Summary Talk: A SOFIA Postmortem with an Eye to the Future

Heritage of SOFIA – Scientific Highlights and Future Perspectives

Stuttgart, Germany 22-26 Apr 2024

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Lim, et al 2019,
Image courtesy of:
De Buizer, Lim, Radomski

SOFIA 19µm, 37µm; Herschel 70µm; Spitzer 3µm
USRA | NASA | SOFIA | Spitzer | Herschel

Anniversaries

- April 25, 1977: Maiden flight of the Boeing 747-SP that was later transformed to SOFIA
- April 26, 2007: SOFIA's first flight after structural modifications and telescope installation

WHY ME?

- Diplomarbeit: 1972, Univ. Göttingen, *Phase Transitions in the Interstellar Medium*
  - ISM Cooling from Ly-alpha, [OI], [NII], [CII], [CI], …
  - Heating from cosmic rays
- PhD-Thesis: 1974, Univ. Göttingen, *Stösse zwischen interstellaren Wolken (Collisions between interstellar Clouds)*
  - ISM Hydrodynamics + heating/cooling + H2 molecule formation/destruction
  - Formation of transitory dense H2 clouds
- Yorke HW, Krügel E, 1977, *The Dynamical Evolution of Massive Protostellar Clouds*, A&A, 54, 183
  - Formation of massive stars
- Yorke HW, 1977, *Calculated Infrared Spectra of Cocoon Stars*, A&A, 58, 423
  - Theoretical SEDs of massive YSOs

SUMMARY

- An impressive amount of superb science has been presented, not only purely from SOFIA data, but also in symbiosis with other facilities.
- Most of the original justifications for SOFIA have been validated (notable exception: as precursor/pathfinder for Herschel).
- SOFIA has enabled additional areas of research not originally contemplated (e.g. magnetic fields, time-domain astronomy). SOFIA was essential for some of this science.
- The importance of the far infrared to astronomy has been well documented (“You can’t escape the far infrared”).
- The cancellation of SOFIA was a bad decision by NASA. The way it was cancelled was despicable.
- The concept of the SOFIA Legacy Program was not universally embraced. I am now convinced that this was the right decision.
- There is still an immense amount of SOFIA data waiting to be mined.

SUMMARY (con't)

- There are alternatives for continued access to Far Infrared
  - Space-based alternatives: FIRRST, PRIMA, SALTUS, …, A Far IR Great Observatory
  - Balloon alternatives: BLASPOL, GUSTO, ASTHROS, *from TIFR*, …
- FIR data repositories
- Clever work-arounds at longer or shorter wavelengths

Many thanks to …

- … the presenters: Dario Fadda, Sebastian Wolf, Javier Goicoechea, Parit Mehta, Jialu Li, Enrique Lopez Rodriguez, Philippe André, Phillip Oakey, Ivana Beslic, Hans Zinnecker, Slawa Kabanovic, Arshia Maria Jacob, Karl Menten, Ngoc Tram Le, Moritz Lietzow-Sinjen, Rolf Güsten, Dariusz Lis, Floris van der Tak, Volker Ossenkopf-Okada, Maryvonne Gerin, Henrik Beuther, Helmut Wiesemeyer, Nick Indriolo, Jonathan C. Tan, Thushara G.S. Pillai, Guido Fuchs, Cornelia Pabst, Albrecht Poglitsch, Agata Karska, Luigi Spinoglio, Umit Kavak, Verena Wolf, Christian Andreas, Mark Morris, Philipp Maier, Paul F. Goldsmith, Alexander Tielens, Jochen Eislöffel, Mélanie Chevance, Miriam Rengel, Friedrich Wyrowski, Wonju Kim, Bringfried Stecklum, Silvia Spezzano, Suzanne Madden, Bhaswati Mookerjea, Elena Redaelli, Bernhard Schulz, Heinz-Wilhelm Hübers, Gordon Stacey, Asantha Cooray, Paul Hartogh, Margaret Meixner, Christian Fischer, Bernd Klein
- … **Posters:** Andre Beck, Aaron Bryant, Michael Busch,Simon Dannhauer, Nadine Fischer, Eduard Keilmann, Chi Yan Law, Shanghuo Li, Yoko Okada, Juan Luis Verbena Contreras,Yaoting Yan

PRIZES

Best posters and talks selected by secret, anonymous committee.

Best Poster:
- Michael Busch: *Far-IR Calibration of the 18cm OH lines with SOFIA HyGAL in Diffuse Clouds*

3 Best Talks:

- **Albrecht Poglitsch**: *Lessons Learned from Making FIFI-LS a Reality*

- **Darek Lis**: *SOFIA Solar System Legacy*

- **Elena Redaelli**: Polarimetry with SOFIA: the interplay between magnetic fields and kinematics in low-mass cores

and a special Prize for the amazing extra talk:
- **Gordon Stacey**

With special thanks to …

… the SOC/LOC

- Maja Kazmierczak-Barthel
- Andre Beck
- Aaron Bryant
- Alfred Krabbe

With assistance from the entire DSI team, and members of the IRS extremely helpful (we would fail without them):

Philipp Maier, Florian Behrens, Benjamin Greiner, Michael Hütwohl
Nadine Fischer, Christian Fischer

Thomas Keilig (solving all our financial issues)

Wilhelm and Else Heraeus Foundation

Dunning-Kruger Effect

The **Dunning–Kruger Effect** is a cognitive bias in which people with limited competence in a particular domain overestimate their abilities [1].

Example:

Newly licensed teen drivers often overestimate their ability to safely steer a vehicle.

Insurance companies radically raise rates.

Example:

Forming opinions based on misinformation, e.g. people refusing vaccinations overestimate their knowledge of vaccine safety.

[1] Kruger, J., Dunning, D., 1999, *Journal of Personality and Social Psychology* 77, 1121

Dunning-Kruger Effect

Example:

The Theranos fiasco: Elizabeth Holmes (college dropout with no business or medical experience) sold investors on her ideas based on flawed medical research. She hired executives (e.g. brother, boyfriend) with no experience to run a company. 2013-2014 Theranos was valued at $10 billion. January 2022 it was dissolved.

Example:

A NRC Decadal Review panel recommended SOFIA's cancellation

To Avoid the *Dunning-Kruger effect* NASA asks expert panels for assessments, recommendations, advice

- Proposal reviews, senior reviews, decadal reviews, TACs, …
  - Decisions are based on expert advice/recommendations
  - NASA may or may not follow recommendations
- Senior Review Panel assess the wisdom of continuing *operating* missions
  - Recognizing that even experts have biases and gaps of knowledge, the project being reviewed has a chance to highlight past accomplishments (~33%) and future benefits (~67%)
- NRC Decadal Review Panel assesses the merits of proposed *future* missions (NRC independent from NASA, NSF, DOE, …)

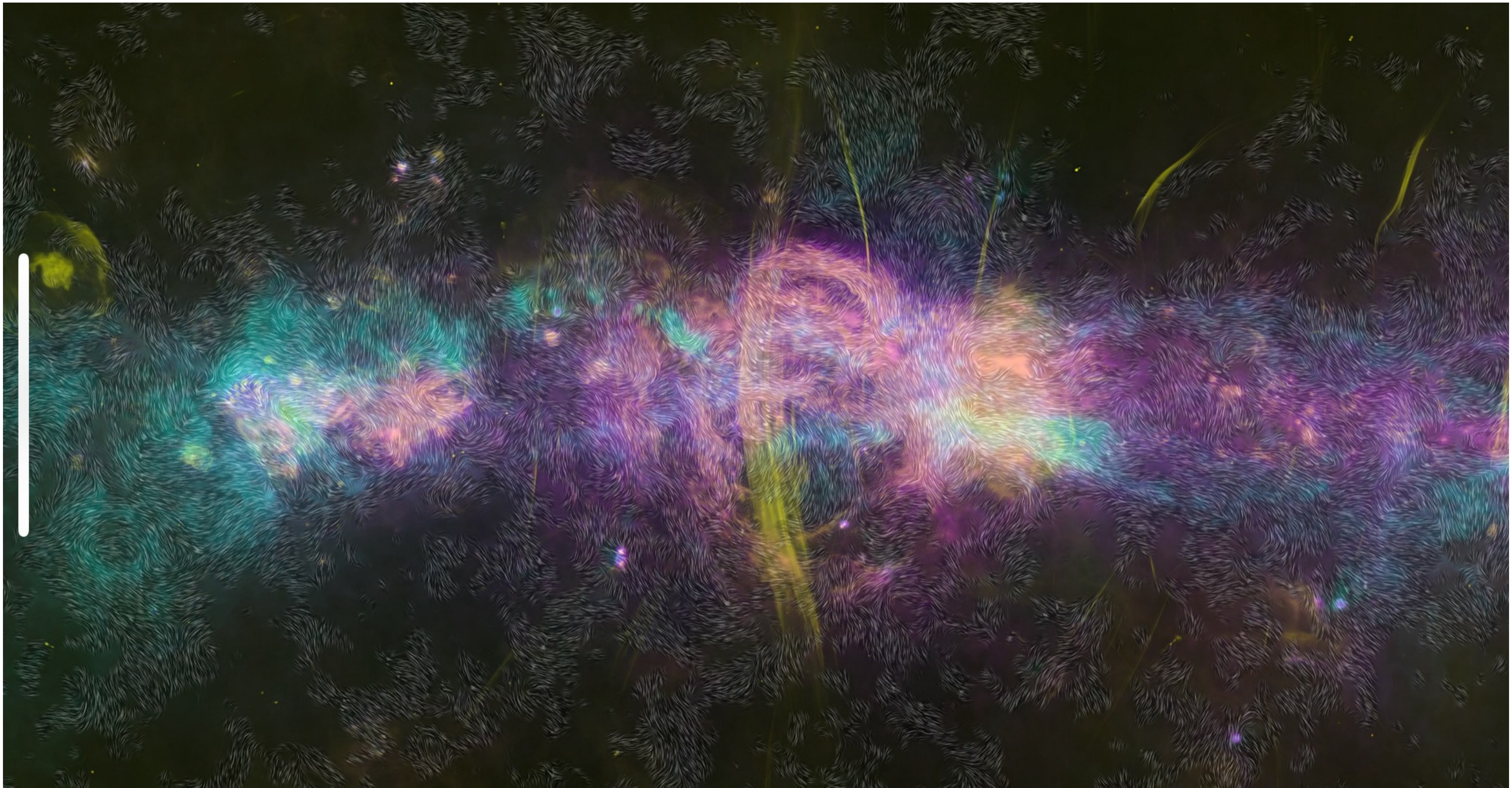
To Avoid the *Dunning-Kruger effect* NASA asks expert panels for assessments, recommendations, advice

- A NASA official asked the chairperson of NRC's *Decadal Survey* panel to assess SOFIA and recommend its cancellation. This request falls outside the charter of NRC's Decadal Surveys and could potentially lead to a *Dunning-Kruger* misjudgment.

- Without requesting input from the SOFIA mission, NRC's *Decadal Survey* panel recommended for the first time cancelling a fully functioning NASA mission.

- NASA followed this recommendation in breakneck speed.

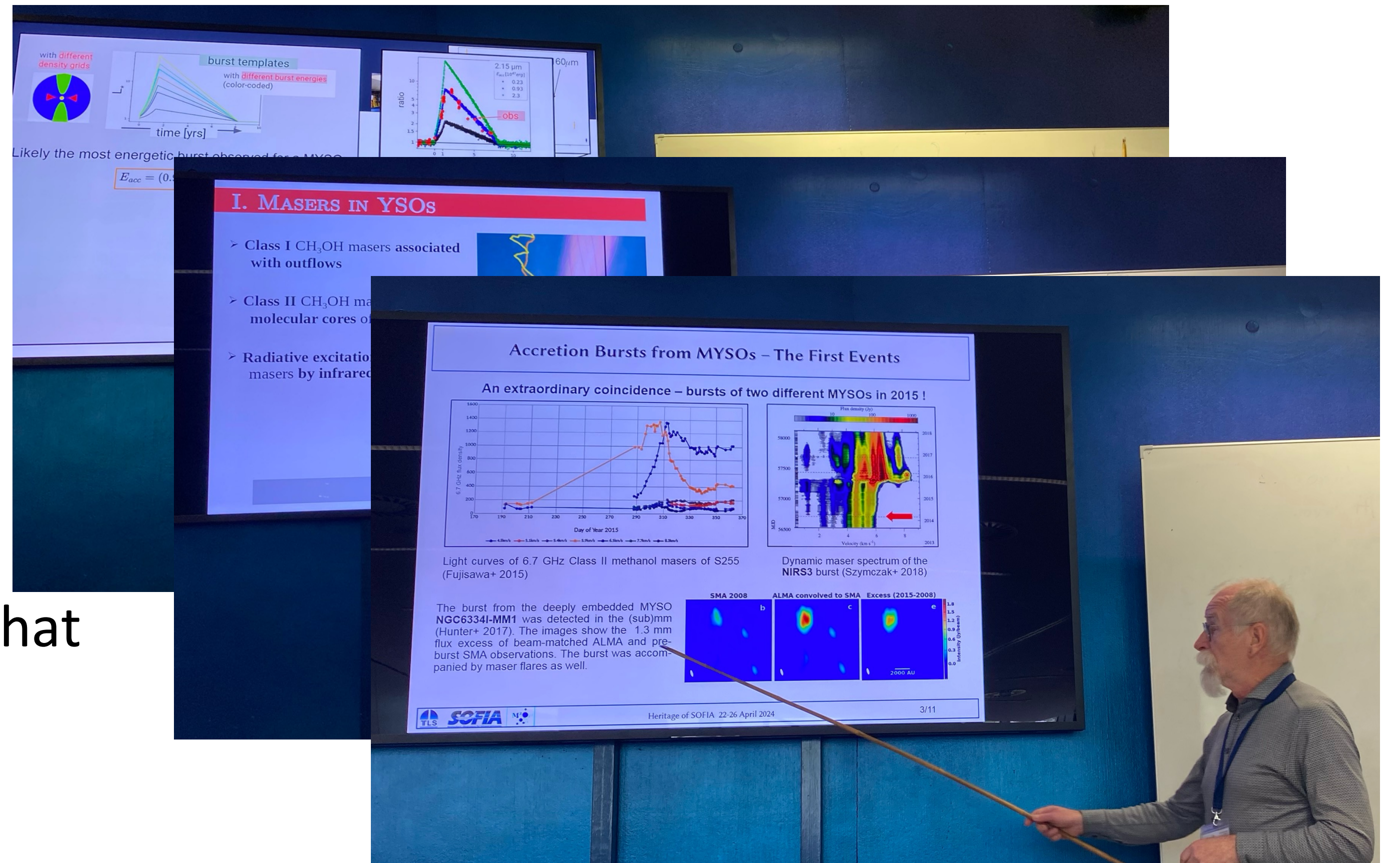
Magnetic Fields




Star Formation science covered with SOFIA
- present here at the conference -
High-resolution spectroscopy
—> Unprecedented ISM maps
Overview —> Zinnecker
Magnetic fields —> Andre, Wolf, Pillai, Redaelli, Rodriguez …
Feedback —> Kabanovic, Goicoechea, Tielens, Pabst …
High-mass star formation (SOMA) —> Oakey, Tan …
Infall —> Wyrowski
Accretion bursts —> Stecklum, Wolf, Andreas …
Envelopes around high-mass stars —> Menten
Water —> Indriolo, Li
Outflows —> Oakey, Karska, Eisloeffel …
Vel. resolved fine-structure lines —> Goldsmith
Physical and chemical structure —> Spezzano
PDRs —> Mookerjea

ACCRETION EVENTS

- Is this the principal mechanism for mass growth of all protostars?
- How does material actually get on the star?
- Maser periodicity; what is its underlying mechanism?



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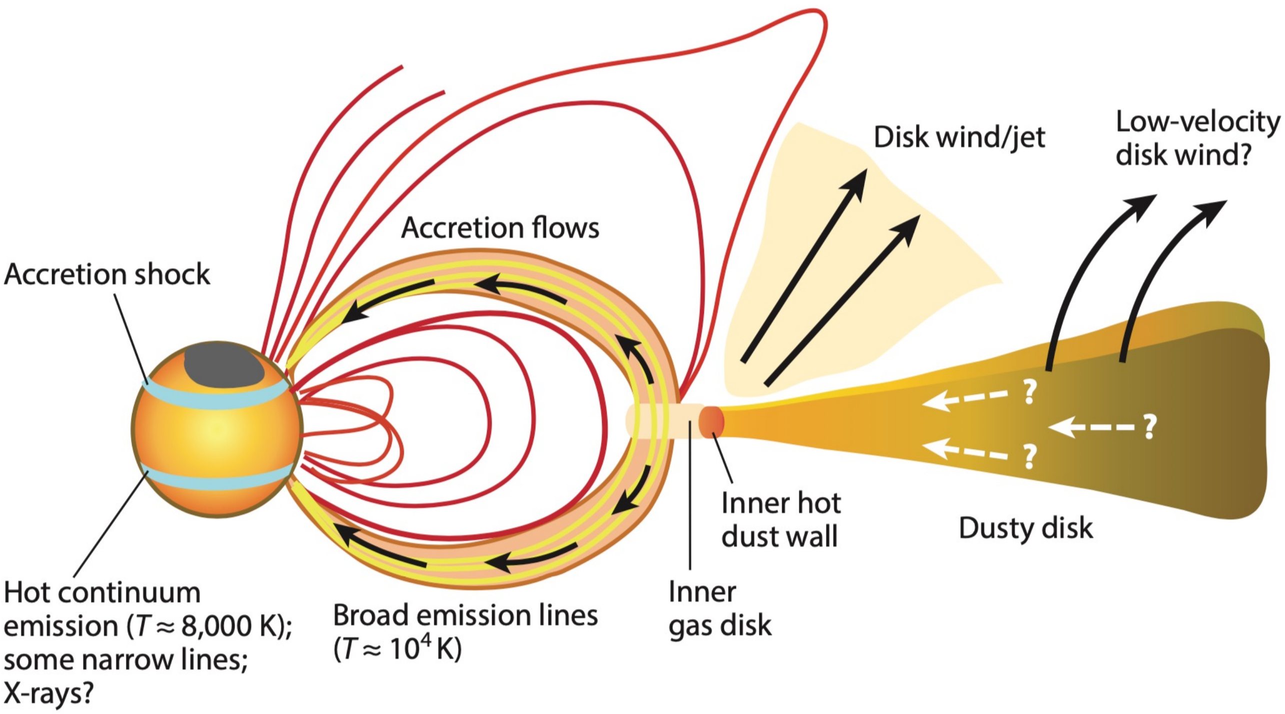
Backup Slides

- How does material get onto a protostar?
  Late accretion stages: A schematic view…



Hartmann, Herczeg, Calvet, 2016, ARAA, 54, 135

Schematic view of a young star accreting from a disk through the stellar magnetosphere.

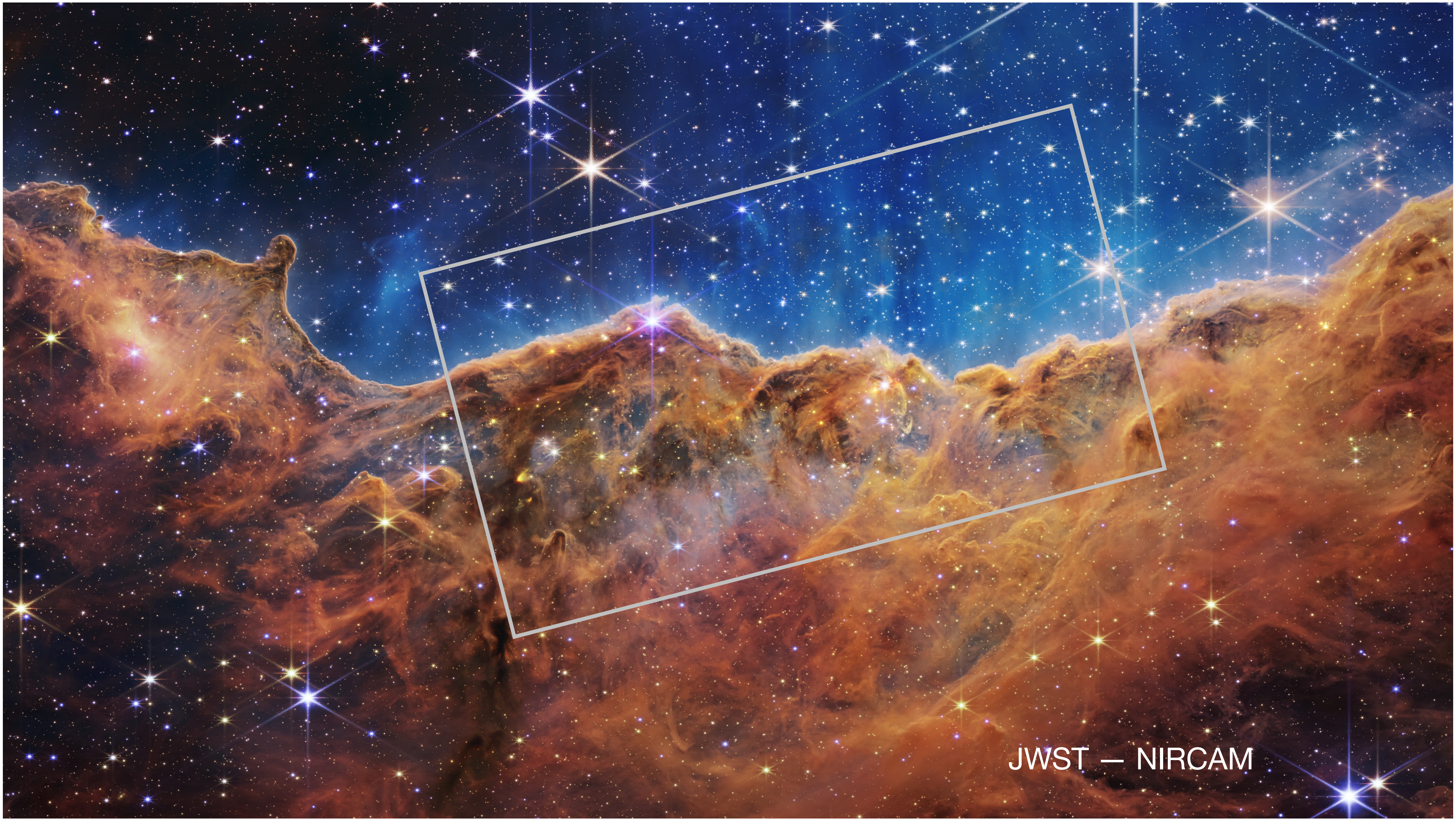
- The strong stellar magnetic field produces large starspots and truncates disk at a few stellar radii.
- Magnetic field lines connected with disk channel material at near free-fall velocities that then shocks at the stellar surface; other magnetic field lines unconnected with the disk produce coronal X-ray emission and/or (unobserved) stellar wind.
- Some field lines become twisted by differential rotation between disk and star, causing field lines to bulge out or even eject matter.
- The inner disk (< 1 AU) produces a bipolar flow or jet, driven by accretion energy; a wind may also be needed to drive disk accretion at larger radii.
- **In general, the mechanisms for transporting mass and angular momentum within the disk are uncertain.**

THE HUMAN EAR

- We have the ability to distinguish the source of a high number of individual sounds simultaneously
  - e.g. Baby crying, Harley-Davidson motorcycle, bird chirping, mosquito buzzing, dog barking, orchestra practicing, …
  - Each of us has developed spectral templates for typical sounds to help ID them
- In astronomy, spectral templates have allowed us to identify physical processes (e.g. shocks, PDRs,

Date: 27 April 2005

From left to right: Tom Phillips, Hal Yorke, Pierre Encrenaz, Paul Harvey, Martin Harwit, Matt Griffin, Göran Pilbratt, Christoffel Waelkens, José Cernicharo, Albrecht Poglitsch, Jacqueline Fischer, Peter Barthel, and Thijs de Graauw. Missing in the picture Gerry Crone and Laurent Vigroux.


JWST — NIRCAM


JWST — MIRI

THE HUMAN EAR

- ca. 15,000 “hairs” in cochlea
- Frequency Response: 20 — 20,000 Hz (significant drop-off at ~15,000 Hz)
- Sensitivity @ 1000 Hz: 0 — 120 dB (6 orders of magnitude energy density)
- Ability to distinguish neighboring frequencies: log ($\Delta\nu$) = 0.0015
- Ability to distinguish high number of individual sources simultaneously
  - e.g. Baby crying, Harley-Davidson motorcycle, bird chirping, mosquito buzzing, dog barking, orchestra practicing, …
  - Each of us has developed templates for typical sounds to help ID them
- By contrast, the full spectral response of eye is mimicked by RGB diodes