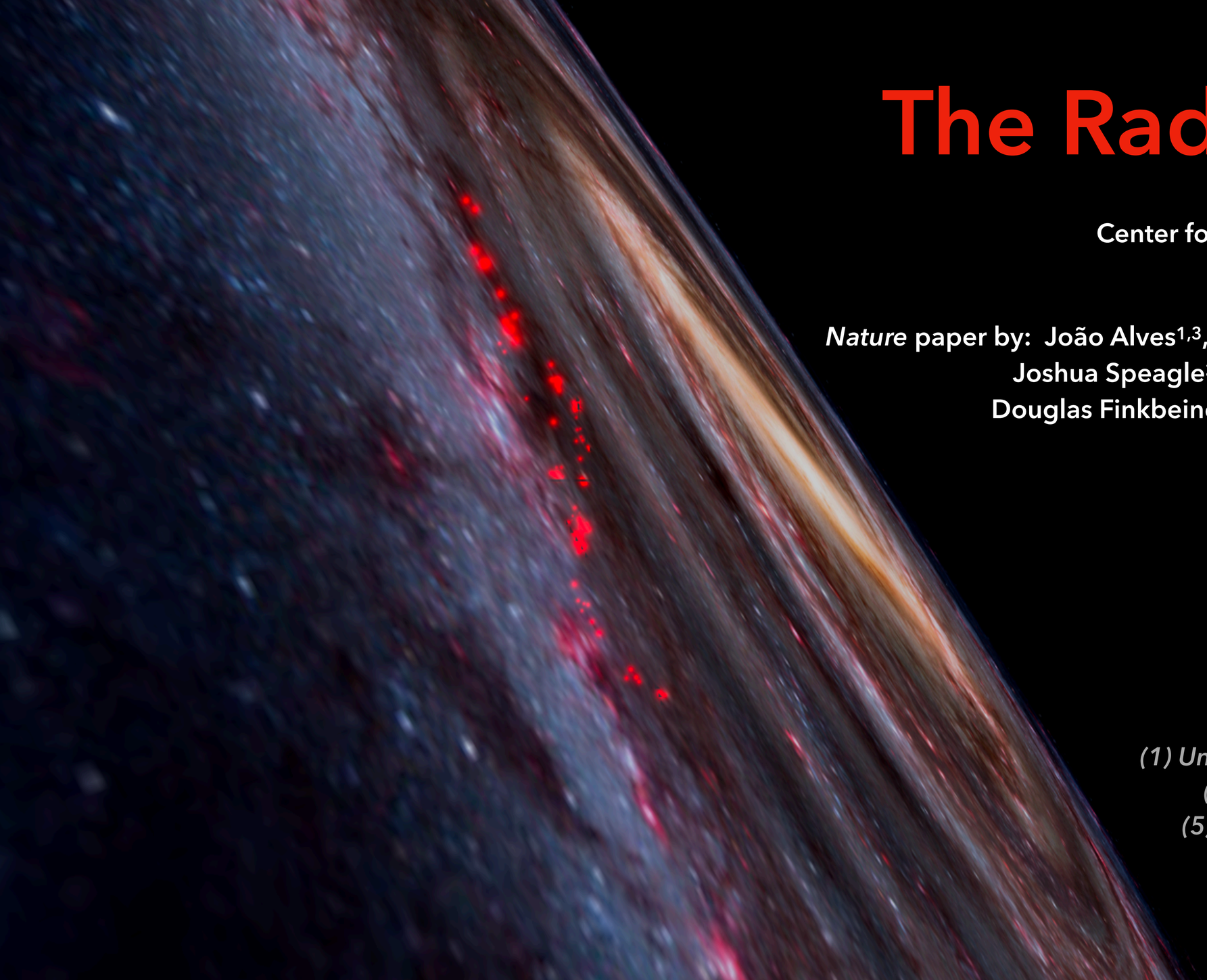


The Radcliffe Wave

presented by Alyssa Goodman,
Center for Astrophysics | Harvard & Smithsonian,
Radcliffe Institute for Advanced Study

Nature paper by: João Alves[1,3], Catherine Zucker[2], Alyssa Goodman[2,3], Joshua Speagle[2], Stefan Meingast[1], Thomas Robitaille[4], Douglas Finkbeiner[3], Edward Schlafly[5] & Gregory Green[6]

representing
(1) University of Vienna; (2) Harvard University; (3) Radcliffe Insitute; (4) Aperio Software; (5) Lawrence Berkeley National Laboratory; (6) Kavli Insitute for Particle Physics and Cosmology

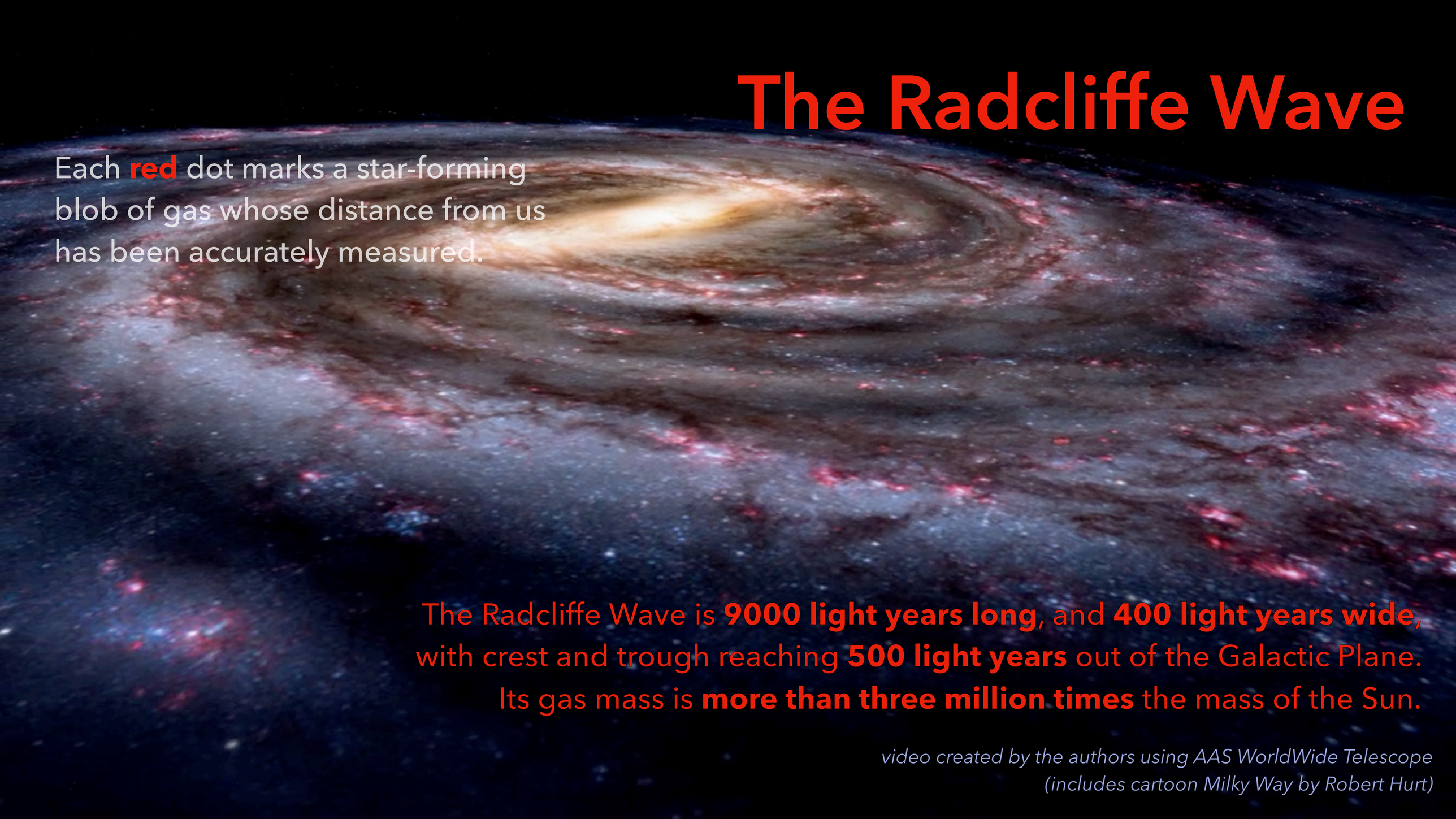
The Radcliffe Wave

CARTOON*

DATA

*drawn by Dr. Robert Hurt, in collaboration with Milky Way experts based on data; as shown in screenshot from AAS WorldWide Telescope

The Radcliffe Wave



Each **red** dot marks a star-forming blob of gas whose distance from us has been accurately measured.

The Radcliffe Wave is **9000 light years long**, and **400 light years wide**, with crest and trough reaching **500 light years** out of the Galactic Plane. Its gas mass is **more than three million times** the mass of the Sun.

video created by the authors using AAS WorldWide Telescope (includes cartoon Milky Way by Robert Hurt)

The Radcliffe Wave

ACTUALLY 2 IMPORTANT DEVELOPMENTS

DISTANCES!!

We can now measure distances to gas clouds in our own Milky Way galaxy to ~5% accuracy.

Zucker et al. 2019; 2020

RADWAVE

Surprising wave-like arrangement of star-forming gas *is* the "Local Arm" of the Milky Way.

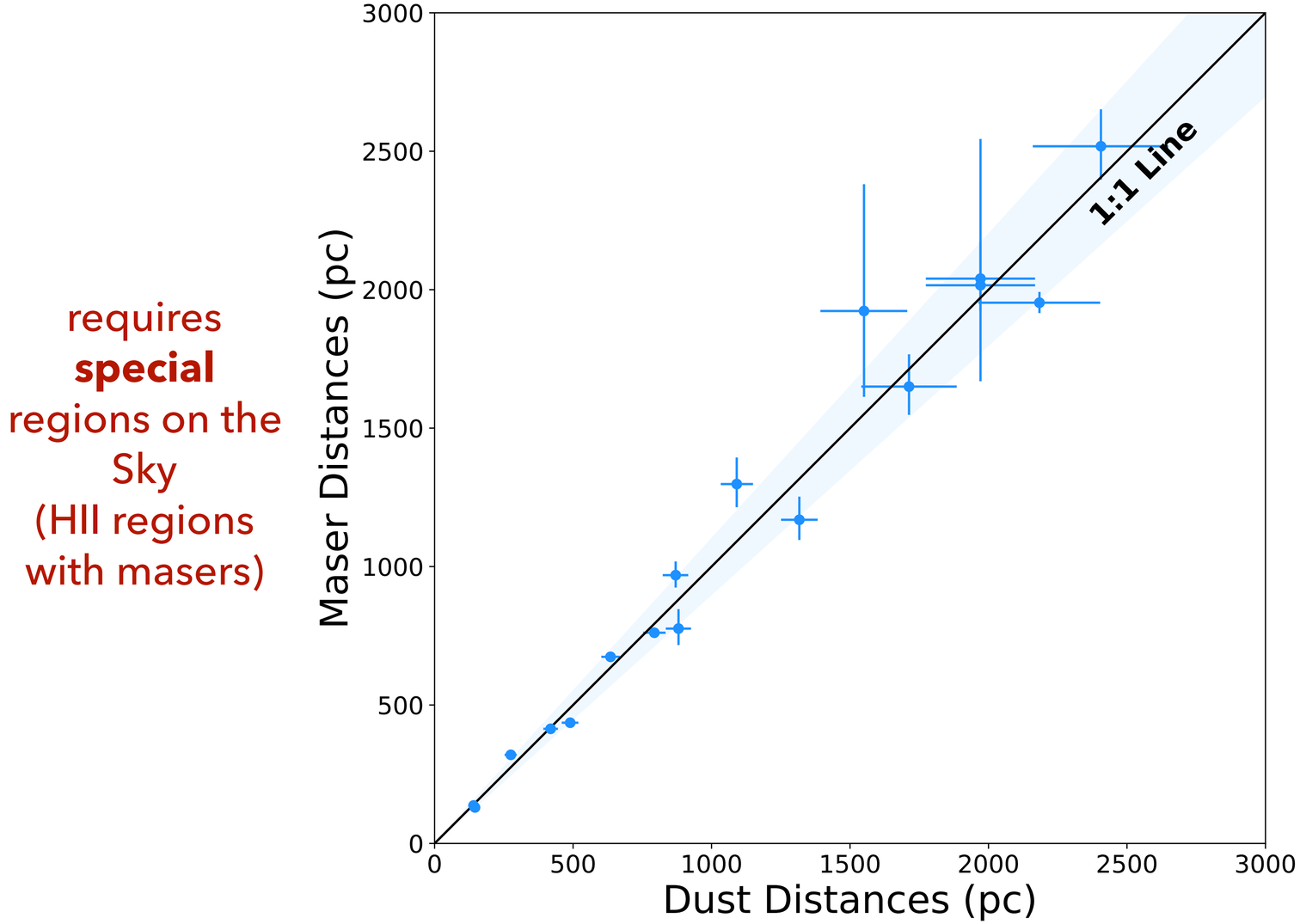
Alves et al. 2020

"Why should I believe all this?"

DISTANCES!!

We can now measure distances to gas clouds in our own Milky Way galaxy to ~5% accuracy.

requires **special** regions on the Sky (HII regions with masers)



can be used **anywhere** there's dust & measurable stellar properties

Zucker et al. 2019

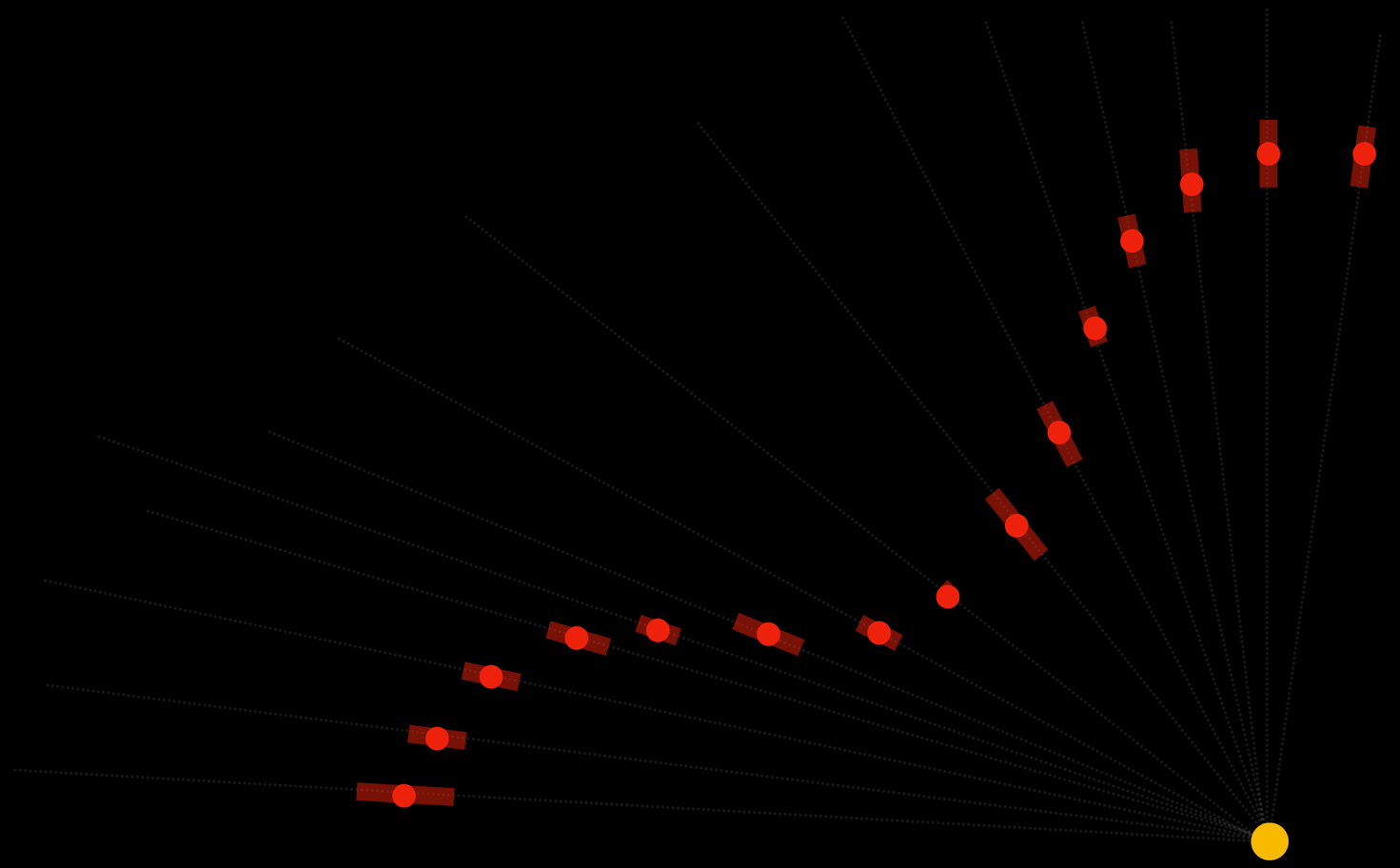
DISTANCES!!

We can now measure distances to gas clouds in our own Milky Way galaxy to ~5% accuracy.

Uncertain Distances

SCHEMATIC CARTOON(!)

Distances estimates **BEFORE** 3D dust mapping & Gaia (~30%)



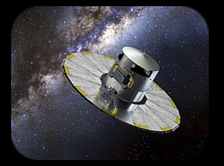
"The Radcliffe Wave"

SCHEMATIC CARTOON(!)

Distances estimates **AFTER** 3D dust mapping & Gaia (~5%)

HOW= 3D dust mapping*

+ Gaia*

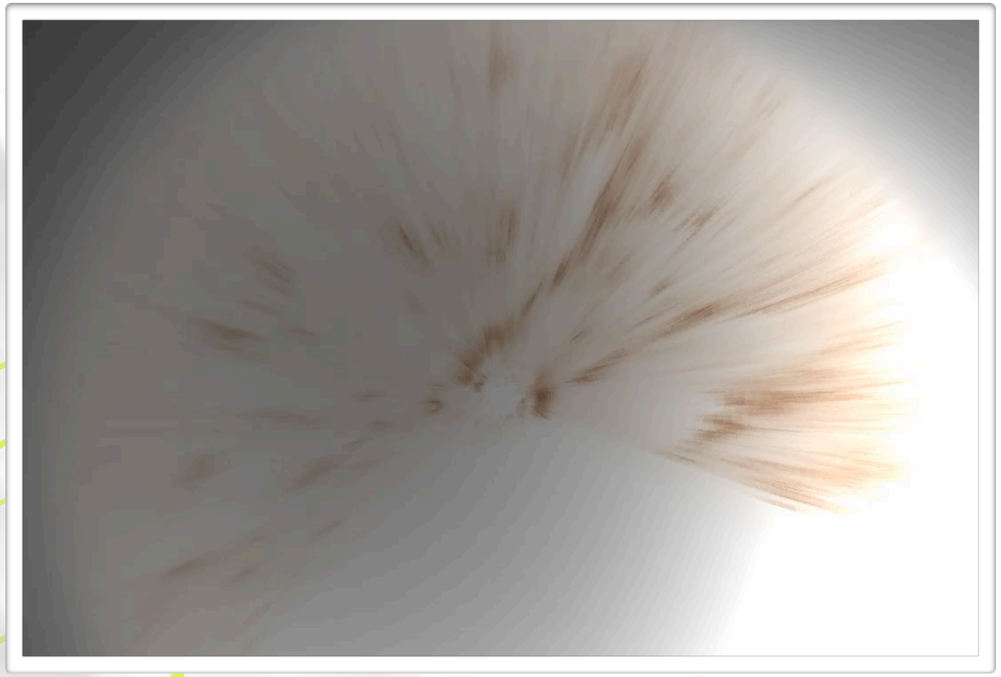


+ glue*

+ WorldWide Telescope

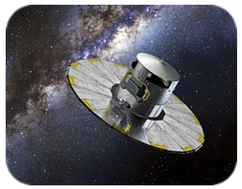
*2 million CPU hours, Harvard *800 million stars, ESA *NASA/JWST, NSF *Microsoft Research, NSF, AAS

Extinction & Reddening, from Color Imaging



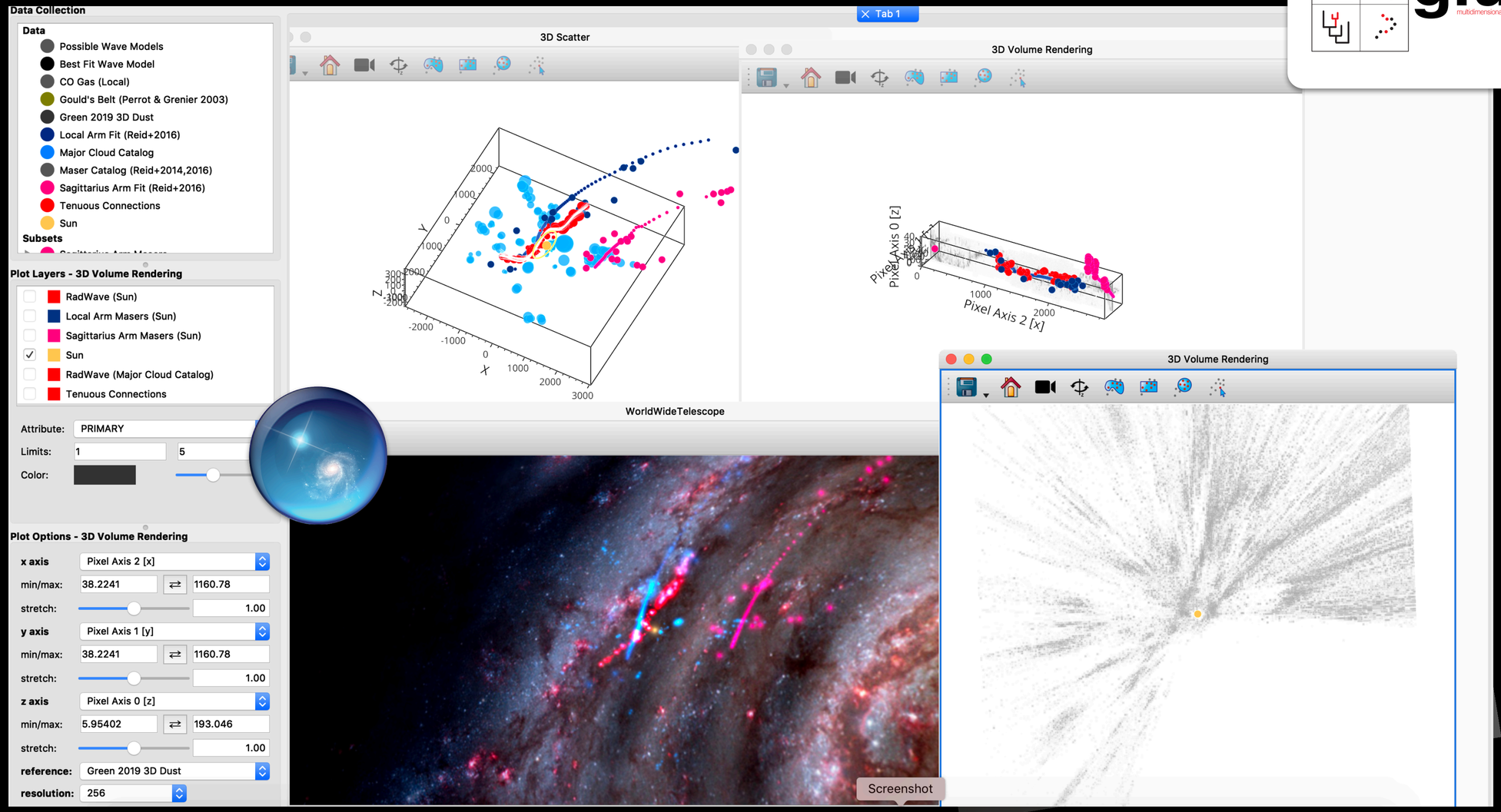
Green et al. 2019

Can infer matter's distance from *dust's* effects on stars.



WARNING: schematic diagram, NOT to scale (credit A. Goodman, 2019)

“Seeing” The Radcliffe Wave, in 3D

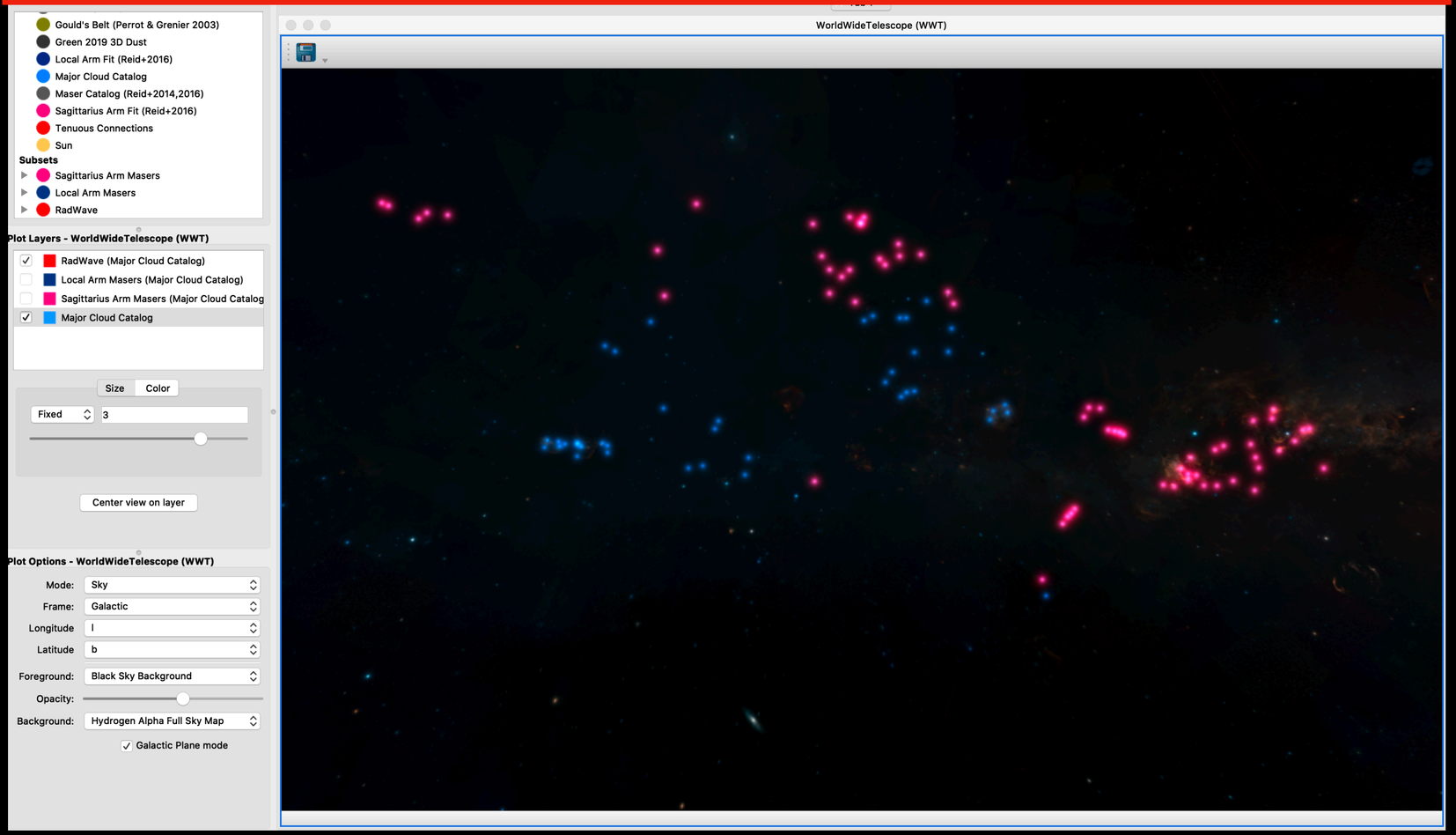


AAS WorldWide Telescope: worldwidetelescope.org

glue: glueviz.org

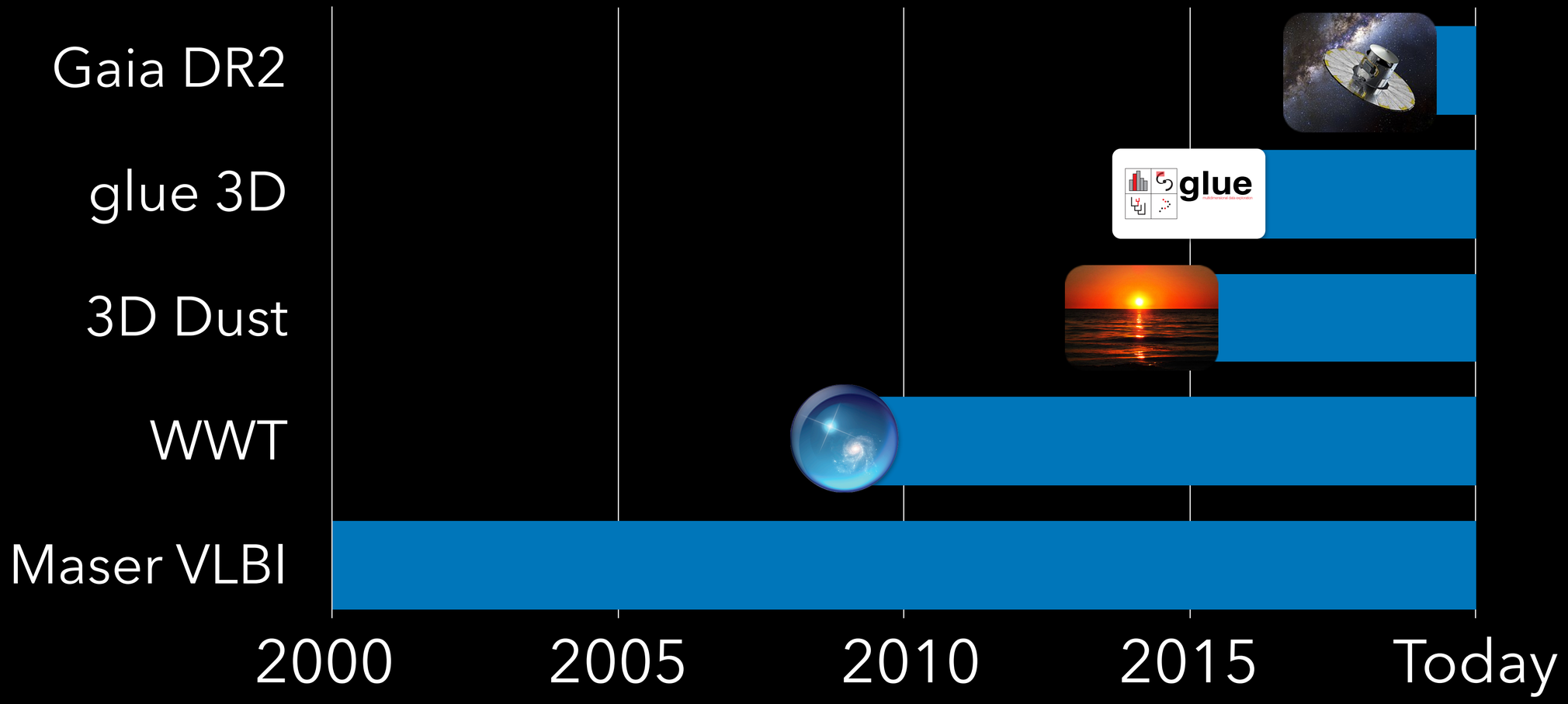
WHY DIDN'T WE FIND THE RADCLIFFE WAVE SOONER?

It's not apparent in 2D on the Sky.



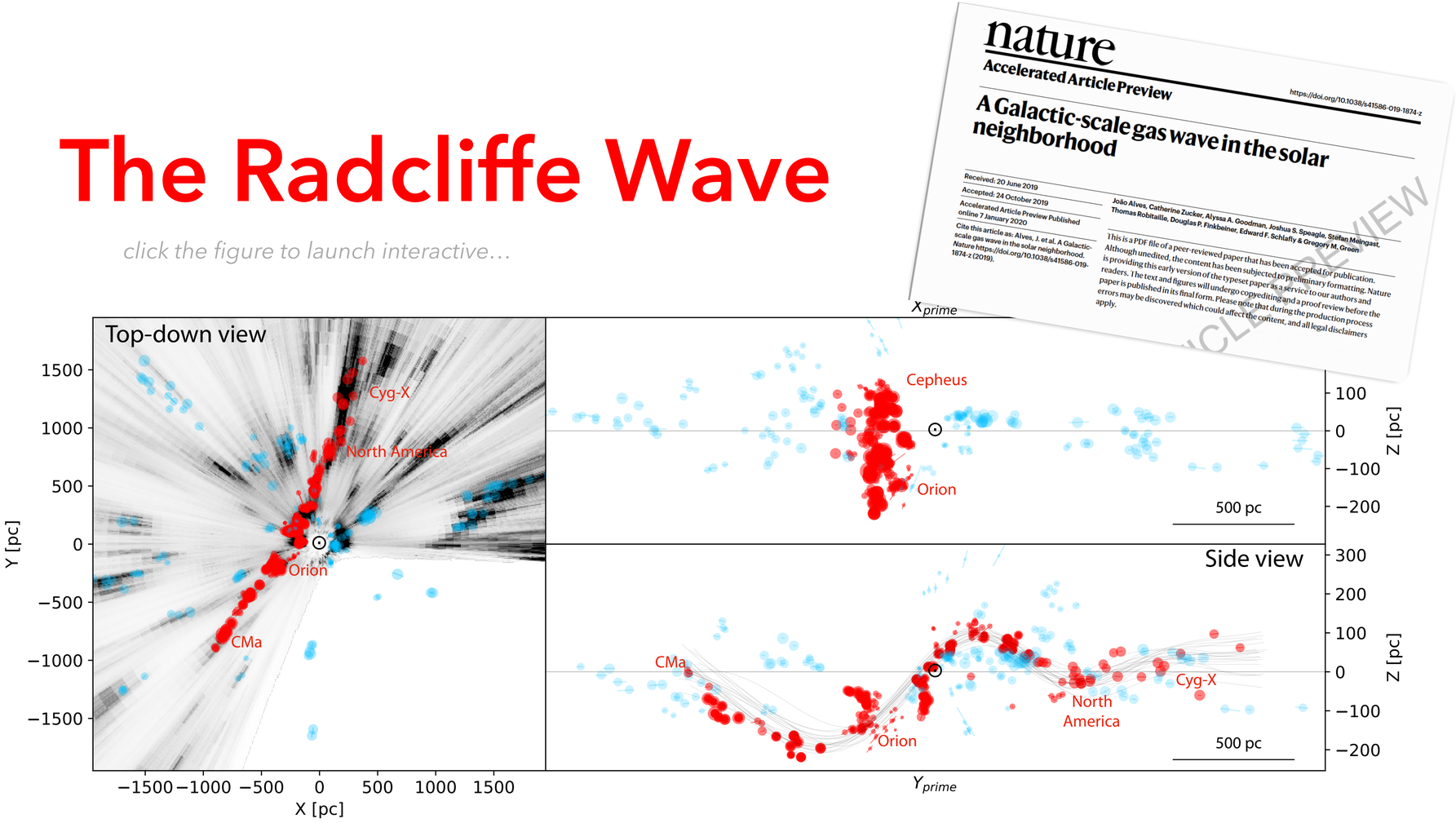
AAS WorldWide Telescope: worldwidetelescope.org glue: glueviz.org

WHY DIDN'T WE FIND THE RADCLIFFE WAVE SOONER?



The Radcliffe Wave

click the figure to launch interactive…



RADWAVE

Surprising wave-like arrangement of star-forming gas *is* the "Local Arm" of the Milky Way.

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

Alves et al. *Nature* paper & two distance catalog papers by Zucker et al. (2019, 2020) include several interactive figures (via plot.ly & bokeh), and deep links to data (on Dataverse) and code (on GitHub) inspired by AAS "Paper of the Future" (Goodman et al. 2015)

RADWAVE
Surprising wave-like arrangement of star-forming gas *is* the “Local Arm” of the Milky Way.

“So What,” for Astronomers?

demise of “Gould's Belt”

end to 100-year-old paradigm

“Local Arm" not shaped as we thought it was, locally

arm is “straight" from top-down

big wave in “arm” never previously observed

wave’s origin unknown (collision? dark matter? accretion?)

Open Questions

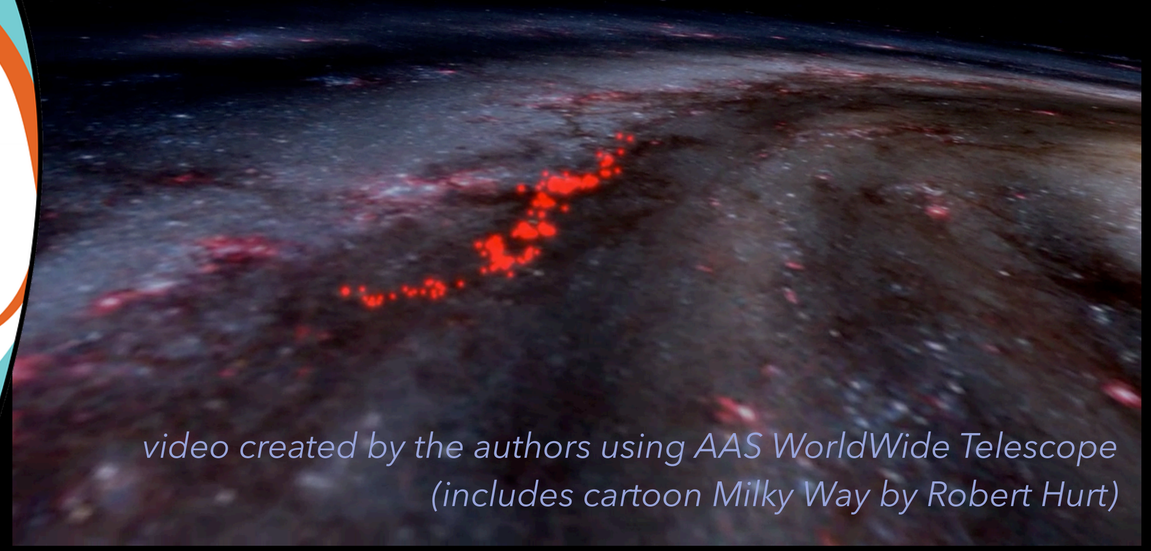
What is the ORIGIN of the Radcliffe Wave? Collision?

Do other parts of the Milky Way show this wavy structure? How about other galaxies? How can we SEARCH?

What do “waves “ mean for the STAR-FORMING HISTORIES of galaxies?

SURF the Radcliffe Wave

It appears that the Sun, on its galactic orbit, crossed the Radcliffe Wave 13 million years ago, and may cross it again in the future.

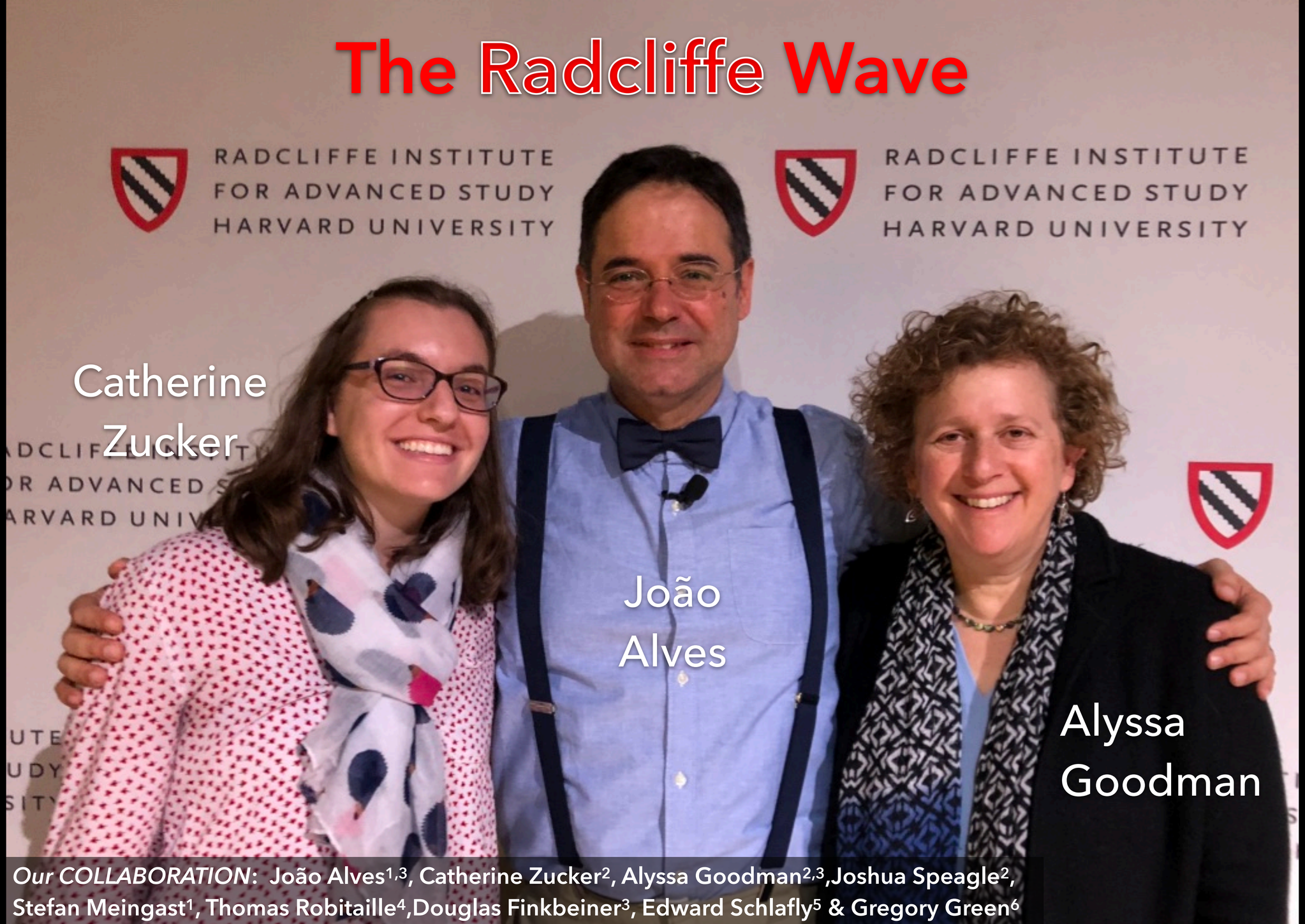


video created by the authors using AAS WorldWide Telescope (includes cartoon Milky Way by Robert Hurt)

Find these slides, the papers, videos, WWT Tours, and much more at: tinyurl.com/RadWave

iPoster Plus presentation today at 6:10 PM

The Radcliffe Wave



Our COLLABORATION: João Alves[1,3], Catherine Zucker[2], Alyssa Goodman[2,3],Joshua Speagle[2], Stefan Meingast[1], Thomas Robitaille[4],Douglas Finkbeiner[3], Edward Schlafly[5] & Gregory Green[6]

Hubble's "Tuning Fork"

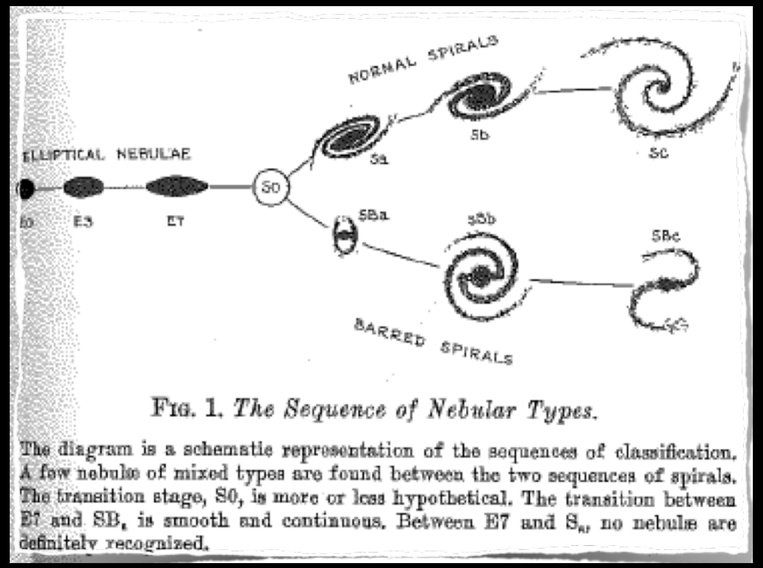


FIG. 1. *The Sequence of Nebular Types.*

The diagram is a schematic representation of the sequences of classification. A few nebulæ of mixed types are found between the two sequences of spirals. The transition stage, S0, is more or less hypothetical. The transition between E7 and SB_a is smooth and continuous. Between E7 and S_a, no nebulæ are definitely recognized.

The Spitzer Infrared Nearby Galaxies Survey (SINGS) Hubble Tuning-Fork

The Spitzer Space Telescope observed 75 galaxies as part of its SINGS (Spitzer Infrared Nearby Galaxies Survey) Legacy Program. The galaxies are presented here in a Hubble Tuning-Fork diagram, which groups galaxies according to the morphology of their nuclei and spiral arms. The designation of these galaxies and their placement in the diagram is based on their visible-light appearance. The main goal of the SINGS program is to characterize the infrared properties of a wide range of galaxy types. The images of the galaxies are composites created from data taken by IRAC (the Infrared Array Camera) at 3.6 and 8.0 μm, and MIPS (the Multiband Imaging Photometer for Spitzer) at 24 μm.

The infrared range probed by these and other observations taken for the SINGS project allows for the detailed study of star formation, dust emission, and the distribution of stars in each galaxy. Light from old stars appears as blue in the images, while the lumpy knots of green and red light are produced by dust clouds surrounding newly born stars. The elliptical galaxies on the left are almost entirely made of old stars, while spiral galaxies like our own Milky Way are rich in young stars and the raw materials for future star formation.

More information can be found at:
http://sings.stsci.edu/

Ellipticals

Irregulars

Strong Bulge

Strong Bulge

Weak Bulge

Weak Bulge

Unbarred Spirals

Intermediate Spirals

Barred Spirals

Poster and composite images created from SINGS observations by Karl D. Gordon (Oct 2007)
Blue=IRAC 3.6μm (stars)
Green=IRAC 8μm
(aromatic features from dust grains/molecules)
Red=MIPS 24μm (warm dust)

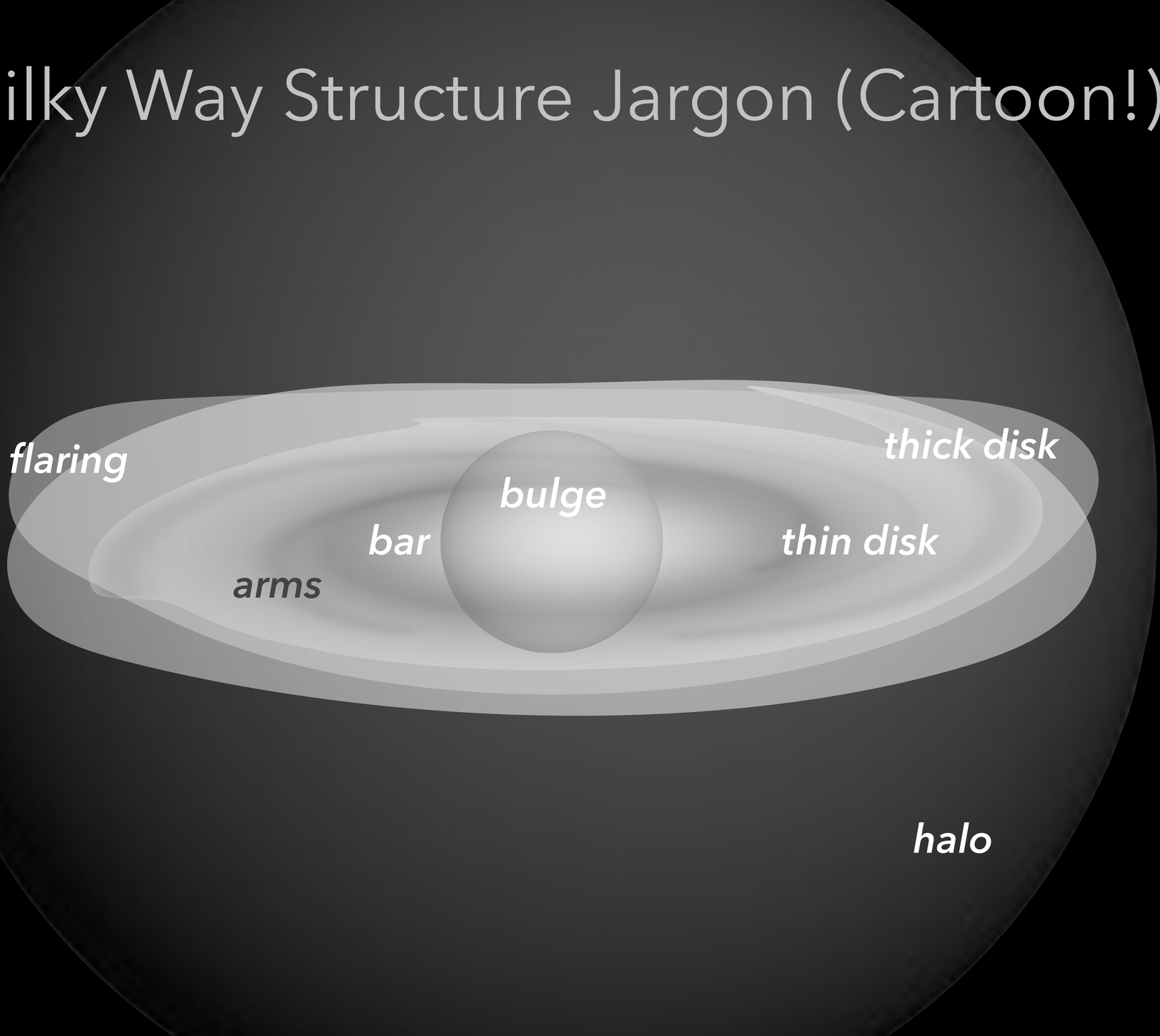
SINGS Team

Robert Kennicutt, Jr. (Principle Investigator), Daniela Calzetti (Deputy Principle Investigator), Charles Engelbracht (Technical Contact), Lee Armus, George Bendo, Caroline Bot, Brent Buckalew, John Cannon, Daniel Dale, Bruce Draine, Karl Gordon, Albert Grauer, David Hollenbach, Tom Jarrett, Lisa Kewley, Claus Leitherer, Aigen Li, Sangeeta Malhotra, Martin Meyer, John Moustakas, Eric Murphy, Michael Regan, George Rieke, Marcia Rieke, Helene Roussel, Kartik Sheth, J.D. Smith, Michele Thornley, Fabian Walter & George Helou

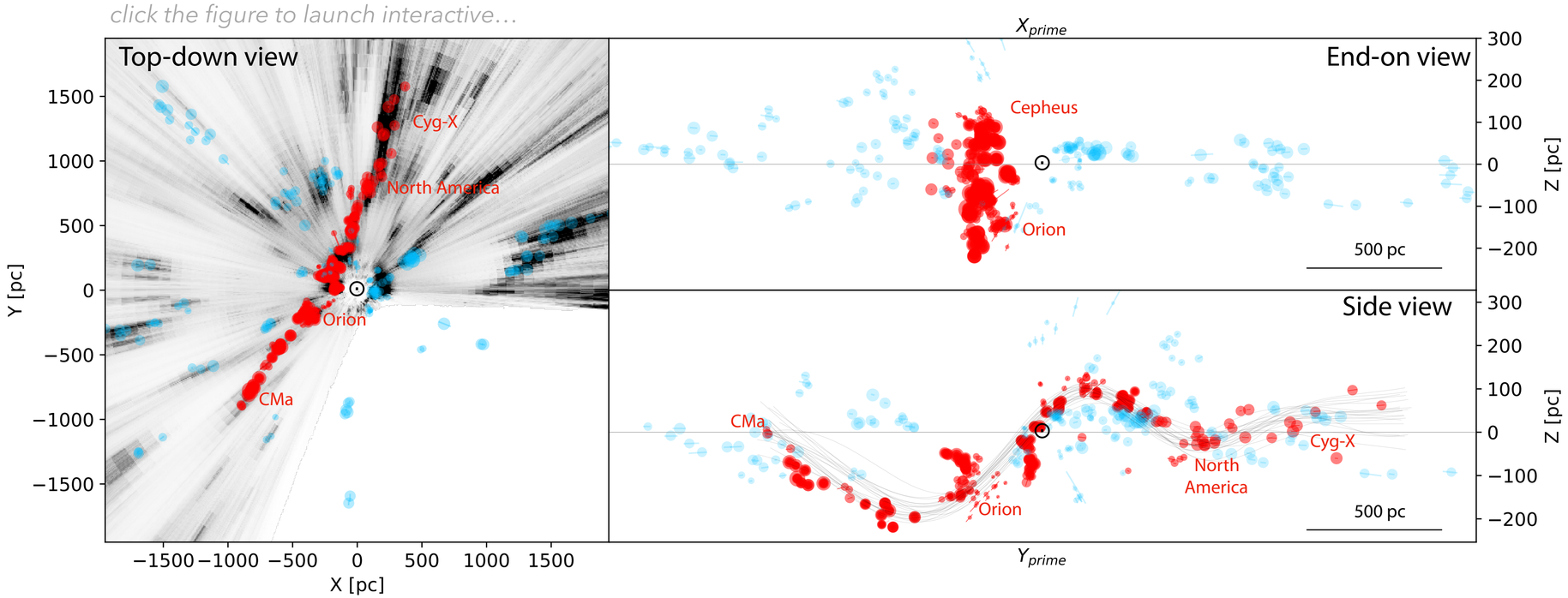
UGC 12158 (Mark Reid's favorite Milky Way analog)

UGC 12158 (Mark Reid's favorite Milky Way analog)

Milky Way Structure Jargon (Cartoon!)



The Radcliffe Wave



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