Brightness Profiles and Spatial Spectra of Dynamical Models for C–rich Circumstellar Dust Shells around Long–period Variables

JAN MARTIN WINTERS, AXEL J. FLEISCHER,
ERWIN SEDLMAYR

Institut f. Astronomie & Astrophysik, TU Berlin, Berlin, Germany

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1 Motivation

Based on dynamical models of circumstellar dust shells (CDS) around long–period variables (LPVs), which include time–dependent hydrodynamics and a detailed treatment of the processes of formation, growth and evaporation of carbon grains, angle– and frequency–dependent radiative transfer calculations have been carried out. The models are completely determined by 6 parameters, comprising the 4 fundamental stellar parameters (M_*, T_*, L_*, $\epsilon_{\rm i}$) and the pulsation period and velocity amplitude at the base of the atmosphere (P, $\Delta u_{\rm P}$). It turns out that these models result in a discrete onion–like structure of the CDS (cf. Fleischer et al. 1992) which decisively influences the shape of the synthetic lightcurves (Winters et al. 1994) as well as the calculated spatial intensity profiles and the corresponding spatial spectra (Winters et al. 1995).

We present consistent theoretical models for the CDS of the extreme carbon stars **IRC +10216** and **AFGL 3068**. The synthetic light curves, the spectral energy distributions at different phases, the terminal wind velocities etc., are in excellent agreement with the observed properties of these objects. Therefore, the values of the fundamental stellar parameters and the distance to the objects, which are not directly accessible by observations, can be derived from the models.

2 IRC +10216

The model for IRC +10216 is determined by:

stellar mass	M_*	=	$1 M_\odot$
stellar luminosity	$L_*(t=0)$	=	$2.4\,10^4 L_\odot$
stellar temperature	T_*	=	2500 K
carbon–to–oxygen ratio	$\epsilon_{\rm C}/\epsilon_{\rm O}$	=	1.20
pulsation period	P	=	650 d
piston amplitude	$\Delta u_{\rm P}$	=	6 km/s

which results in a calculated

- distance to **IRC +10216** = 170 pc
- final outflow velocity = 14.3 km s^{-1}
- mass loss rate = 1.2 10^{-4} $\text{M}_\odot$ yr^{-1}
- dust–to–gas mass ratio = 8.1 10^{-4}

Figure 1 shows the spectral energy distribution for IRC +10216, which gives a distance of 170 pc.

Fig. 2 shows observed (Ridgway & Keady 1988) and calculated spatial spectra for IRC +10216 at different wavelengths. Note the internal structures in the visibility functions at

$\lambda = 12\mu$ and 25μ !

Fig. 3 shows the theoretical brightness profiles, which exhibit a clear step–like structure on a scale of a few stellar radii at longer wavelengths.

In **Fig. 4**, the 1.5μ brightness profile is compared to the result of a lunar occultation observation (Richichi 1993, private communication). A step–like structure in the observed profile is clearly visible already at this short wavelength.

The radial scale, on which the steps occur in the model as well as in the observations is of the same order of only a few stellar radii. The synthetic profiles, however, show steps only at longer wavelengths than the observation. In the models, these steps are produced by the formation of discrete dust layers, whose locations vary in time.

Time resolved, high resolution interferometry in a broad wavelength range would not only provide insight in the **radial structure** of the circumstellar shell, but also in the **dynamics** of the atmosphere and in the nature of the dust grains.

3 AFGL 3068

The model for AFGL 3068 is determined by:

stellar mass	M_*	=	$0.9 M_\odot$
stellar luminosity	$L_*(t=0)$	=	$1.3\,10^4 L_\odot$
stellar temperature	T_*	=	2100 K
carbon–to–oxygen ratio	$\epsilon_{\rm C}/\epsilon_{\rm O}$	=	1.33
pulsation period	P	=	696 d
piston amplitude	$\Delta u_{\rm P}$	=	8 km/s

which results in a calculated

- distance to **GL 3068** = 1.3 kpc
- final outflow velocity = 15.7 km s^{-1}
- mass loss rate = 1.7 10^{-4} $M_\odot$ yr^{-1}
- dust–to–gas mass ratio = 1.6 10^{-3}

Figure 5 shows the spectral energy distribution for AFGL 3068, which gives a distance of 1300 pc.

Fig. 6 shows calculated spatial spectra for AFGL 3068 at different wavelengths. Note that internal structures in the visibility functions are almost absent in this case.

Fig. 7 shows the theoretical brightness profiles, which again exhibit a step–like structure on a scale of a few stellar radii. These steps occur only at even longer wavelengths than in the case of the IRC +10216 model, caused by the larger optical depth in the AFGL 3068 model.

In **Fig. 8**, the 1.5μ and 12μ brightness profiles are shown. In the considerably more extended 12μ profile a step–like structure is visible.

4 Concluding Remarks

Time resolved, high angular resolution observations of circumstellar dust shells around long–period variable stars would provide very specific information about the physical processes relevant for the mass loss mechanism in dusty AGB stars.

These observations could be directly used to test and improve the reliability of current theoretical models. Finally, this would lead to a more thourough understanding of the nature of circumstellar dust and its role for the hydrodynamic and thermodynamic structure and for the temporal behaviour of the circumstellar shell.

Acknowledgements
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References
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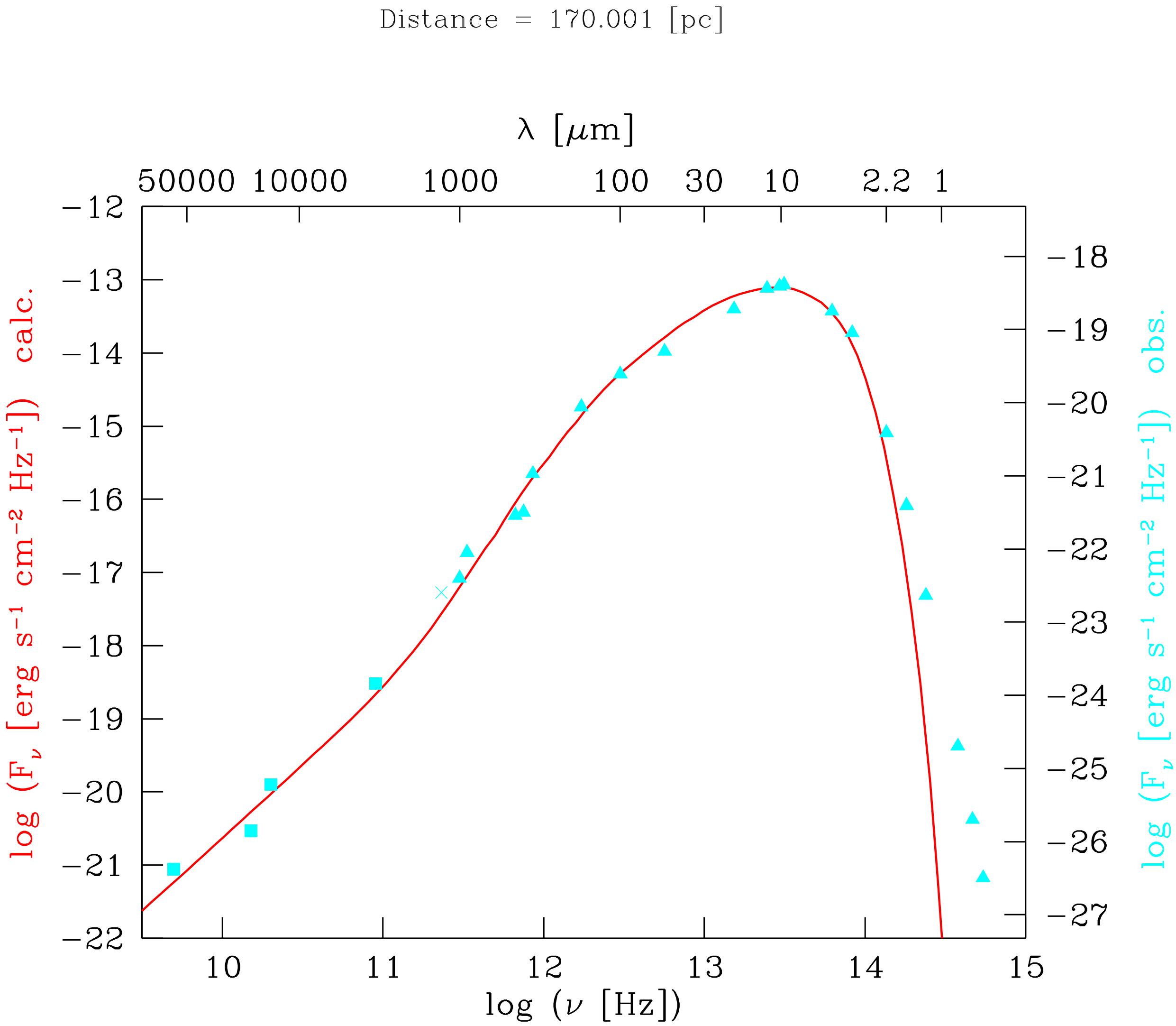

Figure 1: Observed spectrum of **IRC +10216** at **maximum** phase of the lightcurve (blue symbols) and theoretical spectrum of the dust shell model (red solid line) at light maximum

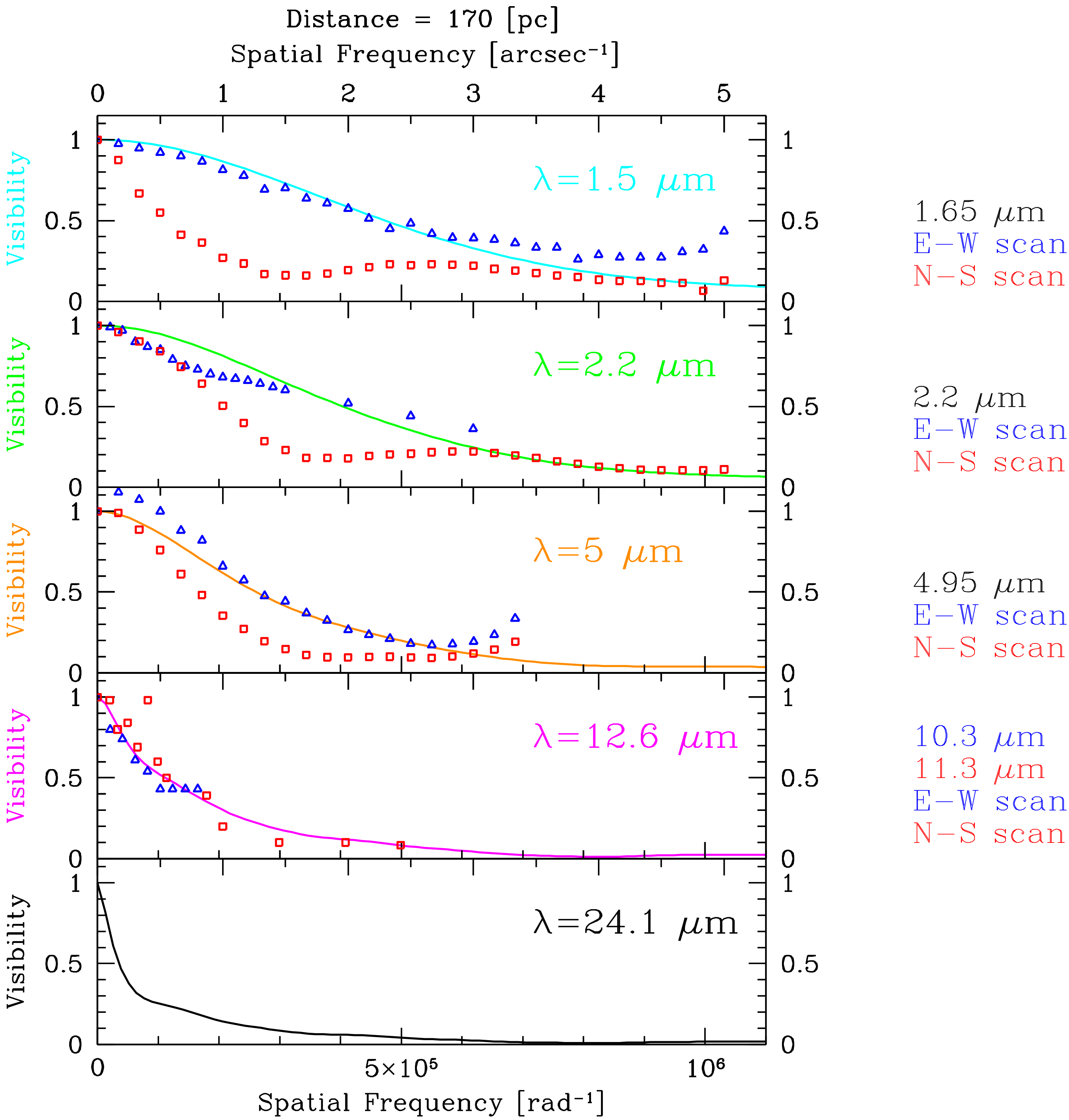

Figure 2: Observed visibilities of **IRC +10216** around **maximum** phase of the lightcurve (blue and red symbols, after Ridgway & Keady (1988)) and theoretical visibilities of the dust shell model (solid lines) at maximum light

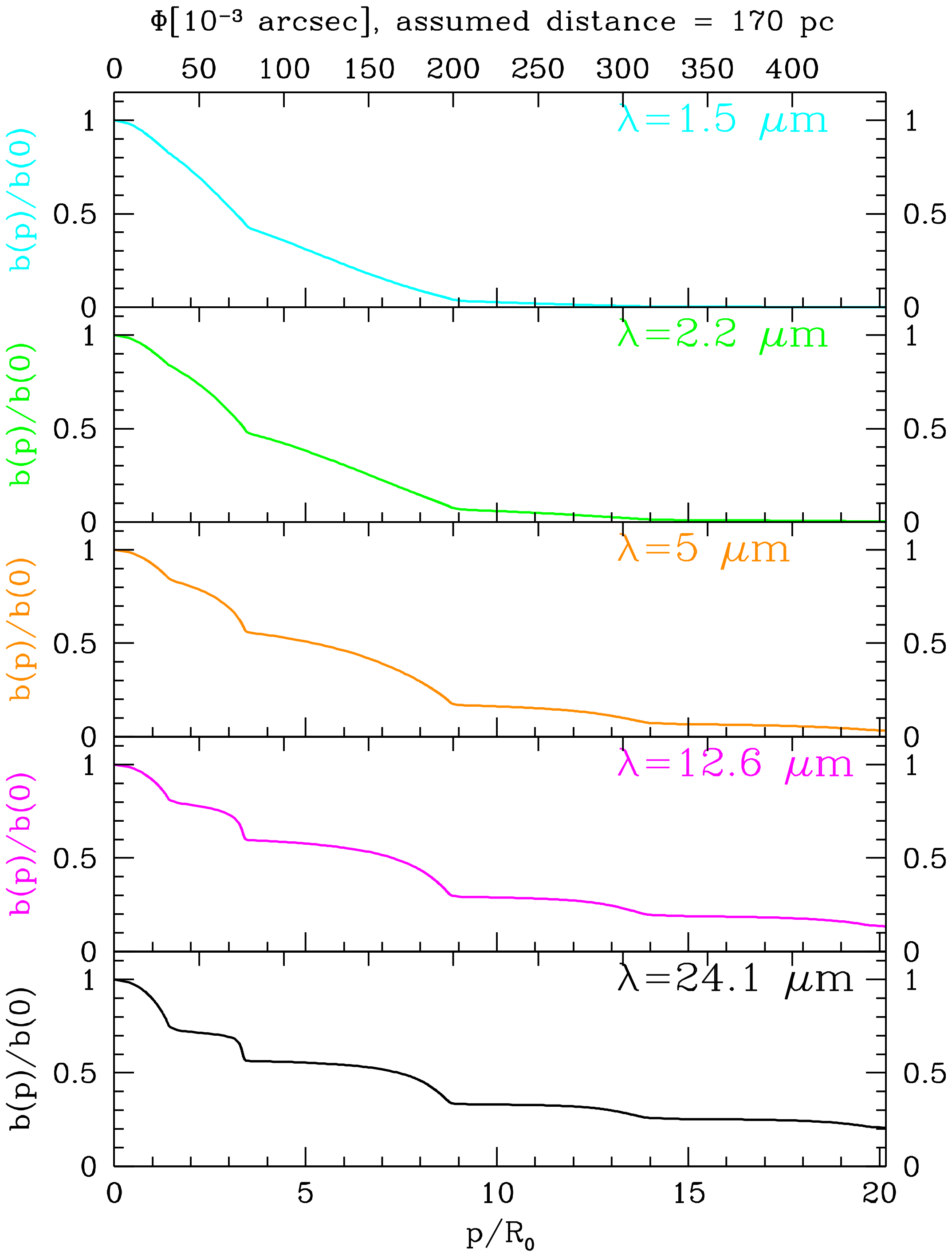

Figure 3: Theoretical integrated brightness profiles of the dust shell model for **IRC +10216** at maximum light

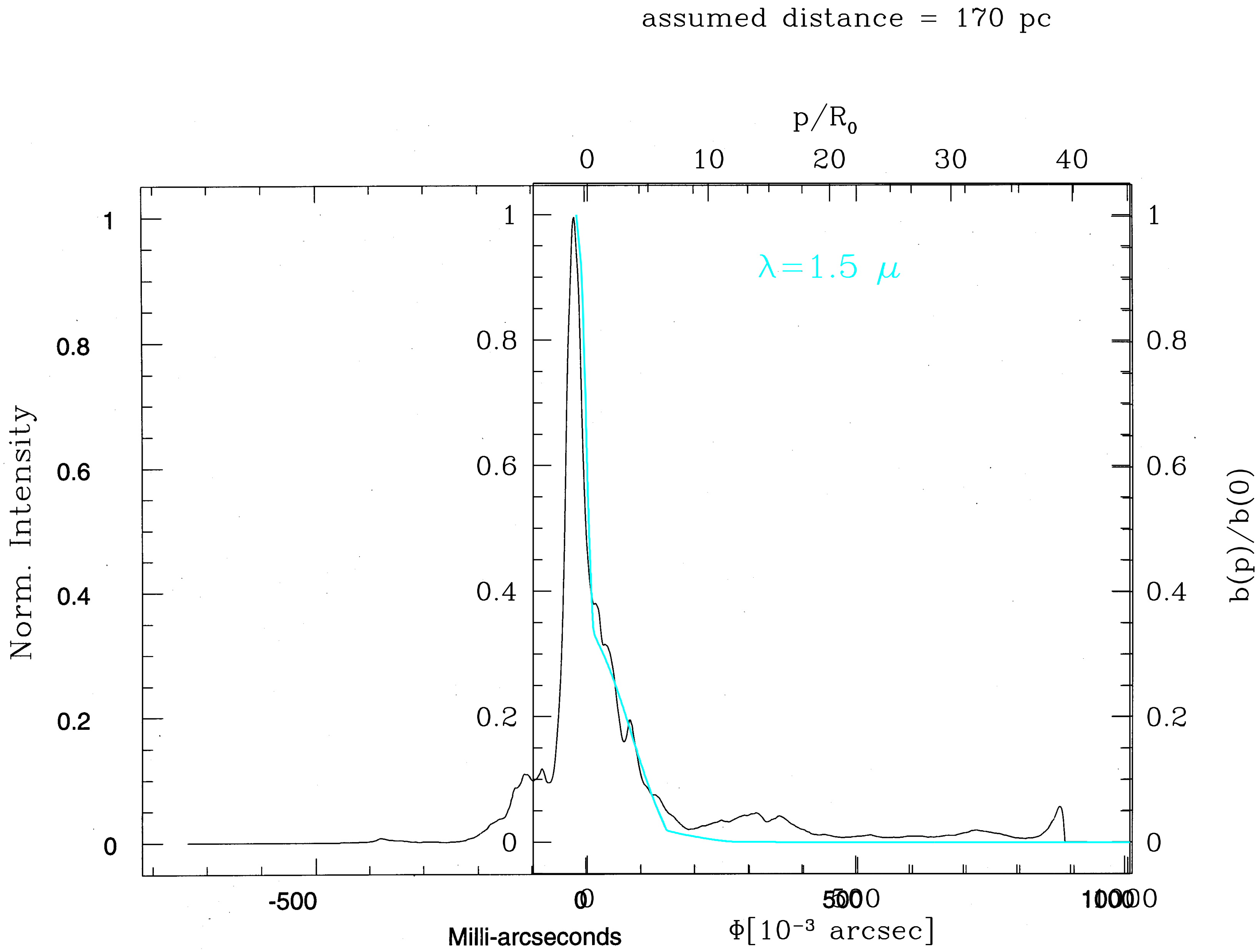

Figure 4: Observed radial brightness profile of **IRC +10216** at $\lambda = 1.65\mu$m, reconstructed from a lunar occultation lightcurve (black solid line, this figure was kindly made available to us by Dr. A. Richichi) and synthetic brightness profile at $\lambda = 1.54\mu$m of the dust shell model (blue solid line)

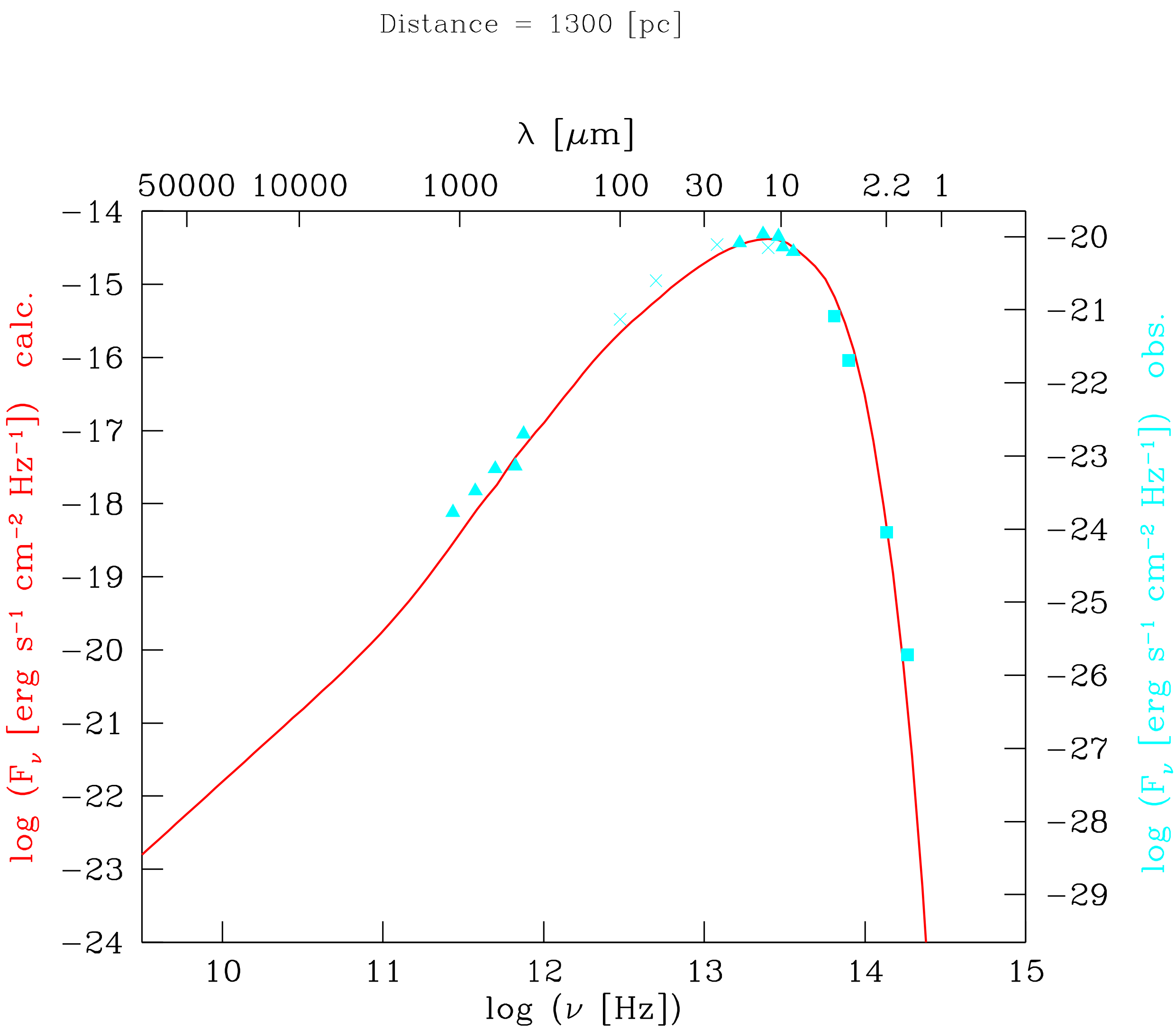

Figure 5: Observed spectrum of **AFGL 3068** at **maximum** phase of the lightcurve (blue symbols) and theoretical spectrum of the dust shell model (red solid line) at light maximum

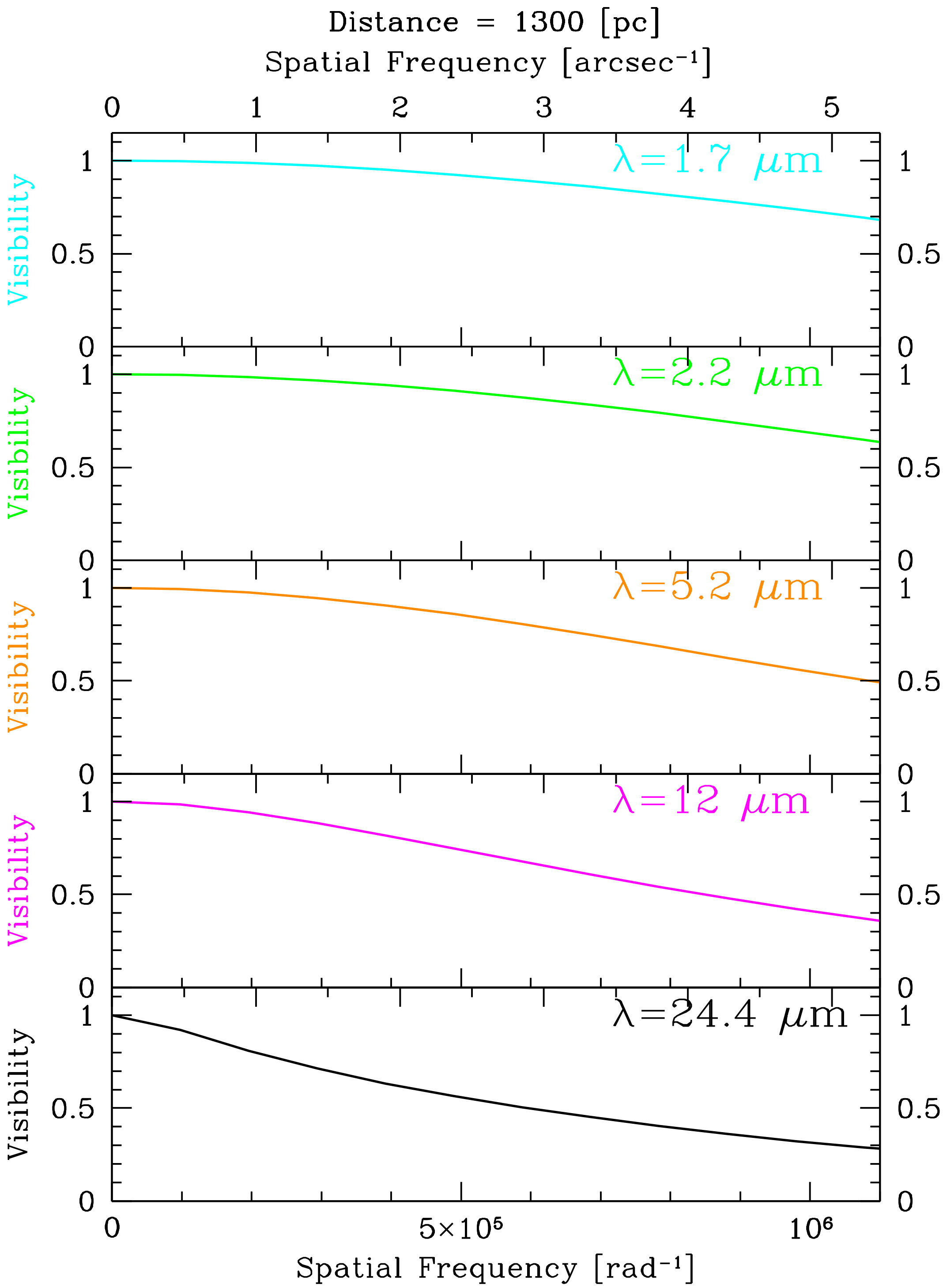

Figure 6: Theoretical visibilities of the dust shell model for **AFGL 3068** (solid lines) at maximum light

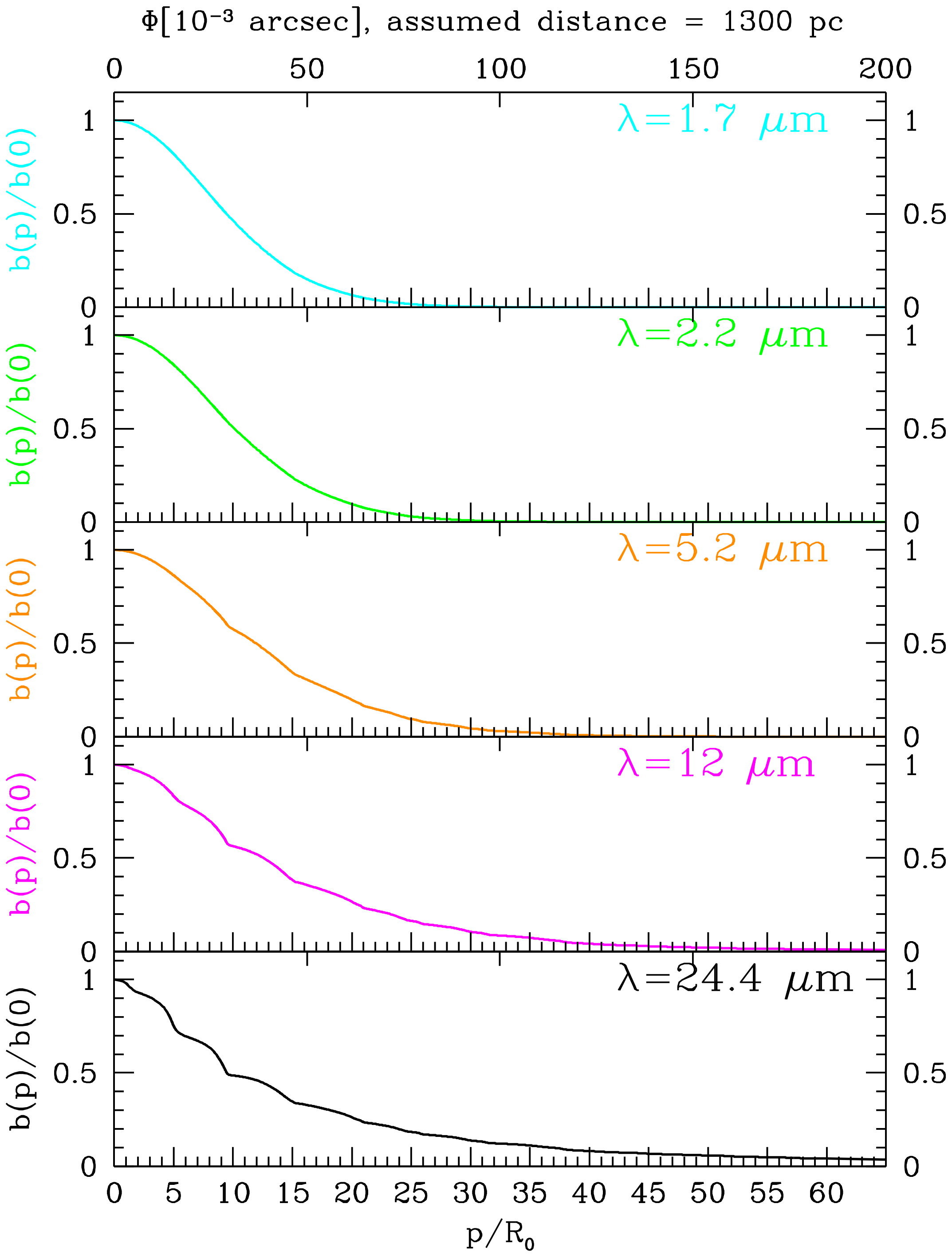

Figure 7: Theoretical integrated brightness profiles of the dust shell model for **AFGL 3068** at maximum light

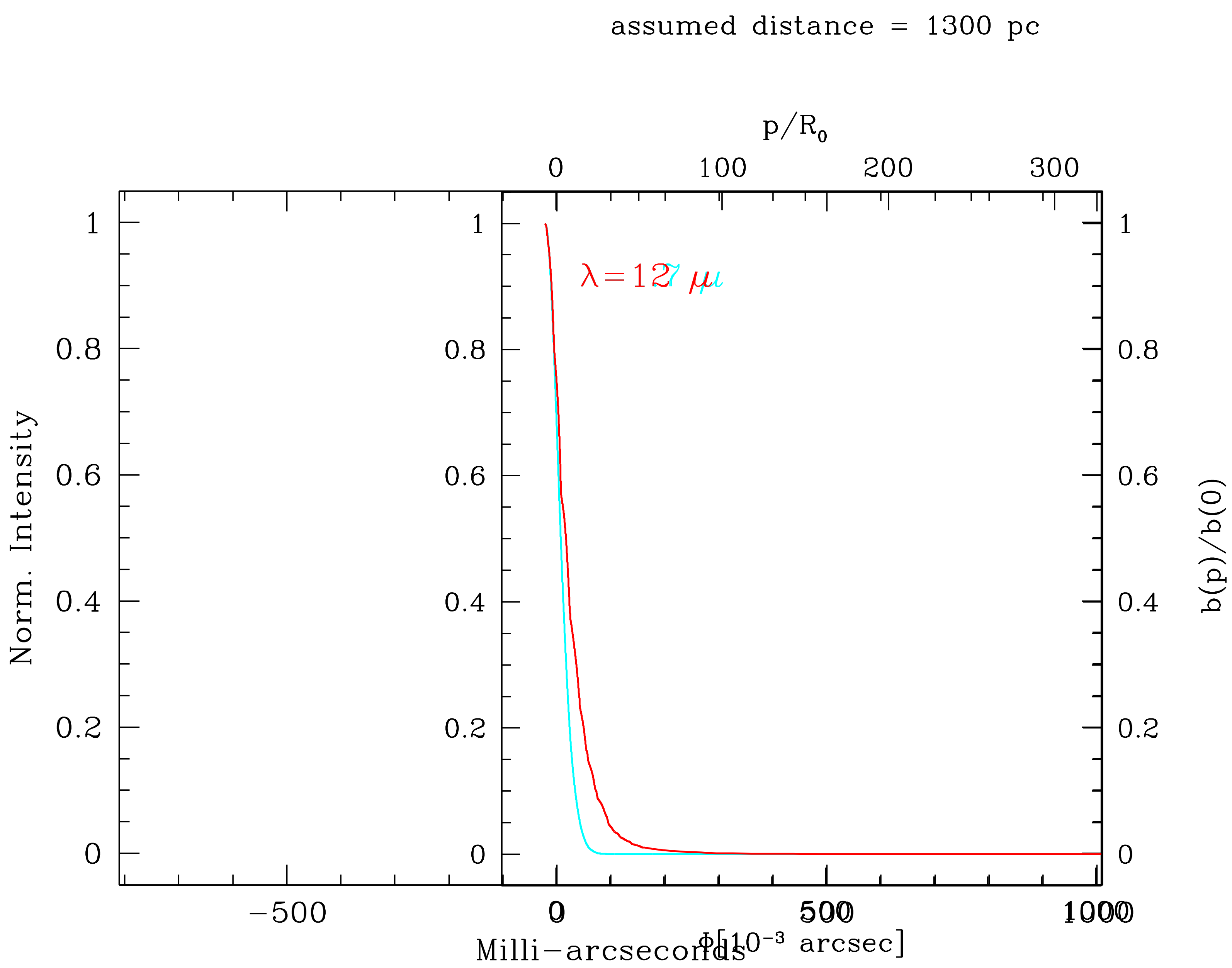

Figure 8: Synthetic brightness profiles at $\lambda = 1.7\mu$m (blue solid line) and at $\lambda = 12\mu$m (red solid line) of the dust shell model for **AFGL 3068**. Corresponding observations are still missing!