EX Lup Outburst in 2008

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- multiple spectral components in CO
- how they develop with time
- origin of disk instability

EX Lup - prototype EXors

compiled by Fedele et al. 2007, A&A, 472, 207

	FUors	EXors
Outburst duration [yr]	>10	~1
Outburst recurrence [yr]	>200	5–10
Mass accreted during an outburst [$M_\odot$]	$>10^{-3}$	10^{-6}–10^{-5}
Magnitude variation [optical mag]	4–6	2–5
Accretion luminosity [$L_\odot$]	few 10^2	>25
Outburst accretion rate [$M_\odot$ yr^{-1}]	10^{-4}	10^{-6}–10^{-5}
Envelope infall rate [$M_\odot$ yr^{-1}]	5×10^{-6}	10^{-7}–10^{-6}
Wind velocity [km s^{-1}]	>300	200–400
Mass loss rate [$M_\odot$ yr^{-1}]	10^{-6}–10^{-5}	10^{-8}–10^{-6}
Spectral features	absorption spectrum F/G-type supergiant like deep CO absorption	emission line spectrum, T Tauri like, Hα inverse P Cyg CO abs./em., Brγ emission

EXLup: 10^{-7}

- (observationally) small brother of FUor
  (FU Ori variables)

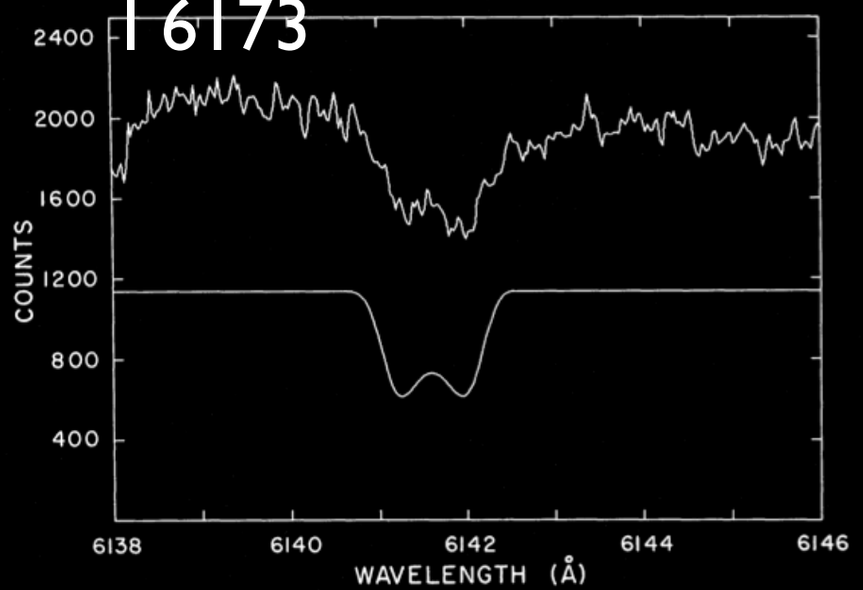
Gras-Velazquez & Ray 2005, A&A, 443, 541
Sipos et al. 2009, A&A

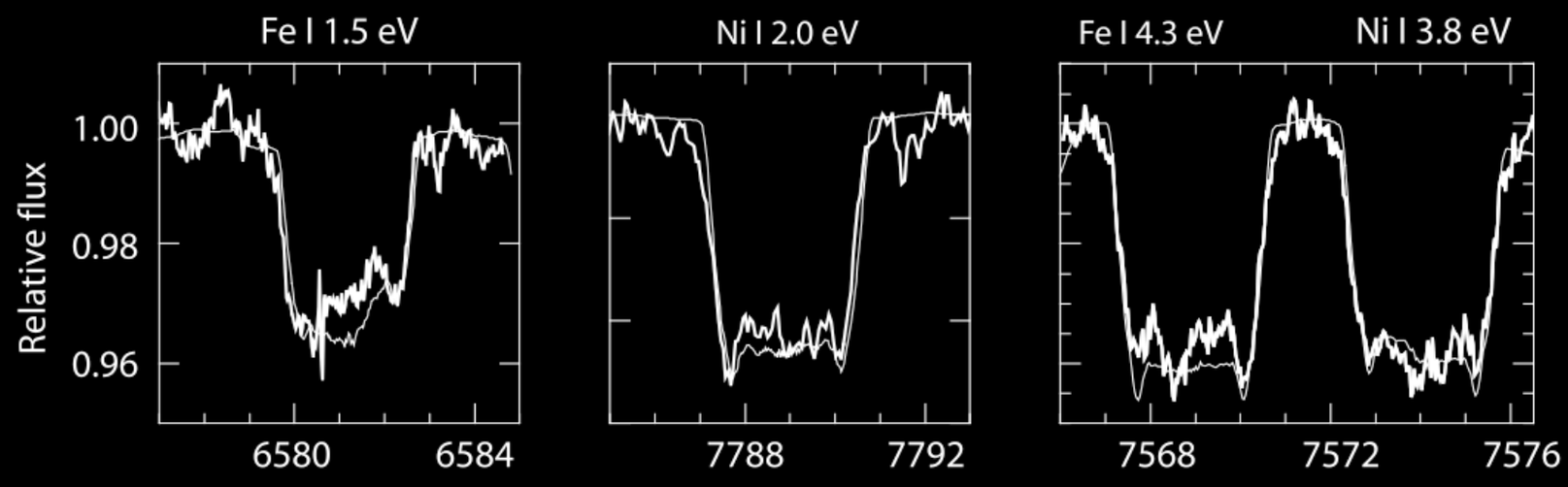
Where is outburst?

- Close to stellar surface - Herbig
  - expanding stellar shell? Herbig 1989 ESO proceeding
  - cool spots on fast rotating star? Petrov & Herbig 2008, AJ, 136, 676
- Disk origin - Hartmann (FUors) Hartmann et al. 2004, ApJ, 609, 906
  - unseen companion Bonnell & Bastien 1992, ApJL, 401, 31
  - infall of protoplanetary core Vorobyov & Basu 2005, ApJL, 633, 137
  - thermal instability * Bell & Lin 1994, ApJ, 427, 987

Disk origin, for sure?

V1057 Cyg
I 6173





FU Ori

Hartmann & Kenyon
1985, ApJ, 299, 462

Petrov & Herbig 2008, ApJ, 136, 676

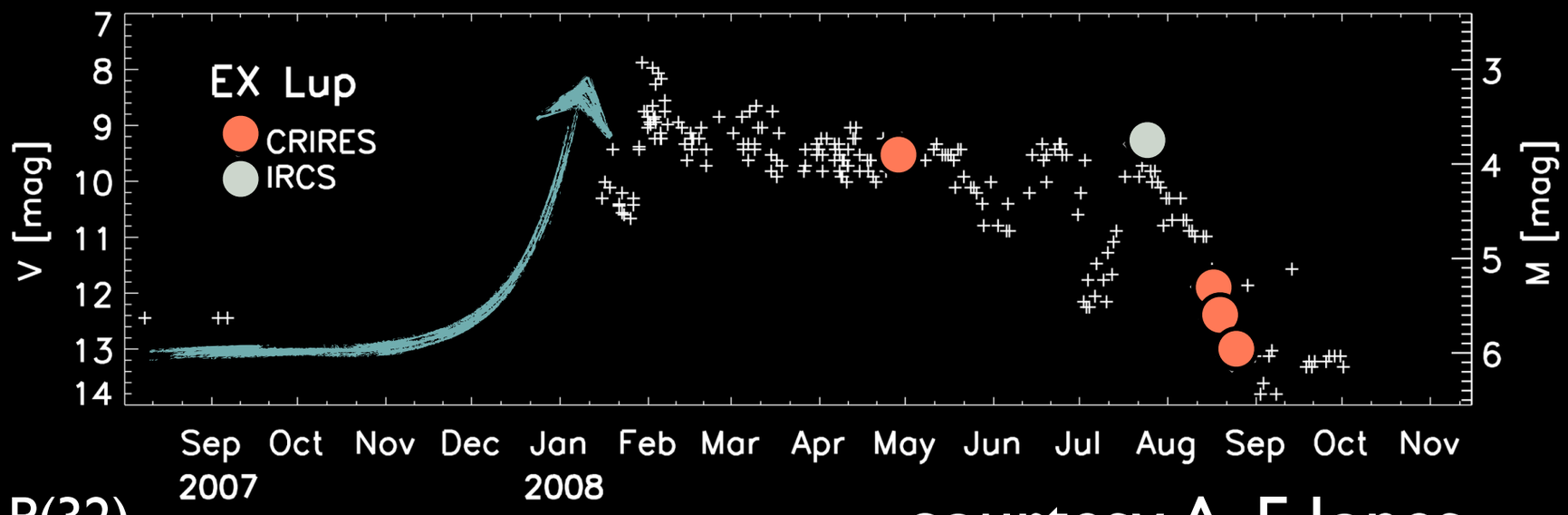
- double peak line interval - FUors
  - cooler outer region rotates slower
- Fair amount of chance it is "photospheric"

Outburst in 2008

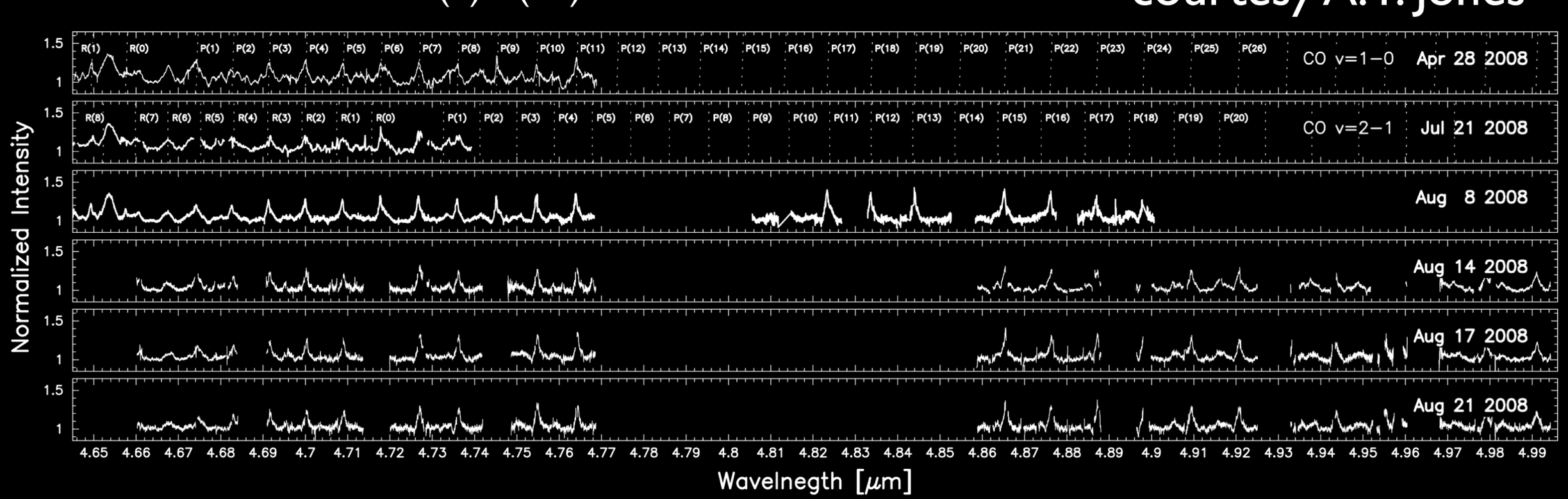
largest in its record

- CRIRES, IRCS
- 6 epochs
- Apr-Aug 2008

R=100,000, R=20,000
dv=3 km/s, 15 km/s)
4.65-4.99 um v=1-0 P(1)-P(32)



courtesy A. F. Jones



c.f.V 1647 Ori (also known as McNeil's Nebula) Brittain et al. 2008, Rettig et al. 2005, Gibb et al. 2006, Caromona et al. 2009 in prep.

Goto et al. in prep.

A14 Carmona / B2 Juhasz

Apr 28 2008 CO v=1−0 R(1) R(0) P(1) P(2) P(3) P(4) P(5) P(6) P(7) P(8) P(9) P(10) P(11)

Jul 21 2008 CO v=2−1 R(8) R(7) R(6) R(5) R(4) R(3) R(2) R(1) R(0) P(1) P(2) P(3) P(4)

Aug 7 2008 CO v=3−2 R(17) R(16) R(15) R(14) R(13) R(12) R(11) R(10) R(9) R(8) R(7) R(6) R(5) R(4) R(3) R(2)

Aug 14 2008 CO v=4−3 R(25) R(24) R(23) R(22) R(21) R(20) R(19) R(18) R(17) R(16) R(15) R(14) R(13) R(12) R(11) R(10) R(9)

Aug 17 2008 CO v=5−4 R(37) R(36) R(35) R(34) R(33) R(32) R(31) R(30) R(29) R(28) R(27) R(26) R(25) R(24) R(23) R(22) R(21) R(20) R(19) R(18)

Aug 21 2008

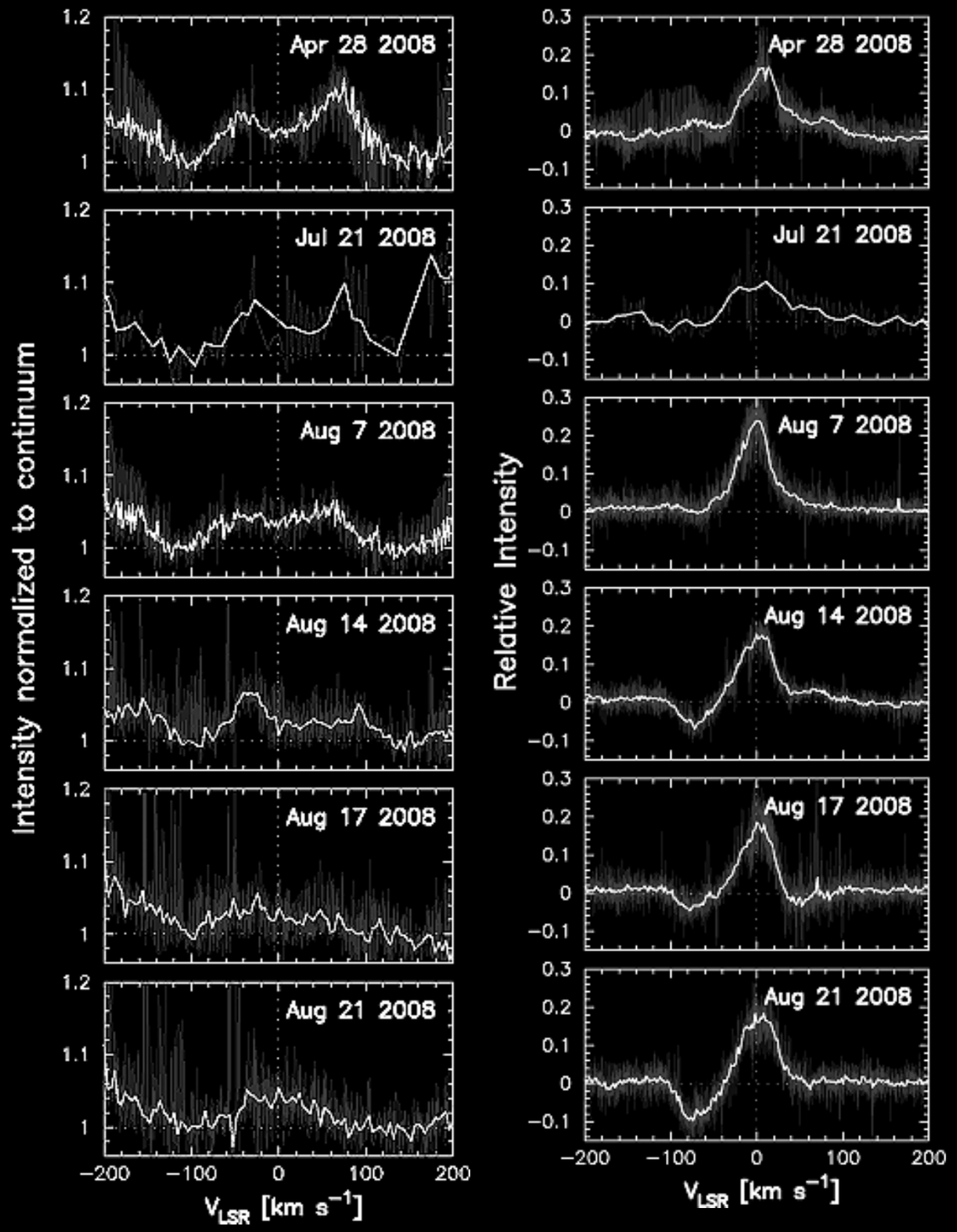
Normalized Intensity

Wavelength [μm]

Two gas components

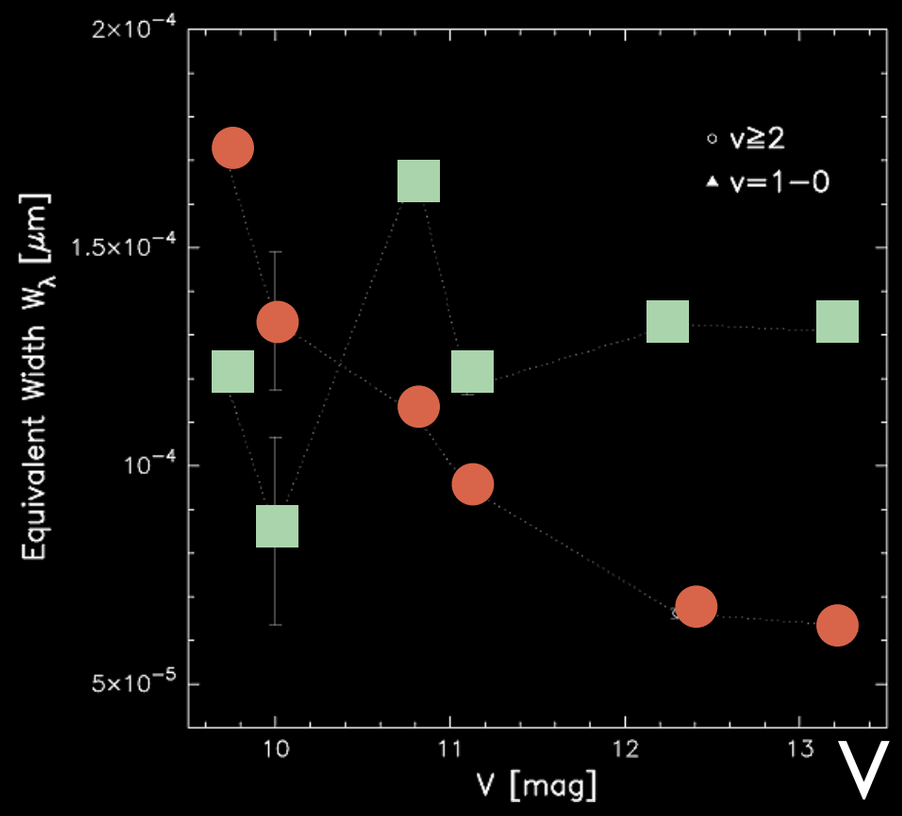
Outburst

Quiescent



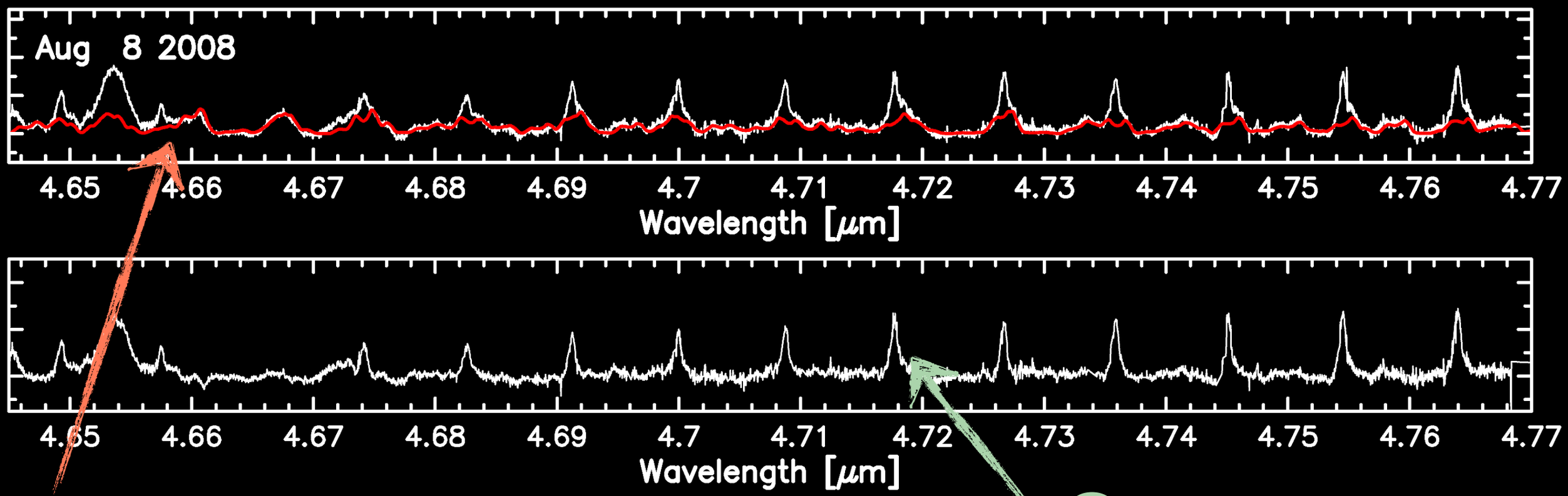
- Outburst
  - decays fast
  - broad (200km/s)
- Quiescence
  - constant
  - narrow (60km/s)

eqw



V mag

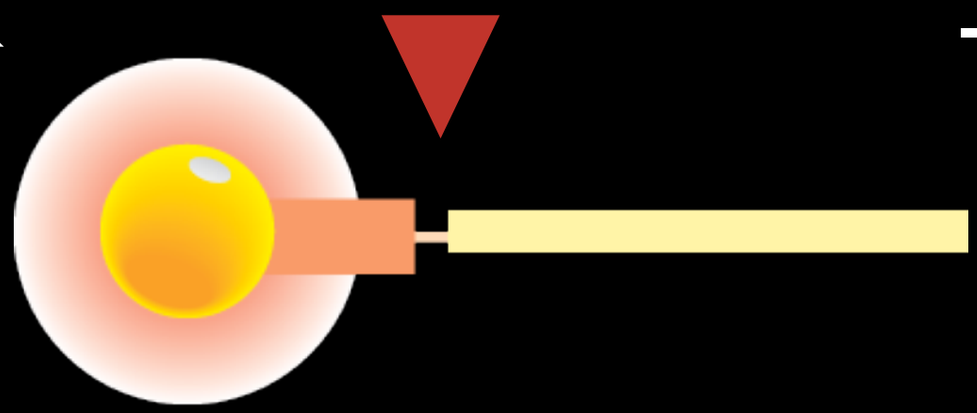
Slab model



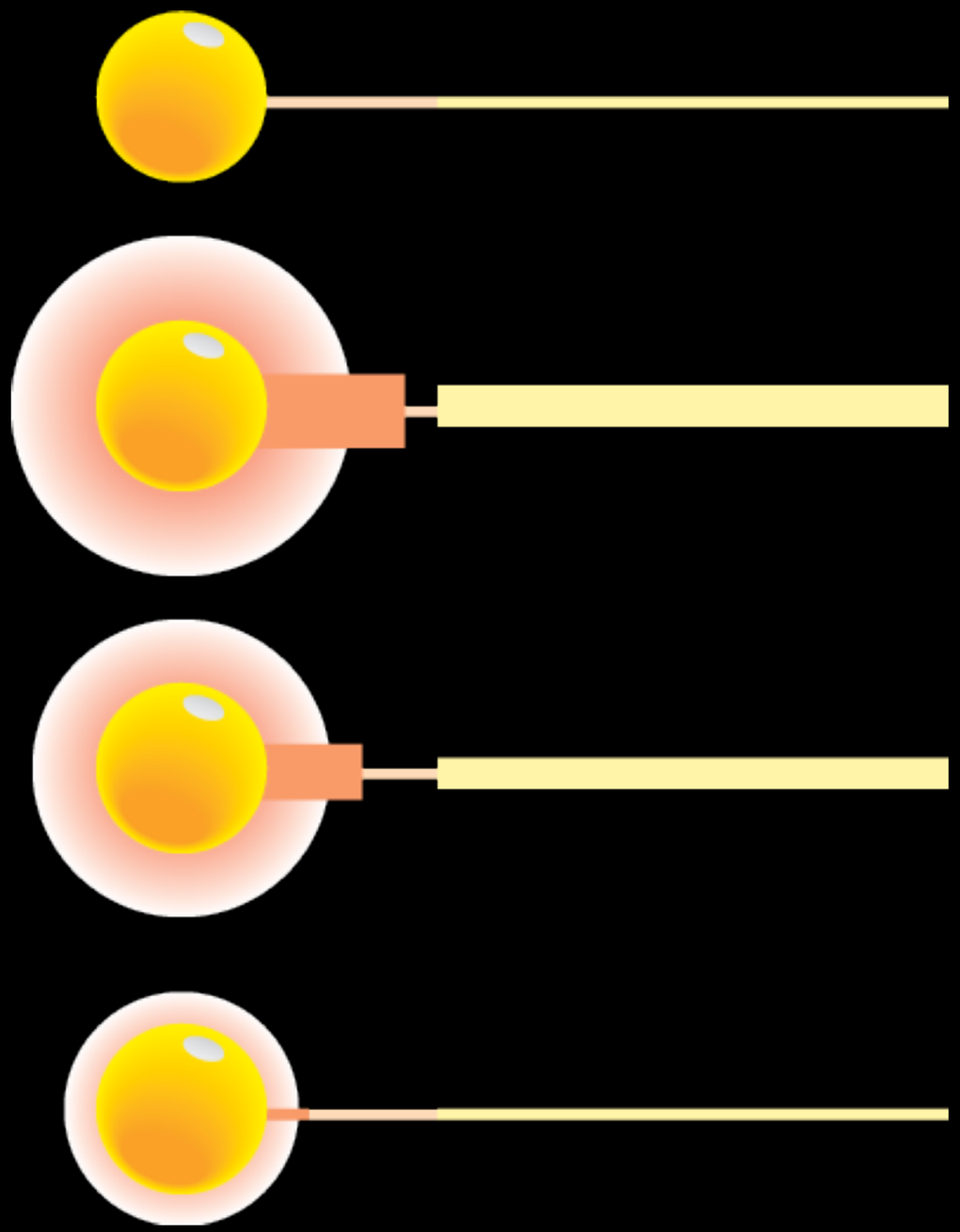
- **Outburst**
  - 0.03-0.2 AU
  - Tv=1500-3000K

- **Quiescence**
  - 0.3 AU
  - Tv < 2000K

transition zone



Picture of Outburst



- Outburst sets off at 0.2 AU

- evolves fast
- Inner disk cut off from outer disk there

- outer disk stays put
- outer disk only passively heated afterward

- wind seen in absorption
- inner disk drained to the star

what transition zone means?

- unseen companion
- protoplanetary cores

} does not explain

Thermal instability

- partially ionized disk

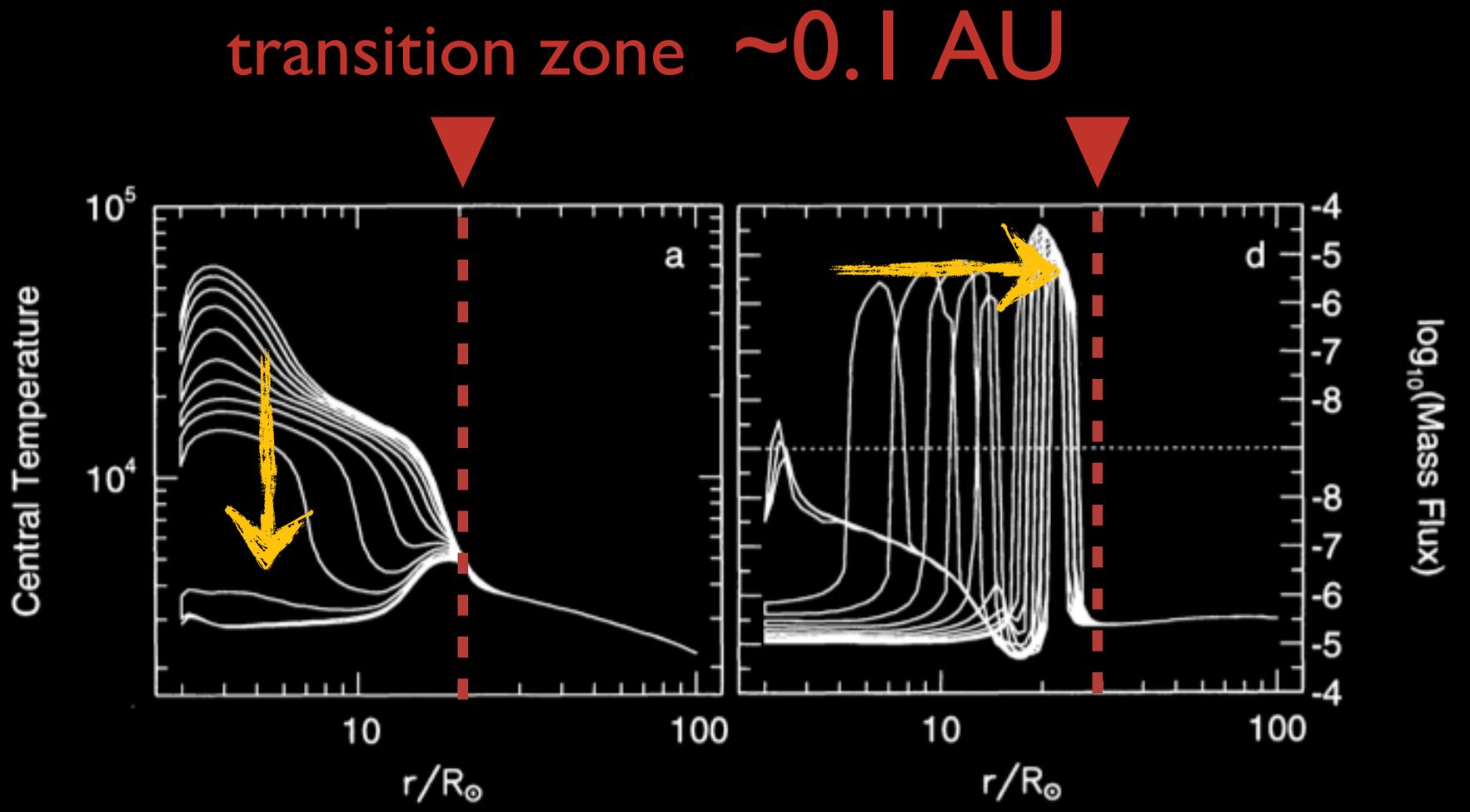
T_{disk} ↗ τ_ν ↘ Qviscous = Qcooling

T_{disk} ↗ τ_ν ↗ H^- opacity

→ run-away local heating

- starts inner edge of the disk
- either internally or externally triggered

Thermal instability

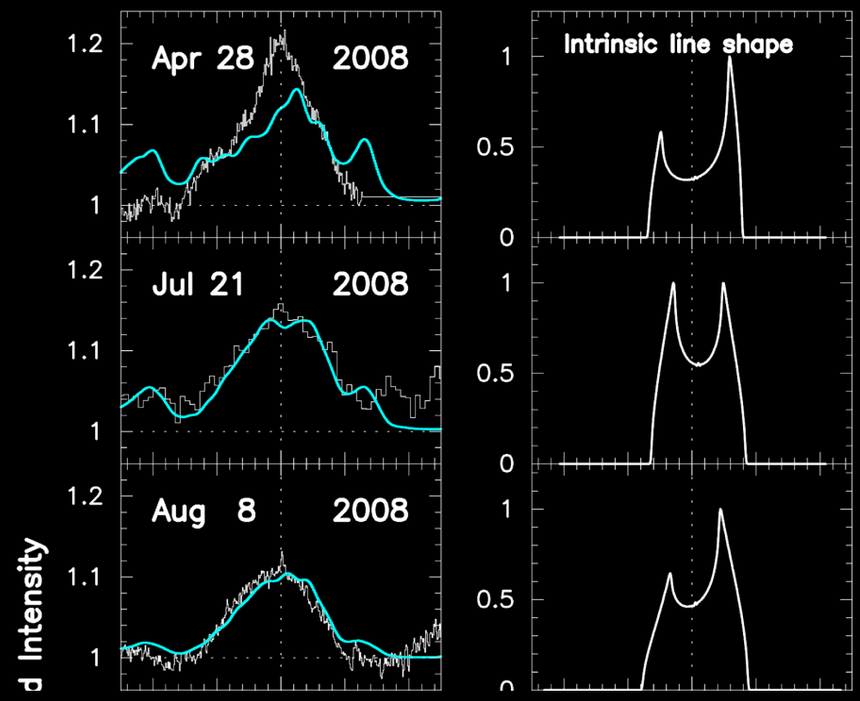


Bell & Lin 1994,
ApJ, 427, 987

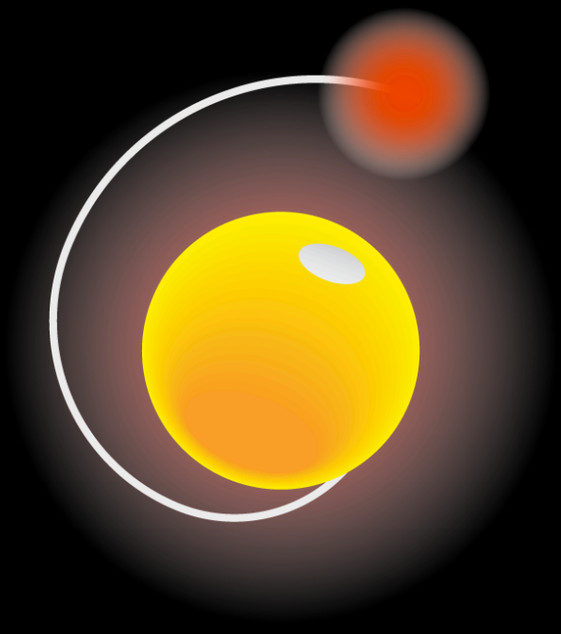
- proceed inside out
- turned off at R_{limit}

Disk in motion picture

- Double peak
  - asymmetric
  - changes by epoch



- Hot spot
  - period is consistent



spiral onto
the star

- Trigger?

Clarke & Armitage 2003, MNRAS, 345, 691

Summary

- EX Lup outburst
  - CO vibrational band at 4.7 um
  - 6 epochs from outburst to quiescent phase
- 3 components
  - outburst (fast, hot, short-lived)
  - quescence (slow, cool, constant)
  - wind
- Transition zone
  - at 0.2 AU
  - massive accretion only within
- Hot spot
  - inhomogeneous accretion