Highlights of Chandra Grating Science

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- Overview: Spectral Diagnostics
- Cool Stars: Pressure, Abundances, Location
- Hot Star Atmospheres
- Cataclysmic Variables: Accretion
- Winds and Relativistic Iron Lines in X-ray Binaries
- Active Galactic Nuclei: Outflows
- Absorption by the Warm-Hot Intergalactic Medium (WHIM)
- Conclusions
Overview: Spectral Diagnostics

- Quantifying the Physical Conditions from the X-Ray Spectrum
  - Collisionally Ionized Plasma
    - Line Flux Diagnostics
    - Thermal Continuum Emission
  2. X-ray Photoionized Plasma
    - Photoionizing Continuum
    - Emission Lines from Ionized Gas
    - Absorption by Ionized Gas
    - Radiative Recombination Continuum
    - Fluorescence Lines

- Timing Studies
  1. Light Curves from Spectral Lines
  2. Doppler Velocities
  3. Flaring Events and Other Variability

- Line Profile Studies
  - Doppler Imaging
  - Wind Diagnostics
The X-ray Spectral Content

Fe L-Shell

Other L-Shell

H- and He-like
Fe  S  Si  Mg  Ne  O

Fe M-Shell

H- and He-like
N  C
Coronal Loop Models of the Emission Measure Distribution

Brickhouse & Drake 2001

Sun (G2 V)  
Extended Emission  
Yohkoh Image

Capella (G8 III + G1 III);  
P=108d; G1 has 8 d rotation  
Expanding Loops  
Schrijver, Lemen, & Mewe 1998
Electron Density Determination

Lower Pressure; \( L = 0.02 \, R_* \)

- Compelling evidence for high density, small emitting region(s)
- Multiple pressures in the system

High Pressure; \( L = 0.003 \, R_* \)

Chandra Gratings
Capella (G8 III + G1 III)
Brickhouse 2001
Abundances: Continuum Modeling and Line-Free Regions

HR 1099
High Ne Abundance
Drake et al. 2001

Capella
Solar Photospheric Abundances
Brickhouse 2001
X-Ray Doppler Imaging with Light Curves and Velocity Profiles

- From light curve analysis:
  - Near the pole of the primary:
    » A small region on the inner face
    » A larger region on the outer face
  - Unmodulated emission

- From line centroids:
  - Dominant velocity follows primary

Chandra HETG
44 Boo (2 ~G8 stars); P=0.268 d
Brickhouse, Dupree, & Young 2001
A New Technique: Composite line profile to increase S/N

Chandra HETG
44 Boo (2 ~G8 stars); P=0.268 d
Hoogerwerf, Brickhouse, & Dupree 2003
Wind shock model shows wind closer to photosphere than expected.

Chandra HETG
ζ Puppis (O4f)
Kramer, Cohen, & Owocki 2003
Binary Motion in EX Hya with Chandra HETG

EX Hydrae
Magnetic CV
Intermediate Polar
Orbital Period = 98 min
Spin Period = 67 bmin

White Dwarf Velocity Measurements

Chandra 54.5 km/s (Hoogerwerf, Brickhouse, & Mauche 2003, in prep)

Optical  69 ± 9  (Hellier et al. 1987)
UV       59.6 ± 2.6 (Belle et al. 2003)
FUV      85 ± 9   (Mauche 1999)

Illustration by Andy Beardmore
Measuring the Height of the Accretion Column Shock?

Chandra HETG Fe XVII and Fe XXII indicate $10^{14}$ cm$^{-3}$ (Mauche et al. 2002). Light curves from lines are different (Hoogerwerf, Brickhouse & Mauche 2003).

Model from ASCA (Allan, Hellier, & Beardmore 1998)
Fe Kα Emission from a Black Hole

Chandra HETG
Cyg X-1 (HMXB)
Miller et al. 2002

Fe Kα reminiscent of broad iron lines in AGN. Continuum is a multicolor disk plus blackbody.

See also Schulz et al. 2002 for softer spectrum, showing absorption lines and edges.
Accretion Disk Corona in an LMXB

Recombination lines from X-ray illuminated bulge where accretion stream impacts disk. Fluorescent Fe Kα from extended disk corona or accretion stream.

Chandra HETG
4U 1822-37 (LMXB)
Cottam et al. 2001
Absorption by Photoionized Gas in NGC 3783

Model fit with 2 kinematically identical ionization components, outflowing velocities of 750 km/s, turbulent velocities of 300 km/s, suggesting they are in pressure balance.

Chandra HETG        Krongold et al. 2003
Resonant Absorption Toward PKS 2155-304

Chandra LETG
PKS 2155-304 (blazar)
Nicastro et al. 2002

X-ray Forest of O VII, Ne IX, (5 σ) at same redshift as FUSE O VI lines, argues for low density IGM.
Conclusions

- Stellar coronae not just extrapolated Suns
- Hot star wind shock models
- High density accretion shock cooling in magnetic CVs
- Accretion and winds in X-ray binaries
- AGN “warm absorbers”: 2-component outflow in pressure balance
- Detection of the WHIM

8. Challenges:
   - Enough Photons
   - Beyond Point Sources
   - Sophisticated Source/Spectral Models

HETG Spectrum
Flanagan et al. 2003
SNR E0102-72:
An ionizing shock