FUTURE IMPROVEMENTS IN DETERMINATIONS OF EARTH ORIENTATION PARAMETERS

- **Present polar motion accuracy**
  - about 30 μas, mostly from GPS
- **Present UT1 accuracy**
  - usually from 4 to 20 μs, but sometimes worse
  - mostly from VLBI, but GPS LOD could add more
- **Improvements possible from better networks, new GNSSs, reduced systematic errors**

Jim Ray, NOAA/NGS

IAG 2009 Scientific Assembly, Buenos Aires, 2 September 2009 – session 3.1, paper 164

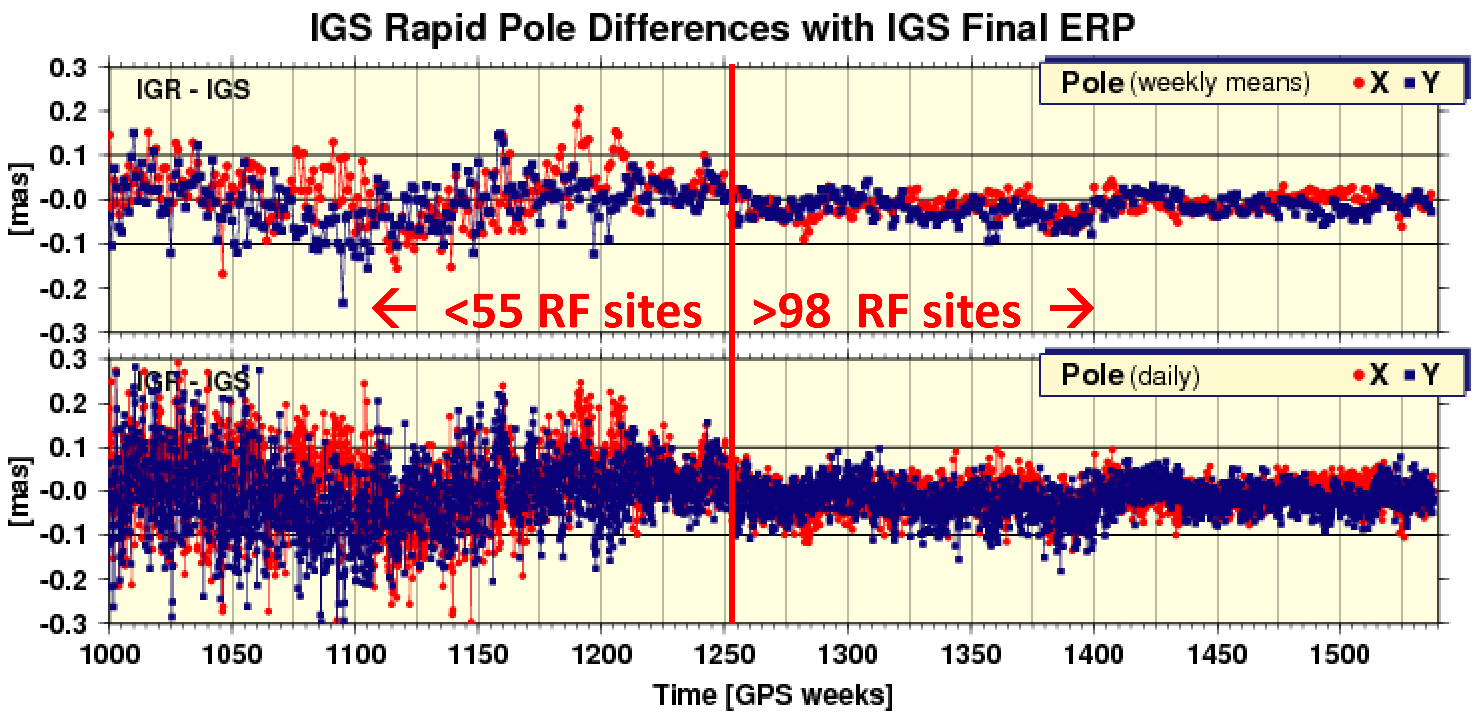
Recent Polar Motion Accuracy

- ITRF2005 multi-technique combination experience
  - scaled formal errors ~30 µas for daily PM-x & PM-y
  - equivalent to net equatorial rotation errors of ~1 mm

- IGS GPS heavily dominates modern combinations
  - due to robust global network & continuous, high-accuracy data
  - SLR & VLBI networks are sparse, non-uniform, & irregularly observed
  - SLR & VLBI PM contribute to rotational frame alignments, less for EOPs
  - DORIS PM noisy due to limited satellite constellation

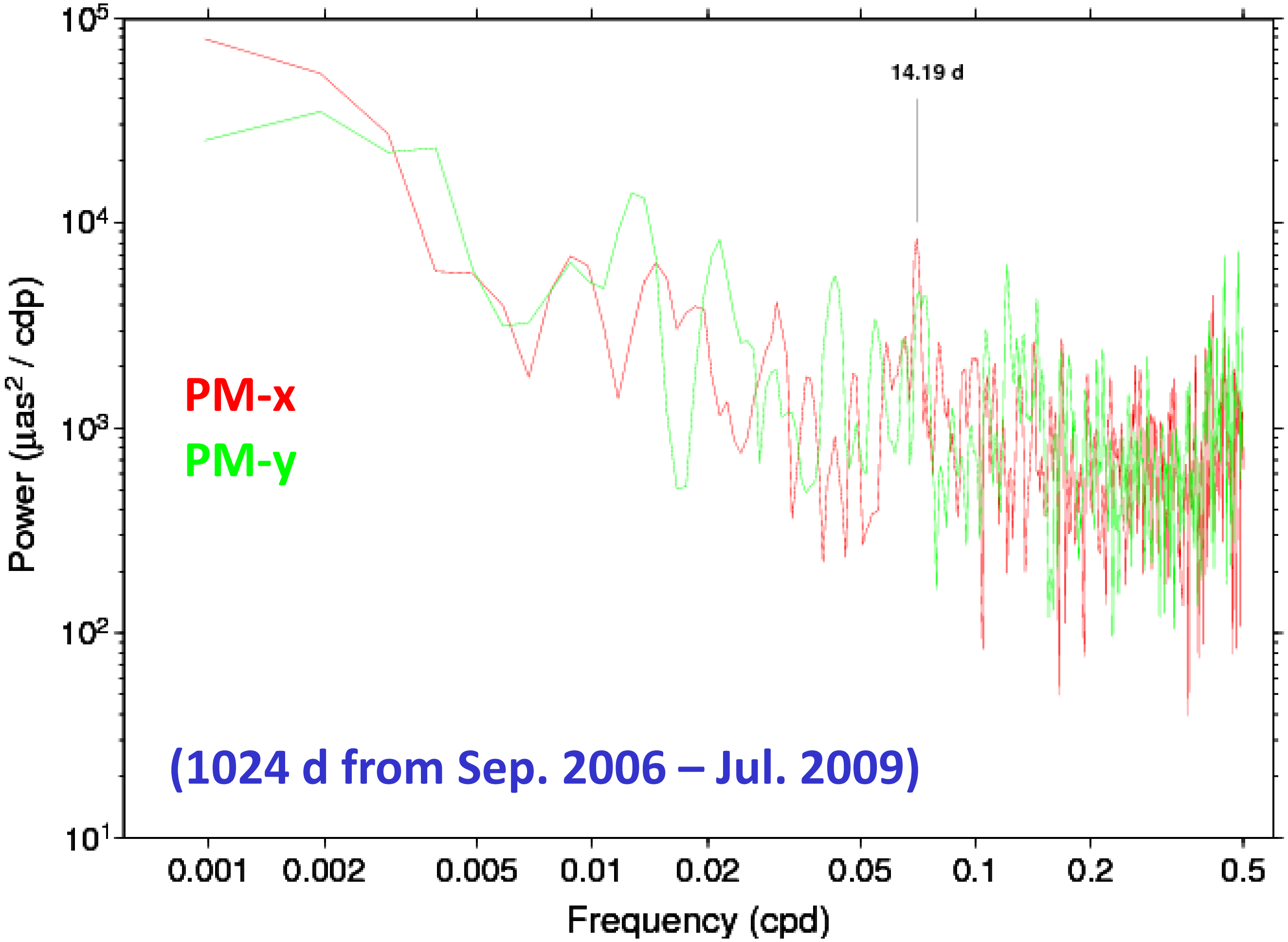
- GPS PM errors difficult to quantify precisely
  - since increase in IGS RF to 99+ sites (Jan. 2004), PM errors <~30 µas
  - recent PM errors due to: orbit mismodeling, subdaily EOP tide model errors, & AC solution constraints
  - can compare Rapid & Final series for some insights
  - current Rapids about 25 to 50% poorer than Finals
  - IGS reprocessing campaign will improve old PM results

IGS Polar Motion Accuracy



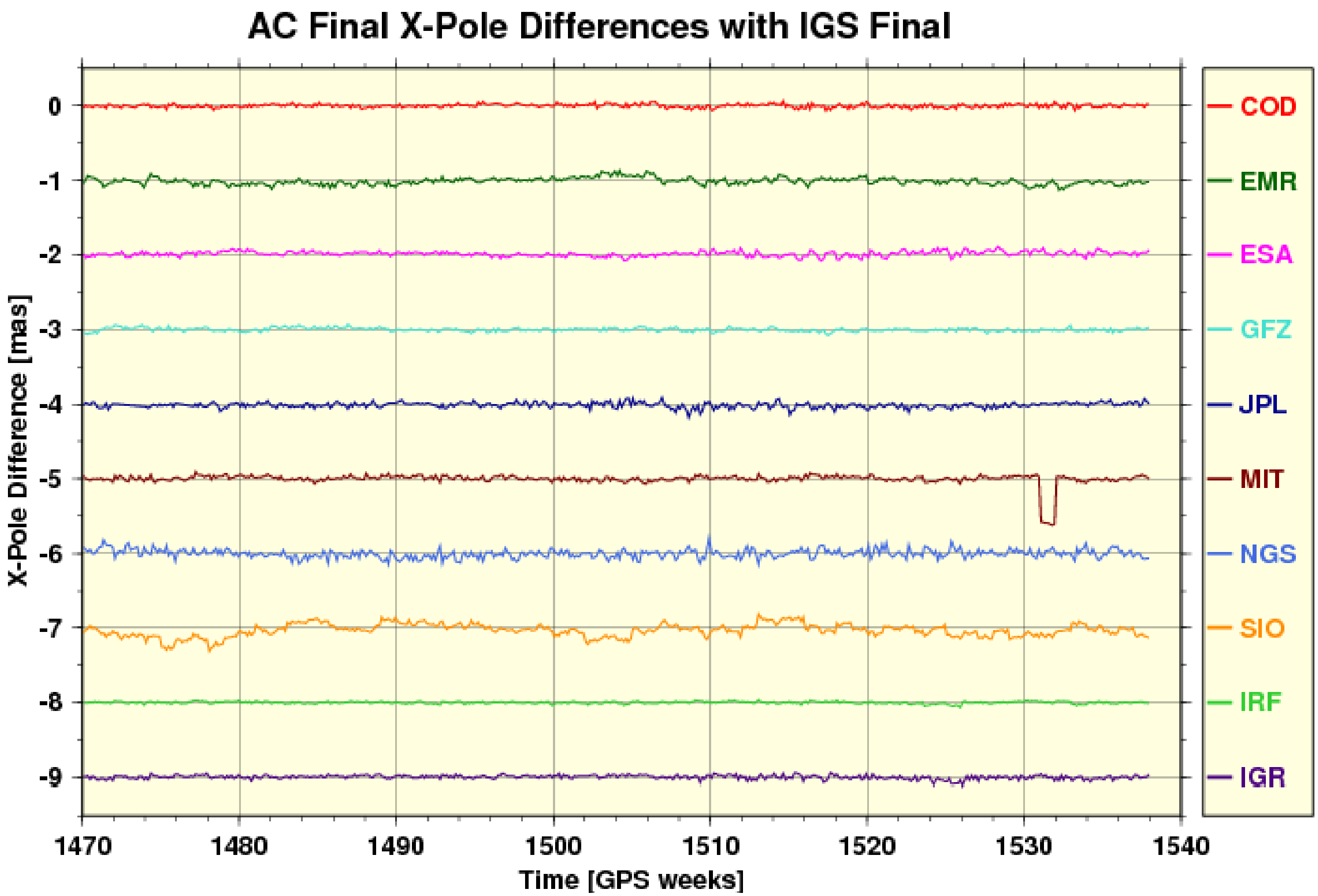
Years (units = µas)	Rapid		Final		Δ(Rapid-Final)	
	$\langle\sigma_x\rangle$	$\langle\sigma_y\rangle$	$\langle\sigma_x\rangle$	$\langle\sigma_y\rangle$	<Δx> ± SDev	<Δy> ± SDev
1999-2001.5	77.3	85.9	44.1	44.4	119.9 ± 153.2	-29.7 ± 113.8
2001.5-2003	47.5	47.3	33.3	35.0	65.4 ± 73.9	6.3 ± 70.0
2004-2006	34.0	39.5	25.6	27.2	7.2 ± 38.7	-1.7 ± 38.8
2007-2009.5	**24.3**	**27.7**	**20.1**	**20.1**	-4.8 ± **28.9**	-1.4 ± **31.1**

Spectra of (Rapid-Final) PM Differences



- **High-frequency noise consistent with ~30 µas accuracy**
  - **but longer period errors might be significant**
  - **fortnightly feature near 14.2 d may signify tide model errors**

PM Differences among IGS ACs



- **Differences among ACs reflect mostly analysis variations**
  - networks, geophysical models, & parameterizations quite similar
  - main analysis differences relate to orbit dynamics & solution constraints

Recent PM-Rate Accuracy

- ITRF2005 multi-technique combination experience
  - scaled formal errors ~90 µas/d for PM-xrate & PM-yrate
  - but these estimates are probably optimistic

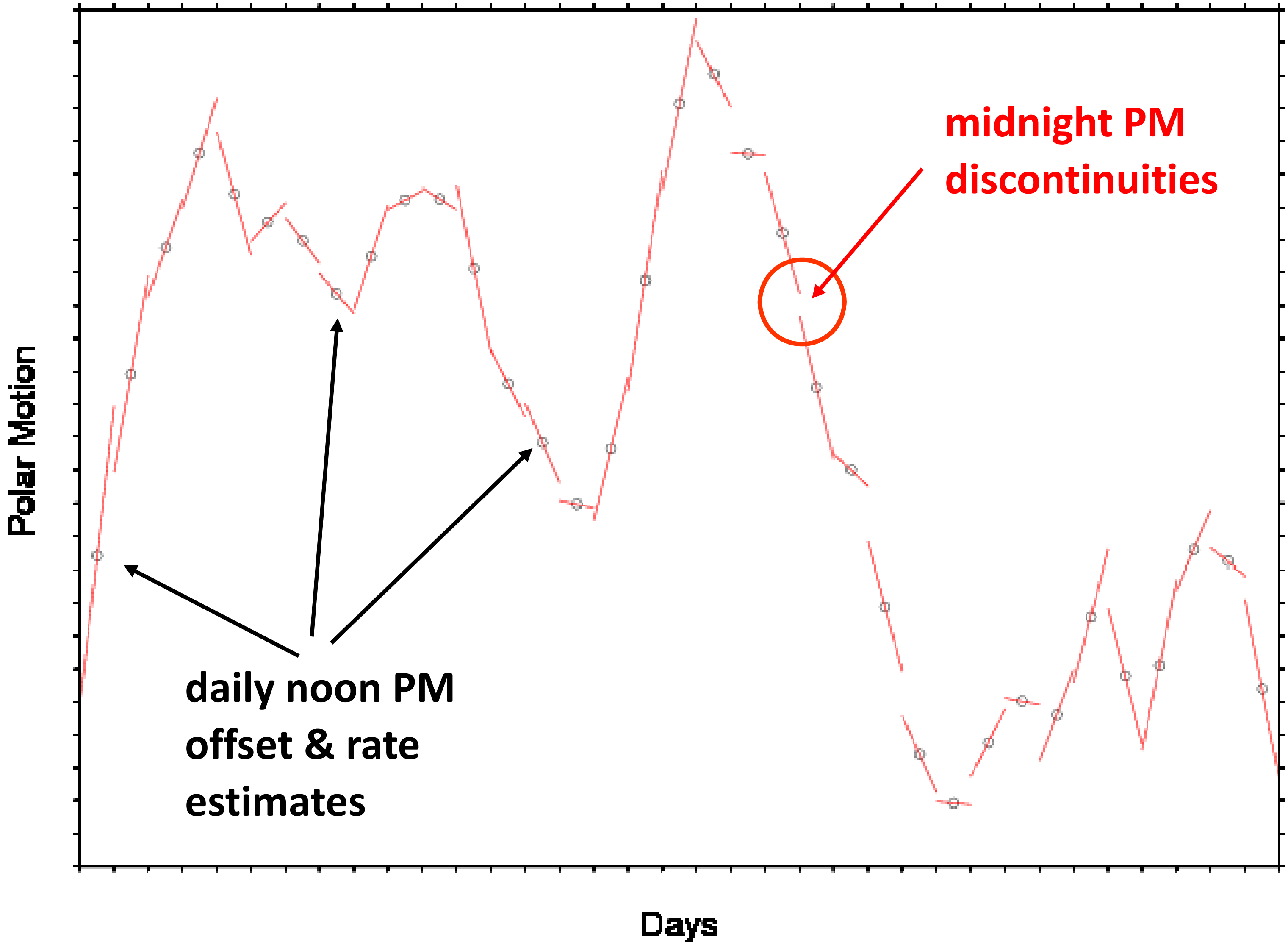
- IGS GPS also dominates PM-rate combinations

- GPS PM-rate errors can be assessed by examining day-boundary discontinuities

- PM-rates very sensitive to subdaily EOP tide model errors
  - imply IERS2003 errors for K1, O1, Q1/N2, & probably other lines
  - odd numbered harmonics of 1.04 cpy point to orbit errors
  - estimated IGS PM-rate errors: ~140 µas/d for xrate; ~180 µas/d for yrate
  - PM-yrate error larger due to greater 1.04 cpy orbit harmonics

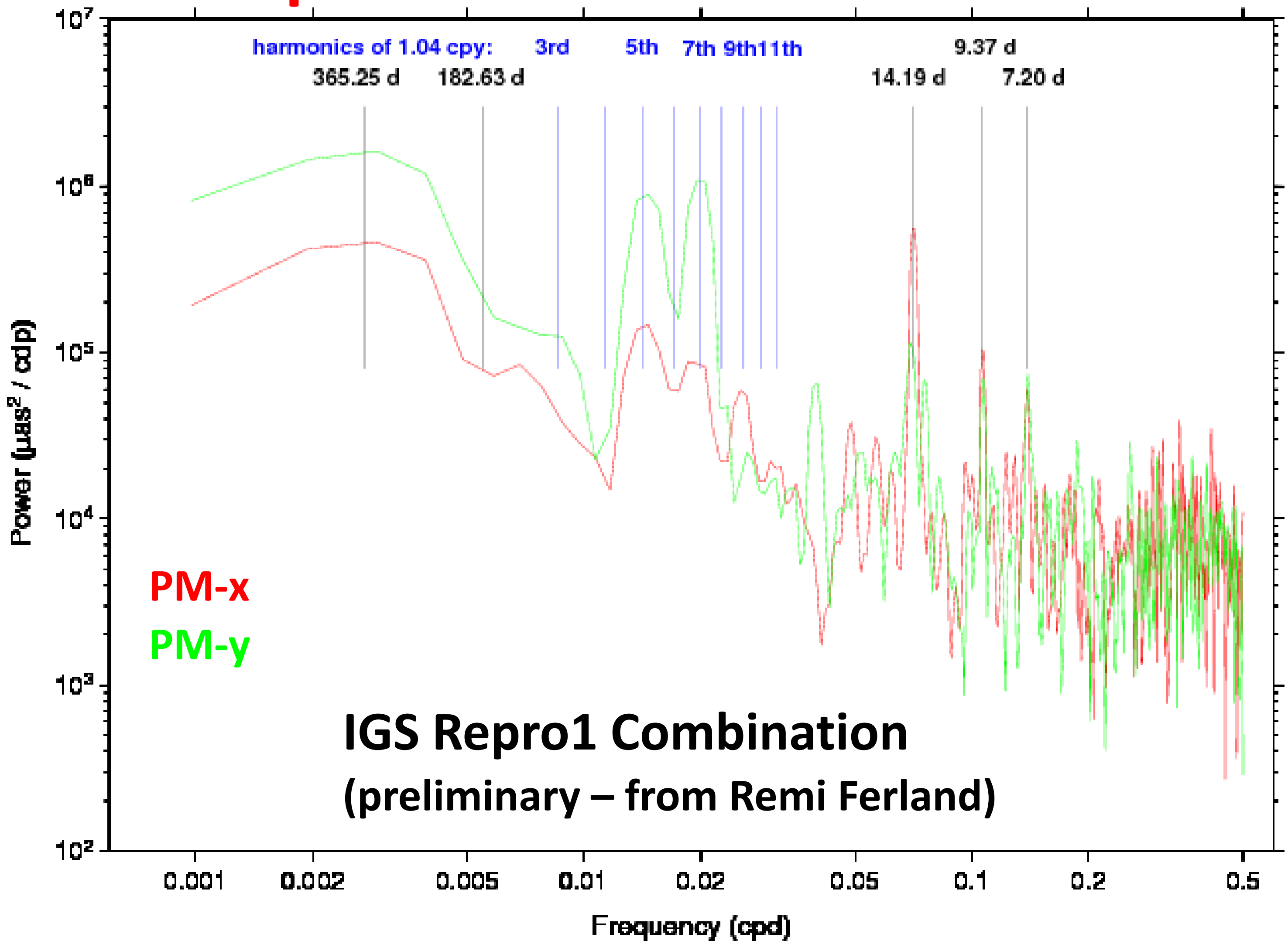
- For excitation studies, probably best to use PM time differences, not directly observed PM-rates

Compute Polar Motion Discontinuities



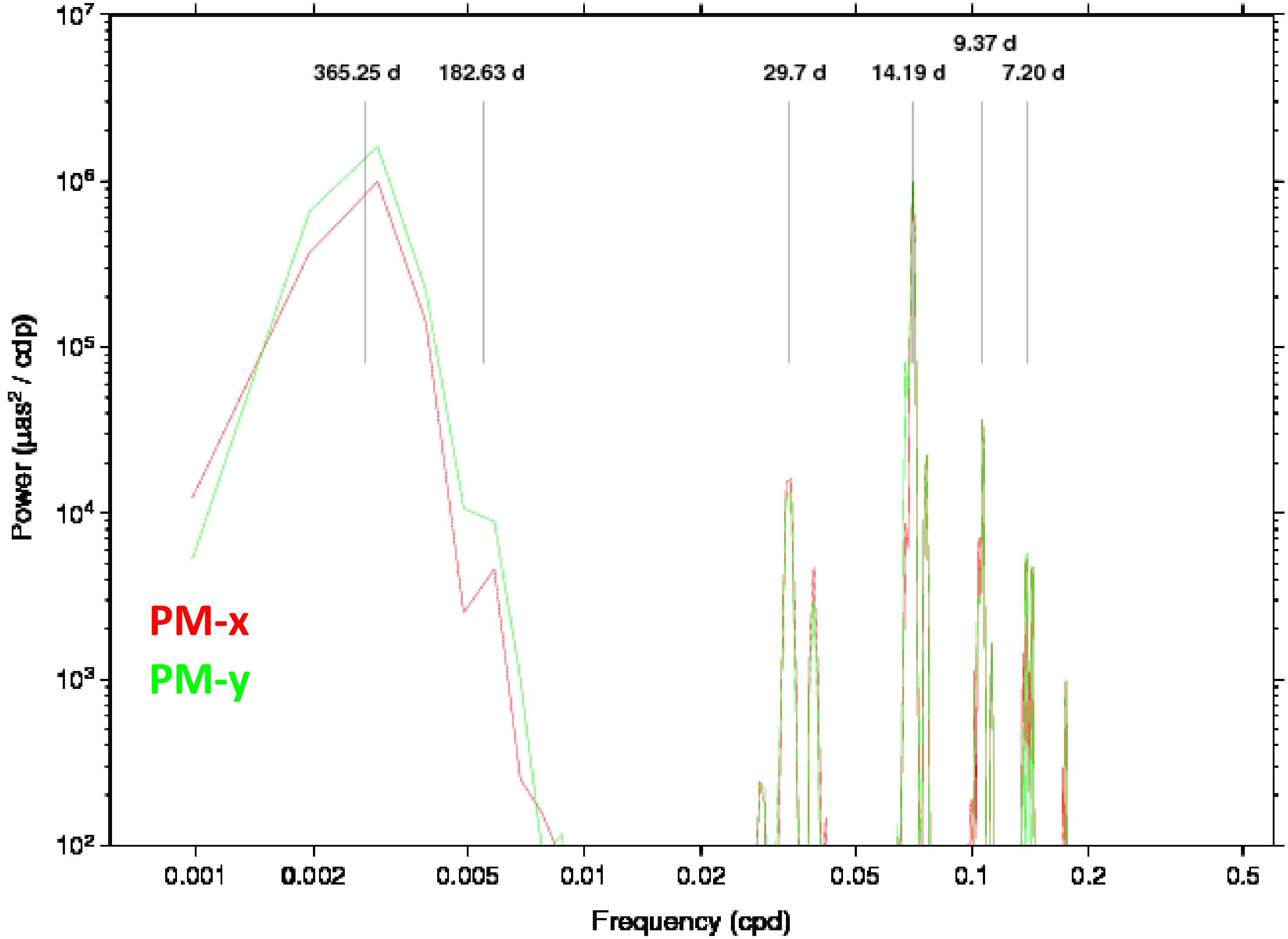
- **Examine PM day-boundary discontinuities for IGS time series**
  - should be non-zero due to PM excitation & measurement errors

Power Spectra of IGS PM Discontinuities



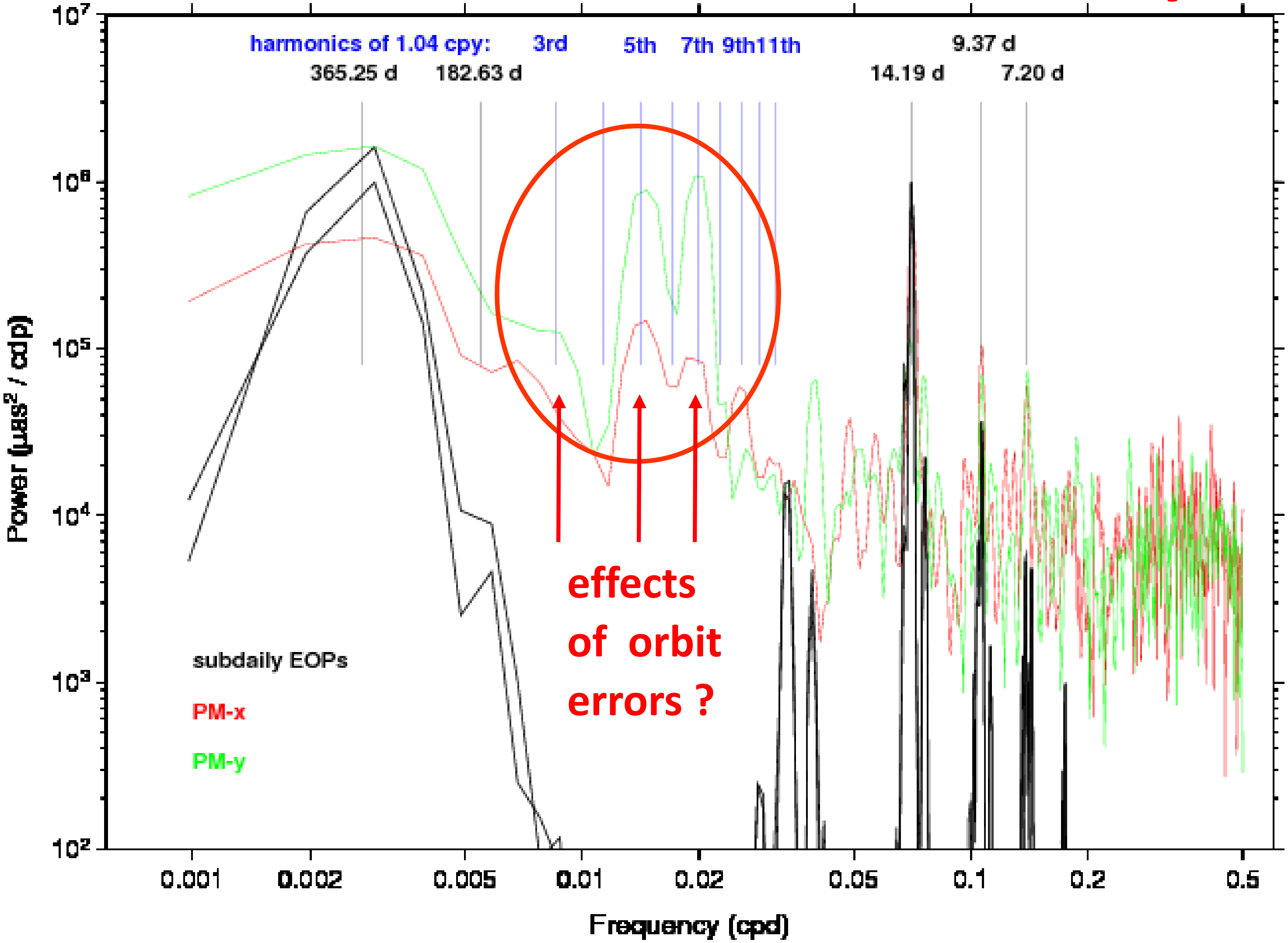
- **Common peaks seen in most AC spectra are:**
  - annual + 5th & 7th harmonics of GPS year (351 d or 1.040 cpy)
  - probably aliased errors of subdaily EOP tide model (IERS2003)

Spectra of Subdaily EOP Tide Model Differences



- Compare TPXO7.1 & IERS2003 (used by IGS) EOP models
  - TPXO7.1 & GOT4.7 test models kindly provided by Richard Ray
  - assume subdaily EOP model differences expressed fully in IGS PM results

Spectra of PM Discontinuities & Subdaily EOPs



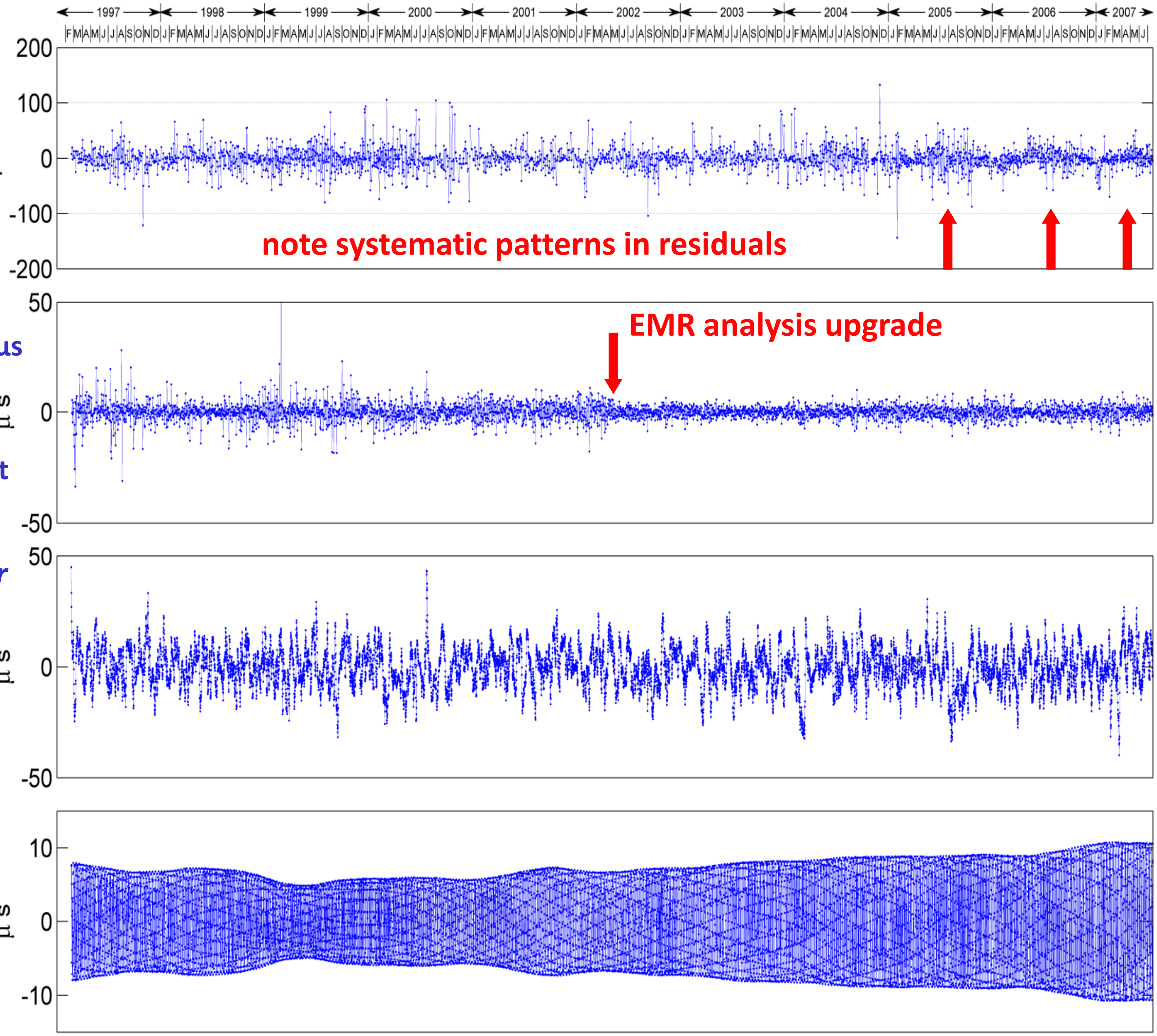
- Aliasing of subdaily EOP tide model errors probably explains:
  - annual (K1, P1, T2), 14.2 d (O1), 9.4 d (Q1, N2), & 7.2 d (σ1, 2Q1, 2N2, μ2)
- Orbit errors presumably responsible for odd 1.04 cpy harmonics

Recent UT1 Accuracy

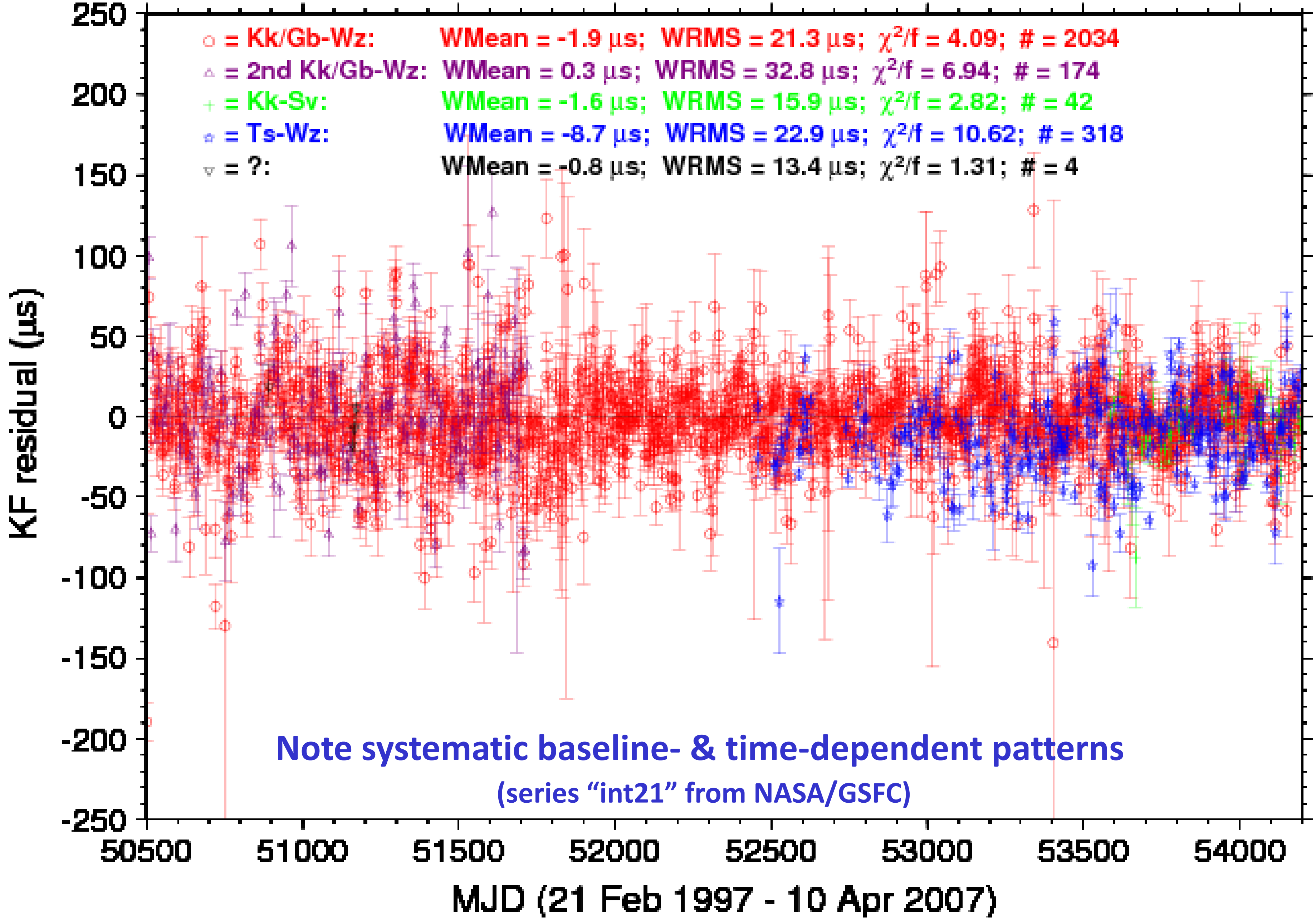
- ITRF2005 multi-technique combination experience
  - mean scaled formal errors ~8.0 μs since 2002.0 (at irregular epochs)
  - equivalent to net equatorial rotation errors of ~3.7 mm
- UT1-UTC only measured by VLBI, but irregular quality & epochs
- For VLBI data since 2002:
  - 24-hr EOP sessions give UT1 formal errors of 2.2 to 2.8 μs (twice weekly)
  - accuracy is about twice formal errors: ~5 μs (= 2.3 mm rotation)
  - other 24-hr sessions have estimated mean accuracy ~20 μs (irregular)
  - 1-hr Intensive sessions have mean formal errors ~13 μs (nearly daily)
  - but Intensives show clear systematic effects that are difficult to handle
- Daily GPS LOD (= -UT1-rate) generally not used optimally
  - must model time-correlated biases – easy in Kalman filter, difficult otherwise
  - LOD residuals from such a Kalman filter are ~4 μs
  - combinations with VLBI UT1 yield best UT1/LOD time series

Some Kalman Filter Combination Outputs

- ***VLBI 1-hr UT1 residuals***
  - show systematic patterns
  - RMS = 20 μs
- ***GPS LOD residuals***
  - approx. white, RMS = 4 μs
  - small peak at 13.7 d
  - possible difference in *a priori* tidal models wrt VLBI
- ***Gauss-Markov values for GPS LOD biases***
  - peak-to-peak range = ± 40 μs
  - RMS = 9 μs
- ***14.19-d periodic***
  - treated as GPS artifact
  - amplitude varies between 5 & 11 μs
  - phase & period vary linearly w/ time



UT1 KF Residuals for VLBI 1-hr Intensives



EOP Error Sources

σ_{EOP} =

Station-related measurements:

- thermal noise
- instrumentation
- propagation delays
- multipath, etc

$\sigma_{Station} \approx 1/\sqrt{N_{Station}}$

+

Geophysical & parameter models:

- esp near S1, K1, K2 tidal periods

+

Source-related errors:

- orbit dynamics (GPS, SLR, DORIS)
- quasar structures (VLBI)

$\sigma_{Source} \approx 1/\sqrt{N_{Source}}$

Possible improvements:

- more robust SLR, VLBI networks ?
- more stable site installations ?
- near asymptotic limit for GPS already

- new subdaily EOP tide model ?
- better handling of parameter constraints ?
- modern theory of Earth rotation ?

- new GNSS constellations
- better GNSS orbit models ?
- quasar structure models (VLBI) ?

→ Multi-technique EOP combinations mostly sub-optimal ! ←

Conclusions

- **Stronger VLBI & SLR contributions will depend mostly on larger, more robust networks & continuous operation**
  - GPS will probably continue to dominate PM for indefinite future
- **GPS PM nearing asymptotic limit for random errors (~20 μas)**
  - smaller systematic errors possible with new GNSSs, better orbit modeling, & better handling of solution constraints
  - better PM-rates require new subdaily EOP tide model & reduced orbit effects – prospects currently unclear
- **VLBI UT1 improvements require attention to station- & network-dependent errors**
  - new GNSSs & orbit models will improve GPS LOD by unknown amount
  - combination methods generally do not match observation accuracy & require better approaches
- **Exploration of subdaily non-tidal EOPs remains distant, but a challenging possibility for UT1**