THE SYNTHETIC ALMA MULTIBAND ANALYSIS OF DUST PROPERTIES OF THE TW HYA PROTOPLANETARY DISKS

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INTRODUCTION

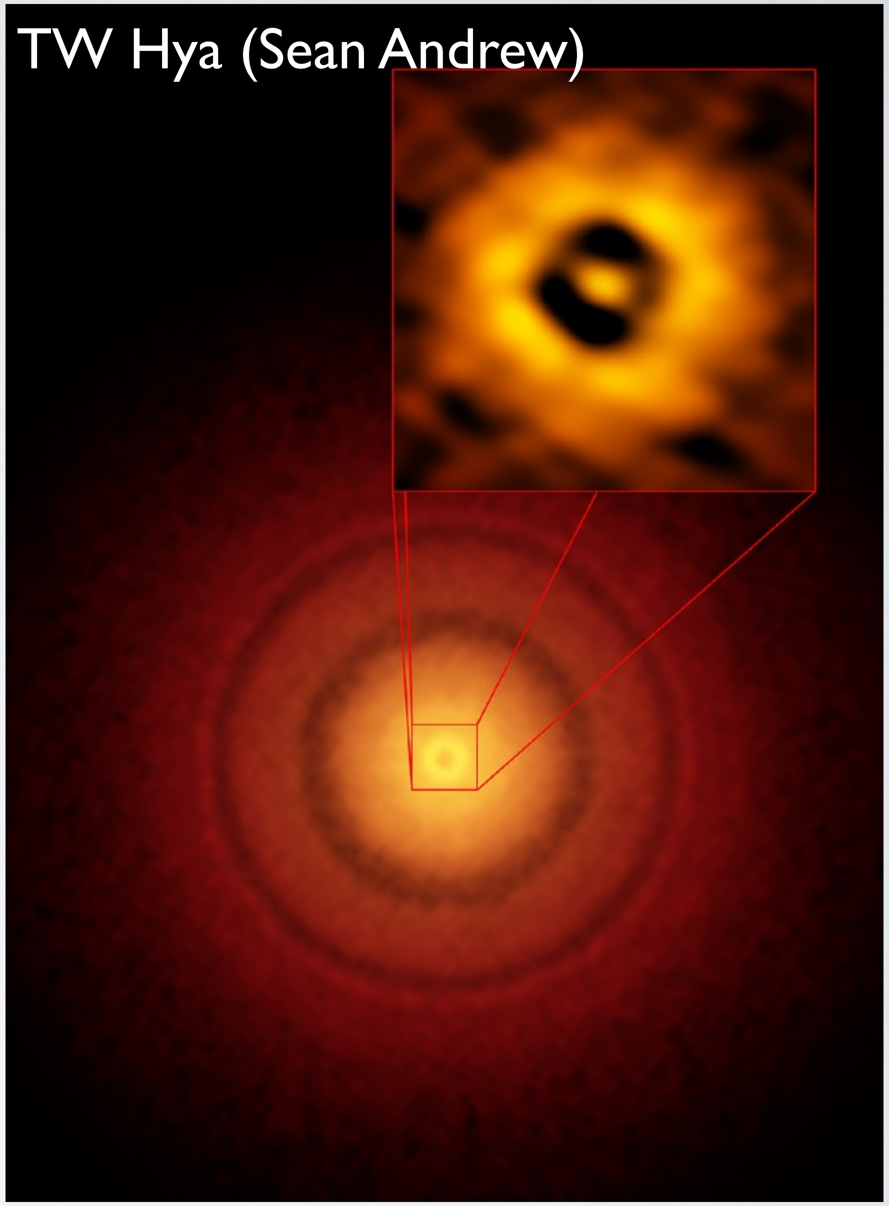
- Protoplanetary disk
  : Rotationally supported gas and dust disk around young pre-main sequence stars

- Importance for Star & Planet formation
  - Early phase of the star formation processes
  - Initial condition for planet formation
    - Mass, Temperature, Chemical composition, etc.

INTRODUCTION: TW HYA

- TW Hya
  - d ~ 54 pc [1]
  - Age ~ 3- 10 Myr [1]
  - $M_\star \sim 0.8\ M_\odot$ with $M_{disk} > 0.05\ M_\odot$ [1]
  - Multiple ring structure [2,3,4]

    1. Dynamics:
       - Disk-Protoplanet interaction?[5,6,7,8]
       - Secular Gravitational instability?[9,10]
    2. Chemistry:
       - Dust growth or destruction at the location of snowlines [11,12]
       - Baroclinic instability induced by dust settling[13]



[1] Andrew et al. 2012, [2] Andrew et al. 2016, [3] Nomura et al. 2016, [4] Tsukagoshi et al. 2016 [5]Kanagawa et al. 2015, [6]Kanagawa et al. 2016, [7]Dipierro et al. 2015 , [8]Dong et al. 2015 , [9]Youdin 2011, [10]Takahashi & Inutsuka 2014, [11]Zhang et al. 2015, [12]Okuzumi et al. 2016, [13]Loren-Aguilar & Bate 2015

PREVIOUS WORK

- The origin of the gaps?
- Under some simple assumptions

$$I_\nu(R) = B_\nu(T_d(R))(1-exp[-\tau_\nu])$$

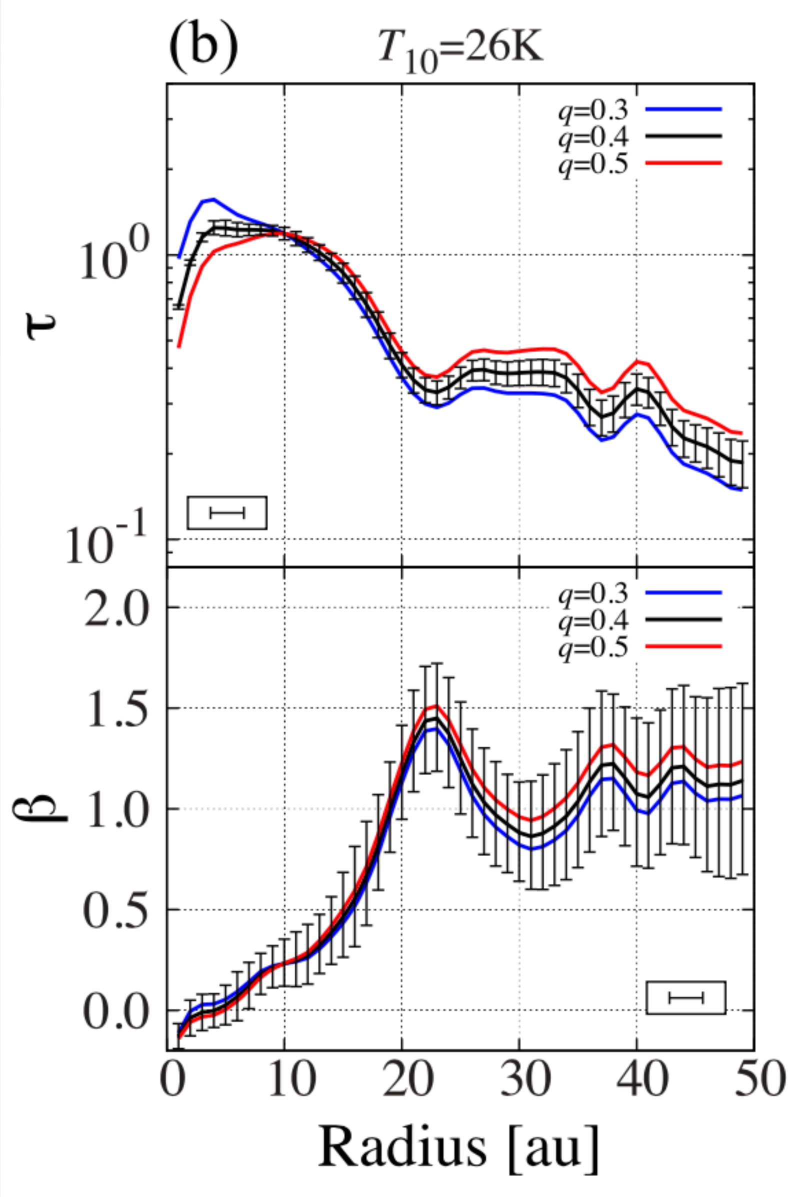
$$\kappa_\nu \propto \nu^\beta$$

$$\alpha(R) = \frac{d\log(I_\nu)}{d\log\nu} = 3 - \frac{h\nu}{k_B T_d(R)} \frac{e^{h\nu/k_B T_d(R)}}{e^{h\nu/k_B T_d(R)}-1} + \beta(R) \frac{\tau_\nu(R)}{e^{\tau_\nu(R)}-1}$$

$$T_d = 26\left(\frac{r}{10AU}\right)^q \quad where \quad q=0.3-0.5$$

Dust continuum of Band 4+6 & spectral index α

⇒ Estimation of τ_ν & β



Tsukagoshi et al. 2016)

- A Bump of β at a gap at ~22 AU ⇒ The existence of planet?

SENSITIVITY PROBLEM IN ANALYSIS

- Adding Band 7 data,

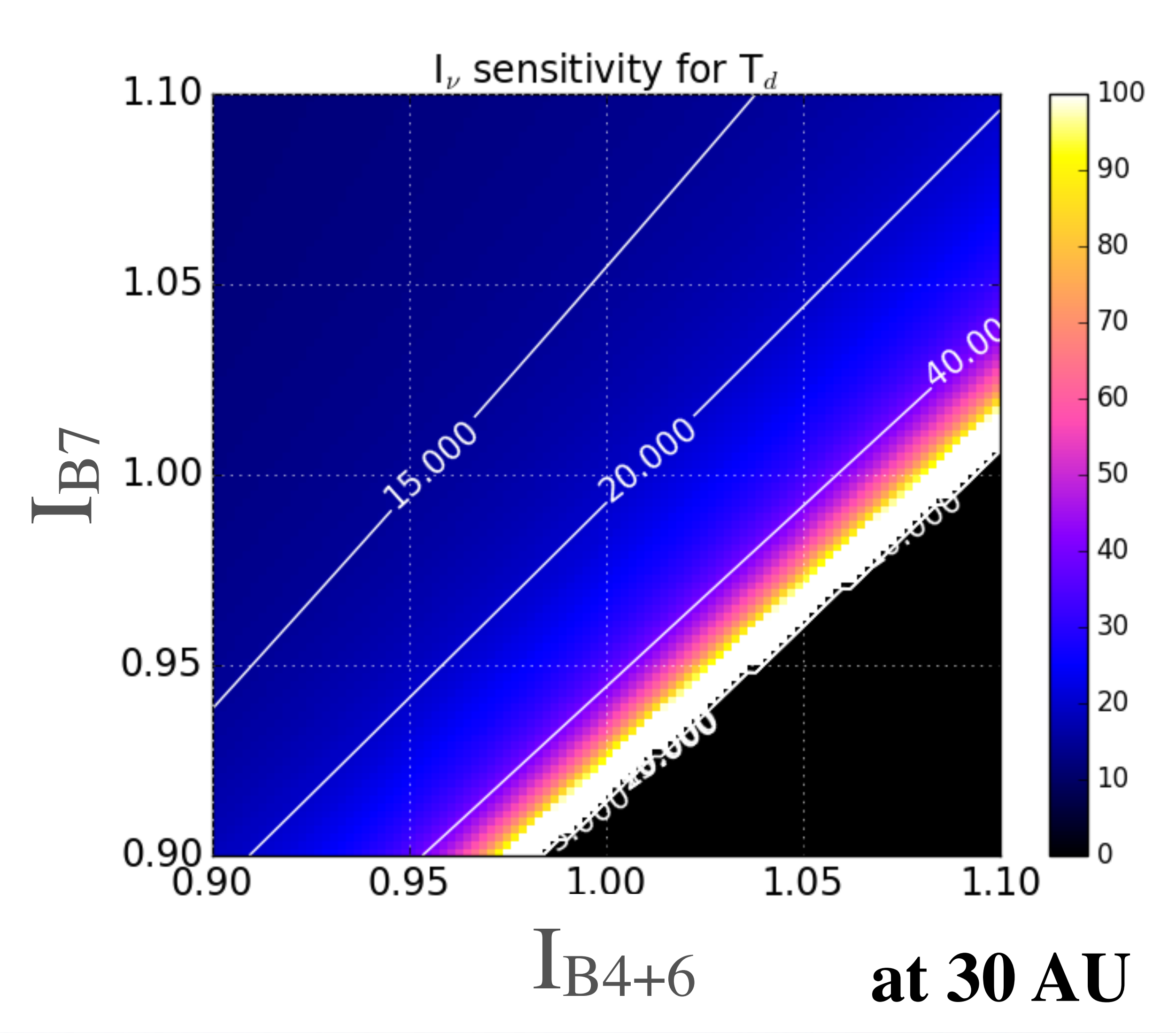
  Andrews+2016

$$I_\nu(R) = B_\nu(T_d(R))(1 - exp[-\tau_\nu])$$

$$\kappa_\nu \propto \nu^\beta$$

$$\alpha(R) = \frac{d\log(I_\nu)}{d\log\nu} = 3 - \frac{h\nu}{k_B T_d(R)} \frac{e^{h\nu/k_B T_d(R)}}{e^{h\nu/k_B T_d(R)} - 1} + \beta(R) \frac{\tau_\nu(R)}{e^{\tau_\nu(R)} - 1}$$

$\Rightarrow T_d$, τ_ν & β



- A large bump at 30 AU

  ∵ The error in T_d has high sensitivity to the observational error

✓ What is the best set of 3 ALMA bands??

SYNTHETIC ALMA MULTIBAND OBSERVATION: MODEL VALUES

- Calculate $I_{\nu,\mathrm{model}}$ from assumed $T_{d,\mathrm{model}}$ and $\tau_{\nu,\mathrm{model}}$ & β_{model}

$$I_\nu(R) = B_\nu(T_d(R))\,(1 - exp[-\tau_\nu])$$

$$\kappa_\nu \propto \nu^\beta$$

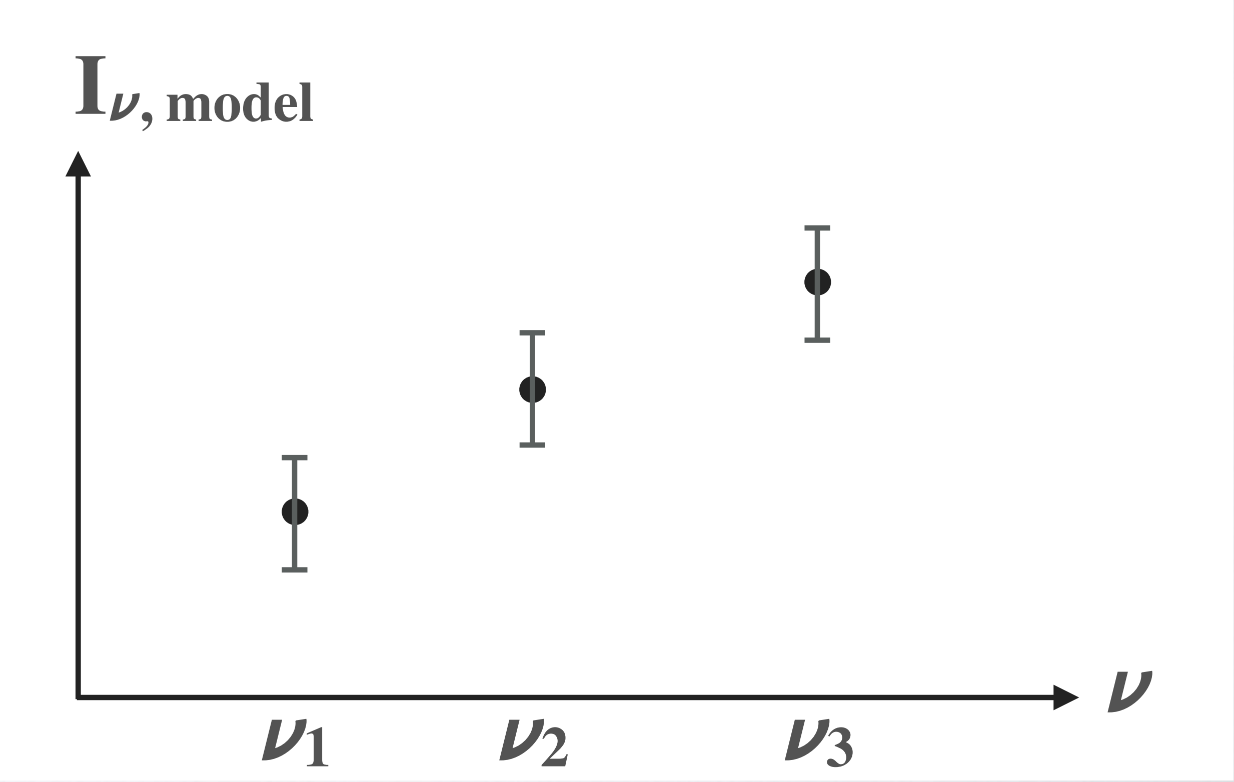
$$\alpha(R) = \frac{d\log(I_\nu)}{d\log\nu} = 3 - \frac{h\nu}{k_B T_d(R)}\frac{e^{h\nu/k_B T_d(R)}}{e^{h\nu/k_B T_d(R)} - 1} + \beta(R)\frac{\tau_\nu(R)}{e^{\tau_\nu(R)} - 1}$$

$T_{d,\mathrm{model}}(R) = 26K(R/10AU)^{0.4}$

+

$\tau_{\nu,\mathrm{model}}(R)$ & $\beta_{\mathrm{model}}(R)$ from

ALMA Band 4+6

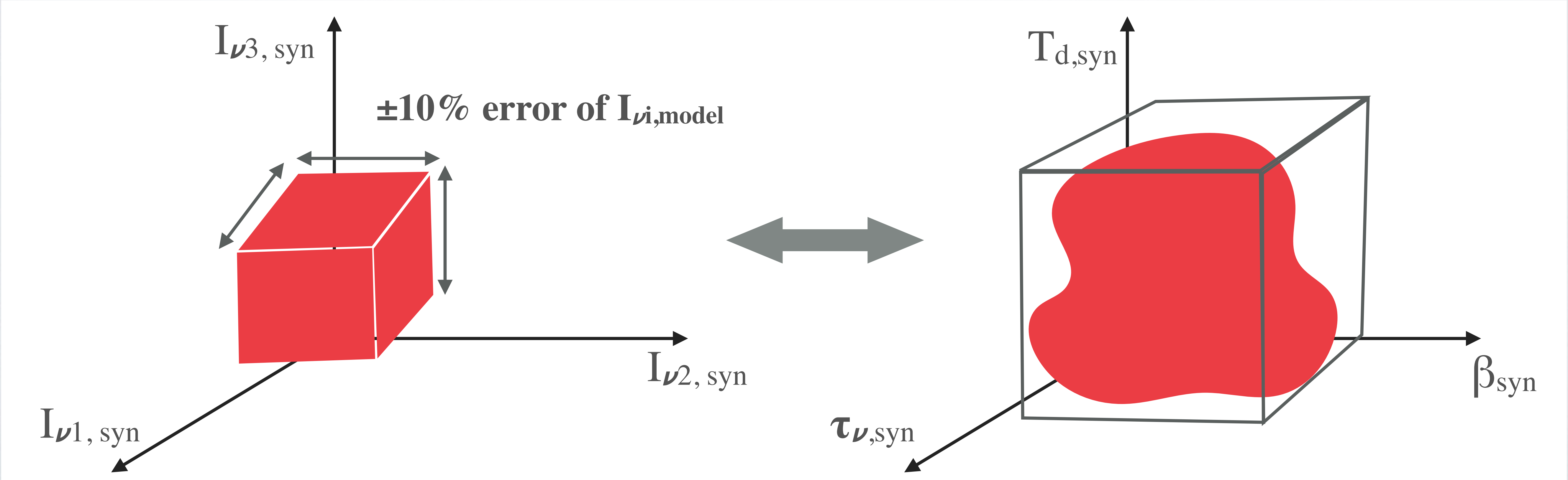


SYNTHETIC ALMA MULTIBAND OBSERVATION: SENSITIVITY ANALYSIS

- Obtain $T_{d,syn}$, $\tau_{\nu,syn}$ & β_{syn} which satisfy $I_{\nu,syn}$ within ±10% error of $I_{\nu,model}$ at 3 bands

$$I_\nu(R) = B_\nu(T_d(R))\,(1-exp[-\tau_\nu])$$

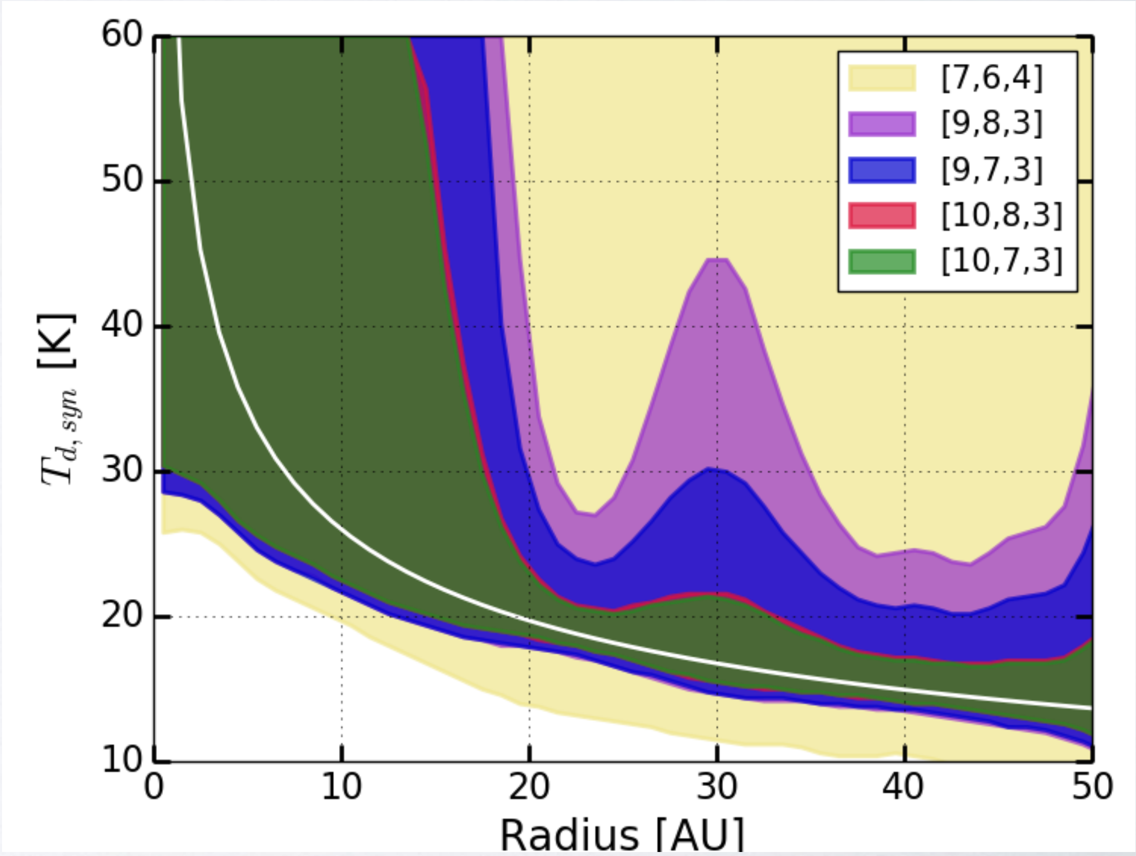
$$\kappa_\nu \propto \nu^\beta$$



RESULT

- All possible combinations of 3 bands among ALMA Band [3, 4, 5, 6, 7, 8, 9, 10].
  - The best set is Band [10, 7,3]

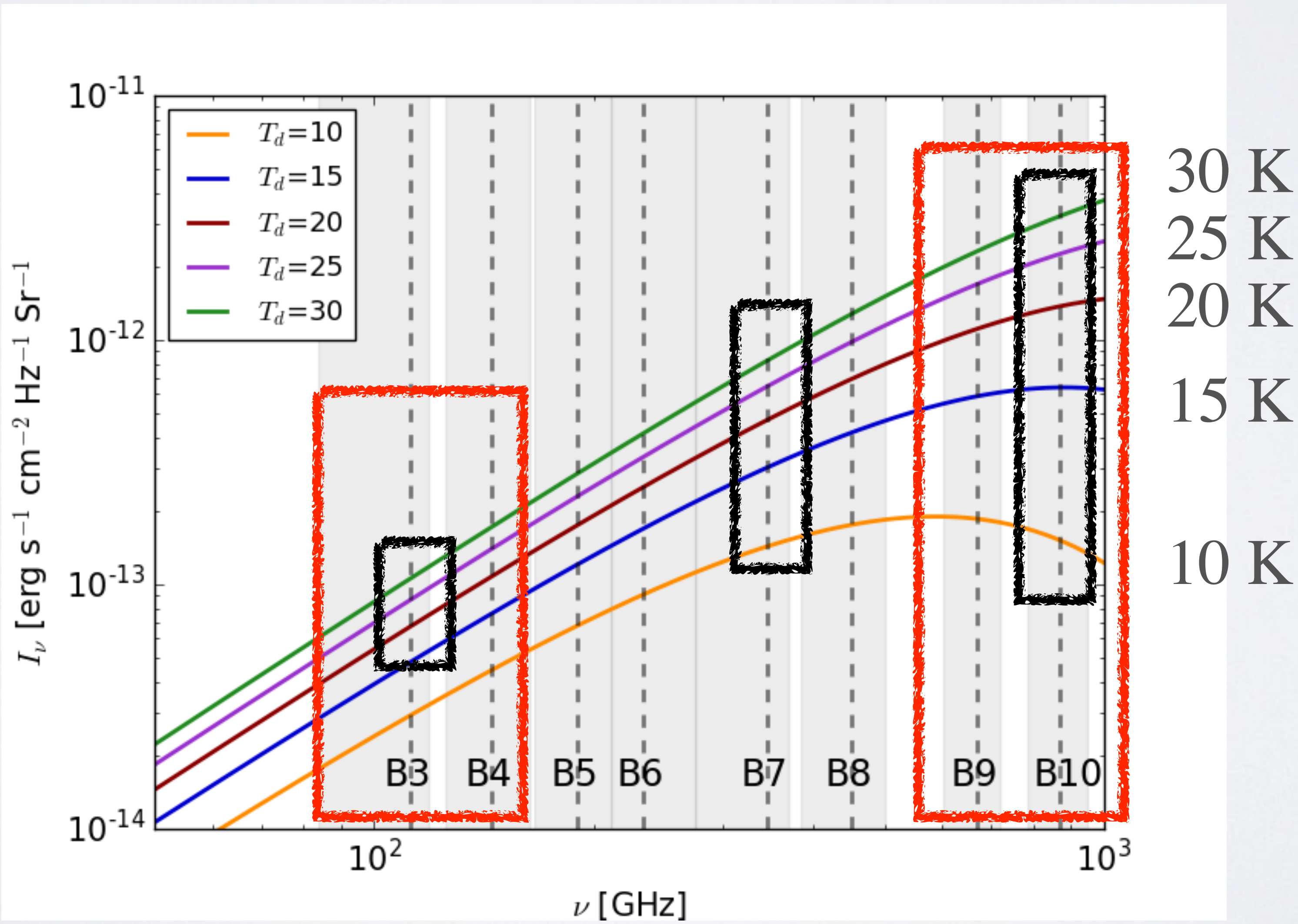
- 2 conditions for good constraint on the $T_{d,syn}$, $\tau_{\nu,syn}$ & β_{syn}
  1. One of [9,10] + One of [3,4]
  2. One more band which has enough frequency interval between the selected bands



$T_{d,model}(R)=26\ K(R/10AU)^{0.4}$

RESULT

- We can constrain T_d, τ_ν & β with combined one band from 9 or 10 and one band from 3 or 4 ($\tau \ll 1$)
- Enough frequency interval constrain T_d, τ_ν & β more accurately



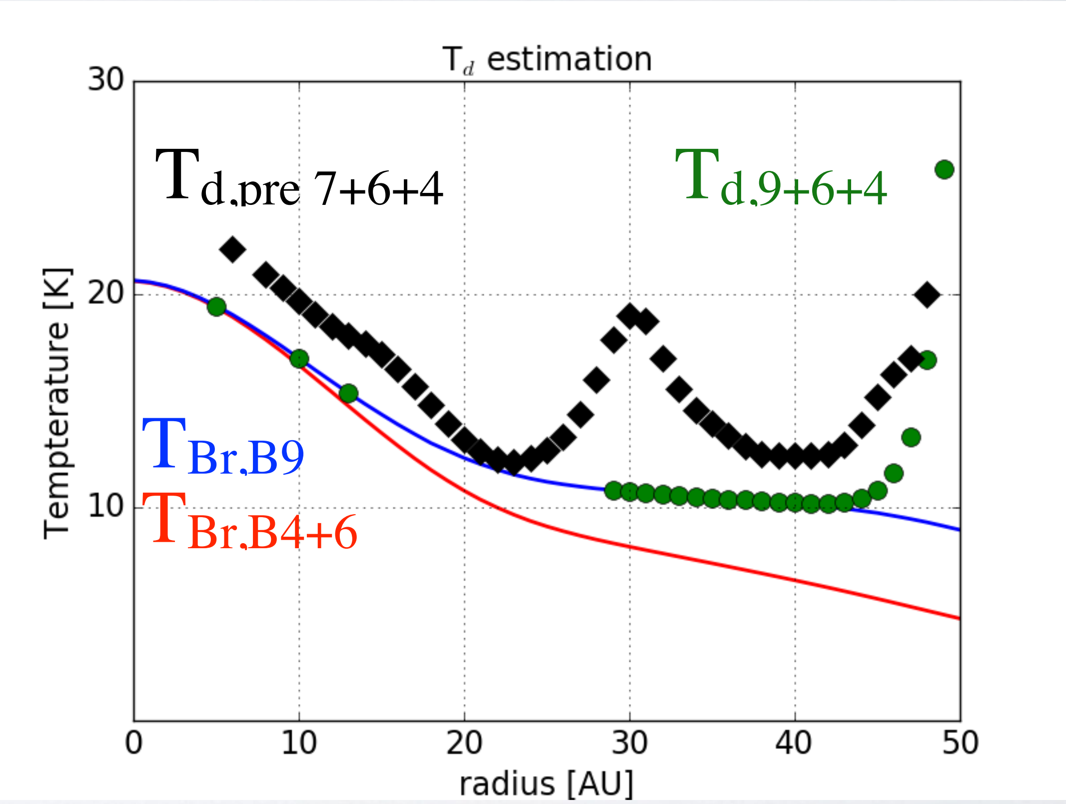
DISCUSSION & FUTURE WORKS

- Applying to observation data of Band [9,6,4]
  Band 9 **(Schwarz+2016)** + Band 4 & 6 **(Tsukagoshi+2016)**

Band [9,6,4] ~ 0.387"×0.218"

vs

Band [7,6,4] ~ 0.088"×0.062"



- We should think about

1. The assumption of $\kappa_\nu \propto \nu^\beta$
2. The vertical structure of the disk

SUMMARY

- ALMA Multiband Analysis for constraining T_d, τ_ν & β of TW Hya PPD
  - Analysis of ALMA Band [7,6,4] observations
    : We find a large bump around 30 AU in $T_d(R)$

  ➡ It's caused by high sensitivity to observational error

- Synthetic Multiband Analysis
  : We find 2 conditions for good constraint on T_d, τ_ν & β

  1. One of Band [9,10] + One of Band [3,4]
  2. One more band which has enough frequency interval between the selected bands