Lasers in space

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ABSTRACT

A variety of laser applications in space, past, present, future and far future are reviewed together with the contributions of some of the scientists and engineers involved, especially those that happen to have South African connections. Historically, two of the earliest laser applications in space, were atmospheric LIDAR and lunar ranging. These applications involved atmospheric physicists, several astronauts and many of the staff recruited into the Soviet and North American lunar exploration programmes. There is a strong interest in South Africa in both LIDAR and lunar ranging. Shortly after the birth of the laser (and even just prior) theoretical work on photonic propulsion and space propulsion by laser ablation was initiated by Georgii Marx, Arthur Kantrowitz and Eugen Saenger. Present or near future experimental programs are developing in the following fields: laser ablation propulsion, possibly coupled with rail gun or gas gun propulsion; interplanetary laser transmission; laser altimetry; gravity wave detection by space based Michelson interferometry; the de-orbiting of space debris by high power lasers; atom laser interferometry in space. Far future applications of laser-photonic space-propulsion were also pioneered by Carl Sagan and Robert Forward. They envisaged means of putting Saenger's ideas into practice. Forward also invented a laser based method for manufacturing solid anti-matter or SANTIM, well before the ongoing experiments at CERN with anti-hydrogen production and laser-trapping. SANTIM would be an ideal propellant for interstellar missions if it could be manufactured in sufficient quantities. It would be equally useful as a power source for the transmission of information over light year distances. We briefly mention military lasers. Last but not least, we address naturally occurring lasers in space and pose the question: "did the Big Bang lase?"

Keywords: Lasers in space, big bang laser, laser propulsion.

1. INTRODUCTION

Lasers are ubiquitous on Earth and underground, where they serve to line up tunnels and even to drill rock. On Earth their range of applications is only partly perceived by the general public, who encounter them in supermarkets and warehouse scanners, in CD players, in lecture room pointers and in the surveillance and medical environments. But people are seldom aware of the specialized medium and high power laser applications: lasers in biology and electronics, laser accelerators, laser fusion, free electron lasers, high average power industrial applications such as cutting, welding and hardening, and especially lasers in communication. Still less is the general public and dare we suggest, even the scientific public, aware of the fact that lasers are poised to invade outer space, where "sci-fi" has of course long preceded them.

In this article we survey the gradual expansion of lasers into space, starting in the mid sixties with atmospheric LIDAR[1,2] and the Apollo and Lunoxod corner cube, laser beam reflectors, placed on the Moon half a century ago. These early achievements will soon be followed by a plethora of experiments involving lasers in low earth orbit (LEO) or at Lagrange points. And not much later, laser communications will stretch out as far as Mars and beyond. One important low Earth orbit (LEO) application is the removal of space debris by Earth based or LEO relayed lasers as promoted by Phipps et al.[3]. Another is military communication. The prominent L1 laser space application is the LISA pathfinder for the triple satellite LISA gravity wave system that will trail the Earth by 20°. Laser propulsion as envisaged by Kantrowitz[4] and Moeckel[5] will initially be a LEO or geostationary activity. Beyond LEO, there is little doubt that because of the much greater bandwidth of laser communication, it will be coupled to microwave systems to communicate with the Moon, Mars and farther afield. Though the planned laser communication with Mars has been put on hold, laser altimetry above the Moon and Mars has been eminently successful[6]. And then in the far future, our descendants will put into practice the laser based ideas of visionaries. The names Saenger[7], Marx[8], and Forward[9] will

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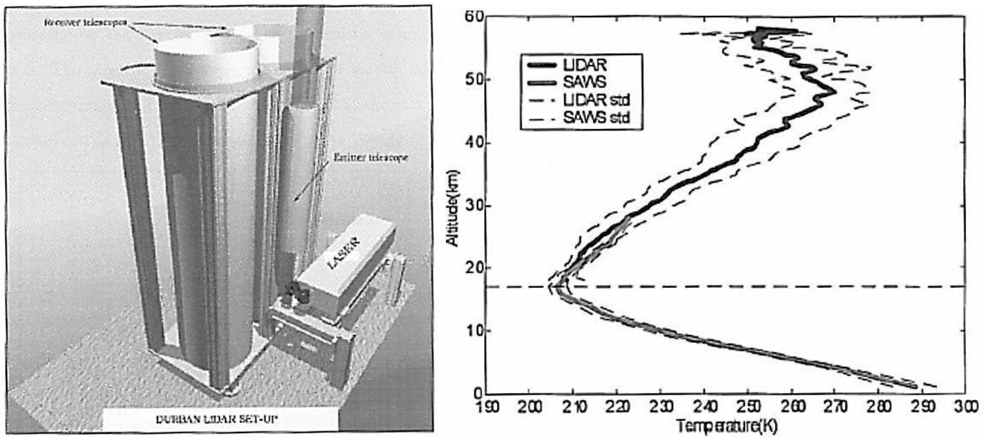
rank with those of Tsiolkolsky and Goddard when pure photon propulsion and antimatter applications in space are realised.

Natural masers and lasers have of course existed since the dawn of time. We take a brief look at the only atmospheric lasers we know, on Mars and Venus and at the possible ASE signals from η–carinae and MWC 349. A short order of magnitude calculation shows that it may be possible to extend the heterodyne spectrometer search to exo–planetary atmospheres. We end the article by asking: “Did the Big Bang lase?”

In respect of each application we will attempt to provide in brief the most relevant theory, present status of research, the scientists or organizations involved, very approximate budgets and future importance and where appropriate, a Southern African connection.

2. ATMOSPHERIC LIDAR

Atmospheric LIDAR which existed well before the first demonstration of lasers in 1960, probably represents mankind’s first active experimental use of light to probe structures above the Earth’s surface, reaching what might be termed “the edge of space”. LIDAR applications came into their own as soon as laser power allowed them to do so, culminating in the lunar ranging experiments described in the next section. Within our own atmosphere, there are many components or structures capable of LIDAR detection: atoms, molecules, dust, aerosols, clouds, ice crystals, impurities or pollutants; structures such as the tropopause, the stratopause and the thermopause, gravity waves, sodium and ozone layers. Detection makes use of the different types of scattering: Rayleigh from atoms and molecules; Mie from dust, ice and aerosols and resonance tuned to various substances. Absorption or reflection are also used in LIDAR systems.



(a) (b)

Figure 1: Atmospheric LIDAR: (a) A typical atmospheric system, the Durban atmospheric LIDAR comprising a 15 W, 30 Hz, pulsed YAG transmitting a green (532 nm) beam through an expander telescope. The return signal is captured by two large (45 cm.) aperture telescopes and fed via fibre optics to the photo-multipliers; (b) Height v. atmospheric temperature. Note the excellent agreement with low altitude balloon sonde data (SAWS) as well as the clear gradient inversions at the tropopause and stratopause.

Unfortunately the return signal is very weak. Single photon counting with sensitive photo-multipliers over several hours is necessary to obtain information from “the edge of space”, just below 100 km: the stratopause at about 60 km and the easier tropopause around 20 km. Special equipment is required to measure ozone concentrations and the ozone layer and the sodium layer at around 90 km. Another form of LIDAR, the differential or DIAL system relies on operation at two nearby wavelengths λ_{on} and λ_{off} corresponding to resonances of the pollutants. One obtains useful data for the pollution concentration as a function of distance. The South African LIDAR initiative has been re-launched by a recent LIDAR workshop in Pretoria-Tswane. The two main SA systems are the Durban atmospheric LIDAR at the University of KwaZulu Natal and the Mobile LIDAR, presently stationed on the CSIR campus in Pretoria. Figure 1(a) shows the Durban LIDAR system with its high power Nd:YAG laser and its four telescopes (one hidden). Figure 1(b) is a typical result plotting temperature versus height with the LIDAR. These LIDAR results agree remarkably with weather balloon result (SAWB) and the CIRA model. Clearly visible are the tropopause and the stratopause gradient reversals as well as gravity waves in the stratosphere. These waves are generated by wind streaming over the nearby 3000 m high Drakensberg Mountains. Once the Durban LIDAR is revitalized it will be possible to measure changes in height of both the tropopause and stratopause. These changes which are attributed to Global Warming have been measured in the Northern hemisphere, but never on the African continent.

The mobile DIAL system will help analyze and quantify South Africa's growing atmospheric urban pollution. Ground based LIDAR systems are a relatively inexpensive means of accessing "the edge of space" for capital amounts well below the $1 000 000 mark.

3. LUNAR AND MARTIAN RANGING

Precise knowledge of distances within the solar system was greatly improved by lunar ranging with lasers and corner cube reflectors. The first reflectors were left by the Apollo 11 astronauts. They were also carried by the Soviet Lunokhod 1 and 2 robotic missions in 1970 and 1973 respectively (see Figure 2). Much improved corner cube reflectors were landed by Apollo 14 and 15. The Apollo 15 is the most popular target as it is the largest and unlike Lunokhod 1, well oriented. Lunar laser ranging (LLR) stations are "photon challenged" so the three hundred 3.8 cm corner cubes of Apollo 15 are a considerable improvement on the Lunokhod $44 \times 19\ \text{cm}^2$ arrays. That photons are scarce – as in atmospheric LIDAR – is obvious from the fact that for a pulsed laser with typical energies of order 10 J, a divergence of order 10 μrad, and a lunar reception area of a thousand cm^2, only a fraction of ca. 10^{-8}, corresponding to the quotient of the corner cube and the beam areas, is retransmitted. And presuming the same divergence for retro-reflection, only 10^{-16} of the issuing pulse is retrieved, assuming also that the transmitting and receiving telescope are one and the same or similar.

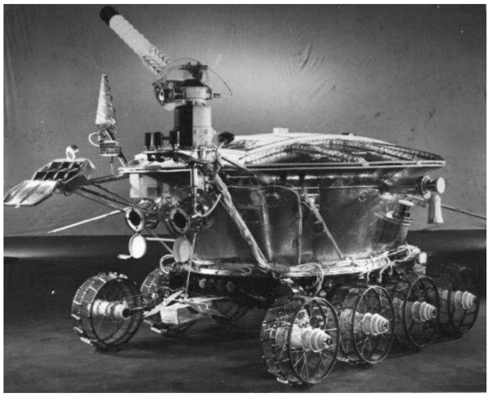


Figure 2: Lunokhod 1.

Notwithstanding the difficulties, LLR is of sufficient importance in astrophysics, geology, as a relativity check, and for space missions, quite apart from the public relations value, that several nations have acquired LLR stations, including France with its LLR at the Observatoire de Haute Provence. South Africa is also preparing to install a LLR observatory near Matjesfontein, a picturesque museum town in the Karoo semi-desert – far enough not to interfere with the South African Large Telescope (SALT) at Sutherland, but close enough to share facilities as well as remarkable "seeing". This is all part of a new South African Space Programme, the previous having been interrupted a decade ago. Lunar ranging which takes scientists beyond Earth's atmosphere is a little more expensive than atmospheric LIDAR but not greatly so. Not counting, of course the cost of placing corner cube reflectors on the lunar surface.

Surely the most distant application of lasers in space, from Earth, was the recent Mars Global Surveyor MOLA (Mars Orbiting Laser Altimeter)[6]. This yielded a global topography of the planet, which will of course be invaluable in planning future Martian exploration. The success of this mission guarantees that similar robotic laser altimetry, will eventually be employed for all the planets and moons of the solar system.

4. GRAVITY WAVE DETECTION BY LASER SPACE INTERFEROMETRY

After over half a century of research into gravity waves (GW) it seems that both ground based and space based interferometers are on the verge of detecting a variety of signals from near space to deep space. Solar oscillations, coalescing binary systems (combinations of white dwarfs, neutron stars and multi-solar mass black holes), massive black holes at the center of our own Milky Way or of other galaxies and possibly the cosmological background may gradually come within GW range of the latest instruments.

Neutron star binaries are statistically the most likely candidates. The reason that it has taken so long since Joseph Weber's pioneering attempts with enormous suspended cylinders and some early Michelson interferometers, is that the expected mirror displacements are fractions of an Angstrom except possibly for rare events such as the 1987A supernova, only 170 thousand l.y. away in the Large Magellan Cloud, which was "missed" due to an unfortunate set of circumstances. The sensitivity depends on the length of the arms of the interferometer and the number of passes down high vacuum tubes up to 4 km long. It is extremely difficult to effectively isolate ground based interferometers from seismic events. This limits ground based systems to signals above 1 Hz. It therefore occurred to K. Danzmann and GW colleagues at Hanover, following some earlier ideas of P. Bender at JILA that space based interferometry would yield less ambiguous results and would extend the range of periods quite considerably. The resulting LISA (Laser Interferometer Space Array) project was born some 15 years ago and is expected to complement the Earth based results.

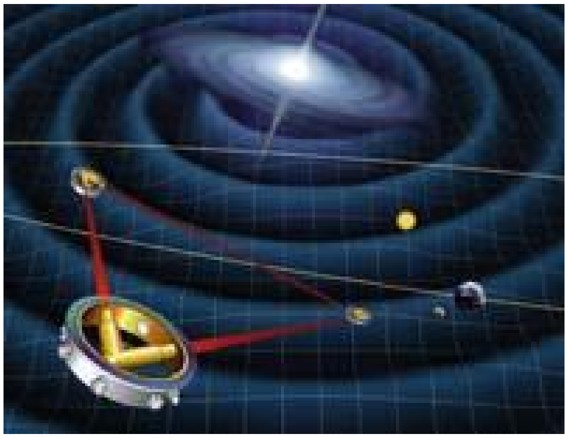


Figure 3: LISA.

4.1 LISA

The full blown LISA will be one of the costliest and challenging space experiments ever, costing ca. $1bn (see Figure 3). It will consist of three spacecraft placed in an unusual circular configuration, such that the center trails the Earth by 20^o as seen from the sun and that the plane of the equilateral triangle that locates the spacecraft lies at 60^o to the ecliptic. The three arms are 5 000 000 km long. Each craft contains a Nd:YAG laser, detectors and telescopic equipment without which the laser beam divergence would destroy the signal. The heart of each satellite is a gold-platinum cube which acts as a reflector, but which floats freely in space (inside the spacecraft). The technology required to achieve zero coupling between the craft and the cube has taken a decade to develop and has never been fully implemented in space. This is the purpose of LISA Pathfinder, due to be launched to the Lagrange L1 region before end 2008. LISA Pathfinder is a replica of the three LISA satellites intended to iron out any unexpected technical or physical problems that would be most difficult to solve at a great distance from earth.

4.2 Atom interferometry in space

Once LISA and LISA Pathfinder have demonstrated total isolation of the freely floating mirrors, other applications of this technology may follow. One is astronomic, namely the optical obscuration of the sun or parent stars which could be accomplished by ultra-precise positioning of optical components in space. The other is a whole series of general relativity experiments, now being planned. The same technology will be coupled with atom interferometers to test the theory in a manner quite impossible on Earth. Atom interferometers can also be regarded as "atom laser" experiments. Although GW detection will not be the prime purpose, it is expected to be an obvious bonus.

5. MILITARY AND OTHER LASERS IN SPACE

The activities of the military in space always parallel civilian. The same is true for space lasers as verified by a long document entitled “Lasers in Space – Technological Options for Enhancing US Military Capabilities” by Lt. Col. Mark E Rogers (1997) and freely available. Most revealing is a table near the end of the report which scores the various laser concepts: high scorers are “space-based laser communication”, “target determination”, “battle field illumination”, “guidance, alignment and docking”, “deep space altimeter”, “sat. to sat. Doppler velocimeter”, “remote sensing” and “enviro-sensing”; quite high are “space-debris cataloging and clearing” as well as various “energy delivery systems”. A low but interesting scorer is “weather modification”. Given that this report is a decade old and quotes the then Air Force Chief of Staff Gen, Ronald Fogleman: “The reality is that in the first quarter of the 21st century it will become possible to find, fix or track and target anything that moves on the surface of the Earth”, we might be surprised by the extent of “lasers in space” activity of several nations.

As to two other laser activities – astronomical and commercial, only the former exists as yet, though clearly commercial laser mining of space ores will one day become practical. And guide-star, adaptive optics telescopes are still only found at major international observatories.

6. LASER PROPULSION

Given the large number of papers in past HPLA Proceedings on this topic, we restrict ourselves to a brief survey of the history of LP and basic theory; we also enumerate recent propulsion results and plans of the leading LP laboratories. And we then take space to stress the importance of J.Kare’s[10] recent report of the fact that there are several new and extremely powerful lasers, close to being capable of breaking the laser launch stagnation period.

Laser and photon propulsion, though never yet successfully applied in space, are half a century old, actually pre-dating the laser. We summarize this long history with a figure (Figure 4) showing the chief proponents: Eugen Saenger[7], who first proposed photon propulsion, with an antimatter or nuclear pumped laser; Georgii Marx[8] who raised some brilliantly controversial issues (see last section); Arthur Kantrowitz[4] who pioneered propulsion by laser ablation and built lasers capable of demonstrating it in the laboratory; Wolfgang Moeckel[5] who laid the foundations for non chemical propulsion and demonstrated ion propulsion with the “Deep Space I” satellite.

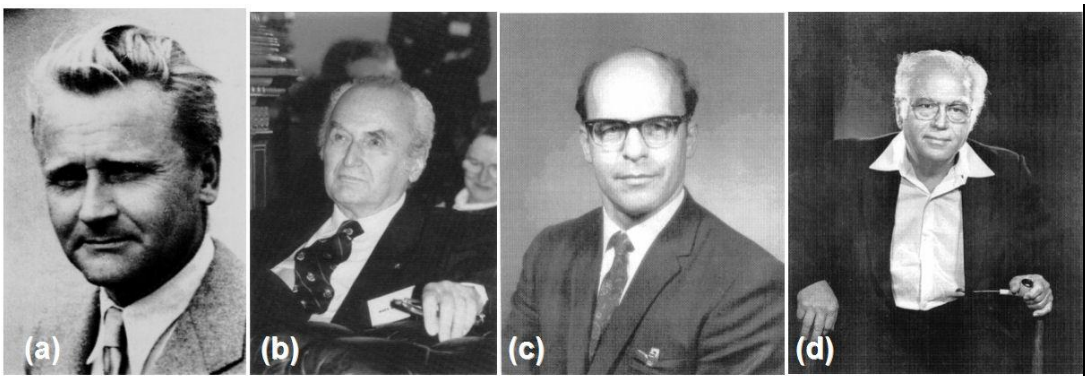


Figure 4: Pioneers of laser propulsion: (a) Eugen Saenger (1905–1964), the first proponent of pure photon propulsion (PPP). (b) Georgii Marx (1927–2002), who developed PPP theory. (c)Wolfgang Moeckel who developed basic theory of non-chemical and ion propulsion. (d) Arthur Kantrowitz who first proposed laser ablation propulsion.

Laser propulsion theory consists of many elements, such as the theory of laser light production, adaptive optics, the propagation of light through the atmosphere and space, the coupling of the laser beam to the light-craft and possible focusing optics, the plasma physics of laser target interaction, the theory of double pulse illumination, space-craft stability and orbital mechanics, stray light and noise production, safety issues etc. (All these theoretical and experimental problems were initially described in the Proceedings of the Los Alamos SDIO workshop on Laser Propulsion, edited by Jordin Kare in 1987[11].

As with the LIDAR topic, we restrict ourselves to directing the reader to four very relevant and more recent references[12–17]: a book entitled “Beamed Energy Propulsion” edited by A.V. Pakhomov and the most recent book by C.R.Phipps

"Laser Ablation and its Applications" , our recent review of LP in South African Journal of Science; and two papers seminal papers, the first by Phipps and one of us[16] being the first ever general article on LP in the open literature and the second by Phipps, Reilly and Campbell[17], being an updated version of the first. It is a little known fact that South Africans conducted laser propulsion experiments[15] with the powerful CO_2 laser chain developed for laser isotope separation of uranium. Three important equations for laser propulsion are the Phipps equations, essentially adaptations of the rocket equation with laser parameters. The cost in Joules per kg to orbit is:

$$C = Q^{*}(\zeta - 1) \tag{1}$$

with

$$\zeta = \exp\left[\frac{v_F}{C_m Q^{*}}\left(1 + \frac{g t_F}{v_F}\right)\right]. \tag{2}$$

This becomes a cost in $ / lb

$$C = Q^{*}\left(F + \frac{B}{f}\right)(\zeta - 1)\,. \tag{3}$$

The key parameters are:

ζ: the payload ratio *M/m* i.e. the mass at launch divided by the mass to orbit (spacecraft and useful payload);

C_m: the momentum coupling constant in dynes.s/J or μN/W;

Q^*: the specific ablation energy in J/g;

C: the launch cost either in J/g or in $/lb;

F and *B*: financial terms for capital costs and running costs respectively;

f: launch frequency.

We end this section by commenting on recent important laser developments that could terminate the long stagnation period that (not unlike other scientific endeavors such as nuclear fusion and lunar exploration) has bedeviled LP. Two of these developments were reported in this HPLA series.

6.1 HALNA and the diode pumped solid state laser (DPSSL) programme

At HPLA III (2000), Sadao Nakai described the Japanese high power DPSSL program which is to culminate with KOYO, the laser fusion reactor. The program aims to produce a DPSSL system with an output similar to NIF or Laser Megajoule, but with a pulse repetition rate (p.r.f.) of around 10 Hz. So far only HALNA 10 (High Average Power Laser for Nuclear Applications) has been operated at its full capacity of 10J at 12 Hz. HALNA 10 has allowed ILE (Osaka) to benchmark KOYO with its 4 MJ/pulse, p.r.f. 12 Hz, overall laser efficiency 12 % and the low cost, long life and robustness associated with the diode pumped, water cooled, amplifier zig-zag beam path in water cooled, Nd doped glass slabs. Once such a laser system has been developed and tested, it would be relatively simple to adapt it for LP application.

6.2 High power diode pumped Alkali lasers (DPAL)

At HPLA V (2004), William F. Krupke described a new class of high power DPAL, specifically at 795 nm (Rubidium) and 895 nm (Cesium) with optical-optical efficiencies of 60 %, and electrical up to 30 %. This might result in a slightly higher efficiency than for DPSSL's. Time will soon tell which is the most economic system. But if DPALs can be scaled up to MJ levels, the absence of a solid and hence damageable active medium seems very attractive for LP. A gas laser would lend itself to gas lens focusing with the long focal lengths of these devices.

6.3 Diode lasers

A third route to high average laser power is that of forming an array of cheap diode lasers – as recently described by J.T. Kare for his 100 MW HX vehicle concept[10] which looks a little like the Space Shuttle, but with a heat exchanger underbelly, in lieu of heat tiles. No need for the array to be coherent with such a large receiver; nor possibly for adaptive optics and a single expensive large aperture telescope – if the HX can get to orbit quickly enough. Alternatively, for the narrow beam required for “conventional” LP, one might attempt to operate a large aperture, phased array of diode lasers, though the technology for this approach, seems difficult.

6.4 Fibre lasers

Kilowatt class, diode pumped fiber lasers have now been demonstrated, so they too could be considered for a phased array. Diode laser efficiencies (ca. 80 % conversion from diode to fiber output) promise wall plug efficiencies as high as 40 %.

These four promising avenues make it very likely that in the next half decade at least one MW average power system, suitable for LP to LEO demonstration, will become available. The “light-craft” have long been demonstrated by Myrabo *et al*.[18]. Only the laser and the adaptive optics need to be built. It is interesting that such a system should be easily affordable to developing nations or groups of nations such as the SADC (Southern African Development Communuity). This will surely mean a healthy end to the control of space by the super powers. It may also mean a more responsible attitude to international space which the super powers have filled with debris.

7. NATURAL LASERS

There are several well known masers in space as well as a few less well known or suspected lasers (for two examples, see Figure 5). The best known is of course the 21 cm line of the neutral hydrogen maser that has revealed many features such as the rotation velocity of the arms of our galaxy and of the galaxy as a whole; also the mass of the galaxies and Big Bang evolution. Suspected lasers are MWC 349 at 169 μm and most impressive of all (if confirmed) η–Carinae, whose singly ionized iron atoms are supposed to radiate amplified spontaneous emission at 250.8 nm. And then there are the atmospheres of Mars and Venus which mase in the infra-red at 10.33 μm when the sun pumps their atmospheric CO_2. Presumably a fraction of the newly discovered exo-planets will be found to do the same? An interesting question is whether the heterodyne experiments of Mumma et al[19] with a CO_2 laser could be repeated for the exo-atmospheres or for other gaseous structures, pumped by nearby stars.

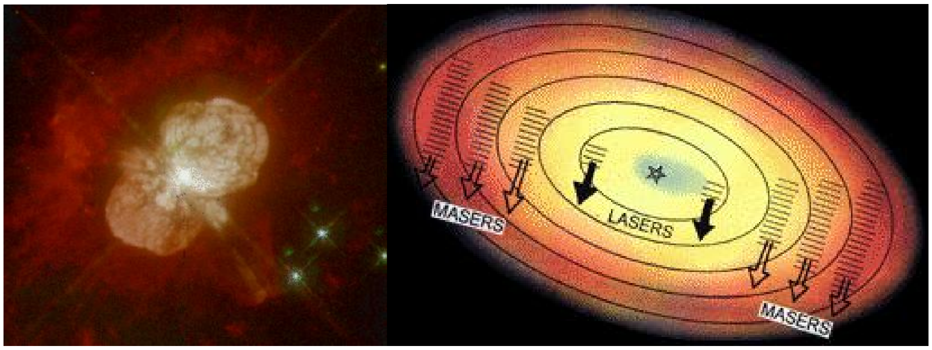


Figure 5: Natural lasers: (a) η–Carinae, possibly the most powerful ASE laser yet discovered. (b) MWC 349.

For the nearest exo-planets the distances scale as ten light years versus eight light minutes, a factor of about half a million. If we assume an increase in sensitivity of two orders of magnitude and a comparable source strength increase for a much larger exo-planet, then the required aperture increase brings the signal just outside the range of the OWLT (Overwhelmingly Large Telescope). There would in addition be the difficulty of subtracting the signal from the parent star or stars.

Of course, the most impressive natural laser of all might have been the Big Bang. But did it lase? To begin to answer this question, one takes a short walk through cosmological and laser physics. Many lasers consist of a flash lamp which pumps an active medium to generate a population inversion. As flash-lamps go, one couldn’t get a bigger one than the Big Bang.

But what about the medium? Just after the BB there was nothing to pump – or was there? Can one pump the vacuum? Let us assume not, in the laser sense. Very soon, earlier than 300 000 years particles started to materialize: electrons, positrons, protons, antiprotons and soon after that date, they started to fuse, creating the primordial atoms of deuterium, tritium (short lived), helium and lithium. As laser mediums go, not very exciting? Especially as during the first period of particle pair-creation, the Universe was opaque, ergo no lasing possible. Lasers need a high degree of transparency. But as the density decreased, the Universe suddenly became transparent.

Could the early Universe have behaved like a gigantic “Q–Switch” (some twelve billion years before R.W.Hellwarth and F.J.McClung invented it)? We will not try to answer that question specifically but rather see if there was “anything to pump”. Almost any laser action is really too complicated to describe in detail in less than a full scientific paper. But there are a few obvious types of lasing action that the Big Bang could have excited. Starting with the hardest cases and moving to the easiest.

7.1 Gamma ray lasers

Nobody has yet built a gamma ray laser, but there is some evidence that they may exist in space. Proton recombination with antiprotons generates short lived pions that decay into gamma rays:

$$p + \overline{p} \to \pi^{+} + \pi^{0} + \pi^{-} \to h\nu$$

Positron-electron recombination also generates gamma rays and recently in the context of the creation of the first positronium molecules, the possibility of creating a gamma ray laser was resurrected. Lest a natural “Graser” sound far fetched, we refer the reader to a paper in Nature by Varma[20] suggesting that the narrowing of gamma ray radiation from the Crab neutron star is due to ASE.

7.2 Soft X–ray lasers

Soft X-ray lasers (once called “Xasers”) have been built in numerous laboratories. But they require a Terawatt laser. The TW beam is usually line focused onto something like a graphite target creating a very energetic carbon plasma. At some very small distance from the target, a population inversion occurs, rather as it does in a “gas dynamic” CO_2 laser. In both cases, expansion is responsible for rapid adiabatic cooling which causes the inversion. In the primordial plasma there was no carbon let alone graphite.

But there was expanding and cooling mono-atomic hydrogen, able to recombine to produce H_2 molecules. In a plasma torch invented by the great plasma physicist Irving Langmuir, the molecules give their 4 eV recombination energy to other molecules generating a temperature high enough to weld tungsten. In the high vacuum of primordial space, the only way the H_2 could form would be by radiating the 4 eV away. There would have been an automatic population inversion: Zetta-tons (or much much more?) of monoatomic hydrogen and a completely empty ground state of H_2. Another laser superlative: the largest population inversion ever?

Also the longest ASE laser ever. Laser gain goes as the gain per meter times the length. Even if the gain was tiny due to the low density of the hydrogen, this would be massively compensated for by the almost unimaginable length of this primordial ASE laser.

There are many objections to this scenario: to name but one – suppose the temperature of the mono-atomic hydrogen was still very high? Lasers only lase at low temperatures – artificially created as in the C VI laser and the CO_2 lasers mentioned above. We therefore propose that a Big Bang H_2 laser is a possibility. Mitigating in its favour, is that H_2 lasers exist in the laboratory.

7.3 Other lasers

The world’s second laser was a gas laser: Javan’s Helium-Neon laser, for many years one of the most popular and versatile. But since there were no stars, there was no neon during the early Big Bang, only a large proportion of Helium (25% of all gas) and it’s the Neon that lases. But what about other combinations? Helium-hydrogen, Helium-lithium, Lithium-hydride? These combinations aren’t good lasers in the lab. But space might be very different with ultra low pressures and immense ASE lengths. We suggest quite a simple experiment – to make a “primordial gas soup” of hydrogen, helium and lithium and study its spectroscopy at 3000 K, in the light of possible lasing under the influence of something similar to primordial radiation.

7.4 Masers

Primordial neutral hydrogen would surely have mased at 21 cm. As already mentioned, the atmospheres of Venus and Mars “mase” every morning under the influence of solar pumping. These are not – strictly speaking – lasers, since they “mase” at around 10 microns. But nobody refers to the CO_2 laser as a maser, though it lases at similar wavelengths.

Nor should the most promising gas lasers for nuclear fusion, the excimer (or excited dimers) be forgotten. These lasers work with molecules which only exist in the excited state and which dissociate after radiating down to the ground state, thus automatically ensuring a population inversion. Maybe some excited molecular combination (with e.g. multiply ionized lithium) exists which lases or mases?

7.5 Plasmas

And what about free electrons and ions? There may have been some strong magnetic fields to cause electrons, positrons, protons and antiprotons to gyrate at high frequencies. Recently, the study of maser action in high magnetic fields, specifically in magnetic mirrors has been revived. If the fields are high enough, electron masers become lasers; just as the electron undulator was converted into the free electron laser by increasing the magnetic field and the electron energy and reducing the spacing between the magnets.

Or was the Big Bang a positronium laser? There again, we have an empty ground state (emptied by recombination in 140 ns for ortho-positronium and 125 ps for para). Never have enough positrons been produced to generate positronium lasing in the laboratory. Once again we notice that a uniquely long lasing length would have existed, but the same caveats apply. Or perhaps a protonium laser? The energy level spacing in positronium is half that in hydrogen. Perhaps excited hydrogen could pump positronium?

To conclude with this question rather unsatisfactorily: the number of lasing possibilities seems too large for the Big Bang not to have lased, but it's hard to say how. And in a philosophical sense, since we are part of the Big Bang, it did lase and still does.

8. CONCLUSION

Not only are lasers designed and built by Man about to proliferate into space, but there are grounds for believing that "natural lasers" as well as the better known natural masers, are widespread and may even date back to the early Universe.

REFERENCES

1. G. Fiocco and L.D. Smullin. "Detection of Scattering Layers in the Upper Atmosphere (60–140 km.) by Optical Radar," *Nature* **199**, pp. 1275, 1963.
2. A Moorgawa. "Applications of Light Scattering and Refraction by Atmospheric Gases," Ph.D. thesis. University of Natal, 2002.
3. C.R.Phipps *et al*. "Orion: Clearing near-Earth space debris using a 20 kW, 530 nm, Earth-based repetitively pulsed laser," *Laser and Particle Beams* **14**, pp. 1–44, 1996.
4. A.R. Kantrowitz, "Propulsion to orbit by ground-based lasers," *Astronautics and Aeronautics* **10**, pp. 74–76, 1972.
5. W.E. Moeckel, "Optimum exhaust velocity for laser driven rockets," *J. Spacecraft and Rockets* **12**, pp. 700–701, 1975.
6. A.Albee *et al*., "Overview of the Mars Global Surveyor Mission," *J. Geophys. Res*. **106**, pp. 23291–23316, 1998.
7. M.M.Michaelis, "Eugen Saenger Memorial," *Proc. HPLA I*, pp. 2–4, 1998.
8. G. Marx, "Interstellar vehicle propelled by terrestrial laser beam," *Nature* **211**, pp. 22–23, 1966.
9. R. Forward, "Antimatter Propulsion," *J. Br. Interplanet. Soc*. **35**, pp. 391–395, 1982.
10. J.T. Kare, "Modular Laser Launch Architecture: Analysis and Beam Module Design," Final Report USRA, 2004.
11. J.T. Kare. Ed. Proc. SDIO Workshop on Laser Propulsion. Los Alamos. N.Mex, 1987.
12. A.V. Pakhomov. Ed. Symp. On Beamed Energy Propulsion. AIP Conf. Proc, 2003.
13. C.R. Phipps. "Laser Ablation and its Applications," Springer, 2006.
14. M.M. Michaelis and A. Forbes. "Laser propulsion: a review," *South African J. of Science* **102**, pp. 289–295, 2006.
15. M.M. Michaelis, A. Forbes, *et al*. "Laser propulsion activity in South Africa," *South African J. of Science* **102**, pp. 296–300, 2006.
16. C.R. Phipps and M.M. Michaelis. "LISP: Laser impulse space propulsion," *Laser and Particle Beams* **12**, pp. 23–54, 1994.
17. C.R. Phipps, J.P. Reilly and J.W. Campbell. "Optimum parameters for laser launching objects into LEO," *Laser and Particle Beams* **18**, pp. 661–695, 2000.

18. L.N. Myrabo, Proc. SDIO Workshop on Laser Propulsion, Los Alamos, NM, pp. 173–208, 1987.
19. M.J. Mumma *et al*. *Science* **212**, pp. 45, 1981.
20. C.M. Varma. "Stimulated gamma ray emission from the pulsar of the Crab," *Nature* **267**, pp. 686–687, 1977.