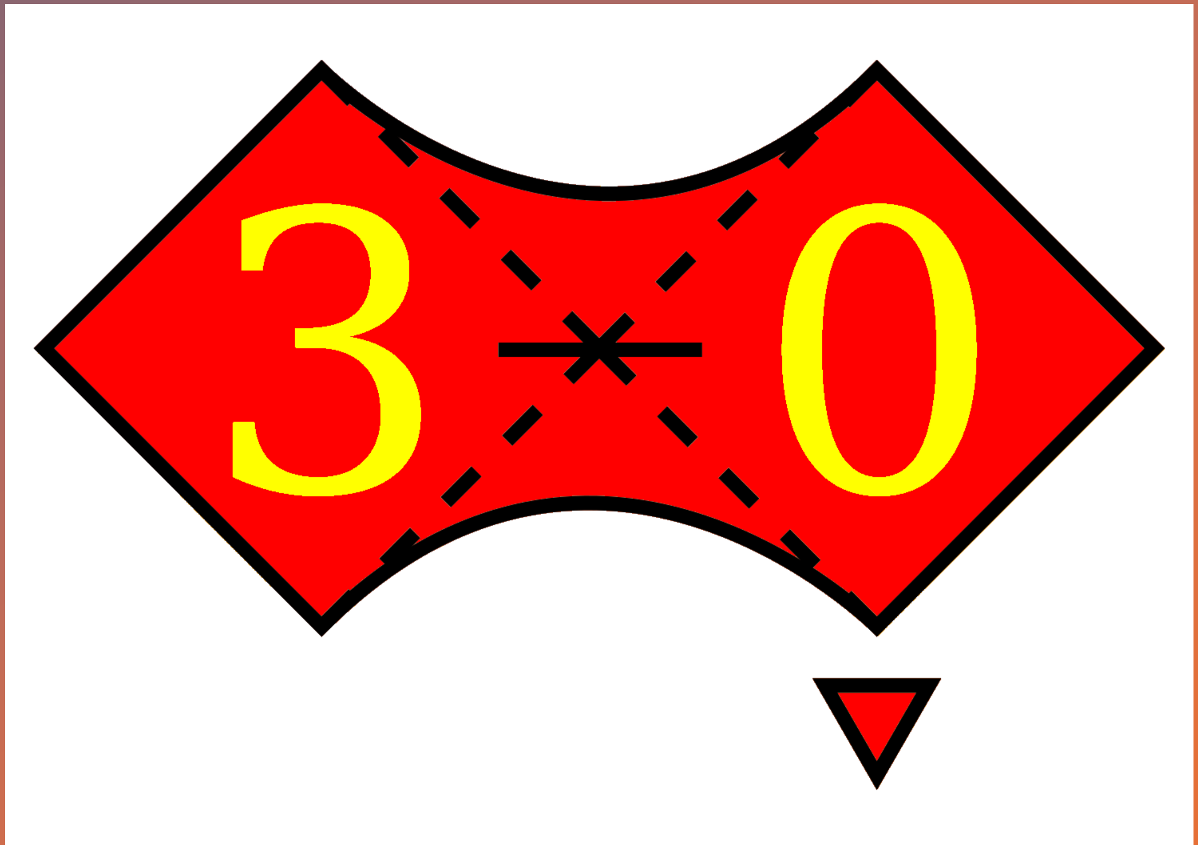
Acknowledgement of Country

The Australian National University acknowledges, celebrates and pays our respects to the Ngunnawal and Ngambri people of the Canberra region and to all First Nations Australians on whose traditional lands we meet and work, and whose cultures are among the oldest continuing cultures in human history.

Reflections on the last 30 years since the birth of the ASGRG

Susan Scott



Founding Meeting

26-30 September 1994 – Centre for Mathematics and its Applications

Old Hanna Neumann Building

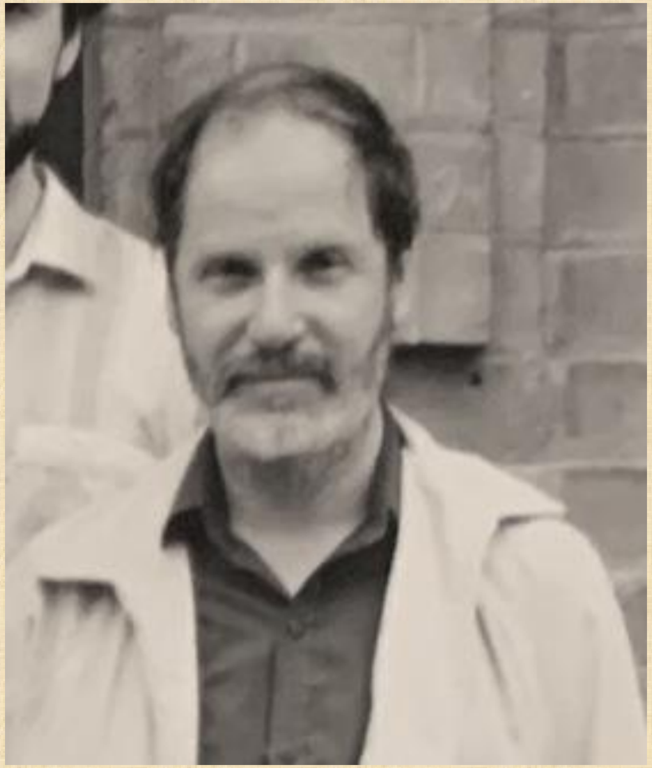
About 50 mathematicians and physicists

THE AIM

to provide a regional forum for researchers who work in a wide range of areas within mathematical, theoretical and experimental gravitation: exact solutions of general relativity, mathematical relativity, numerical relativity, quantum gravity, cosmology, estimation of the gravitational wave signals produced by astronomical sources, and development of techniques and technology for detecting these signals with earth- and satellite-based antennae


Star Trek: The Next Generation “Descent”
8 April 1993

Our Presidents



1. Peter Szekeres
September 1994
- July 1998

2. David McClelland
July 1998
- January 2004

3. Susan Scott
January 2004
– December 2009

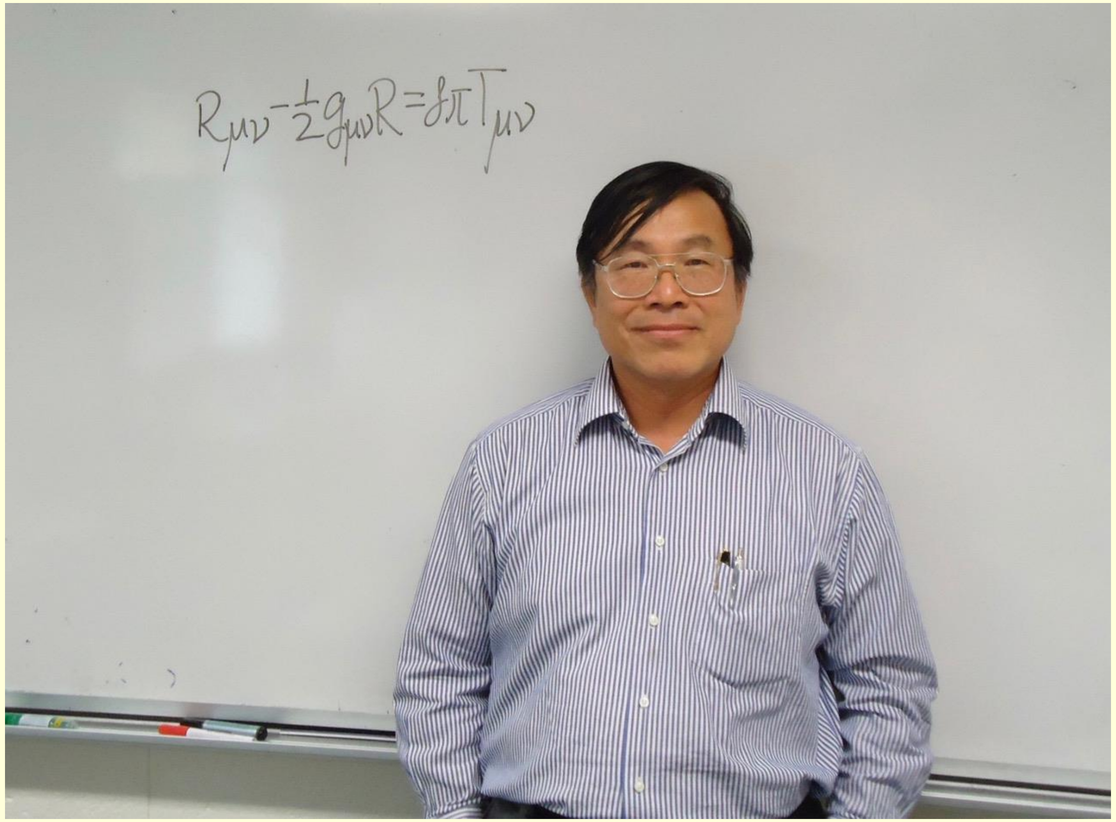
4. David Wiltshire
December 2009
- December 2013

5. Leo Brewin
December 2013
- November 2017

6. Jörg Frauendiener
November 2017
- February 2022

7. Krzysztof Bolejko
February 2022
- present

Our Secretaries



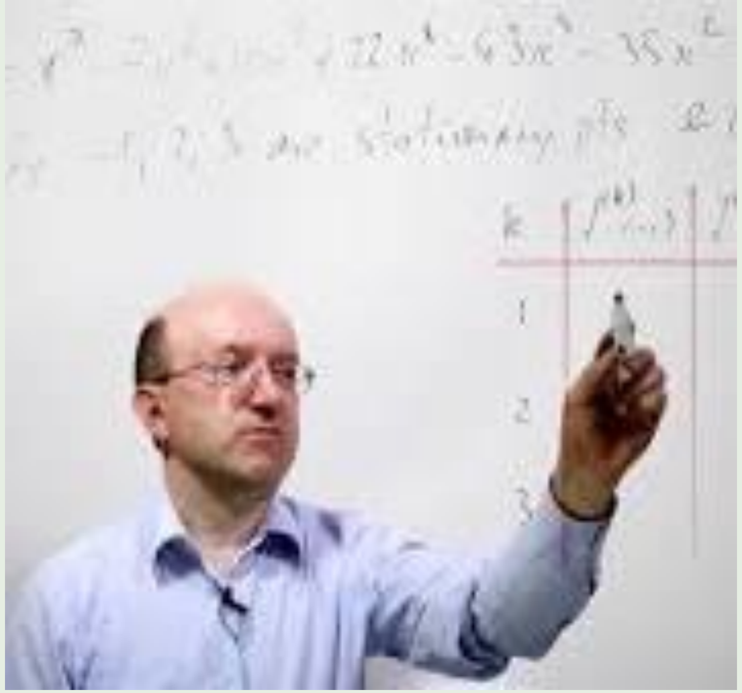
1. Tony Lun
September 1994 - July 2001

2. Malcolm Anderson
July 2001 - present

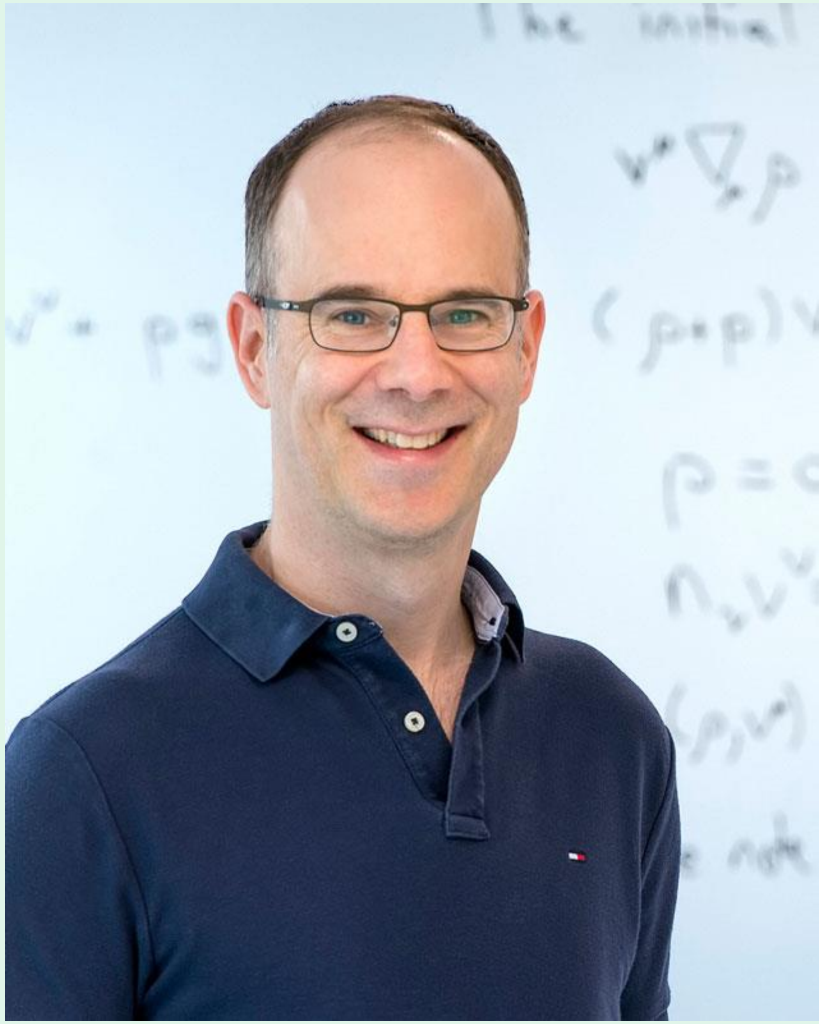
Our Treasurers

1. Susan Scott
September 1994
- January 2004

2. Antony Searle
January 2004
- November 2005



3. John Steele
November 2005
- December 2015



4. Todd Oliynyk
December 2015
- December 2019

5. Karl Wette
December 2019
- present

News items from newsletters

Autumn 1996

Competition for the design of a logo for ASGRG is launched

‘It is an endless source of frustration to Australian researchers in general relativity that there is no ARC subject code for our discipline despite the existence of many other very specific codes for almost every other area of physics and mathematics .... ASGRG President Peter Szekeres has written to the Chair of the ARC, Prof. Max Brennan, to inform him of our existence and to request that a category code for "General Relativity, Gravitation and Cosmology" be established’

Spring 1997

The logo competition was won by Michael Ashley and Geoffrey Ericksson of ANU for their entry depicting the Penrose diagram of the Schwarzschild spacetime superimposed on a map of Australia. A symbolic beam splitter has been added at t=0 to represent the activities of ACIGA

The Sixth Monash Relativity Workshop was held on April 11-12, 1997 at the Department of Mathematics, Monash University to mark the occasion of Colin McIntosh's early retirement. The workshop was organised by Tony Lun

Winter 1998

Members' News Dr Susan Scott has been recently appointed to the position of Lecturer (Continuing) in the Department of Physics and Theoretical Physics, ANU

Media Excerpts From *Panorama* Dec 1997 (Ansett inflight magazine)
David Blair looks at new research which will allow us to hear the scream of dying stars
'In Australia, a consortium of physicists from Perth, Adelaide, Canberra, Melbourne and Sydney have been planning a modestly sized but very powerful new gravity-wave detector for a site at Gingin near Perth, with support from the West Australian government. The new detector will be able to match the much more expensive projects in the US and Europe because of a breakthrough in the use of artificial sapphire for high-power laser optics. So far, Australia is one of the world leaders in this field but many fear that, yet again, this country will fail to capitalise on its innovation and leadership'

Summer 1999/2000

From the President's Desk (David McClelland) 'Of great importance to the gravitational wave detection community is the awarding of the Fourth Amaldi Conference on Gravitational Waves to Perth. This major international meeting will be held in July 2001, immediately before the South African GR conference (which was held in Durban). Hopefully this will encourage visitors from the northern hemisphere to include both meetings in their itineraries'

‘Unfortunately, not all has been positive. The Australian Consortium for Interferometric Gravitational Astronomy (ACIGA) submitted an application for a Special Research Centre to undertake R&D toward gravitational wave detection. Though being highly praised for the research training environment it would provide, the ARC committee had its doubts about whether the innovative technology could be achieved. Obviously there is much work we have to do in educating the broader physics community on what we have already achieved and are currently doing. One event that will aid us in doing this is the opening, in March 2000, of the new gravitational wave physics laboratory in Gingin, WA, a chosen site for a future long baseline detector.’

Editorial (David Wiltshire) ‘It is definitely a difficult time in academia in Australia, with a lot of turmoil. Some of you took part in a letter to "the Australian", relating to the situation at Edith Cowan University. The follow-up news on that one is that Malcolm Anderson (one of our committee) has left Australia to the University of Brunei in South-East Asia.’

Autumn 2000

News The Australian International Gravitational Observatory (AIGO) (the corner-station, end-stations and facilities housing an 80m interferometer) was opened by the Premier of Western Australia, the Hon. R. Court, on 10 March 2000. The opening was held in conjunction with lectures by visiting distinguished physicists, Professor B. Barish (Director of LIGO), Professor A. Giazotto (Director of VIRGO) and Professor R. Ruffini.

'At the completion of speeches the plaque commemorating the opening was 'revealed' by the Premier who cut a ribbon to release a pendulum which, on the second swing, knocked over a weight. The falling weight set off an explosion of streamers and, at the same time, a copy of the black hole art work sprung up to reveal the plaque.'

Members' News Dr Philip Charlton has just completed his ARC funded postdoctoral position with the gravitational wave data analysis group in the Department of Physics at the ANU. He will commence a three-year postdoctoral position at Caltech at the end of April working with the data analysis group of LIGO Laboratory.

Autumn 2001

Bid for GR17 Susan Scott is currently putting together a bid by the Society to hold the international General Relativity conference GR17 - next in the series after this year's meeting in Durban - in Cairns in July, 2004, at the new Cairns Convention Centre ... It failed

Members' News David Wiltshire will be taking up a continuing lectureship at the Dept of Physics and Astronomy, University of Canterbury, Christchurch, NZ from July, 2001

Spring 2001

President's Report (David McClelland) 'relativity research remains in a dire state in Australia. David Wiltshire and Peter Szekeres were leaving Adelaide University without replacement, while Adrian Gentle had moved to Los Alamos and Malcolm Anderson to Brunei. No funding was forthcoming for the national gravity wave facility, and no action had yet been taken on assigning a separate ARC Category Code to general relativity, gravitation and cosmology (the ARC programme manager responsible for this is Laurie Cram)"

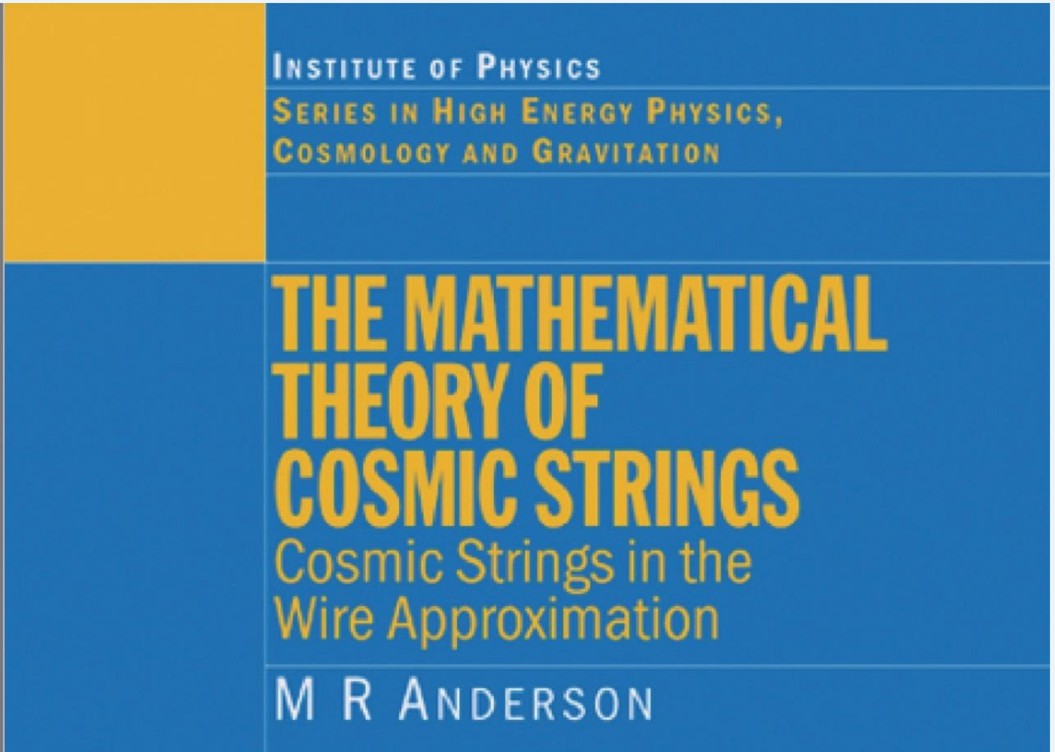
Autumn 2002

It is with great sadness that we report the sudden death of Geoffrey Opat on March 7 of this year. Geoff was a member of the School of Physics at the University of Melbourne, and had been a member of the ASGRG since 1996.

Spring 2002

Members' News Matt Visser returns to New Zealand

After a long stint at the University of Washington in Saint Louis, Matt Visser has returned to New Zealand to take up a position as Reader/Associate Professor in the Mathematics Department at Victoria University in Wellington.



The Institute of Physics has recently published a book by Malcolm Anderson entitled "The Mathematical Theory of Cosmic Strings: Cosmic strings in the wire approximation". 380 pages long, it offers a detailed survey of the current understanding of the dynamics and gravitational properties of zero-thickness cosmic strings

Autumn 2004

Notification of Kerr Fest Black Holes in Astrophysics, General Relativity & Quantum Gravity

A celebration in the year of Roy Kerr's 70th birthday University of Canterbury, Christchurch, New Zealand Thurs 26 - Sat 28, August, 2004

2nd row: Roy Kerr; 1st row: Zoltan Perjés, Brandon Carter, David Robinson

On the bus: facing the camera are Steve Carlip, Susan Scott, Silke Weinfurtner, Stefano Liberati and Andrew Moylan

News Gravity Probe B has finally been launched after being "in the pipeline" for decades

Gravity Probe B's 20-year Launch Anniversary Reunion April 20th, 2024 !!

Meanwhile at GR17 in Dublin in July 2004 I finally won the bid to host the first ever GR meeting (held every 3 years) in Australia in Sydney in 2007

2006

Announcement 18th International Conference on General Relativity and Gravitation (GR18) to be held in DARLING HARBOUR, SYDNEY, 8-13 JULY 2007 running in parallel with the 7th Edoardo Amaldi Conference on Gravitational Waves. Joining forces in Sydney in 2007 these conferences will bring together the world's leading scientists working in the fields of General Relativity and Gravitation.

2007

President's Report (Susan Scott) 'Another promising development was the launch of the prospectus for the Australian International Gravitational Observatory (AIGO) in 2006'

Report on the conferences

Susan Scott Chair of the LOC

David Mclelland Deputy Chair of the LOC

John Steele Treasurer of the LOC

Other LOC members: Malcolm Anderson, Leo Brewin, Li Ju, Peter Veitch, David Wiltshire

Chair of the Scientific Organising Committee: B.S. Sathyaprakash of Cardiff University

360 papers were presented during the parallel sessions at GR18, 15 plenary lectures, and two public lectures. The speakers were drawn from 37 countries around the world.

18TH INTERNATIONAL CONFERENCE ON GENERAL RELATIVITY AND GRAVITATION (GRG18)

8 – 13 July 2007

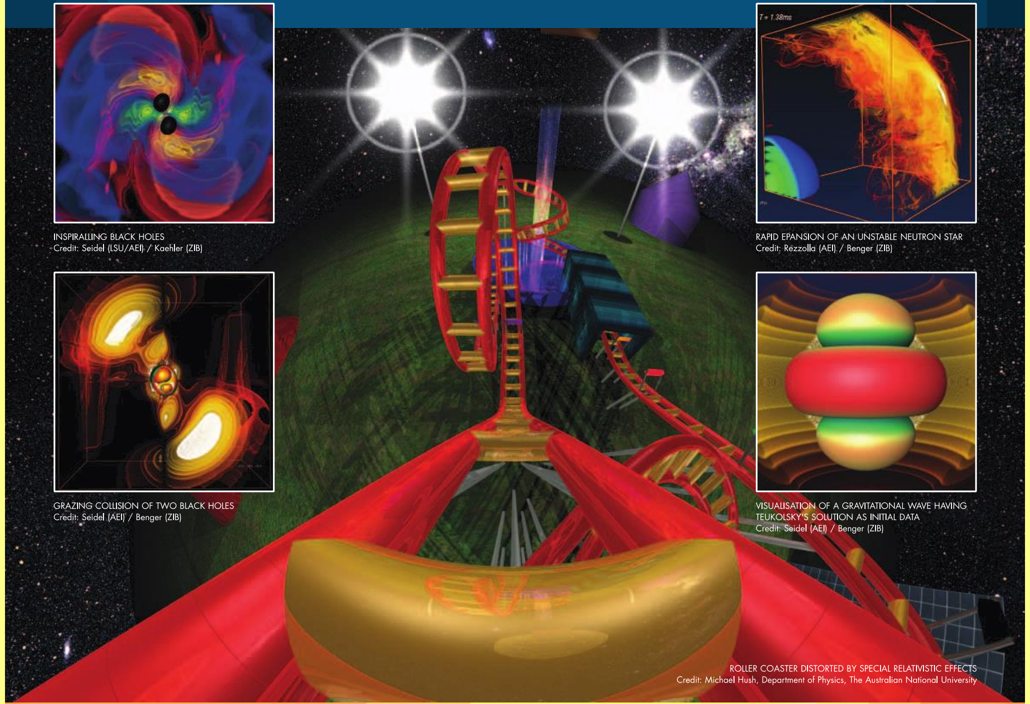
7TH EDOARDO AMALDI CONFERENCE ON GRAVITATIONAL WAVES (AMALDI7)

8 – 14 July 2007

www.grg18.com

www.Amaldi7.com

Sydney Convention & Exhibition Centre • Darling Harbour • Sydney Australia



INSPIRALLING BLACK HOLES
Credit: Seidel (LSU/AEI) / Kaehler (ZIB)

RAPID EPANSION OF AN UNSTABLE NEUTRON STAR
Credit: Rezzolla (AEI) / Benger (ZIB)

GRAZING COLLISION OF TWO BLACK HOLES
Credit: Seidel (AEI) / Benger (ZIB)

VISUALISATION OF A GRAVITATIONAL WAVE HAVING TEUKOLSKY'S SOLUTION AS INITIAL DATA
Credit: Seidel (AEI) / Benger (ZIB)

ROLLER COASTER DISTORTED BY SPECIAL RELATIVISTIC EFFECTS
Credit: Michael Hush, Department of Physics, The Australian National University

The program for GRG18 will incorporate all areas of General Relativity and Gravitation including Classical General Relativity; Numerical Relativity; Relativistic Astrophysics and Cosmology; Experimental Work on Gravity and Quantum Issues in Gravitation.
The program for Amaldi7 will cover all aspects of Gravitational Wave Physics and Detection.

PLENARY LECTURES

Bernd Bruegman (Friedrich-Schiller-University Jena)
Numerical relativity

Daniel Eisenstein (University of Arizona)
Dark energy

Francis Everitt (Stanford University)
Gravity Probe B and precision tests of General Relativity

Jonathan Feng (University of California Irvine)
Collider physics and cosmology

Laurent Freidel (Perimeter Institute)
Non-string quantum gravity

Badri Krishnan (Albert Einstein Institute Golm)
Black hole horizons

Renata Loll (Utrecht University)
Other approaches to quantum gravity

Steve McMillan (Drexel University)
Gravitational dynamics of large stellar systems

Robert Myers (Perimeter Institute)
Gravitational aspects of string theory

Marialessandra Papa (Albert Einstein Institute Golm)
Gravitational wave astronomy from ground and space

Hans Ringstroem (KTH, Stockholm)
Cosmic censorship

Peter Schneider (Bonn)
Gravitational lensing

Daniel Shaddock (JPL California Institute of Technology)
Gravitational wave detection from space: technology challenges

Stan Whitcomb (California Institute of Technology)
Ground-based gravitational wave detection: now and future

PUBLIC LECTURES

Sir Roger Penrose
The Emeritus Rouse Ball Professor of Mathematics
The University of Oxford

Kip S Thorne
The Feynman Professor of Theoretical Physics
California Institute of Technology

GRG18 SCIENTIFIC ORGANISING COMMITTEE

Chair: B.S. Sathyaprakash	*UK*
Miguel Alcubierre	*Mexico*
Nils Andersson	*UK*
Piotr Chrusciel	*France*
Curt Cutler	*USA*
Valeria Ferrari	*Italy*
Bala Iyer	*India*
Roy Maartens	*UK*
Malcolm MacCallum	*UK*
Donald Marolf	*USA*
David McClelland	*Australia*
Jorge Pullin	*USA*
Norna Robertson	*USA*
Misao Sasaki	*Japan*
Bernard F Schutz	*Germany*
Susan M. Scott	*Australia*
Matt Visser	*New Zealand*
Clifford M. Will	*USA*

AMALDI7 SCIENTIFIC ORGANISING COMMITTEE
(The Gravitational Wave International Committee – GWIC)

Chair: Massimo Cerdonio	*Italy*
Eugenio Coccia	*Italy*
Karsten Danzmann	*Germany*
Georgio Frossati	*Netherlands*
Masa-Katsu Fujimoto	*Japan*
Adelberto Giazotto	*Italy*
James Hough	*United Kingdom*
William Hamilton	*United States*
David McClelland	*Australia*
Jay Marx	*United States*
Benoit Mours	*France*
Thomas Prince	*United States*
Peter Saulson	*United States*
Bernard Schutz	*Germany*
Robin Stebbins	*United States*
Kimio Tsubono	*Japan*
Stefano Vitale	*Italy*
Clifford Will	*United States*

LOCAL ORGANISING COMMITTEE

Chair: Susan M. Scott	*The Australian National University*
Deputy Chair: David E. McClelland	*The Australian National University*
Treasurer John D. Steele	*The University of New South Wales*
Malcolm Anderson	*Universiti Brunei Darussalam*
Leo Brewin	*Monash University*
Li Ju	*The University of Western Australia*
Peter Veitch	*The University of Adelaide*
David Wiltshire	*University of Canterbury*

FURTHER INFORMATION
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Email: info@grg18.com or info@Amaldi7.com
Website: www.grg18.com or www.Amaldi7.com


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PLENARY LECTURES

Monday 9 July

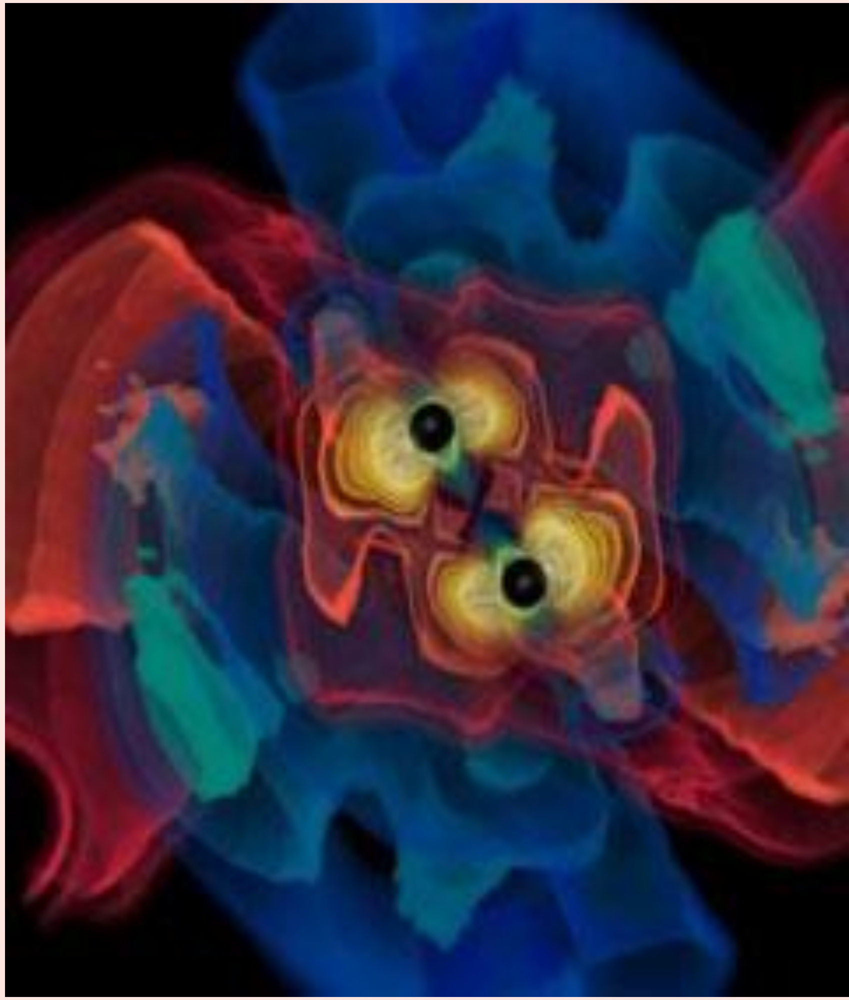
Stan Whitcomb Ground-based gravitational wave detection: now and future
Laurent Freidel Spin foam models or the dynamics of quantum space-time
Steve McMillan Gravitational dynamics of large stellar systems

Tuesday 10 July

Badri Krishnan Quasi-local black hole horizons and their applications
Bernd Bruegmann Numerical relativity
Daniel Eisenstein Observing dark energy

Wednesday 11 July

Peter Schneider Cosmological probes by gravitational lensing
Renata Loll The emergence of spacetime, or, quantum gravity on your desktop
Francis Everitt Testing Einstein in space: Gravity Probe B and STEP



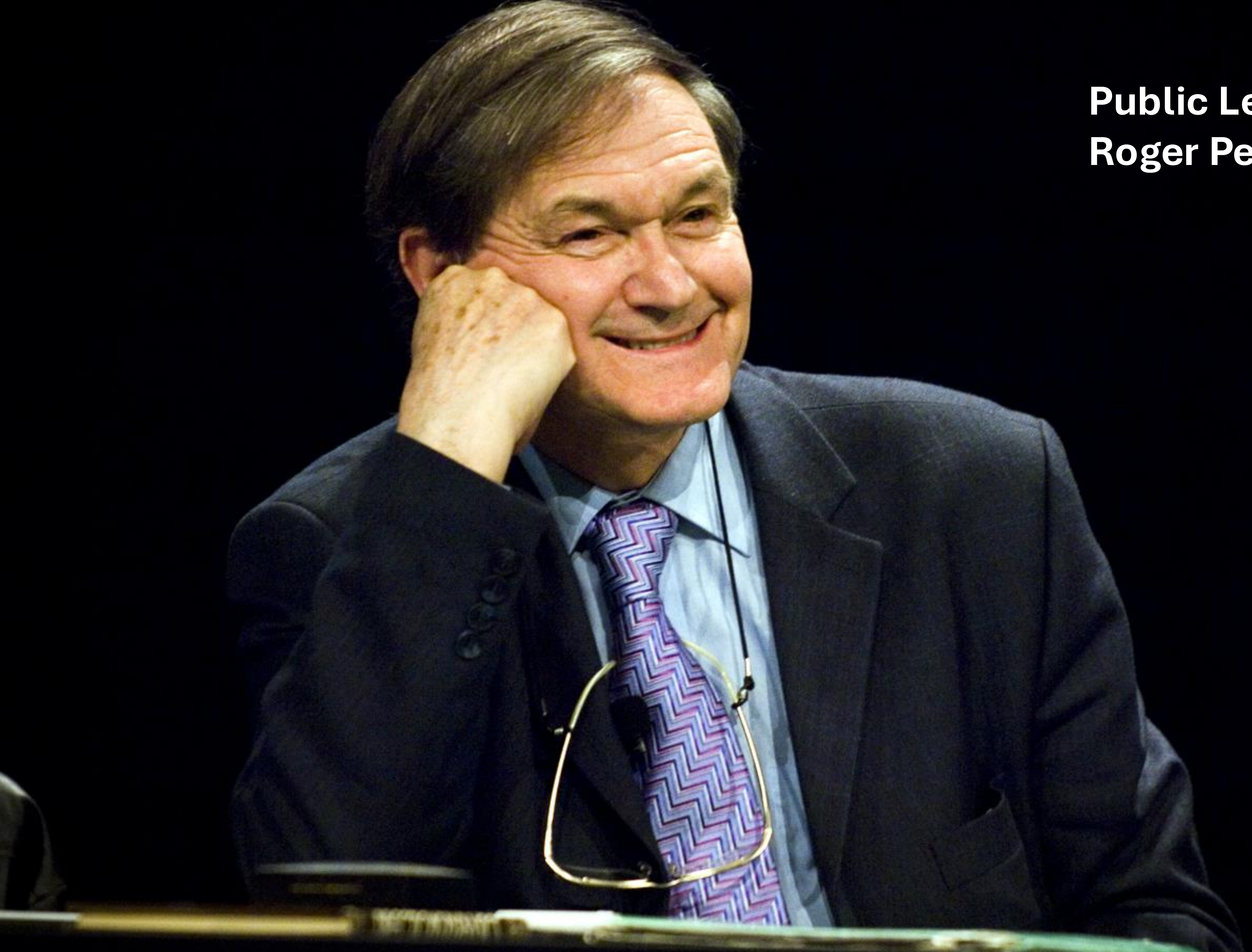
Thursday 12 July

Hans Ringstrom Cosmic censorship
Johnathan Feng Colider physics and cosmology
Daniel Shaddock Space-based gravitational wave detection with LISA

Friday 13 July

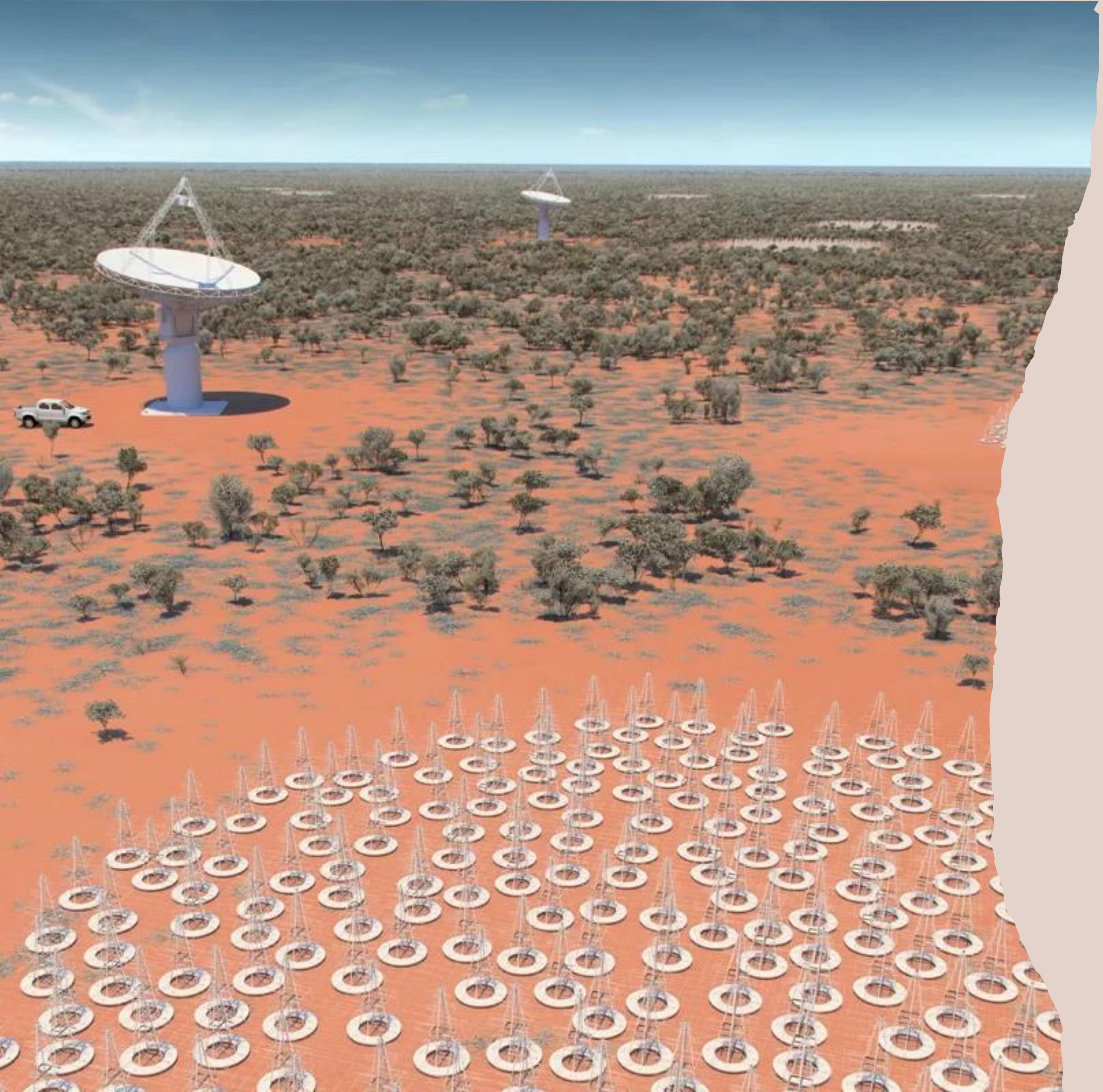
Maria Alessandra Papa Gravitational wave astronomy from ground and space
Robert Myers Quark soup al dente: applied string theory
Ralf Shuetzhold Effective horizons in the laboratory

Public Lecture
Kip Thorne



Public Lecture
Roger Penrose

ASGRG and ACIGA members at GR18 and Amaldi7



2007

Square Kilometre Array (SKA)

Matt Visser suggested that the ASGRG offer public support for the Australian/NZ bid for the SKA, planned to be the world's biggest radio telescope. David McClelland pointed out in response that the SKA was competing for funds with the AIGO. The Meeting decided that the Society will take no position on the SKA.

2008

A 3-day Workshop on mathematical general relativity was held in the Australian Mathematical Sciences Institute (AMSI) Building on the Melbourne University campus in July 2008.

The Workshop was organised by Con Lozanovski of Swinburne Institute of Technology.

The keynote speakers were:

Joerg Frauendiener, University of Otago – the relativistic theory of elasticity in the limit of static spherical symmetry

Susan Scott, Australian National University – the application of conformal structures to future cosmological singularities

Todd Oliynyk, Monash University – second-order Newtonian expansions for perfect fluids

Matthew Choptuik, University of British Columbia – numerical tests of the cosmic censorship conjecture

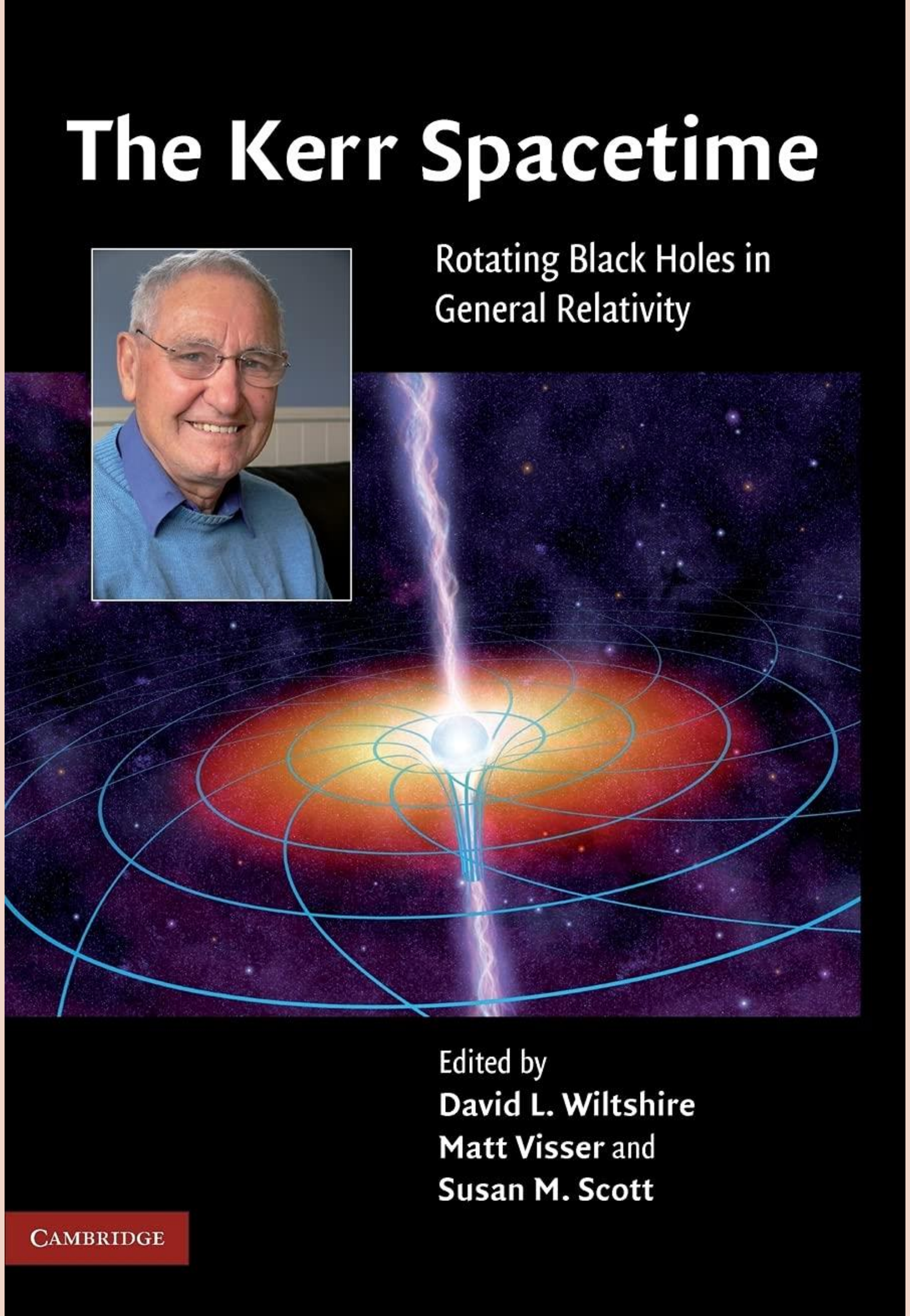
Robert Bartnik, Monash University – geometric boundary conditions for the Ricci tensor

Edward Fackerell, University of Sydney – the 1-Killing-vector vacuum Einstein equations

Peter Szekeres, University of Adelaide – conformal gravity and the variation of fundamental constants

Pengzi Miao, Monash University – the first variation of quasi-local mass.

Celine Cattoen won the prize for the best student presentation and was awarded a copy of Roger Penrose's "The Road to Reality"



2009

Giorgi Melkadze

5.0 out of 5 stars **Kerr's Way**

Reviewed in the United States on **13 June 2023**

The book represents Roy P. Kerr's own way of deriving the metric named after him, and more.

Einstein's field equation is very difficult in the case of a rotating black hole and it is impossible to obtain the solution in a similar way one can derive the Schwarzschild solution. So a different way was needed. There are various ways of obtaining Kerr metric; some of them seems to me artificial (that is, when one knows beforehand what is to be derived and one is making corresponding steps to get that result). Kerr's way is original and natural.

Before you read the book to learn the derivation of Kerr metric, you should heighten the level of your math knowledge by learning Differential Geometry. So this book is an appropriate stimulus to heighten the level of your understanding General Relativity and its mathematical apparatus.


Virgo


LIGO Hanford


LIGO Livingston

2011

President's Report (Susan Scott) 'the Australian Consortium for Interferometric Gravitational Astronomy (ACIGA) has been very active over the last three years, with ACIGA members participating in the final year of the S5 science run of the LIGO gravitational wave detectors, and winning a LIEF grant to develop AIGO in Gingin in 2007. ACIGA became a full partner in Advanced LIGO in 2008, and in the same year LIGO and VIRGO joined forces to form the LIG0-VIRGO Collaboration'

Winter 2015 – the Centenary Year! And the year of discovery!

President's Report (David Wiltshire) 'The last 4 years had been frustrating for the relativity community in Australia, as the proposed gravitational wave observatory (ACIGA) had not been funded, and job prospects in the area were limited. The situation was better in New Zealand, where recent appointments of relativists included Joerg Frauendiener at the University of Otago, and Woe Chet Lim at Waikato'

22 people from Australia and New Zealand attended the Marcel Grossmann meeting in Stockholm (MG13) in 2012, and 27 people from Australia and New Zealand were at the GR20/Amaldi10 conference in Warsaw in 2013.

Winter 2016

President's Report (Leo Brewin) from 3 December 2015 'a proposal for a Centre of Excellence for gravitational wave discovery, prepared by a number of ASGRG members under the umbrella of ACIGA, had made the first cut in the ARC selection procedure. The full proposal was due to be submitted to the ARC on 16 December, and if chosen as one of the 10 successful Centres of Excellence in May 2016 would receive $5 million a year in funding for 5 to 7 years starting in 2017.

No mention of gravitational wave detection!!

WE DID IT ! – Press Conference Parliament House 12 February 2016

1 April 2017

OzGrav
ARC Centre of Excellence for Gravitational Wave Discovery

2024 Olympic 50m freestyle Champion

Matthew Bailes - Director

ASGRG Conferences

ACGRG1 12-17 February 1996 *(University of Adelaide, Adelaide, Australia)*

ACGRG2 6-11 July 1998 *(University of Sydney, Sydney, Australia)*

ACGRG3 11-13 July, 2001 *(University of Western Australia, Perth, Australia)*

ACGRG4 7-9 January, 2004 *(Monash University, Melbourne, Australia)*

ACGRG5 16-18 December, 2009 *(University of Canterbury, Christchurch, New Zealand)*

ACGRG6 8-11 February, 2012 *(University of Otago, Queenstown, New Zealand)*

ACGRG7 8-11 December, 2013 *(Australian National University, Hamilton Island, Australia)*

ACGRG8 2-4 December, 2015 *(Monash University, Melbourne, Australia)*

ACGRG9 27-30 November, 2017 *(University of Western Australia, Gingin, Australia)*

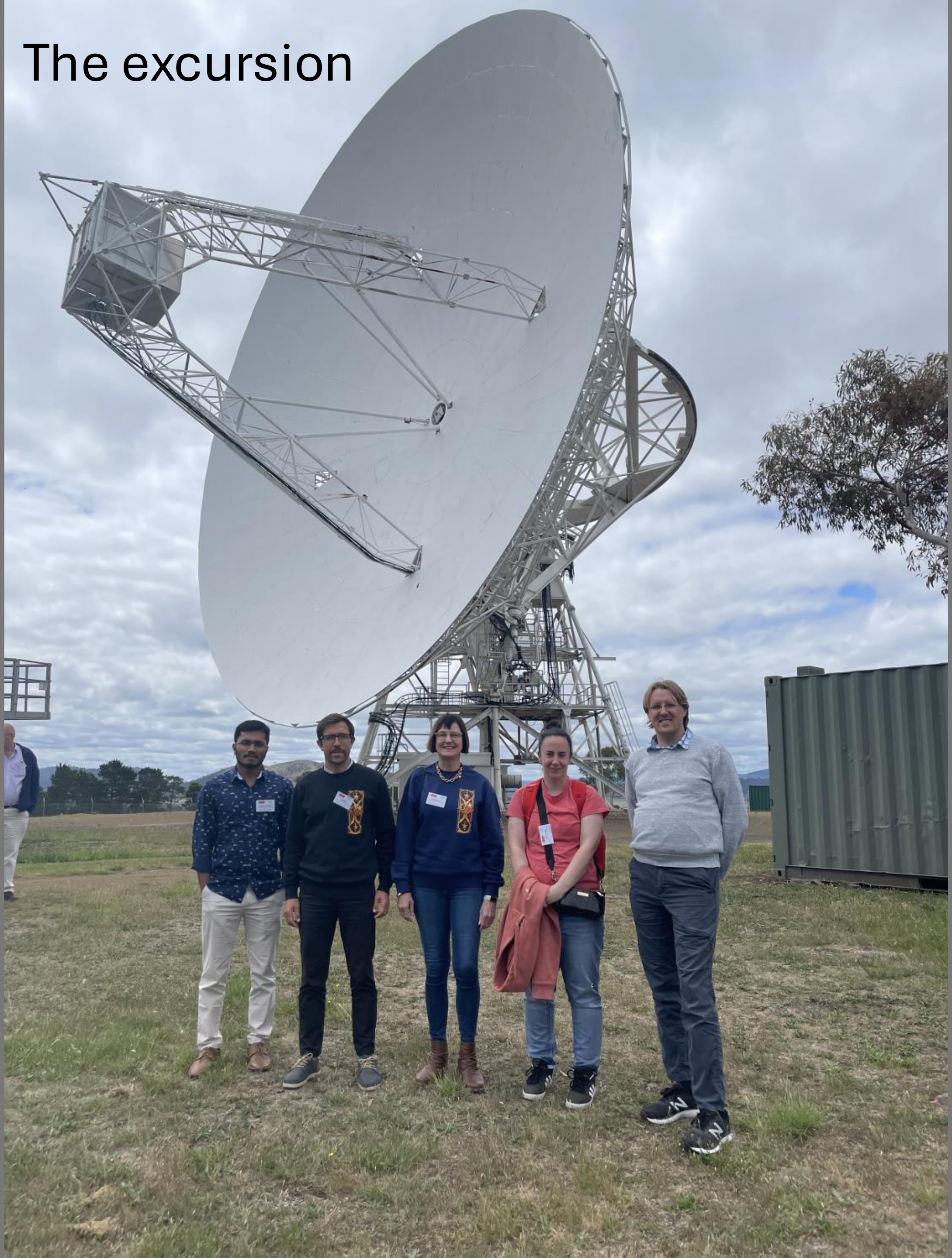
ACGRG10 10-13 December, 2019 *(Victoria University of Wellington, Wellington, New Zealand)*

ACGRG11 2-4 February, 2022 *(online, hosted by University of Tasmania, Hobart, Australia)*

ACGRG12 27 November - 1 December, 2023 *(University of Tasmania, Hobart, Australia)*

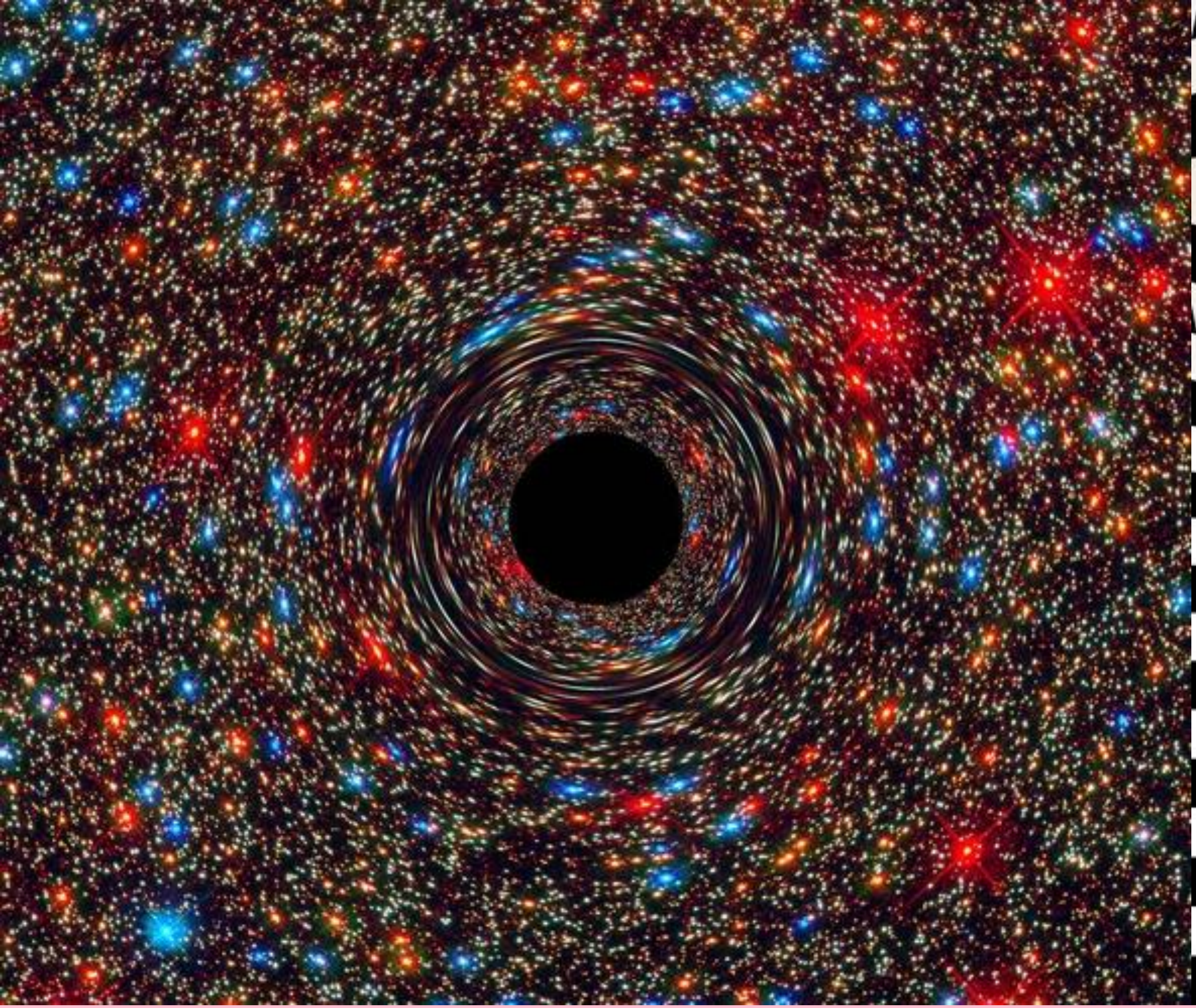
ACGRG12 – 27 Nov -1 Dec 2023

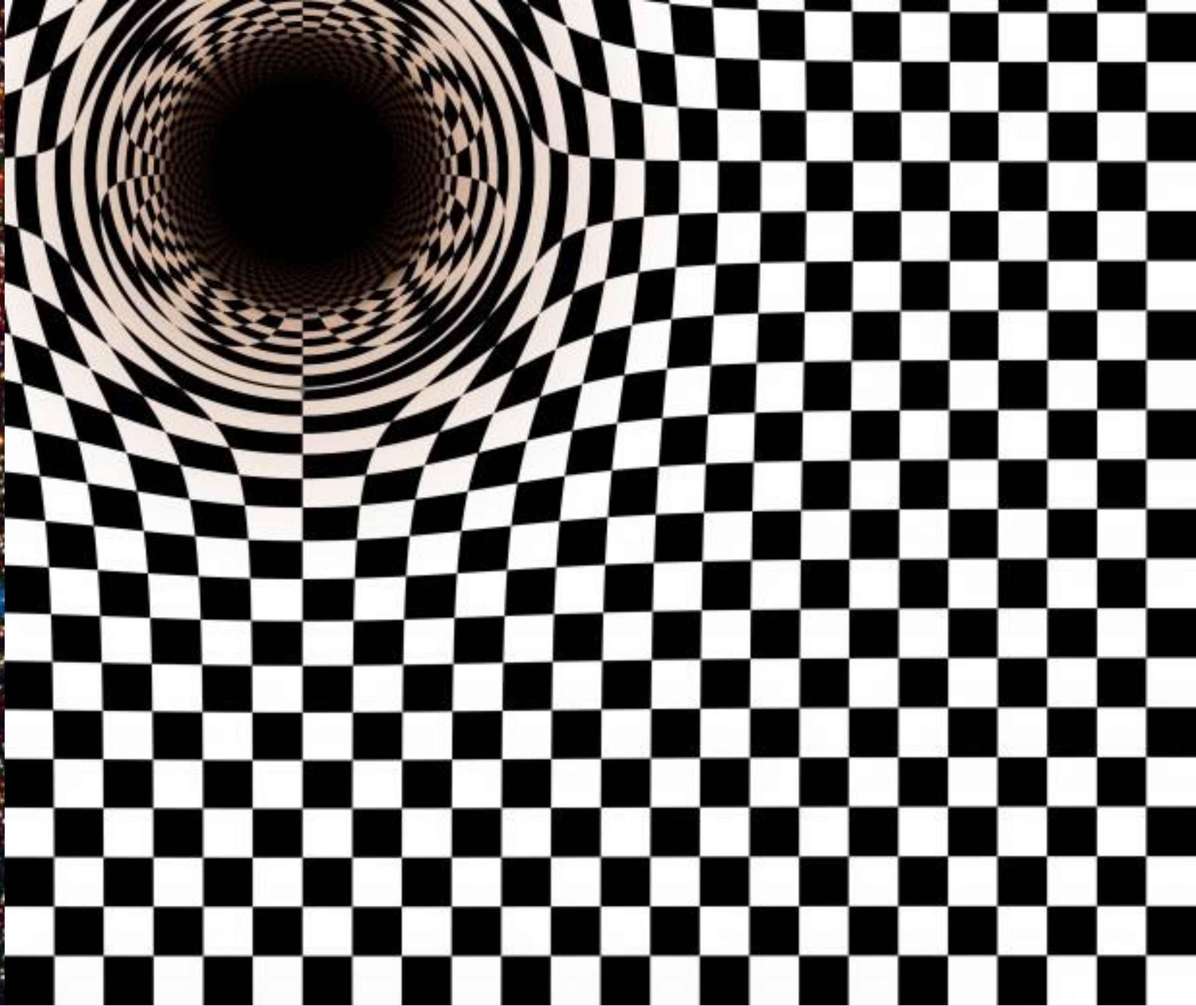
The excursion



The public lecture – David Blair

The committee



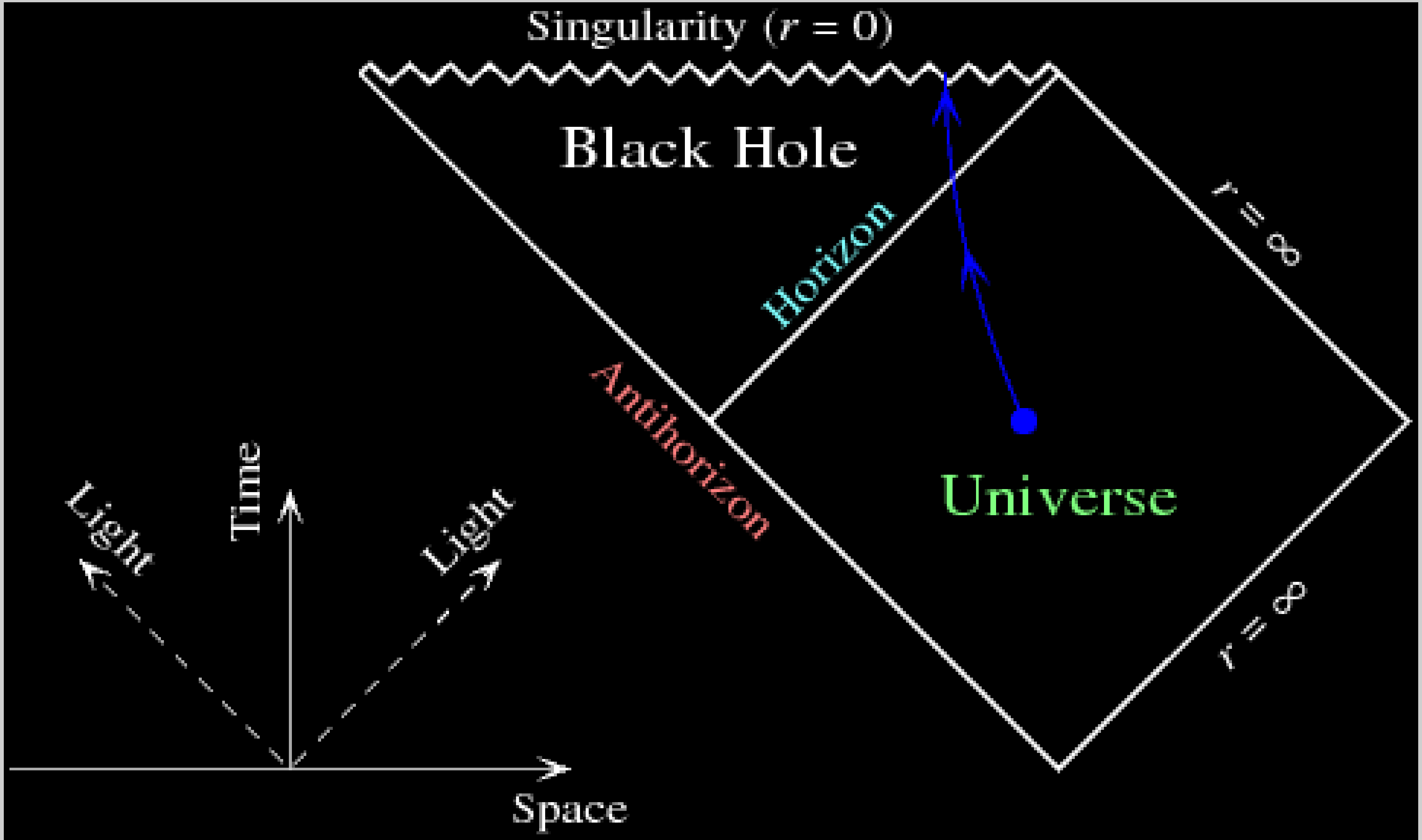


Happy 30th Birthday to The Abstract Boundary – the a-boundary

A boundary construction for spacetime 🎂 🎉 🥳 🎈

Penrose Diagram for Schwarzschild

Martin Kruskal George Szekeres 1960



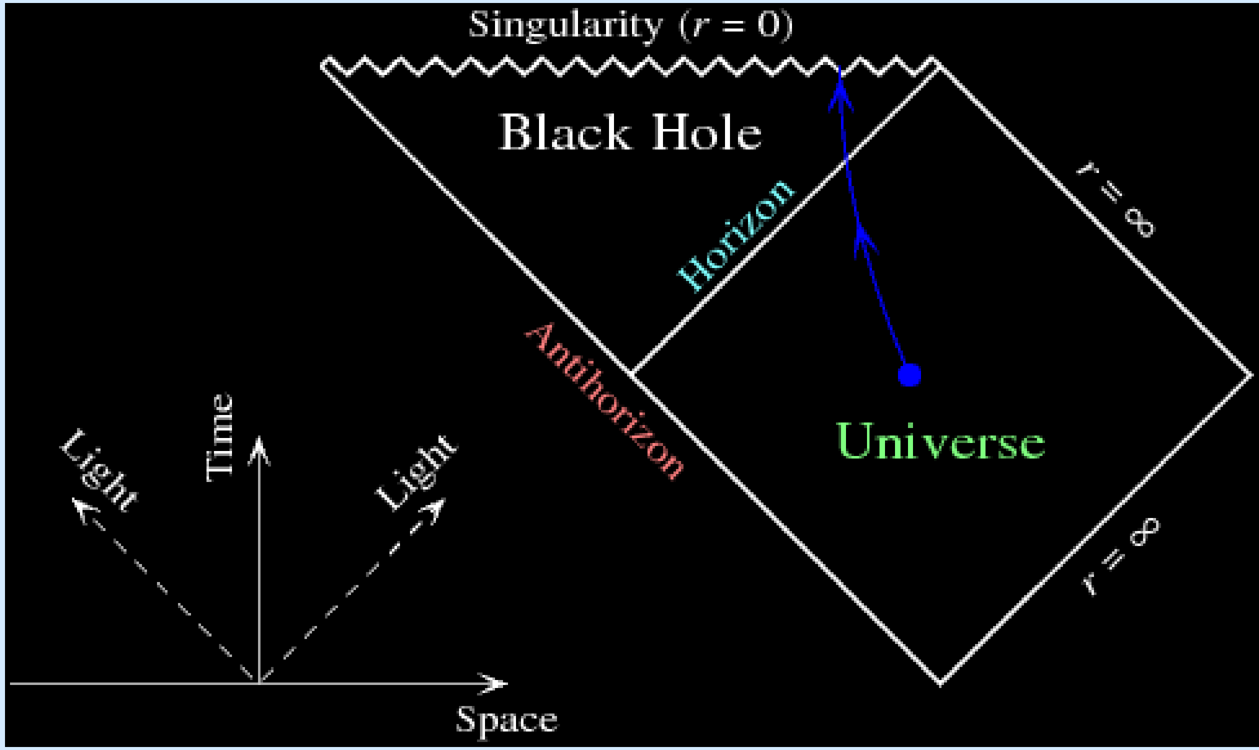
What are singularities? 

For exact solutions, “*places” on the edge of space-time where things go wrong*

Where is that “place” ??? ***The boundary***

In what way can things go wrong ???

These “places” are only physically important if an observer can reach there in finite proper time



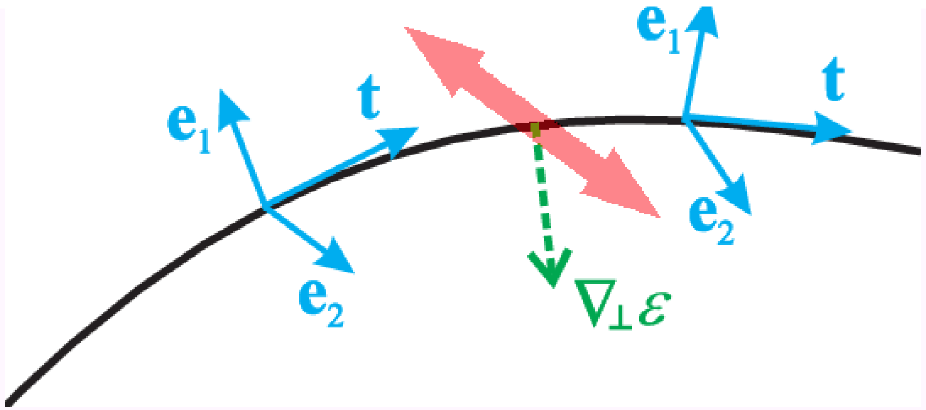
Broad classification of singularities

q is a singular boundary point of $(\mathcal{M}, g)$

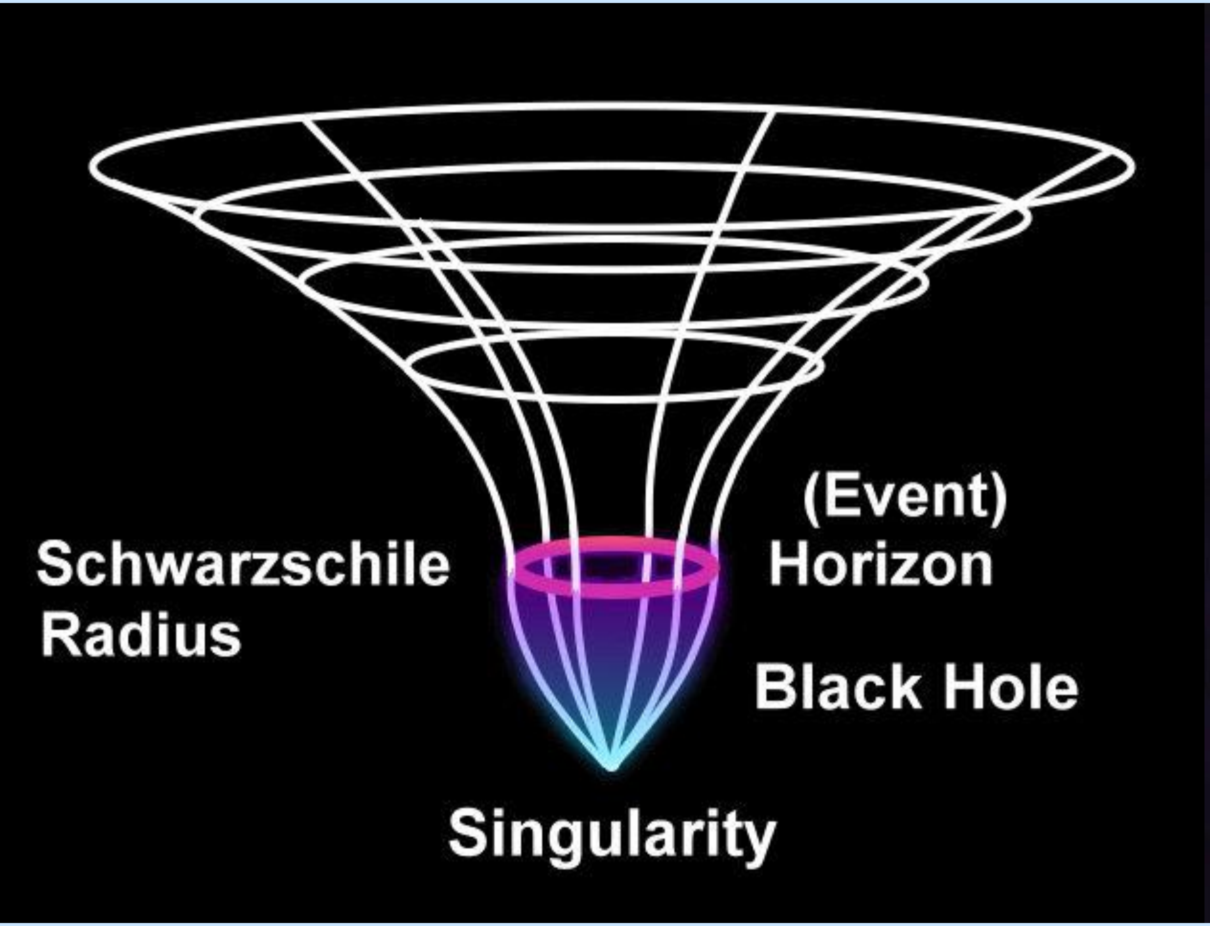
The point $q \in \partial(\mathcal{M})$ (on the boundary of the manifold $\mathcal{M}$) is a C^k *curvature singularity* $(k \geqslant 0)$ if there is a curve $\gamma(v)$ such that when an orthonormal tetrad $\{E_a(v)\}$ parallel propagated along $\gamma(v)$ is used as a basis, at least one curvature tensor component $R_{abcd;e_1 \ldots e_k}(v)$ does not behave in a C^0 way on $[0, v^+]$.

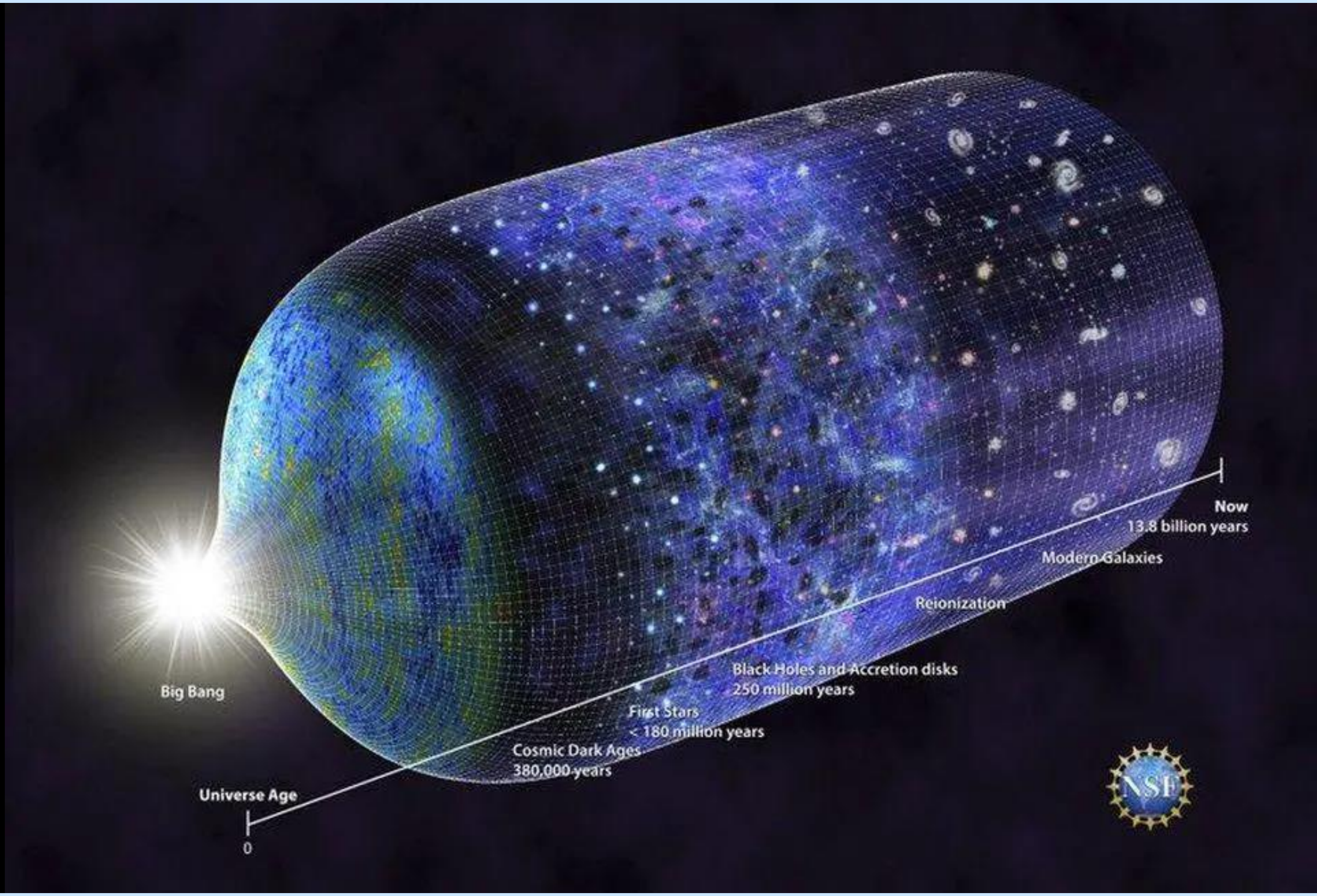
A *curvature singularity* will occur if some physical quantity (e.g. the density or pressure of a fluid) or some curvature tensor invariant (e.g. $R^{abcd}R_{abcd}$) is badly behaved as one approaches q.

The point $q \in \partial(\mathcal{M})$ is a C^k *quasiregular* singularity $(k \geqslant 0)$ if it is not a C^k curvature singularity.



Examples of curvature singularities





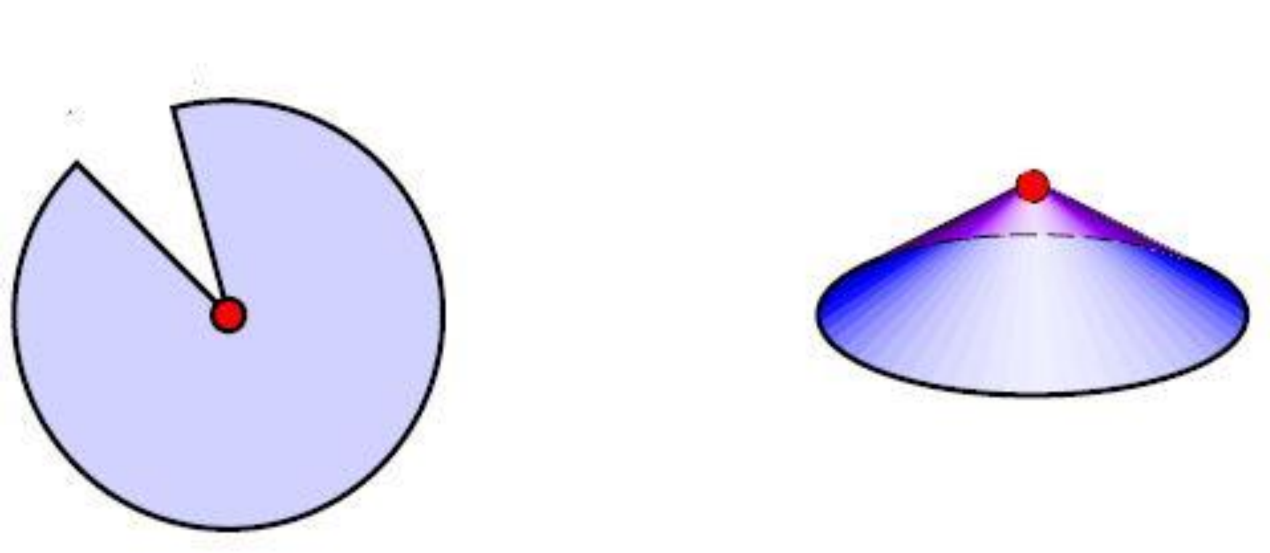
Schwarzschild singularity

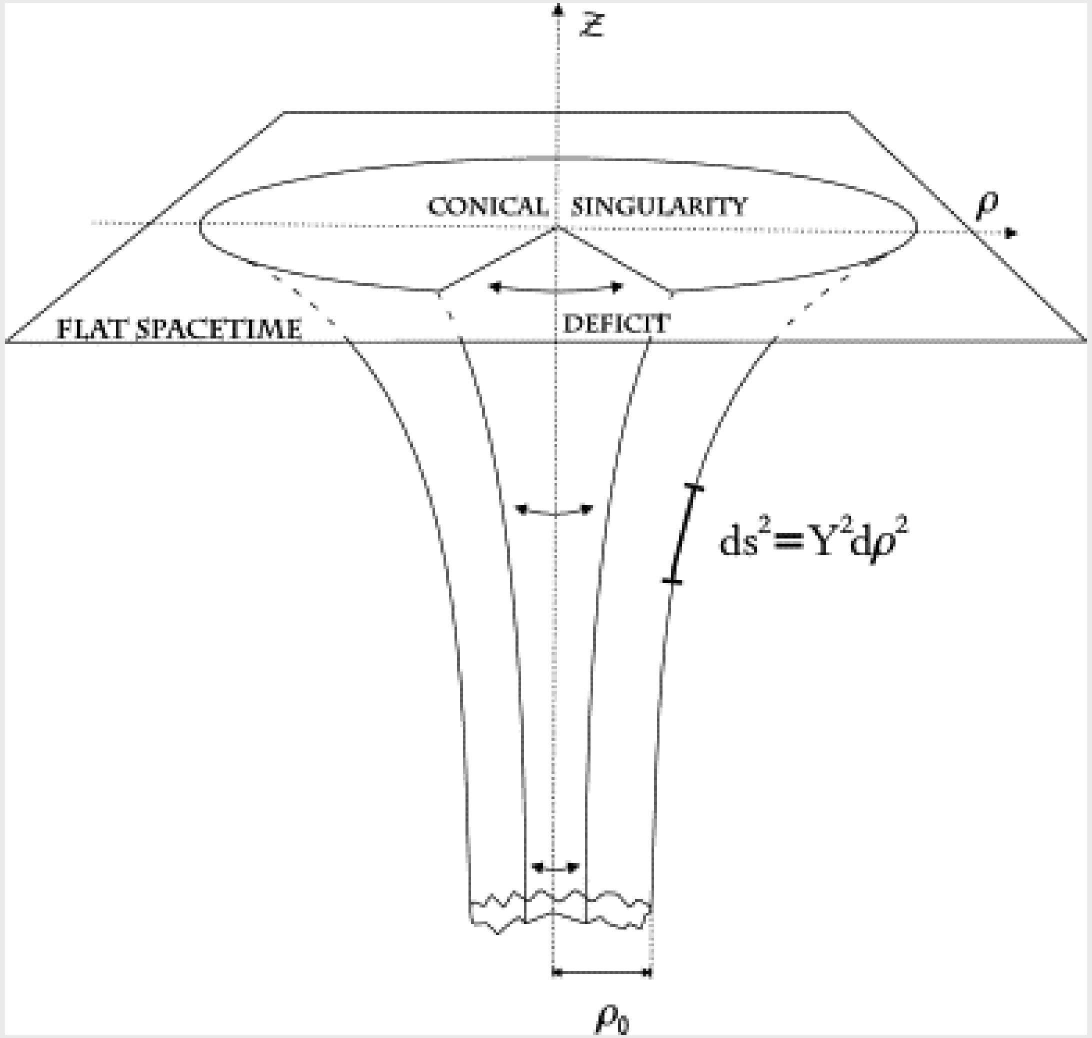
Friedmann-Robertson-Walker Big Bang singularity

Conical singularities

These are a type of *quasiregular* singularity

There is a geometric problem with the space-time
Something has been removed!





Chris Clarke: *every quasiregular singularity is locally extendible*

The situation gets worse 😱

There is another type of singularity often encountered in new exact solutions

These singularities are not part of the standard classification

They are kind of a top-level “raw” singularity

Often exact solutions are not obtained in an optimal coordinate system

This can lead to the presence of singularities which are *jumbled*

They are called *directional singularities*

They were not well understood for many years

There was no precise definition of a directional singularity

It was a puzzle as to what to do with them ... 🤔

The Curzon Solution

The **Curzon metric** is a static, axisymmetric vacuum solution

$$ds^2 = -e^{2\lambda}\,dt^2 + e^{2(\nu-\lambda)}[dr^2 + dz^2] + r^2 e^{-2\lambda}\,d\phi^2$$

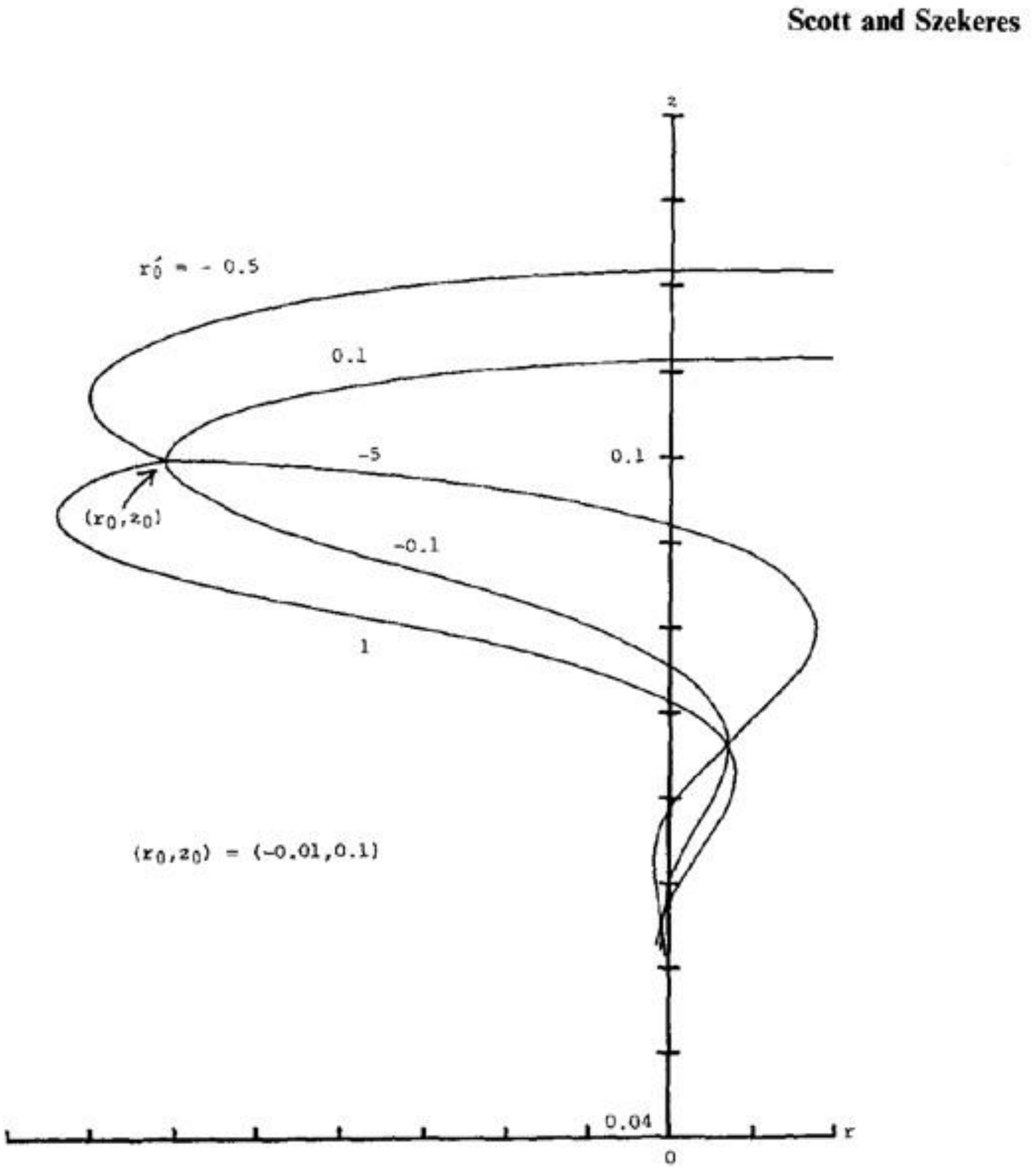
with monopole potential

$$\lambda = -m/R \qquad \text{and} \qquad \nu = -m^2 r^2/2R^4 \qquad \text{where} \qquad R = (r^2 + z^2)^{1/2}$$

The only problem with this metric is when R = 0 – that is, when r = z = 0

The origin of the cylindrical polar coordinate system at R = 0 is a **directional singularity**

Oscillating geodesics in the r-z plane

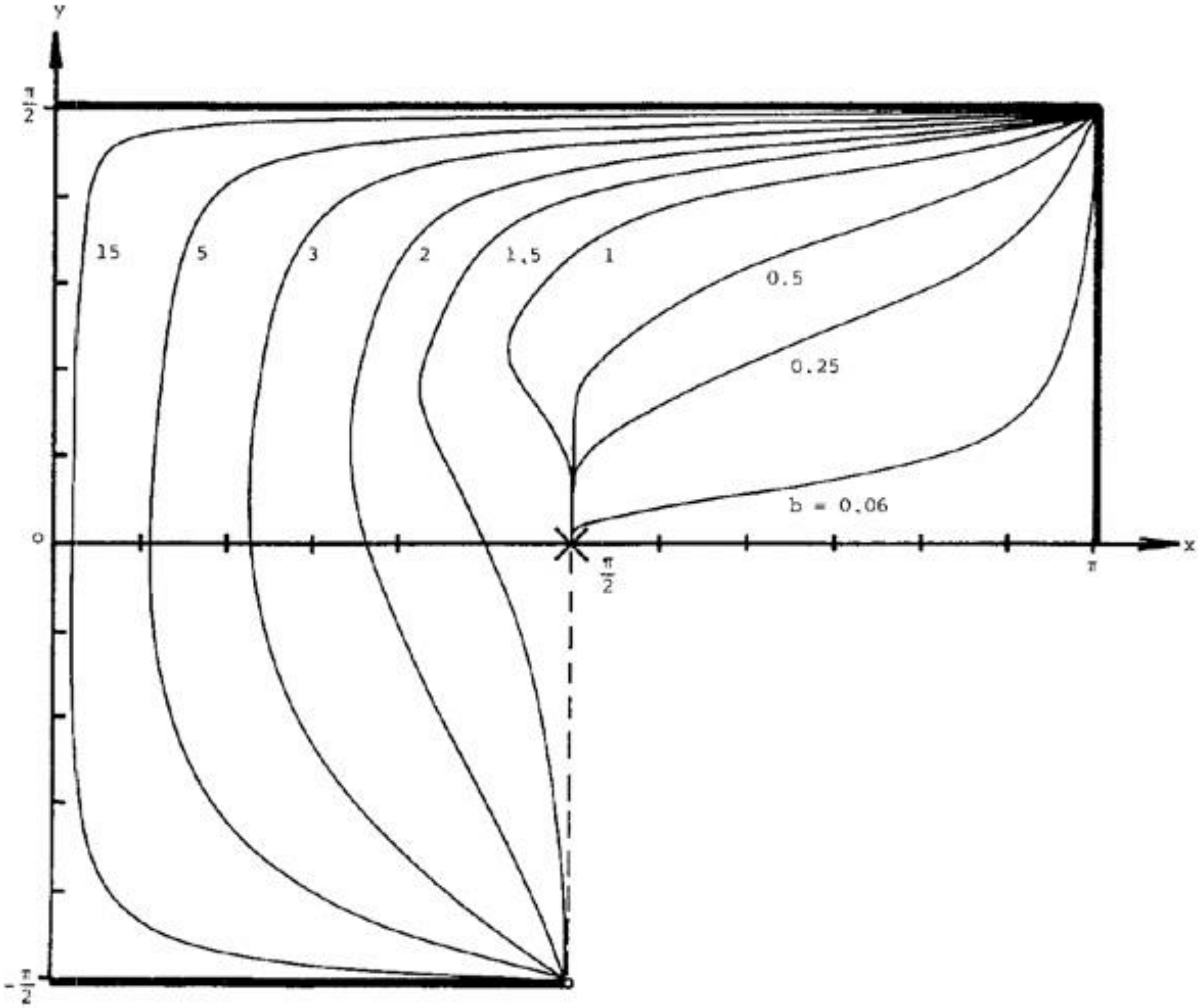


These geodesics **oscillate** about the z-axis as they approach R = 0

Geodesics originating from the point, **reconverge** many times, after every crossing of the z-axis

These points have a countably infinite number of **conjugate points**

The r-z half-plane (z > 0) in new coordinates x, y



The coordinates have been compactified

The curvature singularity X is separated out

There is a new region of spacelike infinity

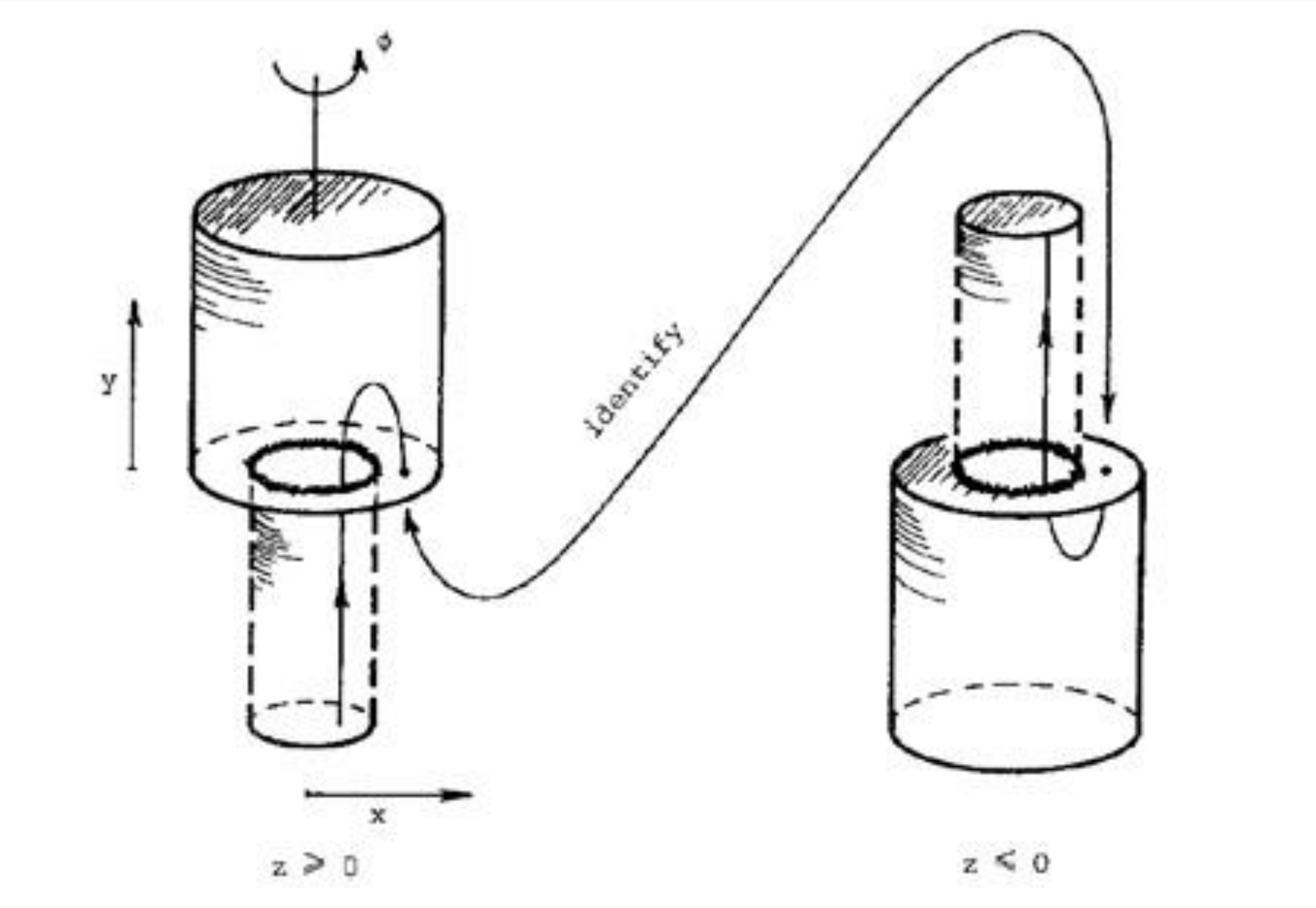
There is also an "edge" of finite curvature

The diagram needs to be rotated

This half of the space-time needs to be connected to the z < 0 half across the horizontal axis

The time coordinate needs to be added

Joining z > 0 with z < 0



Curiously the curvature singularity is a ***ring singularity*** with finite radius but infinite circumference

Designer coordinates for the Curzon solution

(t, r, z, ϕ) $\Rightarrow$ (t, x, y, ϕ) $\Rightarrow$ (T, x, Y, ϕ)

half-advanced, half-retarded time coordinate T

$$T = \tan^{-1}\left[e^{-K}\left(\frac{t}{m} + H\right) + \frac{t}{m}\left(y + \frac{\pi}{2}\right)^3\right] + \tan^{-1}\left[e^{-K}\left(\frac{t}{m} - H\right) + \frac{t}{m}\left(y + \frac{\pi}{2}\right)^3\right]$$

$$x = \tan^{-1}[(r/m)\, e^{m/z}] + \tan^{-1}\{(r/m)\, e^{-[2^{1/2}(m/r)]^{2/3}}\}$$

$$y = \tan^{-1}\left\{3\,\frac{z}{m} - \frac{(z/m)^2\, e^{\psi}}{[R^8 + 1 + \frac{1}{3}(r/m)^2\, R^{-4}]^{1/4}}\right\}$$

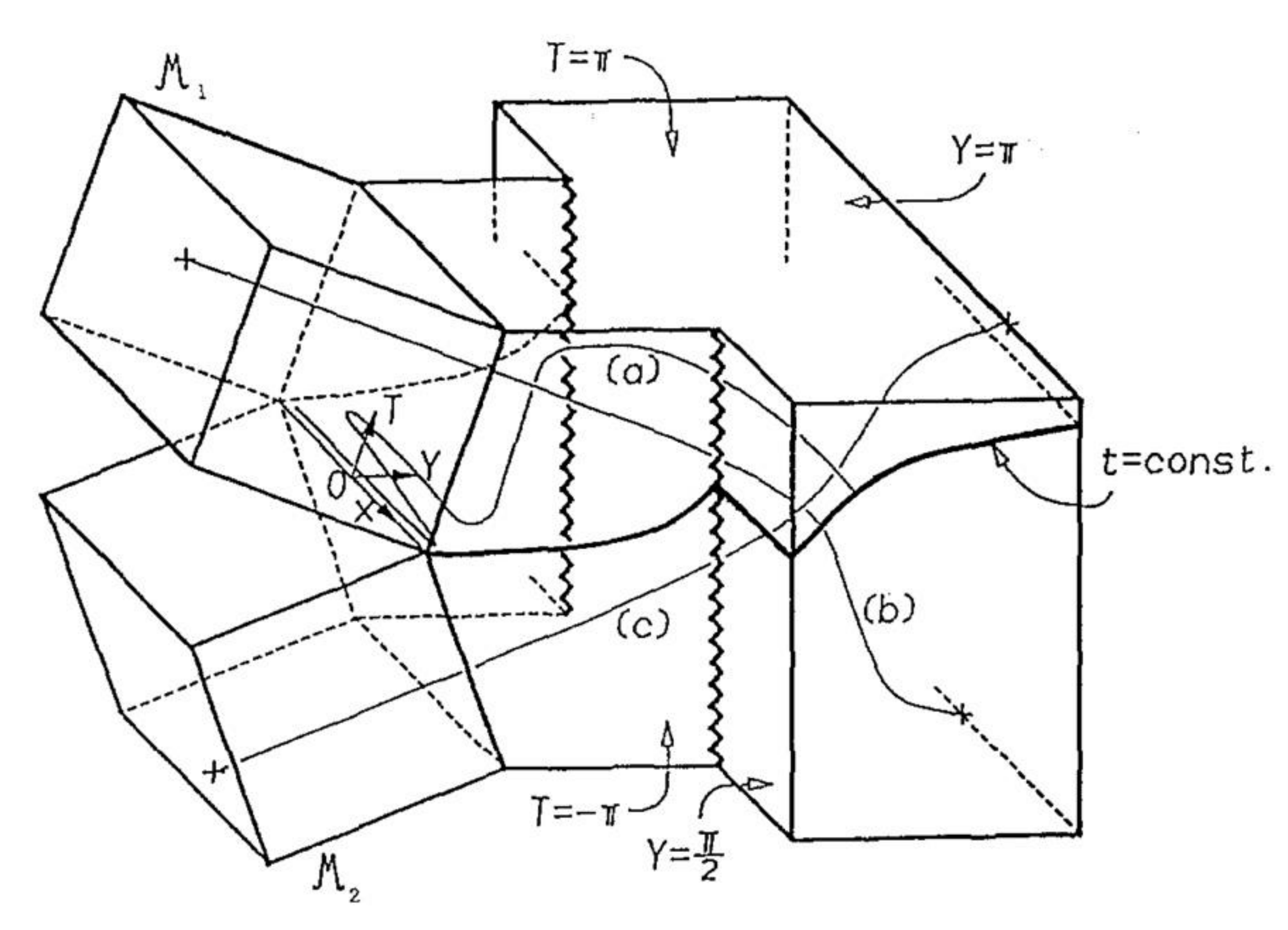
$$\psi = \nu - \lambda = (1/R) - (r^2/2m^2R^4)$$

$$Y = \frac{\pi}{2} + \tan^{-1}\left[ay^3\left(x^2 - \frac{\pi^2}{4}\right)^2\frac{m}{z} + 3\,\frac{z}{m} - \frac{(z/m)^2\, e^{\psi}}{\{R^8[1 + (t/m)^4] + 1 + \frac{1}{3}(r/m)^2\, R^{-4}\}^{1/4}}\right]$$

$$H(r, z) = \int_1^{z/m} e^{2/u}\, du + \frac{1}{2}\left(\frac{r}{z}\right)^2 e^{2m/z}$$

$$K(r, z) = [y + (\pi/2)]R + (\tan x/\tan y)^2$$

Maximally extended Curzon solution in (T, x, Y, ϕ) coordinates



The Curzon solution is extended by two Minkowski half-spaces

The junction surfaces are null surfaces. They are ***event horizons***

The junction across these surfaces is C^∞

The ring singularity is ***naked*** but it is not harmful – any light emanated from it becomes infinitely redshifted at infinity

The major boundary constructions

g-boundary (geodesic boundary) by Geroch
formed by equivalence classes of incomplete causal geodesics
What about other causal curves?

b-boundary (bundle boundary) by Schmidt
this boundary deals with the bundle of frames constructed from the space-time
The b-boundary has been shown, in key examples, to have strange topological properties

c-boundary (causal boundary) by Geroch, Kronheimer and Penrose
the construction is totally based on the causal structure of the space-time
Can be applied to any strongly causal space-time but, again, there are topological issues

Spacetime needs a boundary

A boundary for space-time should include:

regions at ***infinity***

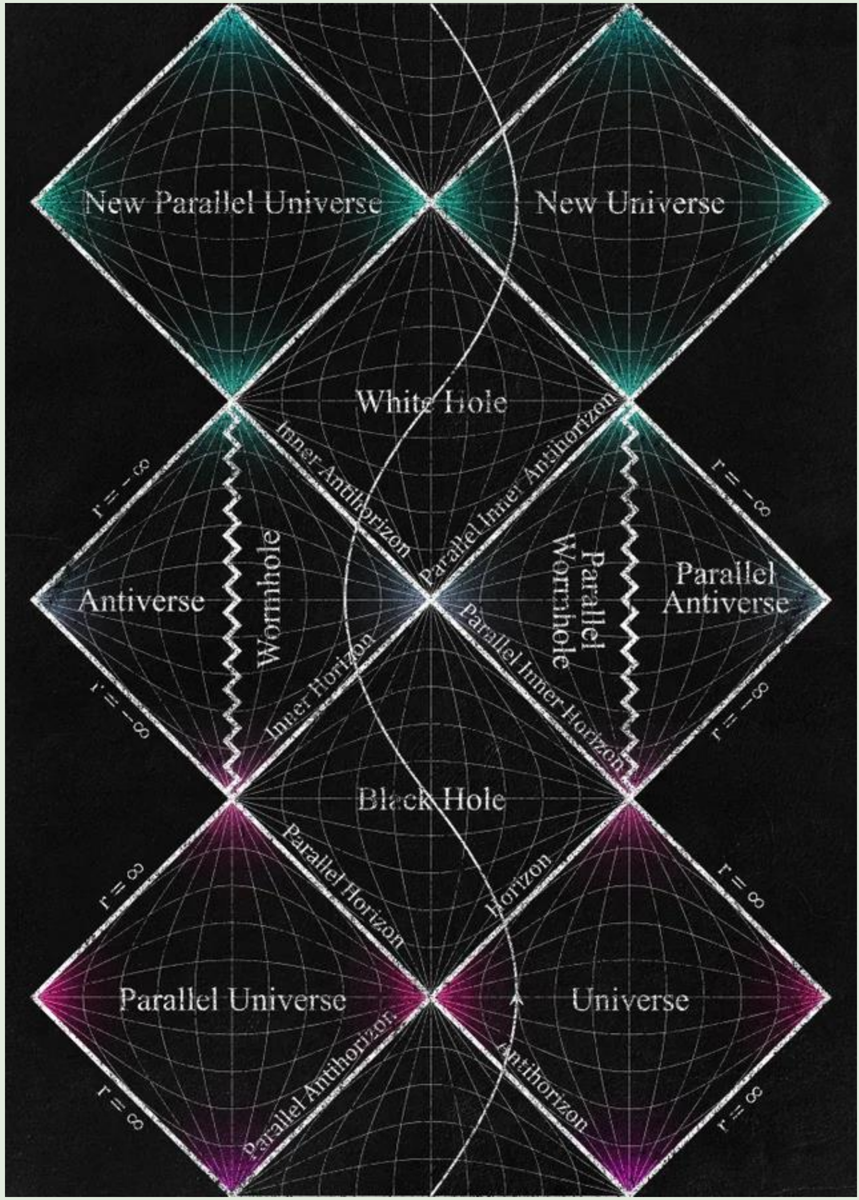
regular points through which the space-time could be extended

singularities – possibly including apparent and directional singularities

We will need to consider classes of curves

Which ones are important - geodesics, curves of bounded acceleration …

What is the best way of attaching a boundary to a spacetime?



The Abstract Boundary (a-boundary)

Scott and Szekeres

We wanted a top-level solution

Where do you start when you have found a raw new exact solution in an arbitrary coordinate system?

We didn't want to require that the space-time is maximally extended

We didn't want to impose causality conditions on the space-time

We wanted the boundary to include everything – singularities, regular points, regions at infinity

Being able to choose the class of curves of interest was important

It was also important to build in flexibility with respect to differentiability

Ultimately, we wanted the a-boundary to be the go-to tool for pursuing singularities

Embeddings

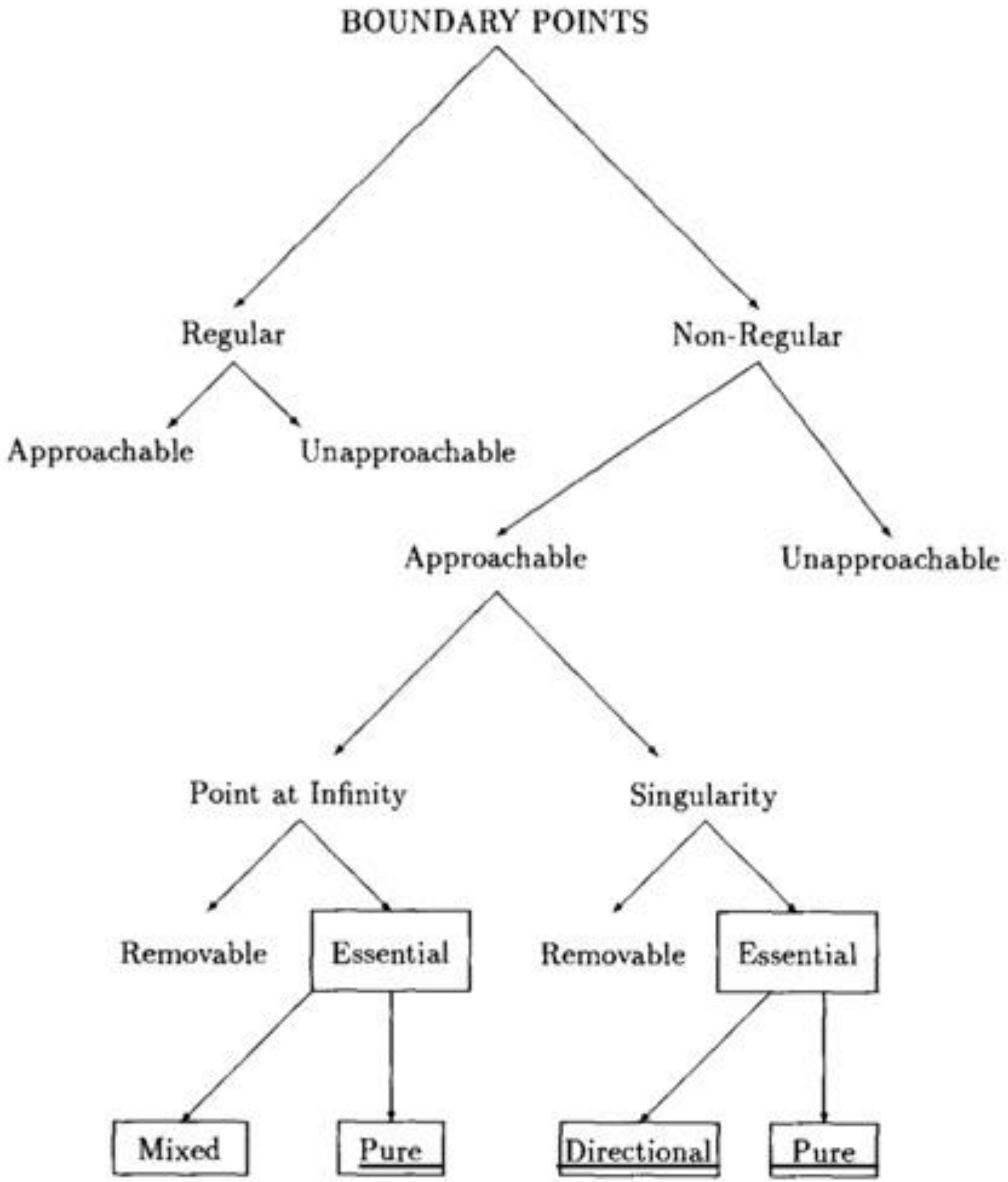
The central idea is to consider all possible embeddings of the space-time into larger manifolds of the same dimension

Each such embedding produces a boundary

Definition 9. An *enveloped manifold* is a triple $(\mathcal{M}, \widehat{\mathcal{M}}, \phi)$ where $\mathcal{M}$ and $\widehat{\mathcal{M}}$ are differentiable manifolds of the same dimension n and ϕ is a C^∞ embedding $\phi : \mathcal{M} \to \widehat{\mathcal{M}}$.

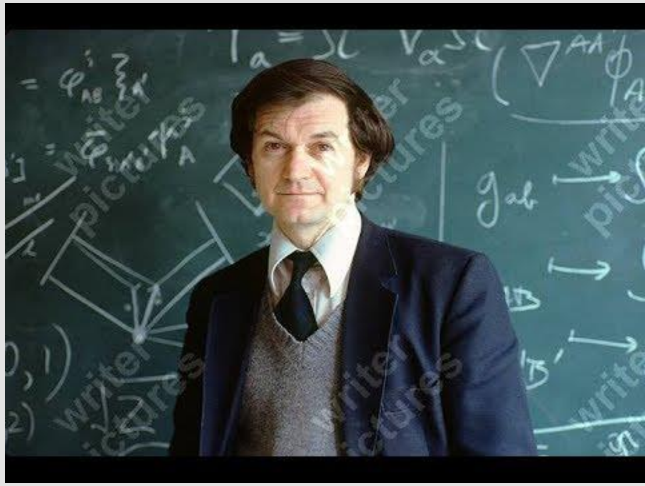
Boundary points in different embeddings can be "compared"

These comparisons lead to the notion of an ***optimal embedding*** and ***optimal boundary***



Schematic classification of boundary points

The singularity theorems of Penrose and Hawking



Singularities are not an artefact arising from symmetry assumptions – they are a prediction of General Relativity

The singularity theorems involve three general elements:

1. an energy condition on the matter in the space-time
2. a causality condition on the space-time
3. a trapping condition – gravity is strong enough somewhere to trap a region

The singularity theorems are incomplete!

The singularity theorems actually predict incomplete, causal geodesics – not singularities!

But WHAT do these incomplete, causal curves begin at or end at?

Is it a singularity? If so, *is it a curvature singularity*? And WHERE is it?

The role of the Abstract Boundary

Two topologies for a manifold together with its a-boundary

The attached point topology

R.A. Barry and S.M. Scott, "The attached point topology of the abstract boundary for spacetime", *Classical and Quantum Gravity* **28**, 165003 (2011)

The strongly attached point topology

R.A. Barry and S.M. Scott, "The strongly attached point topology of the abstract boundary for space-time", *Classical and Quantum Gravity* **31**, 125004 (2014)

Where do the incomplete, causal curves begin or end?

This very general result provides the answer

S.M. Scott and B.E. Whale, "**The Endpoint Theorem**", *Classical and Quantum Gravity* **38**, 065012 (2021)

Theorem 2.1 (The endpoint theorem). *Let $\mathcal{M}$ and $\mathcal{M}_\phi$ be smooth, connected, Hausdorff, paracompact manifolds of dimension n. If $(x_i)_{i\in\mathbb{N}}$ is a sequence of points in $\mathcal{M}$ without an accumulation point, then there exists an open embedding $\phi : \mathcal{M} \to \mathcal{M}_\phi$, such that $\partial\phi(\mathcal{M})$ is diffeomorphic to the $n-1$ dimensional unit ball and the sequence $(\phi(x_i))_{i\in\mathbb{N}}$ converges to some $y \in \partial\phi(\mathcal{M})$.*

We now have a **location** for the singularity theorems "singularities"

The Abstract Boundary can now be unleashed

B.E. Whale, M.J.S.L. Ashley and **S.M. Scott**, "Generalizations of the abstract boundary singularity theorem", *Classical and Quantum Gravity* **32**, 135001 (2015)

Theorem 1.1. *Let $(\mathcal{M}, g)$ be a strongly causal, C^l maximally extended, C^k spacetime $(1 \leqslant l \leqslant k)$. Let $\mathcal{C}$ be the set of affinely parametrized causal geodesics in $\mathcal{M}$. There exists an incomplete curve in $\mathcal{C}$ if and only if the abstract boundary $\mathcal{B}(\mathcal{M})$ contains an abstract C^l essential singularity.*

Theorem 1.2 (The abstract boundary singularity theorem). *Let $(\mathcal{M}, g)$ be a future (past) distinguishing, C^l maximally extended, C^k spacetime $(1 \leqslant l \leqslant k)$ and let $\mathcal{C}$ be the family of generalized affinely parametrized continuous causal curves in $\mathcal{M}$. There exists an incomplete curve in $\mathcal{C}$ if and only if $\mathcal{B}(\mathcal{M})$ contains an abstract C^l essential singularity.*

The Singularity Theorems are now semi-completed

The predicted incomplete, causal curves have an endpoint in an embedding

The singularities have a ***location***

The singularities are ***essential singularities***

They cannot be removed by switching to other embeddings

What remains to complete the singularity theorems?

To show that the predicted singularities are curvature singularities

M.J.S.L. Ashley and S.M. Scott, “Curvature singularities and abstract boundary singularity theorems for space-time”, *Contemporary Mathematics* **337**, 9–19 (2003)

The beginning of gravitational wave data analysis in Australia 1997

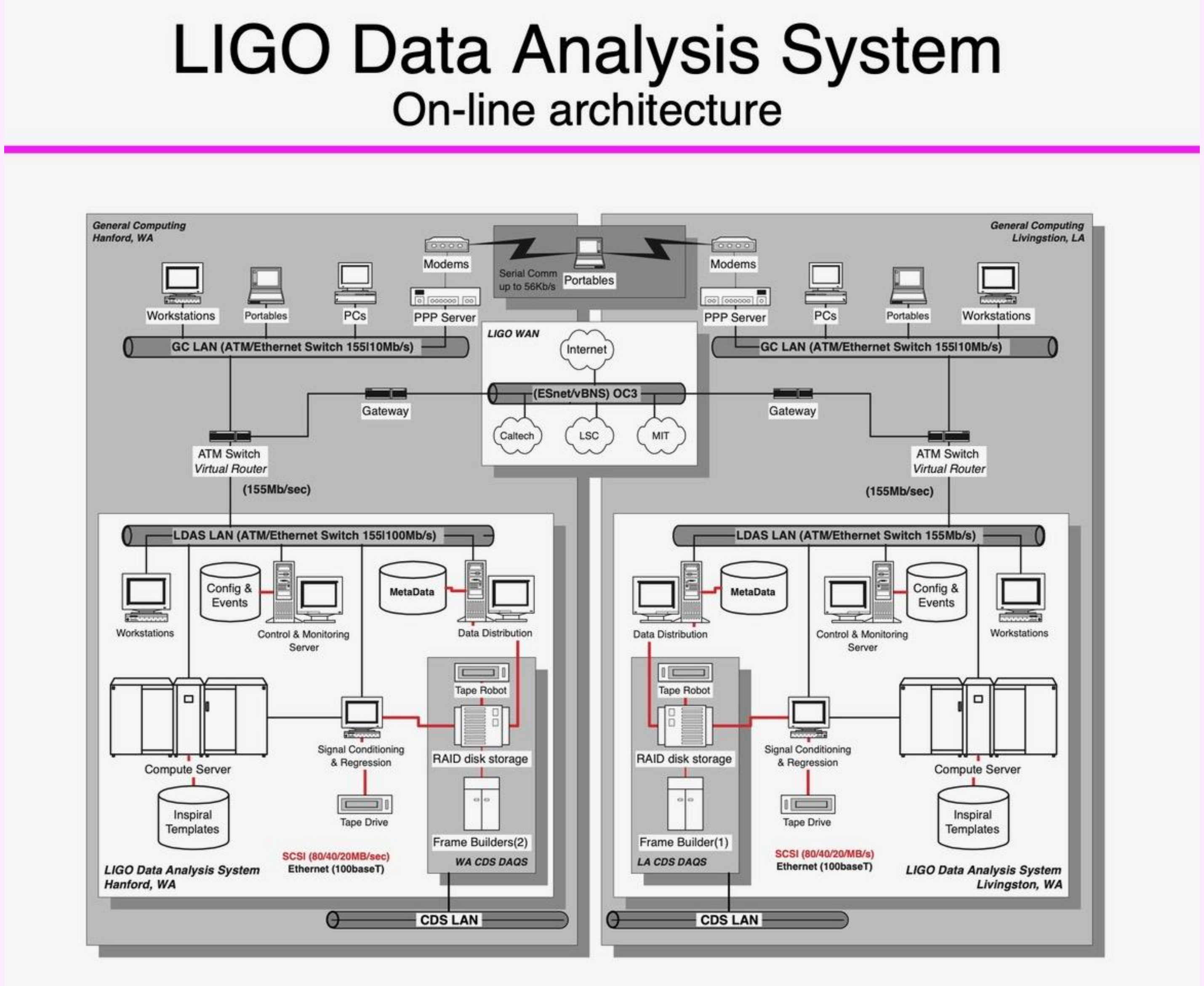
Went to my first LIGO Scientific Collaboration meeting at the Hanford Observatory 12-14 March 1998

Ju Li was there too!

Lots of talking to Albert Lazzarini, Gary Sanders and Kip Thorne …

In 1999 I established a formal collaboration with LIGO in data analysis

Our ANU-based group joined the LIGO Data Analysis System (LDAS) development team based at Caltech



Software contribution to the LIGO Data Analysis System (LDAS) by the ANU Data Analysis Group

- Fast Fourier Transform engine (design, implementation, testing)
- Symmetrised frequency vector (design, implementation, testing)
- Analysis language (design, implementation, testing)
- Mock Data Challenge (implementation, testing)
- Unified Data Type (design, implementation, testing)
- System identification (design, implementation, testing)
- Auto-regression model estimator (design, implementation, testing)
- FIR Whitening action (design, implementation, testing)
- Output-error model estimator (design, implementation, testing)
- Combinatorial Linear Filtering action (design, implementation, testing)
- Line removal (design, implementation, validation)
- Filter coefficient extraction (design, implementation, testing)
- Internal Light-Weight Data (ILWD) parser for MATLAB (design, implementation, testing)
- Coherence action (design, implementation, testing
- Documentation

Antony Searle

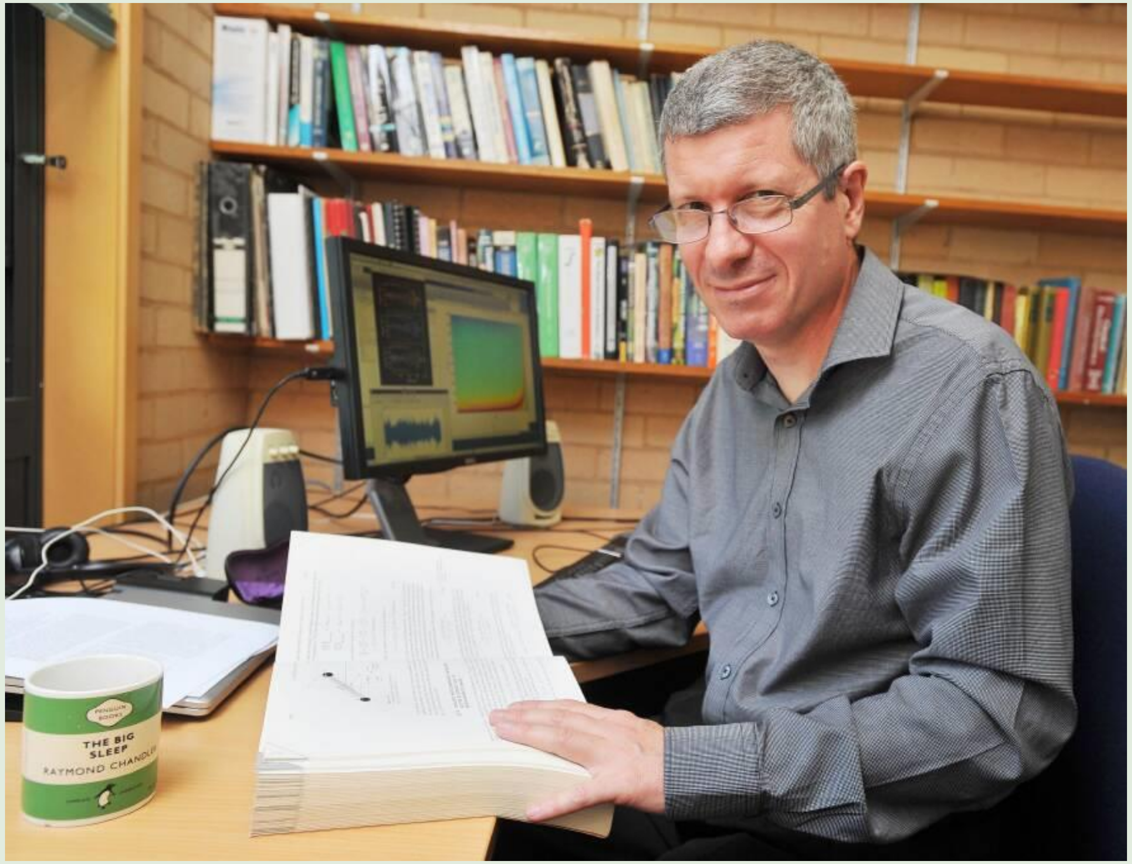
In 1999

Bernard Whiting came over from Florida for a one-year sabbatical

Philip Charlton joined the ANU data group 1999-2000 ⇒ Caltech

– first Australian postdoc in gravitational wave data analysis

Bernard Whiting



Philip Charlton

Noise characterization and spectral line removal

S.M. Scott, P. Charlton, B.F. Whiting, D.E. McClelland and J. Sandeman, "Caltech 40m interferometer characterisation: spectral properties of the data", *Gravitational Wave Detection II, Proceedings of the 2nd TAMA International Workshop on Gravitational Wave Detection* ed. S. Kawamura and N. Mio (Tokyo: Universal Academy Press) (2000) pp241–250

B.F. Whiting, B.L. Coldwell, S.M. Scott, B.J. Evans and D.E. McClelland, "Noise characterisation for laser interferometer gravitational wave detectors", *General Relativity and Gravitation* **32**, 411–423 (2000)

At the LIGO Scientific Collaboration meeting in Rome in 1999 "first light" at LIGO Hanford was announced!

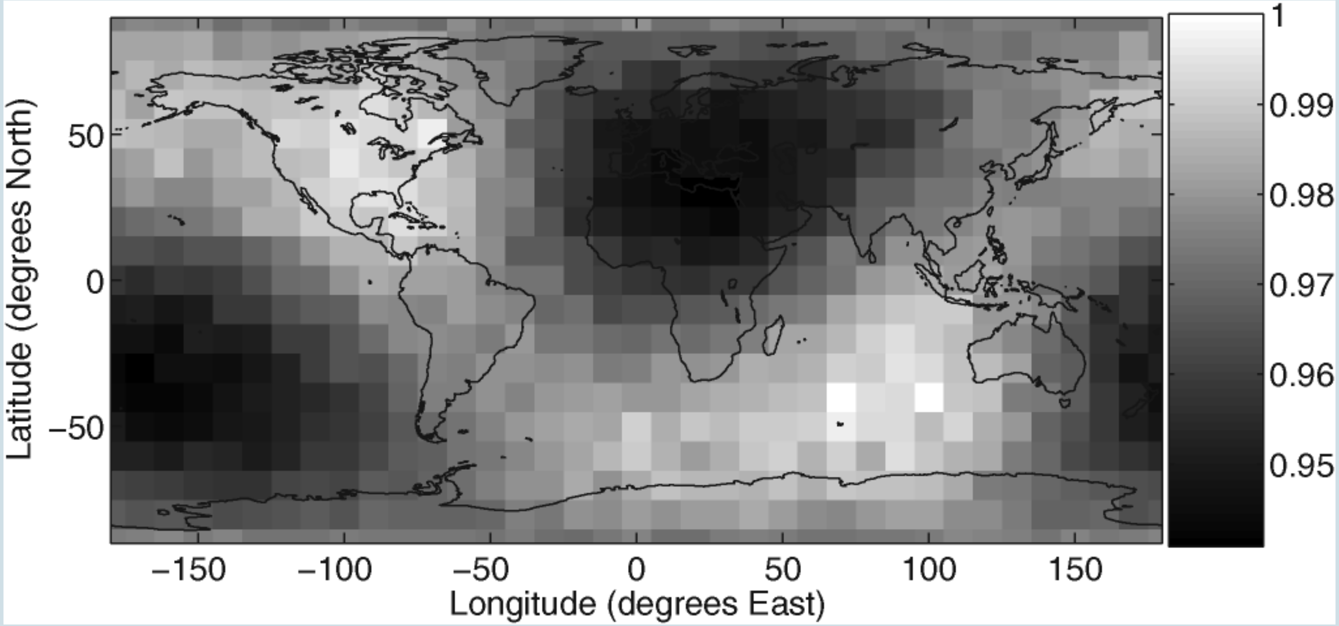
S.M. Scott, D.E. McClelland, A.C. Searle, P. Charlton and B.F. Whiting, "A gaussianity measure for laser interferometer data", *Proceedings of the Ninth Marcel Grossmann Meeting on General Relativity* ed. V.G. Gurzadyan, R.T. Jantzen and R. Ruffini (Singapore: World Scientific) (2002) pp1919–1920

A.C. Searle, S.M. Scott and D.E. McClelland, "Spectral line removal in the LIGO Data Analysis System (LDAS)", *Classical and Quantum Gravity* **20**, S721–S730 (2003)

Optimal location of a new interferometric gravitational wave observatory

A.C. Searle, S.M. Scott and D.E. McClelland, "Network sensitivity to geographical configuration", *Classical and Quantum Gravity* **19**, 1465–1470 (2002)

A.C. Searle, S.M. Scott, D.E. McClelland and L.S. Finn, "Optimal location of a new interferometric gravitational wave observatory", *Physical Review D* **73**, 124014 (2006)



Relative merit of an additional site to augment a network consisting of comparable instruments at the LIGO Hanford, LIGO Livingston, and TAMA sites, in a coherent analysis.

L.S. Finn

Antony Searle – first PhD student to graduate in Australia in gravitational wave data analysis

Data Analysis Infrastructure for Gravitational Wave Astronomy 2004

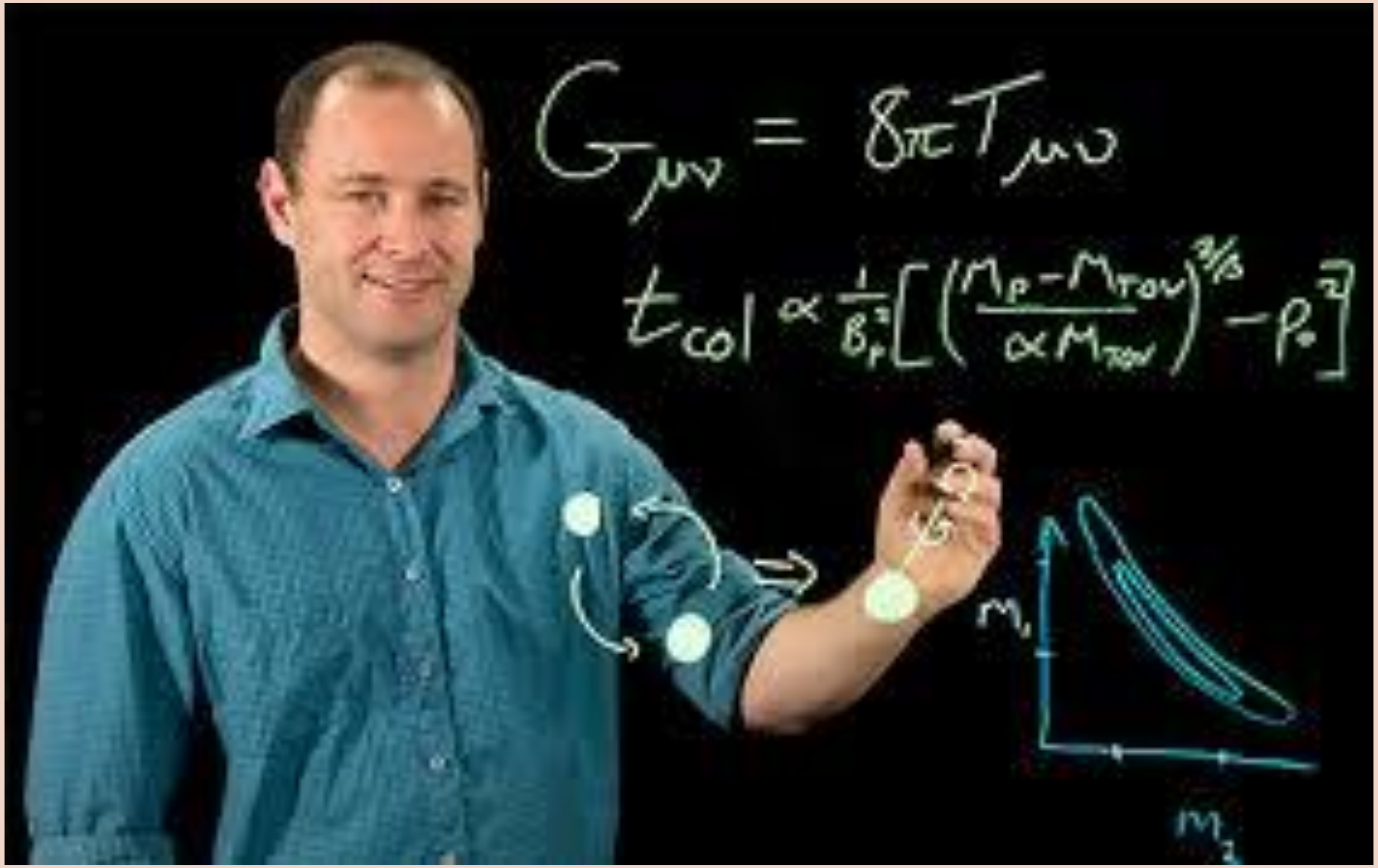
“I have made significant contributions to the data analysis systems of leading observatories, spanning design, implementation, testing, and characterisation of components ranging from basic signal-processing to tailored data conditioning operations. These components have been employed to produce several worlds-best direct observational upper limits on gravitational wave phenomena.

.... I have constructed a suite of models to explore optimal configurations of a global network of observatories for the detection of a variety of proposed gravitational wave source populations, placing particular emphasis on the contribution a proposed Australian gravitational wave observatory would make to the global community.”

3 year ARC Australian Postdoctoral Fellowship 2005-2007 ⇒ Caltech ⇒ Silicon Valley ⇒ Canberra (Liquid Instruments)

Summer Research Scholar 2003-2004

Paul Lasky



Karl Wette Honours thesis 2004 University Medal

Searching for correlations in global environmental noise within the context of gravitational wave detection

Pioneered the exchange of seismometer, power monitor and magnetometer data taken from the LIGO Hanford, LIGO Livingston and Virgo observatories and The ANU Gravitational Wave Facility.

Three seismometers (for three axes), a three-axis magnetometer and a simple grid voltage scaling and filtering circuit.

Designed and undertook a preliminary search for long and short timescale correlations in the merged environmental data from the participating detectors.

Guralp seismometer

K.W. Wette, S.M. Scott and A.C. Searle, “An analysis pipeline for correlated global environmental noise”, *Classical and Quantum Gravity* **22**, S1079–S1086 (2005)

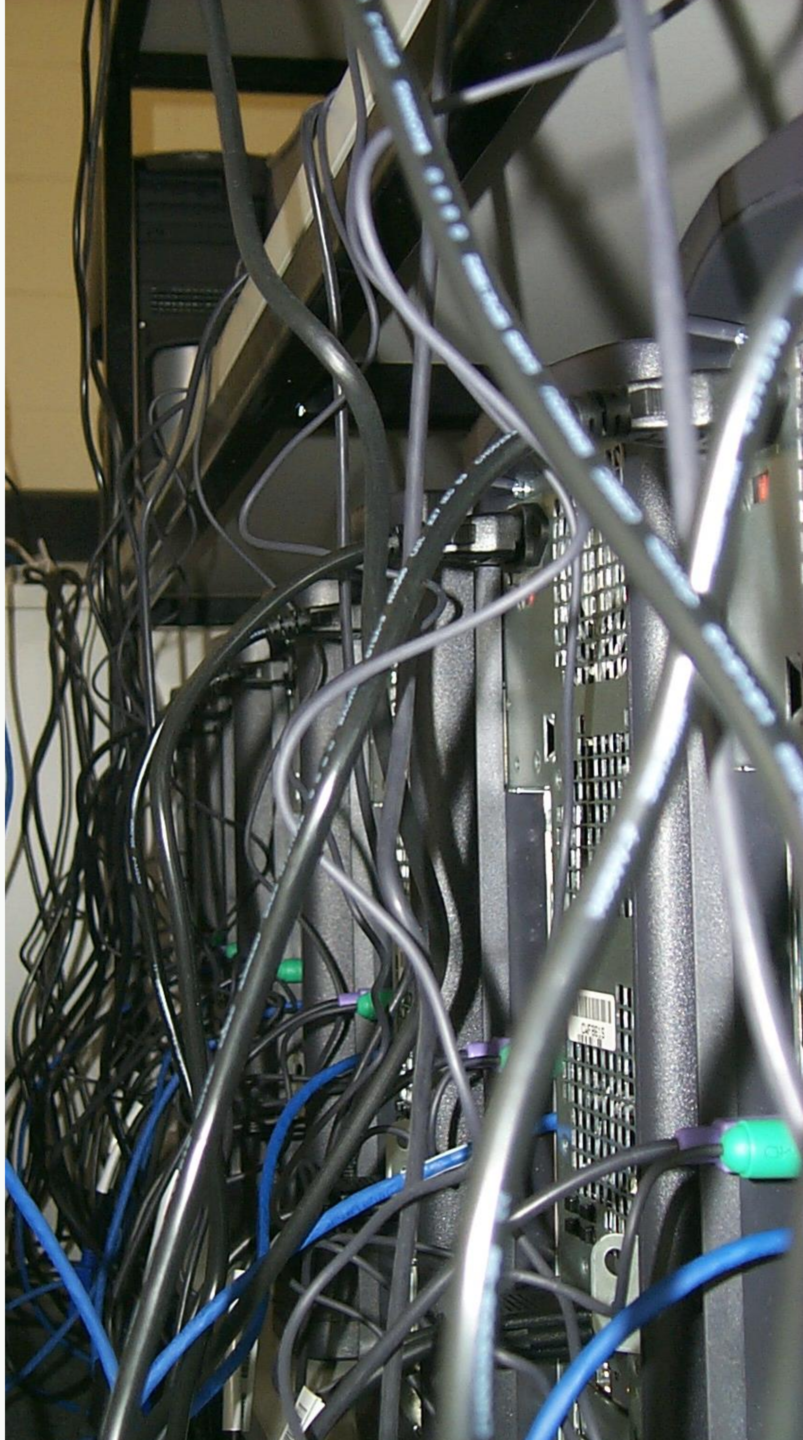
The ACIGA Data Analysis Cluster (ADAC)

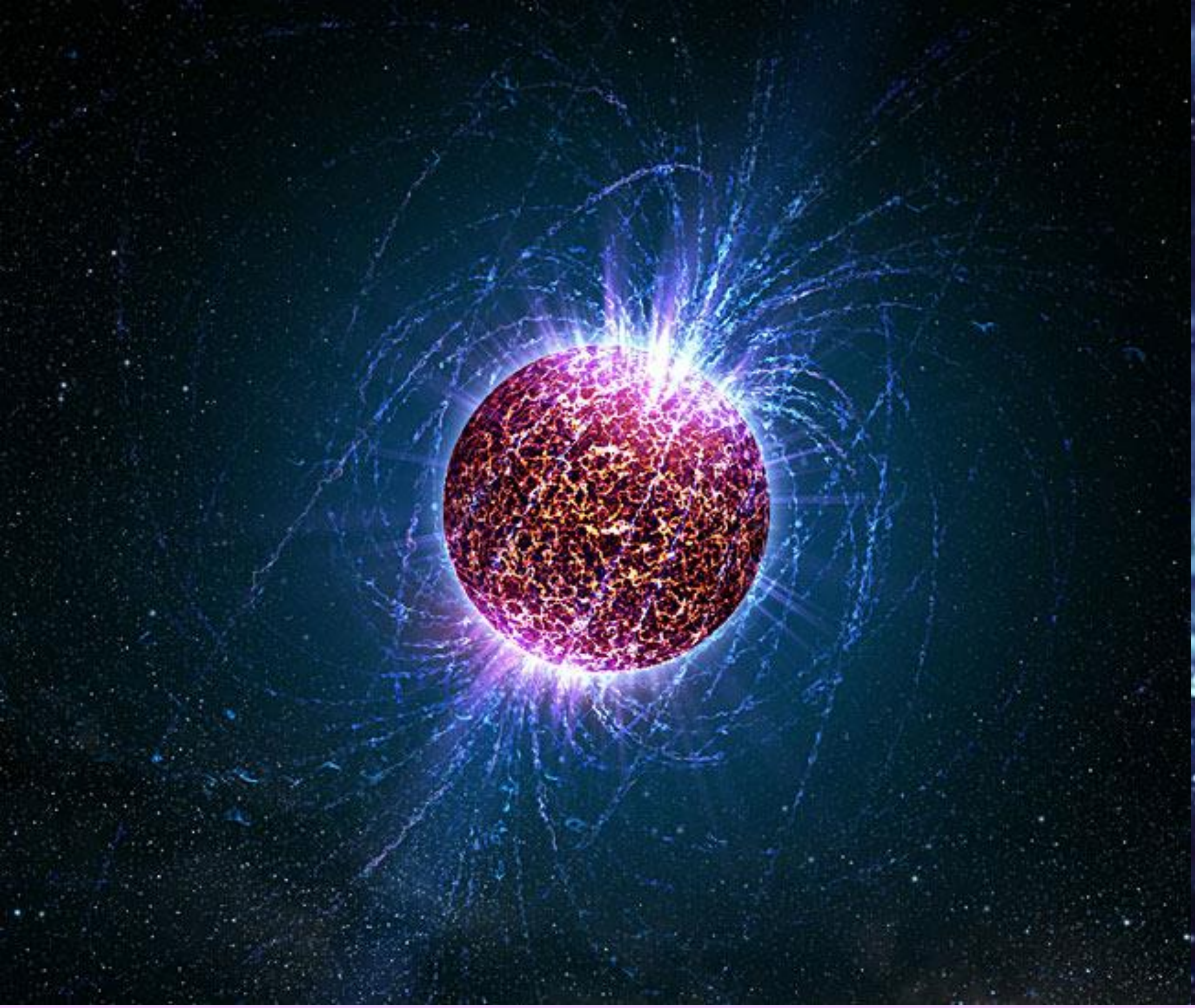
University Research Grant 2001 $23,000
LIGO Gravitational Wave Data Analysis System

"ADAC is a fully-functional LDAS installation in the Department of Physics at The ANU. It consists of three dual-processor servers respectively serving data, performing pipeline pre-processing and managing a Beowulf cluster of eight single-processor nodes, with a terabyte of local storage and a link to the mass data storage system at The ANU Supercomputer Facility. It will give the team local capability to perform, on the extended datasets, the intensive characterization required to fully validate complex algorithms such as line removal, and to employ the algorithms of LDAS for independent ACIGA research on data from the LIGO observatories. The cluster has already been used in the characterization of the performance of line removal tools on actual LIGO data."

"In late 2002 we directly participated in the first science analyses of data taken from LIGO's first observing period, the 'S1 science run'. Our line removal actions were integrated into the stochastic background pipeline, and the impact of correlated spectral lines on the stochastic background search codes was assessed. The analysis culminated in the setting of an upper limit on the strength of a cosmological background of gravitational radiation."

S.M. Scott, A.C. Searle, B.J. Cusack and D.E. McClelland, "The ACIGA data analysis programme", *Classical and Quantum Gravity* **21**, S853–S856 (2004)






A new arrival – Andrew Melatos
Neutron Stars 2002

Karl Wette PhD 2005-2009

Benjamin Owen

Gravitational waves from accreting neutron stars and Cassiopeia A

Karl led the design and implementation of the search, using LIGO S5 data, for gravitational waves from Cassiopeia A whose central compact object is one of the youngest suspected neutron stars in the Galaxy.

Observational upper limits were set on the gravitational wave strain of the compact object which beat the indirect upper limits derived from energy conservation.

This was a flagship program for the LIGO Scientific Collaboration and was the first gravitational search to be carried out under Australian leadership.

K. Wette, B.J. Owen, B. Allen, M. Ashley, J. Betzwieser, N. Christensen, T.D. Creighton, V. Dergachev, I. Gholami, E. Goetz, R. Gustafson, D. Hammer, D.I. Jones, B. Krishnan, M. Landry, B. Machenschalk, D.E. McClelland, G. Mendell, C.J. Messenger, M.A. Papa, P. Patel, M. Pitkin, H.J. Pletsch, R. Prix, K. Riles, L. Sancho de la Jordana, S.M. Scott, A.M. Sintes, M. Trias, J.T. Whelan and G. Woan, "Searching for gravitational waves from Cassiopeia A with LIGO", *Classical and Quantum Gravity* **25**, 235011 (2008)

LIGO Scientific Collaboration: J. Abadie et al., "First search for gravitational waves from the youngest known neutron star", *The Astrophysical Journal* **722**, 1504–1513 (2010)

Andrew Moylan PhD 2004-2008

Highly oscillatory integration, numerical wave optics, and the gravitational lensing of gravitational waves

Andrew developed a general numerical integrator for highly oscillatory functions, and considered the gravitational lensing of gravitational waves.

In the lensing of gravitational waves, the long wavelength, compared with the usual case of optical lensing, can lead to the geometrical optics approximation being invalid, in which case a wave optical solution is needed.

Previously, there had been no automatic integration algorithms capable of solving the irregularly oscillatory ‘diffraction integrals’ that arise in wave-optical gravitational lensing. The new integration algorithm solves these integrals completely automatically.

Using the new numerical method integration the possible effects of gravitational lensing on gravitational waves in two astrophysical scenarios: the lensing by globular clusters of gravitational waves from asymmetric neutron stars in our Galaxy; the lensing by dark matter halos of gravitational waves from the in-spiral phase of merging super-massive black holes

Andrew Moylan

⇒ Stephen Wolfram
⇒ Silicon Valley
⇒ Google (Sydney)

Our group took up a central role in the new LOOCUP project in 2010

Locating and
Observing
Optical
Counterparts to
Unmodeled
Pulses in Gravitational Waves

This has now evolved into the electromagnetic follow-up program

SkyMapper team

Christian Wolf
Christopher Onken
Seo-Won Chang

ARC Discovery Project 2009-2011
Exploring the Transient Universe
Brian Schmidt, Susan Scott, Andrew Melatos

Ra Inta Postdoc 2008 – 2013

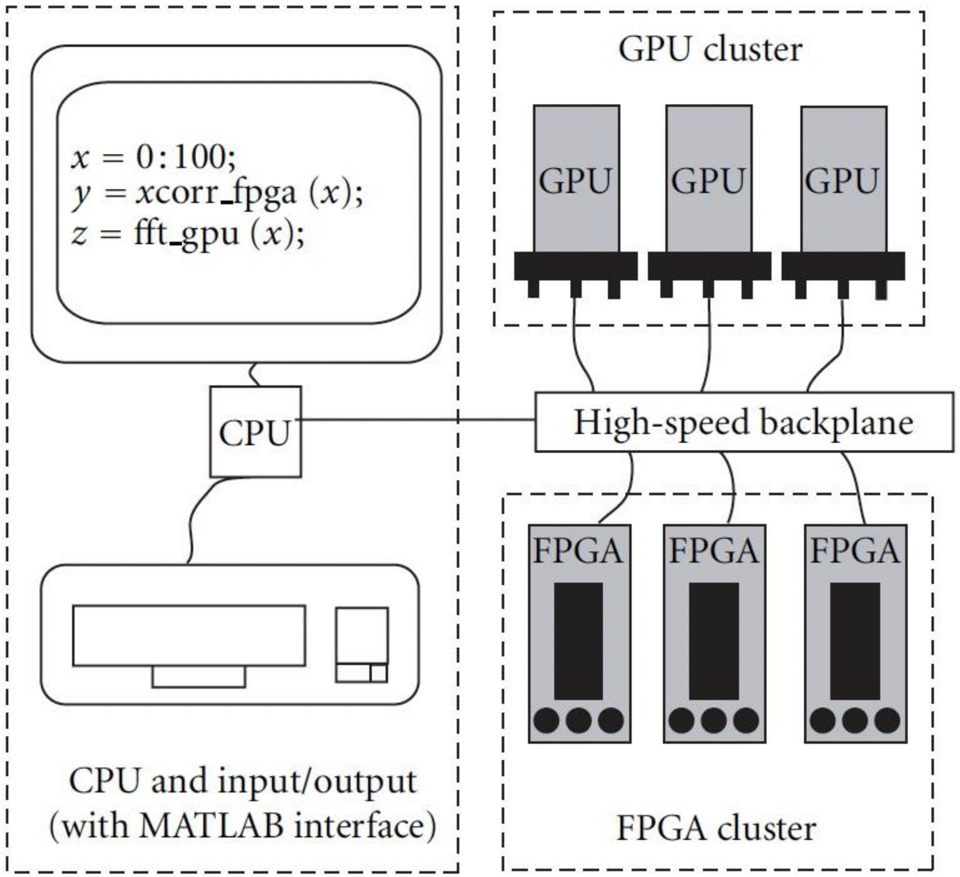


Figure 1: A schematic of our original concept for a heterogeneous CPU/GPGPU/FPGA system.

We introduced an innovative heterogeneous CPU/GPGPU/FPGA desktop computing system (the "Chimera"), built with commercial-off-the-shelf components.

We showed that this platform may be a viable alternative solution to many common computationally bound problems found in astronomy.

We probed the merits of our Chimera system on the entire landscape of parallel computing, through the analysis of representative problems from UC Berkeley's "Thirteen Dwarves."

R. Inta, D.J. Bowman and S.M. Scott, "The Chimera: An off-the-shelf CPU/GPGPU/FPGA hybrid computing platform", *International Journal of Reconfigurable Computing* 2012, 241439

ACGRG9
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The Pinnacles
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2017