# A Study of Stellar Gyrochronology by Using the PTF, LAMOST & K2 Data

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## Abstract

Chang H.Y. et al. (ApJ, 2016) showed that flare activities of the M dwarfs correlate with their corresponding chromospheric Hα emission by analyzing the LAMOST and Kepler K1 data. Stars with rotation periods shorter than 20 hours usually exhibit enhanced Hα emission and frequent occurrence of large flare events. This is consistent with the gyrochronological relation describing the age effect of stellar magnetic activity. To further the flare phenomenon of the M dwarfs might be important to the development of biospheres of Earth-like exoplanets in the habitable zones, we have initiated a project to estimate the Hα emission strength of M dwarfs using the Palomar Transient Factory (PTF) data archive and cross-correlating with LAMOST spectra. We have found a considerable amount of M dwarfs which are all included in the PTF Hα data archive and K2 catalog in just one Campaign of K2. We examine that if the PTF Hα photometric measurements can yield similar results as obtained in medium resolution spectral observations. In the future, we plan to apply this method to M dwarfs in open clusters from which age dependence of the gyrochronological relation can be better understood.

## Introduction

In principle, flares of M-dwarfs are much more violent than other of heavier type stars due to their large area convection which leads to the magnetic activities (Bopp & Moffett 1973; Gershberg & Shakhovskaia 1983). Chang H.Y. et al. 2016 found there is a positive correlation exists between the flares level and Hα emission of M-dwarfs by analyzing only 6 data of targets which had been observed by Kepler Mission K1 and LAMOST (Large Sky Area Multi-Object Fiber Spectroscopic Telescope). In order to investigate in more detail, Kepler K2 mission and PTF Hα data archive are joined this time.

## Kepler K2 Mission

Kepler spacecraft with 0.95-m aperture Schmidt telescope was launched by NASA in March 2009. It has provided an excellent photometric precision (0.1 mag for a star of 12mag) in visible light, near infrared region from 423 to 897 nm (Koch et al. 2010). Its major science goal were to discover the Earth size to super-Earth size exoplanets in or near habitable zones of their host stars. K2 mission started in November 2013, it's searching the larger area in Earth-trailing heliocentric orbit and changed the Campaign (field of view) every three month. So far, K2 has collected 17 Campaigns (Fig. 1.a) data. In this time, we searched the M-dwarfs on the field of Campaign 4 (C4, Fig. 1.b) with the $T_{eff}$ range of M type stars (2500 K ≤ $T_{eff}$ ≤ 3800 K) from the Mikulski Archive at the Space Telescope Science Institute (MAST), and we found 2783 targets on the K2-C4 field (Fig. 1.b). There are two time resolution of the kepler archive data, long cadence (LC) in 29.4 minutes and short cadence (SC) in 58.9 seconds (Gilliland et al. 2010). We used the PDCSAP LC light curve data.

## PTF

On 13 December 2008, a wide-field sky survey, Palomar Transient Factory (PTF), started its mission with a 12Kx8K, 7.8 square degree CCD array camera on Samuel Oschin Telescope at Palomar Observatory. PTF observes the targets with R, G, Hα filters, their data are available on The Water Research Institute (IRSA) data archive. To estimate the Hα emission, we needed to find the targets which have both Hα 656, Hα 663 data and counterparts in the K2-C4 2783 targets, and we found 2718 of them (Fig. 1.c).

## LAMOST spectra

In the forth LAMOST data release (DR4, 2011.10~2016.6), the spectra of 3700Å~9100Å. The Hα emission line is placed at 6564.66Å. 433247 M dwarfs are listed. In DR4, we found 399 M dwarfs have been observed by LAMOST in Kepler K2 C4 field.

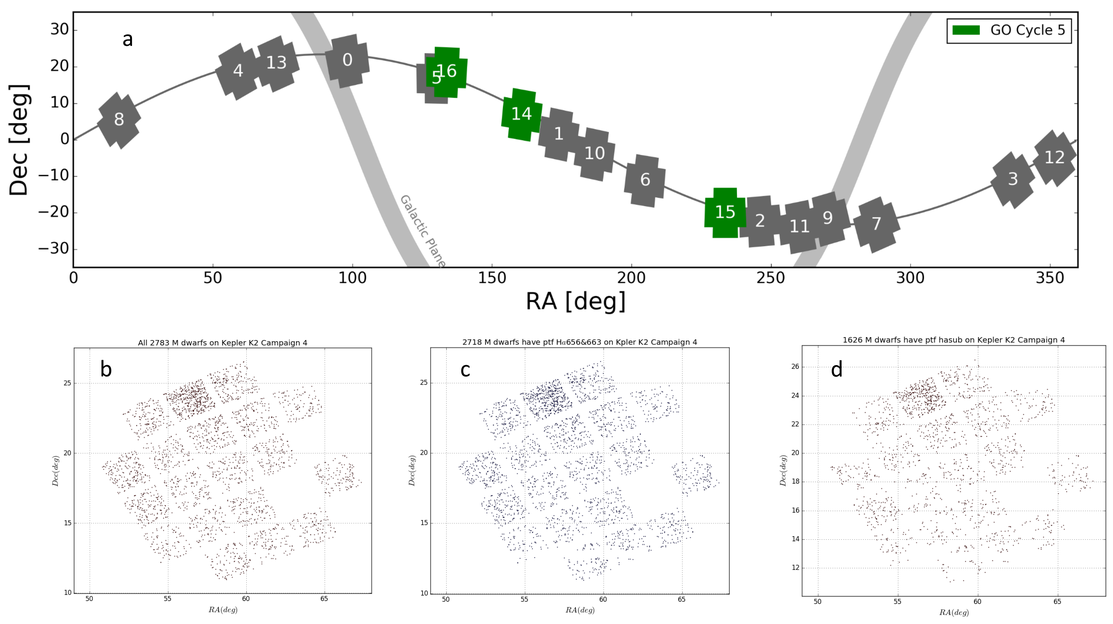
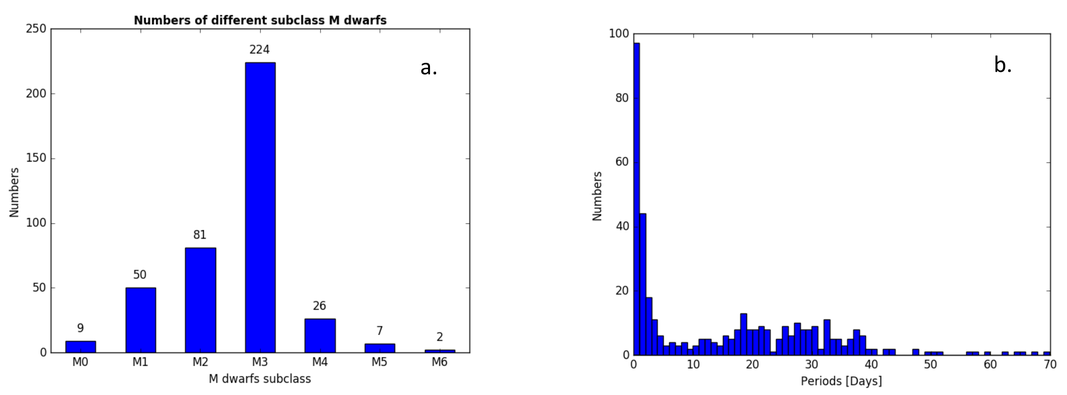



Fig.1. Fig.1.a[a] shows that Kepler K2 mission is searching the larger area in Earth-trailing heliocentric orbit (gray curve) and it's 17 Campaign. Fig.1.b [a] is the field of K2-C4, you can see Kepler's CCD array form and all 2783 M dwarfs we found on the field. Fig.1.c shows the distribution of 2718 of 2783 targets which have the PTF Hα 656 and Hα 663 data on K2 C4 field. Fig.1.d shows the distribution of all 1626 M dwarfs have Hα subtraction value.

[a] from https://keplerscience.arc.nasa.gov/k2-fields.html

## Data Analysis and Results

To understand more detail about the relation between rotation period and Ha emission of M-dwarfs is our whole plan. We estimated the Hα equivalent width using the LAMOST spectrum data. We analyzed the K2 LLC (Long cadence) PDCSAP light curve and estimated the rotation period of each M dwarfs using Lomb Scargle periodogram. For PTF, we used the method called Hα subtraction. We subtracted Hα 663 from Hα 656 PTF catalog of two PTF FITS images to obtain the Hα excess of each M dwarfs.



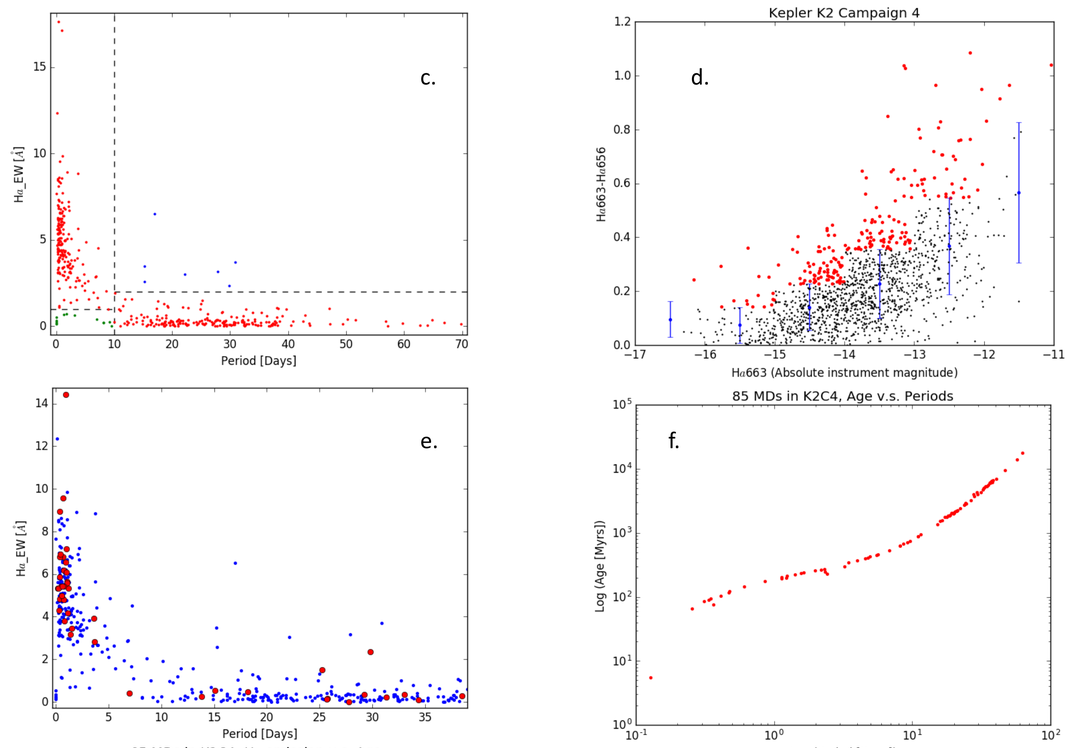




Fig.2.a shows that the subclass of all 399 M dwarfs (from LAMOST DR4), and the most of M dwarfs are M3 star. The latest subclass of M type of sampled M dwarfs is M6. Fig2.b shows the rotation periods of all 399 M dwarfs, and the most of their rotation periods are shorter than 10 days. Fig.2.c, the Hα equivalent width v.s. rotation periods. Fig.2.d, the Hα663- Hα656 v.s. Hα663, to find the M dwarfs with obvious Hα excess. Fig.2.e is same as the Fig.2.c, the red dots are the M dwarfs selected by Fig.2.d. Fig.2.f shows that the M dwarf's period is longer, its age is older. The ages of MDs were estimated by using the age equation as function of period (**Barnes et al. 2010**). Fig.2.g shows the age-period relationship of M dwarfs

## Future

K2 mission also observed the clusters. We want to know that are any our sampled M dwarfs the members of any clusters? If so, we'll be able to know the age of those M dwarfs. We had already known their periods, so we'll compare the obervational result of M dwarfs' age-period relationship with the theoretical one (by Barnes' equation we mentioned above).

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