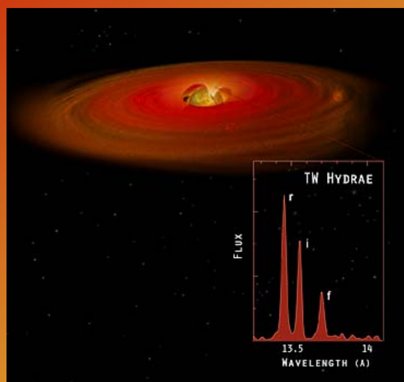
X-RAY DIAGNOSTICS of GRAIN DEPLETION in MATTER ACCRETING onto T TAURI STARS



http://chandra.harvard.edu/photo/2003/twhy/index.html

Paola Testa (MIT)

Jeremy Drake (SAO)

Lee Hartmann (SAO)

Chandra Workshop – July 13 2005

OUTLINE

- Ne/O in ACTIVE STARS:
  - dependency on activity level and implications
- X-ray SPECTROSCOPY of CLASSICAL T TAURI STARS:
  - abundance anomalies
  - signatures of accretion
  - Ne/O in TTS
- Ne/O as DIAGNOSTICS for the ACCRETING MATERIAL

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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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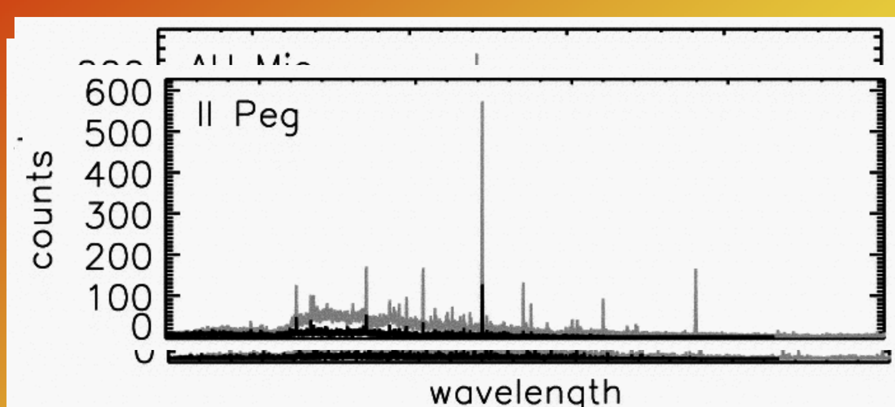
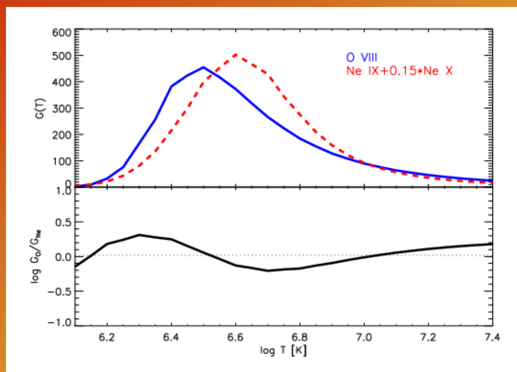
Chandra HETG SPECTRA of ACTIVE STARS



Neon ABUNDANCE in STELLAR CORONAE

(Drake & Testa 2005)



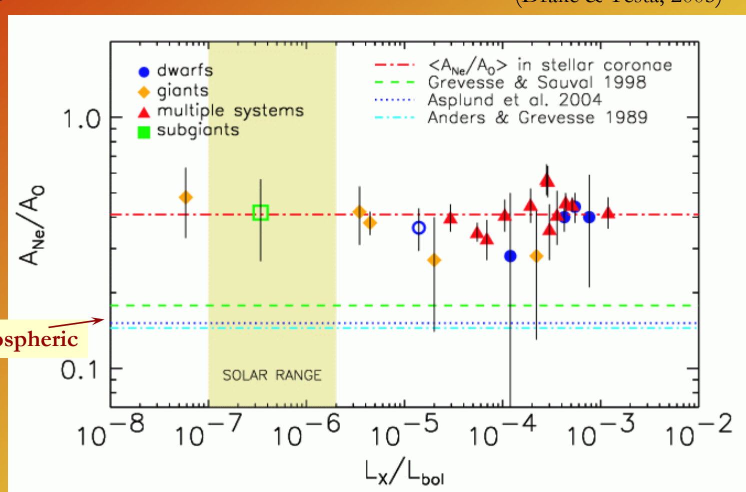
Ne/O diagnostics we use a T-insensitive line ratio of NeIX, NeX, OVIII (similar to the diagnostics used by Acton et al. 1975 on solar spectra)

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

Neon ABUNDANCE in STELLAR CORONAE

➢ Ne/O

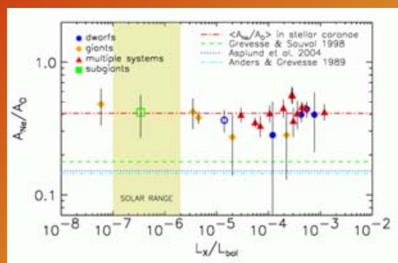
(Drake & Testa, 2005)



solar photospheric

Neon ABUNDANCE in STELLAR CORONAE

- Ne/O



(Drake & Testa, Nature, 2005)

- 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

POSSIBLE IMPORTANT IMPLICATIONS in SOLAR CONTEXT

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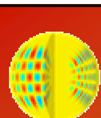
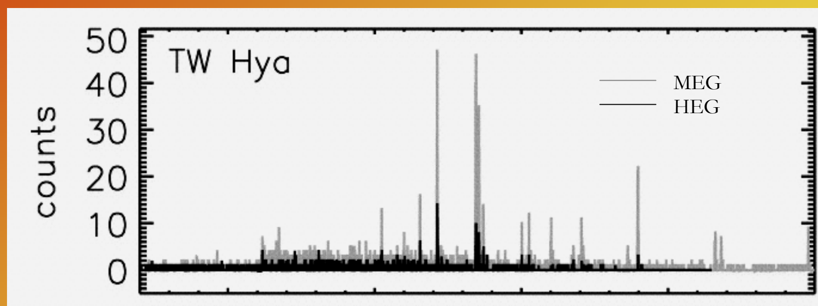


Ne and the SOLAR MODEL PROBLEM

- 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 Hydrae

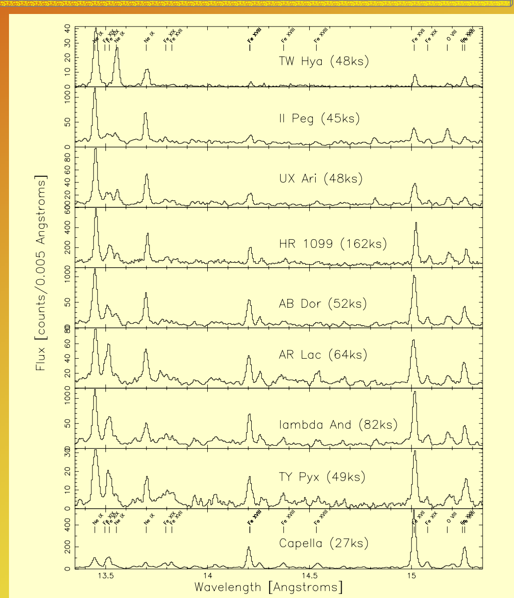


(see Joel Kastner's talk)

X-ray Spectroscopy of CTTS

➢ TW Hydrae

· very high Ne, weak Fe, reminiscent of active stars



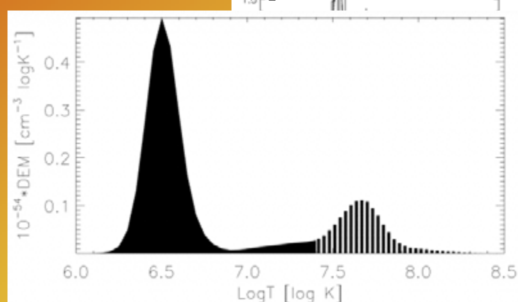
(Kastner et al., 2002)

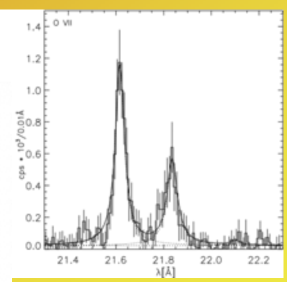
X-ray SPECTROSCOPY of CTTS

➢ TW Hydrae

(Kastner et al., 2002, Stelzer & Schmitt 2004)

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





(Kastner et al., 2002)

X-ray SPECTROSCOPY of CTTS

➢ TW Hydrae

(Kastner et al., 2002, Stelzer & Schmitt 2004)

- very high Ne, weak Fe, reminiscent of active stars
- cool He-like triplets (Ne, O) indicate unusually high plasma density
- thermal distribution extremely peaked

SPECTRUM LIKELY PRODUCED in ACCRETION SHOCK

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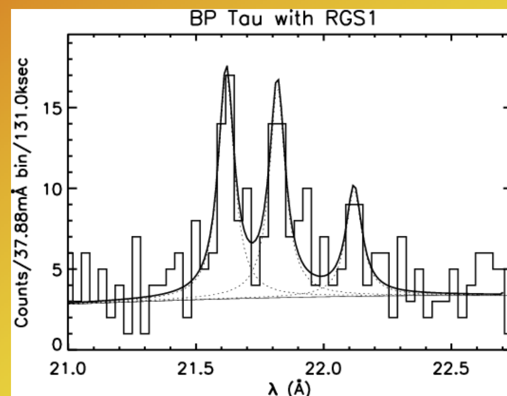
X-ray SPECTROSCOPY of CTTS

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)



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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

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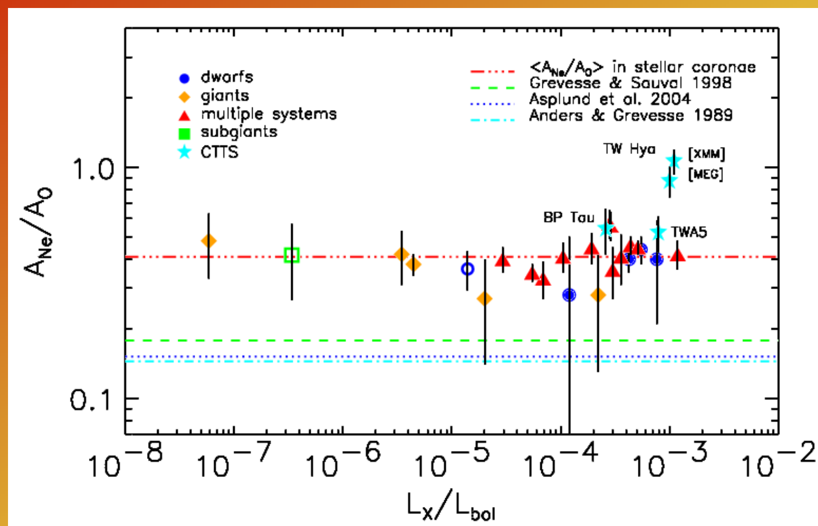
X-ray SPECTROSCOPY of CTTS



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X-ray SPECTROSCOPY of CTTS

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

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DIAGNOSTICS from Ne/O

Why should Ne/O be different in TW Hya?

grain depletion?

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)
- metal-poor X-ray spectrum (Kastner et al. 2002, Stelzer & Schmitt 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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DIAGNOSTICS from Ne/O

Why should Ne/O be different in TW Hya?

grain depletion?

Ne is volatile while O is readily depleted in silicates

Ne/O is a good diagnostics for grain depletion

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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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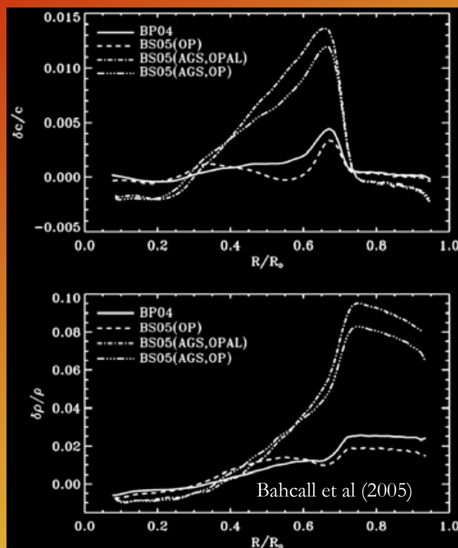
CONCLUSIONS

- **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

Ne and the SOLAR MODEL PROBLEM



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