TOMOGRAPHIC MEASUREMENTS OF THE ATMOSPHERE BY ARTIFICIAL PLASMA FRINGES

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Abstract

Artificial guide stars may be created by radio transmitters. By using intensive beams one can modify and enhance natural or artificial air glow. Interfering radio beams can create or change the plasma distribution at the ionosphere and below it. Oxygen, nitrogen, and other elements and molecules are excited to high states, which later emit visible or infra-red light. Fringes or other patterns in these emissions allow to measure atmospheric turbulence inside a wide field of view, to be corrected by adaptive optics.

The severe shortage of distributed reference sources for wide field adaptive optics has led to the proposal of using multiple laser sources for sodium layer pumping [Foy and Labeyrie 1985]. This allows for tomography of the atmosphere and correction of different turbulence layers, resulting in a wide field of view [Beckers 1988-9, Tallon *et al.* 1992a,b]. Spontaneous sodium emission in high power lasers limits the return signal, but this can be overcome by spreading fringes over a wide area from a bright laser [Baharav *et al.* 1994,6].

Incoherent illumination of the mesosphere [Wirth and Jankevics 1992] by simple sodium lamps is not efficient enough. When imaged at 95 km the spots are too large and diffuse to lock on with a wave front sensor. However, these lamps are significantly less expensive than lasers, and their light might be used in a different manner: a large number of lamps outside the dome illuminate an extended patch of the sodium layer, which can be on the scale of tens to hundreds of meters or even more (the size of that patch depends on the quality of the projection reflectors). Onto this patch one impresses finer interference fringes, created by radio waves (or microwaves) originating from three distant dishes or phased arrays (Figure 1). One possibility would be to quench the visible radiation by using microwave beams and move the excited atoms into another state of different lifetime and wave length. In another option, the existing plasma is concentrated in ridges of the fringes by the ponderomotive force and, more significantly, by local heating of the electrons. These enhancements can modify the scattering of light off the sodium atoms. It is not clear, however, that significant plasma density variations are created by the radio beams. If the effect is below a few percent, probably not much will be seen. It might be possible to create plasma locally, rather than modify it. Once plasma is created, electron scattering off the prevalent gases and their radiative relaxation will occur; this radiation can serve as a reference source for adaptive optics.

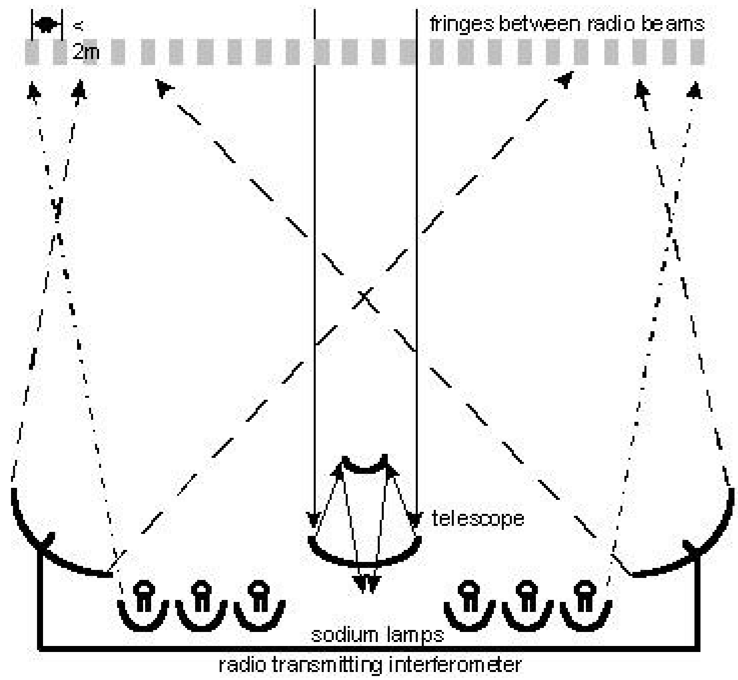

Figure 1: Interference fringes between radio beams modify the area illuminated by sodium lamps.

Baily [1937], Gurevich [1972], Utlaut [1975] and others proposed to create an artificial ionosphere for reflection of radio waves above and behind the horizon. In the simplest scheme (based on the Luxembourg effect), a radio beam heats up and ionizes or creates a break-down in the atmosphere. At an elevation of 30-60 km a patch of plasma is thus created. Efficient reflection of the distant radio waves occurs only at a very high plasma density, so the idea was improved to have two radio beams interfere to create fringes. Radiation density culminates in the fringes where ionization starts, and the few electrons multiply very fast. The ionized fringes serve as a radio Bragg reflector, a more efficient scheme than mere return from a crude plasma volume (Gilednburg and Litvak 1979, Gurevich 1980). In a laboratory experiment, clear visible fringes were apparent and served to trace the plasma distribution [Kuo and Zhang 1990]. Among other applications, the use of artificial ionization was suggested as a means to create a high power nitrogen laser (100 kW inside 1 m^2) in the atmosphere, shining down on the ground [Borisov and Gurevich 1991]. Fringes are created between moving microwave beams, with a crossing area moving down at the speed of light. The advancing breakdown regime is a source of first spontaneous and then stimulated emission. In laboratory tests 3 kW radiation at 337.1 nm were produced [Vikharev *et al.* 1991]. Judging by open literature sources, such experiments were too expensive to run (probably in the range of US$$10^8$ for military applications). Utilization of this scheme for adaptive optics will require a significant reduction in the emitting volume and hopefully a lower price tag.

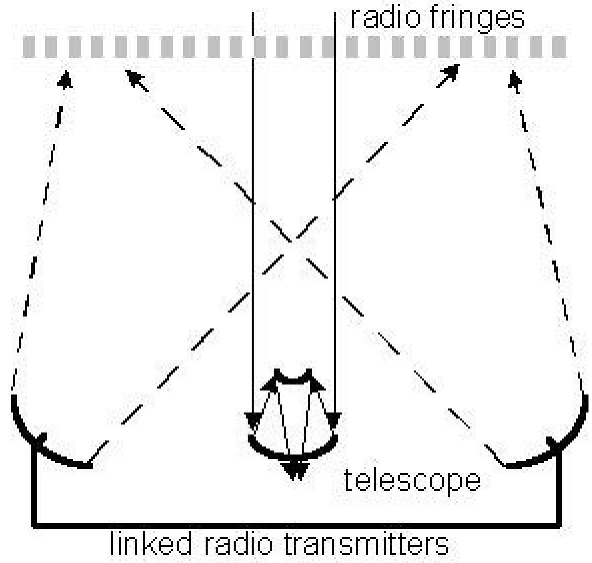

Figure 2: Interference fringes between radio beams create plasma or modify it to induce radiation in narrow lines.

The ionosphere around 250 km [Bernhardt *et al.* 1988] was studied by similar methods: radio heating of a large volume, by a single radio dish, creates plasma and cavitation of the heated volume. The result is enhanced air glow, as well as a typical radio signature, over tens of kilometers. Electrons ionized and/or accelerated in the heated volume spiral out of it along the earth�s magnetic field, and create an illuminated regime when they hit denser neutral species. However, at these elevations (around 200 km) the diffusion of the plasma and the fast winds disperse and shift swiftly any created patterns. In these experiments, relatively low power was required (10 kW - 2 MW), in a continuous mode. At lower elevations, the wavelength has to be shorter (microwave), and because its absorption decreases as more plasma is created, it is necessary to utilize pulses rather than continuous radiation.

The ionospheric air glow is very patchy. This is due to the density variations of the excited volume. In addition, filamentation was observed in the heated area, as well as in laser sodium guide stars. It is not clear what is the typical spatial frequency of the patches and what is their contrast. They have been resolved down to the ten meter scale, consistent with theoretical predictions. Their visible natural intensity is usually tens of Rayleighs, and values above 250 Rayleighs were also produced (a Rayleigh is 1,000,000 photons per second per square centimeter per steradian). This corresponds approximately to 11th magnitude stars. Natural night glow is around 60 Rayleigh, and is widely variable spatially and temporally.

The choice of beacon elevations is important from the point of view of adaptive optics: the higher the better, provided the pattern is stable enough and of high enough contrast on the few arcsecond scale. Above 200 km the random pattern can still be used as a reference source, much in the same way that the solar surface serves for adaptive optics [Acton *et al.* 1996]. Below 100 km the density of the atmosphere is high enough that the plasma mean free path (a few cm) is much shorter than the required fringe period (less than 2m [Baharav *et al.* 1994,6]). Thus the luminescent fringes follow the radio-heated ones. Experiments show that the most efficient air breakdown occurs around 0.5-5 Torr [Kuo and Zhang 1990], corresponding to an elevation of 30-80 km. The sodium layer at 87-95 km seems to be a respectable compromise.

Laser guidestars suffer from the problem of determination of the ascending beam global tilt, which is difficult to measure and remove from the descending beam. Radio beams also suffer from atmospheric turbulence, but it is now independent of the optical turbulence, as the respective beams trace different paths. Blocking of the Rayleigh scattering is another problem with sodium guide stars, which does not exist with radio beams.

However, the atmosphere must be transparent at the wave length of the radio beams.

The reference radiation can be distinguished from the stellar light either temporally or spectrally. If the plasma produces wide band radiation (when it is thick optically), it will be difficult to tell from the scientific object, unless it disappears within a fraction of a millisecond, before the turbulence had changed much. In that case, very short pulses can be shuttered off the astronomical camera or spectrometer.

If the radiation is in lines only, narrow band filters can be used to pick it up, as is done today to separate the beacon radiation (Rayleigh or sodium) from the star light. In atmospheric plasma, oxygen and nitrogen lines are common and useful, but other elements might be preferable: sodium and iron can be found in the mesosphere. The decision which line to choose might be affected by other considerations; it was also found out that the 557.7 nm oxygen line responds instantly whereas the 630.0 nm line is slower. Not much is known about infra-red lines, but they might interfere with astronomical targets at the same wavelengths. However, with the advent of better infrared detectors, perhaps the creation of an infrared beacon should be considered, either by a laser or by beating of microwave frequencies.

The required power for some of these applications could be in the range of tens to hundreds of kilowatts and more. The limitations of laser guide stars are also valid here: high power might be disruptive for aviation and satellites, and special measures need to be taken to prevent accidents. Schemes that use air break-down and plasma might produce hazardous NO_x.

The problem of infrastructure can be significant. Three transmitter dishes [Baharav *et al.* 1994,6] are required to create the necessary pattern. For a fringe frequency of decimeters to meters, and wave length of centimeters to meters, the dishes have to be tens of meters to kilometers away from the telescope. In some sites, topographical limitations such as accessibility might be significant.

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