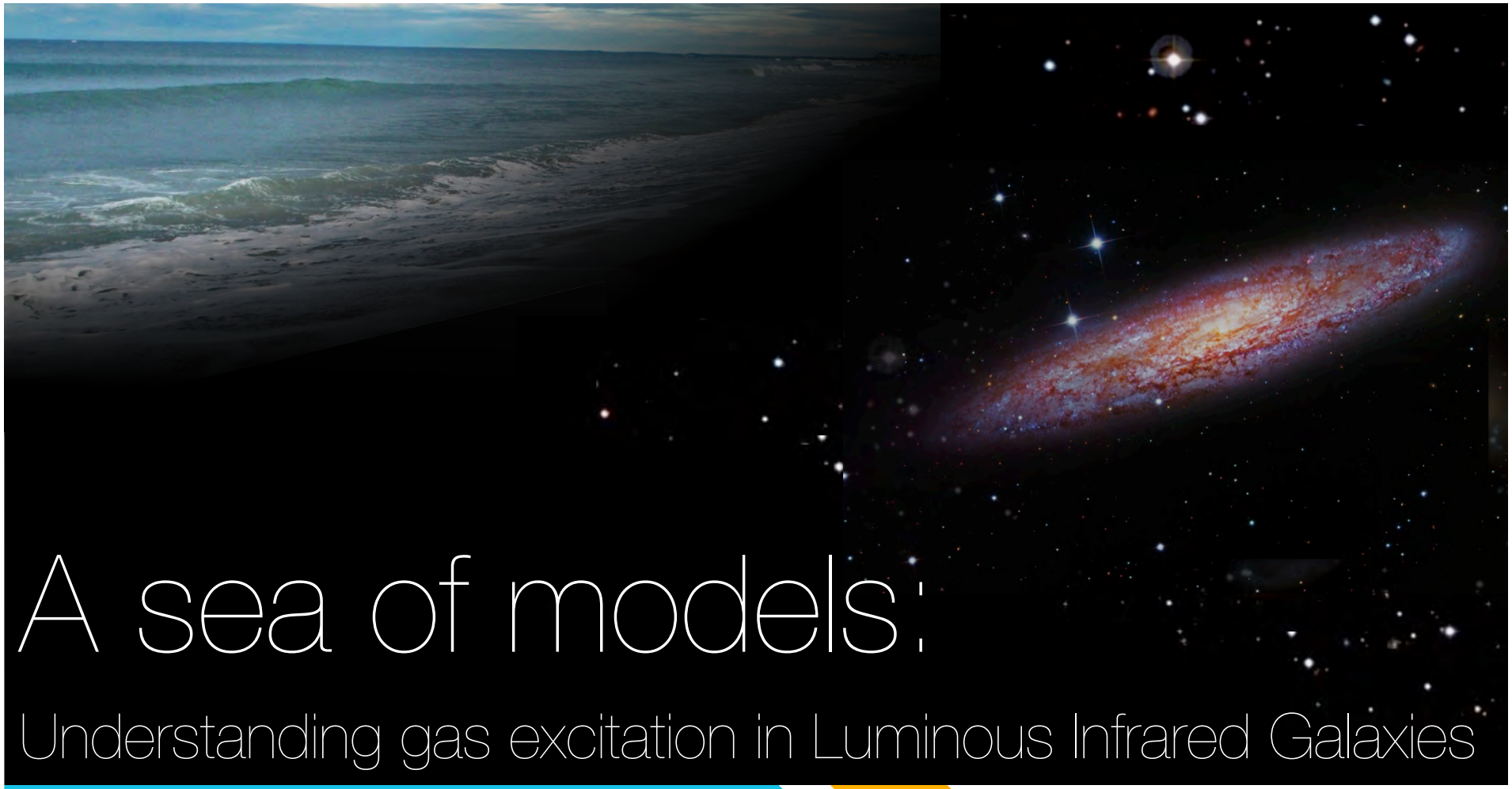

A sea of models:

Understanding gas excitation in Luminous Infrared Galaxies

Marissa **Rosenberg**

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Collaborators: P.P. van der Werf, F.P. Israel, M. Kazandjian, R. Meijerink

Outline

- NGC 253: A nearby laboratory

- Automated fitting method

- Heating mechanisms
  - Photo-Electric Heating
  - X-ray
  - Cosmic Ray
  - Mechanical Heating

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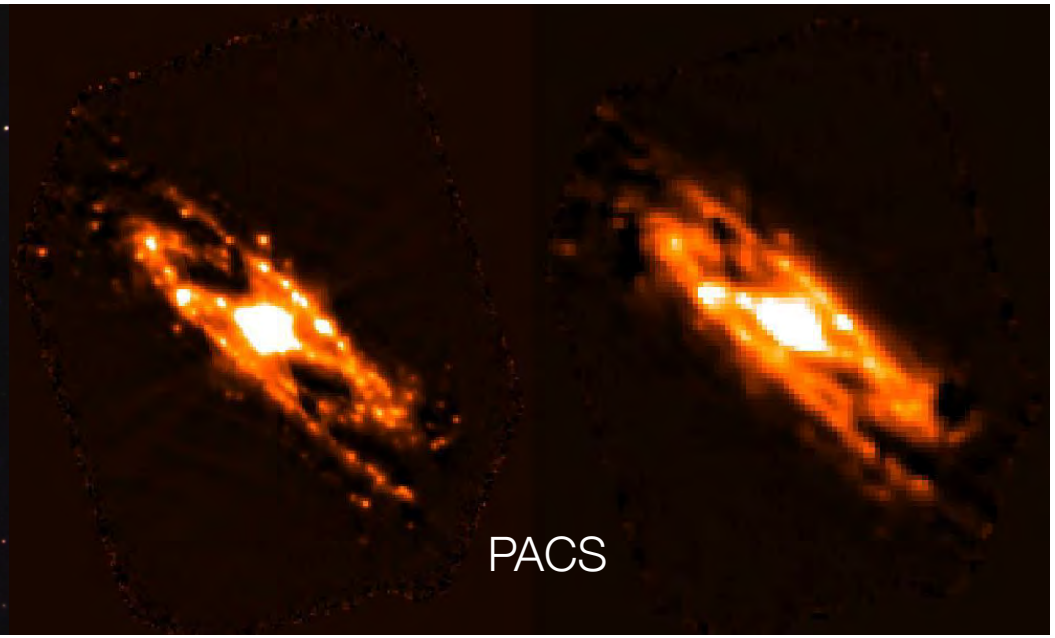
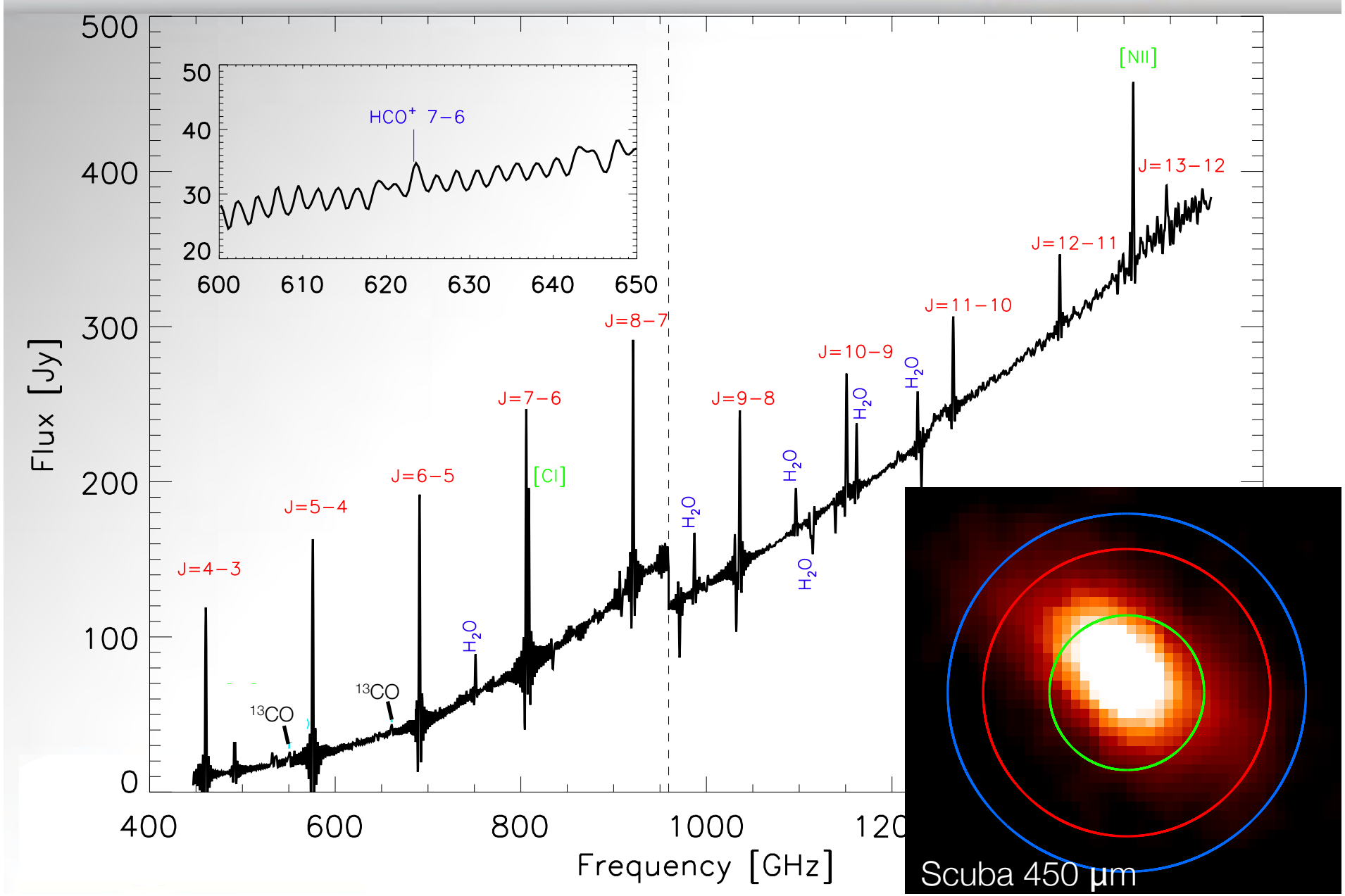
NGC 253

- Nearby case study
- 2.5 Mpc (1”≈12pc)
- Starburst in inner 200 pc
- $L_{FIR}=2 \times 10^{10} L_{\odot}$
- Massive molecular outflows
- $\nu_{SN}=0.03$ year^{-1}
- High CR ionization rate



SPIRE Observations



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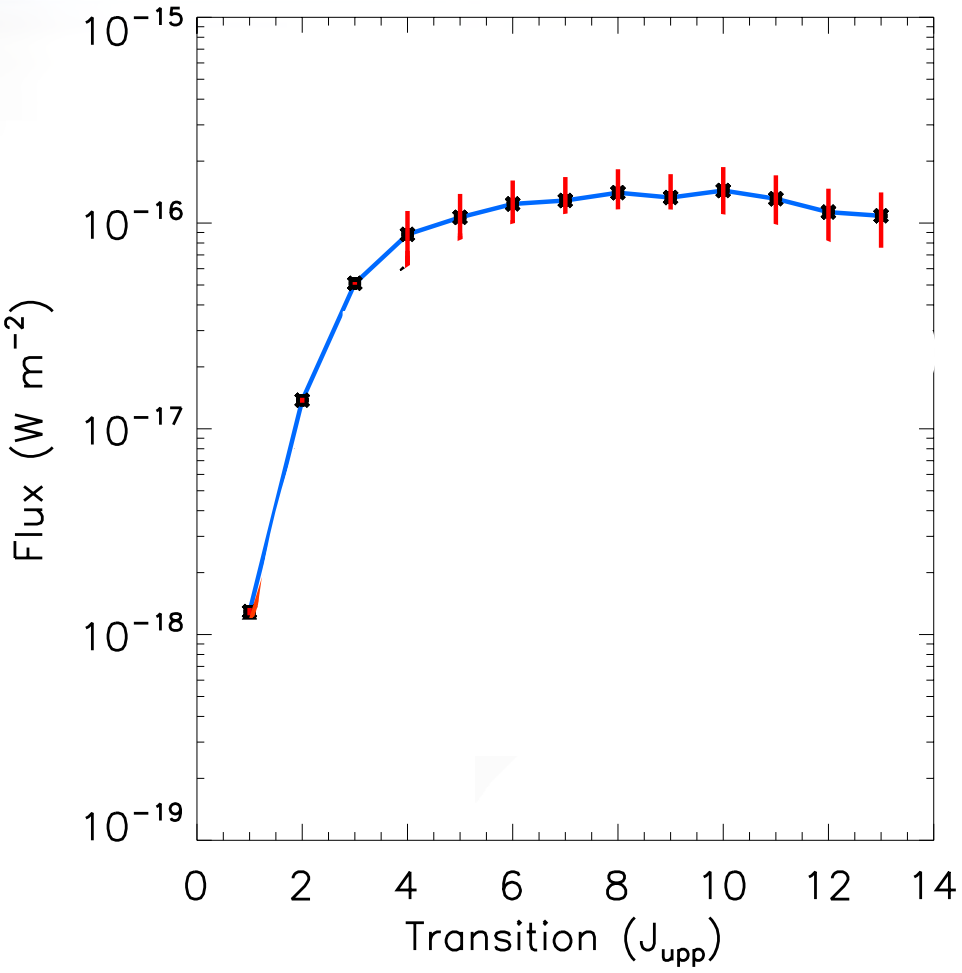
Fitting Method

1. Create ‘CO Ladder’



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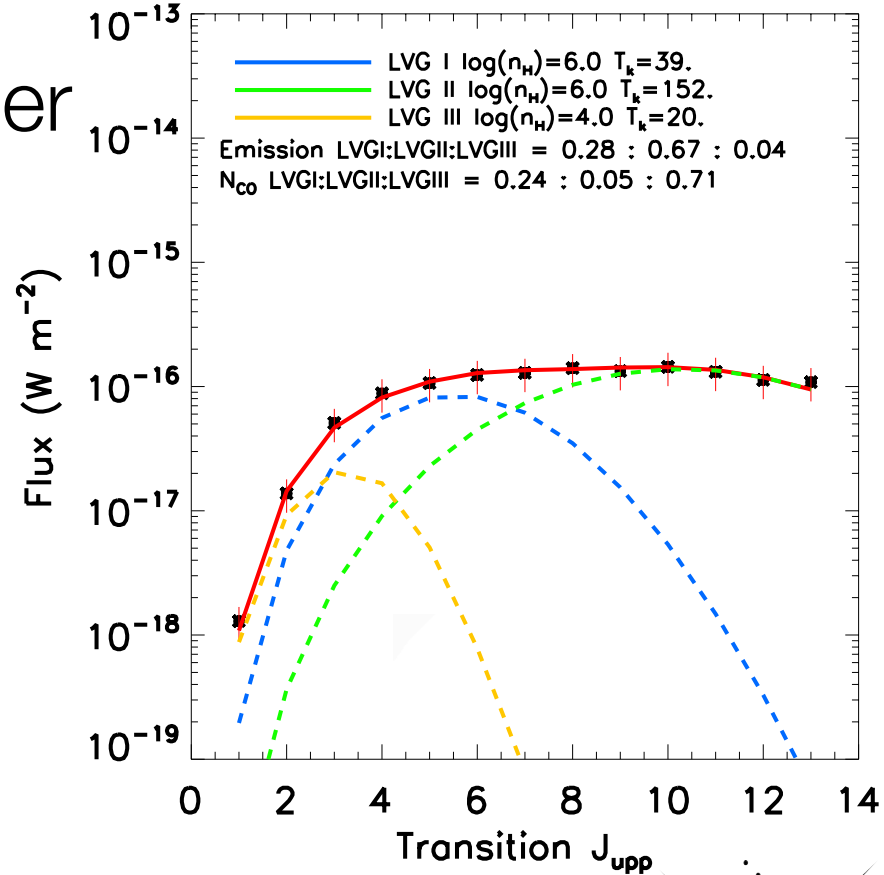
Fitting Method

1. Create ‘CO Ladder’
2. Use models to fit ladder
   - LVG models vary
     - $n_H, T_{kin}, N_{CO}, \delta v$



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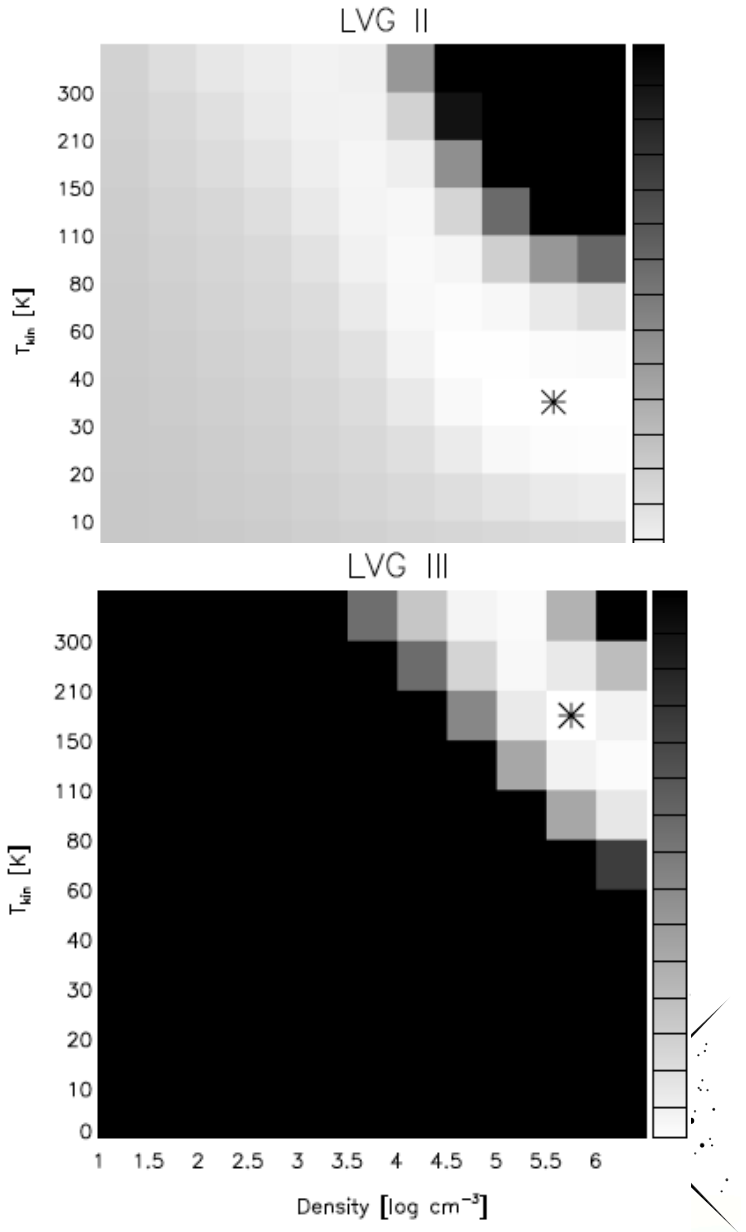
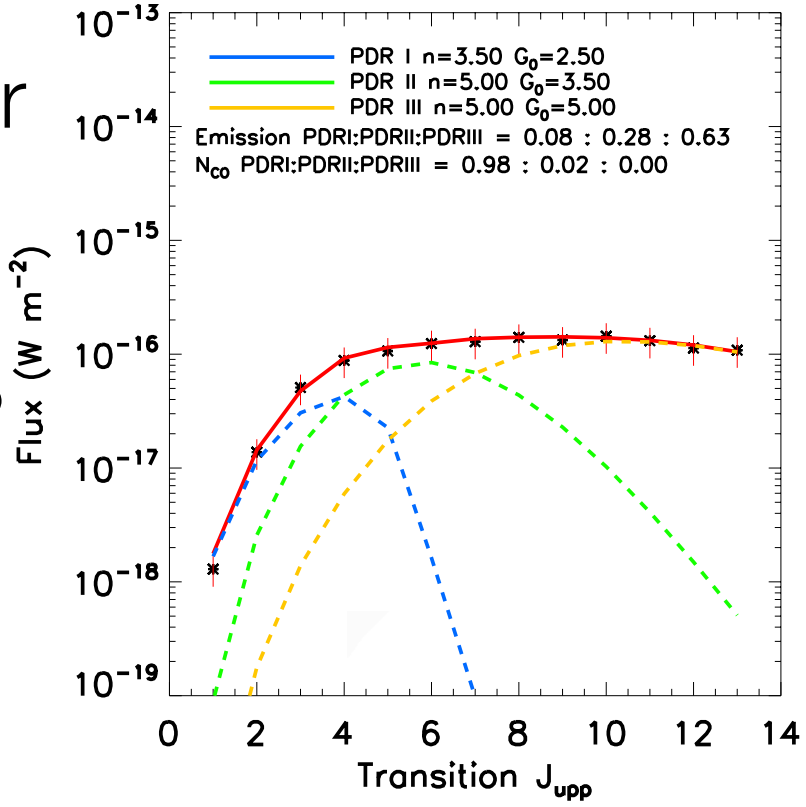
Fitting Method

1. Create ‘CO Ladder’
2. Use models to fit ladder
   - LVG models vary
     - $n_H, T_{kin}, N_{CO}, \delta v$
3. Constrain degeneracy?



Fitting Method

1. Create ‘CO Ladder’
2. Use models to fit ladder
   - LVG models vary
     - $n_H, T_{kin}, N_{CO}, \delta v$
3. Constrain degeneracy?
4. Use (3) as constraint:
   - PDR models vary
     - n_H, G_0, N_{H2}
   - Other models vary
     - F_x, $\Gamma_{mech}, \Gamma_{CR}$, ζ_{CR}



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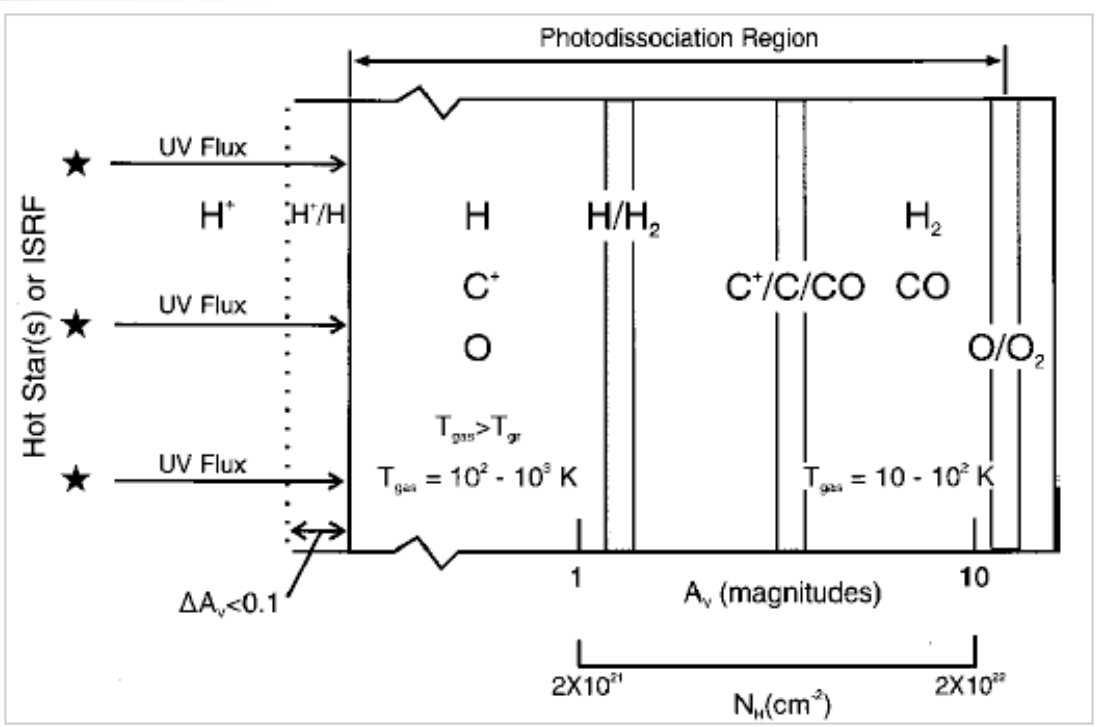
PDR Gas Excitation

- Photon Dominated Region (PDR)
- Surface Heating
- Molecular Layer A_V~5



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Modeling of PDR Emission

- Inputs
  - ^{12}CO and ^{13}CO (contains τ)
  - HCN and HNC (n_{crit} >10^5 cm^{-3})
  - Constraints based on LVG
- Outputs
  - Best fit model
    - n_H, G, N_{H2}, Γ
  - Relative filling factors

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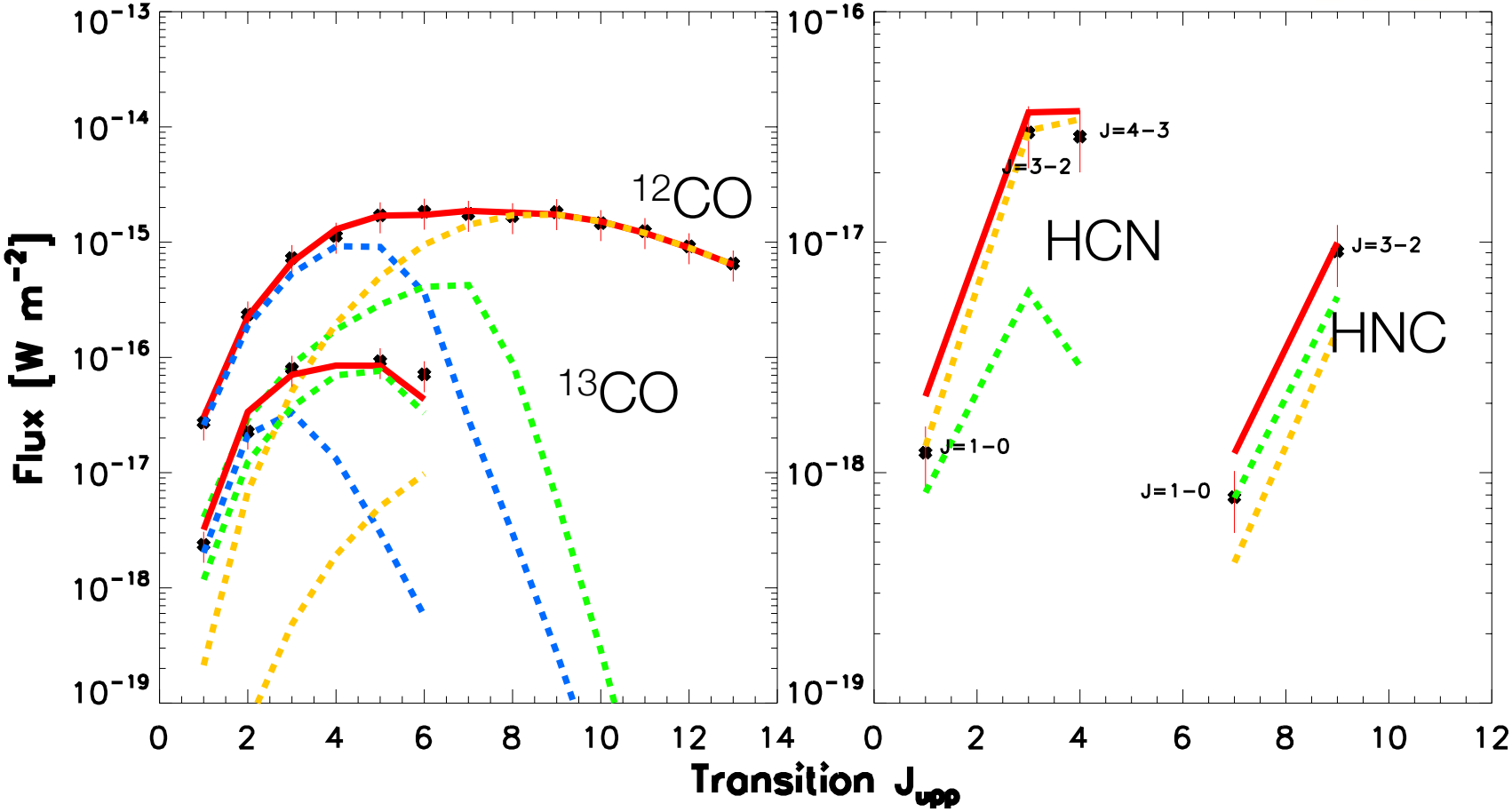
PDR Fit



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Is this physical?

- Is it possible for these 3 PDRs to heat the all the gas?
  - Find observed gas mass
    - Mass=N_{H2} x SA x m_{H2}
  - Find maximum mass of gas heated by PDR
    - Mass=n_{H} x $Volume_{PDR}$ x m_{H2}

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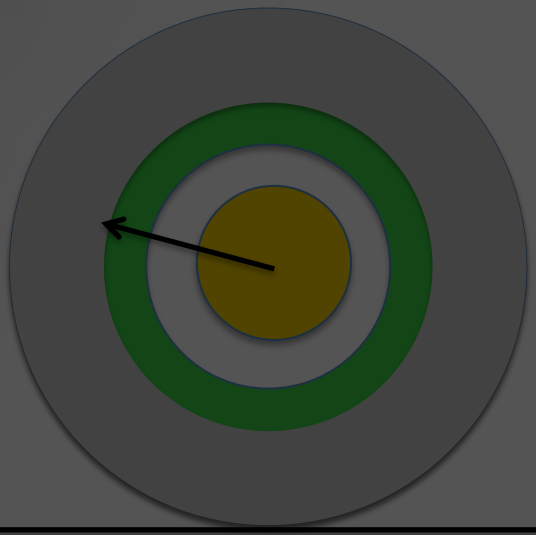
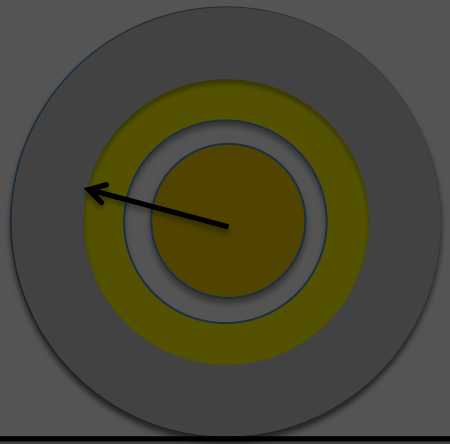
Mass Comparison





PDR I

$\log(n_H)=3.5$

$\log(G_0)=1.5$

$M_{G0}=8\times10^{8}$

$M_{obs}=9\times10^{6}$

PDR II

$\log(n_H)=5.0$

$\log(G_0)=1.0$

$M_{G0}=8\times10^{5}$

$M_{obs}=1\times10^{7}$

PDR III

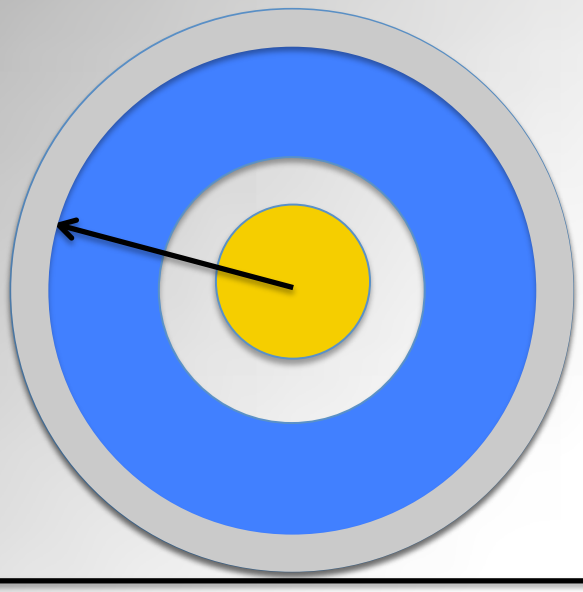
$\log(n_H)=5.0$

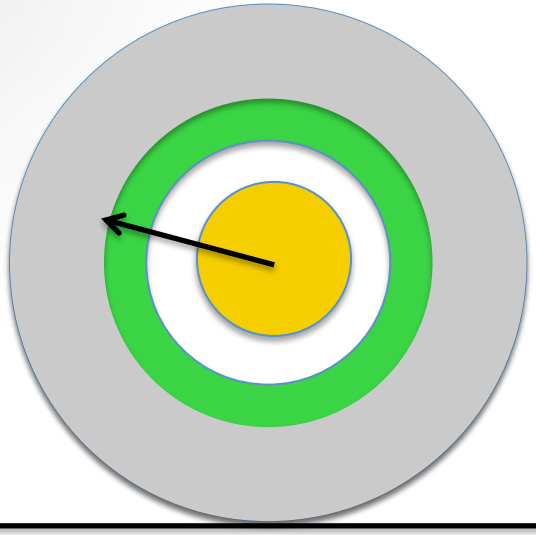
$\log(G_0)=4.5$

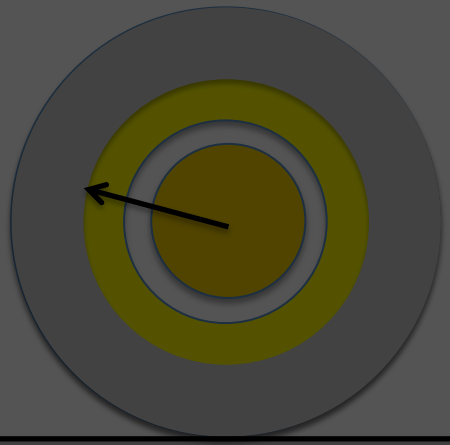
$M_{G0}=8\times10^{5}$

$M_{obs}=3\times10^{6}$

Mass Comparison







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PDR III

$\log(n_H)=5.0$

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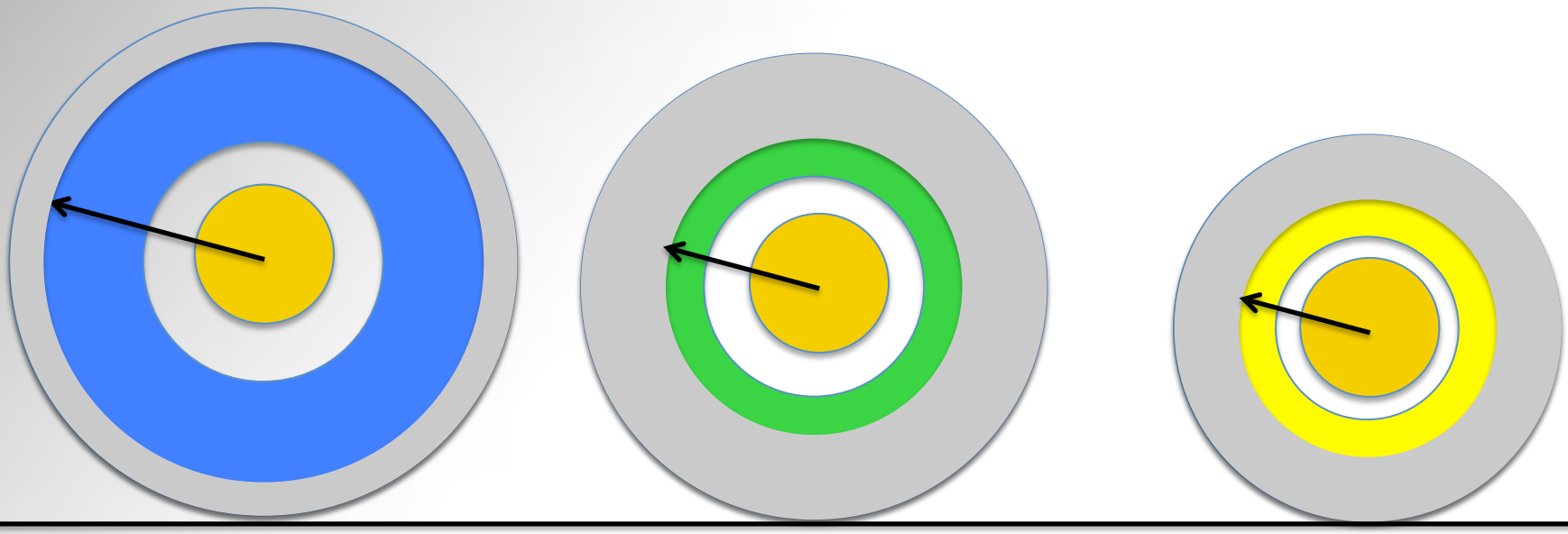
Mass Comparison



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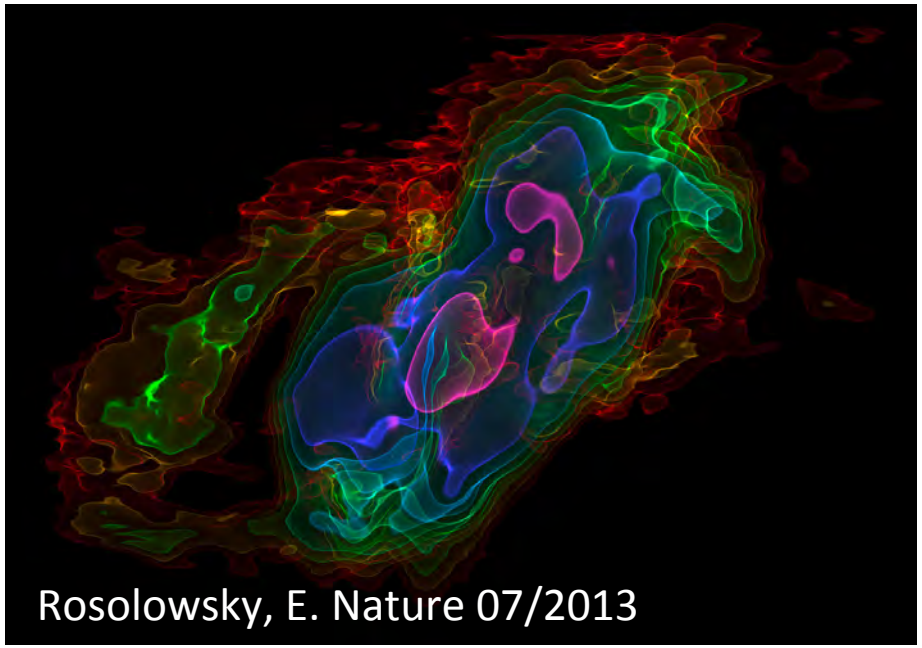
Other Heating Mechanism

- XDR
  - No X-ray bright AGN
    - Unlikely
- CDR
  - Bradford+ (2007)→CRs are main heating source
  - $\zeta_{NGC253}=750 \times \zeta_{Gal}$
- Mechanical Heating
  - [FeII], SiO
  - Molecular Outflow
  - ν_{SN}=0.03 SN/year



Rosolowsky, E. Nature 07/2013

Sea of Models

- **PDR** – Photon dominated region
- **mPDR** – PDR with constant Γ_{mech}
  - $\alpha = \Gamma_{mech} : \Gamma_{PDR,surface}$
  - ζ_{Gal}
- **mCDR** - Same as mPDR *except*
  - ζ=750 x ζ_{Gal}
  - *Allows* for Γ_{mech}

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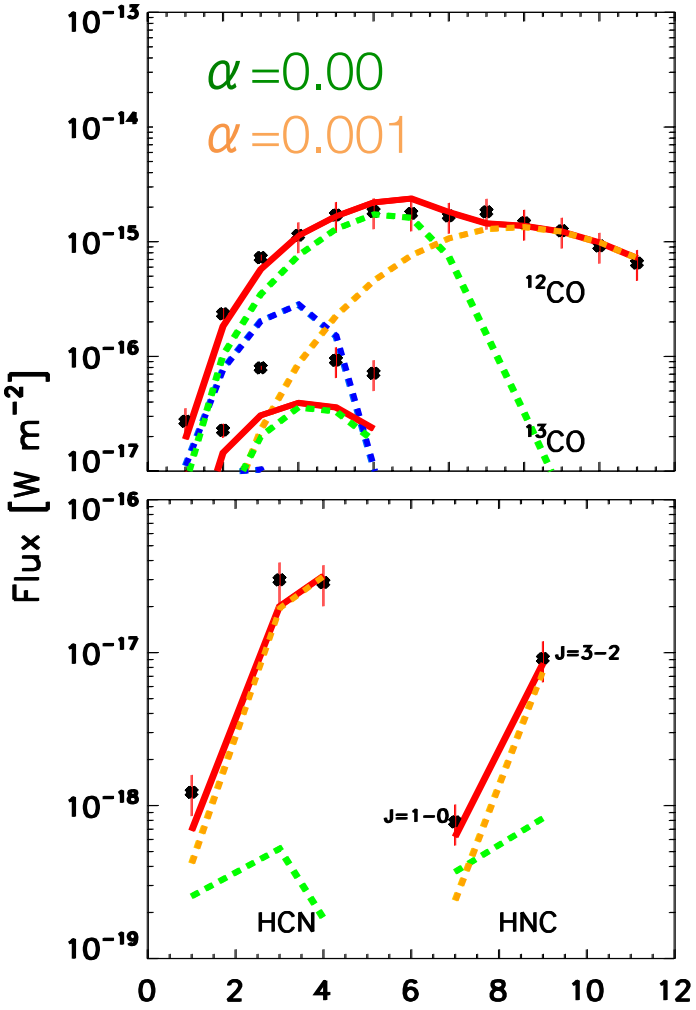
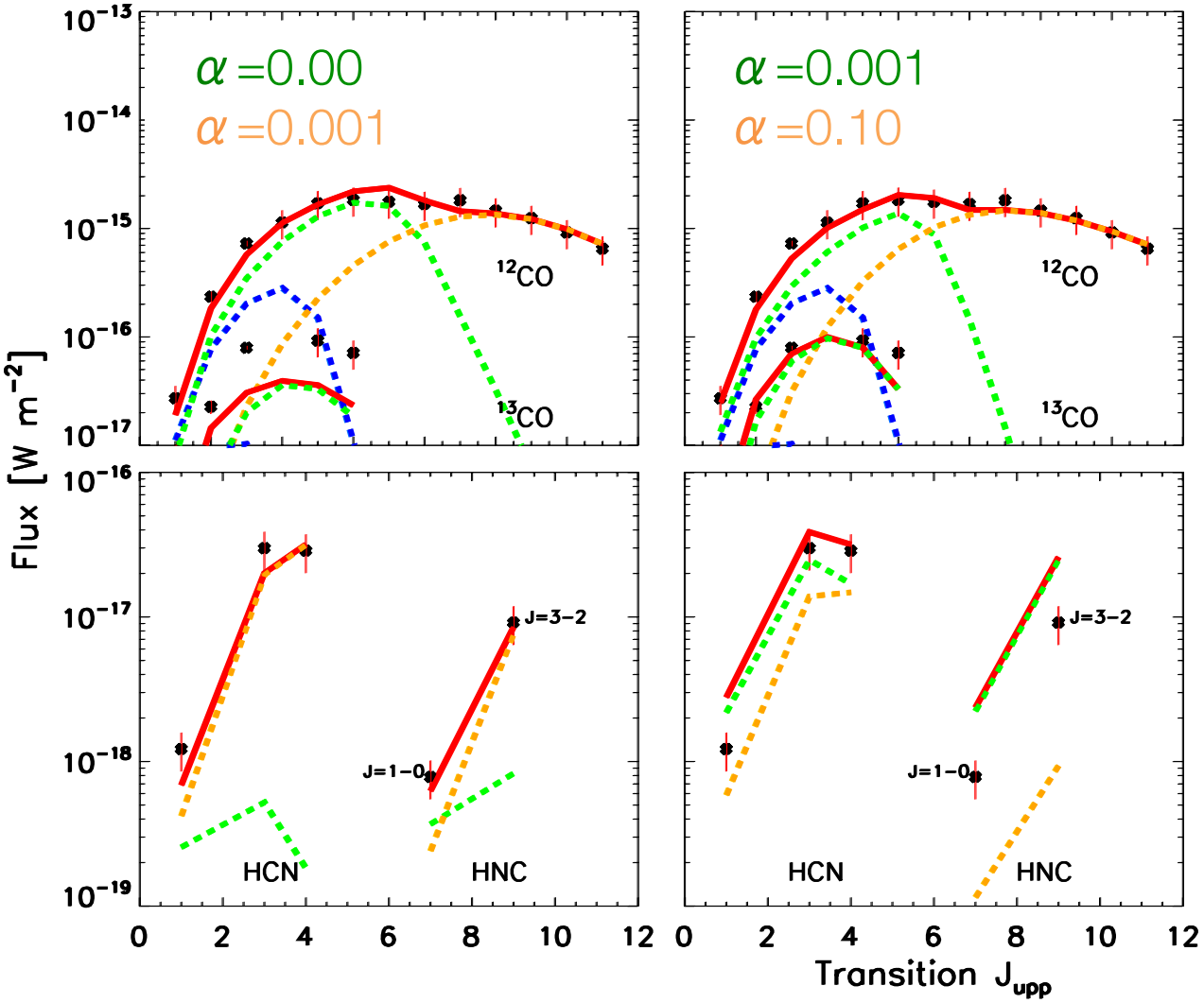
Best Fit?

PDR **C**DR m**C**DR

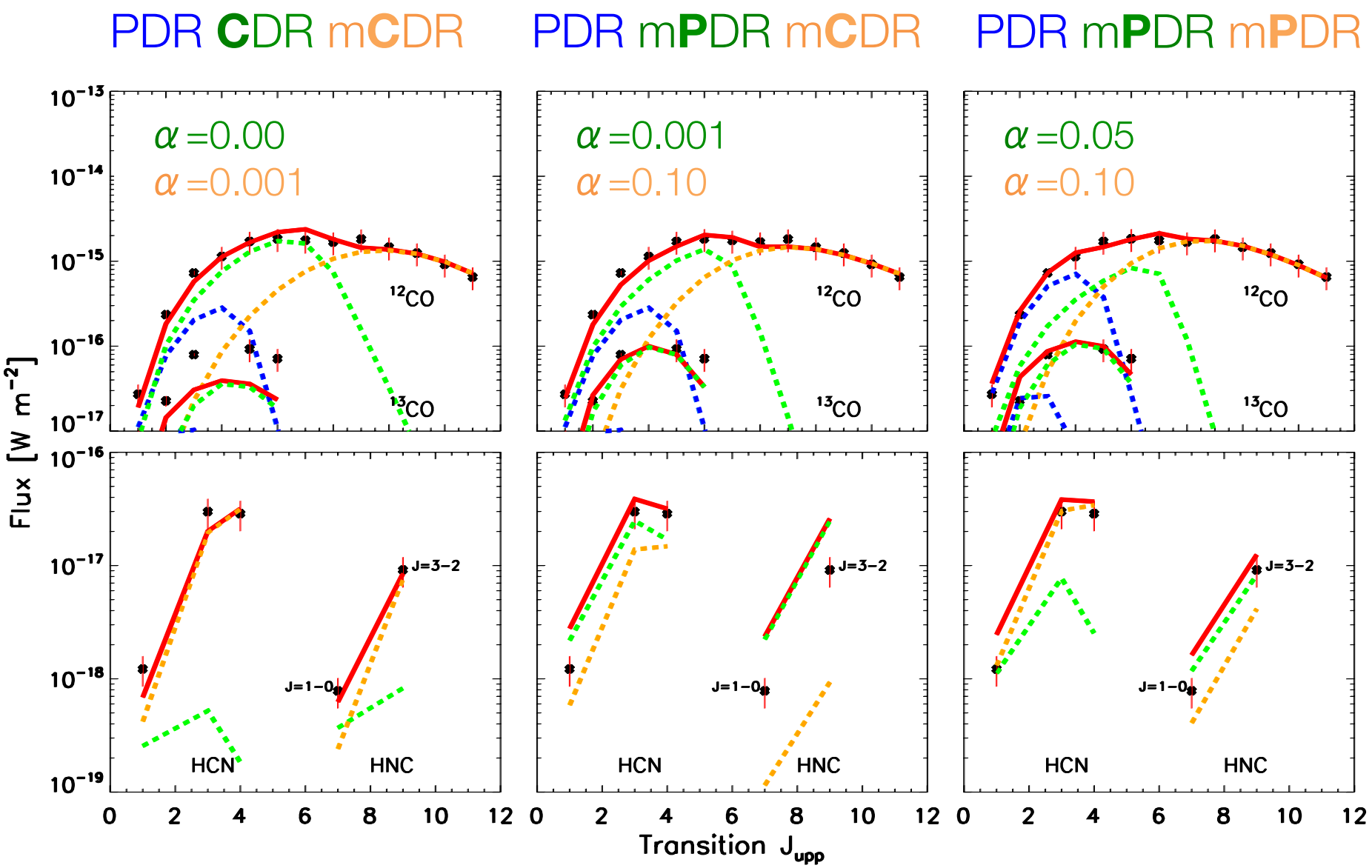


Best Fit?

PDR **C**DR m**C**DR PDR m**P**DR m**C**DR



Best Fit?


PDR CDR mCDR
PDR mPDR mCDR
PDR mPDR mPDR
α =0.00
α =0.001
α =0.001
α =0.10
α =0.05
α =0.10
12CO
13CO
HCN
HNC
J=1−0
J=3−2
Flux [W m−2]
Transition Jupp

Heating Comparison

Total
UV
CR
Mech

Increasing A_V

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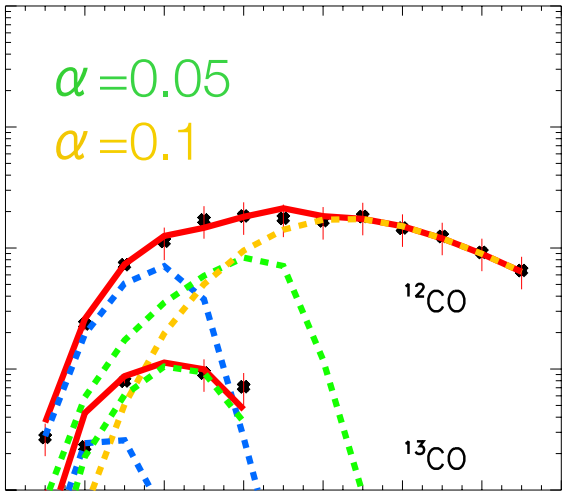
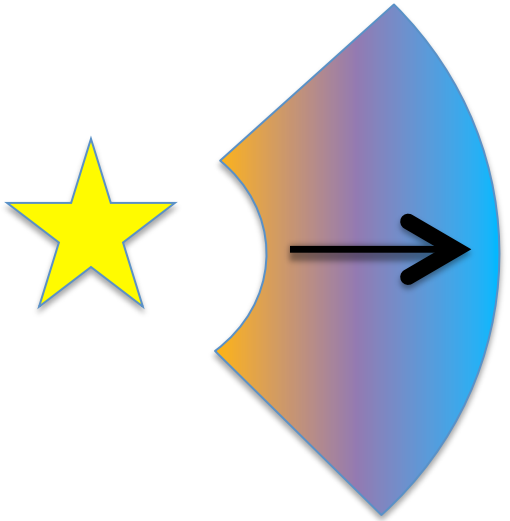
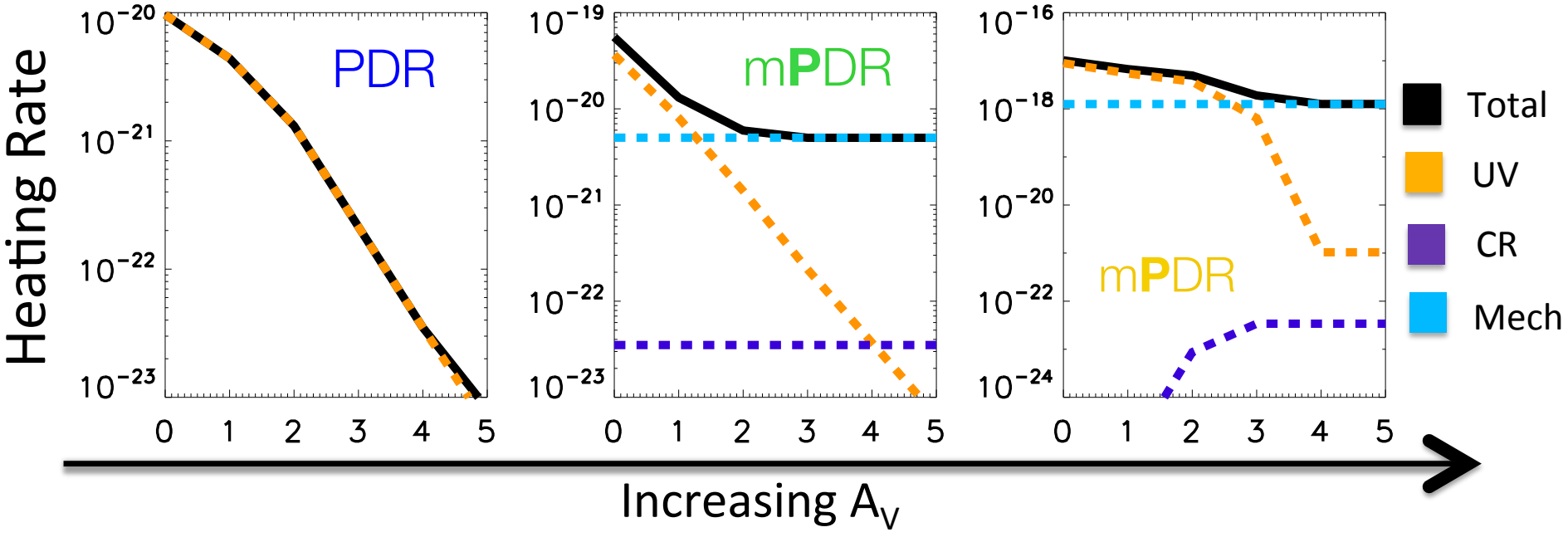
Heating Comparison







NGC 253 Conclusions

- 3 main ISM components
- Need mechanical heating
- Cannot rule out high CR
- **Mechanical heating dominates by A_V=3!**

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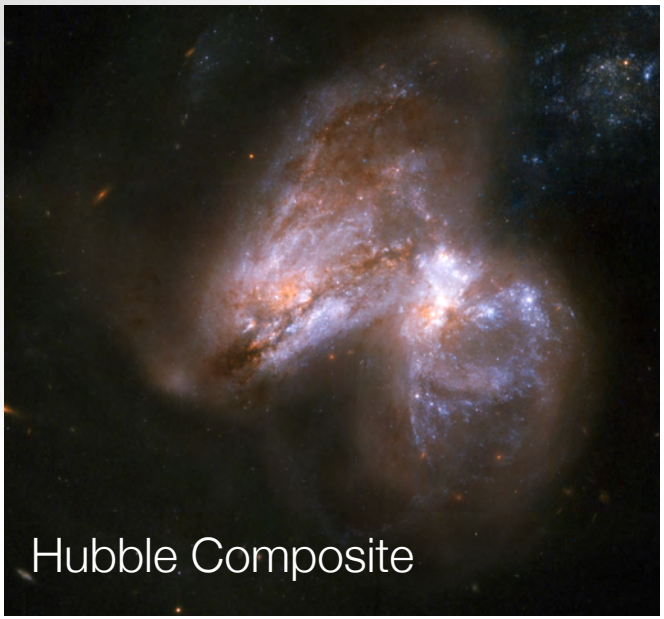
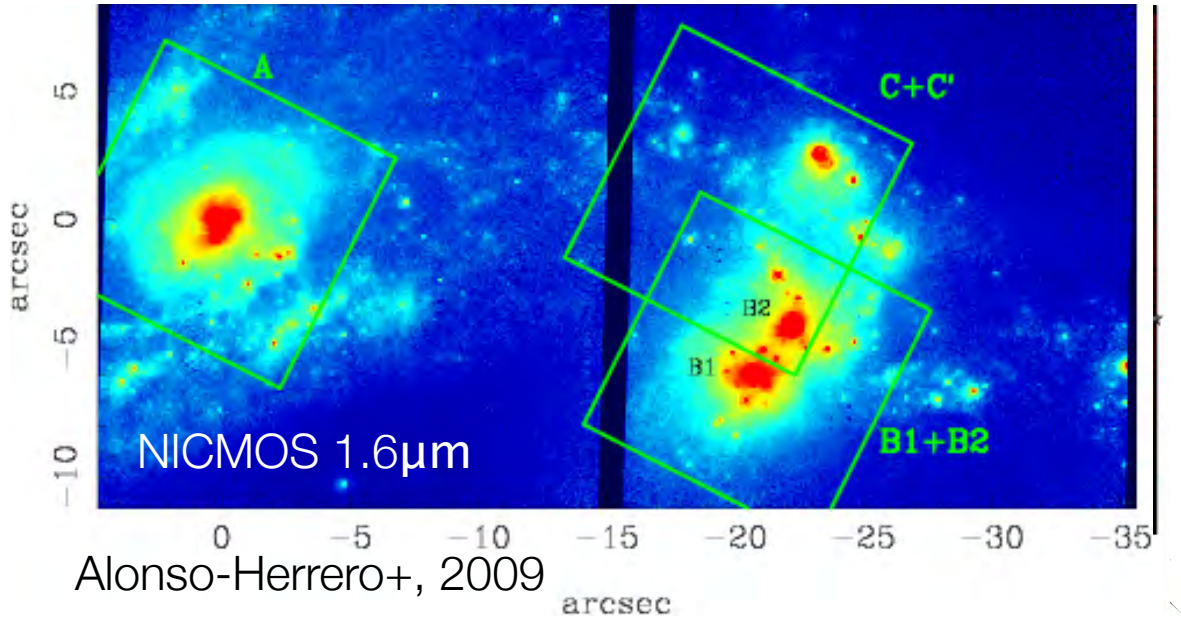
Arp 299

- Nearby LIRG
- 48.1 Mpc (1”≈230 pc)
- Interacting galaxies
- $L_{FIR}=7.6 \times 10^{11} L_{\odot}$

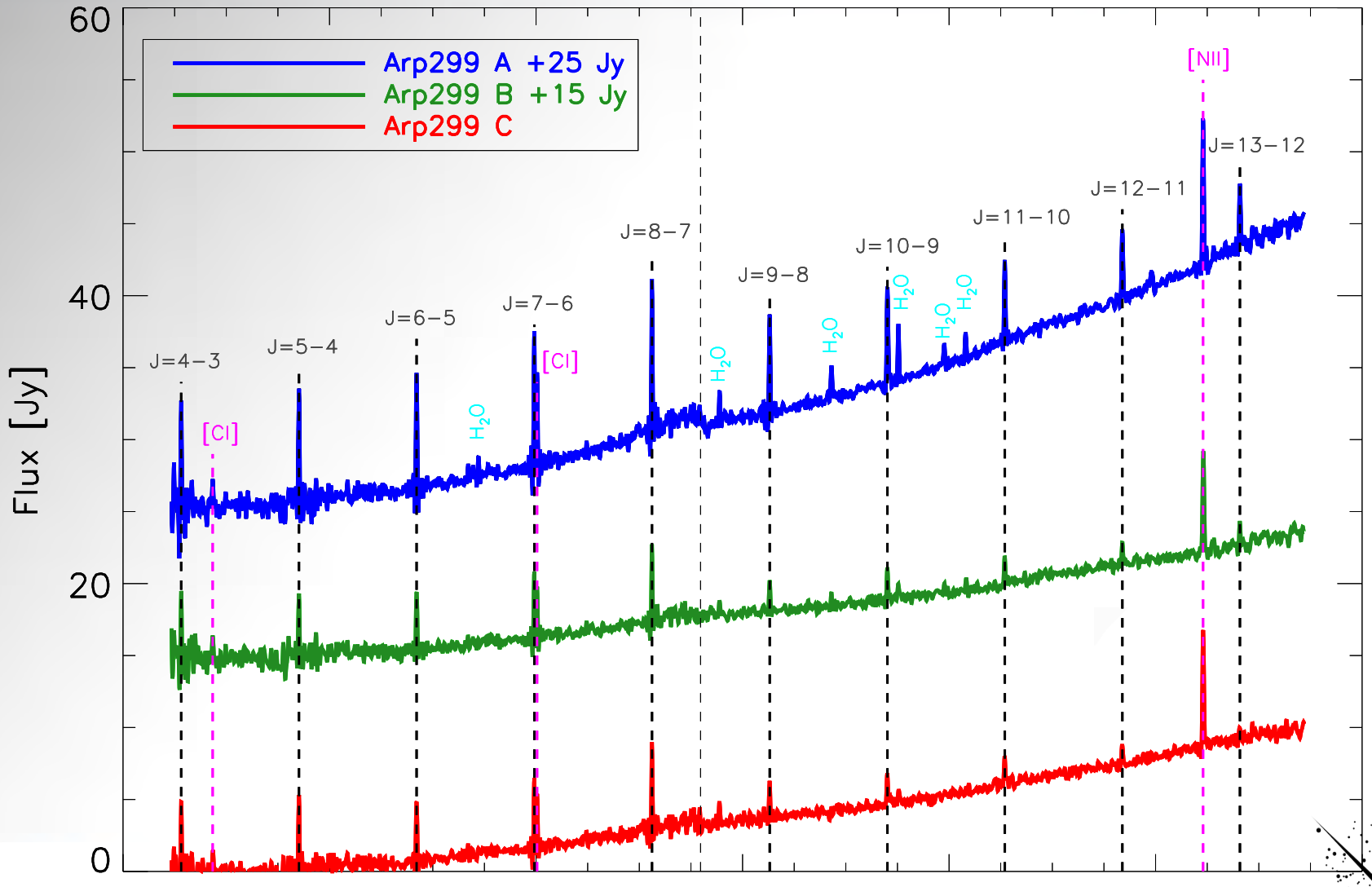
- Arp299 A →AGN
- Arp 299 B → starburst
- Arp 299 C → overlap





Alonso-Herrero+, 2009

Arp299 Spectra



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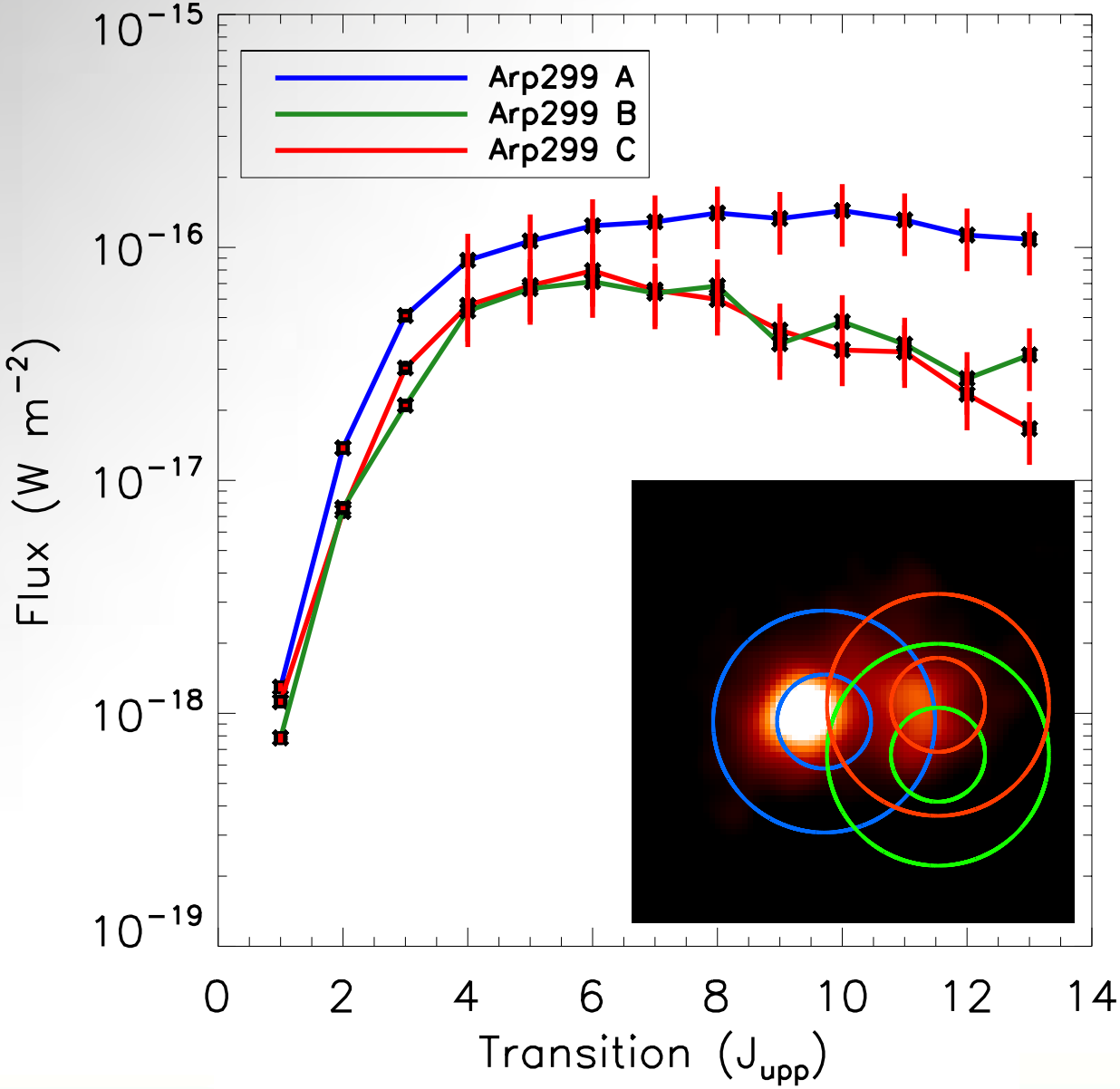
Arp 299 CO Ladders



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Questions?