Quasi Periodic Oscillations (QPO) in Intermediate Mass AGNs and Seeing analysis for telescope site characterisation

Advancements in AGN, Galaxy Cluster and IGM Research

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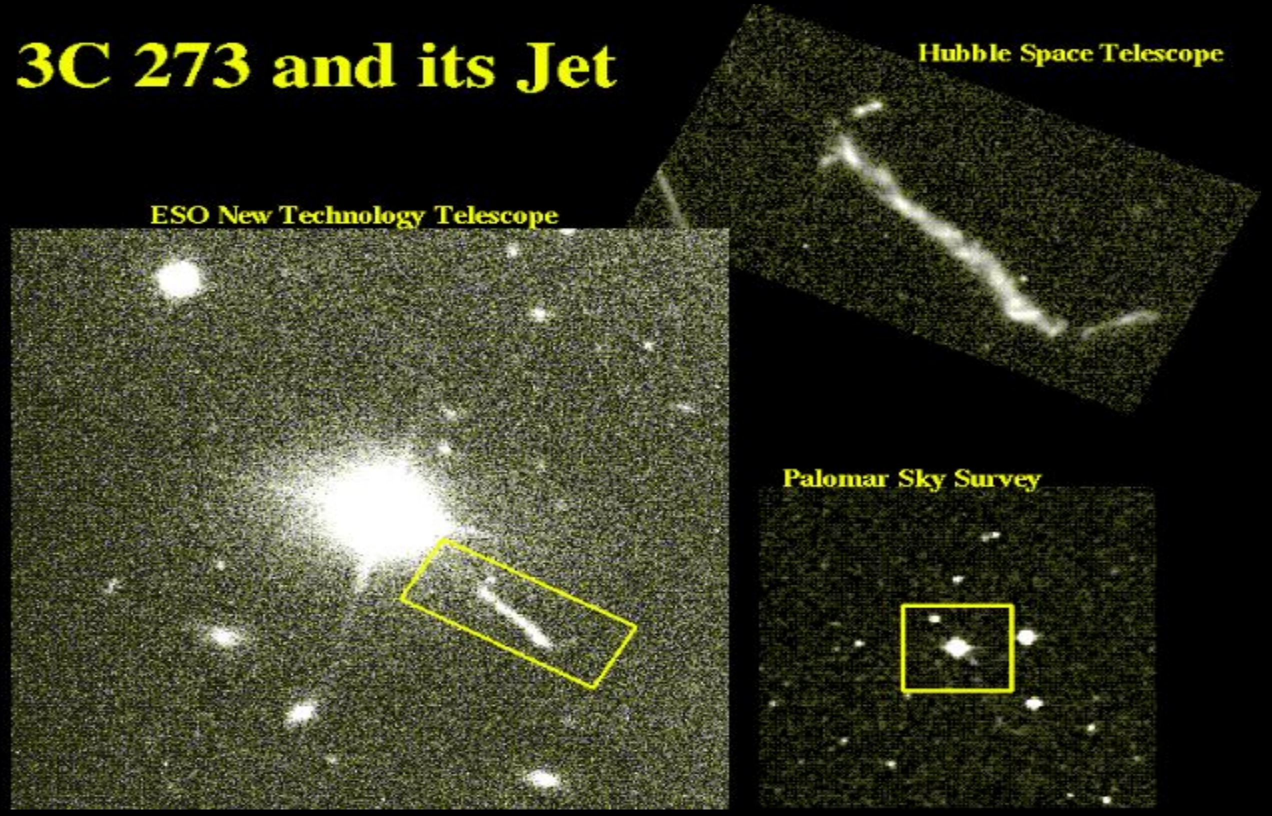
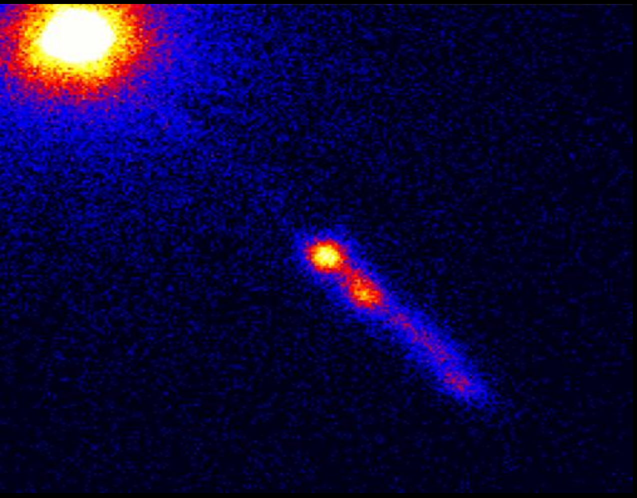
CONTENTS:

Active Galactic Nuclei (AGN)

- Luminous and compact objects at the center of galaxies.
- Powered by a Supermassive Black hole (SMBH)
- Mass in the range of $M_{BH} = 10^8 - 10^9\ M_\odot$
- Thousand times more luminous than Milky way galaxy and emits entire energy in a region approx the size of solar system



https://pages.astronomy.ua.edu/keel/agn/3c273.html



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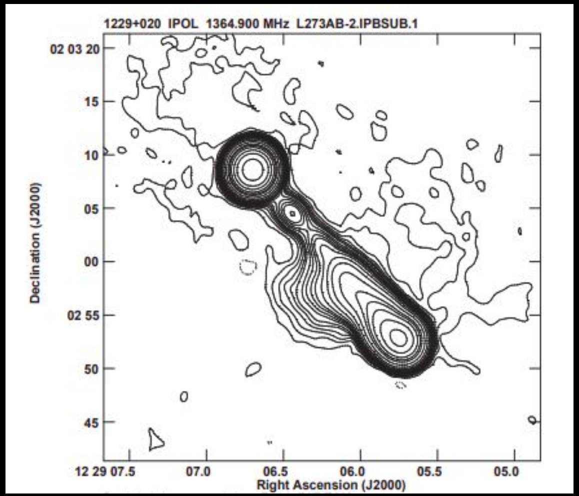
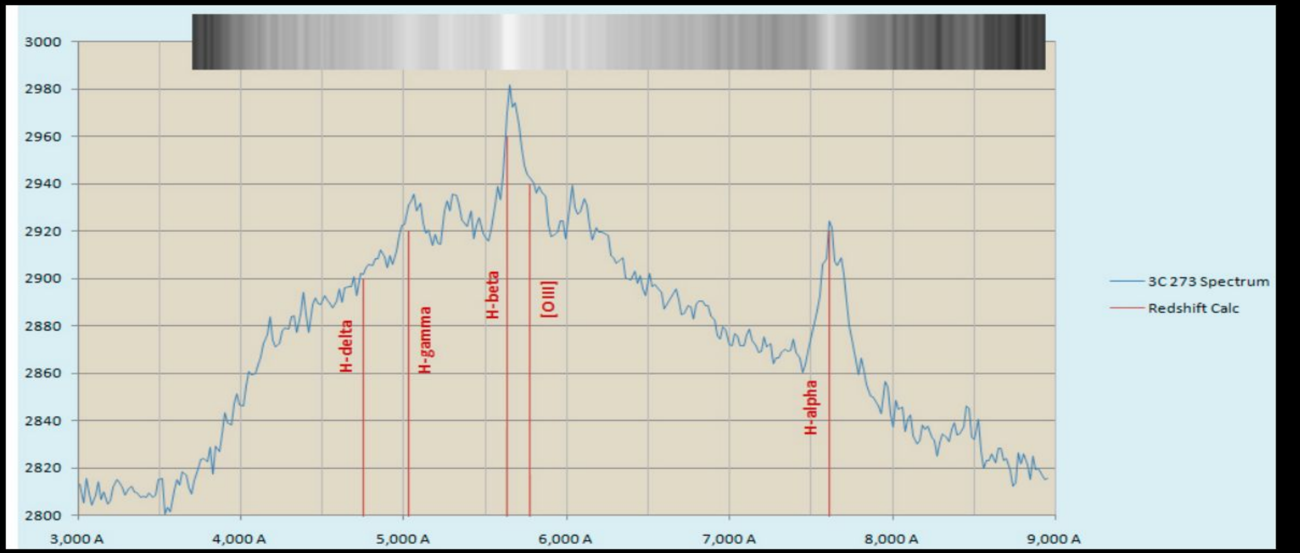
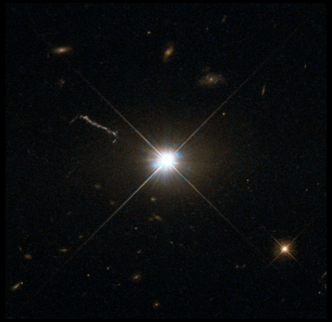


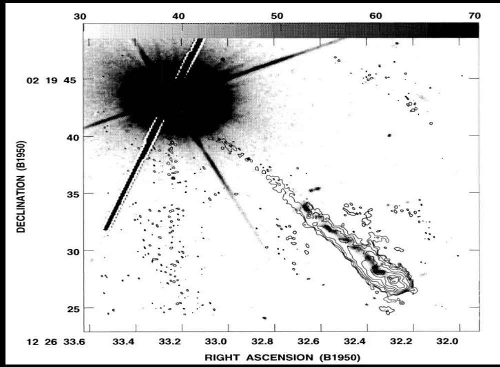
R. A. Perley and K. Meisenheimer



Observed Properties of AGN

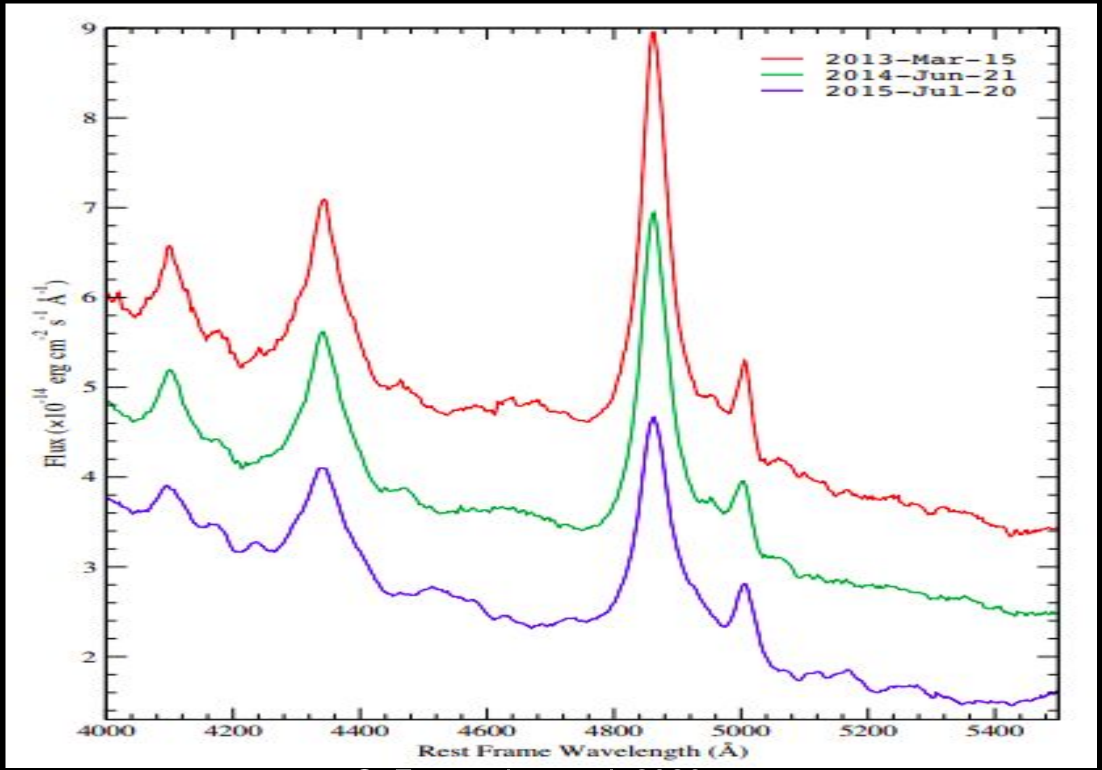
★ Star like objects identified with radio sources





Bahcall et al. 1995

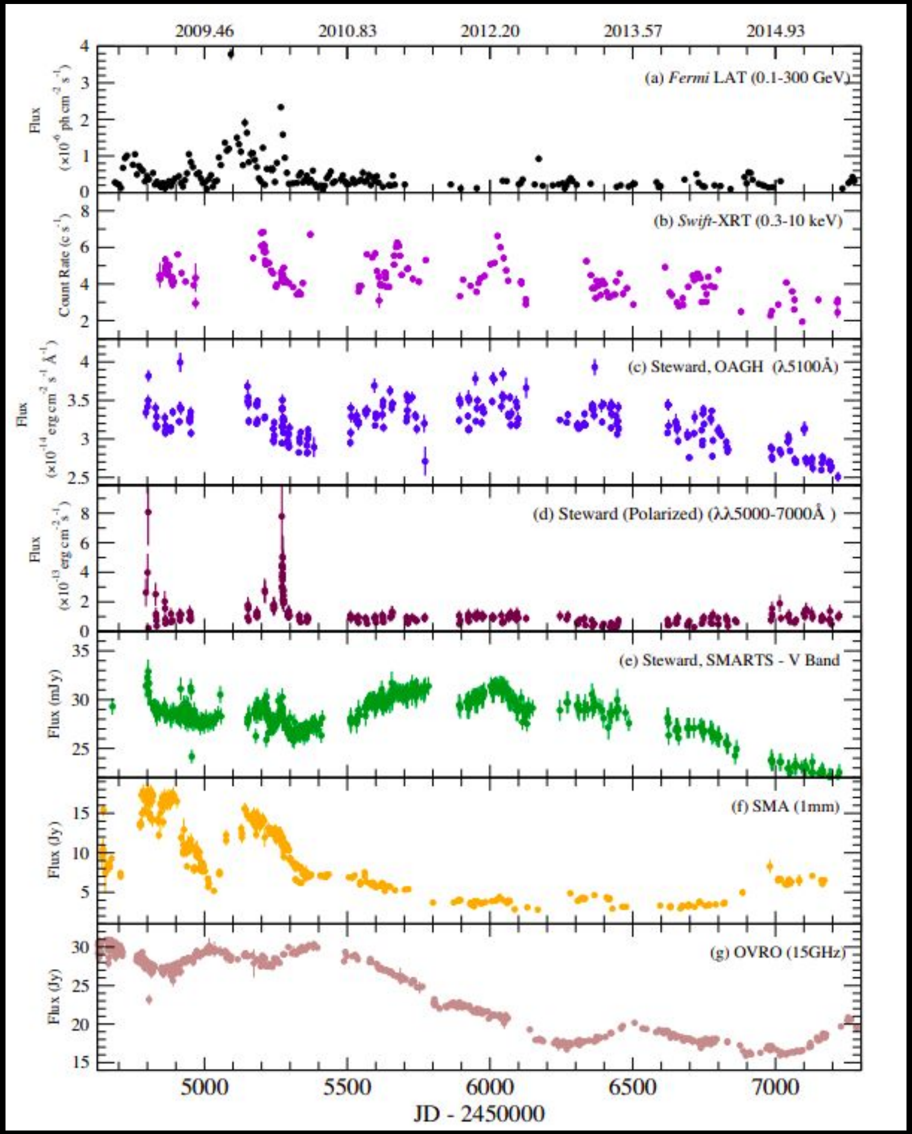
➢ Strong and broad optical/UV emission lines.



S. Fernandes et al. 2020

❖ Emission over a very broad band.

❖ Highly variable



S. Fernandes et al. 2020

AGN Zoo

FSRQ

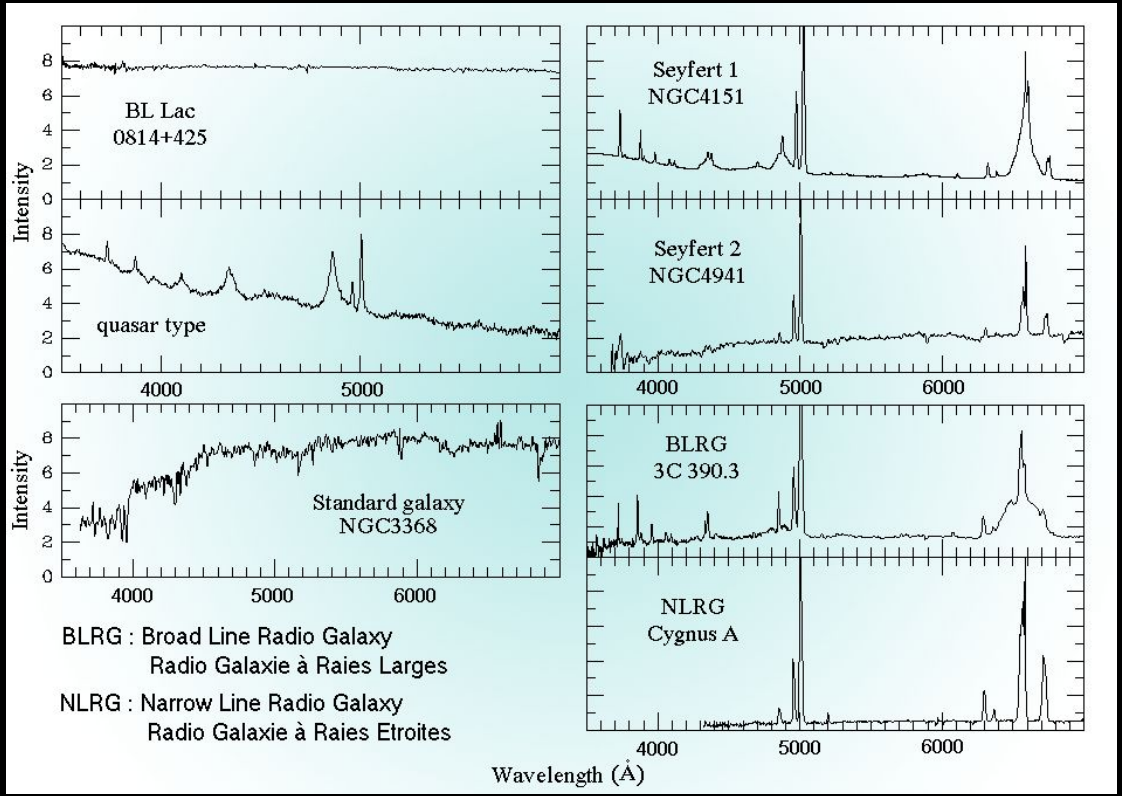
OVV

Weak Line Quasars

LINER

Radio loud quasar

BL Lac Object



Broad Line Radio Galaxy

FR I

Blazars

Narrow Line Radio Galaxy

Syfert1 galaxy

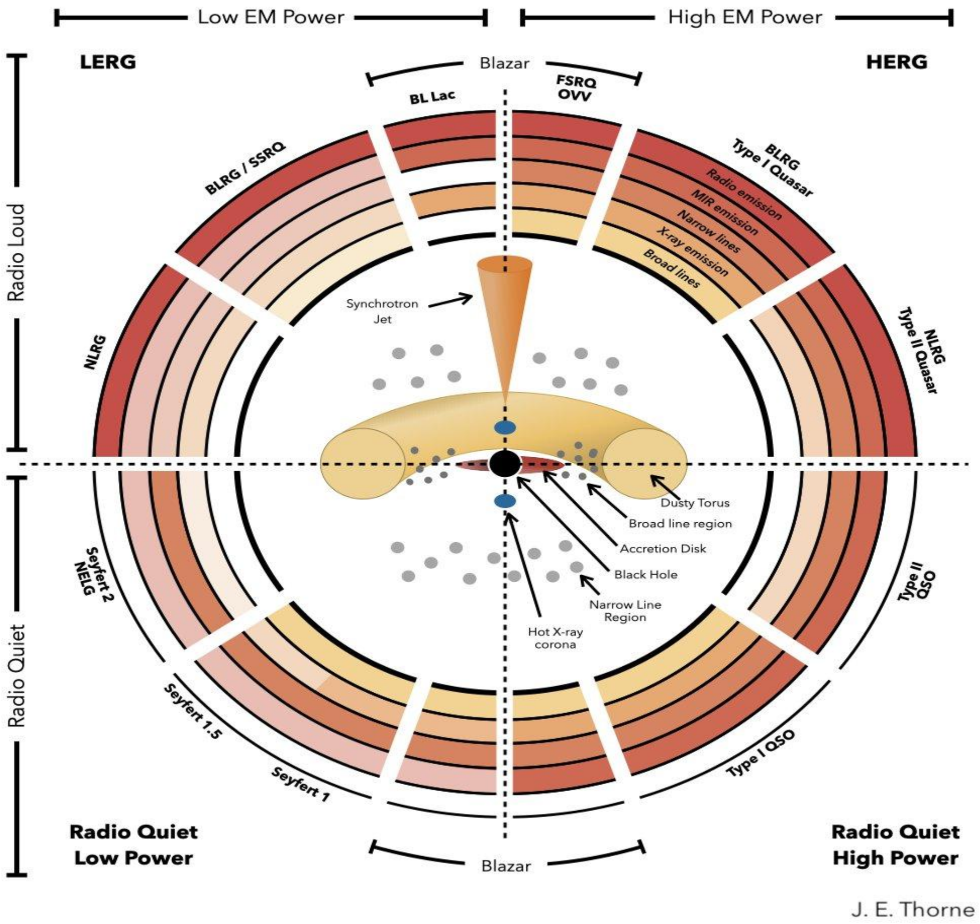
FR II

Radio Quiet Quasar

BAL Quasar

Seyfert 2 galaxy

Type 2 Quasar


Low EM Power
High EM Power
LERG
HERG
Blazar
BL Lac
FSRQ
OVV
BLRG / SSRQ
BLRG
Type I Quasar
Radio emission
MIR emission
Narrow lines
X-ray emission
Broad lines
NLRG
NLRG
Type II Quasar
Radio Loud
Radio Quiet
Synchrotron
Jet
Dusty Torus
Broad line region
Accretion Disk
Black Hole
Narrow Line
Region
Hot X-ray
corona
Seyfert 2
NELG
Type II
QSO
Seyfert 1.5
Seyfert 1
Type I QSO
Radio Quiet
Low Power
Radio Quiet
High Power
Blazar
J. E. Thorne

Variability in AGN Emissions:

★ Compact sizes and large distances limits our ability to study the physical processes in its inner regions.

★ Indirect methods are required to probe the inner regions.

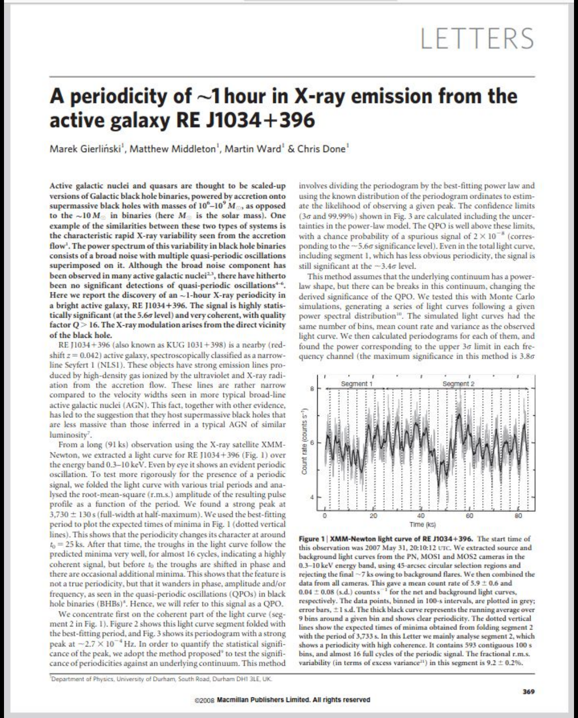
★ One ubiquitous property of AGN is:

Variability

★ AGN variabilities are considered to be aperiodic or stochastic in nature but there are recent claims of quasi periodicities in AGN light curves.

QPO detections

- First robust Qpo in AGN is detected in Xray is reported in Gierliński et al. 2008 having a 1 hr period.



LETTERS

A periodicity of ~1 hour in X-ray emission from the active galaxy RE J1034+396

Marek Gierliński[1], Matthew Middleton[1], Martin Ward[1] & Chris Done[1]

Active galactic nuclei and quasars are thought to be scaled-up versions of Galactic black hole binaries, powered by accretion onto supermassive black holes with masses of 10^6–$10^9 M_\odot$, as opposed to the ~$10 M_\odot$ in binaries (here $M_\odot$ is the solar mass). One example of the similarities between these two types of systems is the characteristic rapid X-ray variability seen from the accretion flow[1]. The power spectrum of this variability in black hole binaries consists of a broad noise with multiple quasi-periodic oscillations superimposed on it. Although the broad noise component has been observed in many active galactic nuclei[2,3], there have hitherto been no significant detections of quasi-periodic oscillations[4–6]. Here we report the discovery of an ~1-hour X-ray periodicity in a bright active galaxy, RE J1034+396. The signal is highly statistically significant (at the 5.6σ level) and very coherent, with quality factor $Q > 16$. The X-ray modulation arises from the direct vicinity of the black hole.

RE J1034+396 (also known as KUG 1031+398) is a nearby (redshift $z = 0.042$) active galaxy, spectroscopically classified as a narrow-line Seyfert 1 (NLS1). These objects have strong emission lines produced by high-density gas ionized by the ultraviolet and X-ray radiation from the accretion flow. These lines are rather narrow compared to the velocity widths seen in more typical broad-line active galactic nuclei (AGN). This fact, together with other evidence, has led to the suggestion that they host supermassive black holes that are less massive than those inferred in a typical AGN of similar luminosity[7].

From a long (91 ks) observation using the X-ray satellite XMM-Newton, we extracted a light curve for RE J1034+396 (Fig. 1) over the energy band 0.3–10 keV. Even by eye it shows an evident periodic oscillation. To test more rigorously for the presence of a periodic signal, we folded the light curve with various trial periods and analysed the root-mean-square (r.m.s.) amplitude of the resulting pulse profile as a function of the period. We found a strong peak at 3,730 ± 130 s (full-width at half-maximum). We used the best-fitting period to plot the expected times of minima in Fig. 1 (dotted vertical lines). This shows that the periodicity changes its character at around $t_0 = 25$ ks. After that time, the troughs in the light curve follow the predicted minima very well, for almost 16 cycles, indicating a highly coherent signal, but before t_0 the troughs are shifted in phase and there are occasional additional minima. This shows that the feature is not a true periodicity, but that it wanders in phase, amplitude and/or frequency, as seen in the quasi-periodic oscillations (QPOs) in black hole binaries (BHBs)[8]. Hence, we will refer to this signal as a QPO.

We concentrate first on the coherent part of the light curve (segment 2 in Fig. 1). Figure 2 shows this light curve segment folded with the best-fitting period, and Fig. 3 shows its periodogram with a strong peak at ~2.7×10^{-4} Hz. In order to quantify the statistical significance of the peak, we adopt the method proposed[9] to test the significance of periodicities against an underlying continuum. This method involves dividing the periodogram by the best-fitting power law and using the known distribution of the periodogram ordinates to estimate the likelihood of observing a given peak. The confidence limits (3σ and 99.99%) shown in Fig. 3 are calculated including the uncertainties in the power-law model. The QPO is well above these limits, with a chance probability of a spurious signal of 2×10^{-8} (corresponding to the ~5.6σ significance level). Even in the total light curve, including segment 1, which has less obvious periodicity, the signal is still significant at the ~3.4σ level.

This method assumes that the underlying continuum has a power-law shape, but there can be breaks in this continuum, changing the derived significance of the QPO. We tested this with Monte Carlo simulations, generating a series of light curves following a given power spectral distribution[10]. The simulated light curves had the same number of bins, mean count rate and variance as the observed light curve. We then calculated periodograms for each of them, and found the power corresponding to the upper 3σ limit in each frequency channel (the maximum significance in this method is 3.8σ

Figure 1 | XMM-Newton light curve of RE J1034+396. The start time of this observation was 2007 May 31, 20:10:12 UTC. We extracted source and background light curves from the PN, MOS1 and MOS2 cameras in the 0.3–10 keV energy band, using 45-arcsec circular selection regions and rejecting the final ~7 ks owing to background flares. We then combined the data from all cameras. This gave a mean count rate of 5.9 ± 0.6 and 0.04 ± 0.08 (s.d.) counts s^{-1} for the net and background light curves, respectively. The data points, binned in 100-s intervals, are plotted in grey; error bars, ±1 s.d. The thick black curve represents the running average over 9 bins around a given bin and shows clear periodicity. The dotted vertical lines show the expected times of minima obtained from folding segment 2 with the period of 3,733 s. In this Letter we mainly analyse segment 2, which shows a periodicity with high coherence. It contains 593 contiguous 100 s bins, and almost 16 full cycles of the periodic signal. The fractional r.m.s. variability (in terms of excess variance[21]) in this segment is 9.2 ± 0.2%.

[1]Department of Physics, University of Durham, South Road, Durham DH1 3LE, UK.

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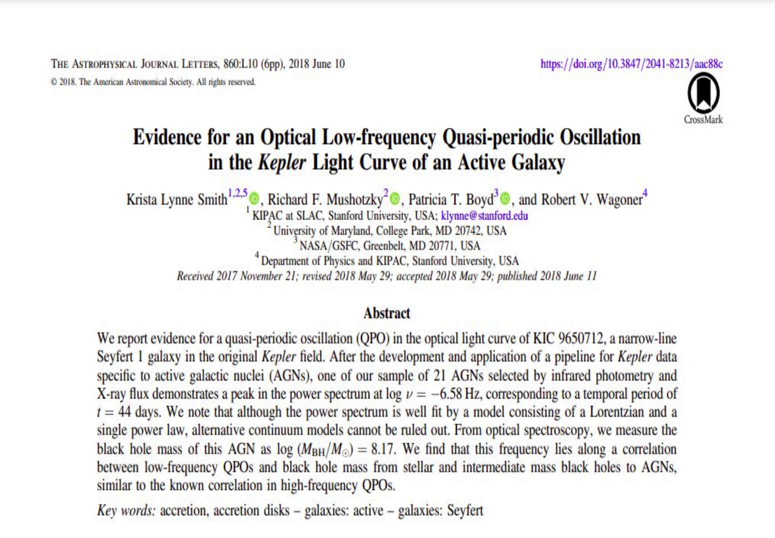
- Optical QPO is reported by Smith et al. 2018 having a 44 day period and BH mass of $10^8 M_\odot$



The Astrophysical Journal Letters, 860:L10 (6pp), 2018 June 10 https://doi.org/10.3847/2041-8213/aac88c

CrossMark

Evidence for an Optical Low-frequency Quasi-periodic Oscillation in the *Kepler* Light Curve of an Active Galaxy

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Abstract

We report evidence for a quasi-periodic oscillation (QPO) in the optical light curve of KIC 9650712, a narrow-line Seyfert 1 galaxy in the original *Kepler* field. After the development and application of a pipeline for *Kepler* data specific to active galactic nuclei (AGNs), one of our sample of 21 AGNs selected by infrared photometry and X-ray flux demonstrates a peak in the power spectrum at $\log \nu = -6.58$ Hz, corresponding to a temporal period of $t = 44$ days. We note that although the power spectrum is well fit by a model consisting of a Lorentzian and a single power law, alternative continuum models cannot be ruled out. From optical spectroscopy, we measure the black hole mass of this AGN as $\log (M_{BH}/M_\odot) = 8.17$. We find that this frequency lies along a correlation between low-frequency QPOs and black hole mass from stellar and intermediate mass black holes to AGNs, similar to the known correlation in high-frequency QPOs.

Key words: accretion, accretion disks – galaxies: active – galaxies: Seyfert

- A 5 year optical QPO of a quasar is reported in Graham et al. 2015

- A 400 and 800 day periodicity is observed in optical light curve of blazar reported in Bhatta et al. 2016

- A 4.6 h xray QPO in BL-LAC have been reported in Lachowicz et al. 2009

- A 120-150 day QPO is Blazar at 15 GHz radio band reported in King et al 2013.

- A 2 year gamma ray QPO in has been reported in Ackermann et al. 2015

- A 1.8 hr x-ray periodicity in NLSY! galaxy is reported in Zhang et al. 2018

- A 317 day period is detected in gamma ray light curves of BL-Lac reported in Sandrinelli et al. 2014

Initial Sample:

- Studies for flux variability are sparse for the Black Holes that fills a huge mass gap between Stellar mass and Supermassive Black Holes, also known as Intermediate mass Black Holes (IMBH) with

- One such attempt is done by Gopal-krishna et al. 2022, where they have studied rapid variabilities in optical band called Intra-Night Optical Variability (INOV) and has found blazar like INOV.

No. of Sources	12
Z	< 0.1
M_{BH}	$10^{5.5}$ - $10^{6.5}$ $M_\odot$
Median mass	10^6 $M_\odot$ None exceeding 2 x 10^6 $M_\odot$
R_{5GHz}	<10
INOV	8 out of 12 sources
Ψ (Variability Amplitude)	> 3

ANALYSIS

Lomb-Scargle Periodogram

- Modified version of Classical periodogram

- Suitable for Unevenly sampled data

Weighted Wavelet Z transform

- Localise waves in both time and frequency space

- Suitable for detecting transient fluctuation

LS

0.0052 day^{-1}

191.5 days^{-1}

WWZ

0.0052 day^{-1}

192.3 days^{-1}

LS

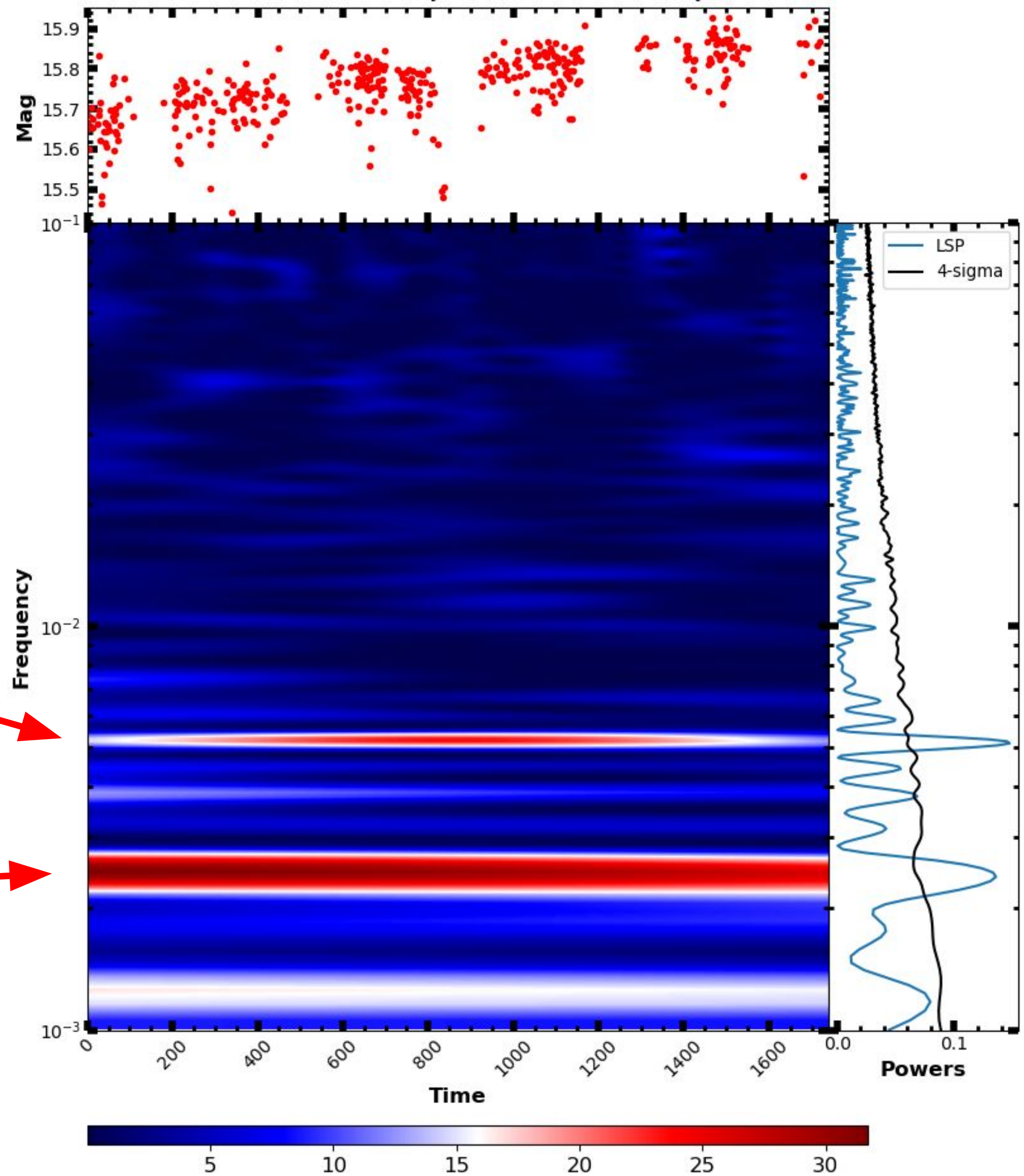
0.0025 day^{-1}

397.6 days^{-1}

WWZ

0.0024 day^{-1}

408.2 days^{-1}



LS

0.0052 day^{-1}

191.5 days^{-1}

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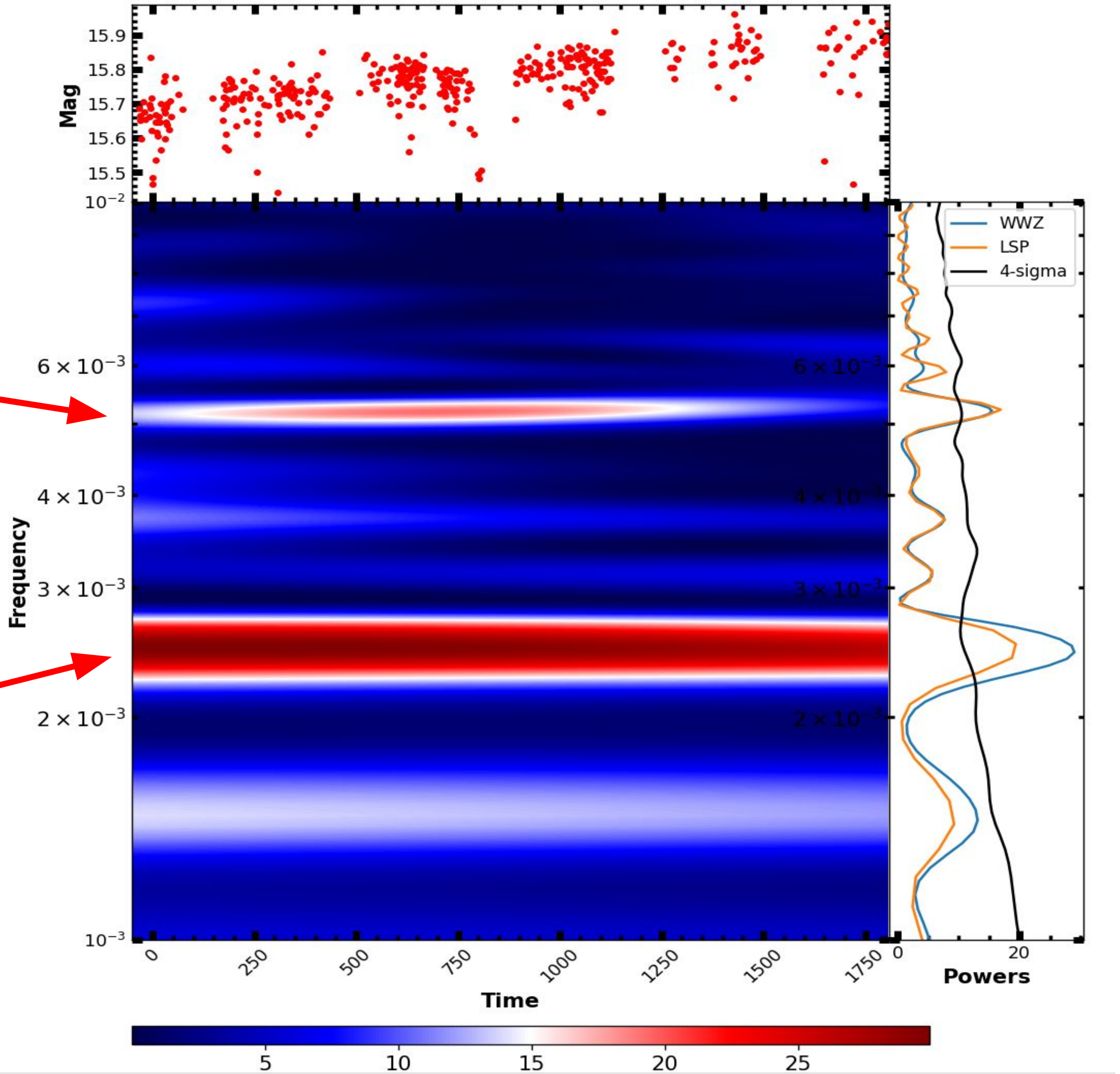
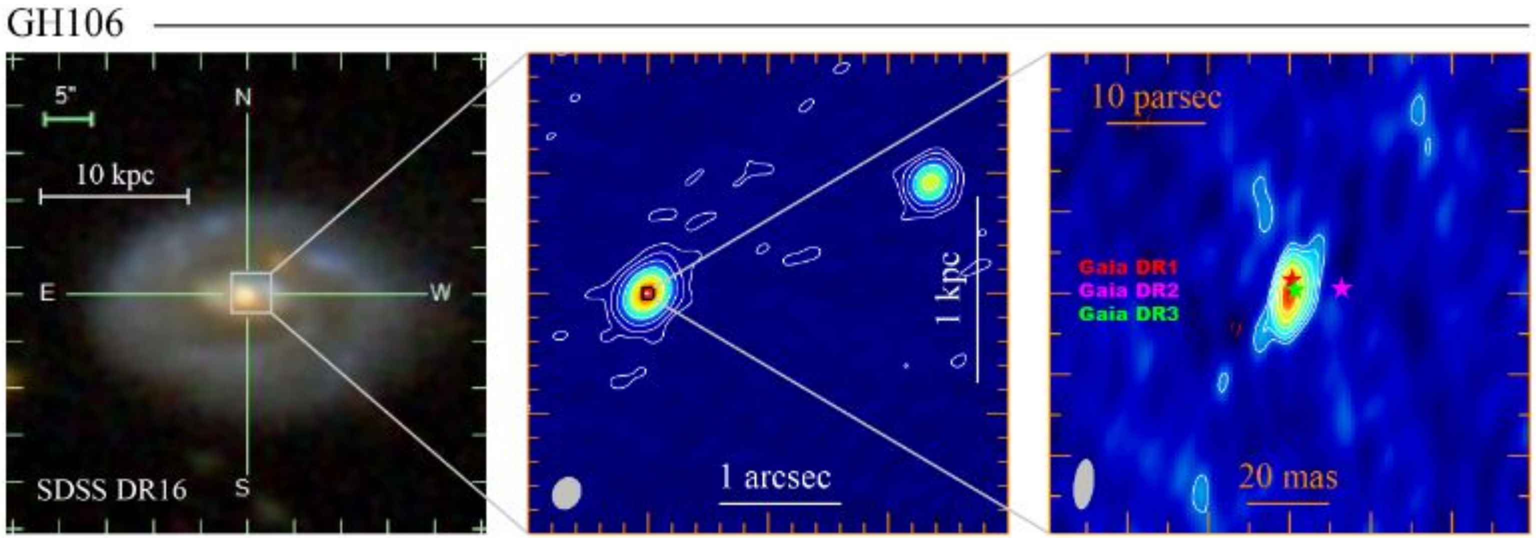


➢ **Statistical Significance**:

- AGNs exhibit red noise type variability feature which can mimic the actual QPO signal.
- We generated artificial light curves with the same power spectral density slope of original light curve using **`DELightcurveSimulation`** `code.`
- The artificial light curves had the same variance and sampling as the data. We used 1000 artificial light curves to establish the mean and standard deviation of the PSD at each point in the period/time plane for the artificial data.

Radio Observation:



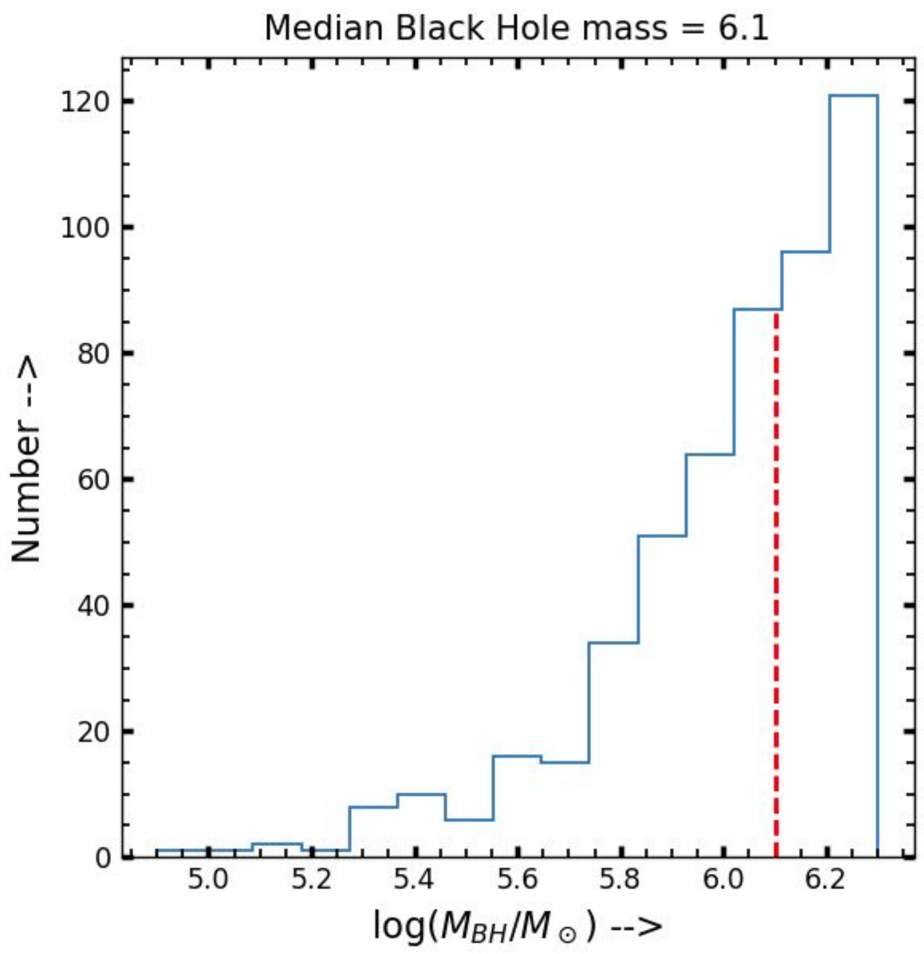
Yang et al 2022

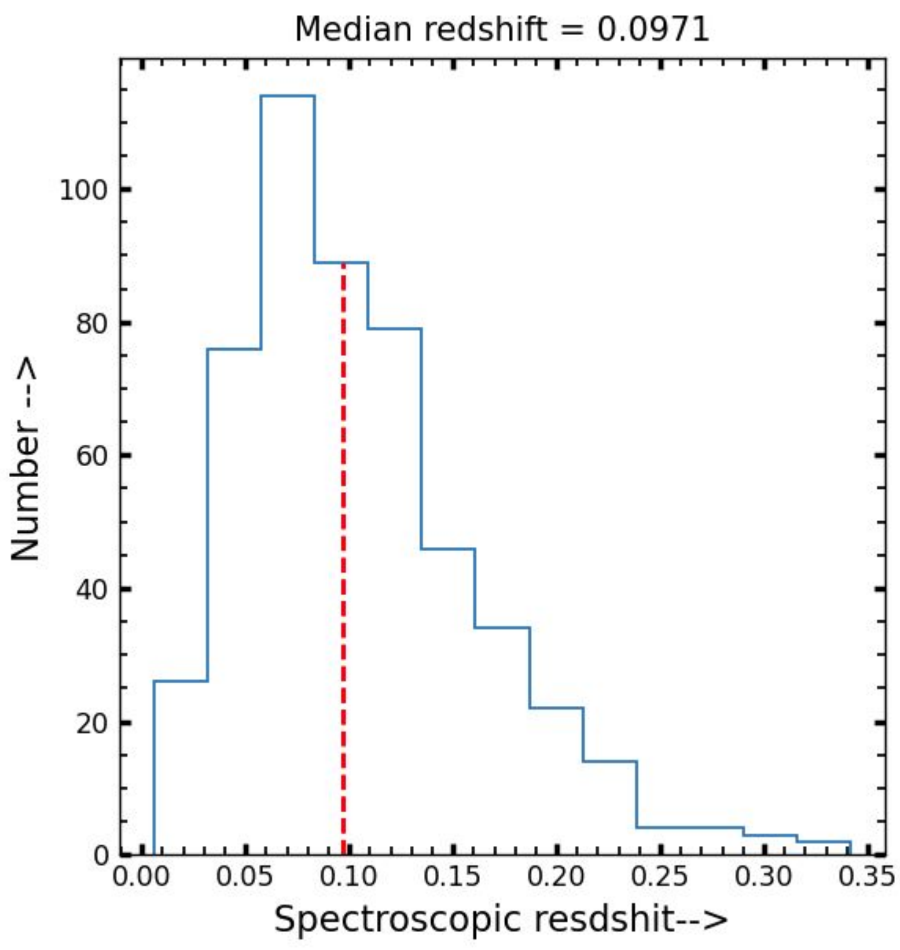
SDSS DR16, VLA A-array X band 9 GHz and VLBA 1.5 GHz image from left to right

- Flat spectral index (-0.26 at 9 GHz)
- The radio emission in these sources at the compact sub-pc to pc scales may originate from corona mass ejection or winds from the accretion disk as indicated by the relative strength of the radio luminosity in comparison with the X-ray luminosity, a regime similar to that in coronal active stars.

Extended Sample:

204 low mass AGNs are compiled by He-Yang Liu *et al* 2018 from SDSS DR7 and 309 such AGNs are compiled by Dong et al 2012, from SDSS DR4 totalling of 513 sources.

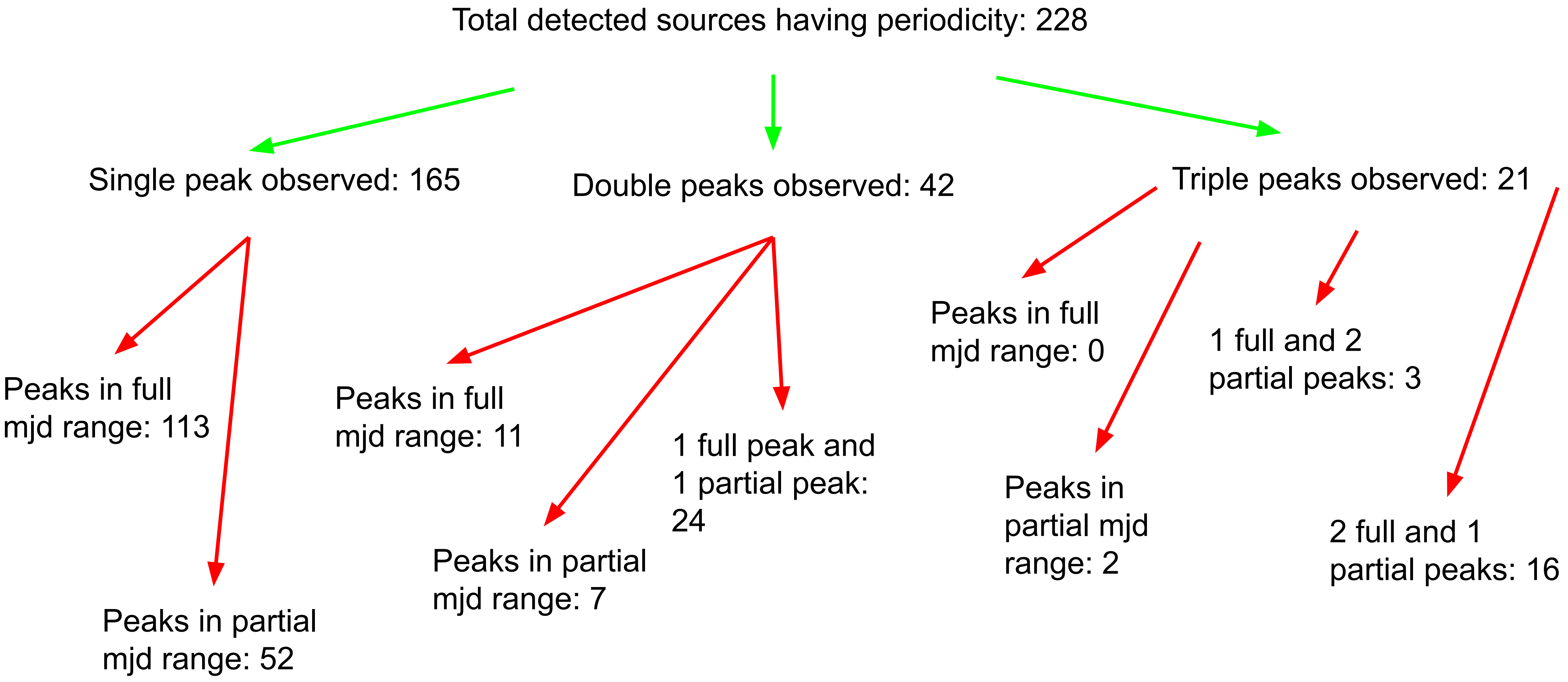




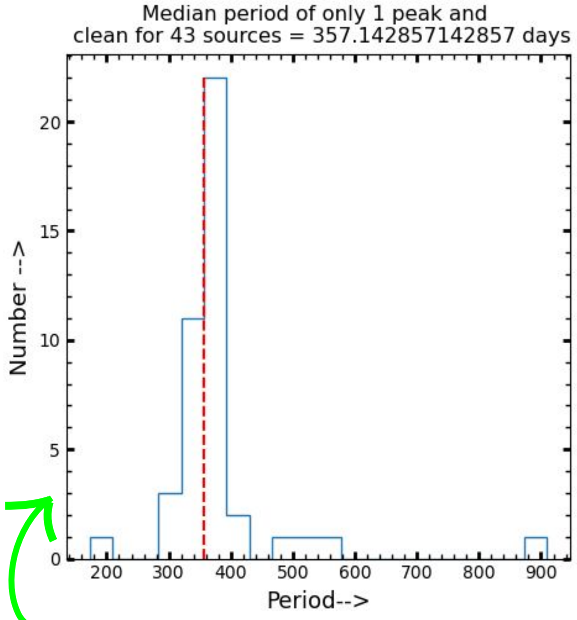
Out of 513 sources:

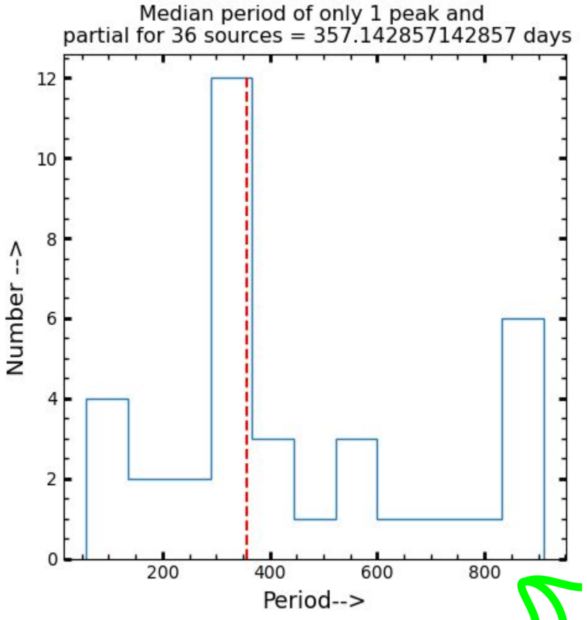
No Periodicity: 122 sources

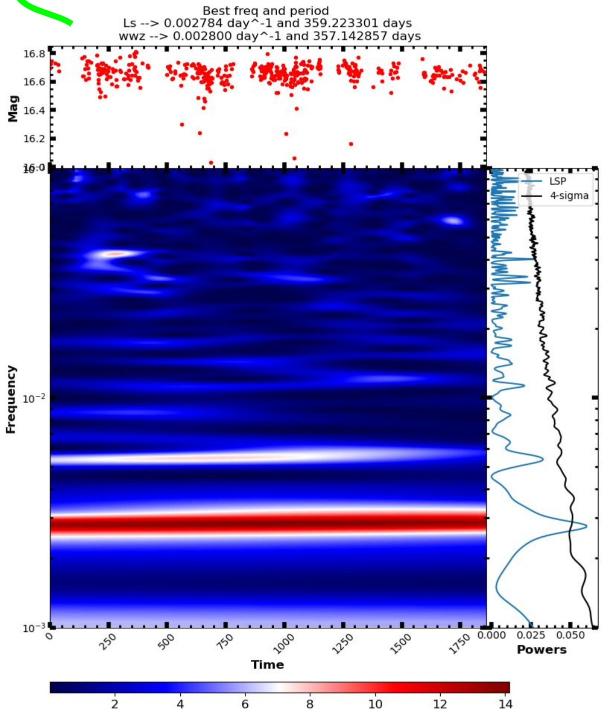
Signal: 228 sources

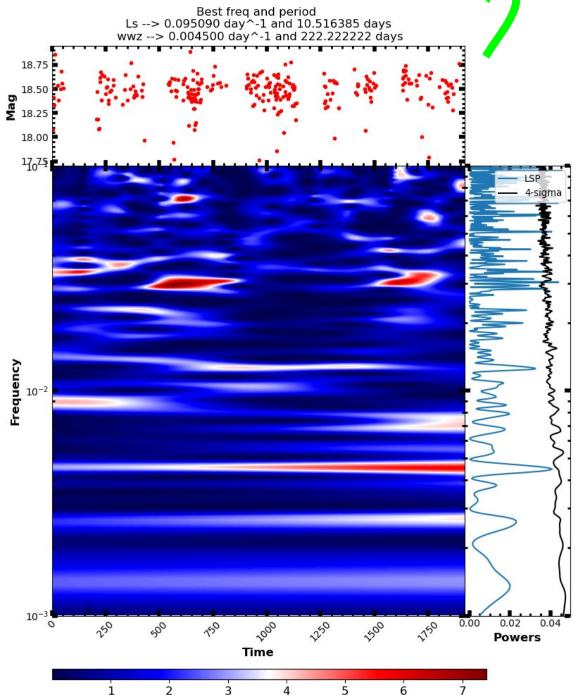


204 sources from DR7

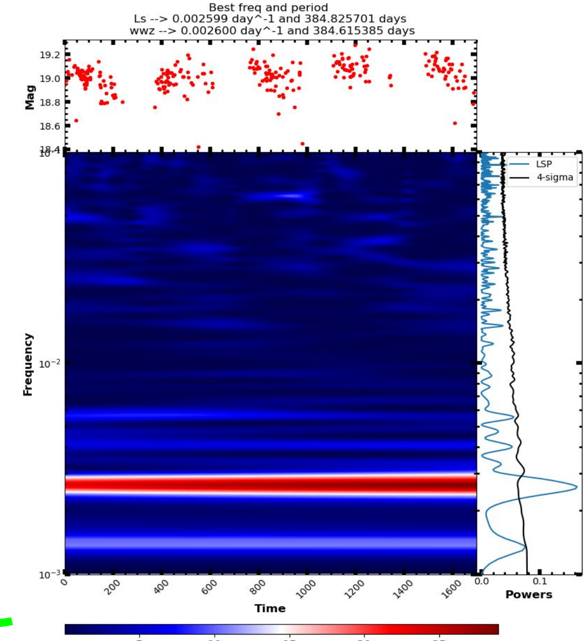


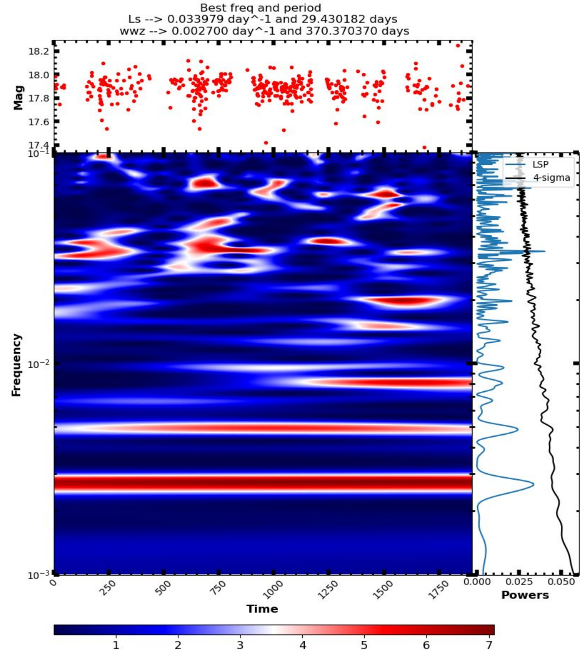


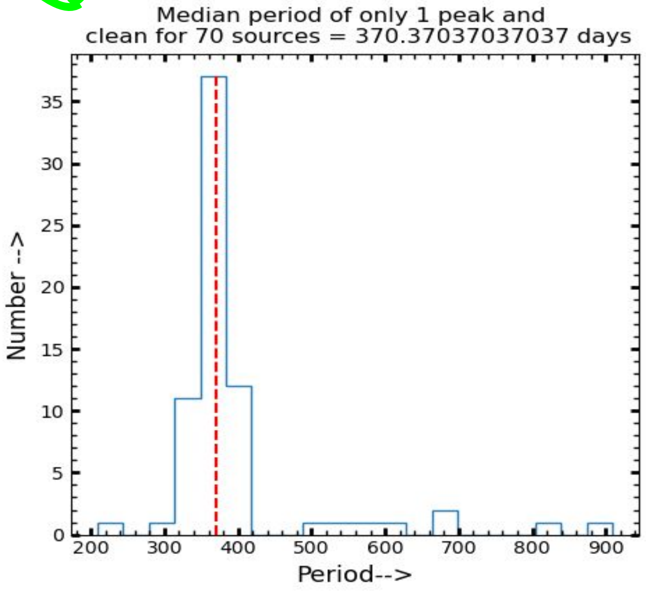


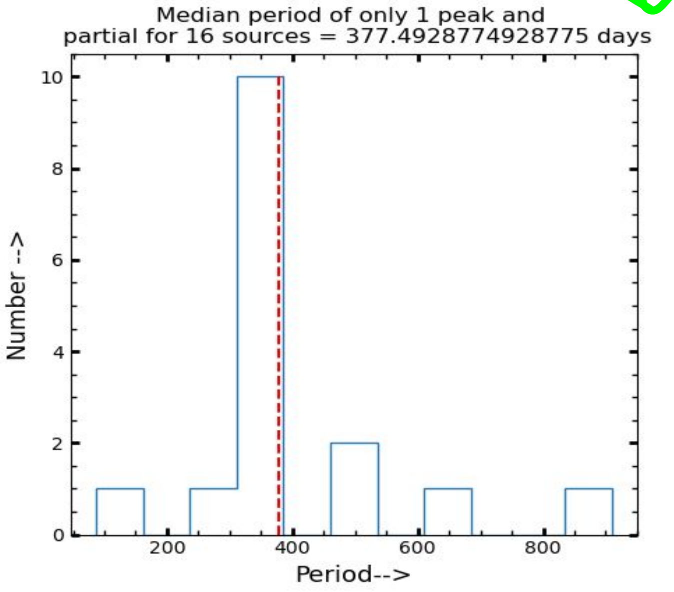


309 sources from DR4

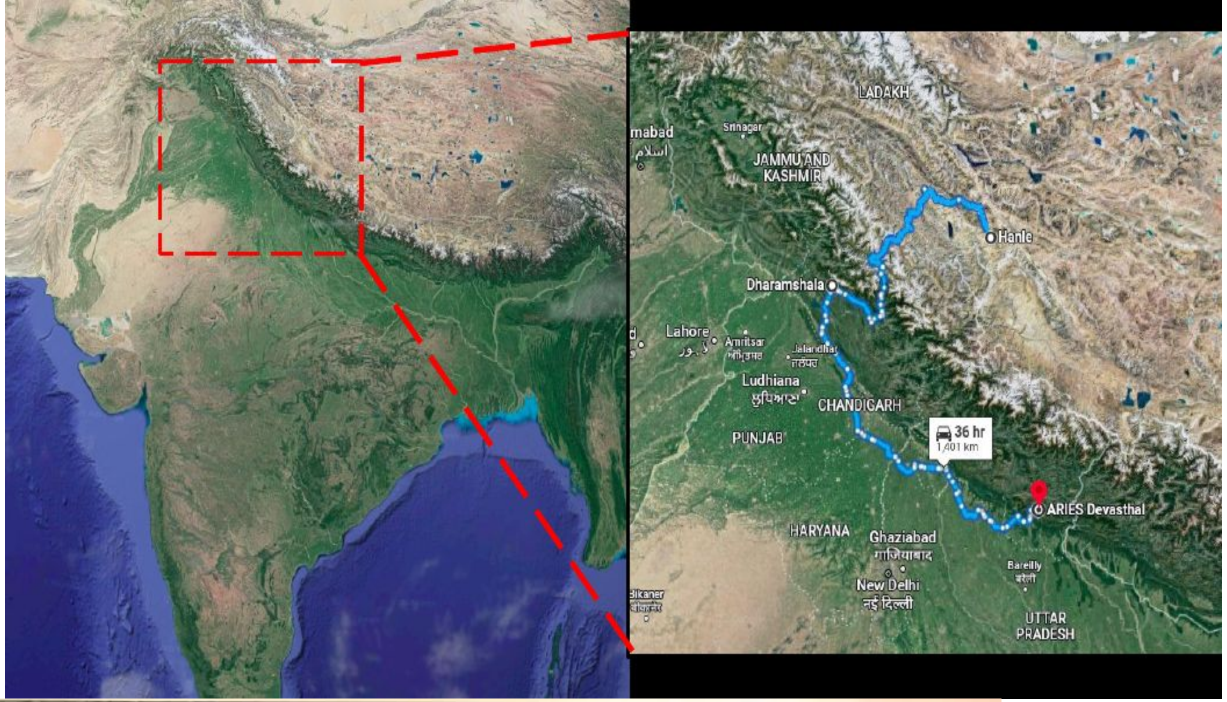








Characterisation Site and Instruments


LADAKH
Srinagar
JAMMU AND KASHMIR
Hanle
Dharamshala
Lahore
Amritsar
Jalandhar
Ludhiana
CHANDIGARH
PUNJAB
36 hr
1,401 km
ARIES Devasthal
HARYANA
Ghaziabad
गाज़ियाबाद
New Delhi
नई दिल्ली
Bareilly
बरेली
UTTAR PRADESH
Bikaner


Cuhp_aws
CUHP_dimm


WEATHER STA
HEAD OFFICE
SENSE

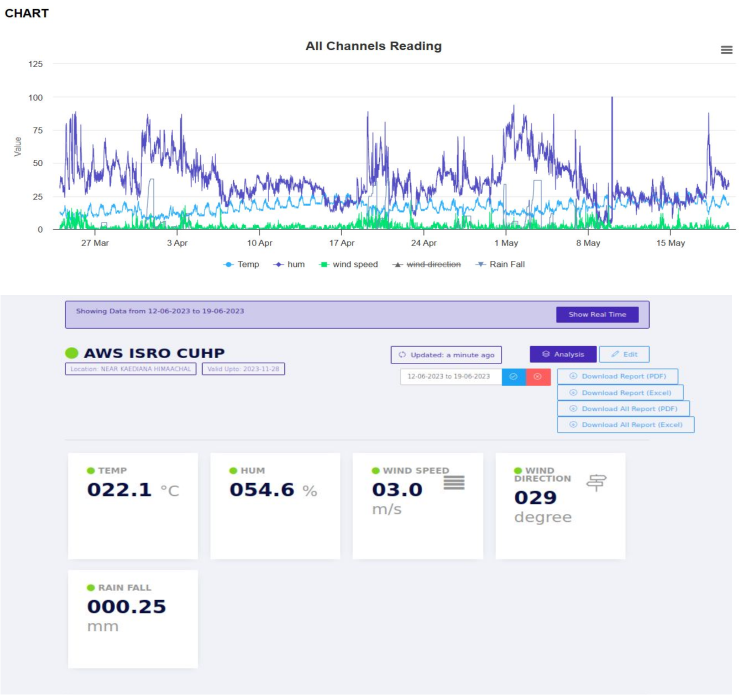
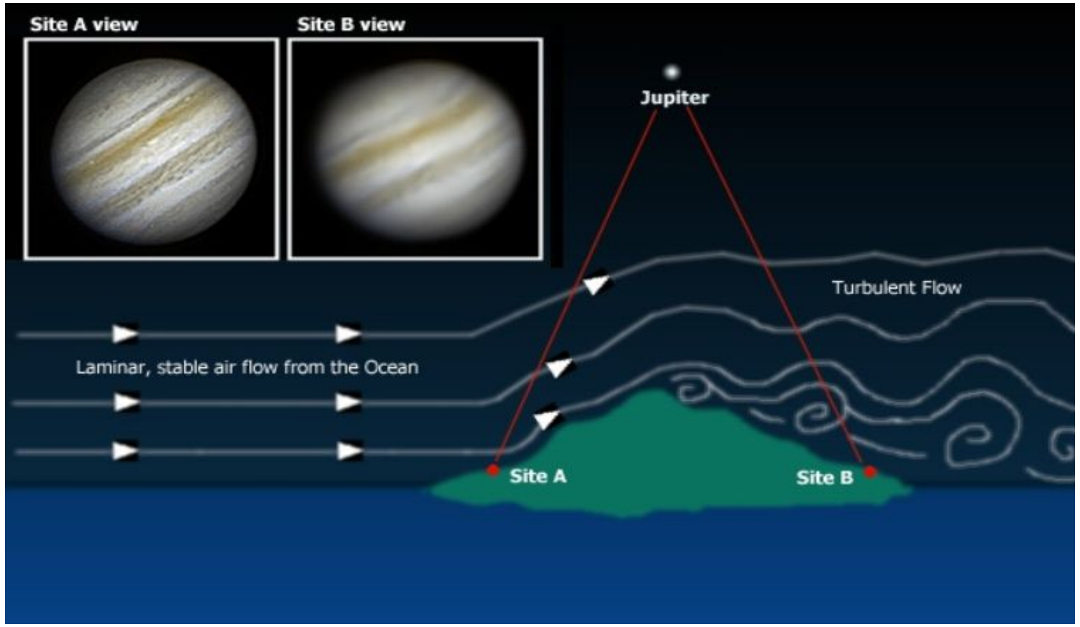


CHART
All Channels Reading
125
100
75
50
25
0
Value
27 Mar
3 Apr
10 Apr
17 Apr
24 Apr
1 May
8 May
15 May
Temp
hum
wind speed
wind direction
Rain Fall
Showing Data from 12-06-2023 to 19-06-2023
Show Real Time
AWS ISRO CUHP
Location: NEAR KAEDIANA HIMAACHAL
Valid Upto: 2023-11-28
Updated: a minute ago
Analysis
Edit
12-06-2023 to 19-06-2023
Download Report (PDF)
Download Report (Excel)
Download All Report (PDF)
Download All Report (Excel)
TEMP
022.1 °C
HUM
054.6 %
WIND SPEED
03.0
m/s
WIND DIRECTION
029
degree
RAIN FALL
000.25
mm

Future Plans:

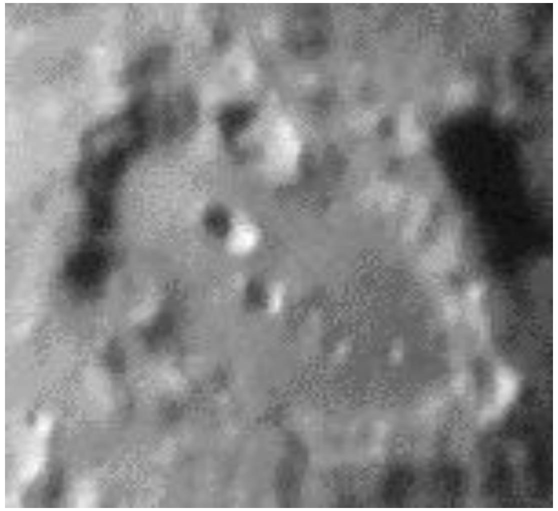
- ➔ Correlation between QPO frequency and mass of BH has been observed for high frequency QPOs. To classify observed QPO and to check the correlation to constrain Black hole mass.
- ➔ In general for radio quiet AGNs QPO is linked to have its origin in accretion disks but the presence of Blazar like INOV indicates to have its origin in jets.
- ➔ For Jet scenario QPO signals are most likely to originate from the precession of high Lorentz factor jets, or the movement of a plasma blob along a helical jet structure.
- ➔ To Explore different models to explain the observed frequency ratio.

Atmospheric Seeing:



https://home.ifa.hawaii.edu/users/meech/a281/handouts/seeing.pdf

- Ground-based astronomy is severely limited by the atmospheric optical turbulence, often called seeing.
- Degradation of the image of an astronomical object due to turbulence in the atmosphere of Earth that may become visible as blurring, twinkling, instantaneous image broadening, and the "image motion" or erratic displacement of the image.



This is a gif "movie" made of 8 individual frames taken from a video of the Lunar crater Clavius. It shows the effect of our Earth´s atmosphere on astronomical images. Camera: Sony CCD-TR2200E Pal. Telescope: Vixen 130mm f/5.

http://salzgeber.at/astro/moon/seeing.html

Seeing Measurements:

- Image degradation produced by atmospheric turbulence is characterized by the so-called r_0 parameter also called Fried parameter. D. L. FRIED 1966

- This r_0 can be imagined as the telescope diameter that would produce a diffraction spot of the same size as that produced by the atmospheric turbulence on a point source.

- The traditional way to characterize image degradation in astronomy is to measure the full width at half-maximum intensity ϵ_{fwhm} of a star at the focus of a telescope.

$$\epsilon = 0.98 \frac{\lambda}{r_0} \; for \; r_0 \ll D$$

- This parameter can be measured from the image motion in a small telescope.

Seeing Measurements contd. :

- The DIMM (Differential Image Motion Monitor) principle is to produce twin images of a star, with the same telescope via two entrance pupils of diameter D separated by a distance d.

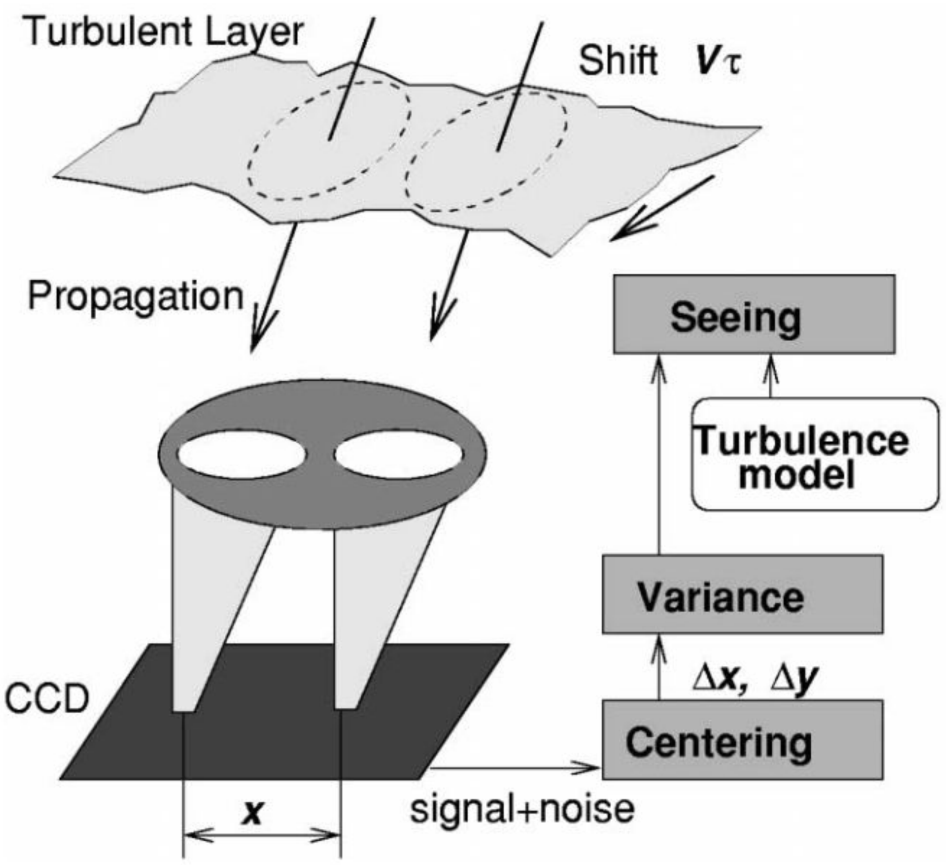
- The Fried parameter is estimated from the variance of the differential image motion using the equation derived by M. Sarazin and F. Roddier 1989.

$$\sigma_l^2 = 2\lambda^2 r_0^{-5/3}\left[0.179D^{-1/3} - 0.0968d^{-1/3}\right]$$

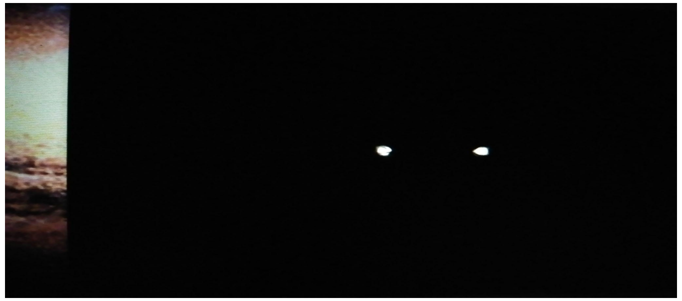
$$\sigma_t^2 = 2\lambda^2 r_0^{-5/3}\left[0.179D^{-1/3} - 0.145d^{-1/3}\right]$$

- This approach has a practical advantage of being insensitive to shake and tracking error.

DIMM Setup:



A. Tokovinin 2002



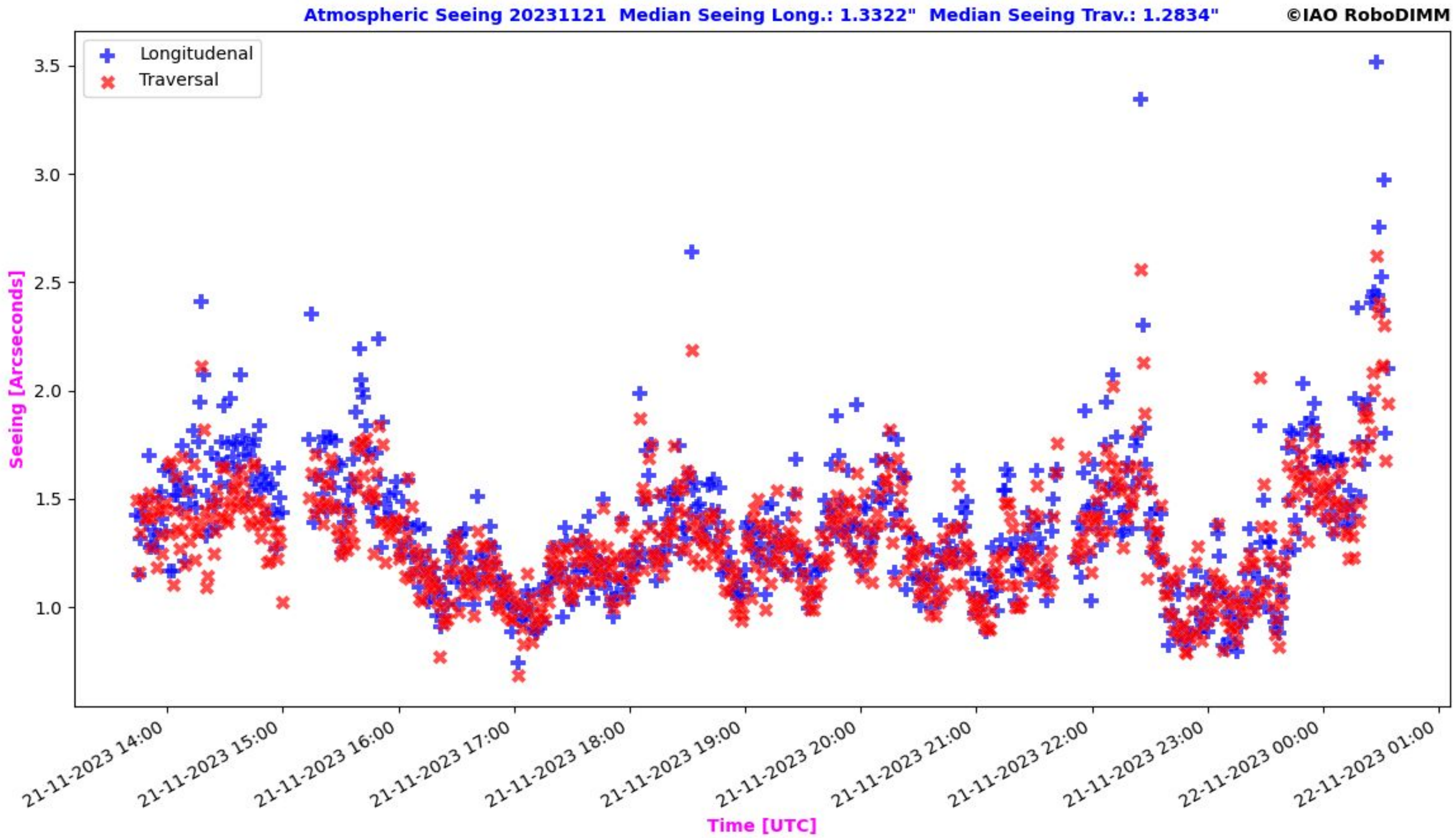
Technical Specification:

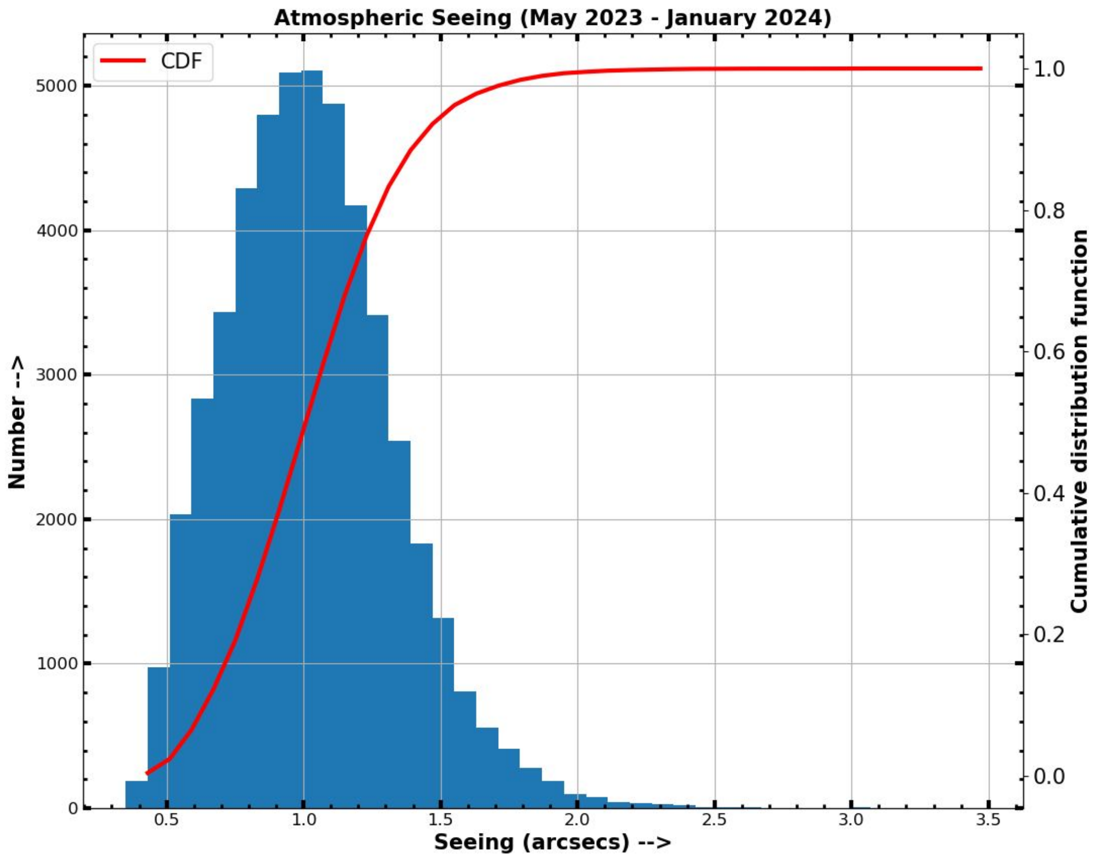
Telescope Type	12" (30 cm)
Telescope diameter	304.8 mm
Telescope focal length	3048 mm
Twin Pupil Diameter (D)	60 mm
Distance between pupils (d)	242 mm
Prism Deviation angle	30 arcsec
CCD Resolution	1920 x 1200 px, 2.3 MP

Script Settings:

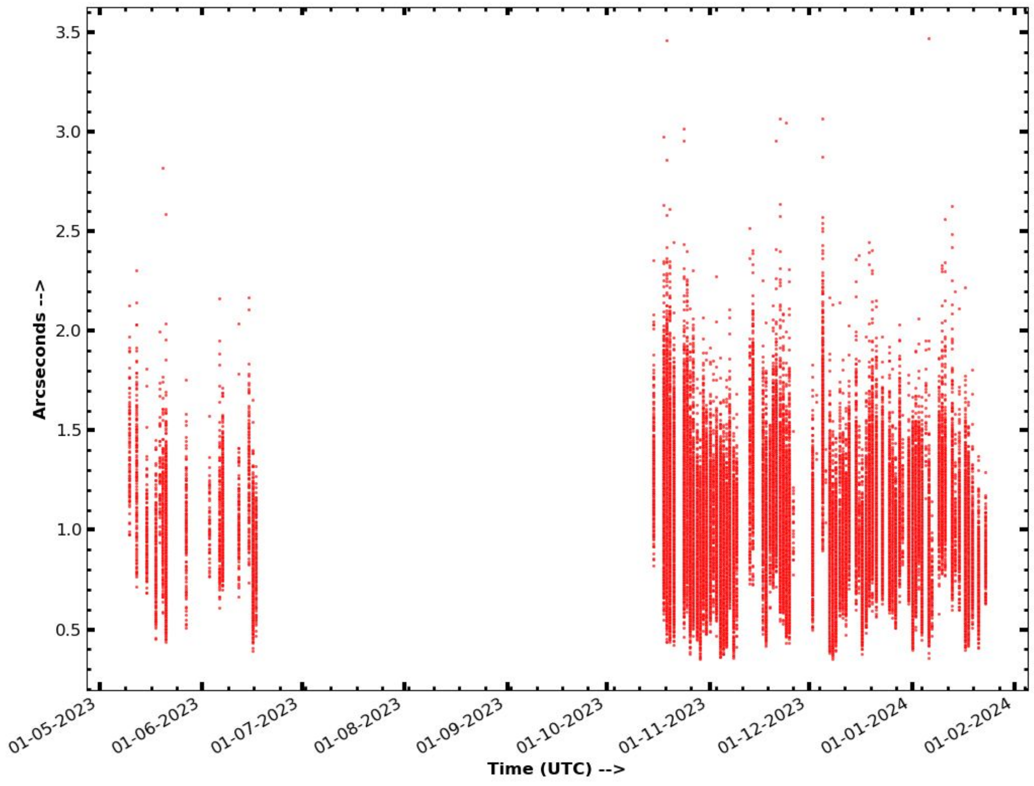
Exposure Time	10 ms
Data Set	300 images (3 sec)
Wavelength of light	500 nm
Astronomical Night	sun altitude < 12 deg
Star Tracking	Star altitude >49 deg

- Seeing data of 90 nights has been observed with over 50,000 data points.
- Seeing data for single night

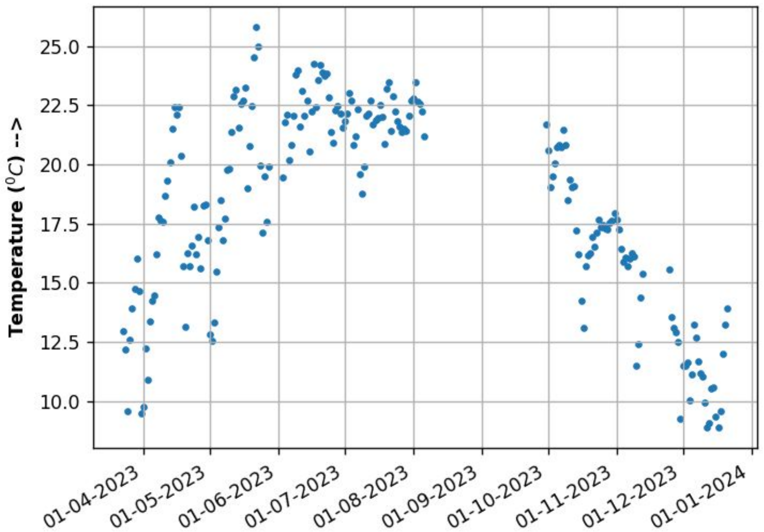


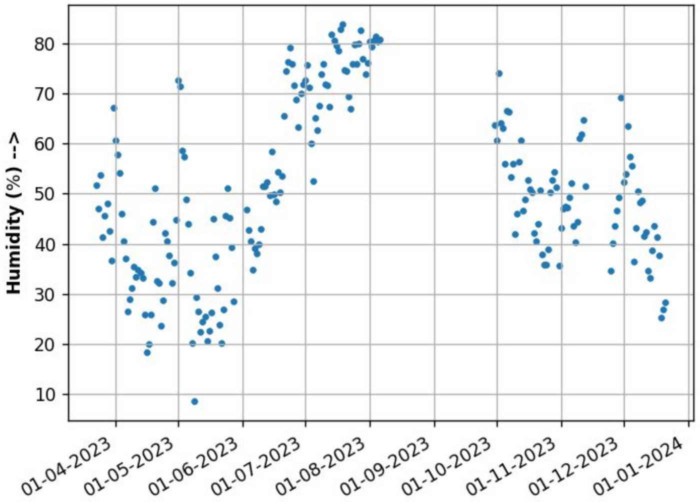


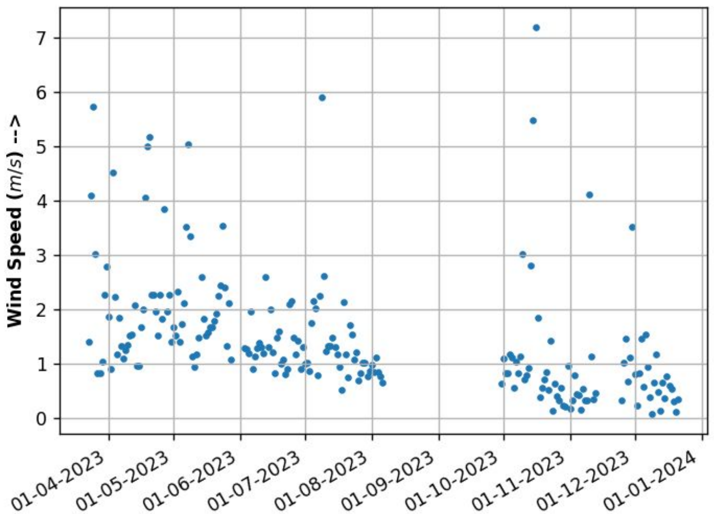
Histogram and Cumulative Distribution function of the Seeing values observed using DIMM

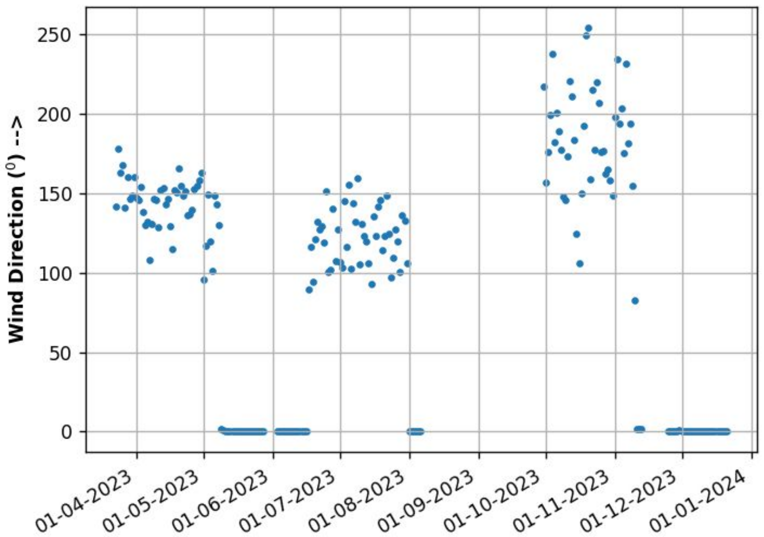


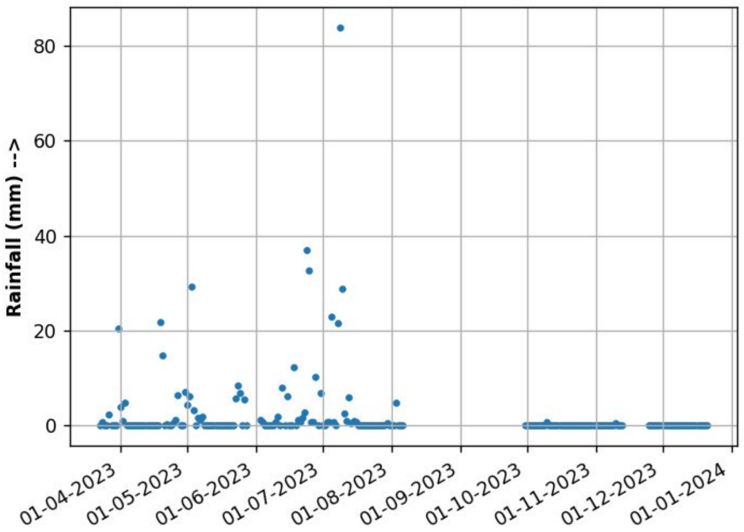
50000 Seeing points in arcseconds are plotted from May 2023 - February 2024


Temperature (^0C) -->
25.0
22.5
20.0
17.5
15.0
12.5
10.0
01-04-2023
01-05-2023
01-06-2023
01-07-2023
01-08-2023
01-09-2023
01-10-2023
01-11-2023
01-12-2023
01-01-2024


Humidity (%) -->
80
70
60
50
40
30
20
10
01-04-2023
01-05-2023
01-06-2023
01-07-2023
01-08-2023
01-09-2023
01-10-2023
01-11-2023
01-12-2023
01-01-2024


Wind Speed (m/s) -->
7
6
5
4
3
2
1
0
01-04-2023
01-05-2023
01-06-2023
01-07-2023
01-08-2023
01-09-2023
01-10-2023
01-11-2023
01-12-2023
01-01-2024


Wind Direction (^{0}) -->
250
200
150
100
50
0
01-04-2023
01-05-2023
01-06-2023
01-07-2023
01-08-2023
01-09-2023
01-10-2023
01-11-2023
01-12-2023
01-01-2024


Rainfall (mm) -->
80
60
40
20
0
01-04-2023
01-05-2023
01-06-2023
01-07-2023
01-08-2023
01-09-2023
01-10-2023
01-11-2023
01-12-2023
01-01-2024

MONTHS	Temperature (^0C)	Humidity (%)	Wind Speed (m/sec)	Wind Direction (^{0})	Rainfall (mm)
March	12.5	45.35	1.6	166	**2.86**
April	16.8	34.80	1.6	145	**2.05**
May	20.0	30.90	1.6	**36.40**	**2.72**
June	22.2	54.20	1.1	**60.86**	**4.61**
July	21.6	75.60	1.1	95	**5.58**
August	22.2	80.50	0.8	**NA**	**0.94**
September	19.8	61.50	NA	292.5	**0.00**
October	17.7	49.60	0.5	140	**0.02**
November	14.3	47.20	**NA**	16	**0.03**
December	10.5	43.90	**NA**	**NA**	**0.00**

Monthly Median Values of the respective sensors data. *NA:* Senors are not working for the particular period. *Blue:* Mean values for the respective month

- What is laminar flow?

Write the scenario of the under developed jet

Introduce inverse mass scaling relation pic

Introduce ztf r band range

Download gif video

Introduce fundamental plane

Defend for the control sample

Thank You

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