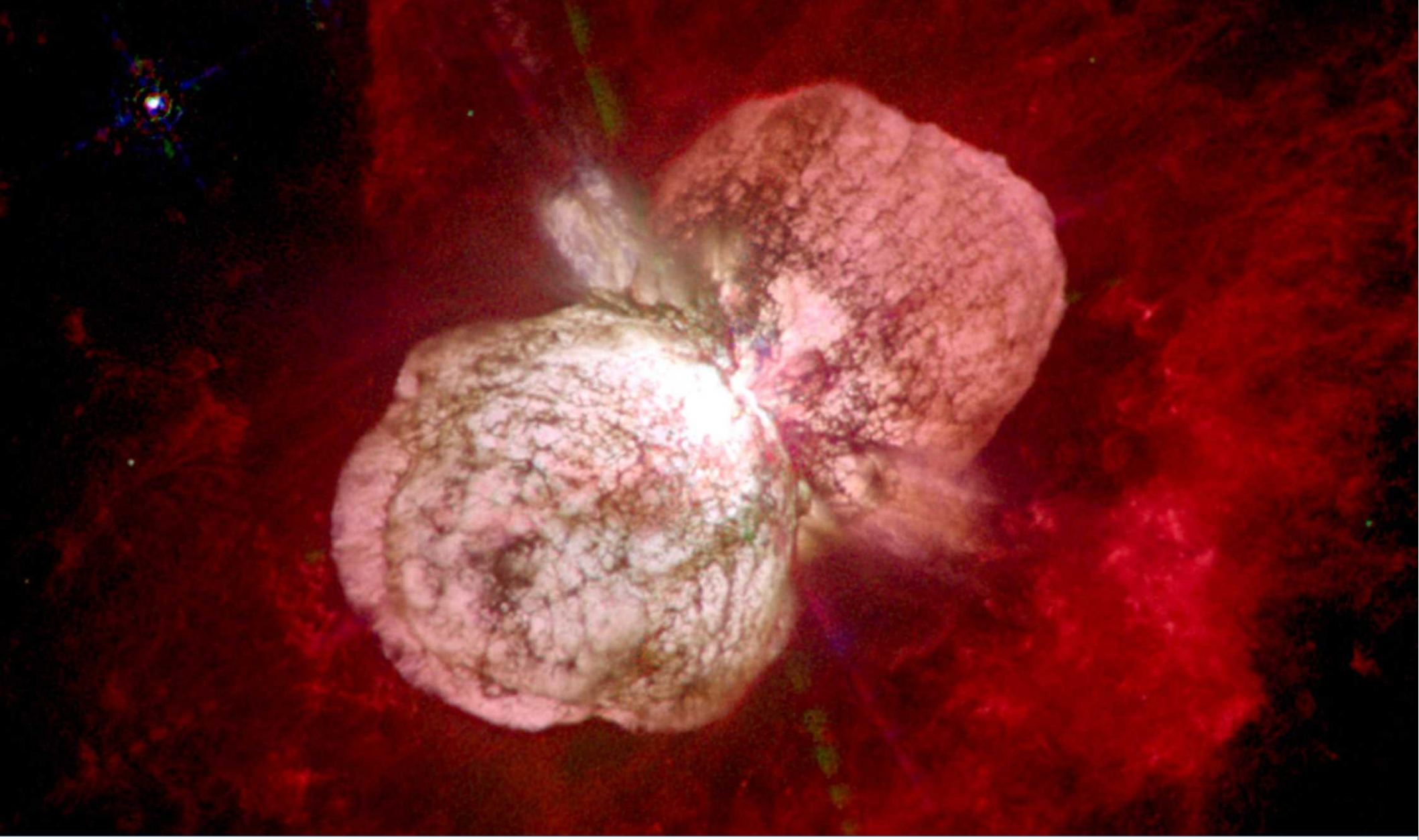


Eta Carinae: 変光する大質量連星（Human-Timescale で変化する主星）

Presented by Bish K. Ishibashi (Nagoya University)

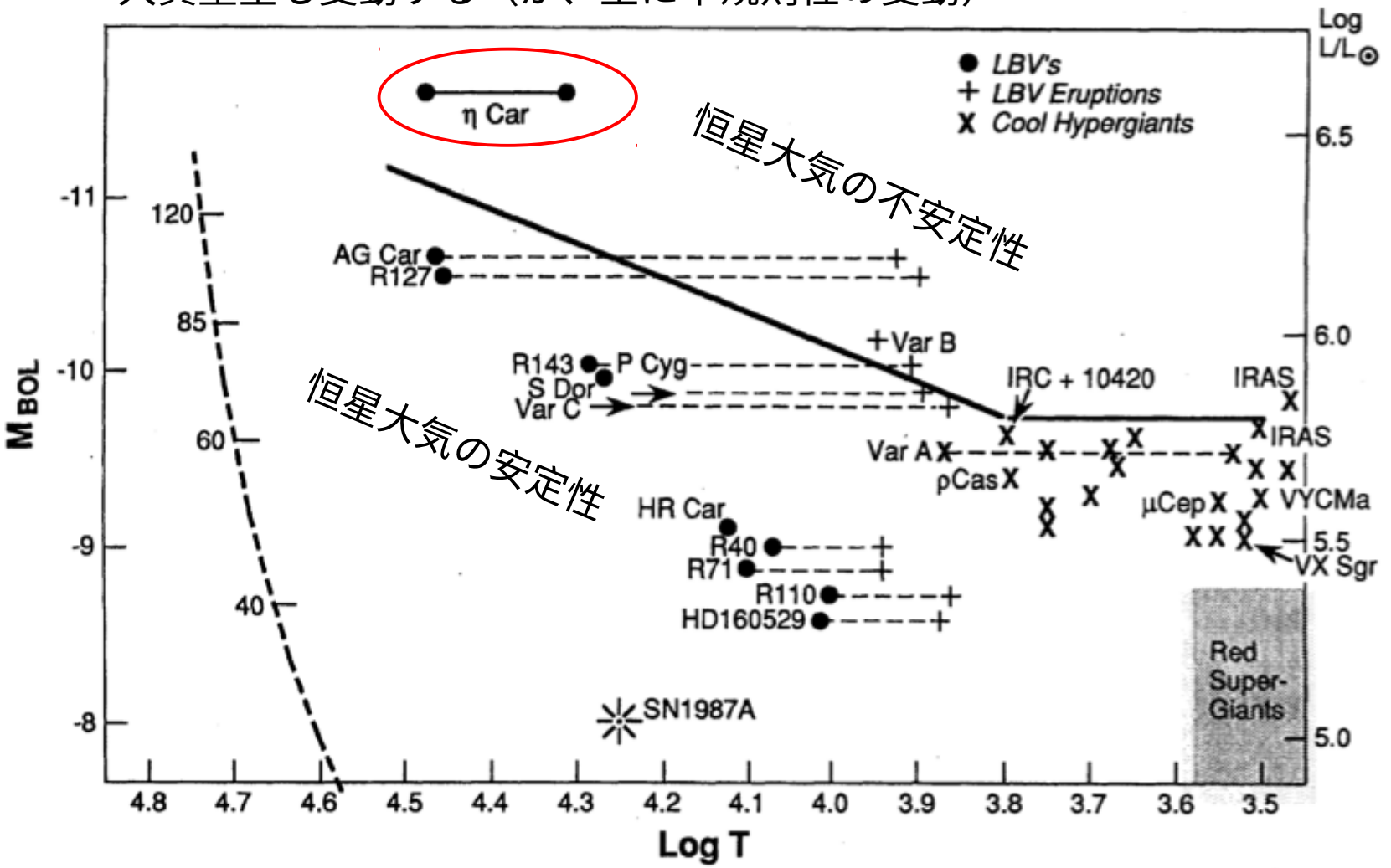
近年、大質量の恒星進化の重要性が宇宙論等でも盛んに議論されるようになりましたが、未だその進化過程について理解されていないことは沢山あります。

その問題を抱える星の一例として、銀河系内で最も大質量と言われる星のひとつ、Eta Carinae についてお話します。

長期的な赤外線とX線観測から見えてくる変動星の研究の面白さ、そして、その物理的理解の難しさなどについて主に触れてみたいと考えています。

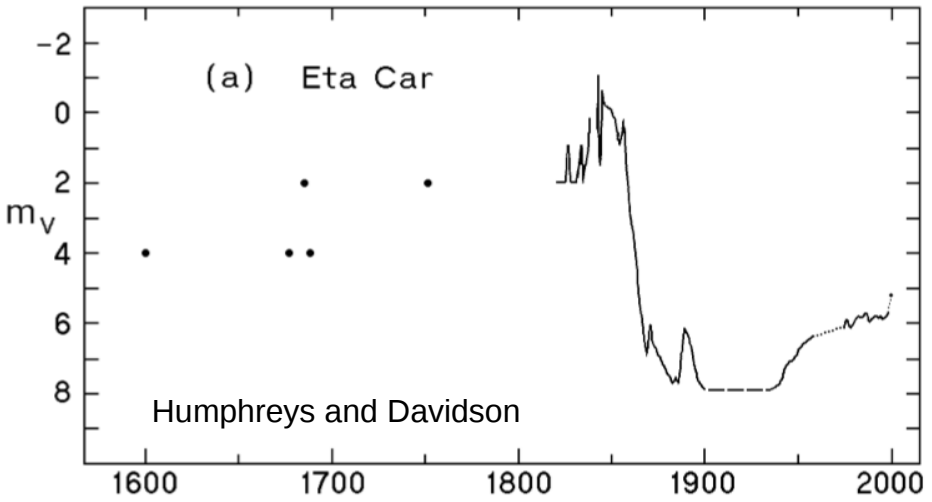
Eta Carinae： 不安定・不可解な恒星大気構造

大質量星も変動する（が、主に不規則性の変動）



宇宙論学者必見！　<u>超大質量星の進化は、***ほぼ全く理解されていない***</u>。

Eta Carinae： 過去の爆発現象について



Eta Carinae は超巨大クラスの LBV：

Mη ~ 100+ Msun
Lη ~ $10^{6.6}$ Lsun (near Eddington Luminosity)
Mass loss rate ~ 10^{-3} ~ 10^{-4} Msun/year

まだ、直接な証拠はないが、まず間違いなく連星系で、４０ Msun ぐらいの伴星が存在か。

Fernández-Lajús et al.: Long-Term Optical Monitoring of η Carinæ *(RN)* 5

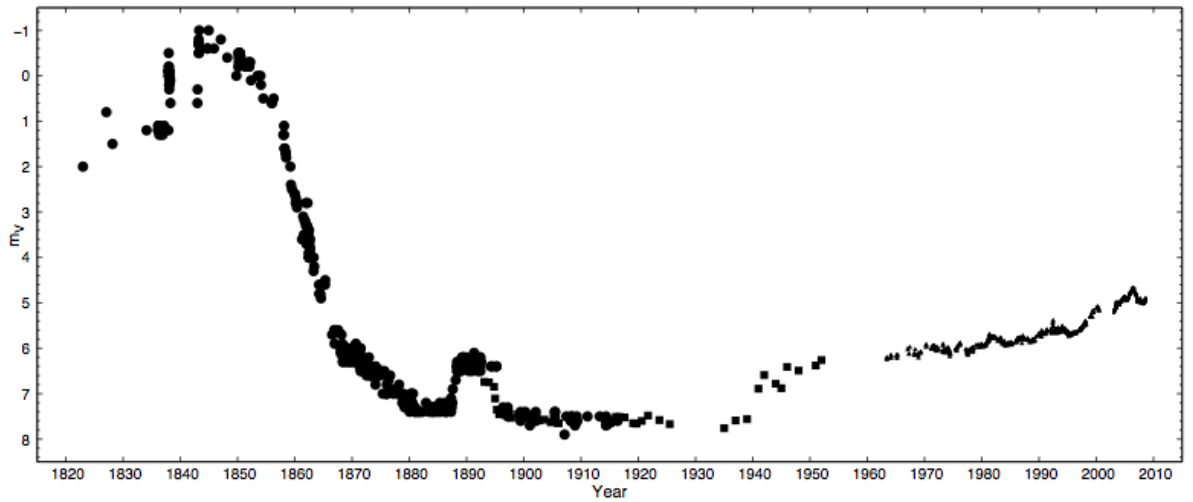


Fig. 3. Light curve of η Car since 1820 until 2008 including visual (●), photographic (■), photoelectric (▲) and our *V* CCD (•) observations. The maximum peak reached in 2006 and the consecutive decline are clearly visible.

Eta Carinae 等の超大質量星の不安定性は、 Eddington Luminosity に近いことが関連していると想定される。

The last explosive event took place in 1840s (and a minor eruption in 1890s). Released 1e49erg of energy.

Eta Carinae： 周期的変動の発見と探索

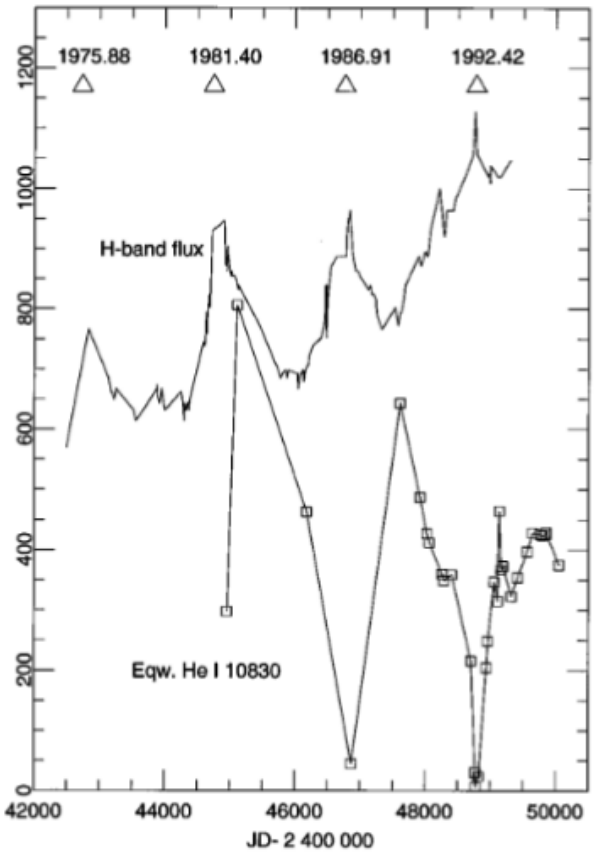
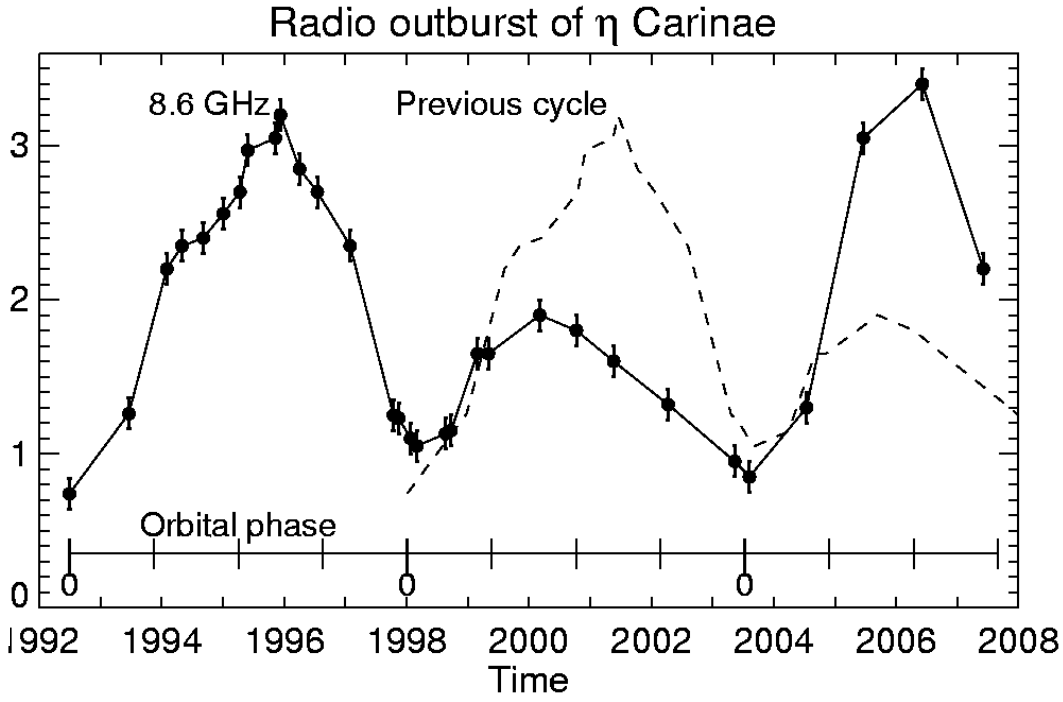


FIG. 1.—*Upper curve*: Flux in the *H* band, in units of 10^{-14} ergs cm^{-2} s^{-1} Å^{-1} data from Whitelock et al. (1994). *Lower curve*: He I W_{eq} = equivalent

周期的変動は見えない物理量の測定に大変有効



一連の発見より、連星系である疑いが持たれる

Eta Carinae： 連星であること

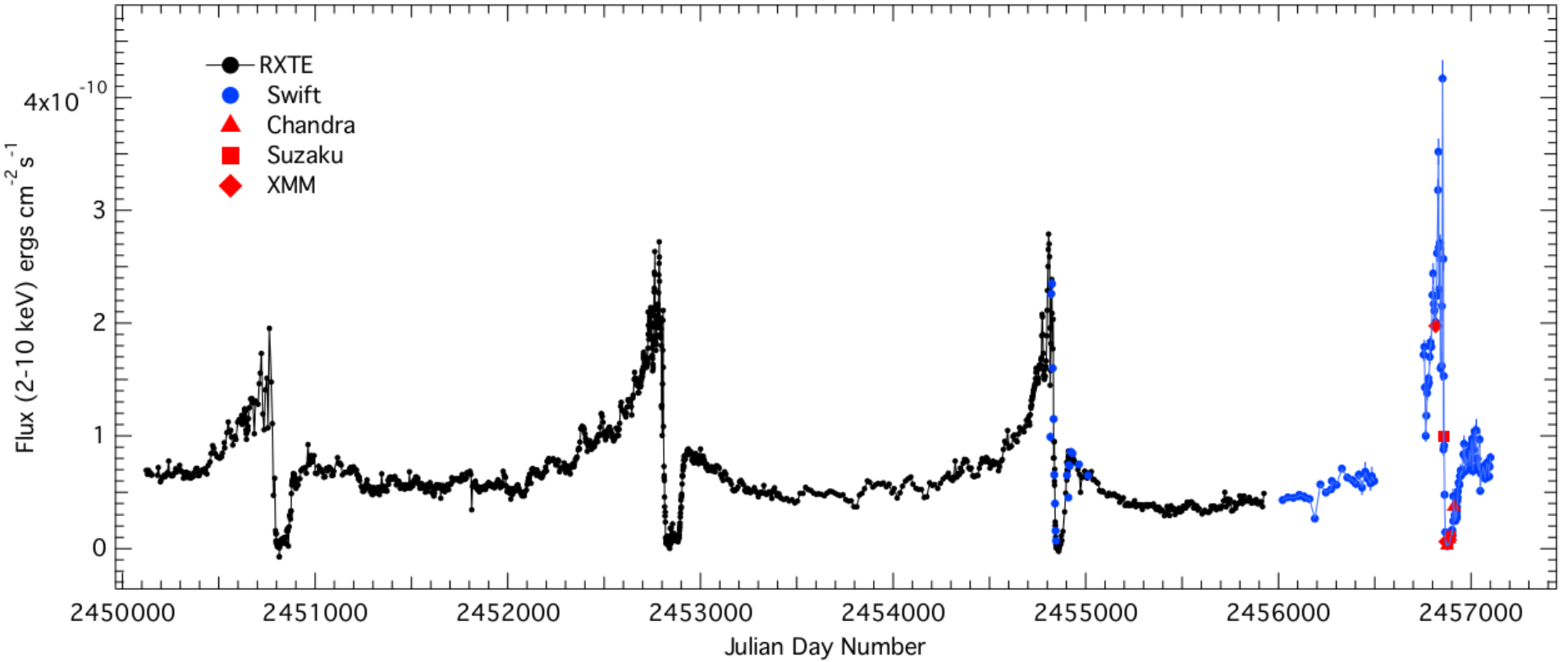
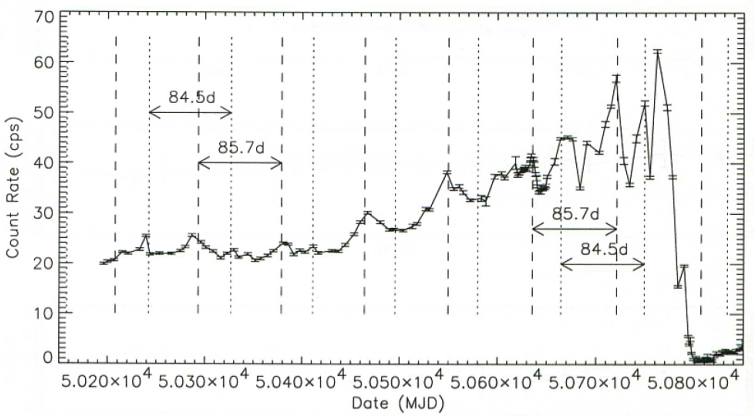
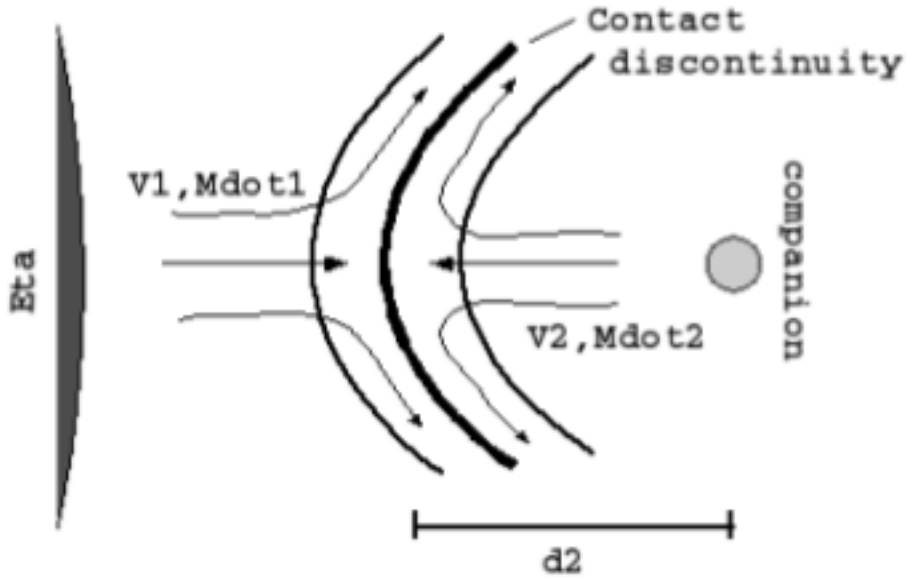


Fig. 2: Flux Variations of η Car, 1996-2014.

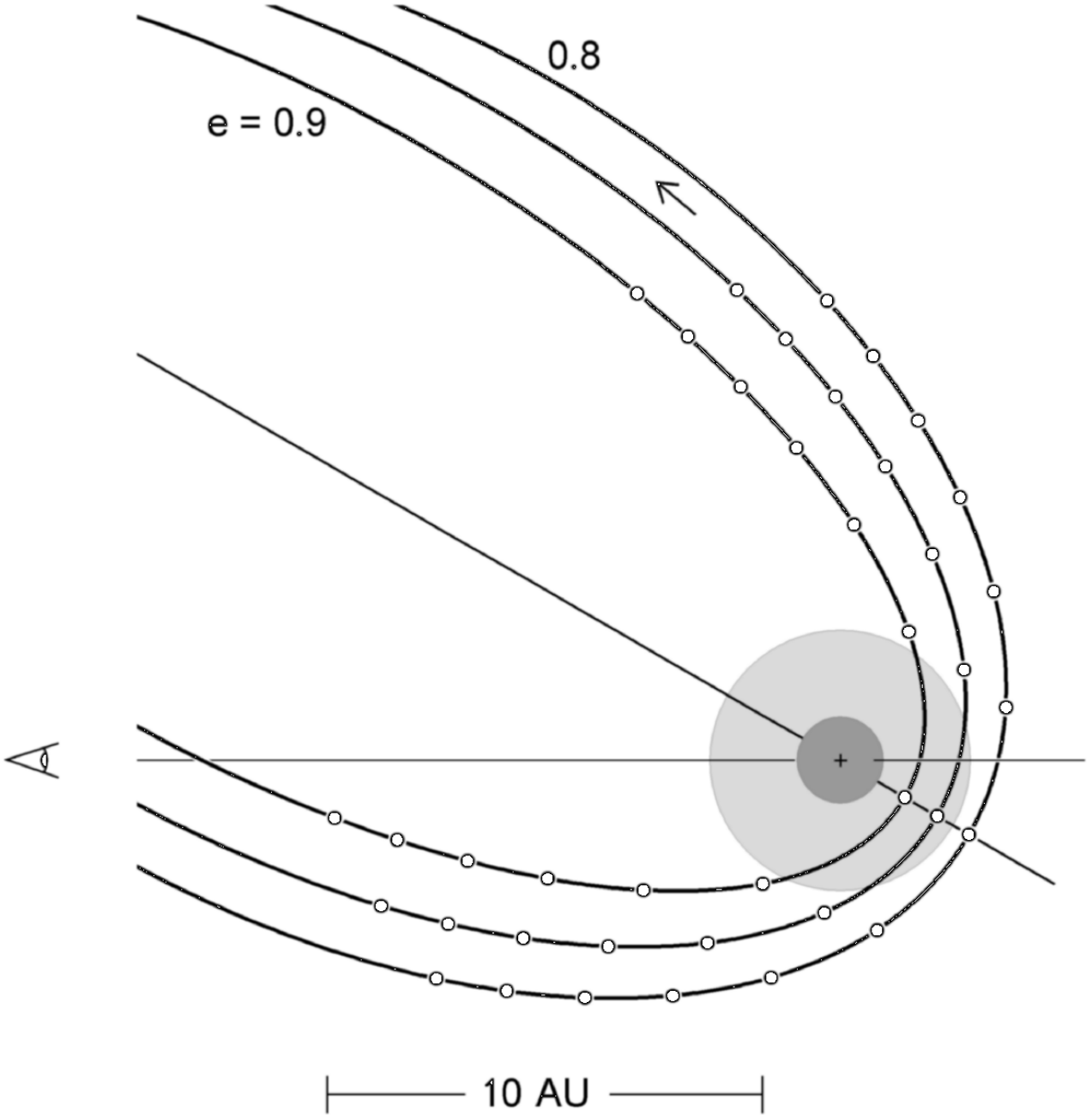


X-ray lightcurve of
Eta Carinae

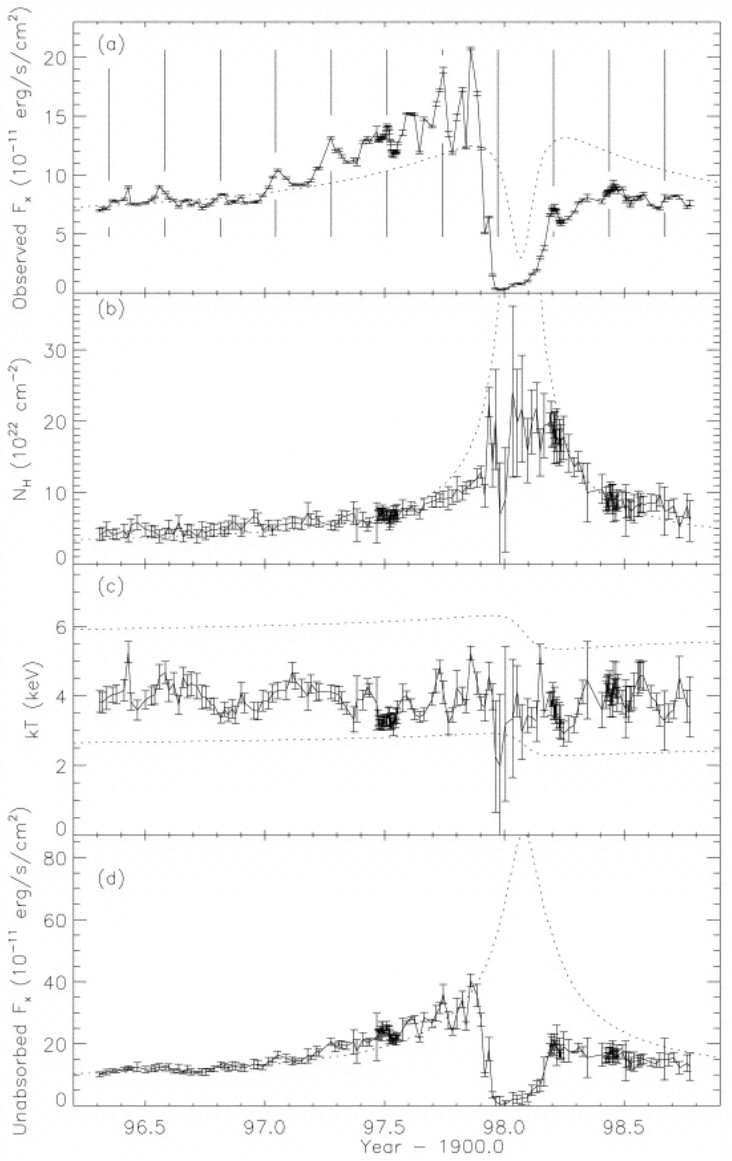
Eta Carinae： 衝突する恒星風と衝撃波



$$L_x \propto \zeta \times \dot{M}_2 v_2^2 \propto \frac{\dot{M}_2}{d_2 T^{3/2}} \times \dot{M}_2 v_2^2 \propto \frac{\dot{M}_2^2}{d_2 v_2} .$$


0.8
e = 0.9
10 AU

Eta Car: 連星であることの証拠

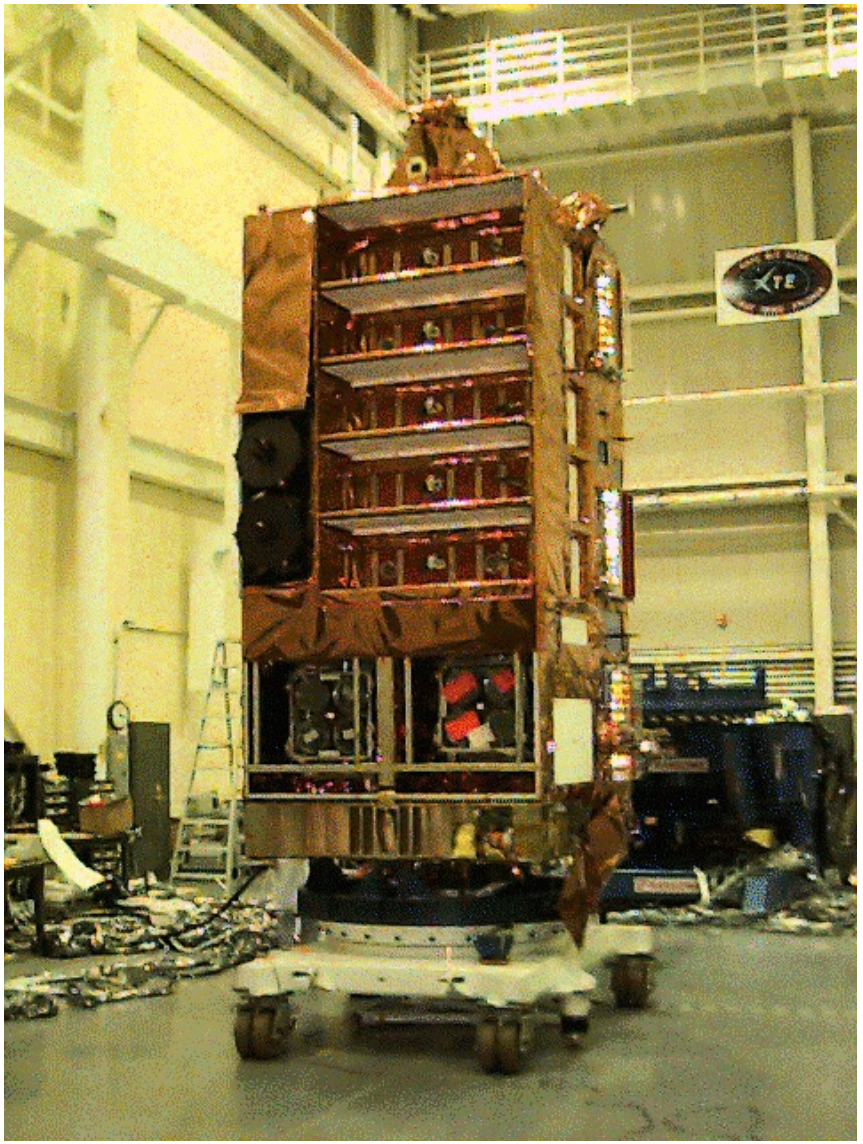


Colliding Wind Model Works.

初めて連星系であることを納得させたとも言われる解析結果。

しかし、これは恒星自体の進化についてあまり深い情報をもたらさない。近年の Eta Carinae の研究は、残念ながらこちらに重点を置きすぎている。

しかし、最も重要なのは恒星である。（岡崎さんの論文も面白い）



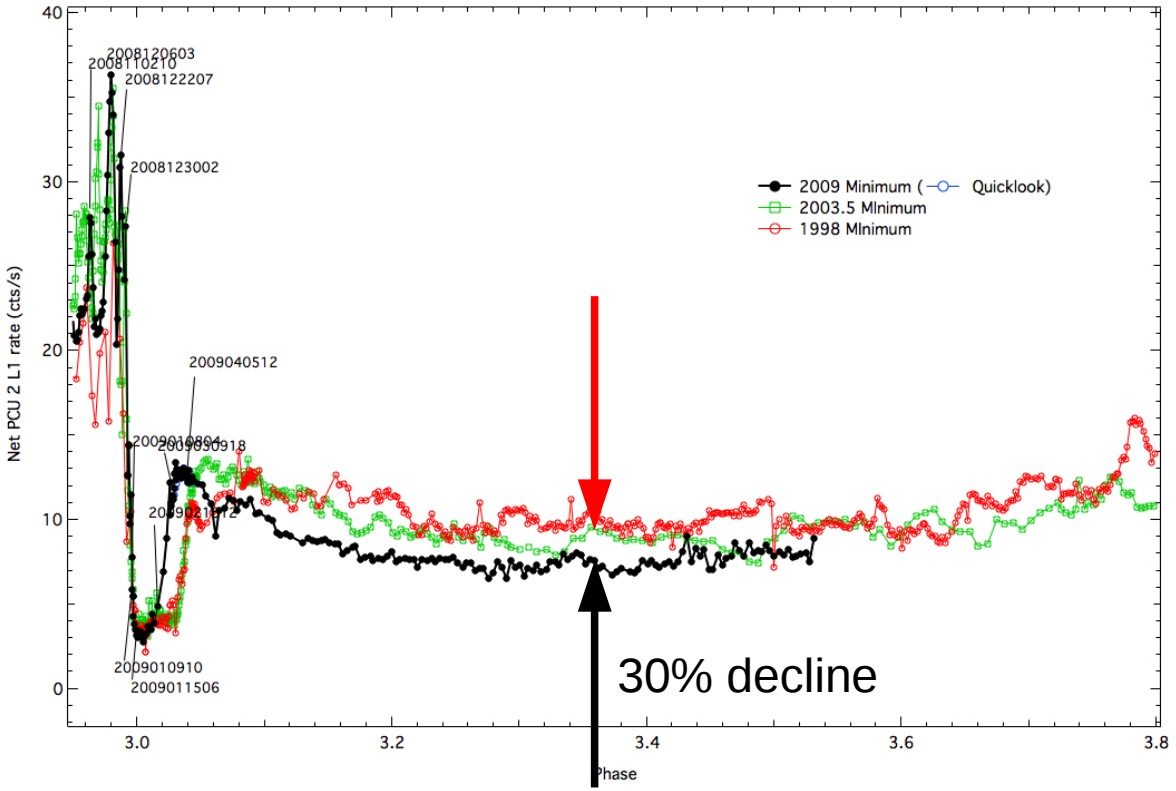
Rossi X-ray Timing Explorer

Proportional Counter Array used

(ガスシンチレータ)

XARM?　さて。。。

Eta Car: 変化する恒星風?



恒星風衝突から発生するＸ線の明るさ:

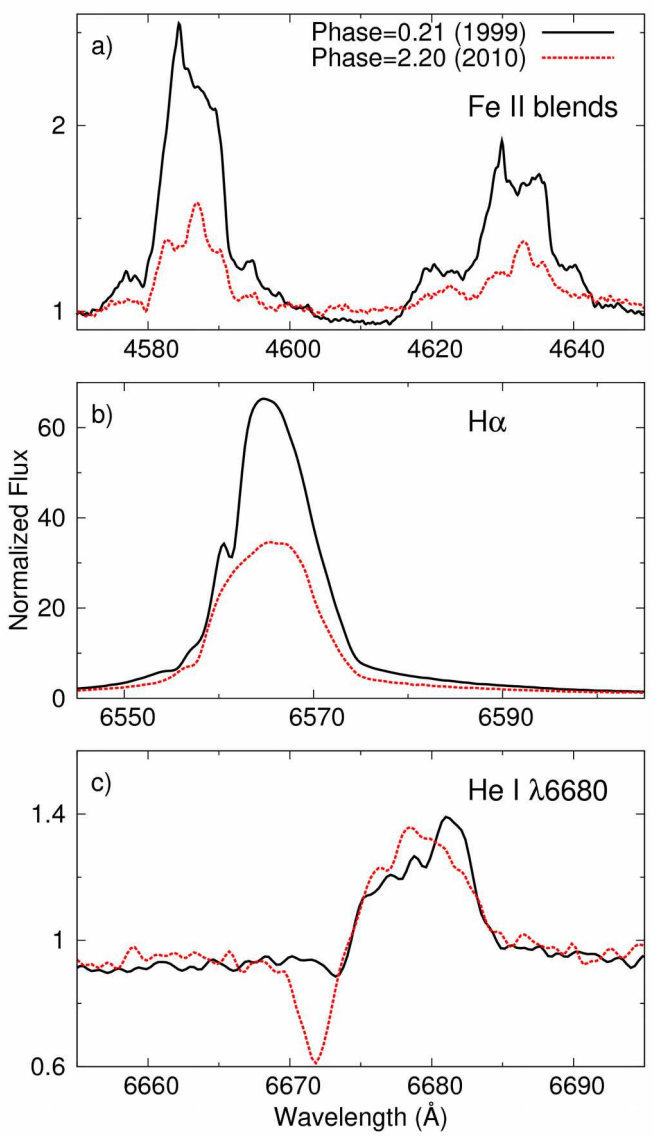
Lx ~ sqrt(Mdot)

光度が 30 %減少するには、恒星風密度を半減させる必要あり。

So the decline in mass loss is likely happening.

http://asd.gsfc.nasa.gov/Michael.Corcoran/eta_car/etacar_rxte_lightcurve/index.html

Eta Car: Out of its 120th year hiatus



Mehner et al. 2010

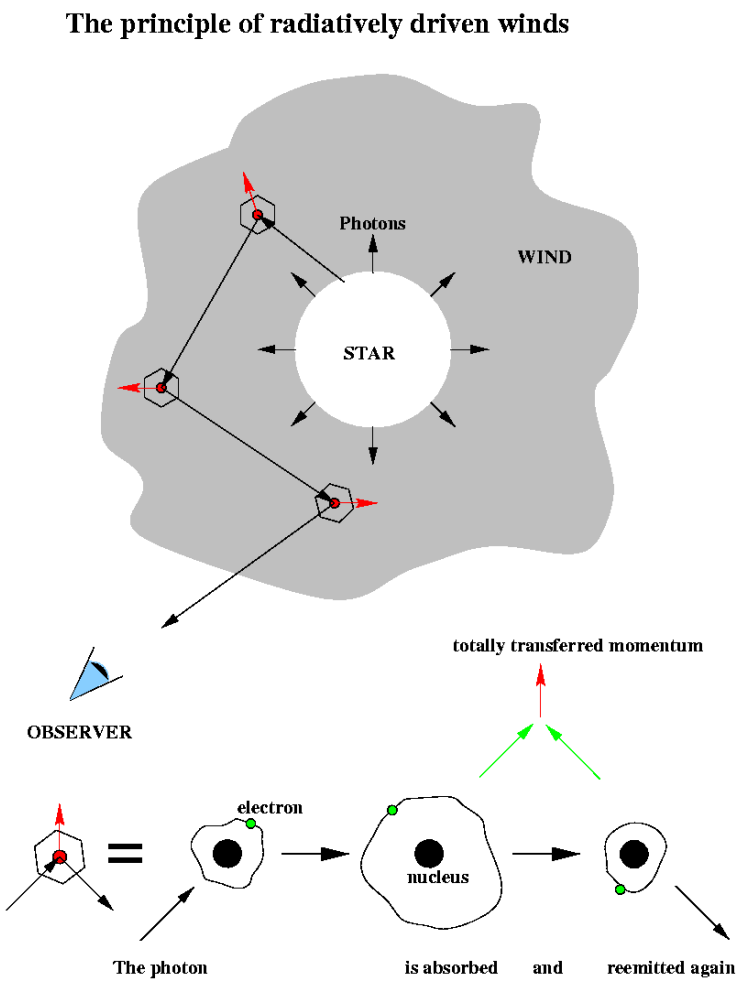
Mehner et al. (2010) discovered that *恒星風起因の輝線がここ 10 年で弱ってきている。 Emission lines are weakening over a decade.*

Prominent hydrogen Balmer lines, FeII, [Fe II] and Cr II lines weakened by a factor of 1.5 ~ 3, whereas He I lines were unchanged.

P Cygni absorption of He I, however, deepened.

赤道領域（視線方向）にて、恒星風起源の幅の広い（５００ km/s ）輝線が弱くなっている。

恒星風の物理



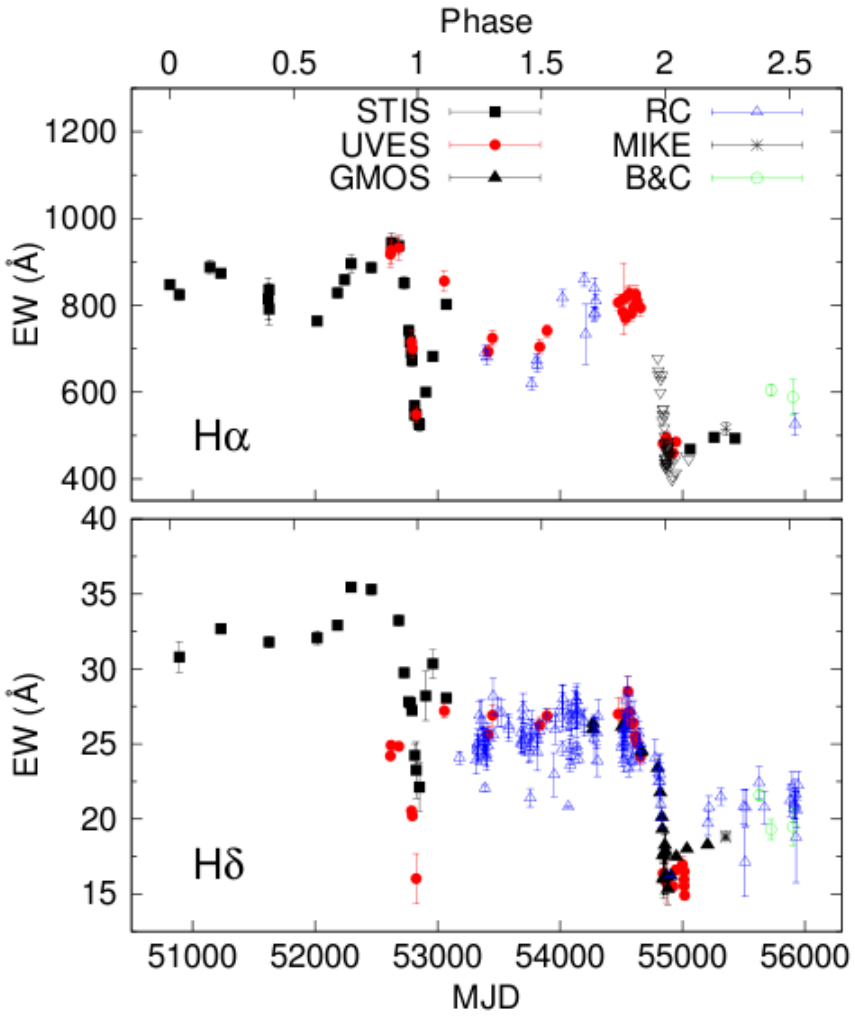
To drive radiatively driven steller wind, we need:

- Ample of ionizing UV photons,
- Resonance scatter with metals [C IV, Si IV, N V, etc.] to enhance momentum transfer from photons to atoms
- Abundance of metals (from CNO cycle, more or less)

強い紫外線が出ると金属が多い大気では風がふく。（太陽風とは別物！）

http://www.ifa.hawaii.edu/~kud/windsfromhotstars/hotwinds.html

Eta Car: 変化する恒星風



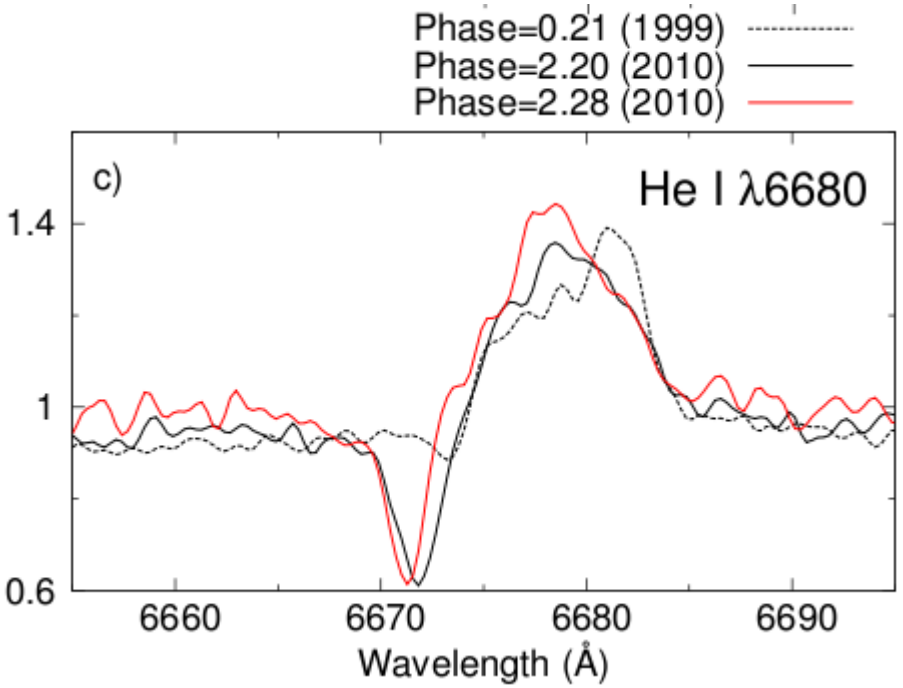
Mehner et al. 2012, in review

The weakening of wind emissions has occurred *discretely*?

The rate of decline implies the decline in mass loss rate by a factor of 2.

恒星風にて運ばれる質量は、ガクッと減ったように見える（半減？）。そのタイミングは、 5.52 年周期と一致する。

Eta Car: 恒星風が薄くなると。。。



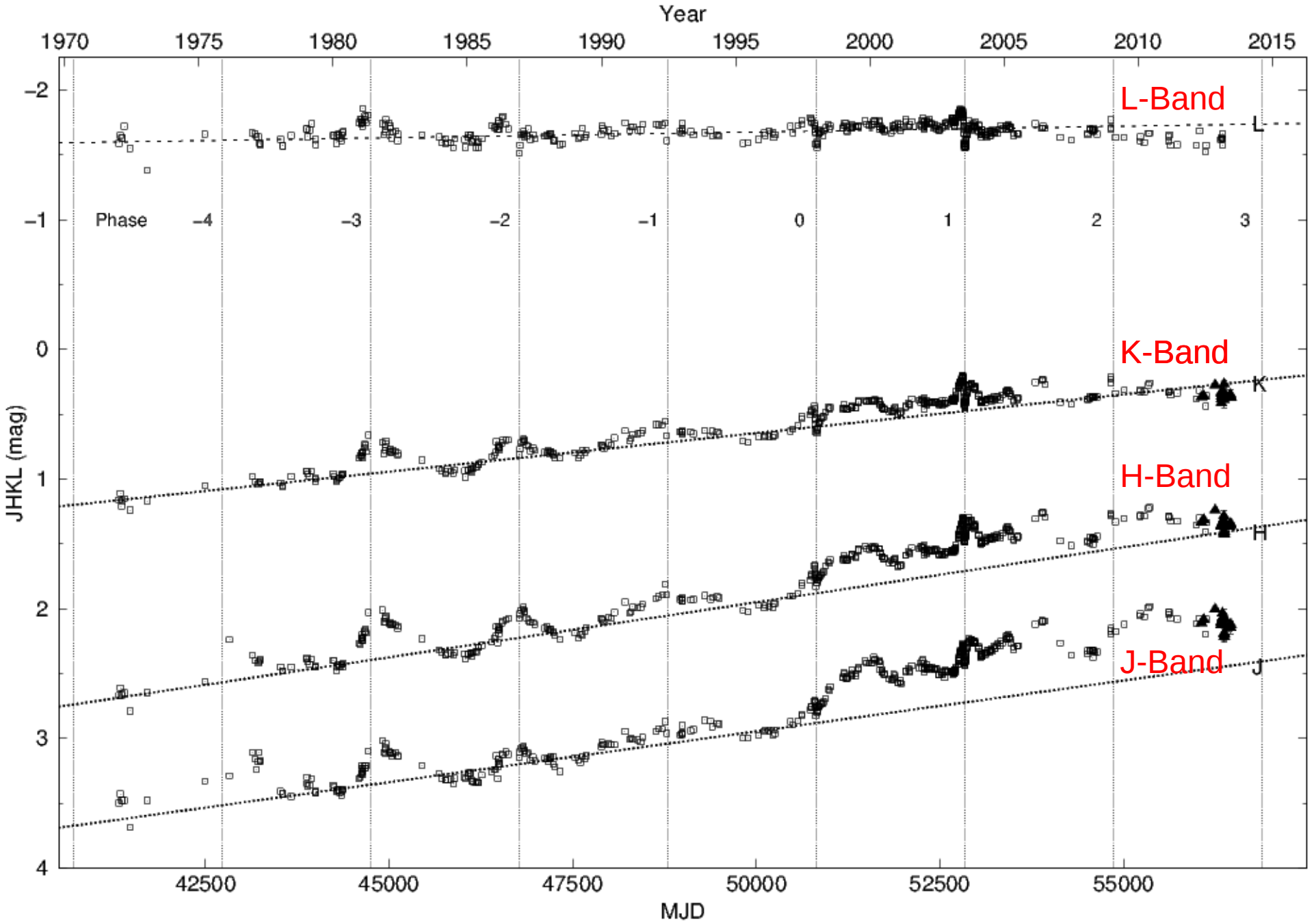
Mehner et al. 2012, in review

Deeper P Cygni absorption in He I lines, while declining the density of its wind, is *not* a problem.

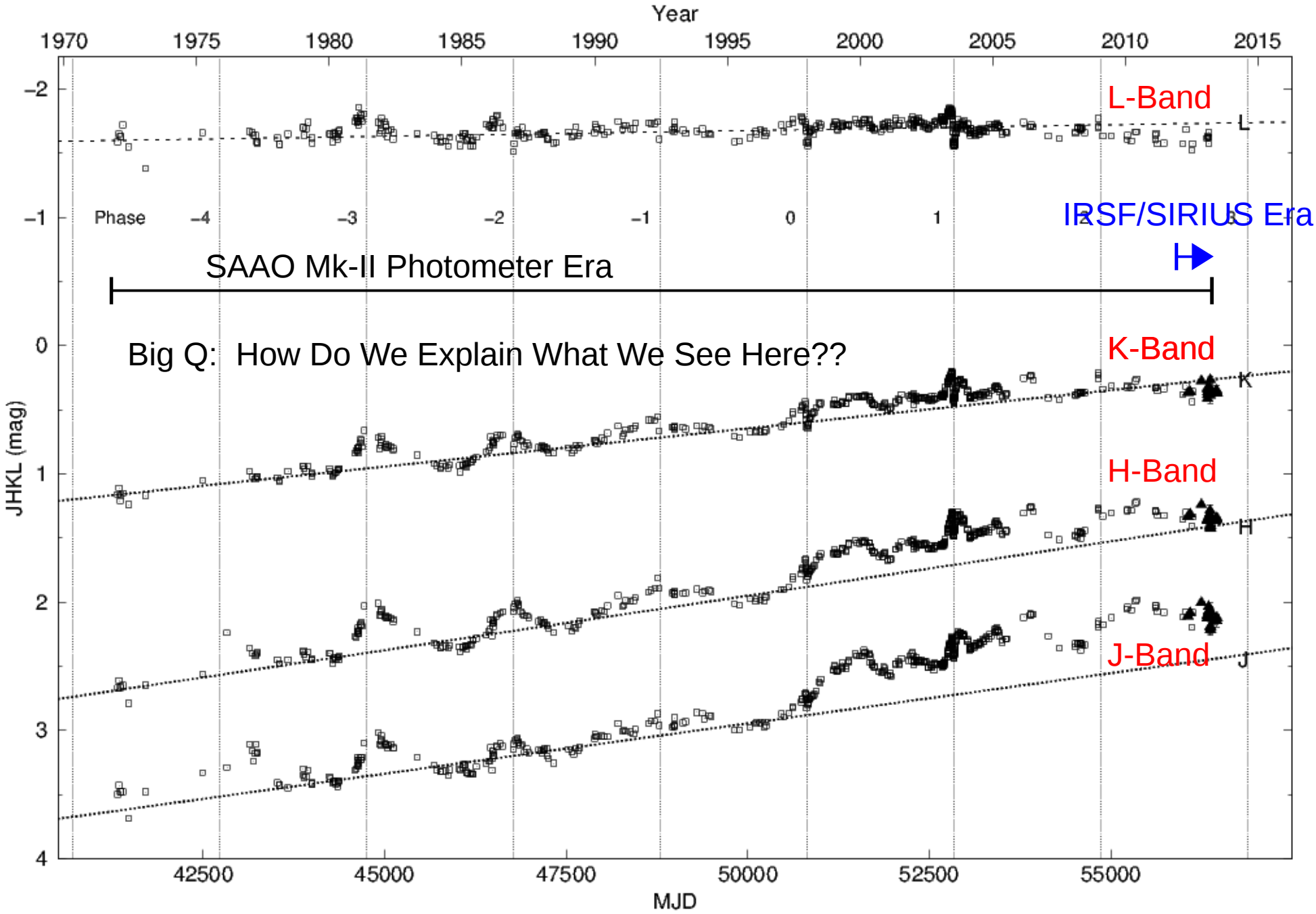
The Population of $n(He^+ + He^0)$ influences the degree of absorption more than $n(He^0)$ alone, since He I λ6680 originates from highly excited energy level, i.e., *easier to ionize first and then balance recommbination and excitation afterward to form P Cygni absorption.*

He I で P Cygni 吸収線が見えるのは、視線方向の Helium の密度が増えたのでなく、 He II の（ ion 化した）密度が増えた為。

Eta Carinae： 近赤外物語（測光観測）



Eta Carinae： 長期間観測が教えてくれること



Near IR observations

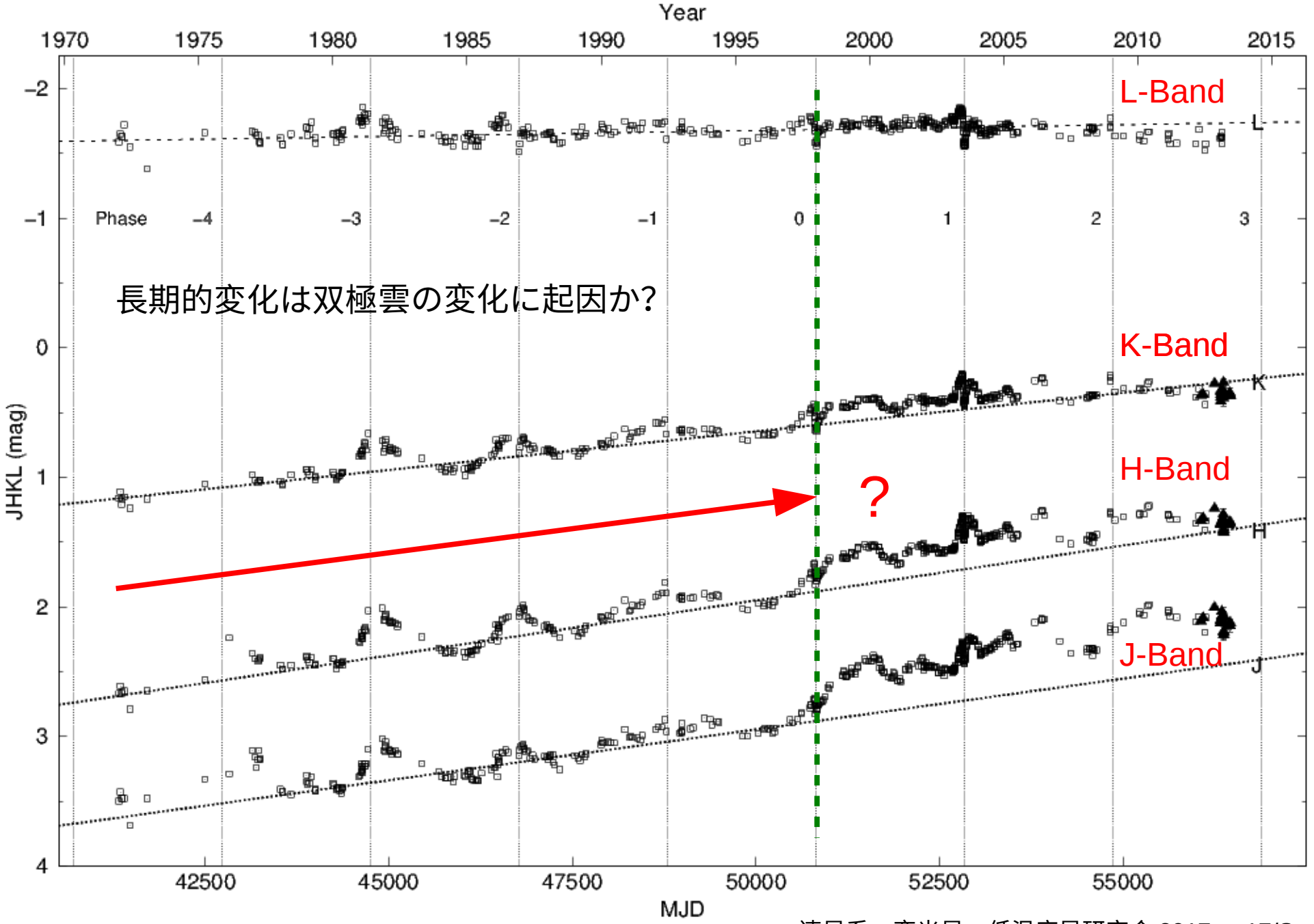
- SAAO Mk-II photometer (JHKL bands)
  See Whitelock et al. (2004)

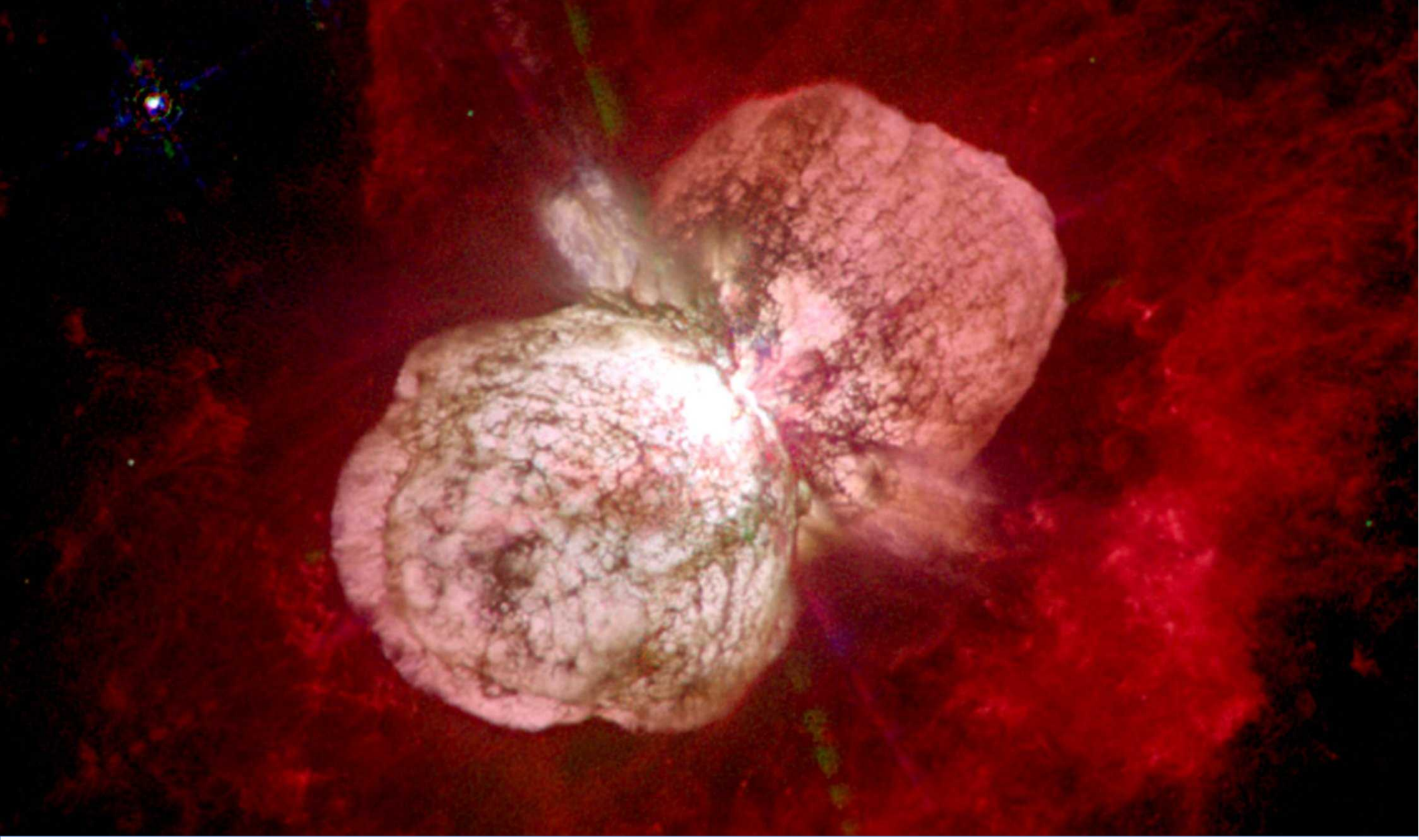
- IRSF/SIRIUS photometry (JHKs bands)
  - Use of two ND filters (1%+10% or 1%+1%)
  - Use of an occulting filter (see Nagayama)
  - Standard stars: BS4450 & BS4382
  - IRAF standard processing package used

SAAO Mk-II to be decommissioned in Sept. 2014...

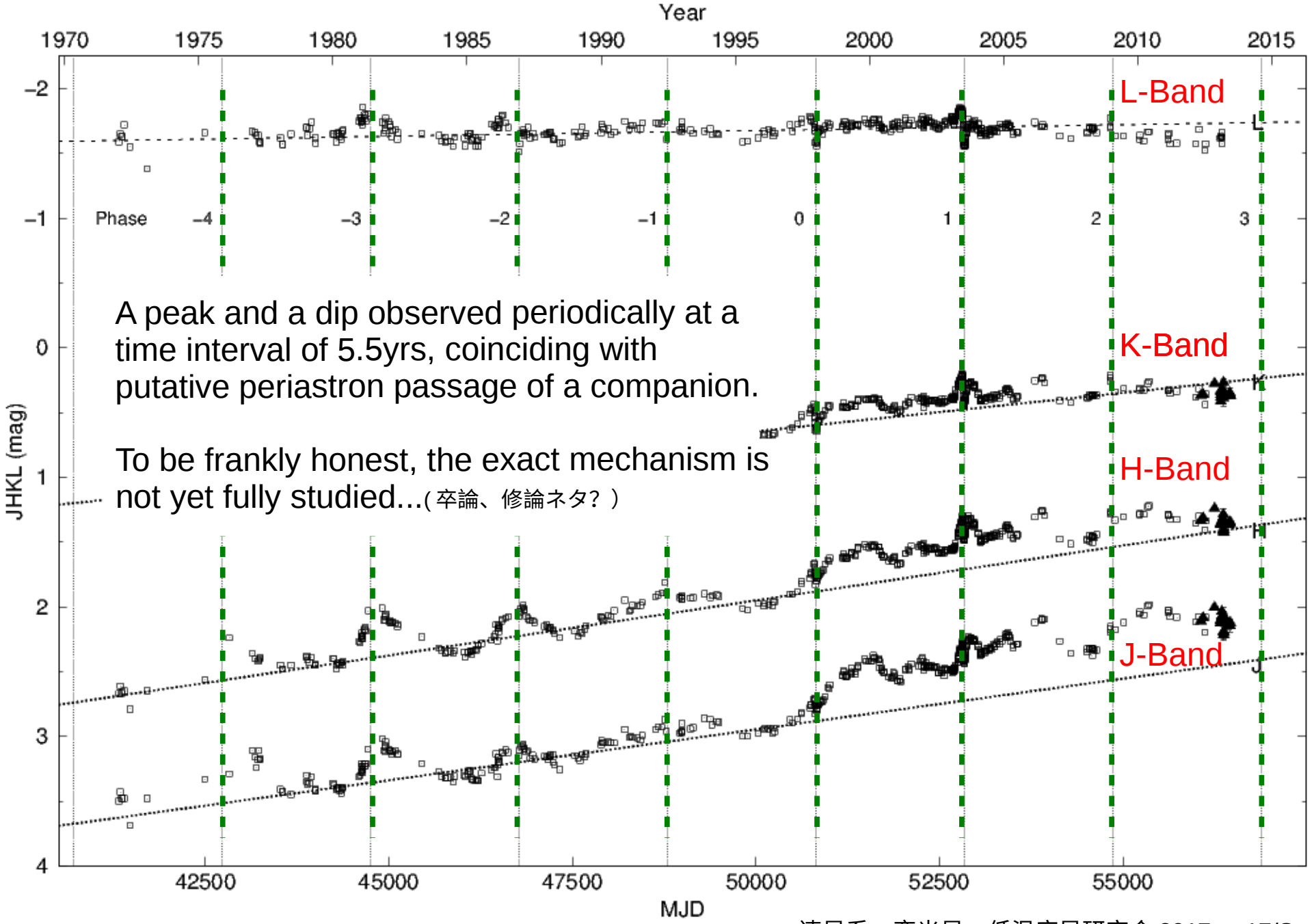
IRSF will hold the key for continuous monitoring of eta Car in NIR.

NIR Light Curve: Long-Term Secular Increase

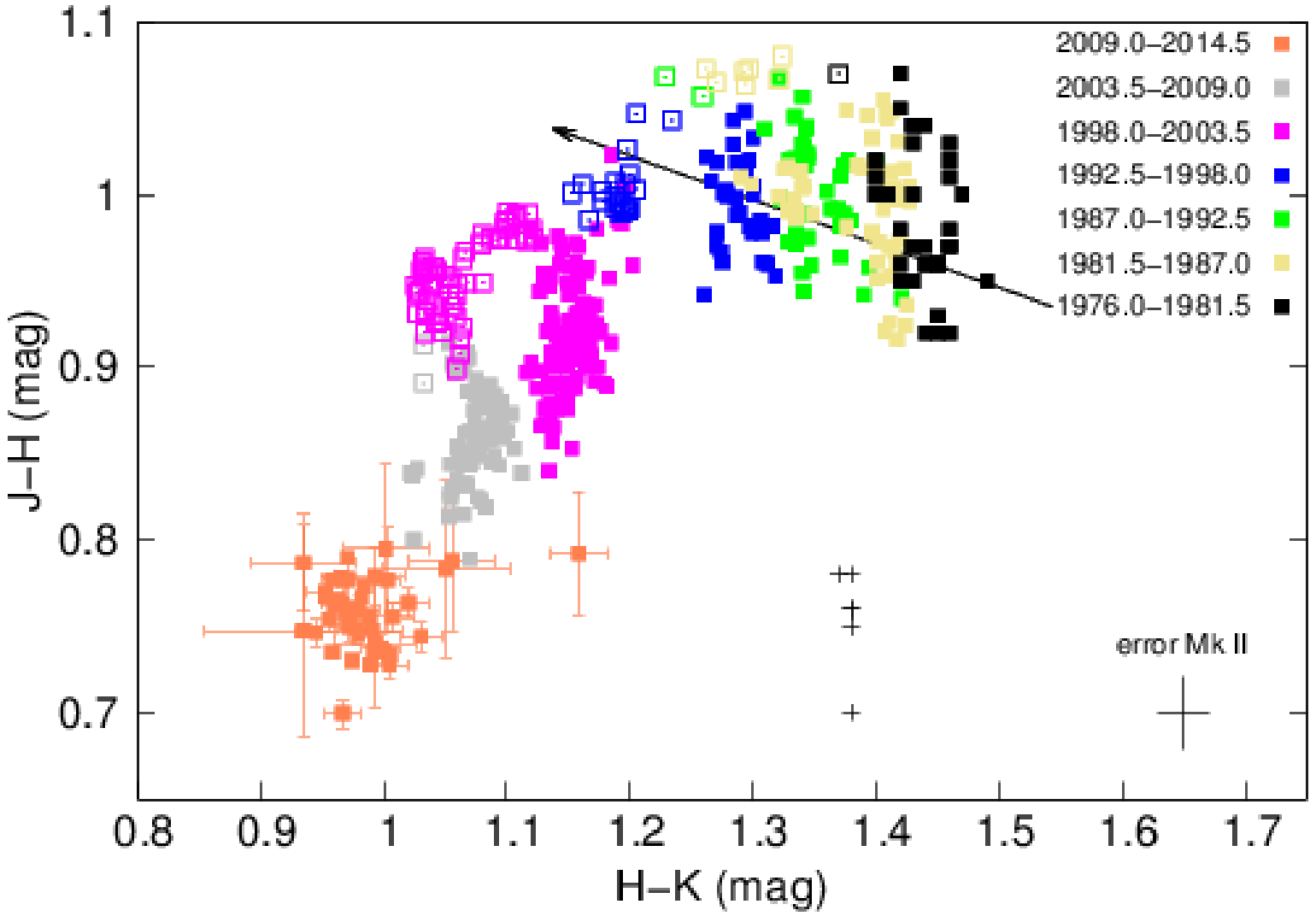




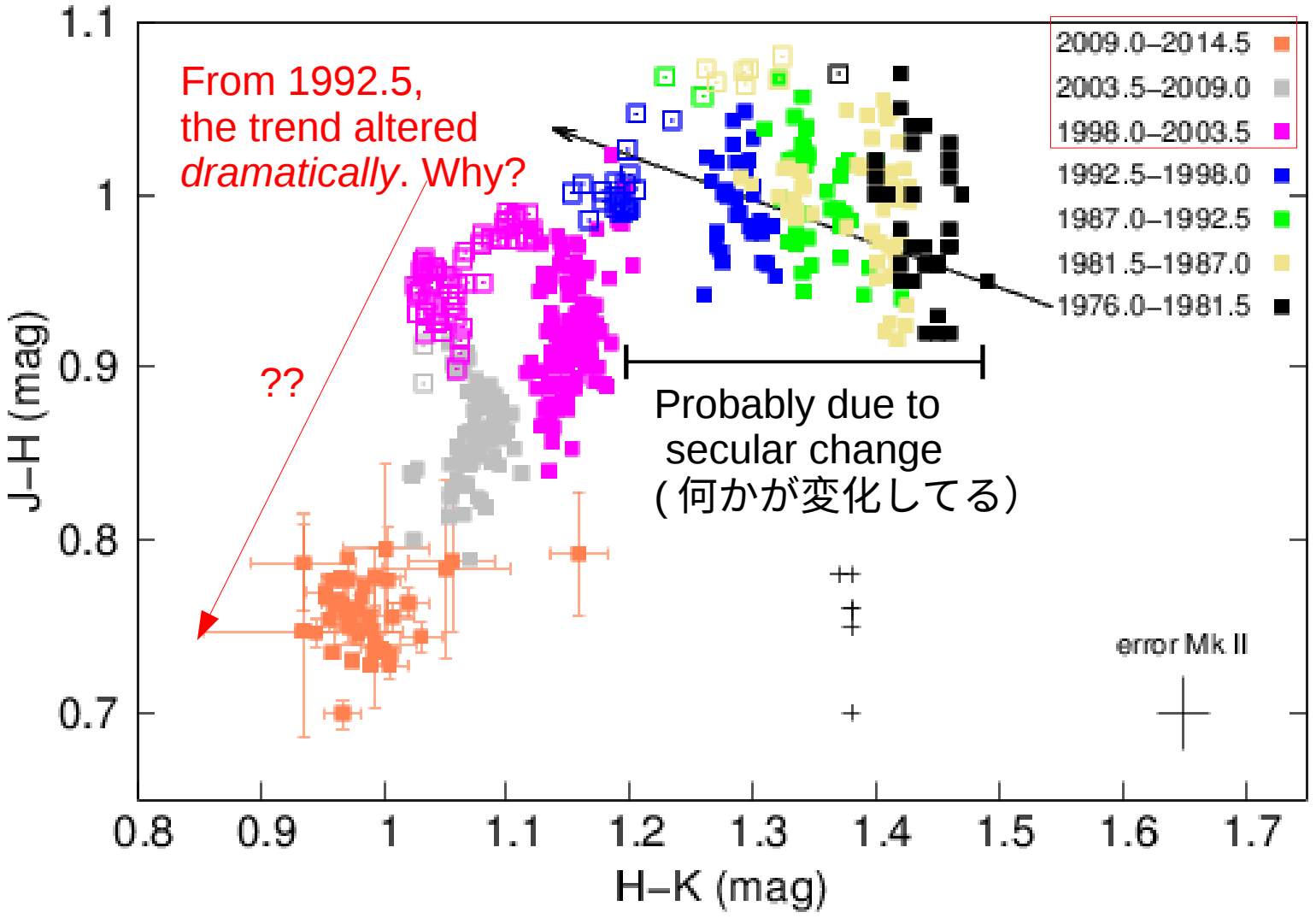
NIR Light Curve: Binary-Related Variabilities



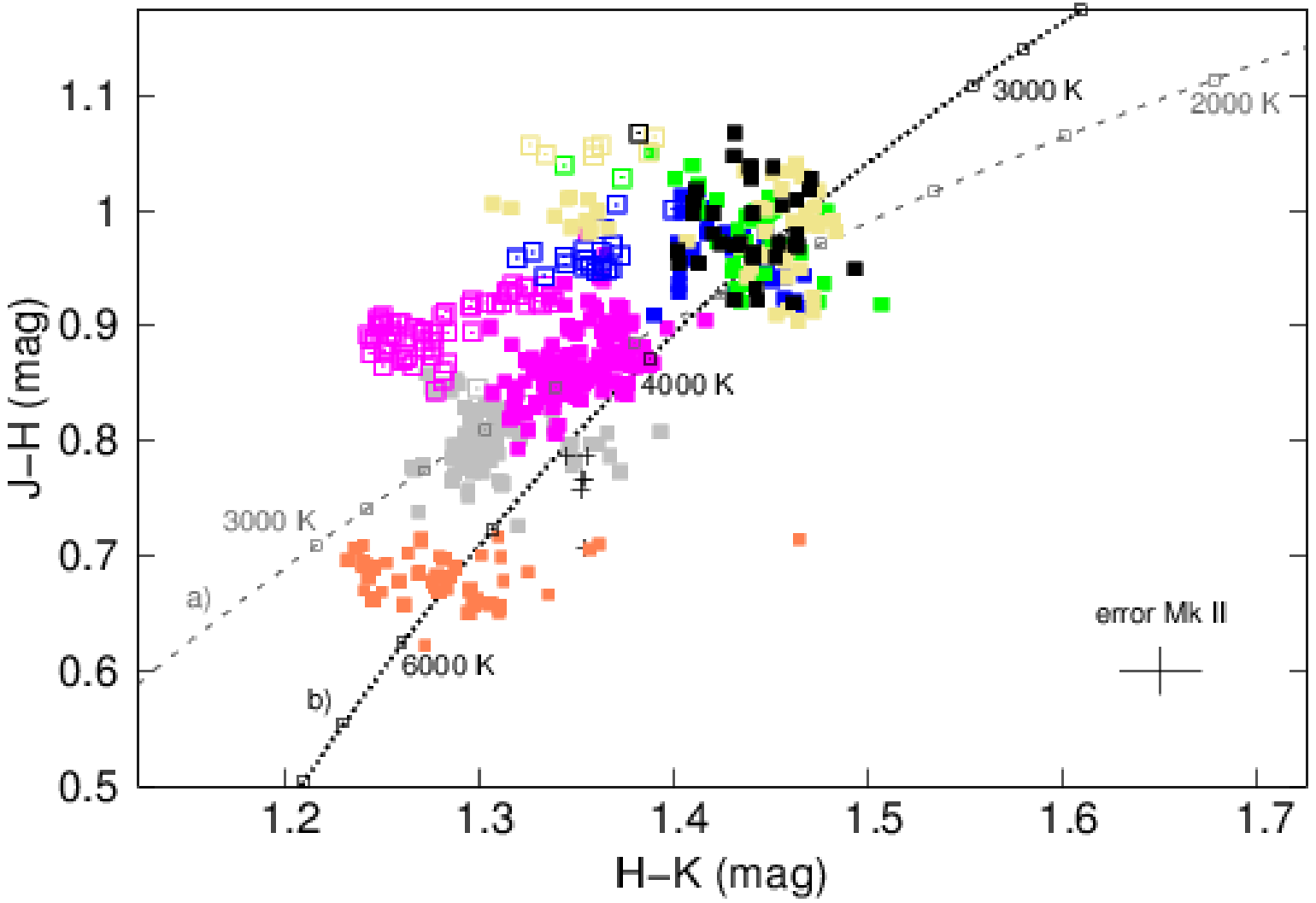
Eta Carinae: 近赤外　色ー色図?



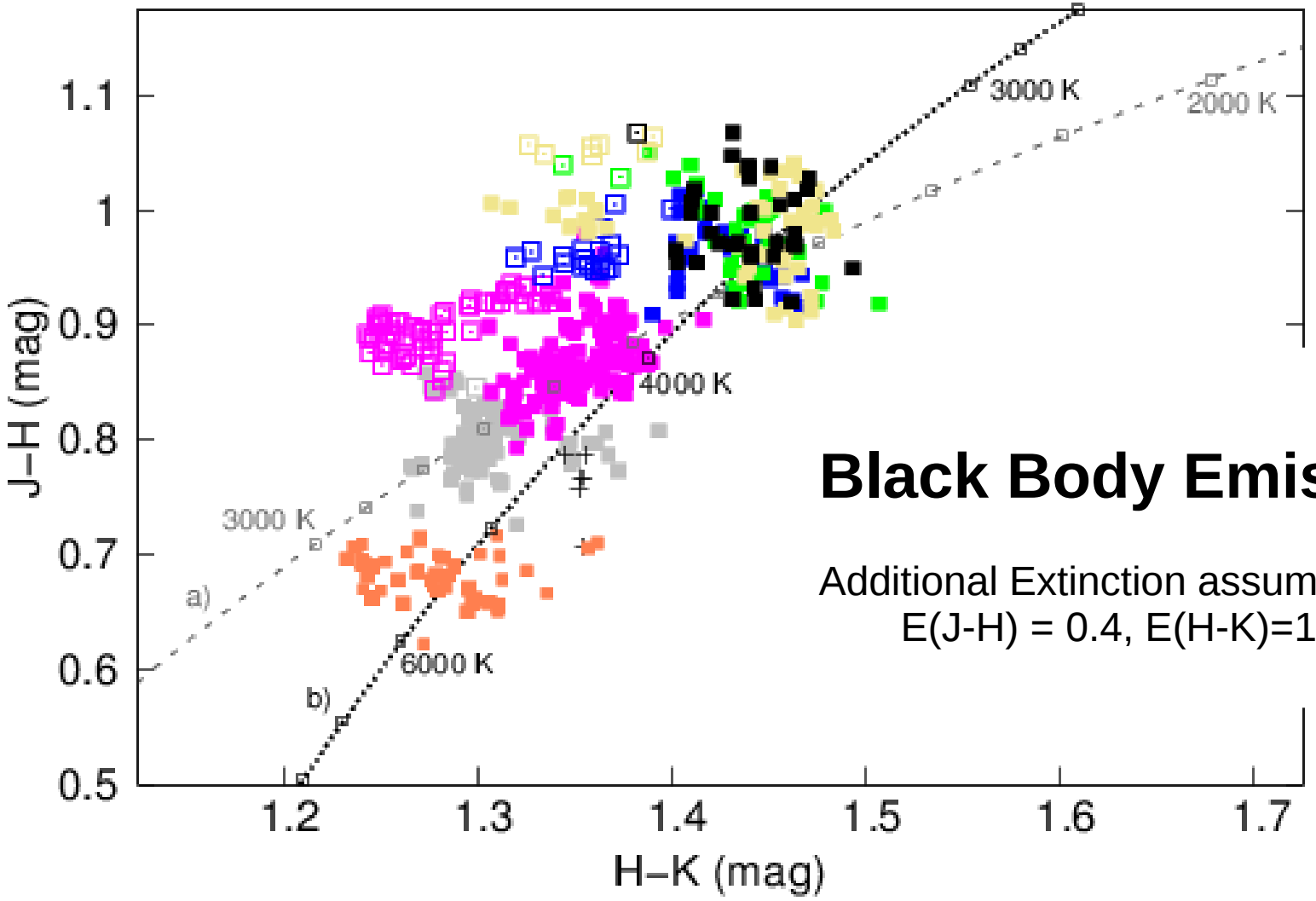
NIR Color-Color Magnitude Diagram



Extinction-Corrected J-H vs. H-K Diagram



Extinction-Corrected J-H vs. H-K Diagram



Black Body Emission ?

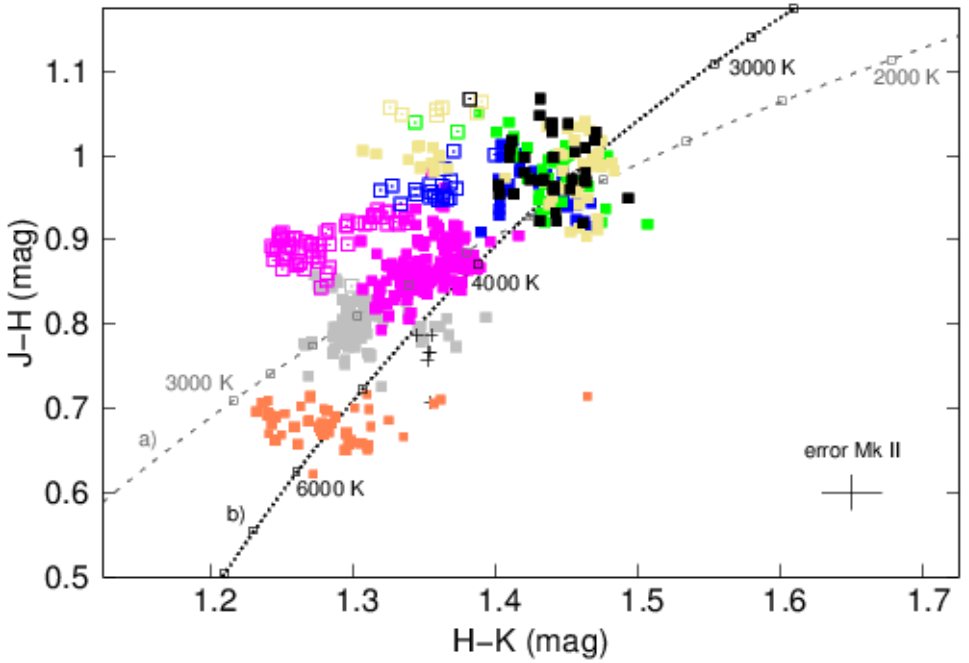
Additional Extinction assumed:
E(J-H) = 0.4, E(H-K)=1.2mag

Let Our Imagination Go Wild...

ダスト生成で説明されていた近赤外の変動だが、、、その物理的可能性は低い。 Ionizing Uv が強すぎるからである。

But, think about it.

Eta Car is freakishly bright and ionizing UV photons permeate through massive winds within 150 A.U....no way that newly formed dust would exist within that radius.



Dust scenario just doesn't work (wrong timescale, wrong location).

It seems more probable that NIR emission originates from thermal plasma near eta Car (or its stellar wind). *And the star is getting hotter*.

どうも星の温度自体が上がってる?

Let Our Imagination Go Wilder...

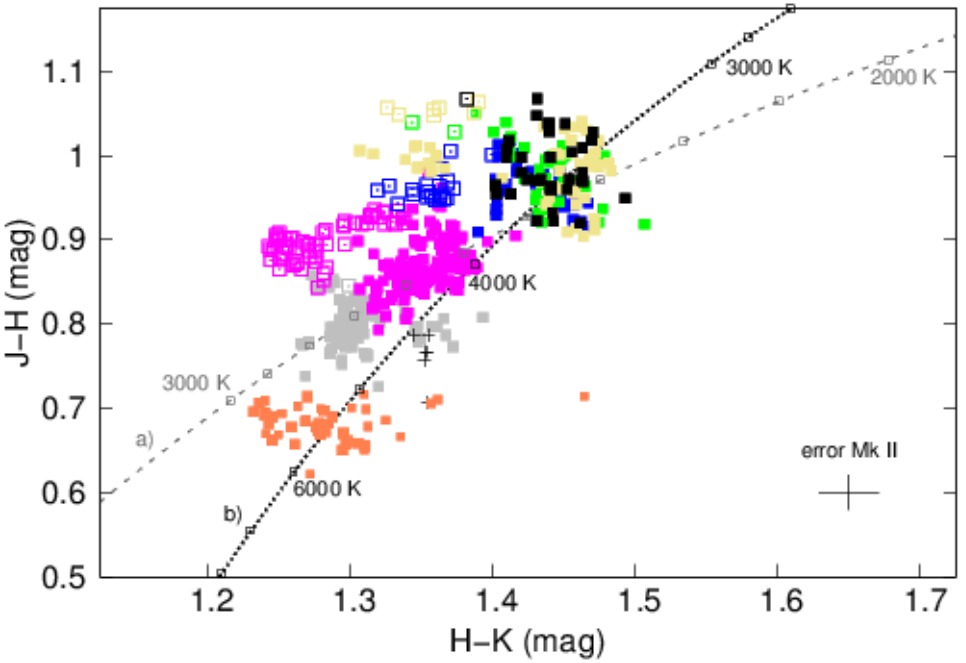
Then, what makes the star hotter?

温度上昇は、*自転速度の上昇*が関係しているのではないか？潮汐力が近星点通過の際に自転速度を増加させる可能性あり？

A tidal force from a putative companion star acts upon eta Car enough that it impulsively spins up the rotational velocity.

Eventually, the rotational velocity reaches its critical rotation limit (~240km/s) and all sorts of weird instabilities could kick in.

The orbital velocity of the companion at periastron is expected to be around 300km/s.



Discrete, impulsive spinning of eta Car by the companion could explain:

- Discrete, periodic changes in its wind properties
- Faster rotation could induce a lower mass loss rate,
  hence exposing hotter (naked) stellar atmosphere (i.e., lower opacity in wind).

Let Our Imagination Go Wildest...

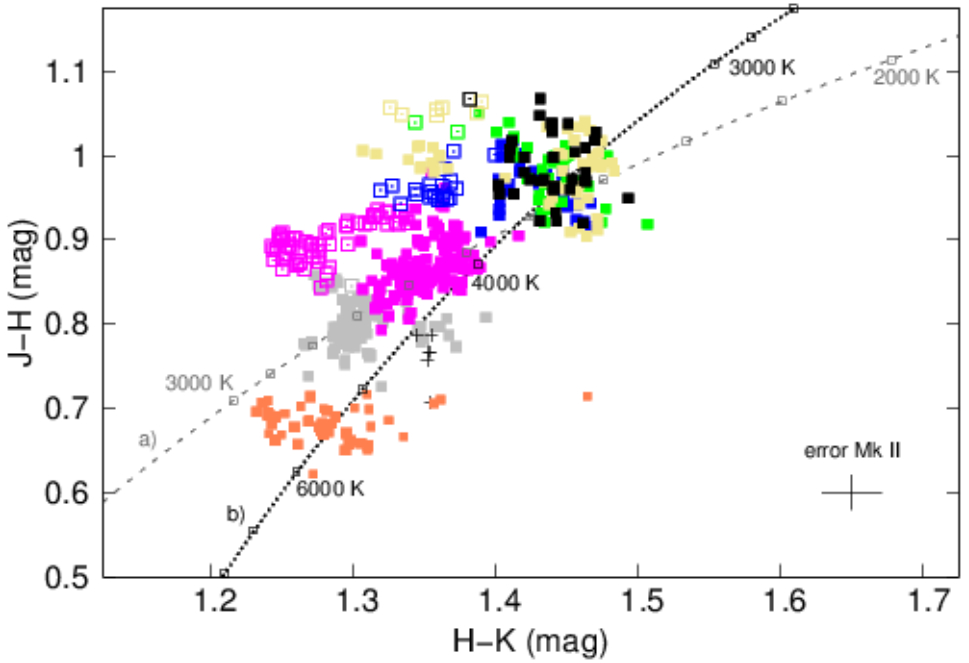
1840 年クラスの爆発現象の予兆か?

In a long run, sure, that is probably true. :-)

It is hypothesized that eta Car reached its critical rotation limit in 1992.5 and started showing the sign of rotational instabilities.

自転速度上昇による不安定性が存在するのか? それが爆発現象を引き起こす可能性は興味深い研究テーマになりうる。

Combined with its internal instability (unique to LBVs), a major eruption is imperative in near future.



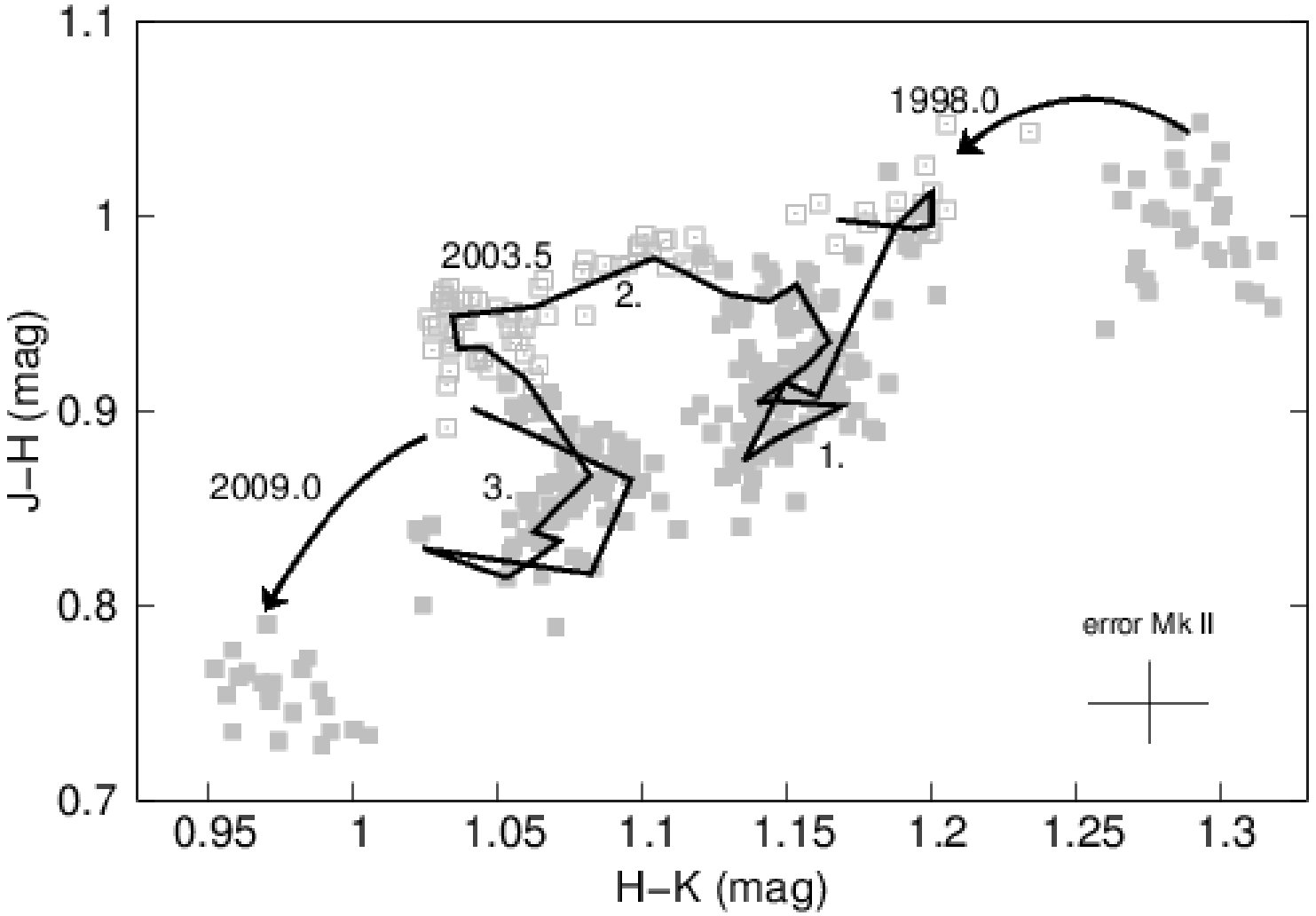
When will it erupt? いつ爆発しうるのか?

不明! でも、次のイベントは 2020 年に予定。宇宙花火が見られるか?

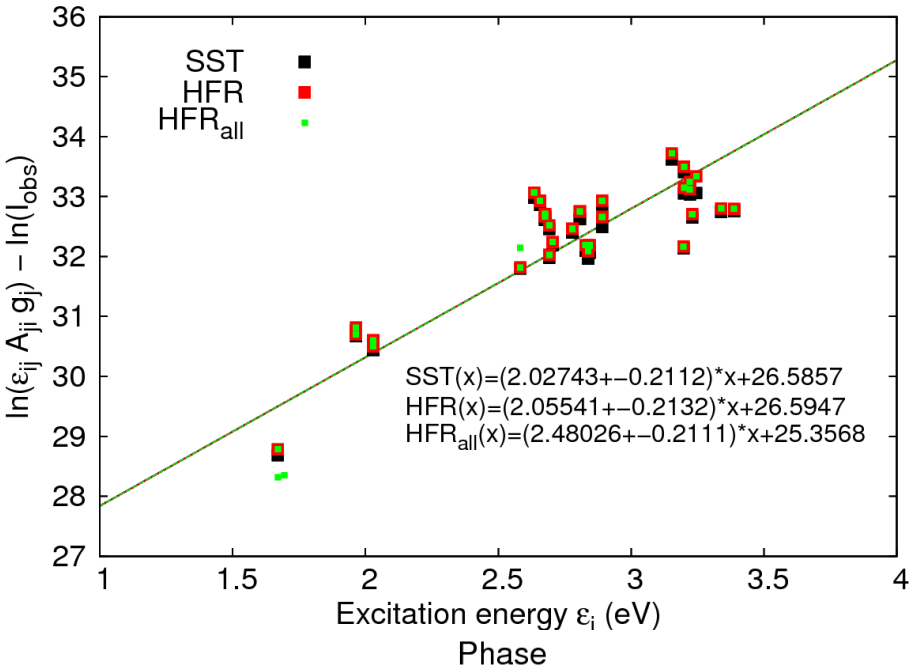
We need your helping hands to keep eyes on the star throughout this event!!

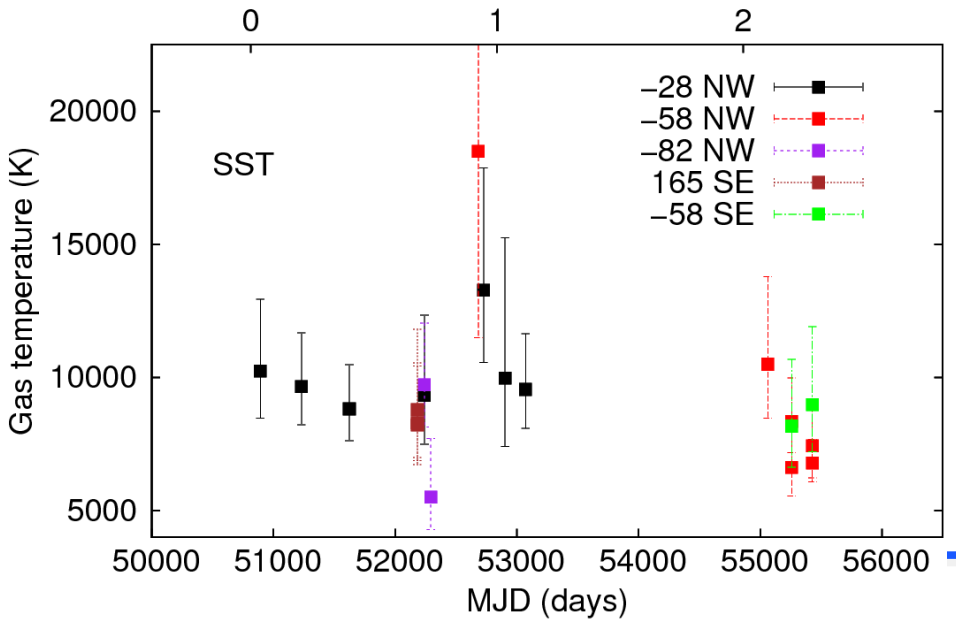
Back-up Slides

Eta Carinae: Periodic Changes in NIR C-C Plot



Eta Car: No Changes in Ionization





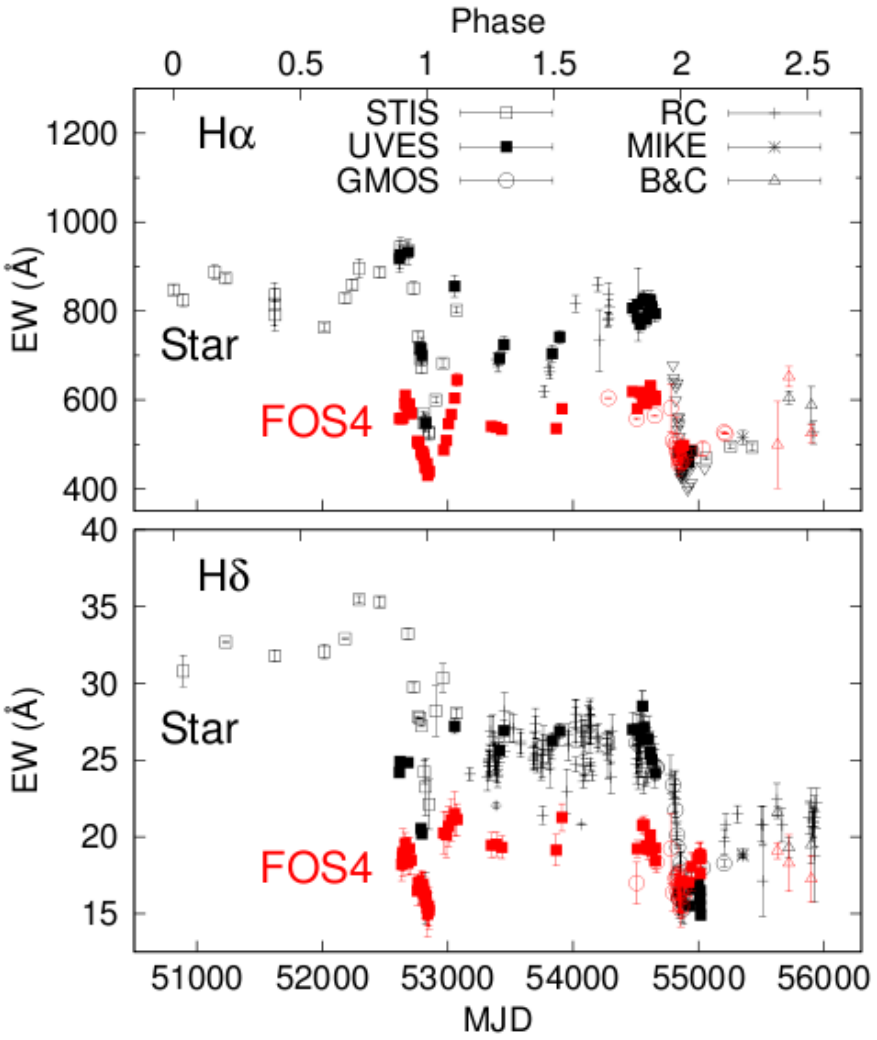
In the polar direction, a nested bipolar nebula (little Homunculus, a.k.a. LH) intersects ionizing photons from the star(s) and re-radiates as it reaches its own LTE.

The electron temperature of LH shows *no significant secular changes*.

This result can be inferred from plasma
diagnostics of permitted and forbidden Fe II
in assumption that LTE is achieved.

Ishibashi & Mehner 2012, in prep.

Eta Car: *Not* Thinning its Wind *in Poles*



Mehner et al. 2012, in review

However...

In the polar direction (along the major axis of the Homunculus Nebula), the reflected emission of the star itself shows *no clear and vivid changes in wind emissions.*

極方向（FOS 4）では、恒星風起源の輝線の強さ（Equivalent Width）が同等の変化を見せていない。