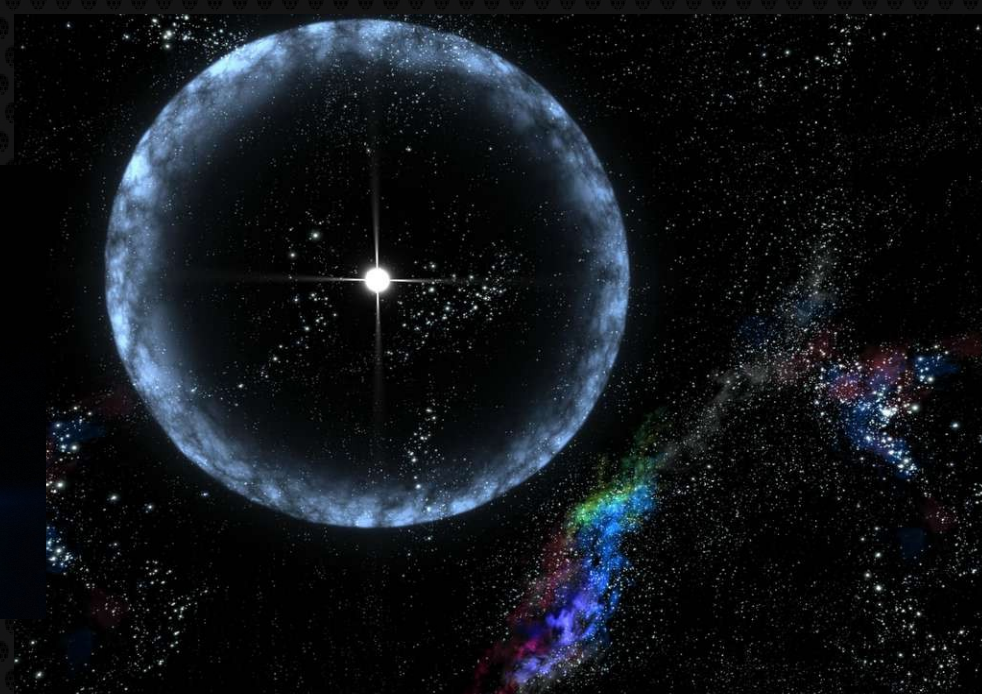
Gravitational Waves Seminar
Friday, October 24, 2014

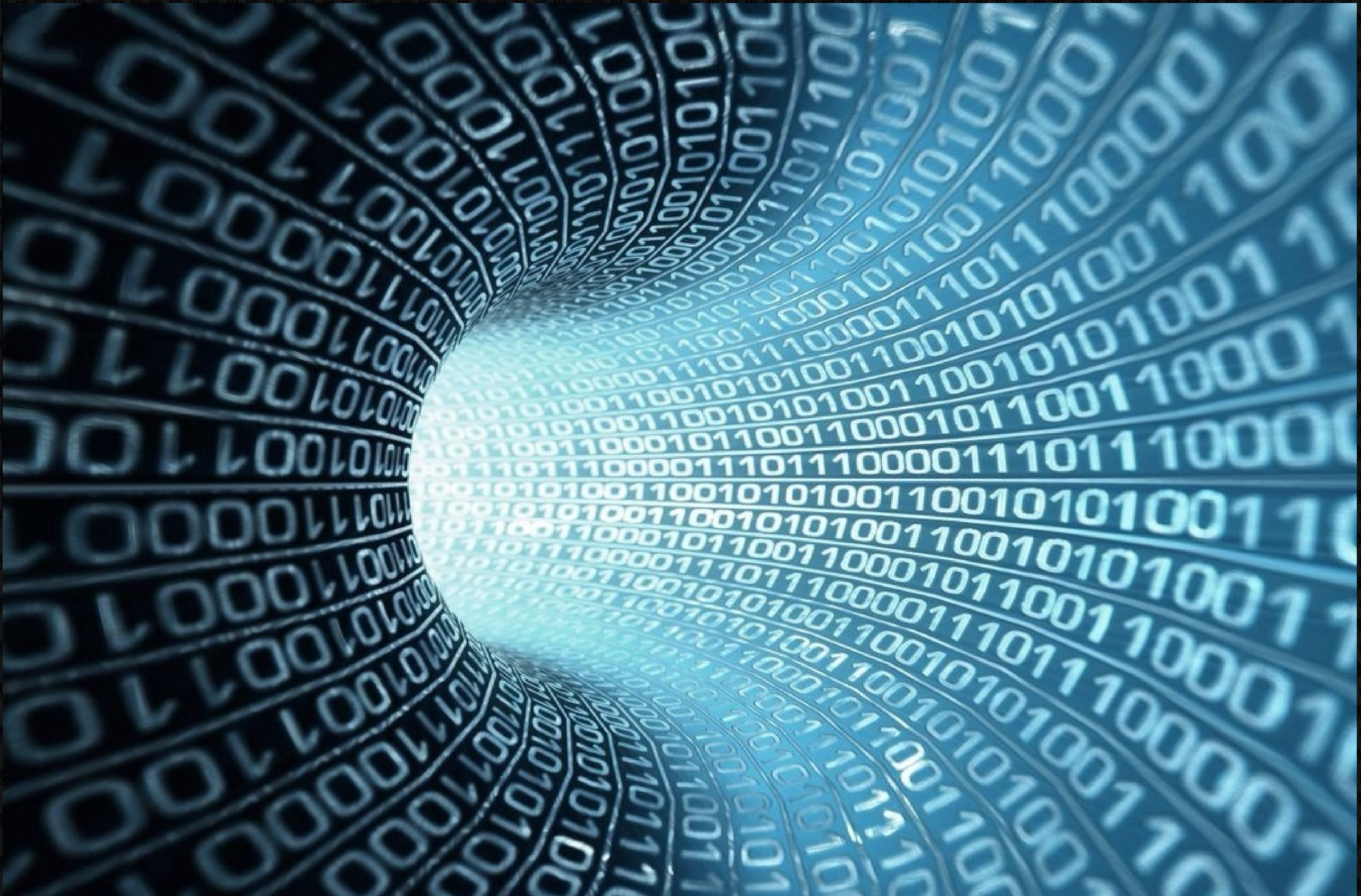
Cardiff University
Prifysgol Caerdydd

CONNECTIONS

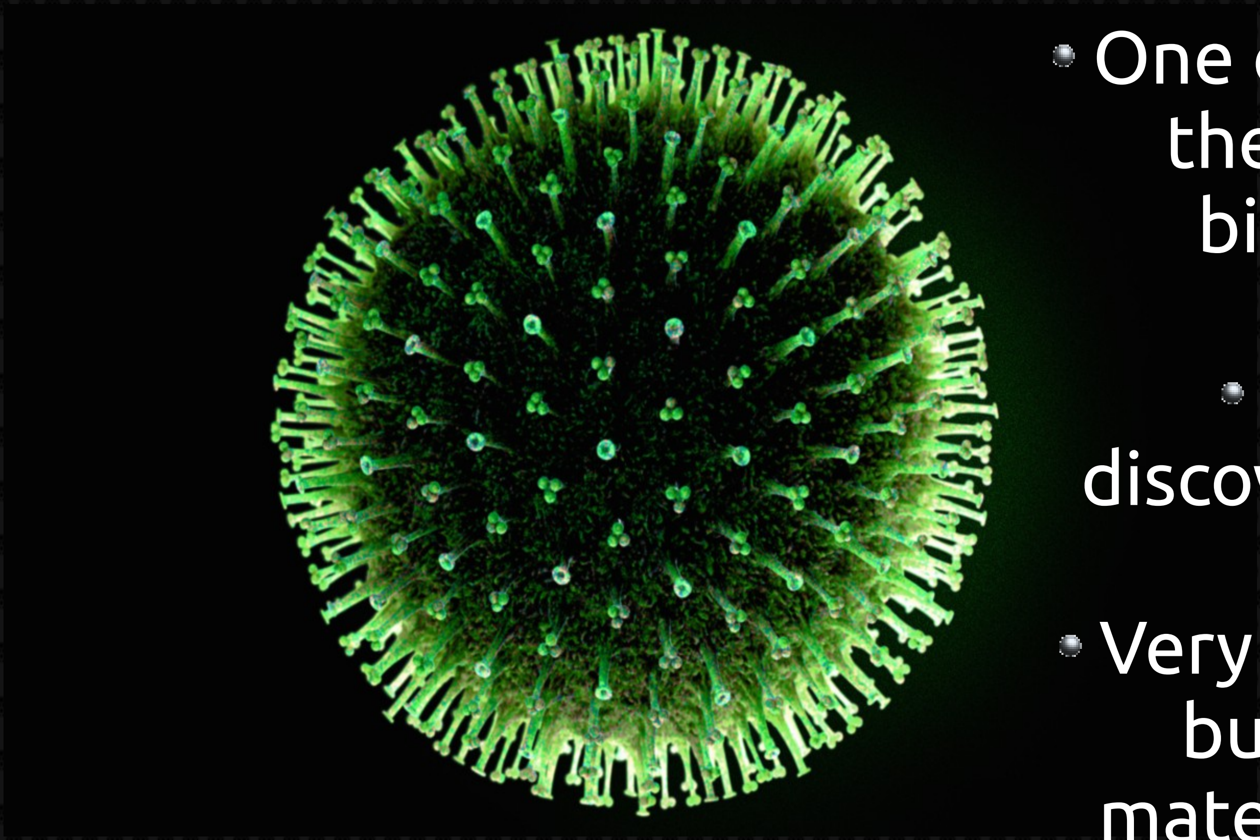
Overview: from small to big



Overview: from small to big



Very small: one virus



- One of the simplest, yet the *most abundant* biological entity;
- Fairly recently discovered (late 1890s);
- Very simple structure: a bundle of genetic material (RNA or DNA) encased in a protein shell; very small: 200-400 nm;

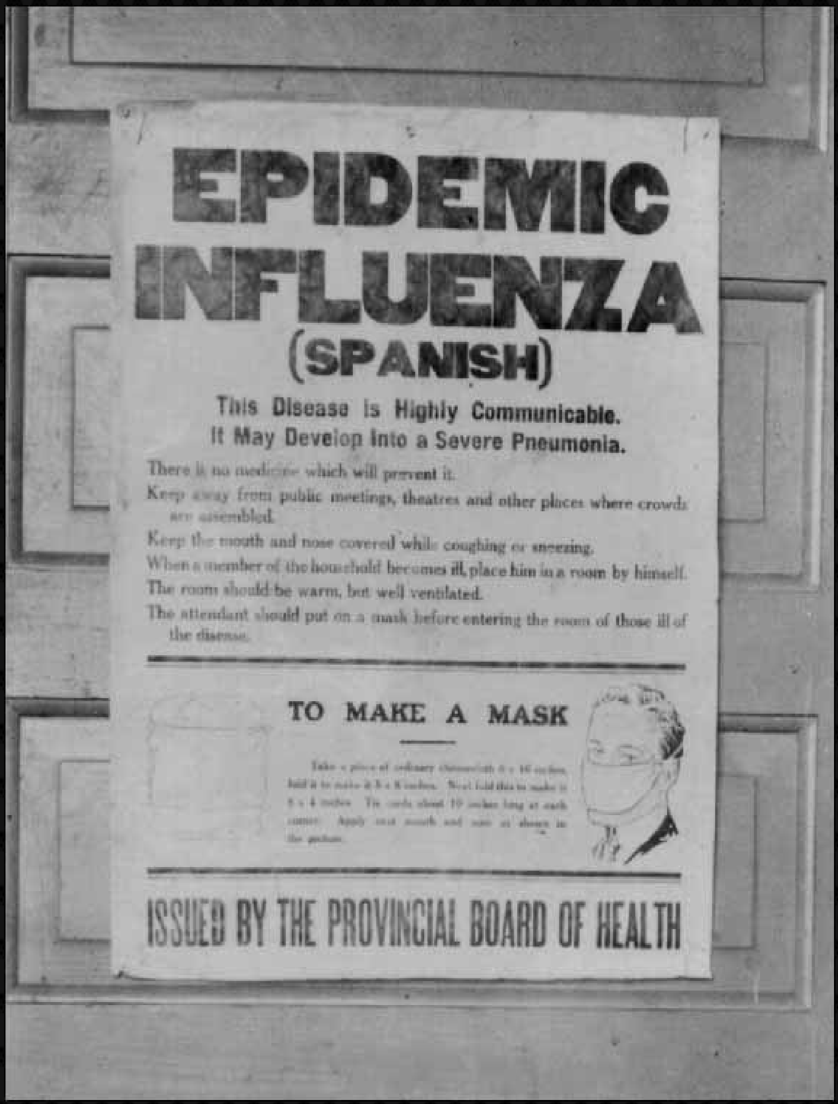
One virus: what it does

- Like a Somali pirate, It hijacks a healthy cell (target) and transfers its genetic material;
- The cell becomes hard-wired to start producing replicas of the original virus;
- It will do so until its premature and violent death: either the viral genetic material kills the cell or, in most cases, it will explode releasing the new viral particles;

Many viruses: serial killers

Spanish flu – A/H1N1

Many viruses: serial killers



- The Spanish flu (1918-1920) spread across the Globe killing 50-100 million people;
- Caused by a mutation from birds to pigs to humans;
- Named Spanish flu due to wartime censorship that was not in effect in Spain (neutral), true origin was France;

Conventional (lab) virology

unconventional

Computational virology

Use mathematical models of viral dynamics and computer power to evaluate virus parameters → predict viral life-cycle and mutations → prevention and treatment (drugs);

No latent phase

$$\frac{dT}{dt} = -\beta TV$$
$$\frac{dI}{dt} = \beta TV - \delta I \qquad (1)$$
$$\frac{dV}{dt} = pI - cV$$

or with a latent phase

$$\frac{dT}{dt} = -\beta TV$$
$$\frac{dE}{dt} = \beta TV - kE \qquad (2)$$
$$\frac{dI}{dt} = kE - \delta I$$
$$\frac{dV}{dt} = pI - cV$$

Ordinary Differential Equation systems

Computational virology

Use mathematical models of viral dynamics and computer power to evaluate virus parameters → predict viral life-cycle and mutations → prevention and treatment (drugs);

No latent phase

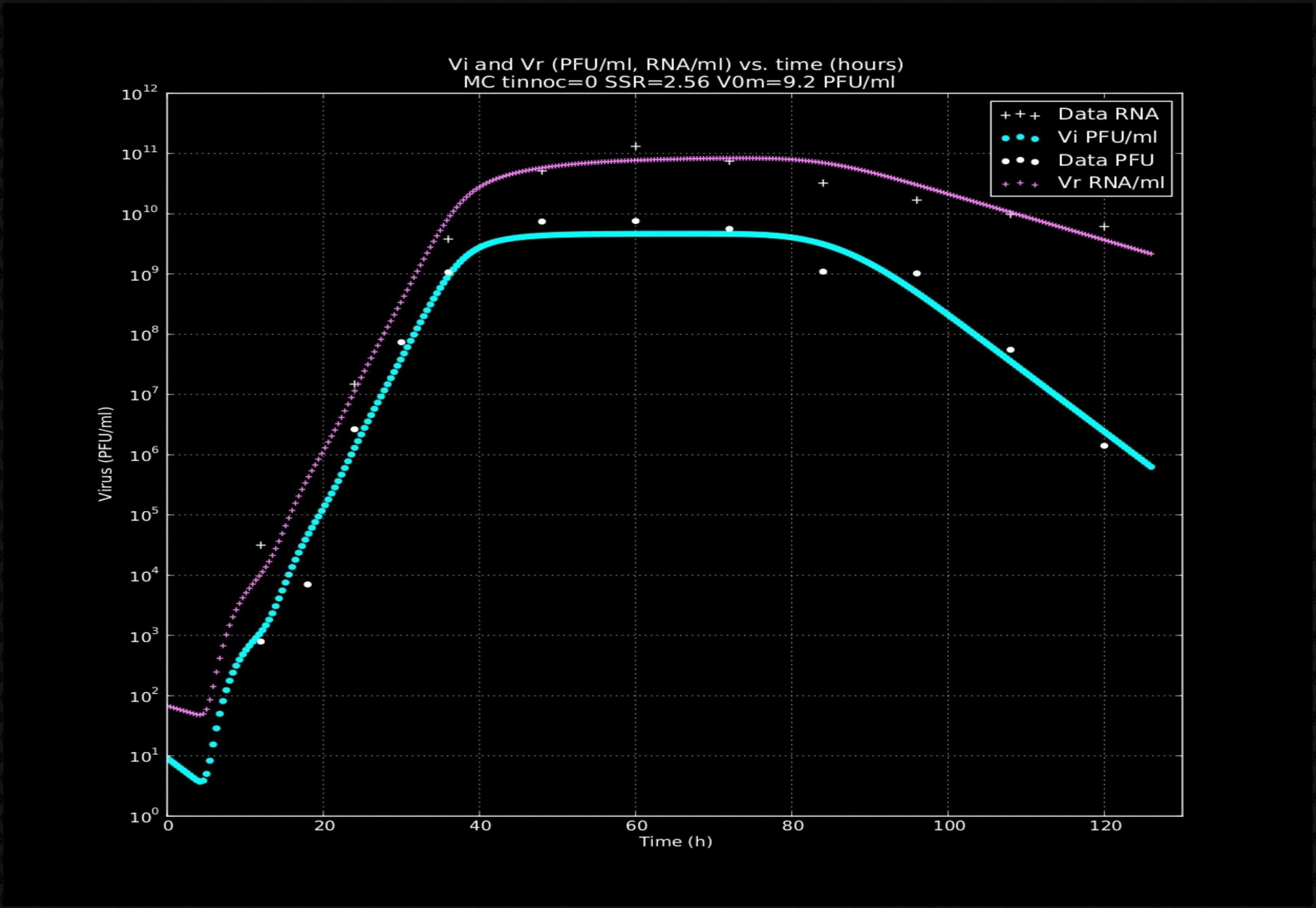
$$\frac{dT}{dt} = -\beta TV$$
$$\frac{dI}{dt} = \beta TV - \delta I \qquad (1)$$
$$\frac{dV}{dt} = pI - cV$$

or with a latent phase

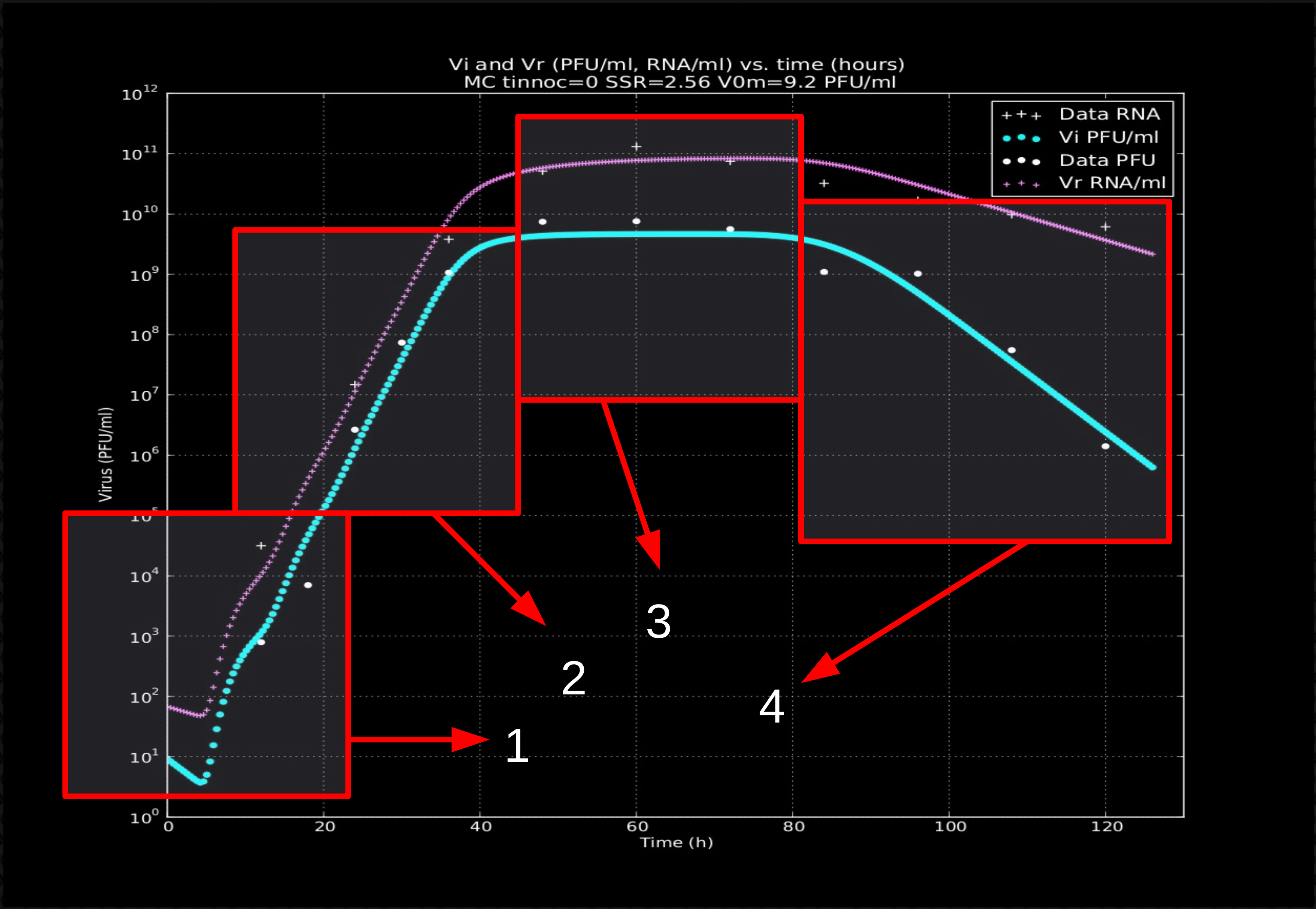
$$\frac{dT}{dt} = -\beta TV$$
$$\frac{dE}{dt} = \beta TV - kE \qquad (2)$$
$$\frac{dI}{dt} = kE - \delta I$$
$$\frac{dV}{dt} = pI - cV$$

Each equation describes one dynamical viral phase

Viral load time evolution



Viral load time evolution



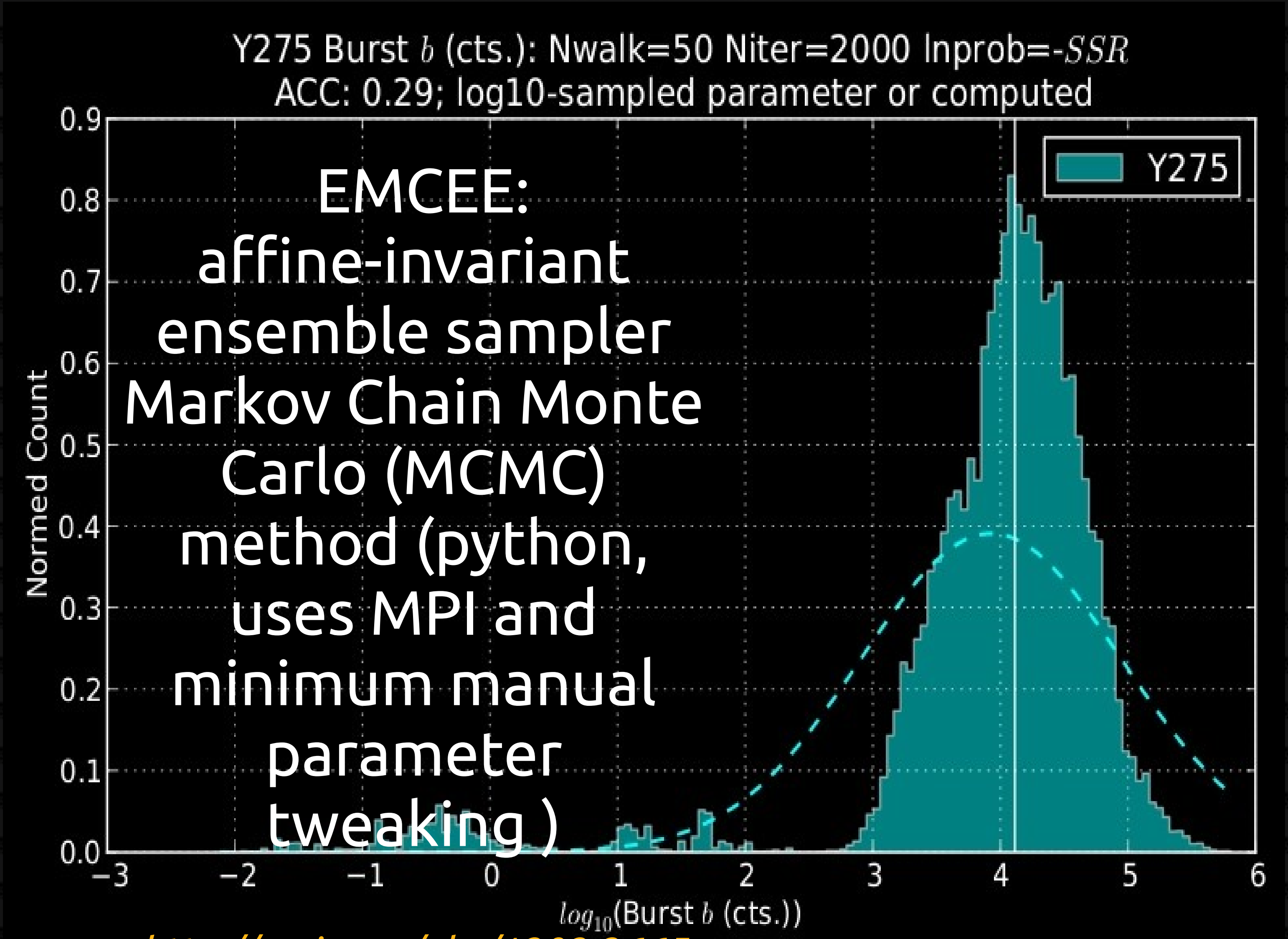
Parameter estimation

8-14 parameters for one single model e.g. Basic Reproductive Number (R_0) → average number of new cases one will generate over an infectious period -

A zombie!

Values of R_0 of well-known infectious diseases[1]		
Disease	**Transmission**	**R_0**
Measles	Airborne	12–18
Pertussis	Airborne droplet	12–17
Diphtheria	Saliva	6–7
Smallpox	Airborne droplet	5–7
Polio	Fecal-oral route	5–7
Rubella	Airborne droplet	5–7
Mumps	Airborne droplet	4–7
HIV/AIDS	Sexual contact	2–5
SARS	Airborne droplet	2–5[2]
Influenza (1918 pandemic strain)	Airborne droplet	2–3[3]
Ebola (2014 Ebola outbreak)	Bodily fluids	1-2 [4]

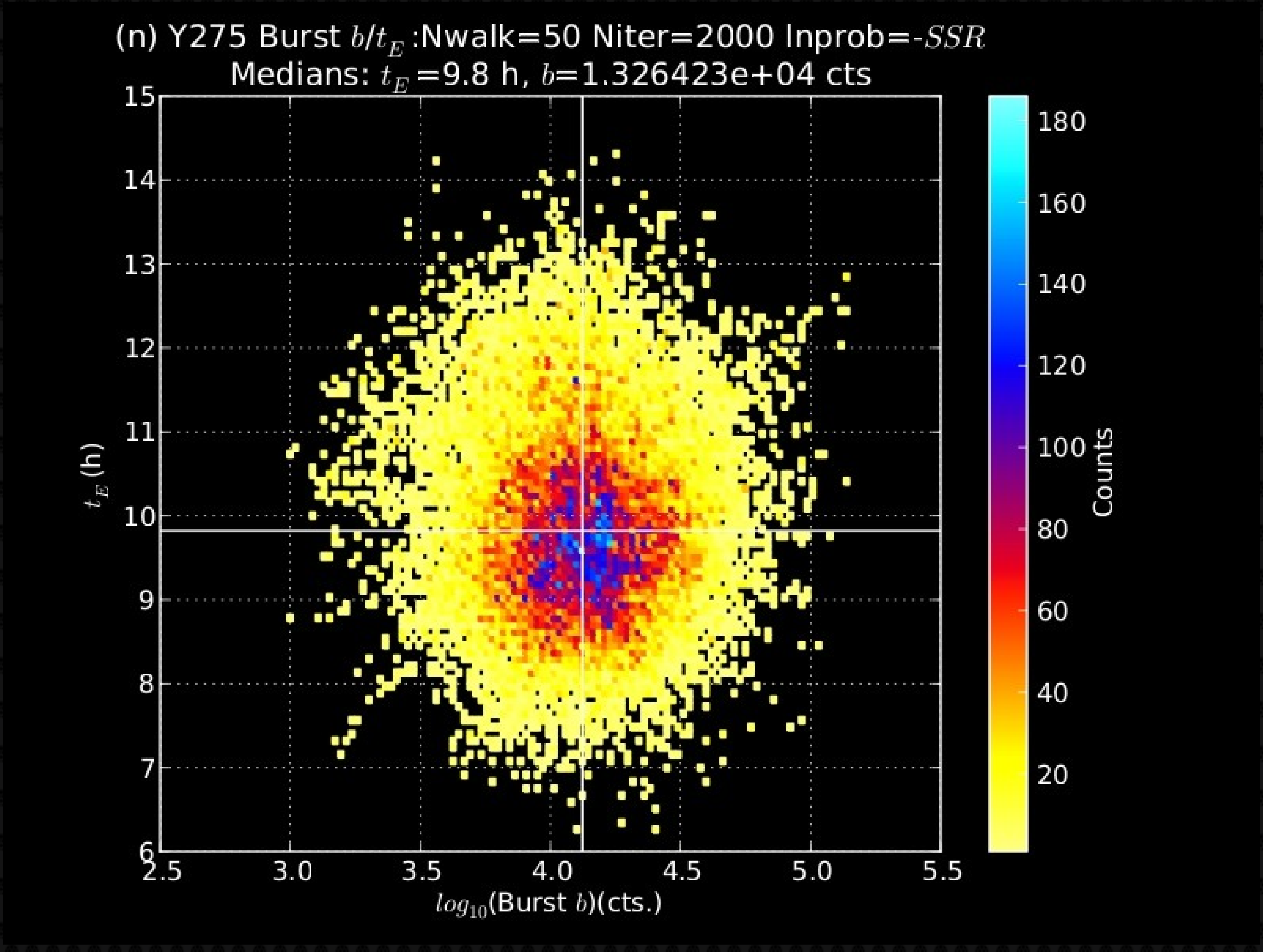
Parameter estimation



EMCEE:
affine-invariant
ensemble sampler
Markov Chain Monte
Carlo (MCMC)
method (python,
uses MPI and
minimum manual
parameter
tweaking)

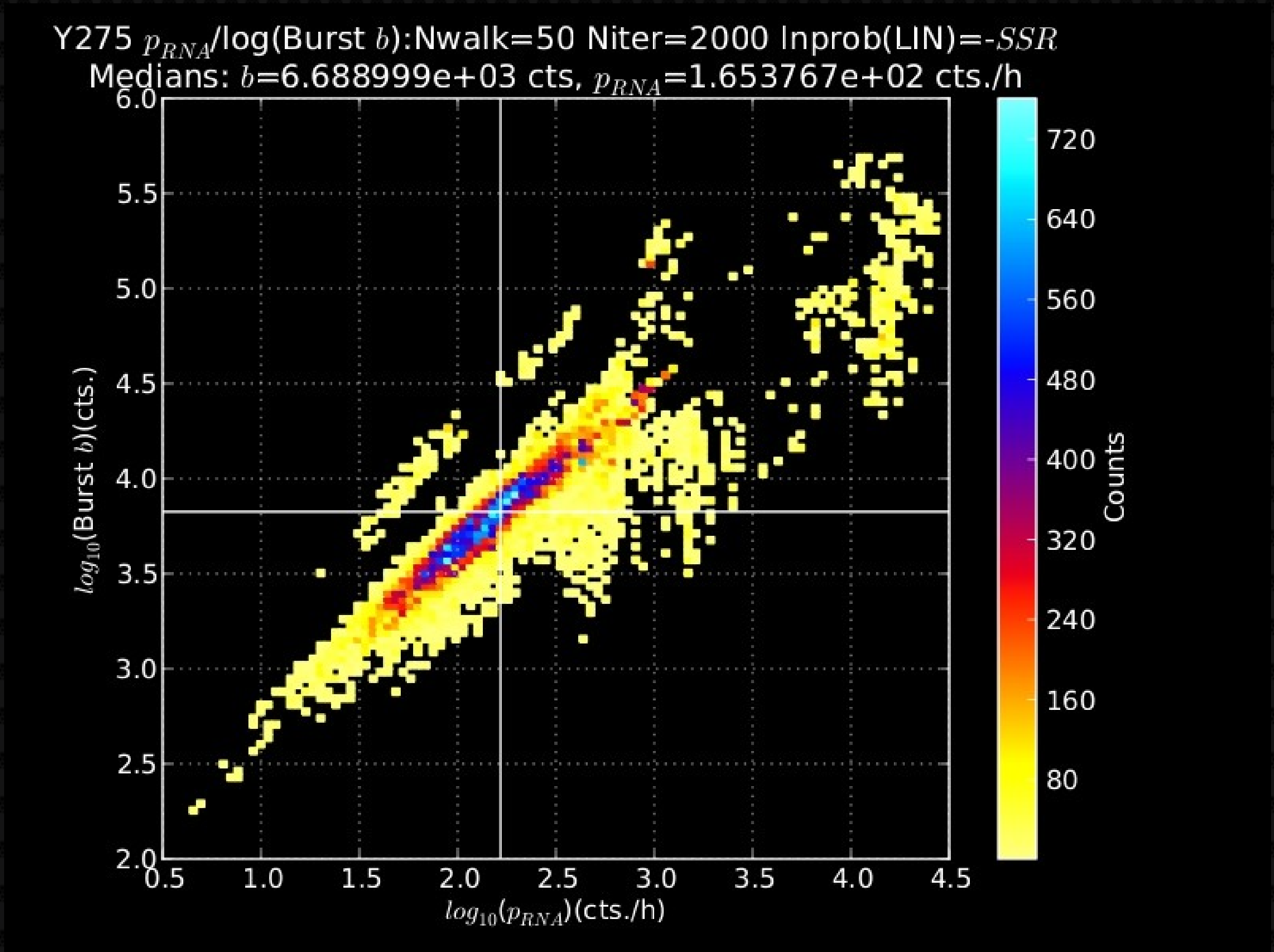
http://arxiv.org/abs/1202.3665

Correlated?



(n) Y275 Burst b/t_E :Nwalk=50 Niter=2000 lnprob=-SSR
Medians: t_E =9.8 h, b=1.326423e+04 cts
t_E (h)
log_{10}(Burst b)(cts.)
Counts
15
14
13
12
11
10
9
8
7
6
2.5
3.0
3.5
4.0
4.5
5.0
5.5
180
160
140
120
100
80
60
40
20

Correlated?



Y275 p_{RNA}/log(Burst b):Nwalk=50 Niter=2000 lnprob(LIN)=-SSR
Medians: b=6.688999e+03 cts, p_{RNA}=1.653767e+02 cts./h
log_{10}(Burst b)(cts.)
$log_{10}(p_{RNA})$(cts./h)
Counts
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
720
640
560
480
400
320
240
160
80

Pro's and con's

Pro: fairly new field with a lot of potential (include bioinformatics → viral genome mapping) and some results (prediction of H1N1-Brisbane 1997 flu mutation);

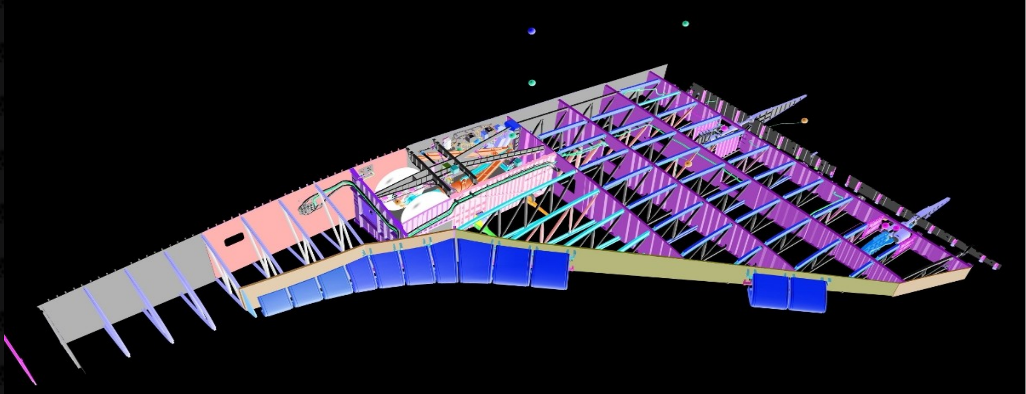
Con: lab data very poor → inconsistencies in data acquisition; very few data points per set, with enormous errors;

Con: strong regulation of publishable material from pharmaceutical companies (main funding sources).

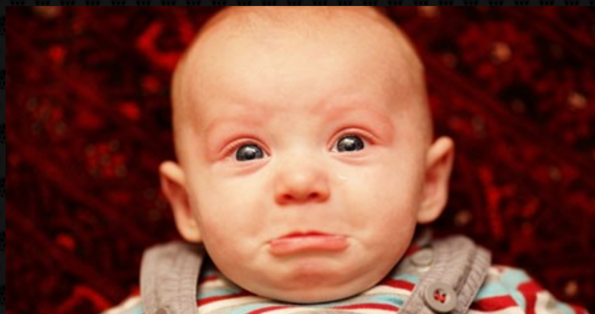
Space Shuttle and MCMC

Use of direct MCMC to determine best re-entry parameters;

MCMC risk analysis before each flight.



Falkland Islands War (1982)



THE STANDARD

CLOSING PRICES

Incorporating the Evening News

We've taken over Falklands, says junta

ARGENTINA INVADES

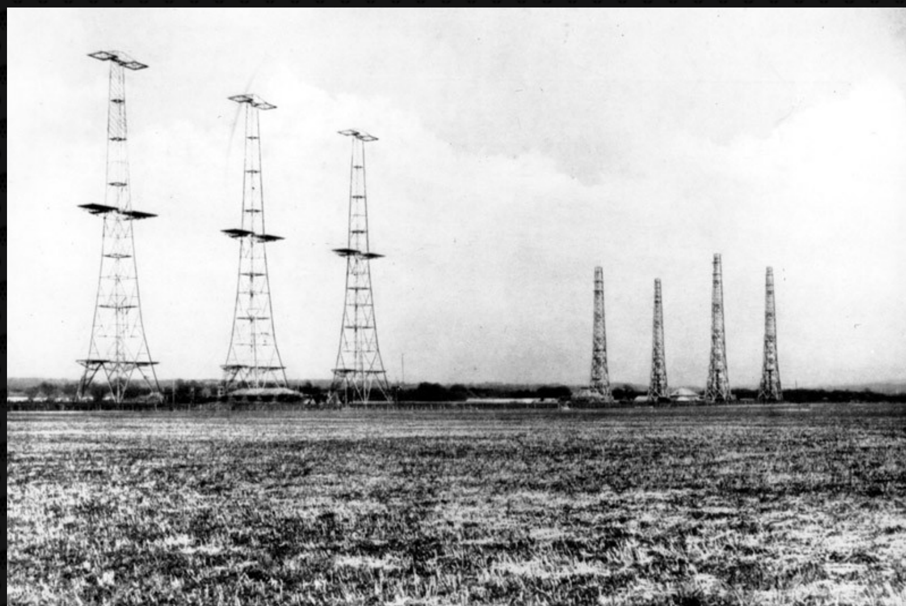
By Robert Carvel, Frank Draper and Standard Foreign News Desk

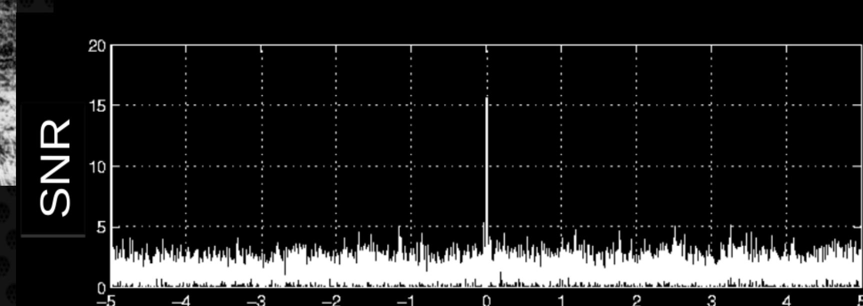
ARGENTINIAN forces today invaded the Falkland Islands, a government broadcast in Buenos Aires announced.

- Oil: the rich prize now at stake
- The islanders who love Britain

Decisive Factors: Harrier

Decisive Factors: Exocet





AM39 “Exocet” (Flying Fish) anti-ship missile: uses fast radar return analysis (matched filtering and Doppler pulse-timing) to choose its target;
→ flies too low to be detected at safe distances.

Decisive Factors: Exocet

Gravitational Waves Data

Gravitational Waves Data

Massive challenge: detection of perturbations of relative size of order $10^{-21} - 10^{-23}$;

Use data that contains high levels of noise (not always of known origin) that, sometimes, perfectly mimics a true signal;

Make a strong detection statement;

Solve the two problems above and do this fast so that other telescopes (optical, X-ray, radio etc.) may follow-up and observe the source.

Gravitational Waves Sources

Lots of big, hot and angry astrophysical objects to look at:

- Compact binary mergers – either two neutron stars, one neutron star and a black hole or two black holes;
- Gamma-ray bursts – long (supernovae) or short (compact mergers);
- Supernovae, X-ray pulsars, neutron stars with mountains, neutron stars with earth(star)quakes, super- and hyper-massive neutron stars.

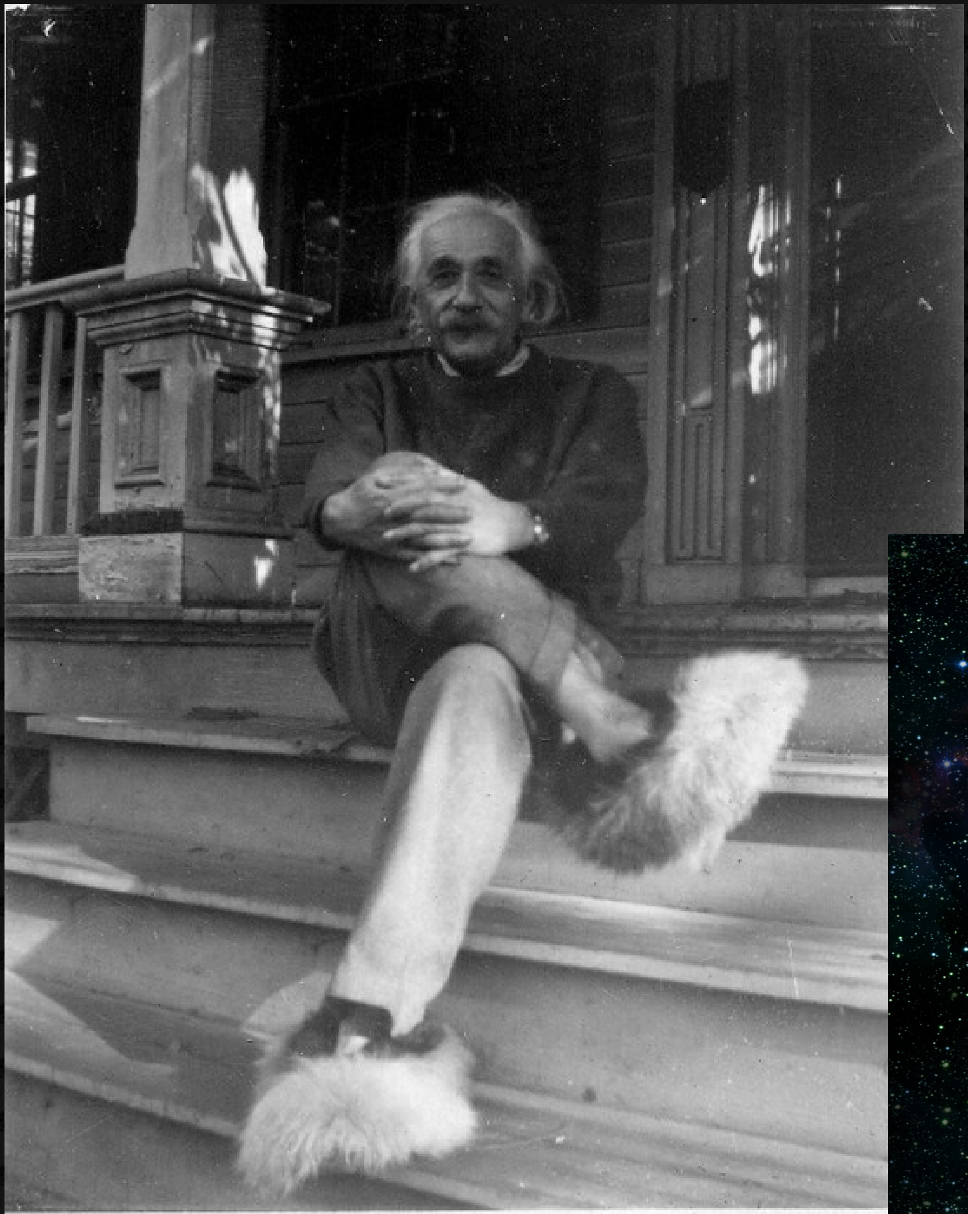
Gravitational Waves Analysis

Lots of advanced tools (geeky stuff):

- Fourier transforms, matched filtering, waveforms (Newtonian approximations or full Numerical Relativity), waveform banks;
- Coherence, incoherence, auto correlation, cross correlation, chi-squared tests;
- ...and lots of Bayesian inference

One does not simply detect Gravitational Waves easily

Gravitational Waves Data



A lot to learn ahead…so come to the Gravitational Physics seminar!