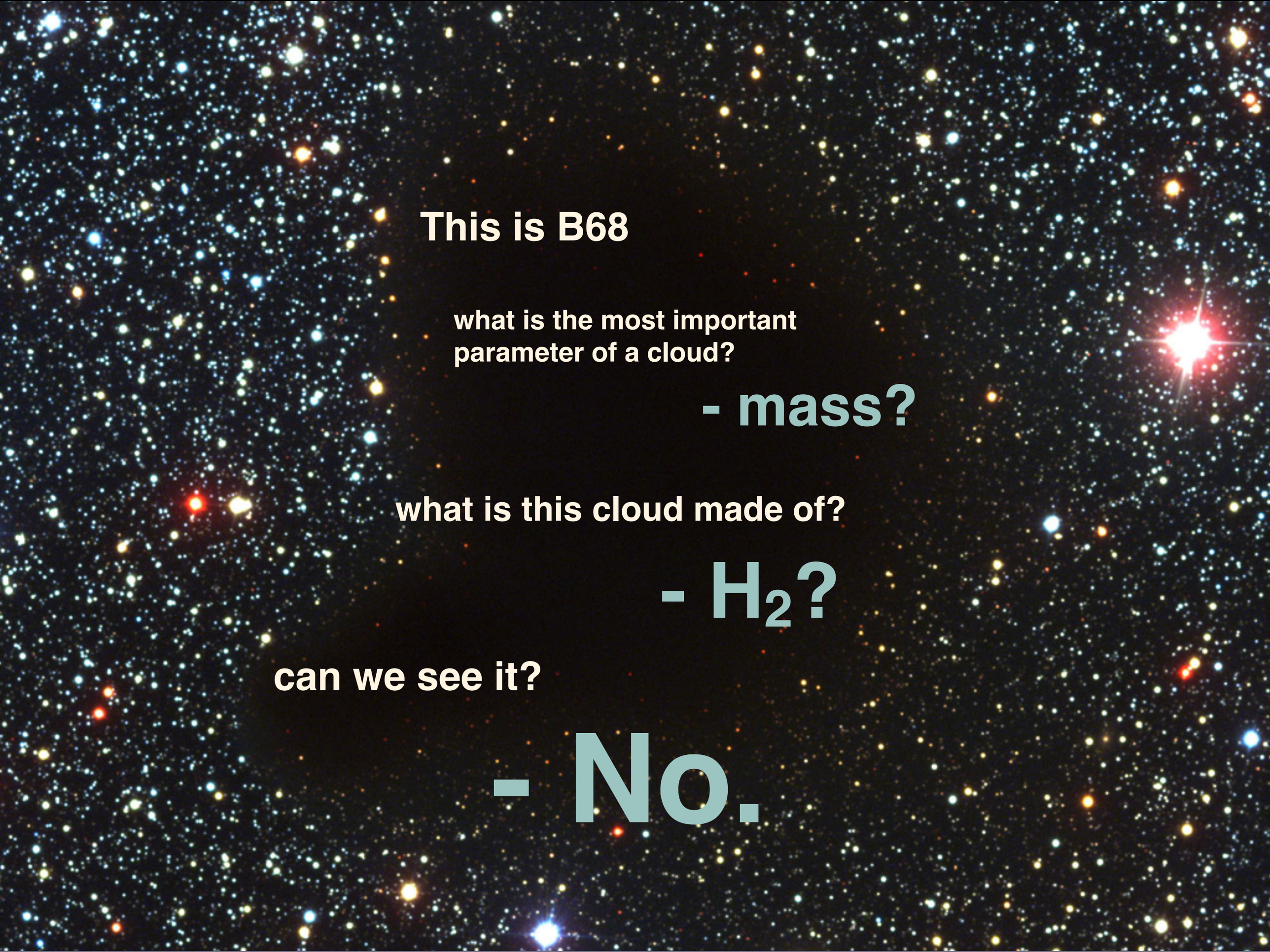
Why I need
laser guide star
for CRIRES

Miwa Goto
(Max Planck Institute for Extraterrestrial Physics)


This is B68
what is the most important parameter of a cloud?
- mass?
what is this cloud made of?
- H_2?
can we see it?
- No.

Internal structure of a cold dark molecular cloud inferred from the extinction of background starlight

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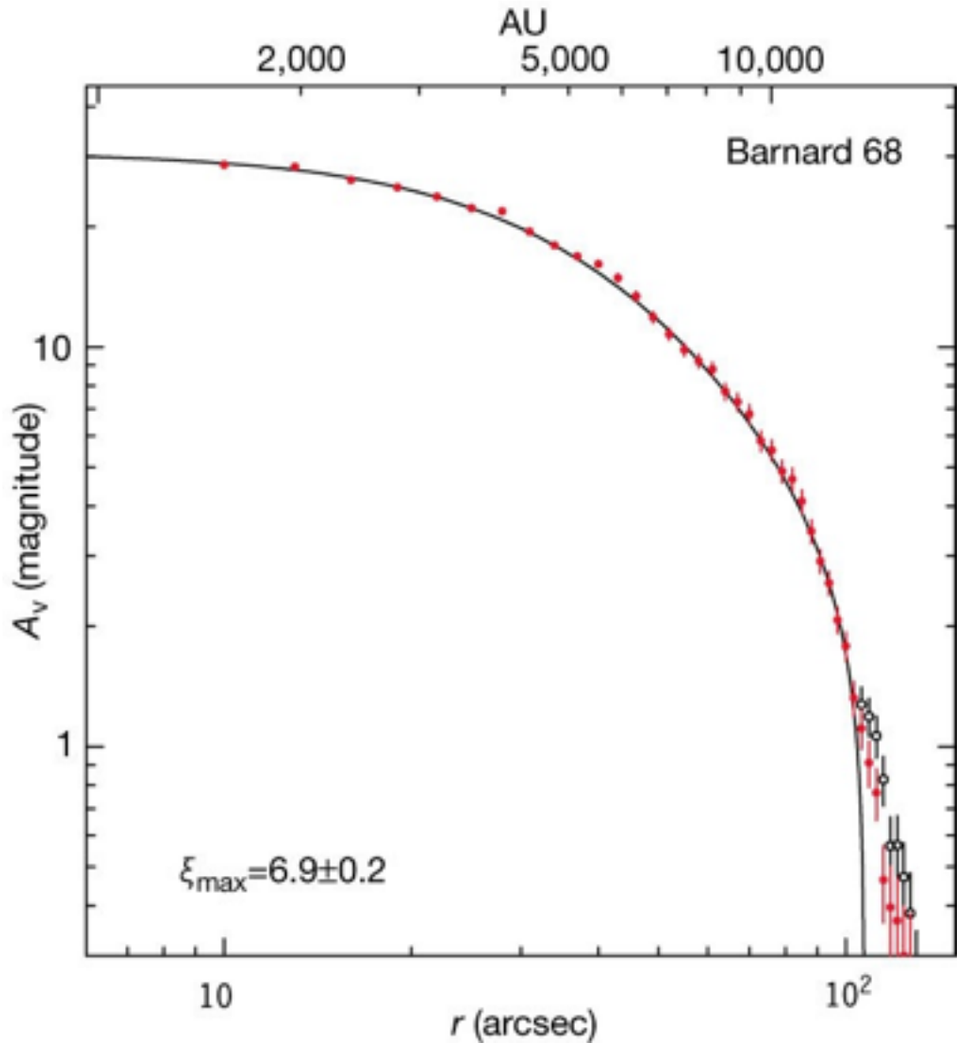
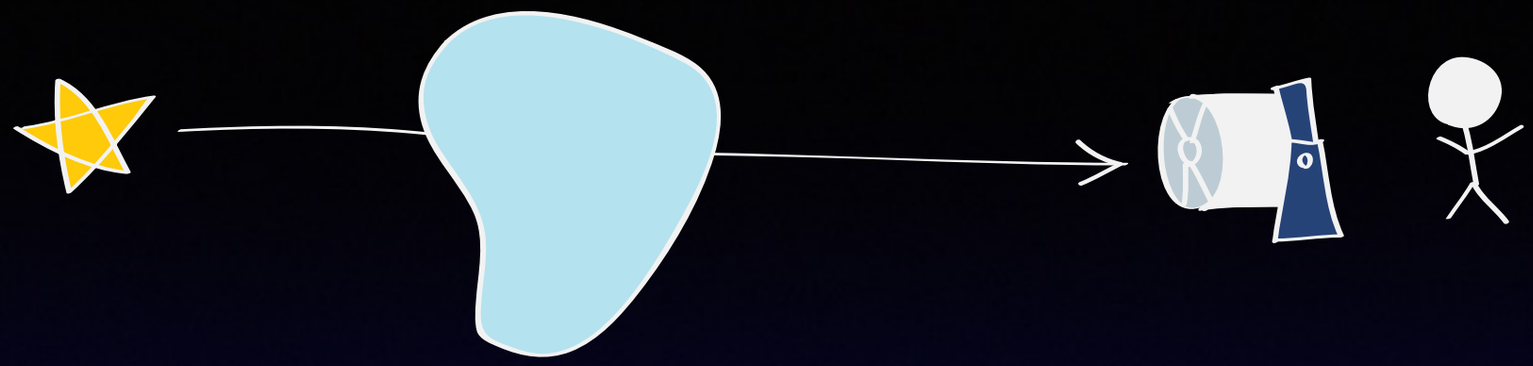
Stars and planets form within dark molecular clouds, but little is understood about the internal structure of these clouds, and consequently about the initial conditions that give rise to star and planet formation. The clouds are primarily composed of molecular hydrogen, which is virtually inaccessible to direct observation. But the clouds also contain dust, which is well mixed with the gas and which has well understood effects on the transmission of light. Here we use sensitive near-infrared measurements of the light from background stars as it is absorbed and scattered by trace amounts of dust to probe the internal structure of the dark cloud Barnard 68 with unprecedented detail. We find the cloud's density structure to be very well described by the equations for a pressure-confined, self-gravitating isothermal sphere that is critically stable according to the Bonnor–Ebert criteria[1,2]. As a result we can precisely specify the physical conditions inside a dark cloud on the verge of collapse to form a star.

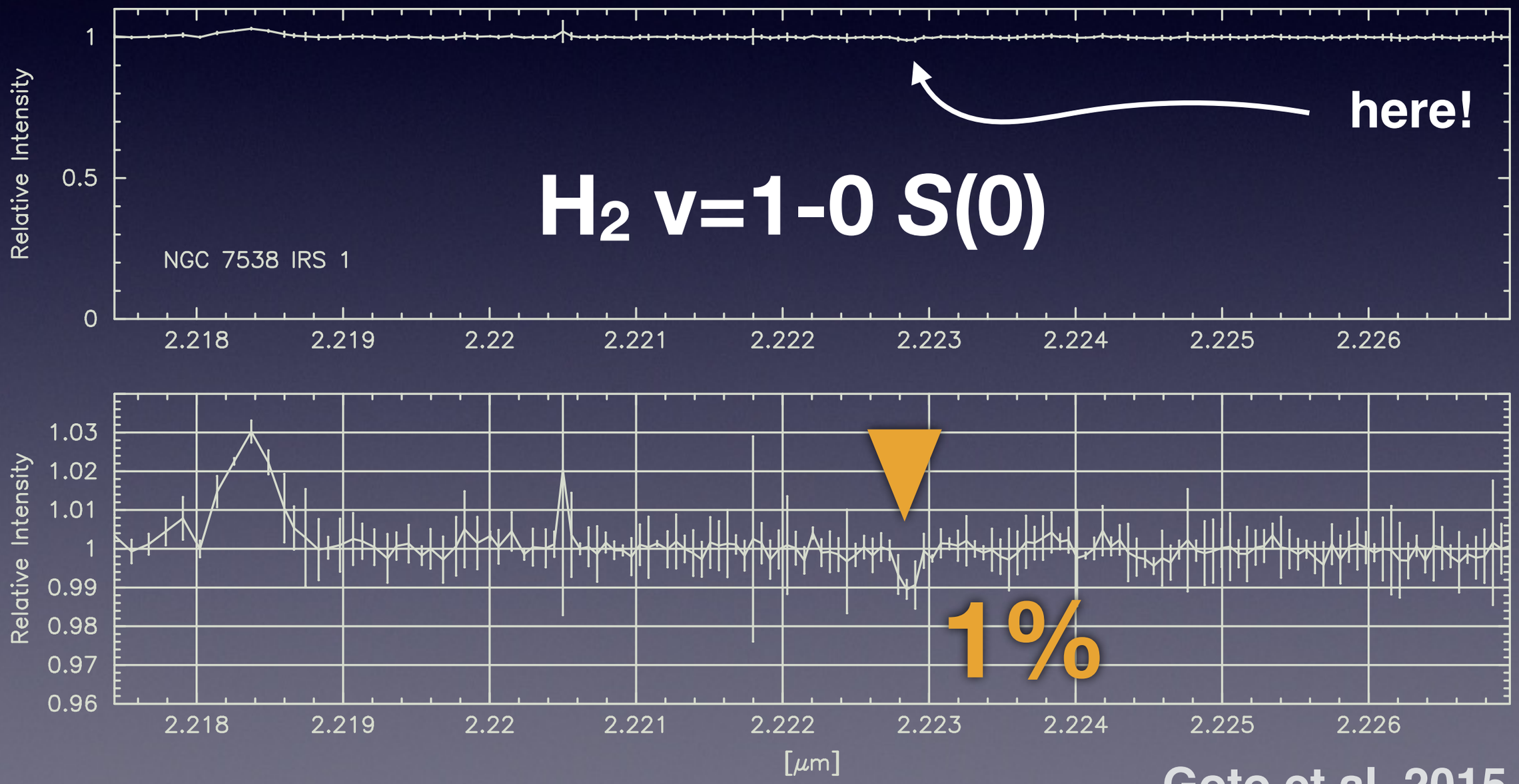


- color excess technique
- self-gravitating
- critically stable core

Alves et al. 2001

“virtually inaccessible”





Goto et al. 2015

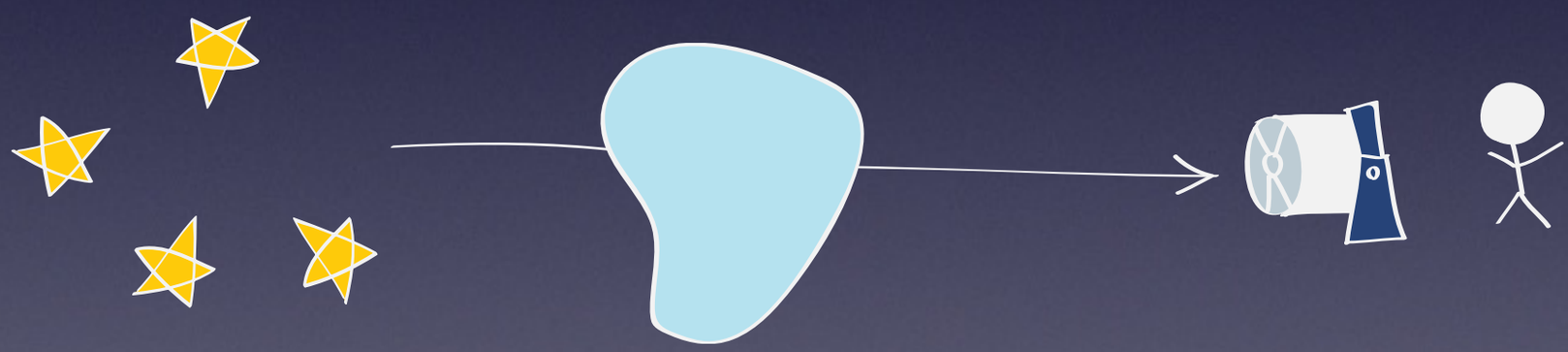
Once upon a time …

High resolution spectroscopy **was**

- **Special** spectroscopy for **Special** objects
- Targets everybody knows

≈ bright

≈ good AO guide star itself



now we have to deal with

- stars with **no** name

(or only 2 MASS IDs)

- in ELT time, even more true

Target Setup
Target source flux distribution type : continuum
Parameters : (none)
Target source magnitude : $K_{(Vega)}$ = 9.00

Target source geometry : Point source

Doppler Shift : not applied

Seeing limited (AO is not enabled)

Atmosphere Setup
Seeing : 0.80 arcsec
Airmass : 1.10
Precipitable Water Vapor (PWV) : 2.50 mm

Instrument Setup
Spectroscopic Mode : Standard Setting: Order:26 , Reference Wavelength:2219.80 nm
Slit Width : 0.20 arcsec
Detector read-out mode : FowlerNsamp
Detector parameters : RON=14.08 e-/pixel/DIT, Da e-/pixel/s

Observation Setup
User requested: Compute NDIT for a given S/N and DIT

CRIRES Transmission Model

Requested wavelength : 2219.800 nm
Overall wavelength range : 2196.00 - 2233.40 nm

Wavelength range detector 1	355 pixels	: 2196.00 - 2199.60 nm
Wavelength range detector 2	1024 pixels	: 2202.50 - 2212.40 nm
Wavelength range detector 3	1024 pixels	: 2215.10 - 2224.50 nm
Wavelength range detector 4	728 pixels	: 2227.00 - 2233.40 nm

Number of pixels in wavelength range: 3131 pixels

Dispersion detector 1 : 1.017e-02 nm/pixel
Dispersion detector 2 : 9.677e-03 nm/pixel
Dispersion detector 3 : 9.189e-03 nm/pixel
Dispersion detector 4 : 8.798e-03 nm/pixel

Signal-to-noise ratio (at requested wavelength) : 301.592 NOTE!

Detector Integration Time for one exposure DIT : 300.000 seconds
Number of detector integrations (rounded up) NDIT : 92
Total exposure time (without overheads) INT=NDIT*DIT : 27600.000 seconds

Max. intensity at central pixel per DIT (object+sky) (at req.wavel.) : 492.715 e-/DIT
Detector linearity limit : 60000 e-
Detector saturation limit : 100000 e-

Spatial Pixel scale
Spatial extension of
Spatial extension of

Object signal in refe
Object signal in ref.a
Total sky backgroun

Slit transmission fac
Overall transmission (excl slit transm., at requested wavelength) : 7.80 %
Overall transmission (incl slit transm., at requested wavelength) : 2.35 %

Note!: The formula to calculate the S/N ratio includes a factor to adjust the value to the observed sensitivity.

Target Setup
t source flux distribution type : continuum
Parameters : (none)
: $K_{(Vega)}$ = 9.00

get source geometry : Point source, AO enabled

Doppler Shift : not applied

AO NGS Setup
Reference star spectral type : A0V , (B-R)=0.00
Reference star magnitude : R = 10.00
Reference star/target Separation : 0.00 arcsec

Atmosphere Setup
Seeing : 0.80 arcsec
Airmass : 1.10
Precipitable Water Vapor (PWV) : 2.50 mm

Instrument Setup
Spectroscopic Mode : Standard Setting: Order:26 , Reference Wavelength:2219.80 nm
Slit Width : 0.20 arcsec
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Detector parameters : RON=14.08 e-/pixel/DIT, Dark=0.5 e-/pixel/s

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Signal-to-noise ratio (at requested wavelength) : 301.339 NOTE!

Detector Integration Time for one exposure DIT : 300.000 seconds
Number of detector integrations (rounded up) NDIT : 17
Total exposure time (without overheads) INT=NDIT*DIT : 5100.000 seconds

Max. intensity at central pixel per DIT (object+sky) (at req.wavel.) : 5114.495 e-/DIT
Detector linearity limit : 60000 e-
Detector saturation limit : 100000 e-

Spatial Pixel scale : 87.000 mas/p
Spatial extension of S/N reference area (arcsec) : 74 arcsec
Spatial extension of S/N r

Object signal in reference
Object signal in ref.area p
Total sky background sig

Estimated Strehl Ratio on
Estimated K-band on-axis
th

Slit transmission factor
Overall transmission (excl slit transm., at requested wavelength) : 7.80 %
Overall transmission (incl slit transm., at requested wavelength) : 5.74 %

Note!: The formula to calculate the S/N ratio includes a factor to adjust the value to the observed sensitivity.

K = 9.0 mag

seeing 0.8”

slit 0.2”

2.2 um

S/N = 300

w/o AO

w/ AO

27600s = 7.6 hr

5100s = 1.4 hr

Target Setup
Target source flux distribution type : continuum
Parameters : (none)
Target source magnitude : $K_{(Vega)}$ = 9.00

Target source geometry : Point source

Doppler Shift : not applied

Seeing limited (AO is not enabled)

Atmosphere Setup
Seeing : 0.80 arcsec
Airmass : 1.10
Precipitable Water Vapor (PWV) : 2.50 mm

Instrument Setup
Spectroscopic Mode : Standard Setting: Order:26 , Reference Wavelength:2219.80 nm
Slit Width : 0.20 arcsec
Detector read-out mode : FowlerNsamp
Detector parameters : RON=14.08 e-/pixel/DIT, Dark=0.5 e-/pixel/s

Observation Setup
User requested: Compute NDIT for a given S/N and DIT

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Wavelength range detector 3	1024 pixels	: 2215.10 - 2224.50 nm
Wavelength range detector 4	728 pixels	: 2227.00 - 2233.40 nm

Number of pixels in wavelength range: 3131 pixels

Dispersion detector 1 : 1.017e-02 nm/pixel
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Total exposure time (without overheads) INT=NDIT*DIT : 27600.000 seconds

Max. intensity at central pixel per DIT (object+sky) (at req.wavel.) : 492.715 e-/DIT
Detector linearity limit : 60000 e-
Detector saturation limit : 100000 e-

Spatial
Spatia
Spatia

Object
Object
Total

Slit tra
Overall transmission (excl slit transm., at requested wavelength) : 7.80 %
Overall transmission (incl slit transm., at requested wavelength) : 2.35 %

Note!: The formula to calculate the S/N ratio includes a factor to adjust the value to the observed sensitivity.

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t source flux distribution type : continuum
Parameters : (none)
: $K_{(Vega)}$ = 9.00

get source geometry : Point source, AO enabled

Doppler Shift : not applied

AO NGS Setup
Reference star spectral type : A0V , (B-R)=0.00
Reference star magnitude : R = 10.00
Reference star/target Separation : 0.00 arcsec

Atmosphere Setup
Seeing : 0.80 arcsec
Airmass : 1.10
Precipitable Water Vapor (PWV) : 2.50 mm

Instrument Setup
Spectroscopic Mode : Standard Setting: Order:26 , Reference Wavelength:2219.80 nm
Slit Width : 0.20 arcsec
Detector read-out mode : FowlerNsamp
Detector parameters : RON=14.08 e-/pixel/DIT, Dark=0.5 e-/pixel/s

Observation Setup
User requested: Compute NDIT for a given S/N and DIT

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Overall wavelength range : 2196.00 - 2233.40 nm

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Wavelength range detector 4	728 pixels	: 2227.00 - 2233.40 nm

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Signal-to-noise ratio (at requested wavelength) : 301.339 NOTE!

Detector Integration Time for one exposure DIT : 300.000 seconds
Number of detector integrations (rounded up) NDIT : 17
Total exposure time (without overheads) INT=NDIT*DIT : 5100.000 seconds

Max. intensity at central pixel per DIT (object+sky) (at req.wavel.) : 5114.495 e-/DIT
Detector linearity limit : 60000 e-
Detector saturation limit : 100000 e-

Spatial Pixel scale : 87.000 mas/pi
Spatial extension of S/N reference area (arcsec) : 4 arcsec
Spatial extensi

Object signal i
Object signal i
Total sky back

Estimated Stre
Estimated K-ba

Slit transmissio
Overall transmission (excl slit transm., at requested wavelength) : 7.80 %
Overall transmission (incl slit transm., at requested wavelength) : 5.74 %

Note!: The formula to calculate the S/N ratio includes a factor to adjust the value to the observed sensitivity.

K = 9.0 mag

seeing 0.8”

slit 0.2”

2.2 um

S/N = 300

w/oAO

w/ AO

impossible

possible

Target Setup
Target source flux distribution type : continuum
Parameters : (none)
Target source magnitude : $L_{(Vega)}$ = 7.00

Target source geometry : Point source

Doppler Shift : not applied

Seeing limited (AO is not enabled)

Atmosphere Setup
Seeing : 0.80 arcsec
Airmass : 1.10
Precipitable Water Vapor (PWV) : 2.50 mm

Instrument Setup
Spectroscopic Mode : Standard Setting: Order:15 , Reference Wavelength:3707.50 nm
Slit Width : 0.20 arcsec
Detector read-out mode : FowlerNsamp
Detector parameters : RON=12.83 e-/pixel/DIT, D[illegible] e-/pixel/s

Observation Setup
User requested: Compute NDIT for a given S/N and DIT

CRIRES Transmission Model

Requested wavelength : 3707.500 nm
Overall wavelength range : 3646.50 - 3740.20 nm

Wavelength range detector 1 1024 pixels : 3646.50 - 3667.10 nm
Wavelength range detector 2 1024 pixels : 3672.90 - 3692.70 nm
Wavelength range detector 3 1024 pixels : 3698.00 - 3717.00 nm
Wavelength range detector 4 1024 pixels : 3721.90 - 3740.20 nm
Number of pixels in wavelength range: 4096 pixels

Dispersion detector 1 : 2.014e-02 nm/pixel
Dispersion detector 2 : 1.935e-02 nm/pixel
Dispersion detector 3 : 1.857e-02 nm/pixel
Dispersion detector 4 : 1.789e-02 nm/pixel

Signal-to-noise ratio (at requested wavelength) : 300.198 NOTE!

Detector Integration Time for one exposure DIT : 180.000 seconds
Number of detector integrations (rounded up) NDIT : 268
Total exposure time (without overheads) INT=NDIT*DIT : 48240.000 seconds

Max. intensity at central pixel per DIT (object+sky) (at req.wavel.) : 7429.141 e-/DIT
Detector linearity limit : 60000 e-
Detector saturation limit : 100000 e-

Spatial
Spatia
Spatia

Object
Object
Total s

Slit tra
Overall transmission (excl slit transm., at requested wavelength) : 13.98 %
Overall transmission (incl slit transm., at requested wavelength) : 4.39 %

Note!: The formula to calculate the S/N ratio includes a factor to adjust the value to the observed sensitivity.

Target Setup
Target source flux distribution type : continuum
Parameters : (none)
[illegible] : $L_{(Vega)}$ = 7.00

Target source geometry : Point source, AO enabled

Doppler Shift : not applied

AO NGS Setup
Reference star spectral type : A0V , (B-R)=0.00
Reference star magnitude : R = 10.00
Reference star/target Separation : 0.00 arcsec

Atmosphere Setup
[illegible] : 0.80 arcsec
Airmass : 1.10
Precipitable Water Vapor (PWV) : 2.50 mm

Instrument Setup
Spectroscopic Mode : Standard Setting: Order:15 , Reference Wavelength:3707.50 nm
Slit Width : 0.20 arcsec
[illegible] read-out mode : FowlerNsamp
[illegible] parameters : RON=12.83 e-/pixel/DIT, Dark=0.5 e-/pixel/s

Observation Setup
User requested: Compute NDIT for a given S/N and DIT

CRIRES Transmission Model

[illegible] : 3707.500 nm
Overall wavelength range : 3646.50 - 3740.20 nm

Wavelength range detector 1 1024 pixels : 3646.50 - 3667.10 nm
Wavelength range detector 2 1024 pixels : 3672.90 - 3692.70 nm
[illegible]tector 3 1024 pixels : 3698.00 - 3717.00 nm
[illegible]tector 4 1024 pixels : 3721.90 - 3740.20 nm
[illegible]wavelength range: 4096 pixels

[illegible] : 2.014e-02 nm/pixel
Dispersion detector [illegible] : 1.935e-02 nm/pixel
Dispersion detector 3 : 1.857e-02 nm/pixel
Dispersion detector 4 : 1.789e-02 nm/pixel

Signal-to-noise ratio (at requested wavelength) : 304.086 NOTE!

Detector Integration Time for one exposure DIT : 180.000 seconds
Number of detector integrations (rounded up) NDIT : 24
Total exposure time (without overheads) INT=NDIT*DIT : 4320.000 seconds

Max. intensity at central pixel per DIT (object+sky) (at req.wavel.) : 28792.181 e-/DIT
Detector linearity limit : 60000 e-
Detector saturation limit : 100000 e-

Spatial Pixel scale : 87.000 mas/pi
Spatial extension of S/N reference area (arcsec) : 0[illegible]7 arcsec
Spatial extensi[illegible]

Object signal i
Object signal i
Total sky back

Estimated Stre
Estimated K-b

Slit transmissi
Overall transmission (excl slit transm., at requested wavelength) : 13.98 %
Overall transmission (incl slit transm., at requested wavelength) : 10.72 %

Note!: The formula to calculate the S/N ratio includes a factor to adjust the value to the observed sensitivity.

L = 7.0 mag

high background

seeing 0.8”

slit 0.2”

3.7 um (H_3^+)

S/N = 300

48240s = 11.8 hr

4320s = 1.2 hr

those background stars are

R = 16-19 mag

K ~ 9 mag, MK giants, V-K=2-4 mag

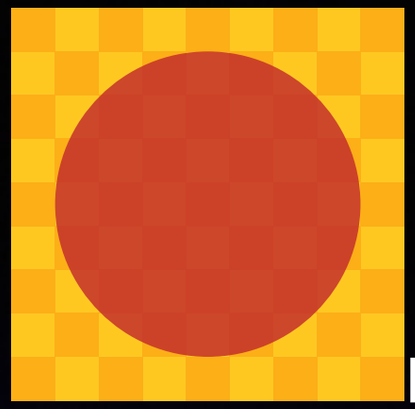
A_V = 10 mag

you can use AO

only if

LGS is available

“don’t worry.
just wait METIS and ELT.
It does not have a slit.”



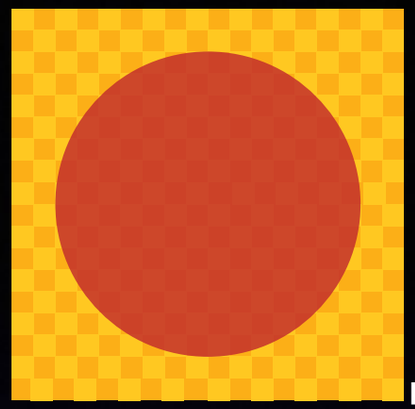
VLT

seeing limited

D	8 m
***S**ignal*	1
***d**iff*	0″.1
***p**ix*	10 x 10
seeing	1″

***n** readout*	$\sqrt{10 \times 10} = 10$
***s** bg/pix*	$\frac{1}{10 \times 10}$
***n** bg*	$\sqrt{\frac{1}{10 \times 10} \cdot 10 \times 10} = 1$

S/N *read*	0.1
S/N *bg*	1



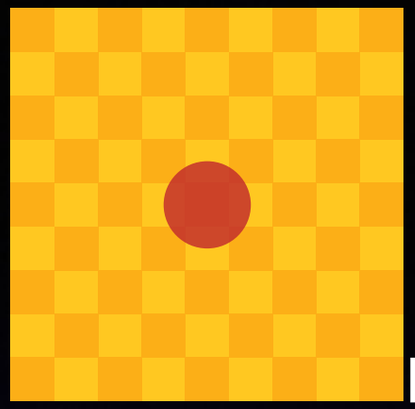
ELT

seeing limited

D	40 m
***S**ignal*	25
***d**iff*	0″.02
***p**ix*	50 x 50
seeing	1″

***n** readout*	$\sqrt{50 \times 50} = 50$
***s** bg/pix*	$\frac{25}{50 \times 50}$
***n** bg*	$\sqrt{\frac{25}{50 \times 50} \cdot 50 \times 50} = 5$

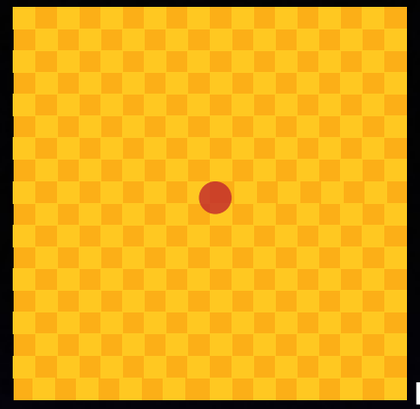
S/N *read*	0.5
S/N *bg*	5



VLT

diffraction limited

D	8 m
***S**ignal*	1
***d**iff*	0″.1
***p**ix*	10 x 10
***d**iff*	0″.1



ELT

diffraction limited

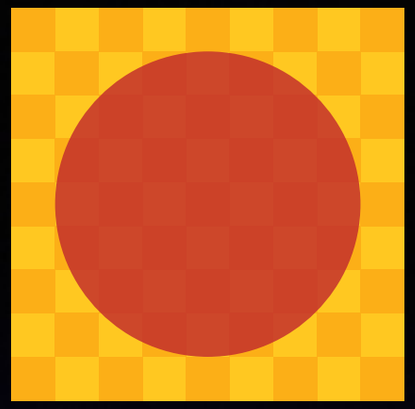
D	40 m
***S**ignal*	25
***d**iff*	0″.02
***p**ix*	50 x 50
***d**iff*	0″.02

n *readout*	$\sqrt{1 \times 1}$
s *bg/pix*	$\frac{1}{10 \times 10}$
n *bg*	$\sqrt{\frac{1}{10 \times 10} \cdot 1 \times 1} = 0.1$

S/N *read*	1
S/N *bg*	10

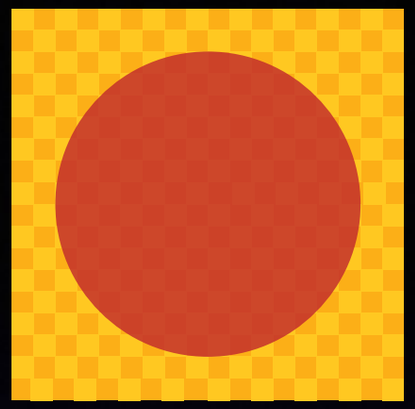
n *readout*	$\sqrt{1 \times 1} = 1$
s *bg/pix*	$\frac{25}{50 \times 50}$
n *bg*	$\sqrt{\frac{25}{50 \times 50} \cdot 1 \times 1} = 0.1$

S/N *read*	25
S/N *bg*	250



VLT
seeing limited

S/N *read*	0.1
S/N *bg*	1



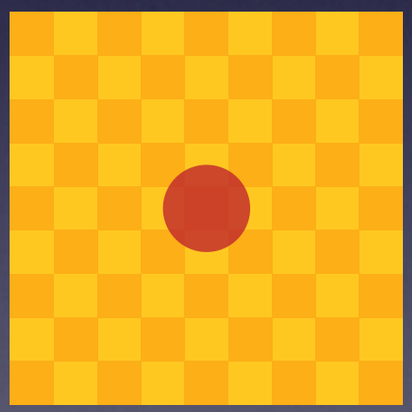
ELT
seeing limited

S/N *read*	0.5
S/N *bg*	5

if you do not use AO

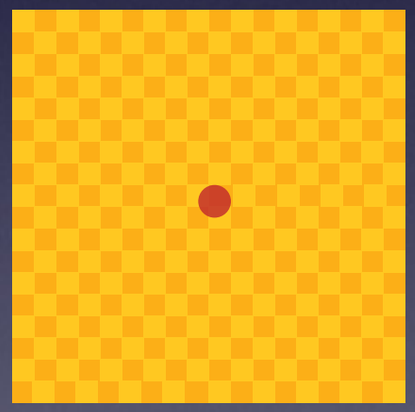
lose **x10** times

lose x **50** times



VLT
diffraction limited

S/N *read*	1
S/N *bg*	10



ELT
diffraction limited

S/N *read*	25
S/N *bg*	250

for spectroscopy

AO is not **nice** to have

but makes an impossible observation

Possible or vice versa

“technically not challenging” (= boring)

“other telescopes are already doing” (= boring)

AO to throw away 99.99999% of photons

AO to increase slit throughput x2

Thank you