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The magnetic field of the L1544 starless dark cloud, traced using near-infrared background starlight (Presentation)

The Magnetic Field of the L1544 Starless Dark Cloud, Traced Using Near-Infrared Background Starlight

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Key Question 1: Is the Magnetic Field (B-field) an important player in cloud and dense core formation and evolution?

Key Question 2: Can background starlight polarimetry (probing plane-of-sky B-fields) be an effective replacement for (expensive) Zeeman Effect polarimetry (probing line-of-sight B-fields)?

Laboratory: L1544 Dark Cloud (dist = 140 pc)

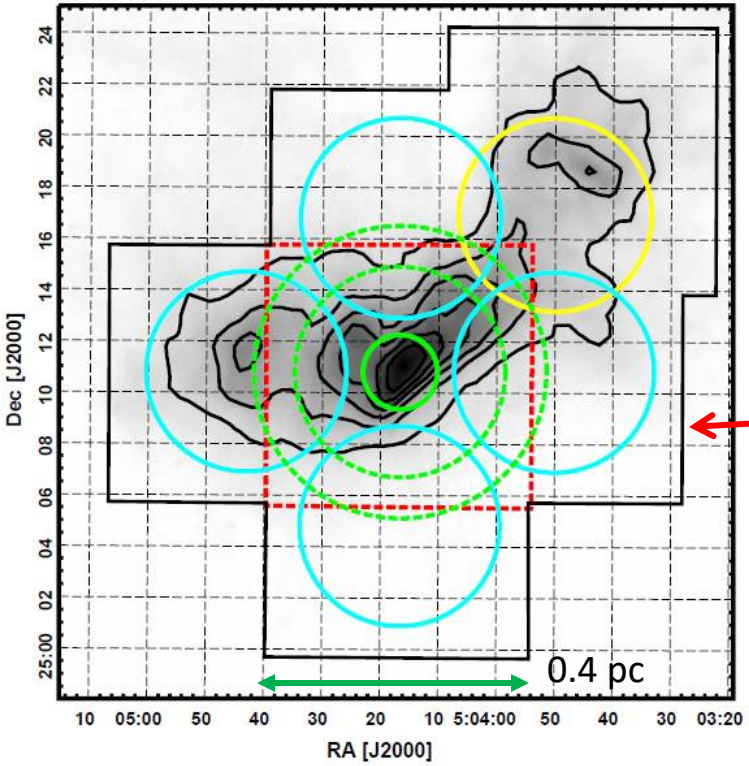
Well-studied and well-characterized (molecular maps, single disk and interferomers, submm cont.).

Dense core, but no protostar.

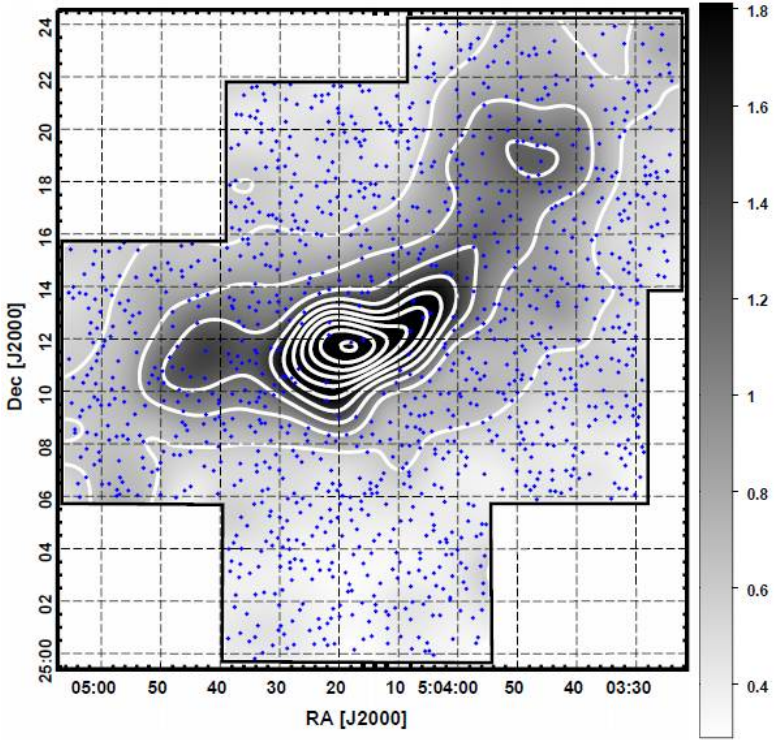
B-field Probes: (1) JCMT/SCUPOL of core (Ward-Thompson+00) ; (2) Radio Zeeman of OH at Arecibo & GBT (Crutcher+09).

Methods Used Here: Near-IR background starlight polarimetry with Mimir instrument; Planck+ Herschel SED analysis; dust characterization; 3-D modeling; Chandrasekhar & Fermi (‘53) method for B-field strengths

L1544 Dark Cloud, as seen by Herschel Dust Emission and Background Starlight Reddening



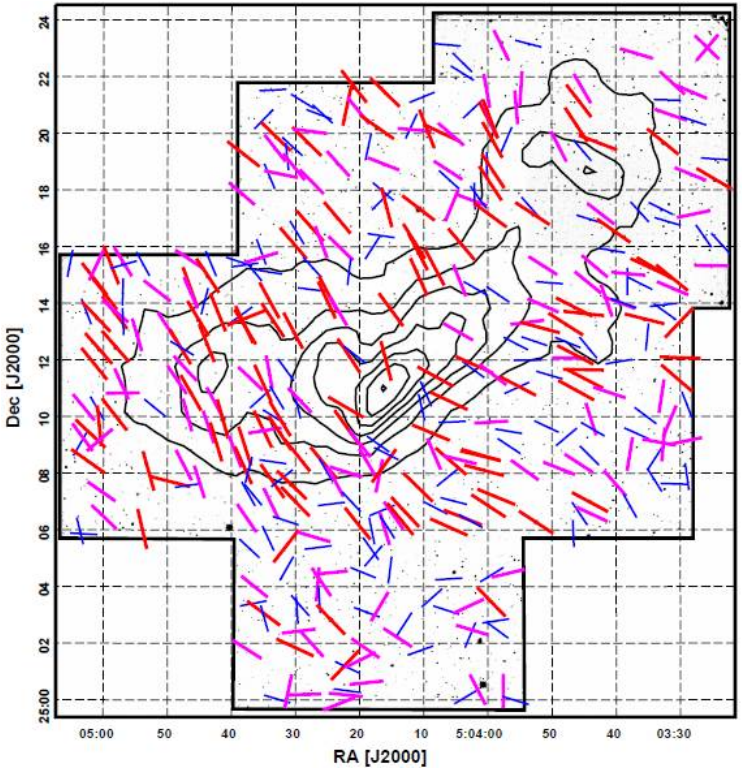
Mimir NIR surveyed region ~12 hours total integration time (mostly in H, defined by black lines; central zone also in K, defined by red dashed box)



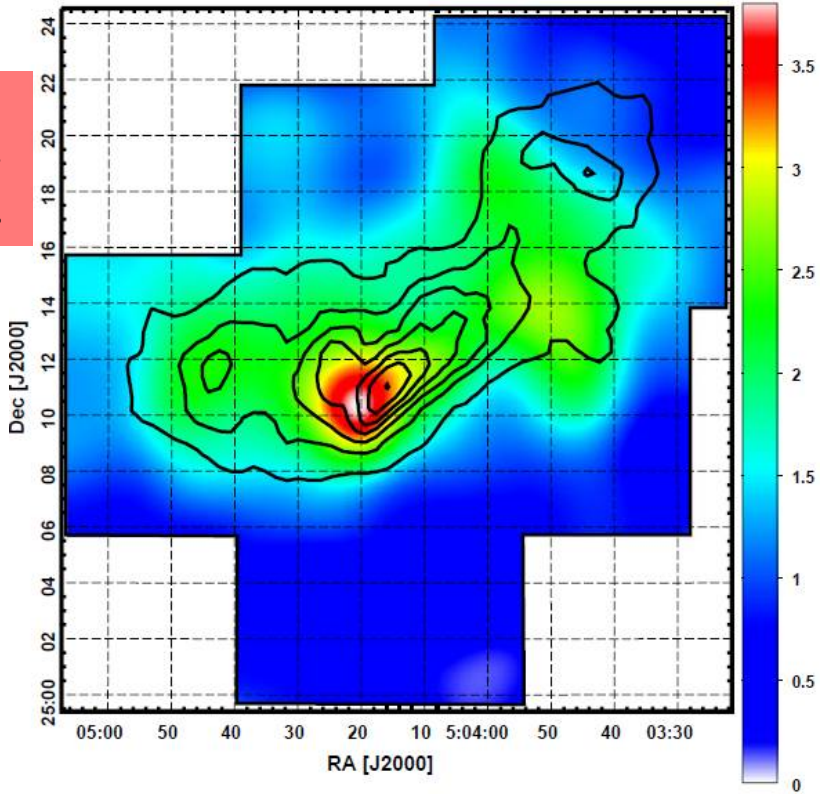
Herschel/SPIRE 250 μm image and contours. Green, cyan circles are Crutcher+09 Arecibo, GBT Zeeman beamsizes, respectively. Yellow is new Effelsberg Zeeman beamsize (Tassis et al., in prep.)

Near-Infrared (H-M) color (2MASS – WISE) image and contours. Blue dots are show locations of stars used in making the map. Lookup table of gray to (H-M) magnitudes of color, at right.

Near-Infrared Imaging Polarimetry in H, K bands using Mimir instrument: 1,712 stars



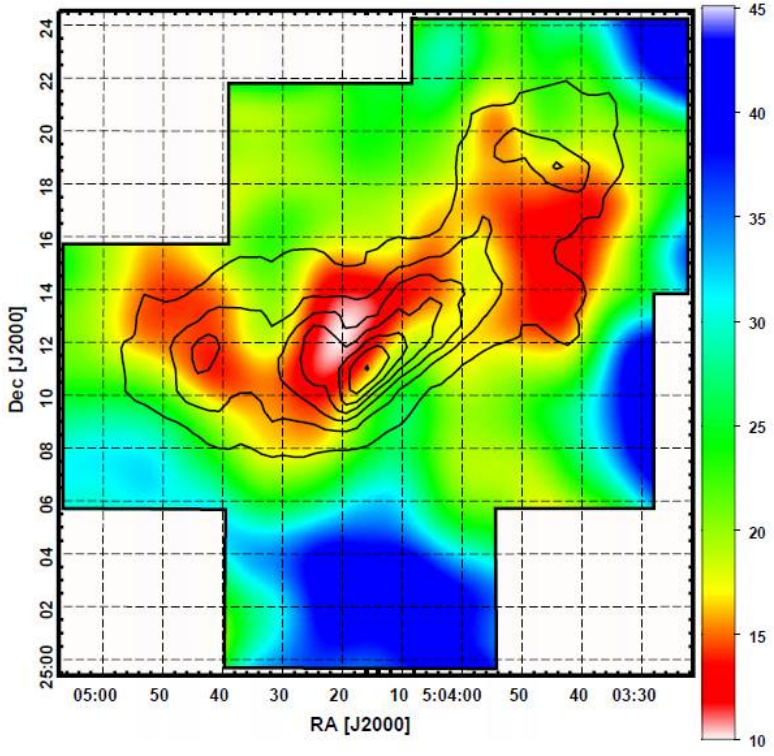
Select highest ~25% SNR stars – lowest PA uncert.



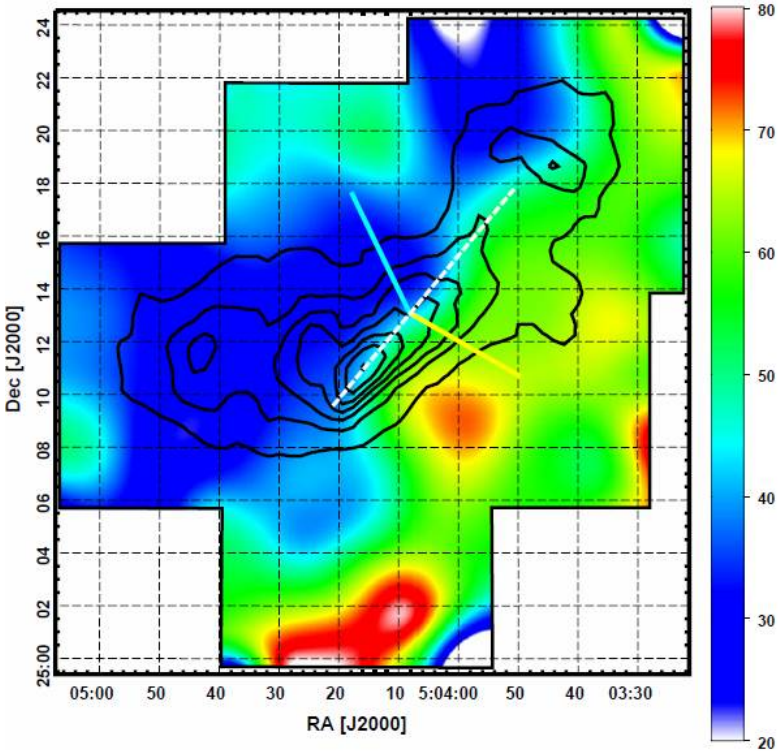
Polarization position angles (PAs) for **~400 stars** with lowest PA uncertainties. Red - $\sigma_{PA} < 10^{\circ}$; Magenta – $10^{\circ} < \sigma_{PA} < 15^{\circ}$; Blue - $15^{\circ} < \sigma_{PA} < 20^{\circ}$. Black contours = Herschel 250 μm dust emission.

Smoothed, interpolated image of mean H-band **percentage polarization, <P>.** Colors references to scale bar at right. Black contours = Herschel 250 μm.

NIR Polarimetry closely reveals B-field (plane-of-sky) of L1544 in all quantities: <P>, Δ_{PA}, <PA>



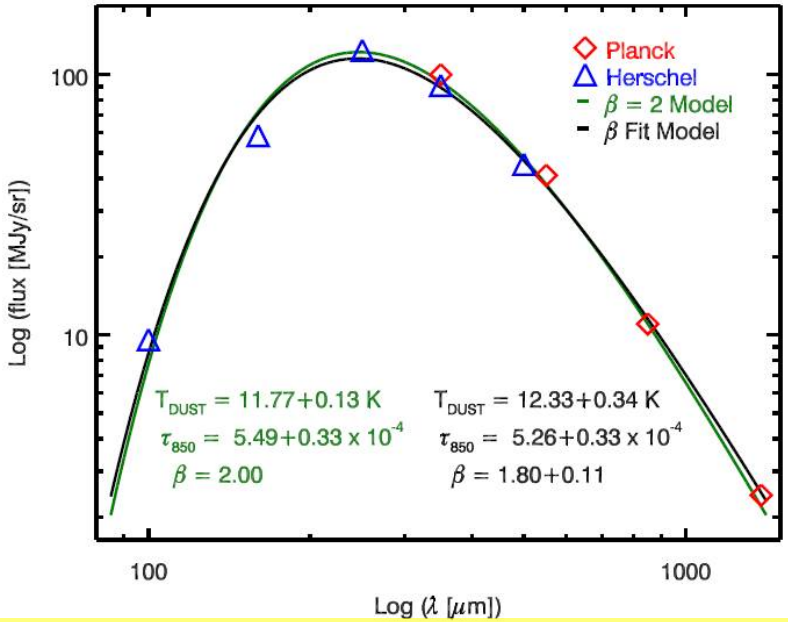
Smoothed, interpolated image of NIR polarization **position angle dispersion**, Δ_{PA}, in degrees. Inverted color lookup highlights low dispersion locations, which correlate well with Herschel 250 μm emission.



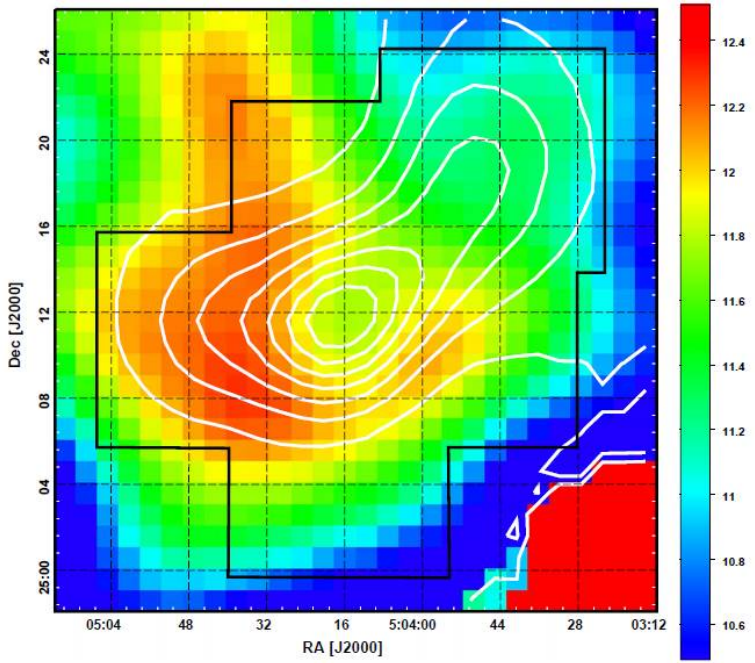
Smoothed, interpolated image of mean NIR **polarization position angle <PA>,** in degrees. Note strong PA orientation change coincident with spine of L1544 traced by Herschel 250 μm emission.

Toward B-field strengths: Finding $<n_{H2}>$, $<\sigma_{RV}>$ to invoke Chandrasekhar-Fermi ('53) Method

- Dust emission SED fits => T_{DUST} , τ_{850} (optical depth at 850μm), β (emissivity index)
- Planck + Herschel FIR photometric maps analysis

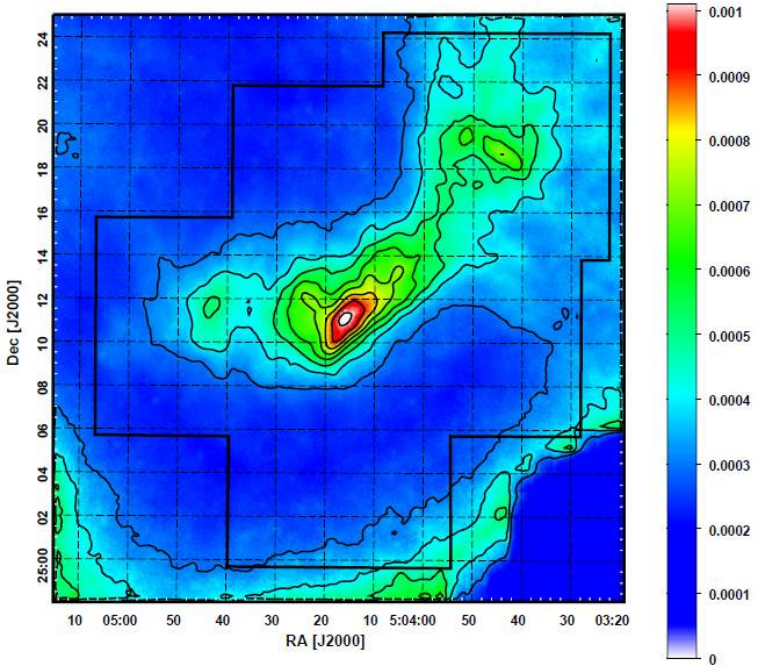


SED and fits for Planck and Herschel data toward one position in the L1544 field. No scaling applied = no missing flux for Herschel small maps. Green curve for β fixed at 2, black for β allowed free to be fit.



Resulting SED fitted map of $\mathbf{T_{DUST}}$ as false-color image, with $\boldsymbol{\tau_{850}}$ white contours. Matched Planck and Herschel resolutions for the input images.

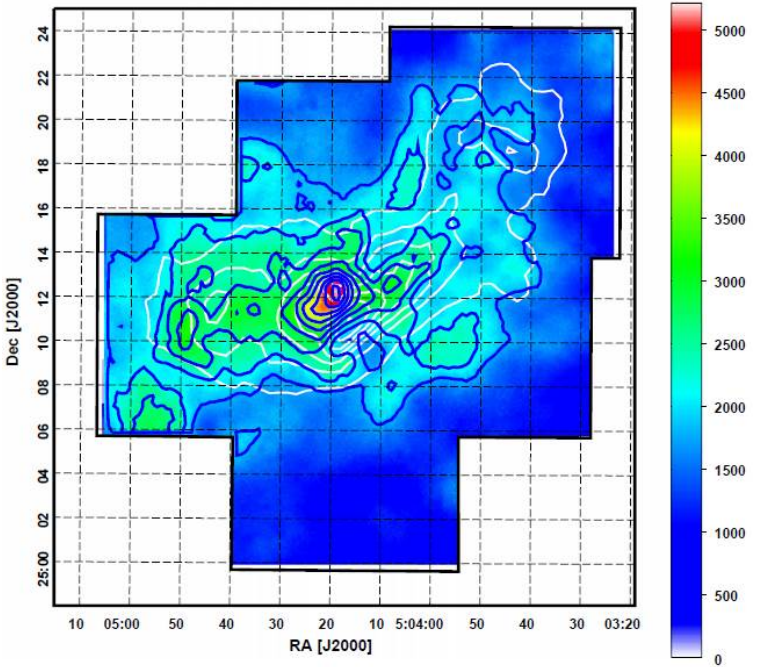
1. Low-Resolution Maps of T_{DUST} and β + Herschel 250 μm = High-Resolution τ_{850} map



False-color image of τ_{850} resulting from using the full, high-resolution Herschel 250 μm dust emission with the low-resolution T_{DUST} and β maps built from Planck + Herschel matched-resolution SED fitting.

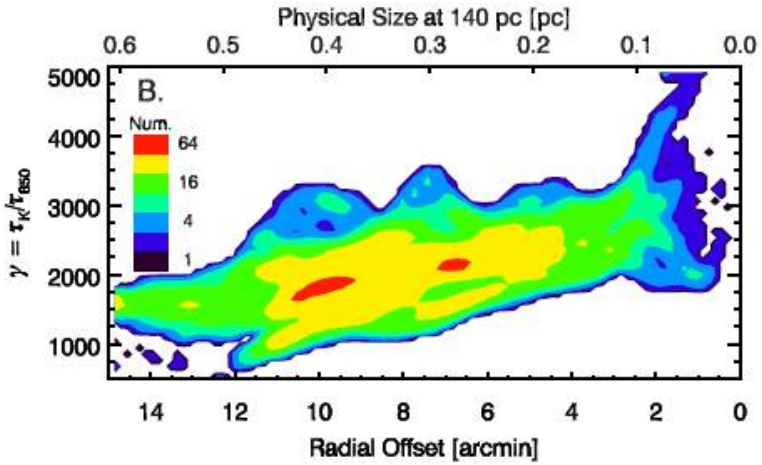
2. Form γ = (H-M) / τ_{850} as tracer of changes in dust properties with location. For best conversion of dust optical depth to Hydrogen molecular column density.

Aside: $\tau_K \sim$ (H-M)



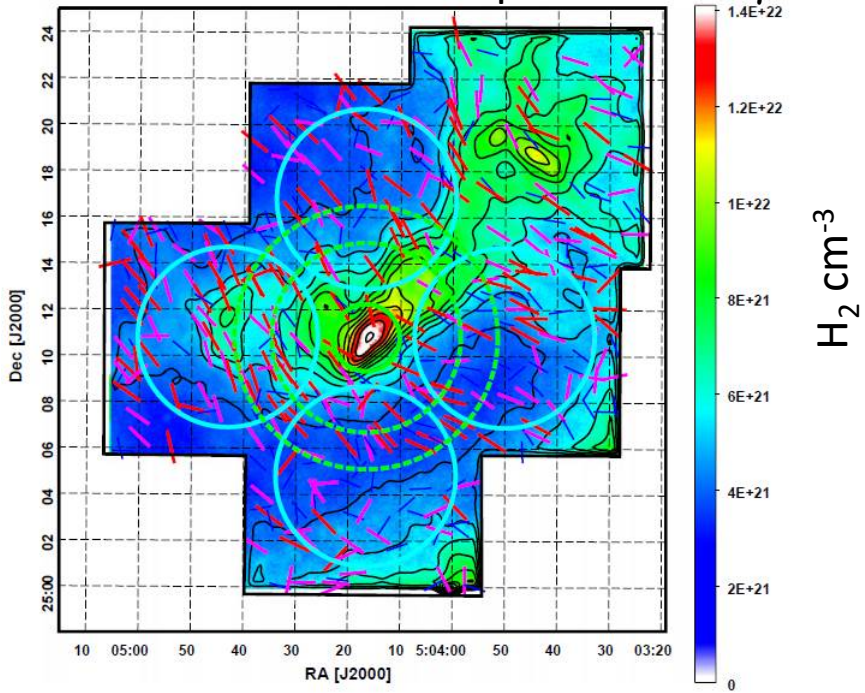
Ratio γ map in false-color and blue contours, with Herschel 250 μm emission in white contours

γ changes with location, so H_2 yield computed per τ_{850} must also change. (grains grow, opacities change, conversion of τ_{850} -> N_{H2} changes).



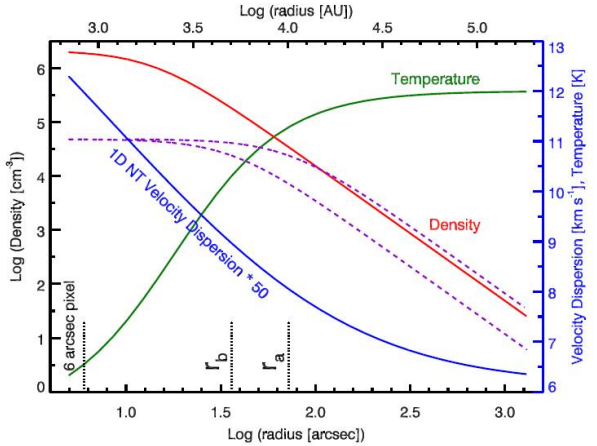
Radial distribution of γ values across L1544. Note rise in γ with proximity to the L1544 dense cloud core.

N_{H2} map, based on: (1) matched-resolution Planck+Herschel SED fitting; (2) Herschel 250 μm emission, and; (3) correction for location dependence of γ



False-color image of **N_{H2}**, with NIR polarization vectors and Crutcher et al. (2009) beamsizes.

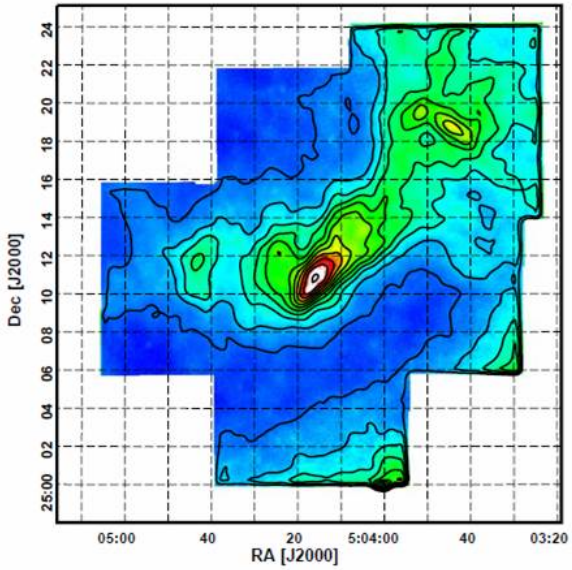
Chandrasekhar-Fermi ('53) Method needs $<n_{H2}>$ => build 3-D, multi-ellipsoid model of L1544



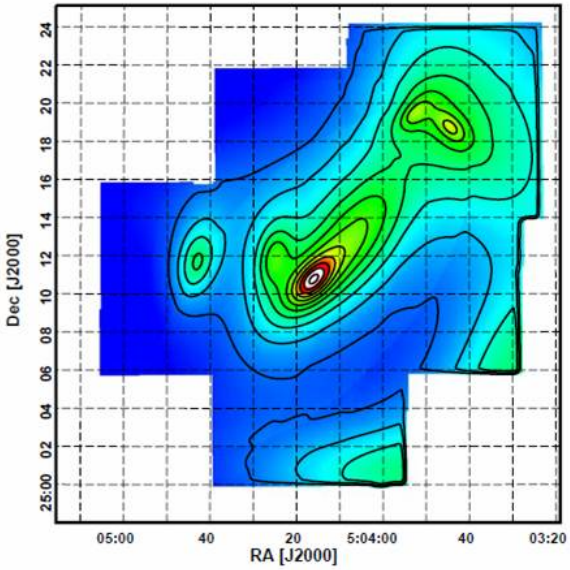
Radial model behaviors of temperature, gas density, and gas velocity dispersion for the L1544 dense cloud core, from Crapsi+07 and Tafalla+02.

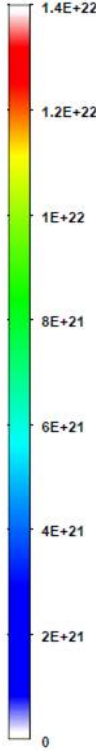
Assumed these radial behaviors for 3D model ellipsoids, with unique central scalings, centers, a:b:c ratios.

N_{H2} from observations



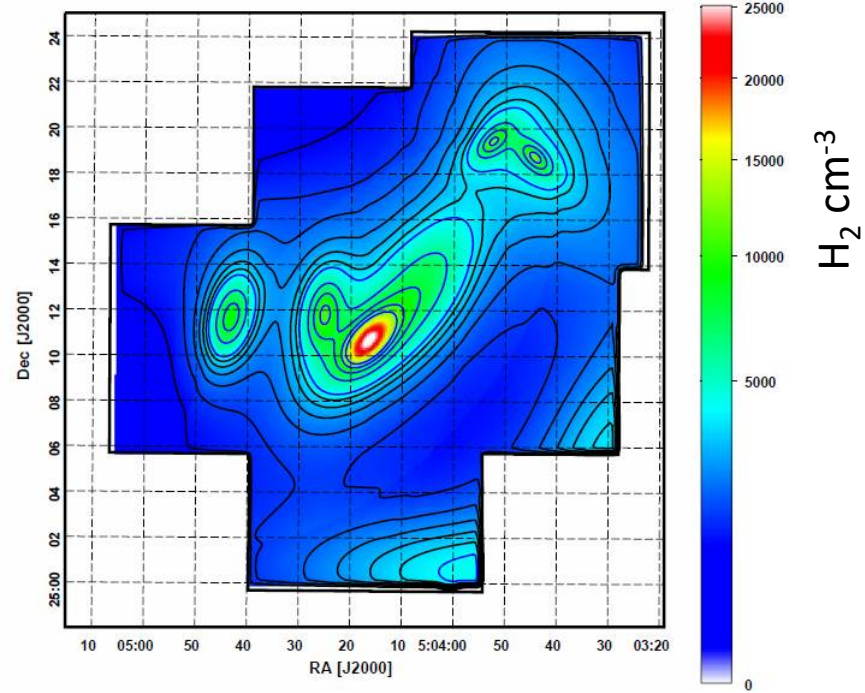
N_{H2} from model





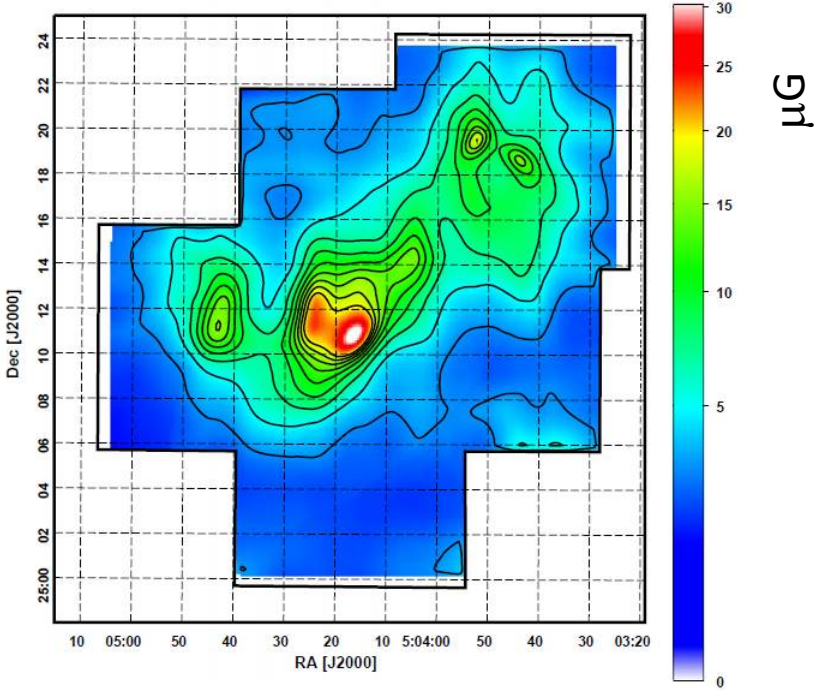
Measured N_{H2} image (left) and **model N_{H2}** image (right). The model contains eleven 3-D ellipsoids, each using the radial behaviors of the physical properties noted at left, chosen to accurately mimic the real data when integrated along the line of sight for each pixel.

Computed $\langle n_{H2} \rangle$ via line-of-sight integration with n_{H2}^{1} weighting. Physically more sound than usual $\langle n_{H2} \rangle = N_{H2} / D_{projected}$



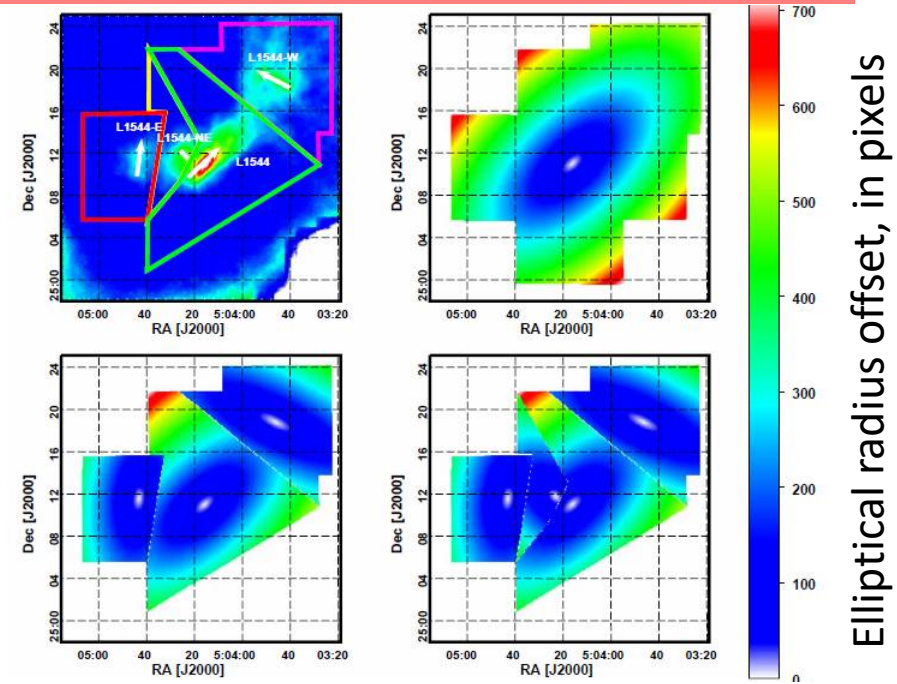
Mean (weighted) hydrogen molecular gas volume density computed for the L1544 field.

B-field (plane-of-sky) strength, from Chadrasekhar-Fermi ('53):
$B \sim (n_{H2})^{0.5} (\sigma_{RV} / \Delta_{PA})$

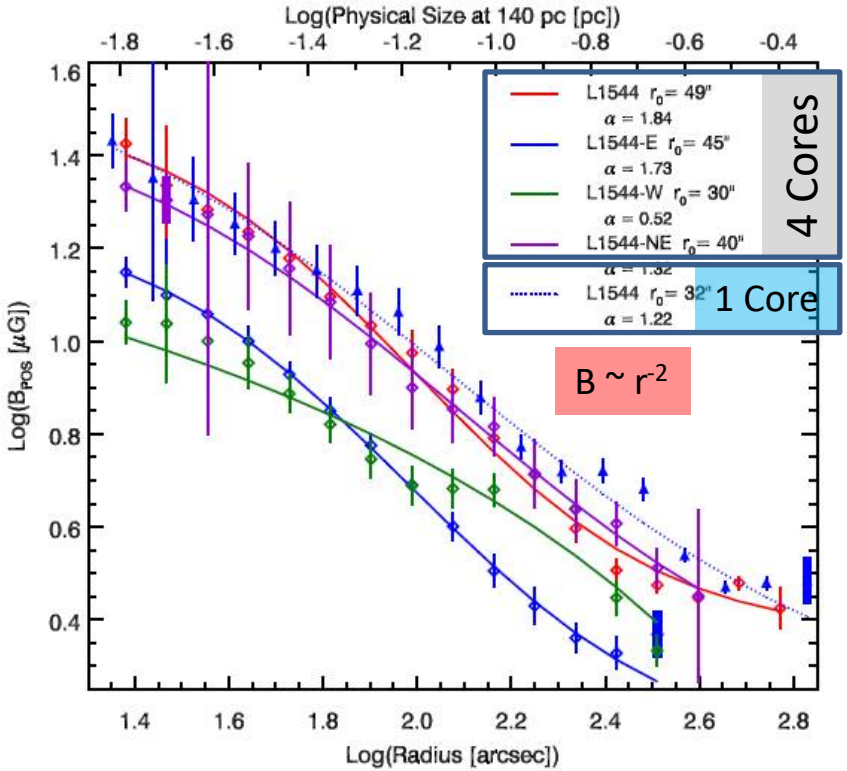


Plane-of-sky B-field strength (in μGauss) across L1544.

But wait! There's more! Single core is not The best characterization. Try 1, 3, 4 cores.

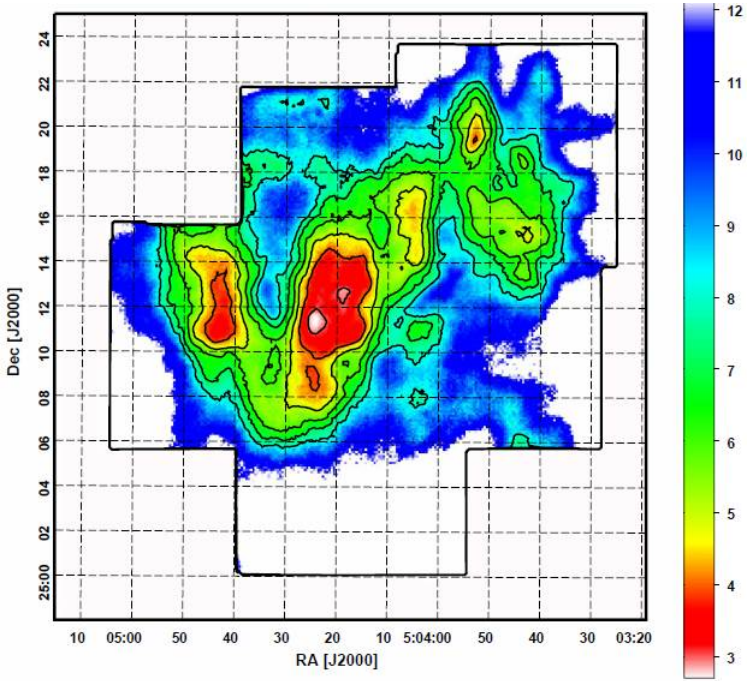


B-field map (upper left), with region boundaries and core elongations indicated. Upper right, lower left, lower right panels show 1, 3, 4 core realizations of projected elliptical radius from local core center



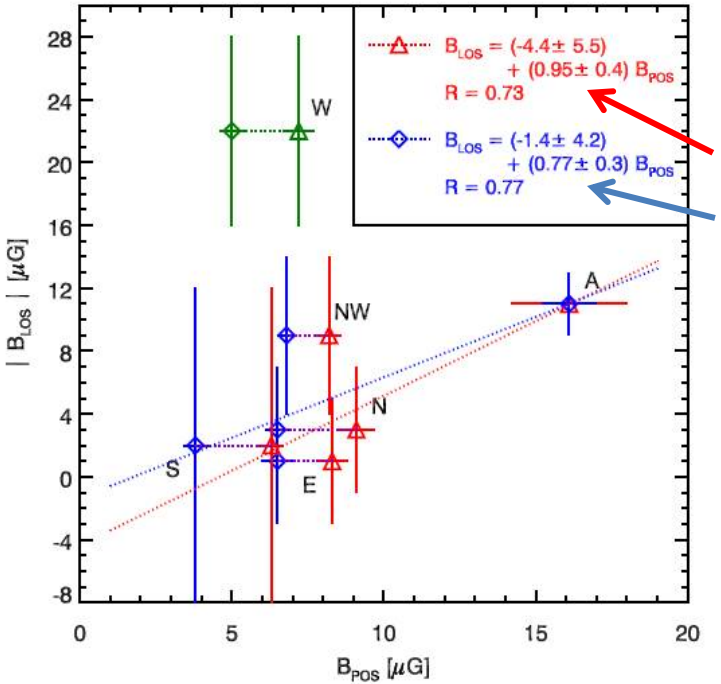
B-field strength versus offset for the 1, 3, and 4 core realizations

Ongoing analyses – Mass-to-Flux map, radial behavior



Preliminary Mass-to-Flux map, using line-of-sight mass and plane-of-sky B-field strength (non-ideal combination)

Background starlight polarimetry versus Radio Zeeman Effect – not wildly different



~Unity slopes

Zeeman Effect traced B_{LOS} (y-axis) strength versus B_{POS} from NIR starlight (x-axis) for the five L1544 Zeeman beams. Red = NIR stellar averages in beams; Blue = averaging NIR B-strength image values across beams