Economics of Industrial Ecology

MIT PRESS BOOK SERIES

Industrial Economics
Miriam Smith and Simon Rattle, editors

Engineering and Economics
Samuel Endgrove

Structural Economics: From Beginning to End
Guang Xi

Economics of Industrial Ecology

Materials, Structural Change, and Spatial Scales

Second Edition

Jeroen van den Bergh and Marco A. Jannsen

The MIT Press
Cambridge, Massachusetts
London, England

ISBN etc.

To our families, with gratitude,
—JB and MJ

"*Begin at the beginning," the King said, gravely, "Then go till you come to the end; then stop."*
—Lewis Carroll, *Alice in Wonderland*

"*You can never get a cup of tea large enough or a book long enough to suit me"*
—C. S. Lewis

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Preface

Here is a sample preface [1] that we will usually see before the beginning of the book.

T. Author
May, 2016

I Environmental Policy Analysis: Various Models for Material Flows in the Economy

This is an introduction to the part

Policy analysis may be divided into a number of subspecialities. . .

1 Environmental Policy Analysis with STREAM: A Partial Equilibrium Model for Material Flows in the Economy

Hein Mannaerts

"What star falls unseen?"
—William Faulkner

"All seats provide equal viewing of the universe."
—Museum guide, Hayden Planetarium

Abstract. Commercial robots are shown to be an effective manufacturing tool, but some shortcomings are noted, particularly their lack of mobility.

Robotics has achieved its greatest success to date in the world of industrial manufacturing. Robot arms, or Manipulators, comprise a $2 billion dollar industry. Bolted at its shoulder to a specific position in the assembly line, the robot arm can move with great speed and accuracy to perform repetitive tasks such as spot welding and painting (figure 1.1).

1.1 Introduction

In the electronics industry, manipulators place surface-mounted components with superhuman precision, making the portable telephone and laptop computer possible.

1.1.1 Test subsection

Yet for all of their successes, these commercial robots suffer from a fundamental disadvantage: lack of mobility.

1.1.1.1 Test Subsubsection A fixed manipulator has a limited range of motion that depends on where it is bolted down. In contrast, a mobile robot would be able to travel throughout the manufacturing plant, flexibly applying its talents wherever it is most effective.

Test Paragraph For example, AGV (autonomous guided vehicle) robots (figure 1.7) autonomously deliver parts between various assembly stations by following special electrical guidewires using a custom sensor. The Helpmate service robot transports food and medication throughout hospitals by tracking the position of ceiling lights, which are manually specified to the robot beforehand (figure 1.8). [1]

The Helpmate service robot transports food and medication throughout hospitals by tracking the position of ceiling lights, which are manually specified to the robot beforehand (figure 1.8). Several companies have developed autonomous cleaning robots, mainly for large buildings (figure 1.9).

This book focuses on the technology of mobility: how can a mobile robot move unsupervised through real-world environments to fulfill its tasks? The first challenge is locomotion itself. How should a mobile robot move, and what is it about a particular locomotion mechanism that makes it superior to alternative locomotion mechanisms?

1.1.2 Key issues for Locomotion

Locomotion is the complement of manipulation. In manipulation, the robot arm is fixed but moves objects in the workspace by imparting force to them. In locomotion, the environment is fixed and the robot moves by imparting force to the environment. In both cases, the scientific basis is the study of actuators that generate interaction forces, and mechinisms that implement disired kinematic and dynamic properties. Locomotion and manipulation thus share the same core issues of stability, contact characteristics, and environmental type:

- stability
- number and geometry of contact points
  - center of gravity
  - static/dynamic stability
    - inclination of terrain
    - characteristics of contact
  - contact point/path size and shape
  - angle of contact
- friction
- type of environment
- structure medium (e.g. water, air. soft or hard ground).

For example, Plustech's walking robot provides automatic leg coordination while the human operator chooses an overall direction of travel (figure 1.3).

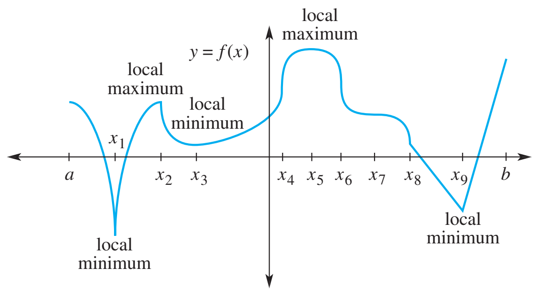

Figure 1.1
Plustech developed the first application-driven walking robot. It is designed to move wood out of the forest. The leg coordination is automated, but navigation is still done by the human operator on the robot.
`http://www.plustech.fi/`

Figure 1.5 depicts an underwater vehicle that controls six propellers to autonomously transports food and medication throughout hospitals by tracking the position of ceiling lights, which are manually specified to the robot beforehand (figure 1.8). Several companies have developed autonomous robots. For example, Plustech's walking robot provides automatic leg coordination while the human operator chooses an overall direction of travel (figure 1.3). Figure 1.5 depicts an underwater vehicle that controls six propellers to autonomously transports food and medication throughout hospitals by tracking the position of ceiling lights, which are manually specified to the robot beforehand (figure 1.8). Several companies have developed autonomous robots.

Table 1.1
Time of the Transition Between Phase 1 and Phase 2[a]

Run	Time (min)
$l1$	260
$l2$	300
$l3$	340
$h1$	270
$h2$	250
$h3$	380
$r1$	370
$r2$	390

[a]Table note text here.

1.1.2.1 Other Commercial Robots Hostile environments such as Mars trigger even more unusual locomotion mechanisms (figure 1.2). In dangerous and inhospitable environments, even on Earth, such teleoperated systems have gained popularity (figure 1.3, 1.4., 1.5). In these cases, the low-level complexities of the robot often make it impossiblefor a human operator to directly control its motions. The human performs localization and cognition activities, but relays on the robot's control scheme to provide motion control stabilize the robot submarine in spite of underwater turbulence and water currents while the operator chooses position goals for the submarine to achieve operate not where humans cannot go but rather share space with humans in human environments (figure 1.6).

1.2 Sample table breaking over pages

Table 1.2
ApJ costs from 1991 to 2013

Year	Subscription cost ($)	Publication charges ($/page)
1991	600	100
1992	650	105
1993	550	103
1994	450	110
1995	410	112
1996	400	114
1997	525	115
1998	590	116
1999	575	115
2000	450	103
2001	490	90
2002	500	88
2003	450	90
2004	460	88
2005	440	79
2006	350	77
2007	325	70
2008	320	65
2009	190	68
2010	280	70
2011	275	68

Table 1.2 (continued)

Year	**Subscription cost ($)**	**Publication charges ($/page)**
2012	150	56
2013	140	55
2014	240	55
2015	245	50

These robots are compelling not for reasons of mobility but because of their autonomy, and so their ability to maintain a sense of position and to navigate without human intervention is paramount For example, AGV (autonomous guided vehicle) robots (figure 1.7) autonomously deliver parts between various assembly stations by following special electrical guidewires using a custom sensor.

$$N = (2k - 1) \tag{1.1}$$

For a biped walker k = 2 legs, the number of possible events N is using a custom sensor. The Helpmate service robot transports food and medication throughout hospitals by tracking positions of ceiling lights, which are specified

$$N = 2l - 1)! = 3! = 31 = 6$$

The six different events are

1. lift right leg
2. left let leg
3. release right leg
4. release left leg
5. lift both legs together
6. release both legs together

Of course, this quickly grows quite large. For example, a robot with six legs has far more gaits theoretically.

1.2.0.1 One Leg The minimum number of legs a legged robot can have is, of course, one. Minimizing the number of legs is beneficial for several reasons. Body mass is particularly important to walking machines, and the single leg minimizes cumulative leg mass.

Omnidirectional locomotion with three spherical wheels The omnidirectional robot depicted in figure 2.23 is based on three spherical wheels, each actuated by one motor. In theis design, the sperical wheels are suspended by three contact points, two given by spherical bearings and one by a wheel connected to the motor axle. This concept provides excellent maneuverability and is simple in design. However, it is limited to flat surfaces and small loads, and it is quite difficult to find round wheels with high friction coefficients.

1.3 Natbib citation mark up

Citations in the New Math book style are made using the Natbib commands.

Single citations may be made using the `\citet` or `\citep` command argument.

Type	**Results**
`\citet{jon90}`	Jones et al. (1990)
`\citet[chap. 2]{jon90}`	Jones et al. (1990, chap. 2)
`\citep{jon90}`	(Jones et al., 1990)
`\citep[chap. 2]{jon90}`	(Jones et al., 1990, chap. 2)
`\citep[see][]{jon90}`	(see Jones et al., 1990)
`\citep[see][chap. 2]{jon90}`	(see Jones et al., 1990, chap. 2)
`\citet*{jon90}`	Jones, Baker, and Williams (1990)
`\citep*{jon90}`	(Jones, Baker, and Williams, 1990)

Multiple citations may be made by including more than one citation key in the `\citet` or `\citep` command argument.

Type	**Results**
`\citet{jon90,jam91}`	Jones et al. (1990); James et al. (1991)
`\citep{jon90,jam91}`	(Jones et al., 1990; James et al. 1991)
`\citep{jon90,jon91}`	(Jones et al., 1990, 1991)
`\citep{jon90a,jon90b}`	(Jones et al., 1990a,b)

See `http://merkel.zoneo.net/Latex/natbib.php` for a reference sheet of natbib commands.

Table 1.3
This is a table that continues over two pages.

Run	Time (min)
*l*1	260
*l*2	300
*l*3	340

Table 1.3 (Continued)

Run	Time (min)
$h1$	270
$h2$	250
$h3$	380
$r1$	370
$r2$	390

2 Gravitational Waves

Abstract. In Einstein's theory of general relativity, gravity is treated as a phenomenon resulting from the curvature of spacetime. This curvature is caused by the presence of mass. Generally, the more mass that is contained within a given volume of space, the greater the curvature of spacetime will be at the boundary of its volume.

2.1 Mass in Spacetime

As objects with mass move around in spacetime, the curvature changes to reflect the changed locations of those objects. In certain circumstances, accelerating objects generate changes in this curvature, which propagate outwards at the speed of light in a wave-like manner. These propagating phenomena are known as gravitational waves. [1]

Gravitational waves are 'ripples' in the fabric of space-time caused by some of the most violent and energetic processes in the Universe. Albert Einstein predicted the existence of gravitational waves in 1916 in his general theory of relativity. Einstein's mathematics showed that massive accelerating objects (such as neutron stars or black holes orbiting each other) would disrupt spacetime in such a way that 'waves' of distorted space would radiate from the source (like the movement of waves away from a stone thrown into a pond). Furthermore, these ripples would travel at the speed of light through the Universe, carrying with them information about their cataclysmic origins, as well as invaluable clues to the nature of gravity itself.

Notation

$g_{\mu\nu}(x^\lambda) = g_{\nu\mu}(x^\lambda)$	symmetric tensor
$g_{\mu\nu} \equiv \eta_{\mu\nu} = \mathrm{diag}(1, 1, 1, 1)$	Minkowski spacetime

The strongest gravitational waves are produced by catastrophic events such as colliding black holes, the collapse of stellar cores (supernovae), coalescing neutron stars or white dwarf stars, the slightly wobbly rotation of neutron stars that are not perfect spheres, and the remnants of gravitational radiation created by the birth of the Universe itself. [2]

> The distance ds between two neighboring events, one with coordinates x^μ and the other with coordinates $x^\mu + \mathrm{d}x^\mu + \mathrm{d}x^\mu$, can be expressed as a function of the coordinates via a symmetric tensor $g_{\mu\nu}(x^\lambda) = g_{\nu\mu}(x^\lambda)$, i.e.,
>
> $$\mathrm{d}s^2 = g_{\mu\nu}\mathrm{d}x\,\mathrm{d}x^\nu \tag{2.1}$$
>
> This is a generalization of the standard measure of distance between two points in Euclidian space. For the Minkowski spacetime (the spacetime of special relativity), $g_{\mu\nu} \equiv \eta_{\mu\nu} = \mathrm{diag}(1,1,1,1)$. (Kostas D. Kokkotas, Article for the Encyclopedia of Physical Science and Technology, 3rd Edition, Volume 7, Academic Press, (2002) `http://www.tat.physik.uni-tuebingen.de/~kokkotas/Teaching/NS.BH.GW_files/GW_Physics.pdf`)

Though gravitational waves were predicted to exist in 1916, actual proof of their existence wouldn't arrive until 1974, 20 years after Einstein's death. Since then, many astronomers have studied the timing of pulsar radio emissions and found similar effects, further confirming the existence of gravitational waves. But these confirmations had always come indirectly or mathematically and not through actual 'physical' contact.

That was the case up until September 14, 2015, when LIGO, for the first time, physically sensed distortions in spacetime itself caused by passing gravitational waves generated by two colliding black holes nearly 1.3 billion light years away! LIGO and its discovery will go down in history as one of the greatest human scientific achievements.

A Dialogue

From the NY Times article of February 11, 2016, *Gravitational Waves Detected, Confirming Einstein's Theory*:

France Córdova Its been decades, through a lot of different technological innovations, [and the foundations advisory board had] really scratched their heads on this one.

Janna Levin I was freaking out!

Robert Garisto [the editor of Physical Review Letters] I got goose bumps while reading the LIGO paper.

The discovery is a great triumph for three physicists Kip Thorne of the California Institute of Technology, Rainer Weiss of the Massachusetts Institute of Technology and Ronald Drever, formerly of Caltech and now retired in

Scotland—who bet their careers on the dream of measuring the most ineffable of Einsteins notions.

> Gravitational waves are not sound waves, and the general public easily could have been led to that conclusion. Sound waves travel only through a medium such as air; ripples in spacetime dont need any medium to support them. Sound waves propagate at the speed of sound; gravitational waves move at the speed of light. Even someone with superhuman hearing could never listen in on a black hole collision.
>
> So why the connection between sound and gravitational waves?
>
> – LIGO detects gravitational waves with frequencies between several hertz and several kilohertz, the sweet spot for human hearing.
> – When two stellar-mass black holes collide, they happen to jiggle spacetime at the same frequency as that of pressure waves in the air that our ears pick up as sound.
>
> The LIGO discovery proves that black hole binaries exist, and that those binaries can merge within the age of the universe. (Physics Today, April 2016 – `scitation.aip.org/content/aip/magazine/physicstoday/news/10.1063/PT.5.2034`)

While the origins of gravitational waves can be extremely violent, by the time the waves reach the Earth they are millions of times smaller and less disruptive. In fact, by the time gravitational waves from the first detection reached LIGO, the amount of space-time wobbling they generated was thousands of times smaller than the nucleus of an atom! Such inconceivably small measurements are what LIGO was designed to make.

Wave passes As a gravitational wave passes an observer, that observer will find spacetime distorted by the effects of strain.

Distances Distances between objects increase and decrease rhythmically as the wave passes, at a frequency corresponding to that of the wave.

This occurs despite such free objects never being subjected to an unbalanced force. The magnitude of this effect decreases proportional to the inverse distance from the source.

I. Inspiraling binary neutron stars are predicted to be a powerful source of gravitational waves as they coalesce, due to the very large acceleration of their masses as they orbit close to one another.

II. However, due to the astronomical distances to these sources, the effects when measured on Earth are predicted to be very small, having strains of less than 1 part in 1020.

    A. Scientists have demonstrated the existence of these waves with ever more sensitive detectors.

1. The most sensitive detector accomplished the task possessing a sensitivity measurement of about one part in 5×1022 (as of 2012) provided by the LIGO and VIRGO observatories.
2. A space based observatory, the Laser Interferometer Space Antenna, is currently under development by ESA.

B. Gravitational waves can penetrate regions of space that electromagnetic waves cannot.

III. They are able to allow the observation of the merger of black holes and possibly other exotic objects in the distant Universe.

Such systems cannot be observed with more traditional means such as optical telescopes or radio telescopes, and so gravitational-wave astronomy gives new insights into the working of the Universe. In particular, gravitational waves could be of interest to cosmologists as they offer a possible way of observing the very early Universe. This is not possible with conventional astronomy, since before recombination the Universe was opaque to electromagnetic radiation.

Precise measurements of gravitational waves will also allow scientists to more thoroughly test the general theory of relativity.

Box 2.1
Frank Wilczek on Einstein and Gravitation

Einstein's general relativity, as a theory of gravitation, is so tight conceptually that it allows only two free parameters: Newtons constant and the cosmological term. It has passed every test that physicists and astronomers have devised. Yet there are reasons to remain dissatisfied.

1. First
First, the strength of gravity is grossly disproportionate to the strength of other forces. If we believe in the unity of natures operating system, how can that be?

1.1. Second
Second, the measured value of the mass density of space devoid of matter—the cosmological term, often called dark energy—is incommensurate with reasonable expectations. Why is it much smaller than theory suggests, yet not zero?

1.1.1. Third
Third, the equations that follow from straightforward quantization of general relativity break down in extreme conditions. What are the consequences? Those issues are important agenda items for the next 100 years of physics. In the boxes, I've indicated a promising way to approach the question of the weakness of gravity. Here I'll offer a few comments on the other issues.

Theorists have estimated several contributions to the cosmological term-positive and negative—whose individual absolute values far exceed the observed total value. Thus the terms observed smallness indicates delicate cancellations that our core theories do not explain. Perhaps, as suggested by Steven Weinberg, the explanation is anthropic. Too large a cosmological term would lead the universe to expand so rapidly that formation of structure in the universe would be inhibited. Neither galaxies nor stars nor planets would form, and thus observers could not emerge. Is that anthropic argument the best physics can do—is resistance futile? Or is some deeper principle at work?

Conceptual difficulty
The conceptual difficulty of reconciling our theory of gravity, general relativity, with the principles of quantum mechanics has been the subject of much hyperbole. I think it is important, therefore, first to bring it down to earth.

(Frank Wilczek, Physics Today, April 2016, `scitation.aip.org/content/aip/magazine/physicstoday/article/69/4/10.1063/PT.3.3137`)

In principle, gravitational waves could exist at any frequency. However, very low frequency waves would be impossible to detect and there is no credible source for detectable waves of very high frequency. Stephen Hawking and Werner Israel list different frequency bands for gravitational waves that could plausibly be detected, ranging from 10–7 Hz up to 1011 Hz.

Acceleration Equations	
With initial velocity	*Starting from rest*
$v_f = v_i + a\Delta t$	$v_f = a\Delta t$
$\Delta d = v_i\Delta t + 1/2a\Delta t^2$	$\Delta d = 1/2a\Delta t^2$
$v_f = \sqrt{v_i^2 + 2a\Delta d}$	$v_f = \sqrt{2a\Delta d}$

In theory, the loss of energy through gravitational radiation could eventually drop the Earth into the Sun. However, the total energy of the Earth orbiting the Sun (kinetic energy + gravitational potential energy) is about 1.14×1036 joules of which only 200 joules per second is lost through gravitational radiation, leading to a decay in the orbit by about 1 × 10–15 meters per day or roughly the diameter of a proton. At this rate, it would take the Earth approximately 1 × 1013 times more than the current age of the Universe to spiral onto the Sun. This estimate overlooks the decrease in r over time, but the majority of

Table 2.1
A table of acceleration equations.

With initial velocity	*Starting from rest*
$v_f = v_i + a\Delta t$	$v_f = a\Delta t$
$\Delta d = v_i\Delta t + 1/2a\Delta t^2$	$\Delta d = 1/2a\Delta t^2$
$v_f = \sqrt{v_i^2 + 2a\Delta d}$	$v_f = \sqrt{2a\Delta d}$

the time the bodies are far apart and only radiating slowly, so the difference is unimportant in this example.

Acceleration Equations	
With initial velocity	*Starting from rest*
$v_f = v_i + a\Delta t$	$v_f = a\Delta t$
$\Delta d = v_i\Delta t + 1/2a\Delta t^2$	$\Delta d = 1/2a\Delta t^2$
$v_f = \sqrt{v_i^2 + 2a\Delta d}$	$v_f = \sqrt{2a\Delta d}$

More generally, the rate of orbital decay can be approximated by [32].

$$\frac{\mathrm{d}r}{\mathrm{d}t} = -\frac{64}{5}\frac{G^3}{c^5}\frac{(m_1m_2)(m_1+m_2)}{r^3},$$

where r is the separation between the bodies, t time, G Newton's constant, c the speed of light, and $m1$ and $m2$ the masses of the bodies. This leads to an expected time to merger of

$$t = \frac{5}{256}\frac{c^5}{G^3}\frac{r^4}{(m_1m_2)(m_1+m_2)}. \tag{2.2}$$

For example a pair of solar mass neutron stars in a circular orbit at a separation of 1.89×108 m (189,000 km) has an orbital period of 1,000

> **Box 2.2**
> Two Theorems and a Corollary
>
> ***Theorem 2.1 (Birkhoff's Theorem)*** *The metric of the Schwarzschild black hole is the unique spherically symmetric solution of the vacuum Einstein field equations.*
>
> $$G^{\mu\nu} = 0.$$
>
> *Stated another way, a spherically symmetric gravitational field in empty space must be static, with a metric given by the Schwarzschild black hole metric.*

Corollary 2.1.1 *A corollary states that the metric inside a spherical cavity inside a spherical mass distribution is the Minkowski metric.*

Theorem 2.2 (Schwarzschild Black Hole) *A black hole with zero charge $Q = 0$ and no angular momentum $J = 0$. The exterior solution for such a black hole is known as the Schwarzschild solution (or Schwarzschild metric), and is an exact unique solution to the Einstein field equations of general relativity for the general static isotropic metric (i.e., the most general metric tensor that can represent a static isotropic gravitational field),*

$$d\tau^2 = B(r)dt^2 - A(r)dr^2 - r^2 \sin^2 \theta \, d\phi^2.$$

In 1915, when Einstein first proposed them, the Einstein field equations appeared so complicated that he did not believe that a solution would ever be found. He was therefore quite surprised when, only a year later, Karl Schwarzschild (1916) discovered one by making the assumption of spherical symmetry.

2.2 Samples of Programming Code

```
procedure bubbleSort( A : list of sortable items )
    n = length(A)
    repeat
       newn = 0
       for i = 1 to n-1 inclusive do
          if A[i-1] > A[i] then
             swap(A[i-1], A[i])
             newn = i
          end if
       end for
       n = newn
    until n = 0
end procedure
```

Algorithm environment:

Algorithm 1 A sample in an algorithm environment.

if $i \geq maxval$ **then**
  $i \leftarrow 0$
else
  if $i + k \leq maxval$ **then**
    $i \leftarrow i + k$
  end if
end if

Box 2.3
Two examples of Programming Code

```
procedure bubbleSort( A : list of sortable items )
    n = length(A)
    repeat
       newn = 0
       for i = 1 to n-1 inclusive do
          if A[i-1] > A[i] then
             swap(A[i-1], A[i])
             newn = i
          end if
       end for
       n = newn
    until n = 0
end procedure
```

And

if $i \geq maxval$ **then**
  $i \leftarrow 0$
else
  if $i + k \leq maxval$ **then**
    $i \leftarrow i + k$
  end if
end if

Exercises

1. For Hooker's data, Exercise 1.2, use the Box and Cox and Atkinson procedures to determine a appropriate transformation of PRES in the regression of PRES on TEMP. find $\hat{\lambda}$, $\tilde{\lambda}$, the score test, and the added variable plot for the score. Summarize the results.

a) The following data were collected in a study of the effect of dissolved sulfur on the surface tension of liquid copper (Baes and Killogg, 1953).

x = Weight % sulfur	Y= Decrease in Surface Tension (dynes/cm), two Replicates	
0.034	301	316
0.093	430	422
011.30	593	586

b) Find the transformations of X and Y sot that in the transformed scale the regression is linear.

c) Assuming that X is transformed to $\ln(X)$, which choice of Y gives better results, Y or $\ln(Y)$? (Sclove, 1972).

i. In the case of Δ_1? **ii.** In the case of Δ_2?

2. Examine the Longley data, Problem 3.3, for applicability of assumptions of the linear model.

a) In the case of Γ_1? **b)** In the case of Γ_2?

$$t = \frac{5}{256} \frac{c^5}{G^3} \frac{r^4}{(m_1 m_2)(m_1 + m_2)}.$$

Chapter Appendix: Dark Matter is not composed of Black Holes

A.1 The Canada France Hawaii Lensing Survey

Did you know that less than 4% of our Universe is made up of regular matter - the type that makes up the Earth, the planets and the stars? The rest is 'dark' and invisible, but we know that it is there through its effects on the regular matter that we can see. The gravity of Dark Matter causes galaxies to clump together in a giant cosmic web, and Dark Energy is pushing space itself apart at an accelerated rate. With some of the world's best telescopes we can directly witness the ongoing battle between these two strange entities.

A.1.1 CFHTL

The Canada-France-Hawaii Telescope Lensing Survey uses an innovative technique called gravitational lensing to observe the invisible dark matter in our Universe. Using data accumulated over five years by the CFHT Legacy Survey, the CFHTLenS team have analysed the images of over 10 million galaxies. The light emitted by these galaxies has taken nearly half the age of the Universe to reach us and has been bent and distorted by the massive clumps of dark matter it has passed by. Exploiting this fact that 'mass bends light', as predicted by Einstein, we have privileged access to the mysterious components of the Universe that cannot otherwise be observed.

A.2 Dark Matter and Black Holes

We know that dark matter exists because of our mathematical graphs of how fast the material in a galaxy is rotating in relation to the center of the galaxy (where most of the galactic material is located). And as a result of these graphs, we know that dark matter surrounds galaxies. In the end, the farther out you go, the more mass grows. . . and it grows by a lot. So in short, we know that dark matter isnt just some black hole that exists out in the middle of intergalactic space based on the way that galaxies rotate and evolve over time.

As Emma Grocutt, from the CFHTL Survey notes:

> "The most interesting thing about dark matter is not simply that we can't see it, it's that we know dark matter is not made of the same stuff as normal baryonic matter. This is actually why we can't see it—baryons interact with each other through gravity, nuclear forces and the electrostatic force. These interactions are what allow baryonic matter (such as stars) to emit light, and what prevent you from putting your hand through a table—the particles of your hand are electrostatically repelled from the particles in the table. Dark matter, however, only interacts through gravity. This is why we see its effects on the motions of galaxies and stars, but why we can't see it directly; it does not emit or absorb light. Dark matter particles can also pass through regular matter almost completely undetected since they don't interact electrostatically, meaning we can't touch it or sense it in any direct way." (`http://futurism.com/the-quest-for-dark-matter-could-the-missing-universe-be-black-holes-2/`)

Notes for Chapter 2

1. Prof. Gabriela González, from Louisiana State University, said: "We have discovered gravitational waves from the merger of black holes. It's been a very long road, but this is just the beginning.

   Now that we have the detectors to see these systems, now that we know binary black holes are out there - we'll begin listening to the Universe."

2. "Gravitational waves go through everything. They are hardly affected by what they pass through, and that means that they are perfect messengers," said Prof Bernard Schutz, from Cardiff University, UK.

“The information carried on the gravitational wave is exactly the same as when the system sent it out; and that is unusual in astronomy. We can’t see light from whole regions of our own galaxy because of the dust that is in the way, and we can’t see the early part of the Big Bang because the Universe was opaque to light earlier than a certain time.

With gravitational waves, we do expect eventually to see the Big Bang itself,” he told the BBC.

In addition, the study of gravitational waves may ultimately help scientists in their quest to solve some of the biggest problems in physics, such as the unification of forces, linking quantum theory with gravity.

A Evaluating the significance of the proof of gravity waves

A.1 On a par with determination of structure of DNA

Prof Karsten Danzmann, from the Max Planck Institute for Gravitational Physics and Leibniz University in Hannover, Germany, is a European leader on the collaboration.[1]

He said the detection was one of the most important developments in science since the discovery of the Higgs particle, and on a par with the determination of the structure of DNA.

"There is a Nobel Prize in it—there is no doubt," he told the BBC.

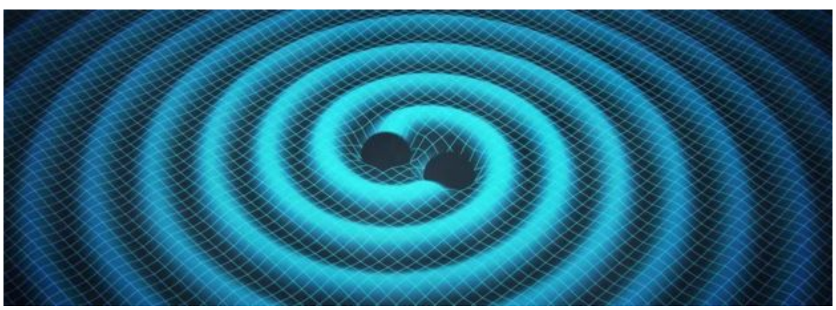

Figure A.1
Graphic showing two black holes generating gravity waves.

"It is the first ever direct detection of gravitational waves; it's the first ever direct detection of black holes and it is a confirmation of General Relativity because the property of these black holes agrees exactly with what Einstein predicted almost exactly 100 years ago."

$$d\tau^2 = B(r)dt^2 - A(r)dr^2 - r^2 \sin^2\theta\, d\phi^2. \tag{A.1}$$

[1] Text and graphics from http://www.bbc.com/news/science-environment-35524440

Figure A.2
(landscape figure) Graphic showing two black holes generating gravity waves.

A.2 Ripples in the fabric of space-time

- Gravitational waves are a prediction of the Theory of General Relativity
- Their existence has been inferred by science but only now directly detected
- They are ripples in the fabric of space and time produced by violent events
- Accelerating masses will produce waves that propagate at the speed of light
- Detectable sources ought to include merging black holes and neutron stars
- Ligo fires lasers into long, L-shaped tunnels; the waves disturb the light
- Detecting the waves opens up the Universe to completely new investigations

A.2.1 Stephen Hawking Agrees on Importance

That view was reinforced by Prof Stephen Hawking, who is an expert on black holes.[2] Speaking exclusively to BBC News, he said he believed that the detection marked a key moment in scientific history. [1]

"Gravitational waves provide a completely new way at looking at the Universe. The ability to detect them has the potential to revolutionise astronomy. This discovery is the first detection of a black hole binary system and the first observation of black holes merging," he said.

"Apart from testing (Albert Einstein's theory of) General Relativity, we could hope to see black holes through the history of the Universe. We may even see relics of the very early Universe during the Big Bang at some of the most extreme energies possible."

A.2.2 Too beautiful to be true?

We found a beautiful signature of the merger of two black holes and it agrees exactly - fantastically - with the numerical solutions to Einstein equations... it looked too beautiful to be true," said Prof Danzmann.

[2] Perhaps somewhat immodestly, this claim is made on Hawking's website (`www.hawking.org.uk`): "Stephen Hawking is regarded as one of the most brilliant theoretical physicists since Einstein." Though, of course, it may well be true!

Table A.1
More relevant tabular information.

Star	Height	d_x	d_y	n	χ^2	R_{maj}	R_{min}	P^a	PR_{maj}	PR_{min}	Θ^b
1	33472.5	-0.1	0.4	53	27.4	2.065	1.940	3.900	68.3	116.2	-27.639
2	27802.4	-0.3	-0.2	60	3.7	1.628	1.510	2.156	6.8	7.5	-26.764
3	29210.6	0.9	0.3	60	3.4	1.622	1.551	2.159	6.7	7.3	-40.272
4	32733.8	-1.2[c]	-0.5	41	54.8	2.282	2.156	4.313	117.4	78.2	-35.847
5	9607.4	-0.4	-0.4	60	1.4	1.669[c]	1.574	2.343	8.0	8.9	-33.417
6	31638.6	1.6	0.1	39	315.2	3.433	3.075	7.488	92.1	25.3	-12.052

[a] Sample footnote for table A.1 that was generated with the LaTeX table environment
[b] Yet another sample footnote for table A.1
[c] Another sample footnote for table A.1

Glossary

Absolute Zero The lowest temperature possible, equivalent to -273.15^{deg}C (or 0^{deg} on the absolute Kelvin scale), at which point atoms cease to move altogether and molecular energy is minimal. The idea that it is impossible, through any physical process, to lower the temperature of a system to zero is known as the Third Law of Thermodynamics.

Alpha Particle (Alpha Decay) A particle of 2 protons and 2 neutrons (essentially a helium nucleus) that is emitted by an unstable radioactive nucleus during radioactive decay. It is a relatively low-penetration particle due its comparatively low energy and high mass.

Angular Momentum A measure of the momentum of a body in rotational motion about its centre of mass. Technically, the angular momentum of a body is equal to the mass of the body multiplied by the cross product of the position vector of the particle with its velocity vector. The angular momentum of a system is the sum of the angular momenta of its constituent particles, and this total is conserved unless acted on by an outside force.

Anthropic Principle The idea that the fundamental constants of physics and chemistry are just right (or "fine-tuned") to allow the universe and life as we know it to exist, and indeed that the universe is only as it is because we are here to observe it. Thus, we find ourselves in the kind of universe, and on the kind of planet, where conditions are ripe for our form of life.

Antimatter Pair production and pair annihilation of hydrogen and antihydrogen particles. A large accumulation of antiparticles—antiprotons, antineutrons and positrons (antielectrons)—which have opposite properties to normal particles (e.g. electrical charge), and which can come together to make antiatoms. When matter and antimatter meet, they self-destruct in a burst of high-energy photons or gamma rays. The laws of physics seem to predict a pretty much 50/50 mix of matter and antimatter, despite the observable universe apparently consisting almost entirely of matter, known as the "baryon asymmetry problem".

Exercises

1. For Hooker's data, Exercise 1.2, use the Box and Cox and Atkinson procedures to determine a appropriate transformation of PRES in the regression of PRES on TEMP. find $\hat{\lambda}$, $\tilde{\lambda}$, the score test, and the added variable plot for the score. Summarize the results.

a) The following data were collected in a study of the effect of dissolved sulfur on the surface tension of liquid copper (Baes and Killogg, 1953).

x = Weight % sulfur		Y= Decrease in Surface Tension (dynes/cm), two Replicates	
0.	034	301	316
0.	093	430	422
0.	30	593	586

b) Find the transformations of X and Y sot that in the transformed scale the regression is linear.

c) Assuming that X is transformed to $\ln(X)$, which choice of Y gives better results, Y or $\ln(Y)$? (Sclove, 1972).

i. In the case of Δ_1? **ii.** In the case of Δ_2?

2. Examine the Longley data, Problem 3.3, for applicability of assumptions of the linear model.

a) In the case of Γ_1? **b)** In the case of Γ_2?

$$t = \frac{5}{256} \frac{c^5}{G^3} \frac{r^4}{(m_1 m_2)(m_1 + m_2)}.$$

Notes

Notes for Frontmatter

1. This is the first test of the note command.

Notes for Chapter 1

1. Several companies have developed autonomous cleaning robots, mainly for large buildings (figure 1.9). One such cleaning robot is in use at the Paris Metro. Other specialized cleaning robots, AGV (autonomous guided vehicle) robots (figure 1.7) autonomously deliver parts between various assembly stations by following special electrical guidewires using a custom sensor.

Notes for Chapter 2

1. Prof. Gabriela González, from Louisiana State University, said: "We have discovered gravitational waves from the merger of black holes. It's been a very long road, but this is just the beginning.

   Now that we have the detectors to see these systems, now that we know binary black holes are out there - we'll begin listening to the Universe."

2. "Gravitational waves go through everything. They are hardly affected by what they pass through, and that means that they are perfect messengers," said Prof Bernard Schutz, from Cardiff University, UK.

   "The information carried on the gravitational wave is exactly the same as when the system sent it out; and that is unusual in astronomy. We can't see light from whole regions of our own galaxy because of the dust that is in the way, and we can't see the early part of the Big Bang because the Universe was opaque to light earlier than a certain time.

With gravitational waves, we do expect eventually to see the Big Bang itself," he told the BBC.

In addition, the study of gravitational waves may ultimately help scientists in their quest to solve some of the biggest problems in physics, such as the unification of forces, linking quantum theory with gravity.

Notes for Appendix A

1. Stephen Hawking said that the detection of gravity waves marked a key moment in scientific history.

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