The Transiting Exocometns
of
HD 172555

C. A. Grady
Eureka Scientific & GSFC
In collaboration with
Alex Brown (Colorado), Inga Kamp and Pablo Riviere-Marichalar (Groningen), Aki Roberge (NASA’s GSFC), Barry Welsh (Eureka Scientific)
Talk Roadmap

• Quick review of β Pic – prototypical transiting exocomet system with disk and planet
• HD 172555 - β Pic’s evil twin and its transiting exocomets
• Implications for planet frequency and searches for additional systems
I. Background - β Pic

• A5V star (T$_{\text{eff}}$ = 8100 ± 200 K)
• Young moving group member (23 ± 3 Myr Mamajek & Bell 2014)
• 2 component disk – outer disk at ~120 AU, viewed edge-on (Dent et al. 2014), inner disk to ~40 AU inclined by 5° with respect to the outer disk (Golimowski et al. 2006)
• Gas: molecular, atomic and a range of ionization stages of abundant elements
The Case of β Pic

- IR excess detected by IRAS
- edge-on debris disk first imaged by Smith & Terrile 1984
- no variability over 15 years Apai + 15
- inner disk inclination with respect to outer disk is 5° (Golimowski et al. 2006)
Edge-on Disk

- Constrain location of planetesimal belt from mm imagery
- Can locate or place upper limits on cold molecular gas
- CO asymmetrically distributed
- Pericenter offset seen with ALMA – indirect signature of planet(s)

Dent+15
What we learn from Line of Sight UV Spectroscopy

• CO absorption at system velocity
  Roberge + 2000

• N(H2) ≤ 1E18 cm⁻²
  Lecavelier des Etangs +01
  CO/H2 > 6E⁻⁴

• low optical depth + radiation field of star – lifetime is <200 years

• gas not primordial, must be sequestered in planetesimals

Roberge + 2000
Atomic and Ionic Gas in the β Pic System

• A-shell star – features superposed on rotationally broadened photospheric spectrum - Slettebak 1975 in Ca II and Na I

• same transitions used to probe ISM, so natural to go to UV where high oscillator-strength transitions of first few ionization stages of cosmically abundant elements are located
High Velocity Gas

- typically redshifted, although blue-shifted events are known - Crawford + 98
- Higher the velocity, the faster the variability
- absorption optically thick, but does not fully cover the stellar disk Lagrange + 1988
- 30 years of data

Vidal-Madjar 1994
Simulations

• assume we are tracking ions in coma of evaporating body – Beust & collaborators (1990, 1995, 1998, 2014)

• periastron varies from event to event
• event duration indicates r<0.5 AU
• longitude of periastron not random
• need high eccentricities
• long duration events => fragmentation
• Same mechanism as for Sun-grazing comets
• Mean Motion Resonances
  – favored mechanism
• implies Jovian mass planet, eccentricity ~0.05 required
Link to $\beta$ Pic b?

- Planet reported from direct imaging (Lagrange + 2010)
- Need refined orbit for the planet to test key prediction, eccentric orbit
- Other A to early F star members of $\beta$Pic Moving Group more distant – require smaller IWA imaging observations for direct planet detection, but 2 known planets in this moving group - $\beta$ Pic and 51 Eri (Macintosh + 2014)
II. HD 172555 – β Pic’s Evil Twin

- A6V, $T_{\text{eff}} = 7800 \pm 200$ K $d = 29.2$ pc (Riviere-Marichalar + 2012), BPMG
- Star is co-moving with CD -64° 1208 (K5Ve, Feigelson +06)
- [O I] (Riviere-Marichalar+12)
- silica and SiO (Lisse et al. 2009, but see Wilson + 2016), suggestive of a hypervelocity impact
- Small disk (Smith +12) to $\sim 24$ au, inferred inclination $i \sim 75°$
HD 172555 - Ca II

• CS absorption well separated from IS feature

• Variable low velocity gas seen in Ca II; no stable gas

• 4 episodes seen in HARPS data (Kiefer +14 ) suggests that FEB presence is at best sporadic

• no Ca II at the epoch of our HST observations
Transiting Exocomets – HST April 2015

C II COS ~6 days separation FEBs in both datasets $-v_{max} = +160 \pm 10$ km s$^{-1}$ Excess signal compared to $\alpha$ Cep

- C II, Si III, and C III 1176 and red wing Ly$\alpha$ – chromospheric emission – star is active – amplitude and velocity <$\beta$ Pic data from 2014
C IV

- C II, C III not the only carbon ions seen.

Comparison with Altair – not perfect but good enough to show excess absorption in C IV
Current Limits to Analysis

- comparison data sparse and essential at $\lambda<1600$ Å
- Large dynamic range of data makes high S/N spectra challenging
- Stellar activity
System Architecture

SED warm belt (280 K) at $r \geq 4$ au, Riviere-Marichalar +12

Smith + 12
III. What Have We Learned?

• Transiting exocomets unexpectedly common in βPMG (at least 40% of A stars), also seen in 49 Cet (Roberge + 2014; Miles + 2016) and potentially other young systems

• Infall features at epoch when Ca II data suggest should not be seen – possibly more than one family of parent bodies?

• Most conspicuous in carbon ions – similar to β Pic and 49 Cet

• Direct imaging limits to planet mass 2-3 M$_{jup}$ at $r>0.5"$ (14.5 AU), 4 M$_{jup}$ at 0.4" (11.68 AU), smaller separations unexplored (Quanz + 2011)

• If have a common origin in high-eccentricity bodies perturbed into star-grazing orbits by Jovian-mass planets, may have a novel technique for finding exoplanets.
Potential Jovian-mass planet frequency in βPMG A stars:

• 2 systems with transiting exocomets known, - data for a third in October...

• Planet frequency for A- early F stars – 25% from direct imaging

• Implication is that Jovian-mass bodies are common, and for the βPMG most probable location(s) are r~8-20 AU – gap in exoplanet searches
C II – optically thick

- adopt $\alpha$ Cep for photospheric spectrum, since Simon, Landsman, & Gilliland 1994 find no net C II emission, and add optically thin CII emission components to make continuum on blue edge of profile flat

- $S/N$ largely dominated by noise in $\alpha$ Cep data ±5% - C II is optically thick and we measure covering factors up to 70%
Follow-on

• Acquisition of additional COS data, suggest single grating setting paralleling obs. of β Pic. – full orbit time-tag observation at or near opposition to minimize geocoronal emission

• Comparison object ι Boo match in Sp.T., color, V magnitude – needed for C IV region; would help with COS region

• Acquisition of comparison object spectra with FEB target observations may open up observations of very late A/early F stars and allow exploration of activity as a function of stellar rotation.