Knitting Together an Amazing new Multi-Color View of the Milky Way, in 3D

Alyssa A. Goodman
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photo credit: Tom Dame
Where are you?
Who are you?

High-school student

Undergraduate student

Graduate student

Postdoc

Research Staff

Faculty Member

None of the above... just interested!
Do you know about...

- Spiral galaxies
- Spectral-line mapping
- Numerical simulation
- Photometric imaging (over time)
- Statistical reconstruction

The Radcliffe Wave
Knitting
Next Generation VLA
Merge Cube

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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/

SINGS Team
Robert Kennicutt, Jr. (Principal Investigator), Daejin Galaz (Deputy Principal Investigator), Charles Schweizer (Technical Contact), Lisa Armus, Georgina Bondi, Caroline Bul, Ernst Bucholtz, John Condon, Daniel Dale, Bruce Draine, Karl Gordon, Albert Graver, David Holmboeck, Tom Jarrett, Lisa Keeney, David Leichtner, Agneta Lidman, Marita Marder, John Mandelkern, Eric Morris, Michael Regan, George Rieke, Marco Rieke, Helene Roussel, Kavitha Sheth, J.D. Smith, Michele Thomsen, Patrick Walter & George Helou

Poster and composite images created from SINGS observations by Karl D. Gordon (Dec 2007)
BlueIRAC 3.6μm (stars)
GreenIRAC 4.5μm
(aromatic features from dust grains/molecules)
RedMIPS 24μm (warm dust)
UGC 12158 (Mark Reid’s favorite Milky Way analog)
NGVLA could resolve the 1 pc-scale structure of molecular clouds in UGC 12158 and easily see 10-pc-scale vertical structure in edge-on disks...
photometric imaging
numerical simulation
photometric imaging (over time)
statistical reconstruction

spiral galaxies
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“Knitting”? 

Dust (density, 3D position) 

Gas (~density, line-of-sight velocity, 2D position) 

Stars (3D velocity, 3D position) 

Dr. Catherine Zucker
"Data" = 3D cubes, 2D images, 1D catalogs, from...

spectral-line mapping  numerical simulation  photometric imaging  statistical reconstruction

Gas in "3D"  p-p-v
Dust in 3D  p-p-p

"Bones"

"Wave(s)"

"Theory" questions re: magnetic fields, feedback, collisions, oscillations, dark matter...
"Knitting" Together the Milky Way

Try tinyurl.com/milkywayknitting to examine and explore these knitting instructions on your own.

(flow chart from 2020 NASA ADAP proposal by Zucker, Finkbeiner, Goodman, et al.)
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(flow chart from 2020 NASA ADAP proposal by Zucker, Finkbeiner, Goodman, et al.)
The Radcliffe Wave

presented by Alyssa Goodman,
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representing
(1) University of Vienna; (2) Harvard University; (3) Radcliffe Institute; (4) Aperio Software;
(5) Lawrence Berkeley National Laboratory;
(6) Kavli Institute for Particle Physics and Cosmology
The Radcliffe Wave

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

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

Zucker et al. 2019; 2020
Alves et al. 2020
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)

Zucker et al. 2019

can be used anywhere there’s dust & measurable stellar properties

Zucker et al. 2019
Uncertain Distances

Distances estimates \textit{AFTER} 3D dust mapping & Gaia (\textasciitilde 5\%)
Distances estimates after 3D dust mapping & Gaia (~5%)

"The Radcliffe Wave"

Schematic Cartoon(!)
HOW = 3D dust mapping*

+ Gaia*

+ glue*

+ WorldWide Telescope

*2 million CPU hours, Harvard
*800 million stars, ESA
*NASA/JWST, NSF
*Microsoft Research, NSF, AAS
Can infer matter’s distance from dust’s effects on stars.
“Seeing” The Radcliffe Wave, in 3D

AAS WorldWide Telescope: worldwidetelescope.org

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

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


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)
"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.

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

Gas in "3D" $p\cdot p\cdot v$
Dust in 3D $p\cdot p\cdot p$

What about 4D??
$(p\cdot p\cdot p\cdot v_z)$
Spectral-Line Data Cubes give line-of-sight gas velocity
Mapping Interstellar Matter in 4D ($p$-$p$-$p$-$v_z$)
“Knitting” Together the Milky Way

Try tinyurl.com/milkywayknitting to examine and explore these knitting instructions on your own.
(flow chart from 2020 NASA ADAP proposal by Zucker, Finkbeiner, Goodman, et al.)
All DATA soon!

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