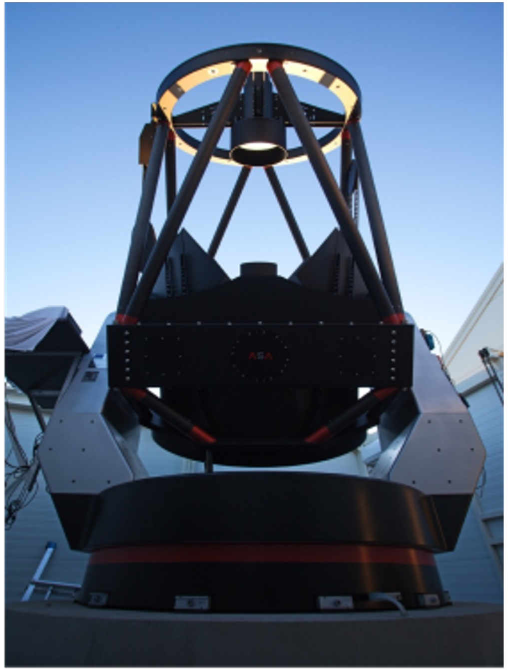
SER-SAG team in-kind contribution to Vera C. Rubin "Legacy Survey of Space and Time"

Luka Č. Popović, Dragana Ilić, Anđelka Kovačević, Jelena Kovačević-Dojčinović, Saša Simić, Viktor Radović, Đorđe Savić, Maša Lakićevič, Slađana Marčeta-Mandić, Marina Pavlović, Mladen Nikolić, Oliver Vince, Ana Vudragović, Isidora Jankov, Iva Čvorović Hajdinjak, Nemanja Rakić, Miljan Knežević

Astronomy at University of Belgrade from 1865th
Astronomical Observatory Belgrade (AOB) founded in 1887



AOB, Main building Belgrade
Astronomical Station Vidojevica

AOB

Astronomy at University of Belgrade from 1865th
Astronomical Observatory Belgrade (AOB) founded in 1887

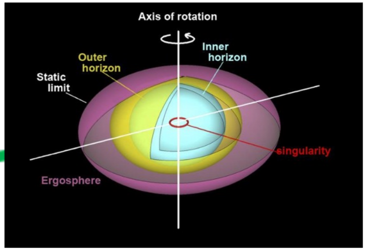
Close collaboration with other research institutes in Serbia

- Department of Astronomy, University of Belgrade - Faculty of Mathematics
- Institute of Physics Belgrade, National Institute of the Republic of Serbia
- Faculty of Science, University of Kragujevac
- Mathematical Institute of the Serbian Academy of Science and Arts
- Institute "Mihajlo Pupin" (Electrical Engineering or Computer Science)
- etc.

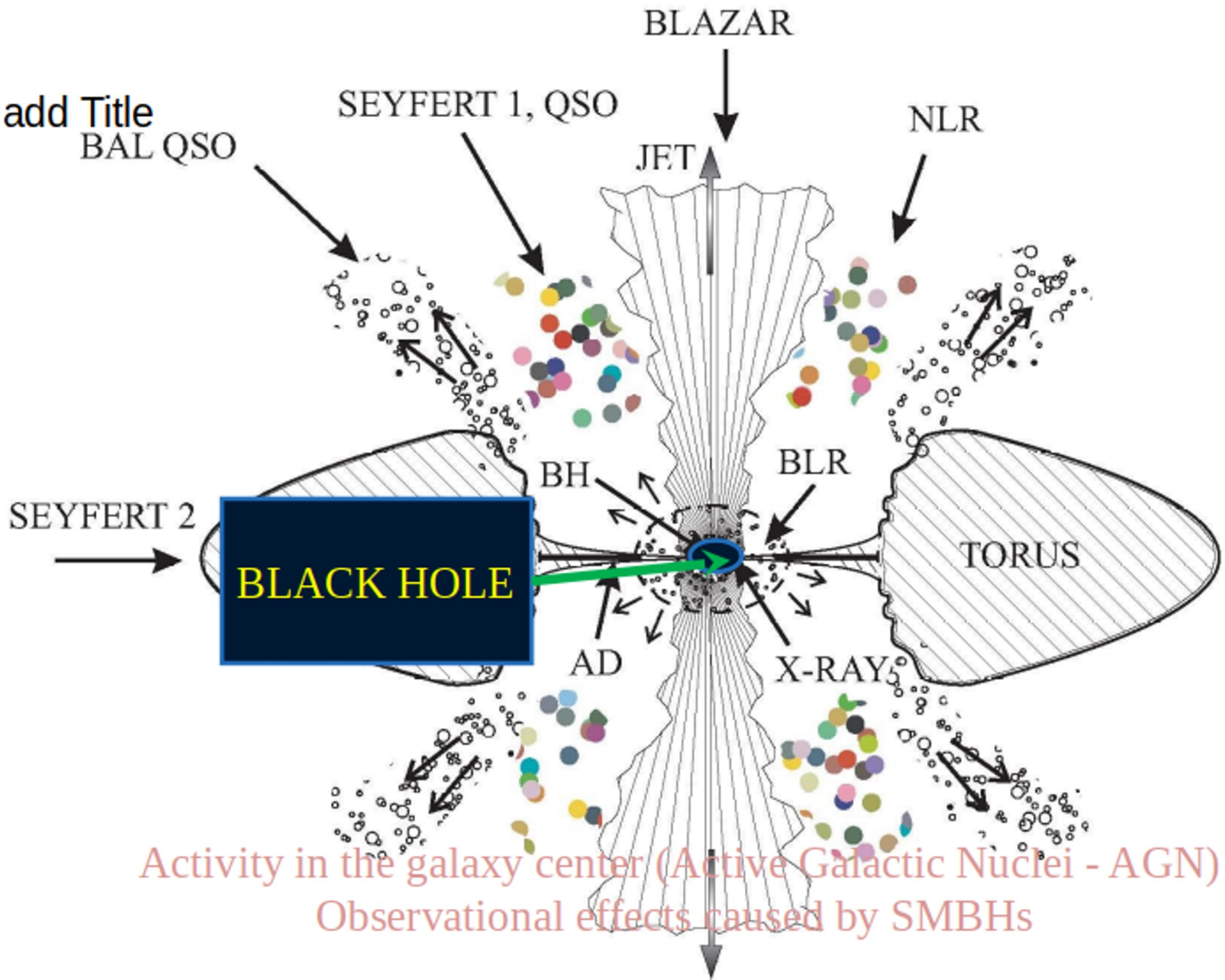
Activity in galaxy caused by SMBH

Activity in galaxy caused by SMBH

BLACK HOLE

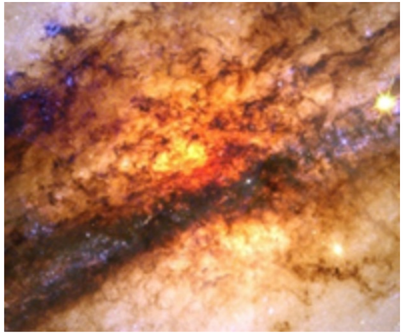


Click to add Title



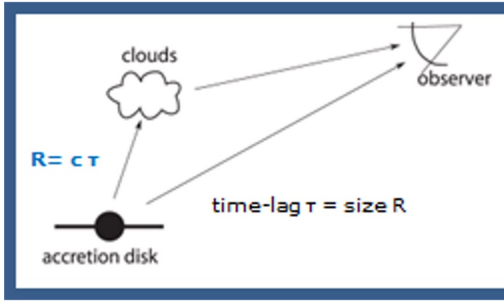
Activity in the galaxy center (Active Galactic Nuclei - AGN)
Observational effects caused by SMBHs

AGN variability → hot topics



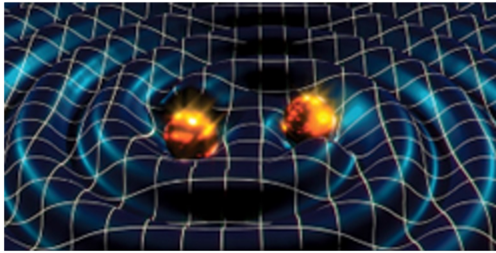
- AGN core difficult to resolve with current optical telescopes (except w/interferometry, e.g. GRAVITY Sturm+2018, EHT Collaboration, 2019)

we can resolve it in time-domain



- study AGN accretion disk and BLR through **reverberation mapping**:

one of the priorities of LSST AGN SC (e.g. Brandt et al. 2018)



- detect oscillation in AGN light curves, **searching for periodicities**

important for detection of close binary SMBHs, and possible GW sources (for a recent review see De Rosa et al. 2020)

SER-SAG in-kind

LSST call for in-kind proposals in september 2020

Serbian AGN Team in LSST ⟶ **SER-SAG**

– members of LSST Science Collaborations: AGN, TVS, GL

Institutions: Astronomical Observatory, University of Belgrade – Faculty of Mathematics

Proposal Lead: Luka C. Popovic

Project Manager: Dragana Ilic

- **we identified possible in-kind efforts:**

  1. **Directable software development** - expertise on analysis of variability of celestial sources, especially AGN
  2. **Optical follow-up observations** with AS Vidojevica

1.4m Milankovic telescope

Proposal for SER-SAG in-kind LSST contribution

to provide access to LSST data rights

submitted in september 2020

Proposal Title: AOB's and UBMatF's In-kind Contributions to the Vera C. Rubin Observatory Legacy Survey of Space and Time

Participating Institutions: Astronomical Observatory – Belgrade (AOB) and University of Belgrade - Faculty of Mathematics (UBMatF)

Program Code: SER-SAG

Key Personnel:

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SER-SAG in-kind LSST contribution

(2 in-kind + Kickstarter Grant + LSSTC DLE project):

Project Manager:Luka Č. Popović (AOB, UB-MATF)

Program Manager: Dragana Ilić (UB-MATF)

1.Directable software development for analysis of variability of celestial sources**:** Andjelka Kovačević(lead), Viktor Radović(postdoc), Mladen Nikolić (scientific computing supervisor)

2. Optical follow-up of bright LSST transients with AS Vidojevica: Jelena Kovačević Dojčinović (lead), Dragana Ilić, Maša Lakićević, Sladjana Marčeta-Mandić, Ana Vudragović, Oliver Vince, Saša Simić, Branislav Vukotić

LSST TVS SC Kickstarter project (UK-PMF) : SašaSimic (lead)

LSST Corp DLE project: Andjelka Kovačević(co-PI), Dragana Ilić(co-PI), Isidora Jankov (PhD student), Nikola Andrić Mitrović (IT student), Iva Čvorović-Hajdinjak (PhD student)

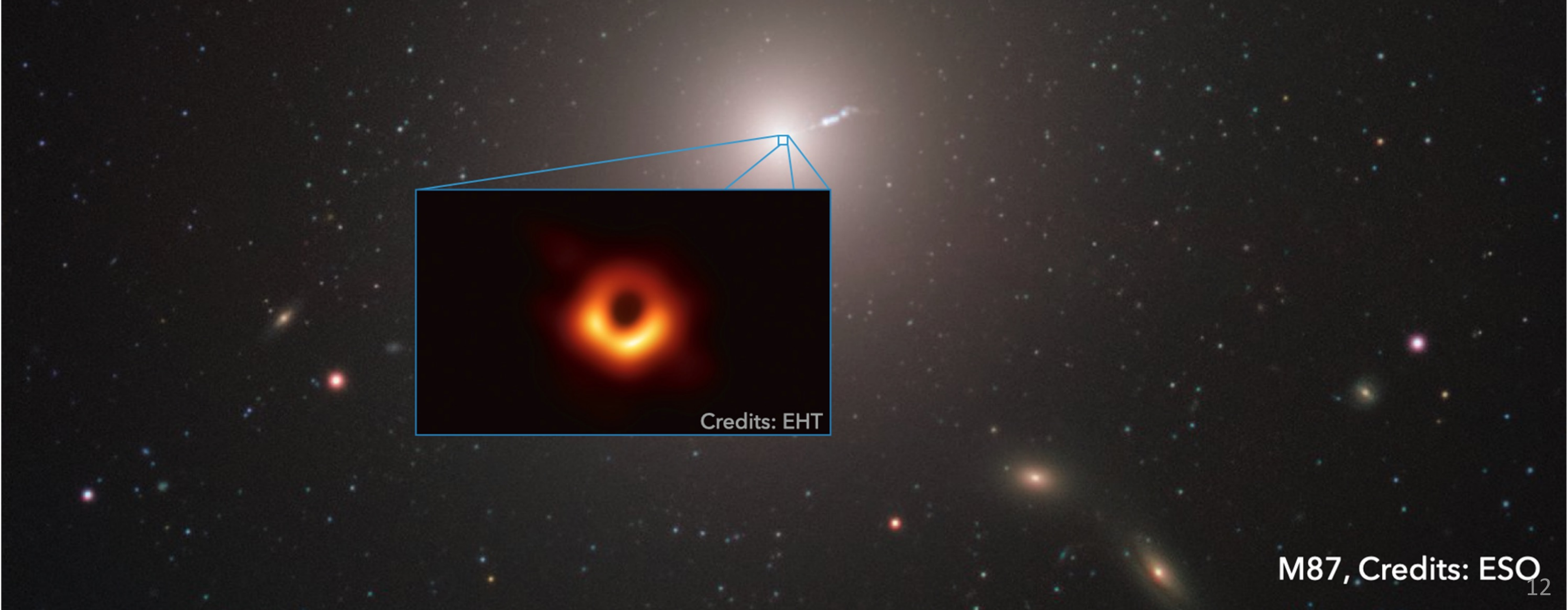
Dragana Ilic

Department of astronomy
University of Belgrade - Faculty of Mathematics

SER-SAG in-kind Project Manager

Active Galactic Nuclei (AGN)

AGNs are powered by the release of gravitational energy related with the accretion of material onto a supermassive black hole (SMBH), with masses larger than $10^6\ M_\odot$



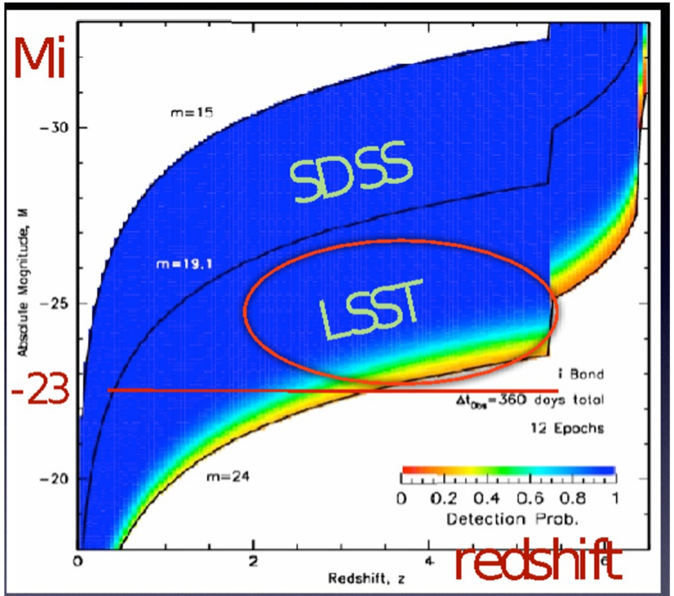
Credits: EHT

M87, Credits: ESO

AGN within the LSST

- discovery about 10 million quasars
  - based on colors, variability, lack of proper motion
  - detection of ~10,000 quasars at 6<z<7.5

- 5 Deep Drilling Fields (DDFs):
  - COSMOS, XMM-LSS, ECDFS, ELAIS-S1, EDFS
- AGN Variability – based on million of light curves with 1000 epochs over 10 years



Top: absolute magnitude vs. redshift diagram for quasars

Learn more through AGN Science Collaboration @https://agn.science.lsst.org

Our contributions…

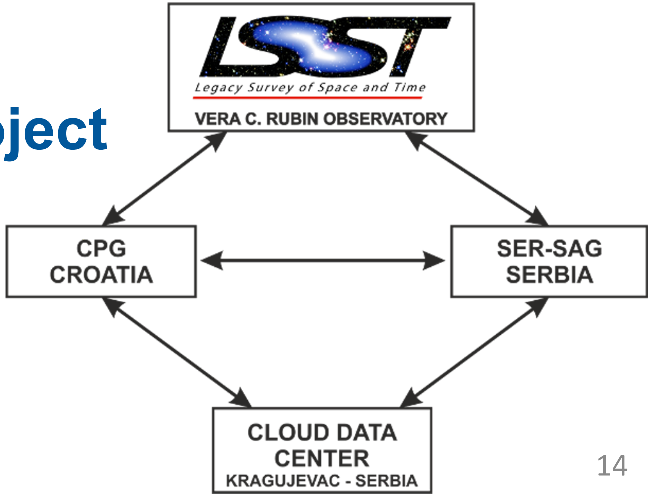
Approved by LSST Corporation

•In-kind directable software contribution, giving us access to data amount with equivalent worth 6 PIs (Data Right Holders)

•Building Deep Learning Engine (DLE) for AGN light-curves

Approved as LSST TVS SC Kickstarter project

-Data storage based on QNAP platform with over 250TB of available disk space



Project DLE: Deep Learning Engines

2021 Enabling Science Call project

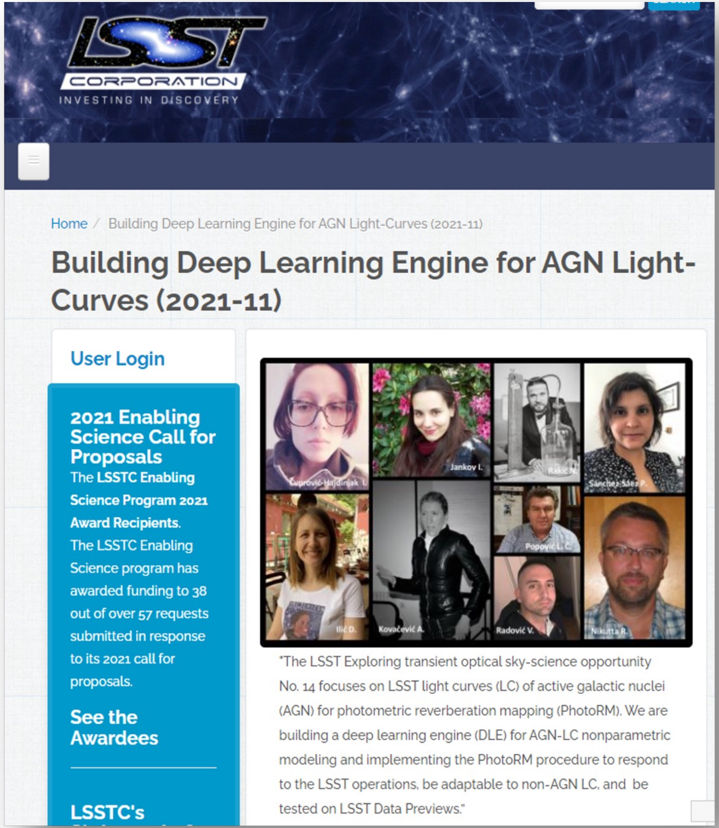
”Building Deep Learning Engine (DLE) for AGN light-curves”

- support for **student research** for 10 months in 2021-2022: we had 3 students

Visit us

@ https://github.com/LSST-sersag/dle

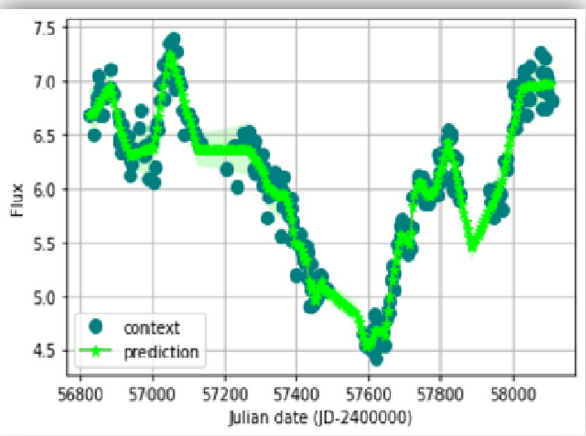
@https://www.lsstcorporation.org/node/265



LSST Enabling science: Two main DLE tasks published in Astronomiche Nachrichten i n 2022

DLE task 1 (DLE1):

Light Curve nonparametric modeling (Conditional Neural Process)

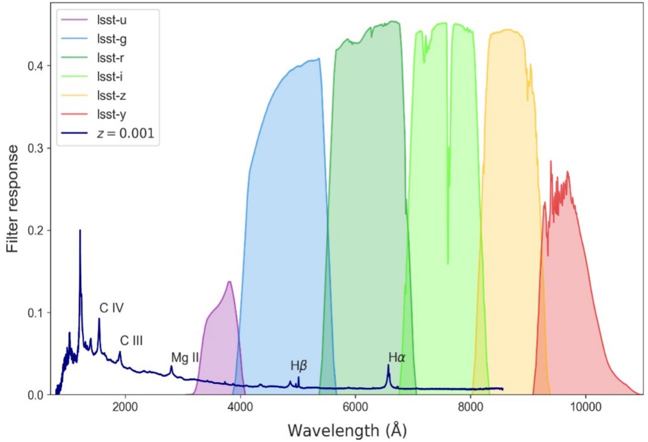


Learned LC will enable us to improve time-lag determination as a goal of PhotoRM. periodicity, etc.

→ see Cvorovic-Hajdinjak et al. 2022

DLE task 2 (DLE2):

photometric reverberation mapping (PhotoRM)



New tools for PhotoRM based on the formalism by Chelouche & Daniel (2012)

→ see Jankov et al. 2022

DLE task 2 (DLE2): **Photometric reverberation mapping** (PhotoRM)

1. New python module (pyZDCF) that emulates ZDCF - available on PyPI from **October 15th**!
2. New tutorial on Astro Data Lab (available soon)

```
# We use non-interactive mode (intr=False)
dcf_df = pyzdcf(input_dir=test_data,
                output_dir=results,
                intr=False,
                parameters = params,
                sep=',')
```

```
pyZDCF begins:

==============================
pyZDCF PARAMETERS:

Autocorrelation?   False
Uniform sampling?  False
Omit zero lags?    True
Minimal # in bin:  11
# of Monte Carlo:  100
Monte Carlo seed:  123456
==============================

Binning with minimum of 11 points per bin and resolution of 0.001

662 bins actually used, 667691 inter-dependent pairs discarded.

ccf_test.dcf written...

pyZDCF ended.
```

- Simple to use
- Familiar interface
- PhotoRM use case available in Astro Data Lab tutorial

Navigation

- Project description
- Release history
- Download files

Statistics

View statistics for this project via Libraries.io, or by using our public dataset on Google BigQuery

Meta

License: MIT License (MIT)

Author: Isidora Jankov

Requires: Python >=3.8, <3.11

Maintainers

cefeida42

Project description

pyZDCF

Description

pyZDCF is a python module that emulates a widely used Fortran program called ZDCF (Z-transformed Discrete Correlation Function, Alexander 1997). It is used for robust estimation of cross-correlation function of sparse and unevenly sampled astronomical time-series. This Python implementation also introduces sparse matrices in order to significantly reduce memory load when running the code on large time-series (> 3000 points).

Developing pyZDCF module, which is based on the original Fortran code fully developed by Prof. Tal Alexander, from Weizmann Institute of Science, Israel (see Acknowledgments for details and further reading) was motivated by the long and successful usage of the original ZDCF Fortran code in the investigation of light curves of active galactic nuclei by our research group (see Kovacevic et al. 2014, Shapovalova et al. 2019, and reference therein).

Purpose

One of the science cases we investigate is photometric reverberation mapping (PhotoRM) in the context of LSST survey strategies (see Jankov et al. 2022) where this module will be utilized, as well as for the PhotoRM with future LSST light curves.

Nontheless, this module is **general** and is meant to be used for cross-correlation of

At this moment, pyZDCF is available on Test PyPI: https://test.pypi.org/project/pyzdcf/

our main tasks

- deep learning of light curves originating close to SMBH, which is completely data driven. Our algorithm is based on PyTorch and currently trained on 150 000 light curves of AGN from already existed databases
- extraction of time signal delay from light curves originating in the vicinity of billions of SMBHs using machine learning techniques
- oscillatory signal mining in time domain (requires powerful GPU resources) from billions of stars and SMBH. The latter is related to GW nGHz candidates
- provide follow-up observations with 1.4m optical telescope

SER-SAG in-kind projects

SER-SAG-1

Science Pipeline Development for analysis of variability of celestial sources in the LSST AGN and TVS Science Collaboration

Contribution lead: Andjelka Kovacevic

SER-SAG-2

Optical follow-up of bright LSST transients with Milankovic 1.4 Telescope

Contribution lead: Jelena Kovacevic Dojcinovic

Andjelka Kovacevic

Department of astronomy
University of Belgrade - Faculty of Mathematics

SER-SAG1 Contribution Lead

Rubin In-Kind half year update on development of time domain pipeline for periodicity searching

A. Kovačević[1], D. Ilić [1], V. Radović[1], R. Street[2], L. Č. Popović[1,3], M. Pavlovic[1,4], M. Nikolić[1], N. Andrić Mitrović[1], I. Čvorović-Hajdinjak[1]

[1]Department of Astronomy, University of Blegrade, Serbia
[2]Las Cumbres Observatory, Goleta, CA , USA
[3]Astronomical Observatory Belgrade, Serbia
[4] Mathematical Institute SASA, Serbia

LSST Community Engagement

SER-SAG contribution to OpSim evaluations

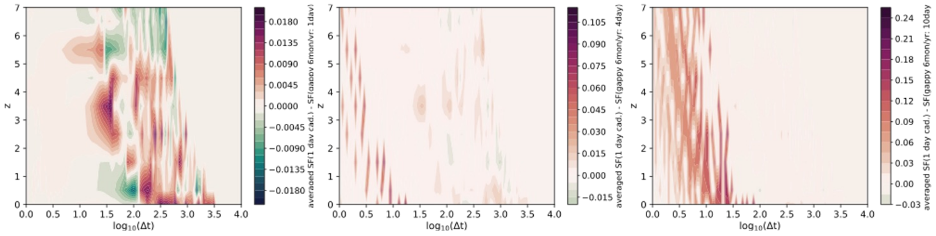
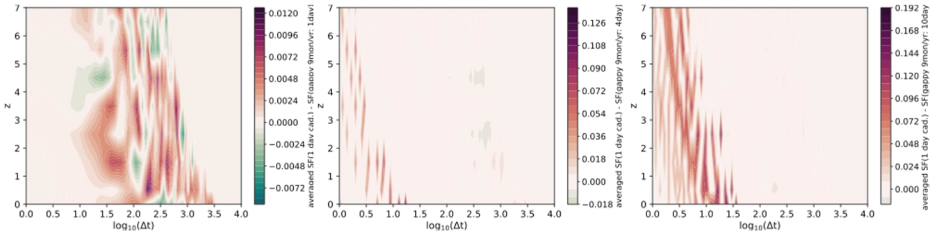


Figure 9. The same as Fig. 8 but for cadence 6 month/yr in the rest frame of quasar.



Andjelka B Kovačević, Dragana Ilić, Luka Č Popović, Viktor Radović, Isidora Jankov, Ilsang Yoon, Neven Caplar, Iva Čvorović-Hajdinjak, Saša Simić, On possible proxies of AGN light-curves cadence selection in future time domain surveys, *Monthly Notices of the Royal Astronomical Society*, Volume 505, Issue 4, August 2021, Pages 5012–5028, https://doi.org/10.1093/mnras/stab1595

Kovacevic, Andjelka, Ilic, Dragana, Jankov, Isidora, Popovic, Luka C., Yoon, Ilsang, Radovic, Viktor, Caplar, Neven, and Cvorovic-Hajdinjak, Iva: LSST AGN SC Cadence Note: Two metrics on AGN variability observable,https://docushare.lsst.org/docushare/dsweb/Get/Document-37645/Cadence_Notes-AGN_var.pdf

SER-SAG contribution to OpSim evaluations

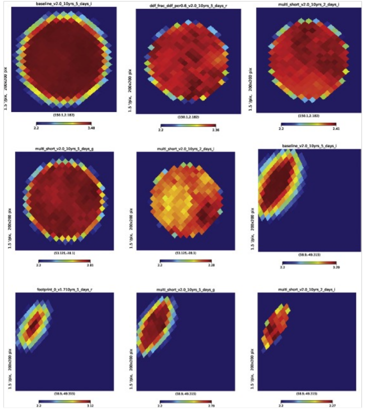


Figure 7. Zoom-in of metric values (indicated in color bars) in DDFs for different cadence strategies (given in panel titles) for the r, g, *and* i bands. Upper row: COSMOS. Middle row: first and second panels: ECDFS; third panel: EDFS_a. Bottom row: EDFS_a.

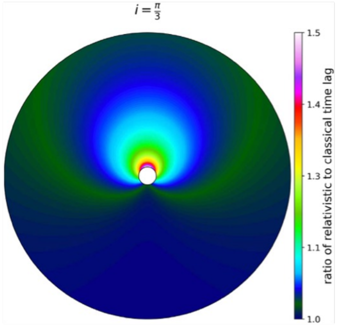


Figure 5. Distribution of ratio of the time delay calculated from a relativistic and a classical spacetime approximation, when $a \to 1$. The inclination of the observer is set to $i = \frac{\pi}{3}$, the region extent to $10r_g$, and the SMBH mass is $10^8 M_\odot$. The dark green color depicts a ratio value of ~ 1.075. The small white circle is a 'plunging region' inside the marginally stable orbit of $r_{ms} = 1.24r_g$. The color bar shows the ratio between relativistic and classical time lags. The ratio is highest where the light-bending effects are largest, i.e., near the SMBH. As the distance increases, the ratio approaches 1, because spacetime is almost flat.

The Astrophysical Journal Supplement Series, 262:49 (37pp), 2022 October https://doi.org/10.3847/1538-4365/ac88ce

The LSST Era of Supermassive Black Hole Accretion Disk Reverberation Mapping

Andjelka B. Kovačević[1,2], Viktor Radović[1], Dragana Ilić[1,3], Luka Č. Popović[1,4], Roberto J. Assef[5], Paula Sánchez-Sáez[6,7], Robert Nikutta[8], Claudia M. Raiteri[9], Ilsang Yoon[10], Yasaman Homayouni[11], Yan-Rong Li[12], Neven Caplar[13], Bozena Czerny[14], Swayamtrupta Panda[14,15,16], Claudio Ricci[17,18], Isidora Jankov[1], Hermine Landt[19], Christian Wolf[20,21], Jelena Kovačević-Dojčinović[4], Maša Lakićević[4], Đorđe V. Savić[4,22], Oliver Vince[4], Saša Simić[23], Iva Čvorović-Hajdinjak[1], and Sladjana Marčeta-Mandić[4]

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Received 2022 April 1; revised 2022 August 8; accepted 2022 August 9; published 2022 October 3

Abstract

The Vera C. Rubin Observatory's Legacy Survey of Space and Time (LSST) will detect an unprecedentedly large sample of actively accreting supermassive black holes with typical accretion disk (AD) sizes of a few light days. This brings us to face challenges in the reverberation mapping (RM) measurement of AD sizes in active galactic nuclei using interband continuum delays. We examine the effect of LSST cadence strategies on AD RM using our metric `AGN_TimeLagMetric`. It accounts for redshift, cadence, the magnitude limit, and magnitude corrections for dust extinction. Running our metric on different LSST cadence strategies, we produce an atlas of the performance estimations for LSST photometric RM measurements. We provide an upper limit on the estimated number of quasars for which the AD time lag can be computed within $0 < z < 7$ using the features of our metric. We forecast that the total counts of such objects will increase as the mean sampling rate of the survey decreases. The AD time lag measurements are expected for >1000 sources in each deep drilling field (DDF; (10 deg^2)) in any filter, with the redshift distribution of these sources peaking at $z \approx 1$. We find the LSST observation strategies with a good cadence ($\lesssim 5$ days) and a long cumulative season (~ 9 yr), as proposed for LSST DDF, are favored for the AD size measurement. We create synthetic LSST light curves for the most suitable DDF cadences and determine RM time lags to demonstrate the impact of the best cadences based on the proposed metric.

Unified Astronomy Thesaurus concepts: Quasars (1319); Accretion (14); Time domain astronomy (2109); Reverberation mapping (2019)

SER-SAG contributions to LINCC White Paper: From Data to Software to Science with the Rubin Observatory LSST: Deep Learning of LSST Light curves

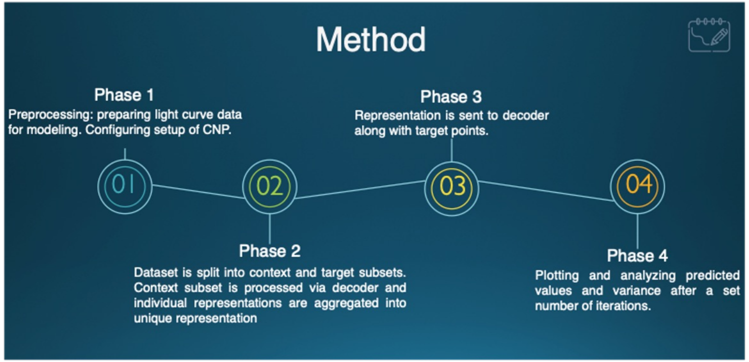

Figure 1. Steps in the conditional neural process method's application. The encoder and aggregator process context points. This process's output is passed to the decoder, together with target points, to calculate predictions. The last unit visualizes both the original and predicted data.

B.4.2. *Conditional Neural Processes for learning AGN light curves*

Contributors: Andjelka B. Kovačević (andjelka@matf.bg.ac.rs), Dragana Ilić (dilic@matf.bg.ac.rs), Paula Sánchez-Sáez (pasanchezsaez@gmail.com), Iva Čvorović Hajdinjak, Robert Nikutta (robert.nikutta@noirlab.edu), Nikola Andrić Mitrović, Mladen Nikolicć (nikolic@matf.bg.ac.rs, Viktor Radović (rviktor@matf.bg.ac.rs), Luka Č Popović (lpopovic@aob.rs)

B.4.2.1. *Abstract*—The next generation time domain surveys, such as Vera Rubin Observatory Legacy Survey of Space and Time (LSST, see Ivezić et al. 2019, and references therein), will provide observations with different cadences over ten years for millions of active galactic nuclei (Bianco et al. 2021; Brandt et al. 2018, AGN) in six filters - *ugrizy*. The consequences of complex, disturbed environments in the vicinity of a supermassive black hole are not well represented by standard statistical models of optical variability in AGN. Thus, developing new methodologies for investigating and modeling AGN light curves is crucial e.g. (Tachibana et al. 2020). Conditional Neural Processes (CNP, Garnelo et al. 2018) are nonlinear function models that forecast stochastic time series based on a finite amount of known data without the use of any object parameters or prior knowledge (kernels). Čvorović-Hajdinjak et al. (2022) provide an initial Conditional Neural Processes (CNP) algorithm that is specifically designed for learning AGN light curves for the intended periodicity pipeline. It was trained using data from:

- the All-Sky Automated Survey for Supernova (ASAS-SN; Holoien et al. 2017), which included 153 AGN
- about 40,000 light curves from Zwicky Transient Facility data release 5 (ZTF DR5; Sánchez-Sáez et al. 2021).

SER-SAG contributions to LINCC White Paper: From Data to Software to Science with the Rubin Observatory LSST: Deep Learning for AGN selection

B.4.5. *Developing machine learning methods for AGN selection and calculating photometric redshift*

Contributors: Đorđe Savić (djsavic@aob.rs), Isidora Jankov (isidora_jankov@matf.bg.ac.rs), Anđelka Kovačević (andjelka@matf.bg.ac.rs), Dragana Ilić (dilic@matf.bg.ac.rs), Luka Č. Popović (lpopovic@aob.rs), Mladen Nikolić (nikolic.matf@gmail.com), Aleksandra Ćiprijanović (aleksand@fnal.gov)

B.4.5.1. *Abstract*—LSST will produce catalogs for a vast number of sources, which will usher astronomy into a new era of "big data." Machine learning (ML) deployment will be helpful in developing efficient models for various classification and regression tasks. We are focused on three main problems 1) AGN selection, 2) parameterization of AGN light curves and 3) estimating photometric redshifts of AGNs and galaxies. Variability will be the cornerstone for separating AGNs from variable stars. The addition of high quality imaging data will be crucial for separating AGNs from regular galaxies, allowing us to train ML classifiers with superb accuracy > 99%. Redshift estimates for the vast majority of LSST AGNs will rely on photometric estimates. Our goal is to develop an empirical regression method using all the possible sources of information: colors, fluxes, variability, differential chromatic refraction and multiwavelength data.

B.4.5.6. *Analysis Workflow* —

1. Data cleaning and identification of artifacts within the data (this will be iterative as we progressively remove/flag bad data from the time-series catalogs)
   - Remove poorly calibrated photometric data and sources flagged with suspicious photometry (e.g., on edge of CCD or diffraction spikes) and/or LSST DM source quality flags.
   - Remove/flag outlier measurements from a light curve.
2. Data storage and archives
   - The processed data at this stage does not require additional storage.
   - For the photometric redshift estimates, the AGN sources will be matched with the multimessenger data for accurate photometric redshift measurements.
3. Training and applying machine learning methods
   - Select sources with $N > N_{\text{threshold}}$ epochs of data, and within a specific SNR range.
   - Compute the LC features for all bands.
   - Training machine learning methods
   - Classifying all selected sources
   - Further development on machine learning methods used on the accurately classified AGNs for deeper understanding of AGN physics.

SER-SAG contributions to LSST AGN SC Data Challenge in prep

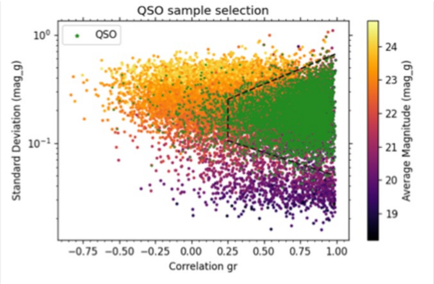

Figure 7. Standard deviation of the light curves vs. $g-r$ band correlation for a random sample of sources. Points are color-coded according to the g-band average magnitude. The black dashed lines define the *wedge* where QSOs (green points) tend to group.

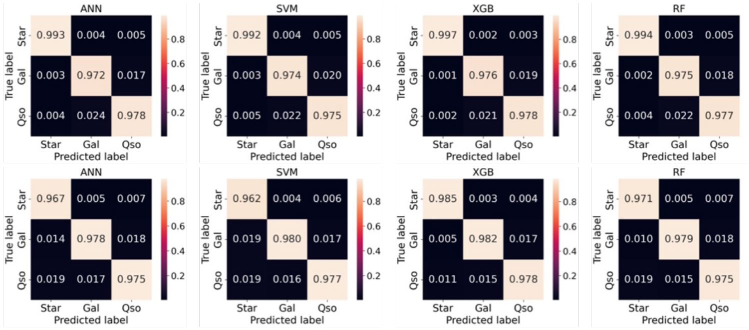

Figure 9. Confusion matrices for each method normalized by purity for tabular data. From left to right: ANN, SVM, XGB RF. Upper panels were computed on a test set, while lower panels were computed for a blinded set. True labels are placed o[n] vertical axis, while the predicted labels are on the horizontal axis.

The LSST AGN Data Challenge: Selection methods

Đorđe V. Savić[1,2] Isidora Jankov[3] Weixiang Yu[4] Vincenzo Petrecca[5,6] Matthew J. Temple[7,*] Qingling Ni[8] Raphael Shirley[9,10] Andjelka B. Kovačević[3,11] Mladen Nikolić[3] Dragana Ilić[3,12] Luka Č. Popović[2,3] Maurizio Paolillo[5,6] Swayamtrupta Panda[13,14,†] Gordon T. Richards[4] and Aleksandra Ćiprijanović[15]

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[8] *Institute for Astronomy, University of Edinburgh, Royal Observatory, Edinburgh EH9 3HJ, United Kingdom*
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ABSTRACT

The Rubin Observatory Legacy Survey of Space and Time (LSST) development comprises a series of Data Challenges (DC) arranged by various LSST Scientific Collaborations (SC) that take place during the project's preoperational phase. The AGN Science Collaboration Data Challenge (AGNSC-DC) is a partial prototype of the expected LSST AGN data, aimed to validate various machine learning approaches for AGN selection and characterization in large surveys. AGNSC-DC took part in 2021 focusing on accuracy, robustness and scalability. The training datasets were constructed to mimic the future LSST release catalogs using the publicly available data from the Sloan Digital Sky Survey Stripe 82 region and the XMM-Newton Large Scale Structure Survey region, with data features divided into astrometry, photometry, color, morphology, redshift, variability and class label.

LSST Inkind contribution - synergy AGN SC +TVS SC

LSST SER-SAG-1 TEAM

(In-kind+LSSTC DLE project):

Project Manager: Luka Č. Popović (AOB, UB-MATF)

Program Manager: Dragana Ilić (UB-MATF)

SER-SAG-1: In-kind directable software contribution (UB-MATF): Anđelka Kovačević (lead), Viktor Radović (postdoc), Marina Pavlovic (soon postdoc),Rachel Street (scientific supervisor), Sheyuan He ,Miljan Knezevic (statistical supervisors), Mladen Nikolić (scientific computing supervisor)

LSST Corp DLE project: Anđelka Kovačević (co-PI), Dragana Ilić(co-PI), Isidora Jankov (PhD student), Nikola Andrić Mitrović (IT student), Iva Čvorović-Hajdinjak (PhD student)

MATФ
University of Belgrade
Faculty of Mathematics

2) SER-SAG-1 Directable Software Team

S1.4.2 Deliverables: One Sentence Summary

SER-SAG staff aims to provide skilled software development effort, using already-secured funding, at the level of 0.9 FTE during the first two years followed by ~~0.6 FTE per year for next 3 years,~~ starting in FY22.

S1.4.3 Deliverables: Timeline

FY22: **Dr. Andjelka Kovacevic** (senior dedicated to software code development, 0.5 FTE), **Viktor Radovic** (postdoc 0.3 FTE), Dr. **Mladen Nikolic (**software engineer, 0.1 FTE),

FY23: **Dr. Andjelka Kovacevic** (senior dedicated to software code development 0.5 FTE), **Viktor Radovic** (postdoc 0.3 FTE), **Dr. Mladen Nikolic (**software engineer, 0.1 FTE),

FY24: **Dr. Viktor Radovic** (postdoc, 0.5 FTE), **Dr. Mladen Nikolic** (software engineer, 0.1 FTE)

FY25: **Dr. Viktor Radovic(**postdoc, 0.5 FTE), **Dr. Mladen Nikolic** (software engineer, 0.1 FTE),

FY26: **New hire postdoc** (0.5 FTE), **Dr. Mladen Nikolic** (software engineer, 0.1 FTE)

FY27-FY35: potential continued contribution of development effort.

Dr. Andjelka Kovacevic will act as a single point of contact with the recipients for this programme, but the other team members will also be embedded within the recipient teams. From FY24, Dr Viktor Radovic will become a single point of contact.

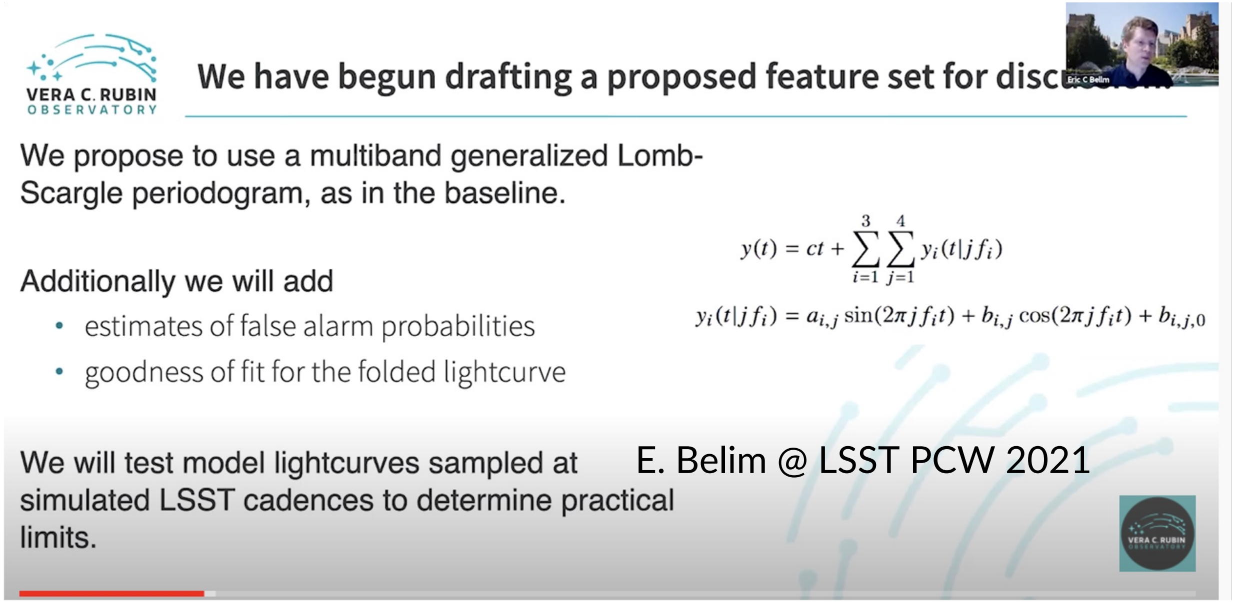
Contribution Lead and Point of Contact: Andjelka Kovacevic: andjelka@math.rs
Program Manager: Dragana Ilic: dilic@math.rs

VERA C. RUBIN OBSERVATORY

1) Motivation-[Draft Rubin Timeseries Features](https://project.lsst.org/meetings/rubin2021/content/timeseries-variability-features)

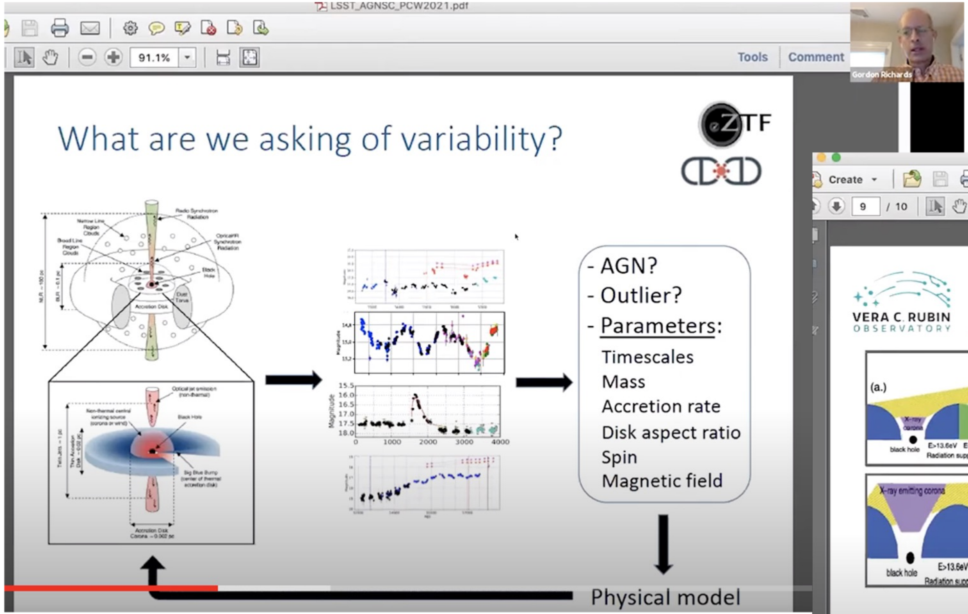
FEATURES ARE SPLIT IN 4 CATEGORIES:

- summary statistic,
- periodicity,
- stochastic variability,
- transient characterisation

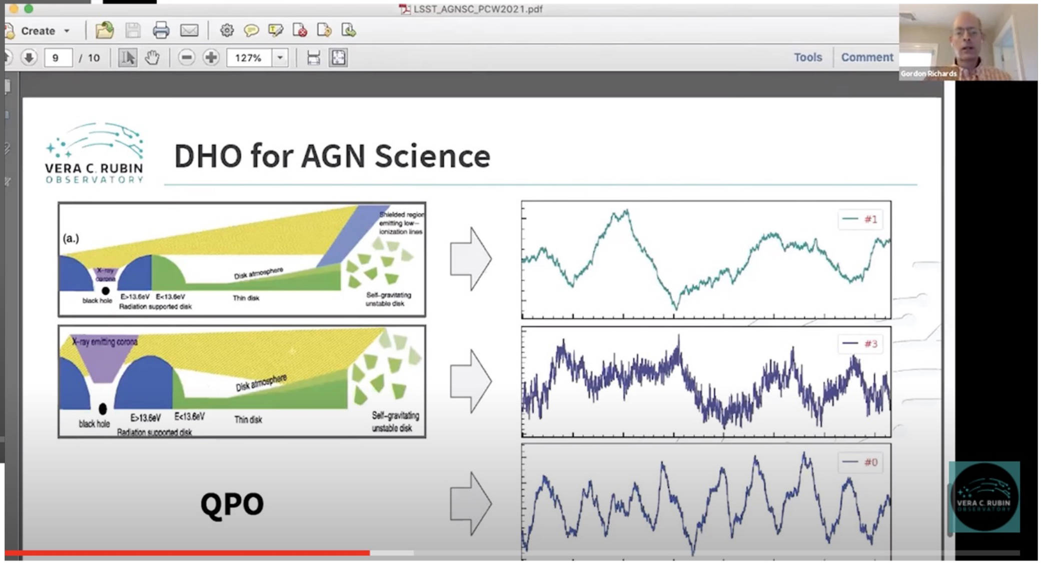


https://project.lsst.org/meetings/rubin2021/content/timeseries-variability-features

1) Motivation-Draft Rubin Timeseries Features



G. Richards, M. Graham @ LSST PCW 2021



G. Richards, W. Yu @ LSST PCW 2021

https://project.lsst.org/meetings/rubin2021/content/timeseries-variability-features

1) Motivation- tie to AGN SC roadmap

Chapter 3: AGN Variability Science

Yan-Fei Jiang, Carole Mundell, Ohad Shemmer, Chelsea L. MacLeod, Aaron Barth, Paulina Lira, Christina Peters, Andy Lawrence, et al.

3.2 Ordinary AGN Variability

Searches for periodically variable quasars have uncovered an increasing number of candidates using data from the Catalina Real-Time Transient Survey (CRTS) and from Pan-STARRS (Graham et al. 2015a,b; Liu et al. 2015; Zheng et al. 2016). Typical examples from CRTS have candidate periods of $\sim 2-4$ yr, corresponding to estimated binary separations of order $\sim 10^{-2}$ pc (Graham et al. 2015b). Some caution is warranted in periodicity searches, however, since DRW or other stochastic behavior can easily produce spurious quasi-periodicities over a short duration, and some false positives are likely to be found when searching large quasar samples. A necessary step is to carry out realistic Monte Carlo simulations to test any possible variability signal against the null hypothesis of aperiodic behavior, in order to assess the probability of a false positive periodicity signal (Vaughan et al. 2016). Once a candidate periodic quasar is identified, further monitoring is needed over longer timescales to test whether the past periodicity predicts future behavior. Any confirmed periodic quasars will be important targets for extensive follow-up to determine their physical properties, and could provide potential candidates for gravitational-wave studies. LSST will excel at producing quasar light curves with high signal-to-noise, long duration, and frequent sampling, which will provide the best database for identifying and verifying possible cases of periodic variability.

VERA C. RUBIN OBSERVATORY

1) Motivation-TVS Software proposals

SER-SAG contribution is embedded in TVS SC

TVS comment on necessity of efforts on periodicity detection:

Lovro Palaversa	Light curve metrics and period search	Although not explicitly mention, most of the DDF and Intrinsic Galactic and Local Universe science cases relevant to TVS imply that software needed to compute basic metrics and determine the periods of the sources will be required.

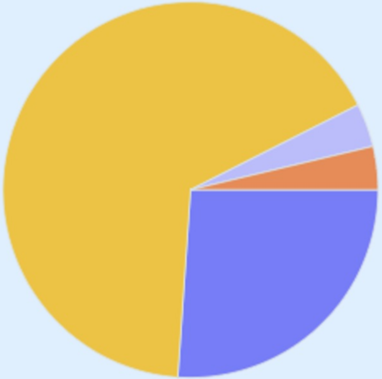
SER-SAG Contribution Team presented Contribution
@TVS Software Workshops:
28 & 29, October 2021; **May 4 & 5, 2022**

VERA C. RUBIN OBSERVATORY

Targeted Audience-based on google form for collecting user-stories https://forms.gle/SstDis1t5KJiMFrY6

General

percents



AGN 25.9 TVS 66.0 DESC 3.7 ISSC 3.7

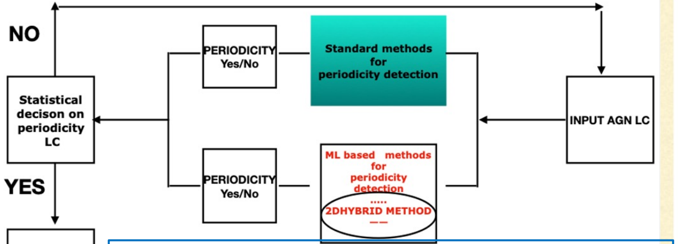
TVS Specific community

- Pulsating variable stars
- luminous red novae
- variable stars, periodic variable stars, anomaly detection
- Supernovae, transients, multi-wavelength/messenger
- WD merger events, RCB stars, stellar pulsations
- Periodic variable stars (EB and pulsating stars) for the distance scale applications.
- Star formation
- RR Lyraes and Cepheids. Developing machine learning classification algorithms.
- variable stars, distance scales, exotic transients
- X-ray Binaries, Provenance, Workflow Management
- Young stellar objects; accretion process; star forming regions

Under the hood period detection unit: 2D Hybrid method

Under the hood periodicity detection-
Sci case (data) supplied by CPG Inkind Team

- preprocessing with DGP, ANN+DGP
- period detection with WWZmatrix coefficients (inhomogenous cadence) + error and significance estimate
- period detection with SUPERLET matrix coefficients (homogenous cadenced LC) + error and significance estimate



Step 0: Gaussian Process/CNP or original LC
Step1: Calculation of c wavelet mztrices and their envelopes
Step2: Spearman correlation of wavelets envelopes

HYBRID METHOD: 3 STEPS

OUGP=Ornstein–Uhlenbeck Gaussian Process
OUGP(raw LC1)=OUGP1
OUGP(raw LC2)=OUGP2

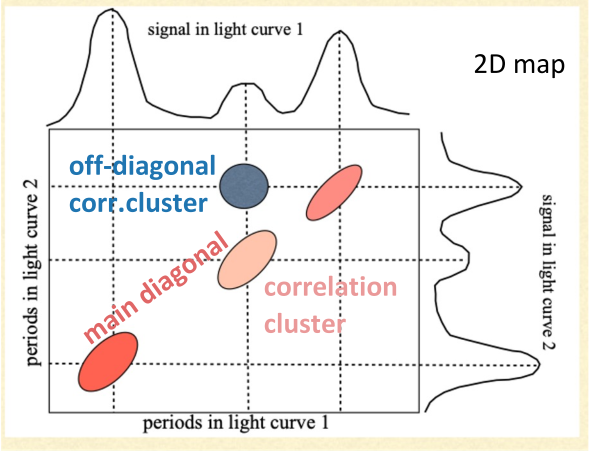
0 STEP: raw data preprocessing

$$\mathrm{CWT}(a,b)=\frac{1}{\sqrt{2\pi a}}\int_{-\infty}^{+\infty}x(t)\mathrm{e}^{[(t/b)^2/a/2]\beta^2}\mathrm{e}^{\mathrm{i}\omega(t-b)/a}\mathrm{d}t,$$

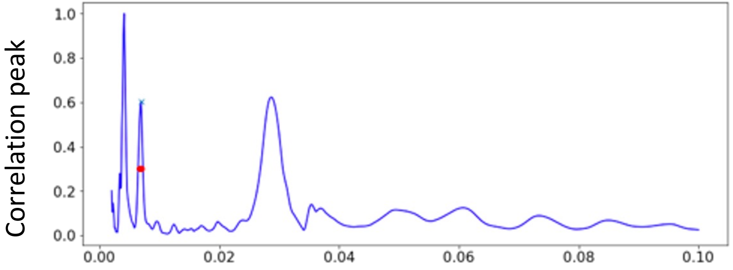
$$\mathrm{env}(a,b)=\sqrt{\mathrm{Re}\{[\mathrm{CWT}(a,b)]^2\}+\mathrm{Im}\{[\mathrm{CWT}(a,b)]^2\}},$$

1 STEP

SpearmanCorrCoeff(env(OUGP1),env(OUGP2)) 2 STEP



map integration along any period axis



Kovačević @ al 2018, 2019, l 2020, 2021

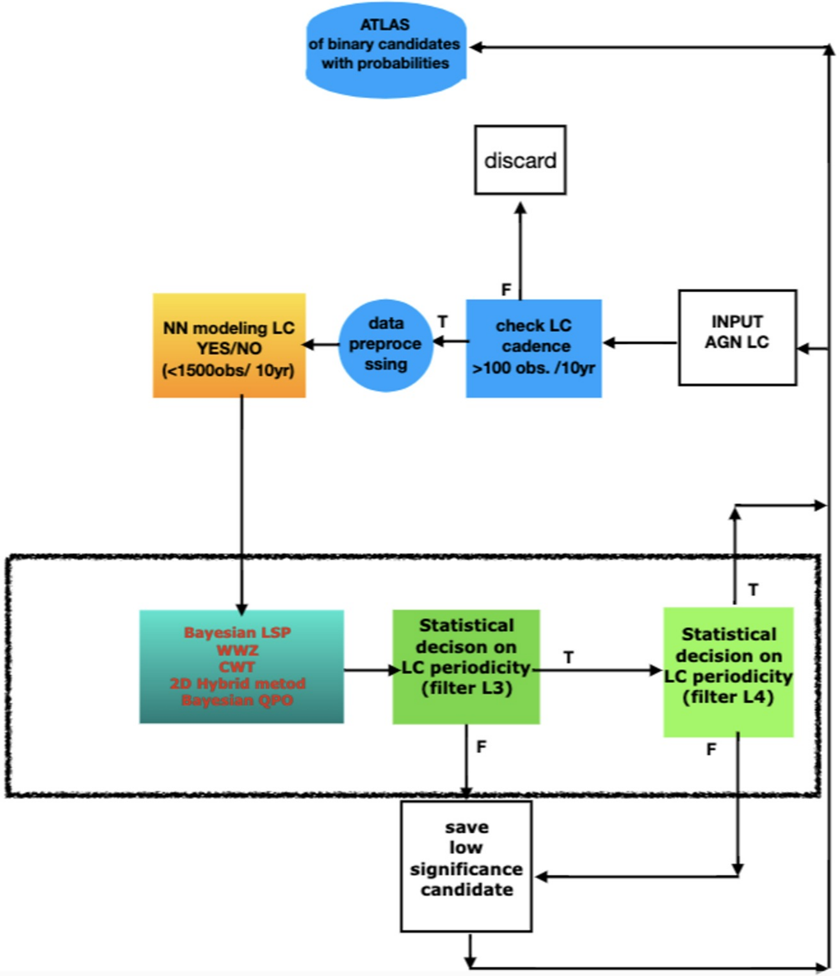
PURPOSE OF PIPELINE

ORIGINAL FEATURES:

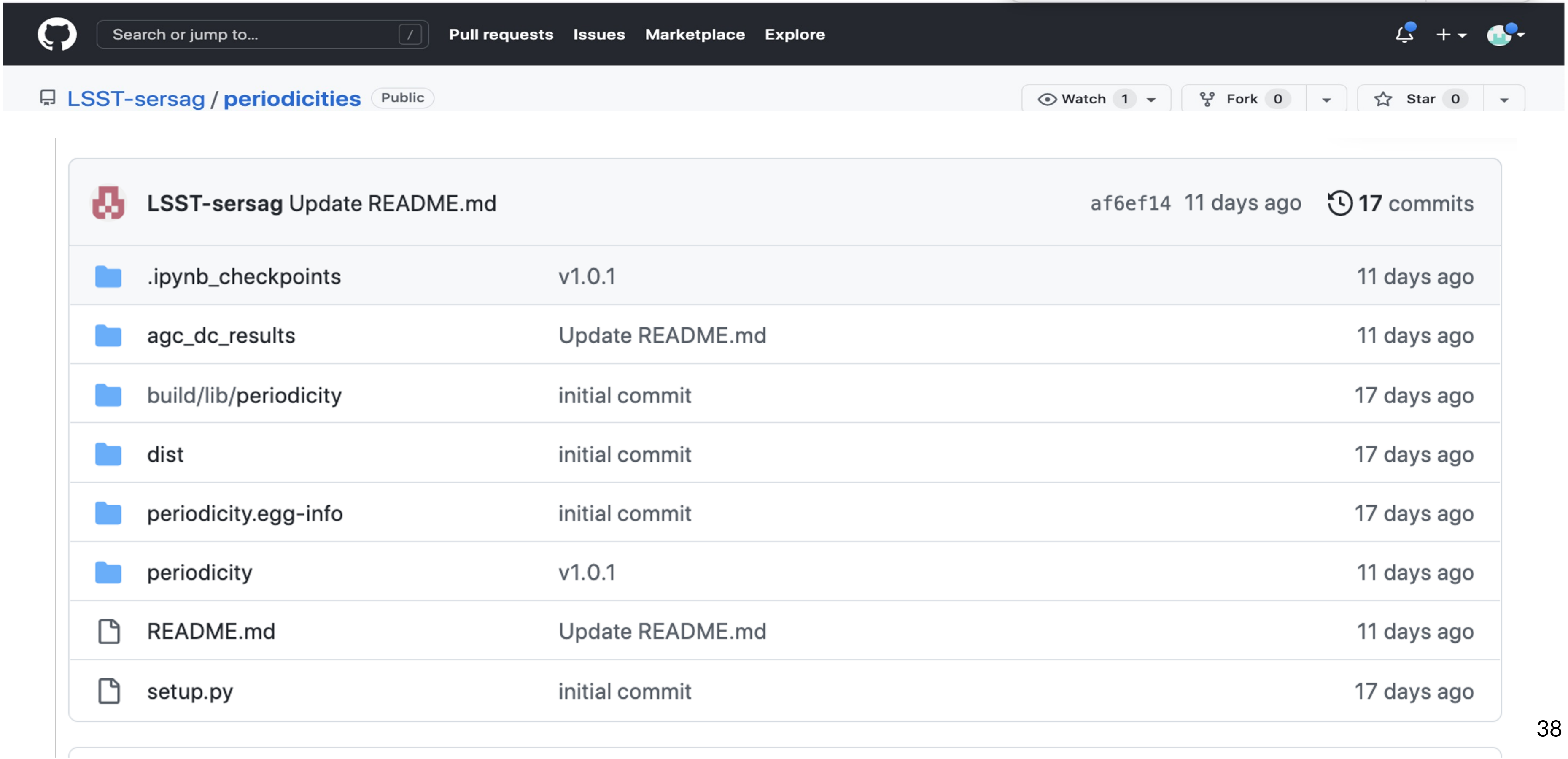
- instead using wavelets to locate signal in time-frequency space, our pipeline using wavelets to locate signal in frequency-frequency space

TOTAL PRODUCTS OF PIPELINE:

- nonparametric modeled LC,
- extracted periodic features of LC (periodicities, uncertainties, significance of periods, 2DHybrid maps, BGLS maps)



3) Current status



Initial run on LSST AGN Data Challenge second version on 1000 lc having >100 points

LSST-sersag Add files via upload Latest commit 62f0008 11 days ago History

1 contributor

983 lines (983 sloc) 82.4 KB

Raw Blame

Search this file...

objectId	period[d]	period_up_err	period_low_err	number	mean samp	median samp
36	46.035216940959764	45.896667084186134	45.96898471248646	126	53686.36174603175	53982.465
43	298.73039581777425	25.78815560725178	0.1003236440341766	129	53688.53217054264	53989.47
45	401.6064257028111	37.30115674893045	10.096441910295596	119	53666.09420168066	53700.38
47	218.6987424822305	12.317749195873006	4.830371352700411	127	53692.02141732282	53989.47
51	224.7191011235953	5.500168853375186	4.16329331640236	110	53685.34463636363	53837.92
78	0.0	0.0	0.0	108	53711.73009259259	53995.47
83	212.99254526091565	13.481332096487165	9.602547953637782	101	53599.92524752475	53681.43
116	231.0803004043903	20.30422622291698	9.460565678391134	118	53679.67728813559	53995.47

LSST-sersag / cnp_agn Private

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Code · Issues · Pull requests · Actions · Projects · Security · Insights

main · 1 branch · 0 tags · Go to file · Add file · Code

andricmitrovic Added saved trained model. 445dd7d on Jul 4 · **27** commits

output	Added saved trained model.	3 months ago
.gitattributes	Restored CNP_AGN_v3.ipynb to git from lfs	6 months ago
.gitignore	Added saved trained model.	3 months ago
CNP_ARCHITECTURE.ipynb	Refactoring code into multiple scripts.	3 months ago
CNP_DATASETCLASS.ipynb	Refactoring code into multiple scripts.	3 months ago
CNP_METRICS.ipynb	Refactoring code into multiple scripts.	3 months ago
CNP_PREDICTION.ipynb	Refactoring code into multiple scripts.	3 months ago
CNP_TRAINING.ipynb	Refactoring code into multiple scripts.	3 months ago
README.md	Update README.md	7 months ago
data_preprocessing.ipynb	Implemented LCs splitting in 200 day interval.	7 months ago
filter_data_STA.ipynb	Added results from model trained on more filtered STA dataset.	6 months ago
preprocessing_STA.ipynb	Implemented RMSE metric and saving figures with predictions	6 months ago
select_predictions.ipynb	Implemented saving and selection of predicted data from LCs.	5 months ago

About

No description, website, or topics provided.

Readme

1 star

7 watching

0 forks

Releases

No releases published

Create a new release

Packages

No packages published

Publish your first package

Contributors 2

andricmitrovic Nikola Andrić Mitrović

CNP examples

Dataset

- Sánchez-Sáez, P., et al. "Alert classification for the alerce broker system: The light curve classifier." *The Astronomical Journal* 161.3 (2021): 141.
- Real data from ZTF telescope (The Zwicky Transient Facility https://www.ztf.caltech.edu/about-ztf.html)
- Parquet file with the light curves contains 50,468,778 observations [ID, name, oid_alerce, mjd, mag, magerr, catflags, ra, dec]
- Csv file with some variability features and information from the original catalogs (~50 features)

objID	oid_alerce	meanra	meandec	n_good_det	timespan_good	T2020_sigma2	mhps_ratio	mhps_low	mhps_high	mhps_non_zero	mhps_PN_flag	Amplitude	Anderson	Autoc

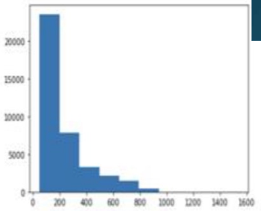
- 38,673 quasars

	oid_alerce	mjd	mag	magerr
270	600115400000062	58277.446759	20.499042	0.150769
271	600115400000062	58280.447870	20.510712	0.151645
272	600115400000062	58283.447500	20.546181	0.154301
273	600115400000062	58286.446076	20.422102	0.143933
274	600115400000062	58292.443738	20.381016	0.140310
...	...	...	...	...
106537366	498106400001568	59211.114086	19.524521	0.111328
106537367	498106400001568	59216.134167	19.357594	0.100389
106537368	498106400001568	59218.102951	19.321796	0.098138
106537369	498106400001568	59220.145822	19.447880	0.106221
106537370	498106400001568	59224.150370	19.445705	0.106078

50470539 rows × 4 columns

	oid_alerce	type
0	5.671073e+14	Q
1	5.771083e+14	AX
2	7.221141e+14	Q
3	8.201032e+14	Q
4	5.701162e+14	Seyfert_1
...	...	...
230459	6.331161e+14	QX
230460	6.801084e+14	Q
230461	4.731143e+14	Q
230462	6.241132e+14	Q
230463	6.241151e+14	QX

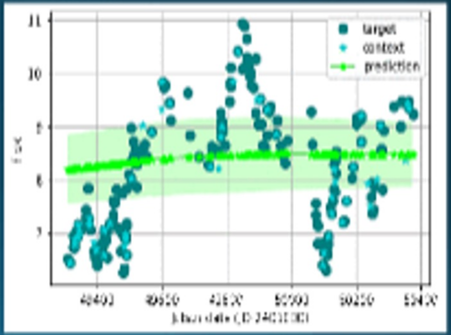
230464 rows × 2 columns



x: number of points
y: number of LCs

Results on ASASSN set

NGC5548 H beta light curve after 2500 iterations. Dark blue dots are acual measured values of flux in time. wResults for fitting NGC5548 H beta light curve after 25000 iterations. Plotting has been done after each 1000 iterations. The prediction (light green) of the light curves alongside the context points (dark blue dots) which represent the original observation points. Light blue band shows predicted distribution in target points, which decreases with each iteration, as the model is trained.



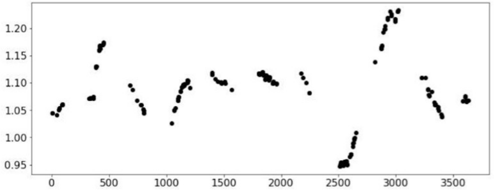
[Čvorović-Hajdinjak @al 2021, 2022]()

ic-Hajdinjak et al 2021

FWD

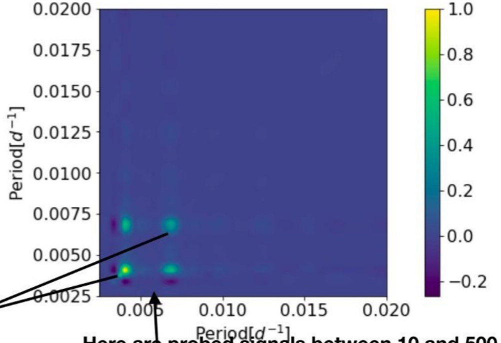
BACK

4) Initial user case for pipeline:

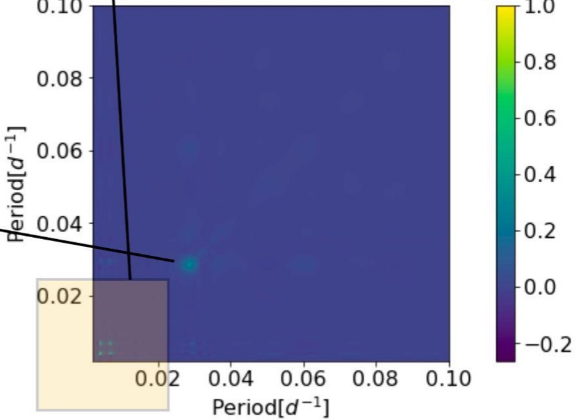


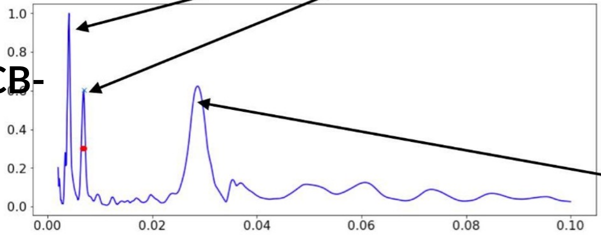
ORIGINAL CURVE: low cadence 197 points over >3500 days. It means that we have only 5% of full base line covered which is very low. Also destruction of most of the LC peaks between 500 days and 2500 days is seen (if they exist at all)

What we got for period: colorbar is correlation.
Due to very low coverage, and destruction of most of the LC peaks between 500 days and 2500 days we got 2 signals on main diagonal, and two signals symetricaly off diagonal which are associated perhaps with gaps and missing peaks. We checked signals between 50 and 400 days



Here are probed signals between 10 and 500 days





peaks @ ~ 244.9, 144.9, 34.8 days

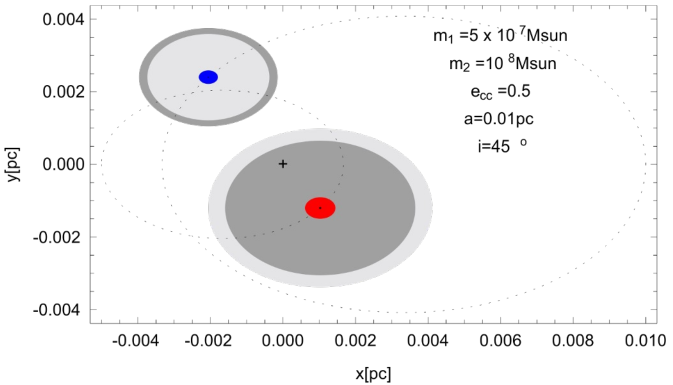
Mock Light curve designed by POL-NCB-S6 Inkind team,
Panda & Czerny 2022

Luka Popovic

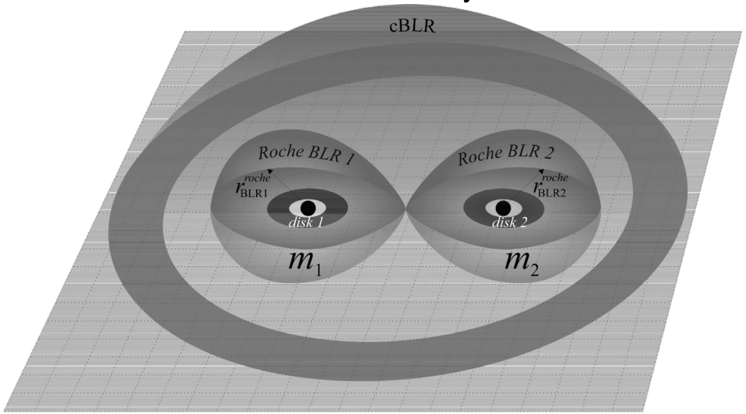
Astronomical Observatory Belgrade

SER-SAG Project Lead

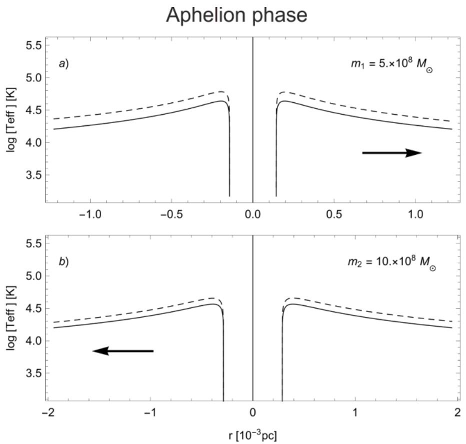
Some future work: Model of Super Massive Binary Black Holes (SMBBHs)

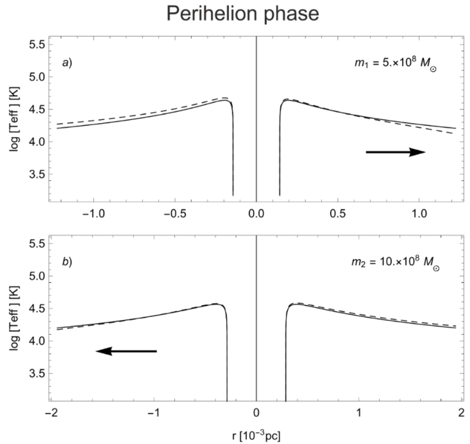


Schematic presentation of SMBBH system



Temperature profile of the disk,
for aphelion and perihelion phase

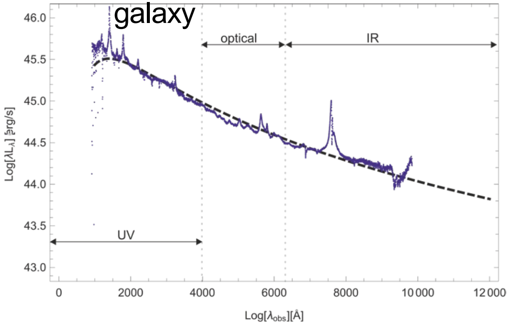


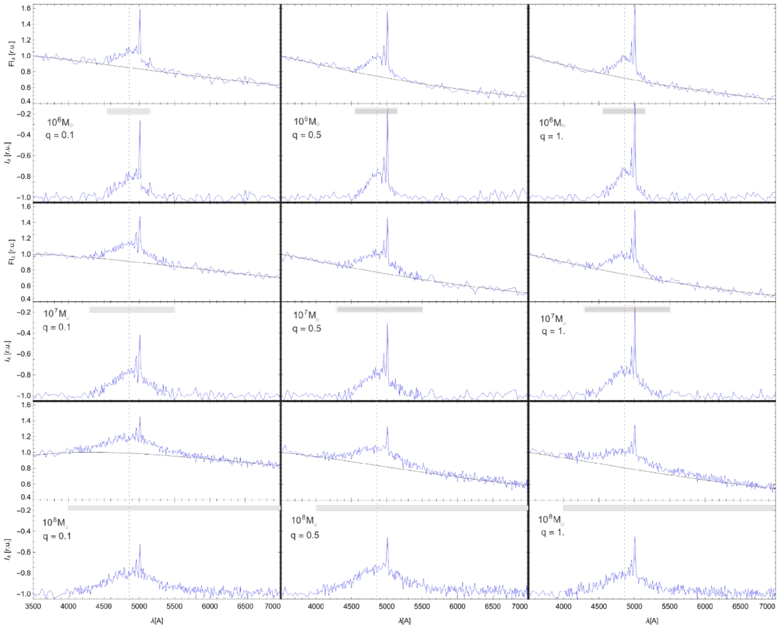


Popović, L. Č.; Simić, S.; Kovačević, A.; Ilić, D. 2021, MNRAS, 505, 51
.

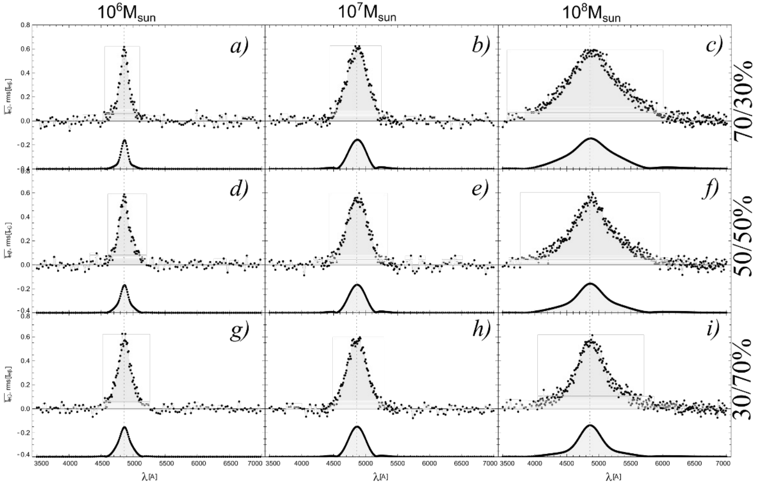
Super Massive Binary Black Hole Model

SED fit in case of 3C273 galaxy



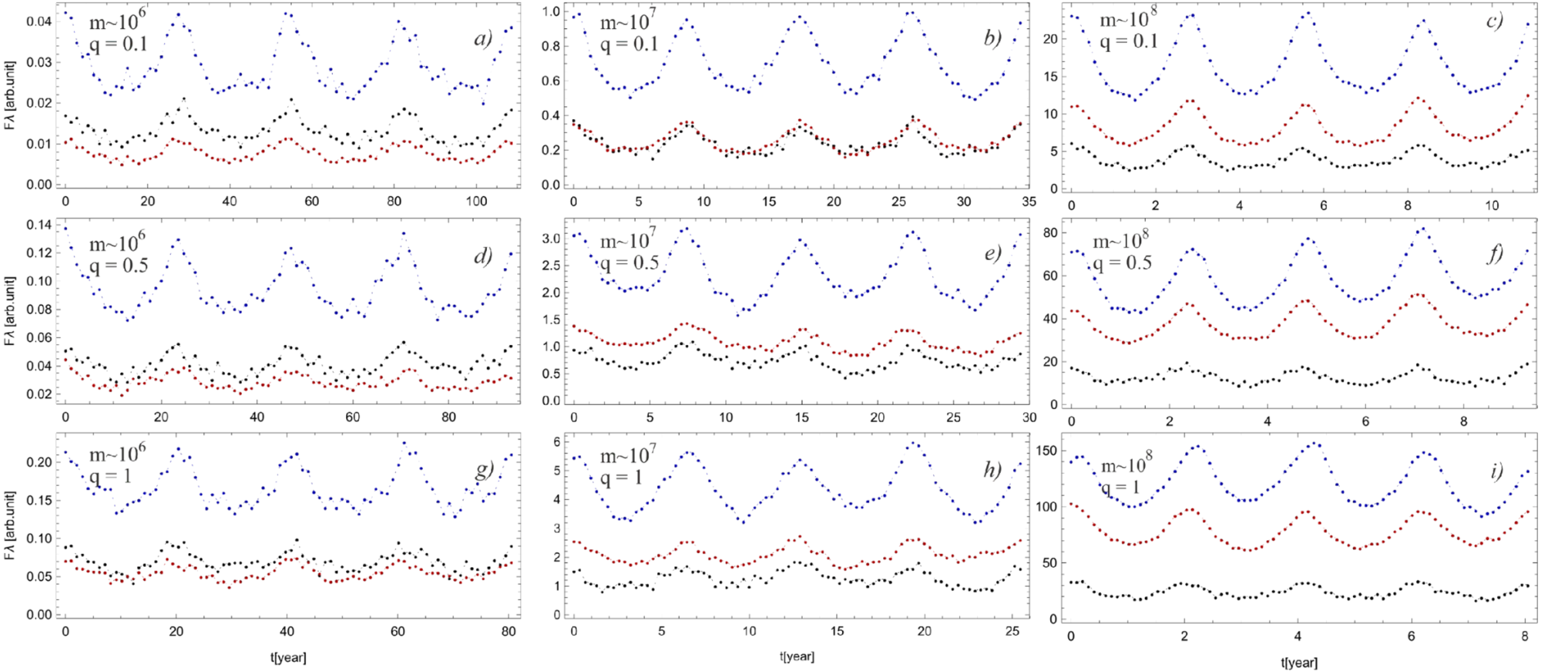


Example of spectra close to the Hbeta line and OIII doublet for aphelion position



Mean profile of Hbeta line during the four full rotation of the system and respectfull *rms*

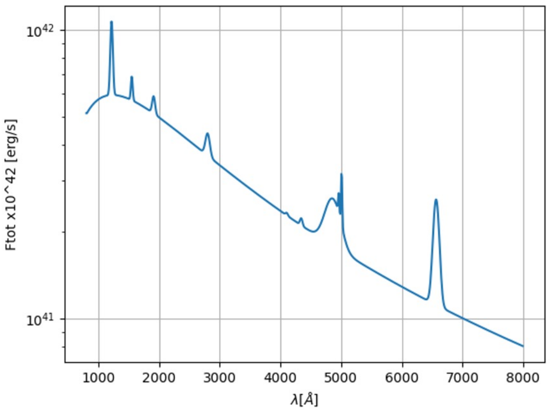
Super Massive Binary Black Hole Model



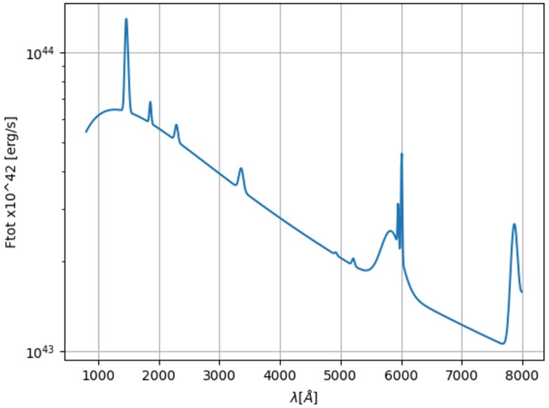
Lilghtcurves for 4 full orbits of the SMBBH system. Blue line 70% and red line 30% contribution of cBLR, black line designate continuum variability.

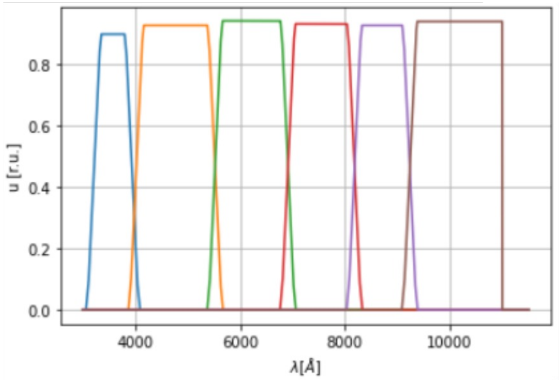
Super Massive Binary Black Hole Model

SMBBH spectra z=0



SMBBH spectra z=0.2





Spectra of UGRIZY filters

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Astronomical Observatory Belgrade

SER-SAG2 Contribution Lead

LSST TELESCOPE IN-KIND CONTRIBUTION (SER-SAG-S2)

- LSST is expected to produce several million alerts per night.

- In order to characterize and supplement the LSST discoveries, follow-up observations of many telescopes around the world are required.

- LSST follow-up observations would be coordinated through the Astronomical Event Observatory Network (AEON) – the network of telescopes ranging from 0.4m to 8m in aperture, distributed across the world.

- our in-kind proposal to LSST for follow-up photometric observations with Milankovic 1.4m telescope at **Astronomical Station Vidojevica (ASV)** is accepted (SER-SAG-S2).

SER-SAG-S2

SER-SAG-S2 Team : Jelena Kovačević Dojčinović (lead), Dragana Ilić, Maša Lakićević, Sladjana Marčeta-Mandić, Ana Vudragović, Oliver Vince, Saša Simić, Branislav Vukotić.

SER-SAG-S2 team tasks:

- securing observing nights within the Astronomical Station Vidojevica Time-Allocation Committee.

- observations will be fully supported by SER-SEG-S2 team

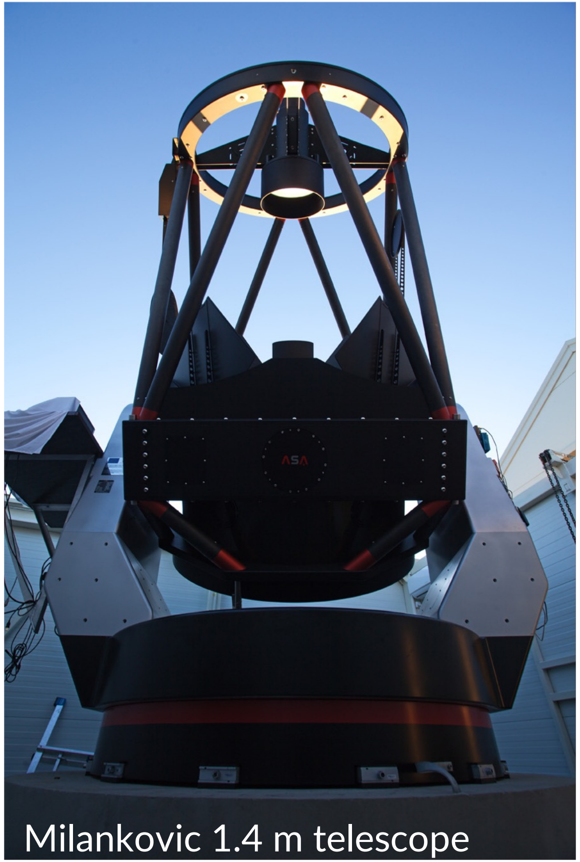
- data will be reduced and available for download in 72h, and kept on the SER-SAG cloud.

Observations at ASV: characteristics of the Milankovic 1.4 m telescope

- About 1/3 of observational nights at ASV are with very good weather for observations. Months with best weather for observations are August and September.

- Average seeing is 1’’-1.5’’ (best seeing ~ 0.7").

- Milankovic 1.4 m telescope: mechanics and optics are of excellent quality. (Mechanics: Astrosysteme Austria (ASA), IkonL CCD camera.)



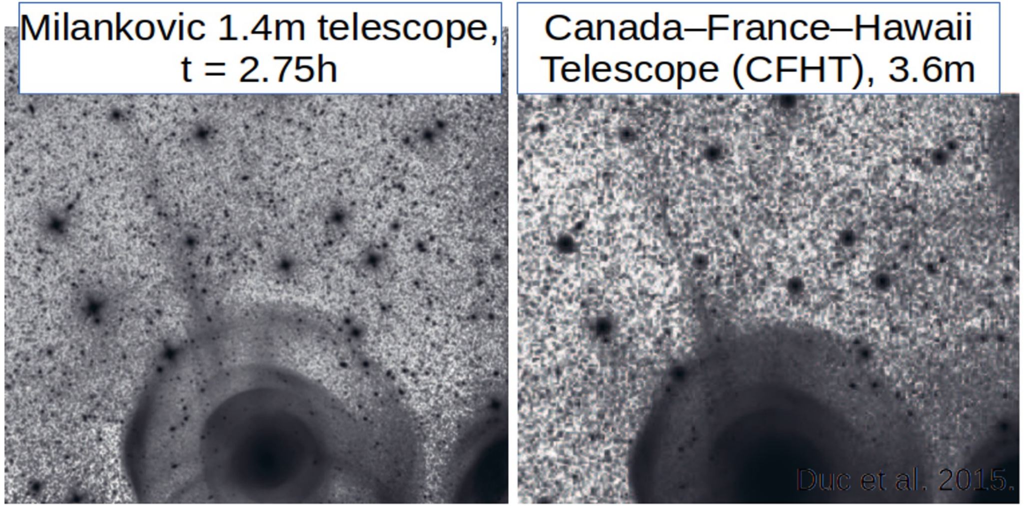
Milankovic 1.4 m telescope

Observations at ASV: characteristics of the Milankovic 1.4 m telescope

- Milankovic 1.4 m telescope we can well observe objects with <19 mag.

- With special technique of observation (L-band, large dithering and large exposure time of few hours), some structures in nearby galaxies can be seen with surface brightness limit of 28.4 ± 0.04 mag/arcsec2 (Vudragovic et al. 2021, Muller et al. 2019).

NGC 474



Duc et al. 2015

- E.g. for exposure time of one hour and a half, the depth of the **SDSS** observations could been reached with Milankovic telescope in all the filters.

What we did up to now...

- applied for and secured 18 observing nights with Milankovic 1.4 m telescope at Astronomical Station Vidojevica (ASV);

- performed photometric observations within allocated nights. Out of 18 allocated, 8 nights were successful, other had poor weather conditions; During these 8 nights, we made 48 observations of 31 different object.

- explored Tom Toolkit possibilities, focusing on the access to alerts. Within the allocated nights, we observed several alerts from different brokers (e.g., Alerce), which were accessed directly through Tom Toolkit;

- developed a customized pipeline in python for data reduction and standard aperture photometry, to assure that the reduced data will be available in 72h after observation;

- made web-page for SER-SAG-S2 at *http://astro-cloud.pmf.kg.ac.rs/asv.html*
- obtained the grant from LSST for SER-SAG cloud storage.
- submitted the FY22 Annual Evaluation Form for SER-SAG-S2.

Future plans:

1. to further develop data reduction pipeline and explore Tom Toolkit possibilities;

1. to train the observers and develop the skills needed for integration of Milankovic 1.4 m telescope in AEON;

1. to accept observing proposals from AEON network.

Summary

Two in-kind contributions:

1. In-kind directable software contribution

2. Telescope in-kind contribution

We are open for regional collaboration

Thank you for your attention!