Exploring the Hot and Energetic Universe, Madrid 2015

# X-ray absorption studies of young stars

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Classical T Tauri (CTTS) stars are surrounded by copius amounts of circumstellar material. Its composition determines the conditions for planet formation. For favorable geometries, we can determine the composition through absorption spectroscopy. Optical/NIR extinction traces the dust while the far more abundant gaseous part is challenging to measure directly. X-ray absorption is sensitive to this gas component and allows us to measure the important gas-to-dust ratio. We present two key systems with time variable absorption. This variability allows us to spatially localize the absorber. We measure the disk's gas-to-dust ratio by comparing the changes in X-ray absorption ($N_H$) and dust extinction ($A_V$). With current instrumentation, we can measure this gas-to-dust ratio and our simulations demonstrate that ATHENA X-IFU observations can even provide individual gas abundances.

## AA Tau: A spatial gas-to-dust ratio gradient (Schneider et al., A&A accepted)

- Major optical dimming event (Fig. 1)
- Increase in
  - $A_V$ by ~4 mag
  - $N_H$ by ~$10^{22}$ cm$^{-2}$
- Extra absorber located at a few AU (from disk emission line profiles)
- Gas-to-dust ratio of extra absorber: ~ ISM-like
- Previous studies (Schmitt & Robrade 2007, Grosso et al. 2007): Gas-rich inner region

→ Spatial gas-to-dust gradient

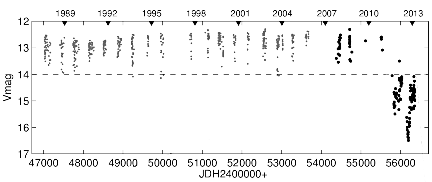


Fig.1: Optical light curve of AA Tau. The drop in brightness around 2013 is caused by the extra absorber (Bouvier et al. 2013)

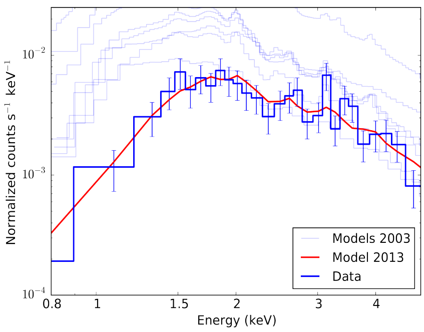


Fig.2: X-ray spectrum during the dim state. The increase in $N_H$ is moderate compared to the increase in $A_V$.

## RW Aur A: ISM-like gas-to-dust ratio

(Schneider et al., A&A subm.)

- Dimming event similar to AA Tau (Petrov et al. 2014)
- Grey extinction up to K band
  - → Large grains (> 1 µm)
  - → Lower limit on dust mass: $2\times10^{-4}$ g cm$^{-2}$
- Increase in NH: $2\times10^{22}$ cm$^{-2}$
- Gas-to-dust ratio: < 200:1

→ Grains grow in circumstellar disks without altering the gas-to-dust ratio

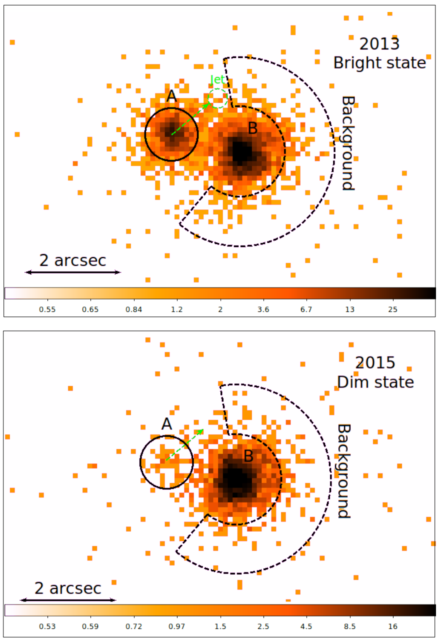


Fig.3: X-ray (0.3 -10.0 keV) images of RW Aur. The X-ray dimming is caused by a strong increase in absorbing column density.

## ATHENA simulations: Individual gas abundances

- Absorption edges enable direct determination of elemental abundances
- Important elements (e.g., C, N, O) have absorption edges within the X-IFU energy range

- Example: RW Aur A with the X-IFU
  - $N_H$ increase: $10^{21}$ cm$^{-2}$, texp: 10 ks
    Abund. accuracy 10% (90% conf.)
  - $N_H$ increase: $10^{22}$ cm$^{-2}$, texp: 50 ks
    Abund. accuracy 1-50 % (90% conf.)
    (depending on absorption edge)

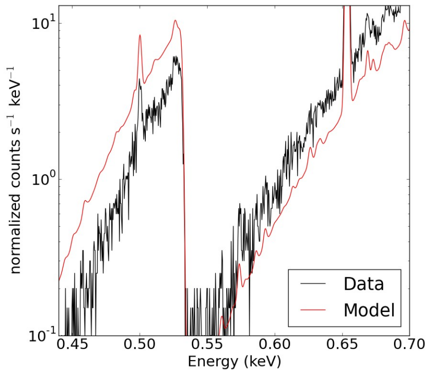


Fig.4: Simulation of a 50 ks RW Aur A observation with the X-IFU. Zoom into the energy range around the oxygen edge. The model assumes a three times enhanced O abundance to highlight the sensitivity of ATHENA X-IFU data to changes in the absorber abundances. The nominal accuracy of the measured O abundance is better than 1%.

## Conclusions

*Current instrumentation (XMM-Newton, Chandra, Suzaku):*

Using time variable absorption, we measured the disk properties at specific radii within the disk. Comparison of X-ray absorption and dust extinction traces the disk's gas-to-dust ratio. We find that the inner disk is gas-rich and that it becomes approximately ISM-like beyond a few AU.

*Athena IFU:*

Individual elemental abundance can be measured through the depth of X-ray absorption edges.

**References**: [1] Schmitt & Robrade 2007, A&A, 462, 41, [2] Grosso et al. 2007, A&A, 475, 607, [3], Bouvier et al. 2013, A&A, 557, 77, [4] Petrov et al. 2014, A&A, 577, 73