# Impact of GNSS orbit modeling on LEO orbit and gravity field determination

EGU2017-14411
European Geosciences Union
General Assembly 2017
23 - 28 April 2017, Vienna, Austria

D. Arnold, U. Meyer, A. Sušnik, R. Dach, A. Jäggi

Astronomical Institute, University of Bern, Bern, Switzerland

## Introduction

On January 4, 2015 the Center for Orbit Determination in Europe (CODE) changed the solar radiation pressure modeling for GNSS satellites to an updated version of the empirical CODE orbit model (ECOM). Furthermore, since September 2012 CODE operationally computes satellite clock corrections not only for the 3-day long-arc solutions, but also for the non-overlapping 1-day GNSS orbits. This provides different sets of GNSS products for precise point positioning, as employed, e.g., in the GNSS-based precise orbit determination (POD) of low Earth orbiters (LEOs). While the impact of the mentioned changes in orbit modeling and solution strategy on the GNSS orbits and geophysical parameters was studied in detail in Arnold et al. (2015) and Lutz et al. (2016), their implications on the LEO orbits were not yet analyzed.

## The extended ECOM

In the ECOM the non-gravitational accelerations in the three orthogonal directions $D$ (satellite-Sun), $Y$ (solar panel axis), and $B$ (perpendicular to $D$ and $Y$) are empirically determined. In the extended version of the ECOM the general decomposition reads (Arnold et al., 2015)

$$D(u) = D_0 + \sum_{i=1}^{n_D} \{ D_{2i,c} \cos 2i\Delta u + D_{2i,s} \sin 2i\Delta u \}$$

$$Y(u) = Y_0$$

$$B(u) = B_0 + \sum_{i=1}^{n_B} \{ B_{2i-1,c} \cos(2i-1)\Delta u + B_{2i-1,s} \sin(2i-1)\Delta u \} ,$$

where $u$ is the satellite's argument of latitude, $\Delta u = u - u_S$, and $u_S$ is the Sun's argument of latitude. Prior to January 4, 2015 CODE computed the GNSS products with $n_D = 0$ and $n_B = 1$. Arnold et al. (2015) have shown that extending the ECOM to $n_D = 1$ or $n_D = 2$ leads to a significant reduction of spurious signals in time series of geophysical parameter estimates. The gain is most visible for GLONASS satellites (which have an elongated satellite body), but also GPS orbits show an improvement.

## Repro-15

In the frame of the European Gravity Service for Improved Emergency Management (EGSIEM) CODE performed a consistent reprocessing of the 1- and 3-day GNSS orbits and clock corrections for the time span 1994-2015, employing the extended ECOM with $n_D = 2$ (i.e., including the $D$ terms up to 4/revolution).

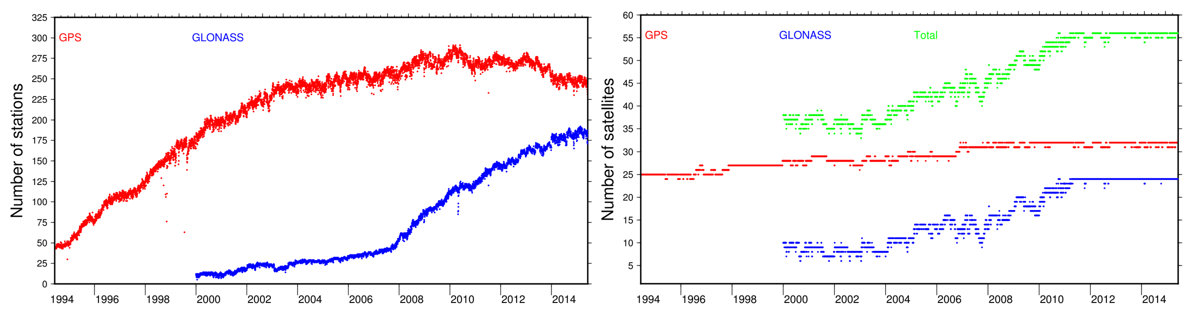


**Figure 1:** Left: The number of GNSS stations (left) and the number of GPS and GLONASS satellites included in Repro-15.

For a clear separation of the impact of the ECOM update a consistent time series of orbits and clock corrections with $n_D = 0$, i.e., with the old version of the ECOM was produced as well. In this study we analyze and compare GRACE orbits and gravity fields based on three different sets of GNSS products:

| ID | GNSS arc length | ECOM expansion |
|---|---|---|
| D4_3 | 3-day | $n_D = 2$ |
| D4_1 | 1-day | $n_D = 2$ |
| D0_3 | 3-day | $n_D = 0$ |

**Table 1:** The GNSS products used for this study and the names of the corresponding GRACE orbit and gravity field solutions.

## GRACE POD

Reduced-dynamic and kinematic GRACE orbits are computed using the latest development version of the Bernese GNSS Software. Based on the ionosphere-free linear combination of undifferenced GPS phase observations the following parameters are estimated in a least-squares adjustment with floating carrier phase ambiguities and with an arc length of 24 h:

- Reduced-dynamic orbits: Initial conditions, constant empirical accelerations in radial, along-track, and cross-track directions, 6 min piecewise-constant accelerations (constrained) in the same directions, receiver clock corrections per epoch, carrier phase ambiguities
- Kinematic orbits: Three-dimensional positions and receiver clock offsets per epoch, carrier phase ambiguities.

For this study the orbit solutions D4_3, D4_1, and D0_3 of the year 2006 are compared. For the generation of all three solutions empirically derived phase center variation (PCV) maps are applied. They are obtained from the stacking of phase residuals from a D4_3-type reduced-dynamic orbit determination.

## Orbit validations

Figure 2 shows the daily RMS values of the ionosphere-free carrier phase residuals for the three solutions.

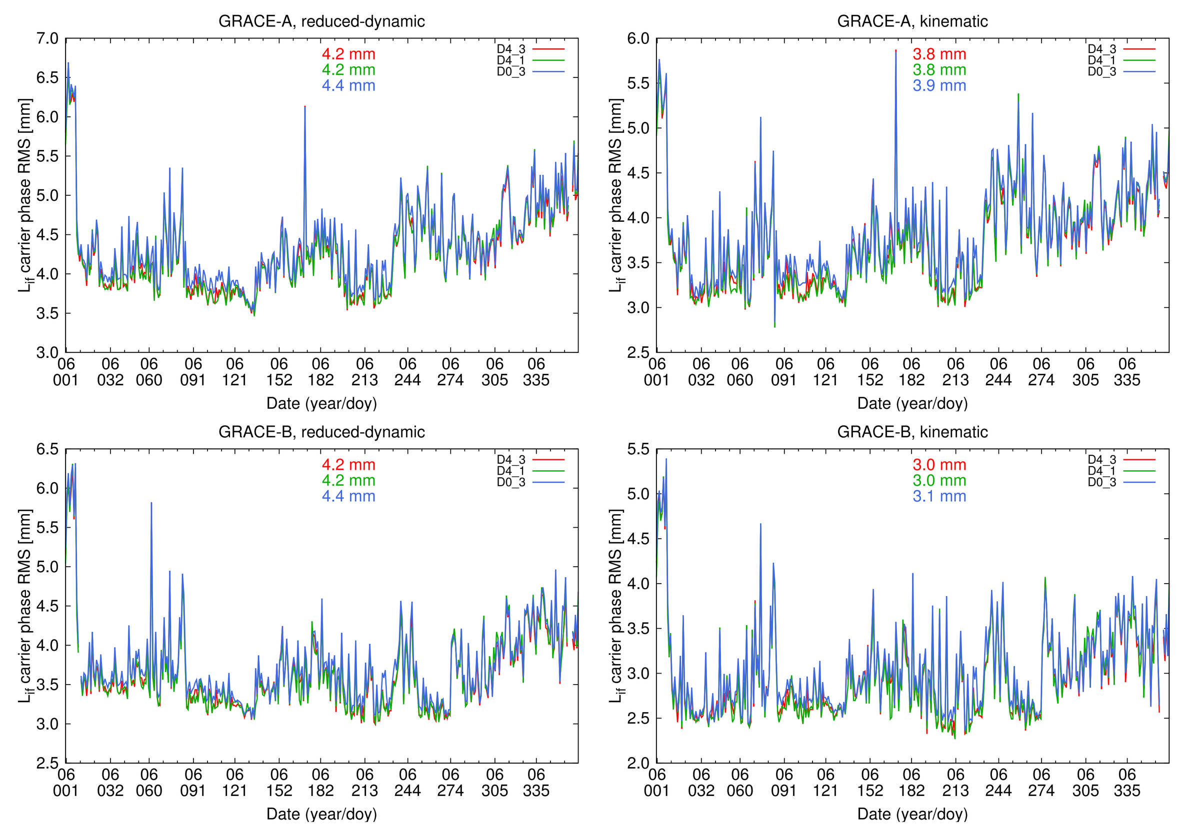


**Figure 2:** Carrier phase residuals of reduced-dynamic (left) and kinematic (right) POD for GRACE-A (top) and GRACE-B (bottom). The numbers indicate the average values over the entire year.

Figure 3 shows the consistency between the reduced-dynamic and the kinematic orbits.

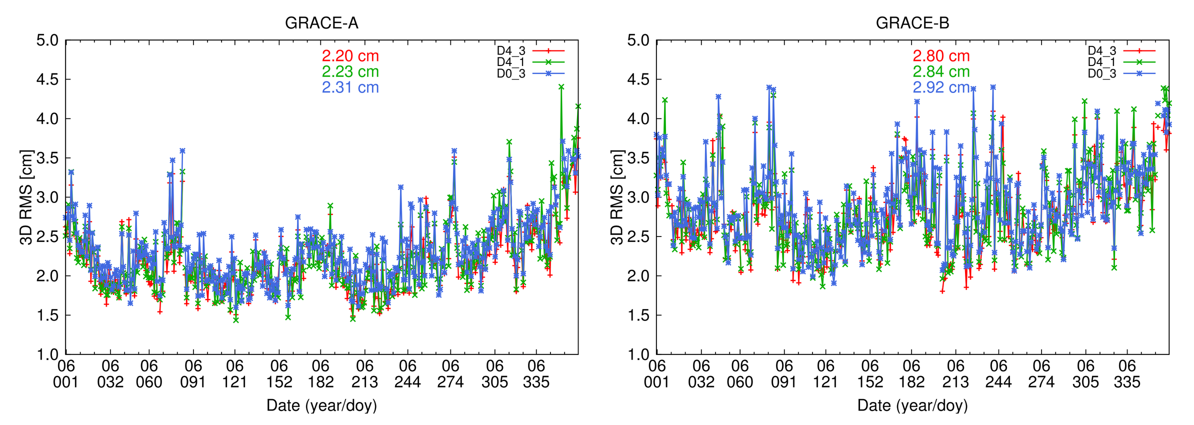


**Figure 3:** Daily RMS values of 3D differences between the reduced-dynamic and the kinematic orbits for GRACE-A (left) and GRACE-B (right). Values larger than 4.5 cm have been removed.

The GRACE satellites are equipped with SLR reflectors, which allow an independent orbit validation in terms Satellite Laser Ranging (SLR). SLR normal points from 18 laser stations were used for the validation, outliers larger than 30 cm have been rejected. Figure 4 shows the SLR residuals (i.e., the differences between the computed and the measured range) for GRACE-A. Table 2 summarizes the mean and RMS values for all cases.

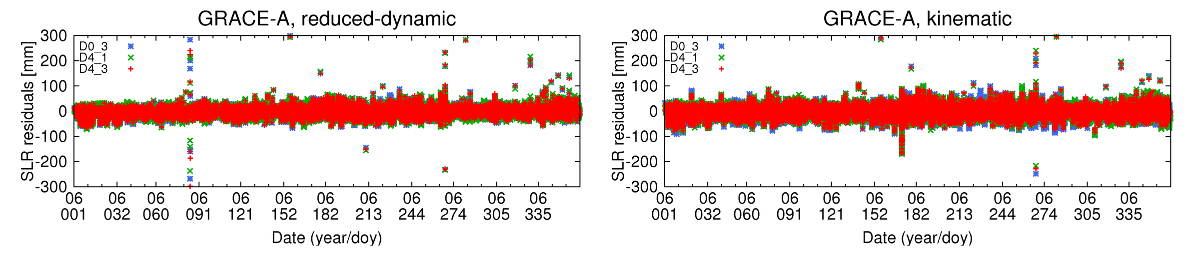


**Figure 4:** SLR residuals for the reduced-dynamic (left) and kinematic (right) GRACE-A orbits.

| | GRACE-A | | GRACE-B | |
|---|---|---|---|---|
| ID | red.-dyn. | kin. | red.-dyn. | kin. |
| D4_3 | -3.2/16.2 | -3.0/21.1 | -3.8/17.6 | -4.8/23.9 |
| D4_1 | -3.2/16.7 | -2.9/21.2 | -3.4/18.1 | -4.2/24.2 |
| D0_3 | -3.3/16.6 | -3.4/22.3 | -4.0/18.0 | -5.2/25.5 |

**Table 2:** Mean and RMS values in mm of SLR residuals over the entire year 2006.

The GRACE K-band observations can be used for an accurate validation of the relative orbits mainly in along-track direction. Figure 5 show the K-band range and range-rate residuals for the three solutions.

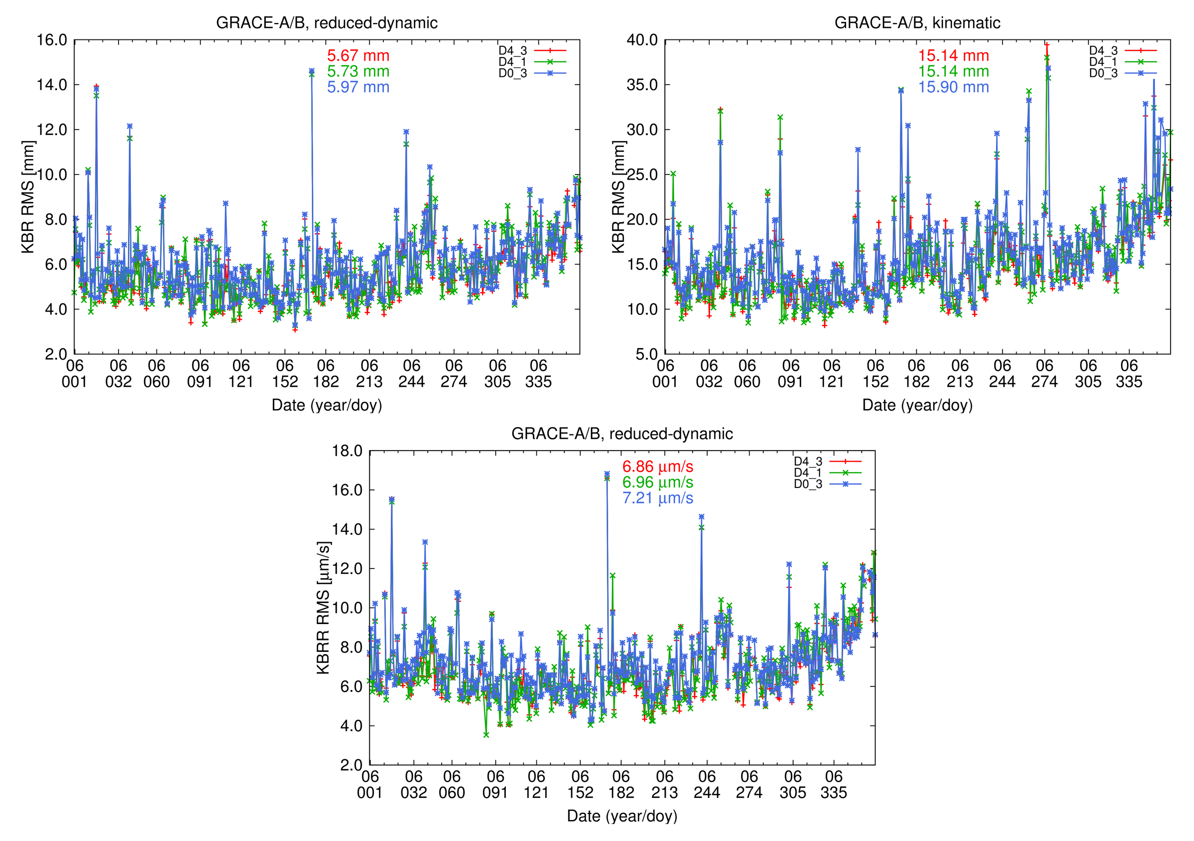


**Figure 5:** Daily RMS values of K-band range and range-rate residuals. Range RMS values larger than 15 mm and 40 mm have been removed for the reduced-dynamic and kinemtic case, respectively. Range-rate RMS values larger than 18 $\mu$m/s have been removed.

Figure 6 shows the differences of the three different orbit solutions for one day.

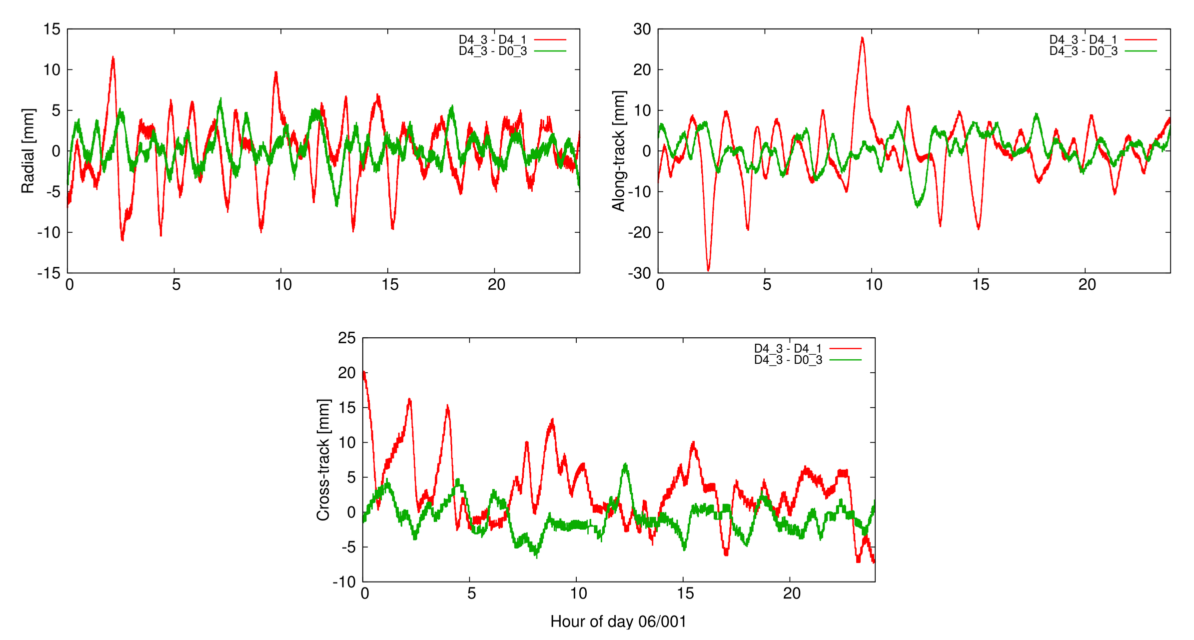


**Figure 6:** Differences between the reduced-dynamic GRACE-A D4_3 and the D4_1 orbit (red) and the D4_3 and the D0_3 orbit (green) for the day January 1, 2006 in radial, along-track, and cross-track direction. The differences due to 1-day GNSS arcs are larger than the differences due to the old version of the ECOM.

## Gravity fields

The kinematic GRACE orbits serve as pseudo-observations for a GPS-only gravity field recovery based on the Celestial Mechanics Approach (CMA, Beutler et al., 2010). Daily normal equations are set up for the parameters listed in Tab. 3. The daily NEQs are then accumulated over longer time spans and inverted.

| | |
|---|---|
| A priori gravity model | AIUB-GRACE03S (icgem.gfz-potsdam.de), d/o 90 |
| Ocean tides | EOT11a |
| Atm. & ocean de-aliasing | AOD1B RL05 |
| Ocean pole tides | Desai, 2002 |
| Arc length | 24 h |
| Data sampling | 10 s |
| Initial state vector | 1/arc |
| Empirical parameters | Constant and 15 min piecewise-constant accelerations in radial, along-track, cross-track direction |
| Gravity field parameters | Spherical harmonics to d/o 90 |

**Table 3:** Models and parameters employed and estimated in the CMA for the gravity recovery.

Figure 7 shows difference degree amplitudes w.r.t. AIUB-GRACE03S of GRACE-A GPS-only gravity fields which are derived from the D4_3, D4_1, and D0_3 kinematic orbits, respectively.

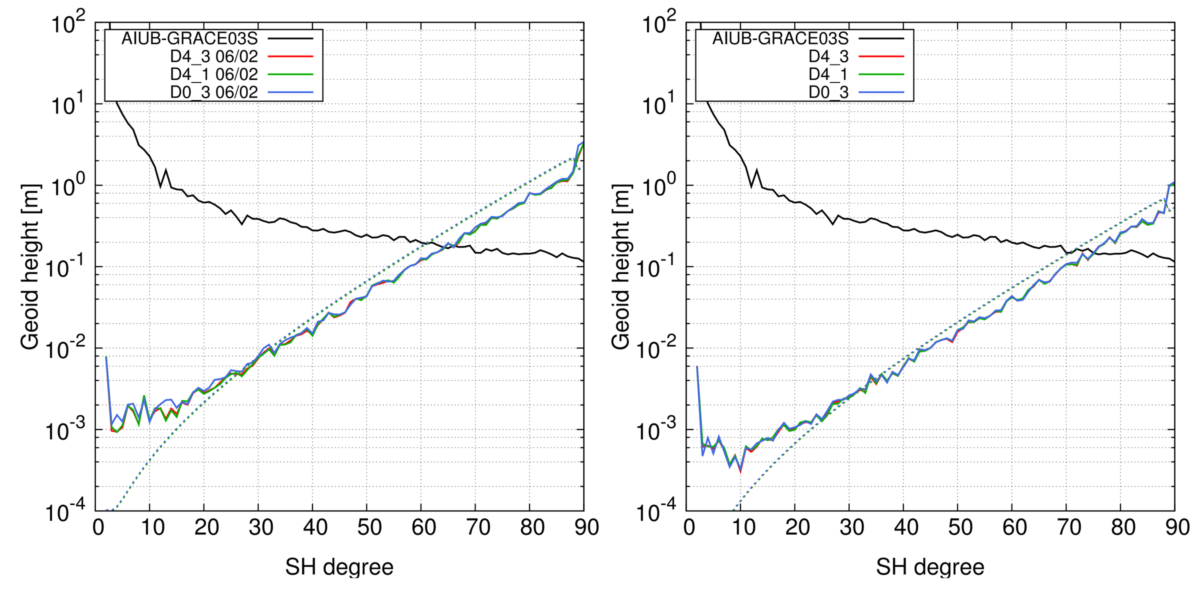


**Figure 7:** Difference degree amplitudes (solid) and formal error degree amplitudes (dashed) of GRACE-A GPS-only gravity fields of February 2006 (left) and of the entire 2006 (right). The three curves of the formal errors are located on top of each other.

The gravity fields obtained from the different kinematic orbits are very similar, the D0_3 solution leads to slightly larger differences w.r.t. AIUB-GRACE03S in the lower degrees for February 2006.

## Summary and conclusions

- To analyze the impact of the GNSS orbit modeling and the arc length used for the GNSS orbit and clock processing, three different, but consistently produced product series have been introduced for GRACE POD. Three orbit series have been computed (see Tab. 1).
- The orbit validations show small differences. In general, the D4_3 solution performs best, followed by D4_1. The D0_3 solution (based on GNSS products obtained with the original version of the ECOM) performs worst.
- Using the CMA, GPS-only gravity fields have been computed from the three series of GRACE-A kinematic orbits. The differences between these gravity fields are marginal, the update of the ECOM seems to be slightly beneficial for the lowest degrees.

## References

Arnold, D., Meindl, M., Beutler, G., Dach, R., Schaer, S., Lutz, S., Prange, L., Sośnica, K., Mervart, L., and Jäggi, A. (2015). CODE's new solar radiation pressure model for GNSS orbit determination. *Journal of Geodesy*, 89:775–791.

Beutler, G., Jäggi, A., Mervart, L., and Meyer, U. (2010). The Celestial Mechanics Approach: theoretical foundations. *Journal of Geodesy*, 84:605–624.

Lutz, S., Meindl, M., Steigenberger, P., Beutler, G., Sośnica, K., Schaer, S., Dach, R., Arnold, D., Thaller, D., and Jäggi, A. (2016). Impact of the arc length on GNSS analysis results. *Journal of Geodesy*, 90(4):365–378.

## Contact address

Daniel Arnold
Astronomical Institute, University of Bern
Sidlerstrasse 5
3012 Bern (Switzerland)
daniel.arnold@aiub.unibe.ch

Poster compiled by Daniel Arnold, April 2017
Astronomical Institute, University of Bern, Bern
daniel.arnold@aiub.unibe.ch