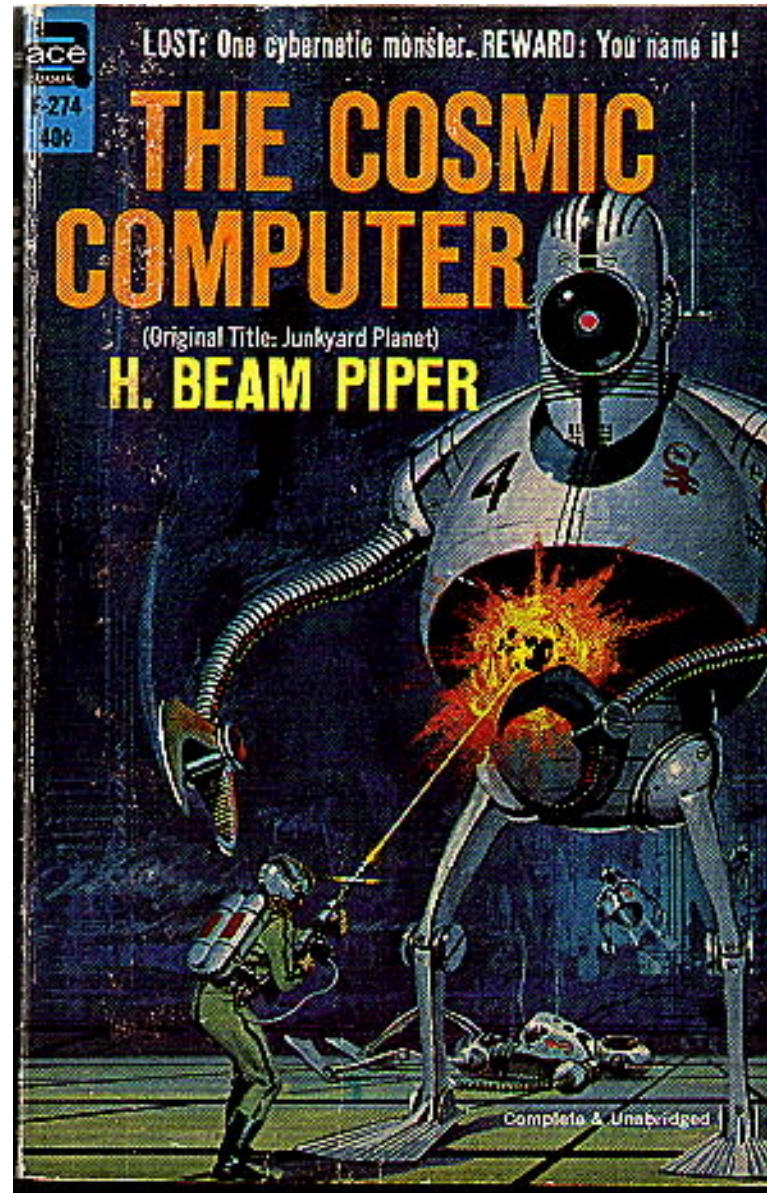




- supercomputing
- numerical modelling

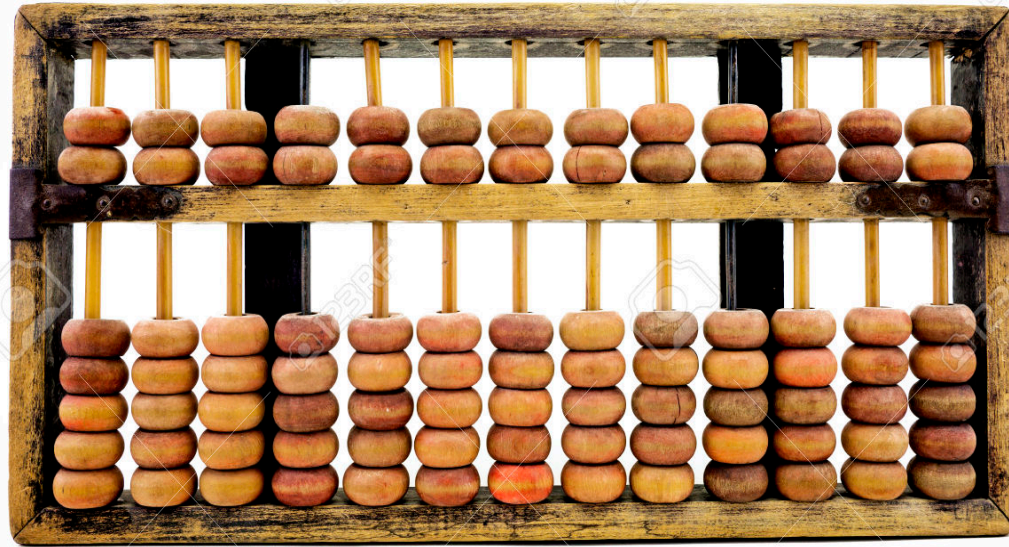


how and when did it all begin?



Eurasia

- suitable for any base system
- developed all across the Eurasian continent thousands of years BC

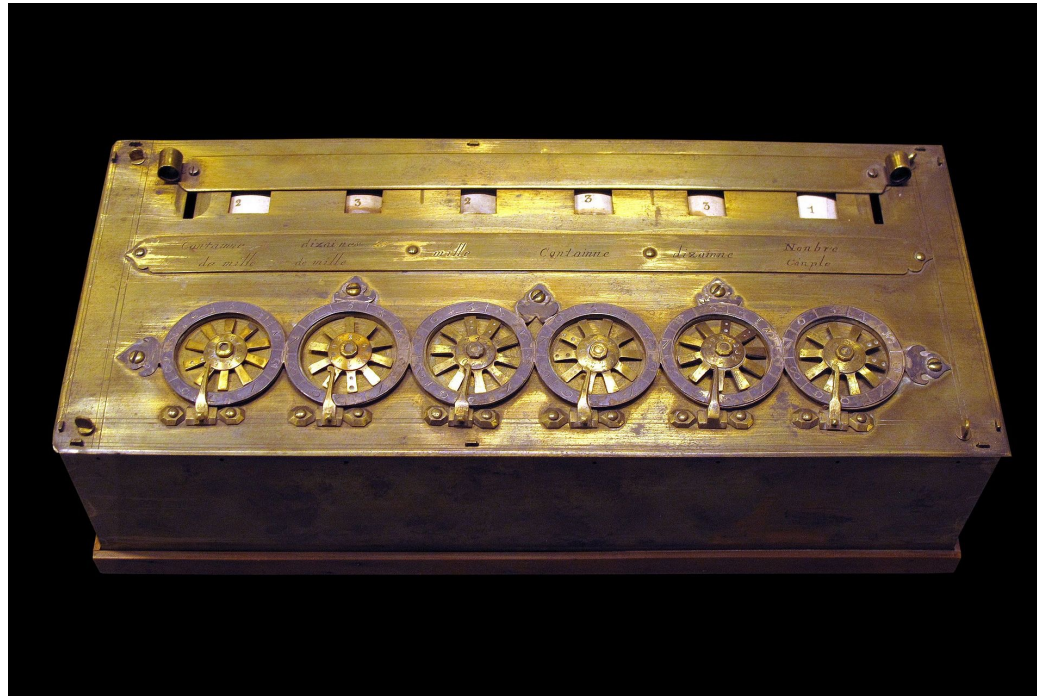


Abacus



Blaise Pascal

- mechanical calculator
- addition/subtraction
- multiplication/division by successive addition/subtraction
- 5 digit accuracy

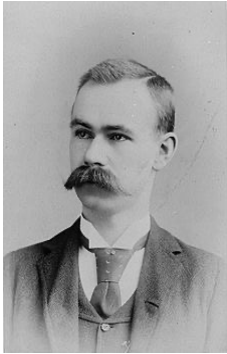




Charles Babbage

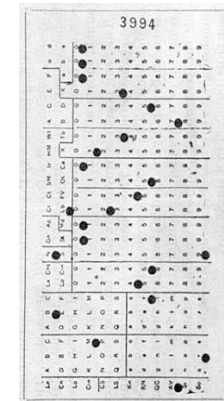
- 4000 parts
- 3 tons
- 3m x 2 m
- 31 digits accuracy
- steam driven
- “difference engine”:
 - designed to tabulate polynomials
 - calculates 2nd order differences

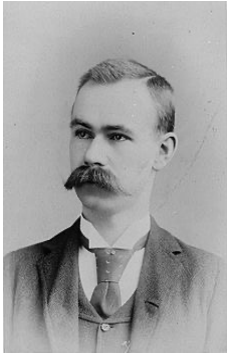




Herman Hollerith

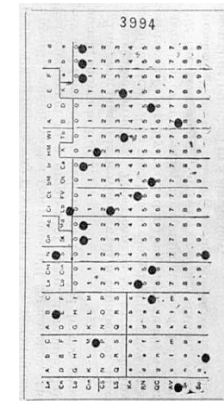
- developed a machine to read punch cards
- machines was used for 1890 census in the USA
- census took only one year to evaluate (prev. 8 years!)
- company: *Computing Tabulating Recording Corporation*

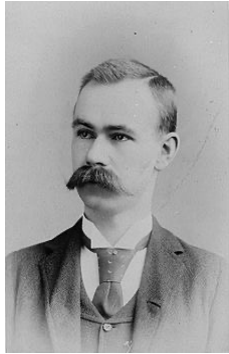




Herman Hollerith

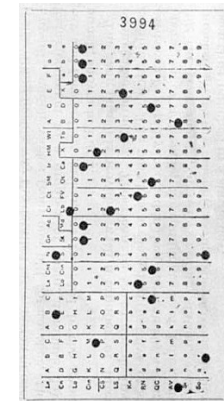
- developed a machine to read punch cards
- machines was used for 1890 census in the USA
- census took only one year to evaluate (prev. 8 years!)
- company: *Computing Tabulating Recording Corporation*
- renamed in 1924 to ...





Herman Hollerith

- developed a machine to read punch cards
- machines was used for 1890 census in the USA
- census took only one year to evaluate (prev. 8 years!)
- company: *Computing Tabulating Recording Corporation*
- renamed in 1924 to ... **International Business Machines (IBM)**





Arthur Scherbius

- Enigma:
 - merely a cipher device
 - heavily used by the Germans during World War II





Arthur Scherbius

- Enigma:
 - merely a cipher device
 - heavily used by the Germans during World War II
- movie right about that application:





Alan Turing

- Turing Machine:

- theoretical concept only:

- reading instructions from printed symbols on a tape
- result printed on back of tape

- foundation for theories about computing, however...

- based upon sequential memory (instead of random-access memory)

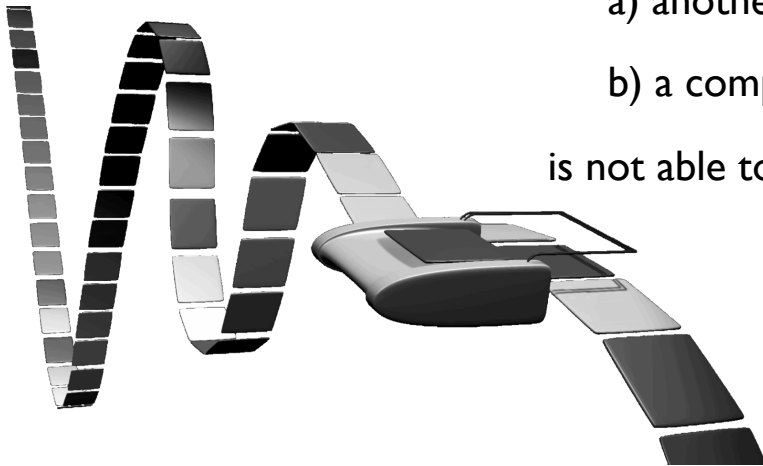
- Turing Test:

- if a human interacting with

a) another human

b) a computer

is not able to tell the difference, the computer is said to “think”





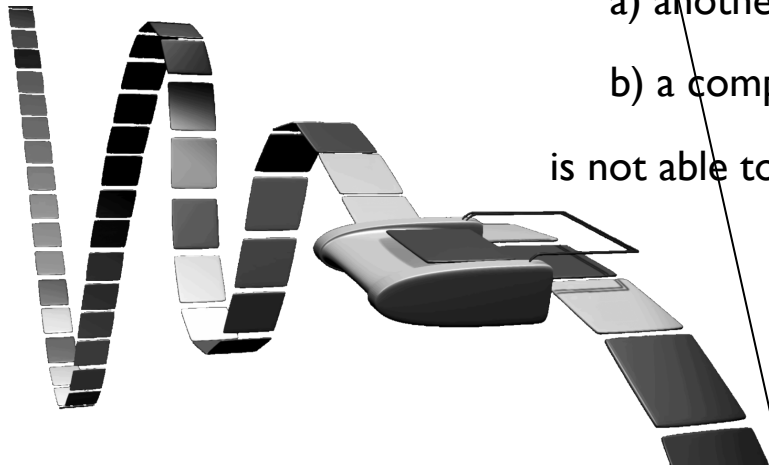
Alan Turing

• Turing Machine:

- theoretical concept
 - reading input
 - result printed
- foundation for the computer
- based upon sequential operations

• Turing Test:

- if a human interviewer asks questions:
 - a) another human
 - b) a computer
- the computer is not able to trick the interviewer



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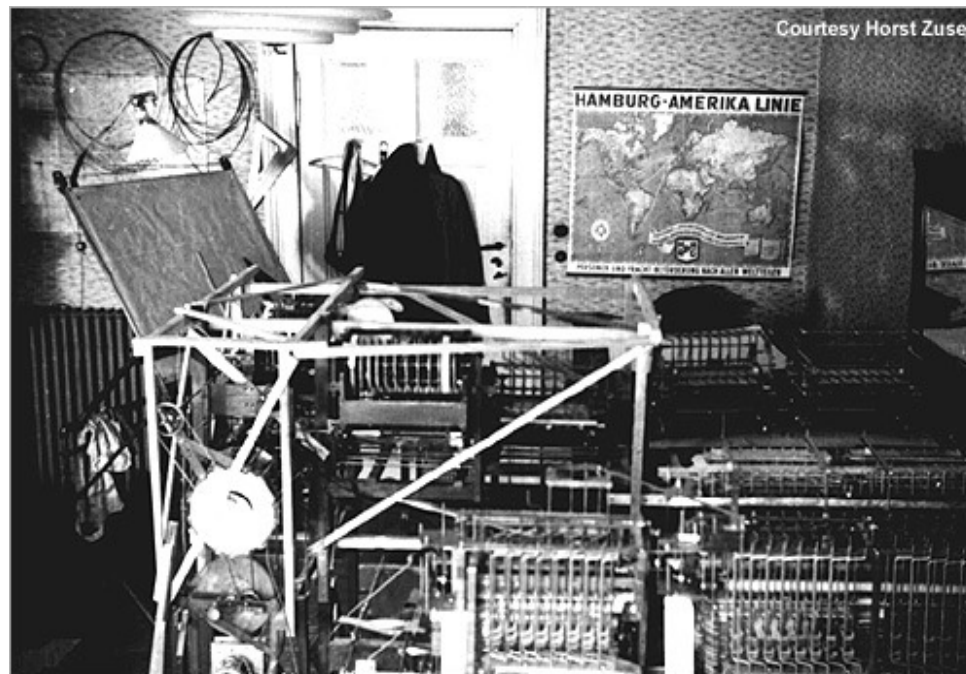
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← Back



Konrad Zuse

- Z1:
 - 30000 parts
 - calculations were performed in binary
 - input and output in decimal system though
 - floating point operations
 - freely programmable via punch cards



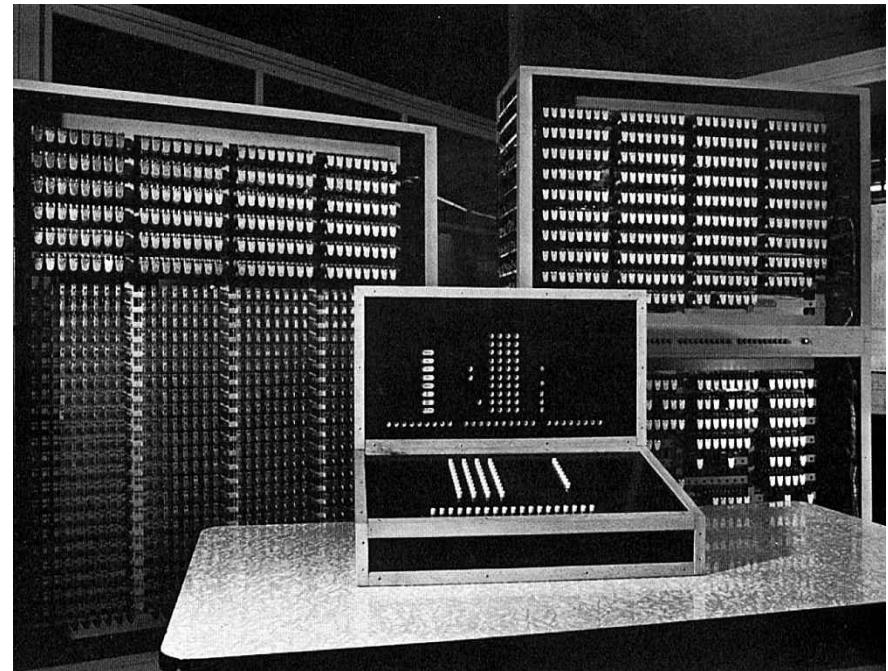
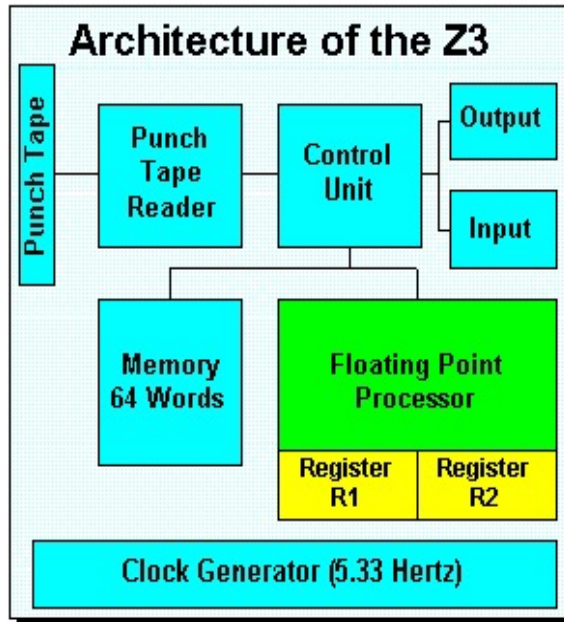
Courtesy Horst Zuse

The original Z1 in Konrad's parent's living room circa 1938



Konrad Zuse

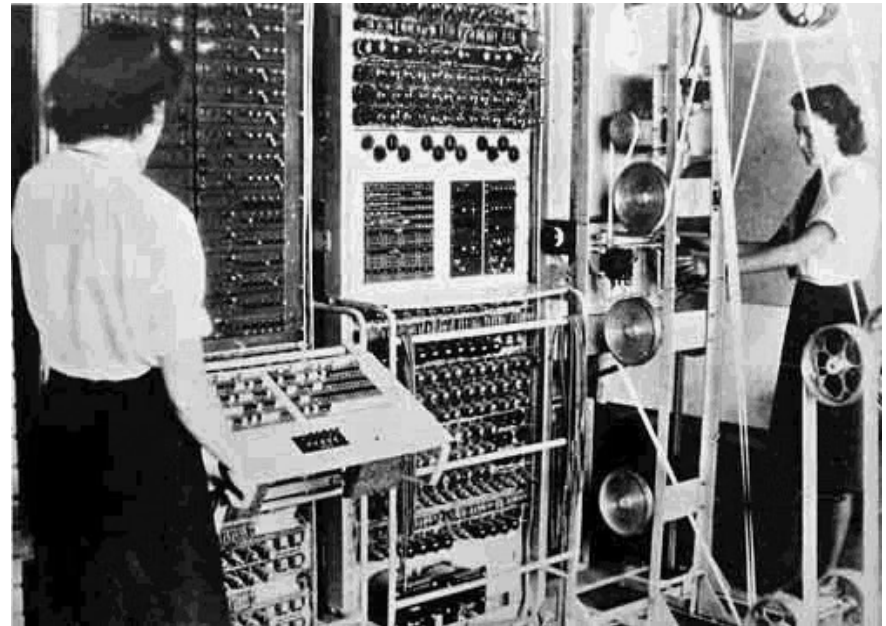
- Z3:
 - 5.3 Hz, 22bit, 176 bytes memory, 2600 relays
 - speed: 0.8sec/+ and 3sec/* (=0.333 flops)
 - floating point operations
 - freely programmable via punch cards





Post Office Research Station

- Colossus:
 - first “commercial” computer
 - five parallel processors
 - developed in order to decrypt German messages (see Enigma)
 - freely programmable via tape





Post Office Research Station

- Colossus:
- first “c
- develo
- freely

www.imdb.com/title/tt0064177/?ref=

Colossus: The Forbin Project (1970) - IMDb

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Colossus: The Forbin Project (1970) ★ 7.1 /10 7,758 ☆ Rate This

M | 1h 40min | Sci-Fi, Thriller | 8 April 1970 (USA)

"A SHOCKER! FASCINATING!"

"A shocker! Baffle to high tension!" - New York Post
 "A shocker! Baffle to high tension!" - New York Post
 "Search for answers! Fast and entertaining!" - New York Times
 "Widely imaginative! The best I've seen in a long time!" - Howard Rosenberg
 "Practically perfect!" - Entertainment Weekly
 "Superb in intent!" - Howard Rosenberg

Thinking this will prevent war, the US government gives an impenetrable supercomputer total control over launching nuclear missiles. But what the computer does with the power is unimaginable to its creators.

Director: [Joseph Sargent](#)
Writers: [James Bridges](#) (screenplay), [D.F. Jones](#) (novel)
Stars: [Eric Braeden](#), [Susan Clark](#), [Gordon Pimental](#) | [See full cast & crew >](#)

[+ Add to Watchlist](#)

Reviews
 110 user | 45 critic

IMDbPro [View production, box office, & company info](#)

1 win & 1 nomination. [See more awards >](#)



and what about today?

- Fugaku “Mount Fuji” (Japan), #1 in 11/2020:
 - 7,630,848 cores, 5000TB RAM
 - speed: 440×10^{15} flop/s (= 440 PetaFlops)
 - freely programmable (not via punch cards...)
 - operation system: Linux (Red Hat)

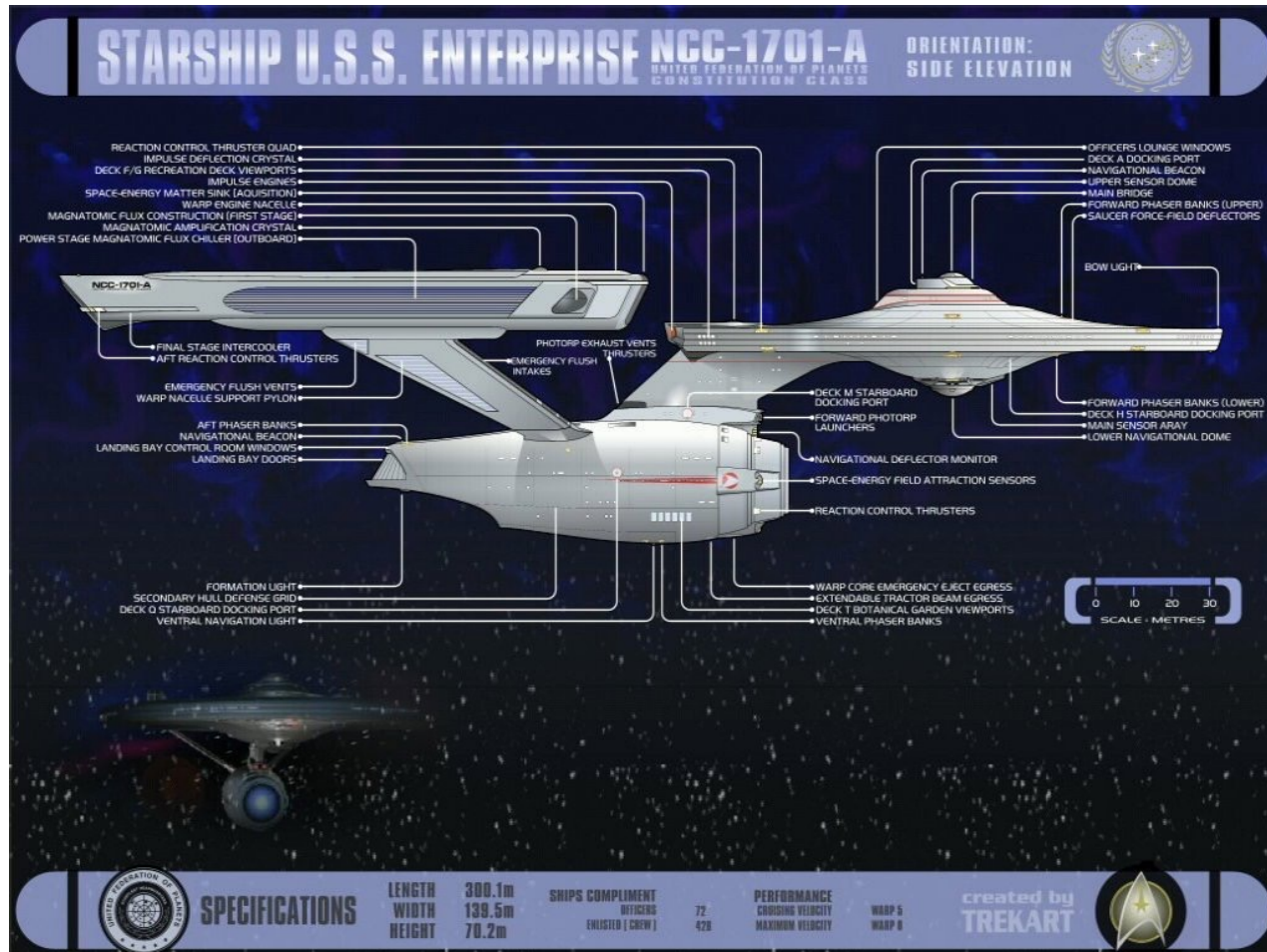


RIKEN Center for Computational Science in Kobe

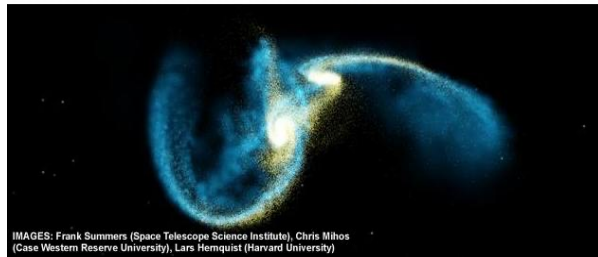
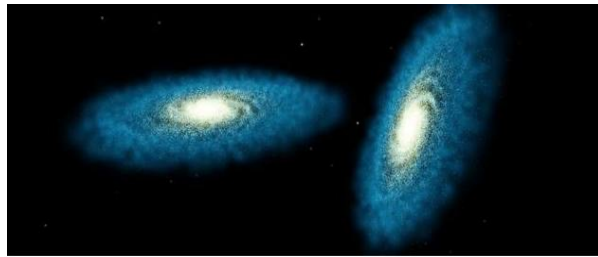
- MareNostrum (Spain), #42 in 11/2020:
 - 153.216 cores, 41TB RAM
 - speed: 7 Pflop/s
 - operating system: Linux (Suse)



Torre Girona Chapel, Barcelona

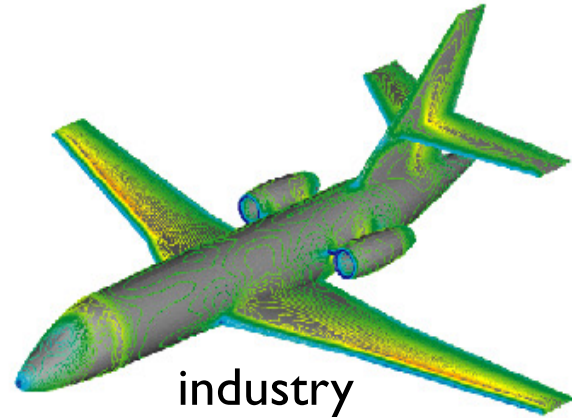


...but what about the science?



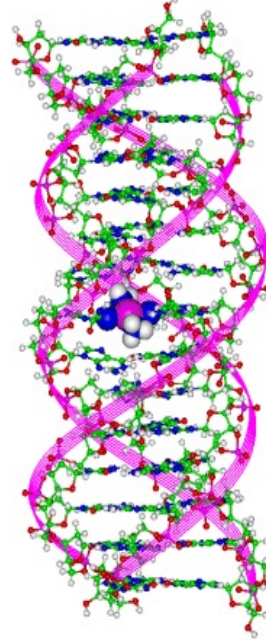
IMAGES: Frank Summers (Space Telescope Science Institute), Chris Mihos (Case Western Reserve University), Lars Hernquist (Harvard University)

astrophysics

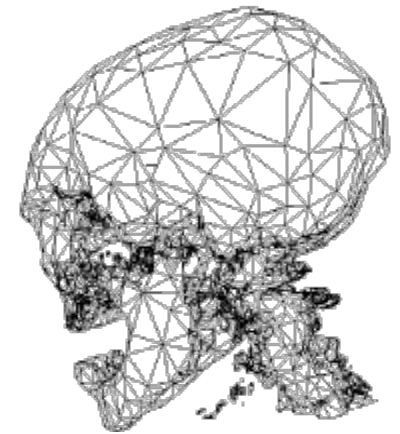


industry

biology



entertainment



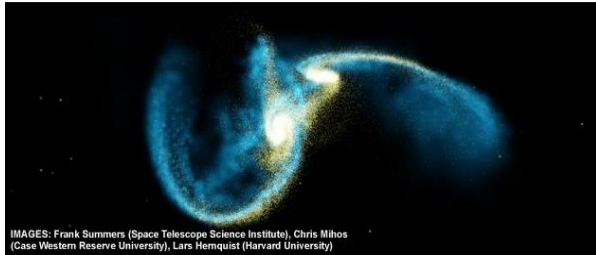
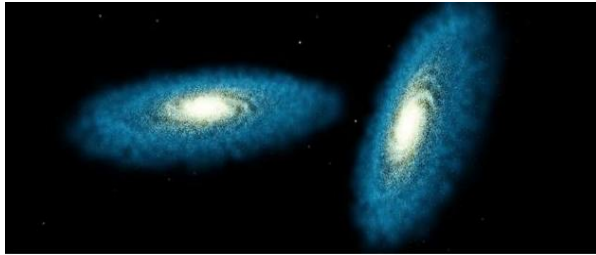
medicine



stock market

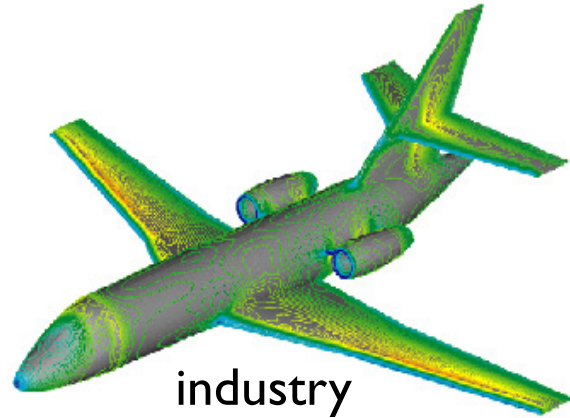


artificial intelligence



IMAGES: Frank Summers (Space Telescope Science Institute), Chris Mihos (Case Western Reserve University), Lars Hernquist (Harvard University)

astrophysics

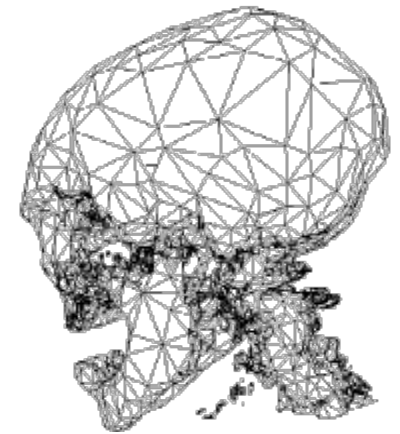


industry

biology



entertainment



medicine

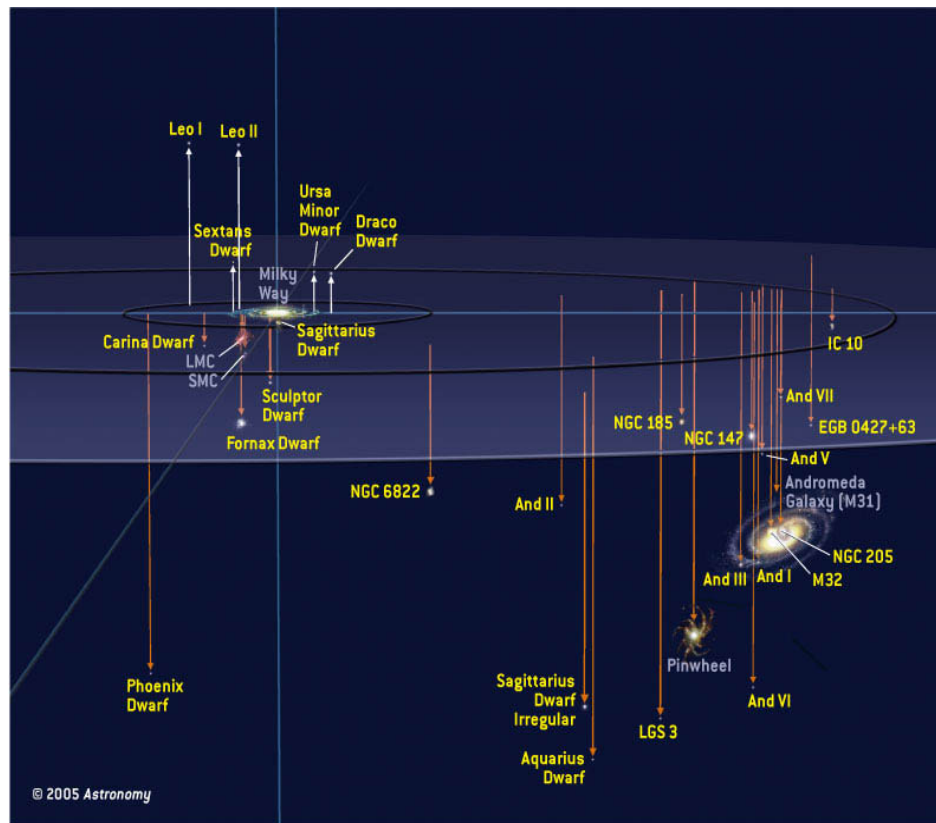


stock market

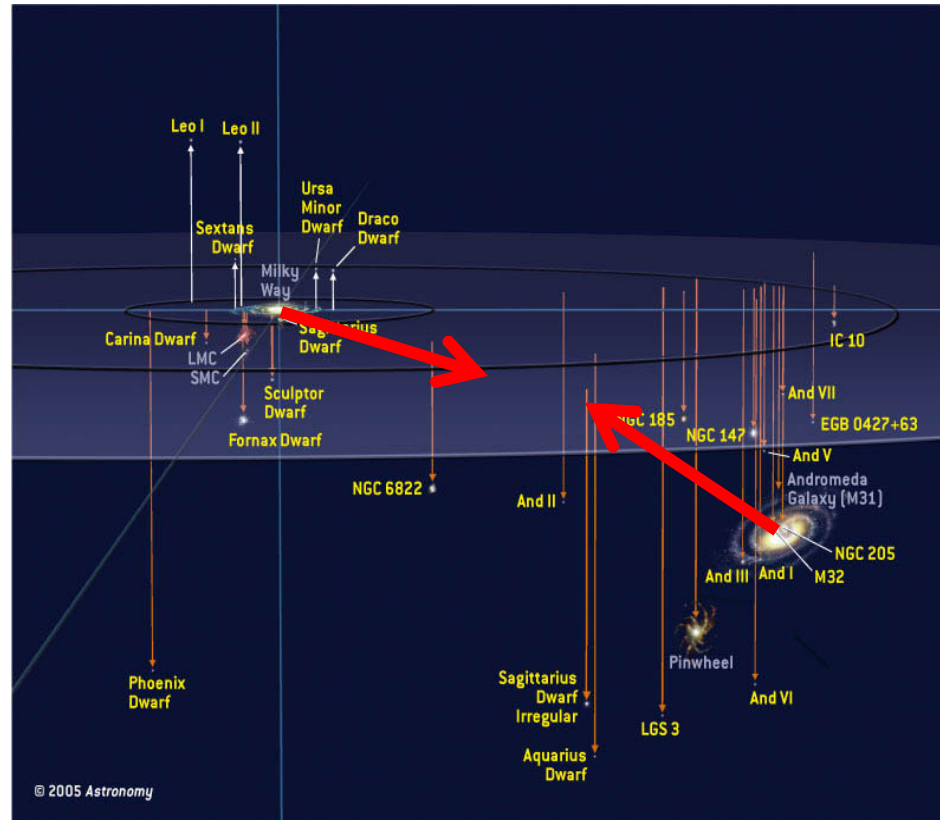


artificial intelligence

The collision of our Milky Way with the Andromeda Galaxy!



The collision of our Milky Way with the Andromeda Galaxy!

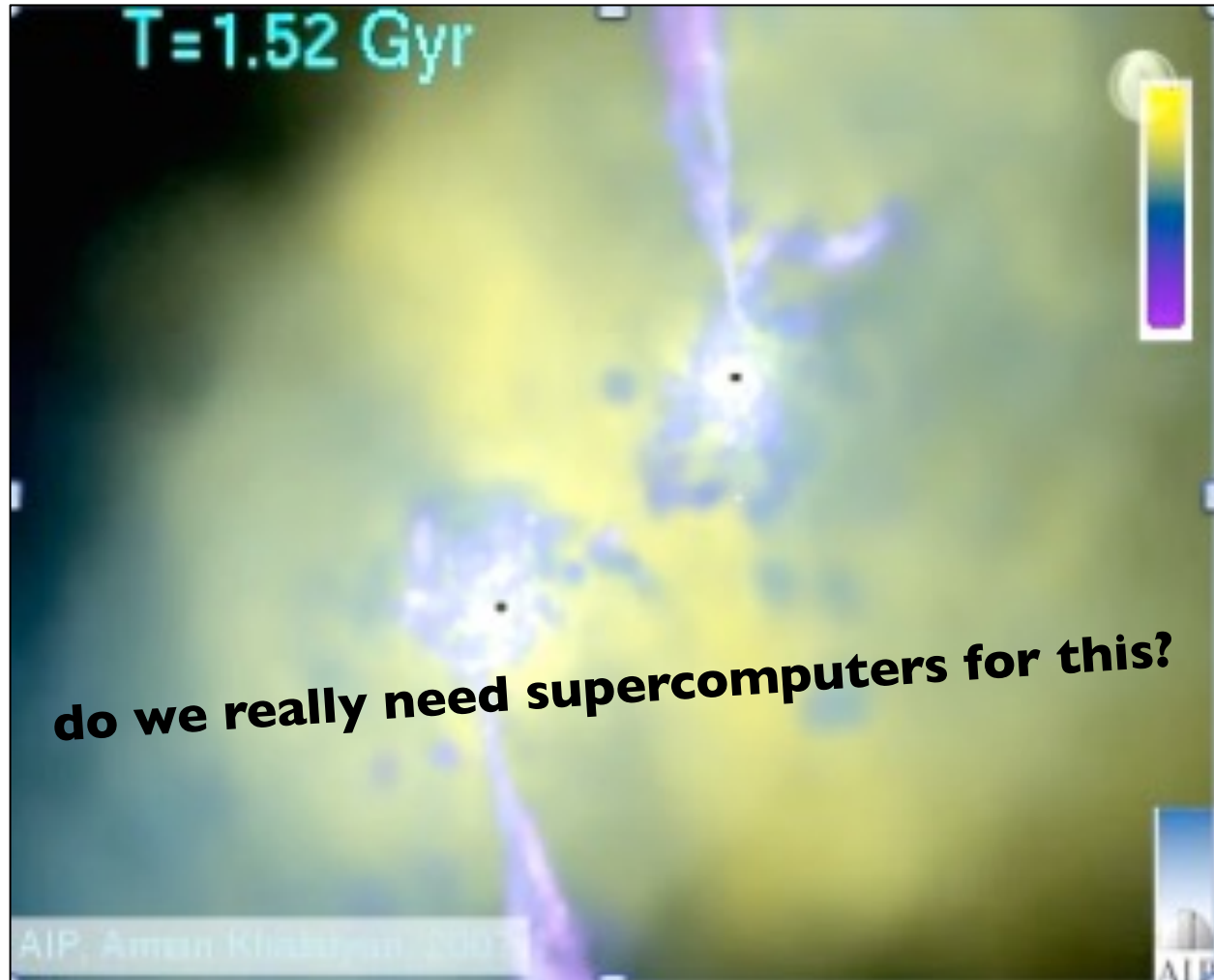


The collision of our Milky Way with the Andromeda Galaxy!



(courtesy Arman Khalatyan, www.clues-project.org)

The collision of our Milky Way with the Andromeda Galaxy!



(courtesy Arman Khalatyan, www.clues-project.org)



Erik Holmberg

THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND
ASTRONOMICAL PHYSICS

VOLUME 94

NOVEMBER 1941

NUMBER 3

ON THE CLUSTERING TENDENCIES AMONG THE NEBULAE

II. A STUDY OF ENCOUNTERS BETWEEN LABORATORY MODELS OF STELLAR SYSTEMS BY A NEW INTEGRATION PROCEDURE

ERIK HOLMBERG

ABSTRACT

In a previous paper¹ the writer discussed the possibility of explaining the observed clustering effects among extragalactic nebulae as a result of captures. The present investigation deals with the important problem of whether the loss of energy resulting from the tidal disturbances at a close encounter between two nebulae is large enough to effect a capture. The tidal deformations of two models of stellar systems, passing each other at a small distance, are studied by reconstructing, piece by piece, the orbits described by the individual mass elements. The difficulty of integrating the total gravitational force acting upon a certain element at a certain point of time is solved by replacing gravitation by light. The mass elements are represented by light-bulbs, the candle power being proportional to mass, and the total light is measured by a photocell (Fig. 1). The nebulae are assumed to have a flattened shape, and each is represented by 37 light-bulbs. It is found that the tidal deformations cause an increase in the attraction between the two objects, the increase reaching its maximum value when the nebulae are separating, i.e., after the passage. The resulting loss of energy (Fig. 6) is comparatively large and may, in favorable cases, effect a capture. The spiral arms developing during the encounter (Figs. 4) represent an interesting by-product of the investigation. The direction of the arms depends on the direction of rotation of the nebulae with respect to the direction of their space motions.

I. THE EXPERIMENTAL ARRANGEMENTS

The present paper is a study of the tidal disturbances appearing in stellar systems which pass one another at small distances. These tidal disturbances are of some importance since they are accompanied by a loss of energy which may result in a capture between the two objects. In a previous paper¹ the writer discussed the clustering tendencies among extragalactic nebulae. A theory was put forth that the observed clustering effects are the result of captures between individual nebulae. The capture theory seems to be able to account not only for double and multiple nebulae but also for the large extragalactic clusters. The present investigation tries to give an answer to the important question of whether the loss of energy accompanying a close encounter between two nebulae is large enough to effect a capture.

A study of tidal disturbances is greatly facilitated if it can be restricted to only two dimensions, i.e., to nebulae of a flattened shape, the principal planes of which coincide with the plane of their hyperbolic orbits. In order to reconstruct the orbit described by

¹ *Mt. W. Contr.*, No. 633; *Ap. J.*, 92, 200, 1940.



Erik Holmberg

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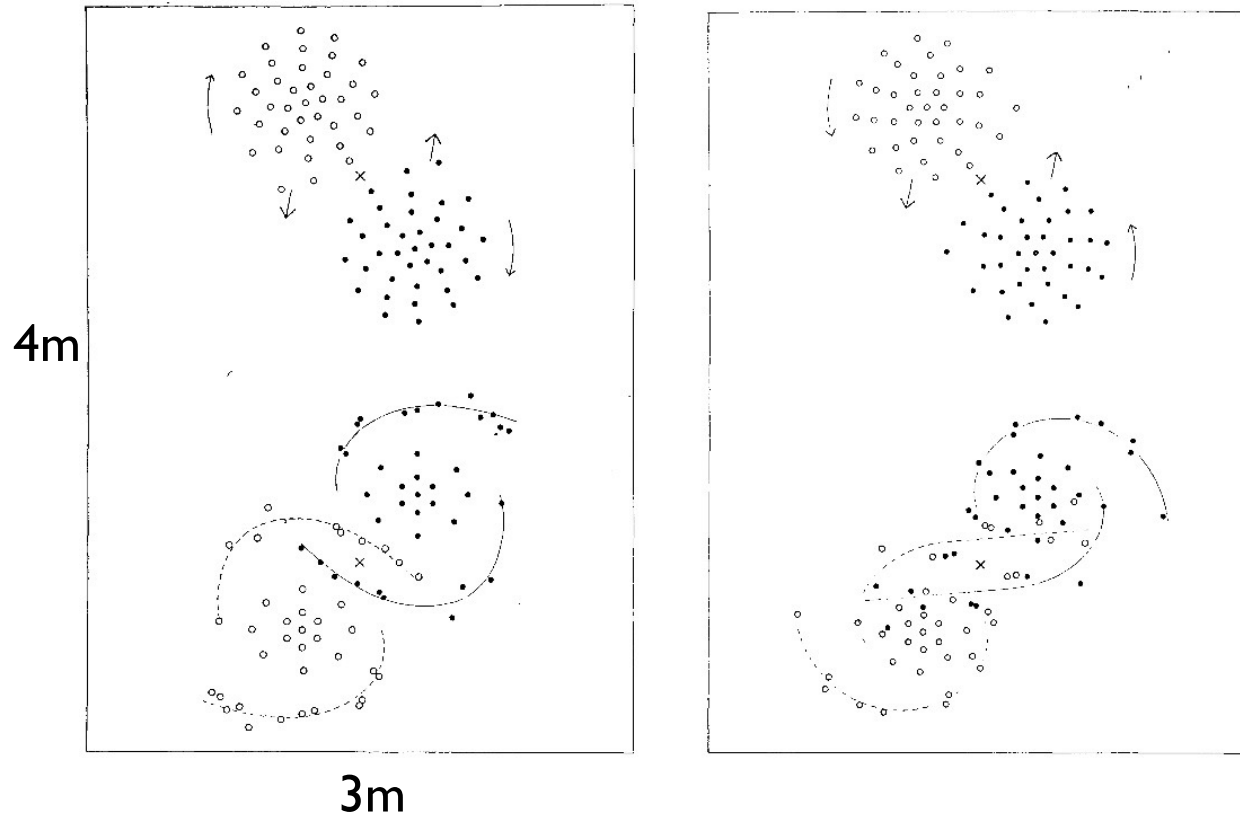


$N = 2 \times 37$

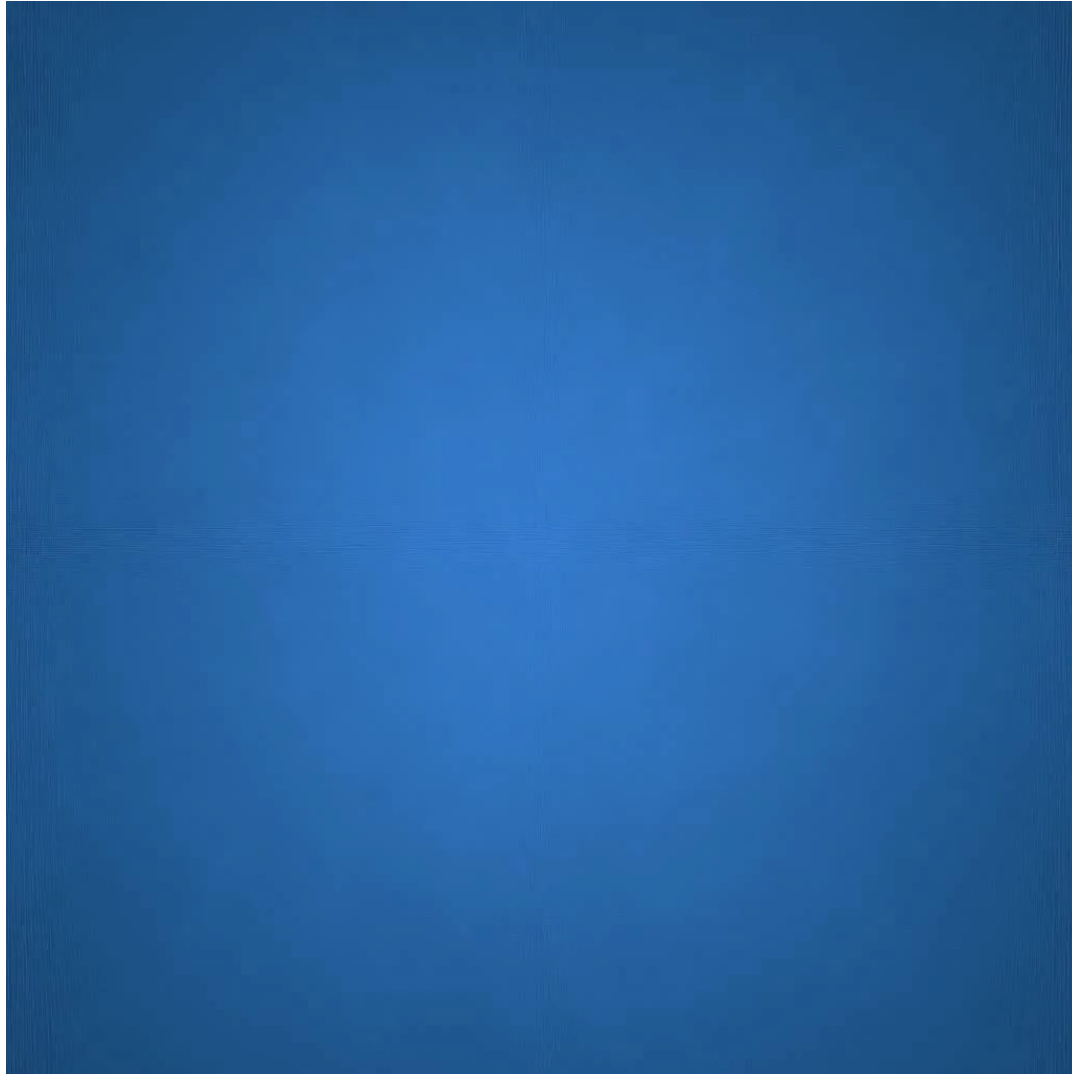


Erik Holmberg

- replacing gravity by light (same $1/r^2$ law)
- formation of tidal features



the formation of our Local Group within full cosmological context



www.cosmosim.org

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CosmoSim

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CosmoSim

The CosmoSim database provides results from cosmological simulations performed within different projects: [MultiDark and Bolshoi](#), [CLUES](#), and [Galaxies](#).

MultiDark Bolshoi

The Spanish MultiDark Consolider project supports efforts to identify and detect matter, including dark matter simulations of the universe.

MDR1 BigMDPL
 SMDPL Bolshoi
 MDPL BolshoiP
 MDPL2

Galaxies

Available now for the MDPL2 simulation - galaxy catalogs contain galaxy properties from different semi-analytical codes.

MDPL2 Galacticus
 MDPL2 SAG
 MDPL2 SAGE

CLUES
 Constrained Local Universe Simulations

The CLUES project produces constrained simulations of the local universe, partially with gas and star formation.

Clues3_LGDM
 Clues3_LGGas

Register to CosmoSim

CosmoSim.org is hosted and maintained by the Leibniz-Institute for Astrophysics Potsdam (AIP).

<https://www.cosmosim.org/#>

www.cosmosim.org

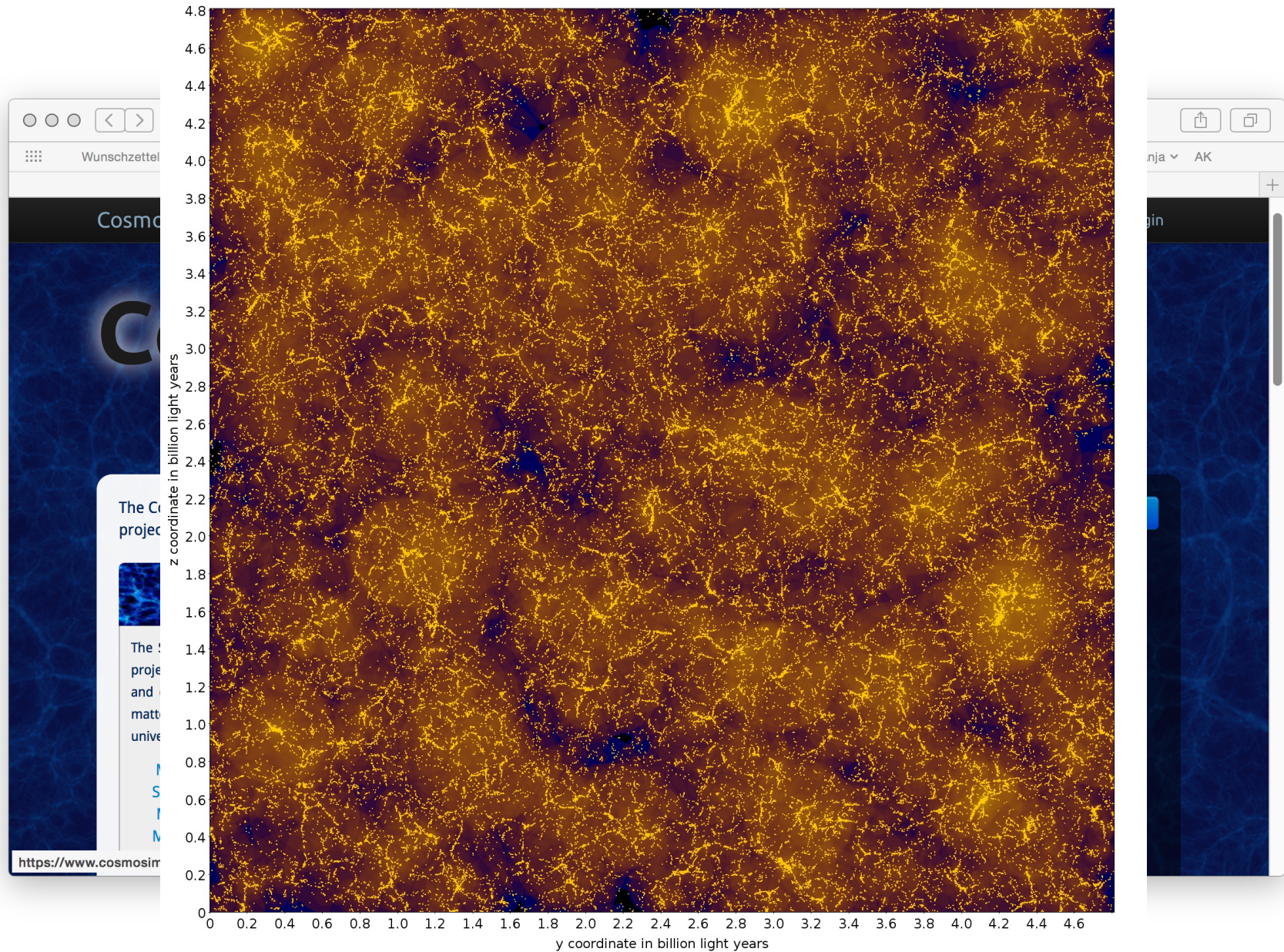
The screenshot shows a web browser window with the URL www.cosmosim.org. The browser's address bar and tabs are visible. The website's navigation menu includes links for CosmoSim, Blog, Documentation, Database, Files, Query, Contact, and Login. The main content area features a large 'CosmoSim' title and a paragraph stating: 'The CosmoSim database provides results from cosmological simulations performed within different projects: [MultiDark and Bolshoi](#), [CLUES](#), and [Galaxies](#).'

Below this text are three project cards:

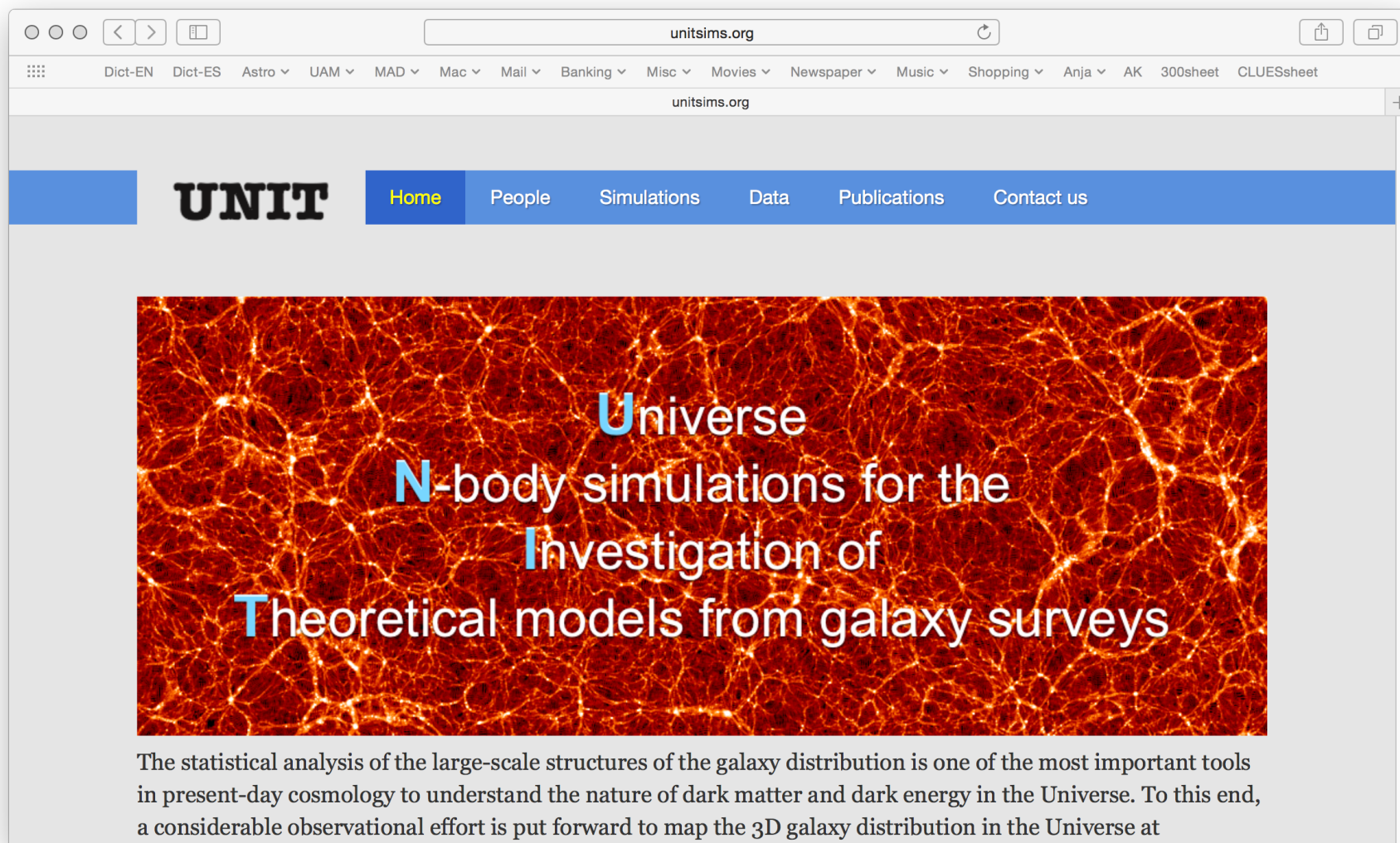
- MultiDark Bolshoi:** The Spanish MultiDark Consolider project supports efforts to identify and detect matter, including dark matter simulations of the universe.
 - MDR1
 - SMDPL
 - MDPL
 - MDPL2
 - BigMDPL
 - Bolshoi
 - BolshoiP
- Galaxies:** Available now for the MDPL2 simulation - galaxy catalogs contain galaxy properties from different semi-analytical codes.
 - MDPL2 Galacticus
 - MDPL2 SAG
 - MDPL2 SAGE
- CLUES:** The CLUES project produces constrained simulations of the local universe, partially with gas and star formation.
 - Clues3_LGDM
 - Clues3_LGGas

On the right side of the page, there is a 'Register to CosmoSim' button, the AIP logo, and text stating: 'CosmoSim.org is hosted and maintained by the Leibniz-Institute for Astrophysics Potsdam (AIP)'. At the bottom right, the GAVO logo is visible.

The URL in the browser's address bar is <https://www.cosmosim.org/#>.



www.unitsims.org



The image shows a browser window displaying the website www.unitsims.org. The browser's address bar shows the URL. The website has a blue navigation bar with the 'UNIT' logo and a menu with items: Home, People, Simulations, Data, Publications, and Contact us. The main content area features a large orange and red background image of a galaxy filament network. Overlaid on this image is the text: 'Universe N-body simulations for the Investigation of Theoretical models from galaxy surveys'. Below this image is a paragraph of text.

unitsims.org

Dict-EN Dict-ES Astro ▾ UAM ▾ MAD ▾ Mac ▾ Mail ▾ Banking ▾ Misc ▾ Movies ▾ Newspaper ▾ Music ▾ Shopping ▾ Anja ▾ AK 300sheet CLUESsheet

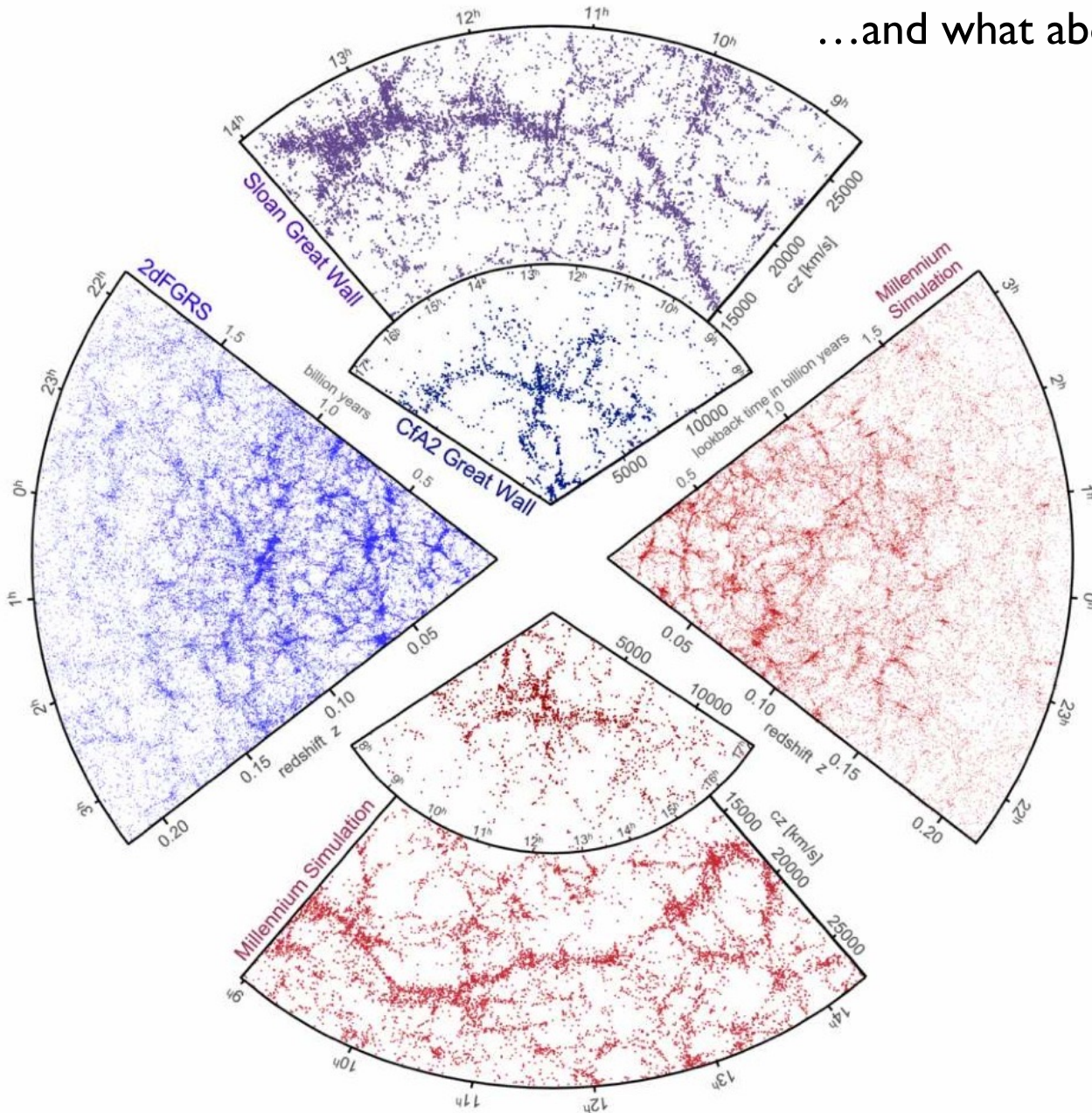
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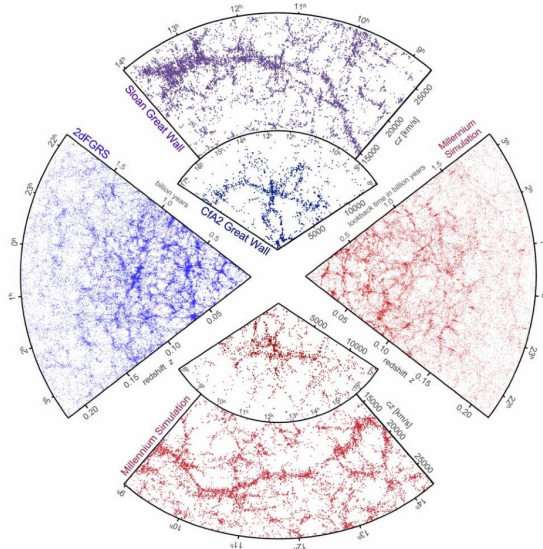
Universe
N-body simulations for the
Ivestigation of
Theoretical models from galaxy surveys

The statistical analysis of the large-scale structures of the galaxy distribution is one of the most important tools in present-day cosmology to understand the nature of dark matter and dark energy in the Universe. To this end, a considerable observational effort is put forward to map the 3D galaxy distribution in the Universe at

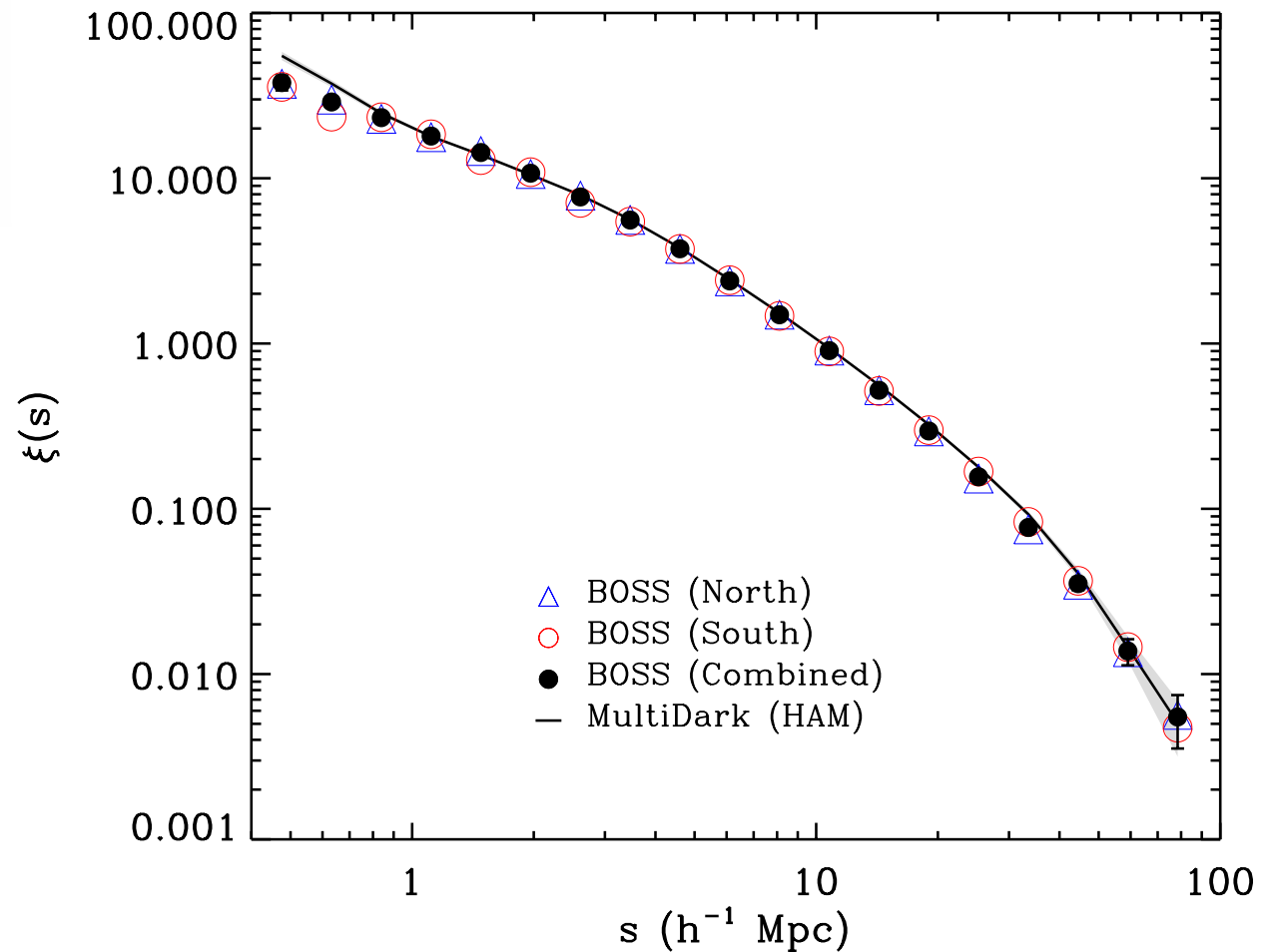
...and what about the results?



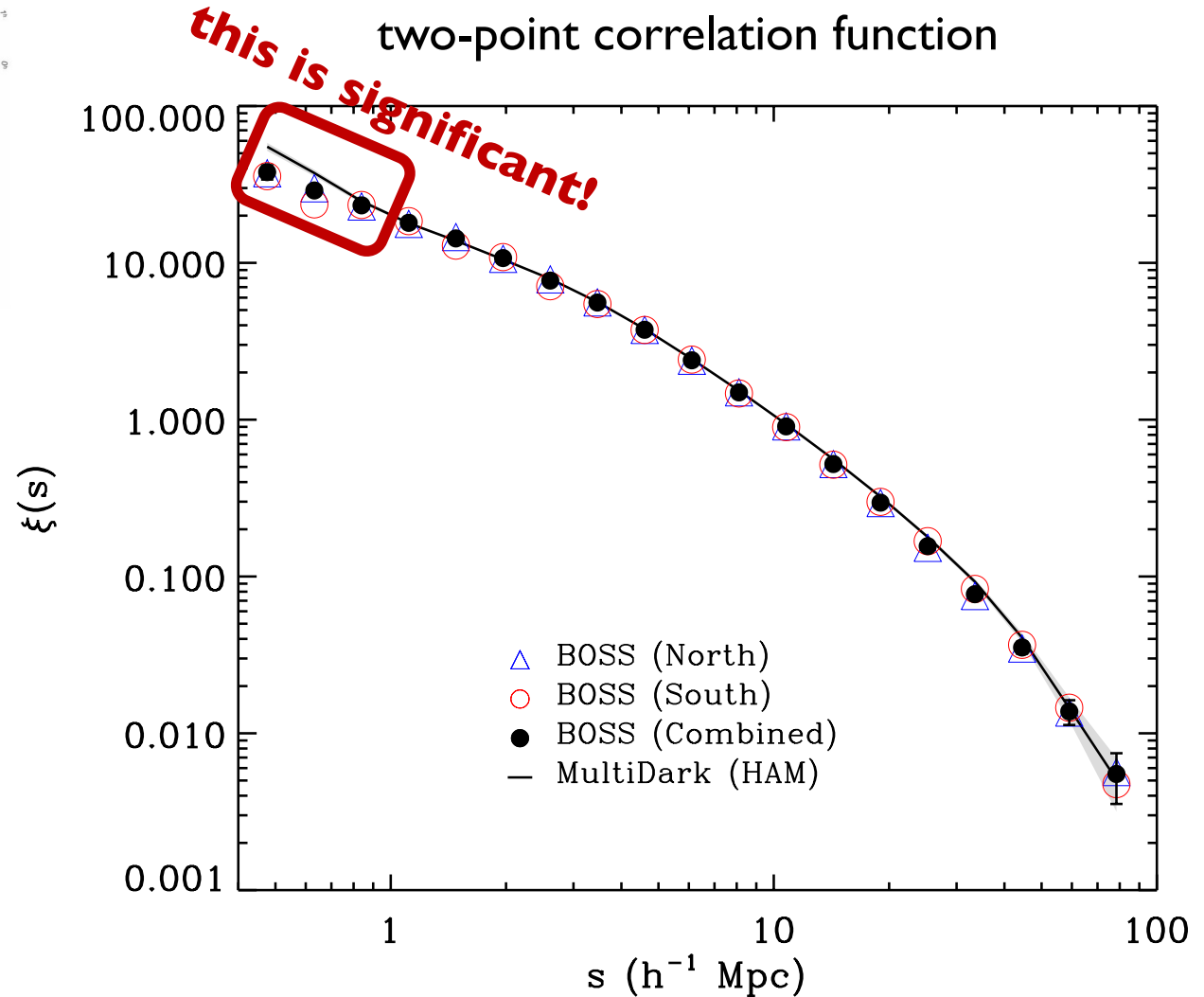
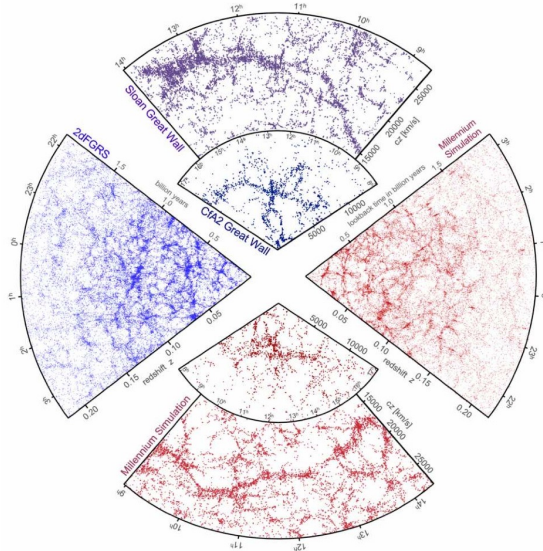
...and what about the results?



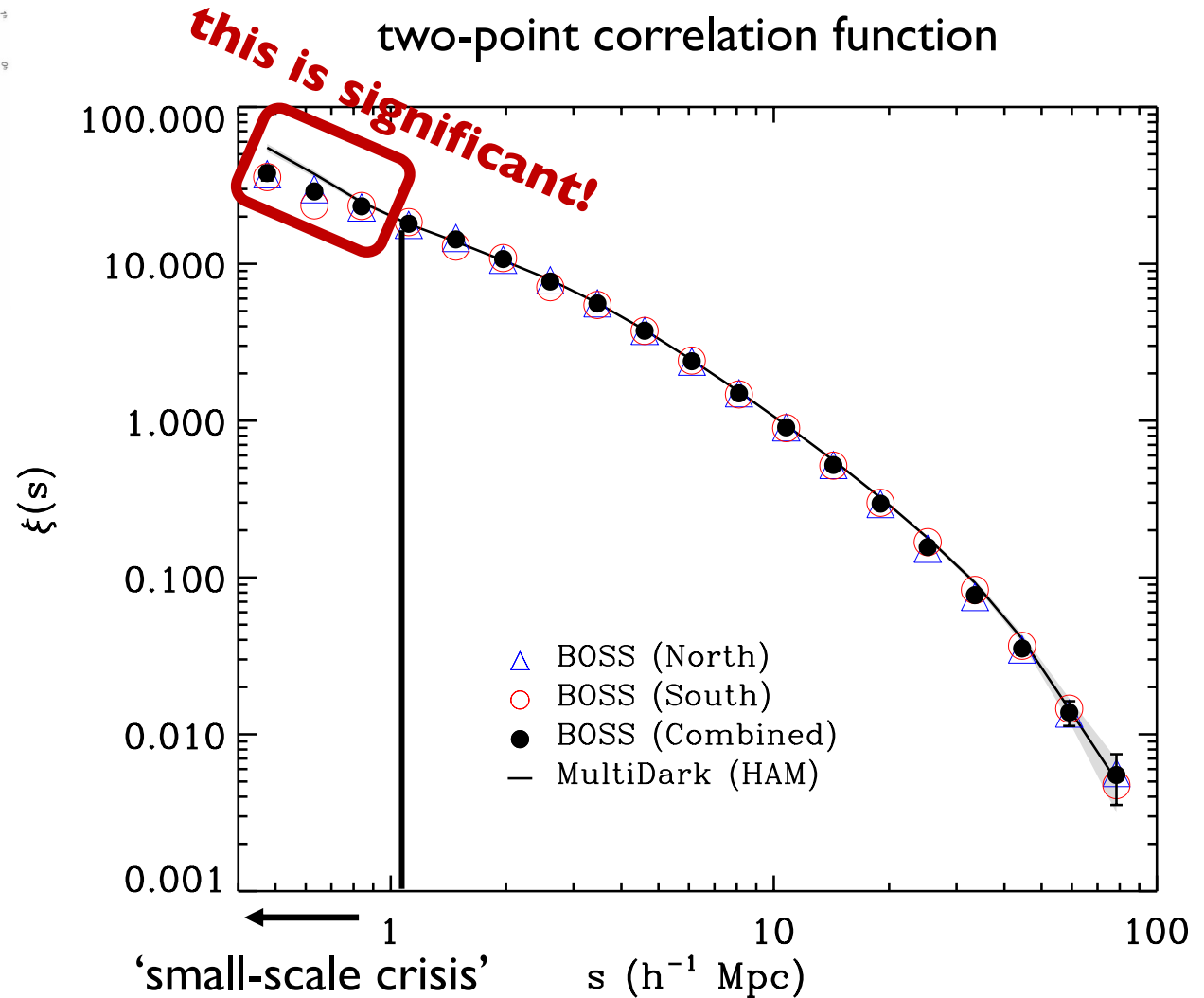
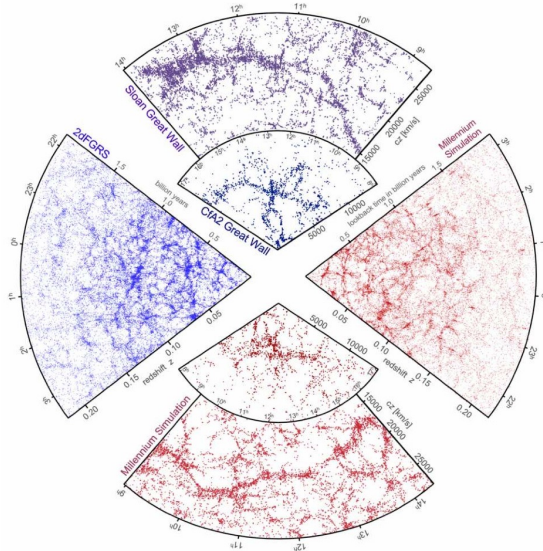
two-point correlation function



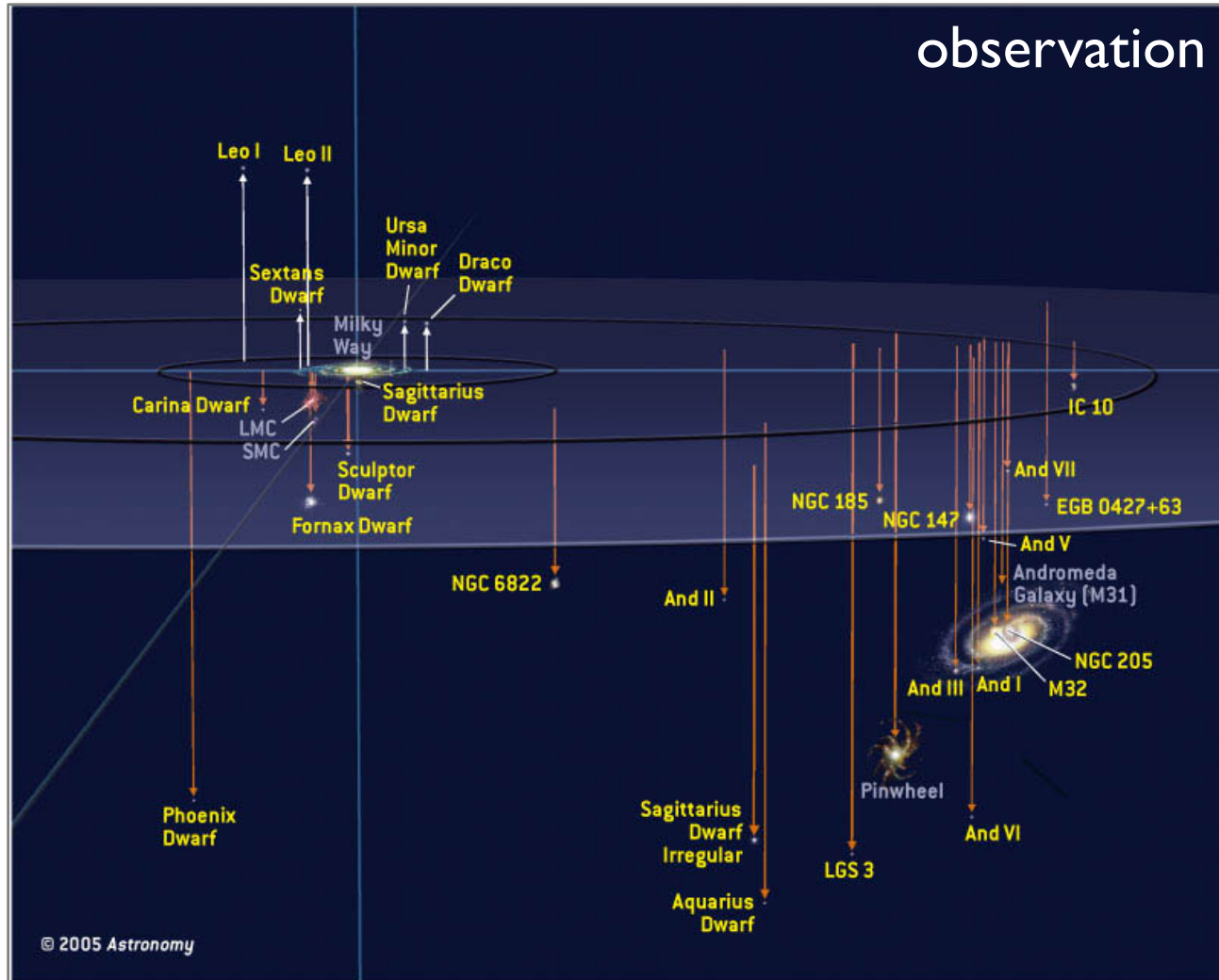
...and what about the results?



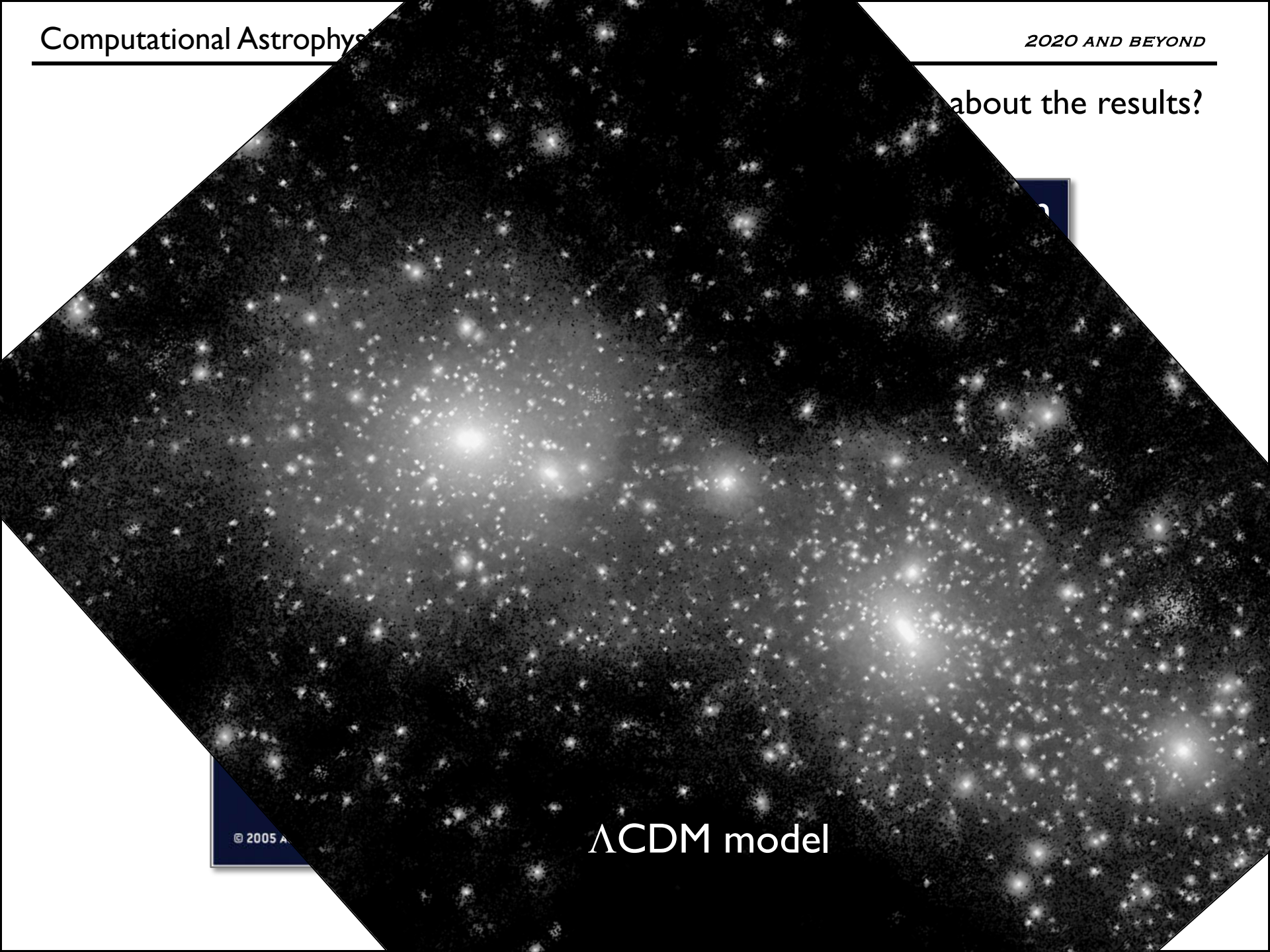
...and what about the results?



...and what about the results?

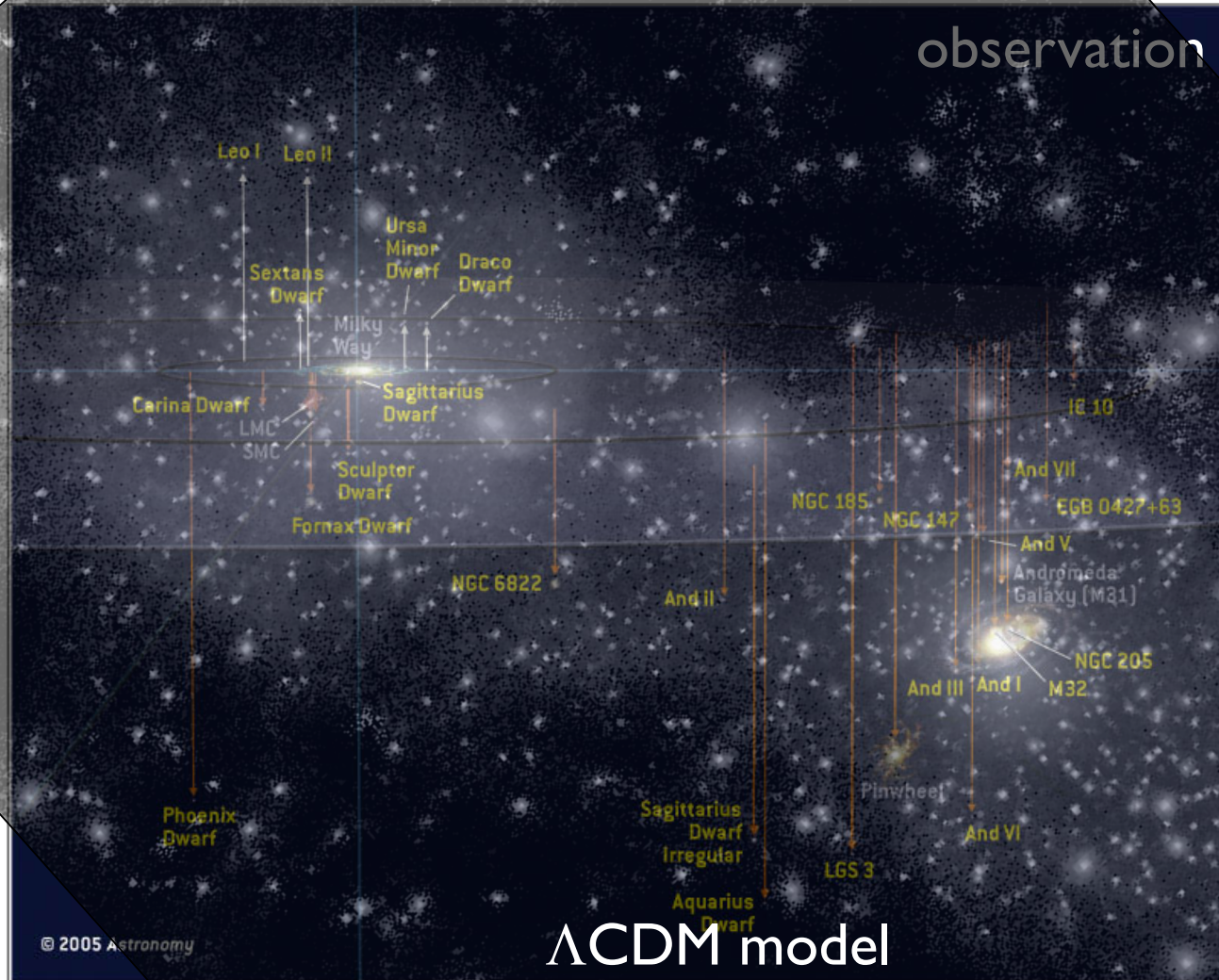


about the results?

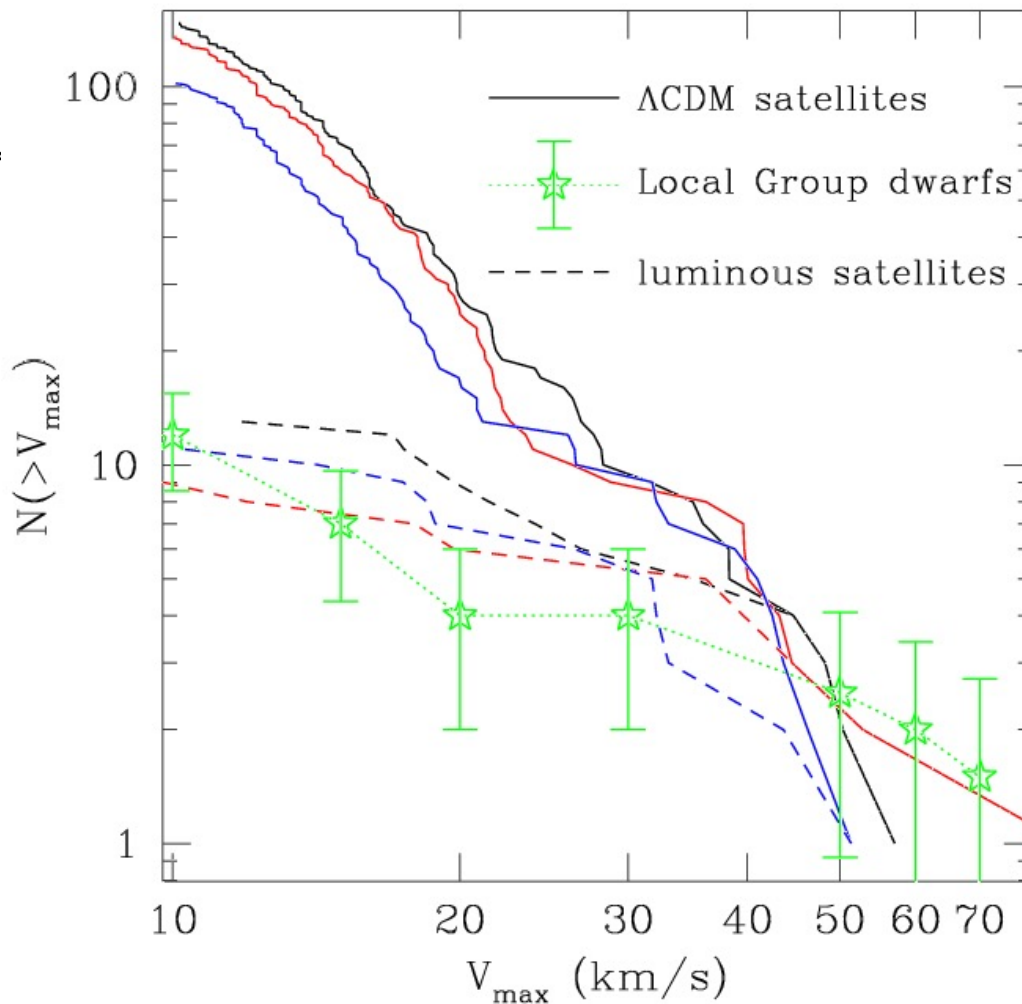
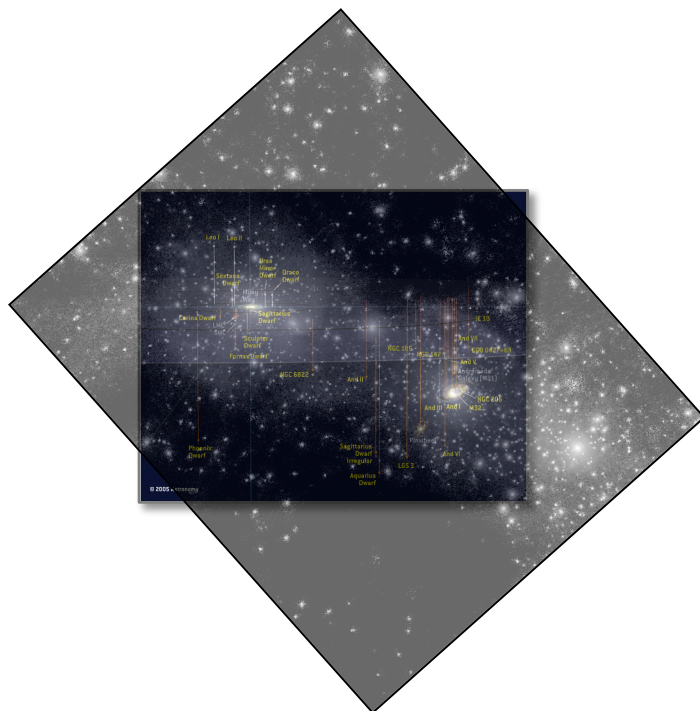


Λ CDM model

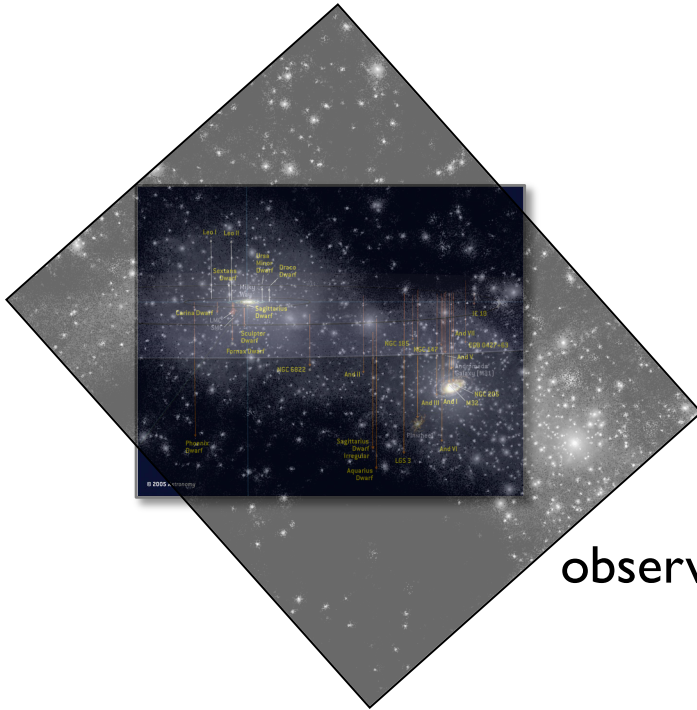
...and what about the results?



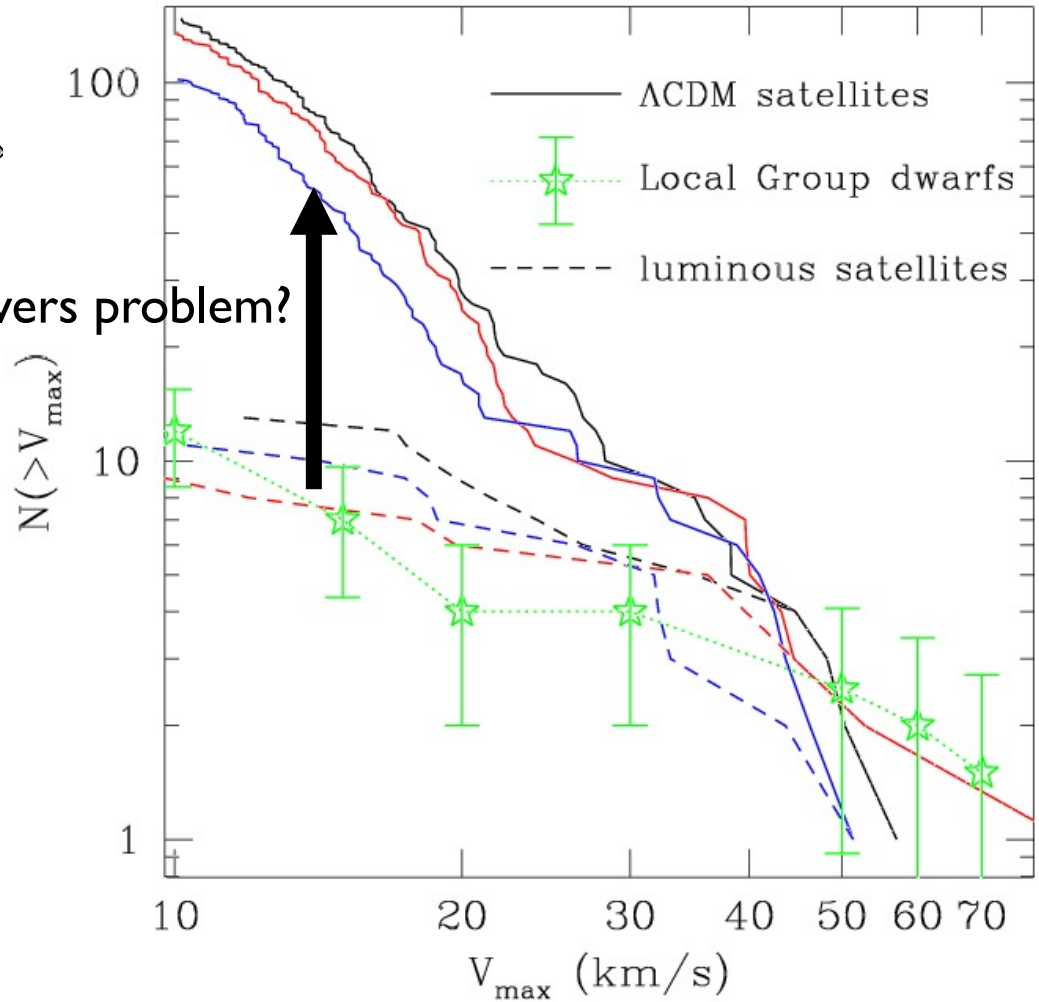
...and what about the results?



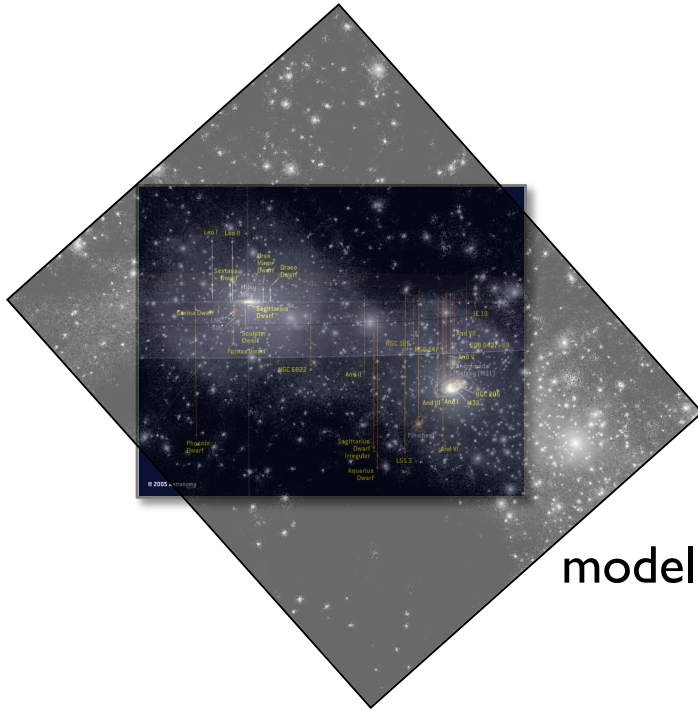
...and what about the results?



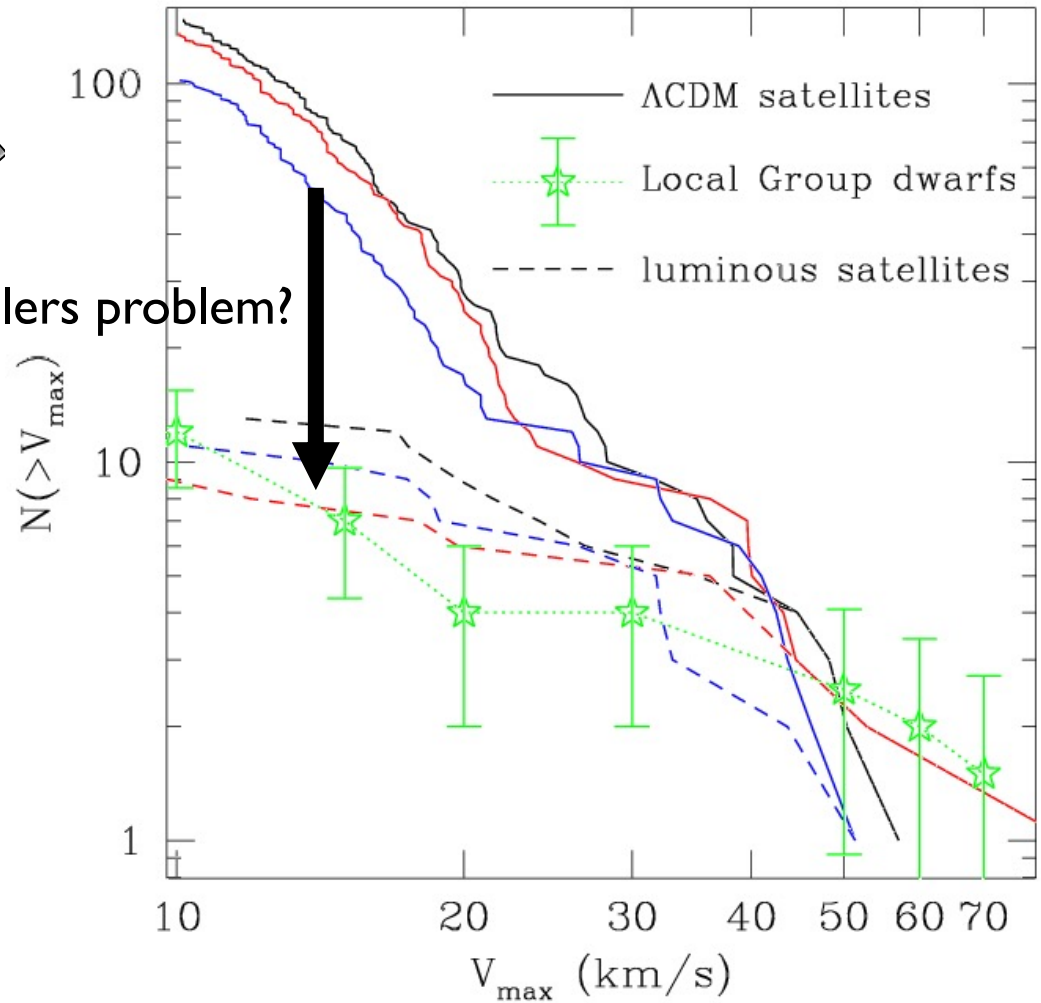
observers problem?



...and what about the results?



modellers problem?



...requires validation of techniques and methods!



SUSSING MERGER TREES

a workshop on
constructing merger trees
for cosmological simulations
in
Midhurst, West Sussex
08/07/2013 - 12/07/2013

nIFTy Cosmology: numerical simulations for large surveys

Perth Simulated Galaxy Clusters Workshop 2015

This wiki page is intended for sharing information around participants of the "Perth Simulated Galaxy Clusters" Workshop, Mar 23-27, 2015 at the [International Centre for Radio Astronomy Research](#) in Perth, Australia.

Cosmic CARnage

Successor to [nIFTy Cosmology](#), held in Madrid during July 2014. The primary goal of this workshop will be to compare and contrast a set of semi-analytic models of galaxy clusters that have all been calibrated to the same observational datasets.

Full program is available [here](#).

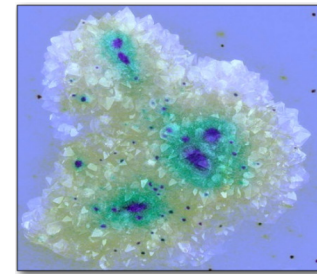
Workshop Location and Dates

Workshop held at the [Carnegie Institution](#) from July 20-24, 2015.



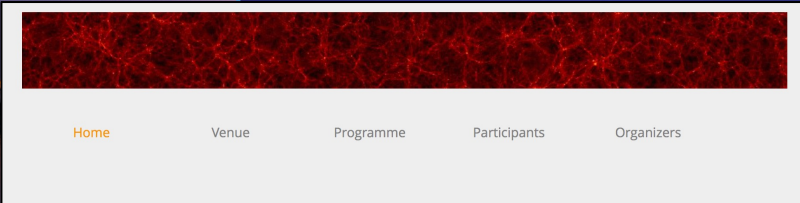
CRYSTAL CLEAR CLUSTERS: where hydrodynamical simulations meet semi-analytical models

SOC:
Alexander Slosar
Fraser Pearce
Chris Power
Gustavo Yepes
Daniel Comins



hands-on workshop on galaxy clusters as found in full physics hydro-simulations and semi-analytical models
June 25-30, 2017 @ "La Cristalera" in Miraflores de la Sierra, Madrid, Spain

[Workshop Program](#) | [The program and the list of invited speakers](#)



MultiDark Galaxies Workshop La Plata, Argentina. 26-30 September 2016.

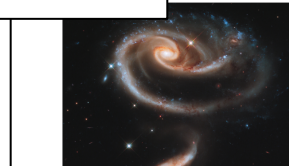
Glenfiddling Galaxy Clusters

...all the information

hands-on workshop on theoretically modelling galaxy clusters
June 4-8, 2018
"Newbattle Abbey" (Edinburgh, Scotland)

<http://popiaft.com/es/GlenfiddlingGalaxyClusters>

SOC:
Romain Teyssie
Alexander Knebe
Fraser Pearce
Chris Power
Gustavo Yepes



- supercomputing
- **numerical modelling**

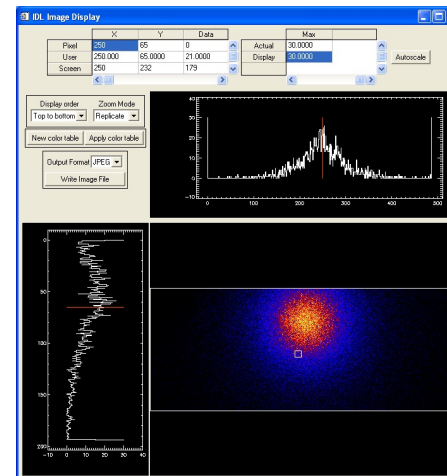
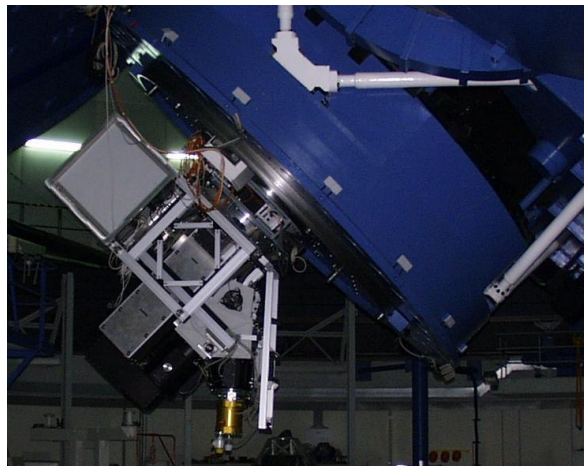
Numerical Modelling (in Astrophysics)



observation via telescope

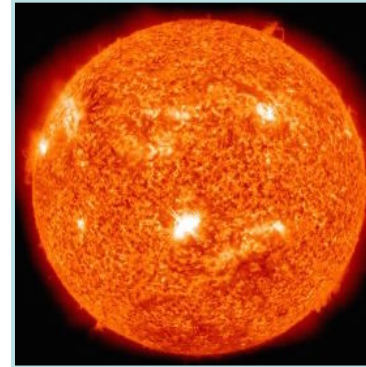


modelling via supercomputers

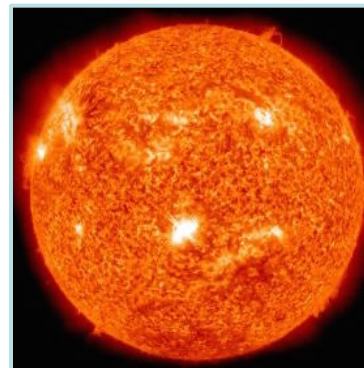
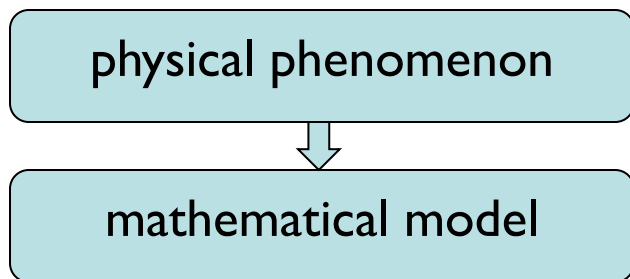


physical phenomenon

physical phenomenon



- what is the physical process we aim at modelling?



- the governing equations

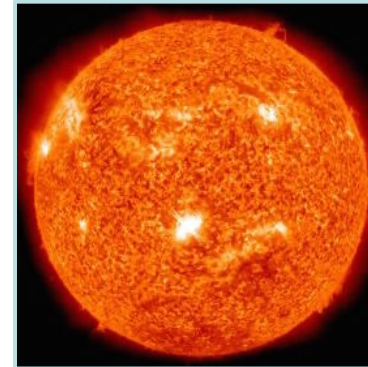
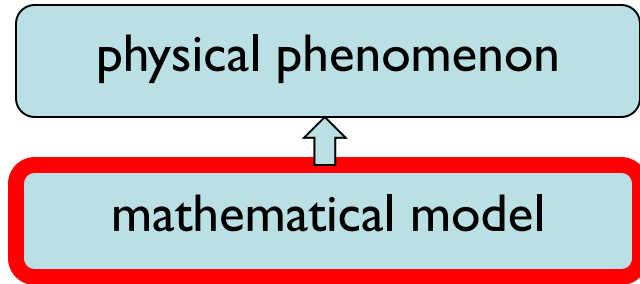
$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{v}) = 0$$

$$\frac{\partial(\rho \vec{v})}{\partial t} + \nabla \cdot \left(\rho \vec{v} \otimes \vec{v} + \left(p + \frac{1}{2\mu} B^2 \right) \vec{1} - \frac{1}{\mu} \vec{B} \otimes \vec{B} \right) = \rho (-\nabla \phi)$$

$$\frac{\partial(\rho E)}{\partial t} + \nabla \cdot \left(\left[\rho E + p + \frac{1}{2\mu} B^2 \right] \vec{v} - \frac{1}{\mu} [\vec{v} \cdot \vec{B}] \vec{B} \right) = \rho \vec{v} \cdot (-\nabla \phi) + (\Gamma - L)$$

$$\frac{\partial \vec{B}}{\partial t} + \nabla \times (-\vec{v} \times \vec{B}) = 0$$

$$\Delta \phi = 4\pi G \rho$$



- the governing equations

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{v}) = 0$$

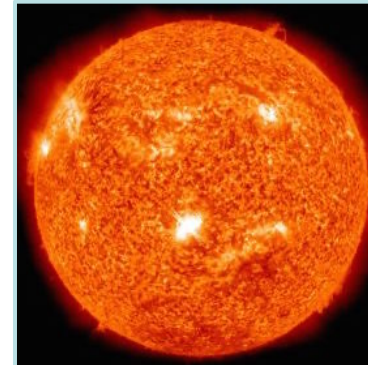
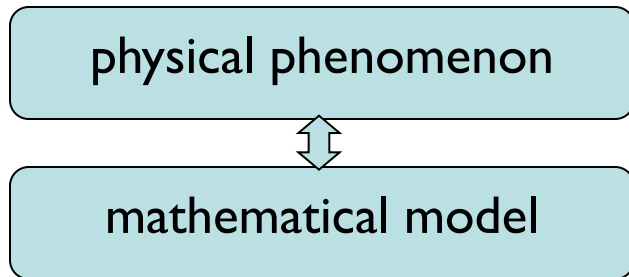
$$\frac{\partial (\rho \vec{v})}{\partial t} + \nabla \cdot \left(\rho \vec{v} \otimes \vec{v} + \left(p + \frac{1}{2\mu} B^2 \right) \vec{1} - \frac{1}{\mu} \vec{B} \otimes \vec{B} \right) = \rho (-\nabla \phi)$$

$$\frac{\partial (\rho E)}{\partial t} + \nabla \cdot \left(\left[\rho E + p + \frac{1}{2\mu} B^2 \right] \vec{v} - \frac{1}{\mu} [\vec{v} \cdot \vec{B}] \vec{B} \right) = \rho \vec{v} \cdot (-\nabla \phi) + (\Gamma - L)$$

$$\frac{\partial \vec{B}}{\partial t} + \nabla \times (-\vec{v} \times \vec{B}) = 0$$

$$\Delta \phi = 4\pi G \rho$$

**this is what we want in the end:
a model that explains the phenomenon!**



- the governing equations

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{v}) = 0$$

$$\frac{\partial(\rho \vec{v})}{\partial t} + \nabla \cdot \left(\rho \vec{v} \otimes \vec{v} + \left(p + \frac{1}{2\mu} B^2 \right) \vec{1} - \frac{1}{\mu} \vec{B} \otimes \vec{B} \right) = \rho (-\nabla \phi)$$

$$\frac{\partial(\rho E)}{\partial t} + \nabla \cdot \left(\left[\rho E + p + \frac{1}{2\mu} B^2 \right] \vec{v} - \frac{1}{\mu} [\vec{v} \cdot \vec{B}] \vec{B} \right) = \rho \vec{v} \cdot (-\nabla \phi) + (\Gamma - L)$$

$$\frac{\partial \vec{B}}{\partial t} + \nabla \times (-\vec{v} \times \vec{B}) = 0$$

$$\Delta \phi = 4\pi G \rho$$

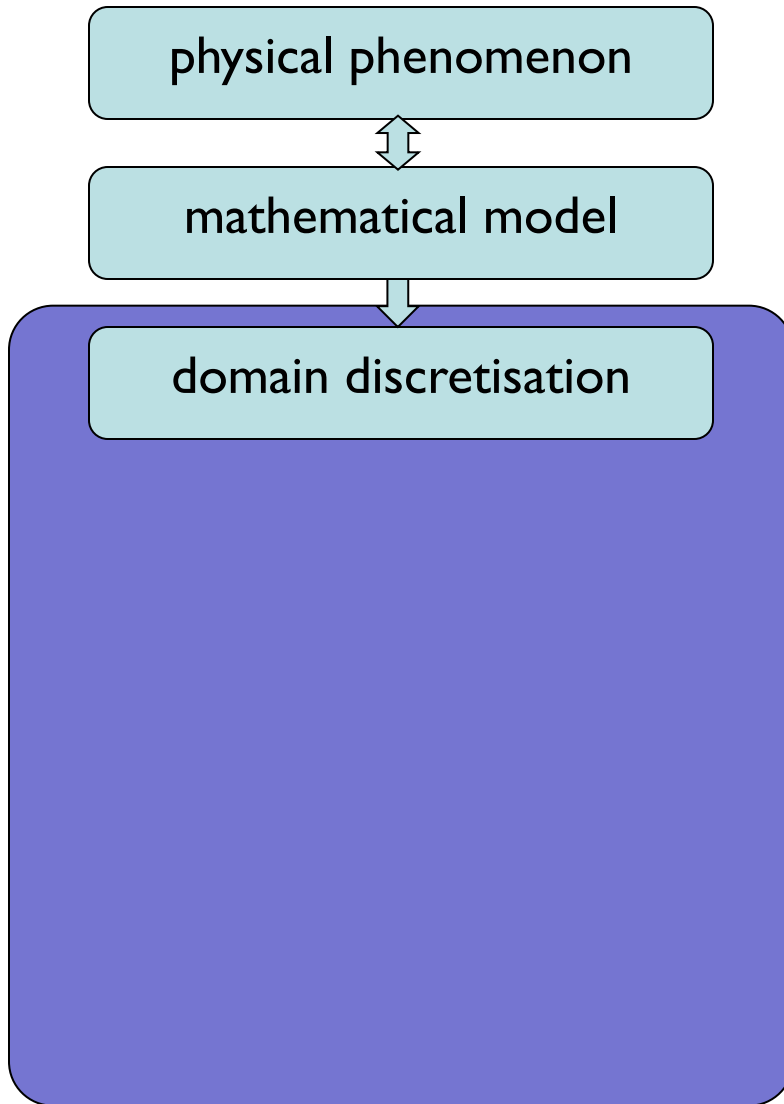
...details in lecture
“astrophysical processes”

physical phenomenon

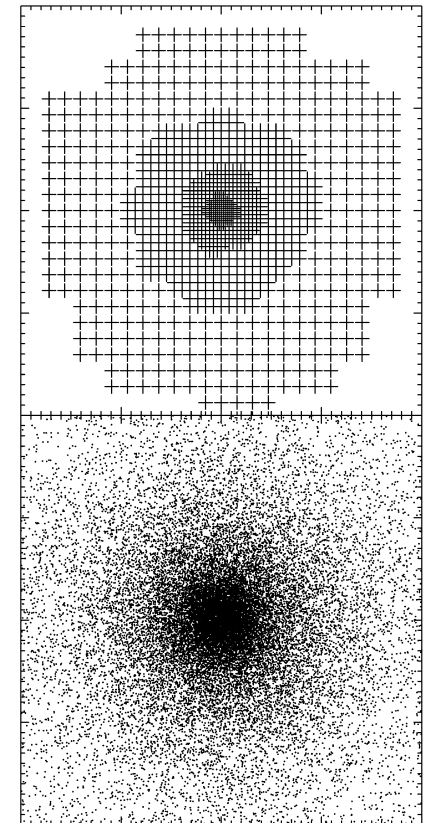
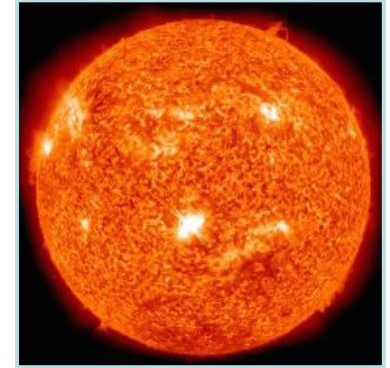


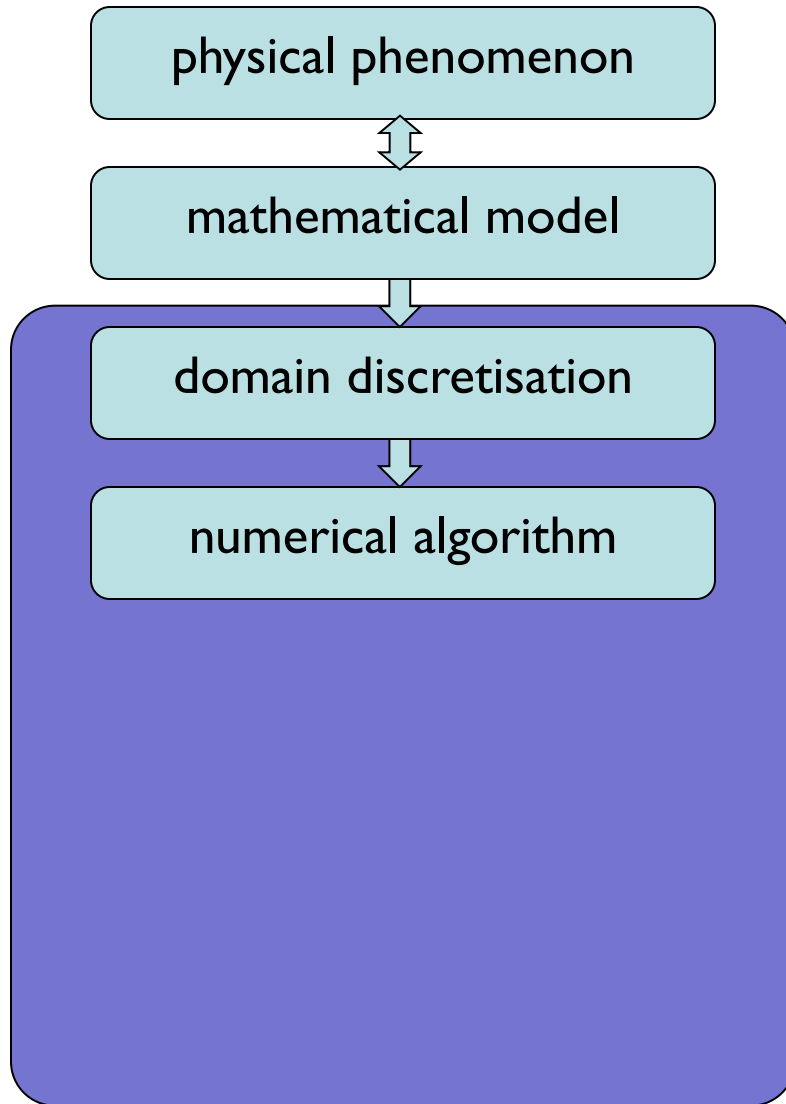
mathematical model

**use a numerical simulation
to verify the model...**

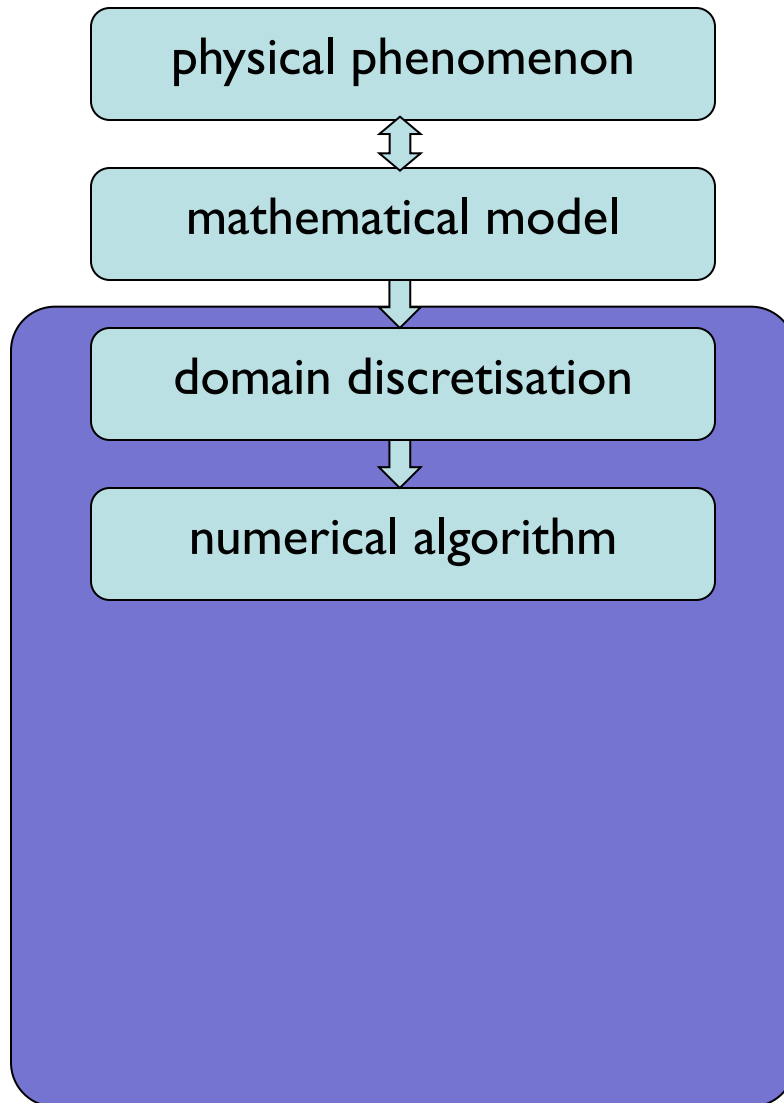


- grid introduction
- particle sampling
- ...





$$I = \int_a^b f(x) dx \Rightarrow \sum_{i=1}^{N-1} \frac{f(x_{i+1}) + f(x_i)}{2} (x_{i+1} - x_i)$$



$$I = \int_a^b f(x) dx \Rightarrow \sum_{i=1}^{N-1} \frac{f(x_{i+1}) + f(x_i)}{2} (x_{i+1} - x_i)$$

...lots of details later!

physical phenomenon



mathematical model



domain discretisation



numerical algorithm



coding

the fun part ;-)

```

27
28
29
30
31 // solve on coarsest grid
32
33 void solve_cg(grid_t *cur_grid)
34 {
35     #ifdef AMFlean
36     flouble *dens_array; /* density array pointer */
37     pgrtr cur_pquad; /* current pquad */
38     cgrtr cur_cquad; /* current cquad */
39     ngrtr cur_nquad; /* current nquad */
40     ngrtr cur_node; /* current node */
41     long i, j, k, ldim, FFTarray_length;
42     double FourPIga;
43
44     /* conversion factor to go from densito to source term */
45     FourPIga = 4*pi*FourPIcalc_super_8(cur_grid->timecounter);
46
47     /* array dimension */
48     ldim = cur_grid->ldim;
49     FFTarray_length = 2*ldim*ldim*ldim;
50
51     /* generate complex [] density array for FFT */
52     if((dens_array = (flouble *) calloc(FFTarray_length, sizeof(flouble))) == NULL)
53     {
54         fprintf(io_logfile, "solve_cg: could not allocate density array for FFT\n");
55         fflush(io_logfile);
56         fclose(io_logfile);
57         exit(1);
58     }
59
60     /* fill density array for FFT ... no need for quad-ll's !! */
61     cur_pquad = cur_grid->pquad;
62     for(k = 0, cur_cquad = cur_pquad->loc; k < ldim; k++, cur_cquad++)
63         for(j = 0, cur_nquad = cur_cquad->loc; j < ldim; j++, cur_nquad++)
64             for(i = 0, cur_node = cur_nquad->loc; i < ldim; i++, cur_node++)
65                 {
66                     dens_array[8*i+j+k*ldim] = cur_node->dens * FourPIga; /* real part */
67                     dens_array[8*i+j+k*ldim+1] = 0.0; /* imaginary part */
68                 }
69
70     /* solve by FFT */
71     fft_potential(dens_array, ldim);
72
73     /* fill node potential values */
74     for(k = 0, cur_cquad = cur_pquad->loc; k < cur_grid->ldim; k++, cur_cquad++)
75         for(j = 0, cur_nquad = cur_cquad->loc; j < cur_grid->ldim; j++, cur_nquad++)
76             for(i = 0, cur_node = cur_nquad->loc; i < cur_grid->ldim; i++, cur_node++)
77                 cur_node->pot = dens_array[8*i+j+k*ldim];
78
79     /* destroy memory assigned to dens_array */
80     free(dens_array);
81
82     #else
83     fprintf(stderr, "%s should not be called when AMFlean is defined.\n",
84             __func__);
85     exit(1);
86     #endif /* AMFlean */
87 }
88
89
90 // =====
91 // test convergence of current grid
92 // =====
93 boolean converged(grid_t *cur_grid)
94 {
95     double trunc_error;
96     double residual;
97

```

physical phenomenon



mathematical model



domain discretisation



numerical algorithm



coding

the fun part ;-)

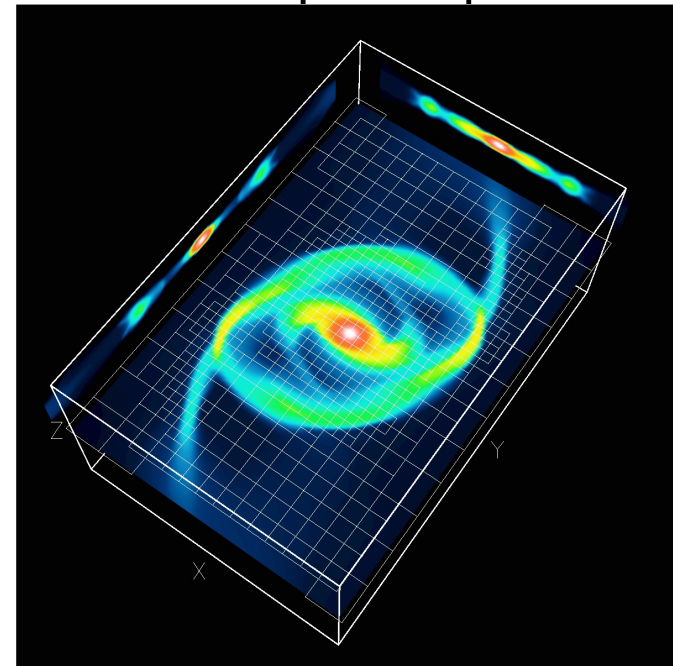
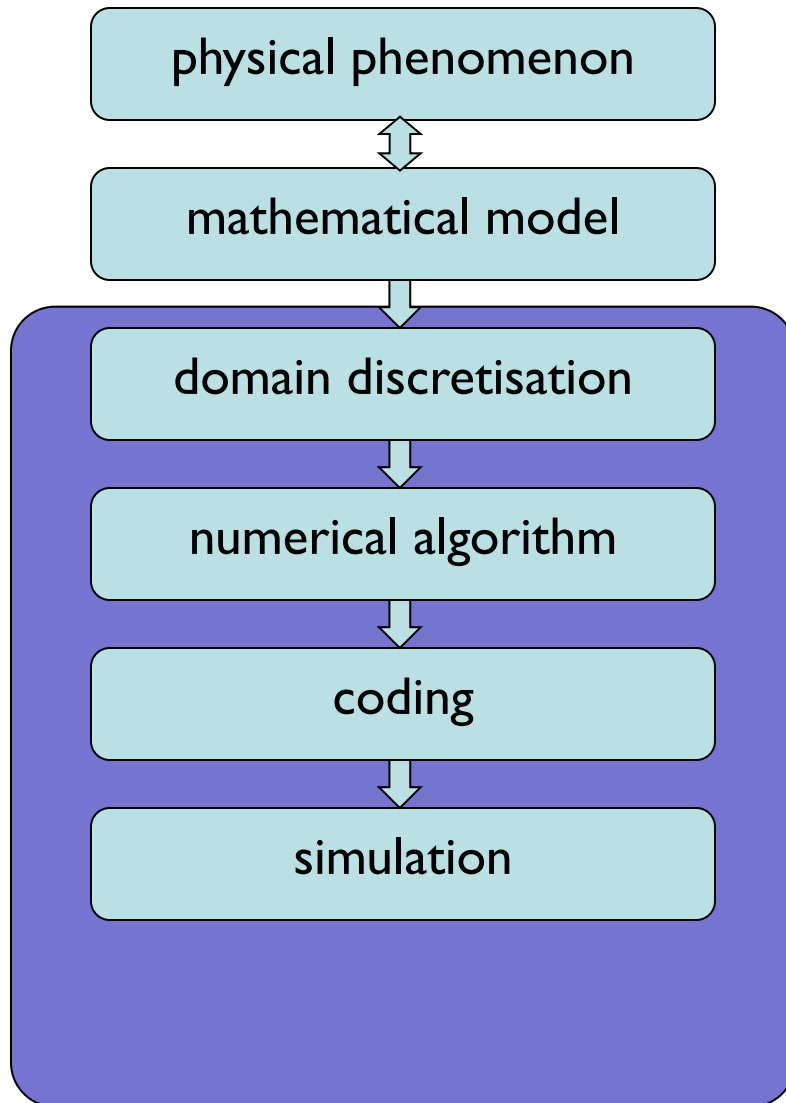
```

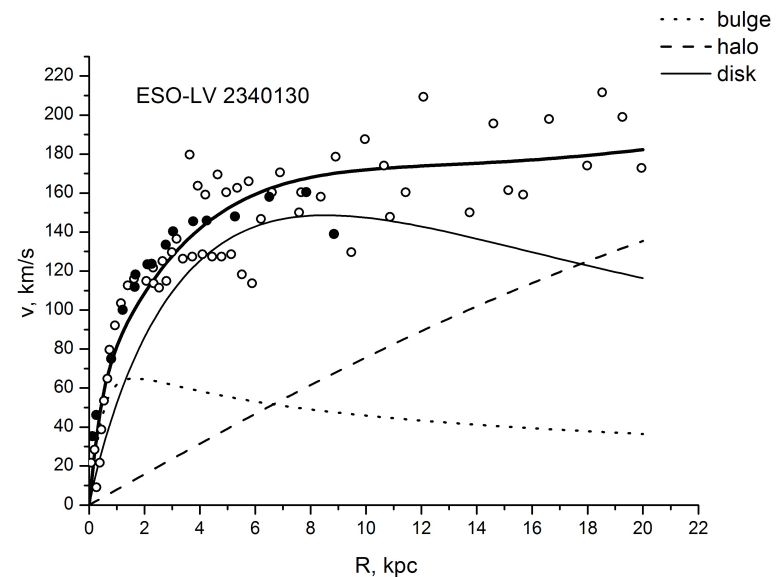
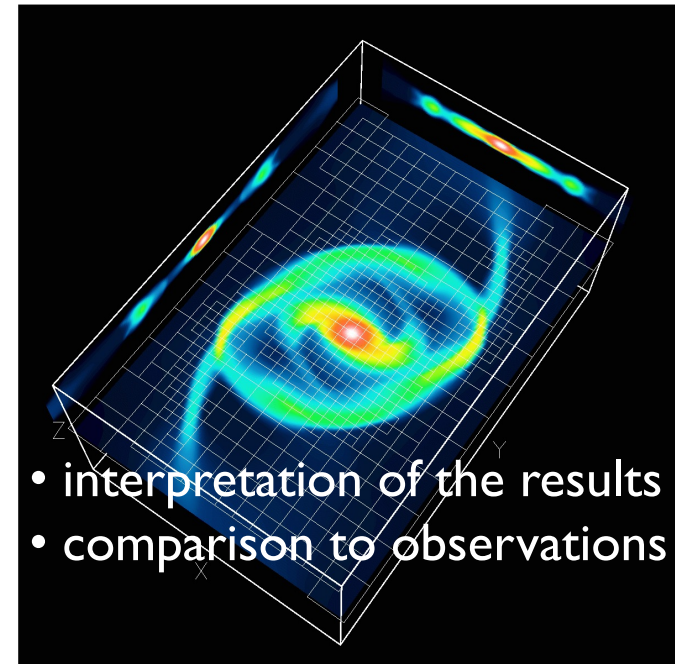
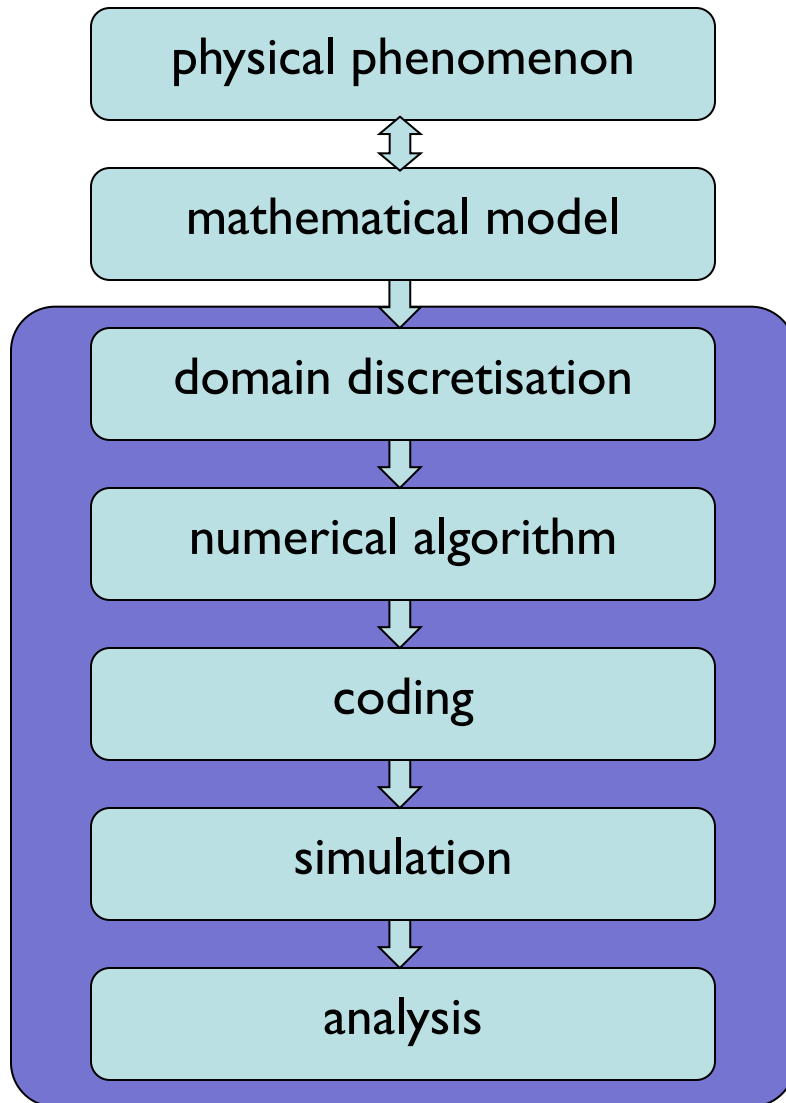
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44         /* conversion factor to go from density to source term */
45         FourPIga = 4*M_PI*G*super_alpha(cur_grid->timecounter);
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48         lldim = cur_grid->lldim;
49         FFTarray_length = 2*lldim*lldim*lldim;
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58             }
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62         for(k = 0, cur_cquad = cur_pquad->loc; k < lldim; k++, cur_cquad++)
63             for(j = 0, cur_nquad = cur_cquad->loc; j < lldim; j++, cur_nquad++)
64                 for(i = 0, cur_node = cur_nquad->loc; i < lldim; i++, cur_node++)
65                     {
66                         dens_array[Re(i,j,k,lldim)] = cur_node->dens * FourPIga; /* real part */
67                         dens_array[Im(i,j,k,lldim)] = 0.0; /* imaginary part */
68                     }
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74         for(k = 0, cur_cquad = cur_pquad->loc; k < cur_grid->lldim; k++, cur_cquad++)
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76                 for(i = 0, cur_node = cur_nquad->loc; i < cur_grid->lldim; i++, cur_node++)
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79         /* destroy memory assigned to dens_array */
80         free(dens_array);
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83         fprintf(stderr, "%s should not be called when AMFlean is defined.\n",
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93 boolean converged(grid_t *cur_grid)
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```

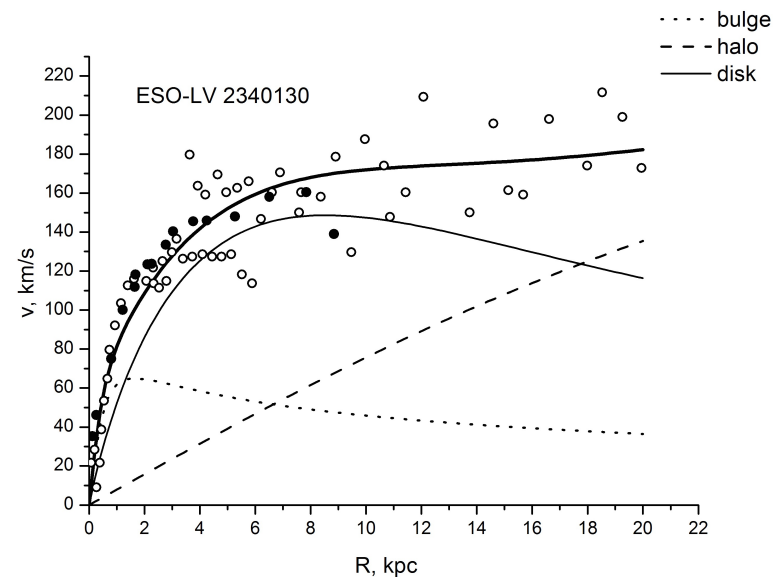
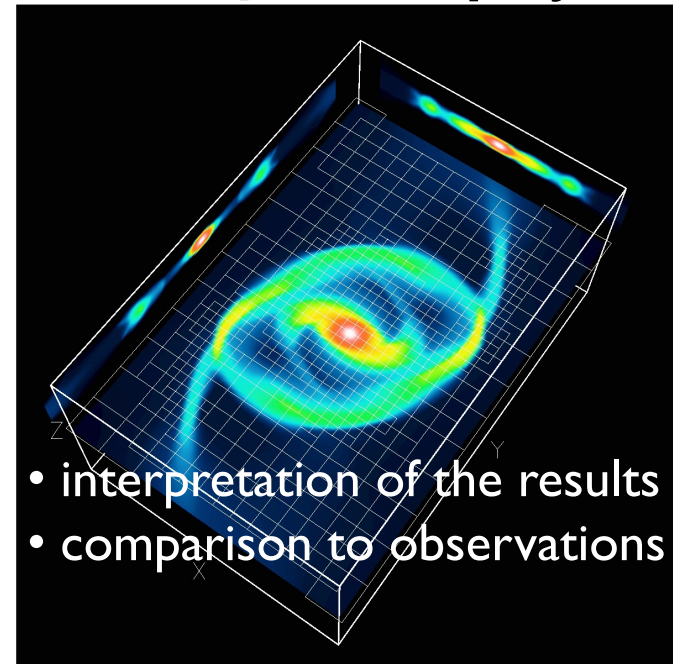
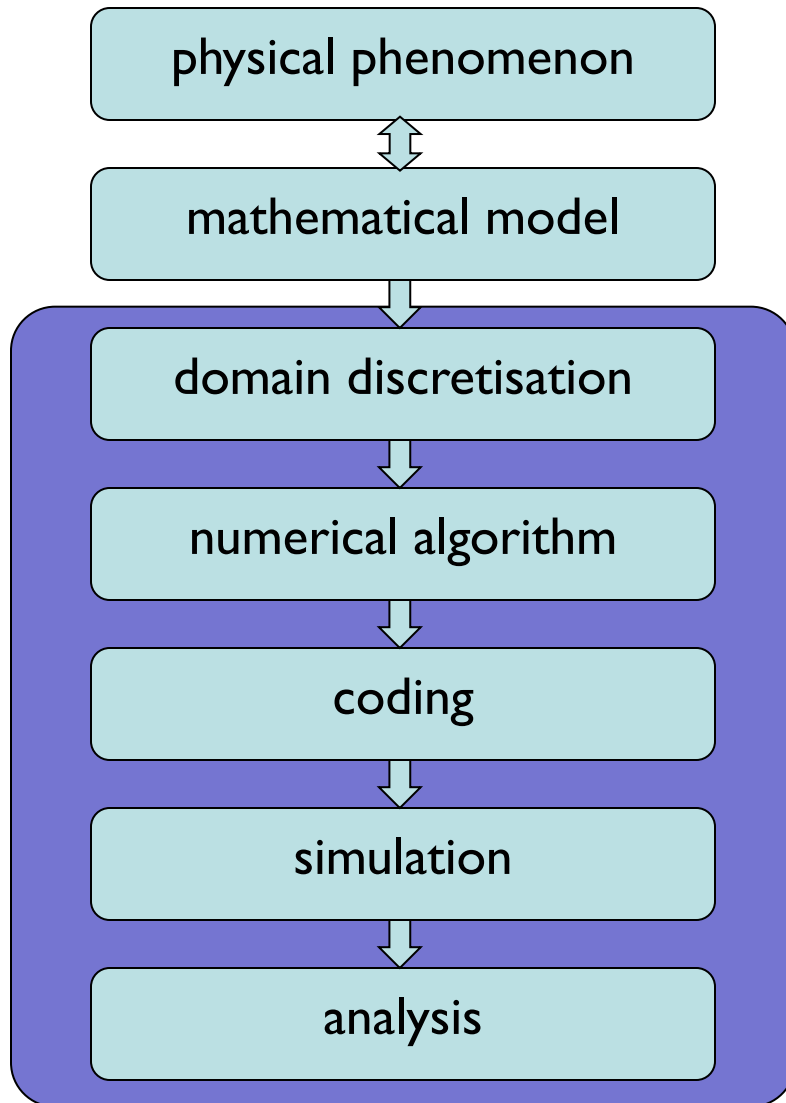
Friday's hands-on coding...

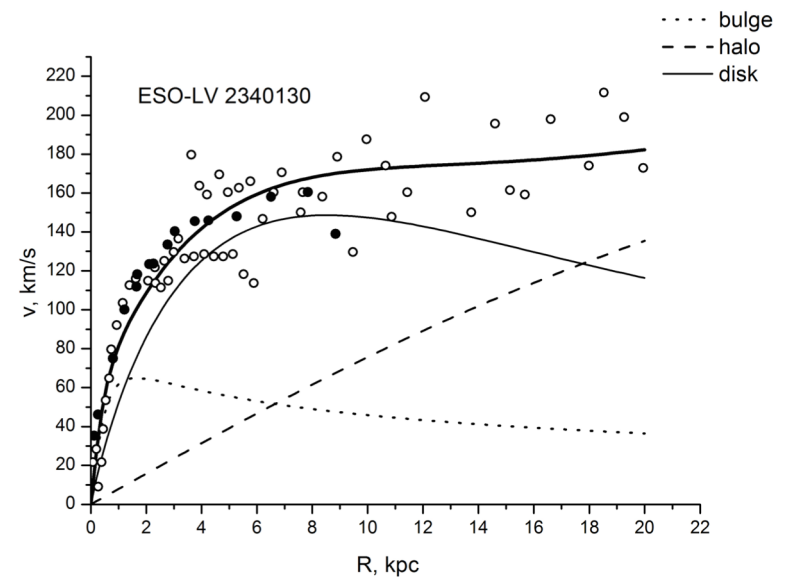
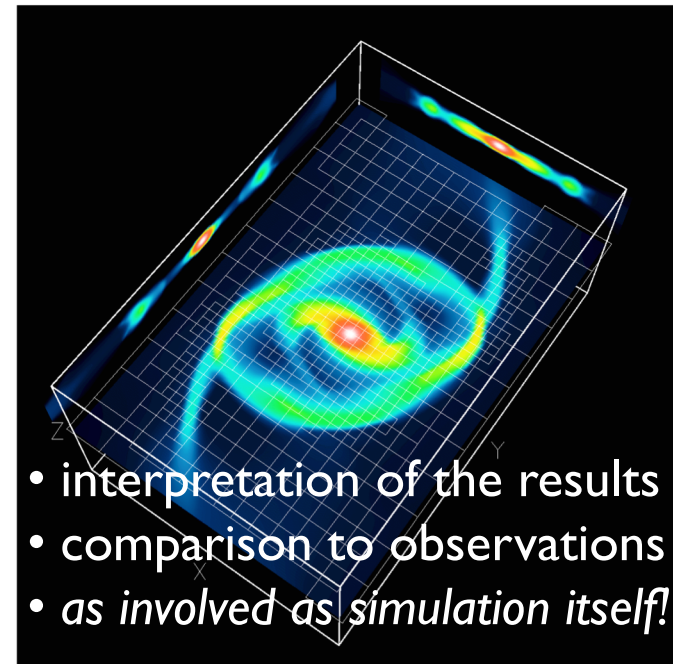
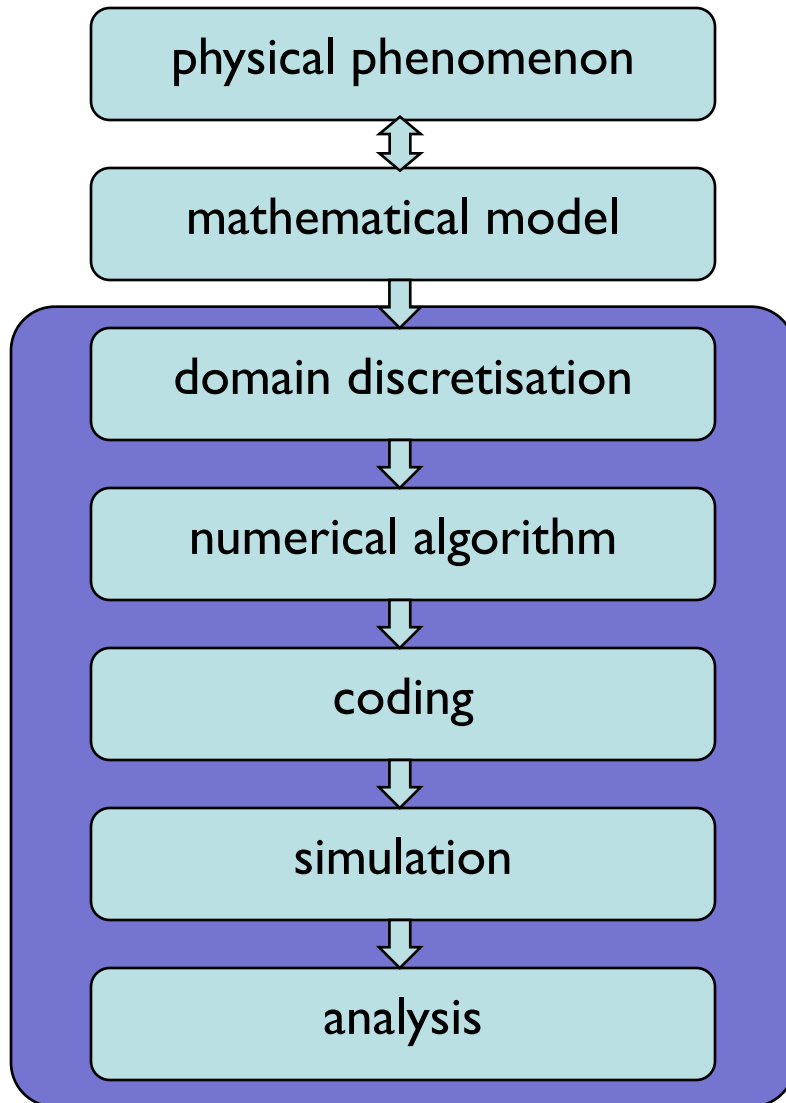
find a supercomputer



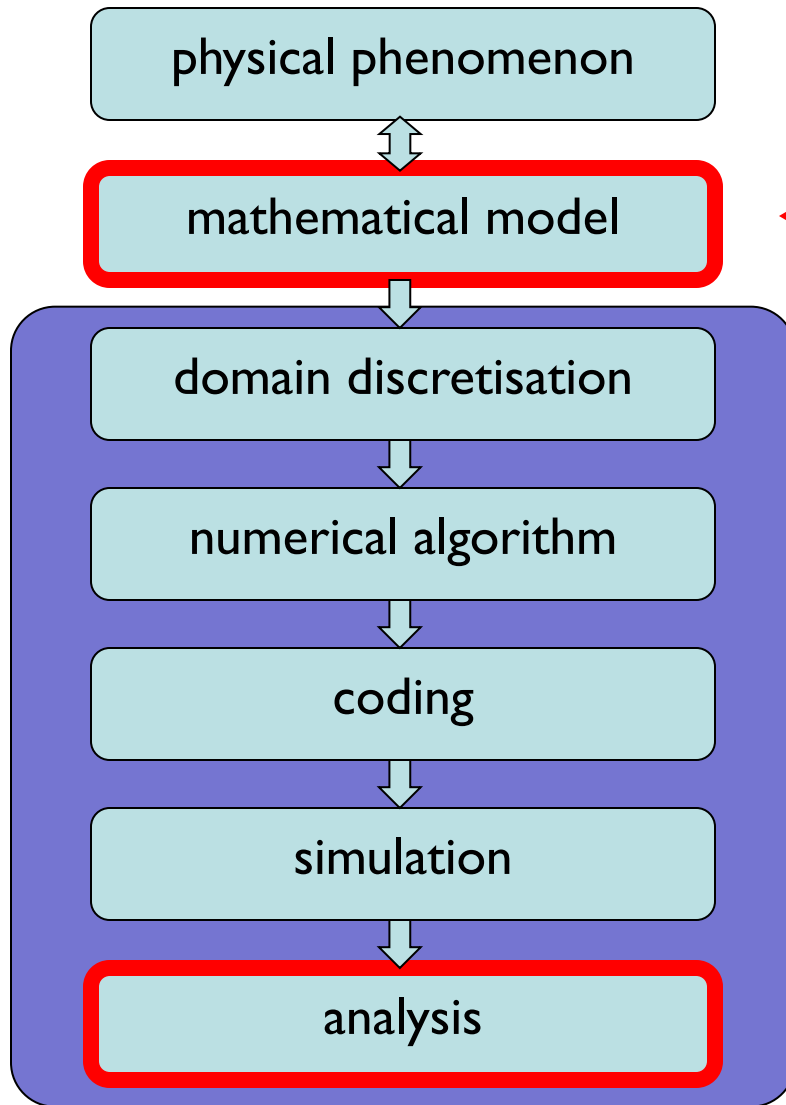


... end-of-course projects

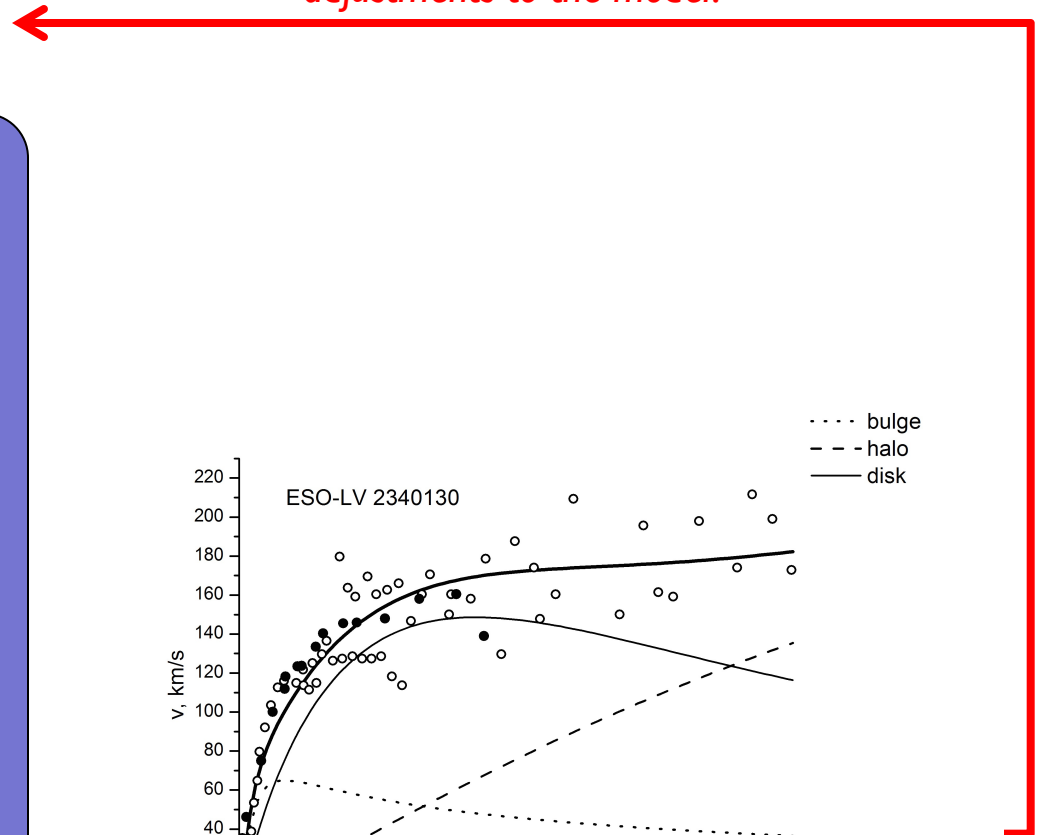




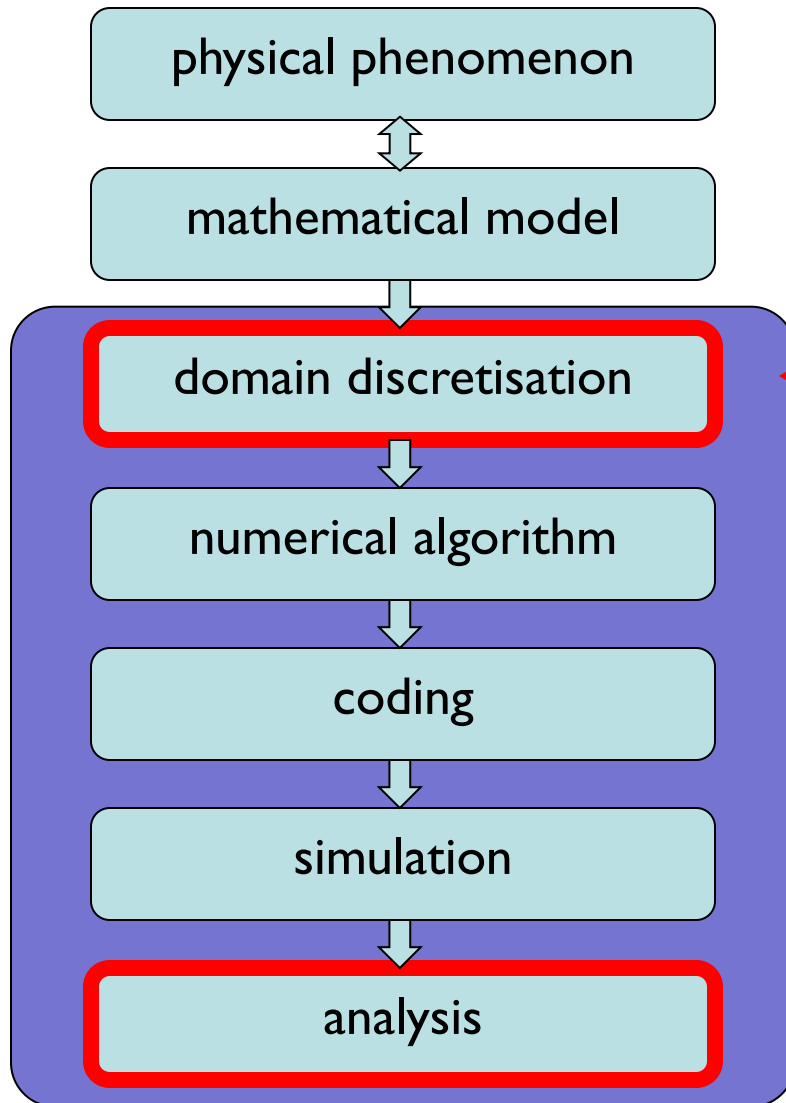
feedback loop:



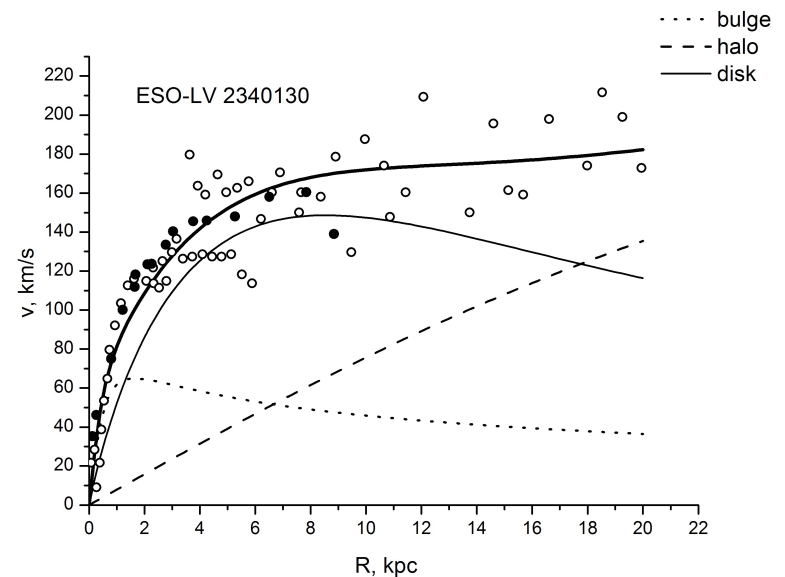
adjustments to the model?



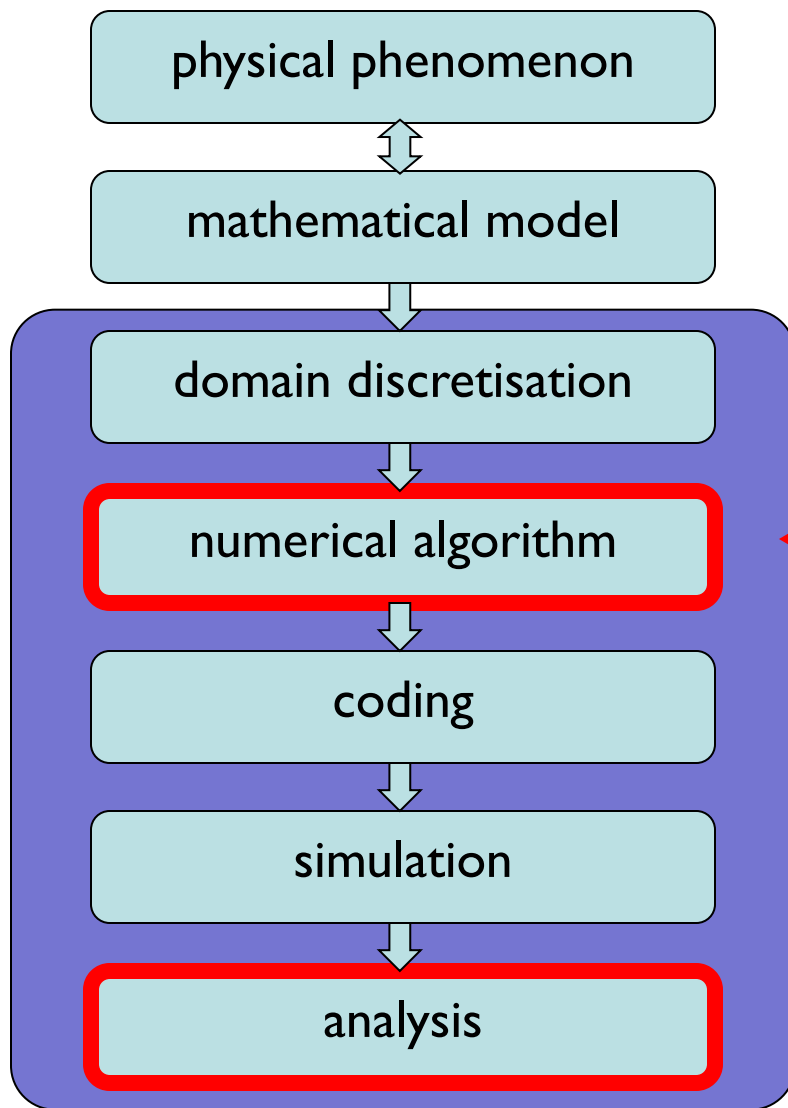
feedback loop:



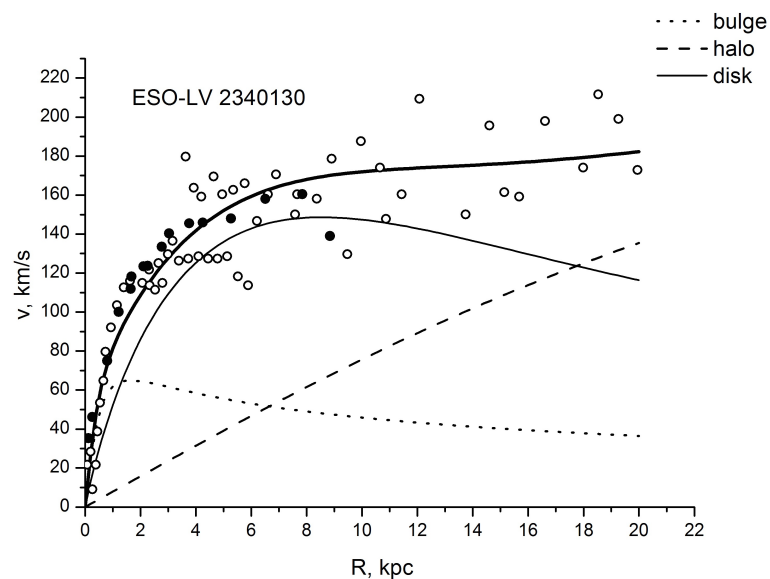
wrong domain discretisation?



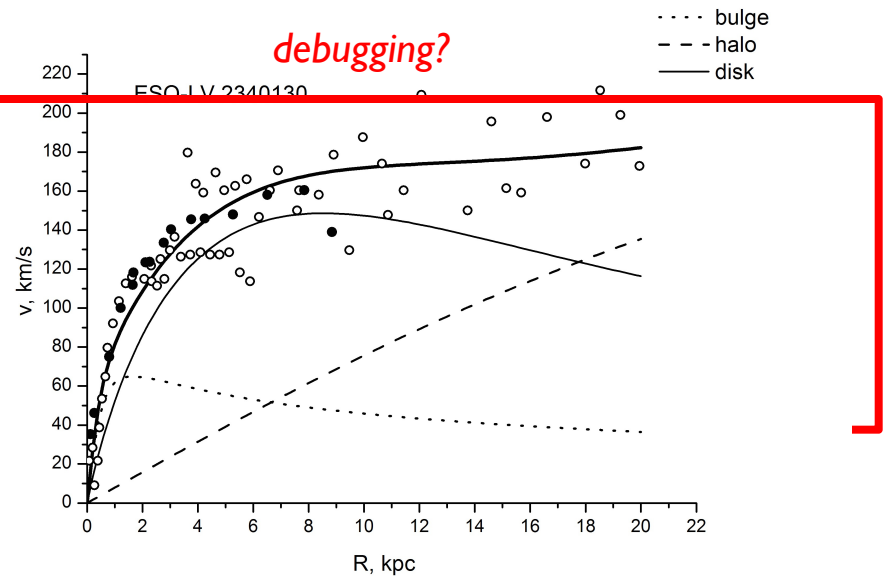
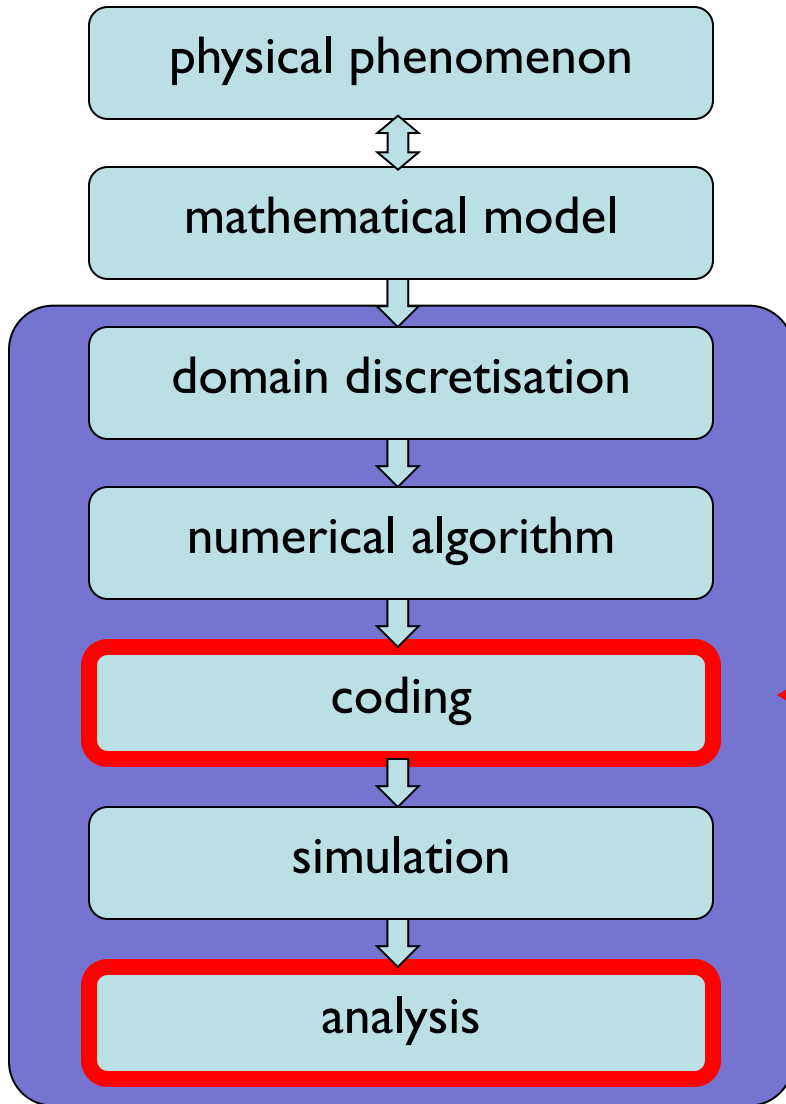
feedback loop:



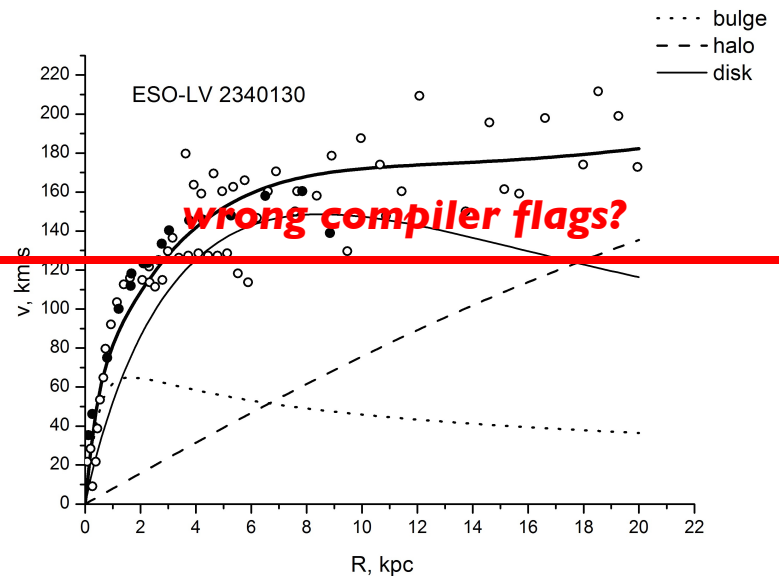
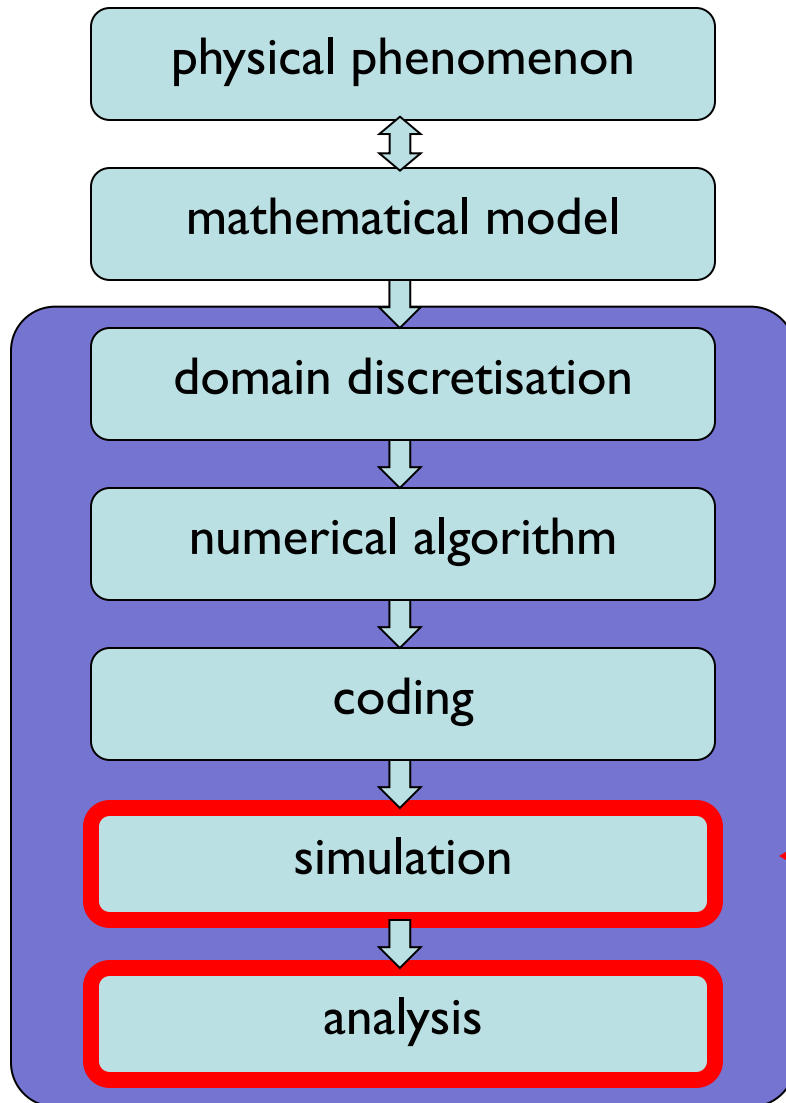
better suited algorithm possible?

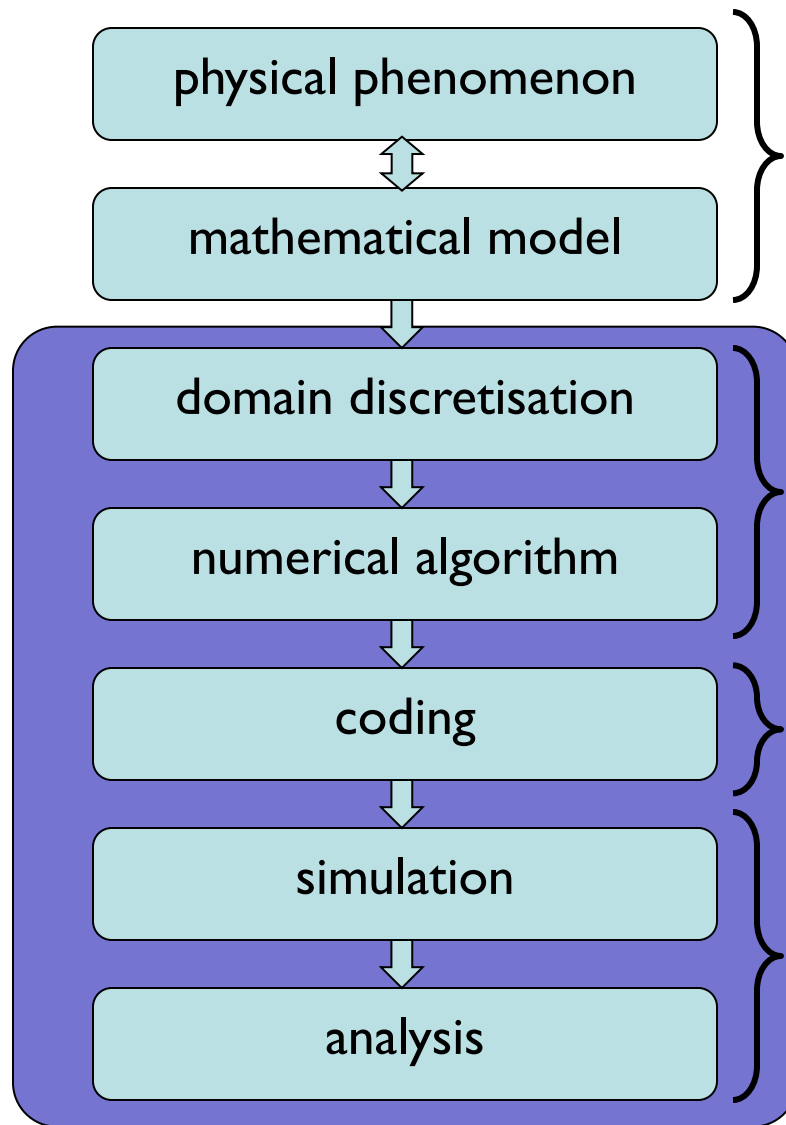


feedback loop:



feedback loop:



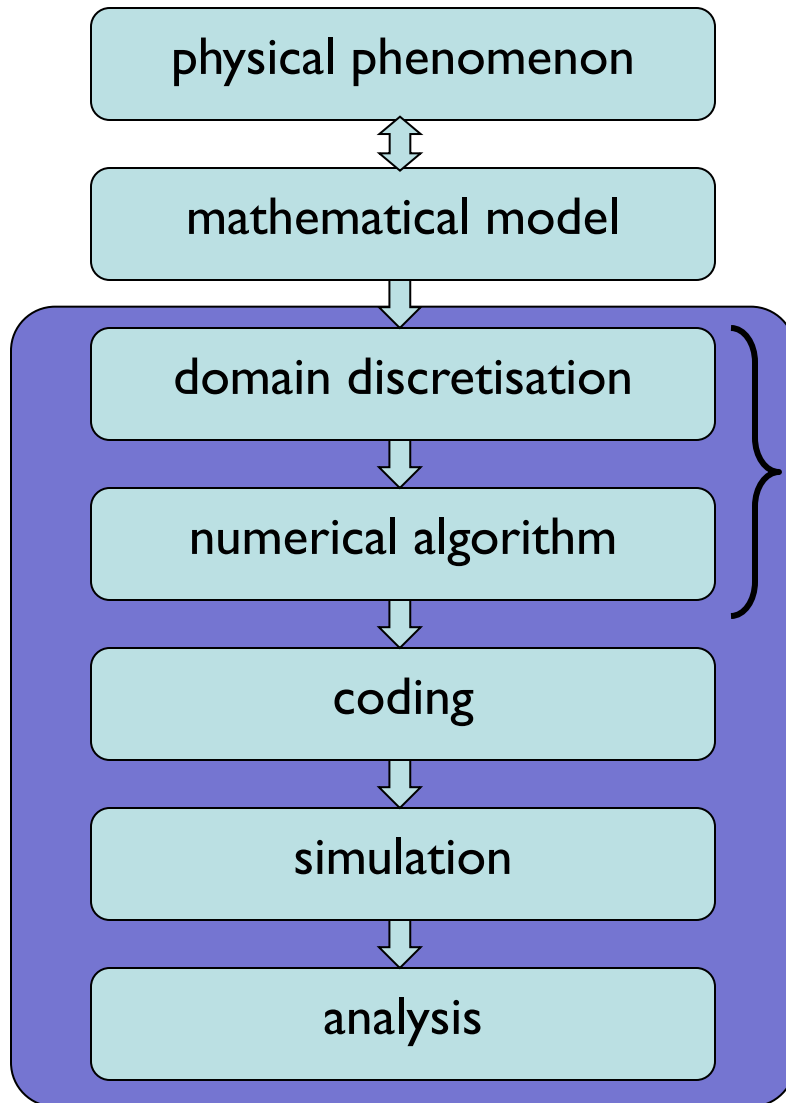


- lecture “astrophysical processes”

- all remaining lectures

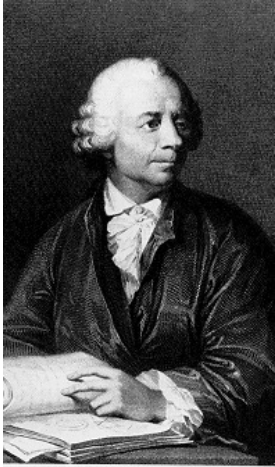
- practical lessons

- exercises & projects



- a few introductory words already now...

- domain discretisation



L. P. Euler
1707-1783

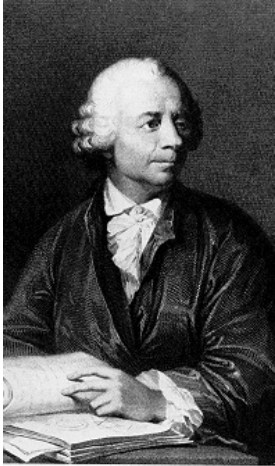
vs.

J.-L. Lagrange
1736-1813



two fundamentally different approaches to solving the same equations

- domain discretisation



L. P. Euler
1707-1783

vs.

J.-L. Lagrange
1736-1813



$$\frac{\partial \rho}{\partial t} + v_i \frac{\partial \rho}{\partial x_i} = -\rho \frac{\partial v_i}{\partial x_i}$$

mass conservation

$$\frac{D\rho}{Dt} = -\rho \frac{\partial v_i}{\partial x_i}$$

$$\frac{\partial v_i}{\partial t} + v_j \frac{\partial v_i}{\partial x_j} = -\frac{1}{\rho} \frac{\partial p}{\partial x_i}$$

momentum conservation

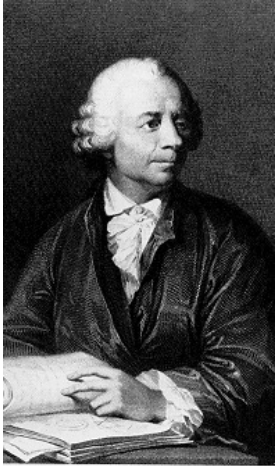
$$\frac{Dv_i}{Dt} = -\frac{1}{\rho} \frac{\partial p}{\partial x_i}$$

$$\frac{\partial e}{\partial t} + v_i \frac{\partial e}{\partial x_i} = -\frac{p}{\rho} \frac{\partial v_i}{\partial x_i}$$

energy conservation

$$\frac{De}{Dt} = -\frac{p}{\rho} \frac{\partial v_i}{\partial x_i}$$

▪ domain discretisation



L. P. Euler
1707-1783

vs.

J.-L. Lagrange
1736-1813



$\partial/\partial t$ = rate of change at a fixed point in space

D/Dt = rate of change following a mass element

$$\frac{\partial \rho}{\partial t} + v_i \frac{\partial \rho}{\partial x_i} = -\rho \frac{\partial v_i}{\partial x_i}$$

mass conservation

$$\frac{D\rho}{Dt} = -\rho \frac{\partial v_i}{\partial x_i}$$

$$\frac{\partial v_i}{\partial t} + v_j \frac{\partial v_i}{\partial x_j} = -\frac{1}{\rho} \frac{\partial p}{\partial x_i}$$

momentum conservation

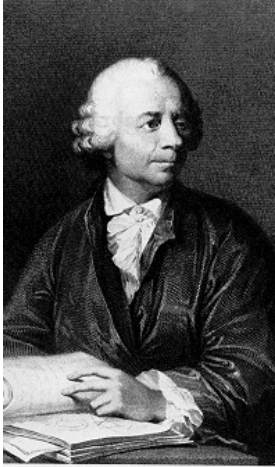
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energy conservation

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- domain discretisation



L. P. Euler
1707-1783

vs.

J.-L. Lagrange
1736-1813

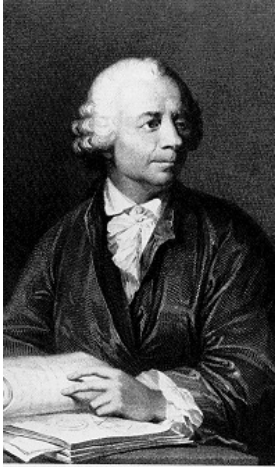


$\partial/\partial t$ = rate of change at a fixed point in space

D/Dt = rate of change following a mass element



- domain discretisation



L. P. Euler
1707-1783

vs.

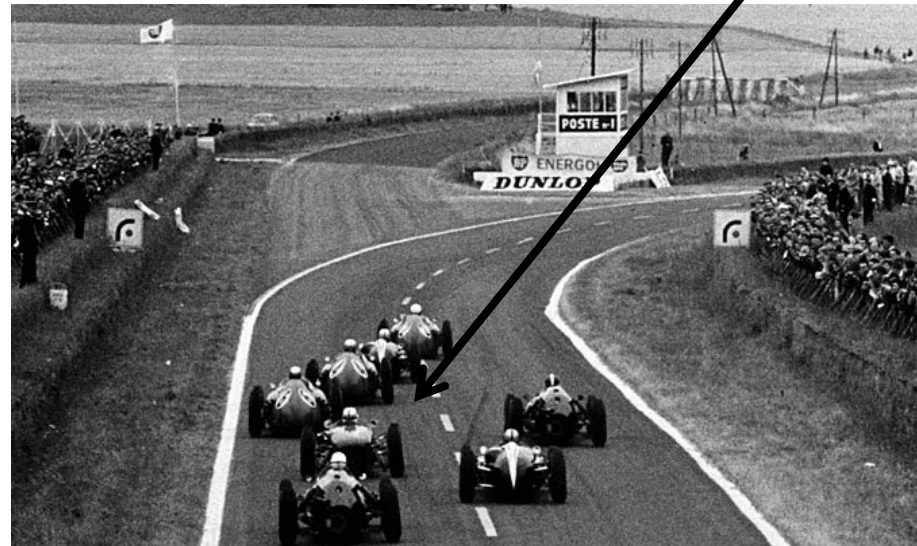
J.-L. Lagrange
1736-1813



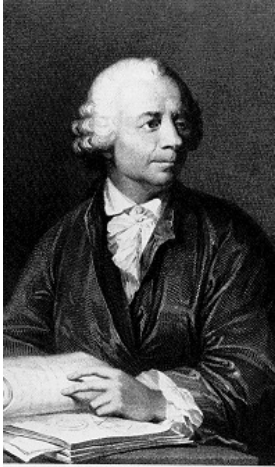
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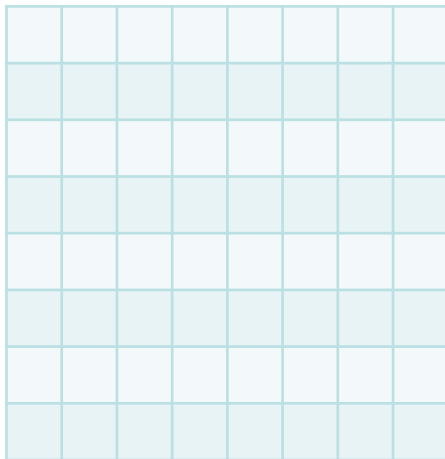
- domain discretisation



L. P. Euler
1707-1783

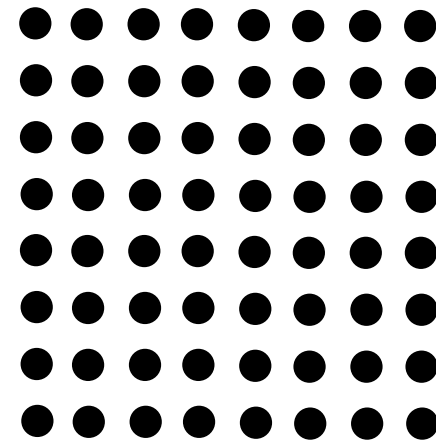
vs.

J.-L. Lagrange
1736-1813



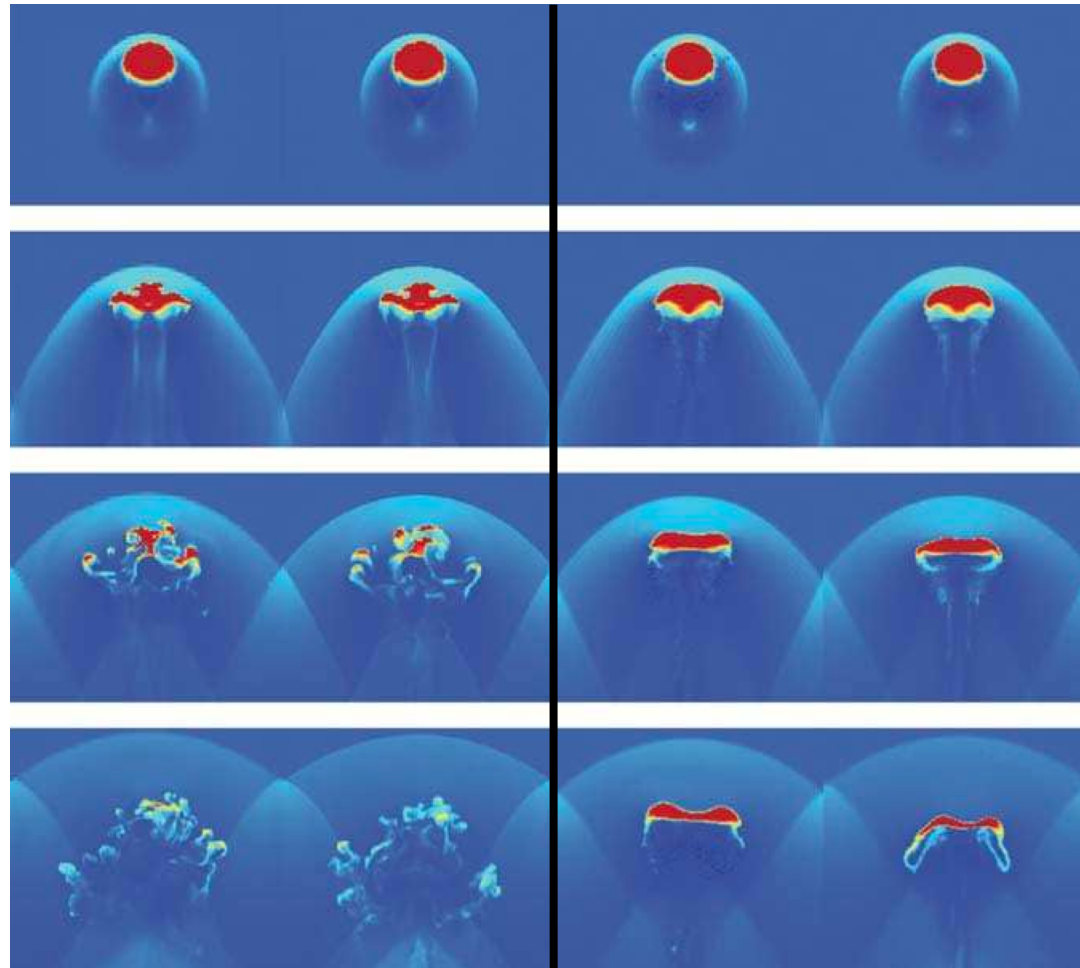
grid-based methods

vs.



particle-based methods

▪ domain discretisation



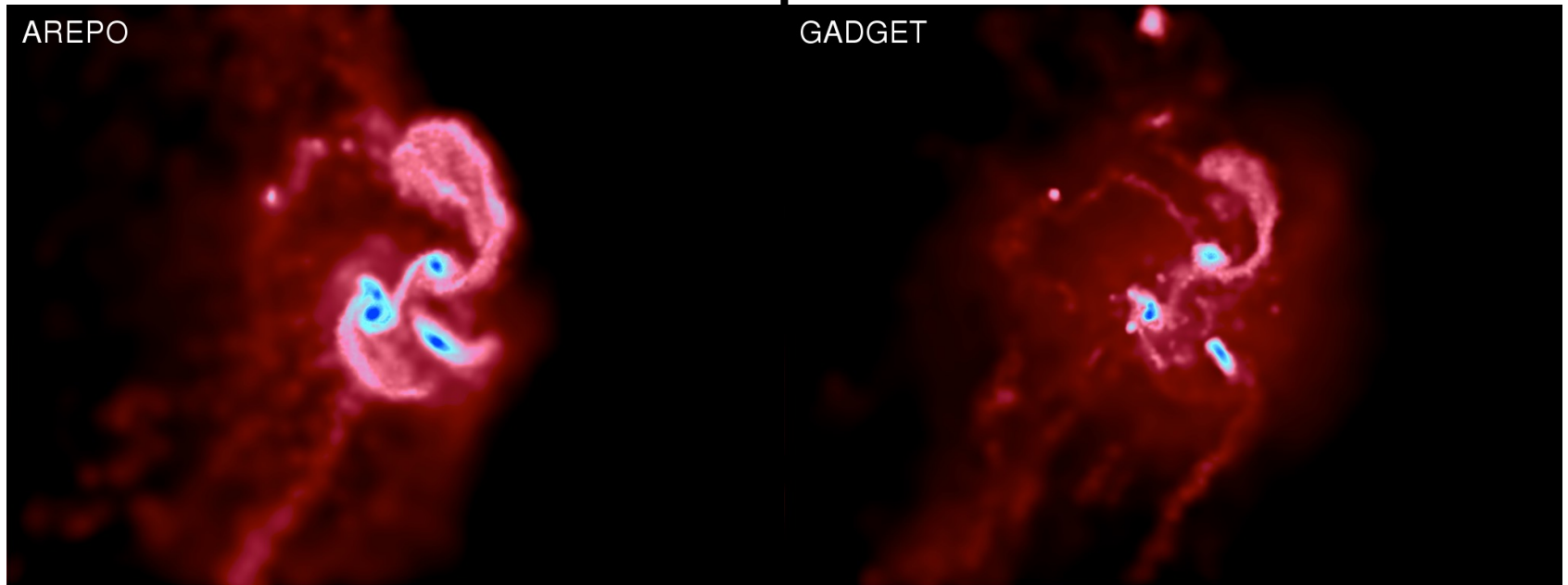
Agertz et al. (2007)

grid-based methods

vs.

particle-based methods

- domain discretisation



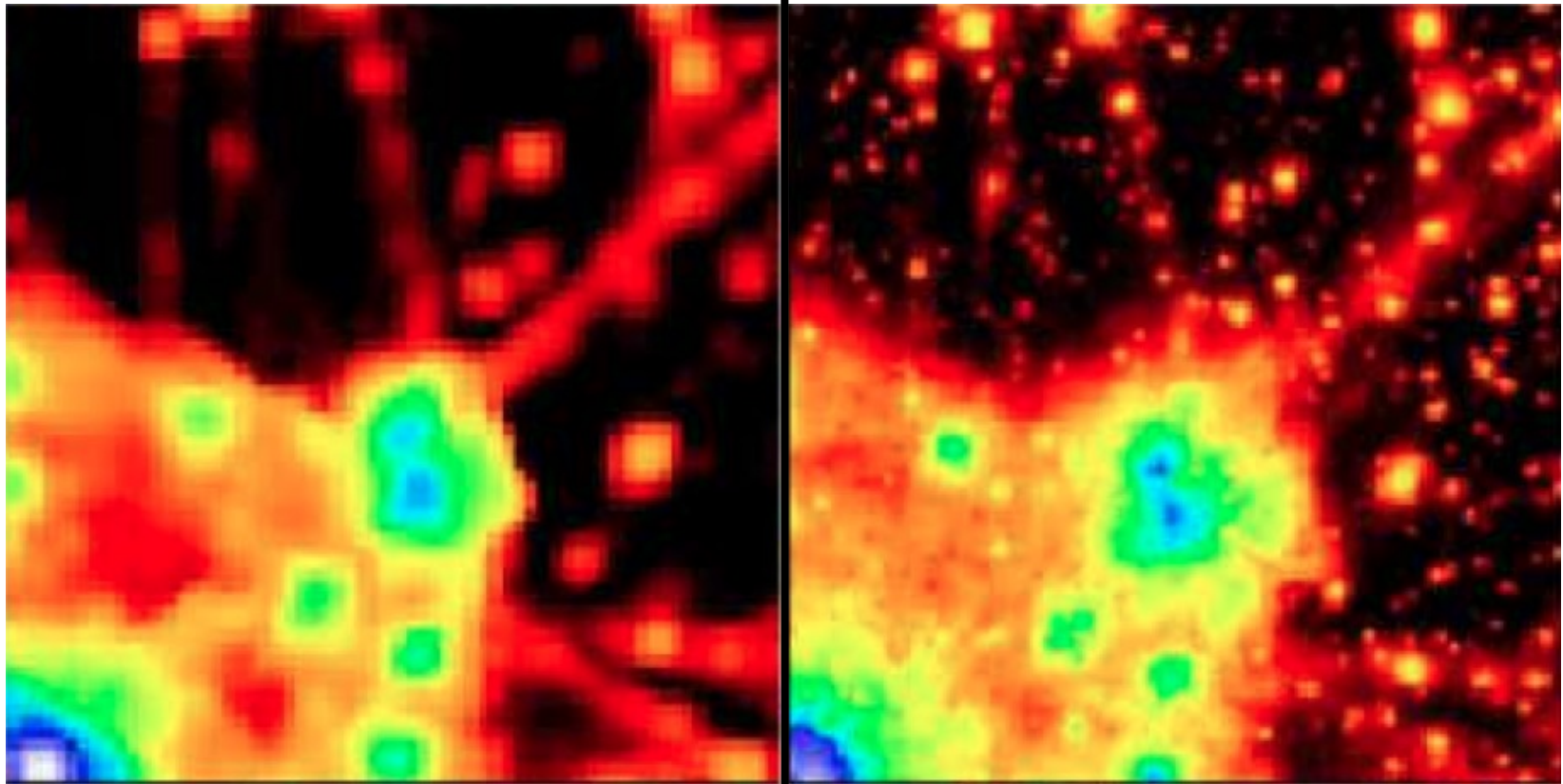
Keres et al. (2011)

grid-based methods

vs.

particle-based methods

- domain discretisation



Vazza et al. (2011)

grid-based methods

vs.

particle-based methods

- domain discretisation

- originate from fluid dynamics

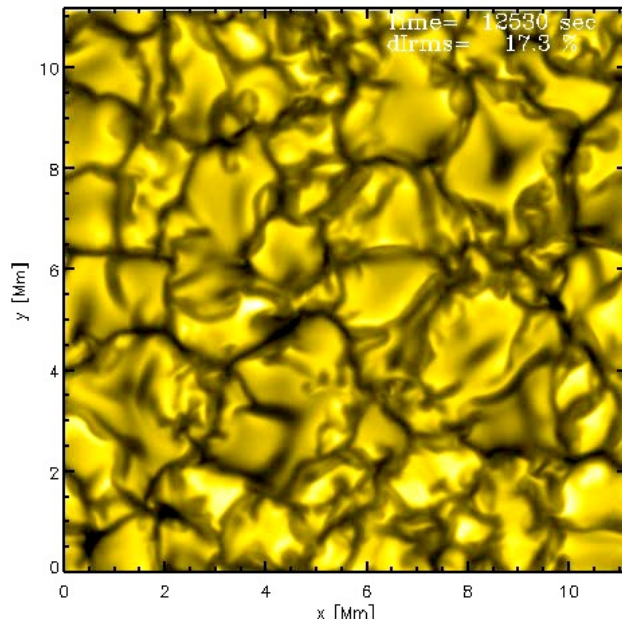
- originate from plasma physics

grid-based methods

vs.

particle-based methods

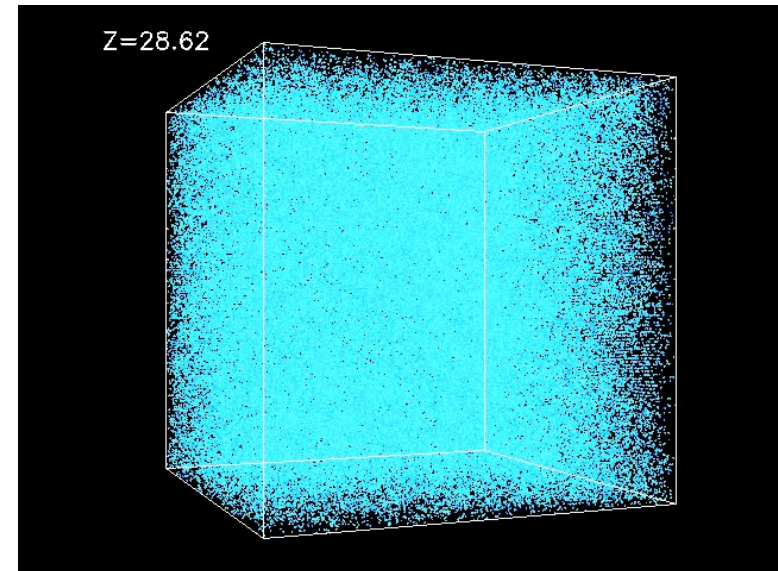
- domain discretisation
 - originate from fluid dynamics
 - in astrophysics primarily used for stellar evolution



grid-based methods

vs.

- originate from plasma physics
- in astrophysics primarily used for cosmology



particle-based methods

- domain discretisation

both methods have their merits and shortcomings...
...and the verdict (if any) is still out there

grid-based methods

vs.

particle-based methods

