TEPID: Time Evolving PhotoIonisation Device

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A novel tool for out-of-equilibrium ionised gas from the optical up to the X-rays

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Photoionised gas at all scales is ubiquitously observed in AGNs, from the optical up to the X-rays. Its density, geometry, velocity represent a unique probe of the innermost accretion disc-scale, as well as on the feeding and feedback connecting the AGN to the host environment.

However, current photoionisation codes usually assume time-equilibrium and, thus, cannot self-consistently model the gas response to a time-variable (or transient) ionising source, as for most of the AGNs, and lead to incorrect results when fitting emission and absorption spectra.
Moreover, gas density and distance are degenerate at equilibrium and, thus, the outflows energy and mass rates can be determined only with order-of-magnitude uncertainties.

Time-evolving photoionisation (coupled with time-resolved spectroscopy) is a unique channel to break this degeneracy.

The timescale t_{eq} over which the gas adjusts to luminosity changes is indeed proportional to the gas density n:

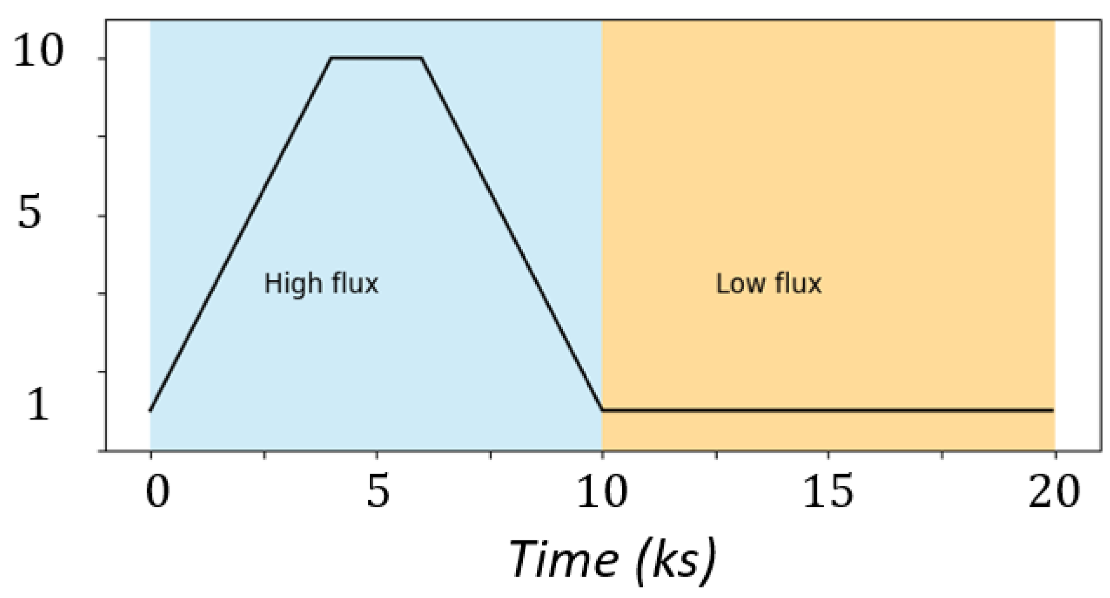
$$t_{eq} = 1/(\alpha^i_{rec} \cdot n)\left(1 + \frac{\alpha^{i-1}_{rec}}{\alpha^i_{rec}} + \frac{n_{i+1}}{n_i}\right)$$

where n_i, n_{i+1} are the $i-th$, $i+1-th$ ionic levels and $\alpha^{i-1}_{rec}, \alpha^i_{rec}$ their respective recombination rates.

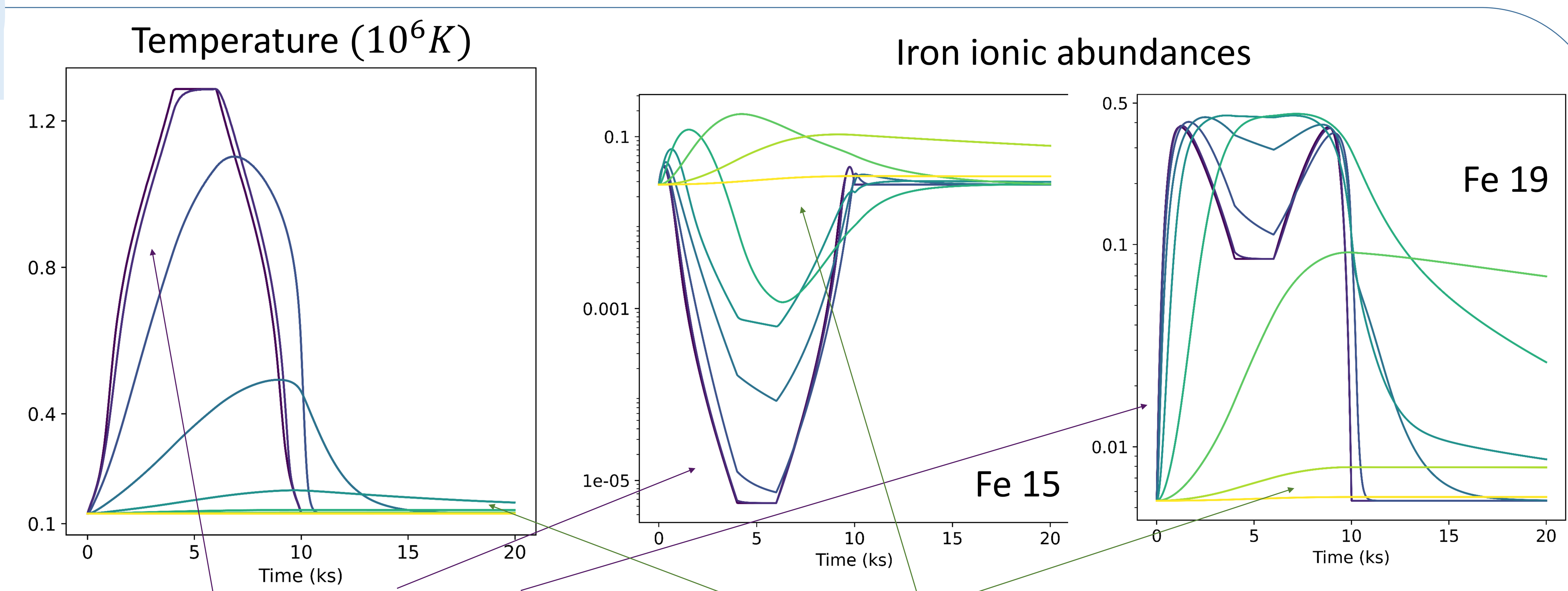
By constraining the gas temporal variations in observed spectra it is possible to derive n and, thus, the distance r and self-consistent values of the wind mass and energetic.

TEPID follows the out-of-equilibrium evolution of the gas ionisation, temperature and computes time-resolved spectra to be compared to observed data.
It is able to model all astrophysical scenarios, from compact objects and Gamma-Ray Bursts to AGNs and intra/inter-galactic environments.

Gas evolution following a two-stage, AGN-like ionising lightcurve:



We assume the gas to be in photoionisation equilibrium at $t = 0$ with $\log(U) = 0.5$. Gas density ranges from $\log(n/cm^{-3}) = 4$ to $= 12$ (lightest to darkest) with steps of 1

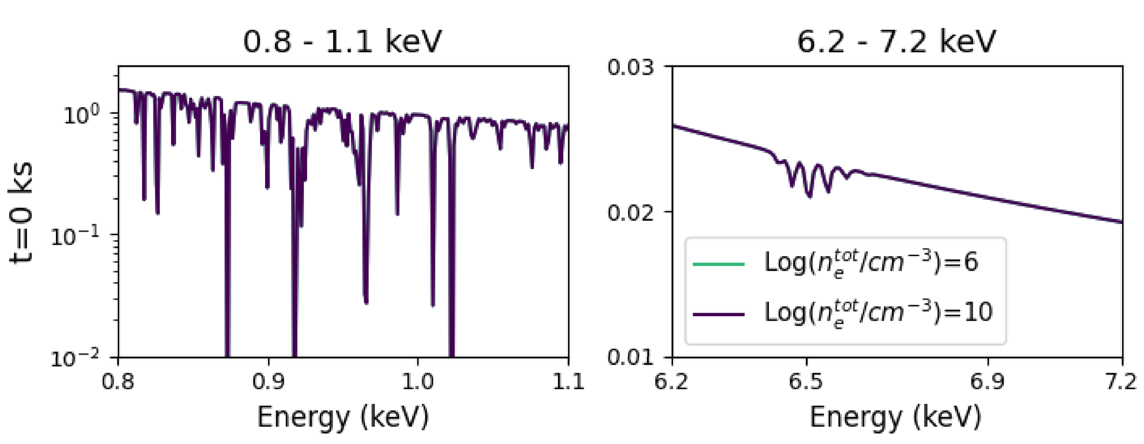


Dense gas ($n = 10^{12} cm^{-3}$): fast evolution
⇒ always in equilibrium with the lightcurve

Tenuous gas ($n = 10^4\ cm^{-3}$): slow evolution
⇒ lags behind luminosity variations

Time-resolved spectra:

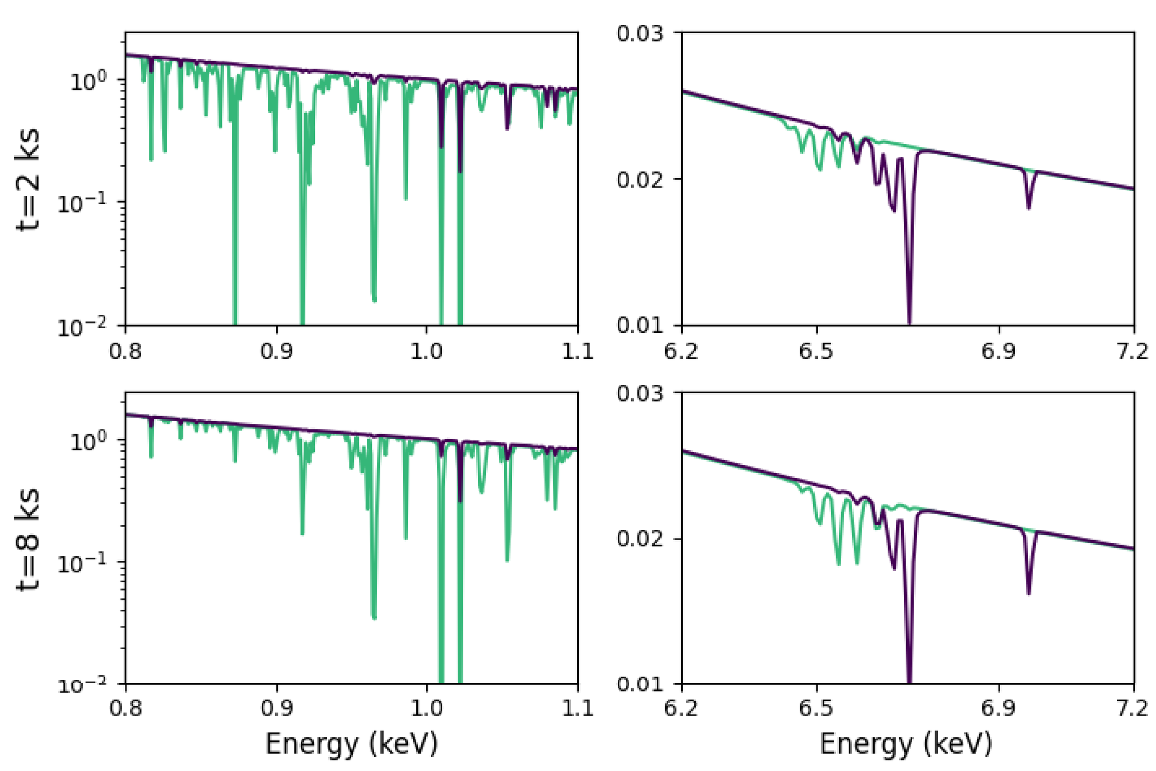
We use the same lightcurve as above and set $\log(U) = 1.5$ at $t = 0$, typical of UV, X-ray Disk Winds and Warm Absorbers

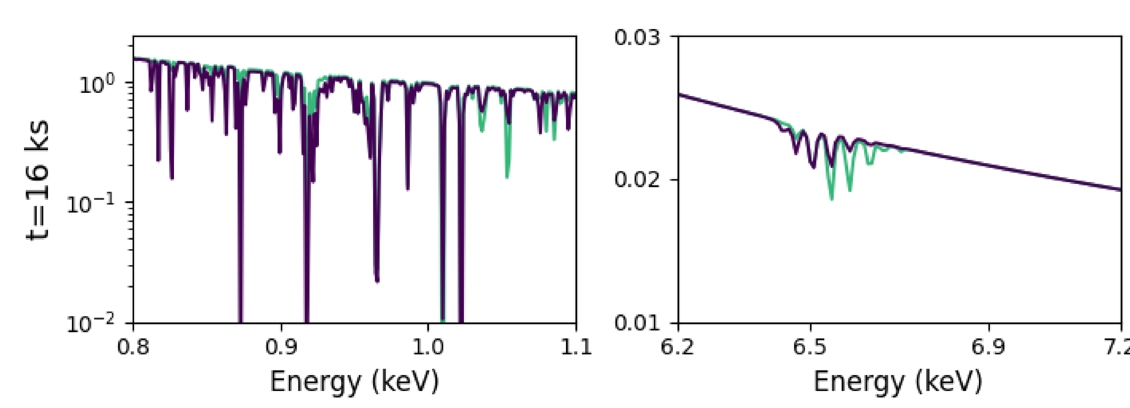


$t = 0\ ks$. Gas in equilibrium, $\log(U) = 1.5$
→ Spectra are identical by construction

$t = 2{,}8\ ks$. Mid-time of the rise and decay phase *(same flux):*

- $\log(n/cm^{-3}) = 10$: gas in equilibrium
  → same opacity
- $\log(n/cm^{-3}) = 6$: gas is overionised
  → *lower opacity at t=8 ks*





$t = 16\ ks$. Same flux as $t = 0$.

- $\log(n/cm^{-3}) = 10$: same spectrum as for $\log(U) = 1.5$
- $\log(n/cm^{-3}) = 6$: overionised spectrum

Time-evolving spectra depend on the gas density n!
Therefore n, and r, can be directly constrained from high-resolution UV and X-ray spectra of variable AGNs with TEPID