Atomic Alignment: New probe for Magnetic fields in diffuse medium

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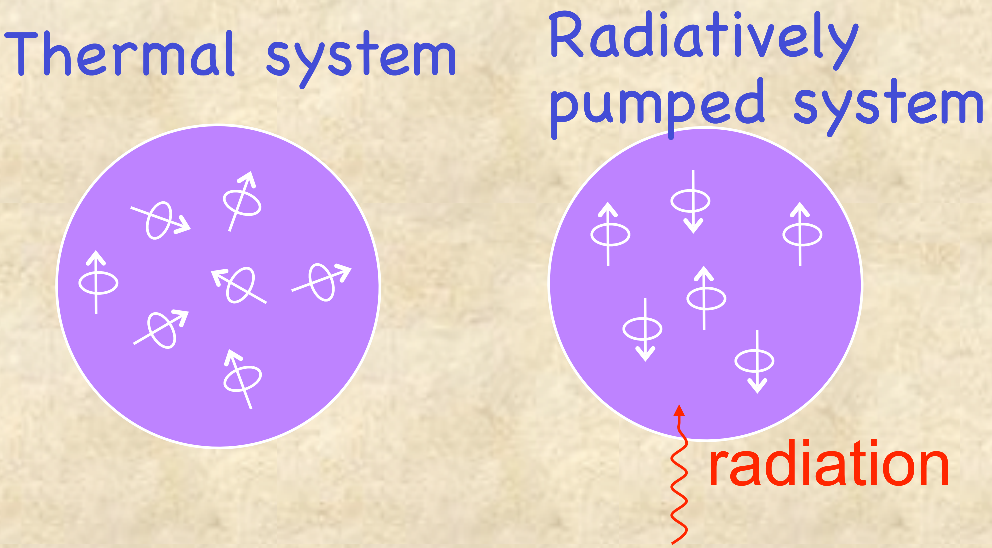
Atoms on the ground state can be aligned by anisotropic radiation

Classical Analogy



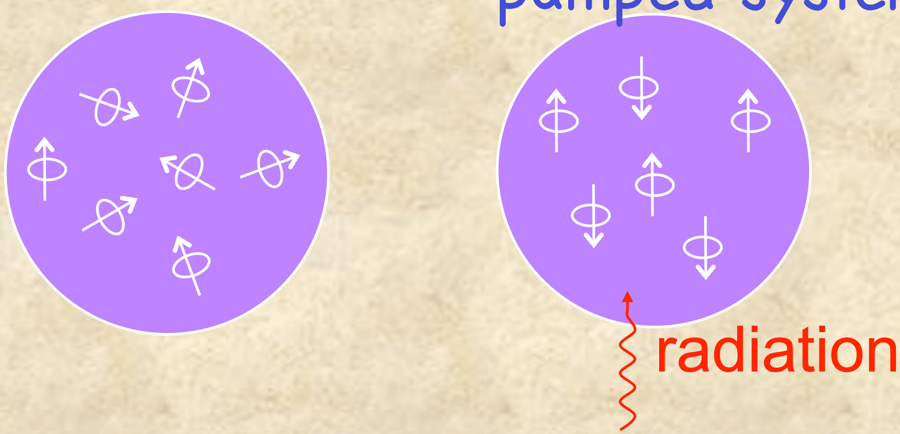
Atomic alignment is differential occupation of the sublevels of **the ground (or metastable) state**.

Atoms on the ground state can be aligned by anisotropic radiation

Classical Analogy

Thermal system

Radiatively pumped system



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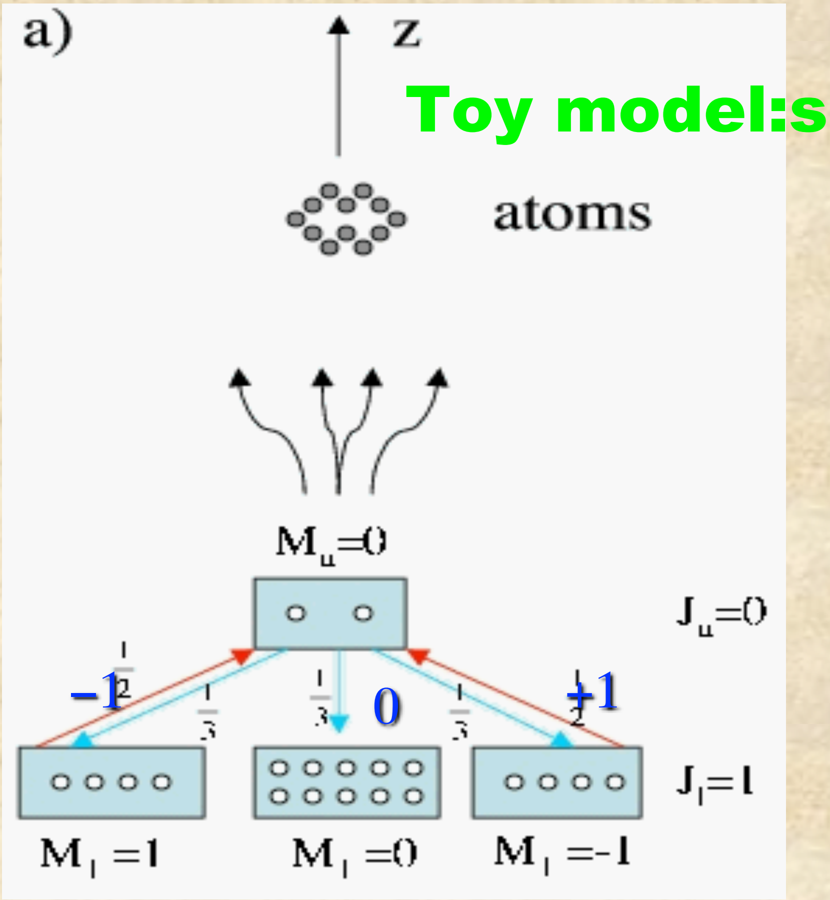
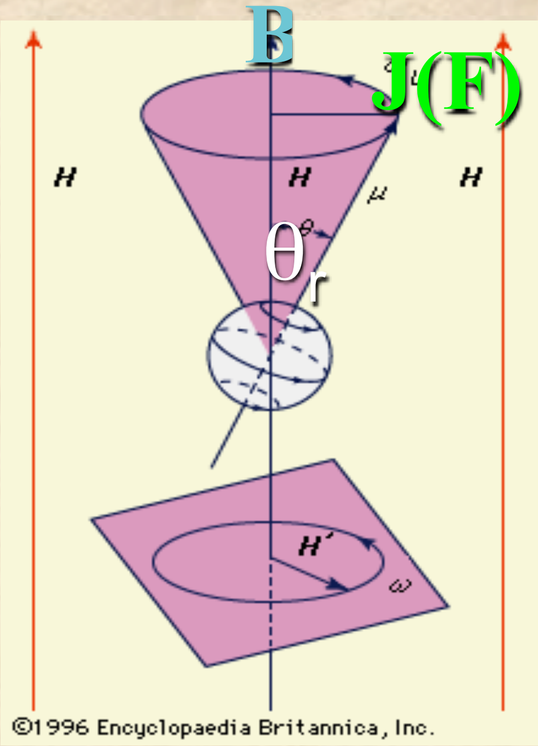
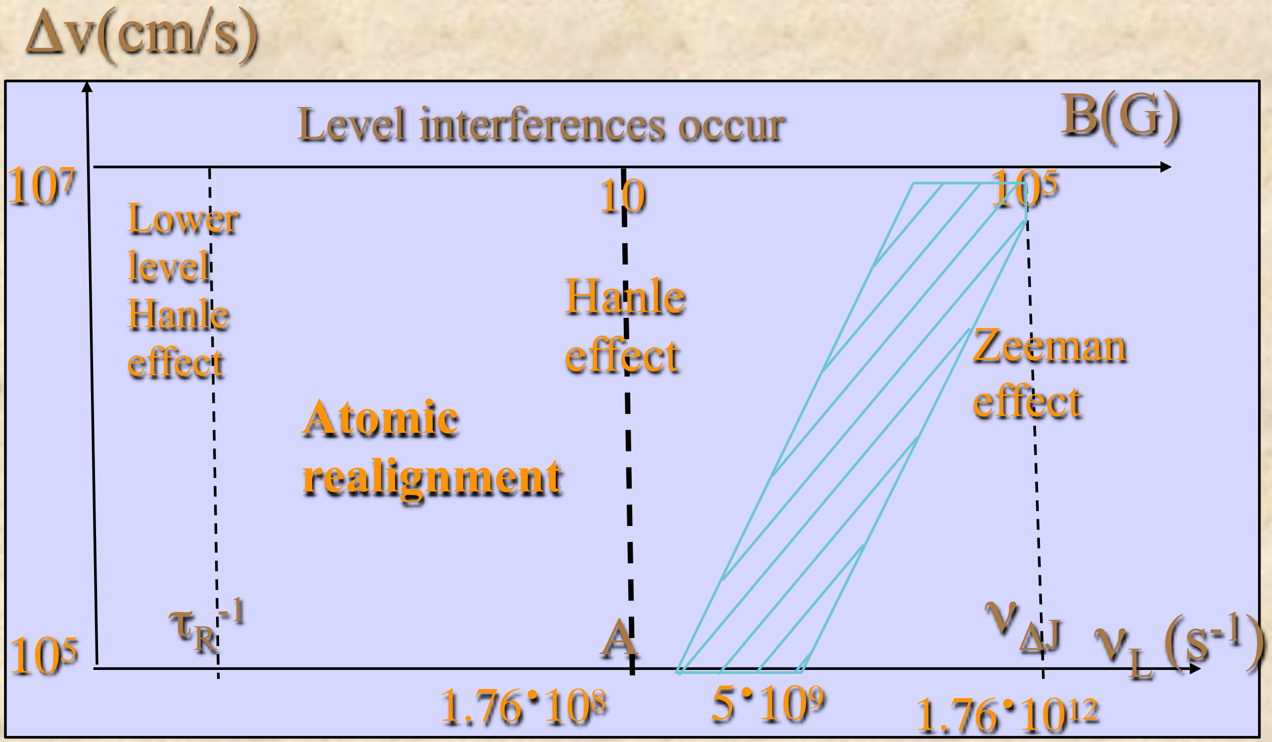


Induced ±1 transition followed by isotropic emission.

Atomic alignment is sensitive to weak magnetic fields



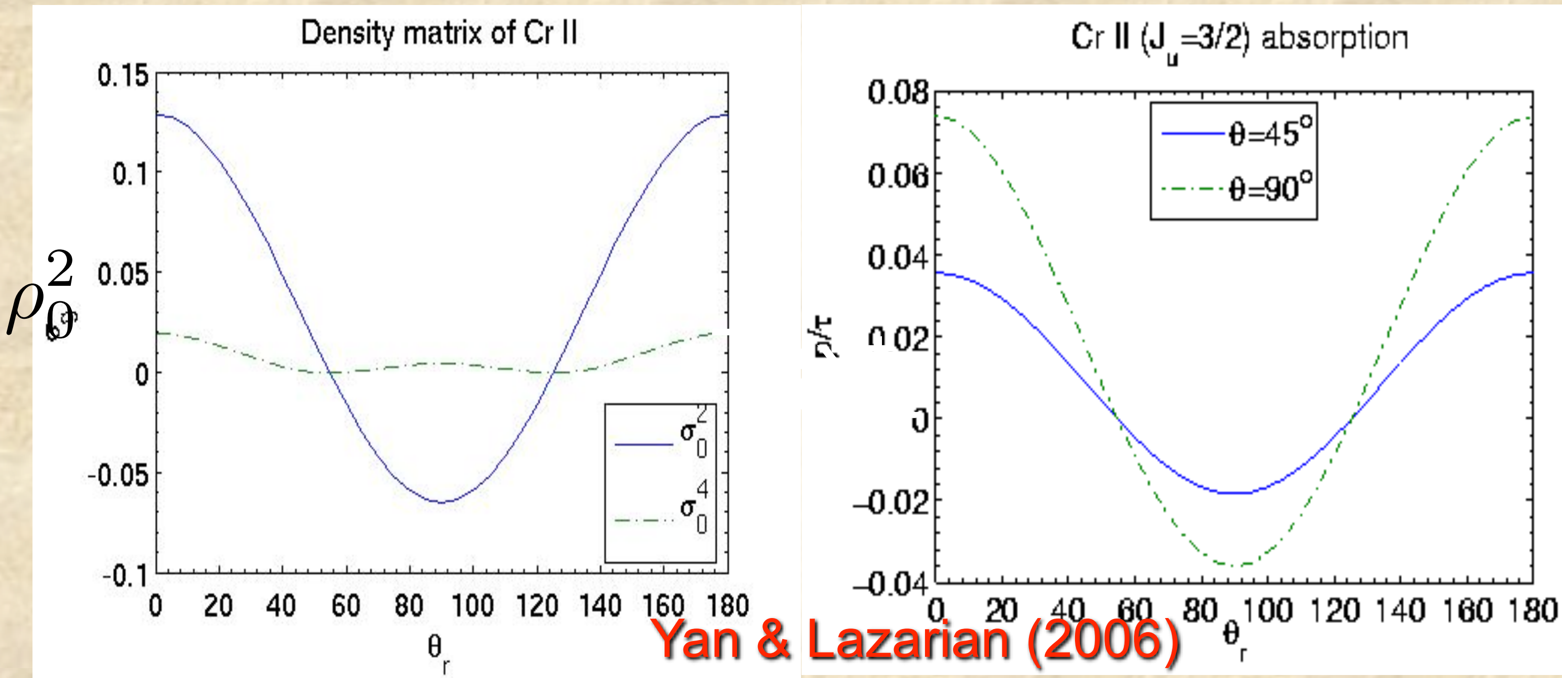


ν_L–Larmor frequency

A-Einstein coefficient, $\nu_{\Delta J}$– $E_{\Delta J}$ /h

For weak field (~nG, 1G), atomic alignment happens.

Polarization of absorption is either || or ⊥ to the magnetic field



Yan & Lazarian (2006)

$\rho^2_0 = (\rho_1 + \rho_{-1} - 2\rho_0)/6^{1/2}$ (for J or F=1)

Polarization changes direction at Van Vleck angle between pumping radiation and magnetic field $\theta_r = 54.7^o, 180^o - 54.7^o$.

Our results: many observed absorption lines have appreciable polarization

Calculated Examples:

Ion	C I	C II	Si I	Si II	O I	S I
Wavl (A)	1329-1561	1336	1695-2529	1265	1302	1807
P_{max}	18%	15%	20%	7%	29%	22%
Ion	S II	Ti II	Cr I	Cr II	NI	S III
Wavl (A)	1250	3385	4254-4290	2741-2767	1200	1012-1202
P_{max}	12%	7%	5%	21%	5.5%	24.5%

Many more lines:

Fe I, Fe II, Fe III, Fe III, Mn II, Ti III, C II, N II, …

Our results: polarization of emission lines from aligned atoms

Calculated Examples:

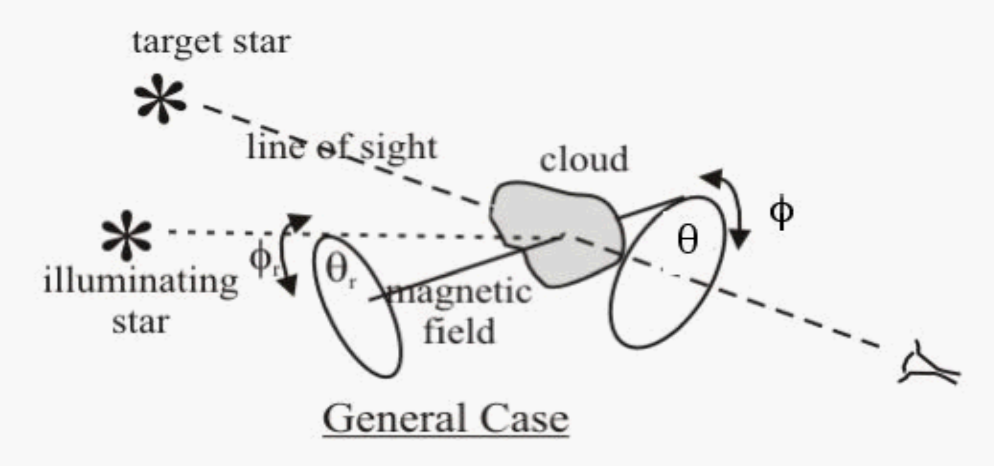
ion	HI (Bal)	Na I	K I	N V	O I	P V	S II	Al II	Ti II
Wavl	3646-6365	5892	7667	1243	5555-7254	1118	1254-1259	8843	3073
P_{max}	25%	21%	20%	22%	2.3%	27%	31%	20%	7.3%

Many more lines:

N I, N II, N III, P III, Al I, Al III, Fe I, Fe II, Fe III, Fe III, Mn II, Ti III, C II, N II, Cr I …

How to observe it? - I. Absorption

• Species w. at least 3 sublevels on the ground state or metastable state
• Spectral resolution: R>20,000
• Wavelengths: Optical & UV

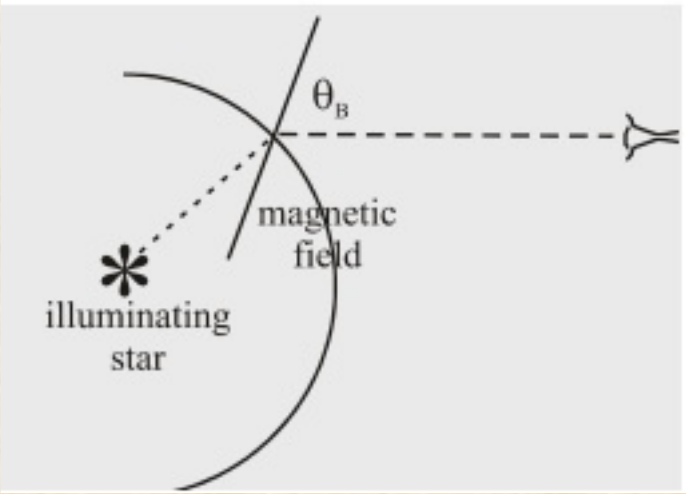


☑exclusive indicator of the alignment effect.
☑qualitative measurement is adequate for determining 2D field in the pictorial plane.

How to observe it? - II. Emission

- Species w. at least 3 sublevels on the ground state or metastable state
- Spectral resolution: R>5,000
- Wavelengths:

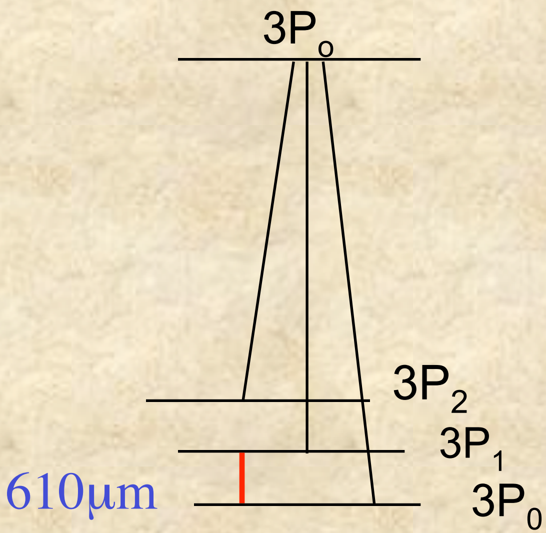
1. Resonance: Optical & UV
2. fluorescence: UV/optical/NIR



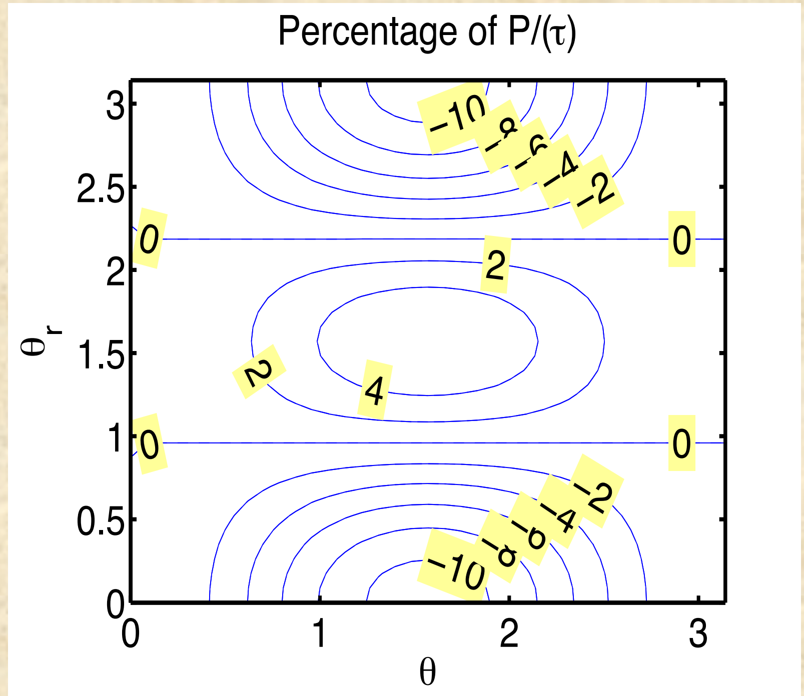
☑ More available lines.
☑ Marginal averaging along line of sight.

3rd possibilty: Forbidden (submm, IR) transitions within the aligned ground state

Schematics of UVpumping of CI 610μm emission (similar to Wouthuysen-Field effect)



[CI] Emission



☑ qualitative measurement is adequate for determining 2D field in the pictorial plane.

Forbidden (submm, IR) transitions within the aligned ground state are

Calculated Examples:

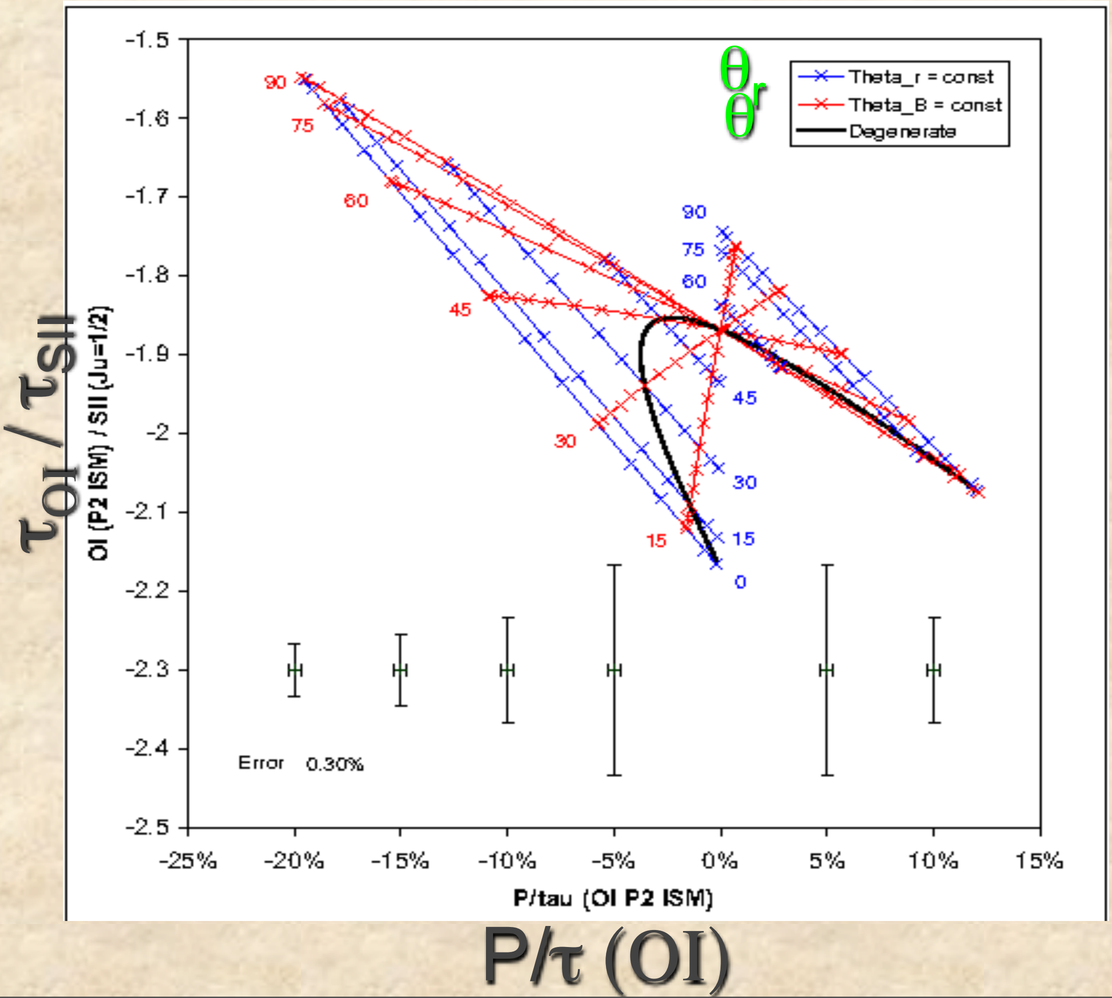
	[O I]	[C I]	[C II]	[Si II]	[S IV]
Lines	$3P_1 \rightarrow 3P_2$	$3P_1 \rightarrow 3P_0$	$3P_{3/2} \rightarrow 3P_{1/2}$	$3P_{3/2} \rightarrow 3P_{1/2}$	$3P_{3/2} \rightarrow 3P_{1/2}$
Wavl	63.2 μm	610 μm	157.7μm	34.8μm	10.5 μm
P_{max}	24%	11%	2.7%	4%	11%

Many more lines:

[H I]	[N V]	[O II]	[O III]	[Fe II]	[S I]
21cm	70.7mm	0.373 μm	51.8/88.4 μm	35μm	25μm
[N III]	[N II]	[S II]	[S III]	[Si I]	[Ne III]
57.3μm	122/205μm	0.67μm	18.7/33.5μm	129.7/68.5μm	15.6μm

Using several lines, it's possible to get 3D B

3D information: from degree of polarization $P(\rho^2_0(\theta_r),\theta)$. Two lines are enough



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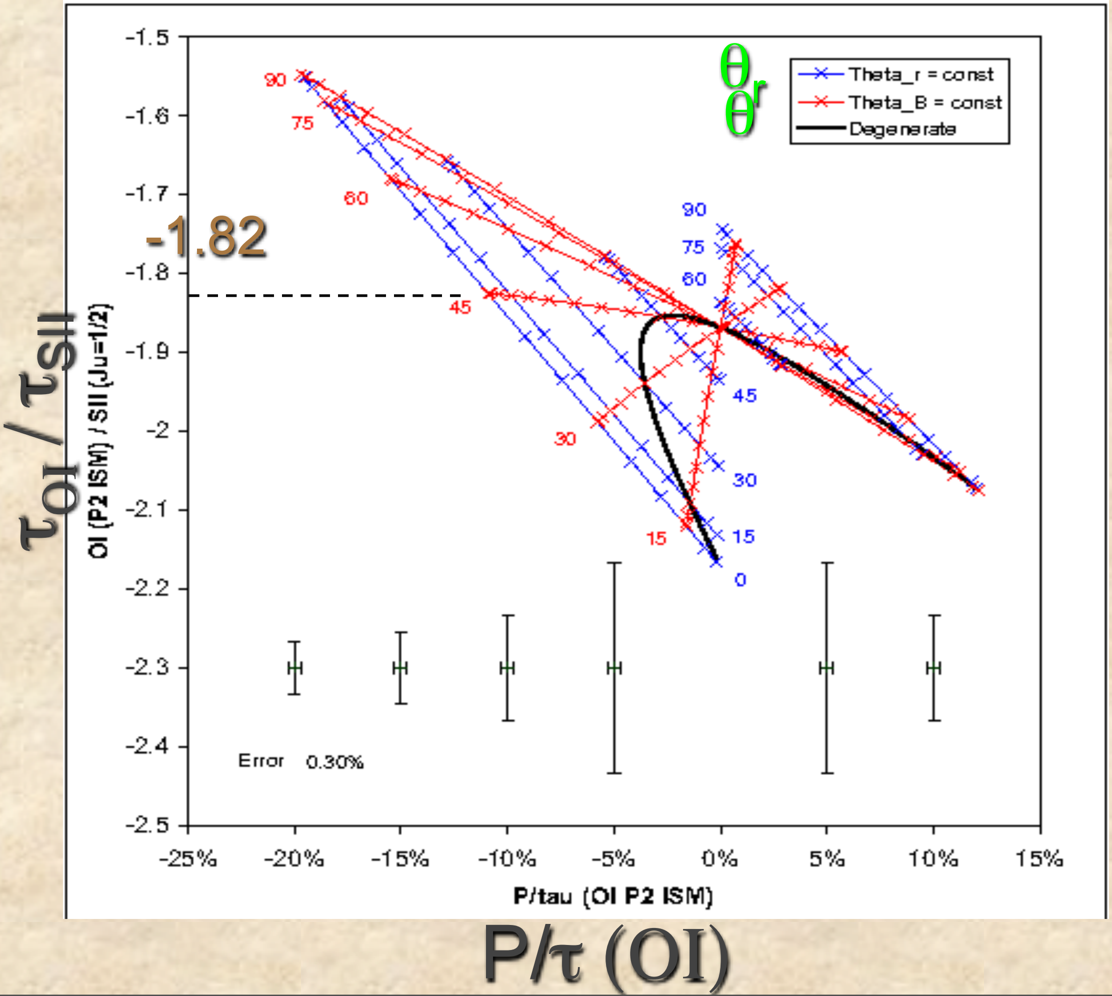

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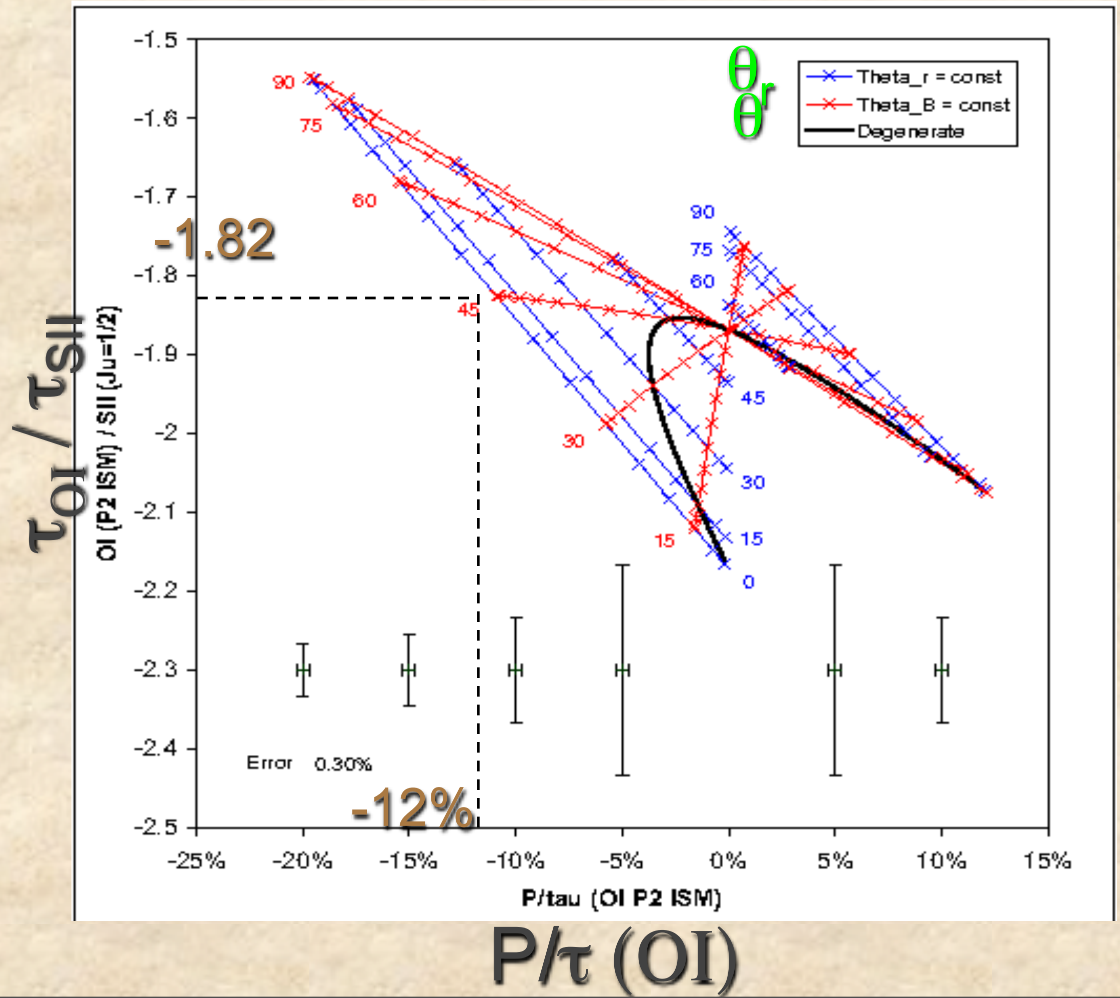

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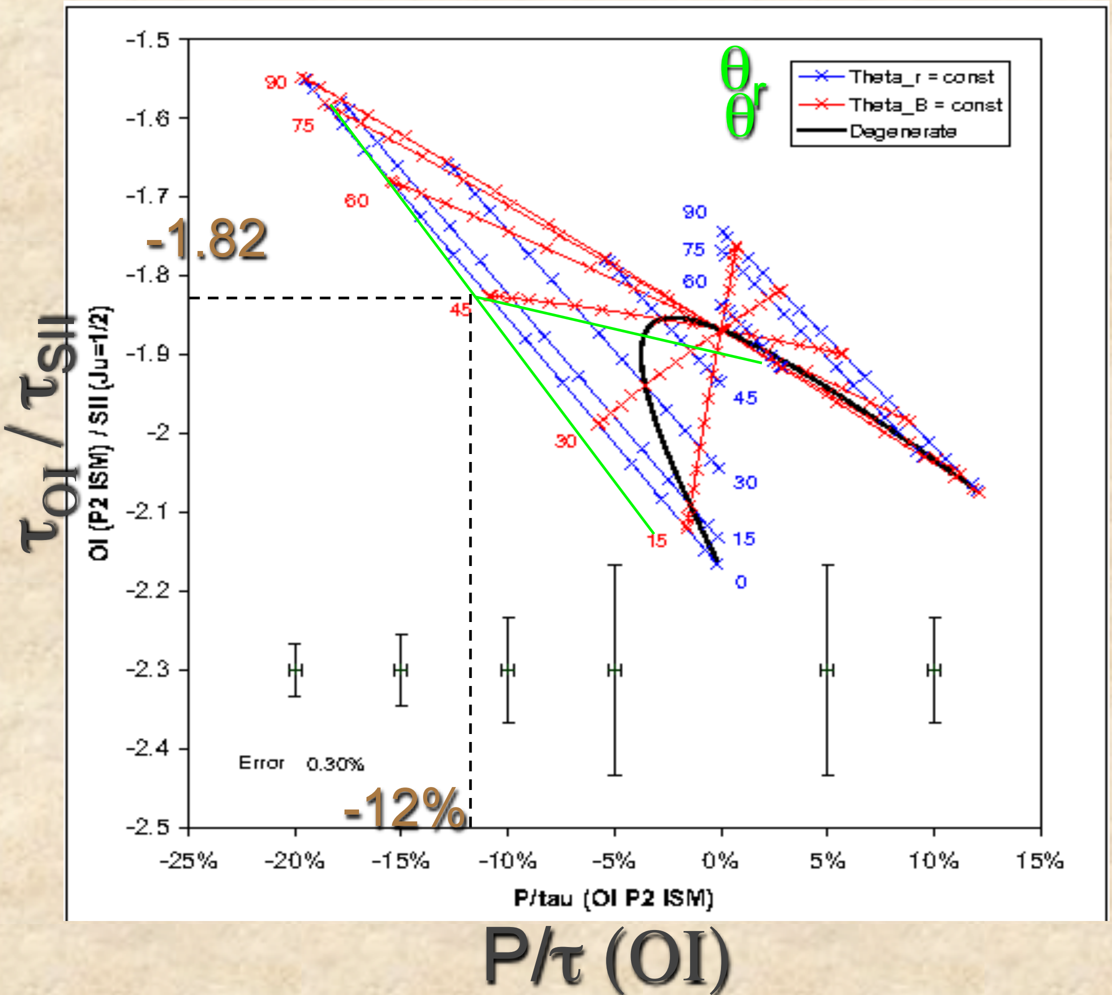

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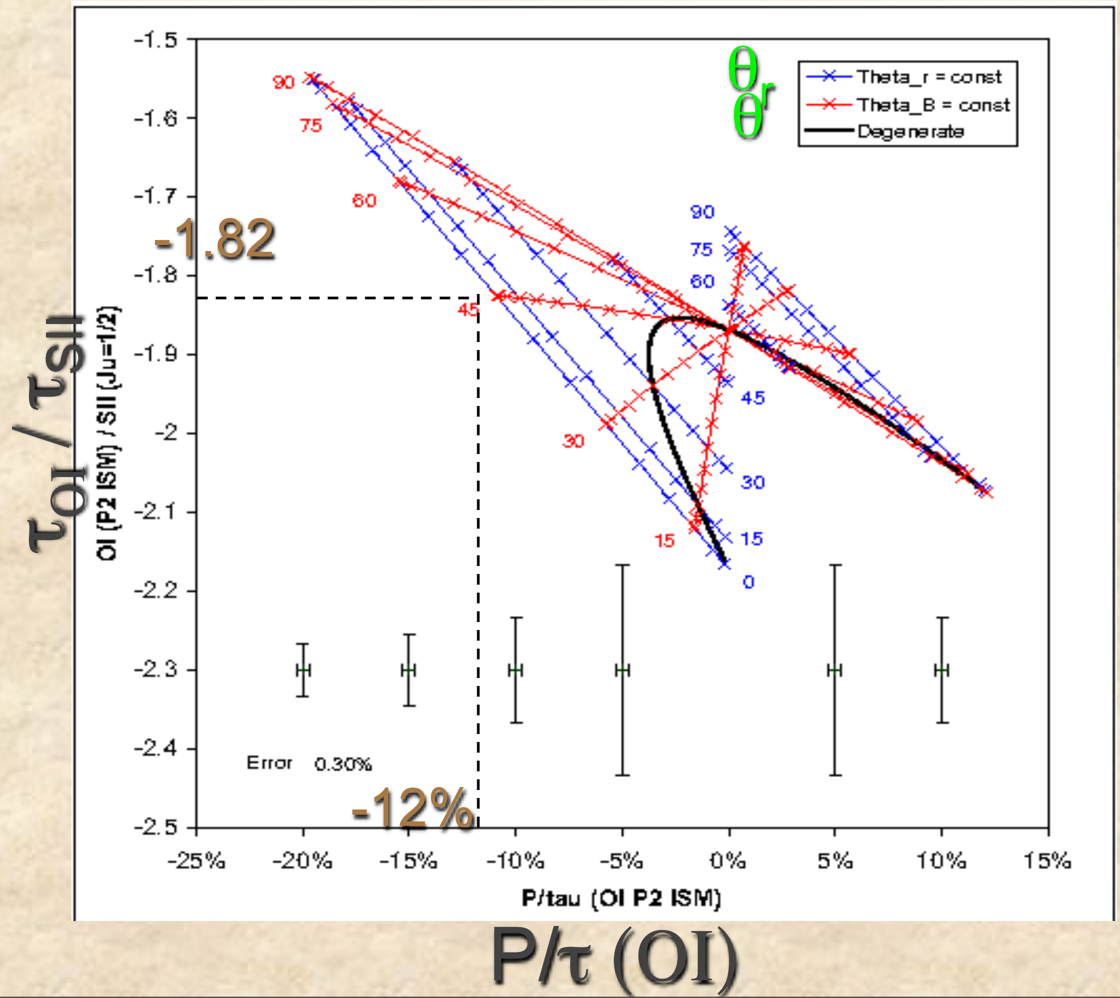
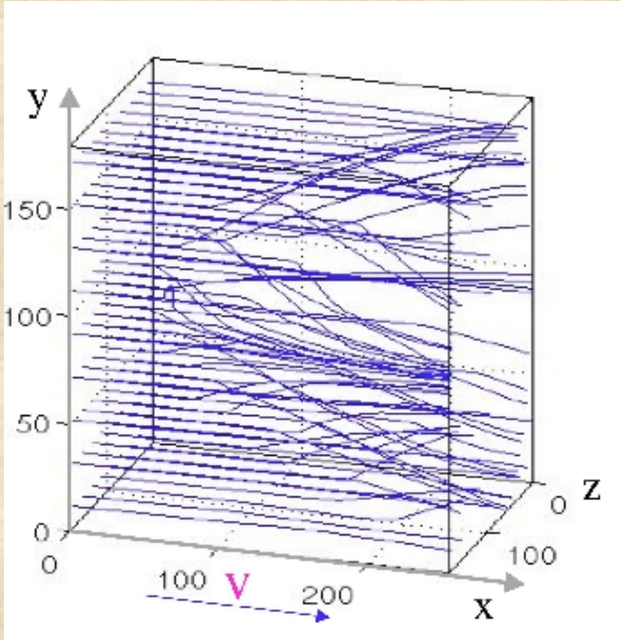


Ex. I: alignment allows studies of interplanetary magnetic field



MHD simulations of comet's wake.

Spatial and temparal variation of turbulent magnetic field can be studied.

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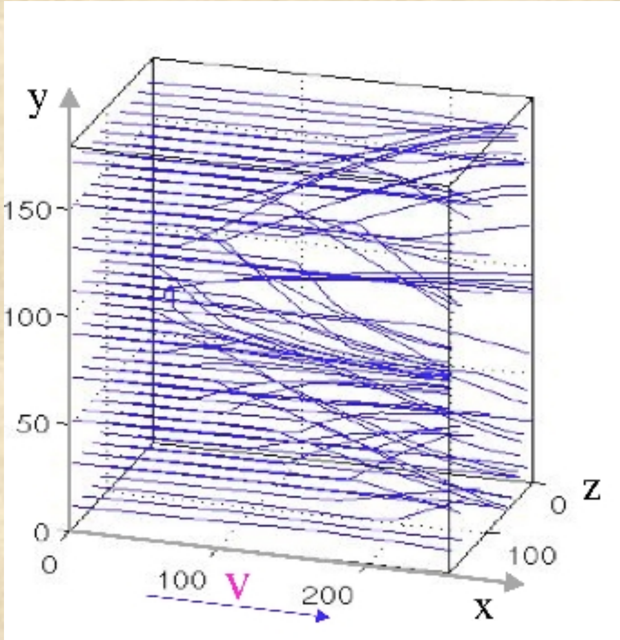

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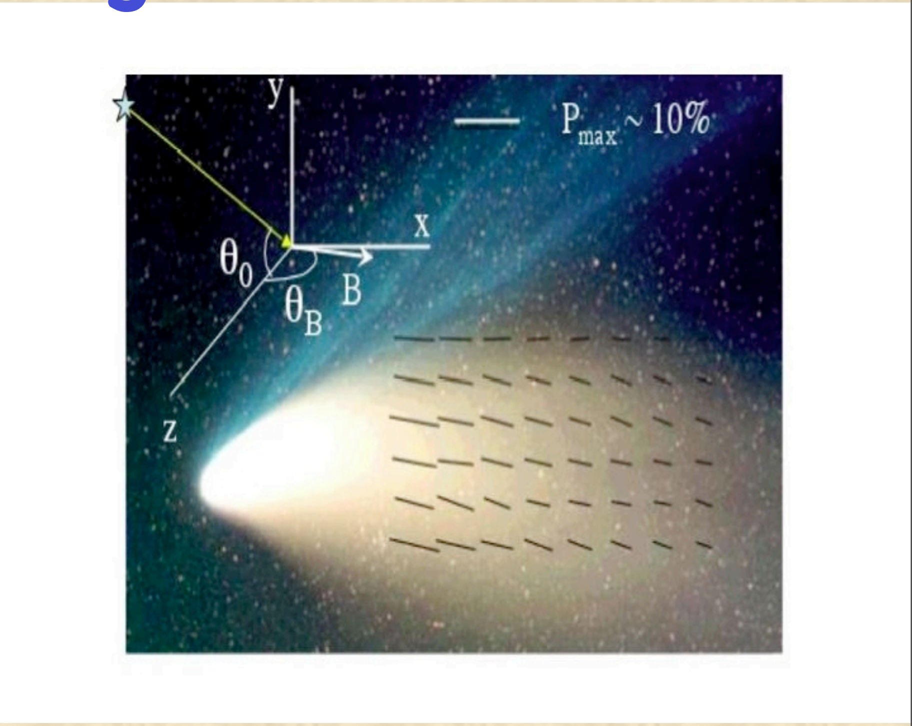

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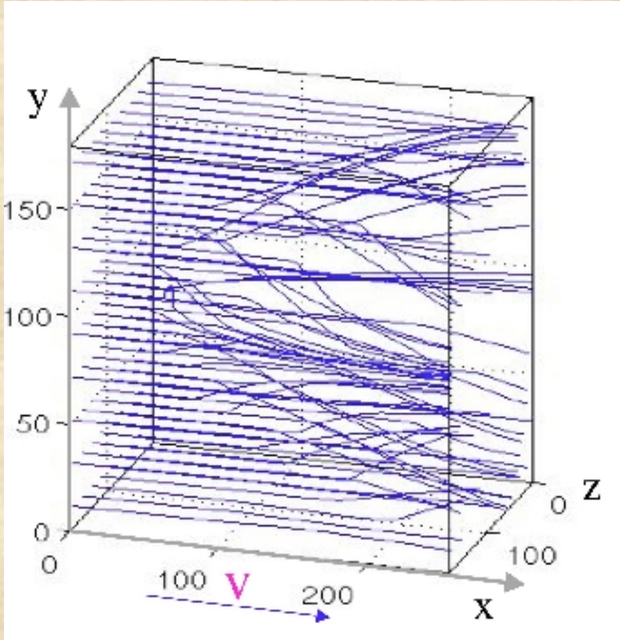

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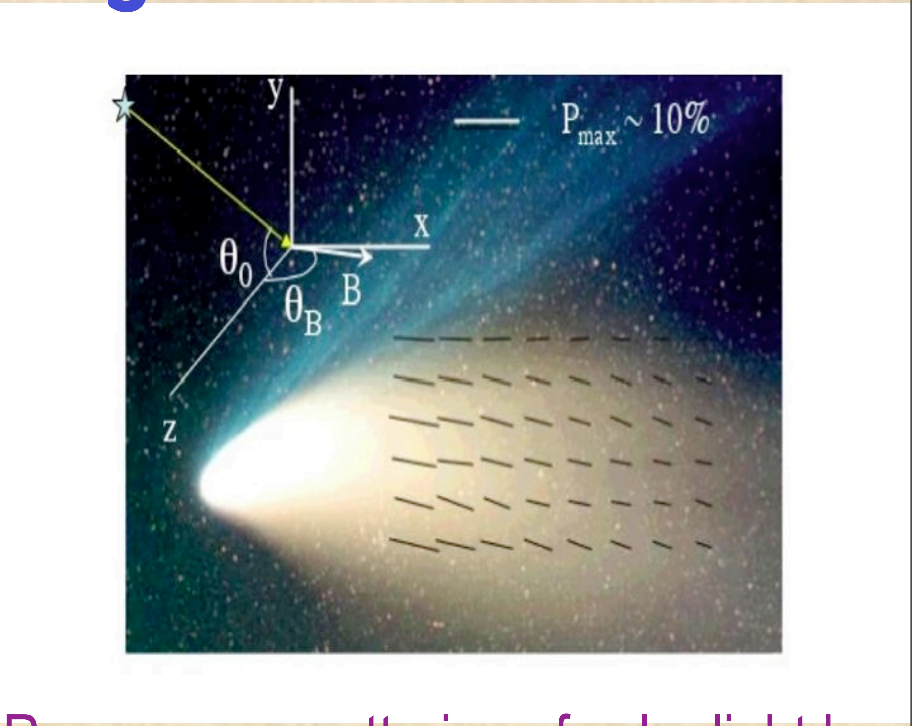

Resonance scattering of solar light by sodium tail from comet.

Spatial and temparal variation of turbulent magnetic field can be studied.

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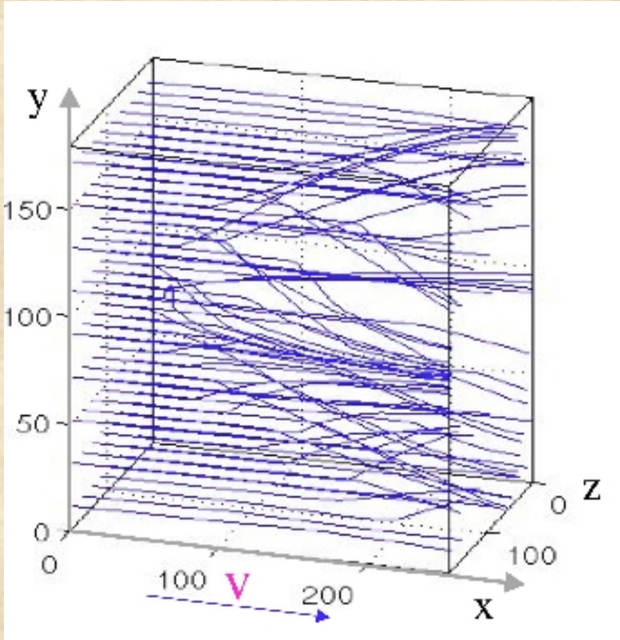

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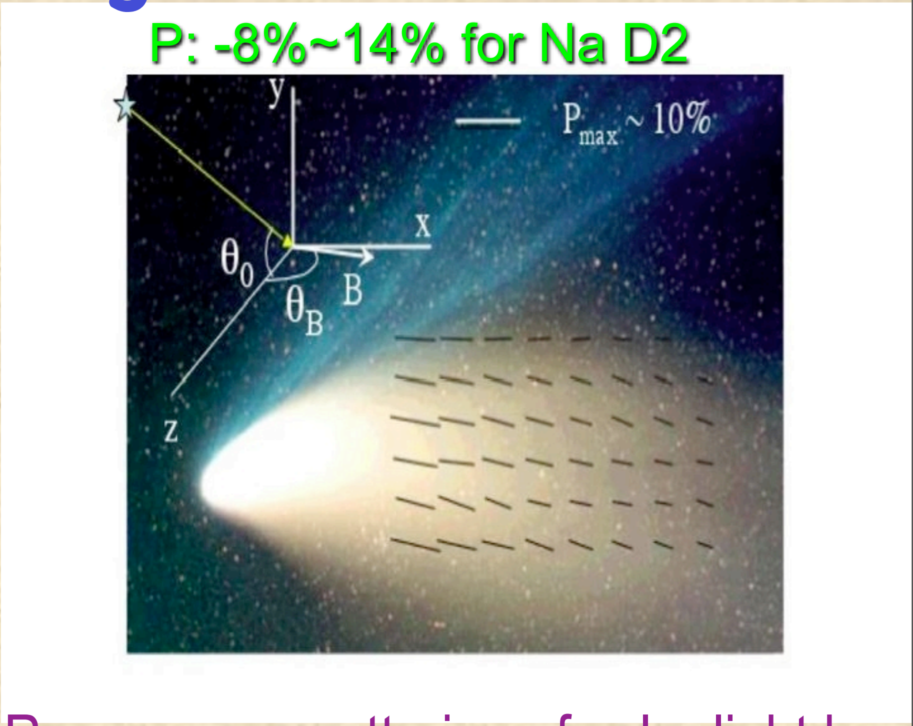

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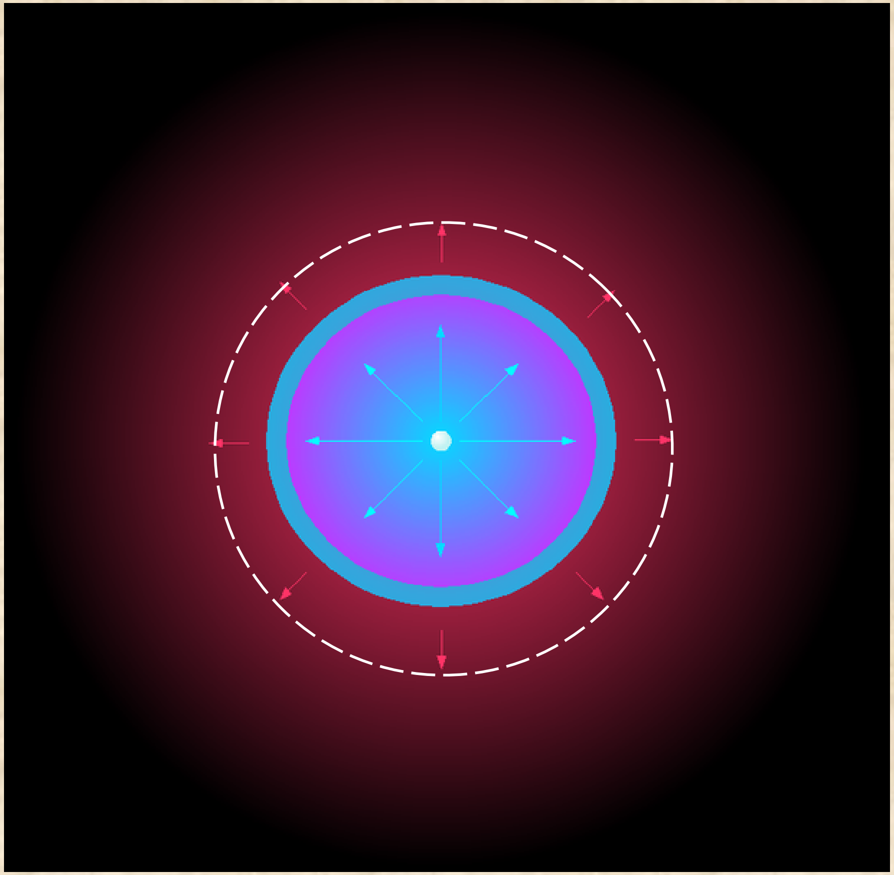
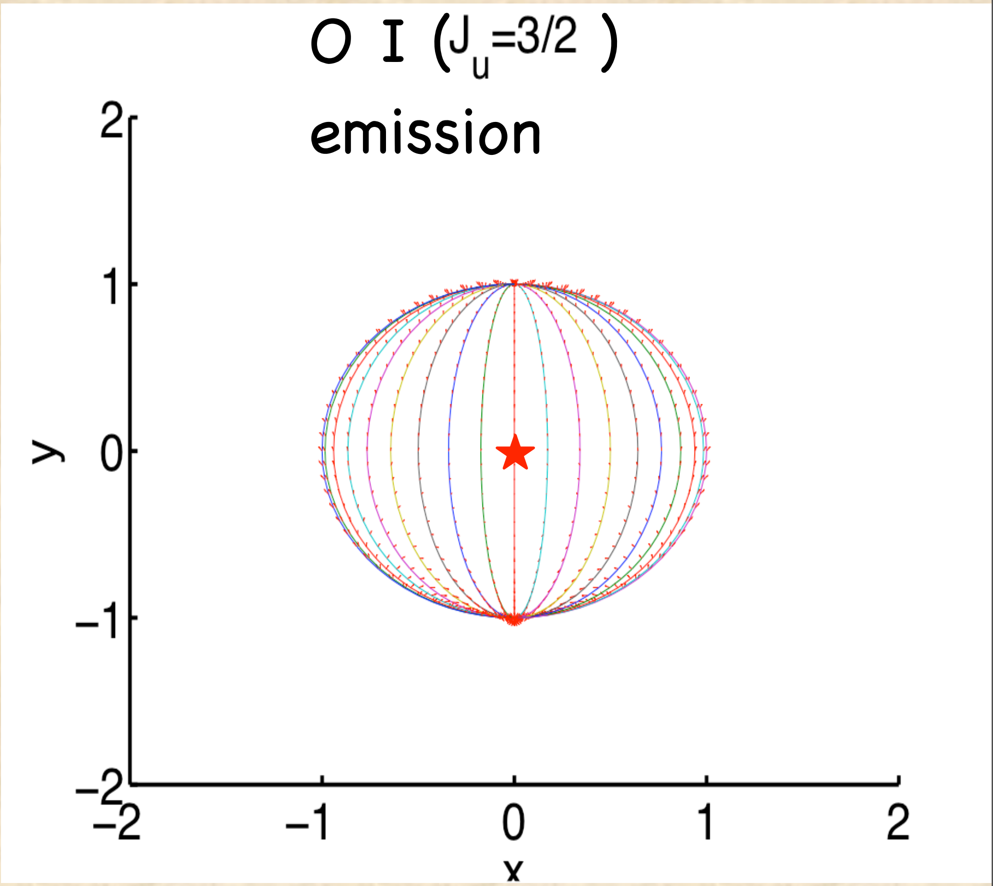
Ex. II: Polarization from circumstellar envelope



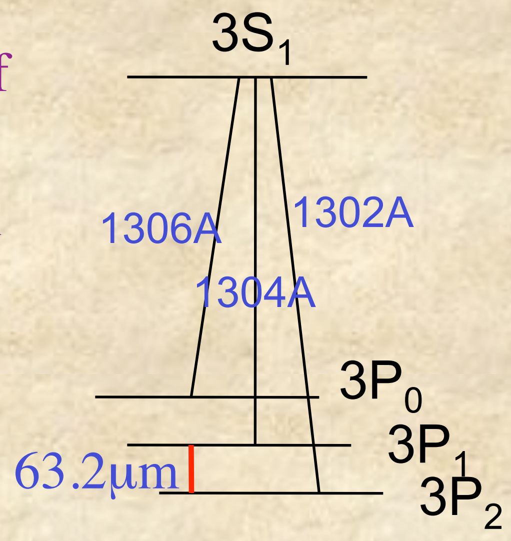


Polarization vectors are centrosymmetric without magnetic realignment

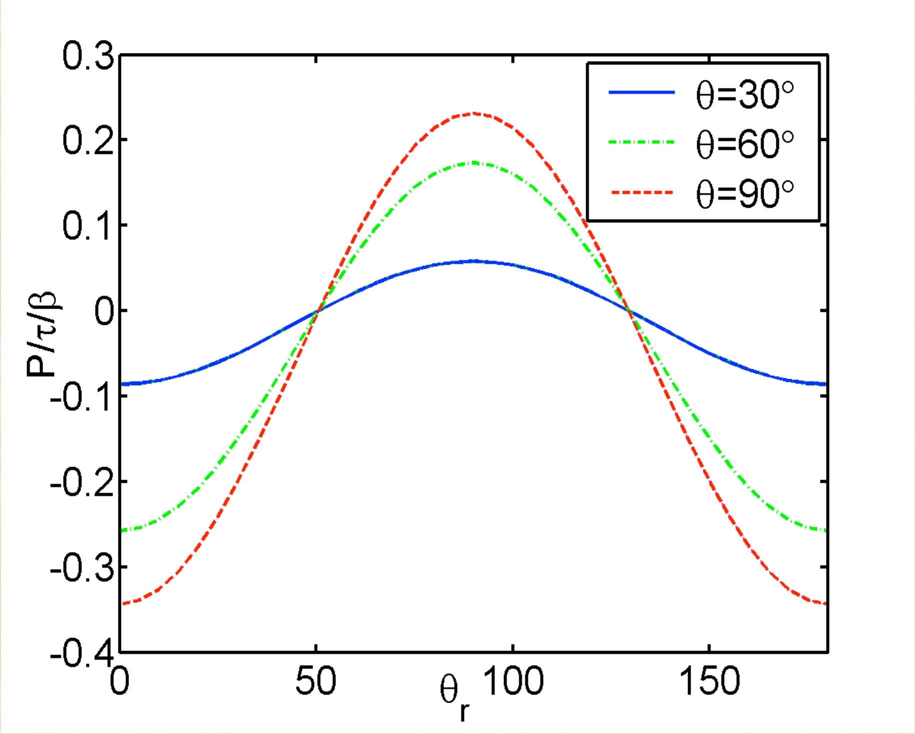
Aligned species produces different polarization pattern from non-aligned species.

Ex. III: alignment allows study of magnetic field in the epoch of Reionization

Schematics of UV pumping of OI 63.2μm emission



Polarization of OI 63.2 μm



β= UV excitation rate/ CMB excitation rate
(Yan & Lazarian 2008)

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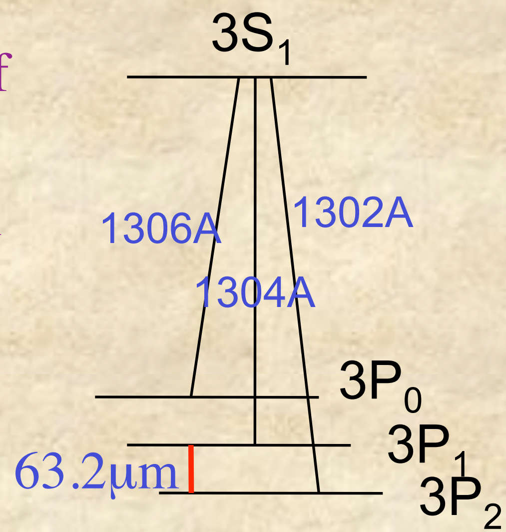
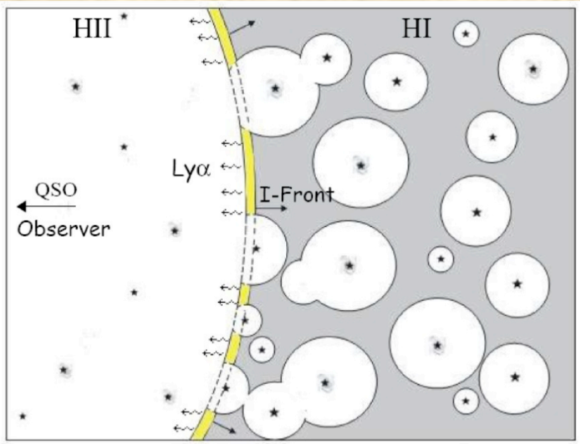


Epoch of reionization



From Cantalupo et al. (2008)

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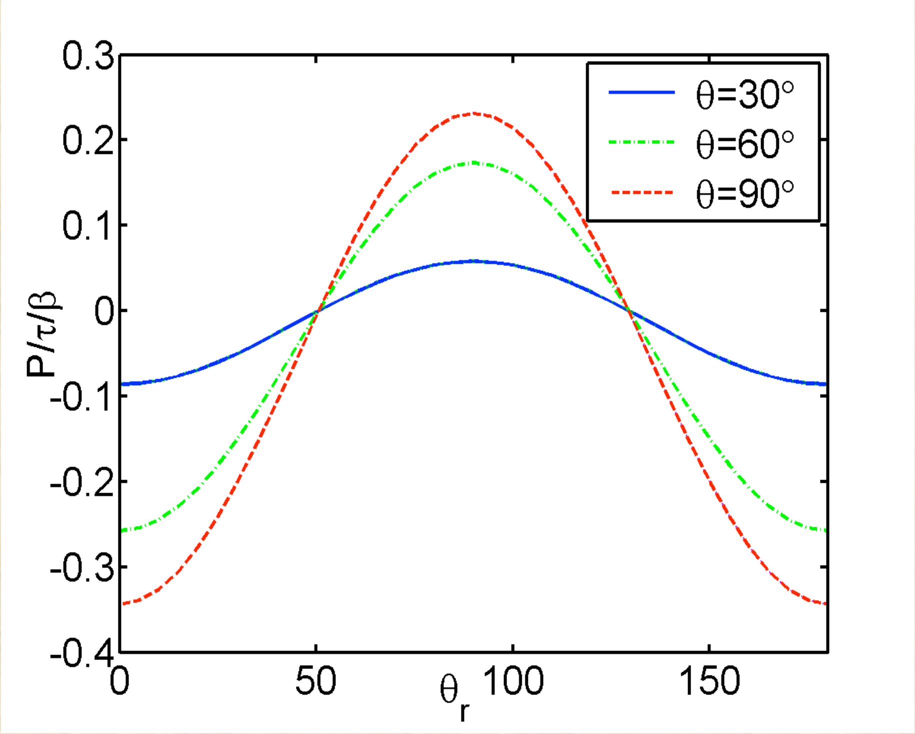

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Ongoing projects


Sounding rocket flight is funded.(PI Nordsieck)


Ongoing observation at Steward MMT(w. H. Meng)

New technique opens wide avenues for magnetic field studies