Shellspec – a tool for modeling the spectra, light curves, and images of interacting binaries and exoplanets

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What is SHELLSPEC?

- A computer code in Fortran90
- Used for stars/planets immersed in a moving circumstellar matter
- Simple radiative transfer along the line of sight in 3D moving media
- Boundary condition: stars or planets with Roche geometry, limb and gravity darkening, reflection effect (default: output of Synspec, Tlusty by Ivan Hubeny)
- Assumes LTE
- Assumes optional but given state quantities and velocity field in 3D
- Scattered light from 1-2 objects can be taken into account assuming that the medium is optically thin
- Dust and non-isotropic Mie scattering included
- Calculates composite synthetic spectra, light curves, 2D intensity maps
- Does not solve the inverse problem: PyShellspec (Broz&Nemravova)

Input

- 3D Model
  - Compose your model from predefined (non)transparent objects:
    - Star, Companion, Secondary, Spot, Stream, Ring, Ellipse, Disc, Envelope, Nebula, Flow, Jets, Oval, Ufo, Shell
  - Read from a file e.g. output of a 3D hydrodynamic simulation:
    - Gas temperature & density, Dust temperature & density
    - Electron number density (optional)
    - Velocity vector, Microturbulence, Shadows
- Abundances
- Atomic data for spectral lines (optional)
- Spectra of nontransparent objects (optional)
- Albedos of nontransparent objects (optional)
- Dust opacities and phase functions (optional)
- Molecular cross-sections (ExoMol,optional)
- Molecular populations (optional)
- Molecular opacities (calculated by Synspec, optional)

Output

- Spectrum emerging from the model from different view points (trailing spectrogram)
- Light curve
- 2D projection images at some frequency at different phases
- Time evolution mode (only for a few objects)
- More details on opacities, emissivities, optical depth,… along some rays

Adopted routines

- Pfdwor (from UCLSYN, Smith & Dworetsky 1988)
- Voigt0, state0, gaunt, gfree (from SYNSPEC, Hubeny et al.1994)

Apart from the above the code was written from the scratch and provides an independent tool to study a large variety of objects and effects.

Tables of phase functions, opacities, albedos, equilibrium temperatures, and radiative accelerations of dust grains in exoplanets

Budaj, Kocifaj, Salmeron, Hubeny (2015)

Assumptions:
complex refractive index n,k
homogeneous spherical grains
Deirmenjian particle size distribution
Mie theory, BHMIE subroutine
(Bohren & Huffman, 1983)

Species:
alumina/corundum, perovskite,
olivines (0,50%Fe),
pyroxenes (0,20,60%Fe),
Carbon(400,1000C),
water ice & liquid, ammonia

modal particle size: 0.01-100micron

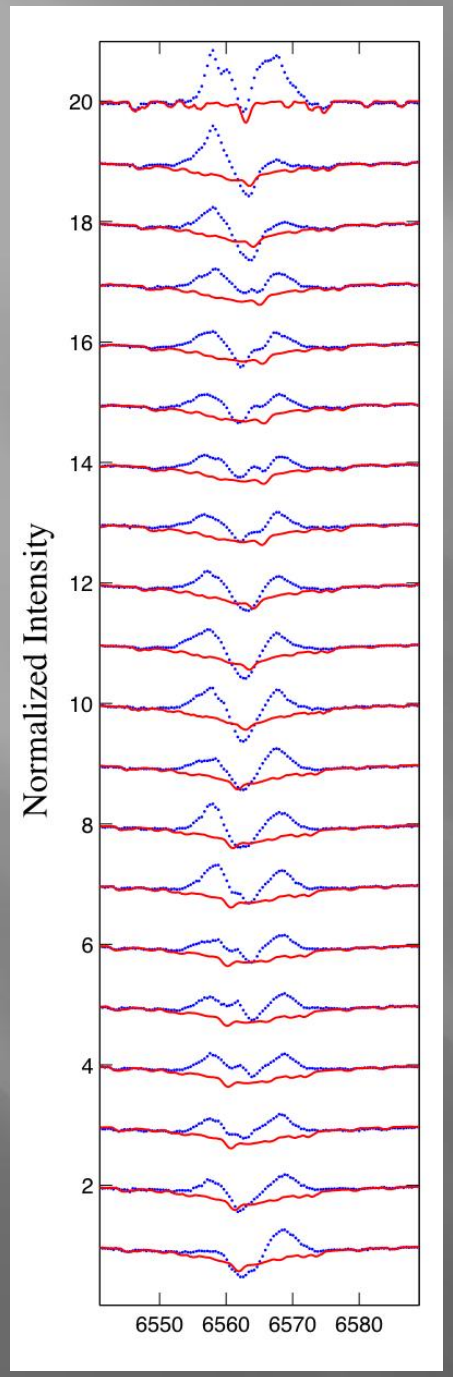
wavelength: 0.2-500micron

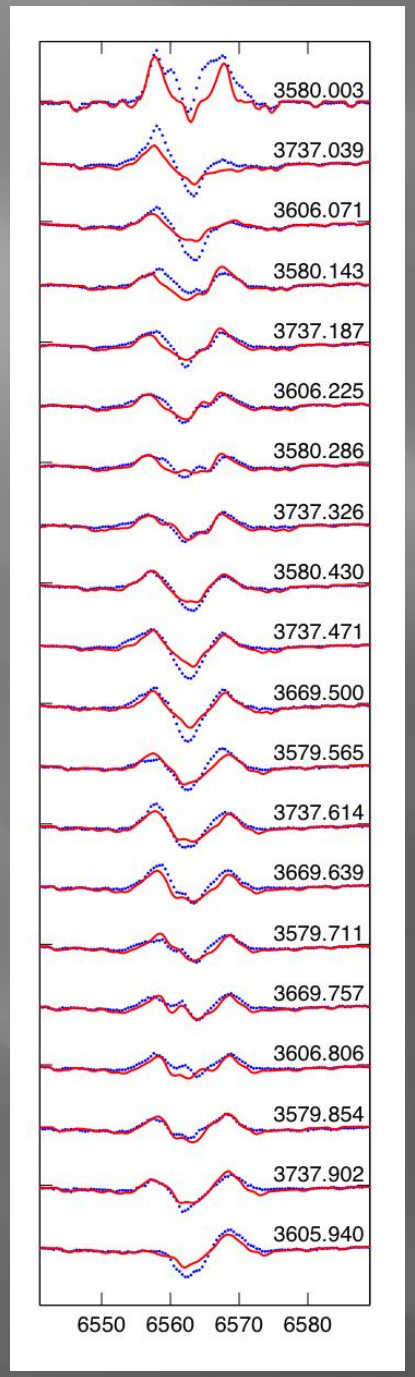
temperatures & accelerations:
Irradiation by non-blackbody objects with T=700-7000K, solid angles: <1e-6,2pi>sr

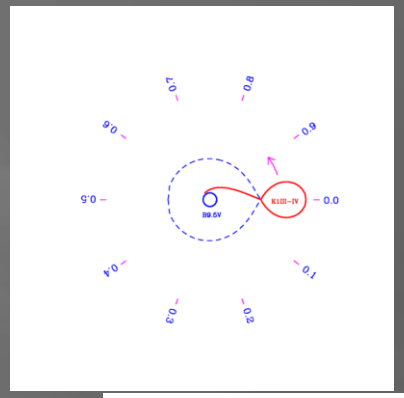
publicly available with references to n,k measurements adopted at:
https://www.ta3.sk/~budaj/dust/

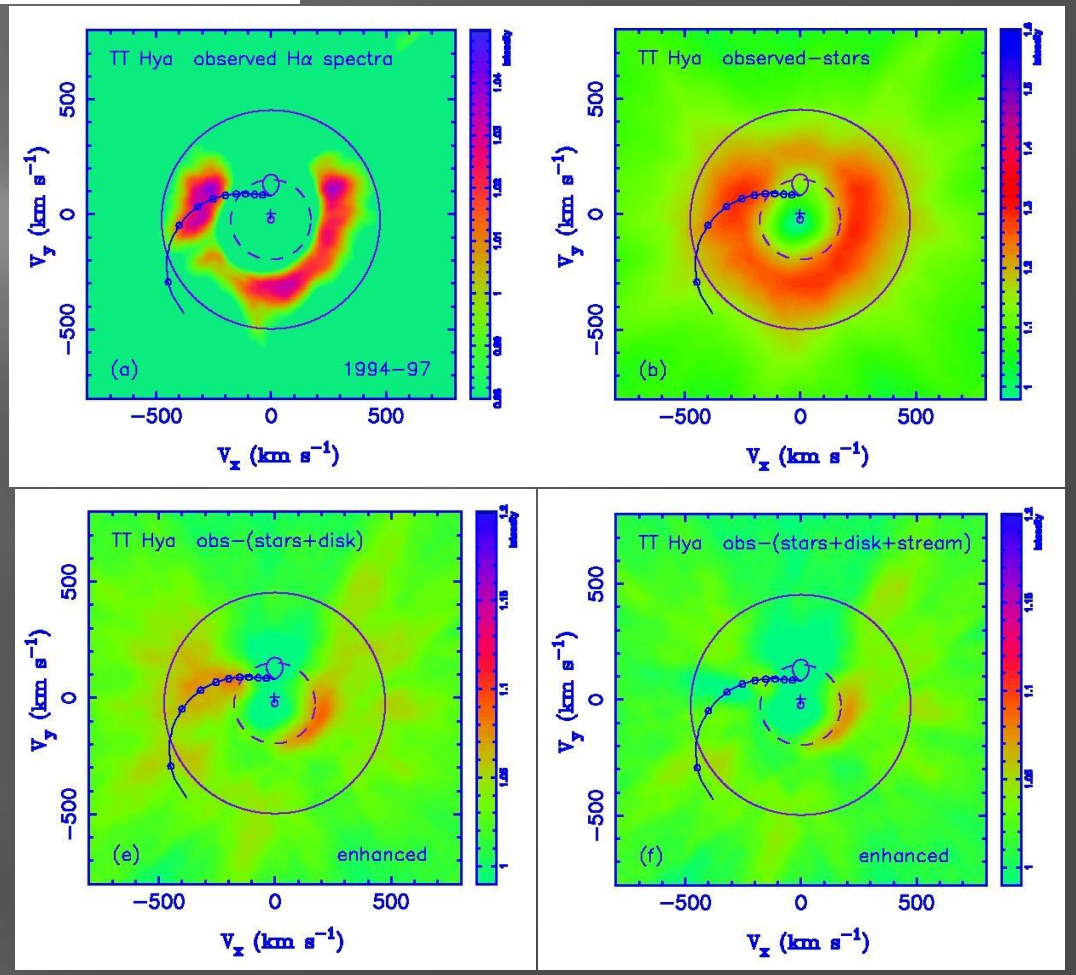
TT Hya: Observations, synthetic spectra & Doppler tomography

Budaj et al. 2005, Miller et al. 2007





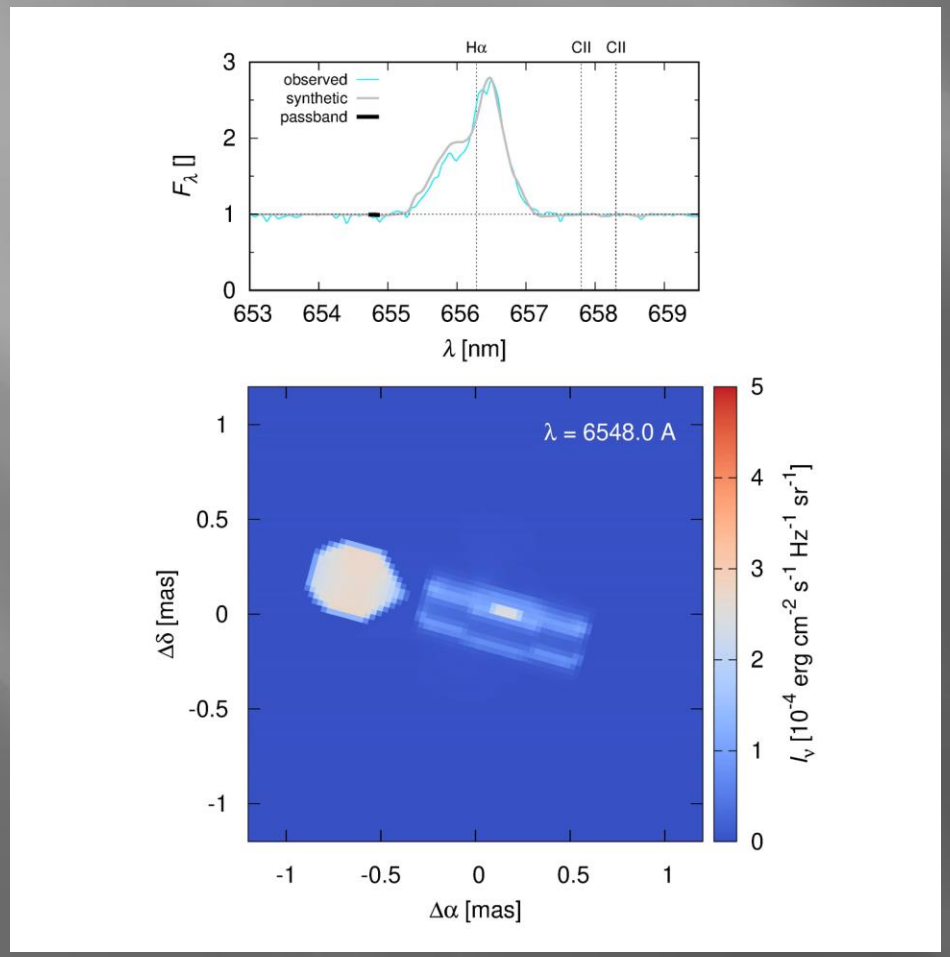


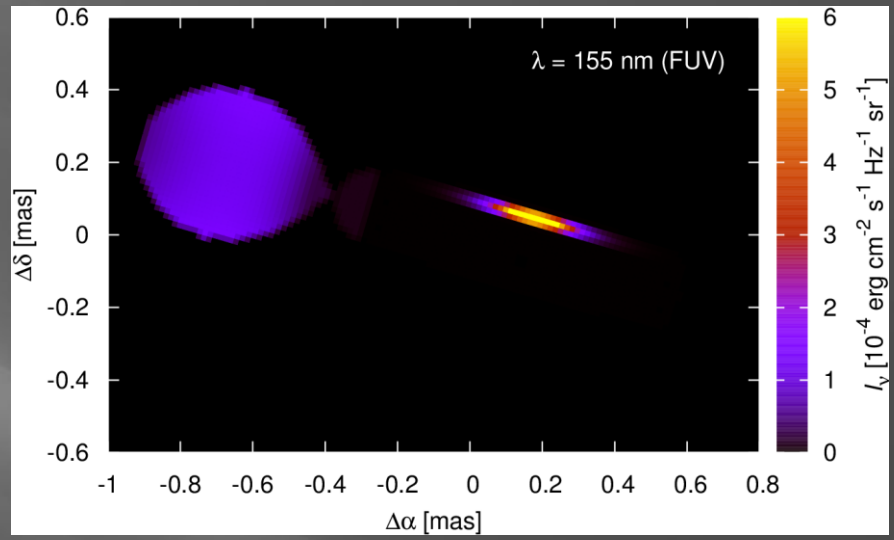


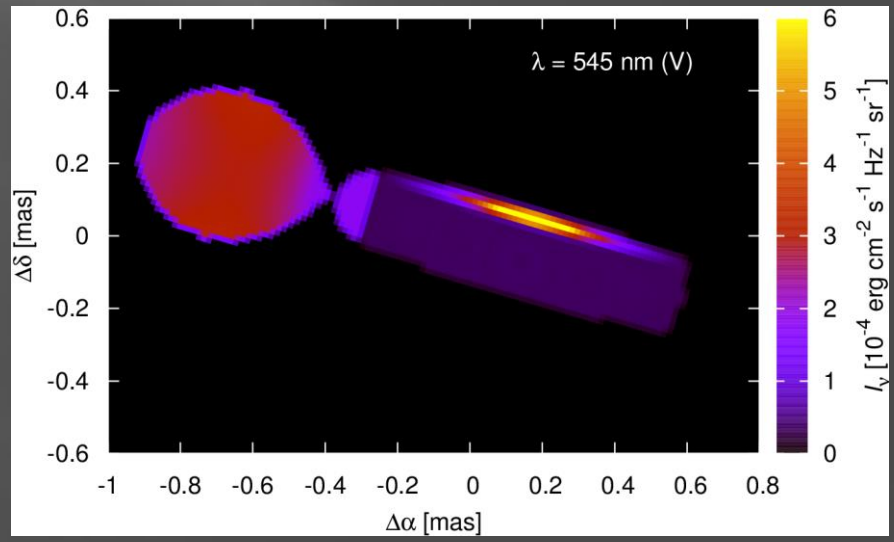
Beta Lyr: photometry & interferometry

Broz & Nemravova: PyShellspec - a Python package that calculates interferometric observables & can fit simultaneously: spectra, light curves, visibilities, closure phases & triple products

Mourard et el. 2018, Broz et al. 2021



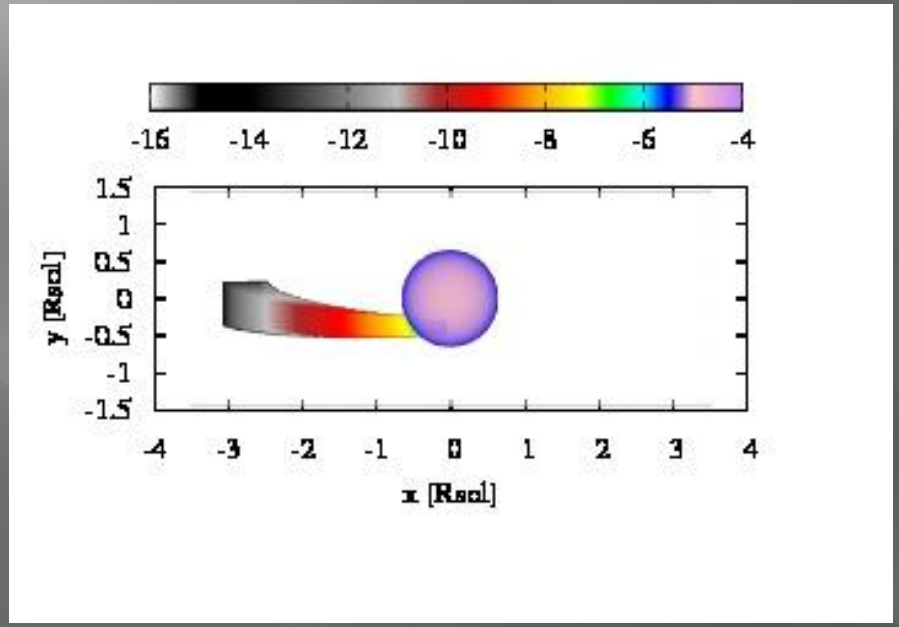


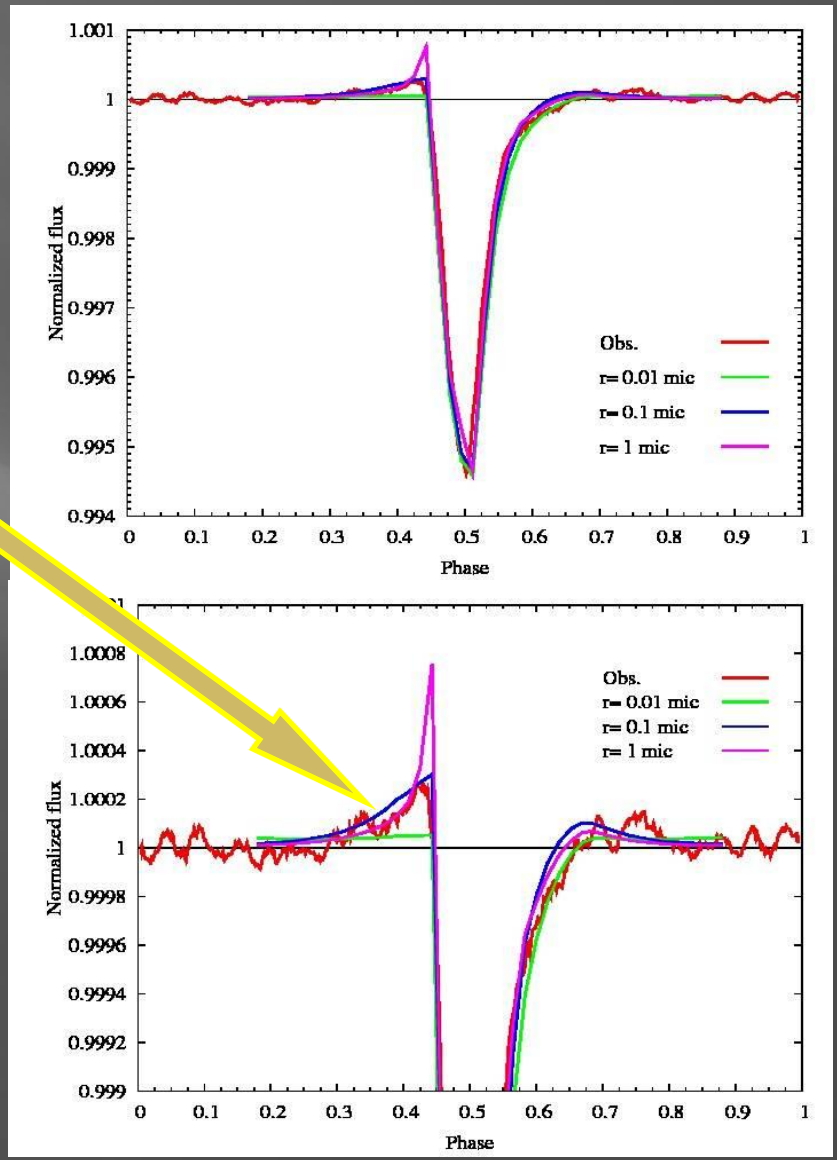


Extrasolar planet: Kepler-1520b

Rappaport et al.2012
Kepler observations, K4V
Transits: variable 0-1.2%, asymmetric, periodic, P=15.7h
Mercury size planet with a comet like dusty tail.
Lost most of its mass -> study planetary interior
Shellspec: particles 0.1-1 mic, silicates
Budaj 2013

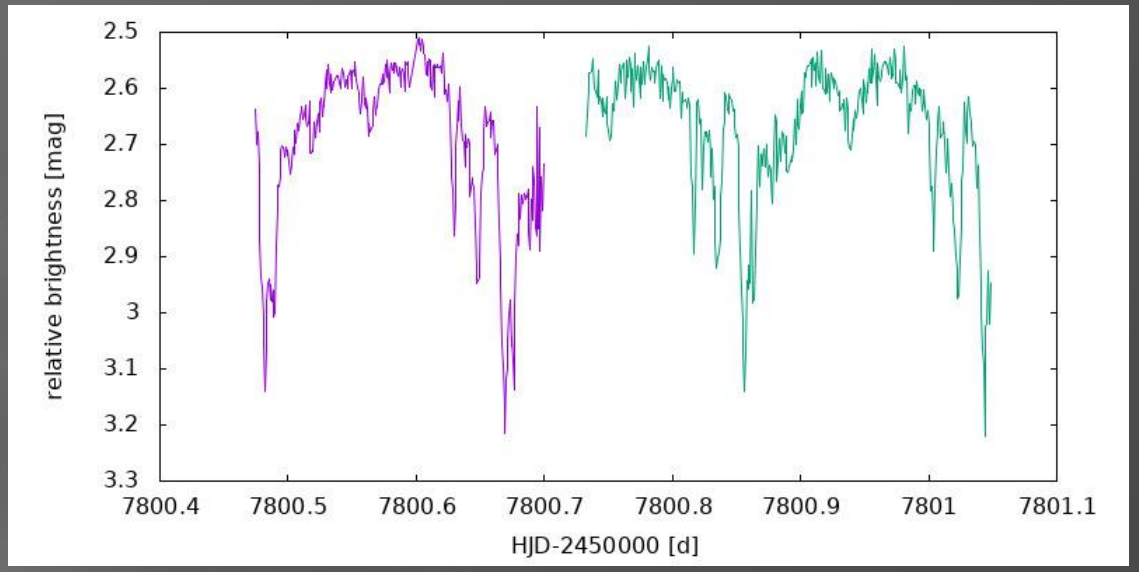
Pre-transit brightening

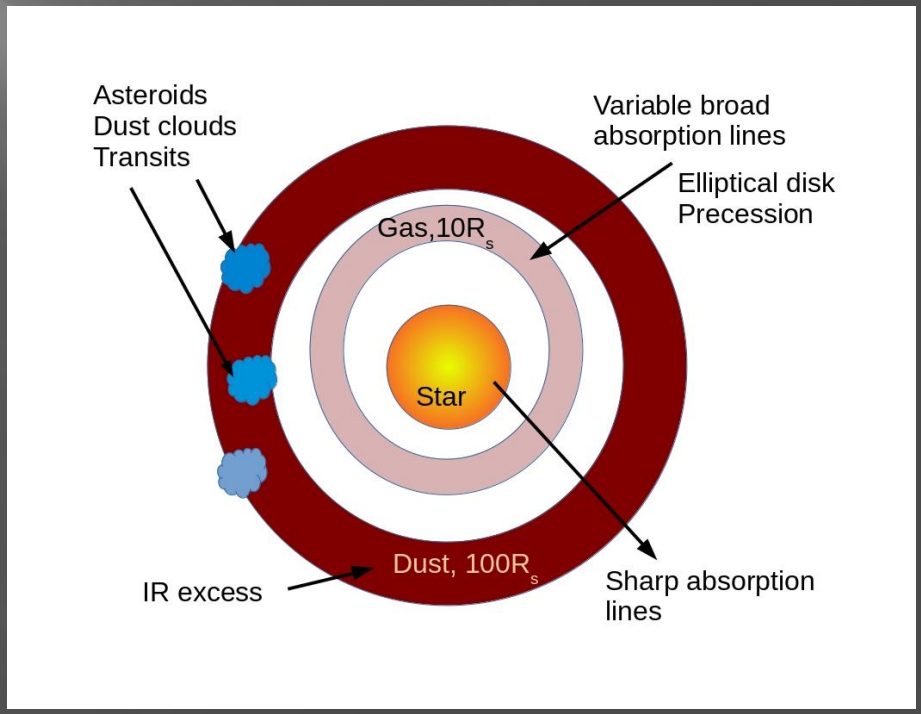




Exoasteroids: WD1145+017

Vanderburg et al.2015
First detection of exoasteroids
K2 data, DBZ white dwarf (T=15000K)
Transits: variable 0-40%, asymmetric, periodic, P=4.5h.
Asteroids are tidally disrupted and are surrounded by dust clouds and dust disk.
Dust evaporates and produces a gaseous structure, gas accretes on the WD, contaminates its atmosphere producing a DBZ WD.

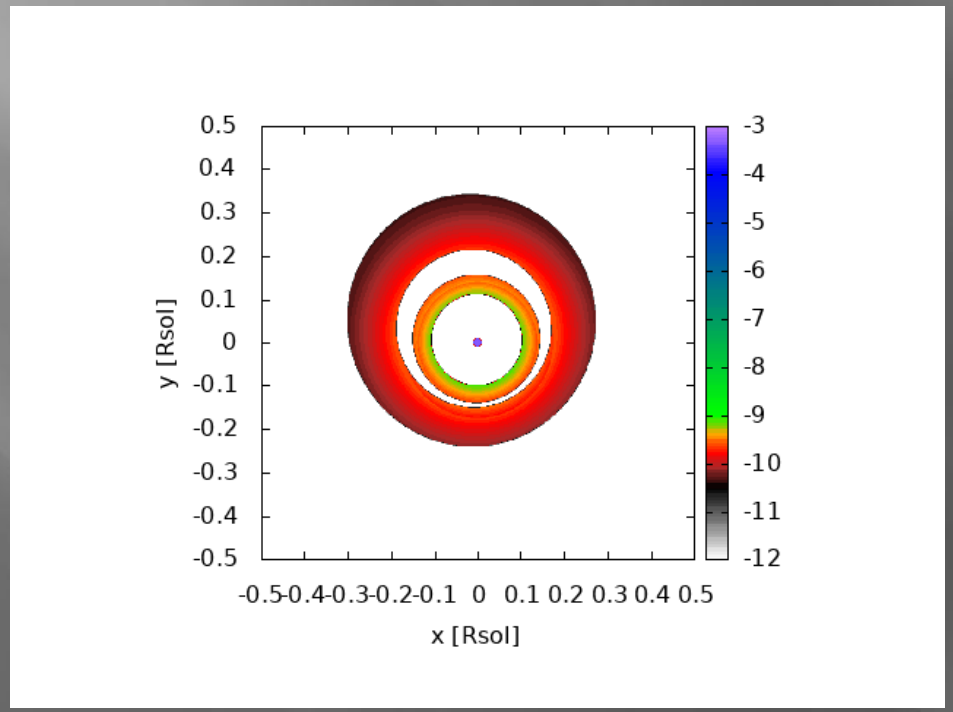




Exoasteroids: WD1145+017

Shellspec:
Model of the gaseous structure
-two edge-on, elliptical, precessing disks (P=3.83yr, GR)

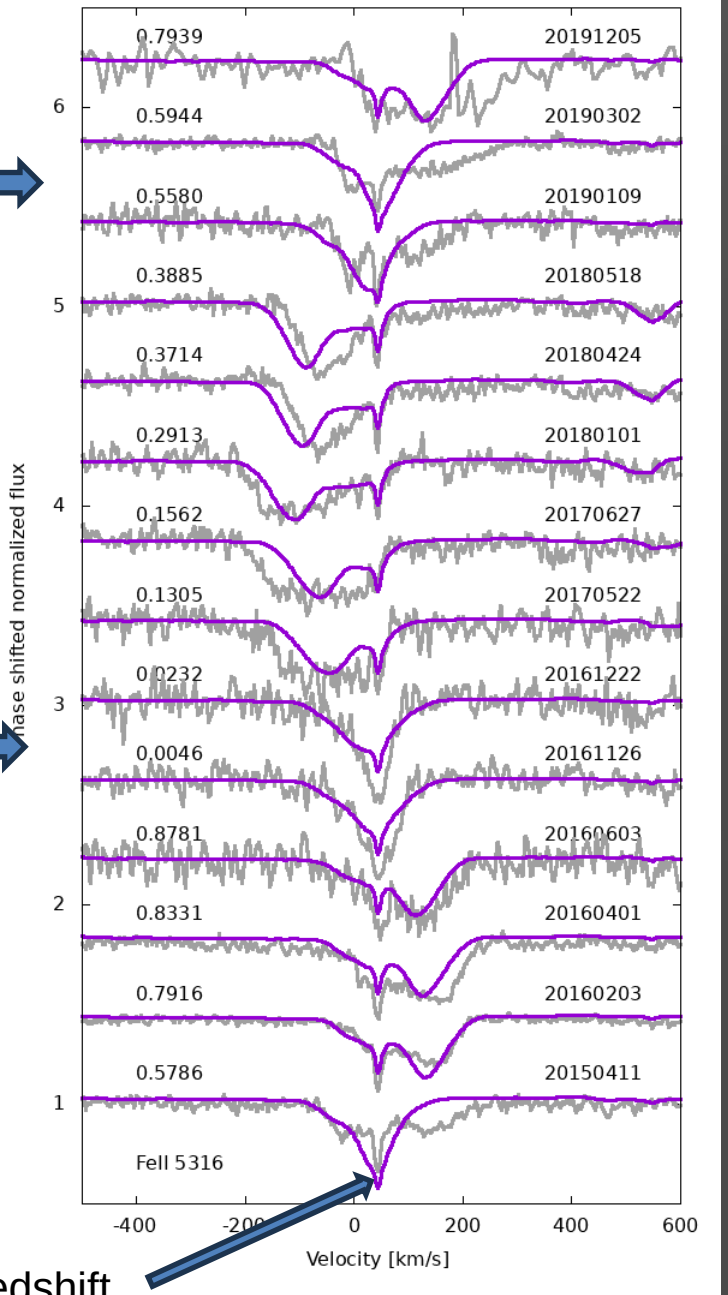
Budaj, Maliuk, Hubeny 2022



Periastron

Apoastron

Gravitational redshift



Summary

- Shellspec -a simple tool to study interacting binaries & some exoplanets
- May also be used for teaching (some examples are ready):
  - spectral line formation: absorption vs. emission lines, rotation, P Cyg profiles, double peak profiles; transits, eclipses,…
- Version49 is publicly available with documentation, examples, and manual at: http://www.ta3.sk/~budaj/shellspec.html
- Any comments, bug reports will be highly appreciated
- PyShellspec –optimization python tool (->Mirek Broz) https://sirrah.troja.mff.cuni.cz/~mira/betalyr

Thank you for your attention!

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