Magnetic Mysteries of the Galaxies

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Magnetic Mysteries of Star Formation

- Introduction and Motivation
- Magnetism and how to observe it
- Discoveries made possible by magnetic studies

B Field: Magnetic field

Original Source: from the Book of the Kings

Norris & Norris (2022): 7 sister story may be 100,000 years old

- Video not playing in pdf format - contact for full access.

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Open Cultural Astronomy Forum

Universe of Cultures: Embracing Diversity in Astronomy

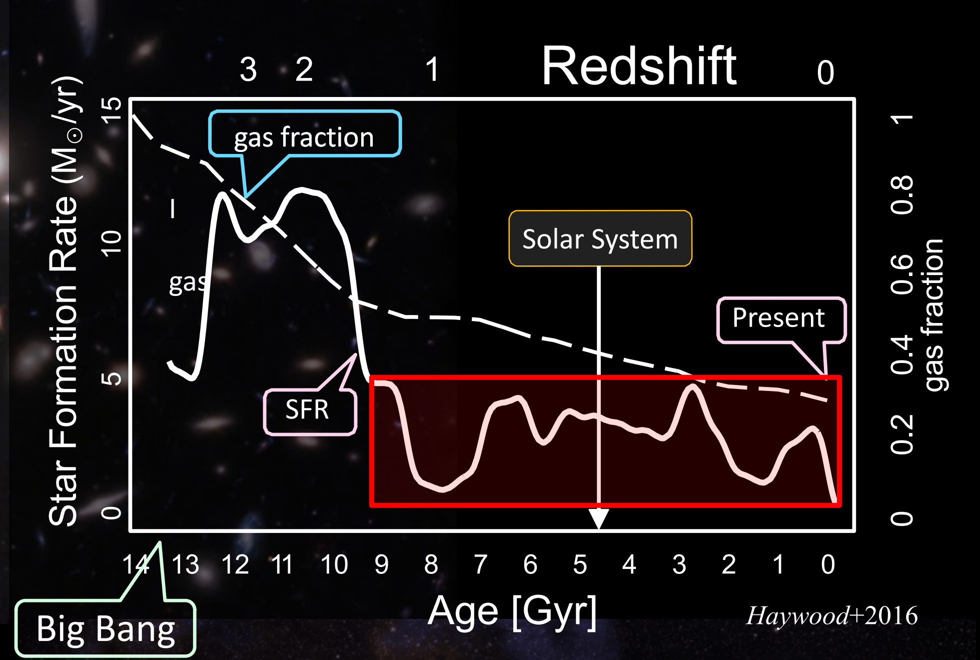
No registration is needed - just show up! Access is via zoom.

Join us on zoom

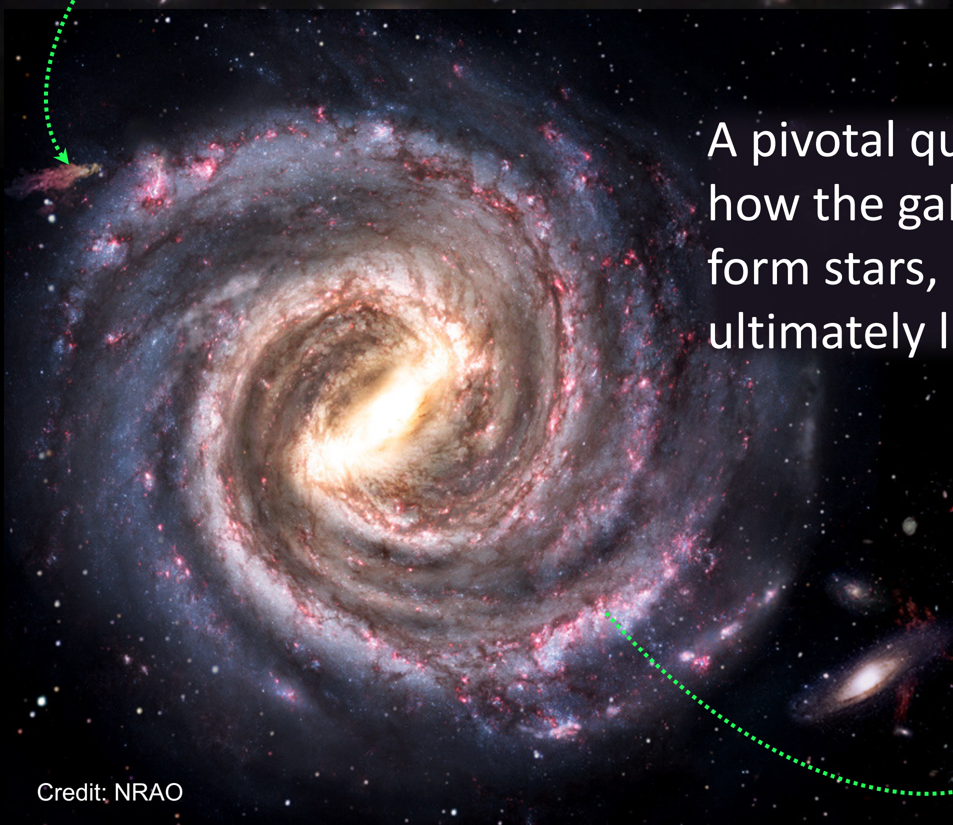
Meeting ID: 960 6348 4885
Passcode: 000000

Upcoming Seminars

Date and Time	Speaker (Affiliation) Title (click for abstract)	Recording
Mar 6, 2025 23:00 UTC (3 PM PST)	Fyza Parviz Jazra (Stanford University) TBD	
Feb 6, 2025 23:00 UTC (3 PM PST)	Ni Emas (Centre for Astrophysics and Supercomputing (CAS), Swinburne University of Technology) TBD	
Dec 5, 2024 23:00 UTC (3 PM PST)	Prof. Bryan Edward Penprase (Soka University of America) What are the limits to our knowledge of the universe?	

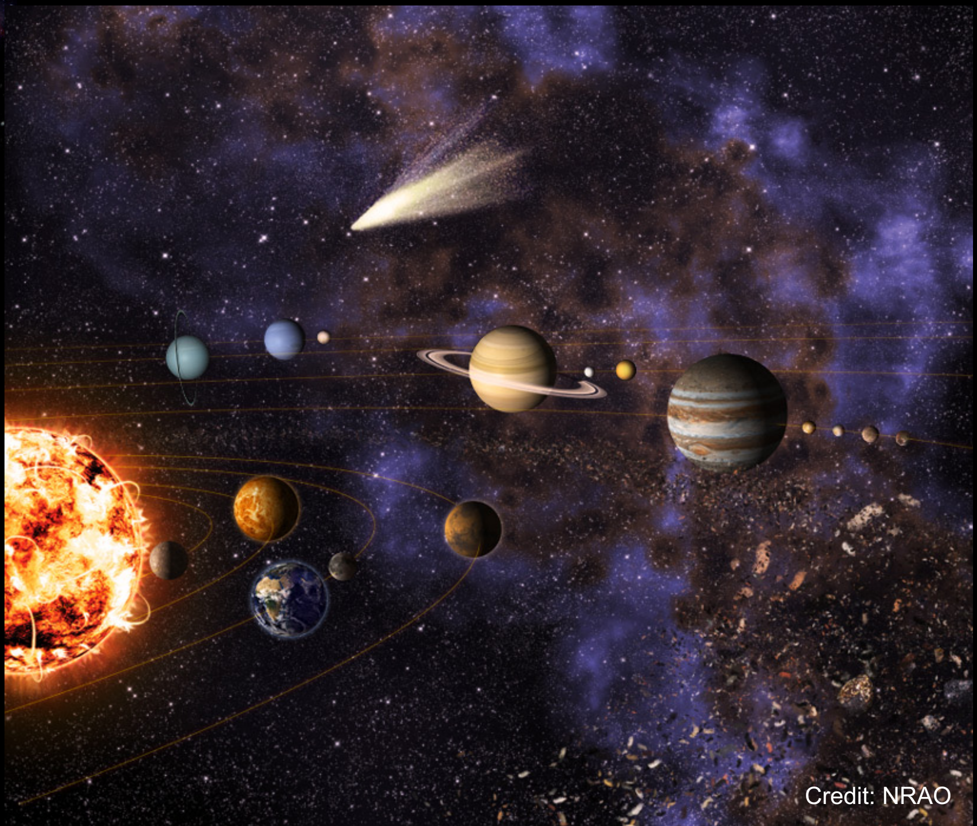


A pivotal question of our time: how the galaxies evolve to form stars, planets, and ultimately life.




Credit: NRAO

Credit: A. Javadzadeh


Credit: NRAO

Interstellar Medium (ISM):

- Ions, molecules, atoms, dust, etc. between stars

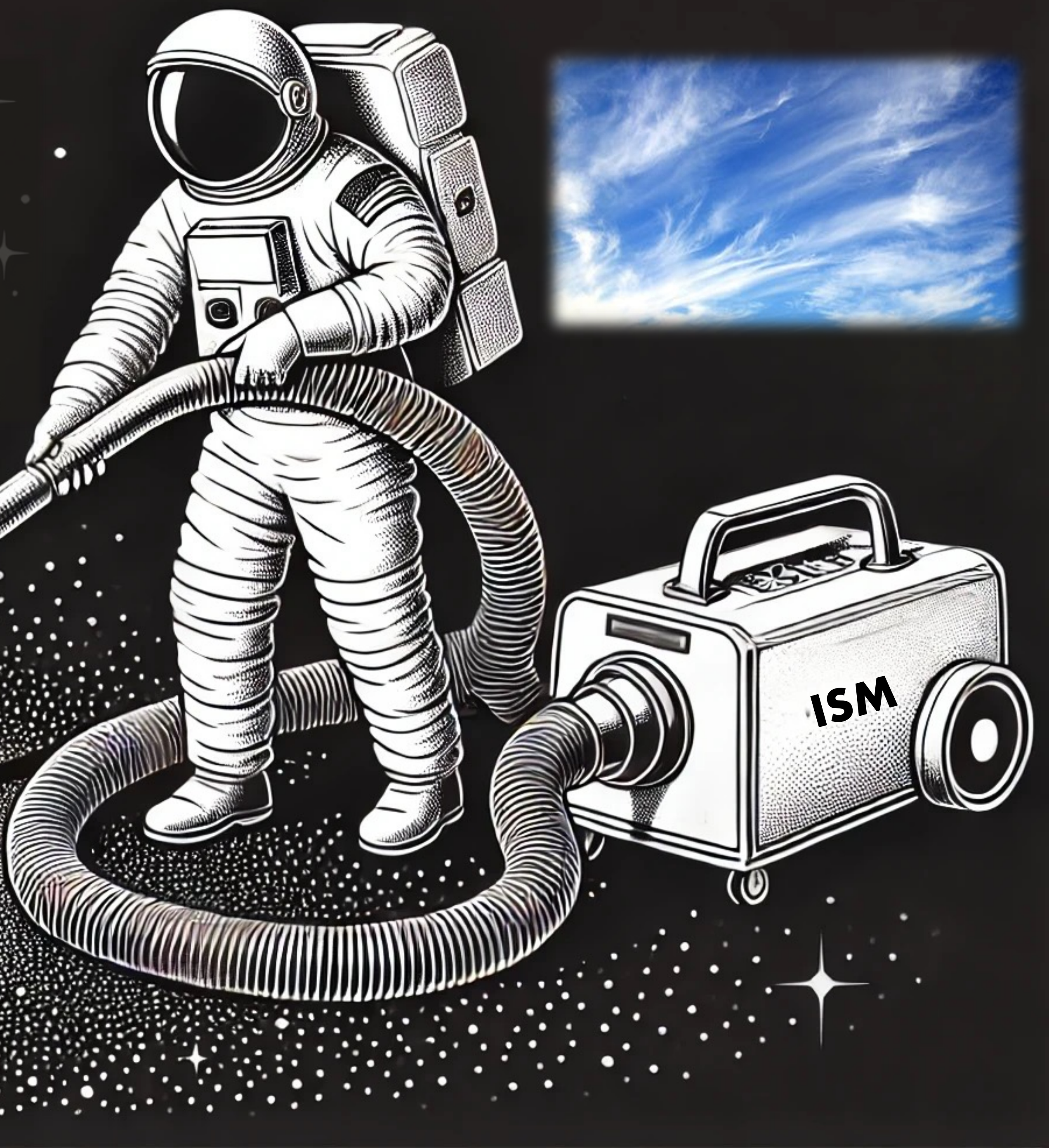


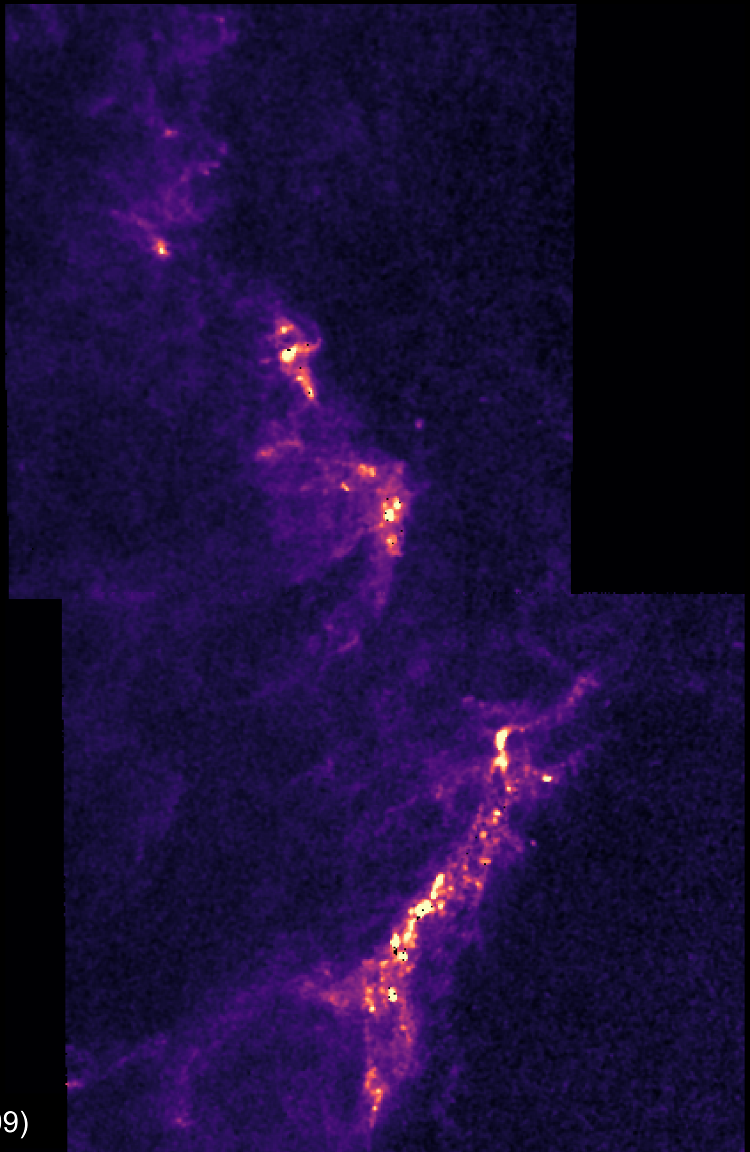


Image credits: Mastering Astronomy

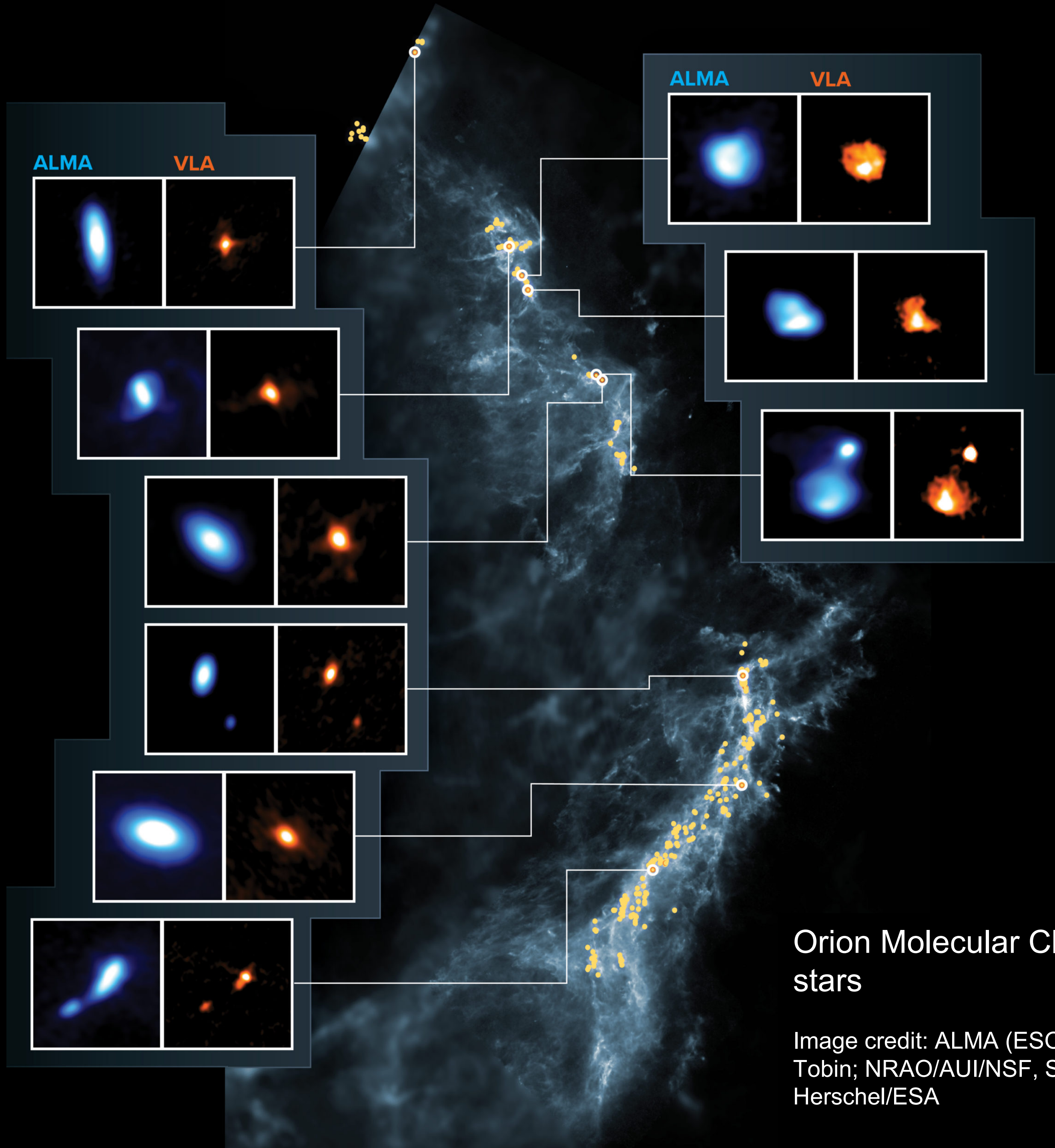
The interstellar medium and stars have similar chemical composition.

"The cosmos is within us. We are made of star stuff. We are a way for the universe to know itself." Carl Sagan

Coldest and Densest Parts of the Interstellar Medium: Molecular clouds



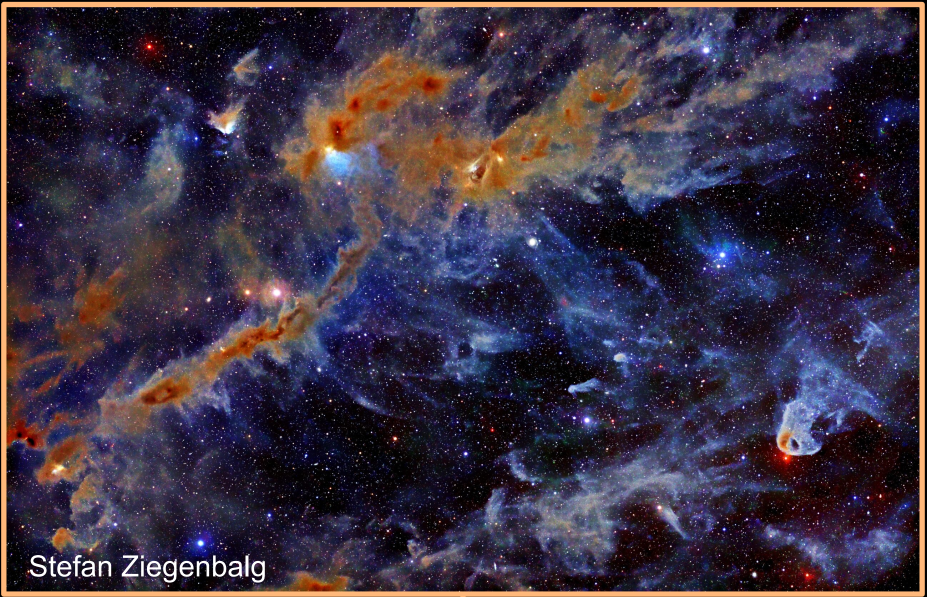
Data: Kainulainen et al. (2009)



Orion Molecular Clouds forming stars

Image credit: ALMA (ESO/NAOJ/NRAO), J. Tobin; NRAO/AUI/NSF, S. Dagnello; Herschel/ESA

Molecular Clouds vs. Atmospheric Clouds



- 100 billion (10^{14}) times bigger in length
  100million times the diameter of the Sun
- A lot more massive (~ $x10^{24}$)
  (have a mass around 1000 to 1 million times bigger than our sun)

- around 1 billiard (10^{15}) times denser
- 10 times warmer

Formation of Stars From Molecular Clouds

UK Astrophysical Fluids Facility

Video not playing in pdf format - contact for full access.

Matthew Bate

UNIVERSITY OF EXETER


Credit: typesofclouds.net


Credit: Wikimedia commons

The Universe is magnetized!

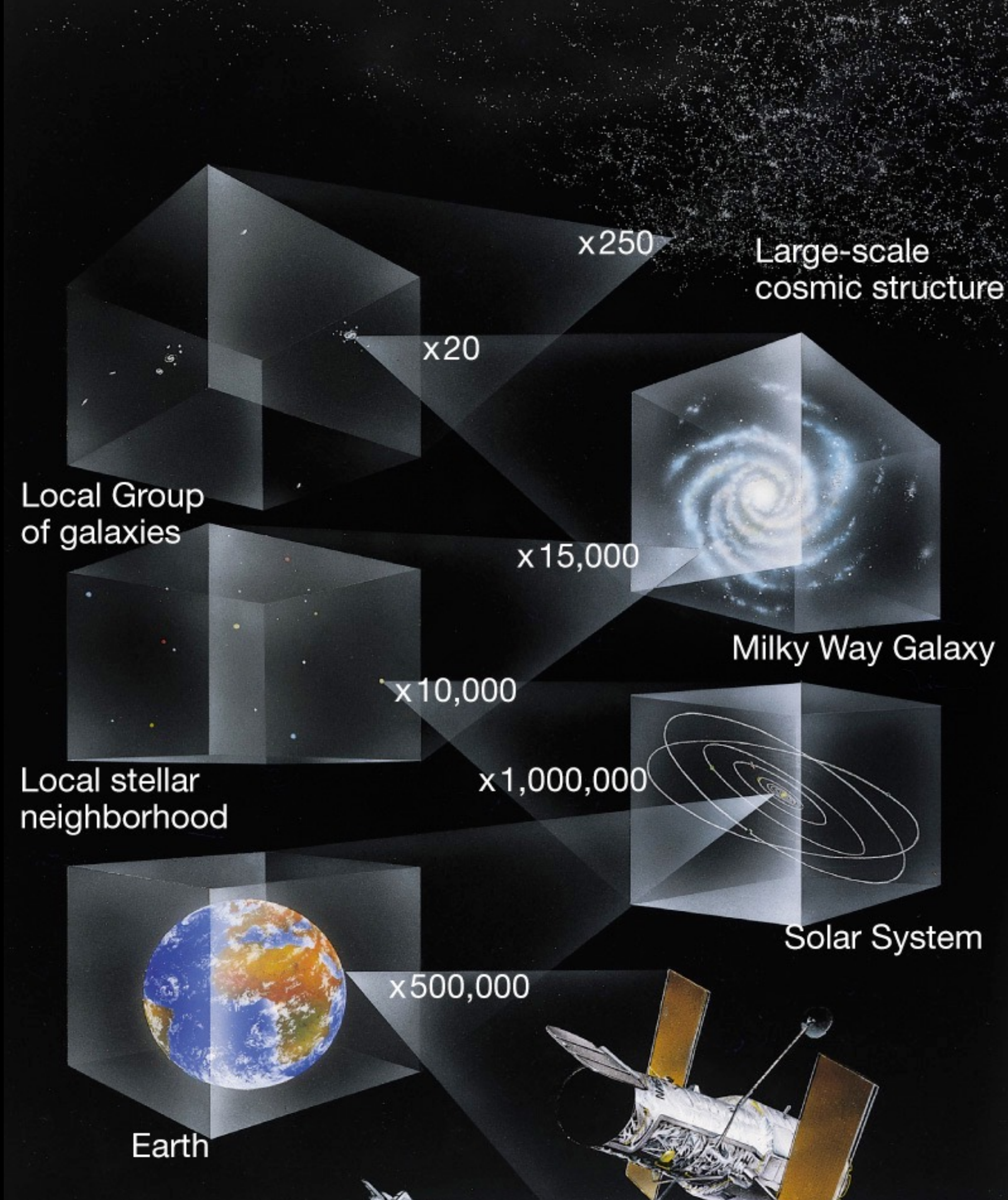
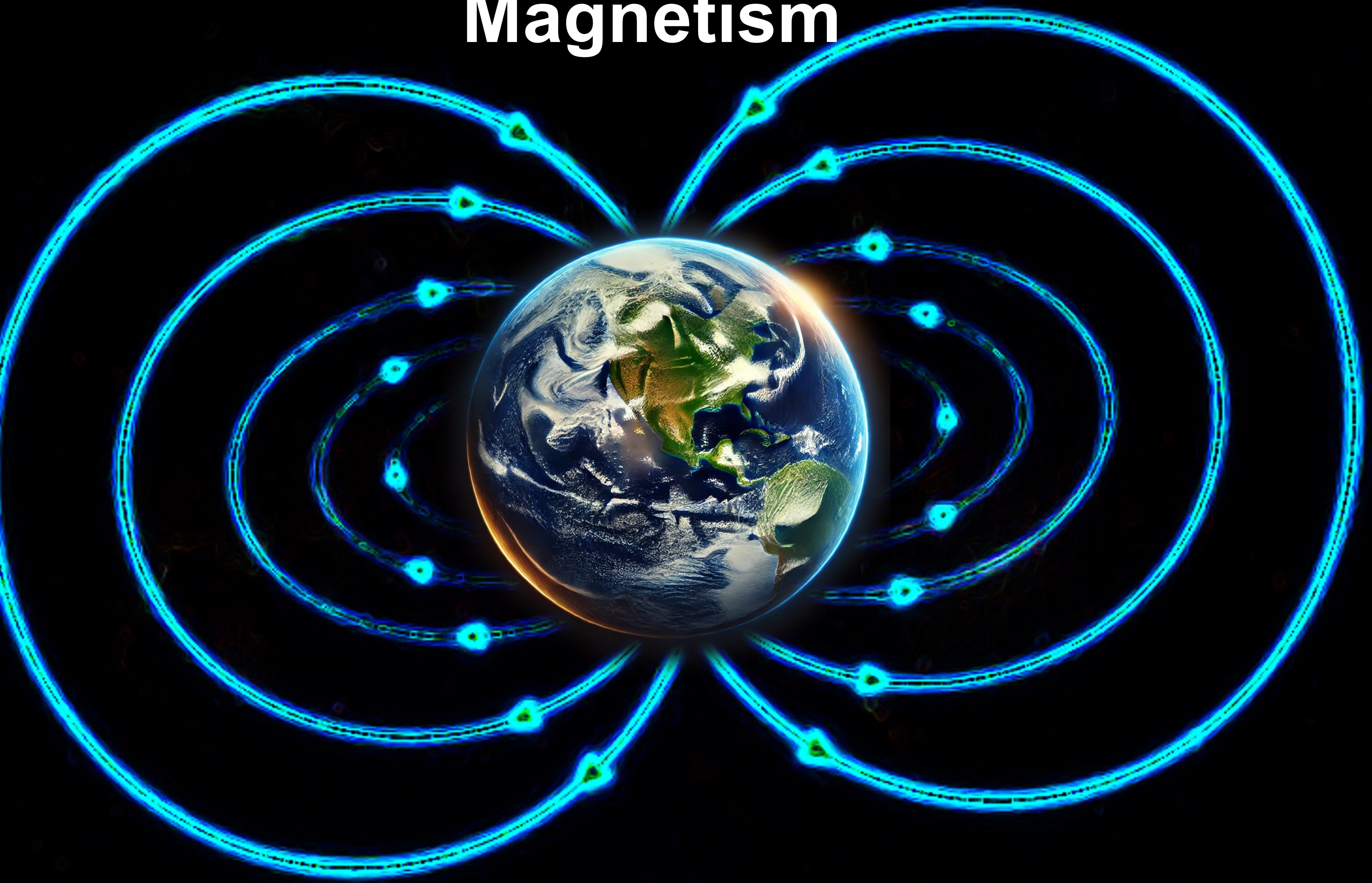
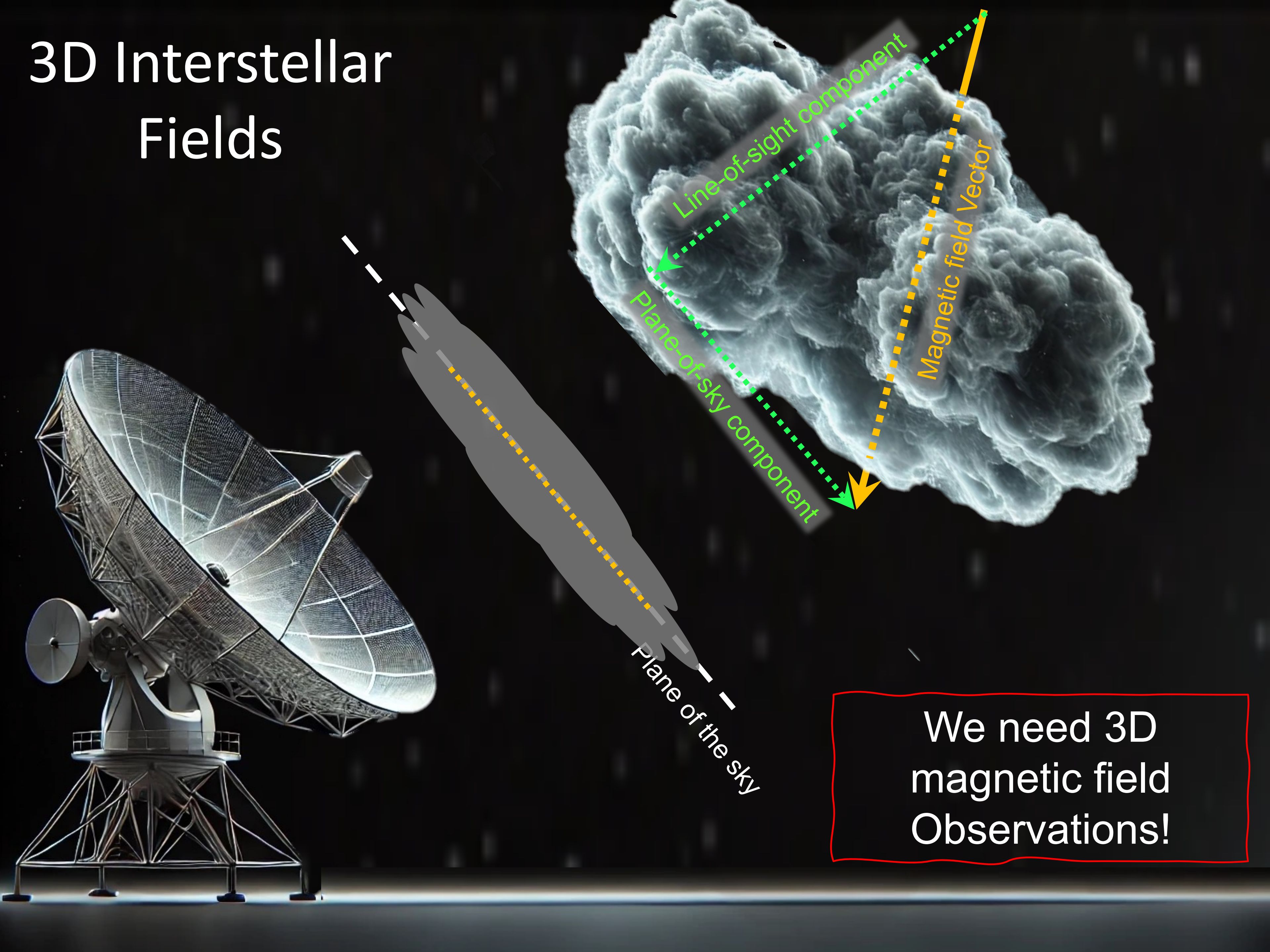


Image credit: Science Alert

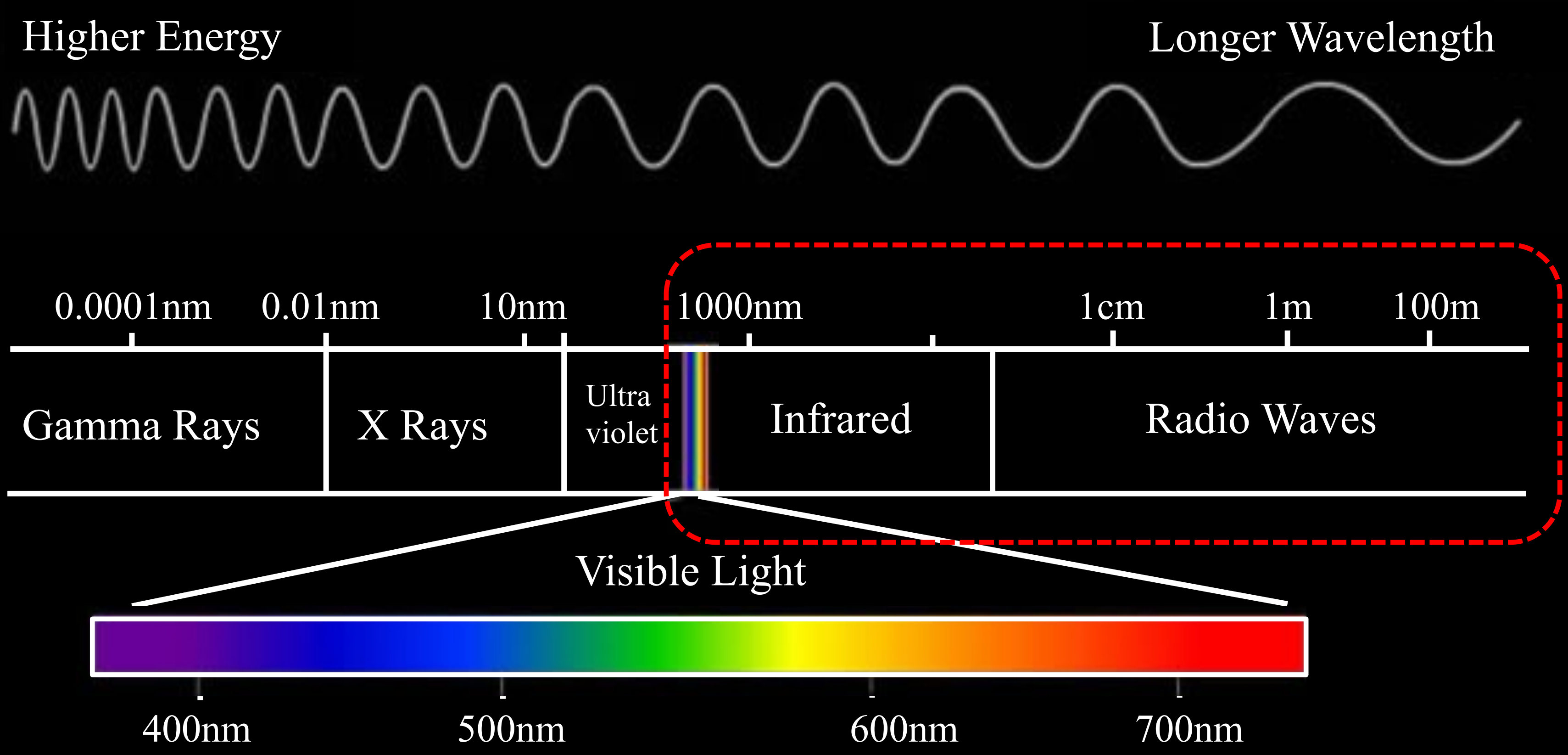
Magnetism



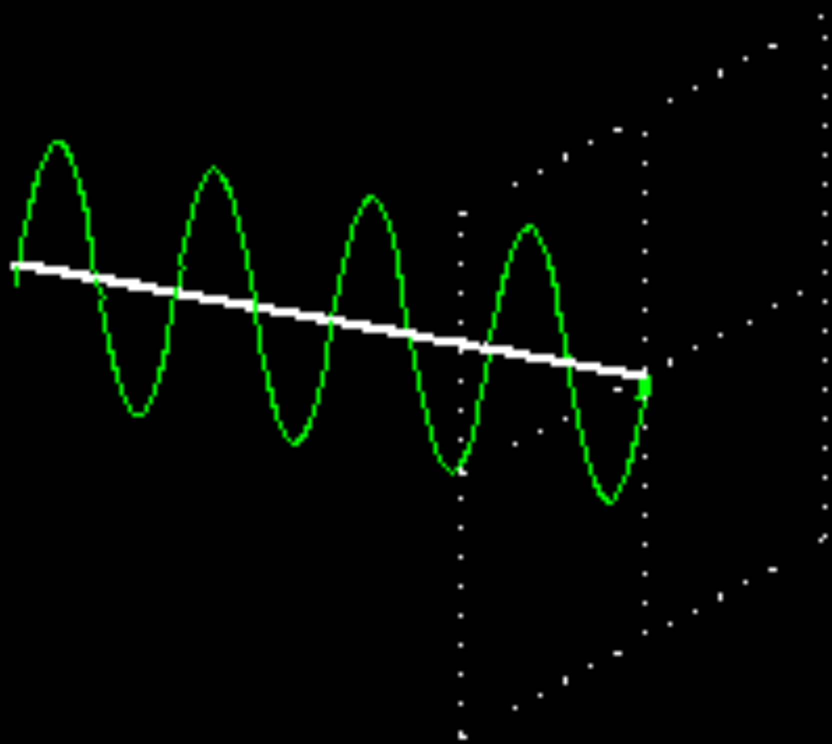
3D Interstellar Fields



We need 3D magnetic field Observations!


Higher Energy
Longer Wavelength
0.0001nm
0.01nm
10nm
1000nm
1cm
1m
100m
Gamma Rays
X Rays
Ultra
violet
Infrared
Radio Waves
Visible Light
400nm
500nm
600nm
700nm

3D view



Front view

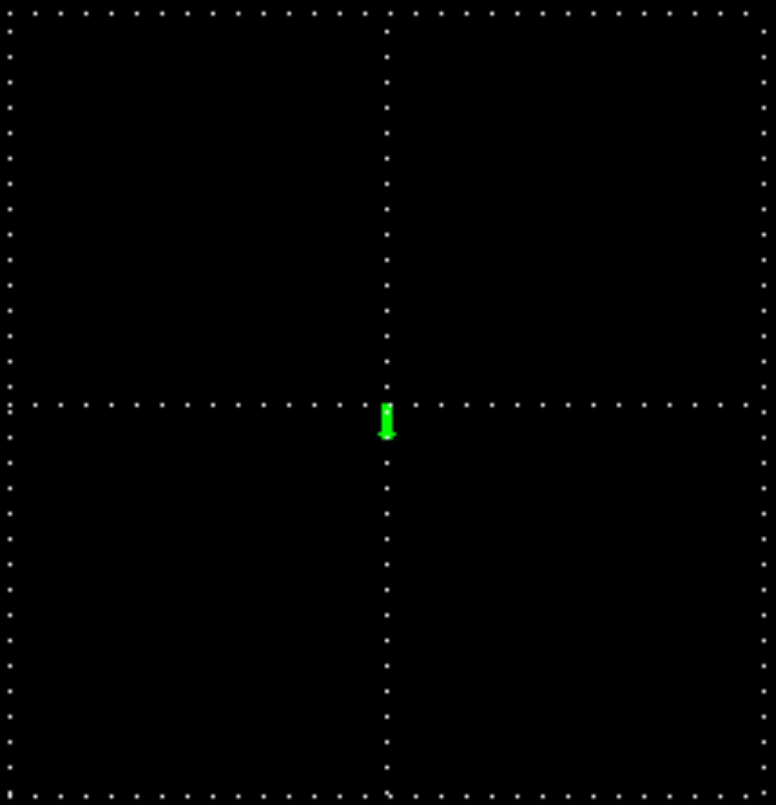
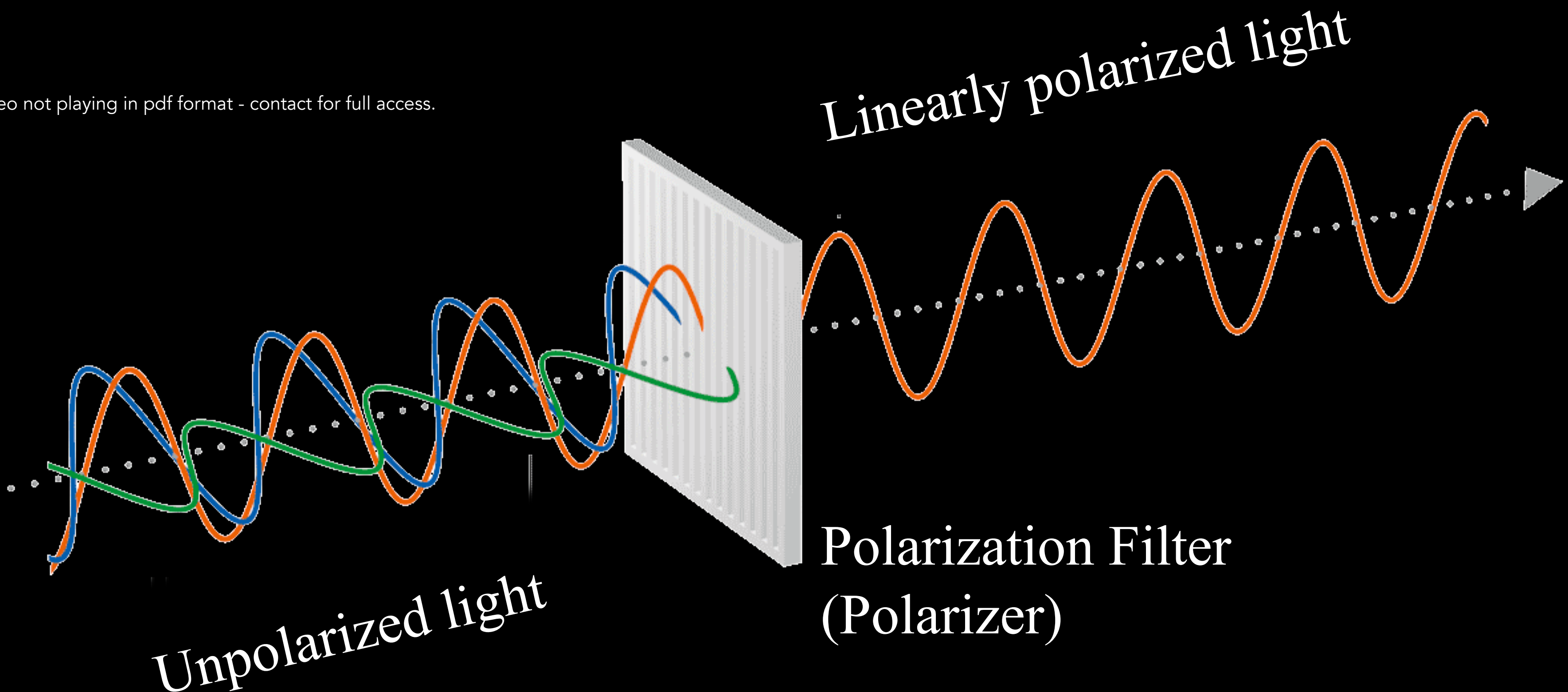
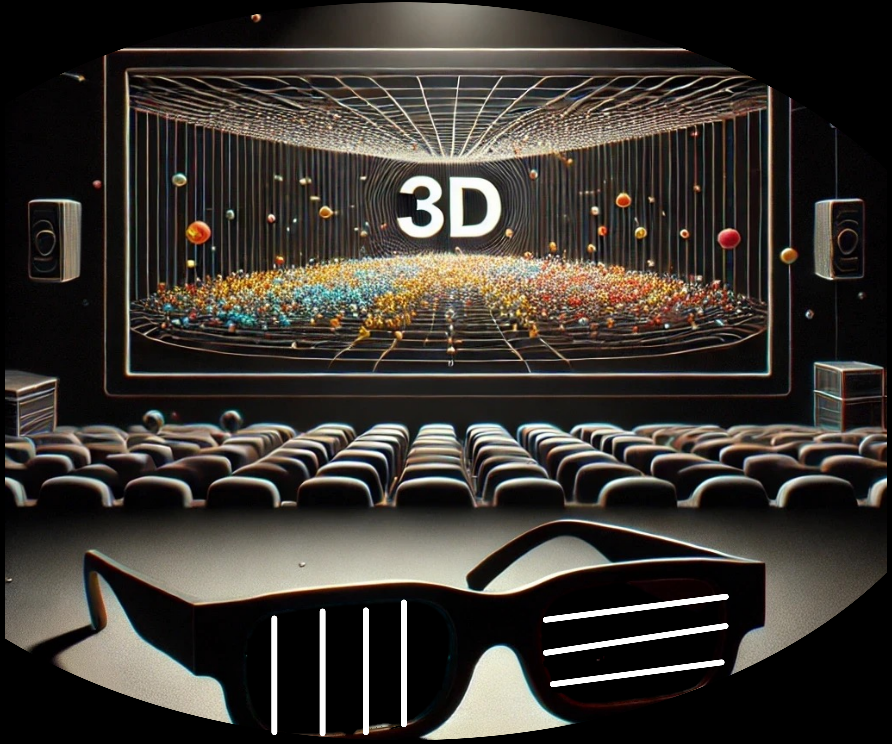
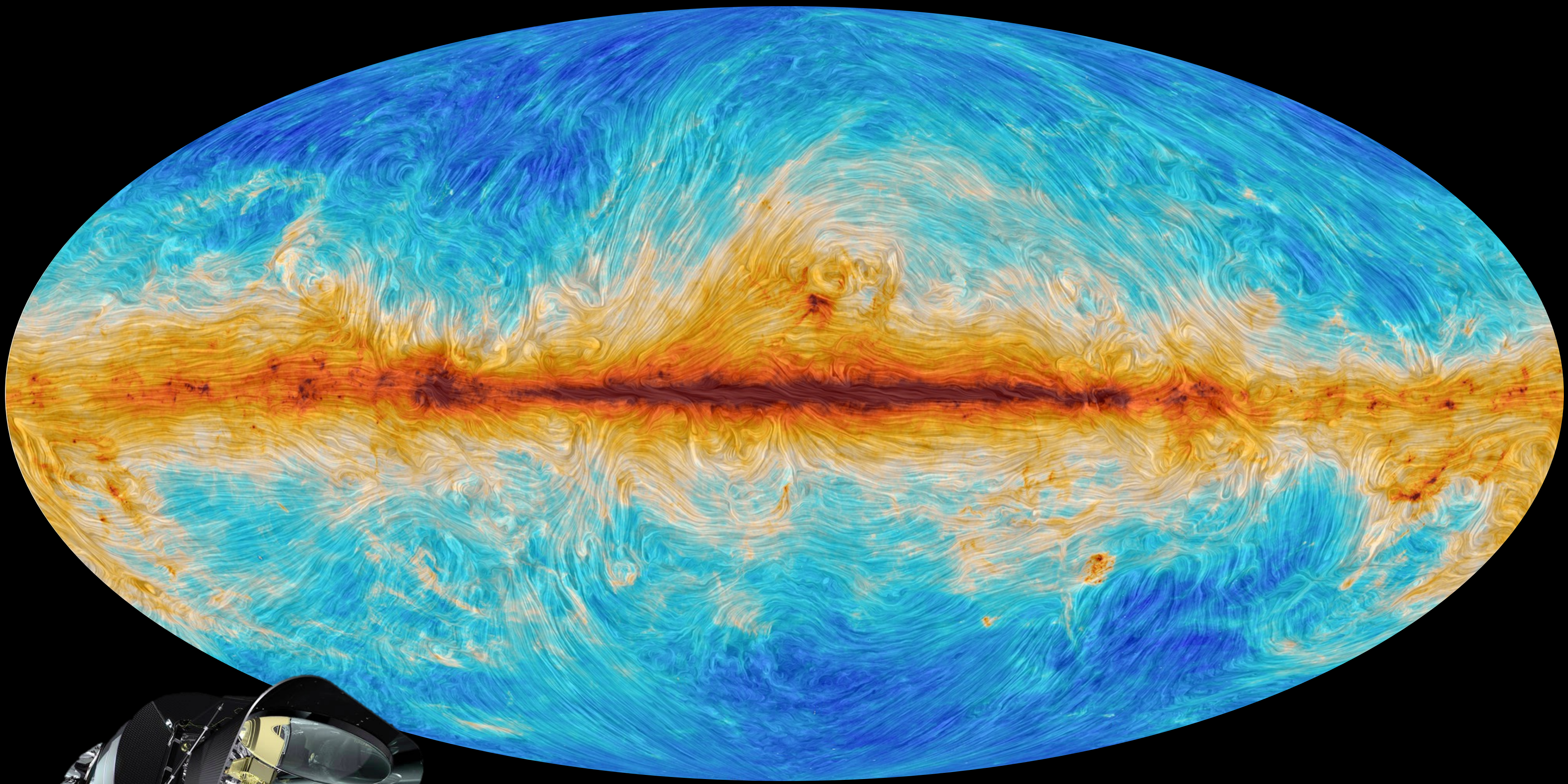


Image credit: szialab.org

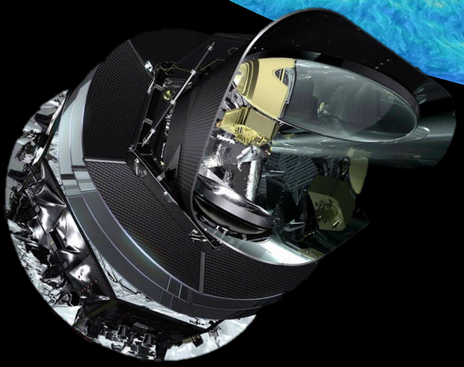
Video not playing in pdf format - contact for full access.




3D

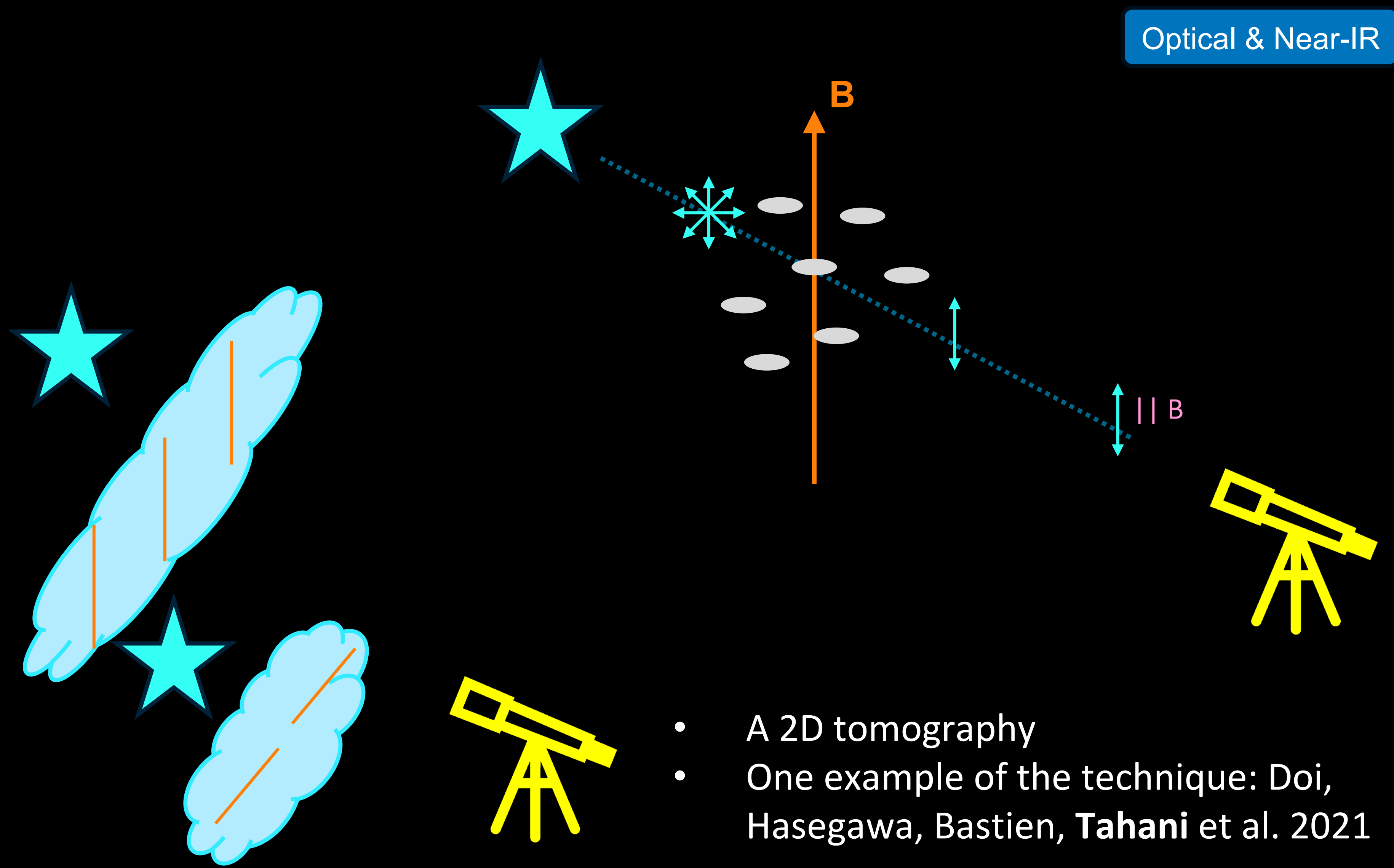


Credit: ESA and the Planck Collaboration



An artist's concept of the Planck spacecraft.
Credit: ESA/NASA/JPL-Caltech

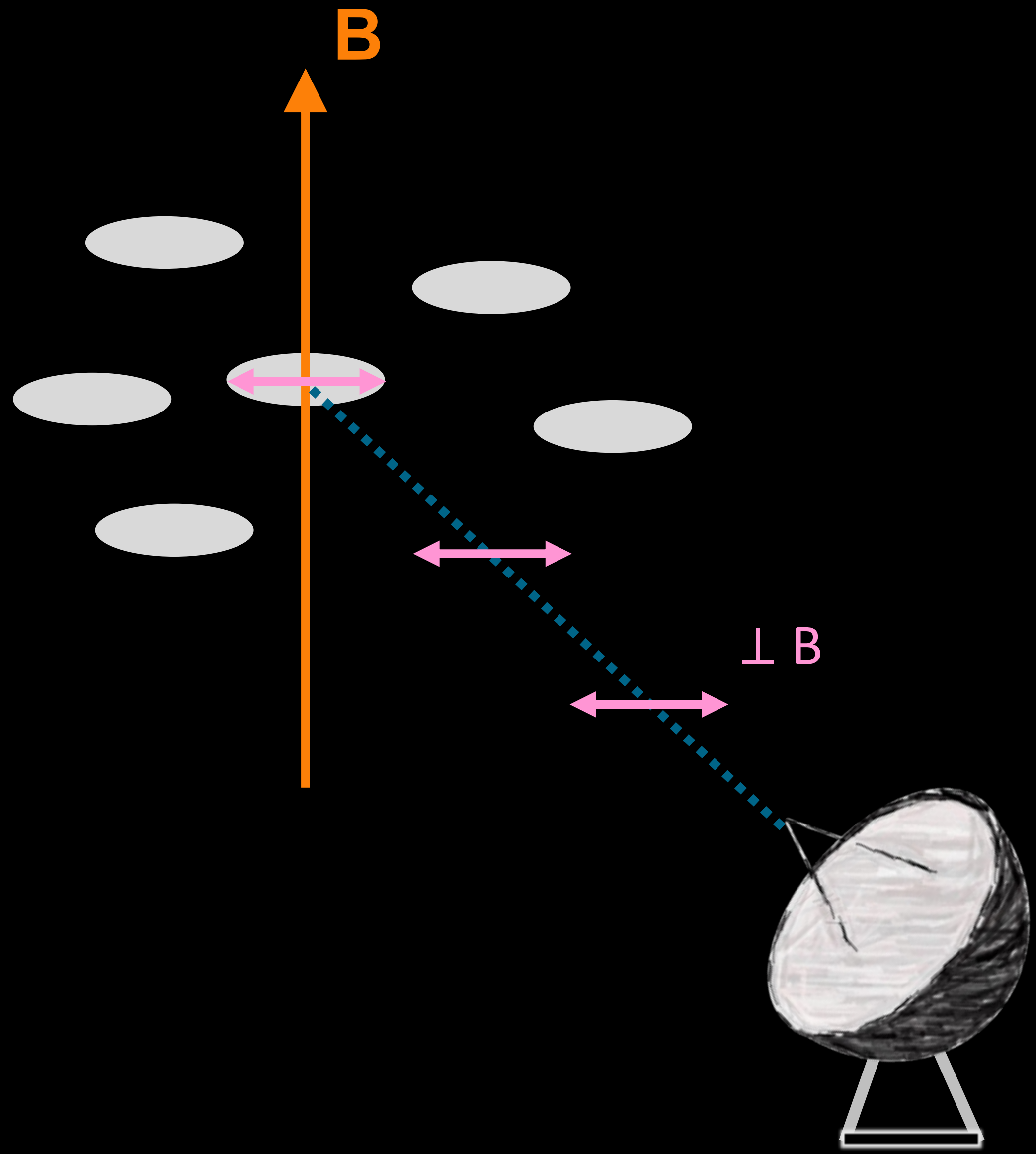
Starlight Polarization



- A 2D tomography
- One example of the technique: Doi, Hasegawa, Bastien, **Tahani** et al. 2021

Dust Emission Polarization

Far-infrared



First observations

- Feb 1949, Hiltner:
  The detected polarisation is due to the ISM.
- Feb 1949, Hall:
  Confirmed Hiltner's Hypothesis and observations.
- Mar 1949, Davis & Greenstein:
  Explained the observed polarisation by dust alignment with respect to galactic B.
- May 1949, Spitzer & Tukey:
  Ferromagnetic grains.

February 18, 1949, Vol. 109 SCIENCE 165

Polarization of Light From Distant Stars by Interstellar Medium

W. A. Hiltner
Yerkes Observatory, University of Chicago

166 SCIENCE February 18, 1949, Vol. 109

Observations of the Polarized Light From Stars

John S. Hall
U. S. Naval Observatory, Washington, D. C.

The Polarization of Starlight by Interstellar Dust Particles in a Galactic Magnetic Field

Leverett Davis, Jr.
California Institute of Technology, Pasadena, California
and
Jesse L. Greenstein
Mount Wilson and Palomar Observatories, California

volume, where f is a fraction depending on the properties of the grain. In this case the deceleration would be independent of angular velocity and would be equally effective for large and small grains. To produce enough deceleration requires $f^{\frac{1}{2}}B \geq 2 \times 10^{-5}$ gauss. It appears then that the acceptance of the hypothesis will depend on discovering some hysteresis mechanism having very large f or some other powerful decelerating mechanism.

If the rotation of the grains can be stopped, it is to be

Interstellar Polarization, Galactic Magnetic Fields, and Ferromagnetism

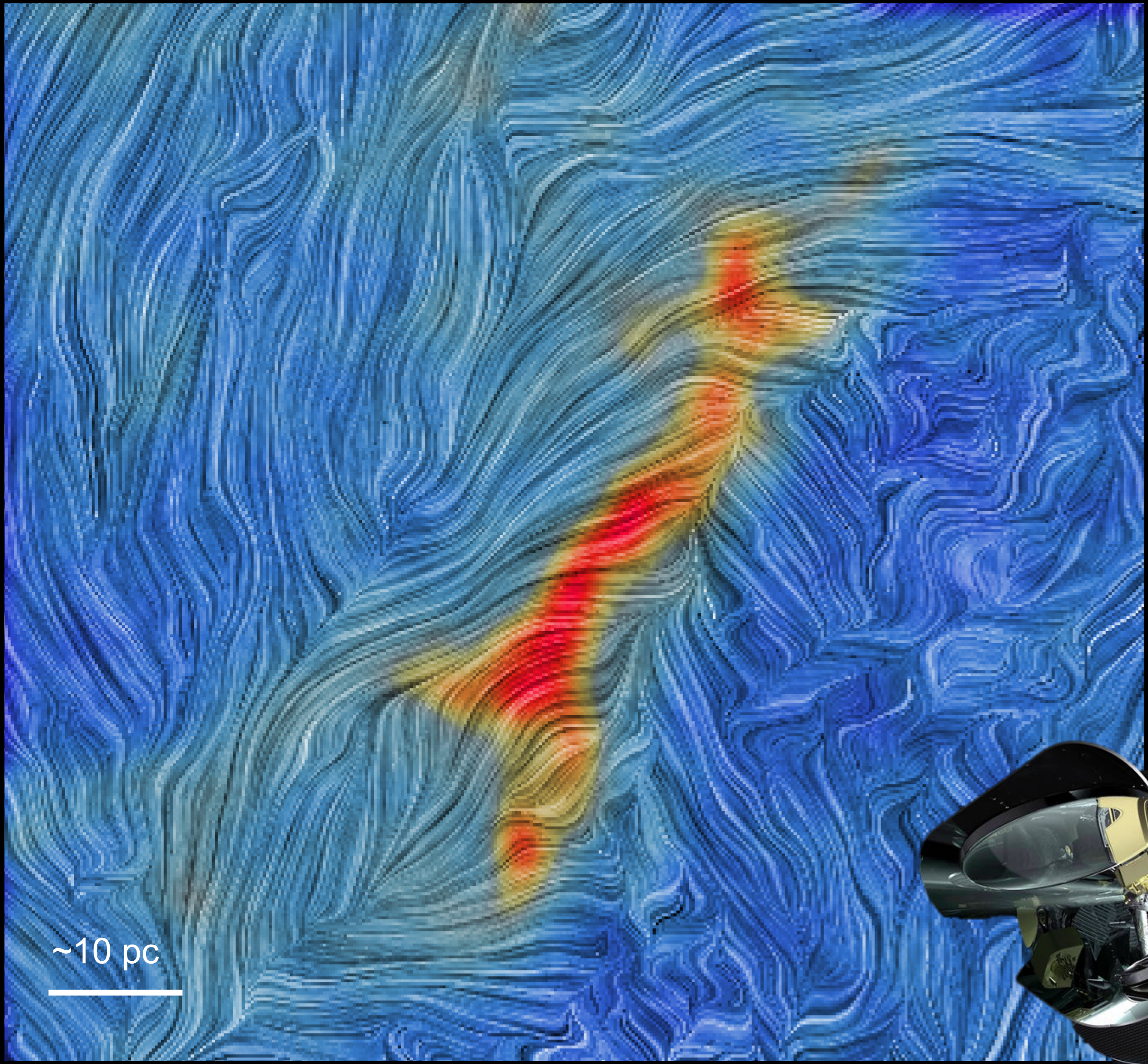
Lyman Spitzer, Jr., and John W. Tukey[1]
Princeton University

Observations by W. A. Hiltner (5, 6) and J. S. Hall (4) indicate that starlight becomes plane polarized in its passage through interstellar space. The effect increases with increasing distance, and according to Hall's data amounts to about 5 percent ($=e^{0.05}$) difference in intensity between the two plane-polarized components for a star whose color excess is 0.50 magnitude. Since the color excess is known to be about one-ninth the total absorption (which thus amounts to $(2.512)^{-4.5} = e^{-4.1}$ for such a star), the absorption must vary by

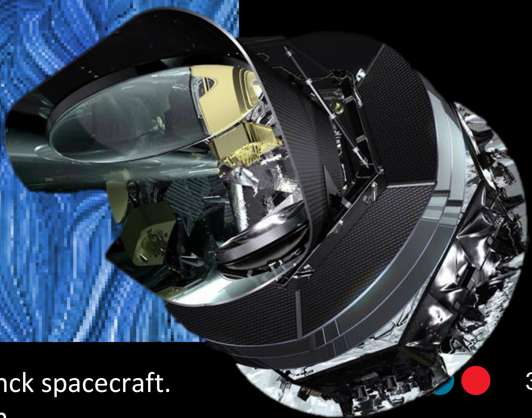
wavelength of visible light, were present in interstellar space, and were oriented by some force. The ratio of the scattering cross sections of such needles for the two planes of polarization would be appreciable; according to the theory by R. Gans (3), for a small prolate spheroid with a length twice its diameter, this ratio is 2.74 if the refractive index in the spheroid equals 2.5. Thus a relatively small number of needles could produce the observed effect.

Two difficulties seem to stand in the way of this explanation: the origin of the needles and their orien-

Plane-of-sky Fields of Orion A



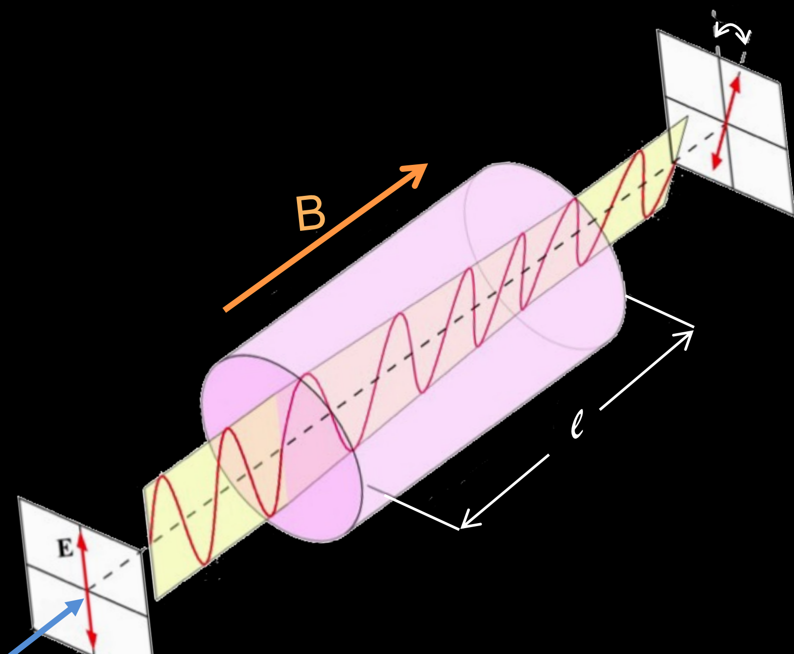
Tahani et al. 2019

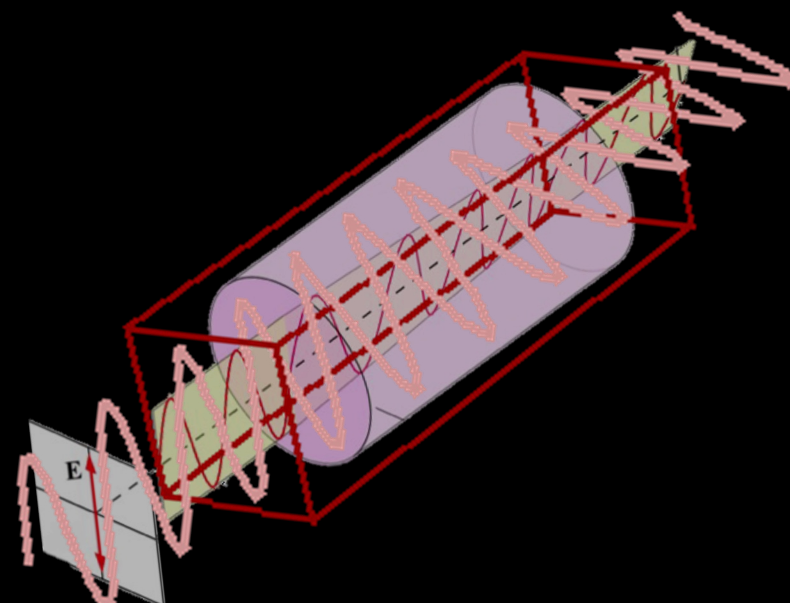


An artist's concept of the Planck spacecraft.
Credit: ESA/NASA/JPL-Caltech

Faraday Rotation

Radio





Probing magnetic field of molecular clouds using Faraday rotation was once considered impossible!

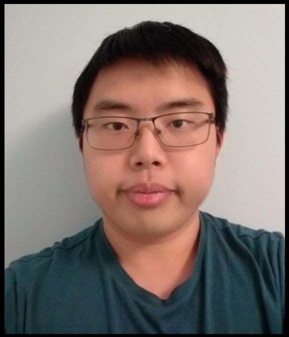
Developed a technique for determining line-of-sight magnetic fields of molecular clouds (Tahani et al. 2018).

Software for Line-of-Sight Magnetic Field Determination

GitHub, MC-BLOS: github.com/MehrnooshTahani/MC-BLOS

Tahani et al. (2024): arXiv e-print: 2407.13005

Development



John Ming Ngo
NRC, U of Alberta

Jennifer Glover
NRC, McGill

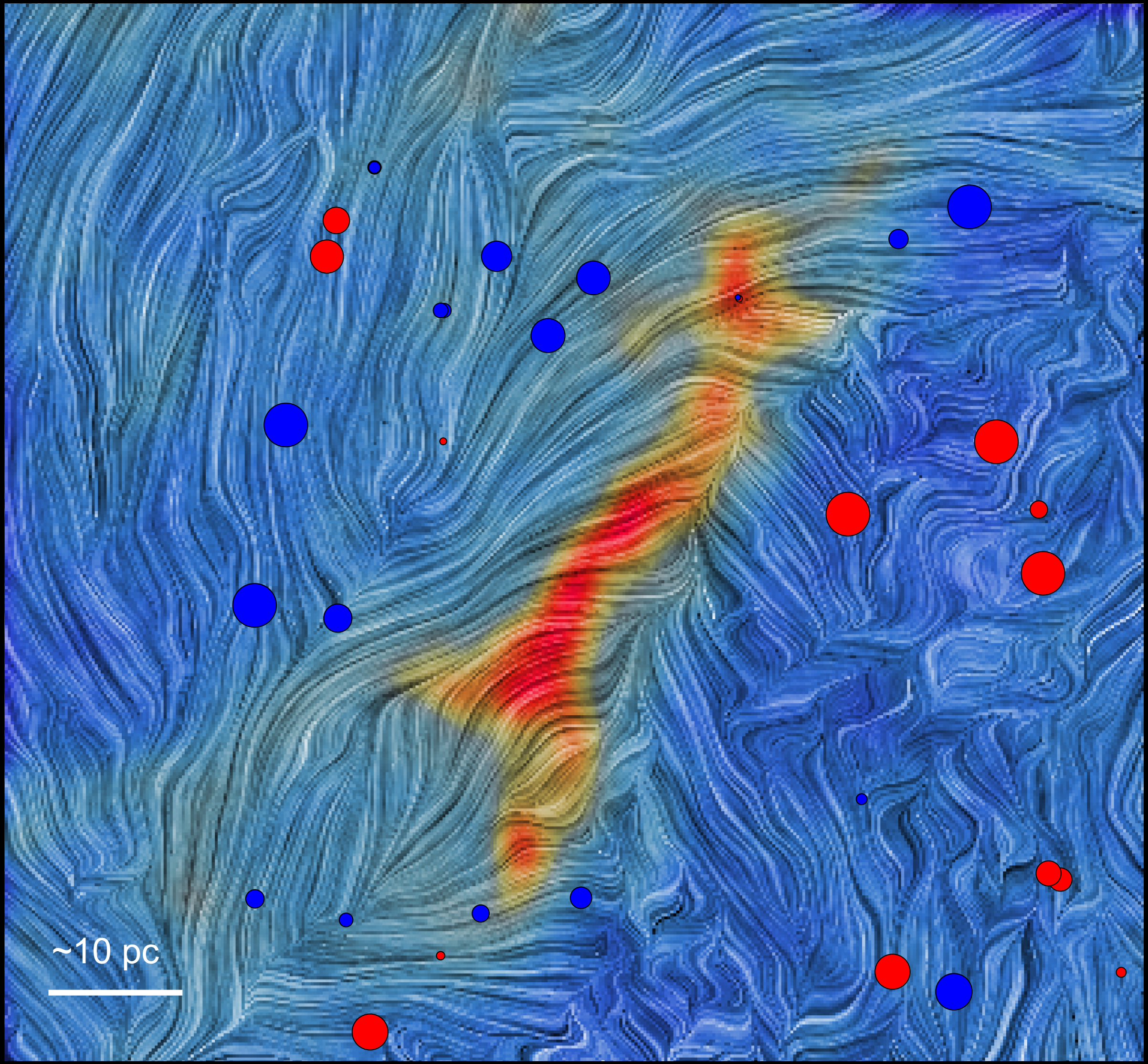
Testing

Ryan Clairmont
Stanford University

Gabriel Munoz Zarazua
San Francisco State University

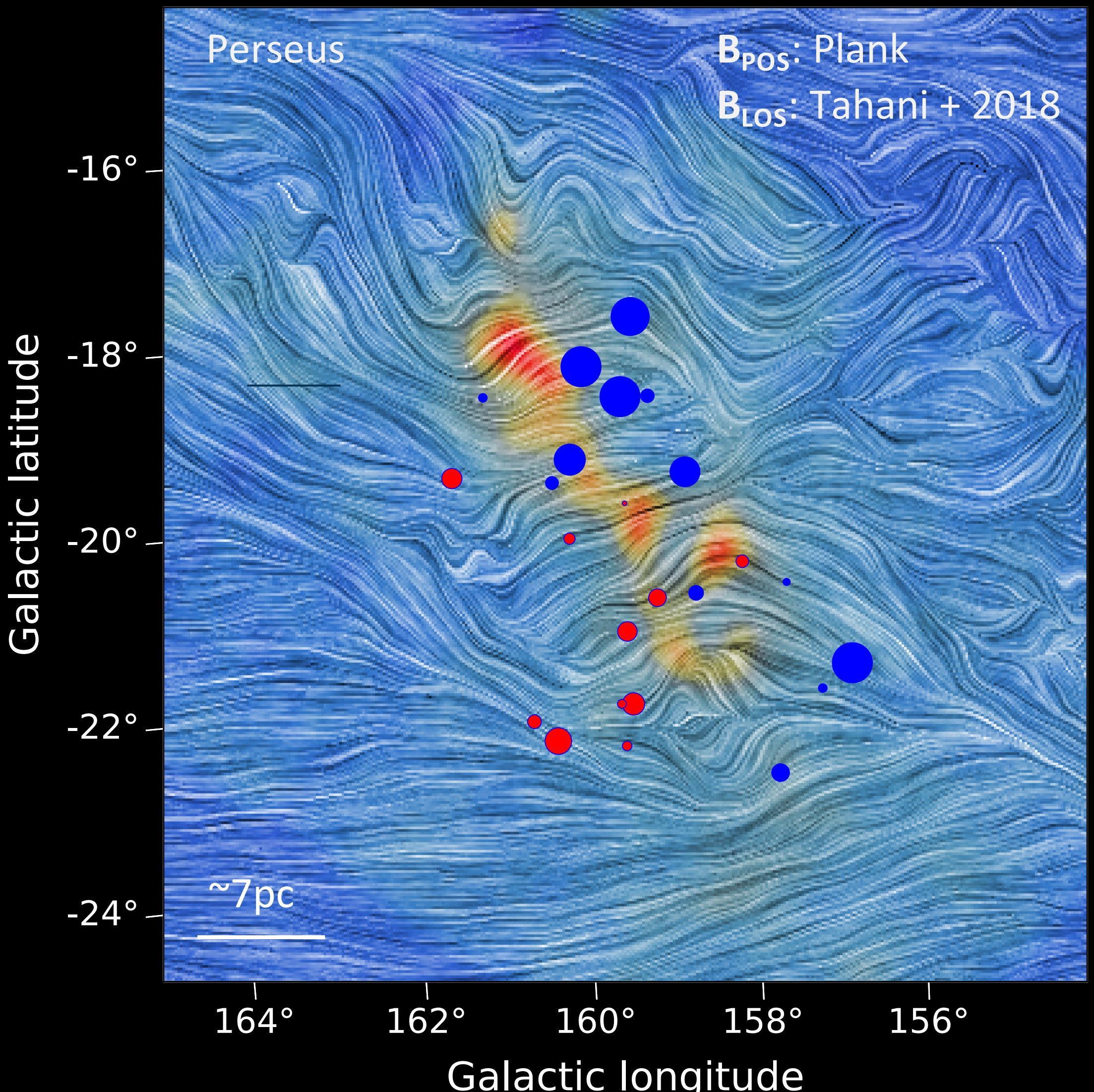
NRC*: National Research Council Canada

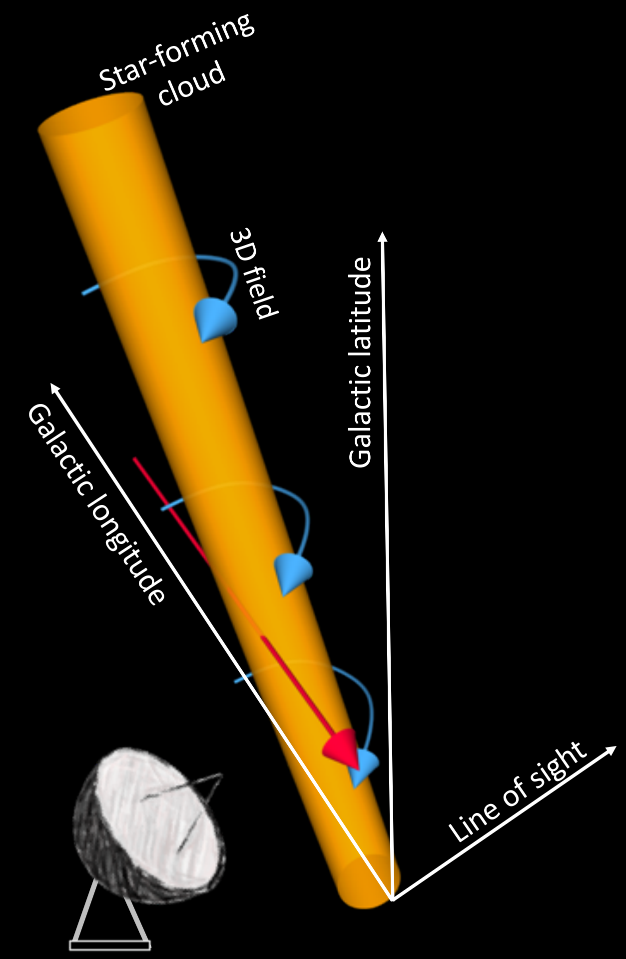
Plane-of-sky Fields of Orion A



Tahani et al. 2019

3D Fields of Perseus Cloud





Tahani, M., Lupypciw, W., Glover, J. et al. 2022, A&A

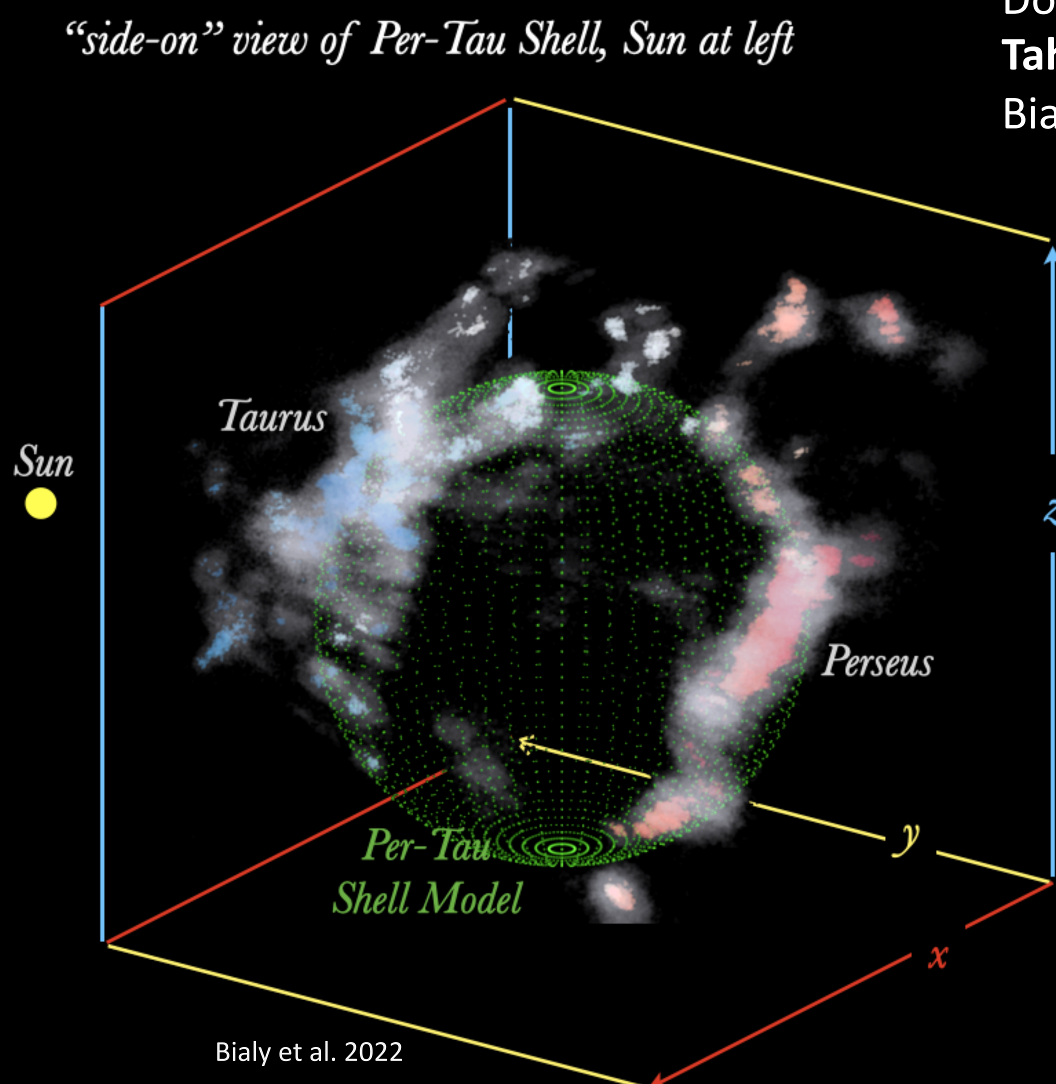
Our research has shown that through 3D magnetic field observations we can:

1) Explain how the clouds are formed and evolve.

2) Identify Galactic and cosmic regions that are not detected in traditional (total emission) observations.

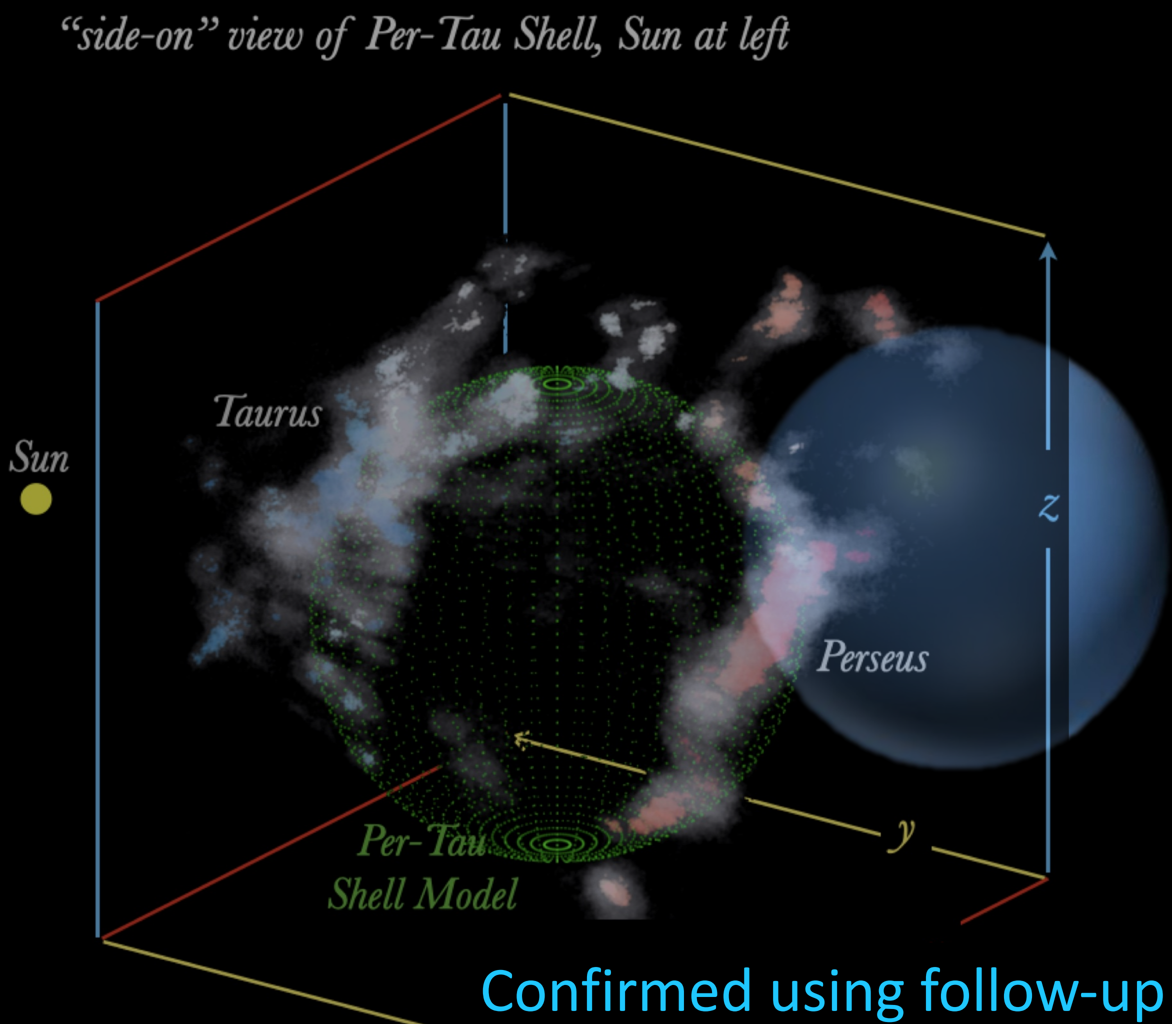
3D Fields Reveal Cloud Formation and Evolution

Doi, Hasegawa, Bastien,
Tahani et al. 2021
Bialy et al. 2022



Bialy et al. 2022

Discovering Cosmic and Galactic Structures

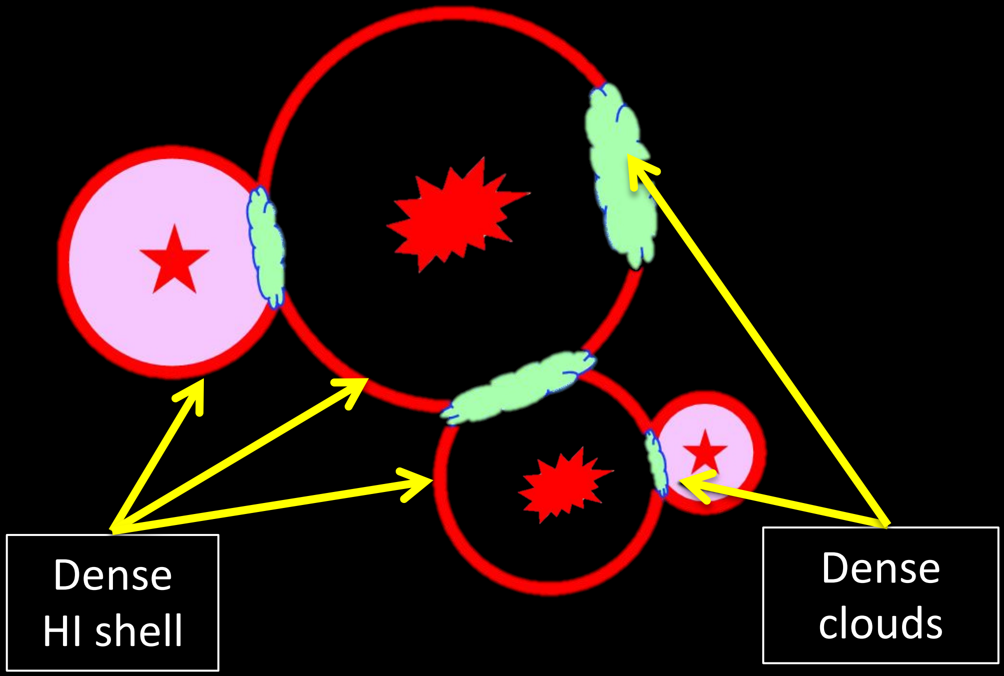


Bialy et al. 2022

Confirmed using follow-up kinematic observations (Kounkel et al. 2022)

Astrophysical Insights from B Field Observations

Cloud Formation



Inutsuka et al 2015
Inoue et al. 2018

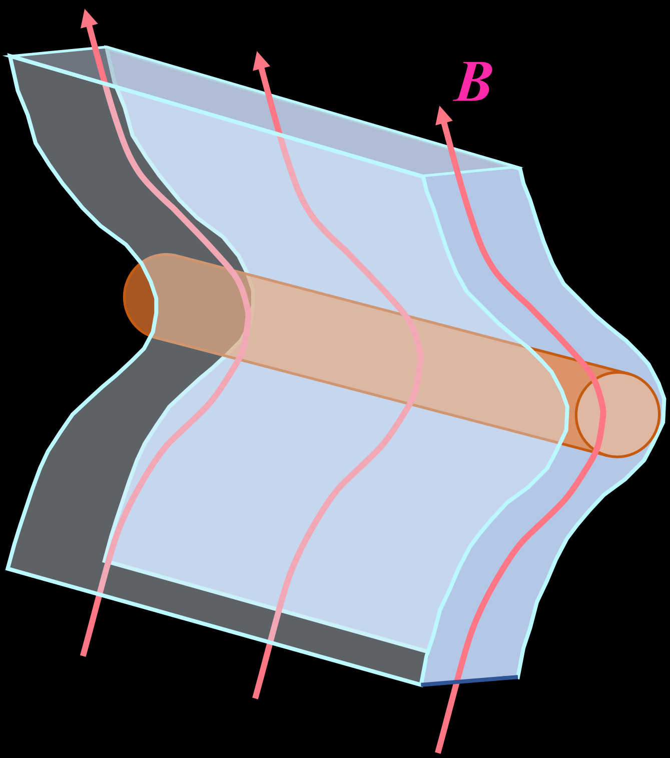
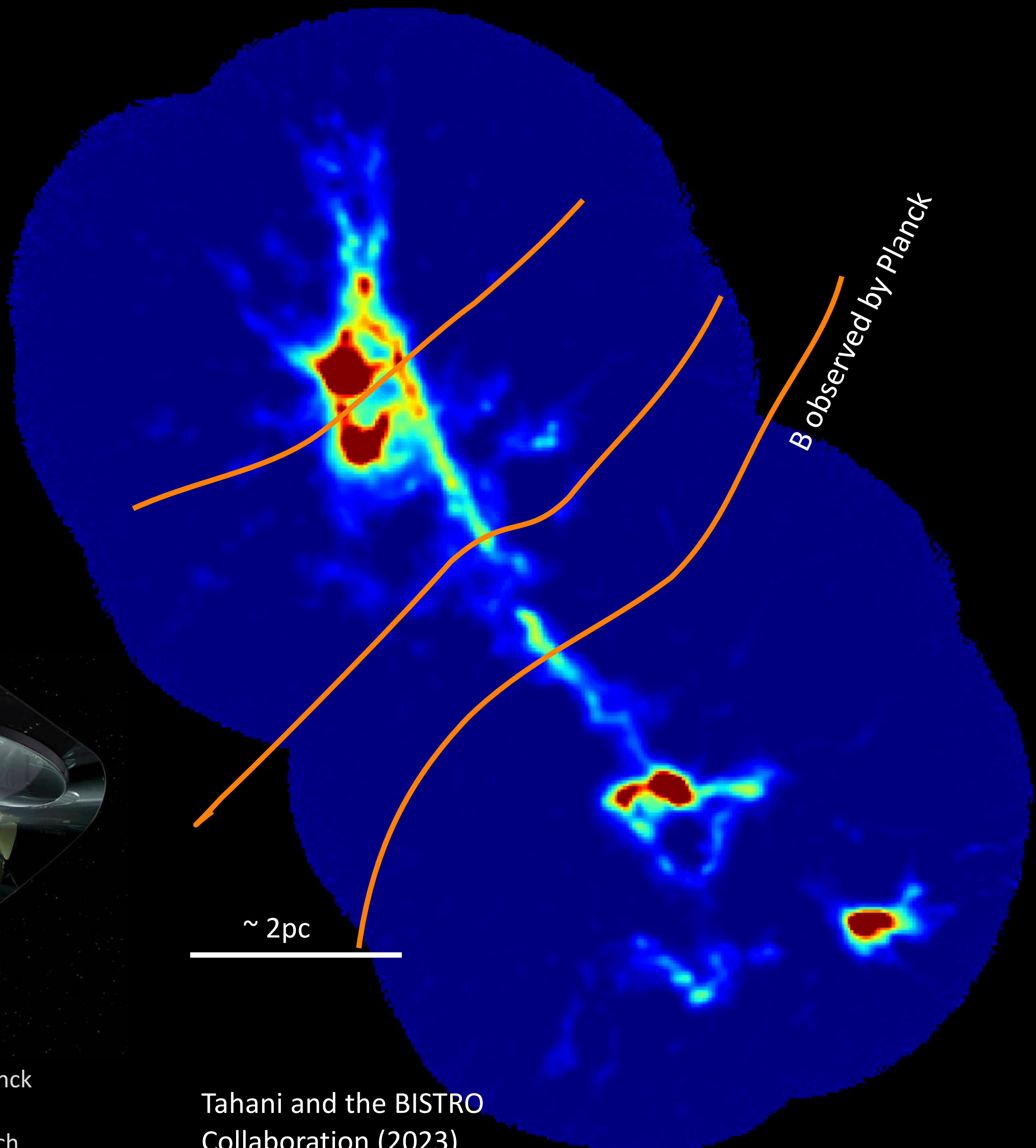
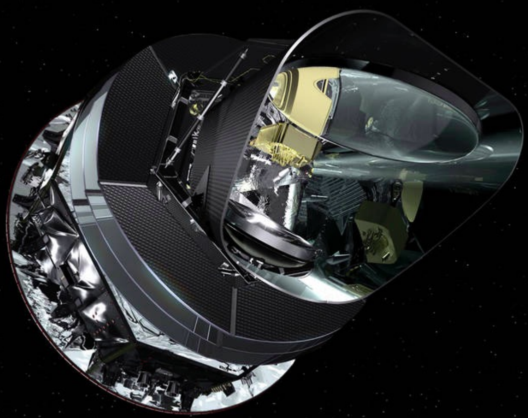


Figure: T. Inoue
Pineda et al. (PPVII) 2023
Abe et al. (2022)

Image credit: Mastering Astronomy, Pearson

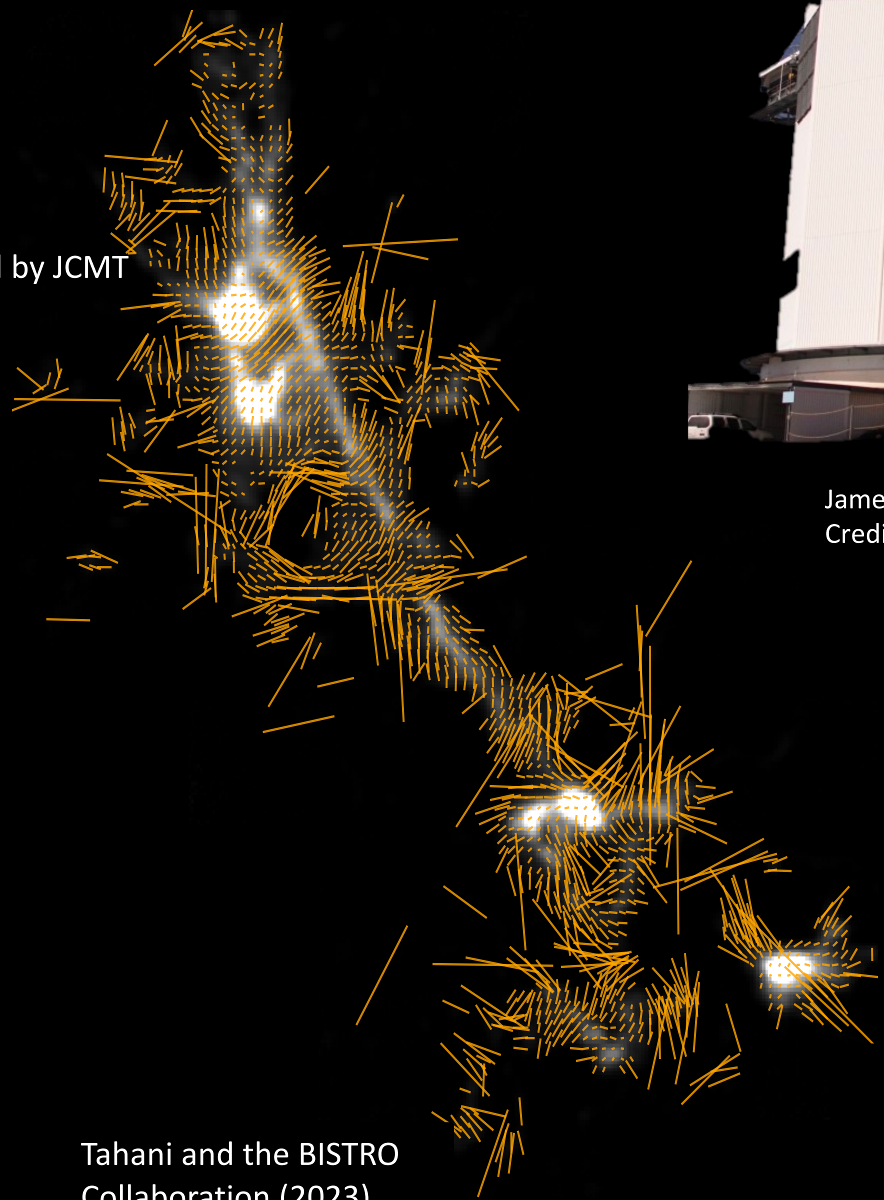




An artist's concept of the Planck spacecraft.
Credits: ESA/NASA/JPL-Caltech

Tahani and the BISTRO Collaboration (2023)

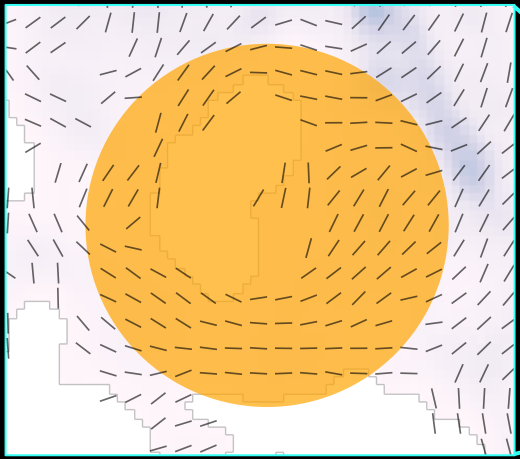
B observed by JCMT



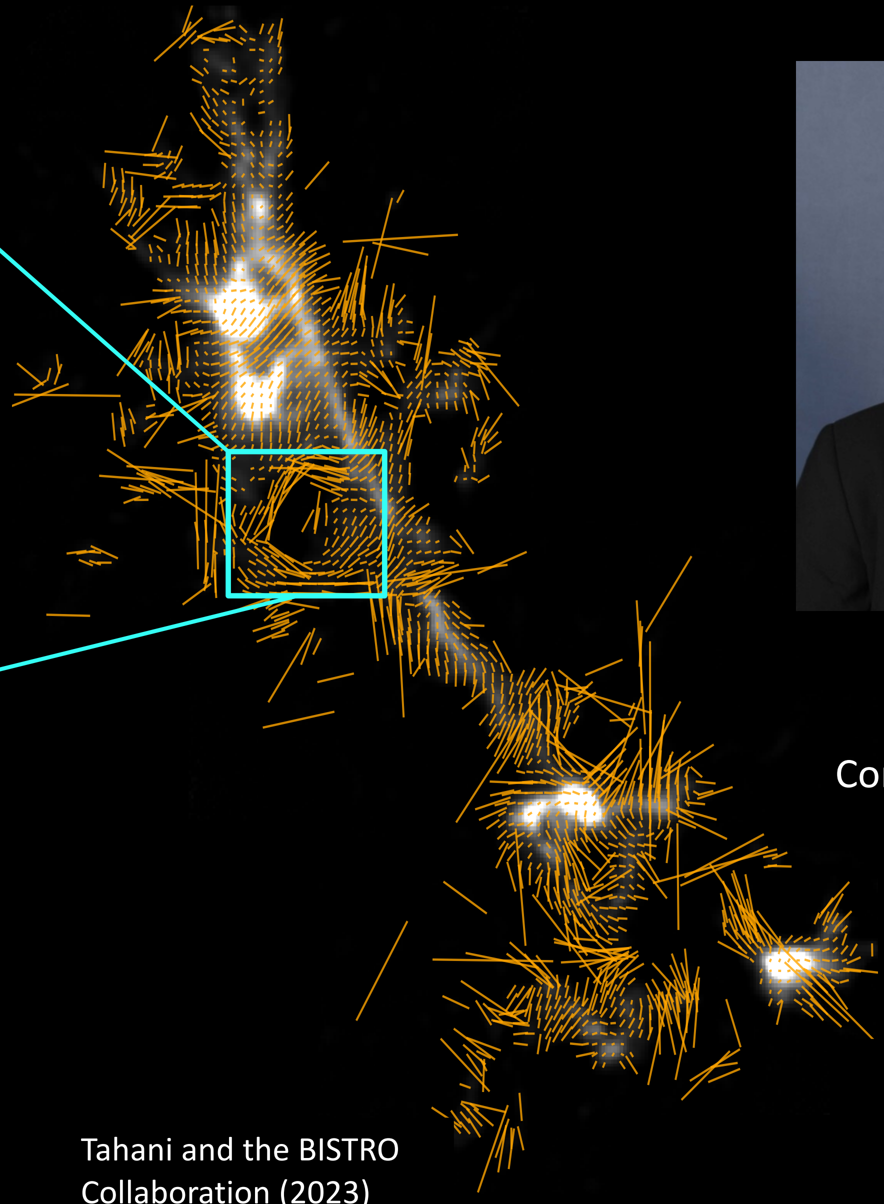
Tahani and the BISTRO Collaboration (2023)

James Clerk Maxwell Telescope (JCMT)
Credit: William Montgomerie

Dust Polarization



Tahani and the BISTRO Collaboration (2023)



Tahani and the BISTRO Collaboration (2023)

Khwaish Billore
Stanford University
Computer Vision Algorithms

Do we know the magnetic mysteries of our galaxy now?

No!

Line-of-sight Magnetic Field Observations

Radio

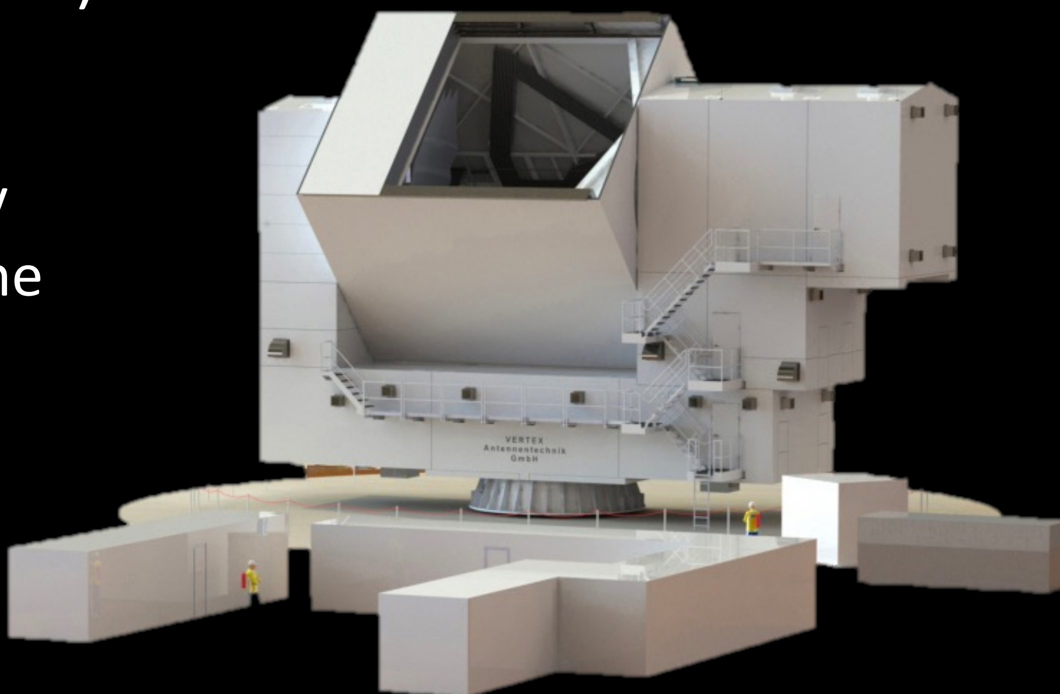
Composite image of the SKA combining all elements in South Africa and Australia. CreditL SKAO

Plane-of-sky Magnetic Field Observations

Far-infrared and sub-millimeter

Fred Young Submillimeter Telescope (FYST; CCAT-Prime):

- 3D magnetic fields of many molecular clouds (CCAT-Prime Collaboration et al. 2023)



Credit: Vertex Antennentechnik GmbH

Dragonfly Telephoto Array

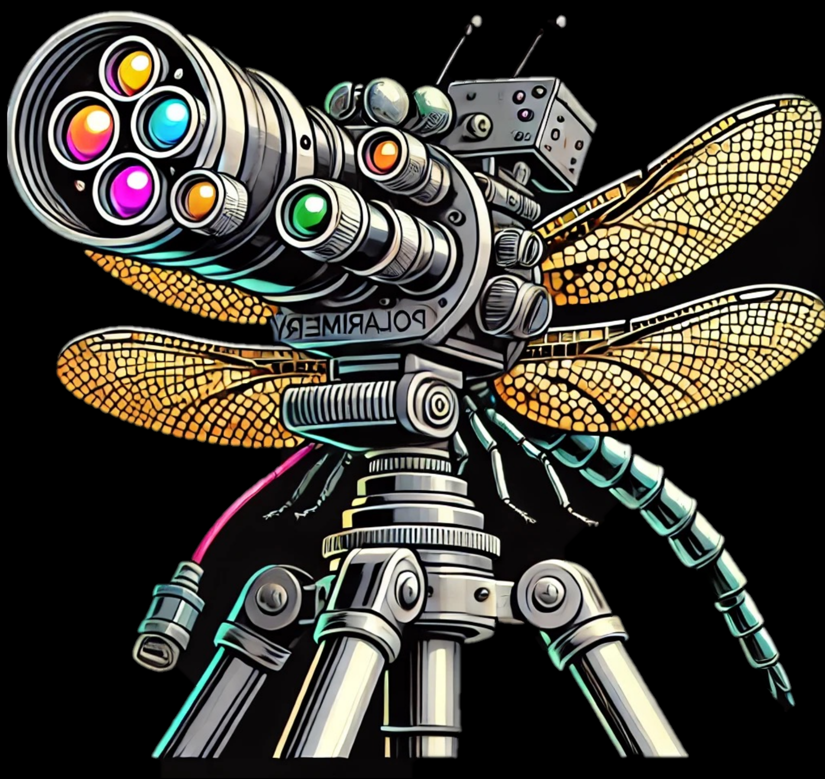
Optical & Near-IR

Image credit: Dragonfly Team

Developing a First-of-its-Kind Wide-Field Optical Polarimetry Observatory!

- Starlight polarization
- 3D structure of the Galaxy
- Early Universe
- Dark matter signatures

Invisible threads to ancient astronomers



Credit: AI and M. Tahani

Summary

- The Universe is threaded with magnetic fields - from the cosmic web connecting galaxies down to the formation of stars and planets. These magnetic forces together with other forces guide the cosmic dance of gas and dust that gives birth to new stars.

- Our innovative techniques have revealed the true three-dimensional structure of these interstellar magnetic fields, allowing us to explain the formation of molecular clouds.

- Looking ahead, next-generation telescopes will help us create unprecedented 3D maps of cosmic magnetism, unveiling how magnetic fields have shaped our galactic home.