CHAPTER 3

OBSERVATION AND DATA REDUCTION

3.1 Photometric observation

The photometric observation of exoplanet GJ3470b were obtained though R filter with Apogee Altra U9000 3056 x 3056 pixels CCD camera attached to the 0.5 meter Schmidt-Cassegrain Telescope located at Thai National Observatory (TNO) and PROMPT 8, 0.6 meter robotic telescope at Cerro Tololo Inter-American observatory (CTIO), Chile, with 2k x 2k CCD camera (Table 3.1). Observations were made on four nights between 2013-2015.

Table 3.1: Observing log of GJ3470b observation.

Observation date	Telescope	Exp time (s)
17 December 2013	TNO 50 cm	20,15[1]
06 January 2014	TNO 50 cm	15
10 January 2014	PROMPT-8 60 cm	10
22 January 2015	PROMPT-8 60 cm	10

3.2 Image reduction for photometry

The original images from photometric observation were reduced with the standard procedure, including dark-image subtraction and flat image correction by using MaxIm DL3 program.

Dark image

The Dark imaging is used to measure the noise caused by a flow of electrons from the temperature of the CCD camera. Imaging of dark image is important for improving

[1] For 17 Dec 2013 observation, exposure time was set to be 20 seconds during first half of observation (296 images) and 15 seconds during second half of observation (288 images).

observed images. Dark image was taken by turning off the camera. At the time of taking Dark image, it CCD must has the same temperature when image of object was taken and with the same exposure time. Sequence of Dark image were combined into a master dark, which is used to subtract from the image of the object.

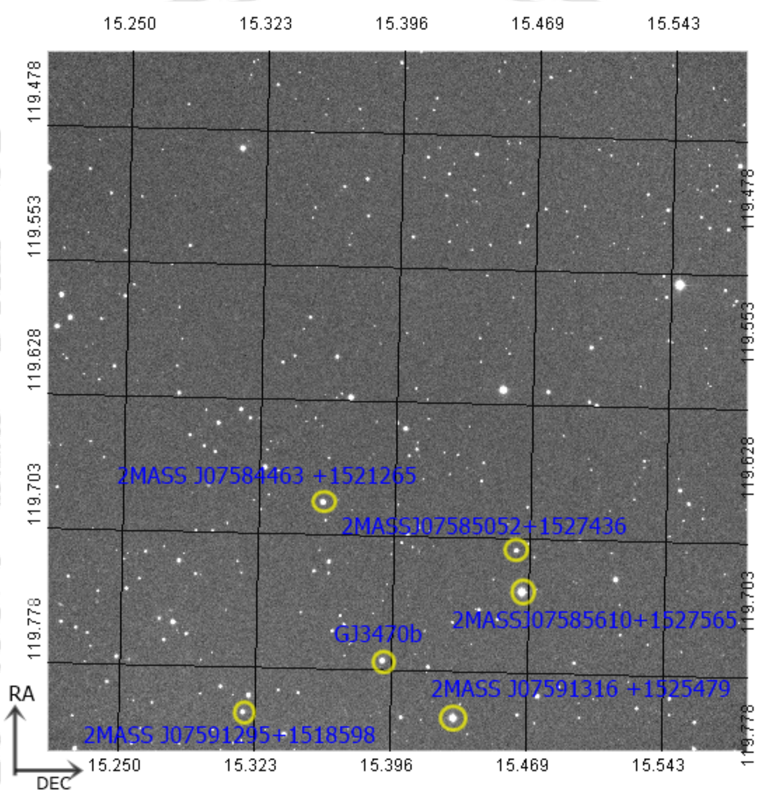

Figure 3.1: The GJ3470b, comparison and check stars.

Table 3.2: The photometric properties of the GJ3470b, comparison and check star.

	Name	RA (J2000)	DEC (J2000)	*R*
Target	GJ3470b	07h 59m 05.87s	+15° 23′ 29.5″	11.2
Reference star	2MASSJ07585052+1527436[1]	07h 58m 50.52s	+15° 27′ 43.6″	12.8
	2MASSJ07585610+1527565[2]	07h 58m 56.1s	+15° 27′ 56.5″	9.8
Check star	2MASS J07584463 +1521265	07h 58m 44.64s	+15° 21′ 26.7″	12.1
	2MASS J07591316 +1525479	07h 59m 13.16s	+15° 25′ 47.8″	-
	2MASS J07591295+1518598	07h 59m 12.95s	+15° 18′ 59.8″	-

[1] Reference star for 17 Dec 2013 and 06 Jan 2014 Observation.
[2] Reference star for 10 Jan 2014 and 22 Jan 2015 Observation.

Flat image

Flat image is obtained from the imaging of intensity distribution of incident light on the CCD camera. The efficiency of the CCD camera is also not necessarily the same for all pixels. From the uniform source of of light, the CCD's readout light intensity is not uniform due to the difference of the sensitivity of each pixel in the CCD camera, which is caused by dust on optical filter, mirror lens, surface of the CCD camera etc. All these effects are corrected by division of a flat on object's image. This can be obtained by using a flat box, sky flat or twilight flat.

Aperture photometry

The photometric analysis is the measurement surface brightness of stars which is the magnitude of the star. This magnitude is instrumental magnitude. Each instrument obtain a different instrumental magnitude which is necessary calibrated to find the real magnitude of star. There are several techniques to find the real magnitude. In this research, the differential photometry technique was used;

$$m_1 - m_2 = -2.5\log\frac{I_1}{I_2} \ , \tag{3.1}$$

where m_1 is the magnitude of the comparison star, m_2 is the magnitude of the object, and I_1, I_2 are the intensity of the comparison star and the object, respectively.

Aperture photometry is performed by using differential photometry routine in MaxIm DL3 program. The list of the target, comparison, and check star is shown in Table 3.2 as well as their image in Figure3.1.

3.3 Light curve analysis

The transit light curves of GJ 3470b were analyzed by using Transit Analysis Package (TAP), an IDL program (Gazak et al., 2012). TAP uses Markov Chain Monte Carlo (MCMC) techniques to perform the fitting light curves by utilizing the analytical model

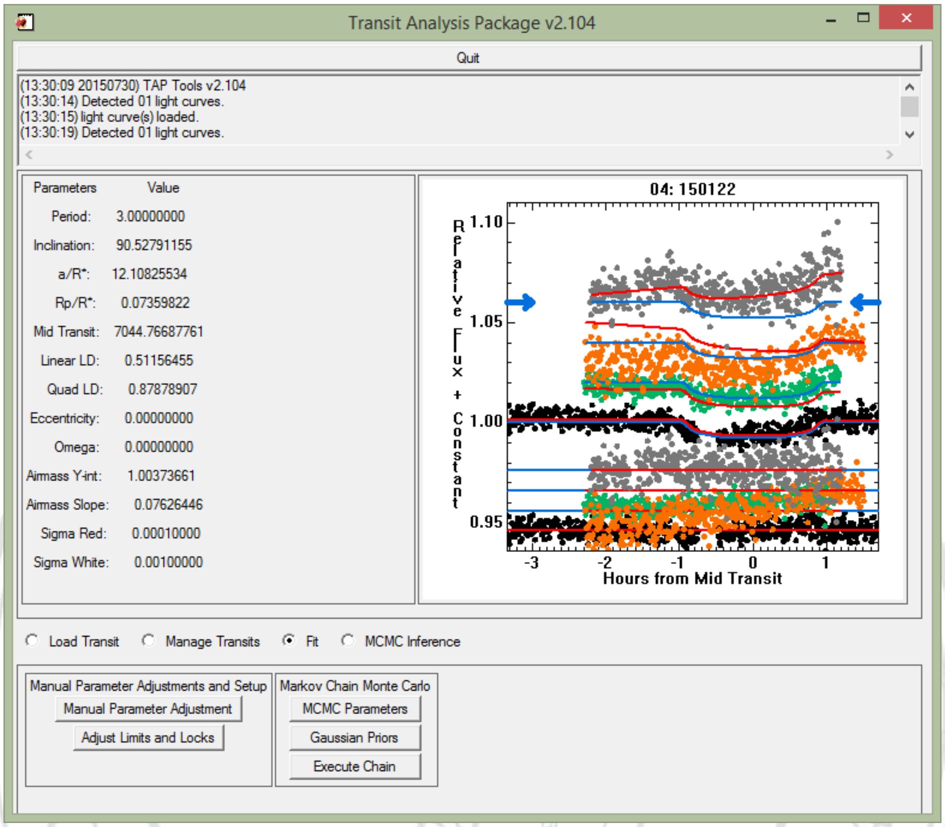

Figure 3.2: The Transit Analysis Package (TAP) Graphical User Interface while executing a Markov Chain Monte Carlo analysis on four light curves of GJ3470b.

of Mandel and Agol (2002). For the analysis, we ran 1,000,000 MCMC steps. TAP assesses the uncertainties using the wavelet based likelihood function developed by Winn et al. (2009).

For the analysis process, we adjusted the value of the period (P), inclination (i), scaled semi-major axis (a/R_*) and planet-star radius ratio (R_p/R_*), except mid transit time (T_0) and noise level, are assumed to be the same, due to the same filter of observation. From the previous studies, the eccentricity of the system is less than 0.051 (Bonfils et al., 2012). Then, in this work, the circular orbit is assumed. The light curves with the best fit from TAP are showed in Figure 3.4. The inclinations of light curves are mainly caused by long period, 23 days, stellar variation of GJ3470 (Fukui et al., 2013). These inclinations are corrected by airmass fitting of TAP program. The light curves with 15-minutes bin are shown in Figure 3.3. The binning light curve are calculated from the average flux in 15 minutes interval. The errorbars show the standard deviation of mean flux.

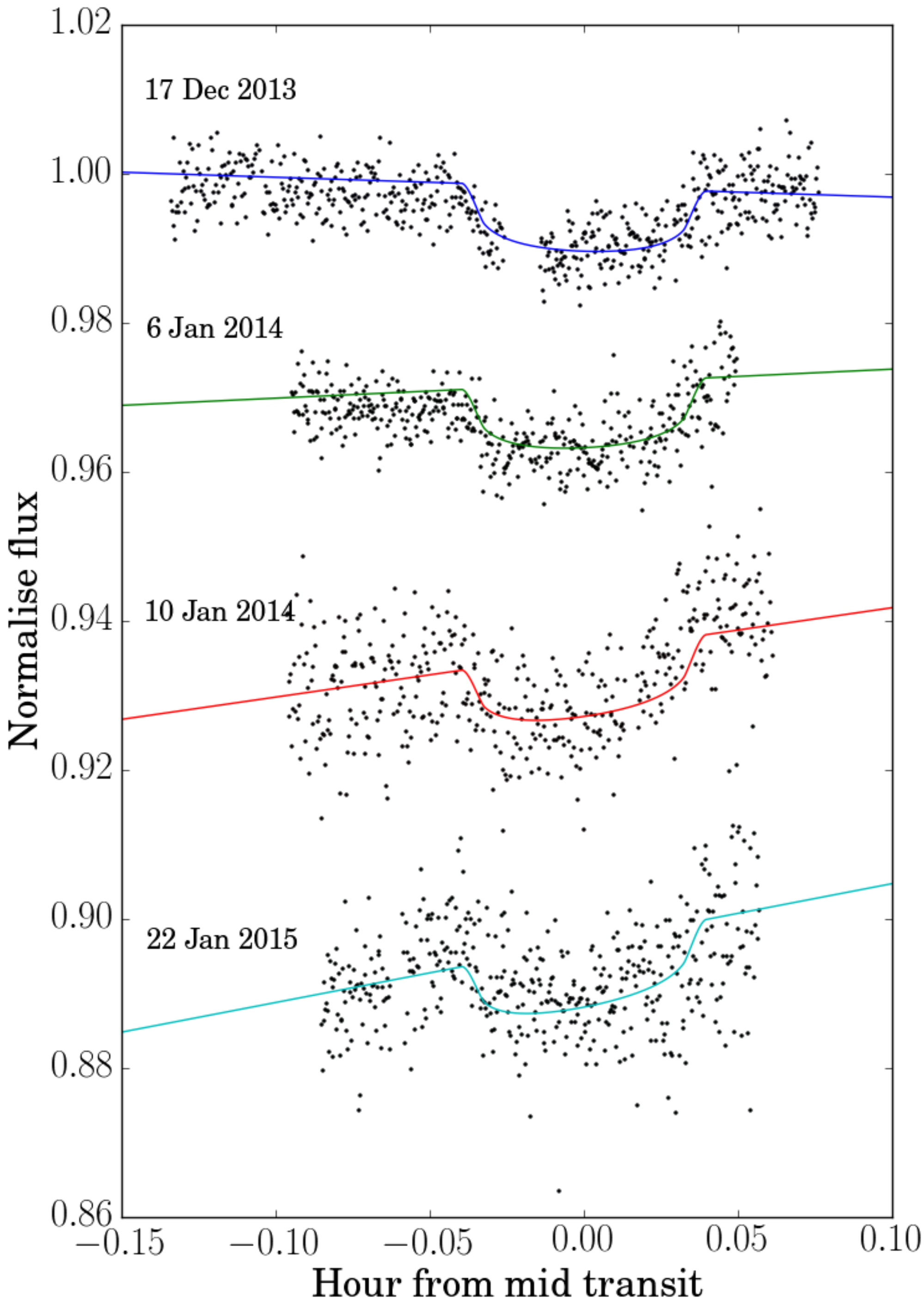

Figure 3.3: Light curves of GJ3470b. Arbitrary off-set (-0.03, -0.06 and -0.09) are added for clarity. Thick lines represent the best fit model from TAP.

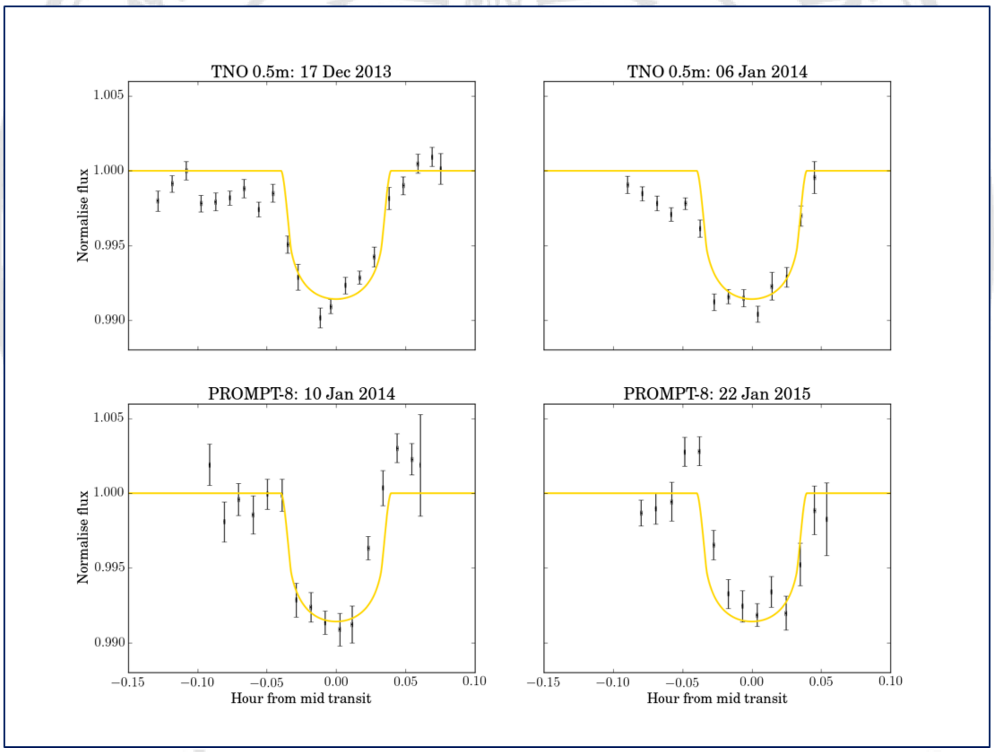

Figure 3.4: 15 minutes binned light curves with best fit model from TAP analysis.