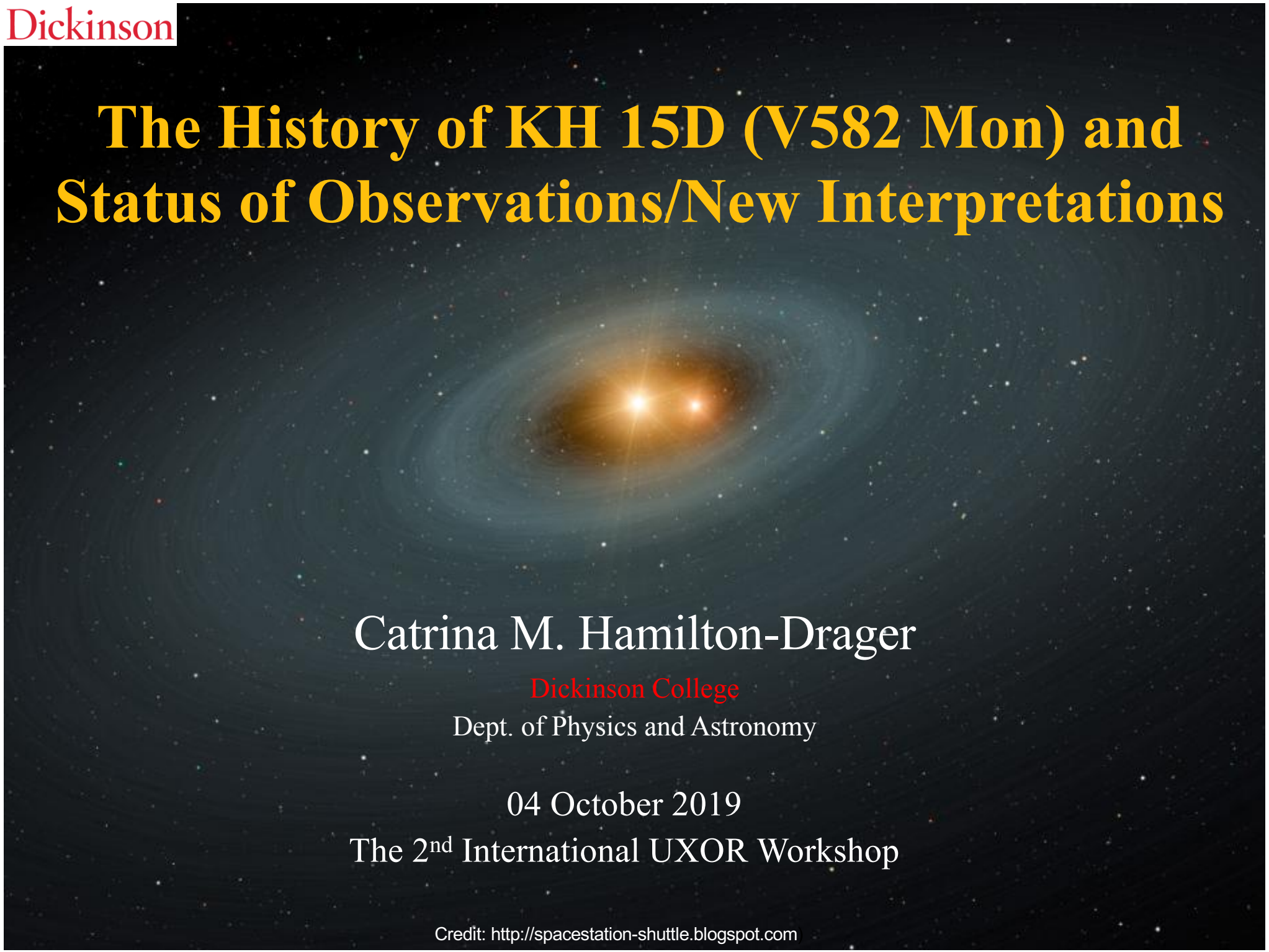
Dickinson

The History of KH 15D (V582 Mon) and Status of Observations/New Interpretations



Catrina M. Hamilton-Drager

Dickinson College

Dept. of Physics and Astronomy

04 October 2019

The 2nd International UXOR Workshop

Credit: http://spacestation-shuttle.blogspot.com

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The Main Take Aways:

1) KH 15D is an **ordinary binary system** that just happens to be **oriented in a unique way**, which we have been utilizing for the past 20 years.

2) As we have seen at this conference, precessing, non-aligned circumbinary/circumstellar rings are everywhere. KH 15D provides us with the **ability to map the inner disk structure/composition** – but not for much longer! We need to exploit the system while we have time!

3) There is still much more to learn!

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A Project to Monitor Variable Stars Begins…

- Photometric monitoring program initiated at Wesleyan University in 1990

  ⇒Goal: Determine rotation periods in the Orion Nebula Cluster (*t*~1 Myr)

- 1995/1996 Monitoring of 4 fields in the young cluster NGC 2264 (*t*~3 Myr) began

  ⇒Goal: Search for evidence of angular momentum evolution

- From these observations, **K**earns & **H**erbst (1998) "discover" a unique and important object: **15D**

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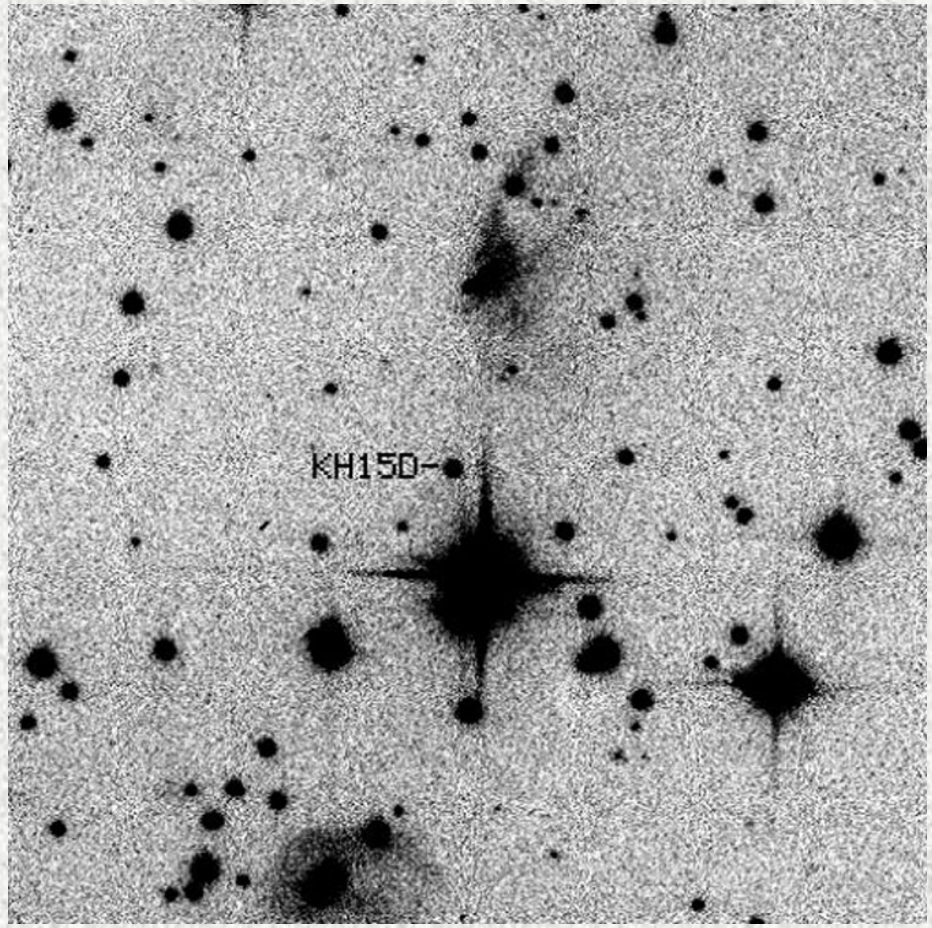
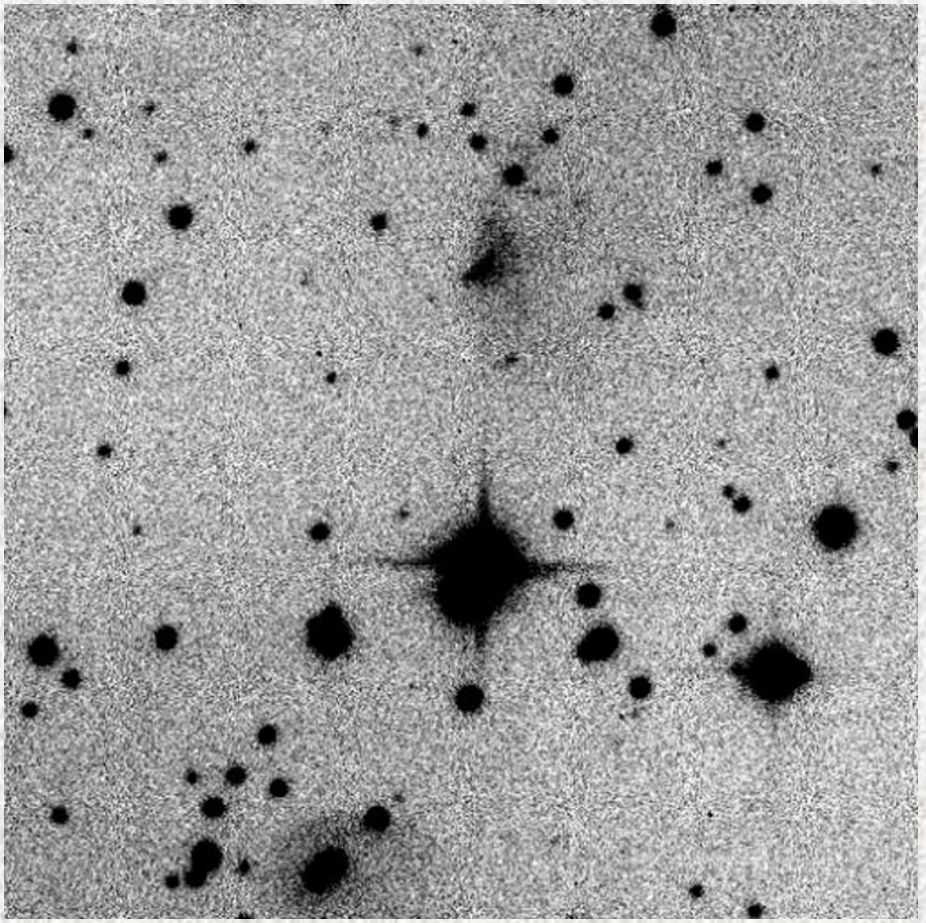
The Eclipsing System KH 15D





- Light diminished by 96%
- Period of ~ 48 days

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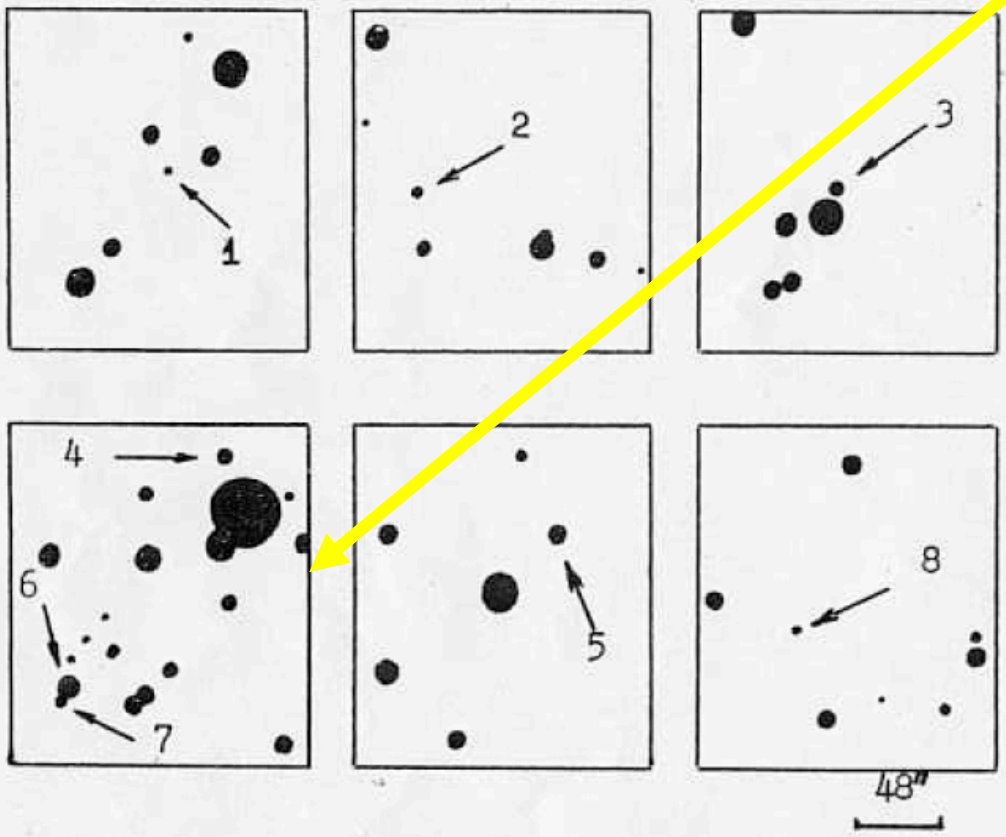
Новые переменные в NGC 2264
New Variable Stars in NGC 2264

Из полученного *Г. С. Бадаляном* нового наблюдательного материала [1] на метровом телескопе системы Шмидта Бюраканской обсерватории, мы выбрали наилучшие по качеству пластинки, из которых были образованы 3 независимые пары. Предельная величина пластинок $m_{pg} = 18.7$. Путем блинкования и последующего просмотра нам удалось найти 8 новых переменных, карты окрестностей которых приведены на рисунке.



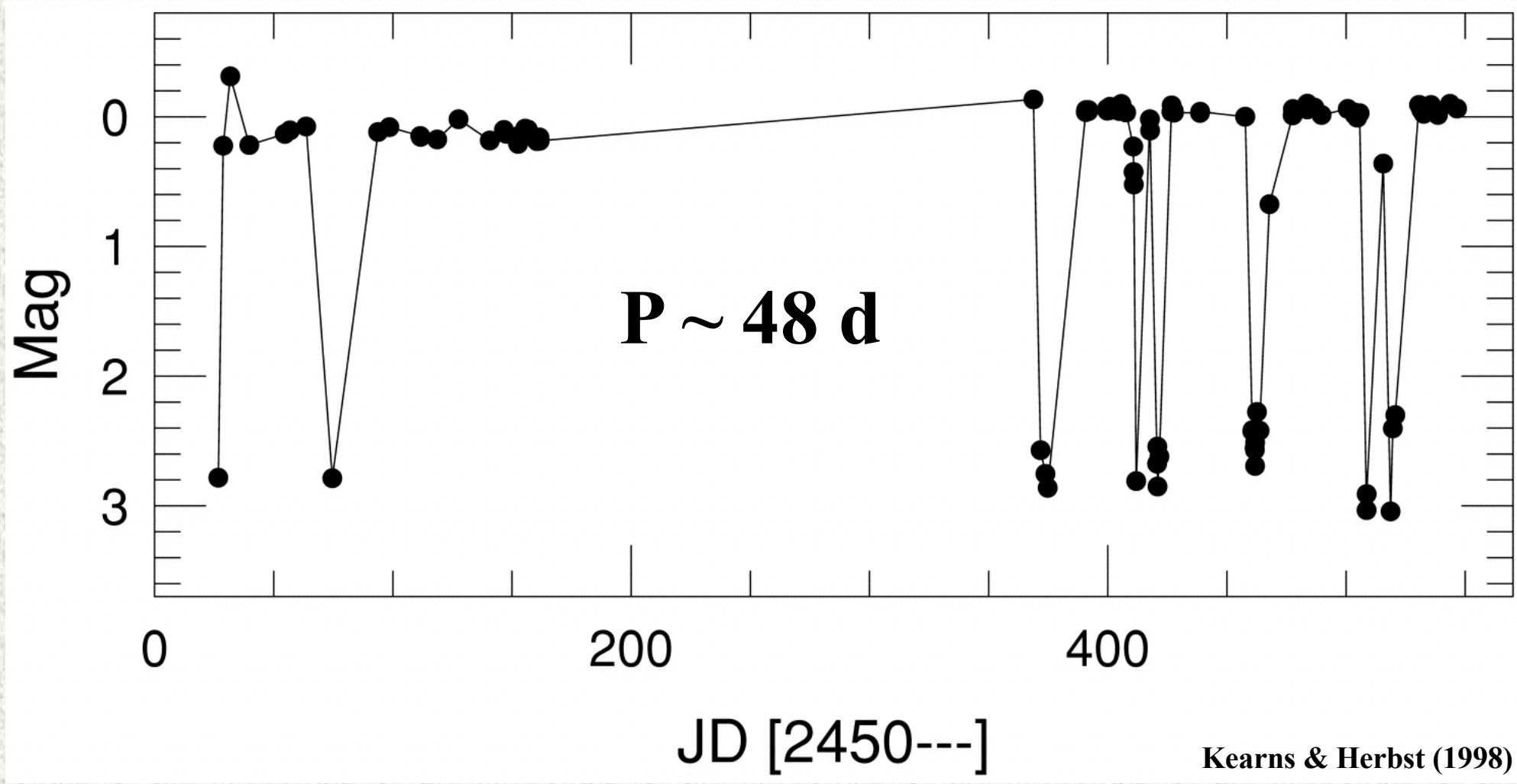
Для наиболее слабых переменных были определены их звездные величины по синей карте Паломарского атласа сравнением со звездными величинами звезд шарового скопления M3 [2]. В пятом столбце таблицы приводятся эти данные.

Таблица

№	СПЗ	$\alpha_{1900.0}$	$\delta_{1900.0}$	m_{pg}	m_{pg}	Наличие Hα
1	1720	$06^h35^m10^s$	09°40′.3	$16^m.97 - 18^m.64$	$19^m.9$	
2	1721	06 35 22	09 34.7	17. 86–(18. 7	21	
3	1722	06 35 35	09 42.3	17. 64–(18. 7	18. 7	
4	1723	06 35 41	09 34.3	16. 20– 17. 34		
5	1724	06 35 44	09 37.5	16. 18– 18. 7	18. 7	
6	1725	06 35 45	09 31.8	14. 52– 15. 79		
7	1726	06 35 45	09 31.7	16. 21– 17. 86		
8	1727	06 36 28	09 48.9	17. 49–(18. 7	18. 2	Apo 73

Badalian & Erastova 1970

Initial Eclipses



Kearns & Herbst (1998)

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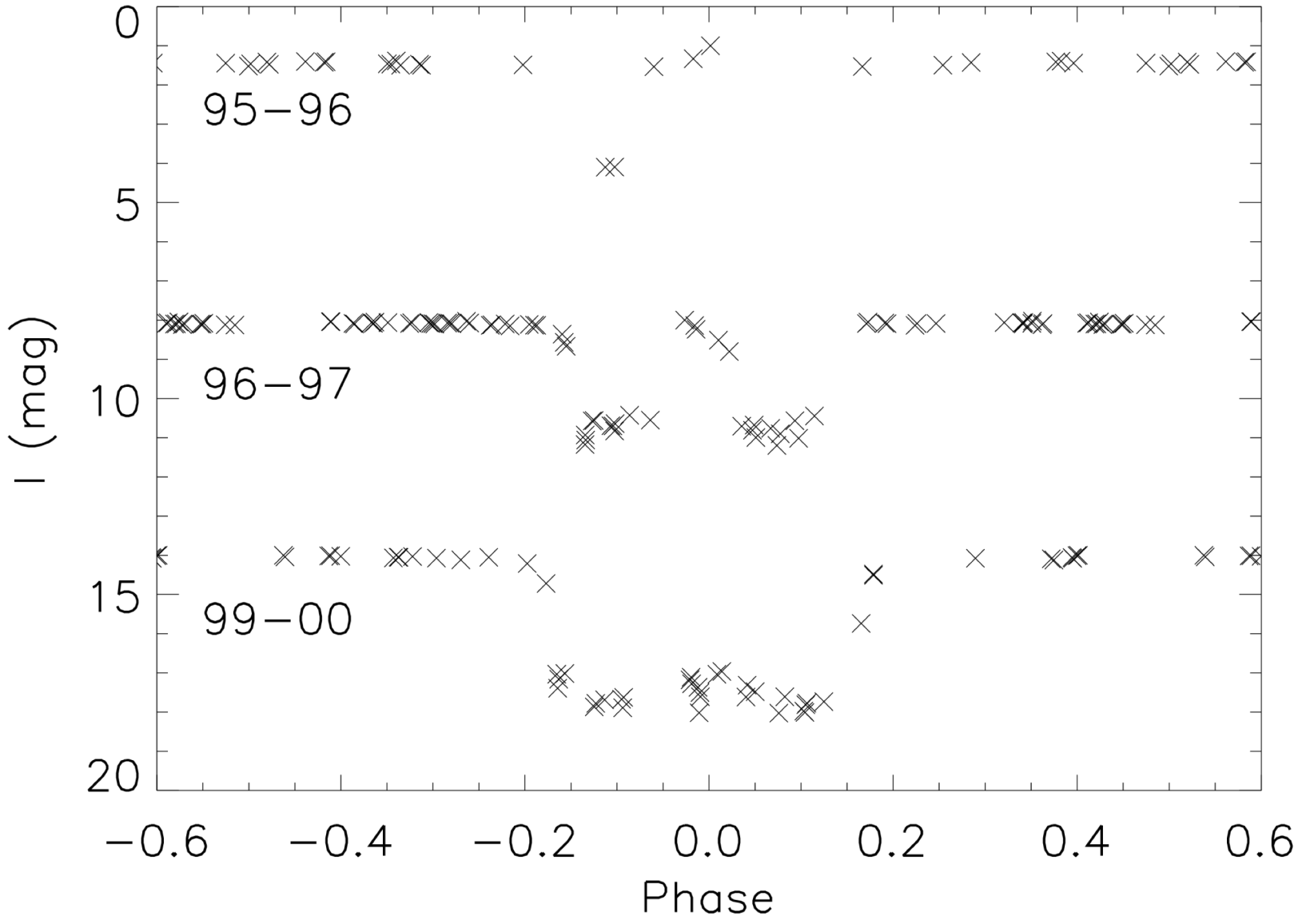
Initial Eclipses Phased



Hamilton et al. (2001)

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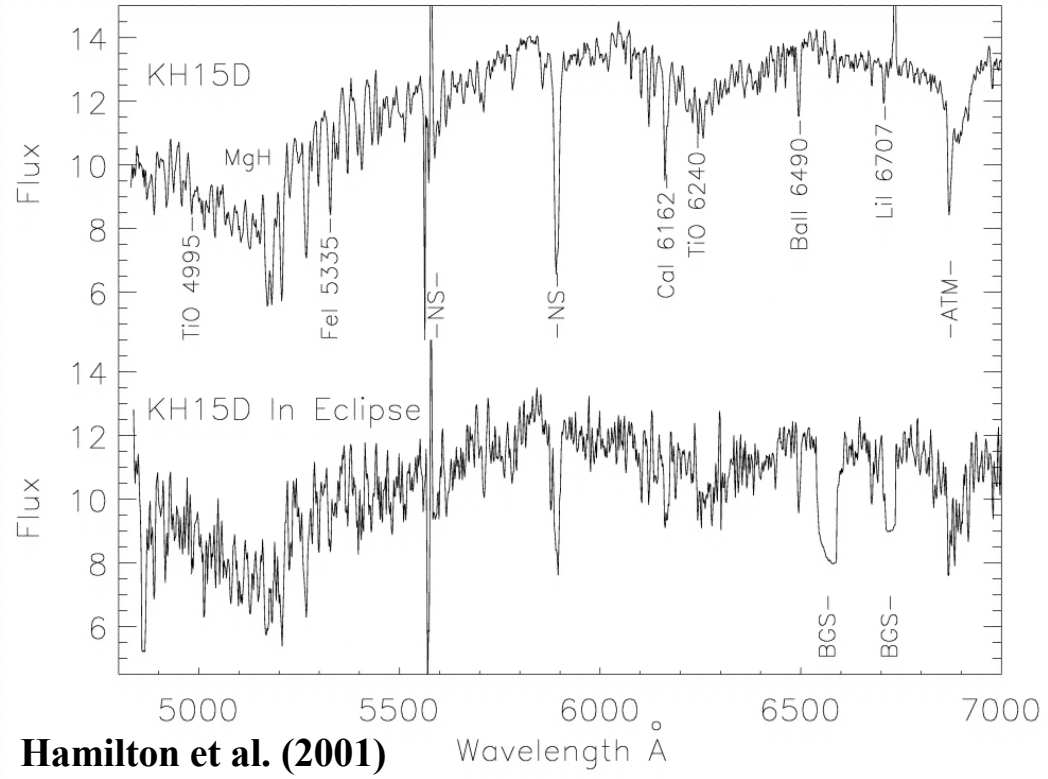
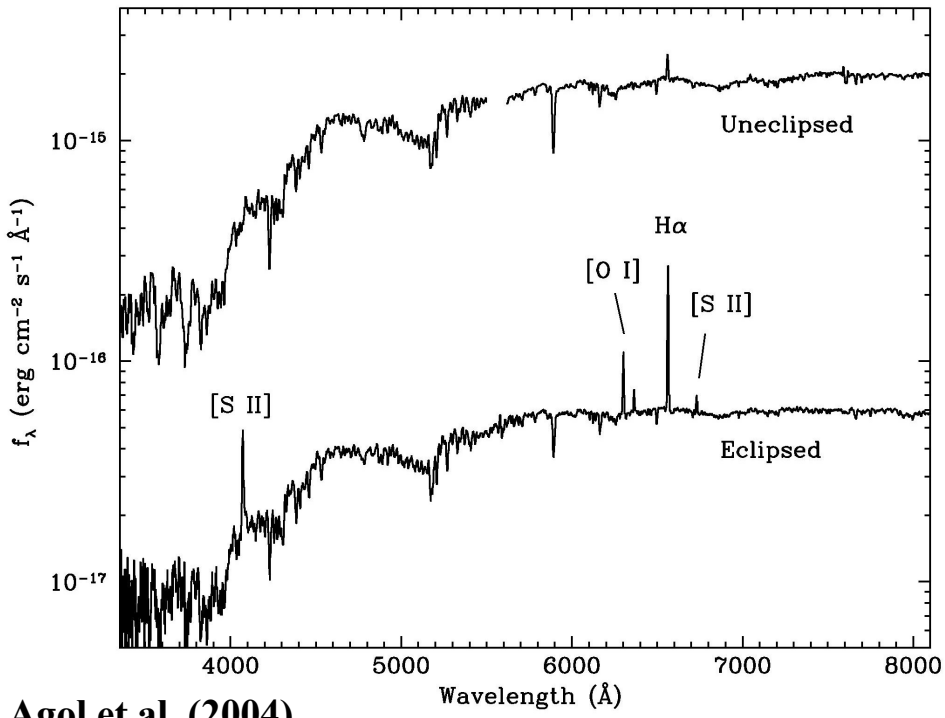
Low Resolution Spectra



Hamilton et al. (2001)



Agol et al. (2004)

- Little or no change is seen in the absorption spectrum
- Suggests that obscuring grains are large, or that the star is occulted by an optically thick disk (**or both**)

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Historical Studies Found…

- No eclipses between 1913 and 1955 (Winn et al. 2003)
- Noted as an irregular variable between 1963 and 1968 (Badalian & Erastova 1970)
- Between 1967 and 1982, the system alternated from bright to faint with the same period as observed today, but 180° out of phase with today's eclipses (Johnson & Winn 2004)

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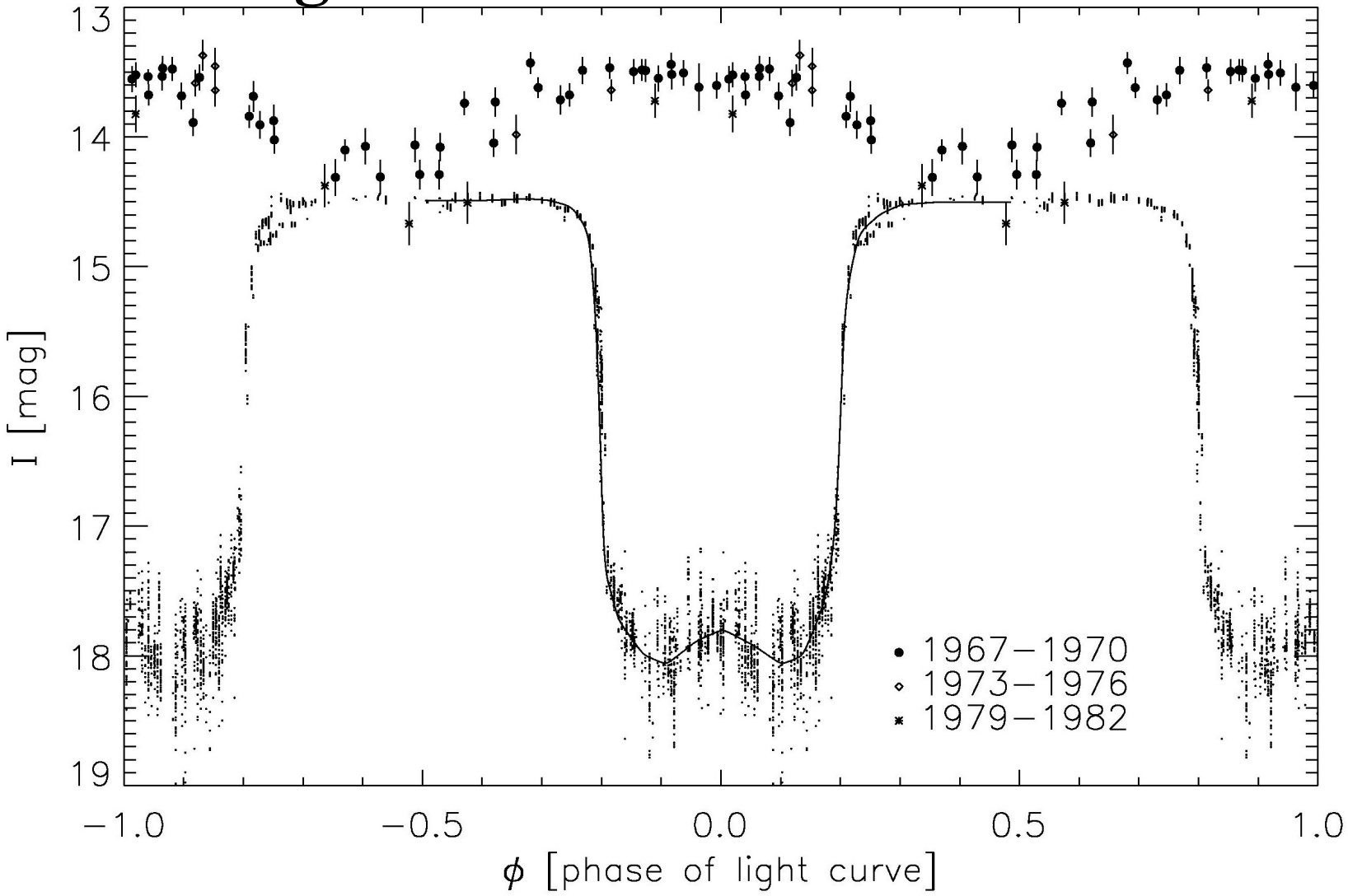
Historical Studies Found…

Light Curve from 1967 – 1982



(Johnson & Winn 2004)

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Historical Studies Found…

- No eclipses between 1913 and 1955 (Winn et al. 2003)
- Noted as an irregular variable between 1963 and 1968 (Badalian & Erastova 1970)
- Between 1967 and 1982, the system alternated from bright to faint with the same period as observed today, but 180° out of phase with today's eclipses (Johnson & Winn 2004)
- Maffei et al. (2005) re-examined blue and IR plates from 1955-1970 and was able to estimate the timeframe when the eclipses began

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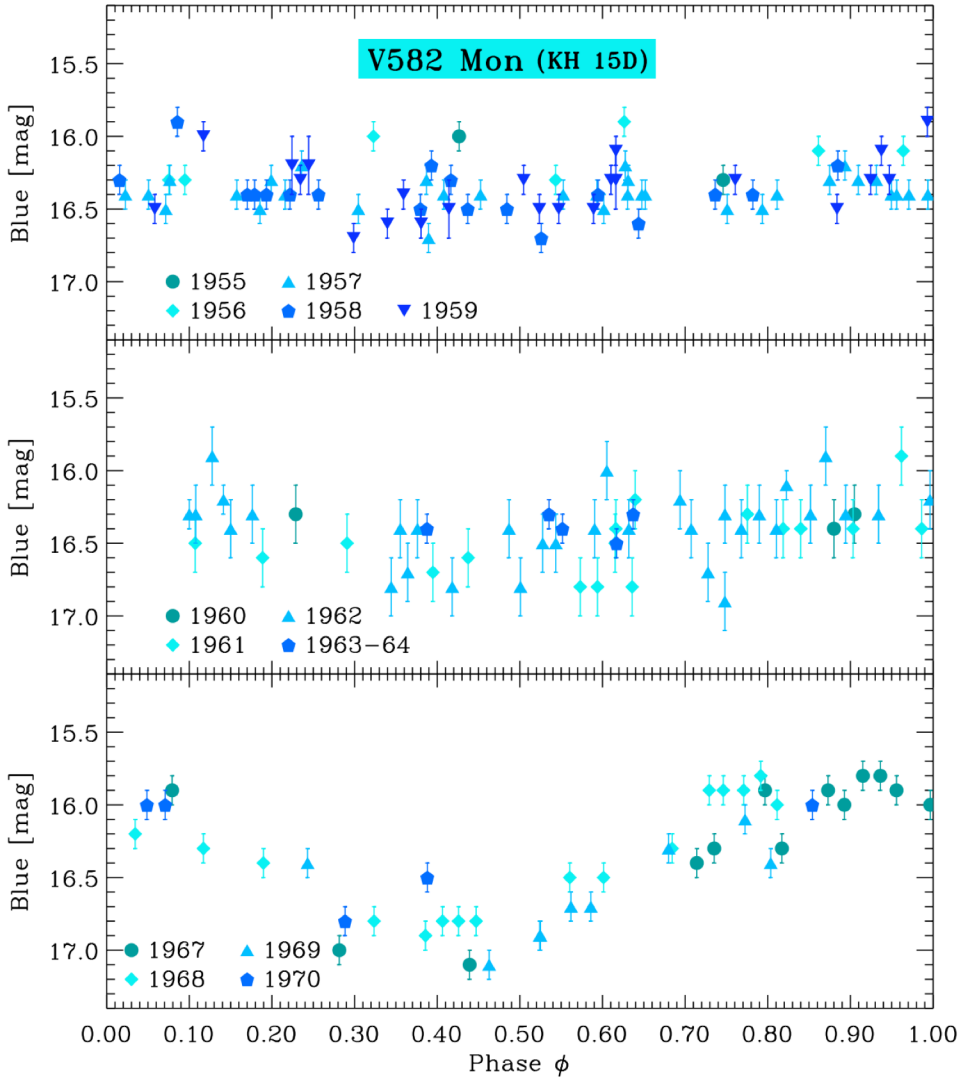
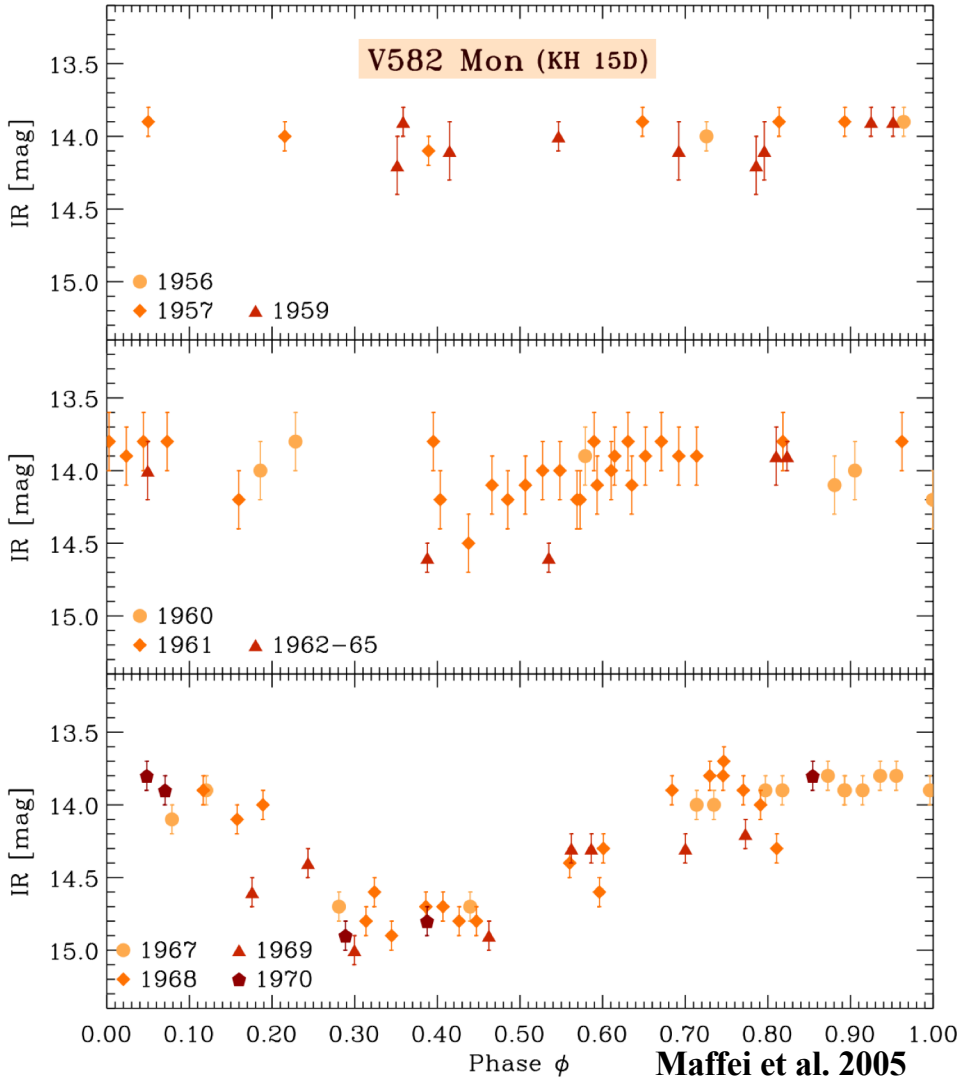
Historical Studies Found…





Maffei et al. 2005

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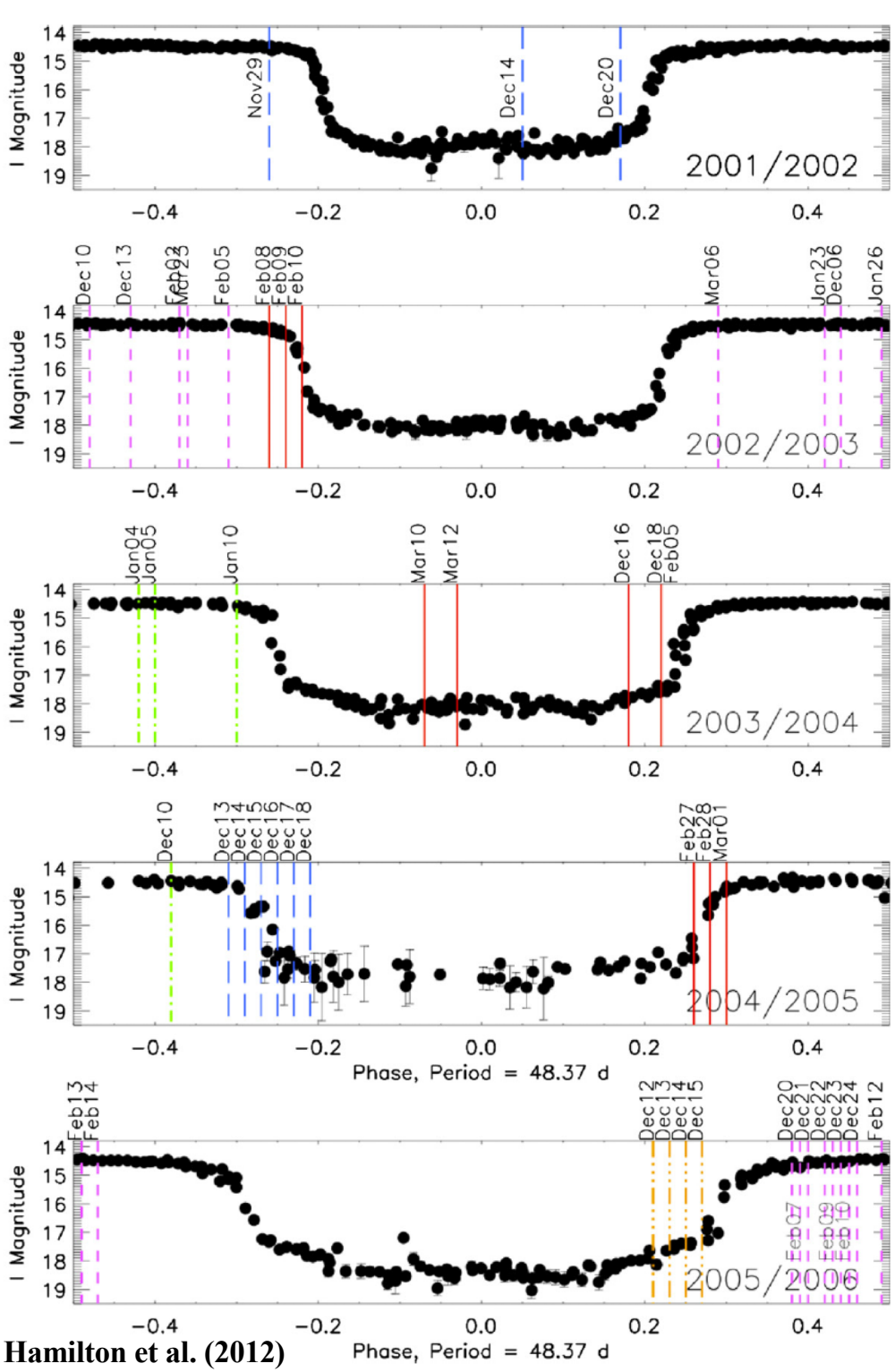
High Resolution Spectra



Hamilton et al. (2012)

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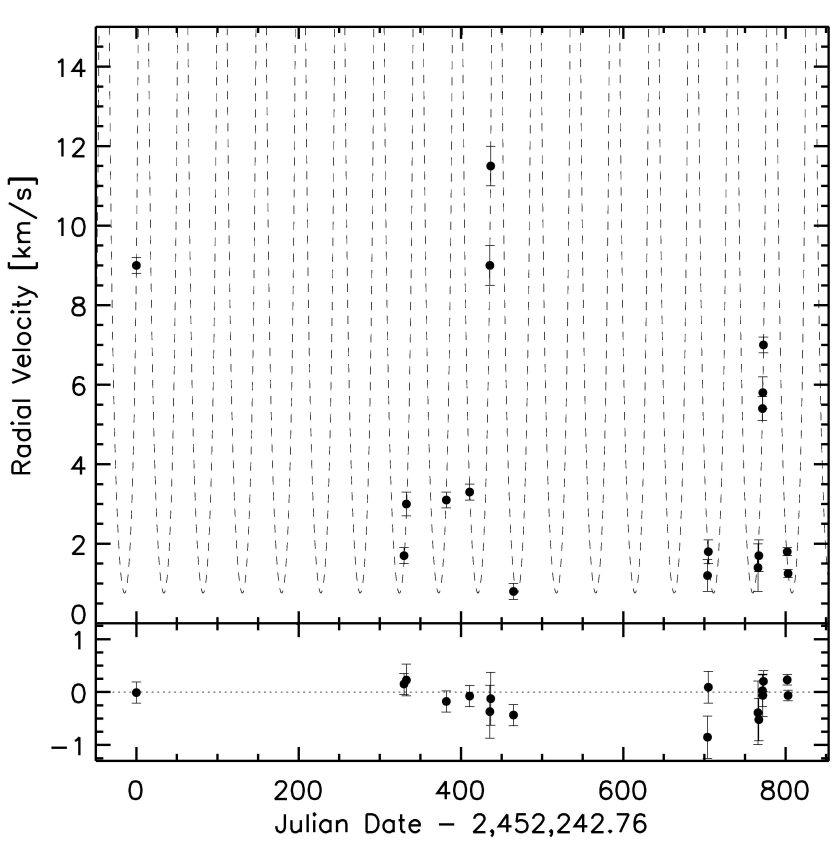
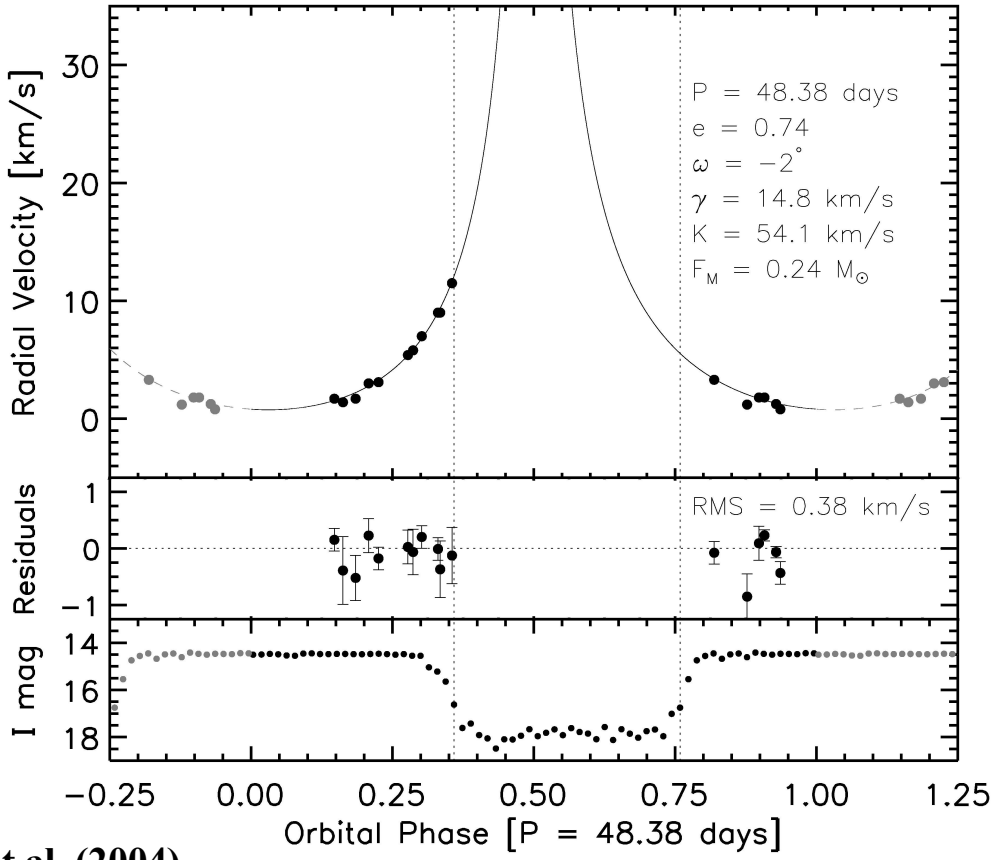
A Radial Velocity Study





Johnson et al. (2004)

• Variations have been observed and are consistent with a **binary companion** with an orbital period equal to the 48-day photometric period

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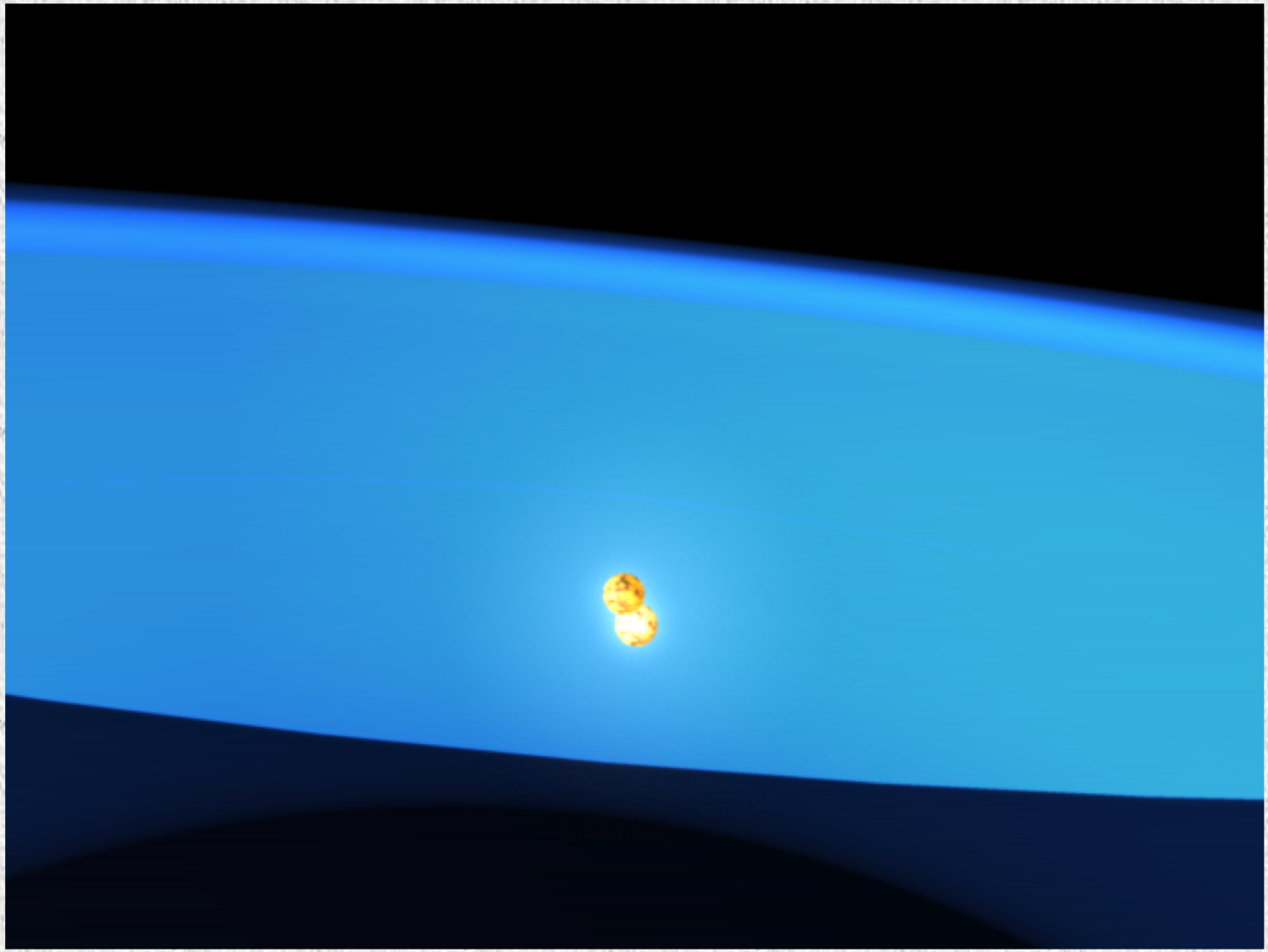
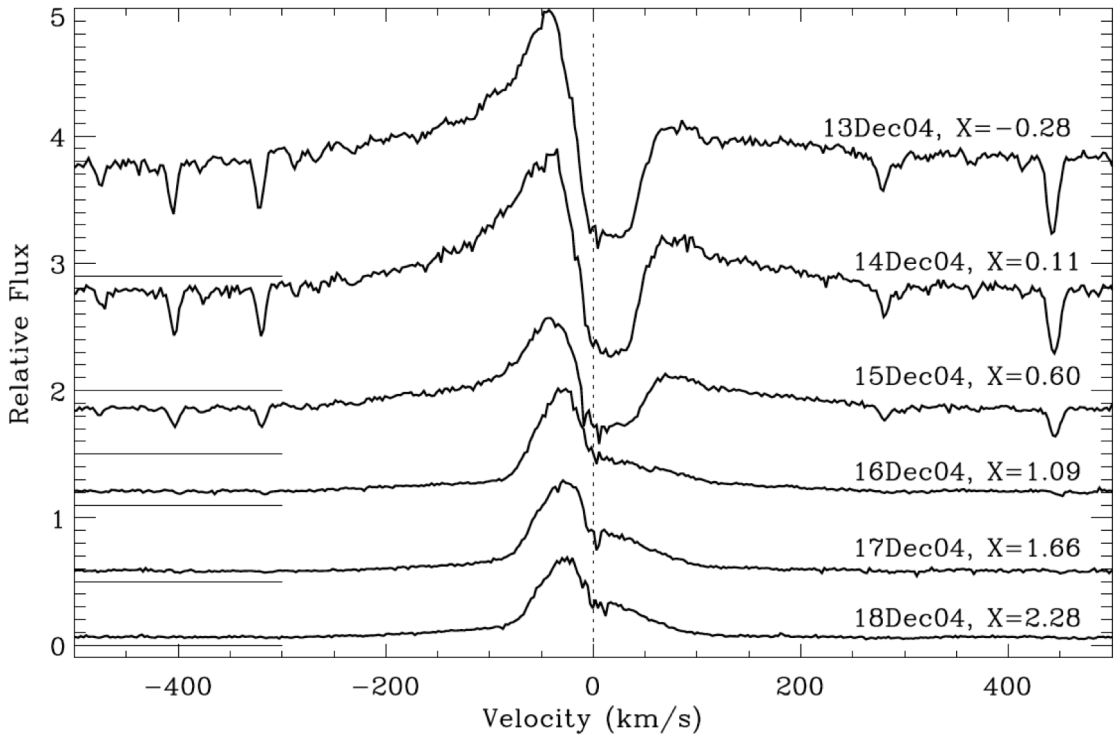
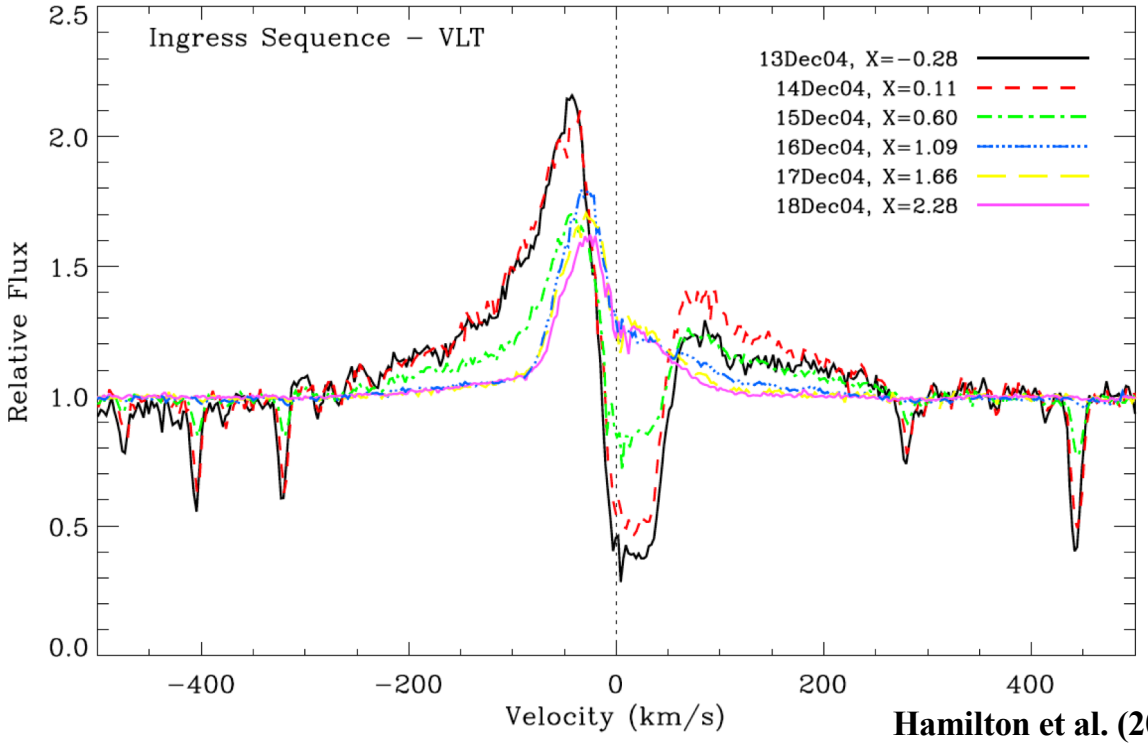
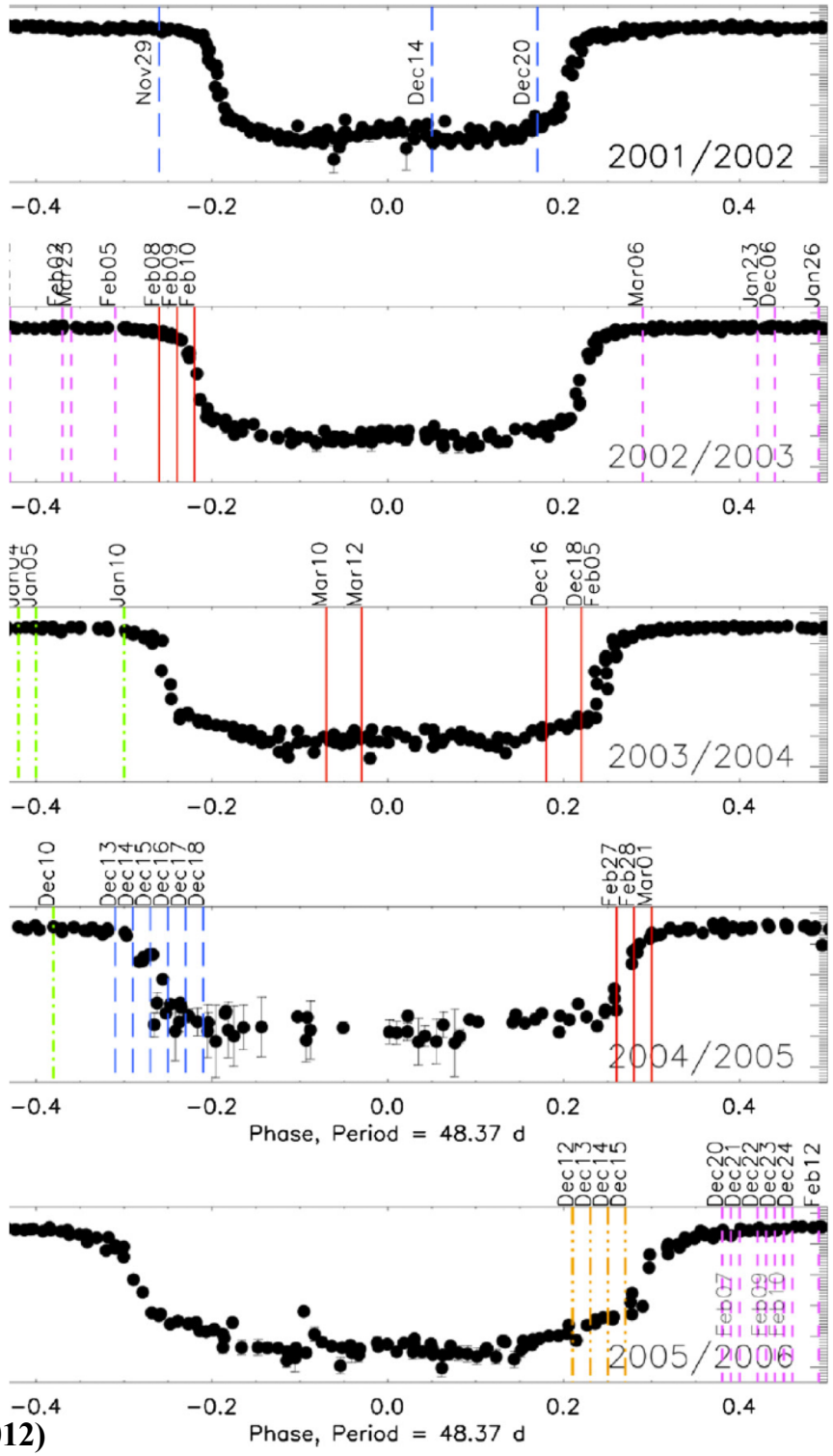
The Eclipsing KH 15D System: Artist's Rendition (~2010)



Credit: Wesleyan University







Hamilton et al. (2012)

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[OI] Profiles

Forbidden emission lines are an important diagnostic for outflows close to a star on scales of 20-40 AU

(Hartigan et al. 1995)

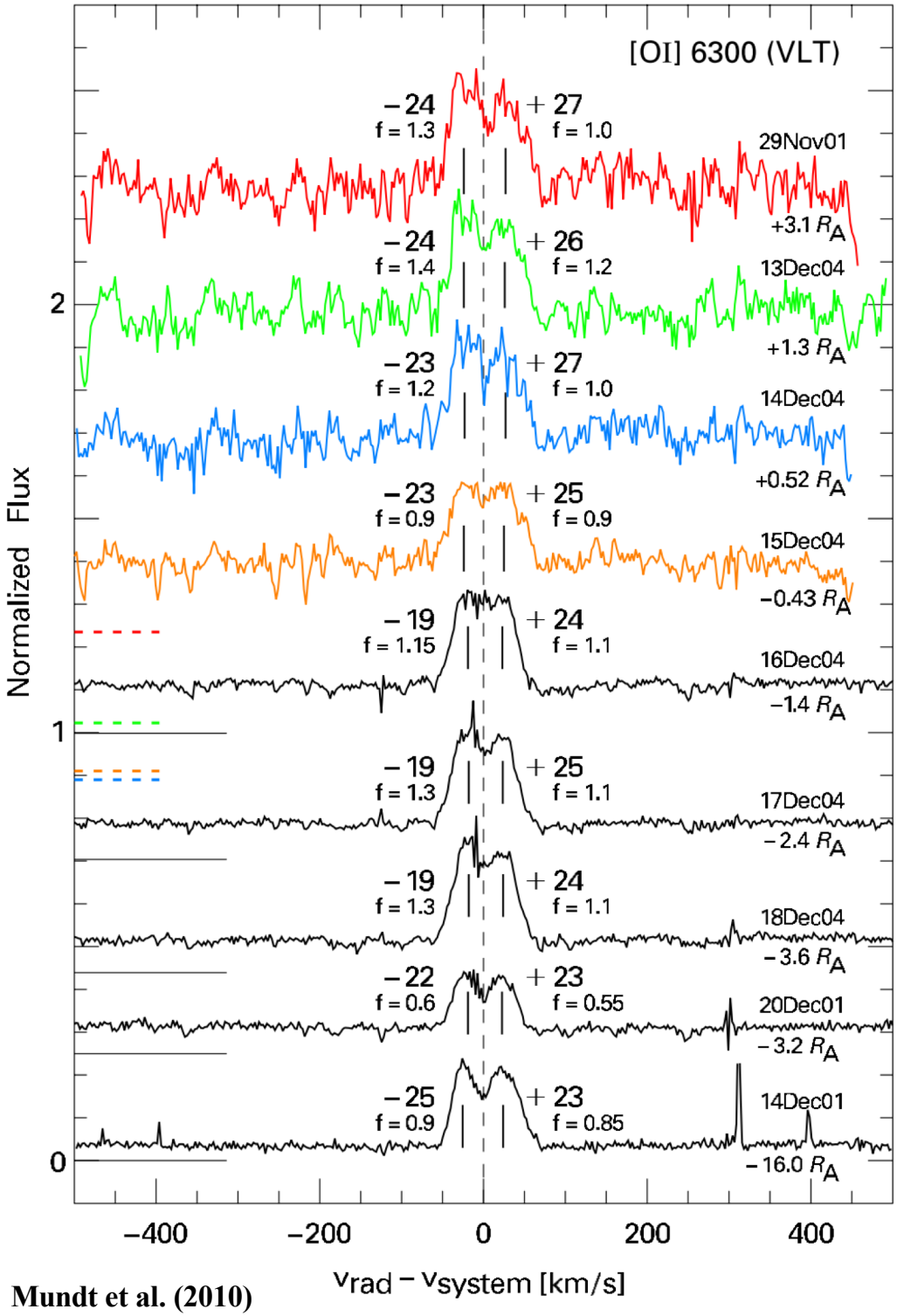
assuming a jet speed of ~200 km s^{-1}

$\longrightarrow i_{jet} = 81°$

<u>New Interpretation!</u>

Profiles arise from the hot surface of a gaseous disk surrounding the binary

(see Fang et al. 2019)



Mundt et al. (2010)

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Evidence of Outflow

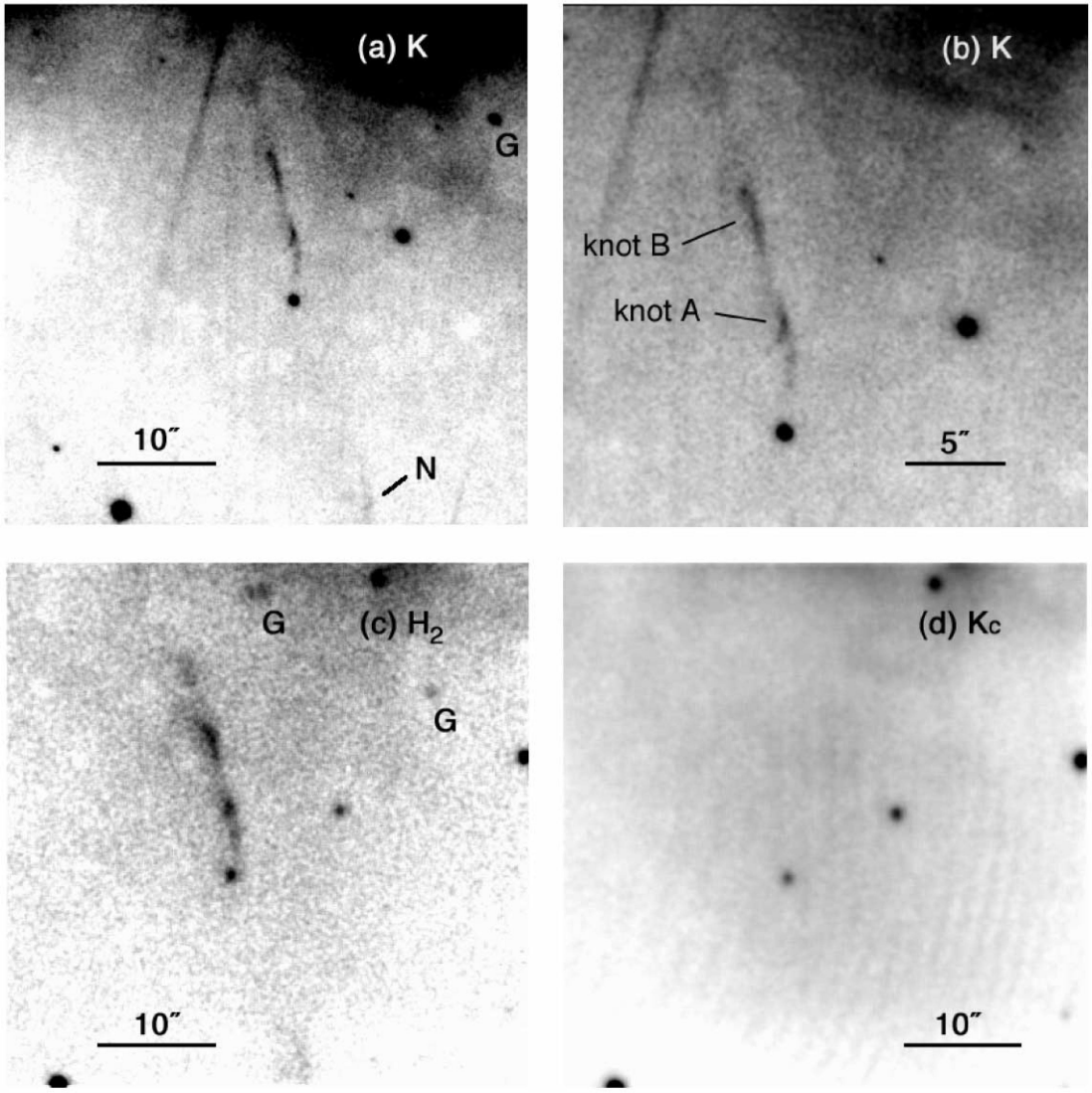

FIG. 1.—Images of KH 15D obtained with the Subaru Telescope. (*a*) *K*-band image. (*b*) Same as (*a*), but expanded to show the details of the filament. (*c*) Narrowband H_2 image. (*d*) Narrowband *K* continuum image. In these figures, north is up, and east is to the left. The filament extends 6″ to the north at a position angle of 1° and then extends 7.″5 to the east at a position angle of 15°. "G" denotes ghost images that arise from the beam splitter in IRCS. "N" denotes faint nebulosity that may be a counterjet.

(Tokunaga et al. 2004)

The Eclipsing System KH 15D/V582 Mon

- Member of NGC 2264, Age ~ 3 Myr, d ~760 pc (Park et al. 2000)
- Pre-main sequence binary, 0.6 $M_\odot$ and 0.7 $M_\odot$ (Johnson et al. 2004)
- P = 48.37 days, e = 0.6, a = 0.25 AU, i ~ 84º (Hamilton et al. 2001, 2003, 2005; Johnson et al. 2004)
- Encircled by a tilted, precessing circumbinary disk that extends from ~ 0.5 AU to ~ 5 AU (Winn et al. 2004, 2006; Chiang & Murray-Clay 2004; Silvia & Agol 2008)
- Evidence for outflow and Hα variability (Tokunaga et al. 2004; Deming et al. 2004; Hamilton et al. 2003, 2012)
- Weak X-ray emitter (Herbst & Moran 2005)

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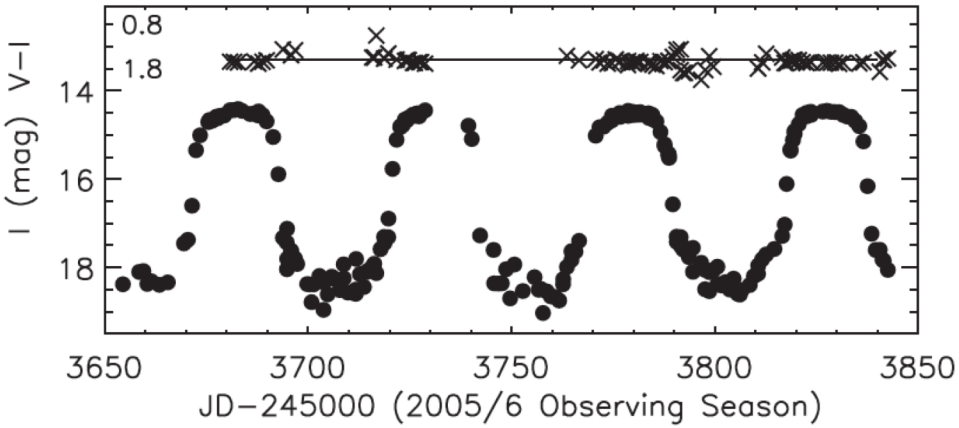
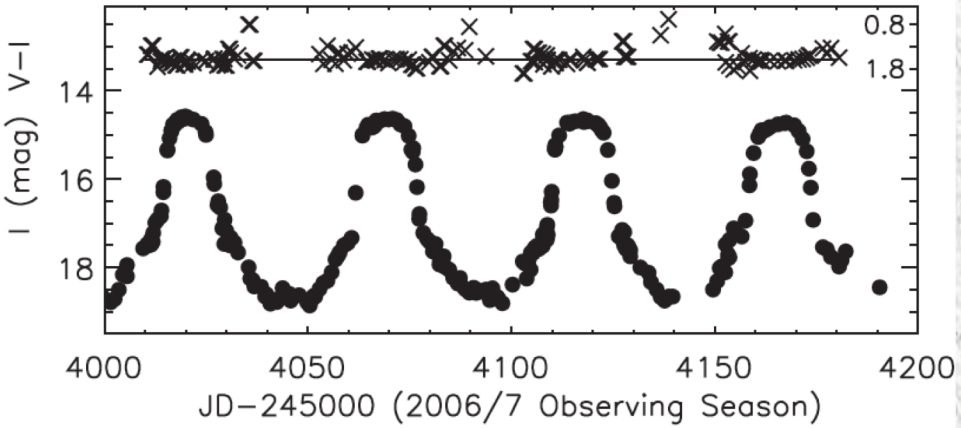
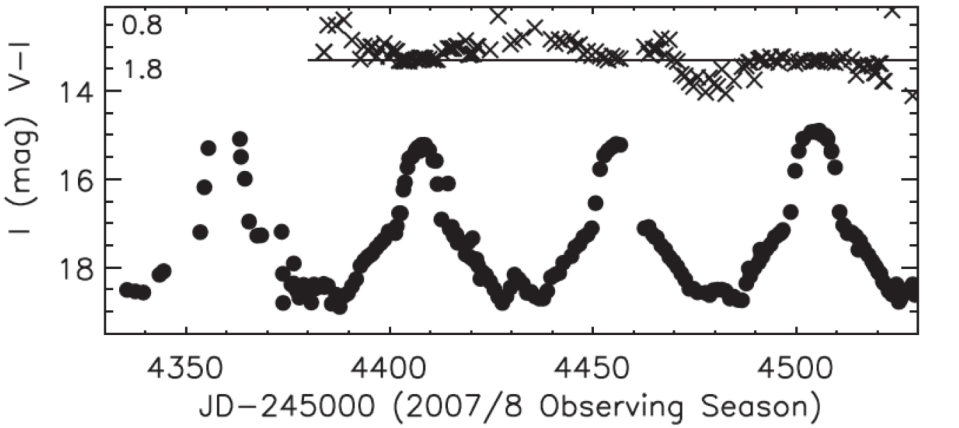
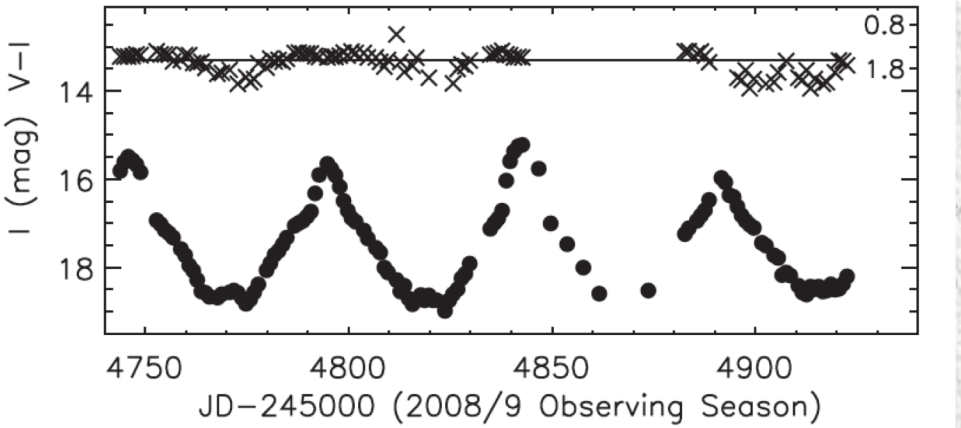
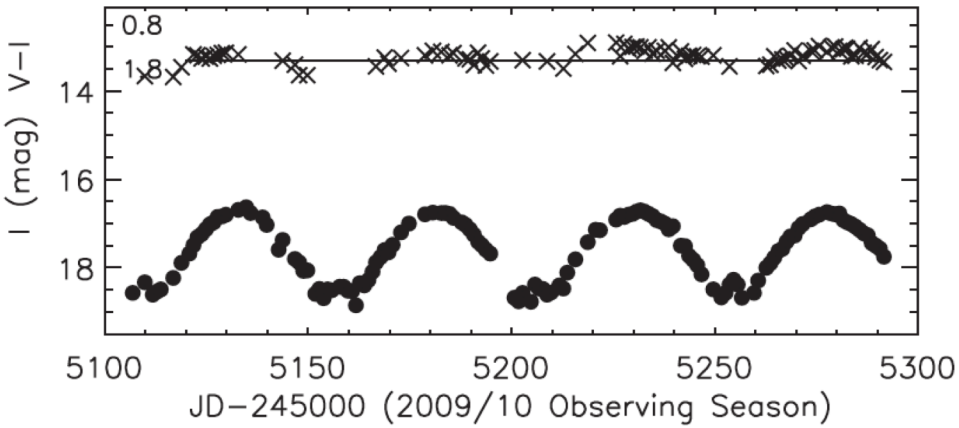
Light Curve Circa 2010











Herbst et al. 2010

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Radio Observations

SMA
2010 Oct 13
2011 Oct 25

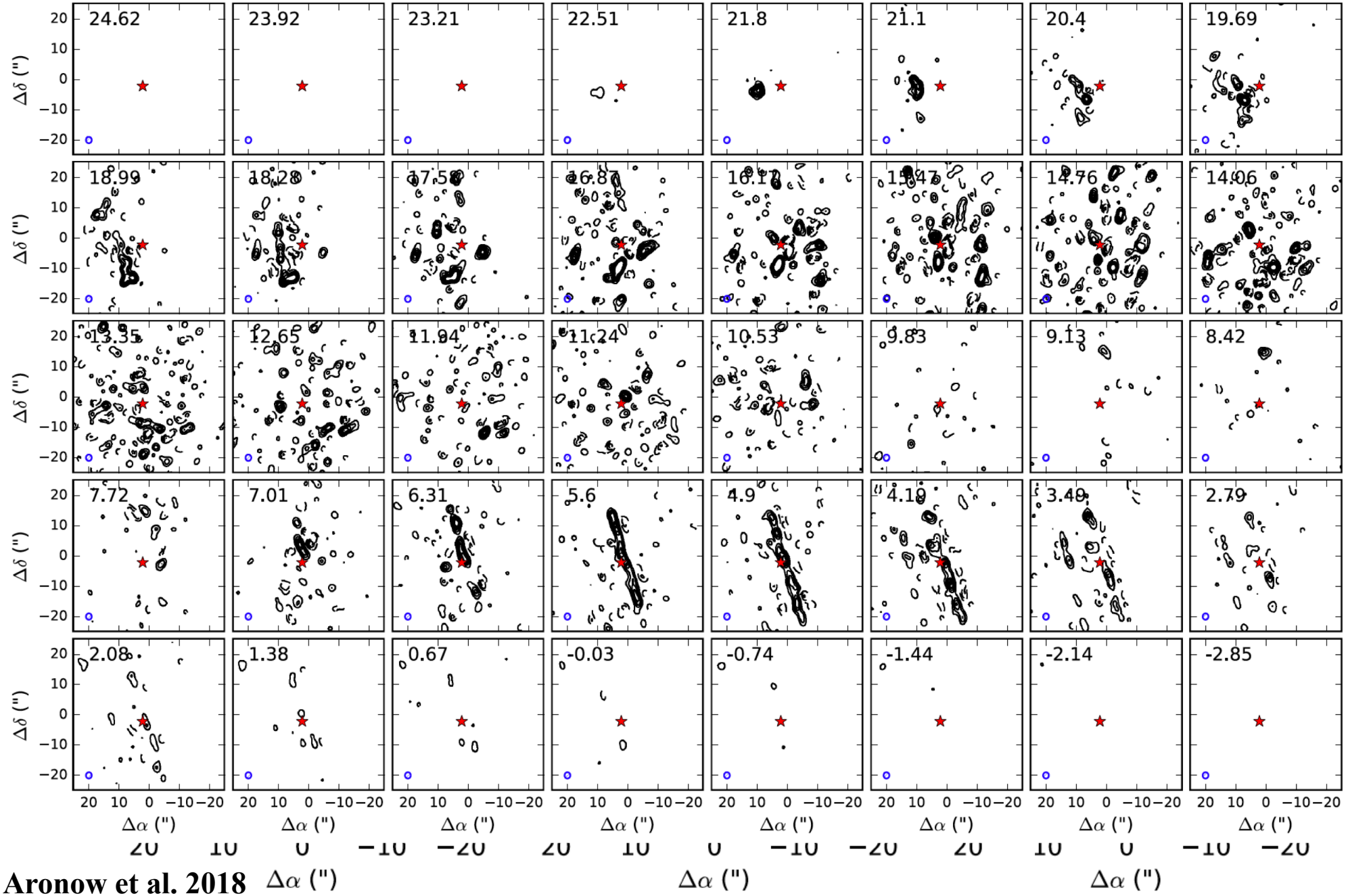
→ Search for 870μm dust continuum emission

- 4σ detection in 2010 (5.1$\pm$1.9 mJy), but non-detection in 2011
- Molecular line emission was detected: CO J = 3-2 line source spatially coincident with the filamentary H_2 jet

Aronow et al. 2018

Dickinson

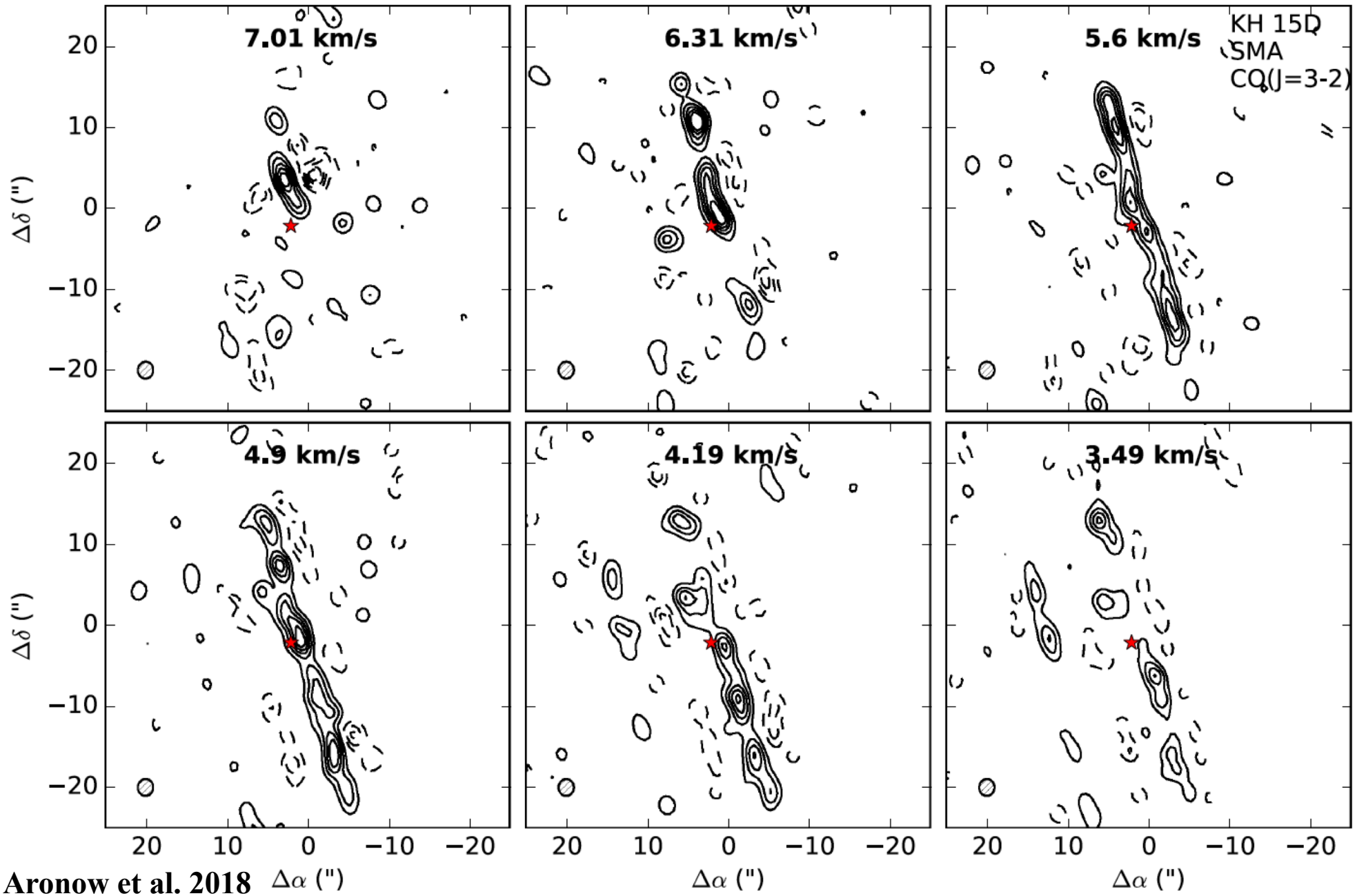
Radio Observations



Aronow et al. 2018

Dickinson

Radio Observations



Aronow et al. 2018

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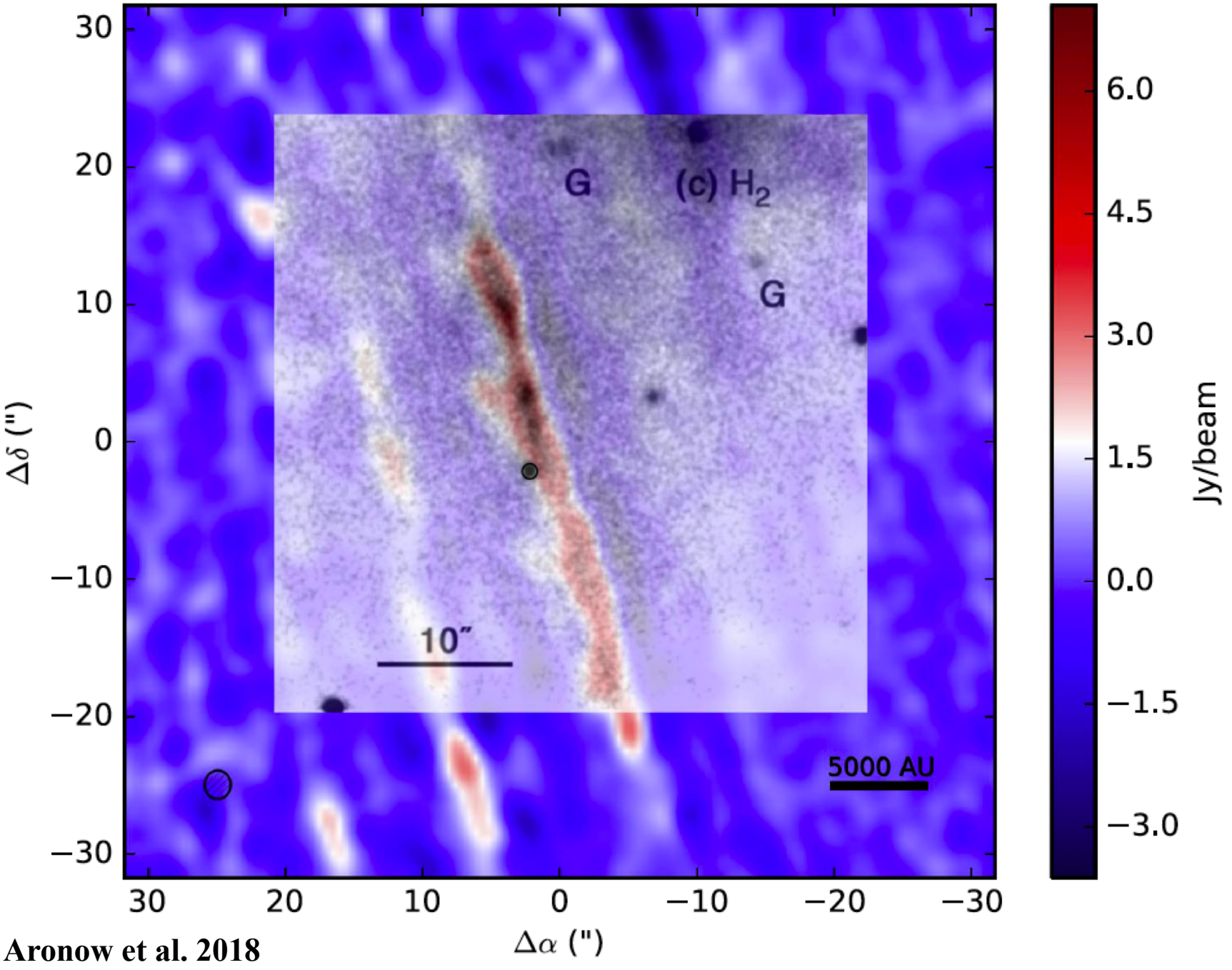
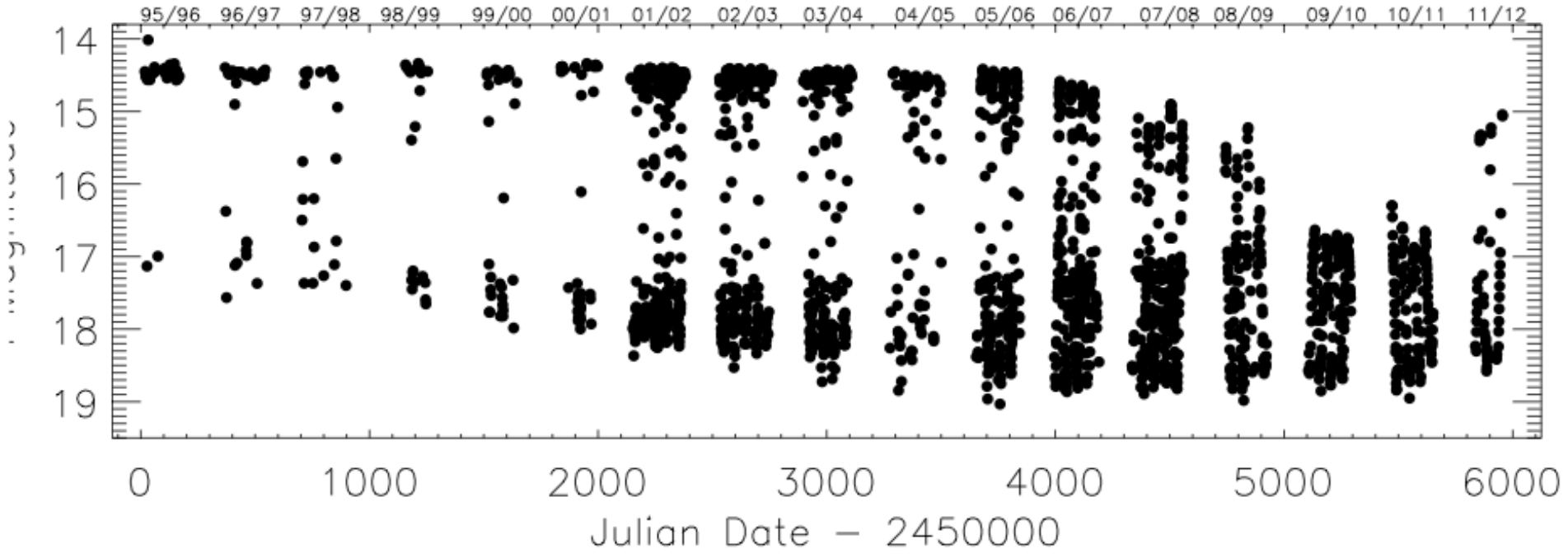
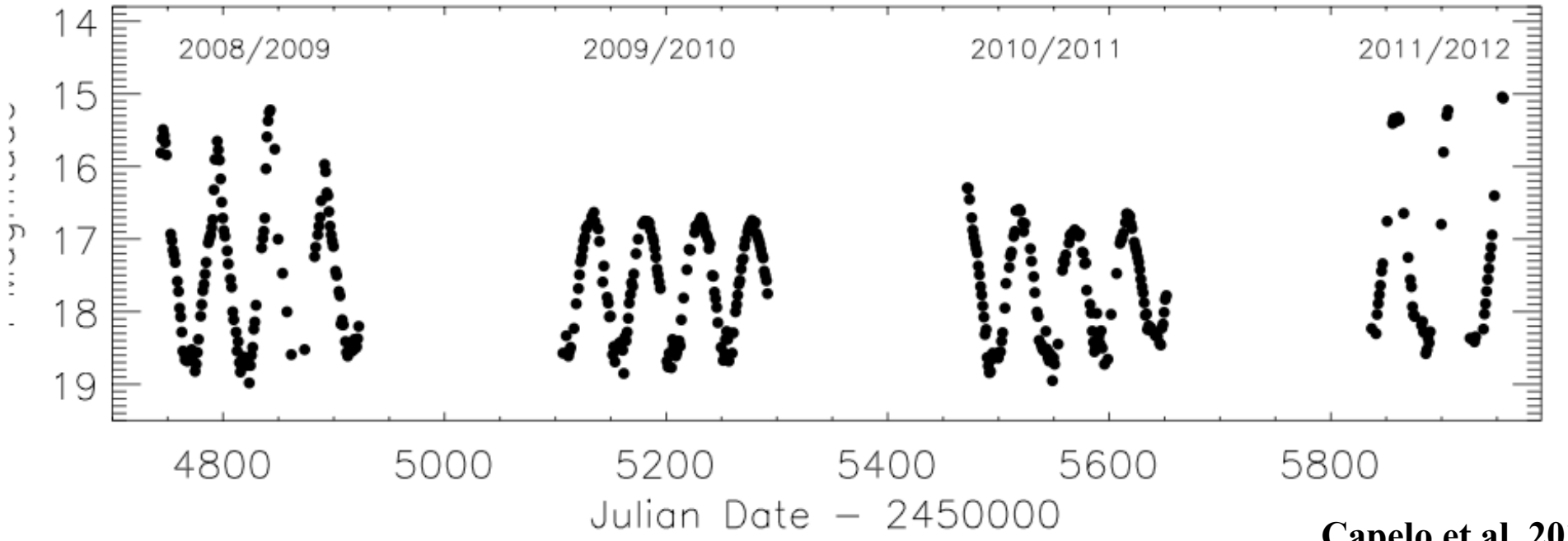
Radio Observations



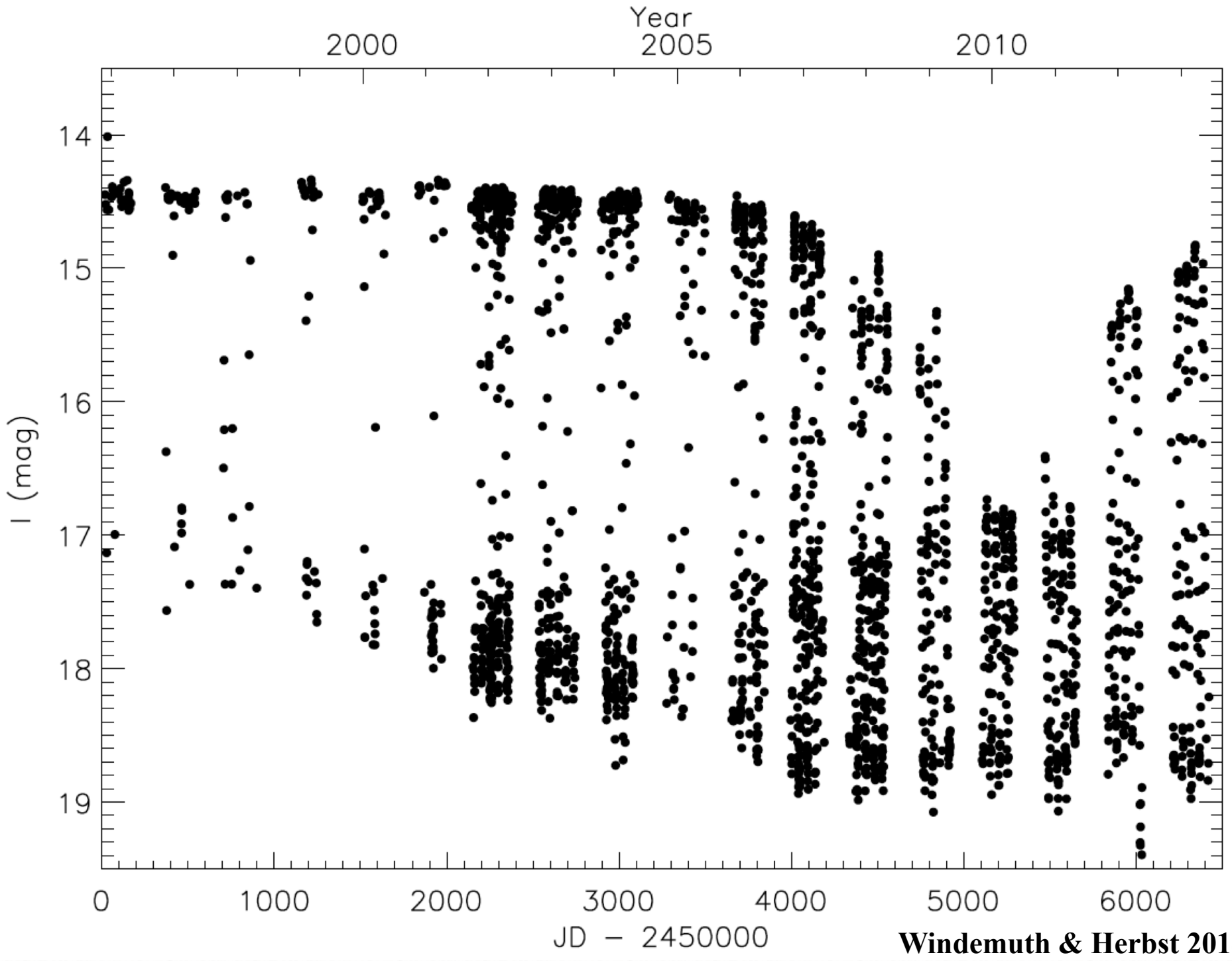
Aronow et al. 2018



Star B is found to be of spectral type K1



Capelo et al. 2012



Windemuth & Herbst 2014

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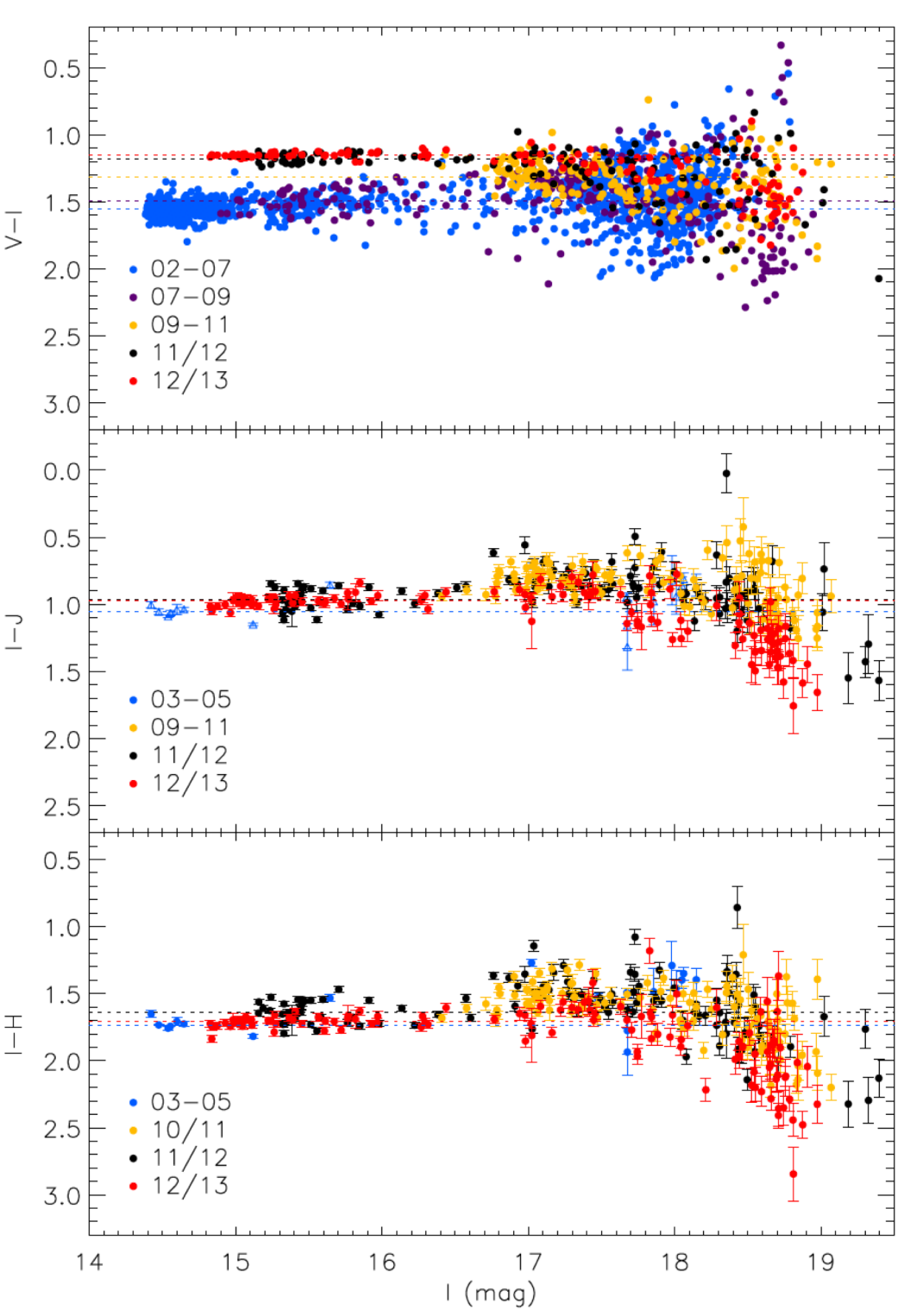
- Two distinct bright phase colors corresponding to Star A (2002-2009) and Star B (2011-2013)
- 2012/2013 color redden dramatically, in excess of the photometric colors of either star A or star B

⟶ Light from a 3rd body?

Windemuth & Herbst 2014



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ALMA Observations

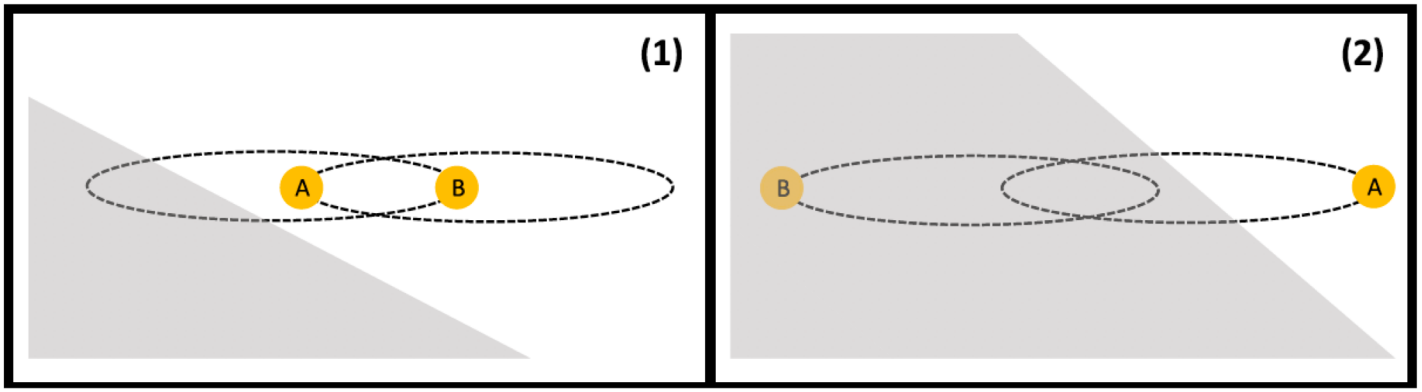
- Observed 16 January 2016; did not reveal a source at the location of KH 15D
- Non-detection sets an upper limit on the 2 mm flux density and allows for an estimate on the upper limit for the total mass of the disk ⇨ ~1.7 M_{Jup}

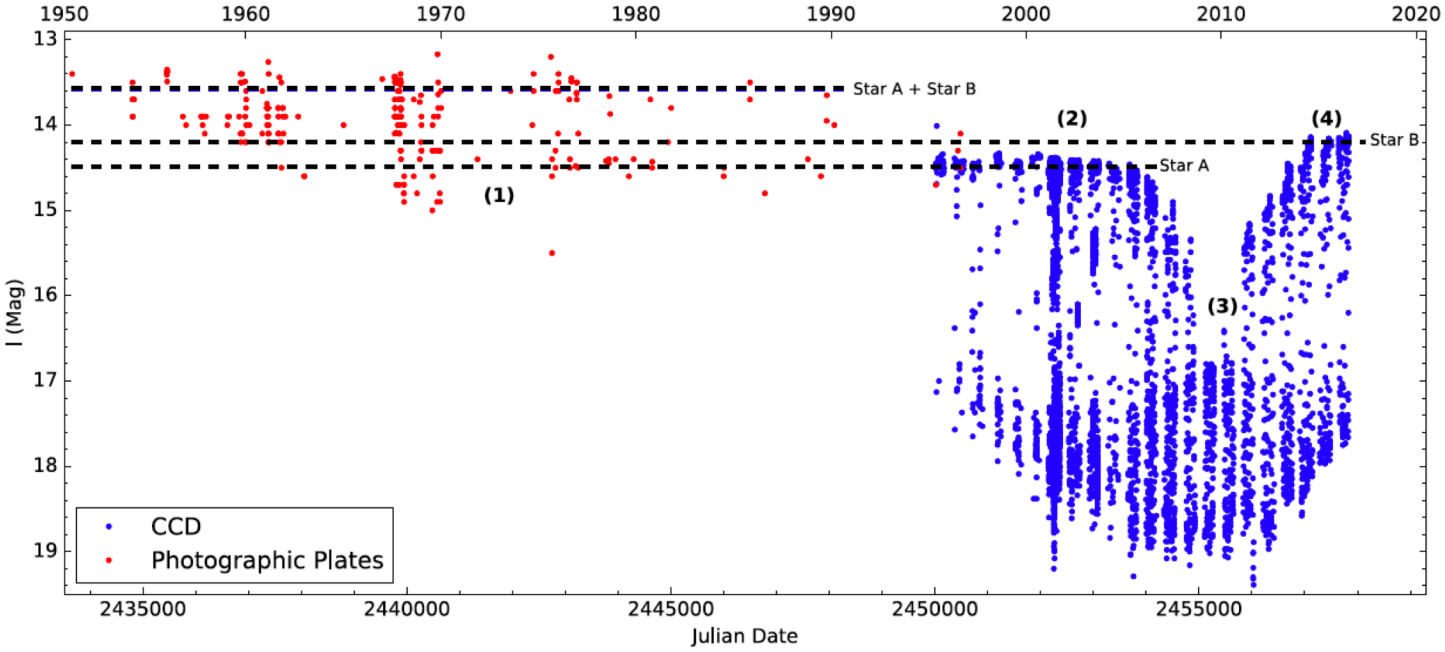
Aronow et al. 2018

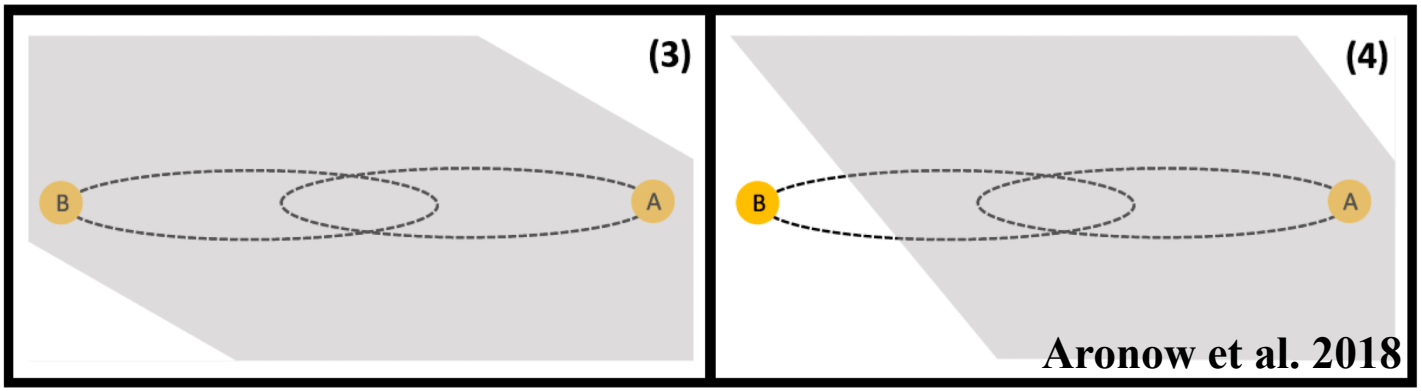
Dickinson

- Projected ring edges move together across the sky at ~ 15 m/s, fully supporting the rigid precession of a ring theory
- Ring radius ~ 4 AU with precession period of ~ 6500 yrs

(Arulanantham et al. 2016)







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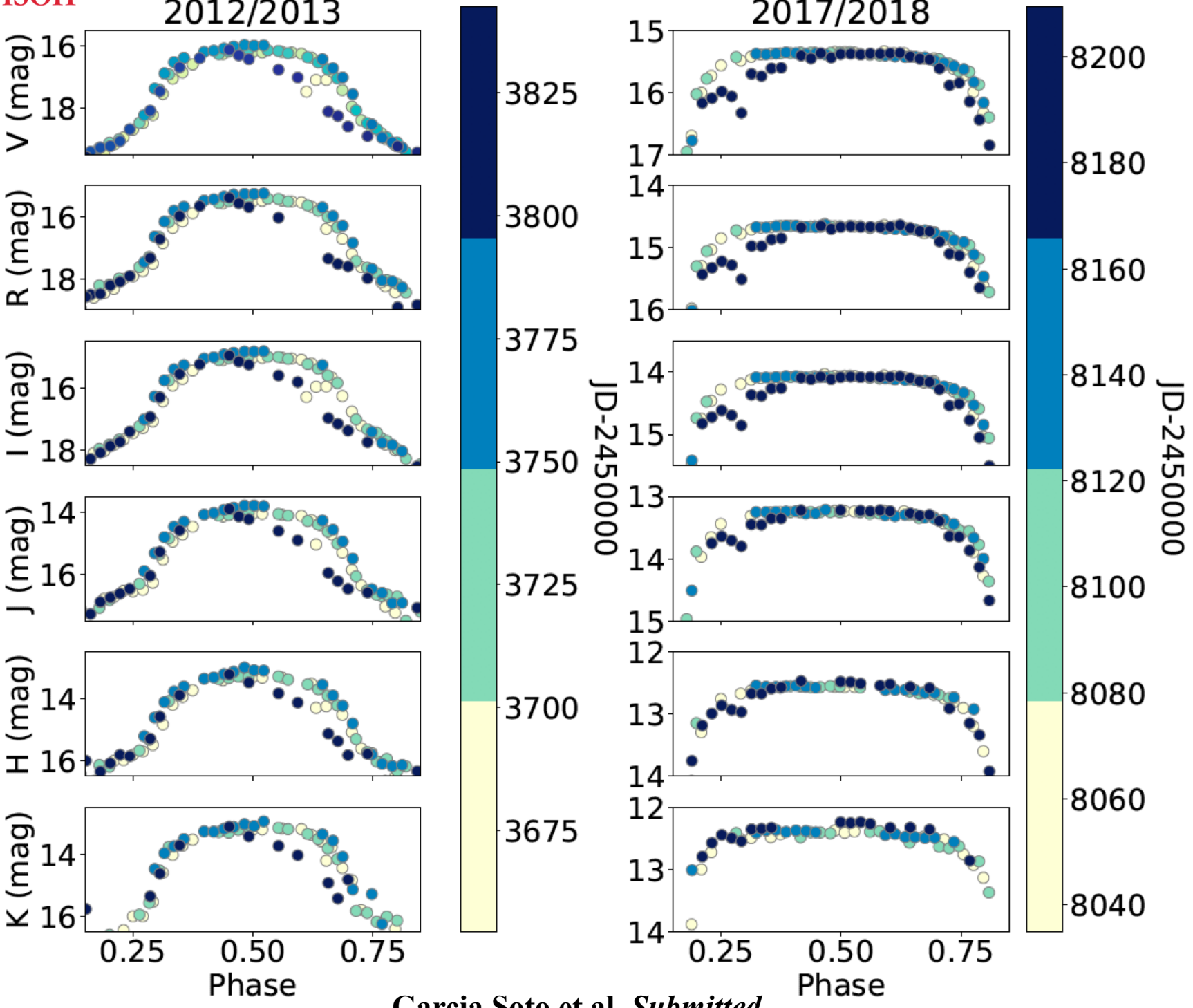

Garcia Soto et al. *Submitted*

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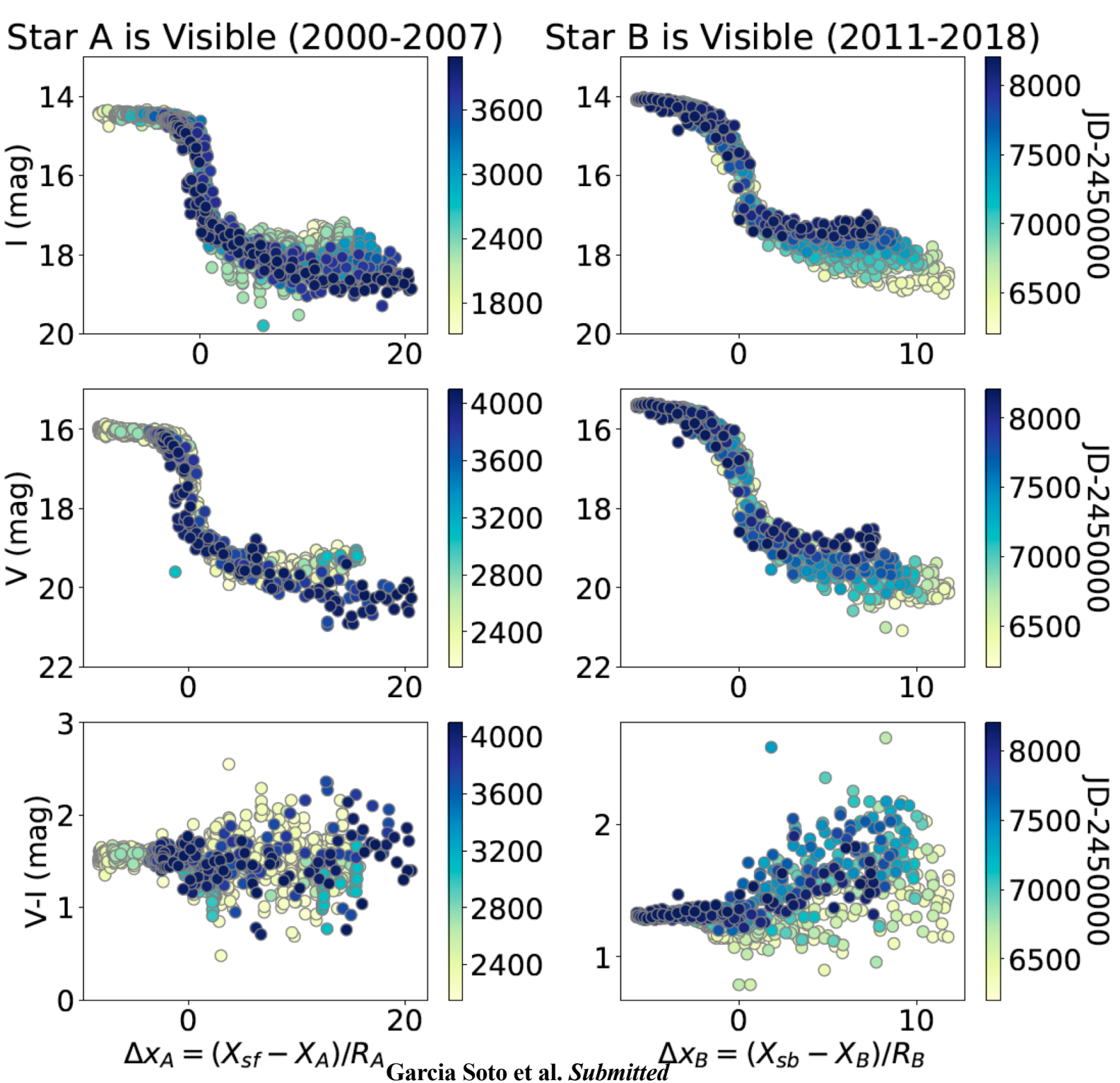
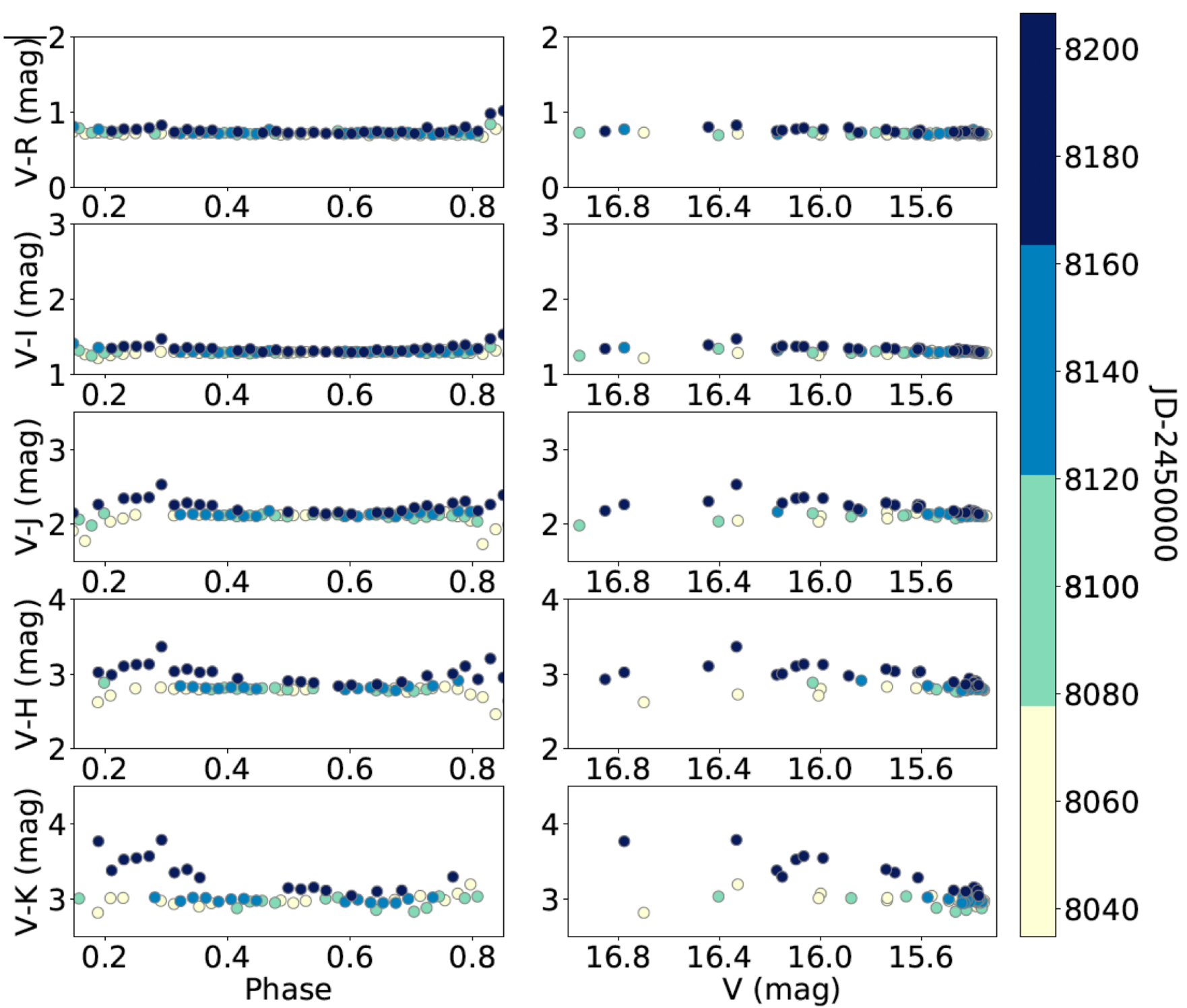


Garcia Soto et al. *Submitted*



Garcia Soto et al. *Submitted*

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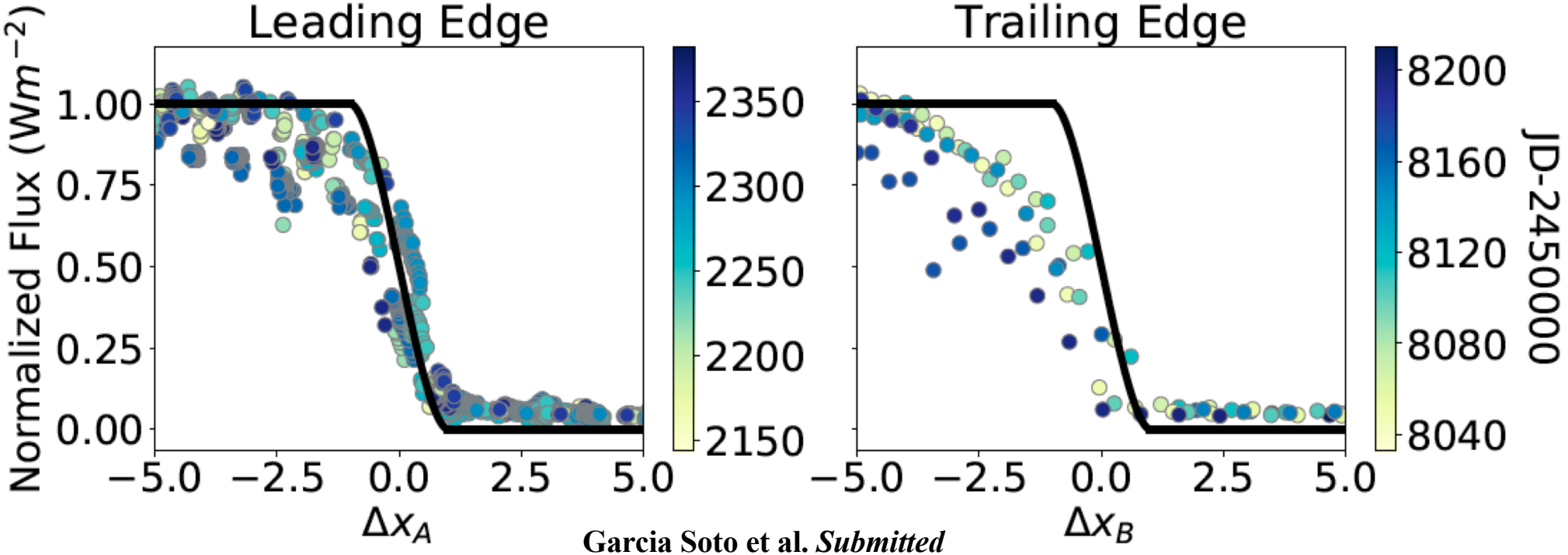
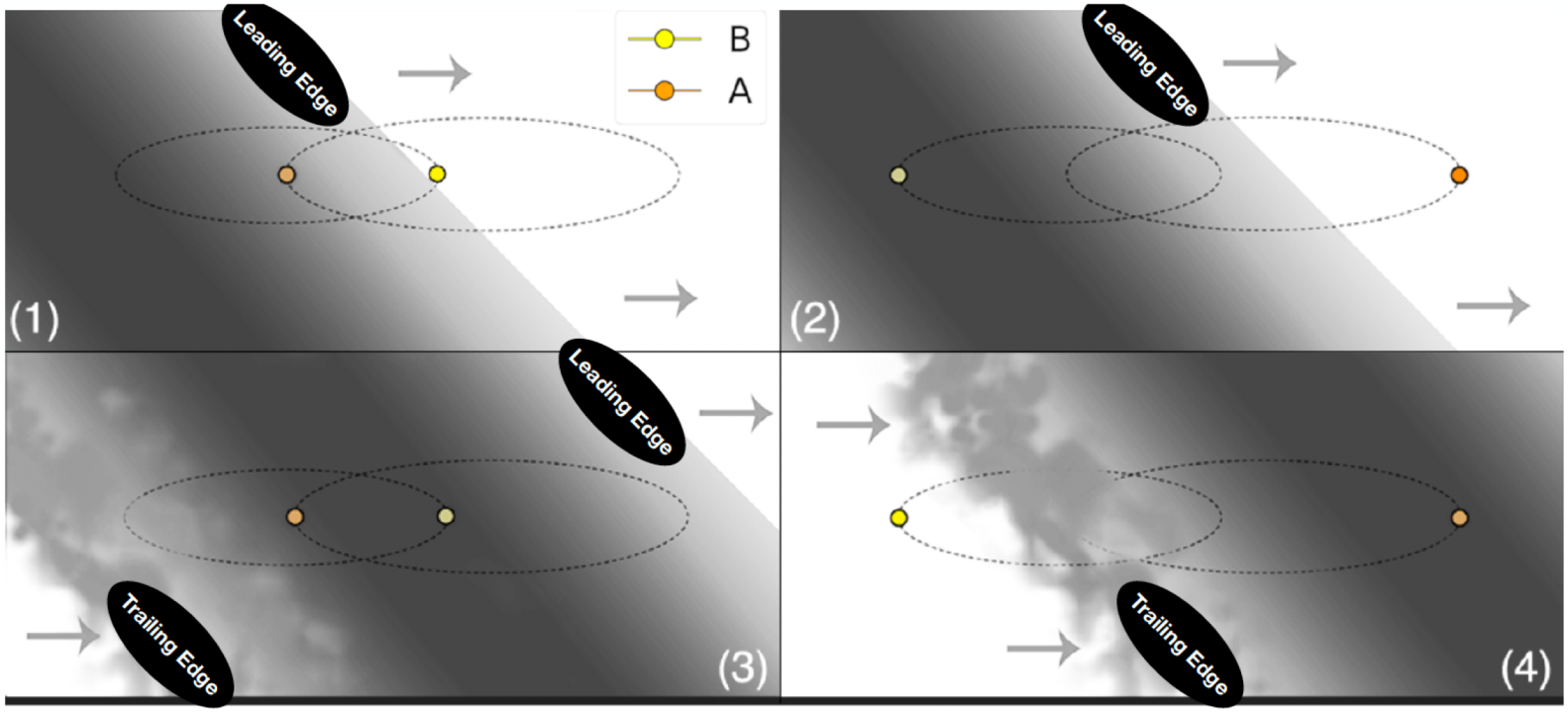
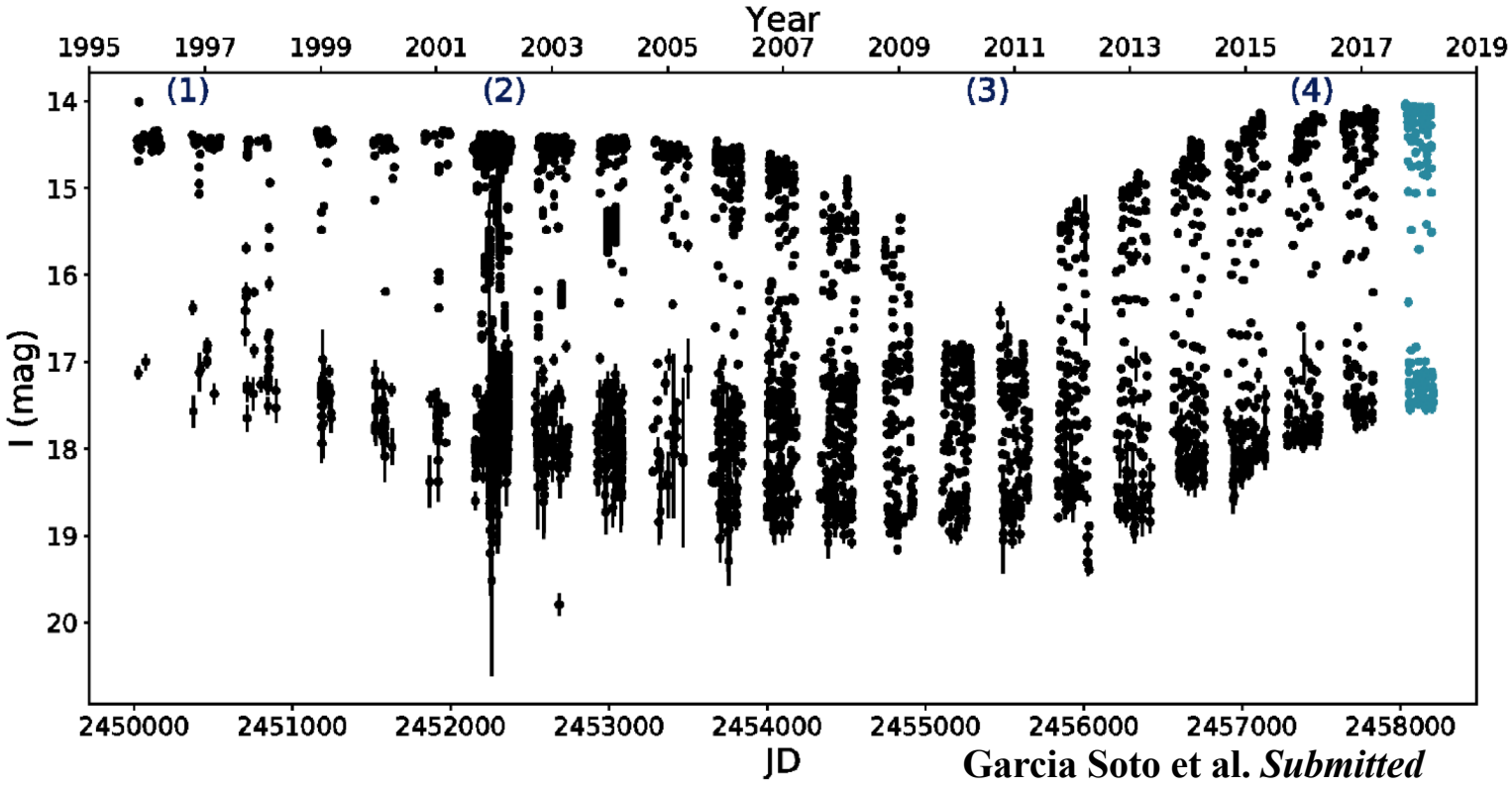


Garcia Soto et al. ***Submitted***

Dickins





Garcia Soto et al. *Submitted*

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Open Questions

- Is it a planet that maintains the rigid precession or something else?

  ⟶ Redder colors during the 2012/2013 season hint at one

  (Windemuth & Herbst 2014)

- New models (Lyra & Kuchner 2013) propose ways to form rings without shepherding planets.

  ⟶ Depends on gas-to-dust ratio of the disk

- Has the environment photoevaporized the outer portion of the disk? (Fang et al. 2019)
- How is the jet launched?

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Conclusions

2018-2019

KEEP WATCHING IT, BECAUSE…

Dickinson

Conclusions

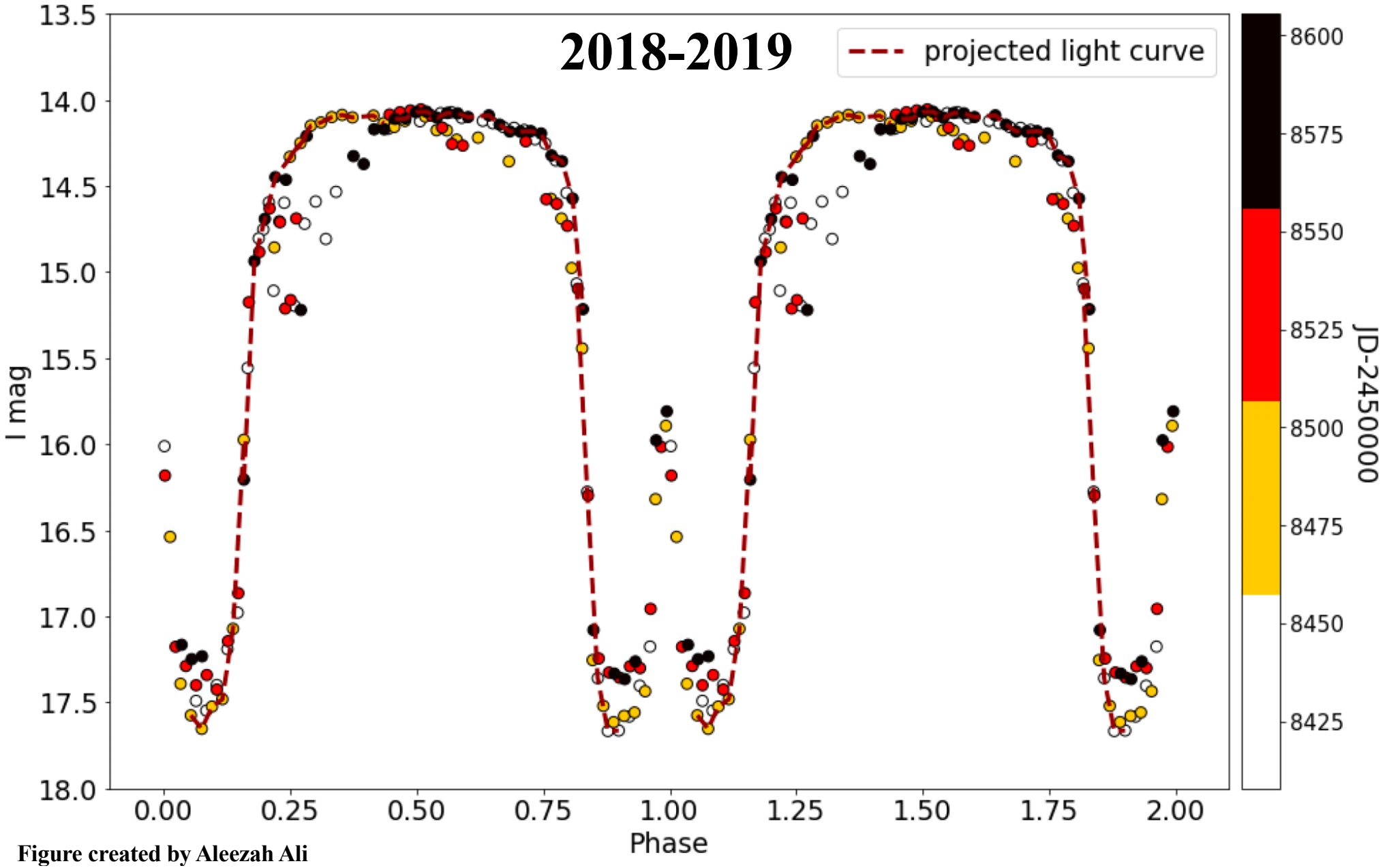

Figure created by Aleezah Ali

Dickinson

Collaborators:

William Herbst, Wesleyan University

Reinhard Mundt, Max Planck Institüt fur Astronomie

Joshua Winn, Princeton

Meredith Hughes, Wesleyan University

Christopher Johns-Krull, Rice University

John Johnson, Cal Tech

Sandy Leggett, Gemini Observatory

David Wilner, Harvard/CfA

Eric Agol, University of Washinton

Lisa Prato, Lowell Observatory

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Master's Students (Wesleyan):

Kristin Kearns (1998)

Kathy LeDuc (2008)

Samantha Lawler (2010)

Holly Capelo (2012)

Diana Windemuth (2014)

Nicole Arulanantham (2016)

Rachel Aronow (2018)

Undergraduate Students:

Aylin Garcia Soto (2019) (Wesleyan U.)

Aleezah Ali (2019) (U. Washington)

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What is needed…

- More photometry! IR options?
- High resolution spectra in optical/NIR

Interested in collaborating?

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