Spectropolarimetry of the starburst galaxy M82: Kinematics of dust outflow

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Abstract

Spectropolarimetry results for the starburst galaxy M82 are presented. The optical emission lines of the filaments in the energetic outflow ("superwind") from the nuclear starburst region of M82 are substantially polarized. The polarized emission lines are redshifted with respect to the emission lines in the total light and systemic motion of the galaxy. The emission line intensity ratios in the polarized light and the electron density N_e derived from the [SII]λ6731/λ6717 line ratio of the polarized light strongly suggest that the emission from the nuclear starburst of M82 is scattered by dust grains entrained and transported outward by the superwind. A simple hollow biconical outflow model shows that the velocity of the outflowing dust grains, v_d, ranges from 100 to 200 km s^{-1} near the nucleus, decreases monotonically with the distance from the nucleus, and reaches ~10 km s^{-1} at around 1 kpc. The motion of the dust is substantially slower than that of both ionized gas ($v_{H\alpha}$ ~ 600 km s^{-1}) and molecular gas (v_{CO} ~ 200 km s^{-1}) at the same distance from the nucleus of M82. This indicates that dust grains in the superwind are kinematically decoupled from both gas components at large radii. Since the dust velocity v_d is much less than the escape velocity of M82 (v_{esc} = 170 km s^{-1} at 1.5 kpc from the nucleus), most of the dust entrained by the superwind cannot escape to intergalactic space, and may fall back into the galaxy disk without any additional acceleration mechanisms (such as radiation pressure).

Introduction

M82 D = 3.6Mpc M_B = -18.95 L_{IR} = 5.4x10$^{10}L_\odot$

v_{sys} = 214 km/s v_{rot} = 135 km/s

Huge dust in the superwind of M82

optical imaging (e.g Ohyama 2002), imaging polarimetry (e.g Scarrott 1991), mid-infrared imaging (e.g Engelbracht 2006, Kaneda 2010), sub-mm imaging (e.g Leeuw 2009)

Can the dust escape from the galaxy to intergalactic space ?

→ Spectropolarimetry to study the kinematics of the scattering material (=dust) in the superwind

Observations

Subaru Telescope + FOCAS

0."6 slit, VPH650 grism → R ≈ 2100

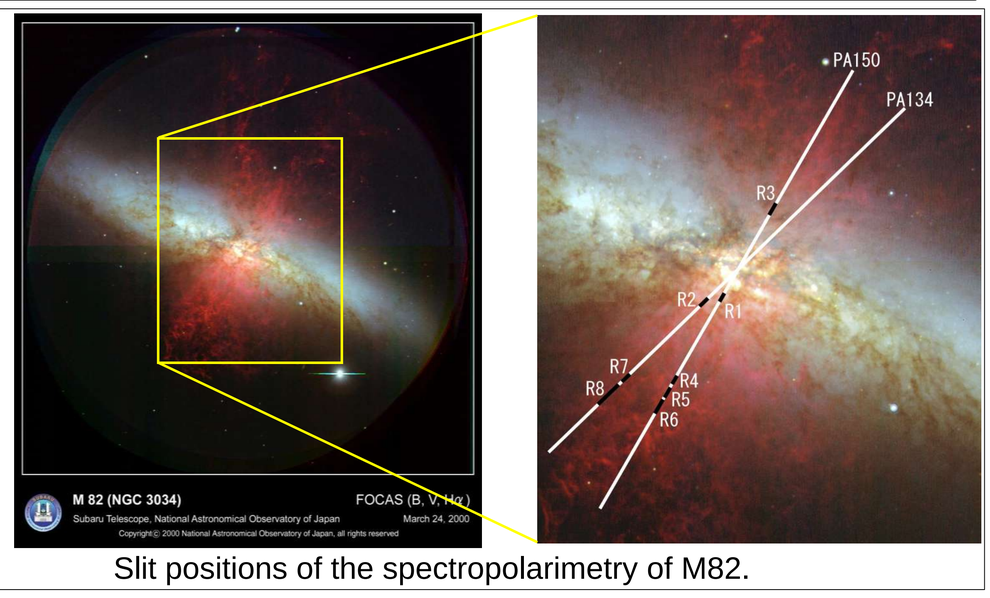
Wollaston prism + half wavelength plate (φ=0˚, 45˚, 22.5˚, 67.5˚)

●2003/12/21 Slit PA=150˚ exp.time 600 sec

●2003/12/22 Slit PA=134˚ exp.time 720 sec x 4

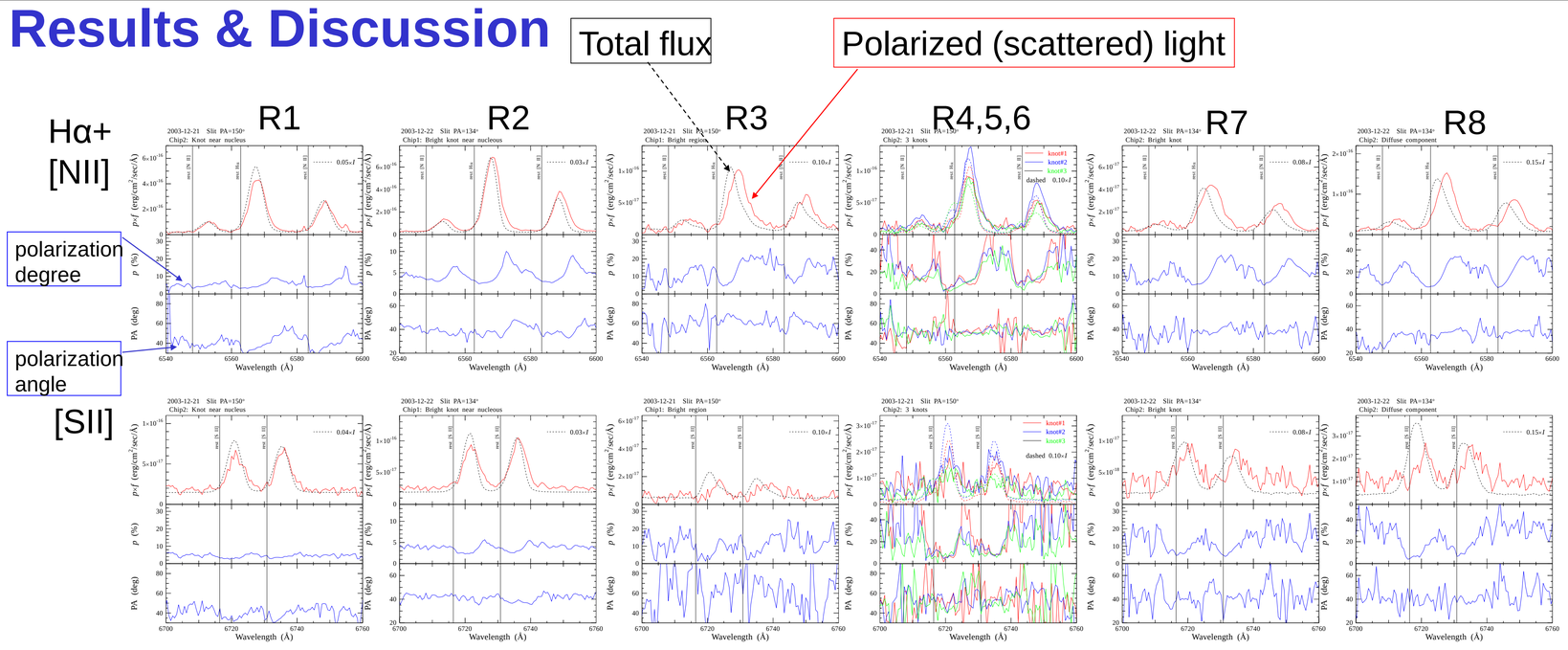
↓

Extract eight regions (see Fig.1) from the obtained spectra



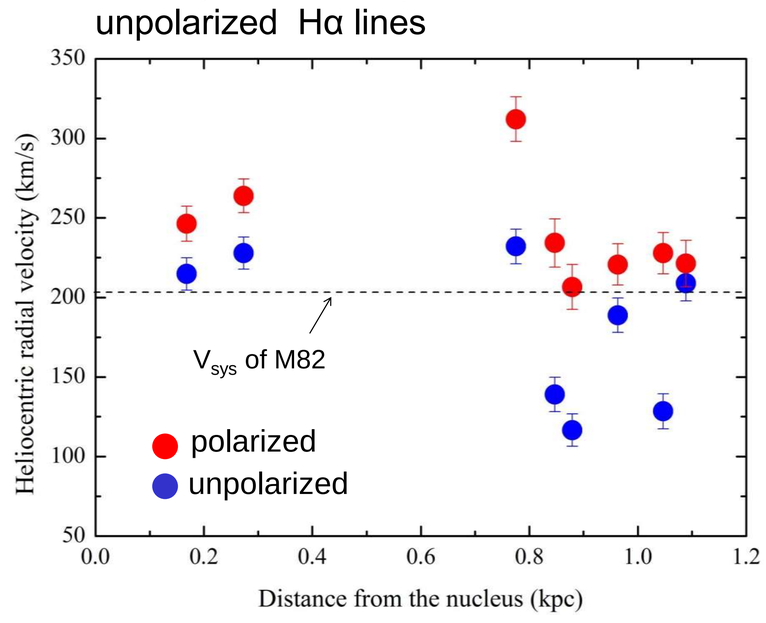
Slit positions of the spectropolarimetry of M82.

Results & Discussion



Observed spectra of M82. Upper panels show Hα+[NII] lines and lower panels show [SII] lines. Polarized flux (solid lines) super-imposed on total (unpolarized)flux (dotted line), polarization degree, and polarization angle are shown in each panel. The polarized emission-lines are systematically redshifted with respect to the unpolarized lines.

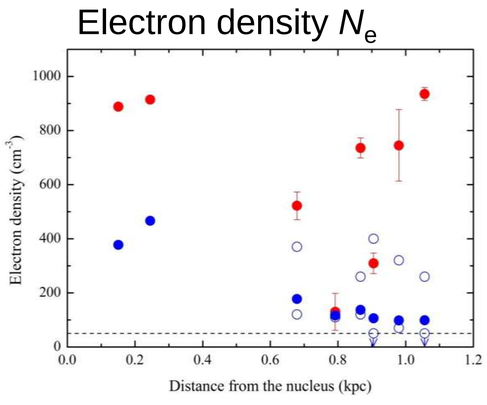
Velocity field of the polarized and unpolarized Hα lines



The radial velocities of the polarized emission lines are higher than the systemic velocity of the galaxy.

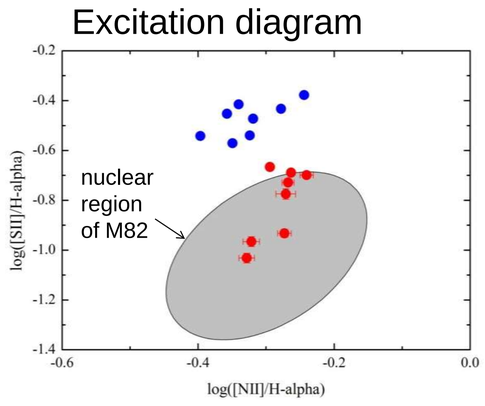
Outflow model

Electron density N_e



The Ne derived from the polarized [SII] lines (red circle) are significantly higher than those derived from the unpolarized lines (blue circle).

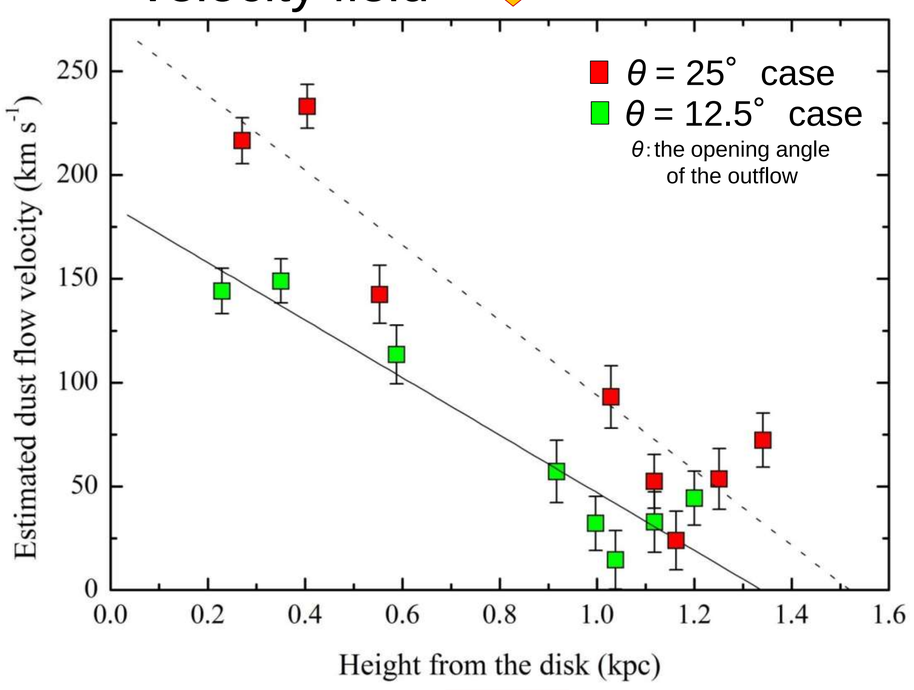
Excitation diagram

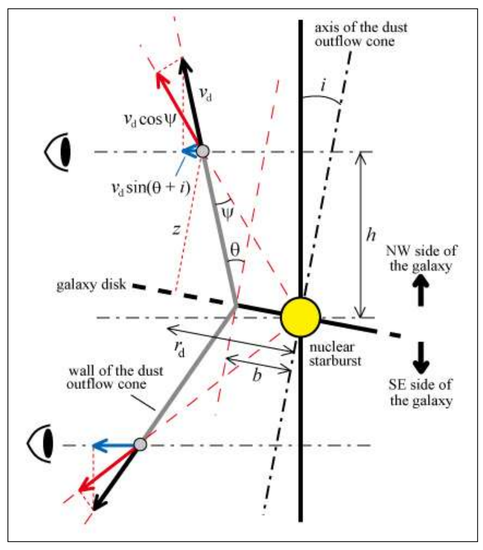


The excitation of the polarized emission lines (red circles) is similar to that of the circum nuclear gas of M82.

The polarized light is the nuclear light scattered by dust in the superwind.

Dust flow velocity field





A hollow cone model of the M82 dust wind. The dust grains in the galaxy disk are entrained by the superwind expelled from a circumnuclear circular region whose radius in the disk is *b*. The entrained dust flows along the walls of a cone whose opening angle is 2 ×θ. The angle of I nclination of the axis of the dust flow cone is *i*. The dust grains in the wind reflect the nuclear emission, acting as mirrors moving at velocity vd cos ψ with respect to the nucleus.

The dust outflow of M82 is monotonically decreasing with the distance from the disk.

Comparison with other elements

Element	Velocity at 1 kpc	Reference
Ionized gas (Hα)	600 km/s	Shopbell & Bland-Hawthorn (1998)
Molecular gas (CO)	220 km/s	Walter et al. (2002)
Dust	**50-100 km/s**	**This work**

The dust is very slow !!

The dust in the superwind of M82 is kinematically decoupled with both of the ionized gas and the molecular gas in the wind.