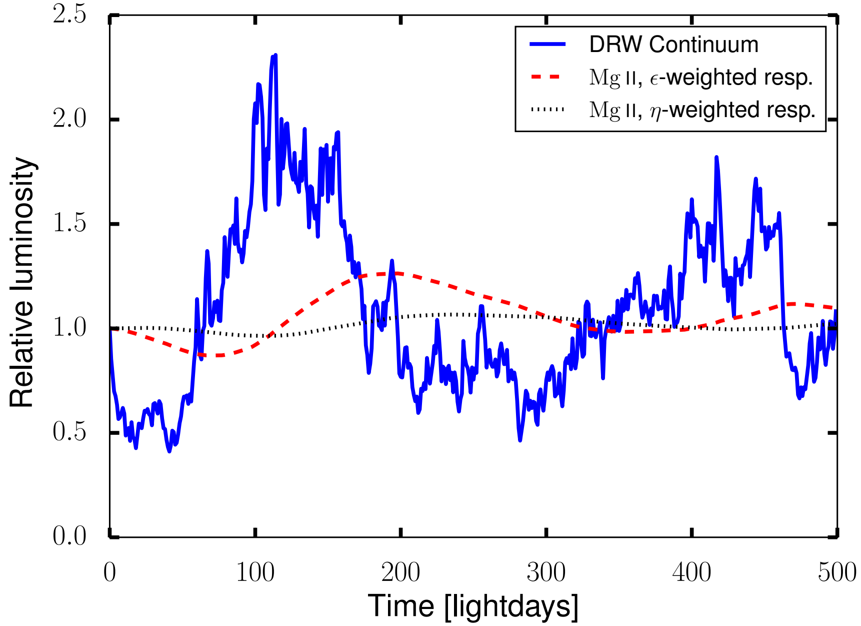
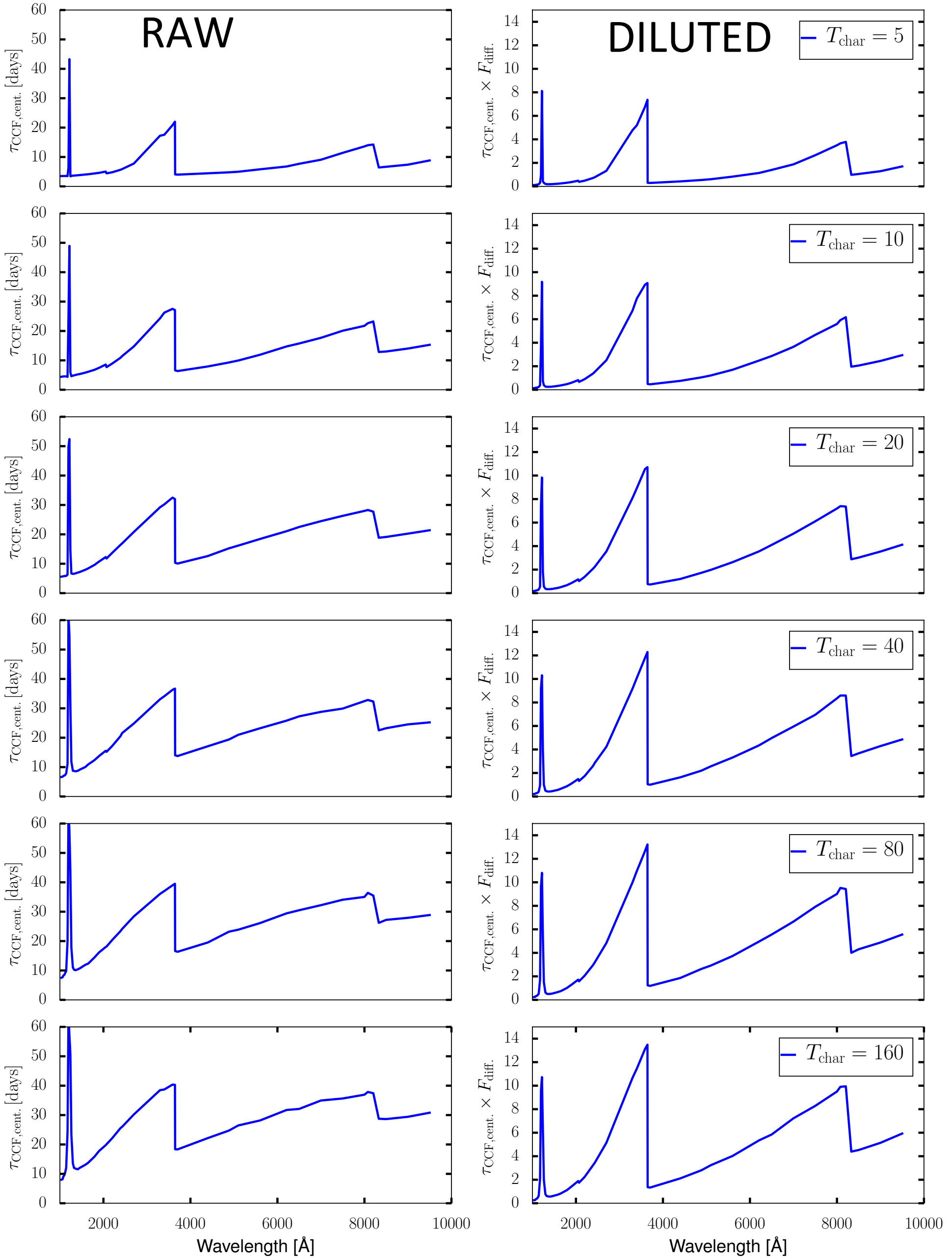

DRW Continuum
C IV, ϵ-weighted resp.
C IV, η-weighted resp.
Relative luminosity
Time [lightdays]
0.0
0.5
1.0
1.5
2.0
2.5
0
100
200
300
400
500


DRW Continuum
Mg II, ϵ-weighted resp.
Mg II, η-weighted resp.
Relative luminosity
Time [lightdays]
0.0
0.5
1.0
1.5
2.0
2.5
0
100
200
300
400
500

Aside :



Dependence on Tchar

	Tchar (days)
1989	~ 80-120
1993	~ 40
2014	~ 10-20

(2) Local optimally emitting clouds (LOC) models

Korista and Goad 2000,2001

At any given radius there exists a range of gas densities/column densities (or simply …..more than one pressure-law!)

Spectrum dominated by selection effects introduced by atomic physics and general radiative transfer within the large pool of line-emitting entities

Strengths:

Summation over cloud distribution leads to:

(i) typical AGN spectrum
(ii) Ionization stratification
(iii) Luminosity-Radius relation arises naturally

Deriving the spectrum:

Give each line emitting entity a weight in 2-dimensions: ***gas density and distance***

Assume*: analytic, separable, and a power-law in each variable*

$$g(n_{\rm H}) \propto n_{\rm H}^{\beta}$$

Baldwin 1997 – composite quasar spectra best fit if indices in both are close to -1.

$$f(R) \propto R^{\Gamma}$$

In our models assume : $\beta = -1$

and fit for Γ

Korista and Goad (2000) found a value of -1.2 gives an Acceptable fit to the line luminosities For NGC~5548

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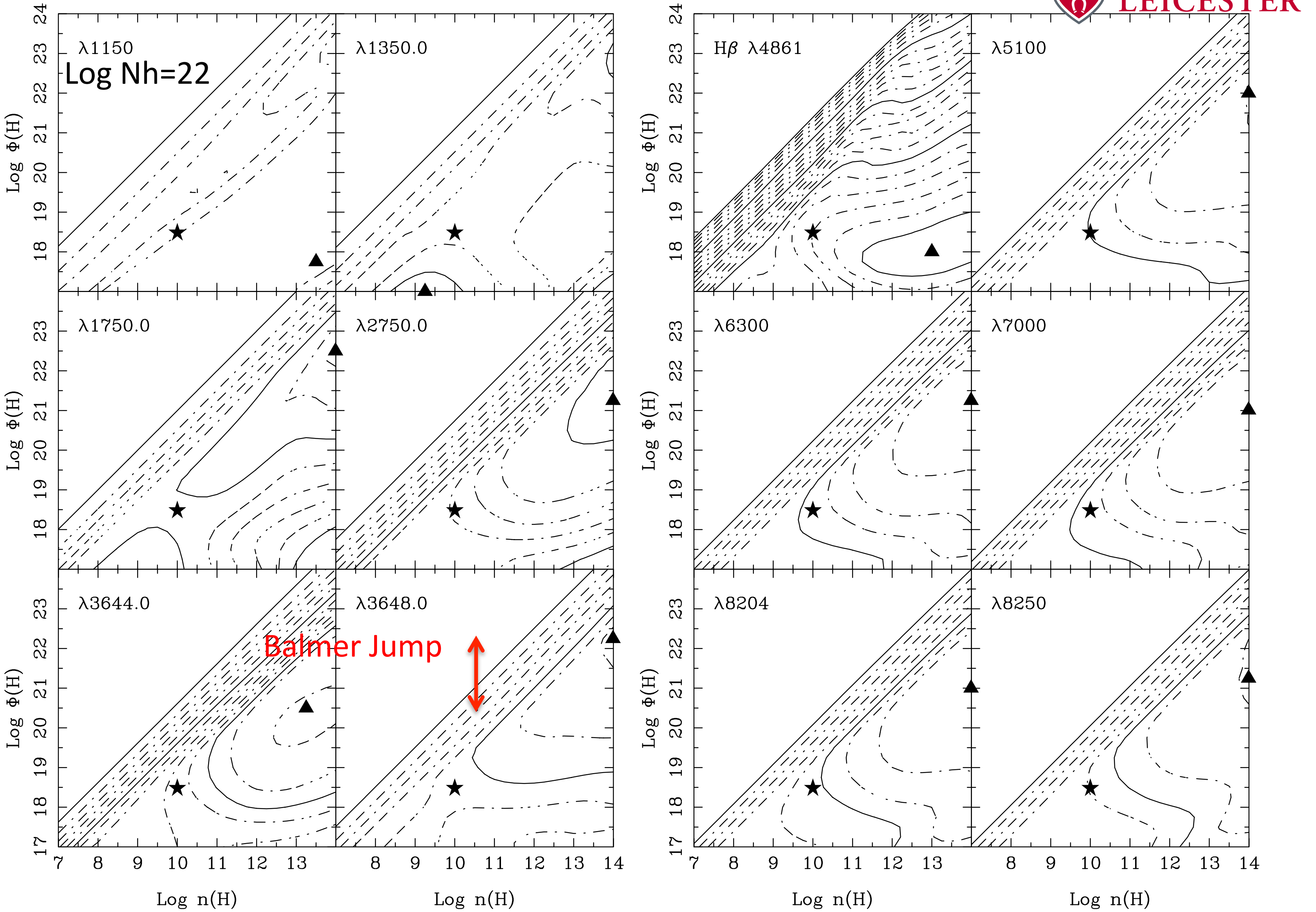

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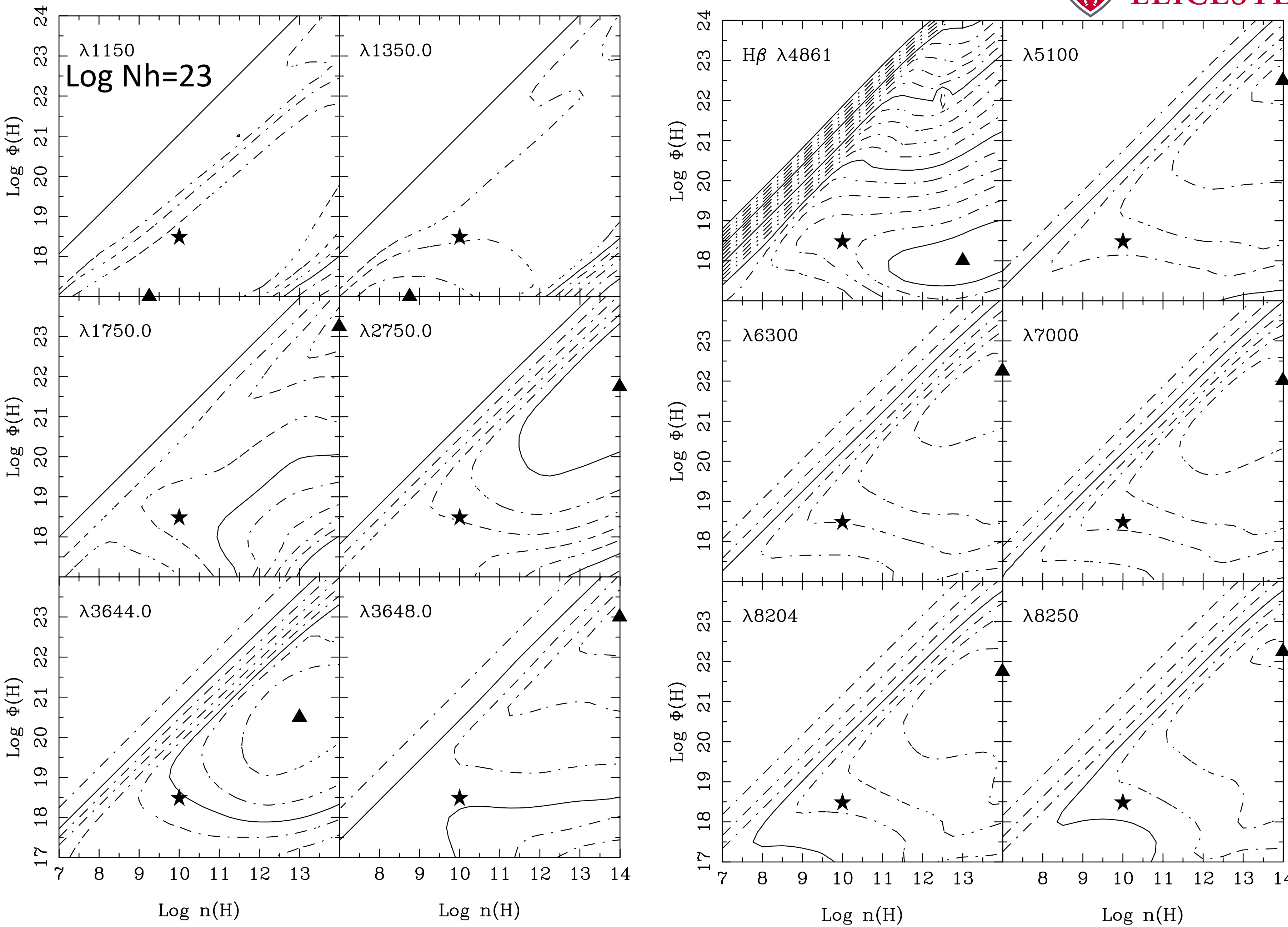

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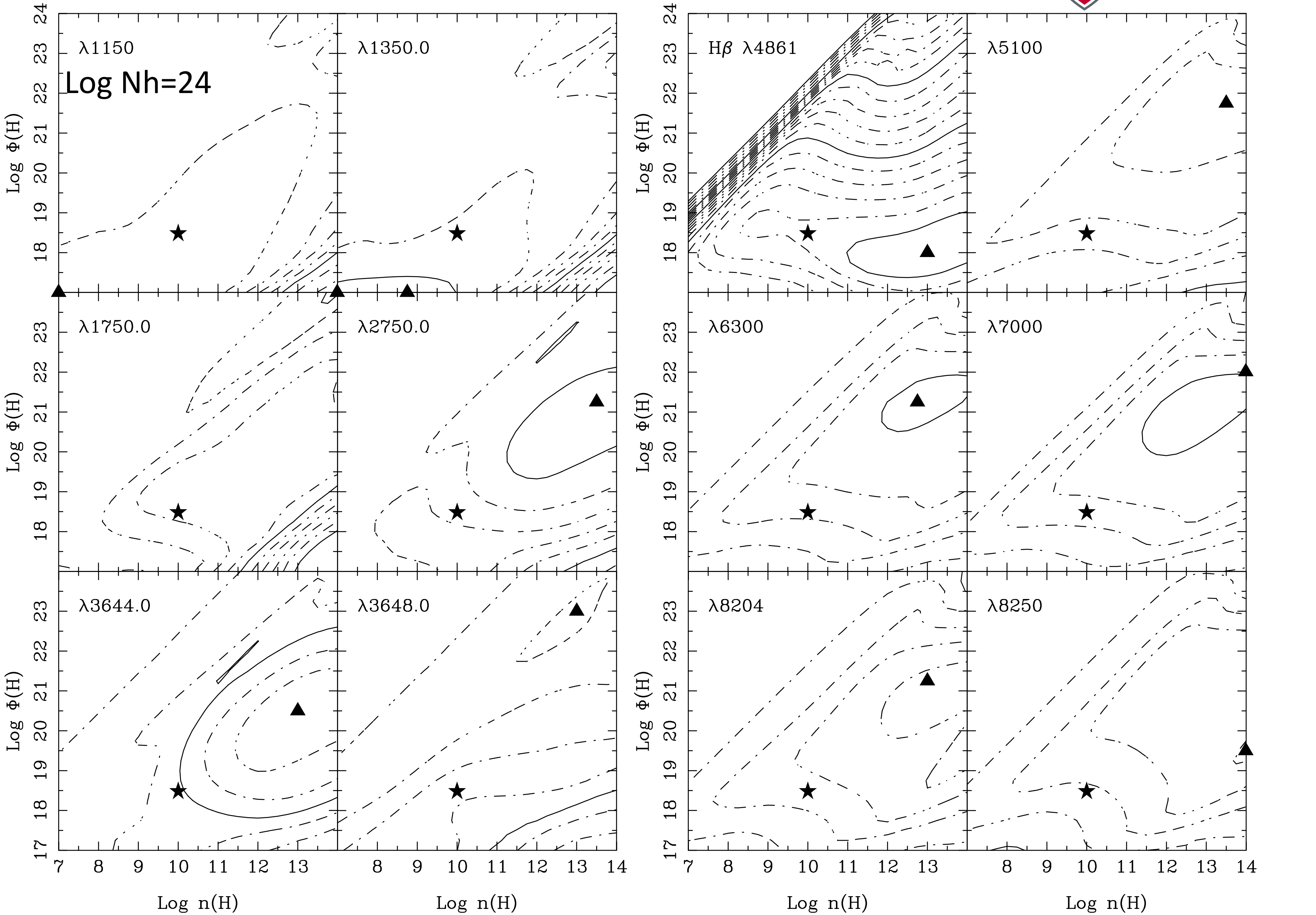

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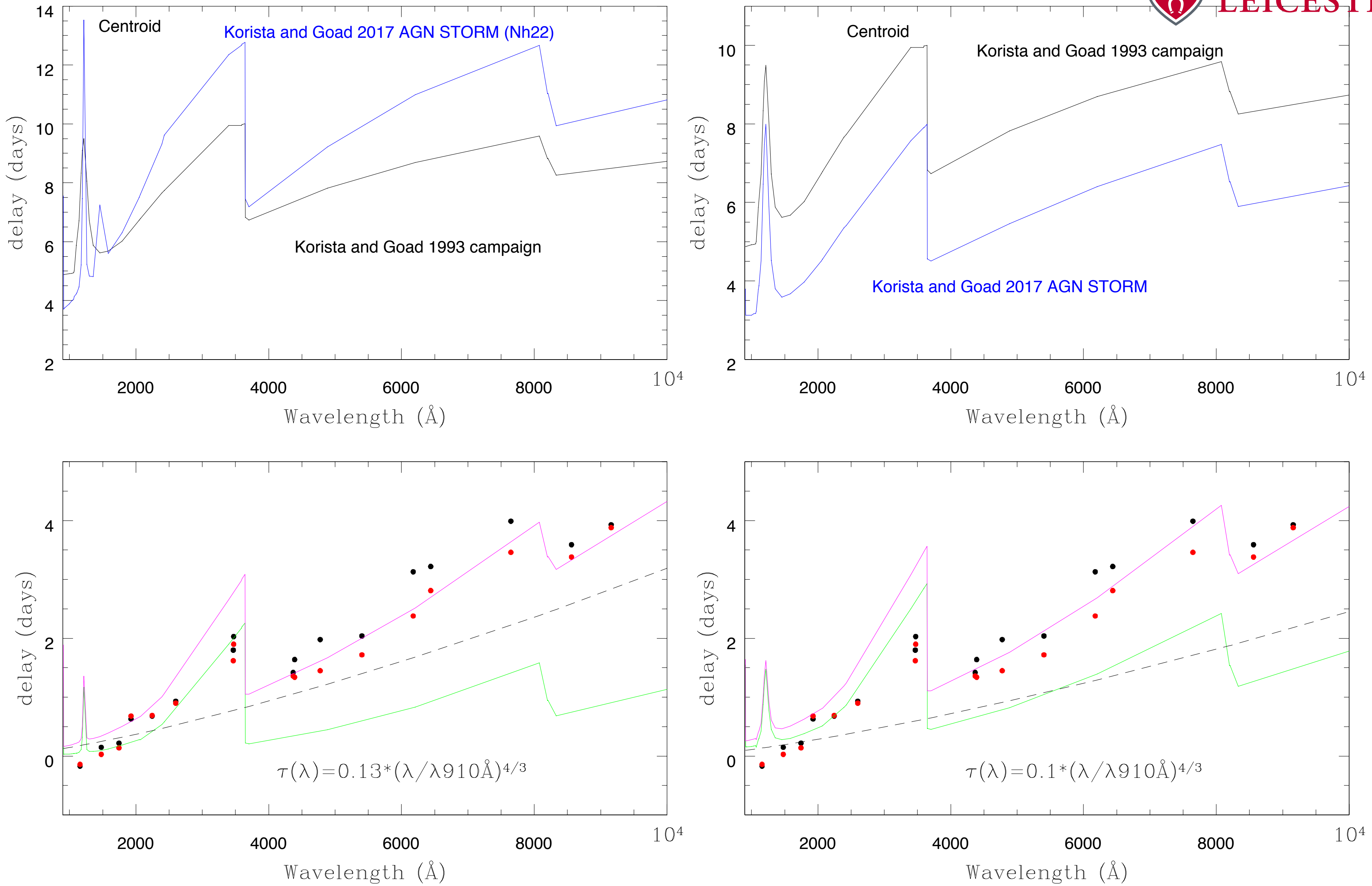

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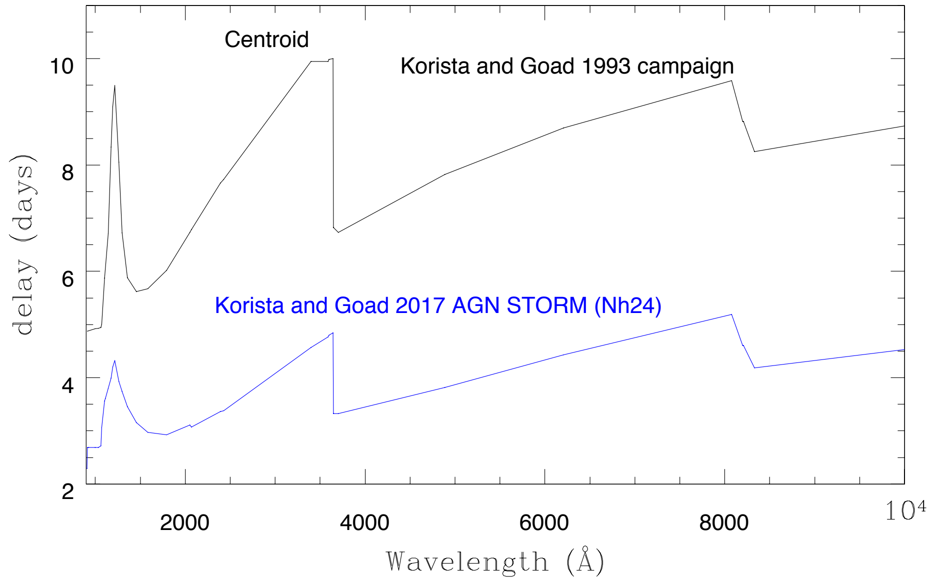
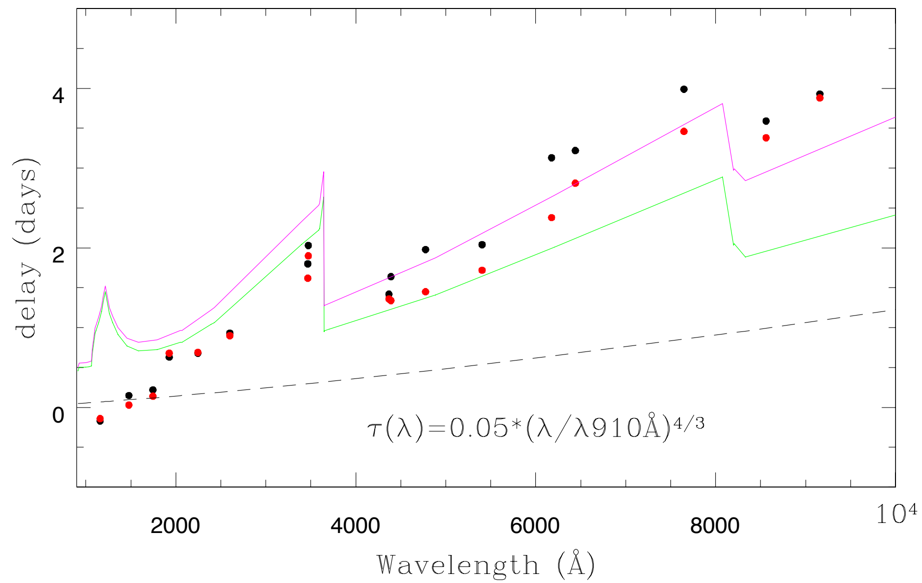
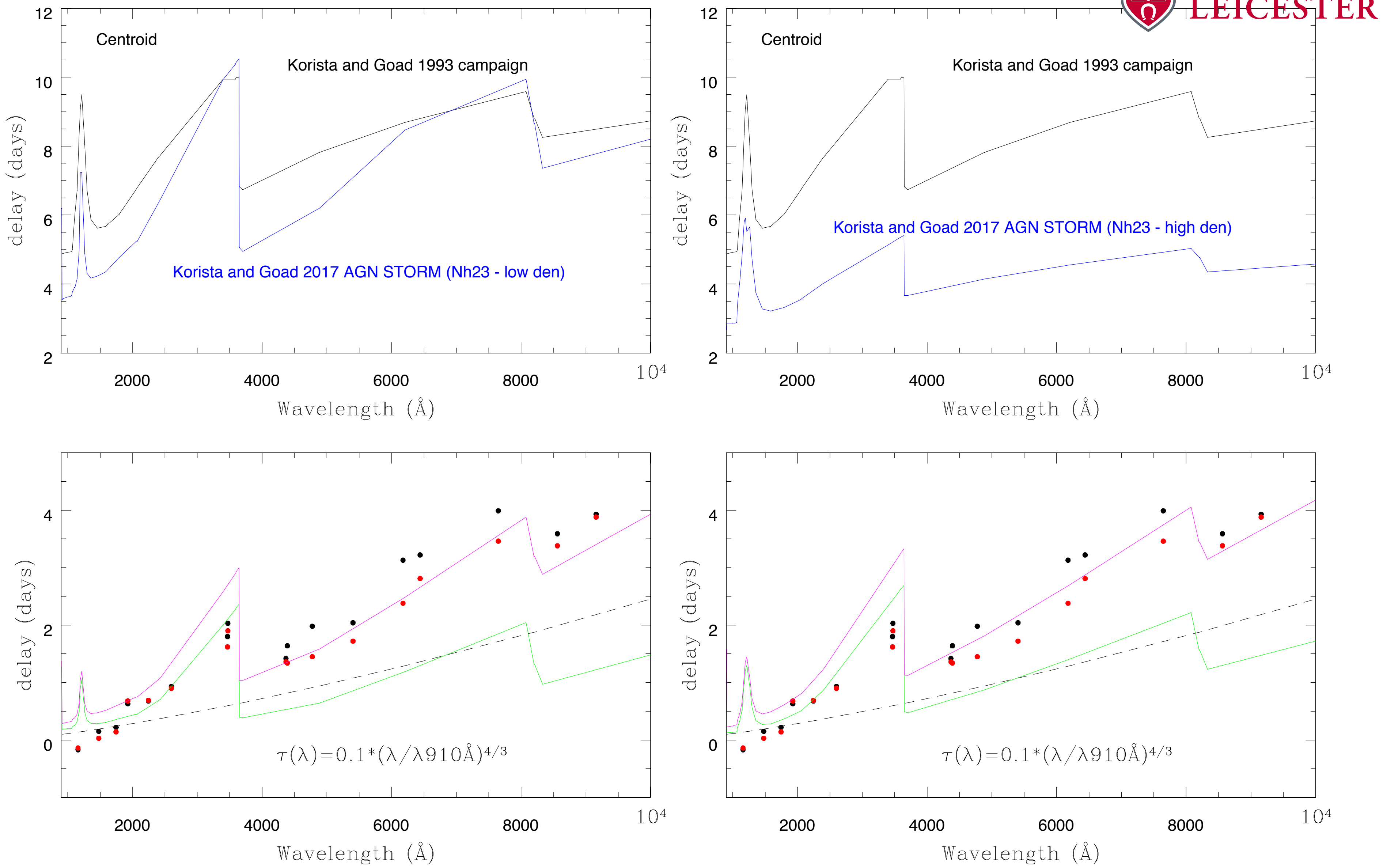

Centroid
Korista and Goad 1993 campaign
Korista and Goad 2017 AGN STORM (Nh24)
delay (days)
Wavelength (Å)
10⁴


delay (days)
τ(λ)=0.05*(λ/λ910Å)^{4/3}
Wavelength (Å)
10⁴


Centroid
Korista and Goad 1993 campaign
Korista and Goad 2017 AGN STORM (Nh23 - low den)
Korista and Goad 2017 AGN STORM (Nh23 - high den)
delay (days)
Wavelength (Å)
$\tau(\lambda)=0.1*(\lambda/\lambda 910Å)^{4/3}$

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Summary:

(1) At typical Nh,nh, U appropriate for BLR there exists a significant diffuse continuum ***arising from the same gas that emits the broad emission-lines***

(2) Form of the delay spectrum (including underlying powerlaw) approximately matches that observed, especially around Balmer and Paschen jumps.

(3) Even when included, disks still appear too large for their luminosity(?)

(4) We need to find new/improved ways (fourier analysis. PCA) of isolating the major variable contributions to the observed continuum bands