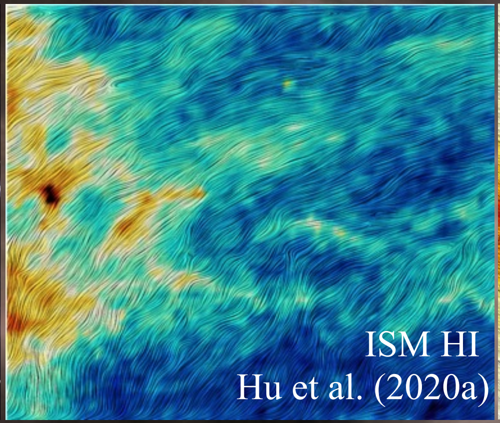
Characterizing Magnetic Fields's Role in Fueling Seyfert Nuclei With SOFIA/HAWC+, Velocity Gradient, and VLA

THE UNIVERSITY of WISCONSIN MADISON

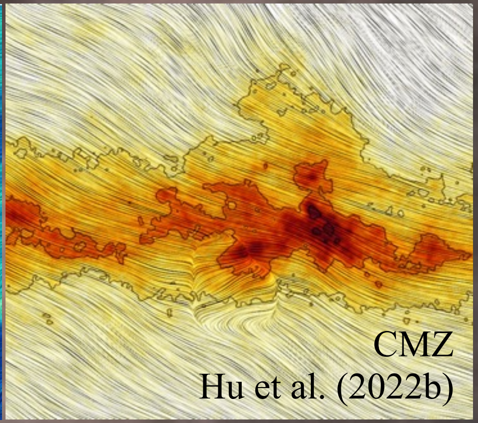
Speaker: Yue Hu Date: 03/22/2023

SOFIA Tel-Talk

Galaxy cluster
Hu et al. (2020c)



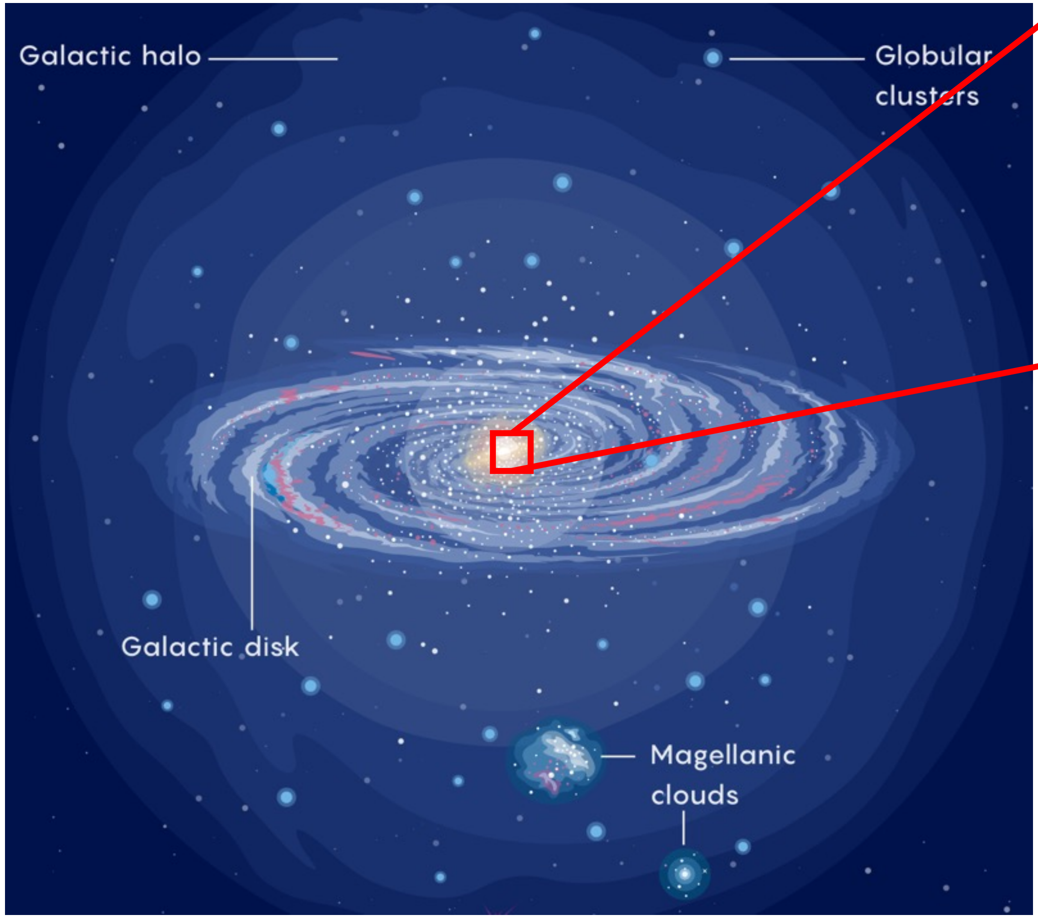
ISM HI
Hu et al. (2020a)



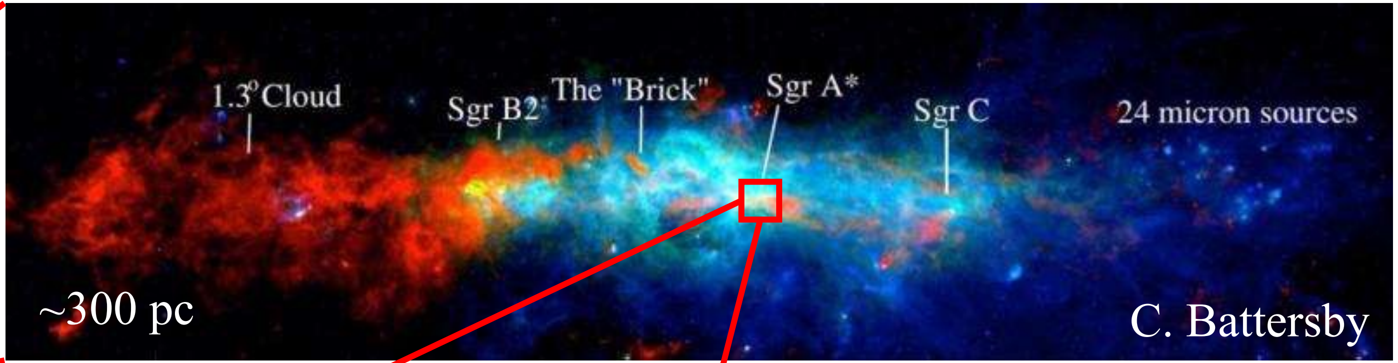
CMZ
Hu et al. (2022b)

Global view of our galaxy

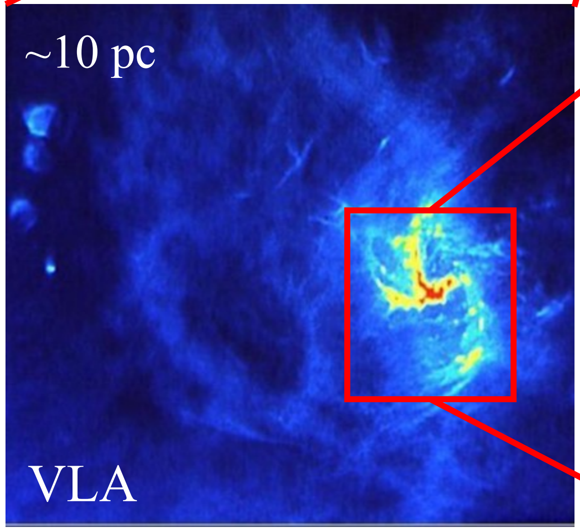
Milky Way



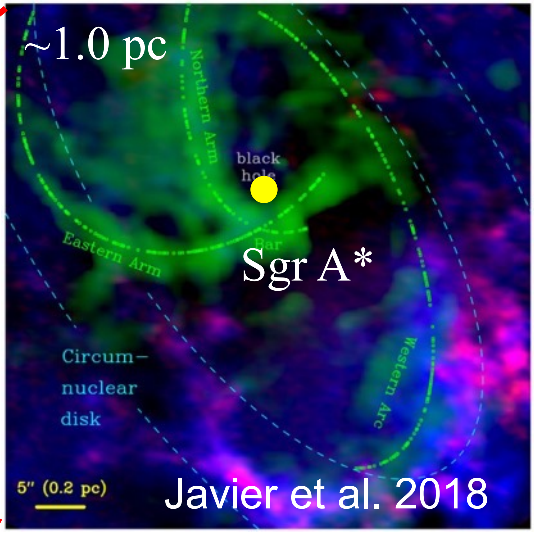
Central Molecular Zone (CMZ)



Sgr A East

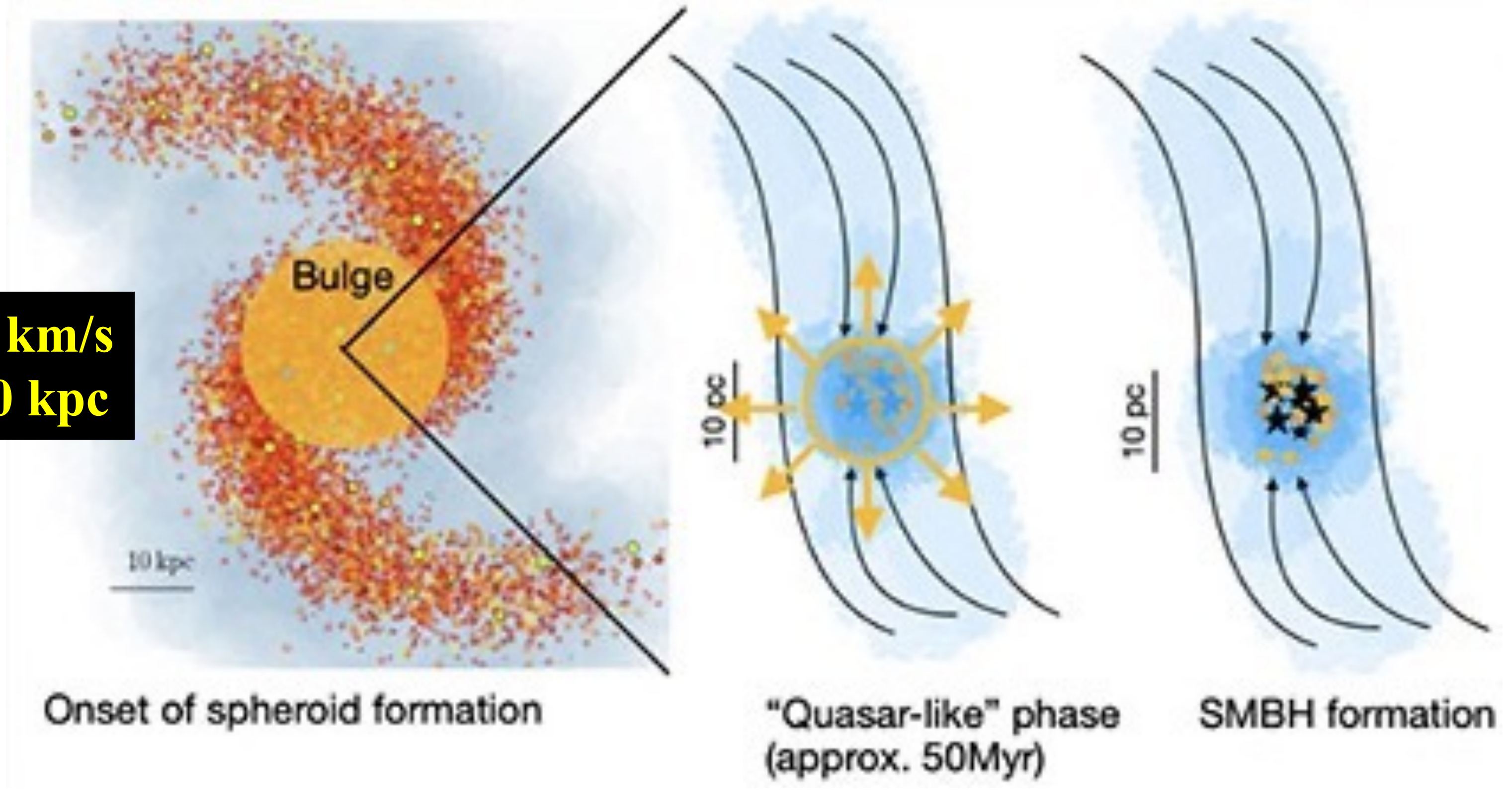


CND



The formation of galactic nucleus and SMBH

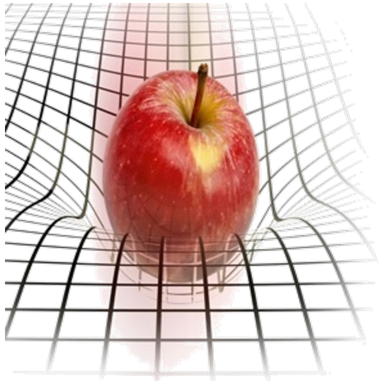
~ 30 km/s at 10 kpc

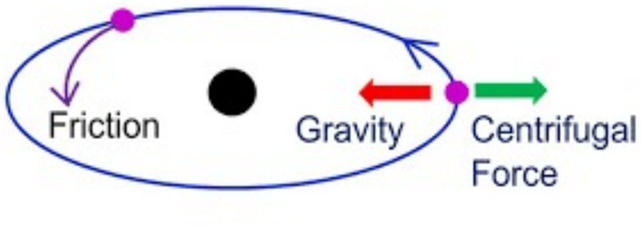


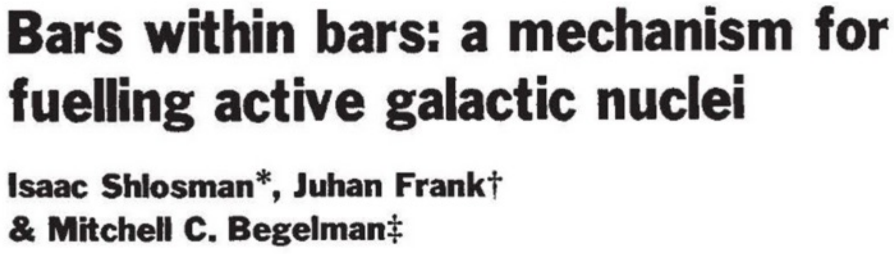
If angular momentum is conserved, ~ 3000 km/s at 10 pc

How does orbiting gas lose angular momentum?

How does orbiting gas lose angular momentum?






Bars within bars: a mechanism for fuelling active galactic nuclei

Isaac Shlosman*, Juhan Frank†
& Mitchell C. Begelman‡

Gravitational perturbation

Viscous torques

Bars within bars

Norman and Silk 1983;
Norman and Scoville 1988;
Lin et al 1988; Lubow 1988.

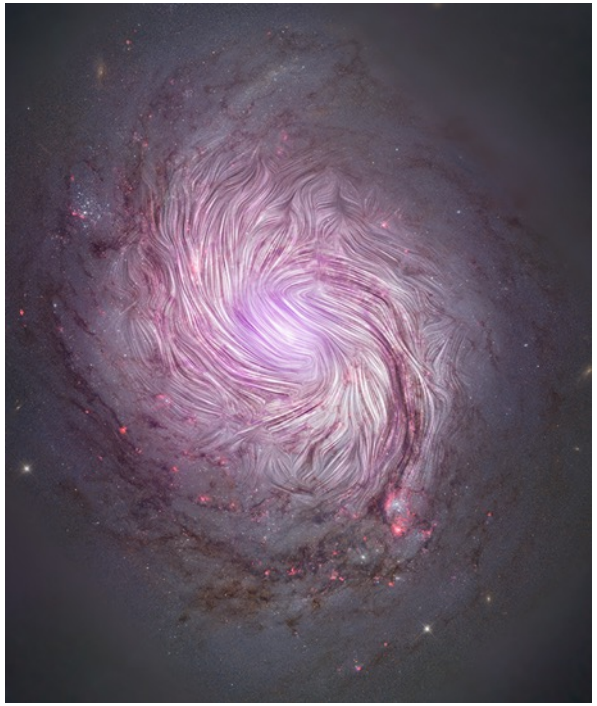
Blandford, R. D. (1988)

Shlosman et al. 1989

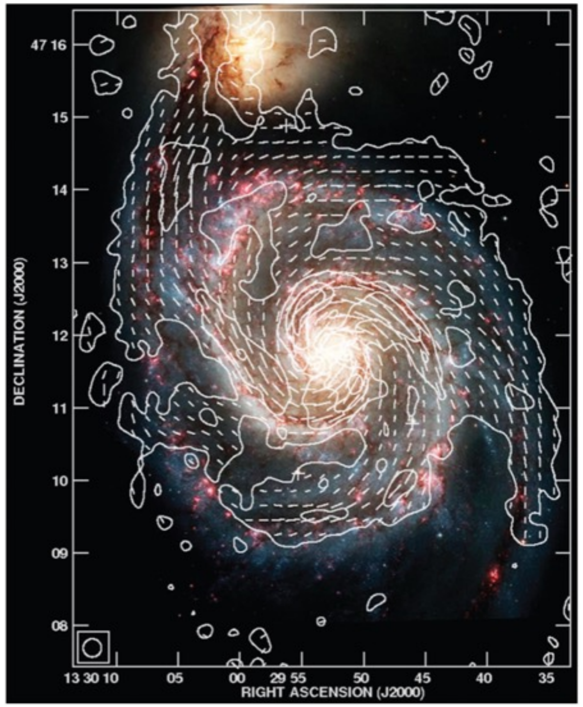
Magnetic tension could provide strong torque

Magnetic Braking Effects

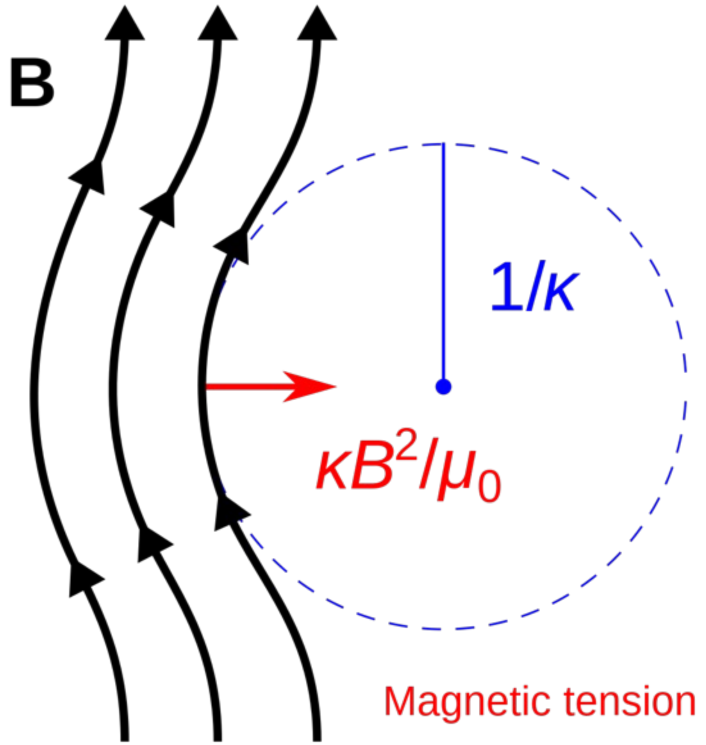
Sparke 1982



NGC 1068
SOFIA/HAWC+ (Far-infrared)
Lopez-Rodriguez et al. (2020)



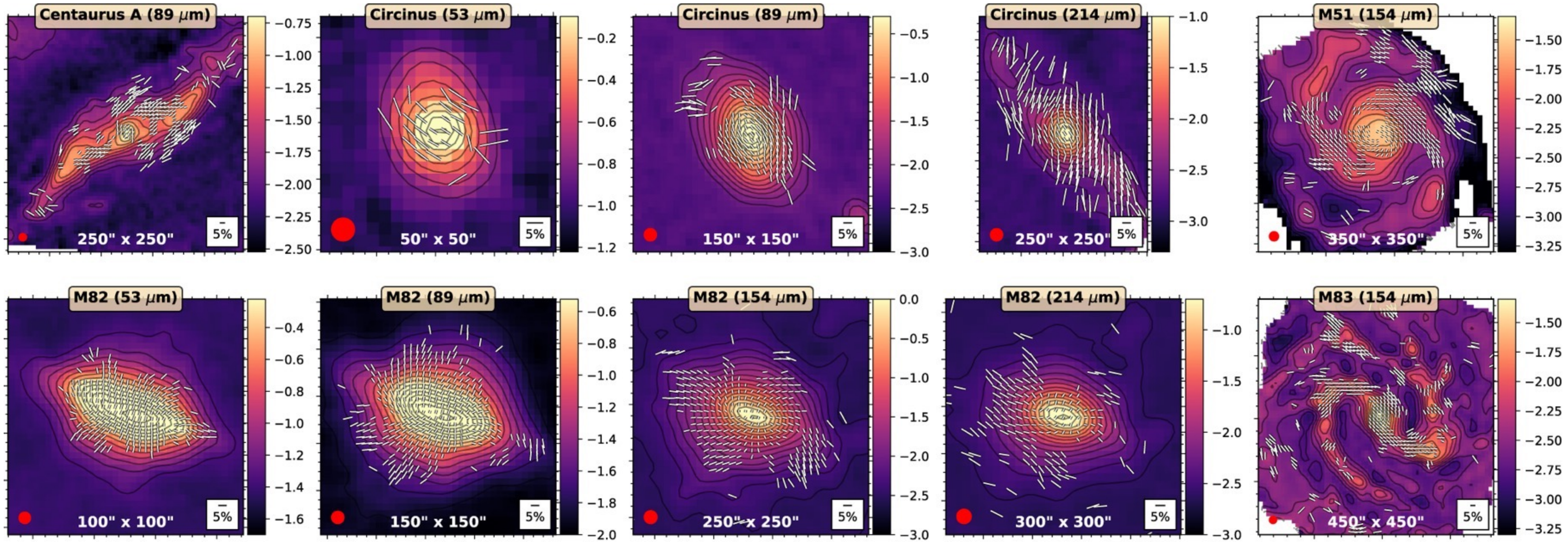
M51
VLA (radio)
Fletcher et al. (2011)



The best candidate: magnetic field

SALSA: SOFIA legacy program

Lopez-Rodriguez et al. (2022b)

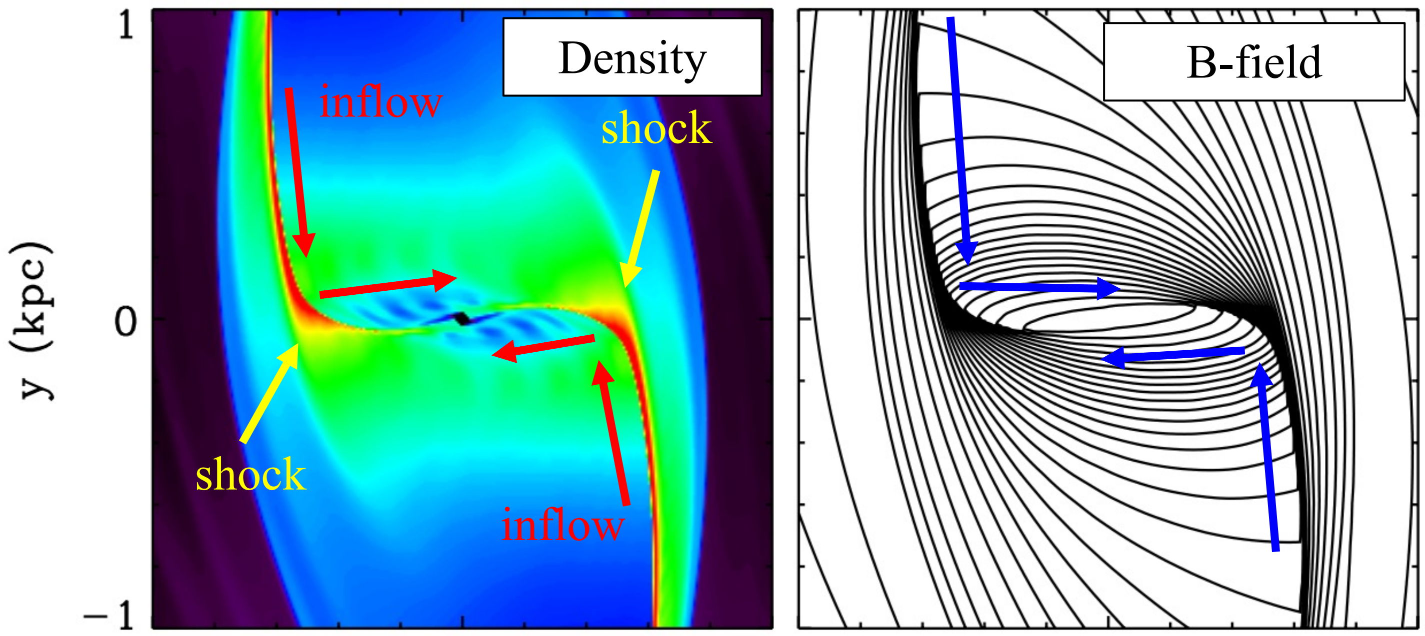


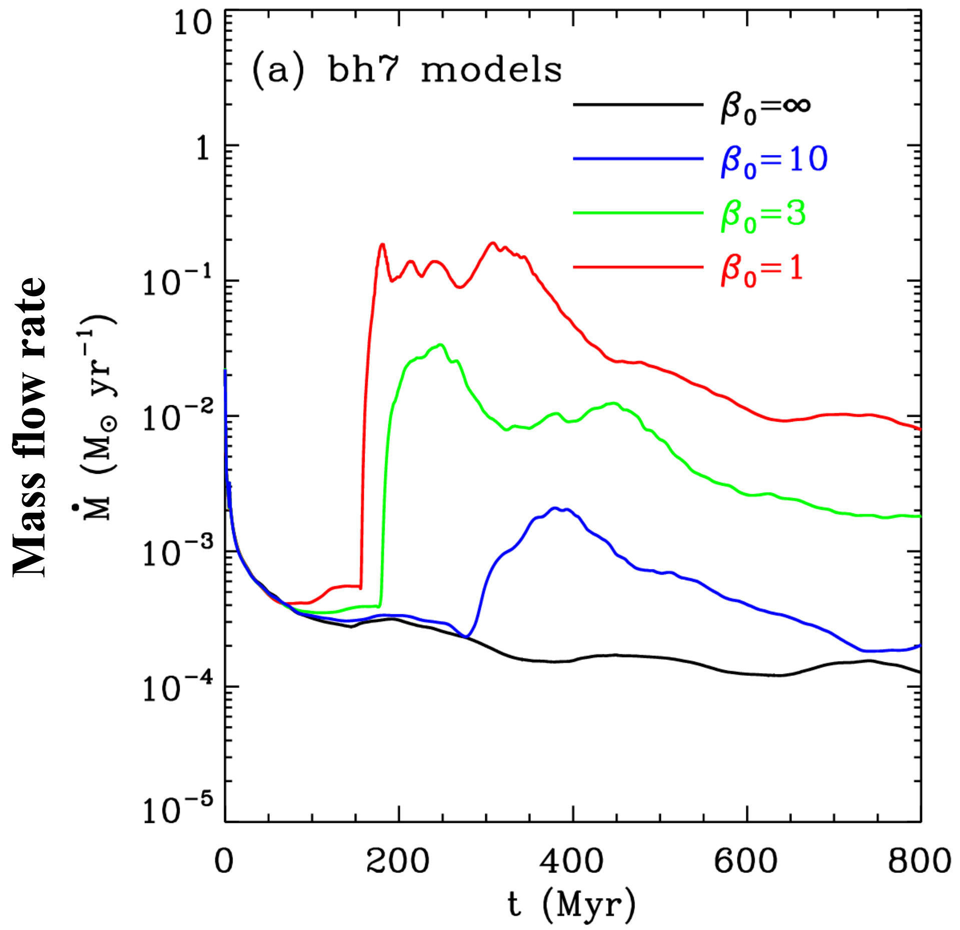
Magnetic Braking Effects

$$\beta = \frac{1}{2}\left(\frac{4\pi\rho c_s^2}{B^2}\right)^2$$

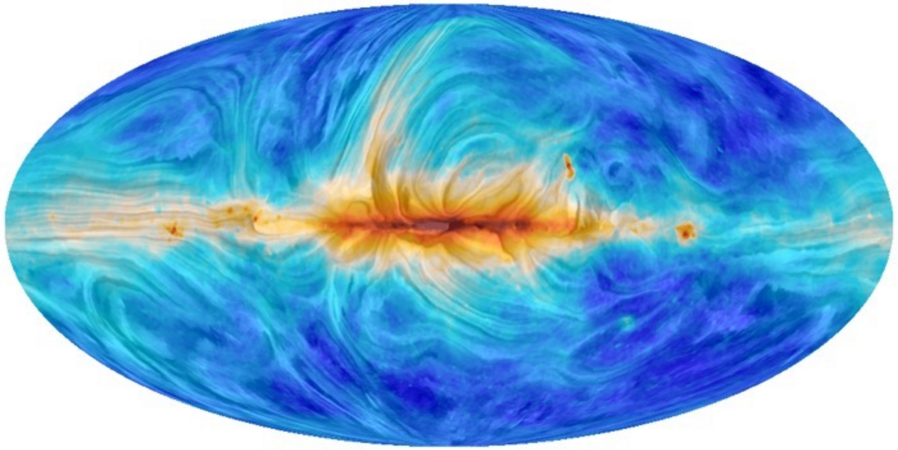
Kim & Stone (2012)

MHD simulation of barred galaxy



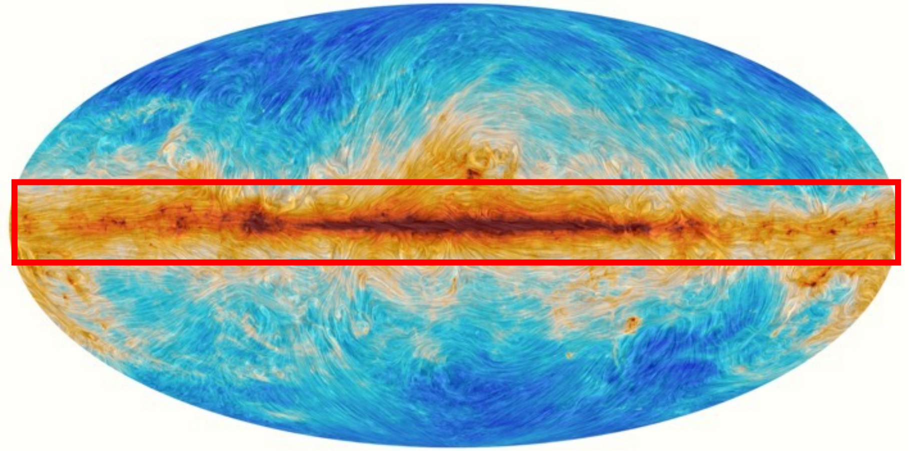


Typical polarization methods for measuring B-field



Planck radio observation (2018)

Warm diffuse gas



Planck FIR observation (2018)

cold HI,
molecular clouds
….

Molecular gas is the most important fueling material

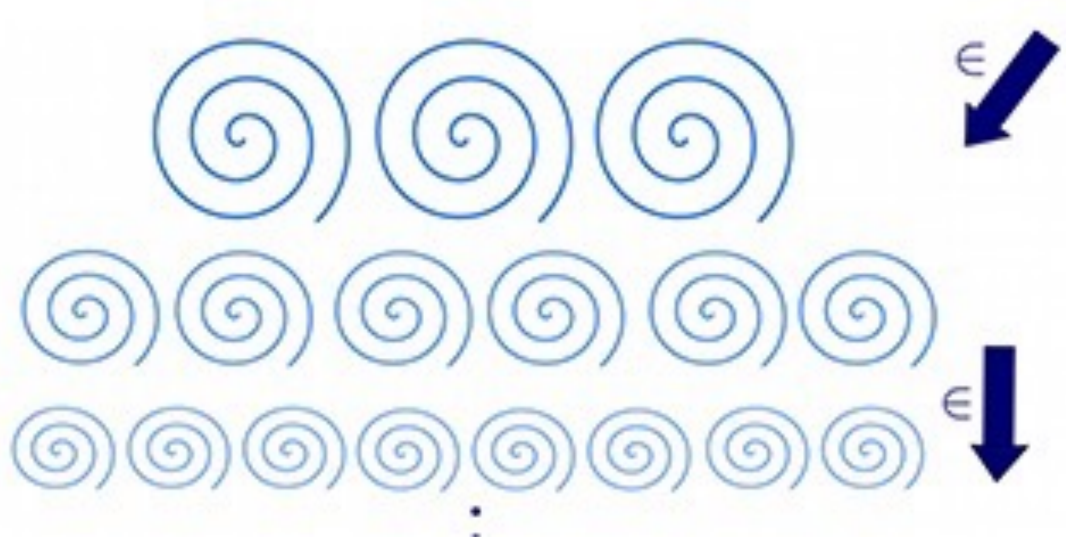
Separate the B-field directly associated with molecular gas

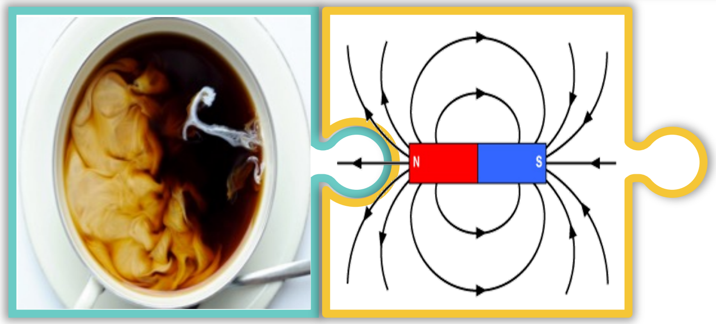
Velocity Gradient Technique

The nature of MHD turbulence

Hydro turbulence

interaction of **isotropic** eddies

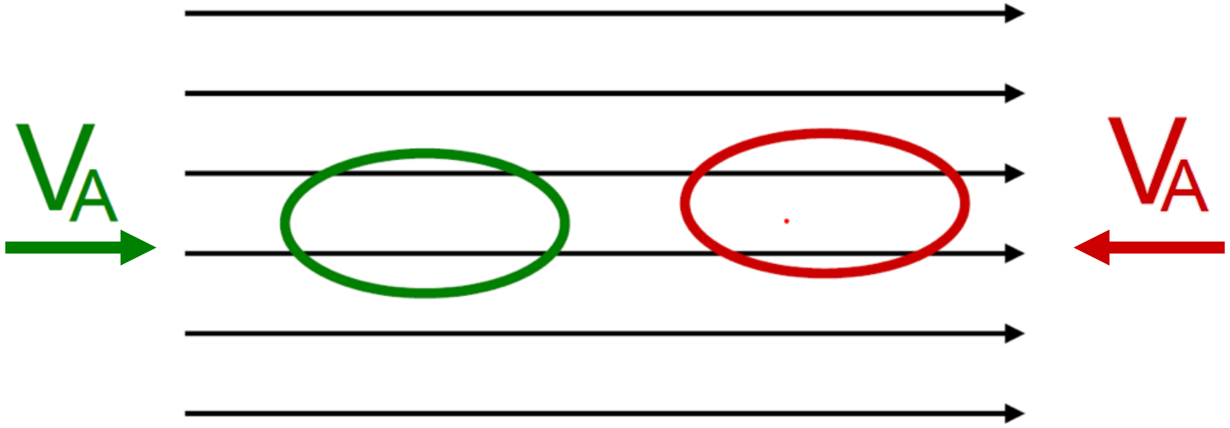




MHD turbulence

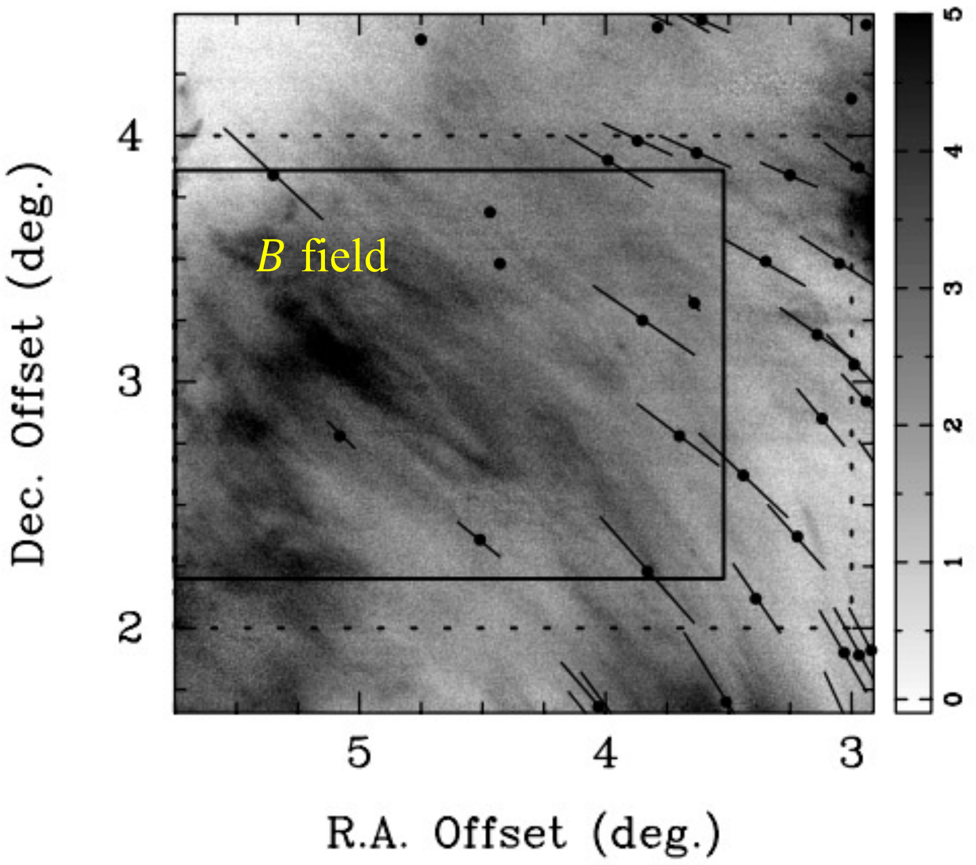
interaction of **anisotropic** wave packets moving with Alfven velocity

$V_A = B_0(4\pi\rho_o)^{-1/2}$



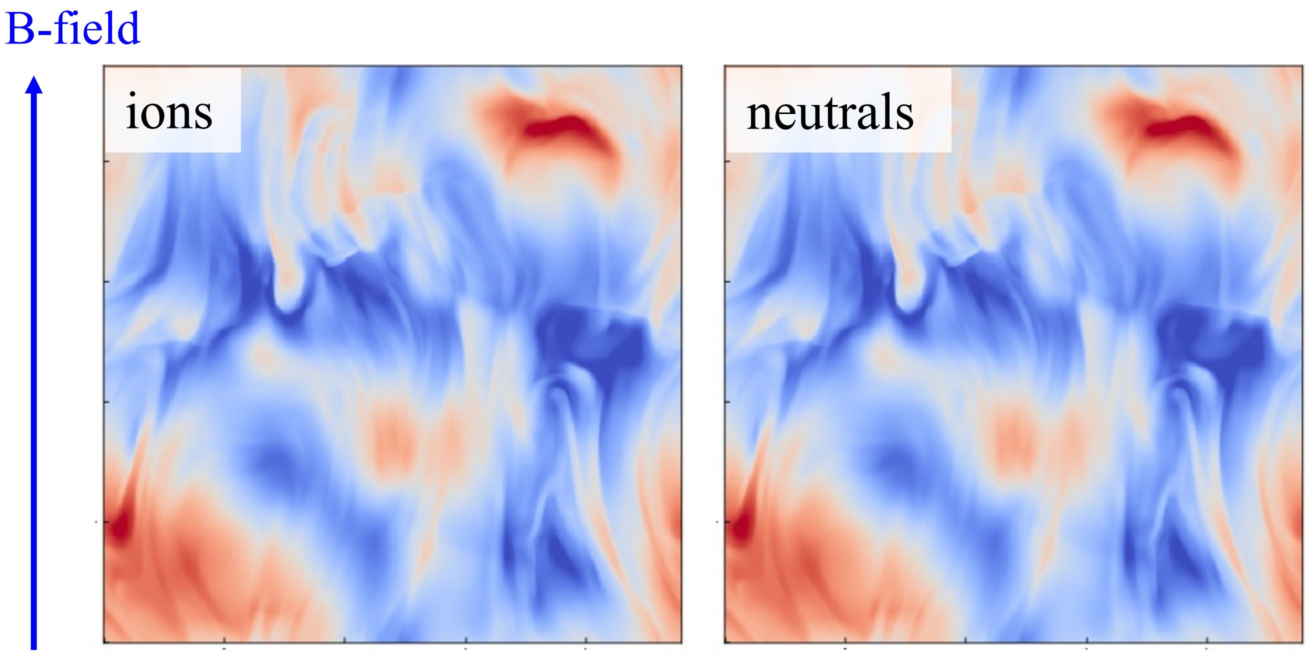
Anisotropy of MHD turbulence

Anisotropy in Taurus



Heyer et al. (2008)

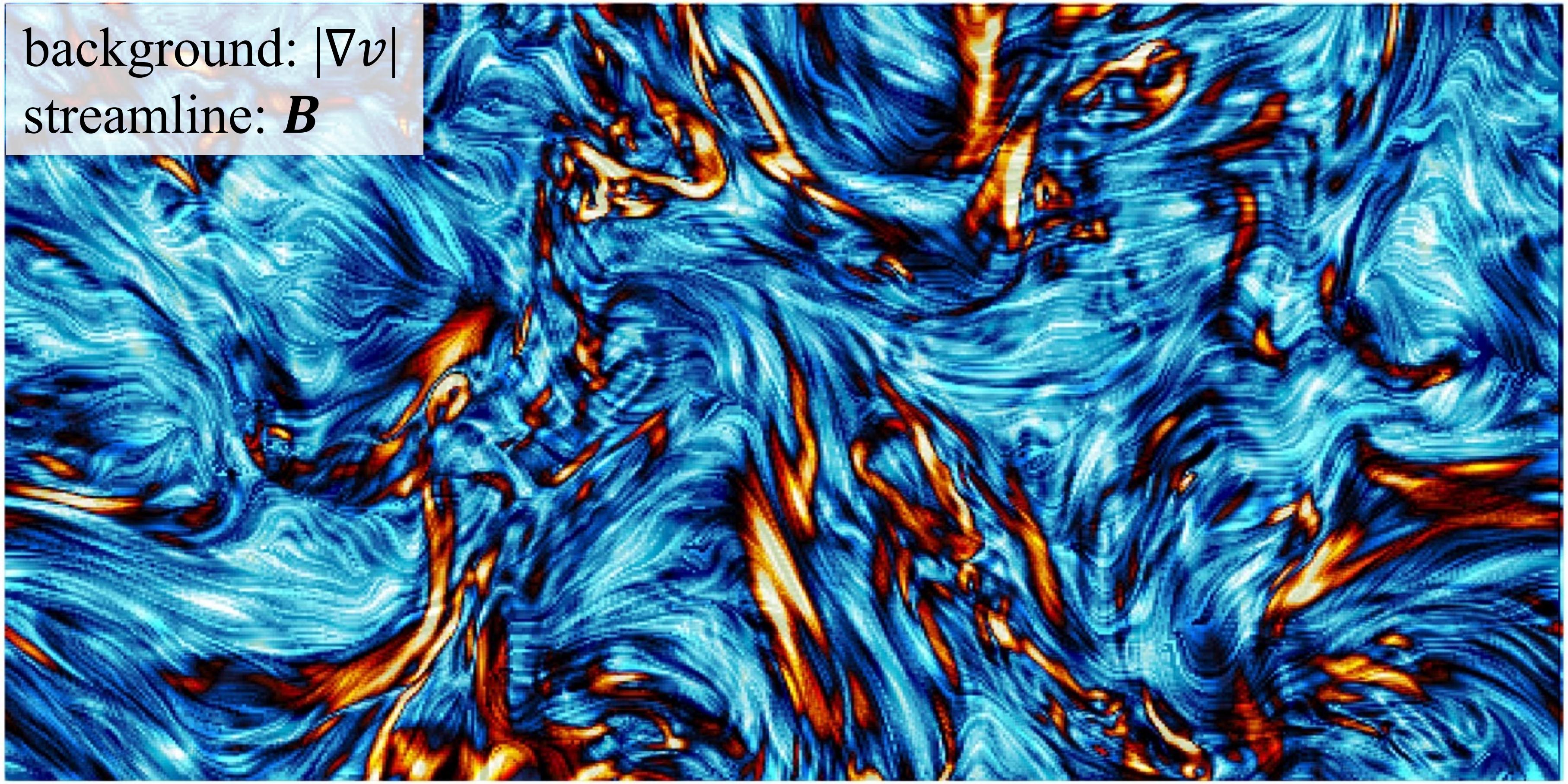
Anisotropy in two-fluid simulation



ions and neutrals are coupled via collision

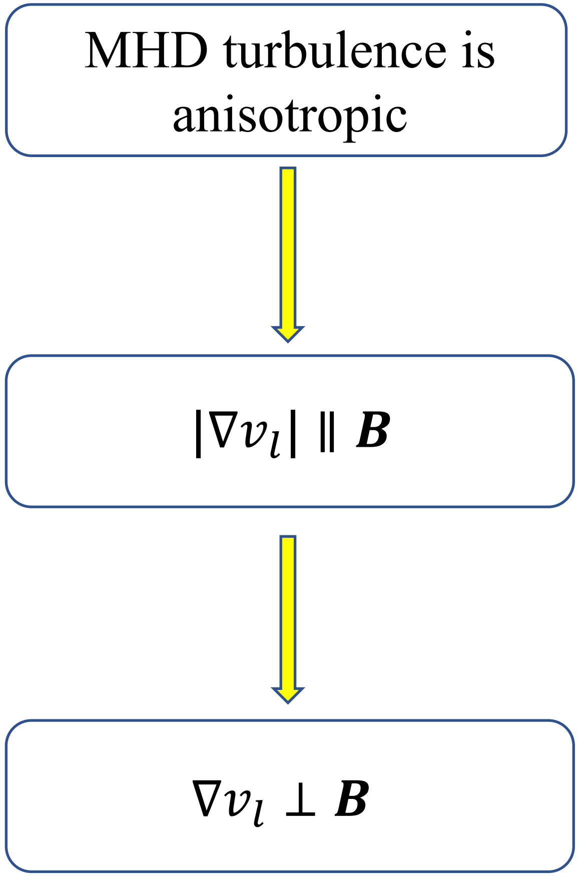
Hu et al. (2023), submitted

Velocity gradients trace turbulent magnetic fields



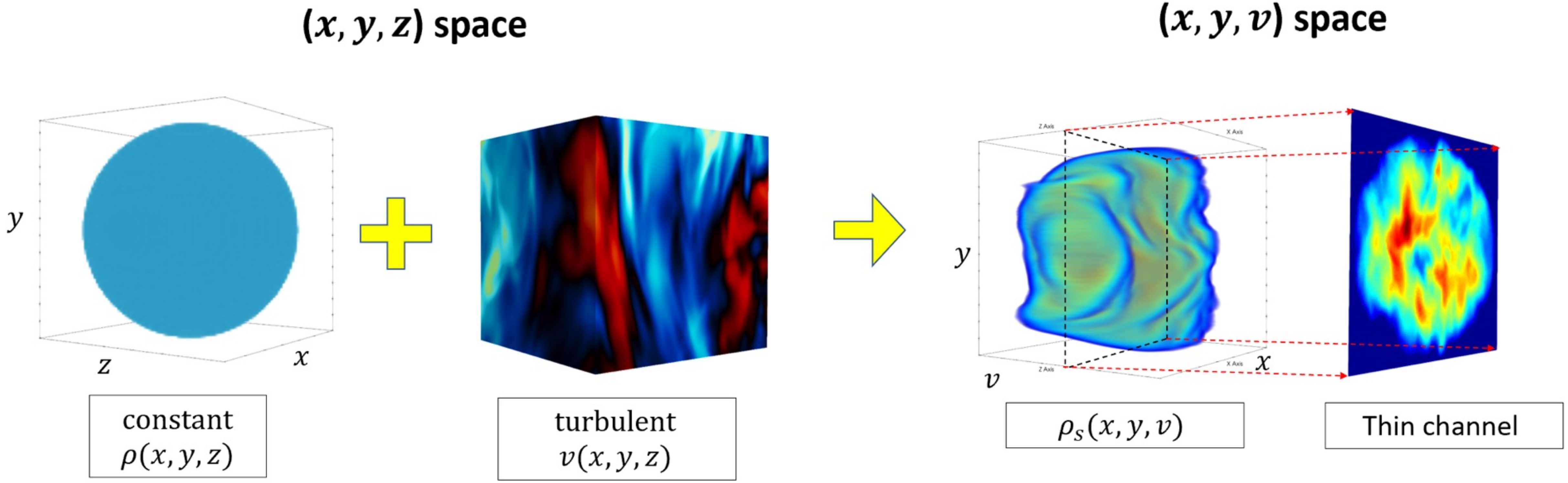
MHD simulation, Hu et al. (2020)

Goldreich & Sridhar (1995)
Lazarian & Vishniac (1999)



Lazarian & Yuen (2018)
Hu et al. (2018)

Obtaining velocity information from spectroscopic observation

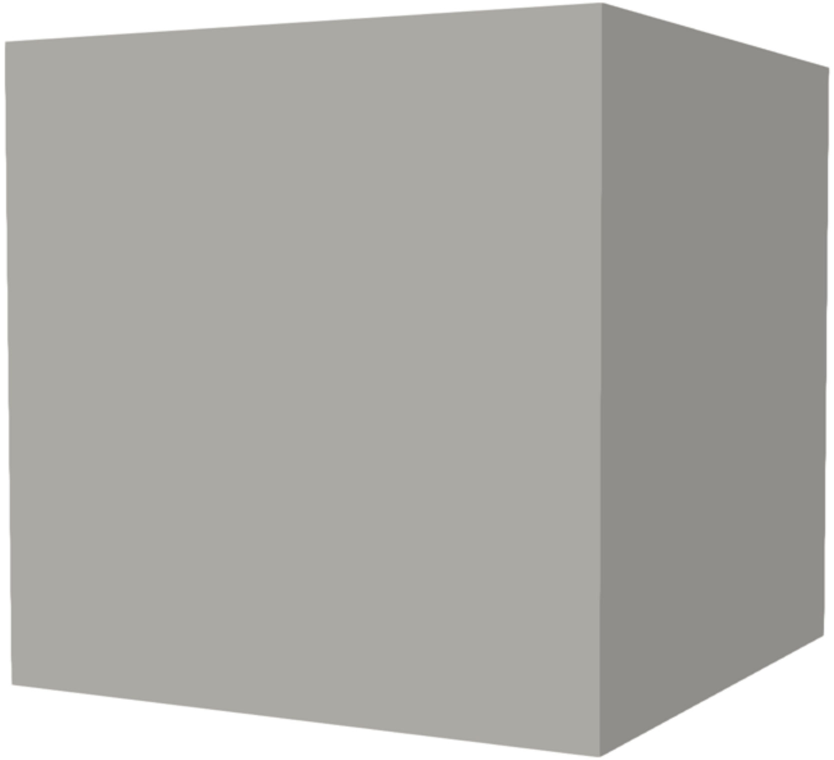


Velocity effect creates anisotropic intensity structures in (x, y, v) space

Lazarian & Pogosyan (2000)

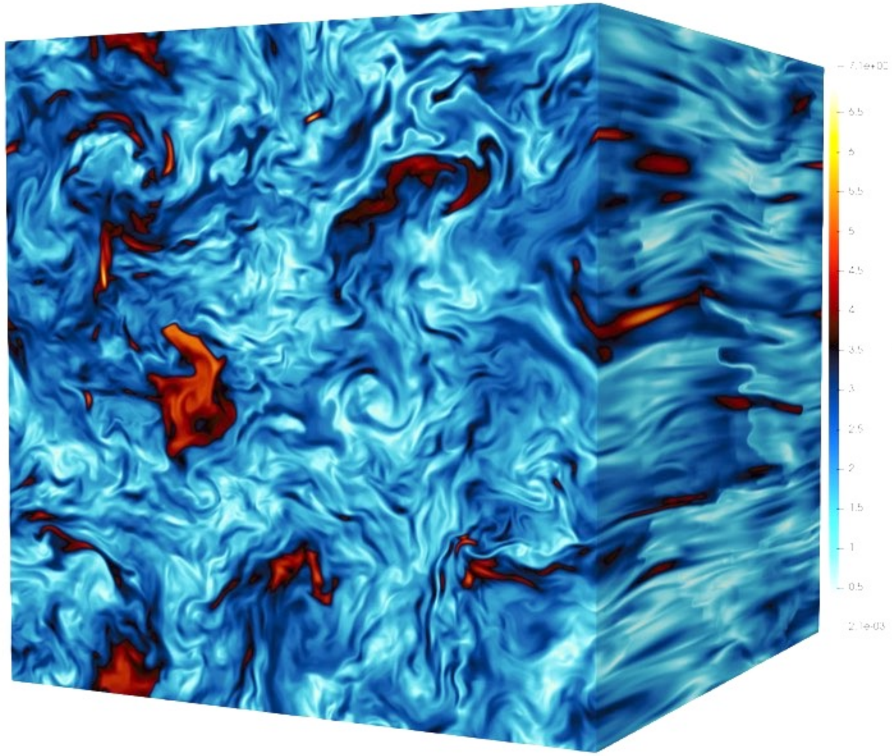
Simulating spectroscopic line with constant density

Constant density cube (x, y, z)



+

Turbulent velocity cube (x, y, z)



3D MHD turbulence simulation ($M_S = 11.0$, $M_A = 0.8$)

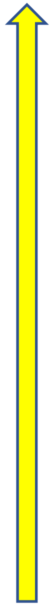
Constant density field $\rho(x, y, z) = 1$

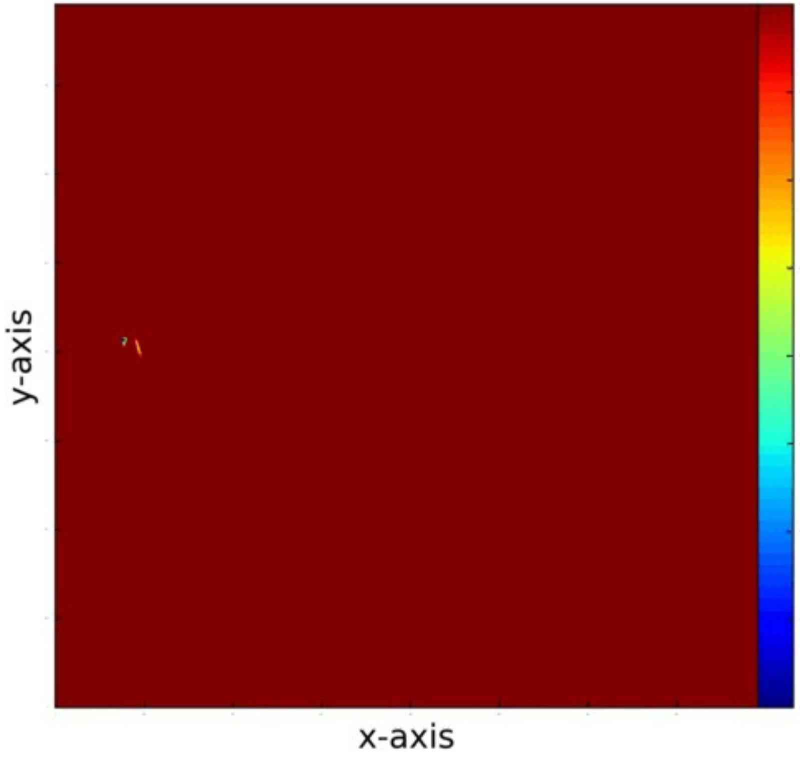
Thin channel is dominated by velocity fluctuations

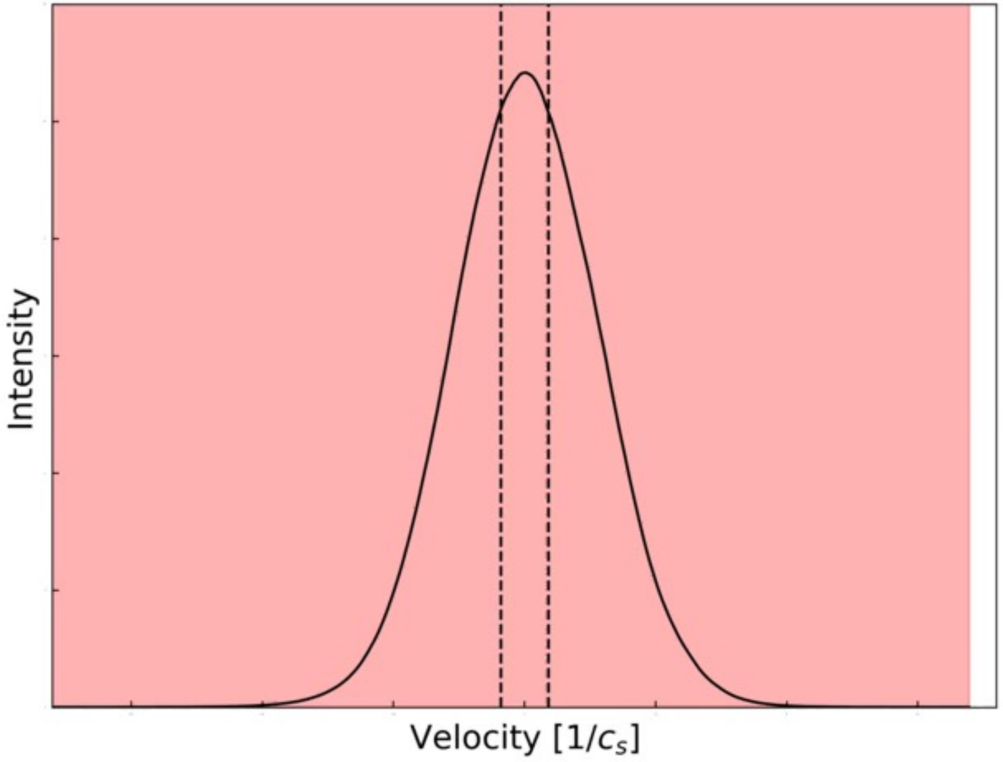
Spectroscopic channel map

decreasing channel width Δv

Mean B-field



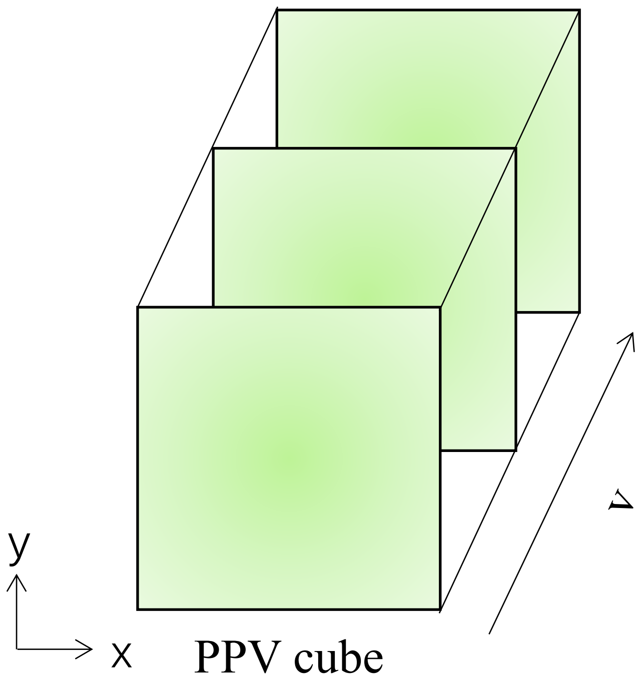


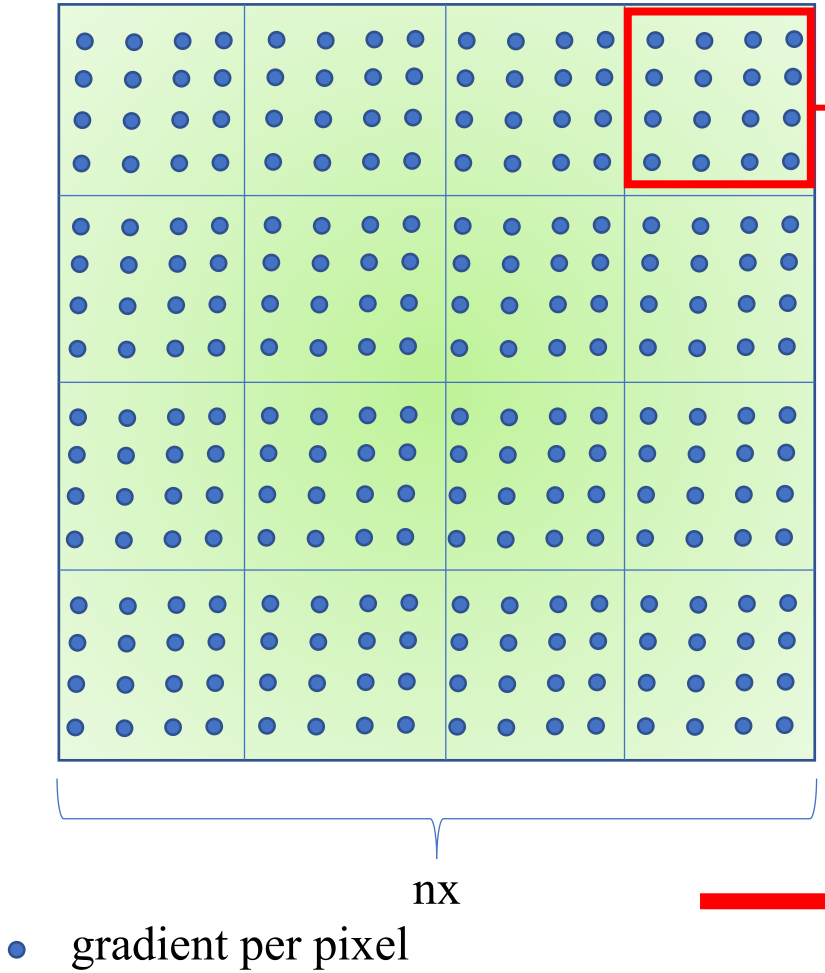


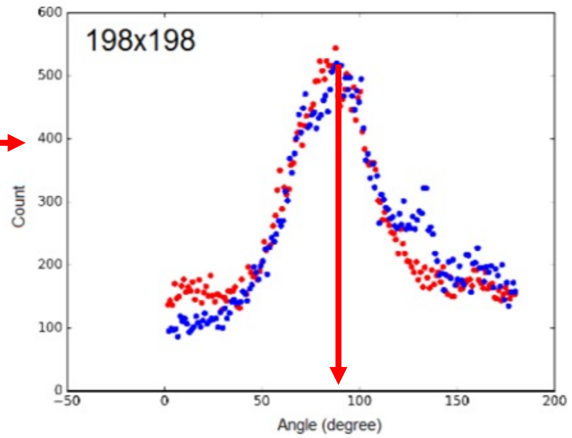
3D MHD turbulence simulation (M_S=11.0, M_A=0.8)
Constant density field $\rho(x, y, z) = 1$

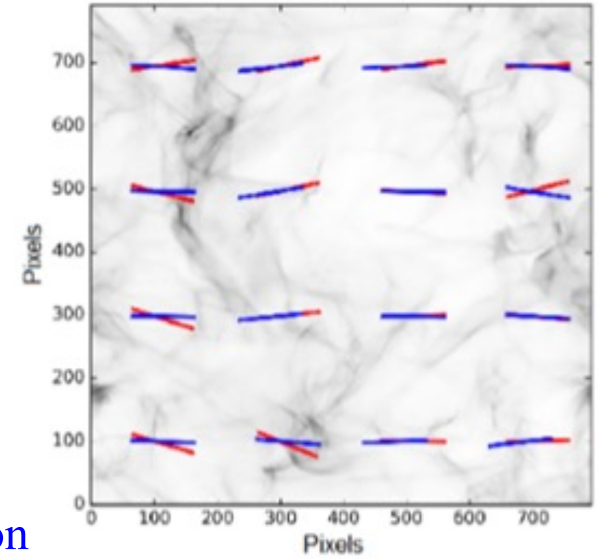
Criterion for velocity effect being dominated: $\Delta v > \delta v$
δv is turbulent velocity dispersion

Peak of local gradient distribution ---> Predicted B-field





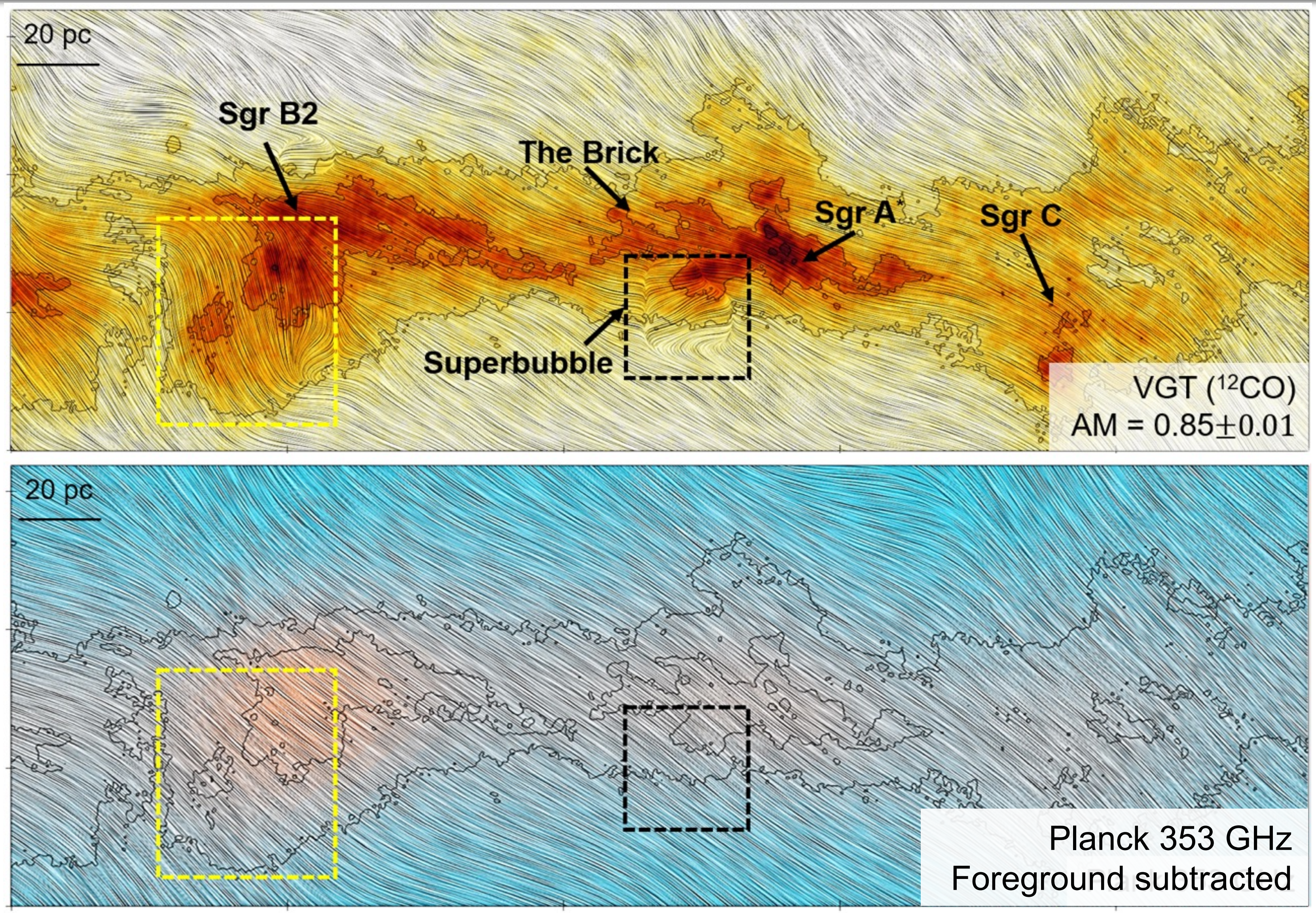




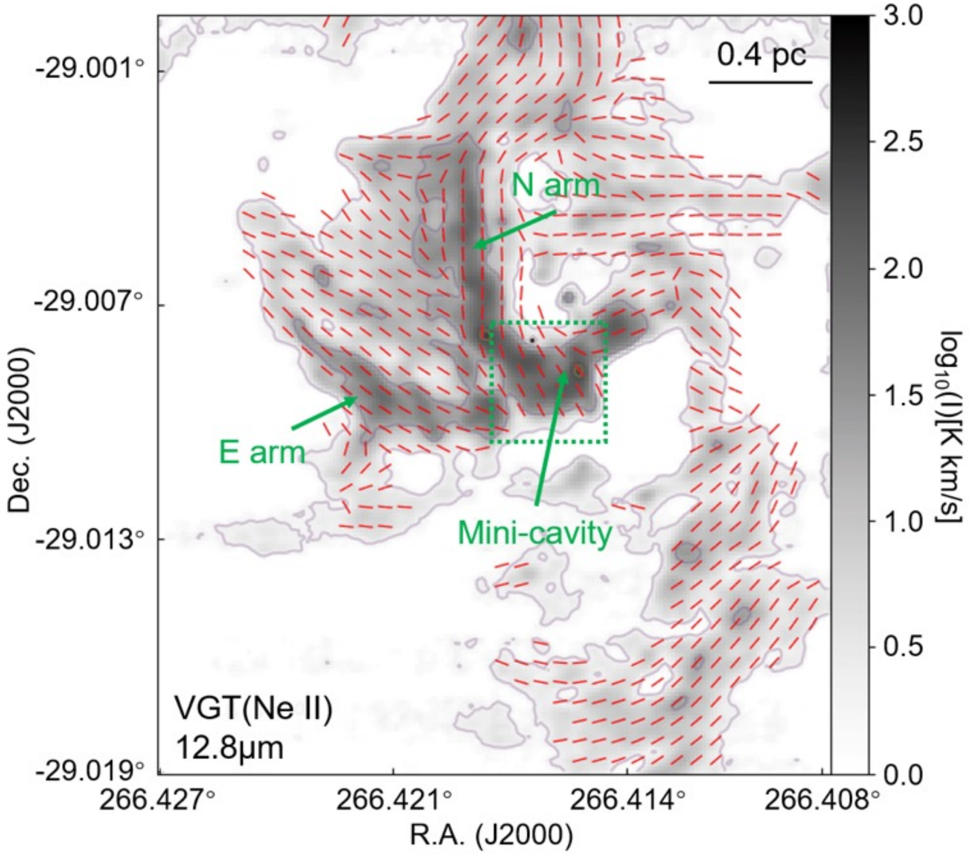
gradient

polarization

Magnetic field in the CMZ: agreement with dust polarization



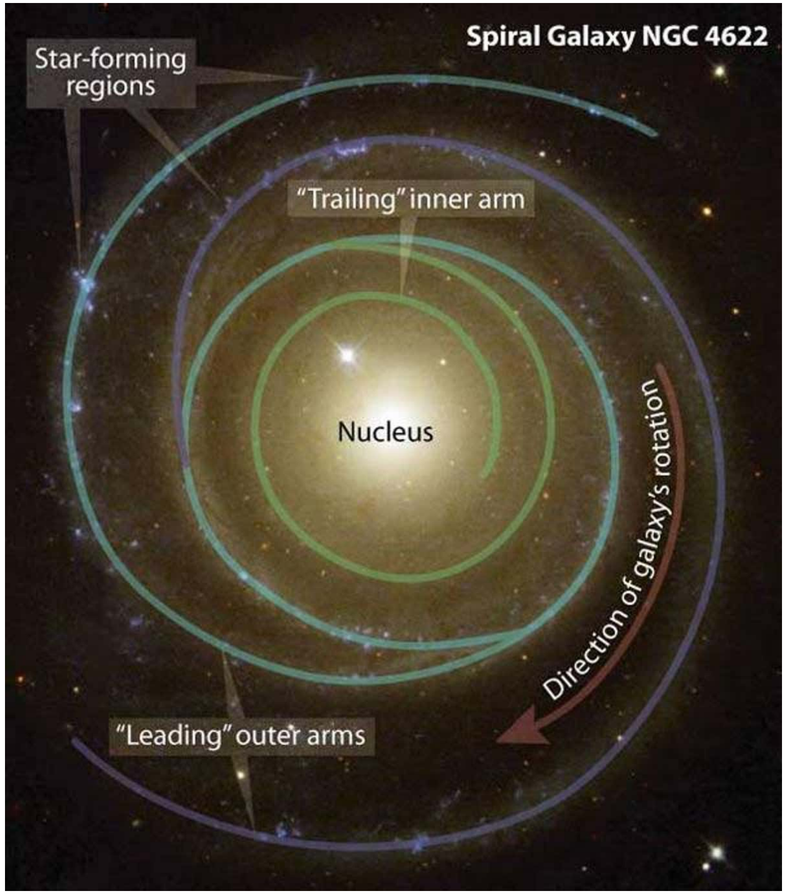
Hu, Lazarian & Wang 2021



Hu, Lazarian & Wang 2021

High - temperature dust around the Sgr A*

Velocity field in galaxy in complicated



Total velocity

=

Turbulent velocity $v \propto l^{1/3}$

Small scale l: follow B-field due to anisotropic MHD turbulence

+

Shear velocity (independent on l)

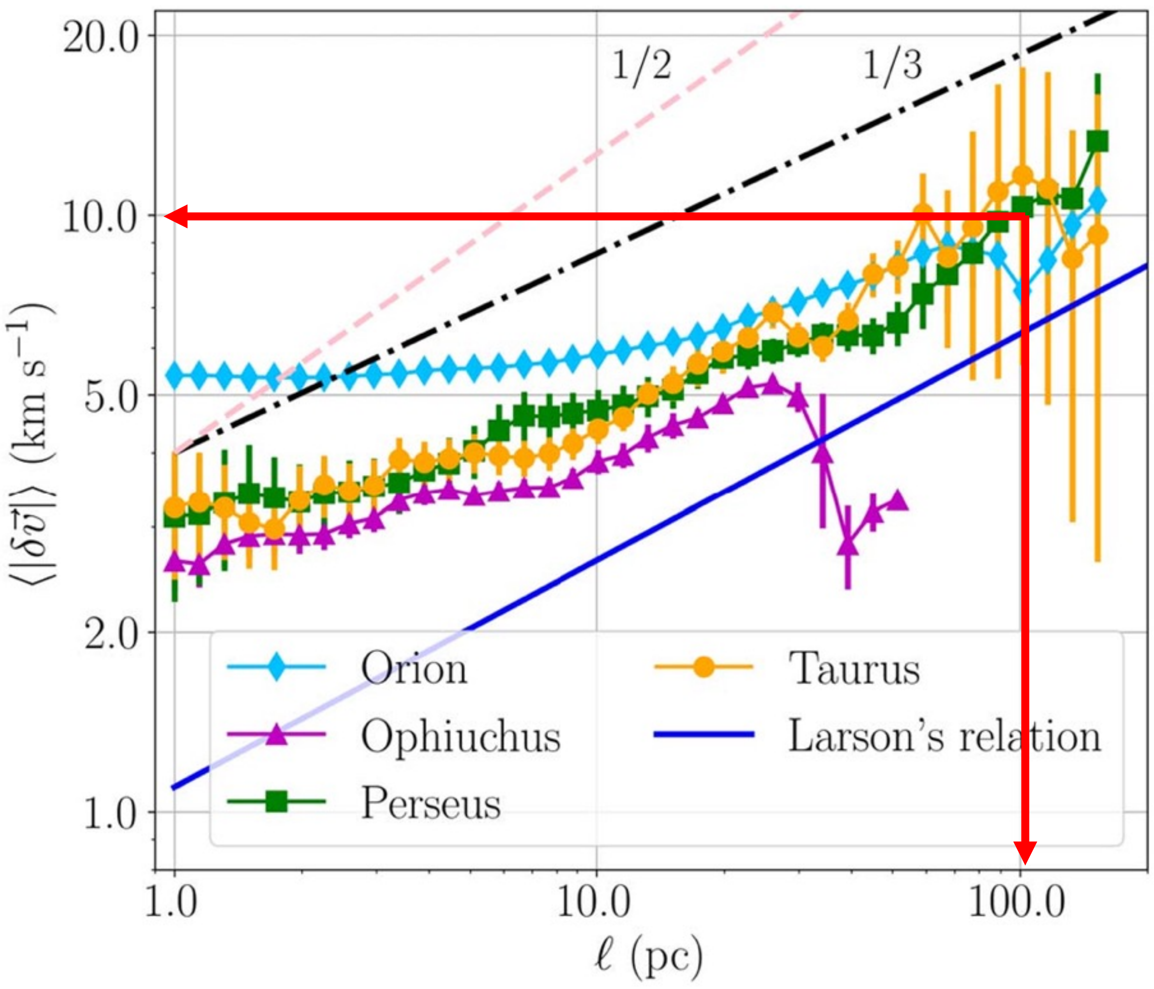
Large scale l: follow B-field due to differential rotation

⋮

Turbulence $\nabla v \propto l^{-2/3}$ dominates small scale

Criteria to use velocity gradient

Turbulence dominates ≤100 pc



Ha et al. (2022)

Criteria for velocity gradients

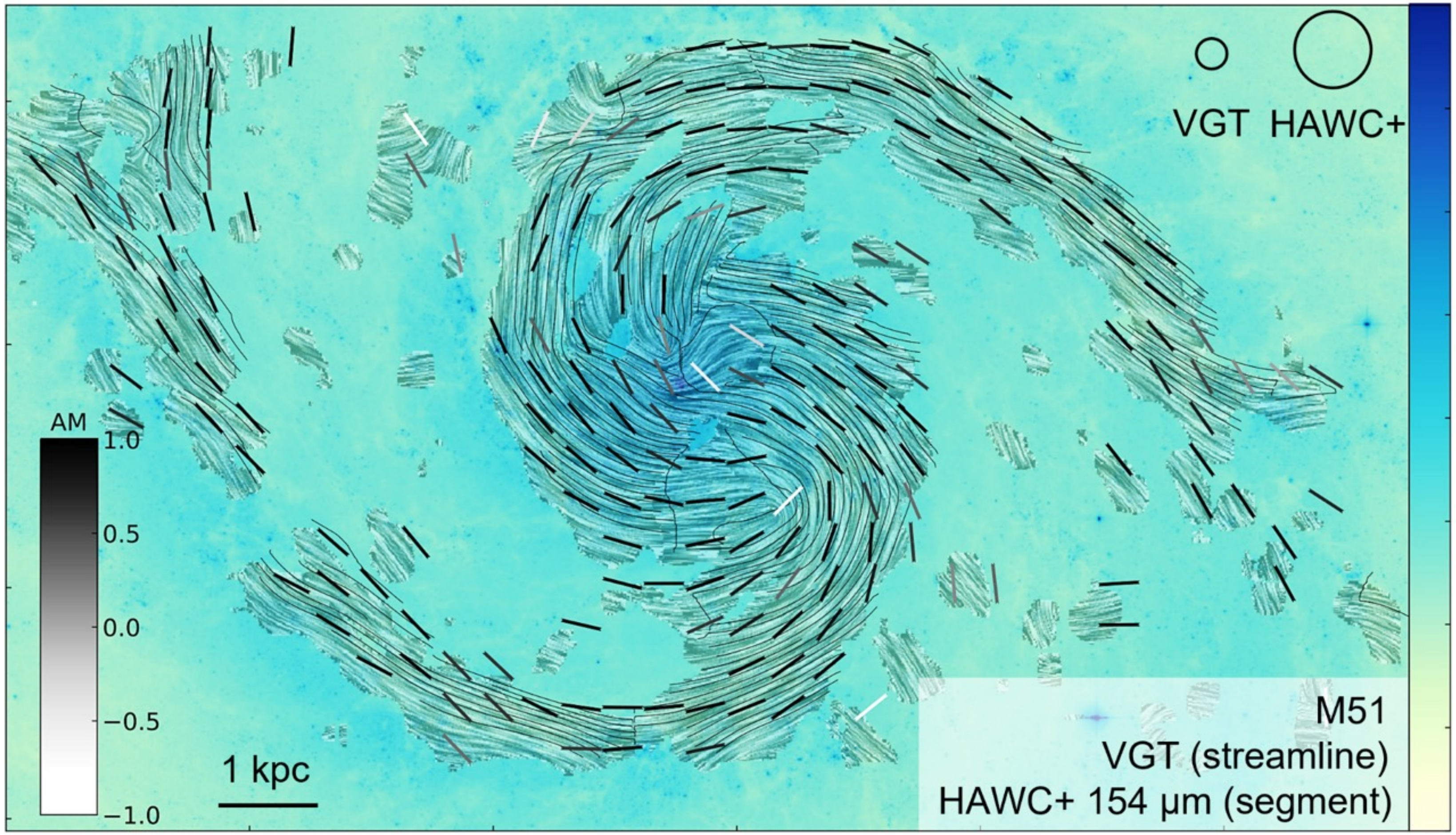
Spatial resolution:
Turbulence scale 100 pc is resolved

Turbulence dominates over shear

Velocity resolution:
Higher than the turbulent velocity 10 km/s

Turbulence dominantly sharpens intensity structures in spectroscopic channel

Magnetic field in the M51: agreement with SOFIA/HAWC polarization



Hu et al. (2022)

Velocity gradient technique (VGT)

PAWS CO emissions for M51:

beam resolution ~ 37 pc

Velocity resolution ~ 5 km/s

$$AM = \cos(2\theta)$$

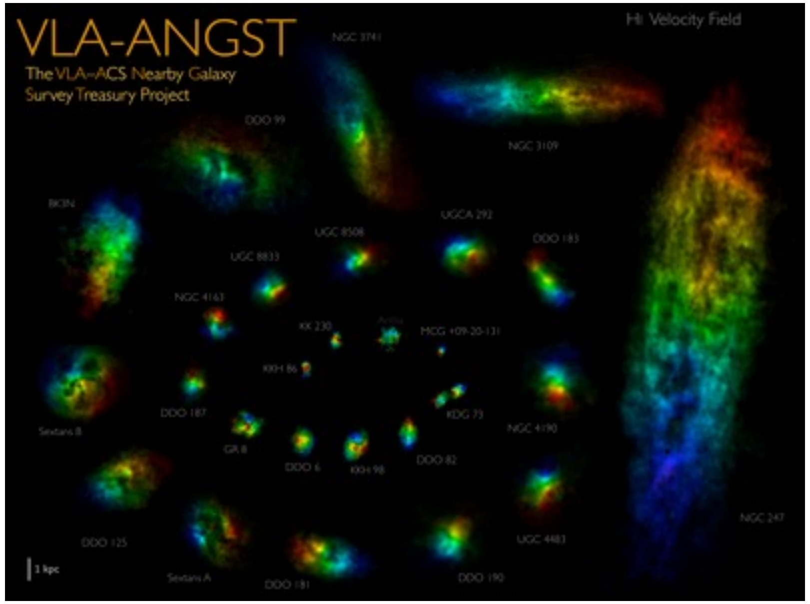
θ: relative angle between two vectors

$AM = 1$: parallel

$AM = -1$: perpendicular

ALMA and VLA resolve nearby galaxies < 100 pc

VLA-ANGST

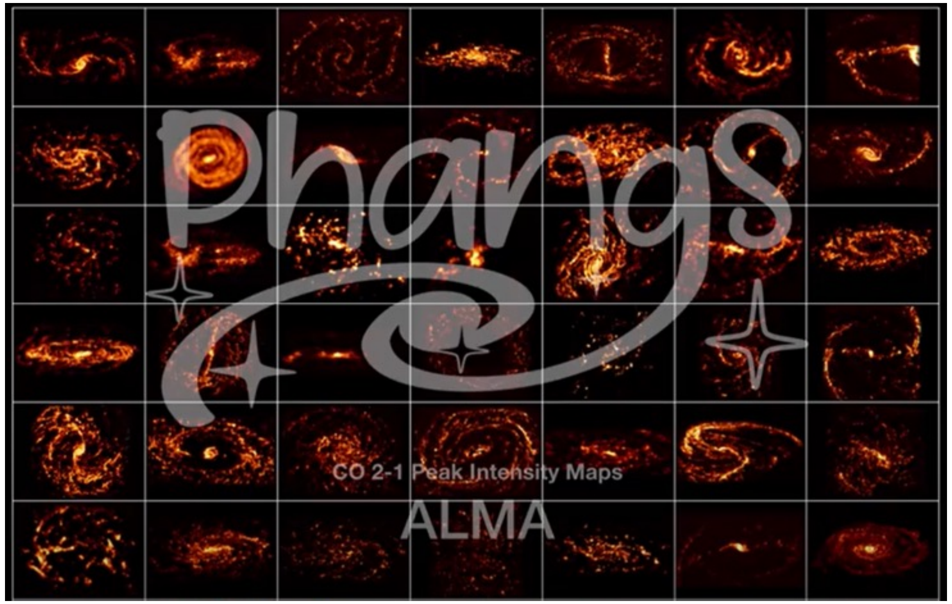


Ott et al. (2012)

H I emission < 100 pc

29 galaxies < 4 Mpc

PHANGS-ALMA



Leroy et al. (2022)

CO & Hα emissions < 100 pc

74 galaxies < 20 Mpc

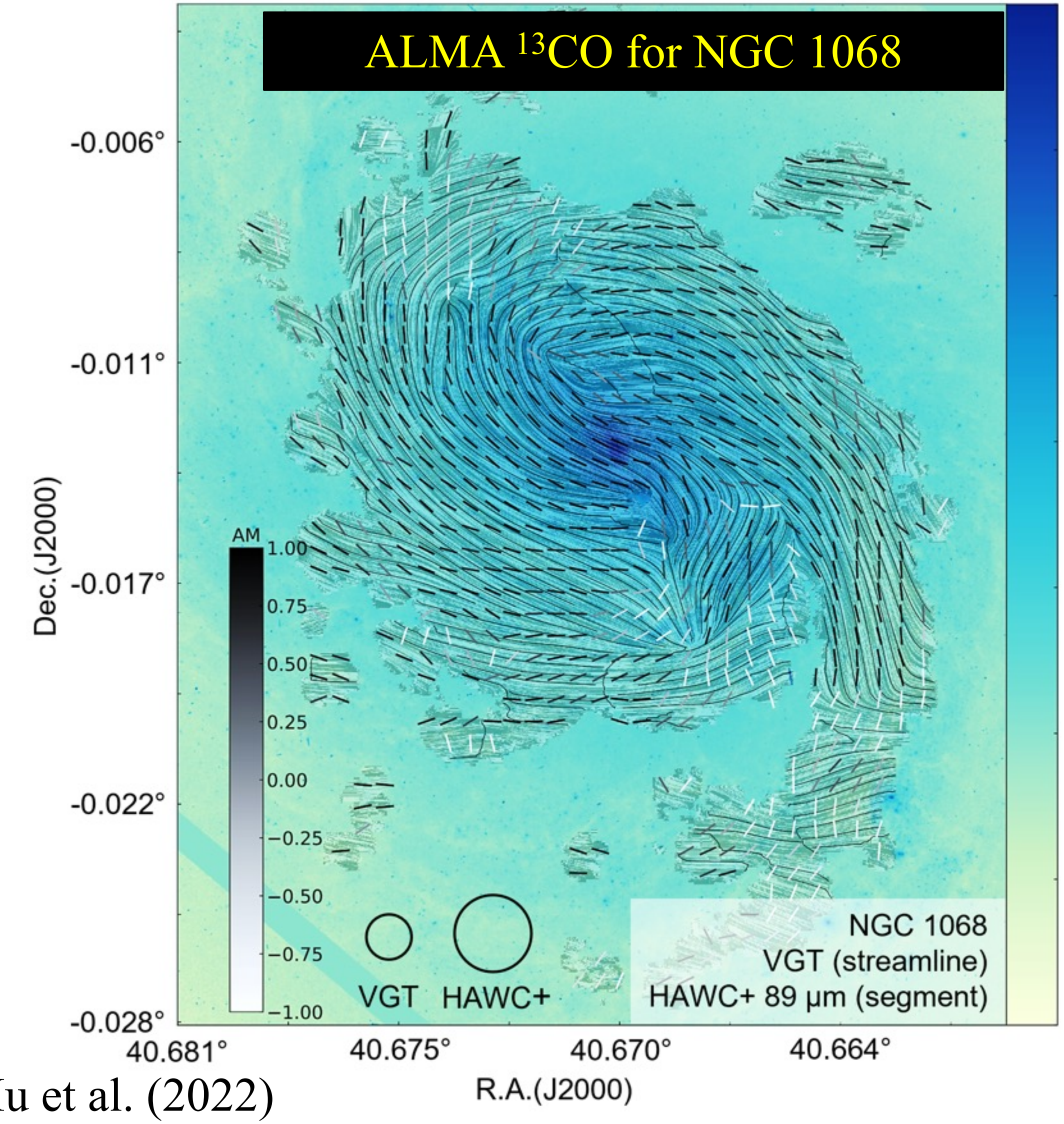
THINGS

Walter et al. (2008)

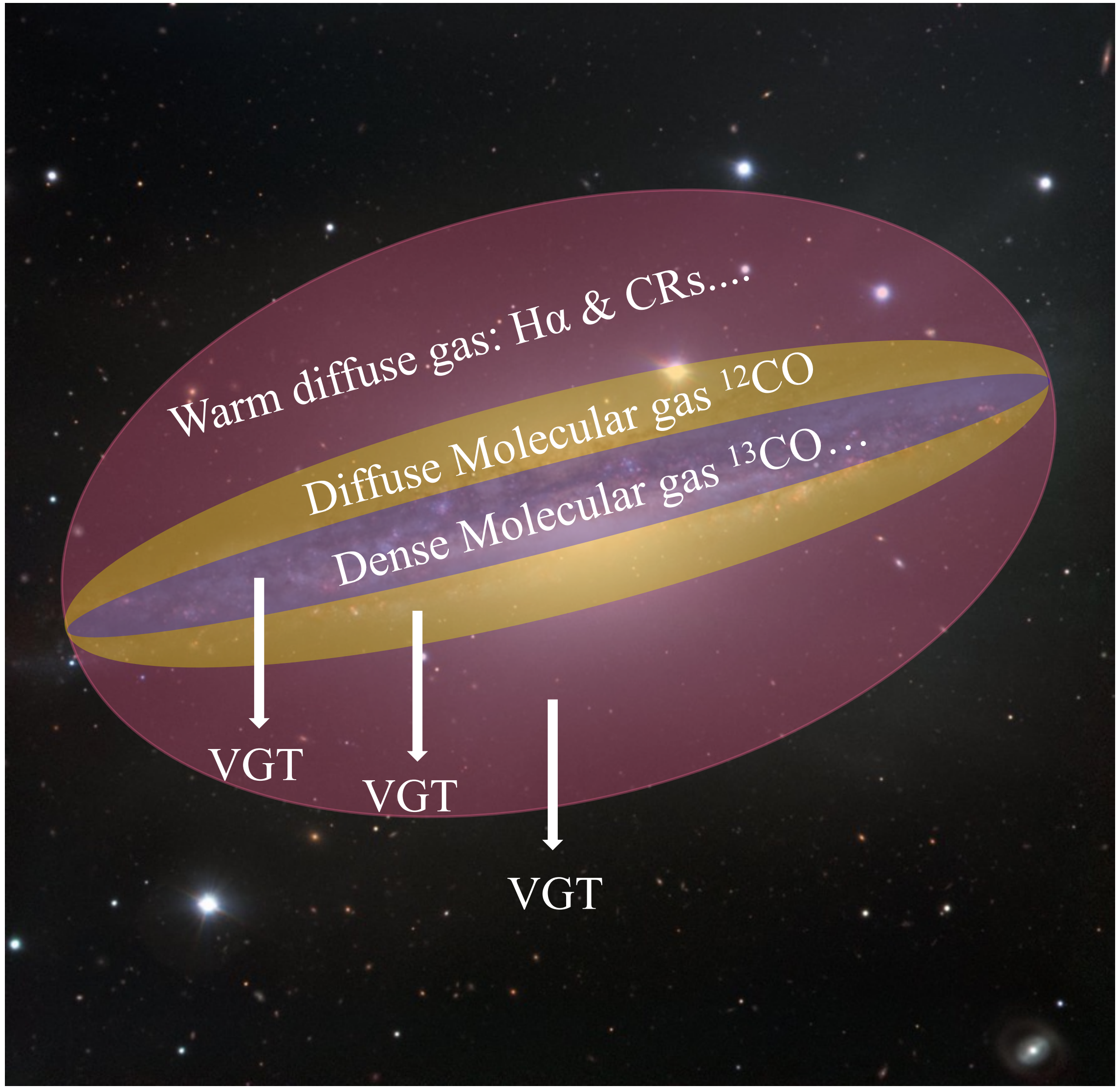
H I emissions < 100 pc

3 Mpc < galaxies < 20 Mpc

B-field survey of nearby galaxies

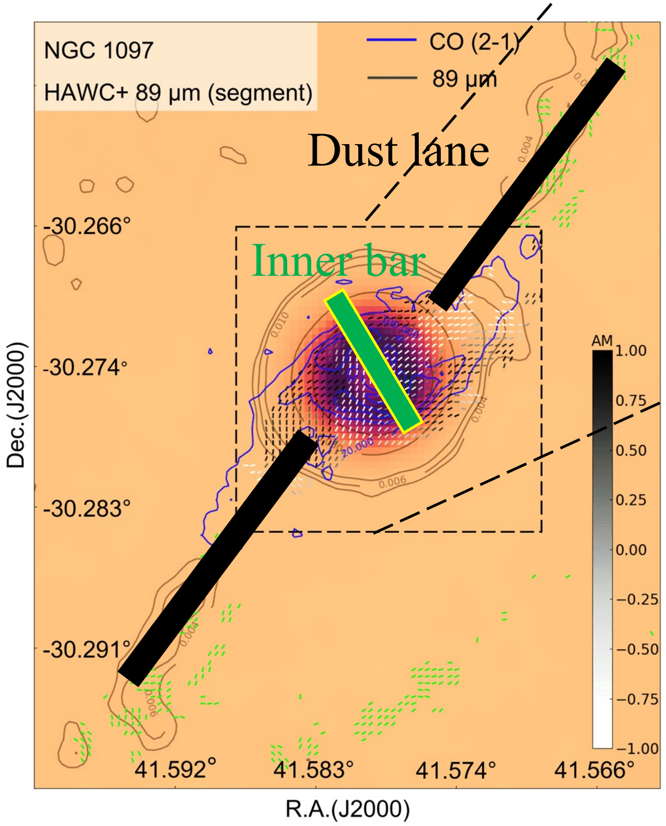


Hu et al. (2022)

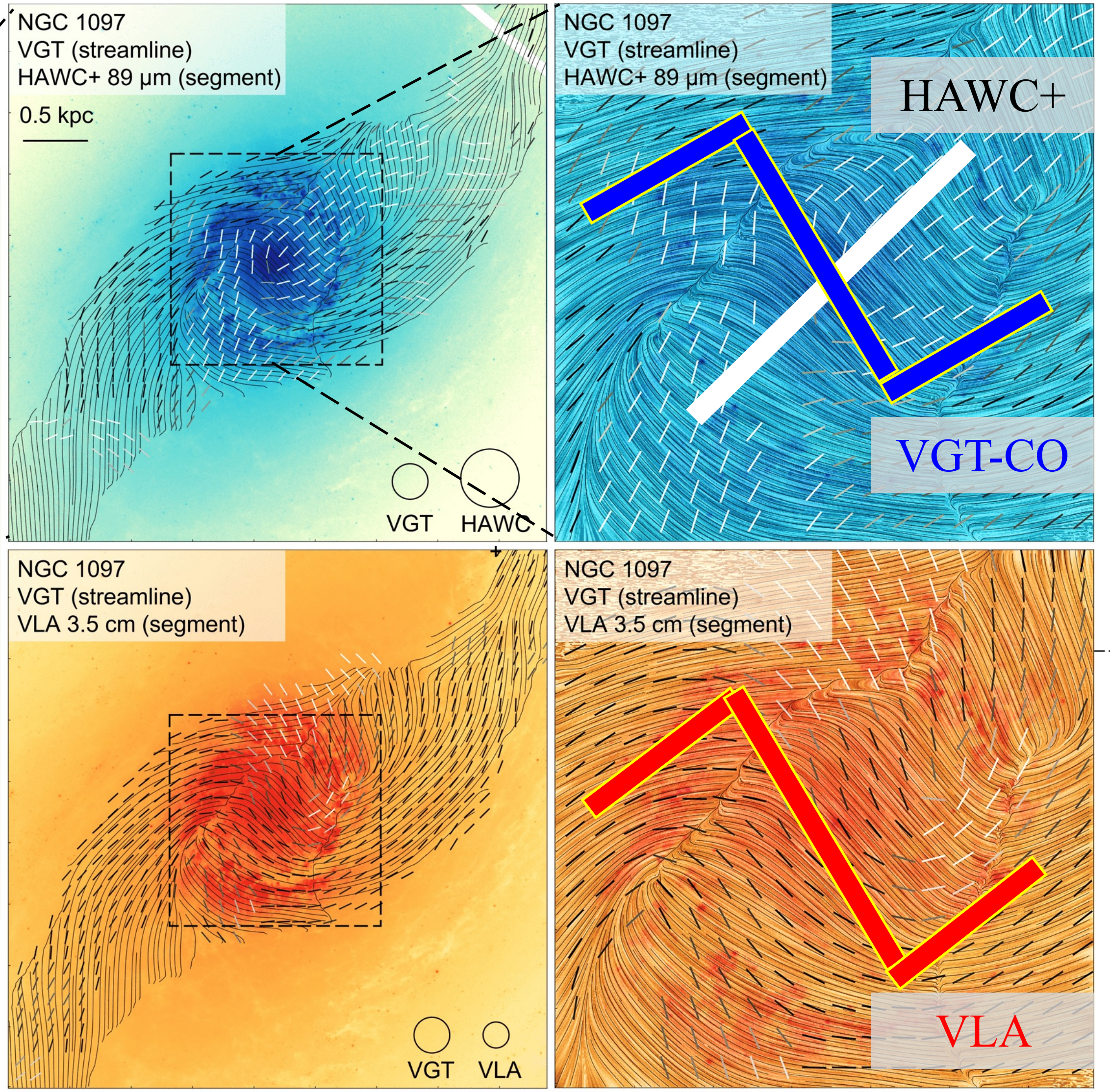


Dynamics in NGC 1097: VGT, HAWC+, VLA

HAWC+: Lopez-Rodriguez. et al. (2022)
VLA: Beck et al. (2005)



Hu et al. (2022)



VGT-CO agrees with VLA

↓

1. Star formation is actively generating cosmic rays (CRs)

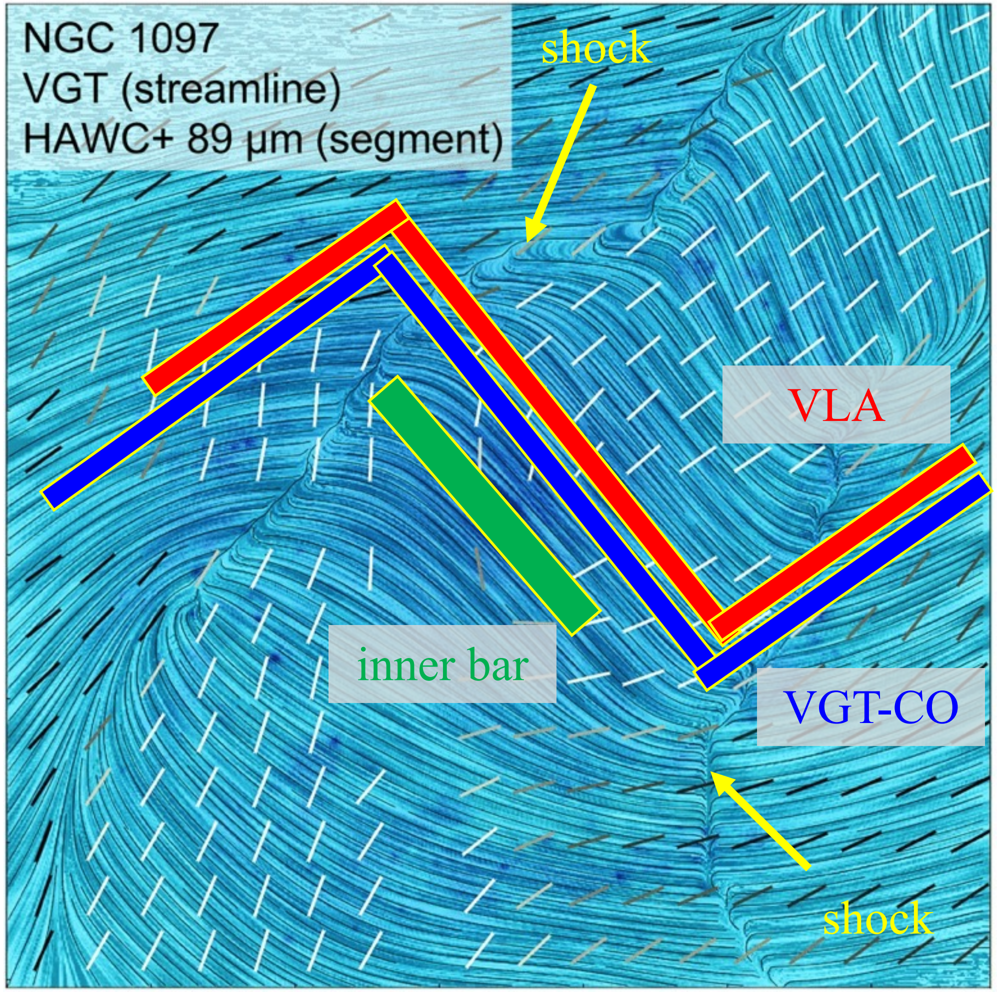
2. Strong B-field in star forming regions dominates: VLA is measuring B-field in the disk

VGT-CO disagrees with HAWC+

↓

Warm & fresh dust

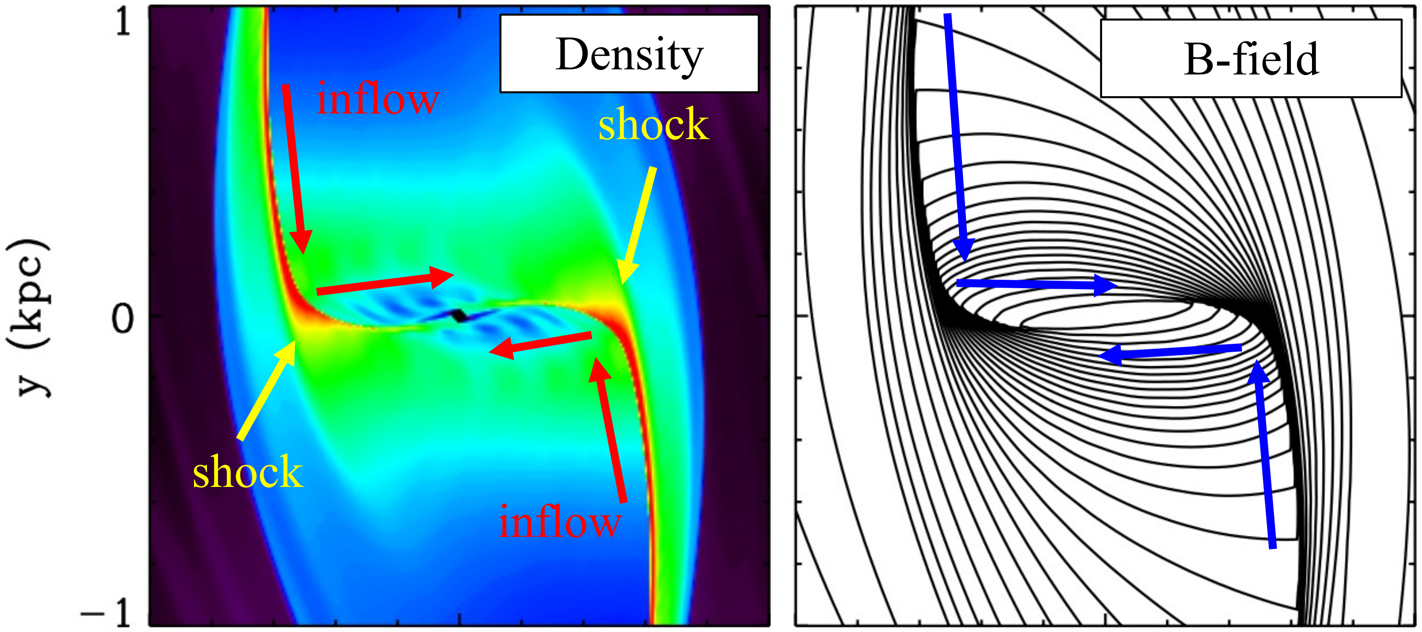
B-field helps with fueling of Seyfert activity



Hu et al. (2022)

Kim & Stone (2012)

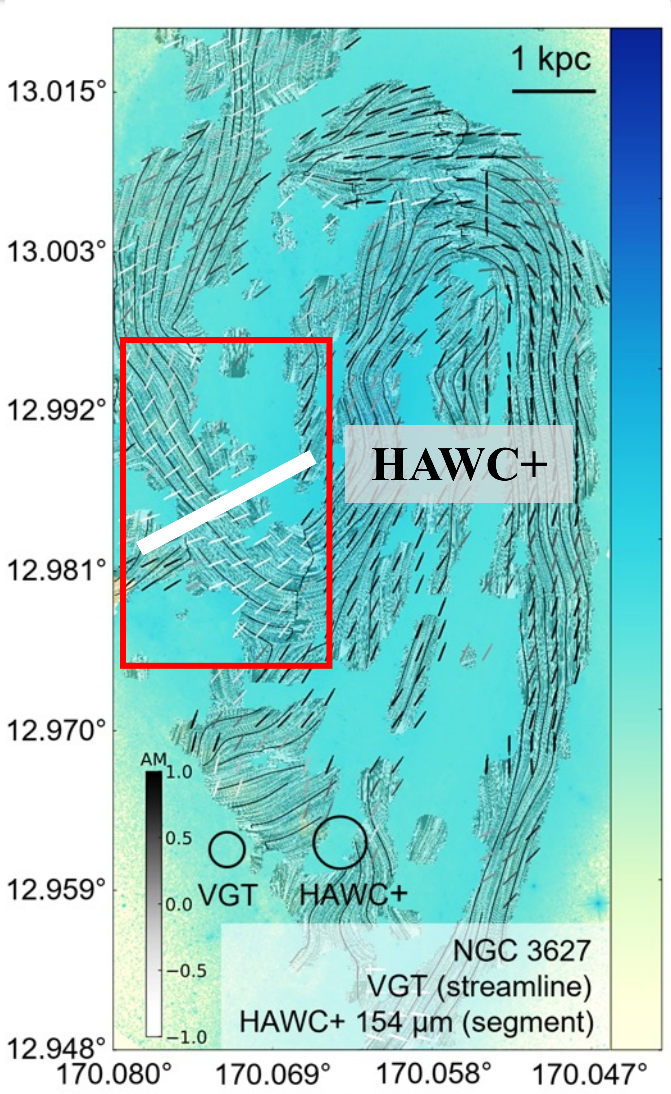
MHD simulation of barred galaxy



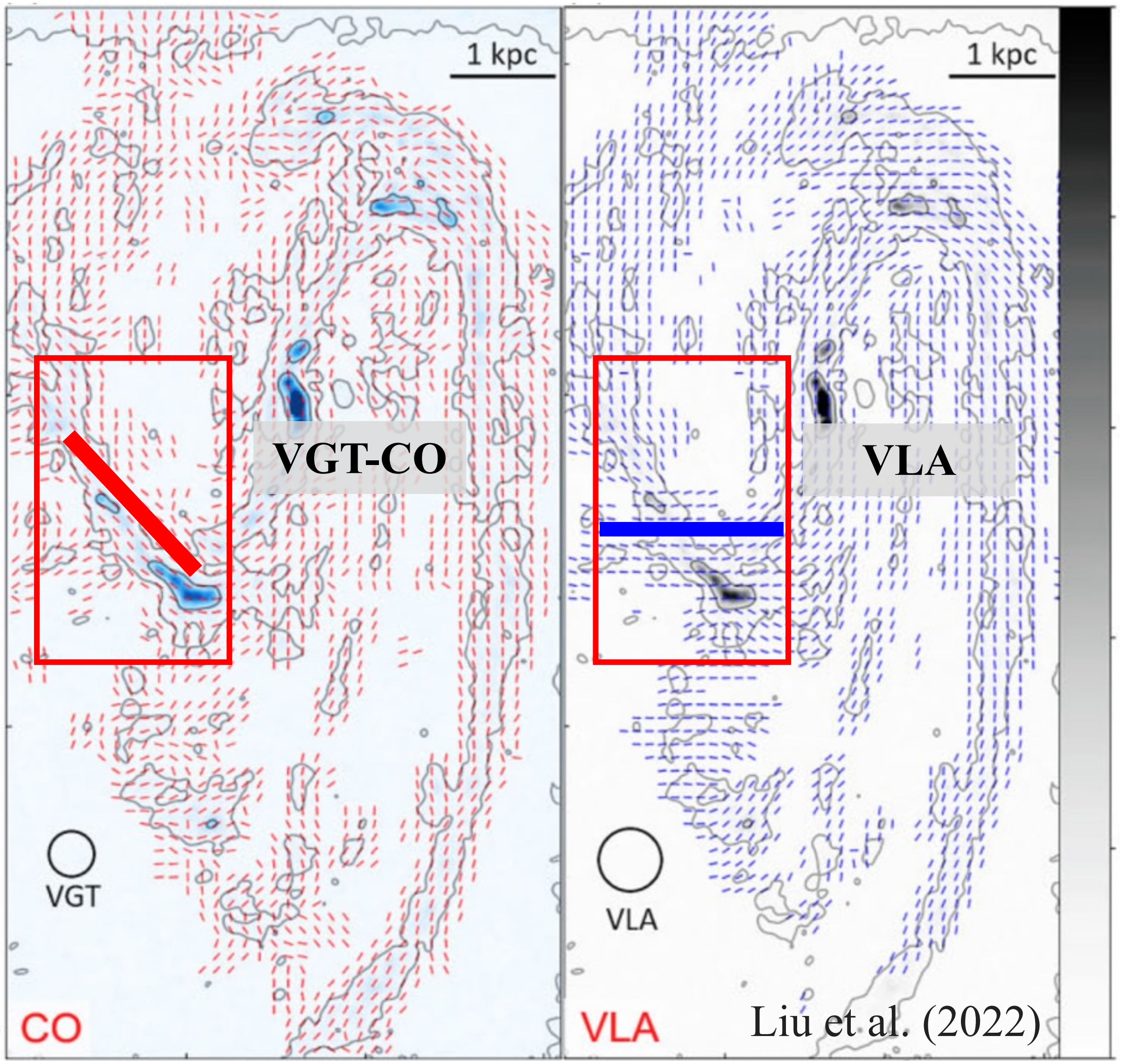
B-field torques remove angular momentum

Warm and cold gas are feeding the central SMBH

Disagreements in NGC 3627



Hu et al. (2022)



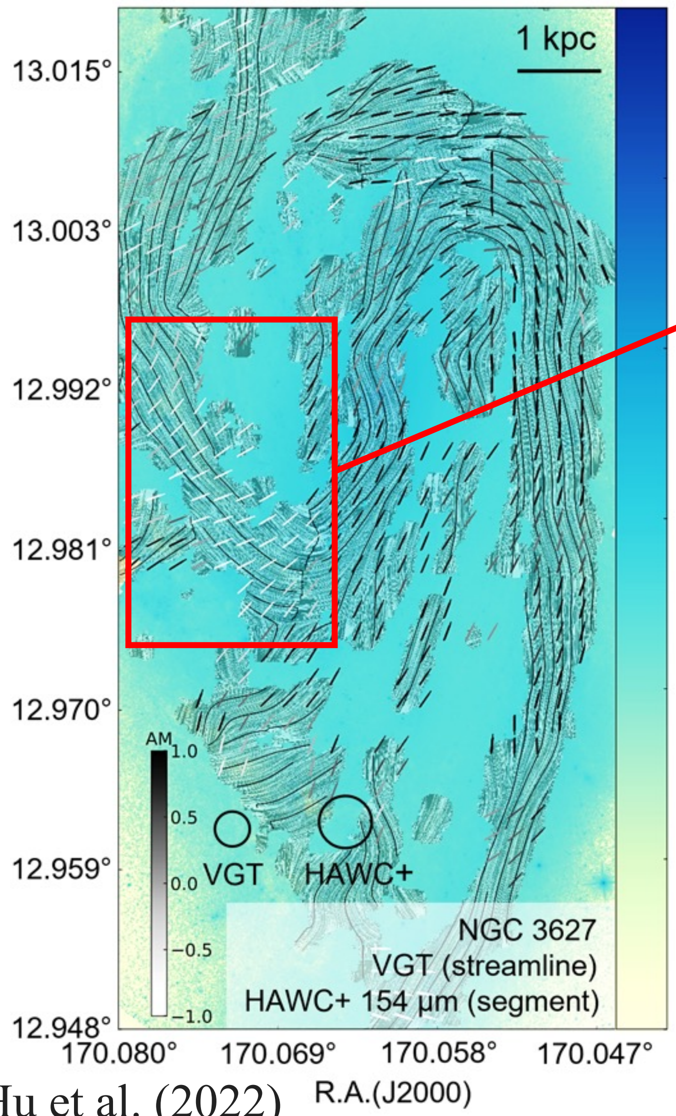
Liu et al. (2022)

VGT-CO disagrees with VLA

HAWC+ disagrees with VLA

HAWC+ disagrees with VGT-CO

Disagreements reveal magnetic fields in different collision stages



Hu et al. (2022)

NGC 3627: a galaxy-dwarf collision?★

M. Weżgowiec[1], M. Soida[2], and D. J. Bomans[1]

[1] Astronomisches Institut der Ruhr-Universität Bochum, Universitätsstrasse 150, 44780 Bochum, Germany
e-mail: mawez@astro.rub.de
[2] Obserwatorium Astronomiczne Uniwersytetu Jagiellońskiego, ul. Orla 171, 30-244 Kraków, Poland

Collision with NGC 3628: ~ 800 Myr

Dust forming time scale > CO forming time scale > CRs cooling time ~ 10 Myr

HAWC+: pre-collision B-field

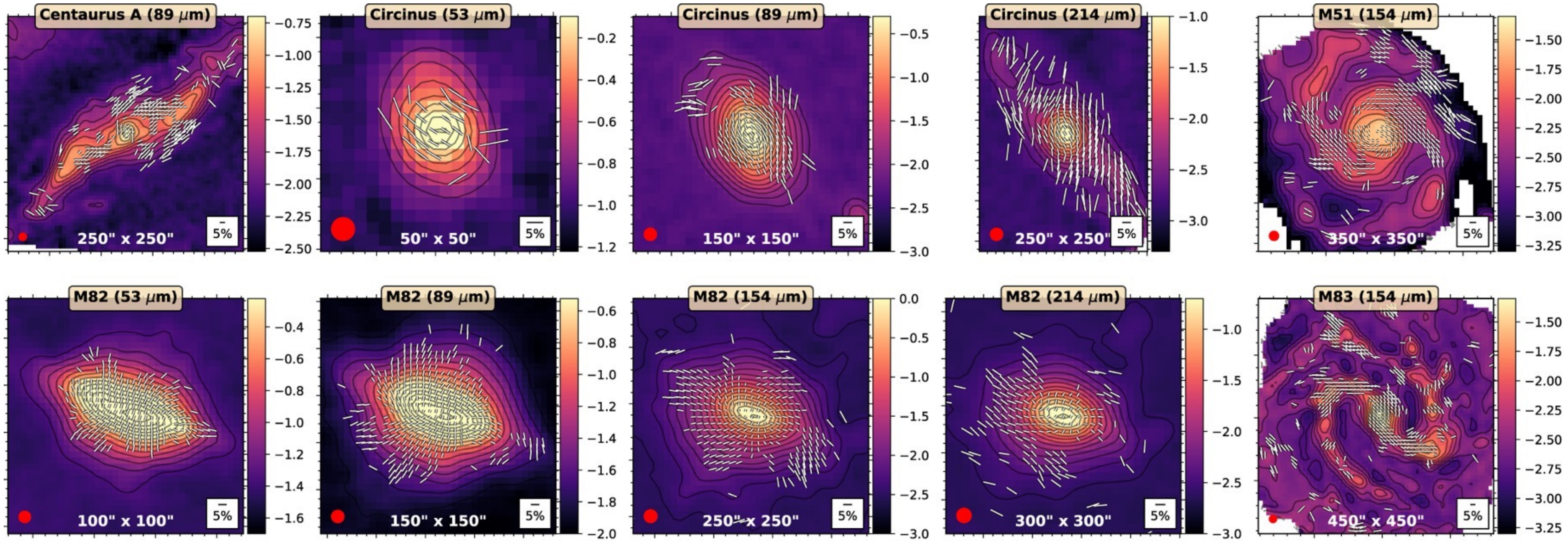
VGT-CO: the mixture of pre-collision and post-collision B-fields

VLA: post-collision B-field

More galaxies are ready for exploration

SALSA: SOFIA legacy program

Lopez-Rodriguez et al. (2022b)



Q & A