The Importance of Historical Astrometry, V2

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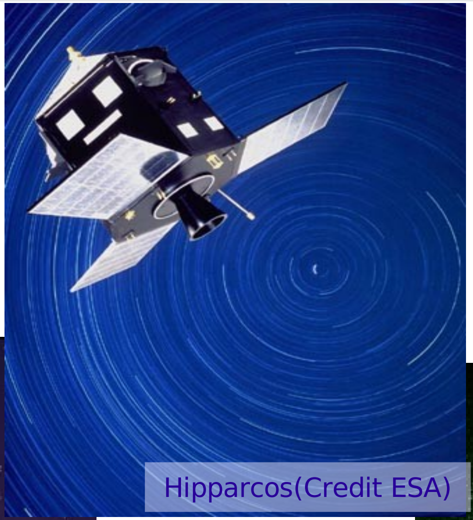


Outline

- SIM-GAIA Synergy via Binaries
  - Binaries are an astrophysical bonus, provide
    - Masses, radii, ..., AGES
  - Also, allow fairly easy investigation of GAIA/SIM synergy
  - Also, fairly easy to incorporate historical data sets
    - Use Hipparcos catalogue ($\pi/\Delta\pi$ >=10)
    - Assume 100% binarity rate & Secondary from IMF
  - **SIGA combination is particularly good for acceleration & jerk**

Some Scales for Long Period Orbits

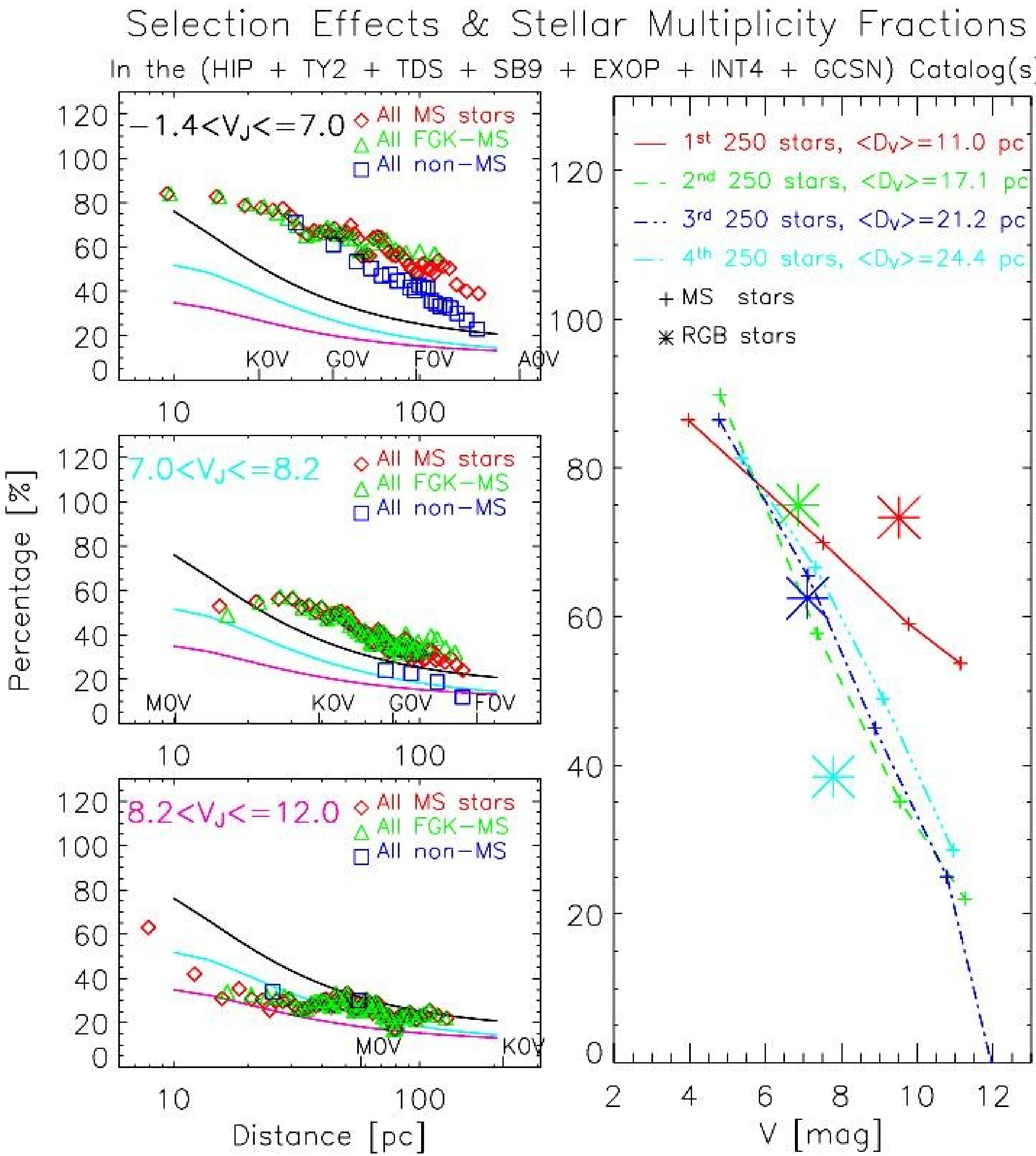
$$a_0 = 95/d_{10pc} \, (P^{+2} \, M_{TOT}^{-2})^{1/3} \, M_{C;J} \quad [\mu as]$$

$$|\mu| = 600/d_{10pc} \, (P^{-1} \, M_{TOT}^{-2})^{1/3} \, M_{C;J} \quad [\mu as/yr]$$

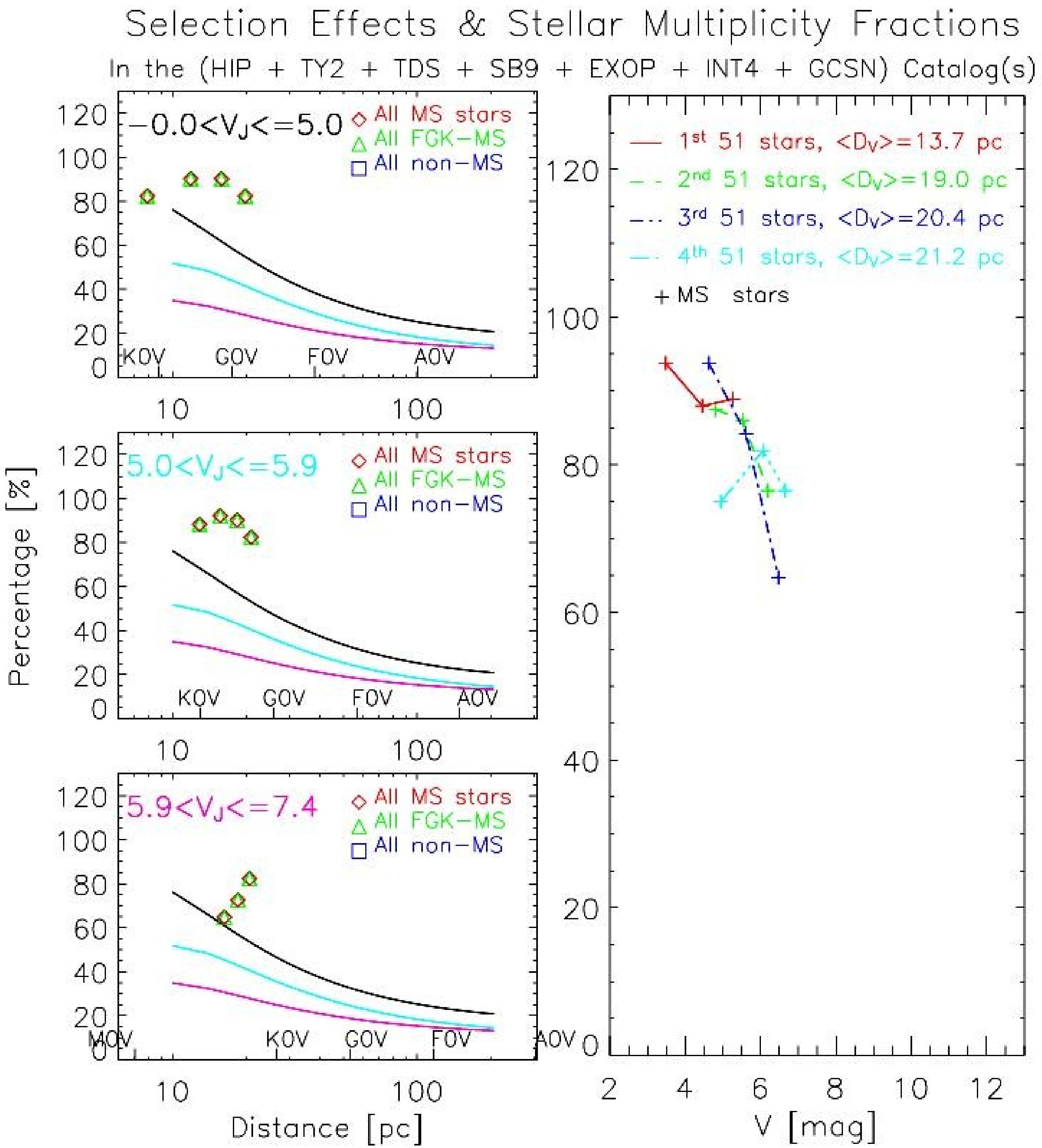
$$|d\mu/dt| = 3800/d_{10pc} \, (P^{-4} \, M_{TOT}^{-2})^{1/3} \, M_{C;J} \quad [\mu as/yr^2]$$

0.1	M_{SUN} @	50 pc		
Period	a_0	$\lvert\mu\rvert$	$\lvert d\mu/dt\rvert$	**Comment**
[yr]	[μas]	[μas/yr]	[μas/yr^2]	
10	8,665	5,444	3,420.6	5 yr; SOF
20	13,755	4,321	1,357.5	
40	21,835	3,430	538.7	
80	34,660	2,722	213.8	
160	55,020	2,161	84.8	
320	87,338	1,715	33.7	3-σ; GAIA 5yr
640	138,641	1,361	13.4	3-σ; SIM 5yr
1,280	220,079	1,080	5.3	3-σ; GAIA+SIM
2,560	349,354	857	2.1	

Multiplicity of Hipparcos Stars



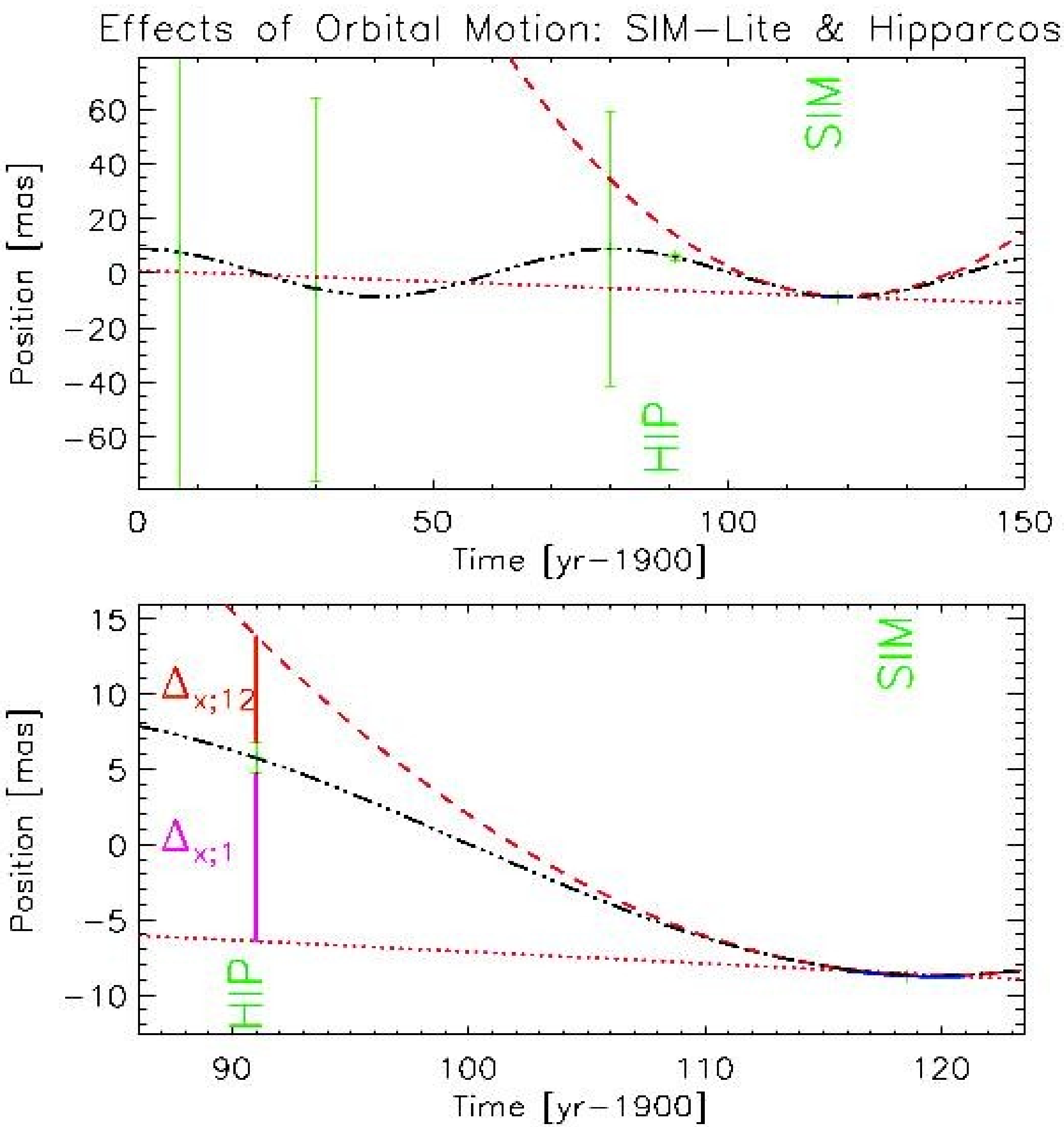
Multiplicity of Nearby G Stars



Around Nearby/Bright-ish Stars

- **Oldest Catalog goes back to early 19th C.**
  - **Astrographic Catalogue(s)**
    - **Epoch: ~1907**
    - **Position errors ~ 220 mas**
    - **Down to V ~ 14th mag**
  - **AGK, GC, ... DSS (1930+, 50-200 mas; V<21)**
  - **Accuracy derived from:**
      - **Matching of Hipparcos stars with early catalogs**
      - **Reject outliers**
      - **Derive local plate constants**
    - **Iterate**
    - **How accurate are these backtrapolations?**

Depends only on Orbits of Binaries



One can study the effects independent of the barycentric motion by looking at:

1) accelerations & up
2) difference between long- short term pms
3) binary-induced position differences

Various Methods Sample Different Δt's

- Long-term proper motions
  - 3 epochs, separated x5 in time
  - 3 epochs, separated x20 in error (ϵ_μ)
    - AC 1907 – SIM 2020 ; 113 yr, ϵ_μ = 1000 μas/yr
    - HIP1991 - GAIA2015 ; 24 yr, ϵ_μ = 42 μas/yr
    - GAIA - SIM ; 5 yr, ϵ_μ = 2 μas/yr

- **SIGA combination particularly good for: dμ/dt and jerk**

	GB	HIP	GB+H	GAIA	SIM	G+H	S+H	S+G	
ΔT	**80**	**3**	**180**	**5**	**5**	**27**	**32**	**10**	**yr**
ε(dμ/dt)	**110**	**1900**	**36**	**4.9**	**2.5**	**2.4**	**1.3**	**0.5**	**μas/yr²**
$\epsilon/_{S+G}$	**555**	**3800**	**74**	**9.6**	**5**	**4.8**	**2.8**	**1**	

- **[Note values have been updated from presentation to include <u>weighted fits</u>: this brings the errors down when adding a catalog with large errors). Unweighted fits increase the error wrt best best catalog.]**

Survey(s)	P_MIN	P_MAX	% of Systems “detected”
	[yr]	[yr]	
Primaries			
HIP	1.6	12.9	1.7
GAIA	0.2	1,578.0	41.0
SIM	0.1	3,480.0	47.2
GAIA+HIP	0.7	1,750.0	35.1
SIM+HIP	0.6	2,639.1	39.5
SIM+GAIA	**0.1**	**9,709.0**	**54.2**
Secondaries			
HIP	0.2	91,340.0	58.9
GAIA	0.0	16,534.5	61.2
SIM	0.0	35,293.0	65.2
GAIA+HIP	0.1	16,835.1	56.8
SIM+HIP	0.1	27,908.0	61.0
SIM+GAIA	**0.0**	**137,298.0**	**72.7**

Simulated Hipparcos catalogue

- d ~ 60 pc
- 100% binaries.

Surveys are tested for 3-sigma acceleration
[as determined for the specific catalog (combination)]

Proper Motion Differences:

- To date limited by limited accuracy of long-term proper motions (of the **primaries**)
  - **HIP-TYC2 Δμ => 12%, P in [1.00, 0.7k] yr**

- Better with GAIA/HIP, SIM/HIP, GAIA/SIM
  - GAIA-HIP Δμ => 59%, P in [0.10, 23.6k] yr
  - **SIM -HIP Δμ => 70%, P in [0.05, 25.5k] yr**
  - GAIA-SIM Δμ => 61% , P in [0.10, 23.5k] yr

Position Differences

Survey	Fraction of Binaries with significant Position Differences	
	LIN_FIT	QUAD-FIT
Ground	20.0%	4.5%
HIP+GB	40.0%	20.0%
GAIA+HIP	47.0%	32.0%
SIM+HIP	50.0%	34.0%
SIM+GAIA	56.0%	31.0%
SIM+GAIA+HIP	56.0%	34.0%

Conclusions & Future Work

- GAIA and SIM, and SIGA in particular will open up the binary-physics field
  - Binaries can be selected:
    - according to orbital mechanics,
      - not statistical contamination criteria
- Accurate accelerations (+vels. + jerks) are crucial (SIGA)
- Existing data (including Hipparcos) can be re-reduced with GAIA astrometry:
  - Carry new ICRF to the past
      - Will improve catalogs by ~ x2
  - Existing cats need to be de-compiled

Backup Slides

- How to estimate SIM acceleration accuracy???
  - Maybe like this? $d\mu/dt \sim (\mu_1-\mu_2)/\tau$
    - **5 yr Mission:**
      - Split observing span in two 2.5 yr segments, separated by τ=(T/2) =2.5 yr
        - Each have ½ data ==> $\varepsilon_{\mu 5} * \sqrt{2}$
        - $\varepsilon_{d\mu/dt}^2 = [(\sqrt{2}\varepsilon_{\mu 5})^2 + (\sqrt{2}\varepsilon_{\mu 5})^2] / (T/2)^2$
        - $\varepsilon_{d\mu/dt} = (\sqrt{8})/T\ \varepsilon_{\mu 5} \sim 0.56 \times 3 \sim 1.7$ μas/yr²
    - **10 yr Mission:**
      - Split observing span in two 5 yr segments, separated by τ=(T/2) =5 yr
        - Each have 100% of 5-yr data ==> $\varepsilon_{\mu 5}$
        - $\varepsilon_{d\mu/dt}^2 = [(\varepsilon_{\mu 5})^2 + (\varepsilon_{\mu 5})^2] / (T/2)^2$
        - $\varepsilon_{d\mu/dt} = 2/T\ \varepsilon_{\mu 5} \sim 0.2 \times 3 \sim 0.6$ μas/yr²
    - **Gaia 5yr:**
        - $\varepsilon_{d\mu/dt;GAIA} = 5/3 \times \varepsilon_{d\mu/dt;SIM} \sim 2.8$ μas/yr²
        - No follow-up
  - Position accuracy at t_{HIP} (ΔT=25 yr)
    - Pro. motion: $\Delta_{Z;1}$ = ΔT x $\varepsilon_{\mu 5}$ = 25 x 3 = 75 μas = $\Delta_{HIP}/13$
    - acceleration: $\Delta_{Z;2} = ½\ \Delta T^2 \times \varepsilon_{d\mu/dt}$ = ½ 25² x 1.7 = 531 μas = $\Delta_{HIP}/2$
      - At ACT(1907;ΔT=110 yr) -> $\Delta_{Z;1}/\Delta_{Z;1;ACT}$ = 0.002; $\Delta_{Z;2}/\Delta_{Z;2;ACT}$ = 0.05;

Backtrapolates: Sensitive to Mass & Period

- **Order-dependent:** $\Delta_{z;n}(\tau) = z_{0RBIT} - \zeta^{n}(\tau)$
  - Can be calculated analytically
- No phase dependence for TOTAL pos. dif.
  - Face-on & circular: $\Delta_{XY;n} = (\Delta_{X;n}{}^{2} + \Delta_{Y;n}{}^{2})^{½}$
- **Periods** can be estimated from $\Delta_{XY;n}$ values
  - $\mathcal{P}_{1,2} = 2/3 \;\; \pi\tau \; \Delta_{XY;1} / \Delta_{XY;2} \quad \sim \; P$ for $P \geq 2\tau$
  - $\mathcal{P}_{2,3} = 1/2 \;\; \pi\tau \; \Delta_{XY;2} / \Delta_{XY;3} \quad \sim \; P$ for $P \geq 2\tau$
    - $\mathcal{P} \sim P$ for $P \ll \tau$
    - $\mathcal{P}$ oscillates strongly for $P \sim [0.5, 1] \times \tau$
    - $\mathcal{P}$ decays (exponentially) towards P for $P \sim [1 \;\; , 2] \times \tau$
- **Masses** follow immediately once P is known