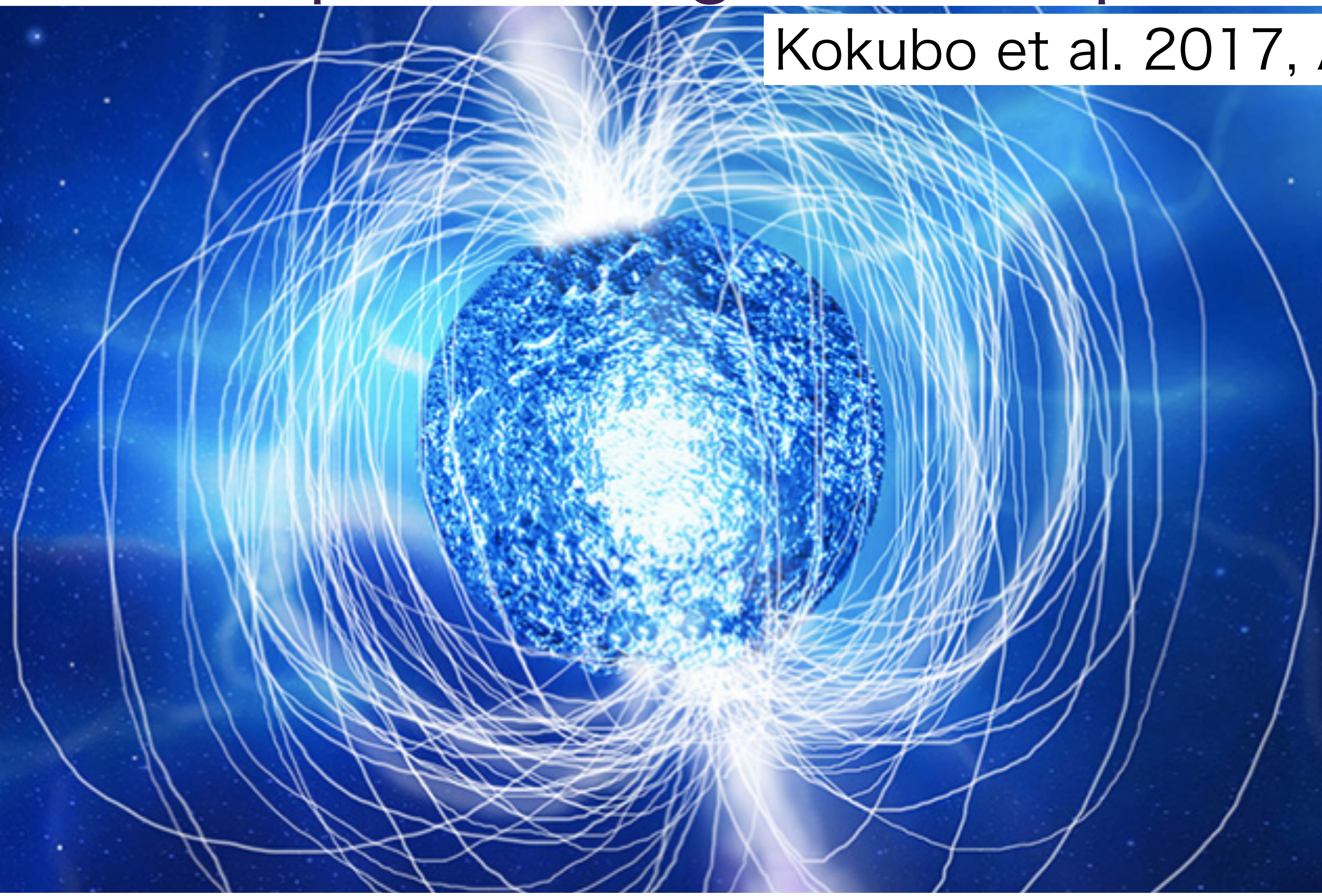
Hα intensity map of the repeating fast radio burst FRB121102 host galaxy from Subaru/Kyoto3DII AO-assisted optical integral-field spectroscopy

Kokubo et al. 2017, ApJ, 844, 95



Mitsuru Kokubo (Tohoku Univ.)

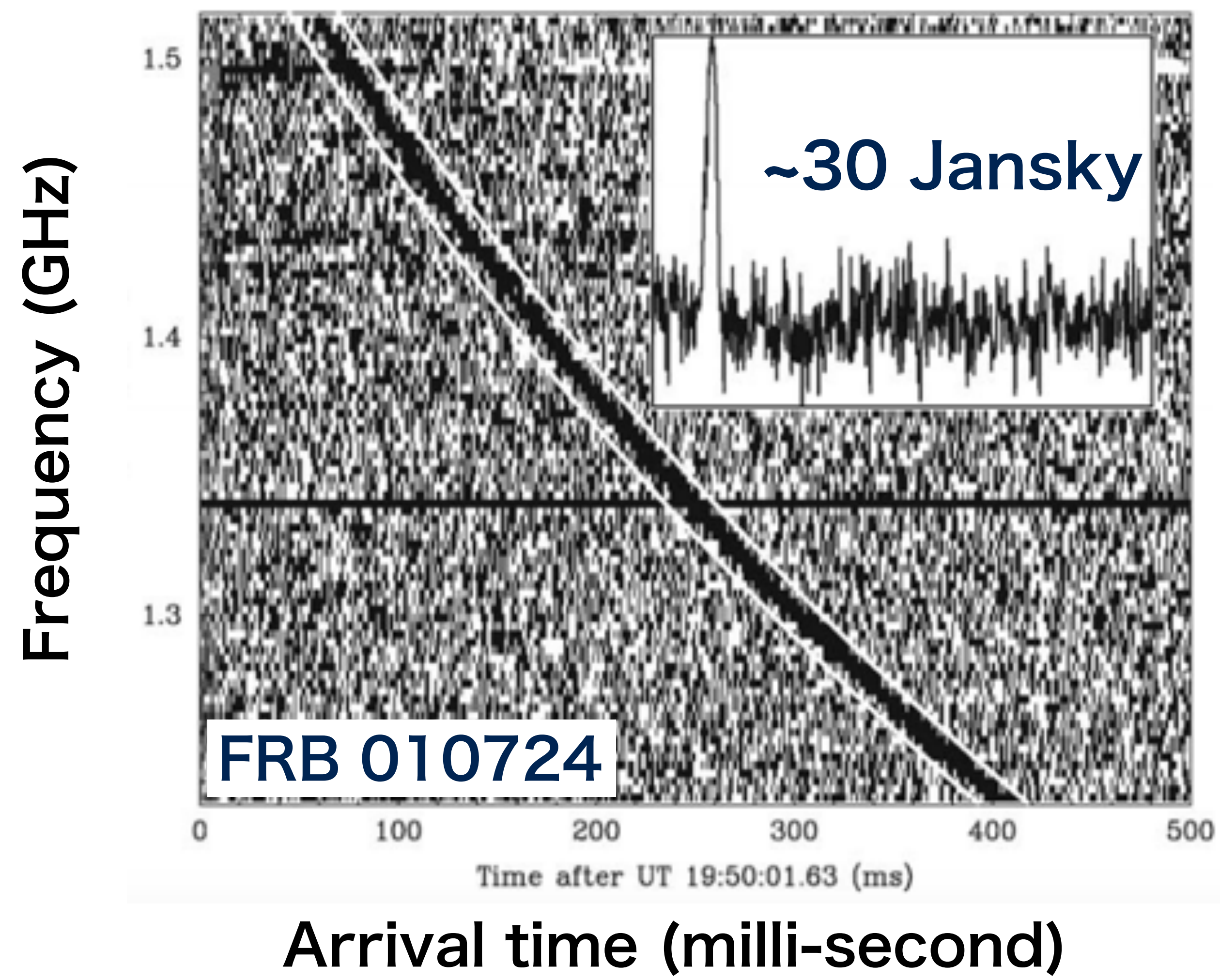
Kazuma Mitsuda, Hajime Sugai, and Kyoto3DII+AO188 team

Cosmological Fast Radio Bursts

- One-off bright milli-second radio pulse

- Huge **Dispersion Measure**:
DM ~ 375 ± 3 [cm^{-3} pc] in FRB010724

$$\mathrm{DM} = \int_0^d n_e \, dl$$



Dispersion Measure (DM)
= column electron density along the line of sight

$$\Delta t = 4.148808\,\mathrm{ms} \times \left[\left(\frac{f_{\mathrm{low}}}{\mathrm{GHz}} \right)^{-2} - \left(\frac{f_{\mathrm{high}}}{\mathrm{GHz}} \right)^{-2} \right] \times \left(\frac{\mathrm{DM}}{\mathrm{cm}^{-3}\,\mathrm{pc}} \right)$$

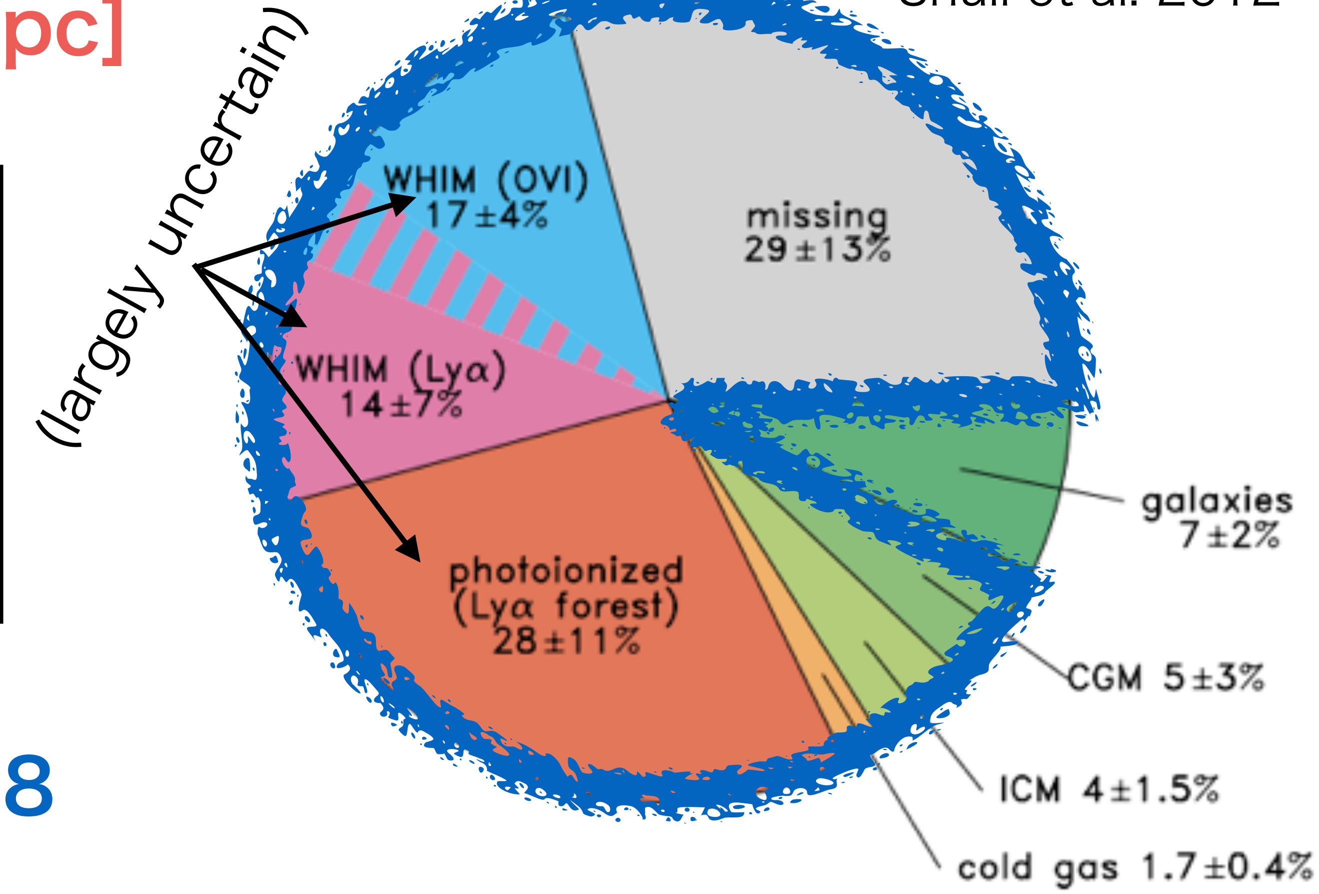
DM excess: IGM contribution

DM in FRB 010724 = 375 [cm^{-3} pc]

DM from Milky Way = 45 [cm^{-3} pc]

—> **DM excess ~ 330 [cm^{-3} pc]**

Shull et al. 2012



FRBs are cosmological
<—>
"Missing baryons" in the IGM can be the dominant DM source

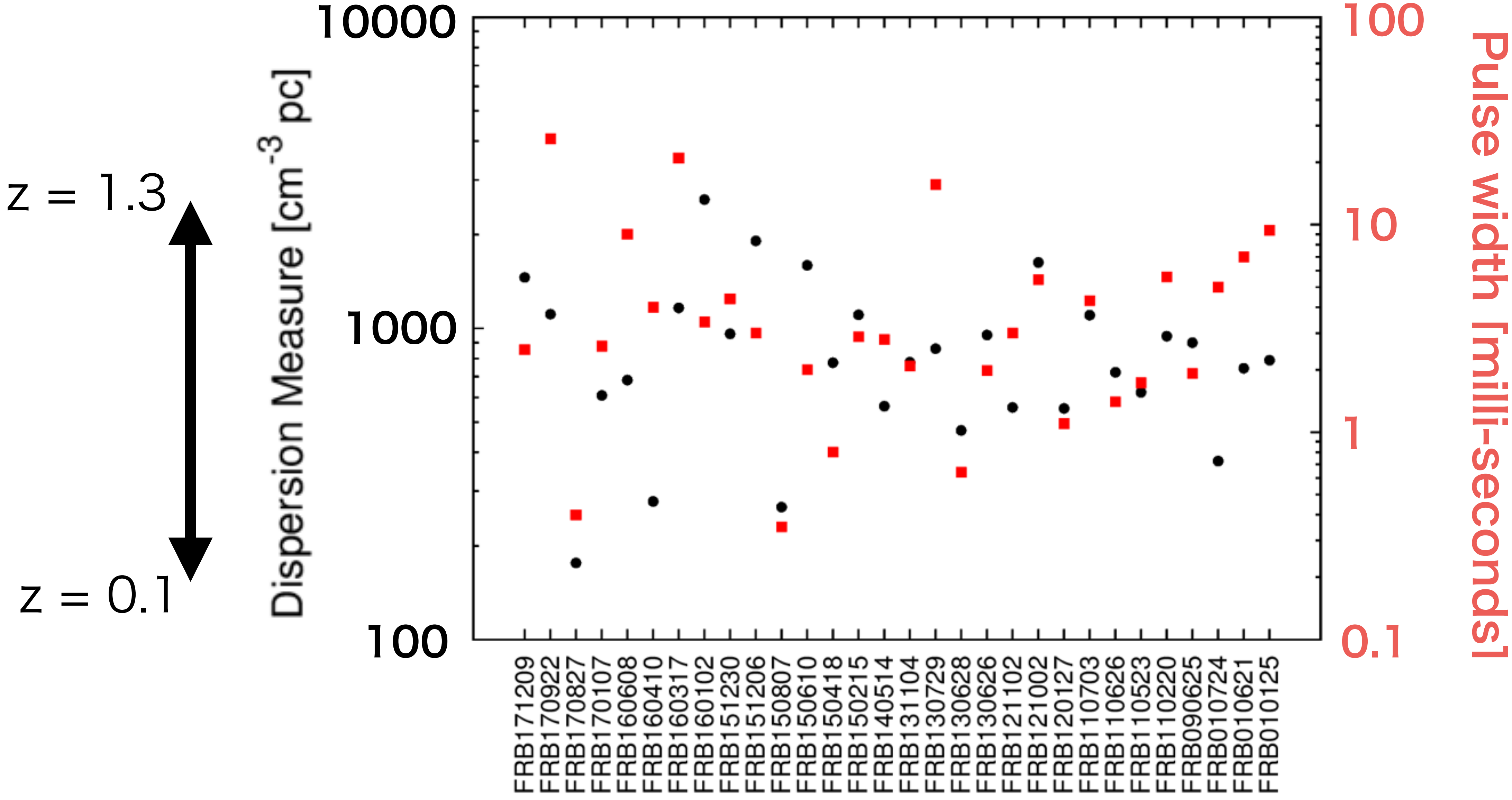
DM ~ 330 [cm^{-3} pc] —> z ~ 0.28

$$\langle \mathrm{DM_{IGM}} \rangle = \frac{3cH_0\Omega_b f_{\mathrm{IGM}}}{8\pi G m_p} \int_0^z \frac{f_e(z')(1+z')}{\sqrt{\Omega_m(1+z')^3+\Omega_\Lambda}} dz'$$

with 20% scatter
(L.o.S variations)

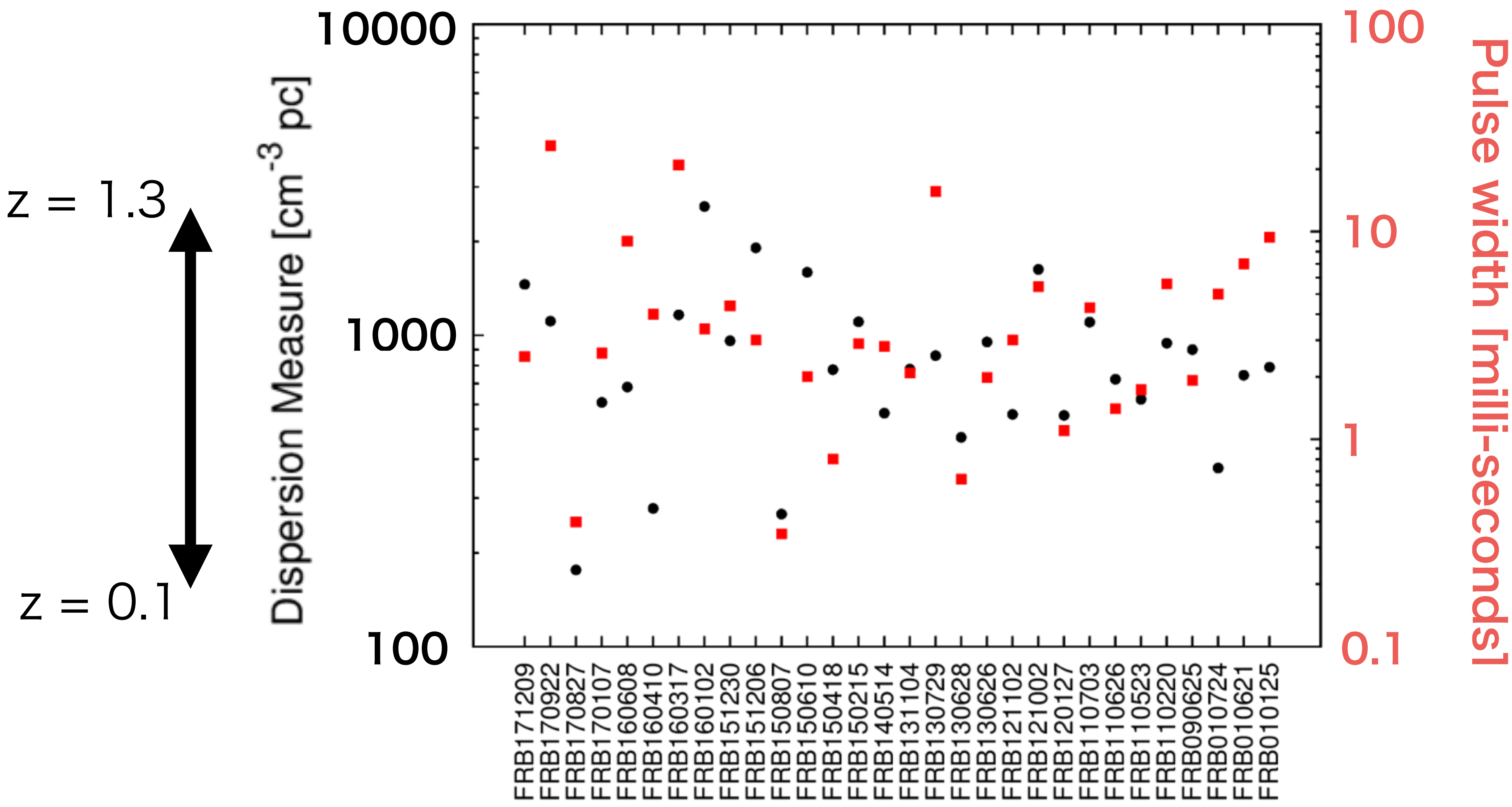
a new probe for the otherwise unobservable "missing baryons"

FRBs : large DM milli-second radio pulse
= Extragalactic compact objects



- 30 FRBs so far
- z ~ 0.16 - 1.30, rate ~ 10000 FRBs/all sky/day
- Object size << c × pulse width = 300 km × (Δt / 1 milli-second)

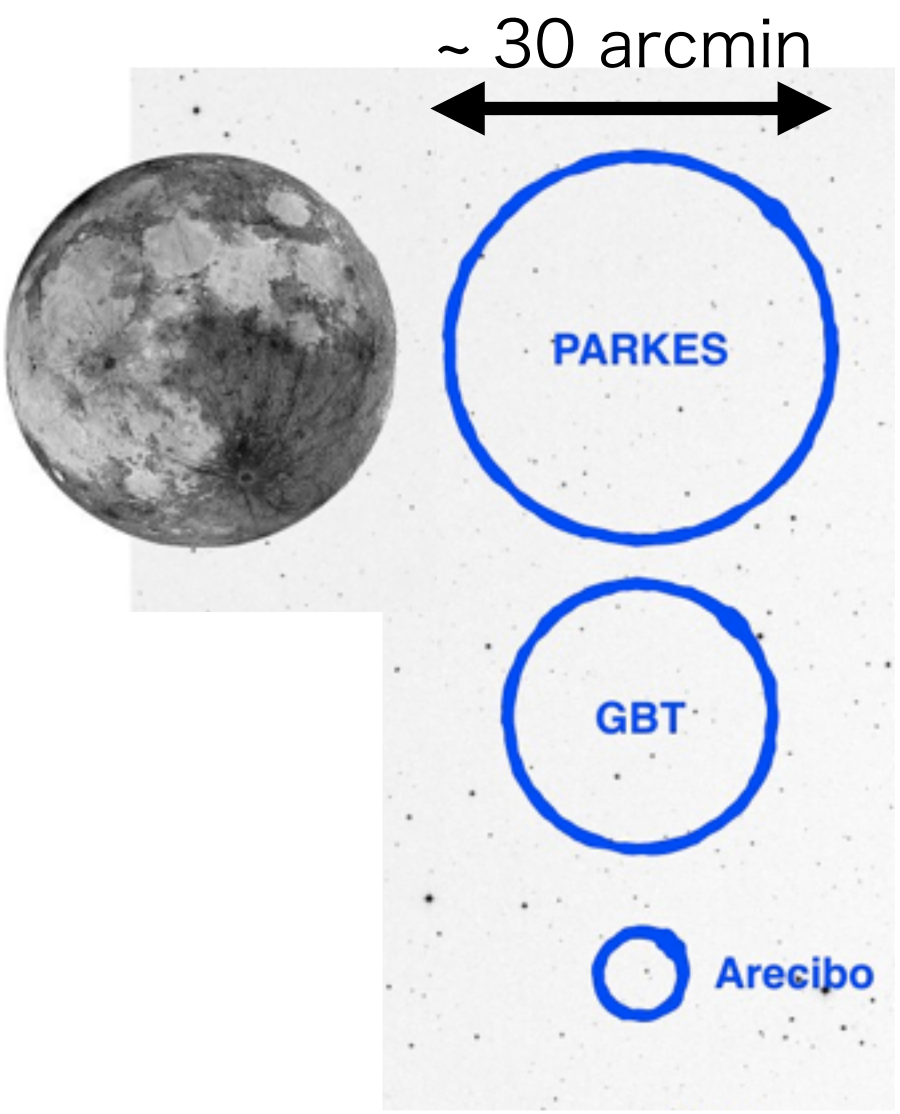
FRBs : large DM milli-second radio pulse
= Extragalactic compact objects



Radio pulses from young neutron stars (NS) or magnetars ?
Collapse of supramassive NSs, binary NS merger ?
…

FRB host galaxies

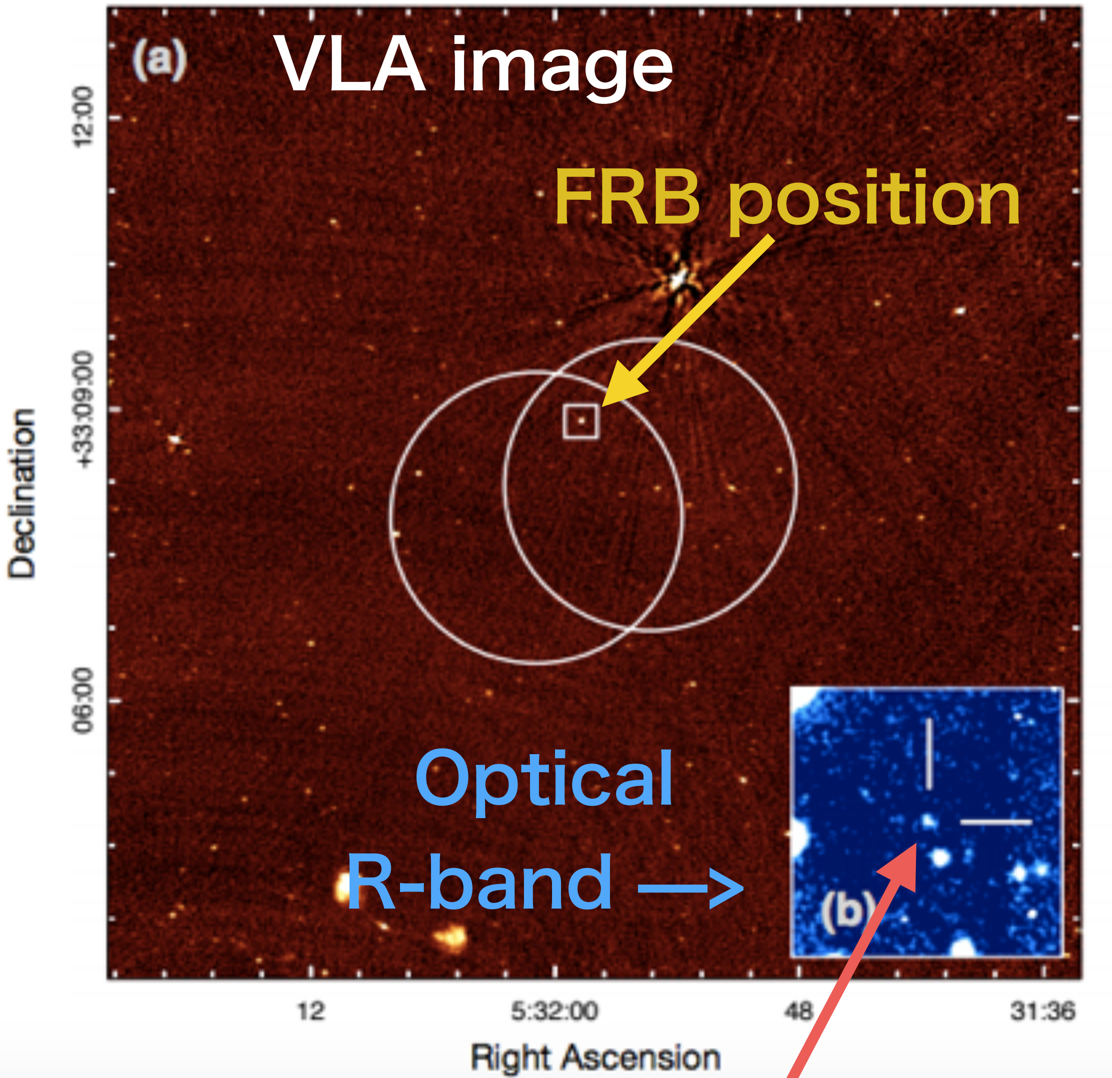
- Host galaxy identification for FRBs is important
  - True redshifts of FRBs
  - Local environment at the site of FRBs
    —> constrains on the progenitor model and the missing baryons
- **Direct localization for FRBs is difficult**
  - Resolution of single-dish telescopes is
    > 3 arcmin
    (>> 100 galaxies are in a beam)
  - FRBs are generally one-off events

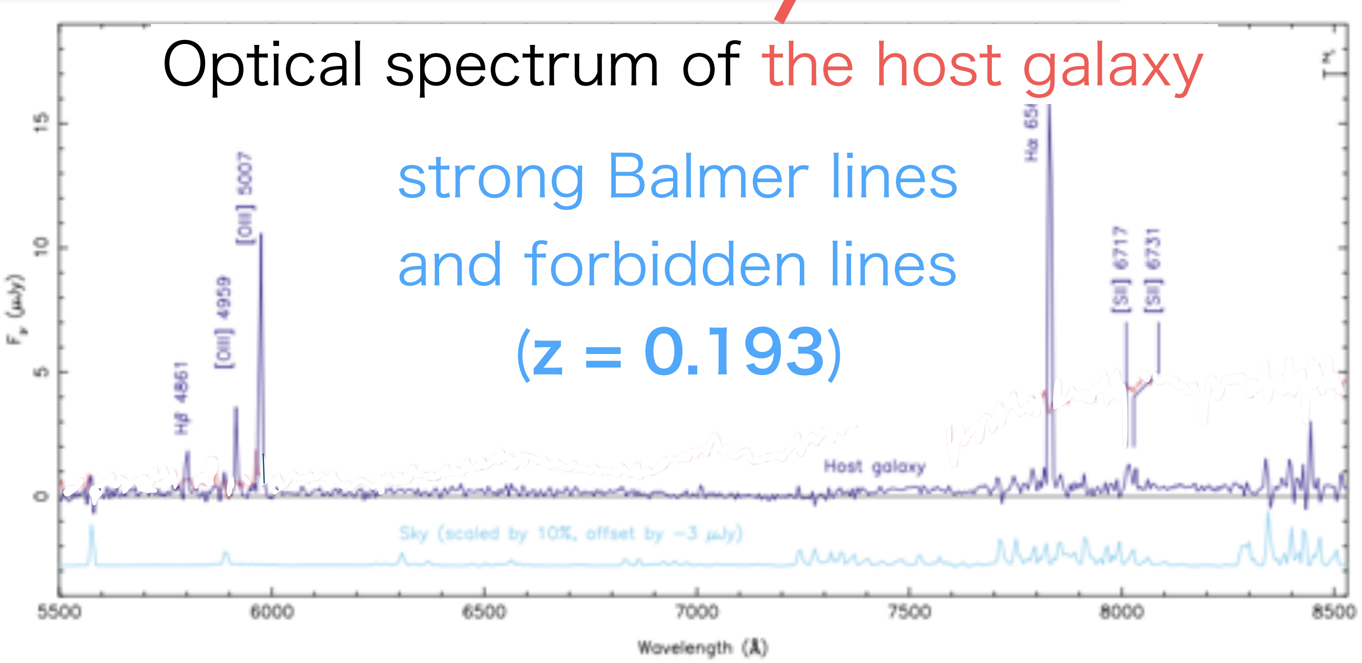


https://twitter.com/caseyjlaw/status/814894259304136704

FRB 121102 is an exception — repetitiveness

Discovery of the repeating FRB 121102





- Multiple detection of radio bursts toward the direction of FRB 121102 since 2014. DM_{obs} = 558 [cm^{-3} pc]
  (e.g., Spitler et al. 2016; Michilli et al. 2018)

- VLA observation determined the FRB position at the precision of 0.1 arcsec
  (Chatterjee et al. 2017).

- Deep optical spectroscopy by the Gemini telescope identified **a very faint dwarf host galaxy at z = 0.193**
  (r ~ 25 mag, M_{star} = 1.3 × 10^8 M_{sun})
  (Tendulkar et al. 2017)

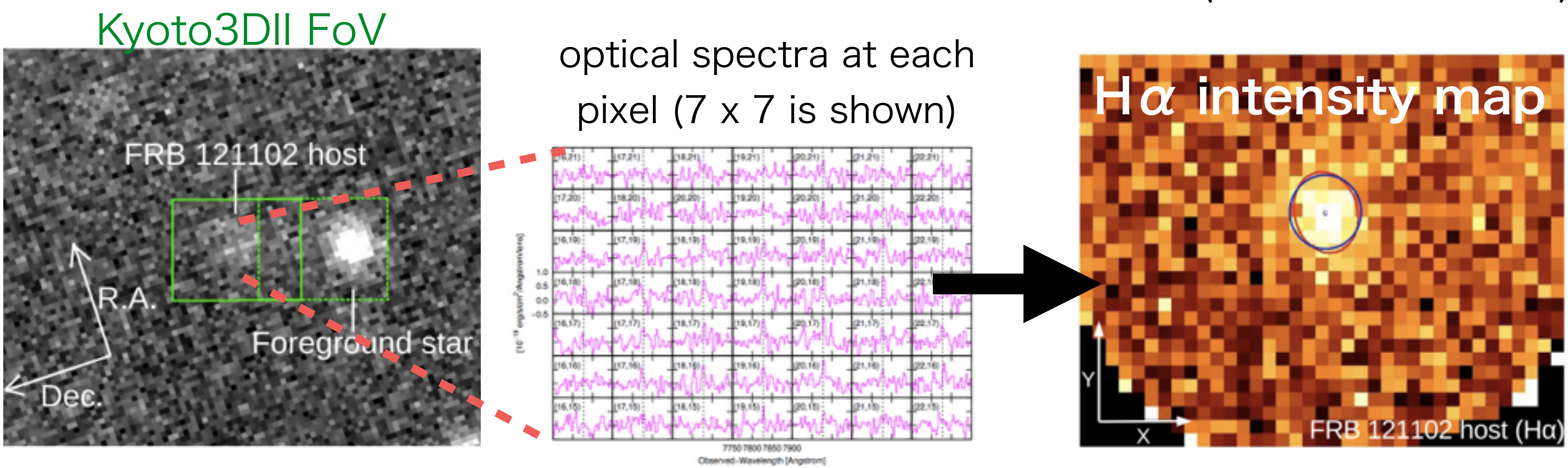
Subaru/Kyoto 3DII observation

on Feb 9, 2017

- Aims
  - Spatially resolve star-forming region(s) in the FRB121102 host
  - The FRB is located inside/outside of the star-forming region ?
    —> put a new constraint on the progenitor models
- Methods
  - Kyoto3DII Integral-field spectroscopy (IFS) mode (3.2''×2.5'' FoV)
    + laser guide star AO mode of AO188 (Matsubayashi et al. 2016)
    - ~ 1.0'' natural seeing FWHM —> ~ 0.5'' AO-corrected FWHM
  - Target line: Hα at z=0.193 (λ = 7300-9200 Å , R~1200)

AO-assisted integral-field spectroscopy (IFS) for the host galaxy of FRB 121102

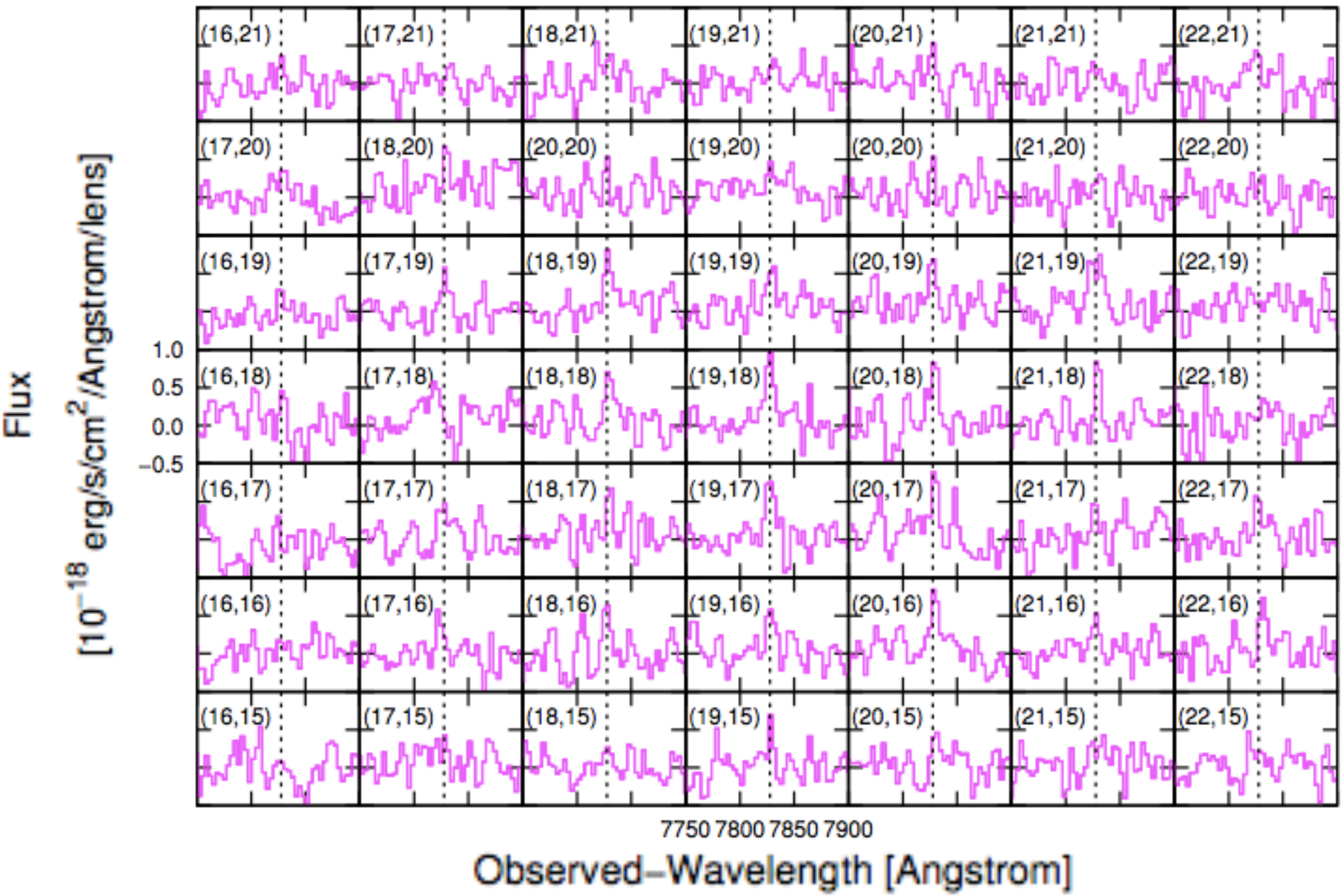
(Kokubo et al. 2017)



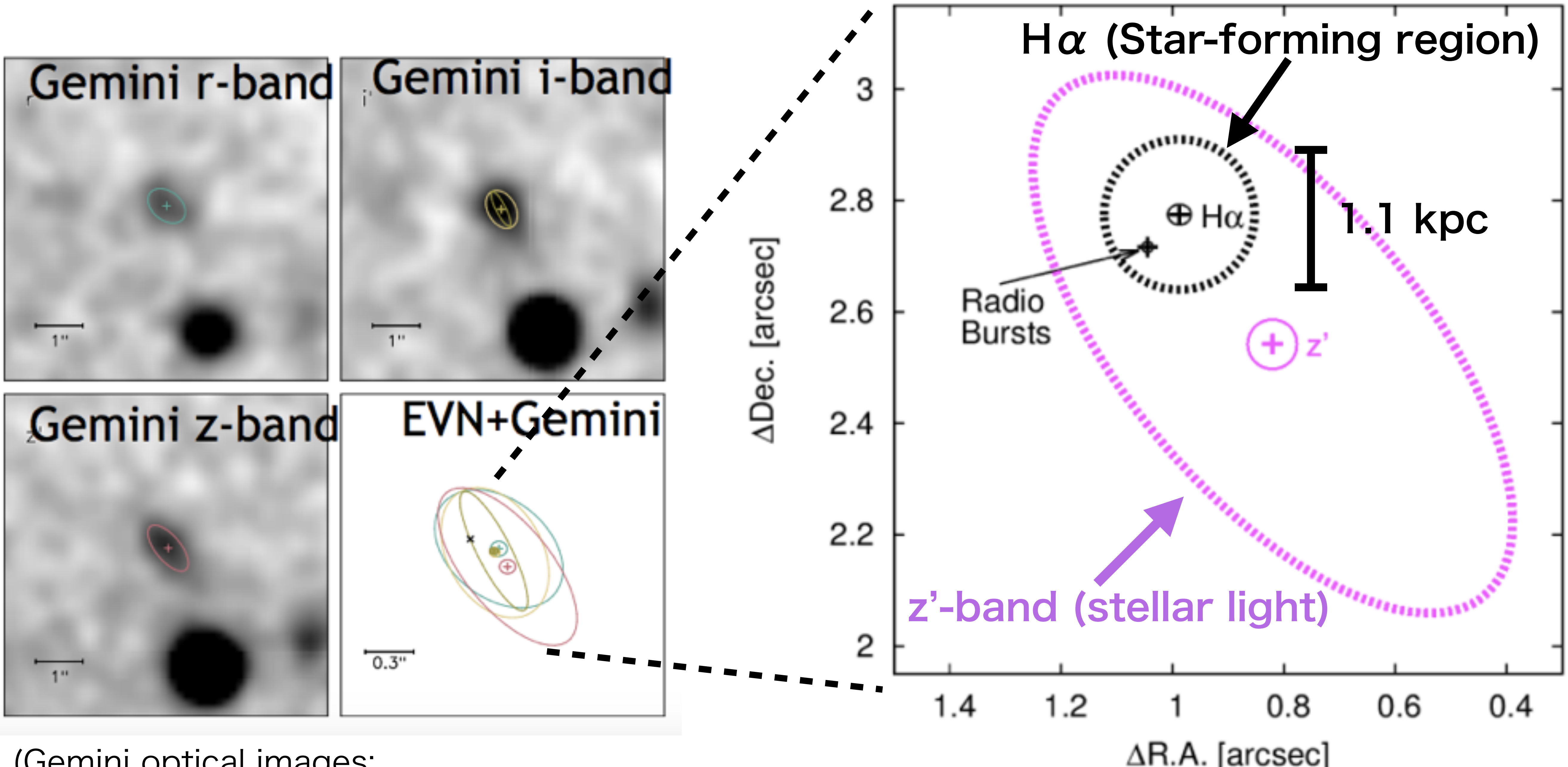
3 hour coadd

- Result
  - A compact Hα emitting region (i.e., star-forming region) is detected within the host galaxy
    PSF-deconvolved size ~ 0.33'' = 1.1 kpc (FWHM)

Hα spectrum at each spaxel (7 x 7)



FRB 121102 is located within the star-forming region of the dwarf host galaxy



(Gemini optical images;
Tendulkar et al. 2017)

(Kokubo et al. 2017)

Discussion

- FRB121102 is located within the star-forming region in the dwarf host galaxy

  - similar to the host environment of long-GRBs, SLSNe-I
    —> FRB 121102 may be a young pulsar/magnetar formed by a massive star explosion

  - FRB 121102 is **un**related to the AGN activities of the host

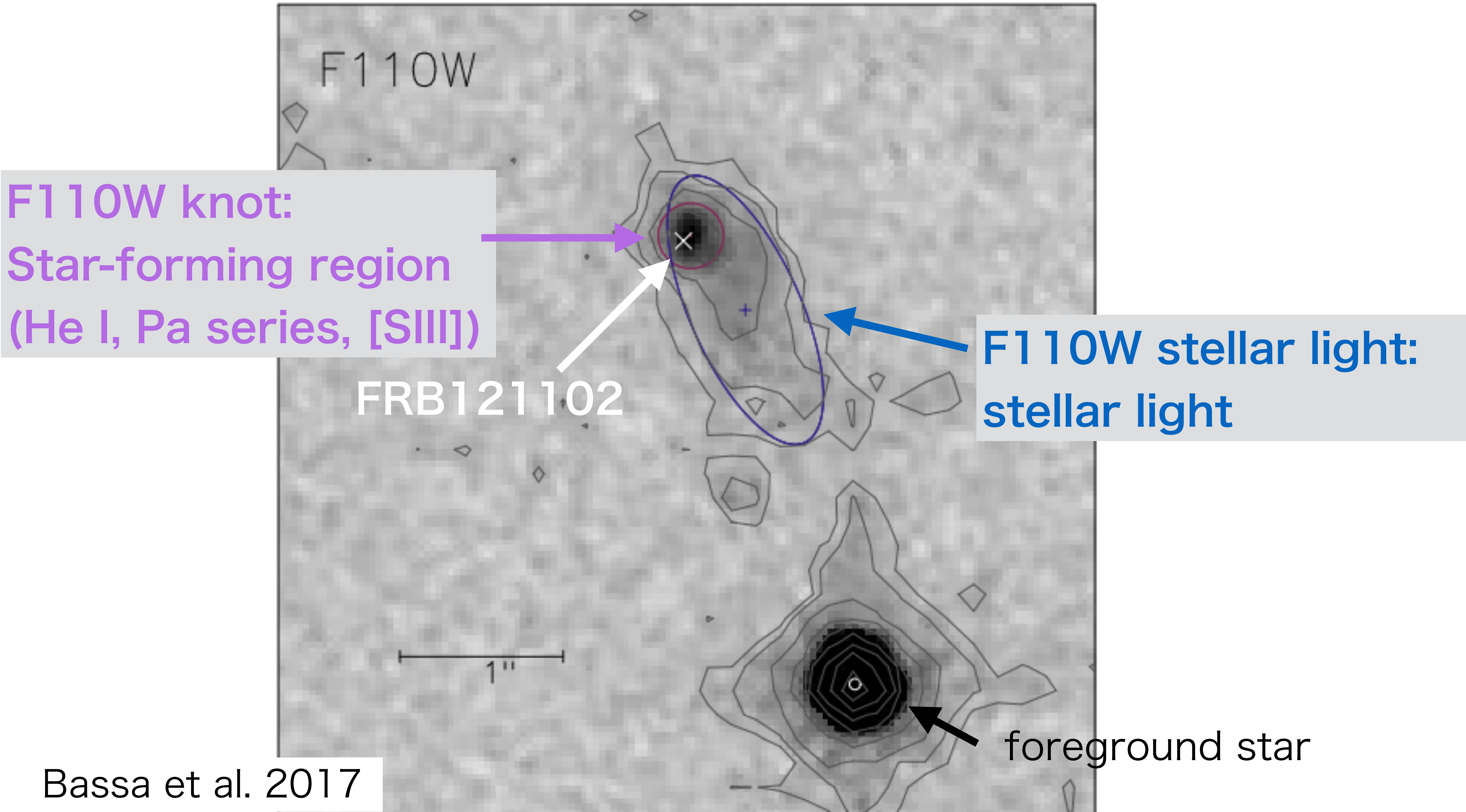
- DM contribution from the star-forming region is uncertain and can be large: $\mathrm{DM}_{\mathrm{host\,H\alpha,\,obs}} = 712\,(\pm 89)\ \mathrm{pc\ cm^{-3}} \times f_{\mathrm{f}}^{1/2} C$
  —> single FRB is difficult to be used as a tool for cosmology

Concluding remarks

- Our Kyoto3DII+AO188 observation revealed that the FRB 121102 is located inside of the star-forming region in the dwarf host galaxy
    - consistent with a young neutron star/magnetar scenario
    - AO-assisted IFS is suitable for studying the host environment of FRBs (but Kyoto3DII was decommissioned, unfortunately.)
- FRB 121102 may be special among FRBs, and a statistical sample of FRBs is needed
    - Next generation radio telescopes (**SKA** and SKA path finders, CHIME, …) will detect ~100 FRBs/year
    - FRB detections + opt/IR follow-up —> cosmology with FRBs

backup slides

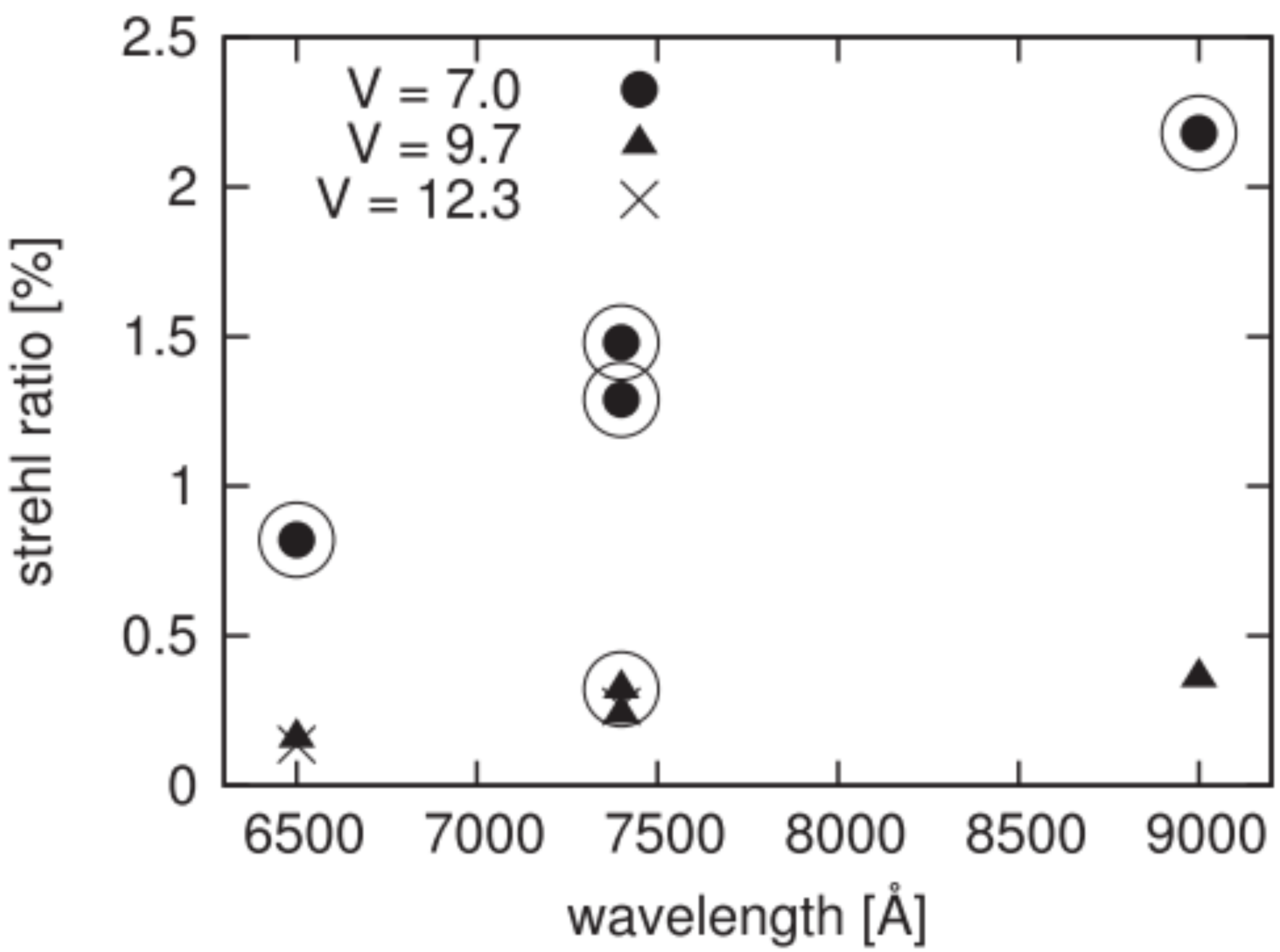
HST/WFC3 observations for FRB121102 host confirmed our findings

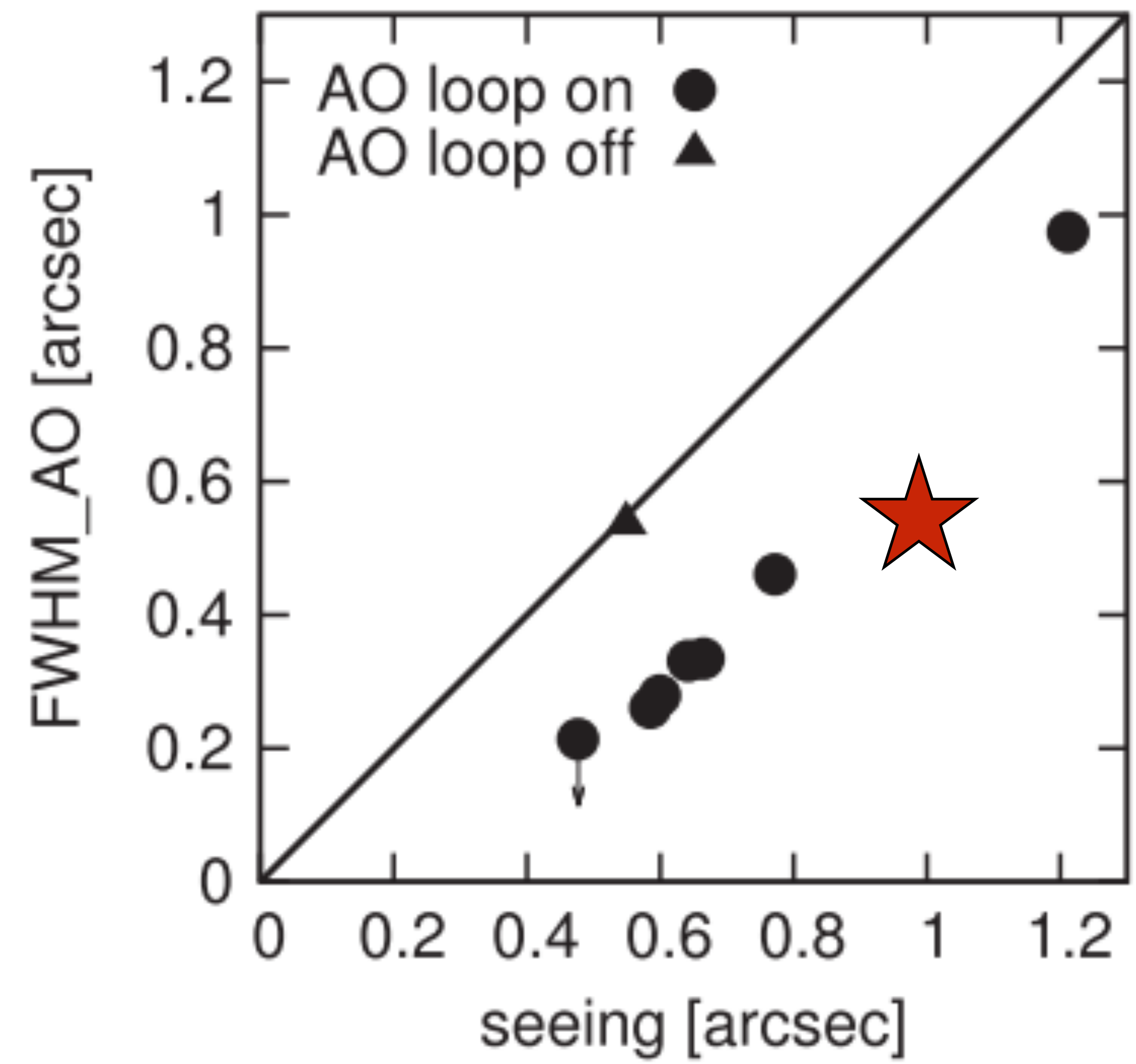


Bassa et al. 2017

Kyoto3DII+AO188 performance

Matsubayashi et al. 2016, PASP





Our FRB science playing field.

FRB params:

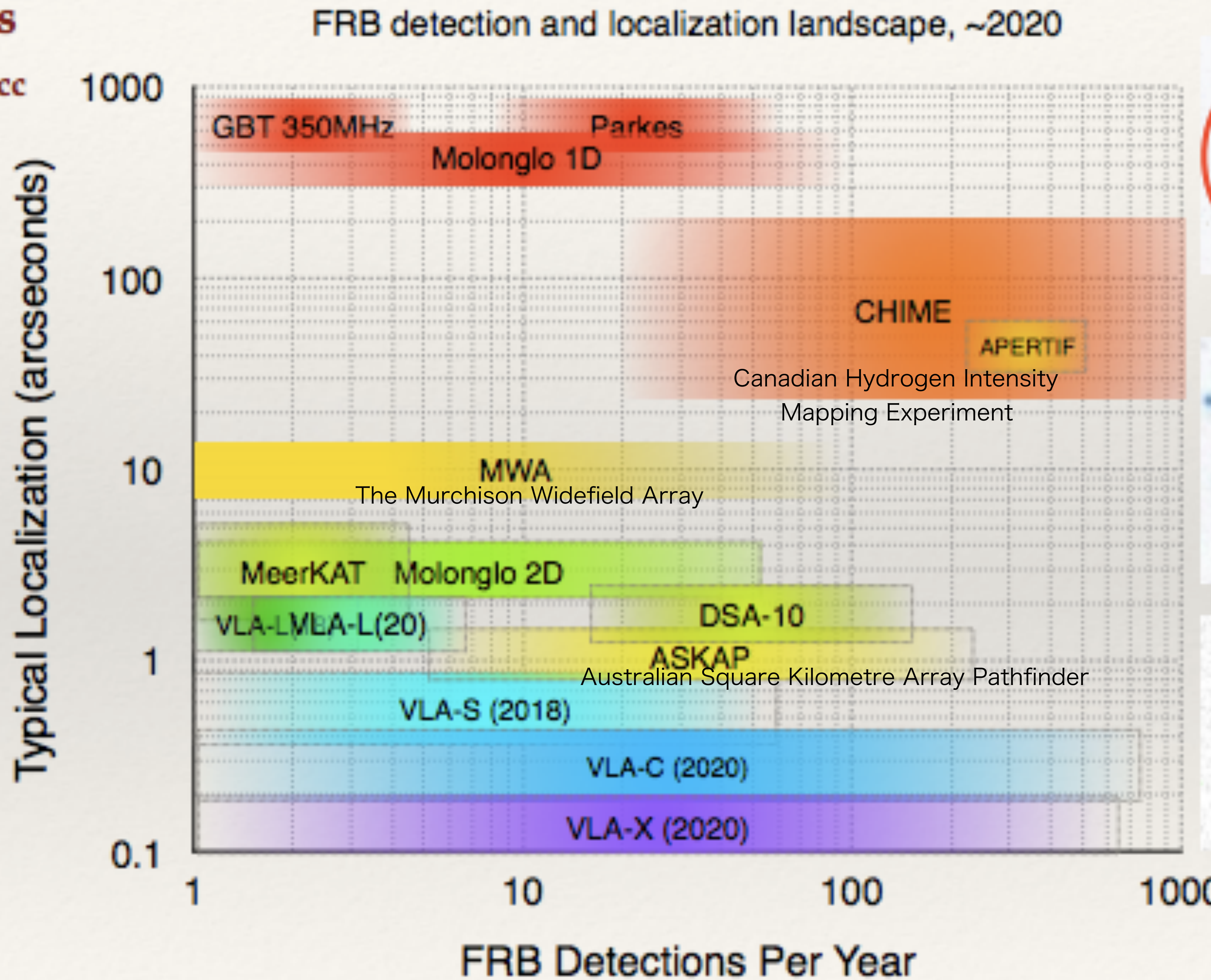
$100us < w_{int} < 3ms$

$0 < \tau_{scat}$ (1GHz) $< 3ms$

$<DM_x> = 400\text{-}800$ pc/cc

$-1.5 < \gamma < -0.5$

$-1.0 < \alpha < 2.0$

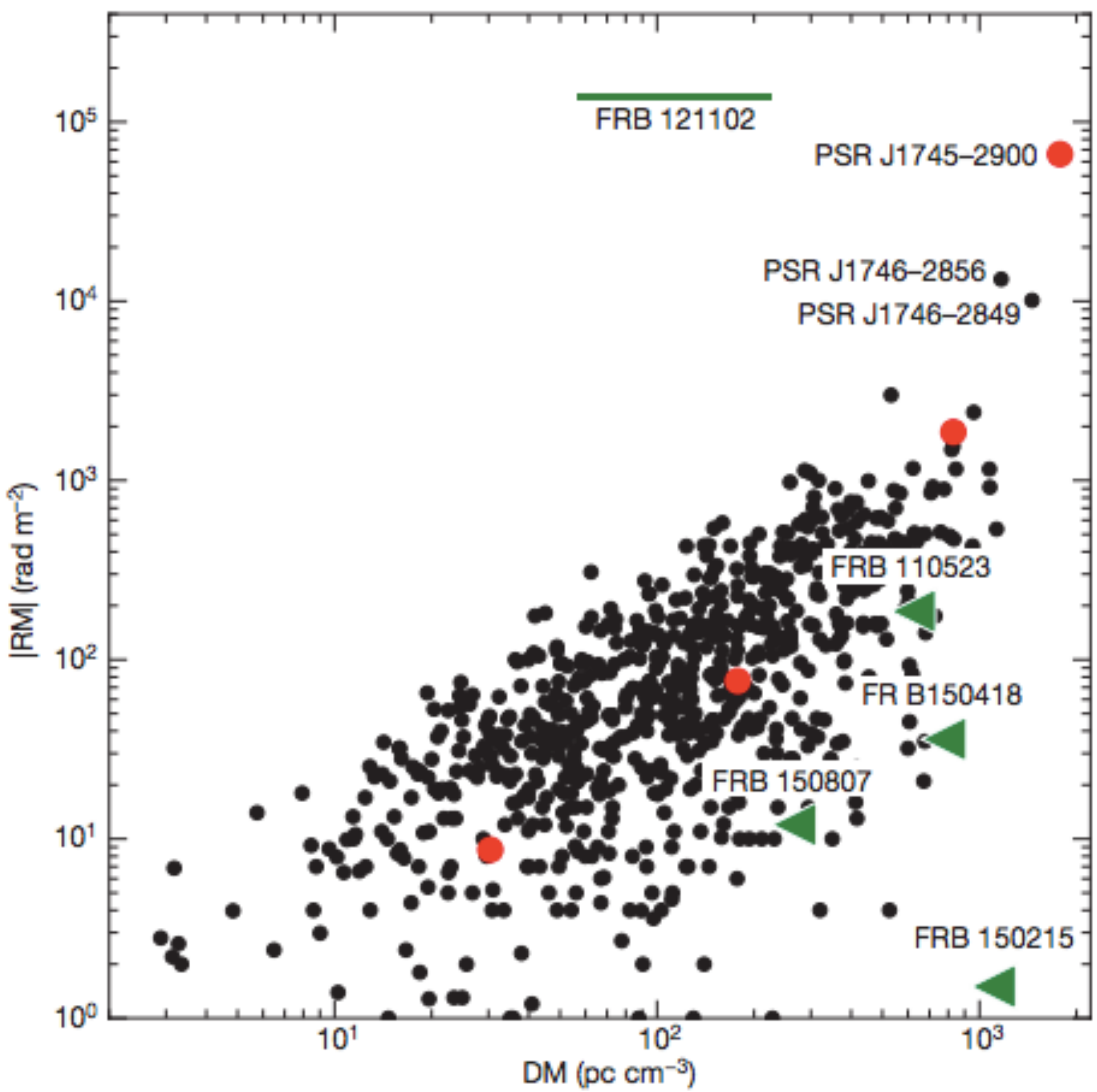


S. Burke-Spolaor's slide, http://aspen17.phys.wvu.edu/

(—> Full SKA in mid 2020 ~ 0.1")

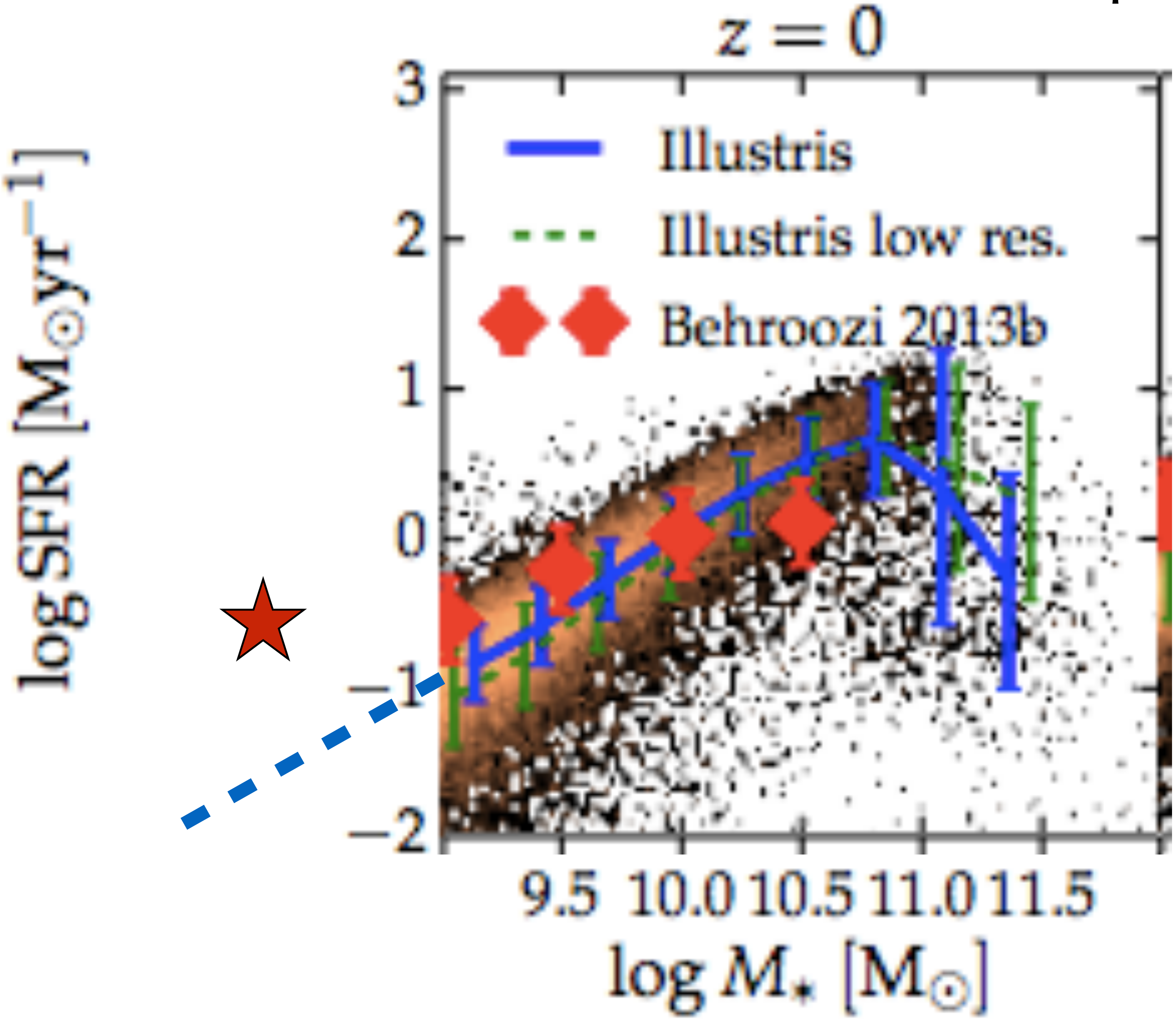
Rotation Measure of FRB121102

FRB121102 is in an extreme environment ?



Michelle et al. 2018, Nature

Star formation main sequence



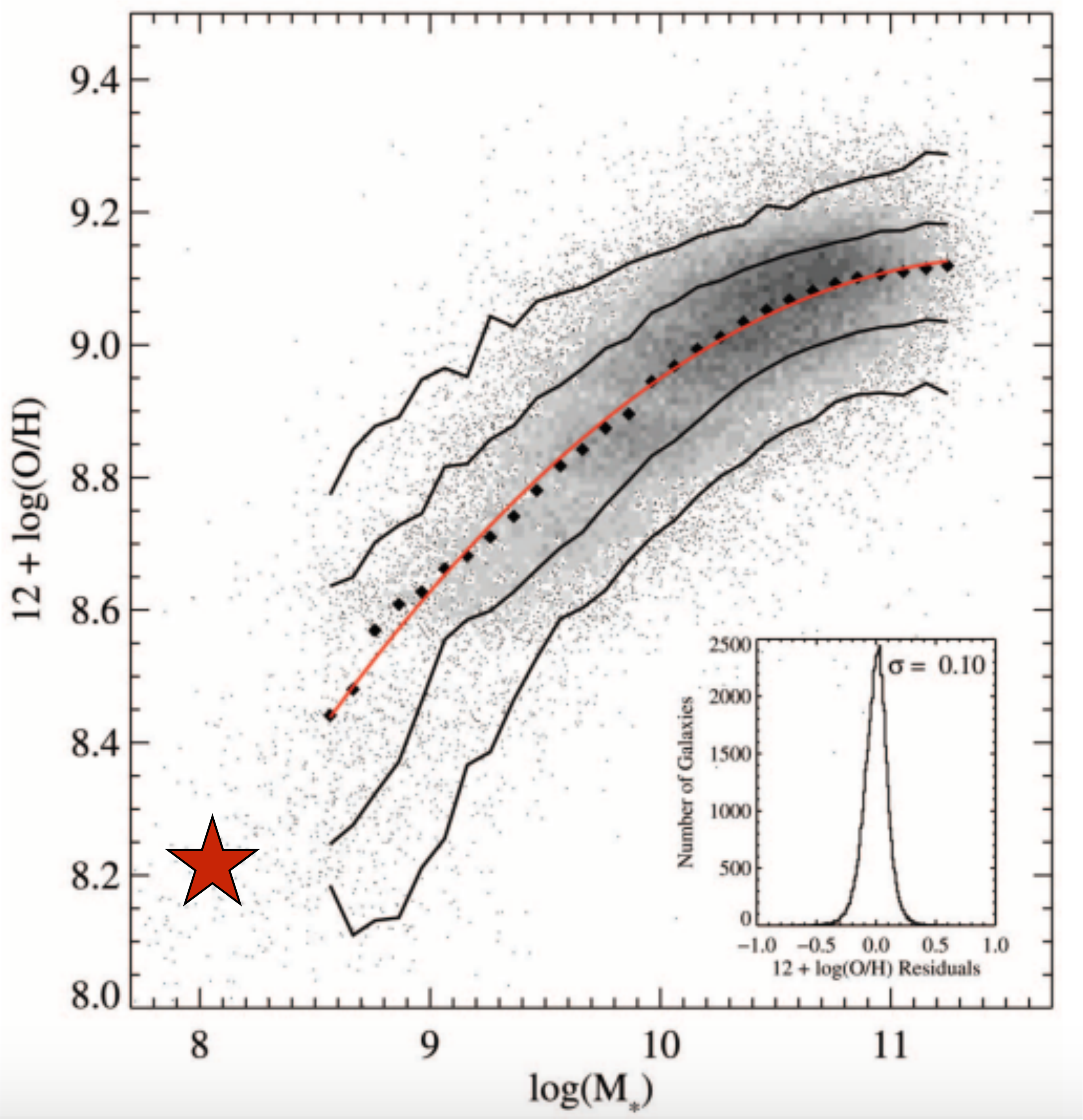
Sparre+2015

FRB 121102 host galaxy:

log (SFR [M_{star} / yr]) = − 0.64

log (M_{star} / M_{sun}) = 8.1

mass-metallicity relation



Tremonti+2004