Linking Stellar Coronal Activity and Rotation at 500 Myr: A Deep *Chandra* Observation of M37

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I. Why M37?

- Calibrations of the stellar age-rotation-activity relation (ARAR) rely on observations of the co-eval stars in open clusters.
- The 600 Myr old Hyades is the only anchor for our understanding of coronal emission between 0.6 and 4.5 Gyr.
- The Hyades's proximity is a drawback for X-ray studies; only *ROSAT* observations of its members are available.
- The 500 Myr old M37, a Hyades analog at ~1.5 kpc, has been extensively surveyed in the optical by Messina et al. (2008) and Hartman et al. (2008, 2009), who measured 660 rotation periods (P_{rot}).
- We present a 450-ks Chandra observation of M37; we detected 770 X-ray sources (see Figure 2), 69 of which are M37 members with P_{rot}.
- Our data make M37 a better testbed than the Hyades for examining the evolution of coronal activity.

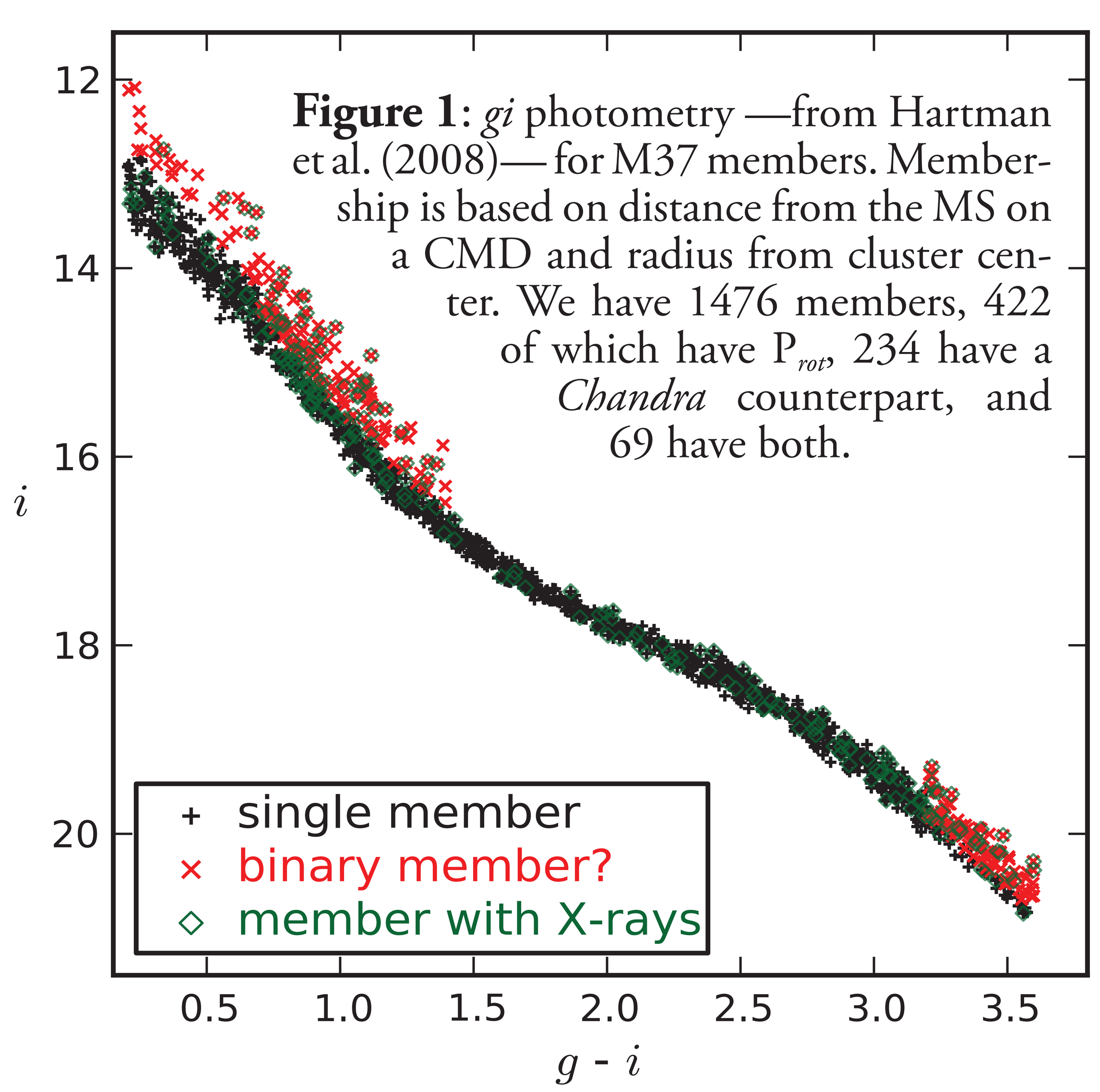

Figure 1: *gi* photometry —from Hartman et al. (2008)— for M37 members. Membership is based on distance from the MS on a CMD and radius from cluster center. We have 1476 members, 422 of which have P_{rot}, 234 have a *Chandra* counterpart, and 69 have both.

II. The X-ray data

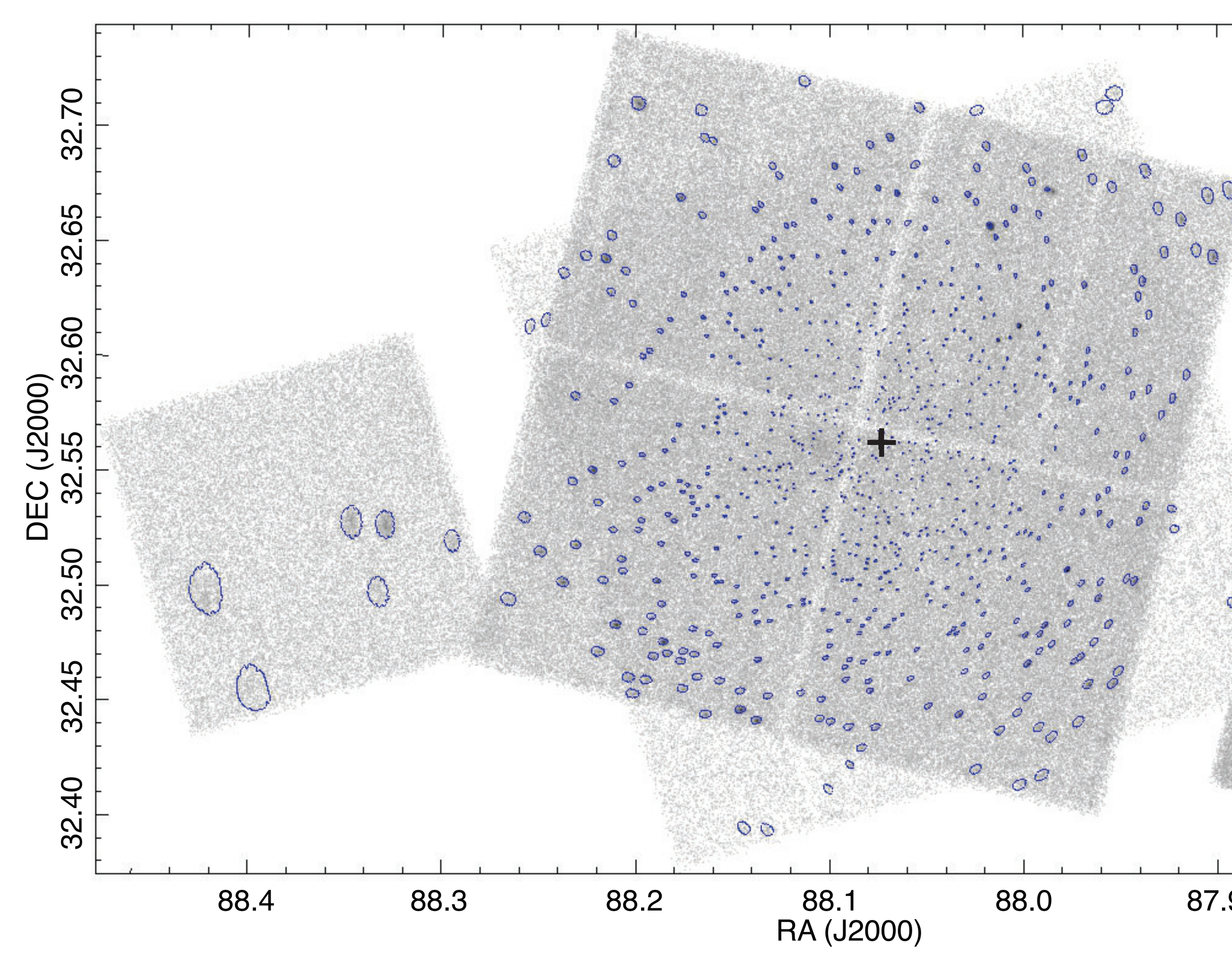

Figure 2: Source regions (blue ellipses) found with CIAO's *wavdetect* and refined with *ACIS Extract* on the combined Chandra image. The plus symbol is the average aimpoint.

- Our 450-ks observation was broken into five visits, ranging from 51 to 165 ks; one had a different roll angle relative to the others.
- We reduced ACIS-I and ACIS-S3 data with CIAO tools, obtained a tentative source regions list with *wavdetect*, and pruned our list and extracted X-ray fluxes using *ACIS Extract* (see Figures 3 and 4).
- Our *Chandra* catalog contains 770 point sources.

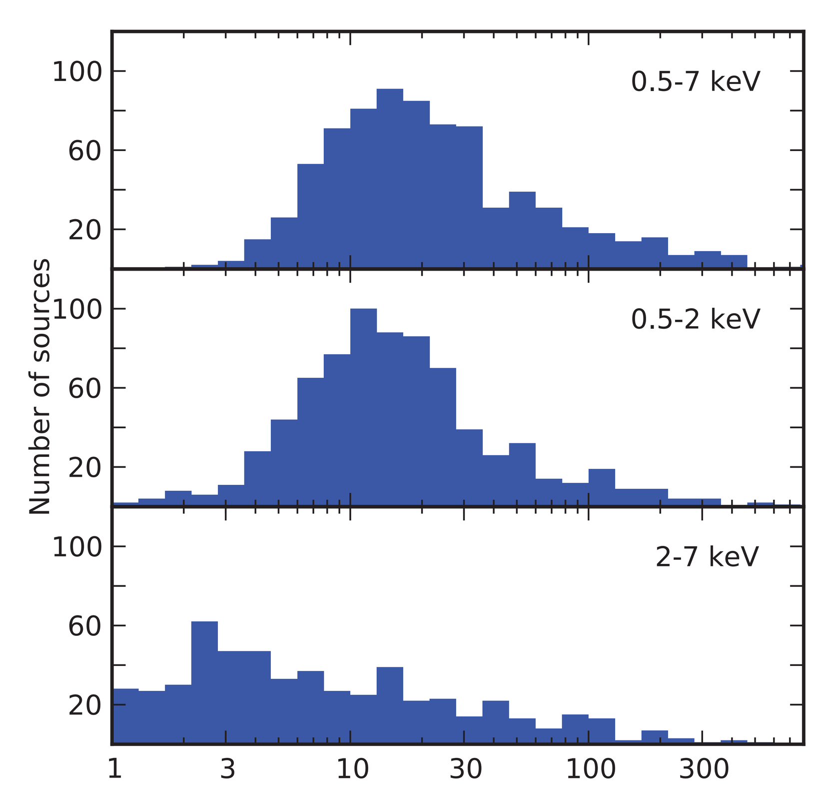

Figure 3: Detected net counts for sources in our *Chandra* catalog in the full (top), soft (middle), and hard (bottom) bands. Significantly fewer sources are detected in the hard band, suggesting that most sources are likely to be stellar in nature.

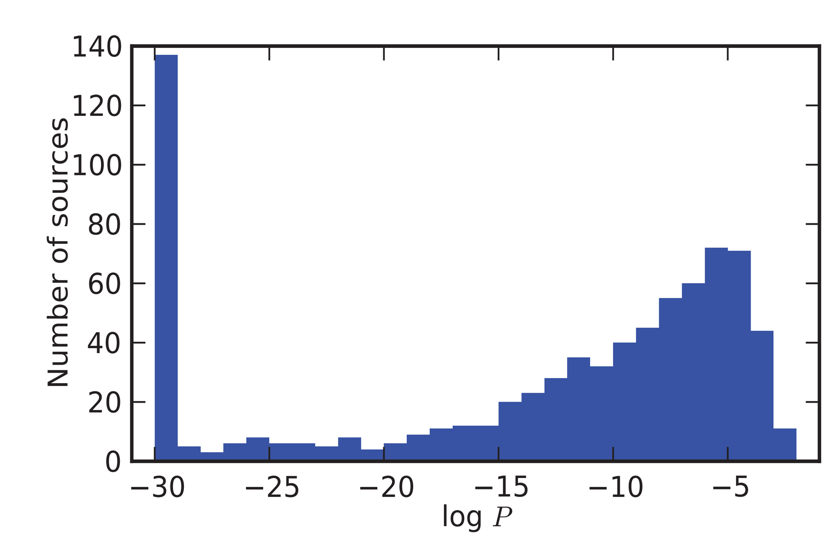

Figure 4: *ACIS Extract*'s binomial no-source probability *P* for sources in our *Chandra* catalog, which excludes sources with log *P* > -2.

III. L_X/L_{bol} v. Rossby # at 500 Myr

- We derived L_X from the soft-band energy fluxes and L_{bol} from *r* photometry.
- We derived convective turnover times τ from *r* and then calculated Rossby numbers $R_o = P_{rot}/\tau$.
- We parametrized the L_X/L_{bol} -R_o relation using a flat region connected to a power-law of the form $L_X/L_{bol} \propto R_o^{\beta}$.
- Using an MCMC algorithm we get β=-2.1, breakpoint $R_{o,sat}$=0.1, and saturation level $\log(L_X/L_{bol})_{sat}$=3.19 (see Figure 6).

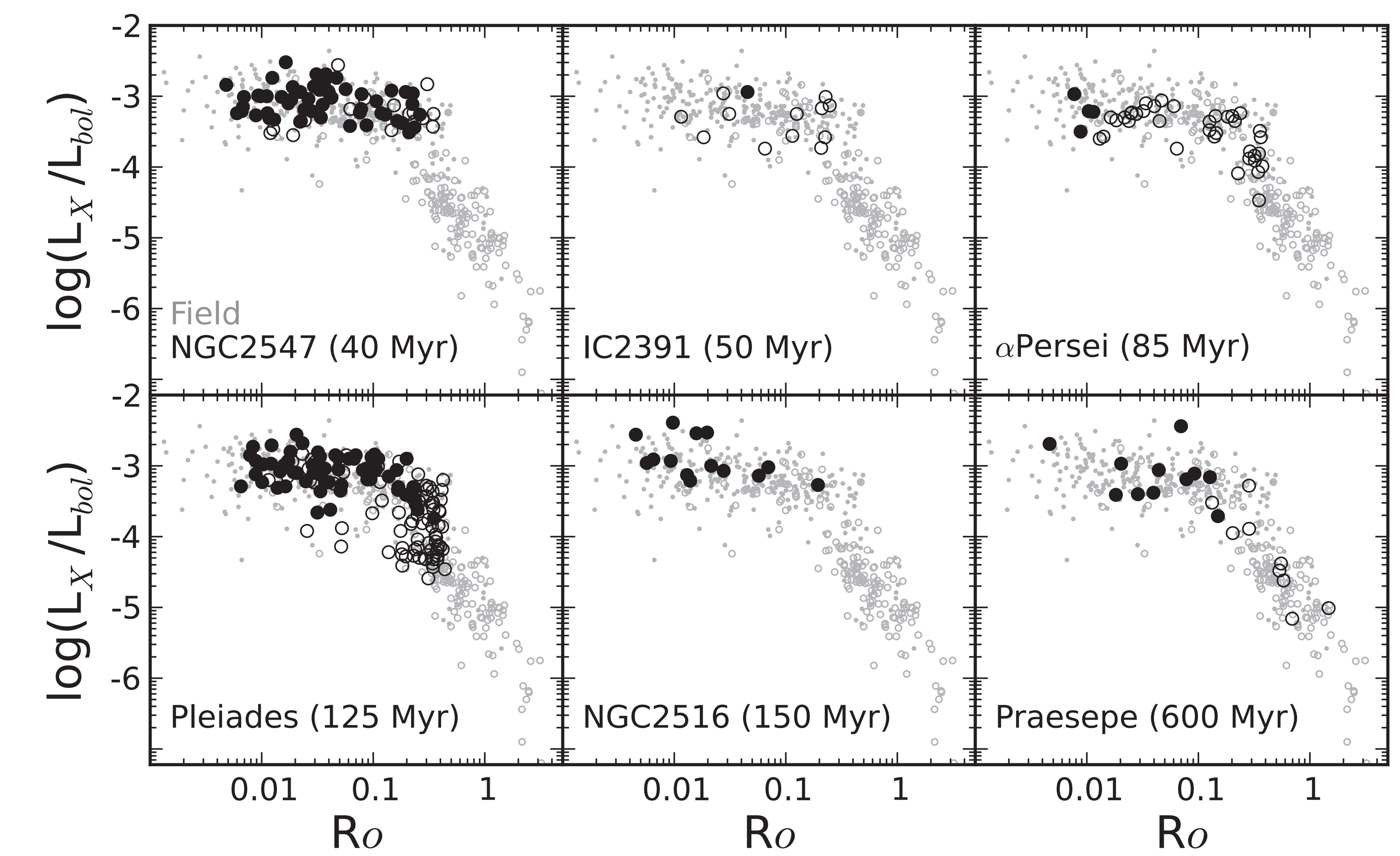

Figure 5: L_X/L_{bol} v. R_o for field (gray) and cluster (black) stars from Wright et al. (2011). No cluster has has enough measurements for the type of analysis of the L_X/L_{bol} -R_o relation at a single age done in this work.

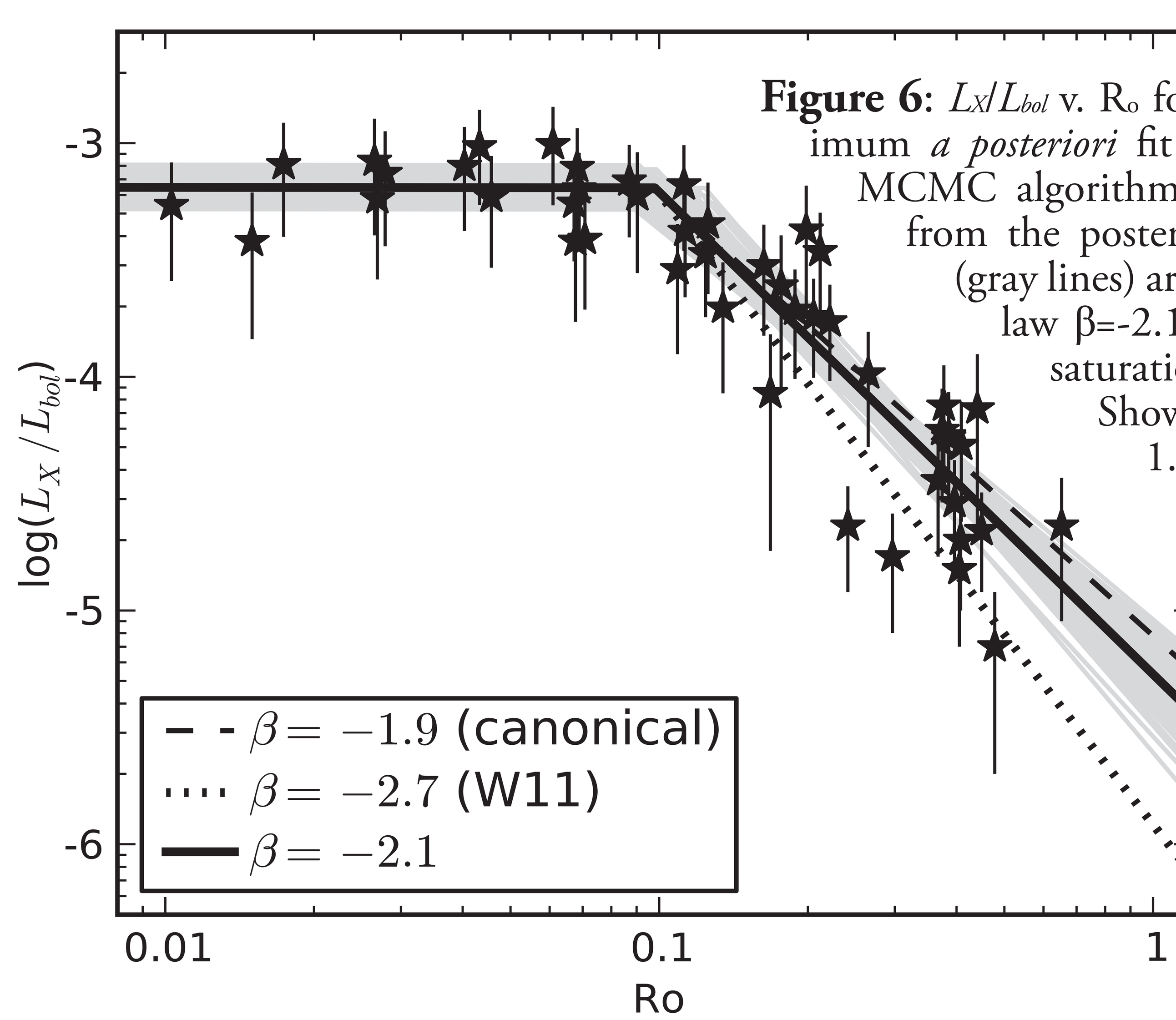

Figure 6: L_X/L_{bol} v. R_o for M37 members. The maximum *a posteriori* fit (black solid line) from an MCMC algorithm and 200 random samples from the posterior probability distribution (gray lines) are shown. We derive a power-law β=-2.1, breakpoint $R_{o,sat}$=0.1, and saturation level $\log(L_X/L_{bol})_{sat}$=-3.19. Shown for comparison are β=-1.9 (Pallavicini et al. (1981)) and β=-2.7 (Wright et al. (2011)).

IV. Next steps

- Examine spectra and light curves for sources with > 200 counts.
- Publish results.

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References

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