Distance of Stars by mean of the Phase-lag Method

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In collaboration with

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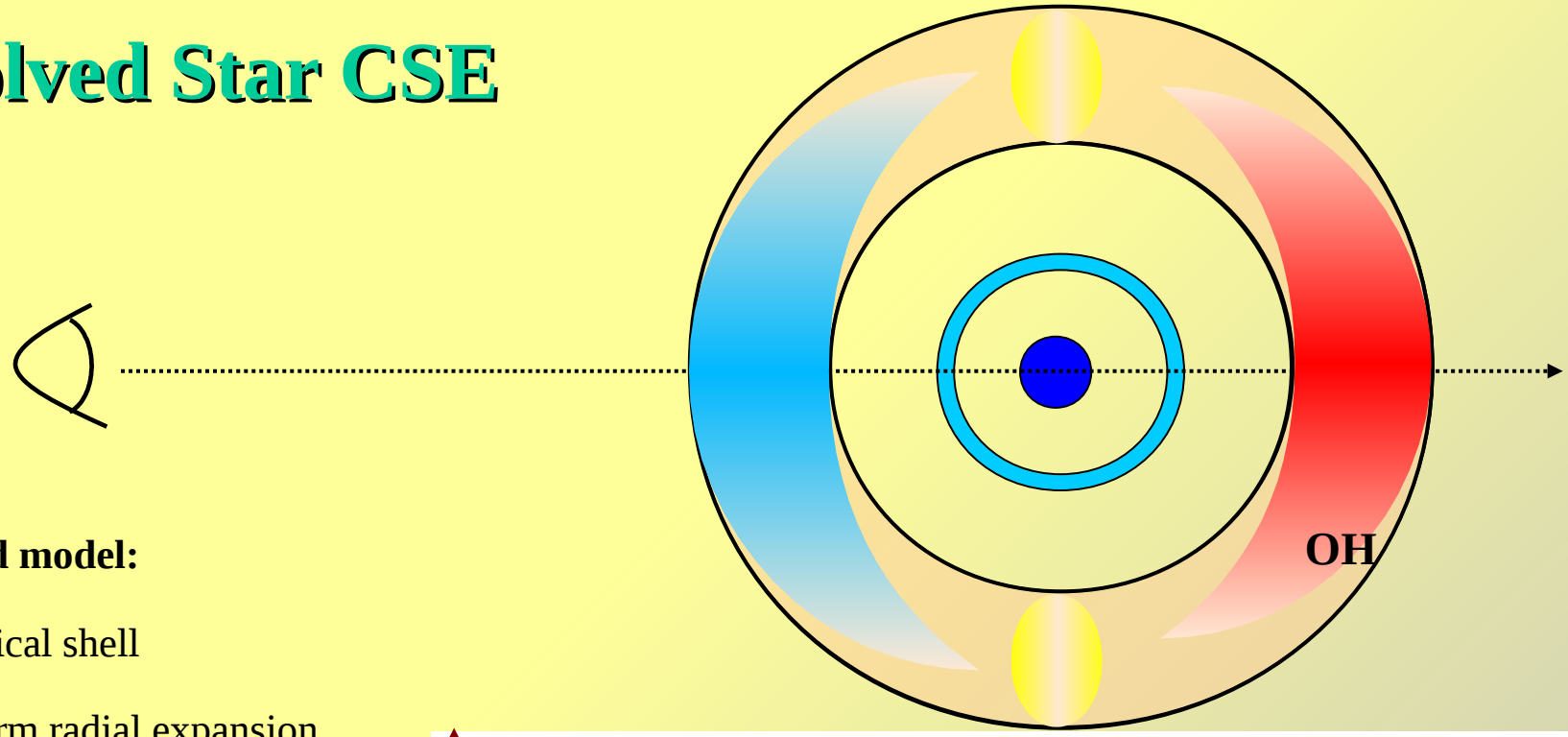
& Anita Richards *(JBCA)*

Introduction

- OH/IR stars
  - ➥ ~Miras BUT optically thick circumstellar dust & gas envelopes (CSEs) - periods: 1 year → >5 years - typical diameter 2000 → 10.000 AU (→ 1.25” @ GC / 0.2” @ LMC)

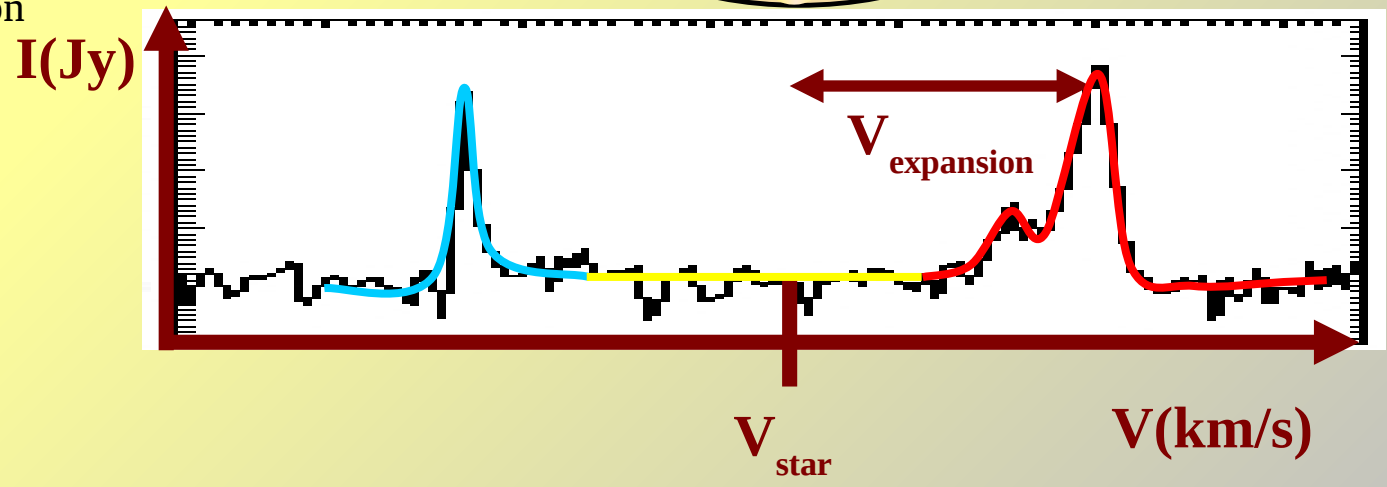
- Distance determination
  - ➥ no optical parallax measurements possible
  - ➥ period-luminosity relation for Miras *(Whitelock et al. 1991)* no longer valid for P> 450 days.
  - ➥ kinematic distances *(from V_rad from OH spectra)* using Galactic rotation curve also impresice *(by up to a factor of 2, Reid et al. 2009)*
  - ➥ VLBI astrometry *(succesfully applied for nearby objects → D< 2kpc, Vlemmings & van Langevelde 2007; Orosz et al. 2017)*
  - ➥ **Phase-lag distances**

Evolved Star CSE



Standard model:

- Spherical shell
- Uniform radial expansion



Phase-lag method

- OH light curves

  time difference btw blue & red OH maser peak (long-term monitoring needed)

  ➥ linear diameter

Phase-lag τ_0 determination by interpolation

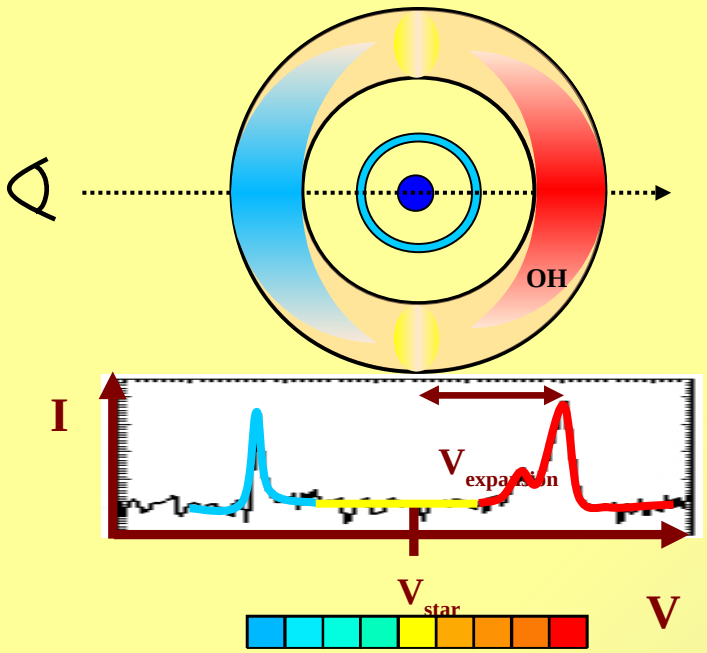
➥ Scaling and shifting of the integrated-flux light curves of the blue peak F_B with respect to the red one F_R

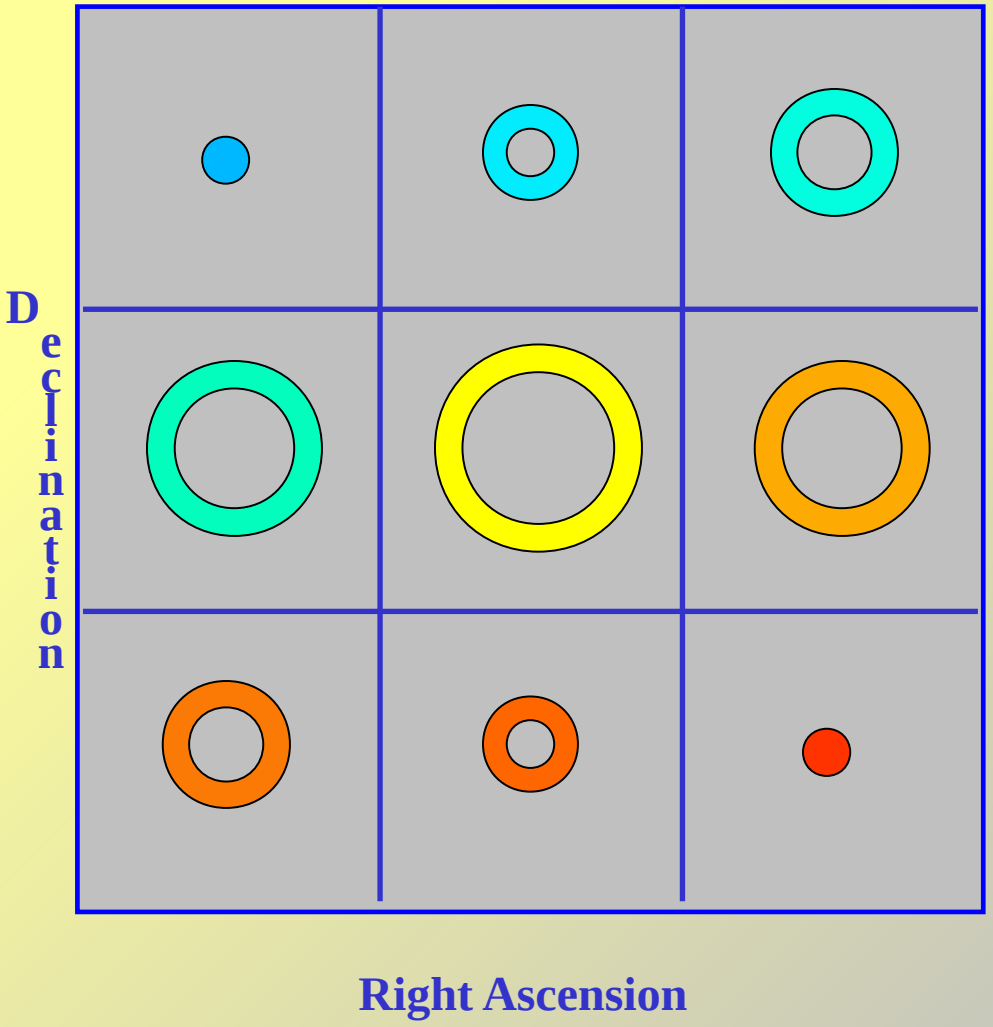
Minimizing the function

$$\Delta F = F_R(t) - a * F_B(t+\tau_0) + c$$

with a, c constants for the amplitude and mean flux

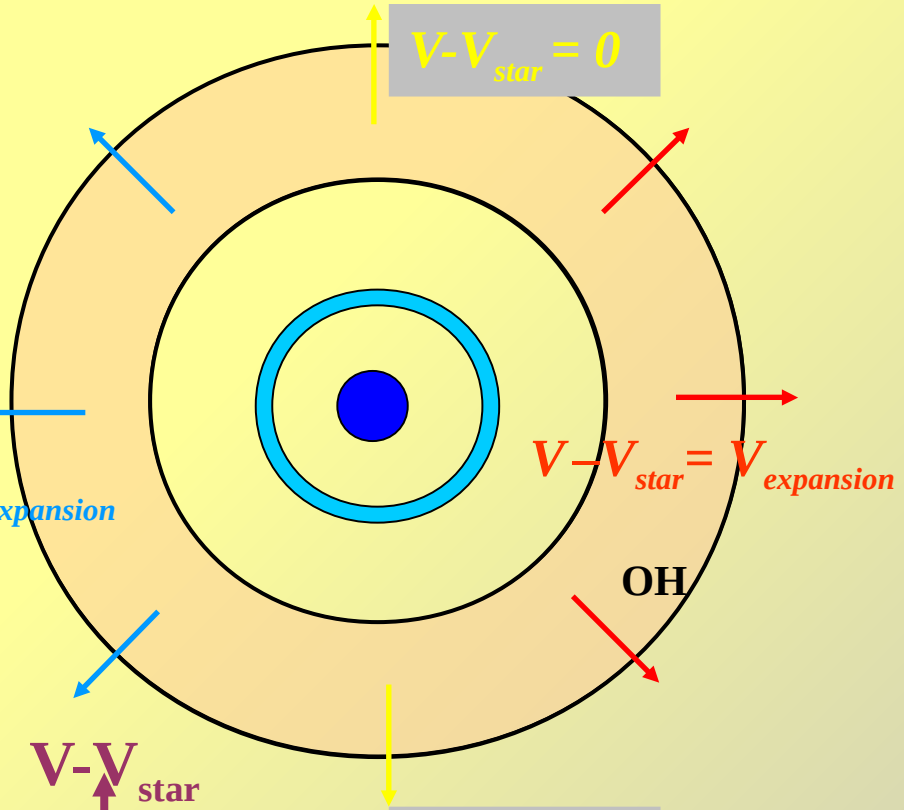
Evolved Star CSE



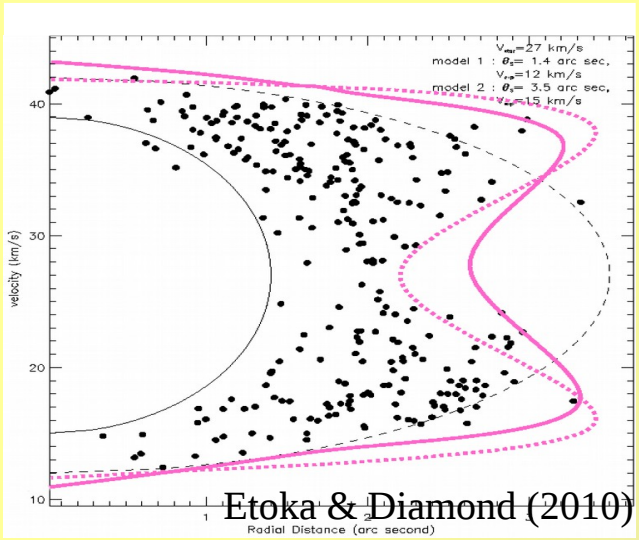


Evolved Star CSE

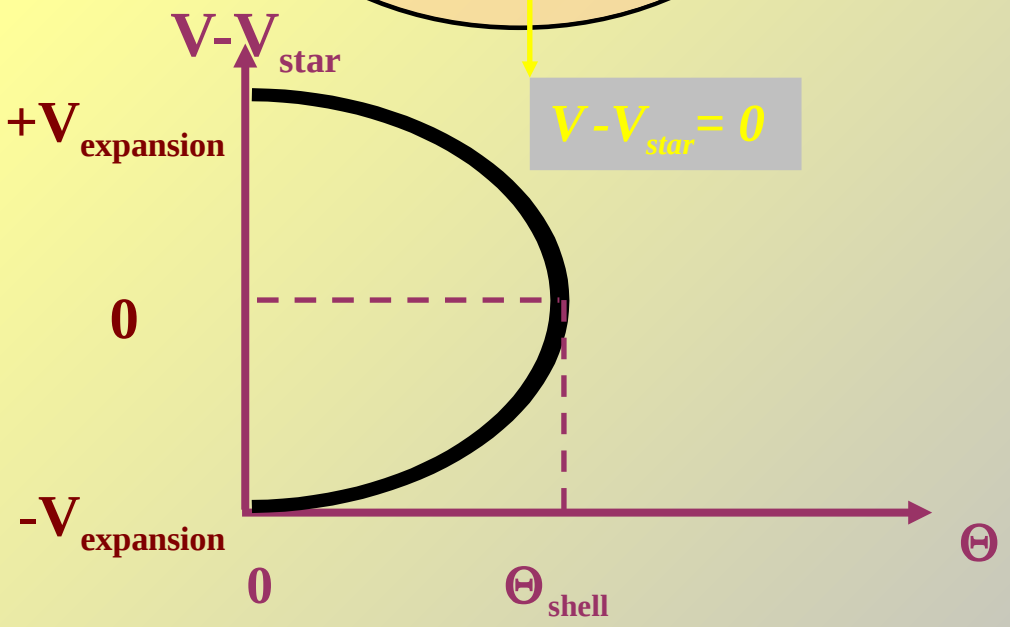




Caveat: deviation from the thin-spherical-shell model



Etoka & Diamond (2010)



Phase-lag method

- OH light curves

  time difference btw blue & red OH maser peak (long-term monitoring needed)

  ➥ linear diameter

- Interferometric maps

  measure of the OH shell extent

  ➥ angular diameter

- Method

  ➥ Proof of concept: Schultz, Sherwood & Winnberg (1978)

  2 years monitoring towards 12 OH/IR stars

  ➥ Systematic exploration:

  Herman & Habing (1985, *29 diameters determined*)

  van Langevelde et al. (1990, *15 sources in common btw the 2 but 5 diameters only matching within 50%)*

Observations

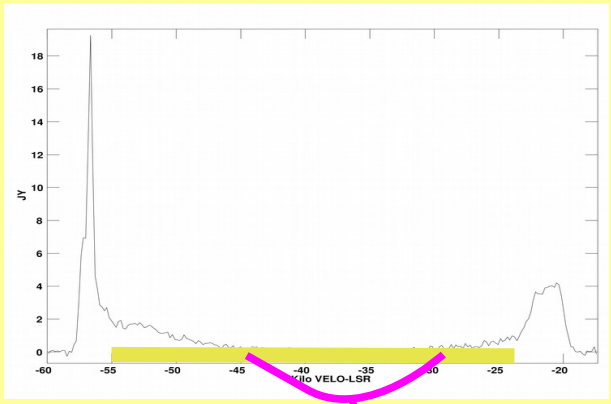
- OH light curves *(linear diameter)*
  - ➥ NRT long-term monitoring of 20 sources (*monthly*, since 2007)

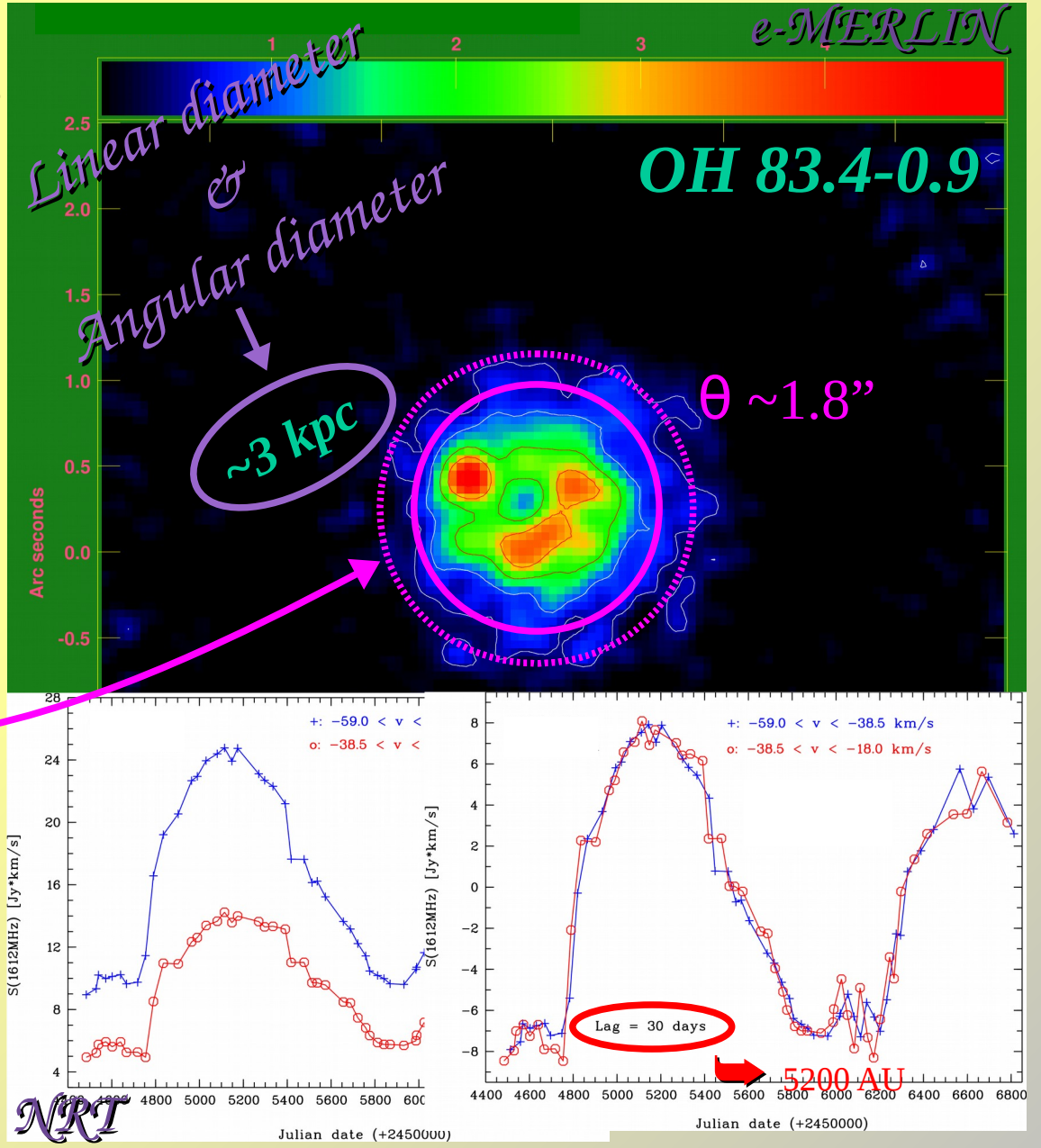
    Sensitivity: 100 mJy – velocity resolution : 0.035 km/s

- Interferometric maps *(angular diameter)*
  - ➥ **eMERLIN & JVLA**

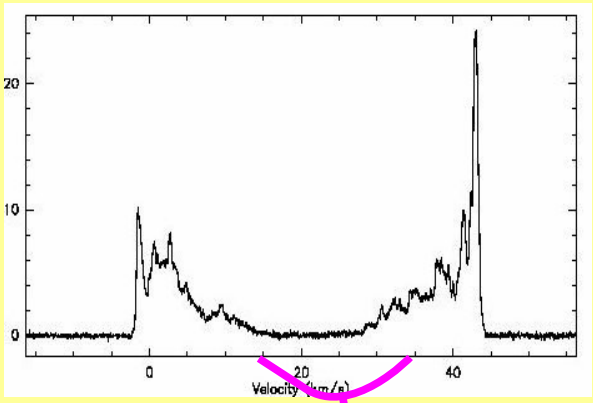
- Aims
  - ➥ new phase-lags *(50% from the 80's sample – 50% new sources)*
  - ➥ improved angular diameter *(detect the faint inter-peak signal – contrain shell (a)symmetry)*
  - ➥ constrain distance uncertainties of the method

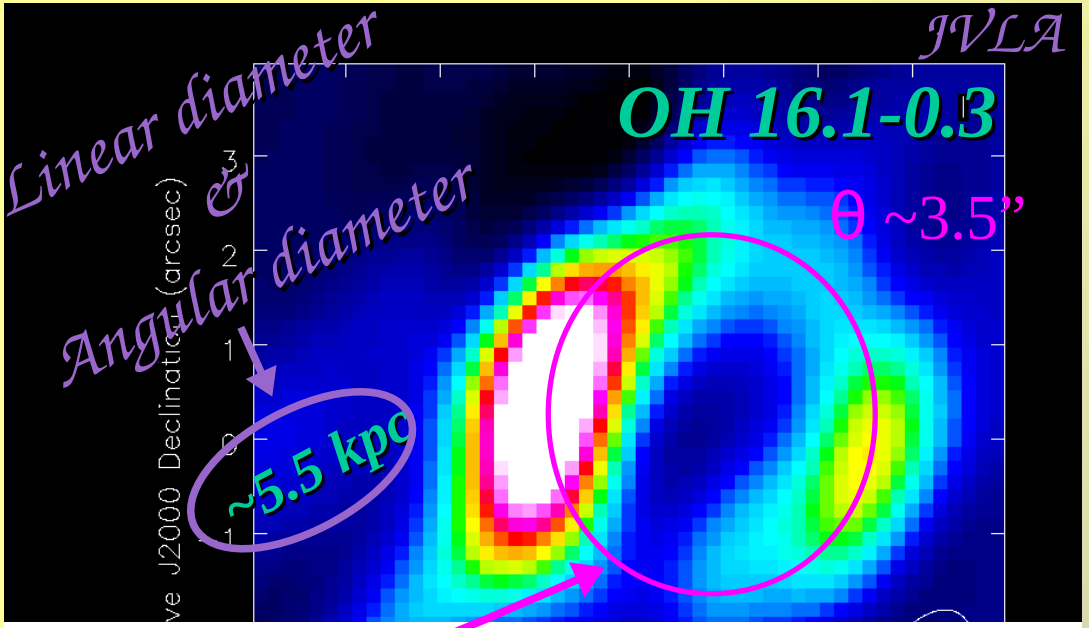
Concrete Examples

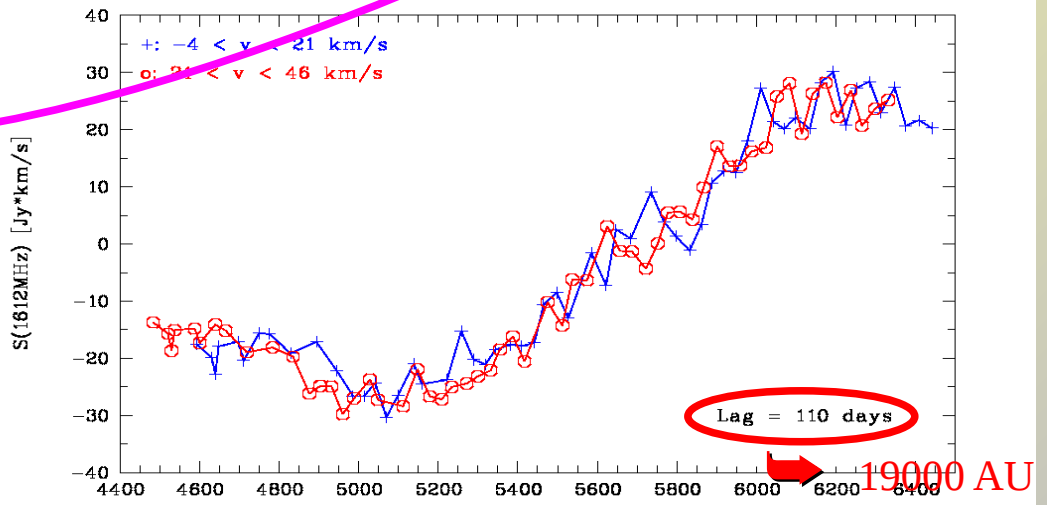




Concrete Examples







NRT

Distance Determination
Preliminary Results

Object	P [yrs]	τ_0 [days]	$2R_{OH}$ [10^3 AU]	ϕ ["]	D [kpc]	Object	P [yrs]	τ_0 [days]	$2R_{OH}$ [10^3 AU]	ϕ ["]	D [kpc]
20234-1357	1.16	< 10	< 1.7			OH 32.0-0.5	4.16	65	11.2	1.07	10.6
OH 44.8-2.3	1.47	15	2.6	2.6	1.0	OH 127.8+0.0	4.36	55	9.5	2.69	3.6
IRC +50137	1.74	10	1.7			OH 26.5+0.6	4.36	35	6.0	4.49	1.4
01037+1219	1.78	25	4.3	8.0	0.5	OH 75.3-1.8	4.52	60	10.4		
05131+4530	2.88	30	5.2			OH 32.8-0.3	4.63	60	10.4	2.74	3.8
OH 39.7+1.5	3.45	17	2.9	4.0	0.7	OH 20.7+0.1	4.71	90	15.6	1.65	9.4
OH 55.0+0.7	3.48	50	8.6			OH 104.9+2.4	4.79	35	6.0	2.88	2.1
21554+6204	3.51	30	5.2			OH 30.1-0.7	5.95	60	10.4	2.69	3.9
OH 138.0+7.2	3.86	10	1.7	0.8	2.2	OH 16.1-0.3	6.03	110	19.0	~3.50	~5.5
OH 83.4-0.9	4.11	30	5.2	~1.8	~3.0	OH 141.7+3.5	6.05	75	13.0	0.76	17.1

eMERLIN & JVLA ***New interferometric obs. completed***

τ_0: phase lag (NRT)

Φ:angular diameter (from lit.)

Agreement within our estimated 20% uncertainty for 4 (out of the 13) Dwingeloo objects

Distance Determination
Preliminary Results

➥ **Shell diameters** cover a range of **~2000 - 19000 AU**
- Generally, diameter larger for longer period

➥ **Many distances still questionable**
- depends on the degree of exploration for the shell extent determination (i.e., faint tangential emission issue)

➥ **Early phase-lag inconsistencies** could be due to
- Incomplete coverage of lightcurves
- Inhomogeneous sampling
- Use of analytical functions to fit the lightcurves

Conclusion

➥ **Phase-lag distance uncertainties <20%, if**

- High cadence of spectral observations (~0.03 P)
- Coverage with observations over >1 period
- Imaging of faint tangential emission available
- Significant shell asymmetries can be excluded

The progress of the project can be followed here:

http://www.hs.uni-hamburg.de/DE/Ins/Per/Engels/engels/nrt_monitoring/index.html