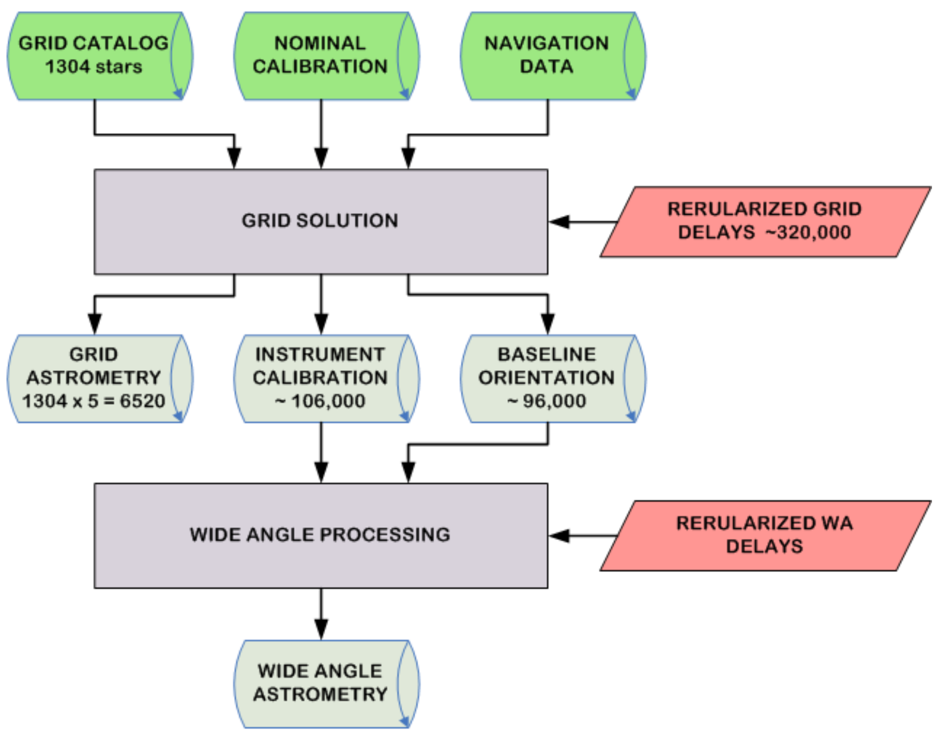
Grid and Reference Frames Global Astrometry with SIM

Valeri Makarov

Grid

- SIM Grid solution is a global, one step LS adjustment of ~200K unknowns in ~300K equations
- Purpose of the Grid:
  - Determine instrument calibration and baseline orientation parameters for subsequent use in Narrow Angle and Wide Angle data processing
  - Establish SIM Reference Frame (SIMRF) better than 1 μas
  - Additional science (e.g., gravitational deflection) – you are encouraged to invent your own!
- Grid objects:
  - 1304 basic grid stars, RV vetted
  - 25—50 optically bright quasars
  - optionally, all NA targets and all reference stars



Regularized Delay Equation

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$$\delta d \cong (B \cdot \delta s) + (\delta B \cdot s) + C + \delta F + \varepsilon$$

- Unknown baseline orientation (δB, 2-vector), apparent position of star (δs, 2-vector), path delay offset C, calibration parameters (δF, up to ~40)
- Condition equation is severely underdetermined and can not be solved from a single measurement or a single tile, hence all sky, global solution needed

$$\sigma_{mission\ average\ per\ star} = M \cdot \sigma_0$$

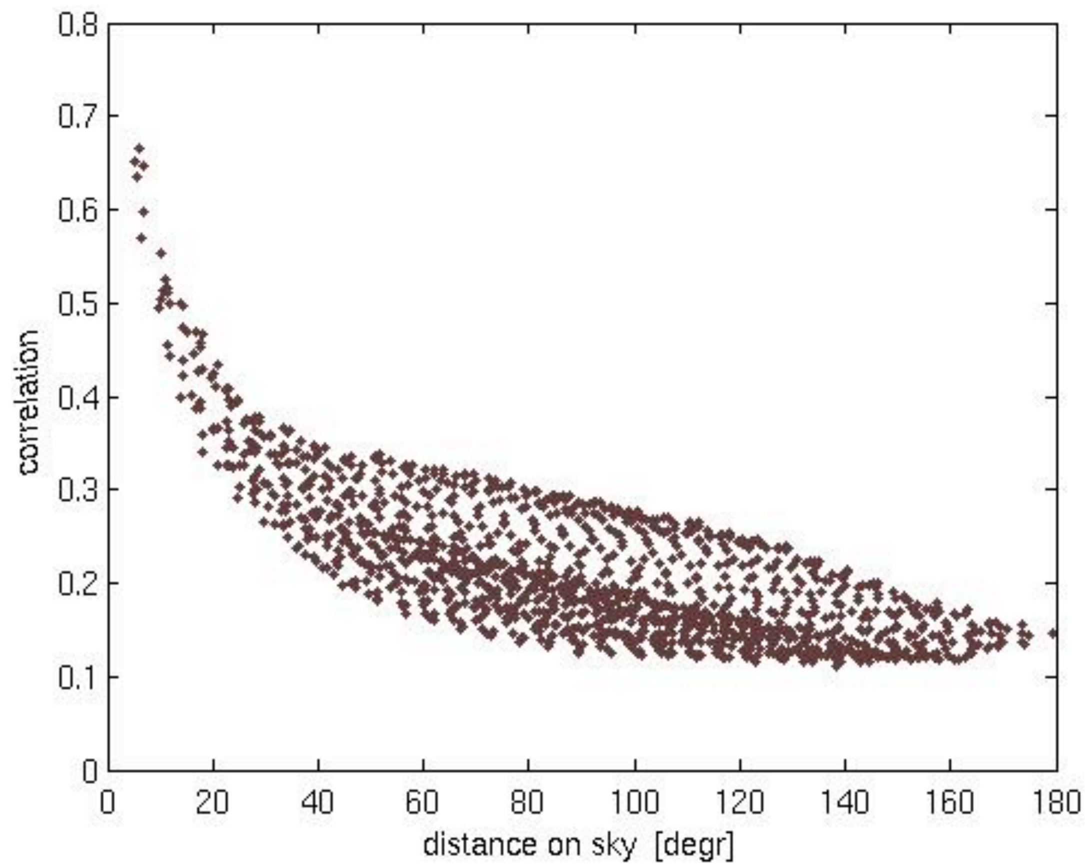
where σ_0 is single delay measurement precision (~ 14 μas), M is grid multiplier

- If the condition equations were perfectly conditioned, M ~ 1/√N ~ 0.07, but in reality M ≈ 0.26 – the loss of condition comes from a coupling of δB and δs unknowns in the finite FOR

Correlated astrometric parameters

- The power spectrum of random errors defined by scalar or vector spherical harmonics is "red", i.e., most error comes in large-scale perturbations
- Astrometric errors are *positively* correlated across the sky
- Differential Wide Angle mode can give a factor of 2 improvement in precision wrt global accuracy

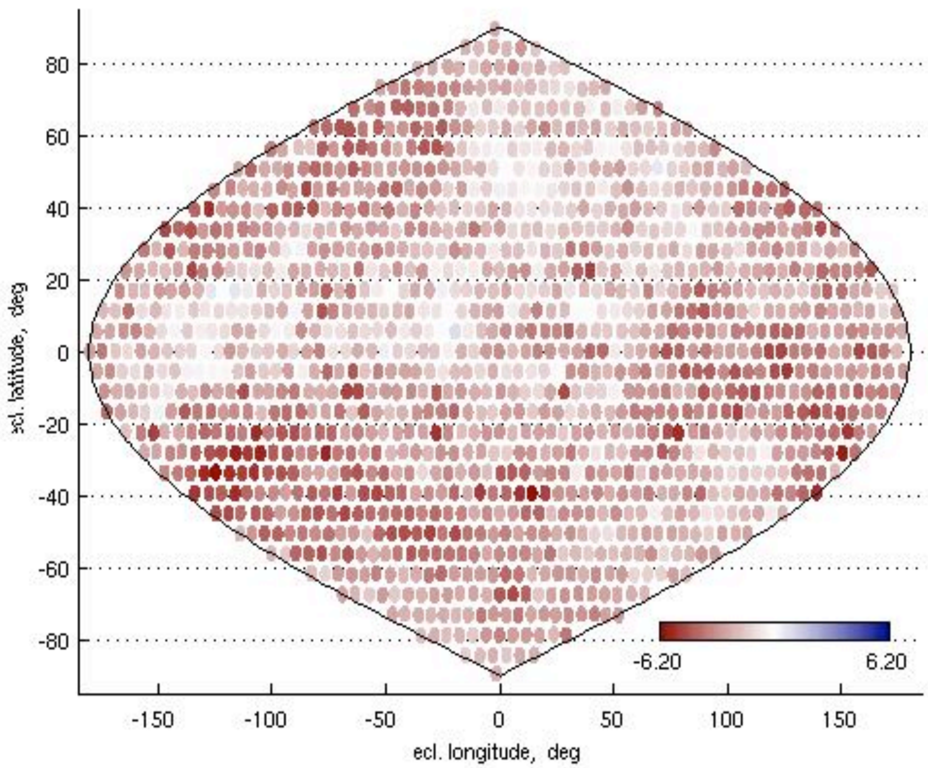
Correlations of parallax for star #1500 with all other grid parallaxes



Parallax zero-point error

- In a typical realization of grid, almost all parallax errors have the same sign because of a dominating zero-point error
- A relatively small number of quasars (25—50) constrain low-order spherical harmonics and lead to dramatically better grid accuracy in parallax

A single realization of grid parallax error



Quasars in the Grid

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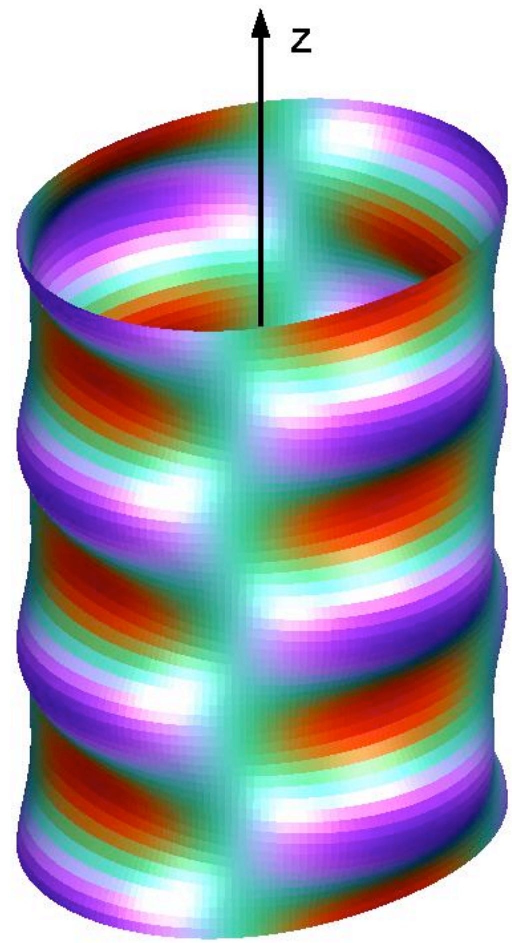
- USNO selected ~110 optically bright, low-variable quasars
- Simulations and covariance analysis of grid solutions with only 23 quasars reveal the benefits of quasar constraints:
  - Overall parallax accuracy improves ~ 17%
  - Parallax zero-point error improves ~60%
  - Greatly improved confidence intervals of parallax mission performance, e.g., the 0.99 confidence level on parallax error drops from 8.05 μas without quasars to 3.97 μas with only 23 grid quasars
  - The SIM Reference Frame (SIMRF) will be inertial to ~ 1 μas/yr in residual spin and ~ 1.7 μas in residual rotation
  - Some harmful systematic errors reduced by a factor of 5, e.g., certain systematic navigation errors and stellar aberration corrections

Why Grid performance is important?

- Correlated zonal errors propagate 100% into Wide Angle astrometry
- Accurate and inertial SIMRF entails fundamental (and free for you) science, for example
  - Galactic rotation and Galactocentric acceleration of the Sun
  - Gravitational bending of light
  - Constraints on relic gravitational waves
  - Speculatively, rotation of the Universe



$$g = h \cos \varpi t \, (\mathbf{xx} - \mathbf{yy})$$

Wide Angle astrometric performance

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Q: Can WA accuracy be better than the Grid?

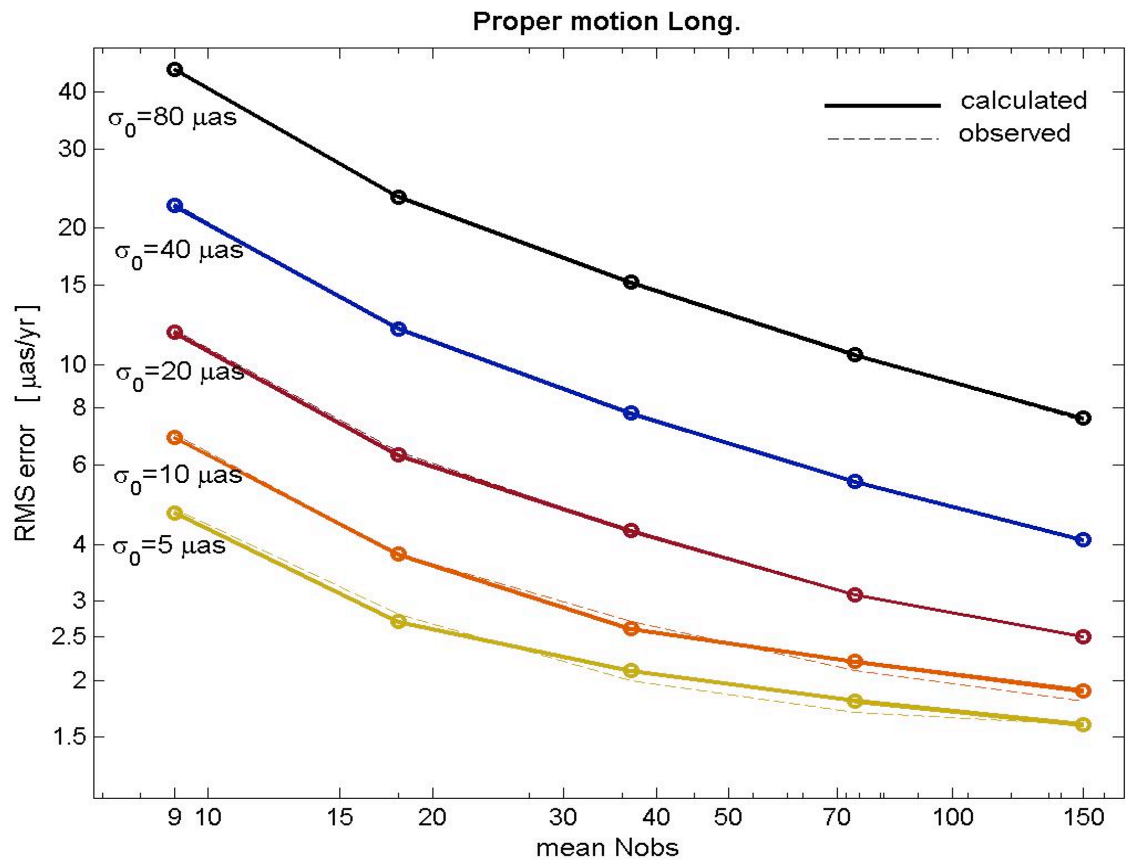
A: Yes, but only slightly, only for bright stars and at a cost

Q: Can single visit integration time be traded for number of observations?

A: Yes, as this plot shows

Q: Does the measurement precision depend on the position within a tile?

A: Yes, see backup slide



Mission-average WA astrometric accuracy of proper motions as function of number of observations and single measurement precision

Optimized schedules

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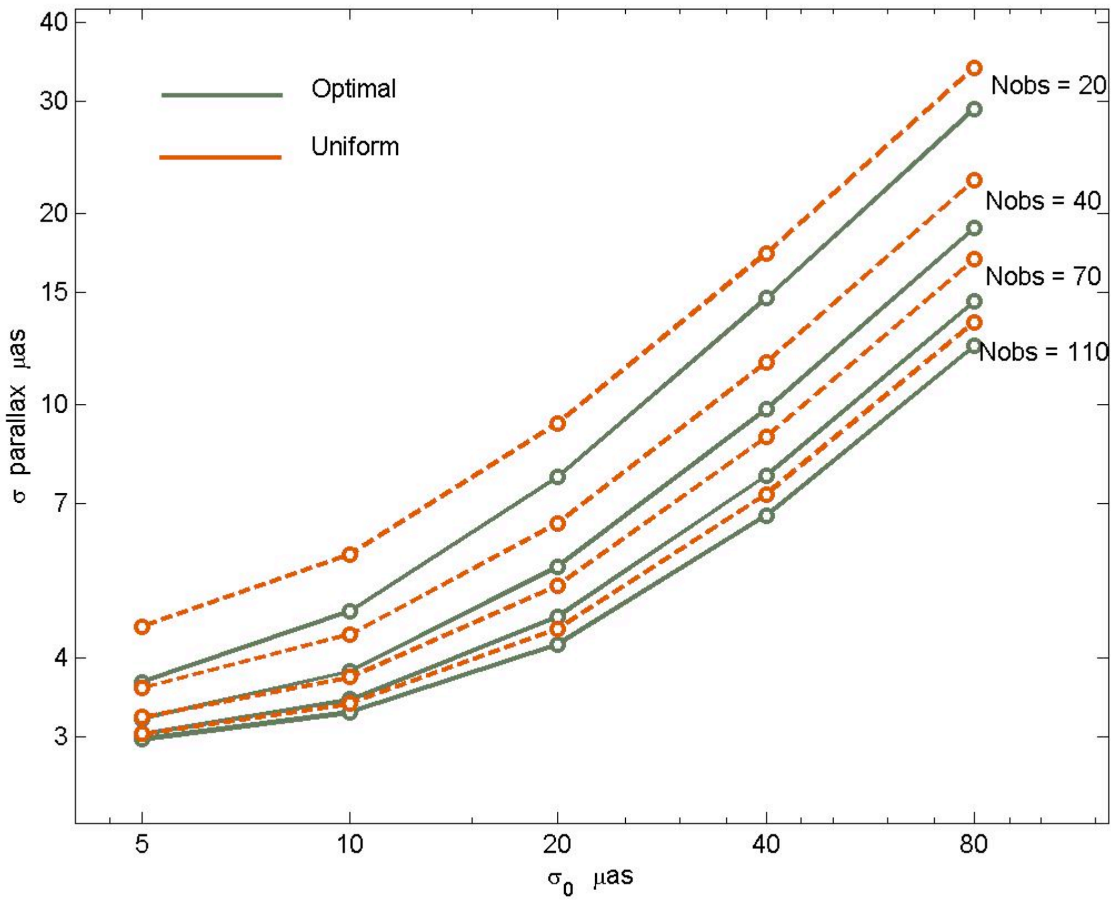
Q: Can accuracy be gained by clever scheduling of a given number of observations?

A: Absolutely, see the plot for a SVD-based optimization on parallax accuracy



Backup Slides

Grid multipliers

freq.	pos.	par.	p.m.	BLL	Z4	Z5	Z6	Z7	Z8	Z9	Z10	Z11	Z12	Z13	Z14	Z15	Z16-Z28
1/480	0.217	0.249	0.150	0.0908	0.0305	-	0.0351	0.0271	0.0957	0.0952	0.0266	0.0332	0.0485	0.0211	0.0492	0.0316	0.0262-0.0859
1/480	0.210	0.243	0.146	0.0323	0.0209	-	0.0253	0.0202	0.0408	0.0345	0.0196	0.0222	0.0295	0.0199	0.0328	0.0218	-
1/480	0.209	0.242	0.145	0.0320	-	-	-	-	-	-	-	-	-	-	-	-	-
1/480	0.209	0.242	0.145	0.0320	-	17.05	-	-	-	-	-	-	-	-	-	-	-
1/480	0.209	0.242	0.145	0.0320	-	-	0.0183	-	-	-	-	-	-	-	-	-	-
1/100	0.286	0.279	0.199	0.2023	0.0755	-	0.0898	0.0781	0.1826	0.1863	0.0509	0.0800	0.1032	0.0473	0.1163	0.0766	0.0630-0.1742
1/100	0.263	0.259	0.183	0.0837	0.0532	-	0.0600	0.0567	0.0922	0.0777	0.0353	0.0532	0.0704	0.0461	0.0759	0.0528	-
1/100	0.255	0.250	0.177	0.0819	0.0396	-	-	-	-	-	-	-	-	-	-	-	-
1/48	0.291	0.270	0.202	0.1212	0.1296	-	0.1263	0.0947	0.1791	0.1602	0.0984	0.1206	0.1468	0.0957	0.1500	0.1053	-
1/48	0.275	0.251	0.191	0.1113	-	-	-	-	-	-	-	-	-	-	-	-	-
1/48	0.275	0.253	0.191	0.1114	-	59.06	-	-	-	-	-	-	-	-	-	-	-
1/48	0.276	0.256	0.191	0.1114	-	-	0.0583	-	-	-	-	-	-	-	-	-	-
1/30	0.321	0.292	0.223	0.1601	0.1978	-	0.1813	0.1375	0.2517	0.2455	0.1364	0.1671	0.2226	0.1512	0.2152	0.1633	-
1/30	0.293	0.258	0.203	0.1364	-	-	-	-	-	-	-	-	-	-	-	-	-
1/30	0.294	0.259	0.204	0.1366	0.0702	-	-	-	-	-	-	-	-	-	-	-	-
1/30	0.294	0.259	0.204	0.1366	-	72.43	-	-	-	-	-	-	-	-	-	-	-
1/30	0.295	0.265	0.205	0.1366	-	-	0.0719	-	-	-	-	-	-	-	-	-	-
1/30	0.294	0.259	0.204	0.1366	-	-	-	0.0902	-	-	-	-	-	-	-	-	-
1/30	0.196	0.237	0.136	-	-	-	-	-	-	-	-	-	-	-	-	0.0808	-
1/30	0.325	0.295	0.226	0.1868	0.2443	1.61e+5	0.2357	0.1615	0.3012	0.2924	0.1603	0.2049	0.2904	178.8	0.3238	0.2015	-
1/24	0.303	0.266	0.211	0.1497	-	-	-	-	-	-	-	-	-	-	-	-	-
1/24	0.307	0.276	0.214	0.1501	-	-	0.0792	-	-	-	-	-	-	-	-	-	-
1/12	0.363	0.328	0.252	0.2018	-	-	-	-	-	-	-	-	-	-	-	-	-
1/6	0.482	0.479	0.335	0.2898	-	-	-	-	-	-	-	-	-	-	-	-	-

Propagation of FDE

- Field-dependent instrument parameters will be determined in the grid and applied to WA delays
- Field-dependent errors sharply increase at the edge of the FOR (tile)