

Modeling the radial distance of the X-ray emitting plasma on the star τ Scorpii

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M. Walter-Range and D. Cohen

Swarthmore College

Summary

We recalculate the O VII, Ne IX, Mg XI, Si XIII, and S XV forbidden-to-intercombination ratios, using the latest atomic model (ATBASE – v.4.3beta), in conjunction with PrismSPECT (v3.0). Comparisons with the old analytic model of Blumenthal, Drake, and Tucker (1972) are also made. One significant difference is the inclusion of both of the $2\ ^3P_{1,2} - 1\ ^1S_0$ transitions.

Note also that there is some dependence in the ‘low density limit’ (R_0) on the plasma temperature. Our simulations use a temperature that produces an ionization fraction of the He-like state that is in excess of 50% (95% for O, 97% for Ne, 55% for Mg, 89% for Si, 89% for S). Blumenthal, Drake, and Tucker do not include this effect in their model.

TABLE 3
He-LIKE FORBIDDEN-TO-INTERCOMBINATION RATIOS

Ion	λ_{UV}^a (Å)	f/i	Formation Radius (R_*)
O VII	1623	<0.13	<10
Ne IX	1263	<0.03	<2
Mg XI	1036	0.48 ± 0.07	2.6–2.9
Si XIII	865	$2.10^{+0.28}_{-0.26}$	1.1–1.5
S XV	743	$2.03^{+1.03}_{-1.14}$	<20

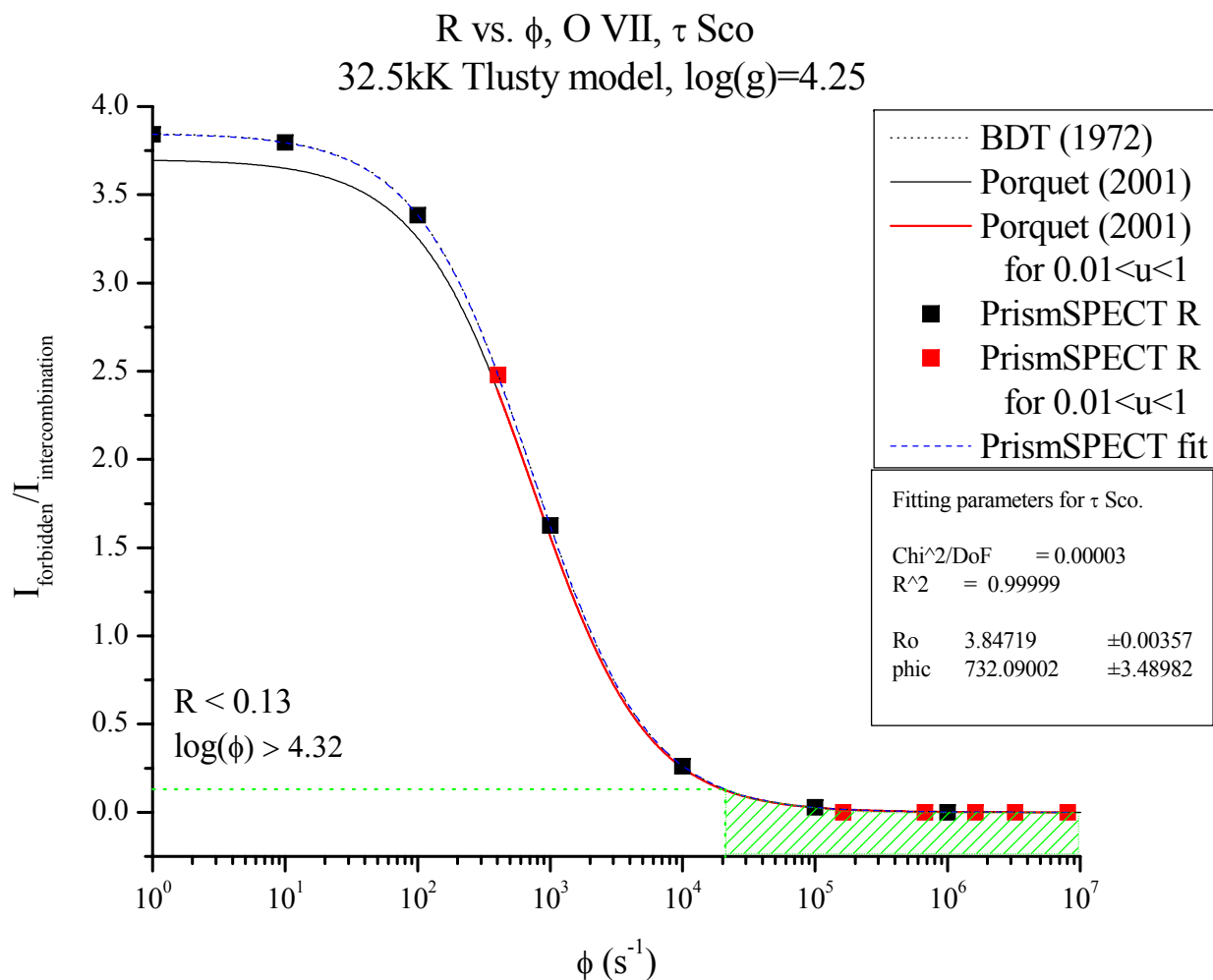
This is Table 3 from the paper by Cohen et al. (2003) that provides analysis of *Chandra* observations of τ Scorpii. The following pages show the results from a series of PrismSPECT simulations for the ions listed in Table 3.

The radiation temperatures that I used for the simulations were calculated from a Tlusty model stellar atmosphere. I selected a model with an effective temperature of 32.5 kK, and a surface gravity of $\log(g)=4.25$. This is not a perfect match for the stellar parameters listed in the Cohen paper, but it was the closest Tlusty model available. Note that is probably hotter than the model used in the original modeling for the paper (which should cause the formation radii to move out a bit).

My method for finding the radial distance of the plasma was as follows:

1. I created a plot of $R(f/i)$ vs. ϕ .
2. I fit a BDT-style function ($R=R_0/(1+\phi/\phi_c)$) to the PrismSPECT data points in order to determine PrismSPECT's values for R_0 and ϕ_c .
3. This new function enabled me to plot the PrismSPECT f/i ratio against the radial distance (I used $u=R_*/r$ because that is how it appears in the formula for the dilution factor).
4. The radial distance can then be found from the plot or from the function I used to fit the data.

Oxygen: the Dependence of f/i upon photoexcitation rate, ϕ



The solid line corresponds to Blumenthal, Drake, and Tucker's (1972) analytic model. The individual data points (red and black) are the f/i ratio calculated by PrismSPECT for a particular value of ϕ .

The dashed blue line is a BDT-type function that fits the PrismSPECT points and determines the parameters R_0 and ϕ_c .

The shaded region shows the range of possible ϕ values for the observed f/i ratio.

The red points and the red line segments are used for the plot on the following page. They represent f/i values that have been calculated for specific radial distances ($1R_* < r < 100R_*$).

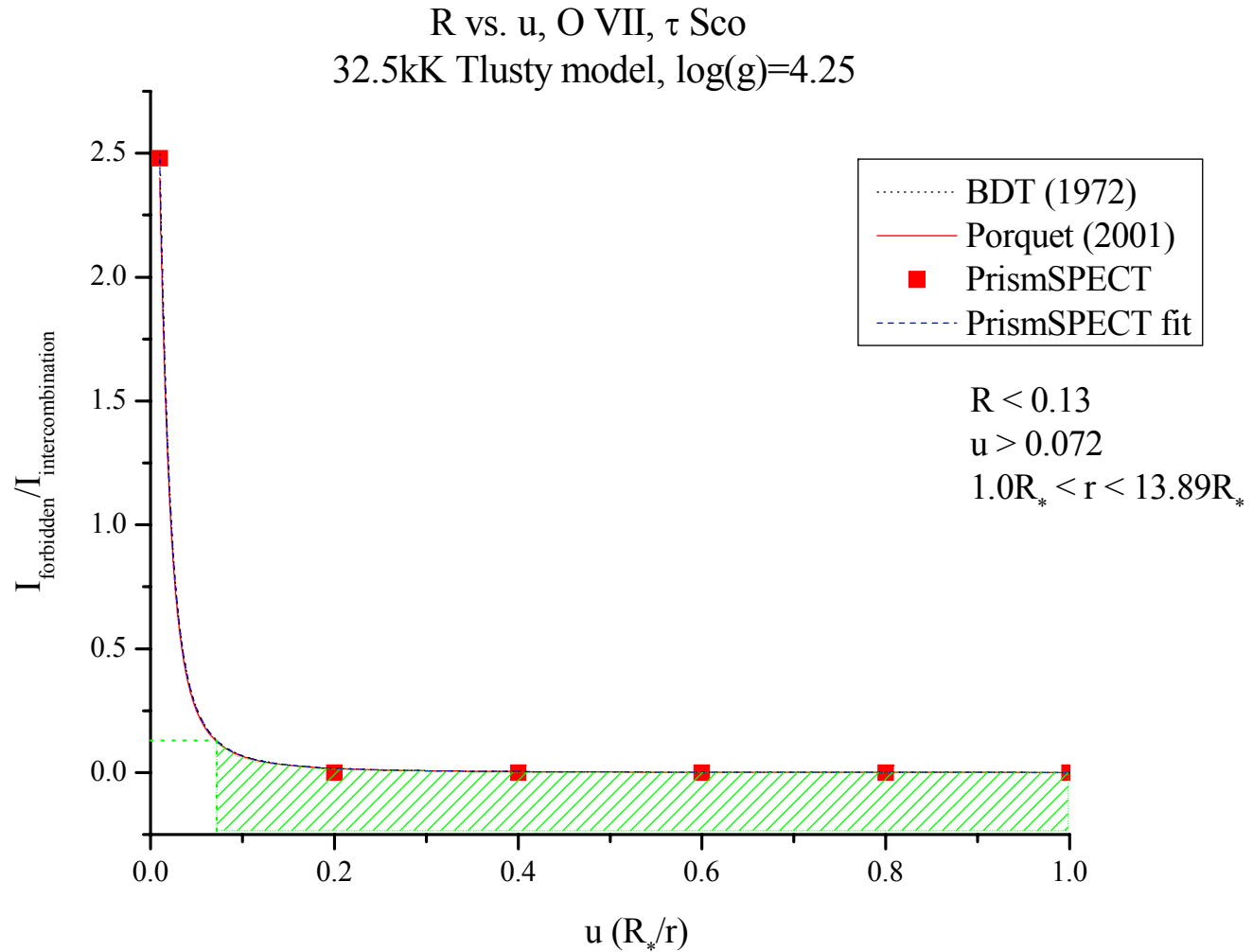
The black points are the f/i ratios calculated by PrismSPECT for $\phi=10^x$.

Executive summary: Don't worry about the difference between the red and black points. The green area represents the possible ϕ values according to the data and PrismSPECT.

Note the excellent agreement between PrismSPECT and BDT for this element:

	PrismSPECT	BDT	Porquet
R_0	3.847	3.85	3.7
ϕ_c	732.09	732	N/A

Dependence of f/i upon scaled radius, $u=R_*/r$

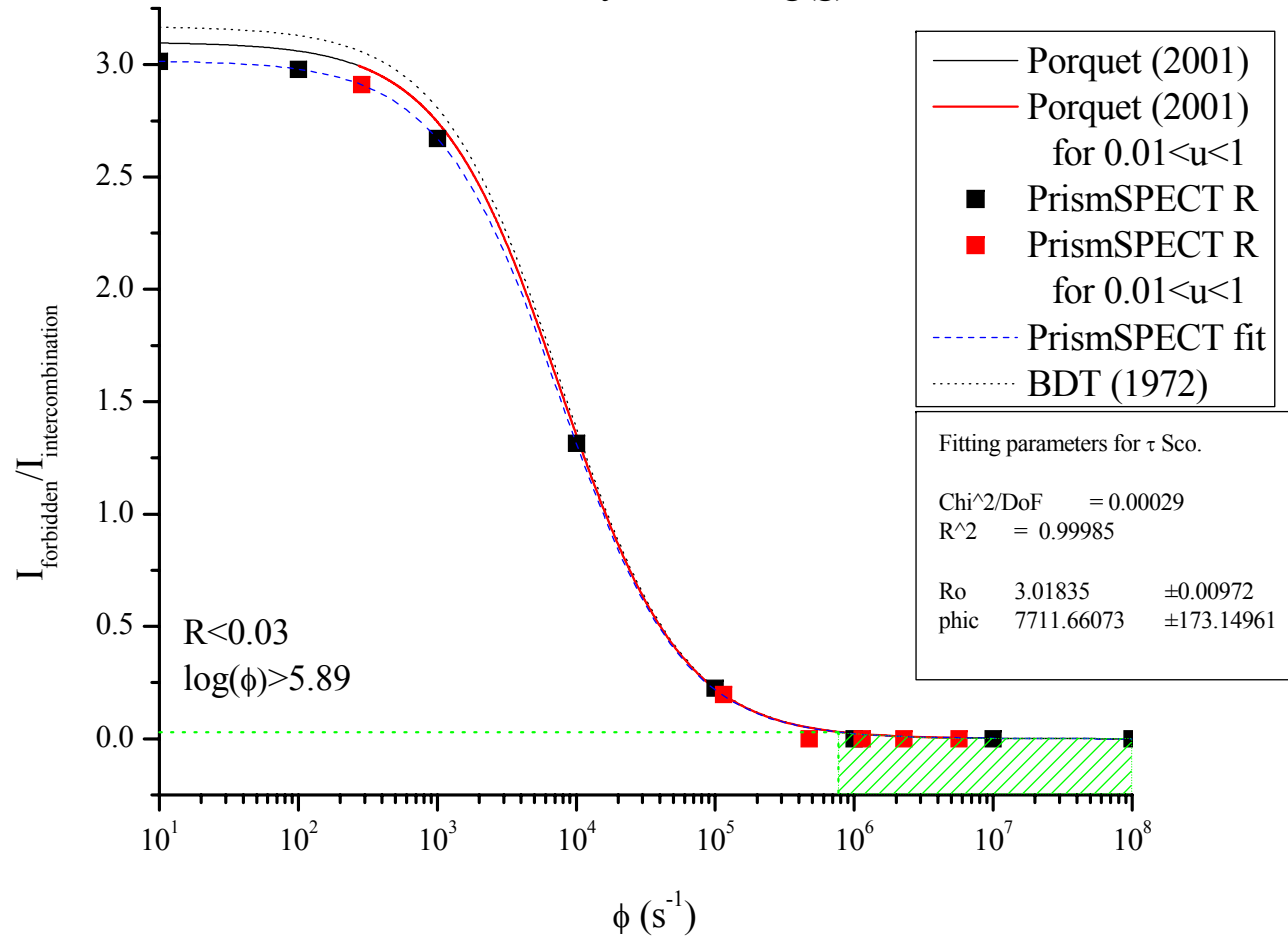


According to PrismSPECT, the radial distance of the X-ray emitting plasma is between 1.0 and $13.89R_*$.

Cohen et al. report a distance of 1.0 to $10 R_*$ for O VII.

Neon: the Dependence of f/i upon photoexcitation rate, ϕ

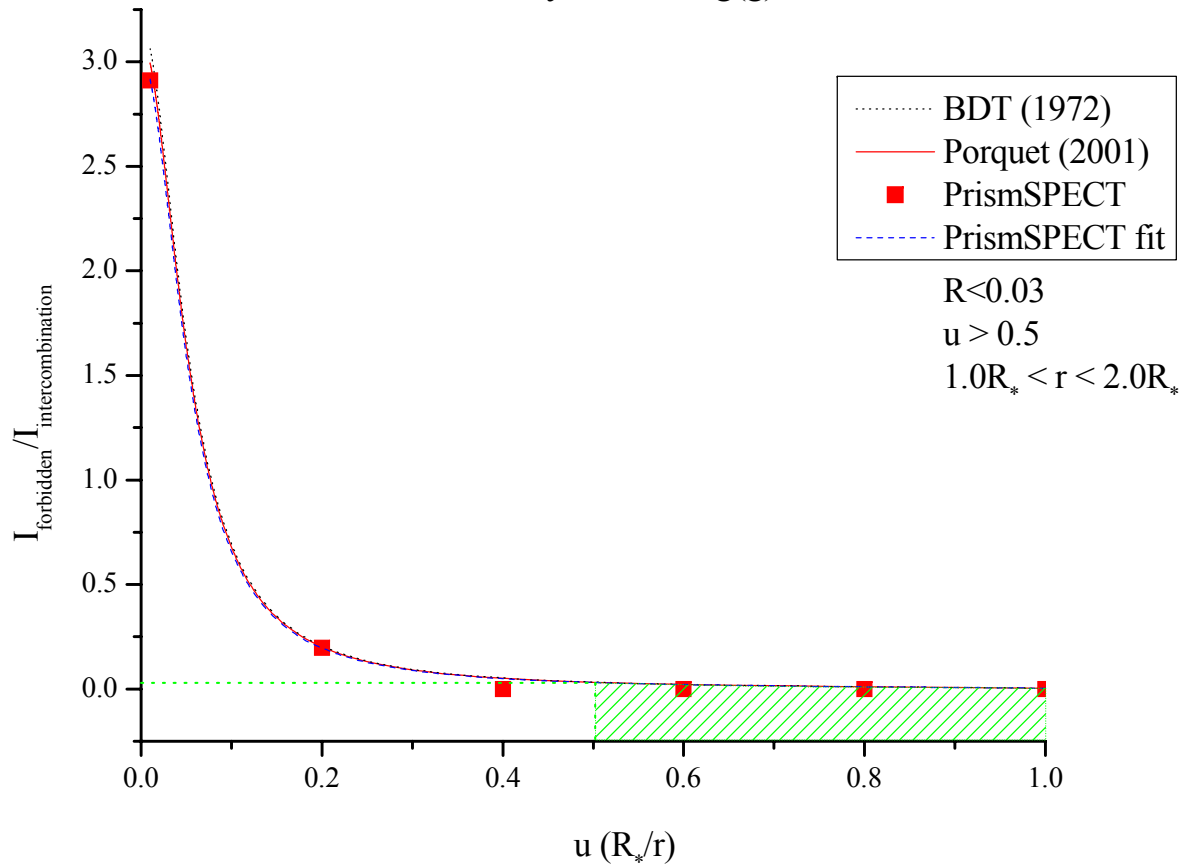
R vs. ϕ , Ne IX, τ Sco
 32.5kK Tlusty model, $\log(g)=4.25$



	PrismSPECT	BDT	Porquet
R_0	3.02	3.17	3.1
ϕ_c	7712	7730	N/A

Dependence of f/i upon scaled radius, $u=R_*/r$

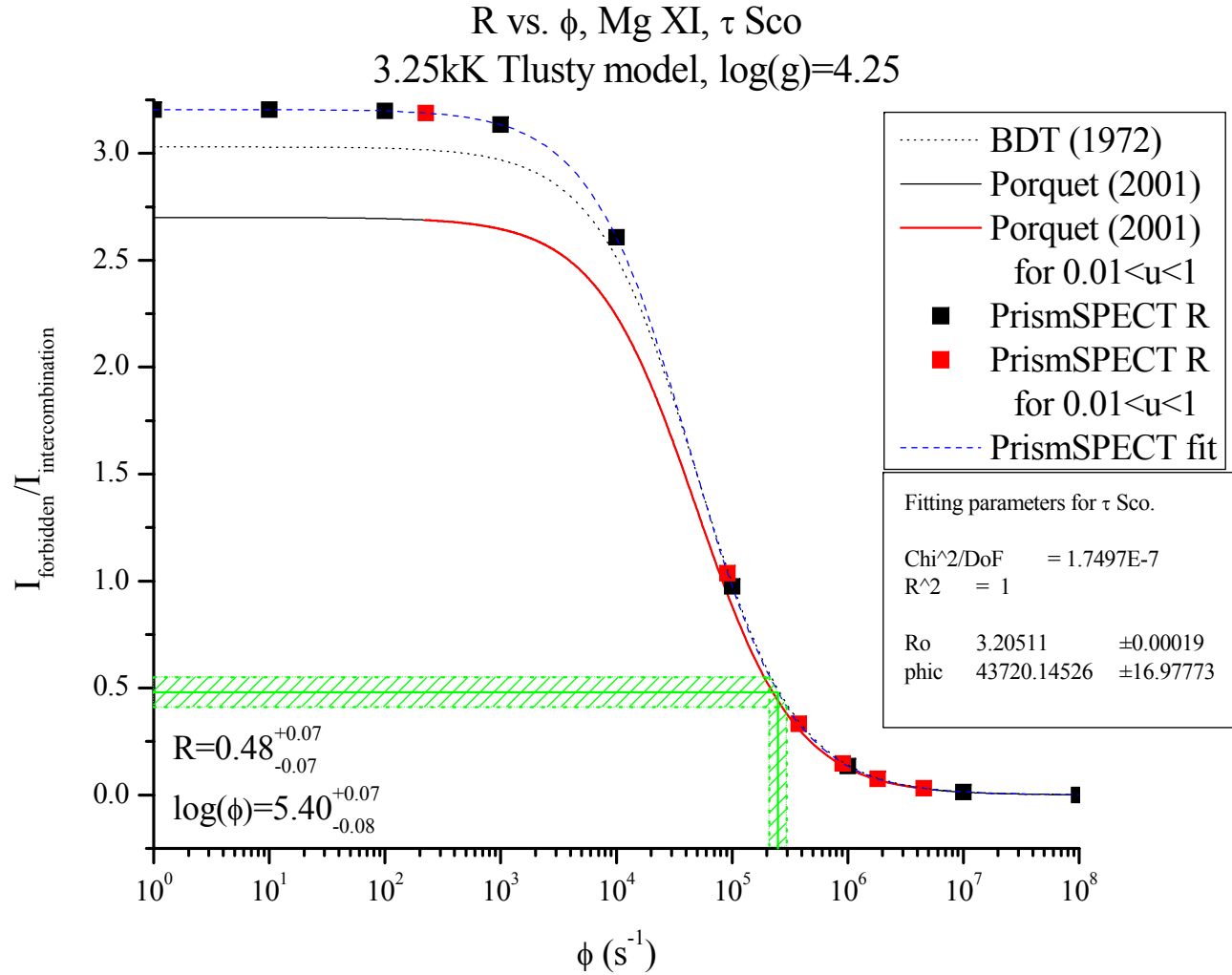
R vs. u, Ne IX, τ Sco
32.5kK Thusty model, $\log(g)=4.25$



According to PrismSPECT, the radial distance of the X-ray emitting plasma is between 1.0 and $2.0R_*$.

Cohen et al. report a distance of 1.0 to $2.0 R_*$ for Ne IX. **This agrees perfectly with the PrismSPECT result.**

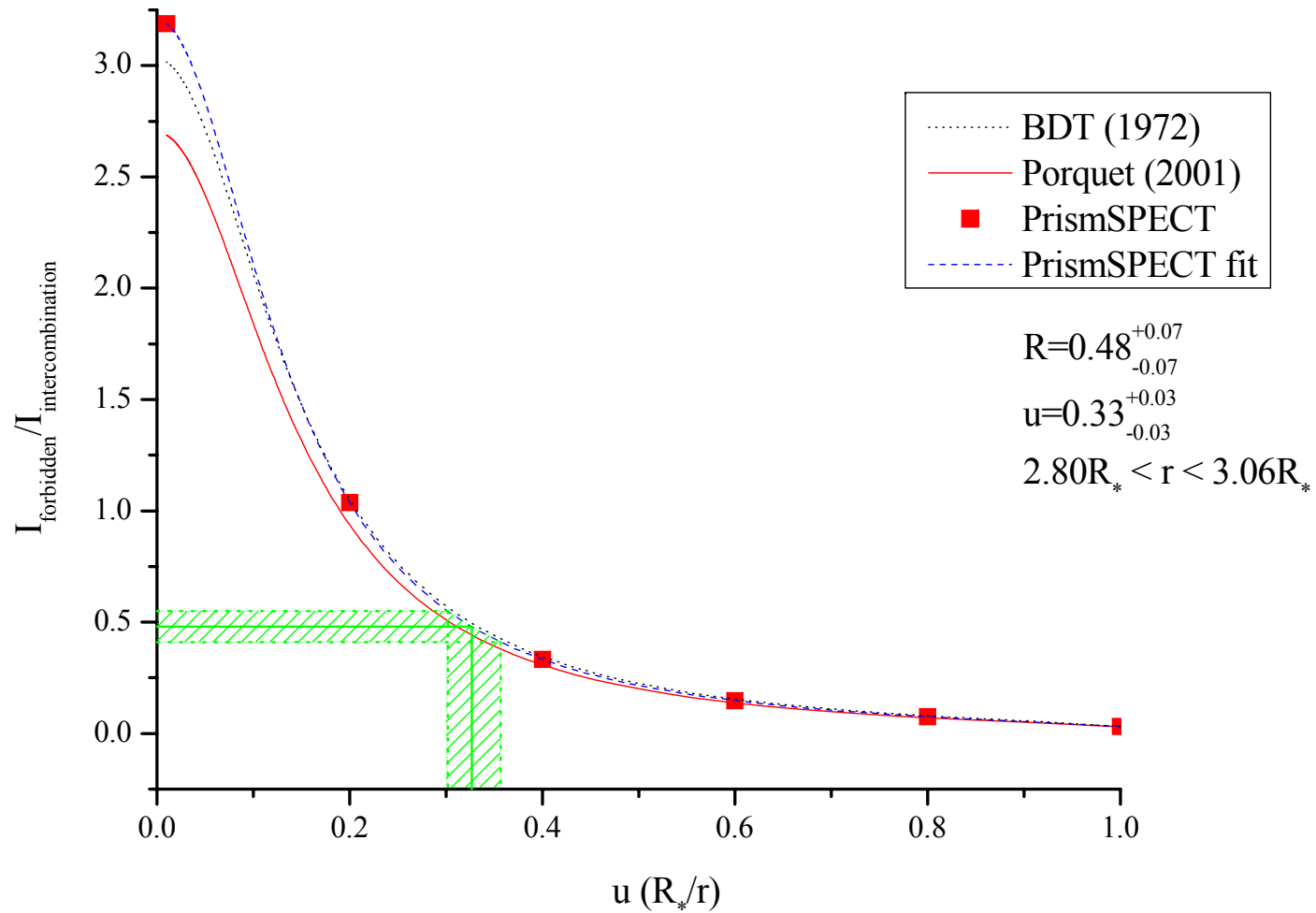
Magnesium: the Dependence of f/i upon photoexcitation rate, ϕ



	PrismSPECT	BDT	Porquet
R_0	3.21	3.03	2.7
ϕ_c	4.37E4	4.86E4	N/A

Dependence of f/i upon scaled radius, $u=R_*/r$

R vs. u, Mg XI, τ Sco.
32.5kK Tlusty model, $\log(g)=4.25$

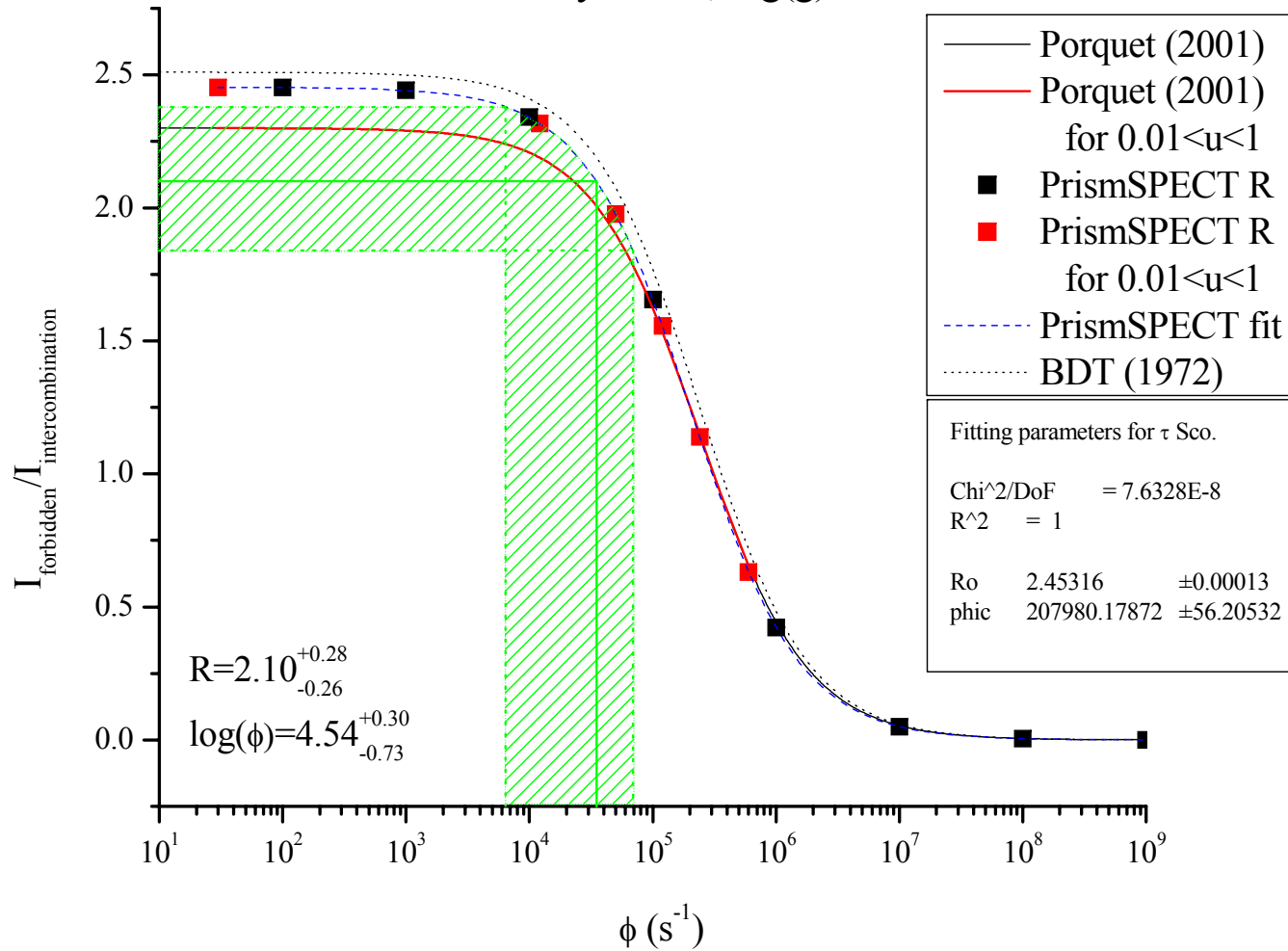


According to PrismSPECT, the radial distance of the X-ray emitting plasma is between 2.80 and $3.06R_*$.

Cohen et al. report a distance of 2.6 to $2.9 R_*$ for Mg XI.

Silicon: the Dependence of f/i upon photoexcitation rate, ϕ

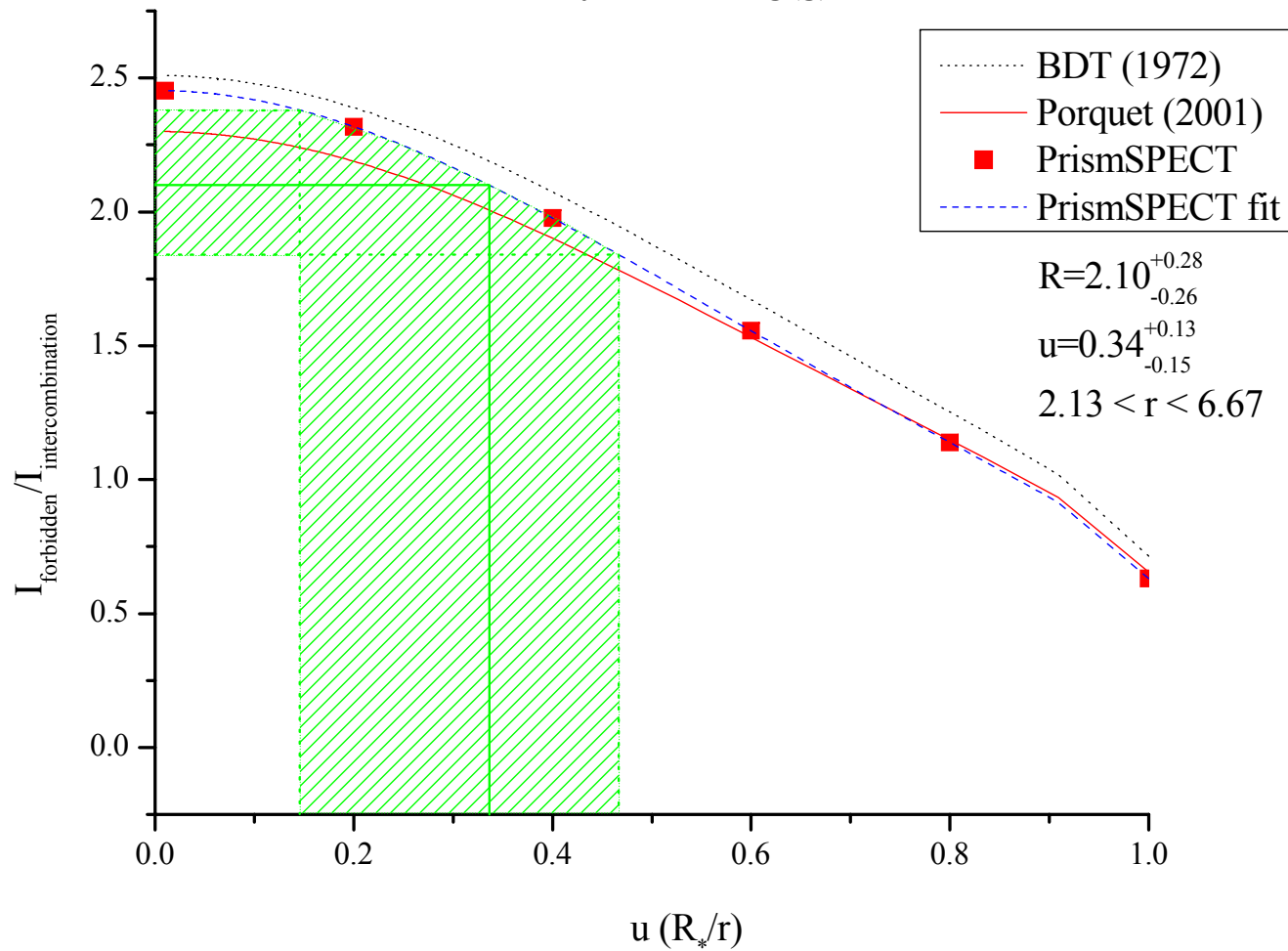
R vs. ϕ , Si XIII, τ Sco
 32.5kK Thusty model, $\log(g)=4.25$



	PrismSPECT	BDT	Porquet
R_0	2.45	2.51	2.3
ϕ_c	2.08E5	2.39E5	N/A

Dependence of f/i upon scaled radius, $u=R_*/r$

R vs. u, Si XIII, τ Sco
32.5kK Thusty model, $\log(g)=4.25$

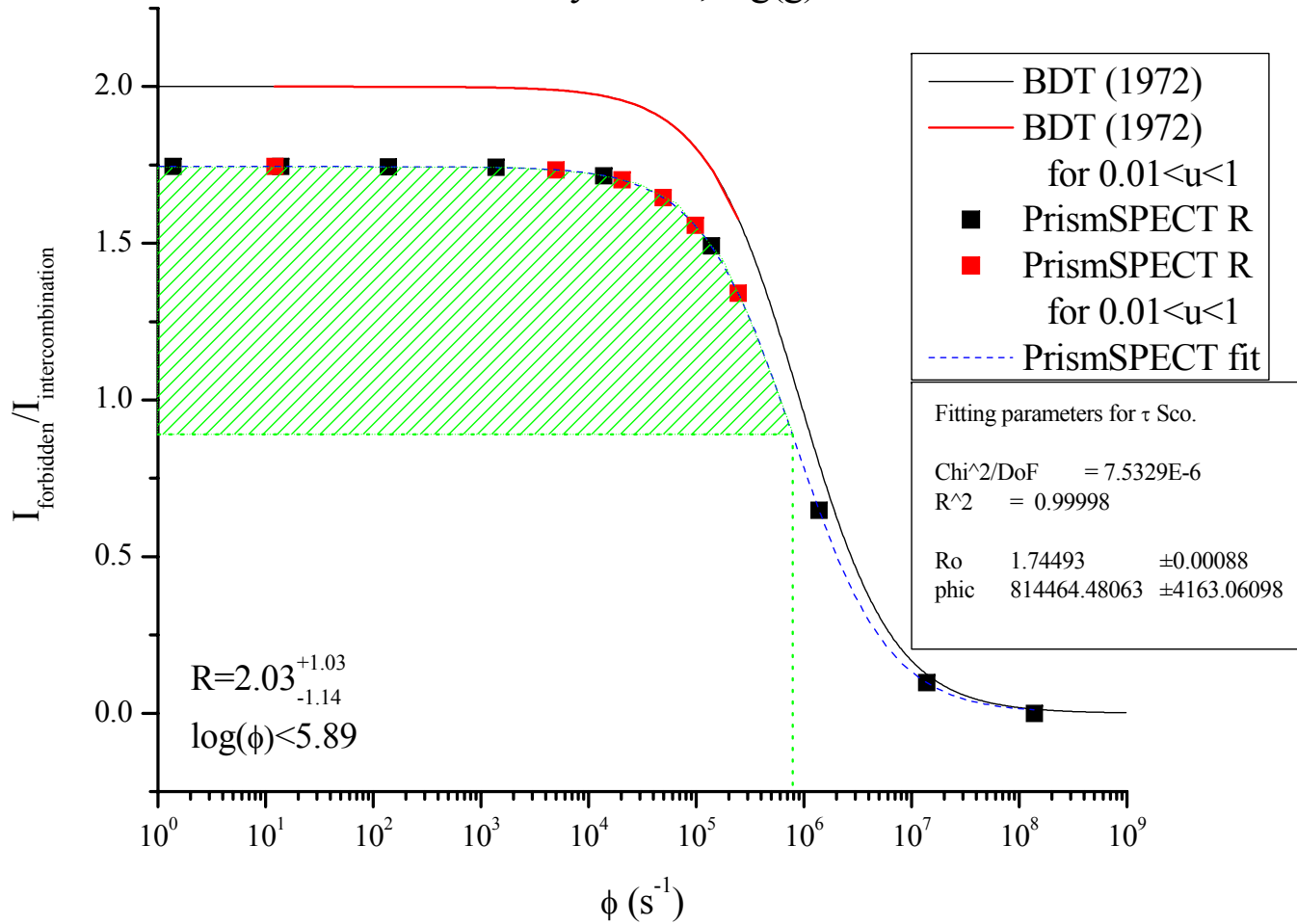


According to PrismSPECT, the radial distance of the X-ray emitting plasma is between 2.13 and 6.67 R_* .

Cohen et al. report a distance of 1.1 to 1.5 R_* for Si XIII. **This is significantly different from the PrismSPECT result.**

Sulfur: the Dependence of f/i upon photoexcitation rate, ϕ

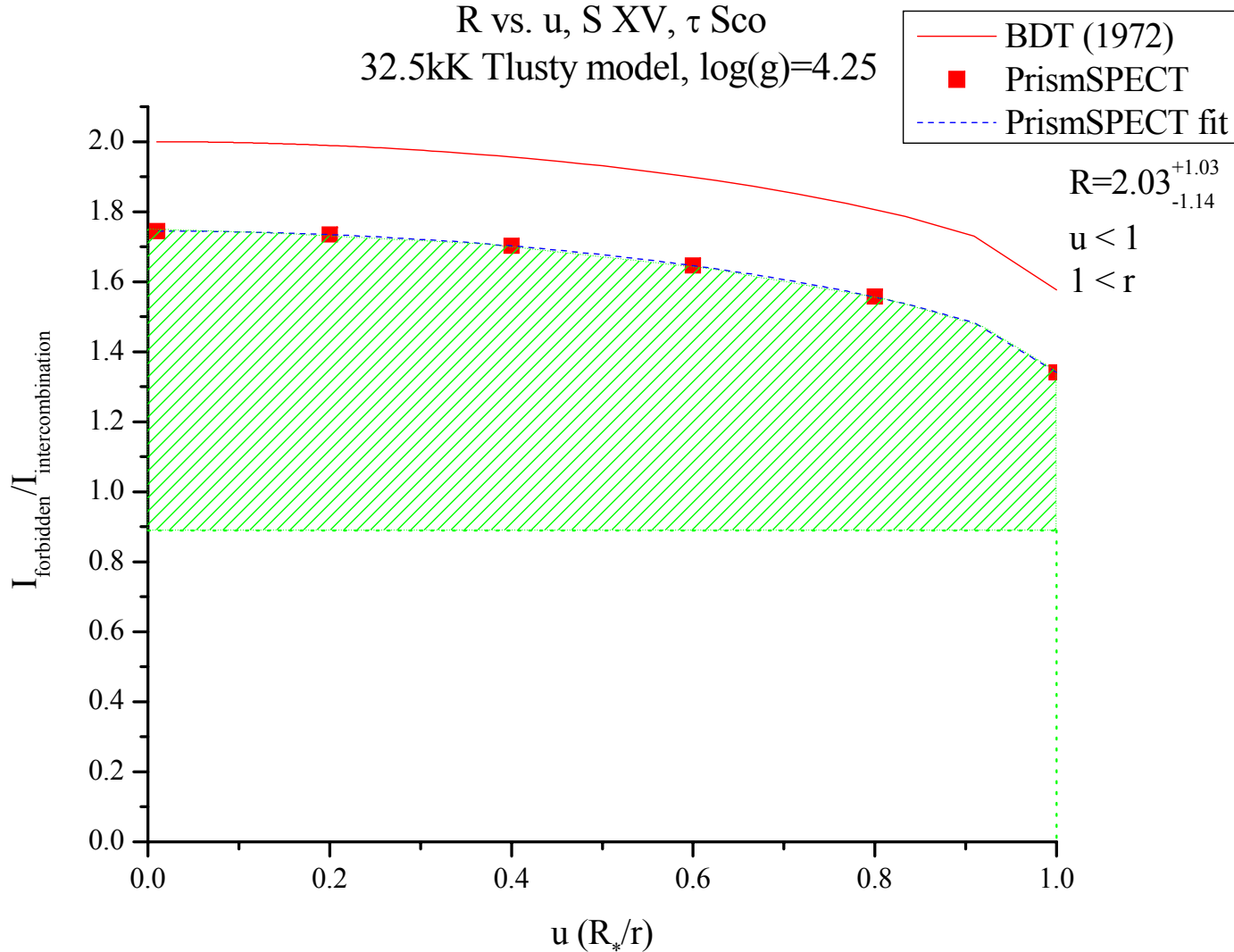
R vs. ϕ , S XV, τ Sco
 32.5kK Tlusty model, $\log(g)=4.25$



	PrismSPECT	BDT	Porquet
R ₀	1.75	2.04	N/A
φ _c	8.15E5	9.16E5	N/A

Dependence of f/i upon scaled radius, $u=R_*/r$

R vs. u, S XV, τ Sco
 32.5kK Tlusty model, $\log(g)=4.25$



According to PrismSPECT, the observational uncertainties in the f/i ratio mean that we cannot find constraints on the radial distance of the X-Ray emitting plasma. It seems that this would also be the case if we were to use BDT's analytical formula.

Cohen et al. report a distance of 1.0 to 20 R_* for S XV.

Conclusions

For the PrismSPECT results, the f/i ratios predict the following radial distances for the X-ray emitting plasma:

	compare values quoted in the paper:
O VII: $1.0 R_* < r < 13.89 R_*$	$1.0 < r < 10 R_*$
Ne IX: $1.0 R_* < r < 2.0 R_*$	$1.0 < r < 2.0 R_*$
Mg XI: $2.8 R_* < r < 3.06 R_*$	$2.6 < r < 2.9 R_*$
Si XIII: $2.13 R_* < r < 6.67 R_*$	$1.1 < r < 1.5 R_*$
S XV: $1.0 R_* \leq r$	$1.0 < r < 20 R_*$

Note that the slightly larger radii in the new calculations (e.g. O, Mg, some portion of the Si reanalysis) are likely due to the relatively high temperature used for the atmosphere model.

Note also that the corrected Si XIII value is now much more in line with the Mg XI results, presenting a more consistent picture of a nearly stationary plasma, relatively far from the photosphere, perhaps consistent with MHD models of the MCWS mechanism.