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A Kalman filter approach for the determination of celestial reference frames

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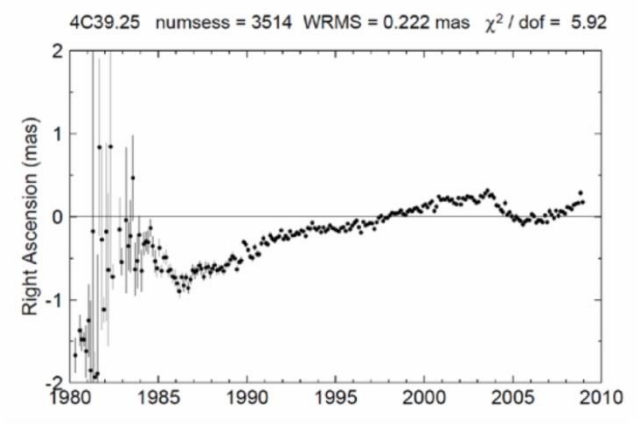
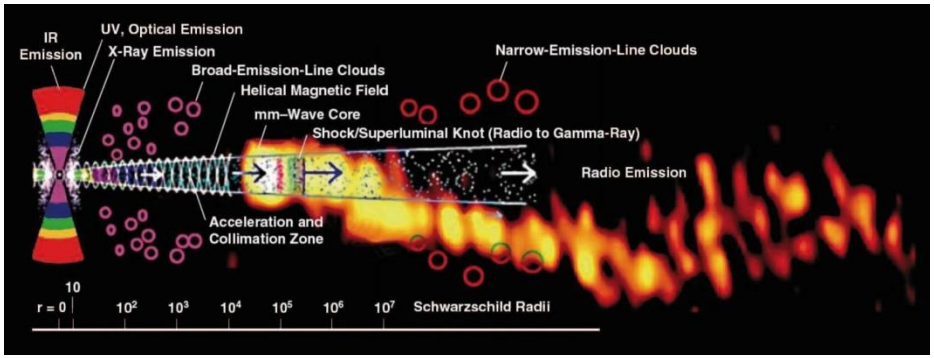
Background

- Extragalactic radio sources exhibit time variability, for example due to (changes in) source structure
- Source structure effects are commonly not accounted for
  → leads to a degradation of the quality of the frame
  - Problem: no correction models exist
  - Example: ICRF2 with a constant coordinate model



[Ma et al., 2009]



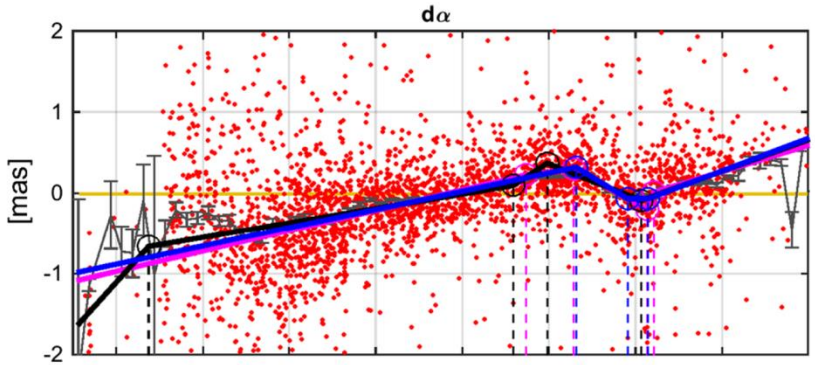
[Marscher, 2006 / Kirchbaum et al., 1999 / Wehrle et al., 2010]

Approaches for considering time variability

- Extension of the coordinate model (Karbon et al., 2016)
  - Source coordinates modeled by linear splines (MARS algorithm)

  → allows for more sources to stabilize the datum

  → improved estimates of nutation by 10%



[Karbon et al., 2016]

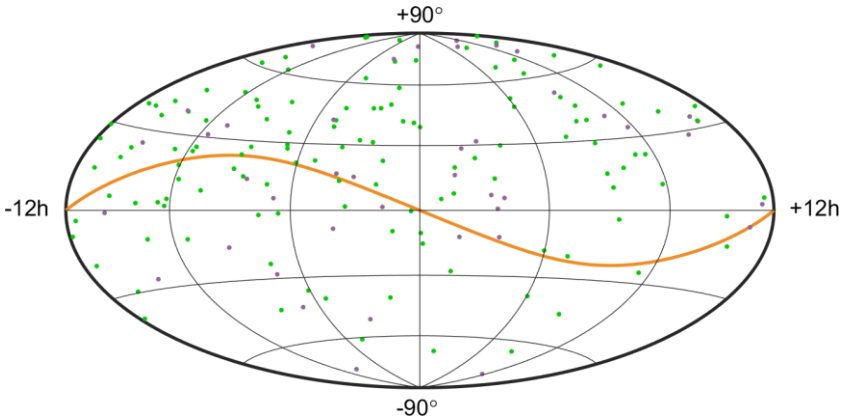
- Time series representation (this talk – using Kalman filtering)
  - Temporal resolution as high as input data
  - Stochastic approach to reflect physical nature
  - Higher computational demands

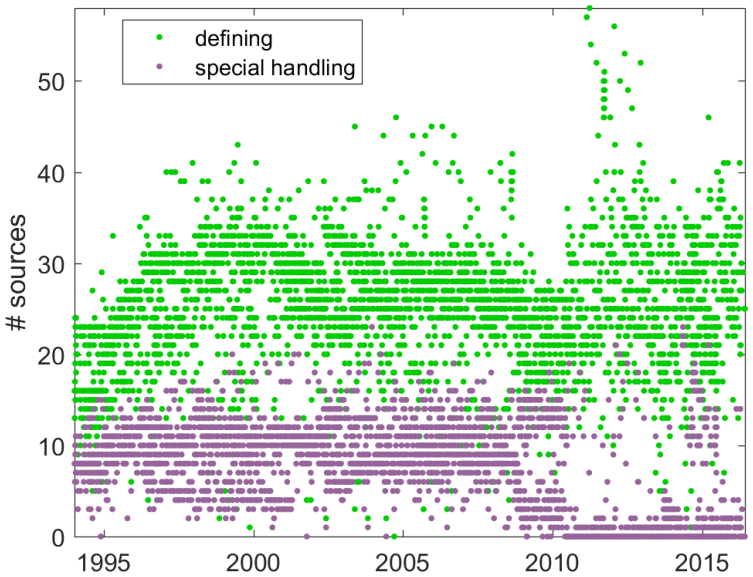
Additional motivation

- JPL is an IERS ITRS combination center (JTRF2014)
- Future goal: joint TRF/EOP/CRF determination
  → eliminate current inconsistencies to improve quality
  - Framework: NASA Postdoctoral Program fellowship
- JPL uses Kalman filtering for their TRF and EOP products
  → CRF also needs to be determined this way
- Discussion of Kalman filtering for TRF creation:
  - Poster by Soja et al. in session G2.2

VLBI data

- Limited data set selected for preliminary tests and investigations
- Time span: 1994 – 2016.5
  - Significant improvement of data quality in early 1990s
- 3119 IVS VLBI sessions
  - No regional sessions
- 166 radio sources
  - 127 defining (out of 295)
  - all 39 special handling





Single-session analysis

- Analysis with least-squares module of VieVS@GFZ
- Correction models according to IERS Conventions 2010
- Estimated parameters
  - Radio sources (NNR constraints w.r.t. ICRF2)
  - 5 EOPs
  - Station coordinates (NNT+NNR constraints w.r.t. ITRF2014)
  - Auxiliary parameters (clocks & troposphere)

Radio source coordinates and their covariances serve as input to the Kalman filter CRF

Kalman filter setup

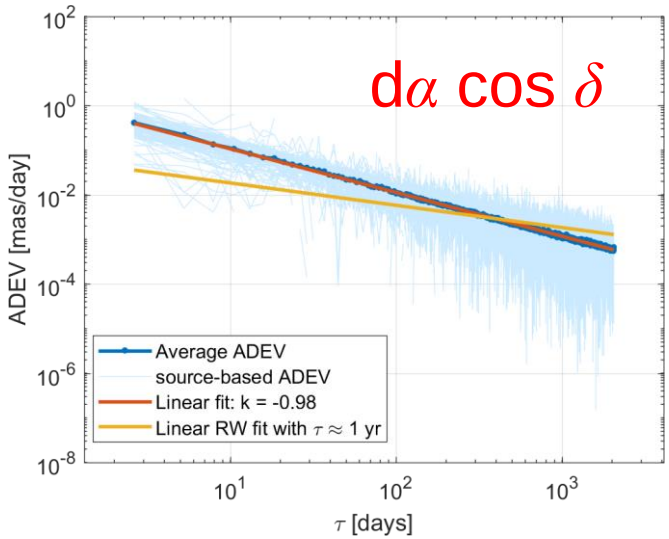
- Kalman filter & smoother
- State updated for every VLBI session (usually every 1-4 d)
- Source coordinates assumed to behave like random walk
- Output: filtered and smoothed α & δ time series

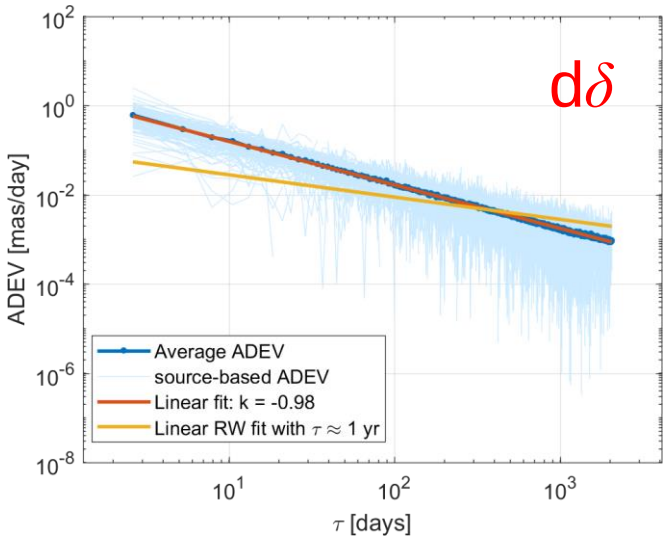
Prediction	Correction
$\tilde{x}_k = F_k x_{k-1} + w_k$	$x_k = \tilde{x}_k + K_k(z_k - H_k \tilde{x}_k)$
$\tilde{P}_k = F_k P_{k-1} {F_k}^T + Q_k$	$P_k = (I - K_k H_k)\tilde{P}_k$

$$K_k = \tilde{P}_k {H_k}^T (H_k \tilde{P}_k {H_k}^T + R_k)^{-1}$$

Process noise of radio source coordinates

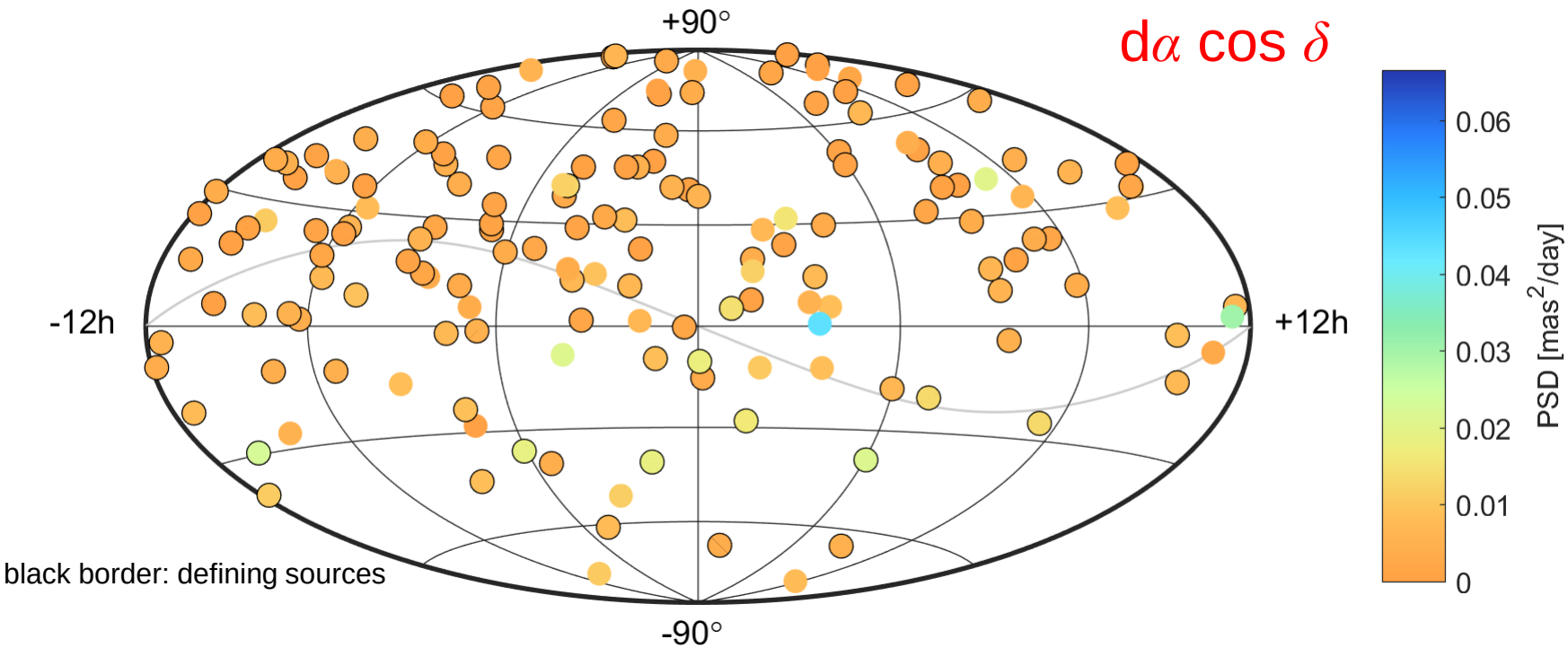
- Lack of external data to derive noise model
- Allan standard deviation (ADEV) computed from single-session coordinate time series of the 166 radio sources
- ADEV shows that coordinate variations behave like *white noise*
- Source-based noise parameters (PSDs) estimated assuming *random walk* to agree with ADEV at period of about 1 year





Source-based process noise sky map

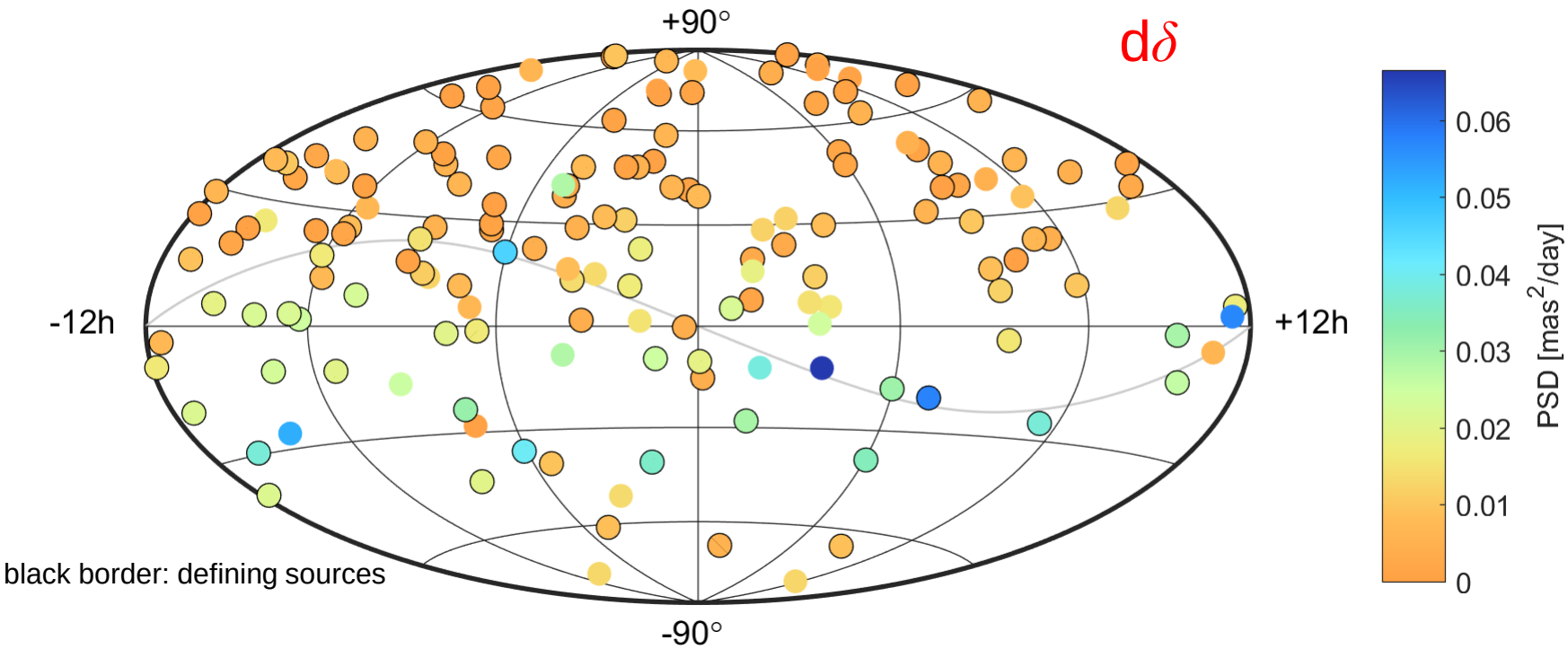
- Average PSD: 0.0034 mas^2/day
- Defining sources: 0.0024 mas^2/day
- Special handling: 0.0056 mas^2/day



black border: defining sources

Source-based process noise sky map

- Average PSD: 0.0079 mas^2/day
- Defining sources: 0.0064 mas^2/day
- Special handling: 0.0109 mas^2/day



black border: defining sources

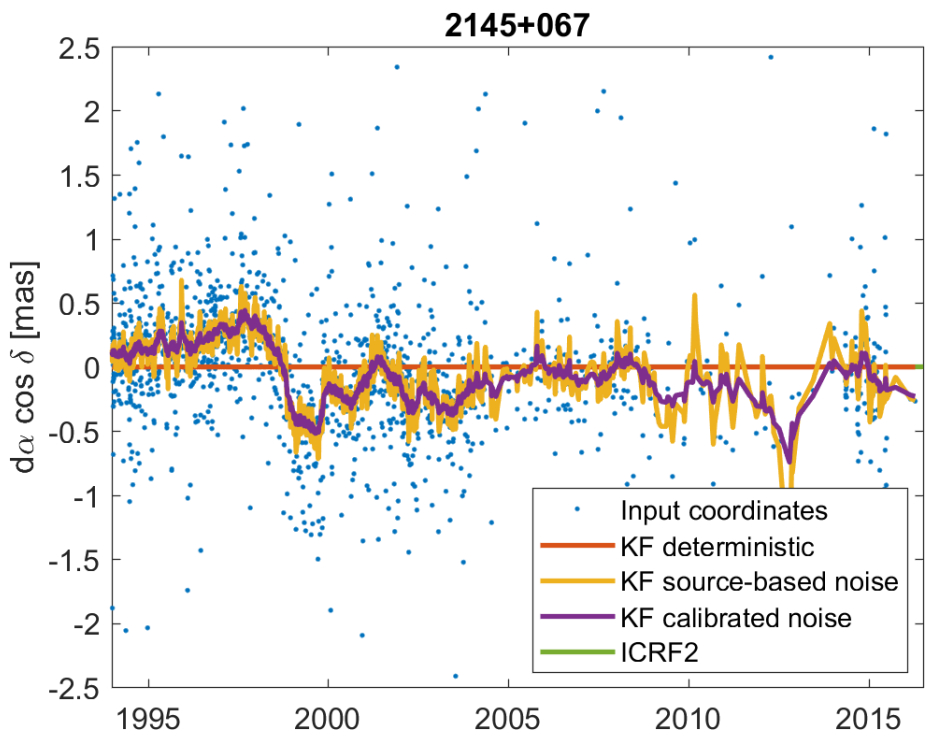
Kalman filter CRF solutions

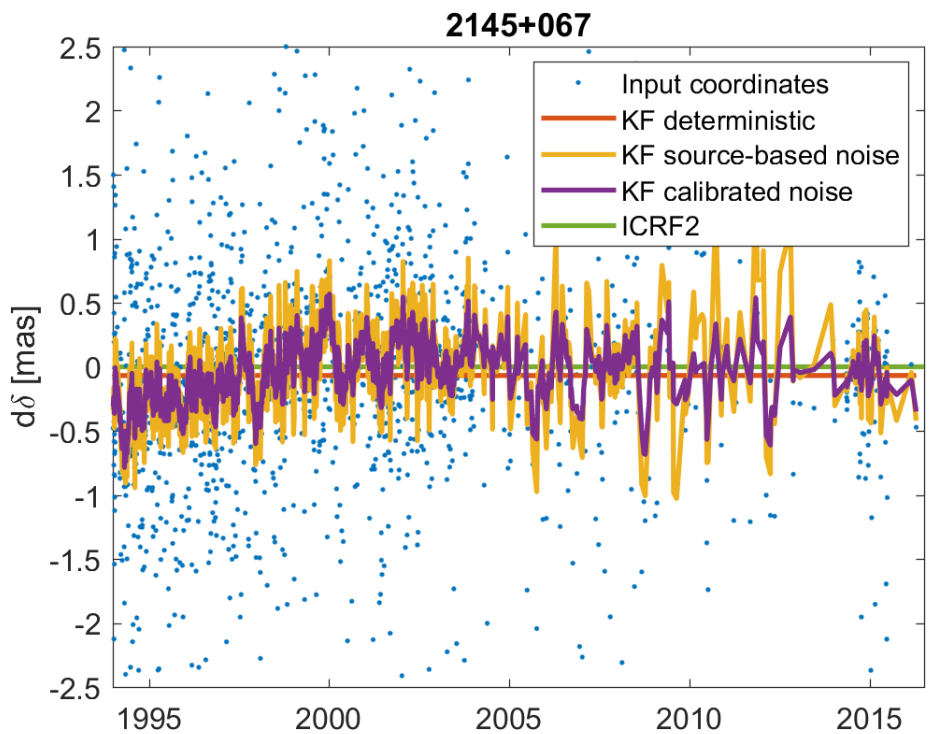
1. All sources deterministic (similar to ICRF2)
2. All sources with source-based noise (see previous slides)
3. Defining sources deterministic, special handling sources with calibrated source-based noise

Average PSD of defining sources subtracted

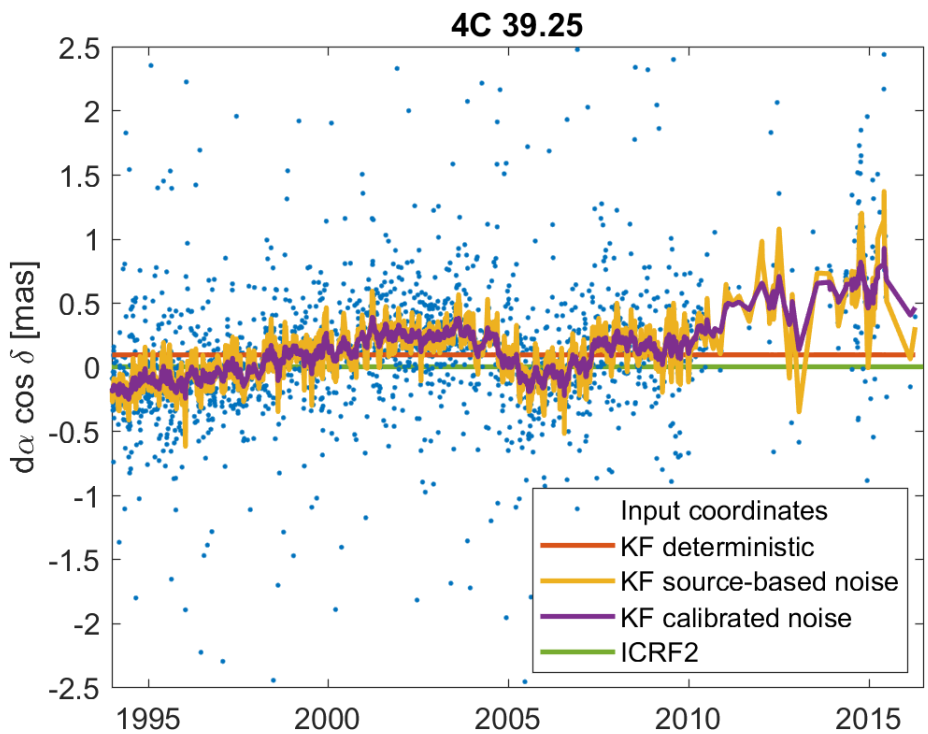
Reference solution: ICRF2

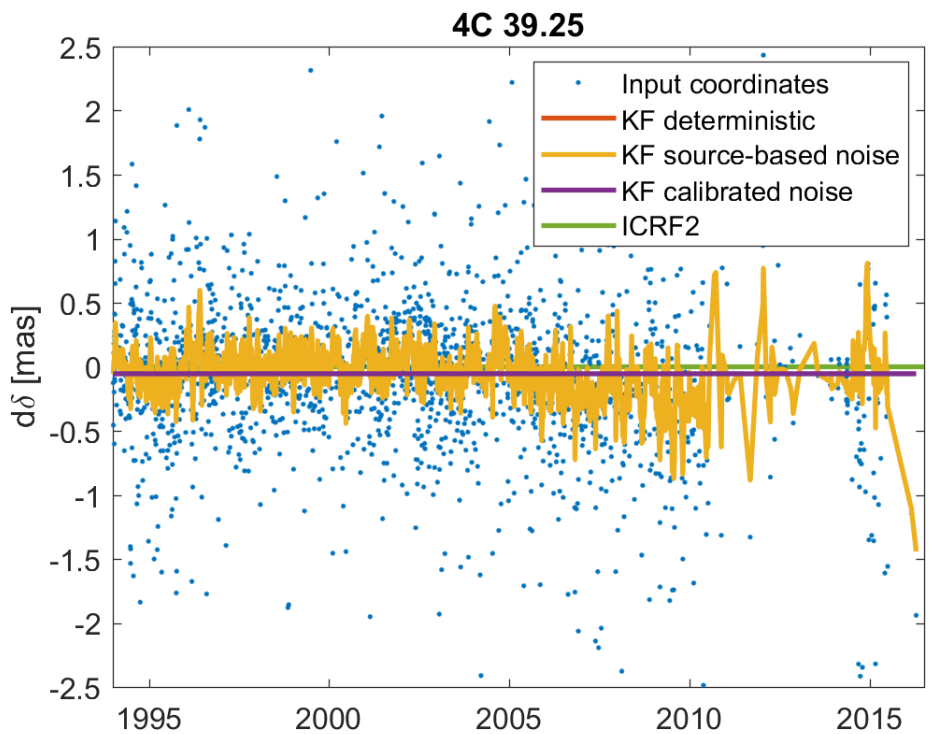
Kalman filter CRF examples



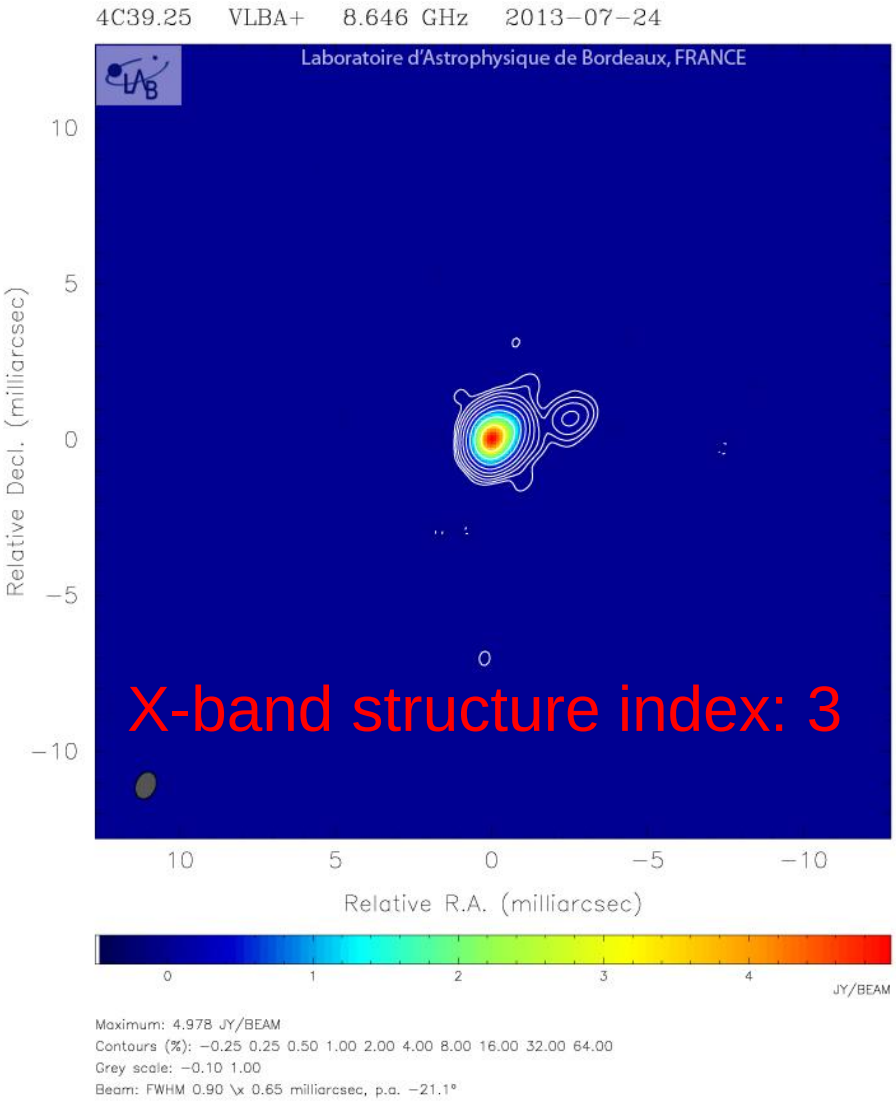


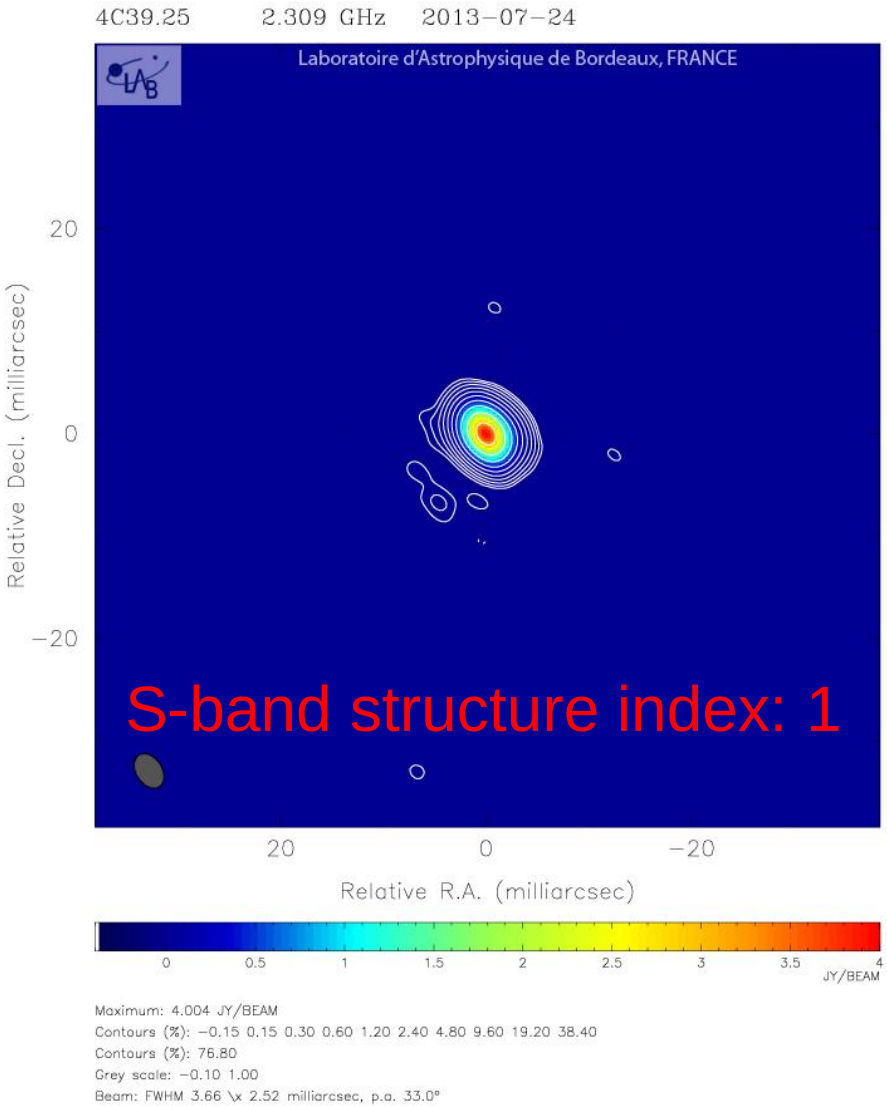
Kalman filter CRF examples





Comparison to radio source images





Conclusions

- First demonstration of a **Kalman filter CRF**
  - Time series approach to take into account **temporal variability**
- **Source-based noise model** from rigorous statistical analysis
  - **Calibration** of noise model using defining sources
- Case study 4C 39.25: agreement with **radio source images**

- **Outlook:**
  - **Extension of input data**, in particular number of radio sources
  - Explore other approaches for determining the **noise model**
  - Develop strategies for **evaluation** of Kalman filter CRFs and the underlying process noise models
  - Compute **joint TRF and CRF** solutions using Kalman filtering

Thanks for your attention!

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VLBI data: IVS (Nothnagel et al., 2015)
ICRF2: IVS / IERS / IAU
Radio source images: Bordeaux VLBI Image Database

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References

- Krichbaum et al., IRAM, 1999.
- Ma et al., 2009: IERS Technical Note, No. 35, Verlag des Bundesamts für Kartographie und Geodäsie, Frankfurt a.M.
- Alan Marscher, 2006: Relativistic Jets in Active Galactic Nuclei and their relationship to the Central Engine, Proc. of Science, VI Microquasar Workshop: Microquasars & Beyond, Societa del Casino, Como, Italy, 18-22 Sep 2006.
- Nothnagel et al., 2015: The IVS data input to ITRF2014. International VLBI Service for Geodesy and Astrometry, GFZ Data Services. doi: 10.5880/GFZ.1.1.2015.002
- Karbon et al., 2016: The extension of the parametrization of the radio source coordinates in geodetic VLBI and its impact on the time series analysis, Journal of Geodesy. doi:10.1007/s00190-016-0954-1
- Wehrle et al., ASTRO-2010, no.310.