SVS13A as archetype for the role of multiplicity in Accretion bursts and Jets

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More details in Lefèvre et al. 2017
A&A Letters

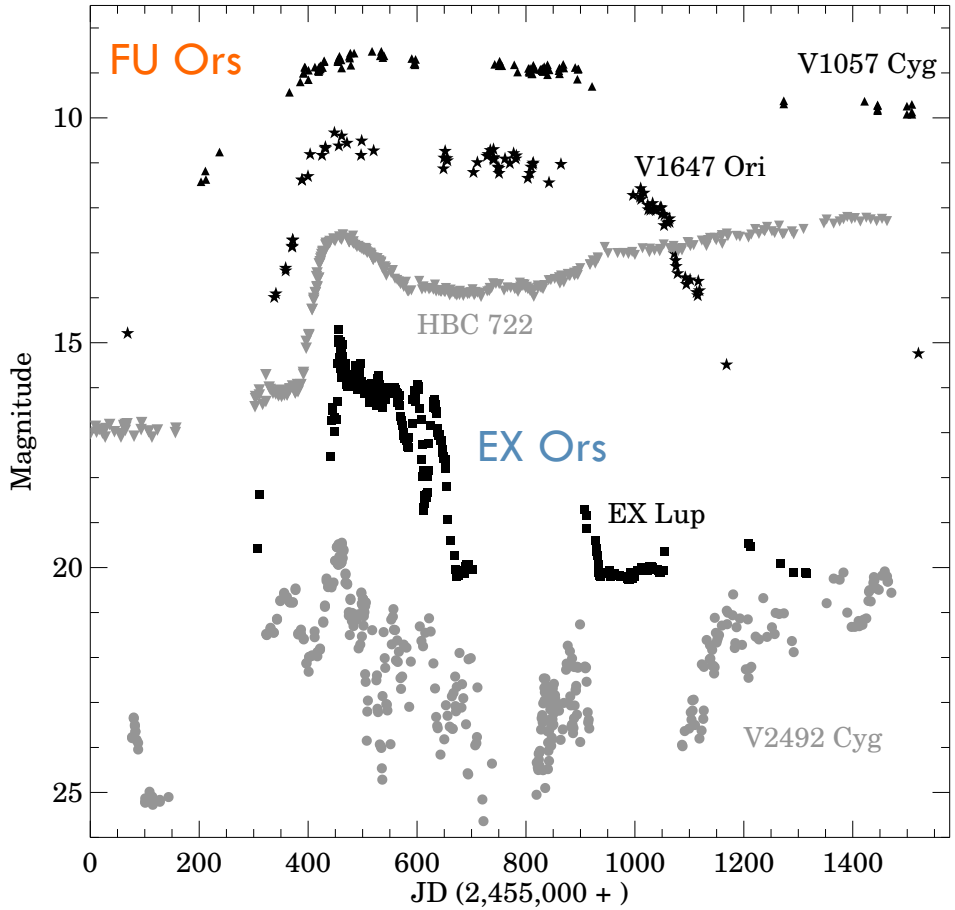
Other outflow results:
Codella+2014 (IRAS2A)
Santangelo+2015 (IRAS4A)
Podio+2016 (L1157)

Origin of Outbursts in YSOs

Highly debated (see PPVI review Audard+2014):

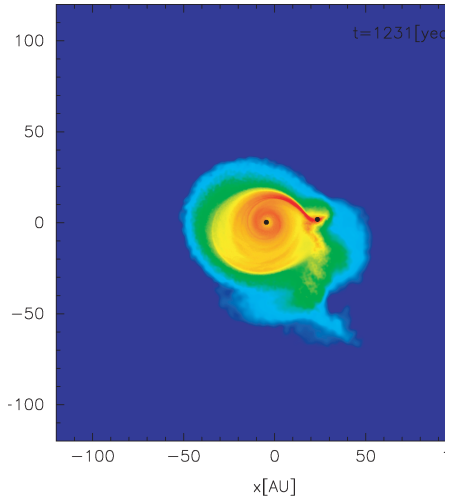
- Internal triggers :
  - disk instabilities
  - Stellar magnetic cycles
- External triggers :
  - Pile-up from infalling envelope (Vorobyov+)
  - Close stellar encounters (Bonnell & Bastien 92):

Many 10-100 au systems in young stars (Goodwin's talk) and FU Ors (Reipurth, Green+2016)



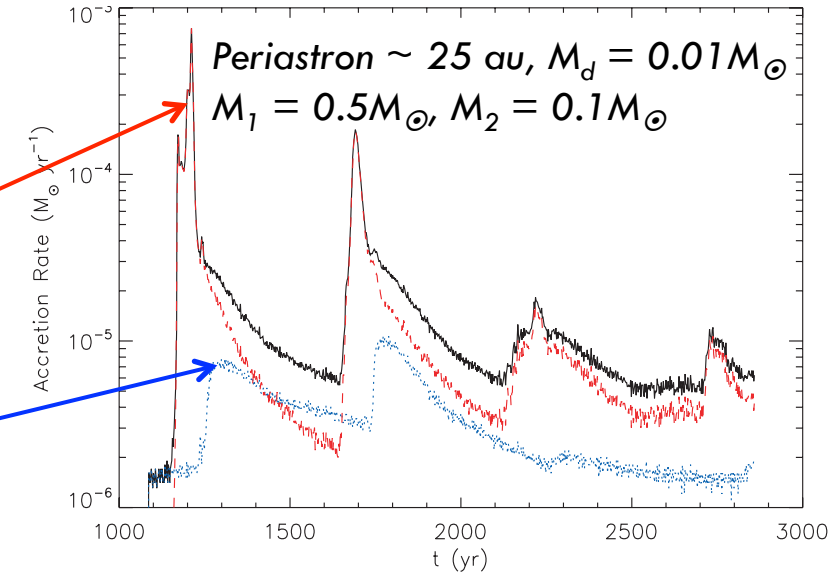
Outbursts from close stellar encounters

- Will have the highest impact on system evolution and planet formation
  - disk truncation, shock heating, radial mixing…
  - orbital migration *(Reipurth +2014, PPVI)*

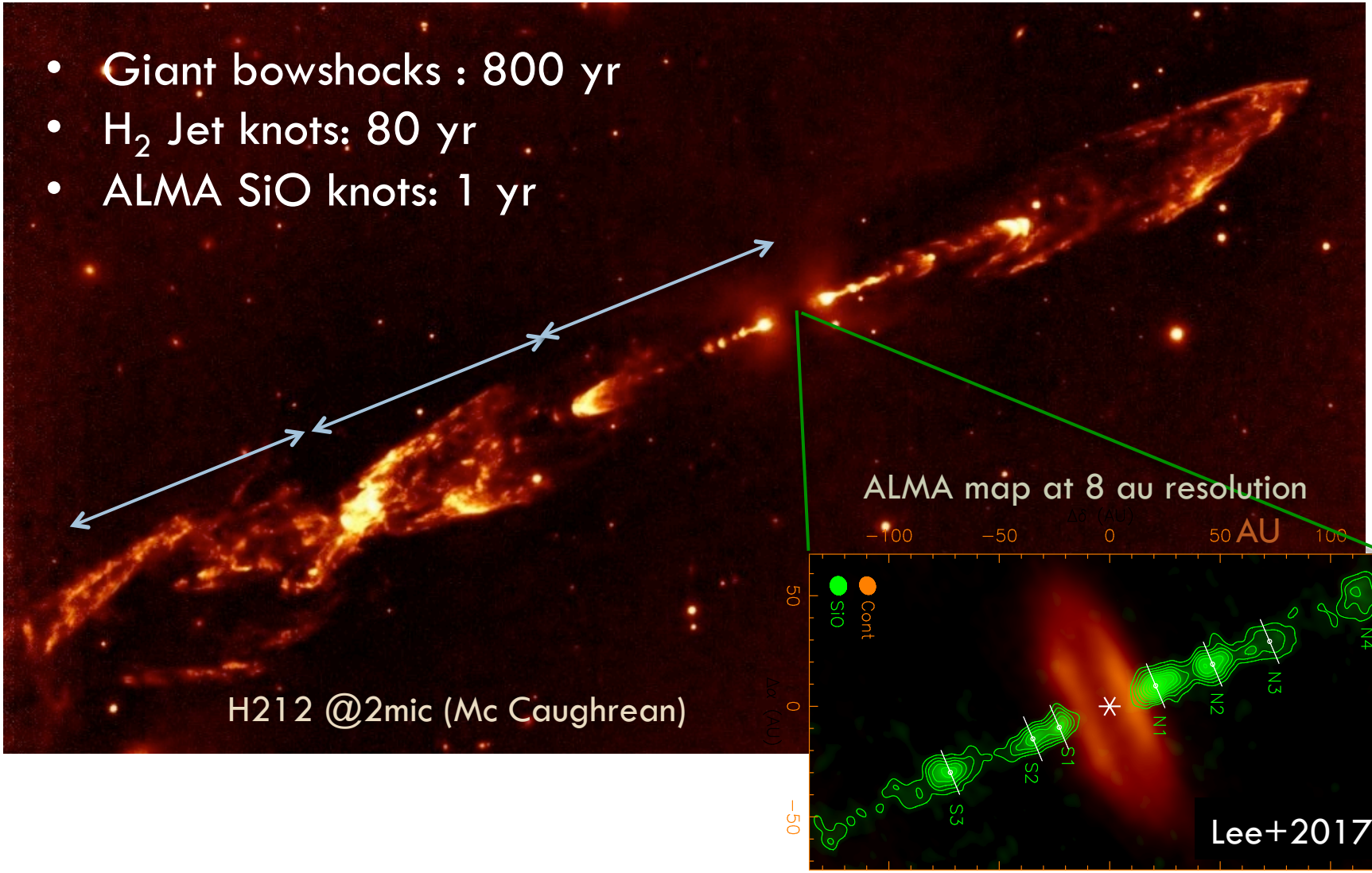


Forgan & Rice 2010

- Signature: quasi–synchronous outbursts *(Forgan & Rice+10)*
  - Secondary : captured material
  - Primary : disk readjustment



Jet obs: Periodic Outbursts !



SVS13A

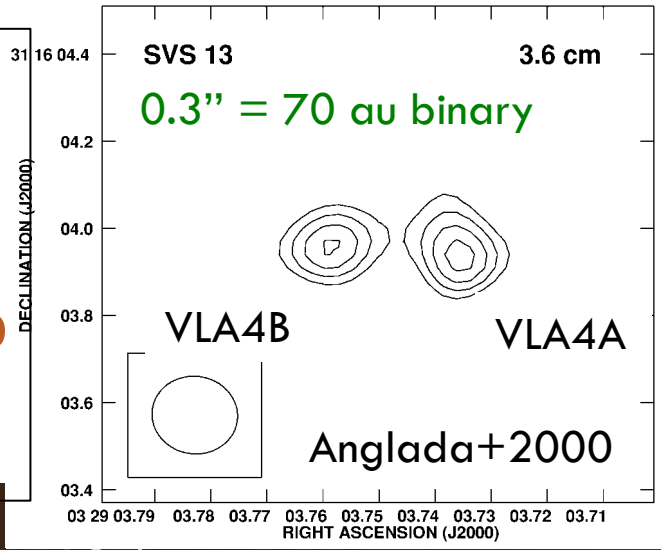
Class 0 / 1 of 25$L_\odot$

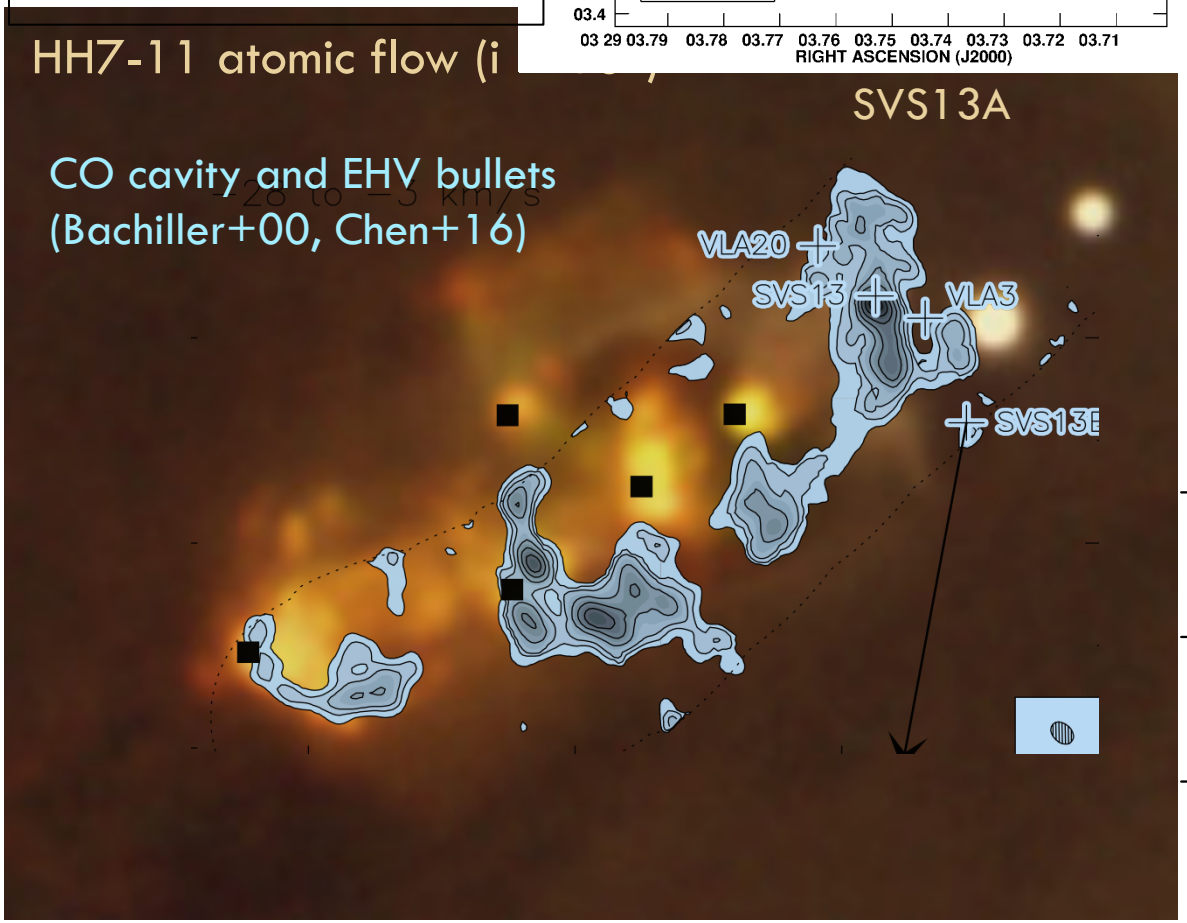
D ~235 pc

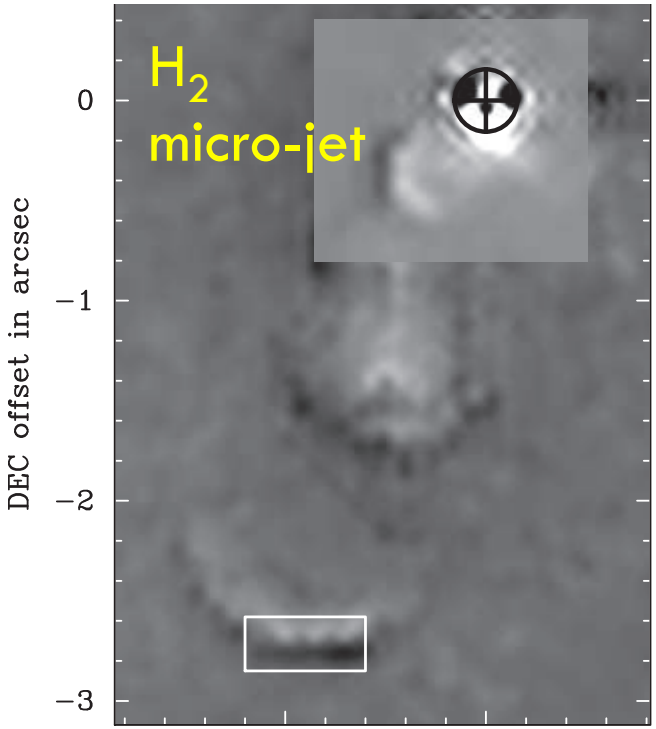
70 au binary

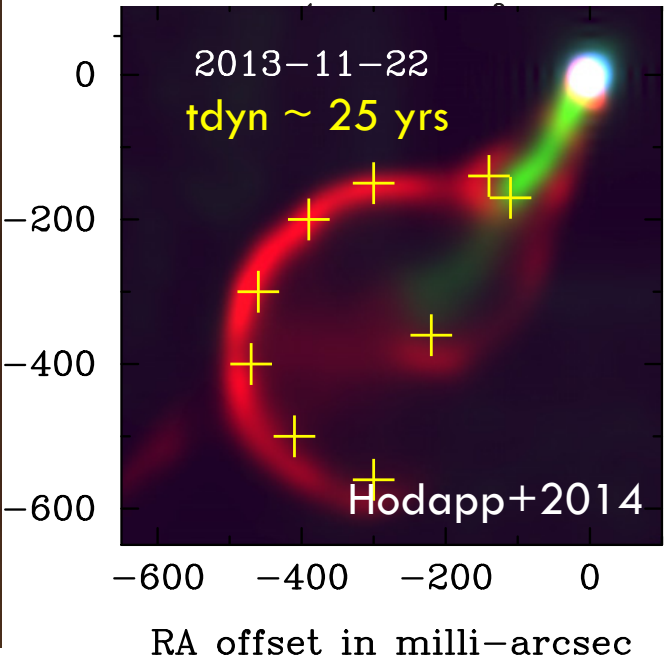
EXOr outburst in 1990

Spectacular outflows





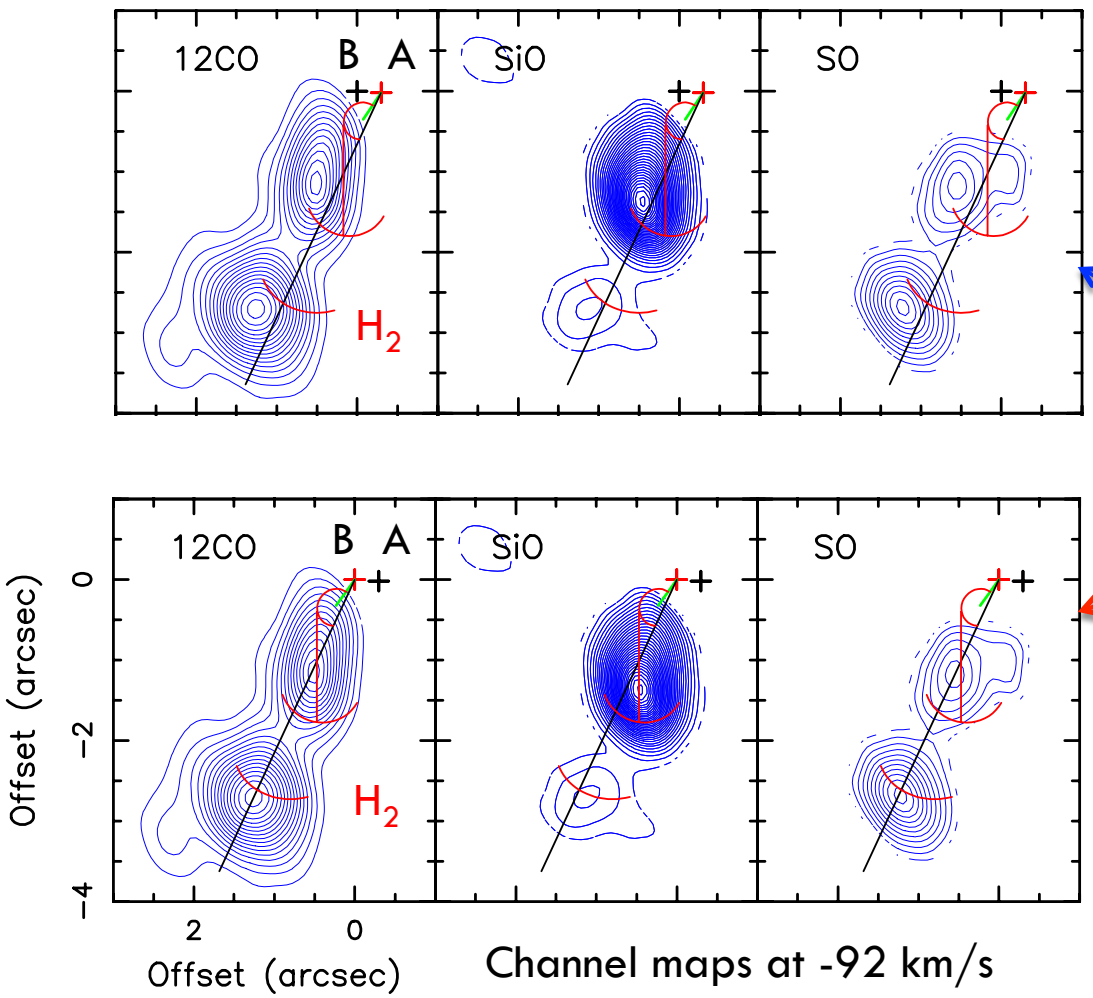




CALYPSO results in a nutshell

- PdBI maps at ~ 0.3”-0.8” in cont, CO, SiO, SO
- Even well-studied systems like SVS13A still hold hidden secrets !
  - It drives not just 1, but 2 or even 3 distinct jets
  - It may harbor a 3rd tighter component at < 30 au
- Its outsanding outflow properties are profoundly affected by multiplicity (wiggling, outbursts, apparently large rotation)
- It provides the first direct evidence for outburst triggering by close stellar encounters

CALYPSO counterparts to H_2 microjet



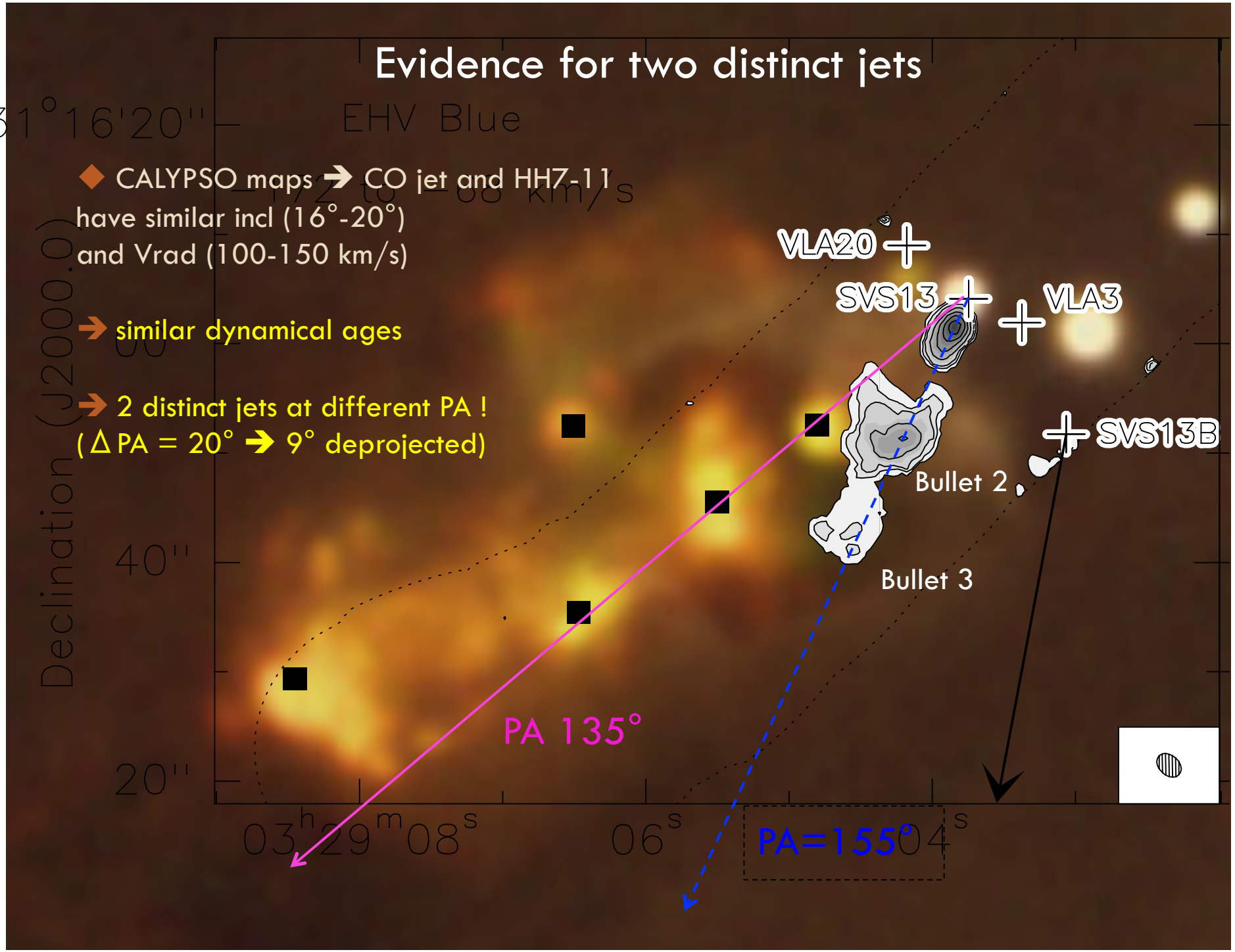
CALYPSO @ PdBI
Beam ~ 0.5" x 0.8"
Absolute Astrometry ~20mas

1) nIR source = VLA4A ?
No, Systematic offset btw H_2 and PdBI maps

2) nIR source = VLA4B ?
Yes, Excellent coincidence !

Can combine Vrad(CO) with H_2 proper motion (Hodapp+14)
➔ Incl (CO jet) ~ 20°
➔ Similar to HH11, i = 16° !

Evidence for two distinct jets

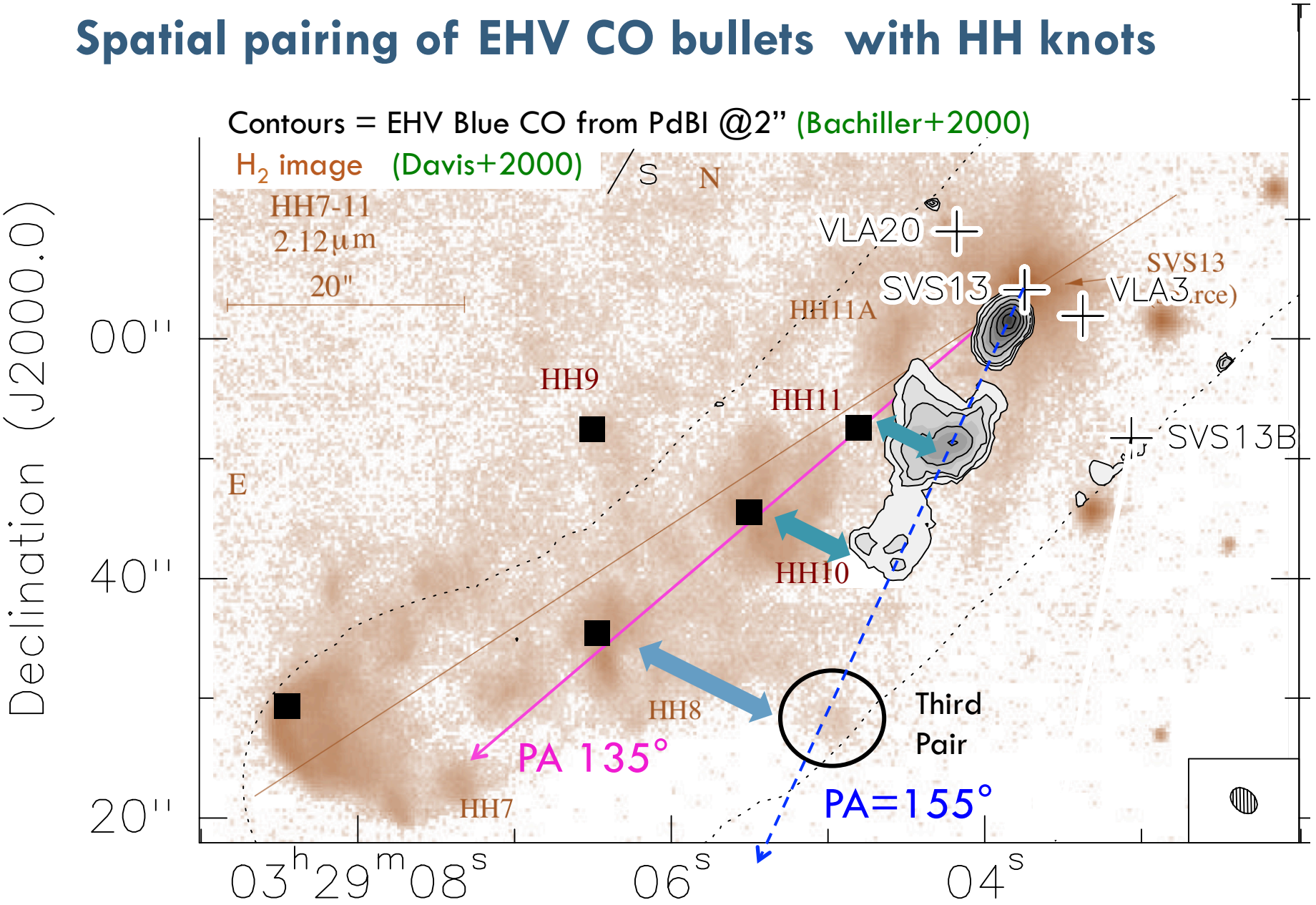


- CALYPSO maps ➔ CO jet and HH7-11 have similar incl (16°-20°) and Vrad (100-150 km/s)

➔ similar dynamical ages

➔ 2 distinct jets at different PA ! (ΔPA = 20° ➔ 9° deprojected)

Spatial pairing of EHV CO bullets with HH knots



External outburst triggering in SVS13A

- Paired CO bullets and HH knots

➔ synchronous outbursts in twin jets

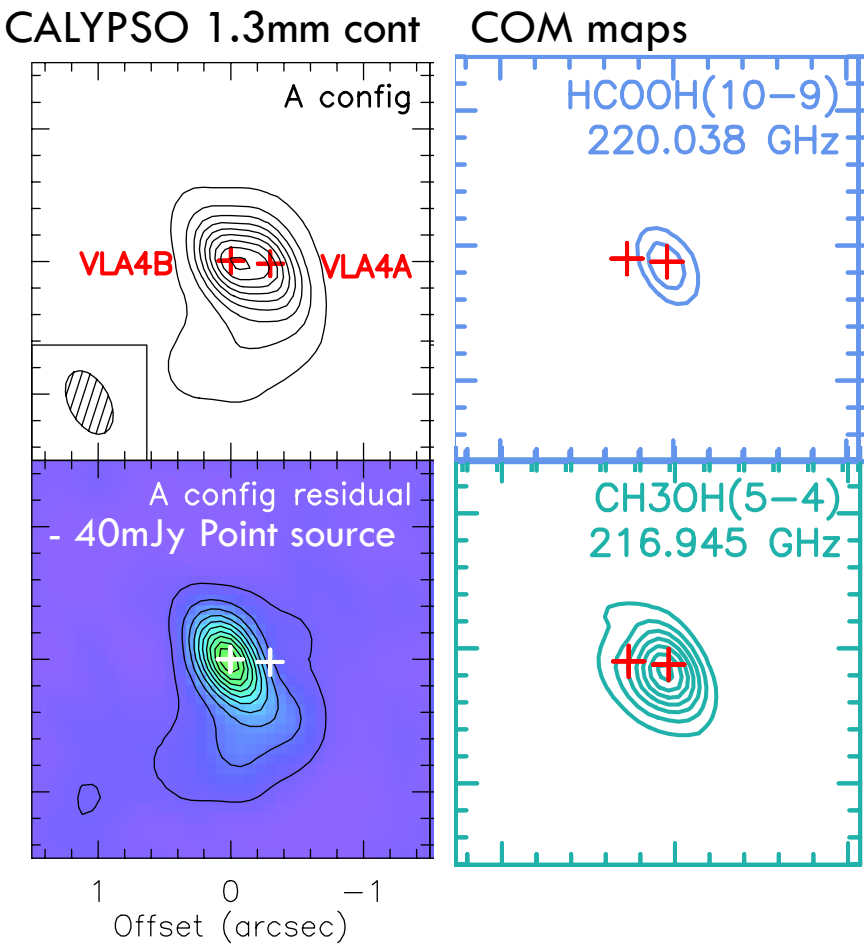
➔ First direct evidence for external triggering !

- Outburst period ~ 300 yr: consistent with VLA 4A-4B close encounters

$$a \simeq 45\,(M_{\rm tot}/M_\odot)^{1/3}(P/300\ {\rm yr})^{2/3}\ {\rm au}$$

- Sep = 70 au ➔ e ~ 0.5, periastron ~ 20au

VLA4A also an active source



- VLA4A has substantial CS dust
  - ~ 0.01Mo inside 50 au
- VLA4A is hot-corino source
  - dense / warm CS gas
- Invisible in nIR
  - embedded
  - 2nd Jet source candidate (radio cm emission)

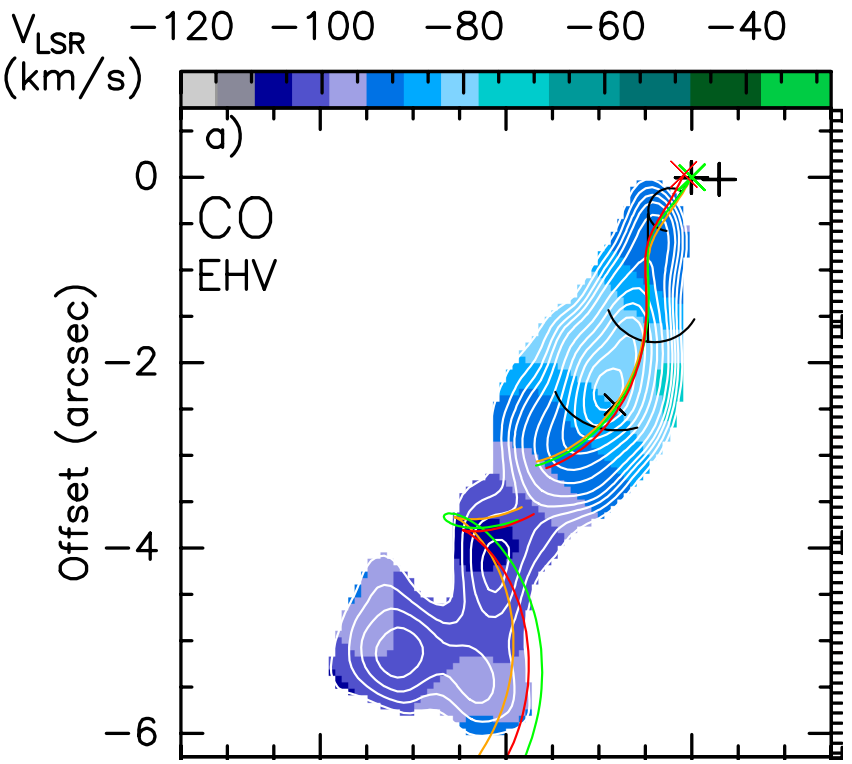
CO and SiO Jet wiggling

- coherent wiggling pattern in CO and SiO
  - Mean PA = 155°
  - $\Delta\,\theta$ ~ 10°
  - wavelength ~ 3" (700 au)

➔ deprojected P ~ 100 yrs

too short for orbit with VLA4A

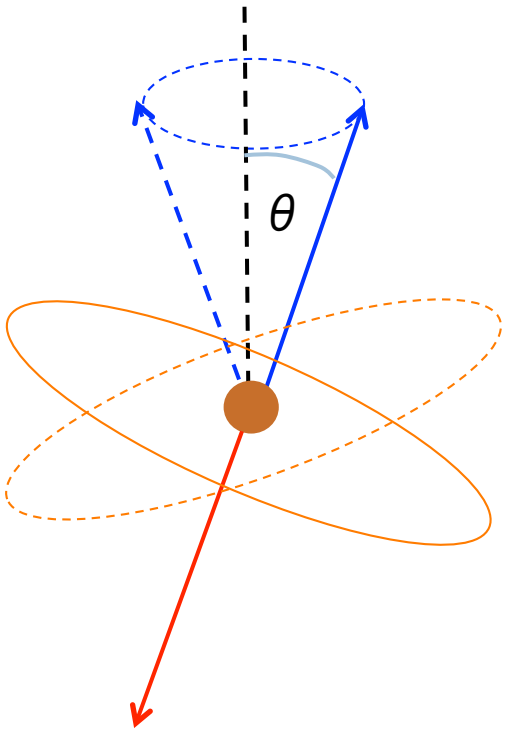
➔ 3rd source ?



Jet wiggling: Precession or orbital ?

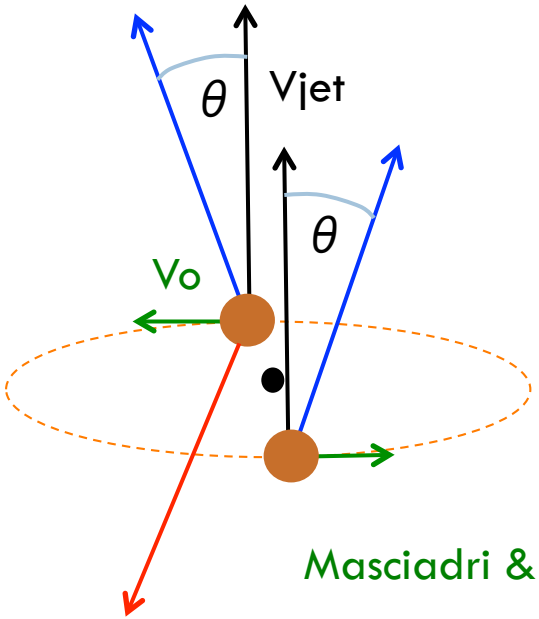
Jet precession:

- θ = precession angle
- λ = Vjet x Period
- S-type symmetry



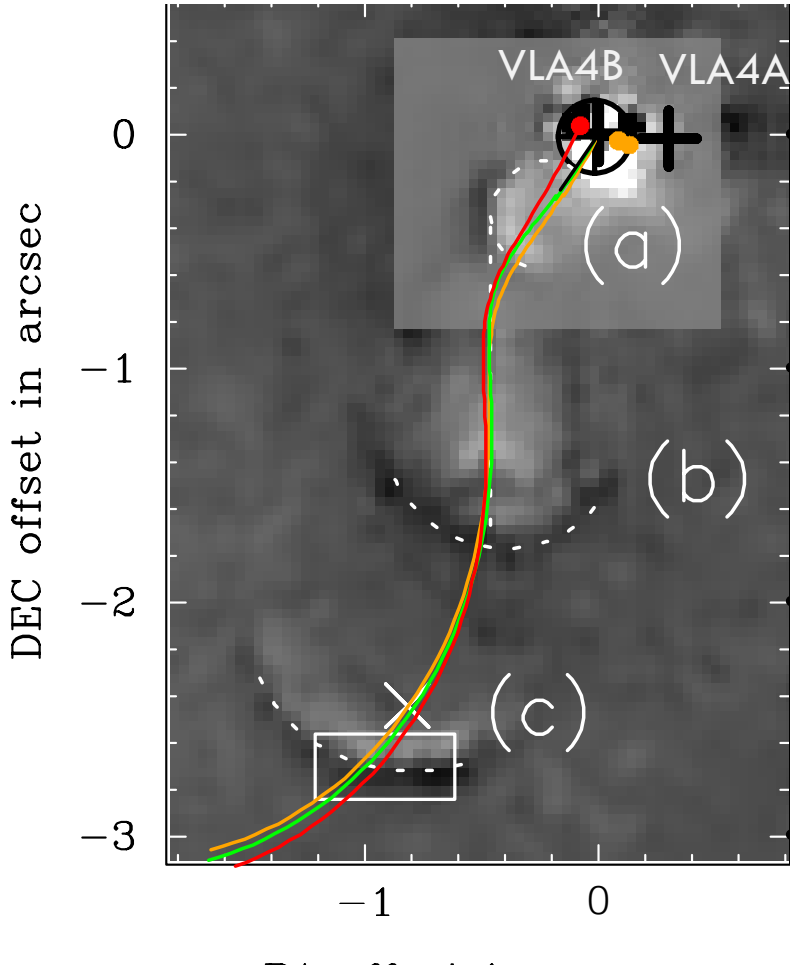
Orbital motion of jet source:

- tan θ = Vo / Vjet
- λ = Vjet x Period ➔ Ro = λ tan θ /2π
- W-type symmetry



Masciadri & Raga 2002

Orbital Model of wiggling



- Orbital motion:
  - $\tau_o = 93$ yrs: cannot be orbit around VLA4A (would need 7-35 $M_\odot$ for e<0.8)
  - ➔ third (unseen) source at sep 20-32 au
  - Ro = $\lambda \tan\theta / 2\pi$ = 18 au

➔ CO source is the least massive

Disk Precession?

- Rigid disk precession induced by inclined companion (Terquem 1999) ?

  - For Rd ≈ a/3 (truncation)

$$\tau_o = 0.1\tau_p\mu/\sqrt{1-\mu}$$

$$\text{with } \mu = M_2/M_{tot}$$

$\tau_p \approx 90$ yrs, θ (orb) $\leq 2°$

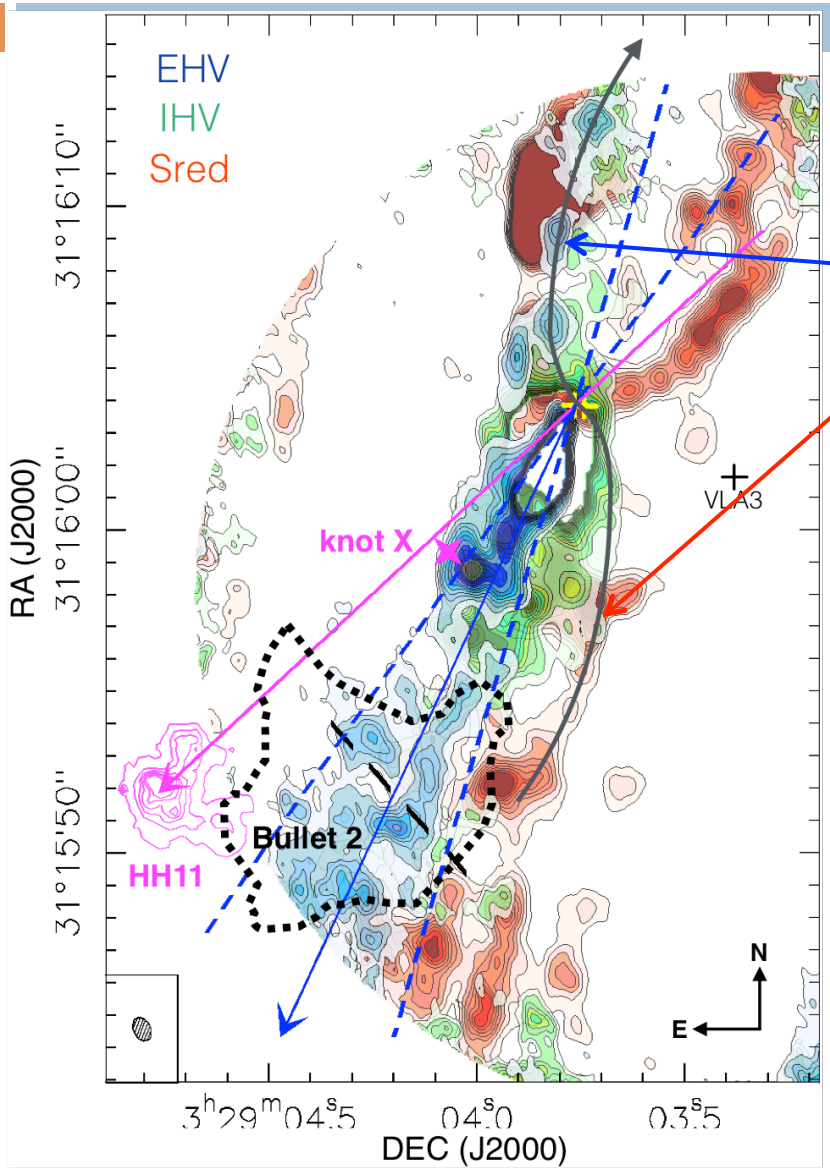
➔ planetary companion

a < 0.5 au, Mc < 30 M_{jup}

PB: will not truncate disk at a/3

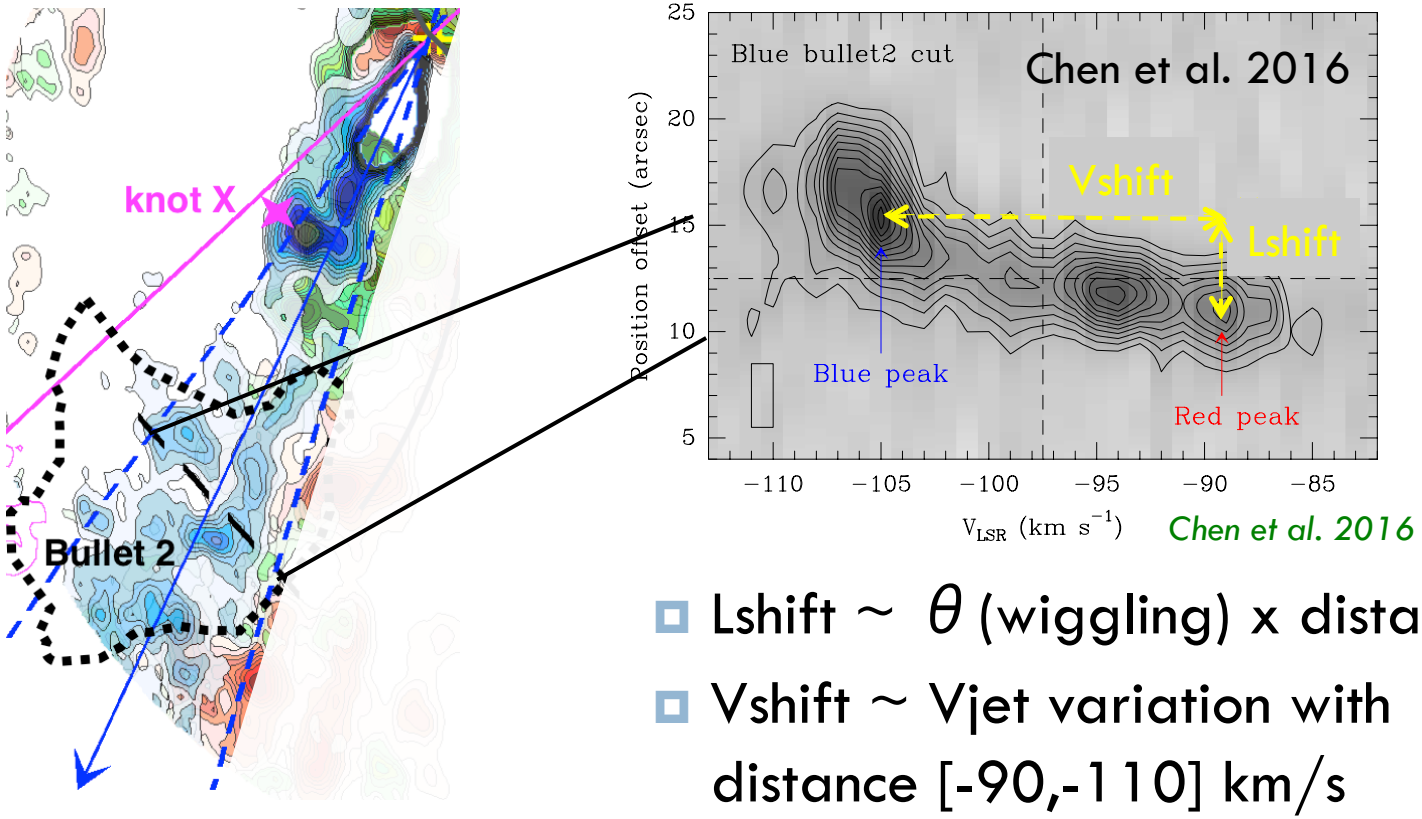
➔ miss self-consistent model

A third jet from SVS13A ?



- S-shaped reversed velocity sign in each lobe:
  - Blue in red (north) lobe
  - Red in blue (south) lobe
- Rotation Unlikely
  - Reversal if $V\phi$ / Vp > 1/tan(i) = 3
  - unlike current MHD disk wind models
- Third jet at PA ~ 0° ?
  - Favors triple system

Rotation in CO bullet or jet wiggling ?



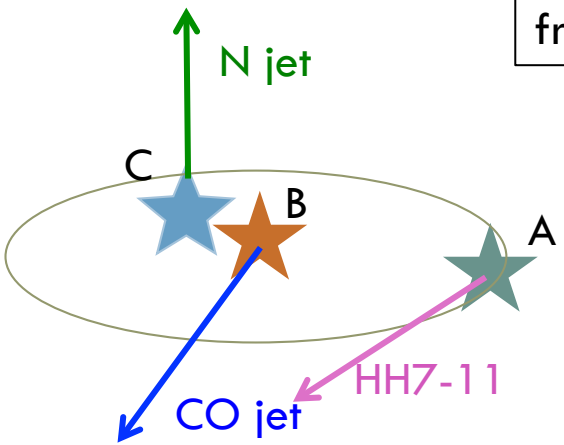
- Lshift ~ θ (wiggling) x distance
- Vshift ~ Vjet variation with distance [-90,-110] km/s

➔ Apparent large rotation could be artefact of jet wiggling combined with velocity variability

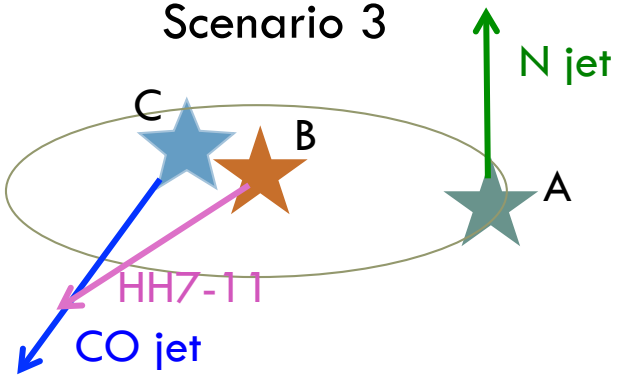
Which source is driving which jet ?

VLA4A is external trigger
But twin outbursts could come from BC (when perturbed by A)

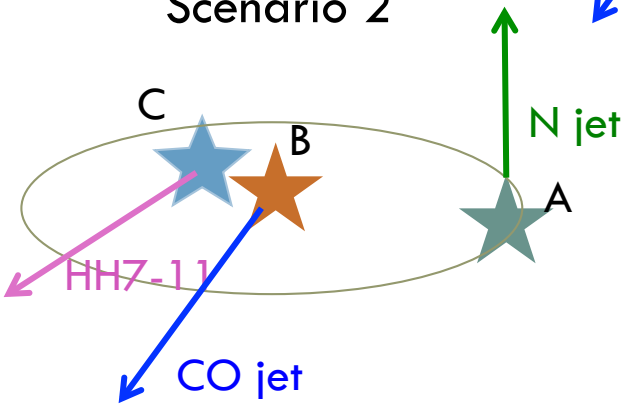
Scenario 1



Scenario 3



Scenario 2



Conclusions: Methodology

- mm-interferometry strong synergy with H_2 AO studies (eg: Vrad vs. ppm ➔ flow inclination)
- Jet wiggling on $\lambda \sim$ arcsec is powerful to reveal close (< 30 au) binaries in embedded protostars
- disk precession also possible. But self-consistent modeling for short $\tau_p \sim 100$ yr strongly needed !
- « Rotation » measurements in wiggling jets must be viewed with great caution, especially at low resolution

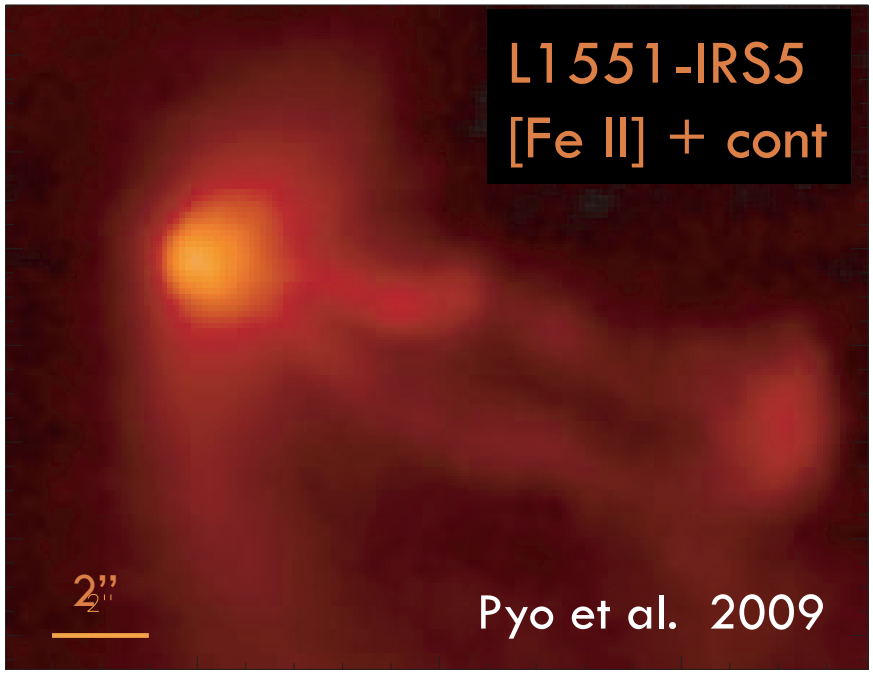
Conclusions: SVS13A

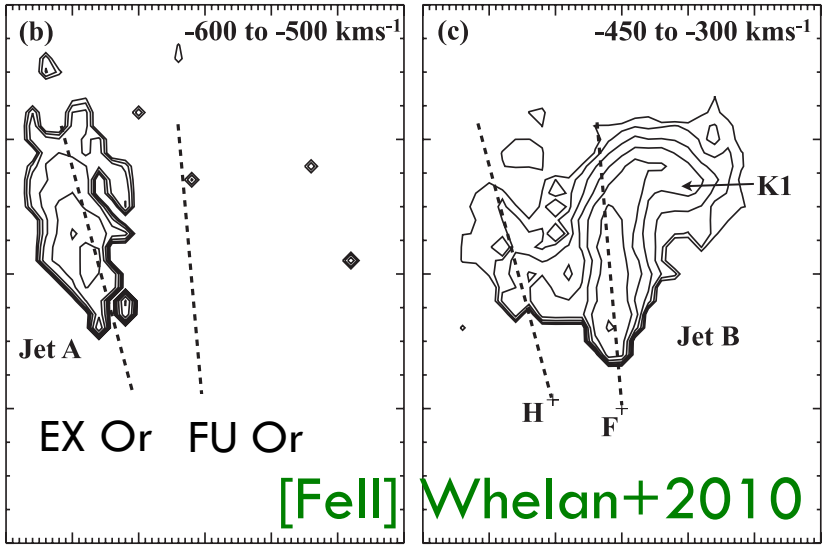
- Even well-studied systems like SVS13A still hold hidden secrets !
  - It drives not just 1, but 2 or even 3 distinct jets
  - It may harbor a 3rd tighter component at < 30 au
- Its outsanding outflow properties are profoundly affected by multiplicity (wiggling, outbursts, apparently large rotation)
- It provides the first direct evidence for outburst triggering by close stellar encounters

Conclusions: Outburst triggering

- Twin jets of SVS13A have quasi-synchronous major outbursts : first direct evidence of external trigger !
- P ~ 300 yr favors triggering by tidal perturbation at periastron of VLA4A-4B
- Highly reminiscent of twin jets in binary FUOr systems L1551-IRS5 and ZCMa
  - Similar orbital separation and $\Delta\theta$ (jets)
  - L1551-IRS5 is also triple (Lim=2006)

Twin jets from L1551-IRS5 and ZCMa





see also Antoniucci+2016

Class 1 FU Or, d=140 pc

- 50 au binary
- Quasi-coplanar disks and jets
- 3rd source at 15 au (Lim +2006)

Class 2 FU Or + EX Or, d=1150 pc

- 115 au binary
- Quasi-coplanar jets
- Wiggling P ~ 4-40 yr ~ EX Or outburst ➔ 3rd source ?