

SEEING BEYOND THE NAKED EYE IN A PLANETARIUM

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ABSTRACT

I have a philosophy that the traditional naked-eye sky, as usually shown in planetariums, should only be an introductory step in portraying the Universe. Consequently, over the years I have produced 'inter alia' various versions of an enhanced Milky Way (the latest based on Axel Mellenger's panorama), the extragalactic sky and the radio sky for projection on planetarium domes. I also put together a three-dimensional planetarium show—the audience being equipped with ChromDepth™ spectacles—which stepped from the Solar System to the cosmic microwave background. The advent of digital technology now makes all this much easier. Currently, Labyrinth, a visualization program developed in-house, serves much the same function as the Hayden Planetarium's Partiview, but also permits rendering and fly-throughs of large-scale structures. It allows viewers to explore local cosmography. Labyrinth can produce images that operate with the 3-D spectacles; we have also produced a version of Partiview that does the same.

This presentation involved many slides and visualisations, including three-dimensional views for which the audience was equipped with ChromoDepth™ spectacles. Only three such images accompany this presentation, but the original PowerPoint presentation may be downloaded from:

http://www.communicatingastronomy/cap_2005/talks/day2/fairall/fairall.ppt

The following text provides the accompanying narration and explanation to that presentation.

INTRODUCTION

Human eyesight is probably the chief reason why members of the public understand so little about the Universe beyond their home planet. We are of course creatures of daylight, designed to see by day and sleep by night. While our eyes may adapt to darkness—and employ our rod receptors—our eyesight at night is nevertheless poor. We cannot see to walk around, and when we look upwards, we get a very shallow view of the Universe, and one that is very difficult to interpret.

As far as looking at the night sky is concerned, there are three basic things wrong with the human eye. The first is its insufficient aperture, never more than 6mm. In a galaxy of billions of stars, our eye can see less than ten thousand. In a Universe of

billions of galaxies, we can barely see our own Galaxy and three others! The second is the limited wavelength range. The sensitivity of our eye has evolved to match that of the blackbody radiation of our Sun. Although the Earth's atmosphere is also transparent to portions of the near infrared and radio waves, our eyes cannot detect those wavelengths. Finally, the stereoscopic vision of our eyes is limited to distances of some 25 metres or less, and all astronomical objects lie way beyond that. There is no perception of distance, so small pebbles hitting the Earth's atmosphere a hundred kilometres up are confused with stars light years away. More obviously the planets in our Solar System are also mistaken for bright stars.

Surprisingly, things are no better in a planetarium! So much effort has gone into recreating the night sky as the human eye sees it that the visual image is no improvement. My personal philosophy is that the traditional planetarium sky should only be a starting point, and that a planetarium should be used to remedy the problems of human eyesight and show what the eye ought to see.

From modern cities the glow of the Milky Way is completely overpowered by the overspill of artificial lighting. Even away in the countryside, a few artificial lights in the vicinity of the viewer are enough to rob our Galaxy of its lustre. It takes a dedicated individual to find a site where no artificial lights are visible and to glimpse one of the spectacles of nature. However impressive it may then look, it is still nowhere close to revealing the true structure of the galaxy.

In a conventional planetarium, the glow of the Milky Way is added into the starry sky by dedicated projectors. These are often simple shadow projectors, where the central lamp is surrounded by an appropriate mask, and no lenses are involved. To enhance the view of the Milky Way, such standard Milky Way projectors need to be switched off and alternative projectors used. In my case I have achieved this using a six-projector 'all-sky' system. Such a system is widely used in major planetariums (though it is currently being surpassed by fully digital systems). Each of the six projectors is a conventional 35mm slide projector, equipped with wide-angle (35mm) projection lenses, and suitable masks. Six pie-shaped segments are 'soft-edged' together, to form a static image over the entire hemispherical projection dome. The computer system that controls the projectors can also set the illumination level. The images of the six panels need to be pre-distorted (from pie shapes to gothic arch shapes) according to the geometry involved. The six projectors are mounted around the periphery of the auditorium and do not ride on the star projector, so the star projector must be suitably orientated to work in register with the all-sky projection.

SEEING OUR GALAXY

Our first all-sky Milky Way (in 1989) was relatively crude and hand-painted by an artist. A couple of years later, it was superseded by an improved version, which our planetarium artist Margie Walter painted using an airbrush. It was based on the panoramic photographic montage put out by the European Southern Observatory (Laustsen, S., Madson, C. & West, R. 1987. *Exploring the southern sky: a pictorial atlas from the European Southern Observatory*, Berlin, Springer-Verlag), and like the original, it was in black and white.

By the mid 1990s we were producing a colour version, which separated the yellowish galactic bulge from the bluish spiral arms. It provided a technical challenge because, unlike the high contrast Kodalith emulsion used previously for the black and white rendition, colour emulsion cannot give a completely opaque black background, and specially designed masks had to be incorporated so that light did not stray into the dark sky outside the Milky Way. We also had to find a compromise level of illumination, where the eye could just see colour, yet still be completely dark adapted. We complemented the airbrushed star clouds with some ten thousand or so additional faint stars concentrated towards the plane of the Milky Way. These were added to the scene by a separate bank of slide projectors (the images being on Kodalith film). As before, the bright stars, those visible to the naked eye, were provided by the regular planetarium projector, working in register with the all-sky scene. The colour version also allowed us to include emission nebulae (though it would have been preferable to have employed a third bank of 'all-sky' projectors, so their illumination level could have been set independently). It was then possible to conduct the planetarium audience on a tour of the Milky Way, including, for example, the Orion Nebula and surroundings, the Vela and Gum supernovae remnants, Eta Carina, the Lagoon Nebula and the Galactic centre.

But better things were still to come. Many readers will be familiar with the magnificent colour photographic panorama of the Milky Way produced by the German physicist Axel Mellenger (see <http://canopus.physik.uni-potsdam.de/~axm/images.html>). It is the clearest exposition of the visual sky as the eye ought to see it, and has been widely reproduced. It shows exactly what we ought to be seeing of our Galaxy. It is of course possible, using the six-projector all sky system, to project a hemispheric view over the planetarium dome, as we have done. However, when so magnified, the images of the bright stars become unrealistically large and less realistic. Accordingly, we have created an edited version of the Mellenger Milky Way, where all stars brighter than sixth magnitude have been removed—see Figure 1.

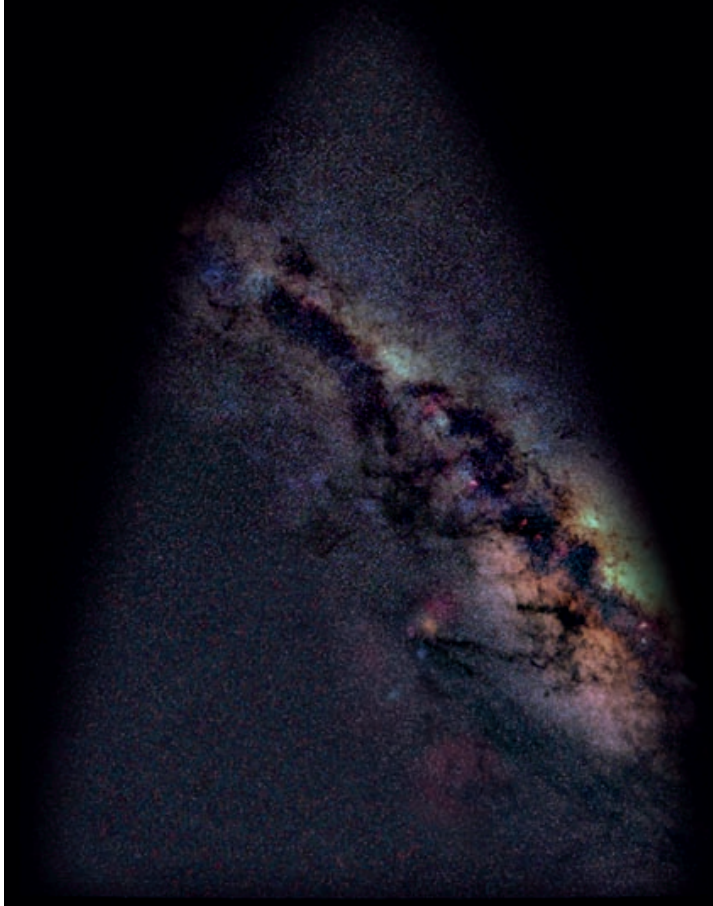


Figure 1. The Galactic Centre is seen in this panel (rotated by 90°), one of six that are joined together seamlessly to form a single image over the hemispherical planetarium dome, via the 'all-sky' system. This image is derived from Axel Mellinger's panorama, but has been edited to remove stars brighter than sixth magnitude, which are inserted by the conventional planetarium star projector instead, working in register.

This version then operates in register with the planetarium star projector, which provides the brighter stars. This has given us the best enhanced Milky Way to date, and most importantly, a means by which our audiences have been able to see the Galaxy in which we live clearly.

As planetariums make the transition to fully digital skies the six-projector all-sky system is rapidly becoming obsolete. However the new digital technology now makes it easier to combine an enhanced Milky Way, such as Axel Mellenger's digital image, with the conventional star-field.

THE RADIO SKY

An alternative view of the Milky Way can be provided by the radio sky. The Rhodes University/HARTRAO 2326 MHz survey image (Jonas, J.L., de Jager, G. & Baart, E.E., 1985. *A&A*, 62, 105) was similarly mapped to six all-sky panels by Wayne Pavard (then an M.Sc. student in the Department of Computer Science) in 1992 using a software recipe devised by the author. As a result we were able to dissolve from optical sky to radio sky. The views of the Milky Way are wonderfully complementary, the radio sky revealing the interstellar gas instead of the stars, while increasing the prominence of the supernova remnants. The radio sky also shows extragalactic sources, including the conspicuous outer lobes of Centaurus A.

THE EXTRAGALACTIC SKY

Perhaps my main motivation behind these all-sky projections was to create an extragalactic sky—since this is where my research specialty lies. Unlike the foreground stars of the Milky Way, which are scattered almost at random—thereby creating the patterns identified as constellations, galaxies concentrate into large-scale structures. I therefore used my Southern Redshift Catalogue (Fairall, A.P. & Jones, A., 1991. *Southern Redshifts: Catalogue and Plots*, Publ. Dept. Astr., Univ. Cape Town, No. 11) as a database. Although a handful of nearby galaxies are close enough to be seen as extended objects, all others have no discernable angular size. Accordingly I used the redshifts to grade the colour of the galaxies from white (near) to blue (distant). Almost by chance I experimented with viewing the scene with ChromoDepth™ glasses and was amazed to see large-scale structures in three dimensions emerge.

The projections have also served as a research tool in the mapping of nearby large-scale structures and voids. In particular they served as a means of identifying the 'Centaurus Wall' (also known as the 'Hypergalaxy'), which in the extragalactic sky (to $cz = 6000$ km/s) is somewhat analogous to the plane of the Milky Way in the starry sky.

THE UNIVERSE IN THREE DIMENSIONS

ChomoDepth™ glasses work by means of chromostereoscopy. Their lenses disperse colours without overall deviation, and their design results in red objects appearing to stand out in front of the screen, while blue objects appear more distant. Intermediate colours of the spectrum appear at intermediate distances. They have the great advantage that only a single, appropriately colour-coded image is needed, from which the spectacles create their own stereoscopic pair. Disadvantages are the obvious false colour, and the fact that RGB monitors or projectors do not give a true continuous range of colours, and stop short of indigo and violet (they simulate violet by mixing red and blue). Furthermore, 10% or more people do not have true colour vision, and for them, chromostereoscopy does not work.

Following the success of viewing the colour-coded extragalactic sky with the 3D spectacles, I experimented with 'full-colour' (red to blue) versions, and finally I produced a sequence of images to convey the Universe in three dimensions, from the scale of the Solar System to that of the Cosmic Microwave Background. The images are circular, each covering half the Celestial Sphere, and can be viewed either as slides (as shown at this conference, and for example in Fairall, A.P. 2000. *Cosmology Revealed*. Praxis-Springer. Chichester) or extended onto the hemispherical screen of a planetarium.

This finally fulfilled my dream of being able to perceive relative distances in a planetarium, and provided the basis for what was apparently the world's first 3-D planetarium show, allowing planetarium audiences to interpret what they can see, when the conventional star-field is dissolved into the colour coded charts. Again, I used the 6-projector 'all-sky' system (described earlier) to project the images onto the planetarium screen. As before, the images work in register with the star projector. Mechanical-optical planetarium projectors do of course produce very realistic looking stars, with high intensities concentrated in almost pinpoint images (which is why such projectors are so expensive). The simple slide projectors of the 'all-sky' system cannot match such quality; experimentation showed that stars had to be portrayed as circular dots, larger dots for brighter stars. While not as realistic as pinpoint stars, I use it to remind the audiences that stars are really spherical incandescent bodies, rather than the misleading spiky shapes so many cultures have unfortunately adopted.

The mapping of stars to the all-sky panels has reasonable registration in that when both all-sky and planetarium star-fields are superposed, the pinpoint planetarium stars fall either within the corresponding coloured dots or immediately outside them.

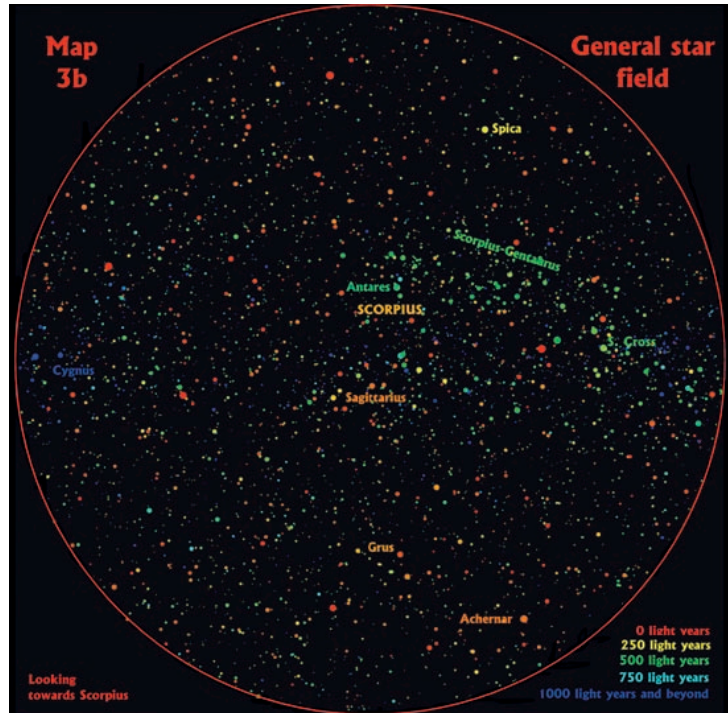
The range of depth shown by chromostereoscopy can be set according to the need. My opening scene portrays the Moon and visible planets of the Solar System, and clearly separates the differing distances of the Moon, inner planets and outer planets, even when they lie in close proximity to one another in the sky. The star-field is colour-coded pure blue to provide the background.

For stars I selected all stars brighter than visual magnitude 6.5 from the Hipparcos database, which carries the most reliable parallax determinations to date. The great range in stellar distances necessitated dividing the star-field into two ranges. The first was 0 to 100 light years, where all stars beyond that range were colour coded pure blue. The pairs of images (each a hemisphere of the Celestial sphere) then show the local stellar neighbourhood, with the nearest stars clearly standing out. It is

illustrative of stellar luminosities to point out that that the very closest stars include not only bright stars (Alpha Centauri, Sirius and Procyon) but also many faint sixth magnitude stars.

For the next set of images, the chromostereoscopic range has been set for 0 to 1000 light years, a range in which almost all visible stars fall. Such an accurate portrayal is only possible due to the Hipparcos results. In general, most well known constellations 'come apart' and are initially difficult to recognise when seen in three dimensions. While the general randomness of the stellar distribution is apparent, the portrayal does allow spatial features that are not otherwise easily discernable to be identified: particularly the extended Hyades cluster and the Scorpius-Centaurus Association – see the example in Figure 2.

Figure 2. 'Map 3a' is one of the images that convey the Universe in three dimensions. It shows a half of the Celestial Sphere, centred on R.A. 18h, Decl. -30d, with Scorpius central and the Southern Cross to the right. Distances to stars have been colour coded from 0 to 1000 light years. When viewed with ChromoDepth™ spectacles, the scene is seen in three dimensions.



For the next pair of images in a sequence of increasing depth, the chromo-stereoscopic range is set for 0 to 30,000 light years, with all visible stars coloured red to form the foreground. The view reveals the spiral arms of the Galaxy, one of the hemispheric views aimed towards the Galactic Centre, the other the anti-centre. License is taken by making the normally dark dust lanes luminous and colour-coded according to distance, as estimated from the foreground star density on the Axel Mellenger

panorama. Thus, when looking towards the Galactic Centre, it is possible to discern dust clouds in the Local Spiral Arm, as distinct from those in the Sagittarius Arm, while the Galactic Bulge appears mainly blue (but a slight colour variation recognises its bar-like nature). The Magellanic Clouds and the Great Galaxy in Andromeda (all pure blue) are apparent.

Beyond the Galaxy, chromostereoscopic depth jumps from 0 to 350 million light years ($0 < cz < 7500$ km/s), the foreground Galaxy is omitted as the scene reverts to the extragalactic sky (much as already described). In recent years, the database for this has switched from the author's catalogue—which was discontinued in the late 1990s to that extracted from the NASA Extragalactic Database. A deeper view—to some 2 billion light years ($0 < cz < 50000$ km/s) — is provided by the distribution of Abell Clusters, using a database provided by H. Andernach (University of Guanajuato, Mexico).

The final scene, with chromostereoscopic depth running all the way to 15 billion light years showed a scattering of distant quasars superposed against the fluctuations found by the COBE satellite. Such a scene is now of course out of date, with the finer detail of the fluctuations found by WMAP (and a more probable distance of 13.7 billion light years) now available.

Successful as it was, the Universe in Three Dimensions, just described, was of course no more than a sequence of static images; whereas digital projections today allow for animations, particularly fly-throughs. Such technology was exemplified in the opening production of the new Hayden Planetarium in New York. The software involved for that production has been adapted into a public version, released as 'Partiview', which enables 'fly-throughs' in a digital Universe, and is an alternative method of perceiving relative distances to stars and galaxies. Since its release, we have been experimenting with its use, particularly as we have also carried out such fly-throughs of galaxy databases since 1993 (thanks mainly to software written by Wayne Pavard), used mainly for research purposes and to a small extent in public presentations.

'Partiview' (from Particle View) is an impressive package, but it did not allow chromostereoscopy to be used, and although it operates with billboards, which, for example could carry galaxy images, it could not portray continuous structures such as the envelopes of the large-scale structures formed by the distribution of galaxies.

Consequently a package of software—now known as Labyrinth—was developed by Carl Hultquist and Samesham Perumal, originally as an 'Honours' project in the De-

LABYRINTH SOFTWARE

partment of Computer Science of the University of Cape Town, following the success of a programme by David Turner that identified and grew ‘Minimal Spanning Trees’ in fly-around visualisations.

Labyrinth also identifies Minimal Spanning Trees to specified criteria that compensate for the increasing incompleteness in the galaxy databases with increasing redshift. It then wraps a surface around each minimal spanning tree. I refer to these surfaces as ‘Tully Bubbles’, as they resemble those seen in visualisations of large-scale structures pioneered by Brent Tully. The three dimensional bodies so created may be visualised as solid or translucent—the degree of transparency may be varied.

Labyrinth has seen many further refinements from Carl Hultquist, and currently forms a multi-faceted visualisation tool. It is able to render individual galaxies as points, with or without full colour or white-blue chromostereoscopy. Alternatively galaxies can be shown as billboards, drawn randomly from a small library of galaxy images. Unlike some other extragalactic visualisations, which have the sizes of galaxies greatly exaggerated for effect, Labyrinth shows galaxies at approximately true size. As already indicated, Labyrinth portrays large-scale structures, with the ability to vary their transparency, and with either white-blue or full colour chromostereoscopy. Both galaxies and large-scale structures can be portrayed together, or one without the other; if need be galaxies outside the large-scale structures can be ‘switched off’. For research purposes, Labyrinth can identify individual large-scale structures, or even just groups and clusters of galaxies, and catalogue the members of each unit.

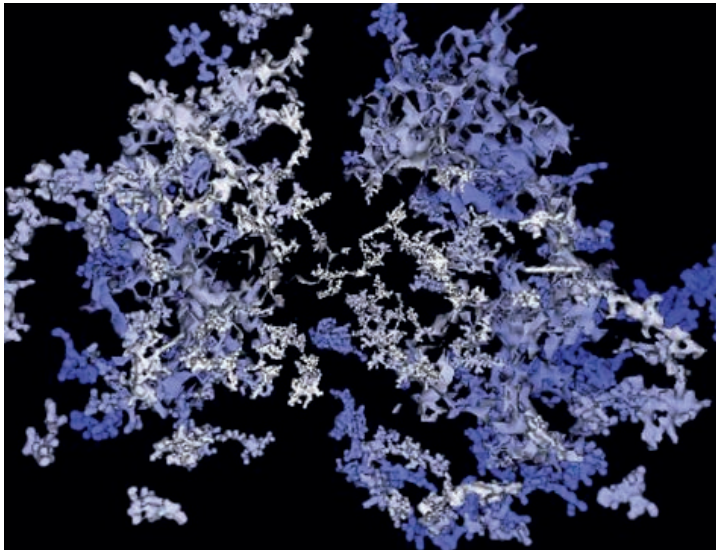
The distance range of the chromostereoscopy, whether white-to-blue or full-colour, can be adjusted. Similarly, the degree of fading of galaxies and structures with increasing distance can be varied.

While ‘travelling’ within the galaxy databases, a readout gives Supergalactic coordinates and direction of view. Labyrinth can be manipulated in real-time fly-throughs of galaxy distributions and large-scale structures. It can create animated fly-throughs along predefined tracks. By gradually increasing the percolation radius of its minimal spanning trees, it can show the ‘growth’ of large-scale structures from their densest cores outwards, as an animated sequence if required.

Such a sequence was shown as part of this presentation using state-of-the-art data from the 6dF survey. The 6dF survey (Jones, D.H. Saunders, W., Colless, M. et al., 2004. MNRAS, 355, 747), which will cover most of the southern sky, is by far the densest coverage of galaxy redshifts in the nearby Universe. It reveals details of the

texture of the 'Cosmic Labyrinth' never previously seen. A sample frame is shown in Figure 3.

The final figure (3) shows a view of the Universe far removed from the experience of the layman. The average member of the public knows little more than the Solar System. Our enormous challenge is to extend his or her scale from a few light hours to billions of light years. Understanding our Galaxy first and then the realm of galaxies and their labyrinth of large-scale structures ought to be basic knowledge. Planetarium presentations that use visualisations to achieve this offer some hope that a small fraction of the Earth's population may yet get to know the Universe in which we live.



CONCLUSION

Figure 3. The texture of the local cosmic labyrinth that surrounds our position (centre of diagram) in the Universe, to a depth of some 1.5 billion light years, using the 6dF data. Labyrinth software shows the large-scale structures in which the galaxies are concentrated. Numerous filamentary structures surround bubble-like voids, somewhat reminiscent of the filaments that surround the cavity created by the Crab Nebula supernova.