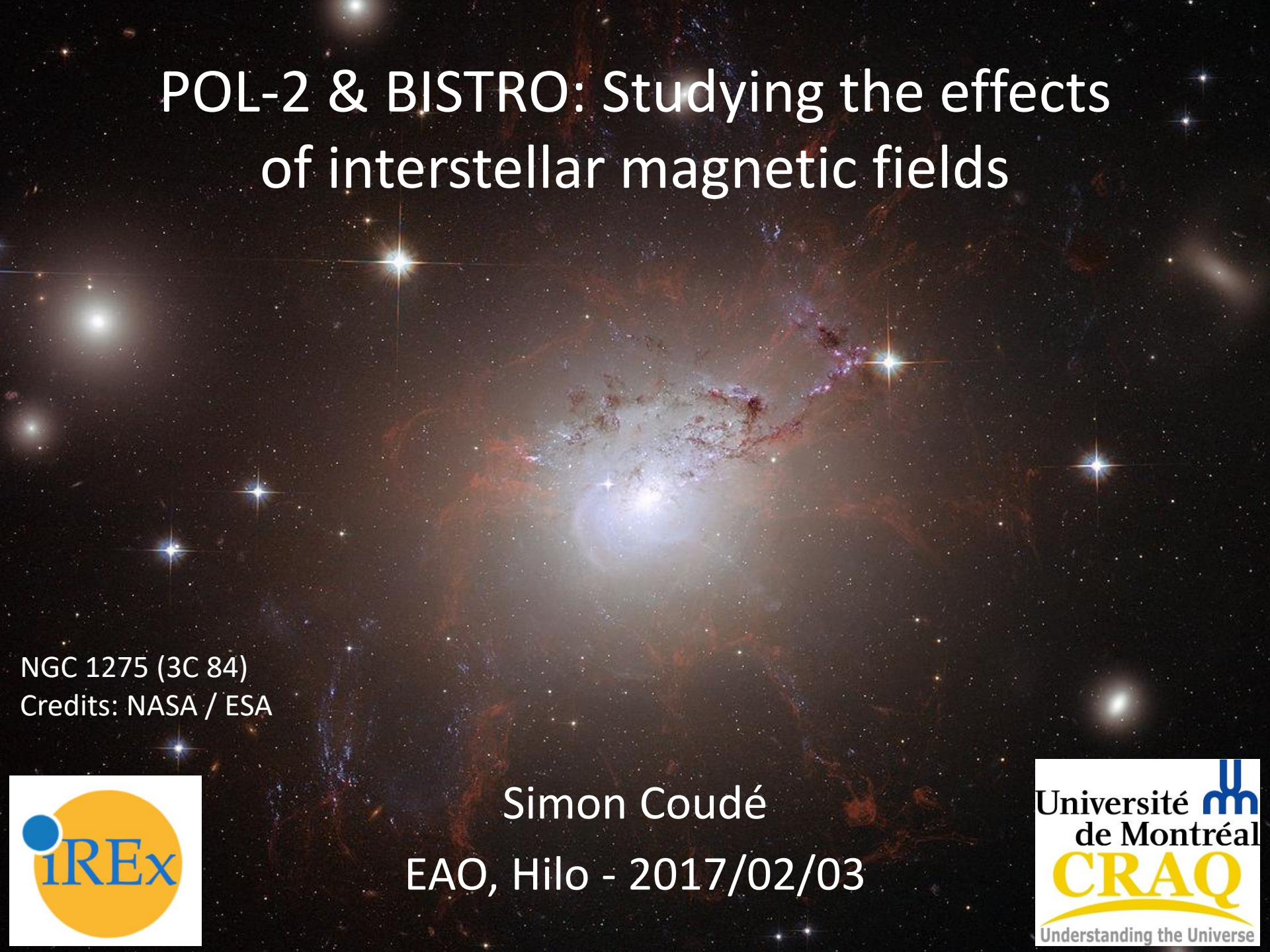
POL-2 & BISTRO: Studying the effects of interstellar magnetic fields



NGC 1275 (3C 84)
Credits: NASA / ESA

Simon Coudé

EAO, Hilo - 2017/02/03

Summary

1. A new age of sub-mm/mm polarimetry
   - Current landscape
   - POL-2 and the synergies of the JCMT

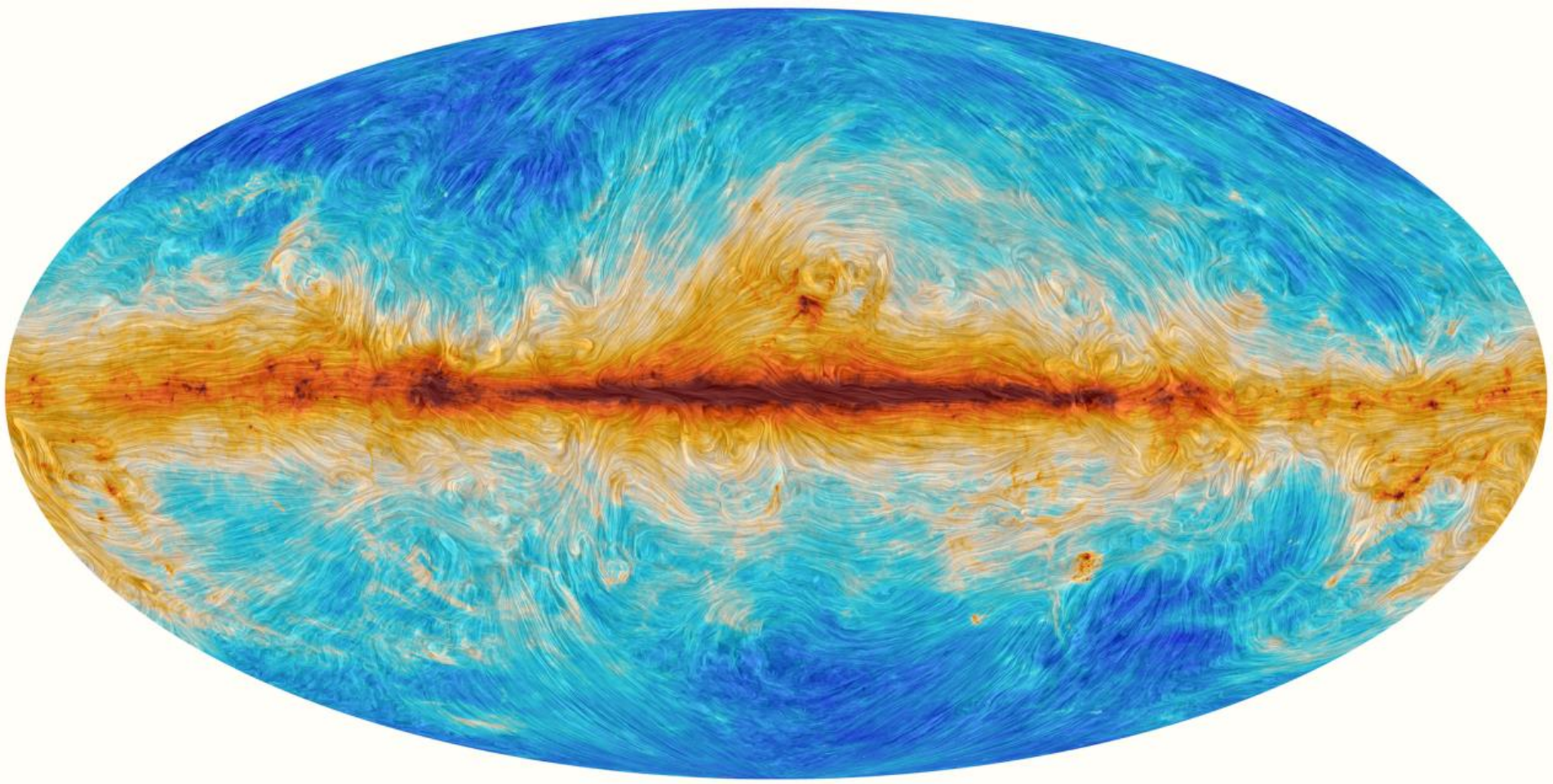
2. Polarisation towards extra-galactic sources
   - Rapid variability towards radio-loud AGN

3. Polarisation towards galactic sources
   - Properties of interstellar dust grains
   - BISTRO and the study of star-forming regions
   - Magnetism in a proto-stellar core

1. A NEW AGE OF SUB-MM/MM POLARIMETRY

The IRAM 30-m telescope
Credit: Nicolas Biver

Planck and the Galactic magnetic field



Credits: Planck/ESA

HAWC+ on SOFIA

Stratospheric Observatory for Infrared Astronomy

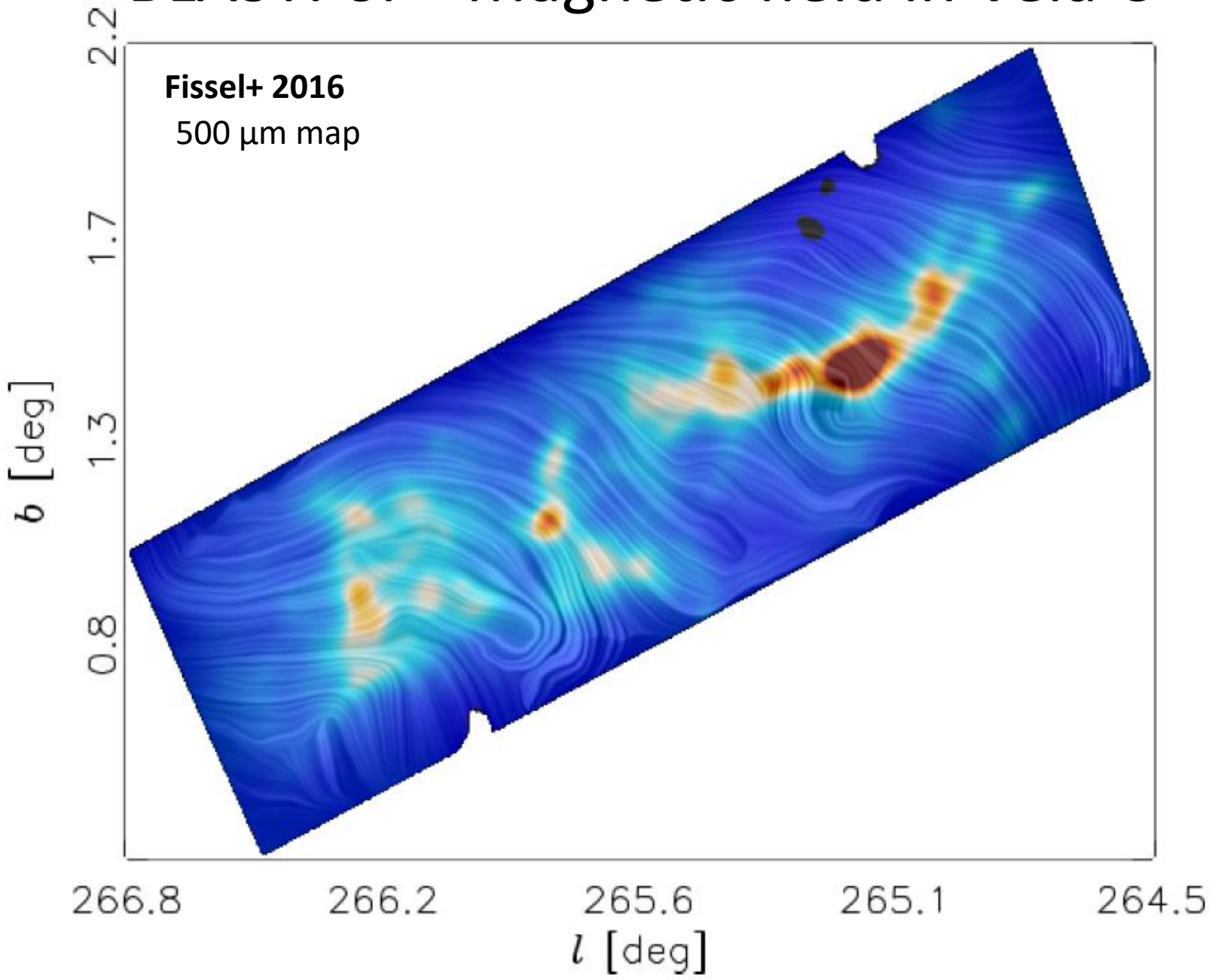
Credit: German Aerospace Center

BLAST-TNG

Balloon-Borne Large Aperture Submillimeter Telescope - The Next Generation
Coming December 2017

BLASTPol in Antarctica
Credit: University of Toronto

BLASTPol – Magnetic field in Vela C



Interferometers

SMA, NOEMA and ALMA

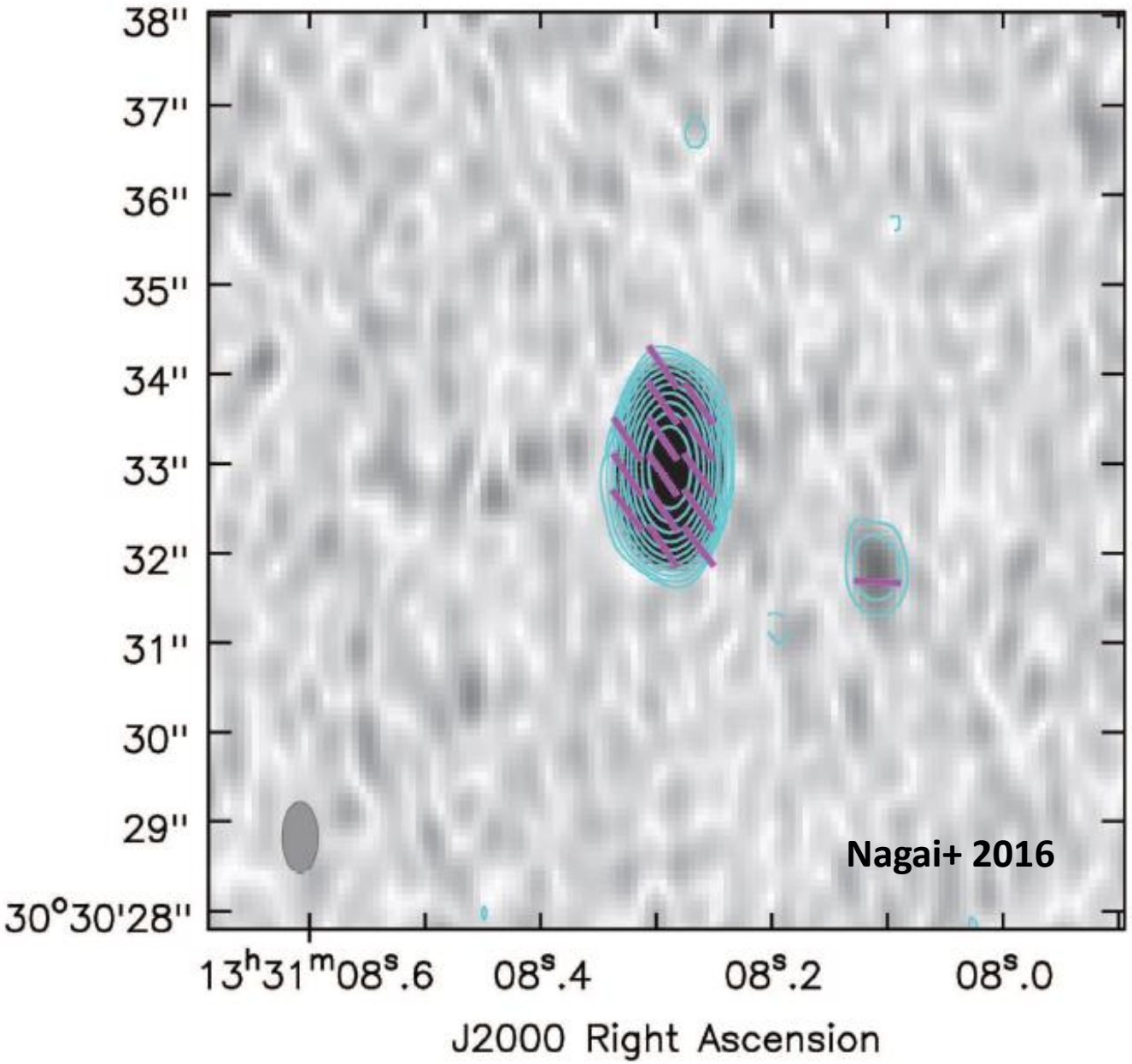
Credit: Bill Dickinson

Submillimeter Array

Credits: Charlène Lefèvre/IRAM

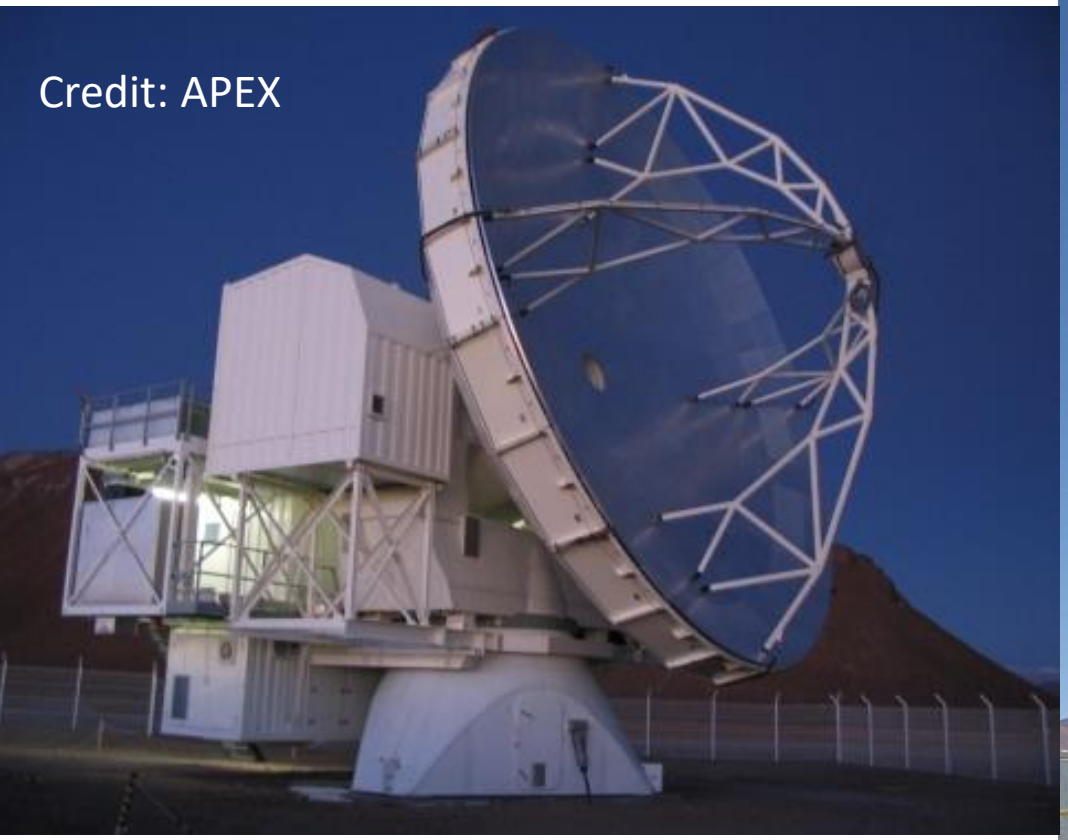
NOrthern Extended Millimeter Array

3C 286 – ALMA PI map at 1.3 mm



PolKa at APEX

Atacama Pathfinder Experiment



APol at ASTE

Atacama Submillimeter Telescope Experiment

NIKA-2 at the IRAM 30-m telescope

Institut de RadioAstronomie Millimétrique

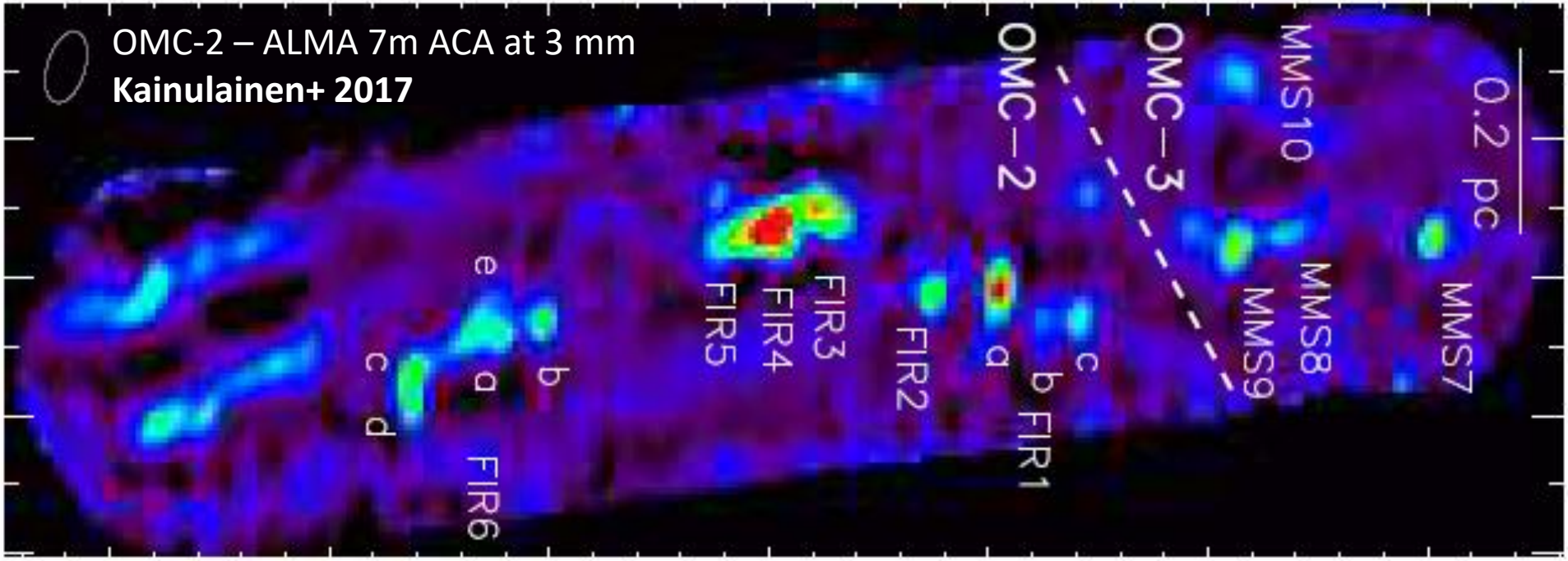

POL-2 AT THE JCMT
James Clerk Maxwell Telescope
Credit: East Asian Observatory

What is the JCMT?

Credit: East Asian Observatory

- Submillimetre observatory
  - Instrumentation for 450 & 850 μm atmospheric windows
  - Continuum, Spectroscopic and Polarimetric synergy
- 15 meters single-dish
  - 7.9'' FWHM at 450 μm
  - 13.0'' FWHM at 850 μm
  - Spatial scales up to ~5'
    - Experiences may vary
- Mauna Kea observatory
  - 4092 meters in elevation
  - > 50 % of time below $\tau_{225} = 0.12$

OMC-2 – SCUBA-2 at 850 µm
Credits: JCMT GBS team IR2



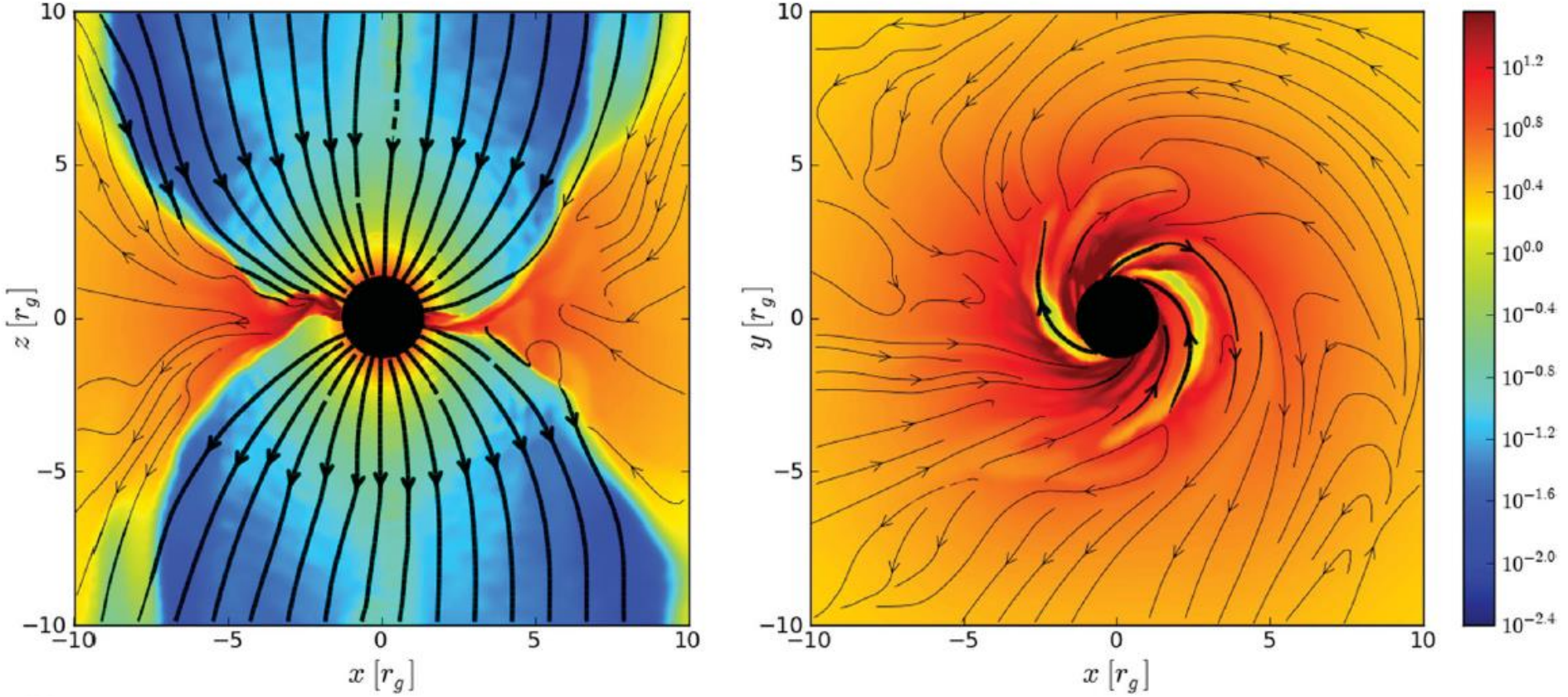
The SCUBA-2 polarimeter (POL-2)

2. POLARISATION TOWARDS EXTRA-GALACTIC SOURCES

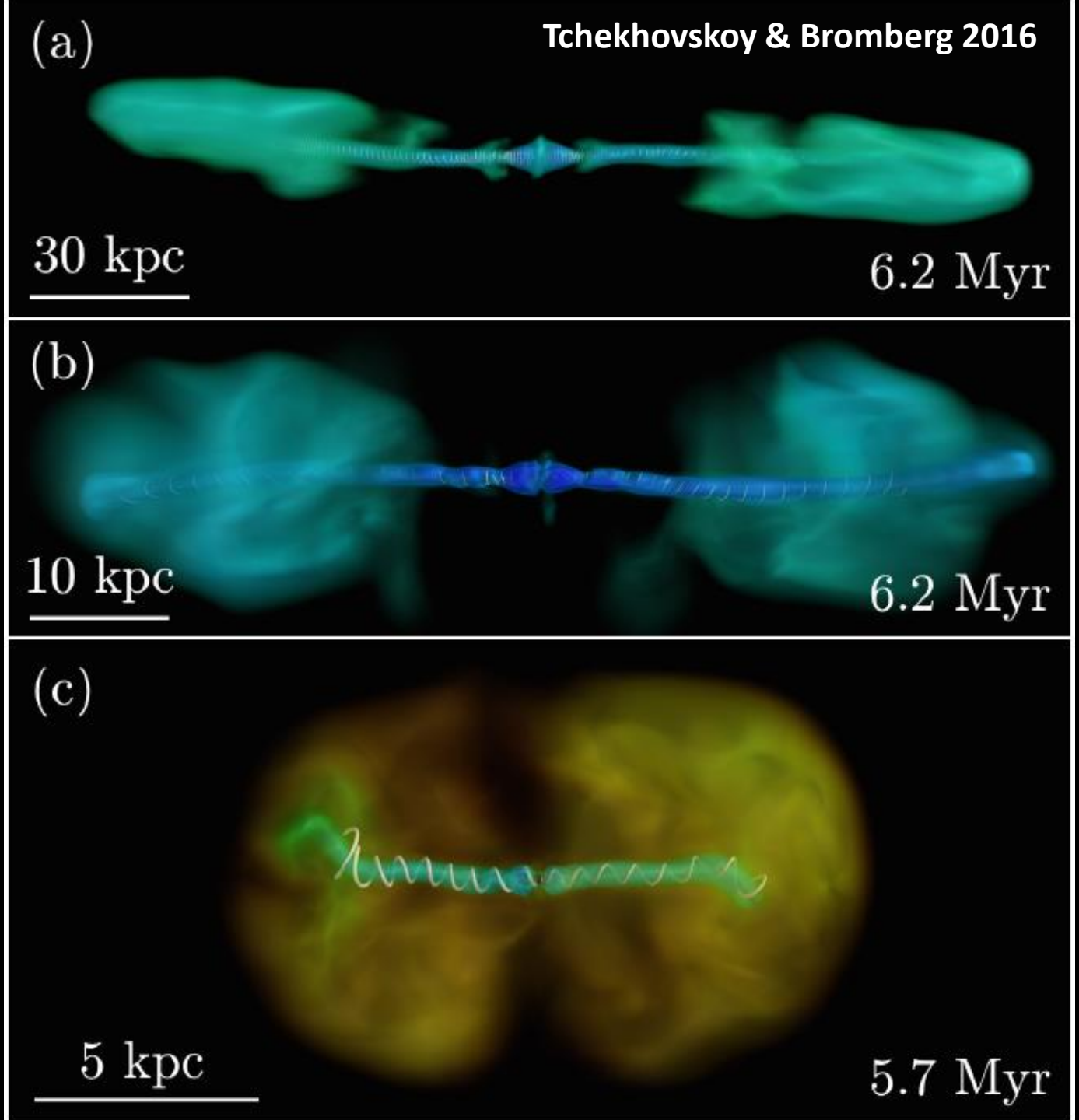
Messier 87 – X-ray + Radio
Credits: NASA/NRAO

Active galactic nuclei (AGN)

Supermassive black holes, accretion & energetic jets



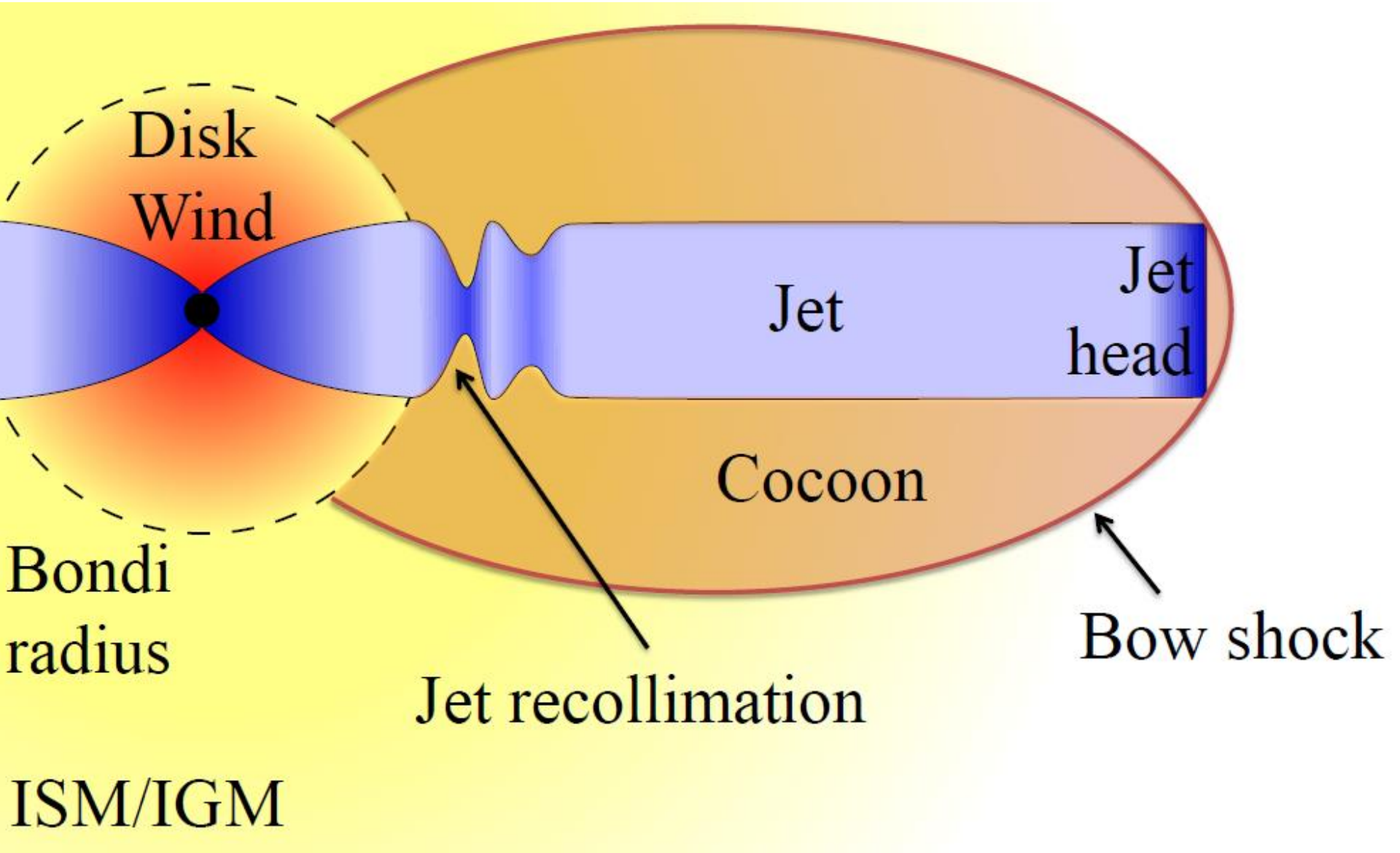
McKinney, Tchekhovskoy & Bladford 2012



Tchekhovskoy & Bromberg 2016

Structure of galactic jets

Tchekhovskoy & Bromberg 2016

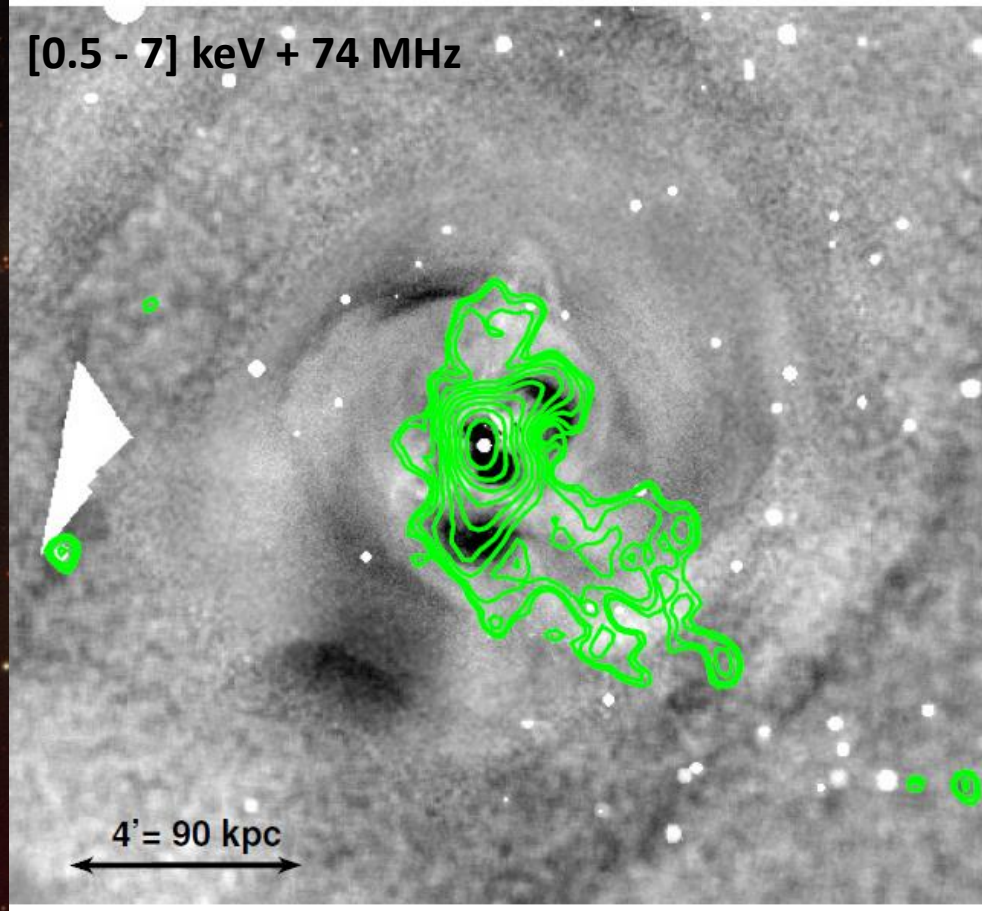


Effect on the intergalactic medium

NGC 1275 (3C 84)

Credits: SDSS/SIMBAD

Composite Chandra and Very Large Array



Gendron-Marsolais+ 2017

POL-2: Monitoring of rapid variability in the submillimetre linear polarisation of four radio-loud AGN - 3C 84, 273, 279 & 454.3

S. Coudé,[1,2]★ M.-L. Gendron-Marsolais,[1,3]† J. Hlavacek-Larrondo,[1,3] P. Bastien,[1,2] R. Rao,[4], K. Lacaille,[5] J. Greaves,[6,7] D. S. Berry,[8] A. Chrysostomou,[9,10] J. Dempsey,[8] P. Friberg,[8] S. F. Graves,[8] M. Houde,[11] D. Johnstone,[12,13] J. Kennedy,[1,14] H. Parsons,[8] K. Pattle,[15] M. G. Rawlings[8] and G. Savini[16]

[1]*Centre de Recherche en Astrophysique du Québec (CRAQ),* [2]*Institute for Research on Exoplanets (iREx) &* [3]*X-TRA Astrophysics Research Group, Université de Montréal, Département de Physique, C.P. 6128 Succ. Centre-ville, Montréal, QC H3C 3J7, Canada*

[4]*Academia Sinica Institute for Astronomy and Astrophysics, Hilo, HI*

[5]*Dalhousie University, Halifax, Nova Scotia*

[6]*University of St-Andrews, UK*

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[8]*East Asian Observatory, 660 N. A'oh¯kū Place, University Park, Hilo, Hawaii 96720, USA*

[9]*University of Hertfordshire*

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[11]*University of Western Ontario, London, Ontario*

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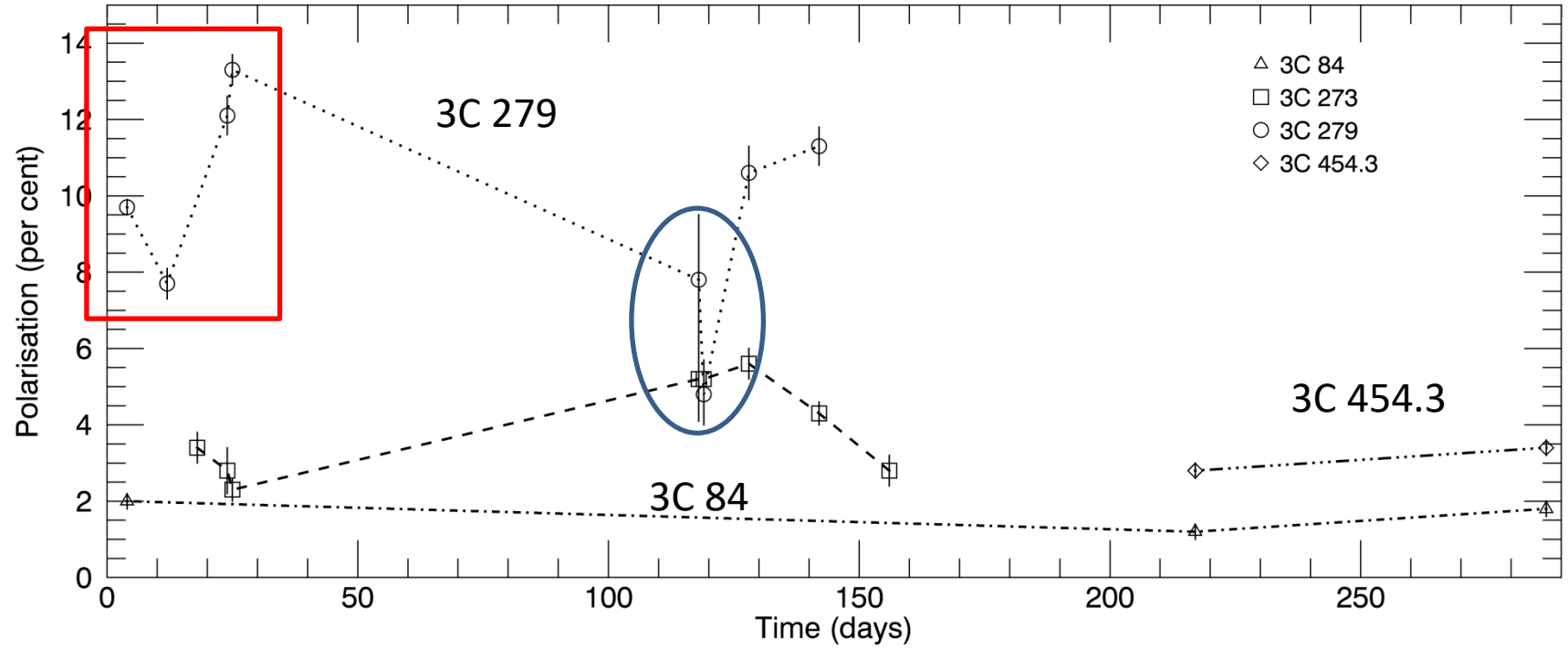
[14]*Secret location, Ottawa, Canada, Planet Earth, Solar System, Milky Way*

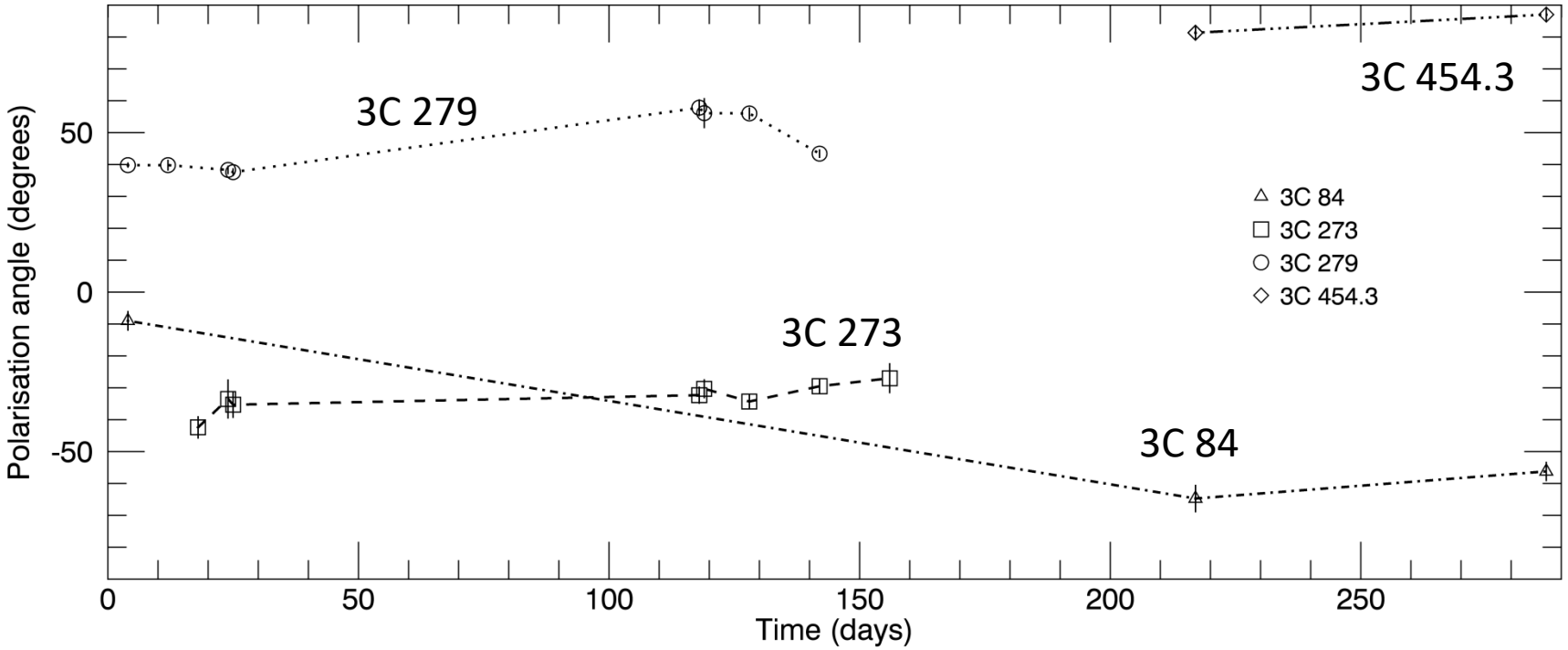
[15]*University of Central Lancashire, Preston, UK*

[16]*University College London, UK*

Unofficial working title

Strange quasi-stellar objects, or how we learned to stop worrying and love active galactic nuclei

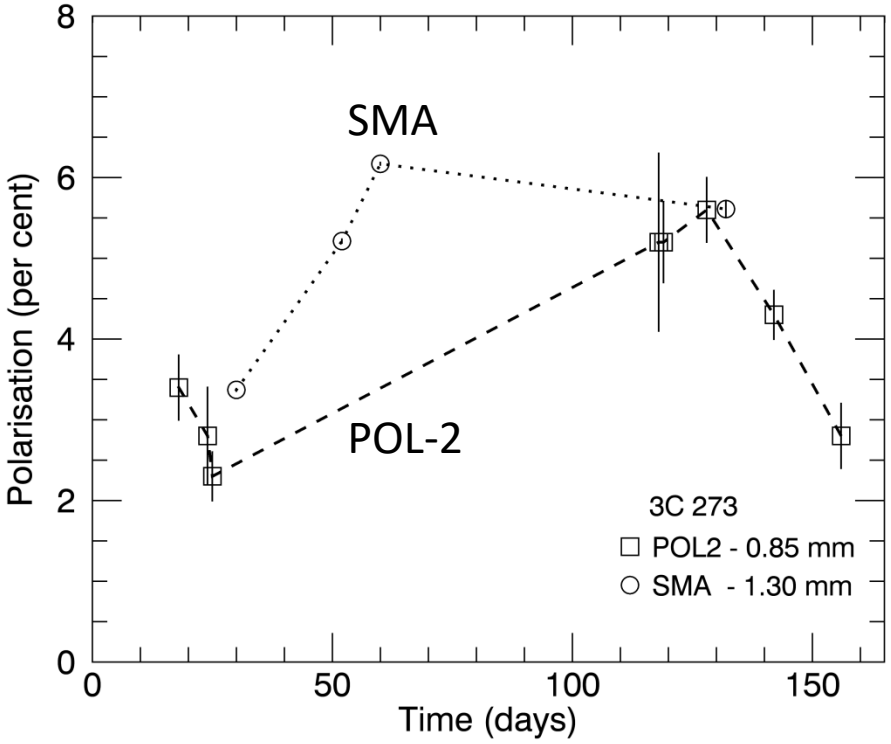

Polarisation (per cent)
Time (days)
3C 279
3C 84
3C 454.3
3C 84
3C 273
3C 279
3C 454.3


Polarisation angle (degrees)
Time (days)
3C 279
3C 454.3
3C 273
3C 84
3C 84
3C 273
3C 279
3C 454.3

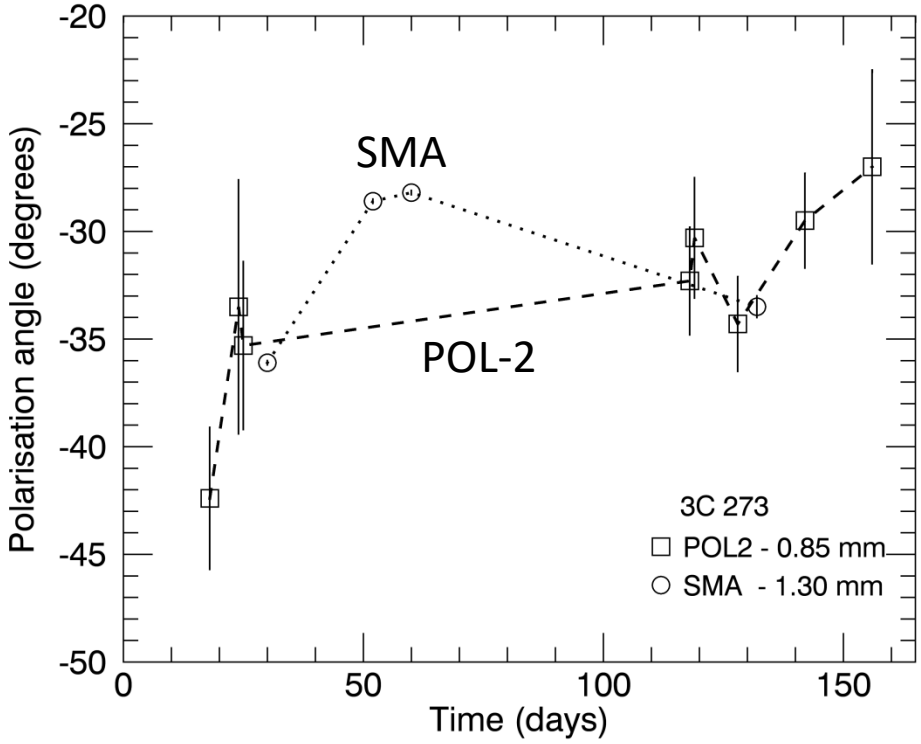
Quasar 3C 273

Combined JCMT 850 μm & SMA 1.3 mm monitoring

Fraction of polarisation



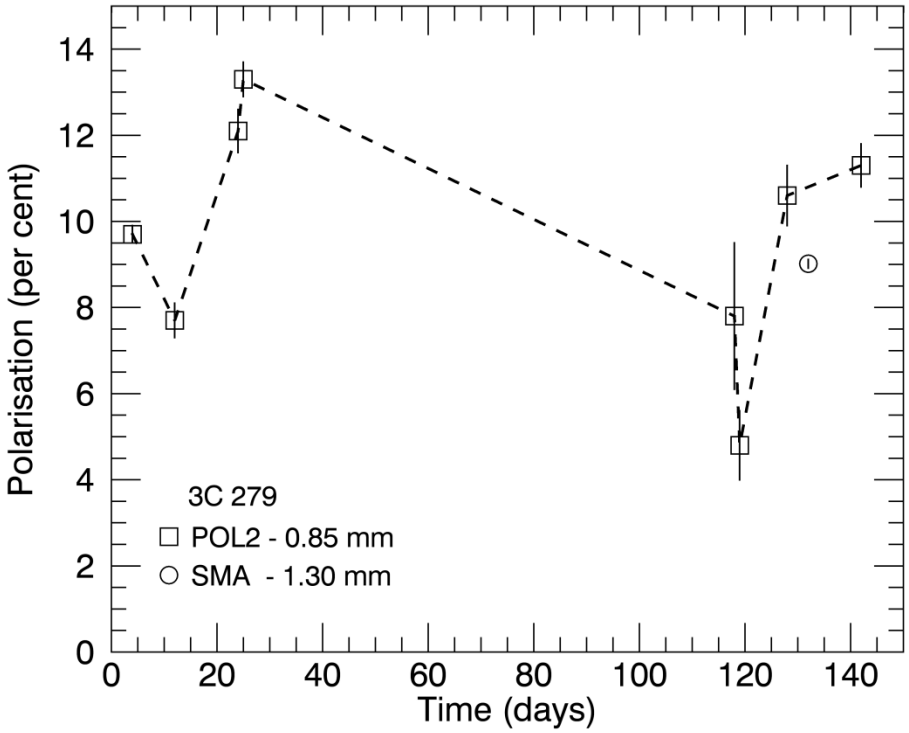
Angle of polarisation



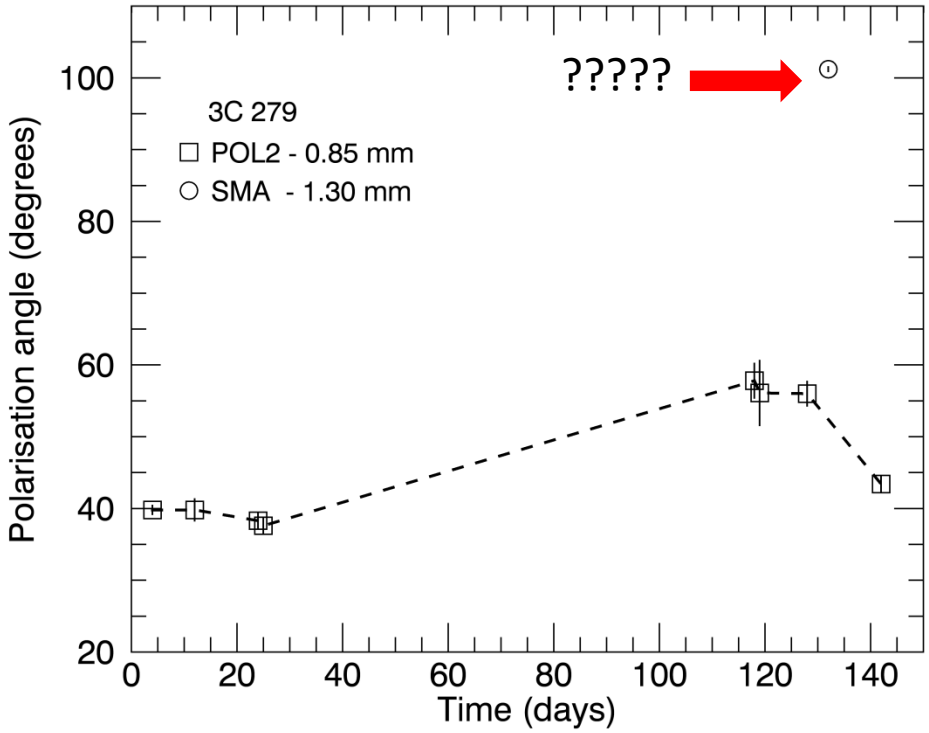
Quasar 3C 279

Combined JCMT 850 µm & SMA 1.3 mm monitoring

Fraction of polarisation



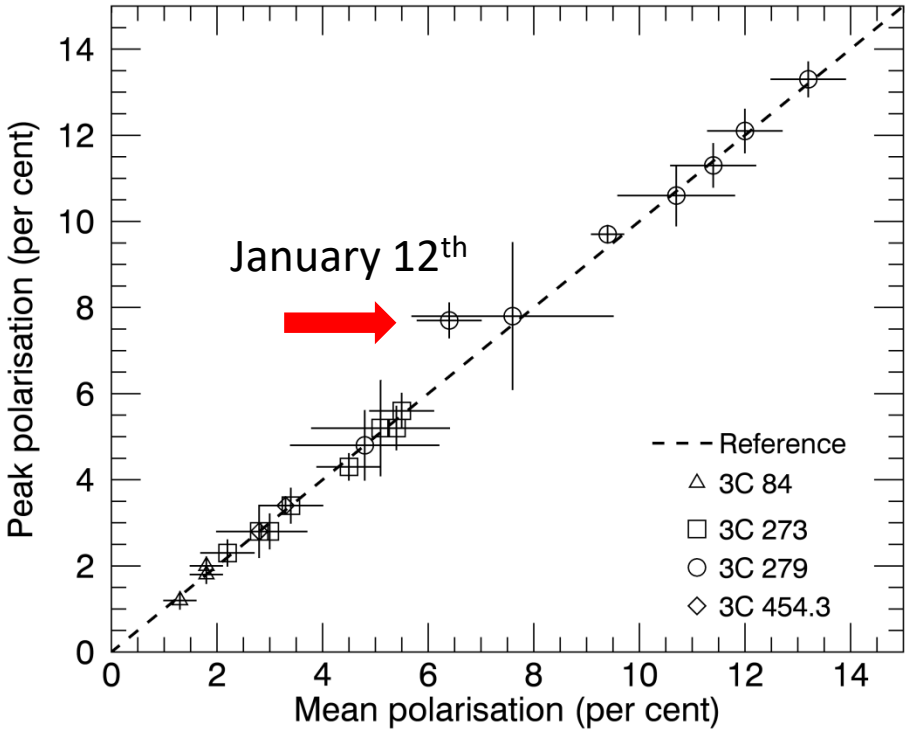
Angle of polarisation



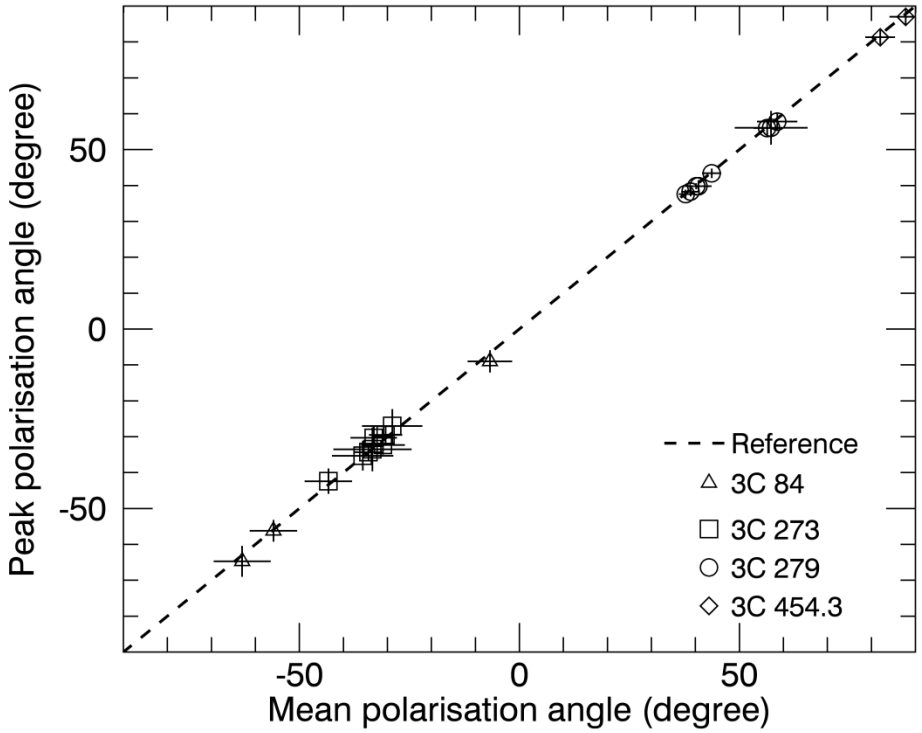
Comparison between methods

Gaussian peak fit -v.s.- binning average

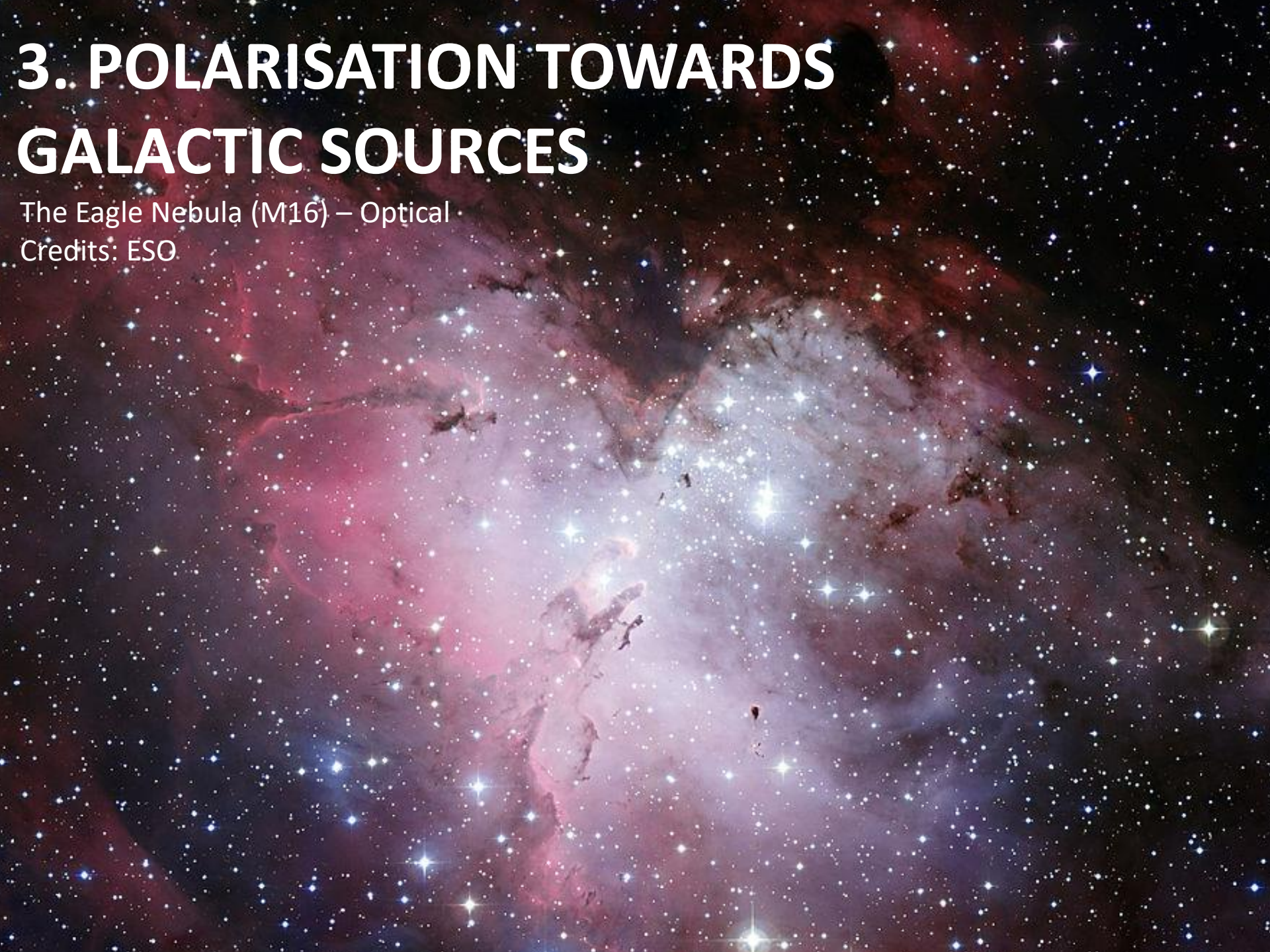
Fraction of polarisation



Angle of polarisation

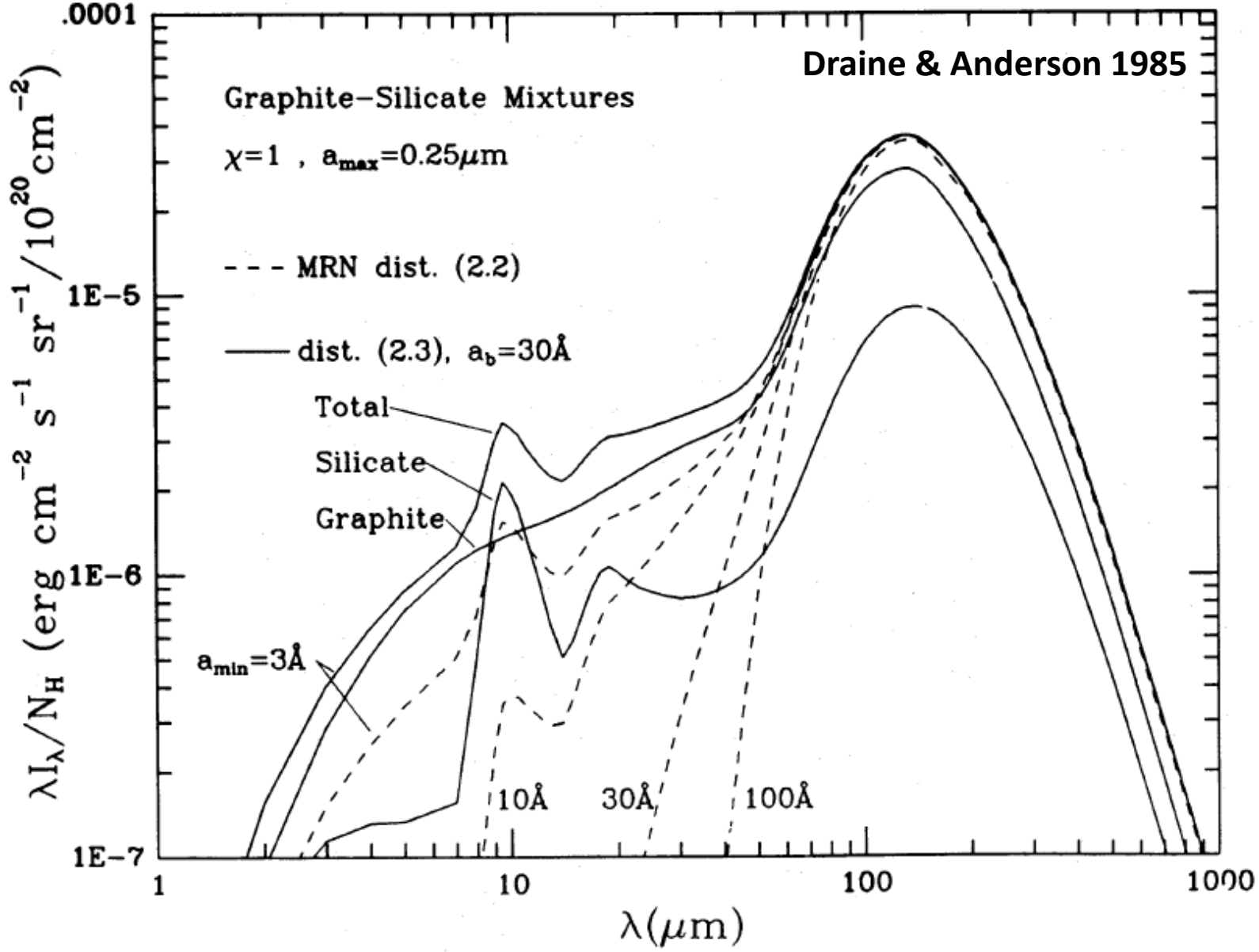


3. POLARISATION TOWARDS GALACTIC SOURCES



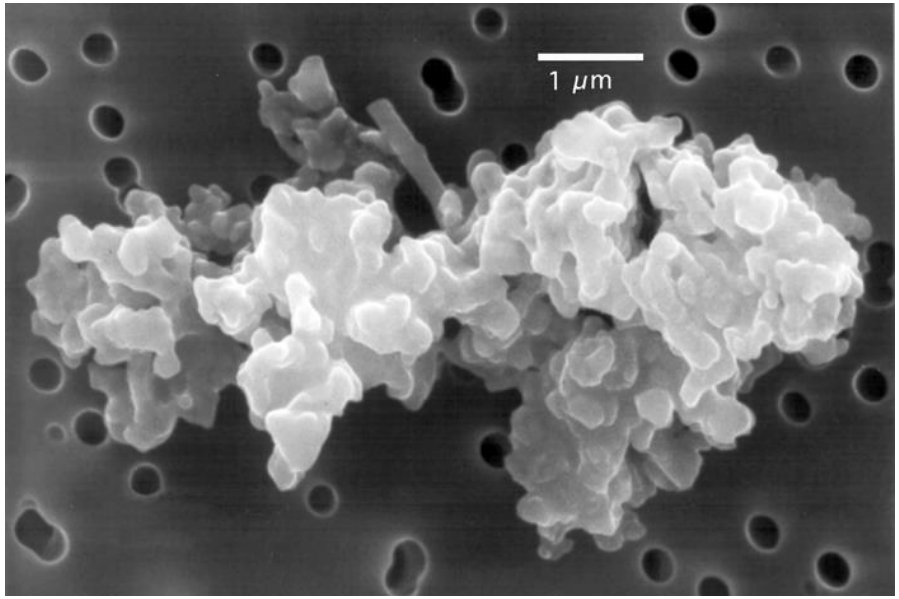
The Eagle Nebula (M16) – Optical
Credits: ESO

Emission from cold interstellar dust grains



Polarisation from thermal dust emission

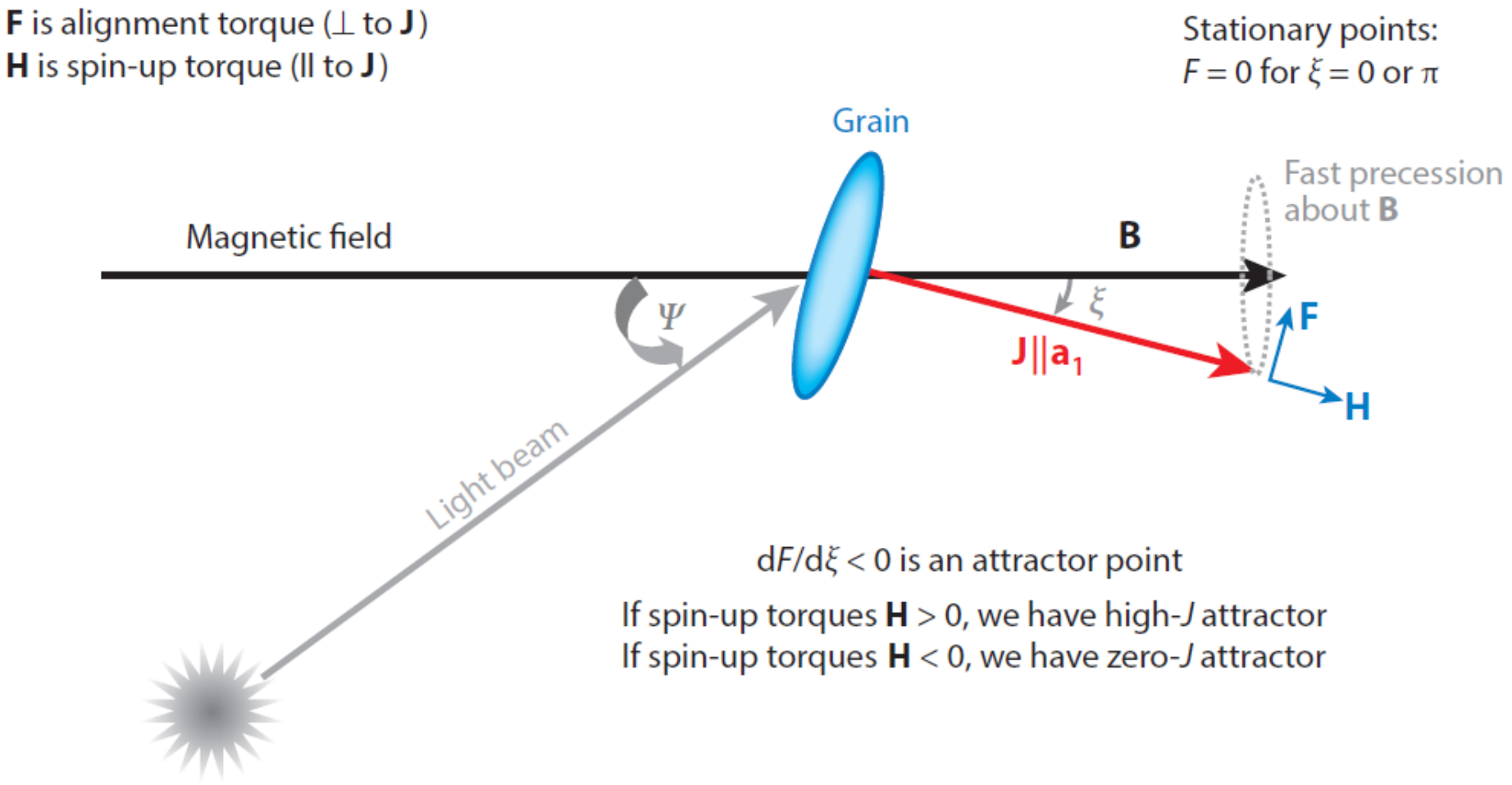
Interplanetary dust particle



Credits: Donald Brownlee & Elmar Jessberger

- Asymmetric particles
  - Hiltner 1949
- Alignment mechanisms
  - Paramagnetic relaxation
    - Davis & Greenstein 1951
  - Radiative Torque (RAT)
    - Draine & Weingartner 1996
  - H_2 formation
    - Andersson+ 2013
  - Mechanical
    - Gold 1952

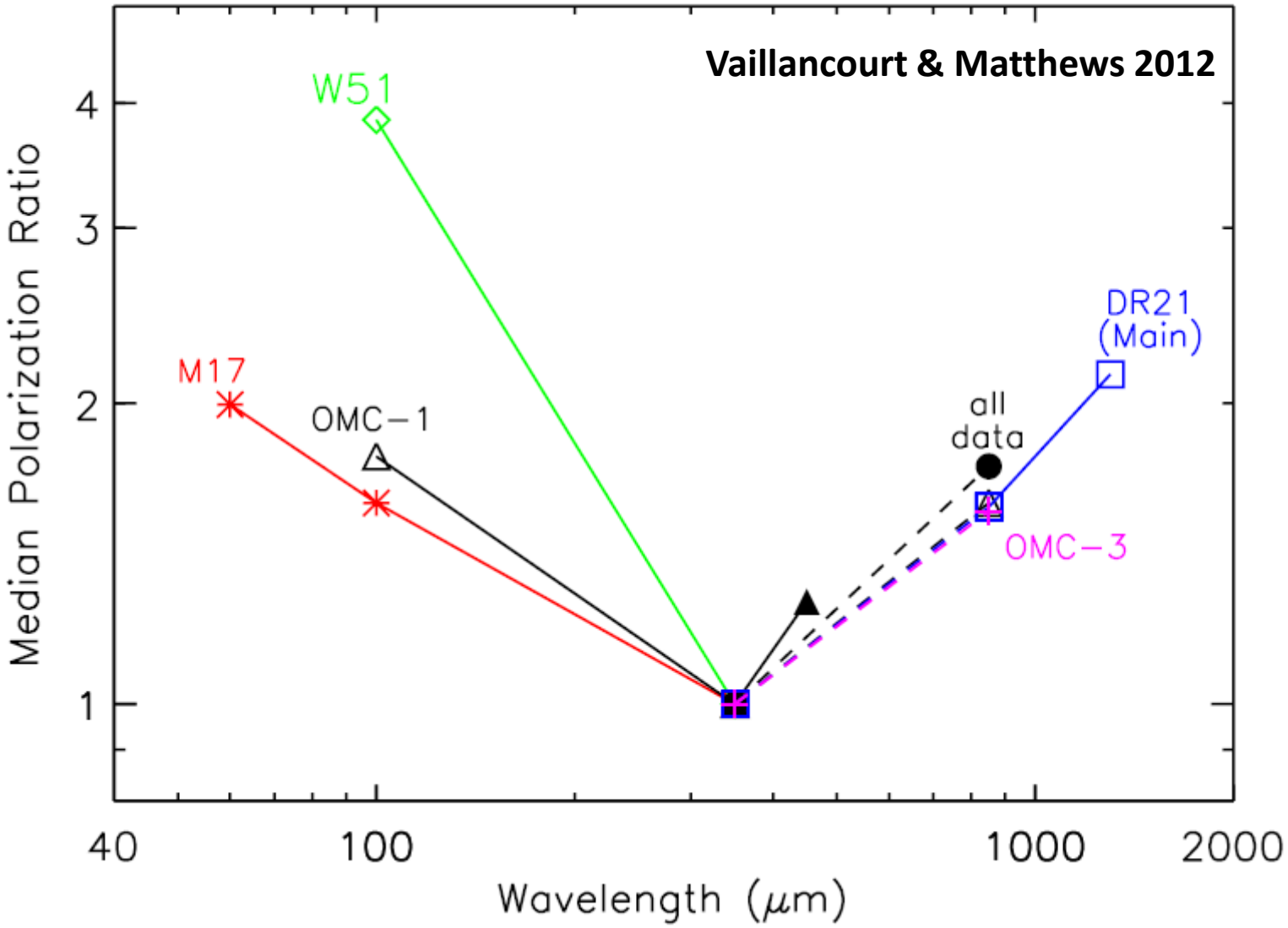
Radiative Alignment Torque (RAT)



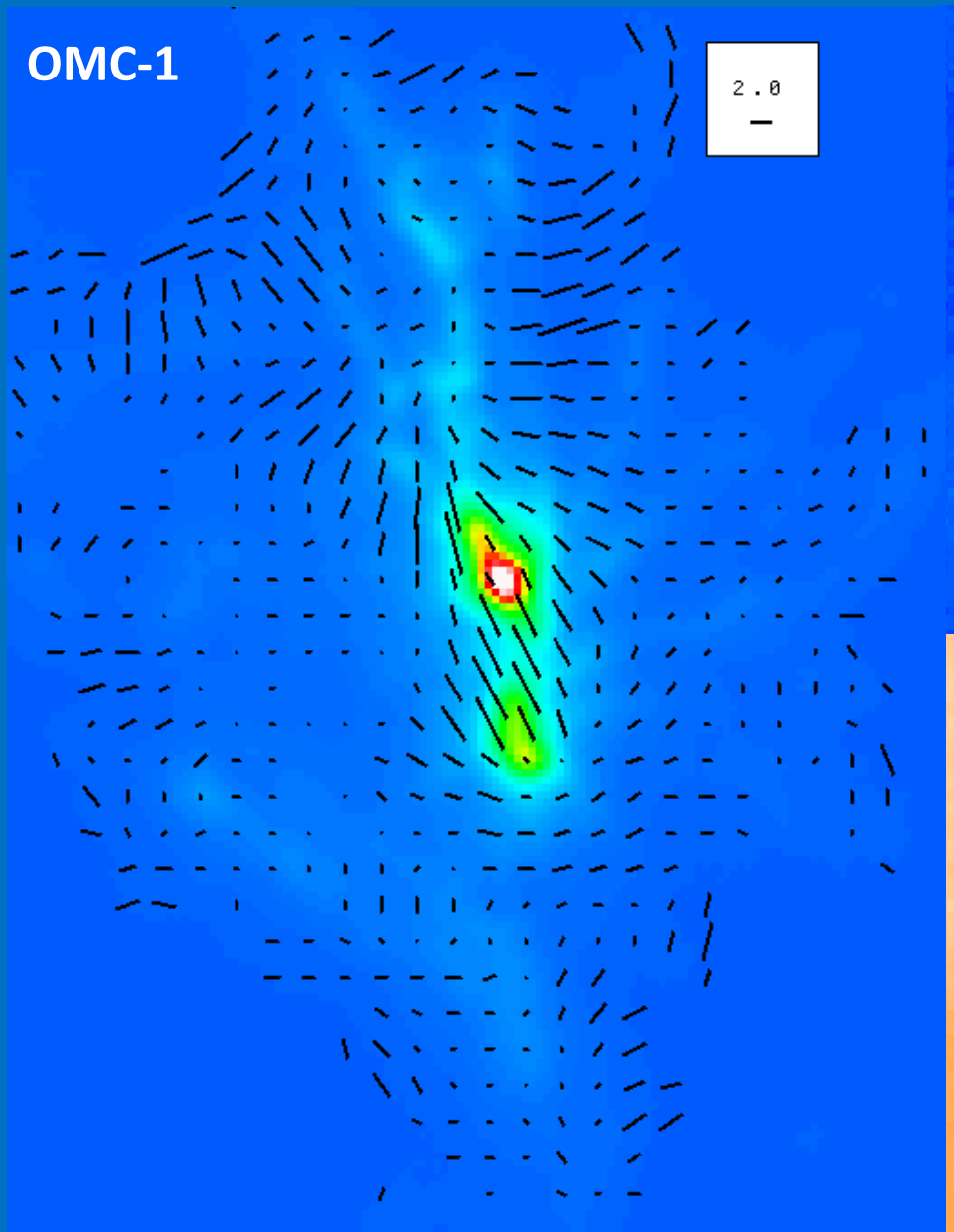
Lazarian & Hoang 2007

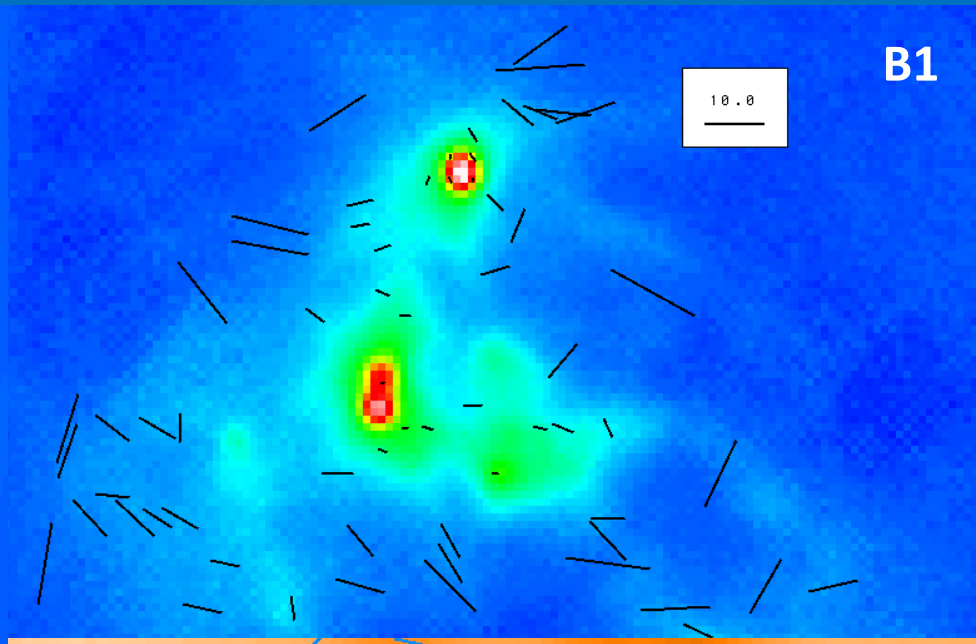
Testing theories of grain alignment

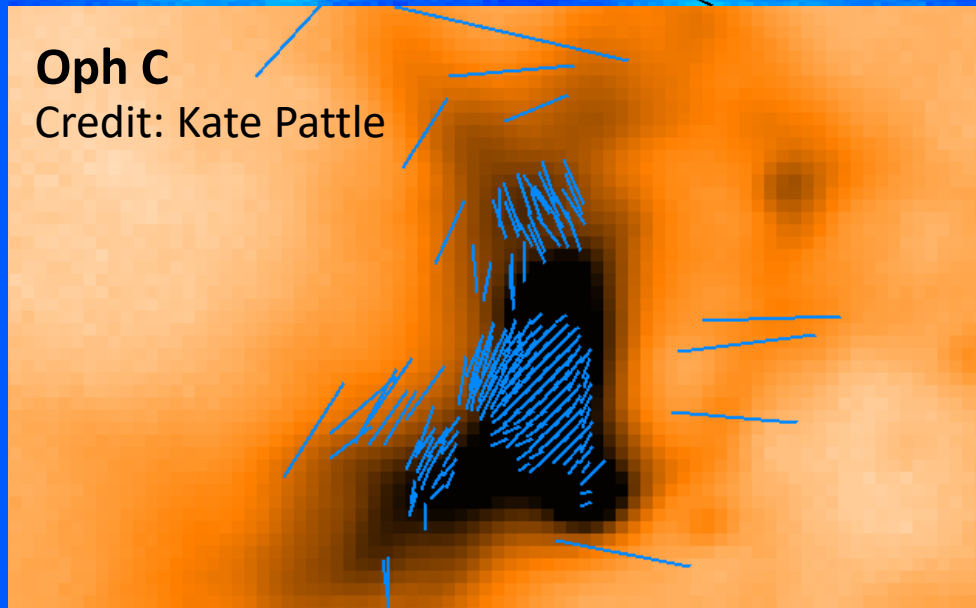
Polarisation spectrum in molecular clouds



BISTRO and the study of magnetism in star-forming regions

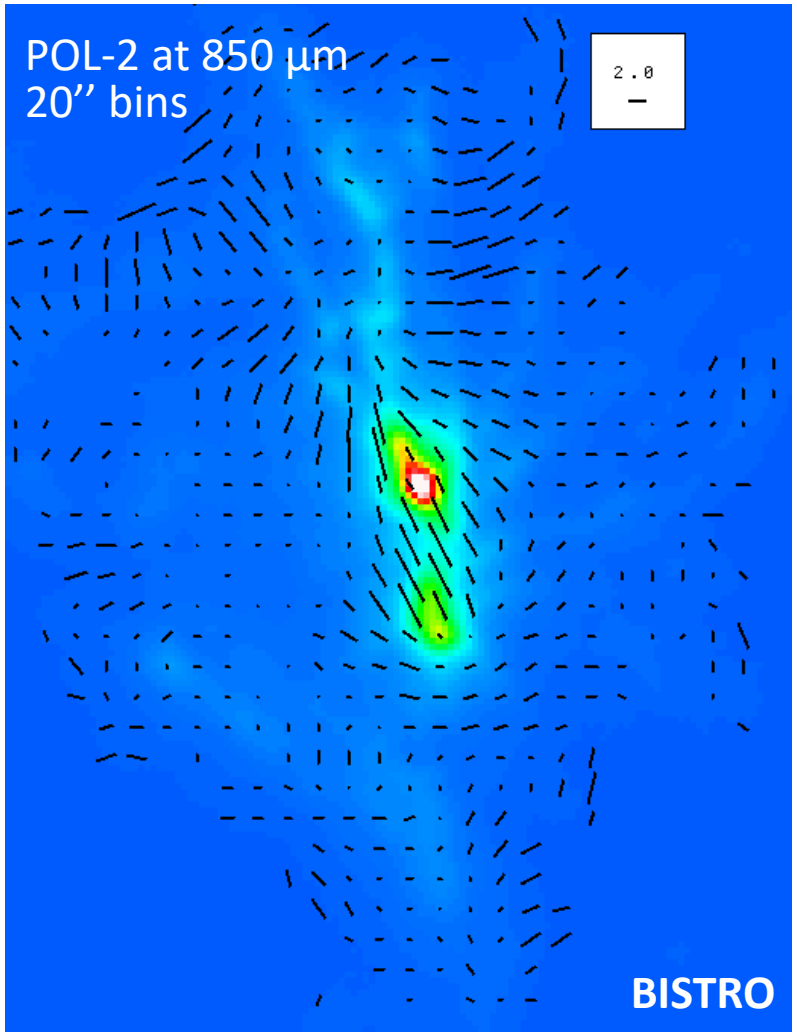


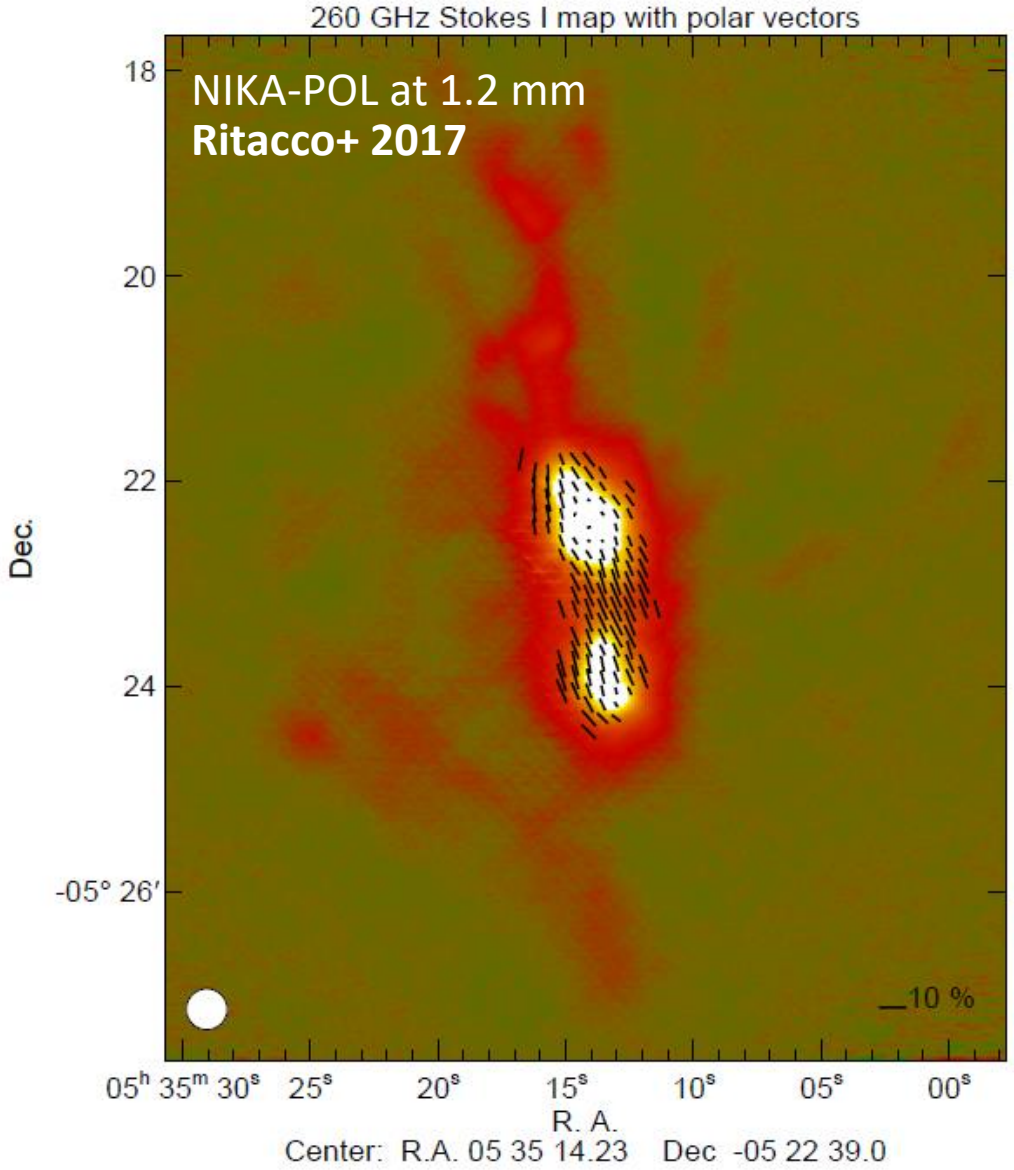




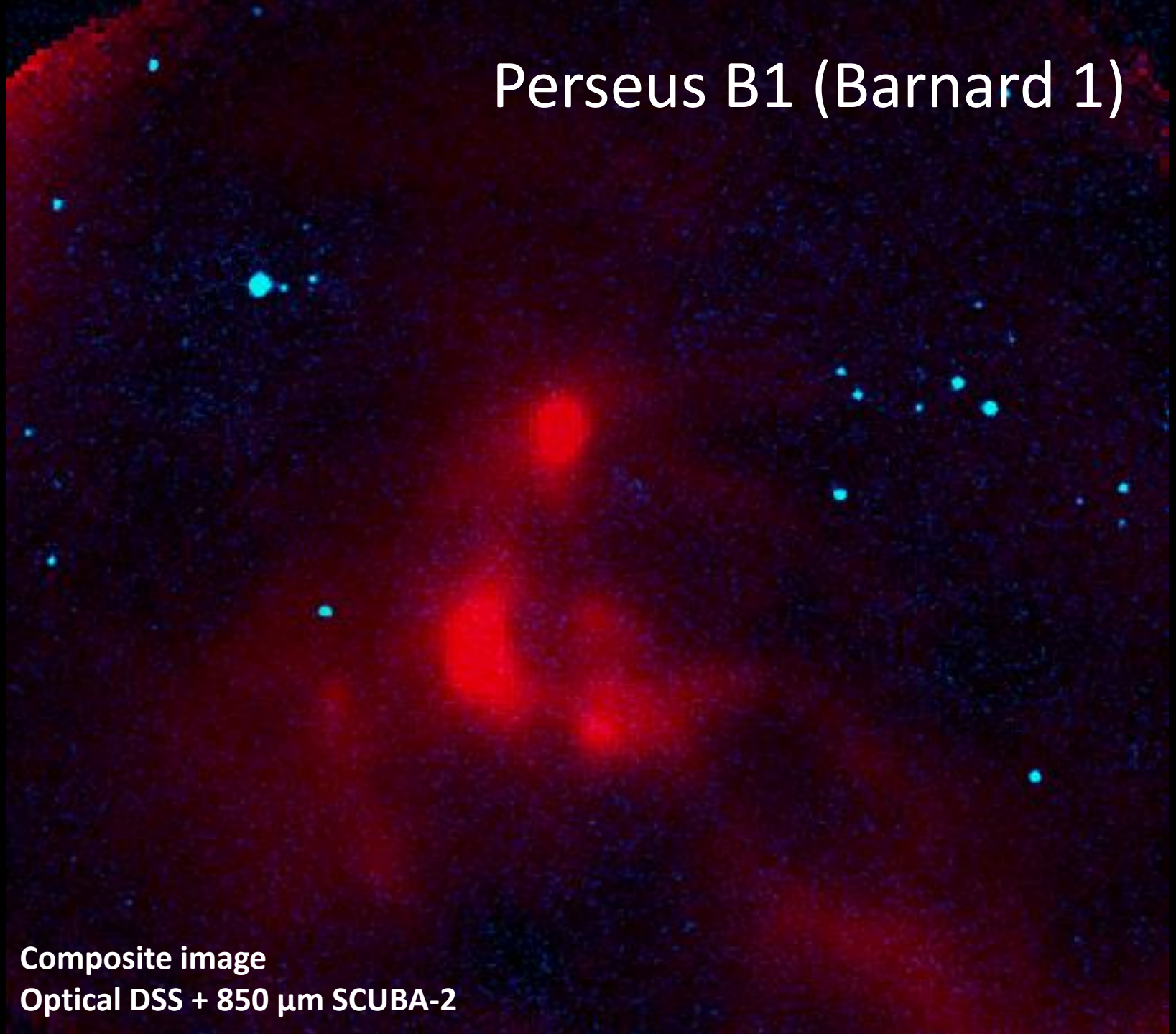
The study of magnetism in star-forming regions

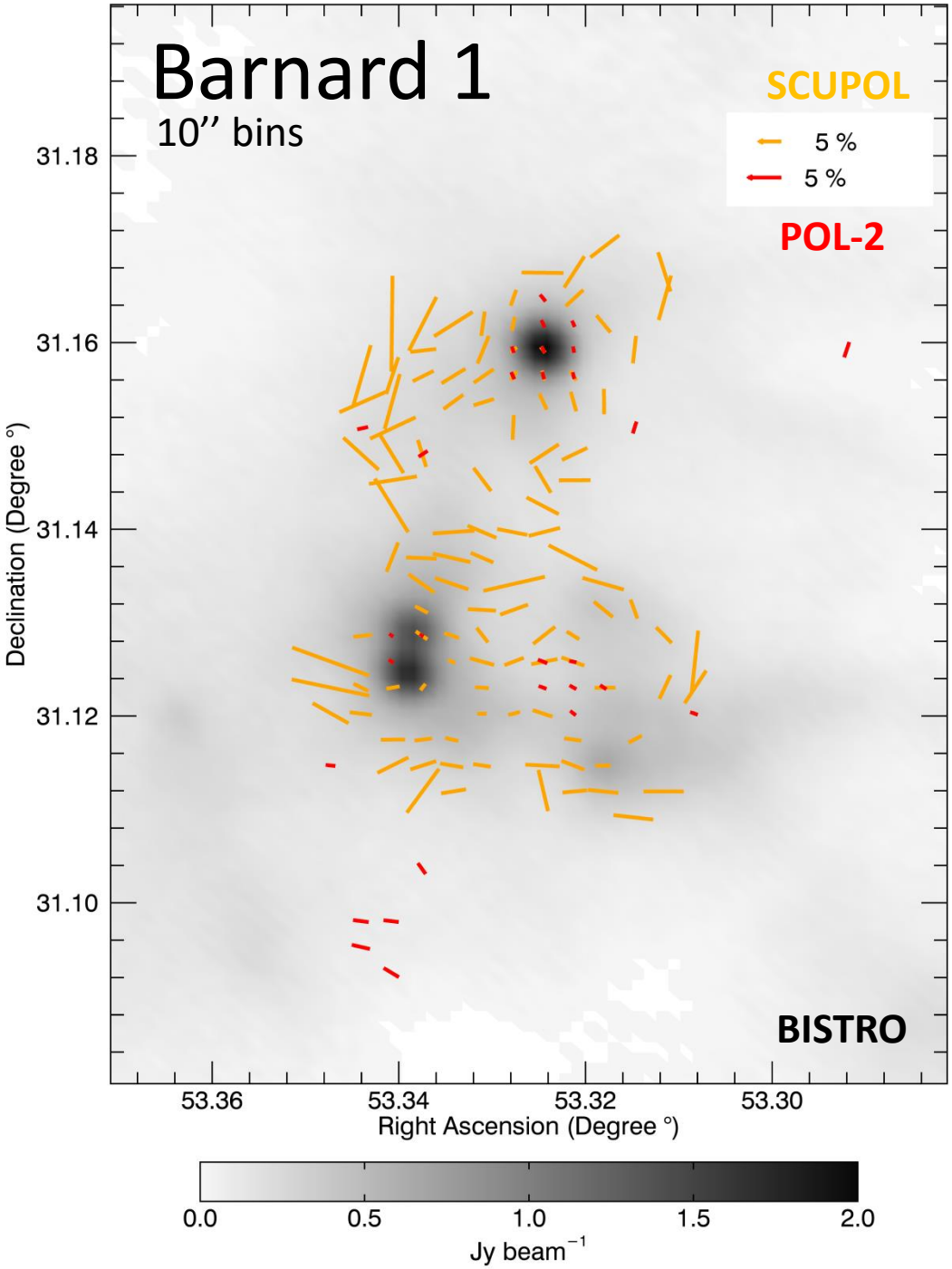
Orion Molecular Cloud 1



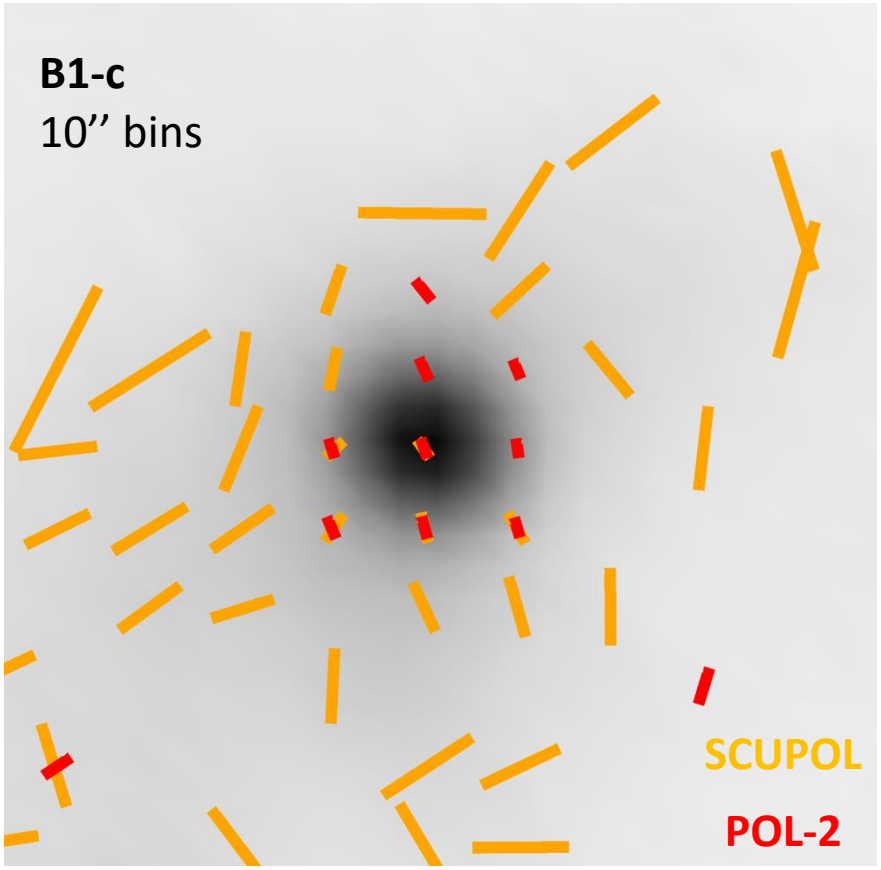


Detailed analysis in **Pattle et al., in prep.** !

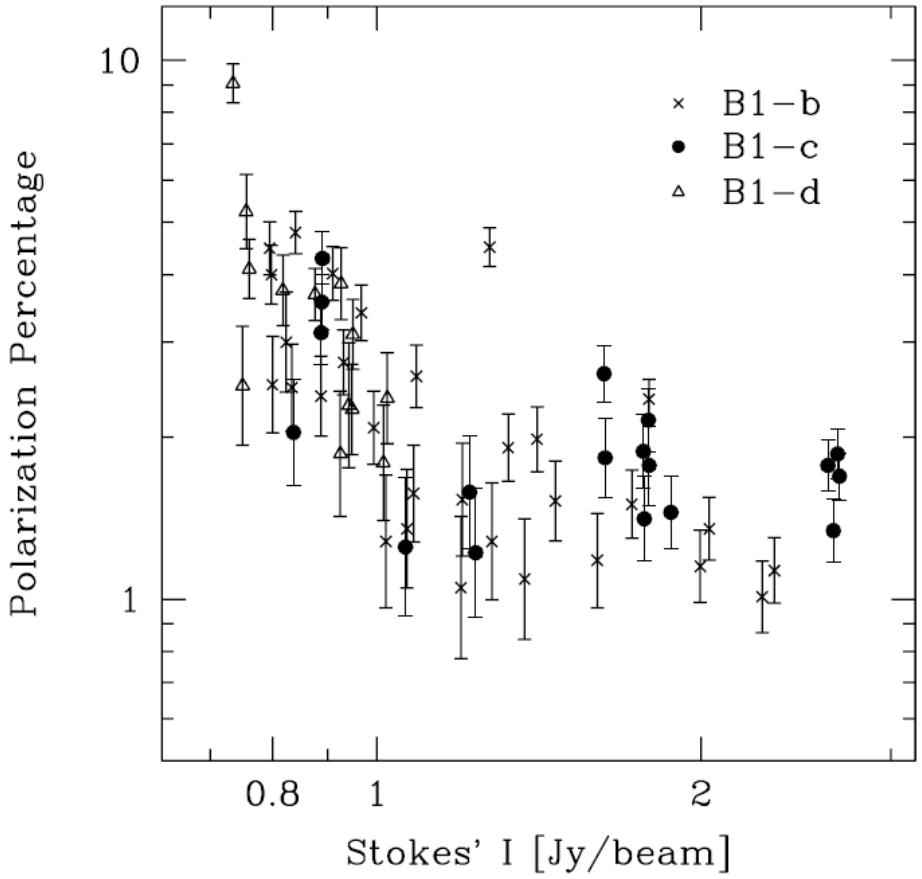

Perseus B1 (Barnard 1)
Composite image
Optical DSS + 850 µm SCUBA-2

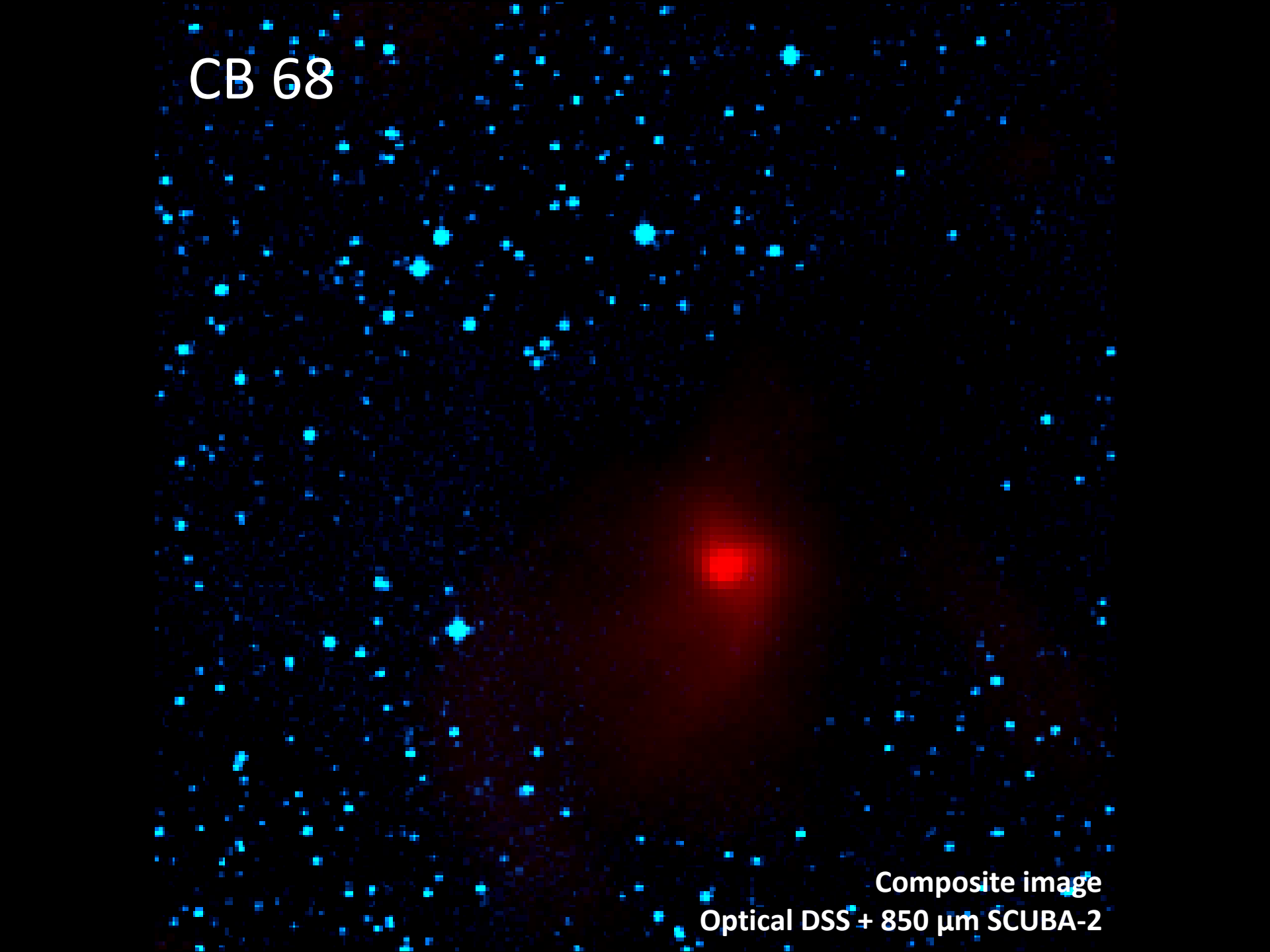

Barnard 1
10’’ bins
SCUPOL
5 %
5 %
POL-2
BISTRO
31.18
31.16
31.14
31.12
31.10
Declination (Degree °)
53.36
53.34
53.32
53.30
Right Ascension (Degree °)
0.0
0.5
1.0
1.5
2.0
Jy beam^{-1}

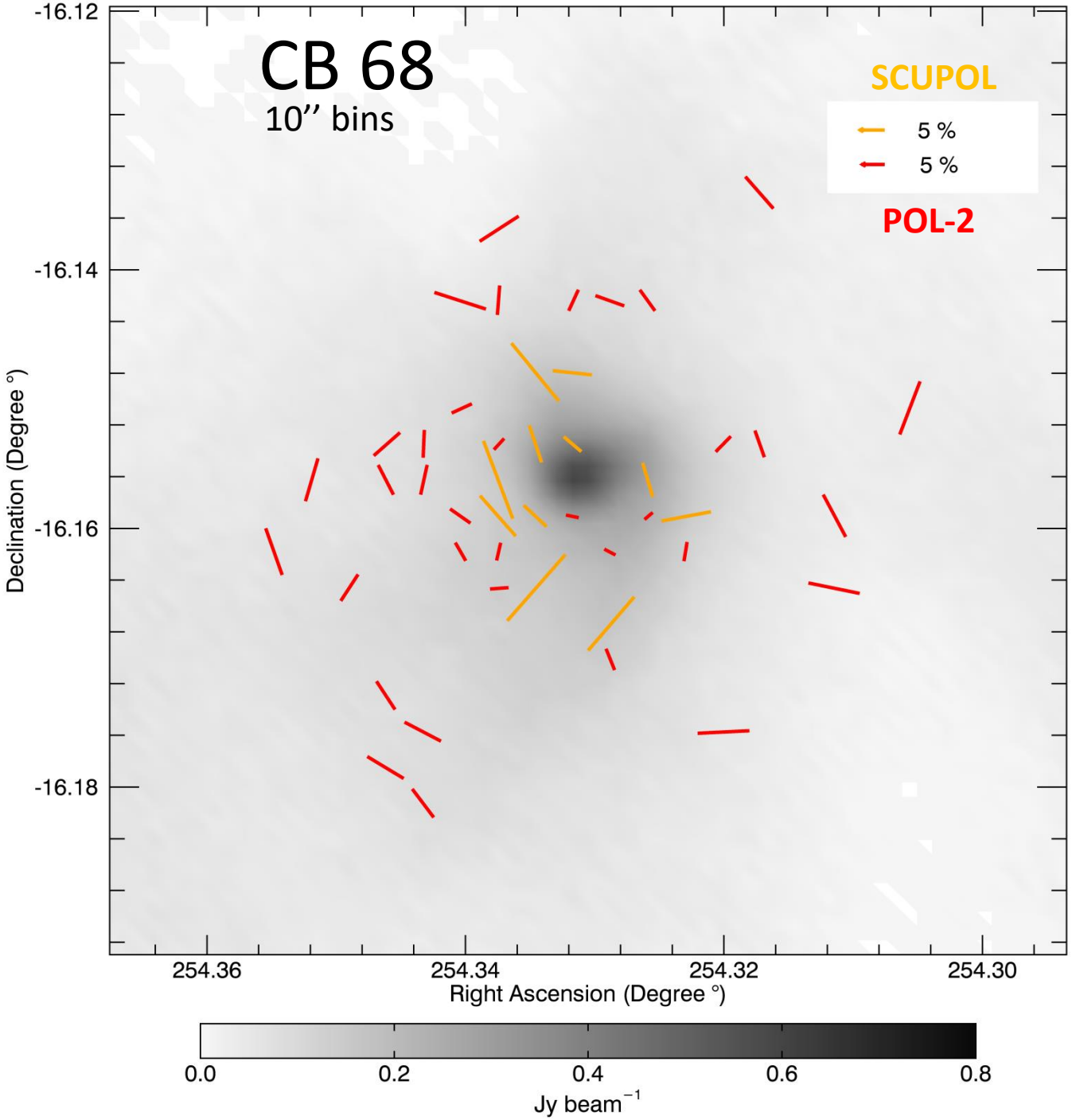
A protostellar core without depolarisation?



Matthews & Wilson 2002

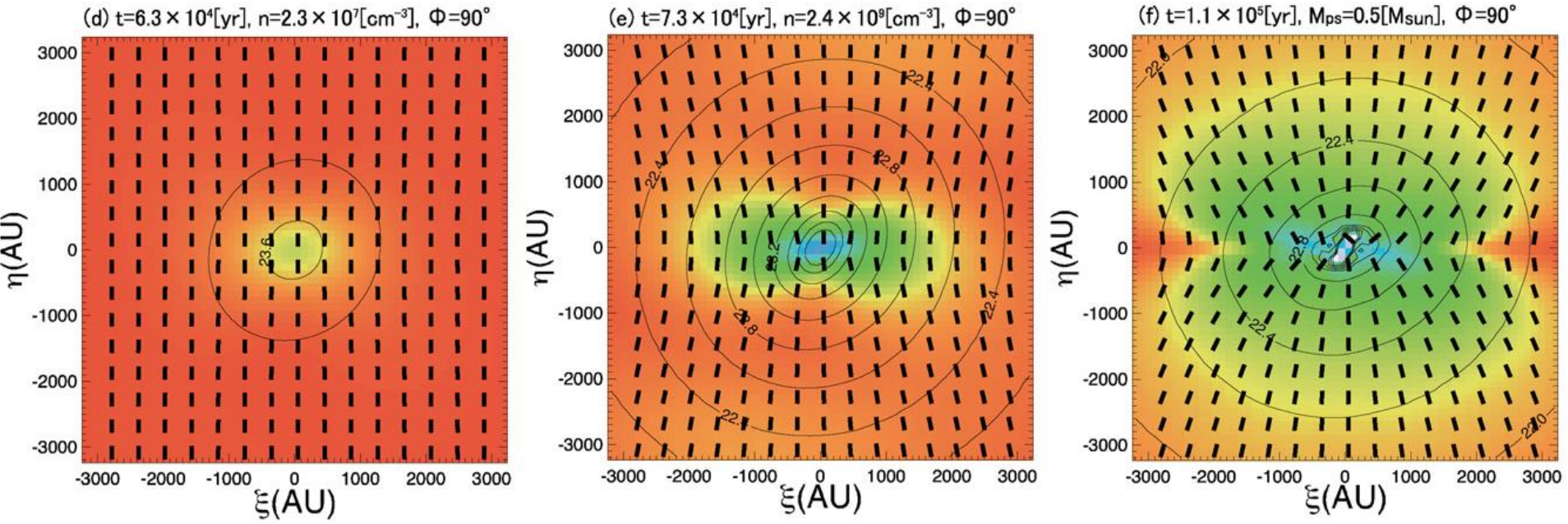



CB 68
Composite image
Optical DSS + 850 µm SCUBA-2


CB 68
10’’ bins
SCUPOL
5 %
5 %
POL-2
-16.12
-16.14
-16.16
-16.18
Declination (Degree °)
254.36
254.34
254.32
254.30
Right Ascension (Degree °)
0.0
0.2
0.4
0.6
0.8
Jy beam^{-1}

Evolution of magnetic fields in protostellar cores

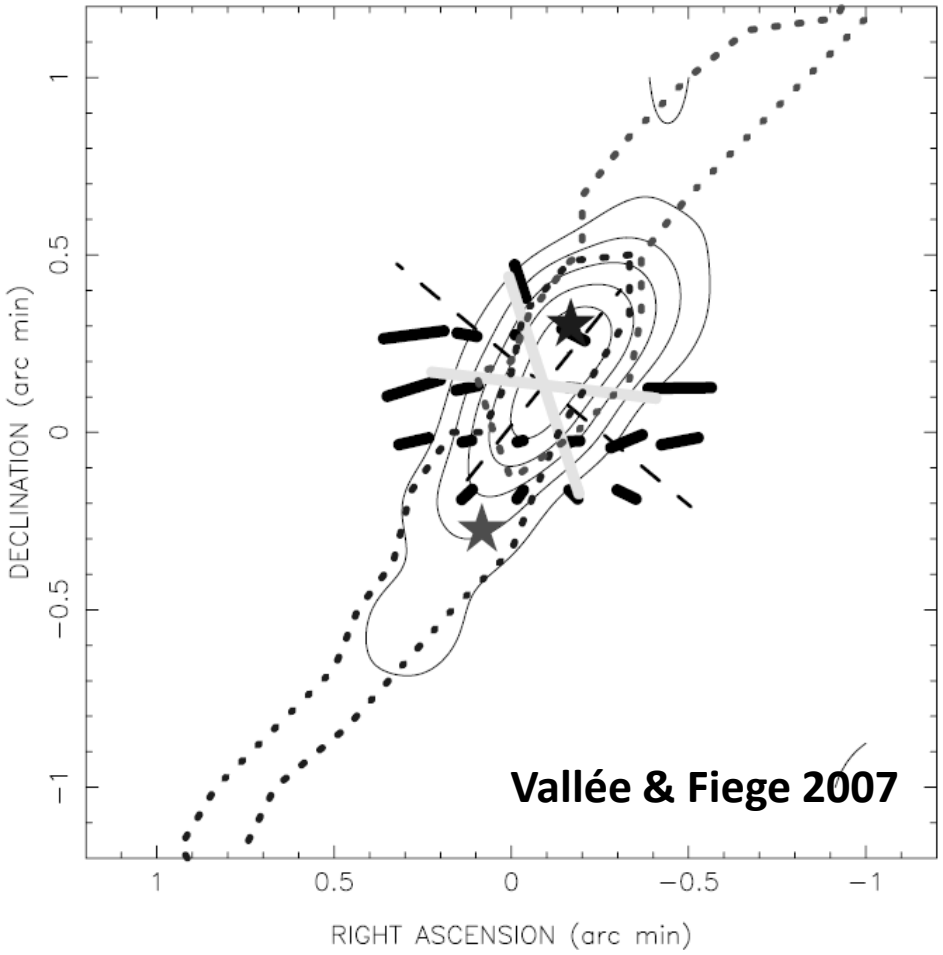
Misaligned magnetic field relative to the core's angular momentum



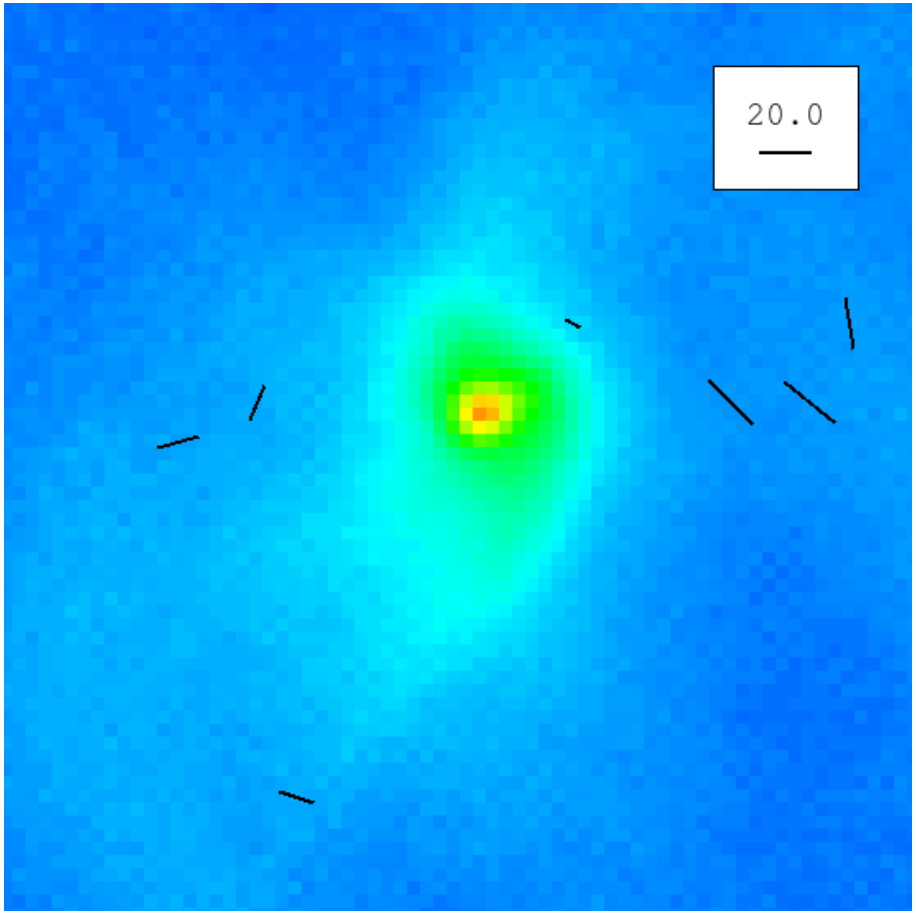
Kataoka, Machada & Tomisaka 2012

Possible interpretations?

1. The magnetic field in the prototypical protostellar core



2. The strangely unpolarised star-forming Bok Globule

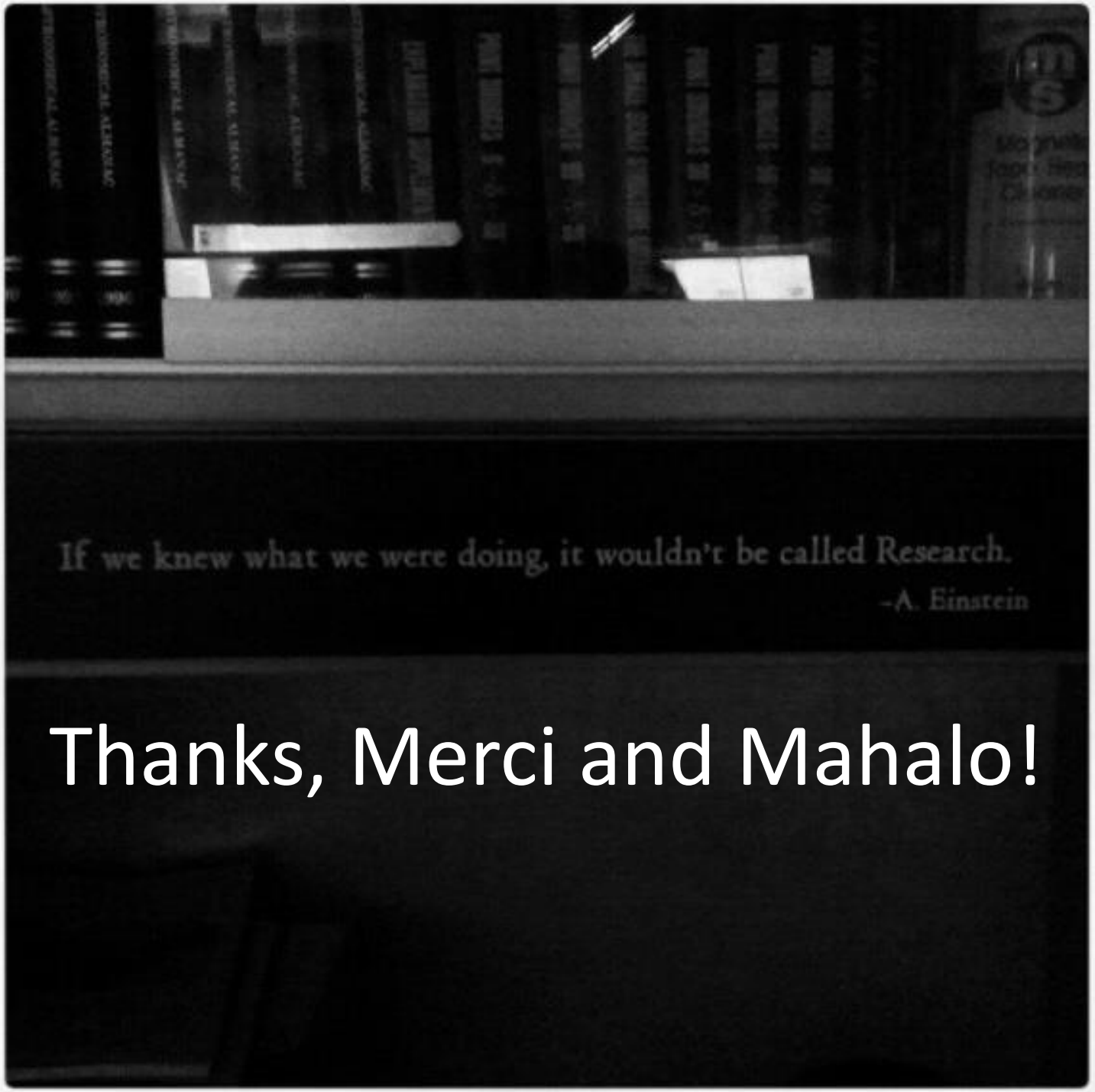


CONCLUSIONS

The Orion Nebula
Credits: NASA/ESA

Conclusions

- A new era for submillimetre polarimetry
  - POL-2 takes advantages of unique JCMT capabilities
  - Multi-scale studies of magnetism
  - Multi-wavelength tests of grain alignment
- Monitoring of fast variability in radio-loud AGN
  - Accretion and jet launching mechanisms in quasars
- Magnetic fields in star-forming regions
  - BISTRO is providing tremendous results, the best results
  - Studying the magnetic field in protostellar cores
  - What about depolarisation?



Thanks, Merci and Mahalo!

References

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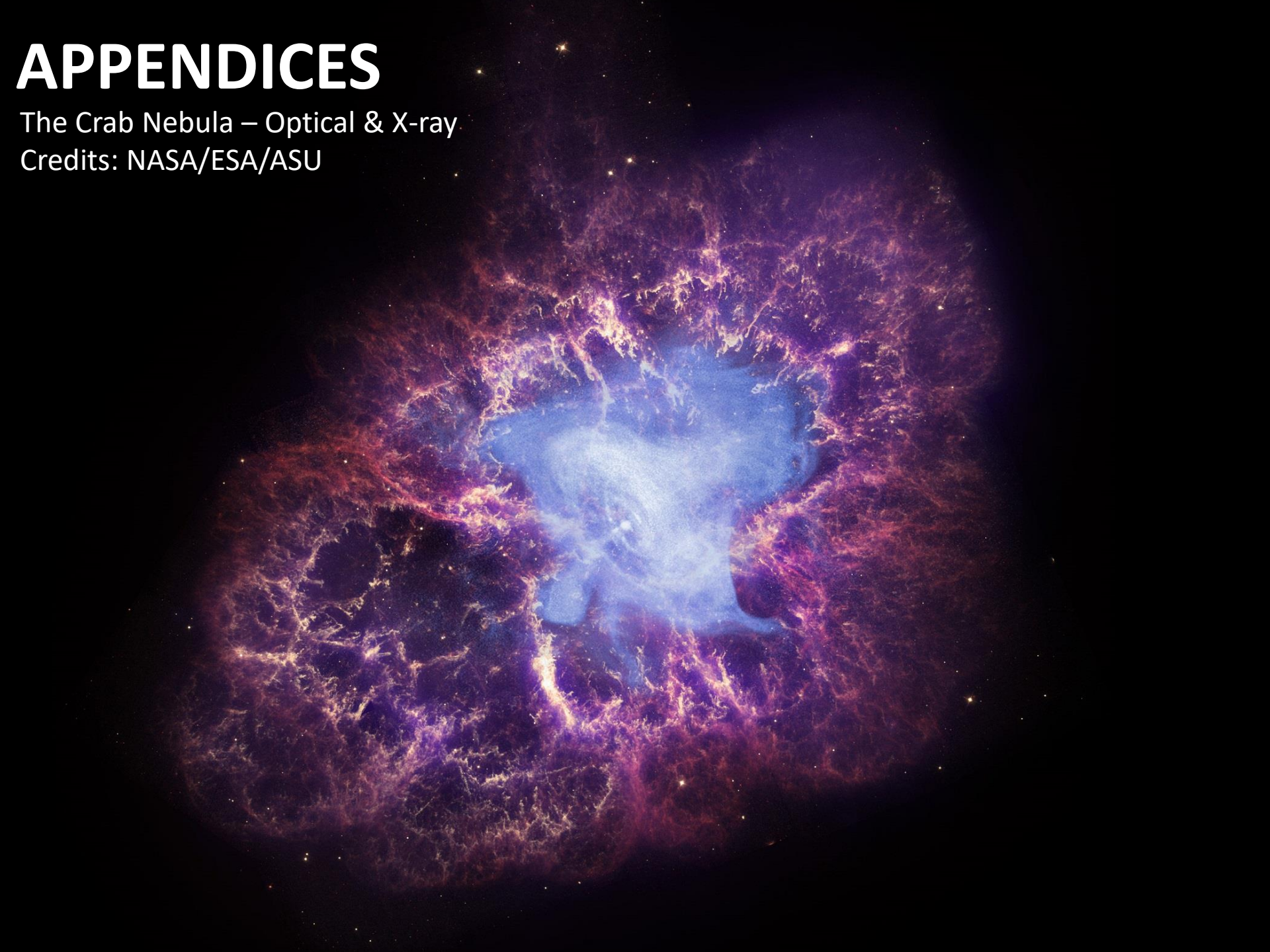
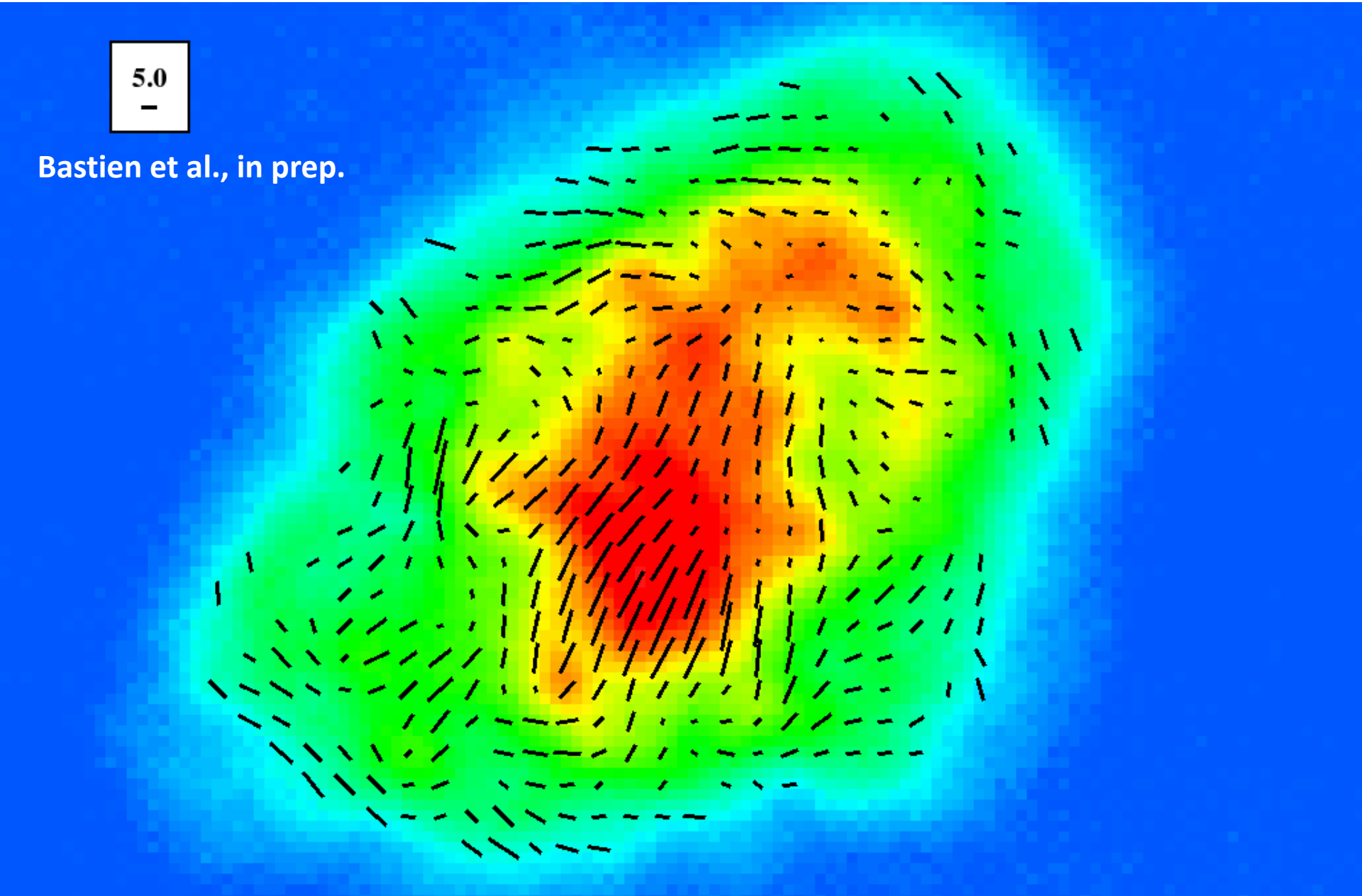
- Kainulainen J. et al., accepted in A&A, arXiv:1603.05688
- Gendron-Marsolais M.-L. et al., accepted in MNRAS, arXiv:1701.03791
- Ritacco A. et al., accepted in A&A, arXiv:1609.02042

APPENDICES

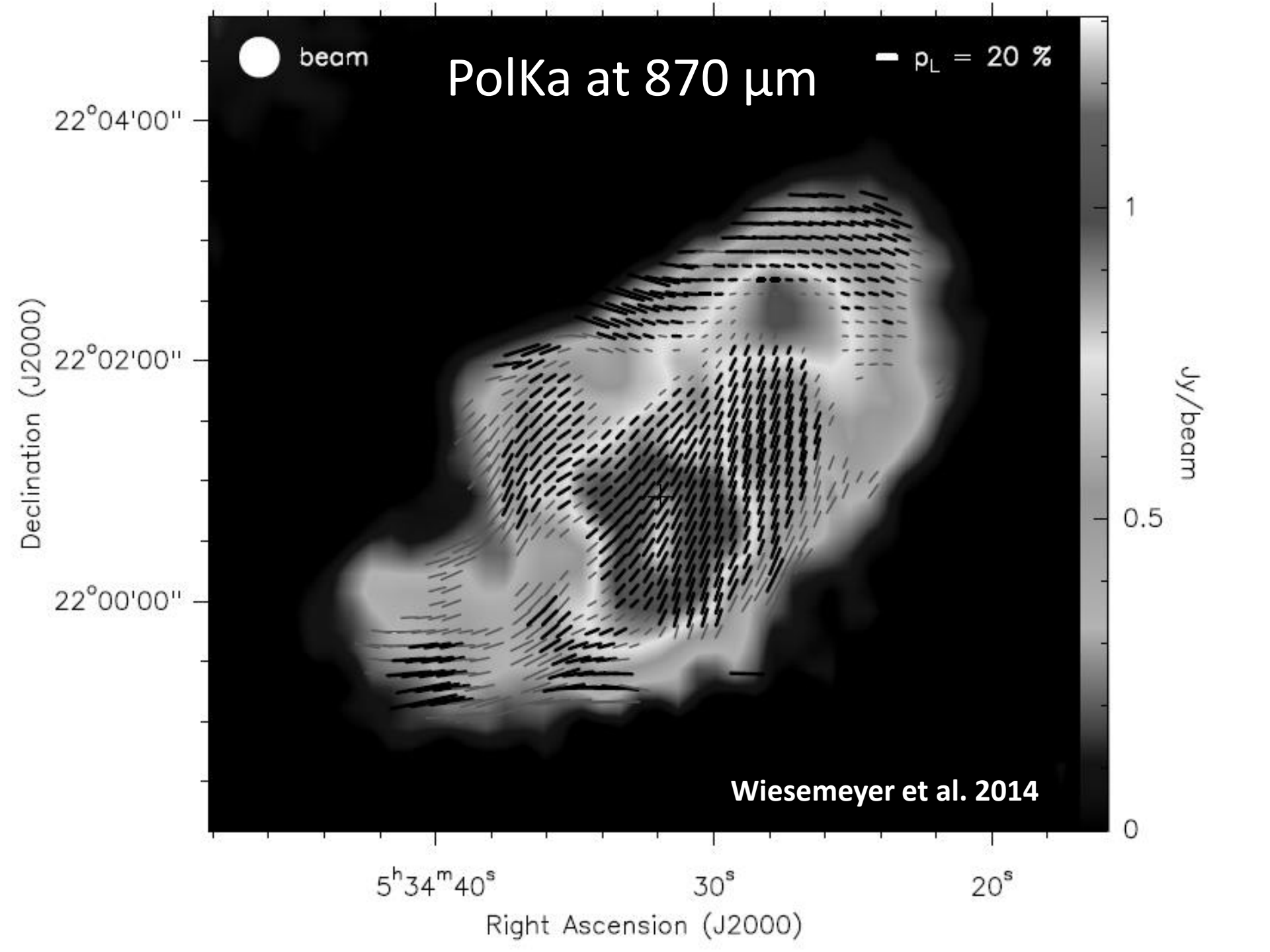
The Crab Nebula – Optical & X-ray
Credits: NASA/ESA/ASU

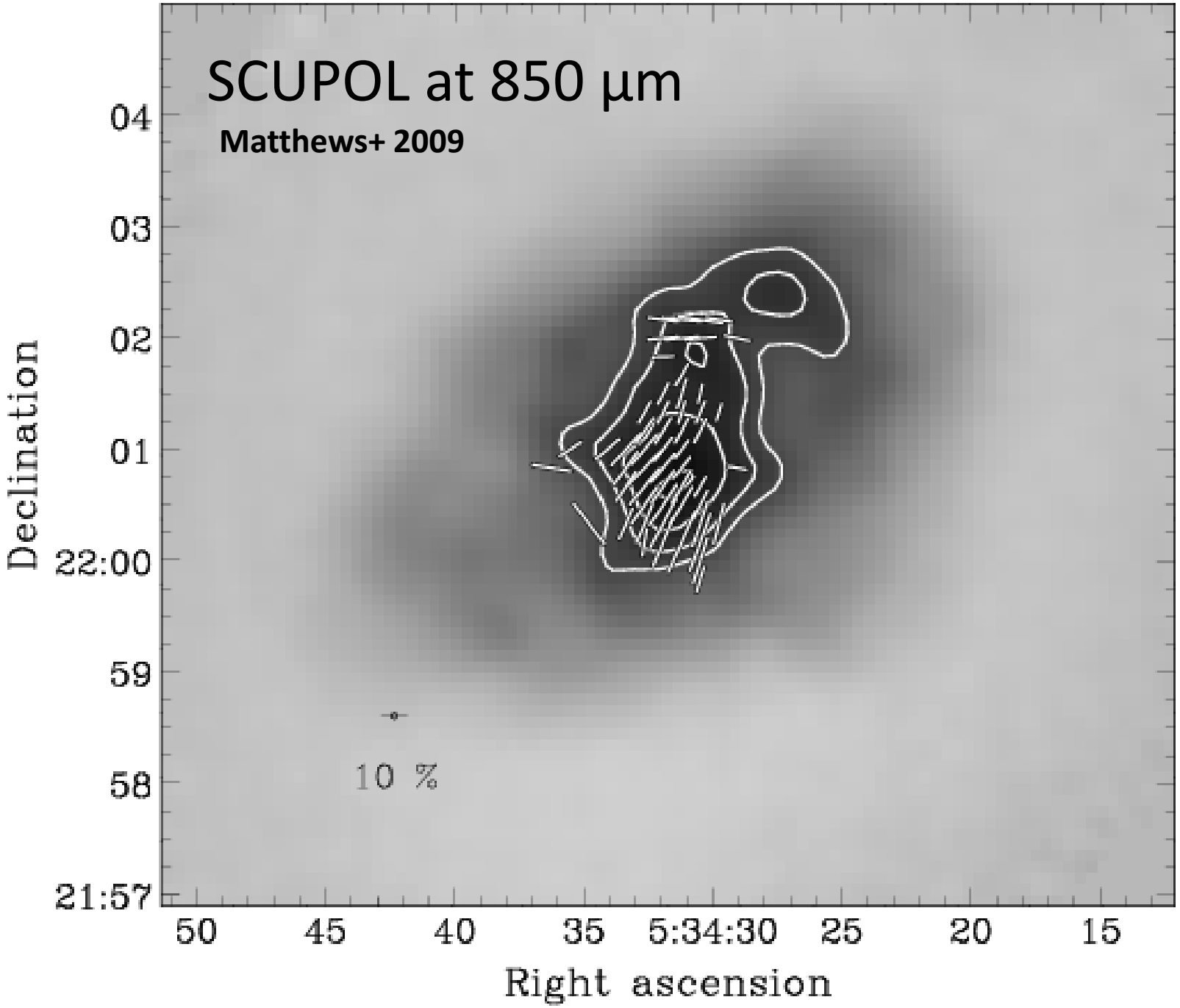


POL-2 – The Crab Nebula

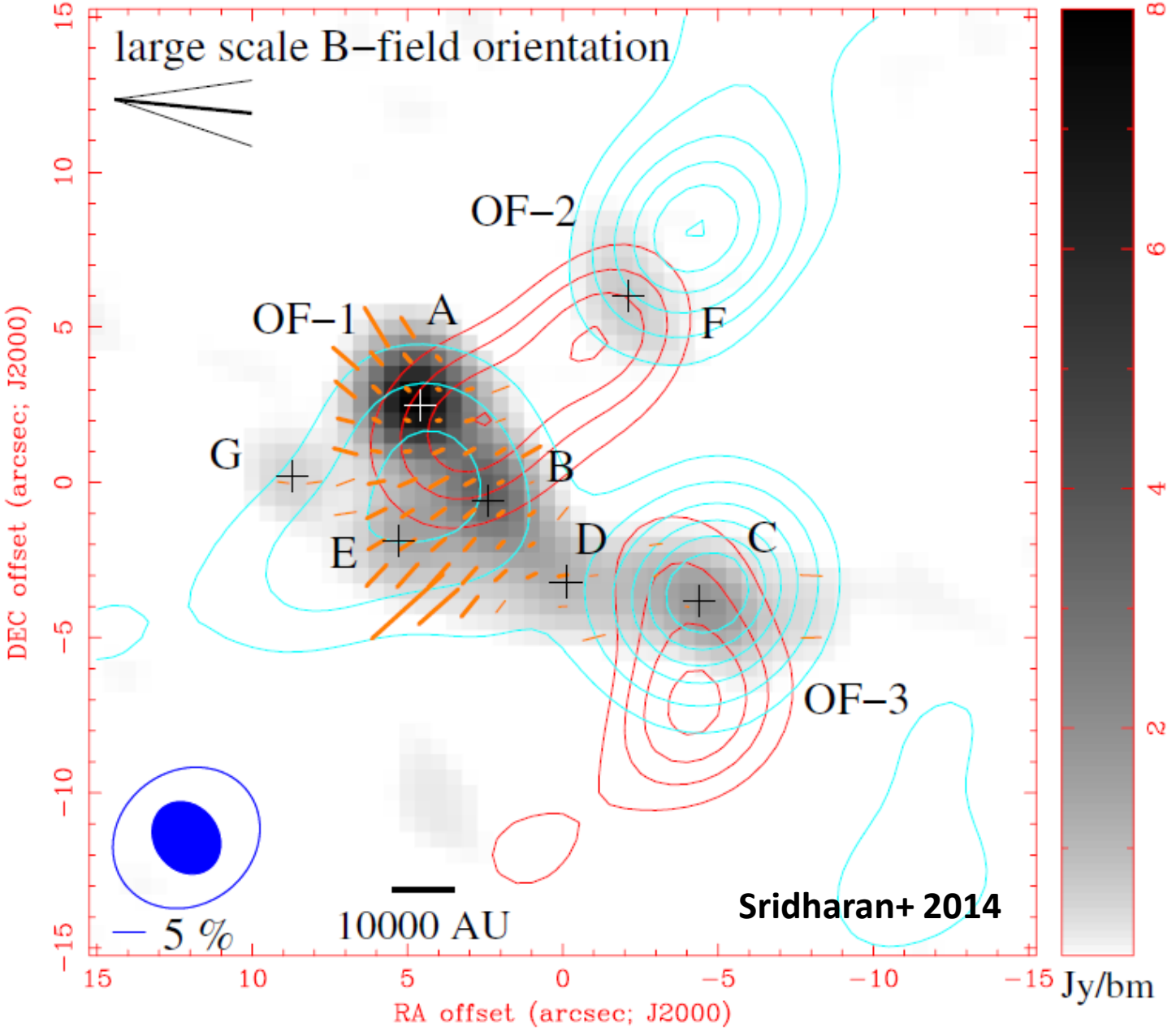


Bastien et al., in prep.


PolKa at 870 µm
beam
p_L = 20 %
22°04'00"
22°02'00"
22°00'00"
Declination (J2000)
1
0.5
0
Jy/beam
5h34m40s
30s
20s
Right Ascension (J2000)
Wiesemeyer et al. 2014

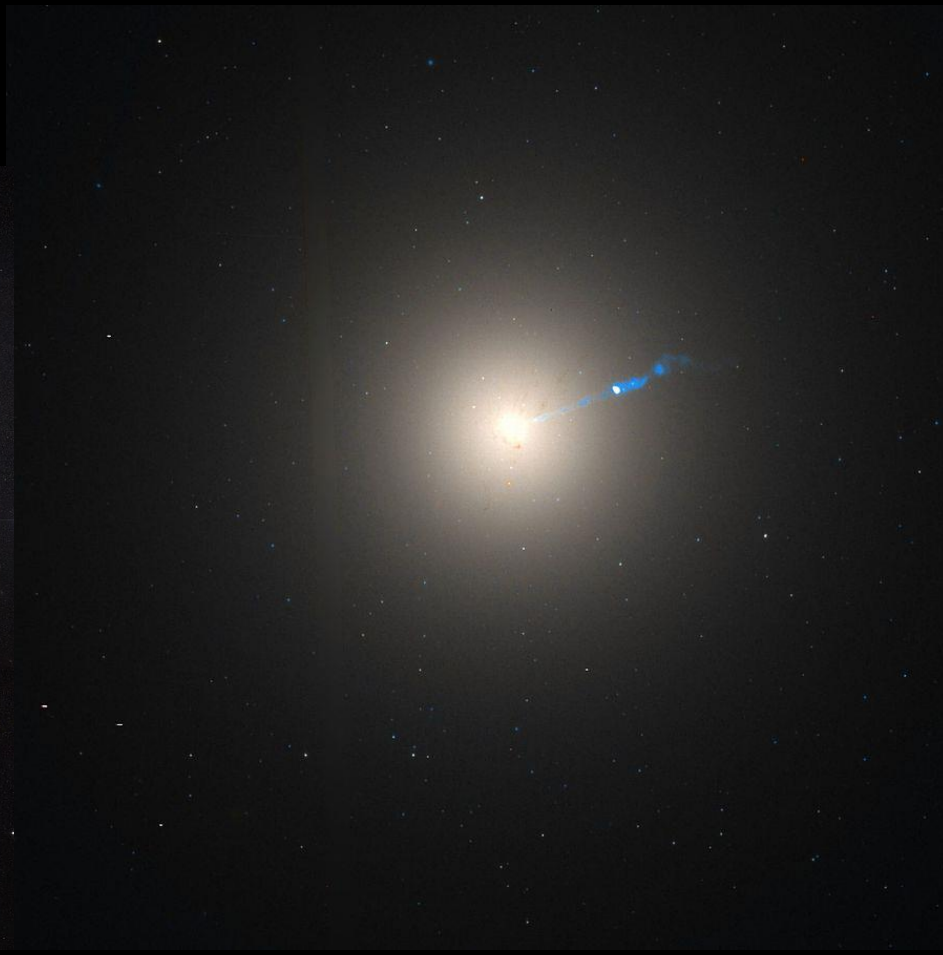

SCUPOL at 850 µm
Matthews+ 2009
04
03
02
01
22:00
59
58
21:57
Declination
10 %
50
45
40
35
5:34:30
25
20
15
Right ascension

W43-MM1 – SMA at ~870 µm



Extra-galactic sources

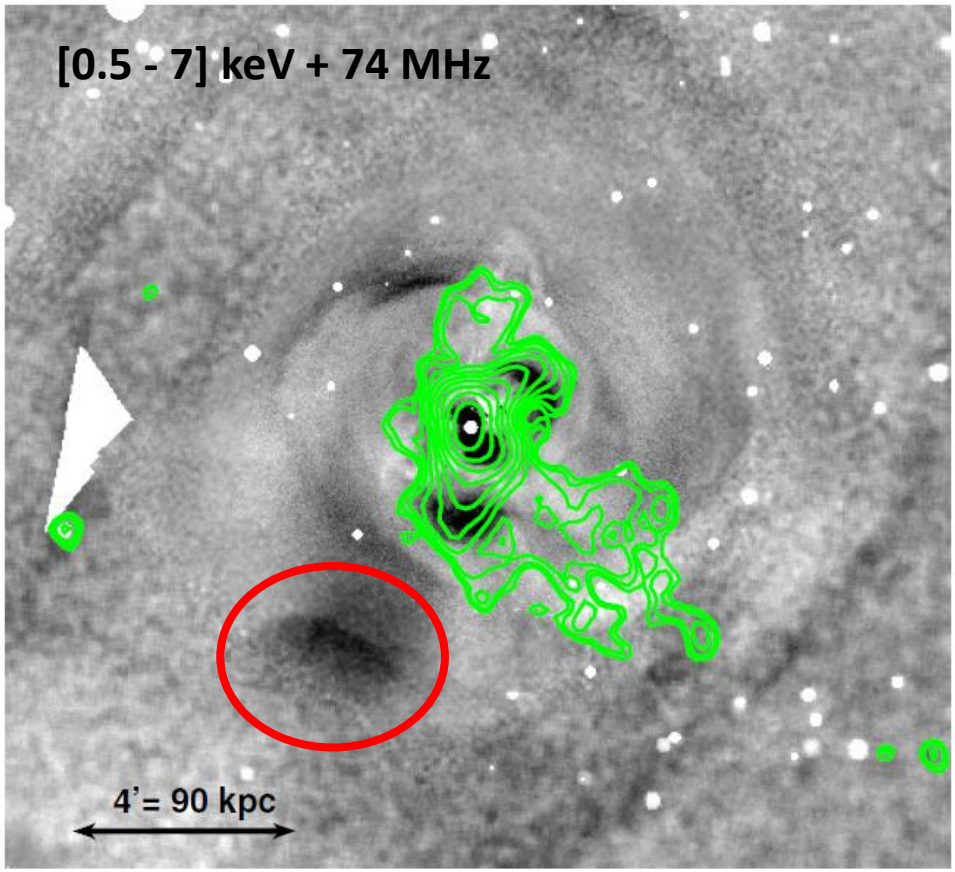
Messier 82
Credit: HST/NASA/ESA

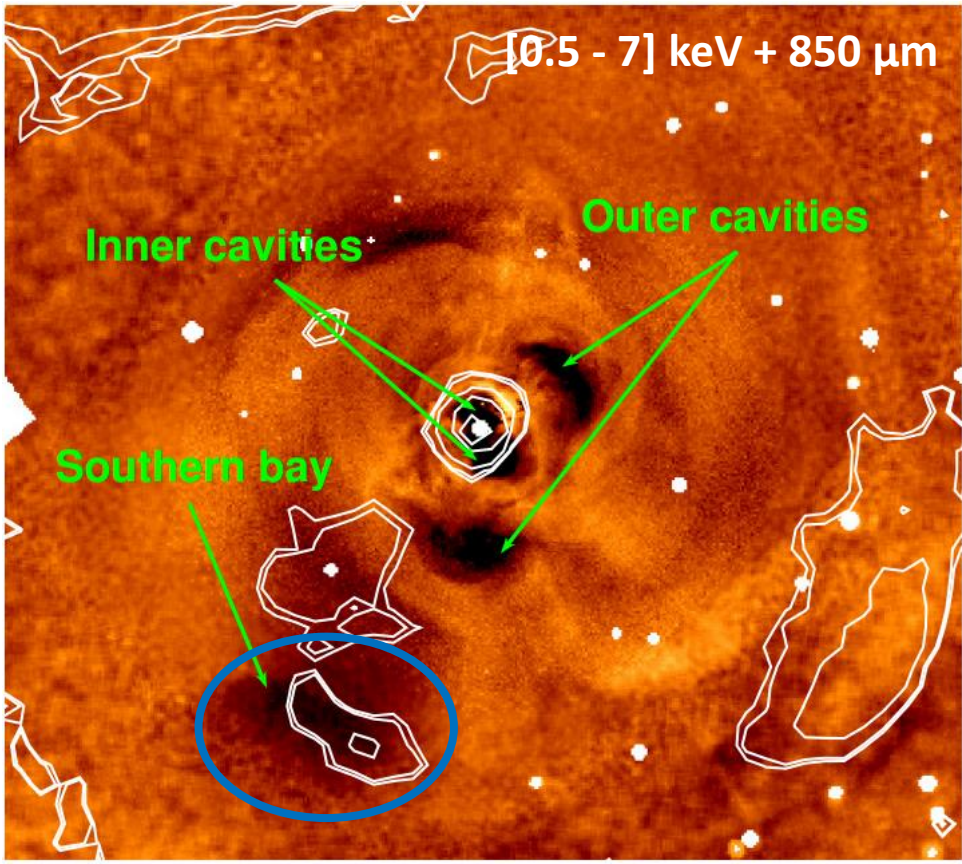


Messier 87
Credit: HST/NASA/ESA

The mystery of the Southern Bay

NGC 1275 (3C 84)





Gendron-Marsolais+ 2017

Emission from cold interstellar dust grains

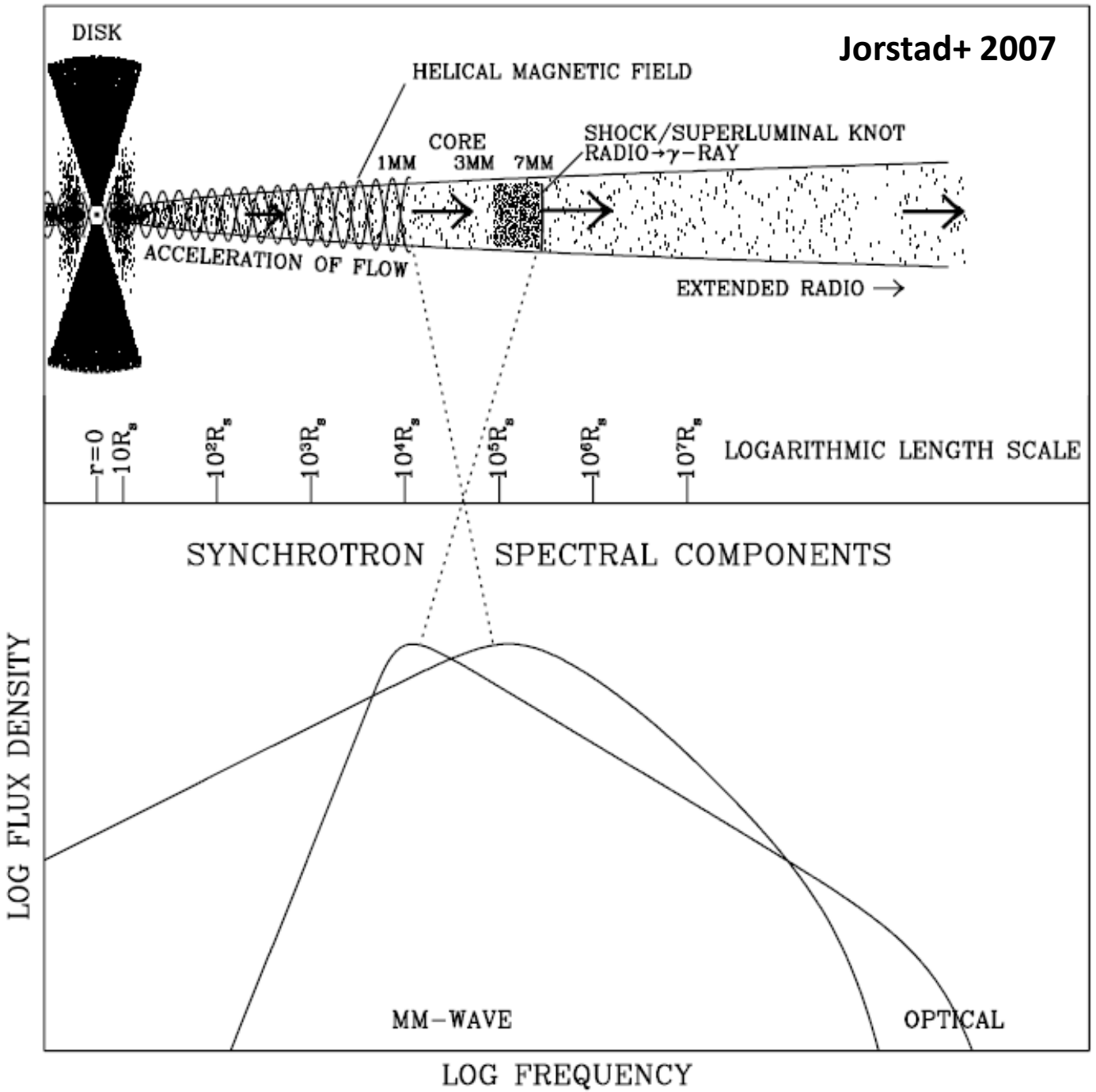
- Grain composition
  - Silicates, carbon (Draine & Lee 1984)
    - Spherical grains, Mie diffusion
  - Refractive mantle (Li & Greenberg 1997)
  - Small grains (Weingartner & Draine 2001)
    - UV extinction

- Size distribution
  - Model from Mathis, Rumpl & Nordsieck 1977

$$dn_i \propto n_H a^{-3.5} da$$

  - Where n_H is the hydrogen density

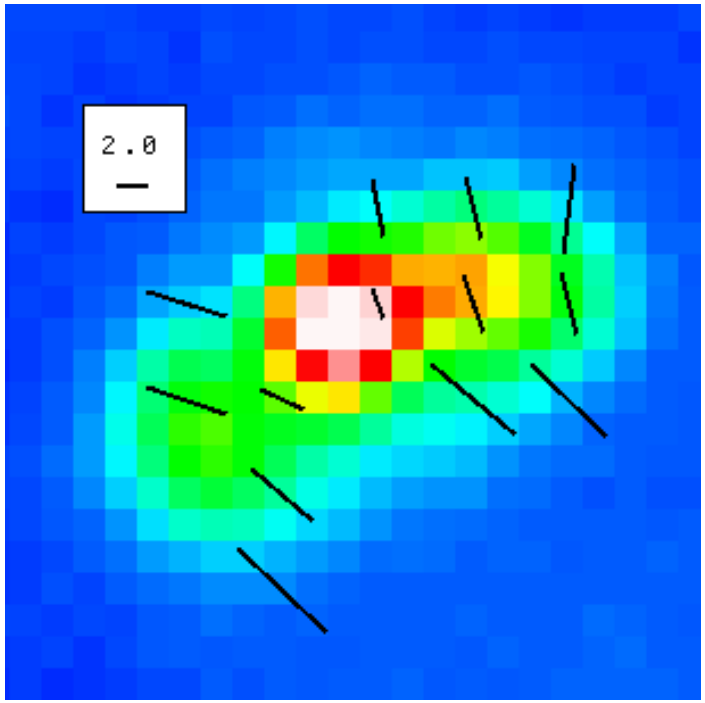
a is the grains radii ($a_{\min} < a_{\max}$)


Jorstad+ 2007
DISK
HELICAL MAGNETIC FIELD
CORE
1MM
3MM
7MM
SHOCK/SUPERLUMINAL KNOT
RADIO→γ−RAY
ACCELERATION OF FLOW
EXTENDED RADIO →
r=0
10Rs
10²Rs
10³Rs
10⁴Rs
10⁵Rs
10⁶Rs
10⁷Rs
LOGARITHMIC LENGTH SCALE
SYNCHROTRON SPECTRAL COMPONENTS
LOG FLUX DENSITY
MM−WAVE
OPTICAL
LOG FREQUENCY

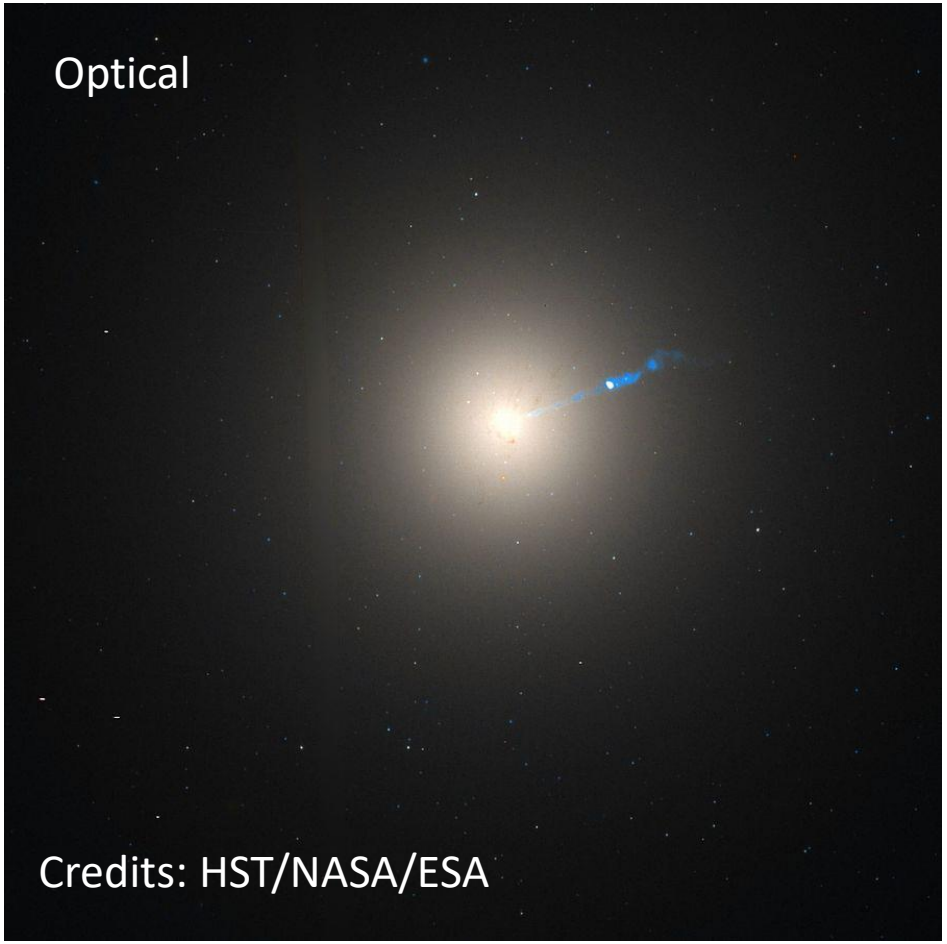
Submillimetre polarisation in M87

POL-2 at 850 µm

12’’ bins



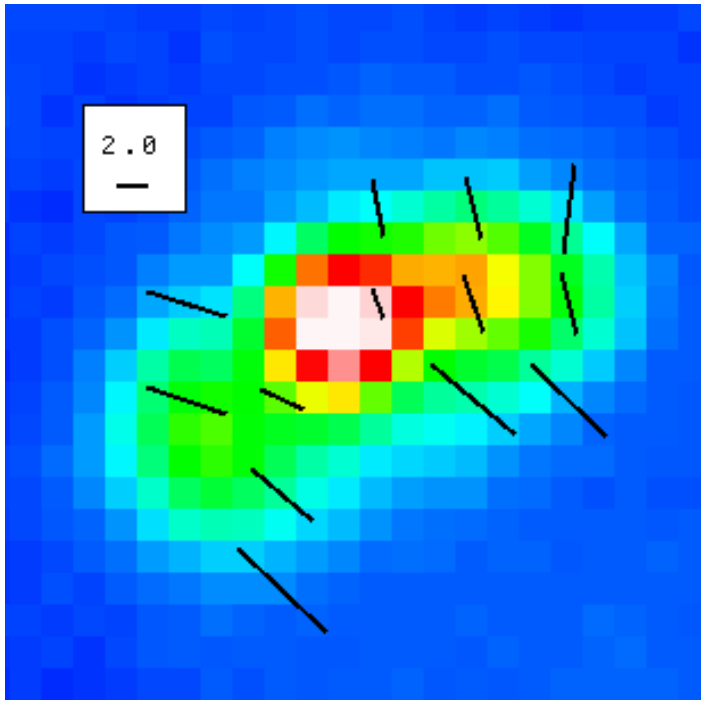
Bastien et al., in prep.



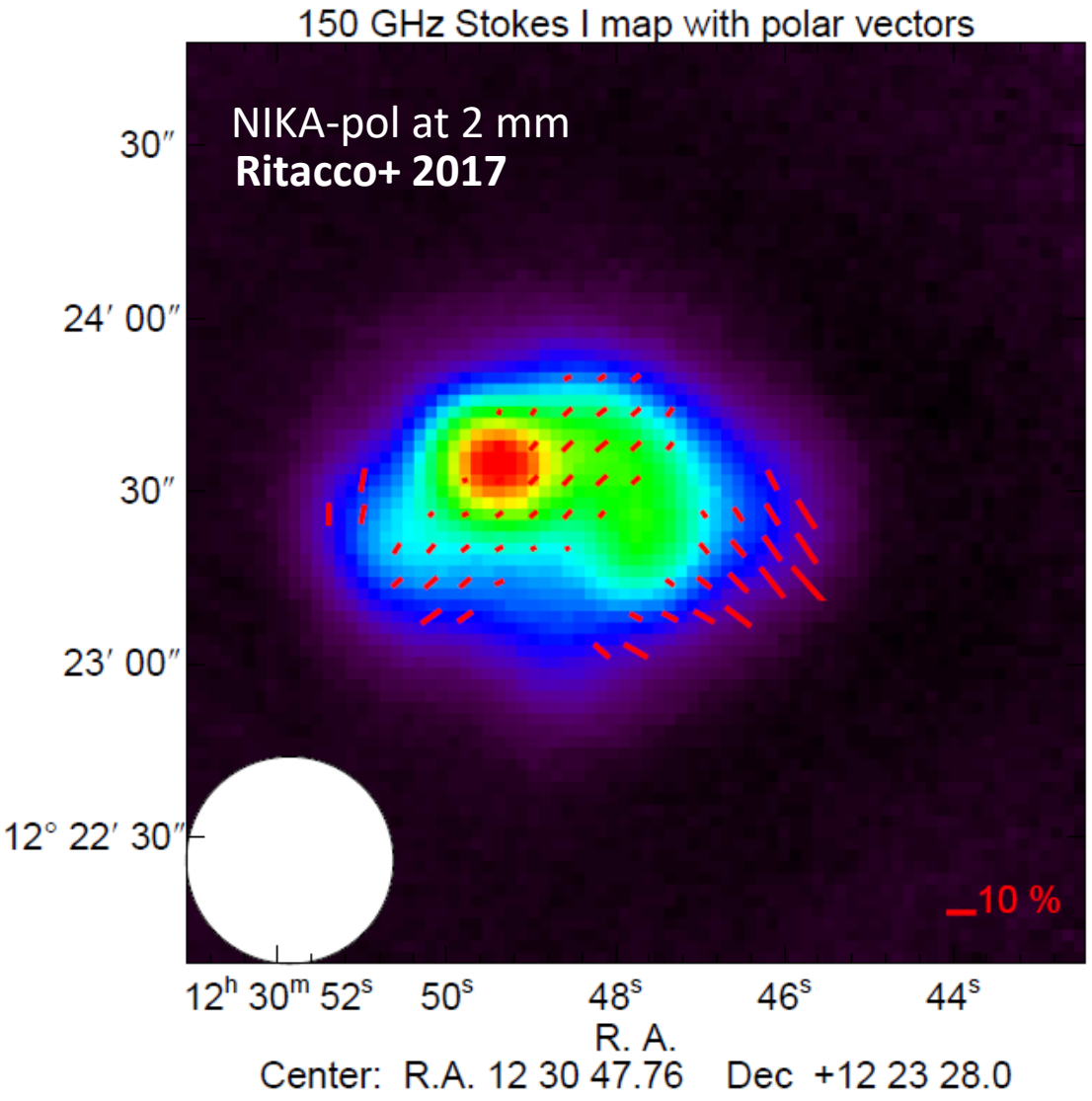
Submillimetre polarisation in M87

POL-2 at 850 µm

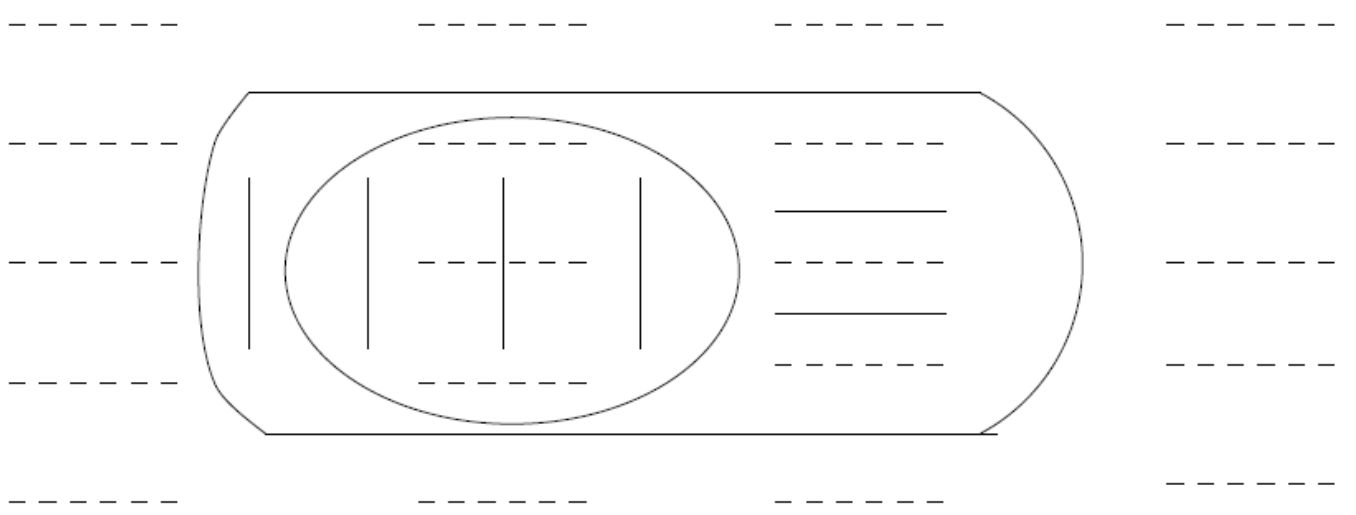
12’’ bins



Bastien et al., in prep.



Magnetic fields in M87



Perlman+ 1999

Key: – – – – – – **Surface of Jet, brightest in radio**

——— **Center of Jet, brightest in optical**