

Anatomy of the AGN in NGC 5548: Long-term variability of the warm absorber

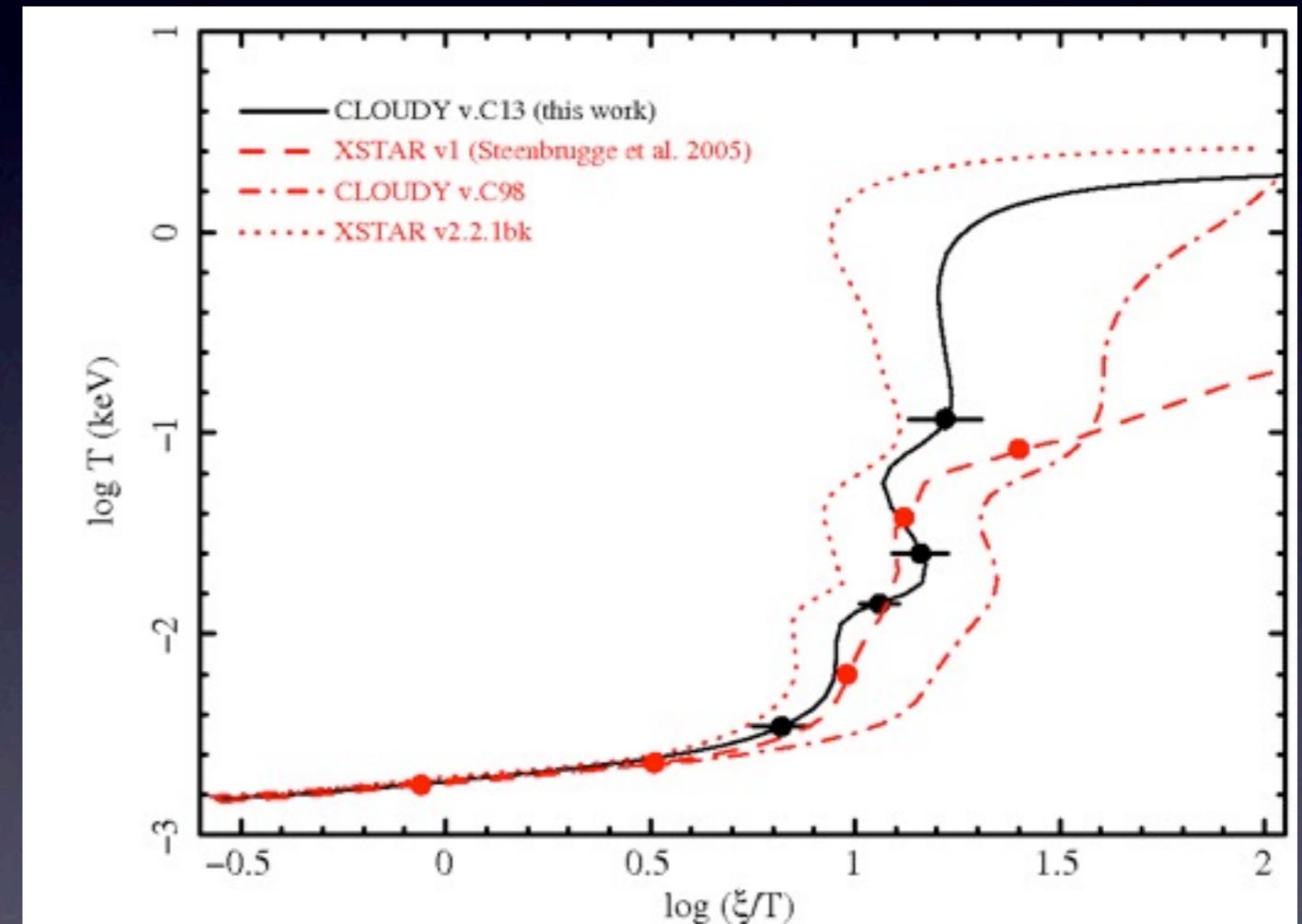
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The NGC 5548 campaign collaboration

Why re-analyze NGC 5548 archival observations?

- Significant differences in the ionization balances produced by different codes
- Need to have a robust baseline model for the warm absorber
- Standardization:
 - Cloudy version C13.01
 - SED from Steenbrugge+05
 - Proto-Solar abundances



The observations

- Nine archival observations:
 - LETGS 1999
 - HETGS 2000
 - RGS 2000
 - RGS 2001 (x2)
 - **HETGS 2002**
 - **LETGS 2002**
 - LETGS 2005
 - LETGS 2007

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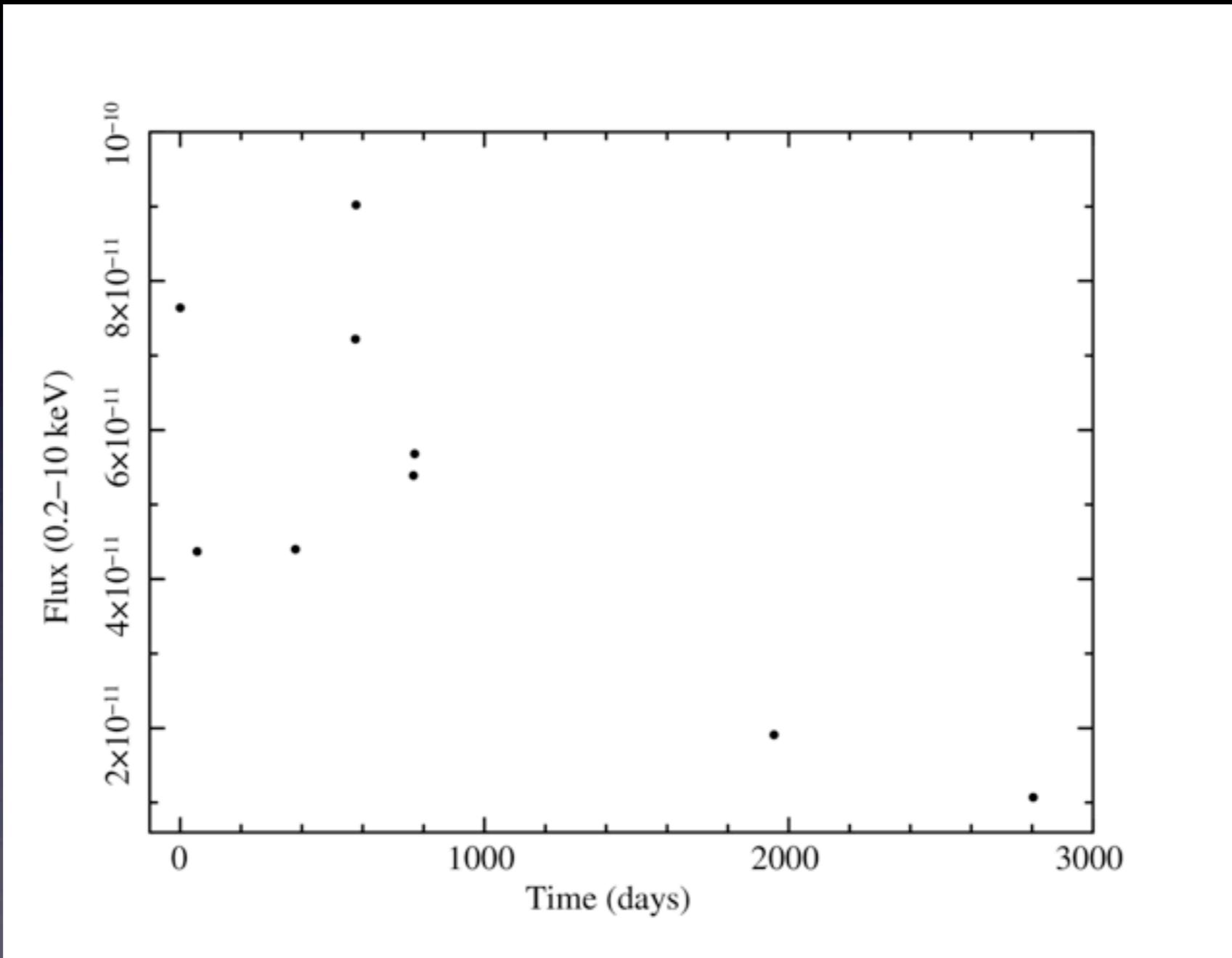
Procedure:

- Joint fit HETGS + LETGS 2002: baseline model for the X-ray WA (**six components A-F**)
- For each epoch the continuum parameters, $\log \xi$, and Ovii (f) flux are free parameters. The rest (outflow velocity, column density, velocity broadening) are frozen.

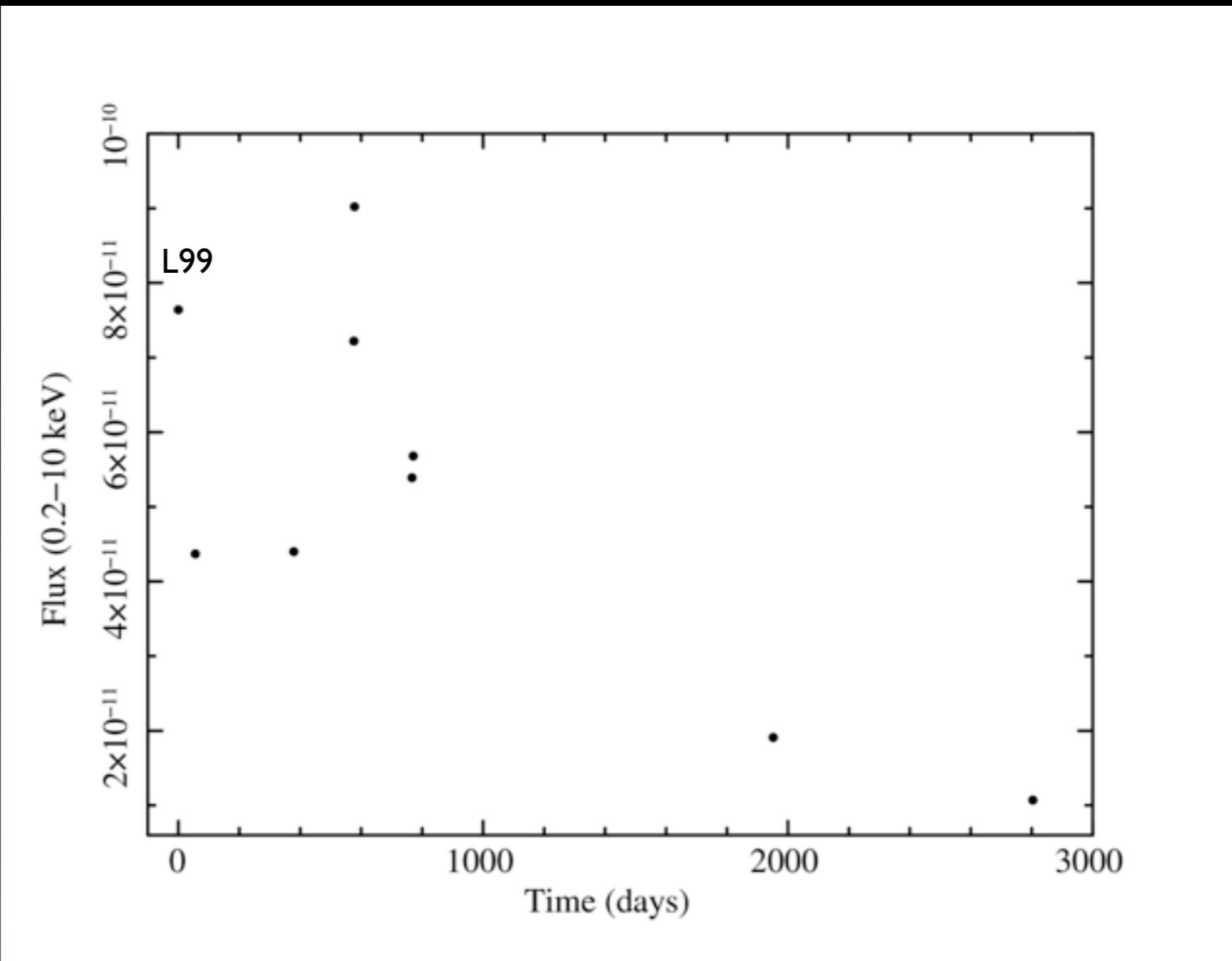
Joint fit results

Component	A	B	C	D	E	F
v_{out} (km/s)	-588 ± 34	-547 ± 31	-1148 ± 20	-254 ± 25	-792 ± 25	-1221 ± 25
σ_v (km/s)	210 ± 40	61 ± 15	19 ± 6	68 ± 14	24 ± 12	34 ± 13
N_H (10^{20} cm^{-2})	2.0 ± 0.6	7.0 ± 0.9	15 ± 3	11 ± 2	28 ± 8	57 ± 17
$\log \xi_{\text{LETGS}}$ (10^{-9} W m)	0.78 ± 0.08	1.51 ± 0.05	2.15 ± 0.03	2.36 ± 0.03	2.94 ± 0.08	3.13 ± 0.05
$\log \xi_{\text{HETGS}}$ (10^{-9} W m)	0.88 ± 0.16	1.67 ± 0.06	2.42 ± 0.10	2.51 ± 0.05	2.89 ± 0.05	3.35 ± 0.04

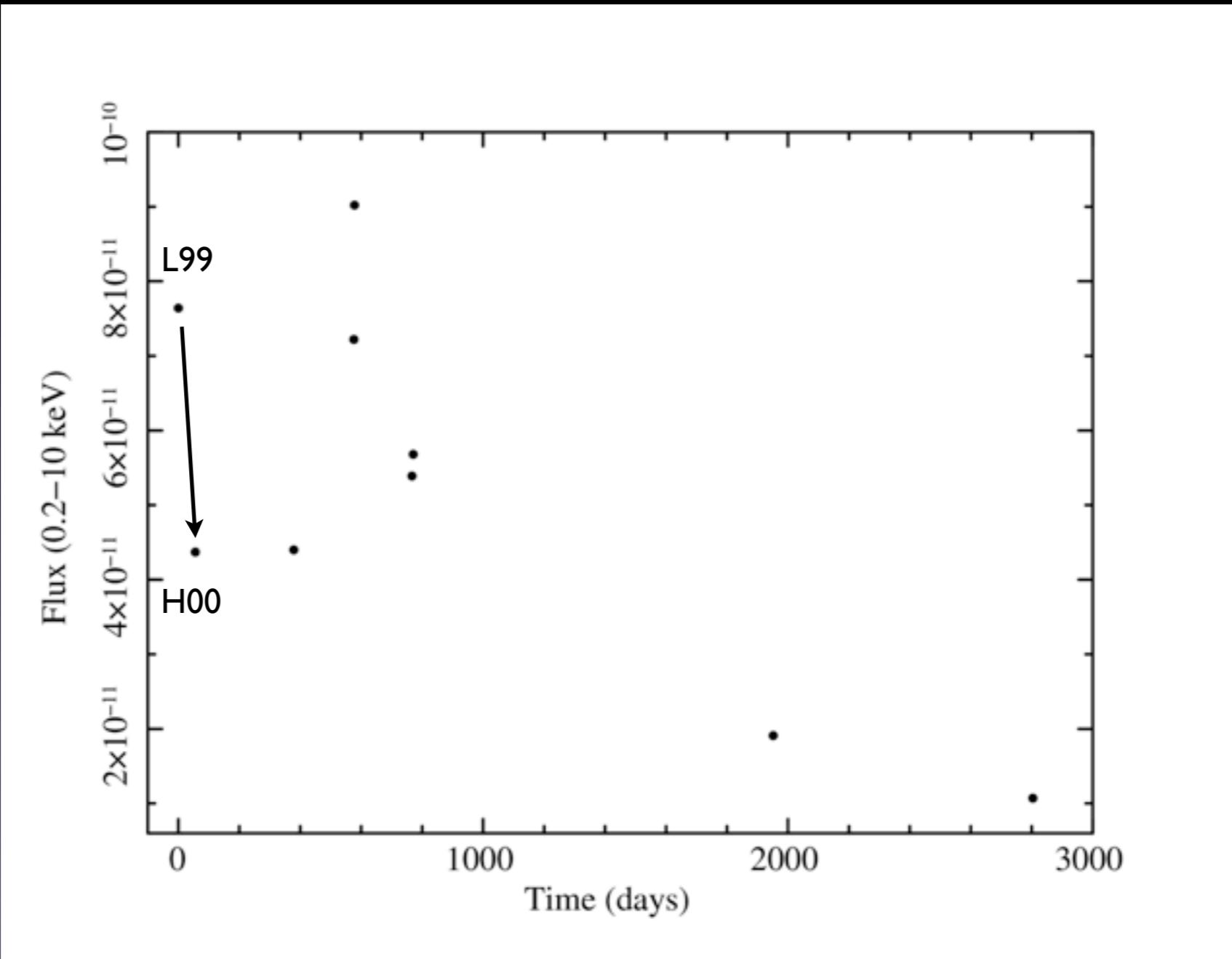
Flux history



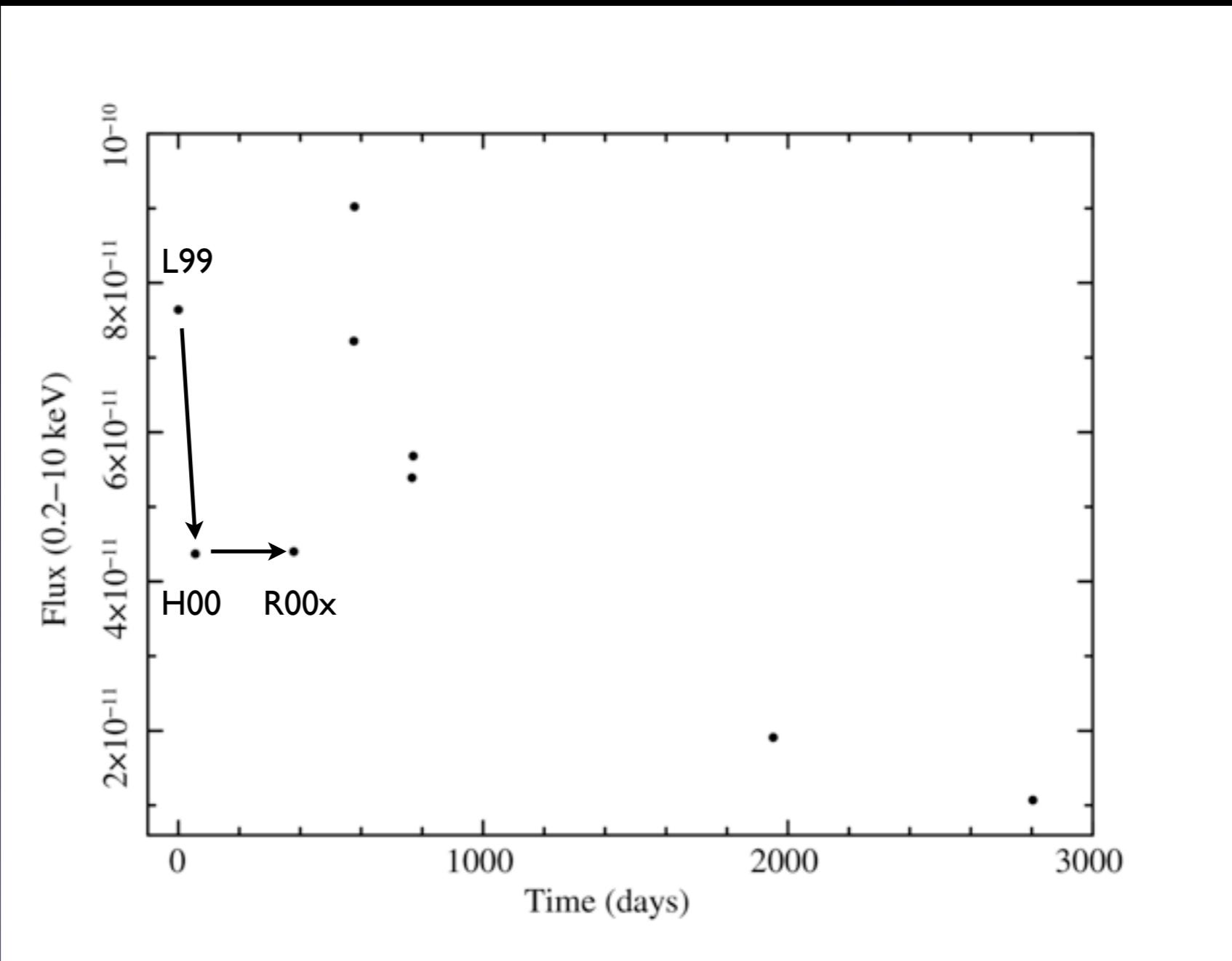
Flux history



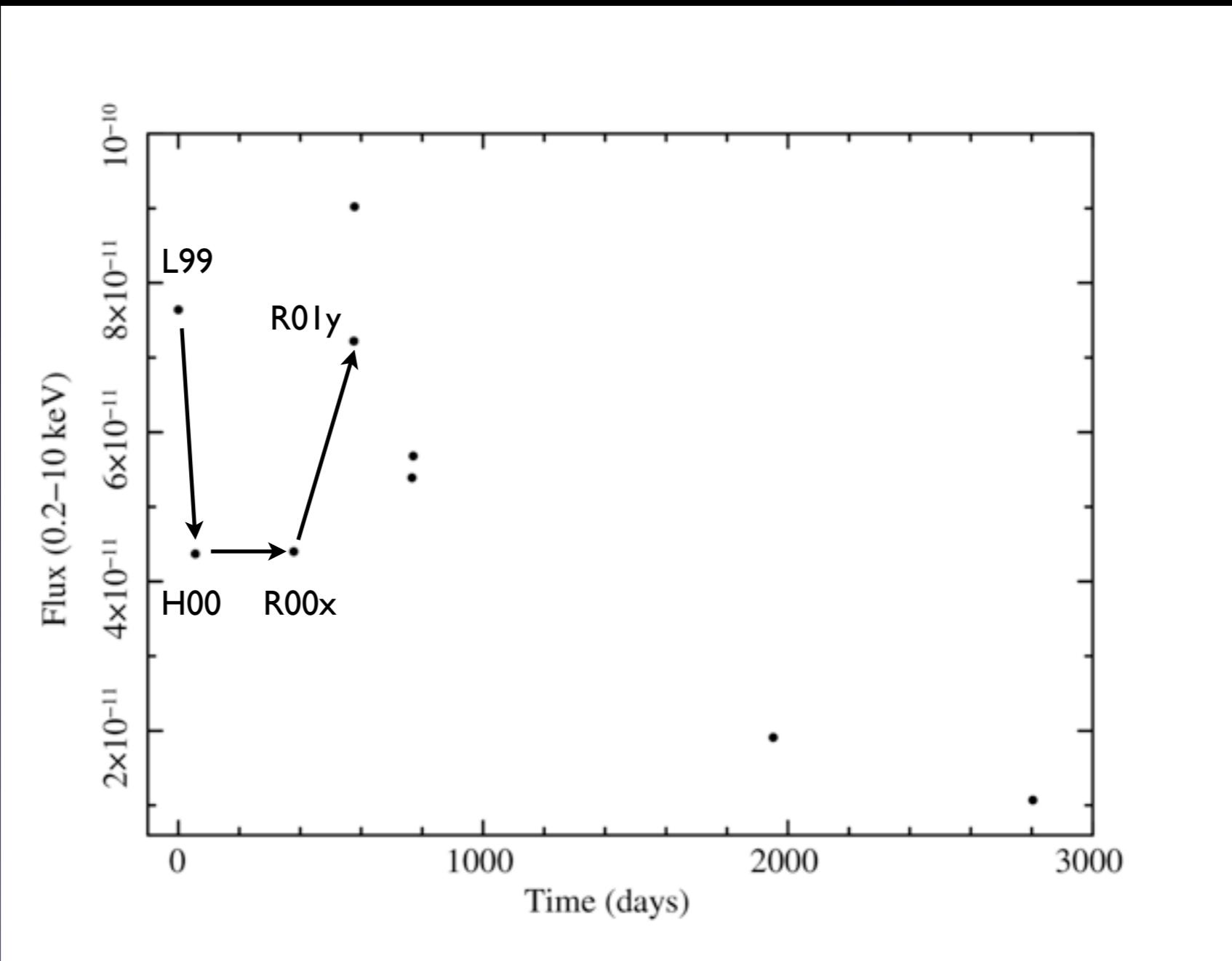
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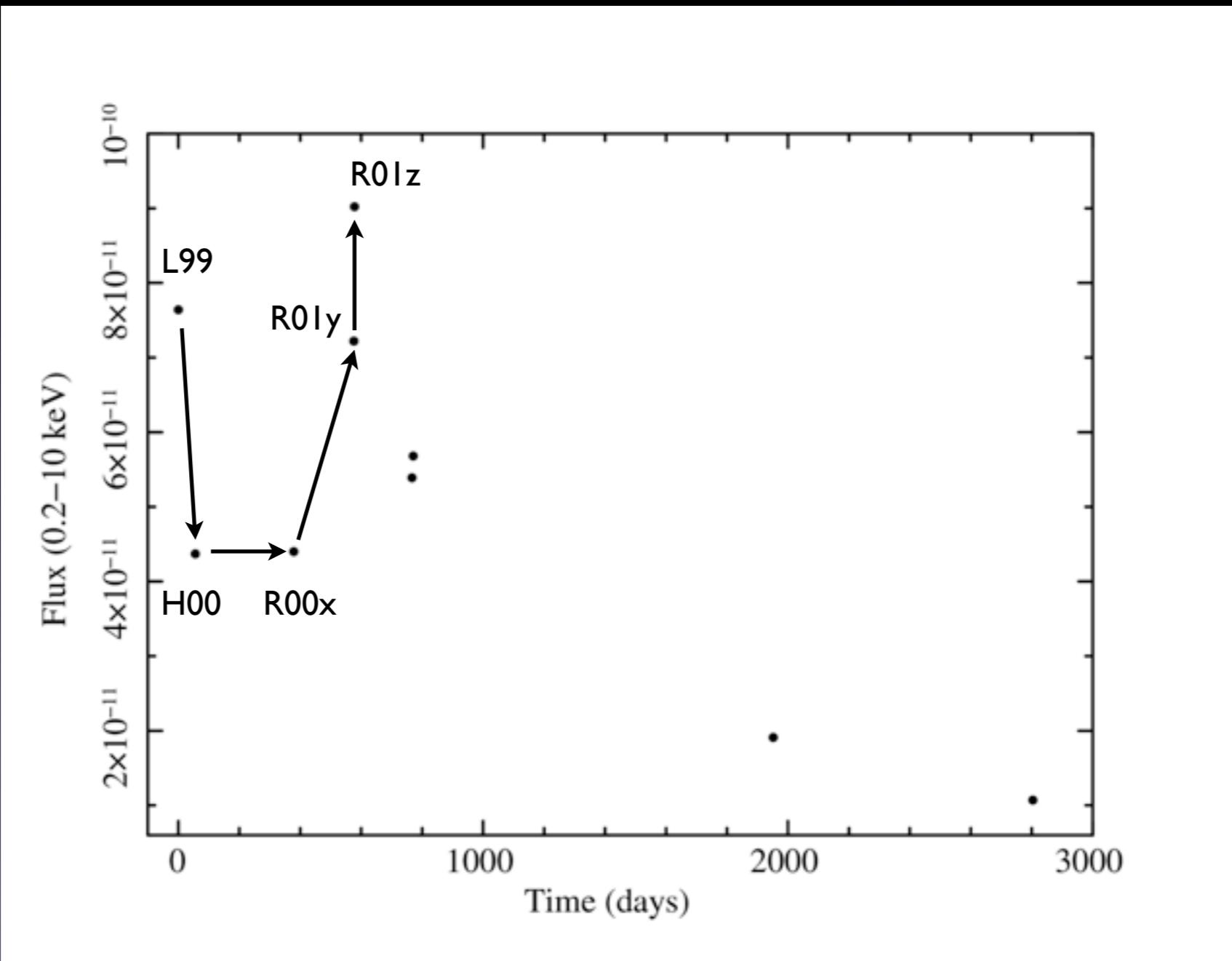
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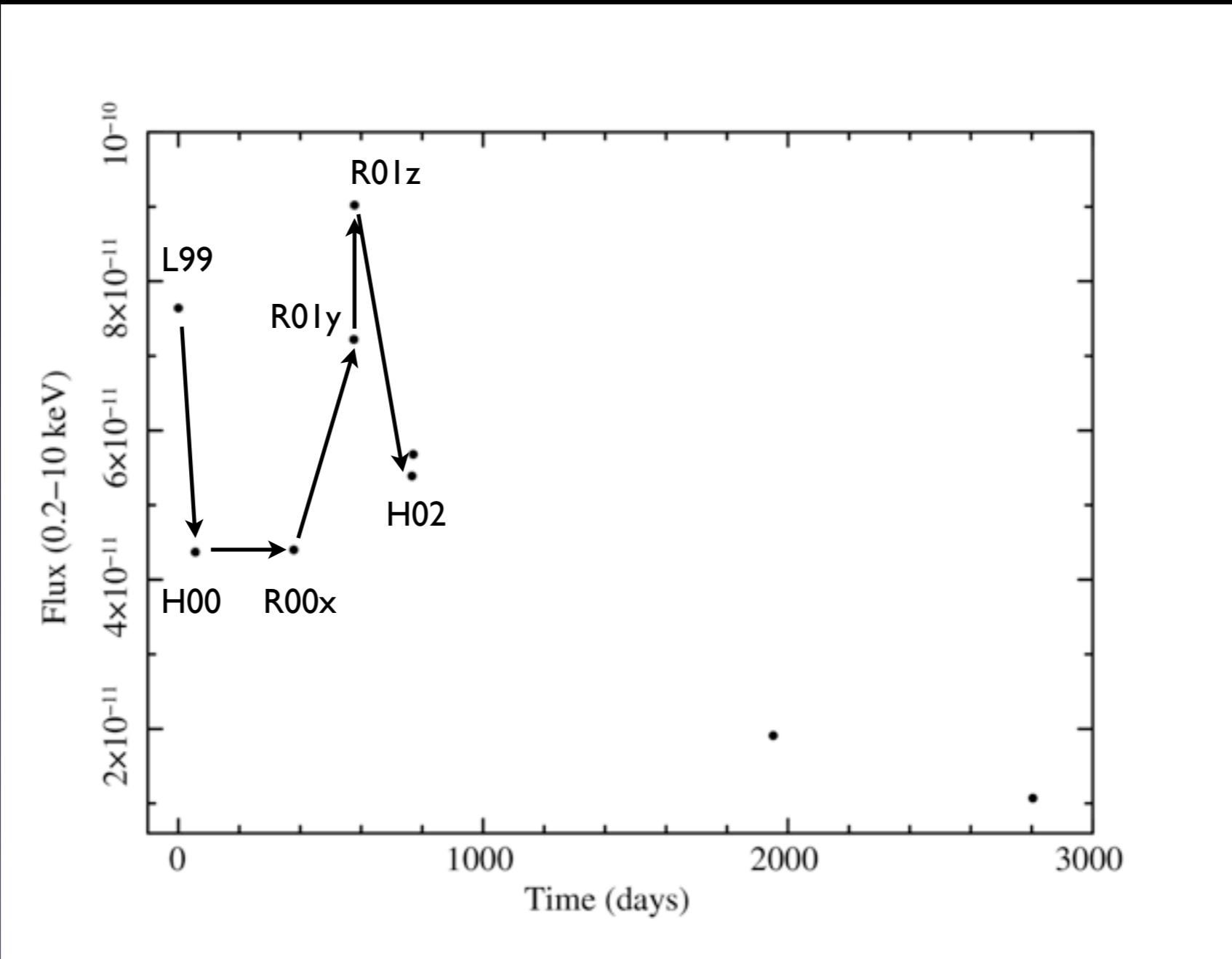
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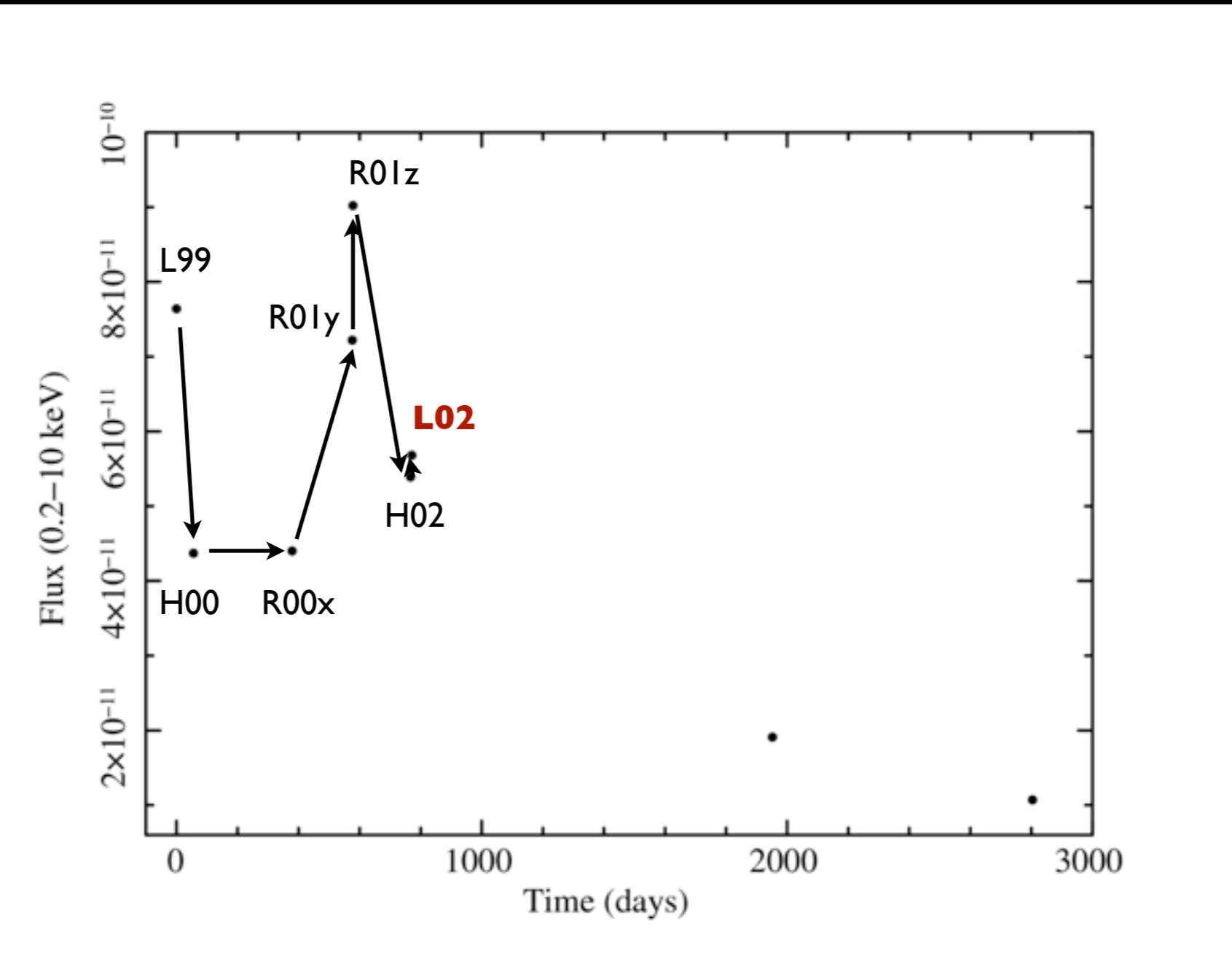
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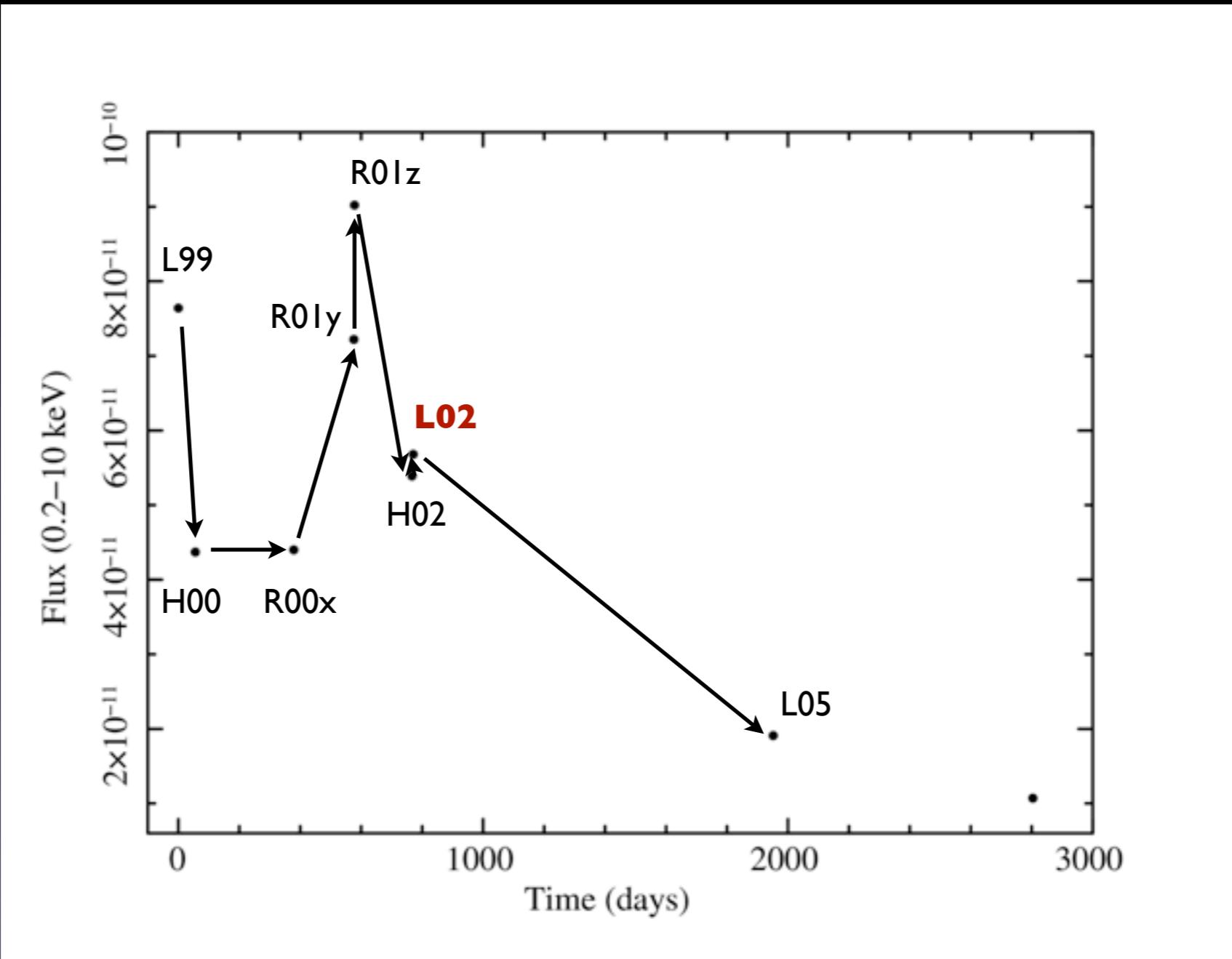
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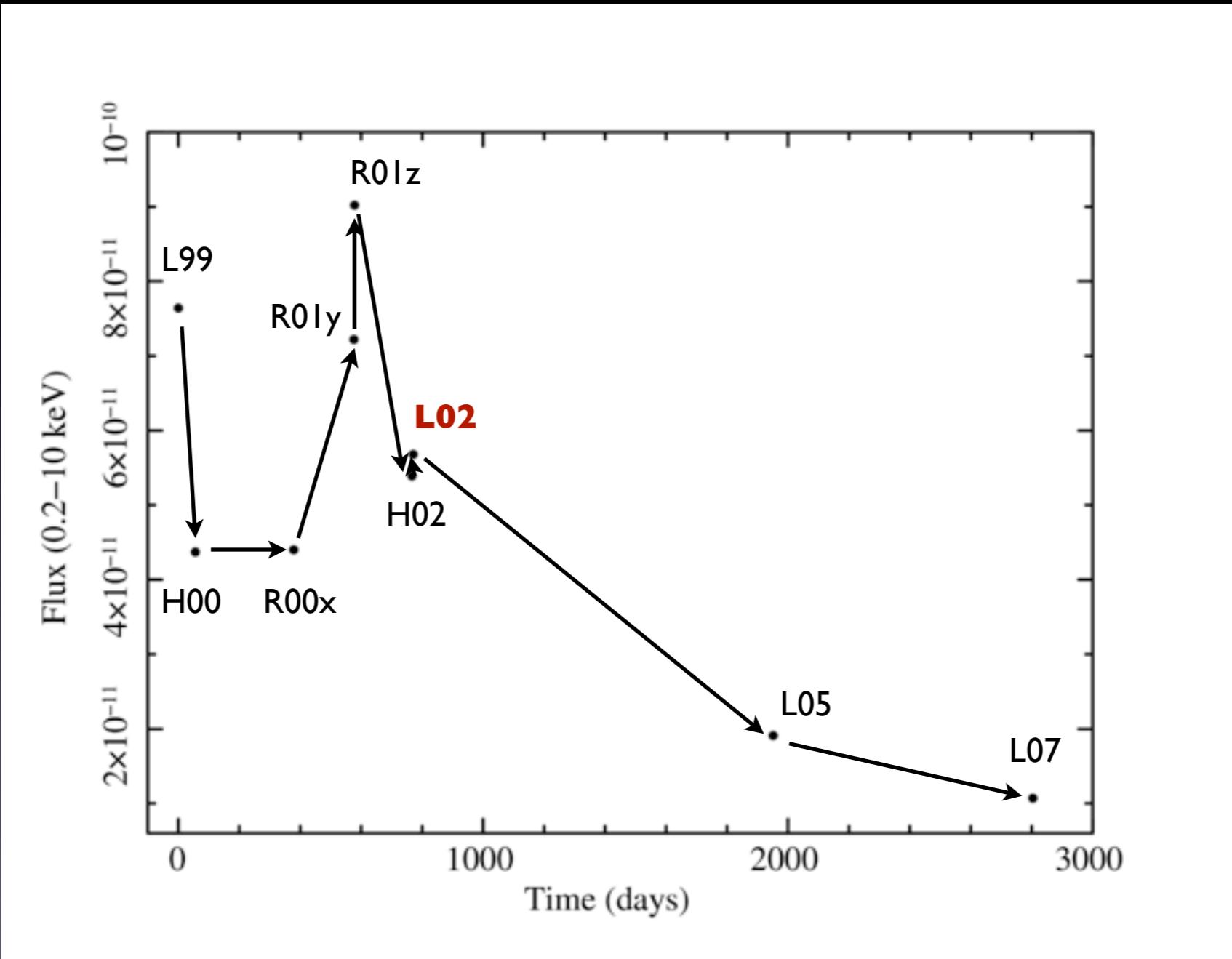
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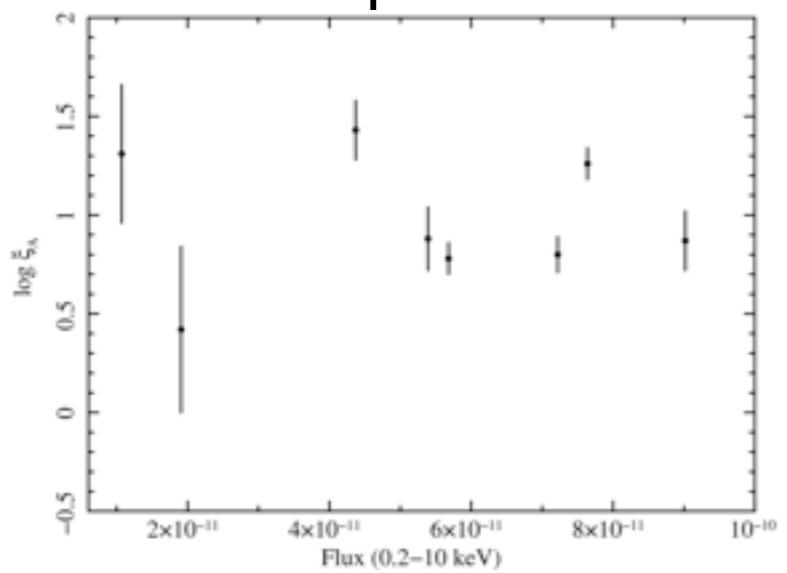


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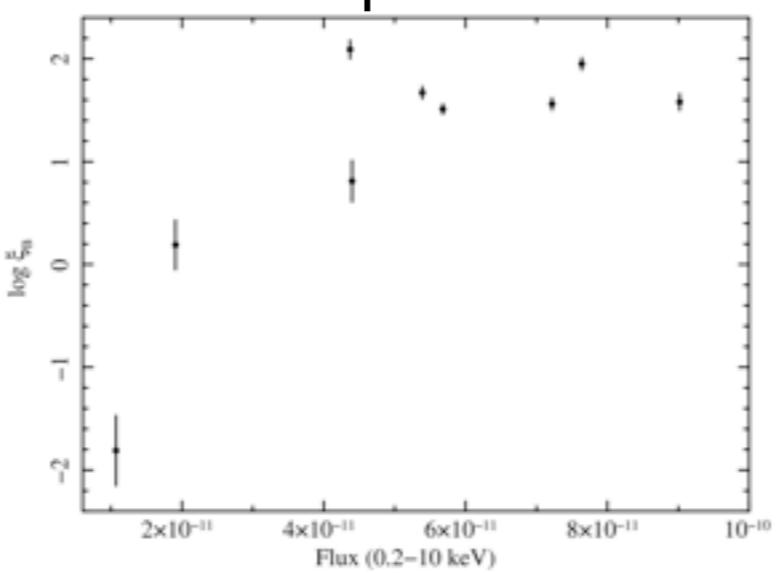


WA vs Flux

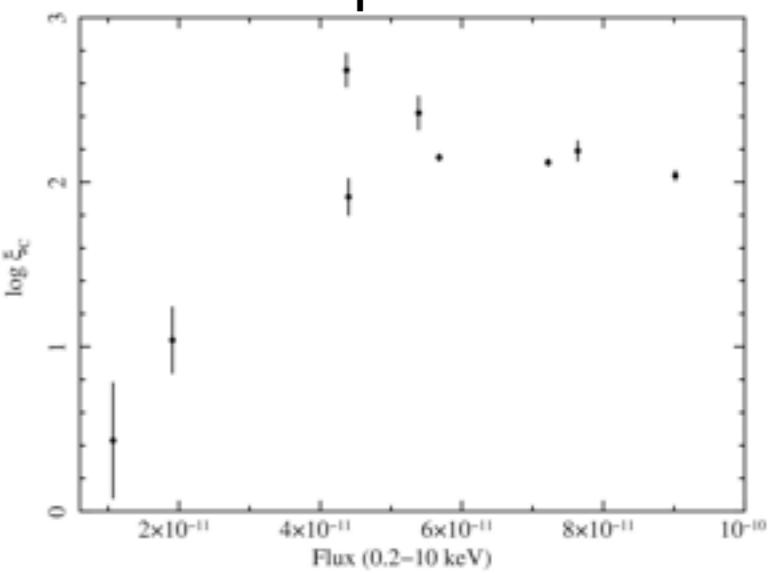
Component A



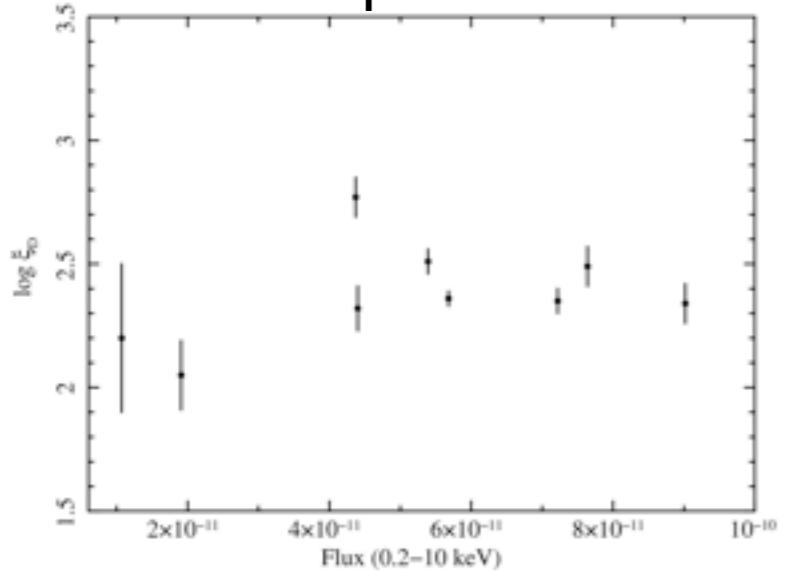
Component B



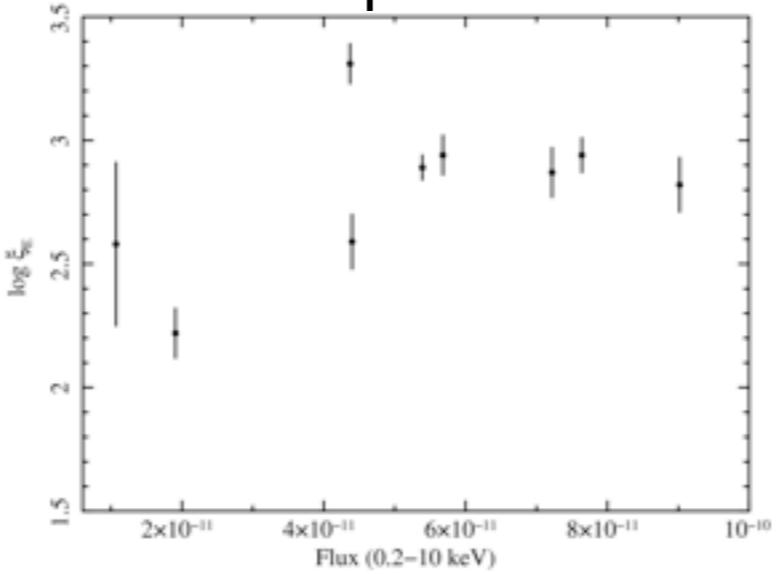
Component C



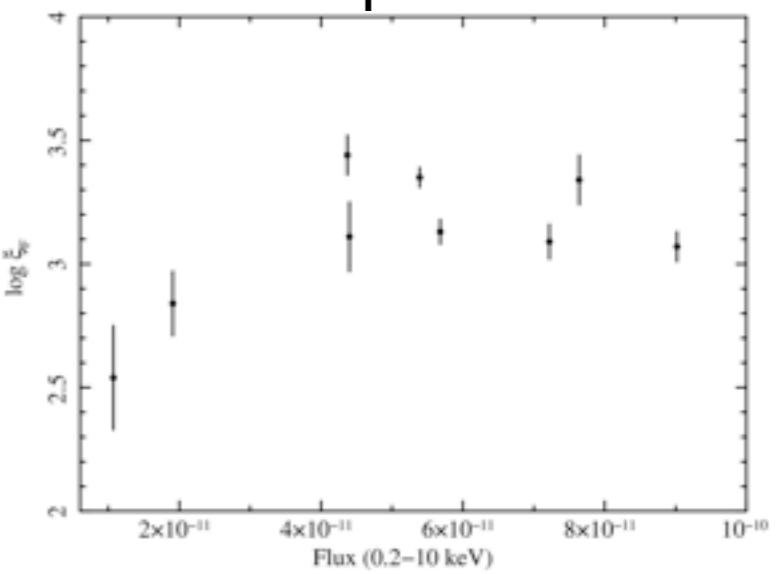
Component D



Component E



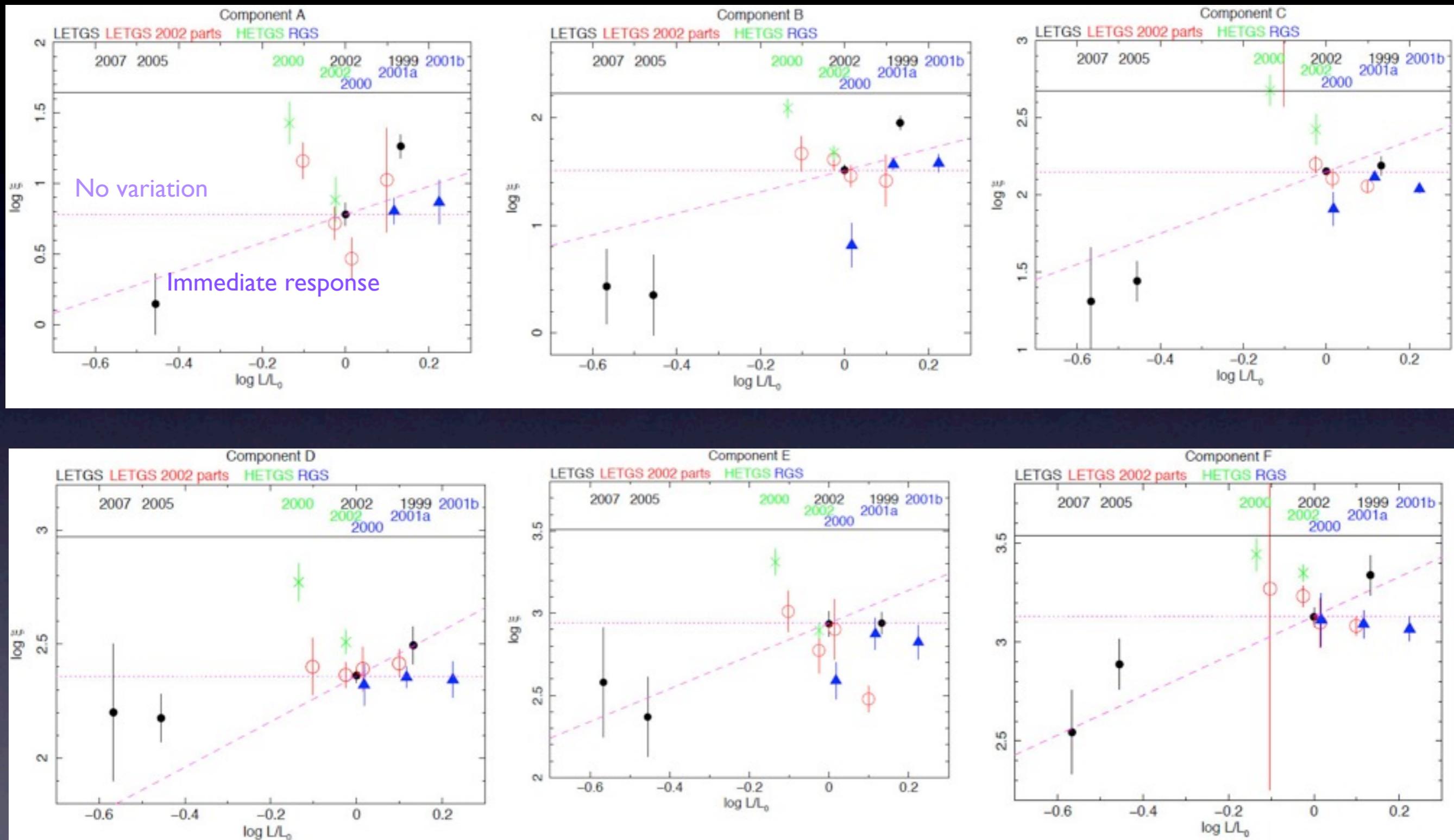
Component F



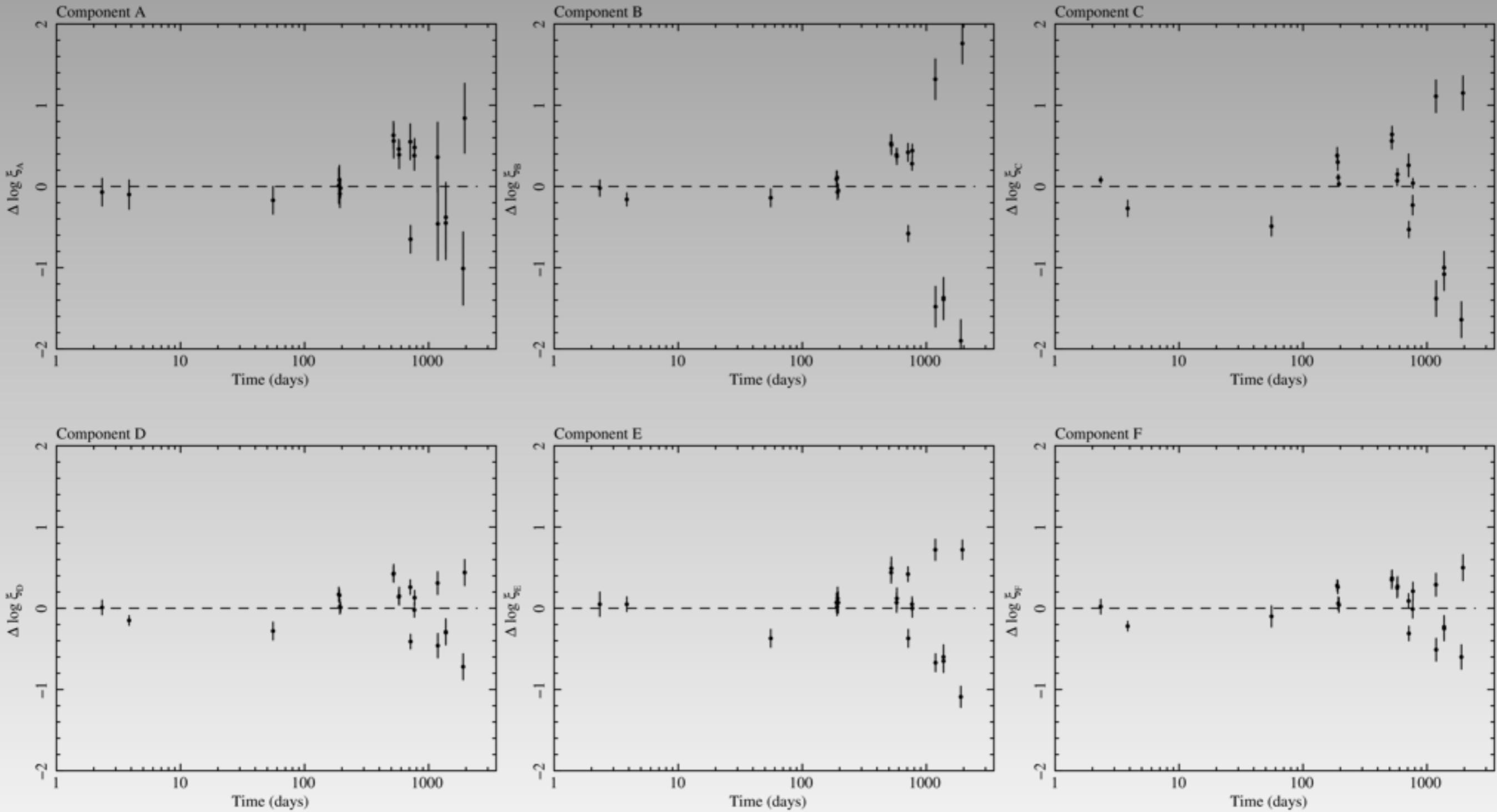
WA constraints from long-term variability

- Archival observations of NGC 5548 allow us to probe changes in the WA at various time-scales, from days to years.
- If changes in the WA are due to the gas responding to variations in the incident flux, they can be used to estimate a lower limit to the density of the gas.
- $t_{\text{rec}} \propto I/n$
- From the definition of the ionization parameter $\xi = L / nR^2$ an upper limit on the distance of the absorber can be derived.

WA variability at different time-scales



WA variability at different time-scales



WA constraints from long-term variability

- In order to do this we look for the ions that contribute the most to each ionization component (strong signatures in the grating waveband).
 - Component A: C V (63%), O V (88%), O VI (68%), Fe VII (82%)
 - Component B: C VI (49%), N VI (56%), O VII (63%), Ne VIII (76%), Fe VIII (62%), Fe IX (87%), Fe X (69%)
 - Component C: Ne IX (50%), Mg XI (54%), Fe XI (70%), Fe XII (91%), Fe XIII (93%), Fe XIV (89%), Fe XV (83%), Fe XVI (77%), Fe XVII (61%)
 - Component D: Fe XVIII (47%)
 - Component E: Fe XX (54%)
 - Component F: Si XIV (58%), Fe XXI (59%), Fe XXII (74%), Fe XXIII (85%), Fe XXIV (91%)

Estimating recombination times

- For each component we calculate the recombination time scales using the auxiliary program *rec_time* from the SPEX fitting package (www.sron.nl/spex):
 - Component A - O V: $n_H * t_{rec} = 1.4 \times 10^{16} \text{ s m}^{-3}$
 - Component A – Fe VII: $n_H * t_{rec} = 2.5 \times 10^{16} \text{ s m}^{-3}$
 - Component B - O VII: $n_H * t_{rec} = 2.2 \times 10^{17} \text{ s m}^{-3}$
 - Component B – Fe IX: $n_H * t_{rec} = 8.6 \times 10^{15} \text{ s m}^{-3}$
 - Component C – Fe XIII: $n_H * t_{rec} = 4.0 \times 10^{15} \text{ s m}^{-3}$
 - Component D – Fe XVIII: $n_H * t_{rec} = 2.2 \times 10^{16} \text{ s m}^{-3}$
 - Component E – Fe XX: $n_H * t_{rec} = 3.5 \times 10^{16} \text{ s m}^{-3}$
 - Component F – Fe XXIV: $n_H * t_{rec} = 2.8 \times 10^{16} \text{ s m}^{-3}$

Distance estimations

Component	$\log \xi$	t_{rec} upper limit (days)	n_H lower limit (m^{-3})	R upper limit (pc)	$R < L / N_H \xi$ (pc)
A	0.78	500	5.8×10^8	56	26800
B	1.53	500	2.0×10^8	40	1470
C	2.16	60	7.7×10^8	10	156
D	2.37	60	4.2×10^9	3.3	131
E	2.94	60	6.7×10^9	1.4	14
F	3.13	4	8.1×10^{10}	0.4	4.4

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F	3.13	4	8.1×10^{10}	0.4	4.4

The WA in NGC 5548 seems to show a stratified structure.

Conclusions

- We re-analyzed the grating archival observations of NGC 5548 using up-to-date codes and atomic physics.
- The WA consists of six distinct ionization states in four kinematic regimes.
- The observations span time-scales from 2 days to 9 years, which can be used to search for long-term variability in the WA components.
- The WA components are likely stratified and are located at pc-scale distances from the central ionizing source.