OREKIT DEVELOPMENT STATUS

Orekit Team (Maxime Journot)

AGENDA

1. History
2. Major features
3. Project Organization
4. Trends – v10.0 & beyond

HISTORY

1

OREKIT HISTORY

Inception | 2002

Orekit intended as a basis for ground segments bids

Failure of the commercial approach | 2008

OPEN-SOURCE !
Permissive license.
Very good reception by space community

Bazaar development model | Since 2011

Collaborative tools
External committers

Exceeds technical expectations, why not propose it by itself ?

Version technically complete | 2006

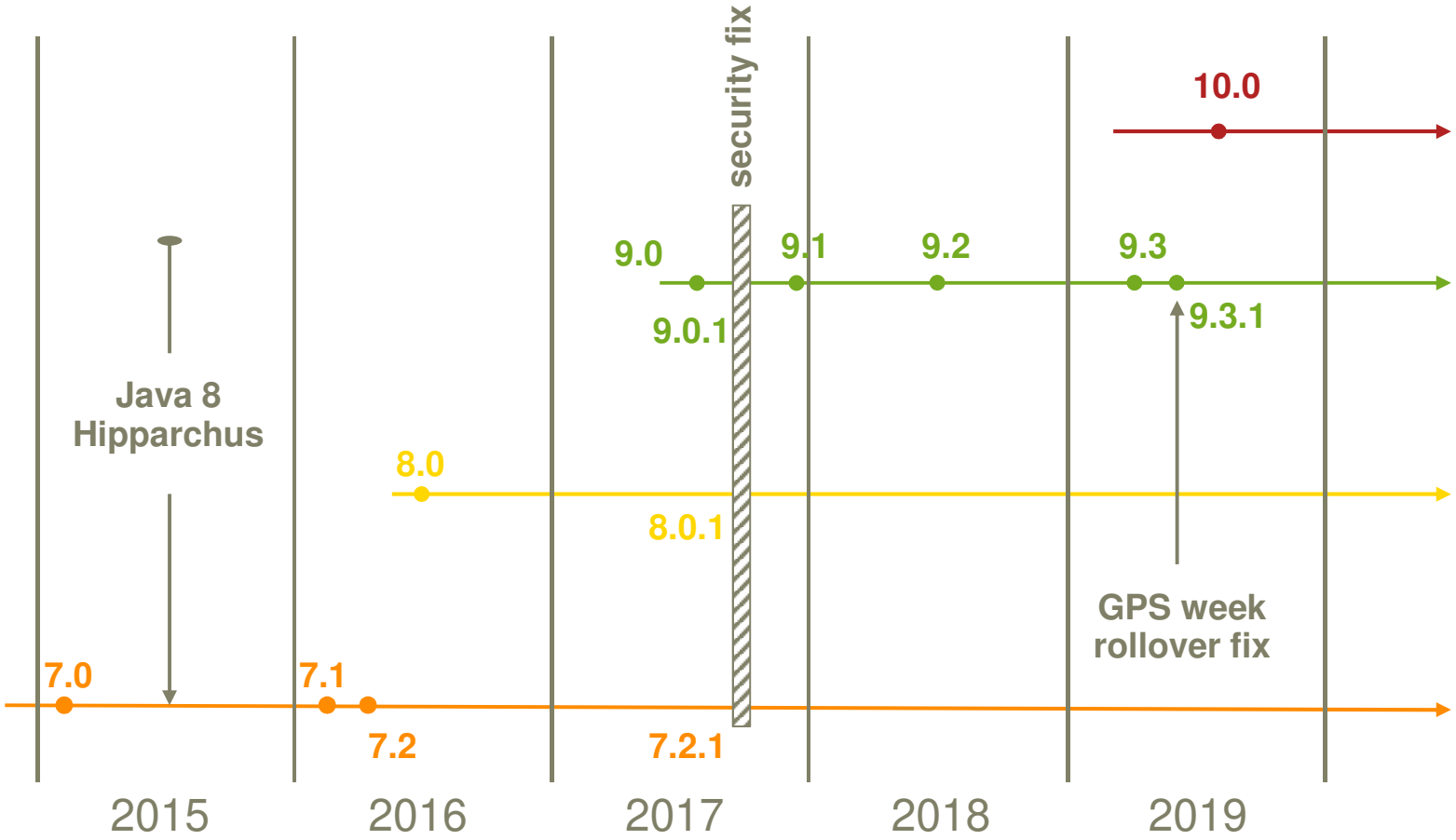
Project teams decide when to release

Cathedral development model | 2008 - 2011

PMC representatives from agencies, academics, private companies

Open governance | 2012

OREKIT RECENT RELEASES



MAJOR FEATURES

2

MAJOR FEATURES BY VERSION (1/2)

- **6.x series**
  - DSST propagator → mean elements propagation
  - Jacobians computation
  - Solid tides & Ocean tides force models
  - New IERS non-rotating origin paradigm for frames
  - Support for IERS 1996, 2003 & 2010

- **7.x series**
  - DSST propagator → short periodic elements propagation
  - Second order derivatives for many model
  - General relativity force model
  - 3 different types of solar radiation pressure

MAJOR FEATURES BY VERSION (2/2)

- **8.x series**
  - Switch to Java 8 & Hipparchus
  - **Batch least-square orbit determination**

- **9.x series**
  - **Extended Kalman filter orbit determination**
  - **Multi satellites orbit determination**
  - Covariance matrix retrieval in orbit determination
  - Parallel, multi-satellite, multi-threaded orbit propagation
  - **Taylor algebra → Field propagators**
  - **GNSS / very high precision → Goal: Precise Orbit Determination**
  - Support for any ITRF version (including latest: 2014)
  - JB2008 and NRL-MSISE 2000 atmospheric models
  - Exceptions' enhancement (**Airbus contribution!**)
  - New tropospheric and Global Pression Temperature models

MAJOR FEATURES – ORBIT DETERMINATION (1/2)

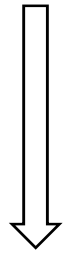
- **Orbit Determination Methods in Orekit**
  - Batch least-square (8.0)
  - Extended Kalman filter (9.2)
- **Measurements**
  - Range, range-rate, az/el, PVT (8.0)
  - Turn-around range, α/δ, inter-satellite range, phase, position only (9.x)
  - Measurements' generation package (9.3)
- **Parameters**
  - Orbits (even partial elements), drag, SRP, station biases & positions (8.0)
  - EOP, parametric accelerations, tropospheric delay, ground points displacements, clock offsets of receivers and emitters (9.x)
- **Features**
  - Multi-satellite orbit determination (9.x)
  - Fast handling of ten of thousands of measurements
  - Tropospheric, ionospheric, weather corrections
  - Modularity: user defined measurements, filters, modifiers etc. are easy to add

MAJOR FEATURES – ORBIT DETERMINATION (2/2)

- **Publication:** Maisonobe et al (SpaceOps, 2018),
  Multi-satellites Precise Orbit Determination, an adaptable open-source implementation
- **Examples:**
  - **Tutorial**: `src/tutorials/…/estimation/OrbitDetermination.java`
    - **Telespazio contribution!**
    - **W3B** satellite on a GEO transfer orbit with a propulsive system leak
    - 182 range & 339 az/el measurements from 5 ground-stations
    - Estimation of: orbit, drag, SRP coefficients, all stations range and az/el biases, thrusters' leak as a parametric acceleration
  - **Tests**: `src/test/…/estimation/leastsquares/OrbitDeterminationTest.java`
    `src/test/…/estimation/sequential/KalmanOrbitDeterminationTest.java`
    - **LAGEOS2:** Ball-like geodesy satellite on a ~6000km circular orbit
      - 258 laser-ranging measurements from 4 ground stations
      - Estimation of: orbit, SRP, some stations' position and biases
    - **GNSS:** Earth pointing yaw-steered GNSS satellite
      - 4009 range measurements (CODE-RINEX) from 5 ground stations
      - Estimation of: orbit, SRP, tropospheric zenithal delay

- **Field Propagation**
  - From **Hipparchus** math library
  - Field T is an **enhanced double**
  - Supports all:
    - Double operations (+, -, *, /)
    - Math functions (sin, …, atanh)
    - IEEE functions (scalb,…, copysign)

```
double f(double x, double y) {
    if (x > 0) {
        return x + g(y);
    } else {
        return x - g(y);
    }
}
```



```
T f(T x, T y) {
    if (x.getReal() > 0) {
        return x.add(g(y));
    } else {
        return x.subtract(g(y));
    }
}
```

- **Predefined fields in Hipparchus**
  - **DerivativeStructure**: automatic differentiation
  - **Decimal64**: used for validation in Orekit
  - SparseGradient = DerivativeStructure for Multi-variables + order 1 derivatives
  - Others: Dfp, FieldDerivativeStructure, Tuple, FieldTuple
  - User defined fields can be designed

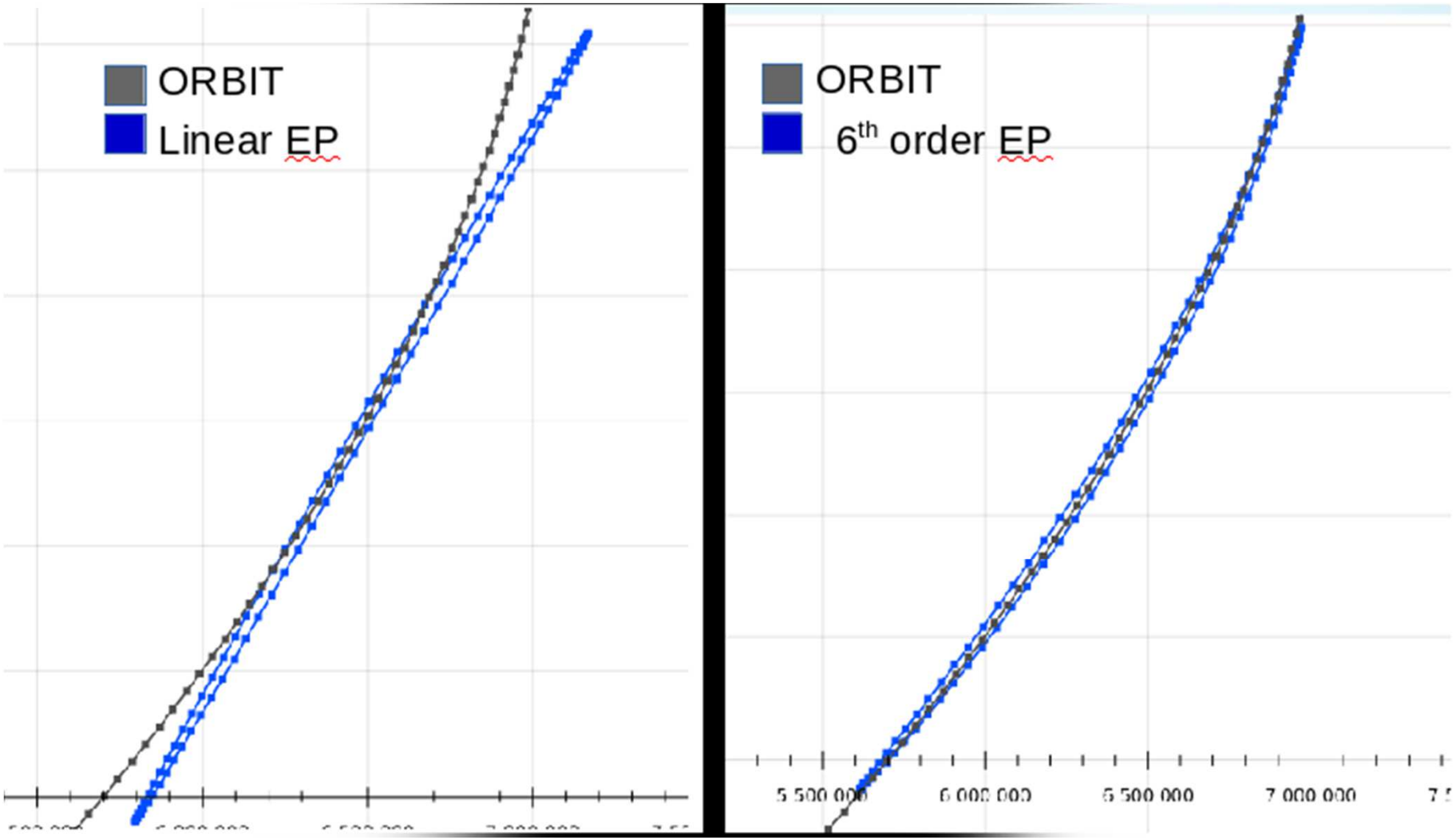
- **Taylor Algebra**
  - Using **DerivativeStructure class**
  - **Propagate derivatives of any parameters to any order !**

    Typically: 6 orbital parameters to derivative order 3
  - **Uncertainties propagation**
  - Very fast **Monte-Carlo analysis**
  - Others:
    - Accurate state transition matrix & easy Jacobian computation
    - Measurements' derivatives, GNSS propagators' derivatives
    - … the potential is huge !!
- **Examples:**
  - **Tutorial**: `src/tutorials/…/propagation/FieldPropagation.java`

    3rd order derivatives of a, i and Ω for a LEO circular orbit
  - **Tests**: `src/test/…/propagation/numerical/FieldNumericalPropagatorTest.java`

    And many other "Field" test classes…

- **Publication:** Antolino A., Maisonobe L. (Stardust Conference, 2016)
  Automatic Differentiation for Propagation of Orbit Uncertainties in Orekit



PROJECT ORGANIZATION

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PROJECT ORGANIZATION – PMC

- **Orekit Project Management Committee (PMC)**:
  - **Role**: Strategic planning, code reviewing, vote on new releases and new committers
  - **Newcomer**: Welcome to Yannick Jeandroz (Airbus DS), arrived in Jan 2019 !
  - **Members as of May 2019**:

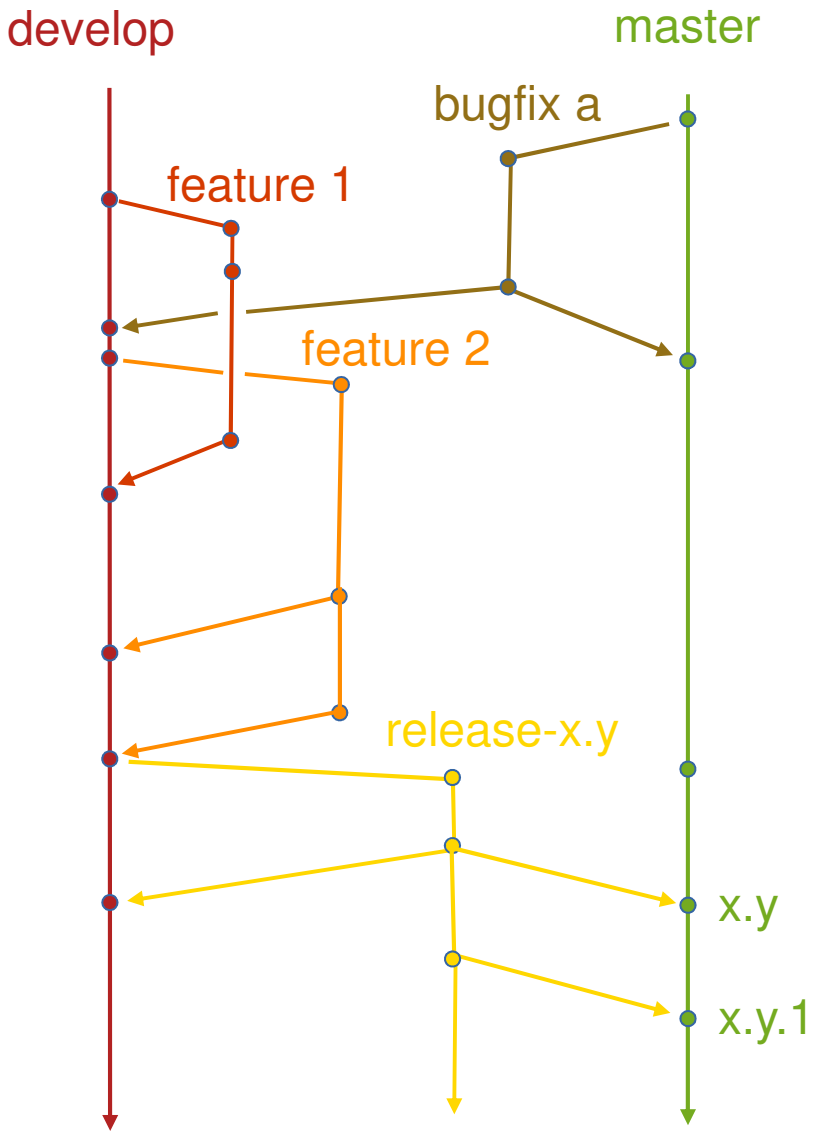
    Paul Cefola (University at Buffalo)
    Frank Dreger (European Space Agency - ESOC)
    Nicolas Frouvelle (CS Systèmes d'Information)
    Hank Grabowski (Independent Expert)
    Sébastien Herbinière (Thales Alenia Space)
    Petrus Hyvönen (Swedish Space Corporation)
    Yannick Jeandroz (Airbus Defense and Space)
    Stéphanie Lizy-Destrez (ISAE - Sup'Aéro)
    Luc Maisonobe (CS Systèmes d'Information)
    Guillermo Ortega (European Space Agency - ESTEC)
    Pascal Parraud (CS Systèmes d'Information)
    Evan Ward (Naval Research Laboratory)

PROJECT ORGANIZATION - LATEST NEWS

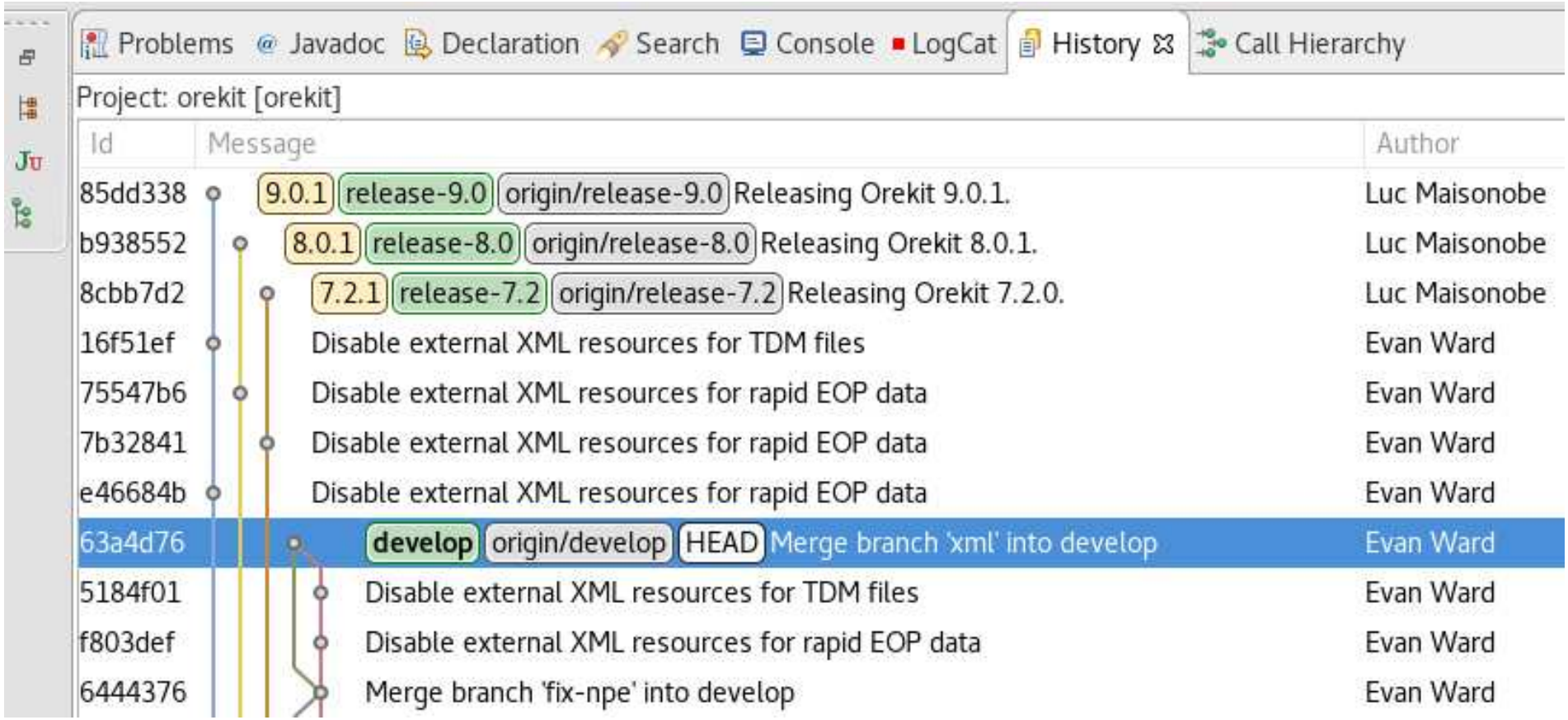
- **Git-flow** like branching model (July 2017)
- **Governance update** - Critical bug fixes release (Nov 2017)
- **New forge** - Gitlab (Aug 2018)
- **New forum** - Discourse (Aug 2018)
- **New PMC Member** - Yannick Jeandroz - Airbus DS (Jan 2019)
- **New developer** - Bryan Cazabonne (CS-SI) (Feb 2019)
- **First Merge Requests** (May 2019)

GIT-FLOW LIKE BRANCHING MODEL

- **Since July 2017**
- **Stability**:
  - Select master branch
  - It points to latest release
- **Maintain a product**:
  - Stick to release x.y
  - It includes patches for x.y
- **Want latest features**:
  - Follow develop branch
  - It is the « bleeding edge » of the library

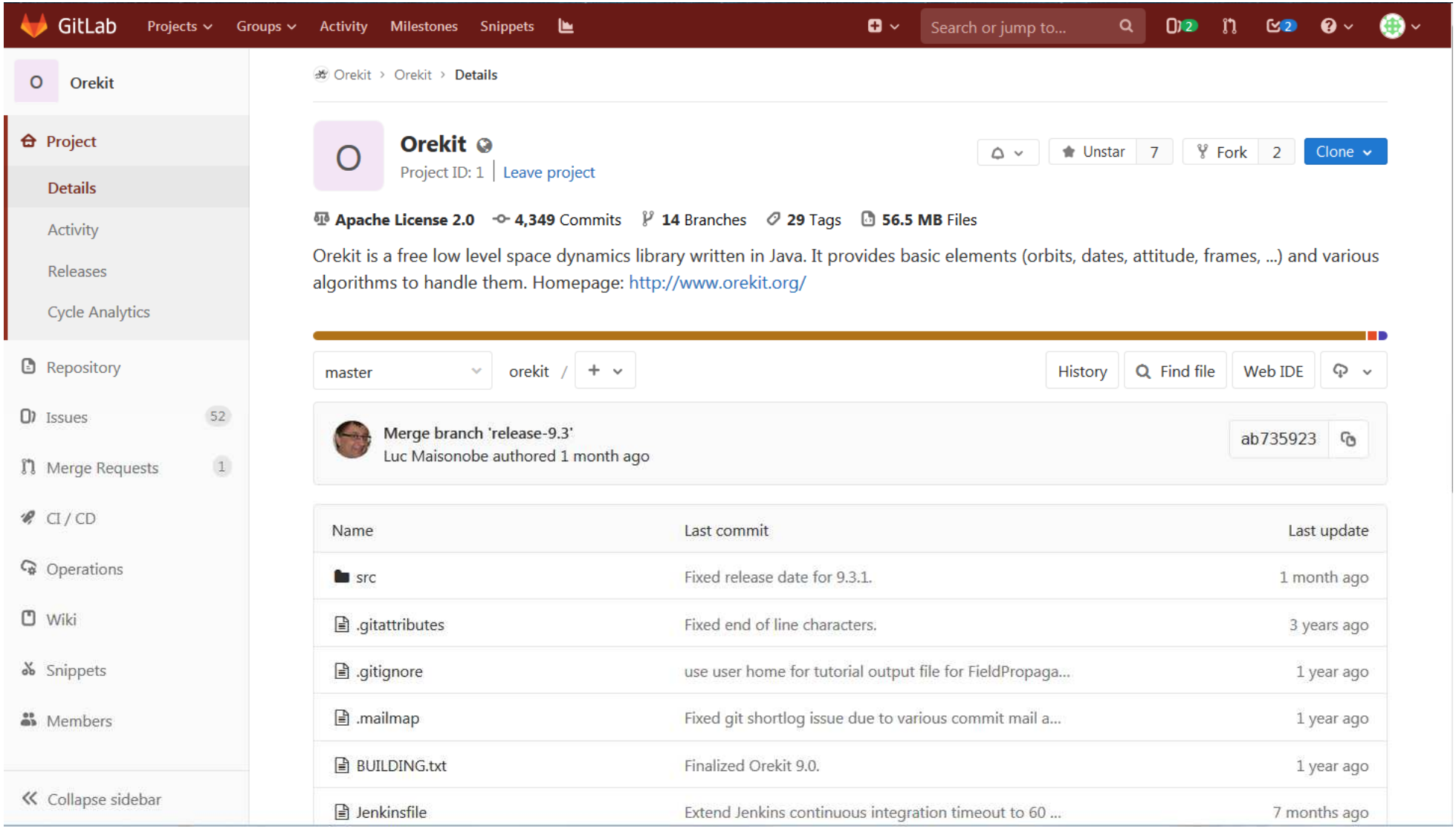


- **Governance Update (August 2017):**
  No more PMC vote delay for urgent security patches



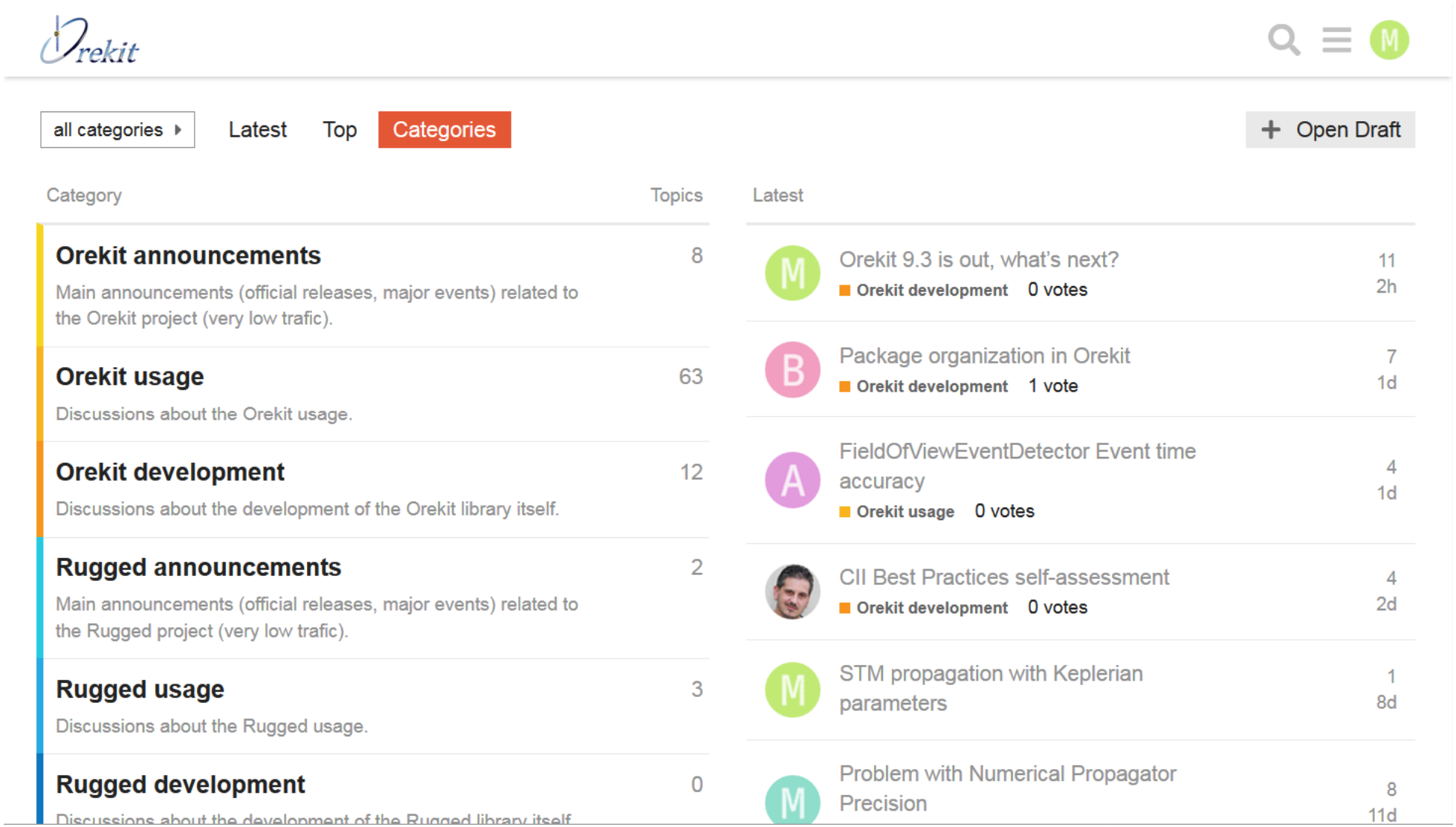
August 2017 example

- **Gitlab forge (August 2018): https://gitlab.orekit.org/orekit/orekit**



PROJECT ORGANIZATION – NEW FORUM

- **Discourse forum (August 2018): https://forum.orekit.org**



PROJECT ORGANIZATION – SOME STATISTICS

- **Discourse forum: Traffic x2** compared to former mailing lists !!
  - ~150 subscribers
  - ~170 topics visited/day (2/3 from anonymous users)
  - First answer in less than 17 hours
- **Orekit website traffic:** ~230 visits - 1200 pages – 21 downloads /day
- **Maven repository traffic:**

TRENDS: V10.0 & BEYOND

4

TRENDS – VERSION 10.0 (1/2)

- **Version 10.0: Next major version of Orekit**
  - Will be released soon (June 2019 ?)
  - Based on Hipparchus 1.5
- **Features:**
  - **DSST Orbit Determination**
    - Estimation in **mean** or **osculating elements** for **batch LS & Kalman filter**
    - Presentation: Bryan Cazabonne (see later…)
    - **Publication: Cazabonne B., Maisonobe L.** (ICATT 2018),

      Open-source Orbit Determination using semi-analytical theory
  - **Propagation in non-inertial frame**
    - Inertial forces due to frame rotation
    - Propagation in any frame including ITRF, Lagrangian points based frames etc
  - **GNSS specialized propagators:** GPS, Galileo, Glonass, Beidou, QZSS
  - **Documentation improvements**: Readme file, mailmap, building instructions…
  - **Various bug fixes**

TRENDS – VERSION 10.0 (2/2)

- **Toward Precise Orbit Determination:** Long term goal
- **Since version 9**
  - Inter-satellite range measurements (9.0)
  - Antenna Phase Center measurements modifiers (9.0)
  - EOP estimation in precise orbit determination (9.0)
  - Ground station displacements (ocean and solid tides' loads) (9.1)
  - Loading of RINEX, ANTEX files
  - CODE measurements, phase measurements (basic) (9.2)
  - **Kouba attitude models** (midnight/noon transition for all constellations' types) (9.2)
  - Tropospheric zenith delay estimation (9.3)
  - Clock offsets estimation (ground-stations & satellite clocks) (9.3)
- **Version 10.0**
  - **Phase measurements** with integer **ambiguity resolution** (lambda method)
  - Ionospheric models: Global Ionosphere map (IONEX files), NeQuick

TRENDS – FUTURE VERSIONS (1/2)

- **New Features suggestions**
  - **Precise OD:**
    - Phase measurements' improvements (M-lambda, wind-up effect etc.)
    - Combined measurements: iono-free…
    - Integration in Orekit OD scheme: tests, cross-validation with available results (IGS files...)
  - **Maneuvers**:
    - Variable thrust maneuvers (future **Airbus contribution**!)
  - **Others**:
    - Better handling of atmospheric models inputs
    - One line element set
    - SPICE Kernel loading
    - ??

Suggestions from the community are welcome !!

- **Project Organization Suggestions**
  - **Forum:** More categories → FAQ, Orekit Python, others ?
  - **Forge:**
    - Merge request guide
    - Issue labels re-organization + explanation
    - Nightly builds publication (with Nexus artifact repository) ?
    - Gitlab-CI + SonarQube replacing Jenkins ?
      - Better integration with Gitlab and merge requests
      - Website and Maven static website publication automation
    - Release Process: Automation for easier release
  - **Documentation**:
    - More tutorials, new tools for tutorials ? (Jupyter with Java/Python kernels, visualization tools (Cesium) etc.)

Suggestions from the community are welcome !!

Thank you for your attention