

What does Jacques Cousteau
have to do with a self-driving car?

Alyssa Goodman, Harvard Club of Boston, October 16, 2019

Calypso



Jacques Cousteau



Calypso



Elon Musk



Calypso to Calypso



Calypso to Calypso



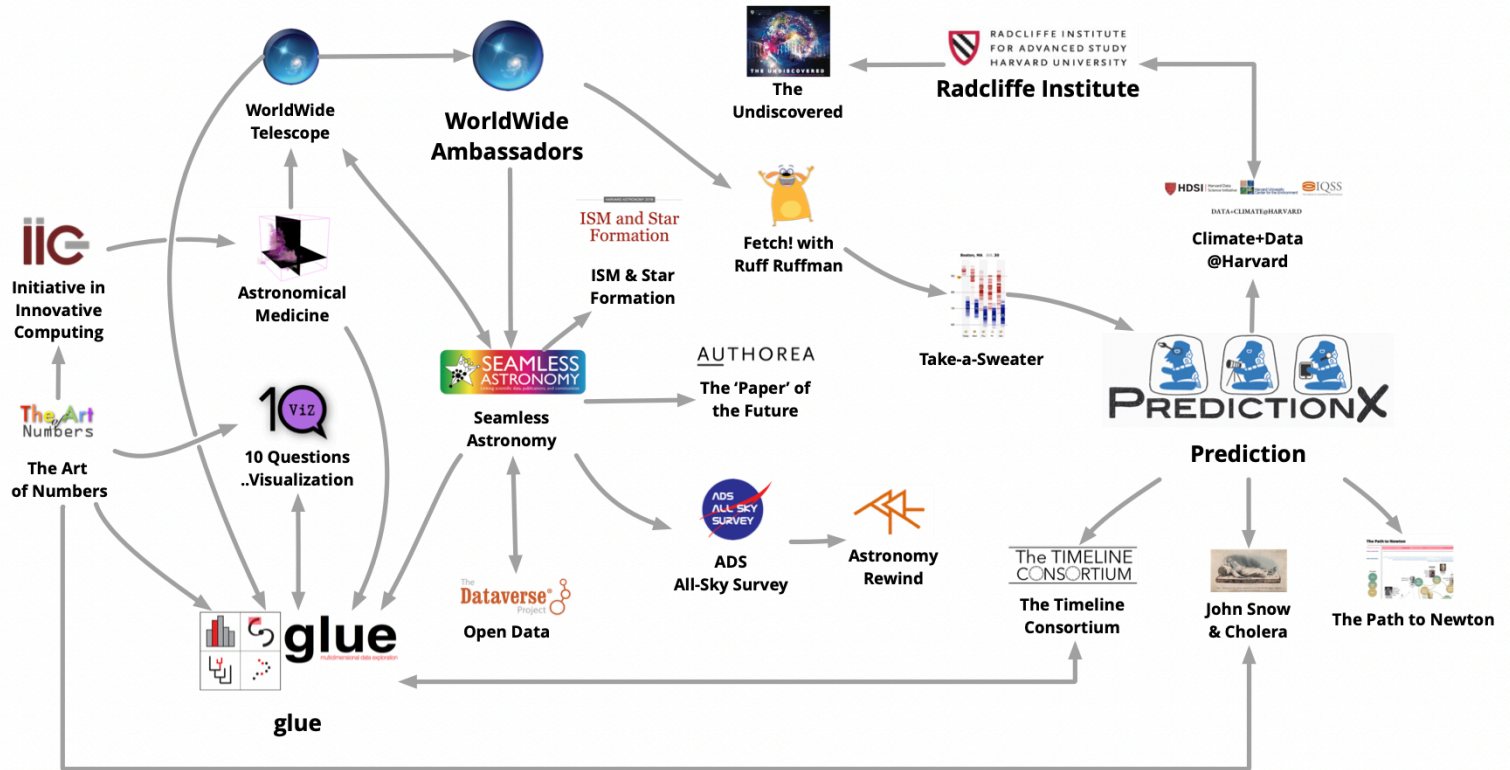
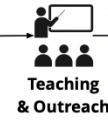


Alyssa





Alyssa



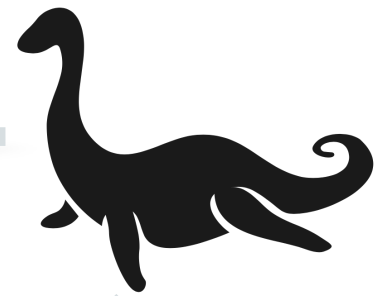
COMPLETE
The COMPLETE Survey of
Star-Forming Regions



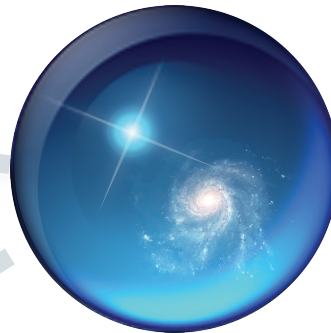
COMPLETE



Star
Formation



Data
Visualization



Teaching
& Outreach



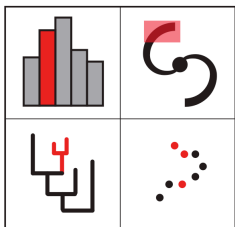
Climate
Change



Galactic
Structure



PREDICTIONX



glue
multidimensional data exploration



Scientific
Computing



COMPLETE



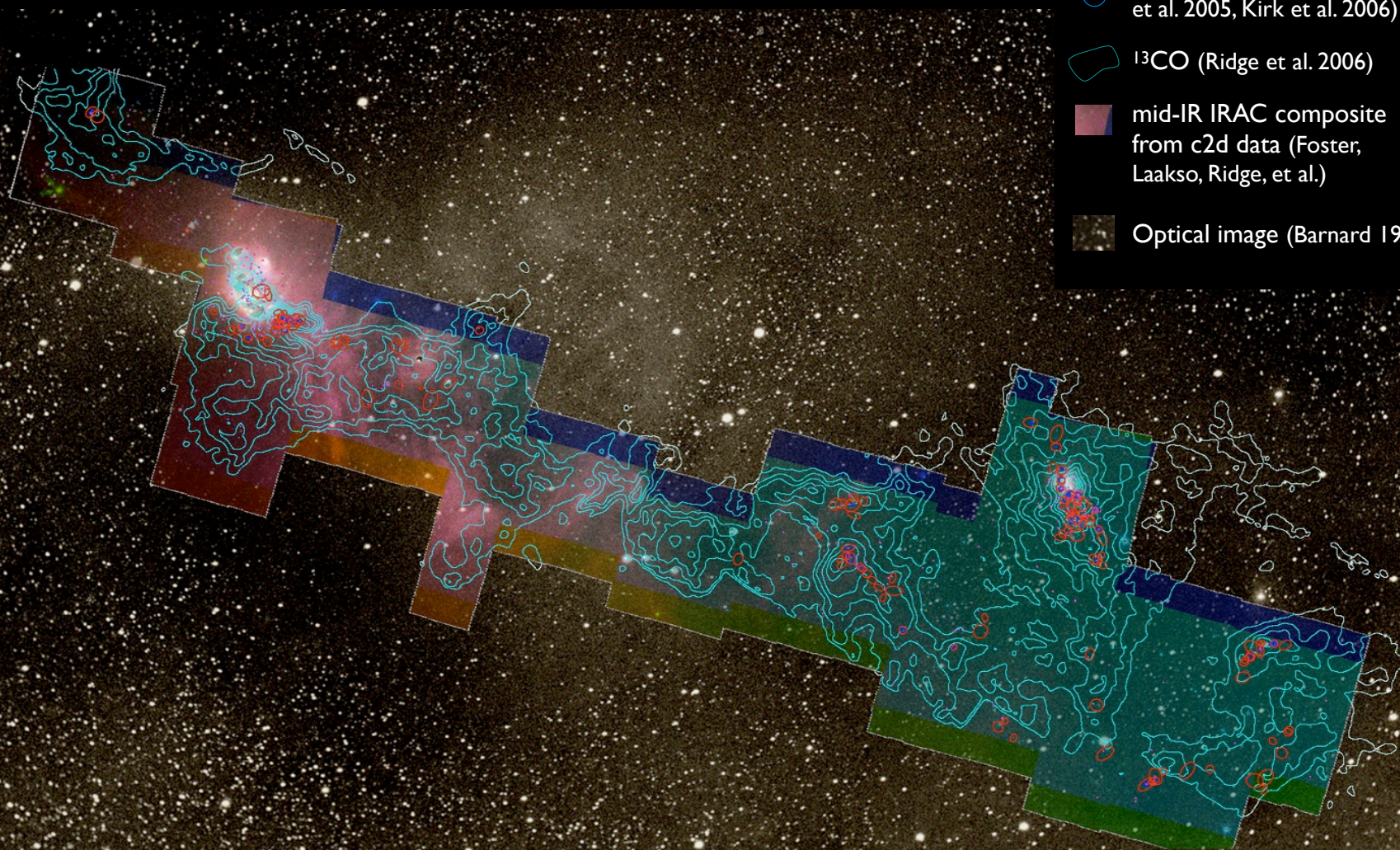
Data
Visualization



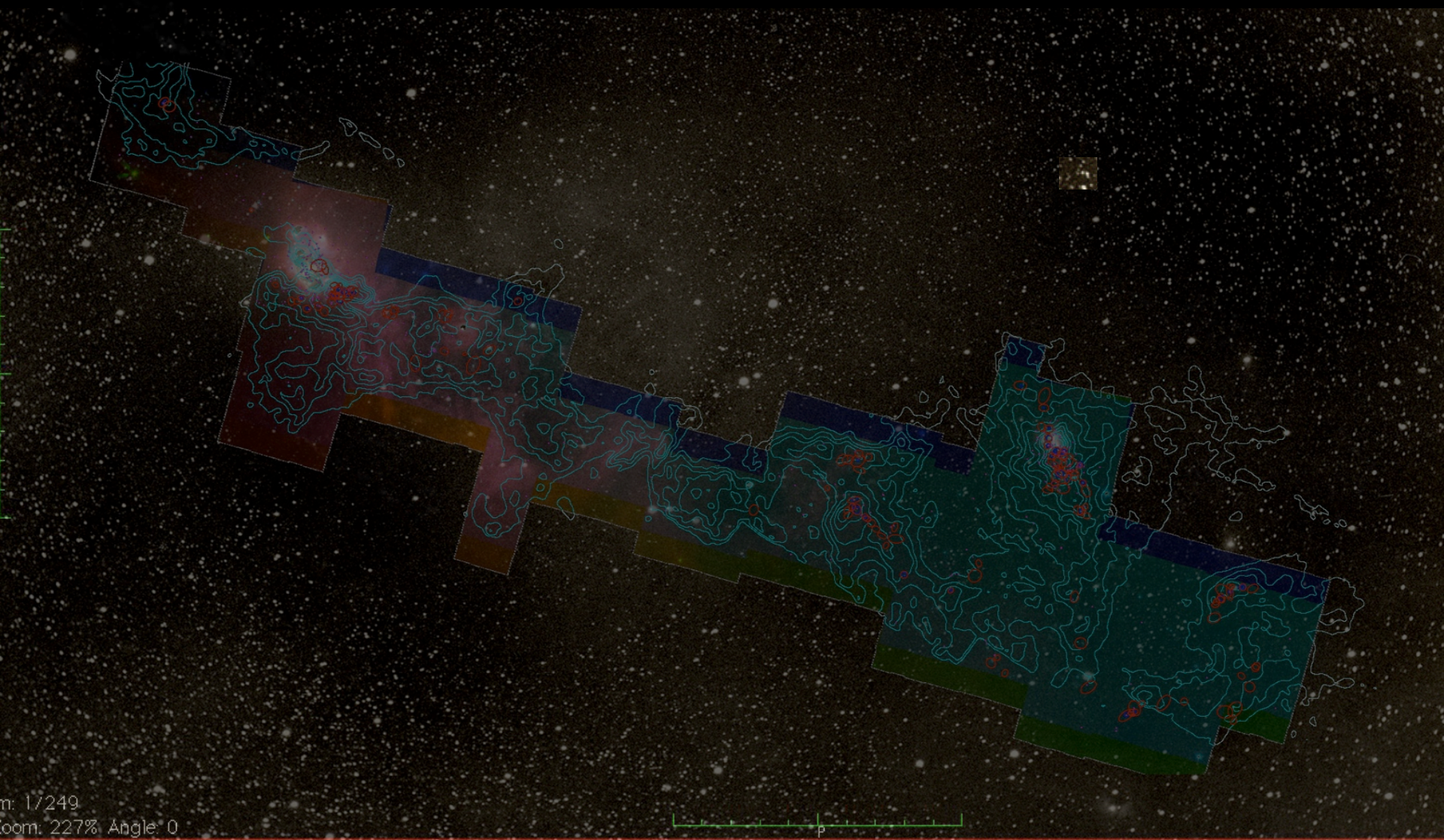
Star
Formation

The **CO**ordinated **M**olecular **P**robe
Line **E**xtinction **T**hermal **E**mission
Survey of Star-Forming Regions
2002-12

COMPLETE

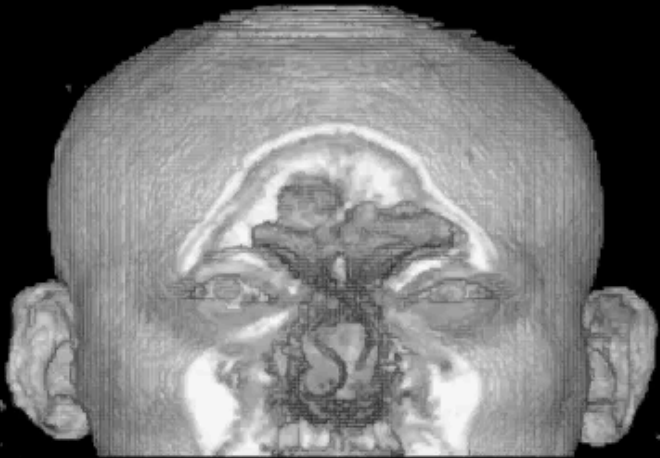


 ^{13}CO (Ridge et al. 2006)



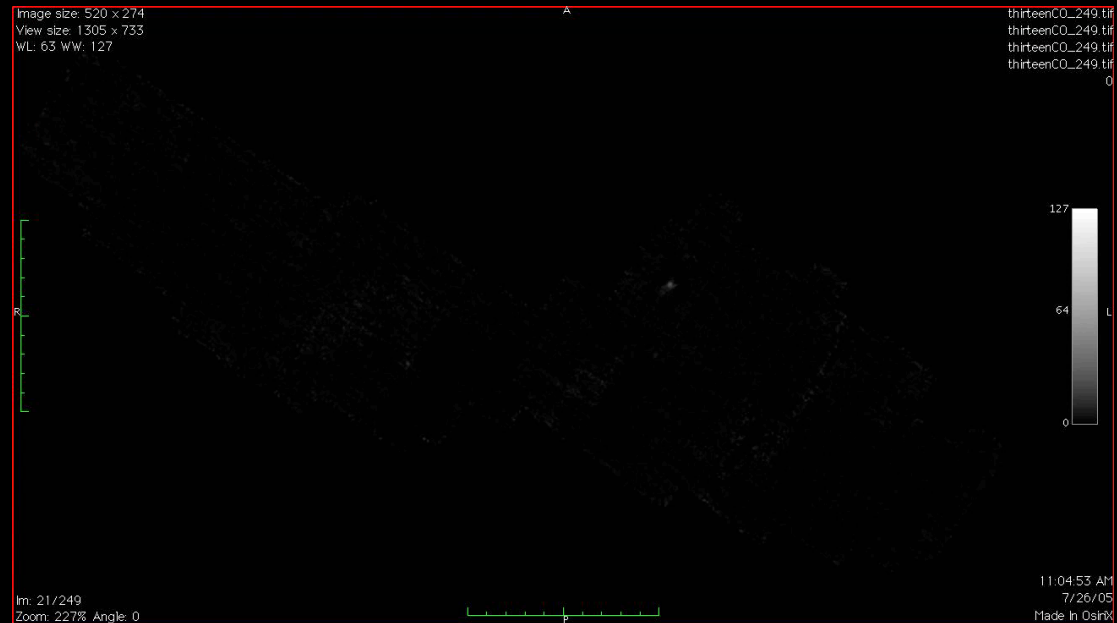
ASTRONOMICAL MEDICINE

"KEITH"



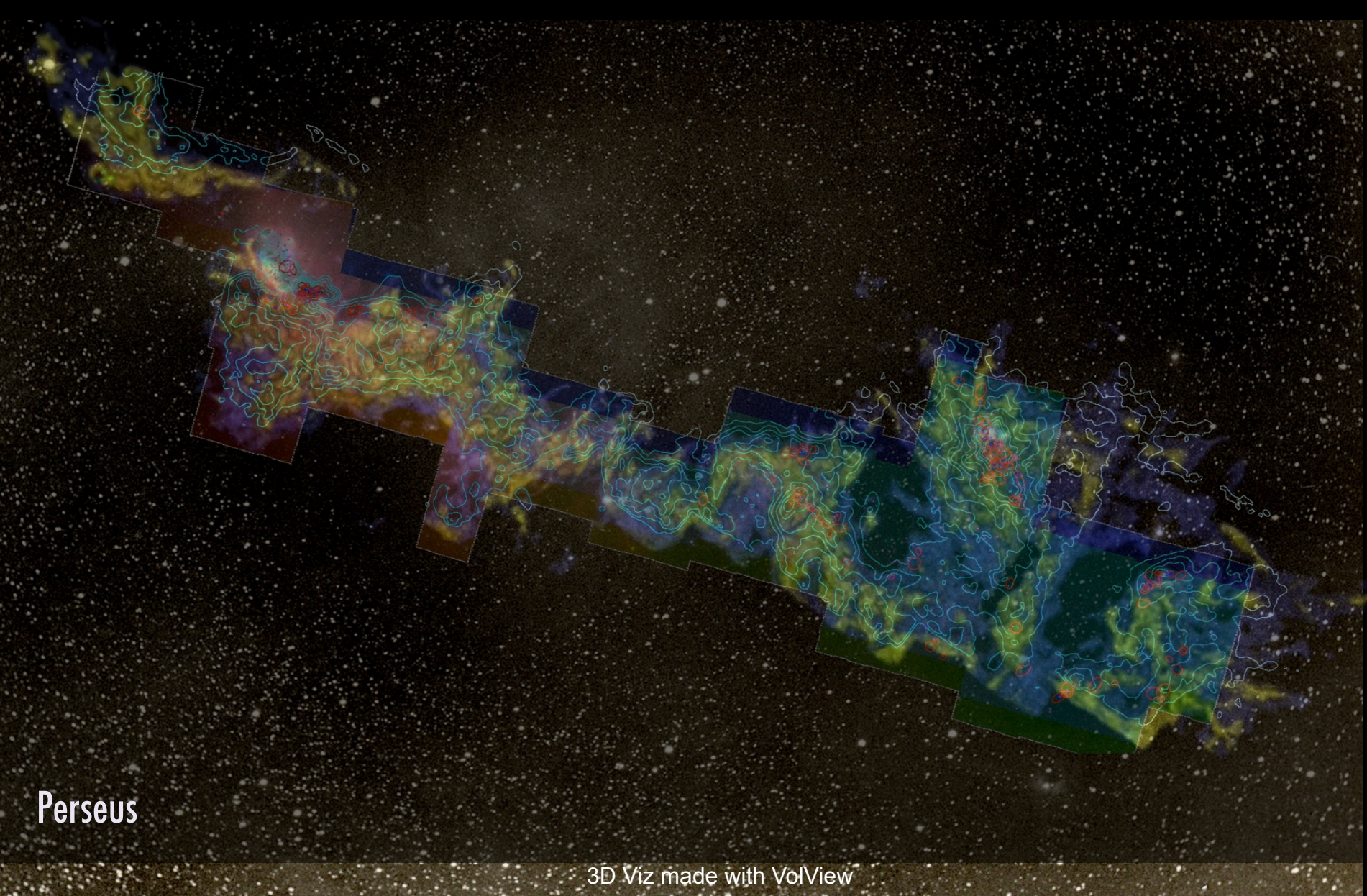
"z" is depth into head

"PERSEUS"



"z" is line-of-sight velocity

"AstroMed" collaborators include Douglas Alan, Chris Beaumont, Michelle Borkin, Jonathan Foster, Michael Halle, Nick Holliman, Jens Kauffmann, Jaime Pineda, Tudor Platon, Erik Rosolowsky, and more



Perseus

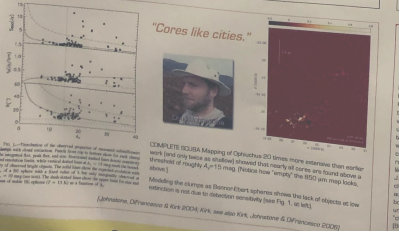
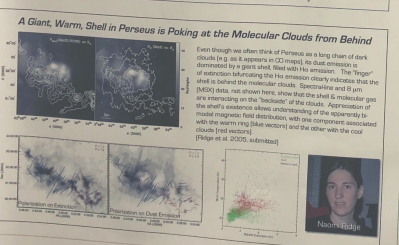
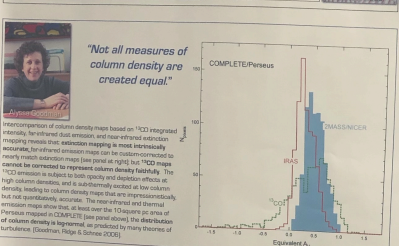
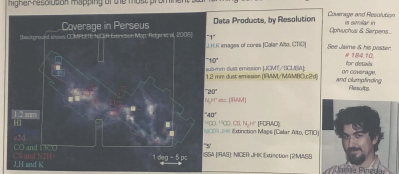
3D Viz made with VolView

Astronomical**Medicine**@ **iig**

COMPLETE

Offerings from the COMPLETE Survey of Star-Forming Regions

The Coordinated Molecular Probe Line Extinction Thermal Emission Survey of Star-Forming Regions provides spectral-line, dust emission and dust absorption maps of the **Persaeus, Ophiuchus**, and **Serpens** regions observed by Spitzer in the cdd Legacy Survey. Phase 1 of COMPLETE, released Jan 2006, provides fully-sampled maps at arcmin resolution. Phase 2, now well-underway, includes higher-resolution mapping of the most prominent star-forming cores in each region.



Be on the lookout for: "All the Outflow in Persaeus" (Arce et al.), "COMPLETE++ Extinction Mapping" (Lombardi & Alves, 2006), "Atomic Gas in the COMPLETE Molecular Clouds" (Liu et al.), "The Real Rho-Oph Cluster, and Ring" (Liu et al.), "Astronomical Medicine" (Goodman et al.), "Clump-finding in Molecular Clouds" (Pineda et al.)

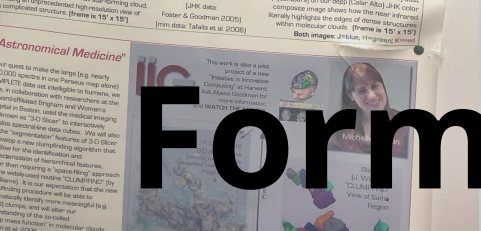
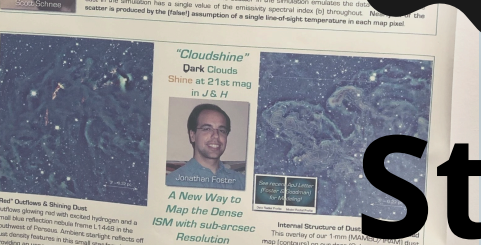
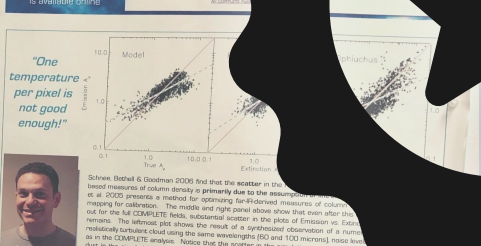
COMPLETE
The Coordinated Molecular Probe Line Extinction Thermal Emission Survey of Star-Forming Regions

Data from COMPLETE are made freely available at the Survey's web site (take a Post-It Pad!)

Also "Phased Data" Summary Pages (Ridge et al. 2006) is available online.

Project Description: COMPLETE is a multi-wavelength survey of star-forming regions in the Milky Way. It includes maps of CO, SiO, and HCN emission, as well as extinction maps and column density maps. The survey is designed to provide a comprehensive view of the star-forming process, from the initial collapse of the gas to the formation of the stars and the outflow of the gas.

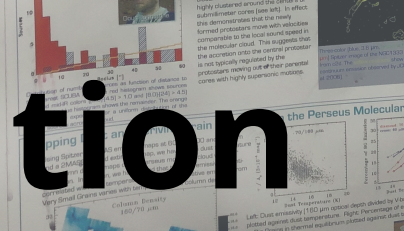
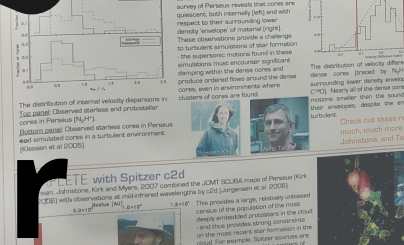
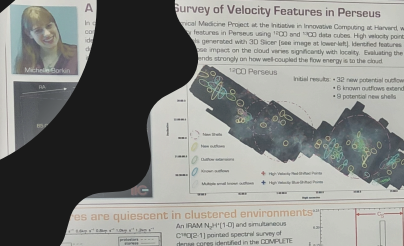
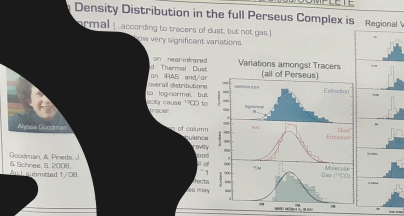
Survey Regions: COMPLETE covers several star-forming regions in the Milky Way, including the Persaeus, Ophiuchus, and Serpens regions. The survey is designed to provide a comprehensive view of the star-forming process, from the initial collapse of the gas to the formation of the stars and the outflow of the gas.



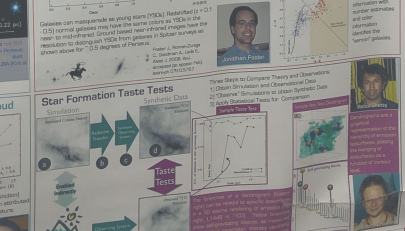
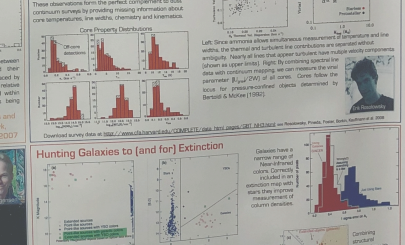
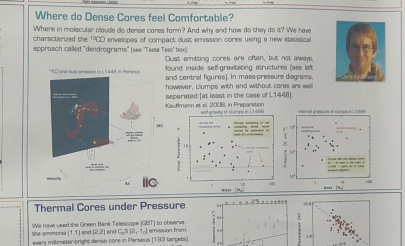
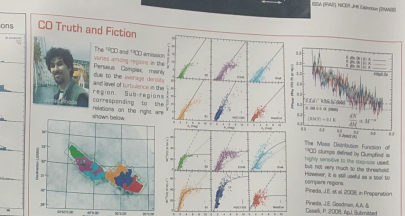
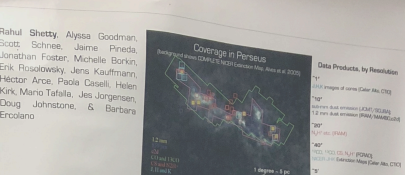
"Astronomical Medicine"
Our quest to make the large (e.g. merely 100000) results in one Persaeus map (see COMPLETE data site) more useful to astronomers has led to a new way of looking at the data. We have developed a new way of looking at the data, one that allows us to see the structure of the gas and the stars in a way that is more useful to astronomers. This new way of looking at the data is called "Astronomical Medicine" and it is a new way of looking at the data that is more useful to astronomers.

COMPLETE Greatest Hits, Volume 2

The Coordinated Molecular Probe Line Extinction Thermal Emission Survey of Star-Forming Regions provides spectral-line, dust emission and dust absorption maps of the **Persaeus, Ophiuchus**, and **Serpens** regions observed by Spitzer in the cdd Legacy Survey. Phase 1 of COMPLETE, released Jan 2006, provides fully-sampled maps at arcmin resolution. Phase 2, now well-underway, includes higher-resolution mapping of the most prominent star-forming cores in each region.



the Persaeus Molecular Cloud
The Persaeus Molecular Cloud is a large, dense cloud of gas and dust in the Milky Way. It is the site of active star formation, with many new stars being born. The cloud is composed of several smaller clouds, each of which is a site of star formation. The Persaeus Molecular Cloud is one of the most active star-forming regions in the Milky Way.



Star Formation Taste Tests
The Star Formation Taste Tests are a series of experiments designed to help astronomers understand the process of star formation. The tests involve measuring the temperature, density, and velocity of the gas in star-forming regions. The results of the tests can be used to determine the conditions under which stars are born.

COMPLETE (in) "WorldWide Telescope"



COMPLETE Data Available

Center on Perseus Center on Ophiuchus Center on Serpens

Full-Cloud Data (Phase I, All Data Available)

	Show	Perseus	Ophiuchus	Serpens	Link
CTIO/Calzetti: HI Data Cube	☒	✓	✓	∅	Data
IRAS: Av/Temp Maps	☒	✓	✓	✓	Data
FCRAO: 12CO	☒	✓	✓	✓	Data
FCRAO: 13CO		✓	✓	✓	Data
JCMT: 850 microns	☒	✓	✓	∅	Data
Spitzer c2d: IRAC 1,3 (3.6,5.8 μm)	☒	✓	✓	✓	Data
Spitzer c2d: IRAC 2,4 (4.5,8 μm)	☒	✓	✓	✓	Data
CSO/Bolocam: 1.2-mm	☒	✓	∅	∅	Data
Spitzer MIPS: Derived Dust Map	☒	✓	∅	∅	Data

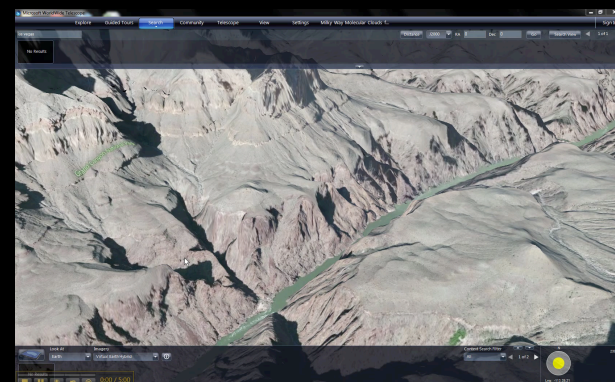
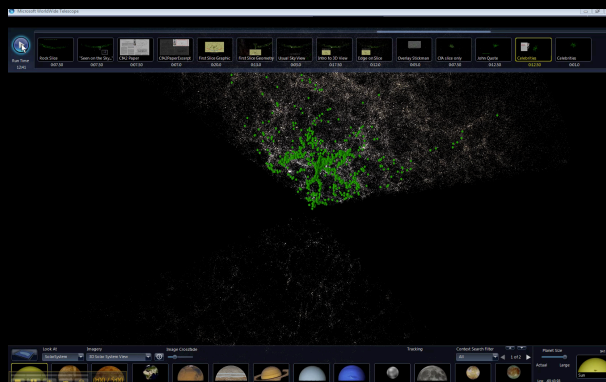
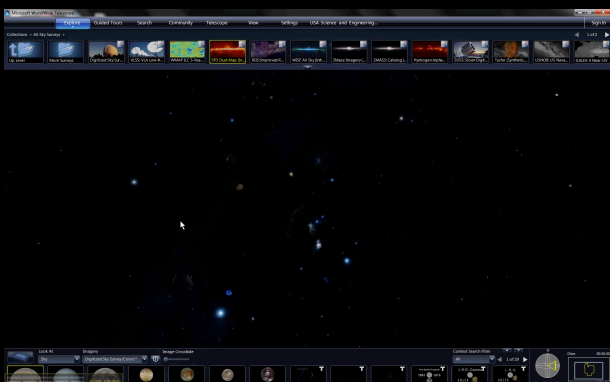
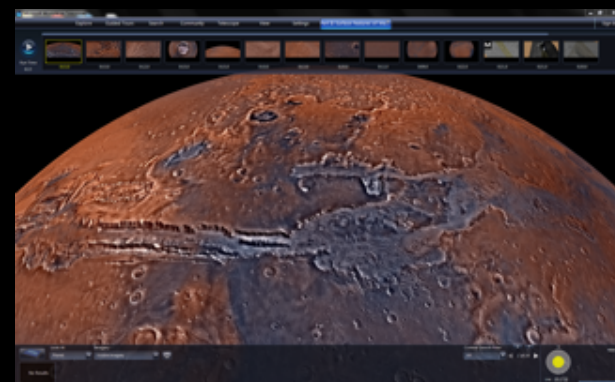
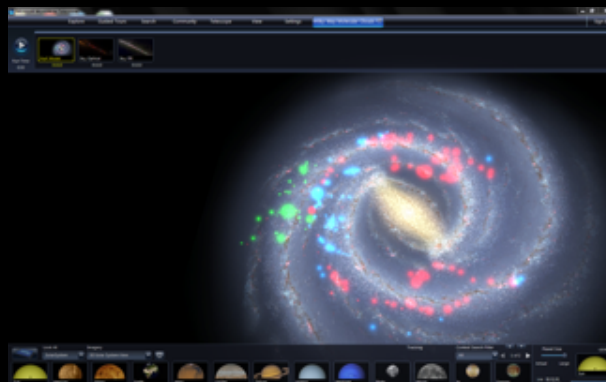
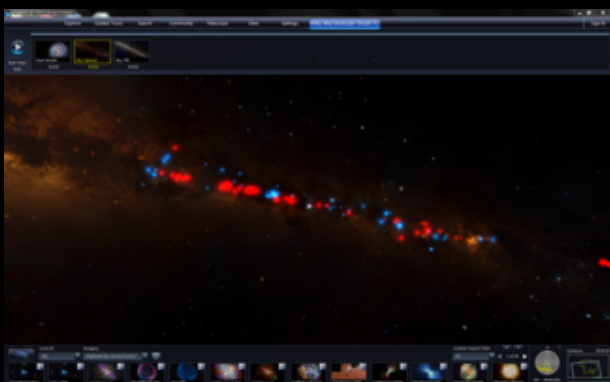
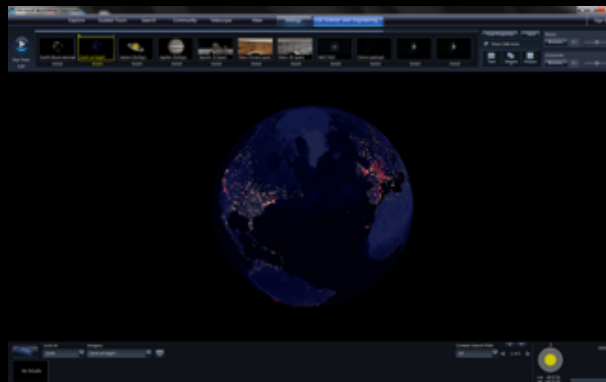
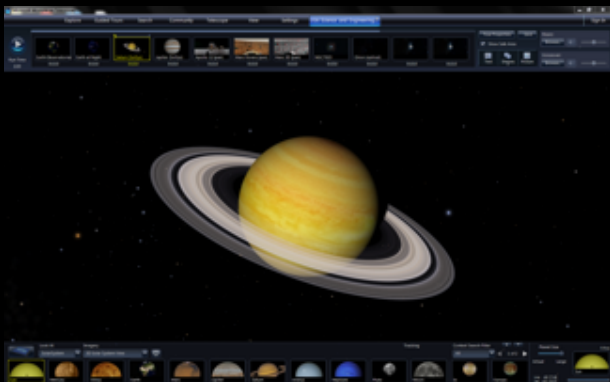
Targeted Regions (Phase II, Some Data Not Yet Available)

CTIO/Calzetti: NIR (J,H,Ks)	☒	✓	✓	∅	Data
IRAM 30-m: N2H+ and C18O	☒	✓	∅	∅	Data
IRAM 30-m: 1.1-mm continuum	☒	✓	∅	∅	Data
Megacam/MMT: r,i,z images	☒	✓	∅	∅	Data

Catalogs & Pointed Surveys

NH3 Pointed Survey	☒	✓	∅	∅	Data
YSO Candidate list (c2d)	☐	✓	✓	✓	Data

WorldWide Telescope" 2007-



Experience WorldWide Telescope, free, at worldwidetelescope.org

[demo]



Teaching
& Outreach



Climate
Change



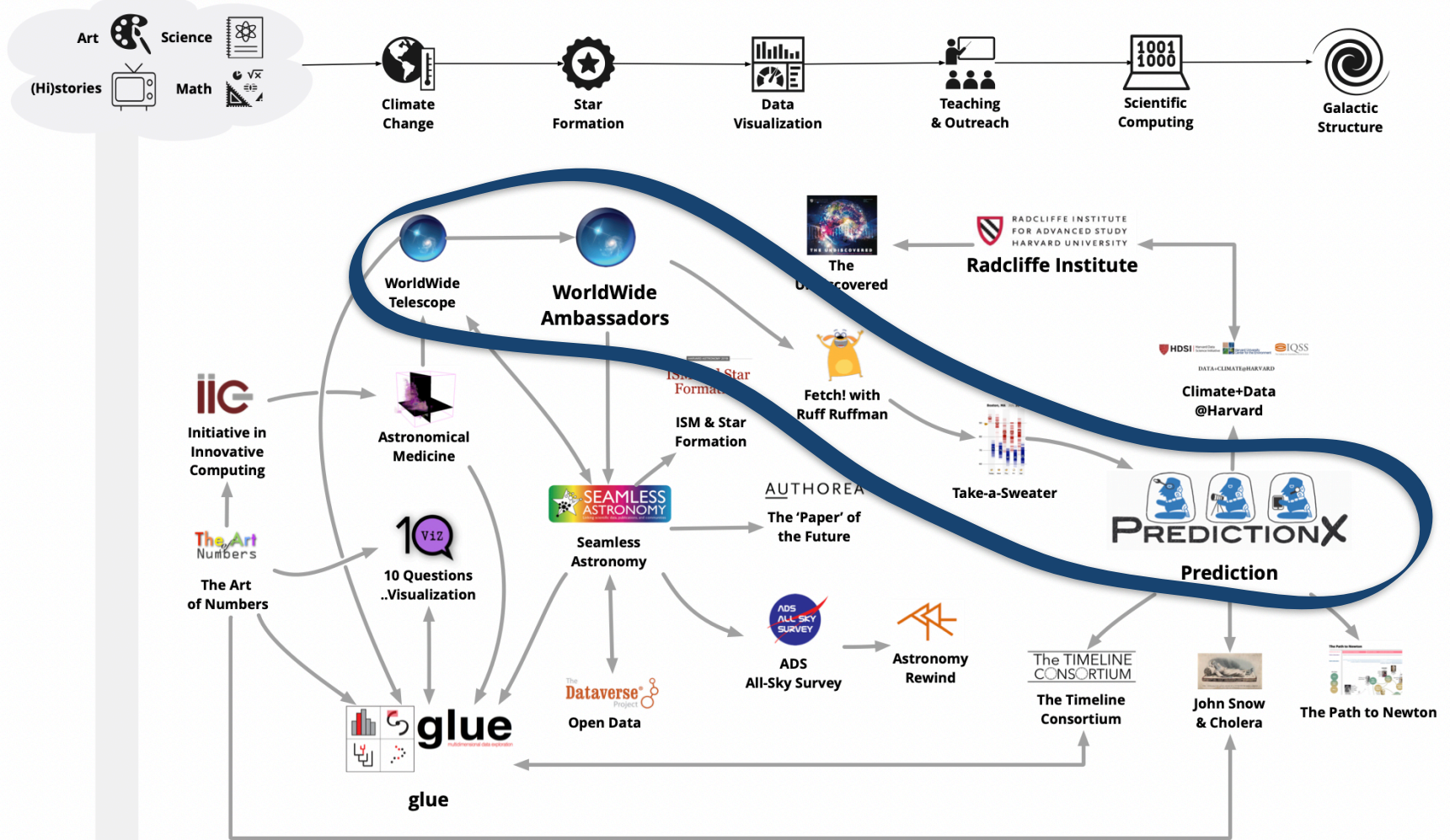
PREDICTIONX



Scientific
Computing

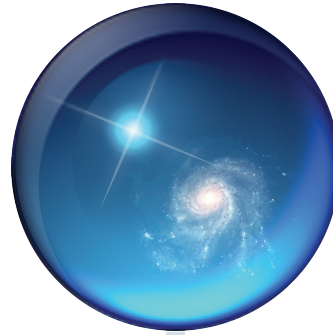


Alyssa



COMPLETE
The COMPLETE Survey of
Star-Forming Regions





Teaching
& Outreach



Climate
Change



PREDICTION~~X~~ ~2014-



Scientific
Computing



PREDICTIONX: THE PAST & PRESENT OF THE FUTURE



ESSENTIALS

**Phenomena
→ Predictions**

**Predictive Systems
Framework**

 **Understanding
Uncertainty**

Study Design

► **Why Predict?**



Omens, Oracles & Prophecies

Mesopotamian
Haruspicy

Roman
Augury

Chinese
Oracle Bones

Oracle
of Delphi

Aztec
Rituals

Egyptian
Priests

Tarot

**The
Diviner's
Guide**

Turkish
Tasseography

Maya
Spacetime

Yoruba
Ifa

Casting
Lots

Greek
Astronomy

Astrology

Comets
of Doom

► **cross-cultural
conversations**



THE RISE OF THEORY

Ancient
Mesopotamia,
Egypt, Greece &
Rome

 **The Path
to Newton**

► Indian
Mathematics
European
Renaissance

► The Royal Society

**Lost without
Longitude
(Navigation)**

 **Help, I'm Lost!**

Tools of the
Navigator



MODERN SIMULATION

Health

► Epidemiology
► Personal Genomics
► Population Genetics

Wealth

► Personal
Finance
(Global)
Economics

**The Future
of the Future:**

► Artificial
Intelligence
 Derek's Day

Earth

► Climate Change
► Tent Tarot
► Earthquakes

Space

Futures
of our Universe

Finished Coming Soon Planned  Interactive Resource ► video(s)  link to edX (often contains videos + interactives, not marked separately here)

HarvardX

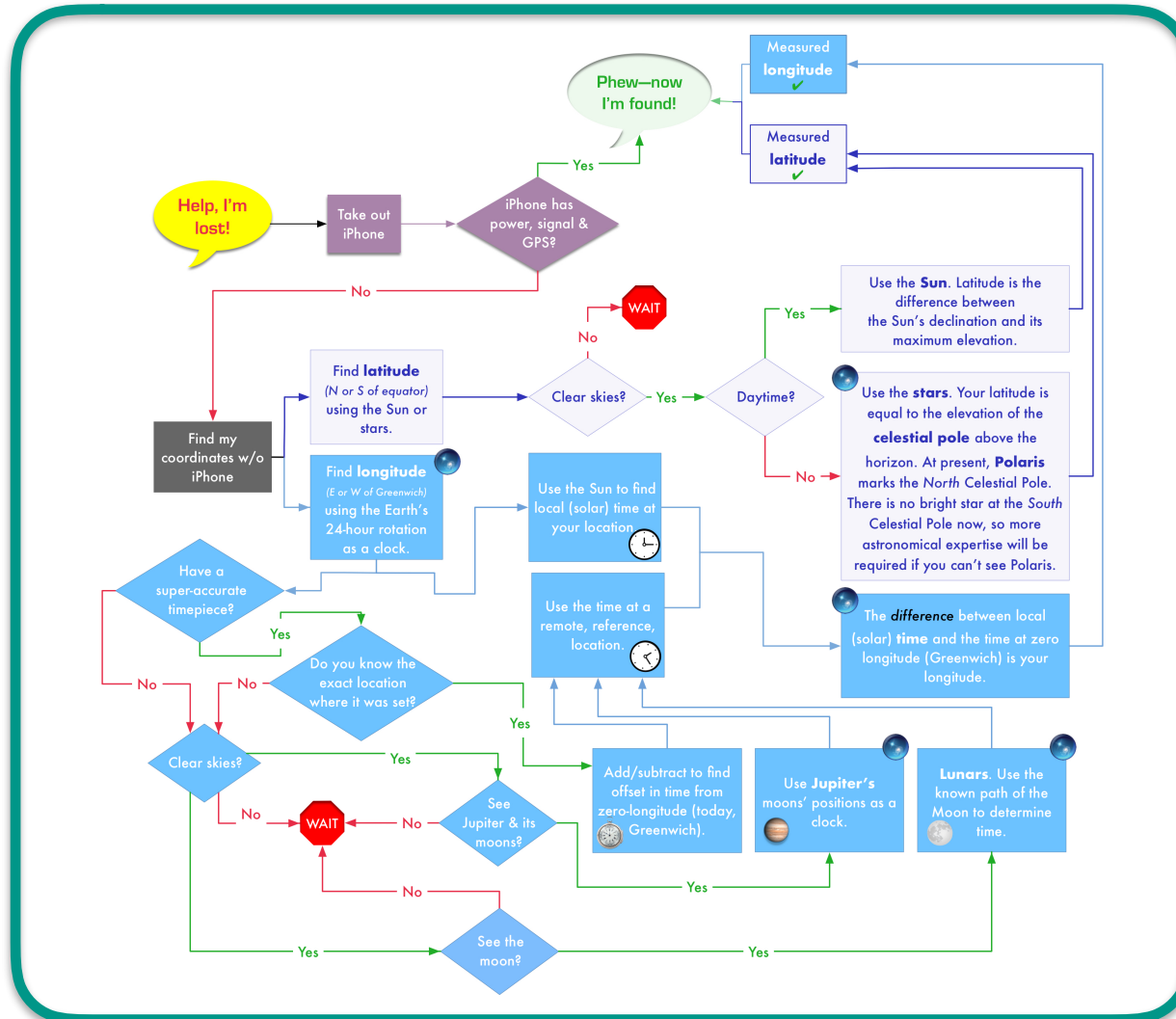


edX

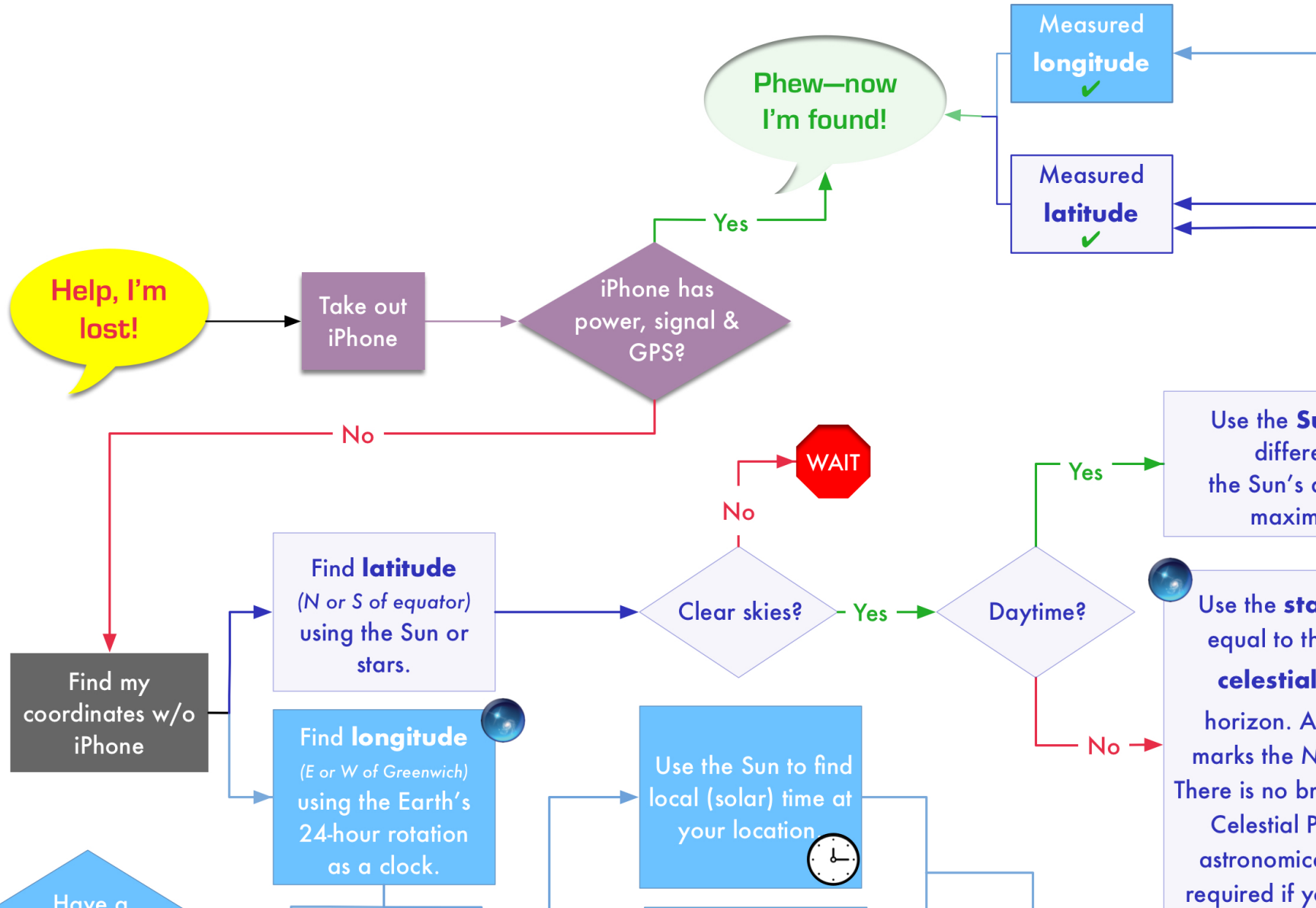
predictionx.org

*with many thanks to HarvardX course producer Drew Lichtenstein,
research assistant Jais Brohinsky, designer Katie Peek + dozens of other experts at Harvard and beyond*

"Lost without Longitude"



"Lost without Longitude"



Earth as a Clock



The Celestial Sphere



Jupiter's Moons



Latitude & Longitude



Lunars on the Sky



Why Lunars are Hard





PREDICTIONX: THE PAST & PRESENT OF THE FUTURE



ESSENTIALS

**Phenomena
→ Predictions**

**Predictive Systems
Framework**

 **Understanding
Uncertainty**

Study Design

▶ **Why Predict?**



Omens, Oracles & Prophecies

Mesopotamian
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Ancient
Mesopotamia,
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 **The Path
to Newton**

▶ Indian
Mathematics
European
Renaissance

▶ The Royal Society

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Tools of the
Navigator



MODERN SIMULATION

Health

▶ Epidemiology
▶ Personal Genomics
▶ Population Genetics

Wealth

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Finance
(Global)
Economics

**The Future
of the Future:**

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Intelligence
 **Derek's Day**

Earth

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Space

Futures
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HarvardX  **edX** **predictionx.org**

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CENTER FOR
ASTROPHYSICS

[illegible]

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The Path to Newton



The Path to Newton

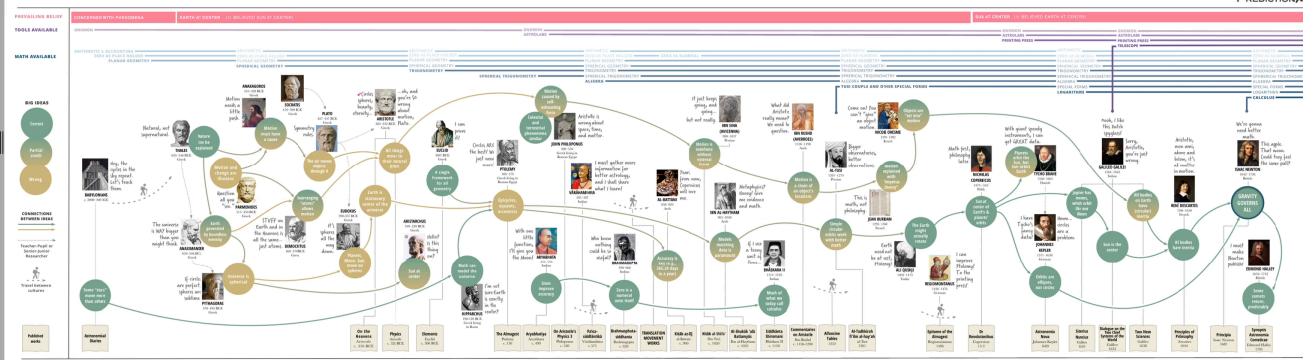
PREAMBLE:

Isaac Newton's theory of gravity was truly revolutionary. For the first time in history, all motion -- from celestial bodies in Space to objects on Earth -- could be mathematically described and predicted. Newton's theory necessitated new mathematics, Calculus, as well as a trove of empirical observations from which to derive and against which to test the math. The observations required instruments, the instruments required inventors, and the inventors required ideas, models, and conceptual systems that tried to make sense of the world and its physical phenomena. Over millennia, the ideas that led to Newton's built on earlier ideas through critique, amendment, and refutation. Newton's theory of gravity was not quite like the other ideas that drove our understanding of how the Universe moves forward, though--it was a monumental paradigm shift, from a world described by empirical rules, like those Kepler had discovered, to a world that could be predicted a priori--with no prior data about a system.

The Path to Newton is an attempt to demonstrate (some) of history behind how Newton knew what he knew and thought what he thought about motion. For many centuries, motion of objects in the Heavens (what we now think of as celestial mechanics) was considered categorically distinct from motion of objects on Earth (what was known as kinematics and, later, dynamics), so the Path focuses on philosophical and mathematical conceptions of the Universe and of how and why objects move on Earth, in order to explain how an ultimately unified theory of motion came to be.

Steps along the Path were facilitated by material technologies and greatly affected by religious doctrine, cultural exchange, and the migration and translation of ideas. The Path highlights the cultures, thinkers and tinkerers who wrestled ideas about motion into the stories, cosmologies, mathematics, tools, and data that lay before Newton as he worked. Each person highlighted along the Path stands in for a constellation of factors, often groups of people, that led to the historical recording or transmission of key ideas. While The Path employs these contributors as representatives and access points to seminal ideas and innovations necessary for a predictive theory of gravity, the immensity of the

The Path to Newton



The Path to Newton

PREVAILING BELIEF

TOOLS AVAILABLE

MATH AVAILABLE

BIG IDEAS

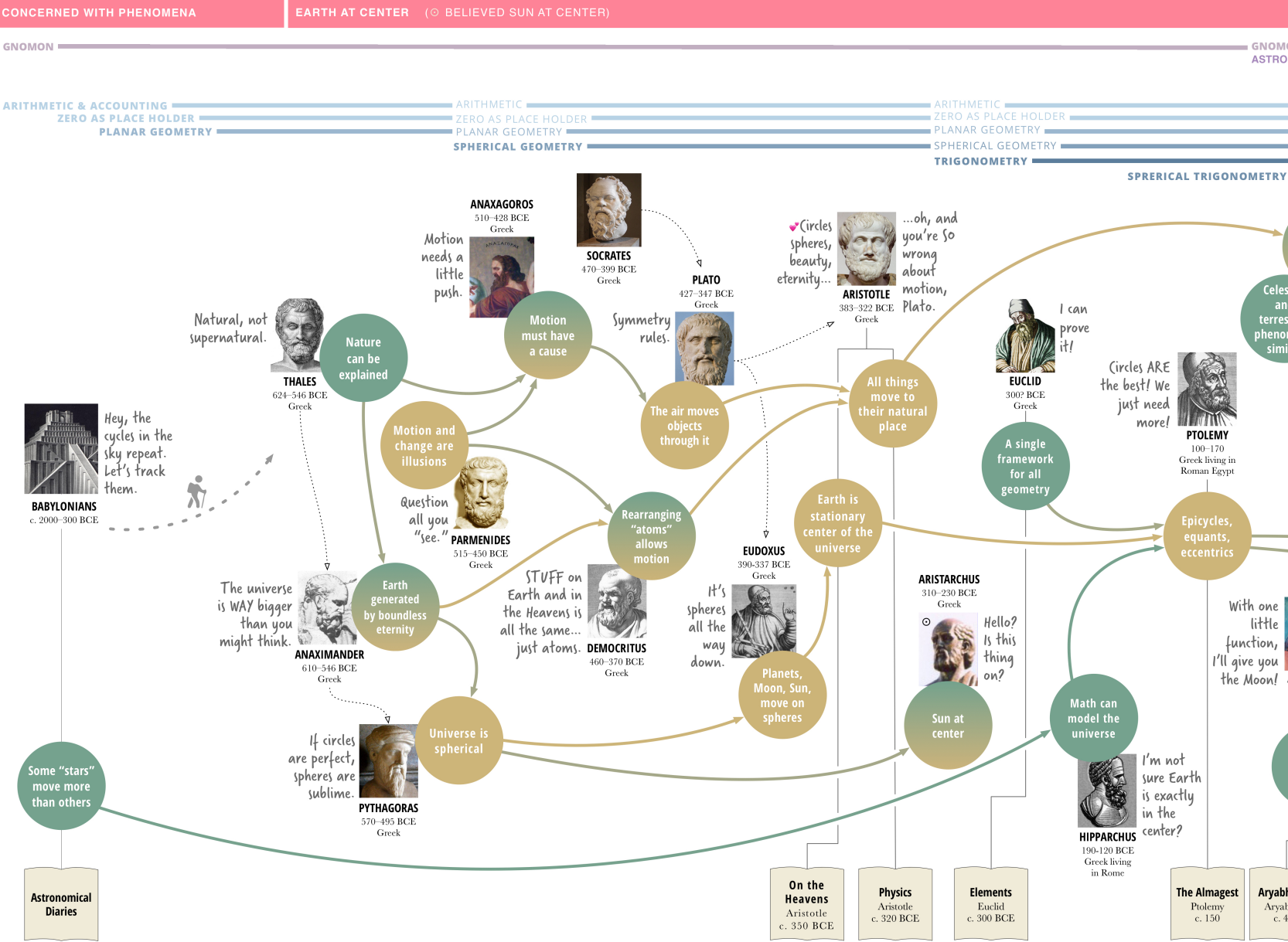


CONNECTIONS BETWEEN IDEAS

Teacher-Pupil or Senior-Junior Researcher

Travel between cultures

Published works

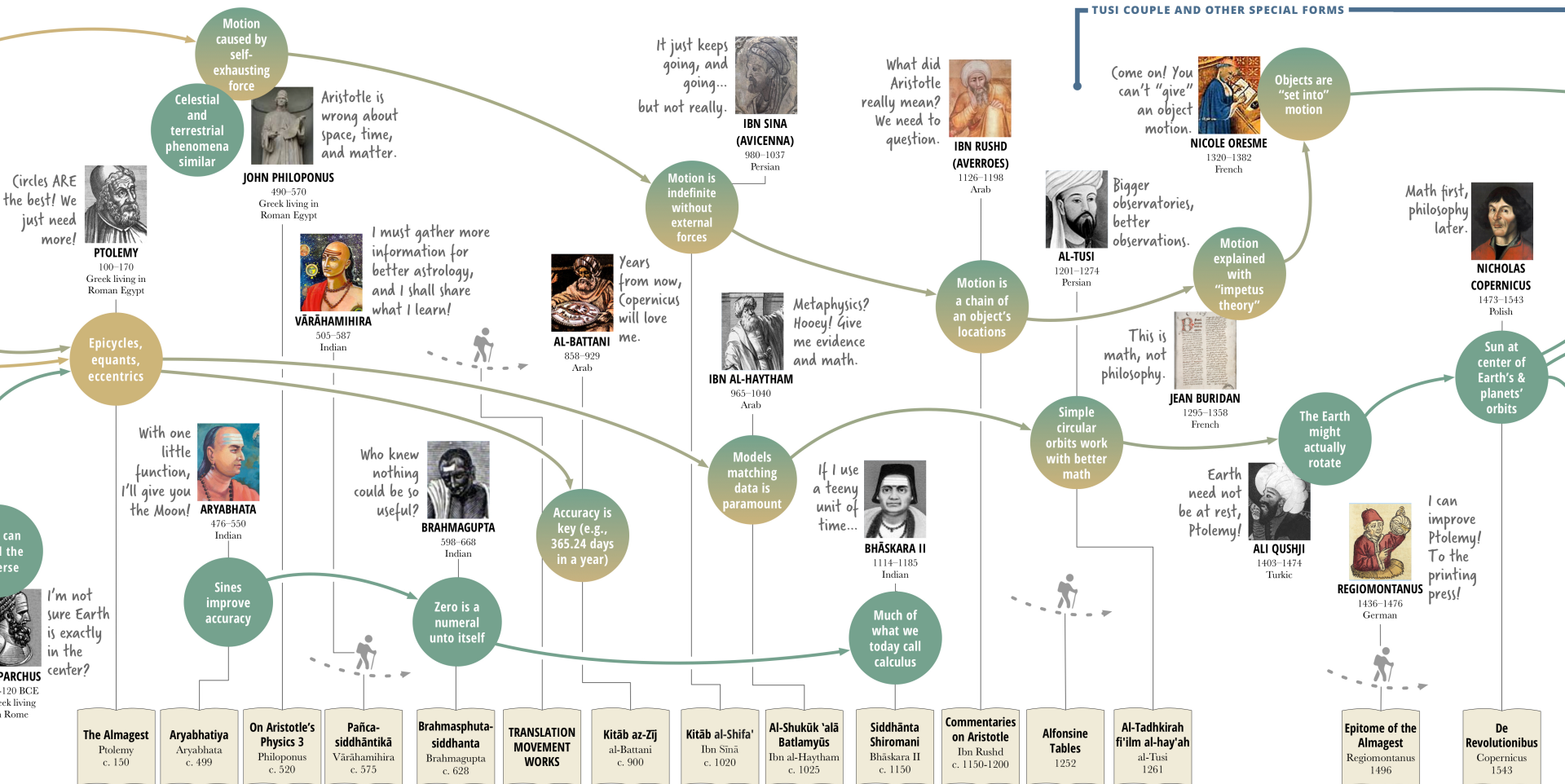


GNOMON
ASTROLABE

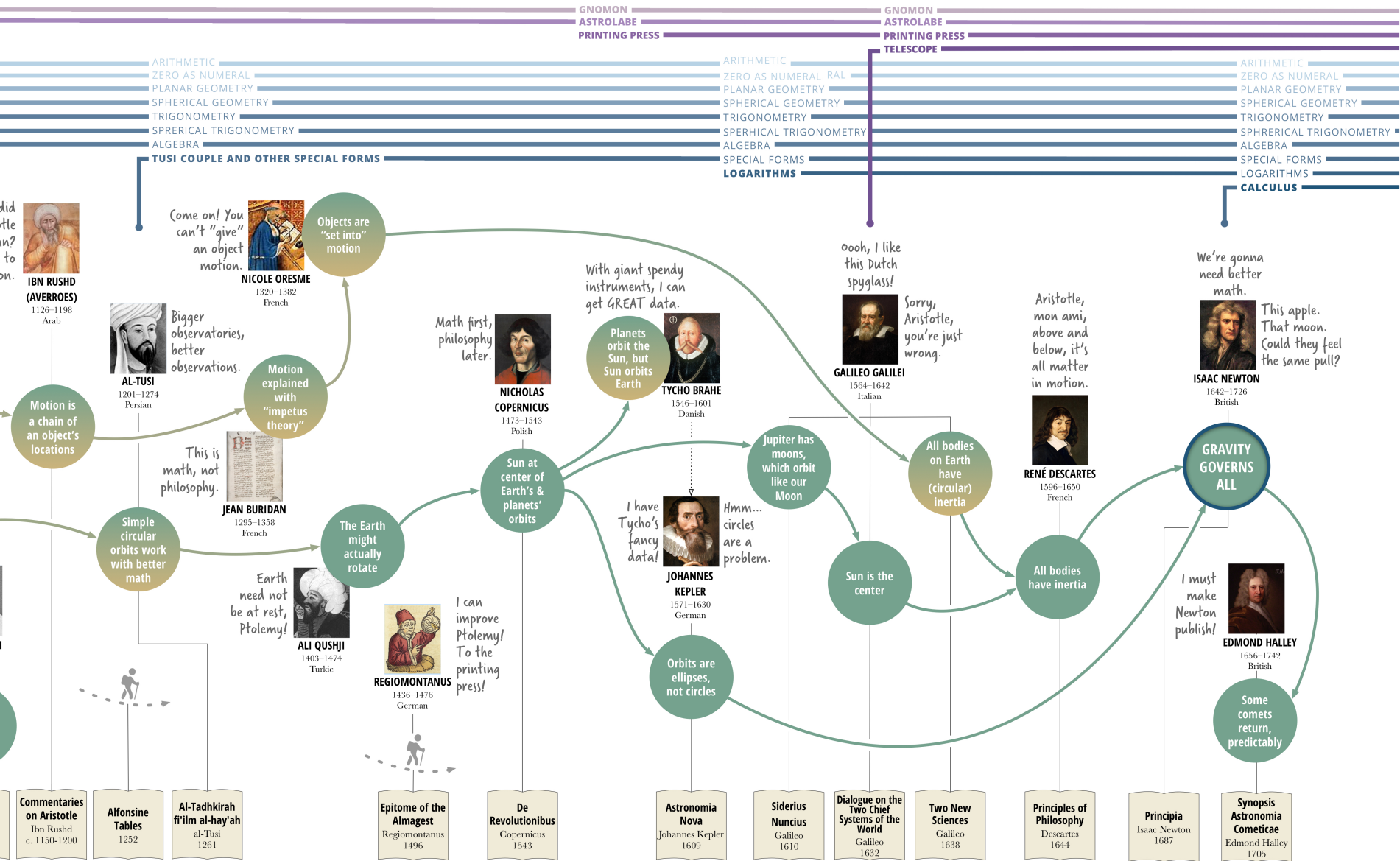
ARITHMETIC
ZERO AS PLACE HOLDER
PLANAR GEOMETRY
SPHERICAL GEOMETRY
TRIGONOMETRY
SPHERICAL TRIGONOMETRY
ALGEBRA

SPHERICAL TRIGONOMETRY

ARITHMETIC
ZERO AS NUMERAL
PLANAR GEOMETRY
SPHERICAL GEOMETRY
TRIGONOMETRY
SPHERICAL TRIGONOMETRY
ALGEBRA
TUSI COUPLE AND OTHER SPECIAL FORMS



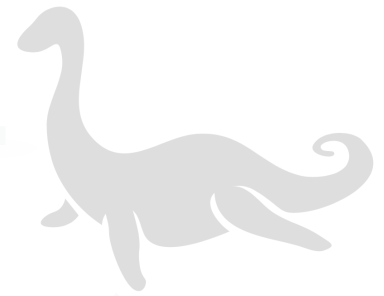
SUN AT CENTER (☉ BELIEVED EARTH AT CENTER)



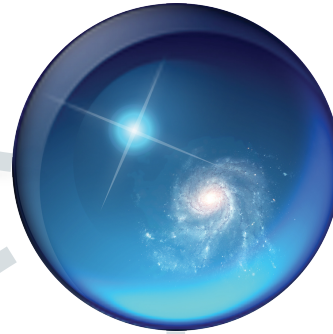
COMPLETE



Star
Formation



Data
Visualization



Teaching
& Outreach



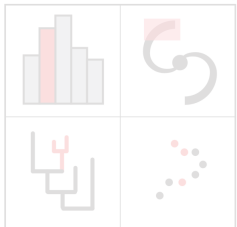
Climate
Change



Galactic
Structure



PREDICTIONX



glue
multidimensional data exploration



Scientific
Computing



Nessie—



The First “Bone” of the **Milky Way**

The Milky Way

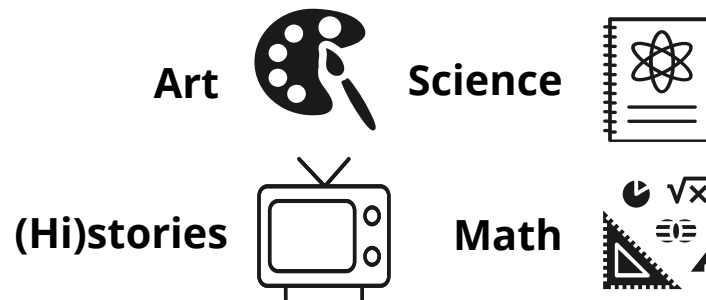
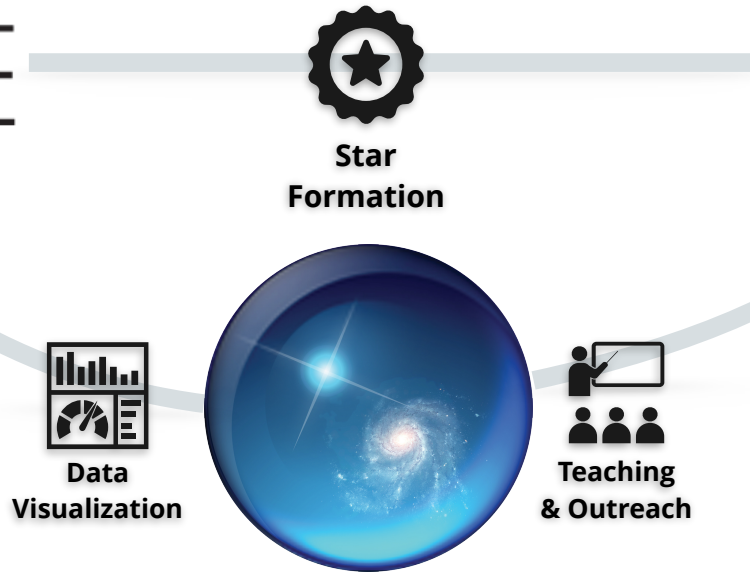
“Galactic Plane”



The Milky Way
(Artist's Conception)



COMPLETE

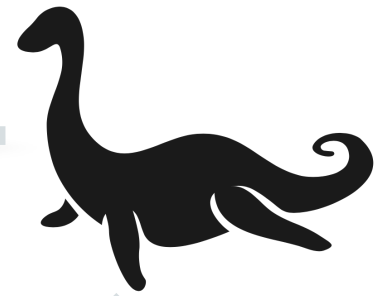


“Whoa!? Who ordered ‘bones’?!”

COMPLETE



Star
Formation



Data
Visualization



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Galactic
Structure



WorldWide Telescope Stories

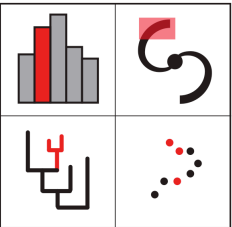


BONES OF THE MILKY WAY

ORIGINS

EVOLUTION

This is a story about how a group of Astronomers found a new way to uncover the structure of our Galaxy, using WWT, in the backof a



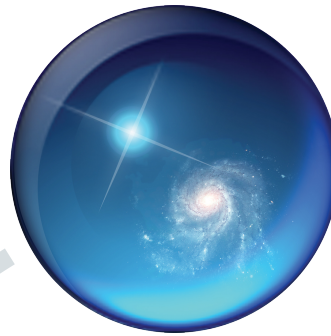
glue
multidimensional data exploration



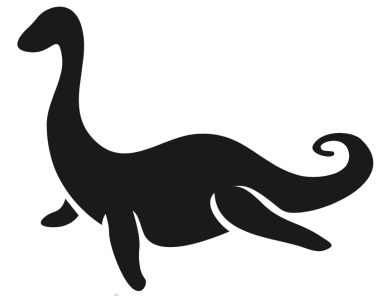
**Data
Visualization**

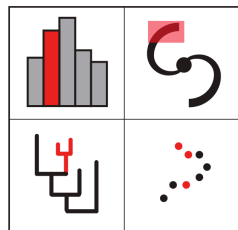


**Scientific
Computing**



**Galactic
Structure**

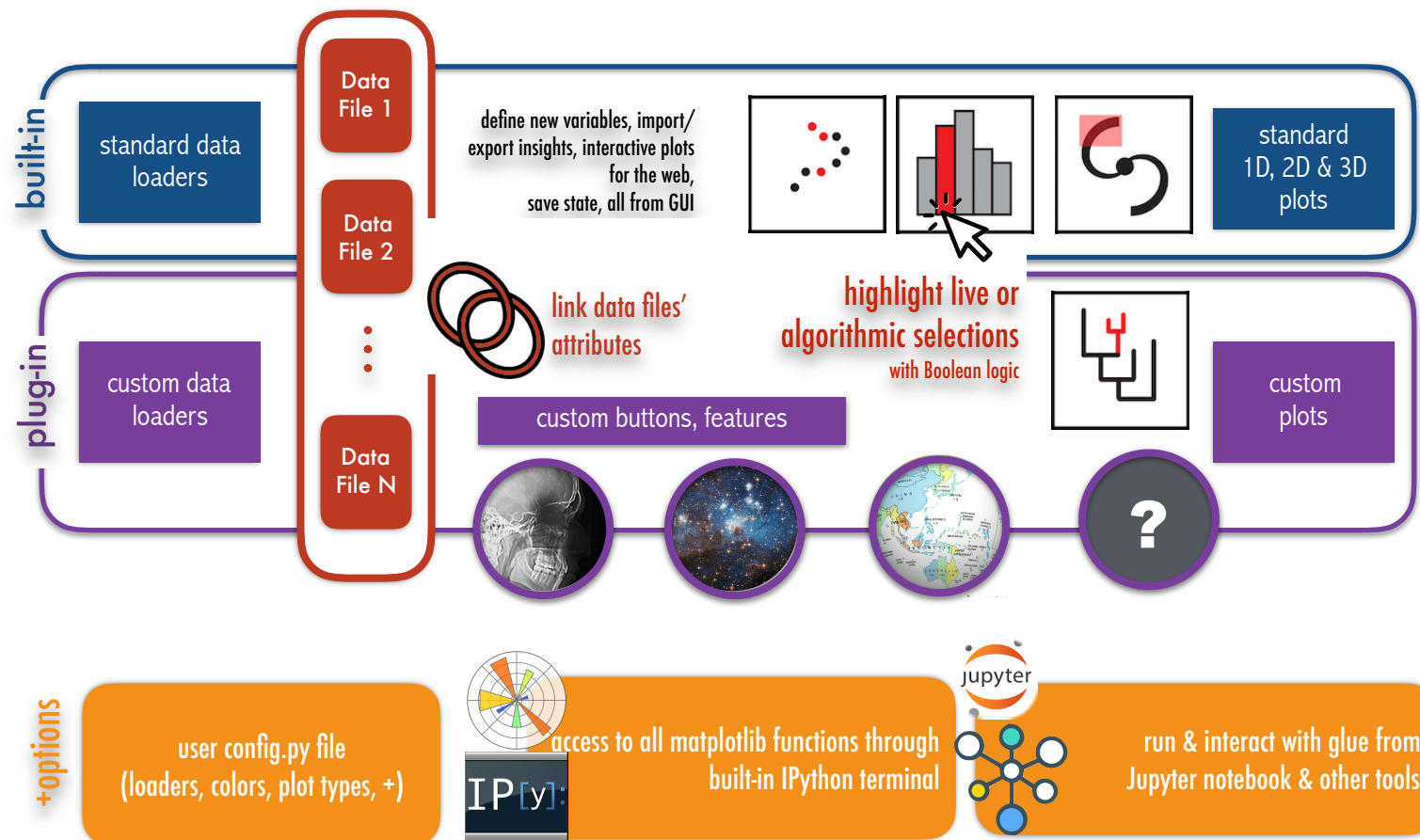




glue

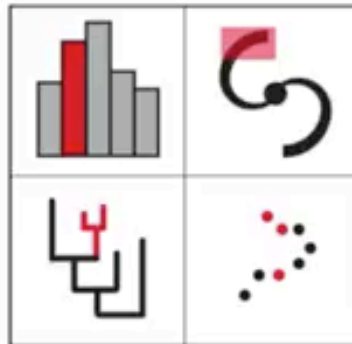
multidimensional data exploration

2011-



Multi-dimensional data exploration with

glue



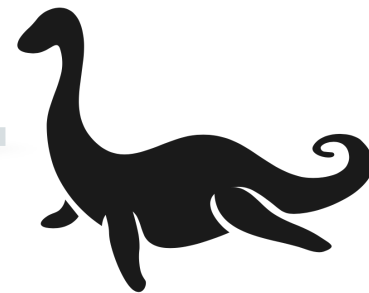
<http://www.glueviz.org>

*video by Tom Robitaille, lead glue developer
glue created by: C. Beaumont, M. Borkin, M. Breddels, P. Qian, T. Robitaille, C. Zucker and A. Goodman, PI*

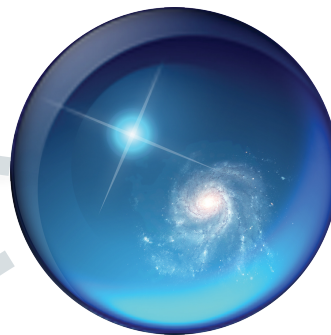
COMPLETE



Star
Formation



Data
Visualization



Teaching
& Outreach



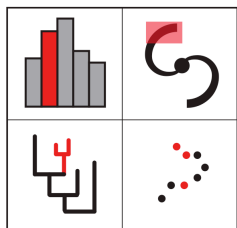
Climate
Change



Galactic
Structure



PREDICTIONX

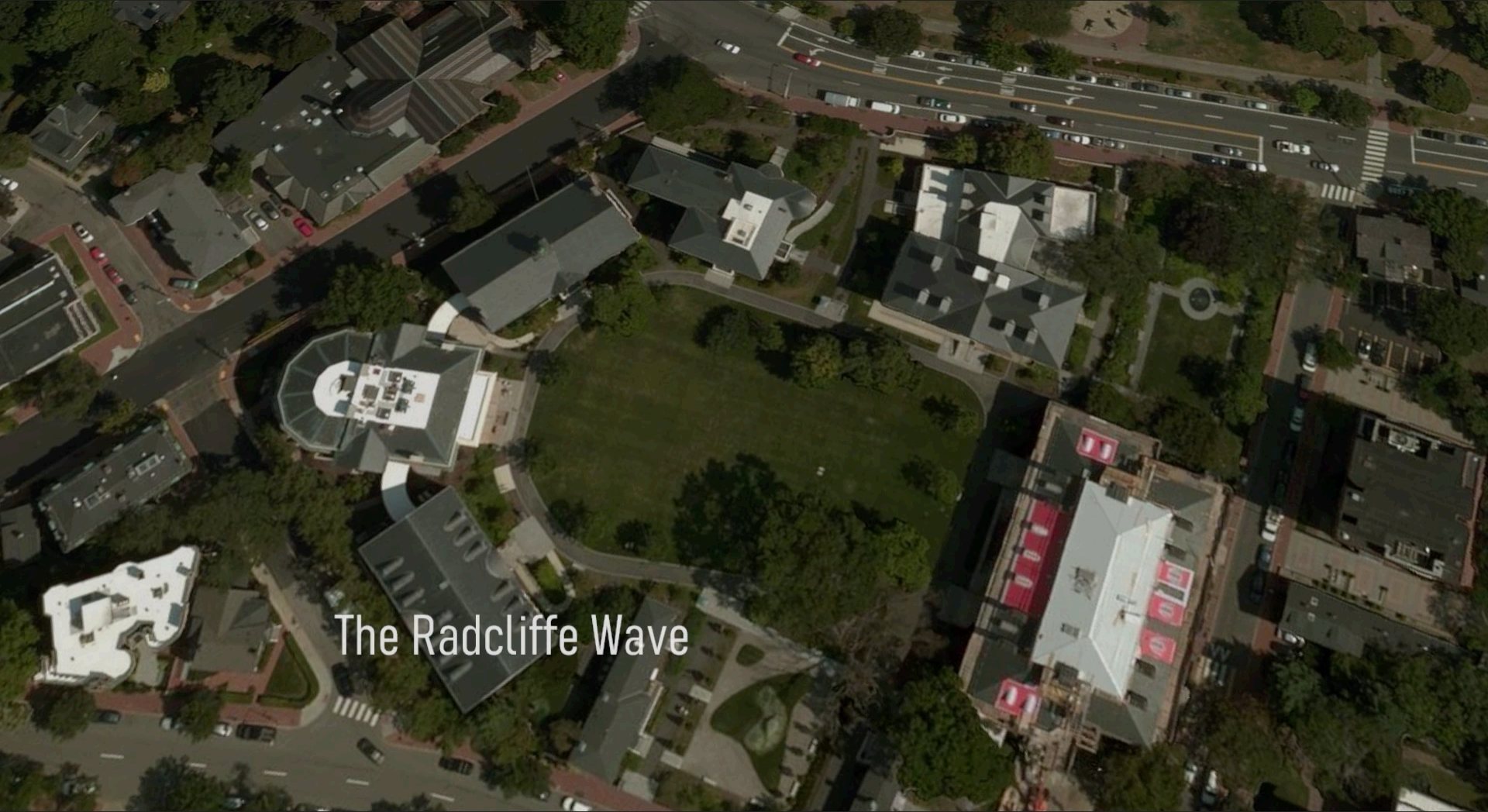


glue
multidimensional data exploration



Scientific
Computing

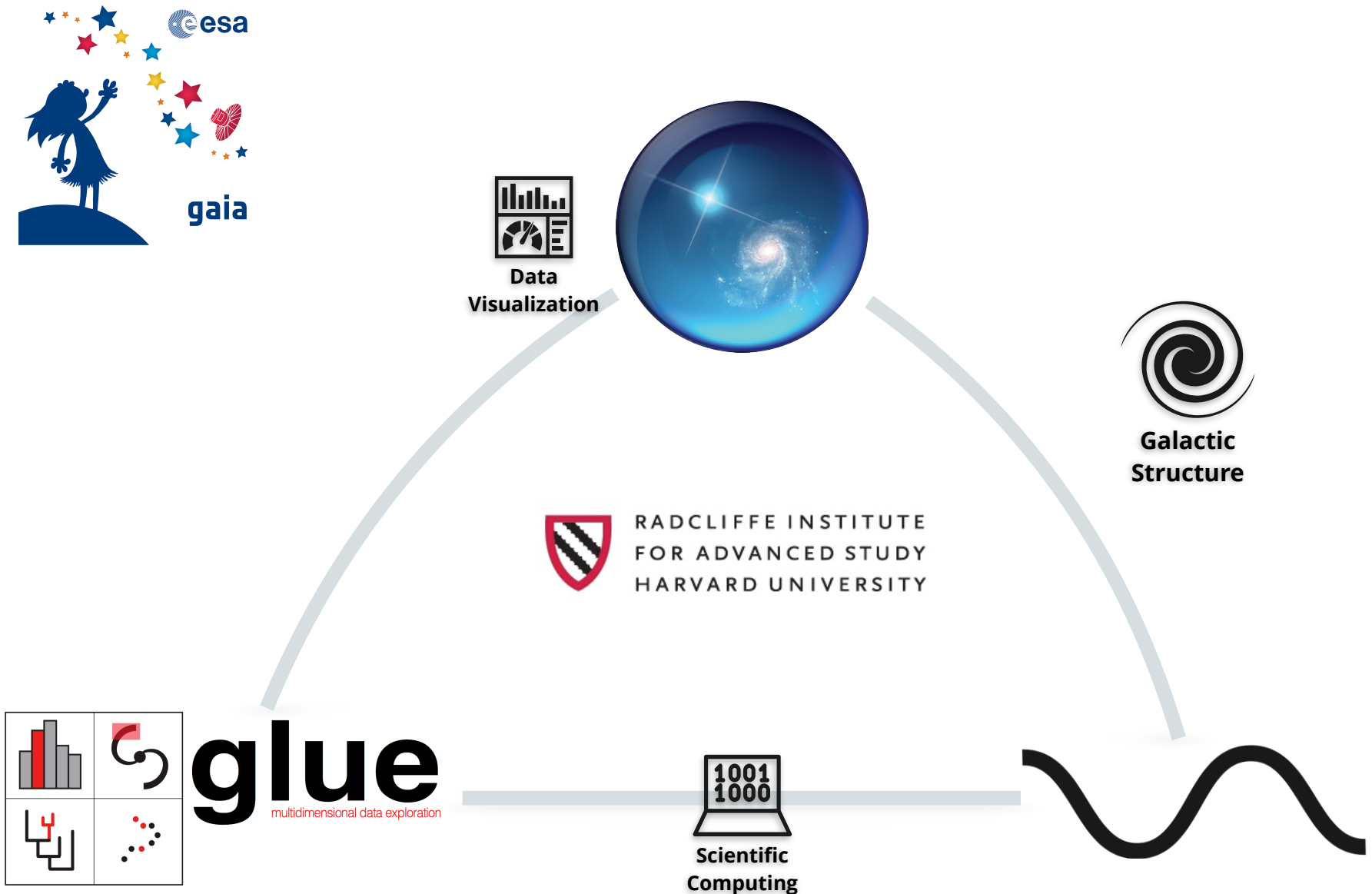




The Radcliffe Wave

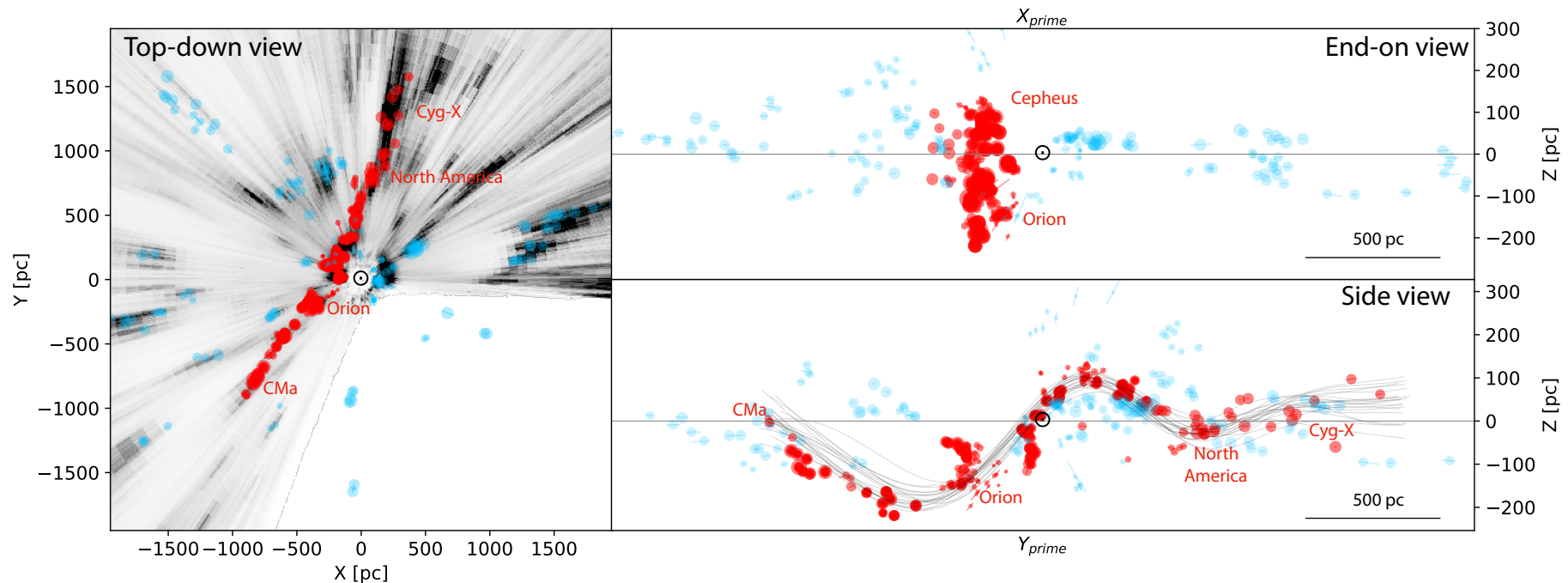
DRAFT PR video shows work of Radcliffe Fellow João Alves, GSAS student Catherine Zucker, AG++
(*Nature*, upcoming, embargoed)

The "Radcliffe" Wave 2019-

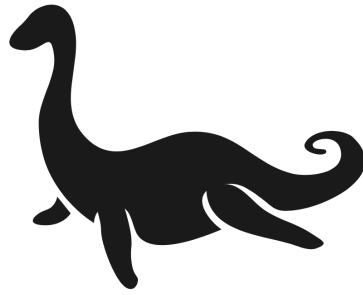


The “Radcliffe” Wave

(embargoed, please do not distribute)

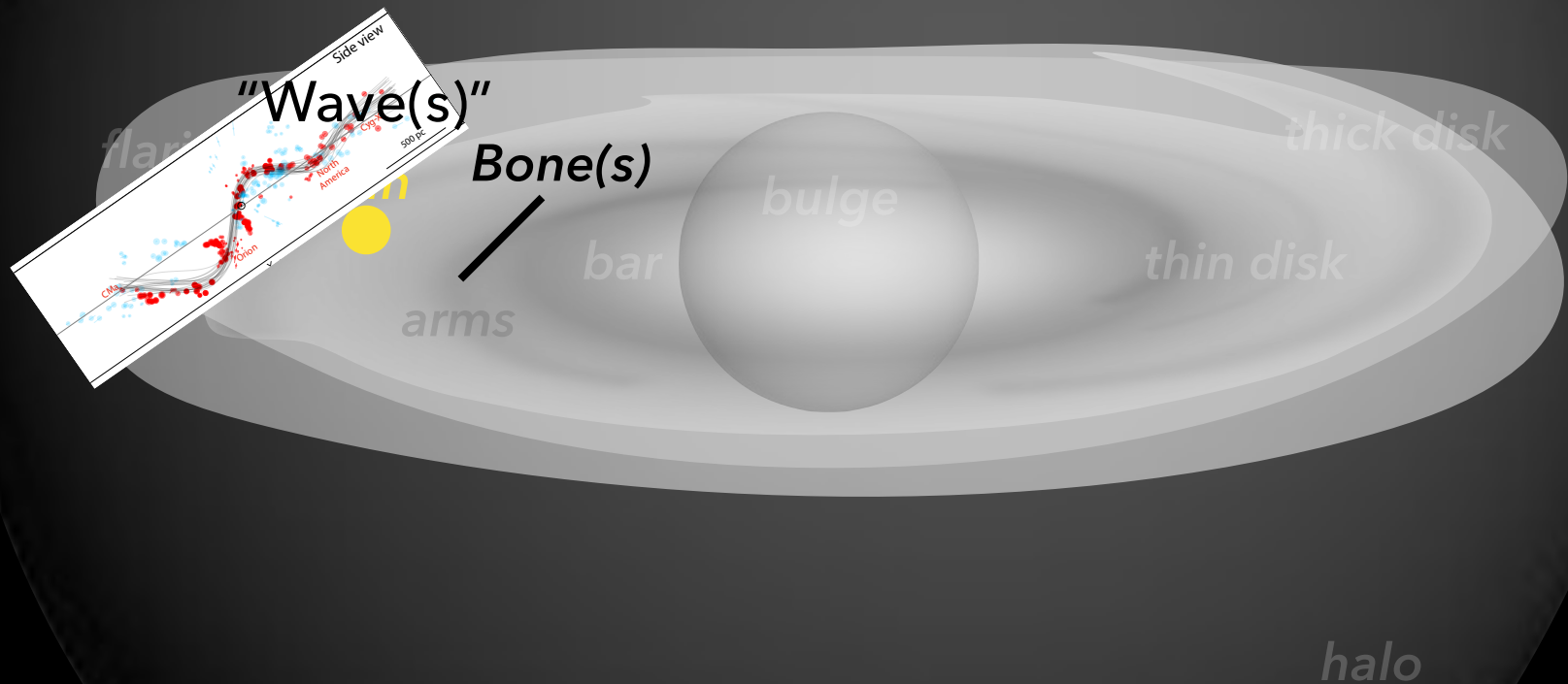


João Alves, Catherine Zucker, Alyssa Goodman, Joshua Speagle,
Stefan Meingast, Thomas Robitaille, Douglas Finkbeiner, Edward F. Schlafly,
and Gregory Green, *Nature* (January 2020)

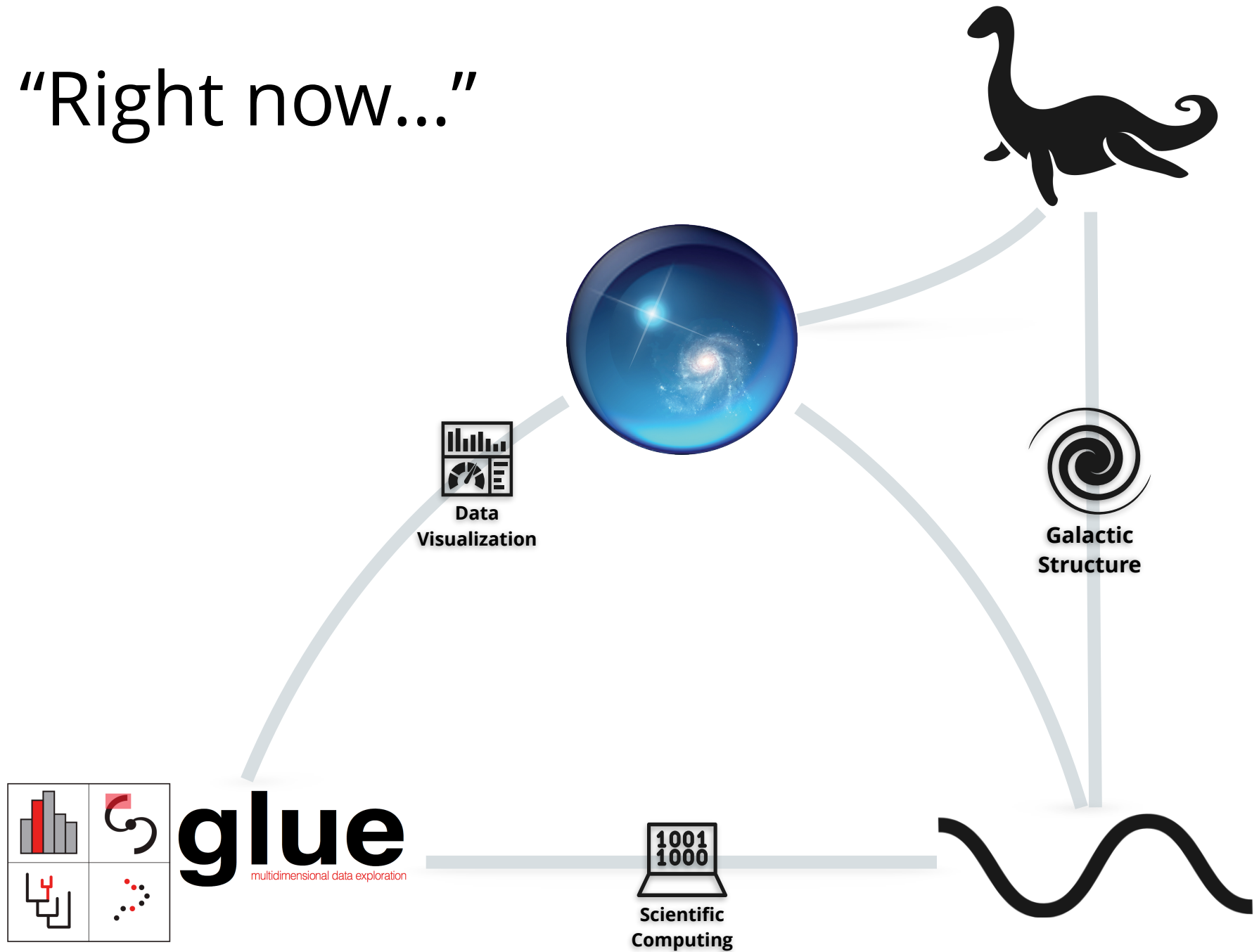


**Galactic
Structure**



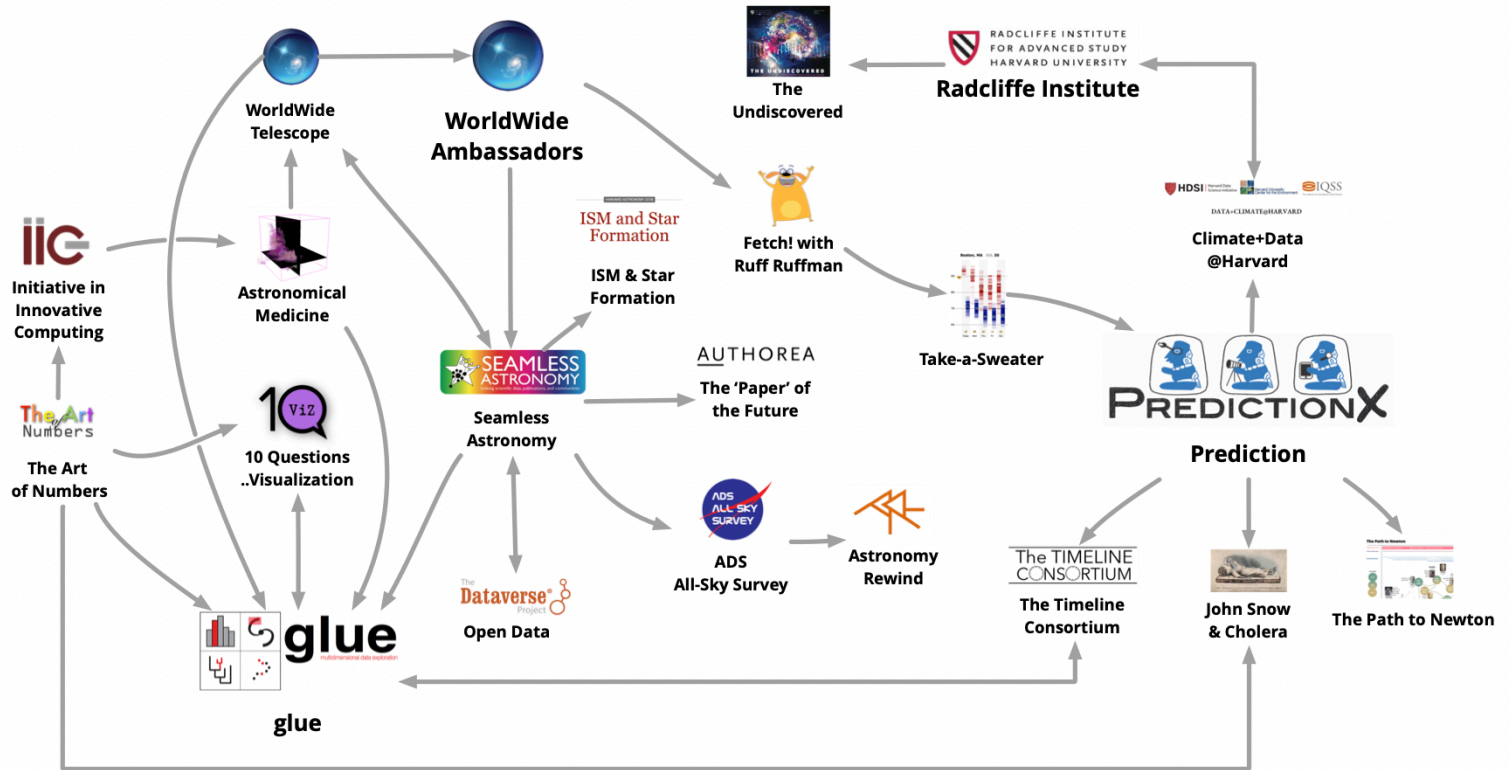
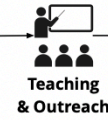


"Right now..."





Alyssa



COMPLETE
The COMPLETE Survey of
Star-Forming Regions



