# STATUS OF IGS ORBIT MODELING & AREAS FOR IMPROVEMENT

- **Earth radiation pressure (albedo) accelerations**
  - see posters by C. Rodriguez Solano *et al.* (this afternoon)

- **Spurious rotations & translations in AC solutions**
  - compare Rapid & Finals daily orbits
  - check indirect AC orbit effects on polar motion, LOD, geocenter
  - study discontinuities between daily orbits

- **Inconsistent AC yaw-attitude models**
  - mostly affects clock estimates during eclipse season

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**EGU 2011, Session G2.4, Vienna, 8 April 2011**

# Approaches to Study Orbit Errors

- SLR ranging is only direct, independent method
  - but just 2 old GPS Block IIA SVs with retro-reflectors (PRNs 05 & 06)
  - PRN05 was decommissioned in 2009
  - results suggest neglect of albedo shifts orbit origin few cm away from sun
  - not considered here → see posters by C. Rodriguez Solano *et al.*

- Or, can check indirect effects on polar motion, LOD, & geocenter estimates
  - net constellation rotations about RX & RY should ideally match polar motion offsets in PMy & PMx
  - LOD changes are indistinguishable from –dRZ/dt, net rate of satellite Right Ascensions (axial rotation rate)
  - compare LOD to independent multi-technique UT1+LOD combinations
  - compare geocenter motion to SLR & load models

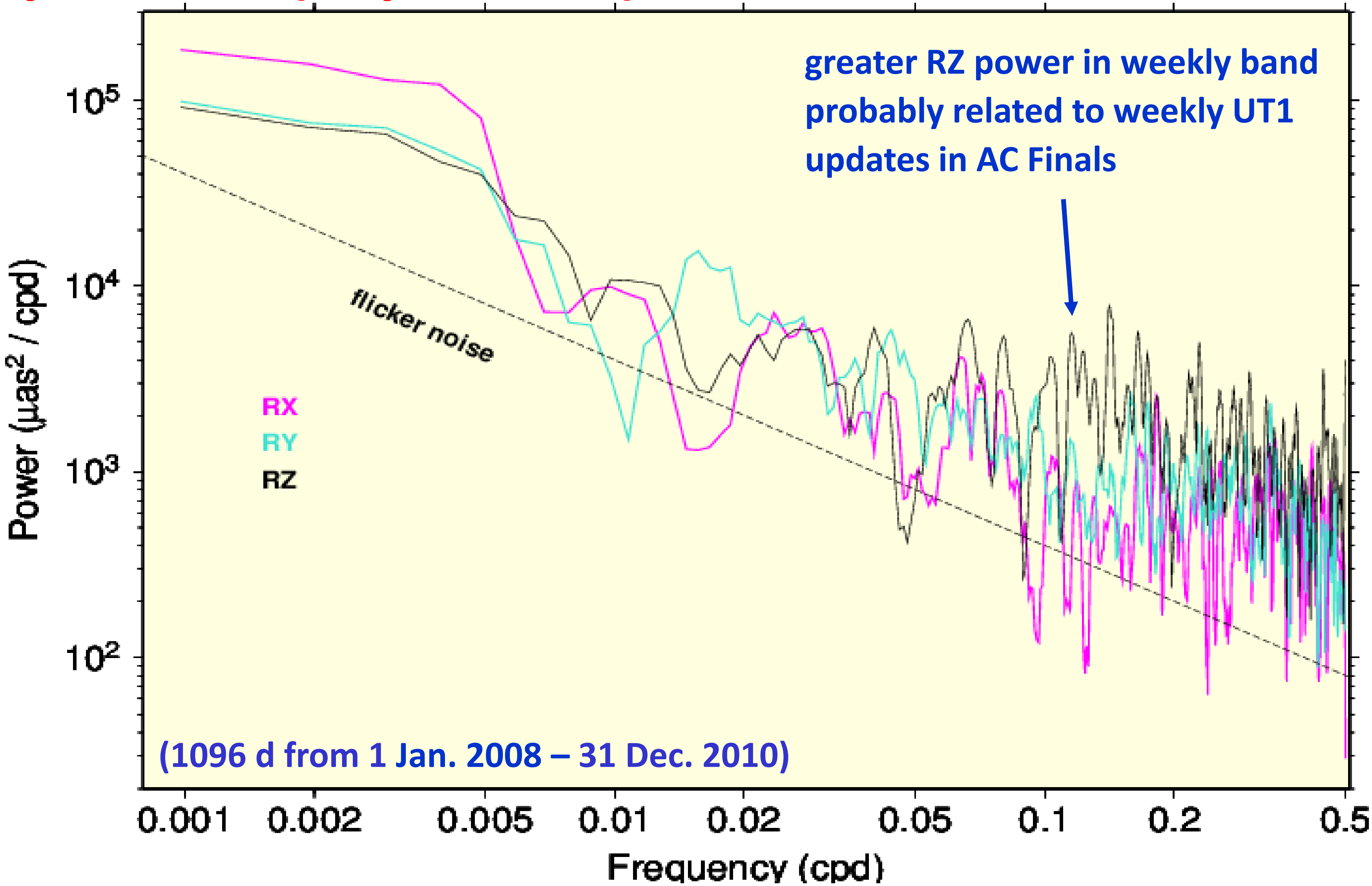
- Can also study discontinuities between daily orbits at ~24:00
  - samples 1 point in orbit per day
  - aliases any subdaily harmonic orbit errors into longer-period features (except S1 & S2)

# IGS Rapid vs Final Orbit Differences (mm)

| | DX | DY | DZ | RX | RY | RZ | SCL | RMS | WRMS | MEDI | TOTAL ERROR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **mean** | -0.2 | 0.1 | -0.1 | 1.7 | **-4.1** | -2.1 | 0.7 | 6.2 | **5.9** | 5.4 | **8.2** |
| **std dev** | 0.7 | 0.8 | 1.4 | **5.0** | **4.7** | **4.6** | 1.4 | 1.0 | 1.0 | 1.0 | **(1D)** |

- **Compare 3 years of daily orbits: 1 Jan 2008 to 31 Dec 2010**
- **Net daily constellation rotations are a leading orbit error**
  - **must come mostly from modeling of satellite dynamics**
  - **note non-zero RY mean bias**
- **Implies short-period orbit precision > 8.2/√2 ≈ 5.8 mm**
  - **this is 1D lower-limit estimate ⇒ 3D precision is >10.1 mm**
  - **common-mode errors (e.g., subdaily EOP tide model) not visible here**
- **Other common-mode IGR/IGS errors also not visible here**
  - **long-period (> 1 d) errors**
  - **e.g., due to Reference Frame or analytical form of empirical orbit model**

# Spectra of (Rapid-Final) Orbit Rotation Differences

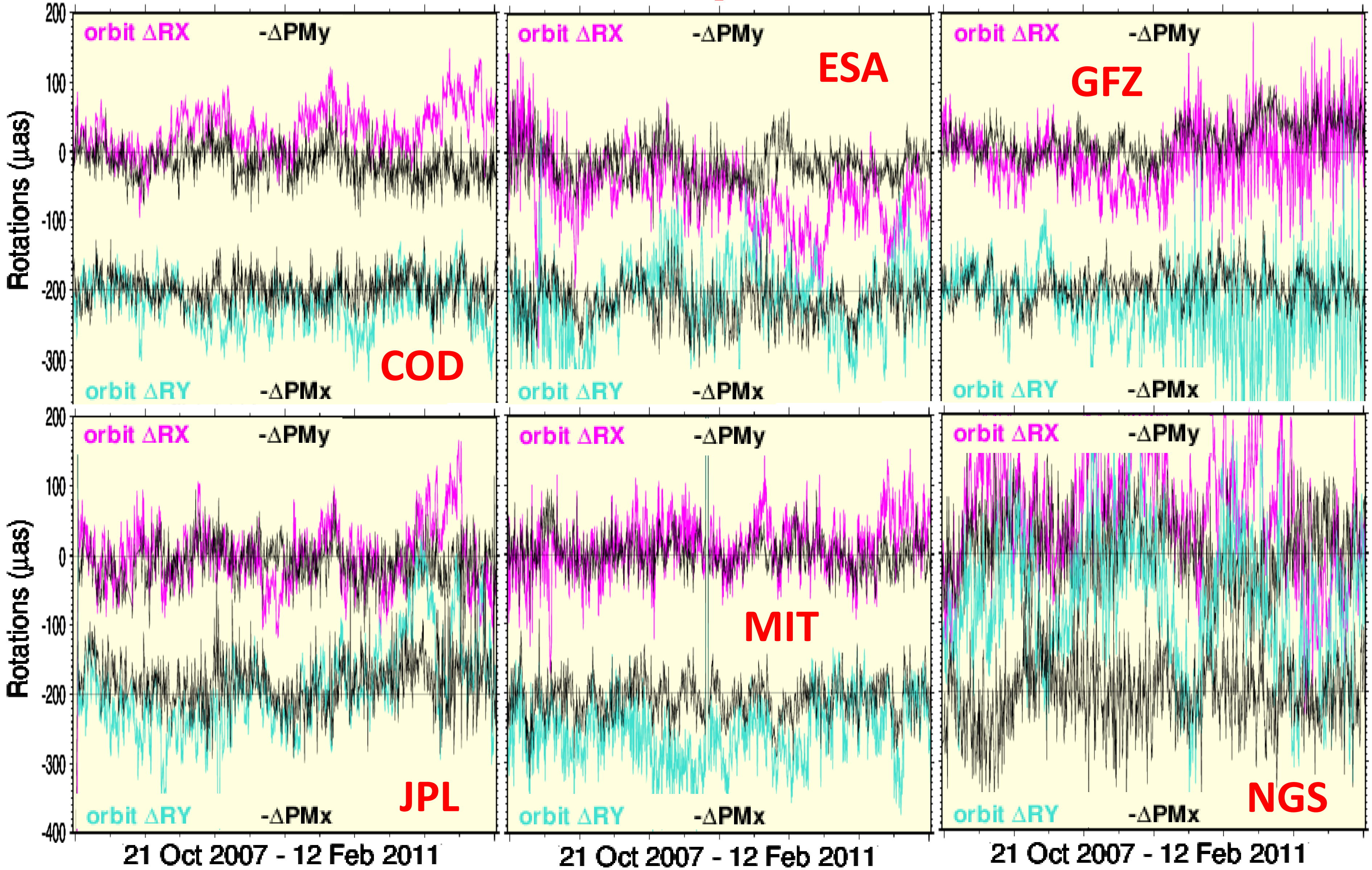



- **Rotation differences nearly featureless**
  - **except for background of flicker noise down to sub-weekly periods**

# AC Orbit & Polar Motion Consistency

- A constant rotational shift of TRF, e.g., should offset orbit frame & polar motion (PM) equally
  - expect: orbit RX ≈ ΔPMy & orbit RY ≈ ΔPMx
- But, a net diurnal sinusoidal wobble of orbit frame will alias entirely into a PM bias
  - does not equal any net rotational offset of orbit frame
- Likewise, prograde diurnal PM errors can alias into empirical once-per-rev (12-hr) orbit parameters
  - e.g., due to errors in ~24-hr terms of subdaily EOP tide model
  - net impact on orbit frame depends on geometry of orbit planes & SRP model terms
- So, check of orbit frame vs PM rotational consistency can provide insights into AC analysis weaknesses
  - note, though, that most ACs apply some over-constraints on orbit and/or PM variations (only ESA & NGS claim none; CODE has strongest)

# Rotational Self-Consistency of IGS Final Orbits/PM




- Orbit rotations more variable than PM residuals for all ACs

# AC Orbit Modeling Differences

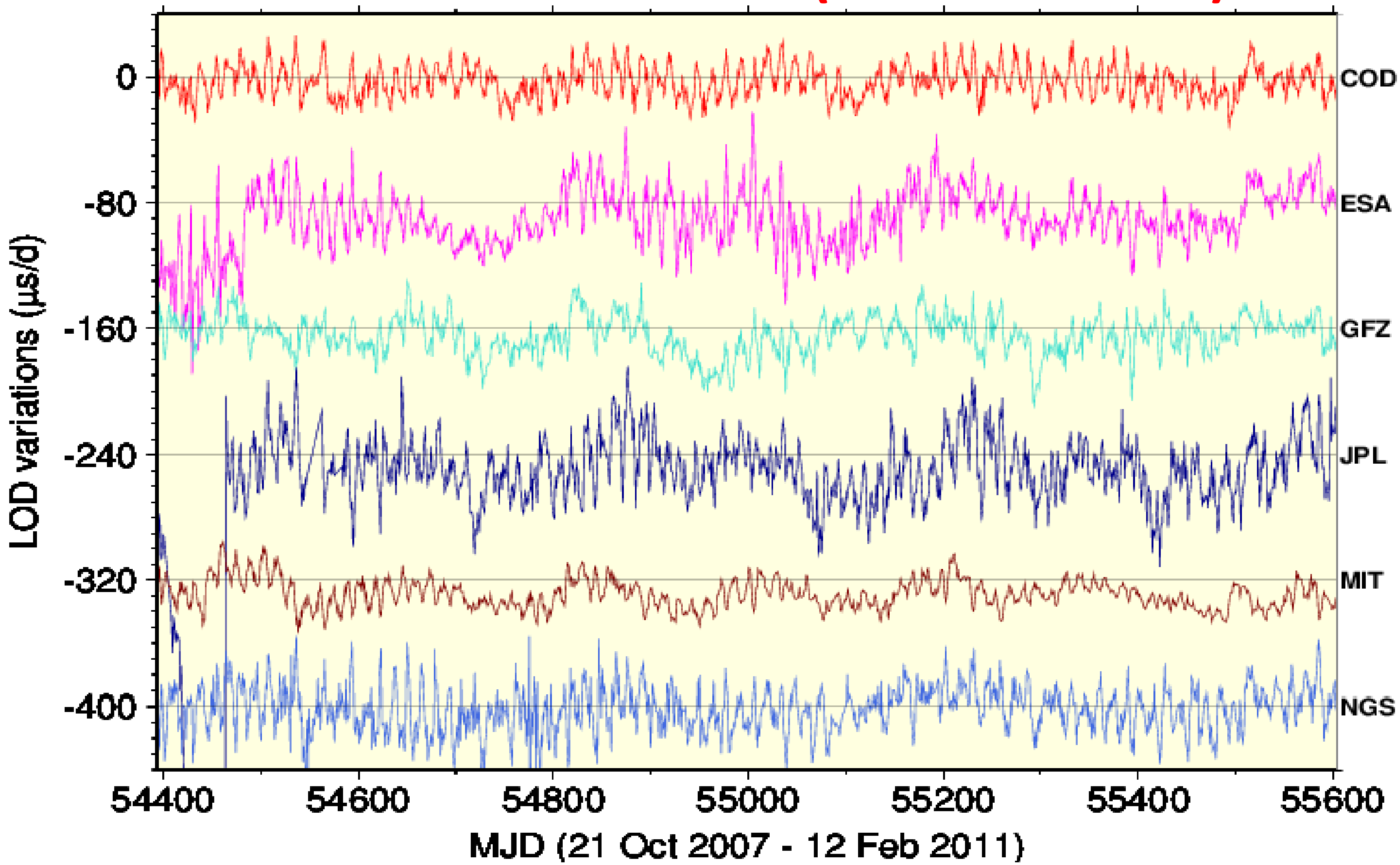
- **Most ACs use CODE Extended Orbit Model in some form, with empirical SRP parameters adjusted deterministically**
  - COD: D,Y,B scales + 1/rev in B + 12-hr velocity brks w/ constraints
  - ESA: D,Y,B scales + 1/rev in B + along-track offset & 1/rev
  - GFZ: D,Y,B scales + 1/rev in B + noon velocity brks
  - GRG: D,Y scales + 1/rev in D,B + velocity brks in eclipse
  - MIT: D,Y,B scales + 1/rev in D,Y,B w/ constraints
  - NGS: D,Y,B scales + 1/rev in B + noon velocity brks
  - SIO: D,Y,B scales + 1/rev in D,Y,B w/ constraints

    (frames oriented toward the Sun)

- **Except 2 ACs that use frame oriented toward the Earth with stochastic SRP estimation**
  - EMR: X,Y,Z scales + stochastic X,Y,Z
  - JPL: X,Y,Z scales + stochastic X,Y,Z

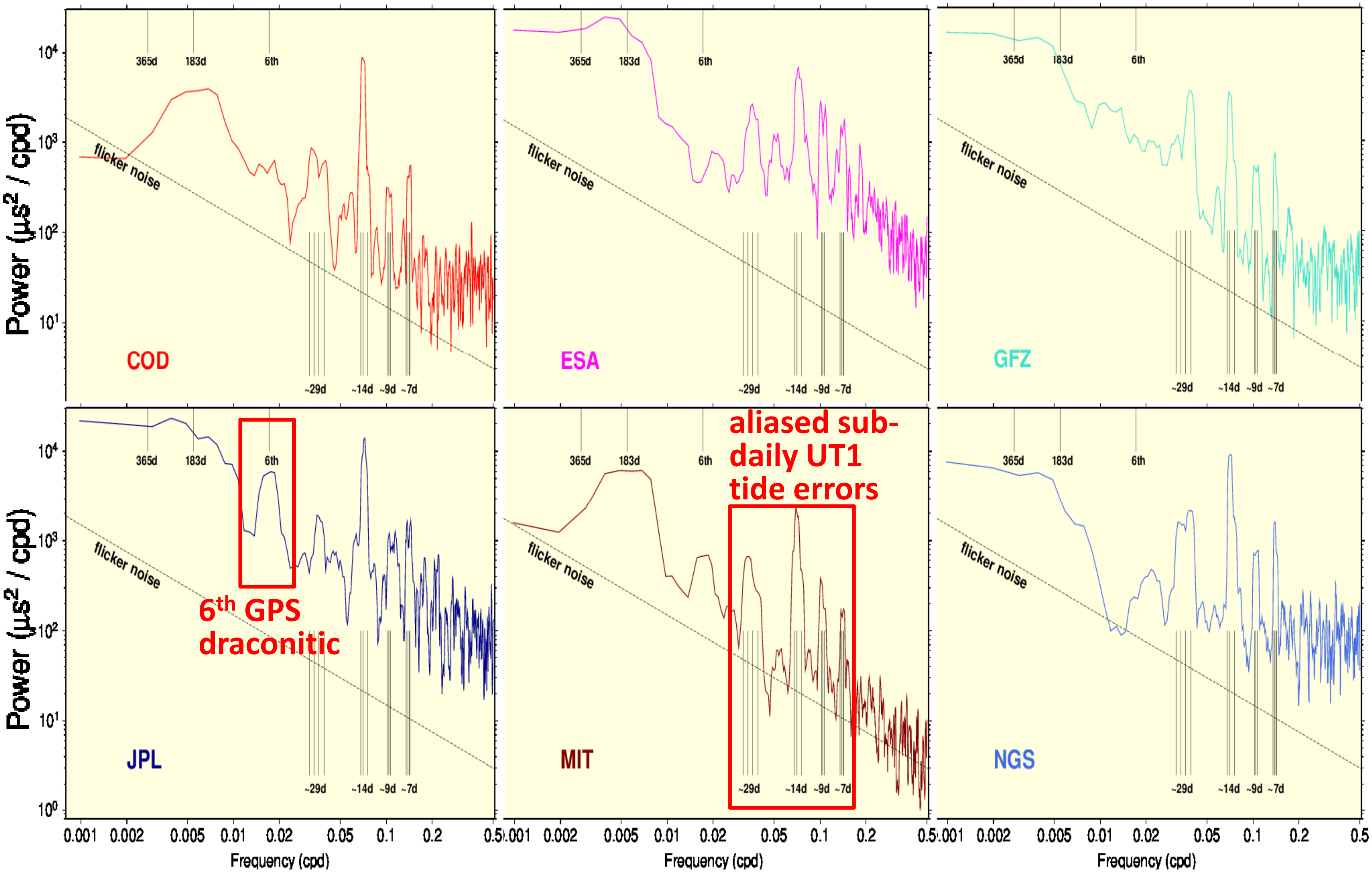
- **Geocenter & LOD estimates (among others) known to be sensitive to solar radiation pressure modeling**
  - especially Y & Z components of geocenter

# IGS Final LOD Residuals (AC – JPL KEOF)



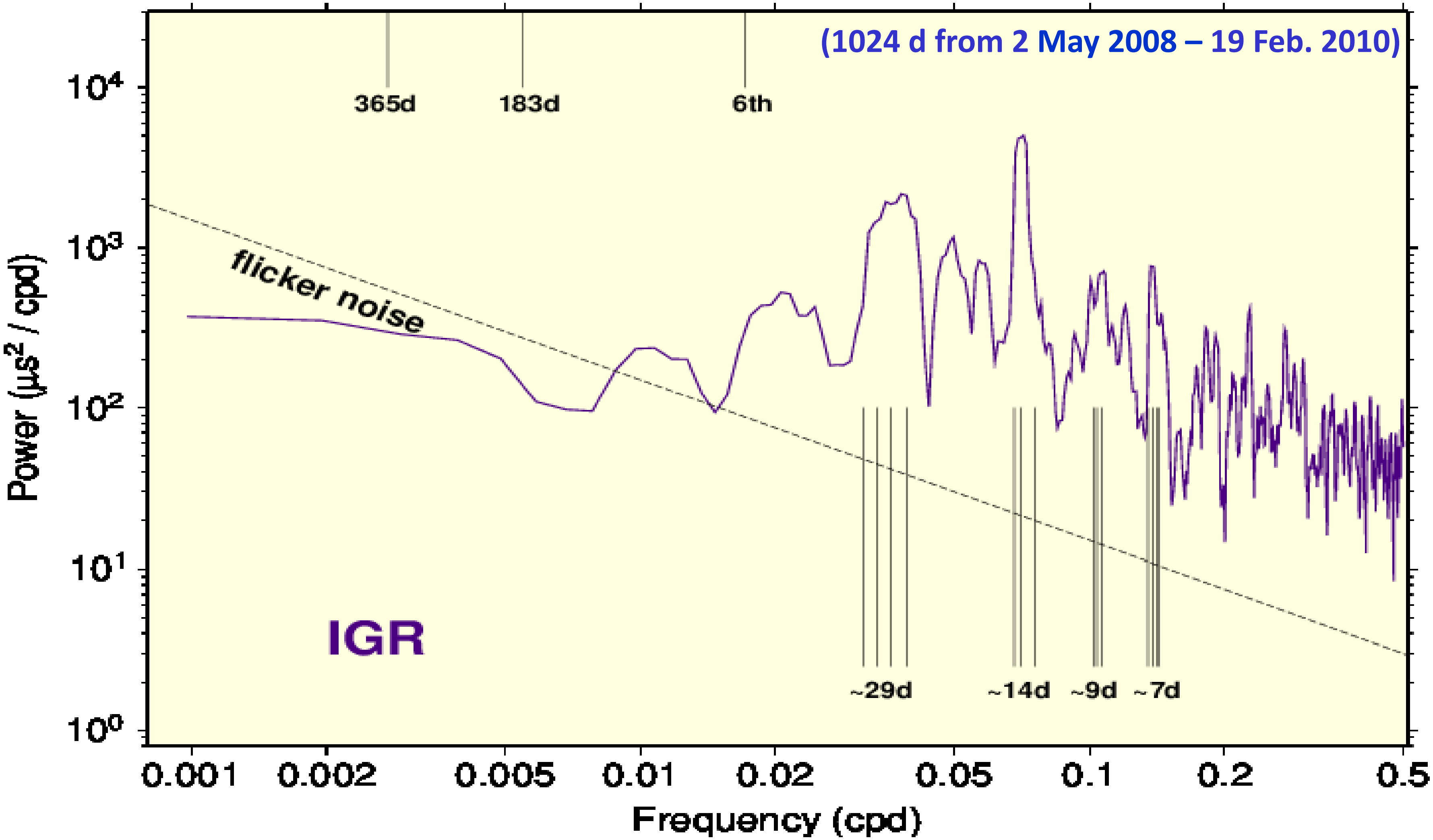

- **Strong harmonic modulations visible for all ACs**
  - **but amplitudes vary among ACs**

# Spectra of AC LOD Differences



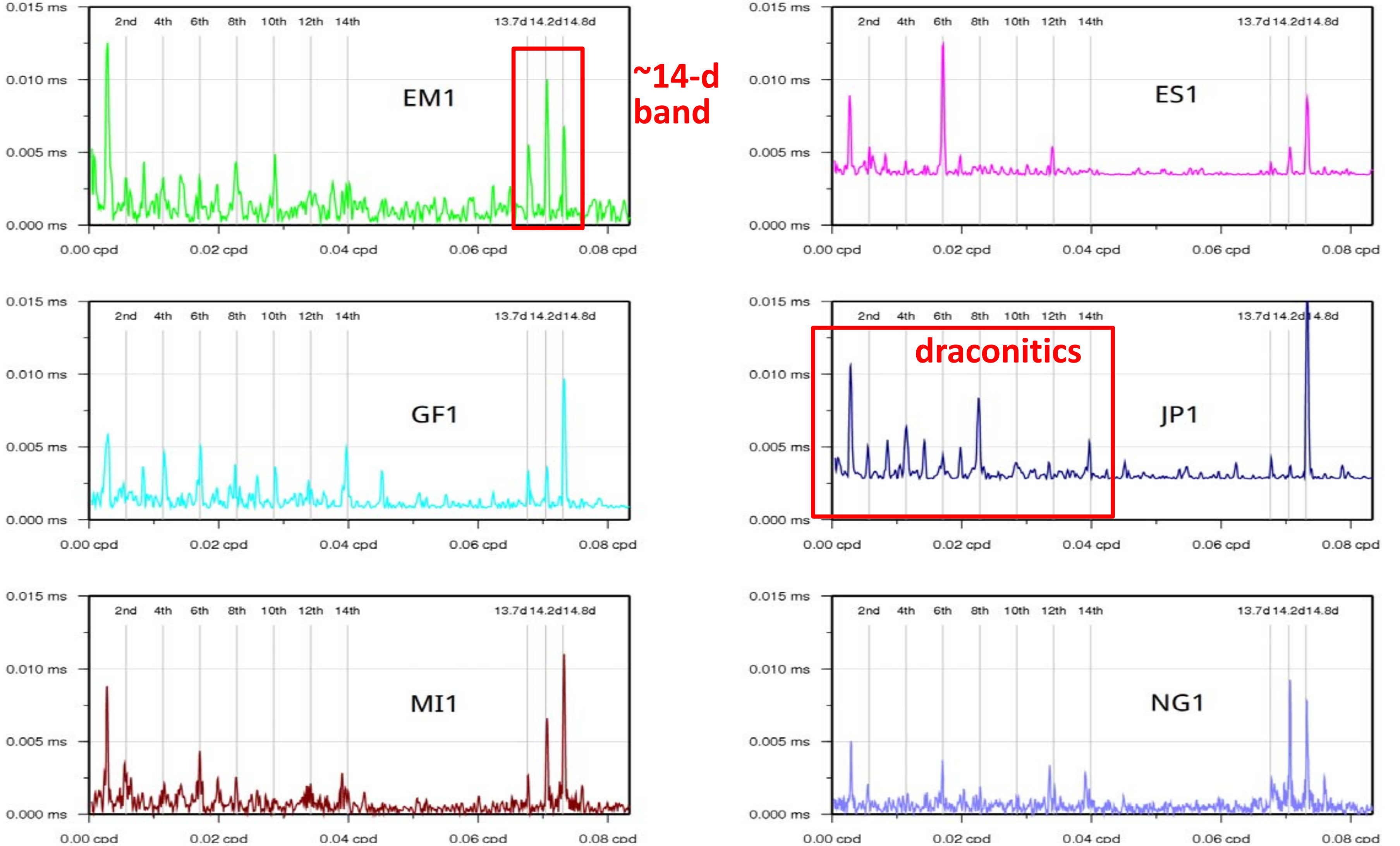

- **Aliased subdaily UT1 errors, semi-annual, & 6th GPS draconitic**

# Spectrum of IGS Rapid Combined LOD Differences




- IGS combination "calibrates" AC LOD biases by comparison with IERS Bulletin A over a 21-d sliding window
  - process seems effective at mitigating most LOD flicker & long-period noise

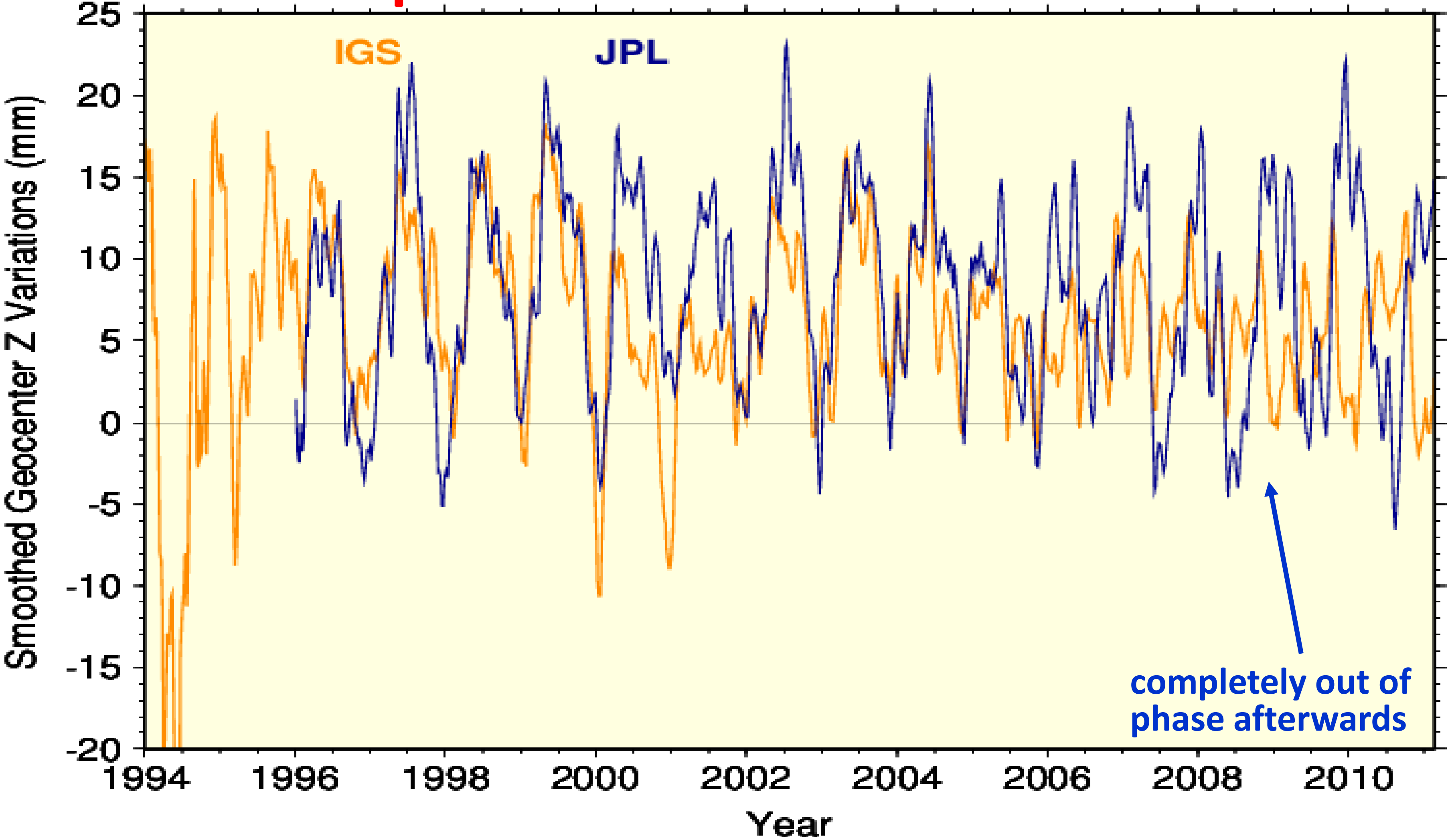
# Draconitics in AC Reprocessed LOD Differences




*(from P. Rebischung, 2011)*

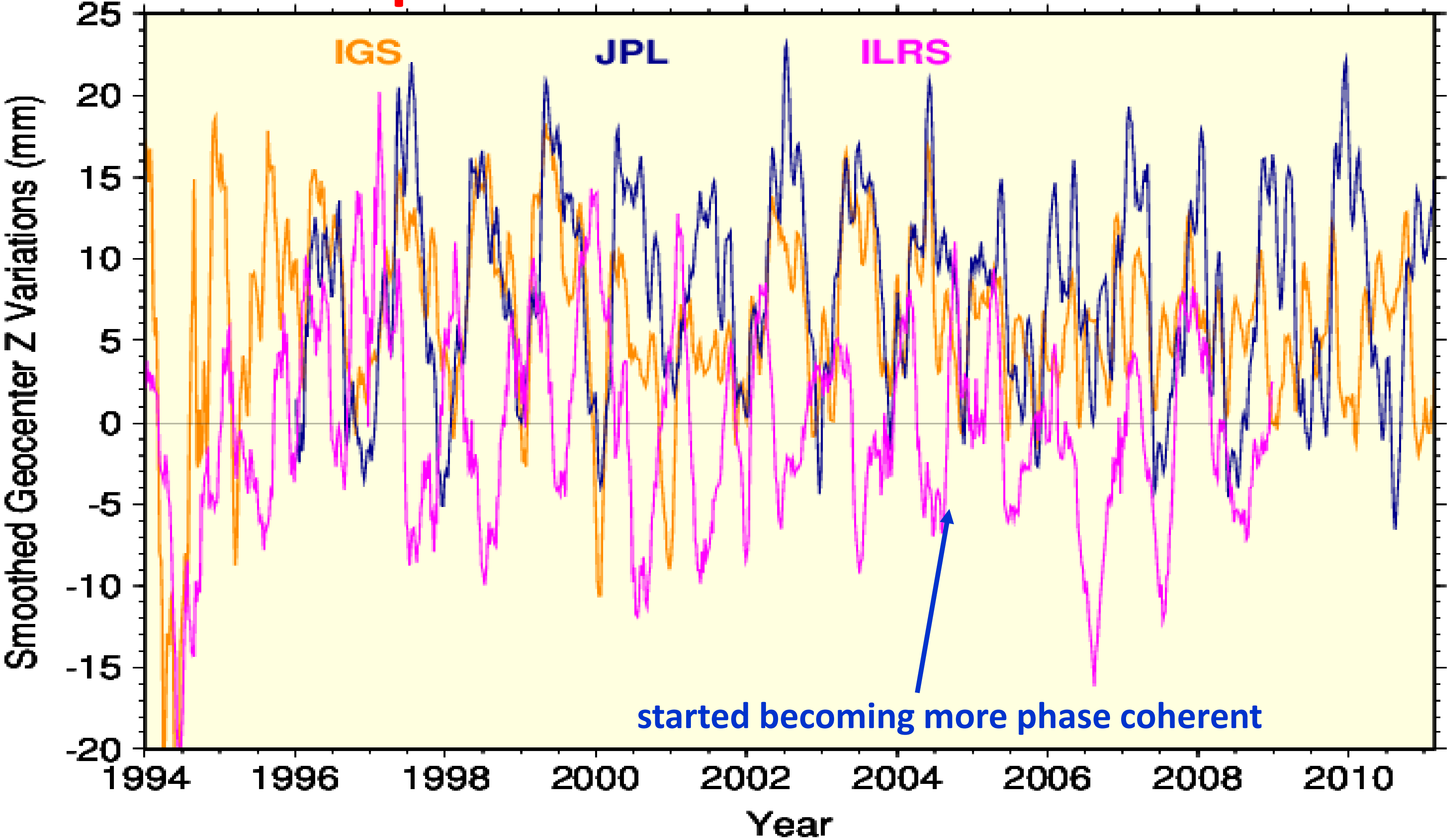
- **Amplitude spectra from reprocessed years 1994/1998 - 2007**
  - **level of draconitics highly variable among ACs (but over long spans)**

# Compare Geocenter Z Variations



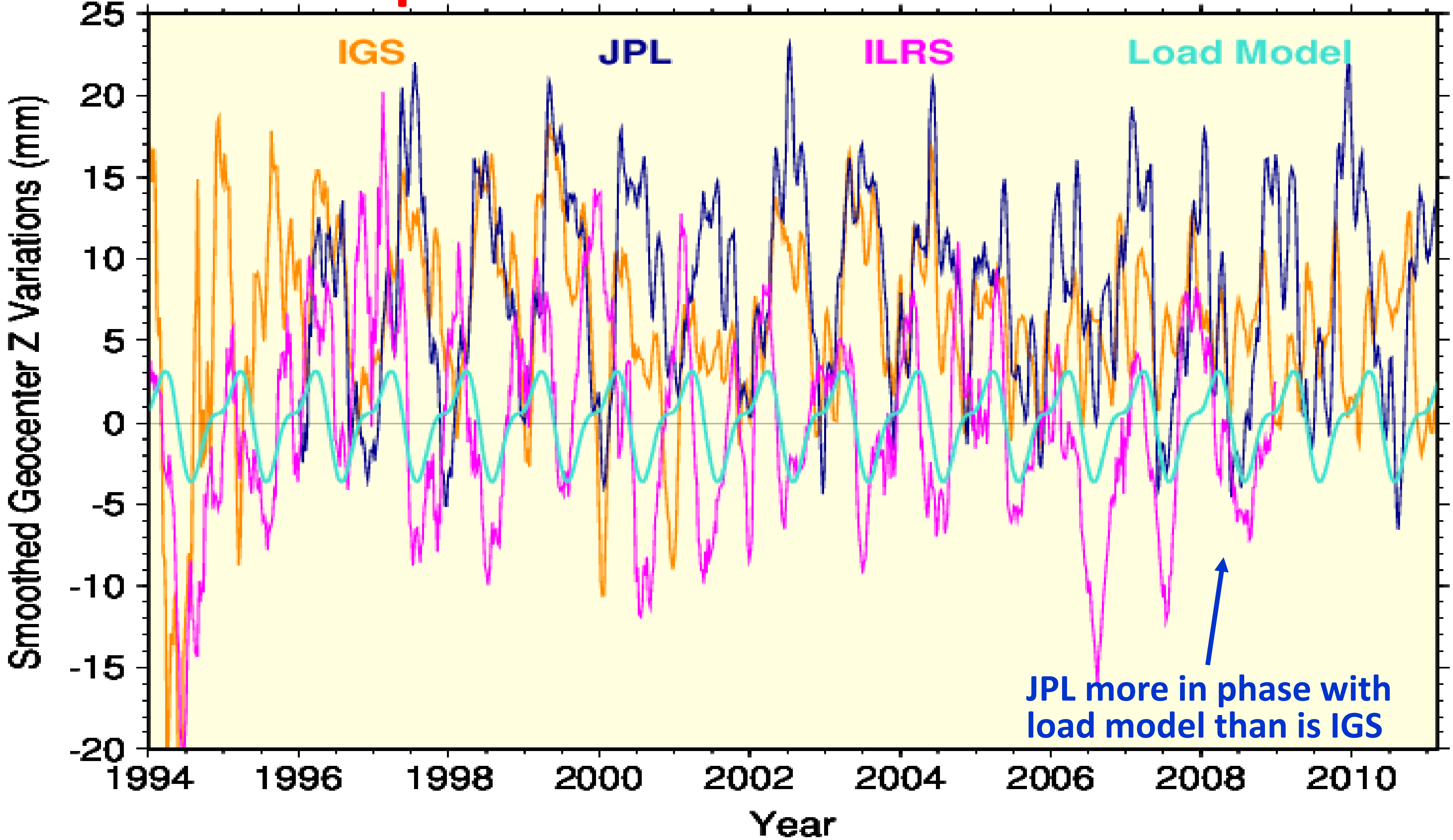

- **IGS & JPL results from reprocessing + operations since 2007**
  - **out of phase with each other since ~2008.5**

# Compare Geocenter Z Variations



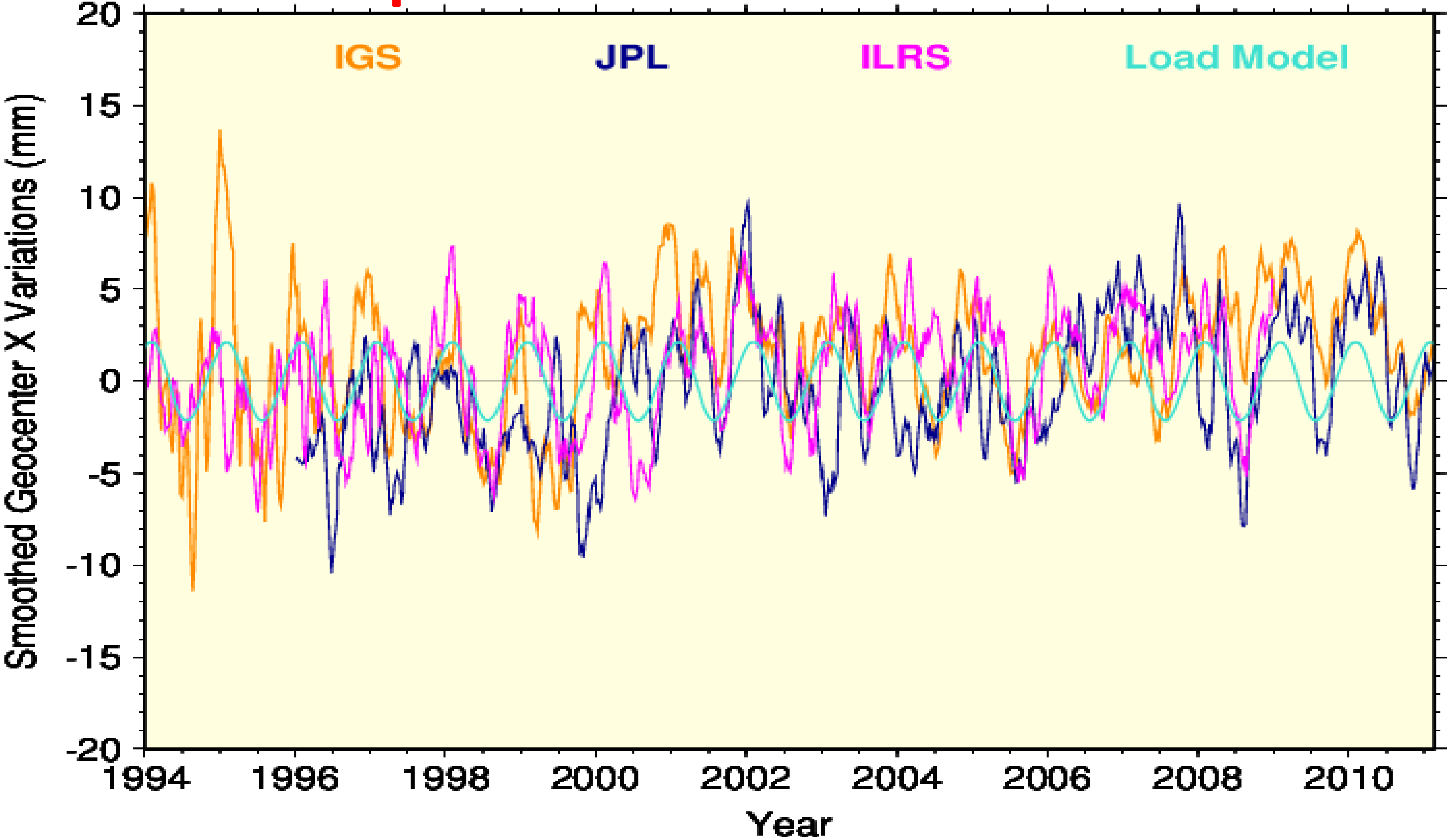

- **ILRS results (from ITRF2008) mostly out of phase with IGS/JPL before ~2004.5**
- **IGS/JPL both show persistent bias**

# Compare Geocenter Z Variations



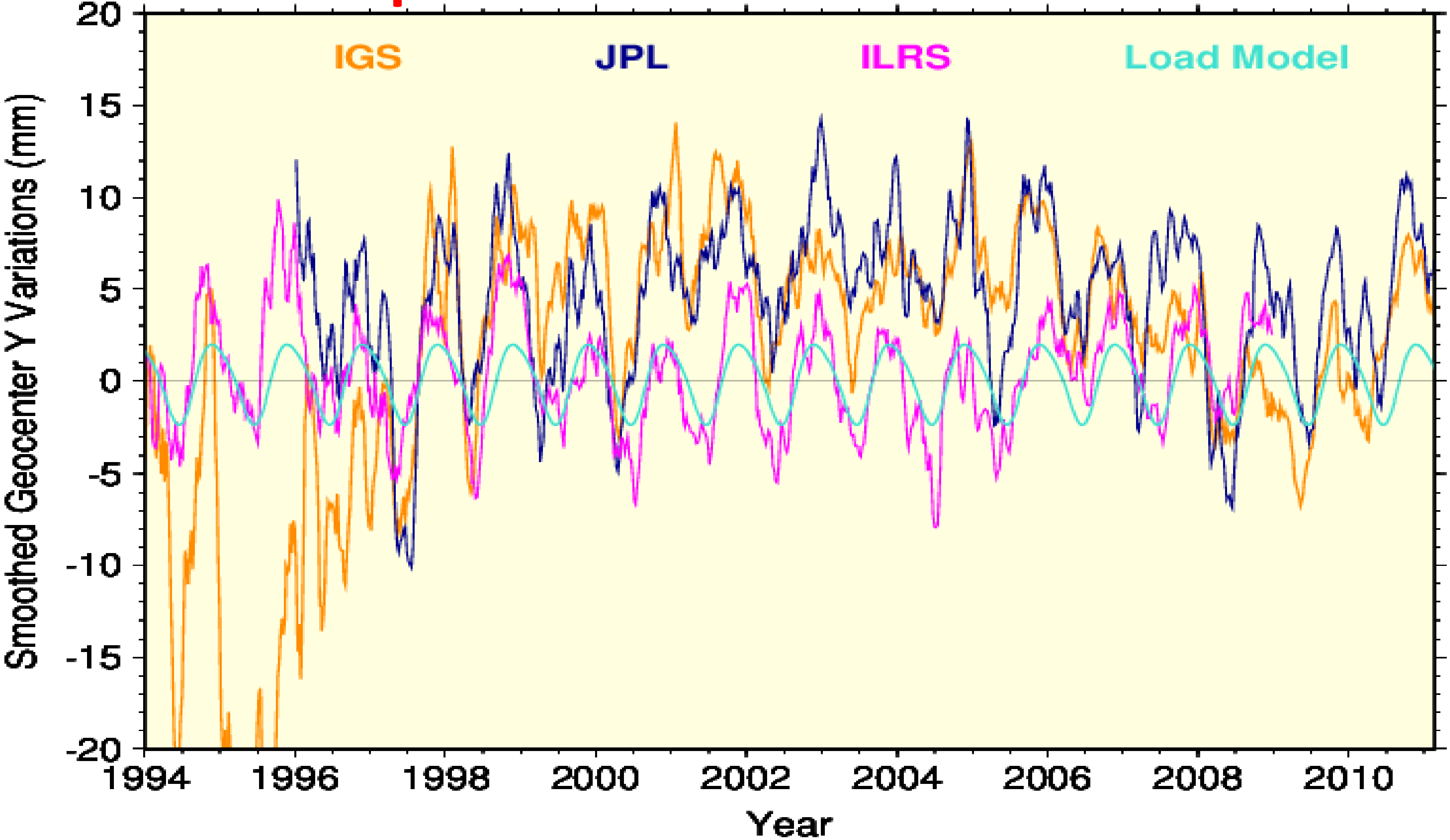

- **JPL Z geocenter more in phase with load model since ~2008**
  - **recent IGS results are completely out of phase**
  - **may suggest recent JPL orbit modeling is better but amps are large**

# Compare Geocenter X Variations




- IGS & JPL agreement generally similar for X geocenter
  - but IGS better at some times (e.g., 1999-2000 &2003-2004)
  - long-term GNSS X origin less stable than ILRS or load model

# Compare Geocenter Y Variations

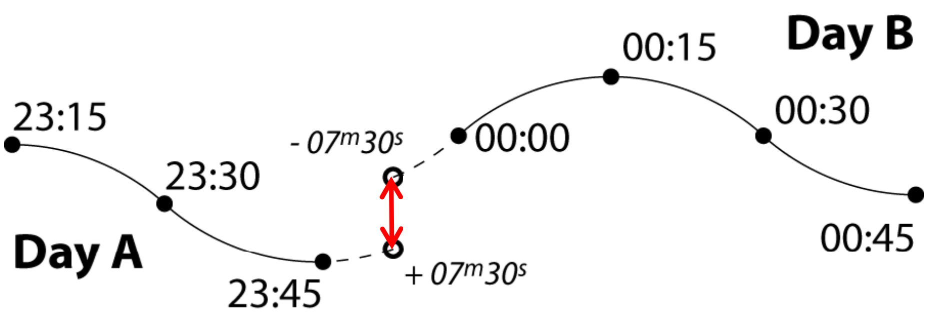



- IGS results strongly skewed before ~1998 for Y geocenter
  - both IGS & JPL poorly centered over most of span
  - probably mostly related to solar radiation pressure modeling

# Compute Orbit Discontinuities

- **Fit orbits for each day with BERNE (6+9) orbit model**
  - fit 96 SP3 orbit positions for each SV as pseudo-observations for Day A
  - parameterize fit as $X, Y, Z, \dot{X}, \dot{Y}, \dot{Z}$ plus 3 SRPs per SV component
  - propagate fit forward to 23:52:30 for Day A
  - repeat for Day B & propagate backwards to 23:52:30 of day before

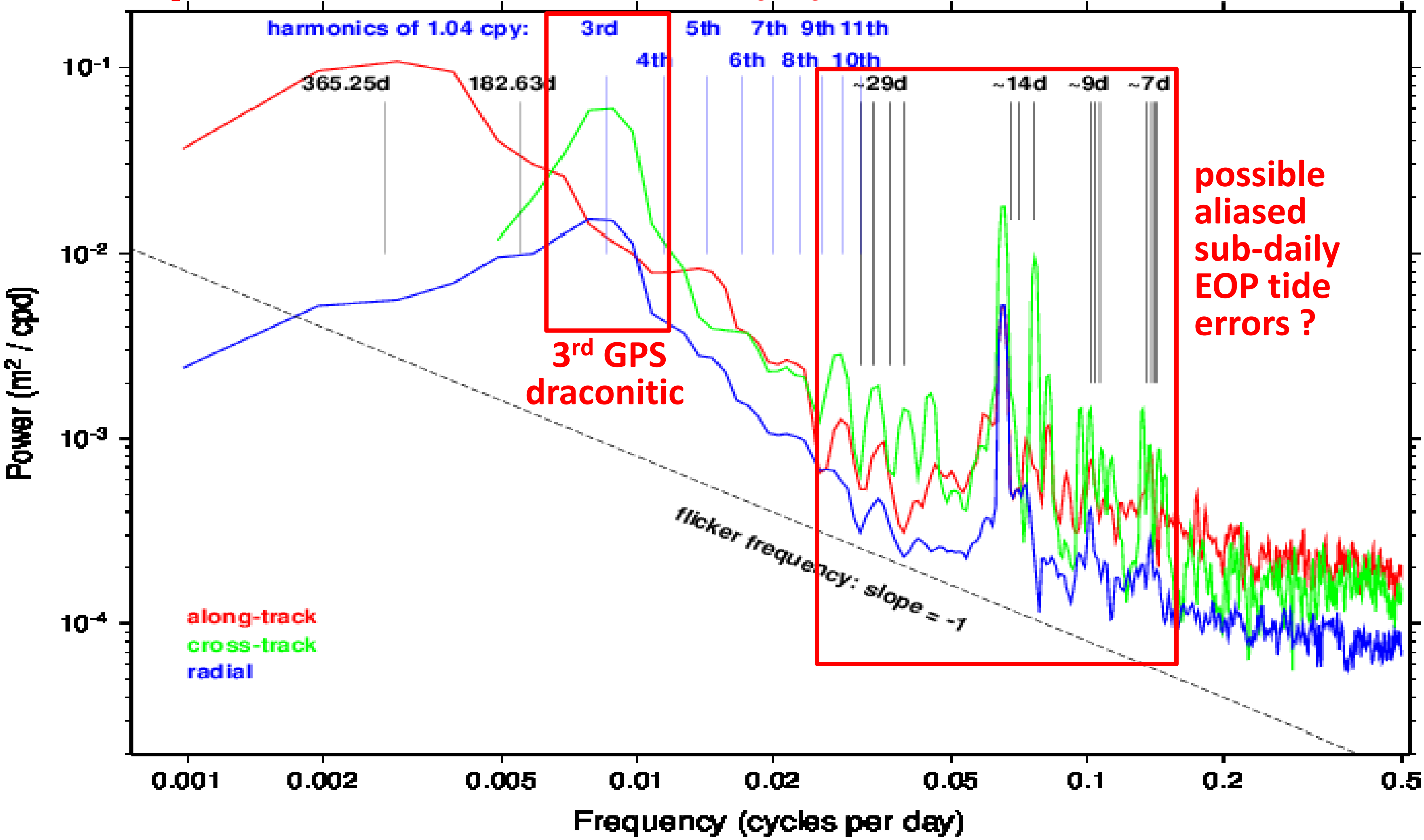
- **Compute A,C,R orbit differences at 23:52:30**




- **Use 2049 d from 23 May 2005 thru 31 Dec 2010**
  - spectra for all SVs stacked for each AC; data gaps linearly interpolated
  - sliding boxcar filter used to smooth across each 3 adjacent frequencies
  - previous procedures have been refined for improved results

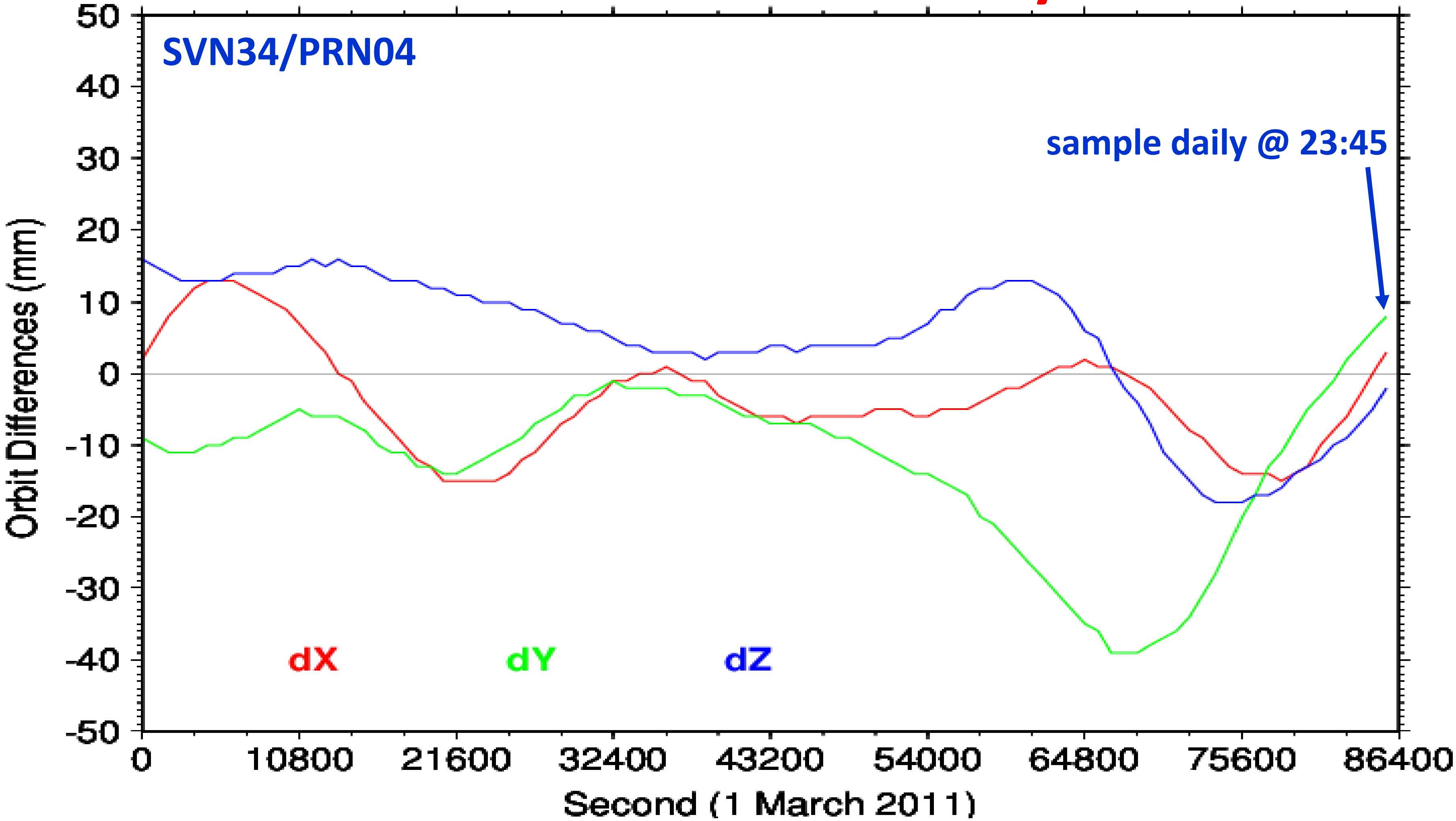
- **Power of fit/extrapolation error "calibrated" using similar test for observed values at 23:45**

# Spectra of IGS Orbit A,C,R Discontinuities



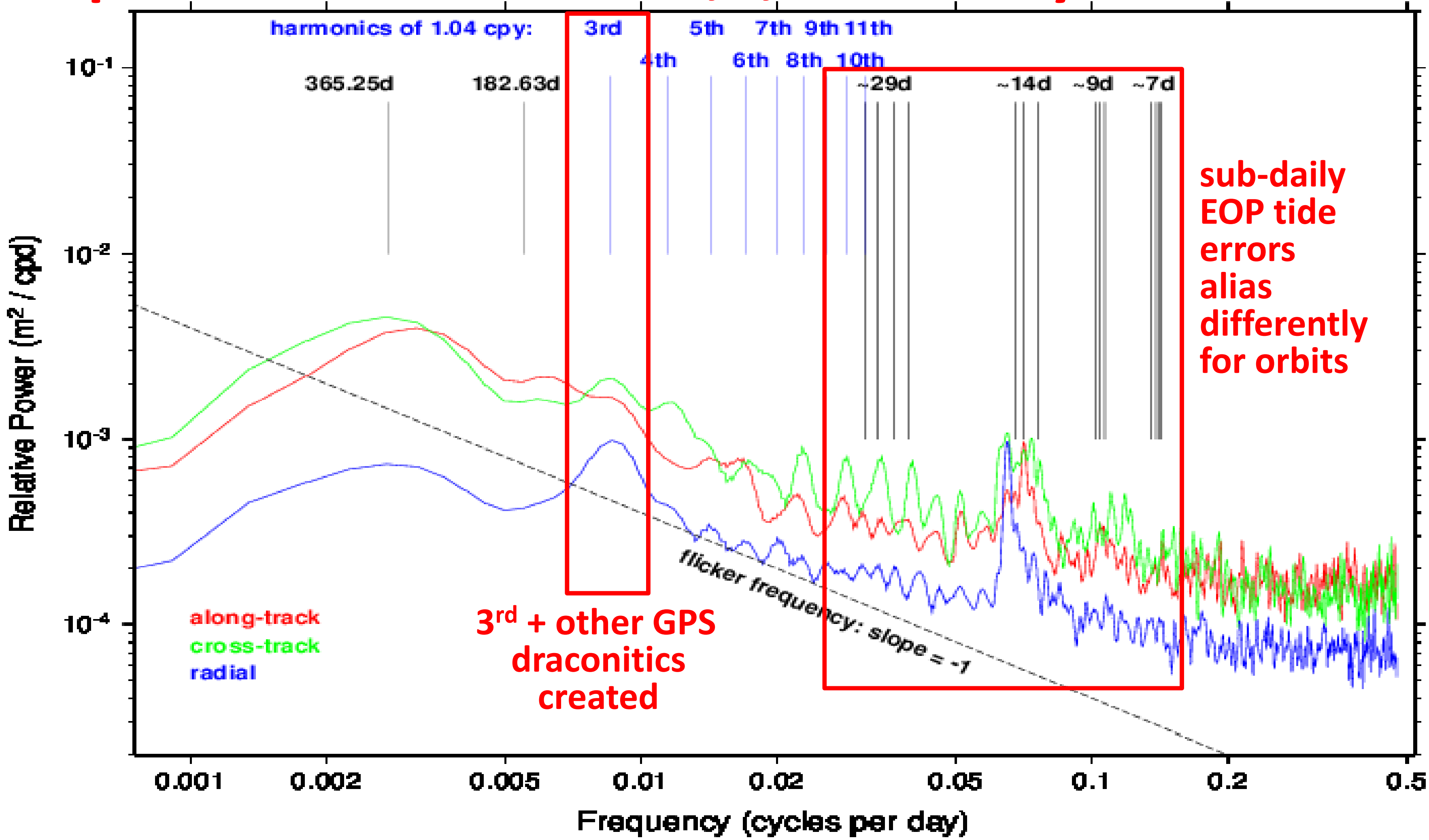

- Strong peaks near same subdaily EOP alias lines as LOD spectra
  - but frequencies do not exactly match aliases for 24-hr sampling
  - also effects differ for each A,C,R component
  - 3rd GPS harmonic important in cross-track & radial components

# Simulate Orbit Errors from Subdaily EOP Model



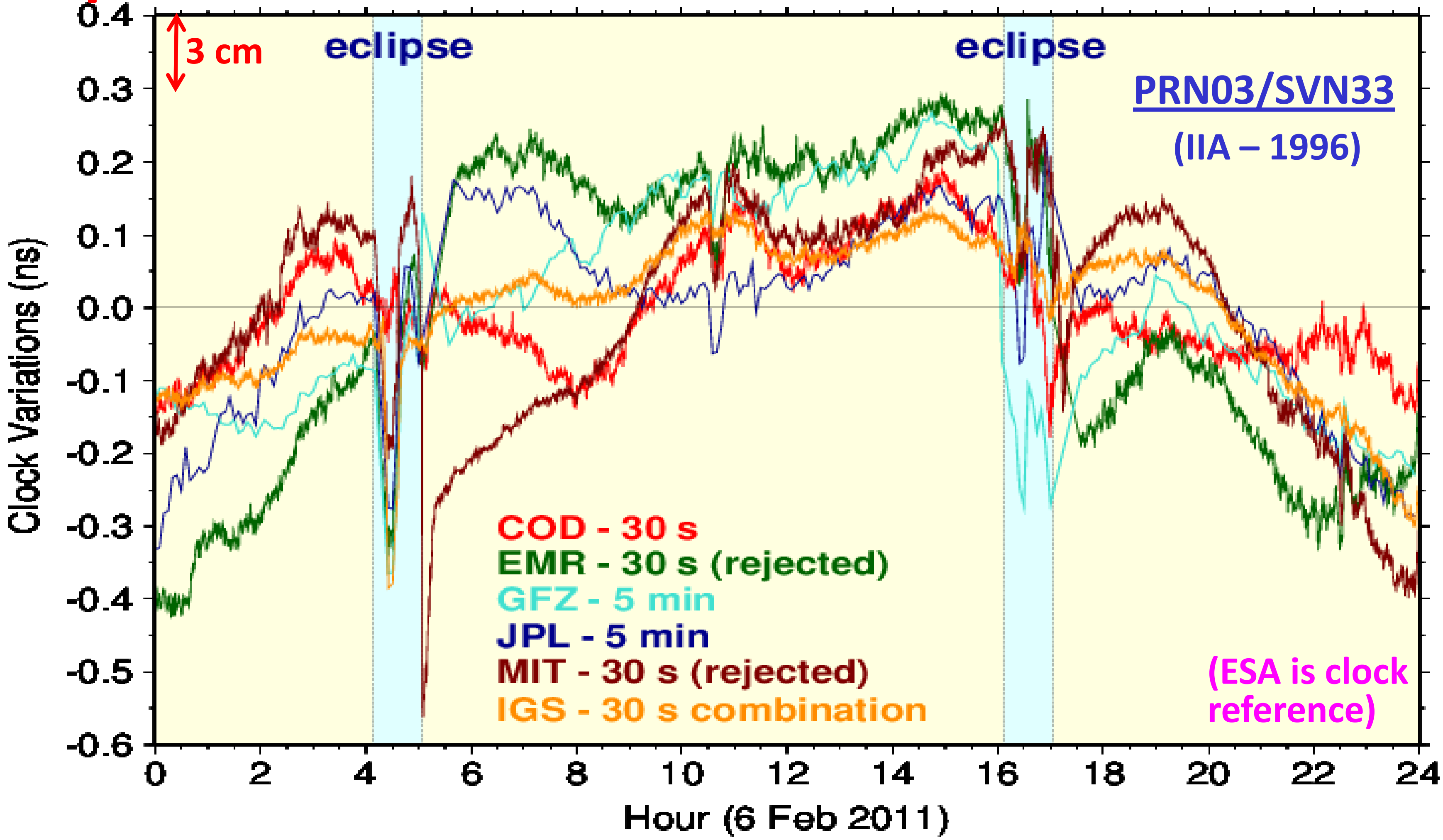

- Compare NGS orbits using IERS & test subdaily EOP model
  - for test EOP model, change tidal admittances by ~20%
  - sample daily differences at 23:45 & convert to A,C,R frame
  - subdaily periodic differences will alias to longer periods in spectra

# Spectra of Simulated A,C,R Subdaily EOP Errors




- Coupling of subdaily EOP errors into orbit parameters is complex
  - normal ~7, ~9, ~14, & ~29 d alias lines are split & frequency shifted
  - apparent draconitic features created, especially 3rd harmonic
  - large annual (K1 alias ?) signal but little semi-annual power

# Impact of AC Yaw-Attitude Models on GPS Clocks




- **Diverse AC models for yaw-attitude variations during eclipse cause large clock discrepancies for older Block IIA GPS satellites**
  - **some ACs get rejected from clock combination**
- **Must adopt a common yaw model for ACs & PPP users**

# Summary & Conclusions

- **Rotational variations are a leading IGS orbit error**
  - background spectrum shows flicker noise
  - probably is main source of flicker noise in station position time series
- **Larger variations in AC orbit frame rotations than polar motion**
  - cause is unclear but must be related to AC analysis methods
  - could be affected by *a priori* AC constraints
  - LODs show clear aliasing of subdaily EOP errors + $6^{th}$ draconitic + semi-annual
- **Orbit discontinuities at day-boundaries reveal error details**
  - subdaily EOP tide errors alias very strongly into orbit parameters, especially in cross-track
  - but alias frequencies shifted & split compared to 1d sampling
  - annual or K1 tide alias errors important in along-track
  - $3^{rd}$ & other draconitic harmonics created by subdaily EOP errors
- **Adoption of common model for yaw variations is mandatory**
  - otherwise combined SV clocks during eclipse are degraded