SORA

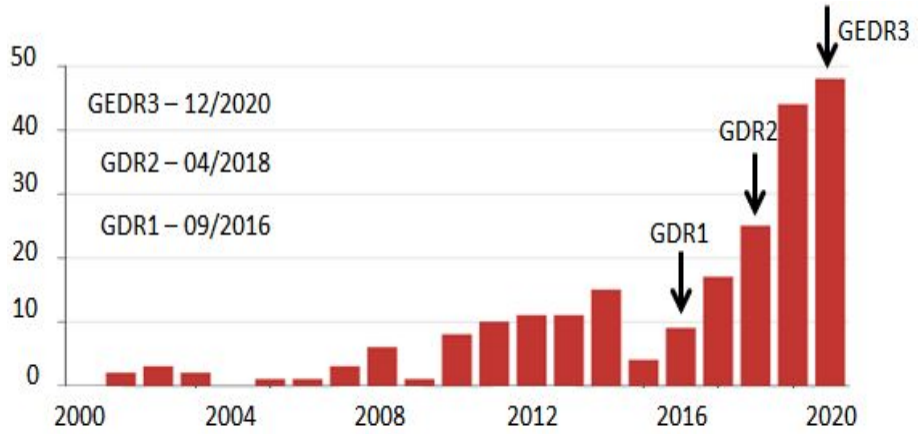
Stellar Occultation Reduction and Analysis

Gomes-Júnior et al.

Stellar Occultations Reduction and Analysis - SORA

- What is it?

Open source and object oriented Python3 library to reduce and analyse stellar occultations.



SORA Main Goals

- SORA was developed aiming to help the collaboration Rio/Granada/Paris in its work involving TNOs/Centaurs.
  - A Python library with a variety of functionalities and tools to reduce and analyse Stellar Occultation data.
  - Modern, faster, more efficient...
  - Access to online databases (Gaia, Vizier, Horizons, ...).;
  - Many levels of automation, from manual to fully automated;
  - Separated by modules.
- The user will be able to create their own pipeline.

GitHub and SORA development

- Ongoing software (now = v0.2)
  - Uses GIT for version control (major . minor . patch).
  - Anyone can help the development (moderated by the core team)
  - Open for new updates and improvements.

- **Core team:**
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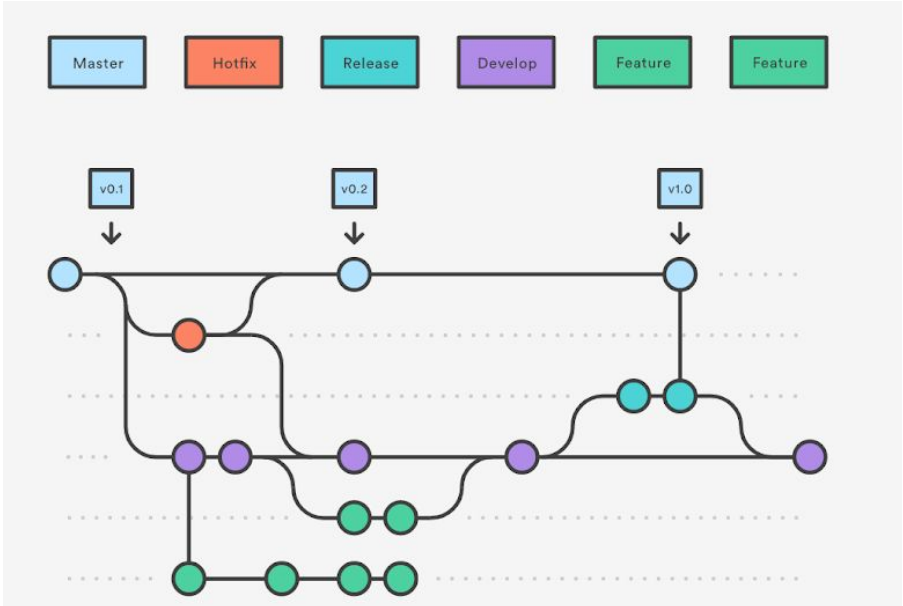

https://github.com/riogroup/SORA

Version: v0.2 (14/06/2021)

- SORA was published on PyPI;
  - pip install sora-astro
- Online full documentation and tutorials.
  - https://sora.readthedocs.io/

Software fully publicly (25/08/2021)

- Paper submitted to MNRAS;
- GitHub repository made public.
  - https://github.com/riogroup/SORA

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SORA: Stellar Occultation Reduction and Analysis

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SORA Modules

- body:
  - Small Body DataBase;
  - Ephemeris from SPICE kernels;
  - Ephemeris from JPL Horizons;
- star:
  - Gaia-DR2 and Gaia-EDR3;
  - Precise position propagation (6 astrometric parameters);
- observer (Minor Planet Center, Spacecraft):
  - Minor Planet Center;
  - Spacecraft (SPICE kernels, Horizons)

SORA Modules

- lightcurve:
  - Determination of the occultations instants;
  - Light diffraction, stellar size, occultation velocity, exposure, readout time;
- prediction:
  - For Earth, an individual observation, or spacecraft.
- occultation:
  - Fit of elliptical shapes to the chords.
- Other features:
  - plots;
  - chisquare.

SORA Overview

Stellar Occultations

A stellar occultation occurs when a solar system object passes in front of a star for an observer on Earth, and its shadow causes a temporary drop in the observed flux of the star. This technique allows the determination of sizes and shapes with kilometre precision and to obtain characteristics of the object, such as its albedo, the presence of an atmosphere, rings, jets, or other structures around the body (Sicardy et al. 2011, 2016, Braga-Ribas et al. 2013, 2014, 2019, Dias-Oliveira et al., 2015, Benedetti-Rossi et al., 2016, 2019, Ortiz et al., 2015, 2017, 2020, Leiva et al., 2017, Bérard et al., 2017, Morgado et al., 2019, Gomes-Júnior et al., 2020, Souami et al., 2020, Santos-Sanz et al., 2021) or even the detection of topographic features (Dias-Oliveira et al. 2017).

[1]:
```
## SORA package
from sora import Occultation, Body, Star, LightCurve, Observer
```

•••

[3]:
```
chariklo = Body(name='Chariklo',
                ephem=['input/bsp/Chariklo.bsp', 'input/bsp/de438_small.bsp'])

star_occ  = Star(coord='18 55 15.65250 -31 31 21.67051') # Occ Chariklo 22-06-2017
```

•••

[4]:
```
occ = Occultation(star=star_occ, body=chariklo, time='2017-06-22 21:18')
```

•••

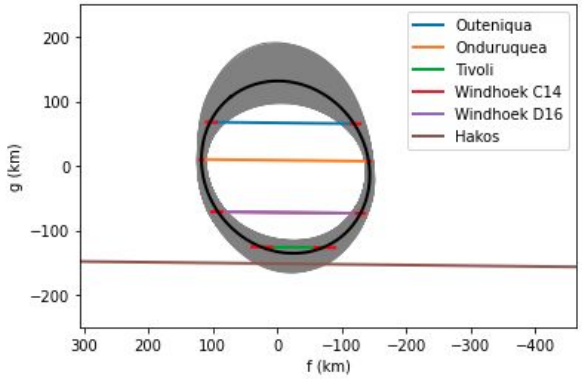
[6]:
```
out = Observer(name='Outeniqua'  ,lon='+16 49 17.710', lat='-21 17 58.170', height =1416)
ond = Observer(name='Onduruquea' ,lon='+15 59 33.750', lat='-21 36 26.040', height =1220)
tiv = Observer(name='Tivoli'     ,lon='+18 01 01.240', lat='-23 27 40.190', height =1344)
whc = Observer(name='Windhoek'   ,lon='+17 06 31.900', lat='-22 41 55.160', height =1902)
hak = Observer(name='Hakos'      ,lon='+16 21 41.320', lat='-23 14 11.040', height =1843)
```

[7]:
```
out_lc = LightCurve(name='Outeniqua lc',
                    initial_time='2017-06-22 21:20:00.056',
                    end_time ='2017-06-22 21:29:59.963',
                    immersion='2017-06-22 21:21:20.329',immersion_err=0.320,
                    emersion ='2017-06-22 21:21:30.343',emersion_err=0.340)

ond_lc = LightCurve(name='Onduruquea lc',
                    initial_time='2017-06-22 21:11:52.175',
                    end_time ='2017-06-22 21:25:13.389',
                    immersion='2017-06-22 21:21:22.213',immersion_err=0.100,
                    emersion ='2017-06-22 21:21:33.824',emersion_err=0.110)

tiv_lc = LightCurve(name='Tivoli lc',
                    initial_time='2017-06-22 21:16:00.094',
                    end_time ='2017-06-22 21:28:00.018',
                    immersion='2017-06-22 21:21:15.628',immersion_err=0.700,
                    emersion ='2017-06-22 21:21:19.988',emersion_err=0.700)

whc_c14_lc = LightCurve(name='Windhoek C14 lc',
                    initial_time='2017-06-22 21:12:48.250',
                    end_time ='2017-06-22 21:32:47.963',
                    immersion='2017-06-22 21:21:17.609',immersion_err=0.240,
                    emersion ='2017-06-22 21:21:27.564',emersion_err=0.260)

whc_d16_lc = LightCurve(name='Windhoek D16 lc',
                    initial_time='2017-06-22 21:20:01.884',
                    end_time ='2017-06-22 21:22:21.894',
                    immersion='2017-06-22 21:21:17.288',immersion_err=0.280,
                    emersion ='2017-06-22 21:21:27.228',emersion_err=0.340)

hak_lc = LightCurve(name='Hakos lc',
                    initial_time='2017-06-22 21:10:19.461',
                    end_time ='2017-06-22 21:30:19.345')
```

Usage of SORA

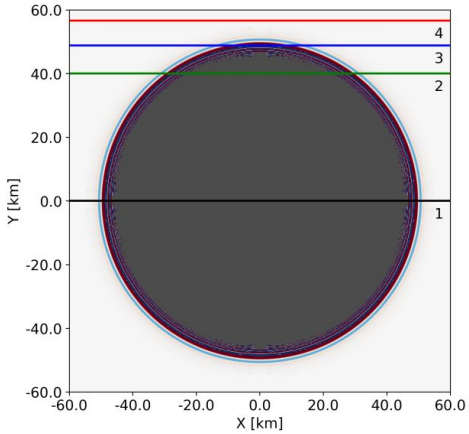
- Python environments;
- Jupyter notebooks;

[34]:
```
occ.chords.plot_chords()
occ.chords.plot_chords(segment='error', color='red')

#plotting the best fitted ellipse, in black
draw_ellipse(**ellipse_chi2.get_values())

# ploting all the ellipses within 3-sigma, in gray
draw_ellipse(**ellipse_chi2.get_values(sigma=3),alpha=1.0,lw=1)

pl.legend(loc=1)
pl.xlim(+170,-330)
pl.ylim(-250,+250)
pl.show()
```

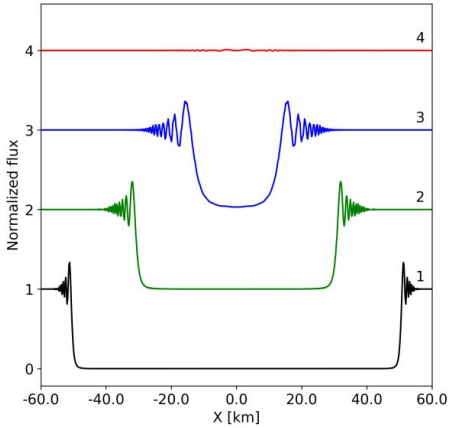


Future of SORA

- LightCurve multiple detection;
- Atmosphere;
- Rings;
- Rotation Phase characterization;
- Fit to 3D Shape models;
- Multiple Stars;
- Analysis of topographical features;
- Occultation Simulation;
- Multiple Occultation fitting process;
- Many other improvements.

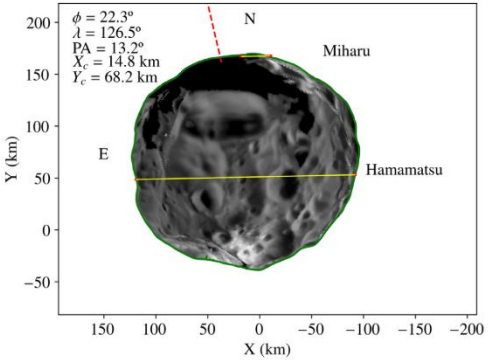


(a) Simulated 2D diffraction pattern

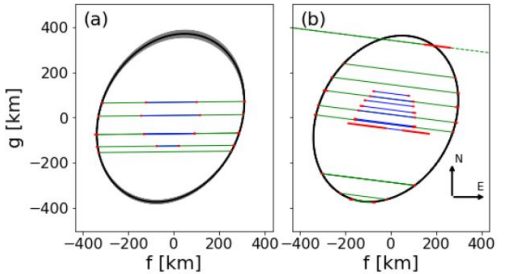


(b) Simulated light curves

Improvement on light curve model



Phoebe occultation (Gomes-Júnior et al, 2020)



Chariklo rings (Morgado et al, 2021)

SORA

Thanks!

SORA - Terms of Use

1. From the **collaboration Rio/Granada/Paris** with objects that are up to discussion by the collaboration (TNOs, Centaurs, ...). In this case, the SORA team may have the possibility to decide if any of its PIs should be co-author of the publication. The SORA team will commit to:

    a. Teach the functionalities of the SORA package in a hands-on session or individually;
    b. Run SORA if necessary;
    c. Fix any bug with urgency;
    d. Implement new requested features with high priority;

2. Anyone **outside** the collaboration or by someone from the collaboration but with objects that are not up to discussion by the collaboration (e.g. Main-Belt Asteroids, NEAs). In this case, the SORA team will not demand the possibility to become a co-author. As a drawback, the SORA team will not consider urgent any bug reported (unless it is a critical bug) in these cases nor be available to teach. If the user wants more priority or attention by the team a discussion will be made in advance to discuss the addition of a specific co-author from the SORA team.