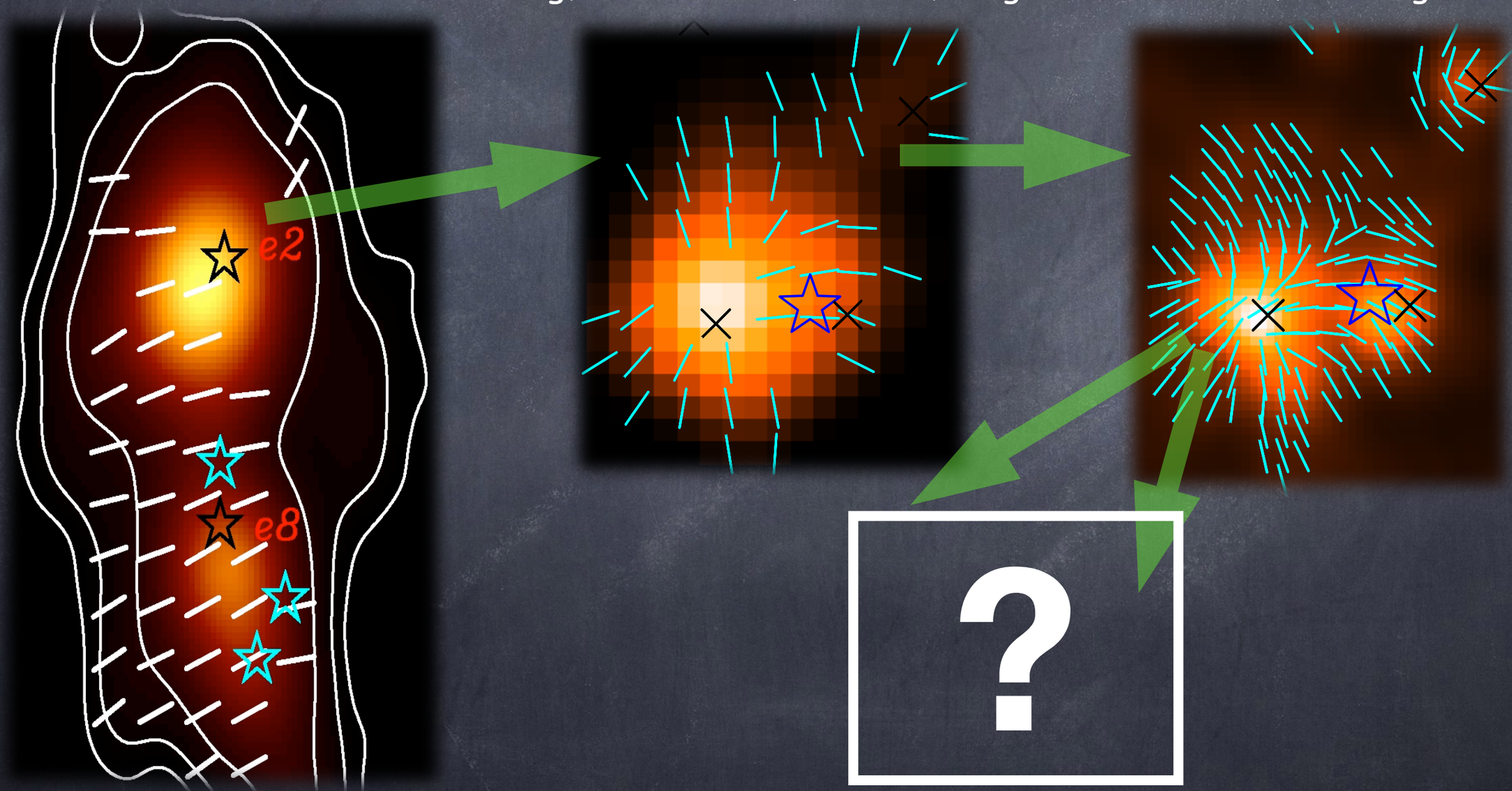
Zooming in: Magnetized Disk in the High-Mass System W51 e2

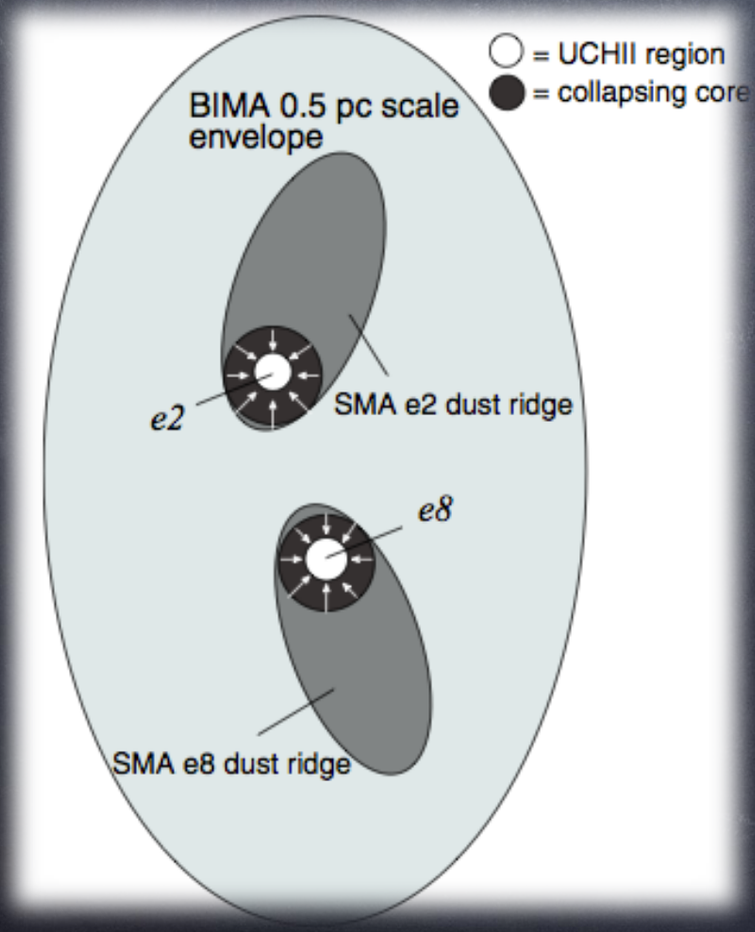
Patrick Koch (ASIAA, Taiwan)

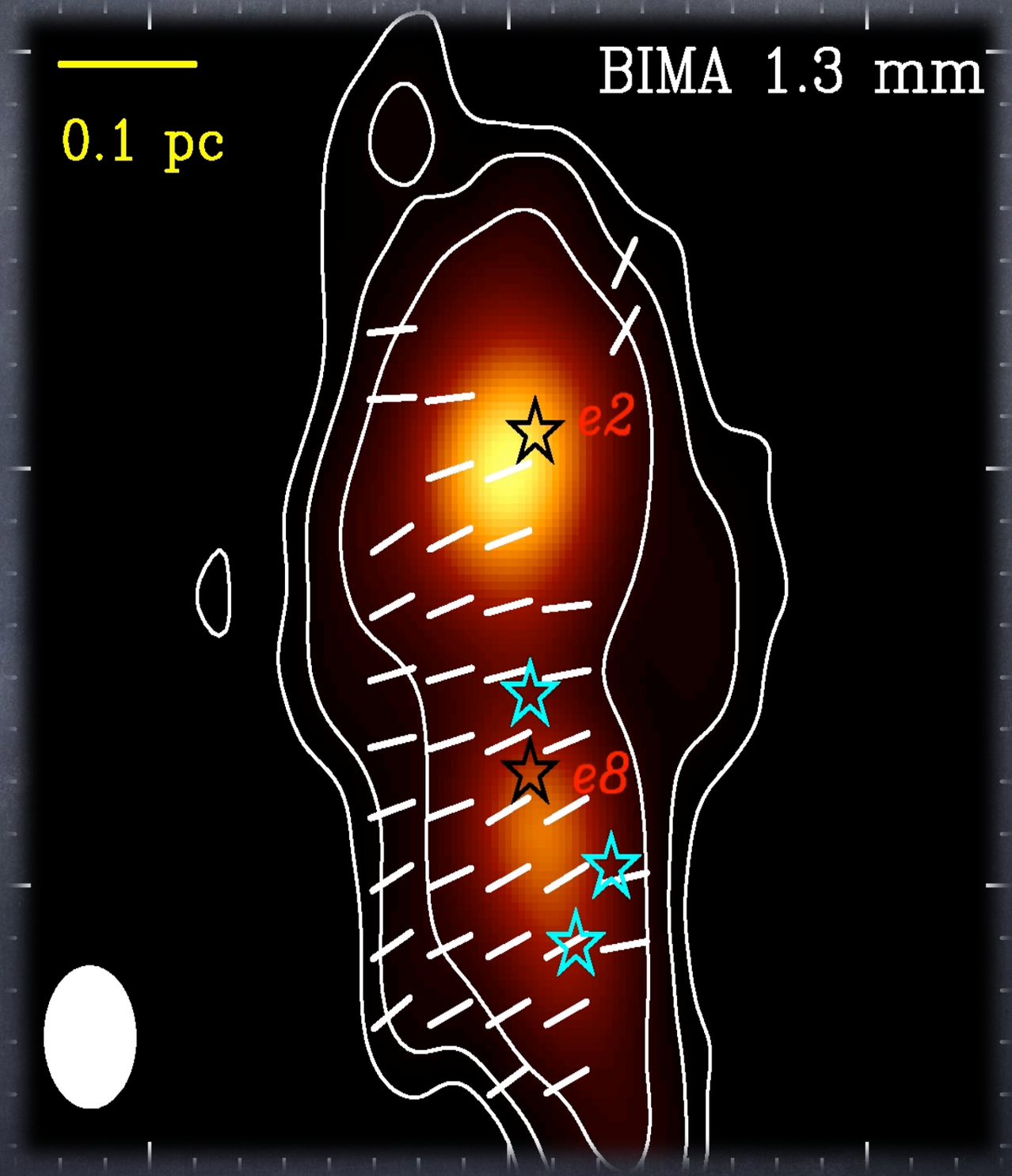
with Ya-Wen Tang, Hsi-Wei Yen, Paul Ho, Shigehisa Takakuwa, Yu-Nung Su



B-field Measurements in W51

- W51 high-mass SF site at d~5.4 kpc
- several UCHII regions and infalling signatures detected (e.g. Zhang+98)
- chemically rich (Ginsburg+2017)
- elongated structure, with B-field mostly perpendicular (BIMA, θ~ 3", Lai+2001)
- SMA observations: resolved B-field in cores with θ~ 0.7" (Tang+2009)





Lai+2001

W51 e2/e8 with BIMA and SMA

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- several UCHII regions and infalling signatures detected (e.g. Zhang+98)
- chemically rich (Ginsburg+2017)
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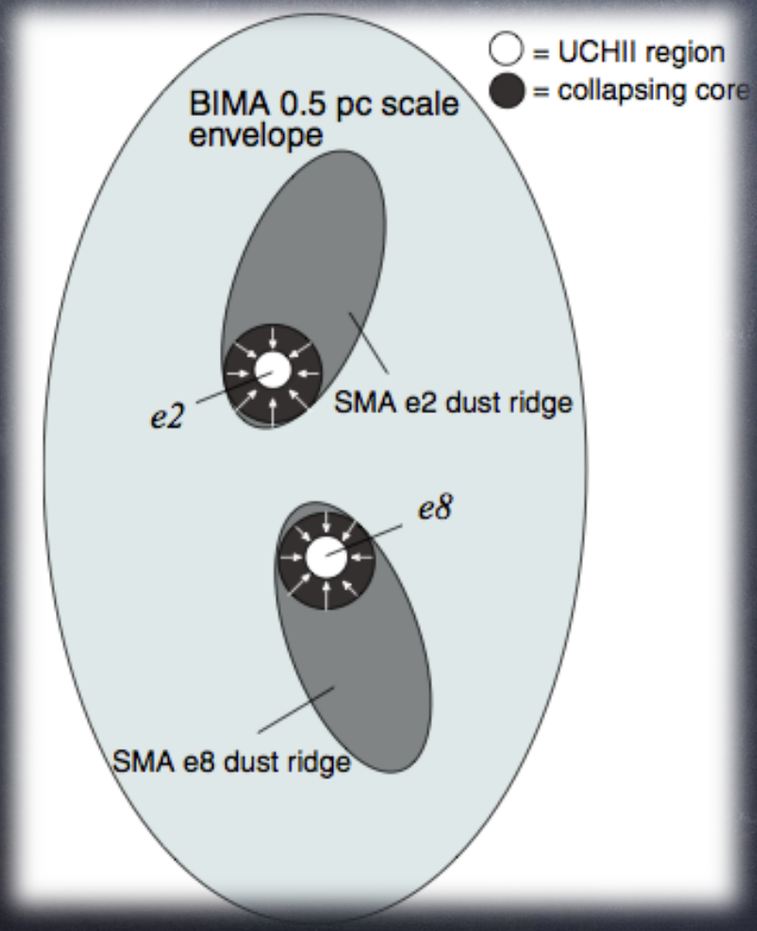
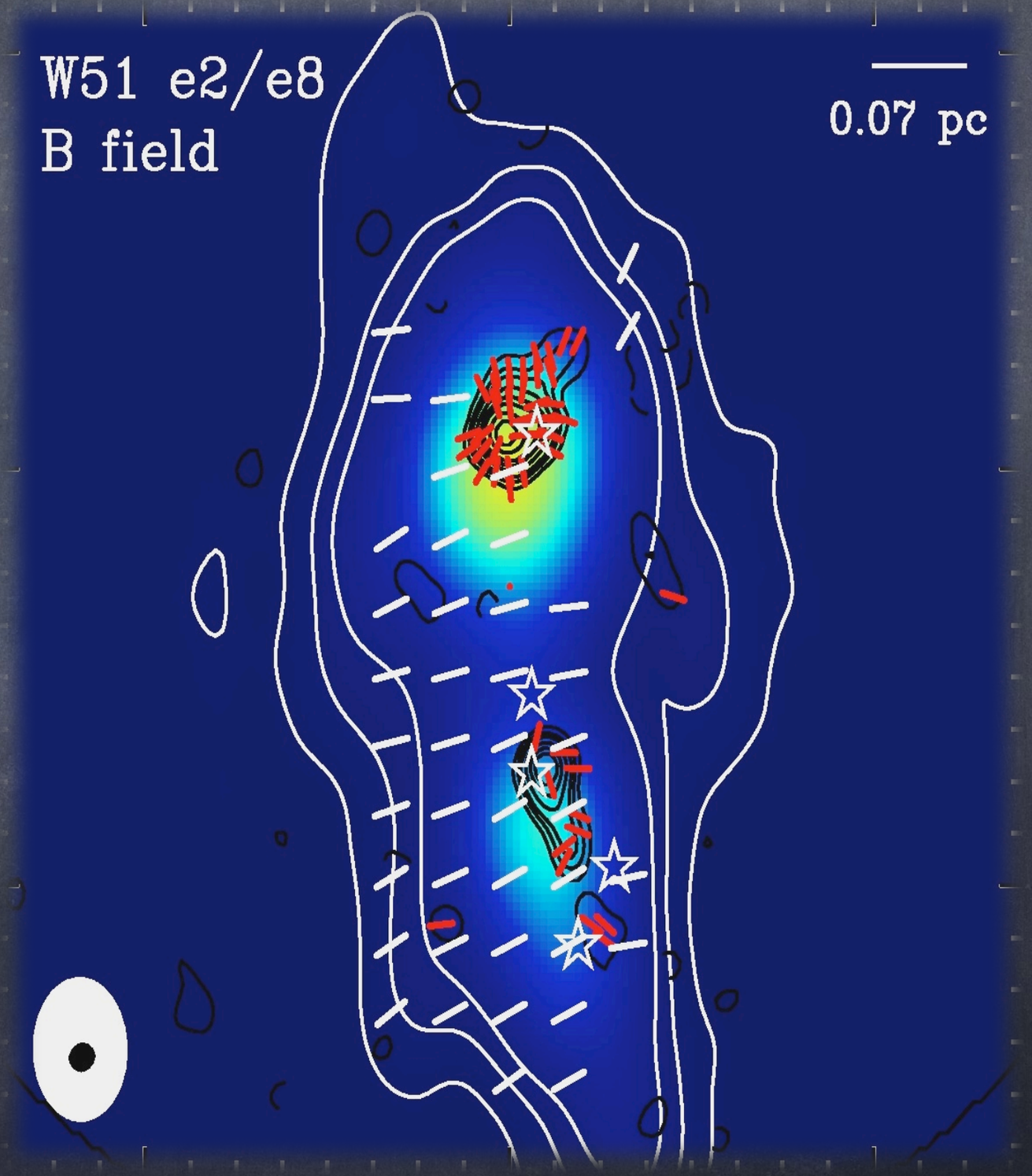
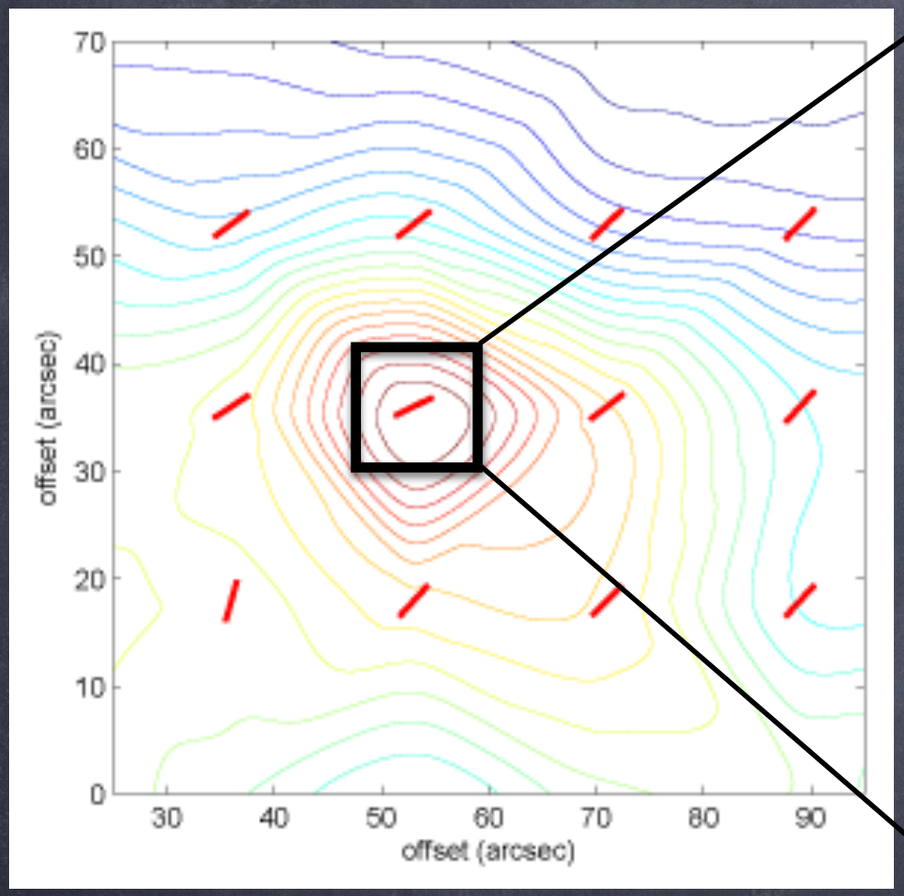




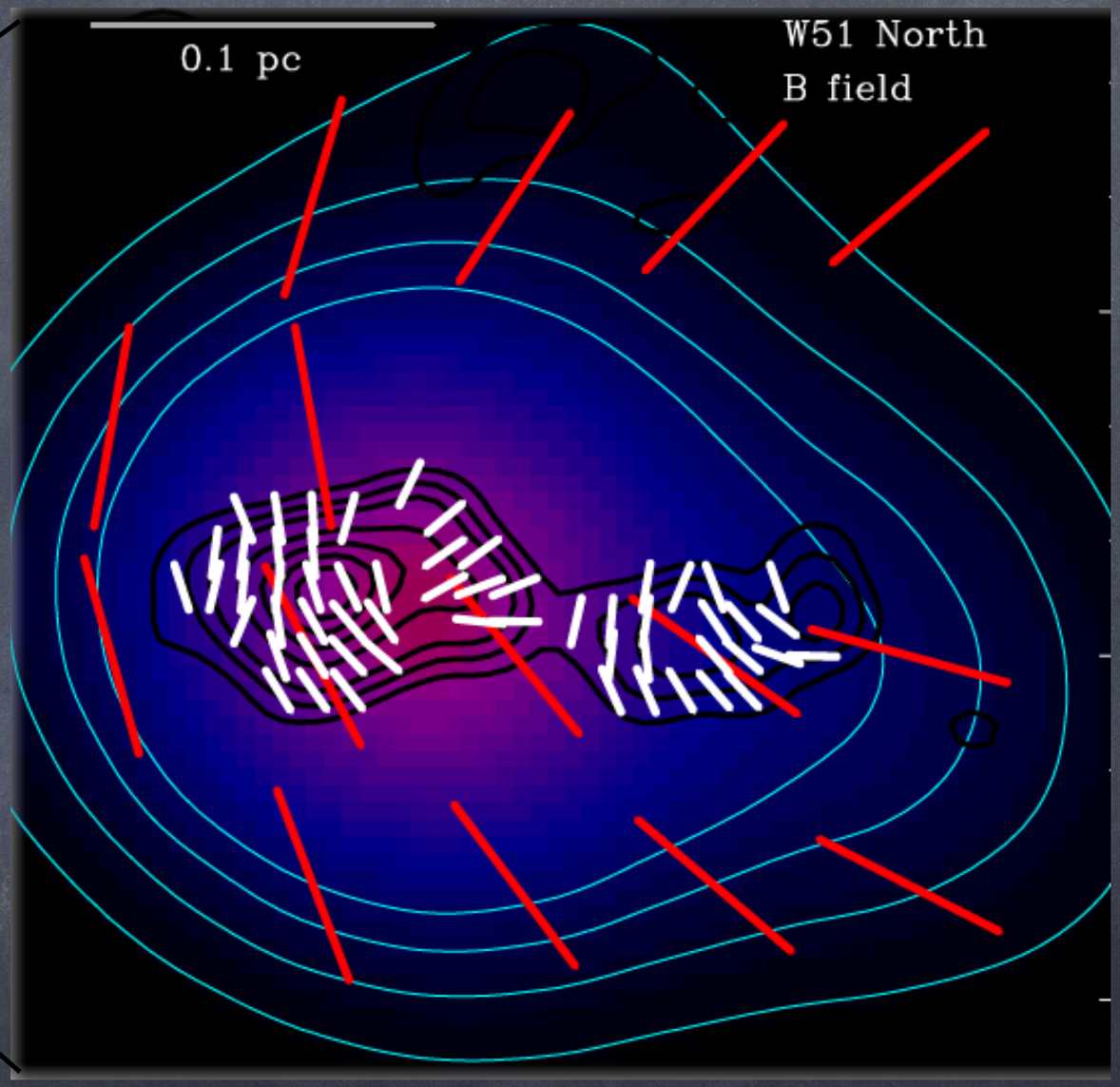
Tang+2009

W51 North with CSO and SMA

CSO/Hertz, 350μm, θ~20”



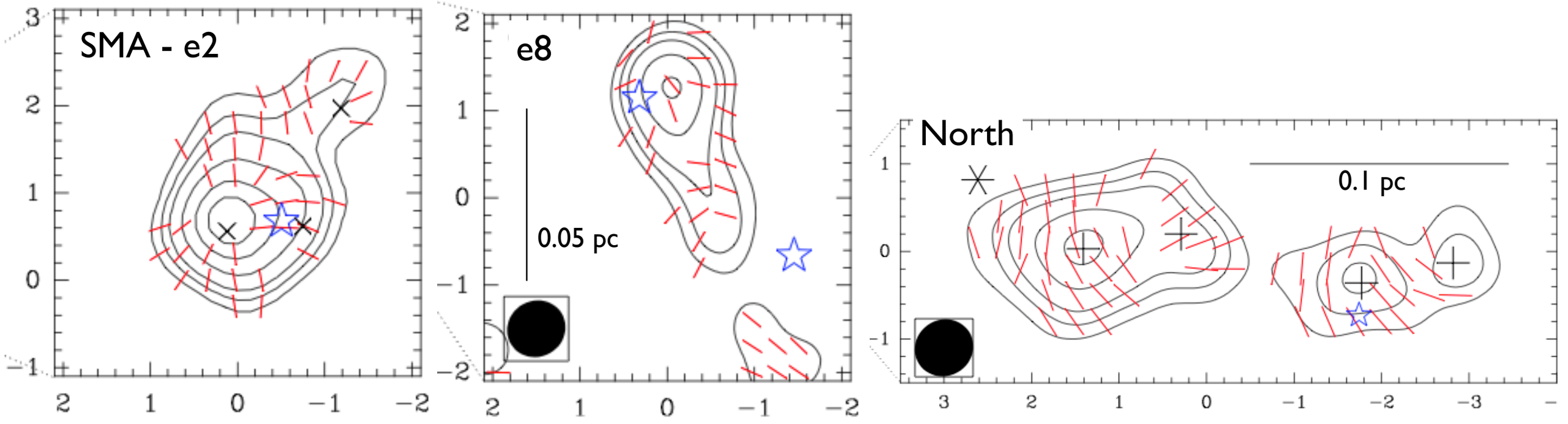
SMA, 870μm, θ~2” and 0.7”



(Tang+2013)

- clearly varying B-field structure as a function of scale
- channeling from North and South towards mid-plane
- denser cores in mid-plane along east-west direction

First ALMA Polarization Observations towards W51



(Tang+2009; 2013)

- ALMA cycle 2/3 (230 GHz (B6), θ ~ 0.26"~ 5 mpc; Koch+2018)
- pol. percentages ~ 0.1 - 10%; sensitivities 1mJy/b in Stokes I, 0.1 mJy/b in Q,U

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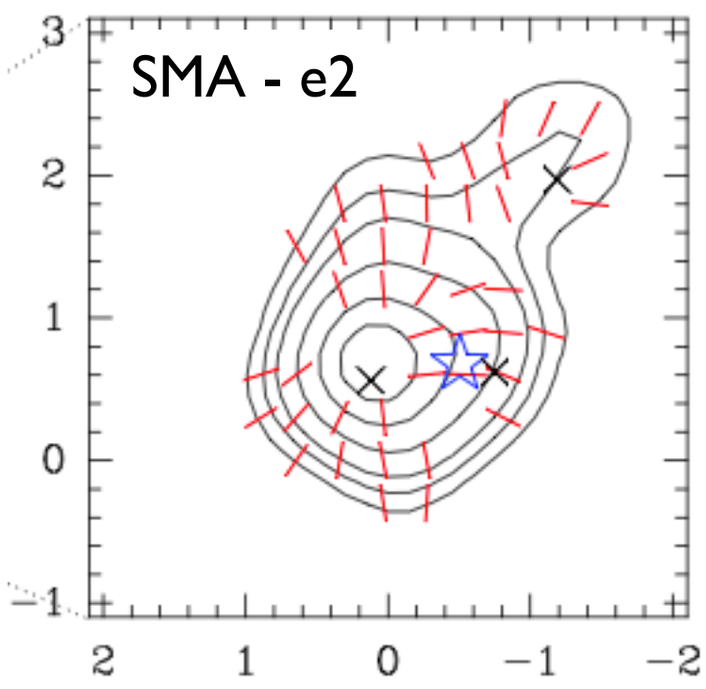
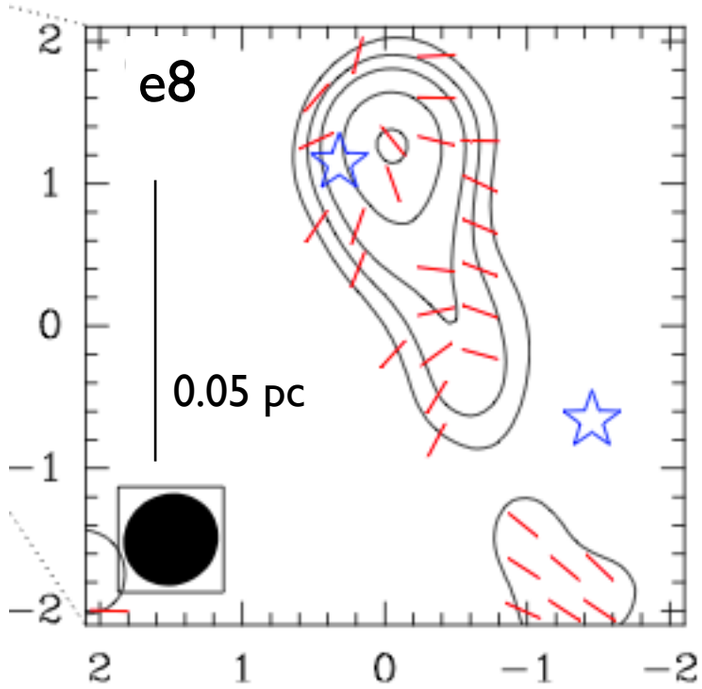
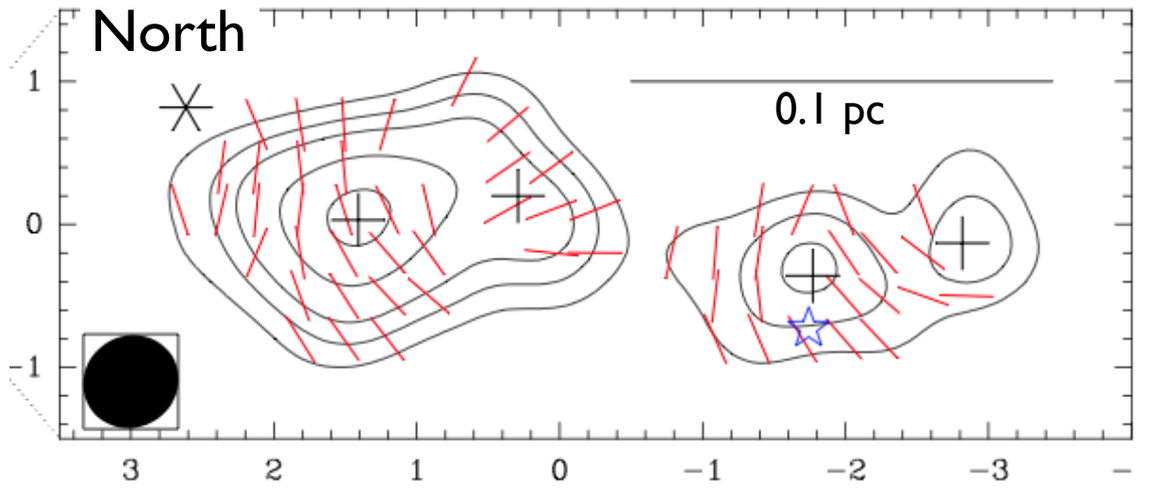
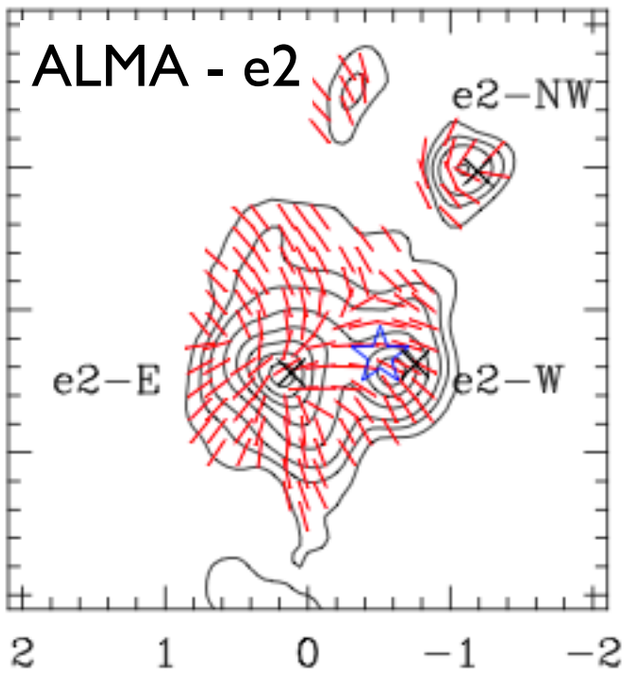
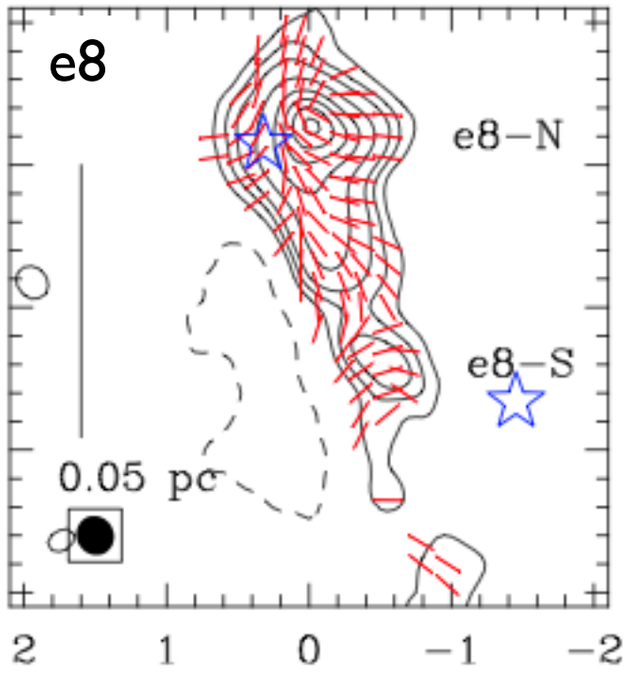


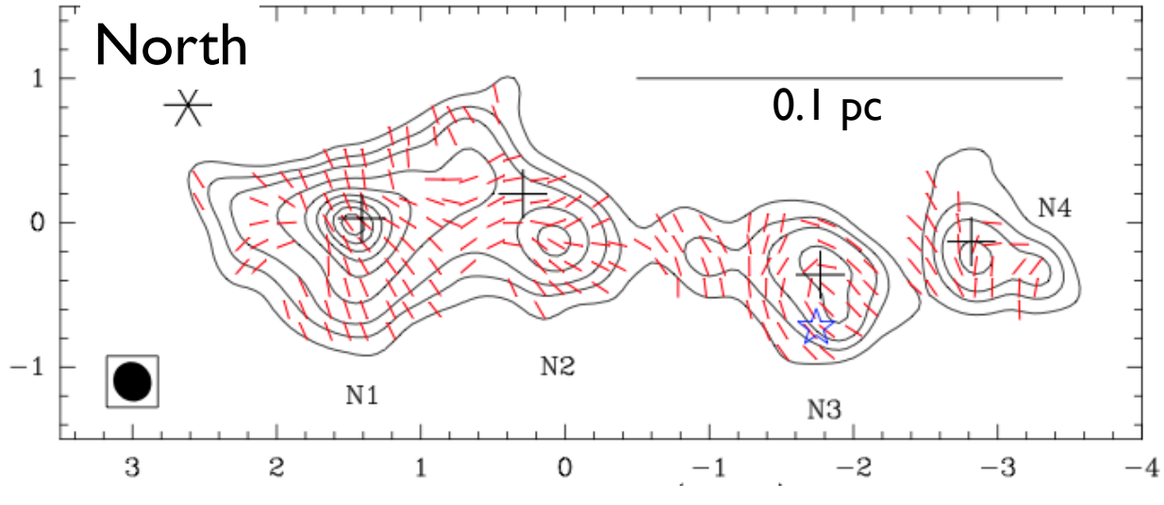




(Tang+2009; 2013)







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- new sub-structures:
  cometary-shaped B-field in e2-NW, e8-S, **symmetric convergence zones** (yellow)

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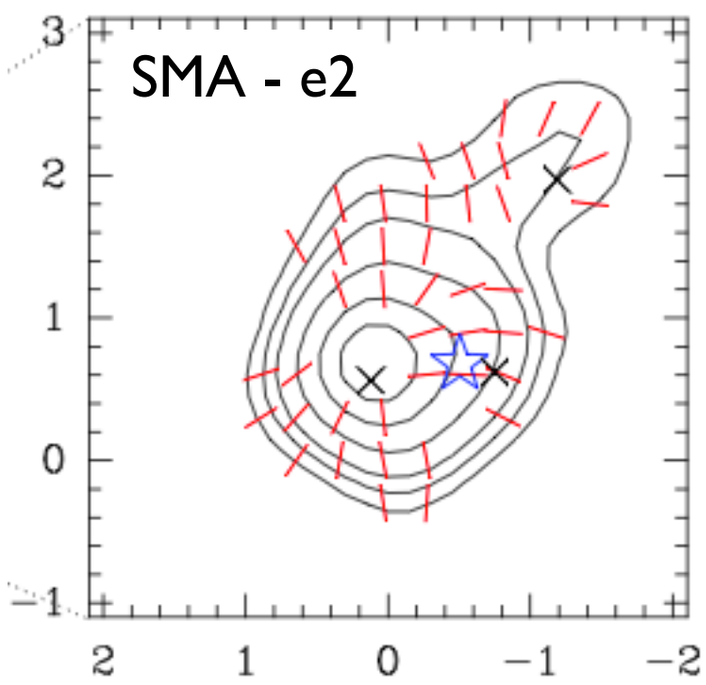

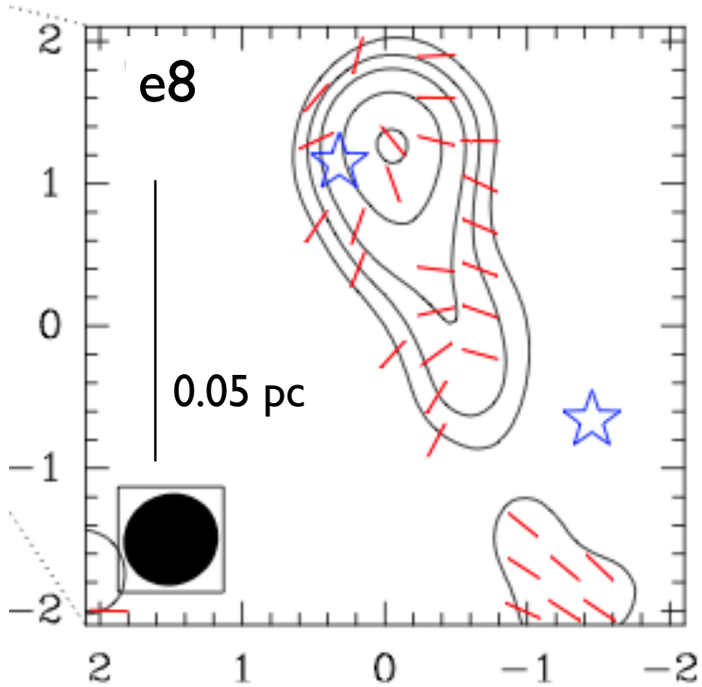

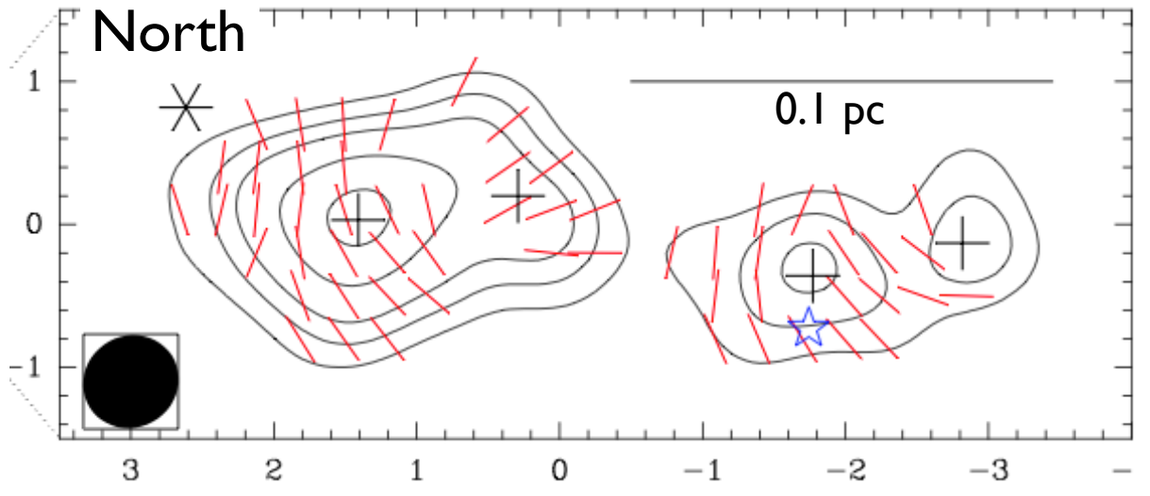

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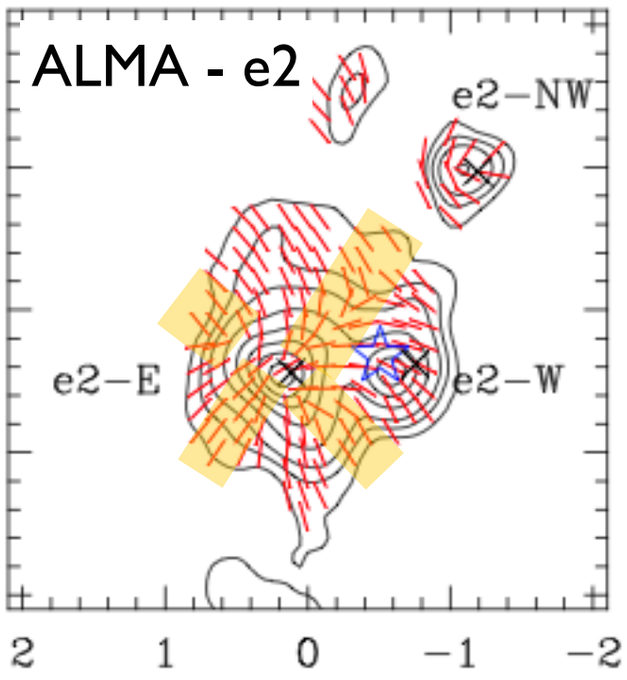

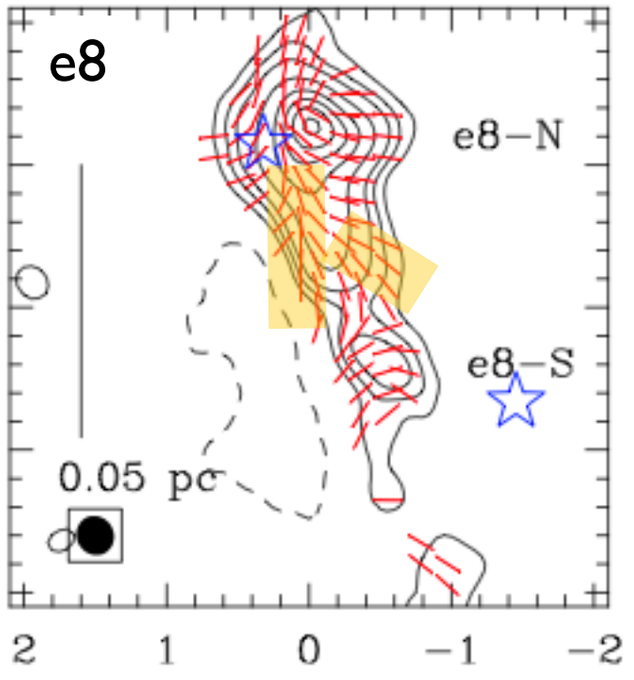

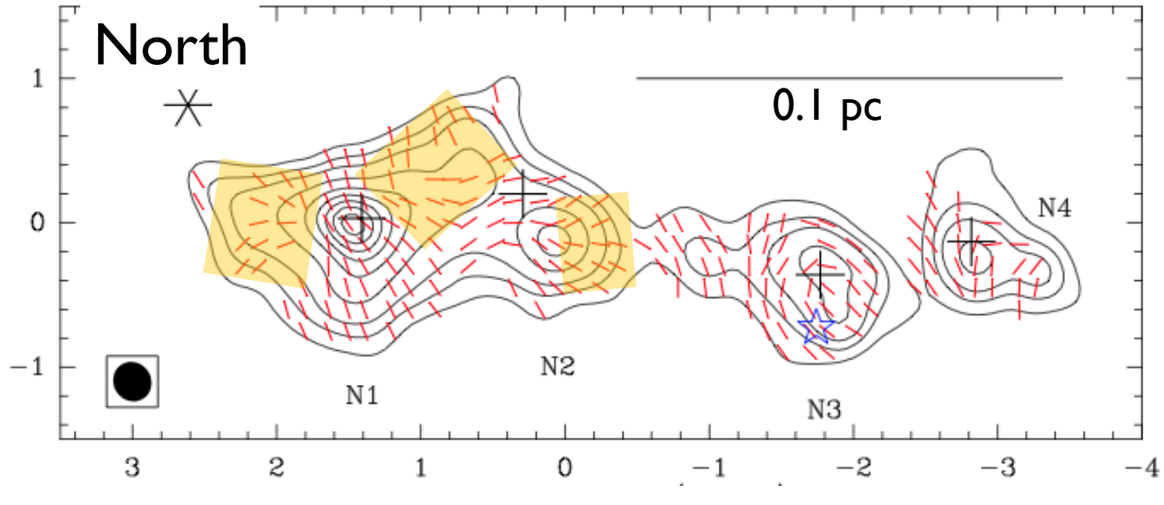

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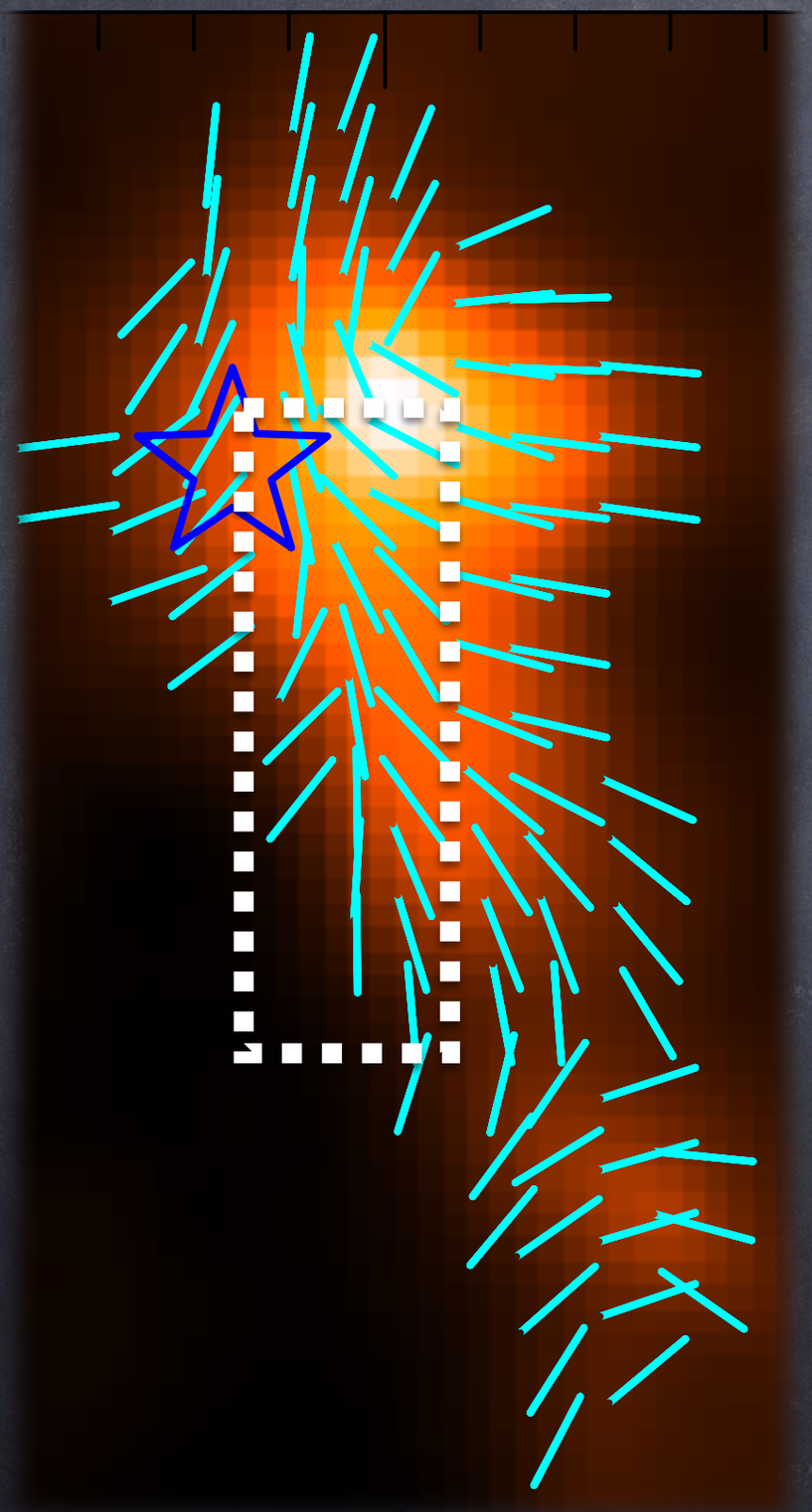
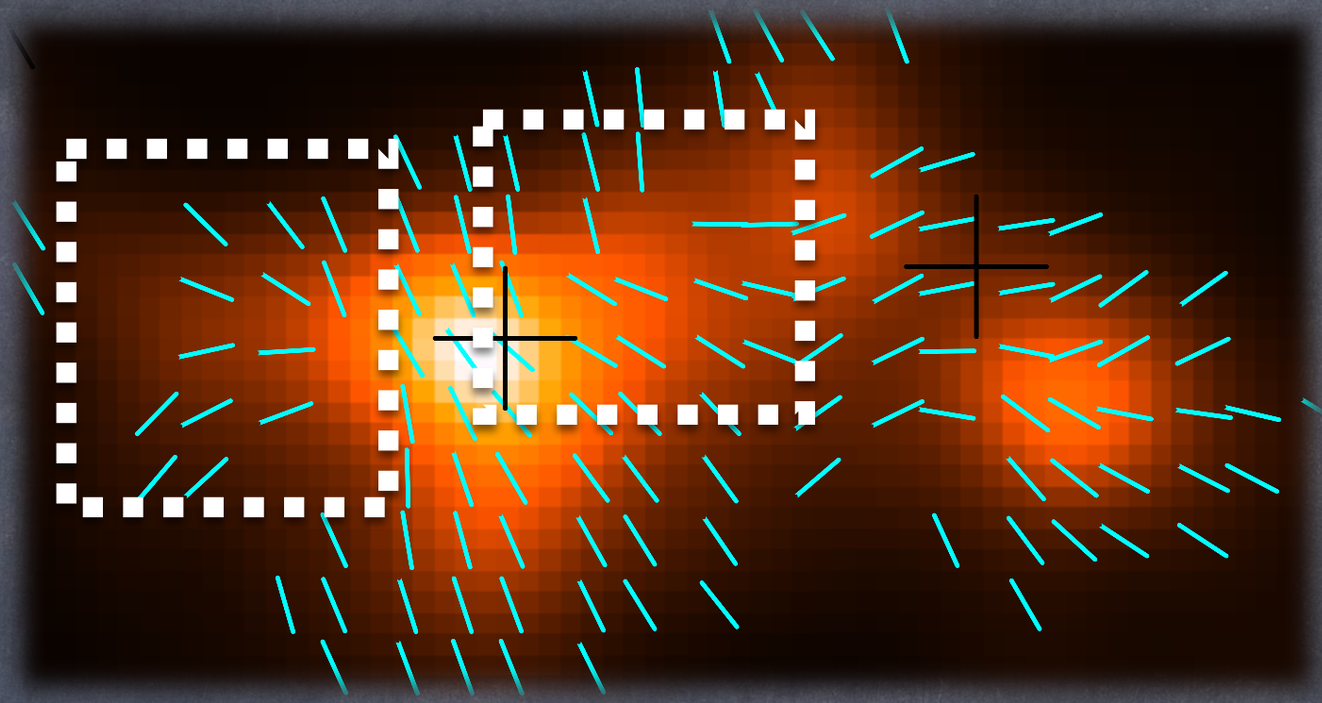
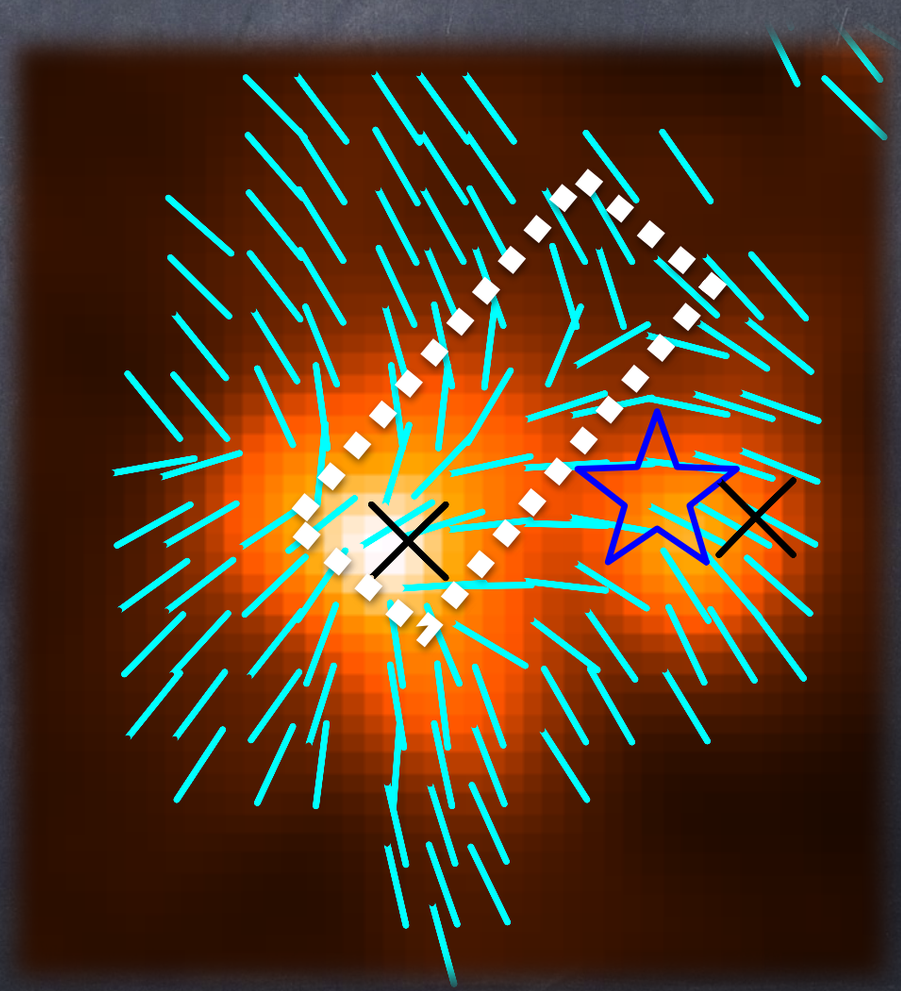
Magnetic Field Convergence Zones



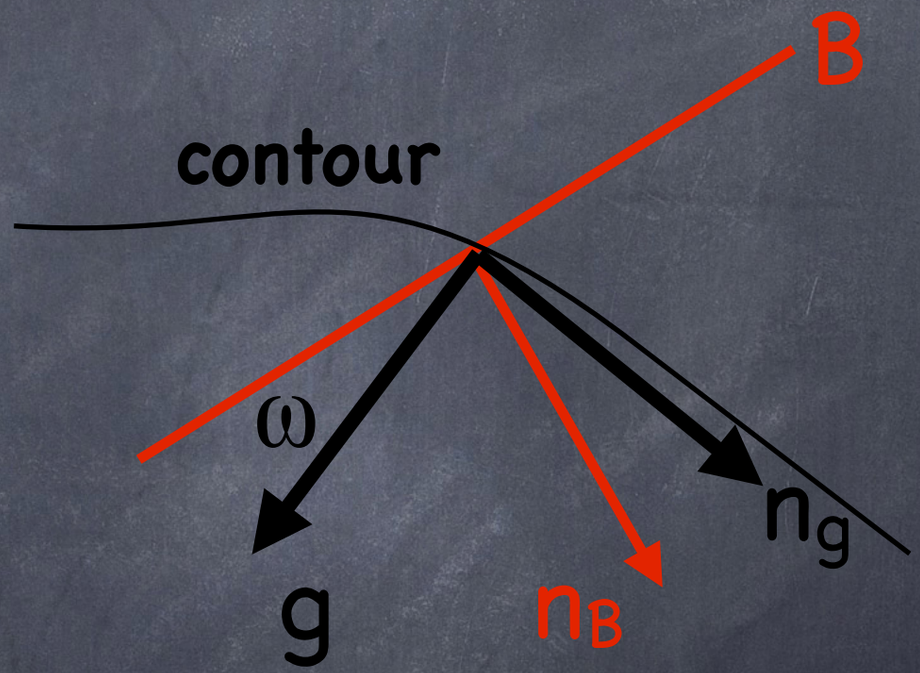




Gravity vs Magnetic Field

- *How important is the magnetic field in e2-E, e2-W and e2-NW ?*
- *In which cores can it still slow down gravitational infall ?*
- *Where is the field already overwhelmed by gravity, and might there be even local differences within the same core?*

- compare local direction of B-field (n_B) with direction of local gravity (g)
- adopt ideal MHD force equation

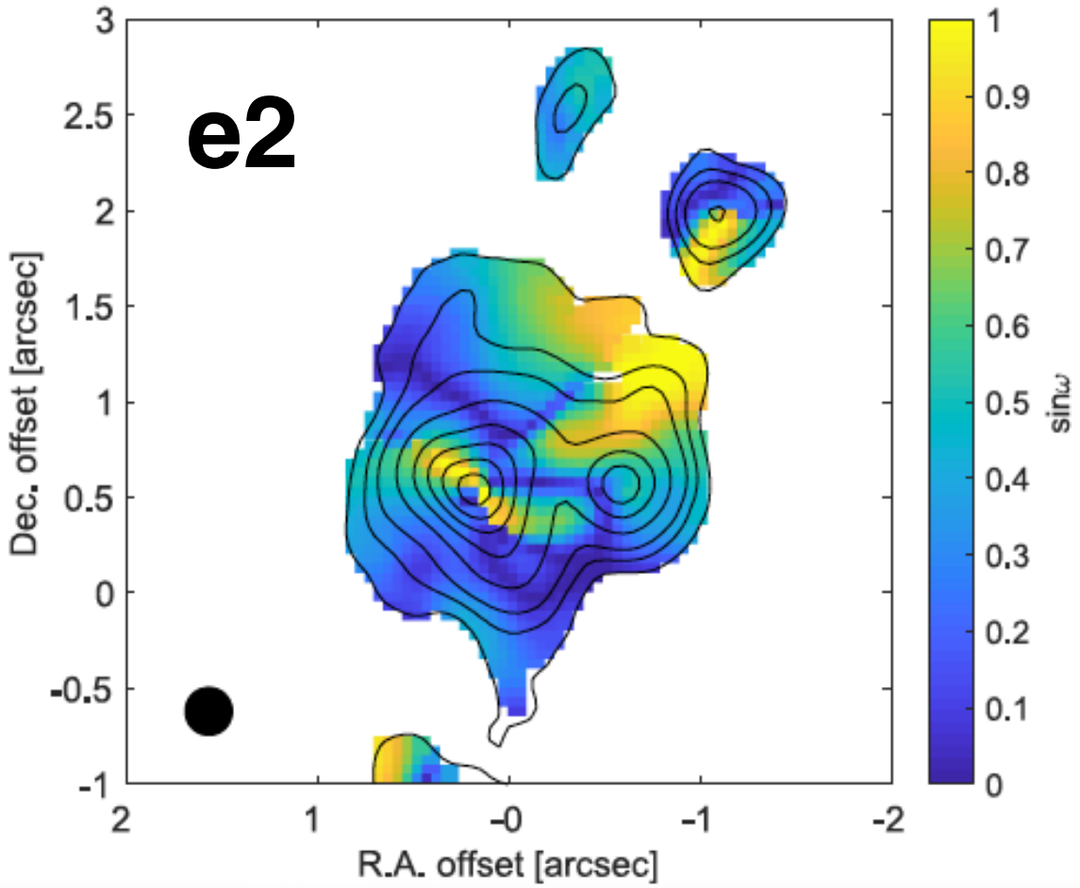


$$\rho\left(\frac{\partial}{\partial t}+\mathbf{v}\cdot\nabla\right)\mathbf{v}=-\nabla P-\rho\nabla\phi+\frac{1}{4\pi}\frac{1}{R}B^2\,\mathbf{n}_B$$

$$\rho\left(\frac{\partial}{\partial t}+\mathbf{v}\cdot\nabla\right)\mathbf{v}=-\nabla P-\rho|\nabla\phi|\mathbf{g}+\frac{1}{4\pi}\frac{1}{R}B^2\,\sin\omega\,\mathbf{g}+\frac{1}{4\pi}\frac{1}{R}B^2\,\cos\omega\,\mathbf{n}_g$$

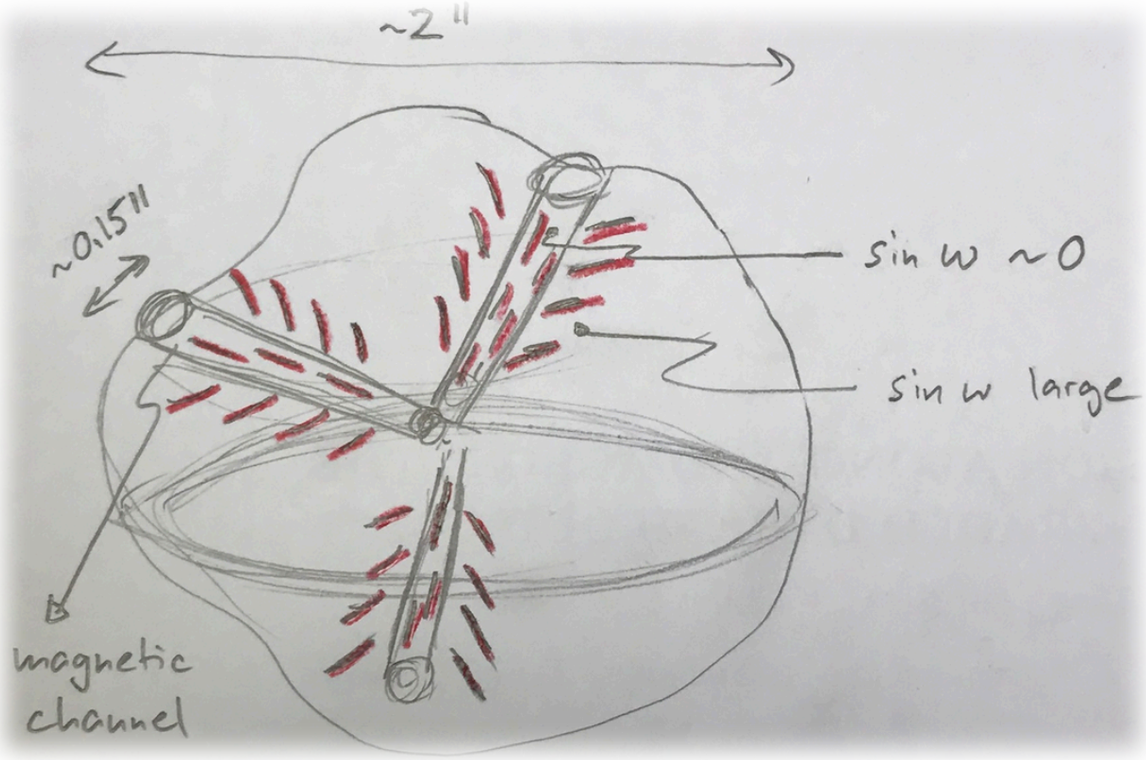
sin ω quantifies B-field effectiveness to oppose gravity (Koch+2018)

Magnetic Convergence Zones and Star Formation Efficiency



- sinω, in the range between 0 and 1, measures how effectively the B-field can oppose gravity.
  sinω~0: gravity/collapse proceeds freely
  sinω~1: B-field works maximally against gravity, holding back material

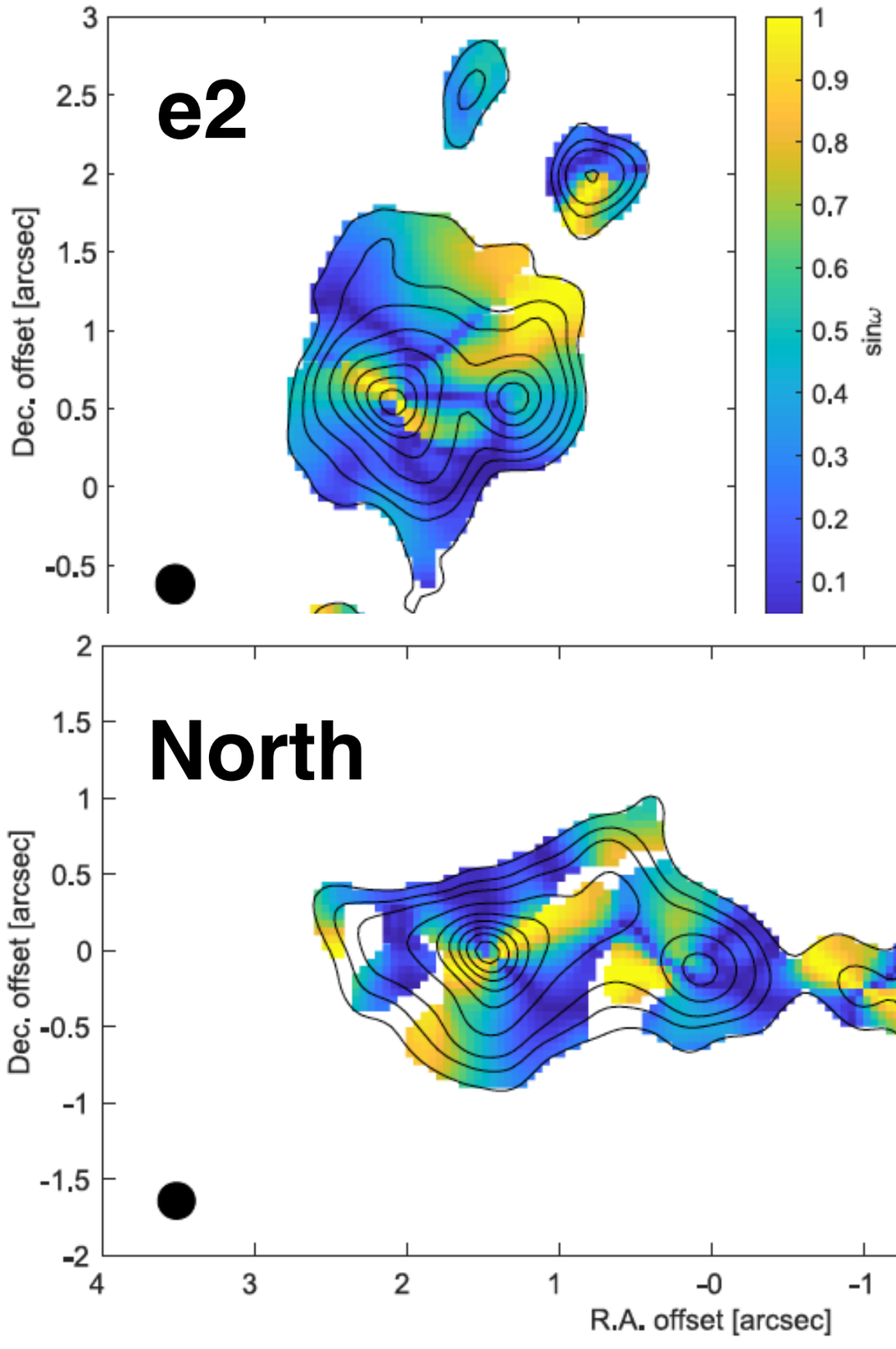
- W51 e2: network of narrow magnetic convergence zones (blue / black) with sinω~0



- *consequence for star formation efficiency?*

  - assume ~ 2" diameter sphere
  - ~0.15" converging channel, ~10 channels
  - 1 channel ~ 0.4% of entire mass (volume); if only mass within channels takes part in star-formation process: star-formation efficiency reduced to ~ 4% for W51 e2

Convergence Zones, Magnetic Channelling and Star Formation Efficiency



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oincide with

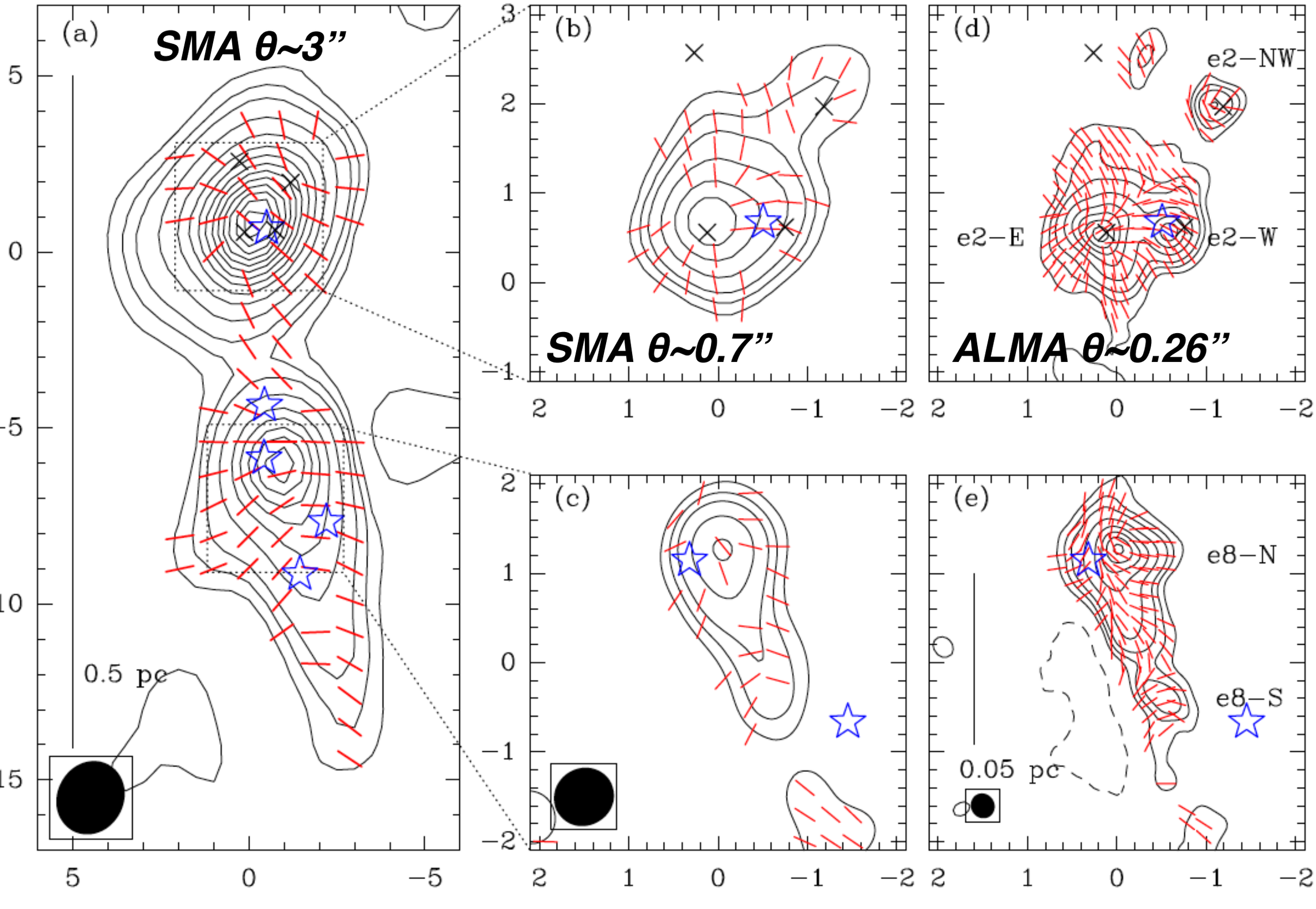
rmation efficiency?

Magnetic Field Structures over 3 Relevant Scales

envelope to core

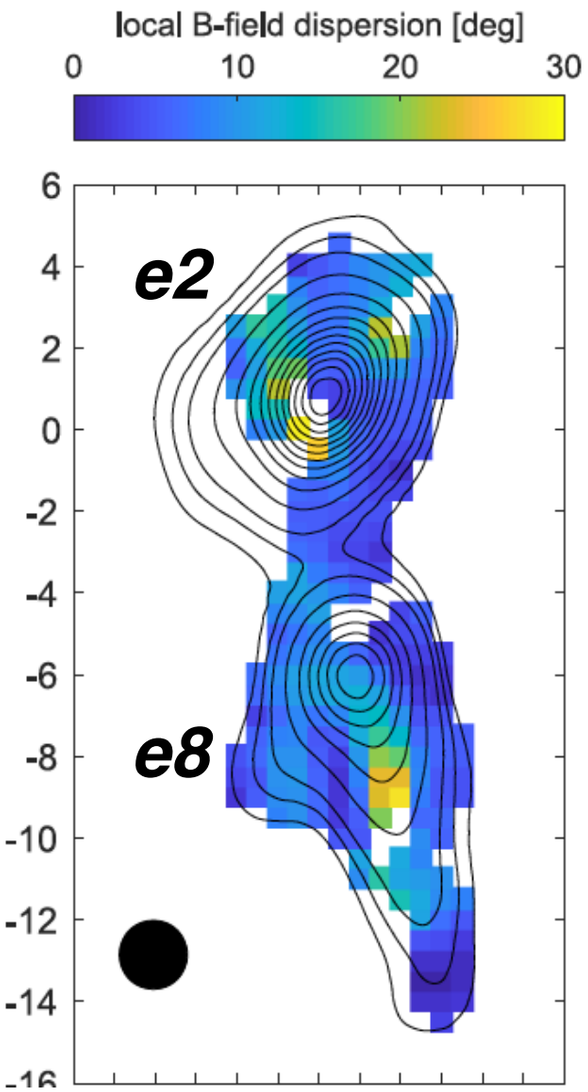
global collapsing core

local collapse convergence in core



Magnetic Field Structures over 3 Relevant Scales

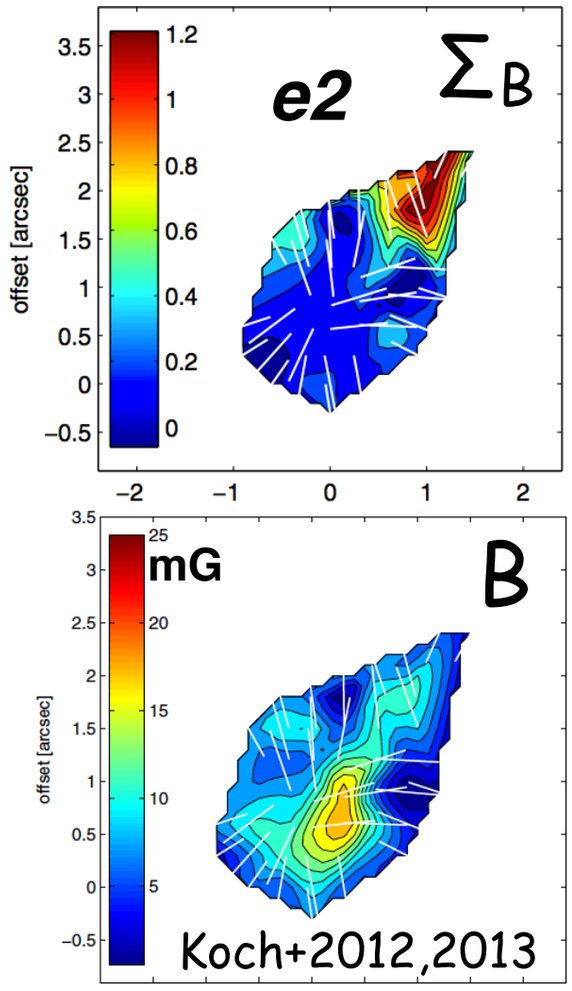
envelope to core



$$\mathcal{S}(\boldsymbol{r}, r_{\rm disp}) = \sqrt{\frac{1}{N}\sum_{i=1}^{N}[\mathrm{PA}(\boldsymbol{r}) - \mathrm{PA}(\boldsymbol{r} + \boldsymbol{r}_{{\rm disp},i})]^2}$$

- *accretion*
- *location+initial scale of gravitational drag towards forming core*

global collapsing core

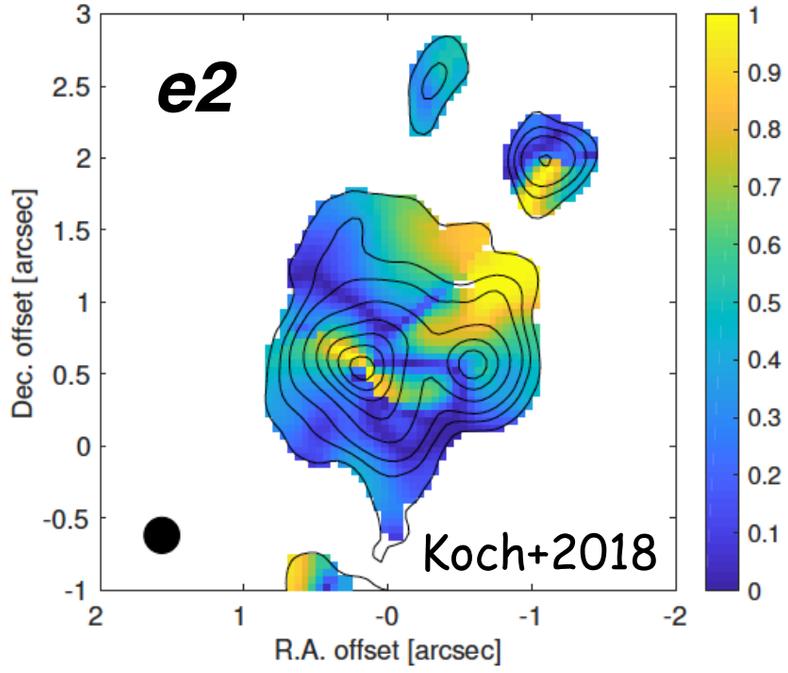


$$\Sigma_B \equiv \frac{\sin\psi}{\sin\left(\frac{\pi}{2} - |\delta|\right)} = \frac{F_B}{|F_G + F_P|}$$

$$B = \sqrt{\frac{\sin\psi}{\sin\left(\frac{\pi}{2} - |\delta|\right)}(\nabla P + \rho\nabla\phi)4\pi\ R}$$

- *competition gravity vs B-field in global collapse*
- *map of local field strength*

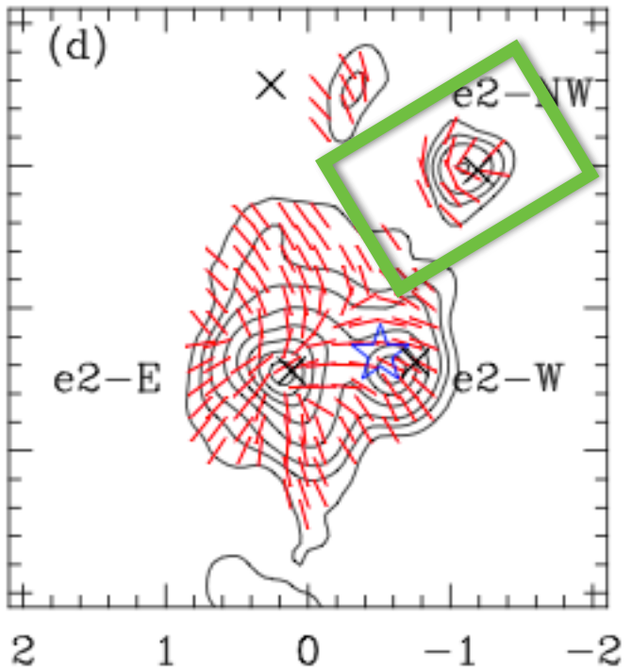
local collapse convergence in core

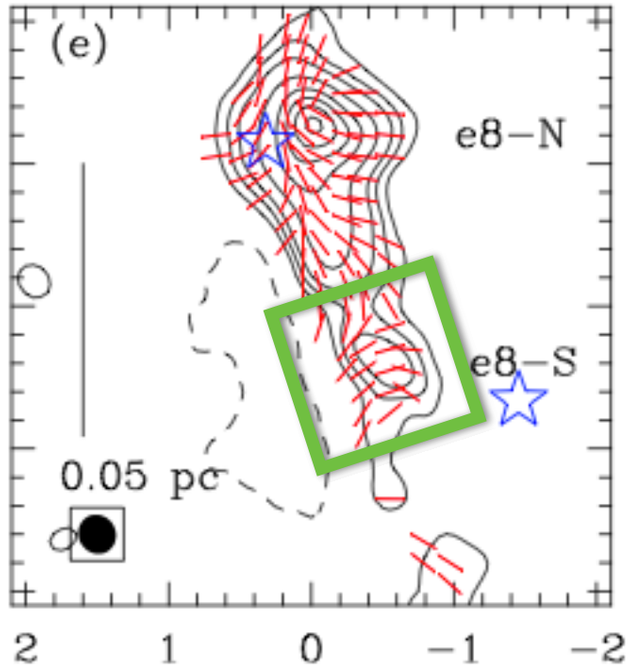


$\sin\omega$ measure

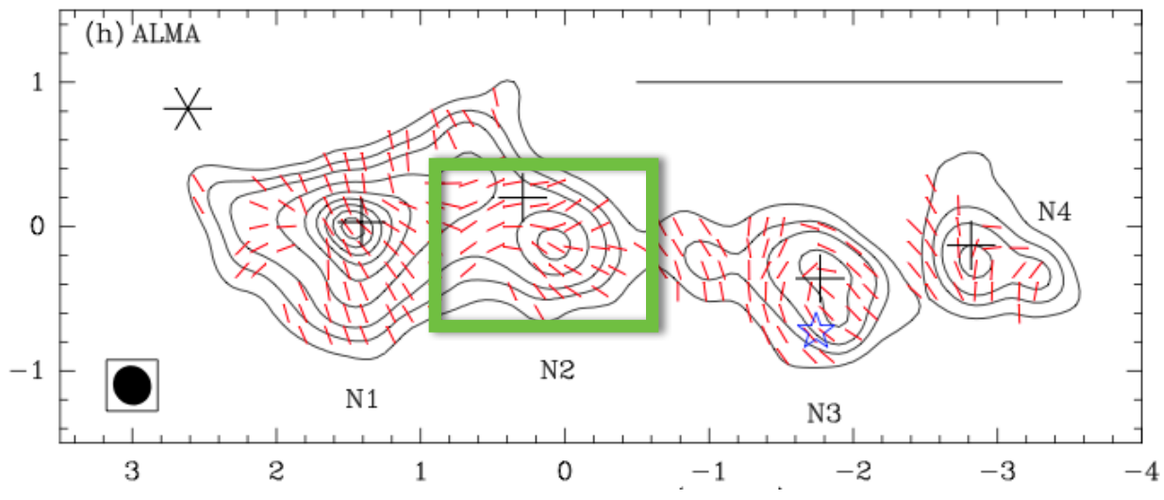
- *identification of local collapse feature*
- *diversified role of gravity and B-field within core*

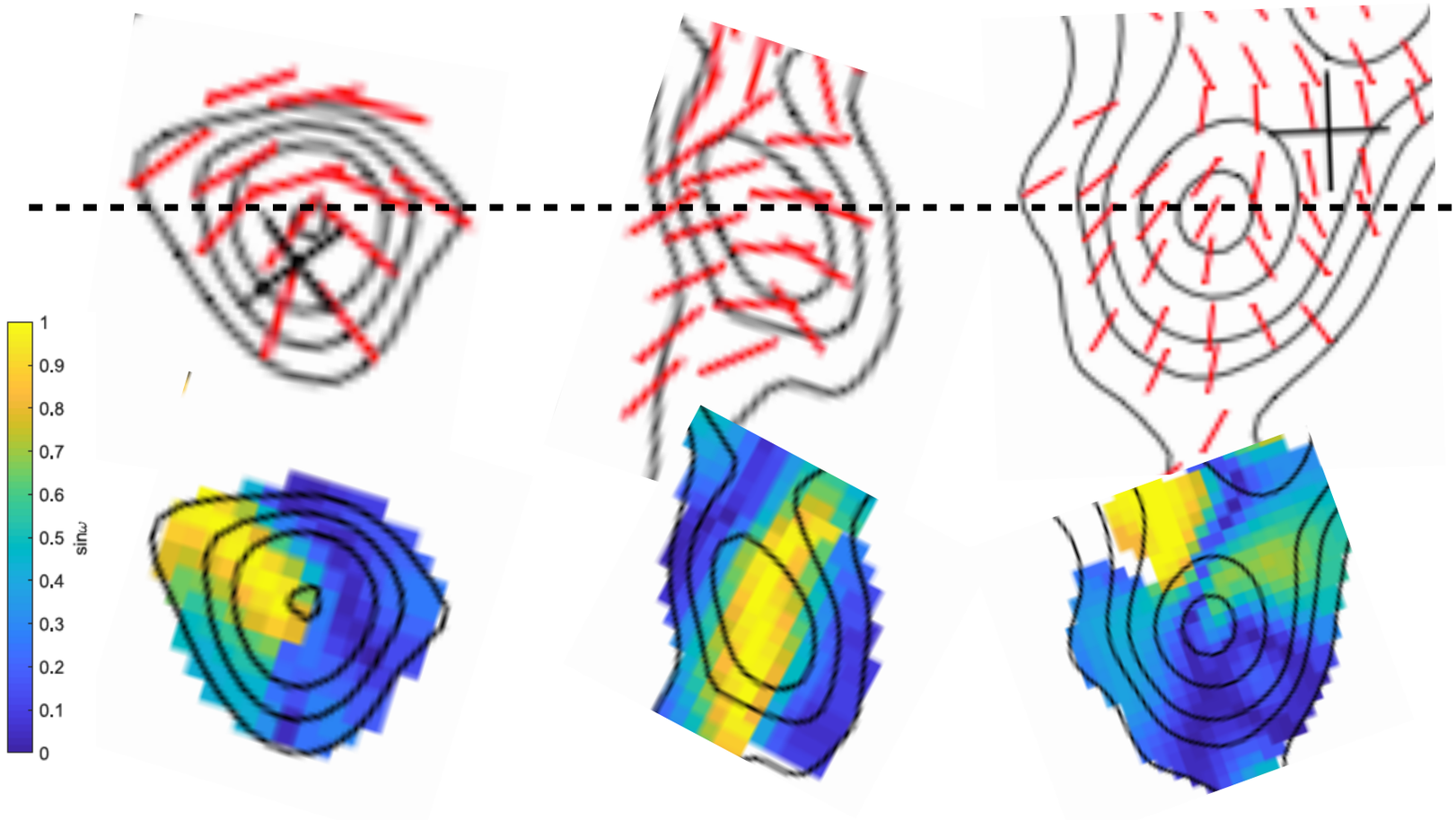
more on Local Collapse within Larger Global Collapse





(Koch+2018)





- compressed morphology
- straightened, opened field lines towards more massive neighbor

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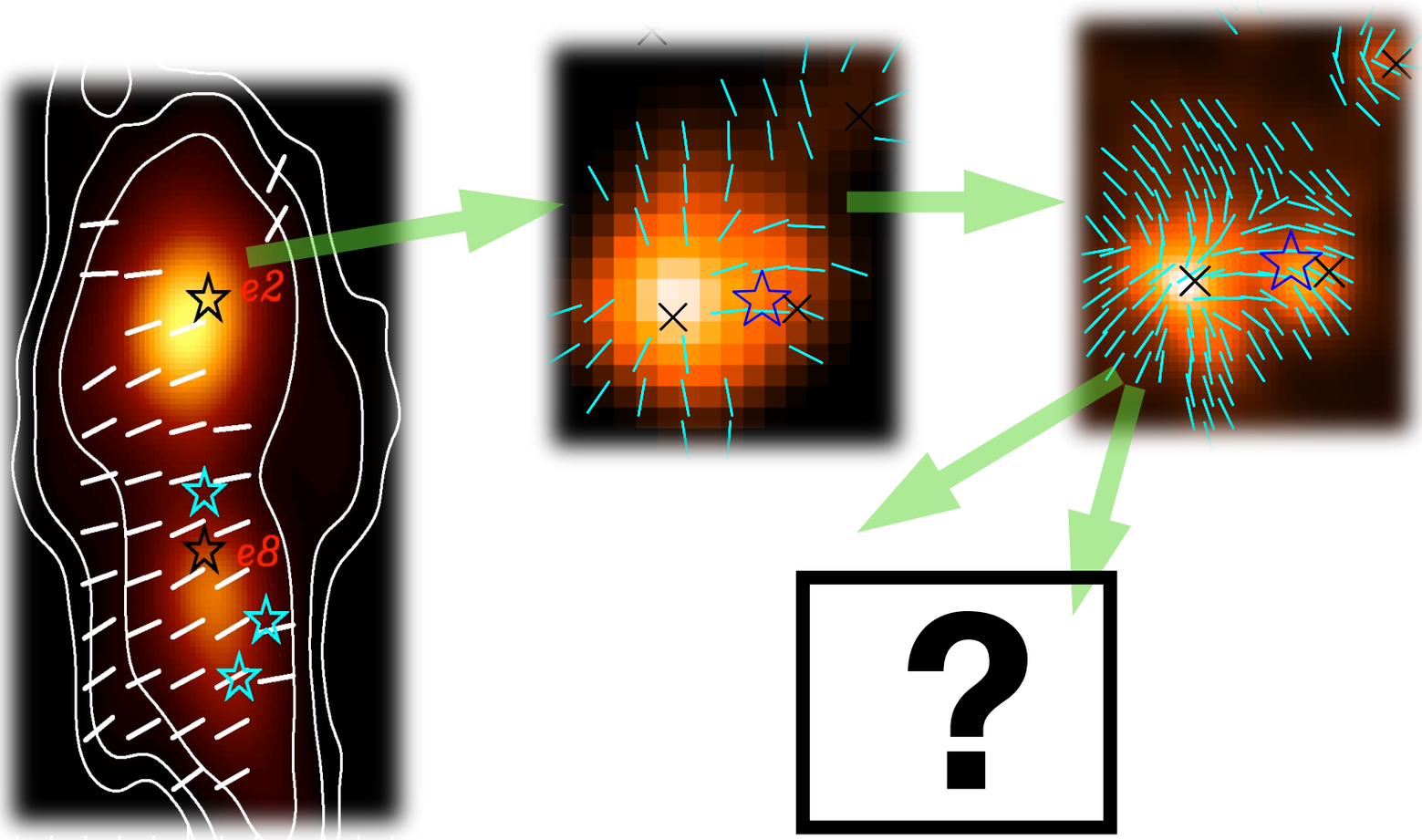
- gravitational bending
- dragged-in morphology

local collapse vs pull to next bigger grav. center: reflected in sinω

What is happening on even smaller scales ?



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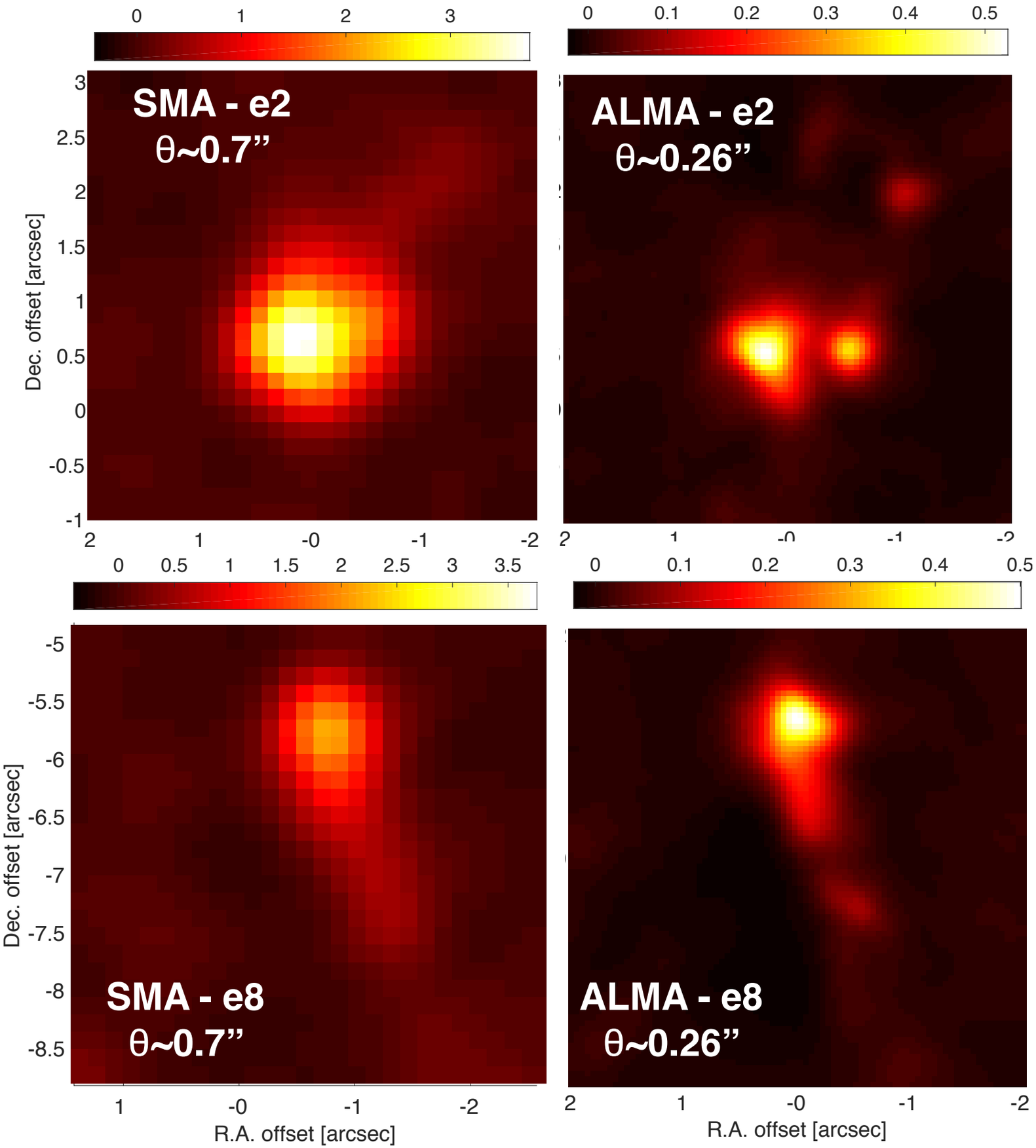

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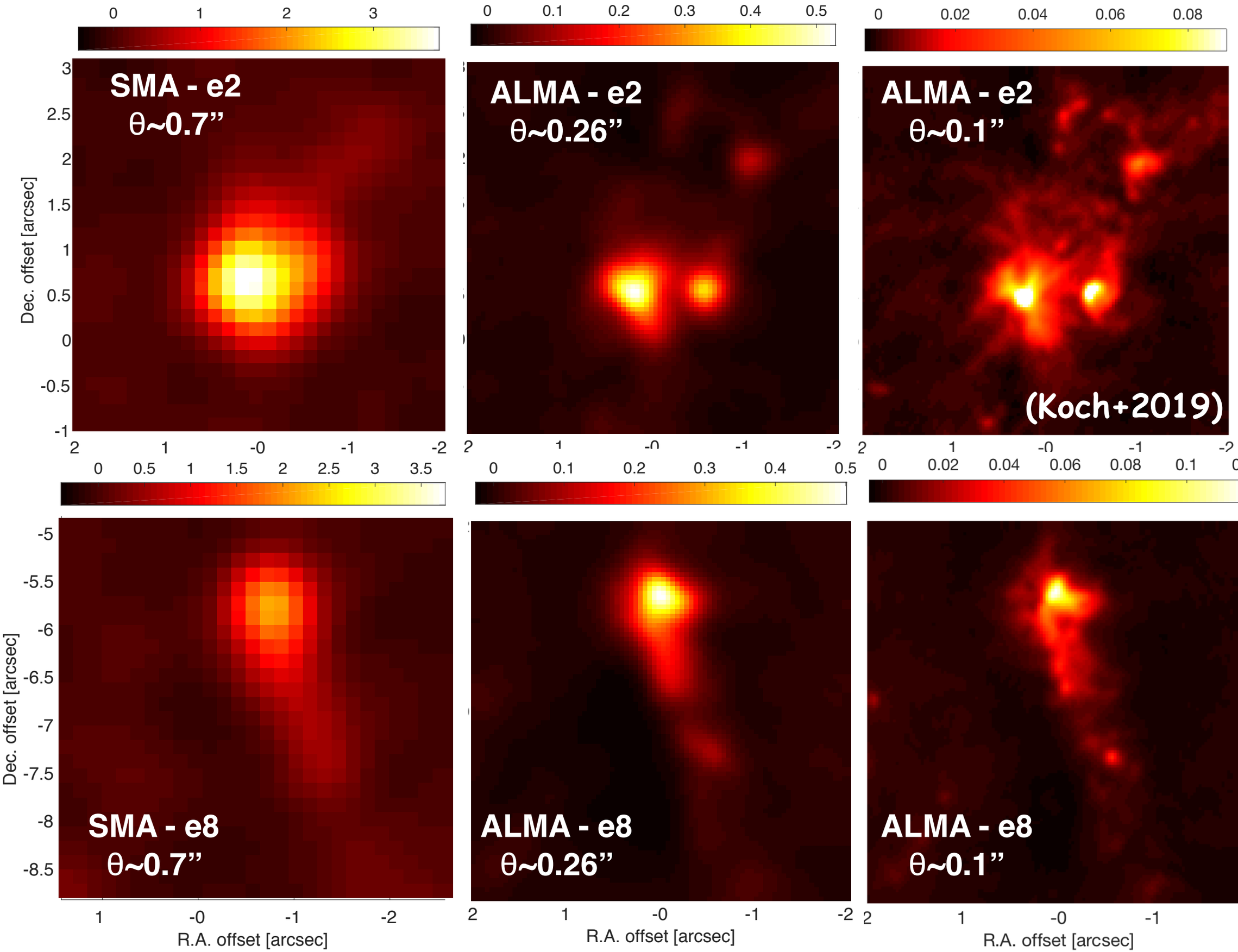
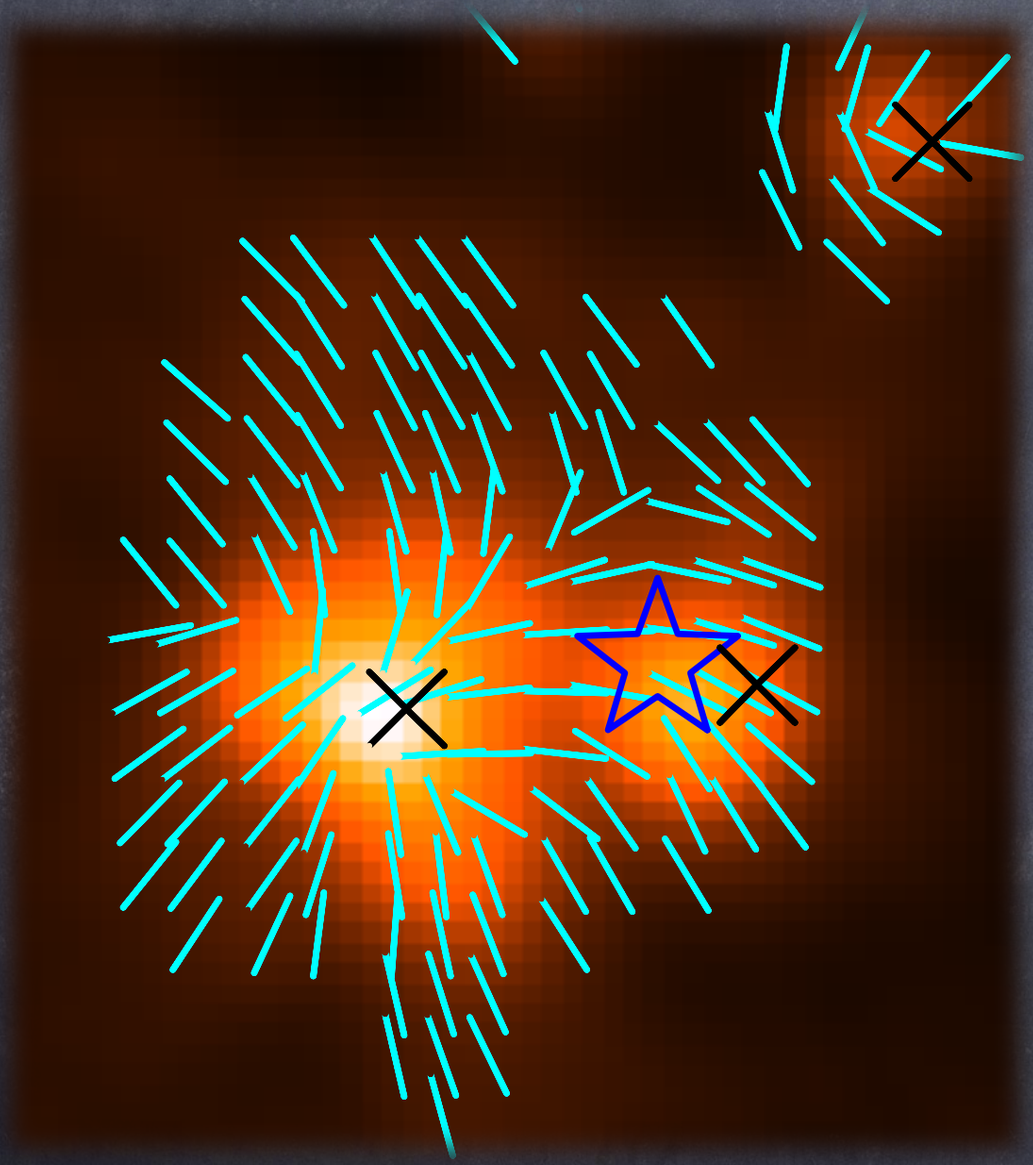


Magnetic Field in a Network of Accreting Fibers

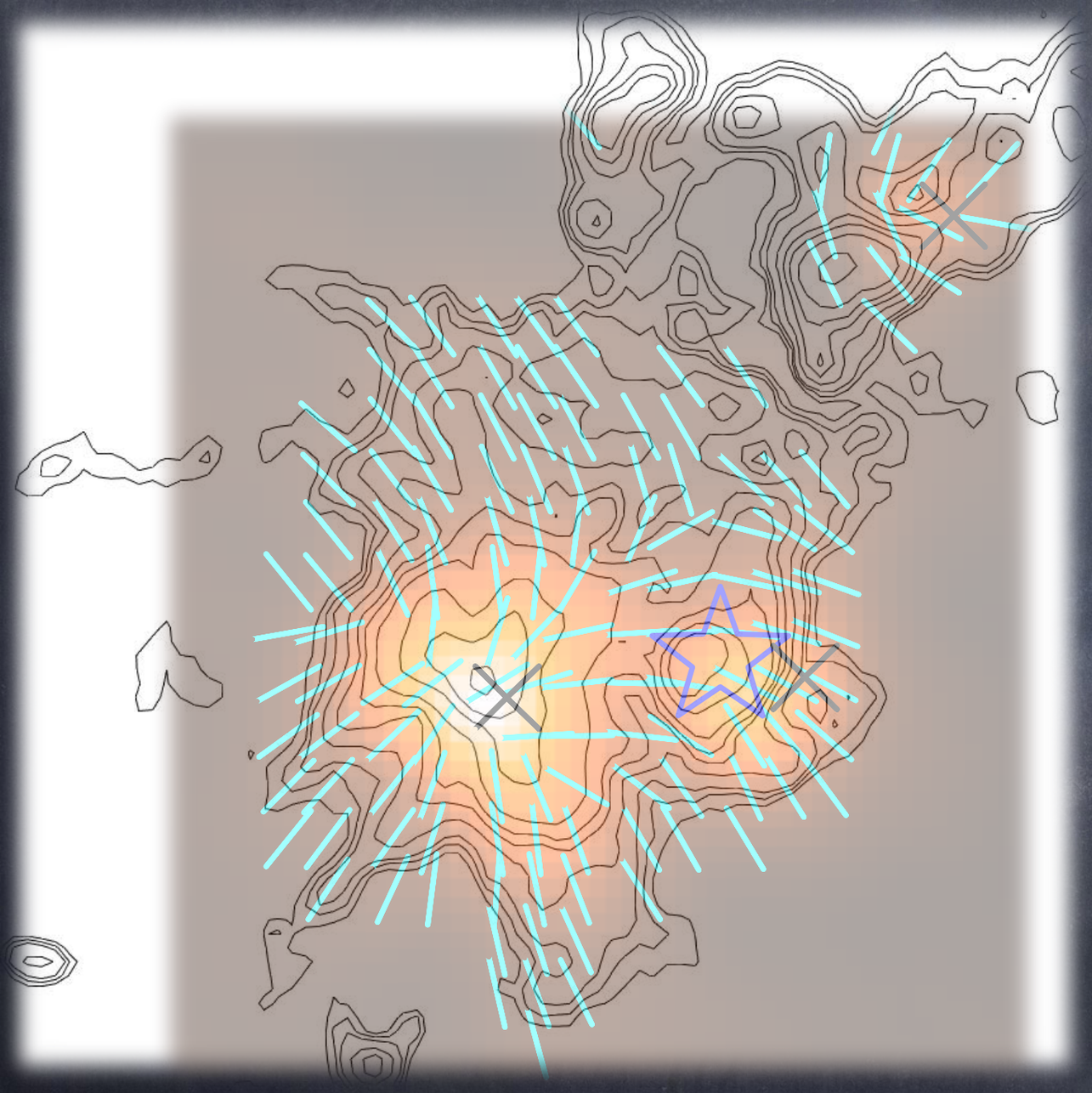
B-field (0.26”)



- *B-field mapping convergence zones*

Magnetic Field in a Network of Accreting Fibers

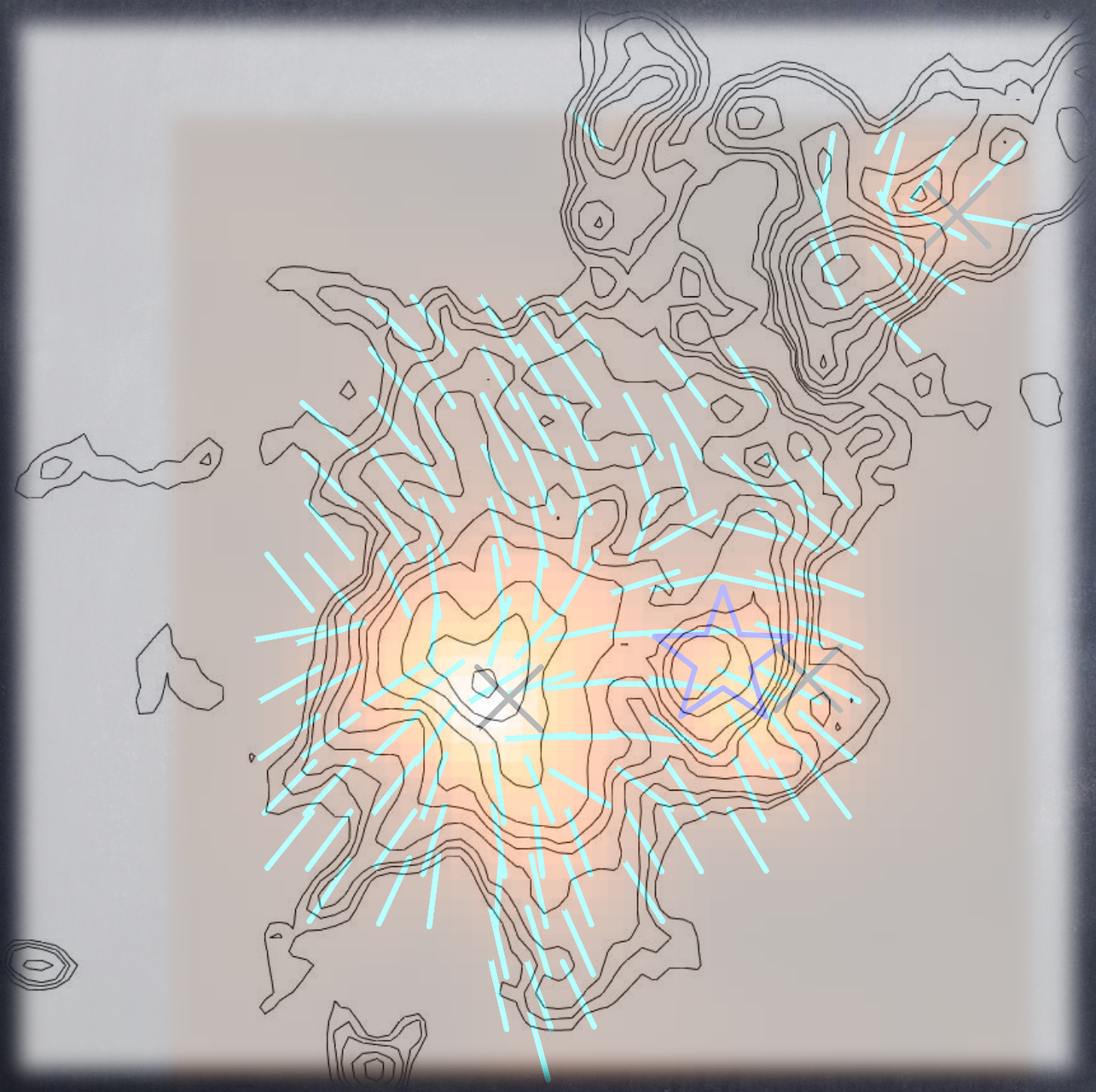
B-field (0.26”) + continuum (0.1”)



- ***B-field mapping convergence zones***
- ***accretion network in higher resolution continuum falling onto convergence zones***

Magnetic Field in a Network of Accreting Fibers

B-field (0.26”) + *continuum (0.1”)*



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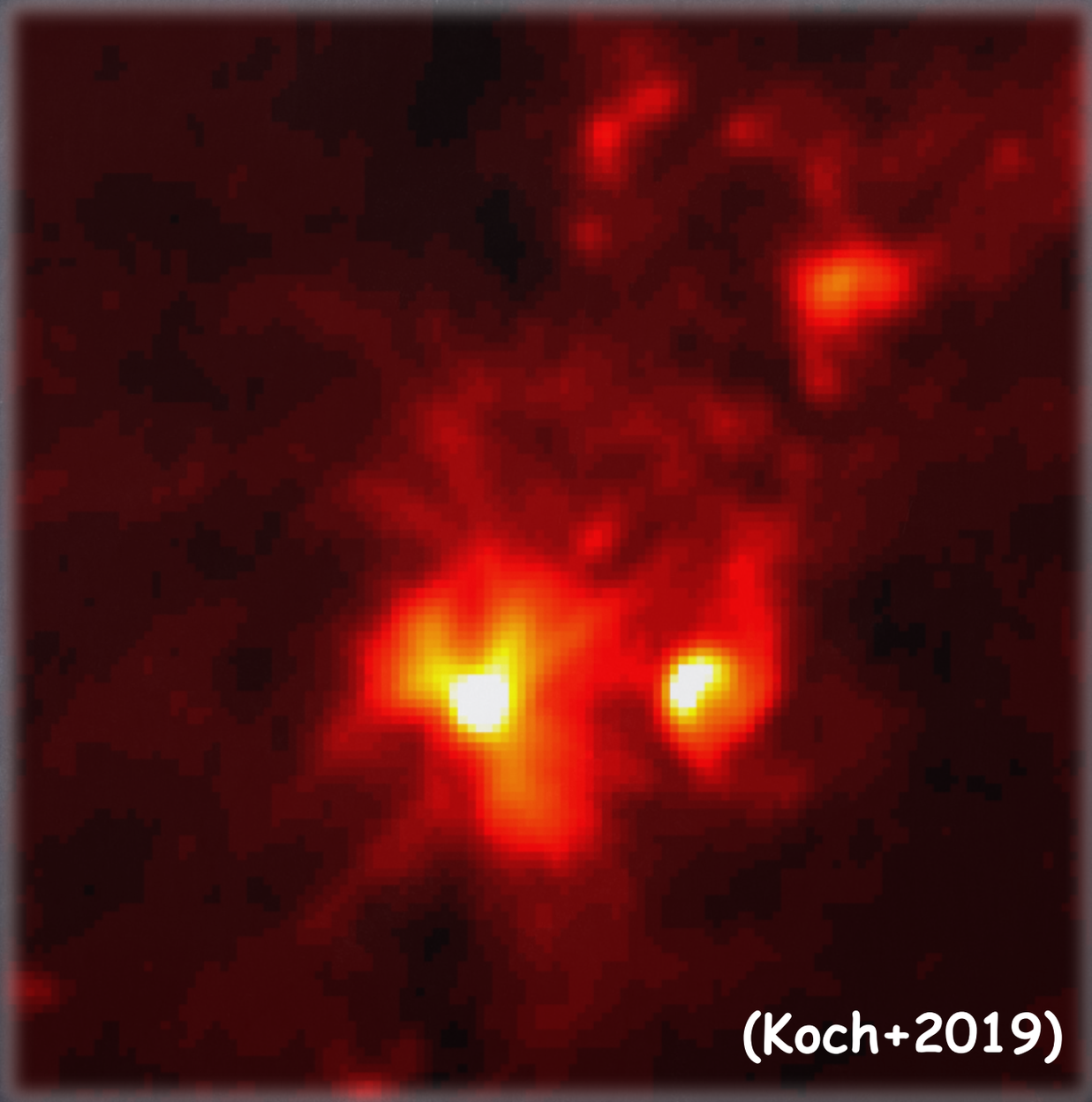
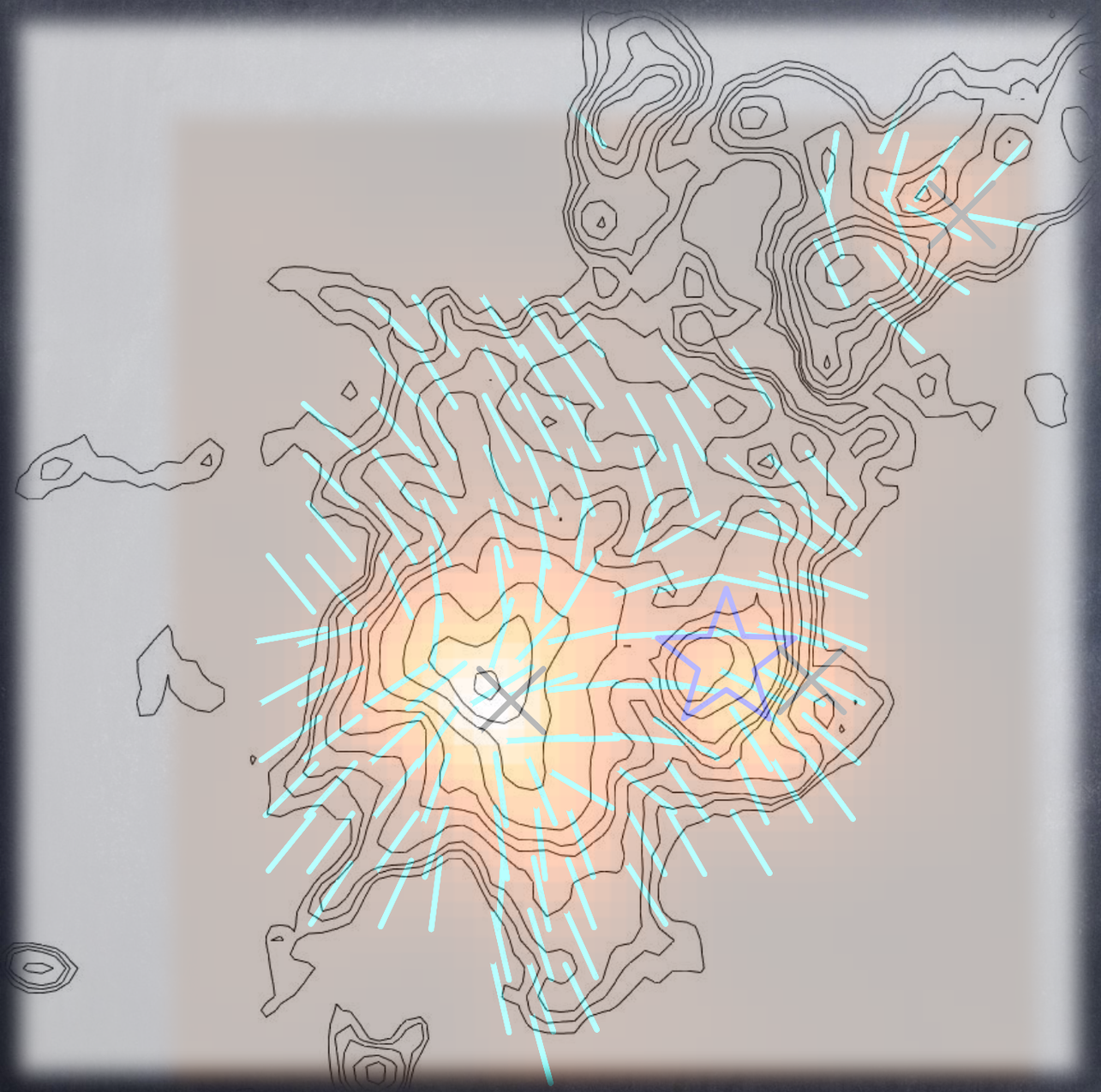
continuum (0.1”)



- *emerging network of accreting fibers*

Magnetic Field in a Network of Accreting Fibers

B-field (0.26”) + continuum (0.1”)



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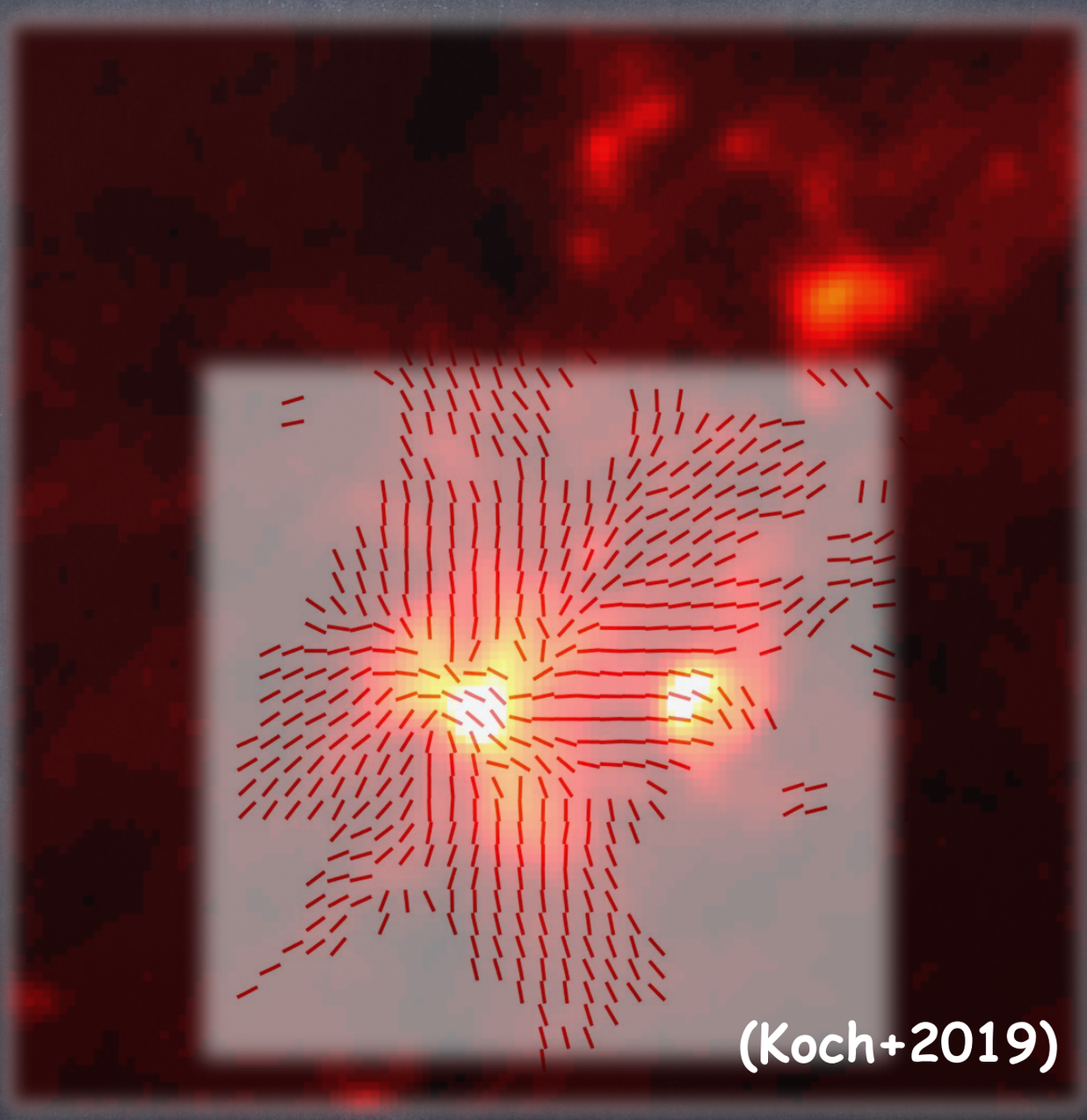
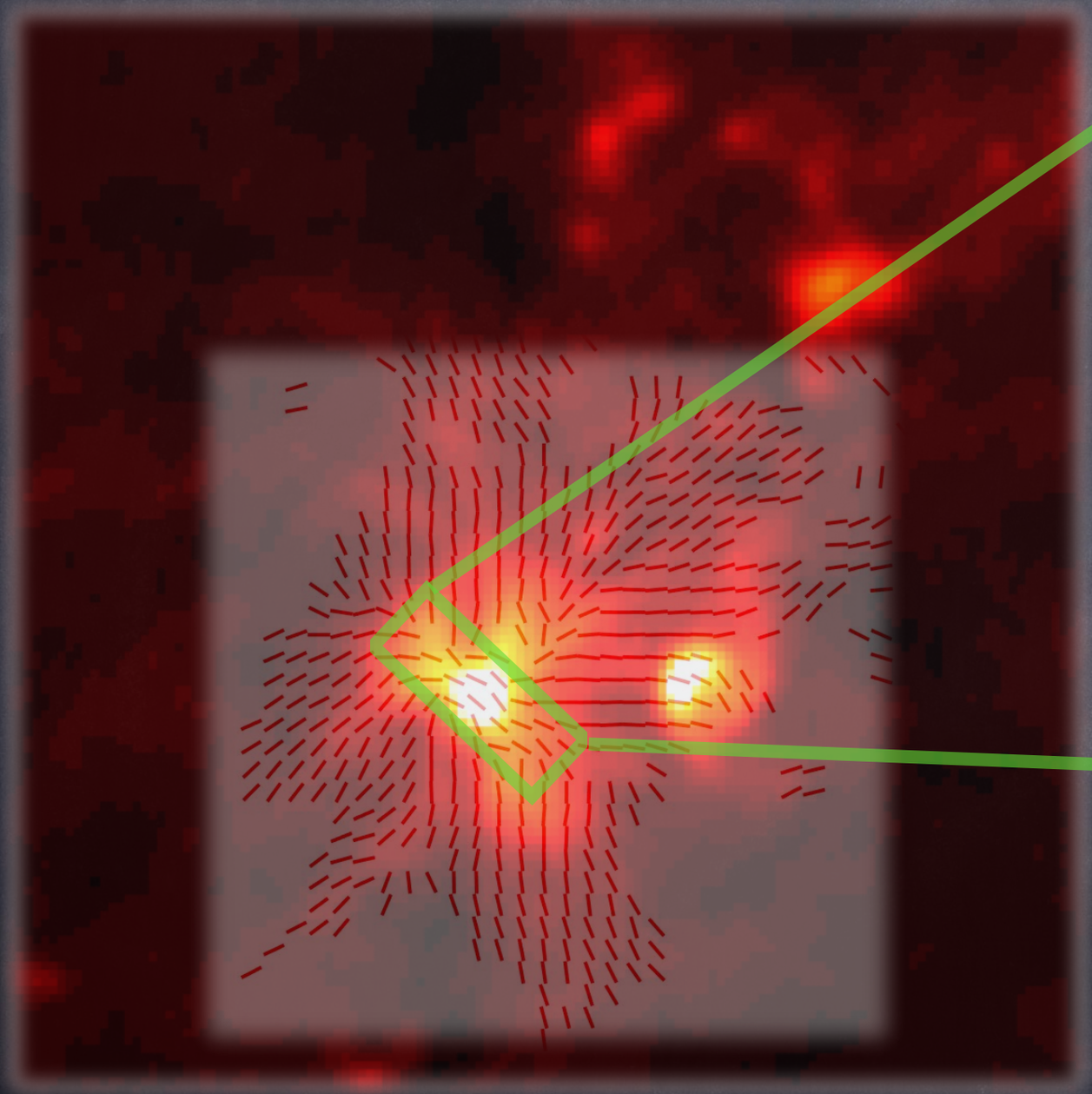
continuum (0.1”) + B-field (0.1”)

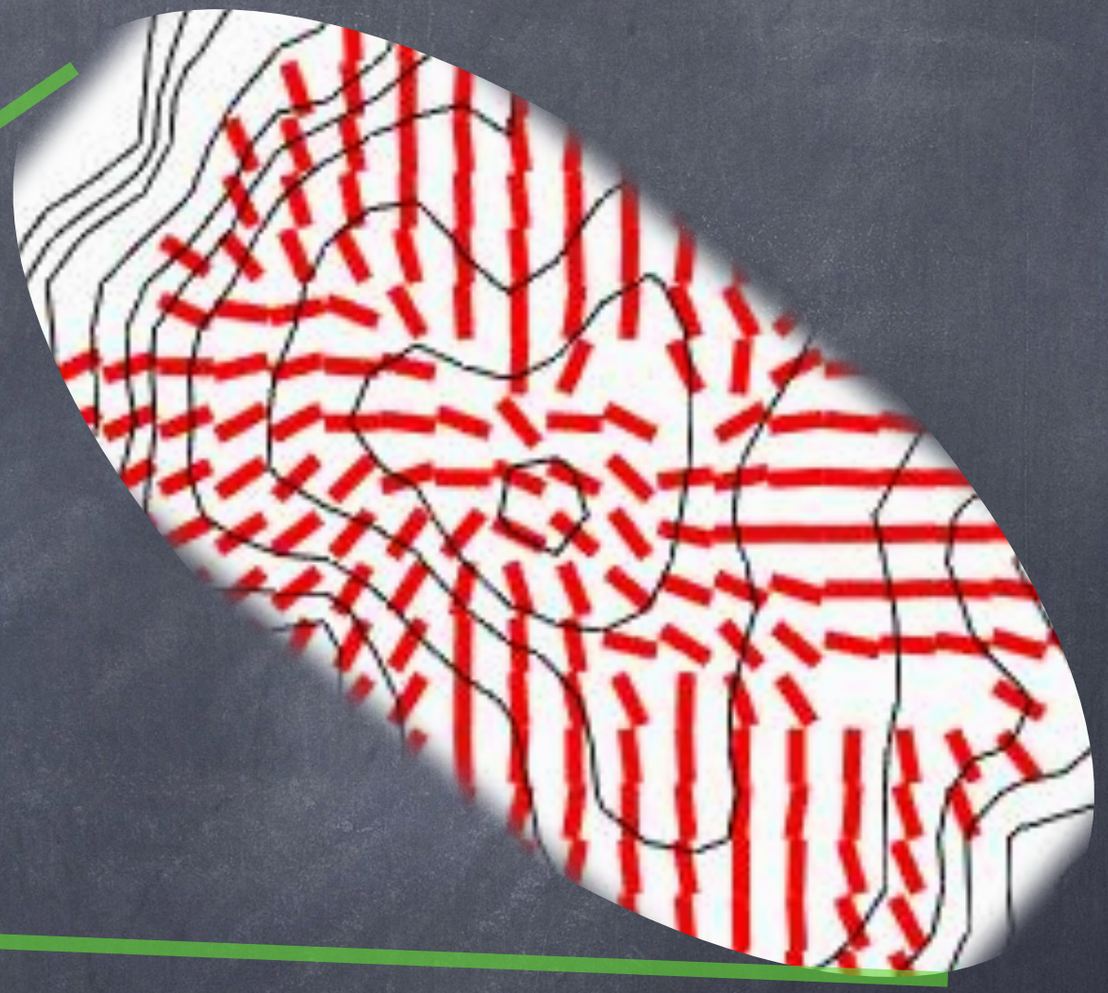


- *emerging network of accreting fibers*
- *B-field at higher resolution <u>aligned</u> with accreting fibers*

Center of e2:
an Emerging Magnetized Pseudo-Disk ?



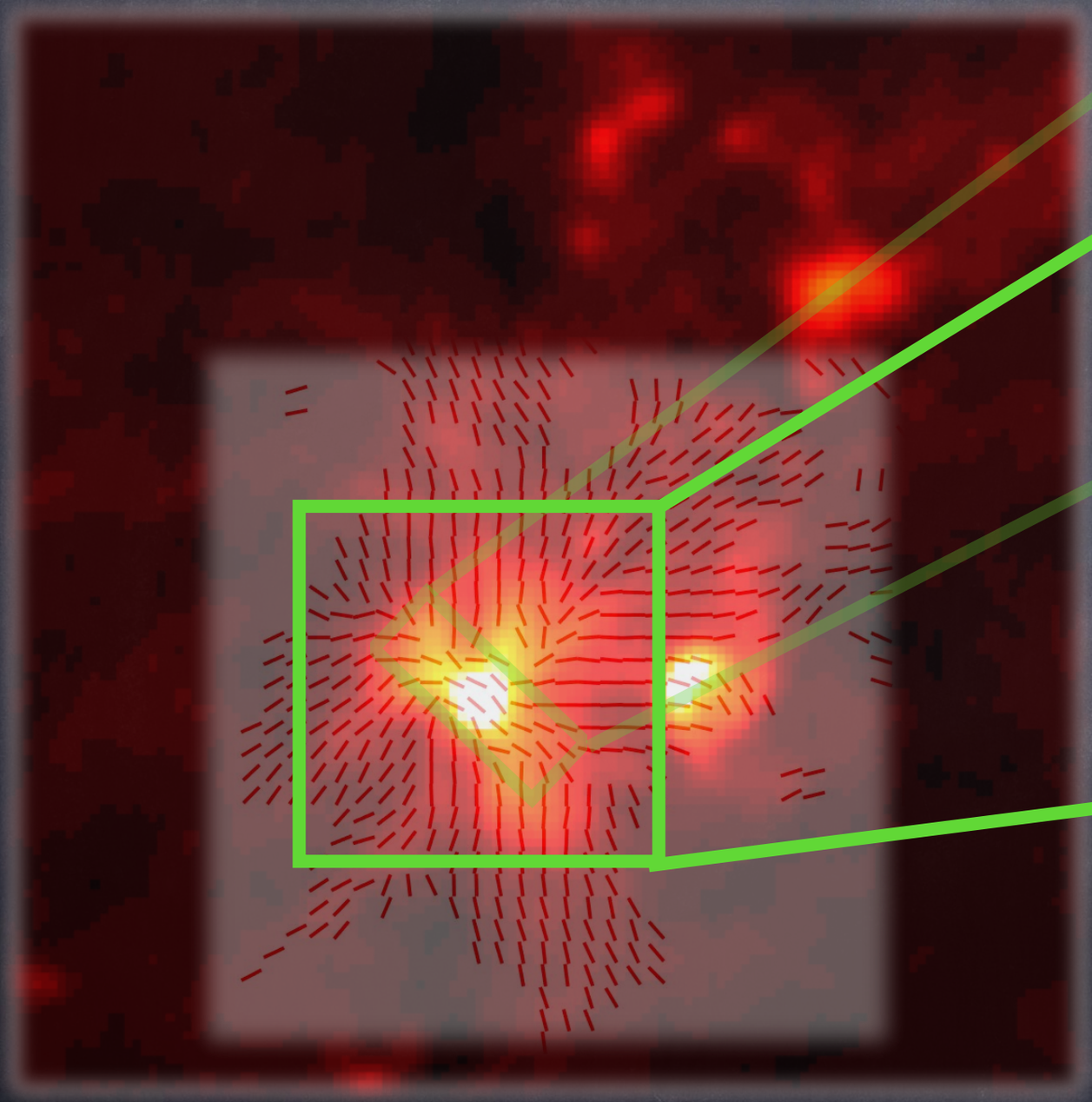
(Koch+2019)



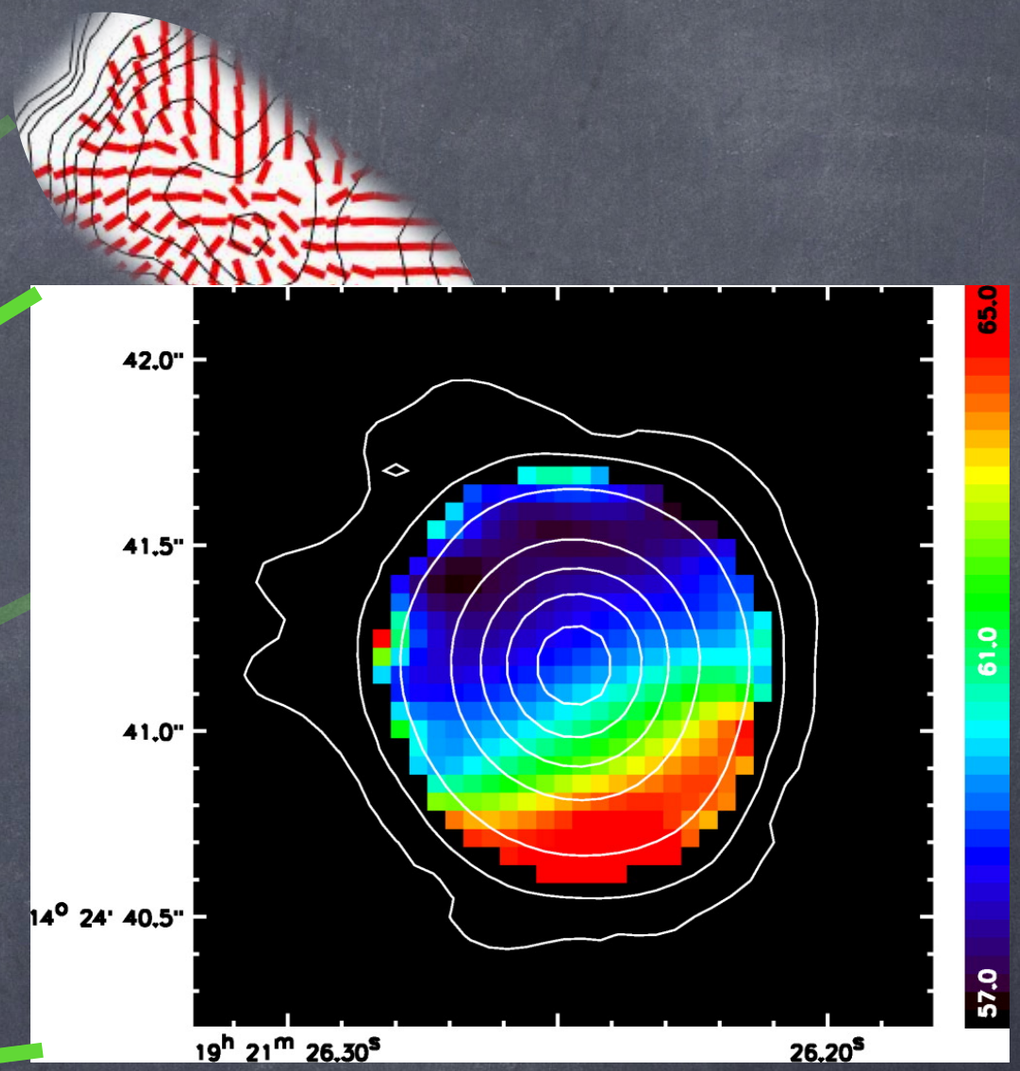
<u>2 striking features:</u>

- ***outer straight field lines, rotated by 90 degrees in adjacent quadrants***
- ***B-field "disk morphology" in center***

Center of e2:
an Emerging Magnetized Pseudo-Disk

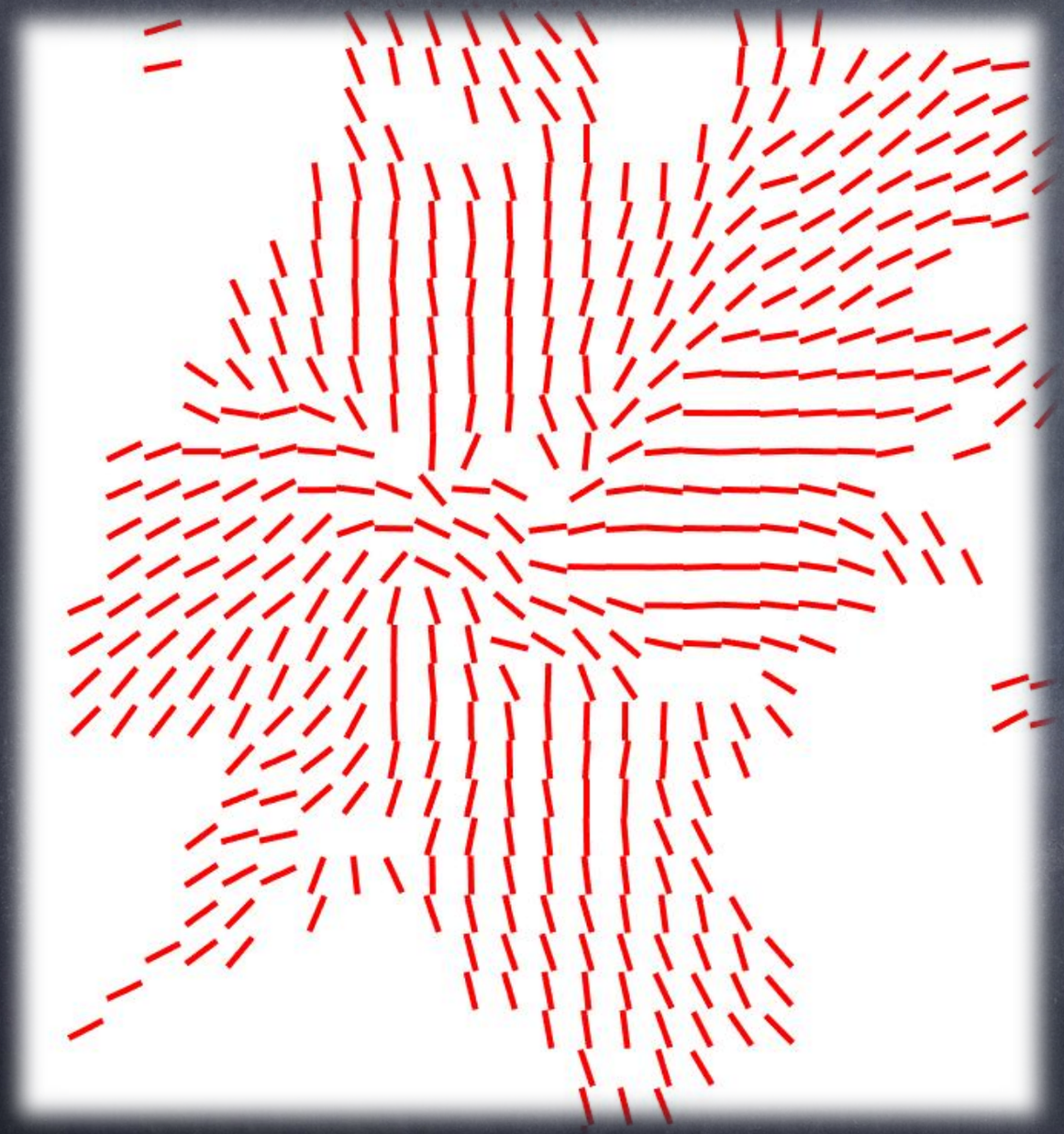


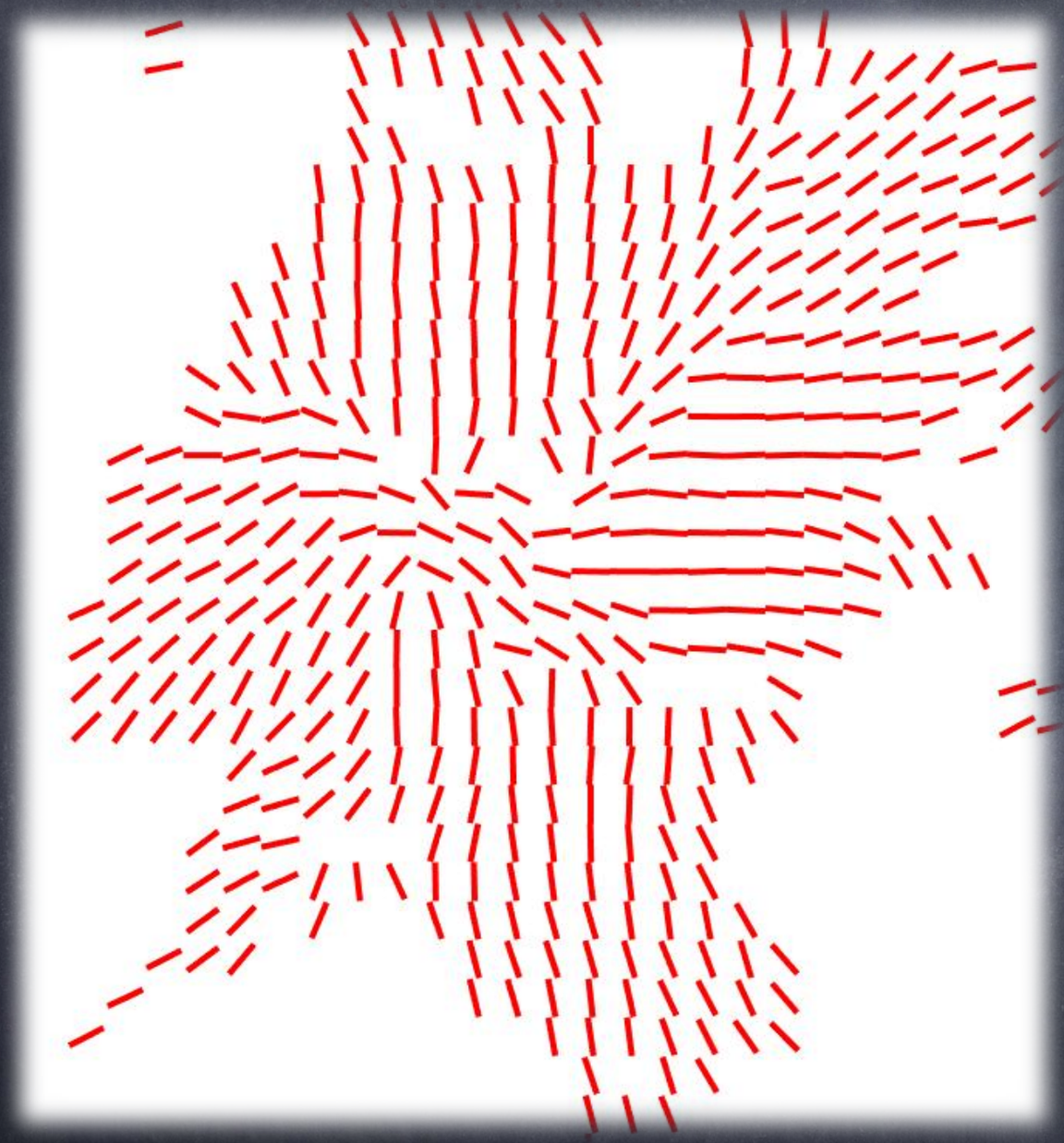
(Koch+2019)

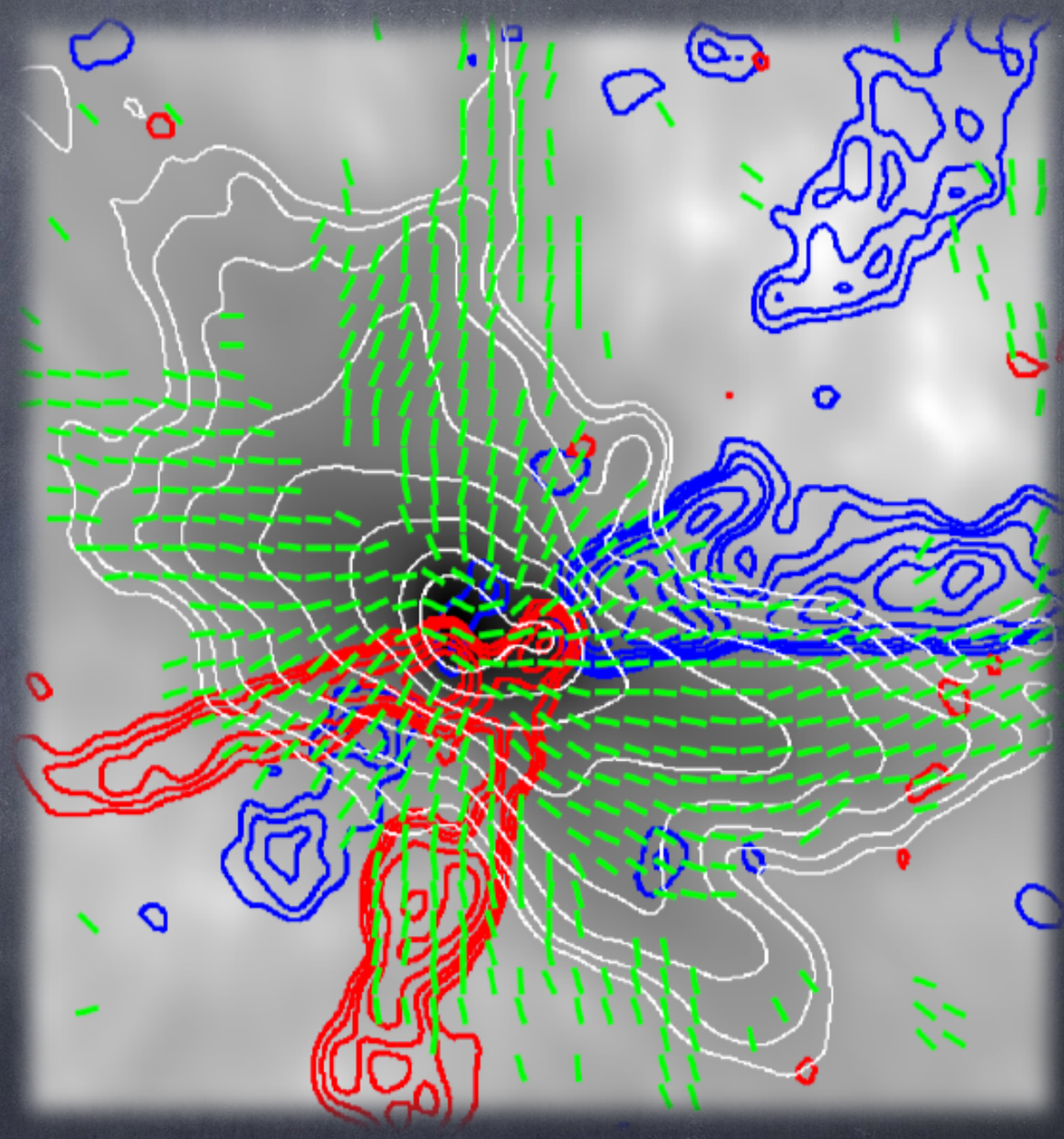


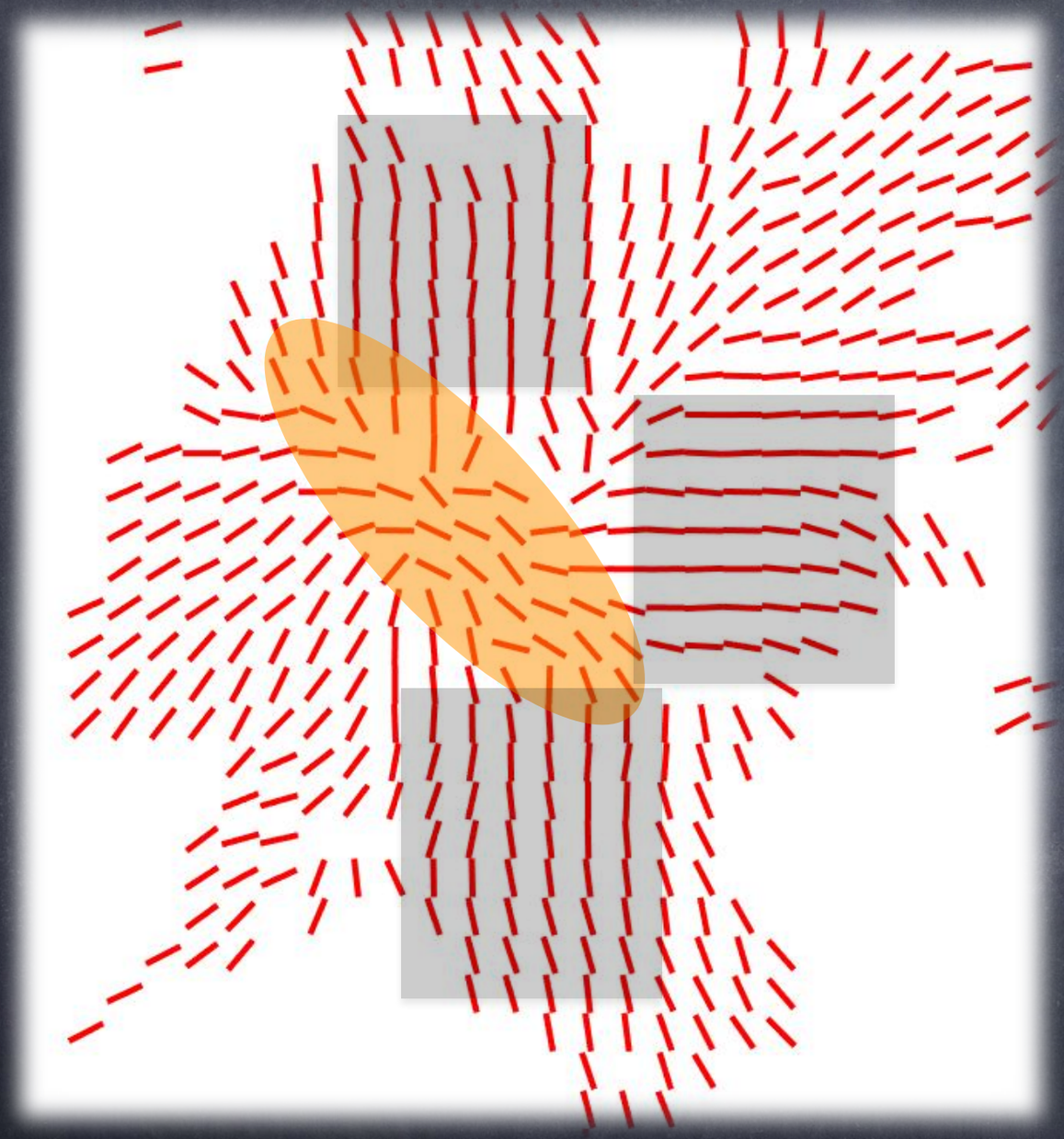
rotation in ionized accretion flow traced in H53α recombination line

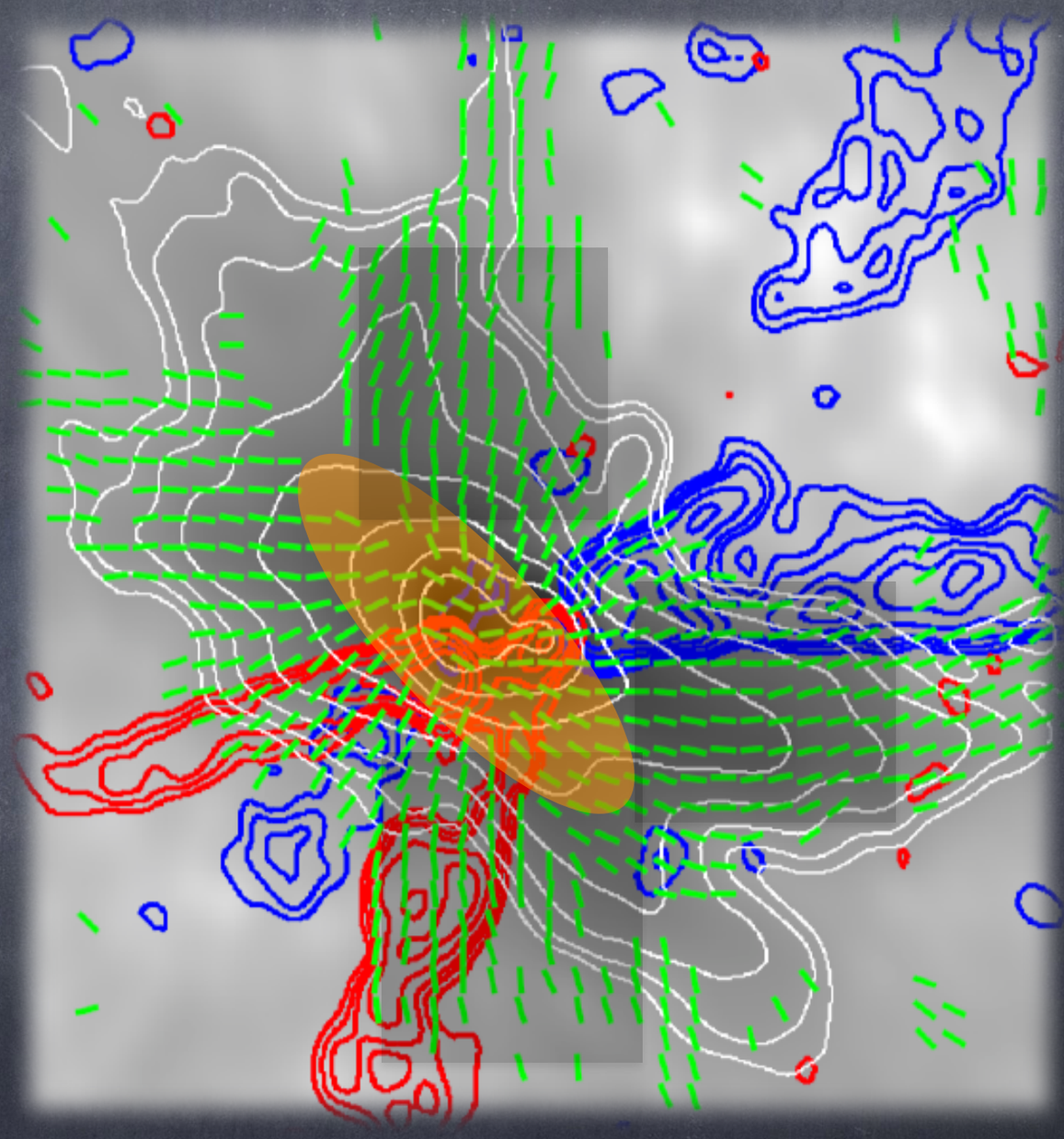
(Keto & Klaassen 2008)



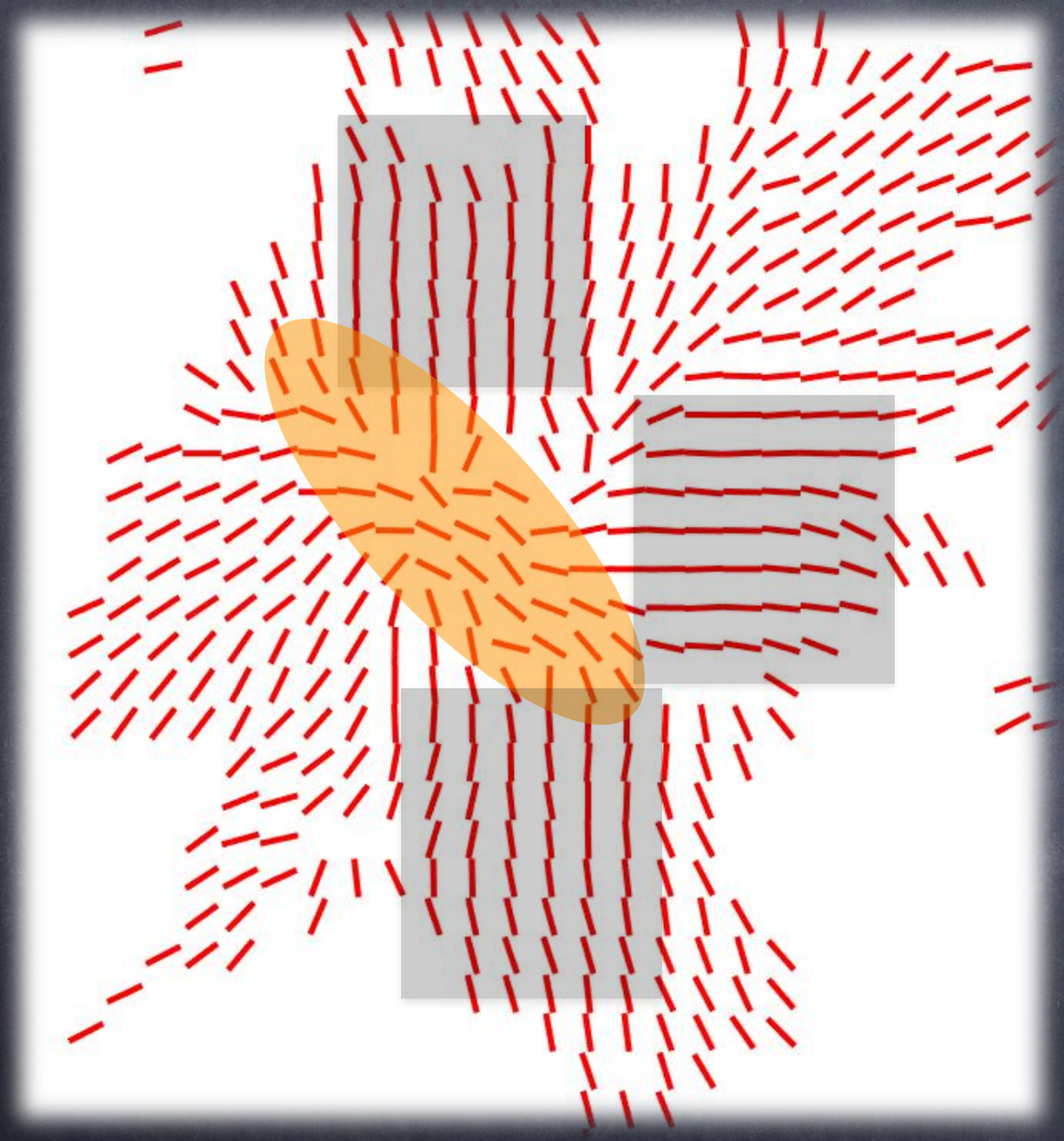








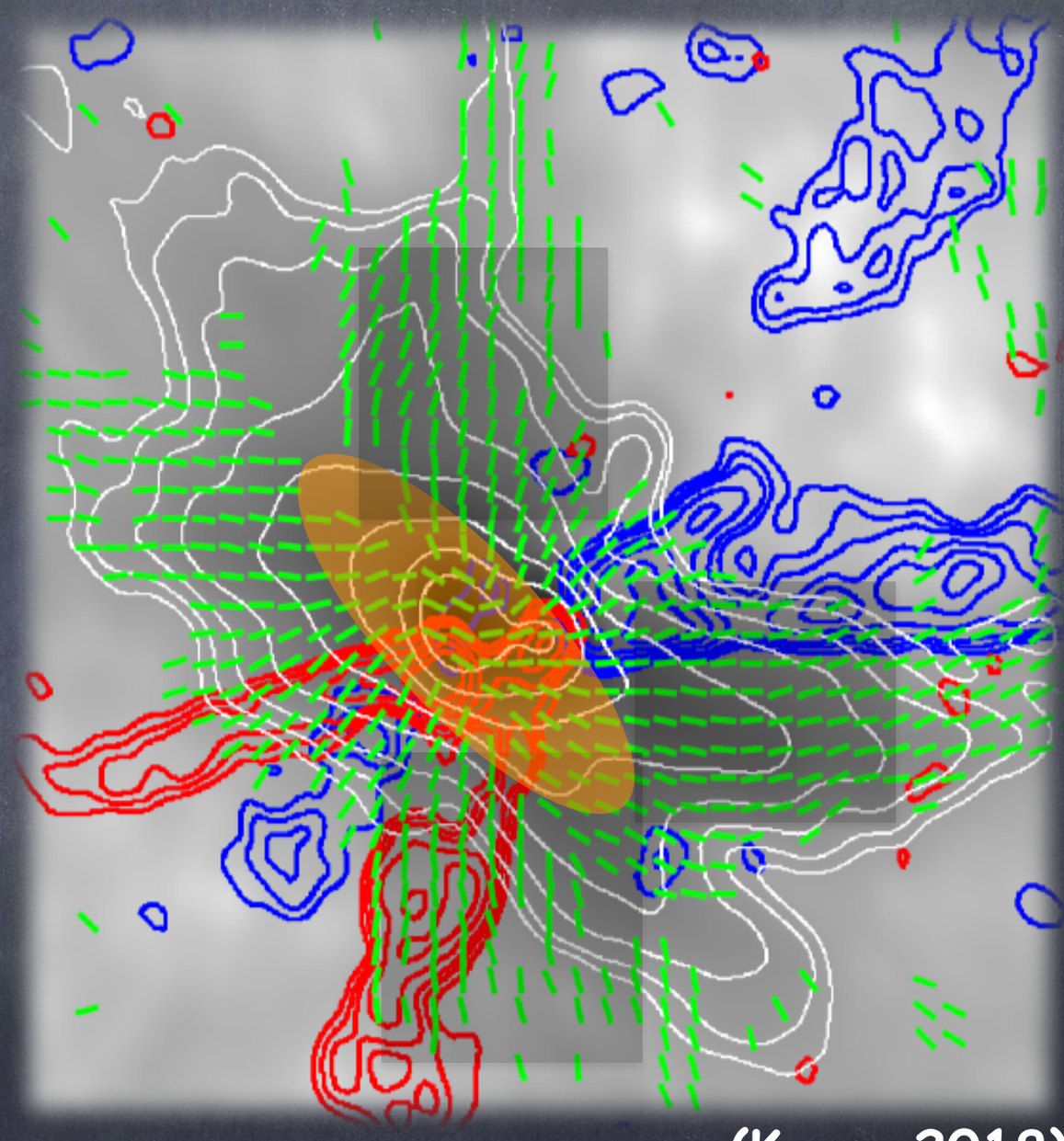
W51 e2 High-Mass



(Koch+2019)

10 mpc

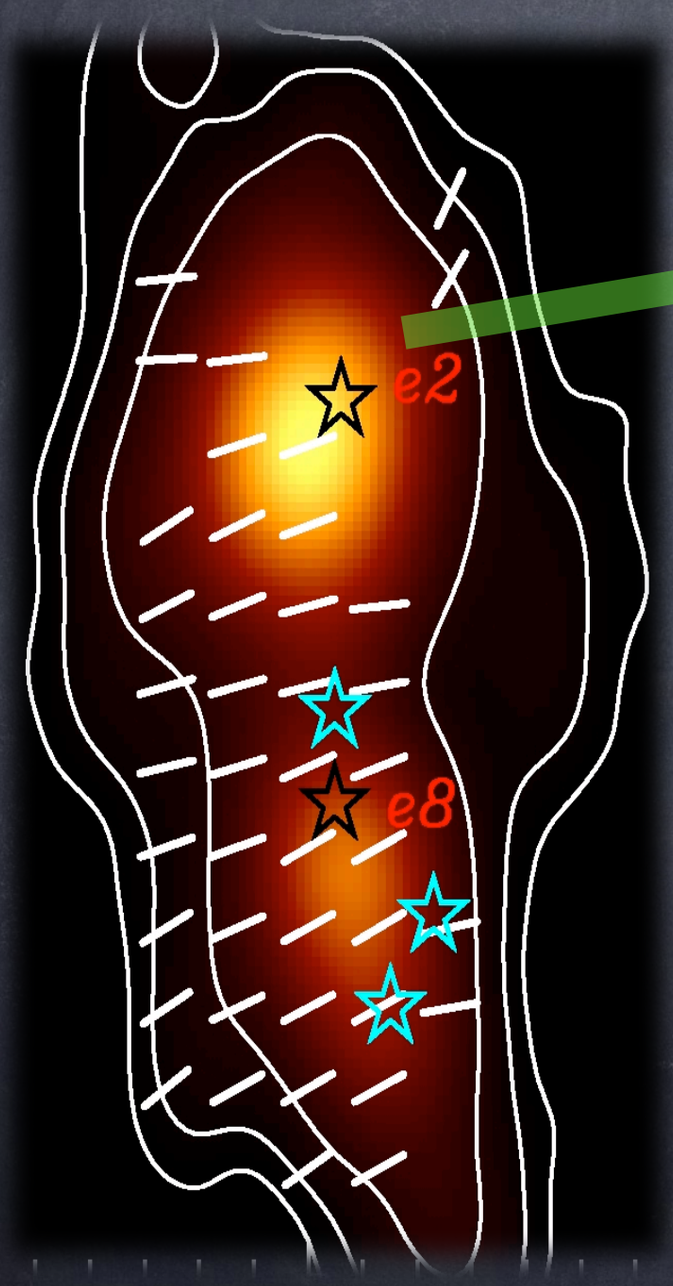
L1448 IRS2 Protostellar System

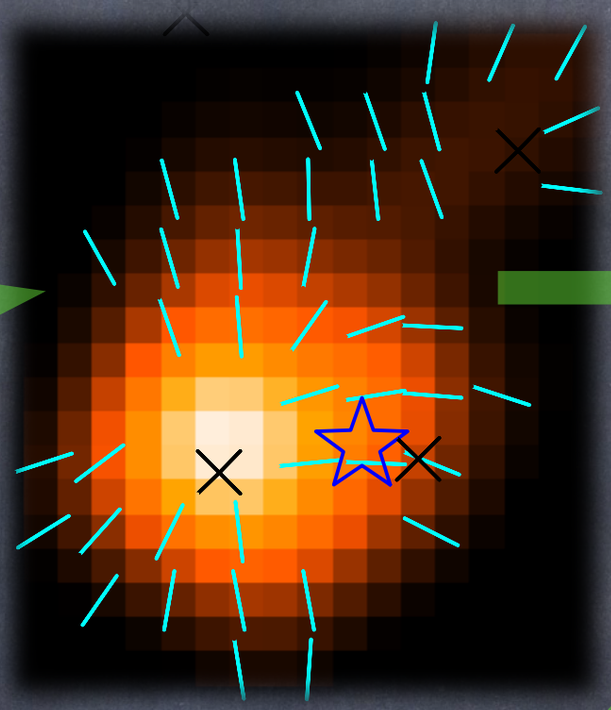


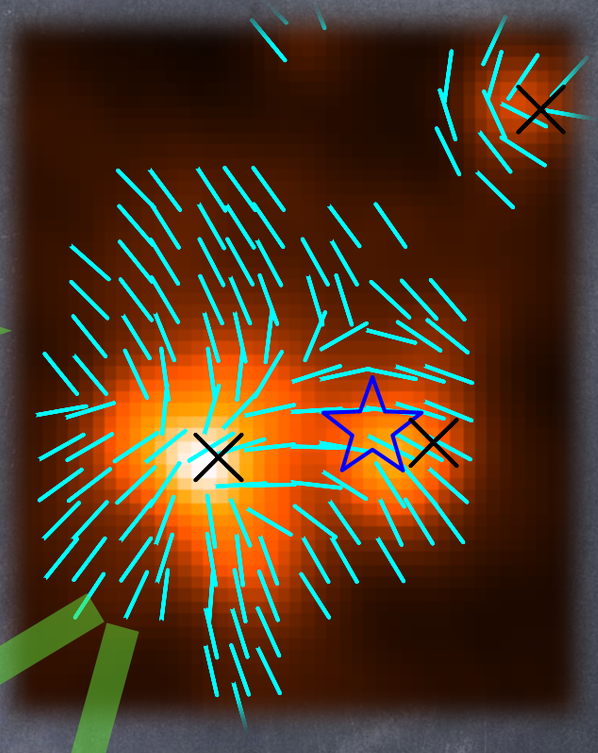
(Kwon+2018)

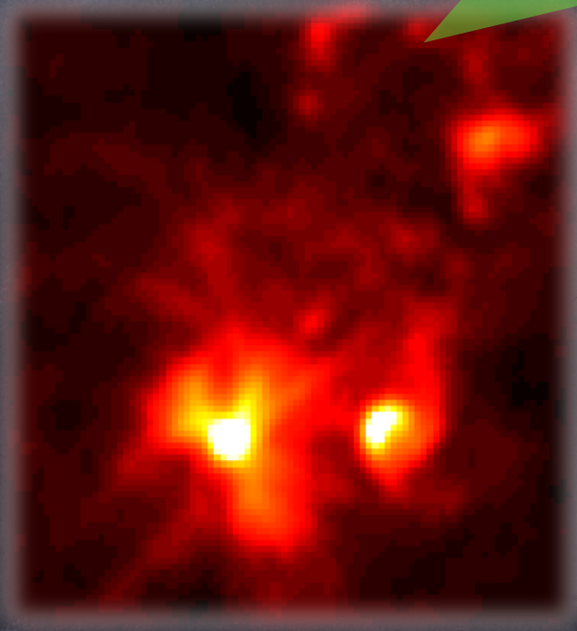
0.5 mpc

W51 e2
from pc-scale envelope to 1000 AU-scale pseudo-disk









Conclusions

- *role of the magnetic field is variable: over scale AND in location; i.e., assessing based on small, limited area (detection) is incomplete*

- *role of the magnetic field is variable, hence analysis tools need to be adjusted, optimized and developed accordingly*

- *3 specific, clearly different, physically relevant scales in W51: envelope to core — global collapsing core — local collapse and convergence*

- *ALMA 0.1” scale (physical resolution: a few mpc) in W51: straightened field structures, rapid change on most inner few mpc, magnetized pseudo-disk structure (self-) similar to smaller protostellar system, B-field aligned with fibres providing stability against radial collapse*