SPECKLE INTERFEROMETRY, SPECKLE MASKING, SPECKLE SPECTROSCOPY AND SPECKLE FRAME SELECTION *

Gerd Weigelt

Physikalisches Institut, Rommel-Str. 1, 8520 Erlangen, Fed. Rep. of Germany

Abstract

High-resolution speckle imaging is one of the most fascinating possibilities of a Very Large Telescope (VLT). Various speckle methods can yield a resolution of about 0.01" with a 8-m to 10-m VLT. As exiting as the resolution is the limiting magnitude of the speckle methods. The limiting magnitude is extremely seeing-dependent. The following limiting magnitudes are possible with speckle interferometry, speckle masking and speckle spectroscopy:

4" seeing: limiting magnitude 15
2" seeing: limiting magnitude 17.5
1" seeing: limiting magnitude 20 (!)

1. Introduction

1986 is the planned launch date of the 2.4-m Space Telescope. The ST will have a resolution of about 0.05" to 0.1" with direct imaging. Speckle roll deconvolution of ST data (Lohmann and Weigelt 1979, Weigelt 1984) can yield a resolution of 0.01" at λ = 130nm and a limiting magnitude of about 22^m. Nevertheless we shall urgently need the VLT for high-resolution speckle work for the following reasons:

(a) at optical wavelengths speckle methods with the VLT can yield 3 times higher resolution than the ST at optical wavelengths

(b) long-baseline methods can yield 10 or 100 times higher resolution than the ST

(c) we need the VLT for high-resolution at IR

The usefulness of the speckle methods will critically depend on the achievable limiting magnitude. We gain 2.5^m in limiting magnitude if the seeing diameter decreases by a factor of 2 (Dainty 1975, Roddier 1975). At 1" seeing the limiting magnitude of various speckle methods is about 20^m. 20^m is possible with speckle interferometry (Labeyrie 1970), speckle masking (Weigelt 1977,

* Based on data collected at the European Southern Observatory, La Silla, Chile

Proceedings of the IAU Colloquium No. 79: "Very Large Telescopes, their Instrumentation and Programs", Garching, April 9–12, 1984.

Weigelt and Wirnitzer 1983, Lohmann et al. 1983, Wirnitzer 1984) and speckle spectroscopy (Weigelt 1981, Stork and Weigelt 1984). Due to the very strong seeing dependence of the limiting magnitude we need:

(a) an excellent site for the VLT

(b) absolutely no dome seeing

(c) excellent mirrors

Fig. 1 illustrates the dome seeing problem. The photograph shows a piece of a 16mm-motion picture film of dome seeing Foucaultgrams. In this dome seeing movie it is obvious that the large, slowly moving air bubbles are caused by dome seeing since the air bubbles circulate in the telescope tube.

In the following sections I will show various speckle results. For the question of the limiting magnitude the measurements of the gravitational-lens QSO PG1115+080 (16.2^m) and Pluto/Charon ($15^m/17^m$) are especially interesting since these measurements were performed under the following relatively bad conditions:

1.5 to 2" seeing (!)
30 min. observing time
1.5-m telescope
8% quantum efficiency

2. Speckle interferometry

Fig. 2-4 show various speckle interferometry results of faint objects, R136a ($\sim 10\text{-}11^m$), Pluto/Charon ($15^m/17^m$) and the gravitational-lens quasar PG1115+080 A (16.2^m). More new results are shown in the Annual Report 1983 of our institute.

3. Image reconstruction by speckle masking

Speckle masking is a new triple correlation method which yields true images since it reconstructs both the modulus and the phase of the object Fourier transform. Speckle masking has the following properties:

(a) true images of general objects can be reconstructed

(b) no point source in the isoplanatic patch of the object is required

(c) image degradation due to the atmosphere and telescope aberrations are overcome

https://doi.org/10.1017/S0252921100108498 Published online by Cambridge University Press

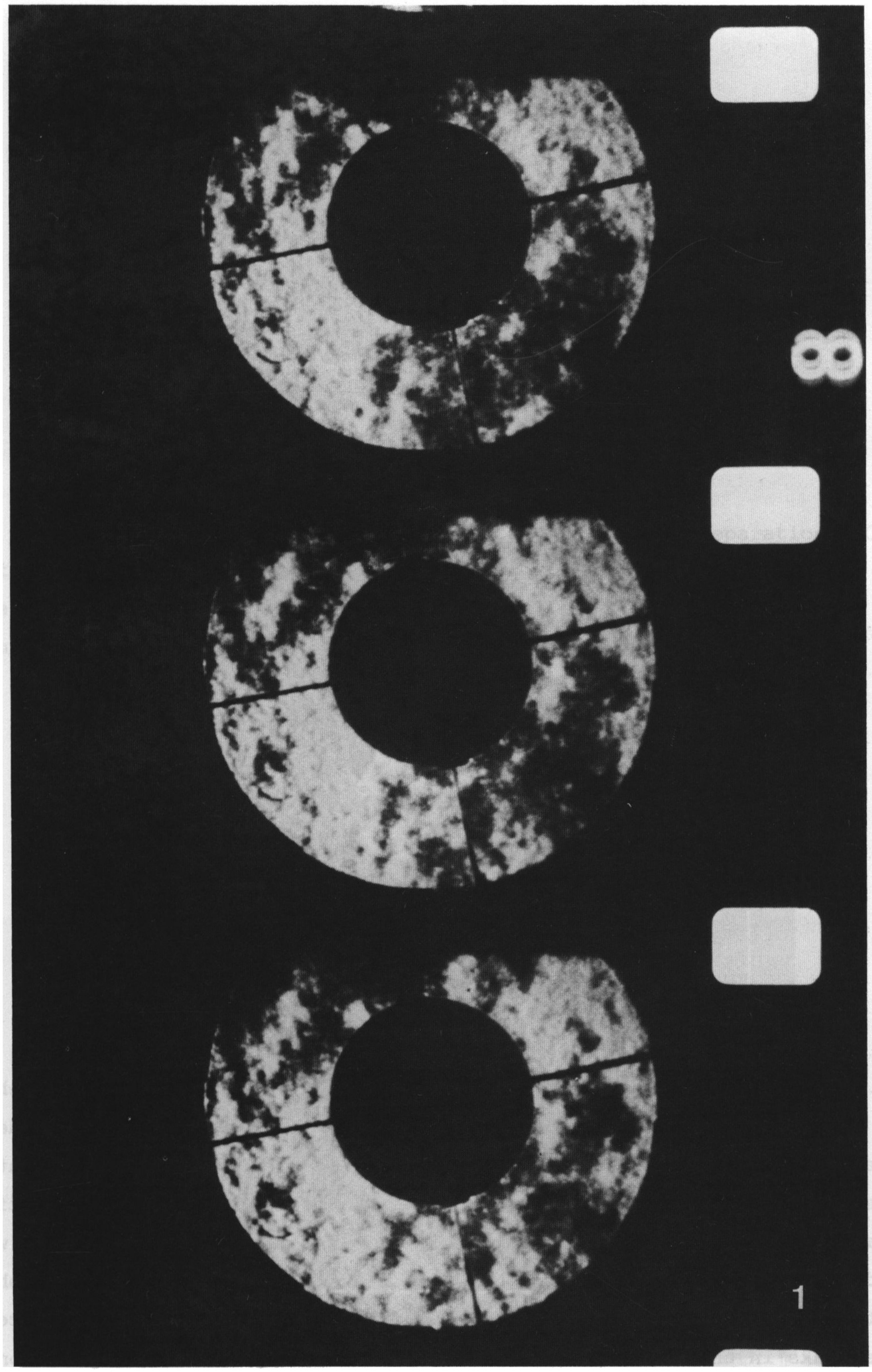


Fig. 1 Foucaultgrams of a dome seeing movie.

https://doi.org/10.1017/S0252921100108498 Published online by Cambridge University Press

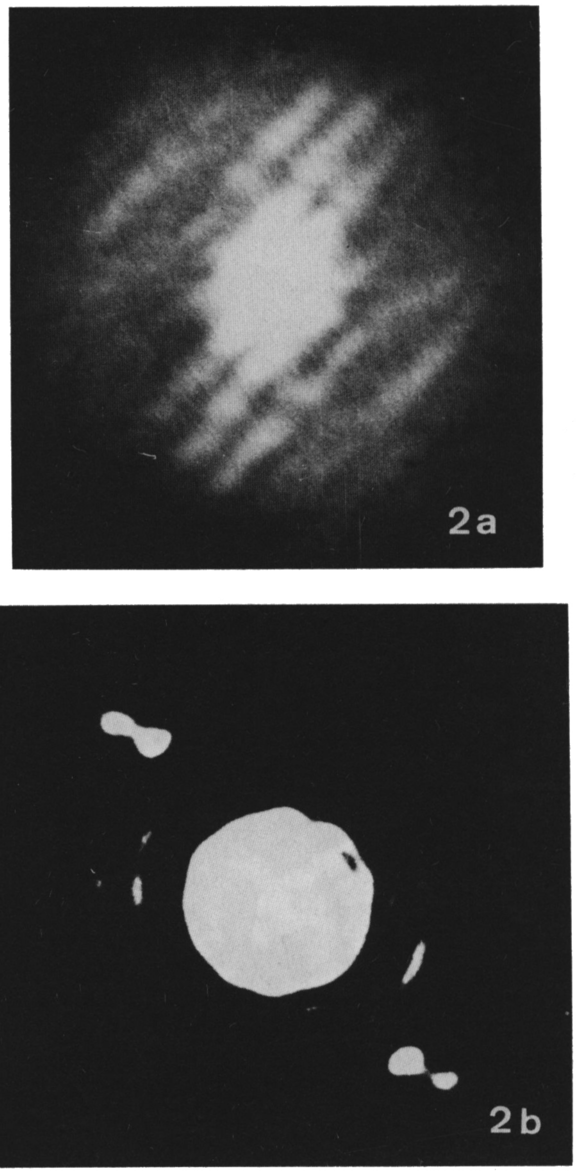


Fig. 2 Speckle interferometry of the central object R136a in the 30 DOR nebula. Fig. 2a is the average power spectrum of 4000 speckle interferograms recorded with the Danish 1.5-m telescope. Fig. 2b is the high-resolution autocorrelation of R136a reconstructed from fig. 2a. The off-axis peaks in the autocorrelation show that the dominating object in R136a is a double source (called a1/a2) with magnitude difference 1^m to 2^m. Probably, a1 or a2 is again a close double object (separation 0.09", position angle 248°, magnitude difference 0^m to 1^m) since the off-axis peaks in the autocorrelation are close double peaks. The separations and position angles of the close off-axis peaks in the autocorrelation are 0.47"/0.56" and 221°/226°, respectively. In addition to these dominating objects we found three fainter stars with separations between 0.5" and 1.5".

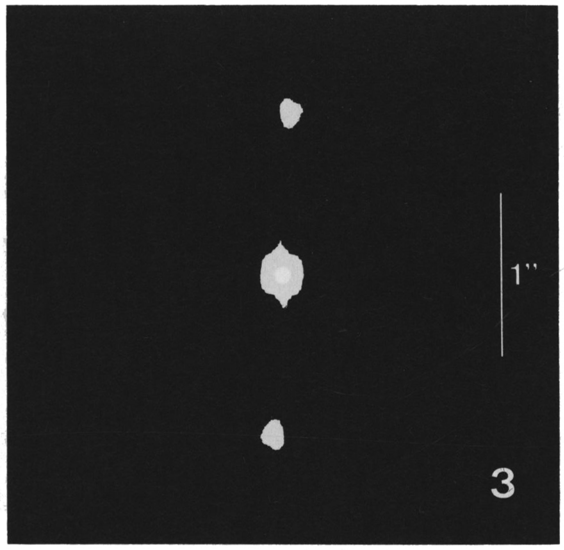


Fig. 3 Speckle interferometry of Pluto/Charon ($15^m/17^m$). (Separation = 0.95", position angle = 170°, epoch: 3 April 1981 6^h00^mU.T., from Hetterich and Weigelt 1983). New Pluto/Charon measurements from 5 different nights are shown in our Annual Report 1983.

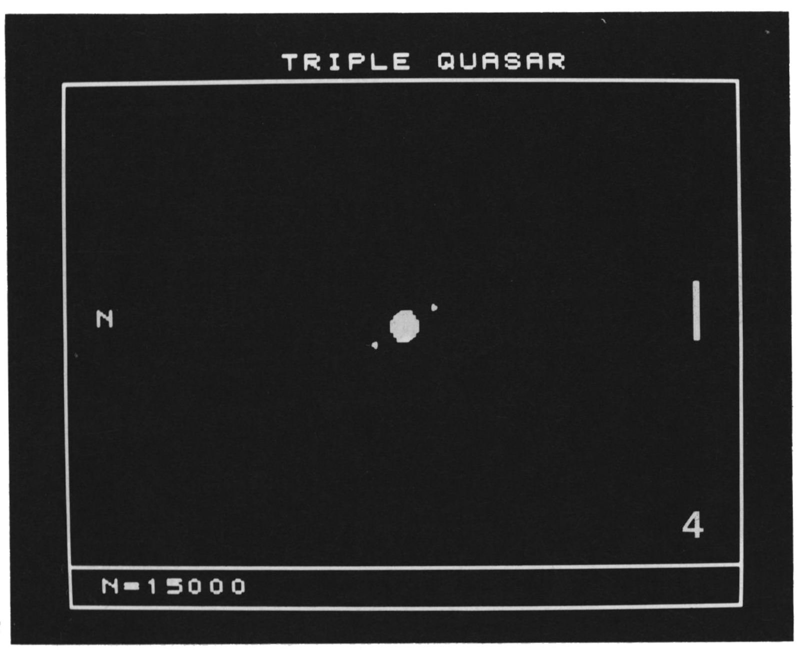


Fig. 4 Speckle interferometry of the gravitational-lens quasar PG1115+080 A (16.2^m, separation = 0.5", position angle = 18°). Another measurement of this object is reported in (Hege et al. 1982). From (Baier et al. 1983).

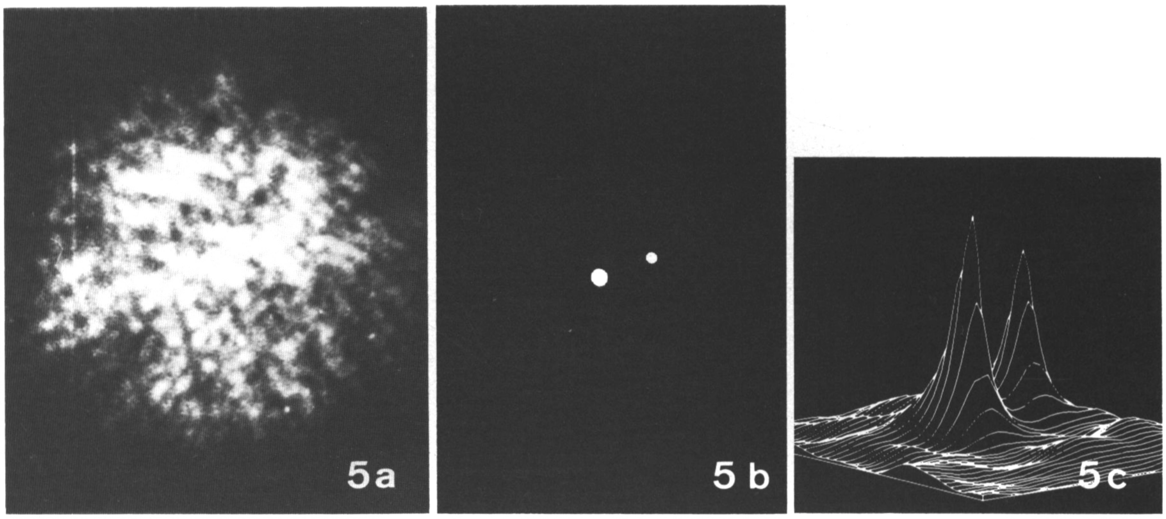
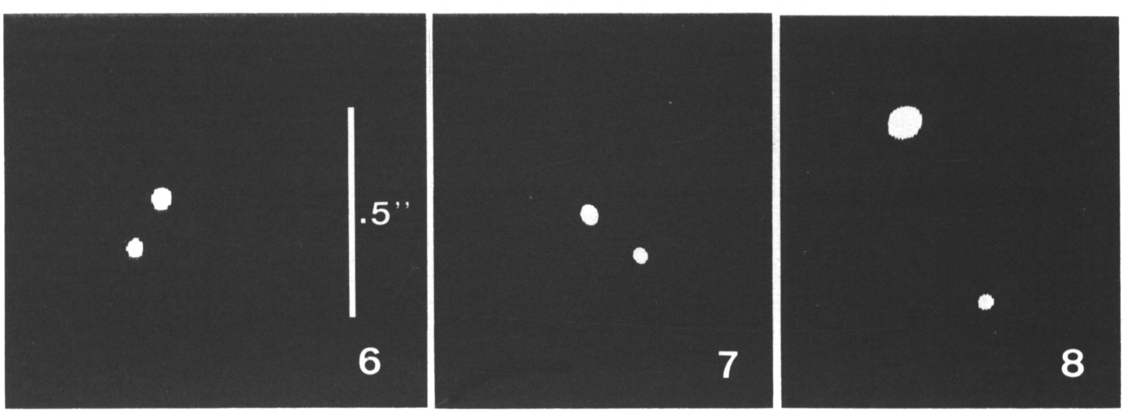


Fig. 5 Speckle masking measurement of the close spectroscopic double star Psi SGR.

a: One of the 150 evaluated speckle interferograms (ESO 3.6-m telescope)

b,c: Reconstructed diffraction-limited image (epoch: 1982.378, separation = 0.184", position angle: 105.6°, intensity ratio: 1.3)

From (Weigelt and Wirnitzer 1983).



Figs. 6-8 Speckle masking measurements of the close spectroscopic double stars Eta VIR (0.137"), 9 PUP (0.159") and Omega LEO (0.463"). From (Weigelt and Wirnitzer 1983).

https://doi.org/10.1017/S0252921100108498 Published online by Cambridge University Press

(d) similar SNR and limiting magnitude as speckle interferometry (Wirnitzer 1984)

Figs. 5-8 show various speckle masking results.

4. Speckle spectroscopy

Speckle spectroscopy yields objective prism spectra with exactly diffraction-limited resolution. The raw data are spectrum speckle interferograms in which each speckle is dispersed to its spectrum. The reconstruction of the objective prism spectrum can be performed by holographic speckle interferometry (with a reference star) or by speckle masking. A digital simulation of speckle spectroscopy with speckle masking is shown in (Stork and Weigelt 1984) and in our Annual Report 1983.

5. Speckle frame selection

Image motion compensation and frame selection have been proposed by many authors. We use such methods to produce digital long-exposure photographs from speckle interferograms. In this way higher resolution and higher photometric accuracy can be obtained than by conventional long-exposure imaging. For example, we have produced a long-exposure from the speckle data of the experiment described in fig. 3. A small deformation on one side of the long-exposure has solved the 180°-ambiguity in the autocorrelation.

Very good image quality can be obtained by speckle frame selection if the following techniques are applied:

(a) Recording of speckle interferograms, i.e. exposure time less than 0.1 sec, compensation of atmospheric dispersion and high magnification to resolve individual speckles. Our speckle data show that exposure times longer than 0.1 sec decrease the achievable resolution already.

(b) Digital selection of the best speckle interferograms.

(c) Digital compensation of image motion and averaging to obtain the long-exposure photograph.

(d) Spatial filtering of the image obtained in (c) to compensate the wide wings in the point spread function.

https://doi.org/10.1017/S0252921100108498 Published online by Cambridge University Press

Conclusion

Intensive site testing (with speckle interferograms) and dome seeing experiments should be started very soon since seeing is the most important parameter, not only for speckle work.

References

Baier, G., Keller, E., Weigelt, G., 1983: Proc. of the Second European Signal Processing Conf., Sep. 12-16, Univ. Erlangen-Nürnberg, FRG

Dainty, J.C., 1975: in Laser Speckle and Related Phenomena, Topics in Appl. Physics, Vol. 9, ed. J.C. Dainty, Springer

Hetterich, N., Weigelt, G., 1983: Astron. Astrophys. 125, 246

Labeyrie, A., 1970: Astron. Astrophys. 6, 85

Lohmann, A.W., Weigelt, G., 1979: in Proc. ESA/ESO Workshop on Astronomical Uses of the Space Telescope, F. Macchetto, F. Pacini, and M. Tarenghi, Eds. (ESO, Geneva, 1979) p. 353

Lohmann, A., Weigelt, G., Wirnitzer, B., 1983: Appl. Opt. 22, 4028

Roddier, F., 1975: Signal-to-Noise Ratio in Speckle Interferometry, in Imaging in Astronomy, AAS/SAO/OSA/SPIE Topical Meeting, Boston

Stork, W., Weigelt, G., 1984: Speckle Spectroscopy, in Conf. Proc. International Commission of Optics (ICO-13), Sapporo, Aug. 1984

Weigelt, G., 1977: Opt. Commun. 21, 55

Weigelt, G., 1981: in Proc. of the ESO Conf. on Scientific Importance of High Angular Resolution and IR and Optical Wavelengths, Edited by M.H. Ulrich and K. Kjär, Garching, March 1981, p. 95

Weigelt, G., Wirnitzer, B., 1983: Optics Lett. 8, 389

Weigelt, G., 1984: High-resolution Astronomical Imaging with Space Telescopes, in Conf. Proc. International Commission of Optics (ICO-13), Sapporo, Aug. 1984

Wirnitzer, B., 1984: Bispectral analysis at low light levels and speckle masking, submitted to Optica Acta; and Annual Report 1983

DISCUSSION

J. Mariotti: Did you apply speckle masking treatment to more complicated objects than double stars (such as R136)?

G. Weigelt: Yes, to the asteroid Juno. We have also started to process the R136 and Eta CAR data by speckle masking.

https://doi.org/10.1017/S0252921100108498 Published online by Cambridge University Press

J.E. Noordam: How do you determine x' for the triple correlation in "masking speckle interferometry"?

G. Weigelt: The triple correlation is defined as a function of x', i.e. the computer calculates the triple correlation for all x'. In the case of double stars we need only one masking vector x', which is obtained from the auto-correlation. In the case of double stars x' is the vector from star A to B or B to A.

R.G. Petrov: What is the spectral resolution of your "speckle spectrograms" and are you considering the possibility to use it for Differential Speckle Interferometry.

G. Weigelt: The spectral resolution depends on the spectrograph used. Our present spectrograph has a resolution of 1Å. We use our speckle spectrograms for speckle spectroscopy.

https://doi.org/10.1017/S0252921100108498 Published online by Cambridge University Press