Ne II Fine-Structure Line Emission from the Outflows of Young Stellar Objects

Hsien Shang

ASIAA

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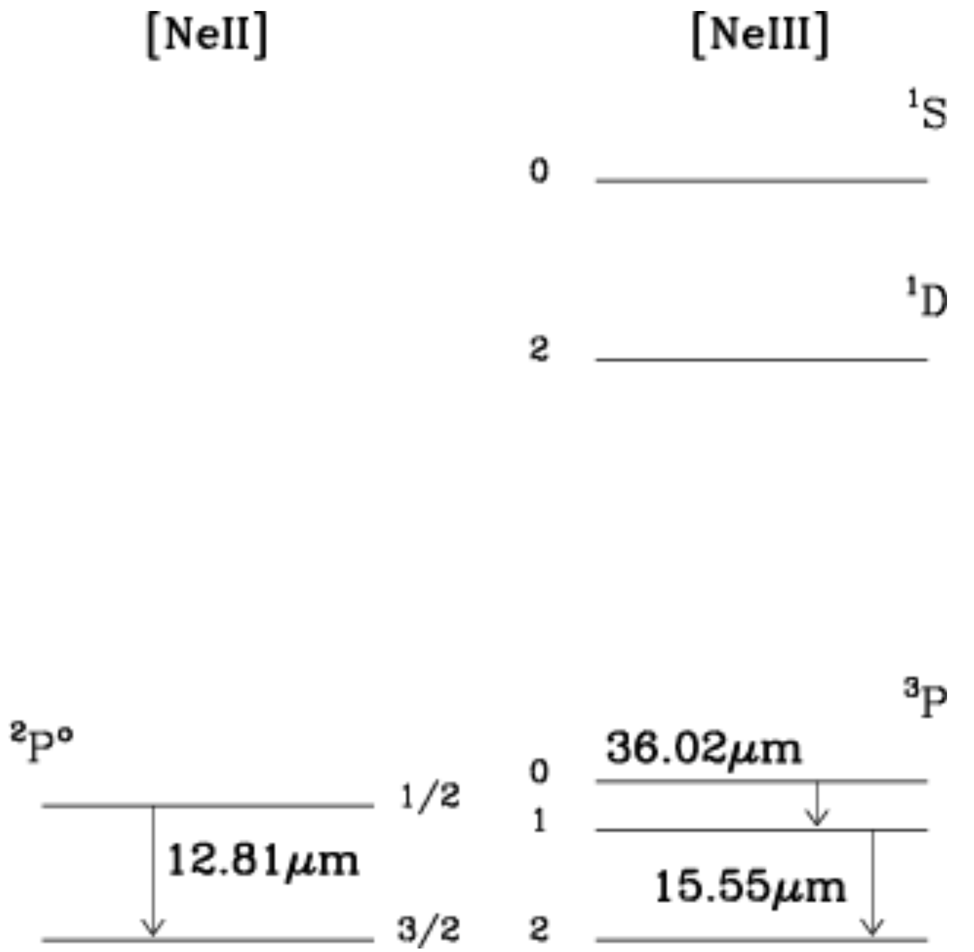
Why Neon?

- Photoionization of Ne requires Lyman continuum photons (as for HII regions), or ***hard X-rays*** (as in disks or jets).
- The Ne^{+} and Ne^{++} ground state fine-structure splitting occurs in the mid-IR.
- Many models have been proposed to explain existing NeII observations, including X-ray irradiated disks/jets, photoevaporated winds, high-velocity shocks, and others.

Ground states of Ne^{+} and Ne^{2+}



Ne^{2+} IP = 63.45 eV

Ne^{+} IP = 40.96 eV

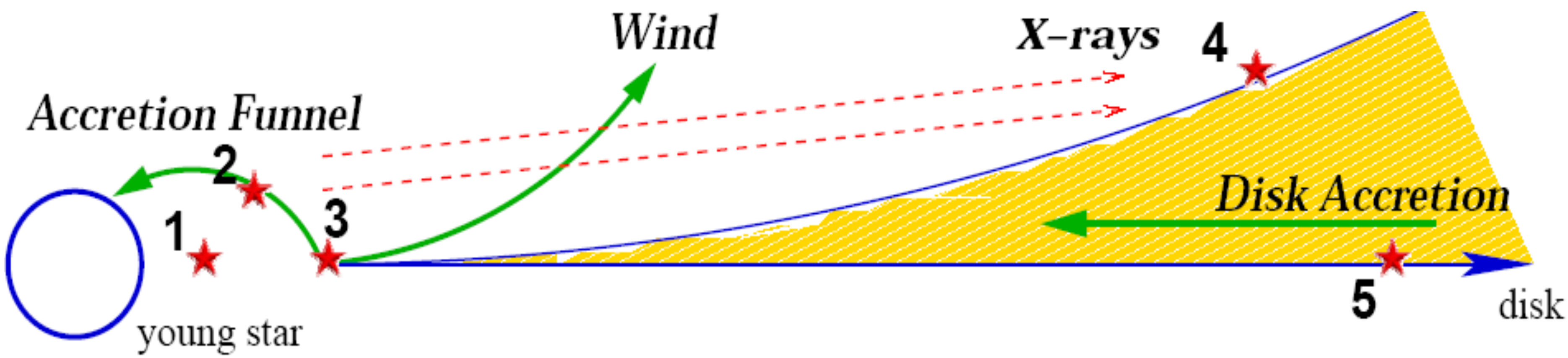
Ne IP = 21.56 eV

Following Glassgold et al. (2007)

Relevance to ALMA

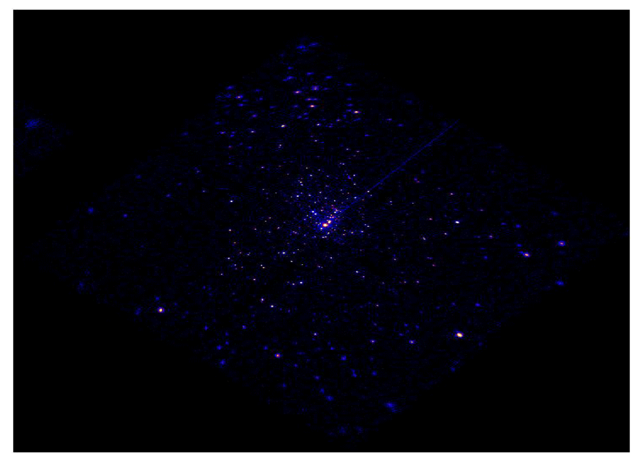
- Tests of XDR models that can correctly produce Neon emissions
- Offering a different angle to model interpretations compared to PDR models in important atomic lines observable through ALMA
- Sensitive measurements of line profiles from lightly ionized winds (jets)
- Complementary studies to submm fine structures lines

Three-Flows in Low-Mass Star Formation



X-ray irradiation zones of interest:

1. reconnection ring interior to disk
2. accretion funnel
3. base of jet and wind
4. disk atmosphere
5. disk mid-plane



COUP

Thermal Structure

Heating/Cooling
Ionization/Recombination

RGS (1990)
Safier (1993)
Garcia et al. (2001)
SGSL (2002)

Glassgold et al (2005):
Role of ambipolar diffusion heating in MHD winds does not depend solely on actual forms and numerical values.

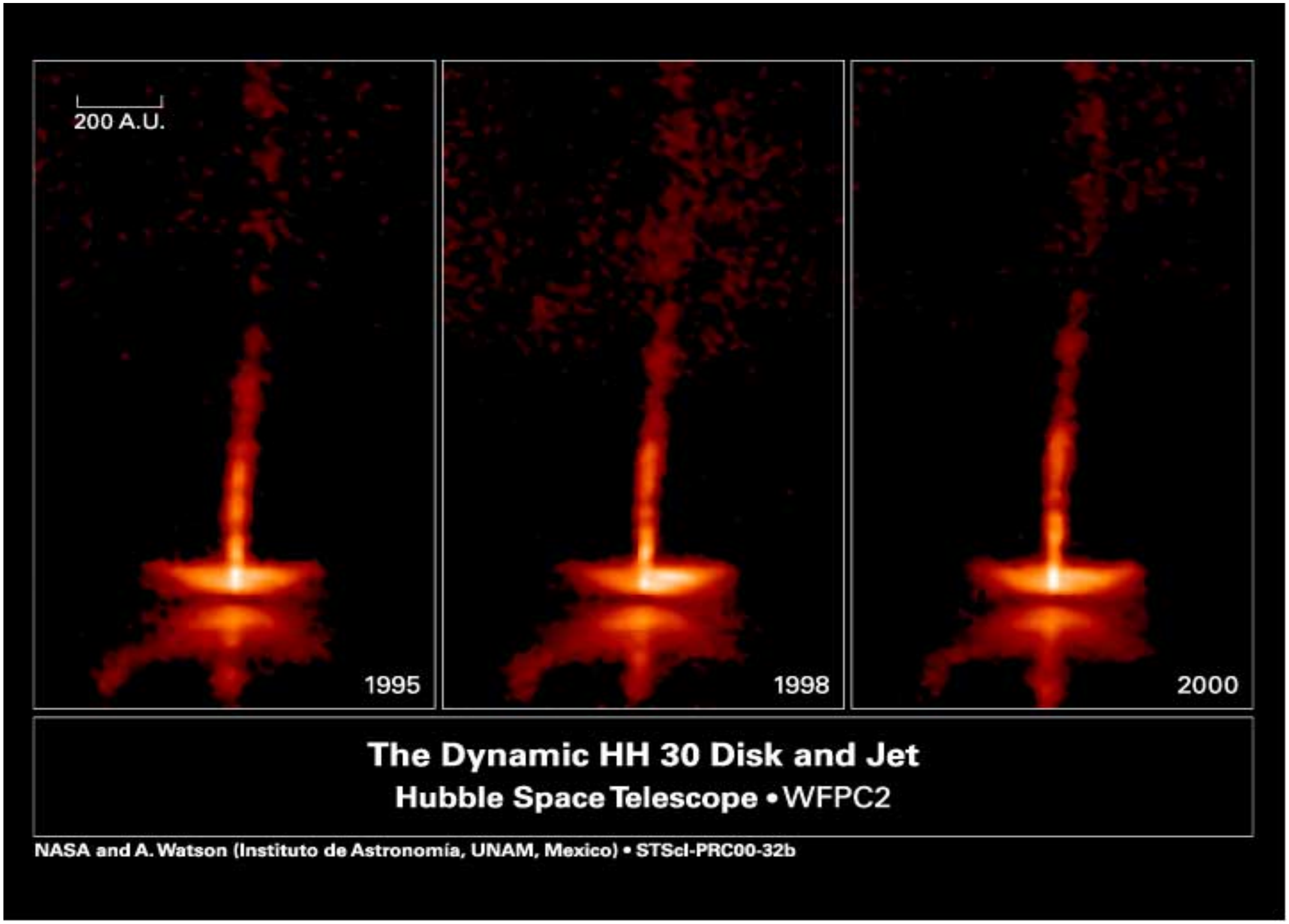
SGSL: X-ray and UV effects, mechanical heating

TABLE 1
PHYSICAL PROCESSES

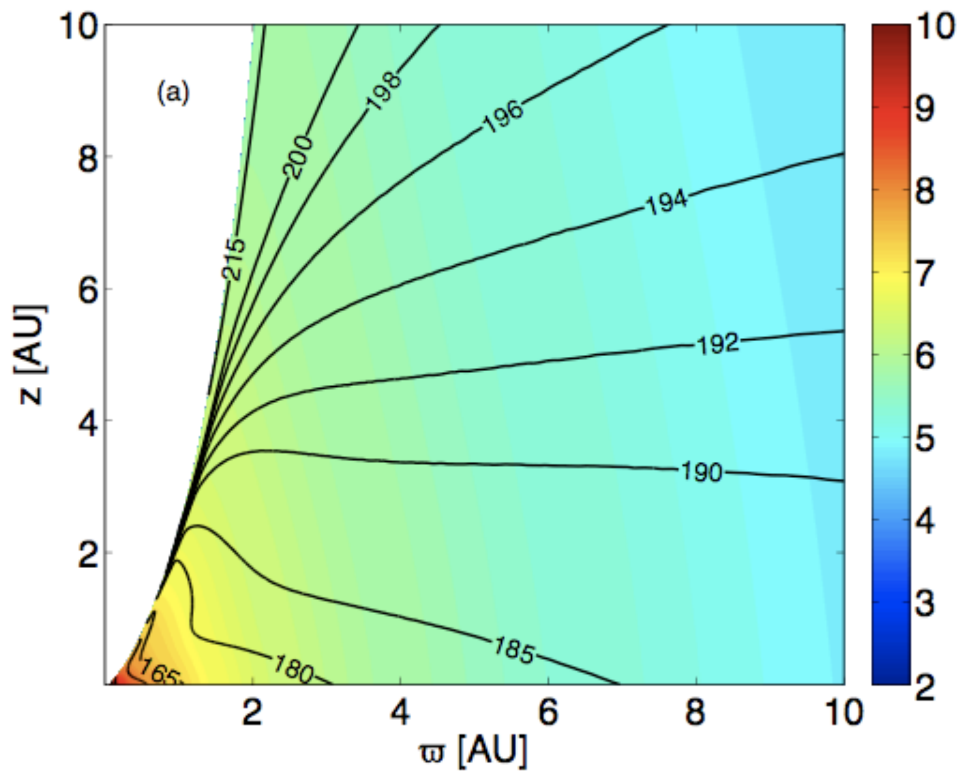
Processes	Discussion
Production of Ionization	
H^- photodetachment	§ 2.4
Balmer continuum photoionization	§ 2.4, Appendix B
Electronic collisional ionization	§ 2.4
X-rays	§ 3, Appendix C
Destruction of Ionization	
Radiative recombination	§ 2.4
Heating	
Photodetachment of H^-	§ 2.4
Balmer continuum photoionization of H	§ 2.4
H^+-H^- neutralization	§ 2.4, Appendix A
Ambipolar diffusion	§ 4, Appendices D and E
X-rays	§ 3
Mechanical	§ 5
Cooling	
Adiabatic	§ 2.2
H^- radiative attachment	§ 2.4
Recombination of H^+	§ 2.4
Lyα	§ 2.4
Collisional ionization	§ 2.4
Heavy-element line radiation	§ 2.5

Shang, Glassgold, Shu, & Lizano (2002) ,SGSL

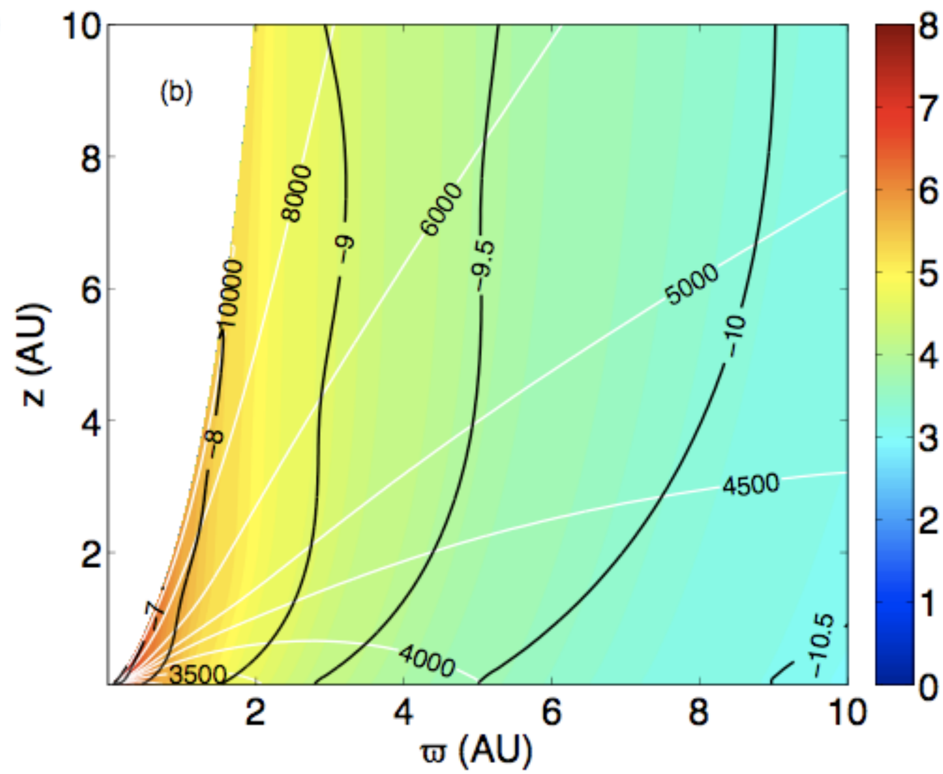
Time-Variability Seen in Optical Knots
If produced by velocity variations, labelled by phenomenological parameter $\alpha=(\delta v/v)^2$



Physical Conditions in Winds

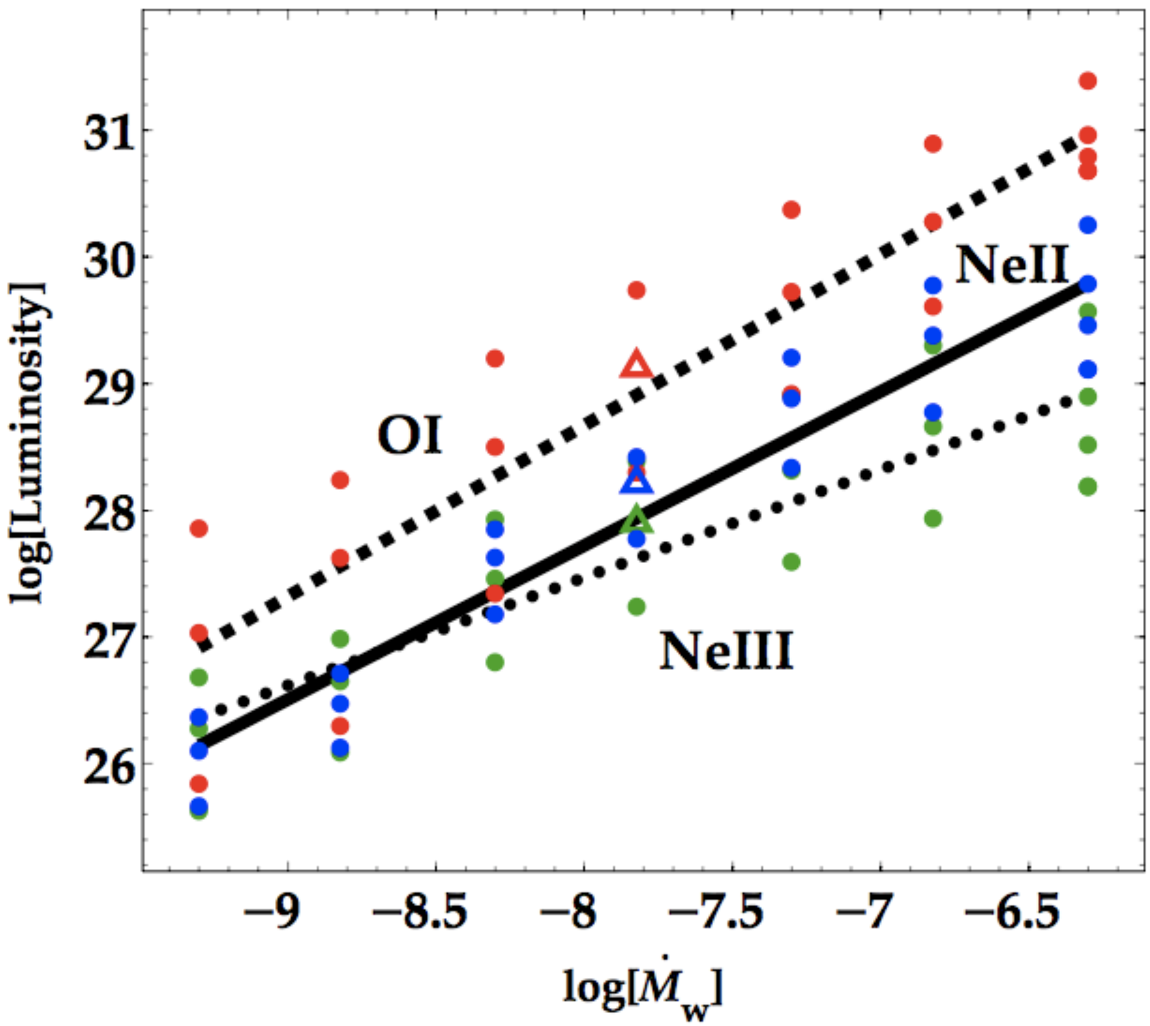


Poloidal Velocity (contour)
Atomic Hydrogen Density (color)



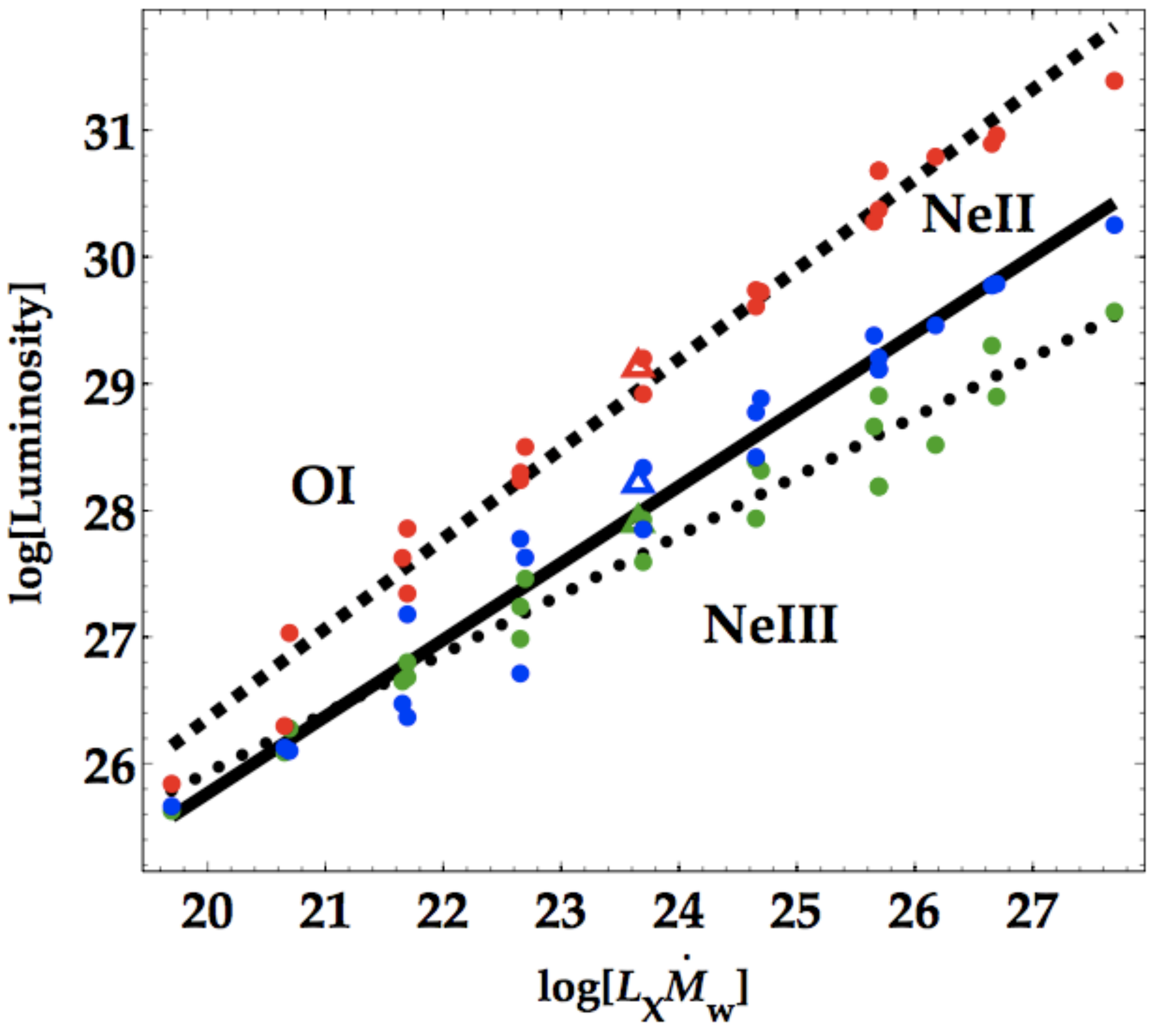
Ionization Rate (black contour)
Temperature (white contour)
Electron Density (color)

Correlations- M_w



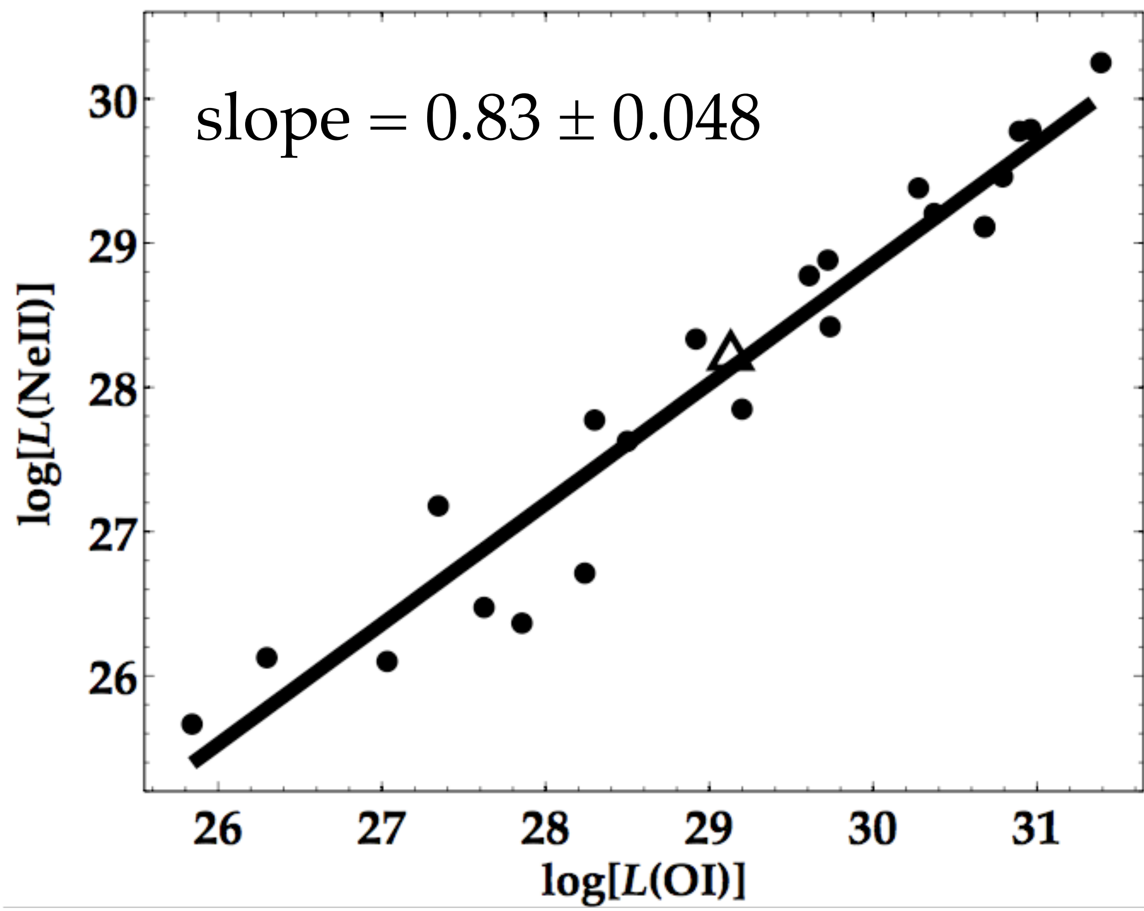
- **Mass-loss rate:** the ***BASIC*** parameter to X-wind model in SGSL
- Scatters are due to variance in L_X
- Larger slope in O I than in Ne II or Ne III
- L(Ne III)/L(Ne II) tends to decrease with M_w since attenuation also increases

Correlations- $L_X M_w$



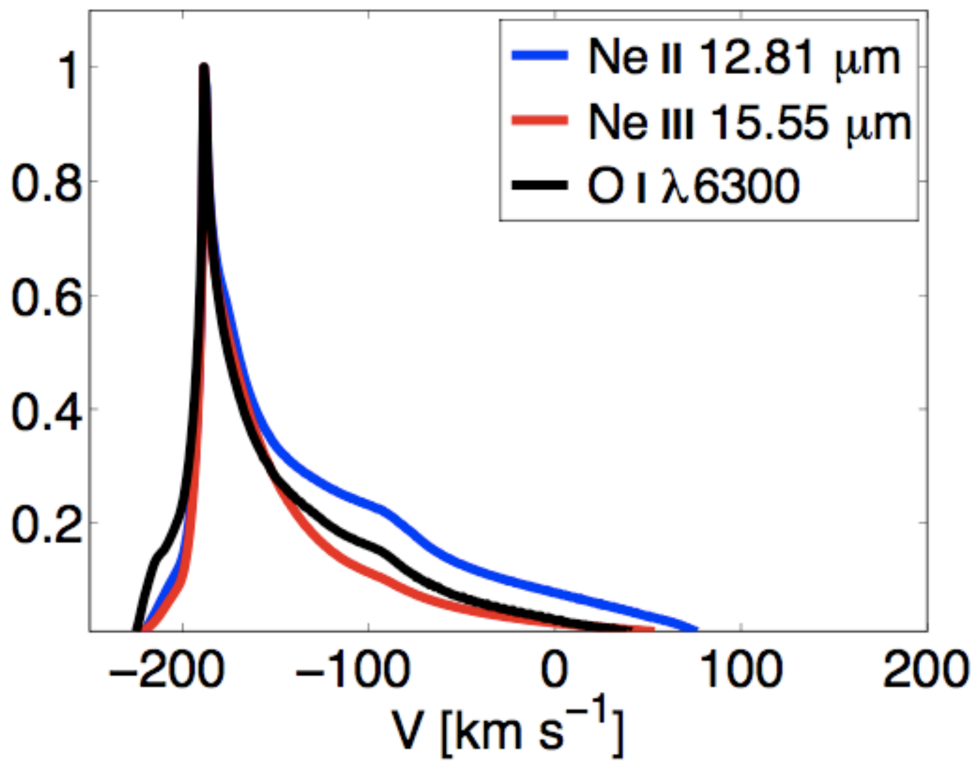
- Empirical parameter introduced in Güdel et al. (2008)
- ***Least*** scattered among all the parameters
- This parameter is an indicator to the square of electron density and reflects the dependence of these collisionally excited lines

Correlation between Lines

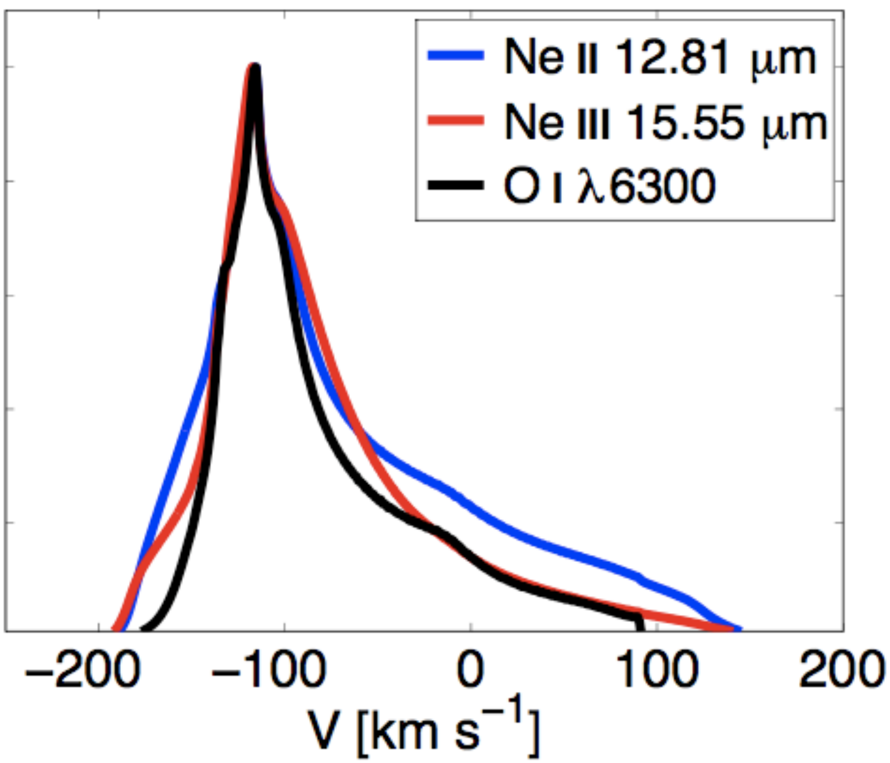


- The good correlations of line luminosities with physical parameters indicates correlation between them
- As for O I, Ne II line is a good tracer to jets from YSOs
- Preliminary observational results support this view

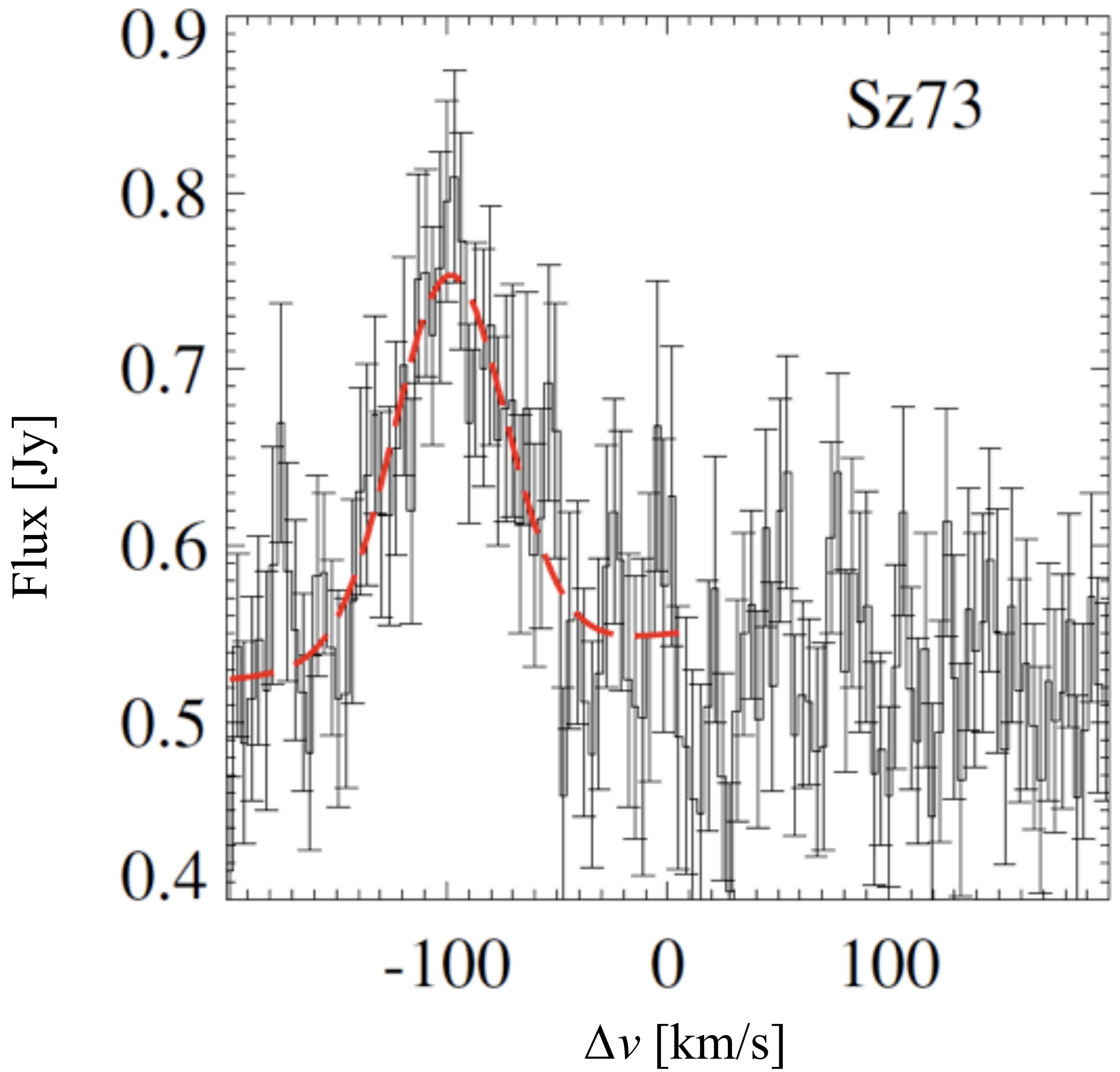
Line Profiles at Different Inclinations



45 degrees



60 degrees



Blueshifted Line Peak

(Pascucci & Sterzik 2009)

$i = ?^{o}$

$v_{\rm ctr} = -99$ km/s

$v_{\rm FWHM} = 60$ km/s

Summary

- Correlations with basic model parameters and and between forbidden lines suggest that neon fine-structure lines are good tracers for X-ray ionization and excitation near the base of jets/winds.
- Distinctive line profiles, having strong peak toward jet terminal velocity and wide wing around stellar velocity, provide crucial tests with observations.
- Our calculations support the viewpoint of "bi-modal" distribution of Ne II luminosity found in observations.
- Ne III lines (MID+Optical 3869/3967) provide novel diagnostic tools for physical conditions of jets and disks around young stars.
- Cross-Correlation of lines can probe the origins of ionization from within the same object

Perspectives

- Using Neon infrared lines as indicators of XDR basic models for disks and outflows from young stars.
- Predictions of fine structure lines [OI] 63 μm, [OI] 145 μm, and [CII] 157 μm with highest angular and spectral resolutions as diagnostics of physical conditions (XDR, PDR, or Shock excitations).
- Calling high spatial and spectral observations of fine-structure lines associated with neon emissions.

Star Formation through Spectroimaging at High Angular Resolution

ASIAA, Taipei, Taiwan

June 20-24

Summer school: June 15-18

Pre-registration coming soon

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