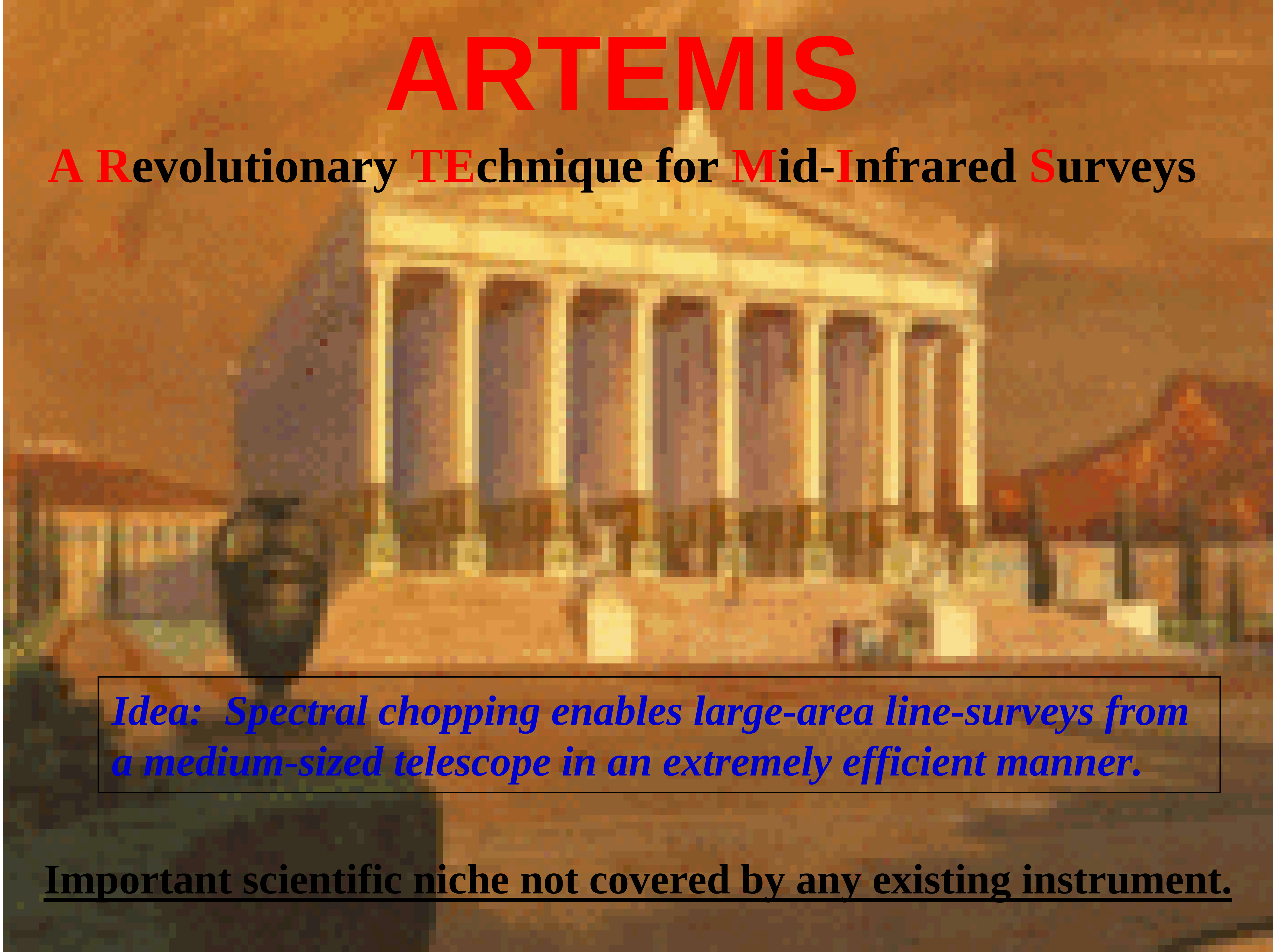


ARTEMIS

A Revolutionary TEchnique for Mid-Infrared Surveys

Idea: Spectral chopping enables large-area line-surveys from a medium-sized telescope in an extremely efficient manner.

Important scientific niche not covered by any existing instrument.

Problems of Ground-based MIR Observations

Mid-IR astronomy from the ground is limited:

- **poor atmospheric transmission**
- **high thermal background**

➔ Space.

However, space missions are

- **expensive, and have**
- **poor spatial resolution.**

Where targets are sufficiently bright large ground-based telescope are advantageous. BUT: faced with additional shortcomings:

1. **Low efficiency (~10%) of MIR observations due to the large overhead involved in chopping, nodding and calibrations.**
2. **Accurate background subtraction requires a flat, nearby “sky” for chopping – problematic for multiple sources and extended targets (often impossible for dense Galactic regions)**

The Conventional Principle

(Variable) Background >> Source flux ➔ chopping at 5-10 Hz between program target and a nearby reference field.

With T **= source + background,** ***B*** **= background, 1,2 = nod positions,** ***S*** **= source**

((one chop sequence of multiple co-added images)) :

$$S = ((T_1 - B_1)) - ((B_2 - T_2))$$

This technique requires:

1. **a representative patch of nearby sky exists**
2. **the telescope (secondary chopping and telescope nodding) performs accurately over an extended period in time**
3. **the beams from both nod-positions are well aligned.**

The ARTEMIS Principle

ARTEMIS **will not chop in the *spatial* but in the *spectral* domain.**

ARTEMIS **will always:**

- **point on-target**
- **require no time-consuming telescope re-pointings**
- **require no secondary mirror moves.**

With T_1 = total flux at λ_1, T_0 = flux at $\lambda_0 = \lambda_1 - \Delta\lambda$, T_2 = flux at $\lambda_2 = \lambda_1 + \Delta\lambda$, and $\alpha \approx \beta \approx 1.0$ are "fine-tuning" parameters:

$$S = \left(\left(T_1 - \frac{\alpha T_0 + \beta T_2}{\alpha + \beta} \right) \right)$$

Why “fine-tuning” parameters?

Background flux B_λ is not a linear function with wavelength:

$$B_\lambda = \frac{2hc^2}{\lambda^5}\left[\frac{\varepsilon}{e^{\frac{hc}{\lambda kT}} - 1}\right]$$

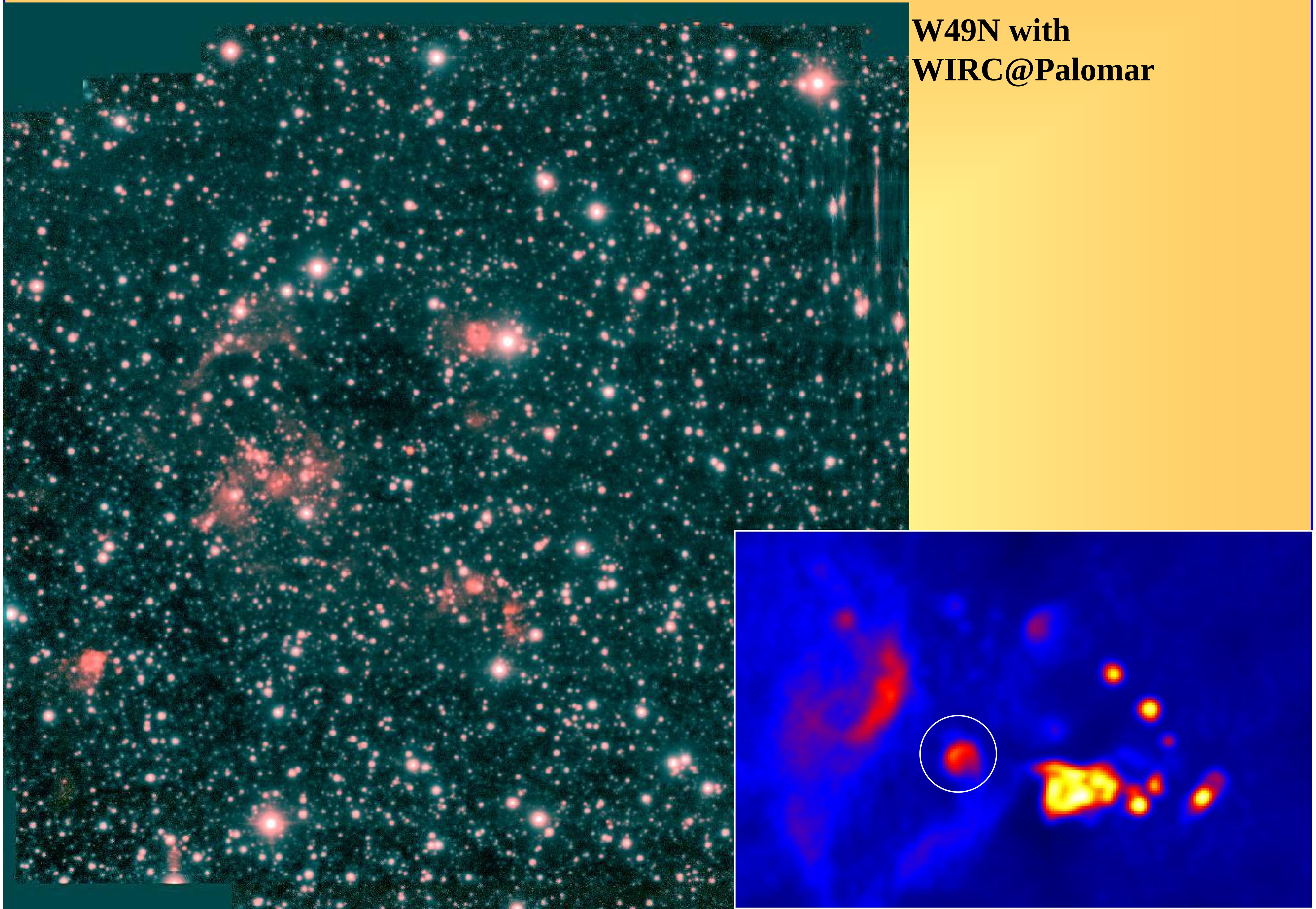
➔ $\Delta\lambda$ has to be sufficiently small, i.e., λ_0, λ_1, and λ_2 have to be very close to each other and require the use of narrow-band filters.

Standard narrowband imaging uses: “line filter” + “continuum filter”
for: target + sky
(=independent to disentangled background from source continuum flux).

BUT: $T = B + S$ and $B >> S$ → T ≈ B.
The missing degree of freedom can be recovered by selecting:

- **the fine-tune parameters α and β**
- **the continuum wavelengths λ_0 and λ_2**

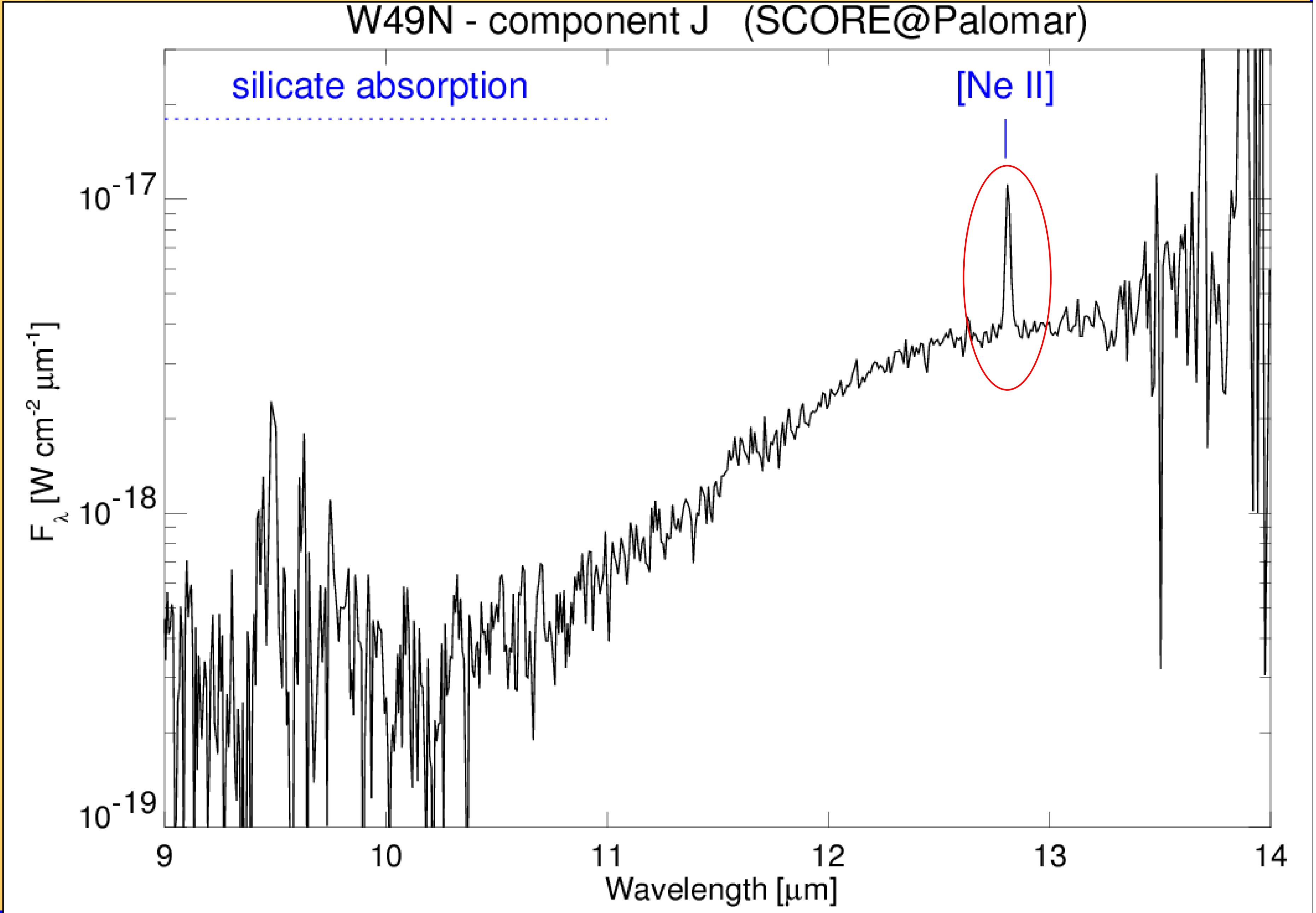
Why a mid-IR emission line?

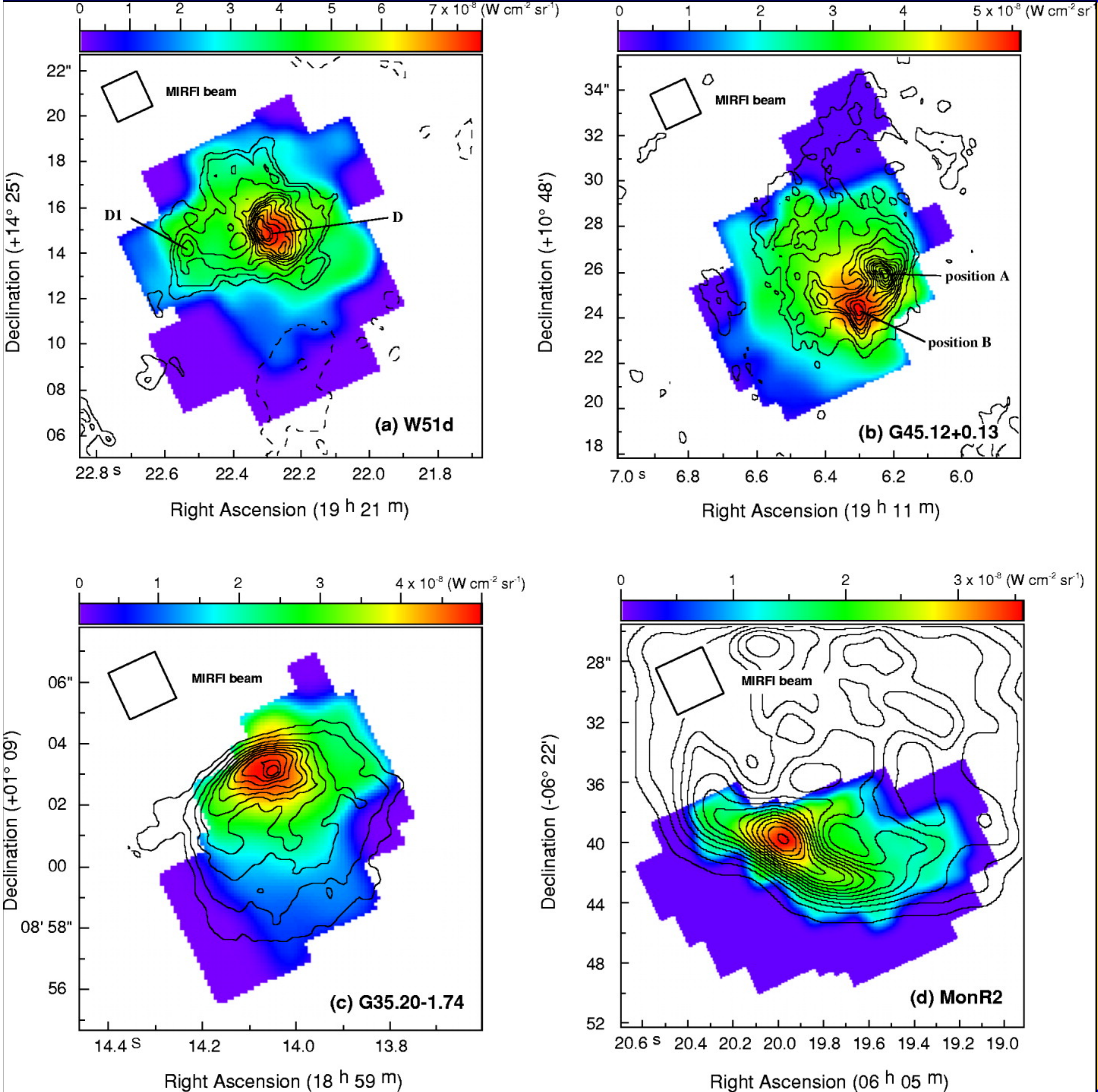


W49N with WIRC@Palomar

Why a mid-IR emission line?

W49N with WIRC@Palomar





←Other examples of [Ne II] (12.8 μm) imaging

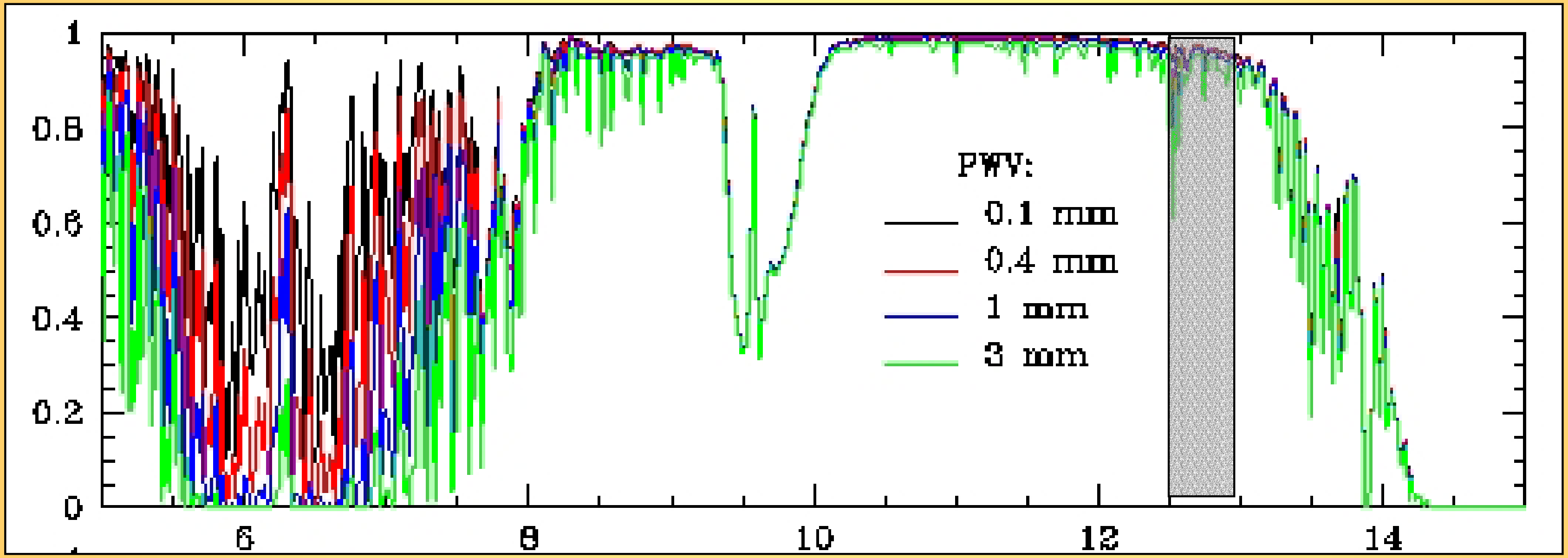
[NeII] is the strongest MIR fine structure line in most Galactic (UC)HII regions

Operating Wavelengths

Goal: high resolution

Resolution of R = 100 → Δλ = 0.128μm

“Chopping” by Δλ to each side covers 12.6μm ≤ λ ≤ 13.0μm.

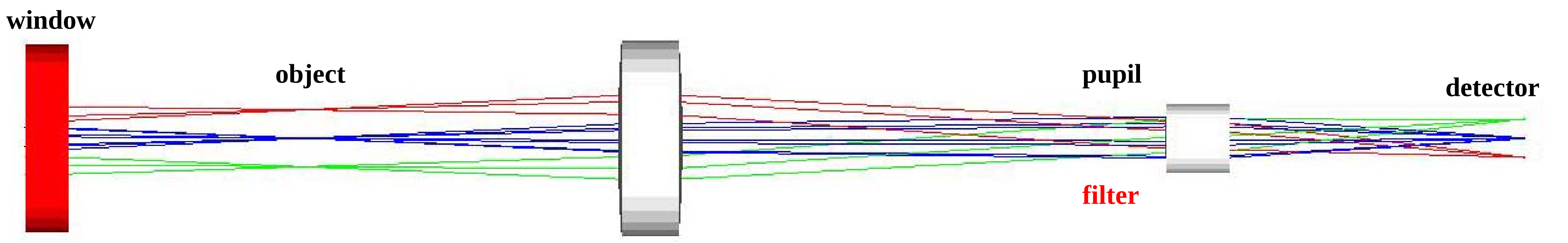


Atmospheric transmission [= f(λ)] for different amounts of precipitable water vapor; the filter coverage is the gray-shaded area.

Camera Design

A simple example:

Camera for the ESO-NTT (3.5m), based on two lenses:



Total length (window-detector)	**347mm**
Image size at detector	**25.6mm**
Pupil diameter	**9.4mm**
Beam divergence at pupil	**10.3deg**

Very simple and compact design

➔ light, easily calibratable, low maintenance, cheap!

…and very efficient!!!

“Mono”-chromatic wavelength

➔ optimized coatings and very few optical elements

➔ high throughput

➔ high efficiency

PSF FWHM @ 12.7μm: 0.73″ → 0.4″ / pixel sampling

With new 1024 × 1024 array (JWST) → 6.8′ × 6.8′ FOV

With 10 minute/position → 1 degree^2 within one night!!!

➔ A powerful spectral mapping machine!

The Filter

Optimal background + continuum subtraction & wavelength selection

➔custom-made linear variable filter (LVF) or circular variable filter (CVF)

All wavelengths use the same physical device → changes in transmission and spectral width should be minimal.

The filter will be located in a mechanism that slides back and forth (LVF) or that rotates in and out (CVF) perpendicular to the beam.

Spectral "chopping" ~ 10 Hz: 80ms integration time + 20ms filter move.

Germanium substrate of $60 \times 15 \times 3 \mathrm{mm}^3$ ~ 14.5 grams only. Moving the filter by one resolution element (~20mm) in 20ms would require an acceleration of 100m/s or 10*g* – no problem!

The Spectral Resolution

The spectral resolution is limited by:

<u>1. The beam divergence</u>. For rays that transmit the filter at different angles a shift in wavelength occurs:

$$\lambda_\vartheta = \lambda_0 \sqrt{1 - \left(\frac{\sin \vartheta}{n_e} \right)^2}$$

For $n_e = 4$ (Germanium) $\lambda_\vartheta / \lambda_0 = 0.999$ → R ≤ 500.

<u>2. The pupil diameter</u>.
Required that the LVF/CVF changes wavelengths by less than half a resolution element over the pupil diameter.

For R = 100 → $\Delta\lambda = 0.064\mu m$ over 9.4mm (prelim. design).

To cover $12.6\mu m \leq \lambda \leq 13.0\mu m$ the size of the filter must be 58.8mm.

Summary: requirements look feasible, and Lagrange invariant $A \times \Omega$ does not limit the resolution in this concept.

Observing Procedure

1. **Point to a nearby target, known NOT to have emission or absorption at [Ne II].**
2. **Adjust the parameters α and β and the continuum wavelengths λ_0 and λ_2 until the best elimination of *both* sky background and continuum source flux is achieved. (Can be automated in software.)**
3. **Go to the program target and start observing.**
4. **Mapping can be done as easily as for optical imaging.**
5. **The computer will monitor the efficiency of the sky subtraction in a median-filtered portion of the image and remind the observer if readjustment of α and β became necessary.**
6. **Images can be co-added and maps can be constructed in real-time. The success of the observations will immediately be known, and not only after a lengthy data reduction process.**

SUMMARY: ***ARTEMIS* is an efficient, cheap, and simple instrument that fills an important niche currently not covered by any other instrument. It would be a mistake not to build it …!**