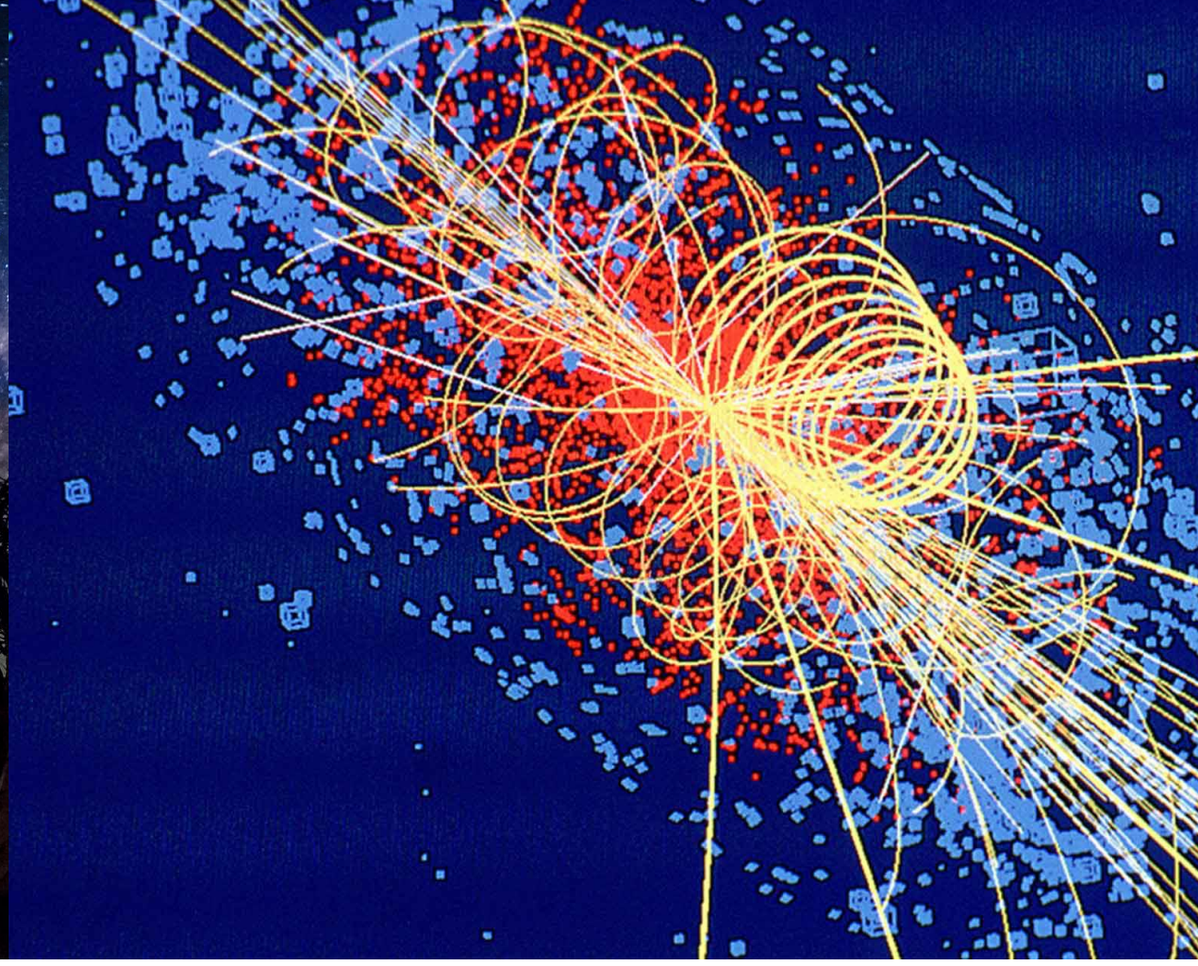

Social Semiotics in Physics and Astronomy Education Research - A Spiral Approach to Teaching and Learning

Urban Eriksson, Ph.D.
The National Resource Center for Physics Education
Lund University
Sweden

Lund University

Lund, Sweden


EIGHT
FACULTIES
And more than 30 world-leading research fields

7 400 employees,
more than 40 000 students

Distribution of students by education cycle

- Undergraduate, programmes 50%
- Undergraduate, freestanding courses 20%
- Master’s, programmes 25%
- Master’s, freestanding courses 5%

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Lund University has educated Nobel laureates, prime ministers, a president and several notable leaders

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Physics department

- **16 Research divisions**, including **ESS** and **MAX IV**
    - 350 faculty members and
      300 PhD students
- **The National Resource Center for Physics Education**
    - In-service teachers education / Professional development courses
    - Physics teacher program
- **Physics and Astronomy Education Research group** recently formed as part of this division.

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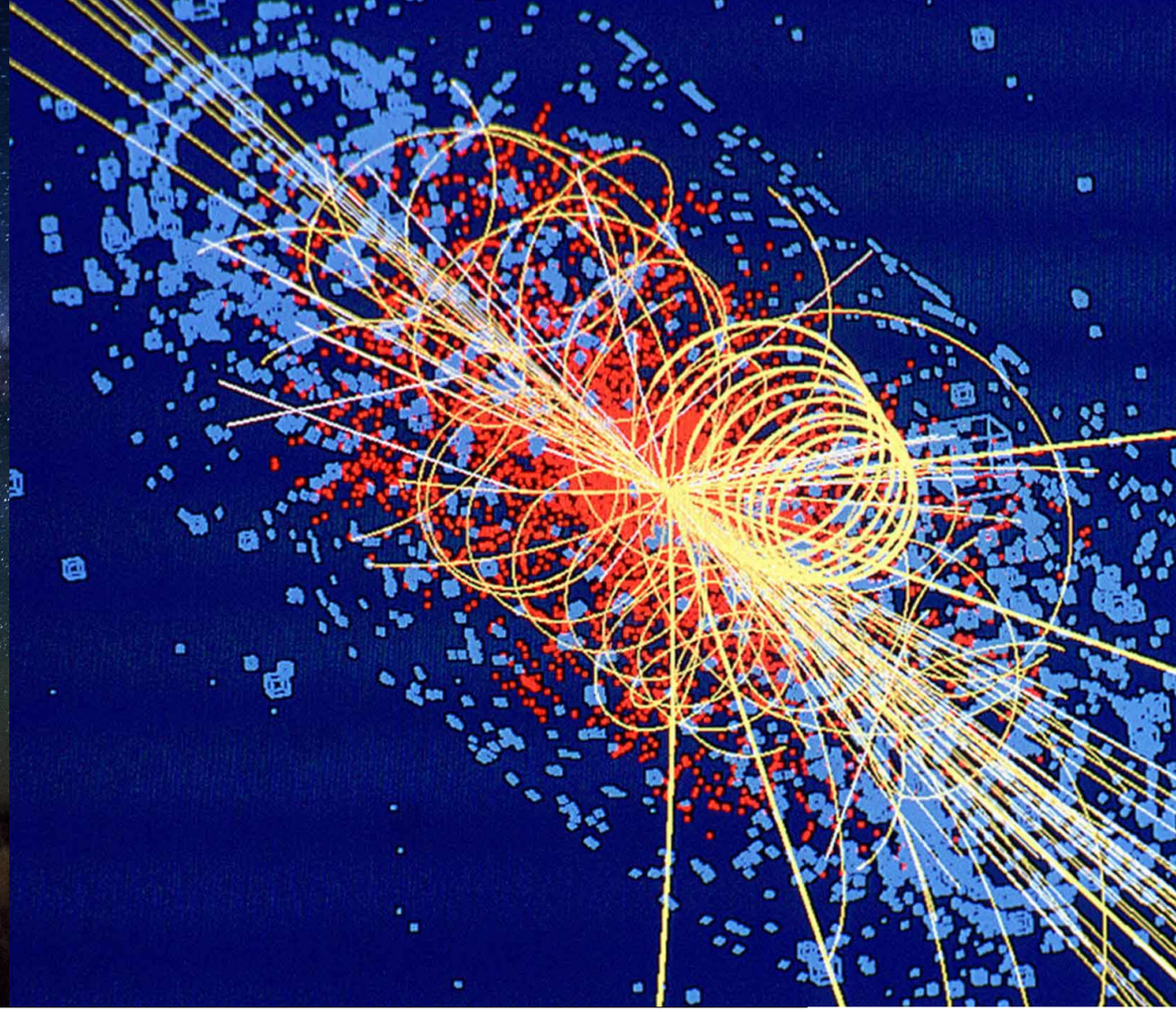
And now over to something more interesting…



The Universe!

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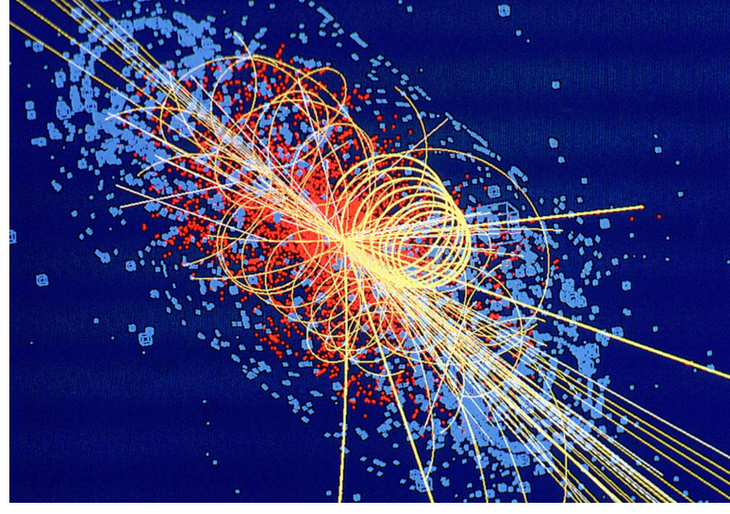

The Universe is both fascinating and interesting!

From a physics point of view:

- **Fascinating** because we can make predictions based on previous discoveries and experiments.
  - Builds on experiments and observations.
  - For **Particle physics** every bit of information is second hand and need a **representation** - no first-hand visual information is in principle available!
- **Learning from representations**
  - ”reading and writing” …

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The Universe is both fascinating and interesting!

From an astronomy point of view:

- **Fascinating** because we can only make predictions based on previous discoveries.
  - In astronomy no experiments are possible
  - Builds on observations only
  - Every bit of information is second hand and need a **representation** - no first-hand visual information is in principle available! (Except for...)
- **Interesting** due to its enthralling uniqueness!
- **Reading the Sky**!

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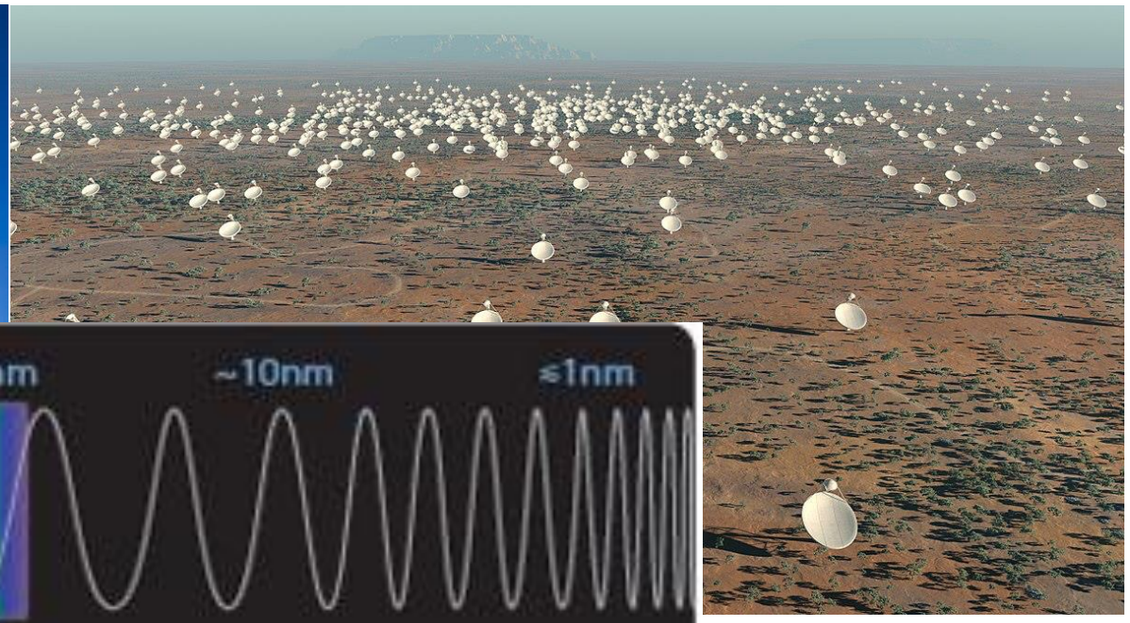
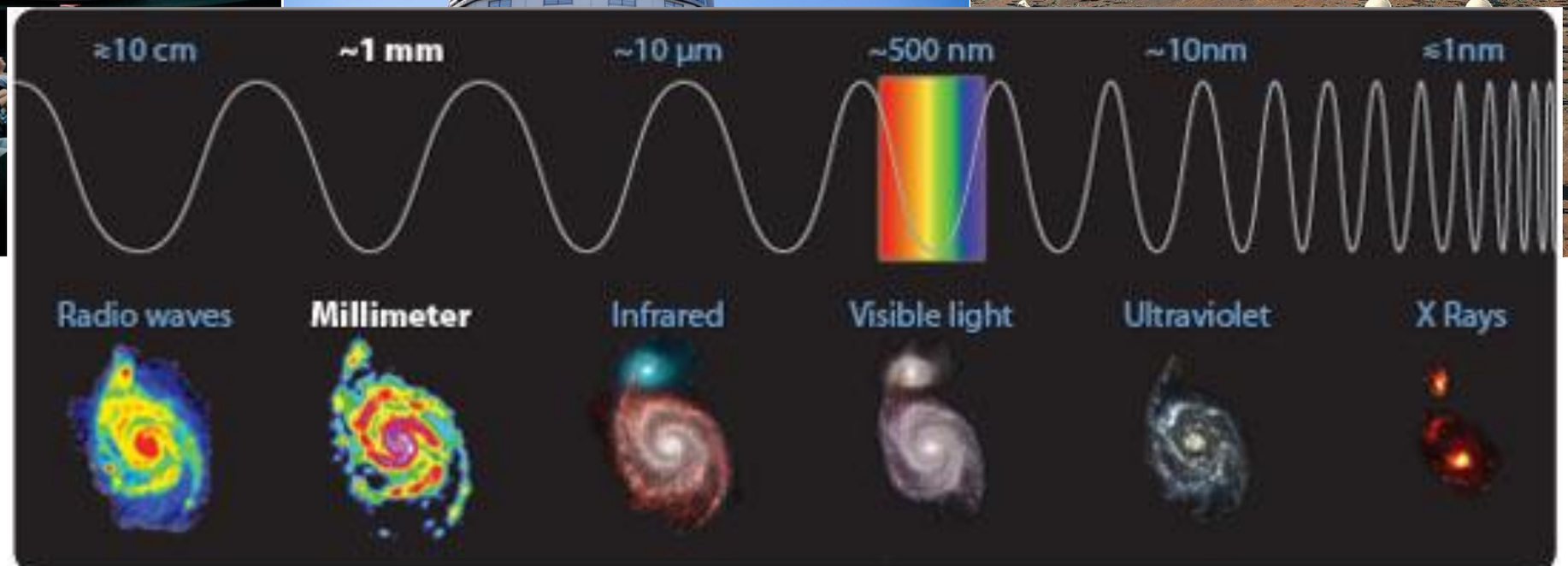
Physics and Astronomy (re-)presented

- Today scientists use **facilities** such as SALT, SKA, CERN, MAX VI to gather information and (re-)present the universe for the the discipline and the public in often beautiful and at the same time realistic manner.
- **Visitor center** and **Planetaria** play a major role for the public!
- What is then meant by (*re-)present* and *realistic*?





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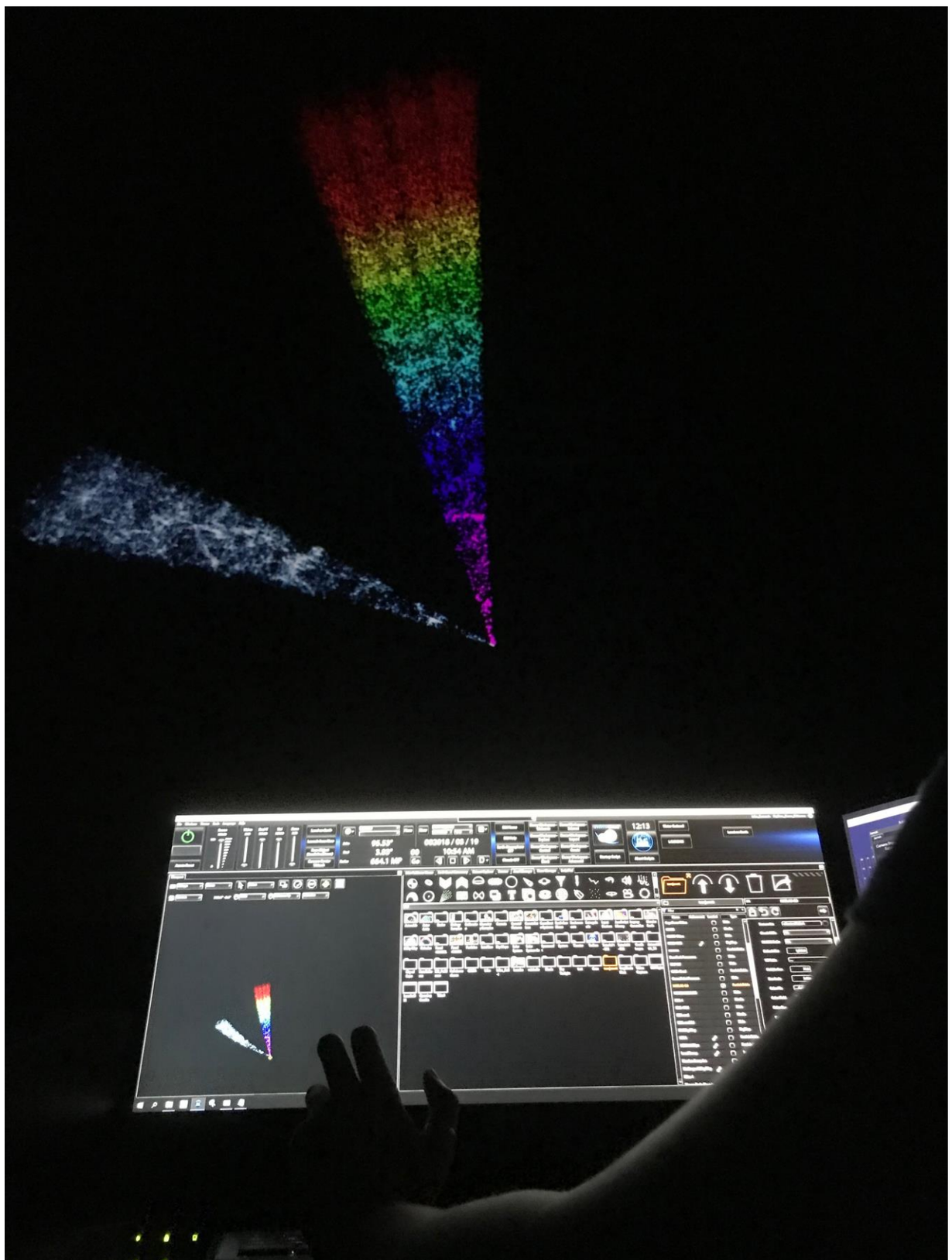
Big Data: An astronomical challenge!



- The amount of information gathered by instruments around the world is so large that scientists cannot easily analyze everything in detail using ”old” techniques.
- Efforts to visualize large data are now being employed in e.g. planetaria and VR as means to visualize, analyse and, most importantly, select interesting data for further analysis.

Mastering physics and astronomy: - What is so special about it?

- Funny and interesting!
- Difficult and challenging…!
- Highly specialized
  - **Disciplinary-specific semiotic resources**.
  - Condensed disciplinary information.
- Multidimensional!
  - Involves a lot of **spatial thinking**!

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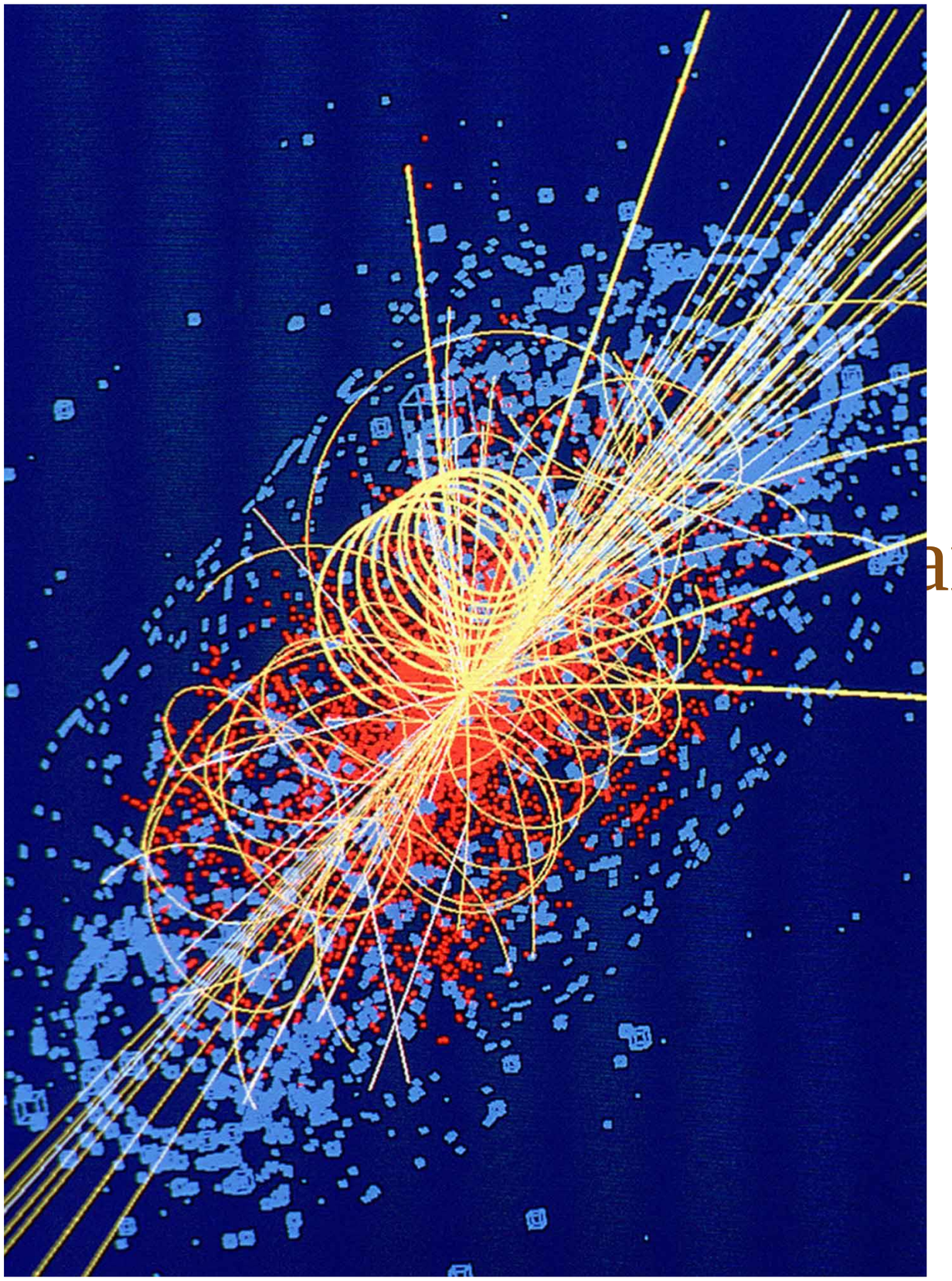

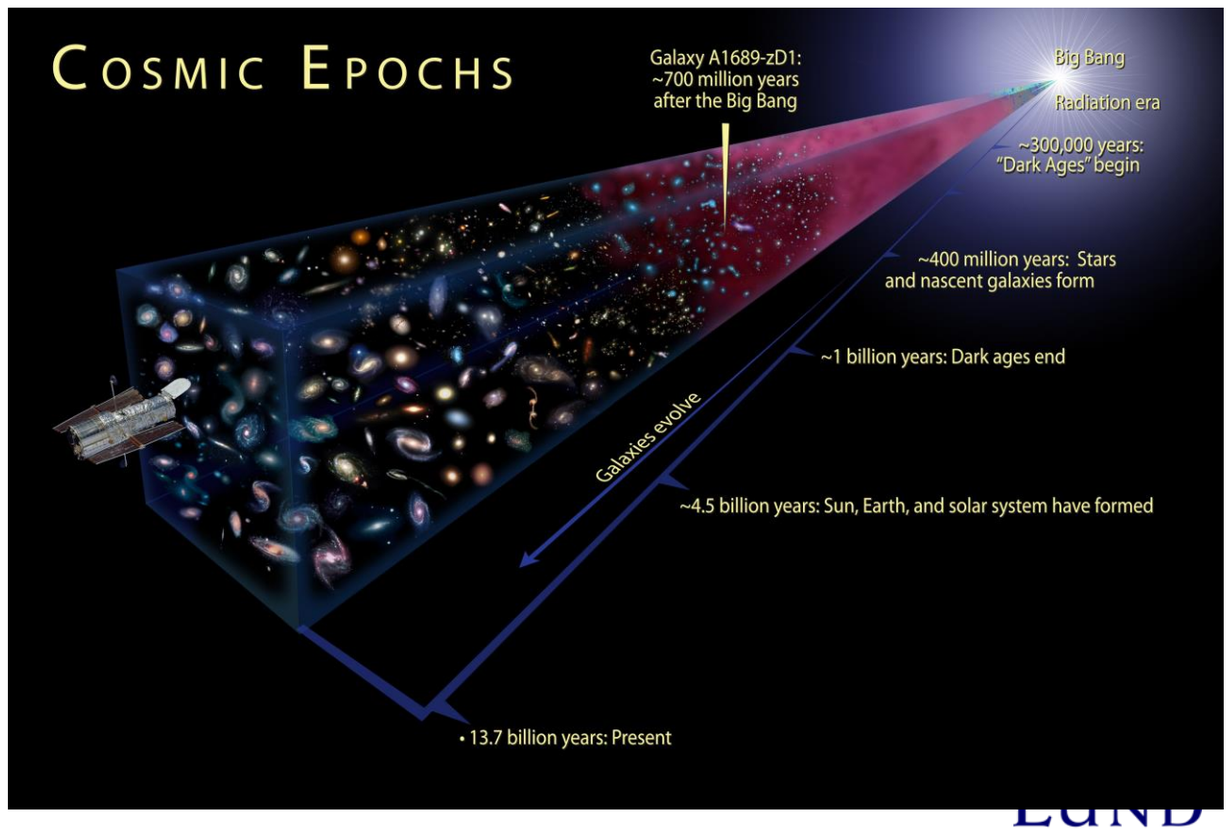

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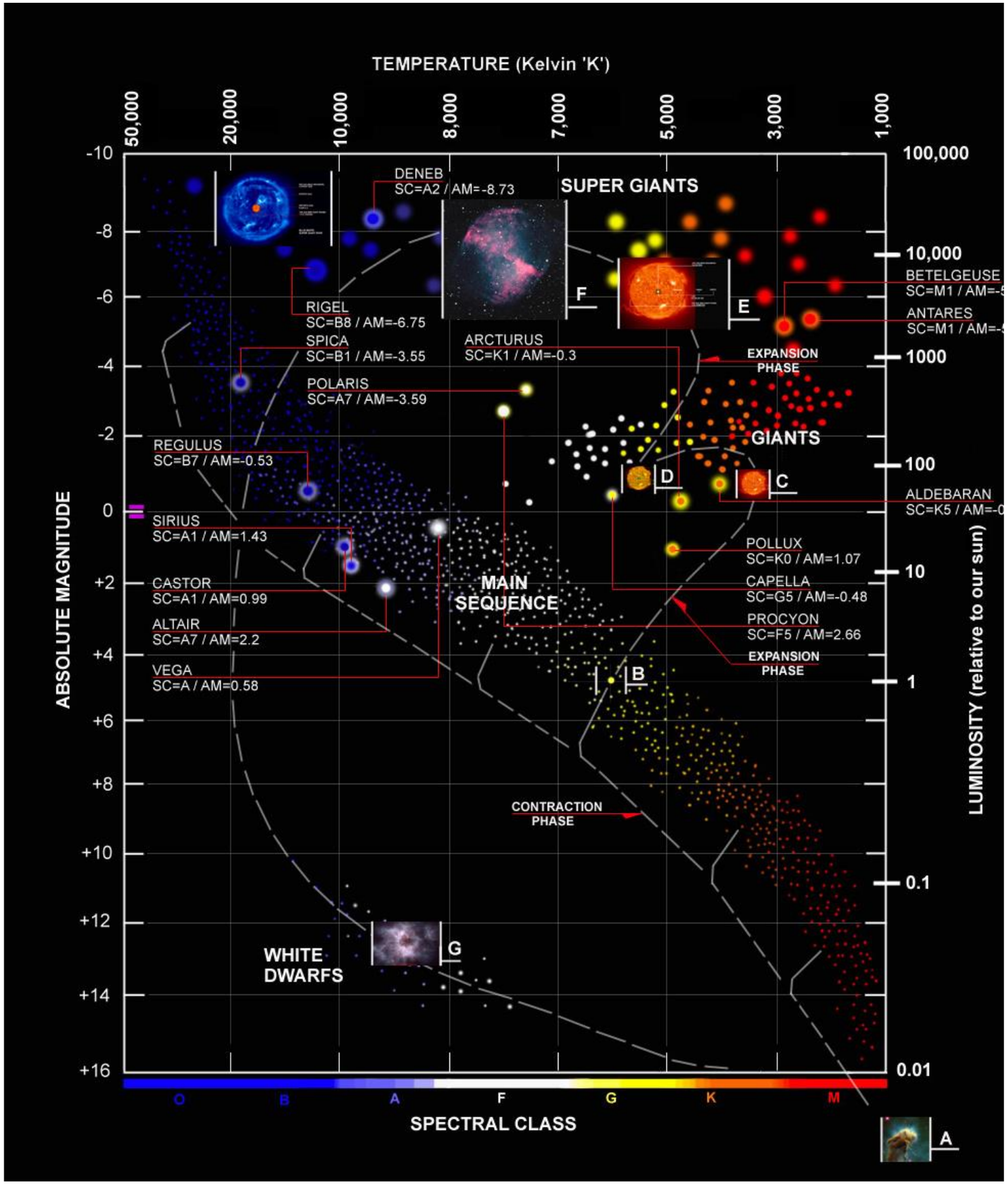
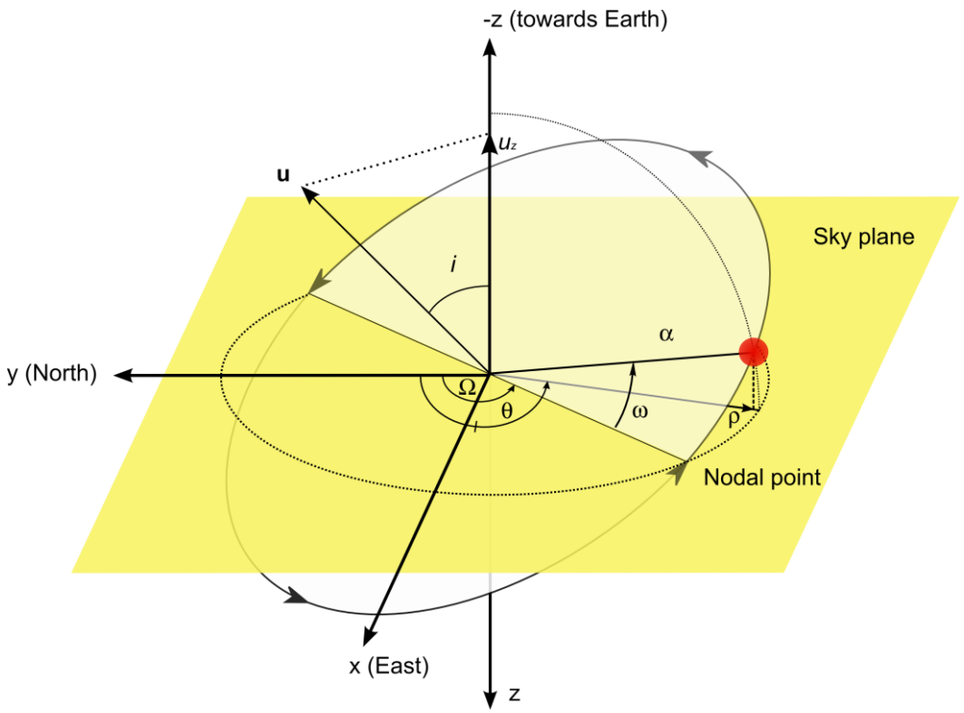
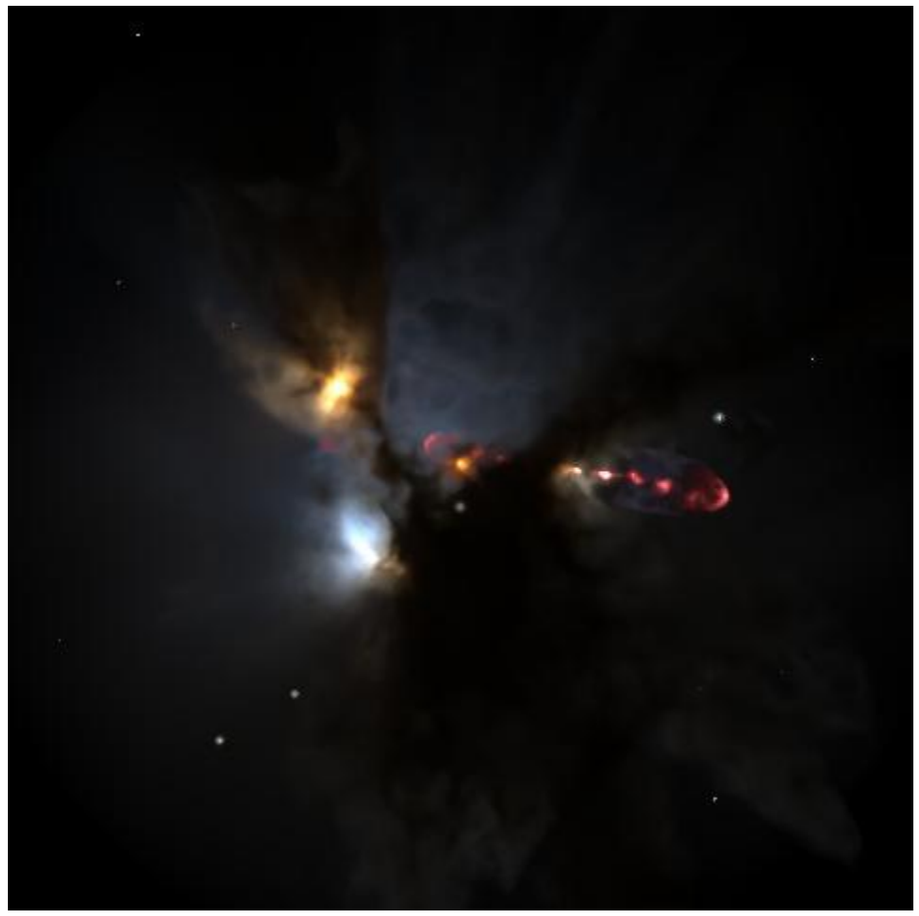




$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + i \bar{\psi} \not{D} \psi + h.c. + \psi_i y_{ij} \psi_j \phi + h.c. + |D_\mu \phi|^2 - V(\phi)$$

Very well, but have we not forgotten something?



- **Dimensionality!**
- 1D - Math, symbols, etc
- 2D - Images, grafs, diagrams, illustrations, etc.
- **3D - Physical objects, simulations, animations**
- **4D? - Simulations(3D) + time**

Extremely important in all of astronomy!!!
Extrapolering three-dimensionality
but…
Very difficult!

Eriksson et al. (2014a)

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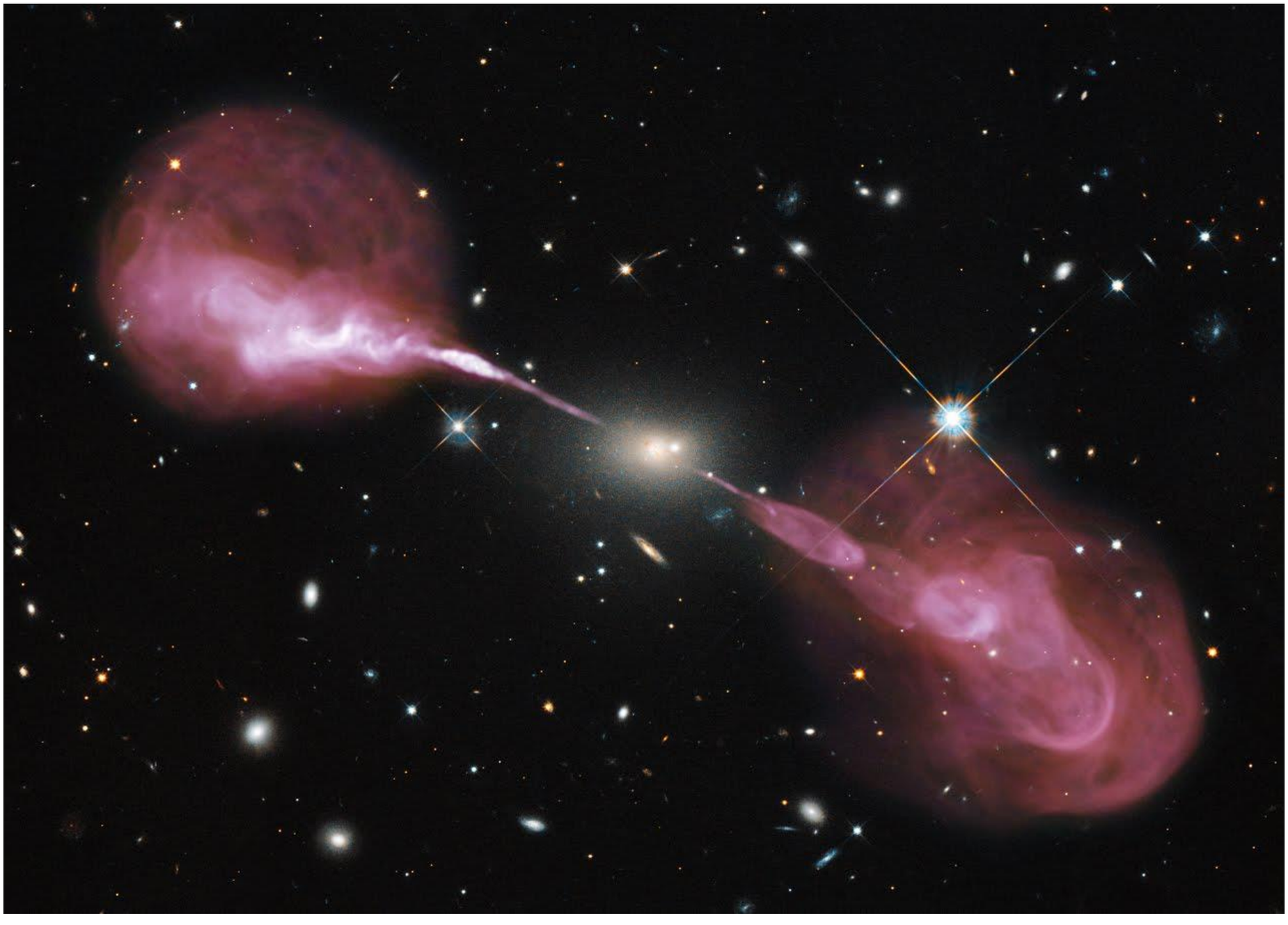
Visualisations important!

- All this implies that visualizations are increasingly becoming central to learning physics and astronomy at all levels.



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So?

- Taking the above as a starting point, how can one theorize around teaching and learning physics and astronomy?

- Representations central
- Semiotic systems and resources
- Communication within the discipline

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Research framework

- **Social semiotics** in Physics Education (Airey & Linder 2017)
  - Developed by the PER group at Uppsala University over some 15 years. (Cedric Linder, John Airey, Urban Eriksson, Tobias Fredlund, Jonas Forsman, etc.)
- **Variation theory**
  - Developed by Ference Marton et al. over the years at Gothenburg University
  - ”Put simply, humans tend to notice that which varies.”

Airey, J., & Linder, C. (2017). Social Semiotics in University Physics Education. In D. F. Treagust, R. Duit, & H. E. Fischer (Eds.), *Multiple Representations in Physics Education* (pp. 95-122). Cham: Springer International Publishing.

Marton, F. (2015). *Necessary conditions of learning*. New York and Oxon: Routledge.

Social Semiotics and Representations

- **Social semiotics** - ”the study of the development and reproduction of specialized systems of meaning making in particular sections of society”.

- A broad construct where all **communication** in a particular social group is viewed as being realized through the **use of semiotic resources**. In social semiotics the particular **meanings assigned** to these semiotic resources are **negotiated** within the **social group** itself and they have often developed over an **extended period of time**.

- Graphs, diagrams, sketches, figures, mathematics, specialist language, etc., commonly referred to as **REPRESENTATIONS**.

Differences between Social Semiotics and representational approach to learning

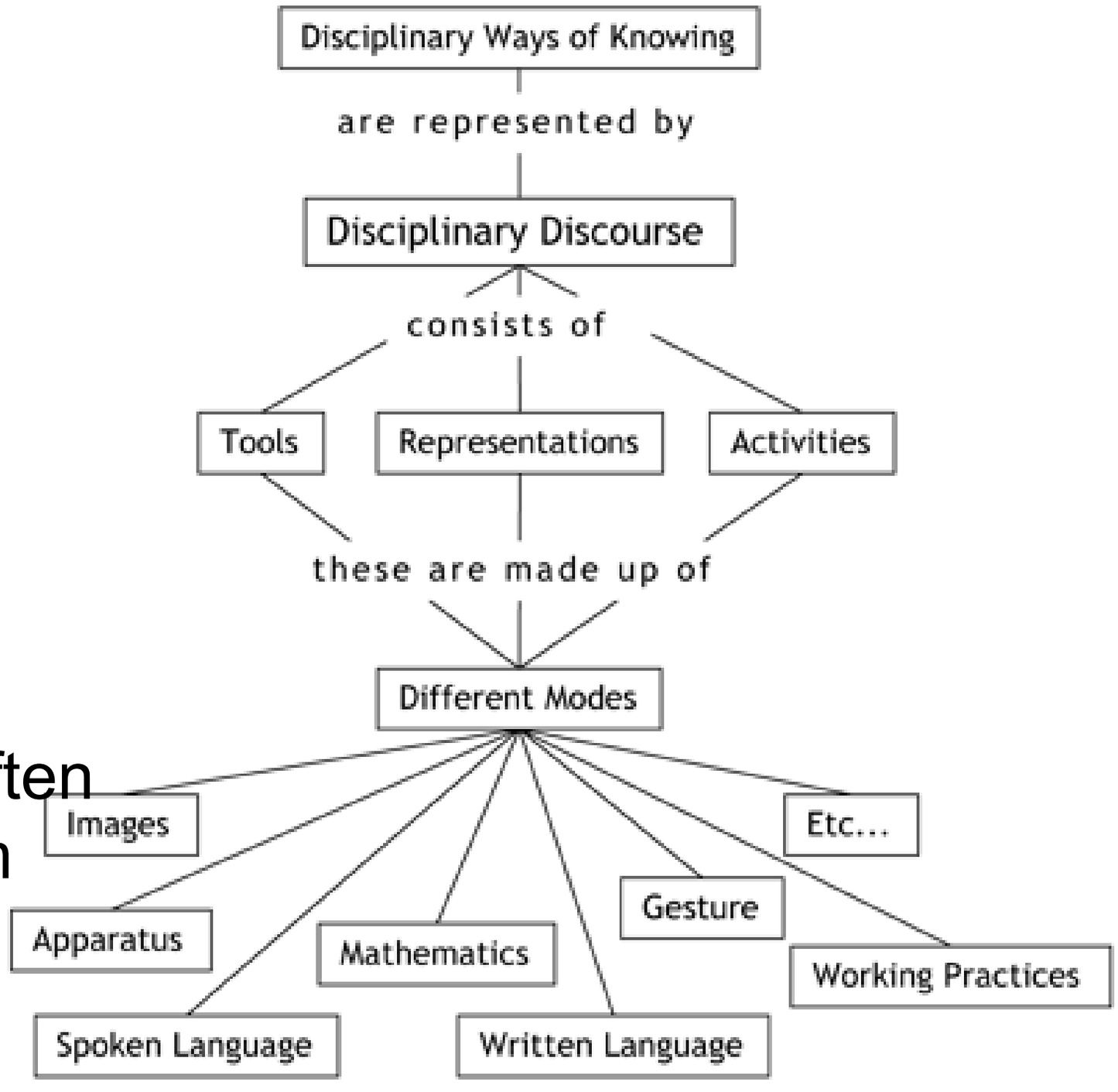
- **Social semiotics** focuses primarily on **group meaning making**
  - starting point: the ways in which professional physicists/astronomers make and share meaning using semiotic resources.

- Social semiotics includes all forms of meaning making - **representations, tools and activities**
  - What **meaning** can this resource convey and **how** is that meaning constructed by students?
  - Contrasted against: ”**What is** this a representation of”?

- **Semiotic resources** have a range of **meaning potentials**
  - **disciplinary affordances**: the agreed meaning making functions that a semiotic resource fulfills for the disciplinary community (Airey 2015).

Semiotic resources

- **Problem**: ”Modes”, ”semitic resources” and ”representations” are often used interchangeably in the literature.

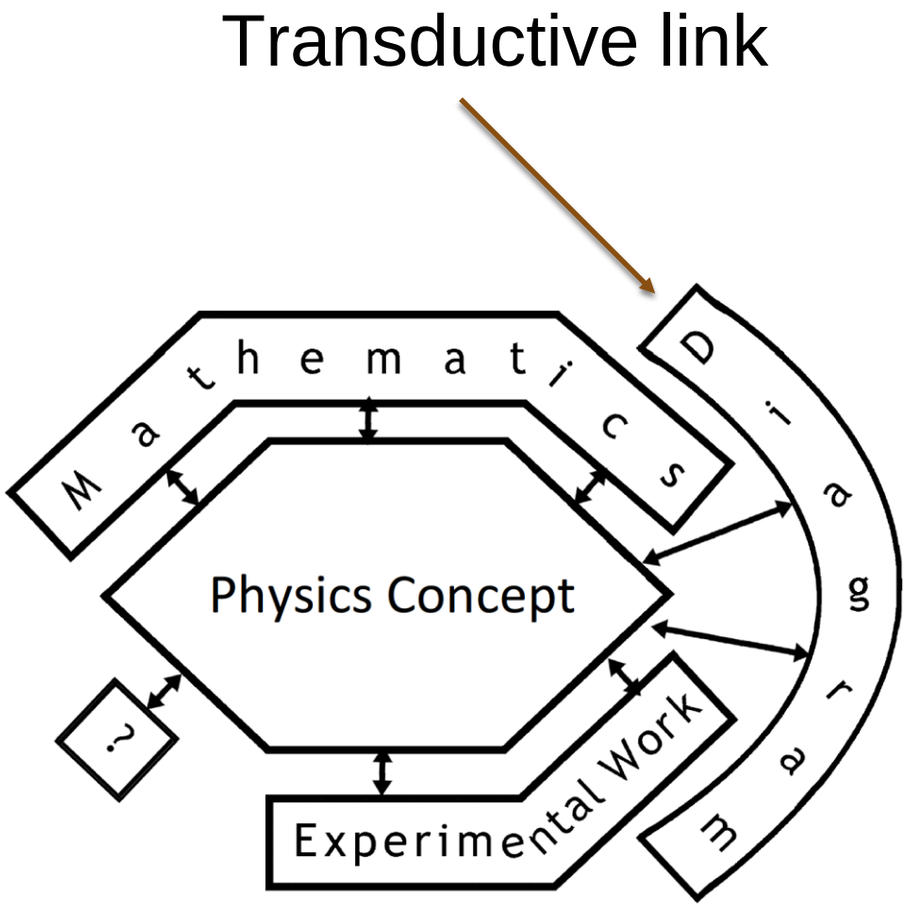


Airey, J., & Linder, C. (2009). A disciplinary discourse perspective on university science learning: Achieving fluency in a critical constellation of modes. *Journal of Research in Science Teaching, 46*(1), 27-49.

Critical constellations of semiotic resources

- ”Think of all the words, symbols, deeds, objects, clothes and tools you need to coordinate in the right way at the right time and place to “pull off” (or recognise someone as) being a cutting edge particle physicist… ” (Gee, 2005:27)

- There is a critical constellation of disciplinary semiotic resources that is necessary for an appropriate experience of disciplinary knowledge.



Airey, J., & Linder, C. (2009). A disciplinary discourse perspective on university science learning: Achieving fluency in a critical constellation of modes. *Journal of Research in Science Teaching, 46*(1), 27-49.

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Fluency

- **Fluency** in a range of disciplinary-specific semiotic resources begins with a process of **repetition**, with students using these semiotic resources to solve numerous physics problems over an extended period of time.
- This stage is then followed by an educational approach that draws on Bruner's (1960) notion of the spiral curriculum that adds depth of **disciplinary discernment** (Eriksson et al., 2014a).
- **Definition**: **fluency** is ”a process through which handling a particular [semiotic resource] with respect to a given piece of disciplinary content becomes unproblematic, almost second-nature”
(Airey & Linder, 2009:33).

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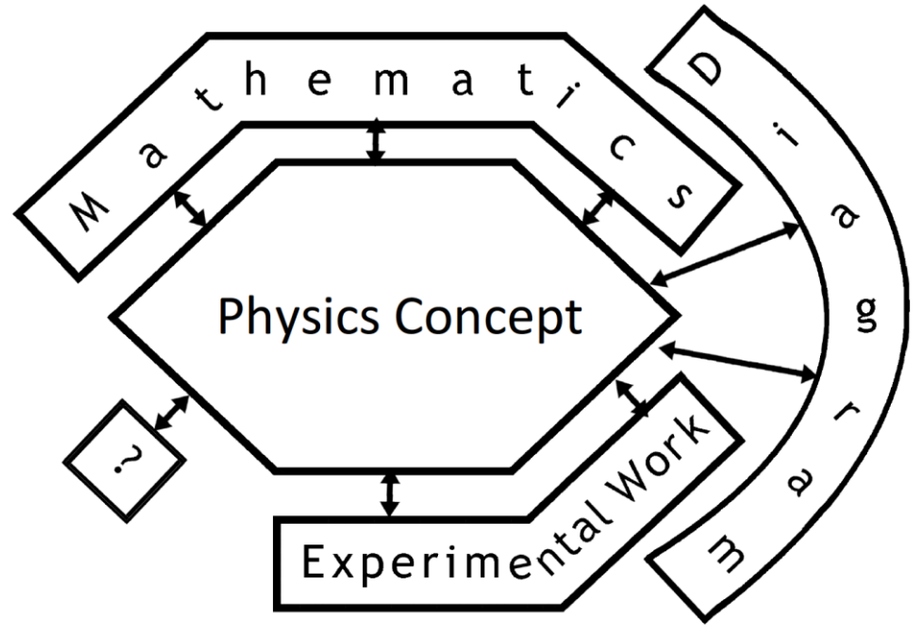

Discourse imitation

- ”MIT undergraduates, when asked to comment about their high school physics, almost universally declared they could “solve all the problems” (and essentially all had received A's) but still felt they “really didn't understand at all what was going on”. di Sessa (1993, p. 152).

- **Definition: Discourse imitation** is the ability to use semiotic resources with limited or no associated disciplinary understanding,
(Airey 2009)

- The student knows the expression and uses it appropriately, but the description carries little, if any, disciplinary meaning.

Airey, J., & Linder, C. (2009). A disciplinary discourse perspective on university science learning: Achieving fluency in a critical constellation of modes. *Journal of Research in Science Teaching, 46*(1), 27-49.

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Disciplinary affordance

- Disciplinary affordance is “the agreed meaning making functions that a semiotic resource fulfills for a particular disciplinary community” (Airey 2015).
- Rather than referring to the discernment of a single individual (or organism), the concept of disciplinary affordance refers to the disciplinary community as a whole (cf. Gibson and Norman)
- “The power of the term for educational work is that learning can now be framed as coming to **discern the disciplinary affordances of semiotic resources**” (Airey et al., 2014, p. 20)
- Also known as **disciplinary discernment** (Eriksson et al. 2014)

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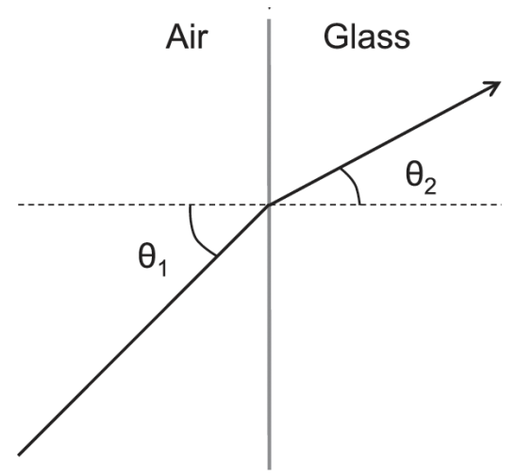

Disciplinary relevant aspects

t

Fredlund, Airey and Linder (2015)

Variation theory

- Disciplinary relevant aspects - what to notice?
- Sameness and difference
- Put simply, humans tend to notice that which varies.

Marton, F. (2015). *Necessary conditions of learning*. New York and Oxon: Routledge.

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On discernment

- A question that then must be central is what people **discern** and **make sense of** from visualizations of the multidimensional and multiwavelength universe.

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On discernment within disciplines

- **Disciplinary Discernment** (Eriksson et al., 2014a)
  - ”Noticing, reflecting and constructing meaning from a disciplinary perspective.”
- Discernment of disciplinary affordances of representations.

On discernment within disciplines - teachers perspective

- The task for a teacher, then, becomes one of encouraging and enhancing the possibility of disciplinary discernment (Eriksson et al., 2014a; Eriksson et al., 2014b).
- This entails noticing and focusing on the appropriate disciplinary aspects across a range of semiotic resources, whilst ‘pushing’ unrelated disciplinary aspects and surface features into background awareness.

Eriksson et al. (2014a), Introducing the Anatomy of Disciplinary Discernment - An example from astronomy. *EJSME*, 2(3), 167-182.

Eriksson et al. (2014b), Who needs 3D when the Universe is flat? *Science Education*, 98(3), 31.

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Disciplinary discernment:
On discernment in astronomy

- The Anatomy of Disciplinary Discernment (ADD) Eriksson *et al.,* (2014a)

- Extrapolating three-dimensionality (E3D) Eriksson *et al.,* (2014b)

Eriksson et al. (2014a), Introducing the Anatomy of Disciplinary Discernment - An example from astronomy. *EJSME*, 2(3), 167-182.

Eriksson et al. (2014b), Who needs 3D when the Universe is flat? *Science Education*, 98(3), 31.

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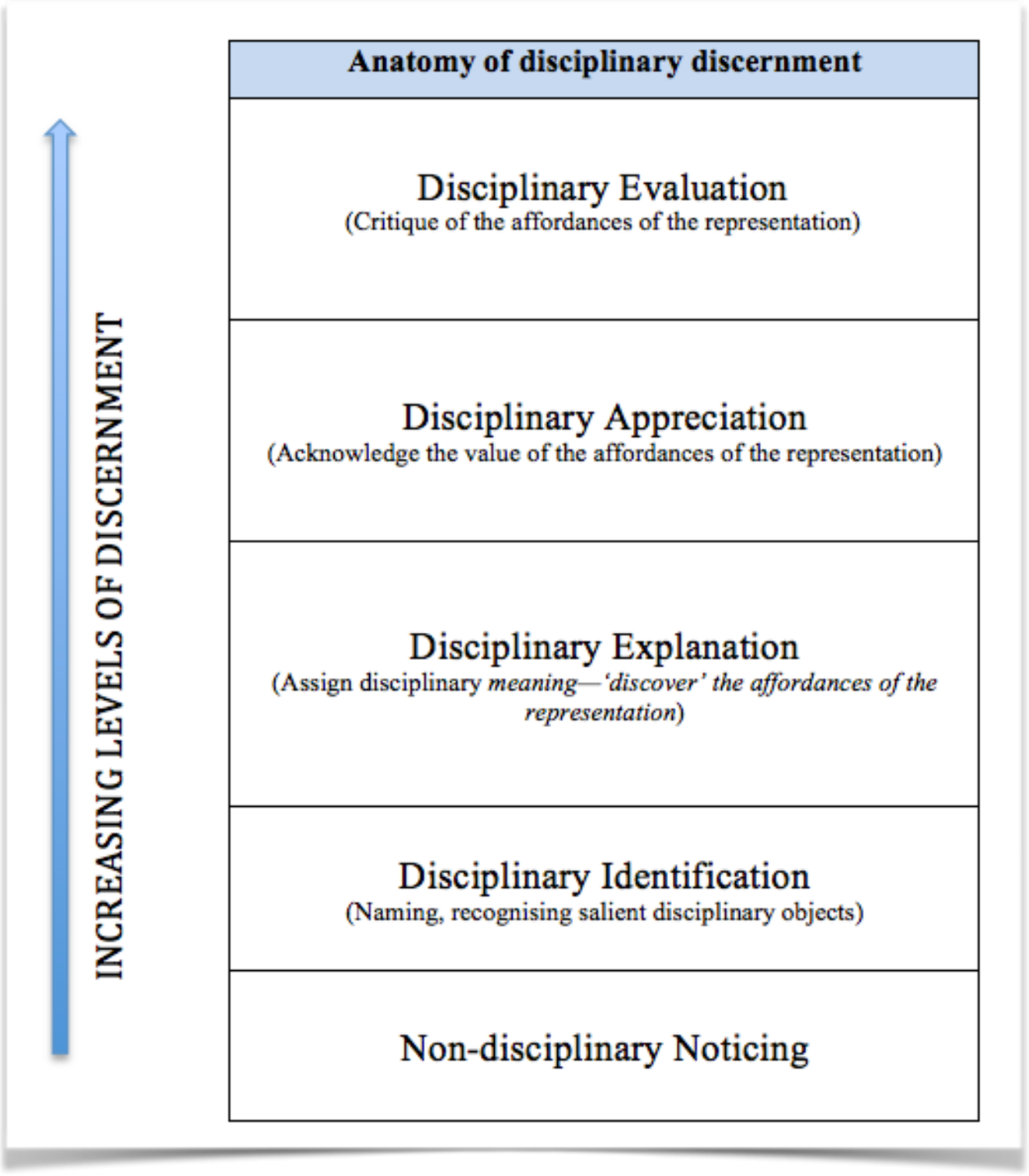
The Anatomy of Disciplinary Discernment (ADD) - a hierarchy of *what* is focused on and *how* it is interpreted in an appropriate, disciplinary manner.

- The ADD encapsulates the increasing complexity of intended meanings of representations, what we refer to as **disciplinary affordances**, and
- the categories can be seen as a hierarchy of discernment progress.
- It describes the ways in which the disciplinary affordances of a given representation may be discerned.



Disciplinary Discernment of multidimensionality - Extrapolating Three-dimensionality

- One *severely* overlooked competency in astronomy education is to ***think spatially***, which we refer to as extrapolating three-dimensionality from a one- or two-dimensional input.
- Human limitations in experiencing 3D due to the large astronomical distances.
- Parallax motion is the key!
  - Simulations and animations could provide the required experience.

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Extrapolating three-dimensionality

- The advanced three-dimensionality awareness category involves a more complete discernment of three-dimensionality.
- The growth of three-dimensionality awareness category includes an awareness of how different astronomical objects change appearance due to motion parallax or a change of position perspective.

	Analytic outcomes: Categories of discernment ordered hierarchically	Clustering of categories as a function of 1-3 dimensionality
Categories of disciplinary discernment	Advanced three-dimensionality	Three-dimensionality
	Growth of three-dimensionality	
	Emergence of three-dimensionality	
	Relative size awareness	Two-dimensionality
	Distance contemplation	One-dimensionality
Baseline category	Motion identification	

- The emergence of three-dimensionality awareness category — discerning structures and details within astronomical objects —includes a level of awareness of depth, i.e., a third dimension.

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- Adding the ADD and E3D leads to a new concept

Reading the Sky

- Inseparable and intertwined with disciplinary knowledge, theory, and practice.
- A *competency* vital for learning astronomy!
- All "reading" is done by human through vision
  Problem: ‘sense-perception is notoriously untrustworth’ (Shapere 1982, p. 508).
  Challenge: -What features are relevant to observe? How do one know?

Eriksson, U. (2014). *Reading the Sky - From Starspots to Spotting Stars.* (Doctor of Philosophy), Uppsala University, Uppsala. Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-234636

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Reading the Sky
- A definition

- *Reading the Sky* is the competency to discern disciplinary affordances of *the Sky* in order to acquire a holistic, (at least) three-dimensional, understanding of the Universe at all levels of scale, dimensions and detail.

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Reading the Sky

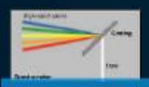
Calls for

Disciplinary Discernment

Extrapolating 3D

By linking

Telescopes



Spectrometers

Cameras

Simulations

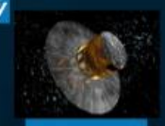
The eye

Observations and Experiences

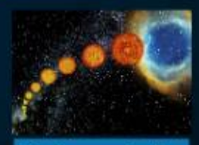
to

Disciplinary Knowledge

Cosmology



Astrometry



Stellar evolution

Planetary formation

and more...

To see...

...through vision

To interpret...

...through the affordance of disciplinary-specific representations

The Universe

Social Semiotics and Learning Physics and Astronomy

- Learning physics and astronomy can be seen as learning a new language, made by all the representations the discipline use to communicate disciplinary knowledge.
- A novice needs to learn to ”read”, ”write”, talk, etc., all these representations and their disciplinary-specific affordances.
- When the student can do that (s)he is part of the discipline and have learnt the disciplinary discourse and its ways to communicate disciplinary knowledge.
- How can that process be optimized?

- **How can *Reading the Sky* be characterized from an educational perspective?**

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Towards optimizing teaching and learning astronomy

- The ADD and the MDH can be framed around the concept of learning by involving two powerful educational ideas:
- The '**Spiral Curriculum**' (Bruner, 1960)
  - Start at a simplified level first, then recursively revisited at more complex levels later on.
- '**Visible Learning**' (Hattie, 2009; 2012)
  - 'Visible Learning and Teaching occurs when teachers see learning through the eyes of students and help them become their own teachers'

Bruner, J. S. (1960). *The process of education*: Harvard University Press.

Hattie, J. (2009). *Visible learning: a synthesis of over 800 meta-analyses relating to achievement*. London: Routledge.

Hattie, J. (2012). *Visible Learning for Teachers: Maximizing Impact on Learning*. Florence, KY, USA: Routledge.

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The Spiral of Teaching and Learning

- Combining:
  - Disciplinary discernment and
  - Extrapolating three-dimensionality with
  - Disciplinary knowledge
- **Knowledge construction**
  A process involving *organizing and categorizing* information through educational experience that follows sequencing based on the ADD and the MDH (Eriksson et al., 2014a,b).

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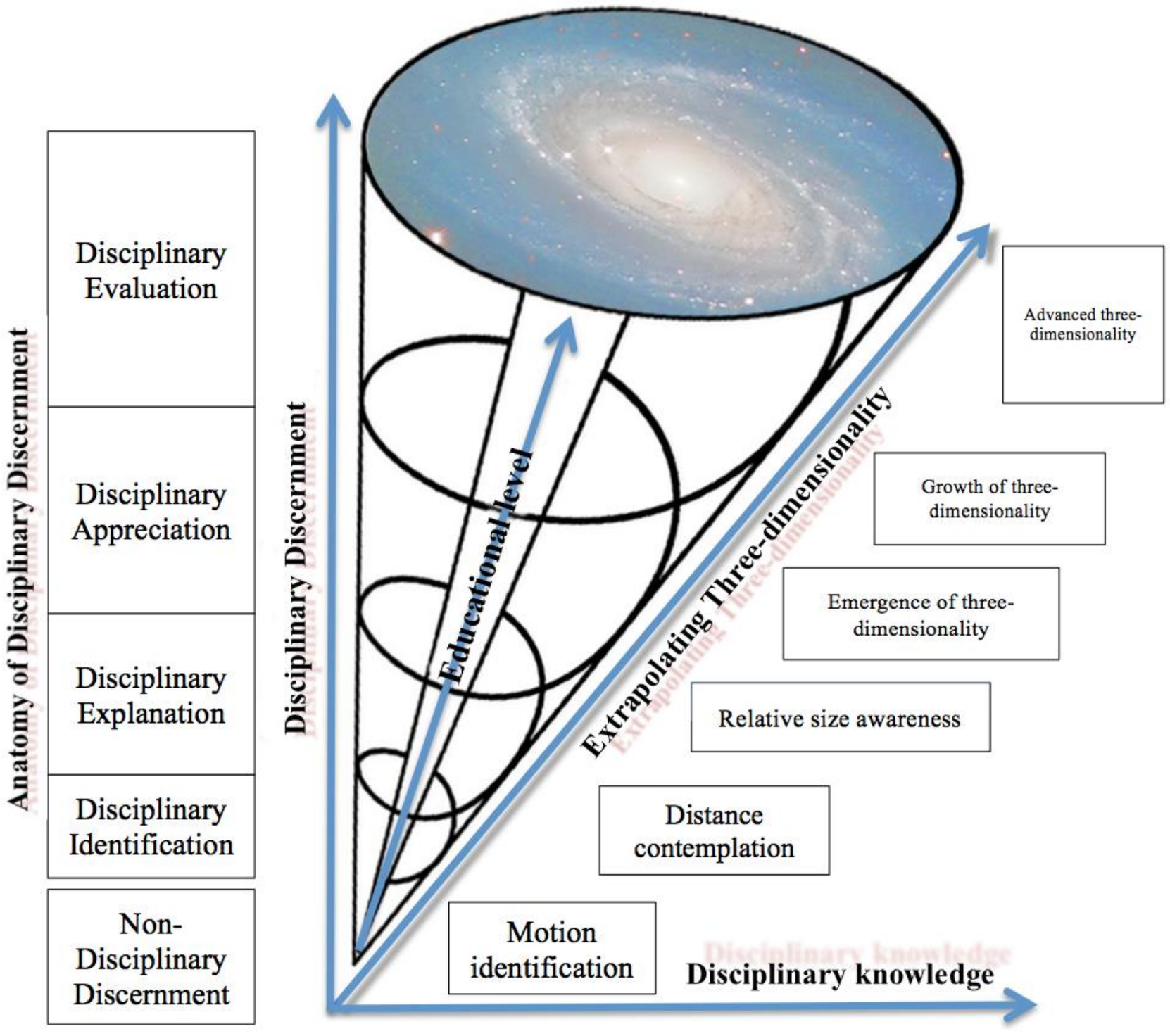
The Spiral of Teaching and Learning



Eriksson (2014)

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An illustrative example from astronomy - Galaxy rotation and rotation curves

1) Find a semiotic resource and evaluate for disciplinary affordances.
2) Lecturer must "become a student".
3) Present it for the students and ask for their discernment, using eg. "Exit tickets”.
4) Analyse the answers using the ADD + MDH to find out the students levels.

- Plan teaching using this information!

5) Discuss the experience of rotation (Identification level).
6) Help the students to discern how galaxies rotate at different radii. Let them explore how rotation can be expressed and explained, using physics, to construct a rotation curve, i.e. they become their own teachers.This expanded disciplinary knowledge may enable the students to discover more disciplinary affordances by the simulation when revisiting it again (Explanation level).
7) Apply this new disciplinary knowledge to other galaxies. The students may be able to appreciate the represented galaxy’s disciplinary affordances and start to construct advanced disciplinary knowledge, including the concept of dark matter, on rotation of spiral galaxies (Appreciation level).

Discussion

- The ADD + MDH describes the developmental characteristics of the ability to discern disciplinary affordances of representations - NEW!
- The difference in competency between expert and novice lies in making the relevant disciplinary discernment.
- Disciplinary experts have developed:
  1) competences in *applying different strategies* to *interpret* discerned details from different representations (Ertmer & Newby, 1996).
  2) competences similar to what Goodwin (1994) calls *professional vision*.
  3) sensitivity to patterns of meaningful information that are not available to novices (Bransford, Brown, & Cocking, 2000) in that they can *evaluate* (Eberbach & Crowley, 2009) and *criticize* (Schneider & Shiffrin, 1977).

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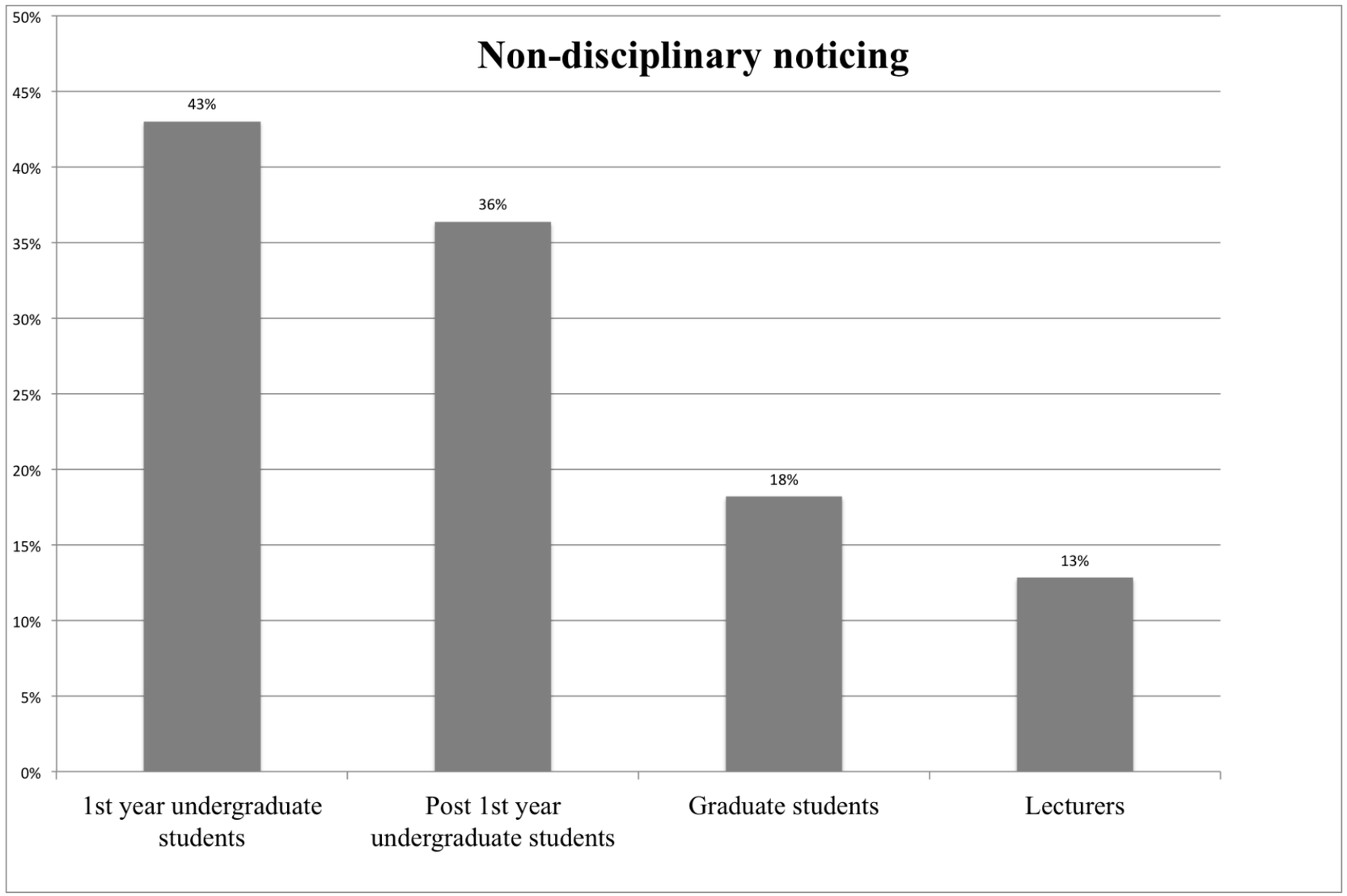
Discussion

- Students then?
- Focus on the wrong things…
  Need to *learn to discern* to become an disciplinary "insider", or expert (cf. Podolefsky & Finkelstein, 2008).



The role of the teacher is to generate the scaffolding needed to help the students cross over category boundaries in the ADD+MDH

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Summary

- The ADD and the MDH describes, from an educational perspective, how disciplinary knowledge can be seen to increase as a function of a growing competency to discern disciplinary crucial aspects from a vast array of potential disciplinary affordances of a given semiotic resource, hence "*Reading the Sky*”.
- *The Spiral of Teaching and Learning* describes the development from disciplinary "outsider" to disciplinary "insider".

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I could not help laughing at the ease with which he [Sherlock Holmes] explained his process of deduction.
"When I hear you give your reasons," I remarked, "the thing always appears to me to be so ridiculously simple that I could easily do it myself, though at each successive instance of your reasoning I am baffled until you explain your process. And yet I believe that my eyes are as good as yours."
"Quite so," he answered, lighting a cigarette, and throwing himself down into an armchair.
"You see, but you do not ~~observe~~" **discern**…

Exchange between Sherlock Holmes and Dr. Watson
A Scandal in Bohemia
Arthur Conan Doyle (1891)

Thank you for listening!

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