Astronomy and Earth's Rotation with **GEODESIE**

Sébastien Lambert

SYRTE, Observatoire de Paris, PSL Research University, CNRS, Sorbonne Universités, UPMC Univ. Paris 06, LNE

PROJET FINANCÉ PAR L'ANR - PROJECT FUNDED BY THE ANR

What Science can we make with Astrogeodetic Techniques?

- Answer is *plenty*
- Some examples within our skills and fields:
  - Geosciences
    - Link polar motion/LOD to climate
    - Describe Earth's interior w/ nutation and deformations
  - Astronomy
    - Understand physics of AGN
    - Measure Solar system acceleration, test GR/SME

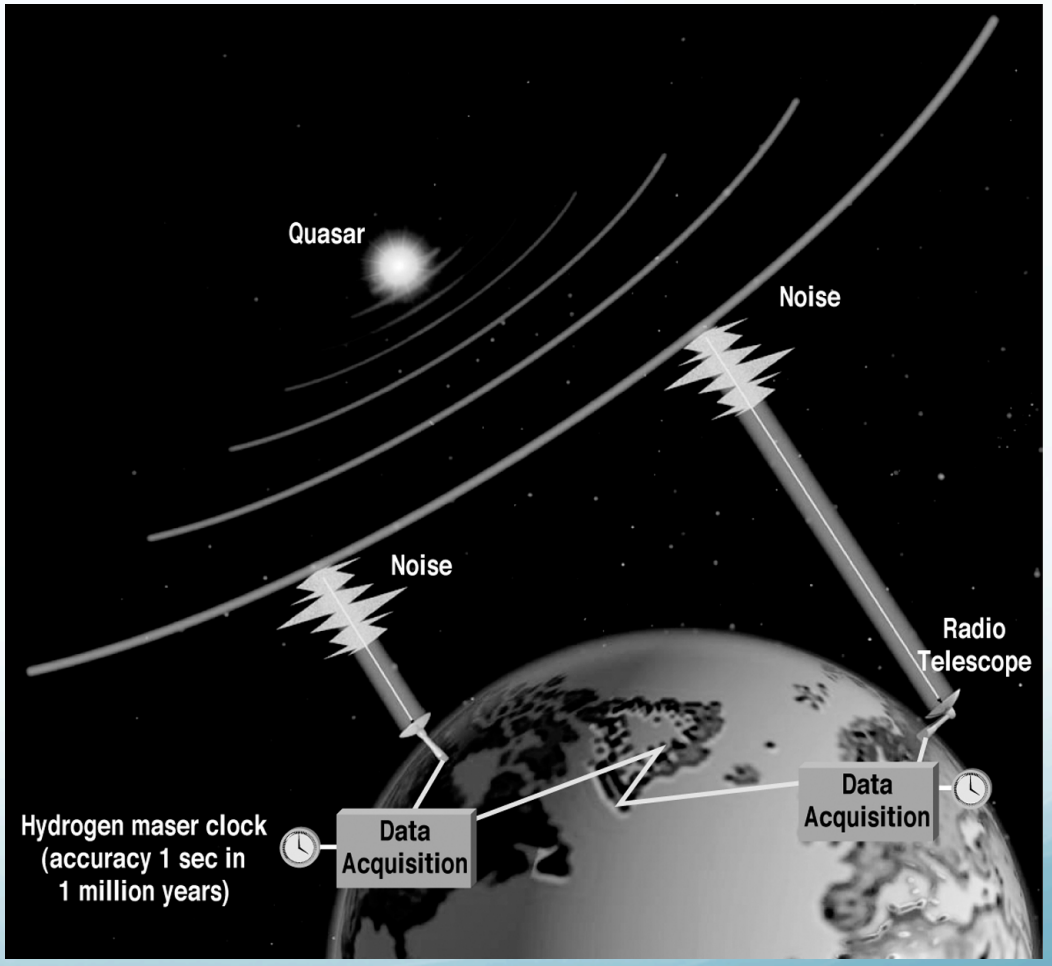
What I Propose Today

- Give GEODESIE some possible directions in link with Earth's rotation, reference frames, and one fundamental technique
- Outline
  - VLBI
  - Celestial Frame Issues
  - Earth Rotation Issues
  - Conclusions

VLBI

VLBI

- Initiated in the 1960s to resolve submas-structure of newly discovered *quasars* (Kellermann and Moran 2001, Clark 2003, Matveenko 2007)
- Sensitive to
  - Radio source position
  - Radio source morphology
  - Earth orientation
  - Earth deformation
  - Atmosphere content
  - Light deflexion



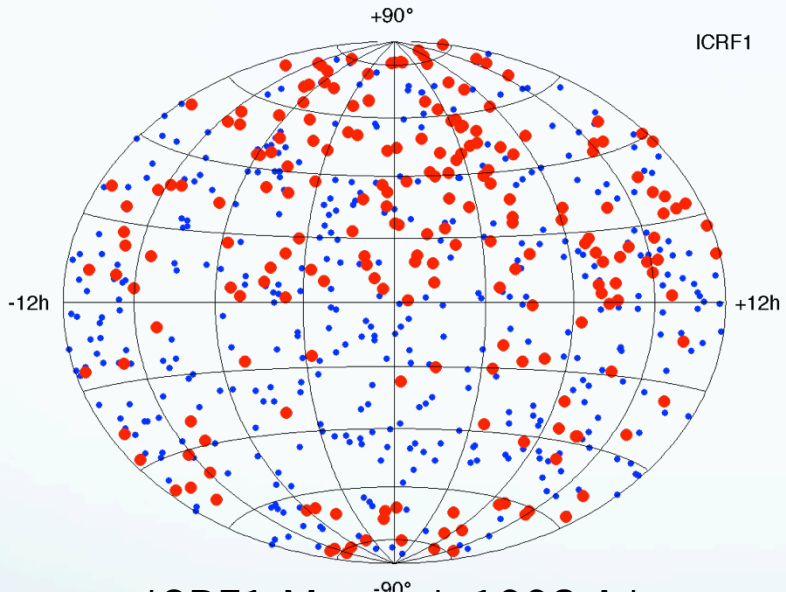
VLBI

- *Geodetic* mode allows measurements of
  - Telescope positions and velocities
  - **Radio source coordinates**
  - Telescopes-to-radiosources transformation: Earth orientation parameters
    - Pole coordinates wrt crust (polar motion and rates)
    - **Earth rotation angle (UT1)**
    - **Pole coordinates wrt space (nutation)**
- Accuracy < 1 cm
- VGOS deployment + Tahiti

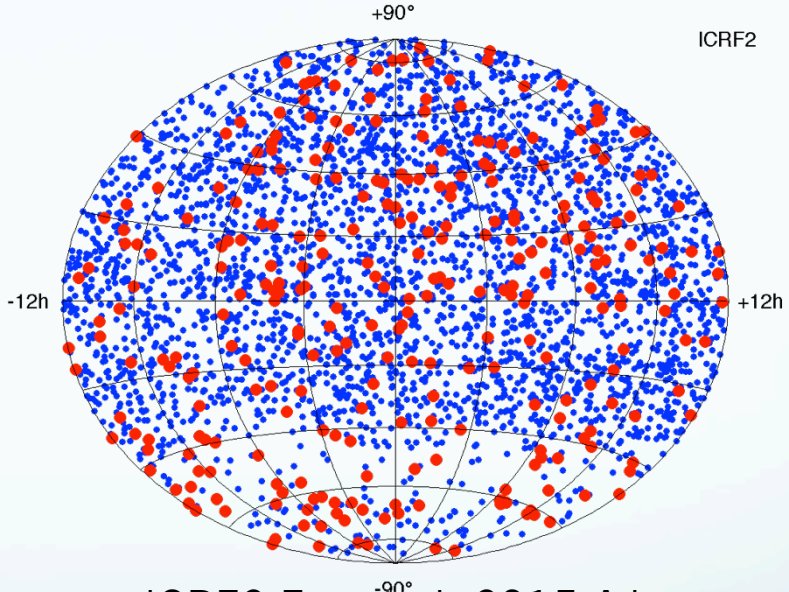
Celestial Frame Issues

Celestial Frame Issues

Network radio sources: ~600 in the 1990s to 4000+ now



ICRF1 Ma et al. 1998 AJ



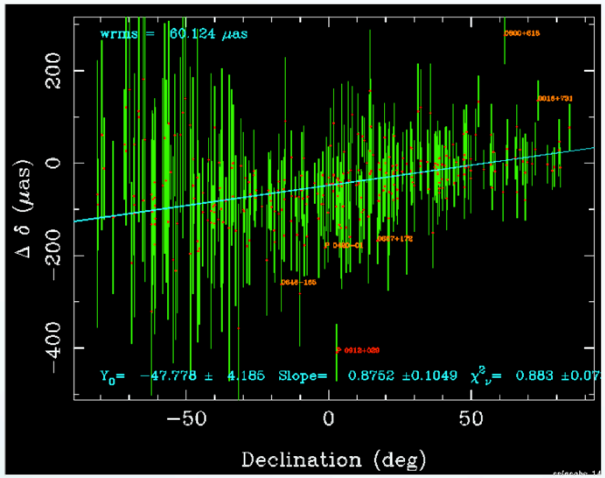
ICRF2 Fey et al. 2015 AJ

Stability ~ 0.02 mas
Accuracy ~ 0.04 mas

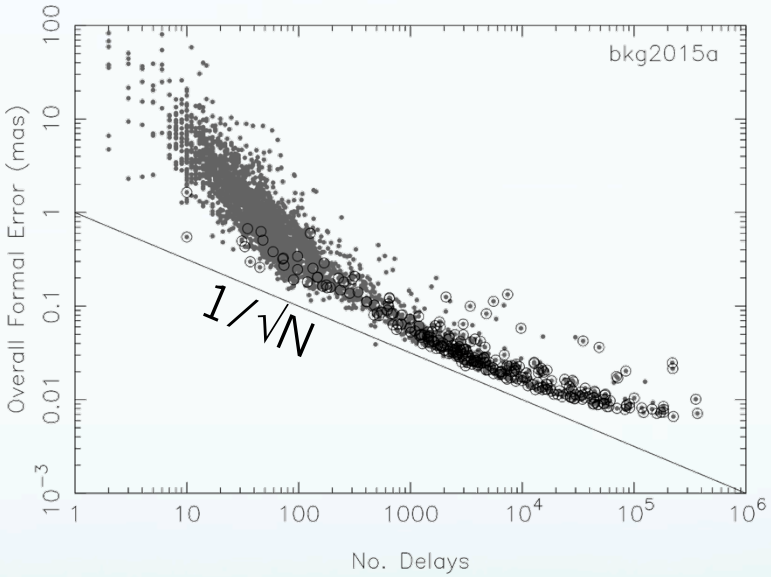
Recent issue: Gaia DR1 (sept. 2017)
Ongoing: ICRF3 (2018)

Celestial Frame Issues

Network radiosources: errors



Difference of new catalogs to ICRF2 Jacobs et al. 2015: evidence of **zonal errors**

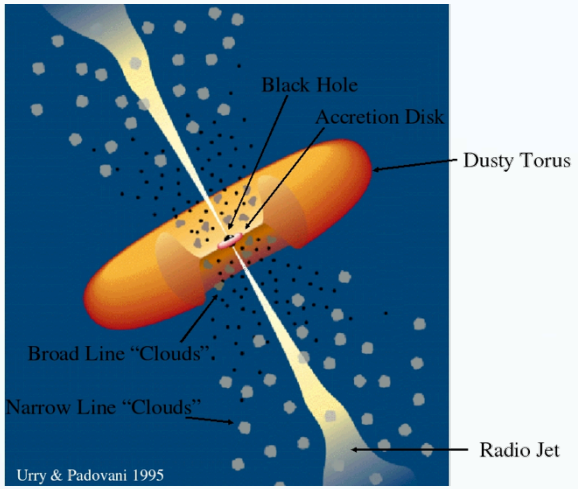


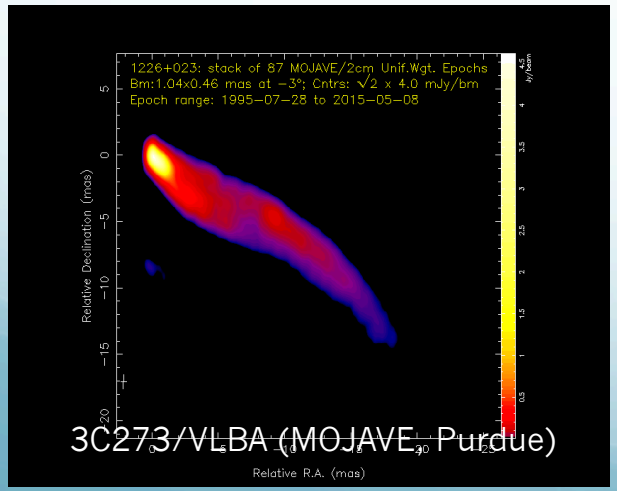
Signature of **non-Gaussian correlated errors** (Gipson 2006; Romero-Wolf et al. 2012; Lambert 2014)

Need better modeling/parameterization of stationd-dependent parameters

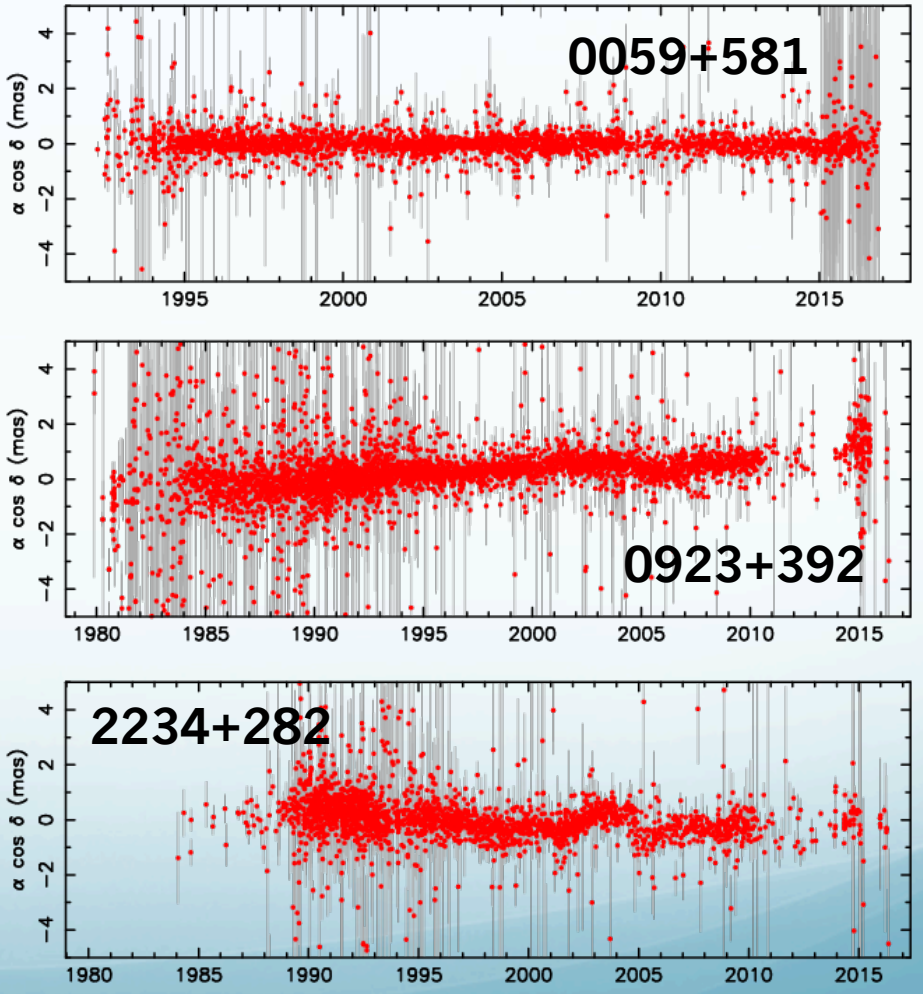
Celestial Frame Issues

Network radio sources: morphology/stability





3C273/VLBA (MOJAVE, Purdue)

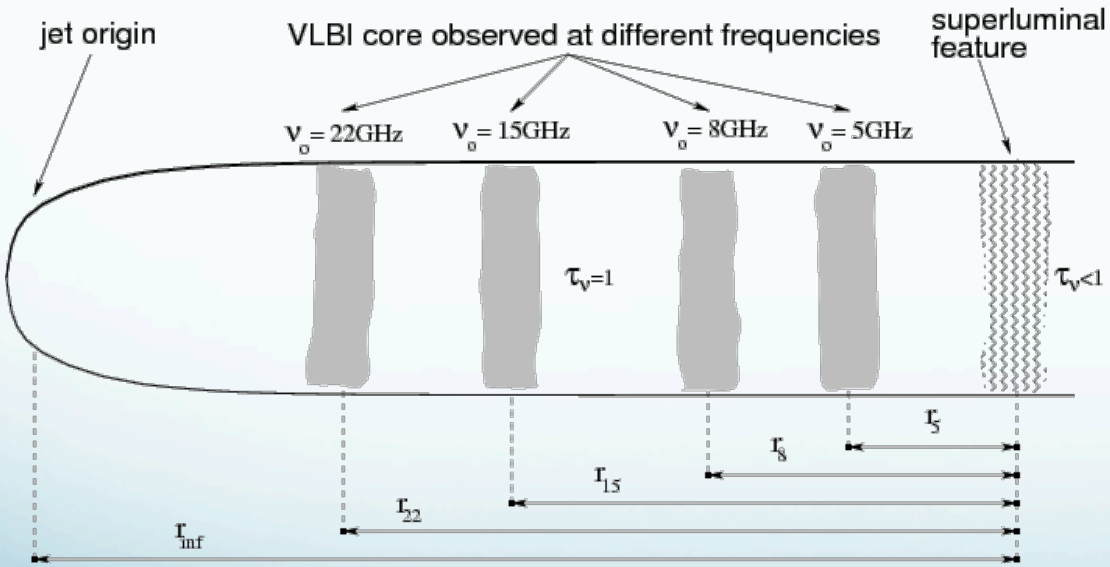


Celestial Frame Issues

Network radio sources: core-shift (opacity)

Frequency dependent position shift of VLBI core.

Kovalev et al. 2008

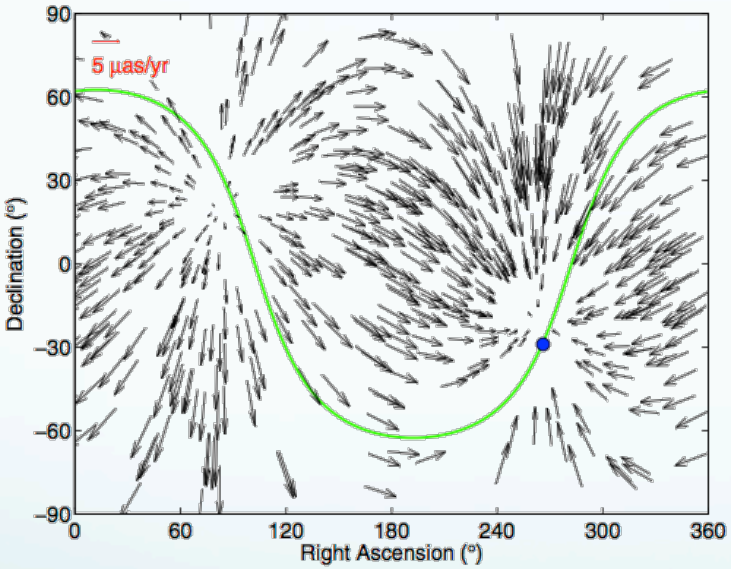


Hot questions:

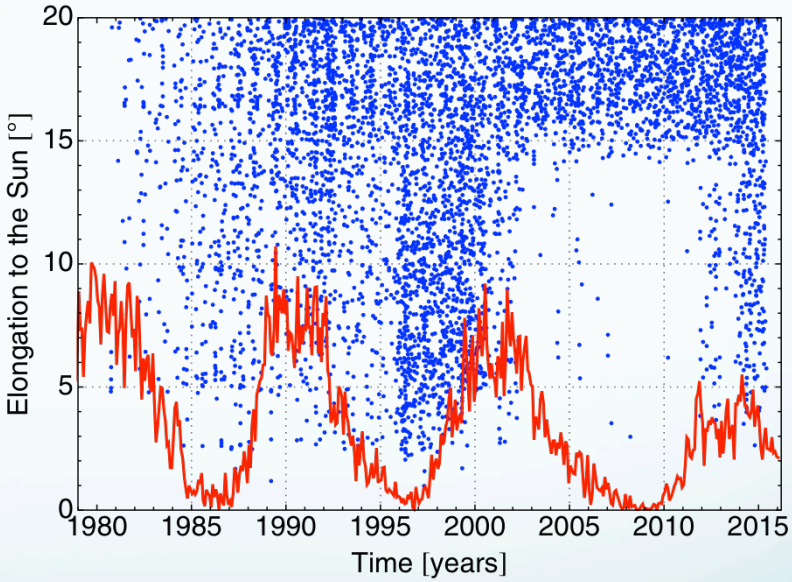
- **Where is the fixed point? (black hole(s))**
- **How to use multi-λ CRFs to retrieve that?**

Celestial Frame Issues

Fundamental physics and cosmology: two achievements at SYRTE



First measurement of the Solar system acceleration (Titov, Lambert and Gontier 2011)

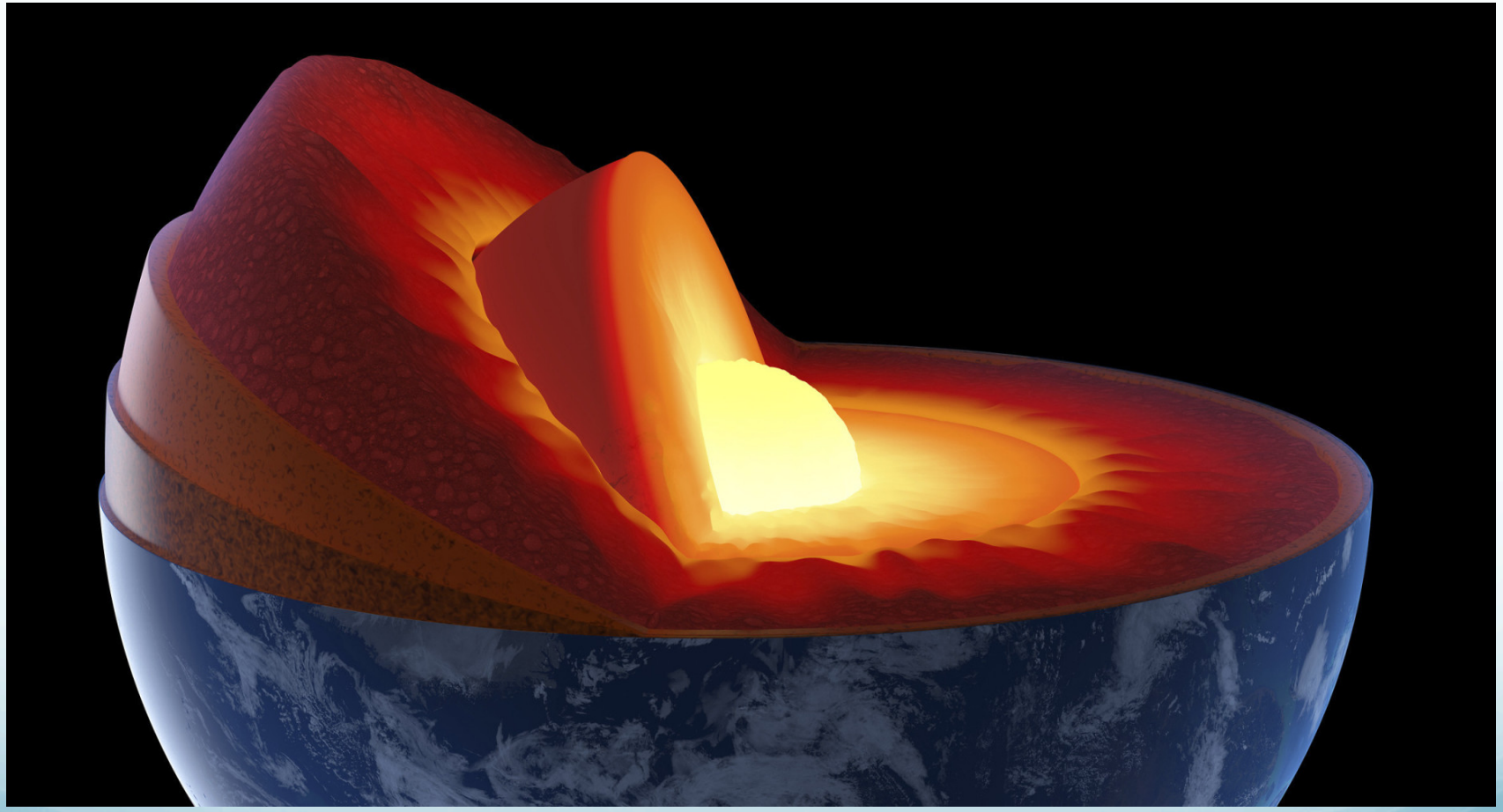


First direct estimate of SME parameter in the pure gravity sectore (Le Poncin-Lafitte, Hees and Lambert 2016)

Celestial Frame Issues

- Still unsolved questions on 9 March 2017 for which GEODESIE could help
  - Reference frame
    - How to choose the reference sources?
    - How to handle moving sources?
  - Correlated errors
  - Core-shift effect in radio source positions
- Synergies w/ ongoing projects
  - ICRF3 effort
  - Gaia DRs in progress
  - Potential for tests of fundamental physics

Earth Rotation Issues



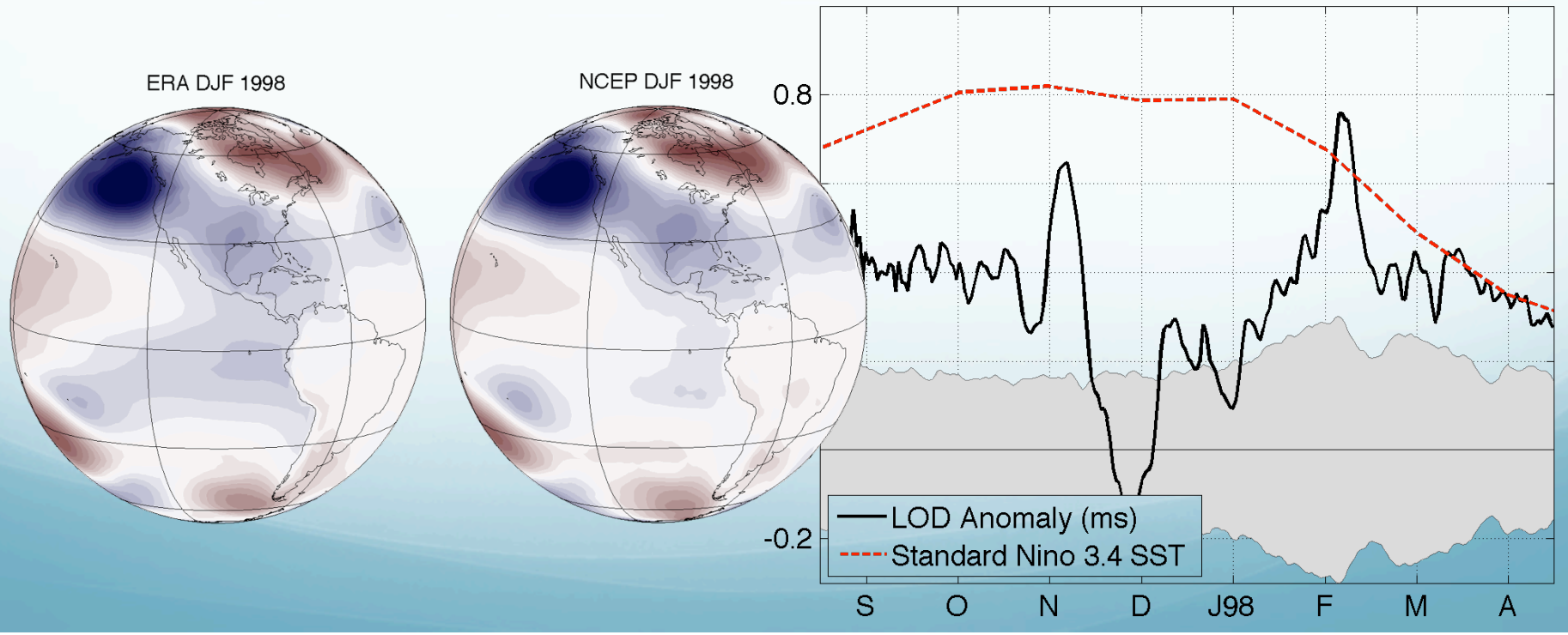
Earth Rotation Issues

- Earth's rotation measures integrate the results of a large number of forcing mechanisms
  - Astronomical
  - Climatic
    - Oscillations in atmosphere, oceans…
    - Terrestrial and submarine volcanism
    - Solar forcing
  - Internal
    - Deformability
    - Core rotation
- Our work is traditionally
  - Understanding interaction between solid Earth and forcing mechanisms
  - Validate forcing models

Earth Rotation Issues

Interannual time scales

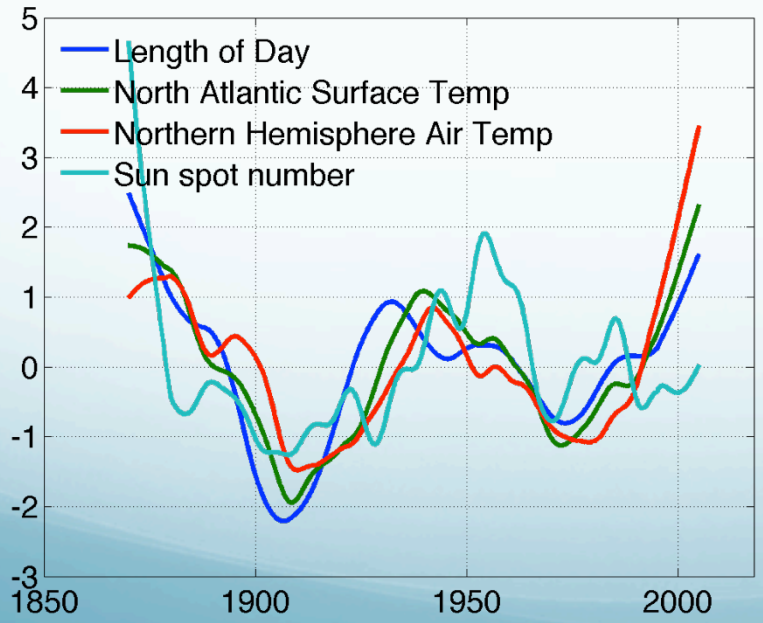
Example: ENSO forcing, how AGCM explain the observed LOD variations?

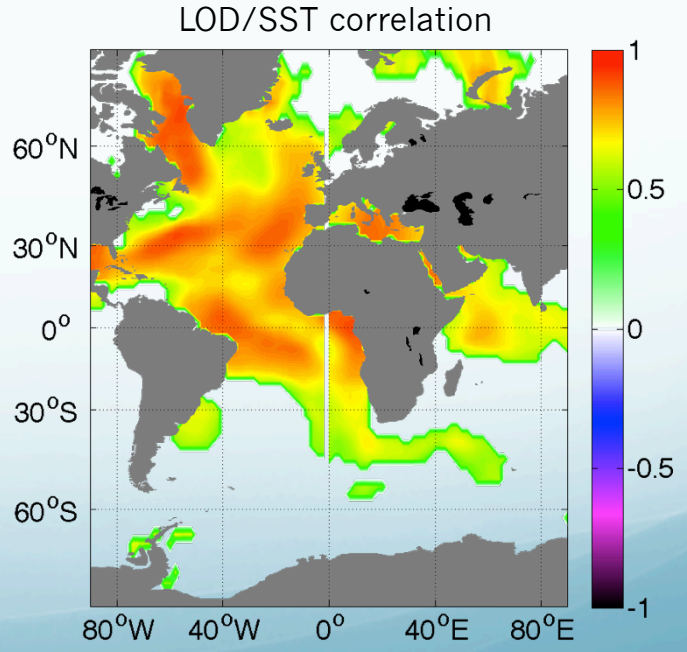


Earth Rotation Issues

Multidecadal time scales / climate change issues

Example: the LOD trend as a climate index (Dickey et al. 2011; Tolstoy 2015; Sottili et al. 2015; Zotov et al. 2016; Marcus 2016), or connections between LOD, climate, and other internal and external forcings

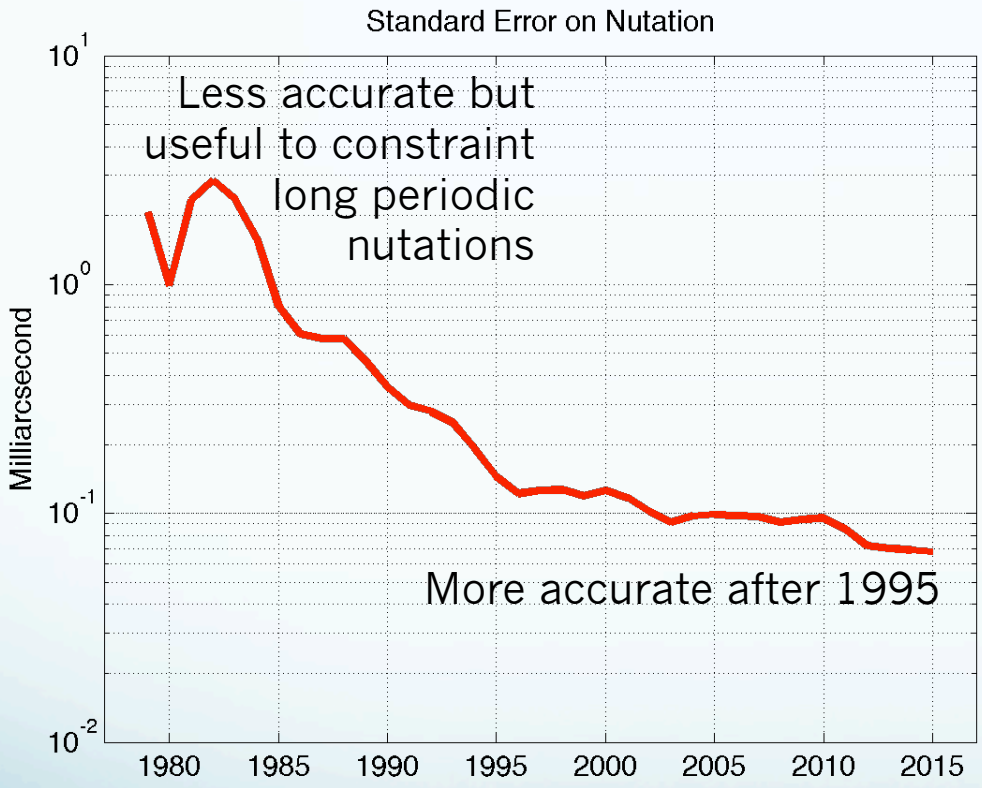


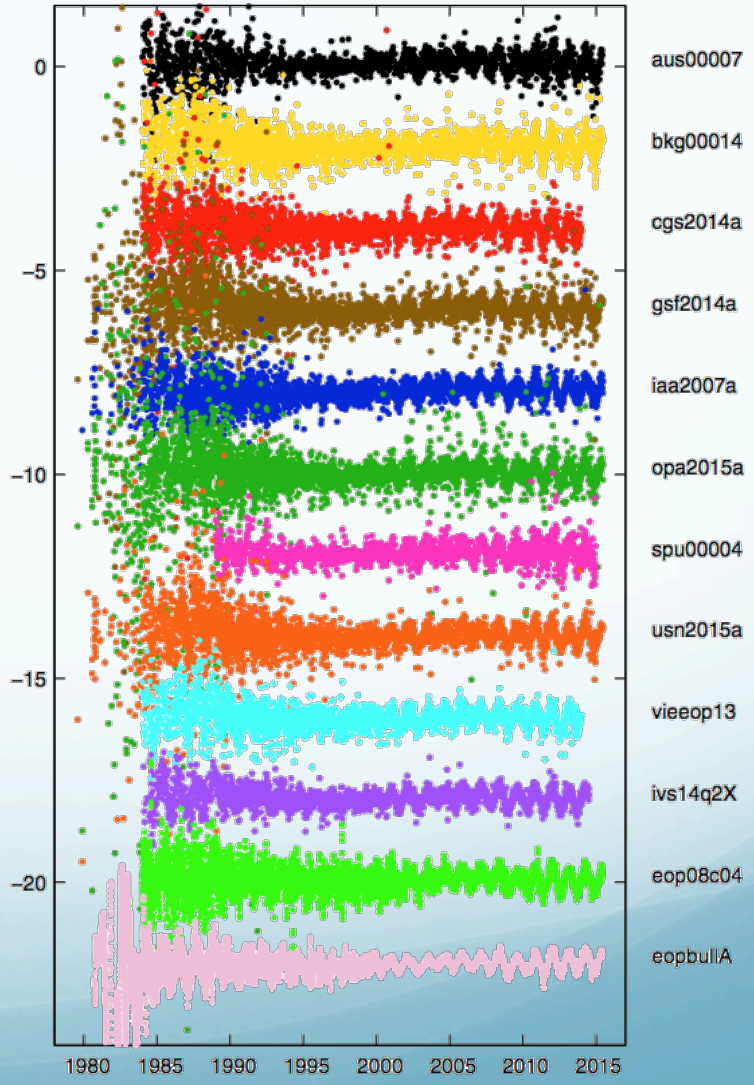


Earth Rotation Issues

- Nutation, LOD, deformations
- Inference of Earth's internal structure and properties
  - Whole/core/inner core flattening + admittances at CMB/ICB (Mathews et al. 2002; Koot et al. 2008)
  - Multidecadal LOD and torsional oscillations in the core (Holme and de Viron 2013; Buffett et al. 2016)
- Some pending **hot** questions
  - Contribution of the atmosphere to nutations
  - Excitation mechanism of the FCN
  - Reliability of the estimation of the FICN period

Earth Rotation Issues





Available series (Gattano et al. 2017) → Issues about observation/analysis strategies to optimize the geophysical signal including combination w/ other techniques

Earth Rotation Issues

- Still unsolved questions on 9 March 2017 for which GEODESIE could help
  - Link between climate oscillations and Earth's rotation
  - Period of the FICN
  - Free modes' excitation mechanisms
- Synergies w/ ongoing projects
  - ORB (V. Dehant's Rotanut ERC)
  - SYRTE
    - Y. Ziegler, postdoc – gravi/VLBI
    - I. Nurul Huda – VLBI

Concluding Remarks

- **GEODESIE** is a way to improve reference frames and Earth's rotation
  - May have a great contribution to CRF
  - May better EOP accuracy
- **GEODESIE** will bring scientific results in
  - Climate branches, as it is primarily designed for!
  - But also possibly in
    - Earth's deep interior
    - Astronomy and fundamental physics