星形成ゼミ

SF Newsletter 349
#6 ~ #10
担当:川邊
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SF news letter 349: #6 - #10

6. **The ODYSSEUS Survey. Motivation and First Results: Accretion, Ejection, and Disk Irradiation of CVSO 109**
ODYSSEUS Survey, C. C. Espaillat et al. ★ The Hubble UV Legacy Library of Young Stars as Essential Standards (ULLYSES) Director's Discretionary Program of low-mass pre-main-sequence stars, coupled with forthcoming data from ALMA

7. **Detection of HC18O+ in a protoplanetary disk: exploring oxygen isotope fractionation of CO**
Kenji Furuya, Takashi Tsukagoshi, Chunhua Qi, Hideko Nomura, L. Ilsedore Cleeves, Seokho Lee, Tomohiro C. Yoshida ★ The oxygen isotope fractionation scenario, which has been developed to explain the oxygen isotope anomaly in

8. **Gaia EDR3 distances of the young stellar clusters in the extended Carina Nebula complex**
C. Göppl, T. Preibisch ★ Context: The Carina Nebula complex (CNC) is one of the most massive and active star-forming

9. **A large catalogue of molecular clouds in the southern sky**
Helong Guo, Bingqiu Chen, Xiaowei Liu ★ We present a large catalogue of molecular clouds with accurate distance

10. **LkHα 225 (V1318 Cyg) South in Outburst**
Lynne A. Hillenbrand, Howard Isaacson, Antonio C. Rodriguez, Michael Connelley, Bo Reipurth, Michael A. Kuhn, Tracy Beck, Diego Rodriguez Perez ★ Magakian et al. (2019) called attention to the current bright state of LkHa

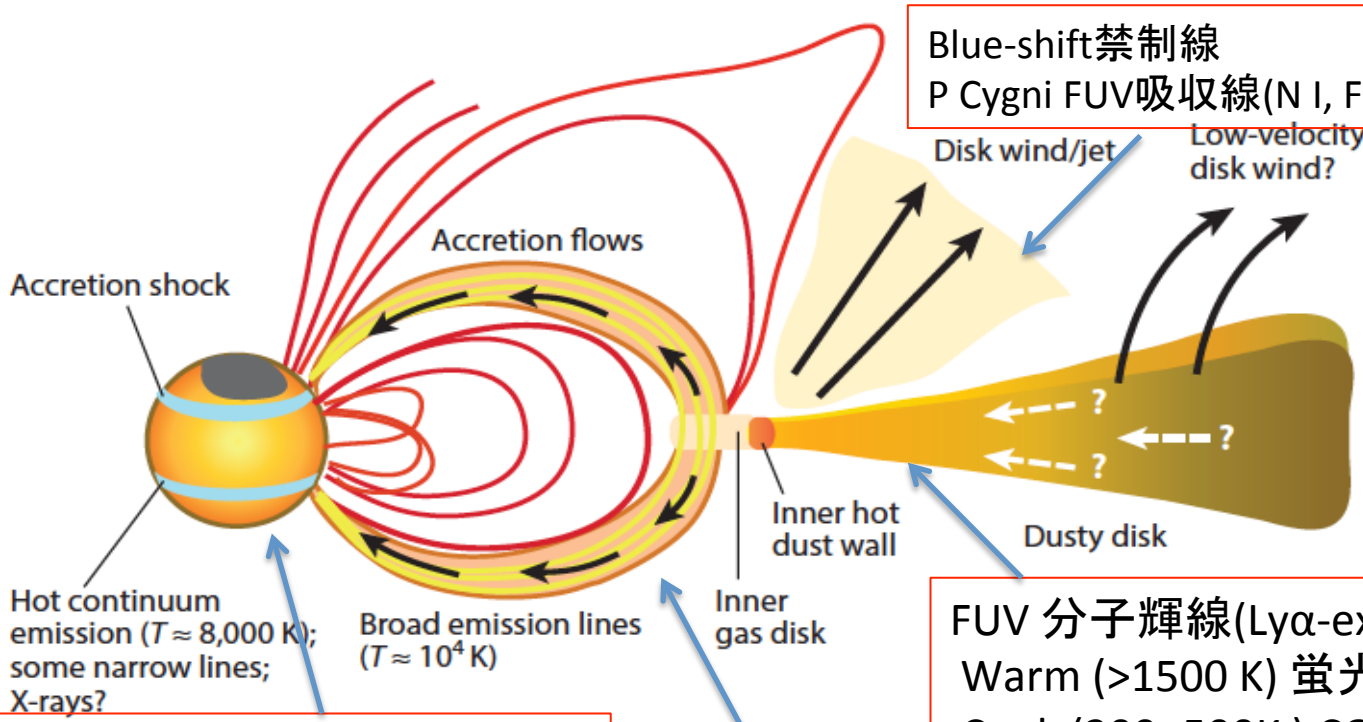
6. **The ODYSSEUS Survey. Motivation and First Results: Accretion, Ejection, and Disk Irradiation of CVSO 109**

ODYSSEUS Survey, C. C. Espaillat et al. ★ The Hubble UV Legacy Library of Young Stars as Essential Standards (ULLYSES) Director's Discretionary Program of low-mass pre-main-sequence stars, coupled with forthcoming data from ALMA

- ODYSSEUS Survey: Outflow and Disks around Young Stars: Synergies for the Exploration of ULLYSES Spectrum
- ULLYSES: Hubble UV Legacy Library of Young Stars as Essential Standards Director's Discretionary Program (DDP) of low-mass pre-main sequence stars (+ALMA & JWST)
- ULLYSES目標 => 若い星とPPDの関連の理解で革新をもたらす
  => 質量降着、アウトフロー、円盤構造の関係から、円盤進化と惑星形成の物理を理解
- 論文目的：ODYSSEUS Surveyの紹介と、CTTS CVS109 (Orion OB1b) の初期成果を示す
- ODYSSEUS Surveyは、ULLYSES 分光データベースを活用、統一的で均一な解析を実施
  1) 降着流が、降着率と磁場構造にどう依存するか?
  2) 星風やジェットの駆動場所がどこで、質量放出率が降着率とどう関係するか?
  3) 惑星形成領域の化学にFUVがどう影響するか?
- 他のデータ: 同時期のX-ray, optical, NIR, ミリ波データを活用する
- Goal: PPDでの正確な質量降着とその進化、化学などを描き出すフレームワークを構築

Magnetospheric Accretion Paradigm

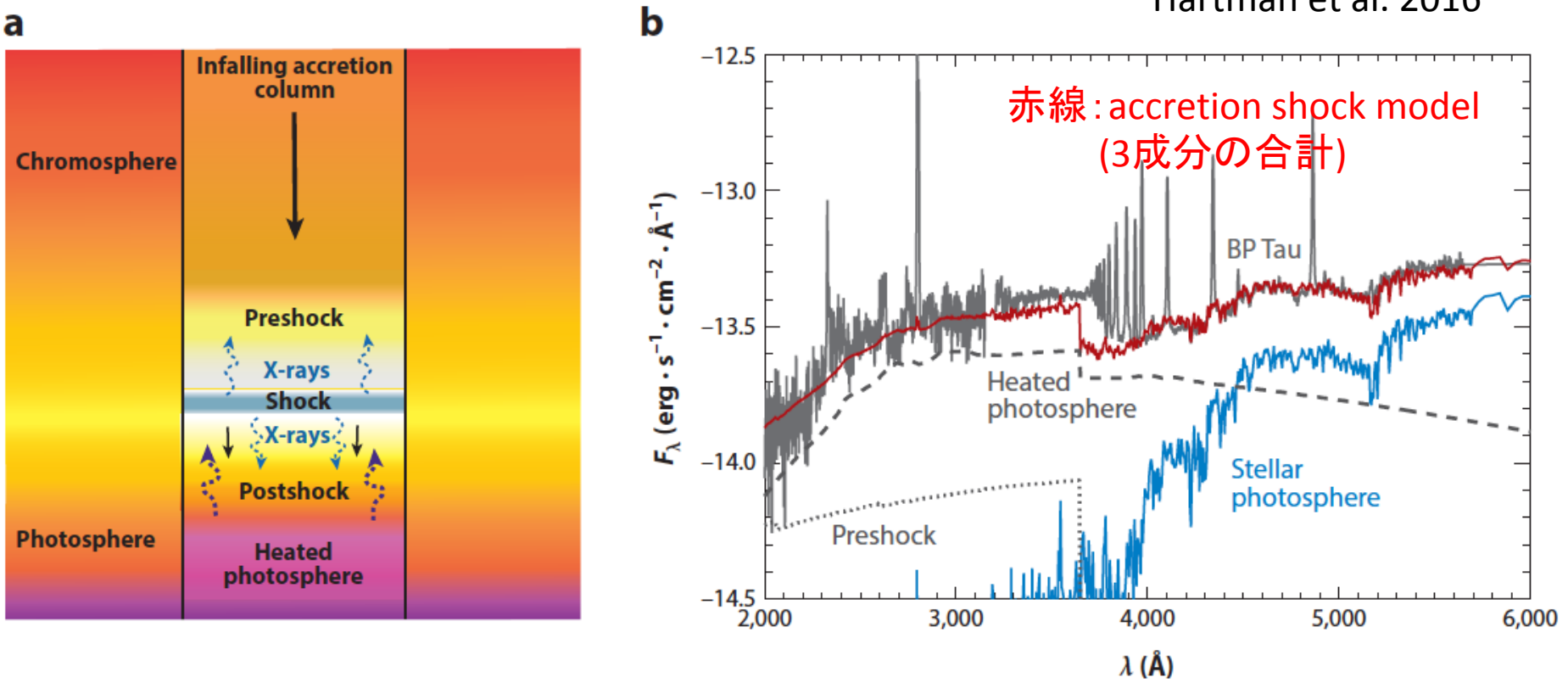
("Accretion on to Pre-Main-Sequence Stars", Hartman et al. 2016)



- 強磁場がPPDをトランケート
- アウトフローはトランケーション半径のところから放出(星半径の数倍のところ)
- 一部は星表面に向かって降着流となり、星表面で衝撃波を作り出す
  衝撃波 => UV, X線, 円盤表面照射, 化学進化、星風駆動を通して円盤の消失へ寄与
- 降着流で駆動されたアウトフローは角運動量を持ち出し、星・PPDの回転構造を制御
- ALMAでは見ることの出来ない内側の構造の情報を、UV観測がもたらす。

降着流衝撃波の構造とSED

Hartman et al. 2016



One column model => muti-component magnetic columns model

Figure 2

(*a*) Schematic diagram of accretion shock structure showing the precursor or preshock region, the postshock or cooling region, and the heated photosphere below the shock. (*b*) Spectral energy distribution of the classical T Tauri star BP Tau (*gray solid line*), stellar photosphere (*blue line*), and accretion shock model (*red line*) showing contributions from the preshock (*gray dotted line*) and heated photosphere–postshock (*gray dashed line*) regions. Shock model courtesy of L. Ingleby.

ULLYSES

- ULLYSES観測: 500 HST orbits で60-70 CTTS (d = 100(60) - 450 pc, K to M-type)
  - Cosmic Spectrograph (COS) FUV spectra (R~ 12,000-20,000)
  - low-resolution (R ~ 500) Space Telescope Imaging Spectrometer (STIS) NUV/ Optical spectra
  - TW-Hya, BP Tau, GM Aur, & RU-Lupの４天体はモニター観測実施: 各天体 24回
- 質量降着via星磁場
  - UV/Opt excess in SEDの有無、質量降着率推定、multi-column accretion flows の有無
  - “hot” FUV lines, Si IV, C IV, N V, He, H, は上記SED解析を補完 (これらの輝線強度は、降着光度と良く相関)
- 質量放出via wind/jet
  - wind signature: 青方偏移した禁制線やP Cygni 吸収線 (He I: λ10830)
  - windの電離バランス: FUV 領域のP Cygni 吸収線 (NI, Fe II, C II, Si II, Si III, C IV)
  - 専用のMHDコード: FUV 領域のP Cygni 吸収線のモデル化
- 惑星形成領域の内縁部の構造と化学
  - ODYSSEUSのgoal: 内縁部から外縁部までのCO, H2O, 有機分子などの分布を得る(外縁部はALMAで)
  - CO/H_2が大事な測定量 (CO depletionの程度)、その半径依存

ULLYSES/HSTを補完する観測

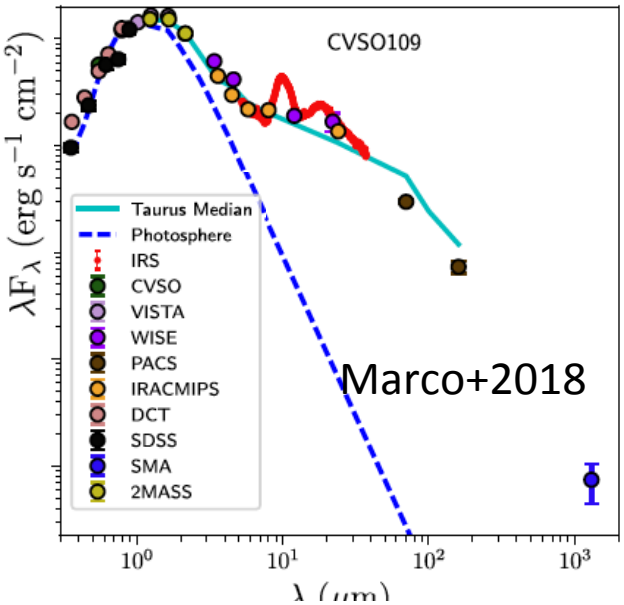
- Optical/NIR spectra : ESO-VLT large program, PENELLOPE
  - VLT/X-shooter, VLT/UVES(Echelle Spectrograph), VLT/ESPRESSO (Echelle Spectrograph for Rockey Exsoplanets and Stable Spectroscopic Observations)
  - National Optical-Infrared Astronomy Research Lab/CHIRON
  - Telescopio Nazionale Galileo/GIARPS
- 測光@Optical: 地上望遠鏡群での測光、モニタリング観測 + TESS
  - Las Cumbres Observatory Global Telescope (NOAO経由)
  - Konkoly Observatory (Hungary)
  - Observatorio Astrofisico di Catania (Italy)

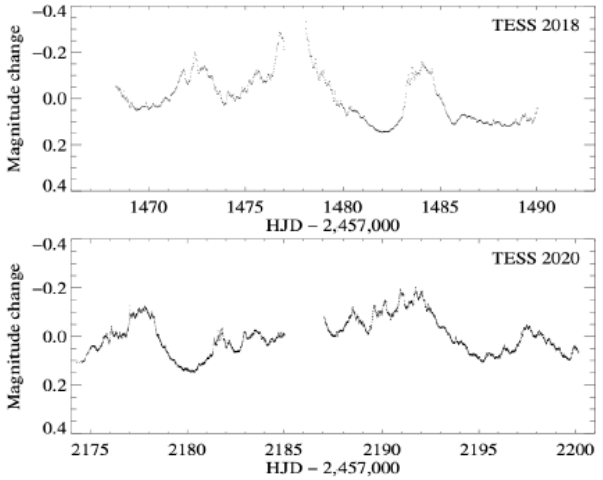
TESS :トランジット系外惑星探索衛星

- X-ray: accretionやcoronal activity 情報を補完
  - ULLYSES monitoring targets(4天体中3つ)に関しては、X線でも同時観測を行う (X-ray Multi-Mirror Mission-Newton and Chandra Obs. ; TW-Hya, BP-Tau, RU-Lup)
- Future data
  - JWST: UV 輻射場 vs 近赤外輝線 の関係
  - ALMA : disk properties- disk mass, inclination etc.

CVSO 109観測の概要

- CVSO 109 AB: CTTS (A; ~ 5 Myrs) −WTTS (B) binary (0.64” separation)
  - Pre-transitional disk in CVSO 109 A? (Marco+2018)
- HST: ULLYSES 4 hour observations (2020 Nov. 28)
- CHIRON fiber-fed echelle spectrograph:
- McDonald Observatory 2.7m Spectra:
  - v sin *i*（光球）& RV 測定
- VLT Spectra:
  - X-Shooter R~ 10,000-20,000) 3000 - 25000 Å
  - UVES (R ~ 70,000) 3300 − 4500 & 4800 - 6800 Å
- TESS (トランジット系外惑星探索衛星)
  - 600 − 1000 nm passband
  - 時間分解能: 10 min in 2020, 30 min in 2018
  - 6.5 day 変動検出
- 地上測光@Optical
- eROSITA X-ray (0.2 − 1 kev)





TESS light curves

Figure 1. *TESS* light curves of CVSO 109 from the 2018 (sector 6) and 2020 (sector 32) observing seasons, showing

CVSO109: 中心星と円盤

- McDonald Observatory 2.7m Spectra:
  - v sin i = 3.5 km/s（光球）& RV 測定
    (v sini が小さい=> face-on viewを示唆)
- Inclinationの推定
  - 6.5 day 周期 + v sini => i ~ 14 deg.
    (R_{star} ~ 1.8 R_{sun}))
- 星と円盤の回転軸が揃っていれば円盤もface-on

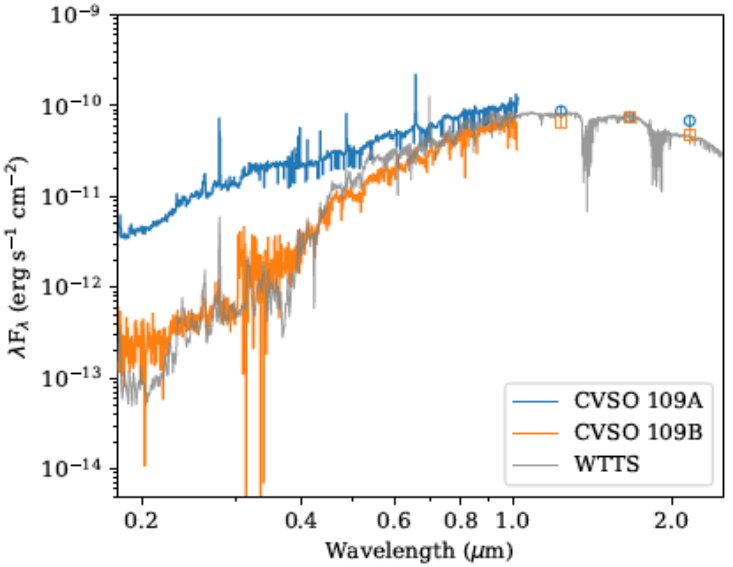


Figure 2. SEDs of CVSO 109A and CVSO 109B. We show *HST*/STIS spectra and NIR photometry derived from X-shooter and magnitude ratios from Tokovinin et al. (2020). For comparison, we plot a combined STIS+X-Shooter WTTS spectrum used in Section 6.1.1. The spectrum is smoothed for clarity.

Table 3. Stellar Parameters of CVSO 109

Star	SpT	$T_{\rm eff}$ (K)	A_V (mag)	$M_\star$ ($M_\odot$)	Log($L_\star$)	$R_\star$ ($R_\odot$)	J (mag)	H (mag)	K_s (mag)	EW(Hα) (Å)
A	$M0^{+0.5}_{-0.5}$	$3767.6^{+81.2}_{-81.2}$	$0.06^{+0.24}_{-0.24}$	$0.50^{+0.07}_{-0.05}$	$-0.226^{+0.110}_{-0.110}$	$1.81^{+0.25}_{-0.25}$	$11.62^{+0.11}_{-0.11}$	$10.98^{+0.13}_{-0.13}$	$10.33^{+0.16}_{-0.16}$	-50^{+1}_{-1}
B	$M1^{+0.5}_{-0.5}$	$3639.4^{+63.4}_{-63.4}$	$0.55^{+0.29}_{-0.29}$	$0.42^{+0.04}_{-0.04}$	$-0.314^{+0.115}_{-0.115}$	$1.75^{+0.24}_{-0.24}$	$11.91^{+0.12}_{-0.12}$	$10.99^{+0.13}_{-0.13}$	$10.74^{+0.21}_{-0.21}$	<-2.0

NOTE—We adopt an RV of the CVSO 109 system of 16.51 ± 0.50 km s^{-1} and assume a distance of 400 pc from Briceño et al.

CVSO109: 変光とHα EW

- Opt連続光(i, r,V, G, B)で変光=> 0.2 mag in Av
- Hα EWの急激な変化(HTS観測時期)
- Hα profileの変化

  - day -1 でinfalling gas/accretion flowを示唆
  - day 0 (HST観測時期) で Hα EW最大
    およびredshifted sideでtail
    => infalling gasに誘発されたmodestな
    accretion shock eventでは

Hα Equivalent Widthの時間変化

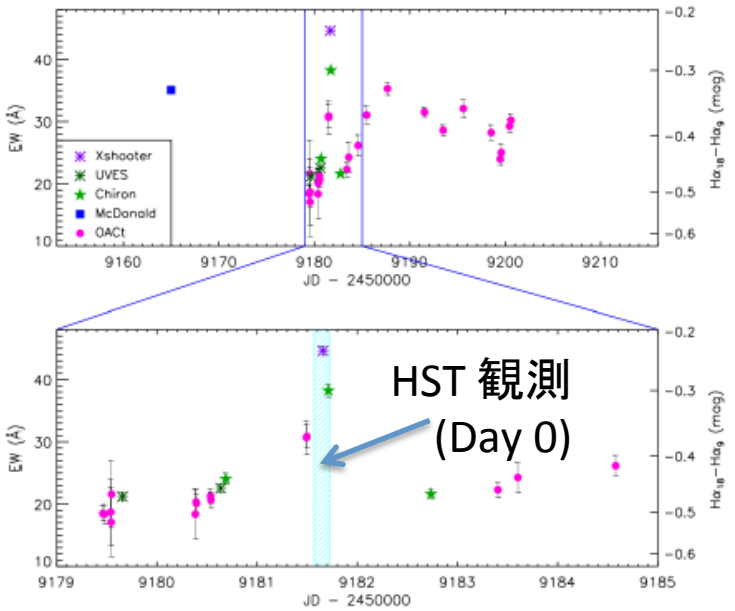
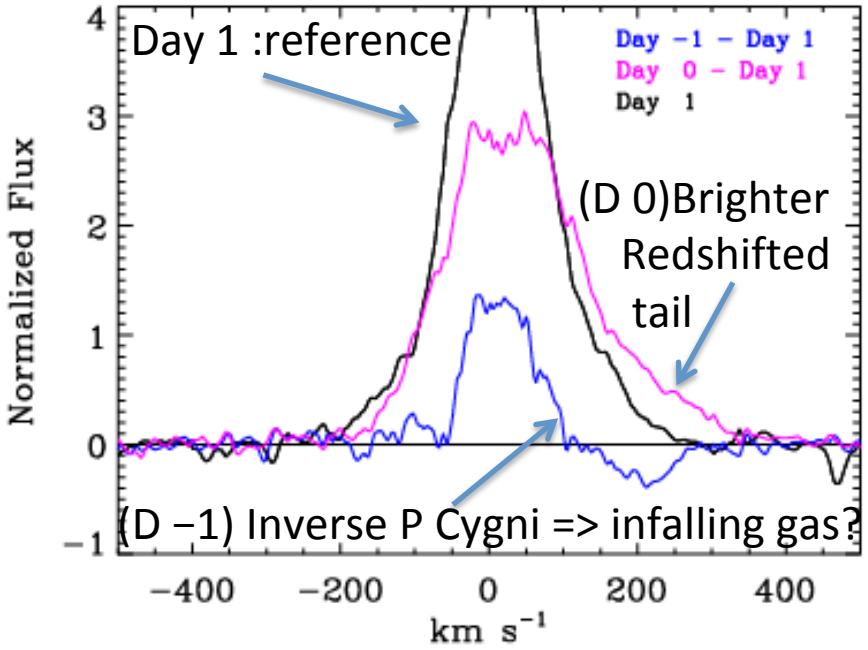


Figure 5. Hα EW derived from the color index measured at OACt (dots) over one month (top) and zoomed into a 15 day interval (bounded by the blue lines on the top plot) to highlight the epoch of *HST* observations. The scale of the color index is shown in the right vertical axis. The Hα EW measured on X-shooter, UVES, CHIRON, and McDonald spectra are overplotted with different symbols as indicated in the legend. A zoom around the *HST* observations (cyan hatched area) is displayed in the lower box.

Hα Equivalent Widthの時間変化(CHIRON)

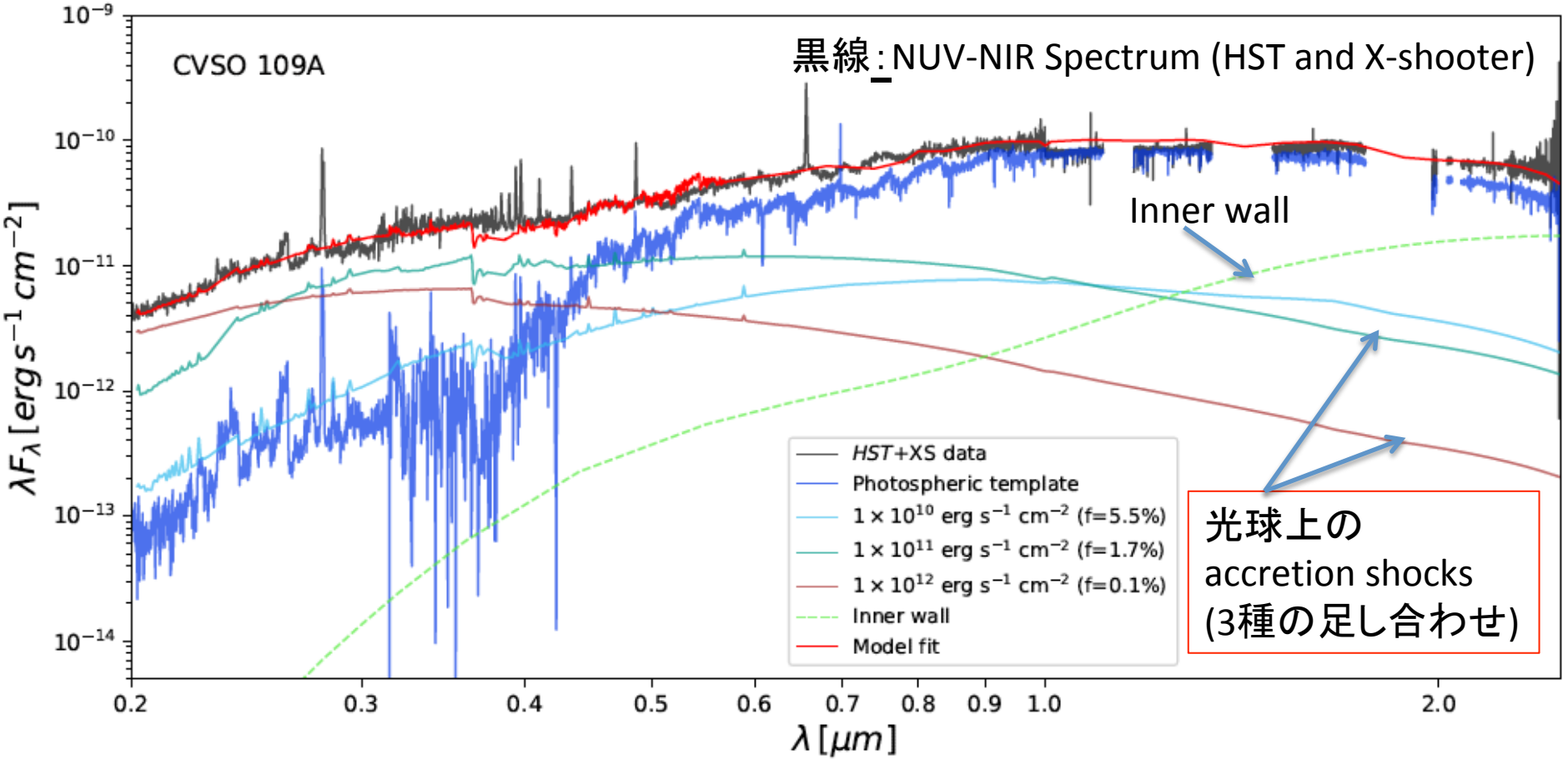


CVSO109: 降着、放出、円盤照射

- NUV-NIR SEDのモデリング: multi-column accretion flows
  - 質量降着率 ~ 3×10^{-8} Msun/yr
  - inner wall radius R_{wall} ~ 0.1 au

$$R_{\rm wall} \sim \left[\frac{(L_* + L_{\rm acc})}{16\pi\sigma_R}\left(2 + \frac{\kappa_s}{\kappa_d}\right)\right]^{1/2} \frac{1}{T_{\rm wall}^2}$$

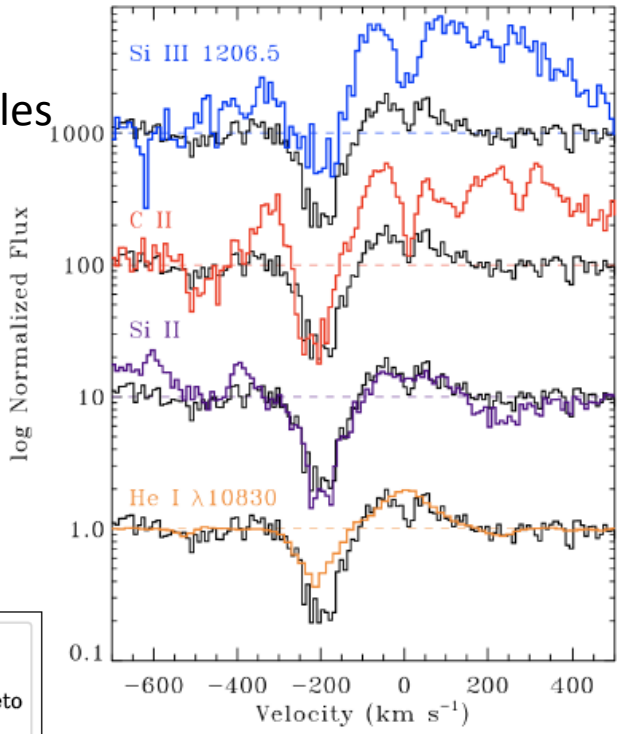
D'Alessio+ 2004



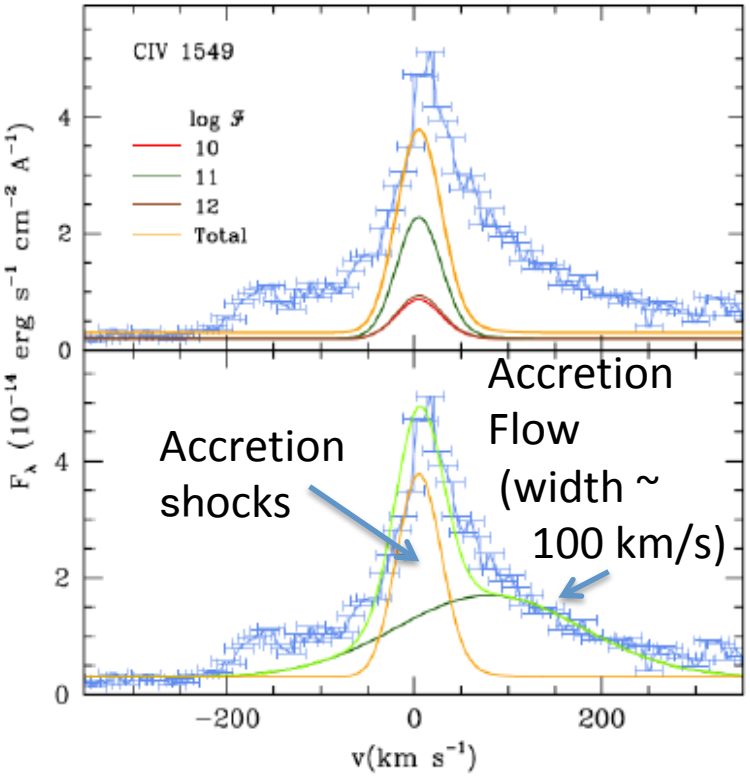
CVSO109: 降着、放出、円盤照射

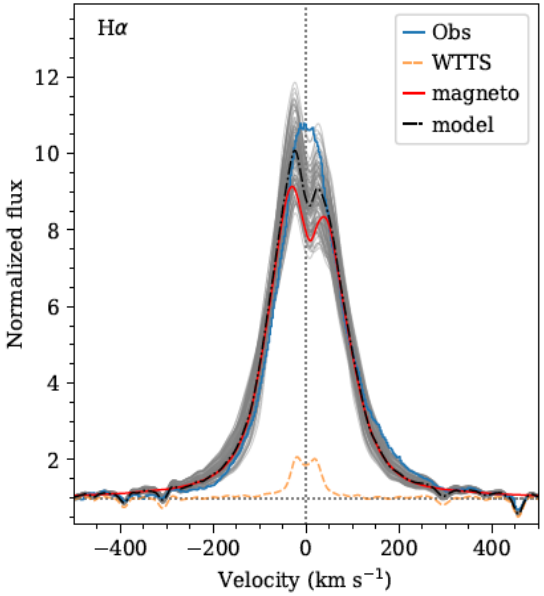
- Magnetospheric accretion flow
  - C IV 1549のbroad comp. を検出
  - Hα, Hβ fit=> ~ 2x10^{-8} M_{sun}/yr & i=40 deg.
- Wind の証拠: FUV lines (I O , He I, S II, CII)
  - mass loss ~ 3x10^{-10} - 6x10^{-9} M_{sun}/yr
    V_{wind} ~ 2km/s, l_{wind} ~ 1 au, & M from O I

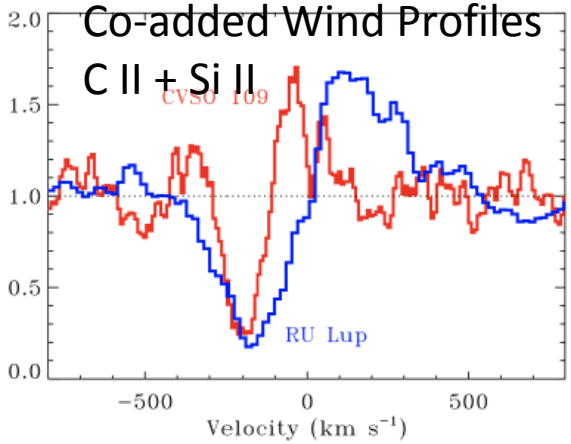
種々の
Wind Profiles



$$\dot{M}_{wind} = M \frac{V_{wind}}{l_{wind}}$$







(補足) O I as an evidence of wind

● Wind Mass Loss Rateの推定:
Fang + 2018 の手法を用いて
[O I]輝線から導出

$$\dot{M}_{\rm wind} = M \frac{V_{\rm wind}}{l_{\rm wind}}$$

- x(O) = 3.2 x 10^{-4}
- T_{gas} = 5000 K を仮定すると、

Mass Loss Rate
~ 1.8 x 10^{-10} Msun/yr

● wind height (l_{wind}) やT などに
大きく依存する。
● wind velocity は [O I]輝線の
“projected peak velocity”から推定
● l_{wind} = Kepler radius for v=FWHM/2

V_{rad} (O I) ~ - 2.0 km/s (narrow comp)
−1.2 km/s (broad comp)

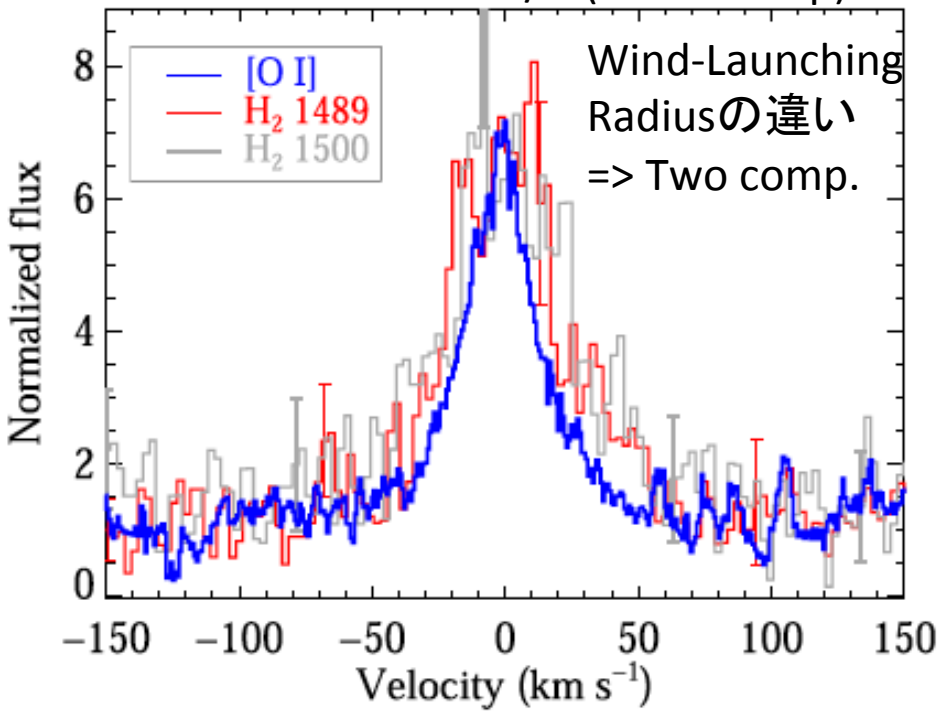
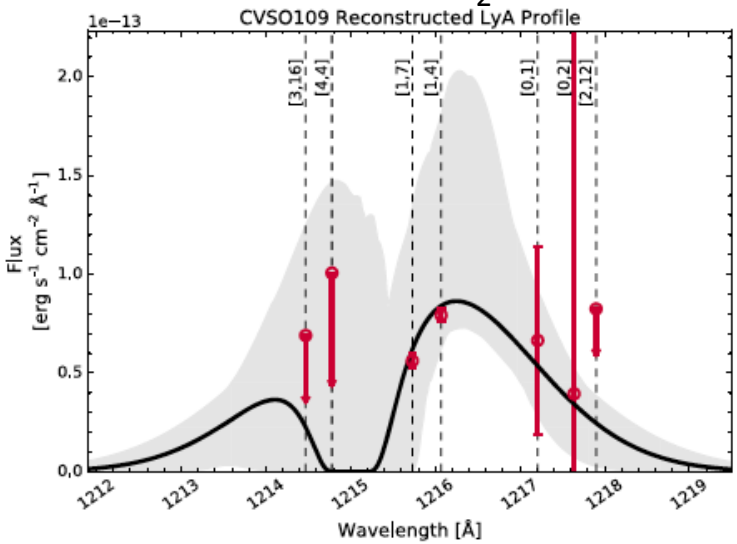


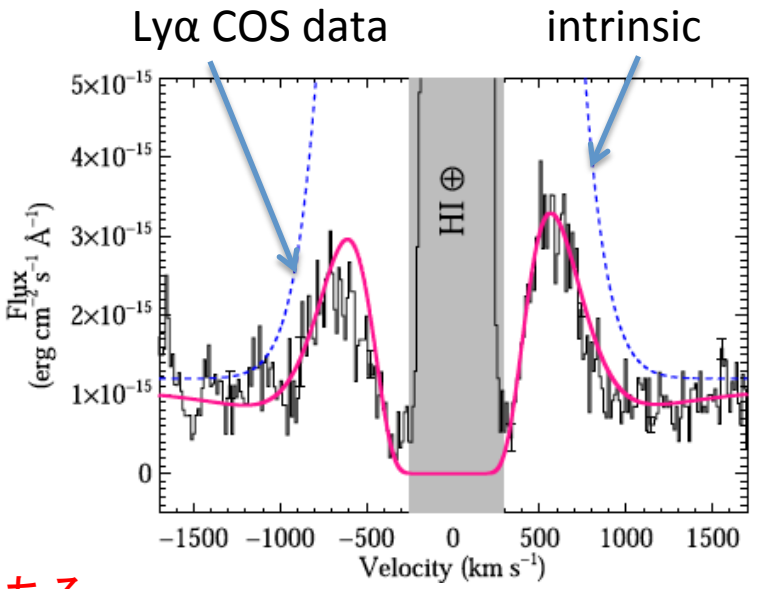
Figure 15. (Top panel) The two-component fit to the [O I] 6300 Å emission from CVSO 109A is illustrated. (Bottom panel) Emission profiles from H_2 [1,4] 1489 Å (red) and [1,7] 1500 Å (gray) compared with [O I] 6300 Å (blue). The H_2 emission lines have widths of ∼ 42–52 km s^{-1} and are consistent with a single component whereas the [O I] profiles are better fit with a two-component model with FWHM([O I])$_{narrow}$ = 19.8 km s^{-1} and FWHM ([O I])$_{broad}$ = 47.1 km s^{-1}.

CVSO109: 降着、放出、円盤照射

- Lyα emission: 蛍光H_2 Emissionから reconstruction (modeling framework 利用:右上図参照。Blue側は制限が甘い)
- Lyα COS data: stellar emission + interstellar absorptionでモデル化
  (log N(HI/cm^2) = 20.32±0.06)
- reconstructed Lyα
  - FWHM=600 $^{+300}_{-200}$ km/s (<= H_2 4点)
  - $\text{outflow}_{\text{absorption}}$ at v= -140 ± 100 km/s
  - wind profile (C II + Si II)とコンシステンと
  - 750± 100 km/s (<= COS data))
- H_2 emitting region
  - 0.06 − 0.6 au (typical of TTS disks)

赤丸:H_2から推定





これらの結果は、ほぼODYSSEUS Surveyの期待通りである。

7. Detection of HC18O+ in a protoplanetary disk: exploring oxygen isotope fractionation of CO

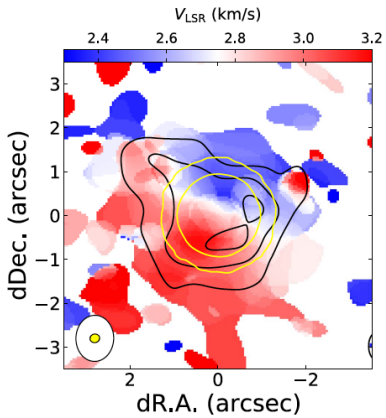
Kenji Furuya, Takashi Tsukagoshi, Chunhua Qi, Hideko Nomura, L. Ilsedore Cleeves, Seokho Lee, Tomohiro C. Yoshida ★ The oxygen isotope fractionation scenario, which has been developed to explain the oxygen isotope anomaly in

Abstract

The oxygen isotope fractionation scenario, which has been developed to explain the oxygen isotope anomaly in solar system materials, predicts that CO gas is depleted in ^{18}O in protoplanetary disks, where segregation between solids and gas inside disks has already occurred. Based on Atacama Large Millimeter/submillimeter Array observations, we report the first detection of $HC^{18}O^+$(4–3) in a Class II protoplanetary disk (TW Hya). This detection allows us to explore the oxygen isotope fractionation of CO in the disk from optically thin HCO^+ isotopologues as a proxy of optically thicker CO isotopologues. Using the $H^{13}CO^+$(4–3) data previously obtained with the SMA, we find that the $H^{13}CO^+/HC^{18}O^+$ ratio in the central $\lesssim$100 au regions of the disk is 10.3 ± 3.2. We construct a chemical model of the TW Hya disk with carbon and oxygen isotope fractionation chemistry, and estimate the conversion factor from $H^{13}CO^+/HC^{18}O^+$ to $^{13}CO/C^{18}O$. With the conversion factor (=0.8), the $^{13}CO/C^{18}O$ ratio is estimated to be 8.3 ± 2.6, which is consistent with the elemental abundance ratio in the local interstellar medium (8.1 ± 0.8) within the error margin. Therefore, there is no clear evidence of ^{18}O depletion in CO gas in the central $\lesssim$100 au regions of the disk, although we could not draw a robust conclusion due to uncertainties. In conclusion, optically thin lines of HCO^+ isotopologues are useful tracers of CO isotopic ratios, which are not very constrained directly from optically thick lines of CO isotopologues. Future higher sensitivity observations of $H^{13}CO^+$ and $HC^{18}O^+$ would allow us to better constrain the oxygen fractionation in the disk.

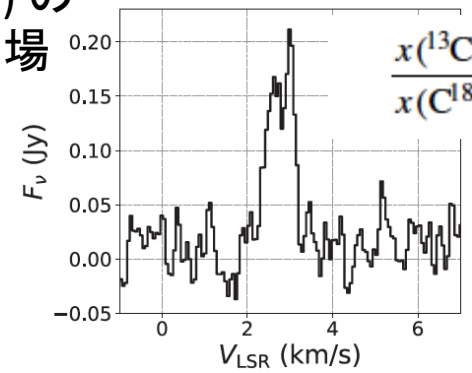
$$H^{12}CO^+ + {}^{13}CO \rightleftharpoons H^{13}CO^+ + {}^{12}CO + 17.4\ \mathrm{K}, \quad (1)$$

$$HC^{16}O^+ + C^{18}O \rightleftharpoons HC^{18}O^+ + C^{16}O + 6.3\ \mathrm{K}. \quad (2)$$



HC18O+ (4-3) の Mon-0, 速度場 (左)

スペクトル (右)



$$\frac{x(^{13}CO)}{x(C^{18}O)} = \frac{k_{ex1}x(CO) + k_{rec}x(e^-)}{k_{ex2}x(CO) + k_{rec}x(e^-)} \times \frac{x(H^{13}CO^+)}{x(HC^{18}O^+)}, \quad (3)$$

k: rate coefficient of electron recombination

k_{rec} for -> & k_{ex} <- in (1) &2)

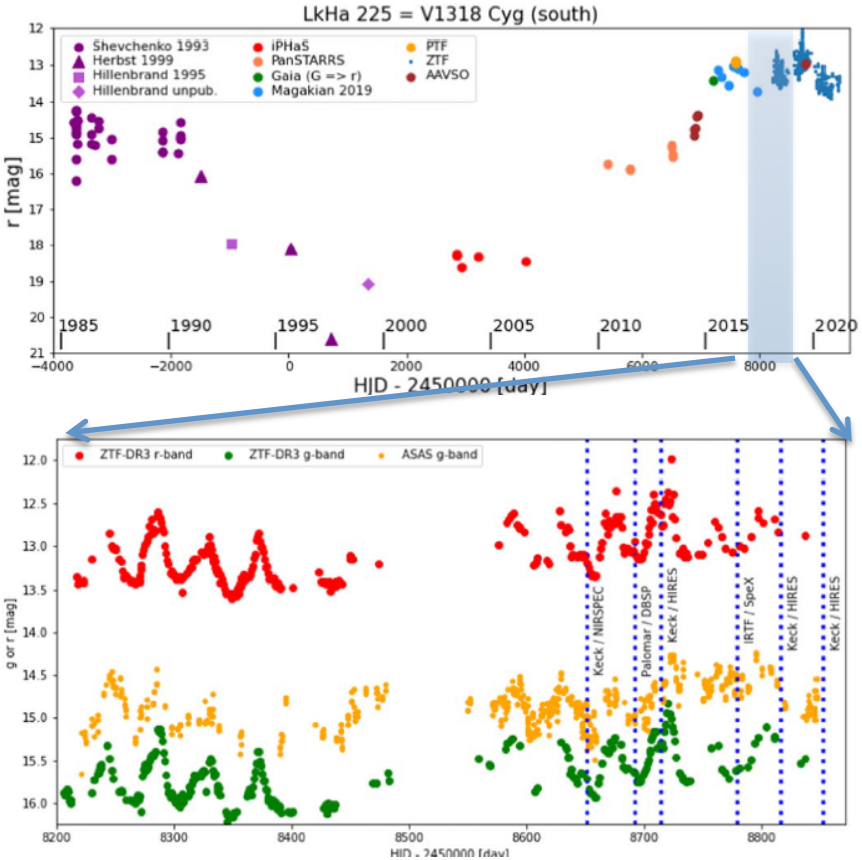
10. LkHα 225 (V1318 Cyg) South in Outburst

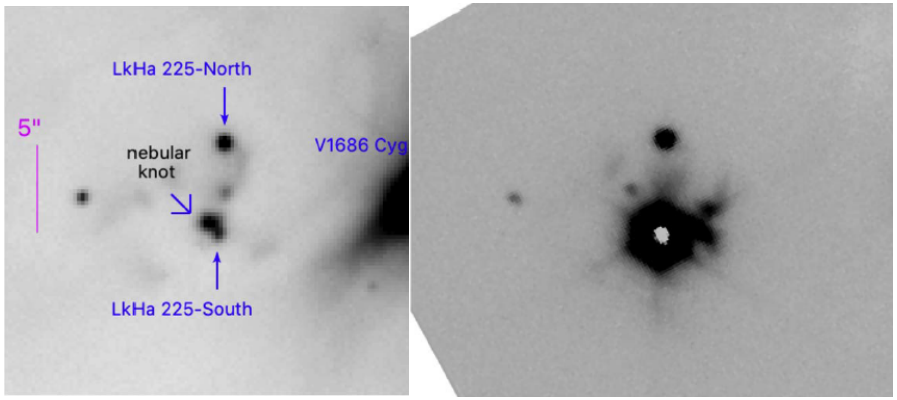
Lynne A. Hillenbrand, Howard Isaacson, Antonio C. Rodriguez, Michael Connelley, Bo Reipurth, Michael A. Kuhn, Tracy Beck, Diego Rodriguez Perez ★ Magakian et al. (2019) called attention to the current bright state of LkHa

Abstract

Magakian et al. called attention to the current bright state of LkHα 225 South, a well-known highly embedded, intermediate-mass young stellar object that over the past two decades has brightened visually from $>20^m$ to $<13^m$. We present recent optical photometric monitoring showing colorless, nonsinusoidal, periodic brightness oscillations occurring every 43 days with amplitude ∼0.7 mag. We also present new flux-calibrated optical and near-infrared spectroscopy, which we model in terms of a Keplerian accretion disk, and high-dispersion spectra that demonstrate similarity to some categories of "mixed-temperature" accretion-outburst objects. At blue wavelengths, LkHα 225 South has a pure absorption spectrum and is a good spectral match to the FU Ori stars V1515 Cyg and V1057 Cyg. At red optical and infrared wav Gaia 19ajj, showing emission in TiO, CO, and metals. Sr II ab There are also signatures of a strong wind/outflow. LkHα 22 well as in the late 1980s, with evidence for deep fades during that LkHα 225 South is another case of a source with episod orders of magnitude, and development of a hot absorption spe also reminiscent in its long brightening time and brightness o IRS7 and ESO Ha 99.

d ~ 900 pc



faint phase

bright phase