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AOB:A O B ,
IHEP:C A I H E P B
AO:

OSCILLATION(SIGNAL) PATTERNS IN AGN LIGHT CURVES

ASTROTOMOGRAPHIC METHODS AND THEIR CLASSIFICATION

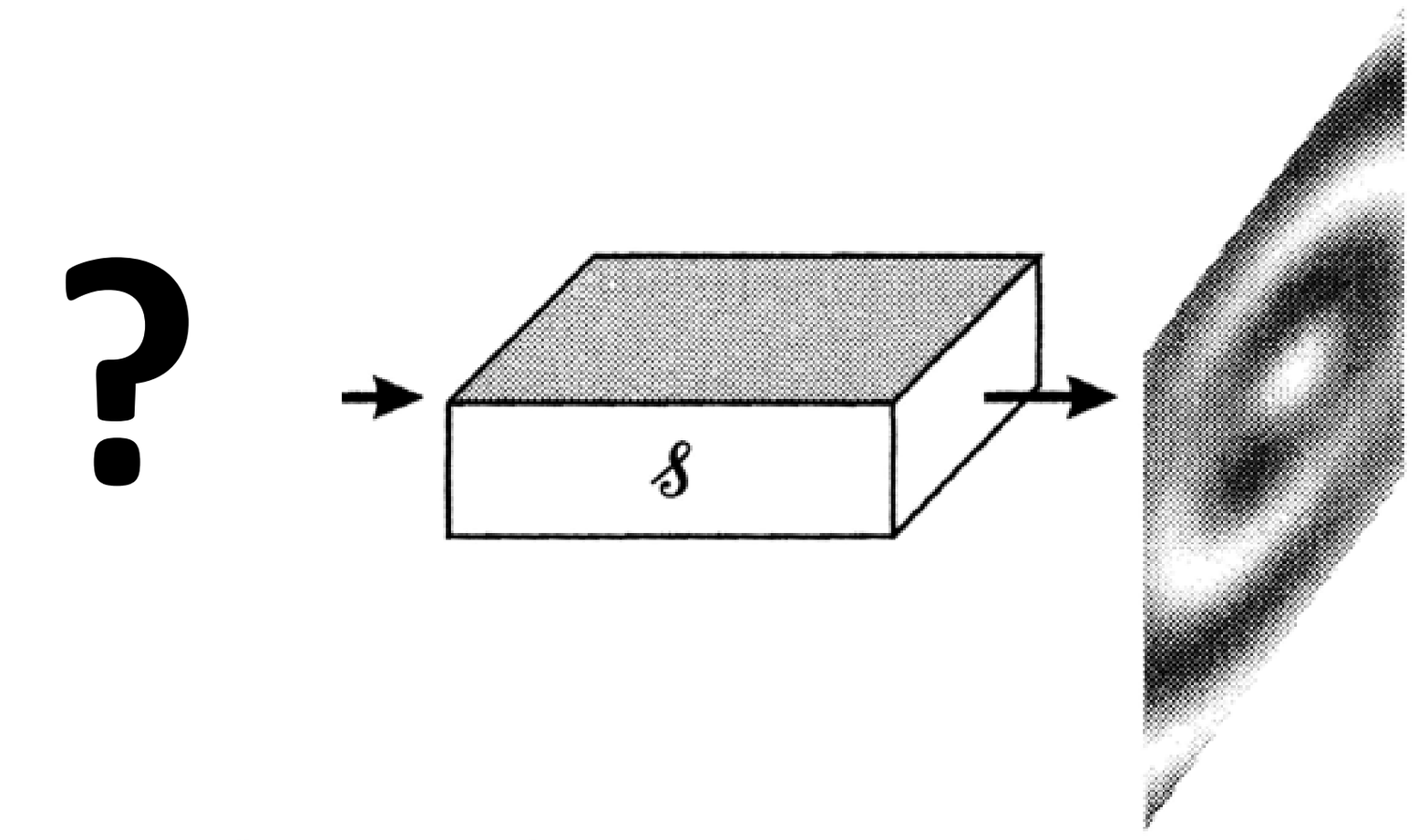
Table 1. Methods that use the rotation of an astronomical object.

Method	Physical event on which the method is based	Astronomical objects under study	Input data (what is observed)	Final result (data processing result)
Eclipse mapping (Cameron et al. 2004; Baptista 2004)	An eclipse of a rotating white dwarf accretion disk by a red-dwarf companion	Cataclysmic Variables (CVs)	Optical or IR eclipse light curves of an accretion disk	The structure, spectrum and time evolution of an accretion disc
Stokes imaging (Potter et al. 1998, 2004)	Linearly and circularly polarized cyclotron emission	White dwarf accreting matter and magnetic field in polars	Four Stokes parameter light curves as a function of orbital phase	2D image of white dwarf cyclotron emission areas in magnetic latitude and longitude coordinates
Doppler tomography (Agafonov et al. 2009; Richards et al. 2012)	Non-relativistic Doppler shift in spectral lines	Gas flows in close binary star systems of different types	Spectral line profiles covering one or more full orbital cycles	Image in the 3D velocity vector components space
Roche tomography (Cameron et al. 2004; Watson, Dhillon, 2004)	Secondary star line emission at different orbital phases	A Roche lobe-filling secondary star in CVs	Spectral line profiles and intensities at different orbital phases	Line intensity distribution on the surface of the Roche-lobe-filling star in CVs
Qualitative Solar Rotational Tomography (QSRT) (Morgan et al. 2009)	Scattering of photosphere light by corona free electrons	The solar corona	2D coronagraph images at different phases of solar rotation	The 3D distribution of the electron density in the solar corona in relative values

Table 2. Methods that do not use the rotation of an astronomical object.

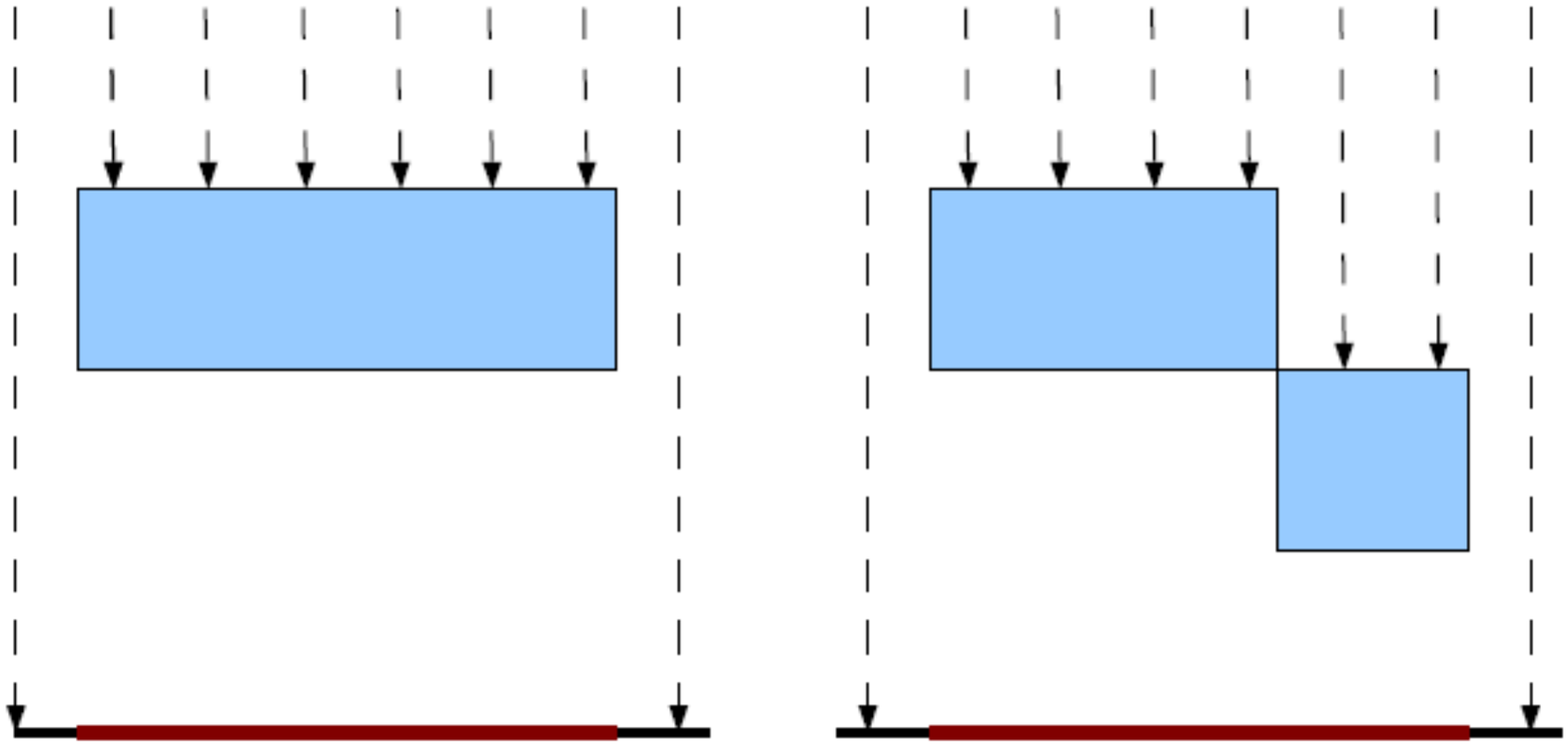
Method	Physical event on which the method is based	Astronomical objects under study	Input data (What is observed)	Final result (data processing result)
Echo-mapping (Bochkarev, Antokhin 1982; Antokhin, Bochkarev 1983; Blandford, McKee 1982; Peterson, Horne 2004)	Reemission of variable ionizing continuum radiation of a central source in spectral lines by a broad line regions (BLR) clouds	Quasars, Seyfert I galaxies	Continuum ionizing radiation of a central source and delayed emission from an ambient BLR in lines from far UV to near IR	Diagrams in continuum intensity–line intensity, lag–ray velocity coordinates. Kinematics and structure of BLR, central black hole mass
Gravitational lensing (microlensing) technique (Kuijken 2003; Hoekstra 2013; Cropper et al. 2013)	Gravitational lensing	Extragalactic objects, stars, exoplanets	Lensed image of an astronomical object	Distribution of gravitating matter over lens and/or its mass
Interstellar scintillation method (Wolszczan, Cordes 1987; Smirnova et al. 1996, 2014)				

GENERAL INVERSE PROBLEM AND IMAGE RECONSTRUCTION

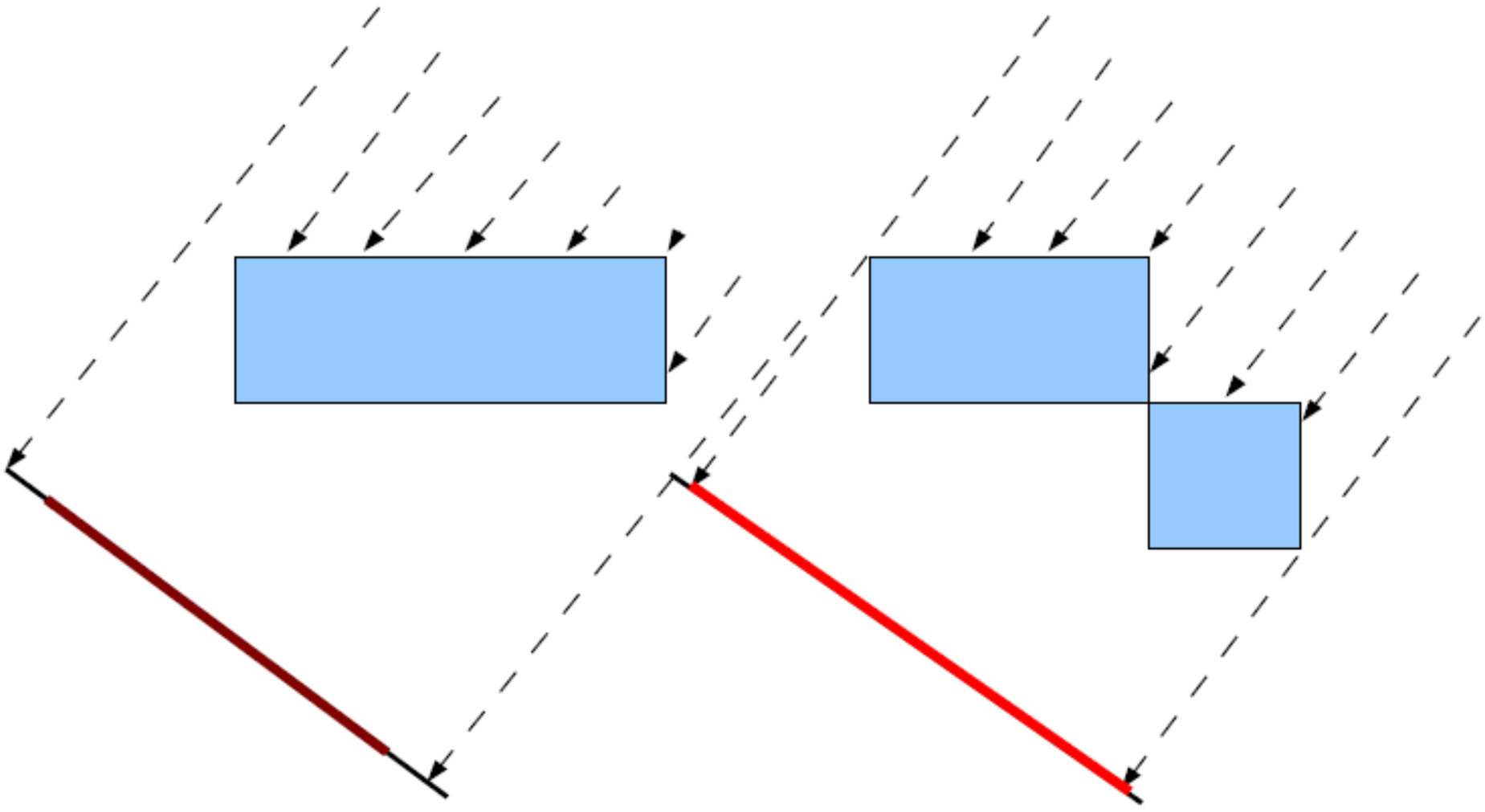


Input f System $\mathcal{S}$ Output g

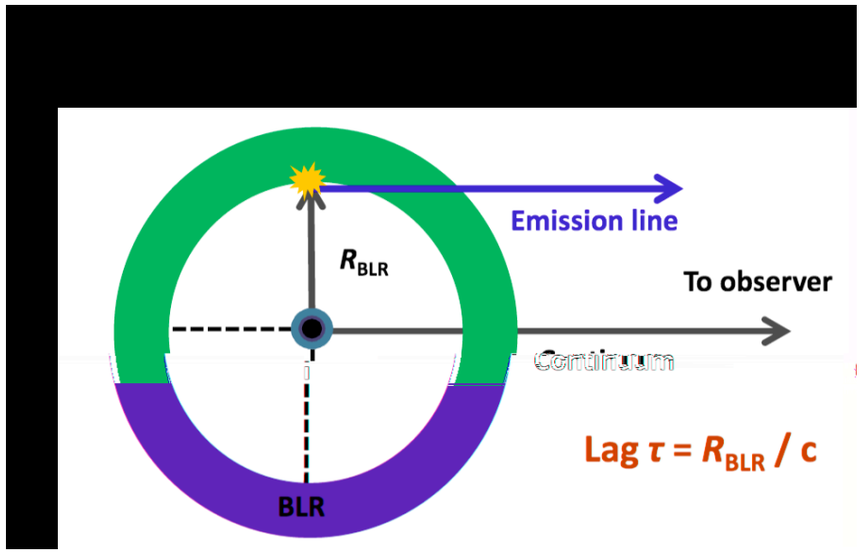
THE FAILURE TO DISTINGUISH OBJECTS



SOLUTION: MORE DIRECTIONS, MORE TECHNIQUES–DO NOT MISS TALK PROF WANG



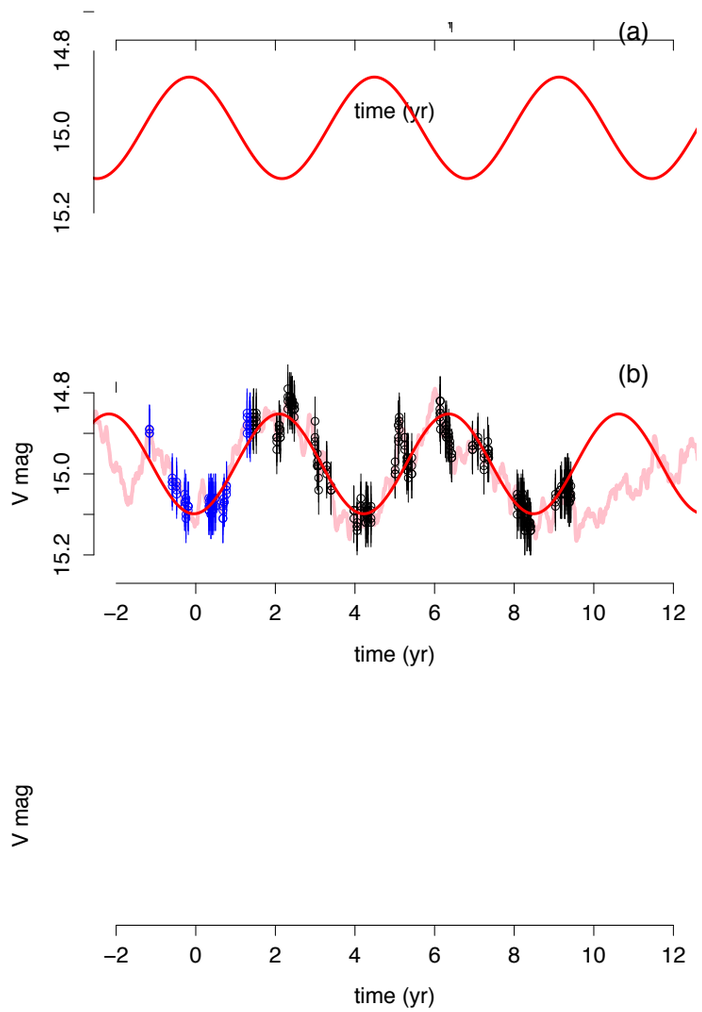
RM–'DAYLIGHT'



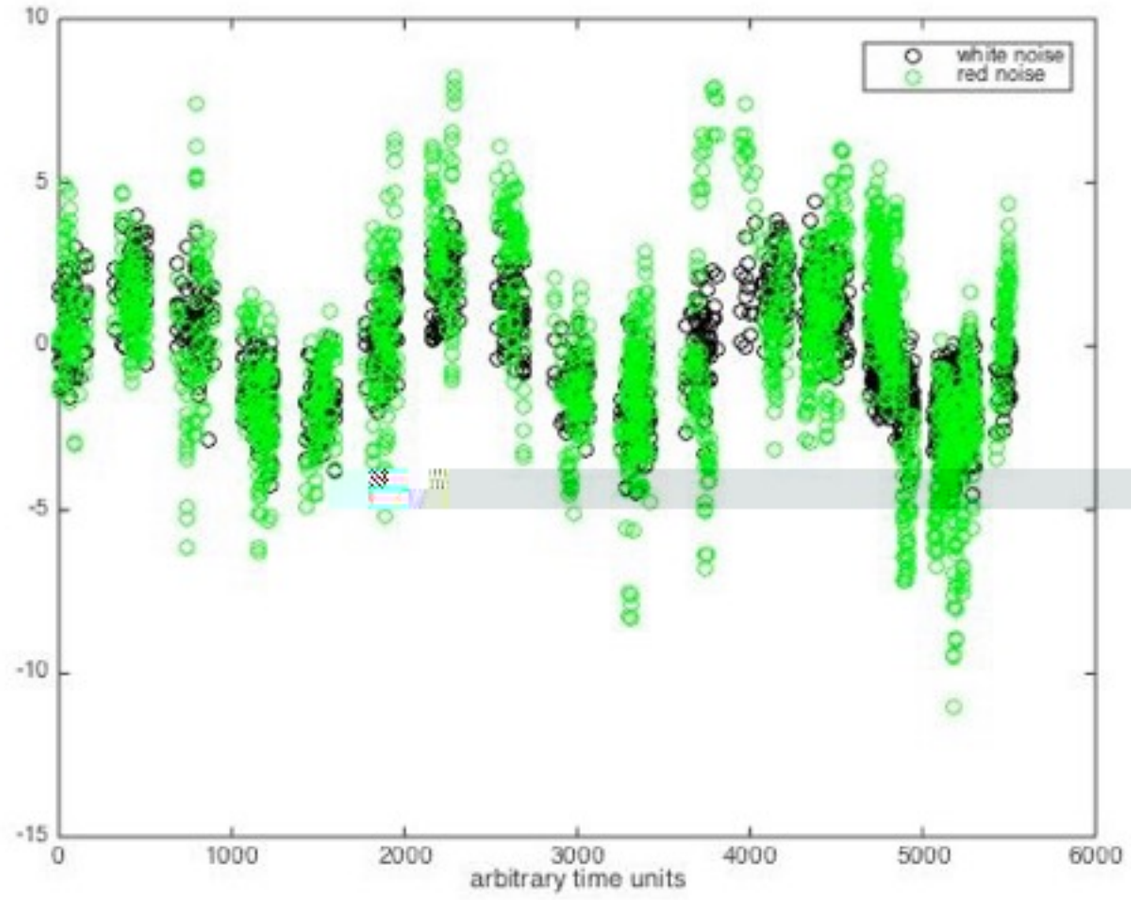
DETECTION PROBLEM

$$m(t, \boldsymbol{p}) = h(t, \boldsymbol{p}) * e(t) + \varepsilon(t) = s(t, \boldsymbol{p}) + \varepsilon(t).$$

$$\begin{cases} H_0: & m(t) & = & \varepsilon(t) \\ H_1: & m(t) & = & s(t) + \varepsilon(t) \end{cases}$$

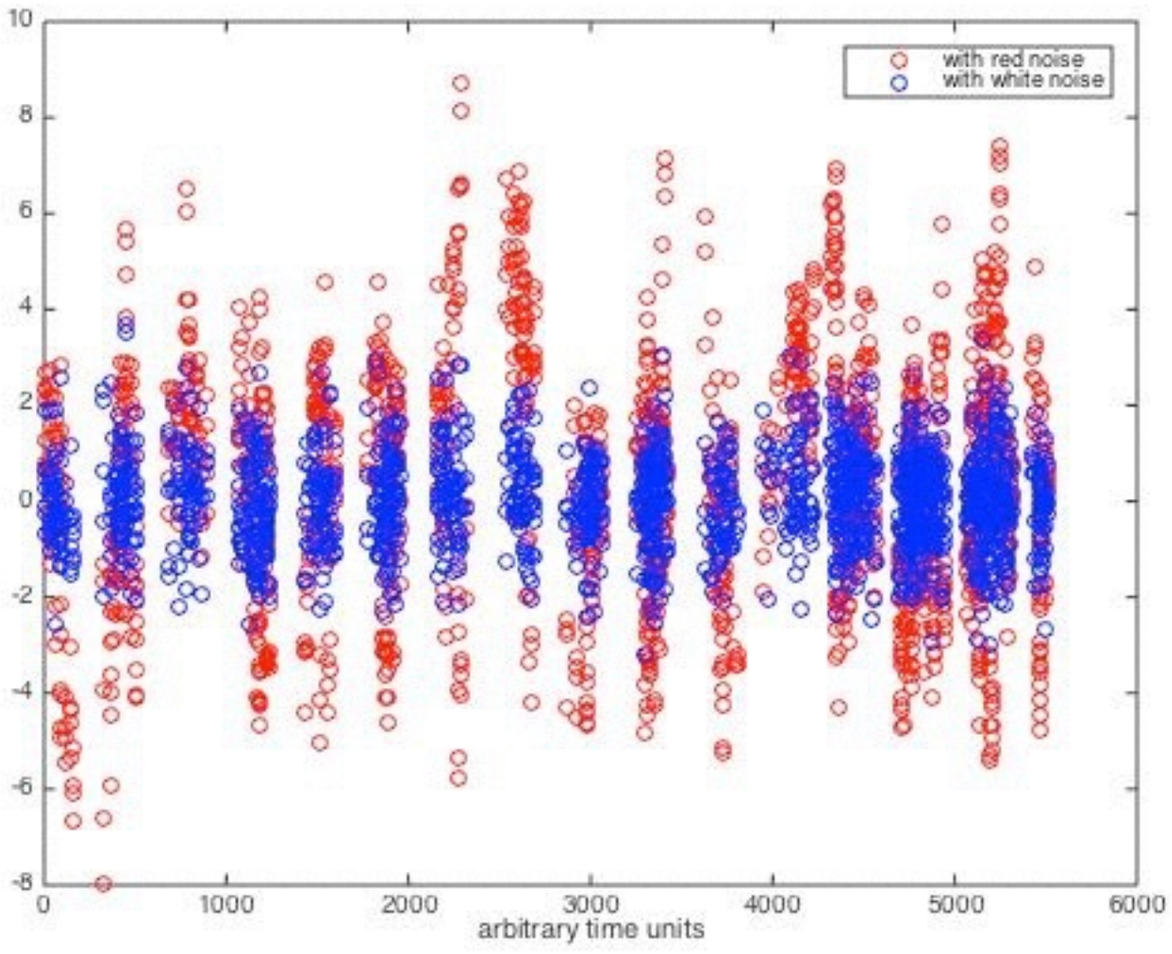


DETECTION PROBLEM



red noise +5*sin(2pit/1880)

white noise 5*+sin(2pit/1880)



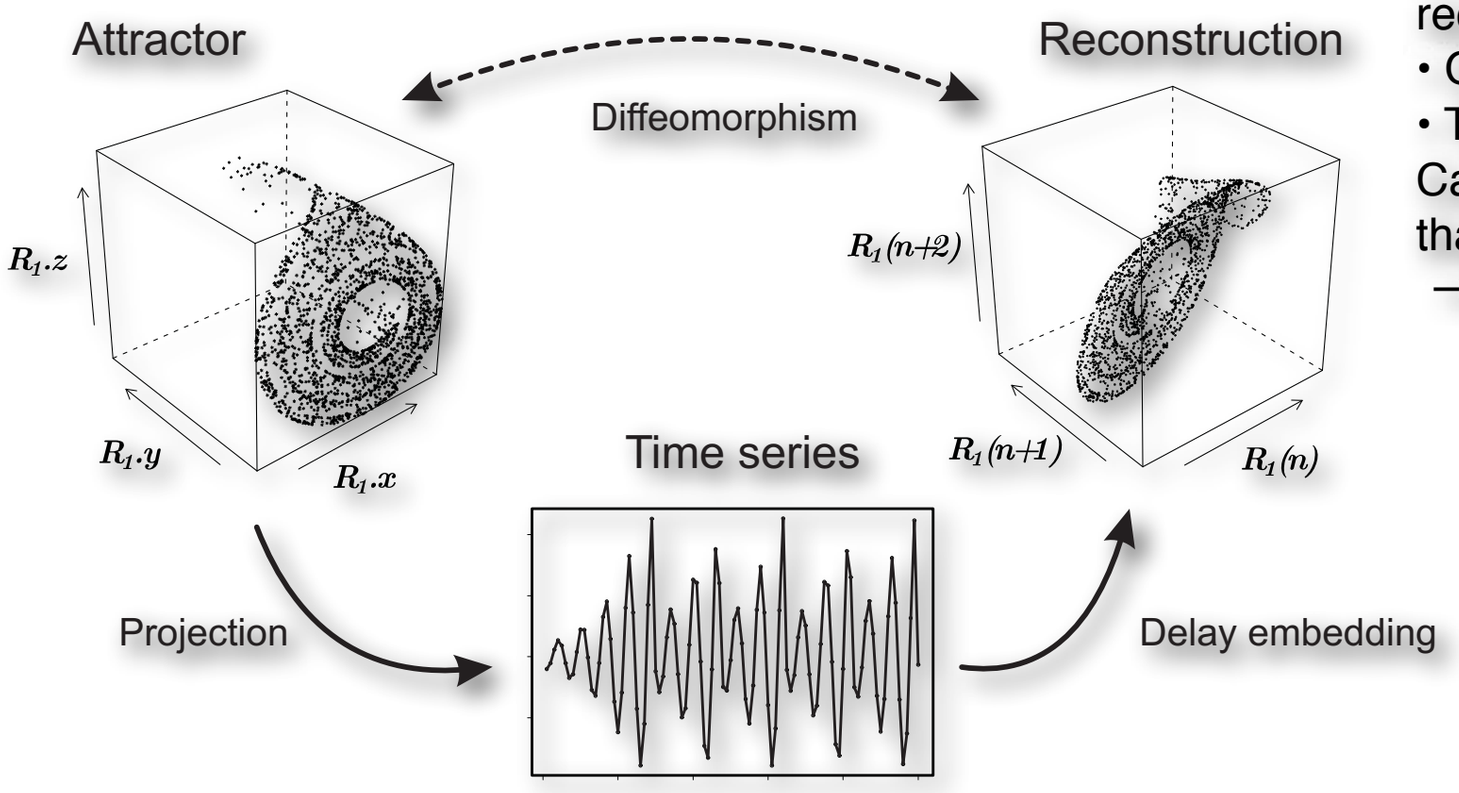
red noise +0.1*sin(2pit/1880

white noise 0.1*+sin(2pit/1880)

NOISE PROCESSING

C D

- time series projection in 2D period (frequency) domain
- time series projection in Hilbert transform phase space



Directly observing the phase space/attractor requires access to all dynamical variables. But:
• Often, only one dynamical variable is available.
• The dimension of phase space is unknown.
Can we obtain from one time series a set that preserves important properties of the attractor?
→ Yes, but it's a bit of work.

time series projection in 2D period (frequency) domain

Perturbation (?stochastic)

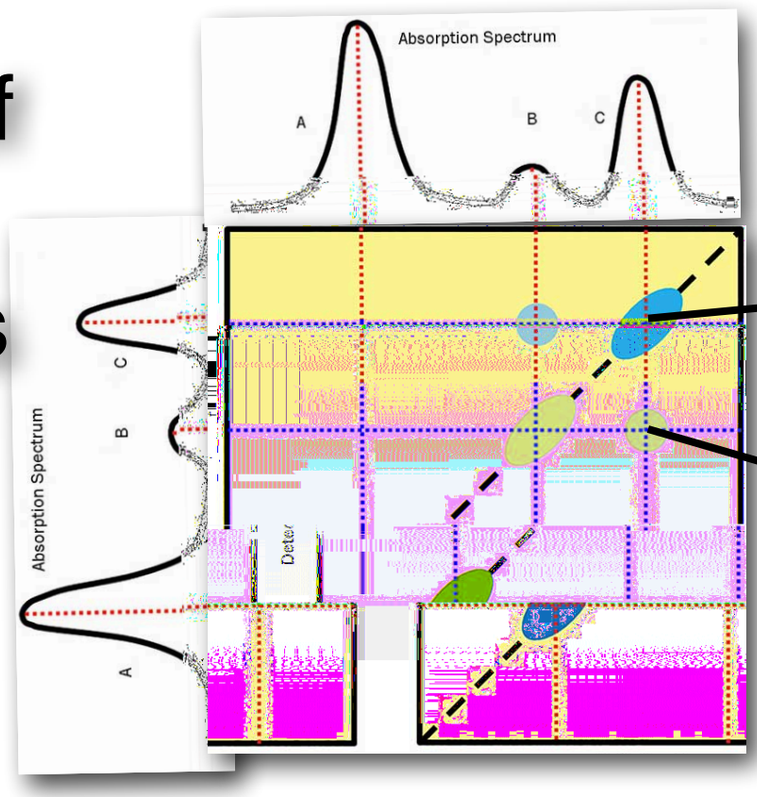
System

? or intrinsic dominant nonlinear-shift/ catastrophic regime

LC(t) = Dynamical(t) x Acceleration(t) x Radiation(t) x Observation(t) [Product]

Hybrid method

Measure dynamic of interactions between oscillations in the light curves



diagonal peak

cross peak

Kovačević at al 2018

HYBRID METHOD: 3 STEPS

OUGP=Ornstein–Uhlenbeck Gaussian Process

OUGP(raw LC1)=OUGP1

OUGP(raw LC2)=OUGP2

0 STEP:
raw data
preprocessing

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

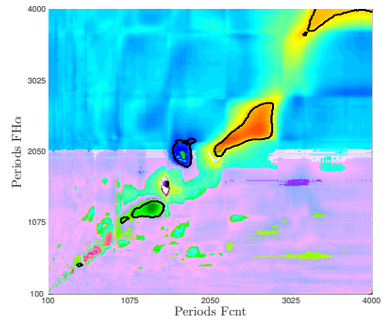
$$\mathrm{env}(a,b) = \sqrt{\mathrm{Re}\{[\mathrm{CWT}(a,b)]^2\} + \mathrm{Im}\{[\mathrm{CWT}(a,b)]^2\}},$$

I STEP

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

The next step is to calculate the correlation coefficients of the envelopes of the wavelet coefficients of each light curve at each wavelet scale using the Spearman rank correlation coefficient. The Spearman coefficient measures statistical dependence between two variables without a normality assumption for the underlying population (i.e. it is a non-parametric measure).

HYBRID METHOD–HIGHLIGHTS



Using hybrid method we show a novelty in the oscillatory patterns of the all surveys combined light curves of 5 well known type I AGN:

i) periodic variations in3C 390.3, NGC 4151, NGC 5548, E1821+643

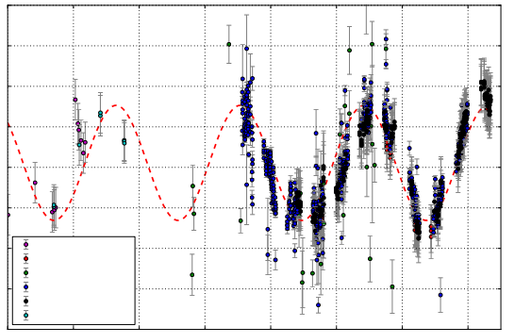
ii) differences in dynamical regimes:
- binary black hole candidates:
  NGC 5548 chaotic regime
  E1821+643 stable regime

-double-peaked Balmer line objects:
 3C 390.3 oscillatory pattern rapidly fluctuate in 2D correlation space
 Arp 102B no oscillations (or weakly coupled oscillatory systems)

iii) confirmation of physical background of detected oscillations:
 our coupled oscillatory models describe oscillatory behavior in the light curves

-even 3C 390.3 and Arp 102B are categorized as double-peaked Balmer line objects,

CHALLENGES PG 1302-102



Graham et al. 2015

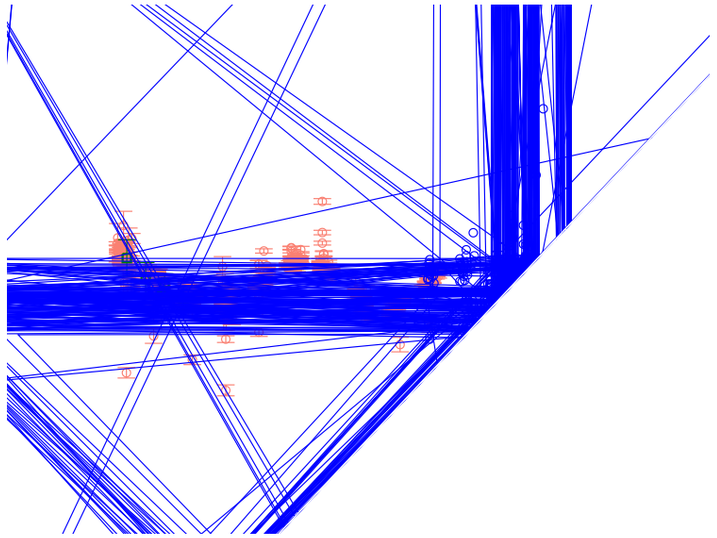
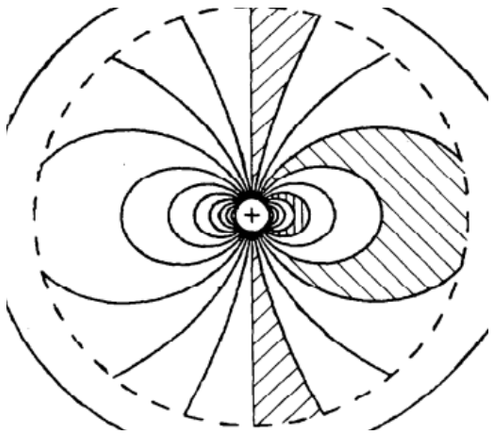
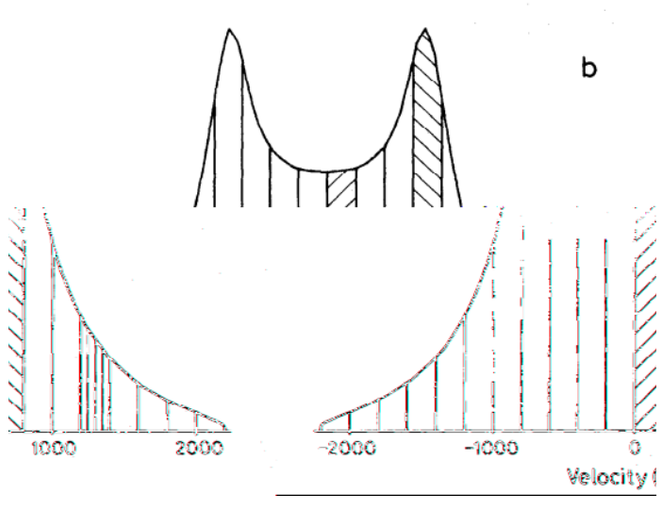


Figure 2 The composite light curve for PG 1302-102 over a period of 7,338 days (∼ 20 years). The light curve combines data from two CRTS telescopes (CSS and MLS) with historical data from the LINEAR and ASAS surveys, and the literature (see Methods for details). The error bars represent one standard deviation errors on the photometry values. The dashed line indicates a sinusoid with period 1,884 days and amplitude 0.14 mag. The uncertainty in the measured period is 88 days. Note that this does not reflect the expected shape of the periodic waveform which will depend on the physical properties of the system. MJD, modified Julian day.

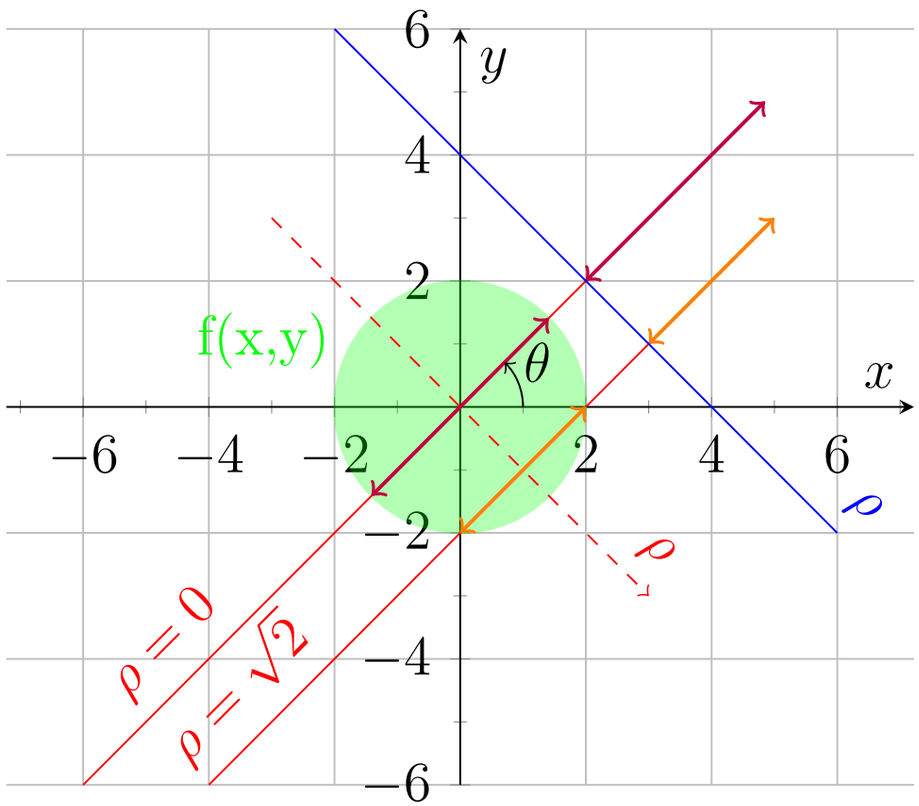
DOPPLER-SHIFTED PROFILE FORMATION





Horne and Marsh (1988)

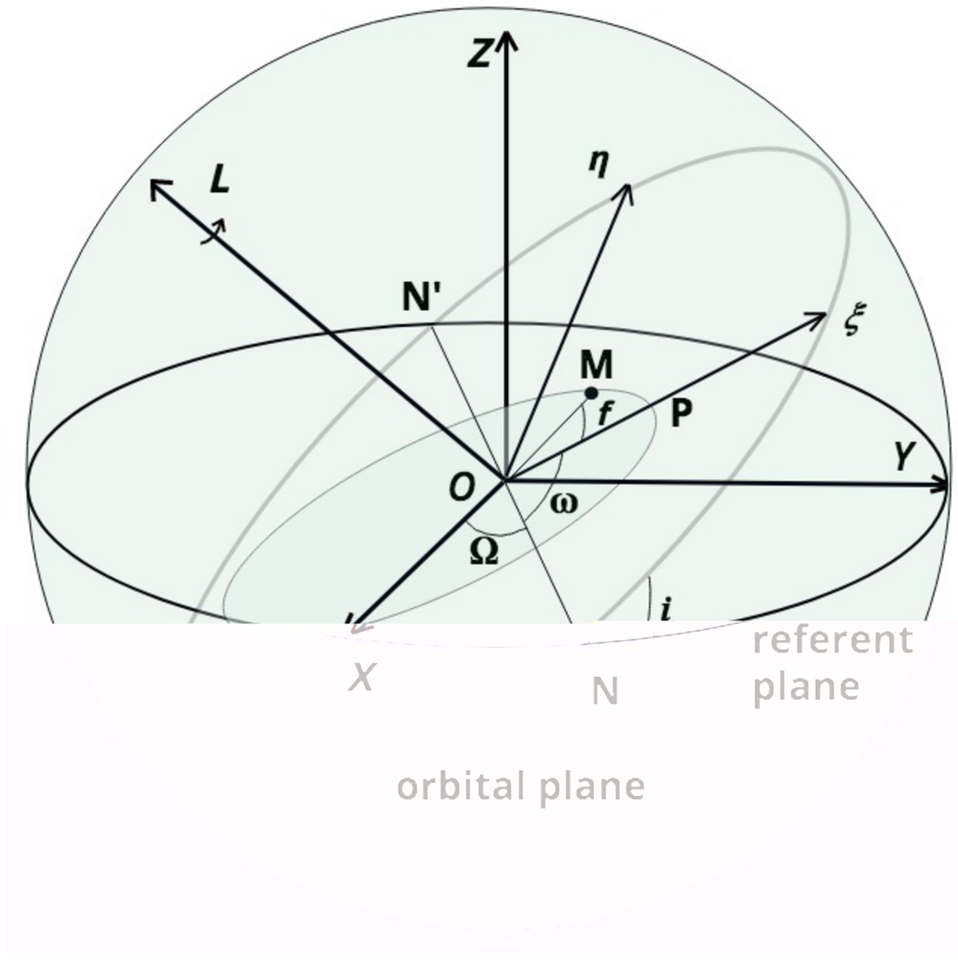
LINE FORMATION–PROJECTION



COMPOSITE 2DTF-ELLIPTICAL CASE

$$\mathcal{L}(V_z, \tau) = \int_{-\infty}^{+\infty} C(t-\tau)\Psi(V_z, \tau)d\tau.$$

ONE OF SIMPLE REALIZATION OF SMBBH ELLIPTICAL SYSTEM



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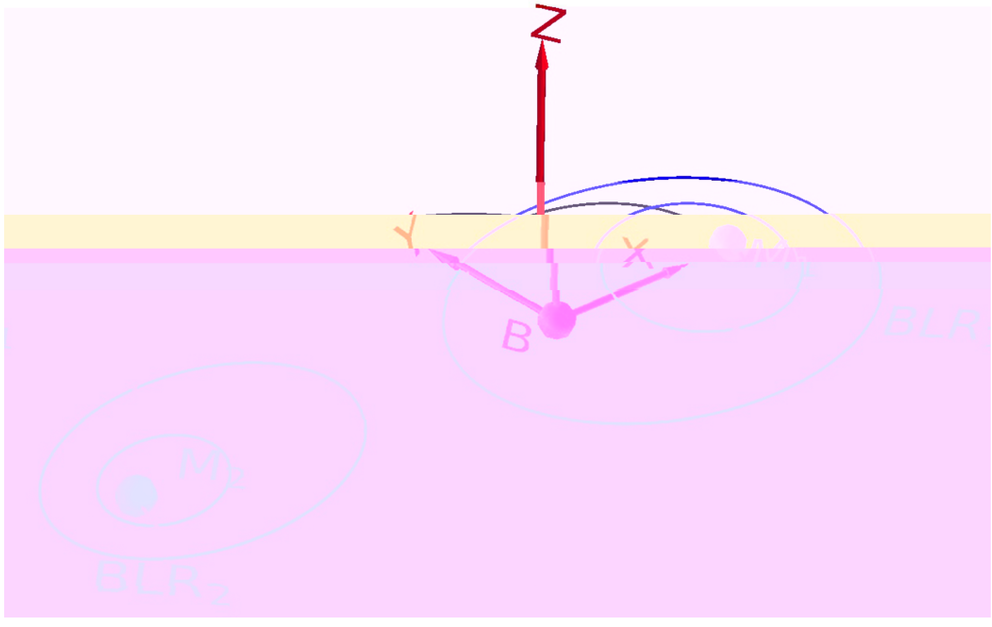
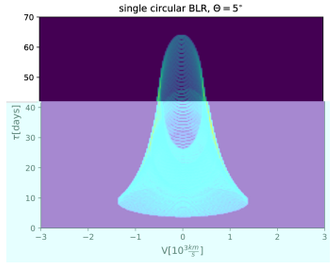


(b)

OSCILLATION(SIGNAL) PATTERNS IN AGN LIGHT CURVES

SIGNLE BLACK HOLE: 2DTF +LINE SHAPES



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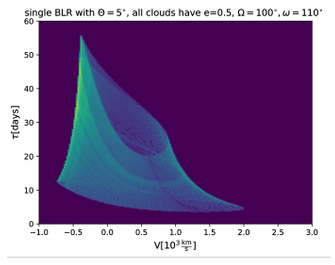

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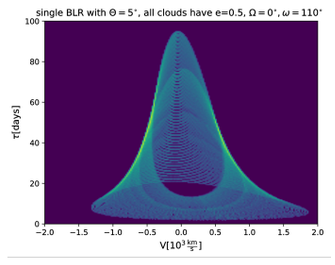

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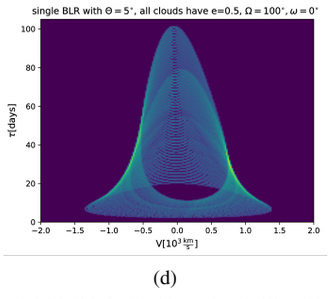

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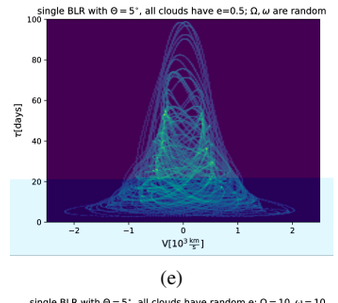

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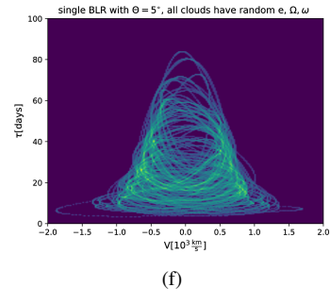

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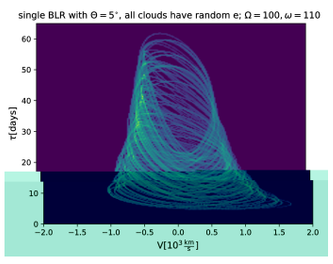

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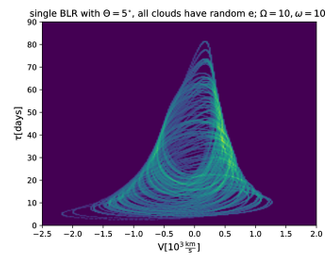

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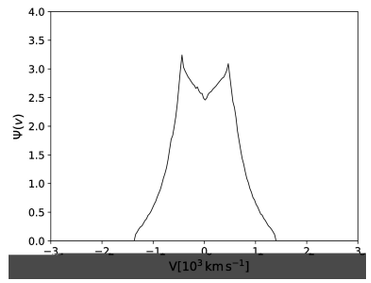

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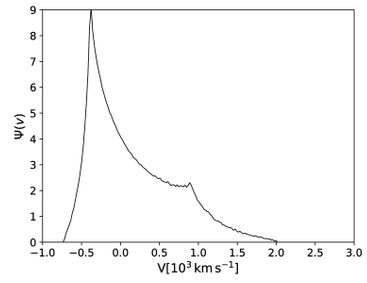

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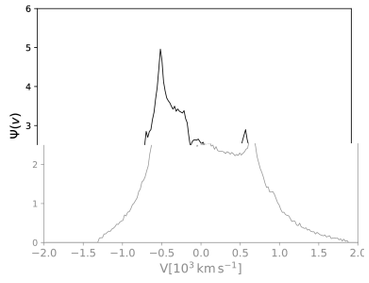

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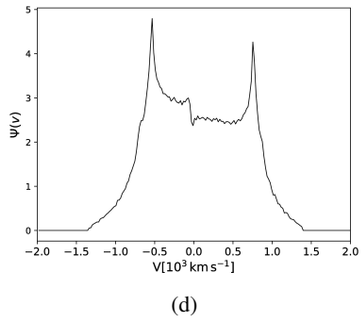

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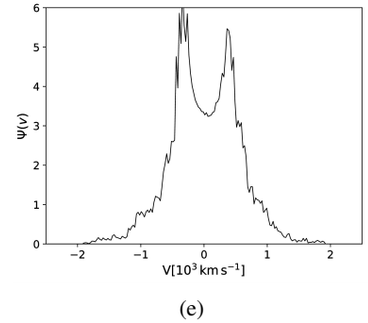

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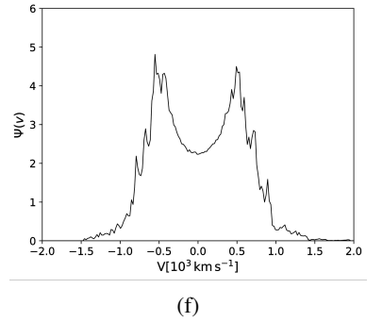

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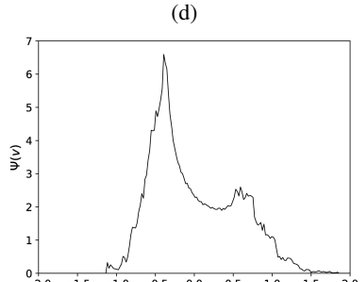

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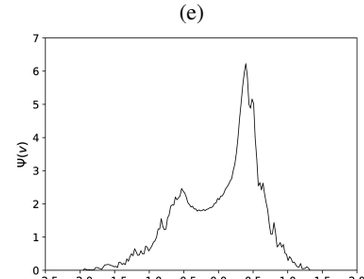
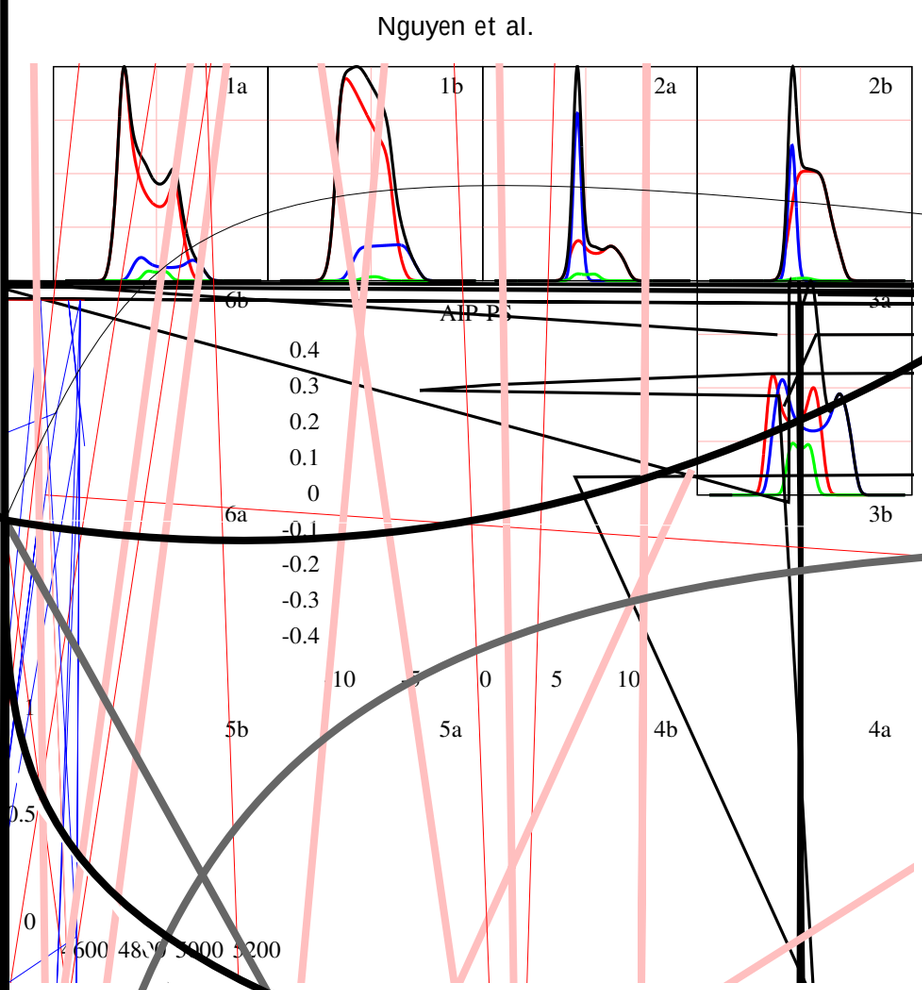
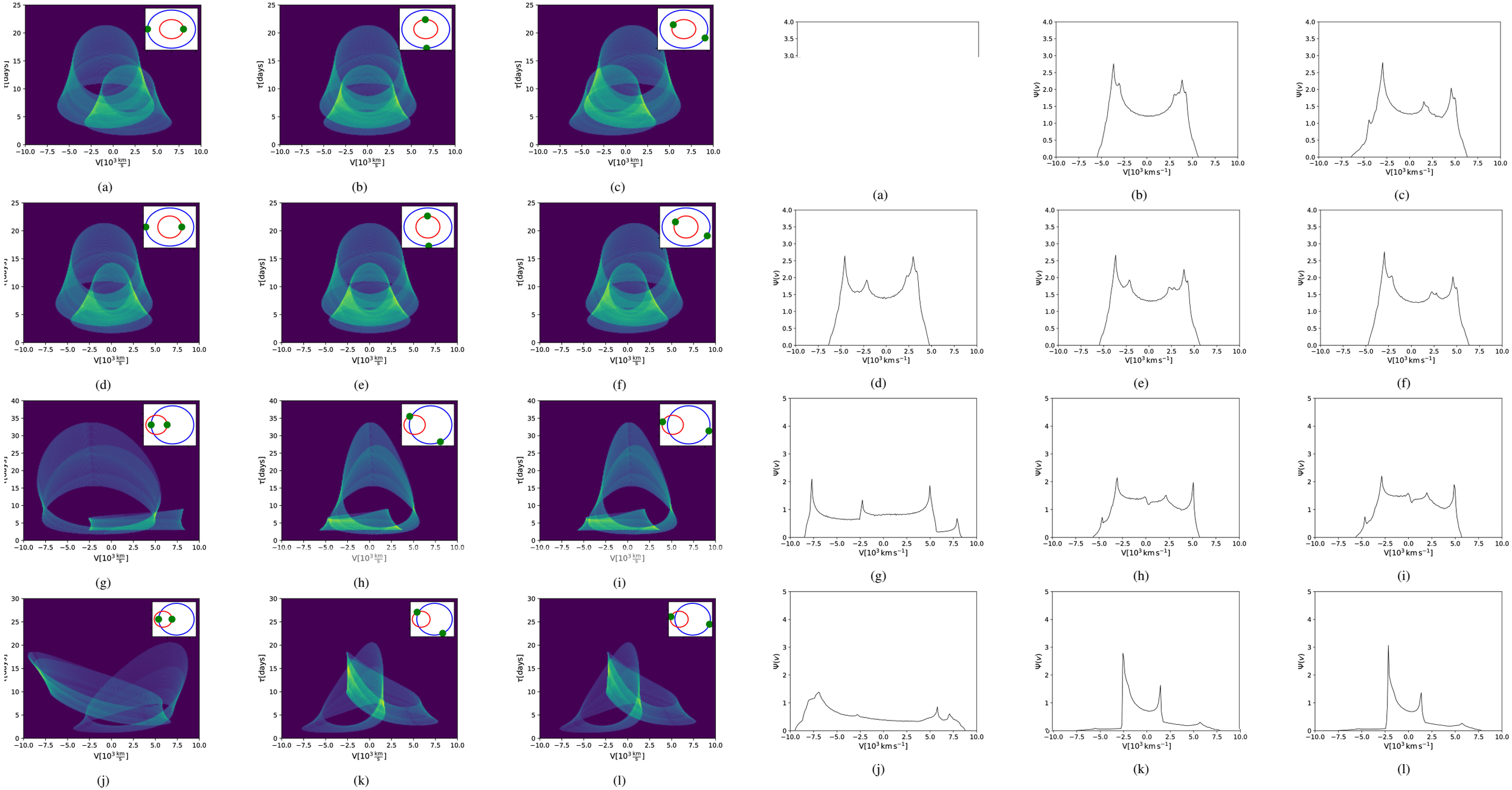


(h)

EXAMPLES FROM LITERATURE

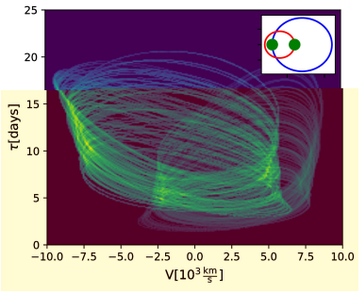


SMBBH: 2DTF+LINE SHAPES



OSCILLATION(SIGNAL) PATTERNS IN AGN LIGHT CURVES

SMBBH:2DTF+LINE SHAPES



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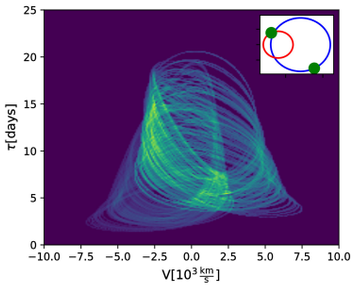

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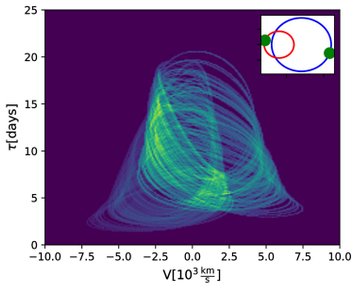

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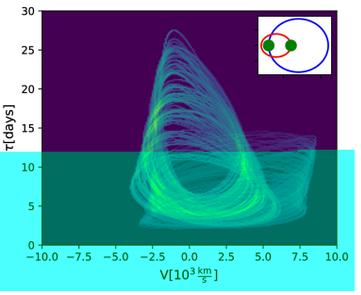

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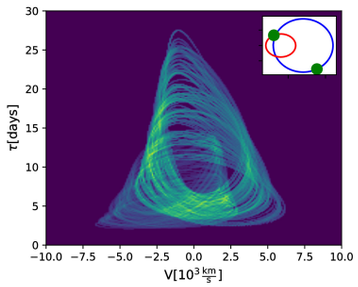

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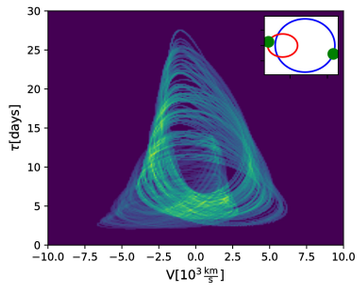

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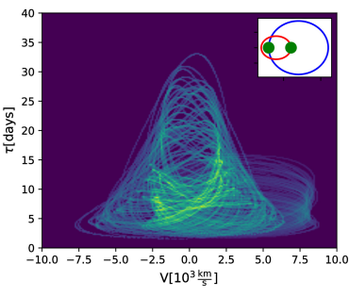

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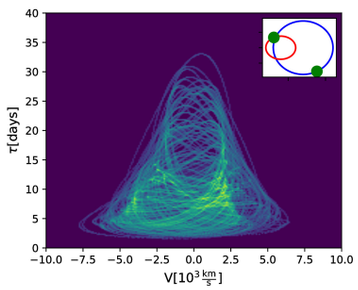

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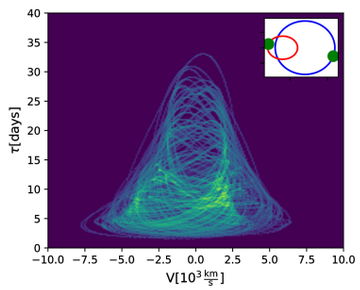

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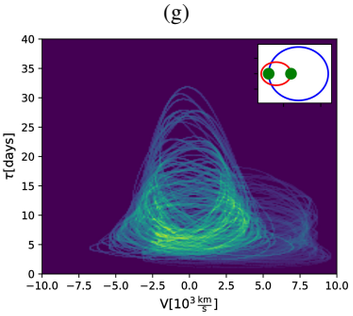

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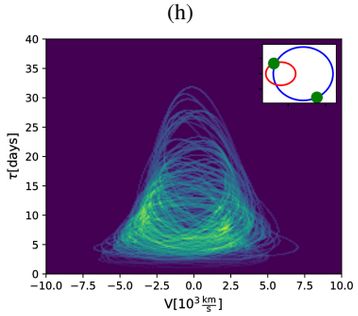

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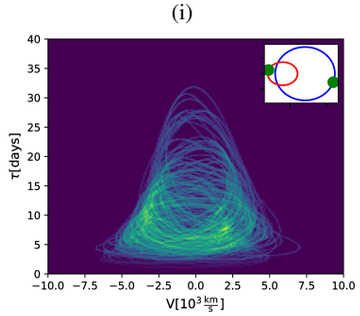

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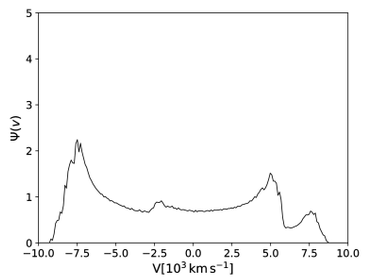
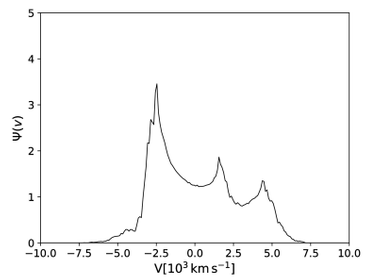


(a)



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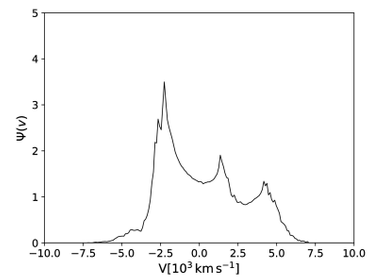

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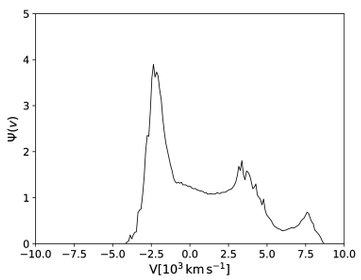

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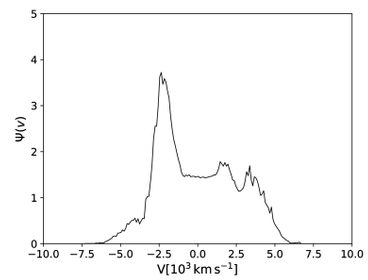

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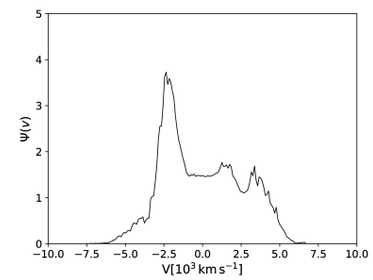

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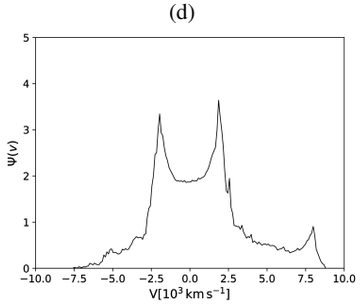

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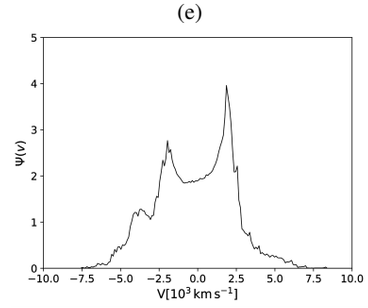

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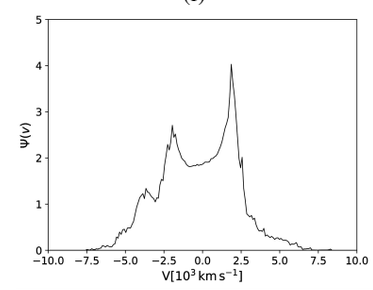

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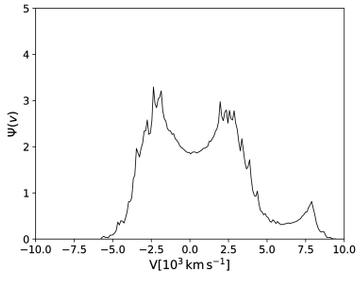

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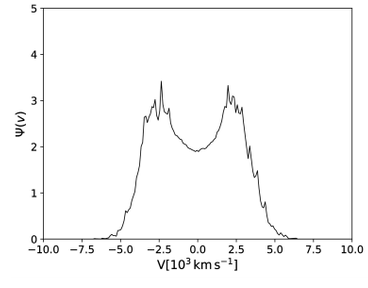

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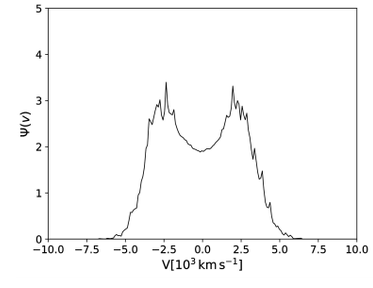
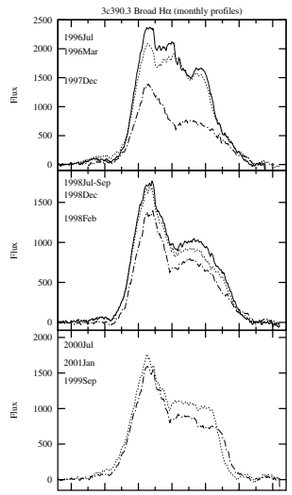


(l)

EXAMPLES FROM LITERATURE



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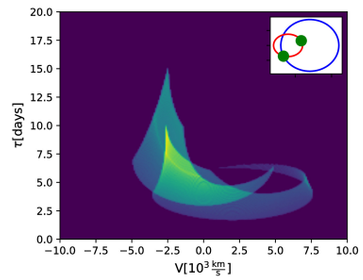

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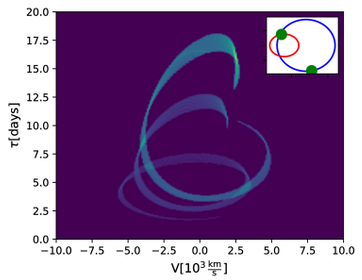

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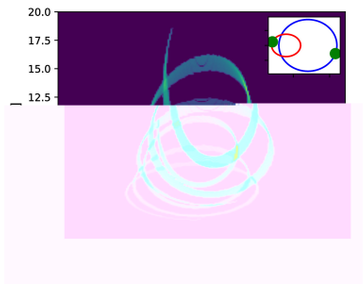

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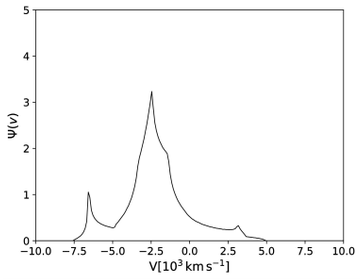

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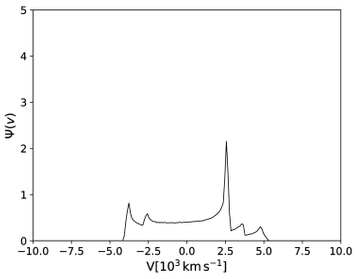

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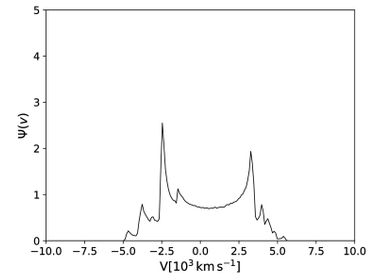

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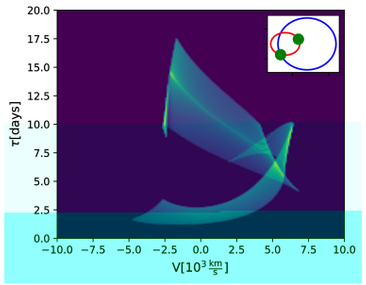

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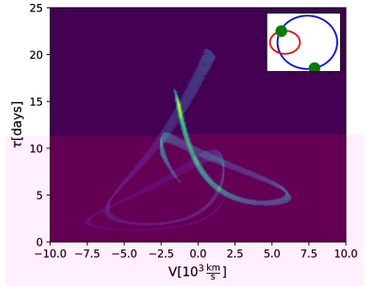

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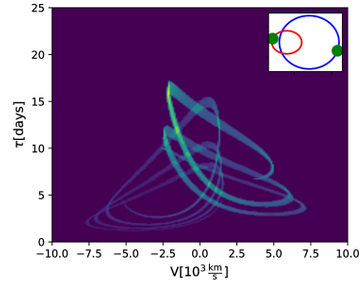

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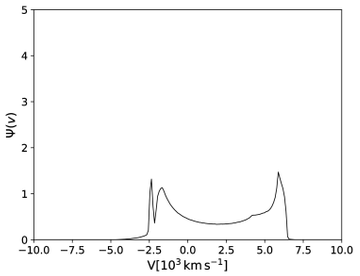

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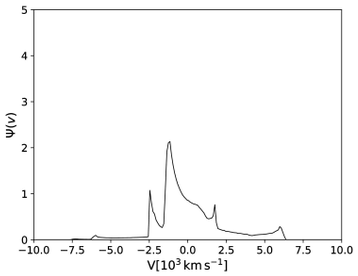

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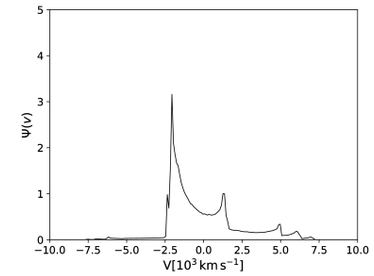

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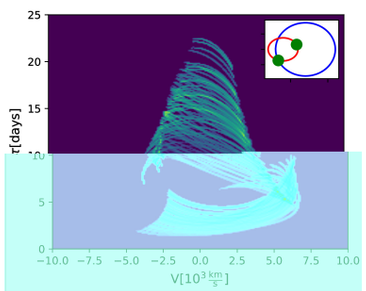

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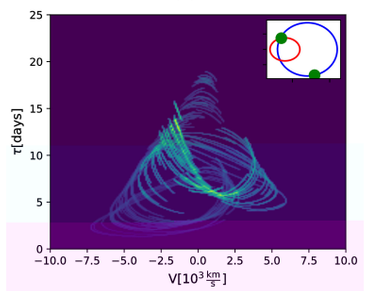

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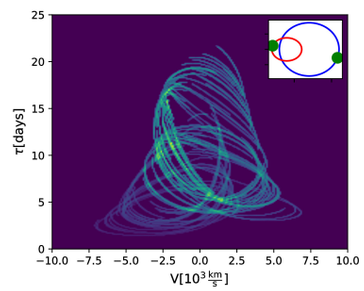

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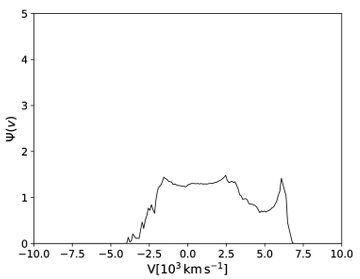

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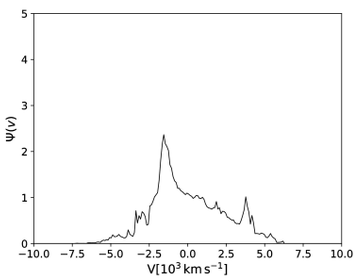

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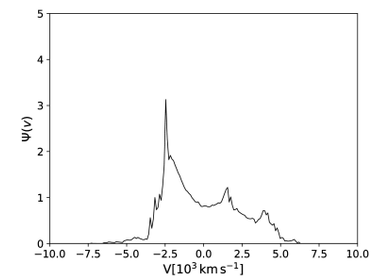

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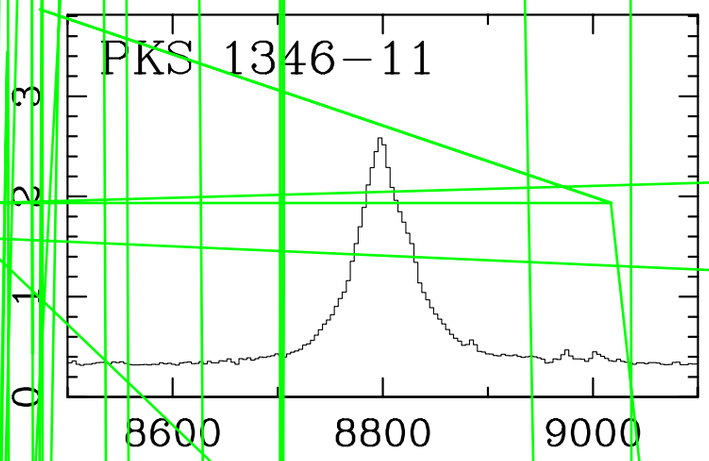
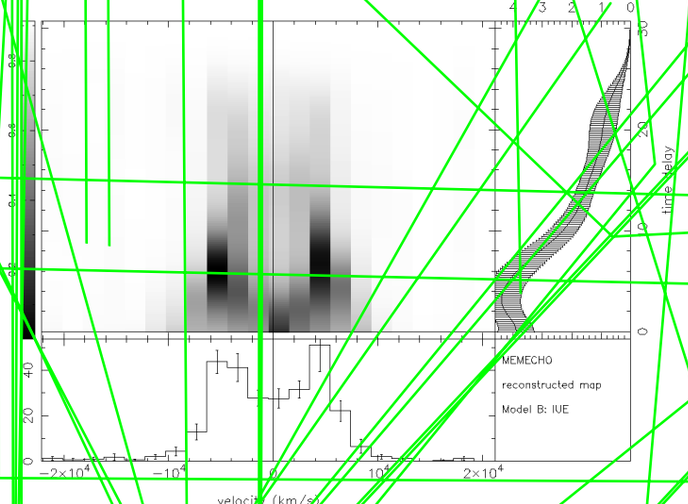
EXAMPLES FROM LITERATURE



Eracleous & Halpern+03



Horne & Peterson+04