The Cold Universe: Science Highlights from the SCUBA-2 Camera

Kate Pattle

Royal Society University Research Fellow

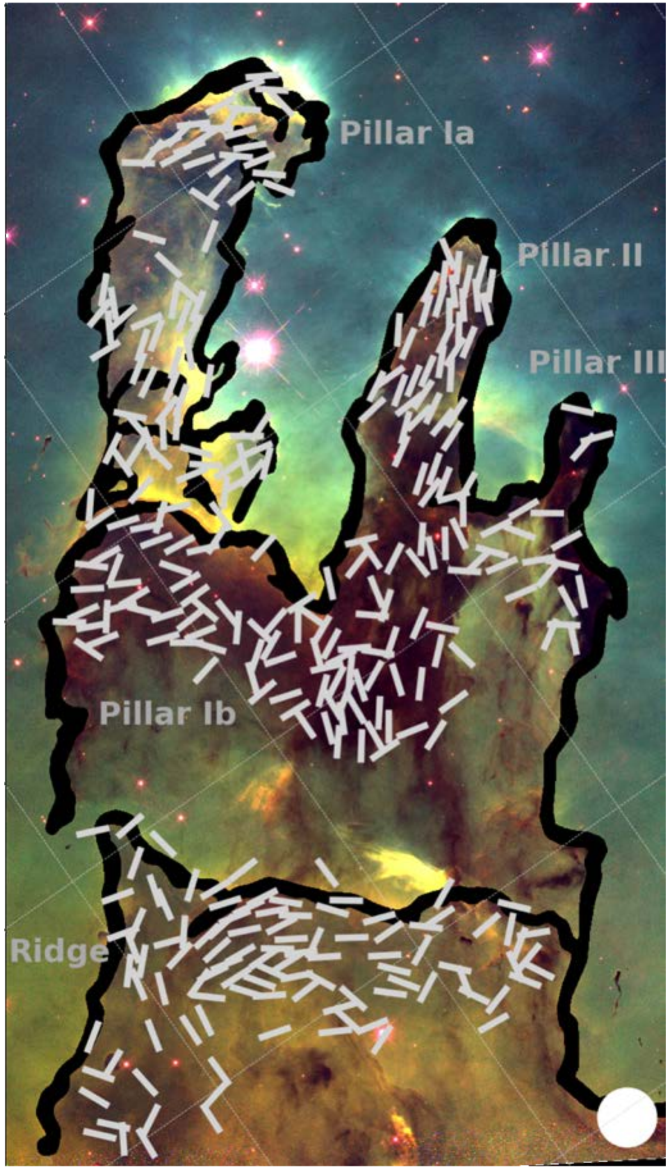
University College London

Tsukuba Global Science Week – 27th September 2022

UCL

THE ROYAL SOCIETY

BISTRO



The Cold Universe

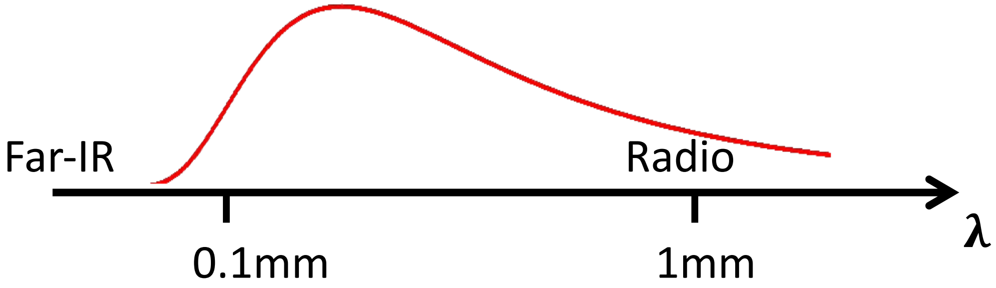
Dense clouds of cold (<100K) molecular hydrogen in which new stars form

The H_2 gas is mixed with "dust" – silicates and carbonaceous compounds – which emits near-blackbody radiation

Dust emission in the Local Universe

Dust at
~10-15 K

100s-1000s
of lightyears

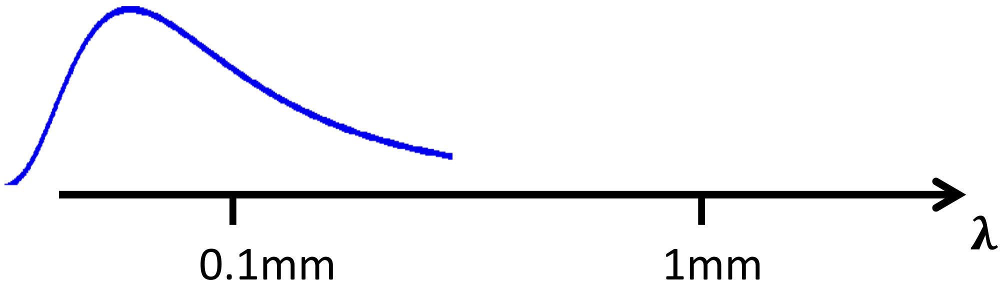


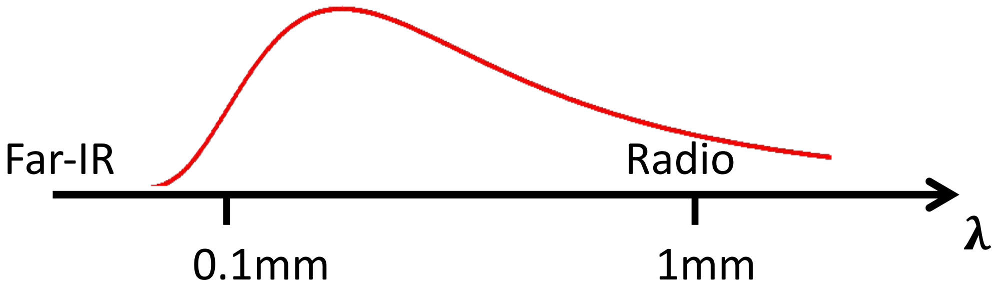
Dust emission at high redshift

Wuyts et al. 2012

Redshift z ~ 2
Dust at ~50 K

Billions of lightyears





The James Clerk Maxwell Telescope

- The JCMT: the largest single-dish submillimetre telescope in the world (15m)
- Operates at the summit of Mauna Kea (~4000m)
- A range of instrumentation:
  - SCUBA-2 camera (850μm & 450μm)
    - POL-2 polarimeter
  - HARP heterodyne array (325-375 GHz)
  - Namakanui heterodyne receiver
    - ʻUʻu (230 GHz)
    - ʻAweoweo (345 GHz)
- Member of the Event Horizon Telescope

The East Asian Observatory

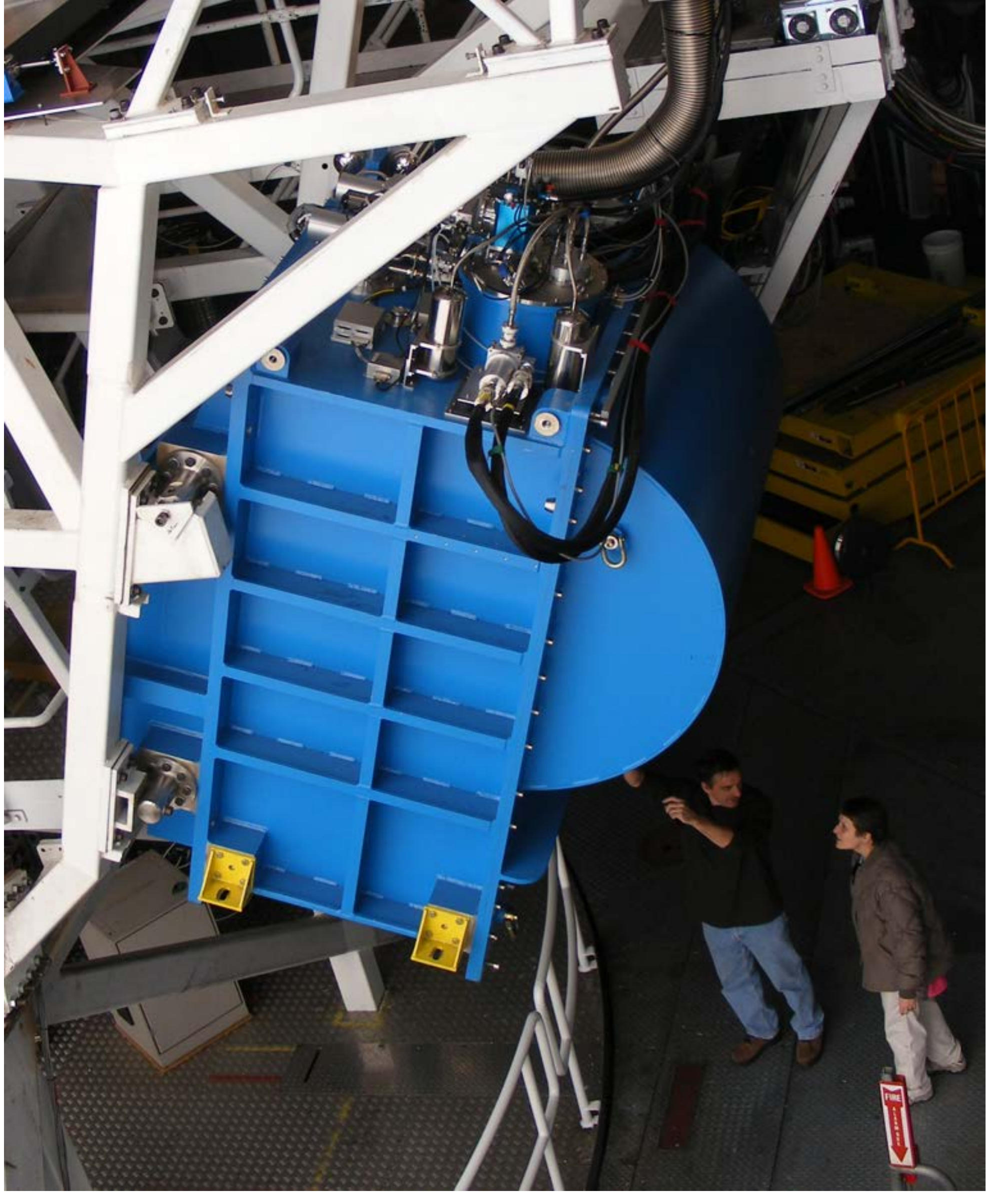
EAO Institutional Partners:
- Center for Astronomical Mega-Science (CAMS) – China
- **National Astronomical Observatory of Japan (NAOJ)**
- Academia Sinica Institute of Astronomy and Astrophysics (ASIAA) – Taiwan
- Korea Astronomy and Space Science Institute (KASI)
- National Astronomical Research Institute of Thailand (NARIT)

EAO Associate Partners:
- The University of Hong Kong (HKU)

EAO Observer Institutions:
- Viet Nam National University Ho Chi Minh City (VNUHCM)
- University of Malaya (UM)
- Institut Teknologi Bandung (ITB) – Indonesia

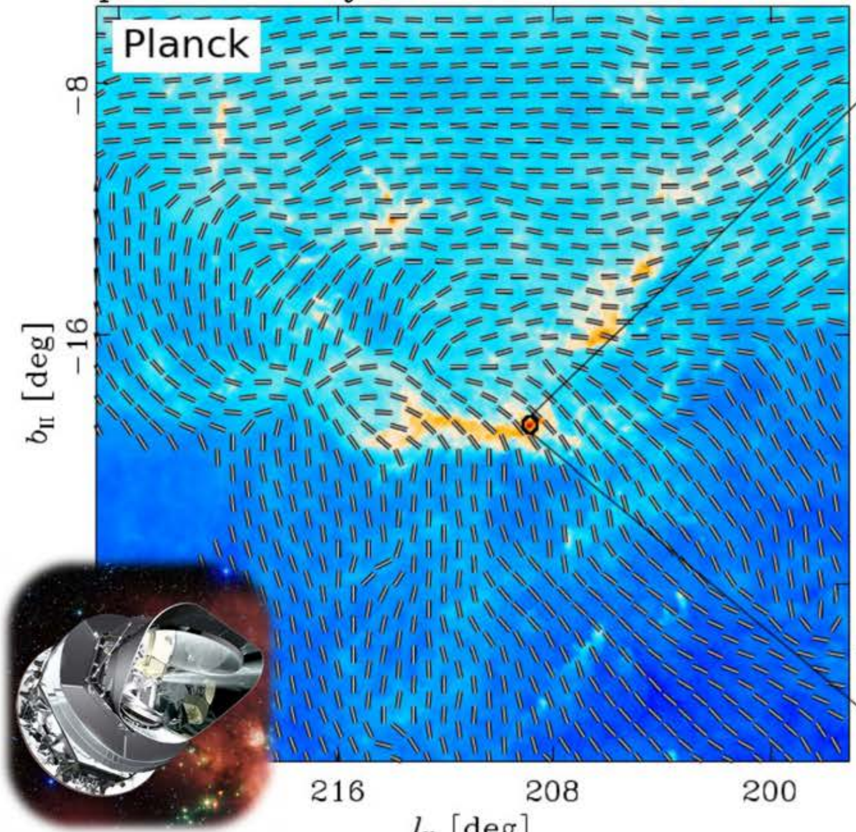
SCUBA-2 on the JCMT

- SCUBA-2: a 10 000-pixel bolometer camera, using transition edge sensors
- Operating simultaneously at 850μm (353 GHz; 14.1″ resolution) and 450μm (667 GHz; 9.6″ resolution)
- Primarily traces dust continuum emission

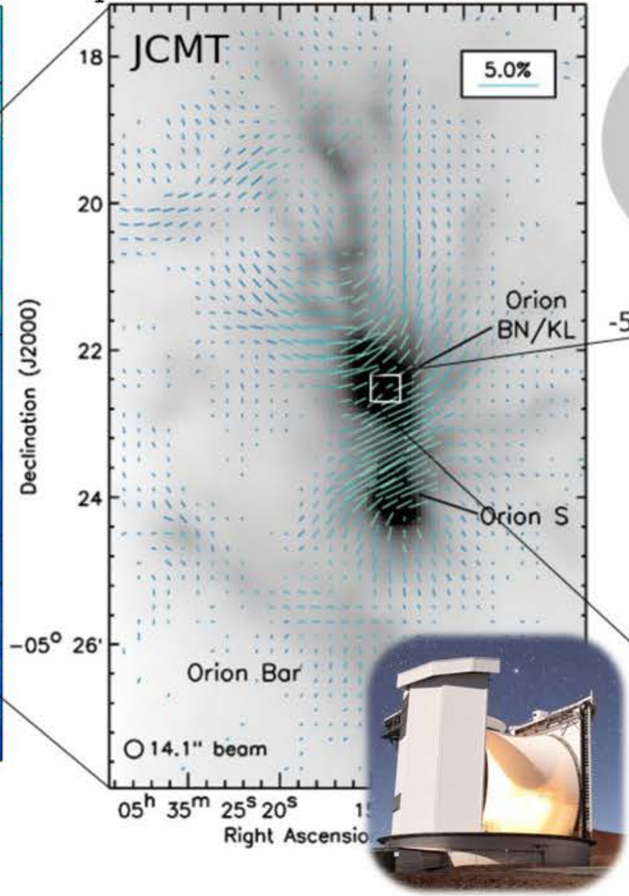


SCUBA-2 on the JCMT: wide-field, high-resolution mapping

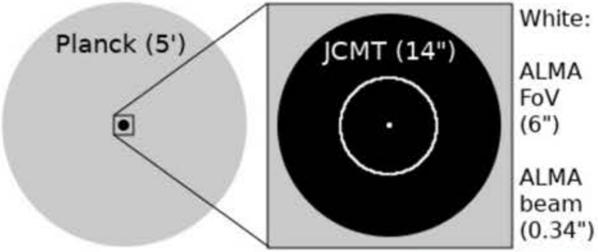
Adapted from Furuya, Pattle et al. 2020, EAO White Paper Series

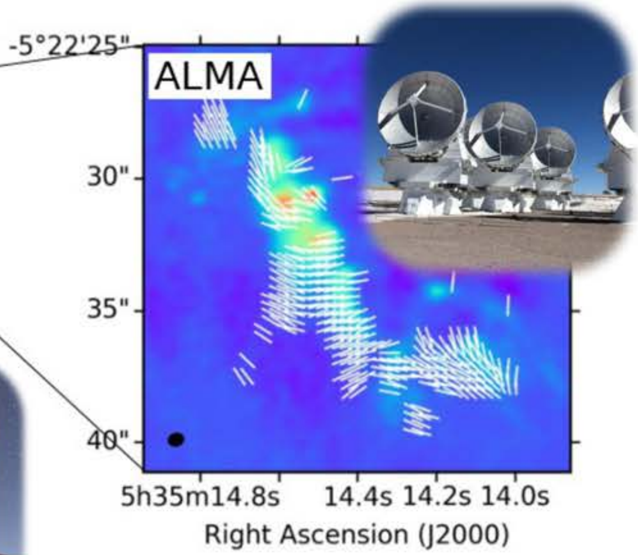


Planck Collab. Int. Results XIX, 2015, A&A 576 A104



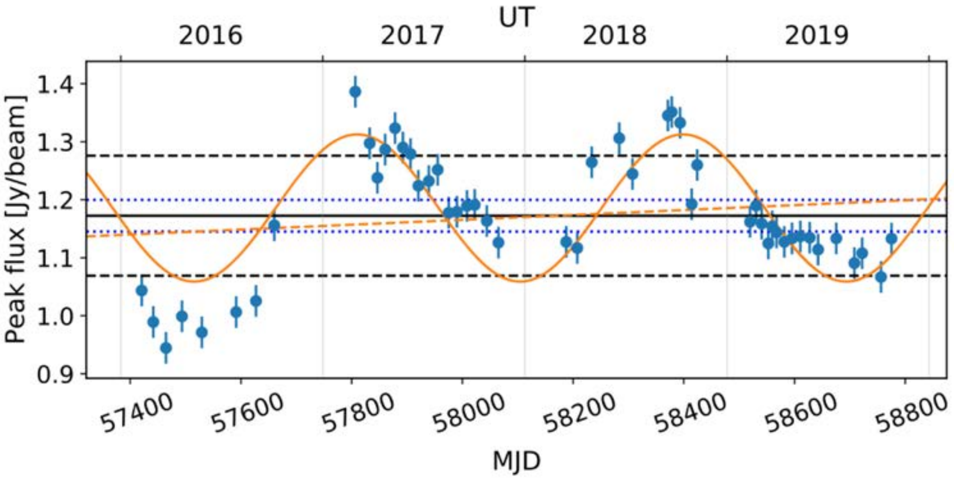
Pattle et al. 2017, ApJ 846 122





Pattle et al. 2021 MNRAS 503 3414

Protostellar Variability



Lee et al. 2021, ApJ 920 119

The Transients Survey: a long-term SCUBA-2 monitoring program

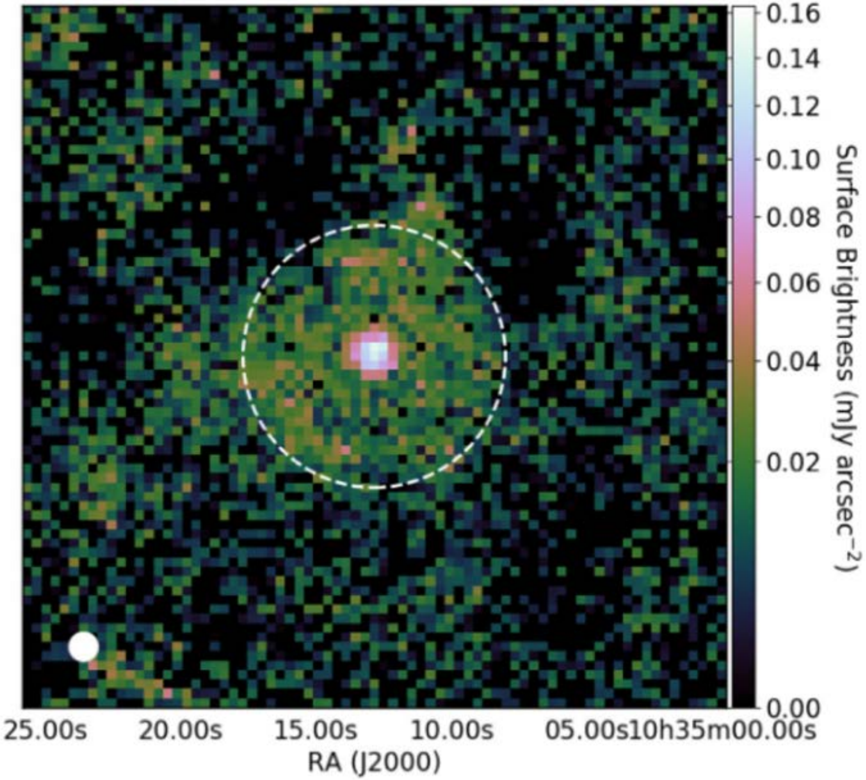
Observing nearby star forming regions (NGC 1333, IC 348, OMC 2/3, NGC 2024, NGC 2071, Ophiuchus, Serpens Main, Serpens South) since 2016

Providing measurements for accretion variability of protostars

Evolved Stars

Asymptotic Giant Branch (AGB) Stars eject mass in the form of a dusty wind.

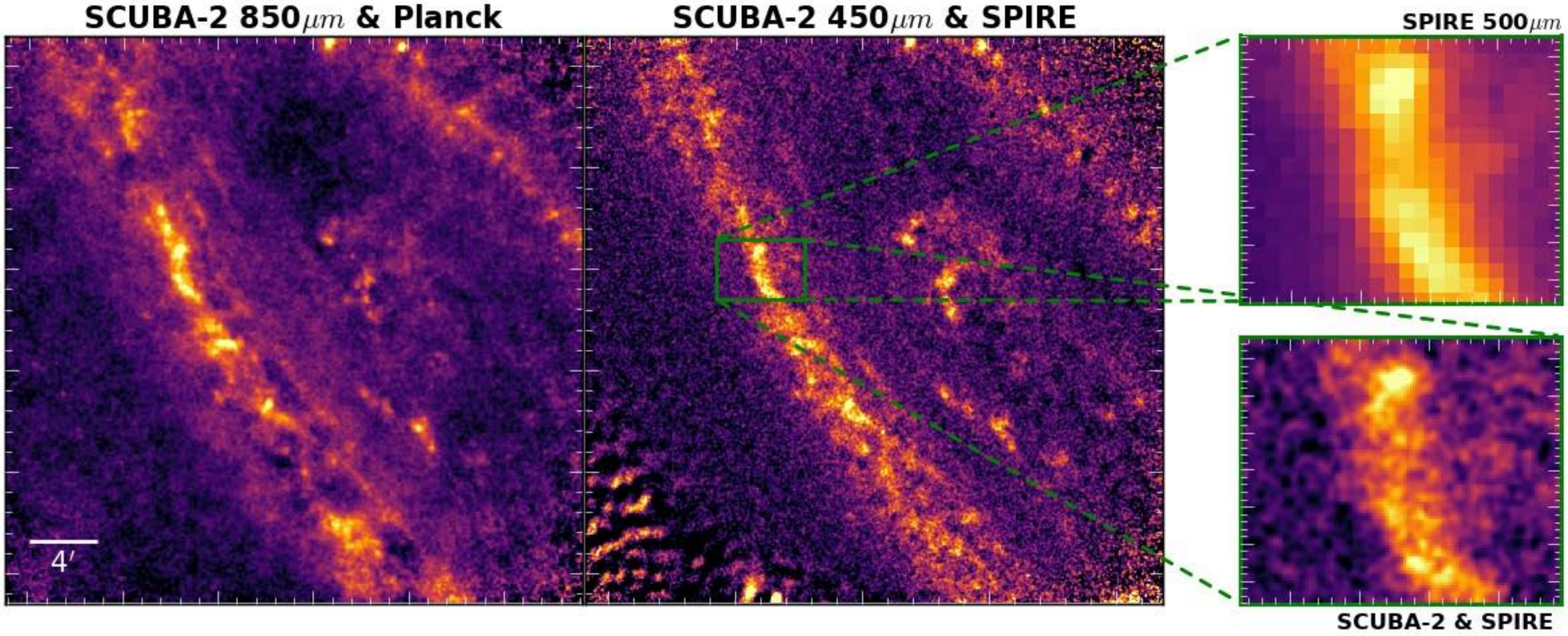
The Nearby Evolved Stars Survey (NESS) targets a volume-limited sample of mass-losing AGB stars to derive the dust and gas return rates in the Solar Neighborhood



The envelope of U Antilae
Dharmawardena et al. 2019, MNRAS 489 3218

Nearby Galaxies

e.g. the HASHTAG Survey: mapping dust in the Andromeda Galaxy

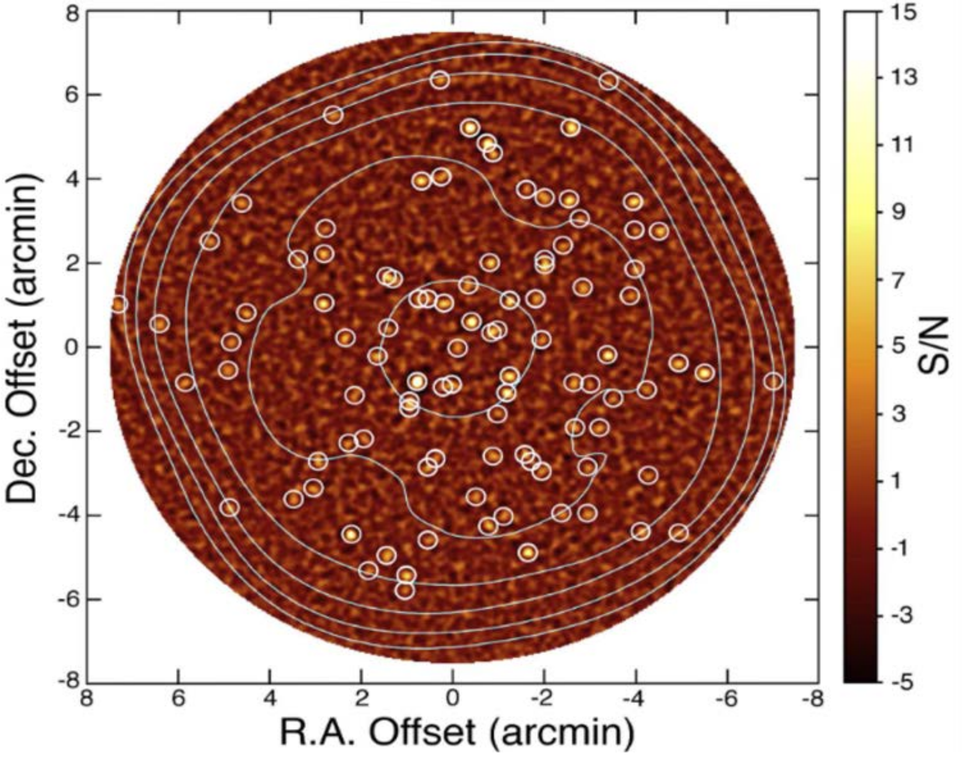


Smith et al. 2021, ApJS 257 52

Submillimeter-bright high-z galaxies

Deep mapping of cosmological fields for number counts and clustering

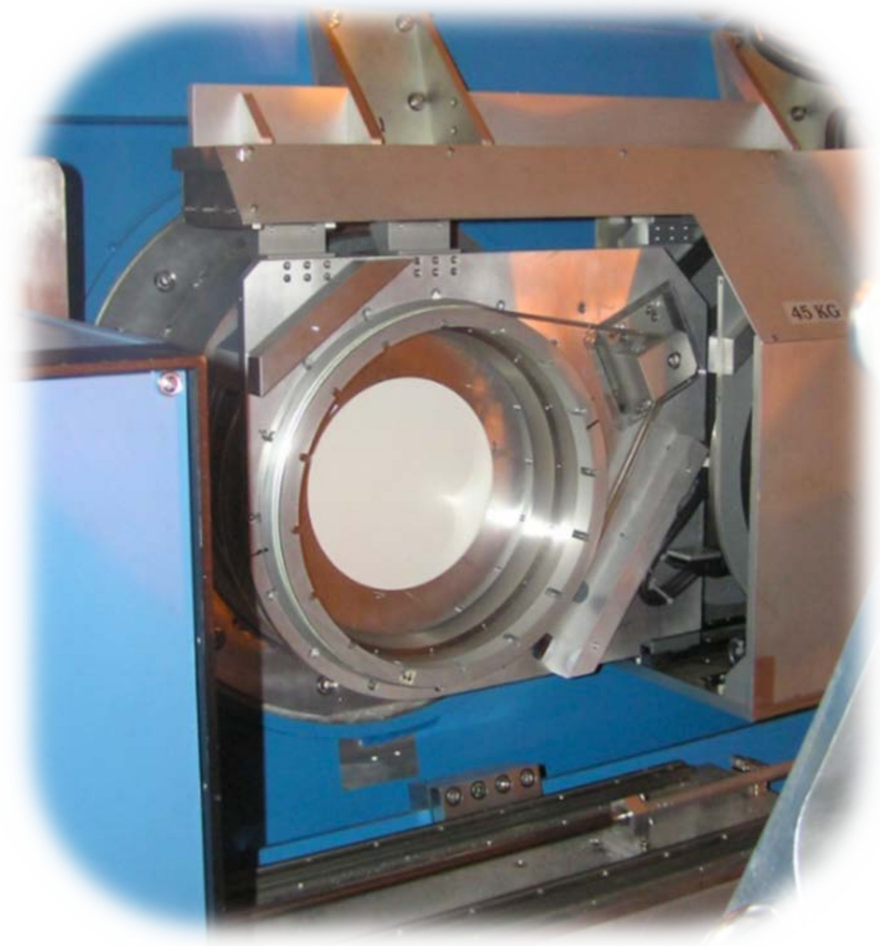
- **S2COSMOS:** wide, 850μm, COSMOS field
- **STUDIES:** deep, 450μm, COSMOS-CANDELS field
- **NEP:** 850μm, North Ecliptic Pole field
- **S2LXS:** very wide, XMM-LSS and E-COSMOS fields



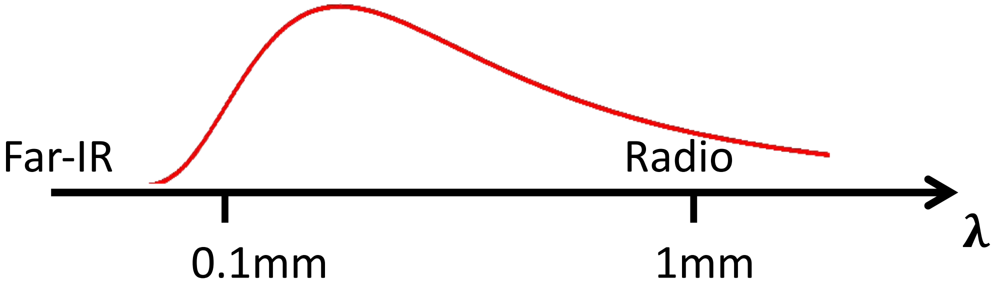
Wang et al. 2017, ApJ 850 37

POL-2 on SCUBA-2

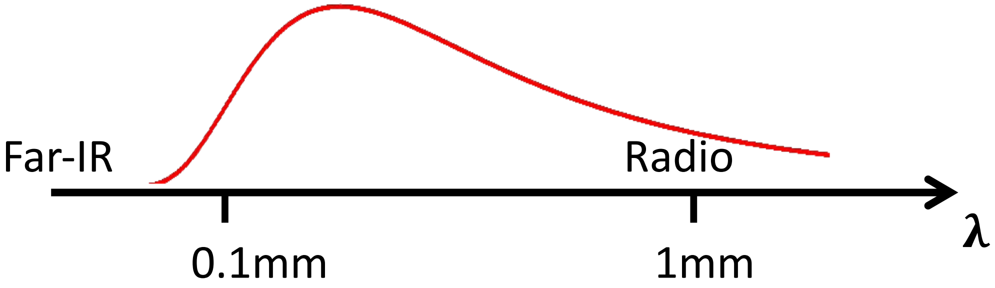
- POL-2: a half-waveplate insertable into the SCUBA-2 light path
- Provides linear polarization measurements
- Can be used to map interstellar magnetic fields and probe dust grain size and composition
- **A unique facility worldwide**



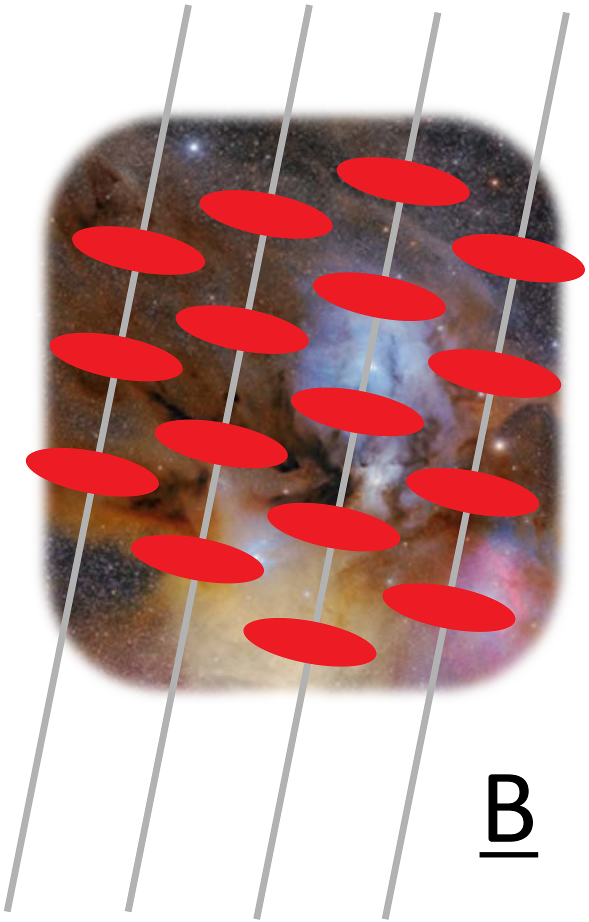
Dust emission polarimetry



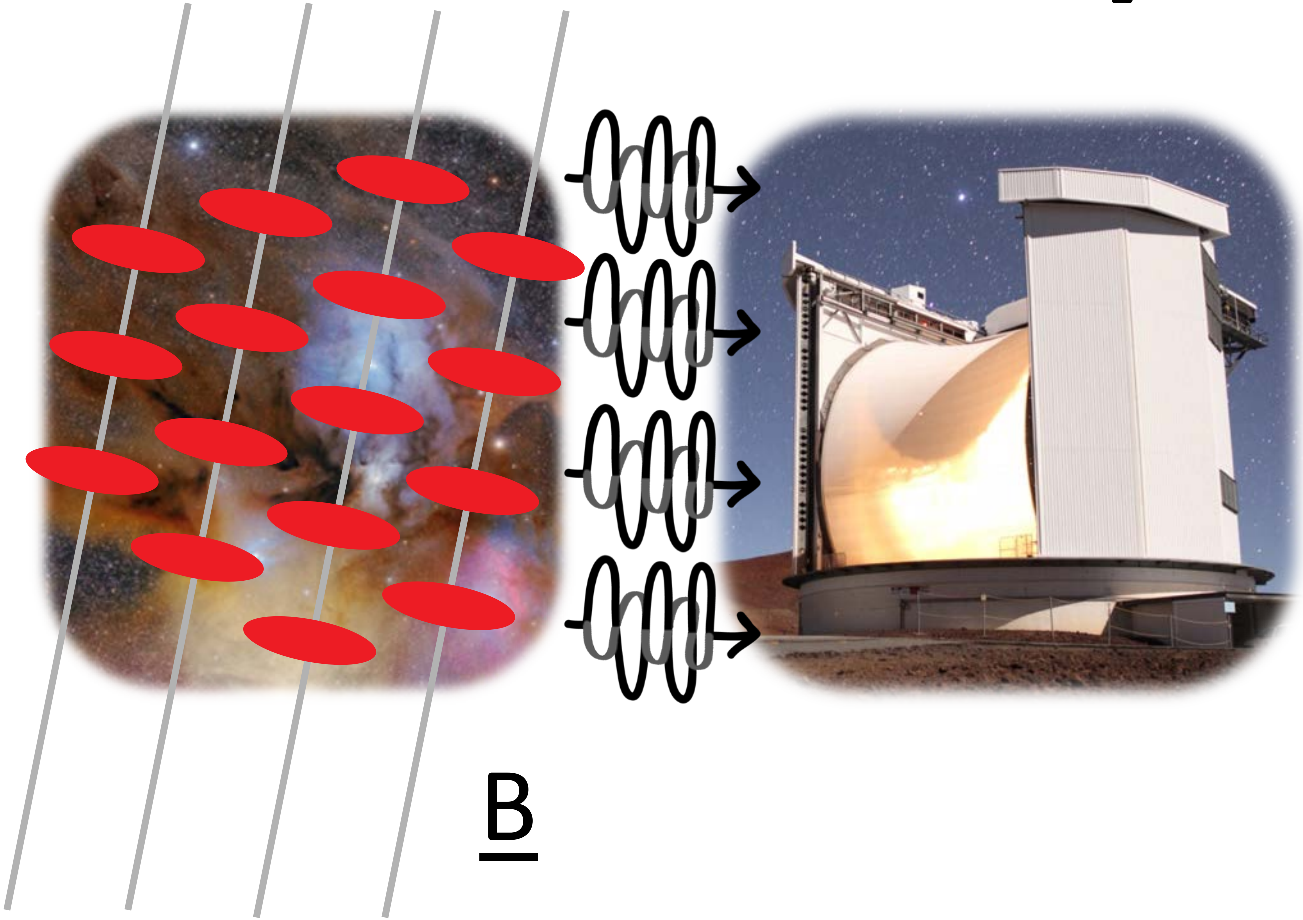
Dust emission polarimetry



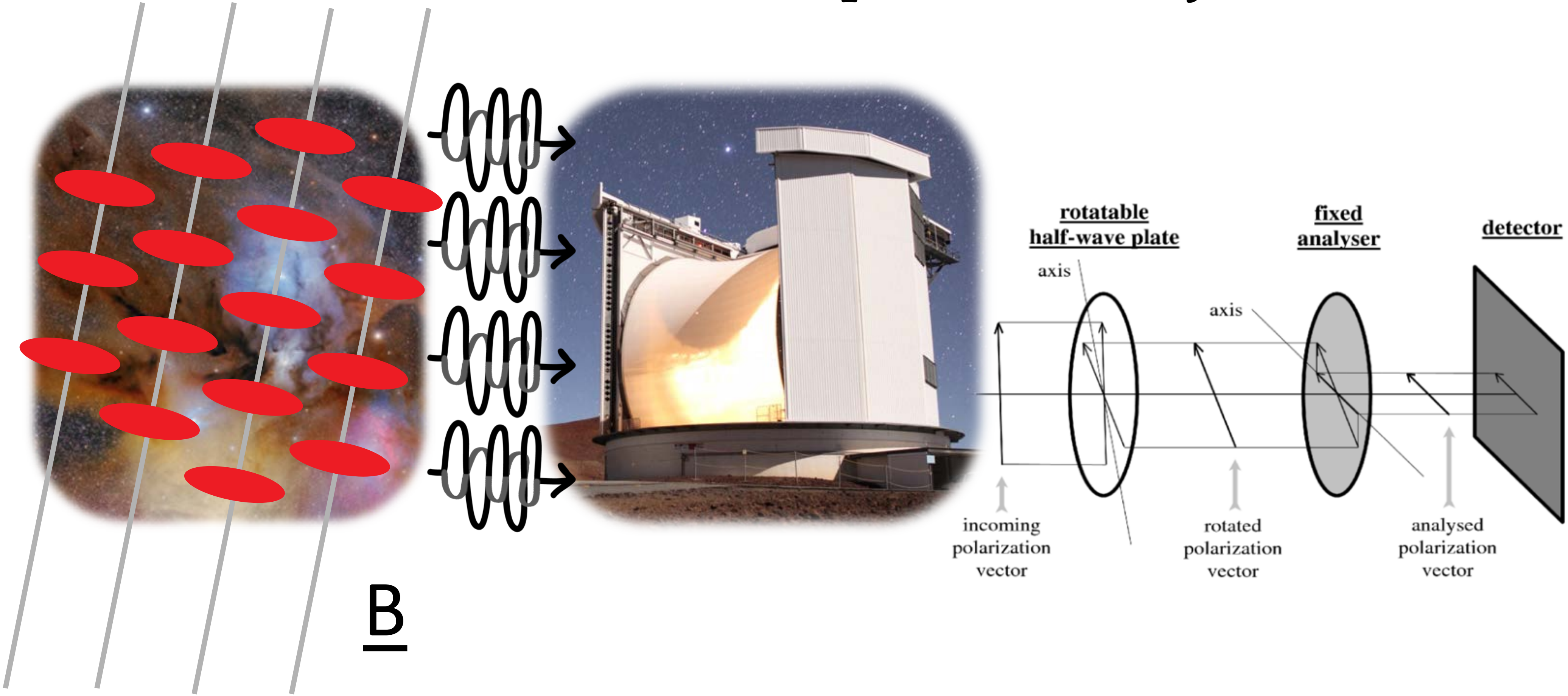
Dust emission polarimetry



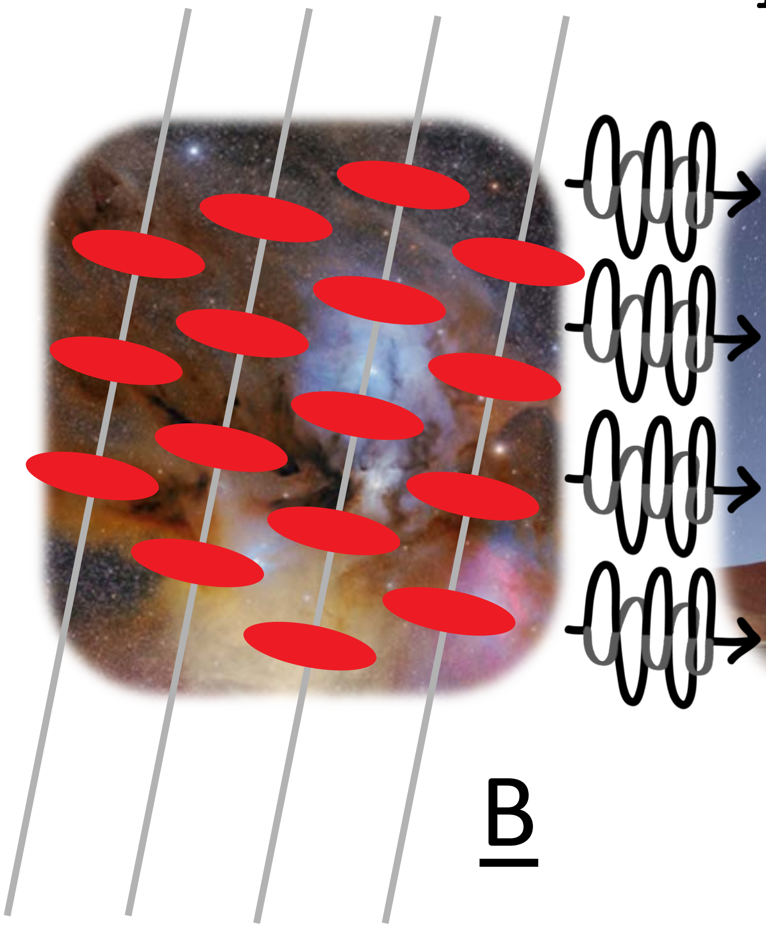
Dust emission polarimetry

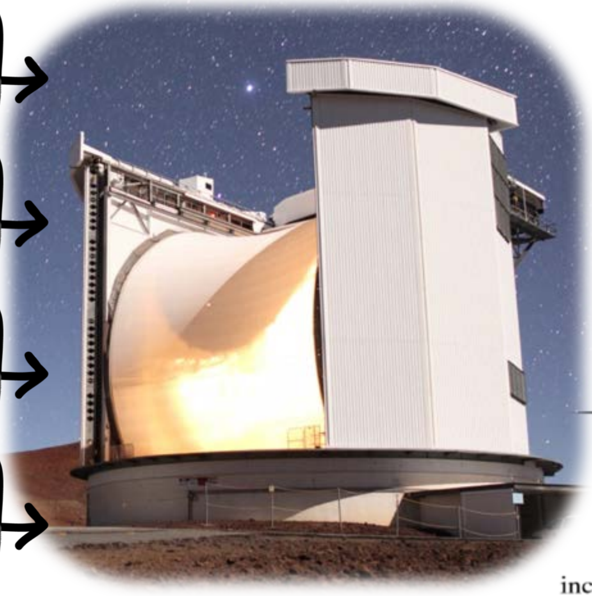


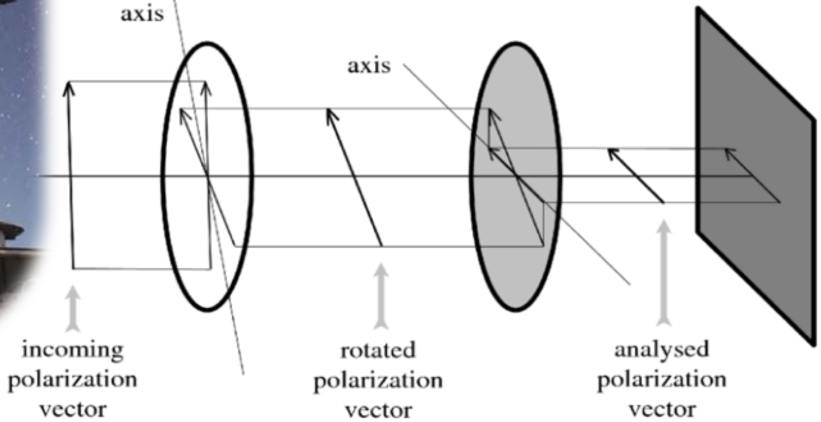
Dust emission polarimetry



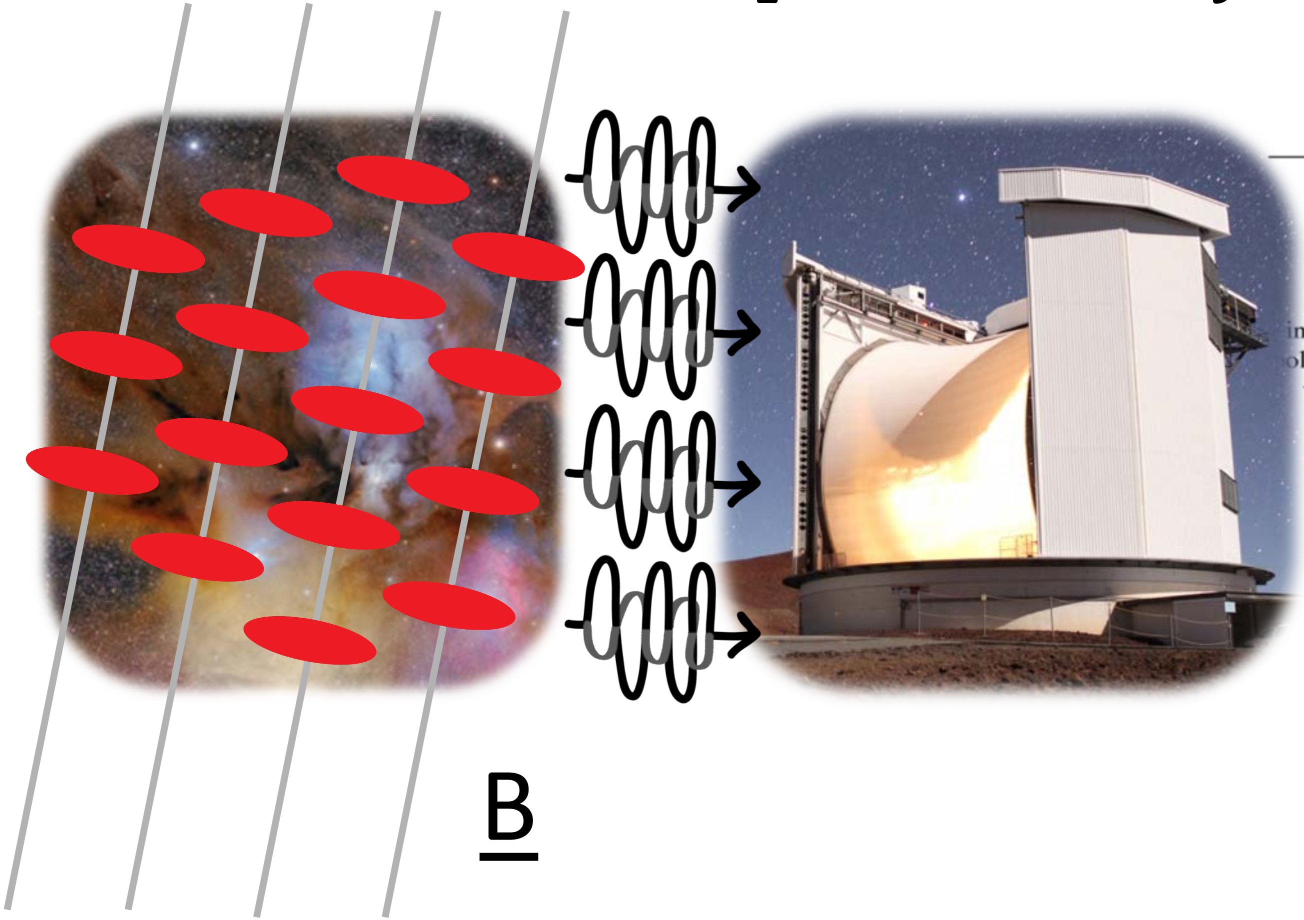
Dust emission polarimetry

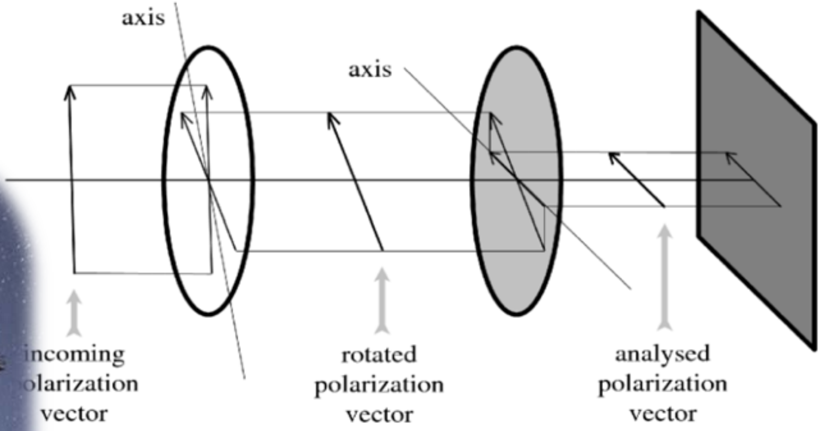






Dust emission polarimetry





Polarization/magnetic field angle:

$$\theta_p = 0.5 \arctan(U, Q)$$

Polarization fraction:

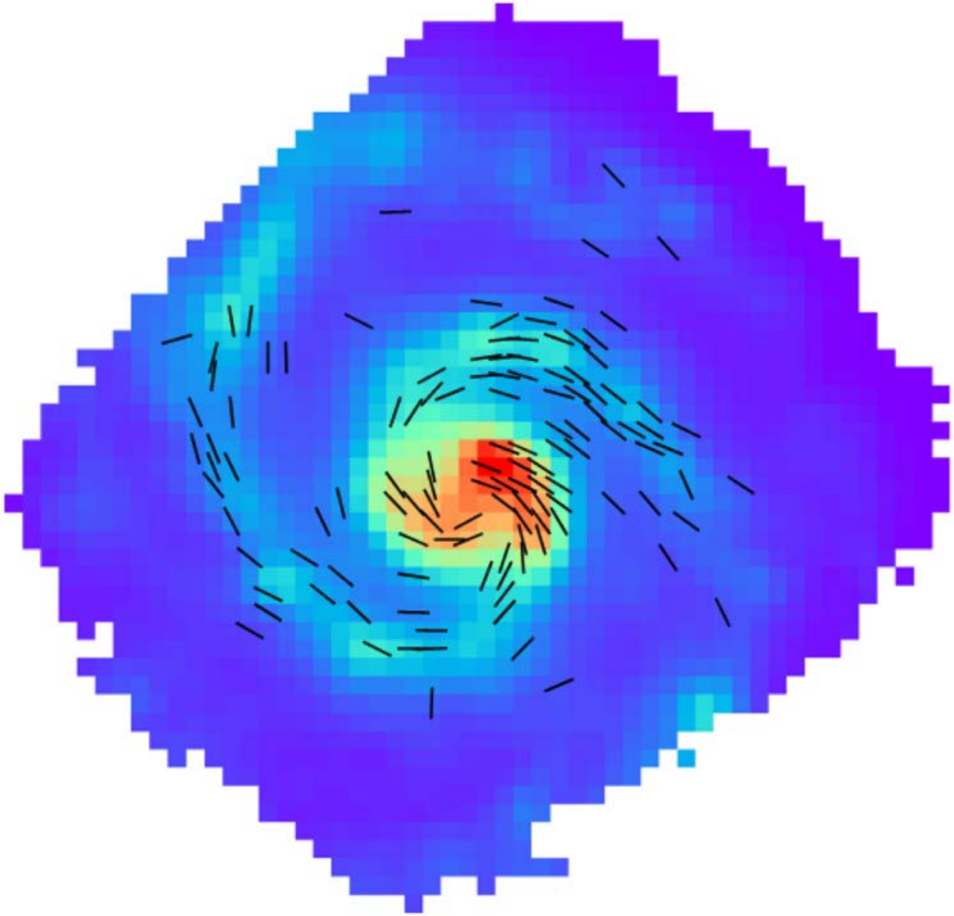
$$p = \frac{\sqrt{Q^2 + U^2}}{I}$$

Galactic dynamos and flux freezing

Magnetic fields are amplified and maintained by a galactic dynamo

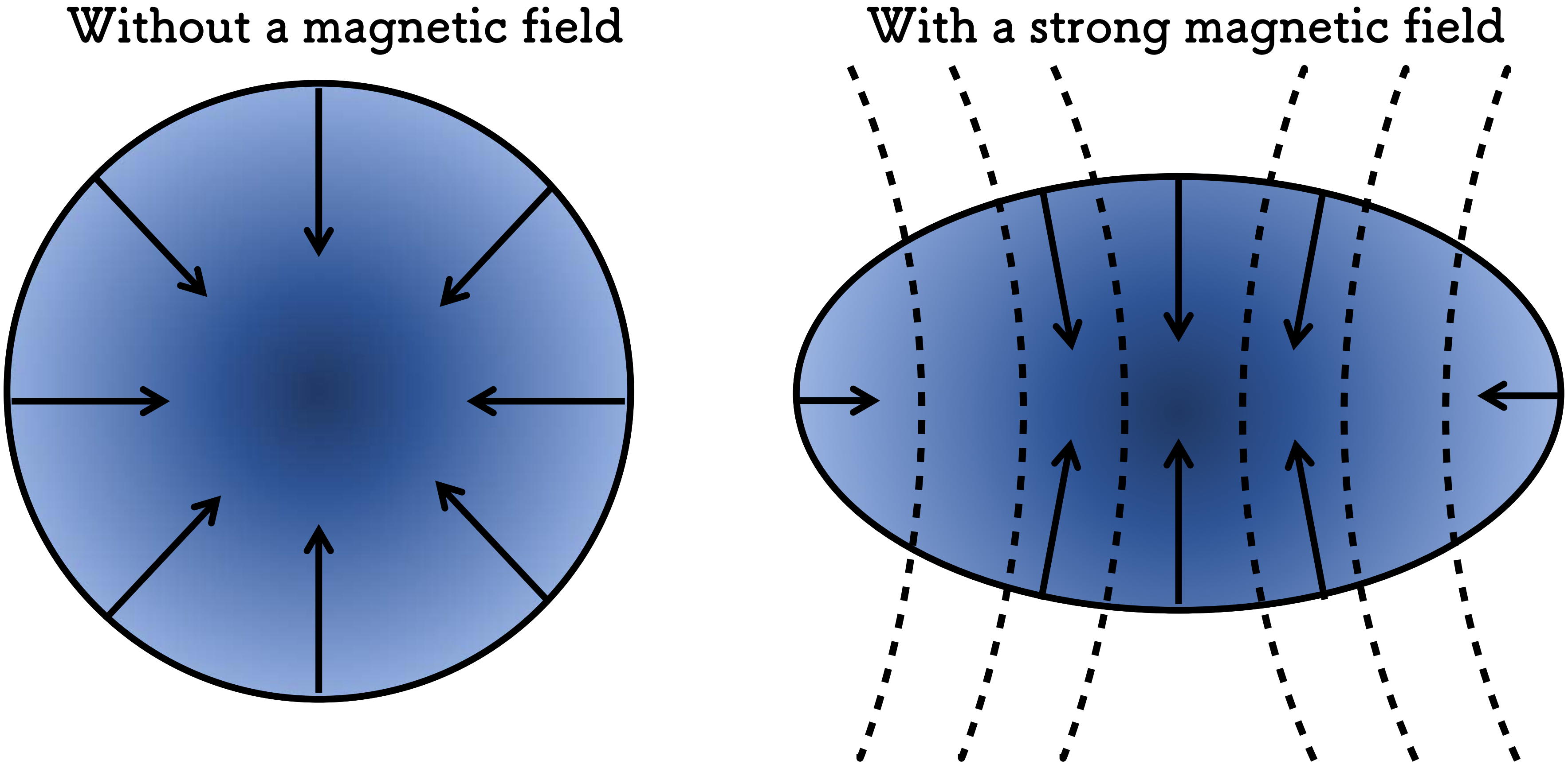
Ion-neutral coupling means that flux-freezing holds and the gas and magnetic field move together despite ionization fractions dropping to < 10^{-7} in the highest-density regions of molecular clouds (e.g. Caselli et al. 1998)

Ionization at high A_V in molecular clouds is maintained by cosmic rays



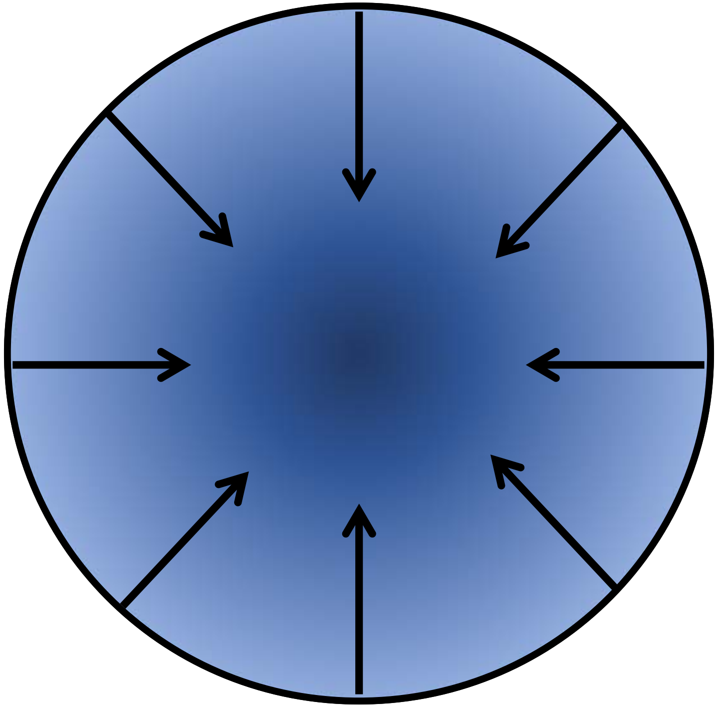
Jones et al. 2019, AJ 160 167

Magnetic fields provide resistance against, and give a preferred direction to, gravitational collapse.

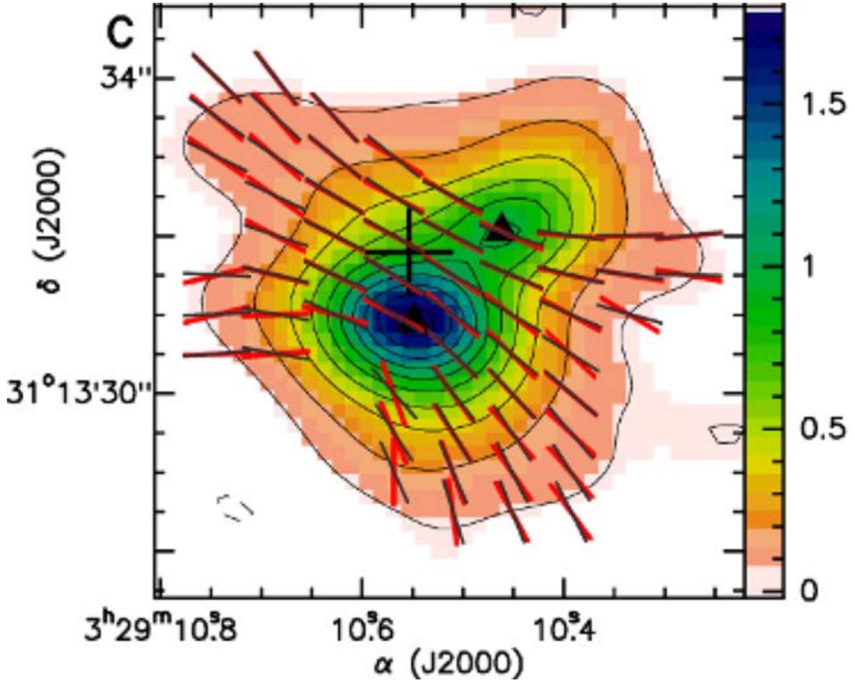


Magnetic fields provide resistance against, and give a preferred direction to, gravitational collapse.

Without a magnetic field

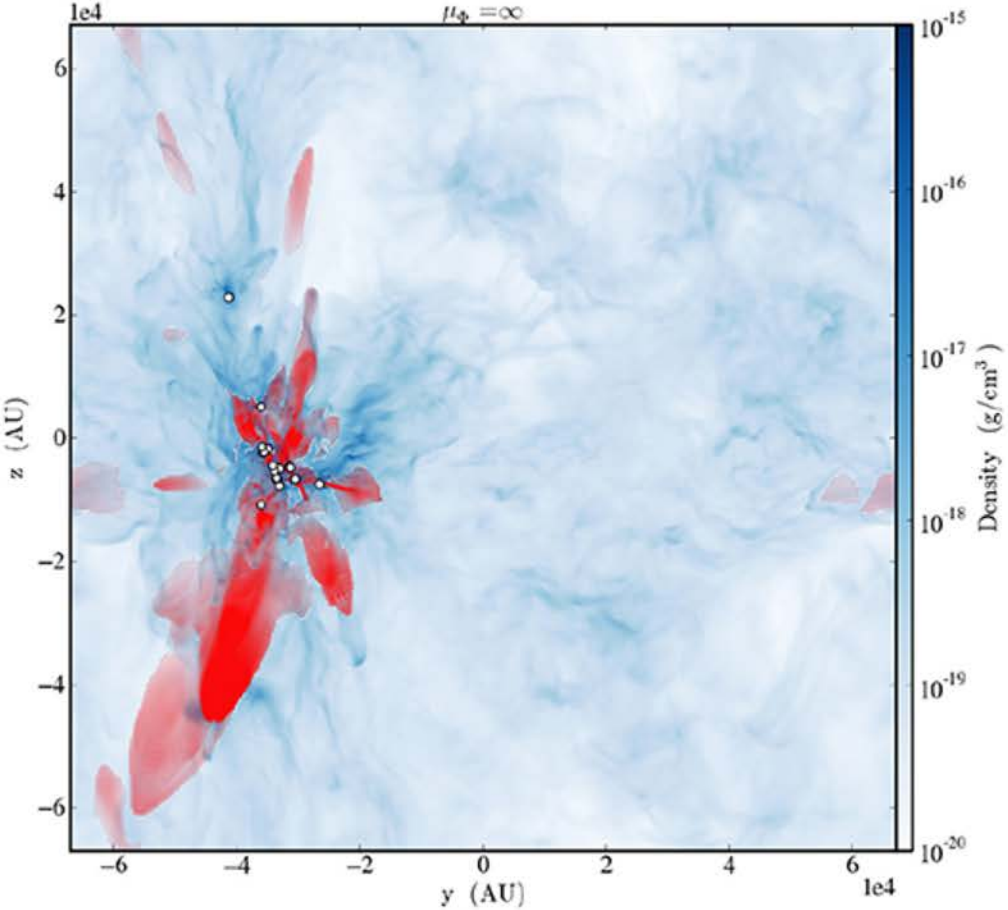


With a strong magnetic field

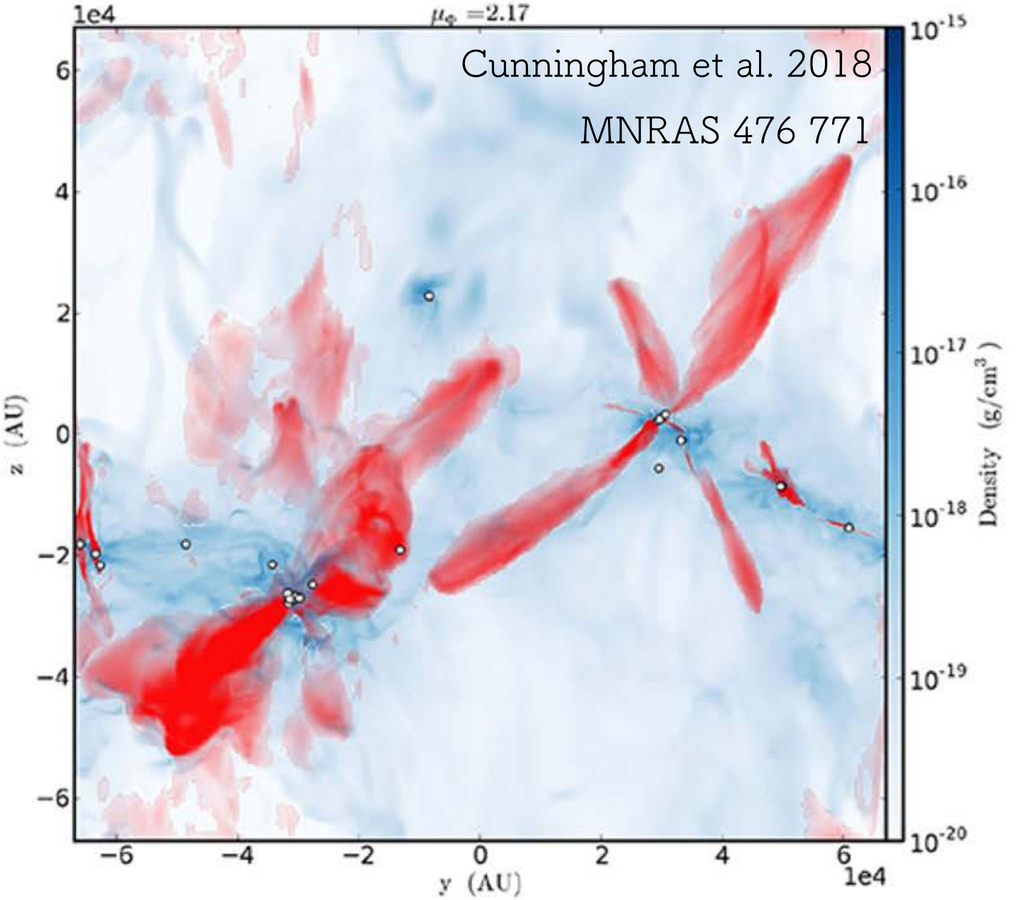


Girart et al. 2006, Science 313 821

Magnetic fields and outflow feedback

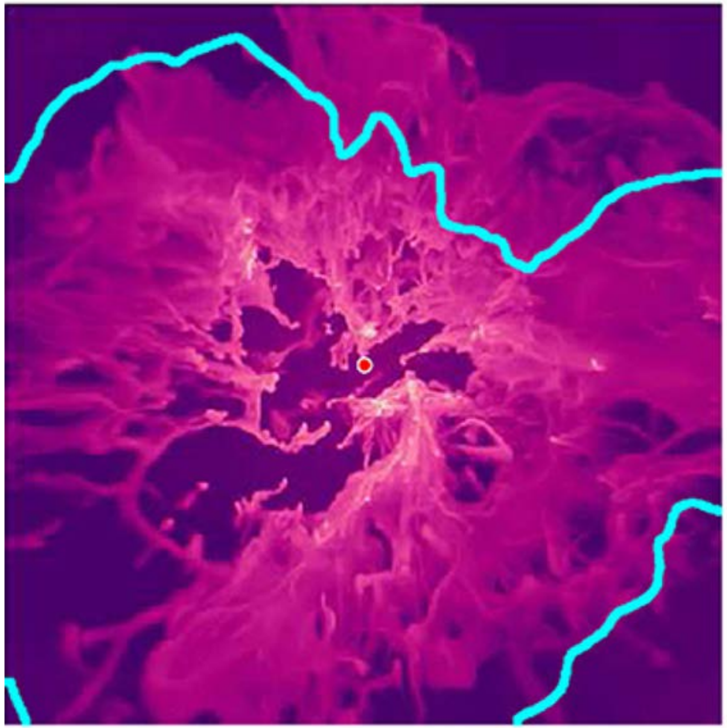


Without a magnetic field

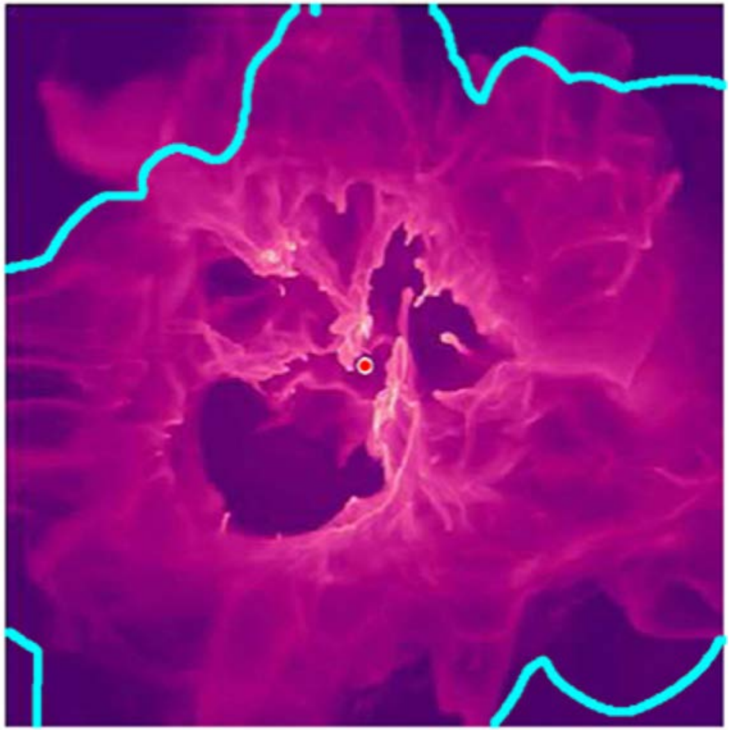


With a magnetic field

Magnetic fields and stellar feedback



Without a magnetic field



With a magnetic field

Geen et al. 2015, MNRAS 454 4484

The JCMT BISTRO Survey

- A James Clerk Maxwell Telescope (JCMT) Large Program mapping Galactic star-forming regions in 850μm and 450μm polarized light with the POL-2 polarimeter
- ~180 survey members across 7 partner regions and the East Asian Observatory.
- P.I.s: Derek Ward-Thompson (UK & Ireland), **Ray Furuya (Japan),** Pierre Bastien (Canada), Keping Qiu (China), Woojin Kwon (Korea), Shih-Ping Lai (Taiwan)

The JCMT BISTRO Survey

- A James Clerk Maxwell Telescope (JCMT) Large Program mapping Galactic star-forming regions in 850μm and 450μm polarized light with the POL-2 polarimeter

---

BISTRO Survey papers to date

Survey paper: Ward-Thompson et al. 2017, ApJ 842 66

Orion A: Pattle et al. 2017, ApJ 846 122

M16: Pattle et al. 2018, ApJL 860 L6

Ophiuchus A: J. Kwon et al. 2018, ApJ 859 4

Ophiuchus B: Soam et al. 2018, ApJ 861 65

Ophiuchus C: Liu et al. 2019, ApJ 877 43

IC5146: Wang et al. 2019, ApJ 876 42

Perseus B1: Coudé et al. 2019, ApJ 877 88

Oph polarization fracs.: Pattle et al. 2019, ApJ 880 27

Perseus NGC 1333: Doi et al. 2020, ApJ 899 28

Outflow/field comparison: Yen et al. 2020, ApJ 907 33

Ophiuchus L1689: Pattle et al. 2021, ApJ 907 88

Auriga: Ngoc et al. 2021, ApJ 908 10

NGC 6334: Arzoumanian et al. 2021, A&A 647 A78

Taurus B213: Eswaraiah et al. 2021, ApJ 912 L27

Rosette: Könyves et al. 2021, ApJ 913 57

More Orion A: Hwang et al. 2021, ApJ 913 85

Orion B: Lyo et al. 2021, 918 85

NGC 1333 filament widths: Doi et al. 2021, ApJL 923 L9

Serpens Main: W. Kwon et al. 2022, ApJ 926 163

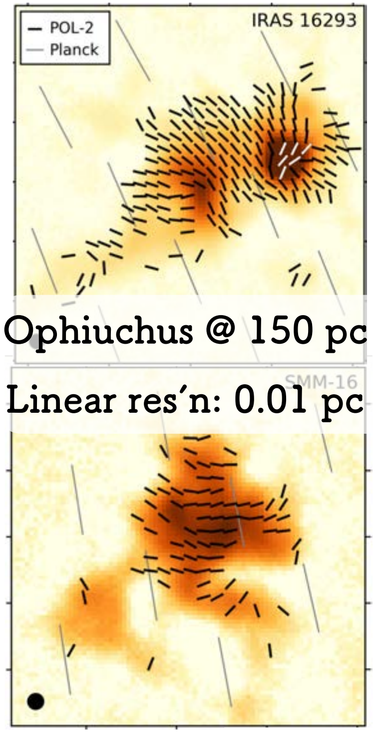
Field vs. core rotation axis: Gupta et al. 2022, ApJ 930 61

Orion B multiwavelength: Fanciullo et al. 2022, MNRAS 512 1985

Ordered and linear fields in low-mass star-forming cores

Pattle et al. 2021

ApJ 907 88



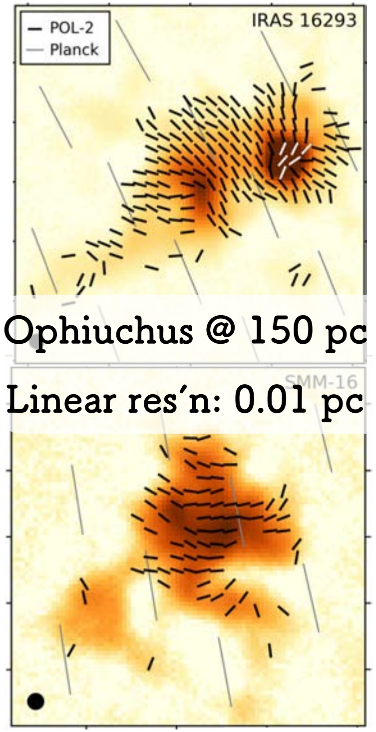
Ophiuchus @ 150 pc

Linear res'n: 0.01 pc

BISTRO

Ordered and linear fields in low-mass star-forming cores

Pattle et al. 2021 ApJ 907 88

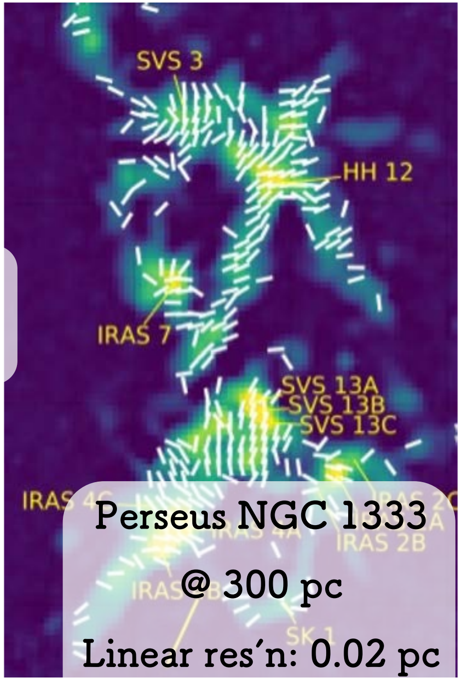


Ophiuchus @ 150 pc

Linear res'n: 0.01 pc

Fields consistently perpendicular to dense filaments

Doi et al. 2020, ApJ 899 28



Perseus NGC 1333 @ 300 pc

Linear res'n: 0.02 pc

Ordered and linear fields in low-mass star-forming cores

Pattle et al. 2021

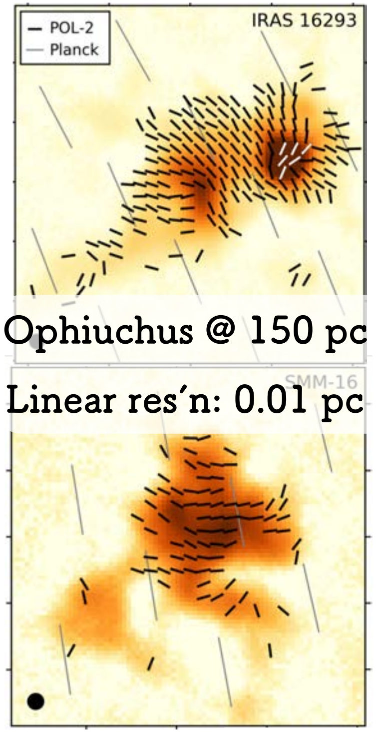
ApJ 907 88

Fields consistently perpendicular to dense filaments

Doi et al. 2020, ApJ 899 28

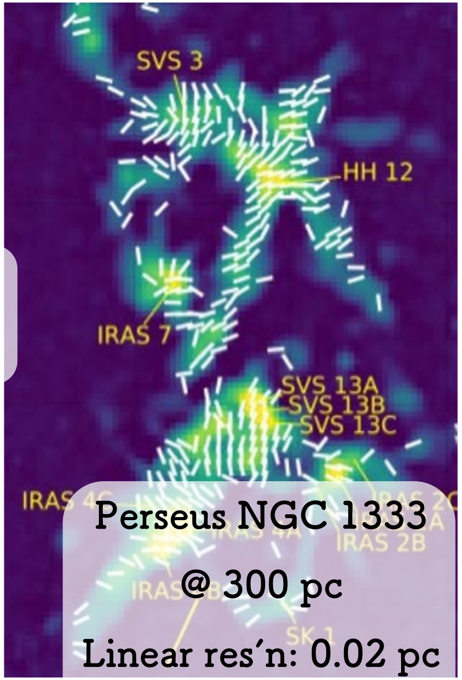
Magnetised accretion onto high-mass star-forming ridges

Arzoumanian et al. 2021, A&A 647 A78



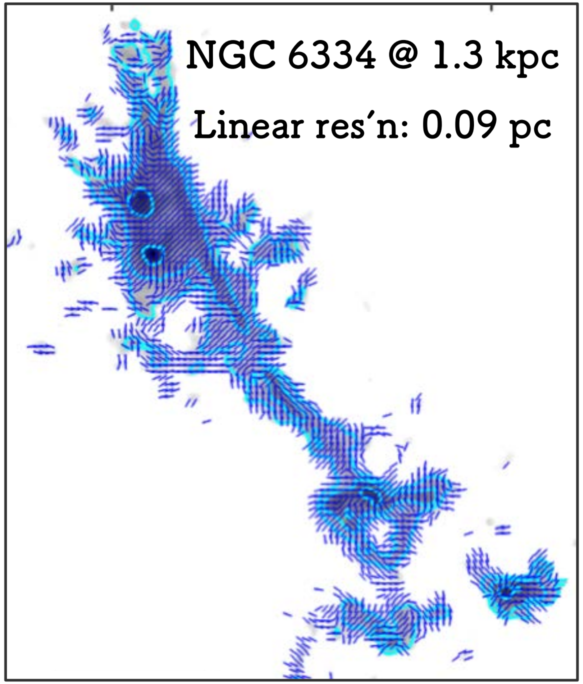
Ophiuchus @ 150 pc

Linear res'n: 0.01 pc



Perseus NGC 1333 @ 300 pc

Linear res'n: 0.02 pc



NGC 6334 @ 1.3 kpc

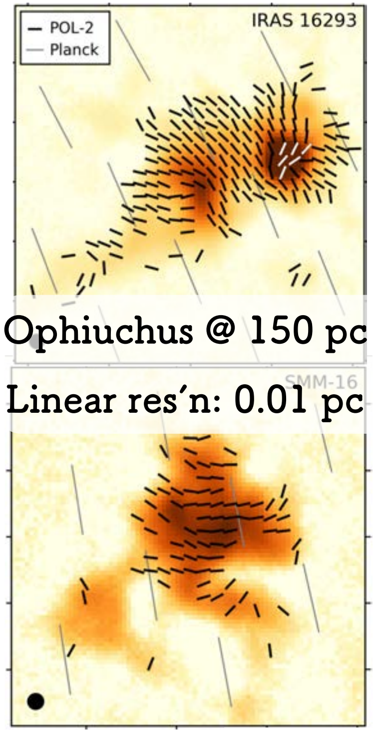
Linear res'n: 0.09 pc

The first measurements of magnetic fields within PDR columns: fields are reshaped under feedback

Pattle et al. 2018, ApJL 860 L6

Ordered and linear fields in low-mass star-forming cores

Pattle et al. 2021 ApJ 907 88

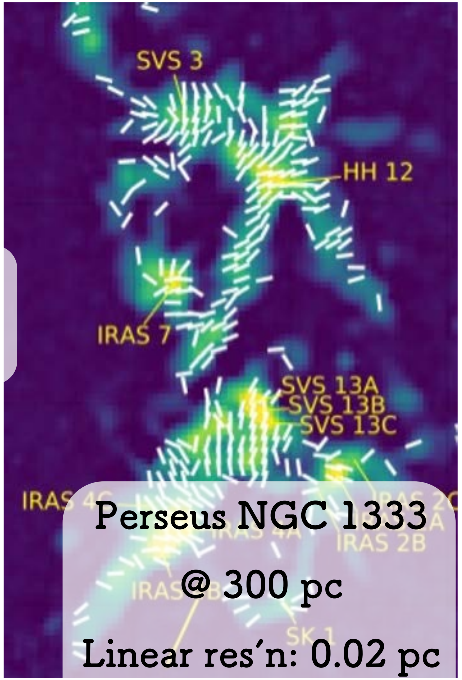


Ophiuchus @ 150 pc

Linear res'n: 0.01 pc

Fields consistently perpendicular to dense filaments

Doi et al. 2020, ApJ 899 28

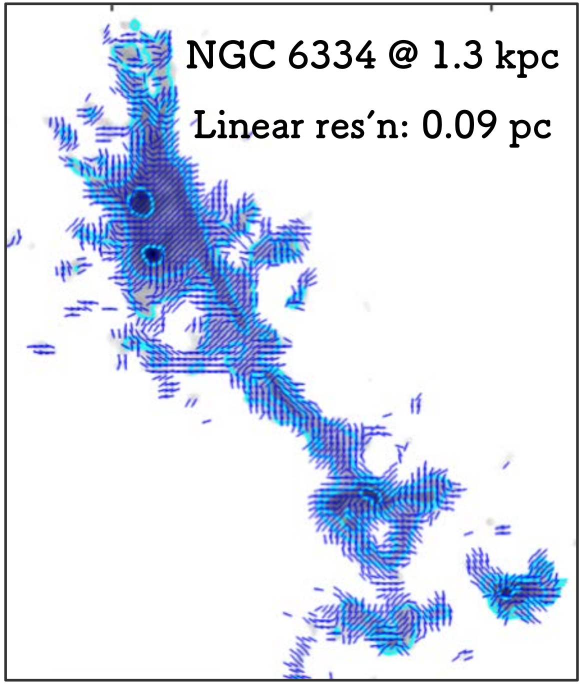


Perseus NGC 1333 @ 300 pc

Linear res'n: 0.02 pc

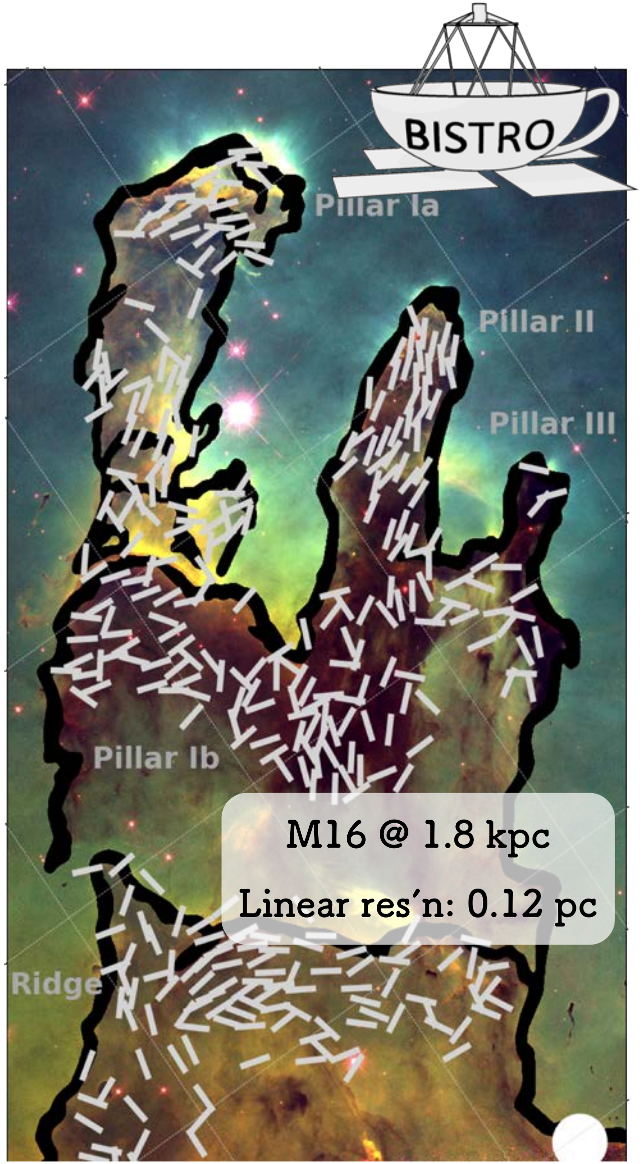
Magnetised accretion onto high-mass star-forming ridges

Arzoumanian et al. 2021, A&A 647 A78



NGC 6334 @ 1.3 kpc

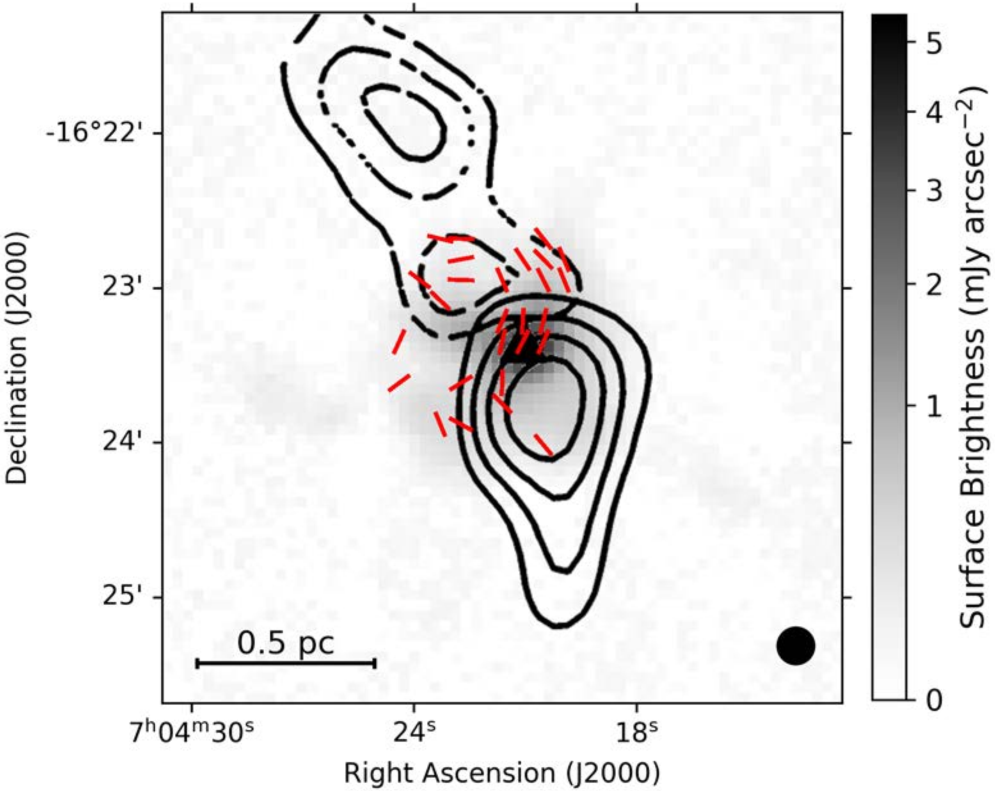
Linear res'n: 0.09 pc



M16 @ 1.8 kpc

Linear res'n: 0.12 pc

Feedback effects: protostellar outflows

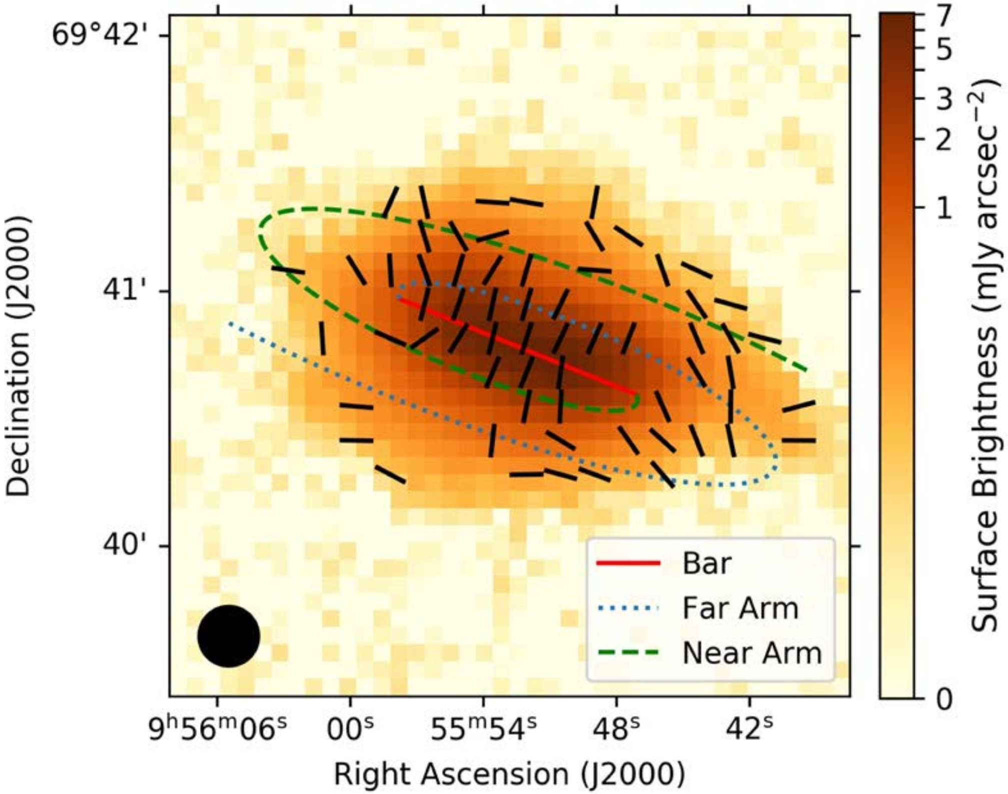


Pattle et al. 2022, MNRAS 515 1026

- Magnetic fields in the vicinity of outflows may be distorted, and/or dust polarization observations may preferentially trace magnetic fields in outflow cavity walls
- Both spectral line and dust polarization measurements are needed to disentangle the physics of the interstellar medium

Magnetic fields in nearby galaxies: M82

Credits: NASA, ESA and the Hubble Heritage Team (STScI/AURA)

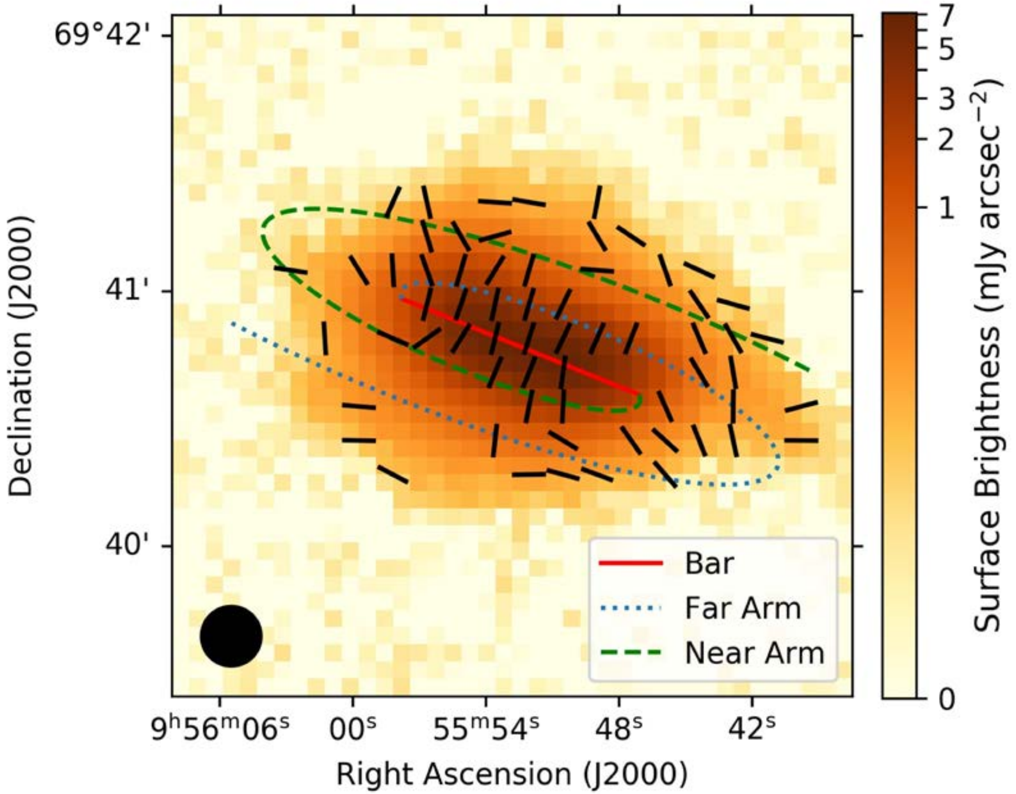


Pattle et al. 2021, MNRAS 505 684

Magnetic fields in nearby galaxies: M82

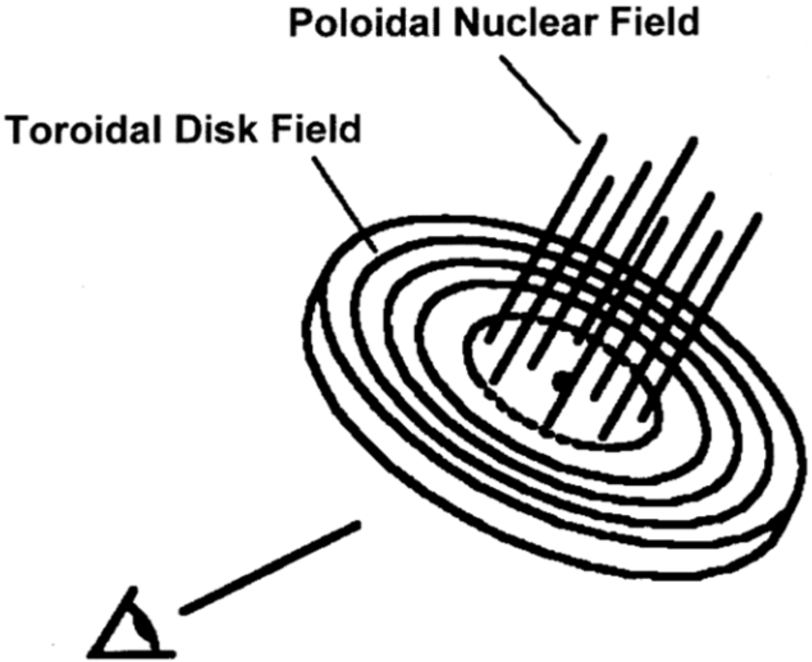
The 850μm polarized dust emission appears to trace:

- a poloidal magnetic field in the central starburst at small galactocentric radii, and
- a spiral-arm-aligned or toroidal field in the disc at large galactocentric radii.

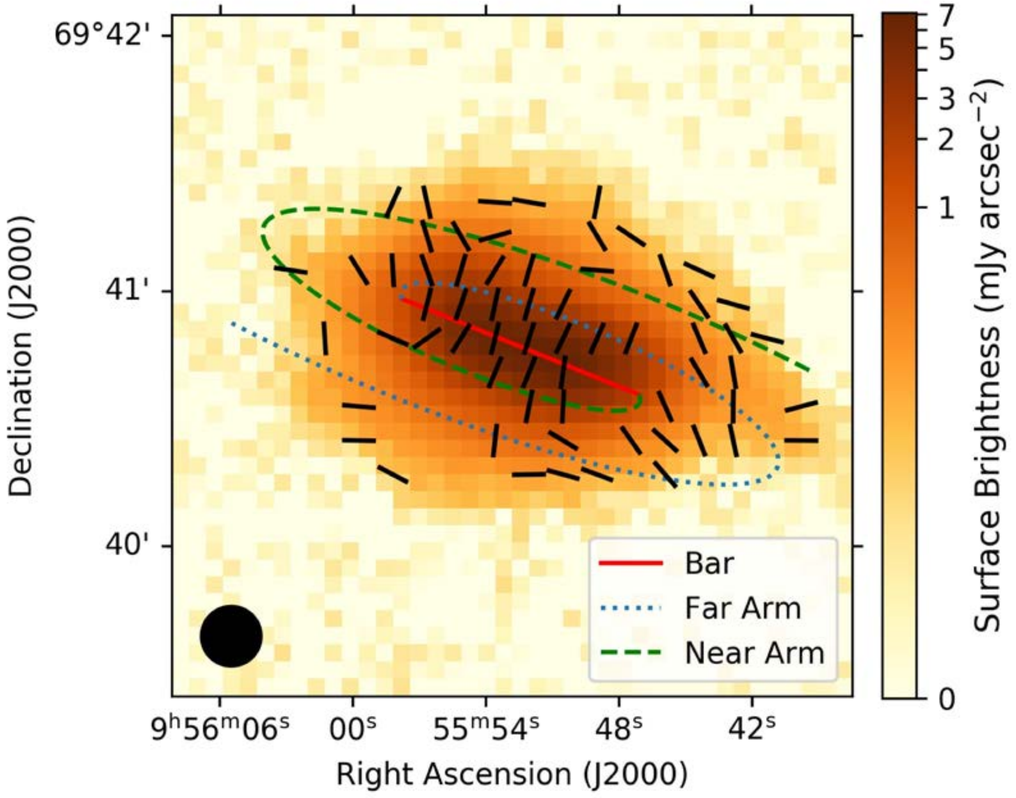


Pattle et al. 2021, MNRAS 505 684

Magnetic fields in nearby galaxies: M82



Jones 2000, AJ 120 2920



Pattle et al. 2021, MNRAS 505 684

The JCMT Semester 23A Call for Proposals is now open!

https://www.eaobservatory.org/jcmt/2022/09/call-for-proposals-23a/

Deadline: **12th October**

Thank you!