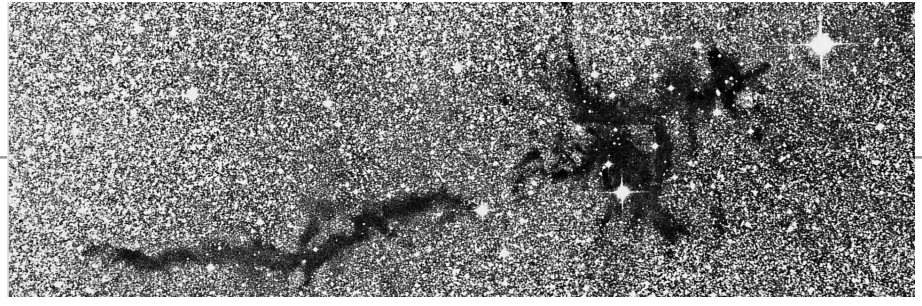
V346 Normae: the post-outburst life of a FUor



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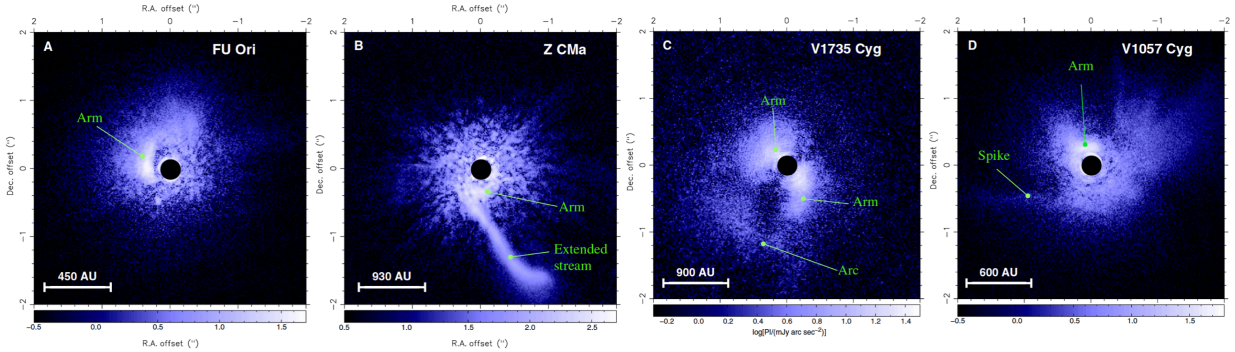
Ágnes Kóspál, Zsófia M. Szabó, Fernando Cruz-Saénz de Miera, Stefan Kraus, Philip W. Lucas, György Mező, Carlos Contreras Peña, Michihiro Takami, Andrzej Udalski, Jacob A. White

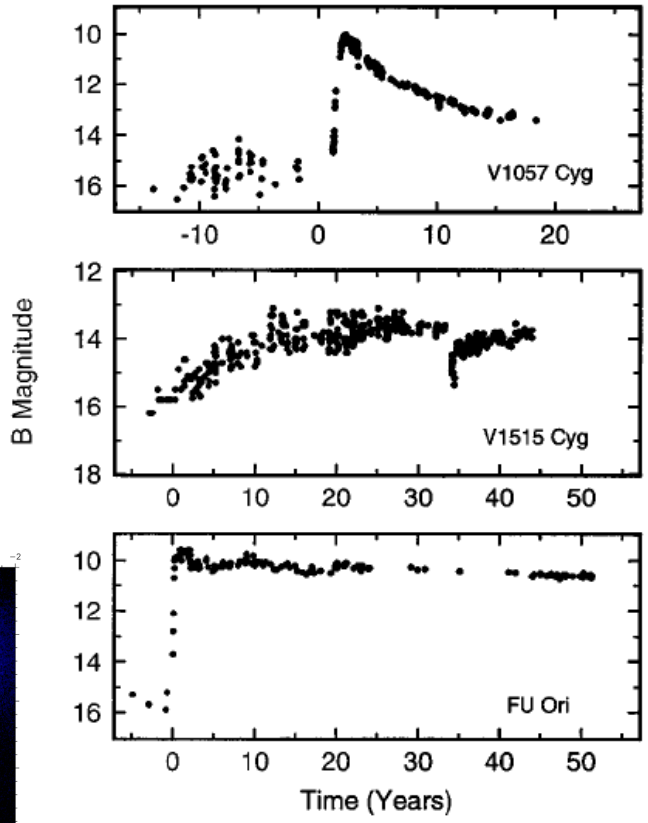
Great barriers in planet formation, Palm Cove, 2019 July 24

FU Orionis-type stars (FUors)

- Young (Class I, Flat spectrum, Class II) stars with large outburst (4-5^{m}) in optical light (Herbig 1966, 1977).
- Outburst lightcurves are heterogeneous
- Reflection nebula, infrared excess
- Spectral type: F-G supergiant (optical), K-M giant or supergiant (near-infrared)
- Special spectroscopic features: blueshifted absorption in Balmer lines, CO bandhead in absorption,...
- Bona fide FUors ~15 (Connelley et al. 2018)

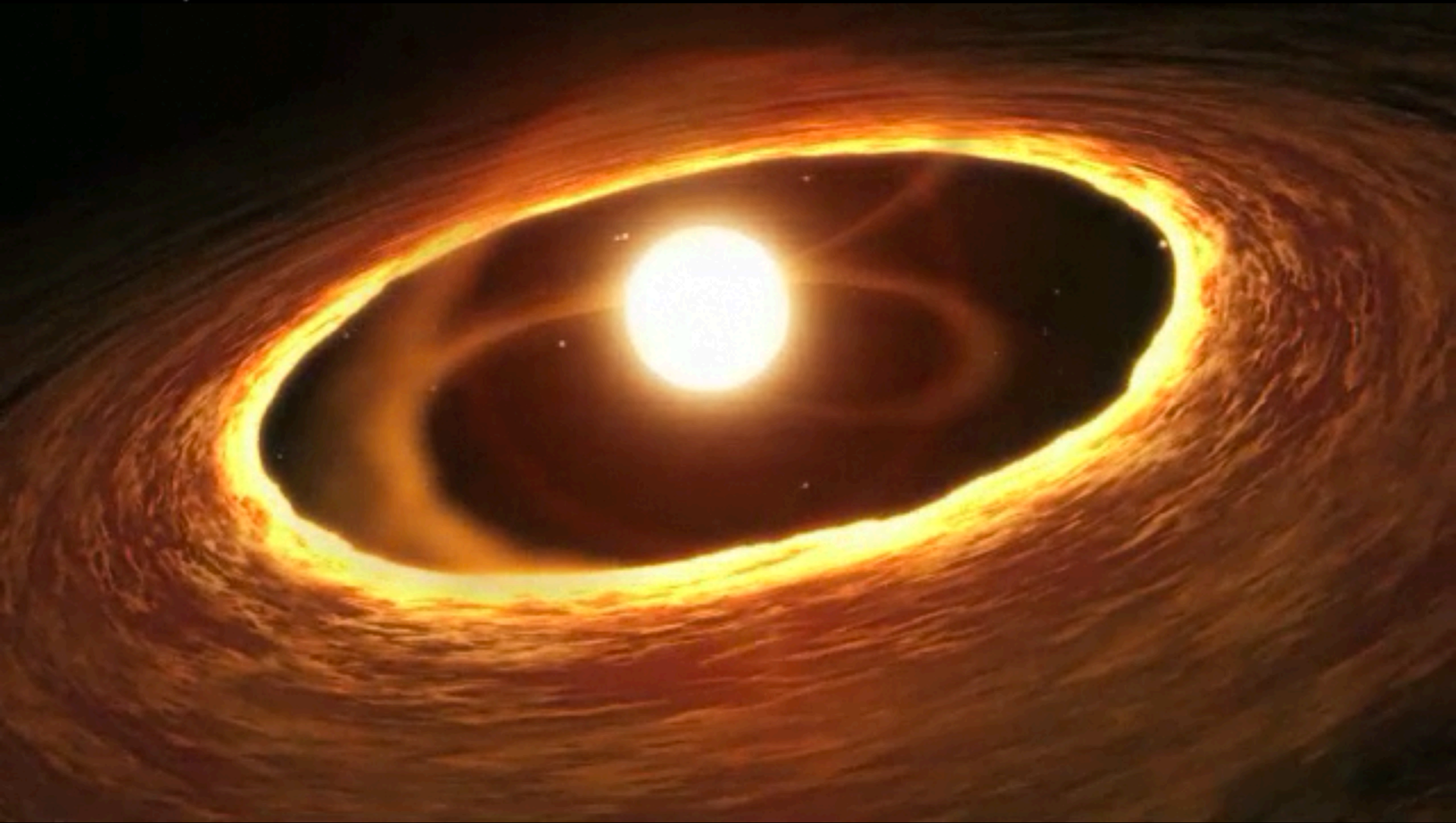


Liu+ (2016)



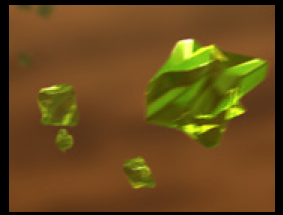
Hartmann & Kenyon (1996)

Barrier for terrestrial planet formation?



Barrier for terrestrial planet formation?

- Density rearrangement (winds, evaporation)
- Snowline moves outward
- Chemical changes (ice mantle evaporation, photo-dissociation of molecules, endothermic reactions)
- Mineralogical changes (crystallization)
- Surface ionization



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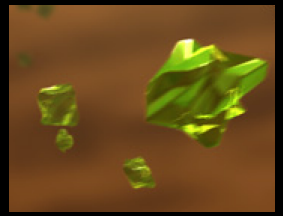
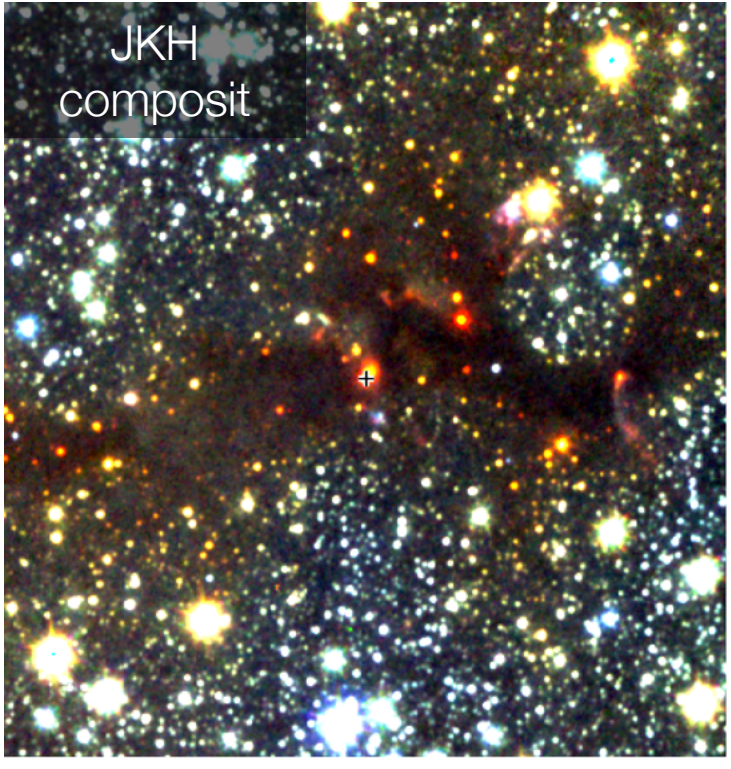


Can we characterize the post-outburst state of the star and the disk observationally?

Known FUors have not finished their outburst yet...

FU Orionis-type star: V346 Normae

- **Located in Sandqvist 187, in the Norma 1 association (*d* = 700 pc)**
- Associated with the Herbig-Haro object HH 57
- Deeply embedded protostar
- Massive envelope (0.1-0.2 $M_{\odot}$), extended CO outflow
- Outburst between 1976-80, outburst luminosity: 135 $L_{\odot}$



(Kóspál et al. 2017a)

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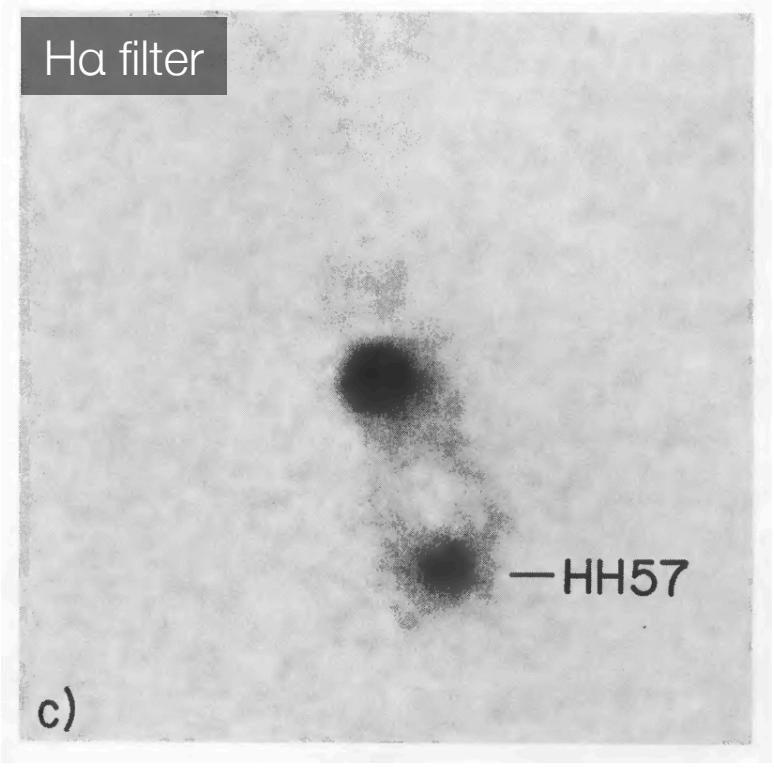

(Graham & Frogel 1985

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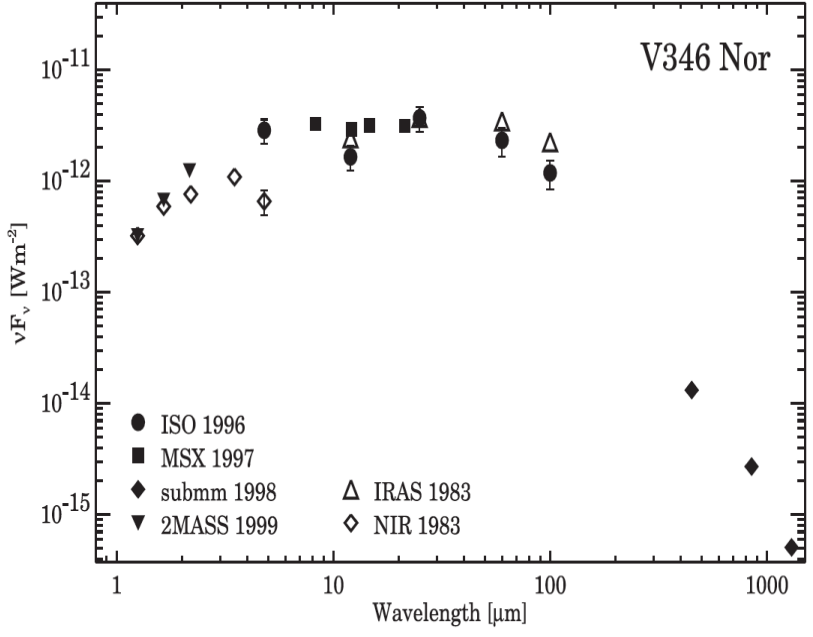

(Ábrahám, Kóspál + 1985

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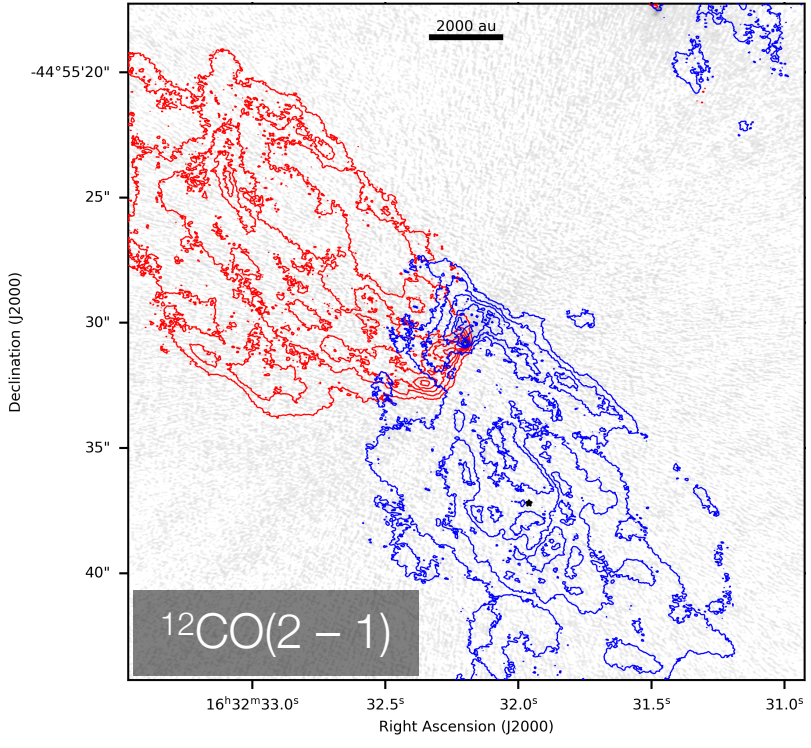

(Ábrahám+ in prep.)

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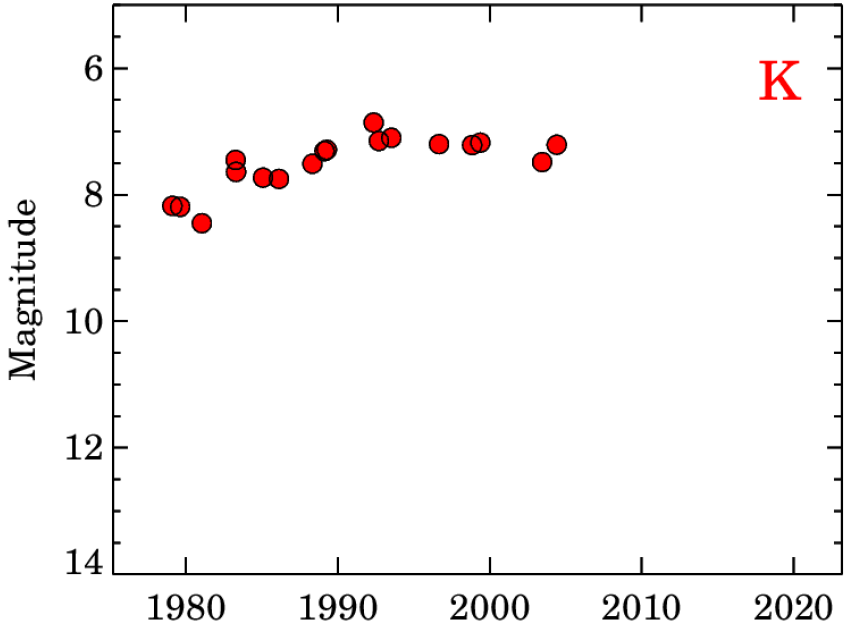

(Adapted from Kraus+ 2016 and Kóspál+ 2017)

FU Orionis-type star: V346 Normae

- Located in Sandqvist 187, in the

V346 Normae: First post-outburst observations of an FU Orionis star ⋆

S. Kraus,[1] A. Caratti o Garatti,[2] R. Garcia-Lopez,[2] A. Kreplin,[1] A. Aarnio,[3] J.D. Monnier,[3] T. Naylor,[1] G. Weigelt[4]

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[2] *Dublin Institute for Advanced Studies, School of Cosmic Physics, Astronomy & Astrophysics Section, 31 Fitzwilliam Place,*
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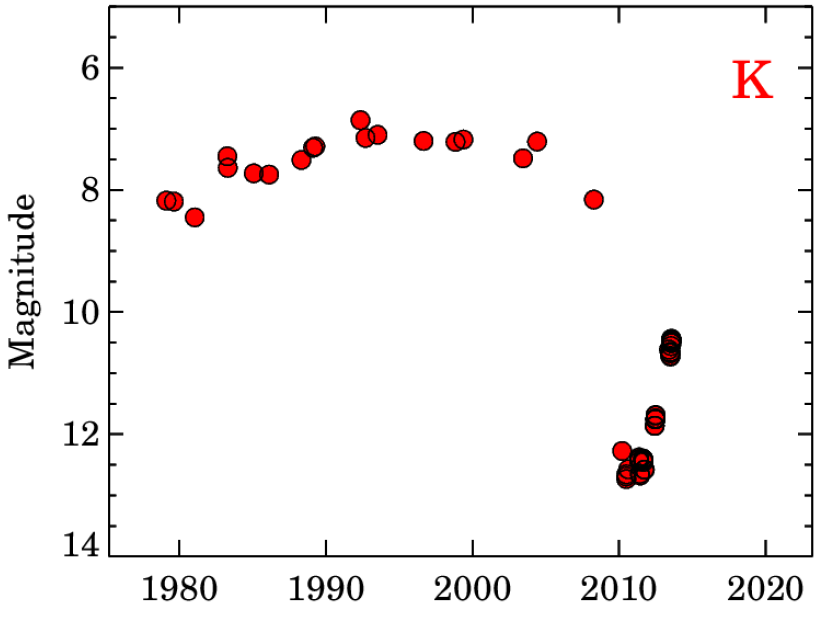
Accepted 2016-06-21. Received 2016-05-27; in original form 2016-04-18

outburst luminosity: 135 $L_\odot$

Characterization of the post-outburst state

IF THE OUTBURST IS INDEED OVER, V346 NOR IS A UNIQUE CASE WHEN WE CAN TRY TO ANSWER:

- what is the progenitor star? Has any special feature?
- how to classify the initial disk? Boring little or great celebrity?
- clues on outburst physics?
- what was the impact of the outburst?



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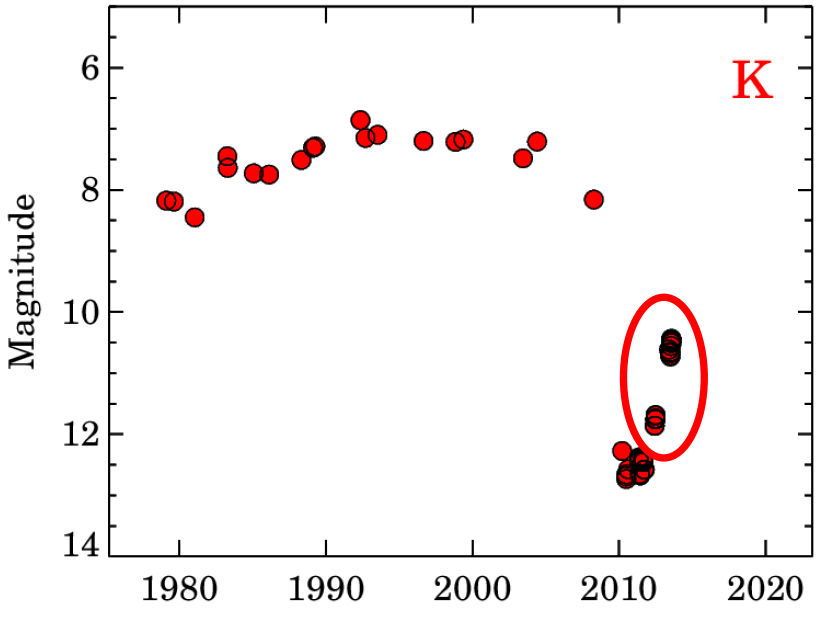
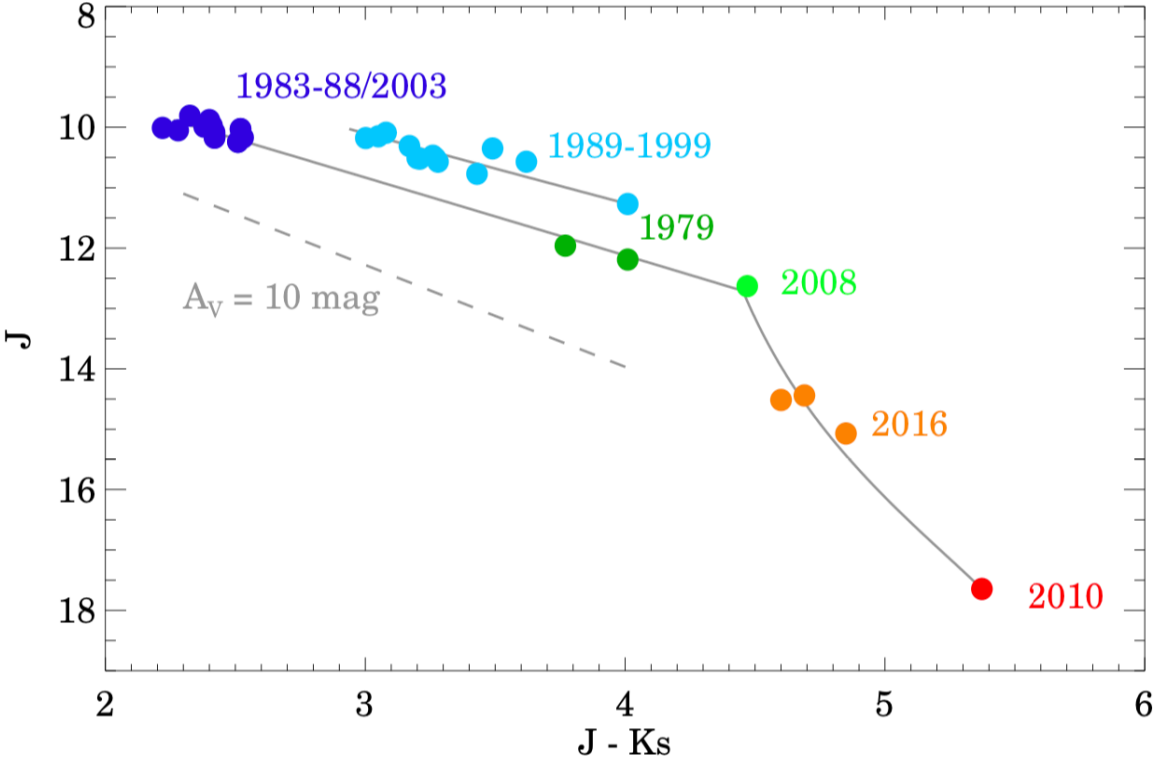


2010-2011: brief return to quiescence(?)



Date	$\dot{M}$ ($M_\odot$/yr)	A_V (mag)
1979	2.1×10^{-5}	16.7
1983-88	1.0×10^{-5}	6.7
1992	9.8×10^{-5}	16.8
2003	1.0×10^{-5}	6.7
2008	4.5×10^{-5}	21.5
2010	$< 4.0 \times 10^{-7}$	21.5

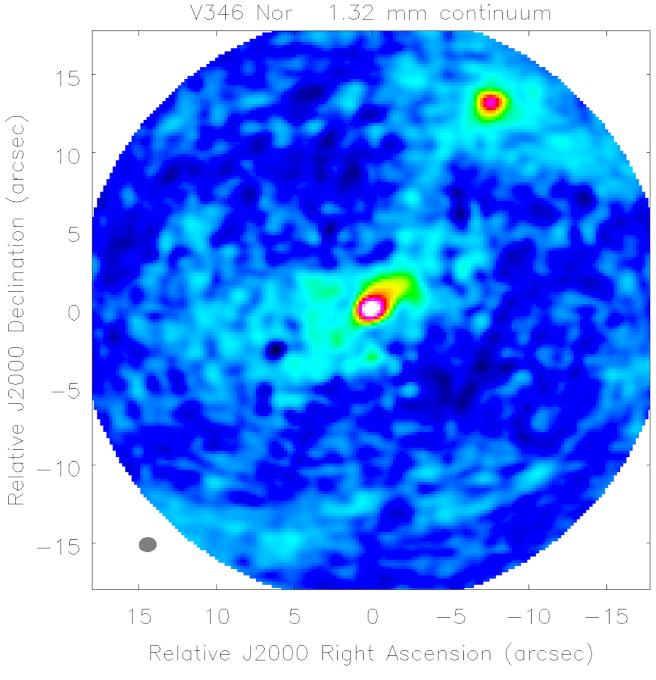
(Kóspál et al. 2017a)

Reddened steady accretion disk model: the 2010-11 fading was an accretion drop

Progenitor: late-type (2900 K) embedded (A_V~21.5 mag) young stellar object

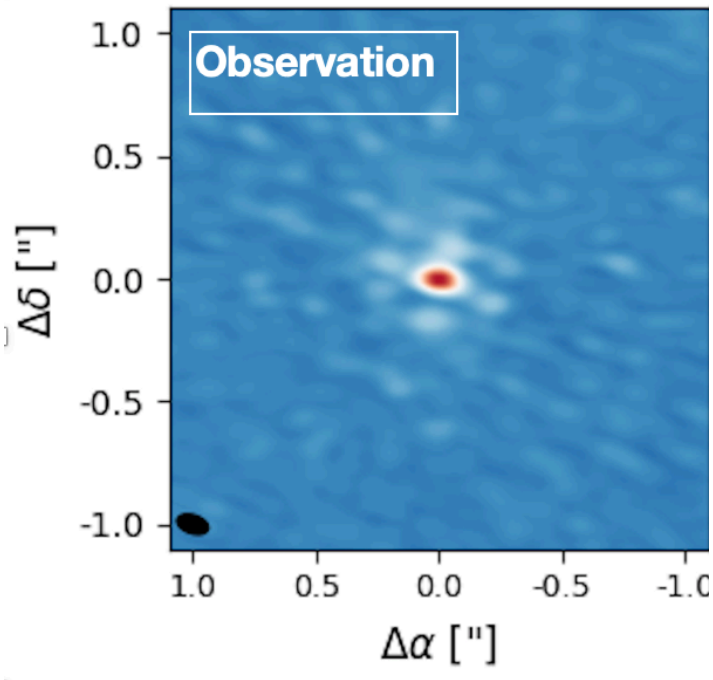
Circumstellar environment with ALMA

Cycle 2 Wavelength: 1.32 mm, Beam: 1.11” x 0.90”



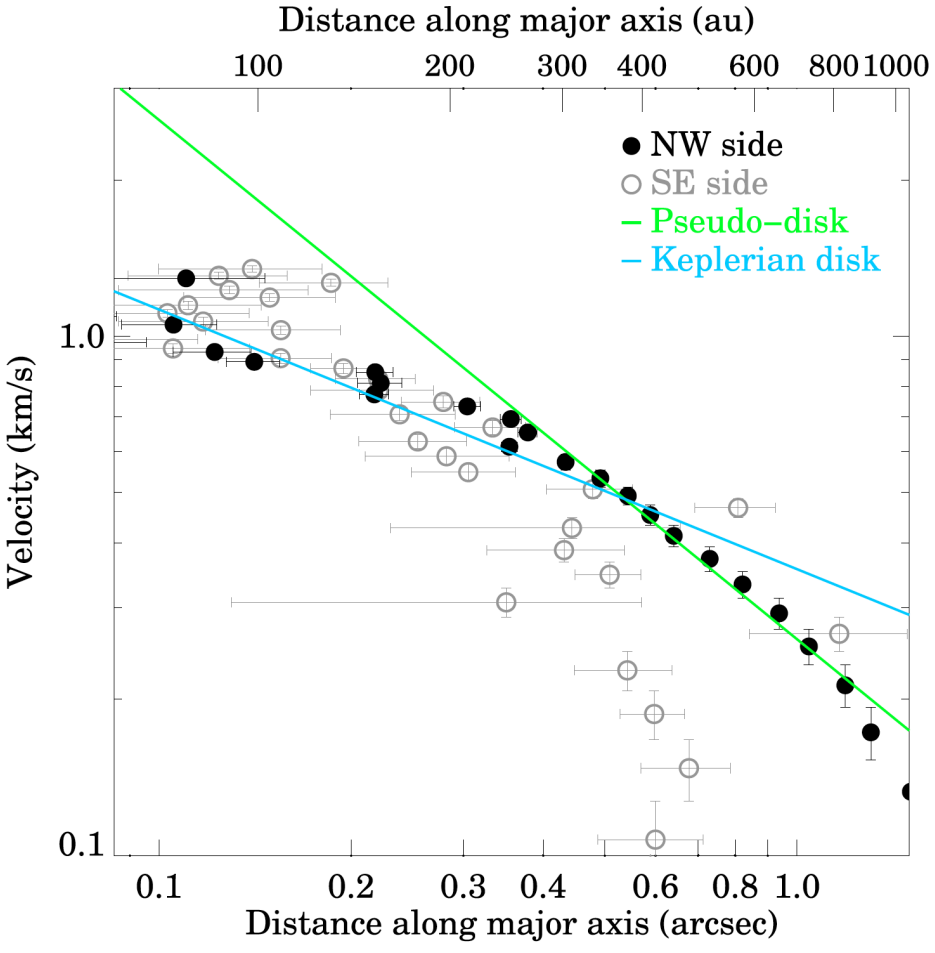
- Deconvolved Gaussian size of the compact source:0.46”x0.60” (~210 au radius @700 pc)
- Extended emission: 12”x5”
- Flux: 27 / 42 mJy
- Central source (T=50K) => **0.07** $M_{\odot}$

Cycle 5 Wavelength: 1.32 mm, Beam: 0.10” x 0.10”



- Deconvolved Gaussian size of the compact source: **0.139**” (~40 au radius @700 pc)
- Extended emission: 12”x5”
- Flux: 11.7 mJy
- Central source (T=50K) => **0.017** $M_{\odot}$

Accretion – infall mismatch



- ALMA CO line observations
- Pseudo disk: rotation + infall
- Keplerian disk: rotation
- $\dot{M}_{\rm infall} = \frac{3}{2}\left(\frac{M_{\rm env}}{R_{\rm env}}\right)\left(\frac{2GM_*}{R_{\rm env}}\right)^{1/2}$
- Dynamical mass ~0.1 $M_\odot$
- Infall rate:
  $\dot{M}_{\rm infall} = 6 \times 10^{-6}\ M_\odot/{\rm yr}$
- Quiescent accretion rate:
  $\dot{M}_{\rm acc} < 4 \times 10^{-7}\ M_\odot/{\rm yr}$

(Kóspál et al. 2017a)

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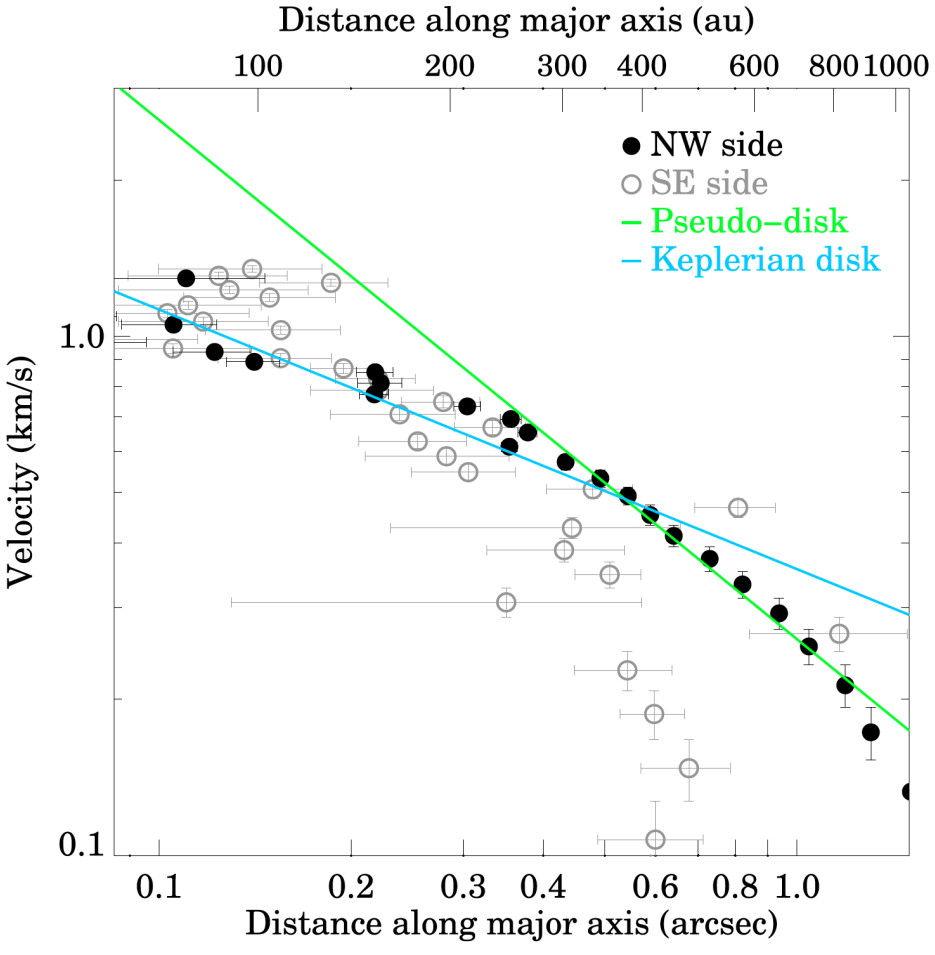

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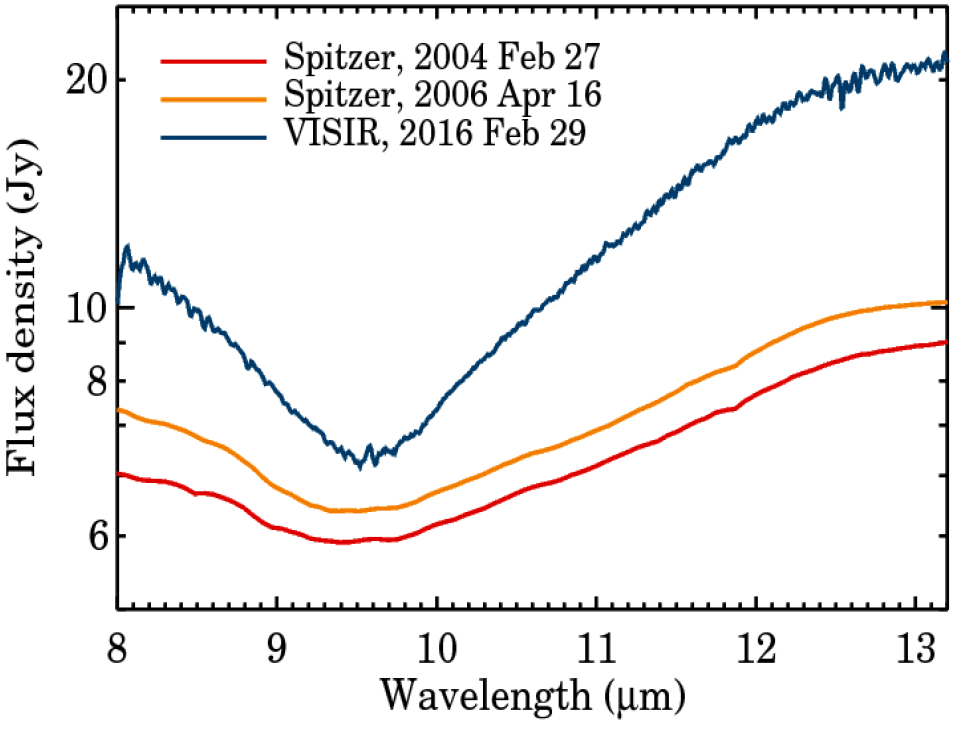
(Kóspál et al. 2017a)

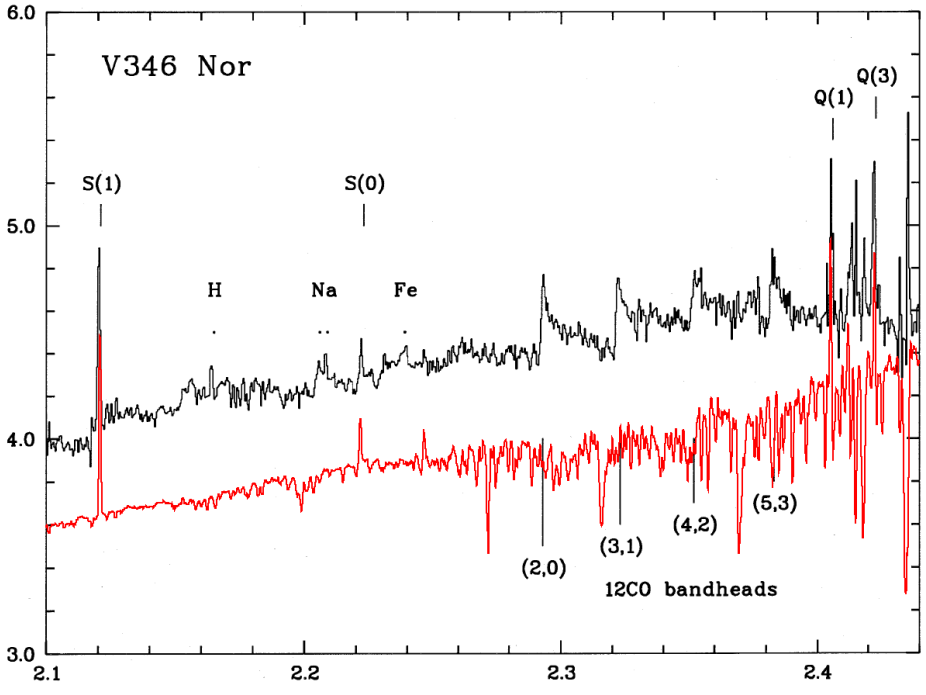
Changes in the circumstellar structure



(Ábrahám et al. in prep.)

- Two Spitzer/IRS spectra during outburst
- One VLT/VISIR spectrum post-outburst (S. Kraus)
- Changes in the optical depth of the 9.7 μm silicate feature
- Changes in the line-of-sight extinction
- Density rearrangements between outburst and post-outburst

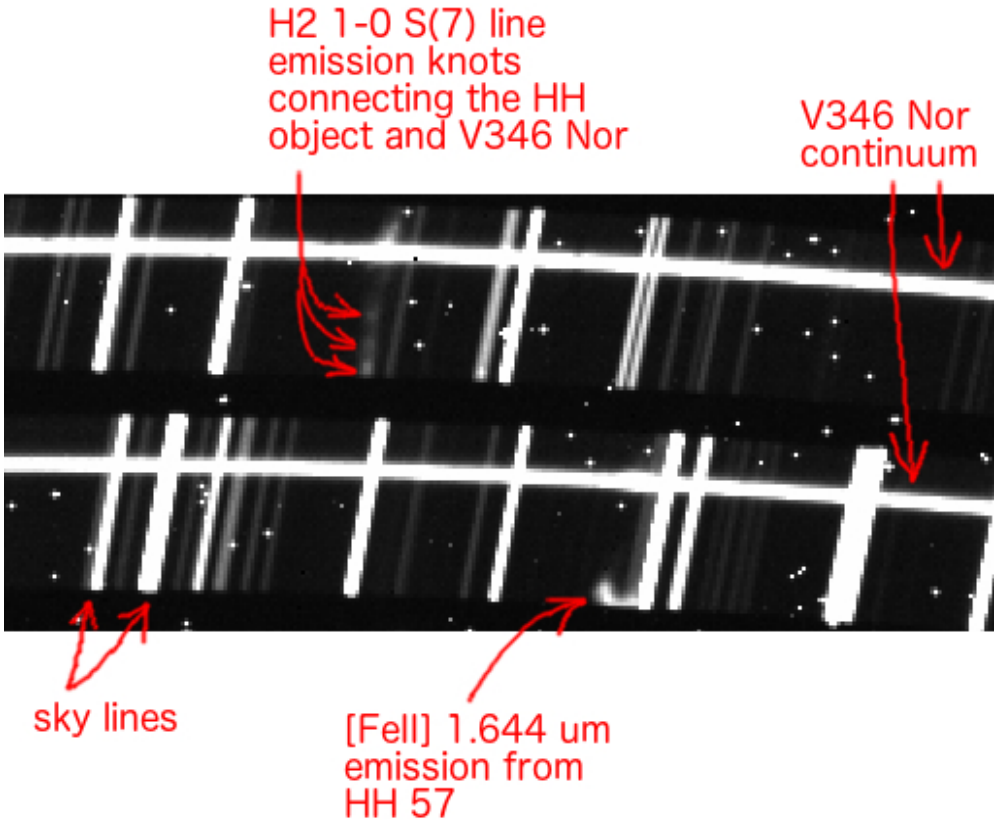
UV-visual-NIR spectroscopy



Based on Reipurth et al. (1997)

- Black: NTT/IRSPEC 1993
- Red: VLT/XSHOOTER 2015 (PI: S. Kraus)
- UV-visual: very low S/N for the continuum, but emission lines are well visible
- NIR: both the continuum and the lines are well detected
- CO bandhead disappeared!
- **Strong wind in outburst, stopped after 2010**

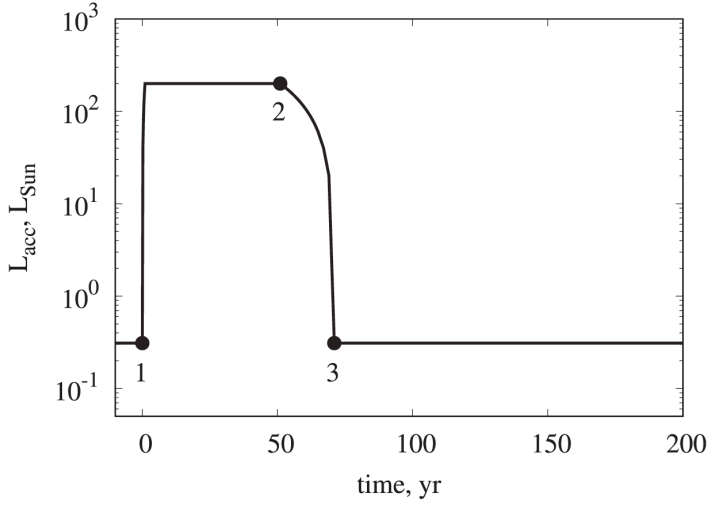
UV-visual-NIR spectroscopy

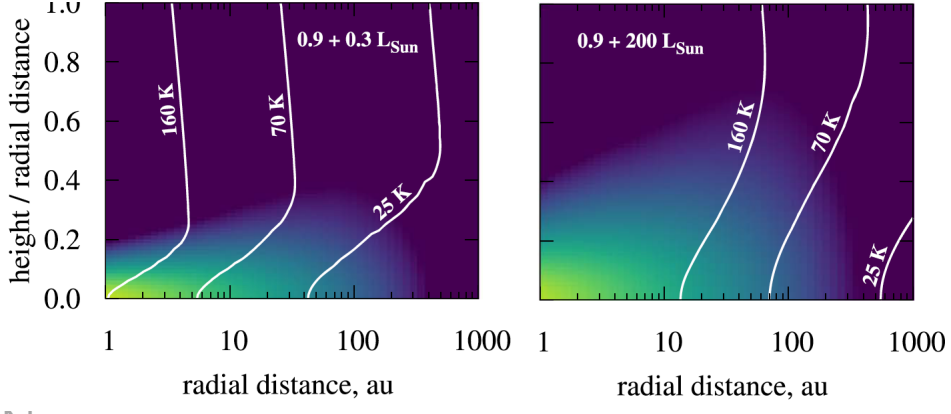


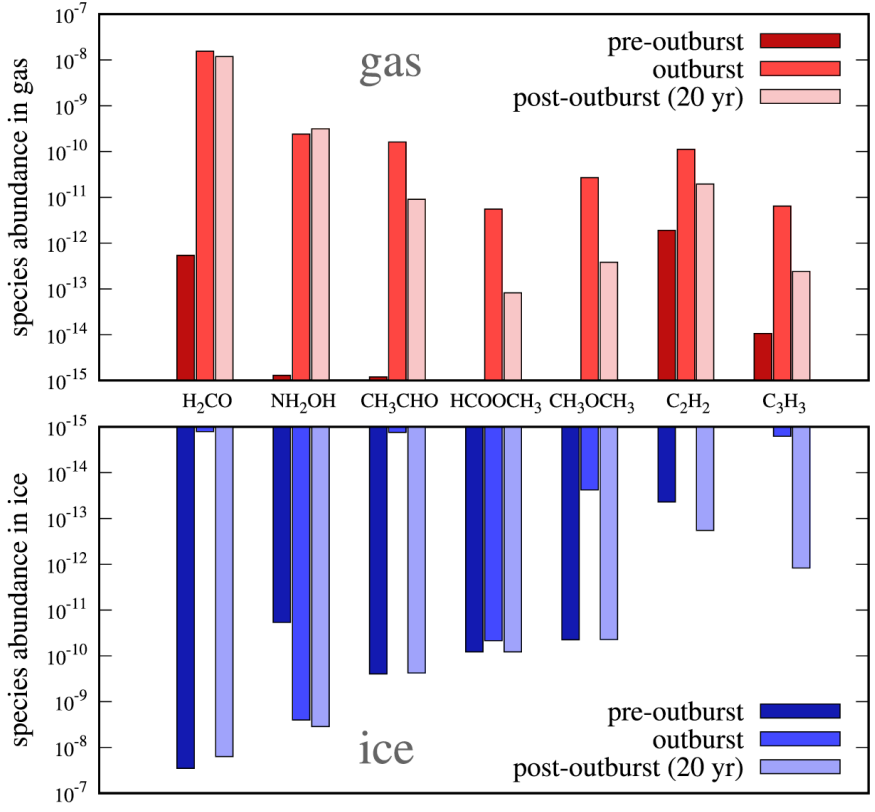
(Kóspál et al. in prep.)

- Analysis of the 2D spectra are ongoing, some preliminary results:
- Strong [FeII] emission from HH 57
- H_2 knots connecting V346 Nor and HH 57
- Complicated velocity pattern

Post-outburst disk chemistry



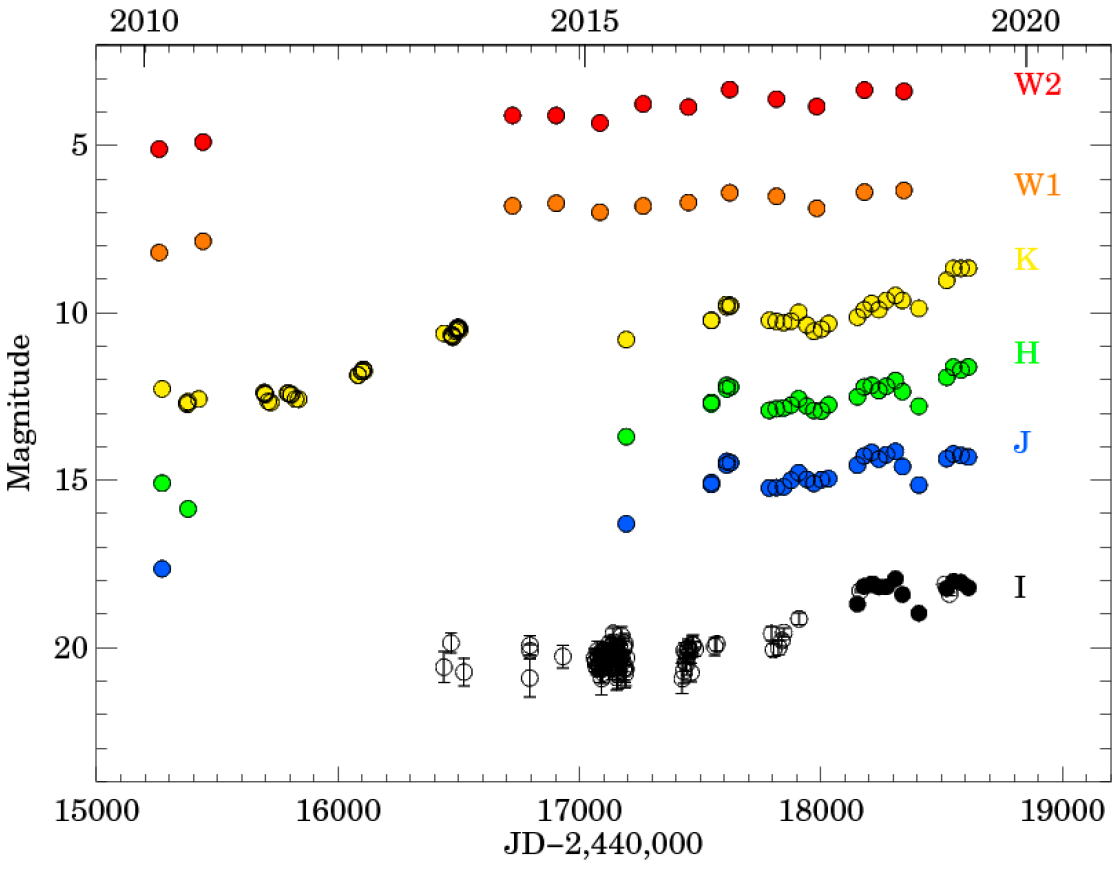




(Molyarova et al. 2018)

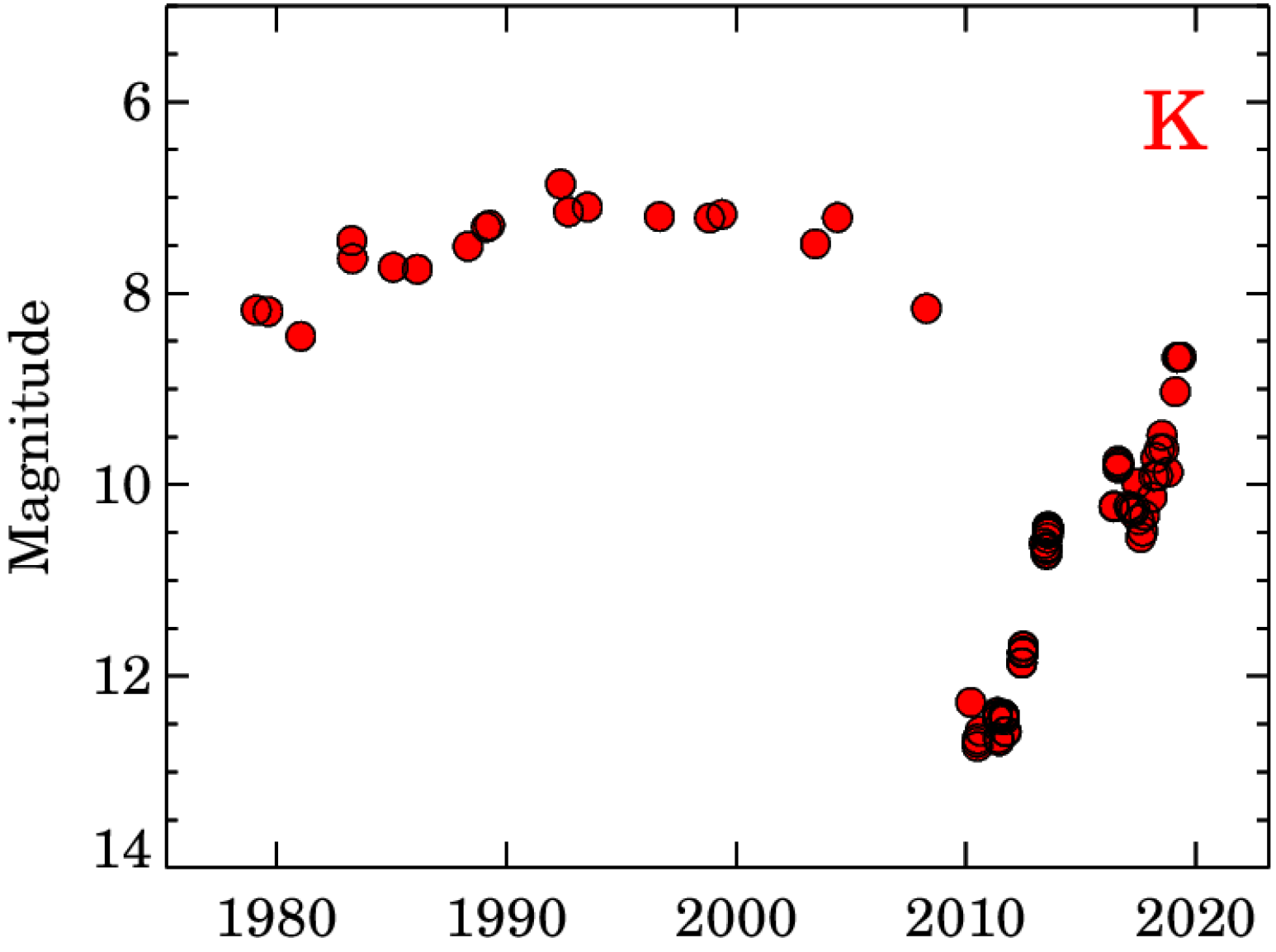
Nor

Our latest photometry



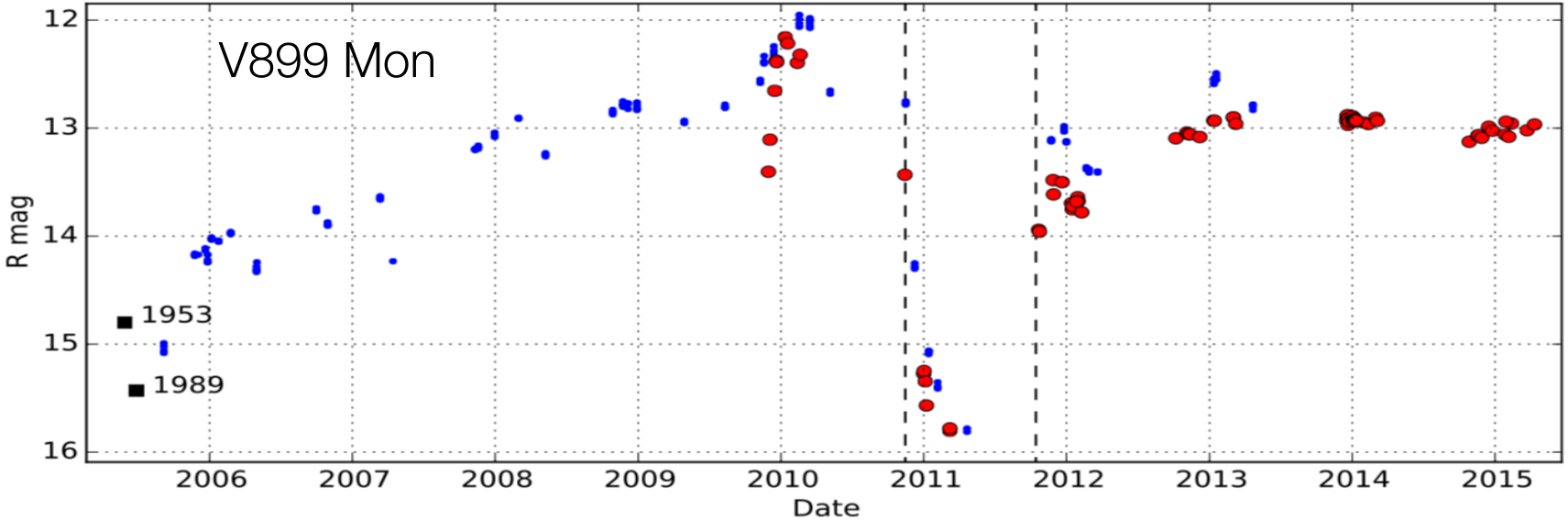
Kóspál et al. (in prep.)

- Data from OGLE, VVV, SMARTS 1.3m, WISE
- Current trend: brighter and redder!
- **Possible explanations:**
  - Combination of increasing accretion and increasing extinction
  - Disk gradually fills up from the outside


K
Magnitude
6
8
10
12
14
1980
1990
2000
2010
2020

Re-started Fuor outburst?

- What constraints do such switch-on/switch-off events give on outburst theories?



(Ninan et al. 2015)

Summary

FUors may have an impact on terrestrial planet formation, and V346 Nor may be THE ideal object to study it.

In quiescence, V346 Nor is a low-mass embedded object surrounded by a compact, (uncomfortably) low-mass disk

Effects of the outburst:

- Outburst wind stopped, jet is being launched
- Fresh matter fills the inner zone from the outside
- Molecules keep high gas abundance for decades (model)

The outburst mechanism can be temporarily shut down

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Not a barrier, more an influencer!