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

Ján Budaj

Astronomical Institute, Tatranská Lomnica, Slovakia

Tatranska Lomnica, Nov. 13, 2018

Content:

- Motivation
- Introduction
- Input
- Output
- Applications to interacting binaries
- Application to exoplanets
- Summary

What is SHELLSPEC?

- A computer code in Fortran90
- 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)
- Stars are immersed in a moving circumstellar matter
- Assumes LTE
- Assumes optional but given state quantities and velocity field in 3D
- Scattered light from 1-2 objects is 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

Input

- 3D Model
  - Compose your model from predefined (non)transparent objects:
    - Star, Companion, Envelope, Spot, Stream, Ring, Disc, Nebula, Flow, Jets, 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)

Output

- Spectrum emerging from the model from different view points (trailing spectrogram)
- Light curve
- 2D projection images at some frequency at different phases
- 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

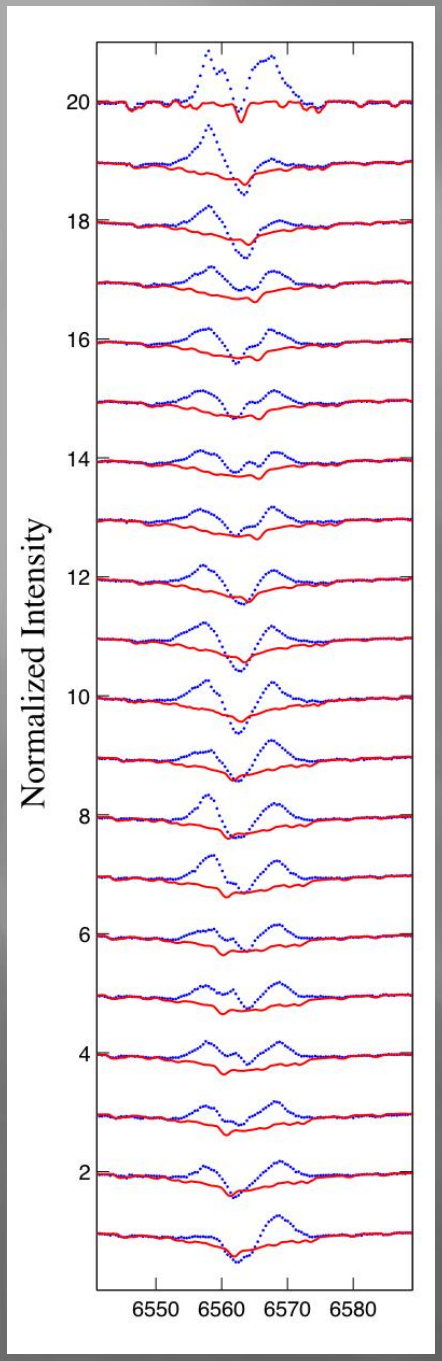
wavelength: 0.2-500micron

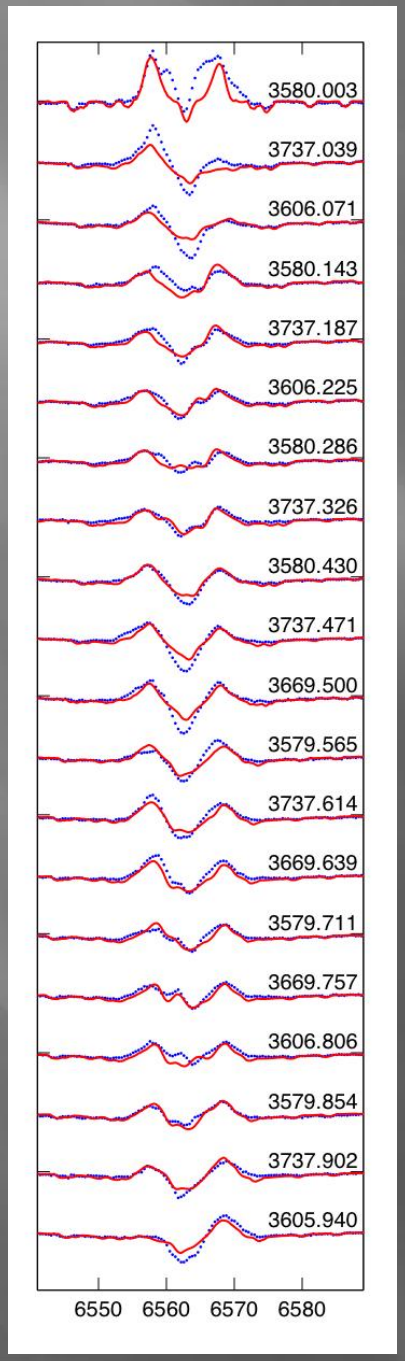
temperatures & accelerations:
Irradiation by non-blackbody objects with T=700-7000K, solid angles: <1e-6,2pi>sr

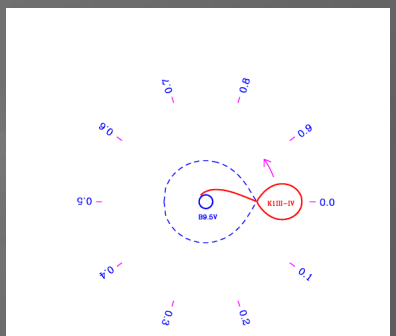
publicly available with references to n,k measurements adopted at:
https://www.ta3.sk/~budaj/dust/

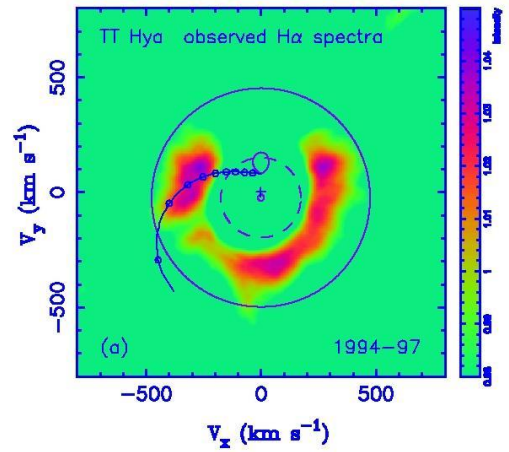
TT Hya: Observations, synthetic spectra & Doppler tomography

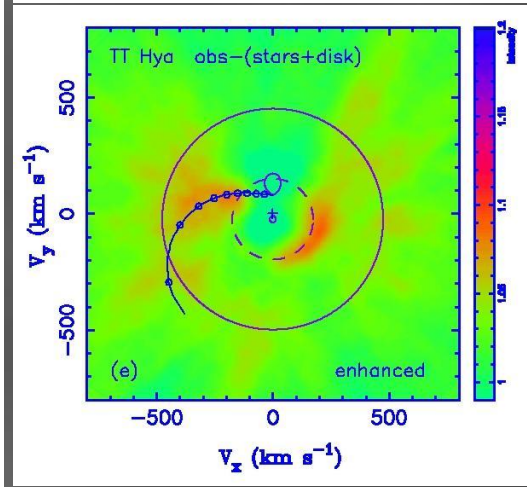
Budaj et al. 2005, Miller et al. 2007





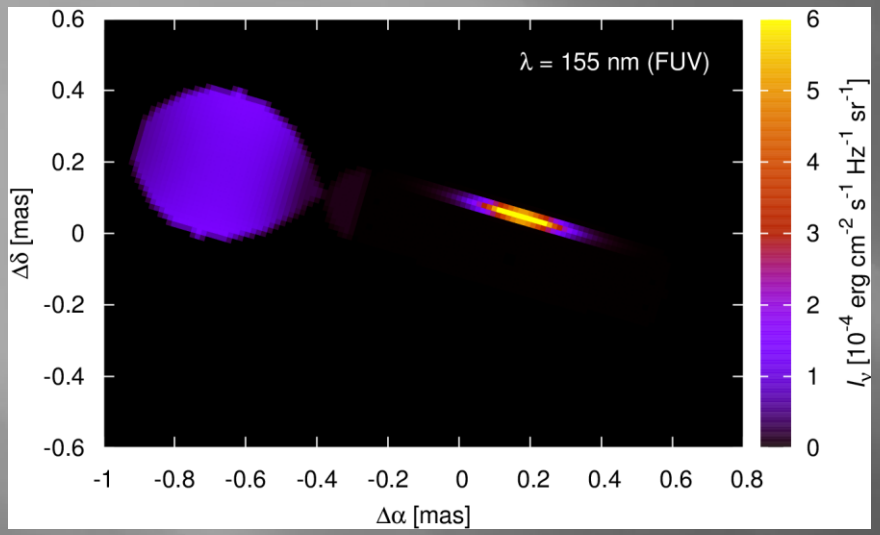


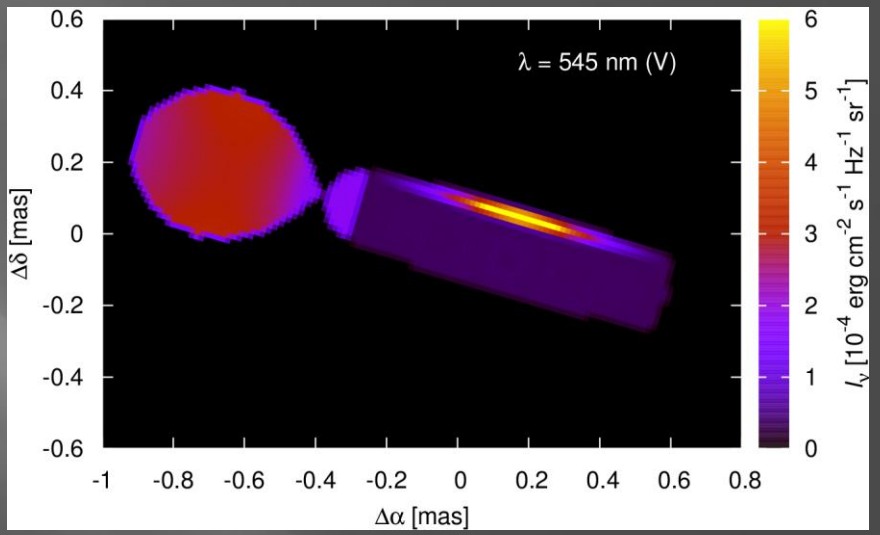


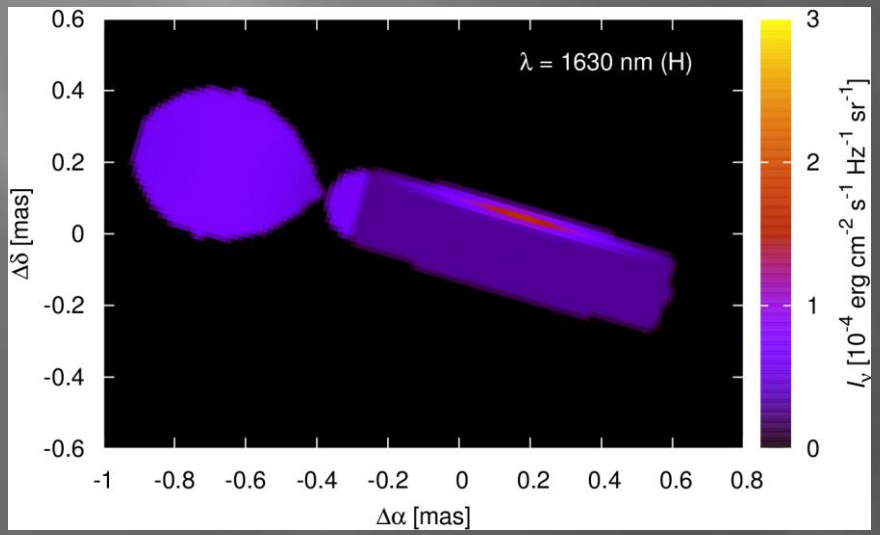


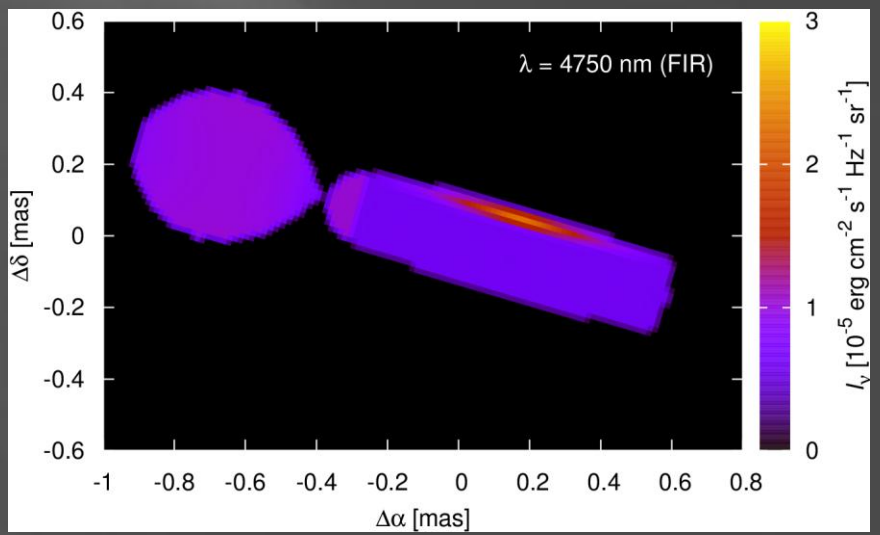
Beta Lyr: photometry & interferometry

Broz & Nemravova: a package for interferometric observables & inverse problem solution
Mourard et al. 2018: simultaneous fit: light curves, visibilities, closure phases & triple products







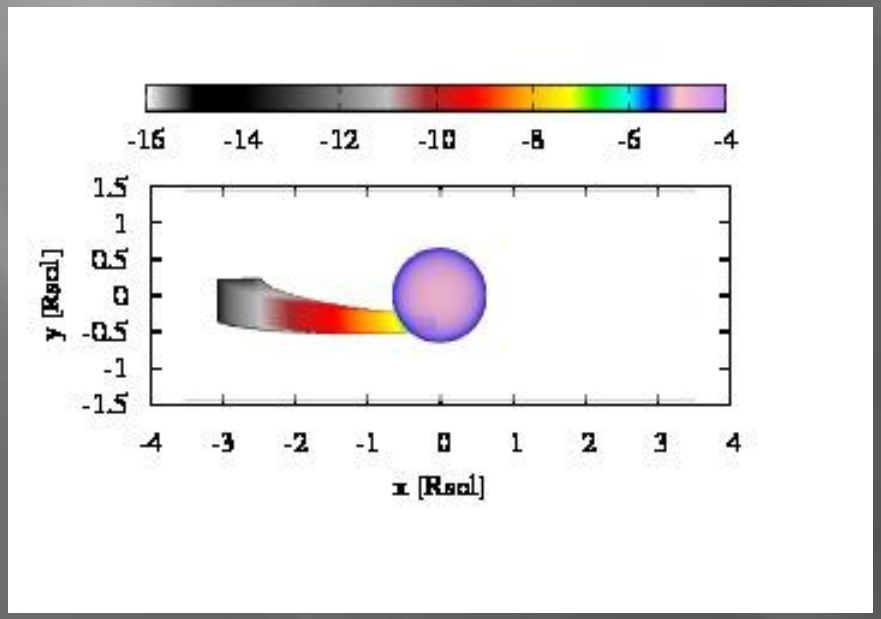


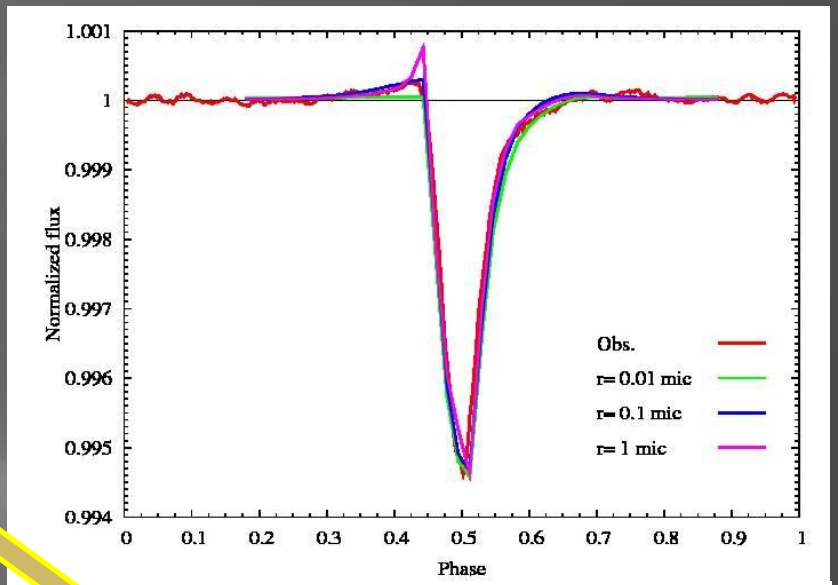
Extrasolar planet: KIC12557548b

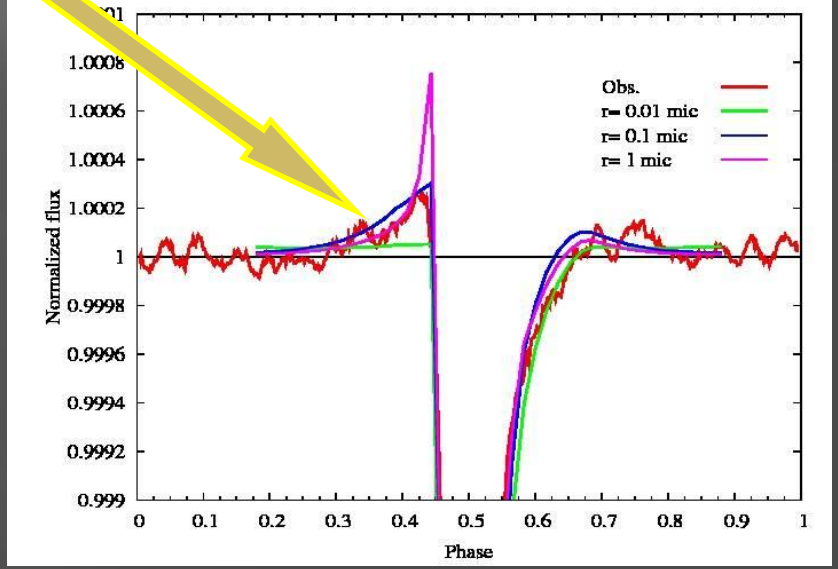
Rappaport et al.2012
Kepler observations, K4V
Transits: variable 0-1.2%, asymmetric, periodic, P=15.7h
Mercury size planet, comet like dusty tail

Budaj 2013

Pre-transit brightening







Summary

- Shellspec -a simple tool to study interacting binaries & some exoplanets
- Version39 is publicly available with documentation, examples, and manual at: http://www.ta3.sk/~budaj/shellspec.html
- Any comments, bug reports will be highly appreciated
- 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,…

Thank you for your attention!

Supported by the VEGA 2/0031/18 and APVV 15-0458 grants