Title: Cosmological laws

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Abstract:

Cosmological Laws

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Laws of Nature: Their Nature and Knowability
Perimeter Institute
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Science of a Unique Entity

Wolfgang Pauli

The natural scientist is concerned with a particular kind of phenomena ... he has to confine himself to that which is reproducible. [...] I do not claim that the reproducible is more important than the unique. But I do claim that the unique exceeds treatment by the scientific method. Indeed it is the aim of this method to find and to test natural laws. (Pauli 1961)

Eliminating Initial Conditions

[We must] find some way of eliminating the need for an initial condition to be specified. Only then will the universe be subject to the rule of theory. ... This provides us with a criterion so compelling that the theory of the universe which best conforms us to it is almost certain to be right. (Sciama 1959)
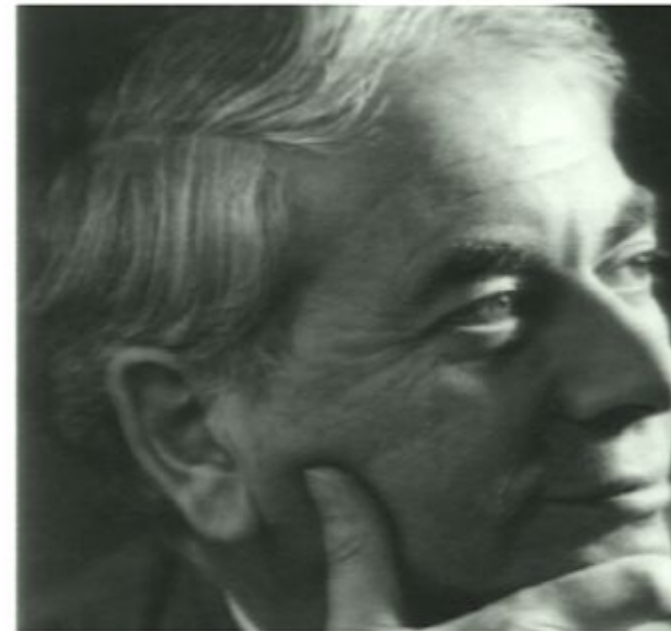
Dennis Sciama

Motivating Questions

- Epistemic limits in cosmology
  - Observational Limits
  - Uniqueness of the Universe
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Outline

1. Limits on Observability
2. Implications of Uniqueness
3. Laws and Initial Conditions

Cosmological Models

Einstein and de Sitter in 1932

Einstein's "Lunge for Totality"

Mach's Principle in GTR?

- "There can be no inertia relative to 'space,' but only an inertia of masses relative to one another."
- De Sitter: boundary conditions, "absolute structure" at ∞

Einstein's static cosmological model

- No boundaries, no boundary conditions! (topologically $S^3 \times \mathbb{R}$)
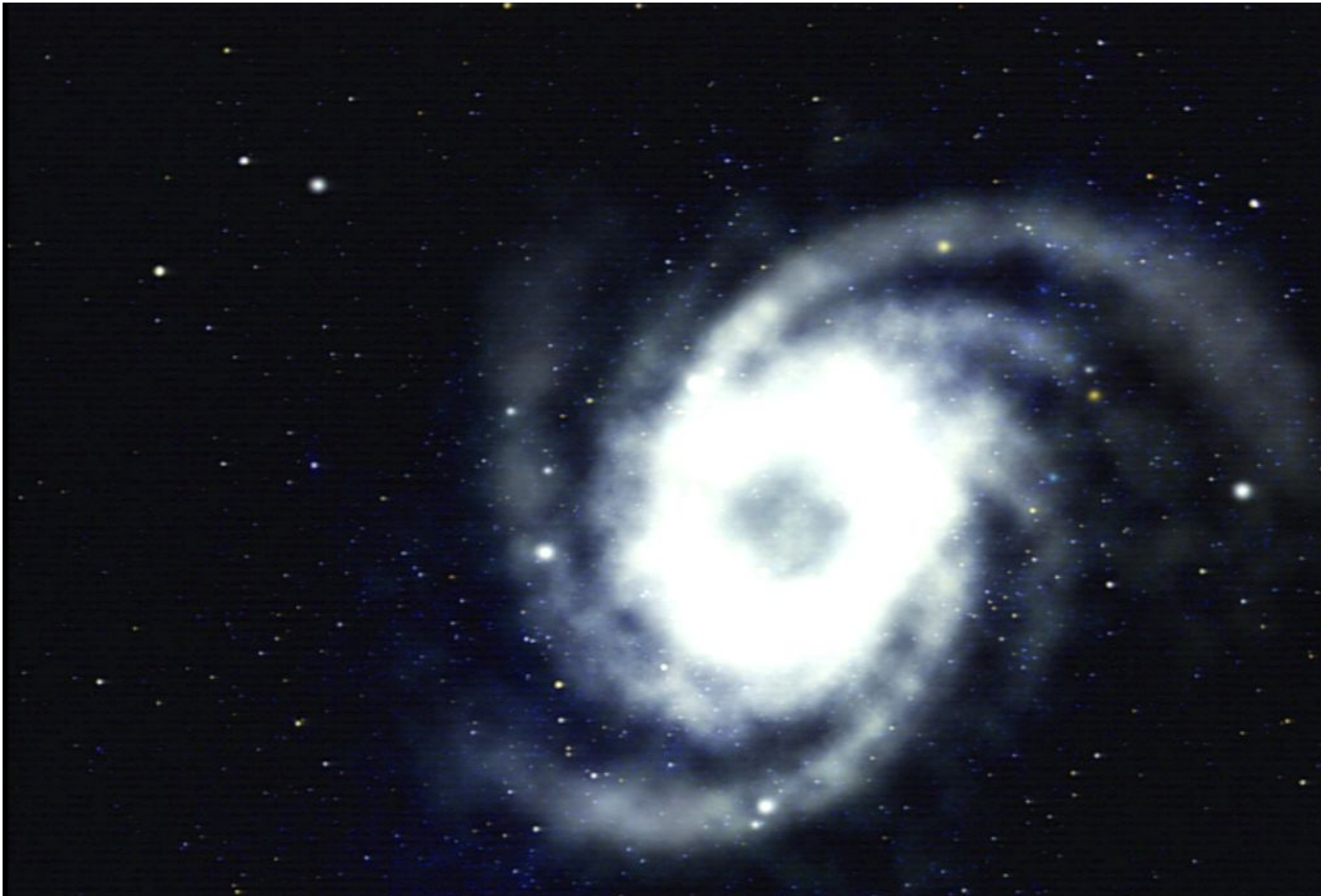- Well defined global properties

Observations in Relativity
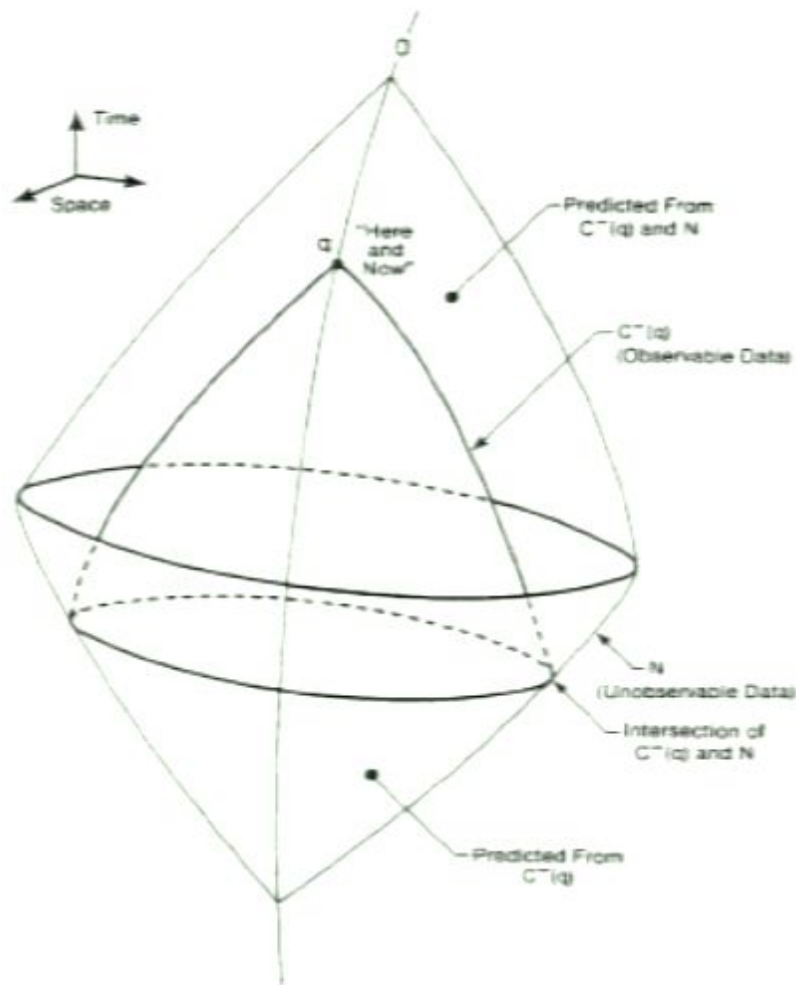
- Observational access to past light cone $J^-(p)$ (including interior)

- "Ideal" observations: sufficient to fix geometry of $J^-(p)$ given dynamics (Ellis 1980); extension beyond this requires "no interference" condition

Figure 2 from Ellis (1980)

Observational Indistinguishability

- Two cosmological models are *observationally indistinguishable* if $\forall p$ in the first model, $\exists p'$ in the second model such that the $I^-(p)$ is isometric to $I^-(p')$. (Glymour 1977, Malament 1977)
  - Every possible observation in first model is recaptured in second model
  - "Clothesline construction": hang the $I^-(p_i)$ for a given model on a line to construct an OI counterpart.
  - Exercise: pick a global property of a cosmological model, and then attempt to construct an OI counterpart *lacking* the property.
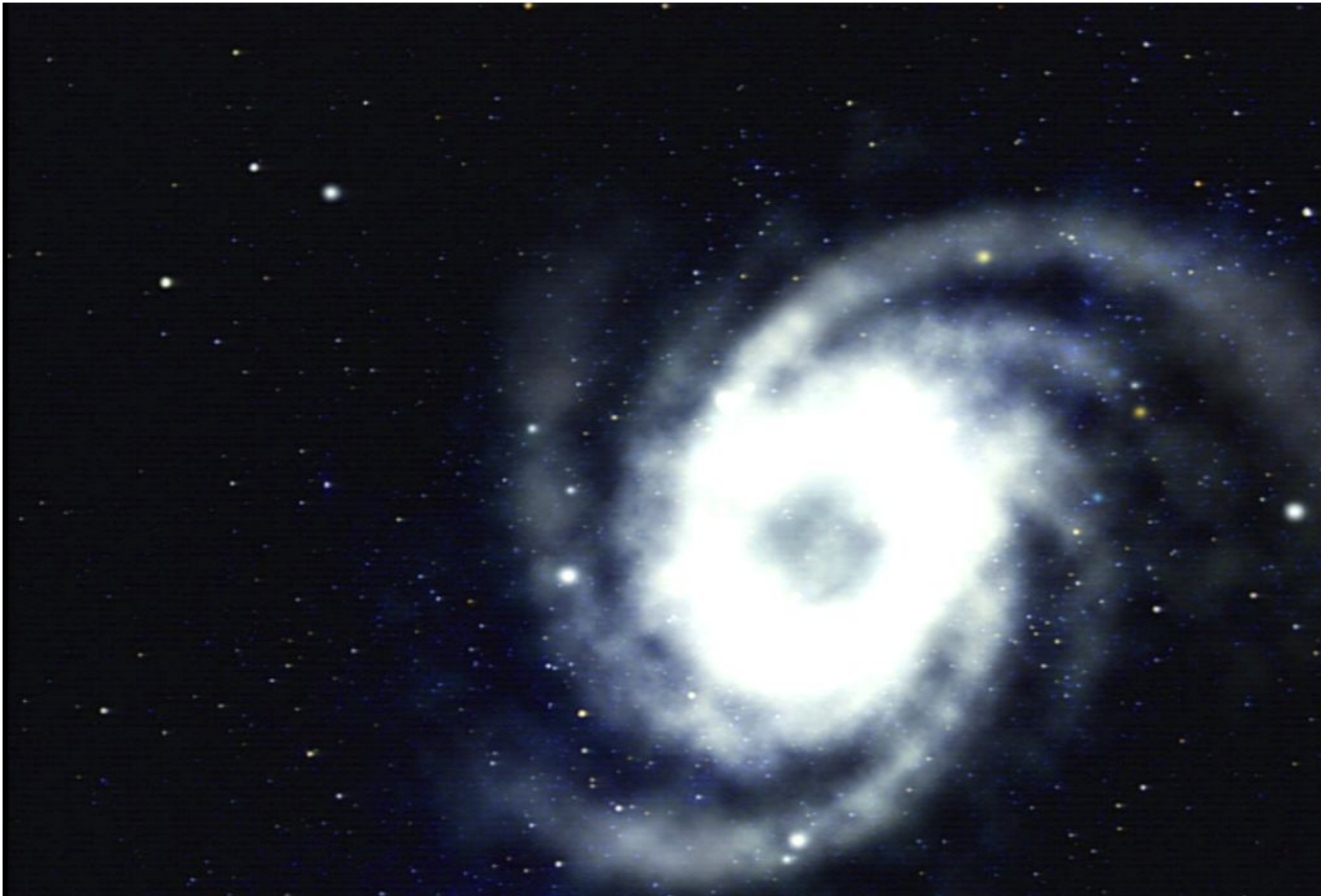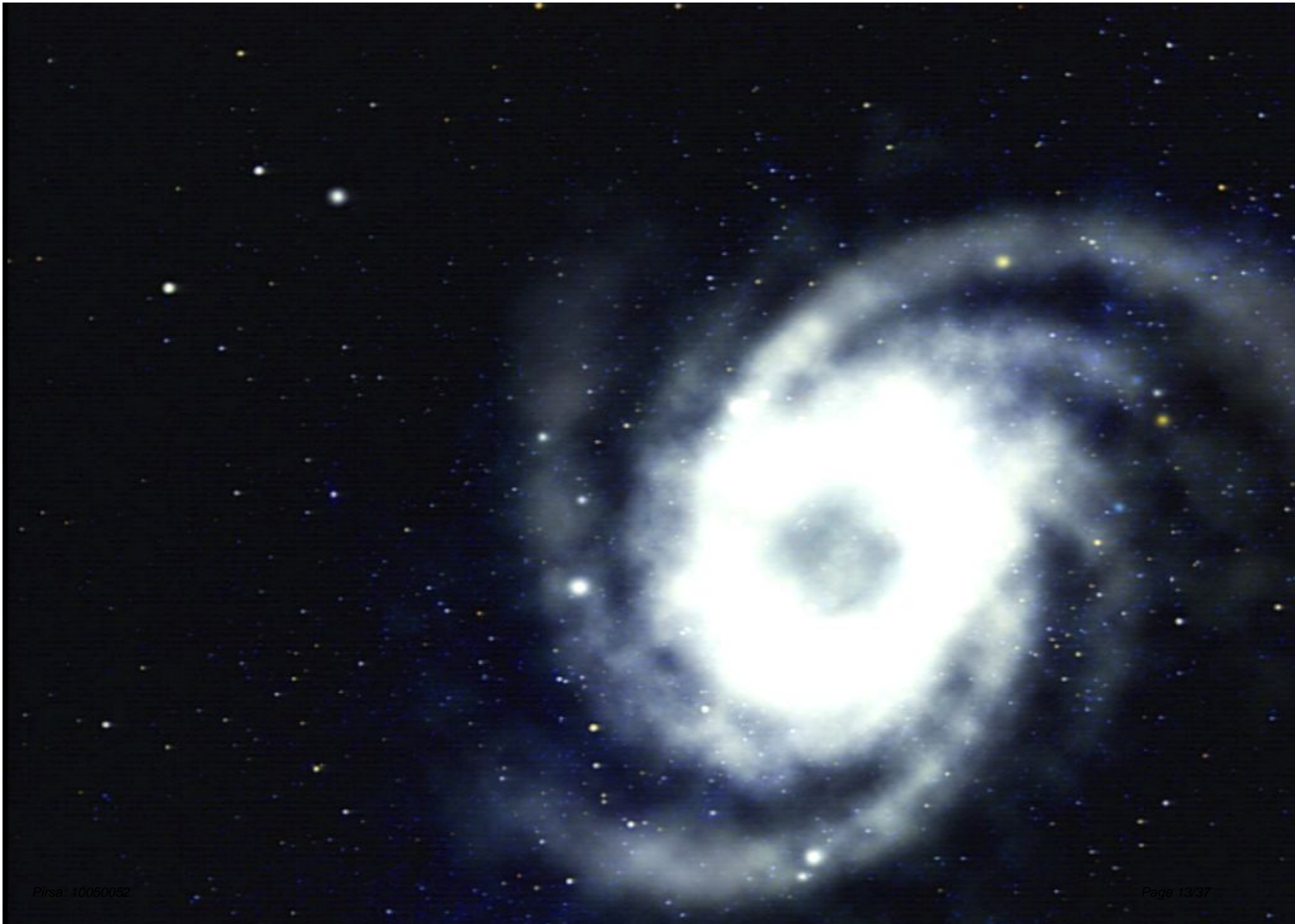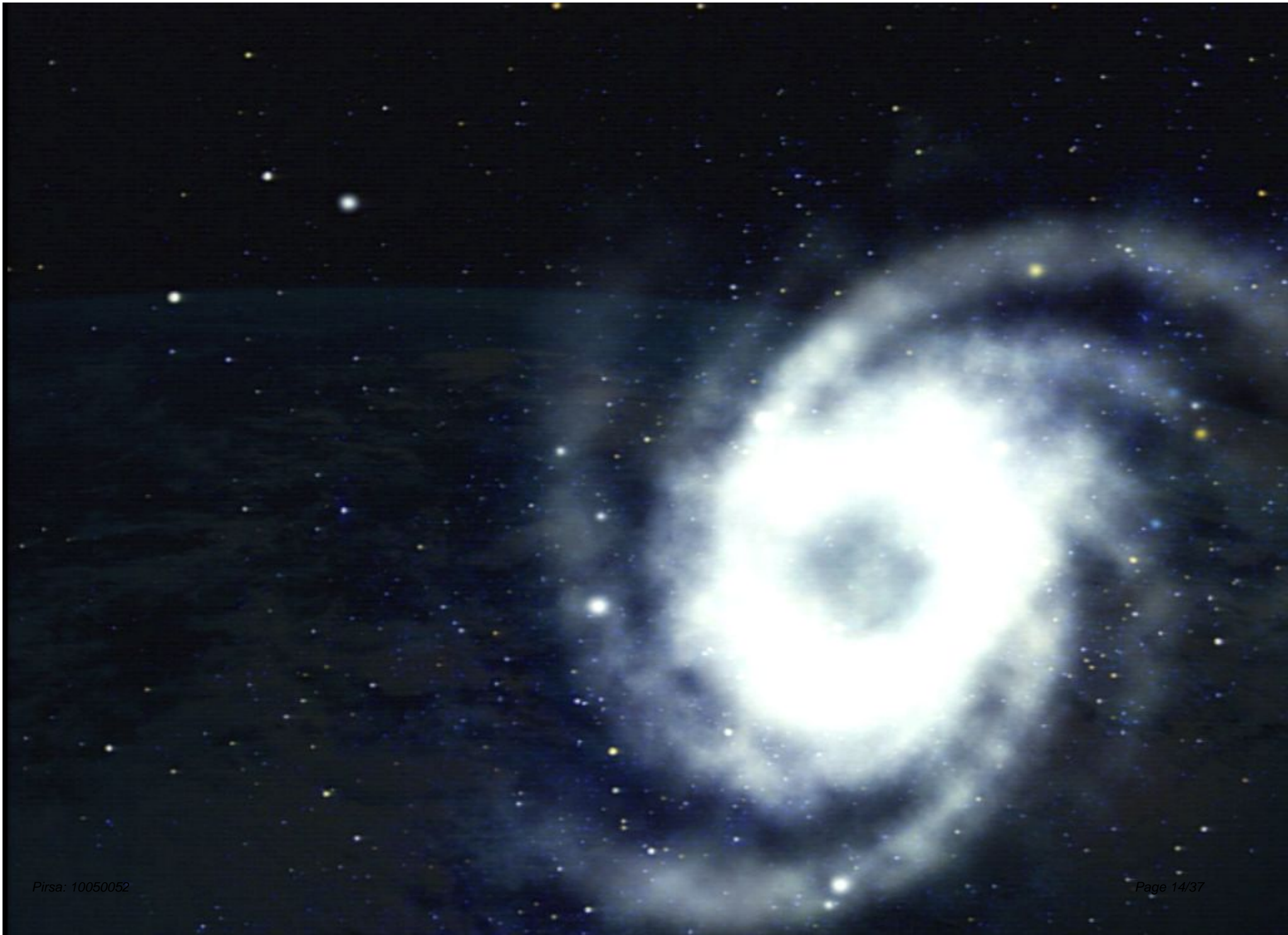
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- Manchak (2009): all spacetimes except those with a point p: $I^-(p) = M$ have OI counterparts.

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Ramifications

- Deflationary response: local-to-global inferences require further *global* assumptions

  - Cosmological principle, "typicality" of observers; similar to principles underwriting other inductive inferences
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- Inaccessibility of global properties $\longrightarrow$ reformulation of theory

    - "Every quantity in a cosmological theory that is formally an observable should in fact be measurable by some observer inside the universe." (Smolin 2000; cf. Markopoulou 1998)

Implications of Uniqueness?

With respect to these familiar laws [of physics] ... we should also mark it as a prerequisite of the very meaning and use of such laws that we be able to refer to an actual or at least possible plurality of instances to which the law applies. For unless there were a plurality of instances there would be neither interest nor sense in speaking of a law at all. If we knew that there were only one actual or possible instance of some phenomenon it would hardly make sense to speak of finding a law for this unique occurrence qua unique. This last situation however is precisely what we encounter in cosmology. For the fact that there is at least but not more than one universe to be investigated makes the search for laws in cosmology inappropriate. (Munitz 1962)

Implications of Uniqueness (quoting G.F.R. Ellis 2007)

A1: The universe itself cannot be subjected to physical experimentation.

A2: The universe cannot be observationally compared with other universes.

A3: The concept of 'Laws of Physics' that apply to only one object is questionable. (Consequence of A1,A2)

We cannot scientifically establish 'laws of the universe' that might apply to the class of all such objects, for we cannot test any such proposed law except in terms of being consistent with one object (the observed universe).

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    - Multiverse approaches: deny uniqueness (and (A2)?)
- Reject Argument
    - What account of laws and method needed to complete the argument?

Laws and Multiple Instantiations

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  - Local laws extrapolated to universe as a whole: e.g., field equations of GR
  Multiple instantiations: every subregion!
- Cosmological laws$_2$:
  - Laws explicitly formulated in terms of *global* properties; laws governing "creation"
  Lack multiple instantiations
  Examples of cosmological laws$_2$?

Laws and Instantiations

Confirmation by Instances

E1 $Fa \wedge Ga$

E2 $Fb \wedge Gb$

... etc. ...

——confirms——

L $\forall x(Fx \rightarrow Gx)$

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Objection: Content of Laws?

- Treats laws as formulated in
  observational language, direct
  empirical content

- Collapses distinction between
  laws and *equations of motion*

Lying Laws?

For bodies which are both massive and charged, the law of universal gravitation and Coulomb's law ... interact to determine the final force. But neither law by itself truly describes how the bodies behave. No charged objects will behave just as the law of universal gravitation says; and any massive objects will constitute a counterexample to Coulomb's law. These two laws are not true; worse, they are not even approximately true. In the interaction between the electrons and the protons of an atom, for example, the Coulomb effect swamps the gravitational one, and the force that actually occurs is very different from that described by the law of gravity. (Cartwright 1983, p. 57)

Ceteris Paribus Clauses

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- Laws vs. Equations of motion (Earman and Roberts 1999, Smith 2002)
  - *Laws* not falsified; phenomena compared to equations of motion derived from the laws (with other conditions)
  - Laws more remote from particular observed regularities

Laws for a "Unique System"?

- Testing laws via implications for:
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Laws for a "Unique System"?

- Testing laws via implications for:
  - Phenomena obtained across distinct systems, experimental reproducibility
  - More detailed aspects of a single system
- Possibility of testing laws for a single system
  - Approach complicated systems via successive approximations: laws tested via role in series of increasingly detailed equations of motion
  - Testability depends on possibility of discovering further details regarding system

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