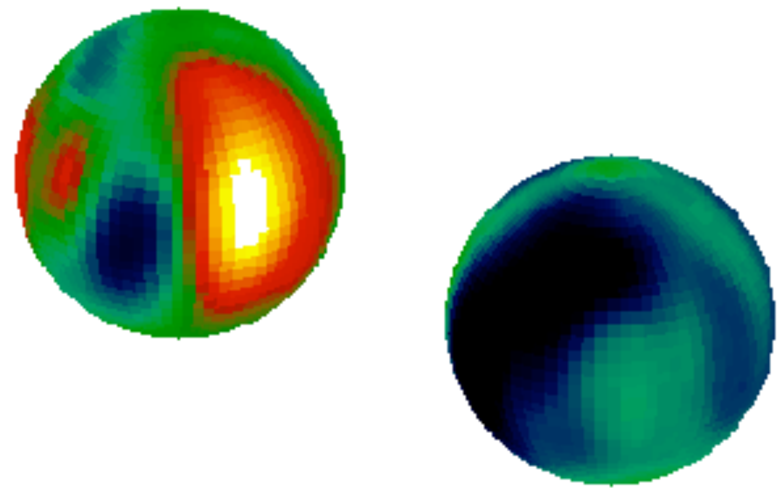
# *Twin binaries as a laboratory for testing wind-driven mass loss theories*

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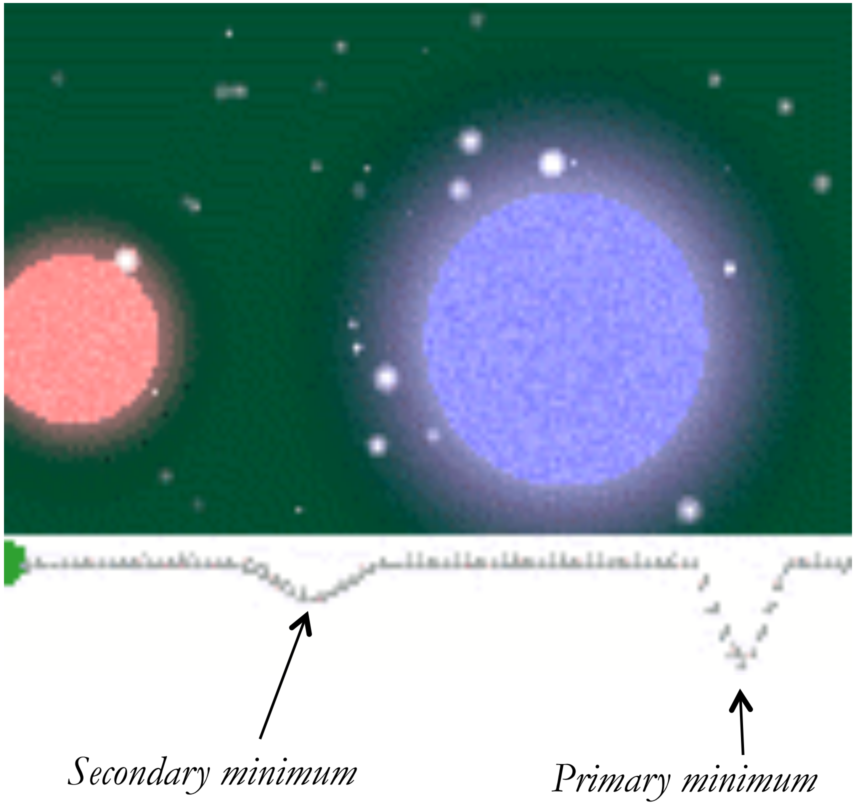
**The 12th Hellenic Astronomical Conference**

**28 June - 02 July 2015, Thessaloniki**

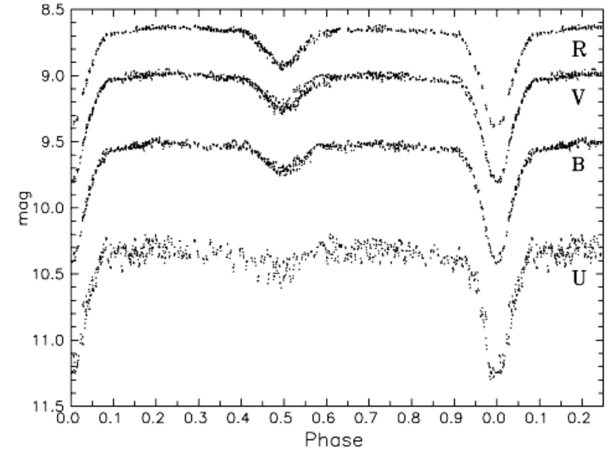
# Eclipsing Binaries



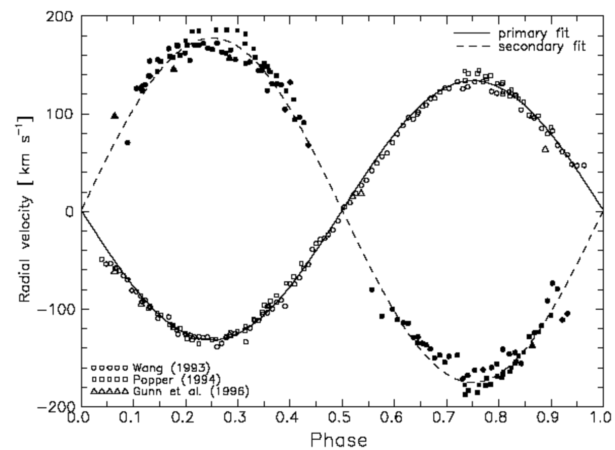

**Accurate determination of orbital / physical parameters:**

*P*, *i*, *q*, *T*, *L*, *M*, *R*, **log*g***

## Light Curve




## R. Velocities Curve



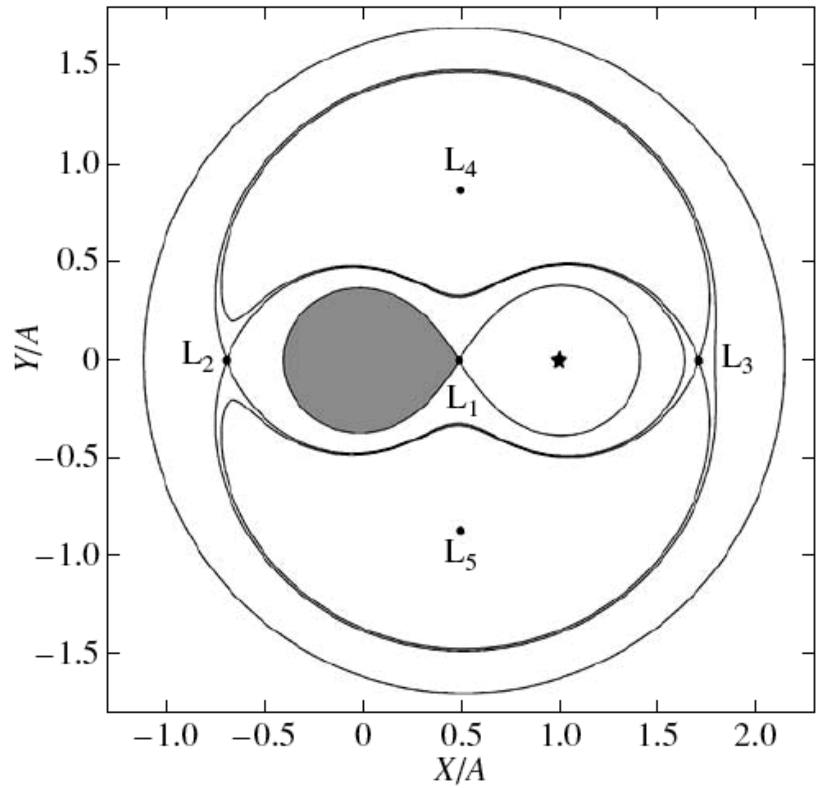

**RT And** (Pribulla et al. 2000)

# Roche geometry
# - Classification -

**Roche lobes:** inner equipotential surface

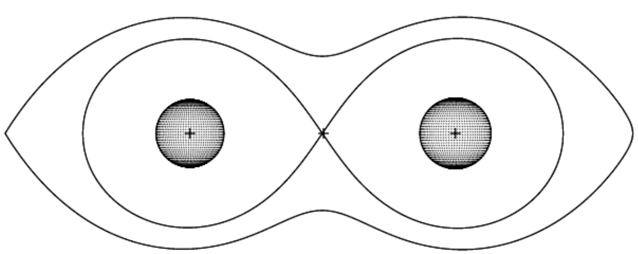
**Lagrangian points:** lowest potential barriers

**L1:** mass transfer
**L2:** mass loss (donor, the more massive)
**L3:** mass loss (donor, the less massive)

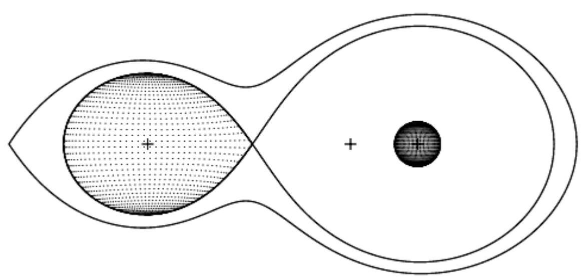



$q$ = **0.93** (Sytov et al. 2007)

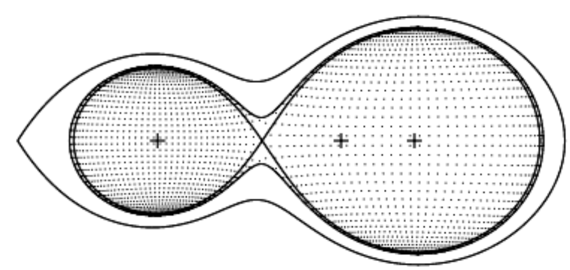
## Detached



## Semi-detached



## Contact



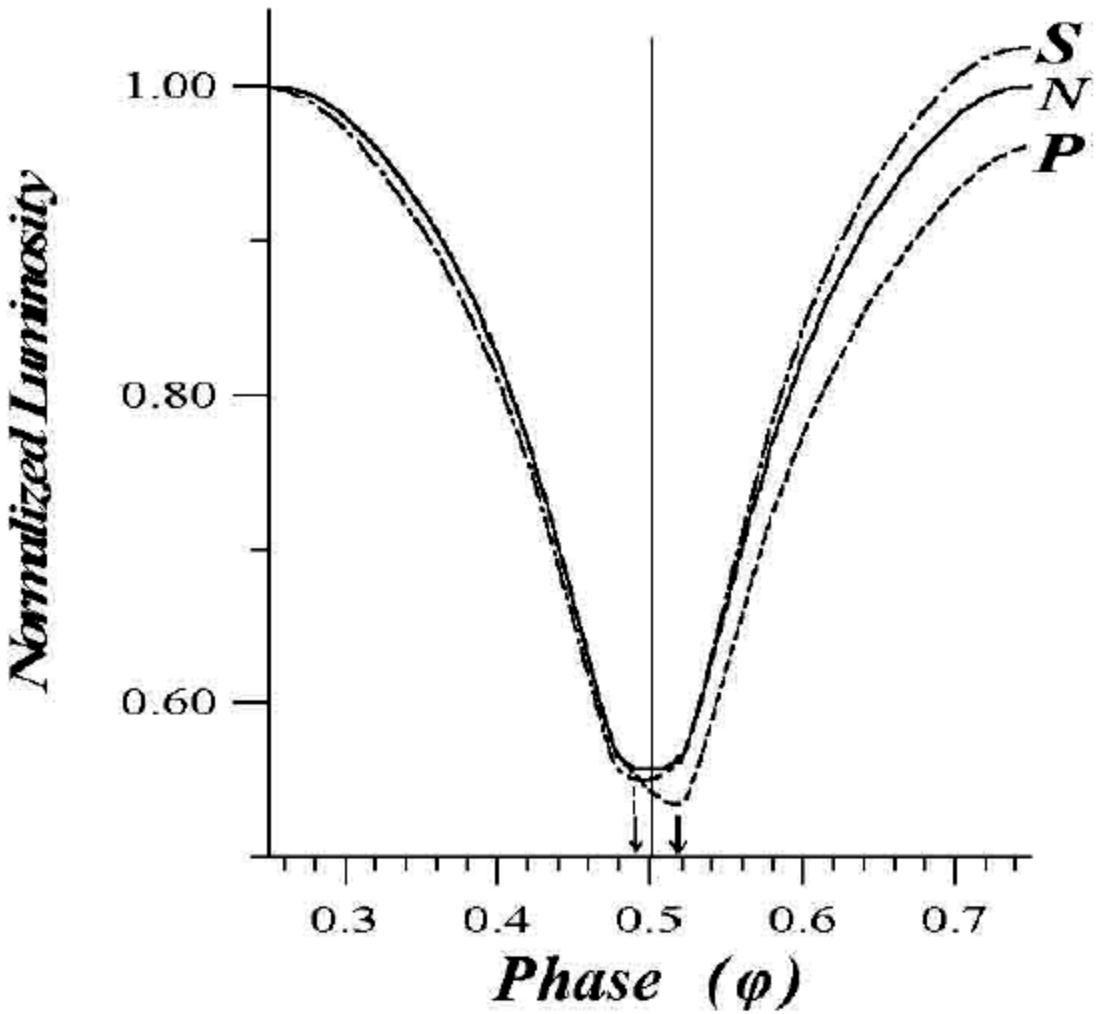
# O-C diagrams (Eclipse Timing Variations)

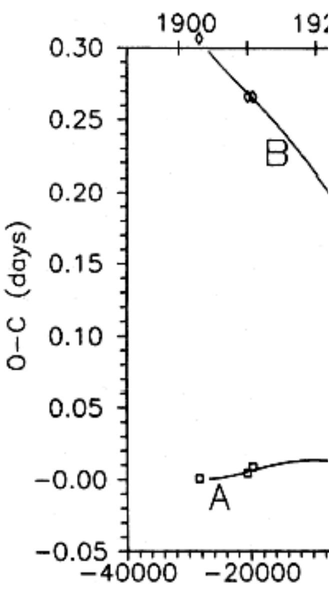
…hemeris
…,$P_e$)

…bital cycle E

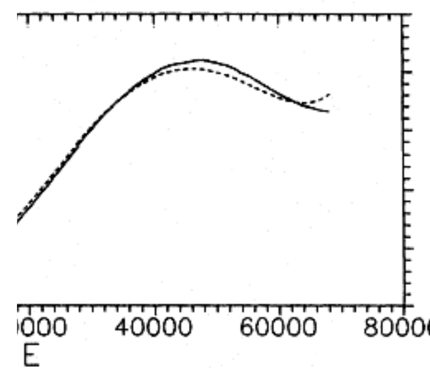
- **C**alculated ti…
- **O**bserved tir…

if $\Delta T(E)$ … - $\Delta T(E)$ – $\Delta T(E\text{-}1)$




(E)




**AB And** (Kalimeris et al. 1994)

# Physical mechanisms for detached systems

- Wind-driven mass loss (P ↑ ).
- Magnetic braking (P ↓ ).
- Gravitational radiation (P ↓ ).
- Tidal interaction (P ↓ ↑ ).

$$\boxed{\dot{J}_{orb} = \dot{J} - \dot{J}_1 - \dot{J}_2}$$

$$J_{orb} = \frac{M_1 M_2 G^{2/3}}{(2\pi)^{1/3}(M_1 + M_2)^{1/3}} P^{1/3}$$

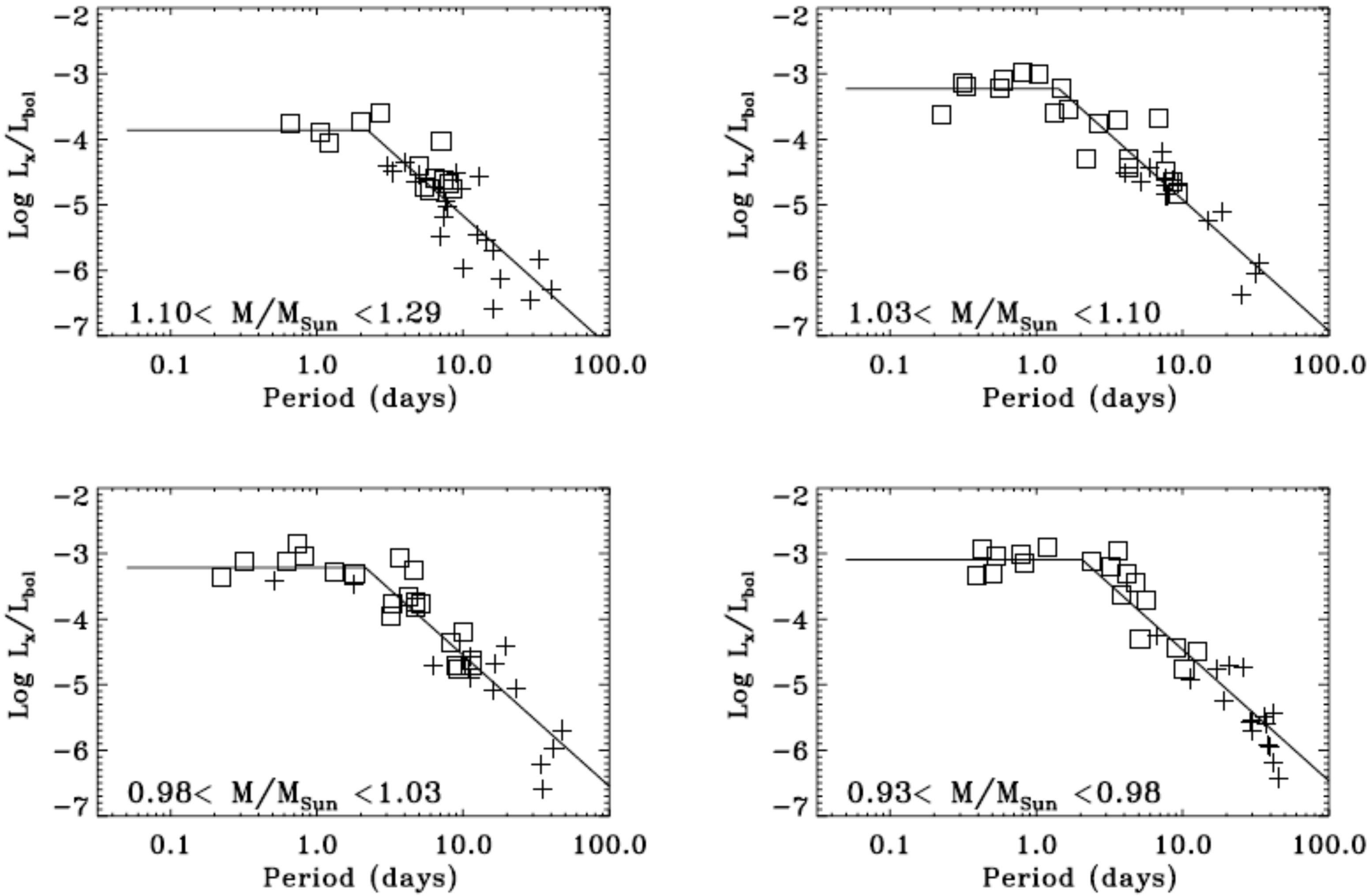
**General framework:**

**ML : Mass loss (P ↑ )**

**vs.**

**AML : Angular momentum loss (P ↓ )**

# Wind-driven mass loss




- ***ℓ***: X-
- **Satu** … 2003).

**Ma**

- The
- The
- Tidal enhancement in close binaries as the stellar radius approaches the Roche lobe radius.

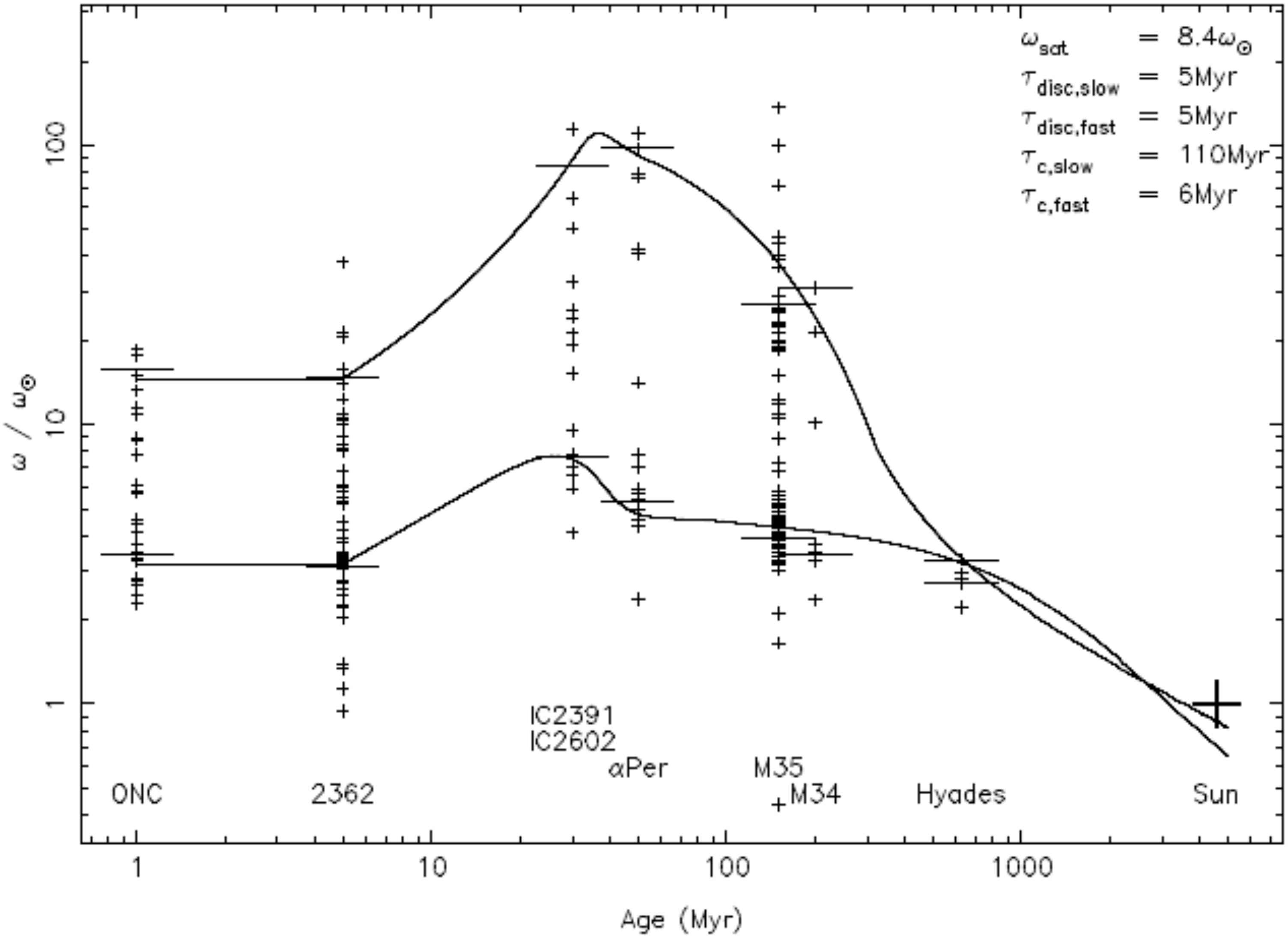
# Magnetic braking

- n:
- m

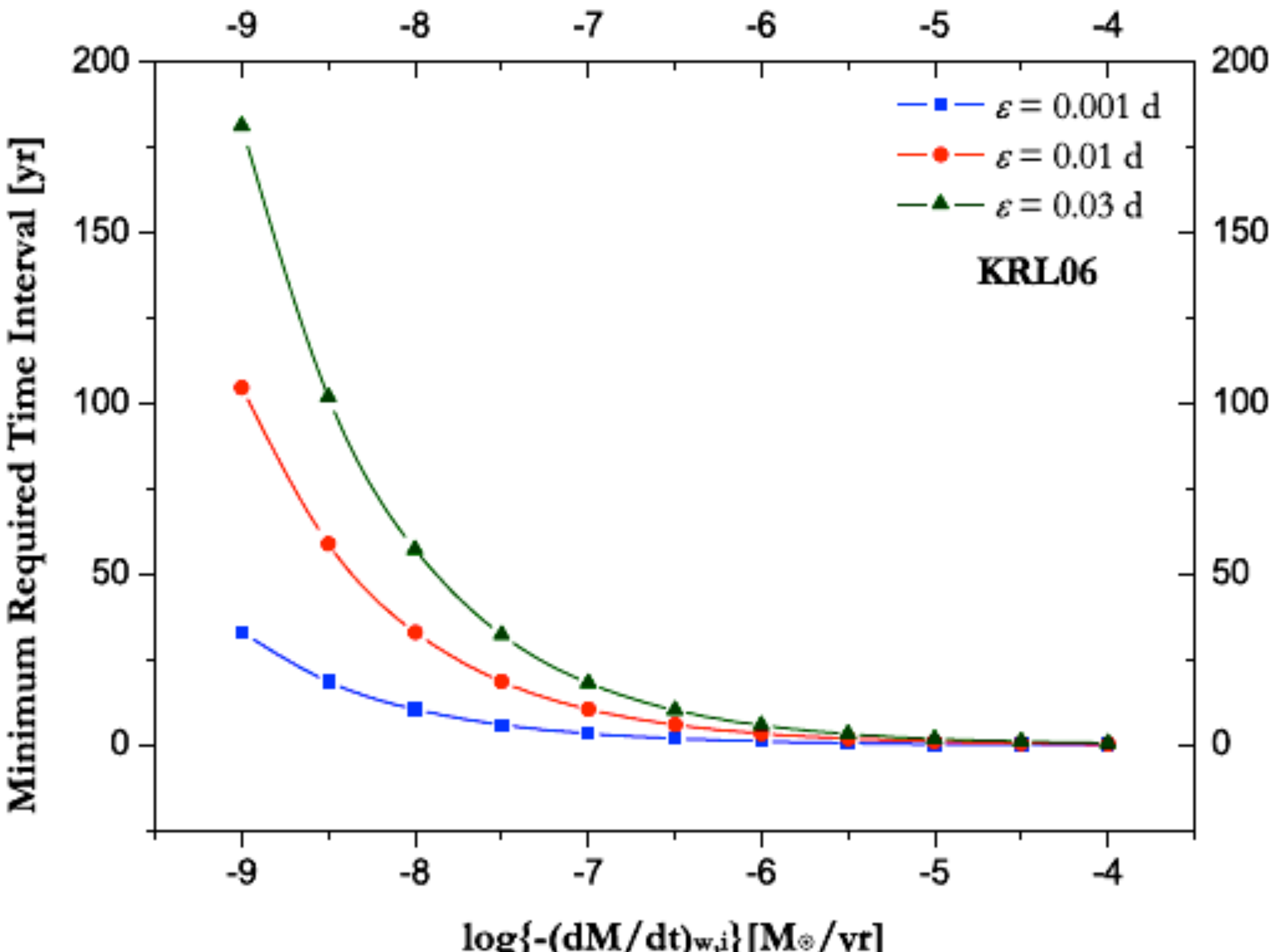
**Calib**

- Cur
- Cha (e.g.

82)

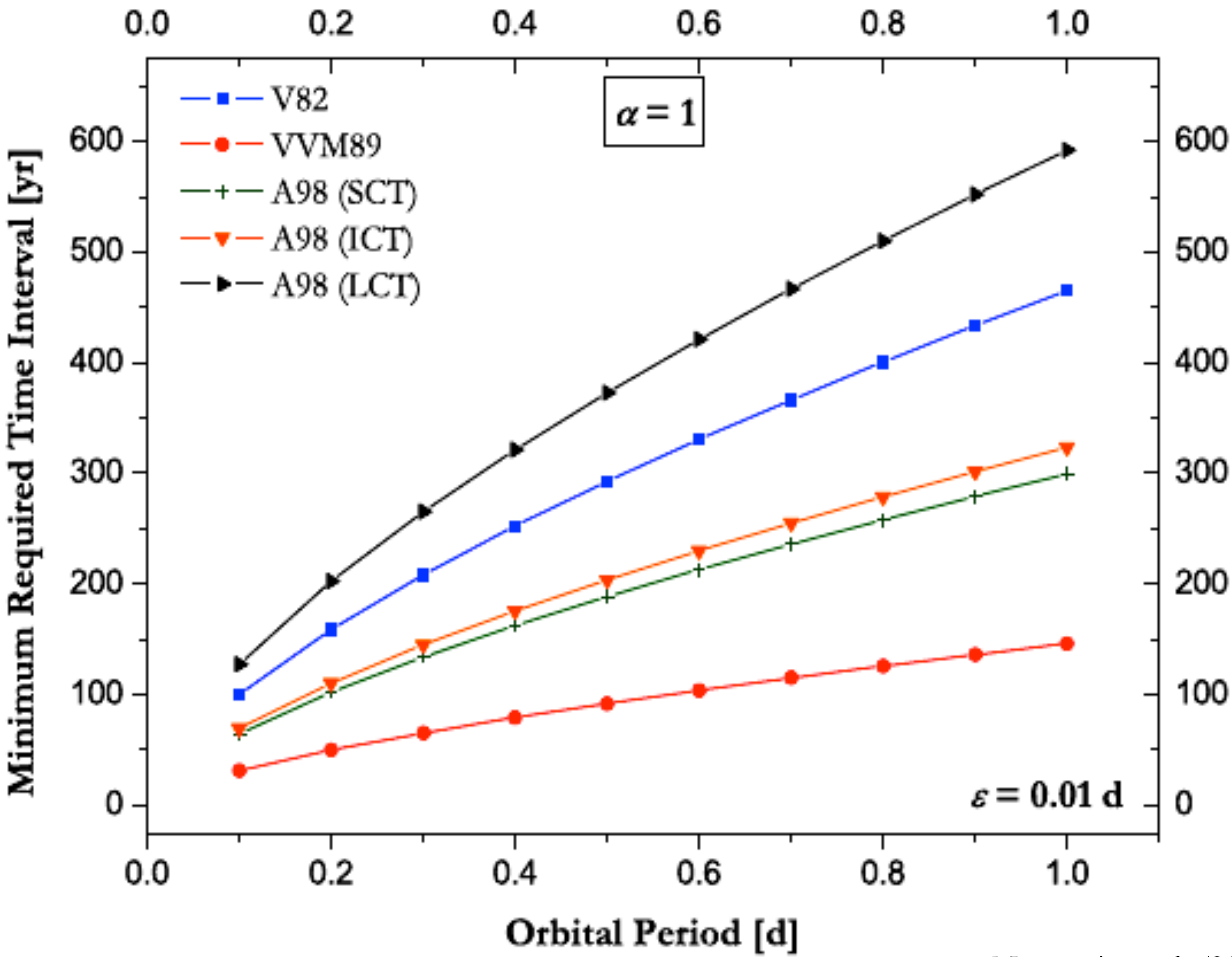


# ETV diagrams traceability: Wind-driven mass loss



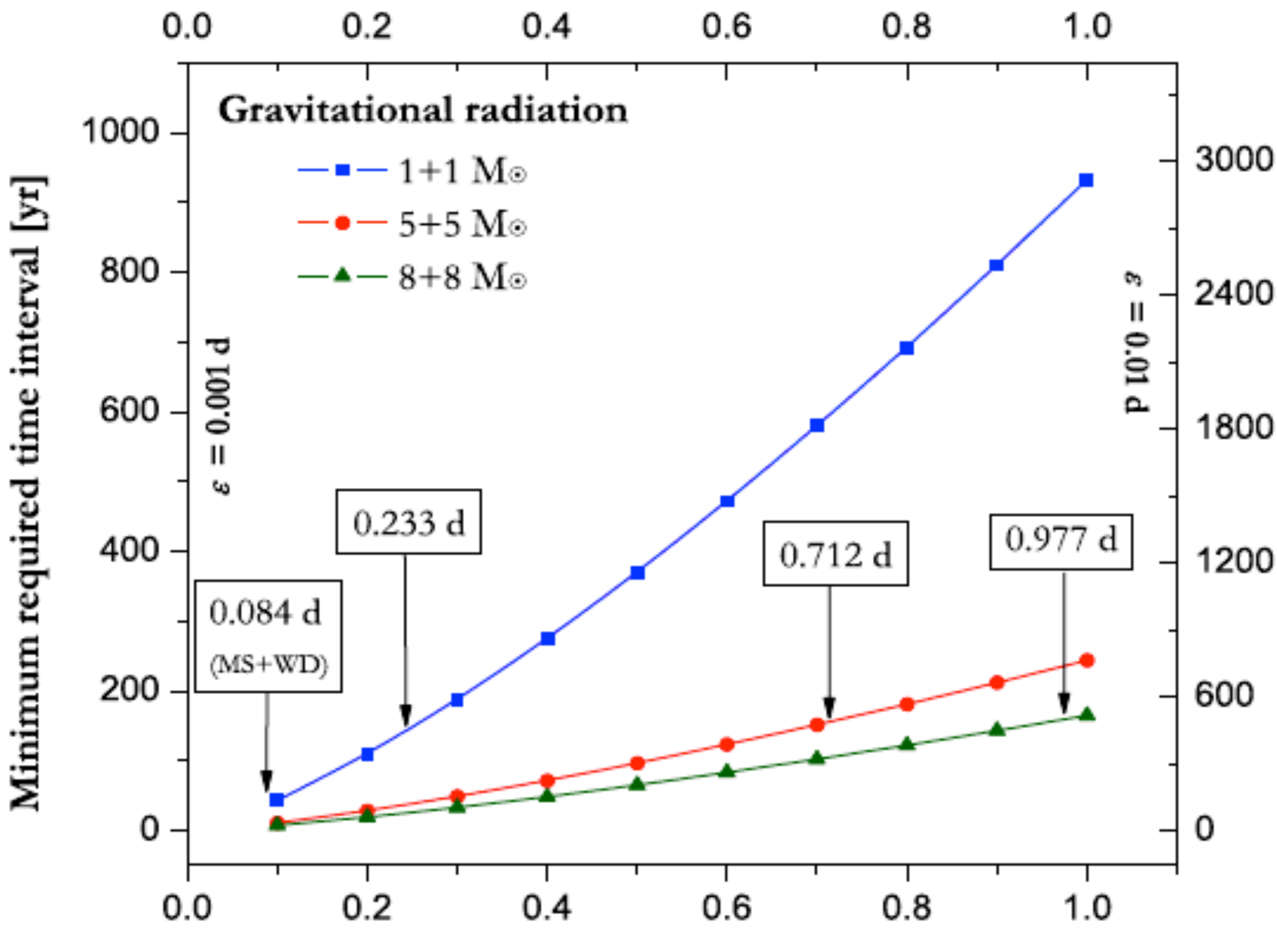

Nanouris et al. (2011, A&A)

# ETV diagrams traceability: Magnetic braking (fast rotators)



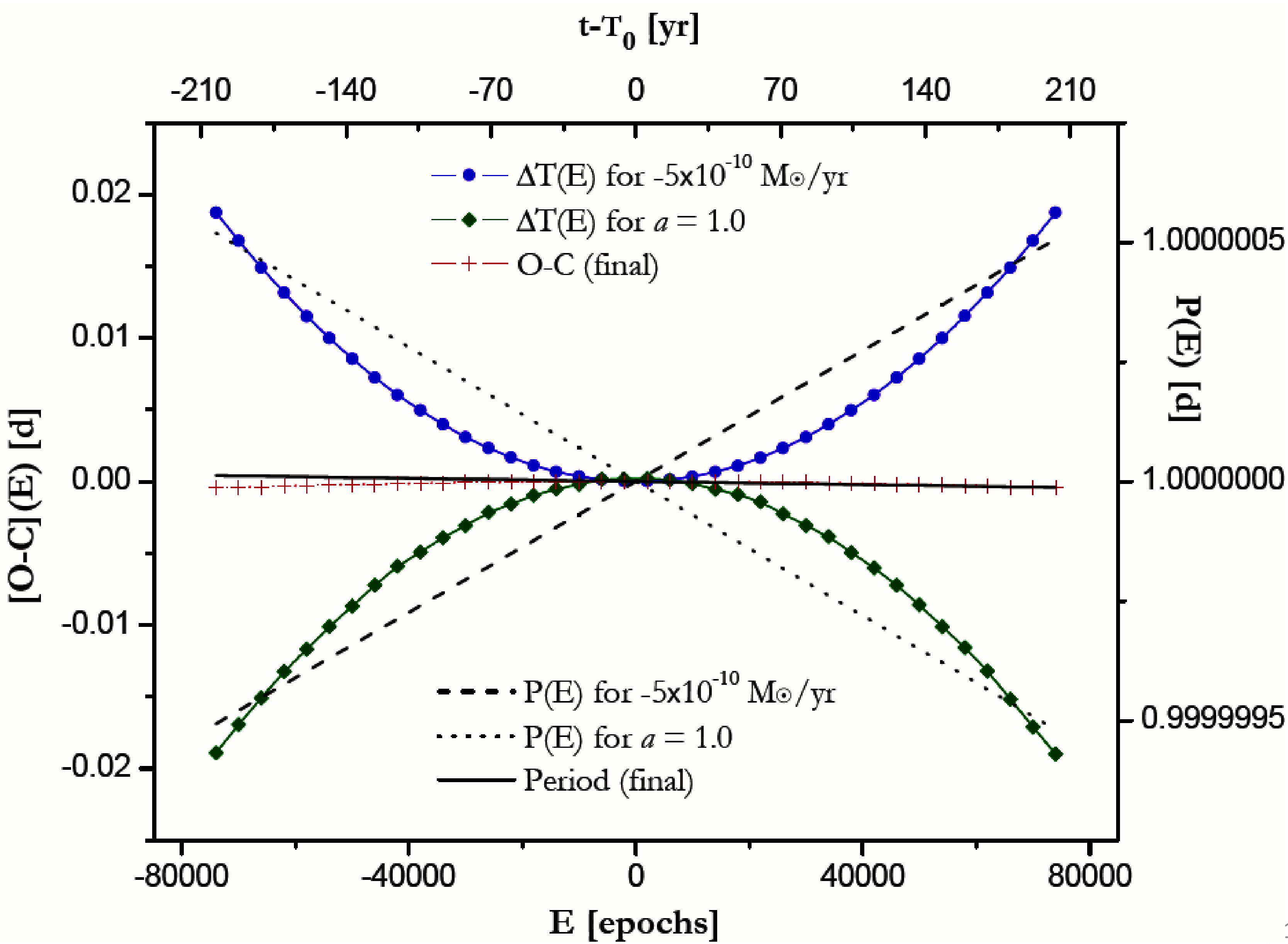

Nanouris et al. (2011, A&A)

# ETV diagrams traceability: Gravitational radiation




Nanouris et al. (2015, A&A)

# Synthetic ETV diagrams: Mass loss vs. magnetic braking






Nanouris et al. (2011)

# Twin binaries: Setting criteria

- Main-sequence stars.
- Late-type stars.
- Detached binary systems.
- Short-period systems.
- **Twin binaries:** components of similar parameters.
- Spin-orbit synchronization.
- Circulized orbits.
- Long observed orbital history.

## Why?

- Well-examined properties.
- **Eliminating the driving mechanisms:** wind-driven mass loss & magnetic braking only
- **Eliminating the number of parameters:** exactly halved.

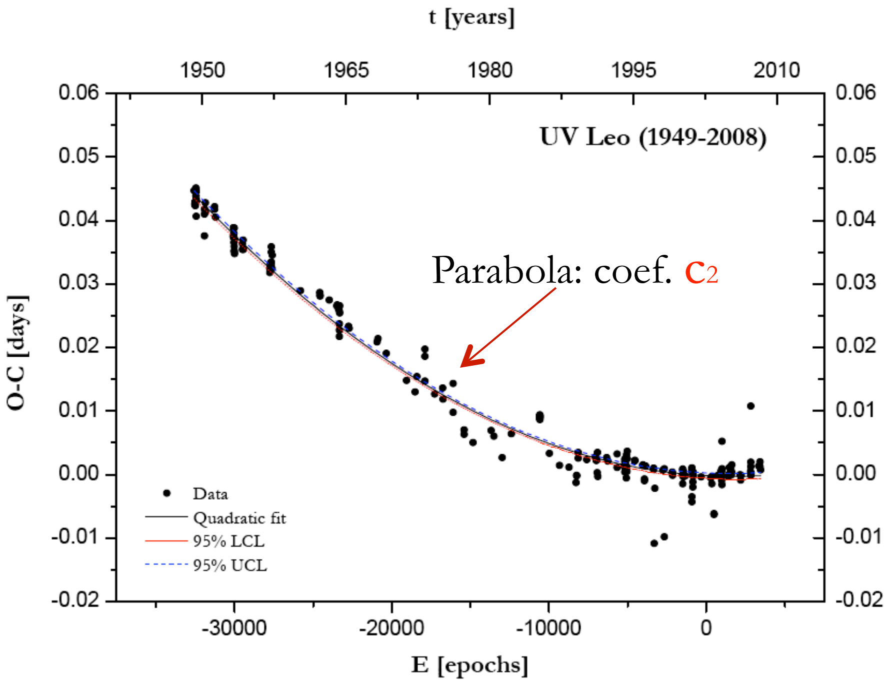
# Twin binaries: Seeking for a sample

- The mass loss rate was left as the only unknown parameter.
- The inferred mass loss rates are compared with the theoretical ones.

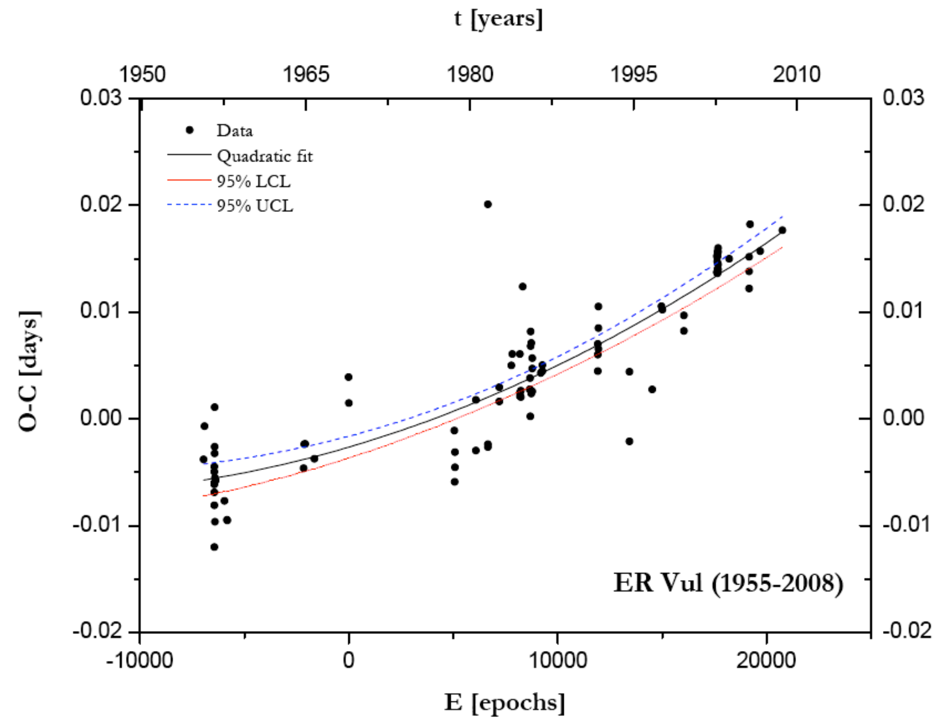
$$\dot{M}_w \approx -\frac{M_1 + M_2}{5} \cdot \left[ \frac{2c_2}{P_e^2} + b P_e^{-\left(a+\frac{1}{3}\right)} \right]$$

*b = b(a, Kkaw, M, R)*

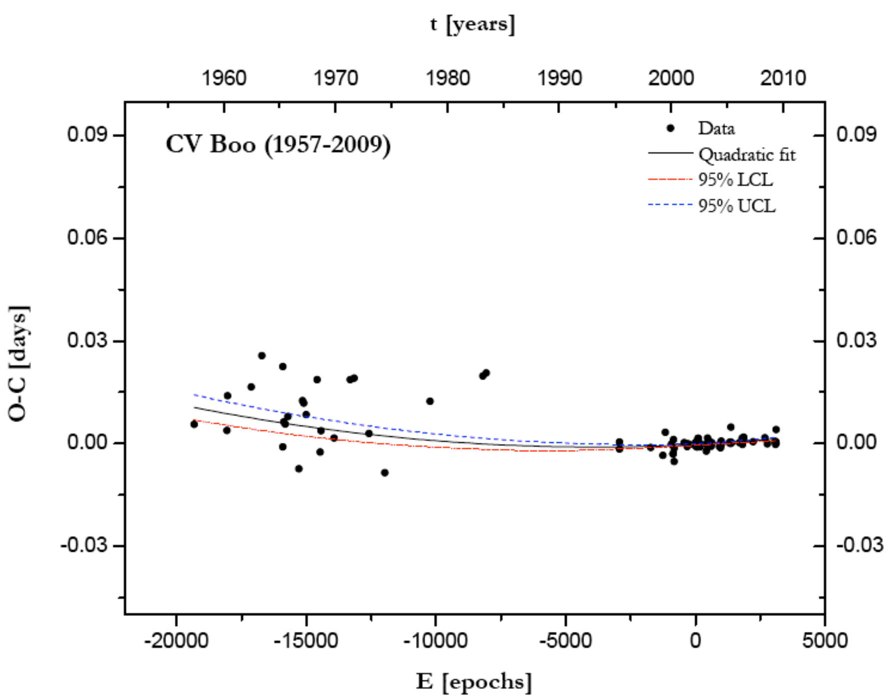
- Seven systems were found (UV Leo, ER Vul, YY Gem, CV Boo, DU Leo, HS Hya, WZ Oph).
- Most of them belong to the RS CVn-type group.



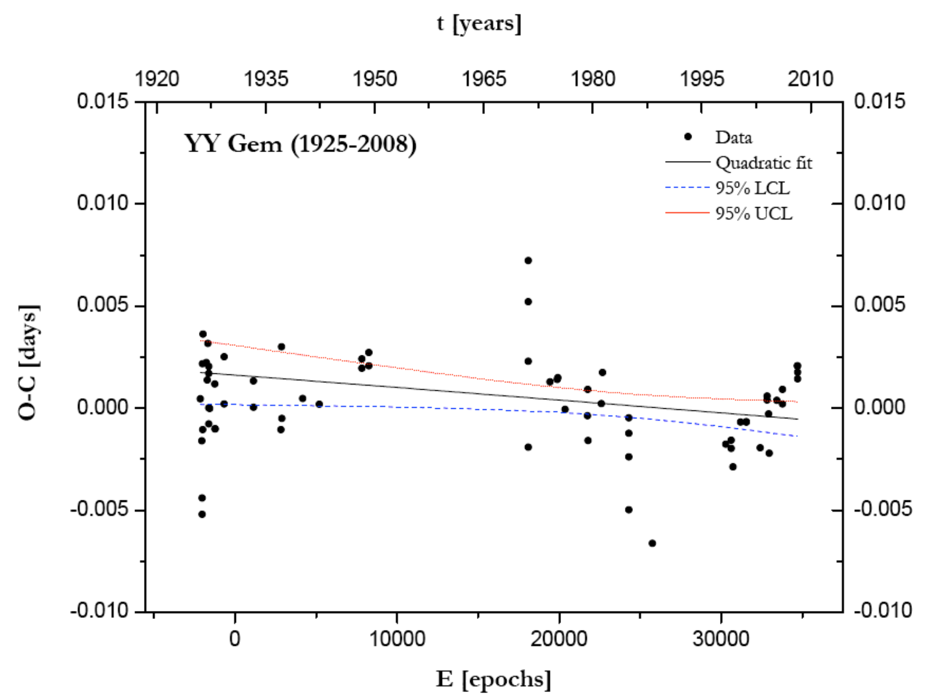
t [years]
UV Leo (1949-2008)
Parabola: coef. c2
Data
Quadratic fit
95% LCL
95% UCL
O-C [days]
E [epochs]

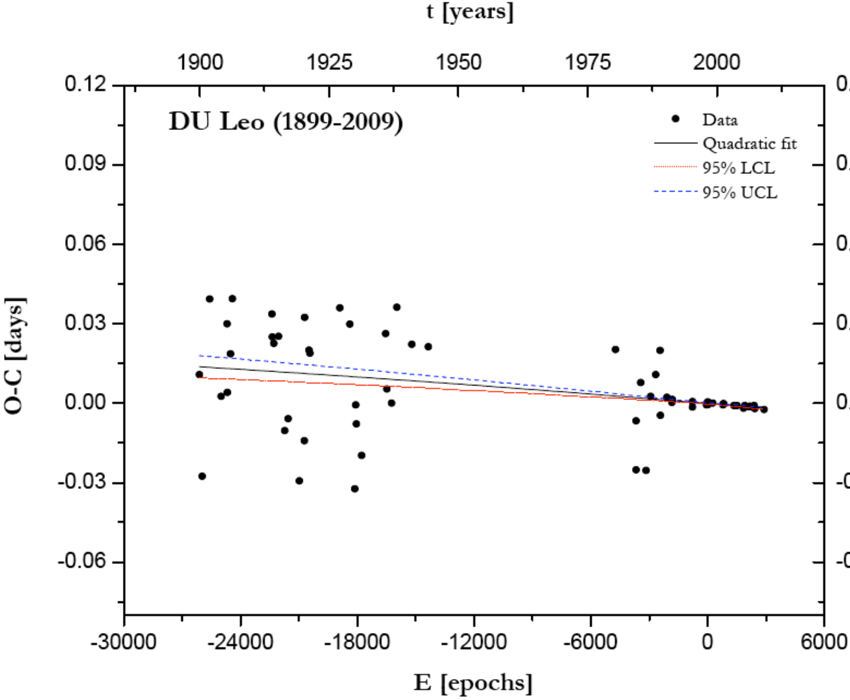
t [years]
Data
Quadratic fit
95% LCL
95% UCL
ER Vul (1955-2008)
O-C [days]
E [epochs]

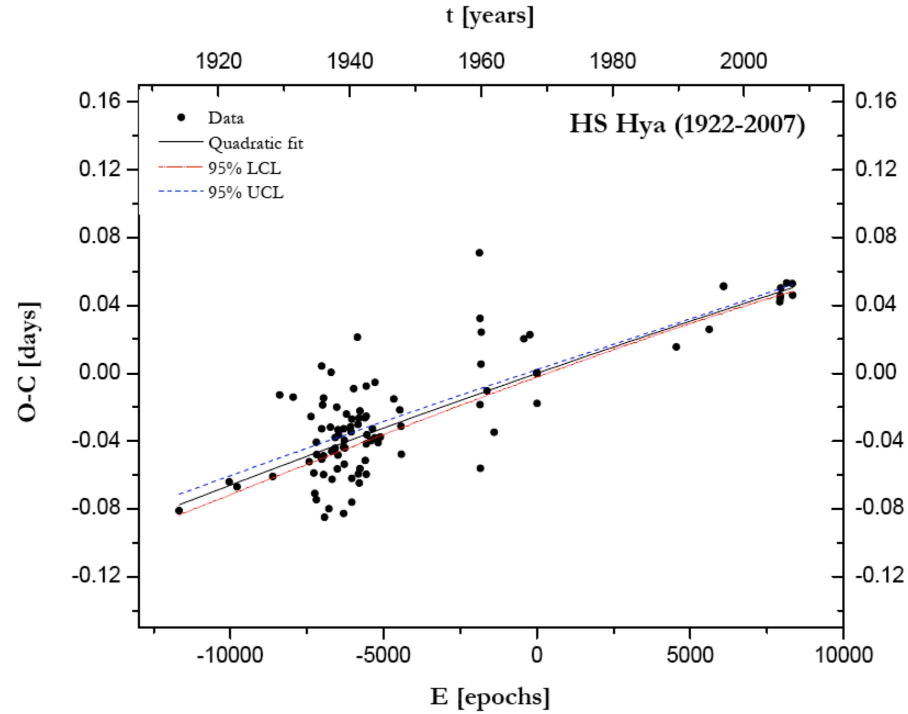



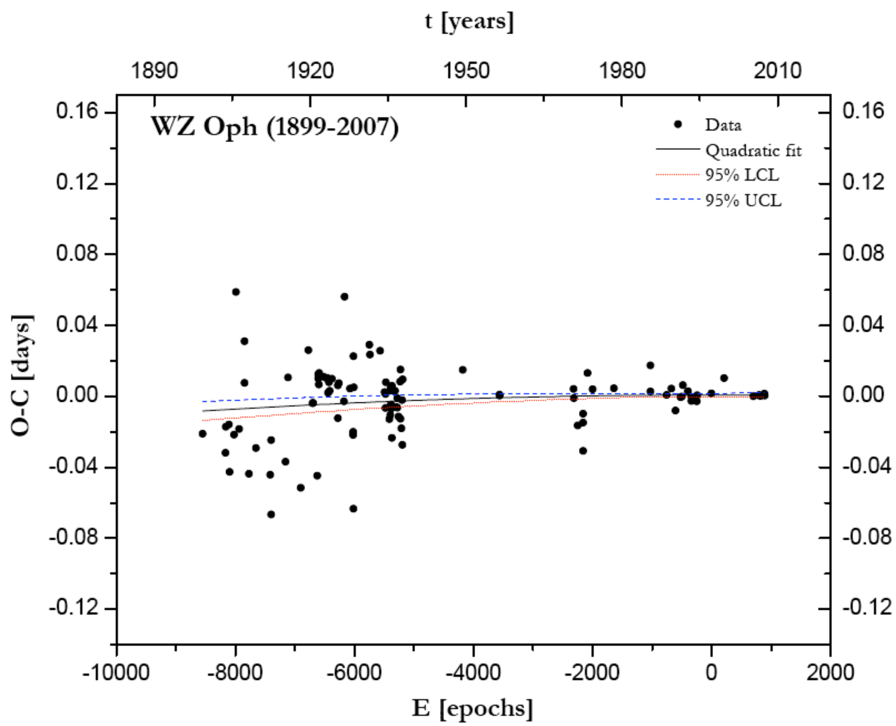
t [years]
CV Boo (1957-2009)
Data
Quadratic fit
95% LCL
95% UCL
O-C [days]
E [epochs]

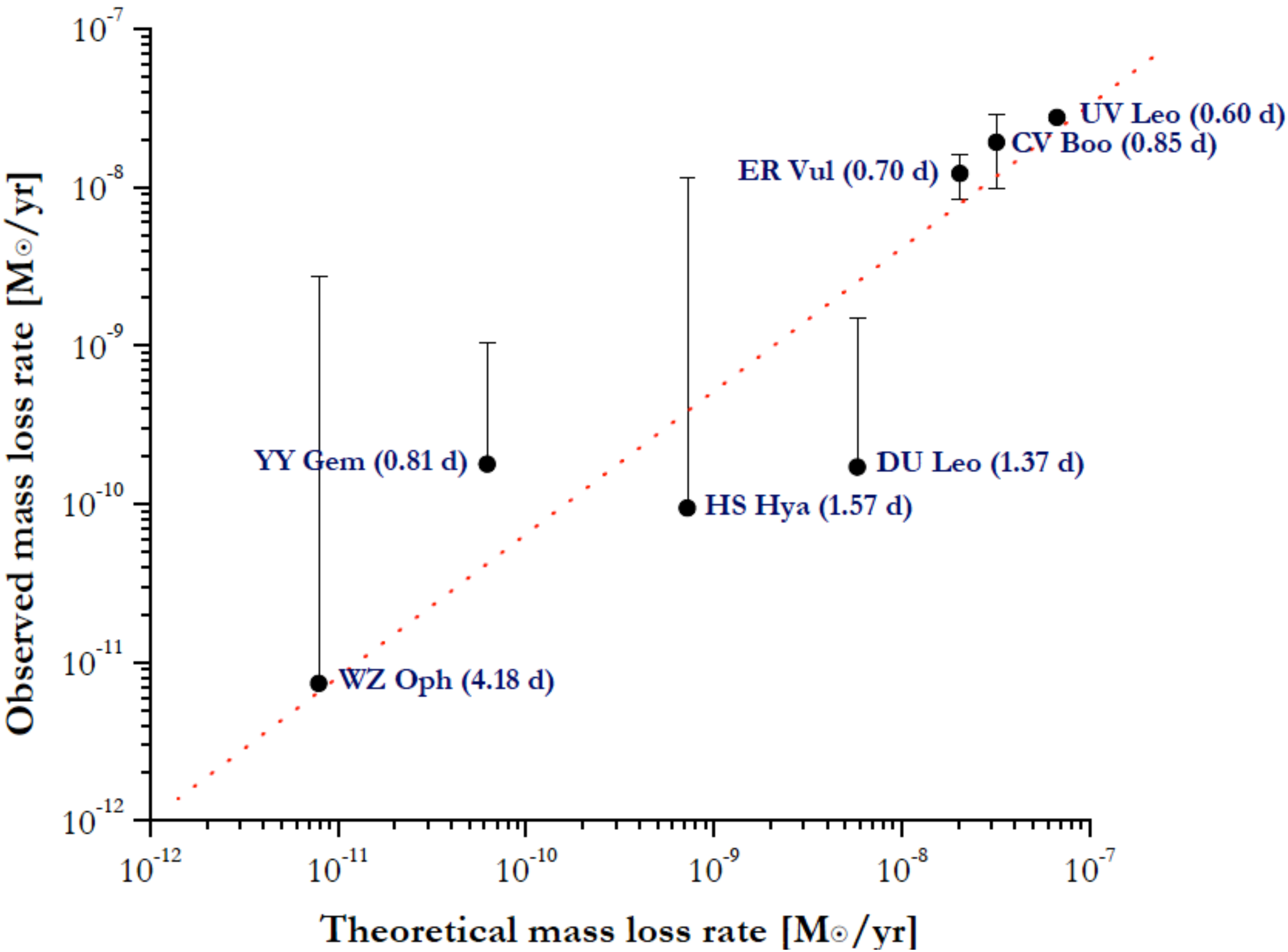
t [years]
YY Gem (1925-2008)
Data
Quadratic fit
95% LCL
95% UCL
O-C [days]
E [epochs]


t [years]
1900
1925
1950
1975
2000
DU Leo (1899-2009)
Data
Quadratic fit
95% LCL
95% UCL
0.12
0.09
0.06
0.03
0.00
-0.03
-0.06
O-C [days]
-30000
-24000
-18000
-12000
-6000
0
6000
E [epochs]


t [years]
1920
1940
1960
1980
2000
HS Hya (1922-2007)
Data
Quadratic fit
95% LCL
95% UCL
0.16
0.12
0.08
0.04
0.00
-0.04
-0.08
-0.12
O-C [days]
-10000
-5000
0
5000
10000
E [epochs]


t [years]
1890
1920
1950
1980
2010
WZ Oph (1899-2007)
Data
Quadratic fit
95% LCL
95% UCL
0.16
0.12
0.08
0.04
0.00
-0.04
-0.08
-0.12
O-C [days]
-10000
-8000
-6000
-4000
-2000
0
2000
E [epochs]

# Observed vs. theoretical mass loss rates




Nanouris, Ph.D. Thesis (2011)

# Impact on the type Ia SNe evolutionary scenarios

- The origin of type Ia SNe is still purely known (single/double degenerate scenario).

- The proposed wind-driven mass loss scheme could be employed in population synthesis codes in order to better reproduce the observed generation rates.

- Nova-like variables with less massive white dwarf than might be also progenitors.

# Concluding remarks

- Both wind-driven mass loss and magnetic braking are competitive mechanisms for driving the observed orbital evolution of close binaries.

- A rotationally- and tidally-enhanced wind-driven mass loss scheme is consistent with the observed rates as inferred from the ETV analysis of twin binaries.

- The proposed scheme might have a significant impact on the single degenerate scenario of type-Ia SNe by potentially increasing the number (and/or the class) of their progenitors.

- A larger sample is needed for decisive conclusions !

# Thank you !

# Synthetic O-C diagrams: Methodology

**Step 1:** **P = P(t)** determination from a $\dot{J} - \dot{m} - \dot{P}$ equation
(e.g. Kruszewski 1964, Tout & Hall 1991, Kalimeris & Rovithis-Livaniou 2006)

⇩

**Step 2:** **t = t(Ẽ)** transformation: $\frac{dt}{d\tilde{E}} = P(t)$

continuous orbital cycle

⇩

**Step 3:** **P = P(Ẽ)** determination

⇩

**Step 4:** **ΔT = ΔT(Ẽ)** determination: $P(\tilde{E}) = P_e + \frac{d(\Delta T(\tilde{E}))}{d\tilde{E}}$

**Initial conditions:** $(\tilde{E}, t, \Delta T(\tilde{E}), P(\tilde{E})) = (0, T_0, 0, P_e)$

⇩

**Step 5 (extra):** detectability range for a given noise level $\varepsilon$ : $\Delta T(\tilde{E}) = \varepsilon \Rightarrow$ **$t(\tilde{E}_{min})-T_0$**