**X-ray Diagnostics of Grain Depletion in Matter Accreting onto T Tauri Stars**

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OURLINE

- Ne/O in ACTIVE STARS:
  dependency on activity level and implications

- X-ray SPECTROSCOPY of CLASSICAL T TAU Ri STARS:
  abundance anomalies
  signatures of accretion
  Ne/O in TTS

- Ne/O as DIAGNOSTICS for the ACCRETING MATERIAL
Neon Abundance in Stellar Coronae

- Solar and stellar studies show some evidence of coronal abundances different from photospheric abundances: interest in study of coronal abundances for coronal plasma physics

- *Chandra* – *XMM* high spectral resolution allows line-based abundances analysis based on strong X-ray emission lines of H-like and He-like abundant ions

- Ne/O ratio interesting because looking very similar in all observed stars

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Chandra HETG Spectra of Active Stars

![Graph](image_url)
Neon ABUNDANCE in STELLAR CORONAE

(Drake & Testa 2005)

Ne/O diagnostics we use a T-insensitive line ratio of NeIX, NeX, OVIII (similar to the diagnostics used by Acton et al. 1975 on solar spectra)

- BASED on STRONG LINES (RELIABLE ATOMIC PHYSICS)
- INDEPENDENT on DEM(T)

Neon ABUNDANCE in STELLAR CORONAE

- Ne/O

(Drake & Testa, 2005)
**Neon Abundance in Stellar Corona**

- Ne/O extremely constant on a wide range of activity levels
- Ne/O in coronae of nearby stars ~2.7 times higher than the assumed solar photospheric value

(Drake & Testa, Nature, 2005)

**Possible Important Implications in Solar Context**

**Ne and the Solar Model Problem**

- Models calculated with latest solar abundances (Asplund et al 2004) fail to predict sound speed, He abundance and depth of convection zone inferred from helioseismology (Bahcall et al 2005; Antia & Basu 2005)
- Ne higher by a factor > 2.6 can solve the solar model problem (Bahcall et al 2005; Antia & Basu 2005; Antia & Basu 2004)
- Ne cannot be measured in solar photosphere
X-ray **HIGH RESOLUTION SPECTROSCOPY**

of **CLASSICAL T TAURI STARS**

- **TW Hydreae**

(see Joel Kastner’s talk)

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X-ray **SPECTROSCOPY of CTTS**

- **TW Hydrae**
  - very high Ne, weak Fe, reminiscent of active stars

(Kastner et al., 2002)
**X-ray SPECTROSCOPY of CTTS**

- **TW Hydrae**

  - very high Ne, weak Fe, reminiscent of active stars
  - peculiar f/i ratio in cool He-like triplets (Ne, O)
  - thermal distribution extremely peaked

  \[\text{(Kastner et al., 2002, Stelzer & Schmitt 2004)}\]

**SPECTRUM LIKELY PRODUCED in ACCRETION SHOCK**
X-ray SPECTROSCOPY of CTTS

is TW Hya the only young object with these peculiar characteristics?

- **BP TAU**: XMM-RGS spectra show high density for OVII
  (Schmitt et al. 2005)

- **HD 163296 (HERBIG Ae STAR)**: remarkably isothermal plasma (BUT only low resolution spectrum, ACIS-I, Swartz et al. 2005)

- **OTHER CTTS** observed at high spectral resolution (SU Aur, DoAr 21) are heavily absorbed Ne, O He-like triplets are inaccessible (e.g. Smith et al. 2005)

**NEED of HIGH RESOLUTION SPECTRA**
What does Ne/O look like in these accreting TTS with respect to the constant value of "normal" stars?

The Ne/O in TW Hya and BP Tau should reflect the composition of the accreting material.

Why should Ne/O be different in TW Hya?

- grain depletion?
- coronal abundance anomalies?
- fractionation effects in magnetospheric accretion?

should be similar in TW Hya and BP Tau
Why should Ne/O be different in TW Hya?

- metal depletion in accreting gas already suggested by:
  - weak or absent Si lines in UV spectra (Valenti et al. 2000, Herczeg et al. 2002), low Si and Al in jet gas (Lamzin et al. 2004)

**BUT**

unlike comparison of Ne with metals (Fe, Si, Mg), the Ne/O diagnostics appears to be robust to the effects of compositional fractionation seen in coronal plasma

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Ne is volatile while O is readily depleted in silicates

**Ne/O is a good diagnostics for grain depletion**
DIAGNOSTICS from Ne/O

Why should Ne/O be different in TW Hya?

- grain depletion?

accreting grains should be destroyed by UV/X-rays

- Ne/O high in TW Hya implies grains are NOT accreted

Why?

DIAGNOSTICS from Ne/O

Why should Ne/O be different in TW Hya and BP Tau?

- TW Hya (~10 Myr) and BP Tau (~ 0.6 Myr) have significantly different ages

  different evolutionary state of the disk

- grains in TW Hya must have developed sufficient size to avoid accretion
**Evidence for Advanced Grain Formation in TW Hya**

- grain formation and coagulation into larger particles  
  (Calvet et al. 2002)

- centimeter size bodies in the TW Hya’s disk (Wilner et al. 2005)

- developing gap possibly caused by a growing protoplanet  
  (Calvet et al. 2002)

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**Conclusions**

- **Neon Abundance**
  - Ne/O constant in stellar coronae
  - Ne/O is ~2 times higher in TW Hya, not in BP Tau which is also accreting
  - O is very likely depleted in the very inner disk of TW Hya
  - Ne/O robust diagnostics for grain depletion, as compared to metal deficiency

- **X-rays Spectra Are Unique Means to Probe**
  - the processes at work in the accretion shock
  - the composition of the accreting material, i.e. the state of the very inner disk
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