

## A SYSTEMATIC CHANGE WITH TIME IN THE SIZE OF BETELGEUSE

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### ABSTRACT

The diameter of Betelgeuse ( $\alpha$  Orionis) has been measured at a wavelength of  $11.15\ \mu\text{m}$  using the Infrared Spatial Interferometer over the past 15 years. During this 1993–2009 time period the star’s size has decreased systematically by 15%.

*Key words:* stars: general – stars: individual (Betelgeuse) – techniques: interferometric

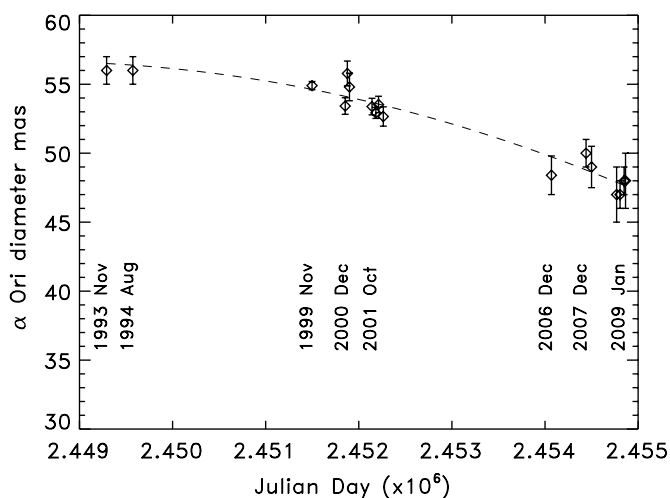
### 1. INTRODUCTION

Betelgeuse ( $\alpha$  Orionis) was the first star to be measured in size. Michelson & Pease (1921) reported a diameter of  $0''.047$  at optical wavelengths, but in addition to a measurement uncertainty of 10%, they estimated that its actual size was probably 10%–15% larger because of limb darkening. Since then it has been measured from time to time by a number of interferometers at various wavelengths, giving values that vary substantially with wavelength. It has now been measured systematically over a period of about 15 years with the Infrared Spatial Interferometer (ISI). The ISI uses a narrow frequency range to avoid spectral lines and mid-infrared (mid-IR) wavelengths which penetrate the surrounding dust well. The diameters measured by the ISI are not particularly inconsistent with previous measurements, are rather accurate, and show clearly that the star has systematically decreased in size by about 15% over the past 15 years.

### 2. GENERAL DISCUSSION

Since all of the interferometric measurements made, except those of the ISI, have used rather broad bandwidths it is not surprising that there have been large variations in the resulting apparent size. What most interferometers measure is partly emission from spectral lines of gas surrounding the star and partly absorption by spectral lines, as well as effects of dust around the star, rather than the stellar continuum directly. Variations in apparent size with wavelength have been previously tabulated (Weiner et al. 2003; Perrin et al. 2004). The variations in apparent diameters from visible wavelengths to  $3\ \mu\text{m}$  are as large as about 50%.

The ISI operates at wavelengths near  $11\ \mu\text{m}$ , using heterodyne detection with  $\text{CO}_2$  lasers as local oscillators. This converts the infrared signal into a microwave frequency signal with a bandwidth of about  $5.4 \times 10^9\ \text{Hz}$ , or  $0.18\ \text{cm}^{-1}$ . The system is tunable so that wavelengths can be chosen to avoid any spectral lines. Measurements reported here were thus made in a narrow frequency range which is free of spectral lines, importantly including any substantial ones due to water vapor. The radiation from the surrounding dust is easily detected, but at  $11\ \mu\text{m}$  wavelength the dust is also rather well penetrated. The distribution of dust and the stellar characteristics are hence easily and clearly separated. Since this wavelength is not scattered as much as shorter ones, the ISI views the stellar continuum rather clearly and directly and gives a reliable measure of the real size of the star, as defined by its effective continuum diameter. Inter-



**Figure 1.** Diameter of  $\alpha$  Ori measured at  $11.15\ \mu\text{m}$  by the ISI over 15 years. Values previously published are: 1994, Bester et al. (1996); 1999, 2000, and 2001, Weiner et al. (2003); 2006, Tatebe et al. (2007). Values from 2007 to 2009 are new measurements. The dashed line is a quadratic fit to the data.

ferometric measurements with the ISI began in 1993 with two movable telescopes that can provide a wide variety of baselines. A third telescope was added in 2002 so that stellar diameters could be measured simultaneously from three directions and point inversion asymmetries detected by phase closure, using the phases of three simultaneous interference signals.

In 2006, the ISI detected a major hot spot on  $\alpha$  Ori, producing about 10% of the total flux at  $11.15\ \mu\text{m}$ , and resulting in some asymmetry in the radiation intensity (Tatebe et al. 2007). This discovery is consistent with theoretical predictions by Schwarzschild (1975). Without correcting for a hot spot, the apparent diameters measured by individual differently oriented baselines differed substantially (Tatebe et al. 2007). But modeling the system as a uniform disk plus a hot spot on one side of the star gives an effective circular diameter for the star of  $48.4 \pm 1.4\ \text{mas}$ . Other ISI measurements, between 1994 and 2009, did not indicate any large hot spots or asymmetries, though these would not have been detected by the ISI before the third telescope was added in 2002.

### 3. RESULTS AND CONCLUSIONS

Measurements of  $\alpha$  Ori’s diameter over the period 1994–2009 show a substantial and systematic change over this period,

**Table 1**  
ISI Diameter Measurements of Betelgeuse 1993–2009

Date (average)	Diameter (mas)	Reference
1993 Oct 30	56.0 ± 1.0	1
1994 Aug 8	56.0 ± 1.0	1
1999 Nov 15	54.9 ± 0.3	2
2000 Nov 5	53.4 ± 0.6	2
2000 Nov 28	55.8 ± 0.9	2
2000 Dec 21	54.8 ± 1.0	2
2001 Aug 20	53.4 ± 0.6	2
2001 Sep 30	52.9 ± 0.4	2
2001 Oct 29	53.5 ± 0.6	2
2001 Dec 19	52.7 ± 0.7	2
2006 Nov 29	48.4 ± 1.4	3
2007 Dec 6	50.0 ± 1.0	
2008 Feb 3	49.0 ± 1.5	
2008 Oct 29	47.0 ± 2.0	
2008 Dec 5	47.0 ± 1.0	
2009 Jan 17	48.0 ± 1.0	
2009 Feb 2	48.0 ± 2.0	

**Reference.** (1) Bester et al. 1996; (2) Weiner et al. 2003; (3) Tatebe et al. 2007.

as may be seen in Figure 1 and Table 1. Data prior to 2007 have been previously reported and the data since this time are new. The measurements were made with baselines of 32–59 m, which allowed adequate resolution of the star. ISI measurements with shorter baselines, sensitive to spatial frequencies related to the dust shells, are not included in the figure. Variations in the luminosity and diameters measured for  $\alpha$  Ori have been previously reported by White (1980), but the data are not good enough to provide very clear-cut conclusions. Also, the modest known variations in luminosity are probably not simply related to size and the visible band photometric record of the AAVSO does not resemble the size variation of Figure 1. Some of the complexities of radiation from  $\alpha$  Ori, particularly due to surrounding molecular gas, are illustrated in the recent report

of ultraviolet, IR, and mm studies of the star by Harper et al. (2009).

ISI measurements over the last 15 years clearly show a systematic change in the diameter of  $\alpha$  Ori. This change may or may not be periodic; if it is, the period is likely rather long, perhaps a few decades. One might attribute some of the change in apparent size to a specific instability connected with the large spot in 2006, but this would only be a possible conjecture. It should be valuable to continue accurate measurements of  $\alpha$  Ori's size and other characteristics in order to understand the dynamics involved in this striking change, and to have systematic long-term measurements of similar stars.

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*Facility:* ISI

## REFERENCES

- Bester, M., Danchi, W. C., Hale, D. D. S., Townes, C. H., Degiacomi, C. E., Mekarnia, D., & Geballe, T. R. 1996, *ApJ*, 463, 336  
 Harper, G. M., Carpenter, K. G., Ryde, N., Smith, N., Brown, J., Brown, A., & Hinkle, K. H. 2009, *Am. Inst. Phys. Conf. Ser.*, 1094, 868  
 Michelson, A. A., & Pease, F. G. 1921, *PNAS*, 7, 143  
 Perrin, G., Ridgeway, S. T., Coudé du Foresto, V., Mennesson, B., Traub, W. A., & Lacasse, M. G. 2004, *A&A*, 418, 675  
 Schwarzschild, M. 1975, *ApJ*, 195, 137  
 Tatebe, K., Chandler, A. A., Wishnow, E. H., Hale, D. D. S., & Townes, C. H. 2007, *ApJ*, 670, L21  
 Weiner, J., Hale, D. D. S., & Townes, C. H. 2003, *ApJ*, 589, 976  
 White, N. M. 1980, *ApJ*, 242, 646